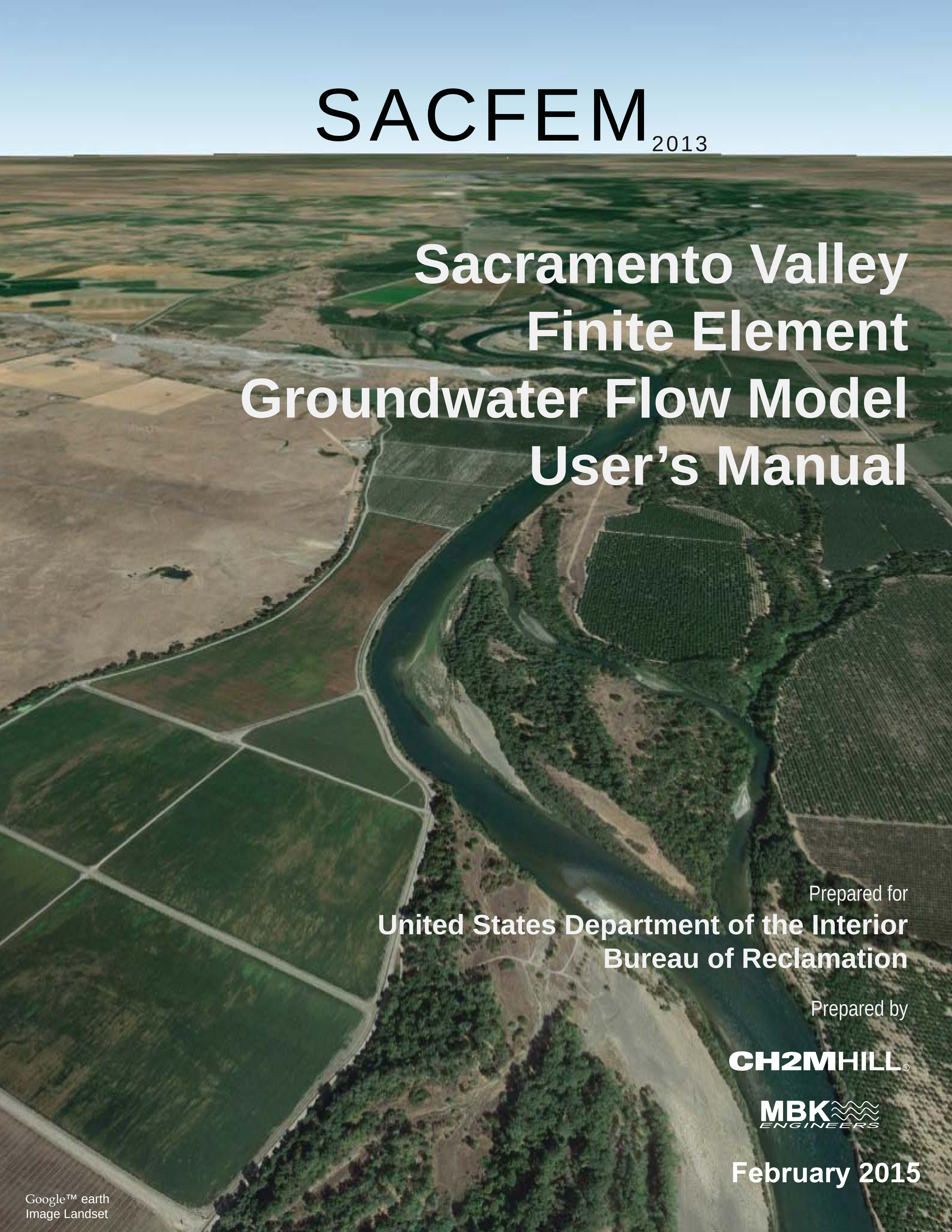

SACFEM2013

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

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Contents

Sections Page

Appendixes

Tables

Figures

Section **Page**

Section **Page**

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

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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.

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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:

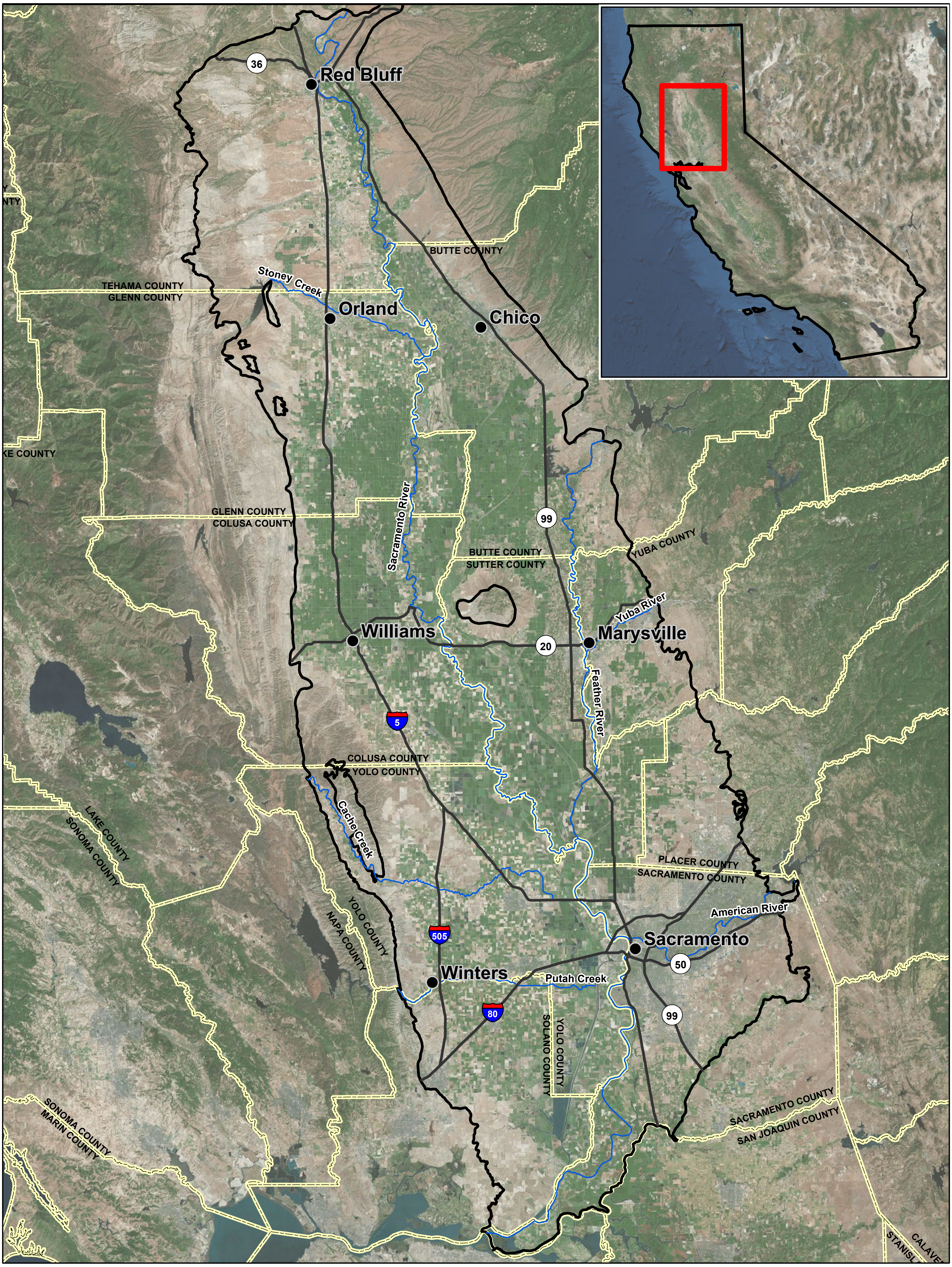
- Groundwater discharge to land surface (including evapotranspiration, discharge to low-lying stream riparian areas, and discharge to low-lying areas such as the Butte Sinks in the Sutter Basin)
- Groundwater discharge to rivers
- Groundwater discharge to wells

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.



LEGEND

● City

Major Road

Major Stream

County Boundary

Sacramento Valley Groundwater Basin

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 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

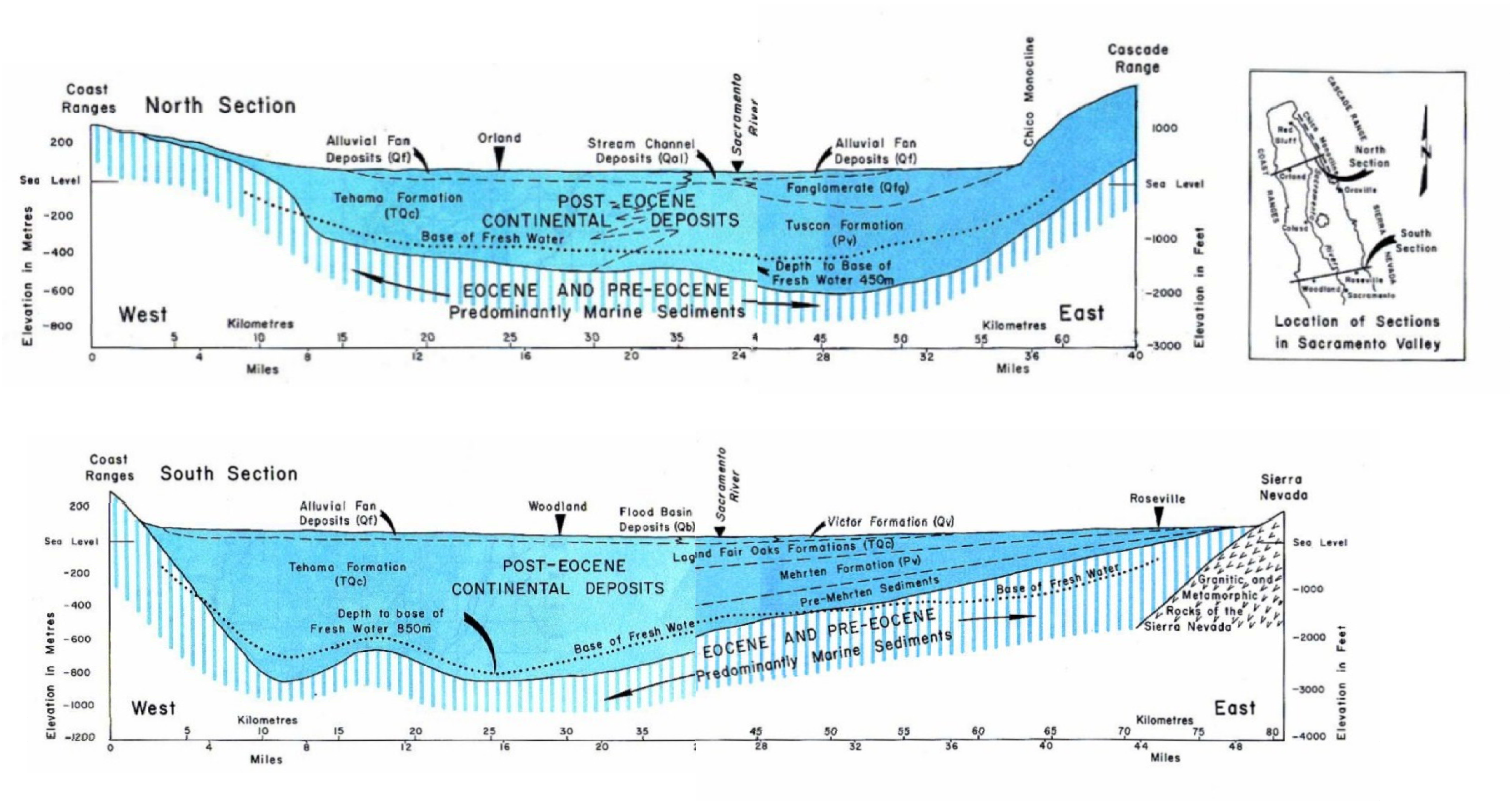
Geologic Unit	Geologic Age	Description	Water-Bearing Properties
Alluvium	Quaternary (Holocene)	Alluvial deposits not included as fans or flood basin deposits are found throughout the Sacramento Valley and consist of stream channel, natural levee, and floodplain deposits. Alluvium consists primarily of 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



Note:
Figure reproduced from DWR (1978).

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

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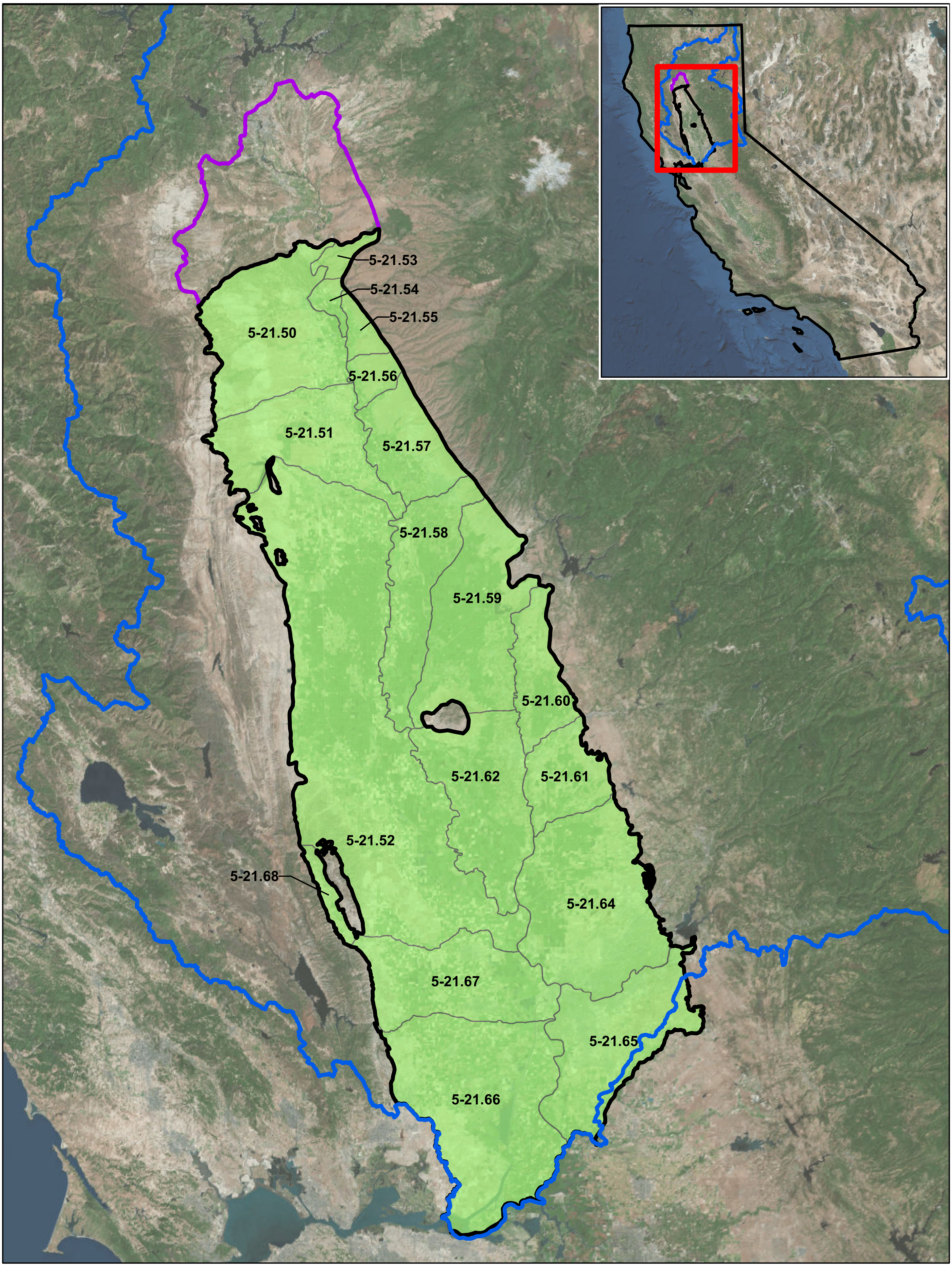

LEGEND

🟪 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

Figure 3
Sacramento Valley
Groundwater Basin
SACFEM2013: Sacramento Valley Finite
Element Groundwater Flow Model
USER'S MANUAL

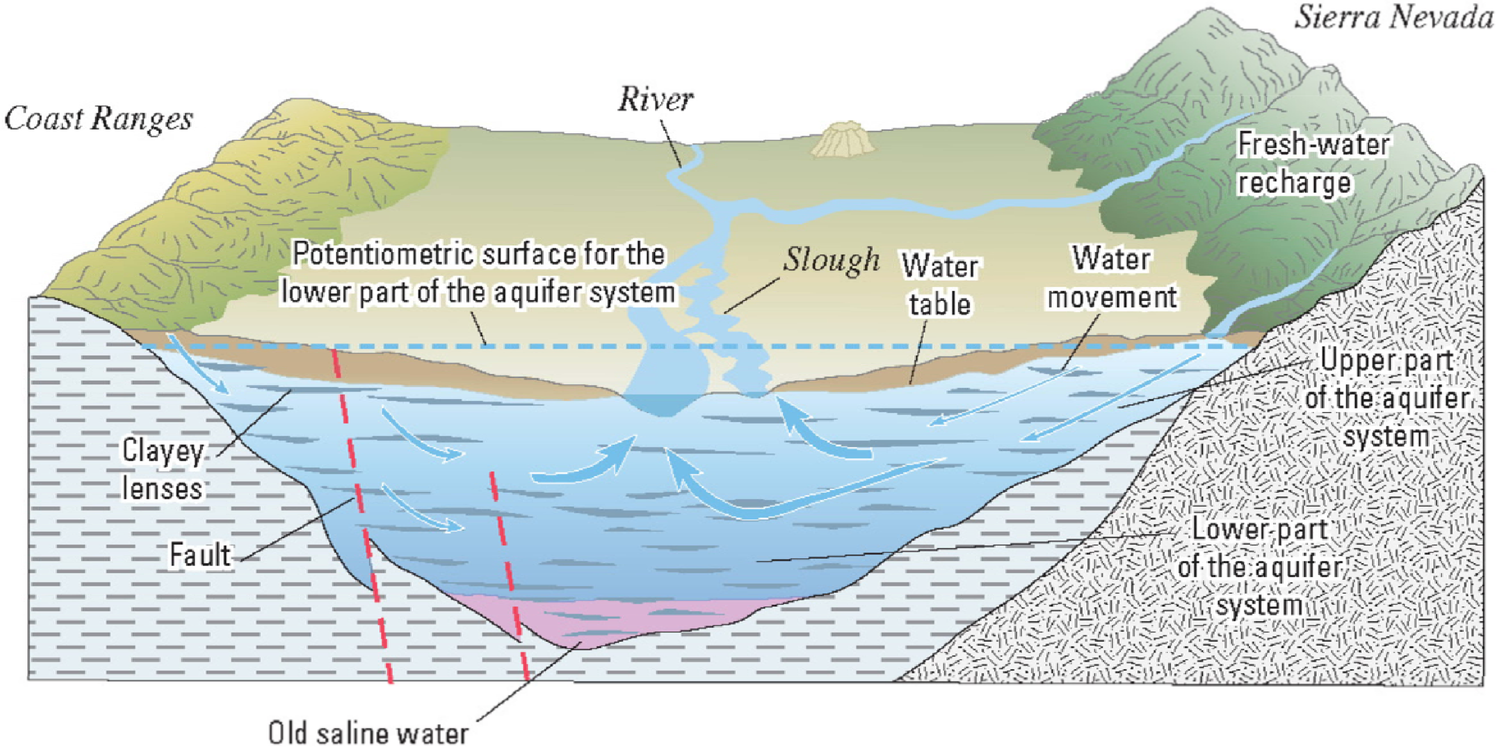

Figure 4

Conceptual Diagram of Groundwater Flow in the Sacramento Valley Groundwater Basin

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

Note:
Figure reproduced from USGS (2009).

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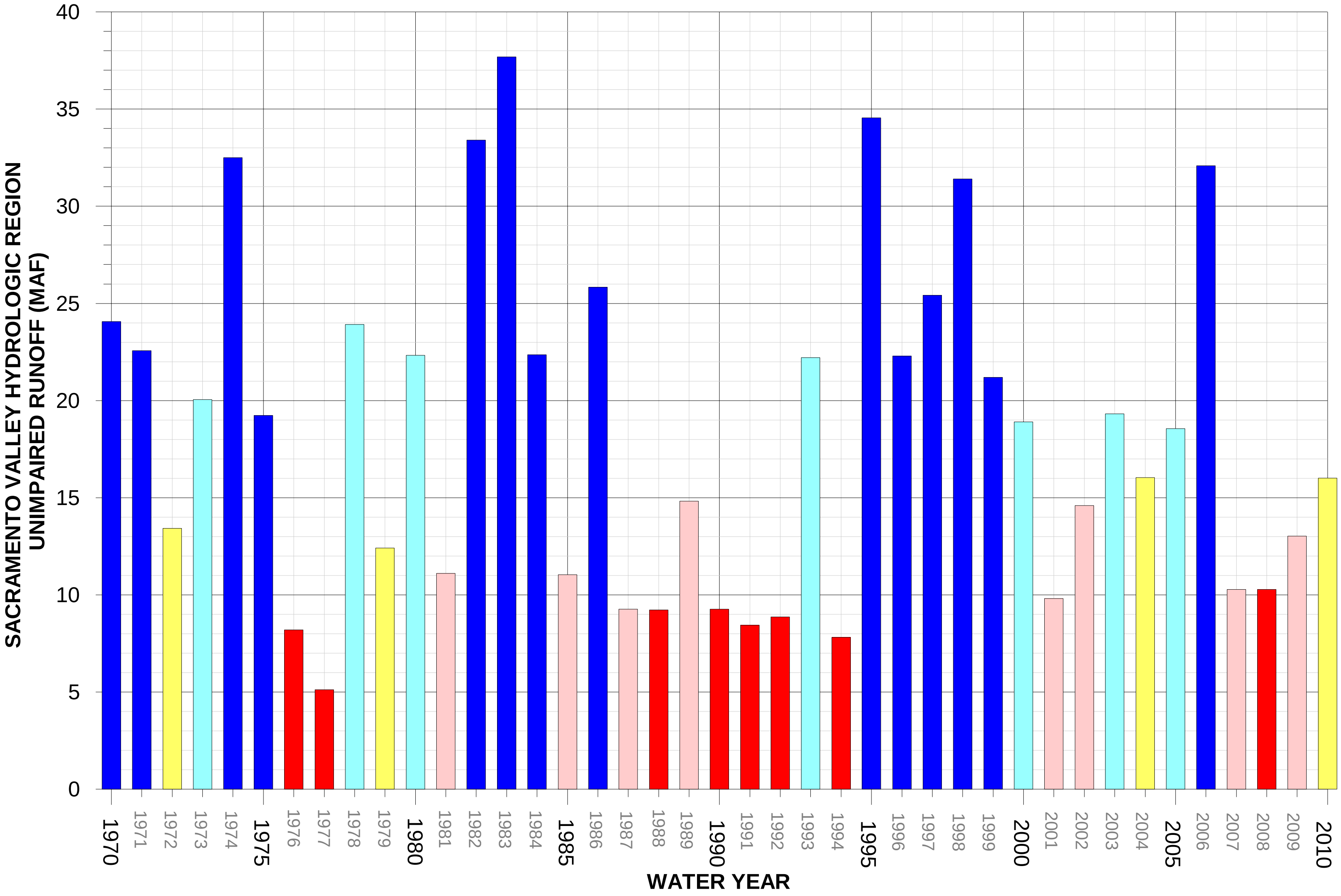
[1] http://cdec.water.ca.gov/

[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).



Legend

🟦 Wet Year

▨ Above Normal Year

🟨 Below Normal Year

▨ Dry Year

🟥 Critical Year

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

Figure 5
Sacramento Valley
Water Year Classification
SACFEM2013: Sacramento Valley Finite
Element Groundwater Flow Model
USER'S MANUAL

SECTION 3

Groundwater Flow Model Construction

3.1 Model Code Description

MicroFEM (Hemker, 1997), a finite-element based, three-dimensional, integrated groundwater modeling package developed in The Netherlands, was chosen to simulate the groundwater flow systems in the SVGB. The current version of the program (4.10) has the ability to simulate up to 25 layers and 250,000 surface nodes. MicroFEM is capable of modeling saturated, single-density groundwater flow in layered systems. Horizontal flow is assumed in each layer, as is vertical flow between adjacent layers.

MicroFEM was the chosen modeling platform for the following reasons:

- The finite-element scheme allowed the construction of a model grid covering large geographic areas (more than 5,960 square miles in the SVGB) with coarse node spacing outside of the simulated project areas and finer node spacing in areas of interest (e.g., near potential project areas). The finer node spacing near simulated production wells provides greater resolution of simulated groundwater levels and stream impacts.
- The graphical interface allows rapid assignment of aquifer parameters and proofing of these values by graphical means.
- The flexible post-processing tools allow for rapid evaluation of transient water budgets for model simulations and identification of changes to stream discharges and other water fluxes across the model domain.

3.1.1 Numerical Assumptions

MicroFEM, as applied to the development of SACFEM2013, is conceptualized mathematically into a single-density subsurface groundwater flow regime. The subsurface flow regime includes the hydraulic properties that control groundwater movement and rates. All model layers are treated as vertically integrated, leaky-confined layers to facilitate accurate simulation of the 3D groundwater flow conditions. The minimum inputs required by MicroFEM to execute a simulation for a given model grid include transmissivity, vertical resistance, and boundary conditions. SACFEM2013 is simulated under confined conditions in all model layers; therefore, the user-defined transmissivity values do not vary during the model simulation.

3.1.2 Scientific Bases

The theory and numerical techniques that are incorporated into MicroFEM have been scientifically tested. The governing equations for saturated subsurface flow are well established and have been solved by several modeling codes over the past few decades on a wide range of field problems. Thus, the scientific bases of the theory and the numerical techniques for solving these equations have been well established. MicroFEM has been developed using strict quality assurance/quality control guidelines and with various levels of testing, from simple analytical solutions to complex field problems.

3.1.3 Data Formats

MicroFEM input and output files use American Standard Code for Information Interchange (ASCII) data formats and can be read and edited outside the program by a text editor.

3.1.4 Limitations

Mathematical models can only approximate processes of physical systems. Models are inherently inexact because the mathematical description of the physical system is imperfect and the understanding of interrelated physical processes is incomplete. CH2M HILL incorporated as many details of the physical system into the numerical model as possible. SACFEM2013 is a powerful tool that, when used carefully, can provide useful insight into processes of the physical system. Section 4.3 discusses potential sources of input and output error.

3.2 Model Construction

The mathematical model design is the result of translating the CSM into a form that is suitable for numerical modeling. The following steps were included in the development of the mathematical model design:

1. Establishing study area boundaries (that is, model domain) and developing a model grid
2. Spatially distributing land surface elevation values
3. Spatially distributing subsurface hydraulic parameter values
4. Selecting a time discretization approach appropriate for evaluating the field problem and fulfilling the modeling objectives
5. Establishing boundary conditions for flow (that is, water budget terms through time)

The following subsections describe the results of these design steps.

3.2.1 Model Domain

In the real world, space is continuous, but a numerical model must use discrete space to represent the hydrologic system. The simplest way to discretize space is to subdivide the study area into many subregions (that is, model elements) of variable size. This was the approach taken for development of the SACFEM2013 grid.

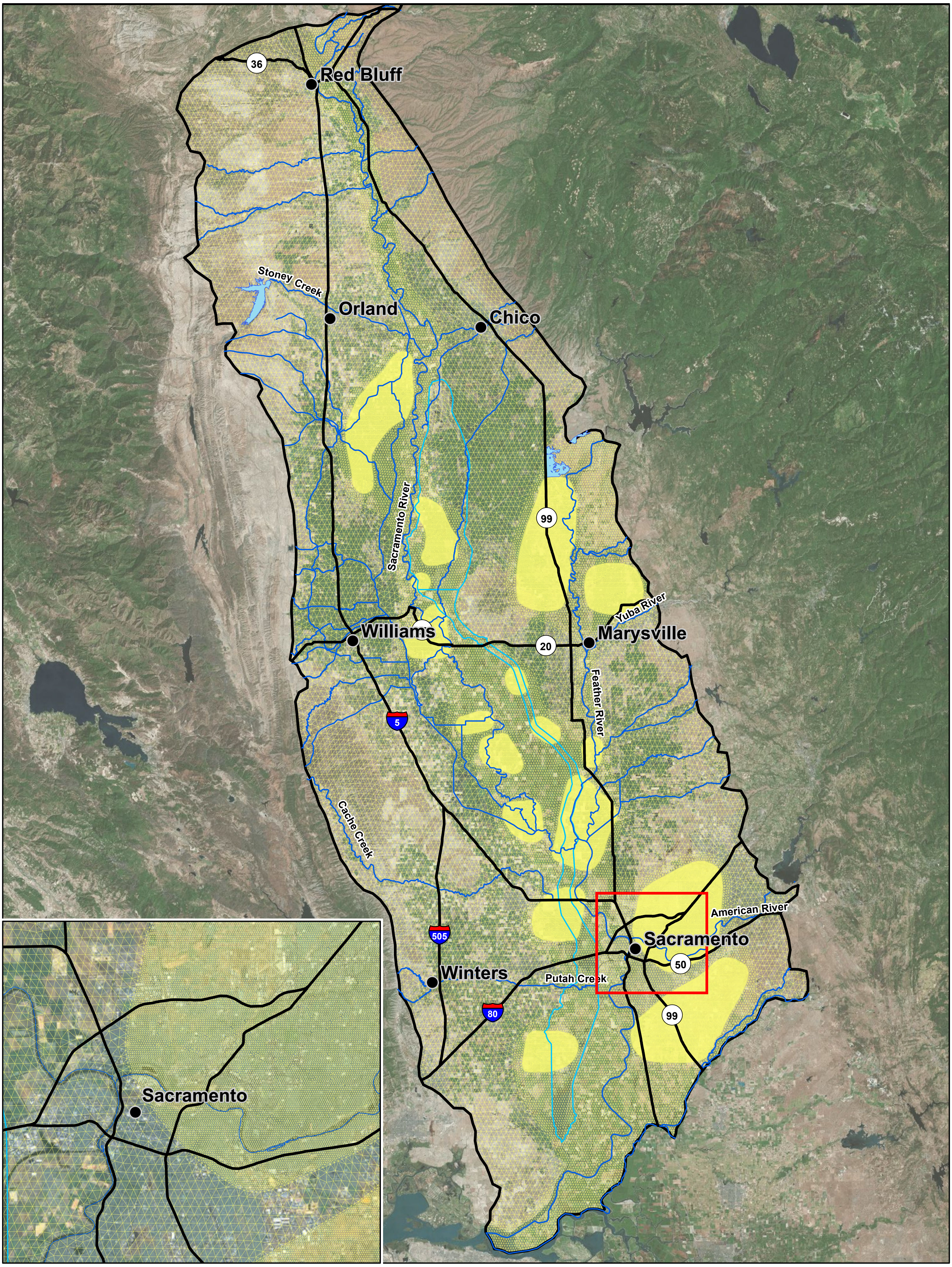
3.2.1.1 Areal Characteristics of Model Grid

The current version of the SACFEM2013 grid consists of 153,812 nodes and 306,813 elements (see Figure 6). The current grid was configured to support evaluation of potential conjunctive water management projects associated with the Long-Term Water Transfer Program; however, SACFEM2013 was designed to be grid independent, and geographic information system (GIS)-based tools have been developed to build a similar model of the Valley on any grid developed to support a particular application. The nodal spacing of the current grid varies from as large as approximately 3,300 feet (1,000 meters) near the model boundary and in areas where long-term water transfer projects are not being evaluated, to as small as 410 feet (125 meters) in areas where long-term water transfer groundwater production is being evaluated. Nodal spacing of approximately 1,640 feet (500 meters) is included along streams and flood bypasses included in SACFEM2013. The finer node spacing near proposed project areas allows for more refined estimates of the effects of groundwater pumping on groundwater levels and groundwater/surface water interaction in the potential project areas. The model domain boundary coincides with the lateral extent of the freshwater aquifer within the SVGB.

Note: The horizontal datum for SACFEM2013 is Universal Transverse Mercator, North American Datum of 1983, Zone 10 North, meters. The vertical datum for SACFEM2013 is North American Vertical Datum of 1988, meters.

3.2.1.2 Vertical Characteristics of Model Grid

As previously discussed, MicroFEM uses the user-defined aquifer transmissivity when executing calculations under confined conditions. When constructing the SACFEM2013 model, aquifer transmissivity was divided into the two components: saturated aquifer thickness and horizontal hydraulic conductivity (transmissivity is equal to saturated thickness multiplied by horizontal hydraulic conductivity). The following section describes the conceptualization of the saturated aquifer thickness.



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

Figure 6
SACFEM2013 Model Grid
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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The total model thickness is defined by the thickness of the freshwater aquifer (less than 3,000 micromhos per centimeter), as defined by Berkstresser (1973) and subsequently refined in the northern portion of the Valley by DWR (2002, 2005). For the southern portion of the model area, elevation contour lines of the base of fresh water, defined by Berkstresser data, along with information from boring locations (point measurements of the elevation of the base of fresh water) were digitized and used to generate a 3D surface defining the elevation of the base of fresh groundwater. For the northern portion of the model area, the locations of geologic cross sections developed by DWR Northern District staff were plotted, along with the estimated base of freshwater elevations obtained from the cross section information, and a base-of-freshwater elevation contour map was constructed. These data sets were then merged to yield a single interpretation of the structural contour map of the base of freshwater across the SVGB (see Figure 7).

Total Aquifer Thickness. Because SACFEM 2013 is simulated under confined conditions, the uppermost boundary of SACFEM2013 is defined at the water table. To develop a total saturated aquifer thickness distribution and, therefore, a total model thickness distribution, it was necessary to construct a groundwater elevation contour map and then subtract the depth to the base of freshwater from that groundwater elevation contour map. Average calendar year 2000 groundwater elevation measurements were obtained from the DWR Water Data Library. These measurements were primarily collected biannually, during the spring and fall periods; and these values were averaged at each well location to compute an average water level for each location. These values were then contoured, considering streambed elevations for the gaining reaches of the major streams included in the model, to develop a target groundwater elevation contour map for the year 2000. As described above, the distribution of the elevation of the base of freshwater was subtracted from this groundwater elevation contour map to provide an estimate of the distribution of the total saturated aquifer thickness across the model domain (see Figure 8).

Model Layer Thickness. The strategy used to develop the overall layering of the SACFEM2013 model was to develop a tool that provides a sufficient number of layers to assess the effects of groundwater pumping on shallow features such as wetlands and streams. The model also was developed to provide sufficient vertical resolution to allow assignment of pumping stresses to appropriate depths within the aquifer that reflect the major producing zones within the aquifer system. Additionally, to facilitate investigation of potential future conjunctive water management projects using the Lower Tuscan aquifer, the layering strategy also provided for two layers explicitly representing this deep aquifer system.

Layer 1 of the SACFEM2013 model was assigned a maximum thickness of approximately 65 feet (20 meters). The thickness of this layer was limited to provide more accurate shallow groundwater elevations with which to support evaluations of the effects of changing groundwater levels on surface streams and wetland/riparian areas. Layers 2 through 5 represent the more regional groundwater-producing zones within the Valley. The thicknesses of these layers were assigned using a specified percentage of the available aquifer thickness at a given location, to provide multiple-depth zones within which to assign regional pumping. The assumed layer thicknesses for Layers 2 through 5 were also selected to reflect typical screened intervals of production wells in the SVGB. The thicknesses of Layers 2 through 4 each represent approximately 10 percent of the total aquifer thickness (1 to 107 meters, 3 to 350 feet), and the thickness of Layer 5 represents approximately 15 percent of the total aquifer thickness on average (1 to 193 meters, 3 feet to 633 feet).

Where the Lower Tuscan aquifer is present (the northeastern and central portions of the Valley), the elevation of the top of Layer 6 was defined by the structural contour surface of the top of the Lower Tuscan aquifer (Figure 9). Two layers were assigned to represent this unit because, in many areas of the model, the depth to the base of fresh water (the base of the model) is as much as 900 feet below the upper surface of the Lower Tuscan. Groundwater production wells drilled into the Lower Tuscan would almost certainly be screened over a much smaller depth interval. To represent this condition in the model, Layer 6 was assigned a thickness of between 250 to 360 feet (75 to 110 meters) in the central portion of the northern SVGB. The total range in Layer 6 thickness is approximately 3 to 580 feet (1 to 177 meters). The remaining Lower Tuscan thickness not apportioned to Layer 6 was assigned to Layer 7. The exception to this convention is in the northeastern portion of the model near the City of Chico. The Lower Tuscan outcrops in the foothills above Chico; thus, in these areas, all layers of the model represent the Lower Tuscan aquifer. Moving west from Chico, a transition zone exists where a decreasing number of layers represents the Lower Tuscan until it is limited to Layers 6 and 7, as discussed above. In areas where the Lower Tuscan is not present, the thicknesses of Layers 6 and 7 represent 18 and 27 percent of the total aquifer thickness, respectively. A contour map of the total saturated aquifer thickness is presented on Figure 8, and cross sections illustrating SACFEM2013 model layers are presented on Figures 10 and 11 (these oversized figures are presented at the end of this report).

3.2.2 Subsurface Hydraulic Parameters

The hydraulic parameters in the SACFEM2013 were initially assigned using available and relevant field data from previous investigations. Subsurface hydraulic properties required by MicroFEM include the horizontal hydraulic conductivity (Kh) and the vertical resistance.

3.2.2.1 Horizontal Hydraulic Conductivity

The distribution of aquifer properties across the SVGB is poorly understood. In certain areas with significant levels of groundwater production, the collection of aquifer test data and the measurement of historical groundwater-level trends in response to known groundwater production rates have provided valuable information on aquifer properties. However, in the majority of the Valley, these data are not available.

To estimate the spatial distribution of aquifer properties across the model domain for this numerical modeling effort, a database of well productivity information was used. In consultation with DWR staff, a database was obtained that included all of the specific capacity yield data that were available from well log records. These data were compiled along with well construction information for each production well to yield a representative data set of well productivity across the Valley. Wells that did not have available construction data were omitted from further consideration. To protect owner privacy, the exact location of each well was modified by DWR staff to reflect the center of the section in which each well was located. This modification in well location did not adversely affect the use of the data to estimate the spatial distribution of aquifer properties, given the extremely large area encompassed by the model domain. Approximately 1,000 wells in the database within the model domain were used in this analysis.

The intent of the modeling analysis described herein is to simulate the effects of operating high-productivity irrigation wells screened within the major producing zones in the Valley to support conjunctive water management projects. Therefore, the aquifer properties that are of primary interest are those of the major aquifer zones tapped by large-diameter irrigation wells. The well database described above was filtered to remove data obtained from tests on low-yield and shallow, domestic-type wells. All test data from wells that reported a well yield below 100 gpm were eliminated from consideration, as were the test data from wells with a total depth of less than 100 feet. The only exception to this second consideration was for wells that were located along the basin margins – where aquifers are thin – that reported what appeared to be valid test results. Data from these wells were considered because they were often the only data available in the basin margin areas.

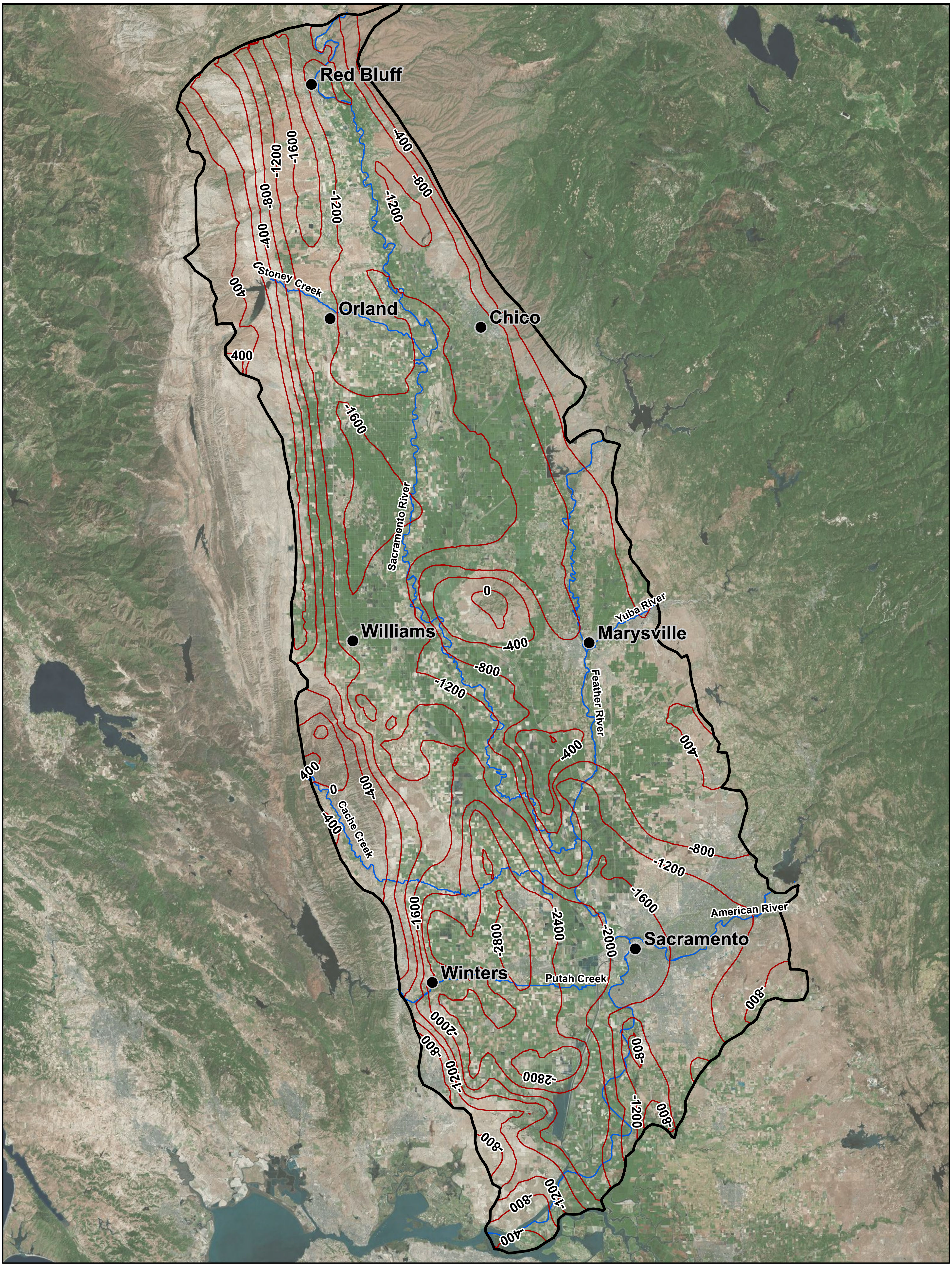
After the data set for consideration was finalized, the reported specific capacity data for each well were used to estimate an aquifer transmissivity for that location. The relationship used to estimate aquifer transmissivity was the following form of a simplified version of the Jacob non-equilibrium equation:

$$S_c = \frac{T}{2000} \tag{1}$$

Where:

S_c = specific capacity of an operating production well (gallons per minute per foot of drawdown)

T = aquifer transmissivity (gallons per day per foot)



LEGEND

- ● City
- — Major Stream
- ▭ SACFEM2013 Model Boundary
- — Simulated Base of Fresh Groundwater (feet NAVD88)

Note:
NAVD88 = North American Vertical Datum of 1988

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

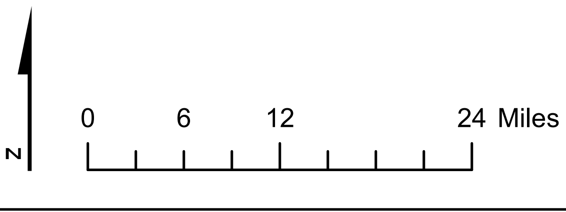
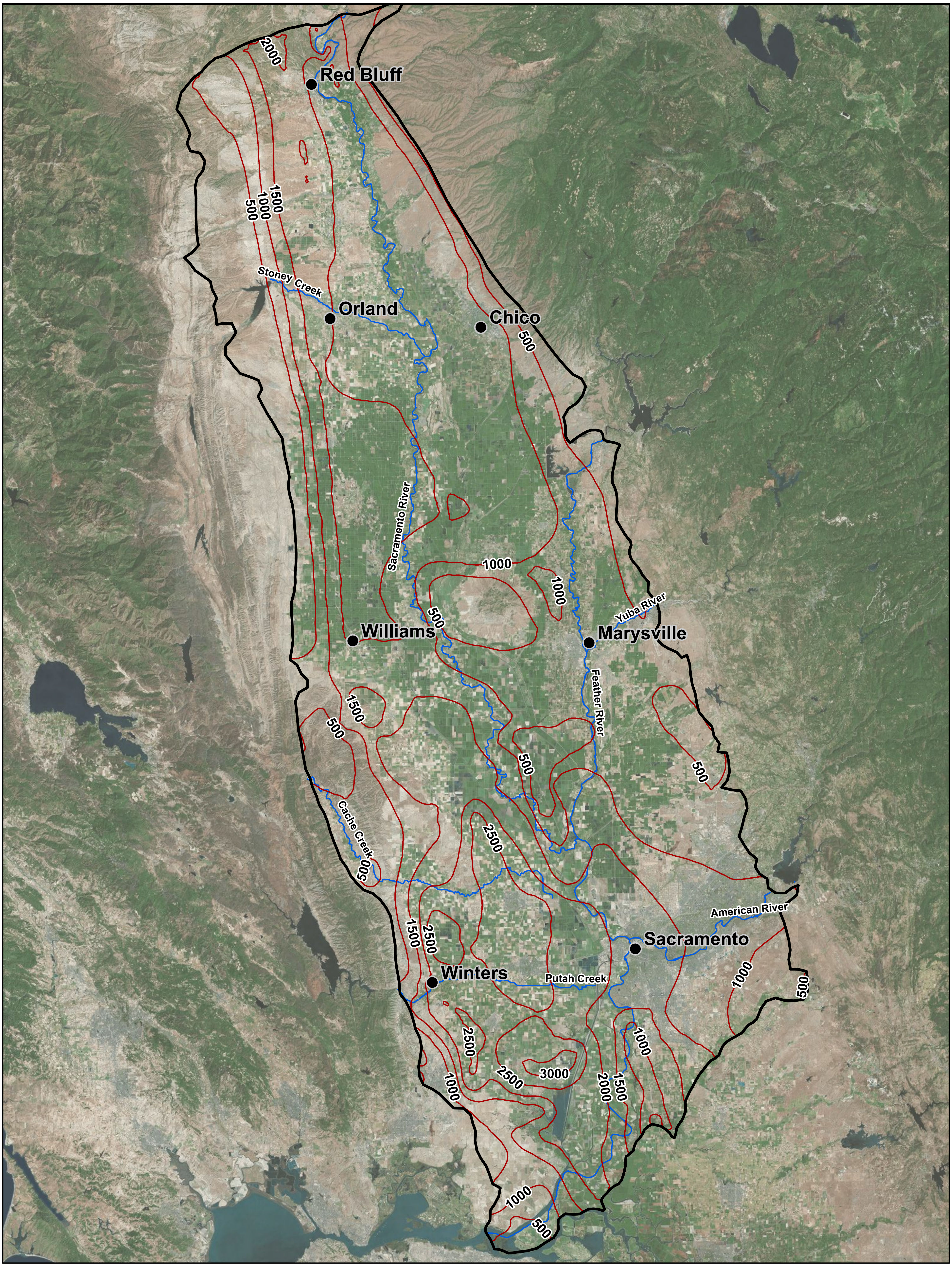


Figure 7
Base of Fresh Groundwater
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL



LEGEND

● City

Major Stream

SACFEM2013 Model Boundary

Contour of Equal Saturated Aquifer Thickness (feet)

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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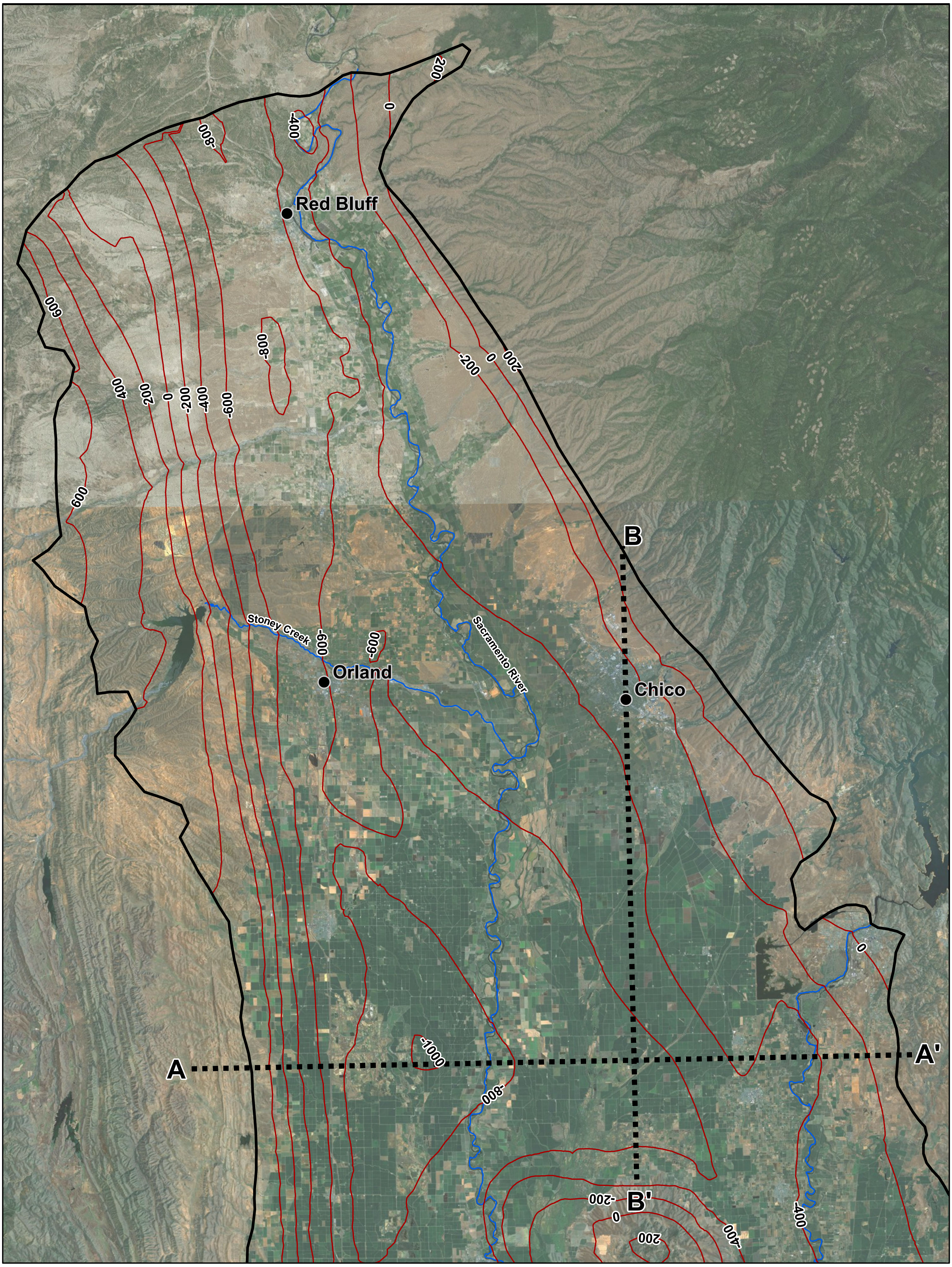
Figure 8
Total Saturated Aquifer Thickness
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL



LEGEND

● City

Major Stream

SACFEM2013 Model Boundary

Cross-Section Location

Contour of Equal Elevation
Top of Model Layer 6 (feet NAVD88)

Note:
NAVD88 = North American
Vertical Datum of 1988

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 9
Elevation of the Top of Model Layer 6
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

CH2MHILL.

After a transmissivity estimate was computed for each location, the transmissivity value was then divided by the screen length of the production well to yield an estimate of the aquifer Kh. The final step in the process was to smooth the Kh field to provide regional-scale information. Individual well tests produce aquifer productivity estimates that are local in nature, and might reflect small-scale aquifer heterogeneity that is not necessarily representative of the basin as a whole. To average these smaller-scale variations present in the data set, a FORTRAN program was developed that evaluated each independent Kh estimate in terms of the available surrounding estimates. When this program is executed, each Kh value is considered in conjunction with all others present within a user-specified critical radius, and the geometric mean of the available Kh values is calculated. This geometric mean value is then assigned as the representative regional hydraulic conductivity value for that location. The critical radius used in this analysis was approximately 6 miles (10,000 meters). The point values obtained by this process were then gridded to develop a Kh distribution across the model domain. The aquifer transmissivity at each model node within each model layer was then computed using the geometric mean Kh values at that node times the thickness of the model layer. Insufficient data were available to attempt to subdivide the data set into depth-varying Kh distributions, and it was, therefore, assumed that the computed mean Kh values were representative of the major aquifer units in all model layers.

The distribution of Kh was used as a calibration parameter for SACFEM2013, and minor adjustments were made during the calibration process. Figures 12 and 13 present the final Kh distributions for model Layers 1 through 5 and model Layers 6 and 7. The final distribution of Kh in model Layer 1 is slightly lower than model Layers 2 through 5 east of Dunnigan Hills; however, this is not readily apparent given the 20-foot contour interval on Figure 12. Further, bedrock areas within the interior of the SVGB were assigned Kh values of 1 foot per day in all model layers.

3.2.2.2 Vertical Resistance

MicroFEM computes vertical flow between adjacent model layers based on the simulated head difference between adjacent model layers and the vertical resistance term. The vertical resistance term in MicroFEM is calculated as follows:

$$c = \left(AF \times \frac{mt_i^2 \div 2}{t_i}\right) + \left(AF \times \frac{mt_{i+1}^2 \div 2}{t_{i+1}}\right) \tag{2}$$

Where:

c = Vertical resistance to flow between an upper model layer (i) and adjacent lower model layer (i+1) (days^{-1})
AF = Anisotropy factor (ratio of horizontal to vertical hydraulic conductivity [Kh:Kv])
Kv = Vertical hydraulic conductivity
mt_i = Saturated thickness of model layer i (length [L])
mt_{i+1} = Saturated thickness of model layer i+1 (L)
t_i = Transmissivity of model layer i (L^2/time [T])
t_i+1 = Transmissivity of model layer i (L^2/T)

The Kh:Kv values were assumed to be 500:1 in Layers 2 through 7 and 50:1 in Layer 1 at all model nodes except those representing bedrock areas. The Kh:Kv in areas of bedrock outcrop (such as the Sutter Buttes, Black Butte, and Dunnigan Hills) was assumed to be 1:1 in all model layers.

3.2.2.3 Aquifer Storage

The specific yield of model Layer 1 was assumed to be 12 percent throughout the SACFEM2013 model domain. The aquifer storativity of model Layers 2 through 7 is 6.5x10^{-5} multiplied by model layer thickness throughout the majority of the model domain, with variations along small portions of the model boundary.

3.2.3 Model Time Discretization

Time is continuous in the physical system, but a numerical model must describe the field problem at discrete time intervals. SACFEM2013 was set up to simulate transient flow conditions between WY1970 and WY2010. The period WY1970 through WY2010 was used because it includes very wet periods such as the winter of WY1983, as well as dry periods such as the WY1976 to WY1977 and WY1988 through WY1992 droughts. Using a climatic period of this type allows for assessing model accuracy and the water budgeting process and replicating observed conditions during periods of extreme hydrologic conditions, as well as the more average conditions that persisted throughout the remainder of the calibration period. The 41-year simulation was discretized with monthly stress periods. As such, model stresses (such as stream stage, groundwater pumping, deep percolation) and model output are assigned/evaluated monthly.

3.2.4 Boundary Conditions

Boundary conditions are mathematical statements describing either the head or the groundwater flux within a model domain (Anderson and Woessner, 1992). Correct selection of boundary conditions is a critical step in model construction because boundaries largely determine the flow pattern in steady-state models. Boundary conditions can represent either physical boundaries, such as impermeable rock, or hydraulic boundaries, such as groundwater divides or streamlines. The following types of boundary conditions are used with the SACFEM2013:

- **Head-dependent flux:** The flux across the boundary is calculated as a function of a defined head and a resistance term (which regulates seepage) by using an appropriate governing flow equation.
- **Specified-flux:** A prescribed groundwater flux is defined along the boundary or within the model domain.

3.2.4.1 Head-dependent Flux Boundaries

Groundwater-Surface Water Interaction. A head-dependent boundary condition was chosen to simulate the major streams, flood bypasses, and reservoirs within the SVGB. The MicroFEM wadi system was used to implement streams within the model domain. MicroFEM’s wadi package is a two-way, head-dependent boundary condition (that is, it can act as a source of groundwater recharge or as a groundwater sink) that calculates the magnitude and direction of nodal fluxes by using the relative values of the user-specified stream stage (wh1) and the calculated head in the upper aquifer (h1), but is limited by a critical depth (wl1). When calculated groundwater elevations fall below this critical depth, it is assumed that the water table de-couples from the river system, and the leakage rate from the river to the aquifer becomes constant. The equations that govern operation of the wadi package are as follows:

Groundwater discharge to a stream is simulated if h1 > wh1:

$$Q_{outflow} = a * (h1 - wh1) / wc1 \qquad (3)$$

In coupled streams (groundwater elevation is above the stream bottom elevation), groundwater recharge from a stream is simulated if h1 < wh1:

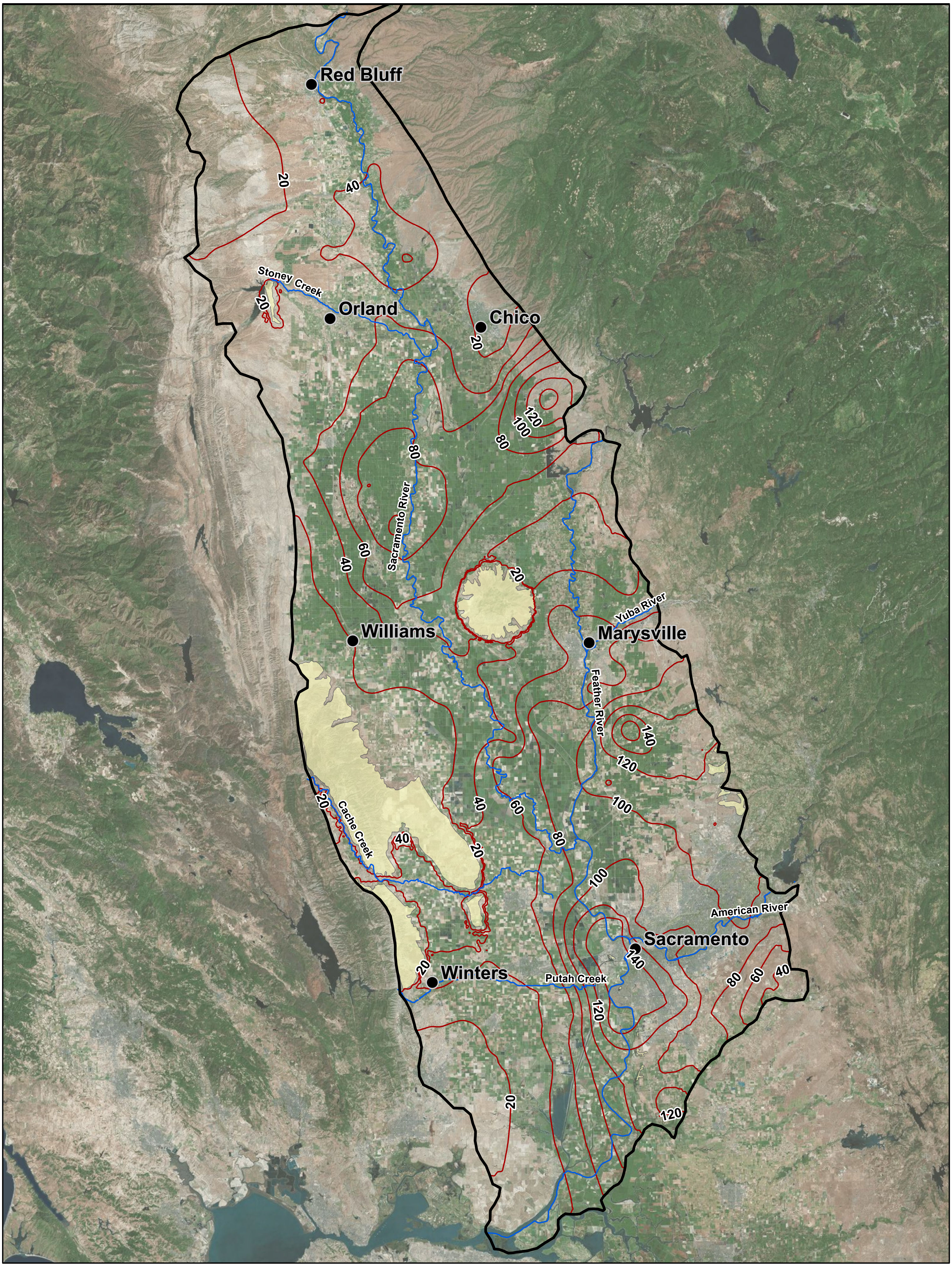
$$Q_{inflow} = a * (wh1 - h1) / wc1 \qquad (4)$$

In de-coupled streams (groundwater elevation is below the stream bottom elevation), groundwater recharge from a stream is simulated if:

$$Q_{inflow} = a * (wh1 - wl1) / wc1 \qquad (5)$$

Where:

Q = volumetric flux (L^3/T)
a = nodal area (L^2)
h1 = simulated groundwater elevation in layer 1 (L)
wh1 = simulated stream stage (L)
wl1 = stream bottom elevation (L)
wc1 = resistance across the streambed (T^{-1})



LEGEND

● City

— Major Stream

▭ SACFEM2013 Model Boundary

🟨 SACFEM2013 Bedrock Outcrop Areas

— Contour of Equal Horizontal Hydraulic Conductivity (feet per day)

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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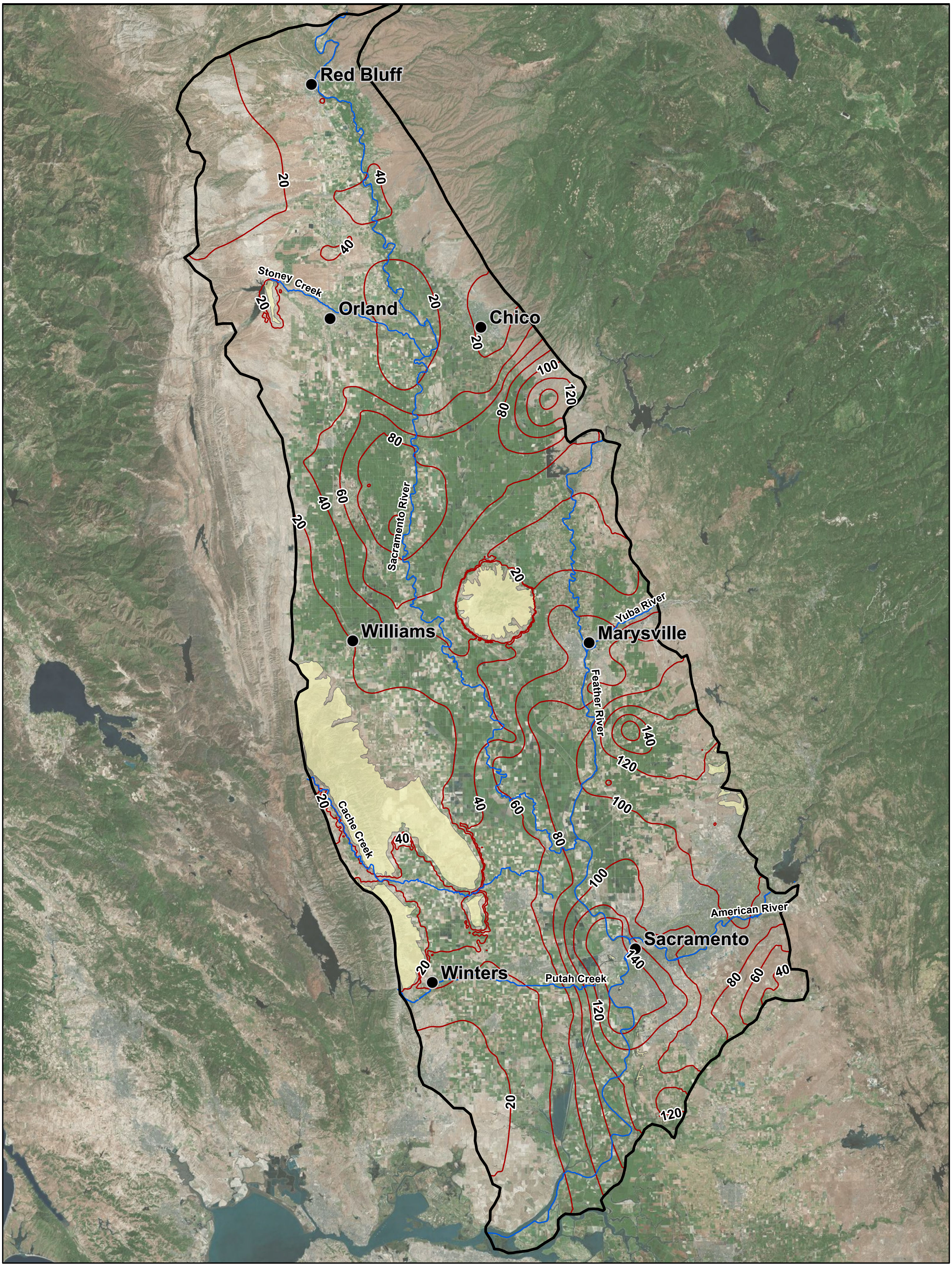
Figure 12
Distribution of Horizontal Hydraulic Conductivity Model Layers 1 through 5
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL



LEGEND

● City

— Major Stream

▭ SACFEM2013 Model Boundary

▭ SACFEM2013 Bedrock Outcrop Areas

— Contour of Equal Horizontal Hydraulic Conductivity (feet per day)

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 13
Distribution of Horizontal Hydraulic Conductivity Model Layers 6 and 7
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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Nodal area is a grid-dependent parameter that can be automatically calculated within MicroFEM. In general, the nodal area around a node that represents a discrete reach of a stream is greater than the surface area of that stream along the reach in the field. The effective resistance term (wc1) incorporates an areal correction factor to account for this discrepancy; the wadi resistance term (wc1) is a measure of the resistivity of the streambed sediments. The resistances are calculated as follows:

$$wc1 = Dr/Kv * (a/LW) \tag{6}$$

Where:

Dr = thickness of streambed sediments (L)
Kv = vertical hydraulic conductivity of streambed sediments (L/T)
L = stream length represented by the model node (L)
W = field width of the wetted river channel within the stream reach represented by L (L)

Fifty individual streams are simulated with MicroFEM’s wadi package in the current version of SACFEM2013. Stream locations were digitized from existing base maps and USGS topographic quad sheets and imported into the model domain. Figure 14 presents the locations of surface water features included in SACFEM2013. Stream length within a given node is a grid-dependent variable calculated by MicroFEM at each river node. The stream-length term is generally overestimated by MicroFEM at stream confluences. Manual corrections of this term were made where necessary. Streambed thickness was assumed to be 3.28 feet (1 meter) for all river nodes. Assumptions of streambed Kv were based on the type of streambed deposits expected given stream size. Further, the streambed Kv for individual streams was included as a calibration parameter for SACFEM2013. Figure 15 presents the final distribution of streambed Kv. These data are also included in Table 2. Streams draining the Sierra Nevada were generally assigned lower streambed Kv values, with all streams except the Bear River and Big Chico Creek having values of 6.6 ft/day (0.0023 centimeters per second [cm/s]) or less. Westside streams were assigned higher values, with most having assigned Kv values greater than or equal to 16.4 ft/day (0.0058 cm/sec).

Wetted stream width was calculated from aerial photographs at two locations along each stream. Table 3 presents the average wetted stream width included in SACFEM2013. Few streams showed greater variability in width to necessitate developing a continuously variable distribution along the stream length. This was accomplished by estimating wetted stream width at several points via examination of aerial photographs and fitting a polynomial to the data points to interpolate between the measured points. The ranges of wetted stream width are included in Table 3 for these streams.

Representation of Streams. Previous versions of SACFEM included average stream stage elevations (wh1) in the model simulations that did not vary through time. SACFEM2013 incorporates transient stream stage elevations to improve the representation of stream-groundwater interaction under varying hydrologic conditions. Review of historical river stage data shows that stage along the Sacramento and Feather rivers can vary by up to approximately 20 feet between high winter flows and low summer flows. Figure 16 is a plot of historical stage data for the Sacramento and Feather Rivers that illustrates this variability.

A data set of transient stream stage (wh1) was developed for use in SACFEM2013. This involved multiple steps and several assumptions as described in the following sections. There are 55 rivers, streams, and surface water canals or drains and reservoirs explicitly represented in SACFEM2013 (see Figure 14). These 55 surface water features are represented by approximately 5,500 model nodes. As discussed in Section 2.1, SACFEM2013 simulates a 41-year period from WY1970 through WY2010 with 492 monthly time-steps. Therefore, transient stream stage inputs for SACFEM2013 number approximately 2.7 million separate inputs for the entire simulation period (i.e., 5,500 nodes multiplied by 492 time-steps).

Estimating Streambed Elevations. The first step in developing transient stream stage inputs was to estimate the streambed elevation for each stream node. MicroFEM input for stream boundary conditions consists of a water surface elevation (WSE) for each node that must relate to the model streambed elevation for the node. Streambed elevations must also relate to model ground surface elevation for surrounding nodes. Therefore, a consistent vertical datum must be used for ground surface, streambed, and WSE.

The ground surface in SACFEM2013 is based on 30-meter digital elevation model (DEM) data. Model ground surface was developed through a GIS analysis that intersected the SACFEM2013 grid with 30-meter DEM data and calculated statistics for areas that contribute to each SACFEM2013 node. Statistics include the maximum, minimum, and mean elevations for areas that contribute to each node. Ground surface elevation for each node was assumed to be equal to the mean DEM elevation. An initial streambed elevation was estimated as the minimum DEM elevation for the area that contributes to each stream node.

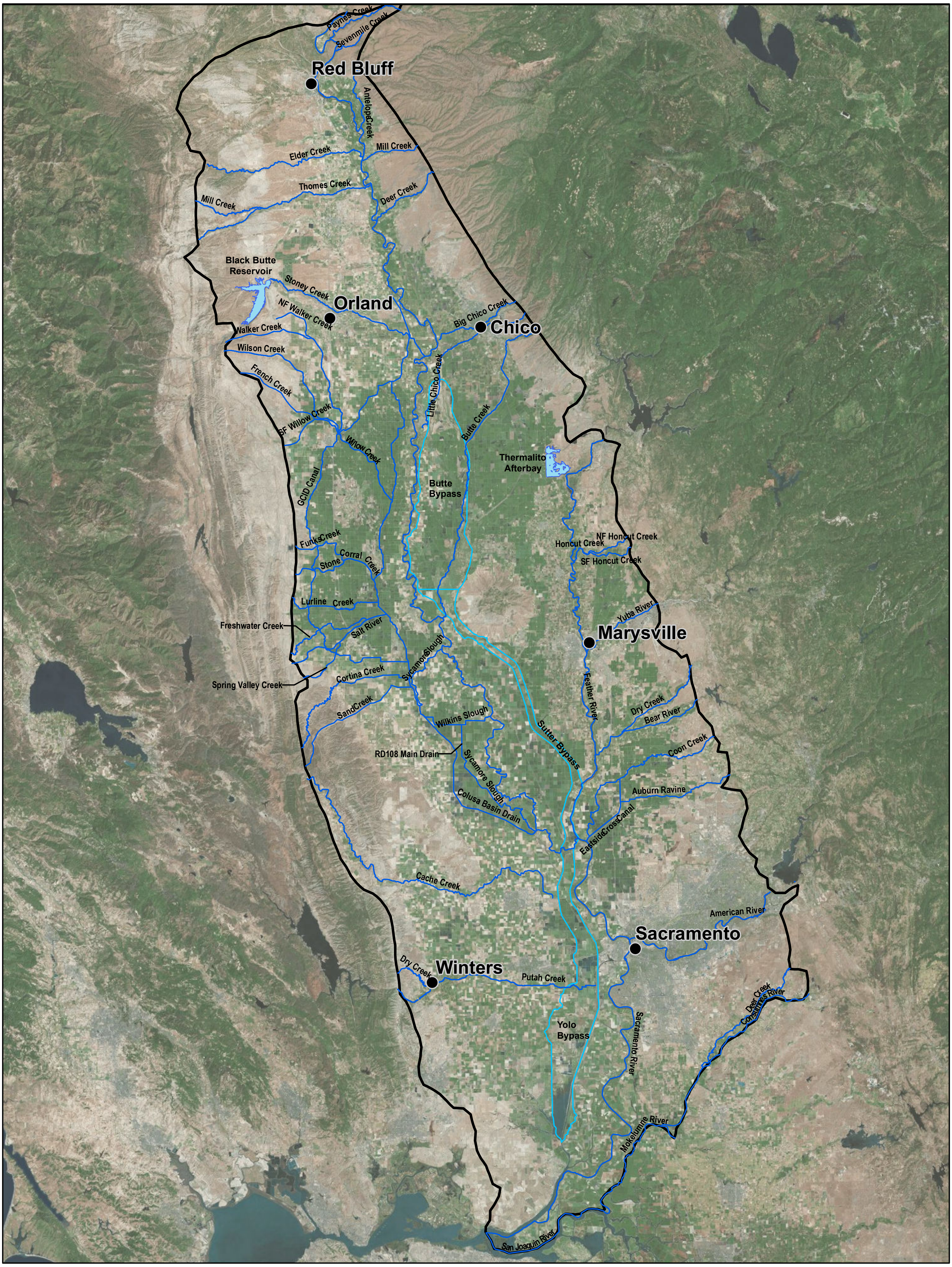
Minimum DEM elevations, or initial streambed elevations, for each stream were reviewed and plotted versus stream node distance from the confluence. These plots illustrate initial streambed elevation based on DEM data from downstream to upstream. Figure 17 is an example of the initial streambed elevation data for all Sacramento River stream nodes.

Review of initial streambed elevations for many streams showed unrealistic increases and decreases in streambed elevations between nodes. For the Sacramento River, minimum DEM elevations provided streambed elevations that are generally flat in the lower reaches of the Sacramento River in and near the Sacramento-San Joaquin River Delta, and a steeper streambed slope at the upstream end of the model. These are expected results based on the topography of the Sacramento Valley. However, there are also areas of significant variation in streambed elevation such as the reach between 75 and 100 miles upstream from the confluence with the San Joaquin River (see Figure 17). These variations illustrate limitations of using 30-meter DEM data and GIS analysis to estimate streambed elevation. Therefore, for each stream, a polynomial trend line was fit through the minimum DEM elevations to provide a more ordered set of streambed elevations. Figure 18 illustrates the trend line used to estimate streambed elevation along the Sacramento River. The trend line provides a set of well-ordered streambed elevations that decrease from upstream to downstream while generally following the topography of the basin.

Stream Stage. A well-ordered estimate of streambed elevation is needed to best utilize available stage and flow data. SACFEM2013 stream stage inputs were developed to represent historical stage that occurred in each surface water feature. Therefore, historical stream stage and flow data were collected and analyzed. These data were collected from a variety of sources including USGS records, DWR gage records and publications, and available data from local water districts and agencies. Available stream stage data are frequently based on different vertical datums, including elevations for individual gages that cannot be related to a standard vertical datum such as North American Vertical Datum of 1988 (NAVD 88). Therefore, it is not possible to establish a consistent vertical datum for all available stage and flow data. Additionally, many gaged streams report only stream flow, not stage, and rating curves are not readily available for most of these streams, or if available, rating curves do not provide the vertical datum.

To utilize as much of the available gage data as possible while addressing the issue of multiple or unknown vertical datums, historical stage data were assumed to approximate stream depth above the streambed elevation. Historical stream depths were then added to estimated streambed elevations to determine water surface elevations for input into SACFEM2013.

There were multiple challenges to develop a complete and realistic dataset of water surface elevations for all surface water features in SACFEM2013. These challenges included estimates for ungaged streams or gaged streams with an incomplete record, estimates for stage along the entire length of the stream based on a single gage location, and methods to estimate water surface elevations at stream confluences.



LEGEND

- ● City
- — SACFEM2013 Stream
- — Flood Bypass
- ▭ SACFEM2013 Model Boundary

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 14
SACFEM Surface Water Features
SACFEM: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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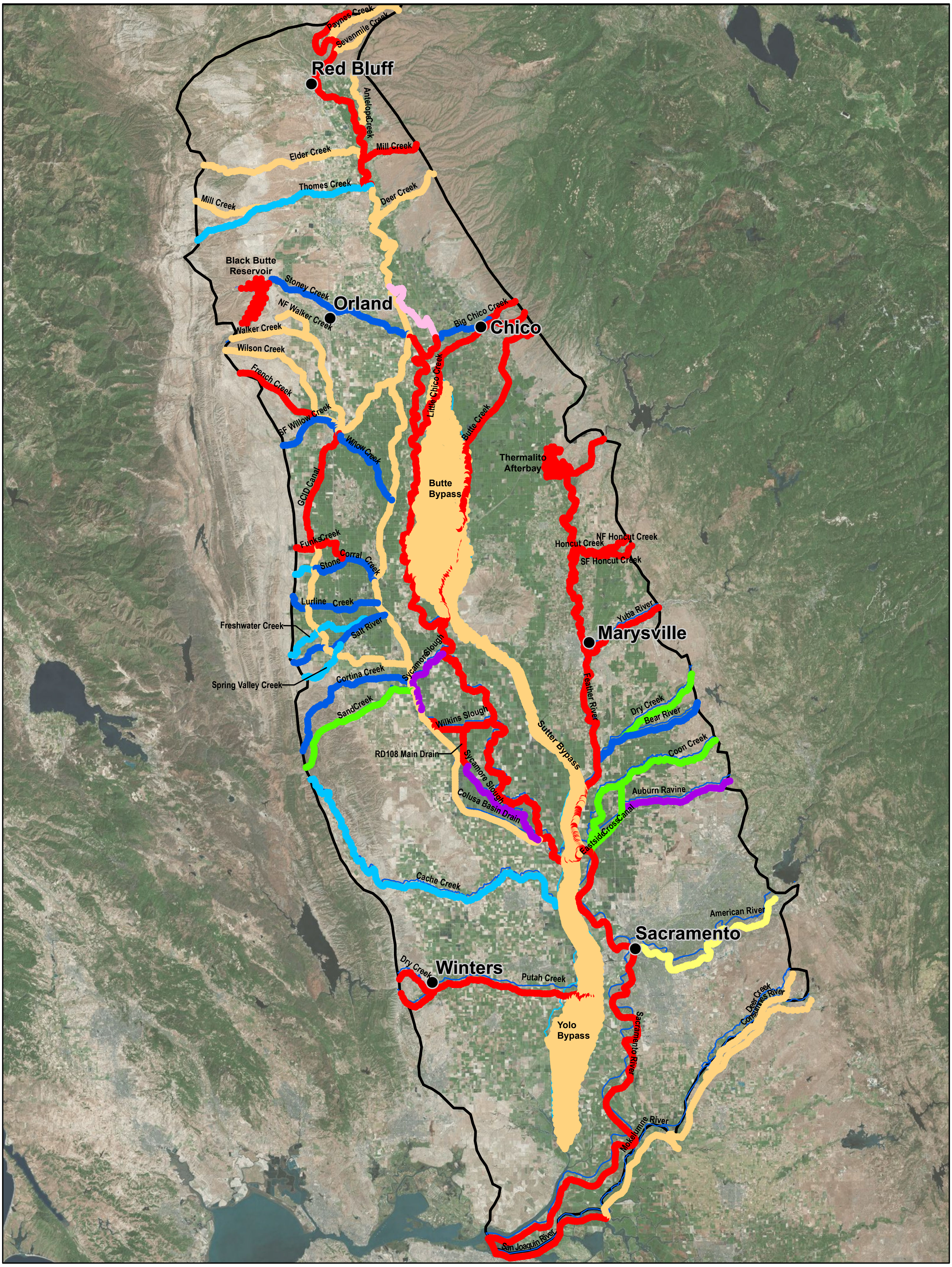

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 15
Distribution of Vertical Hydraulic Conductivity, Surface Water Features
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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TABLE 2

Assumed Streambed Vertical Hydraulic Conductivity

SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Stream	Vertical Hydraulic Conductivity (foot/day)	Vertical Hydraulic Conductivity (centimeters/second)
American River	0.1	3.47E-05
Antelope Creek	0.3	1.16E-04
Auburn Ravine	0.7	2.31E-04
Bear River	32.8	1.16E-02
Big Chico Creek	3.3 – 32.8	1.16E-03 – 1.16E-02
Black Butte Reservoir	3.3	1.16E-03
Butte Bypass	0.3	1.16E-04
Butte Creek	3.3	1.16E-03
Cache Creek	16.4	5.79E-03
Colusa Basin Drain	0.3	1.16E-04
Consumnes River	0.3	1.16E-04
Coon Creek	6.6	2.31E-03
Cortina Creek	32.8	1.16E-02
Deer Creek (Tehama County)	0.3	1.16E-04
Deer Creek (Sacramento County)	0.3	1.16E-04
Dry Creek (Yolo County)	3.3	1.16E-03
Dry Creek (Yuba County)	6.6	2.31E-03
Eastside Cross Canal	6.6	2.31E-03
Elder Creek	0.3	1.16E-04
Feather River	3.3	1.16E-03
French Creek	3.3	1.16E-03
Freshwater Creek	16.4	5.79E-03
Funks Creek	3.3	1.16E-03
Glen Colusa Irrigation District Canal	0.3 – 3.3	1.16E-04 – 1.16E-03
Honcut Creek	3.3	1.16E-03
Little Chico Creek	3.3	1.16E-03
Lurline Creek	32.8	1.16E-02
Mill Creek (Eastern Tehama County)	3.3	1.16E-03
Mill Creek (Western Tehama County)	0.3	1.16E-04
Mokelumne River	0.3	1.16E-04
North Honcut Creek	3.3	1.16E-03
North Fork Walker Creek	0.3	1.16E-04
Paynes Creek	0.3	1.16E-04
Putah Creek	3.3	1.16E-03
RD108 Main Drain	3.3	1.16E-03
South Honcut Creek	3.3	1.16E-03
Sacramento River	0.3 – 3.3	1.16E-04 – 1.16E-03

TABLE 2

Assumed Streambed Vertical Hydraulic Conductivity

SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Stream	Vertical Hydraulic Conductivity (foot/day)	Vertical Hydraulic Conductivity (centimeters/second)
Salt River	32.8	1.16E-02
San Joaquin River	3.3	1.16E-03
Sand Creek	6.6	2.31E-03
Seven Mile Creek	0.3	1.16E-04
South Fork Willow Creek	32.8	1.16E-02
Spring Valley Creek	16.4	5.79E-03
Stone Corral Creek	16.4 – 32.8	5.79E-03 – 1.16E-02
Stoney Creek	3.3 – 32.8	1.16E-03 – 1.16E-02
Sutter Bypass	0.3	1.16E-04
Lower Sycamore Slough	0.7	2.31E-04
Thermalito	3.3	1.16E-03
Thomes Creek	16.4	5.79E-03
Walker Creek	0.3	1.16E-04
Wilkins Slough Canal	3.3	1.16E-03
Willow Creek	32.8	1.16E-02
Wilson Creek	0.3	1.16E-04
Yolo Bypass	0.3	1.16E-04
Yuba River	3.3	1.16E-03

TABLE 3

Wetted Stream Width Values

SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Stream Name	Wetted Stream Width (feet)
American River	394
Antelope Creek	49
Auburn Ravine	33
Bear River	91 – 167
Big Chico Creek	49
Butte Creek	43 – 144
Cache Creek	39 – 108
Colusa Basin Drain	24 – 100
Consumnes River	98
Coon Creek	49
Cortina Creek	33
Deer Creek (Tehama County)	66
Deer Creek (Sacramento County)	49

TABLE 3

Wetted Stream Width Values

SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Stream Name	Wetted Stream Width (feet)
Dry Creek (Yuba County)	49
Dry Creek (Yolo County)	49
Eastside Cross Canal	49
Elder Creek	13 – 79
Feather River	233 – 758
French Creek	16
Freshwater Creek	33
Funks Creek	33
Glen Colusa Irrigation District Canal	43 – 242
Honcut Creek	49
Little Chico Creek	20 – 144
Lurline Creek	33
Mill Creek (Eastern Tehama County)	49
Mill Creek (Western Tehama County)	33
Mokelumne River	312
North Fork Walker Creek	33
North Honcut Creek	66
Paynes Creek	33
Putah Creek	61 – 95
RD108 Main Drain	65
Sacramento River	230 – 4,433
Salt River	16
San Joaquin River	3,248
Sand Creek	33
Sevenmile Creek	33
South Fork Willow Creek	33
South Honcut Creek	49
Spring Valley Creek	16
Stone Corral Creek	33
Stoney Creek	56 – 131
Sycamore Slough	10 – 115
Thomes Creek	49
Walker Creek	49
Wilkins Slough Canal	49
Willow Creek	33
Wilson Creek	33
Yuba River	230 – 356

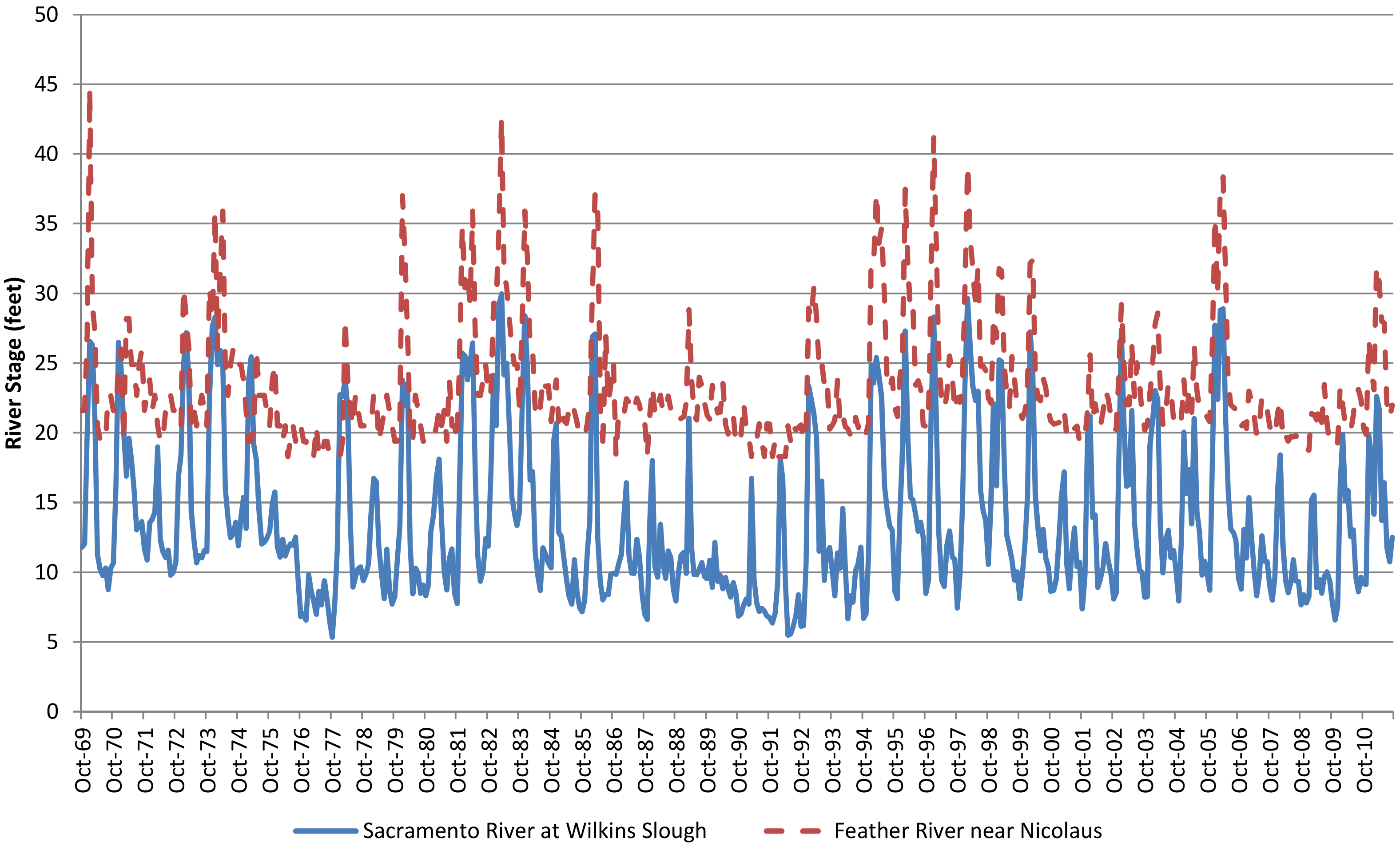


Figure 16
Historical Sacramento and Feather River Stage

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

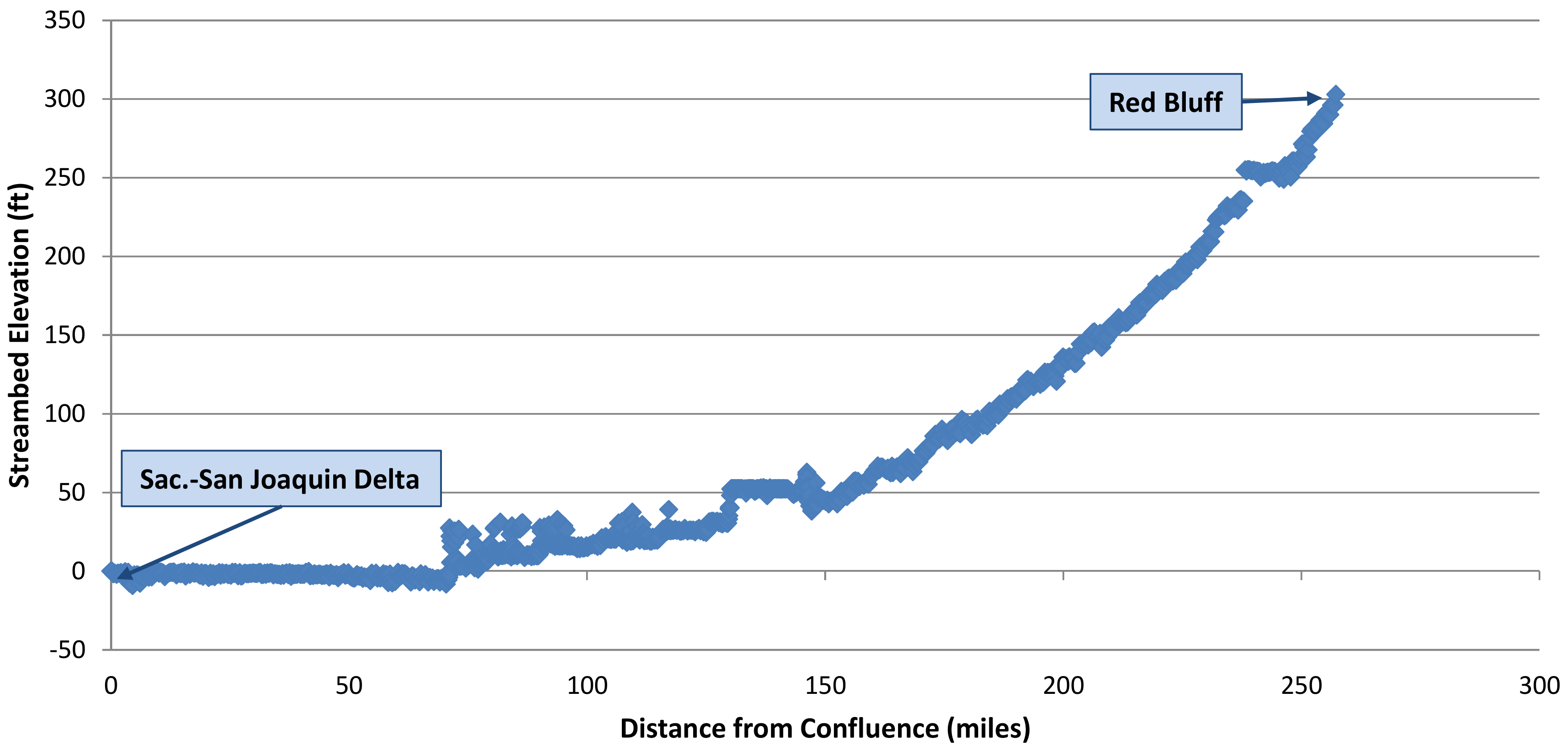


Figure 17
Initial Sacramento River Streambed Elevation based on 30-meter Digital Elevation Model Data

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

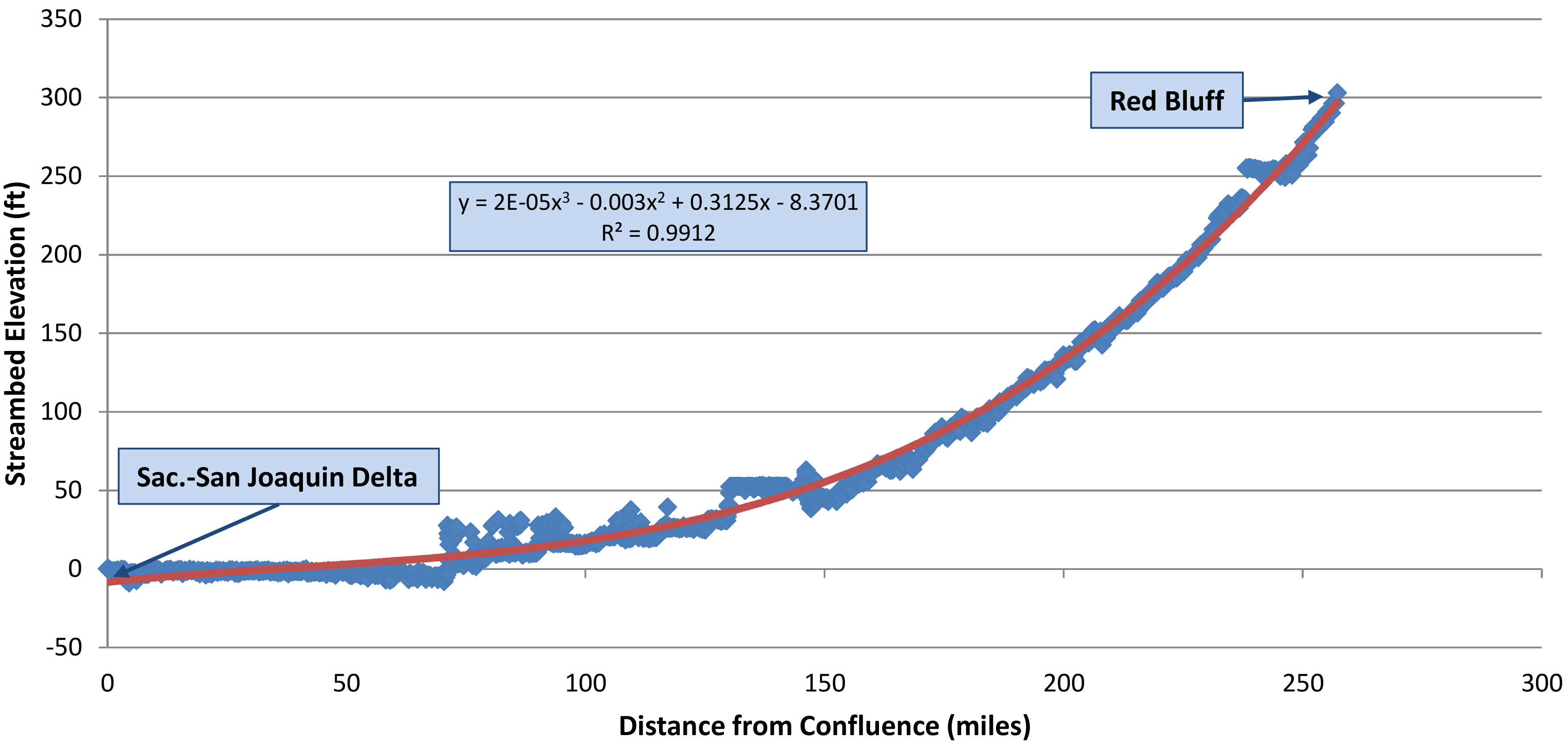


Figure 18
Sacramento River
Streambed Elevation based on Regression Trendline
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

Ungaged Streams and Incomplete Records. Review of available stream stage and flow data identified available records for all or a part of the simulation period for 35 streams and canals explicitly represented in SACFEM2013. The remaining surface water features were estimated using data from nearby and similar gaged streams. The majority of ungaged streams are small streams on the west side of the Colusa Basin or small streams near the Bear River. Incomplete gage records were extended or missing periods filled by correlation with nearby and similar streams with complete records, when an adequate correlation could be developed. When an adequate correlation could not be developed, these streams were estimated based on nearby and similar gaged streams.

Stage along Length of Streams. Most gaged streams are gaged at only one location along the entire length of the stream. This information provides one data point on stream stage that must then be extended along the entire length of the stream for all stream nodes. Absent any additional data, it was assumed that depth of water at the gage location is uniform along the length of the stream. Multiple factors can affect stream stage along the length of the stream including watershed area contributing to flow, diversions and return flows from the stream, channel geometry, and others. Attempting to research and account for all such factors for each stream would be a significant undertaking beyond the scope of this project. Exceptions to this assumption are the Sacramento and Feather Rivers. Multiple gages for flow or stage exist along these two rivers, and these gages were used to develop SACFEM2013 inputs. Table 4 shows the gage data used to estimate stream depth along each river.

TABLE 4
Gage Locations Used to Estimate Sacramento and Feather River Stage
SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Sacramento River Gages	Feather River Gages
Bend Bridge	Gridley
Colusa	Yuba City
Wilkins Slough	Nicolaus
Verona	
Freeport	

Water depth at stream nodes nearest gage locations was set equal to the gage record. Water depth at stream nodes between each gage location was interpolated based on stream distance. Water depths at stream nodes upstream of the most upstream gage (i.e., Bend Bridge on the Sacramento River and Gridley on the Feather River) were assumed to equal depth at the gage. Water depths in the Sacramento River downstream of Freeport were assumed to equal water depth at Freeport. Water depths in the Feather River between Nicolaus and the confluence with the Sacramento River were determined based on gage data at Nicolaus and the estimate of Sacramento River water surface elevation at the confluence as described in the following section.

Stream Confluences. An additional review was undertaken and adjustment was made where tributary streams join the Sacramento and Feather Rivers. In some streams and time-steps, WSE in tributary stream nodes at the downstream end of the stream was below the calculated WSE in the trunk stream where the tributary entered. For these tributary streams and time-steps, the WSE in the tributary stream nodes was set equal to the WSE in the trunk stream to represent a back-water effect at the confluence. This adjustment was made at each tributary stream node where the calculated WSE was less than that in the trunk stream for the given time-step.

Review and Quality Assurance. WSE inputs were calculated for each of the approximately 5,500 stream and canal nodes simulated in SACFEM2013 for each of the 492 model time-steps. A spreadsheet was developed to plot streambed and water surface elevation for a given stream and time-step as a method to review and check the input files. A plot for each time-step was created and saved for a given stream, and all plots were compiled into a single audio video interleave (AVI) file to illustrate stream WSE throughout the simulation period. AVI files were reviewed to ensure that input WSEs were reasonable and varied appropriately through time.

Figure 19 is an example of individual time-step plots for the American River WSE. Figure 19 illustrates WSE and the streambed in February 1986 during a large flood event, and August 1992 during a critical drought.

Figure 19 illustrates change in American River WSE for these two months. Figures such as these were developed for each time-step and reviewed to ensure WSE increased and decreased appropriately through time and relative to simulated streambed elevation. These figures also illustrate how WSE at the downstream end of the American River was adjusted based on the WSE in the Sacramento River in these time-steps. WSE at nodes in the downstream end of the American River is controlled by stage in the Sacramento River in both figures. WSE in these nodes was set equal to the WSE in the Sacramento River at the confluence with the American to represent back-water effects in the lower American River and avoid having adjacent stream nodes with significant differences in simulated WSE.

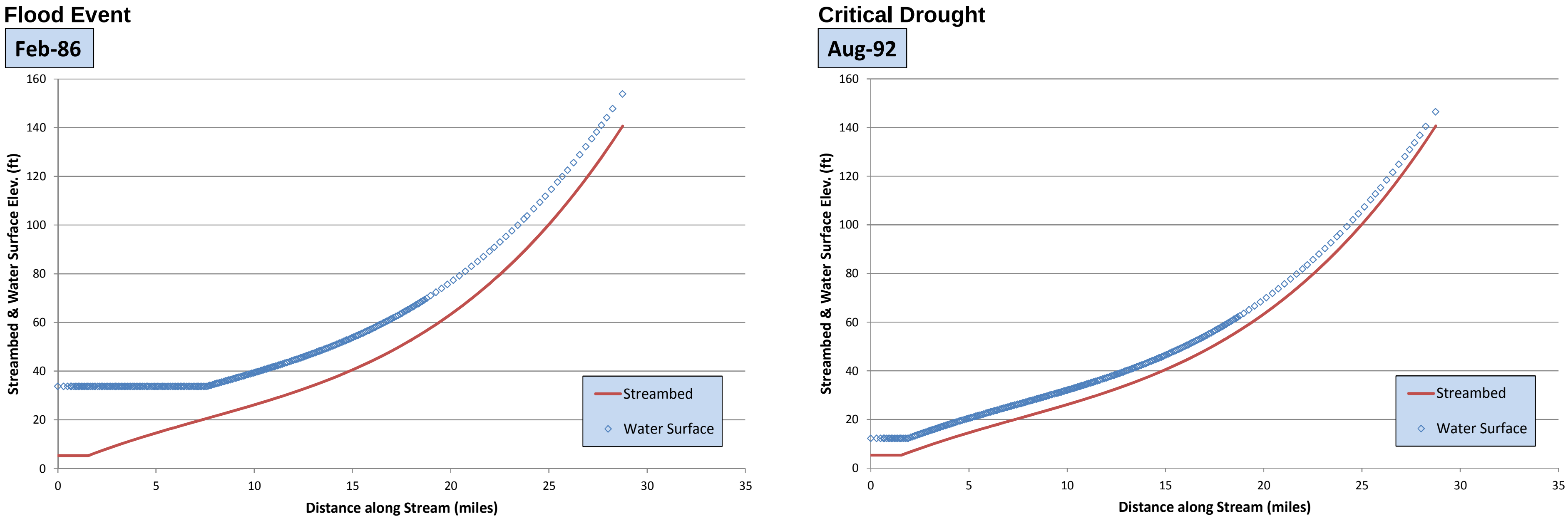
Representation of Flood Bypasses. A similar process was used to estimate water surface elevation within flood bypass areas in the SVGB. These areas differ from stream nodes in that the majority of nodes within the flood bypass areas are typically dry. However, during wet periods some or all of these nodes are flooded and represent a source of aquifer recharge in SACFEM2013.

Definition of Flood Bypass Areas. The first step in calculating WSE inputs in flood bypass areas was to delineate areas within the three major flood bypasses of the Butte Basin, Sutter Bypass, and Yolo Bypass. Each of these three major areas was further divided into sub-areas based on locations of major inflows or outflows. Existing GIS data on locations of levees and bypasses were used to identify bypass areas. Figure 20 illustrates the flood levee locations and the polygons used to represent the flood bypass areas and where those areas were subdivided.

After flood bypass areas were identified in GIS, bypass areas were intersected with the SACFEM2013 model grid to identify model nodes within bypass areas. This process identified 15,742 model nodes within bypass areas. Model ground surface elevation for these nodes was also identified based on 30-meter DEM data statistics for the area contributing to each node. The minimum elevation from the GIS intersection with DEM data was used as ground surface for nodes within bypass areas.

The approach to calculate WSE within flood bypass areas differs from that used for streams and other surface water features. An actual WSE was calculated based on historical flow data and flow-stage relationships from existing hydraulic models of the Sacramento River flood control system. Historical flow data were compiled from a variety of sources including USGS gage records and DWR's Water Data Library and California Data Exchange Center. Flows within bypass areas are from streams such as Butte and Cache Creeks plus flows over the Moulton, Colusa, Tisdale, Fremont, and Sacramento weirs. Flow goes over these weirs and into the bypass areas when stage is high in the Sacramento and Feather Rivers.

Flow was estimated at each of the lines that separate the flood bypass sub-areas on Figure 20. These separating lines represent cross section locations in the hydraulic model. For example, flow was estimated at the horizontal line that separates the upper Butte Basin area (BB1 Upper) from the middle Butte Basin area (BB2 Middle). Streams that contribute to flow in the upper Butte Basin area include Big and Little Chico creeks and Butte Creek. These flows were summed to estimate flow at the cross section between the upper and middle Butte Basin areas. Estimates of flow at downstream cross sections were made by adding additional inflows to the estimated flow at the upstream cross section. For example, flow at the cross section that separates the middle and lower Butte Basin (BB3 Lower) area was estimated by adding spills over the Moulton Weir to flows at the upstream cross section.



Flood Event

Feb-86

Critical Drought

Aug-92

Figure 19
American River Water Surface Elevation during Flood Event and Drought

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model

USER'S MANUAL

Flows at each cross section were used to calculate a WSE at the cross section. Flow-stage relationships from hydraulic models were used to estimate WSE with the same vertical datum as the ground surface in SACFEM2013. It was assumed that WSE changed linearly from upstream to downstream, and WSE at nodes between cross sections was interpolated from WSE at the upstream and downstream cross sections based on distance. WSE in the most upstream section, upper Butte Basin area (BB1 Upper), and most downstream section, lower Yolo Bypass (YB4 Lower), was assumed to be constant. This assumption is reasonable for the lower Yolo Bypass where flow enters the Sacramento-San Joaquin Delta. This assumption was made for the upper Butte Basin because there is little data to estimate inundated areas.

Calculated WSE was compared to ground surface elevation for each node to determine if the node was flooded. Some nodes within flood bypass areas are at higher elevation and may not flood at the same time as lower elevation nodes. WSE is calculated only for nodes that are flooded during a given time-step. Nodes that are not flooded are identified with a WSE of “-99” in the input files.

Review and Quality Assurance. WSE inputs are calculated for each of the 15,742 model nodes located within flood bypass areas for each of the 492 model time-steps. A spreadsheet was developed to plot WSE for all bypass area nodes compared to ground surface to review and check input files in each time-step. These plots were saved and compiled into a single AVI file to allow for easier review. Figure 21 is an example of one plot for the January 1995 time-step when most of the flood bypass areas were flooded.

Figure 21 is a plot of ground surface and WSE for each of the 15,742 model nodes in January 1995. The x-axis is the northing, so that the left side of the plot illustrates the downstream end of the flood bypass areas, the lower Yolo Bypass, and the right side illustrates the upstream end or upper Butte Basin. Cross sections are denoted by the black vertical lines that also mark changes in slope in the WSE line. Multiple ground surface elevations for a given northing indicate the multiple model nodes in the east-west direction across the flood bypass area. In the lower Yolo Bypass, many nodes have ground surface elevations above the WSE in this time-step and are not flooded. This is consistent with the topography of the lower Yolo Bypass where areas on the western side of the bypass are at higher elevation and flood less frequently than the eastern side.

Reservoir Water Surface Elevation. The final surface water bodies simulated in SACFEM2013 using MicroFEM’s wadi package are the major reservoirs located within the interior of the SVGB, Black Butte Reservoir and Thermalito Afterbay. The lake bottom elevations were assumed to be constant for both reservoirs, and were simulated as 100 feet below the average DEM elevation (assumed to represent lake stage) for Black Butte Reservoir and 40 feet below the average DEM elevation for Thermalito Afterbay. The wc1 values were assumed to be 1 for both reservoirs. The lake-stage elevation was assumed to be constant spatially across each reservoir; however, historical data were evaluated to develop monthly-variable lake-stage datasets for the SACFEM2013 simulation period.

Groundwater Discharge to Land Surface. MicroFEM’s drainage package was used to simulate boundary conditions across the top surface of the model, excluding nodes where wadi boundaries exist. Drainage boundary conditions are one-way head-dependent boundaries that allow the transfer of water out of the model domain only. The elevation of the drain boundaries were set at the land surface. The drain boundaries were included in the model to represent a combination of surficial processes that occur in areas of shallow groundwater, including evapotranspiration and groundwater discharge to the surface. Additionally, specific streams and flood bypasses were converted from wadi boundary conditions to drain boundary conditions during periods when a given surface water body was interpreted as being dry.

Groundwater discharge to a drain is simulated as follows if h1 > dh1:

$$Q_{outflow} = a * (h1 - dh1) / dc1 \tag{7}$$

Where:

Q = volumetric flux (L^3/T)
a = nodal area (L^2)
h1 = simulated groundwater elevation in model layer 1 (L)
dh1 = simulated drainage boundary elevation (L)
dc1 = resistance of the drainage boundary (T^{-1})

Groundwater discharge to a drain is simulated as follows if h1 < dh1:

$$Q_{outflow} = 0 \tag{8}$$

The parameter dc1 represents the drain conductance and is a measure of the resistance to flow across the drain boundary. The dc1 was assumed to be 500 throughout the model domain.

3.2.4.2 Specified-flux Boundaries

Three sets of specified-flux boundary conditions were implemented in the SACFEM2013 model. These conditions are as follows: (1) deep percolation of applied water and precipitation along with agricultural pumping, (2) mountain-front recharge, and (3) urban pumping. Each is discussed in more detail below.

Deep Percolation of Applied Water, and Precipitation and Agricultural Pumping. The first set of specified-flux boundary conditions reflects the deep percolation of precipitation and applied water across the Valley, as well as the regional agricultural pumping. The deep percolation flux values were applied to every surface node in the model. The pumping stresses due to agricultural pumping were applied at selected locations in model Layers 2 through 4 (the depths of the regional producing zones across the Valley). The spatial distribution and magnitudes of these fluxes were derived from the surface water budget calculations described in full detail in the Surface Water Budget, Section 3.2.5.

Mountain-front Recharge. The second set of specified-flux boundary conditions represents the subsurface inflow of precipitation falling within the Sacramento River watershed but outside the extent of the model domain. To estimate these flux values, the USGS 30-meter DEM along with GIS-based hydrography coverages for the SVGB were used to delineate the drainage areas that are tributary to the model domain but fall outside of the watersheds of the streams explicitly represented in the model. It is these areas that can contribute water to the model domain but are not accounted for in the wadi boundary conditions defined in the model. After the extents of these watershed areas were defined, they were intersected with monthly PRISM[4] rainfall datasets using GIS tools, and the volume of precipitation falling on the watershed was computed. Using the computed total volume of precipitation, the deep percolation to the groundwater system was calculated using the following empirical relationship developed by Turner (1991):

$$DP = (PPT-2.32)*(PPT)^{0.66} \tag{9}$$

Where:

DP = average annual deep percolation of precipitation (inches per year)
PPT = annual precipitation (inches per year)

The process that was used to estimate the quantity of subsurface inflow, otherwise known as mountain-front recharge, is summarized as follows:

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[4] http://prism.oregonstate.edu/

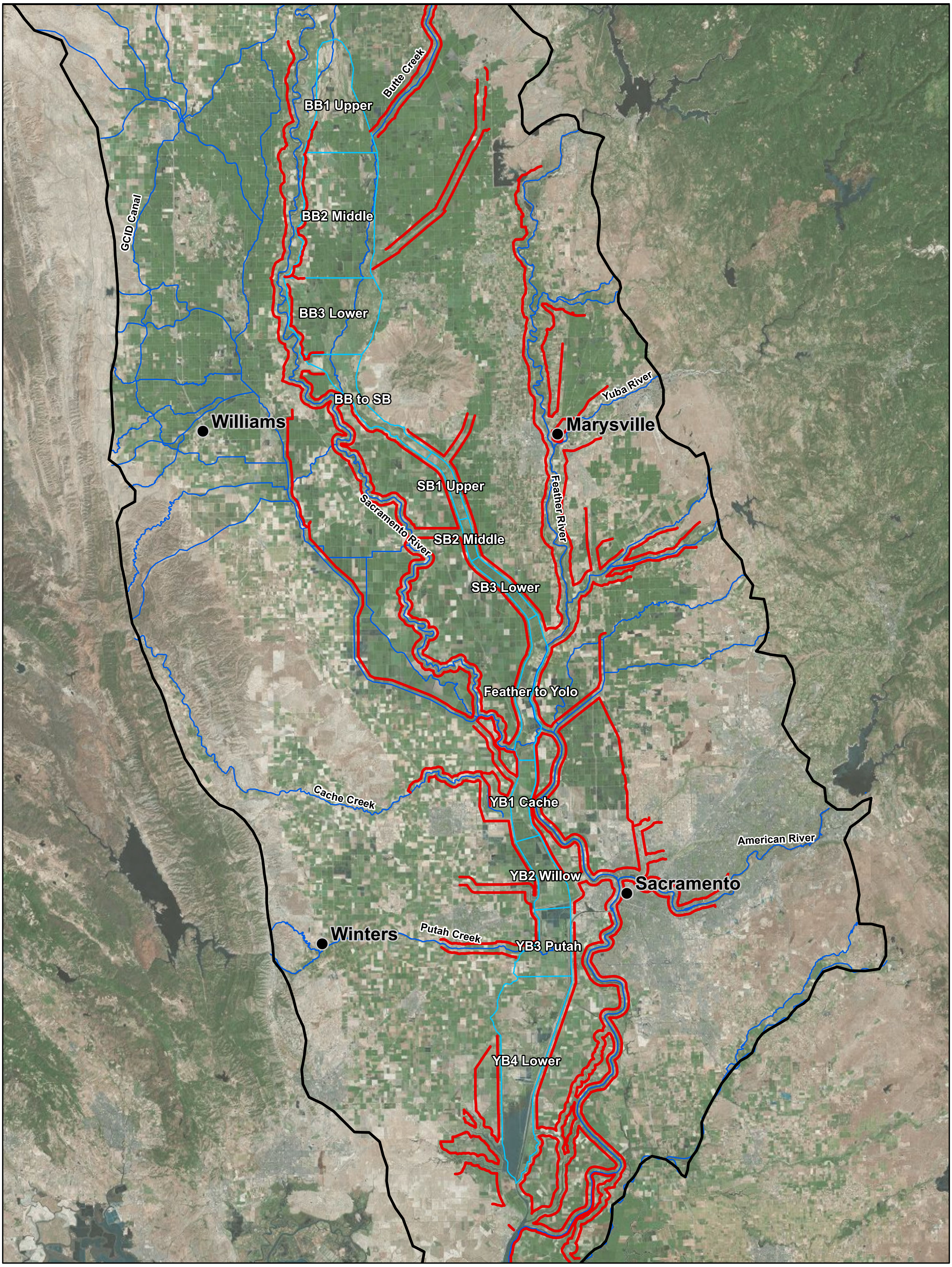
1. The area of each drainage basin tributary to the model domain that is not represented by streams explicitly simulated in SACFEM2013 was computed using a GIS-based analysis of the land surface topography. The extent of these smaller watersheds is shown on Figure 22.
2. Each drainage area polygon was then intersected with a GIS coverage of annual total rainfall estimated using the PRISM model for each year of the simulation period. This distribution of annual average rainfall was then used to calculate the total volume of rainfall falling on the small watershed areas, and an overall average rainfall rate was computed (inches per year).
3. The total annual rainfall rate was then used to compute a deep percolation quantity using the relationship between annual rainfall and deep percolation rate developed by Turner (1991) and described above.
4. The annual volume of deep percolation computed in Step 3 was then converted into monthly values that were based on the monthly distribution of streamflow measured in ungaged sections of Deer Creek (Table 5). These monthly deep percolation quantities were then introduced at the model domain boundary of each small watershed polygon using injection wells into Layer 1. The quantity applied to each model boundary node was proportional to boundary length of each element divided by the total boundary length of the drainage polygon.
5. The deep percolation rates for individual drainage basins were adjusted during SACFEM2013 calibration to improve the match between simulated and measured groundwater elevations. Final factors applied to the deep percolation rates range from 0.5 to 1.5 (Table 6).

TABLE 5

Monthly Distribution of Total Annual Mountain Front Recharge

SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Month	Percentage of Annual Mountain Front Recharge (%)
January	14.2
February	15.2
March	15.4
April	13.6
May	10.3
June	5.1
July	3.1
August	2.6
September	2.4
October	3.0
November	4.9
December	10.2



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

Figure 20
Flood Bypass Areas and Subareas
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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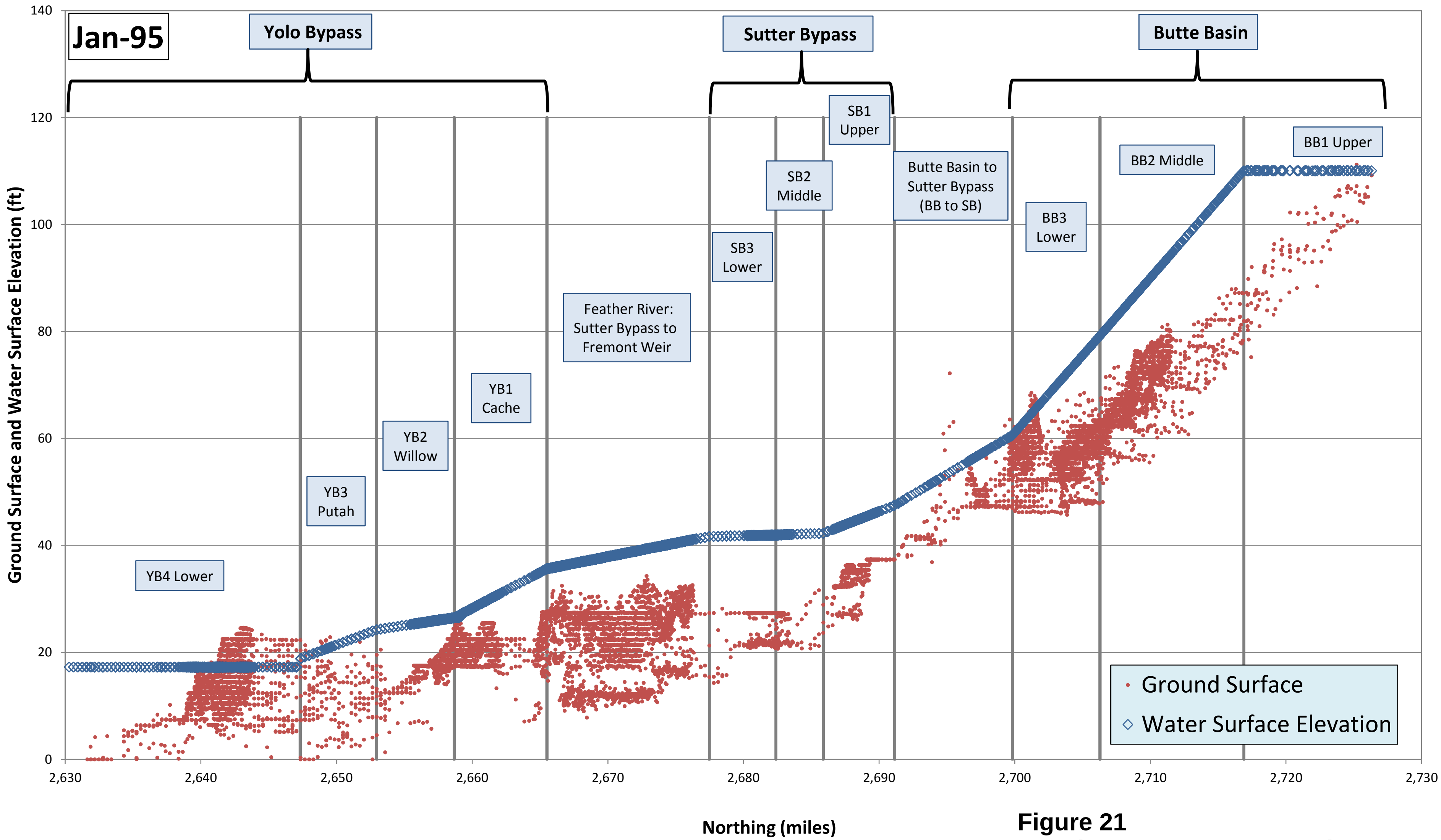

Figure 21
Flood Bypass Area Ground Surface and Water Surface Elevation

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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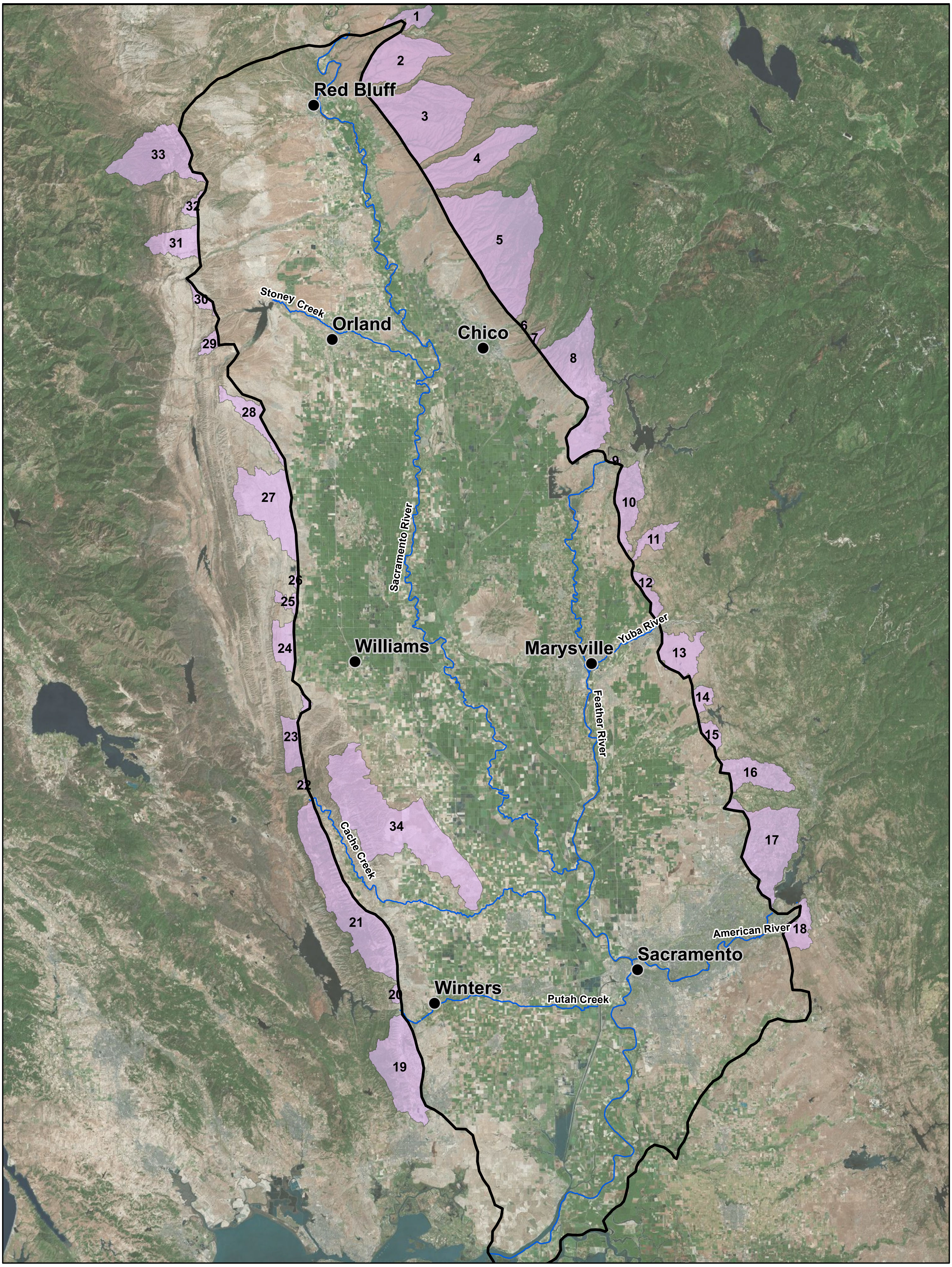

LEGEND

- ● City
- — Major Stream
- ▭ SACFEM2013 Model Boundary
- ▨ SACFEM2013 Mountain Front Polygon

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 22
Mountain Front Recharge Watershed Areas
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

TABLE 6

Mountain Front Recharge Adjustment Factors

SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Sub-watershed Number	Adjustment Factor	Sub-watershed Number	Adjustment Factor
1	0.5	18	0.5
2	0.5	19	1.5
3	0.5	20	1
4	0.5	21	1
5	0.5	22	1.5
6	1	23	1.5
7	1	24	1
8	1	25	1
9	1	26	1
10	1	27	1
11	1	28	1
12	1	29	1
13	1	30	1
14	1.5	31	1
15	1.5	32	1
16	1.5	33	1
17	0.5	34	1

Urban Pumping. The final set of specified-flux boundary conditions applied in the SACFEM2013 model reflects urban pumping within the model domain. The distribution of agricultural pumping that was developed using the surface water budgeting methodologies described below does not include urban pumping. As a first step to estimate the quantity of urban pumping to apply to the model, the year 2010 U.S. Census[5] data were evaluated. Each municipal area with a population greater than 5,000 that used groundwater as a source of municipal supply was further assessed. For municipalities where urban water management plans were available, the reported annual groundwater use was simulated in SACFEM2013. For cities that do not have a current water management plan, a pumping volume that was based on an annual average per capita value of 271 gallons/capita/day was simulated. Further, municipalities in the northern Sacramento area pumping rates were assigned consistent with the SacIGSM model (WRIME, 2011). Table 7 presents the annual urban pumping volumes included in SACFEM2013. Urban pumping was assigned spatially to all SACFEM2013 nodes within a given city area and was apportioned equally to model Layers 2 through 4. Figure 23 presents the locations of municipalities and SacIGSM subareas included in SACFEM2013. The monthly variability in urban pumping quantity was distributed based on typical seasonal trends for municipal water use listed in Table 8.

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[5] http://www.census.gov/2010census/

TABLE 7
Urban Pumping
SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Urban Area	SACFEM2013 Pumping Volume (acre-feet/year)	Source
Beale Air Force Base	401	Per Capita Estimate (census 2010)
Chico	26,800	2010 Urban Water Management Plan
Colusa	1,814	Per Capita Estimate (census 2010)
Corning	2,328	Per Capita Estimate (census 2010)
Davis	11,955	2010 Urban Water Management Plan
Dixon	5,575	Per Capita Estimate (census 2010)
Durham	1,676	Per Capita Estimate (census 2010)
Elk Grove	46,484	Per Capita Estimate (census 2010)
Florin	14,434	Per Capita Estimate (census 2010)
Gold River	2,404	Per Capita Estimate (census 2010)
Gridley	2,000	Per Capita Estimate (census 2010)
La Riviera	3,282	Per Capita Estimate (census 2010)
Lincoln	962	2010 Urban Water Management Plan
Linda	5,399	Per Capita Estimate (census 2010)
Live Oak	5,212	Per Capita Estimate (census 2010)
Marysville	2,365	2010 Urban Water Management Plan
Olivehurst and Plumas Lake	2,900	2010 Urban Water Management Plan
Orland	2,215	Per Capita Estimate (census 2010)
Oroville	0	Urban Water Management Plan
Palermo	0	Urban Water Management Plan
Parkway, Fruitridge, and Lemon	10,389	Per Capita Estimate (census 2010)
Rancho Cordova	19,678	Per Capita Estimate (census 2010)
Red Bluff	4,276	Per Capita Estimate (census 2010)
Rio Vista	2,420	2010 Urban Water Management Plan
Rocklin	0	2010 Urban Water Management Plan for Placer Co. Water Agency
Rosemont	6,890	Per Capita Estimate (census 2010)
Roseville	0	Urban Water Management Plan
Sacramento	0	
South Oroville	1,744	Per Capita Estimate (census 2010)
Thermalito	2,019	Per Capita Estimate (census 2010)
University of California Davis	1,758	Per Capita Estimate (census 2010)

TABLE 7

Urban Pumping

SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Urban Area	SACFEM2013 Pumping Volume (acre-feet/year)	Source
Vacaville	6,500	2010 Urban Water Management Plan
Vineyard	7,545	Per Capita Estimate (census 2010)
West Sacramento	14,808	Per Capita Estimate (census 2010)
Williams	1,556	Per Capita Estimate (census 2010)
Willows	1,937	2010 Urban Water Management Plan
Winters	2,012	Per Capita Estimate (census 2010)
Woodland	13,921	2010 Urban Water Management Plan
Yuba City	3,600	2005 Urban Water Management Plan
North Sacramento SacIGSM Subarea		
Cal-AmAntelope	3,784	SacIGSM (1970-2004 average)
Cal-AmLincolnOaks	8,092	SacIGSM (1970-2004 average)
CarmichaelWD	4,524	SacIGSM (1970-2004 average)
CitrusHeightsWD	3,202	SacIGSM (1970-2004 average)
CityOfFolsom	142	SacIGSM (1970-2004 average)
CityOfSacramentoEast	16,845	SacIGSM (1970-2004 average)
CityOfSacramentoWest	8,917	SacIGSM (1970-2004 average)
FairOaksWD	1,516	SacIGSM (1970-2004 average)
McClellanPark	3,634	SacIGSM (1970-2004 average)
Natomas Unorganized	2,488	SacIGSM (1970-2004 average)
NatomasMWC East	1,650	SacIGSM (1970-2004 average)
NatomasMWC West	1,953	SacIGSM (1970-2004 average)
OrangevaleWC	773	SacIGSM (1970-2004 average)
Rio Linda North	4,873	SacIGSM (1970-2004 average)
Rio Linda South	4,478	SacIGSM (1970-2004 average)
SacIntlAirport	3,670	SacIGSM (1970-2004 average)
SacramentoSuburbanTownAndCountry	27,164	SacIGSM (1970-2004 average)
SacSuburbanNorthHighlands	5,559	SacIGSM (1970-2004 average)
SacSuburbanNorthridge	14,318	SacIGSM (1970-2004 average)
SanJuanWD	527	SacIGSM (1970-2004 average)

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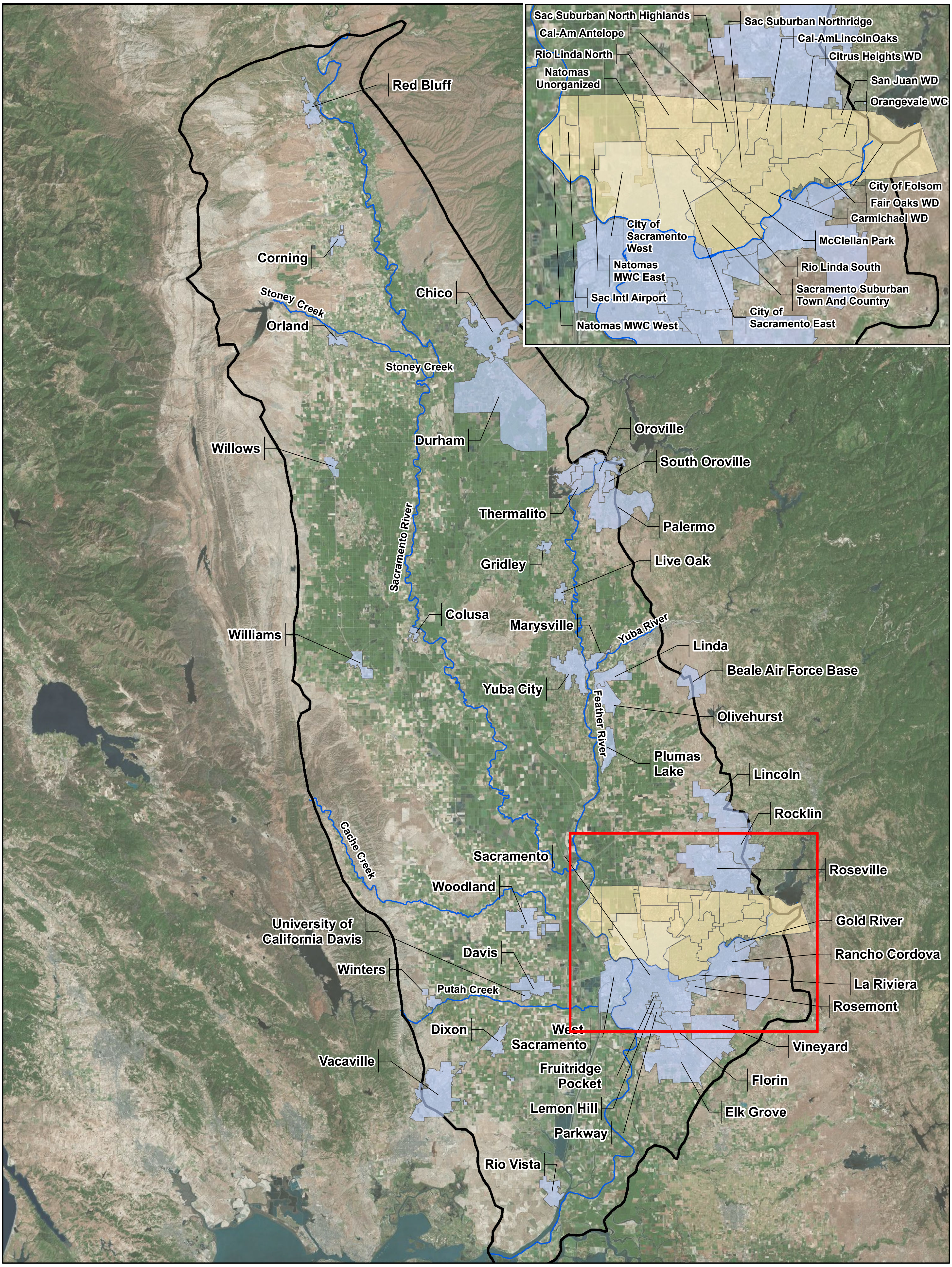

LEGEND

- Major Stream
- ▭ Urban Pumping Municipality
- ▭ SacIGSM Urban Pumping Subarea
- ▭ SACFEM2013 Model Boundary

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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0 6 12 24 Miles

Figure 23
Areas of Urban Groundwater Pumping
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

TABLE 8
Monthly Distribution of Annual Urban Pumping
SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Month	Percentage of Annual Total Urban Pumping
January	4.6
February	4.6
March	4.6
April	6.1
May	6.1
June	10.9
July	14.8
August	15.3
September	13.1
October	10.7
November	4.6
December	4.6

3.2.4.3 No-flow Boundaries

A no-flow boundary was specified across the bottom boundary of the model, representing the freshwater/brackish water interface.

3.2.5 Agricultural Water Budget

One of the most critical components to the successful operation of the SACFEM2013 is computing transient agricultural water budget components. These water budget components were estimated by using a variety of spatial information including land use, cropping patterns, source of irrigation water, surface water availability in different year types and locations, and the spatial distribution of precipitation. Surface water budget components include deep percolation of applied water, deep percolation of precipitation, and agricultural pumping.

3.2.5.1 Background and Approach

A root-zone model was used to calculate agricultural water budgets and determine two major fluxes for input to SACFEM2013; deep percolation of precipitation and applied agricultural water and agricultural groundwater pumping. The root-zone model simulates the movement of irrigation water and precipitation that infiltrates below ground surface and into the root-zone where water is either used by plant evapotranspiration or drained as deep percolation when moisture content exceeds soil holding capacity.

3.2.5.2 Overview of the Method

Root-zone dynamics are simulated using the Integrated Water Flow Model Demand Calculator (IDC) developed by DWR's Bay Delta Office. IDC calculates agricultural demand for applied water based on soil parameters and crop water use, and routes infiltrated applied water and precipitation through the soil column to determine evapotranspiration, deep percolation, and soil moisture storage. An approach was developed to create the needed inputs for SACFEM2013 without simulating the entire SACFEM2013 model domain and grid in IDC. This approach involved simulating root-zone water balances for one unit acre of land for each unique combination of crop type, soil, and historical precipitation throughout the SVGB. This process provides a time-series of deep percolation and demand for applied water. These unit-area time-series are applied to uniquely classified areas developed in GIS to calculate time-series of deep percolation and agricultural groundwater pumping for each node.

3.2.5.3 Development of GIS Dataset

A GIS dataset that contains information on crop type, soils, water source, and geographic location (used to determine the availability of surface water) was developed from a variety of sources. These datasets are intersected with the SACFEM2013 model grid to provide detailed data for the agricultural water budget for each SACFEM2013 model node. The following sections describe the source of data compiled in the GIS dataset.

Land Use. DWR's Land and Water Use Program historically conducted land use surveys of major agricultural counties throughout the state every 5 years. These data are in geo-referenced shapefiles that provide land use at approximately the field level. The most recent surveys of counties within the SACFEM2013 model domain were combined to create a single shapefile.

SACFEM revisions in 2011 included updates to land use data for Glenn and Colusa Counties. These data were developed by Davids Engineering based on multiple sources including DWR land use surveys conducted in 2003, U.S. Department of Agriculture, Glenn County, local water districts, and field surveys by Davids Engineering in 2010 (Davids Engineering, Inc., 2011).Table 9 provides the source and survey year for the land use data of each county within the SACFEM2013 model domain. Land use data were from the most recent surveys available in 2011.

TABLE 9

Land Use Data Source and Year by County

SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

County	Land Use Source, Survey Year
Butte	DWR, 2004[a]
Colusa	DWR, 2003[a] and Davids Engineering, 2010[b]
Glenn	DWR, 2003 and Davids Engineering, 2010[b]
Placer	DWR, 1994[a]
Sacramento	DWR, 2000[a]
Solano	DWR, 1994[a]
Sutter	DWR, 2004[a]
Tehama	DWR, 1999[a]
Yolo	DWR, 1997[a]
Yuba	DWR, 1995[a]

Notes:

[a] California Department of Water Resources land use survey data downloaded from http://www.water.ca.gov/landwateruse/lusrvymain.cfm

[b] Davids Engineering land use data from Davids Engineering, Inc. (2011)

Land use data are aggregated into 20 categories with 16 agricultural crop types, native vegetation, urban areas, bare soil, and water bodies. Figure 24 illustrates the distribution of land use data across the different categories used in SACFEM2013, minus urban areas and water bodies that are not included in the agricultural water budgets. The SACFEM2013 model domain covers approximately 3.6 million acres of land on the Sacramento Valley floor. The largest single land use category within the SACFEM2013 model domain is native vegetation. The largest agricultural crop type is rice.

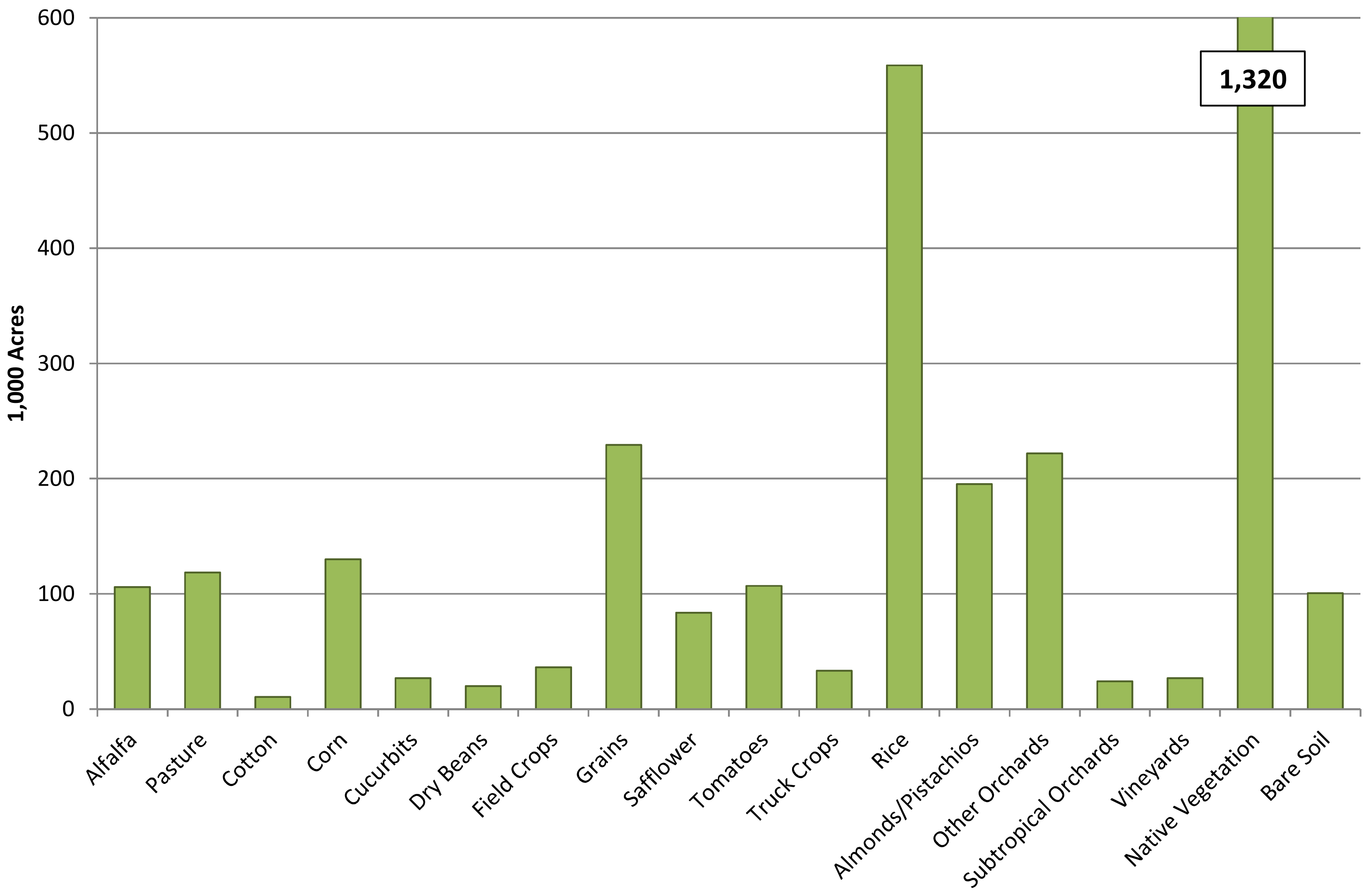


Figure 24
SACFEM2013 Land Use Data

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

Water Source. DWR's land use surveys typically include information on the source of water used for irrigation. Survey data classify the water source as either surface water, groundwater, mixed, or unknown. Water source data are included in the land-use dataset developed for agricultural water budgets and used in calculating agricultural groundwater pumping as described in subsequent sections.

Soils Data. The land use and water source data were joined with hydrologic soils group data from the Natural Resource Conservation Service Soil Survey Geographic (SSURGO) database. The hydrologic soils group characterizes soils and classifies them into four groups (A through D) based on transmission rate of water, texture, structure, and runoff response. Hydrologic soils group data are used to determine inputs to IDC, specifically soil parameters that determine the potential for rainfall or applied water to infiltrate the root zone.

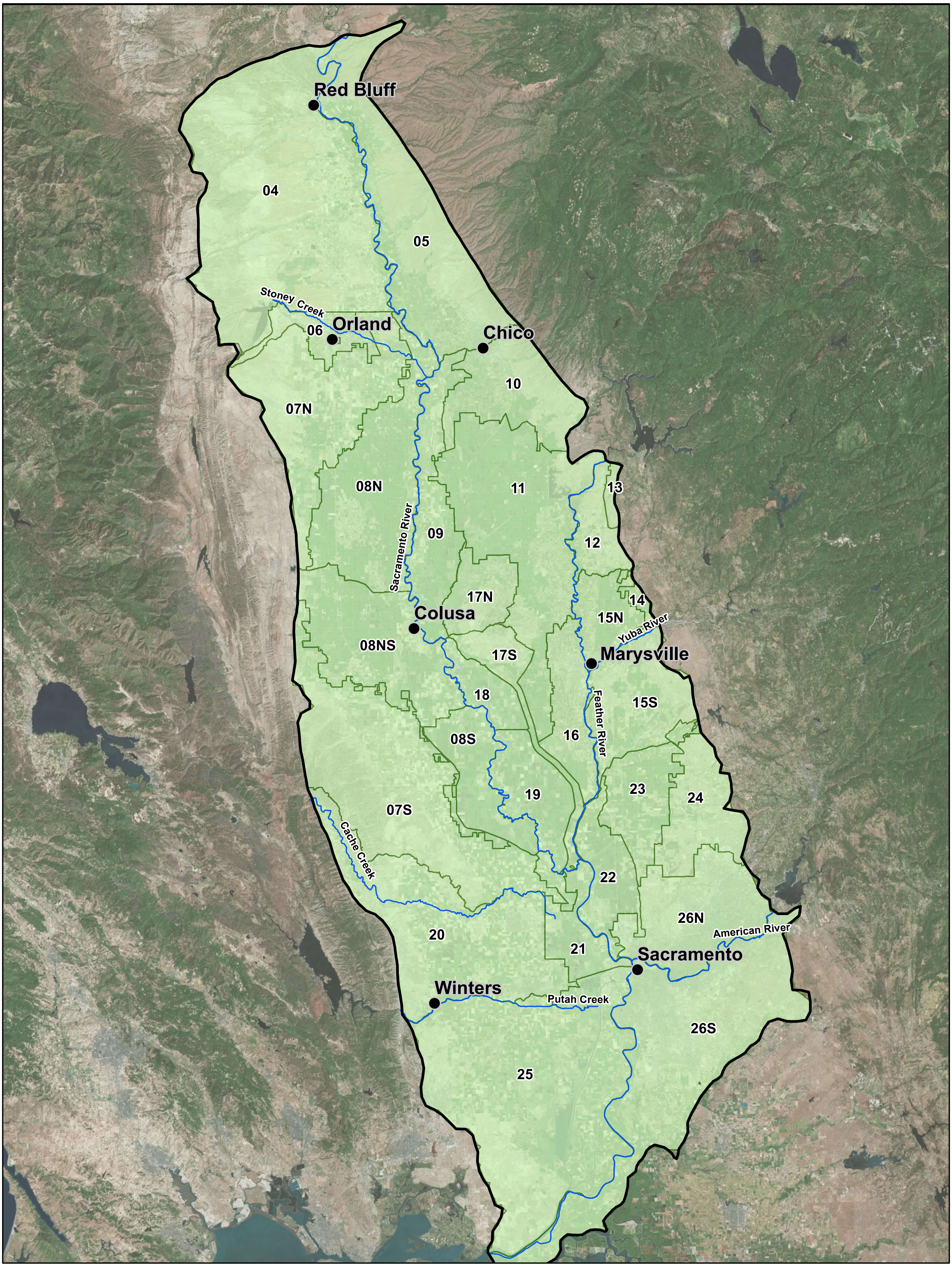
Water Budget Areas. Land use, water source, and soils data are then joined with boundaries of water budget areas (WBAs) within the SVGB. The SVGB was previously disaggregated into WBAs for the purpose of developing water budgets and inputs to other models such as CALSIM III. WBAs were defined by irrigation district boundaries, historical planning areas such as DWR's depletion study areas, and physical boundaries such as rivers, creeks, or canals. WBAs are areas wherein availability and source of water, climate, and other factors that govern water use are similar. WBAs are used to determine IDC inputs for precipitation and availability of surface water as described in subsequent sections. Figure 25 shows how the entire SACFEM2013 model domain is split into various WBAs.

Land Use Data by SACFEM2013 Node. Lastly, the combined data on land use, soils, WBAs, and water source were intersected with the SACFEM2013 model grid and resulting areas for each component were calculated. The result of this final process is a dataset that defines the land use, soils, and WBA of areas that contribute to all of the SACFEM2013 model nodes. There are multiple records for many nodes (that is, the area of a given model node intersects multiple land use, soils, WBA, or water source categories). As such, the final dataset approaches a half million unique records. Acreages in this dataset were combined with unit-area time-series from IDC on deep percolation and applied water demand (AWD) to develop time-series of deep percolation and agricultural groundwater pumping at each node for the SACFEM2013 period of simulation. Figure 26 illustrates the five data sets that are combined in the final GIS data set.

3.2.5.4 IDC Model Inputs

The GIS dataset is combined with unit-area time-series from IDC to calculate SACFEM2013 input. IDC was set up to simulate 1-acre areas for each unique combination of land use, soils, and precipitation. These three factors affect simulation of the root zone and the resulting deep percolation and AWD. IDC simulation of the root-zone was performed on a daily time-step. A daily time-step was appropriate for determining rainfall infiltration, and provides a more accurate calculation of AWD compared to using a weekly or monthly time-step. The following sections describe the source of data used as input to IDC. Additional detail on the computational methods and theory within IDC can be found in the documentation and users' manual (DWR, 2014).

Precipitation. Daily rainfall records from seven stations were collected from the National Climatic Data Center maintained by the National Oceanic and Atmospheric Administration and California Data Exchange Center maintained by DWR. Some WBAs are located between these seven stations and, for these areas, an average of two stations was used. The result of this analysis was a total of 12 different precipitation time-series comprising the seven stations and five averaged time-series from two different stations. Table 10 summarizes the 12 precipitation time-series and associated WBAs. The seven precipitation stations are also shown on Figure 25 in relation to associated WBAs.



LEGEND

- ● City/Precipitation Station
- — Major Stream
- 🟩 Water Budget Area
- ▭ SACFEM2013 Model Boundary

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

Figure 25
Water Budget Areas
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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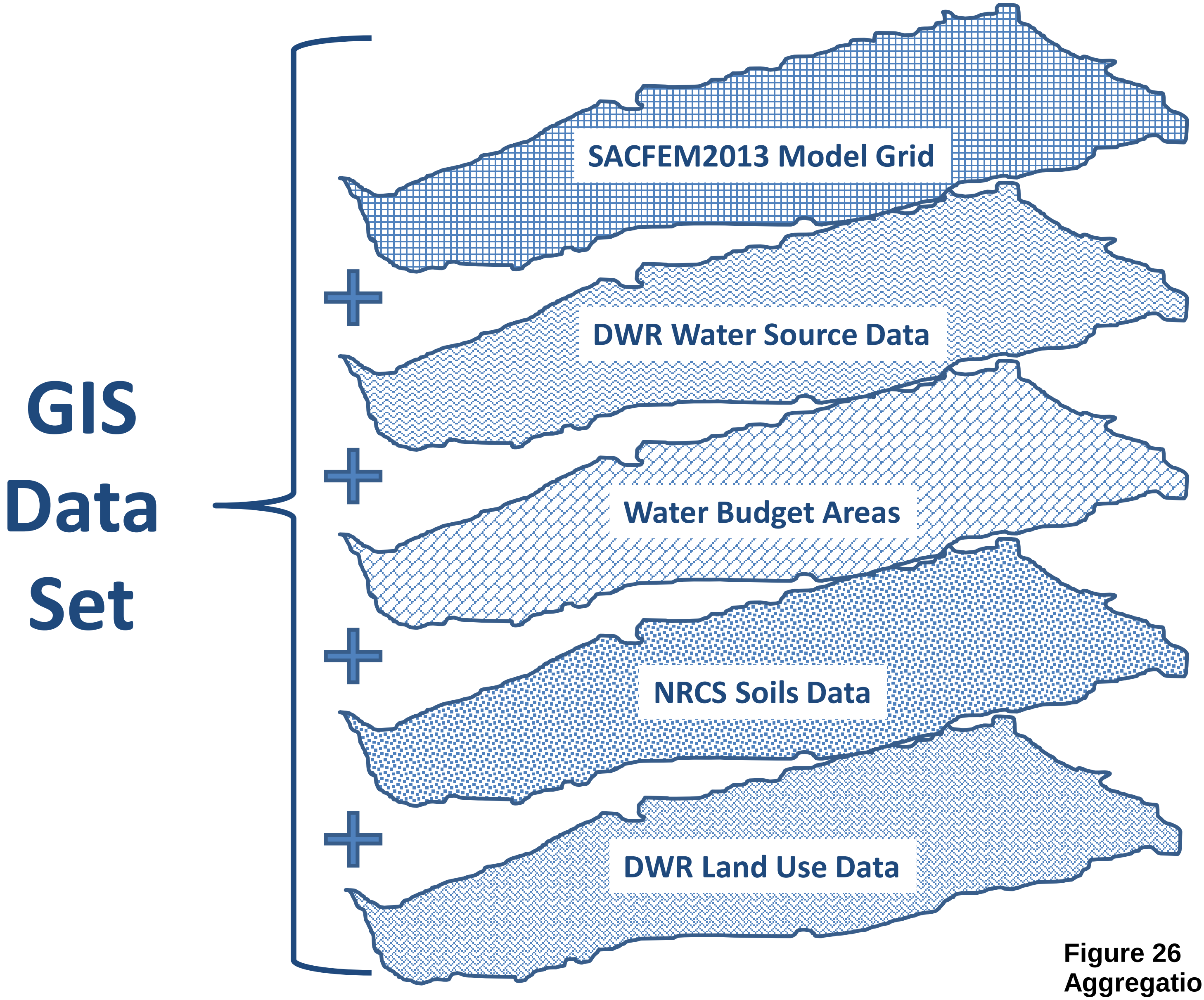

Figure 26
Aggregation of GIS Datasets for Agricultural Water Budgets
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
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TABLE 10

Precipitation Stations and Associated Water Budget Areas

SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Time-Series	Precipitation Station(s)	Associated WBA(s)
1	Red Bluff	4, 5
2	Orland	6, 7N
3	Chico	10
4	Colusa	7S, 8NS, 17N, 17S, 18
5	Marysville	14, 15N, 15S, 16
6	Winters	20, 25
7	Sacramento	21, 22, 26N
8	Avg. Orland & Colusa	8N
9	Avg. Chico & Colusa	9
10	Avg. Chico & Marysville	11, 12, 13
11	Avg. Colusa & Winters	8S
12	Avg. Marysville & Sacramento	19, 23, 24

Evapotranspiration. Monthly evapotranspiration (ET) values used in IDC were developed from data published by the Irrigation Training and Research Center at California Polytechnic State University (ITRC, 2003). ITRC published crop ET values for wet, typical, and dry years for reference ET zones throughout California. The majority of the SVGB is within ITRC zones 12 and 14, and an average crop ET value from these two zones was used in IDC. Therefore, crop ET values used in IDC do not vary spatially throughout the model, but can vary by year for three different year-types of wet, typical, and dry. The Sacramento Valley Water Year Type (40-30-30) Index was used to determine the year-type with above normal and below normal 40-30-30 Index years being defined as typical, dry, and critical 40-30-30 Index years defined as dry, and wet 40-30-30 Index years defined as wet.

Soil Parameters. IDC inputs for soil parameters include field capacity, wilting point, total porosity, pore size distribution index, and saturated hydraulic conductivity. These parameters are used in IDC to characterize the movement of water in the root zone. Soil parameters used in IDC were determined in part by hydrologic soils group and land use. A range of magnitudes covering the classifications of the hydrologic soils group were determined and applied in IDC. Values for rice and native vegetation land uses typically differed from non-ponded crops. For example, it was assumed that rice was grown on soils with lower saturated hydraulic conductivity and a higher field capacity than soil used to grow other crops.

Crop Parameters. An irrigation season is input to IDC for each irrigated crop. The irrigation season flag is used to determine months when AWD is calculated. Most crops are irrigated starting in March or April and continuing through August, September, or October. AWD is not calculated outside of these months. Additionally, rice includes an AWD for cultural practices that flood fields to suppress weed growth and decompose rice straw. The timing and quantity of applied water for spring flood-up and fall decomposition used in IDC is representative of practices in the Sacramento Valley.

A second parameter input to IDC for simulation of the root-zone is the rooting depth for each crop and for native vegetation. Rooting depth, in combination with inputs such as field capacity, is used to determine soil moisture storage capacity. Soil moisture storage affects deep percolation and applied water demand and crops with shallower rooting depths may have more deep percolation because there is less capacity to water in the root zone.

Surface Runoff. IDC uses a modified version of the Natural Resource Conservation Service (previously the Soil Conservation Service) curve number method to simulate rainfall runoff and infiltration of precipitation. The curve number method is described in Technical Reference number 55 and the National Engineering

Handbook (USDA, 2004). A curve number is determined from land use and soil type. IDC uses the curve number in combination with antecedent soil moisture conditions to determine the portion of precipitation that runs off versus infiltrates into the soil.

3.2.5.5 Calculation of SACFEM2013 Inputs

Time-series of output for deep percolation and AWD from IDC for unit-acres of each unique land use and soil type were combined with the GIS dataset for each model node in SACFEM2013. Python scripts were used to calculate time-series of deep percolation and groundwater pumping inputs for each model node. The following sections describe the process used for each input.

Deep Percolation. Output from IDC is a time-series of deep percolation per unit-acre for each unique combination of land use, soil type, and precipitation (indicated by associated WBA). The GIS dataset contains records for all agricultural and native vegetation areas that contribute to each model node. The GIS dataset includes identifiers for WBA, land use, and soil type that are used by the Python script to reference the correct output time-series from IDC and calculate the deep percolation for each node as the sum of the deep percolation for individual areas that contribute to each node. Figure 27 is an example of the calculation performed for an individual node and time-step.

Agricultural Groundwater Pumping. Time-series of groundwater pumping were developed for each SACFEM2013 model node based on land use data, water source data, and surface water availability for areas that contribute to each SACFEM2013 node. Calculated groundwater pumping is based on AWD of the crop as calculated in IDC. A similar process as illustrated on Figure 27 is performed to calculate the AWD for each node. Several additional steps are then performed to calculate agricultural groundwater pumping.

Groundwater pumping for areas identified as being met from groundwater in DWR surveys is the AWD (AWDgw). This is one component of agricultural groundwater pumping calculated for each node in SACFEM2013. For areas met from non-groundwater sources (surface, mixed, or unknown), groundwater pumping is calculated as AWD for the area not identified as met from groundwater in DWR surveys (AWDnon-gw) multiplied by a pumping percentage. The pumping percentage is used to estimate pumping when surface water supplies are not adequate to meet the AWD, such as during drought periods. This is the second component of agricultural groundwater pumping in SACFEM2013. Total groundwater pumping for a node is the sum of these two components, as shown in Equation 10.

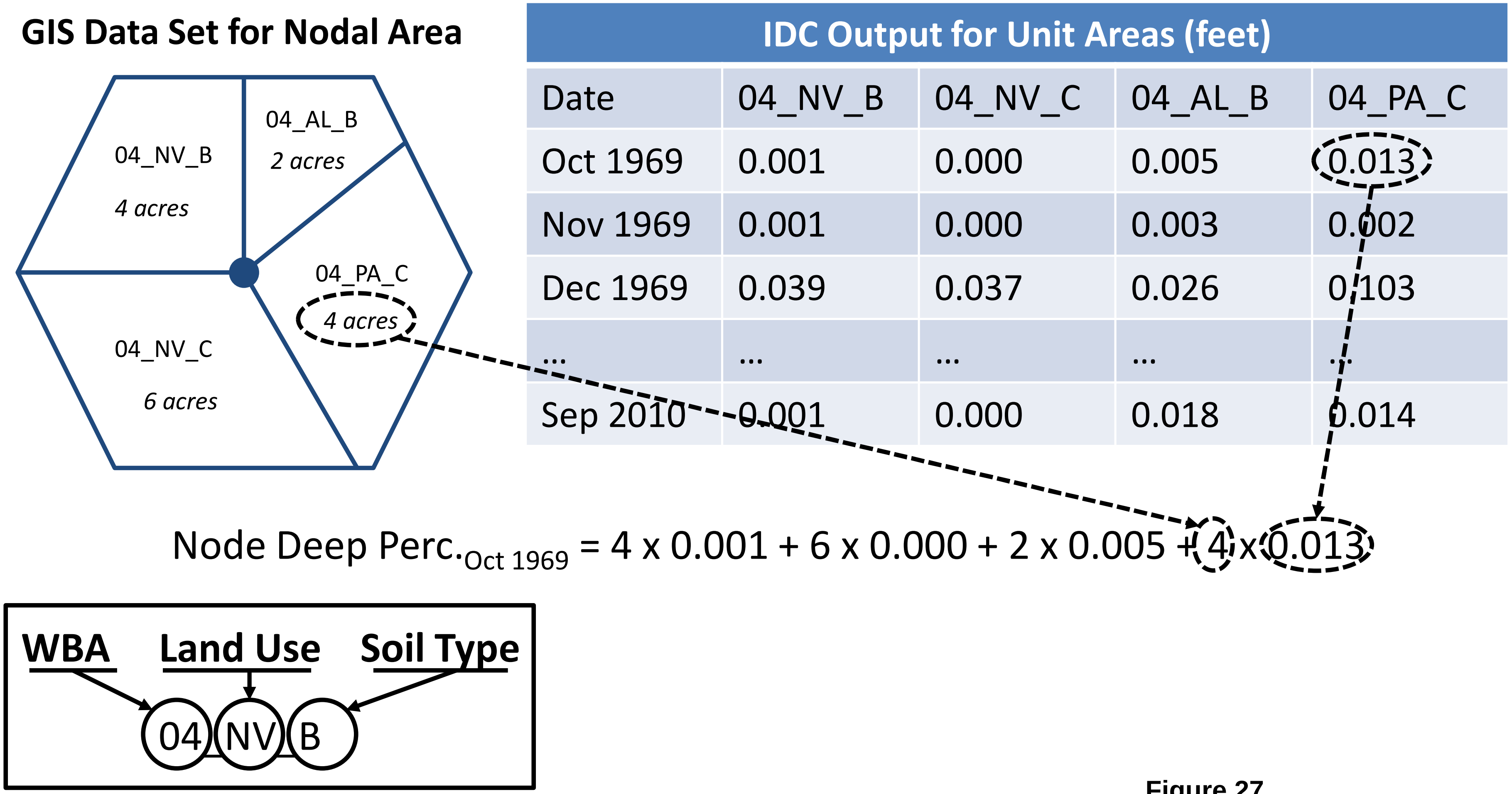
$$Groundwater\ Pumping_{node\ i} = AWD_{non-gw} * Pumping\ Percentage + \ AWD_{gw} \tag{10}$$

Many nodes include areas that are met from both groundwater and non-groundwater sources, areas of different crops and soils and, therefore different AWD or different pumping percentage. Groundwater pumping is calculated separately for each area and summed for the node each month.

Pumping percentage is calculated based on surface water availability. Surface water availability can change from year-to-year and by water district or other boundaries in the SVGB. Surface water availability is identified by WBA. Therefore, pumping percentage is calculated based on AWDnon-gw and available surface water for a WBA with the same water supply, such as Glenn-Colusa Irrigation District. Pumping percentage is calculated annually for each area as follows:

$$Pumping\ Percentage_{area\ j} = 1 - Minimum\left(\frac{Surface\ \ Supply_{\ area\ \ j}}{AWD_{non\ -gw}{}_{\ area\ \ j}}\ or\ 1\right) \tag{11}$$

AWD used in the denominator is the annual AWD of the area minus any AWD from lands identified as supplied by groundwater. In some years, available surface supply can exceed AWDnon-gw and the pumping percentage is zero. An annual pumping percentage is calculated for most areas and multiplied by the AWDnon-gw each month. Available surface water supply was estimated from a variety of data sources including historical diversion records, contracts for water, historical hydrology, CALSIM II output, and assumptions based on knowledge of the Sacramento Valley. Many areas of the Sacramento Valley have



IDC Output for Unit Areas (feet)

Date	04_NV_B	04_NV_C	04_AL_B	04_PA_C
Oct 1969	0.001	0.000	0.005	0.013
Nov 1969	0.001	0.000	0.003	0.002
Dec 1969	0.039	0.037	0.026	0.103
…	…	…	…	…
Sep 2010	0.001	0.000	0.018	0.014

$$\text{Node Deep Perc.}_{\text{Oct 1969}} = 4 \times 0.001 + 6 \times 0.000 + 2 \times 0.005 + 4 \times 0.013$$

Note:
IDC = Integrated Water Flow
Model Demand Calculator

Figure 27
Example Calculation of Nodal Deep Percolation using GIS Dataset and IDC Output
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
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relatively stable surface water supplies that are only reduced during periods of extreme or prolonged drought. Additional detail on estimates of available surface water supply is contained in a technical memorandum titled, *Response to SacFEM Peer Review Tier 1 Findings 1, 2, and 3* (MBK, 2013).

3.2.5.6 Review and Quality Assurance

Deep percolation and agricultural groundwater pumping inputs to SACFEM2013 are large datasets of more than 75 million values each (492 monthly time-steps for the more than 153,000 SACFEM2013 model nodes). Additionally, both input parameters are typically only estimated with little to no available observed data for comparison with calculated values. However, calculated values from IDC and final SACFEM2013 inputs were aggregated for different areas and compared against available data. Additionally, values for the entire SACFEM2013 model domain were aggregated and compared to generally accepted estimates.

Detailed Water Budgets. Calculated values for both groundwater pumping and deep percolation within Glenn-Colusa Irrigation District were compared with detailed water budget estimates developed by Davids Engineering, Inc. for the period 2001 through 2010. Detailed water budgets included applied surface water, groundwater pumping, runoff/return flow, and estimated deep percolation as the closure term based on a root-zone simulation model. IDC-calculated values for groundwater pumping, total applied water demand, runoff/return flow, and deep percolation compared well with measured and calculated values from Davids Engineering, Inc. IDC input values for soil parameters such as field capacity and saturated hydraulic conductivity were adjusted and calibrated as part of this comparison.

Applied Water Demand. AWD is calculated in IDC as a function of crop type, soils data, and precipitation. AWD calculated in IDC was validated by comparison with historical surface water delivery data for areas known to be irrigated only, or primarily with surface water. These comparisons were made for a common period of available IDC output and observed surface water diversion data. Examples of these validations are presented in Appendix A. AWD calculated in IDC compared well for most comparison areas. AWD calculated in IDC is the basis for much of the calculated groundwater pumping.

Model Domain Comparisons. Values for total deep percolation and groundwater pumping were reviewed as monthly and annual time-series and compared for different crop types and soil conditions. Figure 28 illustrates the annual volume of deep percolation for the entire model domain throughout the simulation period plotted with average precipitation for the seven stations used as input to IDC. Figure 28 illustrates how deep percolation generally fluctuates with precipitation and can vary significantly from year-to-year with a range of approximately 0.5 million acre-feet (MAF) to 3.5 MAF.

Figure 29 illustrates annual agricultural groundwater pumping inputs to SACFEM2013. The average annual groundwater pumping for the entire simulation period is approximately 2.75 MAF and generally falls in the range of 2.0 to 2.5 MAF in non-drought years. General estimates of average typical year groundwater pumping for the SVGB are on the order of 2.0 to 2.5 MAF.

3.3 Model Assumptions

The groundwater flow model construction, described in the preceding sections, followed the following inherent assumptions:

- Groundwater flow is simulated under confined conditions under all model layers. This assumes that changes in aquifer transmissivity due to processes such as groundwater extraction are negligible.
- Transmissivity of the modeled system does not change through time.
- Lateral groundwater underflow is not included in SACFEM2013. The model assumes that all groundwater enters and exits the model through the boundary conditions listed in Section 3.2.4.
- Effects of water density and viscosity variations to groundwater flow are negligible.
- Hydrologic variations occurring at a temporal scale finer than monthly are not simulated.

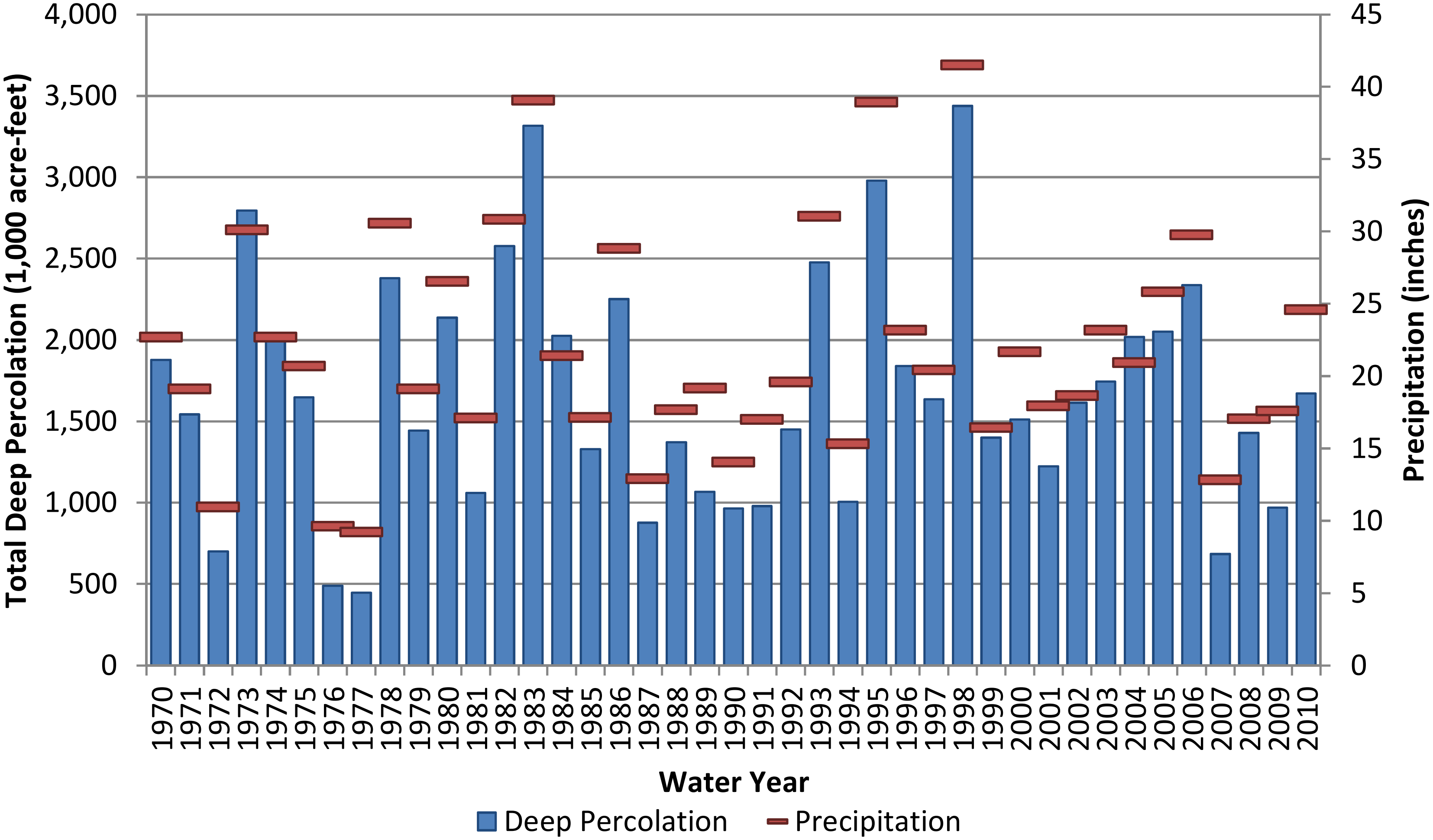

Figure 28
Annual Deep Percolation from Agricultural and Native Vegetation Areas

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
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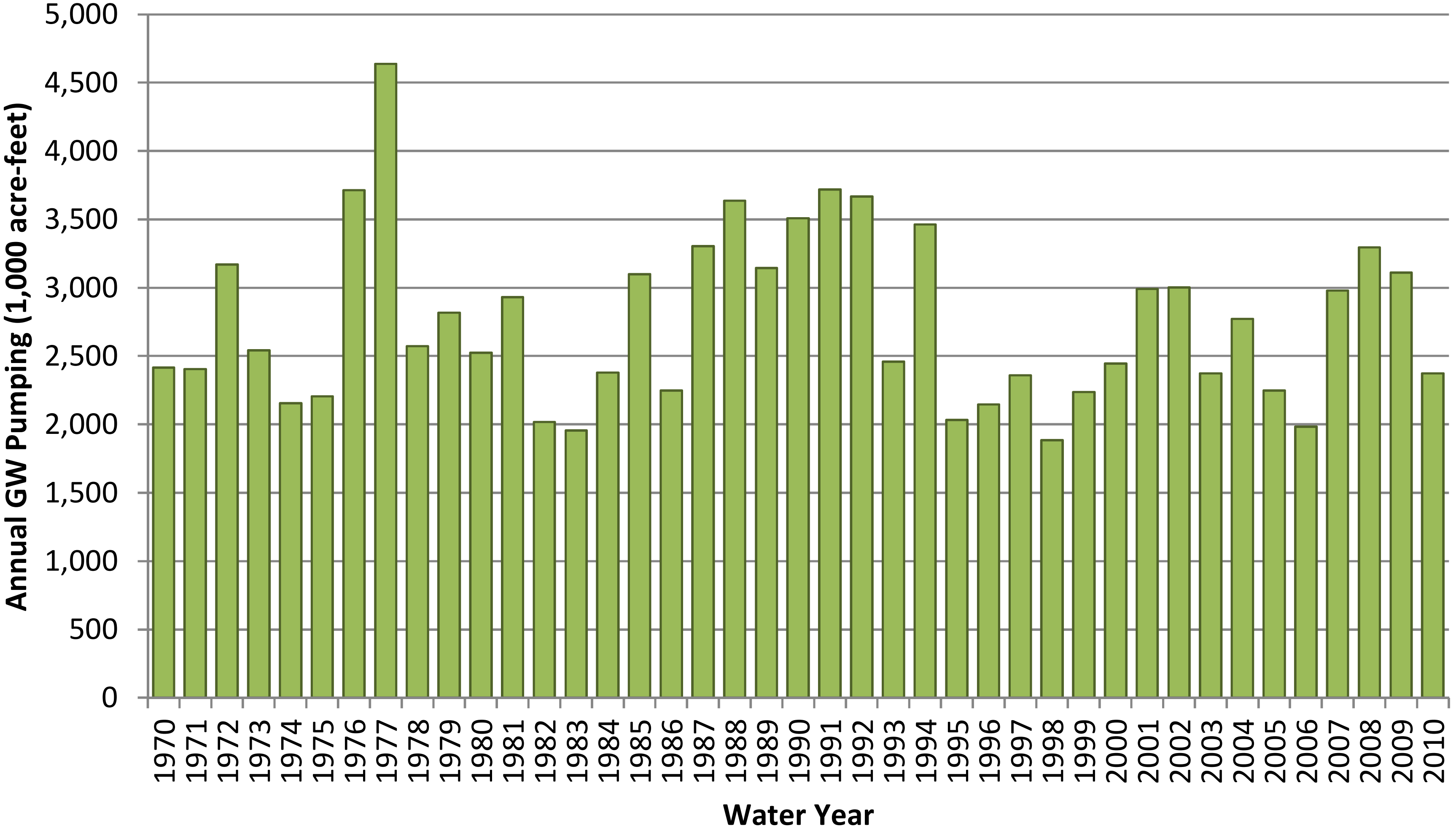

Figure 29
Annual Agricultural Groundwater Pumping

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
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SECTION 4

Groundwater Flow Model Calibration

Model calibration is a process of systematically altering model parameters to simulate subsurface flow conditions measured in the field. For SACFEM2013, this process ensured that the numerical model could accurately replicate the hydrologic processes observed within the SVGB, and that the model was a reliable tool to use to forecast future hydraulic conditions resulting from changes in water management within the basin. SACFEM2013 was generally calibrated in accordance with the *Standard Guide for Calibrating a Ground-Water Flow Model Application* (American Society for Testing and Materials [now ASTM International], 1996).

4.1 Calibration Process

As is discussed in earlier sections of this report, CH2M HILL incorporated details of the SVGB physical system into SACFEM2013, and then a step-wise calibration approach was implemented to achieve sufficient calibration to observed conditions in the Valley as efficiently as possible.

4.1.1 Selection of Calibration Targets

Calibration targets are defined as the selected field-measured values that quantify hydrologic conditions of interest with consideration of data quality and worth. Both qualitative and quantitative calibration targets were selected to evaluate the progress of calibration during development of SACFEM2013. Following is a discussion of how the specific quantitative and qualitative calibration targets were selected for this effort.

4.1.1.1 Quantitative Calibration Targets

SACFEM2013 underwent a transient calibration; therefore, selected field-measured heads recorded between WY1970 and WY2010 served as quantitative calibration targets, or target heads. Calibration target wells were selected from the DWR Water Data Library. The selection process generally proceeded as follows:

- DWR databases were queried to identify all wells with well construction information; wells with unknown construction were eliminated from consideration.
- The number of data records that were associated with each of the remaining wells was summarized within the SACFEM2013 simulation period (WY1970-WY2010); wells with a higher number of records were preferred.
- The spatial location of wells identified in the previous two steps were plotted to ensure that the final wells selected as calibration targets provided a good geographic distribution throughout the model domain, both within individual layers and with depth. This step was performed using a visual identification method as opposed to an automated query.
- The final step was to review additional target well locations recommended during the peer review of the previous version of SACFEM (WRIME, 2011). Select wells that did not necessarily meet the criterion of having a long period of record, but that provided good spatial or vertical (i.e., well clusters) coverage, were added to the calibration target dataset.

The overall result of this process was that 210 wells were identified as transient groundwater elevation targets over the simulation period. The locations of the calibration wells within each model layer are shown on Figure 30. Calibration summary statistics were computed to provide a quantitative measure of the ability of the model to replicate calibration target heads. Head calibration was evaluated using a variety of summary statistics, including the following:

- Residual error, computed as the simulated head value minus the target head value
- Mean error (ME), computed as the sum of all residual errors divided by the number of observations (n)

- Coefficient of determination (R^2), computed as the square of the correlation coefficient
- Root mean squared error (RMSE), computed as the square root of the mean of all residual squared errors
- RMSE divided by the range of target head values (RMSE/Range)

Rather than setting arbitrary goals for individual summary statistics as part of quantitative calibration, CH2M HILL moved forward with the following general goals:

- Minimize spatial bias of residual errors in key areas of the domain
- Minimize residual error, ME, RMSE, and RMSE/Range values
- Have R^2 values as close to 1.00 as possible

Appendix B presents the quantitative calibration targets selected for SACFEM2013, which included 210 target head locations. The target groundwater elevations are also included on the hydrographs in Appendix C.

4.1.1.2 Qualitative Calibration Targets

Qualitative calibration targets refer to general observations of temporal or spatial patterns of the field problem that were compared with model output. These targets included general patterns of gaining and losing streams and bypasses under differing hydrologic conditions. Calibration summary statistics were not used to characterize the ability of SACFEM2013 to replicate qualitative calibration targets; rather, these targets were evaluated to determine if the model is generally able to replicate the expected overall patterns in stream gain/loss. Although the exact stream reaches that gain or lose flow because of surface water/groundwater interaction are not fully delineated, and this relationship changes over time with fluctuating groundwater levels and stream stages, the general pattern observed in the Valley is that the major trunk streams, such as the Sacramento, Feather, and American Rivers, tend to gain flow, especially in their lower reaches. Smaller upper tributaries near the basin margin tend to lose flow to the groundwater system.

4.1.2 Calibration Parameters

Parameter values of streambed Kv, mountain front recharge adjustment factor, Kh, and Kh:Kv were adjusted during the calibration of SACFEM2013. No modifications were made to deep percolation of applied water/precipitation or agricultural pumping data estimated from IDC.

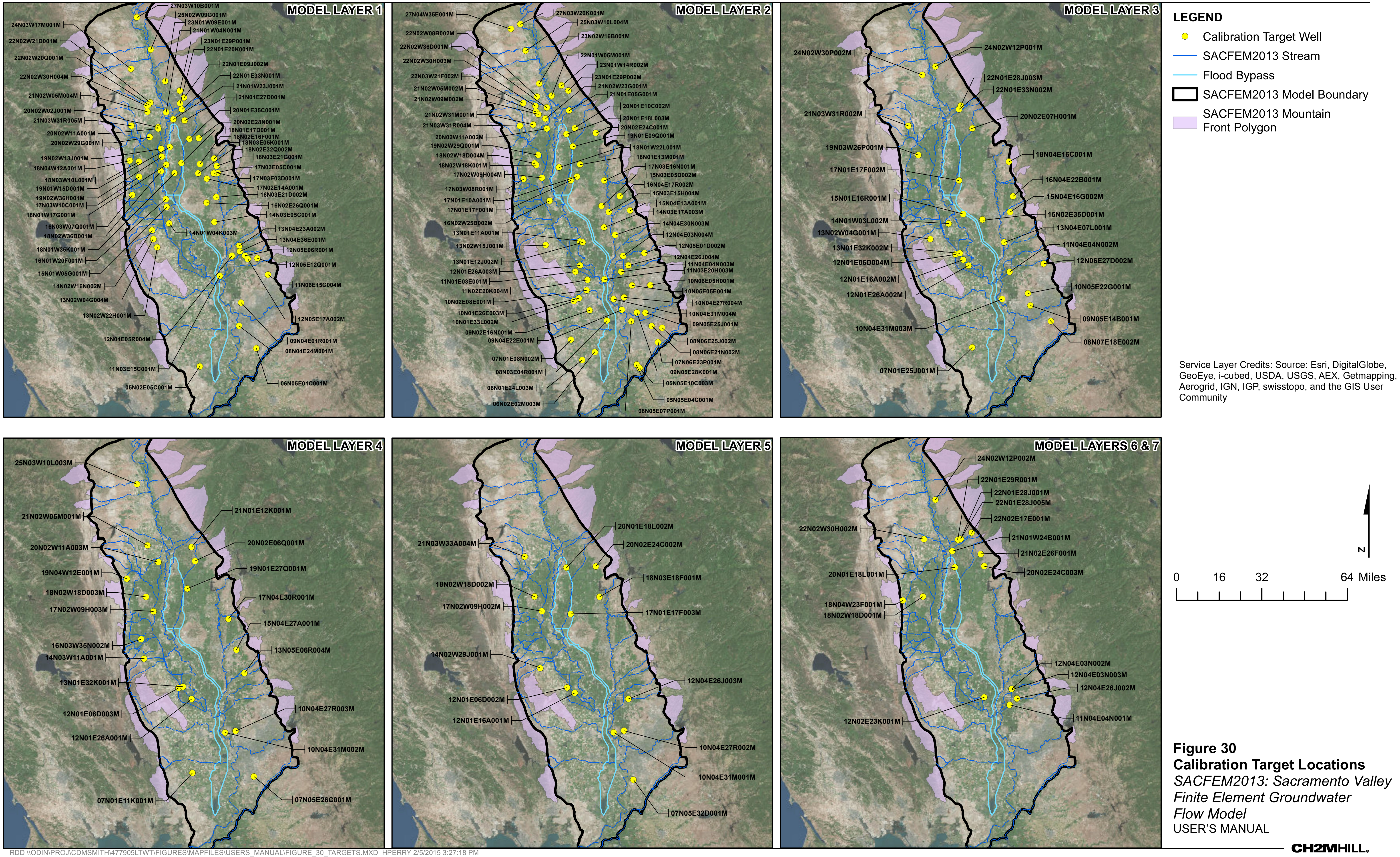
4.1.3 Iterative Manual Calibration Procedure

The general calibration procedure was an iterative process executed using manual techniques. During the calibration phase, property zones were spatially defined and assigned values. This involved manually running the simulations, comparing model results with qualitative and quantitative calibration targets to assess the progress of calibration, and making manual changes to parameter values and boundary conditions (or both) in areas where important calibration mismatches were noted for the next round of simulations. This procedure was repeated until only minor improvements in calibration were achieved with each round of simulations, and the calibration was deemed appropriate.

4.2 Calibration Results

4.2.1 Groundwater Elevations

Locations of SACFEM2013 calibration target wells selected for this evaluation are shown on Figure 30. Measured heads for each calibration target well, along with the associated calibration statistics, are summarized in Appendix B. The purpose of computing summary statistics is to quantify the goodness of fit between simulated and target head data. Goodness-of-fit statistics that accompany model calibration are not necessarily good indicators of the predictive capabilities of a model. Summary statistics are highly sensitive to the number of observations, quality of measured data, and outlier data. Poor calibration statistics can result from a variety of reasons, as described in Section 4.3.



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

Figure 30
Calibration Target Locations
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
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Figure 31 is a scatter plot of individual simulated-versus-target head values. The summary statistics for data presented on Figure 31 and defined in Section 4.1.1.1 are as follows:

- ME = 1.6 feet
- RMSE = 19.6 feet
- Range in calibration target head values = 417.8 feet
- RMSE/Range = 5 percent
- $R^2 = 0.93$
- n = 32,263

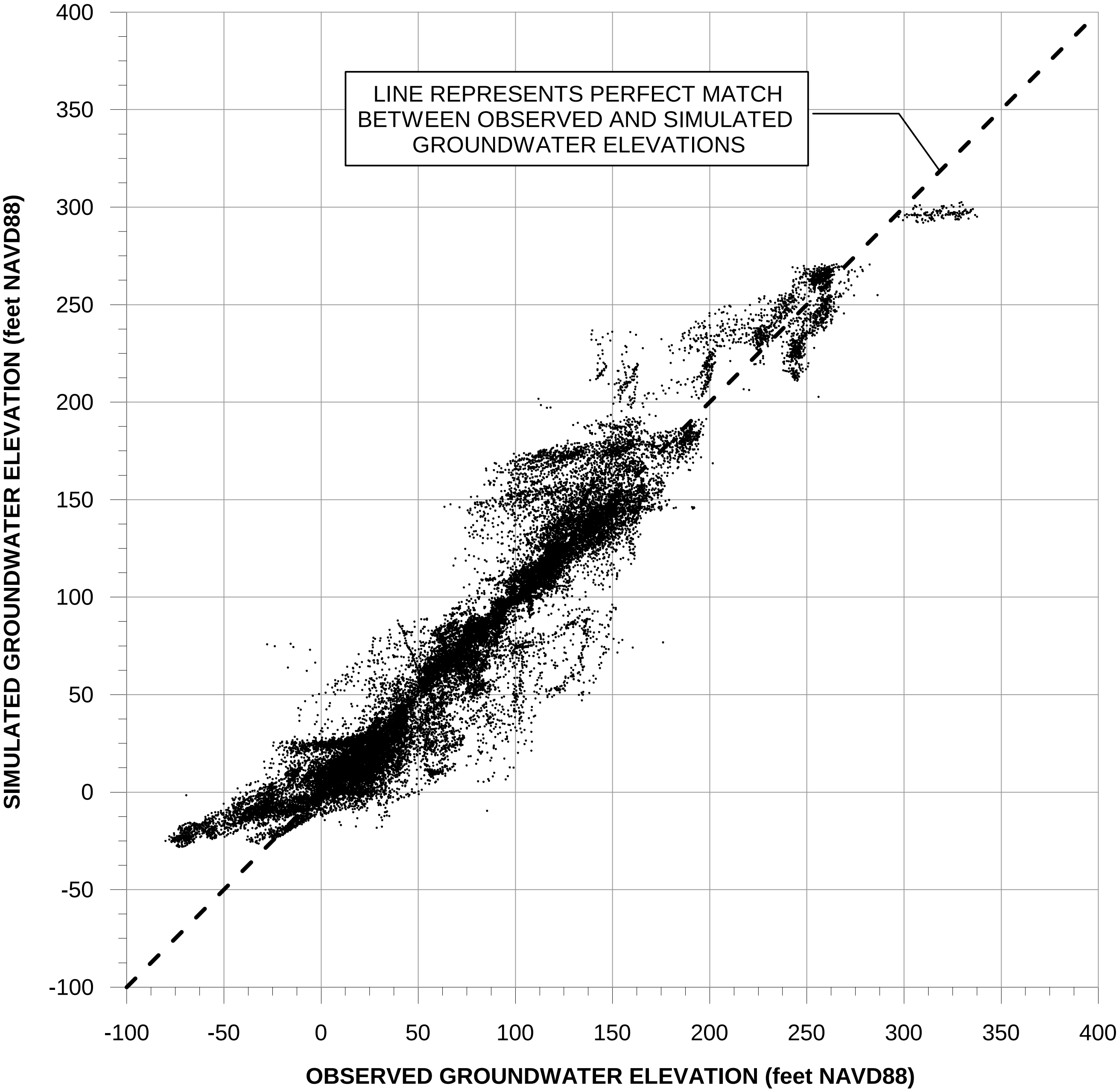
The ME value of 1.6 feet indicates that SACFEM2013 slightly over-predicted heads throughout the domain, as shown by the positive value. However, the ME, RMSE, and RMSE/Range are relatively small, particularly given the scale of the model domain. Additionally, as shown on Figure 31, there is a strong correlation ($R^2 = 0.93$) between simulated and target head data. A well-calibrated model should also have mostly low residual errors, with some simulated heads above and below their target heads. Figure 31 shows that points are above and below the 1:1 correlation line. Thus, the calibration results for this effort do not indicate global bias (that is, all positive or all negative residual errors).

Figure 32 shows the spatial distribution of the mean error in simulated heads that are listed in Appendix B by model layer. The data presented on Figure 32 and in Appendix B indicate that mean error in nearly half of the target wells is within ±5 feet. The data further suggest that there may be slight spatial bias indicating that wells east of Dunnigan Hills and in Placer County/southeastern Sutter County are simulated low, and wells near the southern model boundary (Sacramento County) and in northern Butte County are simulated slightly high. This is likely the result of small-scale features not explicitly simulated in SACFEM2013. Overall, the statistics listed above and presented in Appendix B and Figure 32 are considered to represent good calibration.

The other method used to evaluate the quality of the transient calibration was to compare the simulated hydrographs for each of the 210 target monitoring wells with the measured hydrograph data. These hydrograph comparisons are presented on Appendix C. Examination of the time-series simulated and measured groundwater hydrographs helps to inform the mean errors presented on Figure 32. For example, in the southeastern portion of the model domain (06N05E01C001M, model Layer 1) the time series data show that SACFEM2013 does a good job of replicating the transient groundwater level fluctuations; however, the simulated heads are overestimated. Another example, 15N04E13A001M (model Layer 2) suggests that SACFEM2013 does an excellent job of replicating the later-time measured groundwater elevations; however, there are local factors not explicitly simulated that result in over-estimation of the earlier time groundwater elevations. The result is a mean error of approximately 21 feet, which is biased by the early time data. Finally, there are select calibration targets (such as 07N01E11K001M, model Layer 4) that appear to be in close proximity to a pumping well, as suggested by the large seasonal variability in measured groundwater elevations. Because individual pumping wells are not explicitly simulated in SACFEM2013, the magnitude of simulated groundwater fluctuation is less than observed. Although some deviations remain between simulated and observed data during certain periods at select locations, SACFEM2013 generally does a good job of replicating both the absolute groundwater elevations and transient trends in the majority of the 210 calibration target wells within the model domain.

4.2.2 Stream Gain/Loss

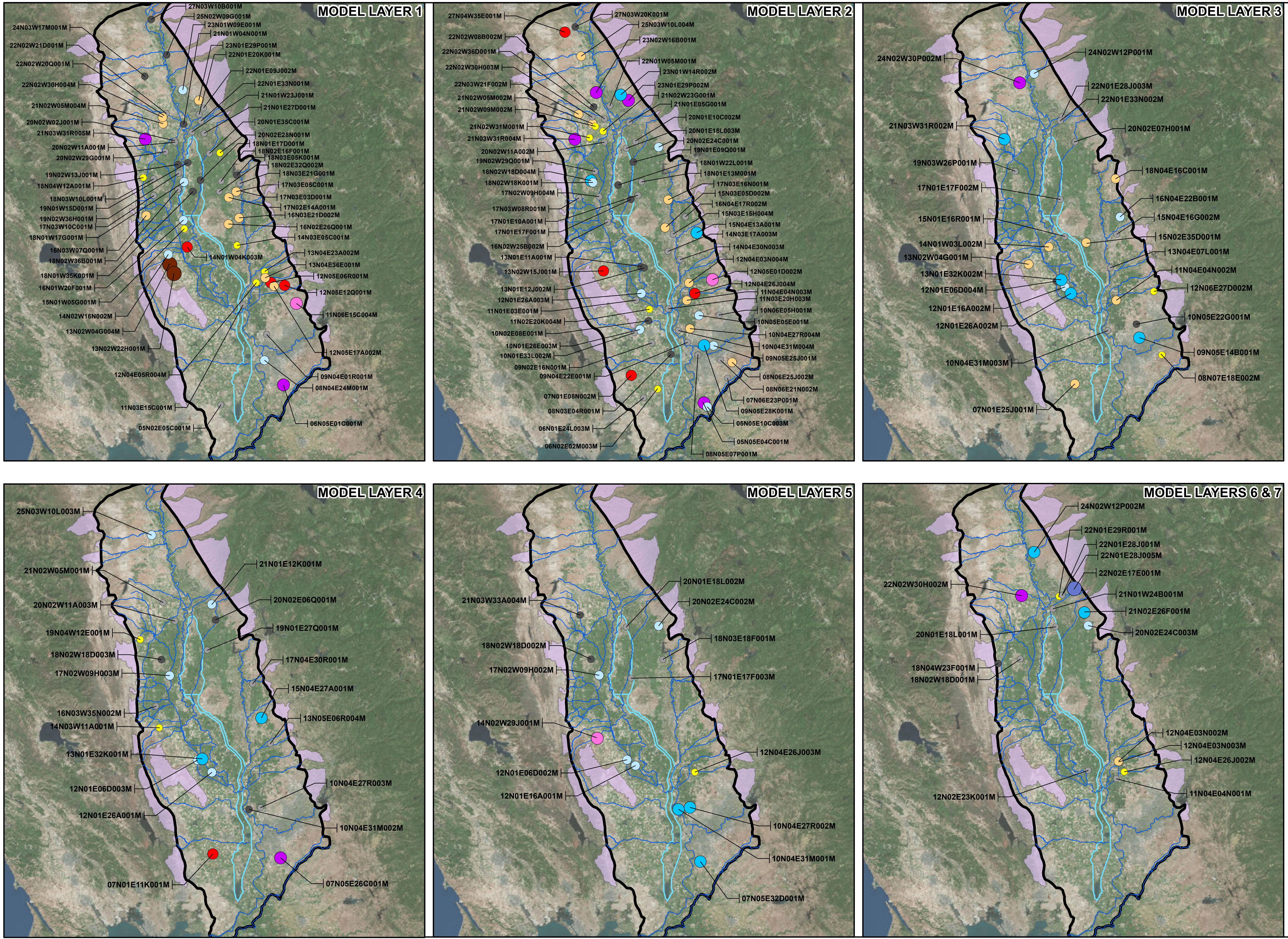
As discussed above, the general patterns of losing and gaining reaches of streams and bypasses were included as qualitative targets during the calibration of SACFEM2013. Figure 5 presents water year type designations for the SACFEM2013 simulation period. Stream and bypass reaches predicted by the model to



n = 32,263
ME (ft) = 1.6
RMSE (ft) = 19.6
Range (ft) = 417.8
RMSE/Range = 0.05
$r^2 = 0.93$

Notes:
1. n = number of measurements
2. ME = mean error
3. RMSE = root mean squared error
4. Range = range in measured groundwater elevations
5. RMS/Range is a measure of model calibration and is equal to the root mean squared error (RMS) divided by the range in measured groundwater elevation.
6. NAVD88 = North American Vertical Datum of 1988.

Figure 31
Simulated versus Observed Groundwater Elevations
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL



LEGEND

- SACFEM2013 Stream
- Flood Bypass
- SACFEM2013 Model Boundary
- SACFEM2013_VoidPolygons

Mean Error (feet)

- ● -71.8 to -50.0
- ● -49.9 to -30.0
- ● -29.9 to -20.0
- ● -19.9 to -10.0
- ● -9.9 to -5.0
- ● -4.9 to 5.0
- ● 5.1 to 10.0
- ● 10.1 to 20.0
- ● 20.1 to 30.0
- ● 30.1 to 50.0
- ● 50.1 to 80.0

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

N

0 16 32 64 Miles

Figure 32
Simulated Mean Error in Groundwater Elevation
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

RDD \\ODIN\PROJ\CDMSMITH\477905LTWT\FIGURES\MAPFILES\USERS_MANUAL\FIGURE_32_MEANERROR.MXD HPERRY 2/5/2015 3:32:55 PM

CH2MHILL.

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gain or lose flow to the groundwater aquifer were evaluated under typical above-normal hydrologic conditions (April 2000, see Figure 33), extreme drought (July 1977, see Figure 34), and wet conditions (January 1983, see Figure 35). As shown on Figure 33, the pattern of predicted stream gain/loss during April 2000 is consistent with what would be expected during an above-normal period. The major trunk streams throughout the Valley, such as the Sacramento and Feather Rivers, are gaining, while the smaller tributaries are losing flow to the groundwater system. Further, the flood bypasses are not active under these hydrologic conditions. Figure 34 presents the distribution of simulated gaining/losing stream reaches in July 1977. Model output suggests that the majority of streams throughout the Valley are losing flow to the aquifer system, which is consistent with what would be expected under this critically dry condition. Many of the smaller tributary streams as well as the flood bypasses are inactive during this period, as evidenced by the lack of stream gain/loss symbology (i.e. blue or yellow circle). Finally, the predicted distribution of stream and bypass gain/loss during January 1983 is presented on Figure 35. Model output suggests that, although there are limited gaining stream reaches, the vast majority of streams and bypasses are losing flow to the groundwater system. This is likely a result of high stream stage elevations during runoff in this extremely wet hydrologic period. Overall, the patterns predicted by the calibrated groundwater flow model are reasonably consistent with expected stream gains and losses under the varying hydrologic conditions, and calibration of SACFEM2013 against this qualitative target is considered good.

4.2.3 Calibrated Hydraulic Parameters

Figures 12 and 13 show the modeled hydraulic conductivity values that resulted from the calibration process. These values are within a reasonable range of literature values for heterogeneous unconsolidated deposits and bedrock. As discussed in Section 3.2.2.2, a Kh:Kv of 50:1 was assigned in model Layer 1, 500:1 was assigned in model Layers 2 through 7, and 1:1 was assigned to bedrock areas in all model layers throughout most of the model domain. The final set of mountain front recharge adjustment factors is included in Table 6, and the final streambed Kv values are presented on Figure 15 and in Table 2.

4.2.4 Groundwater Balance

Figures 36 and 37 summarize the primary inflow and outflow components of the transient groundwater budget for SACFEM2013. These plots were generated by totaling the monthly inflows and outflows for each of the components by water year. The SACFEM2013 model output presented on these figures indicates that the inflows are highly variable from year to year, while the outflows are more or less consistent. Figure 36 presents the annual volumes for the SACFEM2013 inflow components, deep percolation of applied irrigation water and precipitation, groundwater recharge from stream leakage, and groundwater recharge along the mountain front. The pattern in annual volumes of inflow to SACFEM2013 are such that the magnitudes are highest during wet hydrologic periods and lowest during dry hydrologic periods. For example, the maximum annual inflow (approximately 6.5 MAF) occurs during the extremely wet period of WY1983 and the minimum annual inflow (approximately 1.8 MAF) occurs during the critical drought of WY1976-WY1977. Groundwater recharge from streams comprises the largest component of the water budget, ranging from 33 to 68 percent of the annual inflow. Deep percolation of applied water and precipitation ranges from 24 to 54 percent of the annual inflow, and recharge along the mountain front ranges from 4 to 17 percent of the total annual inflow.

Figure 37 presents the annual volumes for the SACFEM2013 outflow components, groundwater pumping, groundwater discharge to streams, and groundwater discharge to land surface. The volumes of outflow from SACFEM2013 have an opposite pattern with respect to hydrologic cycles in the SVGB than groundwater inflow components. The minimum annual outflow occurs during wet periods, such as WY1982-WY1983 and WY1995-WY1999, and the maximum annual outflow occurs during dry periods, such as the critical drought of WY1976-WY1977. Groundwater pumping is by far the largest outflow component of the water budget, ranging from 56 percent (2.3 MAF) to 96 percent (5 MAF) of the annual outflow. Groundwater discharge to land surface ranges from 1 to 33 percent of the total annual outflow, and groundwater discharge to streams ranges from 3 to 13 percent of the annual outflow. It should be noted that the boundary condition used to simulate groundwater discharge to land surface (discussed in Section 3.2.4.1) represents surficial processes including groundwater discharge to low-lying topographic areas, such as riparian to streams, as well as small tributaries not explicitly simulated in SACFEM2013. For practical purposes, this component of the water budget can be considered groundwater discharge to streams.

Figure 38 presents the cumulative change in storage over the WY1970 through WY2010 simulation period. These SACFEM2013 results indicate that simulated changes in aquifer storage correlate to the hydrologic cycles. Periods of decrease in storage correspond to drought cycles, such as WY1976-WY1977 and WY1987-WY1992, and increases in aquifer storage correspond to wetter periods such as WY1982-WY1984 and WY1995-WY1999. Overall, the trends and magnitudes of SACFEM2013 are appropriate and consistent with the generally accepted water balance for the SVGB.

4.3 Potential Sources of Error

Calibration target values and simulated output each have associated errors or error potential, resulting in an overall uncertainty in results. The sources of uncertainty include transient effects, human errors, scaling effects, interpolation errors, and numerical errors (Anderson and Woessner, 1992).

4.3.1 Transient Effects

Groundwater-level measurements in wells could reflect the presence of transient effects in the groundwater system that might not be represented in SACFEM2013. The only available subsurface access for directly monitoring groundwater conditions is through groundwater wells. If transient effects of the groundwater system manifest in groundwater levels at timescales other than those represented in the numerical model, some portion of the residual error between the field-measured groundwater level and the simulated output could be due to these transient effects.

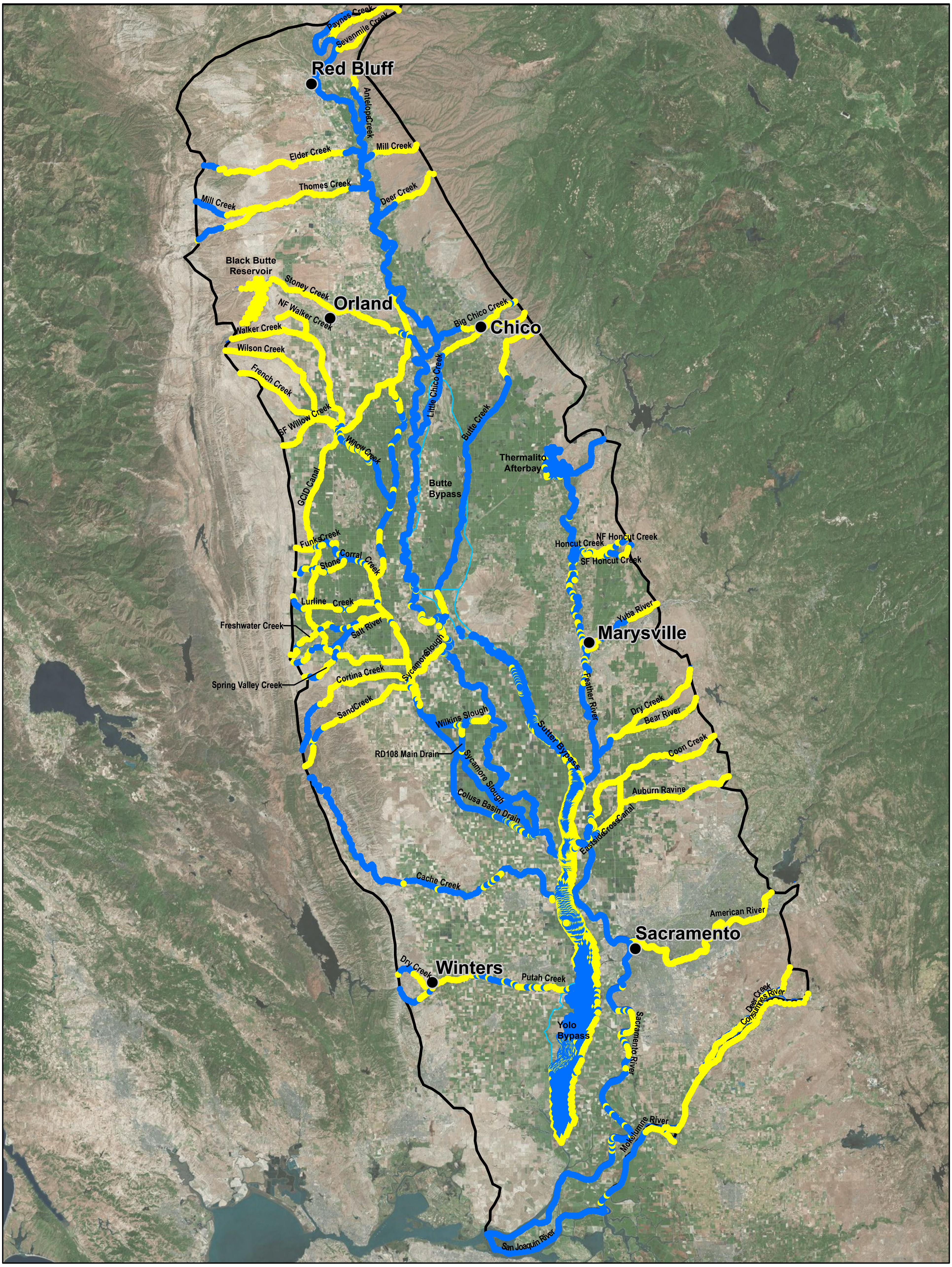
4.3.2 Human Errors

It is not possible to guarantee that the modeling results presented in this manual are free of human error. However, CH2M HILL strived to avoid introducing human errors by adhering to quality assurance protocols. The following are examples of potential sources of human errors:

- **Measurement Errors.** Calibration target values include measurement errors. Measurement errors relate to the accuracy and consistency of the measurement device or structure, the accuracy and consistency of the elevation survey datum, and the diligence of the field or laboratory technician who collects or analyzes the data. Thus, some portion of the residual error between the field-measured data and the simulated output could be due to measurement error in the calibration target value.
- **Data Management Errors.** Errors can be introduced as a result of data management activities. Examples of data management errors include, but are not limited to, associating input data with an incorrect location (resulting in spatial errors), assigning time-series data incorrectly (resulting in temporal errors), or otherwise inputting values incorrectly. Thus, some portion of the residual error between the field-measured data and the simulated output could be due to data management errors.
- **Conceptualization Errors.** Errors can be introduced as a result of inadequately conceptualizing the field problem. The absence of important Site information can lead to errors associated with assumptions that are necessary to perform predictive simulations. Thus, some portion of the residual error between the field-measured data and the simulated output could be due to conceptualization errors.

4.3.3 Scaling Effects

A numerical model uses discrete space to represent the hydrologic system. SACFEM2013 grid was built in an effort to strike a balance between maximizing the number of nodes in key areas of the domain and minimizing the numerical burden and associated model run times. However, numerical grids are subject to errors resulting from scaling effects. Errors associated with scaling effects result when and where significant spatial heterogeneities in the field problem are not represented at the scale of the numerical grid elements.



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

Figure 33
Distribution of Simulated Stream Gain and Loss; April 2000
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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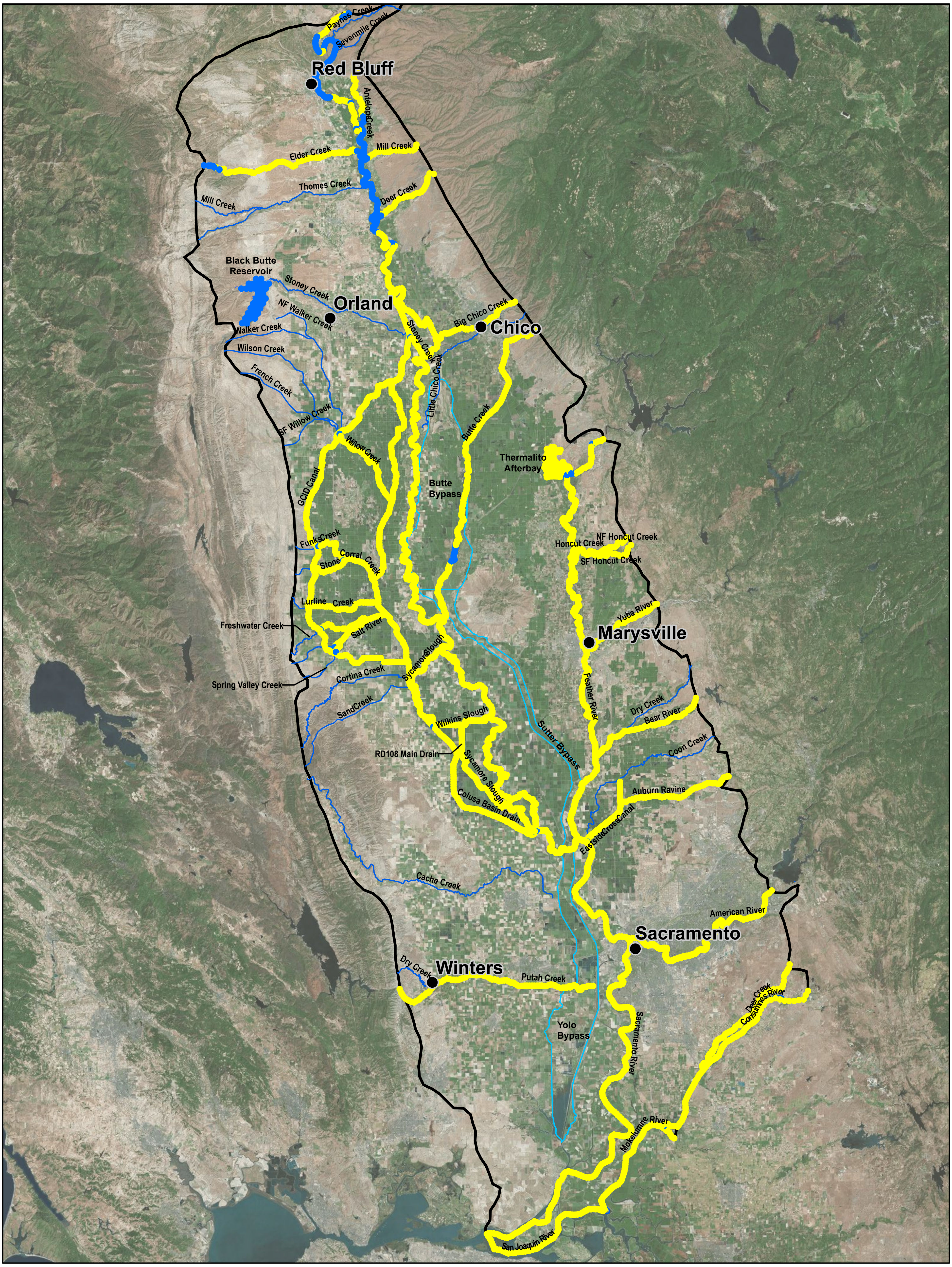


LEGEND

● City

SACFEM2013 Stream

Flood Bypass

SACFEM2013 Model Boundary

● Simulated Losing Stream Reach

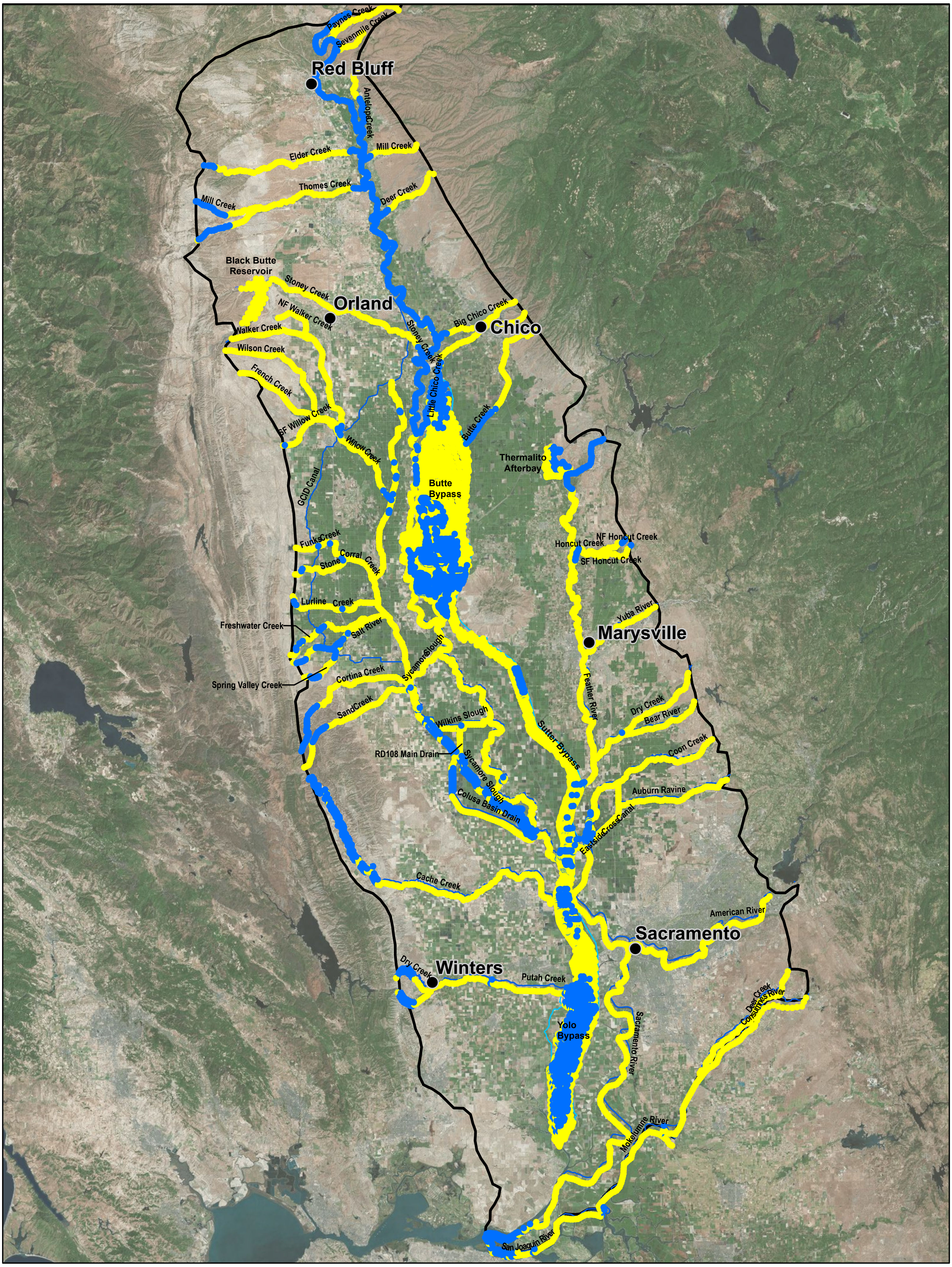
● Simulated Gaining Stream Reach

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

N

0 6 12 24 Miles

Figure 34
Distribution of Simulated Stream Gain and Loss; July 1977
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL



LEGEND

- ● City
- SACFEM2013 Stream
- Flood Bypass
- SACFEM2013 Model Boundary
- ● Simulated Losing Stream Reach
- ● Simulated Gaining Stream Reach

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

N

0 6 12 24 Miles

Figure 35
Distribution of Simulated Stream Gain and Loss; January 1983

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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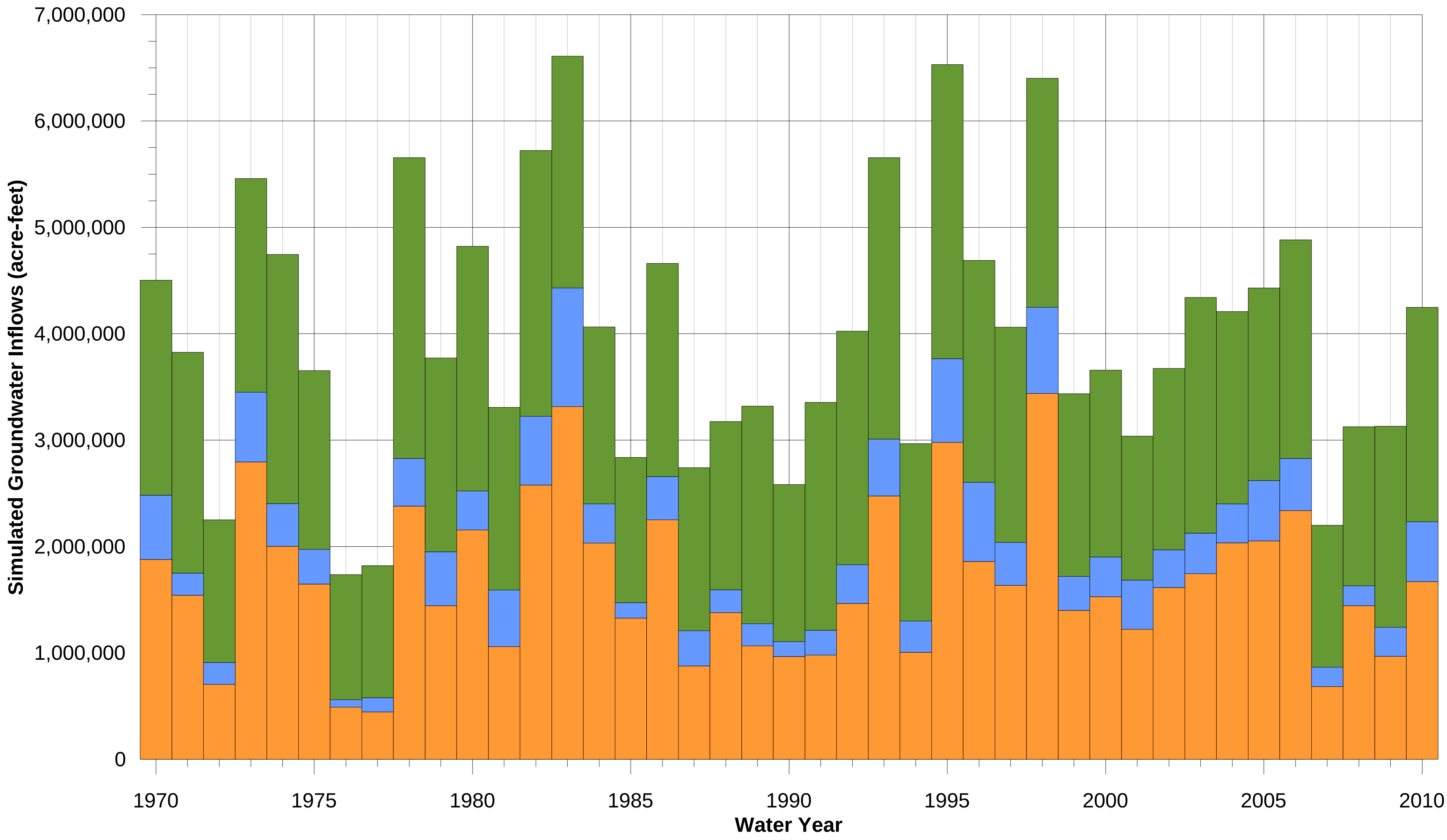
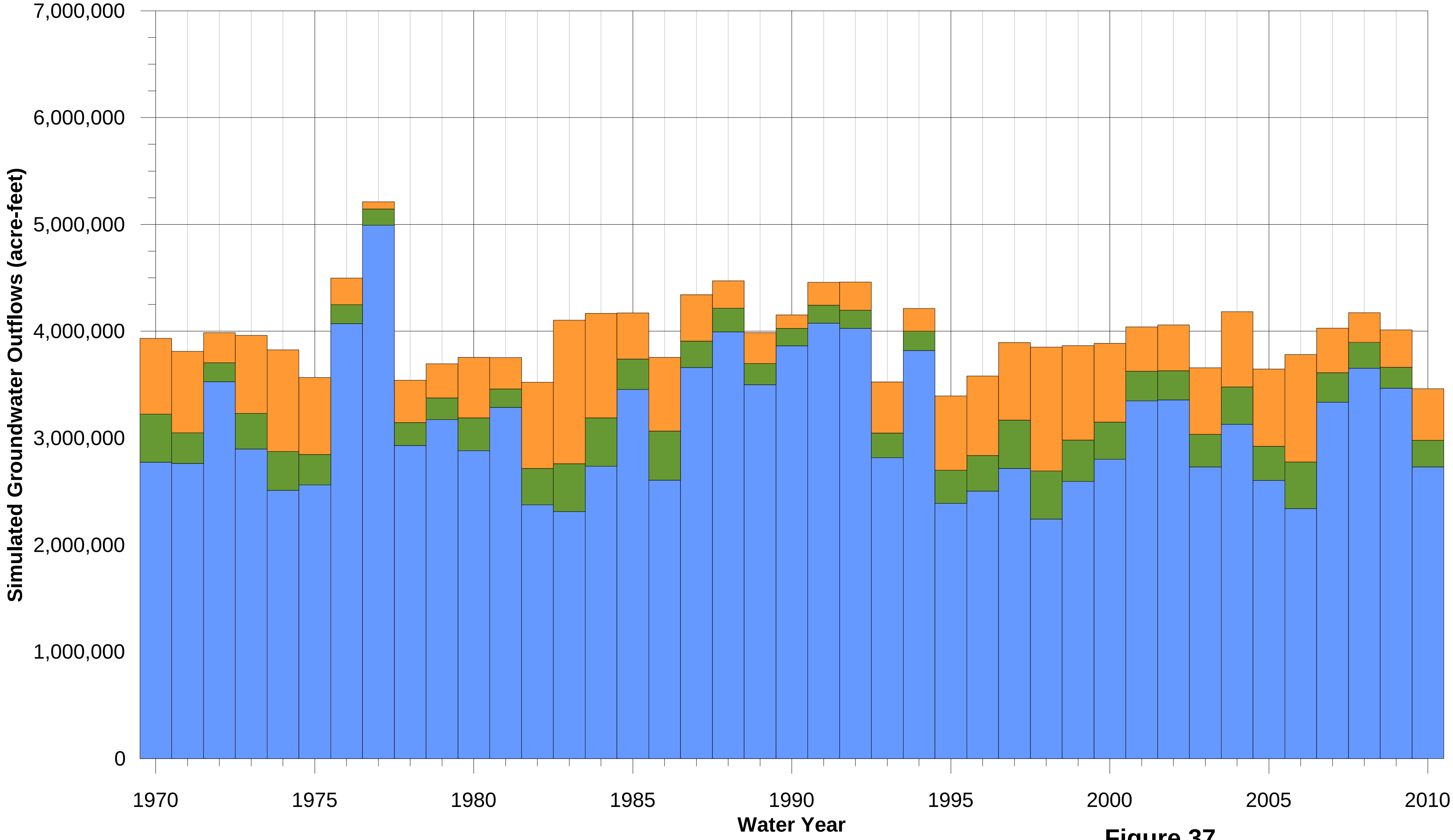


Legend

- 🟧 Deep Percolation
- 🟦 Mountain Front Recharge
- 🟩 Recharge from Stream Leakage

Figure 36
Simulated Inflow Components of Transient Water Budget

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL



Legend

🟦 Groundwater Pumping
🟩 Discharge to Streams
🟧 Discharge to Land Surface

Note:
Discharge to land surface is a boundary condition that represents surficial processes including groundwater discharge to low-lying topographic areas, such as those riparian to streams, as well as small tributaries not explicitly simulated in SACFEM2013.
For practical purposes, this component of the water budget can be considered groundwater discharge to streams.

Figure 37
Simulated Outflow Components of Transient Water Budget
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

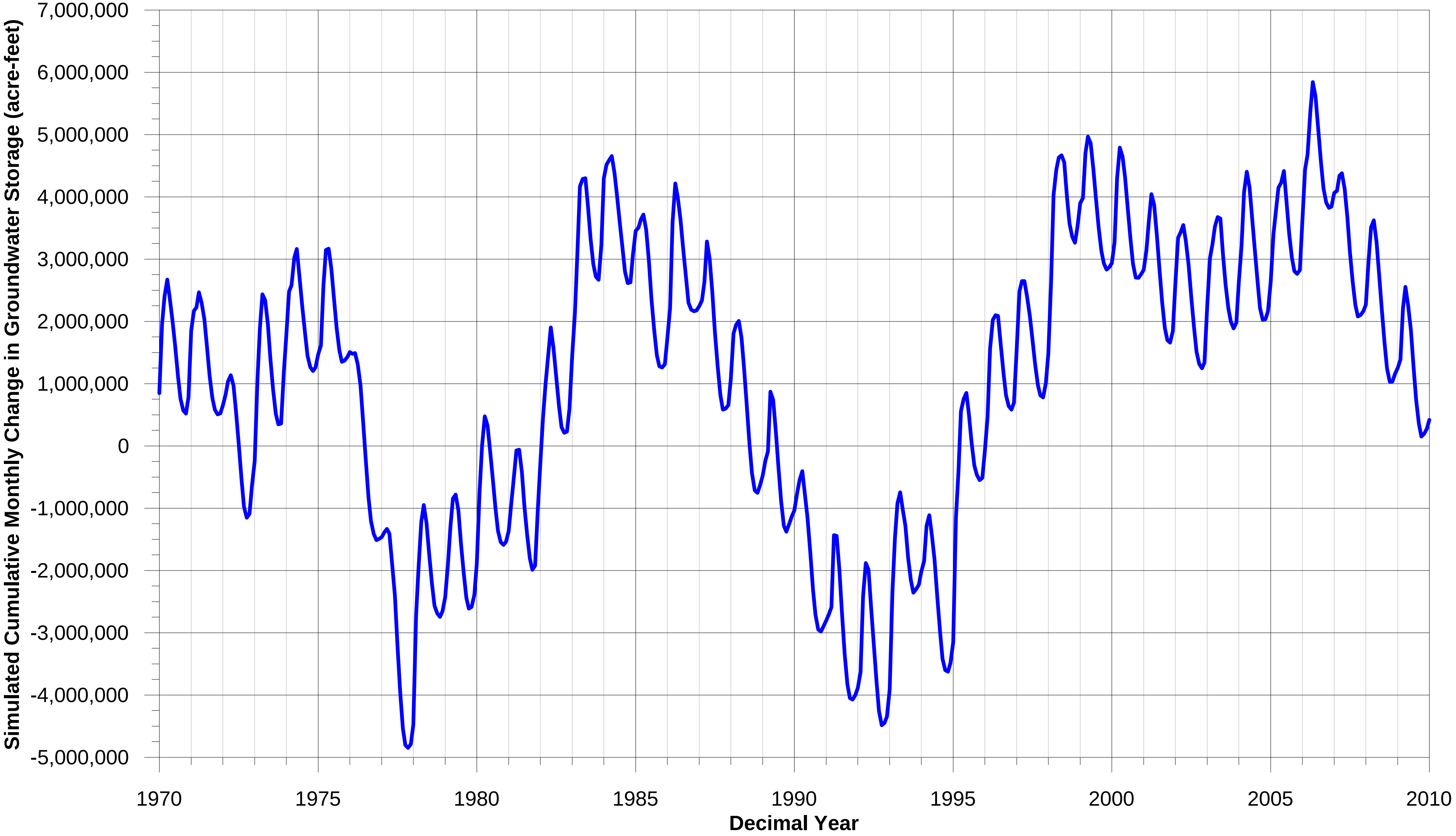


Figure 38
Simulated Cumulative Monthly
Change in Groundwater Storage
SACFEM2013: Sacramento Valley Finite
Element Groundwater Flow Model
USER'S MANUAL

4.3.4 Interpolation Effects

Interpolation errors can result from spatially distributing point values of parameters or stresses over the model domain. In an effort to manage interpolation errors, one of the goals for selecting calibration target locations for SACFEM2013 was to seek a relatively uniform spatial distribution of calibration targets over SACFEM2013 domain. Having a reasonable number of spatially distributed calibration targets and types of calibration targets (for example, qualitative and quantitative) helps make model output more reliable over a wide range of conditions for the entire domain.

4.3.5 Numerical Errors

Errors associated with the way a model solves the governing flow equations, coupled with the assumptions in the governing equations being solved, are inherent in numerical models. Numerical errors are also associated with the selection of convergence closure criteria by the user. User selection of convergence closure criteria is an iterative process during calibration that seeks to strike a balance between making calibration progress by completing as many simulations as possible within the project schedule and achieving adequate accuracy in the numerical solution. Selecting convergence closure criteria that are too low during initial stages of model calibration results in fewer simulations being completed because of longer run times and possible convergence problems. CH2M HILL minimized introduction of numerical errors by selecting convergence criteria that resulted in converged solutions that provided mass balances of flow.

4.4 Calibration Outcome

A relatively high-resolution, three-dimensional numerical groundwater flow model of the SVGB has been developed to support the evaluation of conjunctive water management projects across the Valley. Specifically, SACFEM2013 was developed to assess the transient effects of groundwater pumping on groundwater levels and to estimate changes in surface water/groundwater interaction.

The current finite-element groundwater flow model grid has a resolution on the order of 410 feet (125 meters) in areas where conjunctive water management projects are being considered and effects are being evaluated. The model has been constructed so that future project-specific grids can be developed, and the 41-year agricultural water budget can be projected onto the new grid using a semi-automated GIS-based tool. The vertical resolution of the model consists of seven model layers. The uppermost model layer was limited to 65 feet or less in thickness to allow assessment of impacts on streams as well as riparian habitat and wetlands. Model Layers 2 through 5 were selected to represent typical groundwater production zones within the Valley. Layers 6 and 7 were developed to represent the Lower Tuscan Formation, where it exists, within the northeastern and central portions of the Valley.

The surface water budget, including agricultural pumping and deep percolation of precipitation and applied water, was developed using a GIS-based analysis that considers land use, crop types, water source, seniority of water rights, and availability of surface water on a monthly time step. These deep percolation fluxes and agricultural pumping fluxes are independently computed for each element in the model. The fluxes associated with mountain-front recharge and urban pumping were also simulated on a monthly time-step. Time-variable surface stream and flood bypass stages were defined by using available data, including USGS topographic maps and stream gage elevations.

The SACFEM2013 model was calibrated to transient groundwater elevation data sets. Groundwater elevations recorded during the hydrologic period from water years 1970 through 2010 were used as transient calibration targets. More qualitative calibration targets such as the magnitude of the water budget components and the pattern and magnitude of surface water/groundwater interaction were also considered.

The SACFEM2013 model represents a valuable analytical tool to estimate the effects of groundwater pumping on both groundwater levels and changes in surface water/groundwater interaction within the SVGB.

SECTION 5
SACFEM Application

The following section describes the process of executing a SACFEM2013 model simulation, including preparation of input datasets, description of the SACFEM2013 model files, and post-processing of model output.

5.1 SACFEM2013 Project File

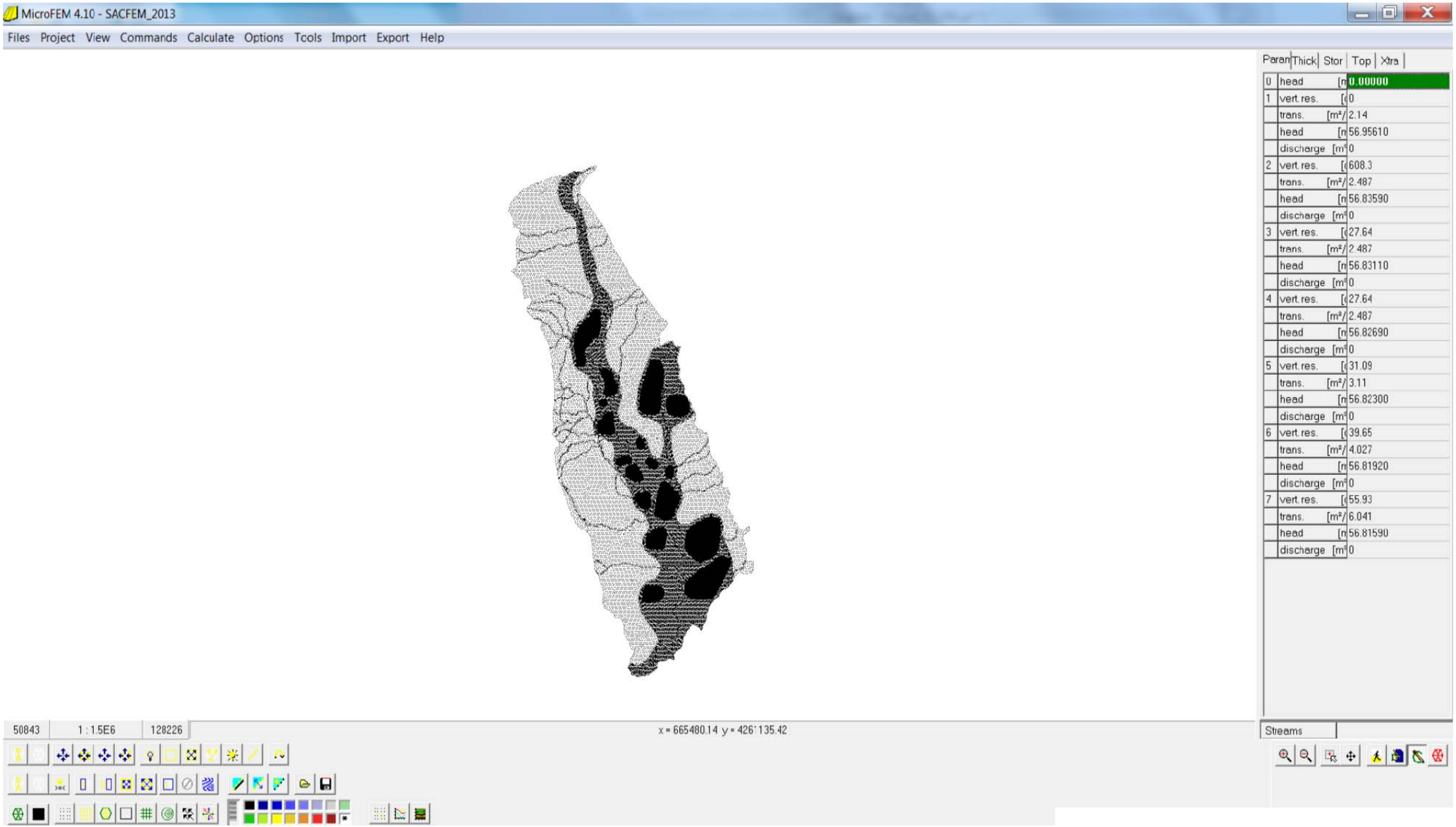
SACFEM2013 comprises numerous individual files, which will be described in more detail below. The primary file is the SACFEM2013 project file (*.fpr). A MicroFEM project file, such as SACFEM_2013.fpr is an ASCII file, which can be opened via a text editor or directly via the MicroFEM interface. When opened with a text editor, the project file is essentially a list of all data files (or parameter files) that make up a groundwater model. The following is a display of the file "SACFEM_2013.fpr" in text editor mode:

```
Base-model=SACFEM_2013.fem
Thickness=SACFEM_2013.thi
Storativity=SACFEM_2013.sto
Precipitation=SACFEM_2013.ppn
Drain system H1=SACFEM_2013.dh1
Drain system C1=SACFEM_2013.dc1
Wadi-recharge system L1=SACFEM_2013.wh1
Wadi-recharge system H1=SACFEM_2013.wh1
Wadi-recharge system C1=SACFEM_2013.wc1
Batch-file=SACFEM_2013.fpr[6]
Xtra=SACFEM_2013.xtr
```

Figure 39 presents the display of SACFEM_2013.fpr when opened directly via the MicroFEM interface. This figure presents the SACFEM2013 model grid (note: nodal points rather than model elements are displayed) in the main body of the display window with the MicroFEM file "tabs" located along the right-hand margin. Each MicroFEM tab contains a different set of data, as described in the following subsections. MicroFEM files can be loaded directly into registers on each of the model tabs or can be loaded via the MicroFEM project manager (see Figures 40 and 41).

---

[6] The MicroFEM batch file is discussed in detail in Section 5.2.2.



0	head [m	0.00000
1	vert. res. [	0
	trans. [m²/	2.14
	head [m	56.95610
	discharge [m	0
2	vert. res. [	608.3
	trans. [m²/	2.487
	head [m	56.83590
	discharge [m	0
3	vert. res. [	27.64
	trans. [m²/	2.487
	head [m	56.83110
	discharge [m	0
4	vert. res. [	27.64
	trans. [m²/	2.487
	head [m	56.82690
	discharge [m	0
5	vert. res. [	31.09
	trans. [m²/	3.11
	head [m	56.82300
	discharge [m	0
6	vert. res. [	39.65
	trans. [m²/	4.027
	head [m	56.81920
	discharge [m	0
7	vert. res. [	55.93
	trans. [m²/	6.041
	head [m	56.81590
	discharge [m	0

50843 | 1 : 1.5E6 | 128226

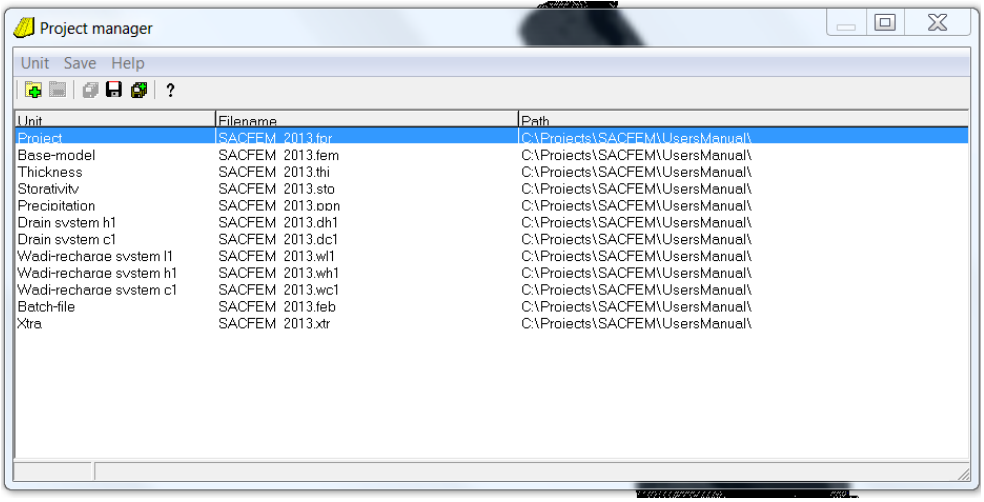
x = 665480.14 y = 426'135.42

Figure 39
View of SACFEM2013.fpr
via MicroFEM Interface

SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

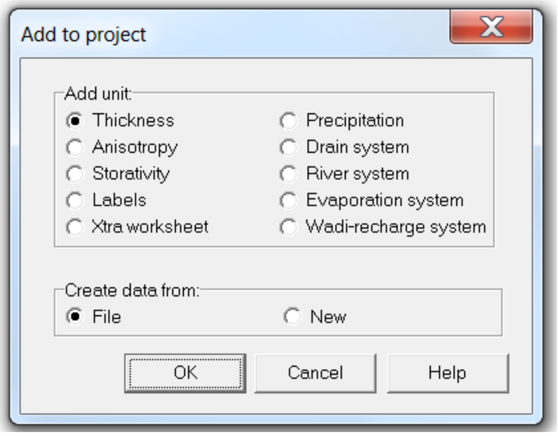
\\ODIN\Proj\CDMSmith\477905LTWT\Figures\Grapher\Figure_39_FPR.grf

FIGURE 40
MicroFEM Project Manager, Main Window



Unit	Filename	Path
Project	SACFEM 2013.fpr	C:\Projects\SACFEM\UsersManual\
Base-model	SACFEM 2013.fem	C:\Projects\SACFEM\UsersManual\
Thickness	SACFEM 2013.thi	C:\Projects\SACFEM\UsersManual\
Storativity	SACFEM 2013.sto	C:\Projects\SACFEM\UsersManual\
Precipitation	SACFEM 2013.ppn	C:\Projects\SACFEM\UsersManual\
Drain system h1	SACFEM 2013.dh1	C:\Projects\SACFEM\UsersManual\
Drain system c1	SACFEM 2013.dc1	C:\Projects\SACFEM\UsersManual\
Wadi-recharge system l1	SACFEM 2013.wl1	C:\Projects\SACFEM\UsersManual\
Wadi-recharge system h1	SACFEM 2013.wh1	C:\Projects\SACFEM\UsersManual\
Wadi-recharge system c1	SACFEM 2013.wc1	C:\Projects\SACFEM\UsersManual\
Batch-file	SACFEM 2013.feb	C:\Projects\SACFEM\UsersManual\
Xtra	SACFEM 2013.xtr	C:\Projects\SACFEM\UsersManual\

FIGURE 41
MicroFEM Project Manager, Load File Window



Add unit:
● Thickness ○ Precipitation
○ Anisotropy ○ Drain system
○ Storativity ○ River system
○ Labels ○ Evaporation system
○ Xtra worksheet ○ Wadi-recharge system

Create data from:
● File ○ New

5.1.1 SACFEM2013 Base-model ("Param" tab)

The first tab displayed in the MicroFEM interface, as presented on Figure 39, is the Parameter tab. The parameter tab is essentially a display of all data included in the MicroFEM Base-model (*.fem file). A MicroFEM Base-model is an ASCII file[7] containing both network (grid) information, and basic groundwater model information. As shown on Figure 39, SACFEM_2013.fem contains nodal values of vertical resistance, transmissivity, head, and discharge for each of the seven model layers. The base-model also retains the "label 1" register; in the example provided on Figure 39, this is a stream label file. Individual parameter files (that is, files containing a list of numerical values for every model node) can be loaded for any of the registers either directly in the MicroFEM interface or via a batch file during transient simulation (as will be discussed in a subsequent section).

**Note – the "head 0" and "vert. resist. 1" registers at the top of the Parameter tab can be used to simulate leakage from a feature, such as a lake, into model Layer 1. These registers are similar to the top system boundary conditions (i.e., there are specified head and resistance terms). In SACFEM_2013.fem, these registers have value of zeros at every node. Non-zero values should NOT be loaded into these registers when running SACFEM2013.*

---

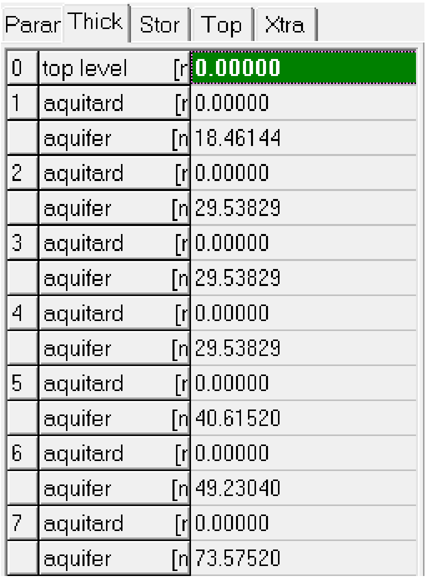
[7] All MicroFEM files are in ASCII format and can be opened in a text editor. The reader is directed to the MicroFEM help menu or User's Manual for additional format/structure of raw data files.

5.1.2 SACFEM2013 Thickness File ("Thick" Tab)

The thickness file (SACFEM_2013.thi) contains the nodal saturated thickness values for all model layers. A display of the thickness tab via the MicroFEM interface is included on Figure 42. As shown on Figure 40, the thickness tab (*.thi file) contains registers for both aquifer and aquitard saturated thickness for all model layers. SACFEM2013 does not include explicit simulation of aquitards; therefore, the values in these registers is zero for all model layers. Individual parameter files (that is, files containing a list of numerical values for every model node) can be loaded for any of the registers either directly in the MicroFEM interface or via a batch file during transient simulation (as will be discussed in a subsequent section).

**Note – the top level register can be populated with water table elevations (H1 values) so that model layer elevations are internally calculated/displayed when viewing the model in profile or when running groundwater flowlines. For the purposes of the current analysis, the top level values in SACFEM2013 are zero for all nodes.*

FIGURE 42
SACFEM2013 Thickness Tab

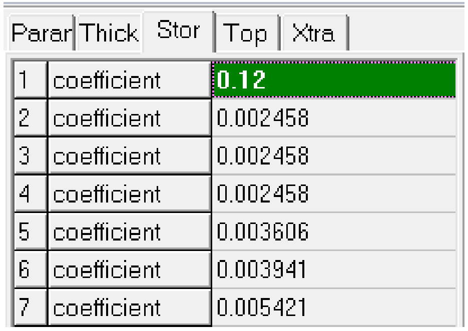


0	top level [r	0.00000
1	aquitard [r	0.00000
	aquifer [n	18.46144
2	aquitard [r	0.00000
	aquifer [n	29.53829
3	aquitard [r	0.00000
	aquifer [n	29.53829
4	aquitard [r	0.00000
	aquifer [n	29.53829
5	aquitard [r	0.00000
	aquifer [n	40.61520
6	aquitard [r	0.00000
	aquifer [n	49.23040
7	aquitard [r	0.00000
	aquifer [n	73.57520

5.1.3 SACFEM2013 Storativity File (Stor Tab)

The storativity file (SACFEM_2013.sto) contains the storage values for all model nodes. This includes the specific yield of model Layer 1 and the specific storage values for model Layers 2 through 7. A display of the thickness tab via the MicroFEM interface is included on Figure 43. Individual parameter files (that is, files containing a list of numerical values for every model node) can be loaded for any of the registers either directly in the MicroFEM interface or via a batch file during transient simulation (as will be discussed in a subsequent section).

FIGURE 43
SACFEM2013 Storage Tab



1	coefficient	0.12
2	coefficient	0.002458
3	coefficient	0.002458
4	coefficient	0.002458
5	coefficient	0.003606
6	coefficient	0.003941
7	coefficient	0.005421

5.1.4 SACFEM2013 Top Systems (“Top” Tab)

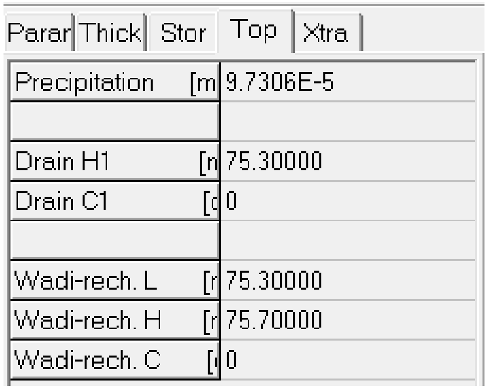
The top systems tab comprises the data for boundary conditions that are applied to the “top” of the SACFEM2013 model. This means that the data are either head-dependent boundary conditions that are calculated relative to the simulated groundwater elevations in model Layer 1 or specified flux conditions that are applied to the top of the water table. SACFEM2013 contains the following top systems, as shown on Figure 44:

- Precipitation file (*.ppn) – includes a linear rate representing groundwater recharge from precipitation and applied irrigation water at every model node.
- Drainage file (*.dh1 and *.dc1) – contains the drain elevation and resistance term for every model node for a given stress period.
- Wadi System (*.wh1, *.wl1, and *.wc1) – contains the stream stage (*.wh1) and streambed (*.wl1) elevations and streambed resistance term (*.wc1) for all active stream nodes for a given stress period.

**Note: In the Example on Figure 44, both the drain and wadi resistance terms are 0, denoting that there are no active head-dependent boundary conditions for this particular node during this stress period (i.e., likely a dry or critical stress period).*

FIGURE 44

SACFEM2013 Top Systems Tab



Precipitation [m	9.7306E-5
Drain H1 [n	75.30000
Drain C1 [c	0
Wadi-rech. L [r	75.30000
Wadi-rech. H [r	75.70000
Wadi-rech. C [	0

As will be discussed in more detail in a subsequent section, the transient SACFEM2013 simulation includes the loading of a new and unique set of top system data files for every stress-period in the 41-year model simulation.

5.1.5 SACFEM2013 Extra Register (“Xtra” Tab)

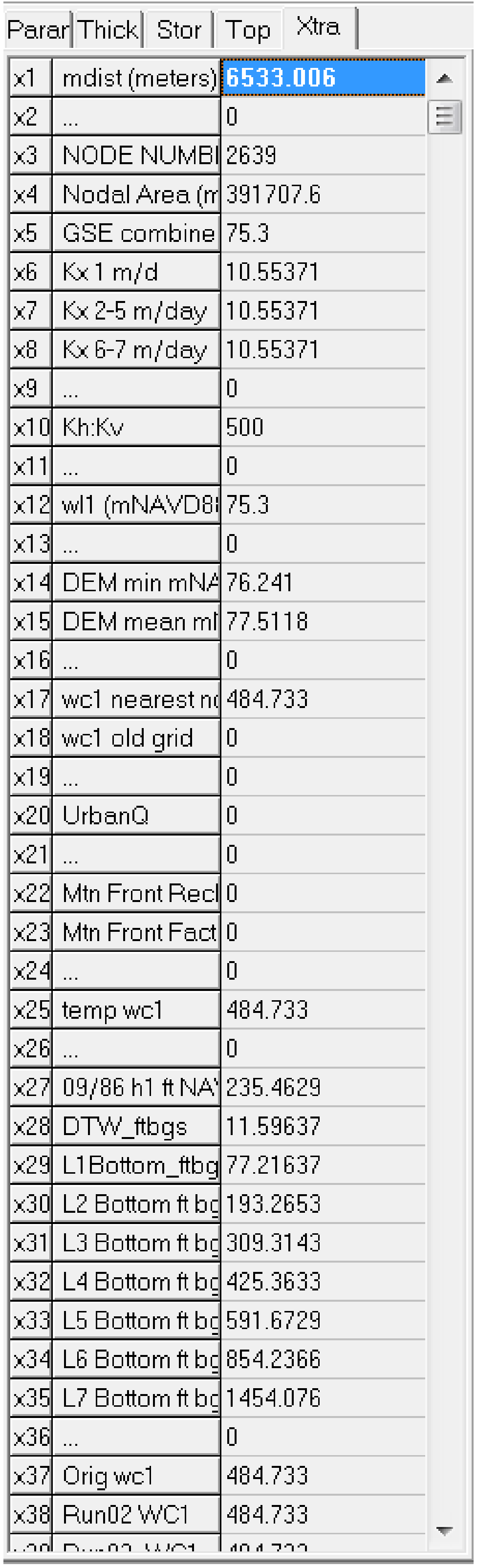
The extra file (SACFEM_2013.xtr) contains 99 registers that are used to store numerical data for every model node. The data stored in the extra register are not used directly by MicroFEM when running the model; however, the data stored in a particular register can be referenced in a calculation during a transient simulation. The first 38 registers of SACFEM_2013.xtr are shown on Figure 45. The use of the extra register during SACFEM2013 simulations is discussed in a subsequent section.

5.1.6 Other MicroFEM Files

There are two other basic types of files used in MicroFEM, label files (*.lb) and parameter files (*.par). These are ASCII files that contain a MicroFEM header line followed by lines containing data for every model node. Label files contain text strings (alpha/numeric characters), and parameter files contain numerical values. Both text and numeric data can be assigned to each of the respective file types for all or a subset of the model nodes. In the event that data are assigned to a subset of the model domain, nodes without data will have null lines in the label file and a value of zero in a parameter file (that is the ASCII file will still have a line for every model node).

FIGURE 45

SACFEM2013 Xtra Register



x1	mdist (meters)	6533.006
x2	...	0
x3	NODE NUMBI	2639
x4	Nodal Area (m	391707.6
x5	GSE combine	75.3
x6	Kx 1 m/d	10.55371
x7	Kx 2-5 m/day	10.55371
x8	Kx 6-7 m/day	10.55371
x9	...	0
x10	Kh:Kv	500
x11	...	0
x12	wl1 (mNAVD8	75.3
x13	...	0
x14	DEM min mNA	76.241
x15	DEM mean ml	77.5118
x16	...	0
x17	wc1 nearest n	484.733
x18	wc1 old grid	0
x19	...	0
x20	UrbanQ	0
x21	...	0
x22	Mtn Front Recl	0
x23	Mtn Front Fact	0
x24	...	0
x25	temp wc1	484.733
x26	...	0
x27	09/86 h1 ft NA	235.4629
x28	DTW_ftbgs	11.59637
x29	L1Bottom_ftbg	77.21637
x30	L2 Bottom ft bg	193.2653
x31	L3 Bottom ft bg	309.3143
x32	L4 Bottom ft bg	425.3633
x33	L5 Bottom ft bg	591.6729
x34	L6 Bottom ft bg	854.2366
x35	L7 Bottom ft bg	1454.076
x36	...	0
x37	Orig wc1	484.733
x38	Run02 WC1	484.733

5.2 Preparation of Input Data-Sets

As discussed in Sections 3.2.4 and 3.2.5, detailed evaluations have been performed to develop transient surface water and agricultural water budgets as well as distributions of stream stage and flood bypass inundation. This section describes the utility that processes these raw data into monthly SACFEM2013 input files. Monthly model input files and the SACFEM2013 transient batch file are generated with the pre-processing utility "*PPN_Q_Generator_SACFEM_2013.xlsm.*" This utility is an Excel-based file containing several macros to generate the various SACFEM2013 files.

5.2.1 SACFEM2013 Input File Generation – The "Input" Worksheet

The Input worksheet of the pre-processing utility contains three macros that are used to generate the monthly deep percolation of precipitation/applied water (*.PPN), pumping (*.q), and wadi/drain (*.wh1, *.wc1, and *.dc1) files.

5.2.1.1 Water Budget Input File Information

This portion of the worksheet (see Figure 46) directs the macros to the water budget and stream stage files. In the first row, the user should enter the complete file path to the folder in which the files are saved. The file names for the deep percolation, agricultural pumping, and stream stage files are entered on the following lines. The files are in a space-delimited ASCII format where rows represent data for each SACFEM2013 model node and columns represent each month of the simulation period. The data contained in the deep percolation and agricultural pumping files are in units of acre-feet per month (ac-ft/month). As will be discussed below, the pre-processing utility converts these arrays to the appropriate units for input to SACFEM2013, m/day (*.PPN) and m^3/day (*.q). The surface water stage file contains data representing the stream, bypass, or reservoir stage (in units of meters [m] NAVD88) for each SACFEM2013 model node. A flag of -99 is assigned to non-surface water nodes (for all stress periods) and to surface water nodes for stress periods when the stream or bypass is dry. The use of this flag in the SACFEM2013 input file generation will be discussed further below.

Note: If any of the water budget or stream input files are revised in the future, it is important that they be formatted consistently with the ASCII text files included in the SACFEM2013 release. Any differences in number of header rows, column spacing/number, etc. could result in generation of input files with incorrect values or failure of the macro to run successfully.

5.2.1.2 SACFEM2013 Model Data Input File Information

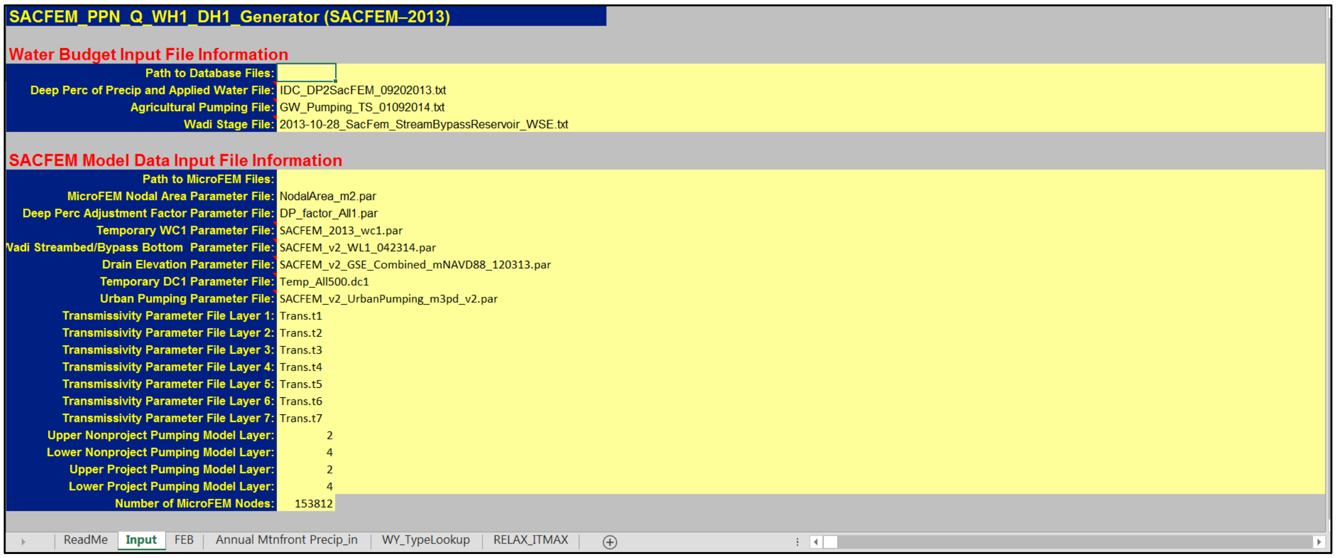
This portion of the worksheets (see Figure 46) directs the macros to generate the SACFEM2013 parameter files necessary for the various calculations and conversions. The first line is where the user inputs the file path to the parameter files. The necessary parameter files include the following:

- **MicroFEM nodal area**: a parameter file that contains the area of every SACFEM2013 model node (m^2)
- **Deep percolation adjustment factor**: a parameter file that can be used to assign multipliers to the groundwater recharge arrays for all or a subset of the model domain. For SACFEM2013, the adjustment factors are 1 for all model nodes, meaning that no adjustments are made to the IDC deep percolation values.
- **Temporary wc1**: a parameter file containing the streambed resistance term ($days^{-1}$) for stream, bypass, and reservoir nodes (calculated using Equation 6) and a value of 0 for all non-surface water nodes. These data are used when generating *.wc1 files.
- **Wadi streambed/bypass bottom**: a parameter file containing the stream, bypass, and reservoir bottom elevations (mNAVD88) and a value of 0 for all non-surface water nodes. These data are used to assign *.wl1 values.
- **Drain elevation**: a parameter file containing ground surface elevations (mNAVD88) for all SACFEM2013 model nodes. These data are used when generating *.dh1 files.

- **Temporary dc1**: a parameter file containing the drain resistance term (for SACFEM2013 this value is 500 for all nodes). This file is used when generating *.dc1 files.
- **Urban pumping**: a parameter file containing total annual urban pumping (described in Section 3.2.4.2) values (m^3/day). These data are combined with the agricultural pumping data when generating *.q files.
- **Transmissivity parameter**: parameter files containing nodal transmissivity values (m^2/day) for all SACFEM2013 nodes for each model layer. These data are used to apportion pumping to model layers based on relative transmissivity.
- **Upper and lower nonproject pumping model layer**: these rows are where the user specifies the upper and lower layers to which agricultural and urban pumping will be assigned. For SACFEM2013, agricultural and urban pumping are assigned to model Layers 2 through 4.
- **Upper/lower project pumping model layer**: these rows are where the user specifies the upper and lower layers to which any additional pumping (for a “with project” simulation) will be assigned. This user’s manual assumes a no-action simulation; however, it is necessary to populate these rows for the macros to run.
- **Number of MicroFEM nodes**: the user inputs the total number of model nodes in this cell.

FIGURE 46

PPN_Q_Generator_SACFEM_2013.xlsm, Input Worksheet (Upper Portion)



SACFEM_PPN_Q_WH1_DH1_Generator (SACFEM–2013)

Water Budget Input File Information

Path to Database Files:
Deep Perc of Precip and Applied Water File: IDC_DP2SacFEM_09202013.txt
Agricultural Pumping File: GW_Pumping_TS_01092014.txt
Wadi Stage File: 2013-10-28_SacFem_StreamBypassReservoir_WSE.txt

SACFEM Model Data Input File Information

Path to MicroFEM Files:
MicroFEM Nodal Area Parameter File: NodalArea_m2.par
Deep Perc Adjustment Factor Parameter File: DP_factor_All1.par
Temporary WC1 Parameter File: SACFEM_2013_wc1.par
Vadi Streambed/Bypass Bottom Parameter File: SACFEM_v2_WL1_042314.par
Drain Elevation Parameter File: SACFEM_v2_GSE_Combined_mNAVD88_120313.par
Temporary DC1 Parameter File: Temp_All500.dc1
Urban Pumping Parameter File: SACFEM_v2_UrbanPumping_m3pd_v2.par
Transmissivity Parameter File Layer 1: Trans.t1
Transmissivity Parameter File Layer 2: Trans.t2
Transmissivity Parameter File Layer 3: Trans.t3
Transmissivity Parameter File Layer 4: Trans.t4
Transmissivity Parameter File Layer 5: Trans.t5
Transmissivity Parameter File Layer 6: Trans.t6
Transmissivity Parameter File Layer 7: Trans.t7
Upper Nonproject Pumping Model Layer: 2
Lower Nonproject Pumping Model Layer: 4
Upper Project Pumping Model Layer: 2
Lower Project Pumping Model Layer: 4
Number of MicroFEM Nodes: 153812

Note: Agricultural and or project pumping should never be assigned to model Layer 1 using this pre-processing utility, as the data will be over-written with the mountain-front recharge data calculated/ assigned during the transient model simulation. If shallow pumping is desired, these data should be manually assigned in the SACFEM2013 batch file.

Note: The user-defined upper/lower pumping model layers cannot vary by stress periods. This means that the user-defined layers for agricultural/urban and pumping model layers are the same for the entire simulation period (i.e., pumping will always be assigned to model Layers 2 through 4 in this example on Figure 46 and will not shift to shallower or deeper layers for individual stress periods).

5.2.1.3 Output File Information

This section of the worksheet (see Figure 47) provides the macros to generate the output file information. The first row is where the user inputs the file path to the folder where all SACFEM2013 input files created by the macros will be stored. The next row is where the user specifies the MicroFEM header information that the macros include when generating the parameter files. The final set of rows is where the user defines the beginning and ending month/year for the simulation period. The macros use this information when naming the parameter files.

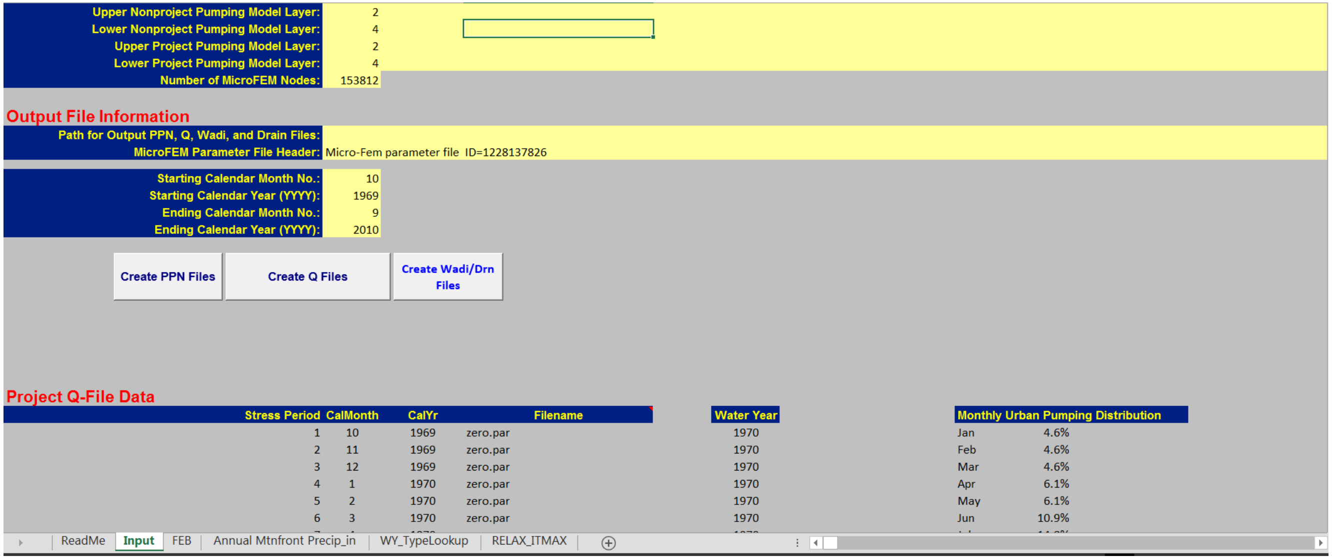
5.2.1.4 Project Q-File Data

As previously discussed, this user's manual describes the construction and calibration of a no-action version of SACFEM2013. Should the user wish to perform simulations that include additional project pumping (for example, to evaluate potential impacts of conjunctive water management projects), this Project Q-File Data section of the worksheet (see Figure 47) is where these data are incorporated. Although not completely displayed on Figure 47, this section of the worksheet includes rows for each of the 492 SACFEM2013 stress periods, with columns for the stress period number, the calendar month of the stress period, the calendar year of the stress period, and project pumping file name. The last column is where the user can input the name of a file containing nodal project pumping data (m^3/day). This file should contain pumping data only for nodes representing wells/project areas and should contain a value of 0 for all other nodes. The file name is entered only in cells representing stress periods when this additional pumping will occur (for example, during the irrigation season of dry or critical water years). The pumping information will then be apportioned vertically based on the model layer assignments defined in the preceding section and will be added to the agricultural/urban pumping data. In the example included in Figure 47, the parameter file zero.par is assigned to all stress periods. This means that when the macro is run, a value of 0 extra pumping will be added to the agricultural/urban pumping data.

This portion of the worksheet also includes the monthly distribution factors that the macro uses to distribute the annual urban pumping information (see Table 8).

FIGURE 47

PPN_Q_Generator_SACFEM_2013.xlsm, Input Worksheet (Lower Portion)


Upper Nonproject Pumping Model Layer: 2
Lower Nonproject Pumping Model Layer: 4
Upper Project Pumping Model Layer: 2
Lower Project Pumping Model Layer: 4
Number of MicroFEM Nodes: 153812

Output File Information

Path for Output PPN, Q, Wadi, and Drain Files:
MicroFEM Parameter File Header: Micro-Fem parameter file ID=1228137826

Starting Calendar Month No.: 10
Starting Calendar Year (YYYY): 1969
Ending Calendar Month No.: 9
Ending Calendar Year (YYYY): 2010

Project Q-File Data

Stress Period	CalMonth	CalYr	Filename	Water Year	Monthly Urban Pumping Distribution	
1	10	1969	zero.par	1970	Jan	4.6%
2	11	1969	zero.par	1970	Feb	4.6%
3	12	1969	zero.par	1970	Mar	4.6%
4	1	1970	zero.par	1970	Apr	6.1%
5	2	1970	zero.par	1970	May	6.1%
6	3	1970	zero.par	1970	Jun	10.9%

5.2.1.5 Create PPN Files Macro

The "Create PPN Files" button on the Input worksheet runs the macro that generates the monthly *.PPN input files. The macro reads the deep percolation of precipitation/applied water array, multiplies the data by the deep percolation adjustment factor (all 1 for SACFEM2013), and converts the data from values in units of ac-ft/month to linear rates of m/day. The macro then generates parameter files for each of the 492 stress periods with the naming convention of mm_yy.ppn, where mm represents the calendar month and yy represents the last two digits of the calendar year.

5.2.1.6 Create Q Files Macro

The "Create Q Files" button on the Input worksheet runs the macro that generates the monthly *.q input files. In general, the macro performs the following for each stress period:

- Reads the agricultural pumping array and converts the data from values in units of ac-ft/month to rates of m^3/day
- Apportions the annual urban pumping data based on the monthly distribution (see Table 8)
- Combines the agricultural and project-specific pumping data and apportions vertically based on the user-defined upper/lower model layers. The macro uses a weighting factor based on the relative transmissivity at each node for each model layer to apportion the pumping data. For example, the weighting factor for model Layer 2 is as follows:

$$Factor = \frac{T_2}{T_2 + T_3 + T_4} \tag{12}$$

Where T is the transmissivity (L^2/T) for a given model layer (2 through 4).

- Reads the project pumping parameter file and apportions vertically to the user-defined upper/lower “project” model layers using a similar factor as that defined in Equation 12 (modified as appropriate for the assigned model layers)
- Combines the agricultural, urban, and project (if included) pumping for all stress periods

The macro then generates parameter files for each of the 492 stress periods with the naming convention of mm_yy.q$_x$, where mm represents the calendar month, yy represents the last two digits of the calendar year, and x represents the model layer.

5.2.1.7 Create Wadi/Drain Files Macro

The “Create Wadi/Drn Files” button on the Input worksheet runs the macro that generates the monthly *.wh1, *.wc1, and *.dc1 input files. As will be discussed in Section 5.3.2, the streambed elevation (*.wl1) and drain elevation (*.dh1) values are assigned during the first stress period and do not vary throughout the SACFEM2013 simulation. This macro reads the stream/bypass/reservoir elevation array and writes the values to *.wh1 files for each of the SACFEM2013 stress periods. The macro also uses this array to generate stream (wc1) and drain (dc1) conductance files as follows:

- If the flag “-99” is present for any node/stress period, the macro will output a value of 0 to the corresponding *.wc1 file (meaning that the stream/bypass/reservoir is inactive at that node for that stress period) and will write the corresponding value from the user-specified temporary dc1 file (defined in the SACFEM2013 Model Data Input File Information section of the worksheet) to the *.dc1 file at that node for that stress period.
- If the flag “-99” is **not** present (i.e., a “true” elevation value is present) for any node/stress period, the macro will output the corresponding value from the user-specified temporary wc1 file (defined in the SACFEM2013 Model Data Input File Information section of the worksheet) to the *.wc1 file (meaning that the stream/bypass/reservoir is active at that node for that stress period) and will write a value of 0 (meaning that the drain boundary condition is inactive for that node/stress period) to the corresponding *.dc1 file at that node for that stress period.

Similar to the deep percolation and pumping files, the naming conventions for the wadi and drain files are mm_yy.wh1, mm_yy.wc1, and mm_yy.dc1.

5.2.2 SACFEM2013 Batch File Generation – The “FEB” Worksheet

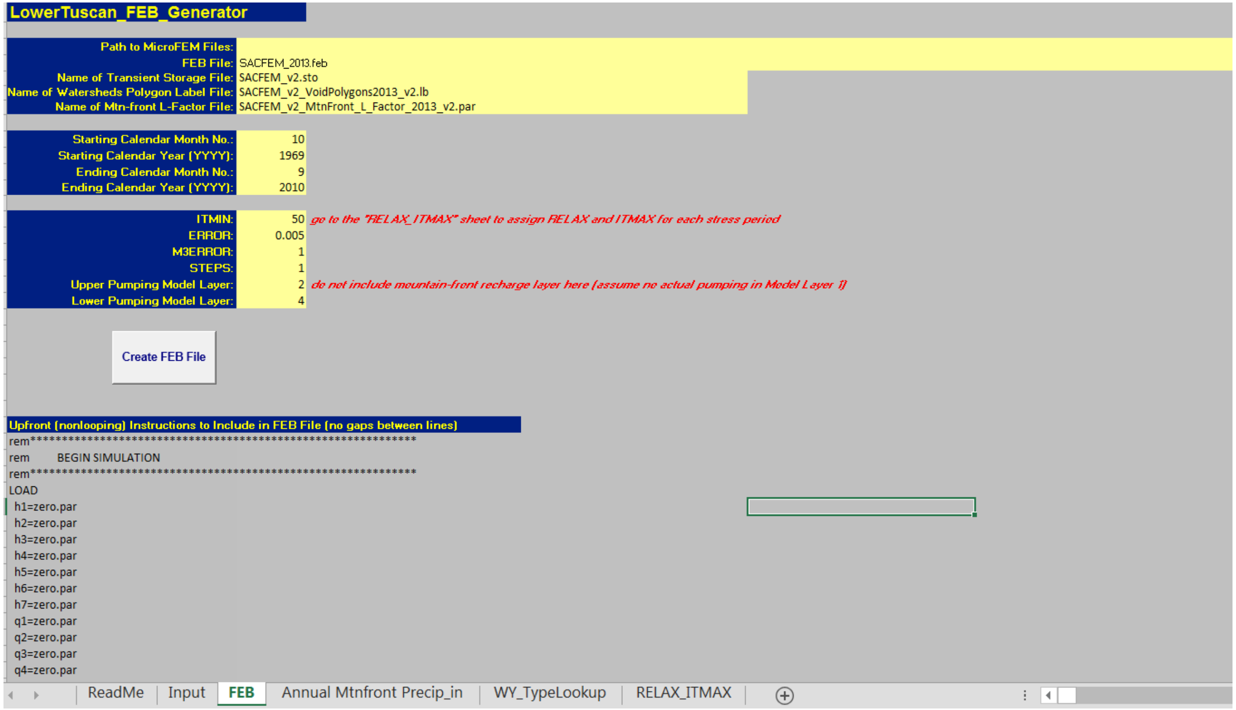
The FEB worksheet of the pre-processing utility contains one macro that is used to generate the batch file (*.feb) that runs the transient SACFEM2013 simulation. The SACFEM_2013.feb file is included as Appendix D for reference and is discussed in detail in Section 5.3.

5.2.2.1 User-Defined Information

The first section of the FEB worksheet includes cells where the user can define specific model input files as follows (see Figure 48):

- **Path to MicroFEM Files**: The user specifies the file path to the folder where the *.feb file will be saved in this cell.
- **FEB File**: The user specifies the name of the *.feb file in this cell.
- **Name of Transient Storage File**: The user specifies the name of the SACFEM2013 storage file in this cell. The file will not be accessed by the macro; however, the file name will be written to the *.feb file in the appropriate locations where it will be accessed during the transient simulation.
- **Name of Watersheds Polygon Label File**: The user specifies the name of the SACFEM2013 label file containing for the mountain-front recharge polygons in this cell. The file will not be accessed by the macro; however, the file name will be written to the *.feb file in the appropriate locations where it will be accessed during the transient simulation.
- **Name of Mtn-front L-Factor File**: The user specifies the name of SACFEM2013 parameter file used to scale the total mountain-front recharge for each polygon in this cell. The file will not be accessed by the macro; however, the file name will be written to the *.feb file in the appropriate locations where it will be accessed during the transient simulation.

FIGURE 48
PPN_Q_Generator_SACFEM_2013.xlsm, FEB Worksheet



LowerTuscan_FEB_Generator

Path to MicroFEM Files:
FEB File: SACFEM_2013.feb
Name of Transient Storage File: SACFEM_v2.sto
Name of Watersheds Polygon Label File: SACFEM_v2_VoidPolygons2013_v2.lb
Name of Mtn-front L-Factor File: SACFEM_v2_MtnFront_L_Factor_2013_v2.par

Starting Calendar Month No.: 10
Starting Calendar Year (YYYY): 1969
Ending Calendar Month No.: 9
Ending Calendar Year (YYYY): 2010

ITMIN: 50 go to the "RELAX_ITMAX" sheet to assign RELAX and ITMAX for each stress period
ERROR: 0.005
M3ERROR: 1
STEPS: 1
Upper Pumping Model Layer: 2 do not include mountain-front recharge layer here (assume no actual pumping in Model Layer 1)
Lower Pumping Model Layer: 4

Upfront (nonlooping) Instructions to Include in FEB File (no gaps between lines)

```
rem************************************************************
rem       BEGIN SIMULATION
rem************************************************************
LOAD
 h1=zero.par
 h2=zero.par
 h3=zero.par
 h4=zero.par
 h5=zero.par
 h6=zero.par
 h7=zero.par
 q1=zero.par
 q2=zero.par
 q3=zero.par
 q4=zero.par
```

The next section of the FEB worksheet includes cells where the user defines the beginning and ending calendar months and years for the simulation period (see Figure 48). The following section includes cells where the user defines criteria that are written to the TIME and RUN statements for each stress period. These include ITMIN (minimum number of iterations for each stress period), ERROR (closure criteria for error in heads, m), M3ERROR (closure criteria for water budget error for all stress periods, m^3/day), and STEPS (number of time steps for all stress periods). The assignment of ITMAX (maximum number of iterations for each stress period) and RELAX (solver relaxation factor) will be discussed in the macro execution section. The upper and lower pumping model layer cells are used to define the shallowest and deepest model layers where pumping (agricultural, urban, or project) occurs. The macro uses this information to determine how many *.q files for which to write load statements for all stress periods.

5.2.2.2 Non-Looping Batch File Text

The section of the FEB worksheet (following the cell containing the text “Upfront [non-looping] Instructions to include in FEB File [“no gaps between lines”]) includes syntax that is written verbatim directly to the batch file (See Figure 48). A detailed discussion of this portion of the batch file is provided in Section 5.3.1. In general, this portion of the batch file assigns initial model input parameters and opens model output files. If the user would like to change any input our output files, the file names and calculations can be updated in this portion of the pre-processor. Refer to Appendix D for an example of the SACFEM_2013.feb file and to Section 5.3.1 for a complete discussion of the syntax.

*Note: There can be no blank rows in this portion of the worksheet. The macro will only write text to the *.feb file up to the first blank row.*

5.2.2.3 Other Worksheets

There are three other worksheets accessed by the macro that generates the SACFEM2013 batch file, including “*Annual Mtnfront Precip_in,*” “*WY_TypeLookup,*” and “*RELAX_ITMAX*” (see Figure 48). The “*Annual Mtnfront Precip_in*” worksheet contains the data written to the *.feb file to estimate subsurface inflow along the margin of the model domain (see Figures 49a through 49d). The worksheet contains a column for each of the 34 mountain-front recharge polygons shown on Figure 22. The first three rows list the polygon number, the adjustment factor (multiplier to increase or decrease recharge for each polygon), and the area (in acres) of each polygon. The worksheet contains the following “blocks” of data that progress through the calculation of deep percolation for each calendar year and mountain front recharge polygons:

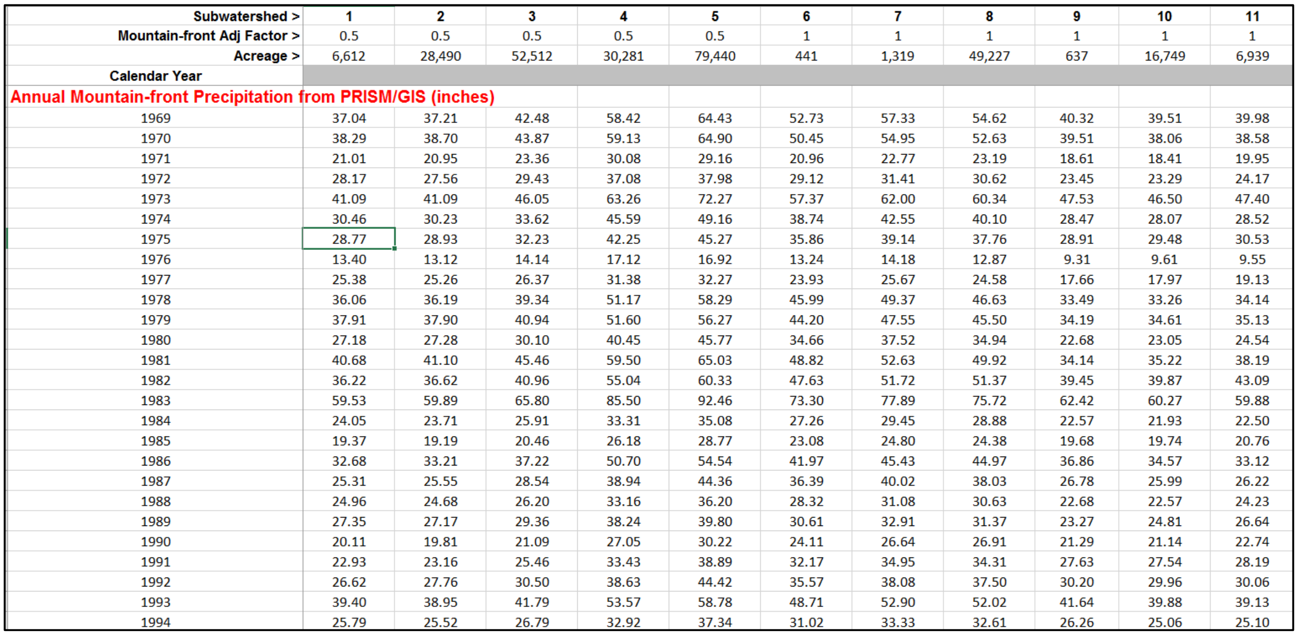
- Average precipitation (inches) across each polygon based on the PRISM dataset (see Box 47a)
- Deep percolation of precipitation (inches) for each polygon calculated using Equation 9 (see Figure 49b)
- Volumetric deep percolation of precipitation (m^3), calculated using the deep percolation values in the previous bullet and the polygon areas (see Figure 49c)
- Monthly distribution factors for mountain front recharge based on the distribution of unimpaired runoff of Deer Creek at the Vina stream gage (see Figure 49d).

The “*WY_TypeLookup*” worksheet contains data related to the water year index for the Sacramento and San Joaquin Valleys (see Figure 50). These data include unimpaired runoff, water year index, and water year classification. In SACFEM2013, this information is written as the header for each stress period of the simulation period for informational purposes only.

The “*RELAX_ITMAX*” worksheet is where the user can paste the simulation summary information from a previous simulation (see Figure 51) from the SACFEM2013 Run Log Reader (discussed below in Section 5.5.1). This information is used to determine if additional iterations or solver relaxation are needed for any stress periods.

FIGURE 49A

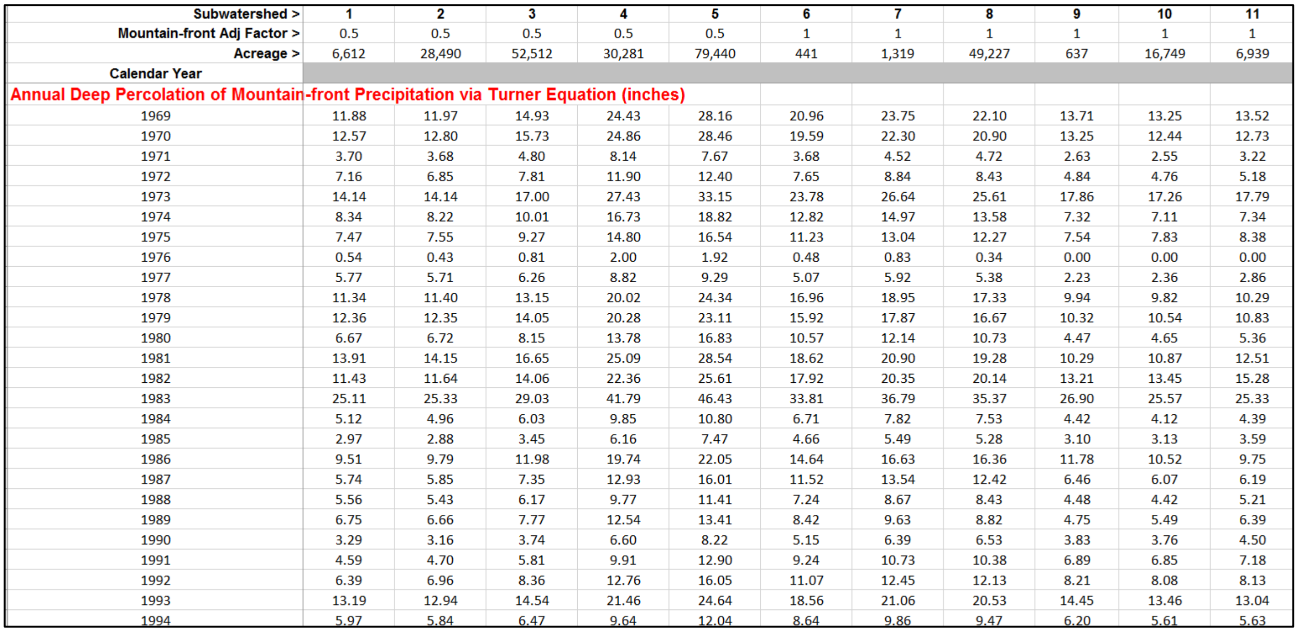
PPN_Q_Generator_SACFEM_2013.xlsm, Annual Mtnfront Precip_in Worksheet, PRISM Data



Subwatershed >	1	2	3	4	5	6	7	8	9	10	11
Mountain-front Adj Factor >	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1
Acreage >	6,612	28,490	52,512	30,281	79,440	441	1,319	49,227	637	16,749	6,939
Calendar Year											
Annual Mountain-front Precipitation from PRISM/GIS (inches)											
1969	37.04	37.21	42.48	58.42	64.43	52.73	57.33	54.62	40.32	39.51	39.98
1970	38.29	38.70	43.87	59.13	64.90	50.45	54.95	52.63	39.51	38.06	38.58
1971	21.01	20.95	23.36	30.08	29.16	20.96	22.77	23.19	18.61	18.41	19.95
1972	28.17	27.56	29.43	37.08	37.98	29.12	31.41	30.62	23.45	23.29	24.17
1973	41.09	41.09	46.05	63.26	72.27	57.37	62.00	60.34	47.53	46.50	47.40
1974	30.46	30.23	33.62	45.59	49.16	38.74	42.55	40.10	28.47	28.07	28.52
1975	28.77	28.93	32.23	42.25	45.27	35.86	39.14	37.76	28.91	29.48	30.53
1976	13.40	13.12	14.14	17.12	16.92	13.24	14.18	12.87	9.31	9.61	9.55
1977	25.38	25.26	26.37	31.38	32.27	23.93	25.67	24.58	17.66	17.97	19.13
1978	36.06	36.19	39.34	51.17	58.29	45.99	49.37	46.63	33.49	33.26	34.14
1979	37.91	37.90	40.94	51.60	56.27	44.20	47.55	45.50	34.19	34.61	35.13
1980	27.18	27.28	30.10	40.45	45.77	34.66	37.52	34.94	22.68	23.05	24.54
1981	40.68	41.10	45.46	59.50	65.03	48.82	52.63	49.92	34.14	35.22	38.19
1982	36.22	36.62	40.96	55.04	60.33	47.63	51.72	51.37	39.45	39.87	43.09
1983	59.53	59.89	65.80	85.50	92.46	73.30	77.89	75.72	62.42	60.27	59.88
1984	24.05	23.71	25.91	33.31	35.08	27.26	29.45	28.88	22.57	21.93	22.50
1985	19.37	19.19	20.46	26.18	28.77	23.08	24.80	24.38	19.68	19.74	20.76
1986	32.68	33.21	37.22	50.70	54.54	41.97	45.43	44.97	36.86	34.57	33.12
1987	25.31	25.55	28.54	38.94	44.36	36.39	40.02	38.03	26.78	25.99	26.22
1988	24.96	24.68	26.20	33.16	36.20	28.32	31.08	30.63	22.68	22.57	24.23
1989	27.35	27.17	29.36	38.24	39.80	30.61	32.91	31.37	23.27	24.81	26.64
1990	20.11	19.81	21.09	27.05	30.22	24.11	26.64	26.91	21.29	21.14	22.74
1991	22.93	23.16	25.46	33.43	38.89	32.17	34.95	34.31	27.63	27.54	28.19
1992	26.62	27.76	30.50	38.63	44.42	35.57	38.08	37.50	30.20	29.96	30.06
1993	39.40	38.95	41.79	53.57	58.78	48.71	52.90	52.02	41.64	39.88	39.13
1994	25.79	25.52	26.79	32.92	37.34	31.02	33.33	32.61	26.26	25.06	25.10

FIGURE 49B

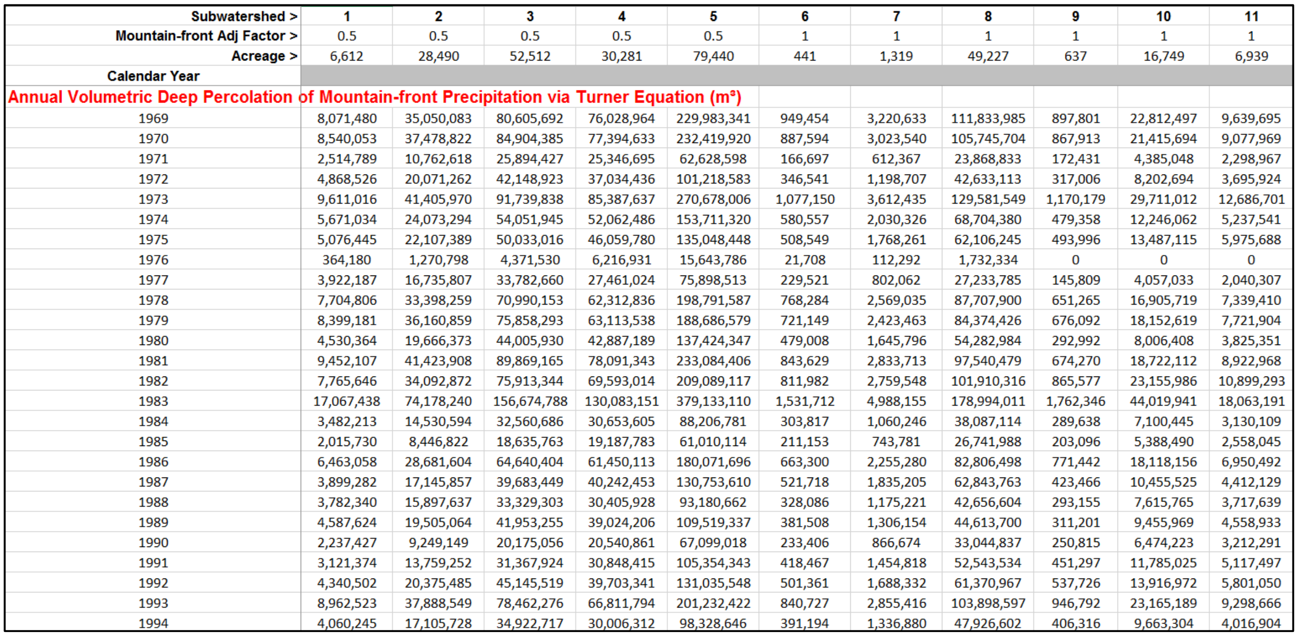
PPN_Q_Generator_SACFEM_2013.xlsm, Annual Mtnfront Precip_in Worksheet, Deep Percolation (inches)



Subwatershed >	1	2	3	4	5	6	7	8	9	10	11
Mountain-front Adj Factor >	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1
Acreage >	6,612	28,490	52,512	30,281	79,440	441	1,319	49,227	637	16,749	6,939
Calendar Year											
Annual Deep Percolation of Mountain-front Precipitation via Turner Equation (inches)											
1969	11.88	11.97	14.93	24.43	28.16	20.96	23.75	22.10	13.71	13.25	13.52
1970	12.57	12.80	15.73	24.86	28.46	19.59	22.30	20.90	13.25	12.44	12.73
1971	3.70	3.68	4.80	8.14	7.67	3.68	4.52	4.72	2.63	2.55	3.22
1972	7.16	6.85	7.81	11.90	12.40	7.65	8.84	8.43	4.84	4.76	5.18
1973	14.14	14.14	17.00	27.43	33.15	23.78	26.64	25.61	17.86	17.26	17.79
1974	8.34	8.22	10.01	16.73	18.82	12.82	14.97	13.58	7.32	7.11	7.34
1975	7.47	7.55	9.27	14.80	16.54	11.23	13.04	12.27	7.54	7.83	8.38
1976	0.54	0.43	0.81	2.00	1.92	0.48	0.83	0.34	0.00	0.00	0.00
1977	5.77	5.71	6.26	8.82	9.29	5.07	5.92	5.38	2.23	2.36	2.86
1978	11.34	11.40	13.15	20.02	24.34	16.96	18.95	17.33	9.94	9.82	10.29
1979	12.36	12.35	14.05	20.28	23.11	15.92	17.87	16.67	10.32	10.54	10.83
1980	6.67	6.72	8.15	13.78	16.83	10.57	12.14	10.73	4.47	4.65	5.36
1981	13.91	14.15	16.65	25.09	28.54	18.62	20.90	19.28	10.29	10.87	12.51
1982	11.43	11.64	14.06	22.36	25.61	17.92	20.35	20.14	13.21	13.45	15.28
1983	25.11	25.33	29.03	41.79	46.43	33.81	36.79	35.37	26.90	25.57	25.33
1984	5.12	4.96	6.03	9.85	10.80	6.71	7.82	7.53	4.42	4.12	4.39
1985	2.97	2.88	3.45	6.16	7.47	4.66	5.49	5.28	3.10	3.13	3.59
1986	9.51	9.79	11.98	19.74	22.05	14.64	16.63	16.36	11.78	10.52	9.75
1987	5.74	5.85	7.35	12.93	16.01	11.52	13.54	12.42	6.46	6.07	6.19
1988	5.56	5.43	6.17	9.77	11.41	7.24	8.67	8.43	4.48	4.42	5.21
1989	6.75	6.66	7.77	12.54	13.41	8.42	9.63	8.82	4.75	5.49	6.39
1990	3.29	3.16	3.74	6.60	8.22	5.15	6.39	6.53	3.83	3.76	4.50
1991	4.59	4.70	5.81	9.91	12.90	9.24	10.73	10.38	6.89	6.85	7.18
1992	6.39	6.96	8.36	12.76	16.05	11.07	12.45	12.13	8.21	8.08	8.13
1993	13.19	12.94	14.54	21.46	24.64	18.56	21.06	20.53	14.45	13.46	13.04
1994	5.97	5.84	6.47	9.64	12.04	8.64	9.86	9.47	6.20	5.61	5.63

FIGURE 49C

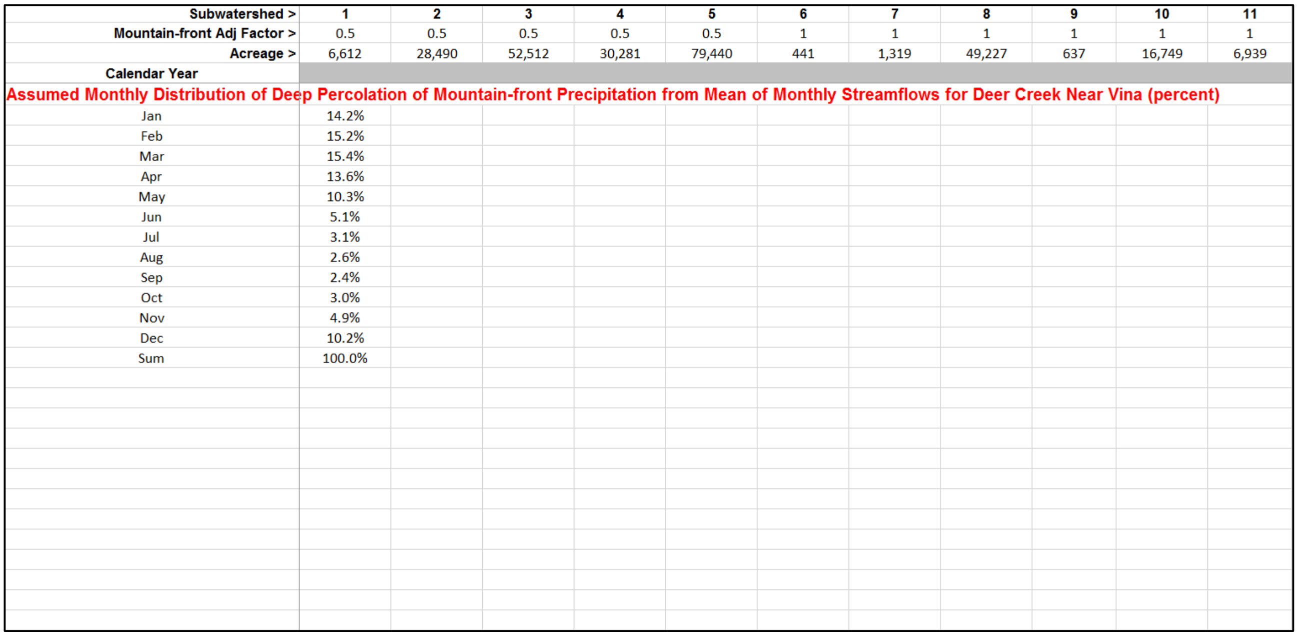
PPN_Q_Generator_SACFEM_2013.xlsm, Annual Mtnfront Precip_in Worksheet, Deep Percolation (cubic meters)



Subwatershed >	1	2	3	4	5	6	7	8	9	10	11
Mountain-front Adj Factor >	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1
Acreage >	6,612	28,490	52,512	30,281	79,440	441	1,319	49,227	637	16,749	6,939
Calendar Year											
Annual Volumetric Deep Percolation of Mountain-front Precipitation via Turner Equation (m^3)											
1969	8,071,480	35,050,083	80,605,692	76,028,964	229,983,341	949,454	3,220,633	111,833,985	897,801	22,812,497	9,639,695
1970	8,540,053	37,478,822	84,904,385	77,394,633	232,419,920	887,594	3,023,540	105,745,704	867,913	21,415,694	9,077,969
1971	2,514,789	10,762,618	25,894,427	25,346,695	62,628,598	166,697	612,367	23,868,833	172,431	4,385,048	2,298,967
1972	4,868,526	20,071,262	42,148,923	37,034,436	101,218,583	346,541	1,198,707	42,633,113	317,006	8,202,694	3,695,924
1973	9,611,016	41,405,970	91,739,838	85,387,637	270,678,006	1,077,150	3,612,435	129,581,549	1,170,179	29,711,012	12,686,701
1974	5,671,034	24,073,294	54,051,945	52,062,486	153,711,320	580,557	2,030,326	68,704,380	479,358	12,246,062	5,237,541
1975	5,076,445	22,107,389	50,033,016	46,059,780	135,048,448	508,549	1,768,261	62,106,245	493,996	13,487,115	5,975,688
1976	364,180	1,270,798	4,371,530	6,216,931	15,643,786	21,708	112,292	1,732,334	0	0	0
1977	3,922,187	16,735,807	33,782,660	27,461,024	75,898,513	229,521	802,062	27,233,785	145,809	4,057,033	2,040,307
1978	7,704,806	33,398,259	70,990,153	62,312,836	198,791,587	768,284	2,569,035	87,707,900	651,265	16,905,719	7,339,410
1979	8,399,181	36,160,859	75,858,293	63,113,538	188,686,579	721,149	2,423,463	84,374,426	676,092	18,152,619	7,721,904
1980	4,530,364	19,666,373	44,005,930	42,887,189	137,424,347	479,008	1,645,796	54,282,984	292,992	8,006,408	3,825,351
1981	9,452,107	41,423,908	89,869,165	78,091,343	233,084,406	843,629	2,833,713	97,540,479	674,270	18,722,112	8,922,968
1982	7,765,646	34,092,872	75,913,344	69,593,014	209,089,117	811,982	2,759,548	101,910,316	865,577	23,155,986	10,899,293
1983	17,067,438	74,178,240	156,674,788	130,083,151	379,133,110	1,531,712	4,988,155	178,994,011	1,762,346	44,019,941	18,063,191
1984	3,482,213	14,530,594	32,560,686	30,653,605	88,206,781	303,817	1,060,246	38,087,114	289,638	7,100,445	3,130,109
1985	2,015,730	8,446,822	18,635,763	19,187,783	61,010,114	211,153	743,781	26,741,988	203,096	5,388,490	2,558,045
1986	6,463,058	28,681,604	64,640,404	61,450,113	180,071,696	663,300	2,255,280	82,806,498	771,442	18,118,156	6,950,492
1987	3,899,282	17,145,857	39,683,449	40,242,453	130,753,610	521,718	1,835,205	62,843,763	423,466	10,455,525	4,412,129
1988	3,782,340	15,897,637	33,329,303	30,405,928	93,180,662	328,086	1,175,221	42,656,604	293,155	7,615,765	3,717,639
1989	4,587,624	19,505,064	41,953,255	39,024,206	109,519,337	381,508	1,306,154	44,613,700	311,201	9,455,969	4,558,933
1990	2,237,427	9,249,149	20,175,056	20,540,861	67,099,018	233,406	866,674	33,044,837	250,815	6,474,223	3,212,291
1991	3,121,374	13,759,252	31,367,924	30,848,415	105,354,343	418,467	1,454,818	52,543,534	451,297	11,785,025	5,117,497
1992	4,340,502	20,375,485	45,145,519	39,703,341	131,035,548	501,361	1,688,332	61,370,967	537,726	13,916,972	5,801,050
1993	8,962,523	37,888,549	78,462,276	66,811,794	201,232,422	840,727	2,855,416	103,898,597	946,792	23,165,189	9,298,666
1994	4,060,245	17,105,728	34,922,717	30,006,312	98,328,646	391,194	1,336,880	47,926,602	406,316	9,663,304	4,016,904

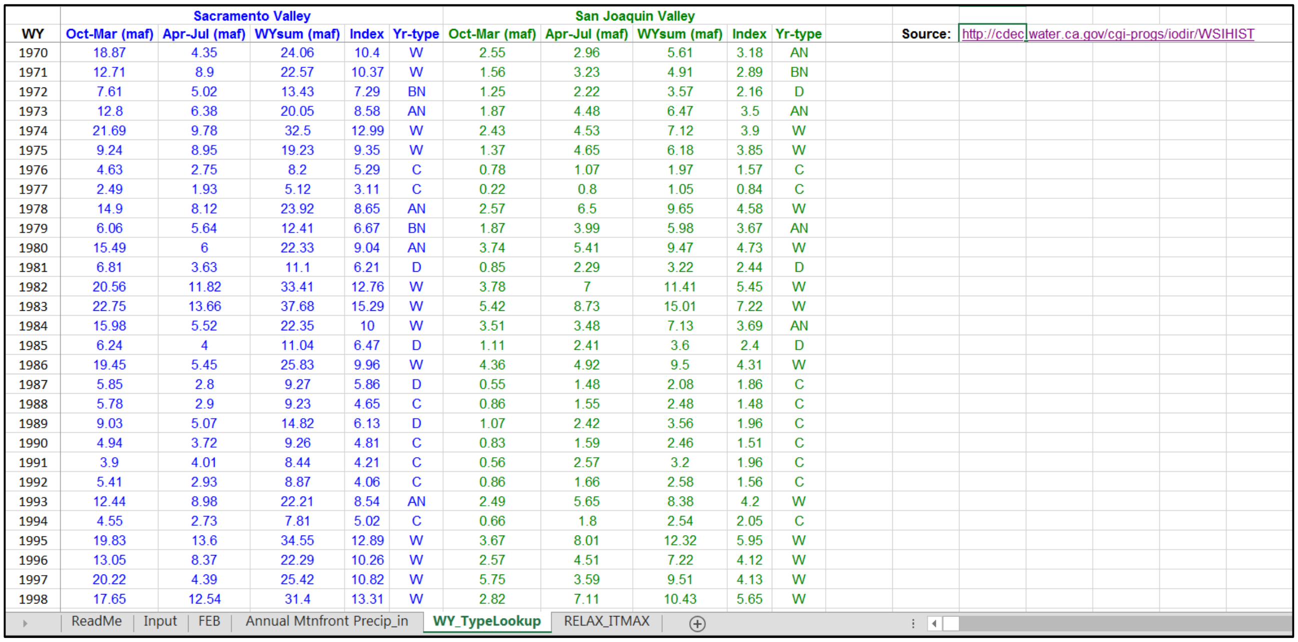
FIGURE 49D

PPN_Q_Generator_SACFEM_2013.xlsm, Annual Mtnfront Precip_in Worksheet, Monthly Distribution



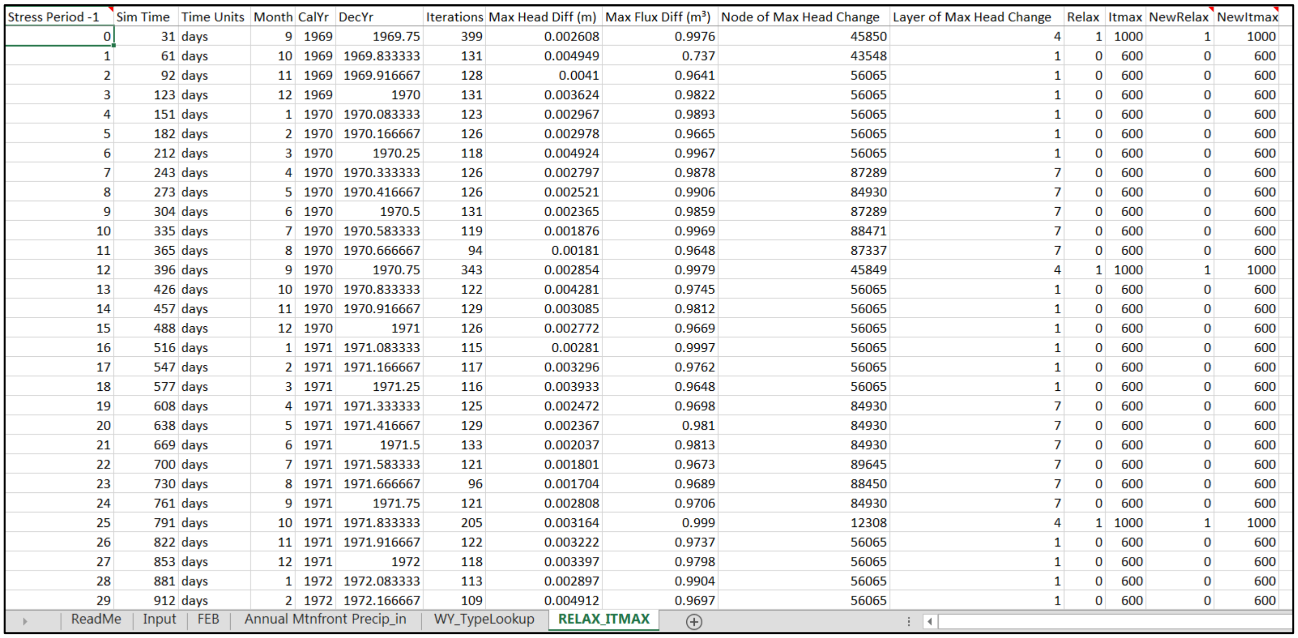
Subwatershed >	1	2	3	4	5	6	7	8	9	10	11
Mountain-front Adj Factor >	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1
Acreage >	6,612	28,490	52,512	30,281	79,440	441	1,319	49,227	637	16,749	6,939
Calendar Year											
Assumed Monthly Distribution of Deep Percolation of Mountain-front Precipitation from Mean of Monthly Streamflows for Deer Creek Near Vina (percent)											
Jan	14.2%										
Feb	15.2%										
Mar	15.4%										
Apr	13.6%										
May	10.3%										
Jun	5.1%										
Jul	3.1%										
Aug	2.6%										
Sep	2.4%										
Oct	3.0%										
Nov	4.9%										
Dec	10.2%										
Sum	100.0%										

FIGURE 50
PPN_Q_Generator_SACFEM_2013.xlsm, WY_TypeLookup Worksheet



	Sacramento Valley					San Joaquin Valley					
WY	**Oct-Mar (maf)**	**Apr-Jul (maf)**	**WYsum (maf)**	**Index**	**Yr-type**	**Oct-Mar (maf)**	**Apr-Jul (maf)**	**WYsum (maf)**	**Index**	**Yr-type**	**Source:** http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST
1970	18.87	4.35	24.06	10.4	W	2.55	2.96	5.61	3.18	AN	
1971	12.71	8.9	22.57	10.37	W	1.56	3.23	4.91	2.89	BN	
1972	7.61	5.02	13.43	7.29	BN	1.25	2.22	3.57	2.16	D	
1973	12.8	6.38	20.05	8.58	AN	1.87	4.48	6.47	3.5	AN	
1974	21.69	9.78	32.5	12.99	W	2.43	4.53	7.12	3.9	W	
1975	9.24	8.95	19.23	9.35	W	1.37	4.65	6.18	3.85	W	
1976	4.63	2.75	8.2	5.29	C	0.78	1.07	1.97	1.57	C	
1977	2.49	1.93	5.12	3.11	C	0.22	0.8	1.05	0.84	C	
1978	14.9	8.12	23.92	8.65	AN	2.57	6.5	9.65	4.58	W	
1979	6.06	5.64	12.41	6.67	BN	1.87	3.99	5.98	3.67	AN	
1980	15.49	6	22.33	9.04	AN	3.74	5.41	9.47	4.73	W	
1981	6.81	3.63	11.1	6.21	D	0.85	2.29	3.22	2.44	D	
1982	20.56	11.82	33.41	12.76	W	3.78	7	11.41	5.45	W	
1983	22.75	13.66	37.68	15.29	W	5.42	8.73	15.01	7.22	W	
1984	15.98	5.52	22.35	10	W	3.51	3.48	7.13	3.69	AN	
1985	6.24	4	11.04	6.47	D	1.11	2.41	3.6	2.4	D	
1986	19.45	5.45	25.83	9.96	W	4.36	4.92	9.5	4.31	W	
1987	5.85	2.8	9.27	5.86	D	0.55	1.48	2.08	1.86	C	
1988	5.78	2.9	9.23	4.65	C	0.86	1.55	2.48	1.48	C	
1989	9.03	5.07	14.82	6.13	D	1.07	2.42	3.56	1.96	C	
1990	4.94	3.72	9.26	4.81	C	0.83	1.59	2.46	1.51	C	
1991	3.9	4.01	8.44	4.21	C	0.56	2.57	3.2	1.96	C	
1992	5.41	2.93	8.87	4.06	C	0.86	1.66	2.58	1.56	C	
1993	12.44	8.98	22.21	8.54	AN	2.49	5.65	8.38	4.2	W	
1994	4.55	2.73	7.81	5.02	C	0.66	1.8	2.54	2.05	C	
1995	19.83	13.6	34.55	12.89	W	3.67	8.01	12.32	5.95	W	
1996	13.05	8.37	22.29	10.26	W	2.57	4.51	7.22	4.12	W	
1997	20.22	4.39	25.42	10.82	W	5.75	3.59	9.51	4.13	W	
1998	17.65	12.54	31.4	13.31	W	2.82	7.11	10.43	5.65	W	

FIGURE 51
PPN_Q_Generator_SACFEM_2013.xlsm, RELAX_ITMAX Worksheet



Stress Period -1	Sim Time	Time Units	Month	CalYr	DecYr	Iterations	Max Head Diff (m)	Max Flux Diff (m^3)	Node of Max Head Change	Layer of Max Head Change	Relax	Itmax	NewRelax	NewItmax
0	31	days	9	1969	1969.75	399	0.002608	0.9976	45850	4	1	1000	1	1000
1	61	days	10	1969	1969.833333	131	0.004949	0.737	43548	1	0	600	0	600
2	92	days	11	1969	1969.916667	128	0.0041	0.9641	56065	1	0	600	0	600
3	123	days	12	1969	1970	131	0.003624	0.9822	56065	1	0	600	0	600
4	151	days	1	1970	1970.083333	123	0.002967	0.9893	56065	1	0	600	0	600
5	182	days	2	1970	1970.166667	126	0.002978	0.9665	56065	1	0	600	0	600
6	212	days	3	1970	1970.25	118	0.004924	0.9967	56065	1	0	600	0	600
7	243	days	4	1970	1970.333333	126	0.002797	0.9878	87289	7	0	600	0	600
8	273	days	5	1970	1970.416667	126	0.002521	0.9906	84930	7	0	600	0	600
9	304	days	6	1970	1970.5	131	0.002365	0.9859	87289	7	0	600	0	600
10	335	days	7	1970	1970.583333	119	0.001876	0.9969	88471	7	0	600	0	600
11	365	days	8	1970	1970.666667	94	0.00181	0.9648	87337	7	0	600	0	600
12	396	days	9	1970	1970.75	343	0.002854	0.9979	45849	4	1	1000	1	1000
13	426	days	10	1970	1970.833333	122	0.004281	0.9745	56065	1	0	600	0	600
14	457	days	11	1970	1970.916667	129	0.003085	0.9812	56065	1	0	600	0	600
15	488	days	12	1970	1971	126	0.002772	0.9669	56065	1	0	600	0	600
16	516	days	1	1971	1971.083333	115	0.00281	0.9997	56065	1	0	600	0	600
17	547	days	2	1971	1971.166667	117	0.003296	0.9762	56065	1	0	600	0	600
18	577	days	3	1971	1971.25	116	0.003933	0.9648	56065	1	0	600	0	600
19	608	days	4	1971	1971.333333	125	0.002472	0.9698	84930	7	0	600	0	600
20	638	days	5	1971	1971.416667	129	0.002367	0.981	84930	7	0	600	0	600
21	669	days	6	1971	1971.5	133	0.002037	0.9813	84930	7	0	600	0	600
22	700	days	7	1971	1971.583333	121	0.001801	0.9673	89645	7	0	600	0	600
23	730	days	8	1971	1971.666667	96	0.001704	0.9689	88450	7	0	600	0	600
24	761	days	9	1971	1971.75	121	0.002808	0.9706	84930	7	0	600	0	600
25	791	days	10	1971	1971.833333	205	0.003164	0.999	12308	4	1	1000	1	1000
26	822	days	11	1971	1971.916667	122	0.003222	0.9737	56065	1	0	600	0	600
27	853	days	12	1971	1972	118	0.003397	0.9798	56065	1	0	600	0	600
28	881	days	1	1972	1972.083333	113	0.002897	0.9904	56065	1	0	600	0	600
29	912	days	2	1972	1972.166667	109	0.004912	0.9697	56065	1	0	600	0	600

5.2.2.4 Create FEB File Macro

The “Create FEB File” button on the FEB worksheet runs the macro that generates the SACFEM2013 transient batch file. As described above, the static (non-looping) text included on the FEB worksheet is written directly to the batch file. For each stress period, the macro performs the following:

- Writes statements for each mountain front polygon to assign the annual volumetric deep percolation of precipitation (from the *Annual Mtnfront Precip*_worksheet) along the mountain front to an extra register
- Writes equations for each mountain front polygon to calculate the daily volumetric flux for the stress period, incorporating the monthly distribution factor and the mountain-front recharge adjustment factor (from the *Annual Mtnfront Precip*_worksheet) as well as the number of days in the month
- Writes a statement to apportion the mountain-front recharge among the nodes for each polygon and loads/saves the volumetric flux as a *.q1 (model Layer 1 pumping file)
- Writes a header specifying the water year type (from the *WY_TypeLookup* worksheet)
- Writes statements to load the *.ppn, *.wh1, *.wc1, *.dc1, and *.q files (based on the user-defined upper/lower pumped layers on the FEB worksheet)
- Writes the TIME and RUN statements populated with the user-defined time steps, iterations, and closure criteria. For ITMAX and RELAX, the macro reads the specified number of iterations and the actual number of iterations used on the *RELAX_ITMAX* worksheet. If the model failed to converge for a given stress period for a previous simulation, the macro increases the ITMAX from 600 to 1,000 and assigns a RELAX value of 1.
- Writes statements to save the head files at the end of the stress period

5.3 Running SACFEM2013 – The MicroFEM Batch File

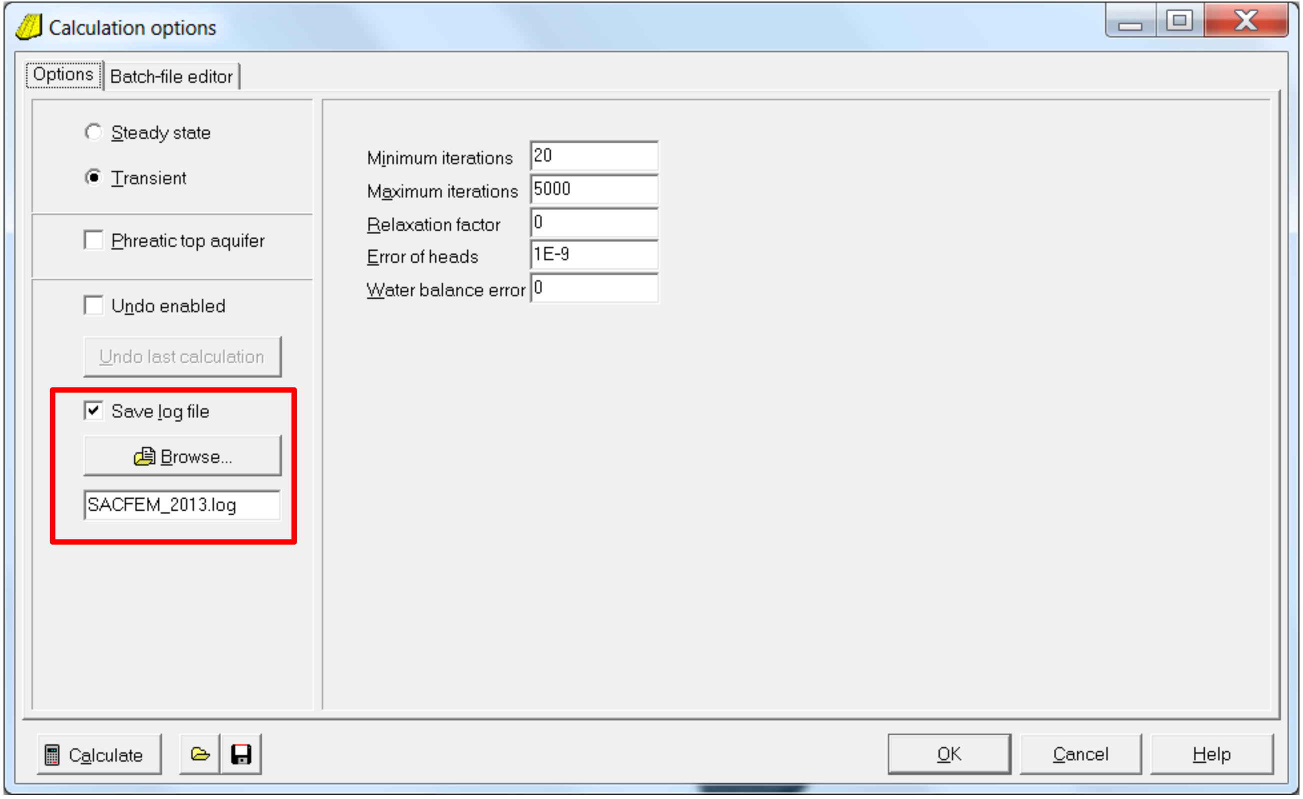
Model calculations can be performed in two manners by MicroFEM. The first is by direct steady-state calculation in the MicroFEM calculation window (see Figure 52). The second is by loading a batch file (*.feb) into the MicroFEM project (either by adding a batch file to the *.fpr file name in a text editor or by opening an *.fpr file through the calculation window [see Figure 53]). The MicroFEM batch file (*.feb) is an ASCII file that can be opened and edited either in the MicroFEM calculation window or in a text editor. The *.feb file contains all commands necessary to perform a given model simulation (loading, calculating, and assigning model input parameters; executing the run statement; managing model output). Refer to the MicroFEM User’s Manual or help menu for a list of commands available for use in a *.feb file.

**Note: if storage values of zero are assigned, a steady-state simulation can be executed via a MicroFEM batch file.*

An example batch file, SACFEM_2013.feb, is included in Appendix D. This is the batch file currently used for the baseline condition (no project) SACFEM2013 calibration simulation. As discussed in the preceding section, SACFEM_2013.feb is generated with the pre-processing utility “*PPN_Q_Generator_SACFEM_2013.xlsm*.” The following sections describe and explain the syntax used in each portion of the batch file.

FIGURE 52

MicroFEM Calculation Window, Options Tab



○ Steady state

● Transient

☐ Phreatic top aquifer

☐ Undo enabled

☑ Save log file

SACFEM_2013.log

Minimum iterations 20

Maximum iterations 5000

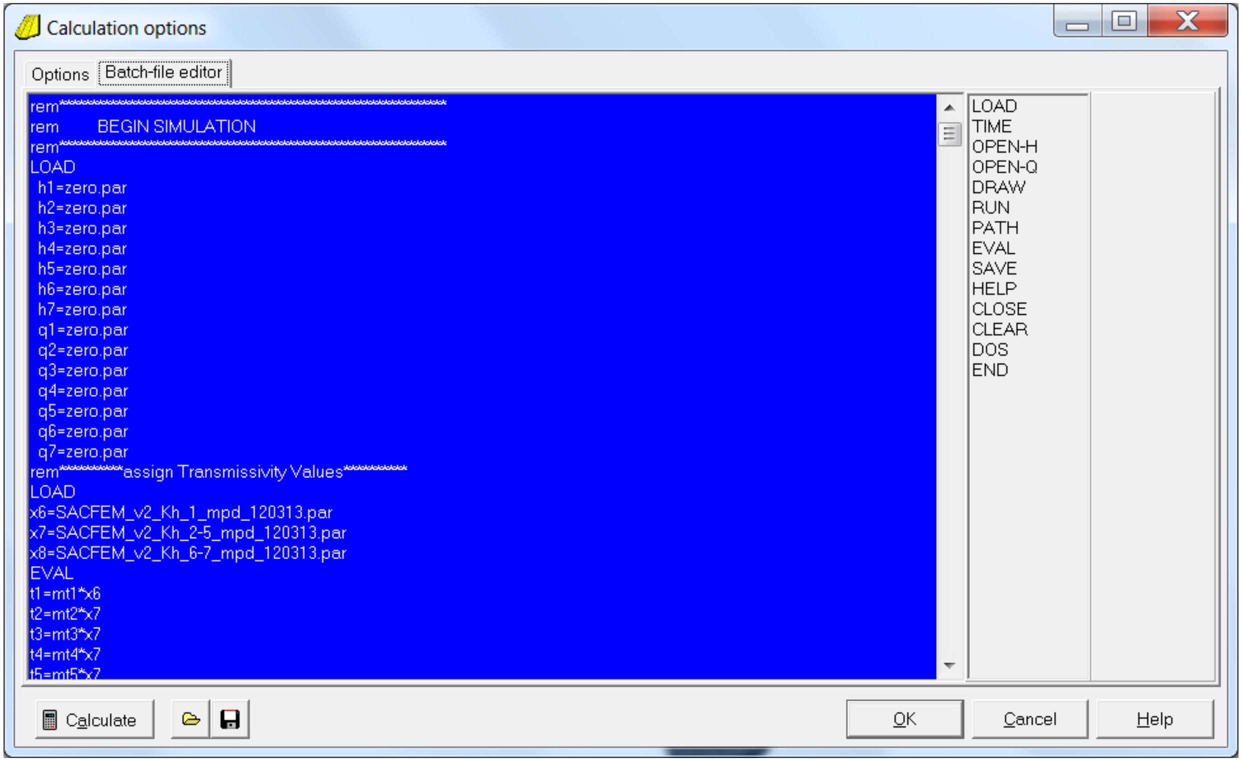
Relaxation factor 0

Error of heads 1E-9

Water balance error 0

FIGURE 53

MicroFEM Calculation Window, Batch-file Editor Tab



```
rem************************************************************
rem       BEGIN SIMULATION
rem************************************************************
LOAD
 h1=zero.par
 h2=zero.par
 h3=zero.par
 h4=zero.par
 h5=zero.par
 h6=zero.par
 h7=zero.par
 q1=zero.par
 q2=zero.par
 q3=zero.par
 q4=zero.par
 q5=zero.par
 q6=zero.par
 q7=zero.par
rem**********assign Transmissivity Values**********
LOAD
x6=SACFEM_v2_Kh_1_mpd_120313.par
x7=SACFEM_v2_Kh_2-5_mpd_120313.par
x8=SACFEM_v2_Kh_6-7_mpd_120313.par
EVAL
t1=mt1*x6
t2=mt2*x7
t3=mt3*x7
t4=mt4*x7
t5=mt5*x7
```

5.3.1 Non-Looping Batch File

5.3.1.1 Assignment of Model Input Parameters

The non-looping portion of SACFE_2013.feb is responsible for assigning initial model parameters and opening of model output files.

*Note: Each line of a *.feb file that begins with "rem" represents remarks (i.e., notes) for the reader. MicroFEM does not read/consider "rem" statements in the model calculation.*

The first section of the non-looping batch file (following the "BEGIN SIMULATION" header) zeros out the initial head and pumping parameters for all nodes/layers. This is done by loading (via the LOAD command) a parameter file, Zero.par, containing a value of zero for every model node into each head and discharge register.

The next section of the batch file (following the rem**********assign Transmissivity Values********** header) calculates the transmissivity values for all model nodes/layers. The first step in the process involves loading parameter files containing horizontal hydraulic conductivity values for each "grouping" of model layers (described in Section 3.2.2) into extra registers. In the case of SACFEM_2013, these are registers x3, x4, and x5. The MicroFEM "Eval" command is then used to directly calculate and assign the transmissivity for each model layer (t1 through t7) by multiplying the model layer thickness (mt1 through mt7) by the horizontal hydraulic conductivity contained in the extra register. For example, the formula to calculate the transmissivity of t1 is as follows:

$$t1 = mt1 \times x3 \tag{13}$$

Where:

t1 = transmissivity of model layer 1 (L^2/T)
mt1 = thickness of model layer 1 (L)
x3 = extra register containing the horizontal hydraulic conductivity of model layer 1 (L/T)

*Note: The current version of SACFEM2013 assumes that the thickness register has been populated with the appropriate thickness values for each model layer (i.e., SACFEM_2013.thi is loaded into the *.fpr); therefore, thickness values are not directly assigned in the batch file.*

The batch file then saves (using the SAVE command) parameter files for each model layer containing transmissivity values for all model nodes.

As previously discussed, SACFEM2013 does not explicitly simulate aquitards between model layers; however, vertical resistance to groundwater flow across model layer interfaces is simulated using the vertical resistance term. The next portion of the batch file (following the rem**********assign vertical resistance values ********** header) calculates the vertical resistance terms for each model layer (c2 through c7). The first step involves loading a parameter file (SACFEM_v2_KhKv_Ratio_500.par) containing the Kh:Kv values for each model node into extra register x6. The values included in the parameter file are those described in Section 3.2.2. The batch file then calculates the vertical resistance term using Equation 2 and the previously assigned model transmissivity, thickness, and Kh:Kv values. The calculations use a Kh:Kv of 50:1 for model Layer 1 and the anisotropy factors loaded into x6 for all other model layers.

Following assignment of vertical resistance terms, the batch file loads two parameter files (ground surface elevation and streambed elevation) into the extra register. This process loads the data for user review; however, the extra registers are not used for subsequent calculations in the SACFEM2013 simulation.

5.3.1.2 Opening Transient Water Budget Files

The final section of the batch file (following the rem**********open ftq files********** header) opens transient head (*.fth) and flux (*.ftq) files that can be used to evaluate model calibration and potential impacts (in the case of a "with project" simulation). Transient head files are used to save time series (for each stress period) simulated head data for a user-defined set of model nodes. Transient flux files save volumetric flux data for all water budget components for a user-defined set of model nodes. Refer to the MicroFEM User's Manual or Help menu for more information about these files.

The first transient water budget file opened in the batch file is the "all.ftq" file. The first step in the process is to load a label file into the Label 1 register (default register included in the *.fem file) that contains the text "all" at every node within the SACFEM2013 model domain. Next, the transient flux file "all.ftq" is opened using the syntax "open-q all=all.ftq upper=1 lower=7." MicroFEM opens the transient flux file and aggregates the water budget components for every node containing the text "all" in the label register (in this case, every node in the model domain). This file ultimately contains the total volumetric fluxes (i.e., summed for all model nodes) for each of the water budget components for each stress period. MicroFEM saves the volumetric fluxes for each model layer separately. The "upper=1 lower=7" syntax tells MicroFEM to open the transient flux file for model Layers 1 through 7.

The second set of transient water budget files opened in the batch file (following rem**********open ftq files for Water Budget Areas**********) are for sub-areas of the model domain representing the WBAs presented on Figure 25. The first step involves loading the label file *SACFEM_v2_WBAs_121013.lb* into the label 1 register. Each model node has a text string in this label file corresponding to the appropriate water budget area (i.e., all model nodes that are located within the spatial extent of Water Budget Area 2 are assigned the label WBA_2). Next, separate transient water budget files are opened for each group of nodes containing common text strings. Similar to the all.ftq file, the water budget area *.ftq files are opened for all model layers.

The final set of transient water budget files opened in SACFEM_2013.feb (following rem**********open ftq files for streams**********) are for streams simulated in SACFEM2013. A label file, *SACFEM_v2_Streams_FTQ_042314.lb*, is loaded into the label 1 register. This file contains text representing the name of each stream, bypass, and reservoir included in SACFEM2013. The text strings are assigned only to those nodes representing the spatial location of each surface water feature (i.e., non-stream nodes are blank). Separate transient water budget files are then opened for each group of nodes containing common text (i.e., each stream, bypass, or reservoir). FTQ files for surface water features are only opened for model Layer 1, as this is the only model layer that interacts with MicroFEM top system boundary conditions.

As previously described, transient head files save time series simulated groundwater elevation data for a user-defined set of nodes. The portion of the SACFEM2013 batch file following ********open fth for WDL wells******** opens a *.fth file for wells contained in the DWR Water Data Library. A label file containing the unique state well number (SWN) for each well, *SACFEM_v2_WDL_Wells.lb*, is loaded into the label 1 register. Each SWN included in the label file is preceded by the character "^". A single transient head file is then opened for all nodes that contain a "^". Although a single *.fth file is opened, simulated head data are saved and can be read for each individual model node containing a "^" in the label file. As indicated by the "upper=1 lower=7" syntax, head data are saved for all model layers.

Prior to the onset of the transient (looping) portion of the batch file (following ********assign initial heads********), initial head files are loaded into SACFEM2013. This set of initial heads were selected from a previous SACFEM2013 simulation. September 1986 was chosen as the representative stress period for the initial head condition.

5.3.2 Looping Batch File

As described in Section 5.2, Model Pre-processing, the looping portion of SACFEM_2013.feb represents the transient model simulation. A similar set of model commands is executed for each of the 492 model stress periods, following:

```
rem**********************************************
rem             BEGIN TRANSIENT SIMULATION
rem**********************************************
```

5.3.2.1 Mountain-Front Recharge

As discussed in Section 3.2.4.2, deep percolation of precipitation within the Sacramento Hydrologic Region in areas outside of the SACFEM2013 model domain is incorporated as a specified-flux boundary condition along the model boundary, mountain-front recharge. The first set of syntax in the *.feb for each stress period of the transient SACFEM2013 simulation (following rem*************assign mountain-front recharge**********) includes calculations to assign the mountain front recharge for each of the 34 polygons presented on Figure 22.

The first step in the process involves loading a label file containing text strings associated with each of the mountain front recharge polygons into the label 1 register, *SACFEM_v2_VoidPolygons2013_v2.lb*. The label file contains text associated with the spatial location of each polygon along the SACFEM2013 model boundary; all other nodes are blank. The batch file then zeros out pumping for all nodes in each model layer by loading a parameter file, Zero.par, containing values of zero for all nodes into each pumping register. This is done to avoid carry-over pumping between model stress periods.

In the next step, the total annual volumetric deep percolation of precipitation (in units of cubic meters) is assigned to all nodes corresponding to each of the mountain-front polygons. This is accomplished using the MicroFEM “EVAL” command to directly assign the deep percolation values to extra register x22. For example, for stress period 1 (October 1969) the syntax EVAL; x22=8071480 label=1 indicates that a value of 8,071,480 m^3 is assigned to all nodes containing the text “1” in the label 1 register.

The next section of the *.feb file (following rem*************adjust mountain-front recharge**********) contains syntax to convert the total annual volumetric deep percolation values to daily rates. The batch file firsts loads a parameter file, SACFEM_v2_MtnFront_L_Factor_2013_v2.par, into the x23 register. This parameter file contains a weighting factor for each node of a given polygon to scale the total deep percolation values. For each node in a polygon the weighting factor is calculated as follows:

$$Scaling\ Factor = \frac{Length\ of\ Individual\ \ Node}{Total\ \ Length\ of\ \ All\ Nodes\ \ in\ Mountain\ \ \ Front\ \ Polygon} \tag{14}$$

The total volumetric values are then converted to daily rates given the following:

$$Daily\ Rate = \frac{Total\ \ Annual\ \ Volume\ *Monthly\ Distribution\ \ \ Factor\ *Adjustment\ \ \ Factor}{Days\ \ in\ Month} \tag{15}$$

As previously discussed in Section 3.2.4.2, the “Monthly Distribution Factor” apportions the annual deep percolation values for each month based on monthly distribution of streamflow measured in ungaged sections of Deer Creek (see Table 5). The “adjustment factors” for each mountain-front polygon are multipliers for each polygon developed during the calibration process. An example of the SACFEM_2013.feb syntax is as follows: EVAL; x22=p*0.030*0.50/31 label=1. For this process, MicroFEM takes the p (present value, total annual volumetric flux), multiplies by the monthly distribution factor of 3 percent for October and the calibration adjustment factor of 0.5 for mountain-front polygon 1, and divides by 31 (the number of days in October). As the end of this calculation, the total volumetric deep percolation value is converted to a daily rate, but the total daily rate is assigned to each node of a given polygon.

*Note: when running a batch file that includes performing calculations for subsets of the model domain based on a label file, it is important to have only the label 1 register active (i.e., have no labels loaded into the label 2 through 5 registers). If a label is accidentally loaded twice (that is, the label is present in any of the label 2 through 5 registers and is loaded into label 1 as part of a *.feb file), MicroFEM will perform the calculation multiple times (each time it “sees” the specified text string in any of the label registers).*

Note: Leap years are not considered in SACFEM; therefore, February stress periods are always 28 days long.

The final set of syntax in this portion of the *.feb file scales the deep percolation based on the factors described in Equation 14. The syntax included in the *.feb file is “q1=x22*x23*-1.” This means that for all nodes in the model, the Layer 1 pumping register is assigned a value representing the total daily deep percolation rate multiplied by the nodal scaling factor. The “-1” indicates that the specified flux is an inflow value (i.e., in MicroFEM, negative pumping values represent injection and positive values represent extraction).

5.3.2.2 Model Calculation

The final section of the looping batch file contains syntax to conduct the model calculation for each of the 492 monthly stress periods. The first section loads several parameter files specific to each stress period. These include the deep percolation of applied water/precipitation file (*.PPN), the wadi head file (*.wh1), the wadi conductance file (*.wc1), the drain conductance file (*.dc1), and the pumping files for each model layer (*.q).

Note: For stress period, one these additional parameter files is loaded: model storage file (SACFEM_v2.sto), streambed elevation file (SACFEM_v2_WL1_042314.par, wl1), and drain elevation file (SACFEM_v2_GSE_Combined_mNAVD88_120313.par, dh1). These parameters remain constant throughout the model simulation period.

The next section of the batch file defines the time discretization for each stress period. For stress period 1, the syntax is as follows:

```
TIME
days=31
steps=1
```

The duration of each stress period is 1 month; therefore, the number of days in a given month is specified (as assigned during model pre-processing described in Section 5.2). A single time step is used in each stress period. The time-step duration is variable, but always equates to the length of the month being simulated.

The next section of the batch file contains the run statement. For stress period 1, the syntax is as follows:

```
RUN
  itmin=50
  itmax=600
  relax=0
  error=0.005
  m3error=1
```

The syntax “itmin” represents the minimum number of iterations, specified as 50 for all stress periods. “Itmax” represents the maximum number of iterations for each stress period. The default value is 600 iterations; however, as discussed in Section 5.2.2.3, a value of 1000 is assigned during model preprocessing if the model failed to converge for a given stress period for a previous simulation. The “relax” is an adjustment factor used by the MicroFEM solver (successive over-relaxation, SOR). The default value of 0 is assigned; however, as with the maximum iterations, a value of 1 is assigned if the model failed to converge for a given stress period during a previous simulation. The “error” term defines the closure criteria for the heads, specified as 0.005 meter for all stress periods, while the “m3error” defines the closure criterion for the model water budget (1 m^3/day for all stress periods). Model convergence is only achieved for a given stress period if these error criteria are met.

5.4 The MicroFEM LOG File

The *.log file contains the details of a given model simulation. The *.log file is opened by checking a box in the MicroFEM calculation window and specifying a file name (see Figure 52). The *.log file essentially follows the format of the *.feb file for a given simulation, but includes additional information regarding model calculations and summary of model calculation for each stress period. It is important to note that a transient MicroFEM simulation will stop if MicroFEM is unable to load a specified parameter or label file. The MicroFEM *.log file is essential to verify the success of a model simulation.

When calculations are included in a batch file (with the EVAL command), the *.log file will include syntax such as “New values assigned to X nodes”, where X represents the number of nodes to which a given parameter is assigned. If MicroFEM is not successful in implementing a calculation, syntax such as “New values assigned to 0 nodes” or “Cannot Evaluate” will be written to the *.log file, ***but the model simulation will continue with the incorrect parameter values***.

At the end of each stress period, a summary of the stress period calculation is written to the *.log file. This includes the current time (cumulative number of days for the simulation to that point), number of iterations used for the stress period, the maximum change in head for the stress period (in meters), the water budget error for the stress period (in m^3/day), the node containing the maximum change in head, and the layer containing the maximum change in head. This summary information should be examined to confirm that the closure criteria were met for each stress period. MicroFEM will continue a simulation regardless of whether the criteria are met and does not write an error message to the *.log file to designate stress periods that failed to converge. A post-processor has been developed to facilitate evaluation of the *.log file and is discussed in the following section.

5.5 Model Post-processing

Several transient output files are generated during the SACFEM2013 simulation. Two pre-processors have been developed to process and summarize these data, *RunLogReader_SACFEM_2013.xls* and *Hydrographs_SummaryStatsTool_SACFEM_2013.xlsm*.

5.5.1 Run Log Reader

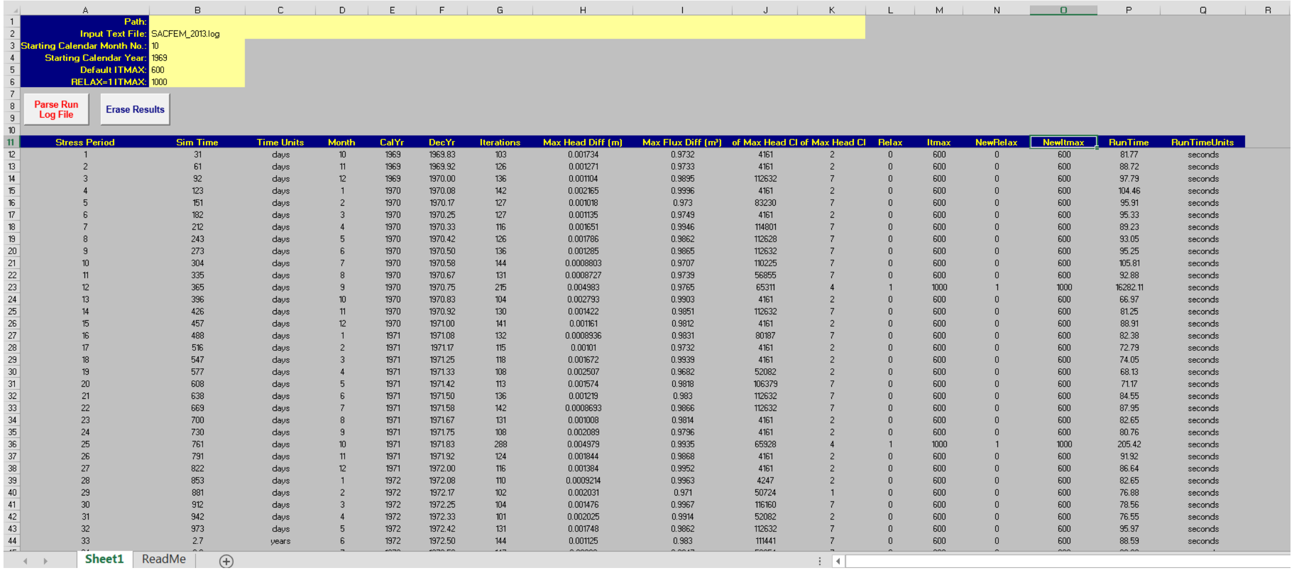
The SACFEM2013 run log reader summarizes the simulation information for each stress period from the *.log file. The user inputs SACFEM2013 file information in the first six rows including: path in *.log file, file name (including extension), starting month (calendar month), starting year (calendar year), default maximum number of iterations, and number of iterations to include if the model fails to converge for a given stress period (see Figure 54). The run log reader contains two macros. The “Erase Results” button clears the summary information from the previous simulation, if present. The “Parse Run Log File” button reads through the SACFEM_2013.log file and searches for the text string below (which is written to the *.log file at the end of each stress period).

CurrentTime Iterations MaxHeadChange (m) M3Error (m^3/d) NodeMaxHeadChange LayerMaxHeadChange

The macro then writes summary information for each stress period to the “Sheet 1” worksheet (see Figure 54). Finally, the macro compares the number of iterations used to the user-specified default number of maximum iterations. If the number used is greater than or equal to the default, the macro populates the “NewItmax” column with the user-specified value in row 6, and the “NewRelax” column with a 1. The summary information included in “Sheet 1” can be pasted into the “RELAX_ITMAX” of the pre-processing utility “PPN_Q_Generator_SACFEM_2013.xlsm.” As discussed in Section 5.2.2.3, the new itmax and relax values for stress periods that failed to converge will be modified in the *.feb file for the next simulation.

FIGURE 54

RunLogReader_SACFEM_2013.xls, Sheet 1



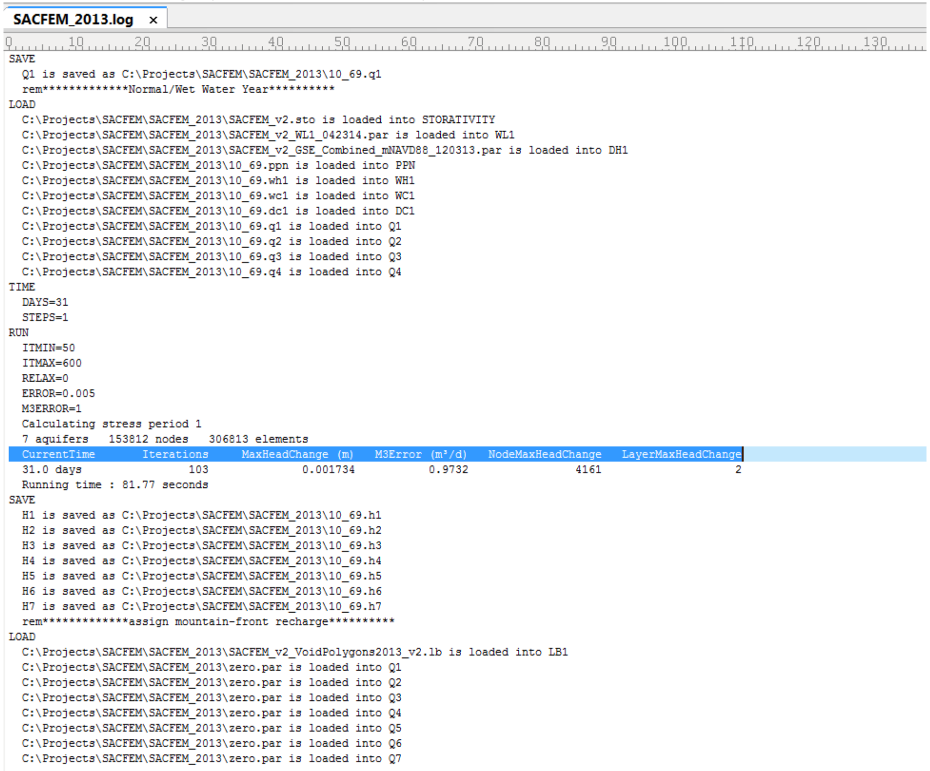
Path:
Input Text File: SACFEM_2013.log
Starting Calendar Month No.: 10
Starting Calendar Year: 1969
Default ITMAX: 600
RELAX=1 ITMAX: 1000

Stress Period	Sim Time	Time Units	Month	CalYr	DecYr	Iterations	Max Head Diff (m)	Max Flux Diff (m³)	of Max Head Cl	of Max Head Cl	Relax	Itmax	NewRelax	NewItmax	RunTime	RunTimeUnits
1	31	days	10	1969	1969.83	103	0.001734	0.9732	4161	2	0	600	0	600	81.77	seconds
2	61	days	11	1969	1969.92	126	0.001271	0.9733	4161	2	0	600	0	600	88.72	seconds
3	92	days	12	1969	1970.00	136	0.001104	0.9895	112632	7	0	600	0	600	97.79	seconds
4	123	days	1	1970	1970.08	142	0.002165	0.9996	4161	2	0	600	0	600	104.46	seconds
5	151	days	2	1970	1970.17	127	0.001018	0.973	83230	7	0	600	0	600	95.91	seconds
6	182	days	3	1970	1970.25	127	0.001135	0.9749	4161	2	0	600	0	600	95.33	seconds
7	212	days	4	1970	1970.33	116	0.001651	0.9946	114801	7	0	600	0	600	89.23	seconds
8	243	days	5	1970	1970.42	126	0.001786	0.9862	112628	7	0	600	0	600	93.05	seconds
9	273	days	6	1970	1970.50	136	0.001285	0.9865	112632	7	0	600	0	600	95.25	seconds
10	304	days	7	1970	1970.58	144	0.0008803	0.9707	110225	7	0	600	0	600	105.81	seconds
11	335	days	8	1970	1970.67	131	0.0008727	0.9739	56855	7	0	600	0	600	92.88	seconds
12	365	days	9	1970	1970.75	215	0.004983	0.9765	65311	4	1	1000	1	1000	16282.11	seconds
13	396	days	10	1970	1970.83	104	0.002793	0.9903	4161	2	0	600	0	600	66.97	seconds
14	426	days	11	1970	1970.92	130	0.001422	0.9851	112632	7	0	600	0	600	81.25	seconds
15	457	days	12	1970	1971.00	141	0.001161	0.9812	4161	2	0	600	0	600	88.91	seconds
16	488	days	1	1971	1971.08	132	0.0008936	0.9831	80187	7	0	600	0	600	82.38	seconds
17	516	days	2	1971	1971.17	115	0.00101	0.9732	4161	2	0	600	0	600	72.79	seconds
18	547	days	3	1971	1971.25	118	0.001672	0.9939	4161	2	0	600	0	600	74.05	seconds
19	577	days	4	1971	1971.33	108	0.002507	0.9682	52082	2	0	600	0	600	68.13	seconds
20	608	days	5	1971	1971.42	113	0.001574	0.9818	106379	7	0	600	0	600	71.17	seconds
21	638	days	6	1971	1971.50	136	0.001219	0.983	112632	7	0	600	0	600	84.55	seconds
22	669	days	7	1971	1971.58	142	0.0008693	0.9866	112632	7	0	600	0	600	87.95	seconds
23	700	days	8	1971	1971.67	131	0.001008	0.9814	4161	2	0	600	0	600	82.65	seconds
24	730	days	9	1971	1971.75	108	0.002089	0.9796	4161	2	0	600	0	600	80.76	seconds
25	761	days	10	1971	1971.83	288	0.004979	0.9935	65928	4	1	1000	1	1000	205.42	seconds
26	791	days	11	1971	1971.92	124	0.001844	0.9868	4161	2	0	600	0	600	91.92	seconds
27	822	days	12	1971	1972.00	116	0.001384	0.9952	4161	2	0	600	0	600	86.64	seconds
28	853	days	1	1972	1972.08	110	0.0009214	0.9963	4247	2	0	600	0	600	82.65	seconds
29	881	days	2	1972	1972.17	102	0.002031	0.971	50724	1	0	600	0	600	76.88	seconds
30	912	days	3	1972	1972.25	104	0.001476	0.9967	116160	7	0	600	0	600	78.56	seconds
31	942	days	4	1972	1972.33	101	0.002025	0.9914	52082	2	0	600	0	600	76.55	seconds
32	973	days	5	1972	1972.42	131	0.001748	0.9862	112632	7	0	600	0	600	95.97	seconds
33	2.7	years	6	1972	1972.50	144	0.001125	0.983	111441	7	0	600	0	600	88.59	seconds

*Note: The number of characters (spaces) in the text string above (that the macro searches the *.log file for) periodically changes with new MicroFEM releases. If the macro fails to run, open the VBA module and the log file, highlight the entire text string from the log file (see Figure 55), and paste into the VBA module (see Figure 56).*

FIGURE 55

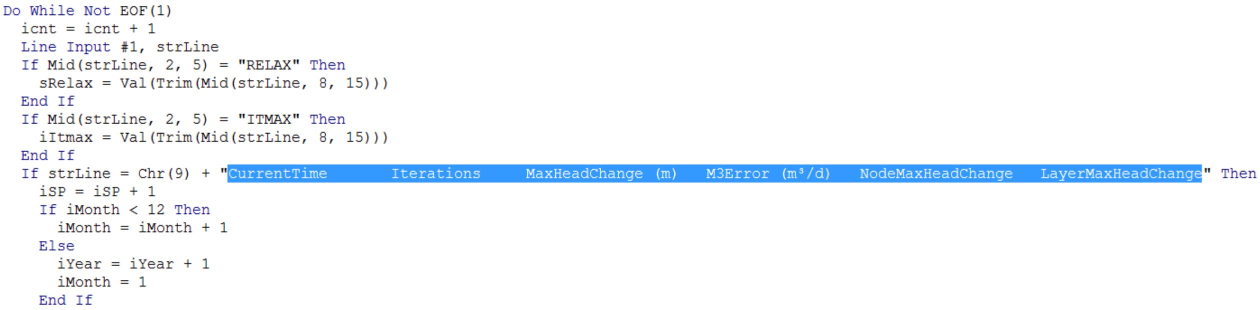
SACFEM2013.log Syntax to Search/Replace



```
SAVE
  Q1 is saved as C:\Projects\SACFEM\SACFEM_2013\10_69.q1
  rem************Normal/Wet Water Year**********
LOAD
  C:\Projects\SACFEM\SACFEM_2013\SACFEM_v2.sto is loaded into STORATIVITY
  C:\Projects\SACFEM\SACFEM_2013\SACFEM_v2_WL1_042314.par is loaded into WL1
  C:\Projects\SACFEM\SACFEM_2013\SACFEM_v2_GSE_Combined_mNAVD88_120313.par is loaded into DH1
  C:\Projects\SACFEM\SACFEM_2013\10_69.ppn is loaded into PPN
  C:\Projects\SACFEM\SACFEM_2013\10_69.wh1 is loaded into WH1
  C:\Projects\SACFEM\SACFEM_2013\10_69.wc1 is loaded into WC1
  C:\Projects\SACFEM\SACFEM_2013\10_69.dc1 is loaded into DC1
  C:\Projects\SACFEM\SACFEM_2013\10_69.q1 is loaded into Q1
  C:\Projects\SACFEM\SACFEM_2013\10_69.q2 is loaded into Q2
  C:\Projects\SACFEM\SACFEM_2013\10_69.q3 is loaded into Q3
  C:\Projects\SACFEM\SACFEM_2013\10_69.q4 is loaded into Q4
TIME
  DAYS=31
  STEPS=1
RUN
  ITMIN=50
  ITMAX=600
  RELAX=0
  ERROR=0.005
  M3ERROR=1
  Calculating stress period 1
  7 aquifers   153812 nodes   306813 elements
  CurrentTime       Iterations     MaxHeadChange (m)   M3Error (m³/d)   NodeMaxHeadChange   LayerMaxHeadChange
  31.0 days                103              0.001734           0.9732                4161                    2
  Running time : 81.77 seconds
SAVE
  H1 is saved as C:\Projects\SACFEM\SACFEM_2013\10_69.h1
  H2 is saved as C:\Projects\SACFEM\SACFEM_2013\10_69.h2
  H3 is saved as C:\Projects\SACFEM\SACFEM_2013\10_69.h3
  H4 is saved as C:\Projects\SACFEM\SACFEM_2013\10_69.h4
  H5 is saved as C:\Projects\SACFEM\SACFEM_2013\10_69.h5
  H6 is saved as C:\Projects\SACFEM\SACFEM_2013\10_69.h6
  H7 is saved as C:\Projects\SACFEM\SACFEM_2013\10_69.h7
  rem************assign mountain-front recharge**********
LOAD
  C:\Projects\SACFEM\SACFEM_2013\SACFEM_v2_VoidPolygons2013_v2.lb is loaded into LB1
  C:\Projects\SACFEM\SACFEM_2013\zero.par is loaded into Q1
  C:\Projects\SACFEM\SACFEM_2013\zero.par is loaded into Q2
  C:\Projects\SACFEM\SACFEM_2013\zero.par is loaded into Q3
  C:\Projects\SACFEM\SACFEM_2013\zero.par is loaded into Q4
  C:\Projects\SACFEM\SACFEM_2013\zero.par is loaded into Q5
  C:\Projects\SACFEM\SACFEM_2013\zero.par is loaded into Q6
  C:\Projects\SACFEM\SACFEM_2013\zero.par is loaded into Q7
```

FIGURE 56

RunLogReader_SACFEM_2013.xls, Visual Basic Code to Search/Replace



```
Do While Not EOF(1)
  icnt = icnt + 1
  Line Input #1, strLine
  If Mid(strLine, 2, 5) = "RELAX" Then
    sRelax = Val(Trim(Mid(strLine, 8, 15)))
  End If
  If Mid(strLine, 2, 5) = "ITMAX" Then
    iItmax = Val(Trim(Mid(strLine, 8, 15)))
  End If
  If strLine = Chr(9) + "CurrentTime       Iterations     MaxHeadChange  (m)   M3Error  (m³/d)   NodeMaxHeadChange   LayerMaxHeadChange" Then
    iSP = iSP + 1
    If iMonth < 12 Then
      iMonth = iMonth + 1
    Else
      iYear = iYear + 1
      iMonth = 1
    End If
```

5.5.2 Hydrograph and Summary Statistics Utility

As discussed in Section 5.3, transient heads files are opened for all monitoring wells included in the DWR water data library database at the beginning of the SACFEM2013 simulation (WDL_Hydrographs.fth). The post-processing utility "*Hydrographs_SummaryStatsTool_SACFEM_2013.xlsm*" is used to examine simulated-versus-measured groundwater elevation data for SACFEM2013 calibration target wells. Worksheets in this utility include the following:

ReadMe: Contains information about the processing utility and disclaimer on use

- **Inputs:** Contains macros to populate and erase data on the "*SimHeads*" worksheet as well as to generate hydrographs.
- **SimHeads:** Worksheet is populated with simulated groundwater elevation data for each SACFEM2013 target well listed on the "*Inputs*" worksheet.
- **ObsHeads:** Contains measured groundwater elevation data for target wells. The date range for the data is limited to the SACFEM2013 simulation period (that is, no data earlier/later than WY1970 and WY2010 can be included). Data should only be included for SACFEM2013 calibration target wells (i.e., the same list of wells included on the "*Inputs*" worksheet and in ReadFTH.inp).
- **NodeNoLayerLookup:** Contains look-up information for SACFEM2013 calibration target wells, including SACFEM2013 model node number, SACFEM2013 model layer number, well coordinates, and ground surface elevation at the well.
- **TemplatePlot:** Worksheet contains the template plot used to format hydrographs. The user can modify the format of the graph (axes, series format, etc.) on this worksheet, and the changes will be propagated to all hydrographs when the "Create Hydrographs" macro is run.
- **Hydrographs:** When the "Create Hydrographs" macro on the "*Inputs*" worksheet is run, this worksheet is populated with hydrographs for all SACFEM2013 calibration target wells.
- **PairedMeasSimHeads:** Contains macros to erase previous simulation results, pair simulated/measured groundwater elevation data for all SACFEM2013 calibration targets, and calculate calibration statistics.
- **C.Scatterplot:** Contains a scatterplot of all data from the "*PairedMeasSimHeads*" worksheets, including calibration statistics for the entire calibration dataset.
- **CalibrationStats_L1……L7:** When the "Compute Calibration Stats" macro is run on the "*PairedMeasSimHeads*" worksheet, these worksheets are populated with calibration statistics for SACFEM2013 target wells for each respective layer.

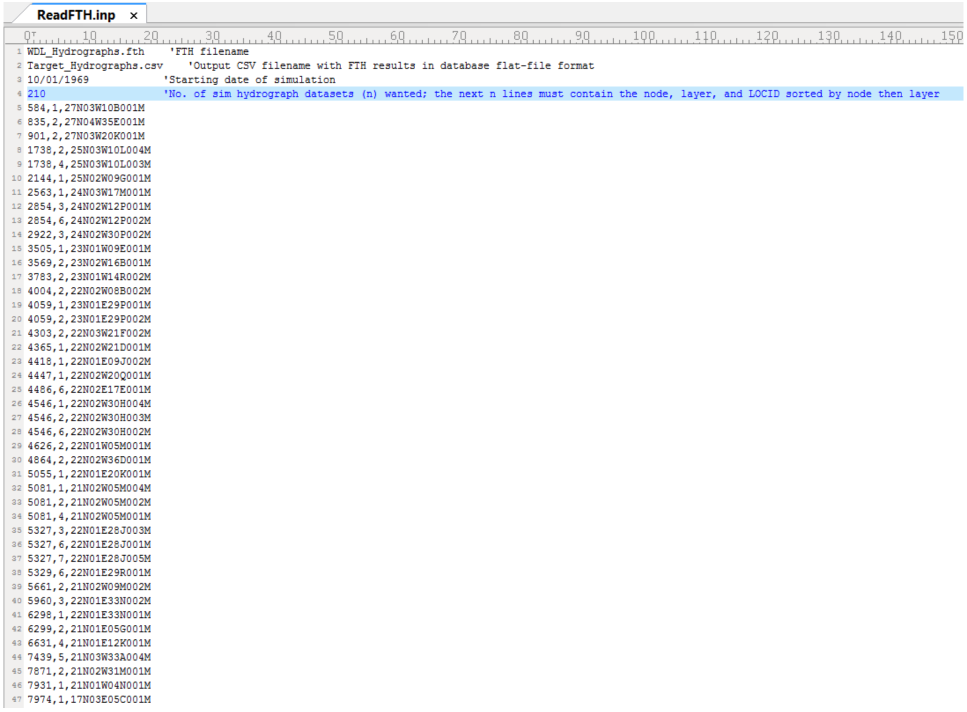
5.5.2.1 ReadFTH

Prior to running any macros in the Excel utility, the *.fth file is converted to a format that is easier for the utility to process. This is done with the utility, ReadFTH.exe. This utility consists of an executable and an input file, which should be located in the same folder as the *.fth file. The input file (ReadFTH.inp) is an ASCII file that can be read/modified via a text editor. The file contains four header rows that include the following information: name of the *.fth file, name of the output file (*.csv file format), starting date of the model simulation, and number of target wells. This information is followed by the list of calibration targets. Each calibration target is listed on its own row with the following information: SACFEM2013 model node number, SACFEM2013 model layer, SWN. This information should be comma-delimited and sorted by ascending SACFEM2013 model node number (see Figure 57). The utility will write the simulated head information for the specified model layer for each well listed in the *.inp file to an Excel *.csv file. This *.csv file is read by the "*Hydrographs_SummaryStatsTool_SACFEM_2013.xlsm*" utility.

*Note: The utility ReadFTH.exe will write the initial heads information to the *.csv output file. The user should open the *.csv file, manually delete the stress period 0 data rows (as this does not represent converged simulated heads to be considered in calibration statistics), and resave the file.*

FIGURE 57

ReadFTH.inp File



```
WDL_Hydrographs.fth    'FTH filename
Target_Hydrographs.csv    'Output CSV filename with FTH results in database flat-file format
10/01/1969            'Starting date of simulation
210                   'No. of sim hydrograph datasets (n) wanted; the next n lines must contain the node, layer, and LOCID sorted by node then layer
584,1,27N03W10B001M
835,2,27N04W35E001M
901,2,27N03W20K001M
1738,2,25N03W10L004M
1738,4,25N03W10L003M
2144,1,25N02W09G001M
2563,1,24N03W17M001M
2854,3,24N02W12P001M
2854,6,24N02W12P002M
2922,3,24N02W30P002M
3505,1,23N01W09E001M
3569,2,23N02W16B001M
3783,2,23N01W14R002M
4004,2,22N02W08B002M
4059,1,23N01E29P001M
4059,2,23N01E29P002M
4303,2,22N03W21F002M
4365,1,22N02W21D001M
4418,1,22N01E09J002M
4447,1,22N02W20Q001M
4486,6,22N02E17E001M
4546,1,22N02W30H004M
4546,2,22N02W30H003M
4546,6,22N02W30H002M
4626,2,22N01W05M001M
4864,2,22N02W36D001M
5055,1,22N01E20K001M
5081,1,21N02W05M004M
5081,2,21N02W05M002M
5081,4,21N02W05M001M
5327,3,22N01E28J003M
5327,6,22N01E28J001M
5327,7,22N01E28J005M
5329,6,22N01E29R001M
5661,2,21N02W09M002M
5960,3,22N01E33N002M
6298,1,22N01E33N001M
6299,2,21N01E05G001M
6631,4,21N01E12K001M
7439,5,21N03W33A004M
7871,2,21N02W31M001M
7931,1,21N01W04N001M
7974,1,17N03E05C001M
```

5.5.2.2 Inputs Worksheet

The "Inputs" worksheet of the post-processing utility contains macros to clear simulated data from a previous simulation, read the simulated heads files, and generate hydrographs of simulated and measured data. There are several rows at the top of the worksheet (see Figure 58) where the user defines the following categories of information:

- **FTH-CSV File Path and File**: path to the *.csv file, including the file name
- **Starting Date**: starting date of the simulation
- **Desired Number of Plots Per Row**: number of hydrographs to plot on a given row
- **Desired Plot Width (characters)**: width of each hydrograph

- **Desired Plot Height (characters)**: height of each hydrograph
- **Desired Y-Range on Plots**: y-axis range on hydrographs – if a value is populated in this cell, all hydrographs will have the user-specified range (the macro will select the axis minimum/maximum). If the cell is left blank, all hydrographs will have the exact y-axis value/range as the template plot

Below the user-specified information is a toggle box for the desired output units as well as buttons for each of the macros. The last section of the "*Inputs*" worksheet contains the list of calibration targets, including SWN, SACFEM2013 model layer, and SACFEM2013 model node number. The list should contain the same calibration target wells as ReadFTH.inp and should be sorted in ascending order by SACFEM2013 node number (see Figures 57 and 58).

As previously discussed, three macros are included on the "Inputs" worksheet.

- **ResetSimHeads**: clears the data from the "SimHeads" worksheet.
- **Summarize FTH Results**: reads user-defined *.csv file and writes the simulated groundwater elevation data for all SACFEM2013 calibration target wells listed on the "*Inputs*" worksheet to the "SimHeads" worksheet.
- **Create Hydrographs**: generates hydrographs of simulated and measured groundwater elevations for all SACFEM2013 calibration target wells listed on the "*Inputs*" worksheet. Simulated groundwater elevation data are read from the "*SimHeads*" worksheet, and measured groundwater elevation data are read from the "*ObsHeads*" worksheet. The macro formats the hydrographs consistent with the graph included on the "*TemplatePlot*" worksheet.

Note: the utility is designed to process data between WY1970 and WY2010. Modifications are required to process data for a different simulation period.

FIGURE 58

Hydrographs_SummaryStatsTool_SACFEM_2013.xlsm, Inputs Worksheet

SACFEM2013 - Transient FTH-Measured Head Scatterplot Utility

FTH-CSV File Path and File: \\C:\SACFEM2013\Target_Hydrographs.csv
Starting Date: 10/1/1969
Desired Number of Plots Per Row: 3
Desired Plot Width (characters): 400
Desired Plot Height (characters): 200
Desired Y-Range on Plots: 160 *use this value to establish min/max from median on Y-axes*

Hydrograph Units (input units are meters)
○ meters ● feet

SWN	Model Layer	Node No.
27N03W10B001M	1	584
27N04W35E001M	2	835
27N03W20K001M	2	901
25N03W10L004M	2	1738
25N03W10L003M	4	1738
25N02W09G001M	1	2144
24N03W17M001M	1	2563
24N02W12P001M	3	2854
24N02W12P002M	6	2854
24N02W30P002M	3	2922
23N01W09E001M	1	3505
23N02W16B001M	2	3569
23N01W14R002M	2	3783
22N02W08B002M	2	4004
23N01E29P001M	1	4059
23N01E29P002M	2	4059
22N03W21F002M	2	4303

5.5.2.3 PairedMeasSimHeads Worksheet

The "*PairedMeasSimHeads*" worksheet of the post-processing utility contains macros to clear data from a previous simulation and to calculate calibration statistics (see Figure 59). The "Clear Stats Sheets" macro clears the data from the "*PairedMeasSimHeads*" worksheet as well as the calibration statistics worksheets for each model layer. The "Compute Calibration Stats" macro performs the following functions:

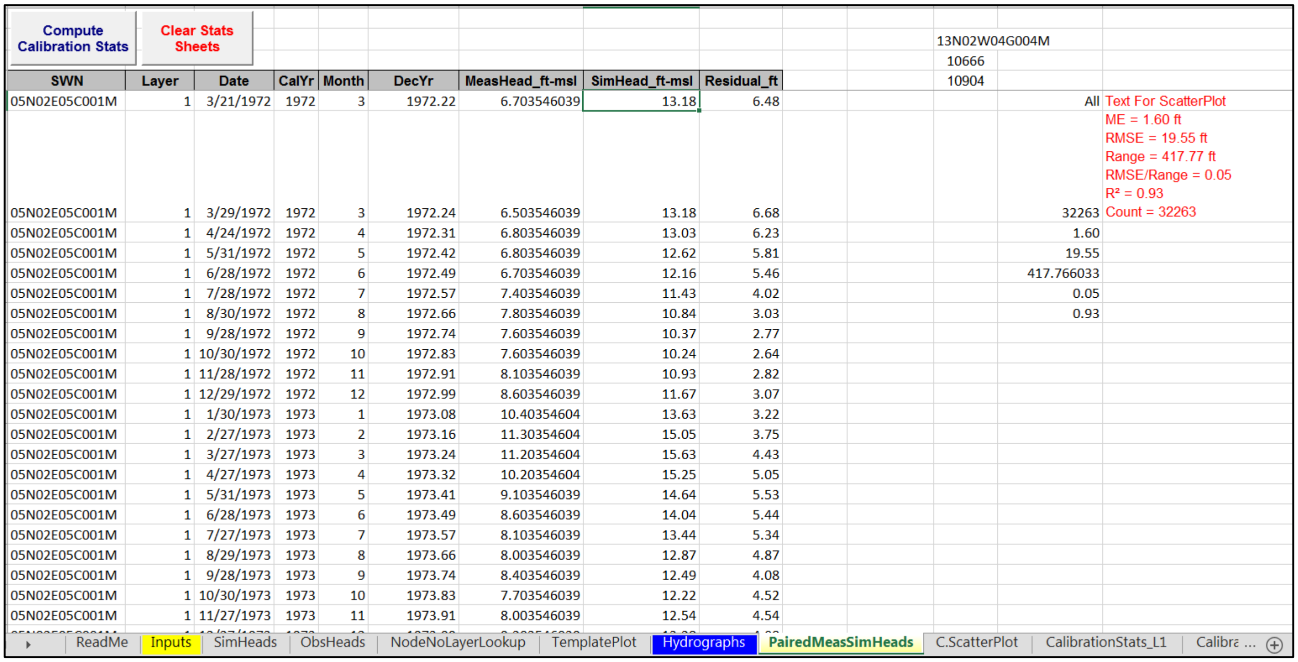
- For each measured groundwater elevation on the “ObsHeads” worksheet, the macro pairs a quasi-contemporaneous simulated groundwater elevation from the “SimHeads” worksheet. The macro interpolates the simulated groundwater elevation data between stress periods to matches the date of the measured groundwater elevation data. The simulated, measured, and residual error in heads are written to the “*PairedMeasSimHeads*” worksheet for each data point (see Figure 59).

- The macro computes the summary calibration statistics (ME, RMSE, range in measured heads, RMS divided by range in measured heads, R^2, and count) for the entire “paired” dataset, which are computed and written to the worksheet.

- The graph on the “*C.Scatterplot*” worksheet automatically updates with the simulated and measured data and the calibration statistics included on the “*PairedMeasSimHeads*” worksheet (see Figure 60).

- For each SACFEM2013 target well listed on the “*Inputs*” worksheet, the macro computes the calibration statistics for the entire “paired” dataset and writes this information to the calibration statistics worksheet corresponding to the model layer for each of the target wells (CalibrationStats_L1 through CalibrationStats_L7).

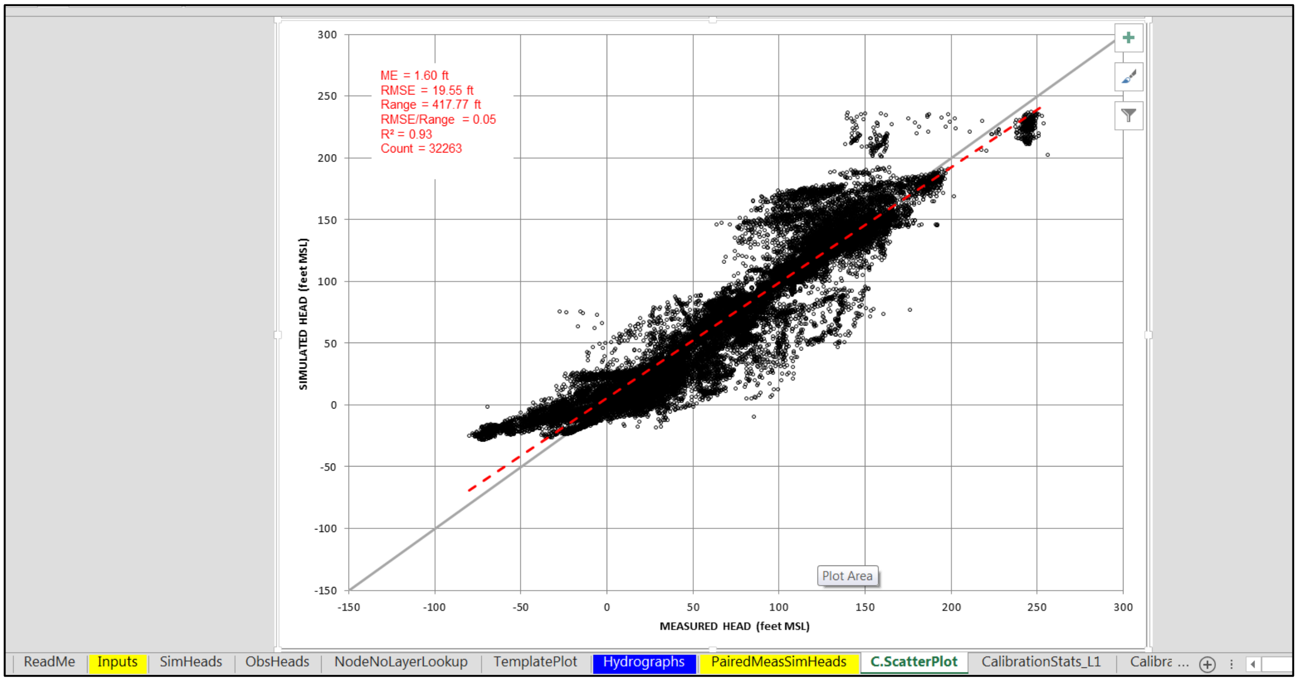
FIGURE 59
Hydrographs_SummaryStatsTool_SACFEM_2013.xlsm, PairedMeasSimHeads Worksheet



											13N02W04G004M		
											10666		
SWN	Layer	Date	CalYr	Month	DecYr	MeasHead_ft-msl	SimHead_ft-msl	Residual_ft			10904		
05N02E05C001M	1	3/21/1972	1972	3	1972.22	6.703546039	13.18	6.48				All	Text For ScatterPlot
05N02E05C001M	1	3/29/1972	1972	3	1972.24	6.503546039	13.18	6.68				32263	ME = 1.60 ft RMSE = 19.55 ft Range = 417.77 ft RMSE/Range = 0.05 R² = 0.93 Count = 32263
05N02E05C001M	1	4/24/1972	1972	4	1972.31	6.803546039	13.03	6.23				1.60	
05N02E05C001M	1	5/31/1972	1972	5	1972.42	6.803546039	12.62	5.81				19.55	
05N02E05C001M	1	6/28/1972	1972	6	1972.49	6.703546039	12.16	5.46				417.766033	
05N02E05C001M	1	7/28/1972	1972	7	1972.57	7.403546039	11.43	4.02				0.05	
05N02E05C001M	1	8/30/1972	1972	8	1972.66	7.803546039	10.84	3.03				0.93	
05N02E05C001M	1	9/28/1972	1972	9	1972.74	7.603546039	10.37	2.77					
05N02E05C001M	1	10/30/1972	1972	10	1972.83	7.603546039	10.24	2.64					
05N02E05C001M	1	11/28/1972	1972	11	1972.91	8.103546039	10.93	2.82					
05N02E05C001M	1	12/29/1972	1972	12	1972.99	8.603546039	11.67	3.07					
05N02E05C001M	1	1/30/1973	1973	1	1973.08	10.40354604	13.63	3.22					
05N02E05C001M	1	2/27/1973	1973	2	1973.16	11.30354604	15.05	3.75					
05N02E05C001M	1	3/27/1973	1973	3	1973.24	11.20354604	15.63	4.43					
05N02E05C001M	1	4/27/1973	1973	4	1973.32	10.20354604	15.25	5.05					
05N02E05C001M	1	5/31/1973	1973	5	1973.41	9.103546039	14.64	5.53					
05N02E05C001M	1	6/28/1973	1973	6	1973.49	8.603546039	14.04	5.44					
05N02E05C001M	1	7/27/1973	1973	7	1973.57	8.103546039	13.44	5.34					
05N02E05C001M	1	8/29/1973	1973	8	1973.66	8.003546039	12.87	4.87					
05N02E05C001M	1	9/28/1973	1973	9	1973.74	8.403546039	12.49	4.08					
05N02E05C001M	1	10/30/1973	1973	10	1973.83	7.703546039	12.22	4.52					
05N02E05C001M	1	11/27/1973	1973	11	1973.91	8.003546039	12.54	4.54					

FIGURE 60

Hydrographs_SummaryStatsTool_SACFEM_2013.xlsm, C.Scatterplot Worksheet



5.5.3 Transient Water Budget Files

As discussed in Section 5.3.1, several transient water budget files are opened at the beginning of the SACFEM2013 simulation. These are tab-delimited ASCII 2 files that can be opened in a text editor or copied into a spreadsheet for further analysis. There are several header rows followed by simulated data (in m^3/day) for all components of the water balance. The first “block” of data represents the uppermost specified model layer (“upper=” in the open-q statements) and is displayed with header titles for the water balance component (which are in columns). Rows in the *.ftq files represent data for each stress period (in ascending order). Successive “blocks” of data represent additional model layers (i.e., model layers between “upper=” and “lower=” in the open-q statements) and are displayed without column headers. The user is referred to the MicroFEM help menu or user’s manual for additional information about transient water budget files.

SECTION 6

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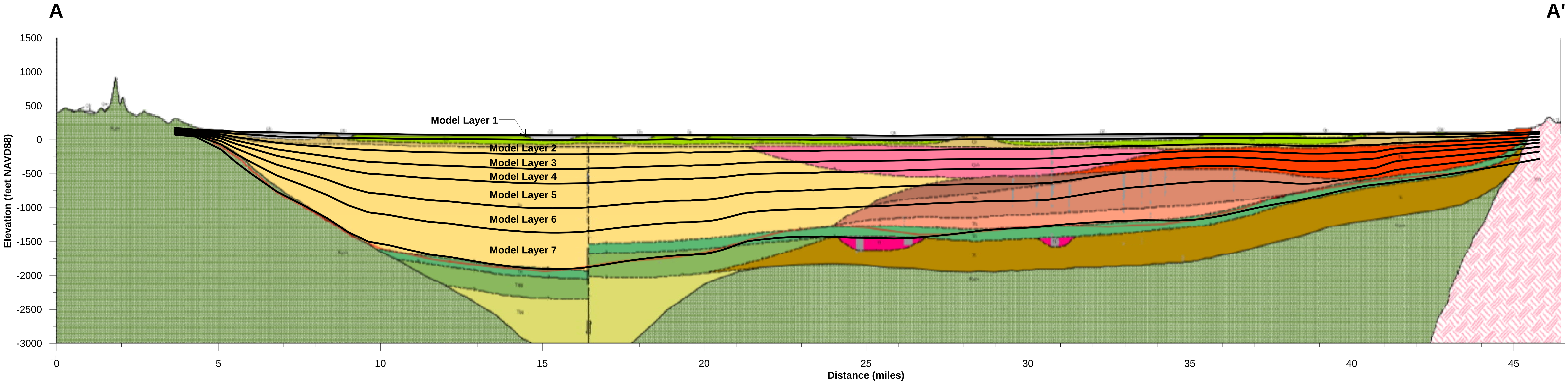
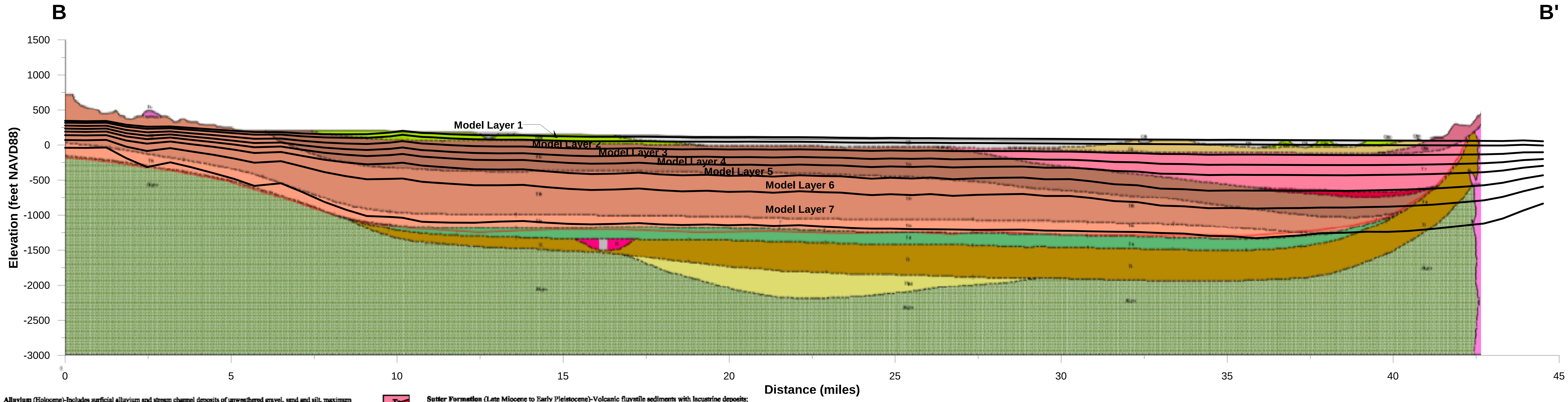


Qa	**Alluvium** (Holocene)-Includes surficial alluvium and stream channel deposits of unweathered gravel, sand and silt, maximum thickness 80 ft. *(adapted from Helley & Harwood, 1985)*.
Qb	**Basin Deposits** (Holocene)-Fine-grained silt and clay derived from adjacent mountain ranges, maximum thickness up to 200 ft. *(adapted from Helley & Harwood, 1985)*.
Qm	**Modesto Formation**, undifferentiated (Pleistocene)-Alluvial fan and terrace deposits consisting of unconsolidated weathered and unweathered gravel, sand, silt and clay; maximum thickness approximately 200 ft. *(adapted from Helley & Harwood , 1985)*.
Qr	**Riverbank Formation**, undifferentiated (Pleistocene)-Alluvial fan and terrace deposits consisting of unconsolidated to semi-consolidated gravel, sand and silt; maximum thickness approximately 200 ft. *(adapted from Helley & Harwood, 1985)*.
Qtl	**Turlock Lake** (Pleistocene)-Weathered and dissected arkosic gravels with minor amounts of resistant metamorphic rock fragments and quartz pebbles, sand and silt; maximum thickness approximately 100 ft. *(adapted from Helley & Harwood, 1985)*.
Qvb	**Volcanic Basalts**, undifferentiated (Pleistocene)-Younger basalt flows found primarily on the east side of the Sacramento Valley, includes minor exposures of andesite; maximum thickness 100 ft. *(adapted from Helley & Harwood, 1985)*.
Qtm	**Tuff Breccia** (Plio-Pleistocene)-Tuff breccia forming outer ring surrounding the Sutter Buttes *(adapted from Helley & Harwood, 1985)*.
Qta	**Volcanic Andesites**, undifferentiated (Plio-Pleistocene)-Younger andesites forming the center of the Sutter Buttes *(adapted from Helley & Harwood, 1985)*.
Tte	**Tehama Formation** (Plio-Pleistocene)-Includes Red Bluff Formation on west side. Pale green, gray and tan sandstone and siltstone with lenses of pebble and cobble conglomerate; maximum thickness 2,000 ft. *(adapted from Helley & Harwood, 1985)*.
Ttd	**Tuscan Unit D** (Plio-Pleistocene)-Fragmental flow deposits characterized by monolithic masses containing gray hornblende and basaltic andesites and black pumice, maximum thickness 160 ft. *(adapted from Helley & Harwood, 1985)*.
Ttc	**Tuscan Unit C** (Plio-Pleistocene)-Includes Red Bluff Formation on east side. Volcanic lahars with some interbedded volcanic conglomerate and sandstone, and reworked sediments; maximum thickness 600 ft. *(adapted from Helley & Harwood, 1985, DWR Bulletin 118-7, 2001, draft report)*.
Ttb	**Tuscan Unit B** (Pliocene)-Layered, interbedded lahars, volcanic conglomerate, volcanic sandstone and siltstone; maximum thickness 600 ft. *(adapted from Helley and Harwood, 1985; DWR Bulletin 118-7, 2001, draft report)*.
Tta	**Tuscan Unit A** (Pliocene)-Interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone containing metamorphic rock fragments; maximum thickness 400 ft. *(adapted from Helley & Harwood, 1985; DWR Bulletin 118-7 (in progress), 2001)*.
Tla	**Laguna Formation** (Pliocene)-Interbedded alluvial gravel, sand and silt; maximum thickness 450 feet. *(adapted from Helley & Harwood, 1985; Olmsted and Davis, 1961; DWR Bulletin 118-6, 1978)*.
Tv	**Basalts and Andesites**, undifferentiated (Pliocene)-Older basalts and andesites found on the northeastern portion of the Sacramento Valley and southwest of Winters; maximum thickness up to 230 ft. *(adapted from Helley & Harwood, 1985)*.
Ts	**Sutter Formation** (Late Miocene to Early Pleistocene)-Volcanic fluvatile sediments with lacustrine deposits; maximum thickness approximately 1,800 ft. *(adapted from Garrison, 1962)*.
Tn	**Neroly Formation** (Miocene)-Marine to non-marine sediments, tuffaceous andesitic sandstone with interbeds of tuff and tuffaceous shales and occasional conglomerate lenses; max. thickness 500 ft. *(adapted from Redwine, 1972; Wagner and Saucedo, 1990)*.
Tl	**Lovejoy Basalt** (Miocene)-Black, dense, hard microcrystalline basalt; maximum thickness 65 ft. *(adapted from Helley & Harwood, 1985)*.
Tupg	**Upper Princeton Valley Fill** (Late Oligocene to Early Miocene)-Non-marine sediments composed of sandstone with interbeds of mudstone and occasional conglomerate and conglomerate sandstone; maximum thickness 1,400 ft. *(adapted from Redwine, 1972)*.
Ti	**Ione Formation** (Eocene)-Marine to non-marine deltaic sediments, light colored, commonly white conglomerate, sandstone and siltstone, which is soft and easily eroded; max. thickness 650 ft. *(adapted from DWR Bulletin 118-6, 1978; Creely, 1965)*.
Tlpg	**Lower Princeton Submarine Valley Fill** (Eocene)-includes Capay Formation. Marine sandstone, conglomerate and interbedded silty shale, maximum thickness 2,400 ft. (*adapted from Redwine, 1972*)
JKgvs	**Great Valley Sequence** (Late Jurassic to Upper Cretaceous)-Marine clastic sedimentary rock consisting of siltstone, shale, sandstone and conglomerate; maximum thickness 15,000 ft.
m	**Mixed Rocks** (pre-Cenozoic)-Undivided metasedimentary and metavolcanic rocks of greatly varying types *(adapted from Jennings, 1977)*.
Mzv	**Volcanic and Metavolcanic Rocks** (Mesozoic)-Undivided volcanic and metavolcanic rocks, andesite rhyolite flow rocks, greenstone and volcanic breccia *(adapted from Jennings, 1977)*.
um	**Ultramafic Rocks** (Mesozoic)-Primarily composed of serpentine, with peridotite, gabbro and diabase *(adapted from Jennings, 1977)*.
gb	**Gabbro** (Mesozoic)-Gabbro and dark diotric rocks *(adapted from Jennings, 1977)*.
gr	**Undifferentiated Granitic Plutons** (Mesozoic-Paleozoic)-Undivided granitic plutons and related rocks *(adapted from Jennings, 1977)*.
Pz	**Paleozoic Metasedimentary Rocks** (Paleozoic)-Undivided metasedimentary rocks including slate, shale, sandstone, chert, conglomerate, limestone, dolomite, marble, phyllite,schist, hornfels and quartzite *(adapted from Jennings, 1977)*.
Pzv	**Paleozoic Metavolcanic Rocks** (Paleozoic)-Undivided metavolcanic rocks, primarily flows, breccia, and tuff, including greenstone, diabase and pillow lavas *(adapted from Jennings, 1977)*.

Notes:
1. Modified from DWR (2005)
2. NAVD88 = North American Vertical Datum of 1988

Figure 10
East-West Cross-Section
of SACFEM2013 Model Layering
SACFEM: Sacramento Valley Finite
Element Groundwater Flow Model
USER'S MANUAL

\\ODIN\Proj\CDMSmith\477905LTWT\Figures\Grapher\Figure_10_SectionA-A'_rev.grf



Qa	**Alluvium** (Holocene)-Includes surficial alluvium and stream channel deposits of unweathered gravel, sand and silt, maximum thickness 80 ft. *(adapted from Helley & Harwood, 1985)*.
Qb	**Basin Deposits** (Holocene)-Fine-grained silt and clay derived from adjacent mountain ranges, maximum thickness up to 200 ft. *(adapted from Helley & Harwood, 1985)*.
Qm	**Modesto Formation**, undifferentiated (Pleistocene)-Alluvial fan and terrace deposits consisting of unconsolidated weathered and unweathered gravel, sand, silt and clay; maximum thickness approximately 200 ft. *(adapted from Helley & Harwood , 1985)*.
Qr	**Riverbank Formation**, undifferentiated (Pleistocene)-Alluvial fan and terrace deposits consisting of unconsolidated to semi-consolidated gravel, sand and silt; maximum thickness approximately 200 ft. *(adapted from Helley & Harwood, 1985)*.
Qtl	**Turlock Lake** (Pleistocene)-Weathered and dissected arkosic gravels with minor amounts of resistant metamorphic rock fragments and quartz pebbles, sand and silt; maximum thickness approximately 100 ft. *(adapted from Helley & Harwood, 1985)*.
Qvb	**Volcanic Basalts**, undifferentiated (Pleistocene)-Younger basalt flows found primarily on the east side of the Sacramento Valley, includes minor exposures of andesite; maximum thickness 100 ft. *(adapted from Helley & Harwood, 1985)*.
Qtm	**Tuff Breccia** (Plio-Pleistocene)-Tuff breccia forming outer ring surrounding the Sutter Buttes *(adapted from Helley & Harwood, 1985)*.
Qta	**Volcanic Andesites**, undifferentiated (Plio-Pleistocene)-Younger andesites forming the center of the Sutter Buttes *(adapted from Helley & Harwood, 1985)*.
Tte	**Tehama Formation** (Plio-Pleistocene)-Includes Red Bluff Formation on west side. Pale green, gray and tan sandstone and siltstone with lenses of pebble and cobble conglomerate; maximum thickness 2,000 ft. *(adapted from Helley & Harwood, 1985)*.
Ttd	**Tuscan Unit D** (Plio-Pleistocene)-Fragmental flow deposits characterized by monolithic masses containing gray hornblende and basaltic andesites and black pumice, maximum thickness 160 ft. *(adapted from Helley & Harwood, 1985)*.
Ttc	**Tuscan Unit C** (Plio-Pleistocene)-Includes Red Bluff Formation on east side. Volcanic lahars with some interbedded volcanic conglomerate and sandstone, and reworked sediments; maximum thickness 600 ft. *(adapted from Helley & Harwood, 1985, DWR Bulletin 118-7, 2001, draft report)*.
Ttb	**Tuscan Unit B** (Pliocene)-Layered, interbedded lahars, volcanic conglomerate, volcanic sandstone and siltstone; maximum thickness 600 ft. *(adapted from Helley and Harwood, 1985; DWR Bulletin 118-7, 2001, draft report)*.
Tta	**Tuscan Unit A** (Pliocene)-Interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone containing metamorphic rock fragments; maximum thickness 400 ft. *(adapted from Helley & Harwood, 1985; DWR Bulletin 118-7 (in progress), 2001)*.
Tla	**Laguna Formation** (Pliocene)-Interbedded alluvial gravel, sand and silt; maximum thickness 450 feet. *(adapted from Helley & Harwood, 1985; Olmsted and Davis, 1961; DWR Bulletin 118-6, 1978)*.
Tv	**Basalts and Andesites**, undifferentiated (Pliocene)-Older basalts and andesites found on the northeastern portion of the Sacramento Valley and southwest of Winters; maximum thickness up to 230 ft. *(adapted from Helley & Harwood, 1985)*.
Ts	**Sutter Formation** (Late Miocene to Early Pleistocene)-Volcanic fluvatile sediments with lacustrine deposits; maximum thickness approximately 1,800 ft. *(adapted from Garrison, 1962)*.
Tn	**Neroly Formation** (Miocene)-Marine to non-marine sediments, tuffaceous andesitic sandstone with interbeds of tuff and tuffaceous shales and occasional conglomerate lenses; max. thickness 500 ft. *(adapted from Redwine, 1972; Wagner and Saucedo, 1990)*.
Tl	**Lovejoy Basalt** (Miocene)-Black, dense, hard microcrystalline basalt; maximum thickness 65 ft. *(adapted from Helley & Harwood, 1985)*.
Tupg	**Upper Princeton Valley Fill** (Late Oligocene to Early Miocene)-Non-marine sediments composed of sandstone with interbeds of mudstone and occasional conglomerate and conglomerate sandstone; maximum thickness 1,400 ft. *(adapted from Redwine, 1972)*.
Ti	**Ione Formation** (Eocene)-Marine to non-marine deltaic sediments, light colored, commonly white conglomerate, sandstone and siltstone, which is soft and easily eroded; max. thickness 650 ft. *(adapted from DWR Bulletin 118-6, 1978; Creely, 1965)*.
Tlpg	**Lower Princeton Submarine Valley Fill** (Eocene)-includes Capay Formation. Marine sandstone, conglomerate and interbedded silty shale, maximum thickness 2,400 ft. (*adapted from Redwine, 1972*)
JKgvs	**Great Valley Sequence** (Late Jurassic to Upper Cretaceous)-Marine clastic sedimentary rock consisting of siltstone, shale, sandstone and conglomerate; maximum thickness 15,000 ft.
m	**Mixed Rocks** (pre-Cenozoic)-Undivided metasedimentary and metavolcanic rocks of greatly varying types *(adapted from Jennings, 1977)*.
Mzv	**Volcanic and Metavolcanic Rocks** (Mesozoic)-Undivided volcanic and metavolcanic rocks, andesite rhyolite flow rocks, greenstone and volcanic breccia *(adapted from Jennings, 1977)*.
um	**Ultramafic Rocks** (Mesozoic)-Primarily composed of serpentine, with peridotite, gabbro and diabase *(adapted from Jennings, 1977)*.
gb	**Gabbro** (Mesozoic)-Gabbro and dark diotric rocks *(adapted from Jennings, 1977)*.
gr	**Undifferentiated Granitic Plutons** (Mesozoic-Paleozoic)-Undivided granitic plutons and related rocks *(adapted from Jennings, 1977)*.
Pz	**Paleozoic Metasedimentary Rocks** (Paleozoic)-Undivided metasedimentary rocks including slate, shale, sandstone, chert, conglomerate, limestone, dolomite, marble, phyllite,schist, hornfels and quartzite *(adapted from Jennings, 1977)*.
Pzv	**Paleozoic Metavolcanic Rocks** (Paleozoic)-Undivided metavolcanic rocks, primarily flows, breccia, and tuff, including greenstone, diabase and pillow lavas *(adapted from Jennings, 1977)*.

Notes:
1. Modified from DWR (2005)
2. NAVD88 = North American Vertical Datum of 1988

Figure 11
North-South Cross-Section of SACFEM2013 Model Layering

SACFEM: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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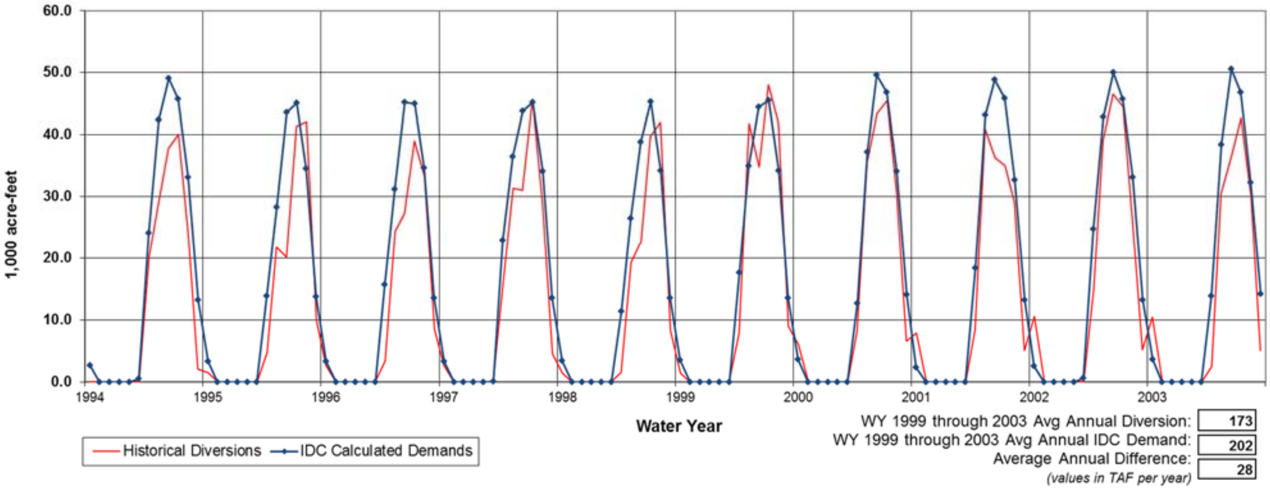
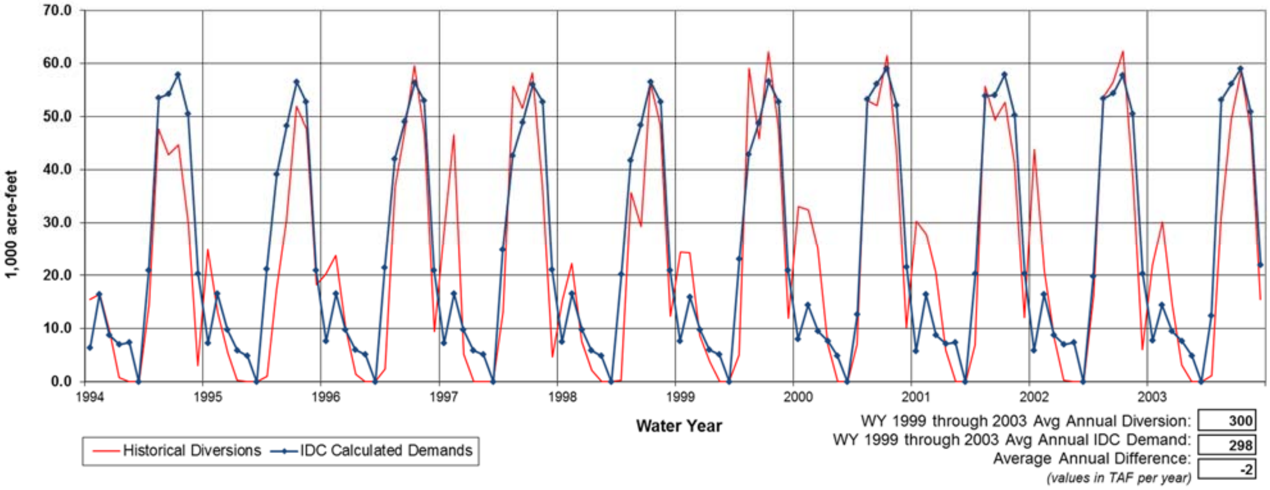
Appendix A
Historical Surface Water Diversion Data and IDC Applied Water Demand Comparisons



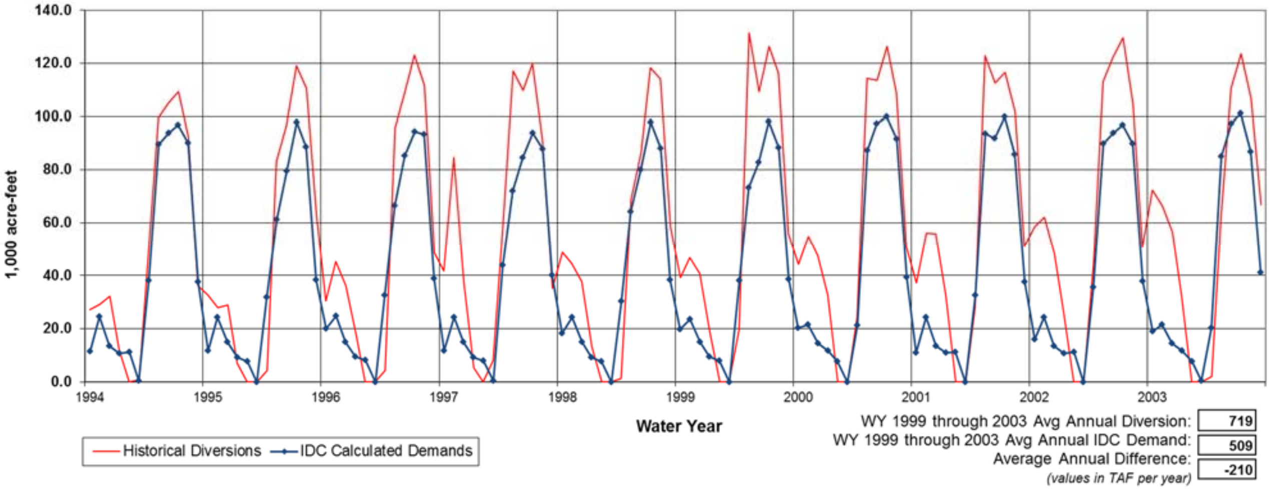
WY 1999 through 2003 Avg Annual Diversion: 173
WY 1999 through 2003 Avg Annual IDC Demand: 202
Average Annual Difference: 28
(values in TAF per year)

Figure A-1 Annual Historical Diversions and IDC Calculated Demands for RD 108 and River Garden Farms



WY 1999 through 2003 Avg Annual Diversion: 300
WY 1999 through 2003 Avg Annual IDC Demand: 298
Average Annual Difference: -2
(values in TAF per year)

Figure A-2 Annual Historical Diversions and IDC Calculated Demands for Western Canal



WY 1999 through 2003 Avg Annual Diversion: 719
WY 1999 through 2003 Avg Annual IDC Demand: 509
Average Annual Difference: -210
(values in TAF per year)

Figure A-3 Annual Historical Diversions and IDC Calculated Demands for Joint Water District

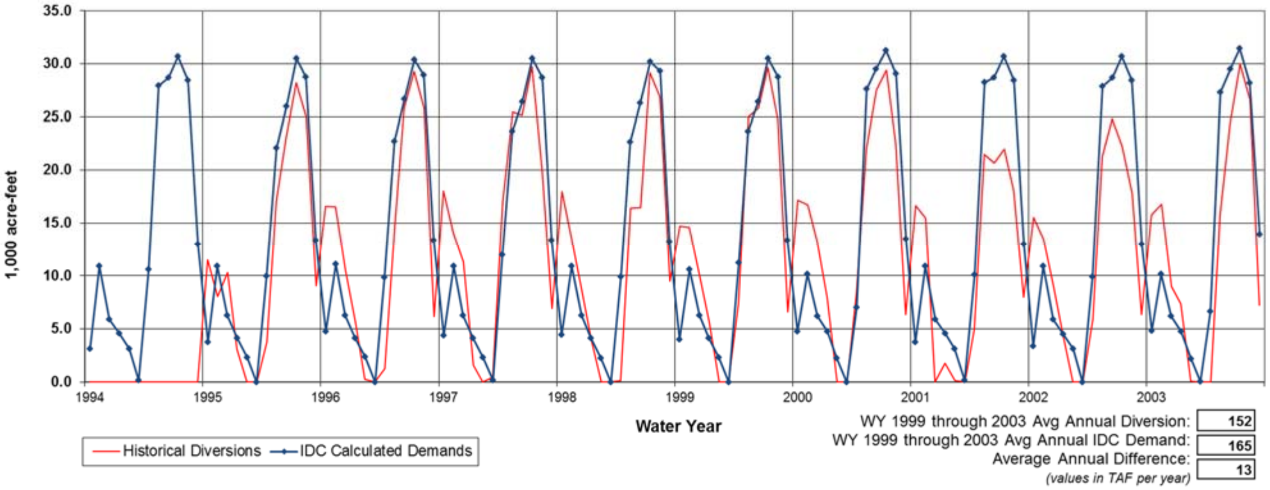


Figure A-4 Annual Historical Diversions and IDC Calculated Demands for YCWA

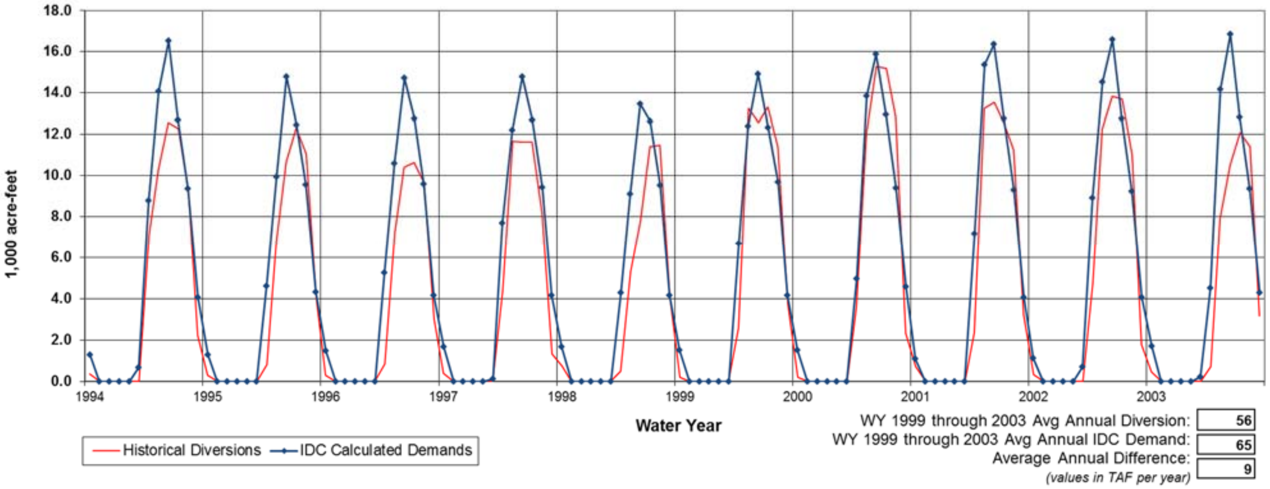


Figure A-5 Annual Historical Diversions and IDC Calculated Demands for Meridian, Newhall, Tisdale, and Short Form Contractors in WBA 18

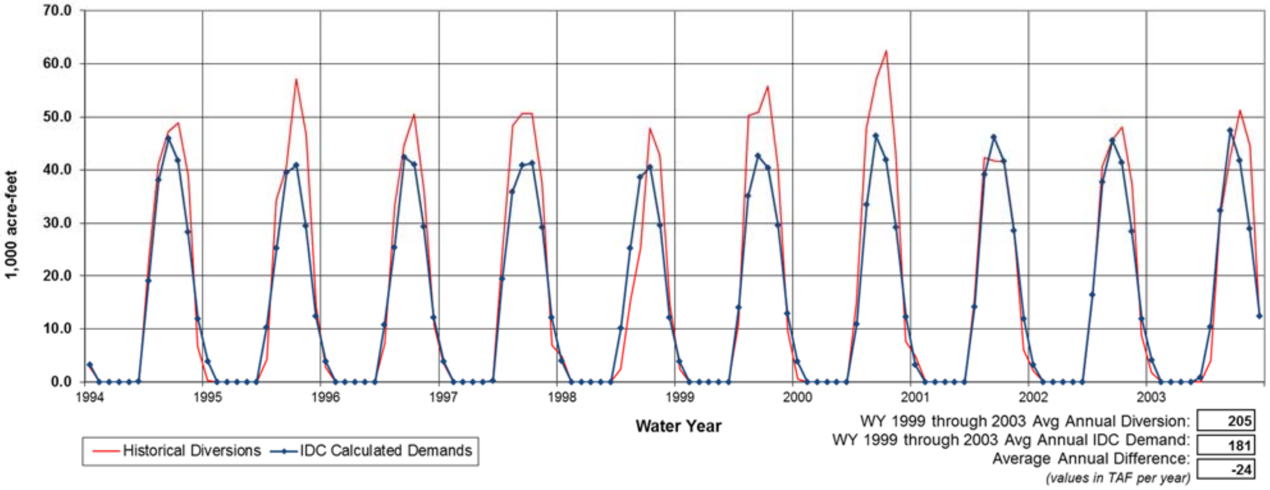


Figure A-6 Annual Historical Diversions and IDC Calculated Demands for Sutter Mutual

Appendix B

Summary of Quantitative Calibration Targets

APPENDIX B

Summary of Quantitative Calibration Targets by Well

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

State Well Number	SACFEM 2013 Model Layer	Earliest Year with Measured Data	Latest Year with Measured Data	Minimum Measured Groundwater Elevation (feet NAVD88)	Maximum Measured Groundwater Elevation (feet NAVD88)	Range in Measured Groundwater Elevation (feet)	Number of Measurements	Mean Error (feet)	Root Mean Squared Error (feet)
05N02E05C001M	1	1972.22	1999.76	2.2	14.3	12.1	318.0	-0.3	4.9
05N05E04C001M	2	1969.9	2002.35	-55.5	-22.5	33.0	335.0	30.2	30.7
05N05E10C003M	2	1969.87	2010.57	-42.5	-10.6	31.9	94.0	19.7	21.1
06N01E24L003M	2	1970.24	2010.25	14.4	33.0	18.6	75.0	-1.4	4.9
06N02E02M003M	2	1970.24	2010.24	-8.3	24.3	32.6	72.0	-8.6	14.6
06N05E01C001M	1	1969.9	2006.7	-80.1	-42.8	37.3	425.0	43.9	44.3
07N01E08N002M	2	1972.64	1994.63	64.6	87.5	22.9	235.0	-24.5	25.0
07N01E11K001M	4	1994.09	1998.42	-17.5	51.9	69.4	51.0	-26.4	33.0
07N01E25J001M	3	1991.6	1999.25	-69.3	33.4	102.7	77.0	-10.4	19.8
07N05E26C001M	4	1970.21	2008.9	-63.9	-31.0	32.9	75.0	31.5	32.0
07N05E32D001M	5	1978.79	1991.2	-51.3	-27.1	24.2	26.0	26.1	26.4
07N06E23P001M	2	1969.9	1998.94	-38.1	1.4	39.5	317.0	-0.8	4.8
08N03E04R001M	2	1970.28	2010.67	-35.8	17.9	53.7	414.0	8.2	10.0
08N04E24M001M	1	1969.9	2001.41	-12.6	3.0	15.6	142.0	13.9	14.1
08N05E07P001M	2	1970.21	2010.7	-5.5	5.7	11.2	349.0	3.3	3.6
08N06E21N002M	2	1969.81	2004.17	-28.4	1.6	30.0	122.0	3.7	6.9
08N06E25J002M	2	1970.21	2010.57	-14.7	85.5	100.2	79.0	-13.8	19.2
08N07E18E002M	3	1984.2	2010.58	-28.9	28.7	57.6	51.0	-8.7	15.8
09N02E16N001M	2	1969.9	2010.67	-27.0	48.1	75.1	461.0	-2.5	11.0
09N04E01R001M	1	1970.82	2010.31	-18.5	13.1	31.6	70.0	0.4	4.6
09N04E22E001M	2	1969.9	2007.83	2.9	15.1	12.2	162.0	1.9	2.8
09N05E14B001M	3	1980.77	2010.57	-49.6	-20.8	28.8	61.0	24.0	24.7
09N05E25J001M	2	1977.5	2010.7	-45.7	-7.4	38.3	346.0	18.3	19.4
09N05E28K001M	2	1970.21	2010.57	-37.4	-4.8	32.6	81.0	20.4	21.4
10N01E26E003M	2	1970.26	2010.32	-20.2	55.5	75.7	86.0	15.7	19.5
10N01E33L002M	2	1972.55	2010.3	2.0	74.6	72.6	88.0	-0.3	13.6
10N02E08E001M	2	1970.84	2010.32	-20.2	51.5	71.7	82.0	5.9	12.2
10N04E27R002M	5	1996.77	2010.67	-32.5	-16.0	16.5	110.0	26.1	26.3
10N04E27R003M	4	1996.77	2010.67	-6.1	7.1	13.2	111.0	-0.6	2.2
10N04E27R004M	2	1996.77	2010.67	6.7	18.2	11.5	111.0	-10.9	11.3

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APPENDIX B

Summary of Quantitative Calibration Targets by Well

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

State Well Number	SACFEM 2013 Model Layer	Earliest Year with Measured Data	Latest Year with Measured Data	Minimum Measured Groundwater Elevation (feet NAVD88)	Maximum Measured Groundwater Elevation (feet NAVD88)	Range in Measured Groundwater Elevation (feet)	Number of Measurements	Mean Error (feet)	Root Mean Squared Error (feet)
10N04E31M001M	5	1997.19	2010.67	-18.5	-9.9	8.6	109.0	22.8	23.0
10N04E31M002M	4	1997.52	2010.67	-8.4	4.9	13.3	106.0	9.5	9.7
10N04E31M003M	3	1997.52	2010.67	2.4	15.1	12.7	106.0	1.9	2.9
10N04E31M004M	2	1997.52	2010.67	5.2	13.7	8.5	106.0	2.0	2.7
10N05E05E001M	2	1970.21	2010.57	-39.2	-13.2	26.0	80.0	18.6	19.4
10N05E22G001M	3	1969.87	1995.36	-43.1	4.4	47.5	283.0	9.9	12.8
10N06E05H001M	2	1969.9	2010.7	-17.7	28.2	45.9	450.0	-3.2	8.2
11N01E03E001M	2	1970.21	2010.25	-21.7	37.1	58.8	118.0	-1.6	10.8
11N02E20K004M	2	1970.23	2010.67	-20.1	37.3	57.4	405.0	-5.4	8.6
11N03E15C001M	1	1970.22	2010.67	7.5	32.2	24.7	123.0	3.7	5.5
11N03E20H003M	2	1970.23	2010.55	14.0	29.3	15.3	83.0	2.5	4.7
11N04E04N001M	7	1994.02	2010.71	-8.6	15.1	23.7	209.0	-2.2	4.2
11N04E04N002M	3	1994.1	2010.71	4.4	27.2	22.8	208.0	-13.2	13.6
11N04E04N003M	2	1994.1	2010.71	11.6	28.7	17.1	208.0	-11.2	11.5
11N06E15C004M	1	1970.23	2008.77	33.3	62.7	29.4	147.0	-40.6	42.2
12N01E06D002M	5	1997.77	2010.73	-7.0	28.7	35.8	95.0	10.4	12.2
12N01E06D003M	4	1997.77	2010.73	-29.3	29.2	58.5	94.0	15.7	20.6
12N01E06D004M	3	1997.77	2010.73	-11.6	29.6	41.2	95.0	8.5	11.4
12N01E16A001M	5	1997.77	2010.73	-14.9	28.4	43.3	85.0	11.0	13.6
12N01E16A002M	3	1997.77	2010.73	-15.1	29.9	45.1	86.0	16.0	20.5
12N01E26A001M	4	1996.85	2010.73	-18.6	21.1	39.7	103.0	19.6	21.7
12N01E26A002M	3	1996.85	2010.73	-21.5	23.0	44.5	104.0	21.0	24.0
12N01E26A003M	2	1996.85	2010.73	-0.3	22.6	22.9	104.0	14.1	15.3
12N02E23K001M	6	1969.78	2009.95	15.5	20.9	5.4	93.0	4.1	4.7
12N04E03N002M	7	1996.77	2010.67	-6.5	44.7	51.2	113.0	-13.8	16.1
12N04E03N003M	6	1996.77	2010.67	-1.5	41.3	42.8	112.0	-11.1	13.7
12N04E03N004M	2	1996.77	2010.67	10.1	45.0	34.9	113.0	-18.7	19.7
12N04E05R004M	1	1970.22	2010.71	-0.3	37.7	38.0	398.0	-9.0	10.5
12N04E26J002M	7	1996.77	2010.67	-17.8	24.4	42.2	114.0	-5.3	9.1
12N04E26J003M	5	1996.77	2010.67	-17.5	24.6	42.1	113.0	-7.2	9.9

APPENDIX B

Summary of Quantitative Calibration Targets by Well

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

State Well Number	SACFEM 2013 Model Layer	Earliest Year with Measured Data	Latest Year with Measured Data	Minimum Measured Groundwater Elevation (feet NAVD88)	Maximum Measured Groundwater Elevation (feet NAVD88)	Range in Measured Groundwater Elevation (feet)	Number of Measurements	Mean Error (feet)	Root Mean Squared Error (feet)
12N04E26J004M	2	1996.77	2010.67	2.6	38.3	35.8	114.0	-21.4	22.6
12N05E01D002M	2	1970.21	2010.57	49.6	77.3	27.7	91.0	-32.6	35.2
12N05E06R001M	1	1970.21	2010.57	-7.5	52.5	60.0	86.0	-22.4	24.8
12N05E12Q001M	1	1969.83	2007.68	22.8	73.0	50.2	446.0	-24.7	31.4
12N05E17A002M	1	1970.21	2010.7	-1.9	41.4	43.3	402.0	-13.9	16.9
12N06E27D002M	3	1969.9	2003.83	39.4	95.0	55.6	160.0	-6.6	22.3
13N01E11A001M	2	1970.19	2010.59	18.7	31.8	13.1	98.0	5.2	6.0
13N01E12J002M	2	1970.22	2010.67	23.8	32.8	9.0	135.0	6.3	6.9
13N01E32K001M	4	1997.77	2010.73	-24.7	23.3	48.0	94.0	23.7	27.0
13N01E32K002M	3	1997.77	2010.73	-13.1	20.4	33.5	94.0	20.4	21.9
13N02W04G001M	3	1969.81	2010.59	38.1	120.0	81.9	449.0	-17.5	32.4
13N02W04G004M	1	1978.45	2010.59	97.3	148.0	50.7	239.0	-51.3	53.7
13N02W15J001M	2	1975.25	2010.59	31.0	111.9	80.9	215.0	-27.8	34.8
13N02W22H001M	1	1970.21	2010.27	106.8	176.0	69.2	77.0	-61.3	63.3
13N04E07L001M	3	1996.3	2010.72	26.1	39.7	13.6	115.0	-2.3	3.1
13N04E23A002M	1	1970.22	2010.57	15.0	57.9	42.9	99.0	-8.6	12.5
13N04E36E001M	1	1969.79	1995.47	-25.9	43.4	69.3	199.0	-10.0	16.0
13N05E06R004M	4	1996.3	2010.72	27.5	61.9	34.4	116.0	3.2	6.3
14N01W03L002M	3	1970.19	1983.76	-21.1	40.8	61.9	84.0	-10.8	16.6
14N01W04K003M	1	1970.19	2010.59	25.8	36.2	10.4	96.0	-26.0	28.2
14N02W16N002M	1	1969.81	1988.19	46.5	87.8	41.3	142.0	13.3	16.1
14N02W29J001M	5	1970.82	2010.59	57.5	107.2	49.7	225.0	-33.2	38.2
14N03E05C001M	1	1970.21	2004.8	3.1	42.5	39.4	66.0	-5.0	7.6
14N03E17A003M	2	1970.23	2010.58	2.0	38.1	36.1	345.0	-0.8	4.2
14N03W11A001M	4	1970.21	2010.59	48.5	107.6	59.1	95.0	-5.1	16.3
14N04E30N003M	2	1995.74	2010.72	4.7	33.4	28.7	152.0	4.0	6.6
15N01E16R001M	3	1969.78	2003.22	29.7	40.3	10.6	72.0	-2.7	6.4
15N01W05G001M	1	1976.19	2010.59	26.2	47.6	21.4	88.0	-6.7	9.0
15N02E35D001M	3	1970.24	2010.57	31.5	44.7	13.2	87.0	-11.8	13.5
15N03E05D002M	2	1970.22	2004.21	30.7	58.7	28.0	63.0	-14.8	15.6

APPENDIX B

Summary of Quantitative Calibration Targets by Well

SACFEM2013: Sacramento Valley Finite Element Groundwater Model; User’s Manual

State Well Number	SACFEM 2013 Model Layer	Earliest Year with Measured Data	Latest Year with Measured Data	Minimum Measured Groundwater Elevation (feet NAVD88)	Maximum Measured Groundwater Elevation (feet NAVD88)	Range in Measured Groundwater Elevation (feet)	Number of Measurements	Mean Error (feet)	Root Mean Squared Error (feet)
15N03E15H004M	2	1970.22	2010.67	32.0	46.7	14.7	137.0	0.7	2.4
15N04E13A001M	2	1970.8	2010.59	13.4	88.1	74.6	90.0	21.4	28.2
15N04E16G002M	3	1996.29	2010.72	31.1	59.1	28.0	114.0	4.8	5.9
15N04E27A001M	4	1970.23	2006.28	-13.5	61.4	74.9	82.0	28.4	34.2
16N01W20F001M	1	1970.19	2010.59	24.7	55.7	31.0	114.0	16.1	17.1
16N02E26Q001M	1	1970.22	2010.58	39.3	60.9	21.6	91.0	-17.4	18.5
16N02W25B002M	2	1969.88	2010.59	28.1	51.4	23.3	335.0	-3.8	5.6
16N03E21D002M	1	1970.22	2010.58	44.6	69.1	24.5	115.0	-16.4	17.0
16N03W07Q001M	1	1975.25	2010.59	105.7	111.3	5.6	90.0	-11.4	11.7
16N03W35N002M	4	1970.19	2010.22	60.6	70.5	9.9	97.0	0.8	5.0
16N04E17R002M	2	1988.84	2010.69	37.1	79.4	42.3	122.0	-2.2	8.0
16N04E22B001M	3	1995.74	2010.72	41.9	85.1	43.2	154.0	10.0	13.2
17N01E10A001M	2	1970.22	2010.59	28.1	60.7	32.6	124.0	4.9	7.1
17N01E17F001M	2	1992.89	2010.59	51.9	59.8	7.9	69.0	5.8	8.2
17N01E17F002M	3	1992.89	2010.59	51.9	62.6	10.7	69.0	3.5	5.8
17N01E17F003M	5	1992.89	2010.59	51.6	62.3	10.7	69.0	3.1	5.0
17N02E14A001M	1	1970.22	2010.69	56.2	84.2	28.0	140.0	-16.6	18.3
17N02W09H002M	5	2004.06	2010.59	24.4	68.7	44.4	64.0	10.9	16.5
17N02W09H003M	4	2004.06	2010.59	11.1	68.0	56.9	63.0	11.8	21.0
17N02W09H004M	2	2004.06	2010.59	53.4	67.3	13.9	64.0	2.2	4.2
17N03E03D001M	1	1970.22	2010.59	61.9	89.8	27.9	139.0	3.4	5.2
17N03E05C001M	1	1970.22	2002.79	75.6	95.6	20.0	105.0	-13.0	13.7
17N03E16N001M	2	1970.22	2010.69	66.4	82.6	16.2	141.0	-15.8	16.7
17N03W08R001M	2	1975.25	2010.59	86.6	98.1	11.5	139.0	4.1	5.0
17N03W10C001M	1	1970.19	2010.59	85.9	93.3	7.4	226.0	-4.8	5.5
17N04E30R001M	4	1970.21	2010.69	-26.4	82.4	108.8	129.0	4.2	10.6
18N01E13M001M	2	1970.23	2002.79	61.1	75.5	14.4	90.0	1.9	4.7
18N01E17D001M	1	1970.21	2001.56	63.8	71.6	7.8	80.0	5.5	11.6
18N01W17G001M	1	1970.21	2010.22	50.4	79.4	29.0	137.0	13.3	14.7
18N01W22L001M	2	1970.21	2009.81	32.0	70.2	38.2	136.0	5.5	11.5

APPENDIX B

Summary of Quantitative Calibration Targets by Well

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

State Well Number	SACFEM 2013 Model Layer	Earliest Year with Measured Data	Latest Year with Measured Data	Minimum Measured Groundwater Elevation (feet NAVD88)	Maximum Measured Groundwater Elevation (feet NAVD88)	Range in Measured Groundwater Elevation (feet)	Number of Measurements	Mean Error (feet)	Root Mean Squared Error (feet)
18N01W35K001M	1	1970.19	2001.78	58.4	62.2	3.8	86.0	7.2	11.9
18N02E16F001M	1	1970.76	2010.59	74.2	79.1	4.9	138.0	4.3	7.1
18N02E32Q002M	1	1970.23	2002.79	69.3	74.8	5.5	267.0	-2.3	6.2
18N02W18D001M	6	2007.33	2010.59	77.1	81.7	4.6	17.0	4.8	5.1
18N02W18D002M	5	2007.33	2010.59	73.7	78.5	4.8	17.0	7.9	7.9
18N02W18D003M	4	2007.33	2010.59	74.3	78.6	4.3	18.0	6.7	6.8
18N02W18D004M	2	2007.33	2010.59	40.5	77.4	36.9	17.0	24.2	27.8
18N02W18K001M	2	1975.25	2010.59	-27.8	78.2	106.0	63.0	13.1	32.0
18N02W36B001M	1	1970.19	2010.59	60.5	73.2	12.7	100.0	0.8	3.3
18N03E05K001M	1	1970.22	2002.79	89.3	106.3	17.0	104.0	9.9	10.3
18N03E18F001M	5	1970.22	2010.59	86.2	98.6	12.4	139.0	-4.8	6.3
18N03E21G001M	1	1970.22	2010.59	80.5	96.9	16.4	140.0	-0.2	3.5
18N03W10L001M	1	1969.88	2010.59	89.5	95.6	6.1	222.0	1.1	3.1
18N04E16C001M	3	1970.22	2010.59	93.3	136.3	43.0	135.0	-11.3	16.5
18N04W12A001M	1	1970.21	2010.22	98.9	129.0	30.1	124.0	-7.1	12.4
18N04W23F001M	7	1970.21	2010.59	128.0	149.0	21.0	130.0	7.8	11.9
19N01E09Q001M	2	1991.66	2010.59	48.1	92.6	44.5	93.0	5.1	10.0
19N01E27Q001M	4	1978.39	2010.59	60.1	86.8	26.7	172.0	-1.3	5.0
19N01W15D001M	1	1970.21	2010.59	66.8	89.7	22.9	142.0	9.7	12.8
19N02W13J001M	1	1969.88	2010.59	73.6	88.3	14.7	223.0	6.2	7.3
19N02W29Q001M	2	1970.21	2010.59	77.5	92.4	14.9	130.0	-2.5	4.3
19N02W36H001M	1	1970.21	2010.59	70.6	83.9	13.3	130.0	-1.1	3.9
19N03W26P001M	3	1974.19	2010.59	91.6	102.3	10.7	122.0	-3.1	4.7
19N04W12E001M	4	1969.88	2010.59	63.5	170.0	106.5	355.0	-5.6	25.6
20N01E10C002M	2	1973.26	2010.59	70.3	126.8	56.5	130.0	0.0	9.2
20N01E18L001M	6	2000.12	2010.59	99.8	113.8	13.9	102.0	-3.8	4.3
20N01E18L002M	5	2001.89	2010.59	100.8	108.0	7.1	75.0	-2.1	2.9
20N01E18L003M	2	2001.89	2010.59	103.5	108.1	4.5	74.0	-3.1	3.7
20N01E35C001M	1	1970.23	2010.59	93.8	101.0	7.2	137.0	4.2	4.6
20N02E06Q001M	4	1970.23	2010.59	97.6	134.3	36.7	141.0	6.7	8.9

APPENDIX B

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

State Well Number	SACFEM 2013 Model Layer	Earliest Year with Measured Data	Latest Year with Measured Data	Minimum Measured Groundwater Elevation (feet NAVD88)	Maximum Measured Groundwater Elevation (feet NAVD88)	Range in Measured Groundwater Elevation (feet)	Number of Measurements	Mean Error (feet)	Root Mean Squared Error (feet)
20N02E07H001M	3	1990.84	1997.84	91.1	128.7	37.6	99.0	4.6	6.2
20N02E24C001M	2	2000.01	2010.59	105.8	130.6	24.8	81.0	15.5	16.0
20N02E24C002M	5	2000.01	2010.59	105.9	130.6	24.7	84.0	16.2	16.6
20N02E24C003M	7	2000.01	2010.59	105.6	130.7	25.1	85.0	18.1	18.5
20N02E28N001M	1	1969.89	2010.59	112.8	121.6	8.8	400.0	-5.4	7.0
20N02W02J001M	1	1970.21	2010.59	114.8	125.6	10.8	131.0	1.5	3.9
20N02W11A001M	1	1976.88	2010.59	110.4	124.6	14.2	633.0	-1.7	4.5
20N02W11A002M	2	1978.24	2010.59	91.2	121.4	30.2	313.0	0.2	4.2
20N02W11A003M	4	1978.24	2010.59	75.1	123.1	48.0	320.0	3.7	6.5
20N02W29G001M	1	1969.88	2010.59	110.4	116.7	6.3	161.0	-2.3	4.5
21N01E05G001M	2	1969.98	1997.56	113.5	144.9	31.4	116.0	-3.3	4.3
21N01E12K001M	4	1970.23	2010.52	81.1	165.2	84.1	108.0	15.7	21.7
21N01E27D001M	1	1970.23	2010.59	87.0	132.1	45.2	169.0	0.1	9.1
21N01W04N001M	1	1970.21	2010.59	106.6	129.2	22.6	152.0	9.1	9.6
21N01W23J001M	1	1970.23	2010.59	104.2	120.2	16.0	168.0	0.5	3.1
21N01W24B001M	6	1995.29	2010.59	96.0	127.4	31.4	122.0	1.0	4.9
21N02E26F001M	7	1970.23	2008.19	102.0	146.7	44.7	119.0	27.0	29.9
21N02W05M001M	4	2002.41	2010.59	117.3	167.8	50.5	95.0	-3.6	6.4
21N02W05M002M	2	2002.41	2010.59	133.5	181.1	47.6	96.0	-11.8	13.3
21N02W05M004M	1	2002.41	2006.89	159.1	178.4	19.3	63.0	-12.1	12.6
21N02W09M002M	2	1970.21	2010.23	118.3	172.0	53.7	128.0	-8.7	12.8
21N02W23G001M	2	1970.21	2010.59	107.4	147.9	40.5	149.0	-5.5	7.9
21N02W31M001M	2	1970.21	2010.23	94.7	155.5	60.8	126.0	-8.4	13.4
21N03W31R002M	3	1969.81	2008.19	68.2	166.1	97.9	488.0	30.0	40.2
21N03W31R004M	2	1969.81	2008.19	76.3	166.9	90.6	480.0	32.3	42.6
21N03W31R005M	1	1969.81	2008.19	92.4	166.0	73.6	482.0	30.3	39.4
21N03W33A004M	5	1970.21	2010.27	99.3	169.0	69.7	75.0	9.3	22.0
22N01E09J002M	1	1970.23	2002.79	133.8	165.4	31.6	91.0	-1.8	13.8
22N01E20K001M	1	1969.89	2010.59	112.5	154.9	42.4	229.0	-3.2	9.4
22N01E28J001M	6	1972.24	2010.59	115.0	162.2	47.2	326.0	-1.5	10.5

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

State Well Number	SACFEM 2013 Model Layer	Earliest Year with Measured Data	Latest Year with Measured Data	Minimum Measured Groundwater Elevation (feet NAVD88)	Maximum Measured Groundwater Elevation (feet NAVD88)	Range in Measured Groundwater Elevation (feet)	Number of Measurements	Mean Error (feet)	Root Mean Squared Error (feet)
22N01E28J003M	3	1971.99	2010.59	122.1	164.4	42.3	329.0	-2.8	7.5
22N01E28J005M	7	1971.99	2010.59	116.1	160.2	44.1	330.0	3.7	12.0
22N01E29R001M	6	1970.23	2010.59	106.5	156.4	49.9	137.0	-5.4	10.3
22N01E33N001M	1	1994.28	1997.54	121.4	150.5	29.1	19.0	-0.5	10.1
22N01E33N002M	3	1994.28	1997.54	105.8	143.4	37.6	19.0	2.6	4.8
22N01W05M001M	2	1970.23	2010.59	115.4	148.3	32.9	117.0	3.4	6.4
22N02E17E001M	6	1971.19	2003.57	138.5	256.0	117.5	140.0	57.1	60.4
22N02W08B002M	2	1969.88	2010.59	117.1	201.6	84.5	211.0	9.4	17.5
22N02W20Q001M	1	1973.8	2010.59	165.4	198.2	32.8	146.0	-8.0	9.4
22N02W21D001M	1	1970.21	2010.59	145.8	191.2	45.4	122.0	3.3	8.7
22N02W30H002M	6	2004.39	2010.59	86.3	140.8	54.5	48.0	46.7	48.3
22N02W30H003M	2	2004.39	2010.59	144.5	193.1	48.6	47.0	0.3	8.9
22N02W30H004M	1	2004.39	2010.59	183.5	195.5	12.0	46.0	-11.2	11.4
22N02W36D001M	2	1970.21	2010.59	128.3	162.0	33.7	150.0	-2.8	6.2
22N03W21F002M	2	1977.49	2010.59	223.1	253.9	30.8	321.0	-19.2	20.2
23N01E29P001M	1	1969.89	1990.18	141.3	192.0	50.7	129.0	-12.7	19.7
23N01E29P002M	2	1991.18	2010.59	129.8	164.9	35.1	97.0	33.9	35.2
23N01W09E001M	1	1970.23	2010.59	131.9	170.1	38.2	293.0	20.0	21.7
23N01W14R002M	2	1986.17	2010.59	137.9	171.1	33.2	116.0	26.6	27.3
23N02W16B001M	2	1970.22	2010.22	114.5	170.8	56.3	93.0	31.9	33.5
24N02W12P001M	3	1999.99	2010.59	194.4	202.9	8.6	62.0	13.1	13.6
24N02W12P002M	6	1999.99	2010.59	194.6	202.9	8.3	62.0	21.5	21.6
24N02W30P002M	3	1993.21	2010.22	111.9	196.0	84.1	56.0	33.9	38.1
24N03W17M001M	1	1973.18	2010.59	236.0	286.4	50.4	144.0	5.4	11.3
25N02W09G001M	1	1973.19	2010.59	219.0	234.4	15.4	176.0	6.9	7.7
25N03W10L003M	4	1969.89	2010.59	179.7	248.5	68.8	344.0	19.6	23.1
25N03W10L004M	2	1969.89	2010.59	236.6	269.1	32.5	321.0	-10.8	12.0
27N03W10B001M	1	1970.55	2010.59	243.1	269.3	26.2	331.0	6.5	7.1
27N03W20K001M	2	1969.84	1975.25	249.6	257.4	7.8	34.0	7.0	7.5
27N04W35E001M	2	1970.23	2010.59	297.3	337.7	40.4	133.0	-21.9	23.9

Appendix C
Simulated and Measured Groundwater Hydrographs

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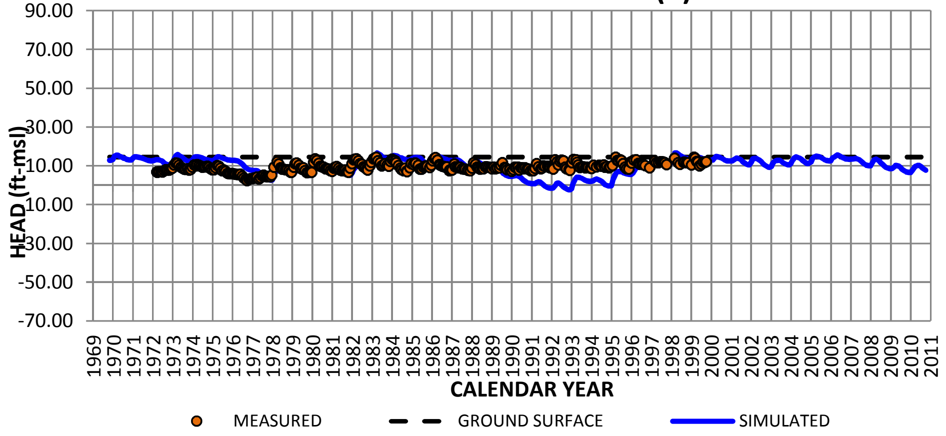

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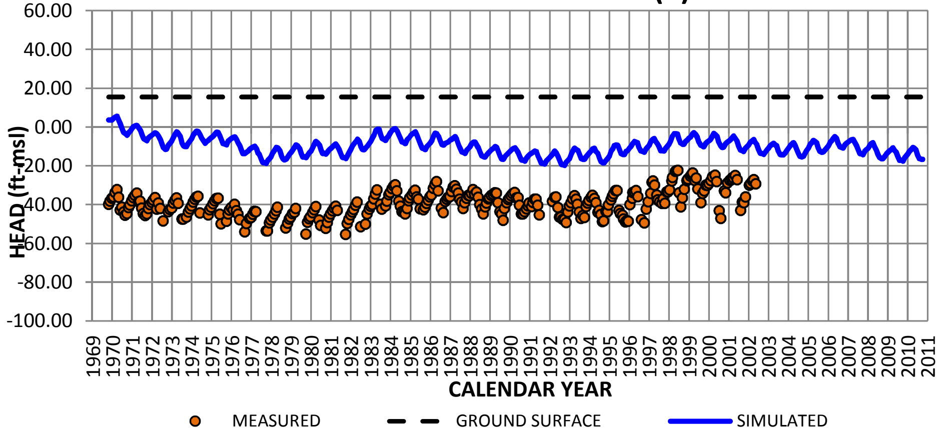

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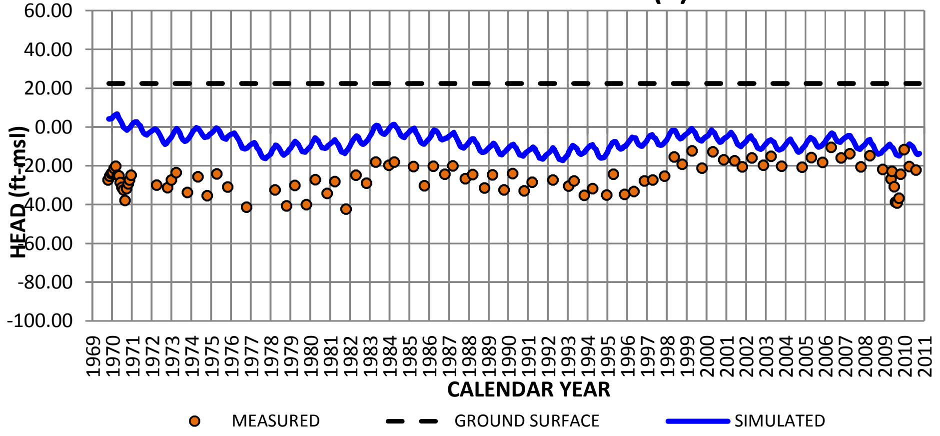

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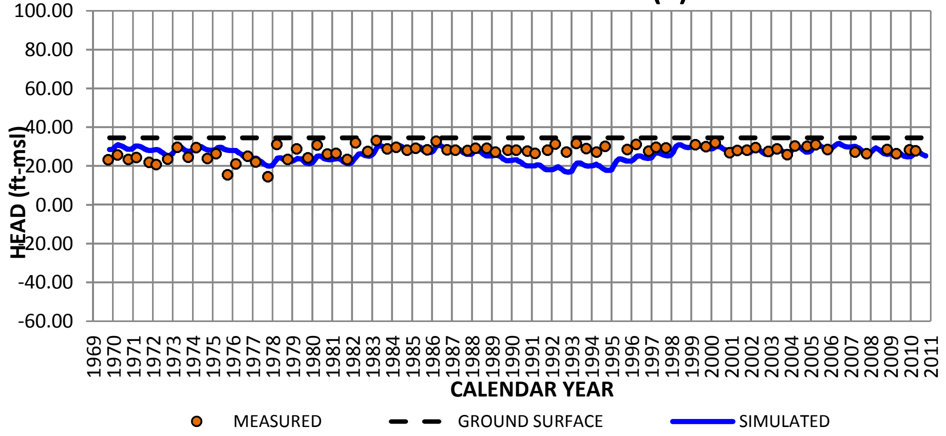

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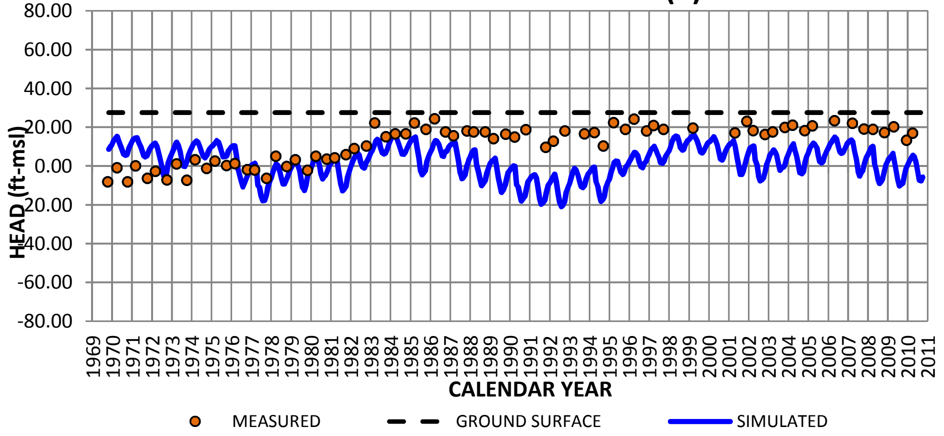

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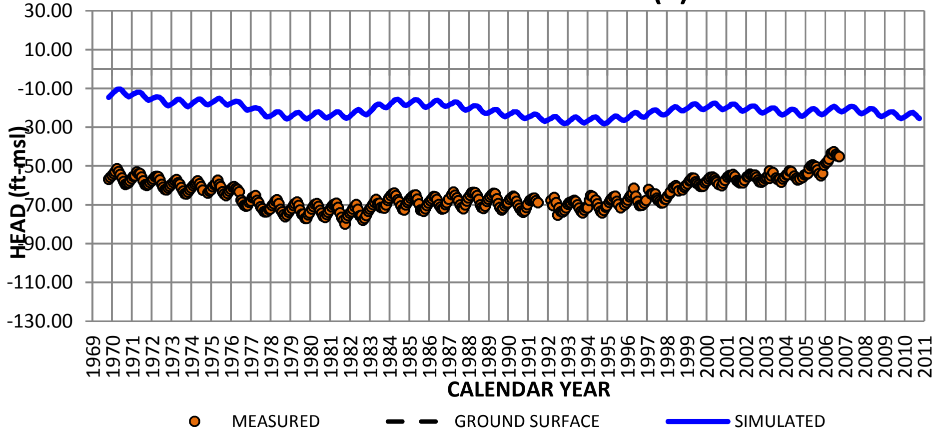

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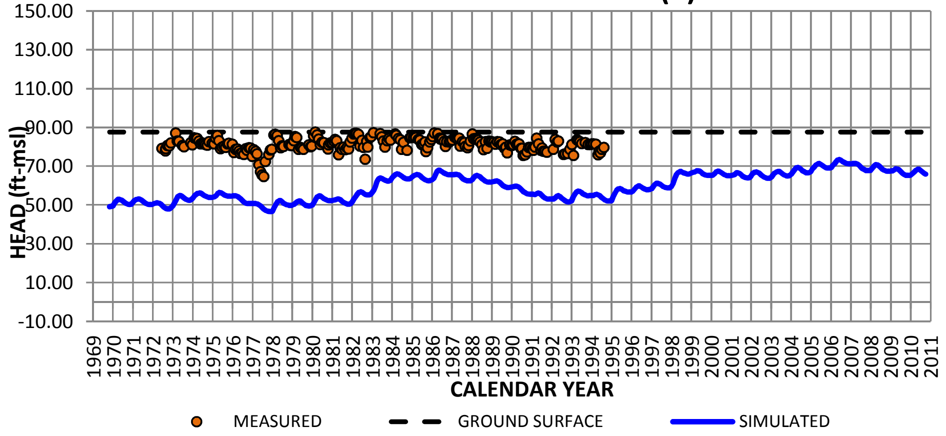

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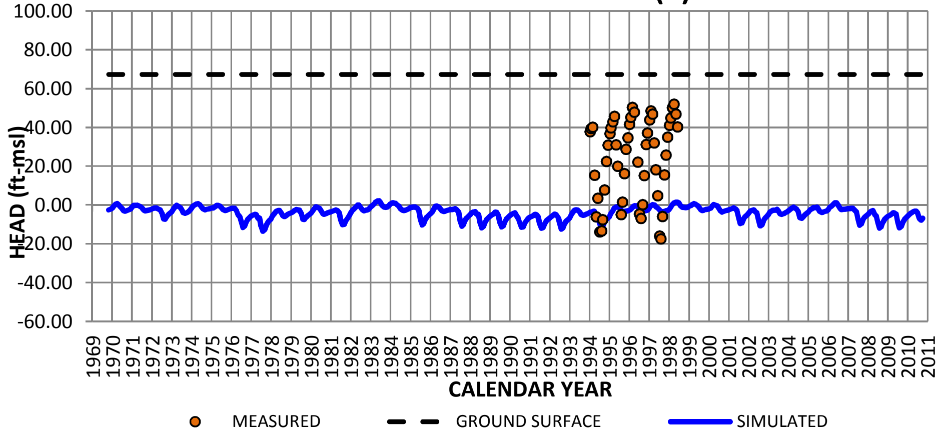

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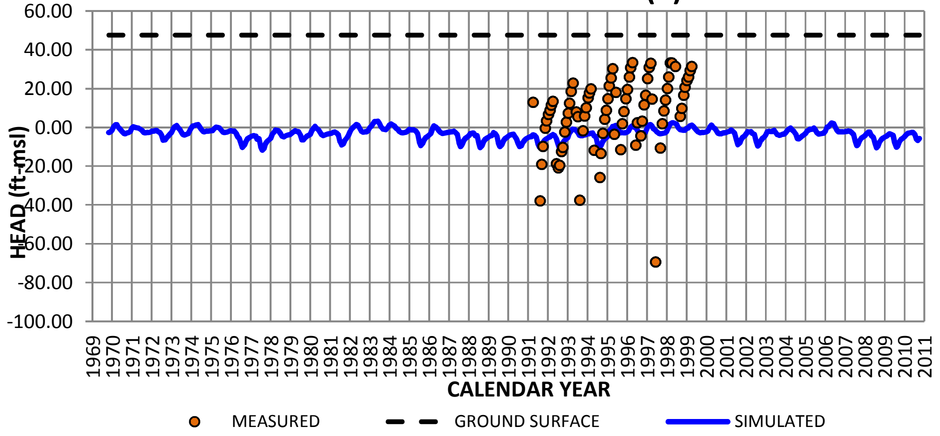

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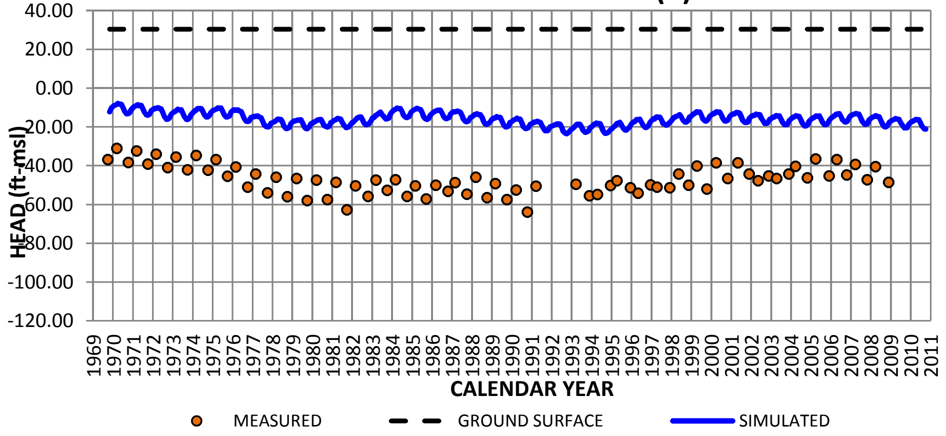

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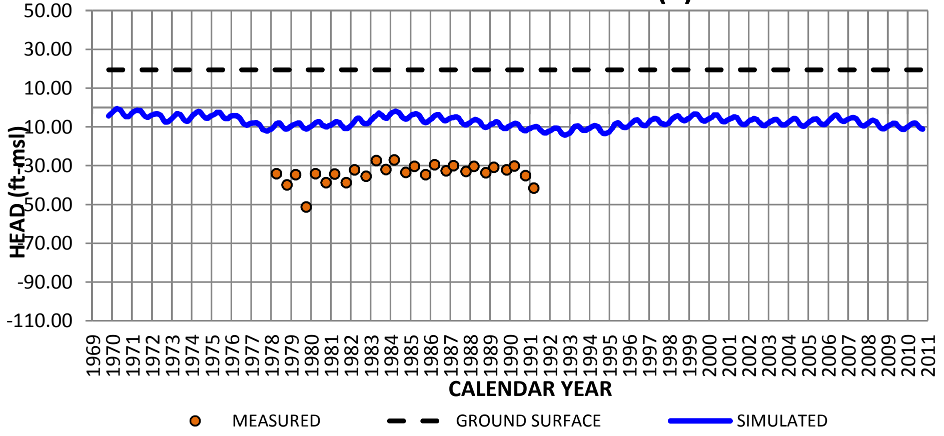

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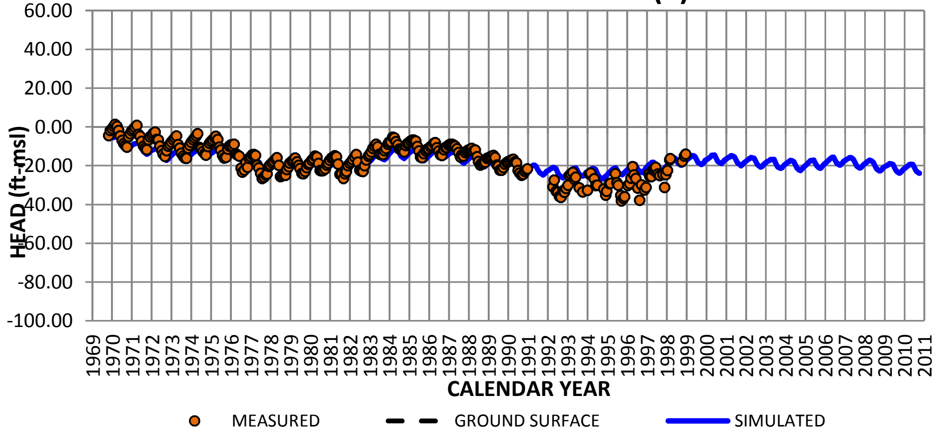

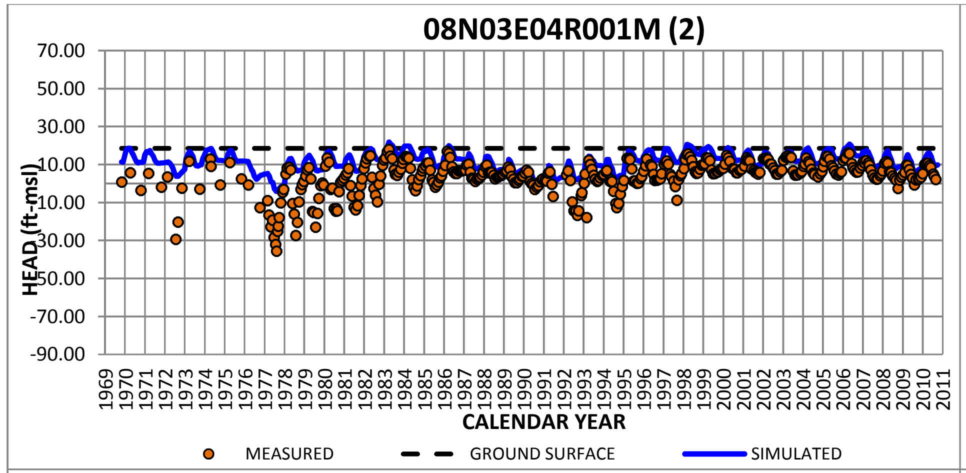
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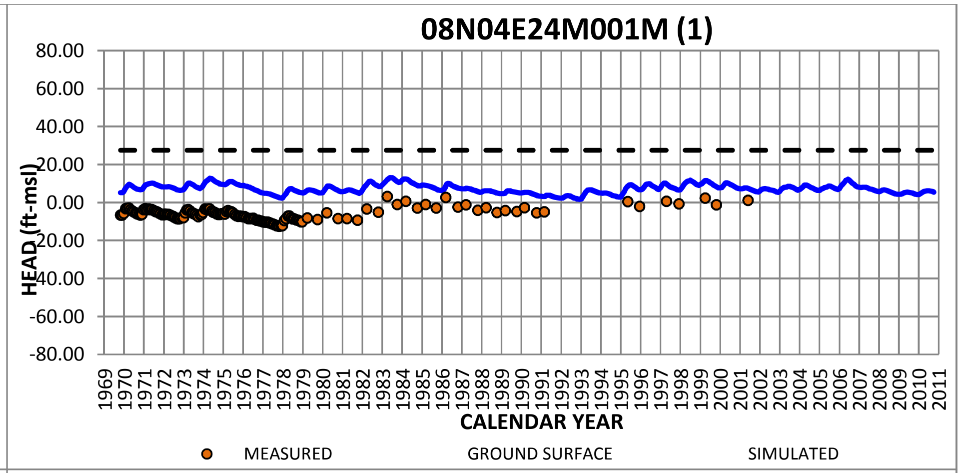
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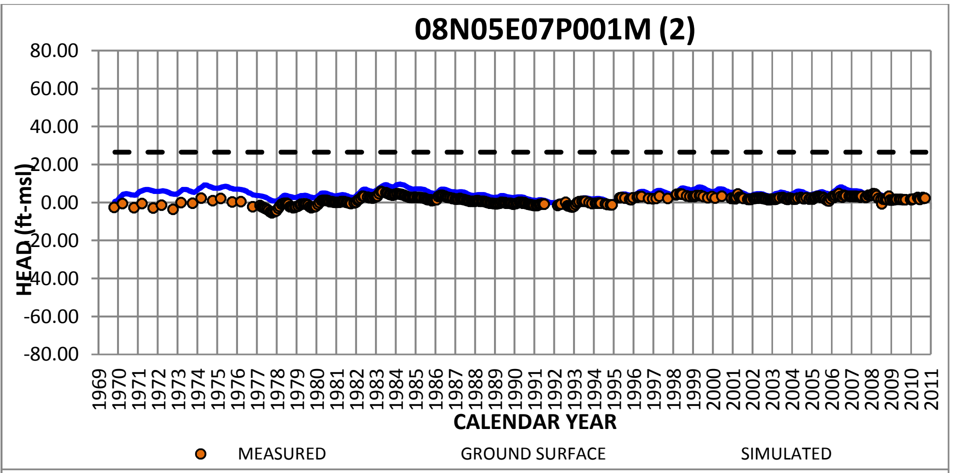
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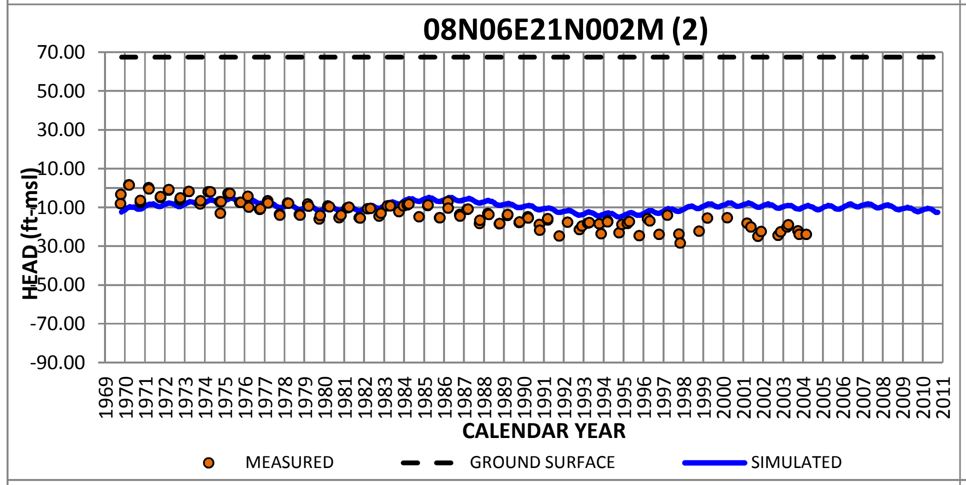
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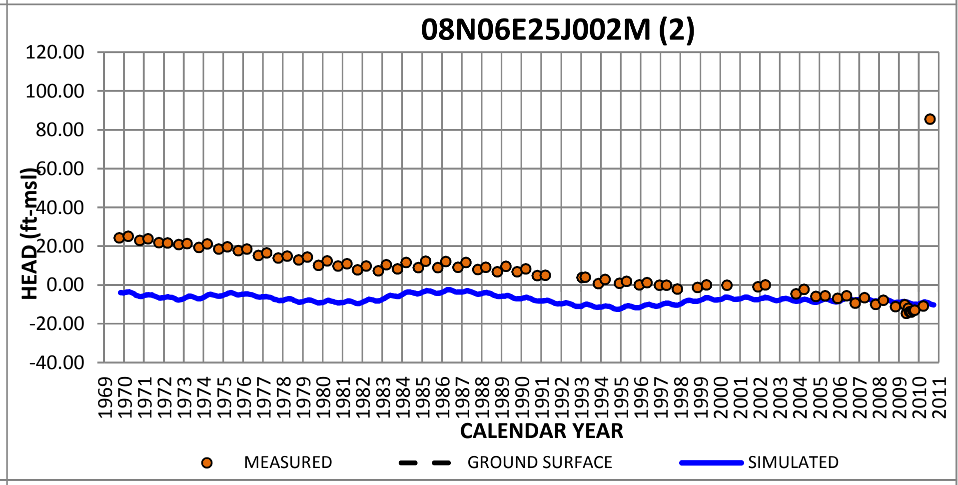
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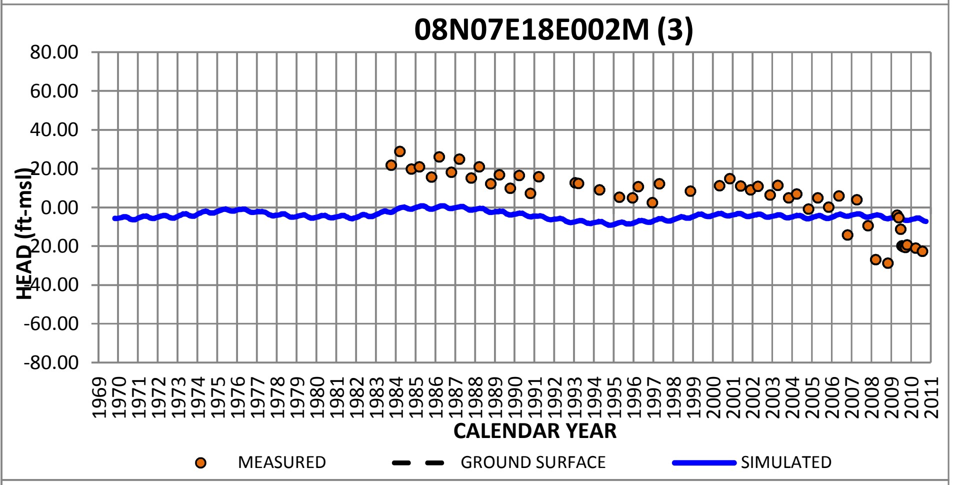
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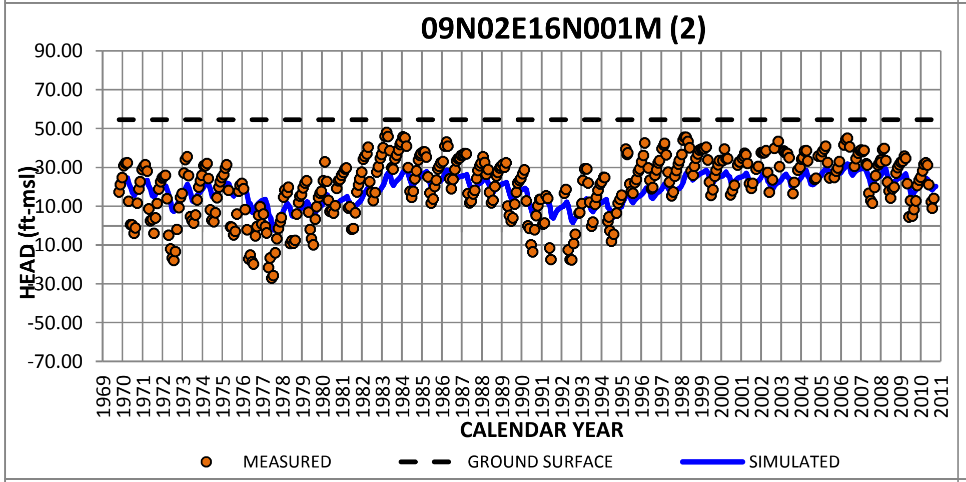
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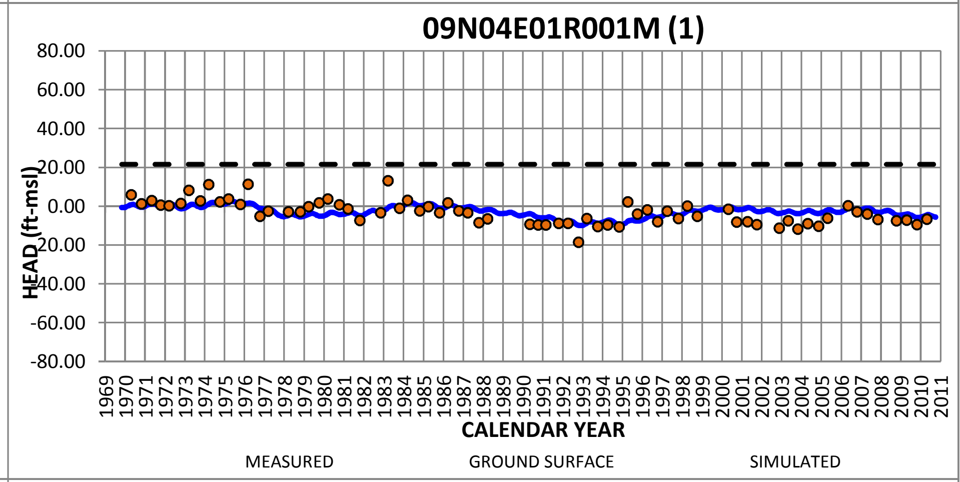
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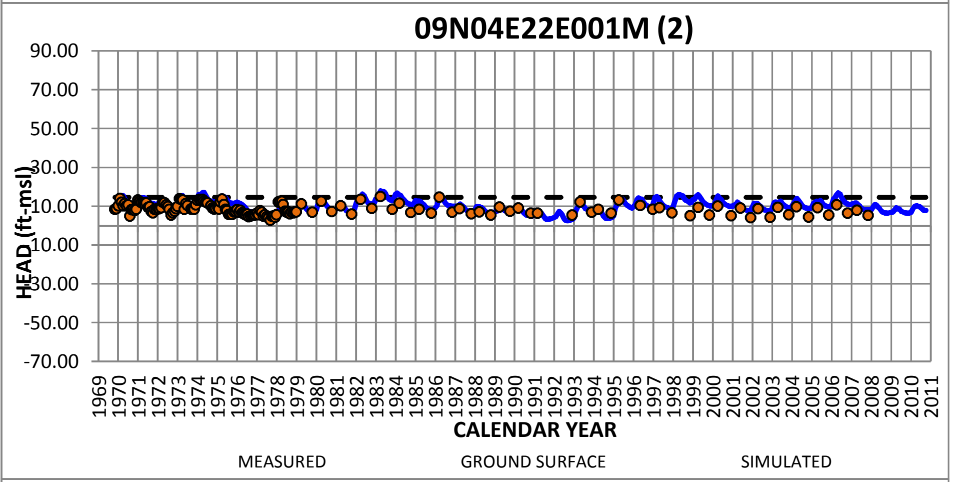
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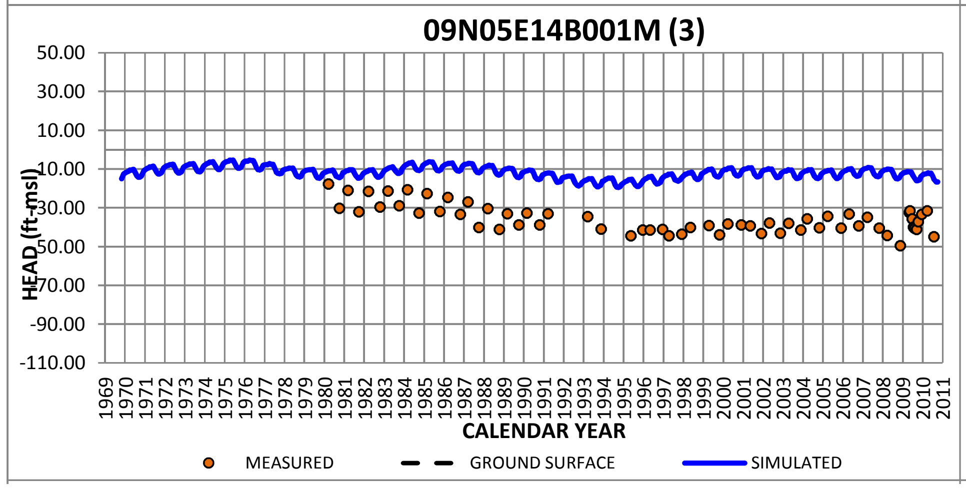
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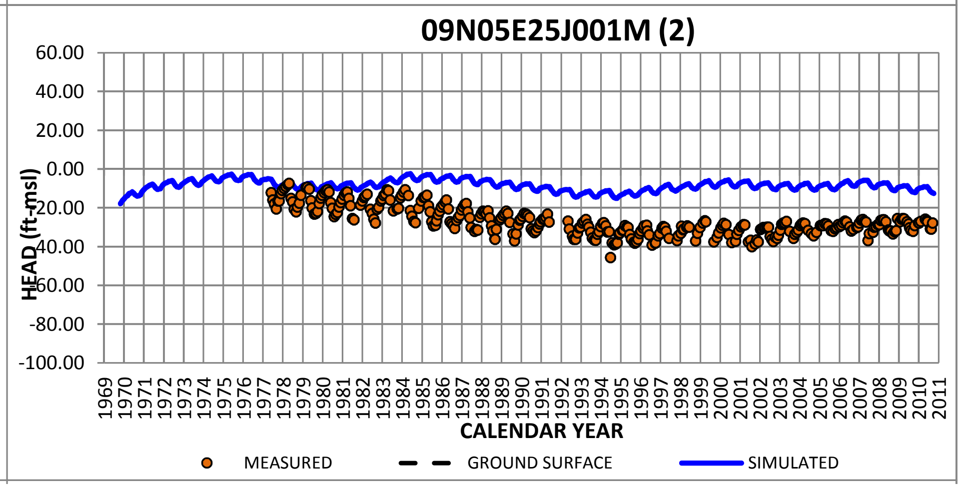
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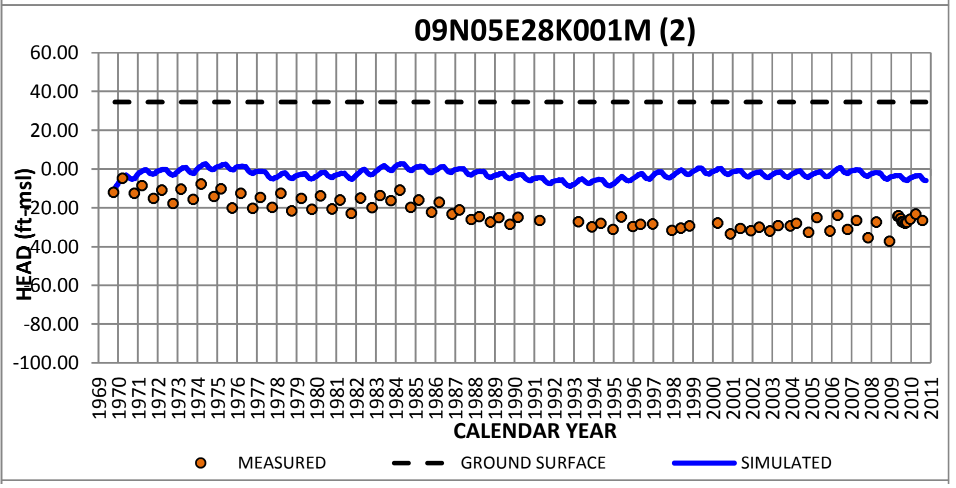
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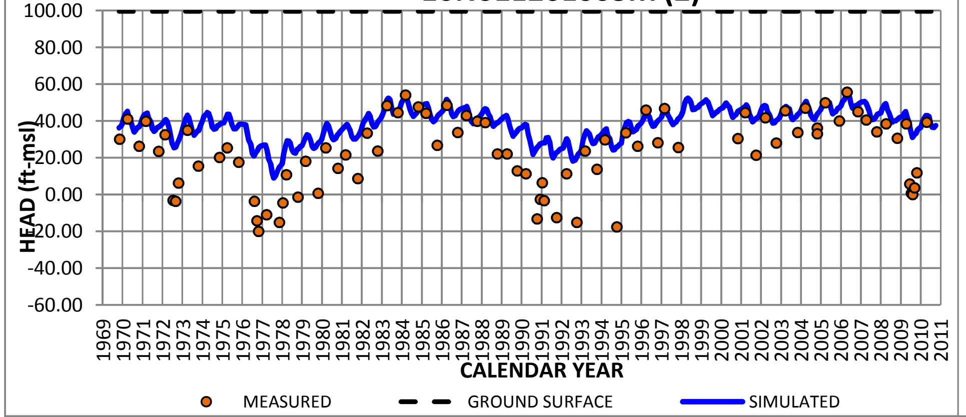

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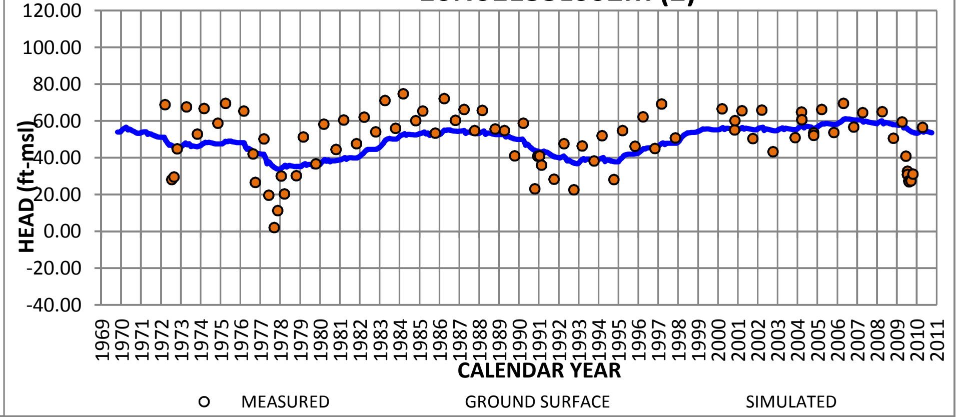

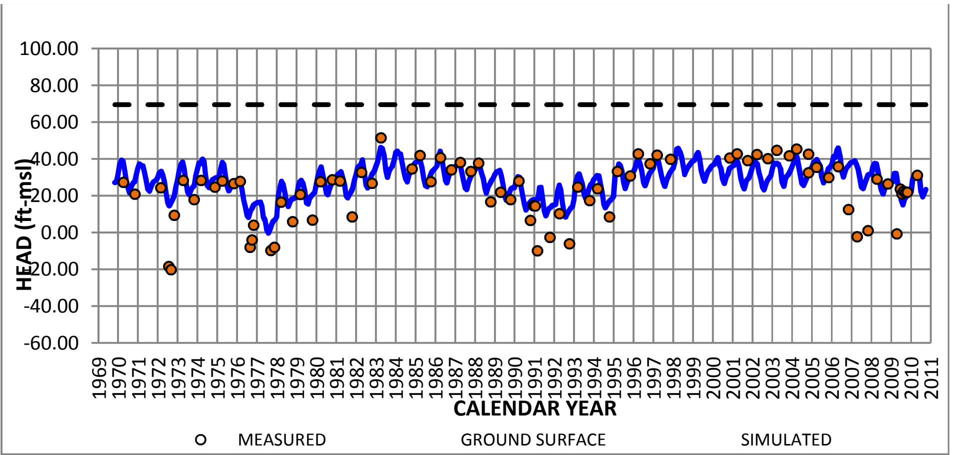

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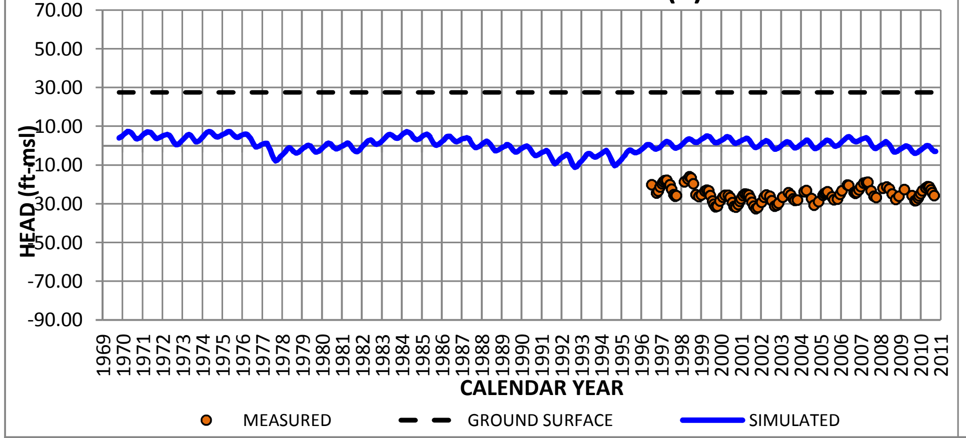

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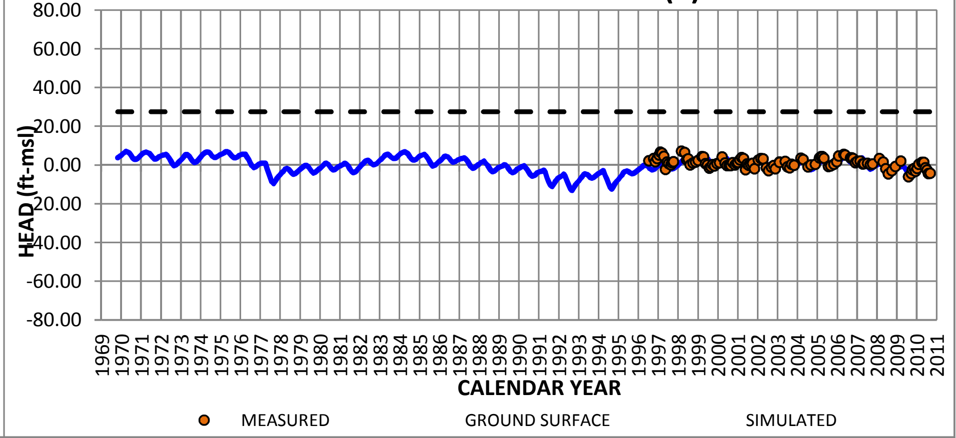

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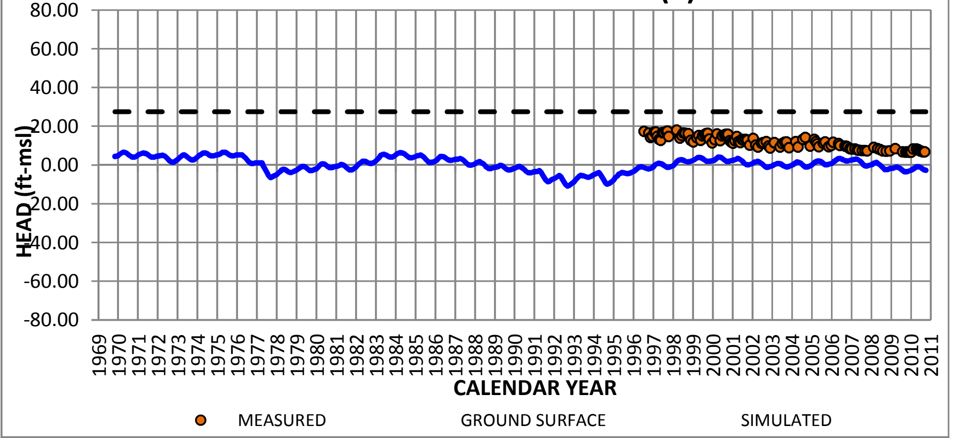

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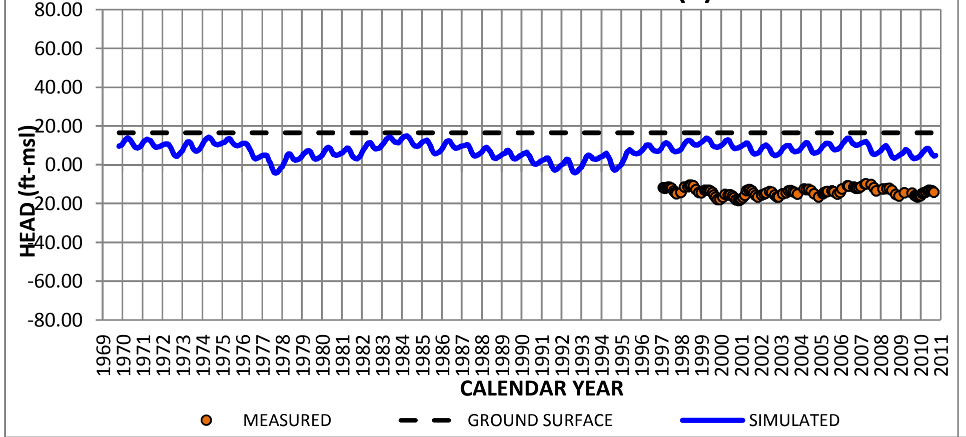

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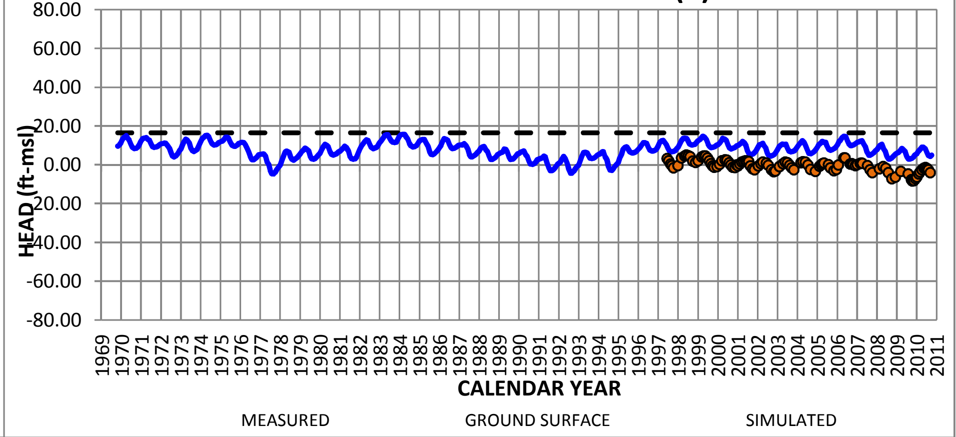

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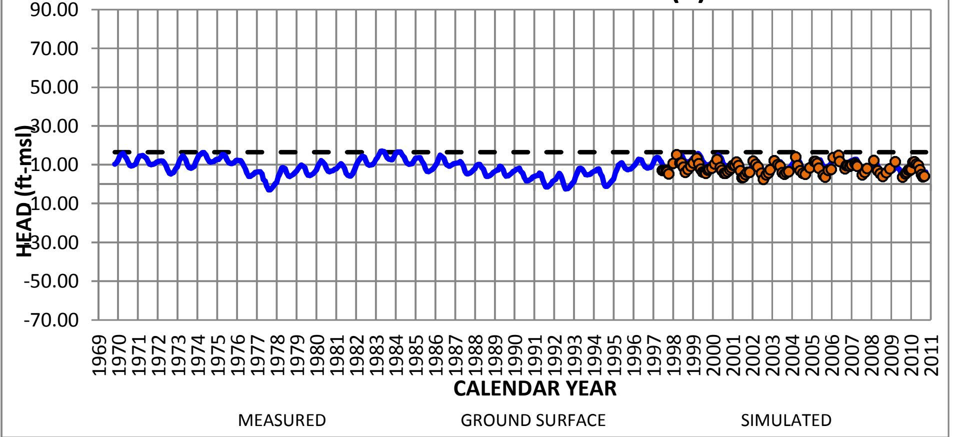

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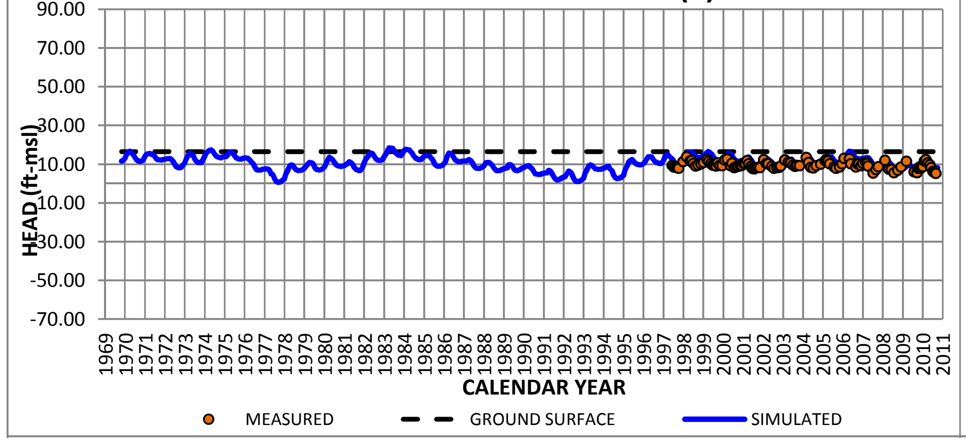

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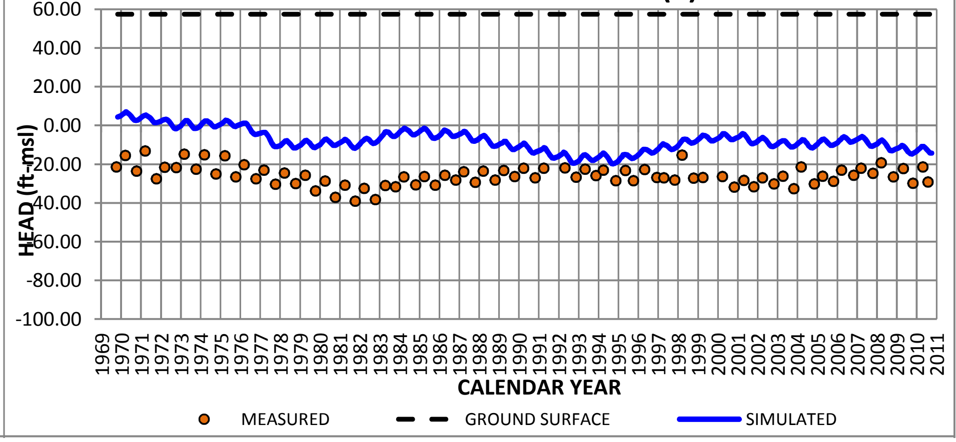

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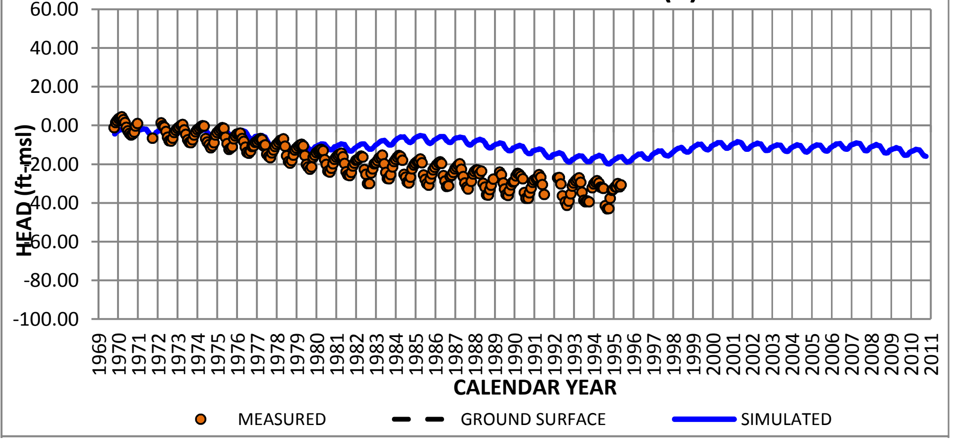

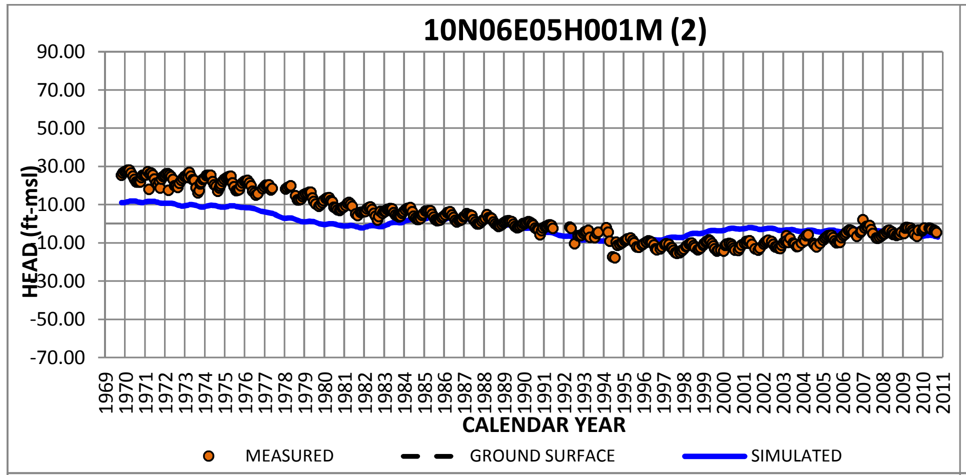
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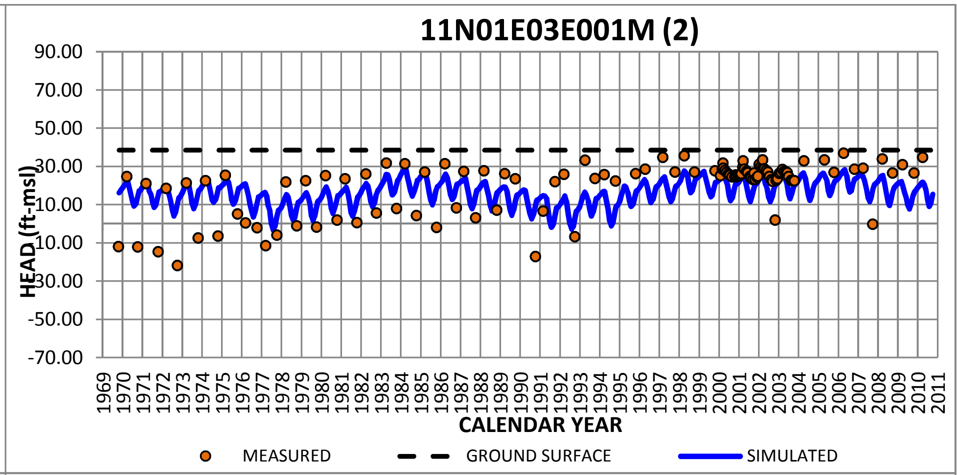
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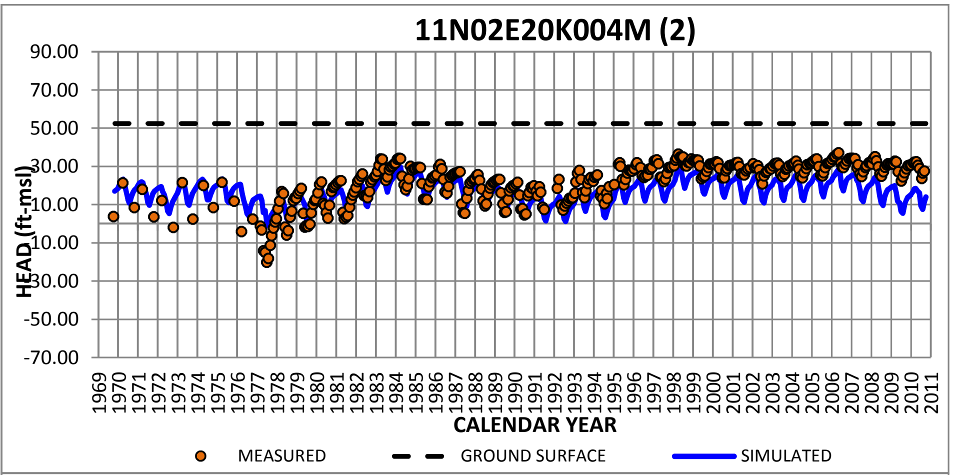
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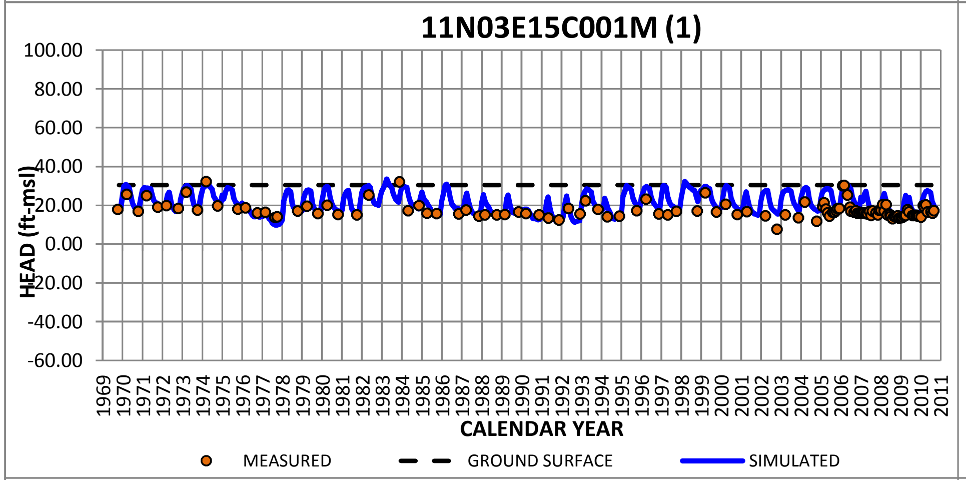
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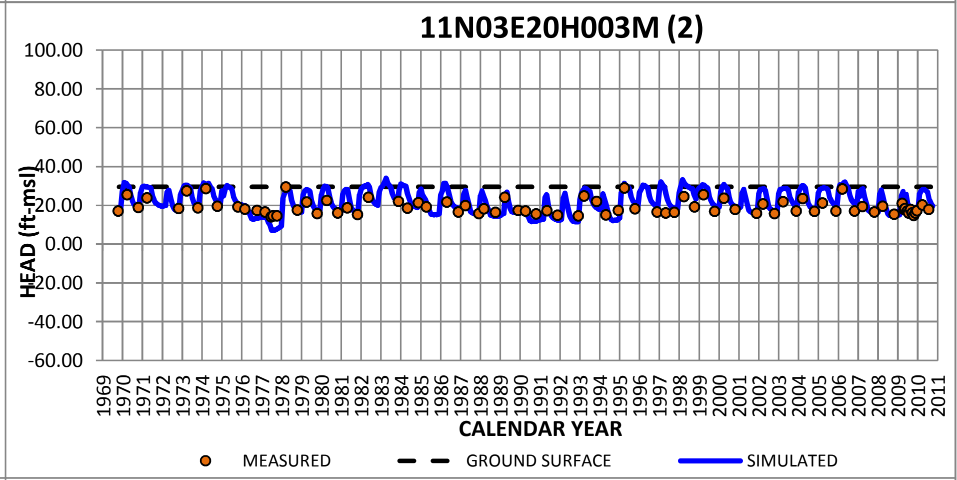
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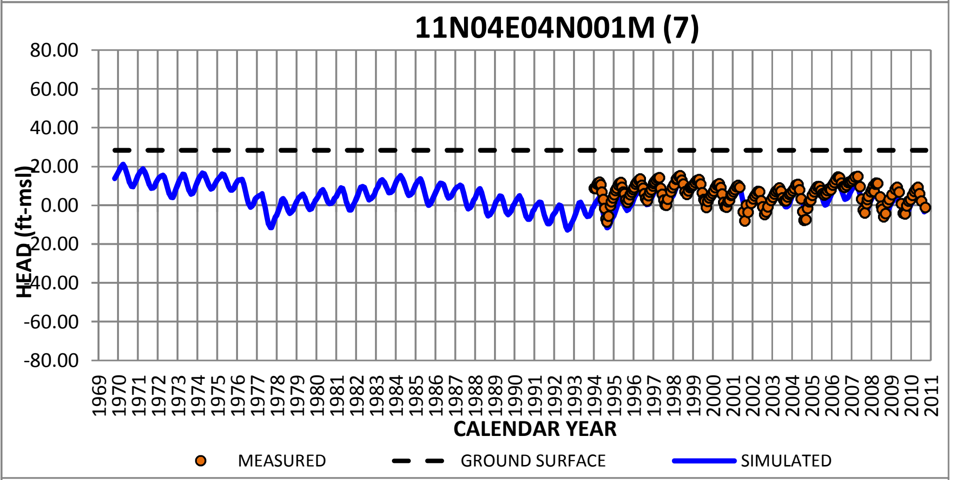
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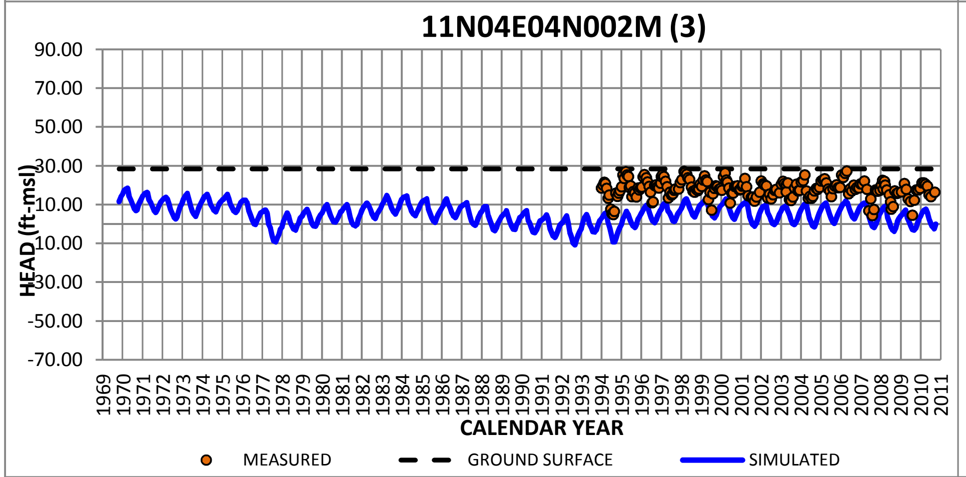
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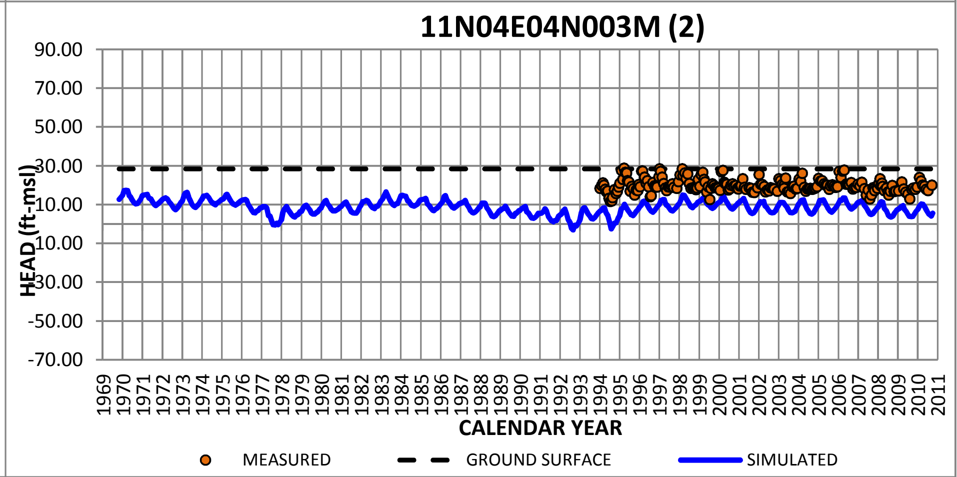
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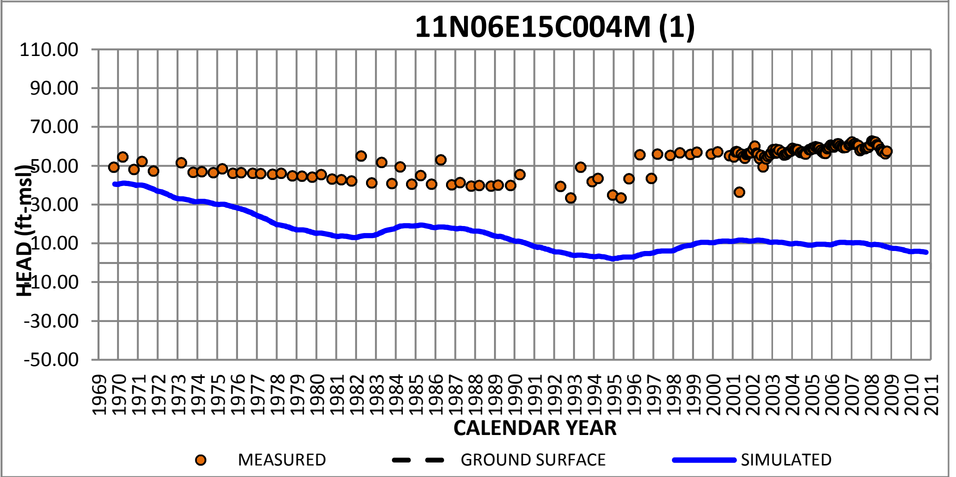
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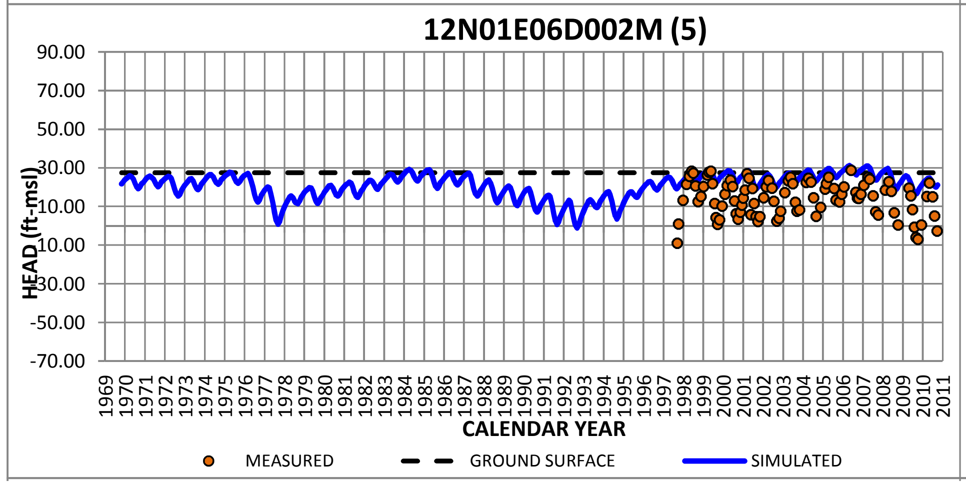
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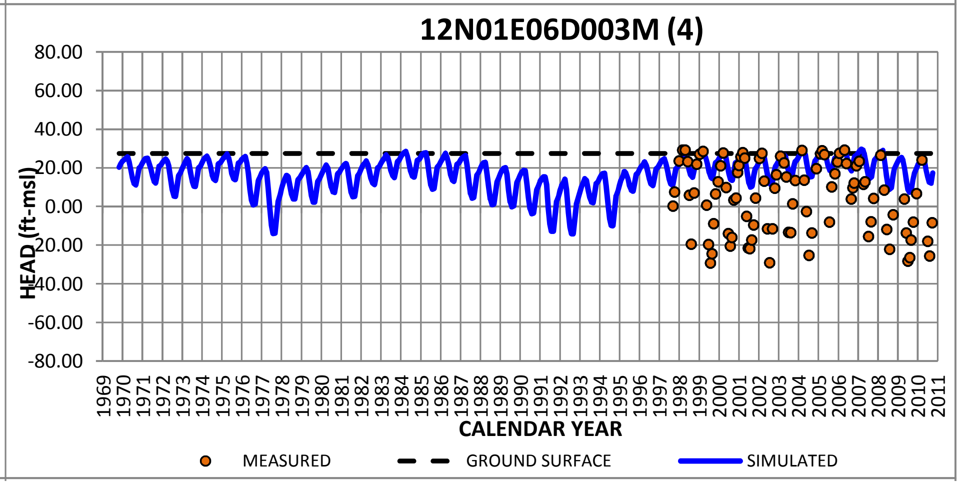
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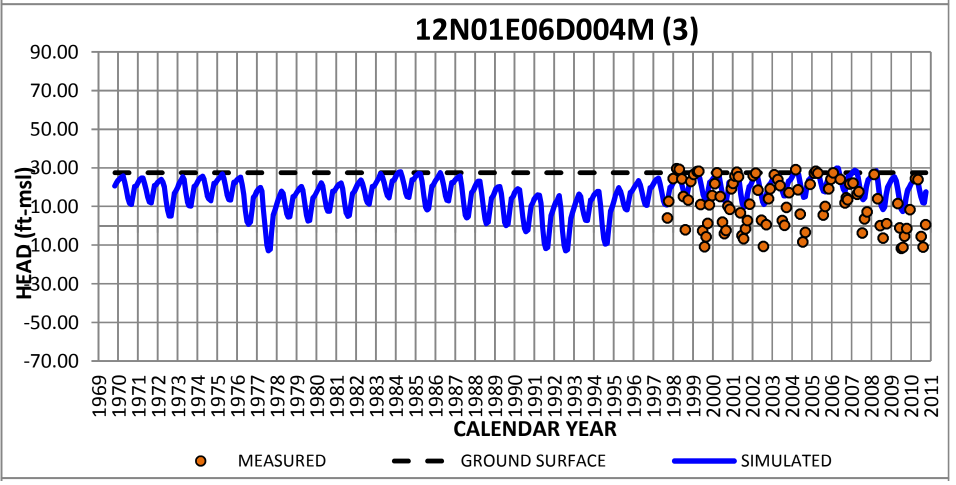
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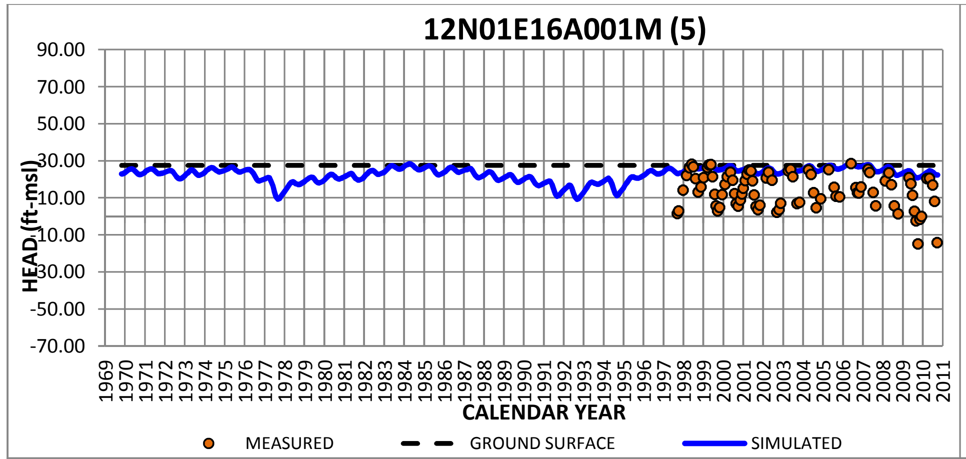
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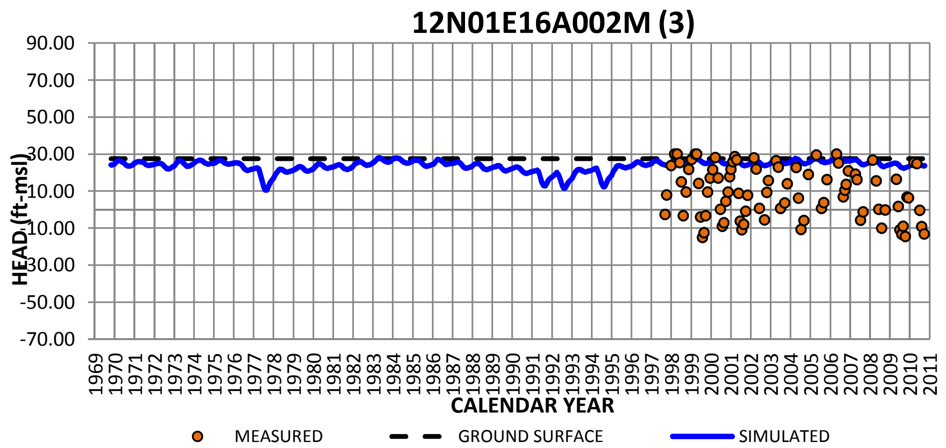
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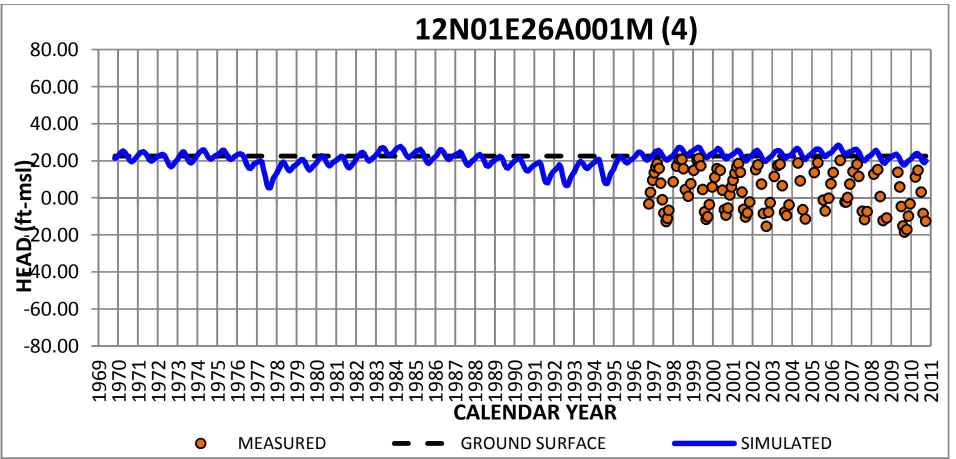
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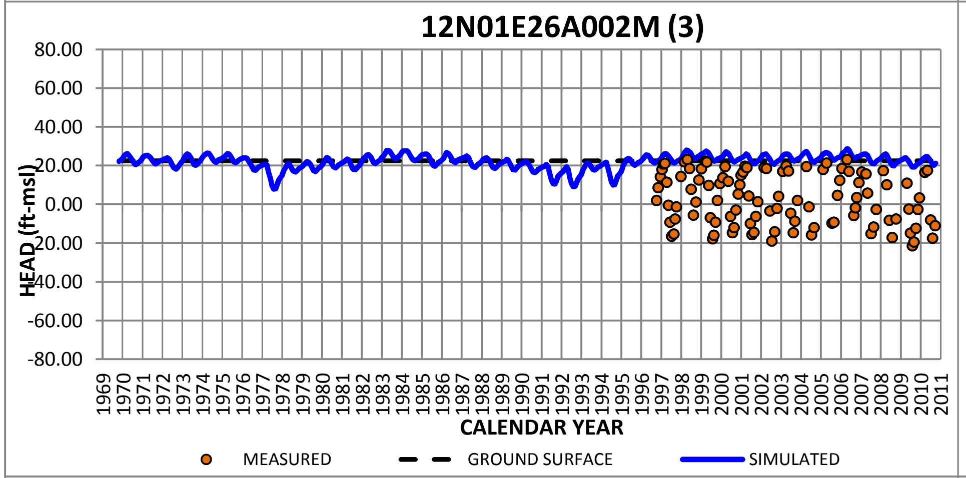
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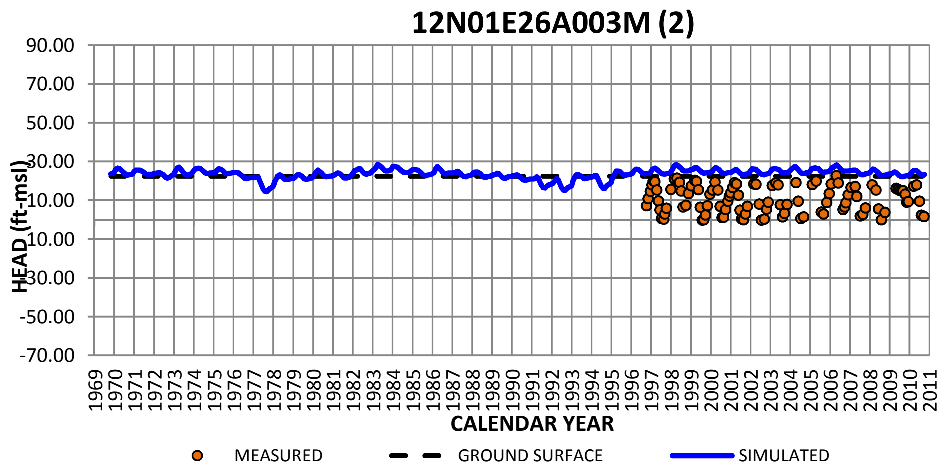
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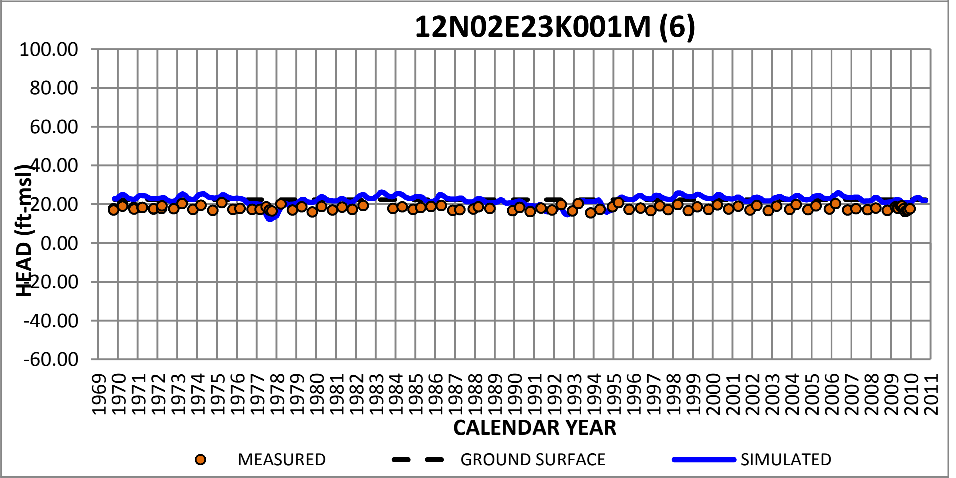
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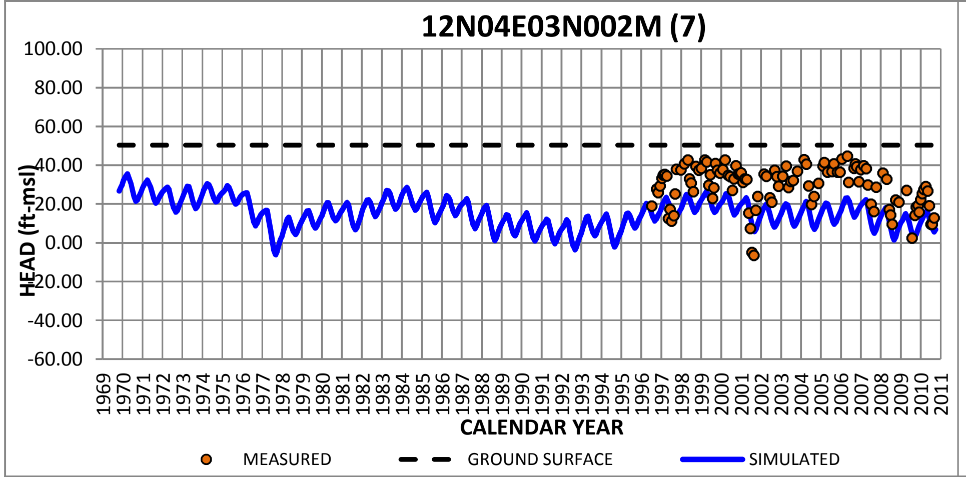
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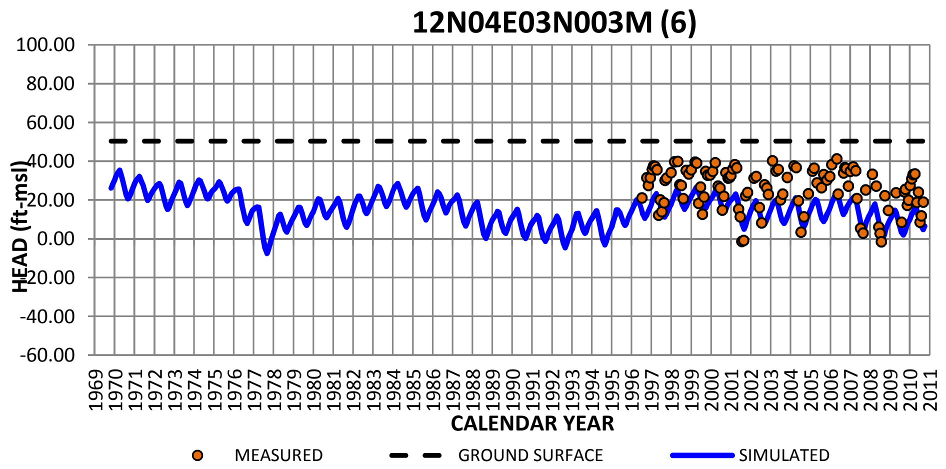
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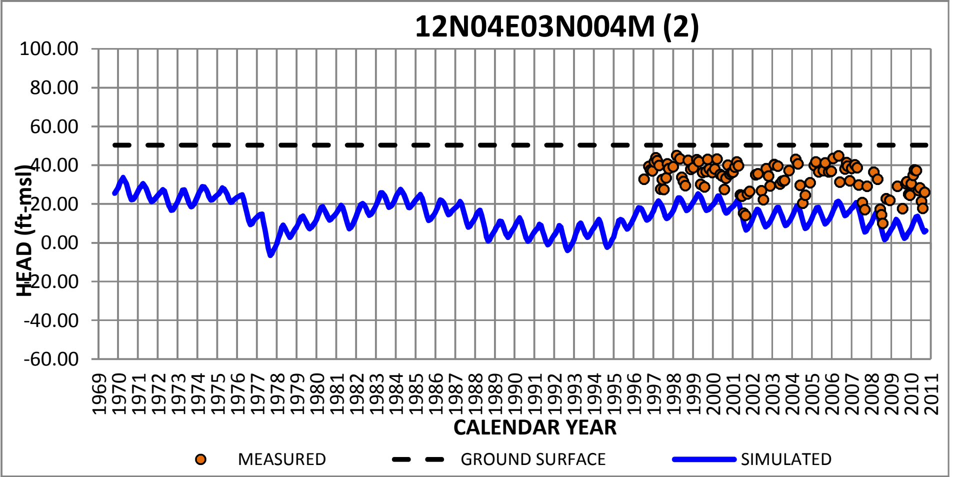
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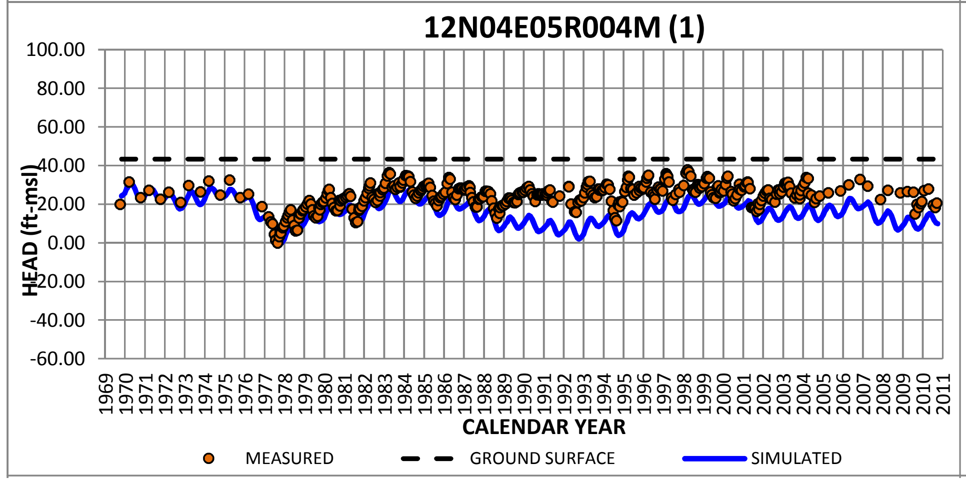
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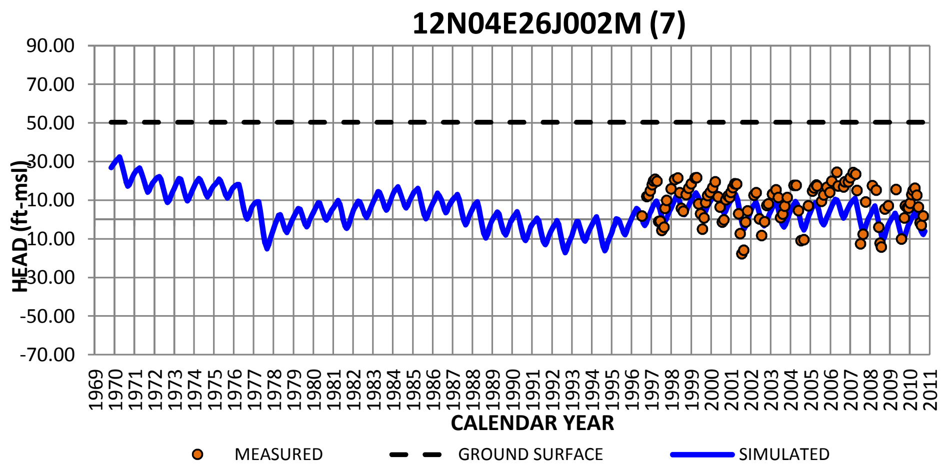
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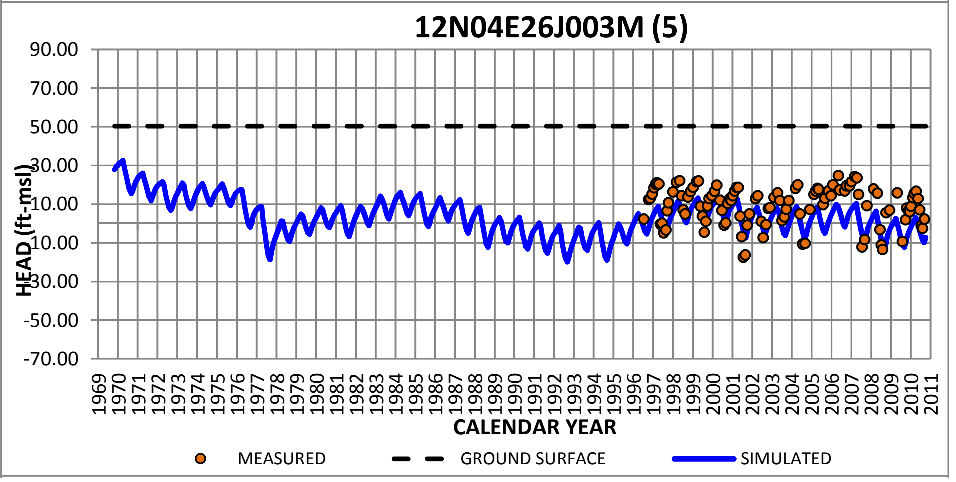
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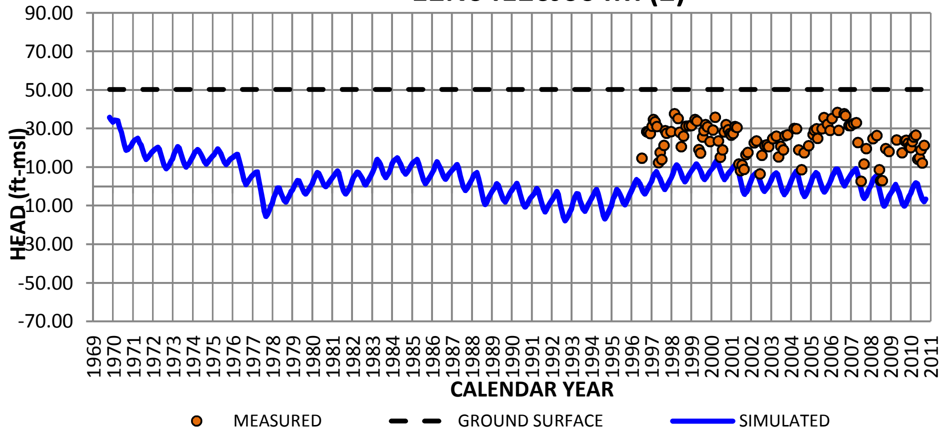

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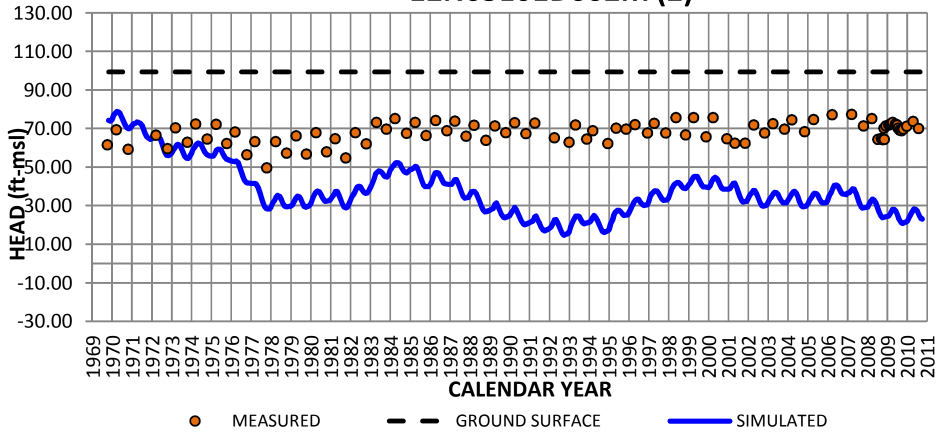

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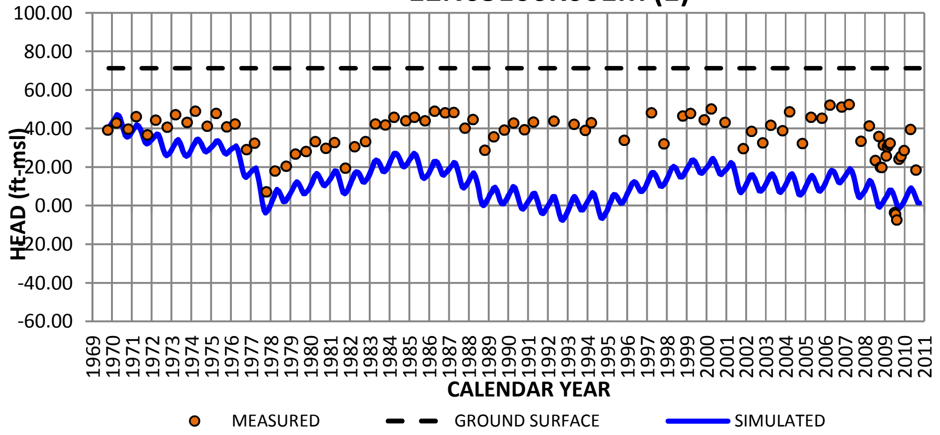

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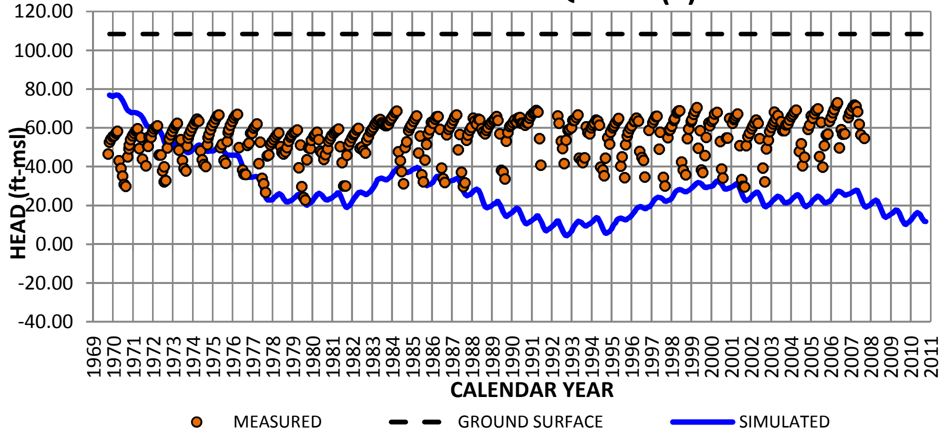

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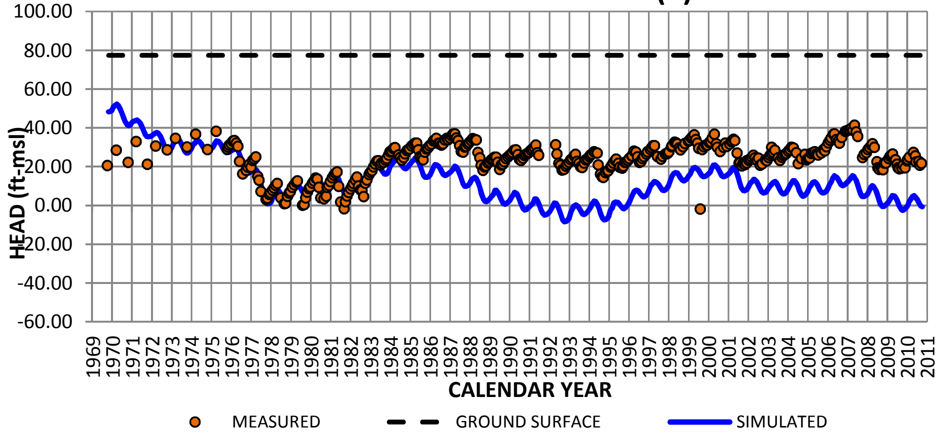

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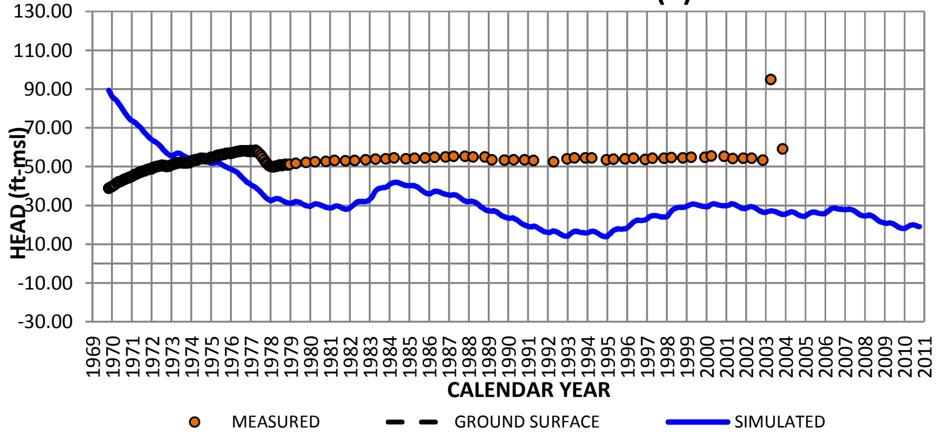

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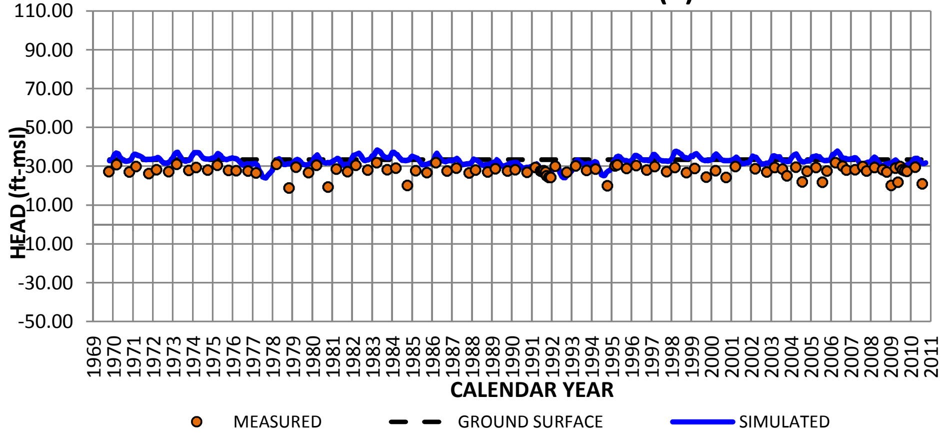

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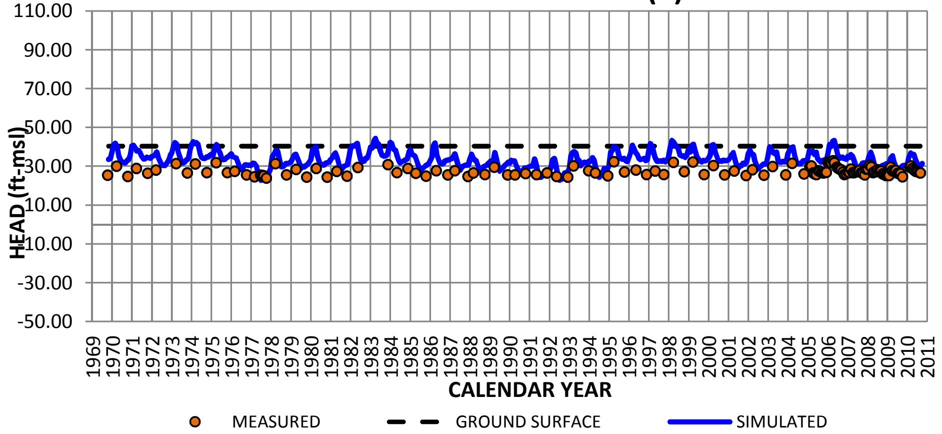

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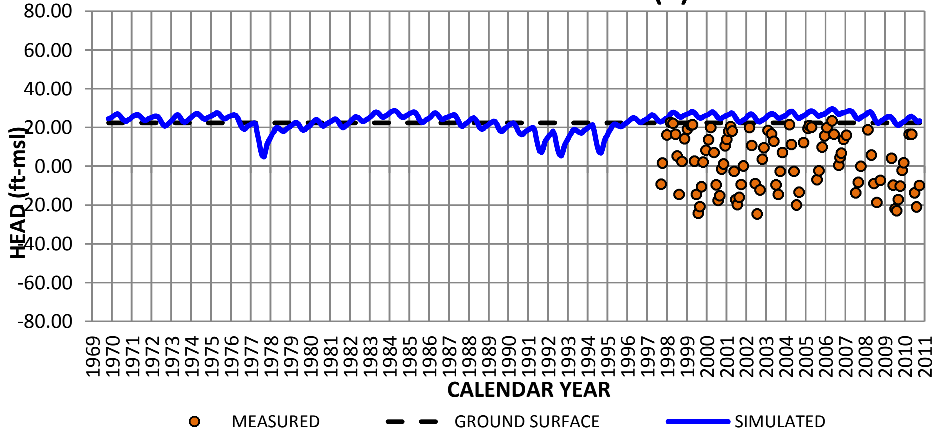

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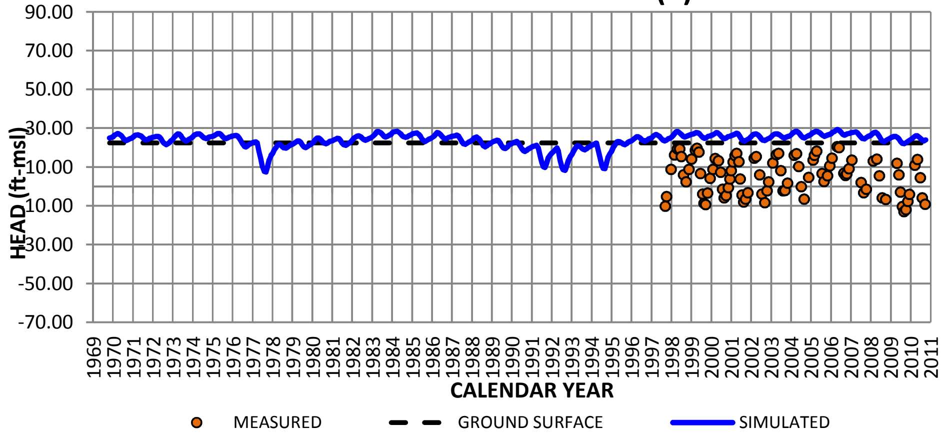

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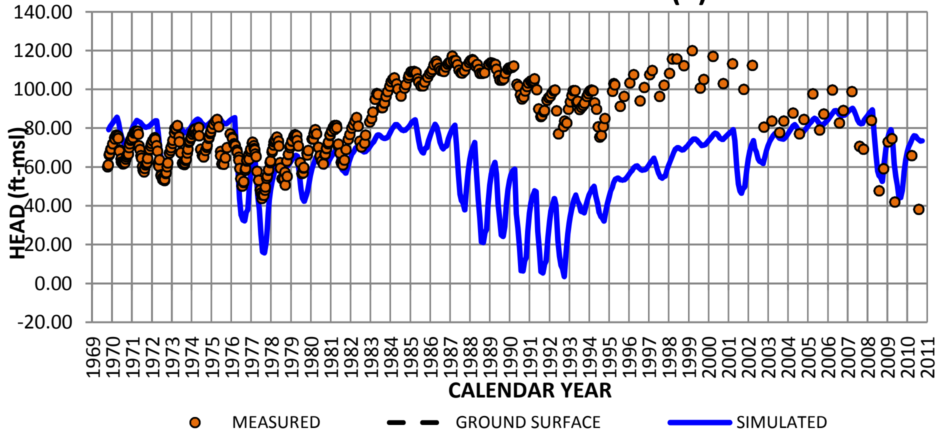

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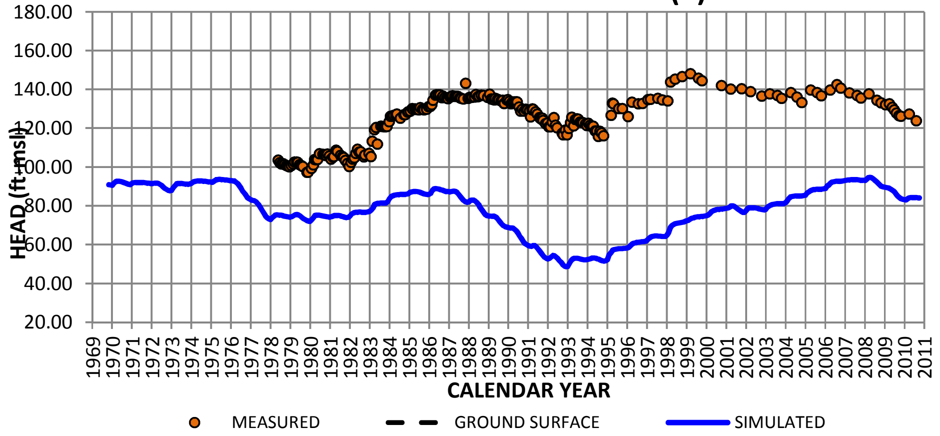

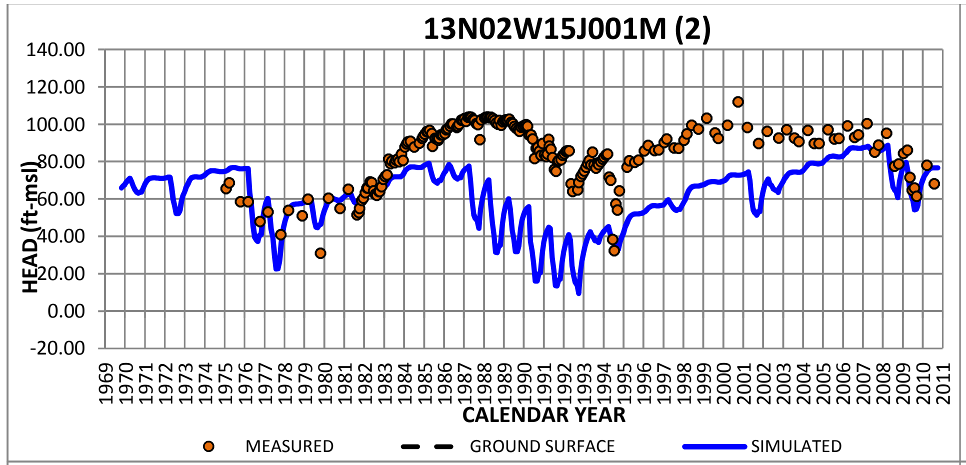
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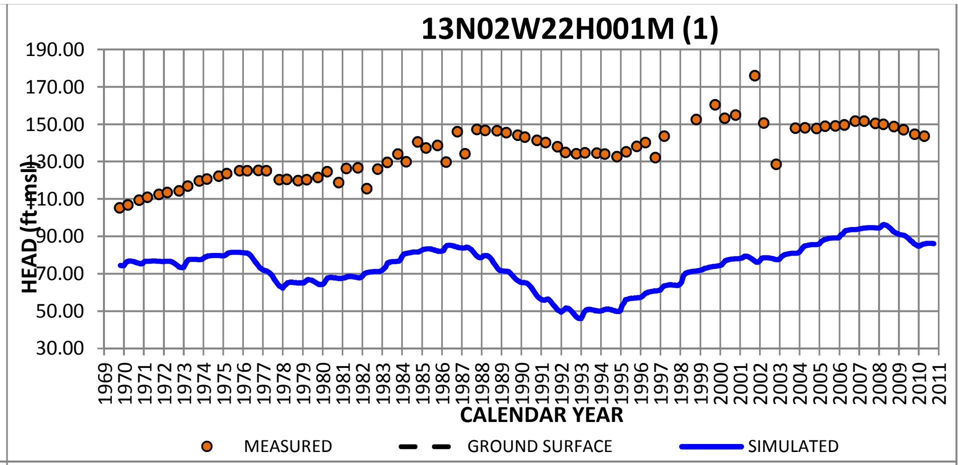
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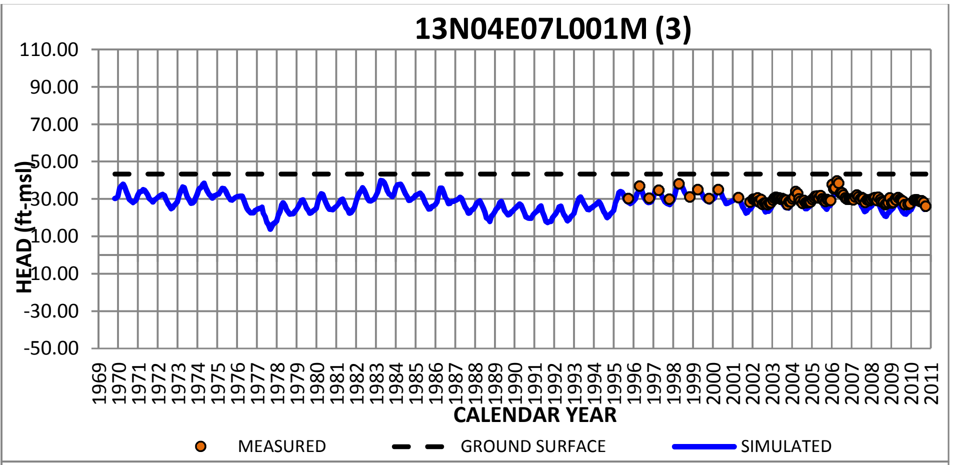
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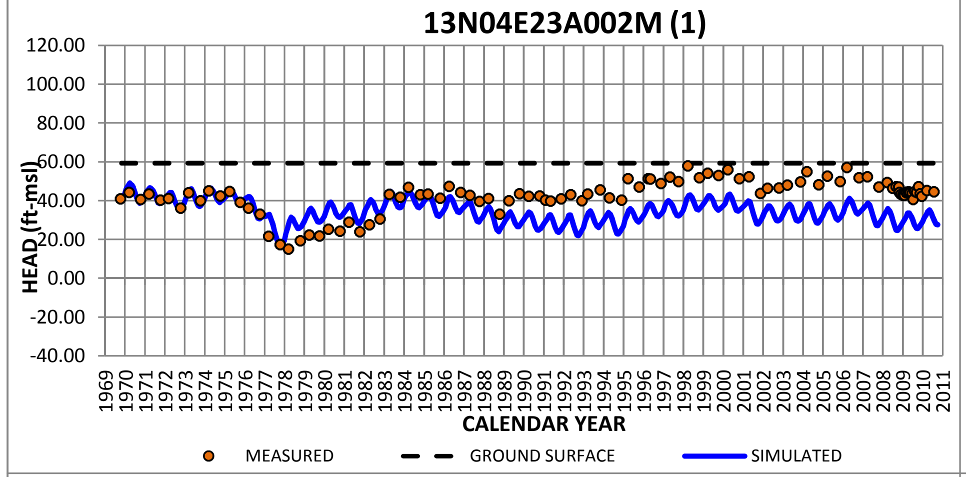
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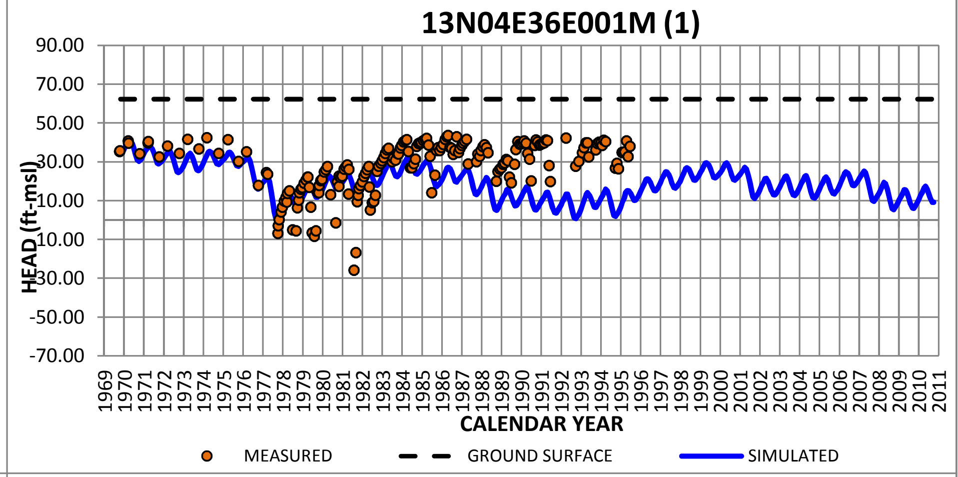
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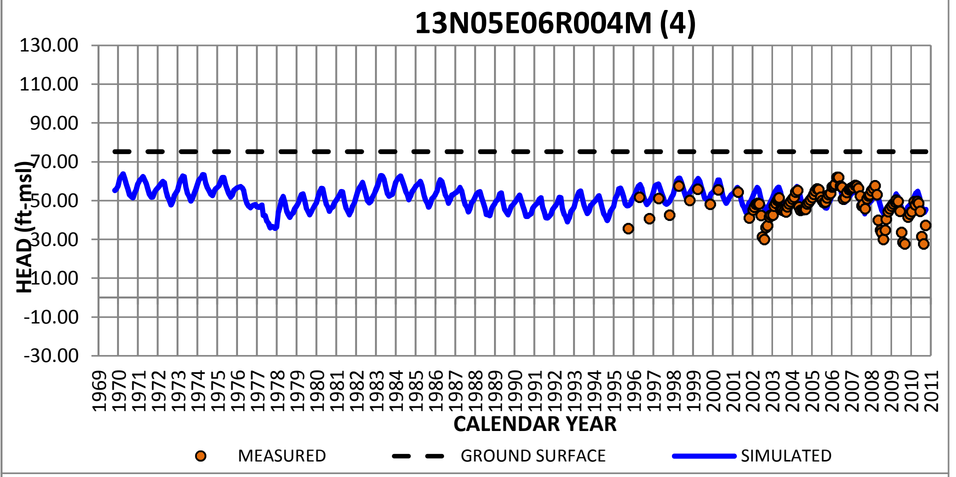
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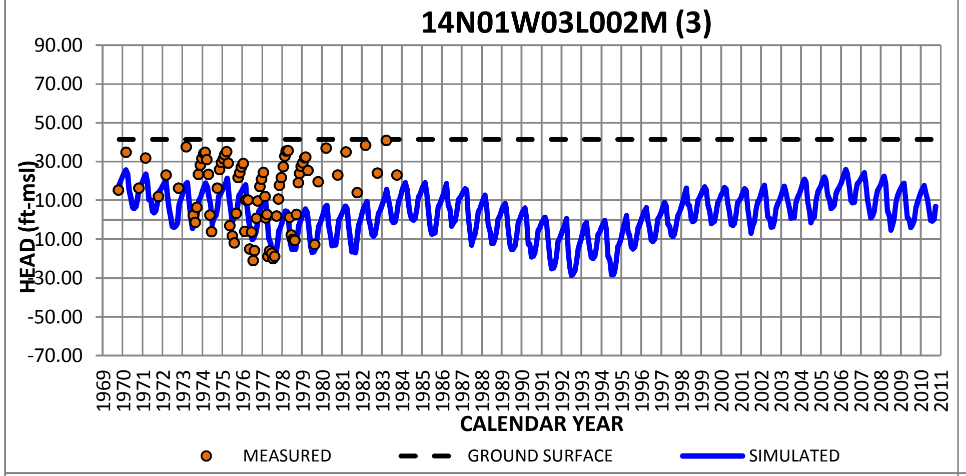
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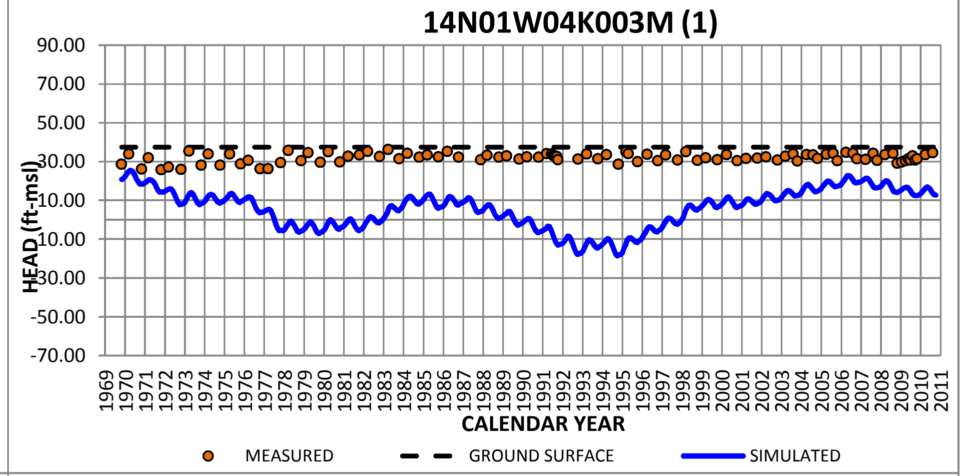
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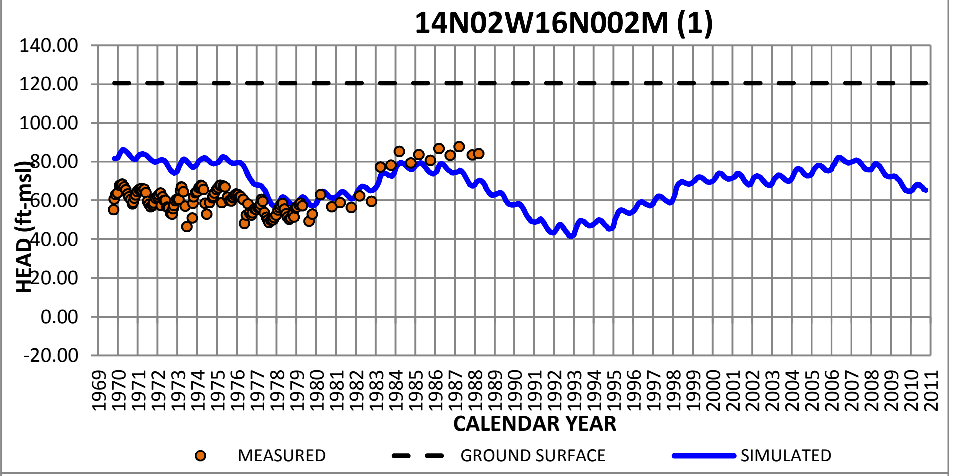
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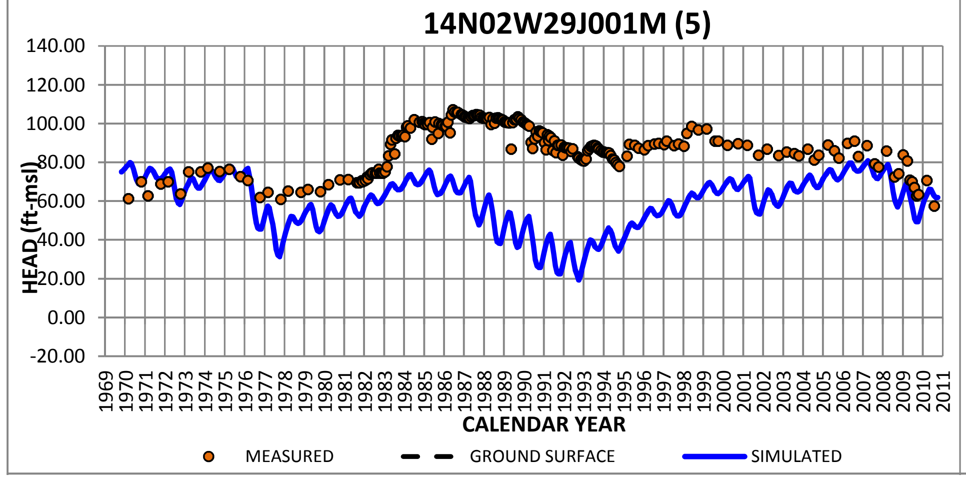
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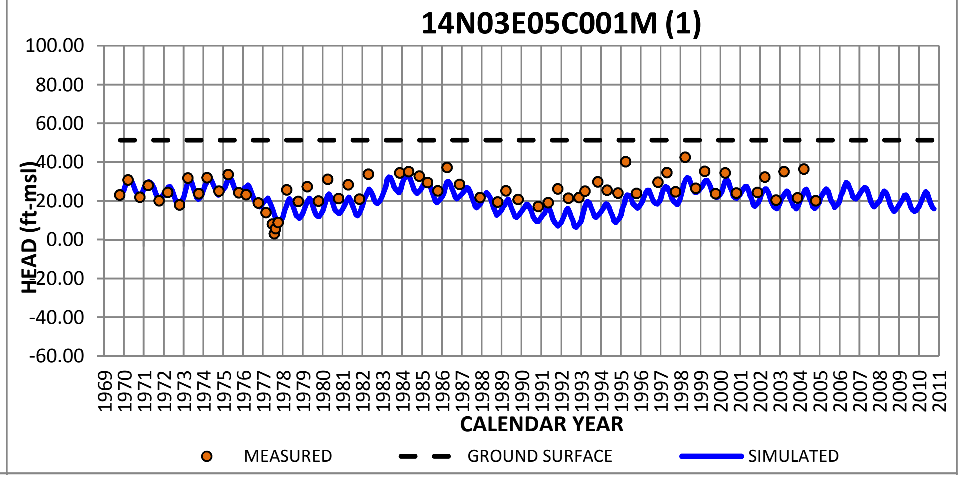
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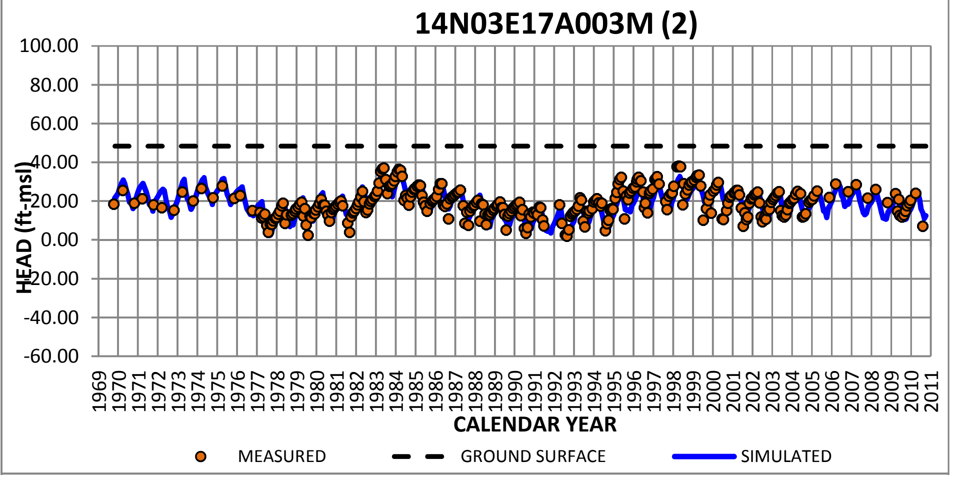
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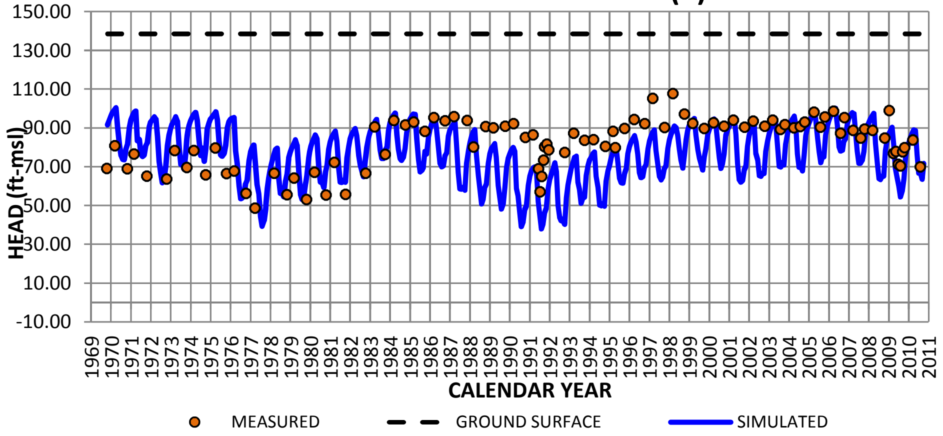

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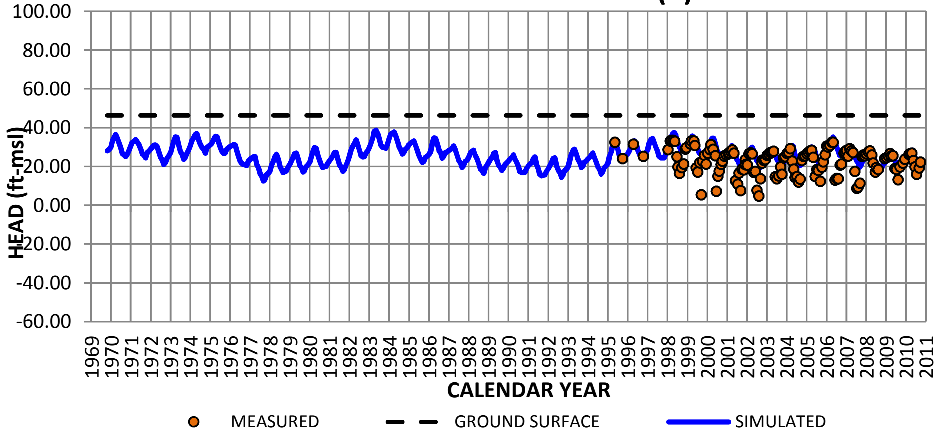

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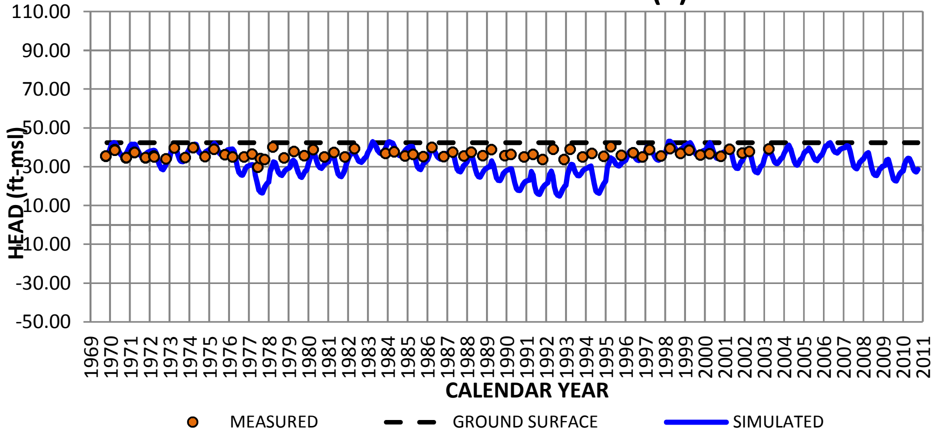

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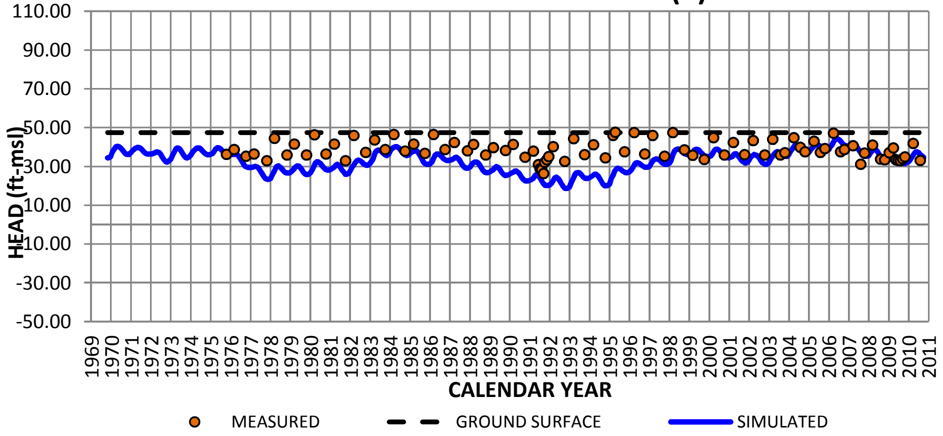

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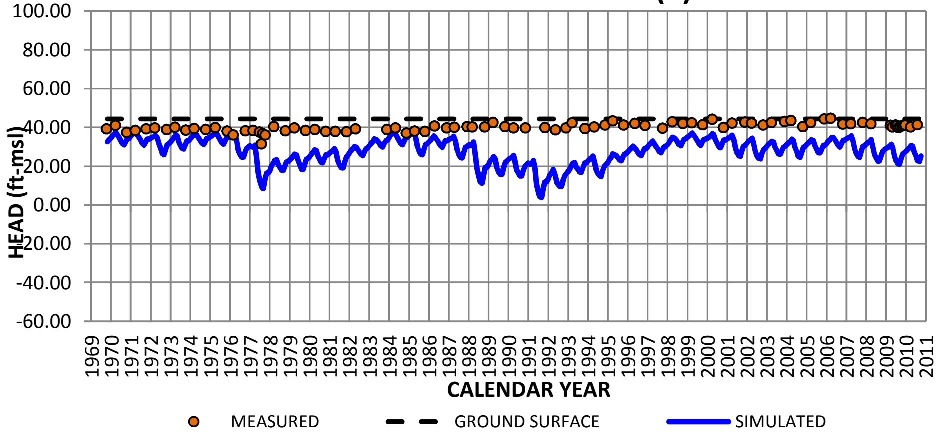

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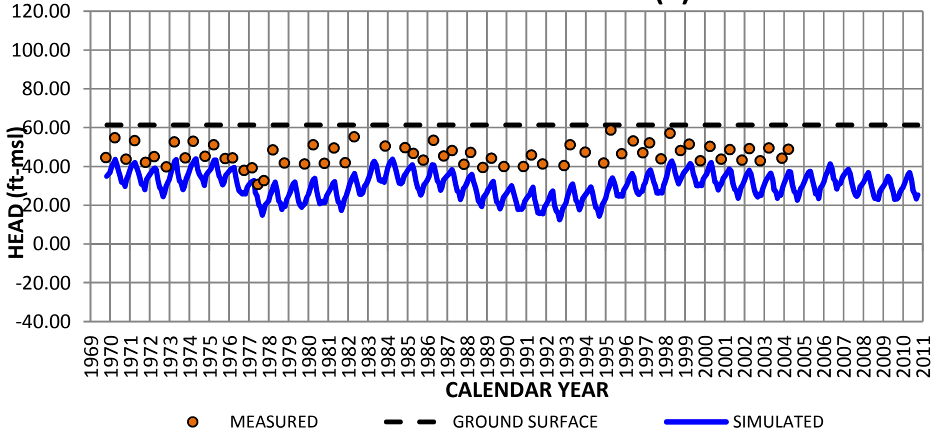

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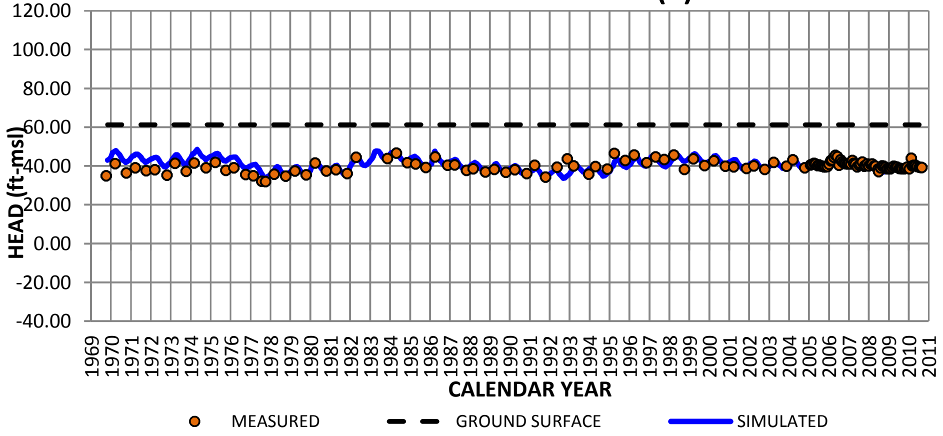

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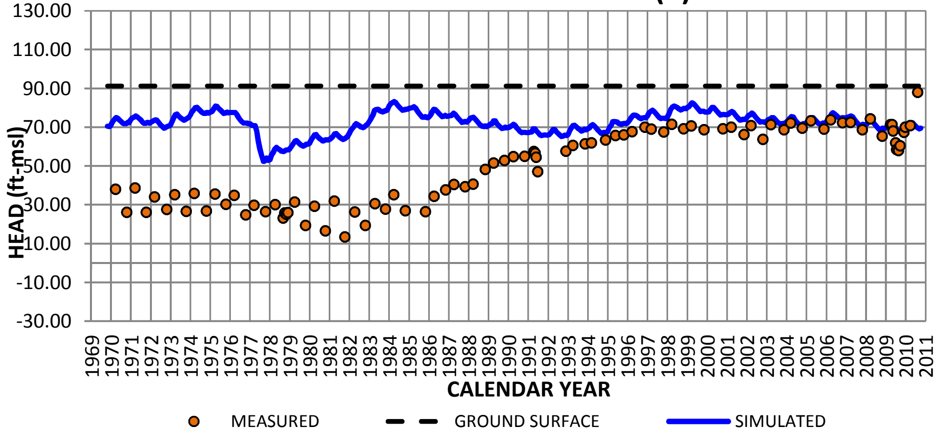

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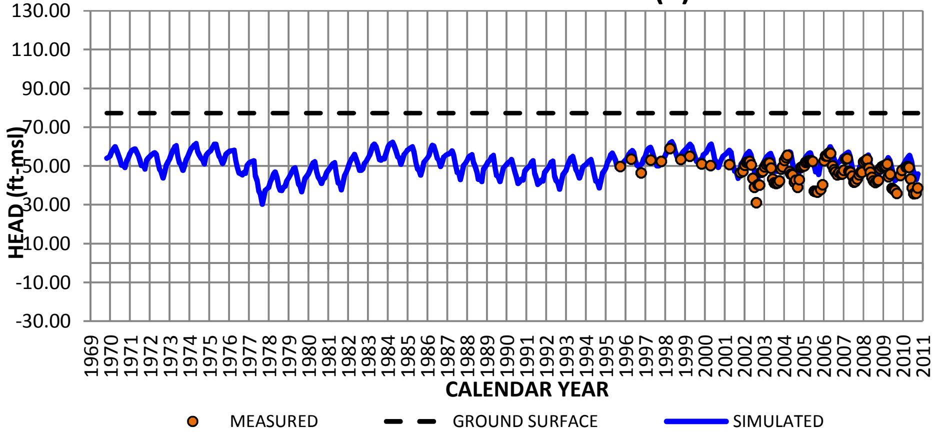

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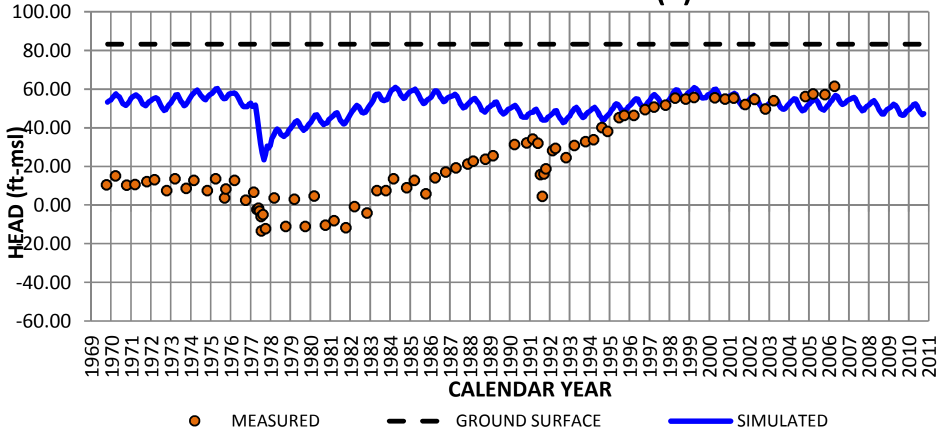

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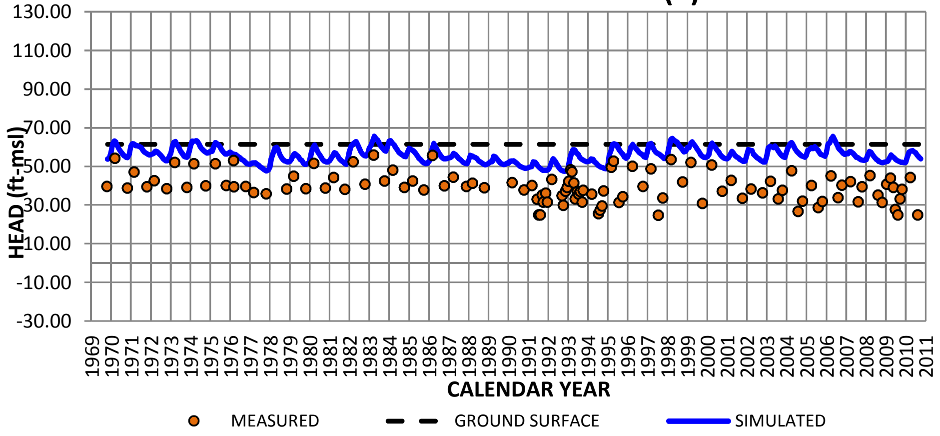

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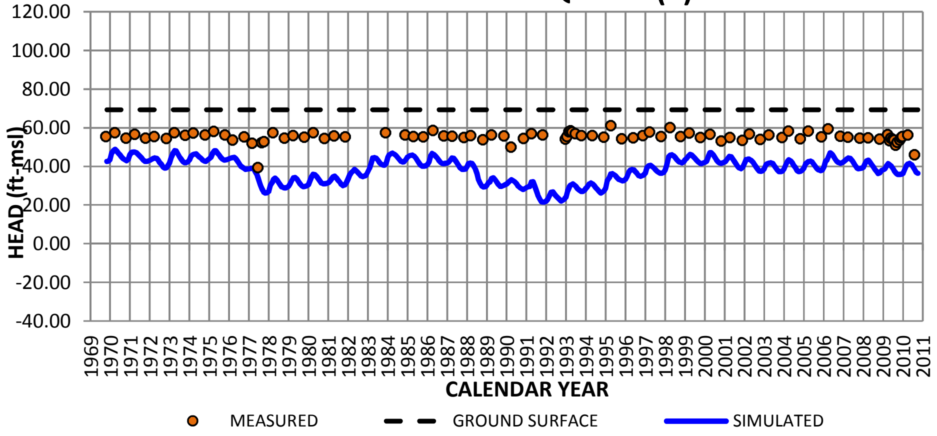

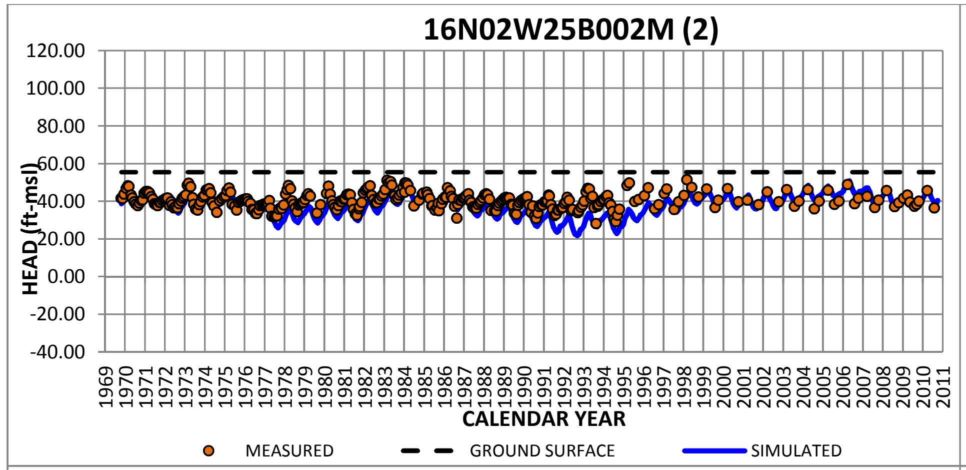
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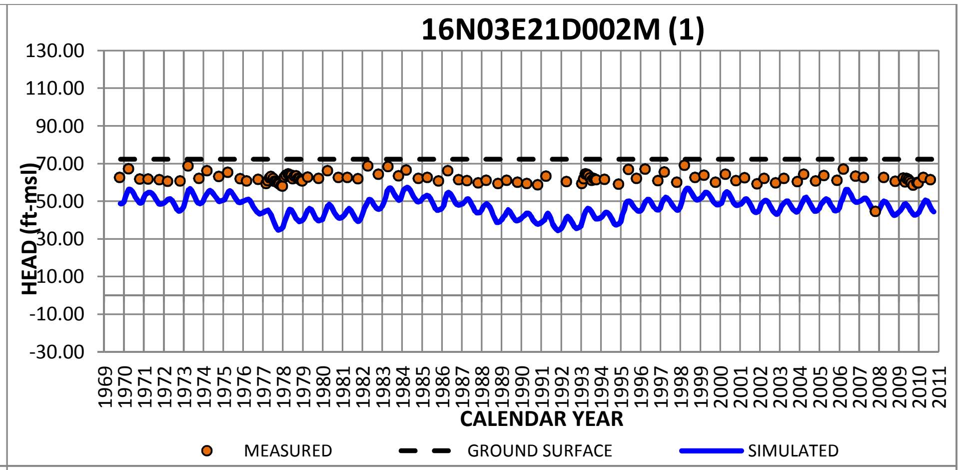
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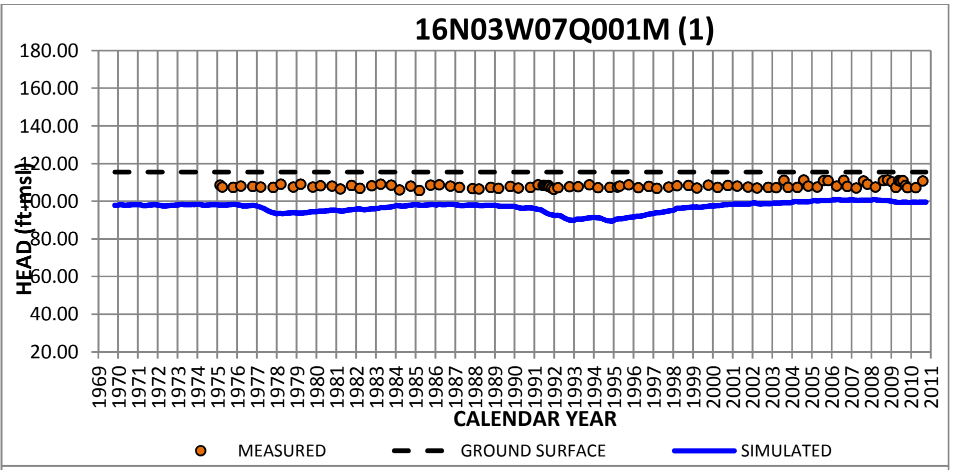
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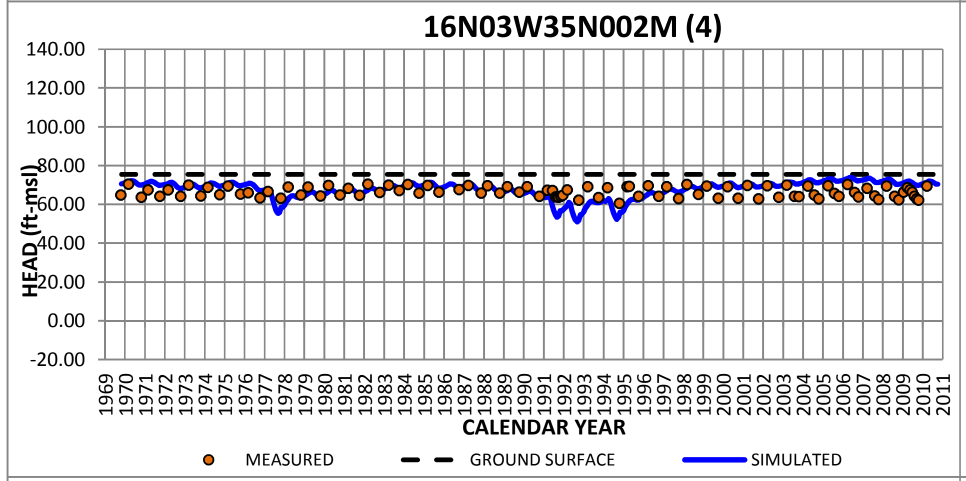
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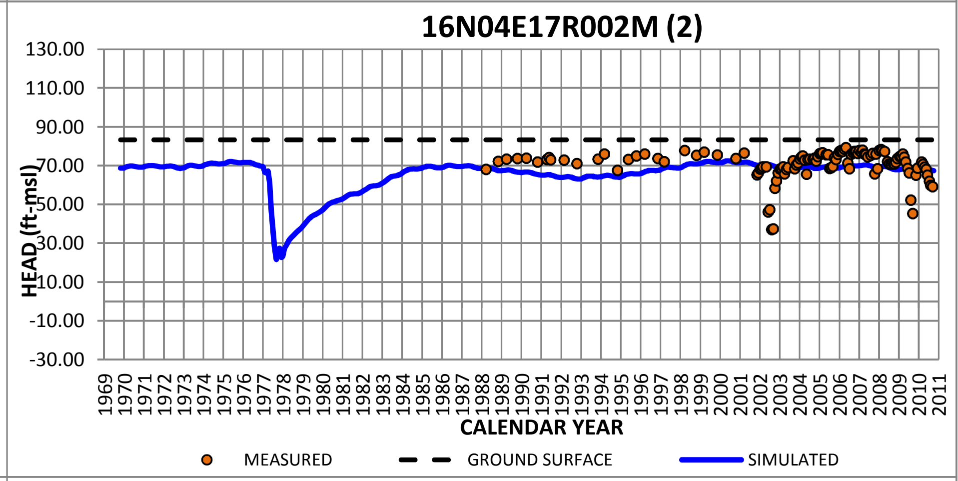
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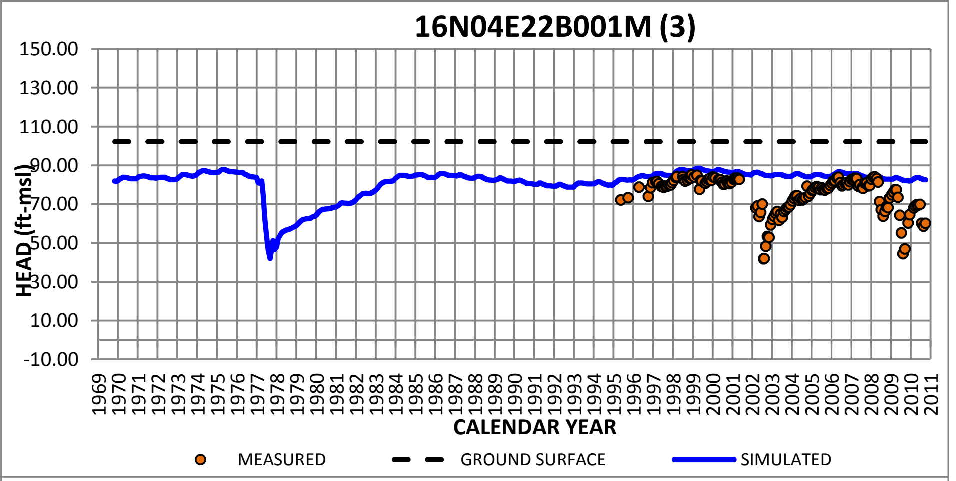
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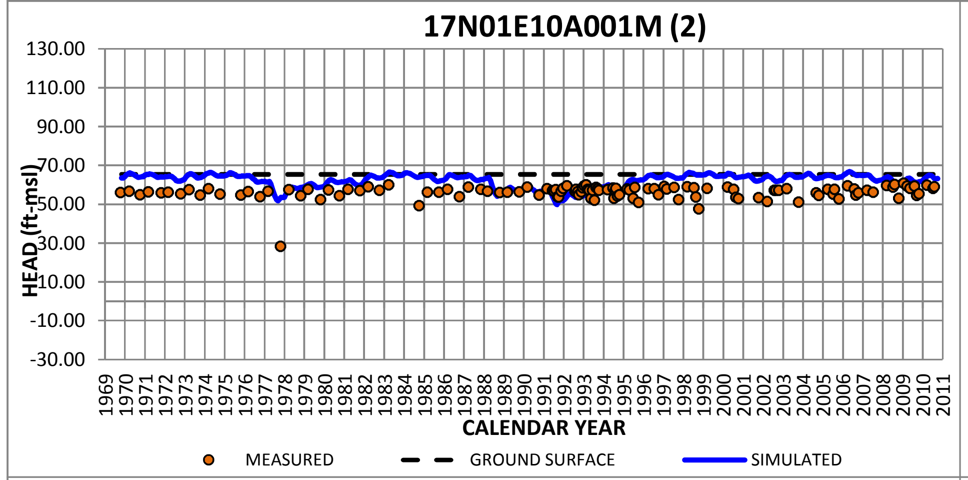
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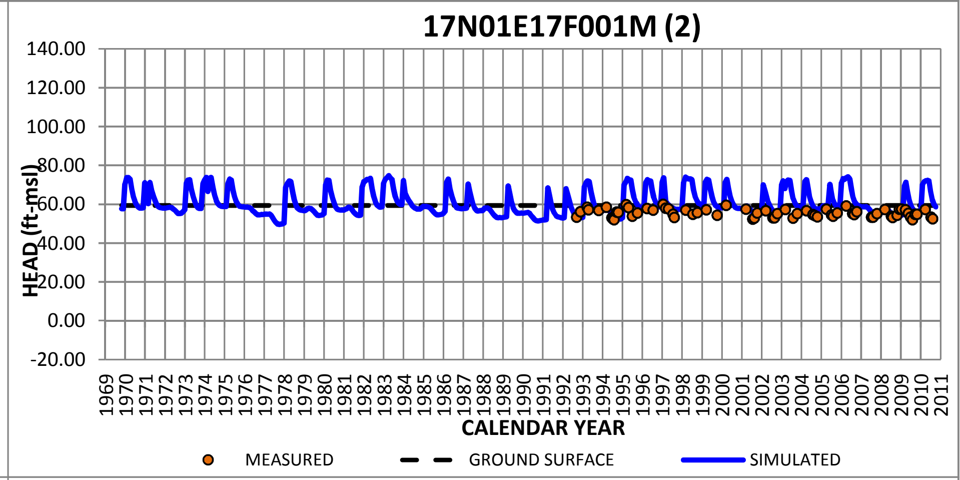
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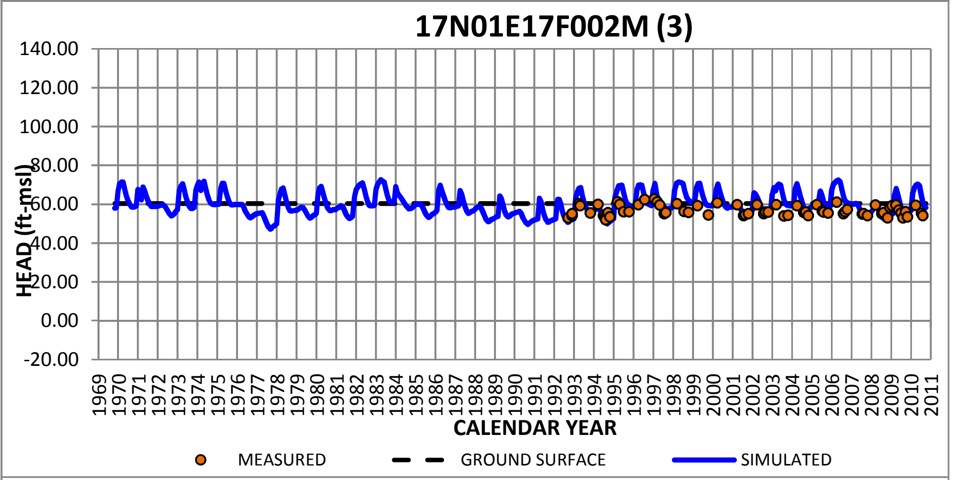
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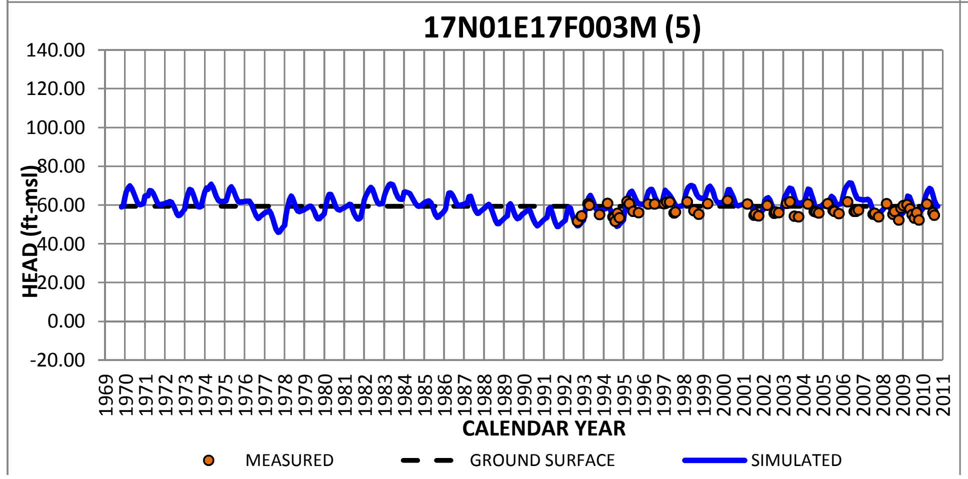
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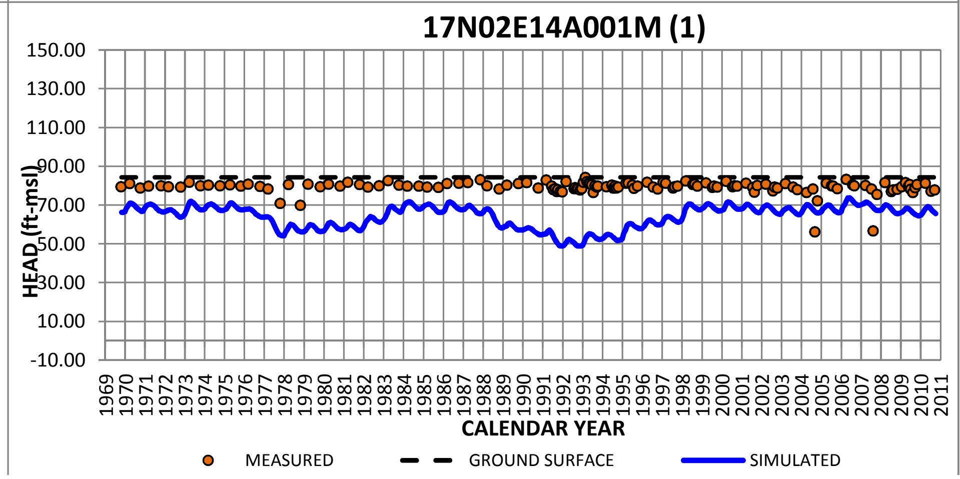
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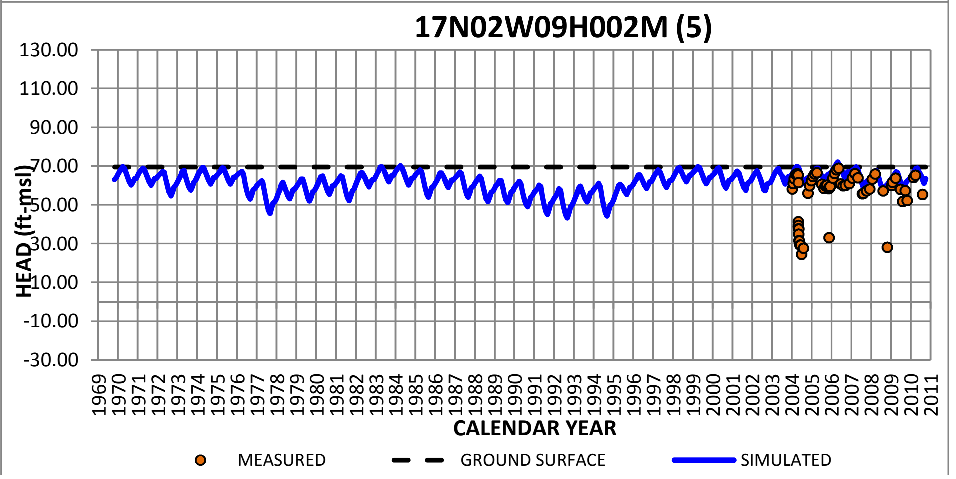
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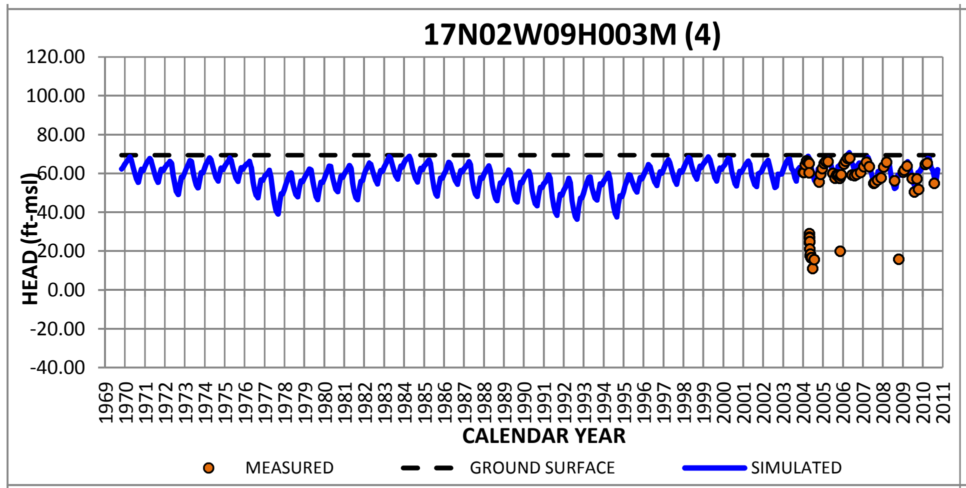
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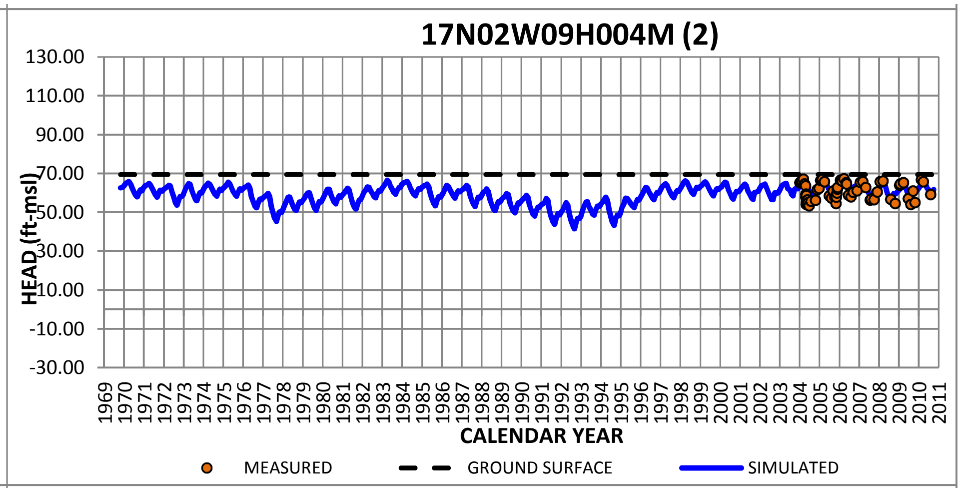
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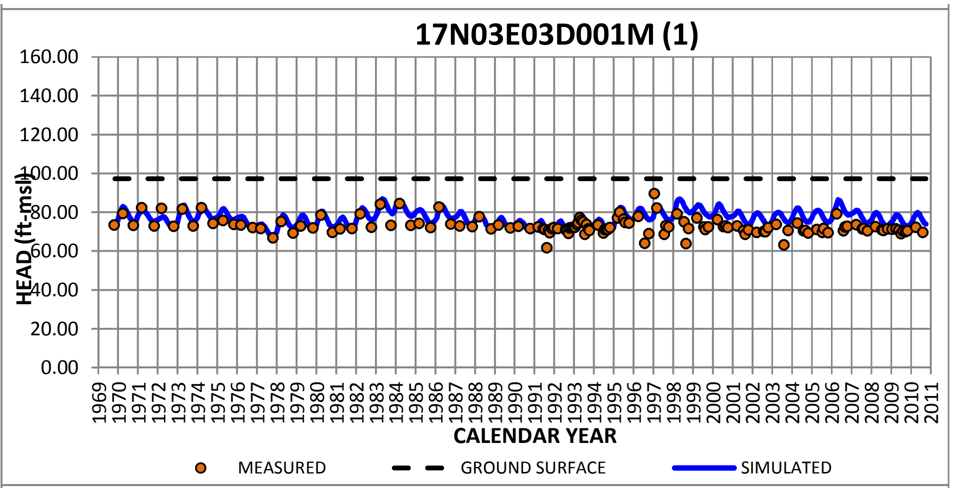
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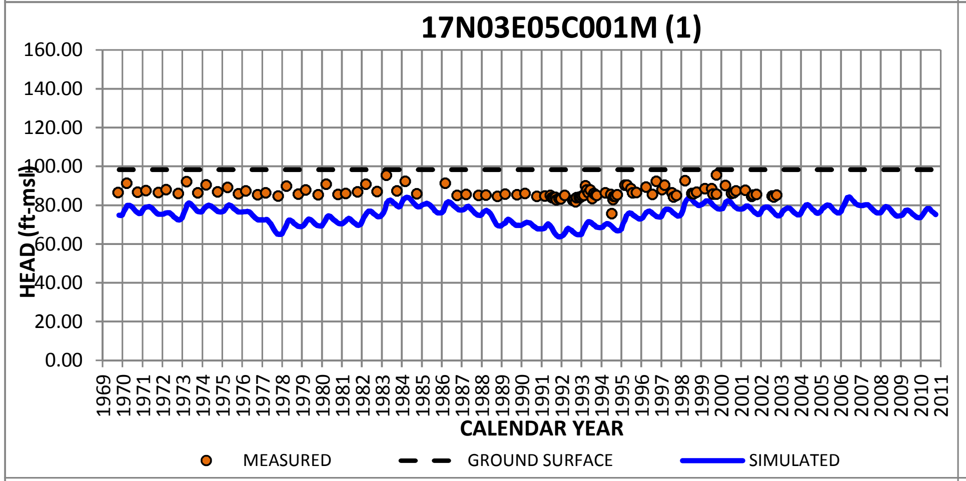
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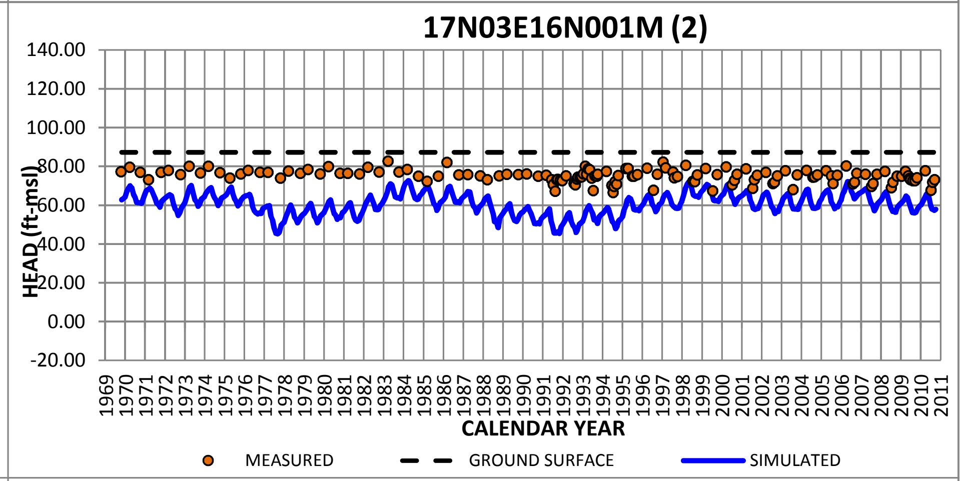
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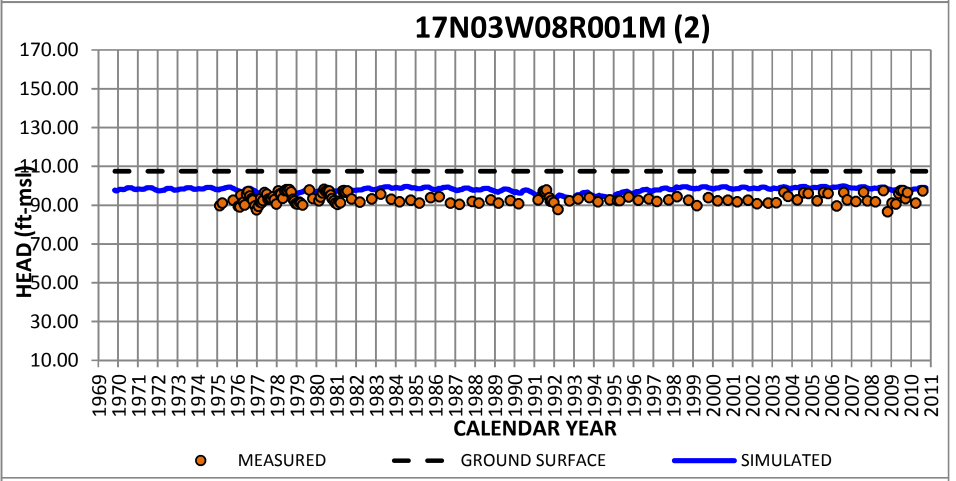
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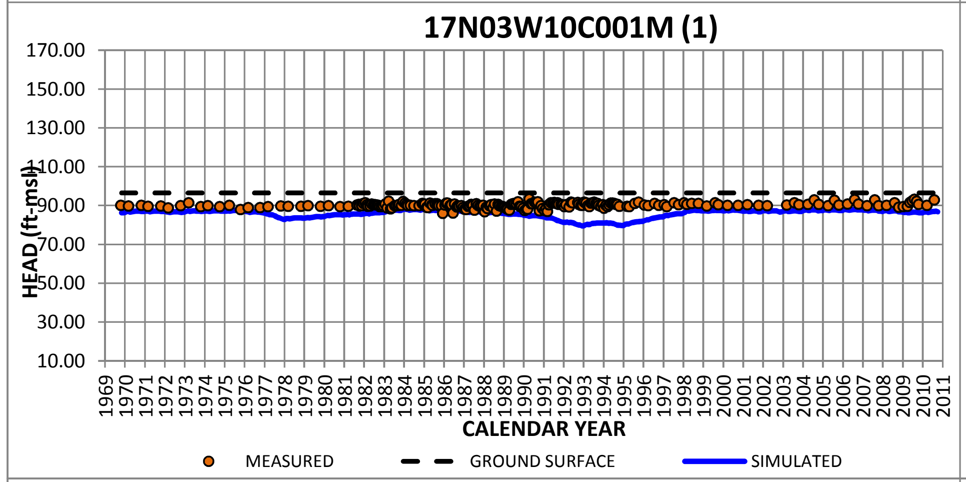
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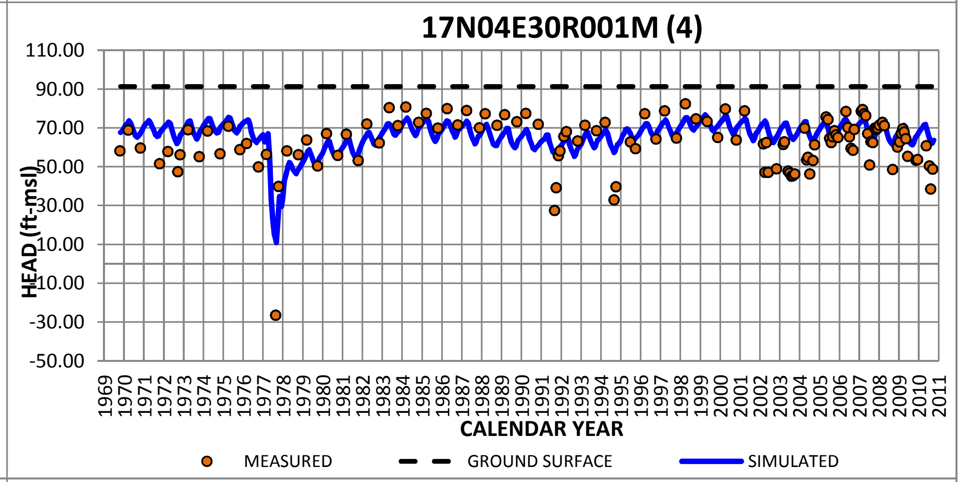
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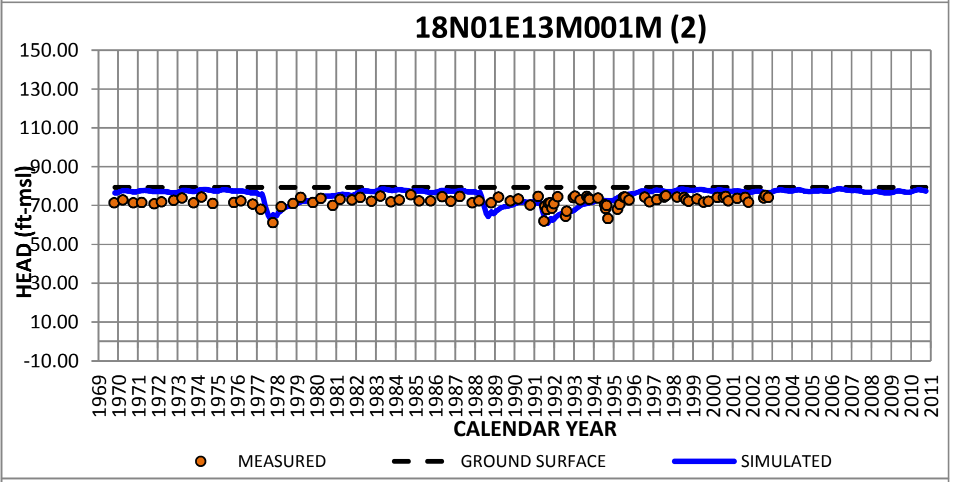
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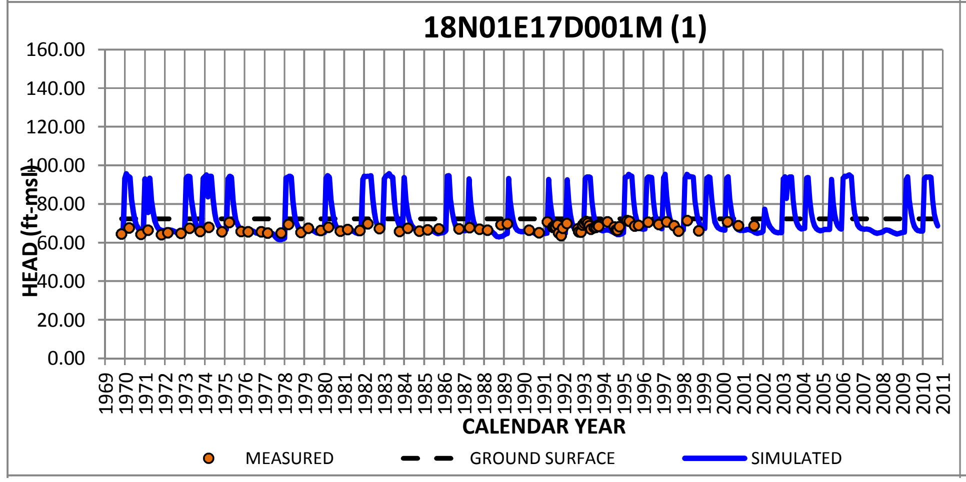
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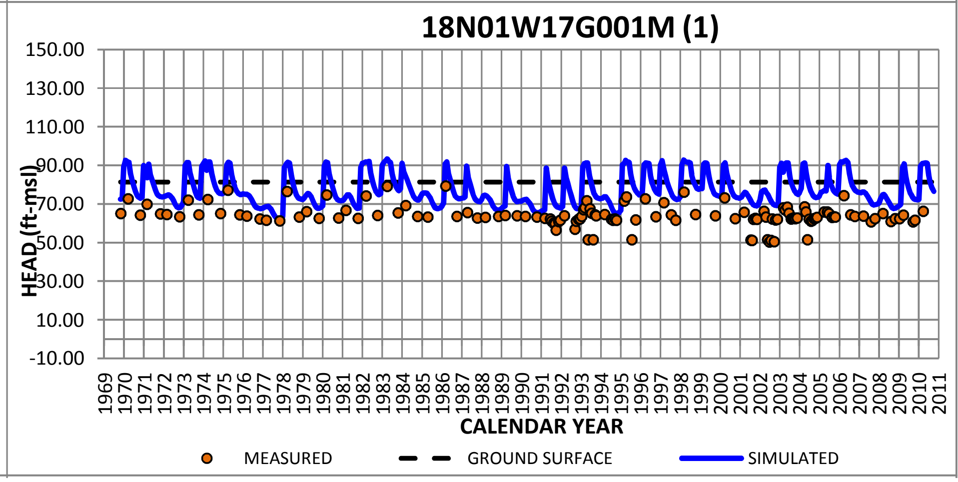
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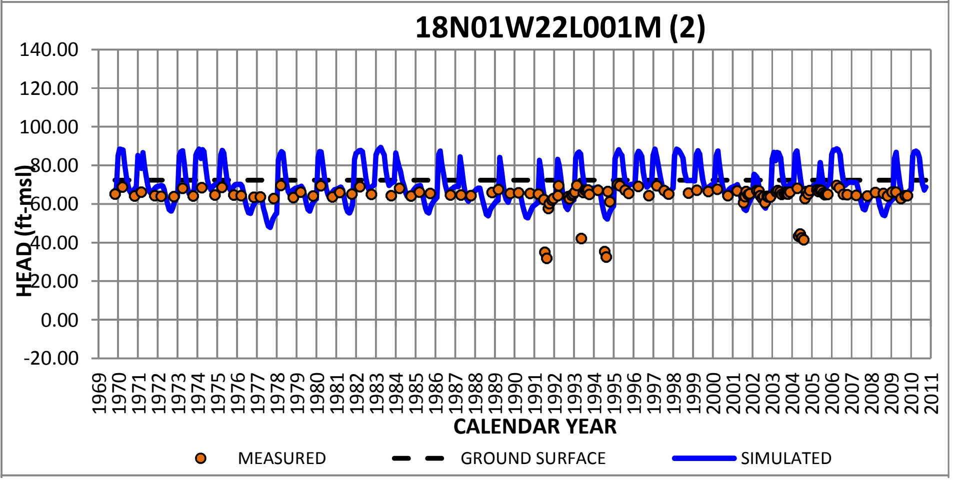
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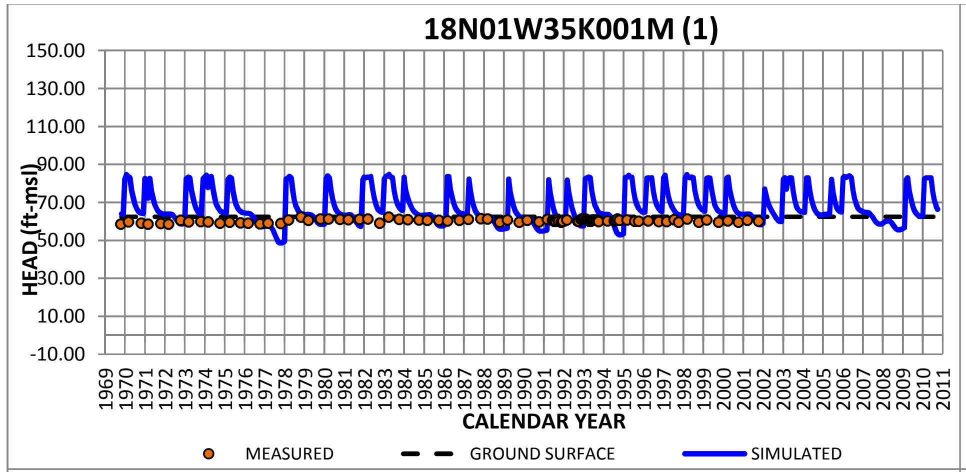
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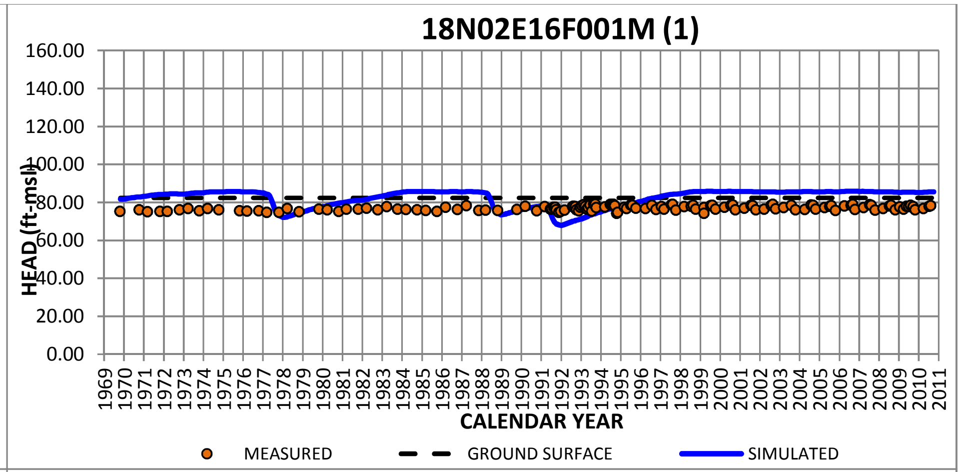
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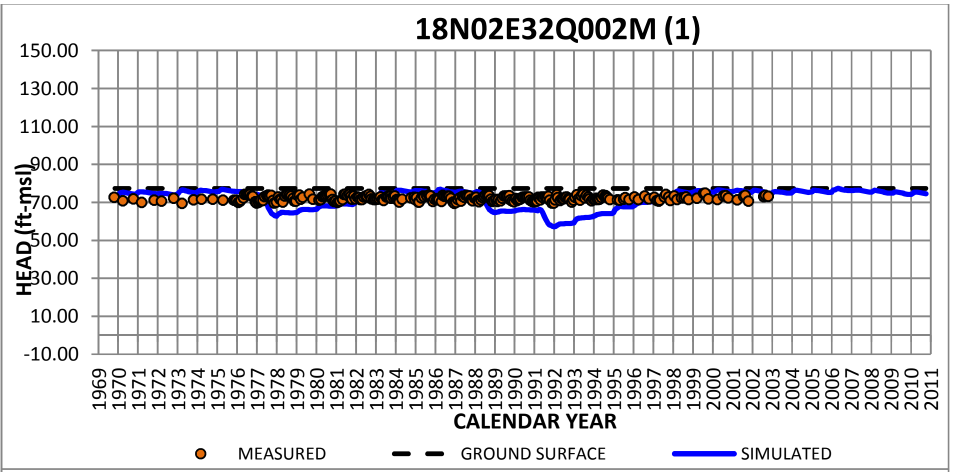
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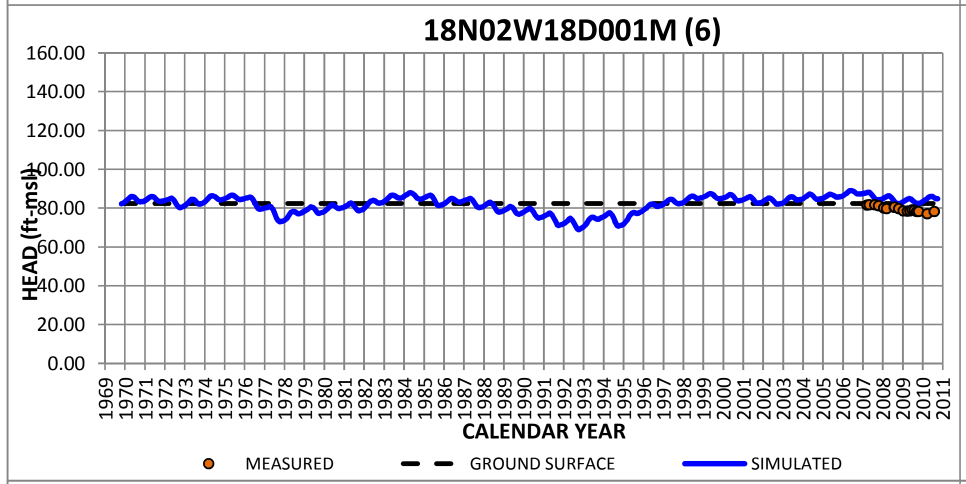
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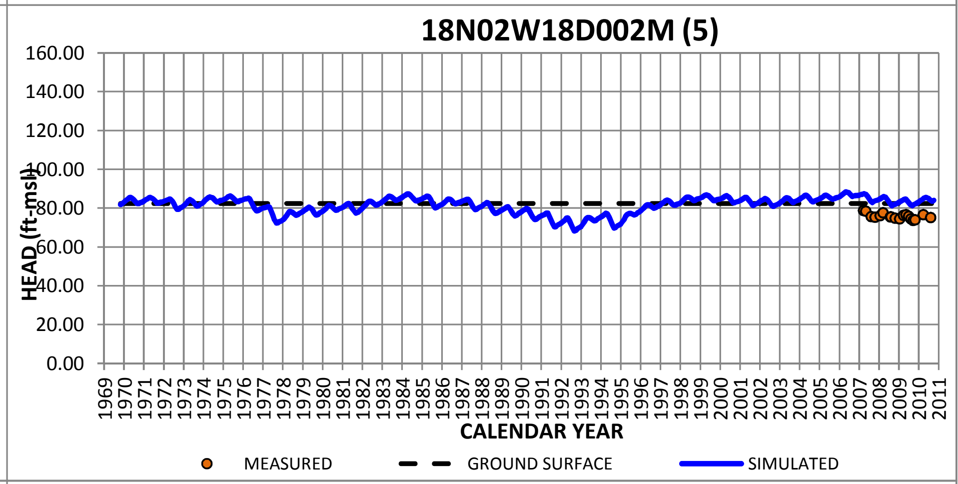
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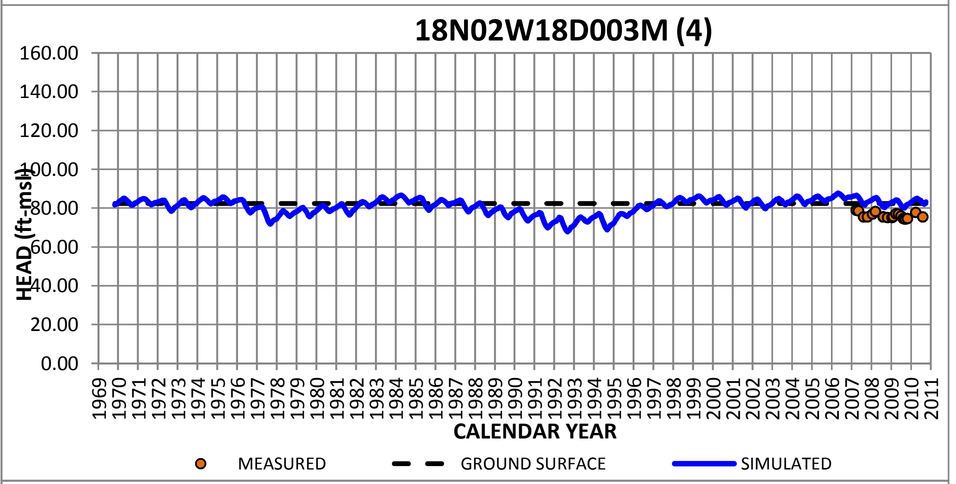
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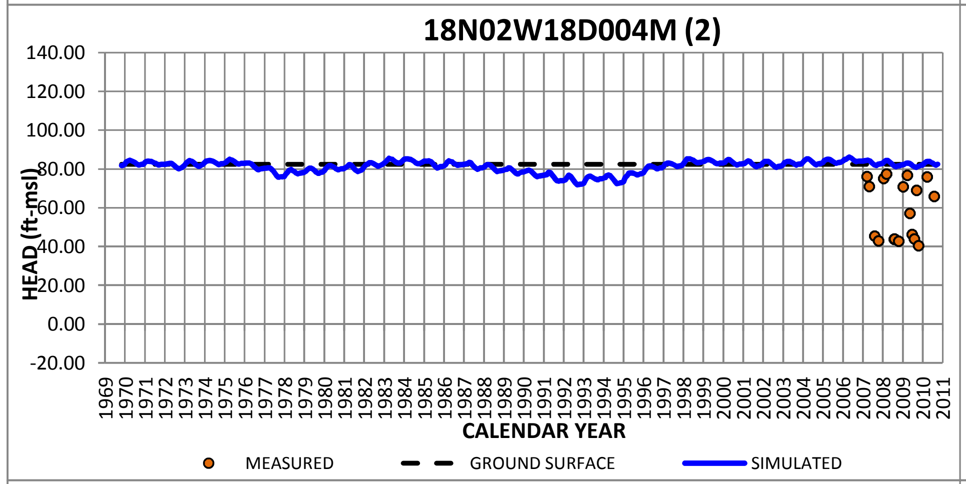
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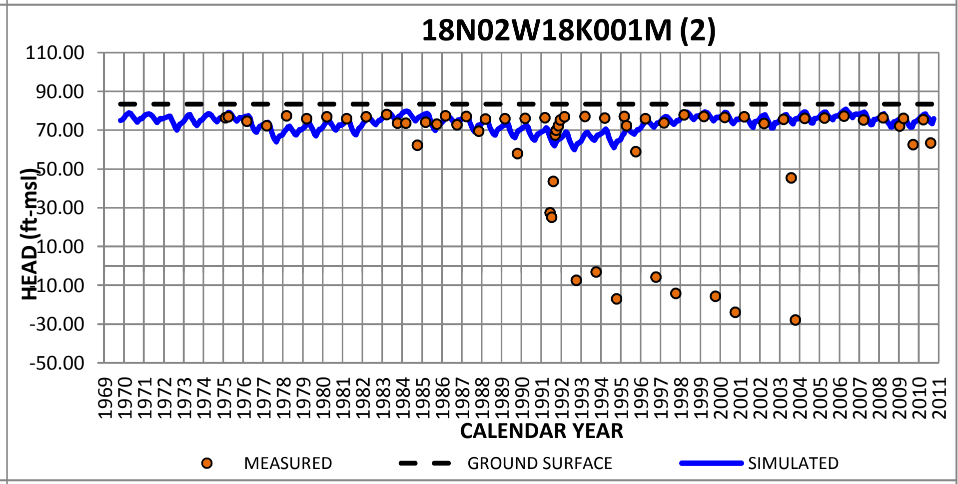
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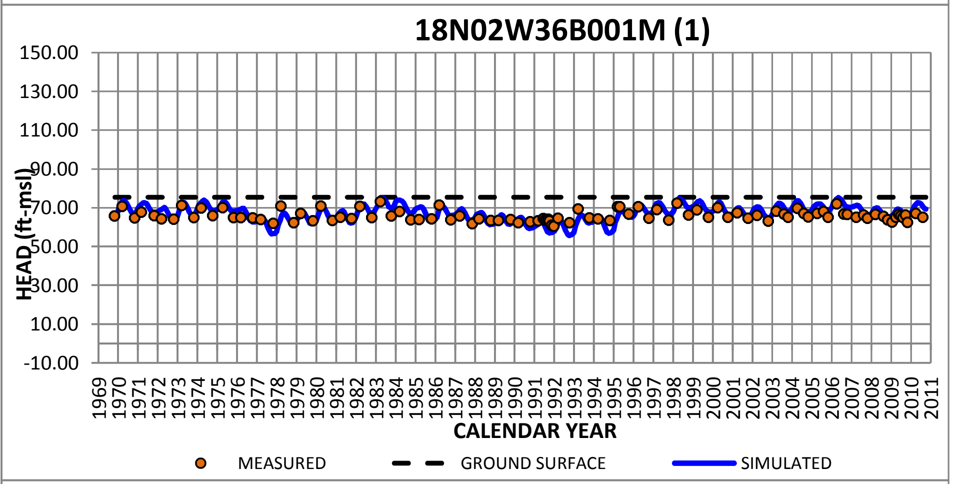
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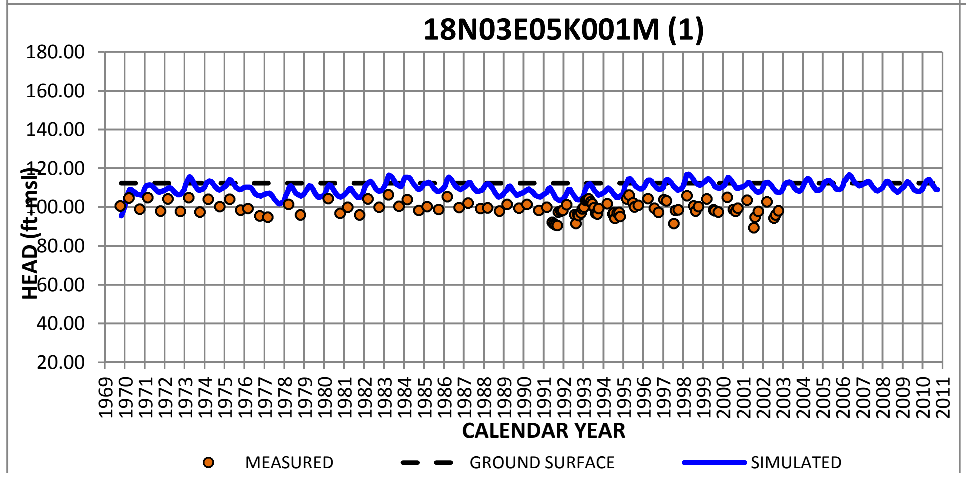
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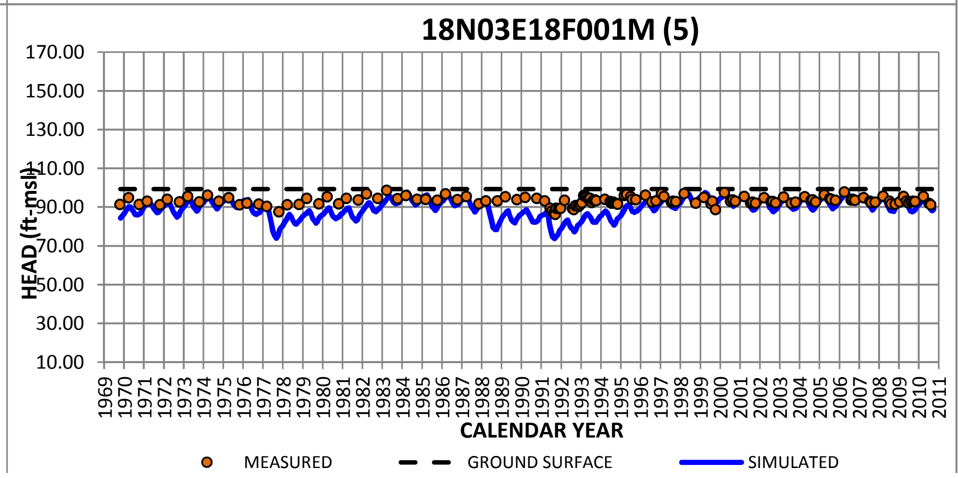
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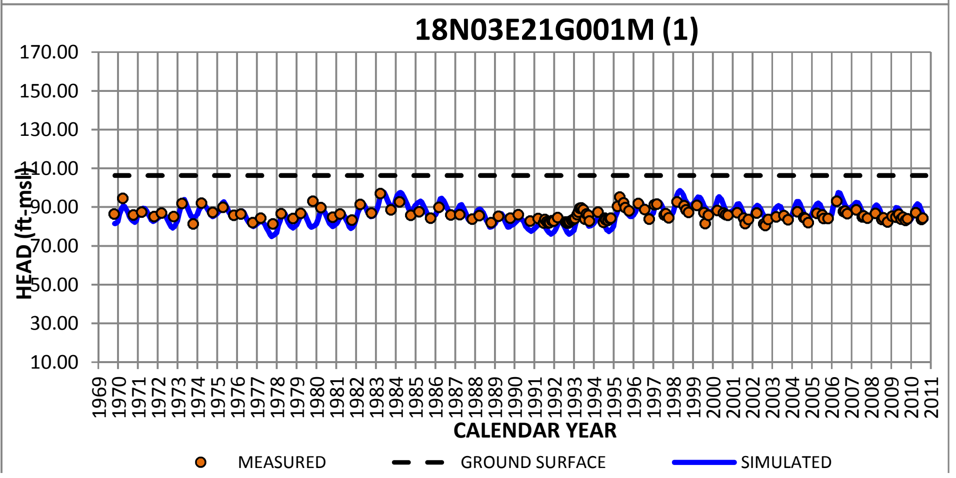
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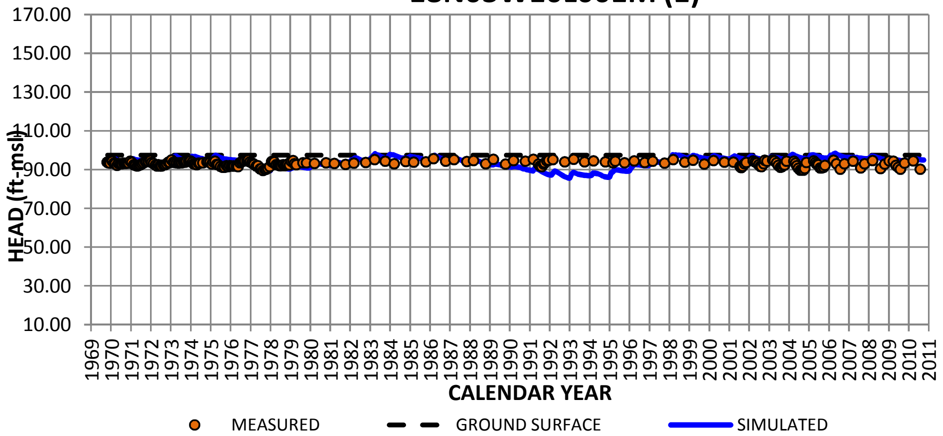
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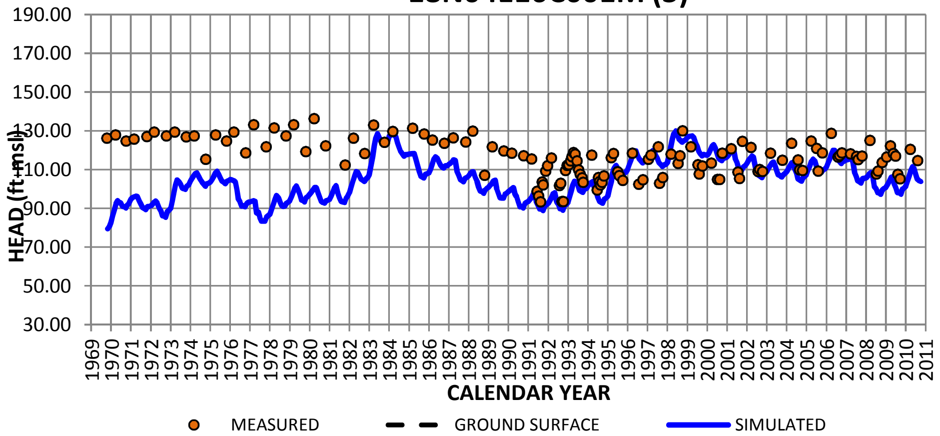
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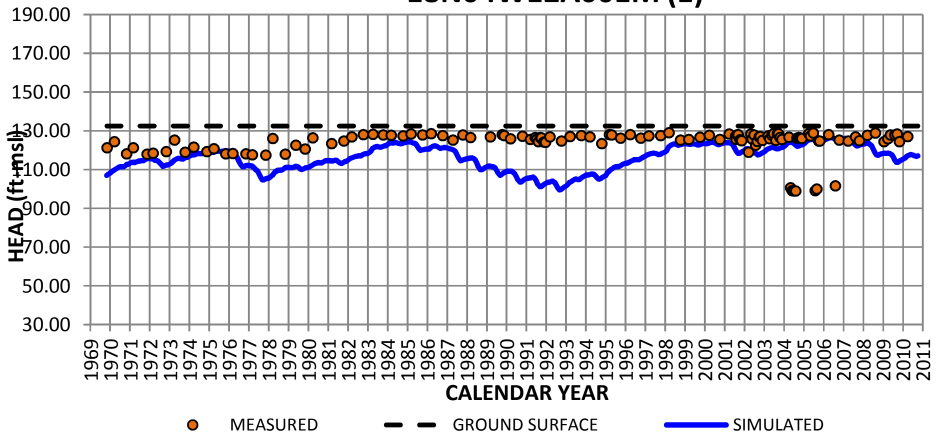
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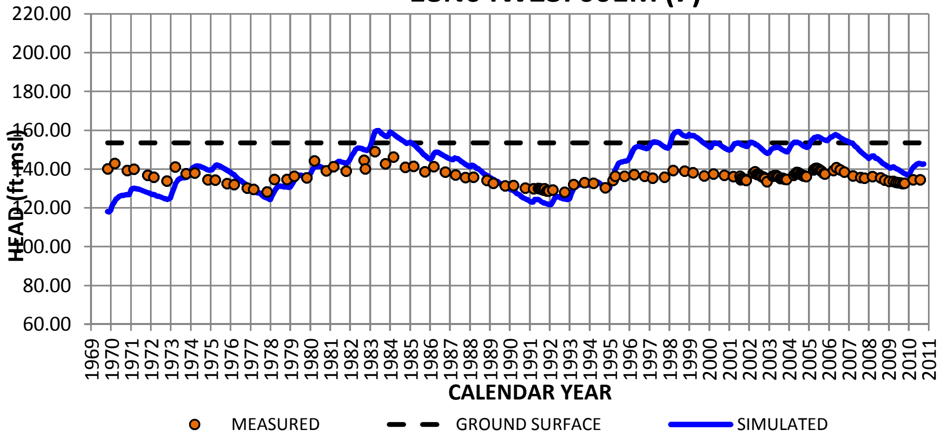
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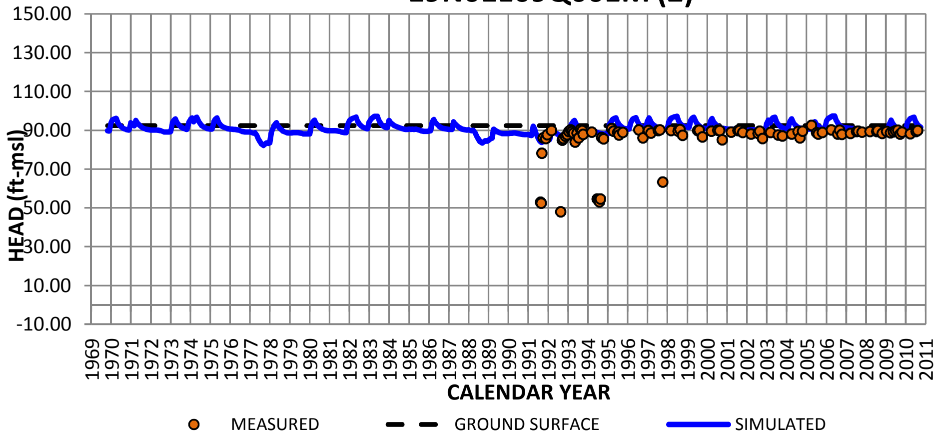
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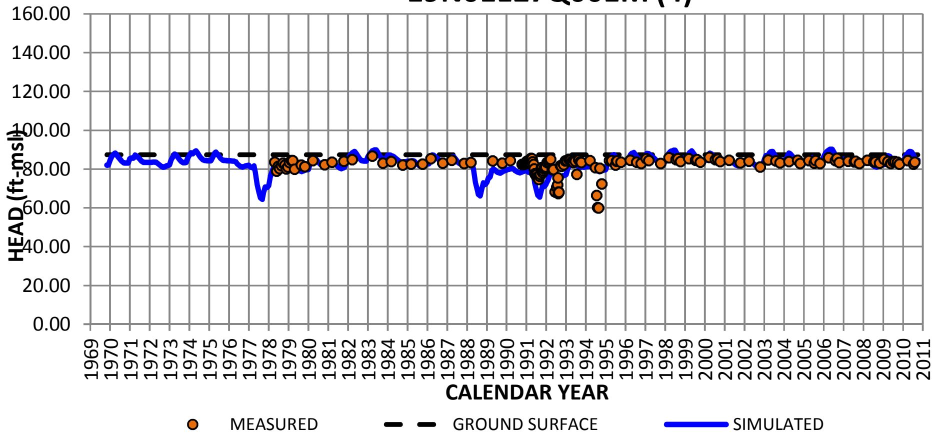
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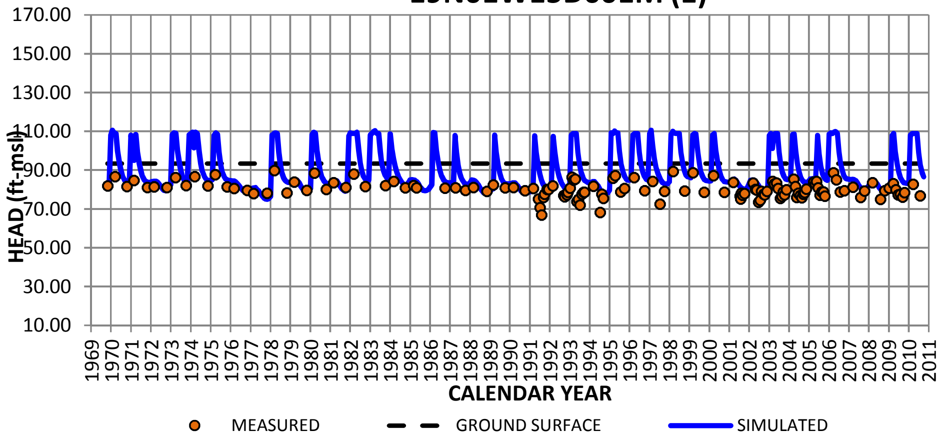
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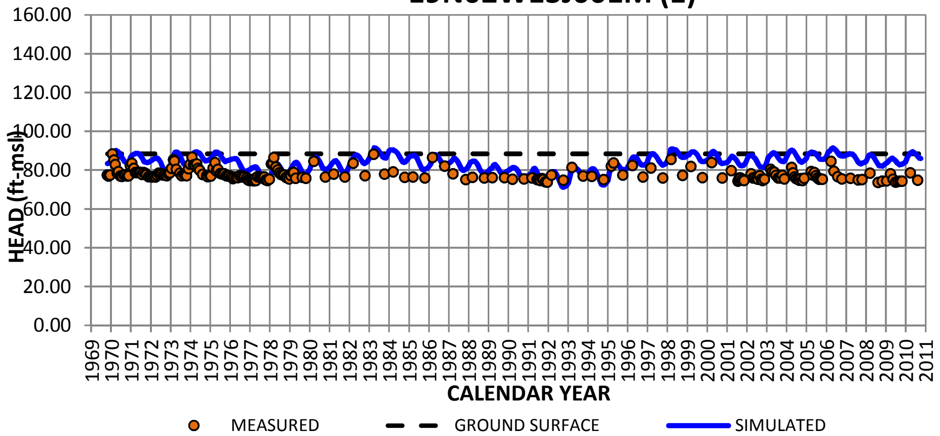
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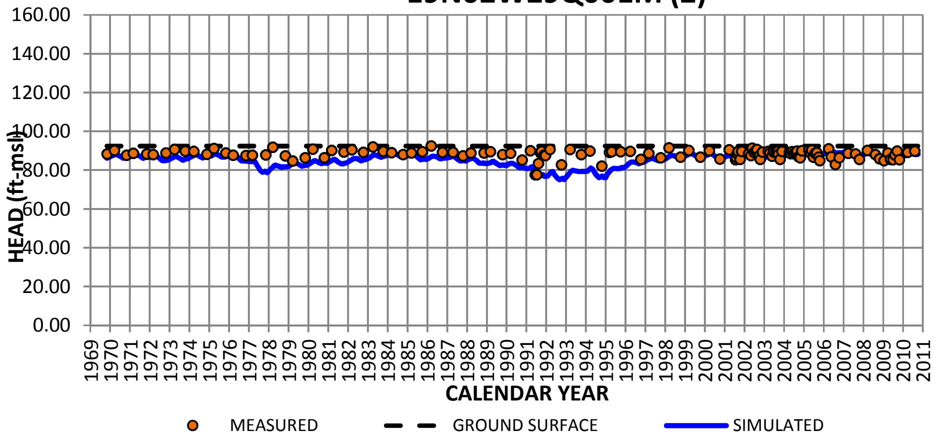
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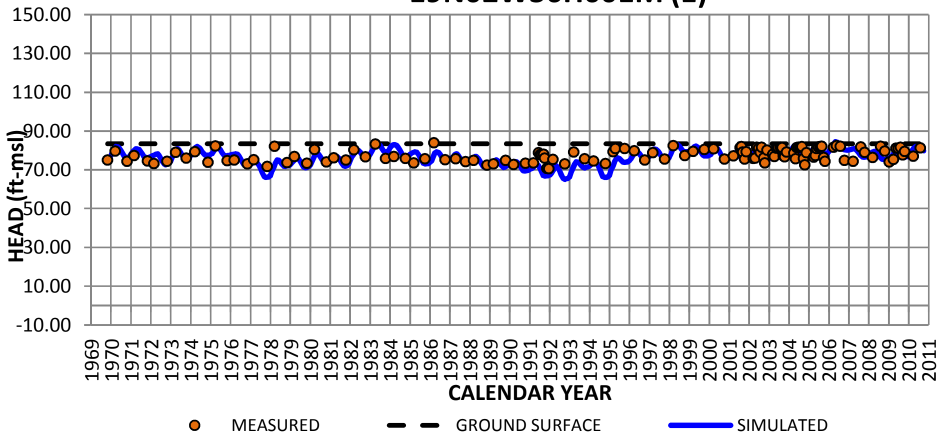
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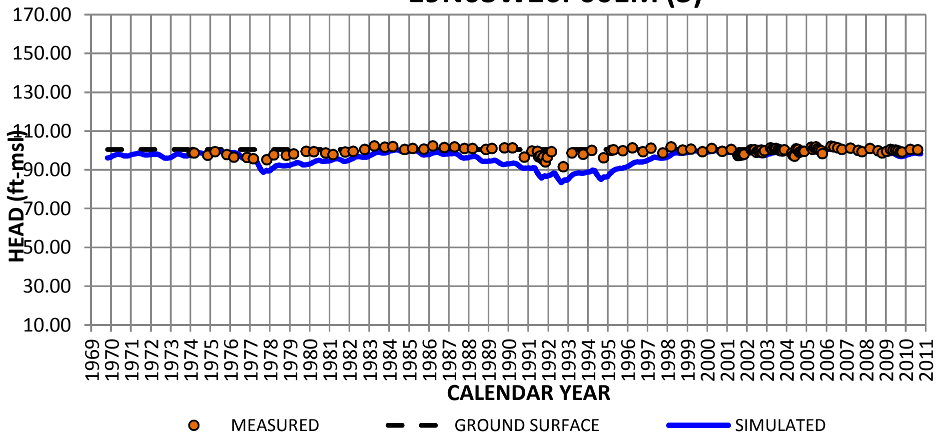
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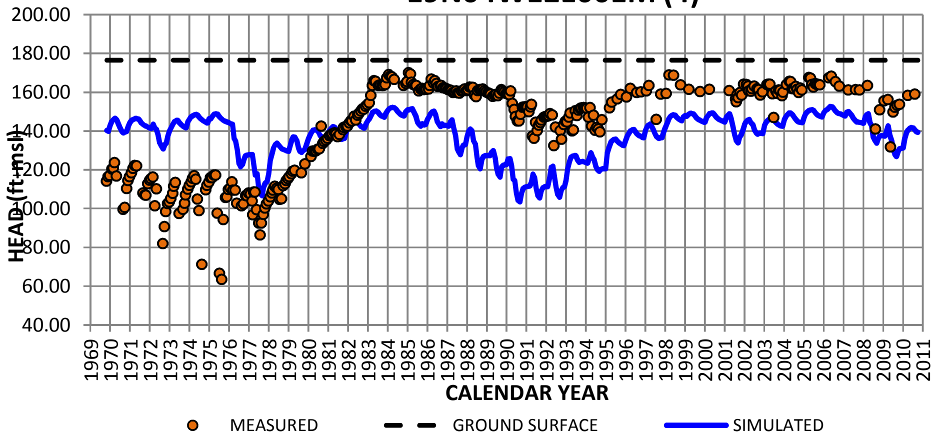
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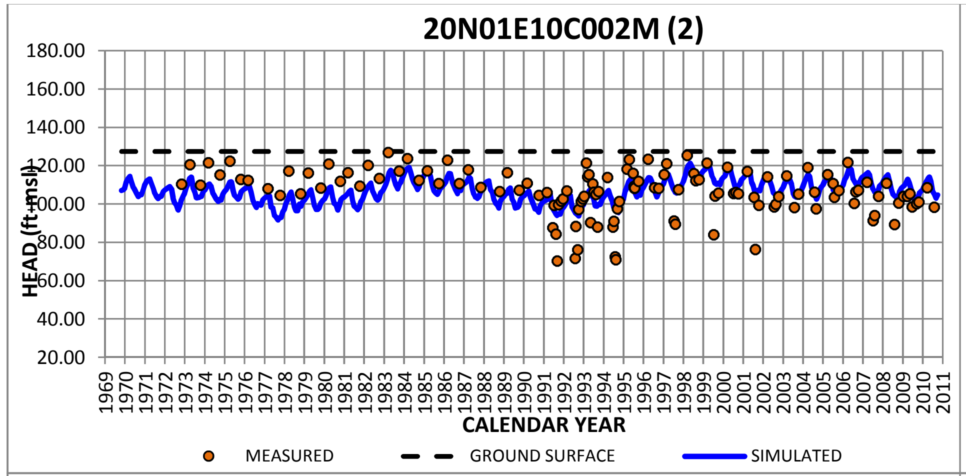
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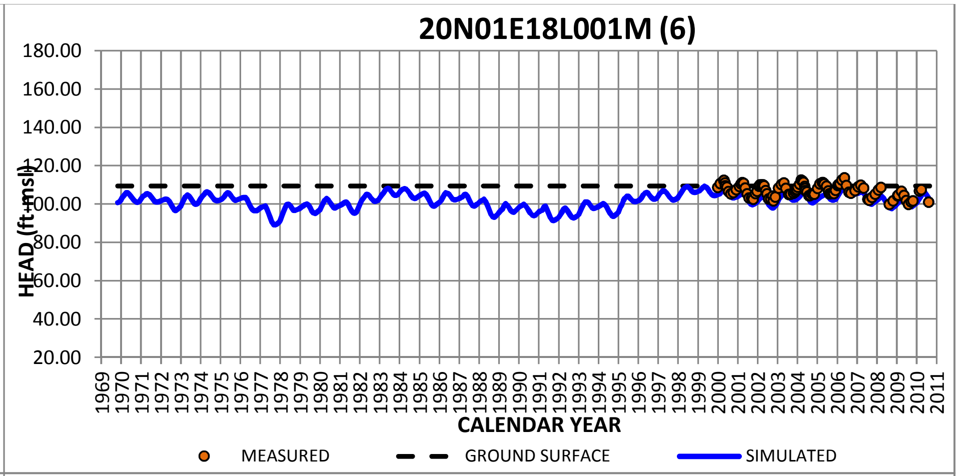
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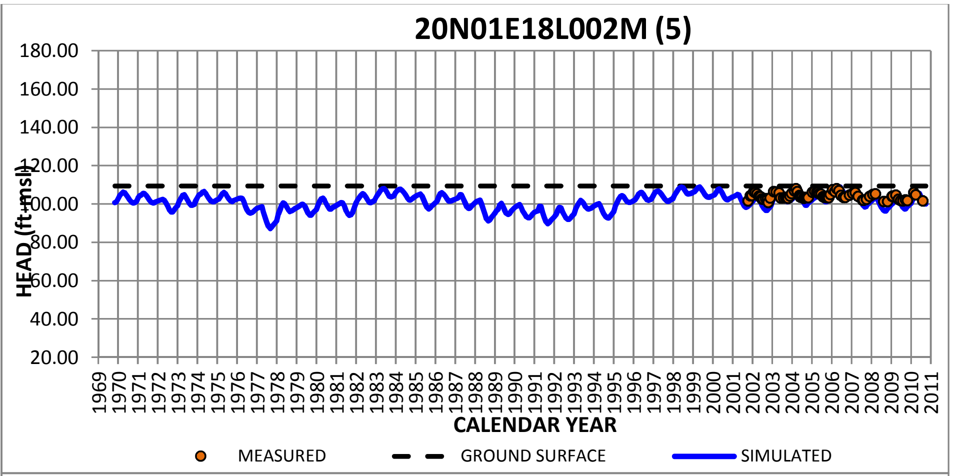
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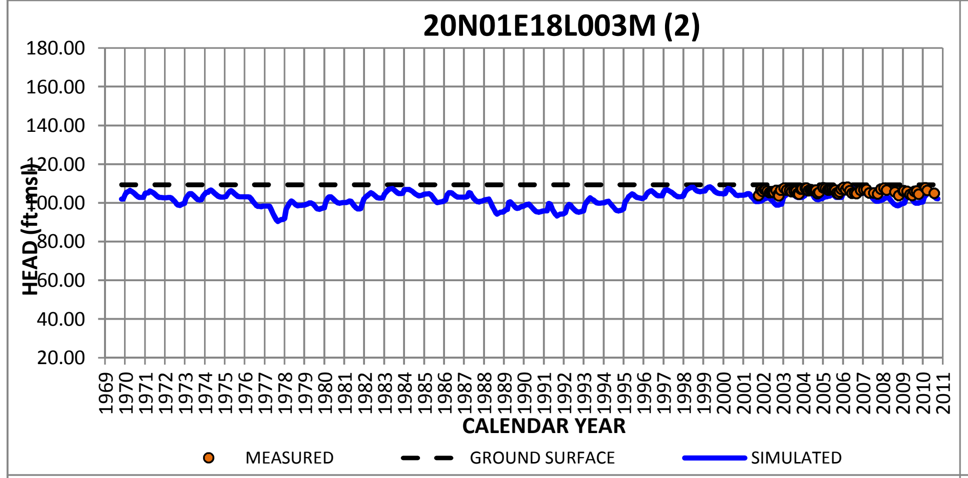
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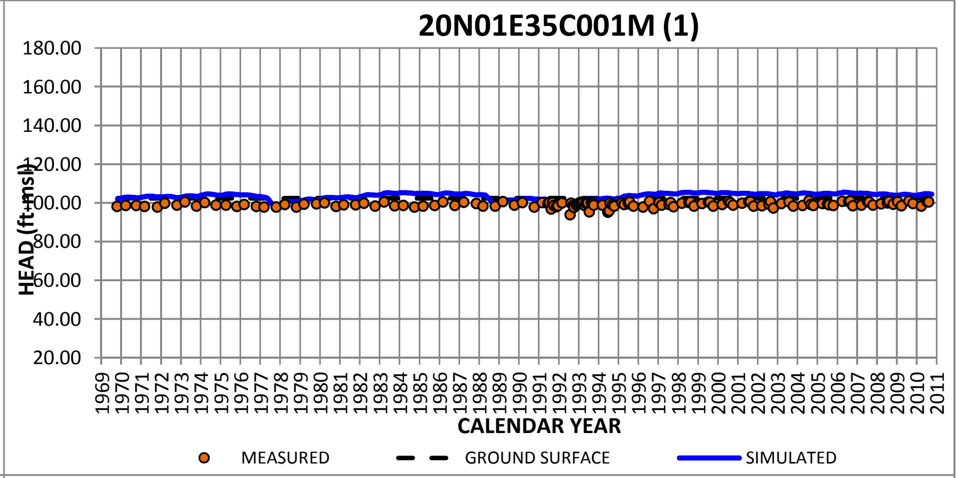
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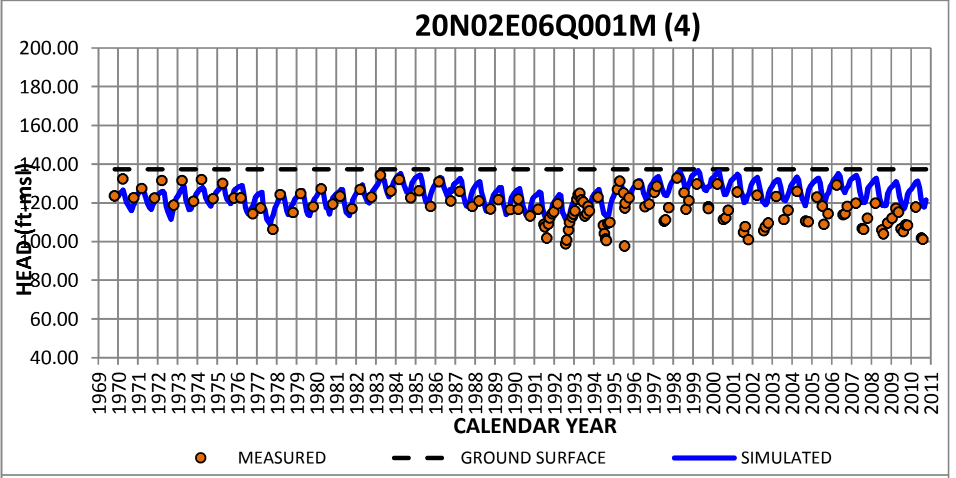
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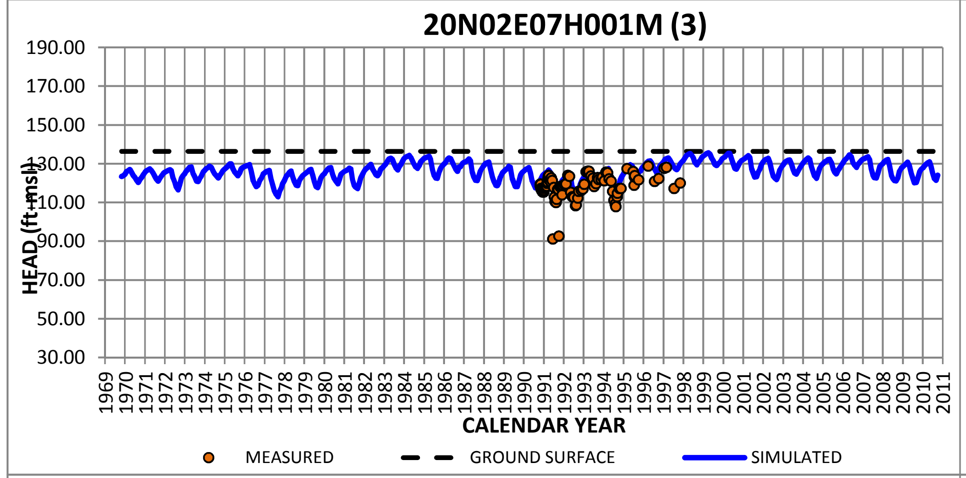
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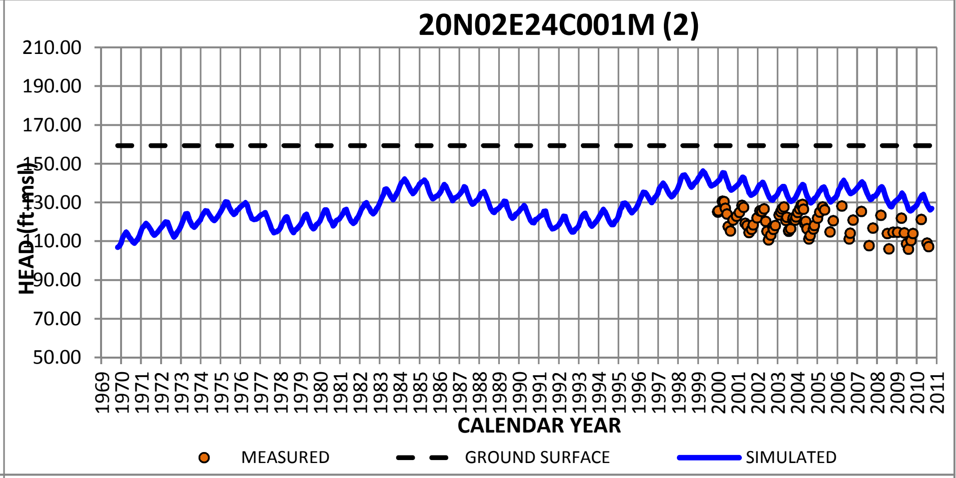
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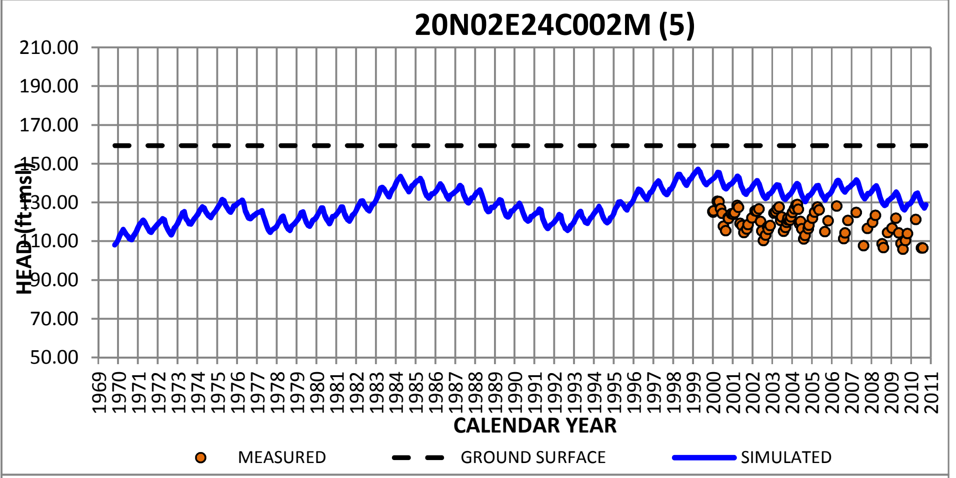
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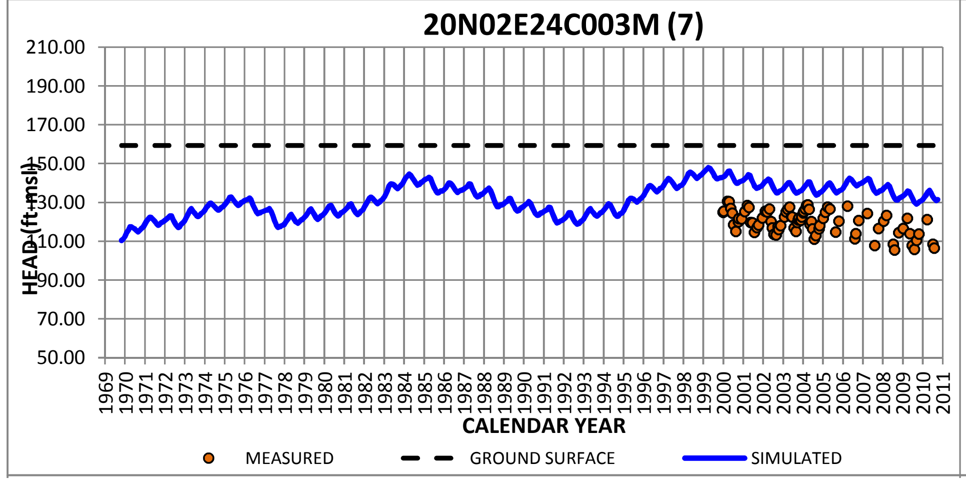
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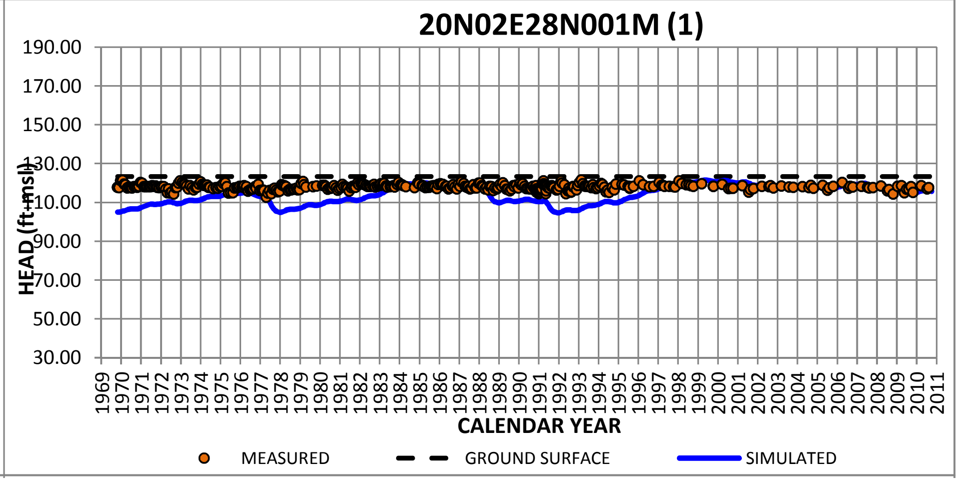
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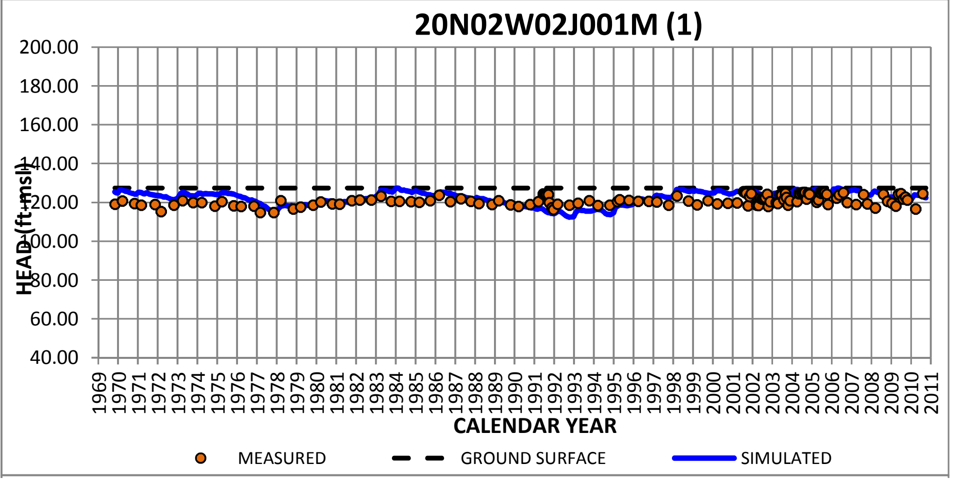
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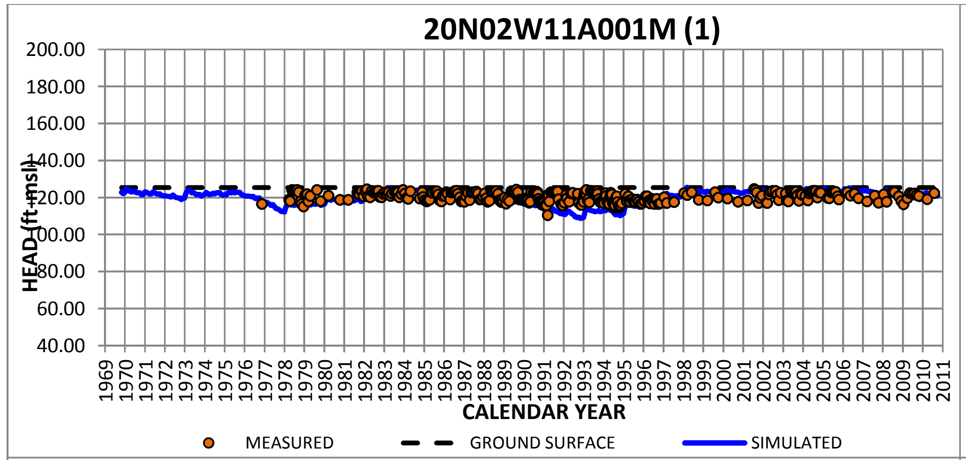
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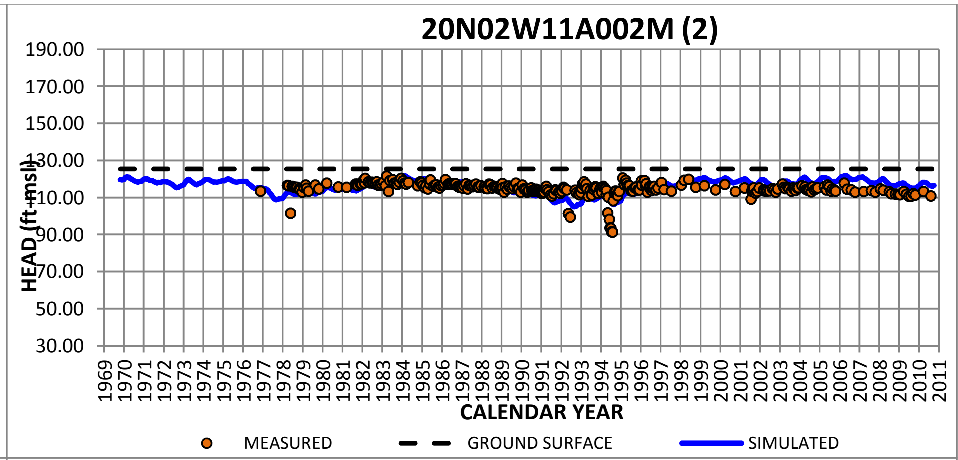
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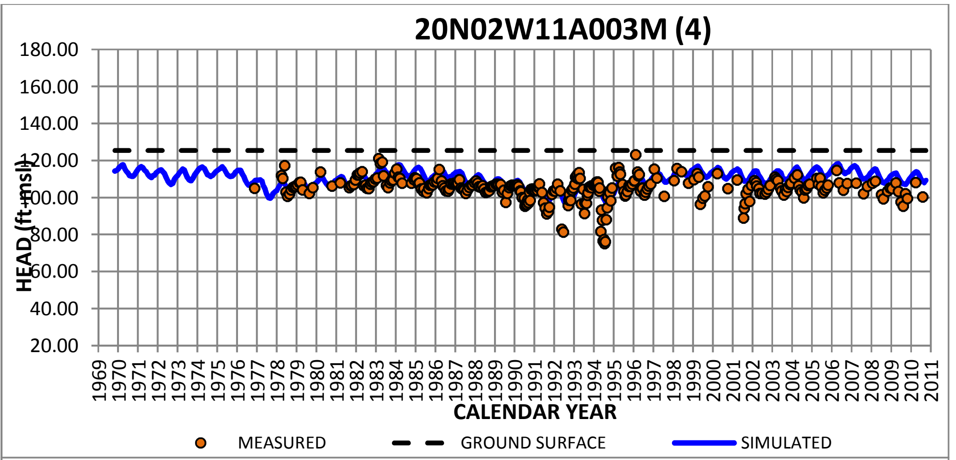
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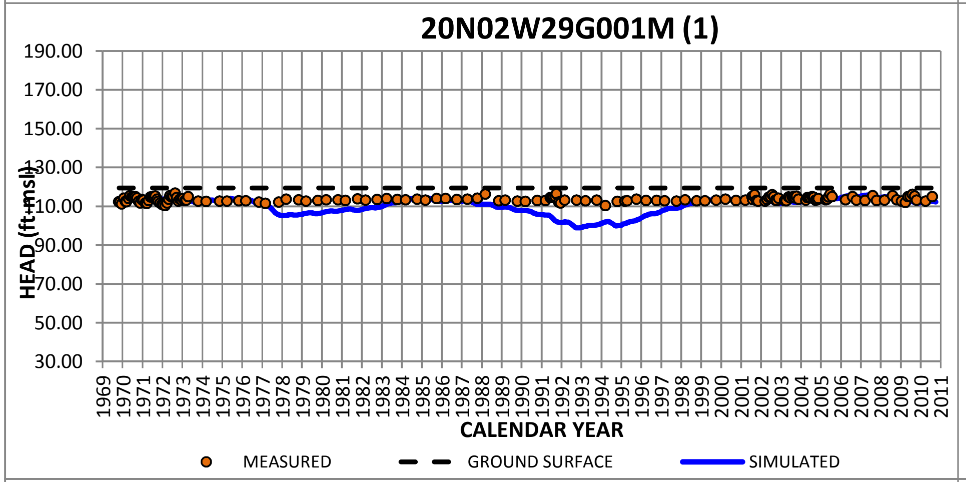
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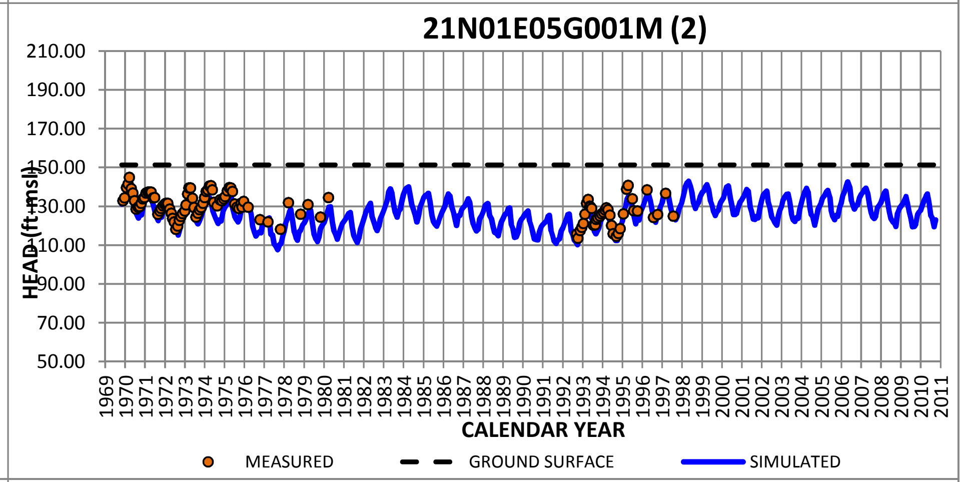
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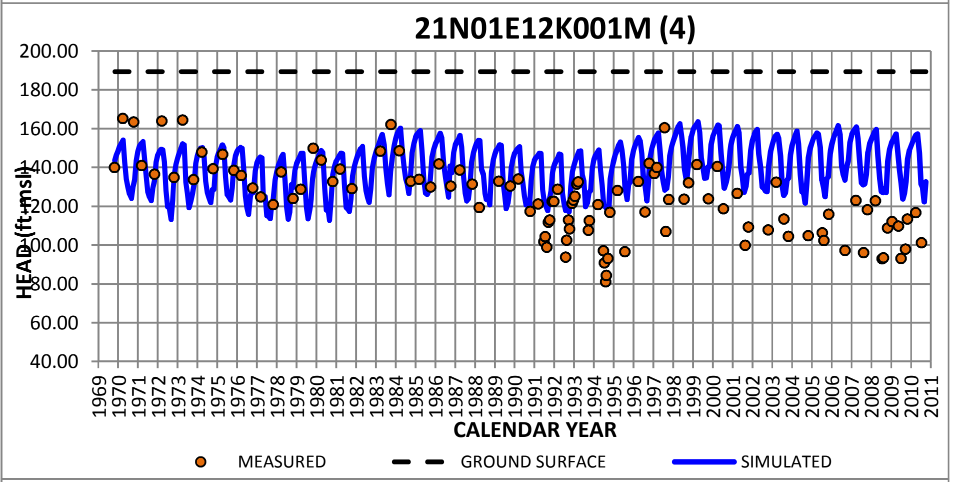
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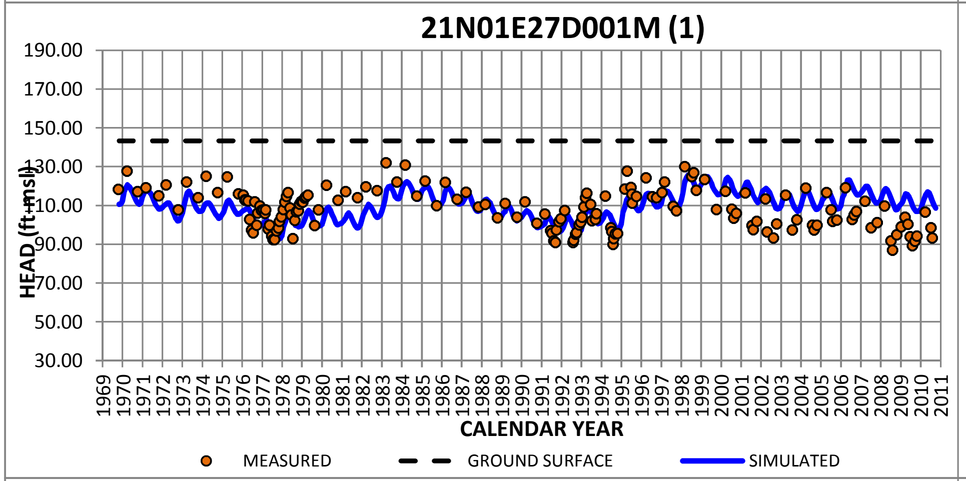
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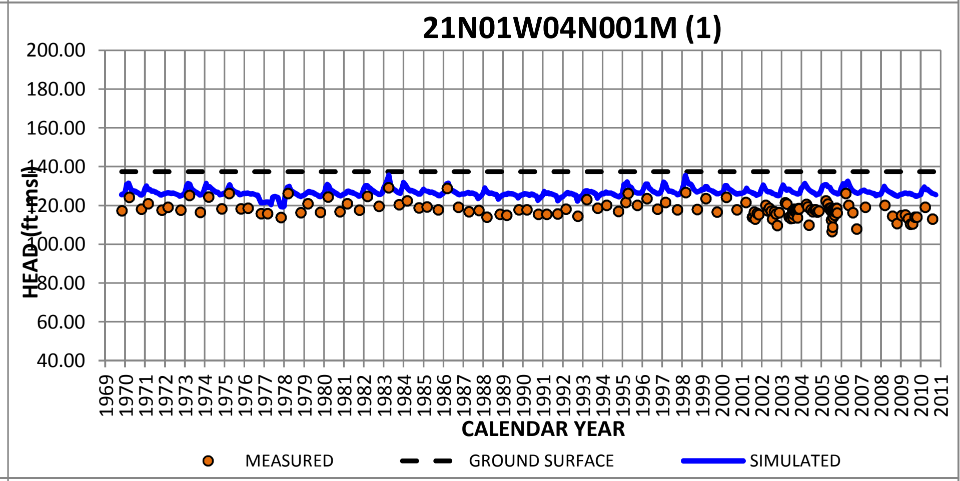
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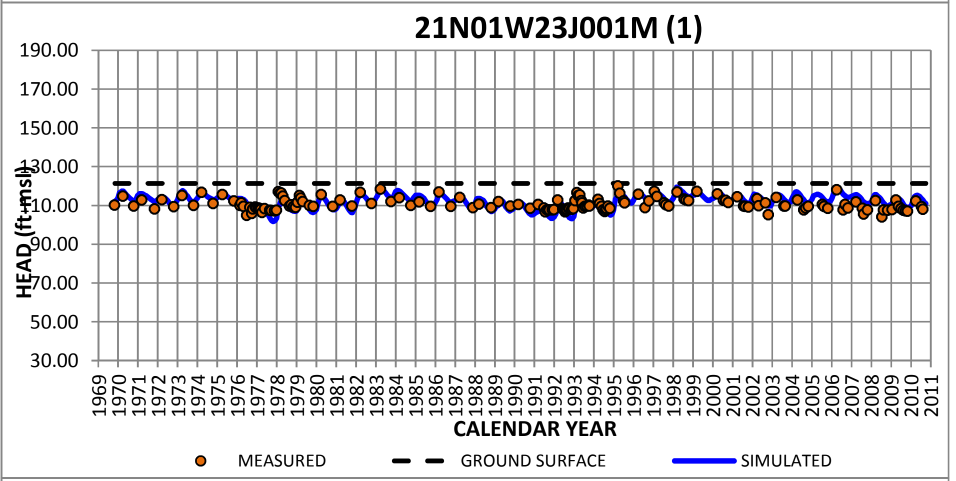
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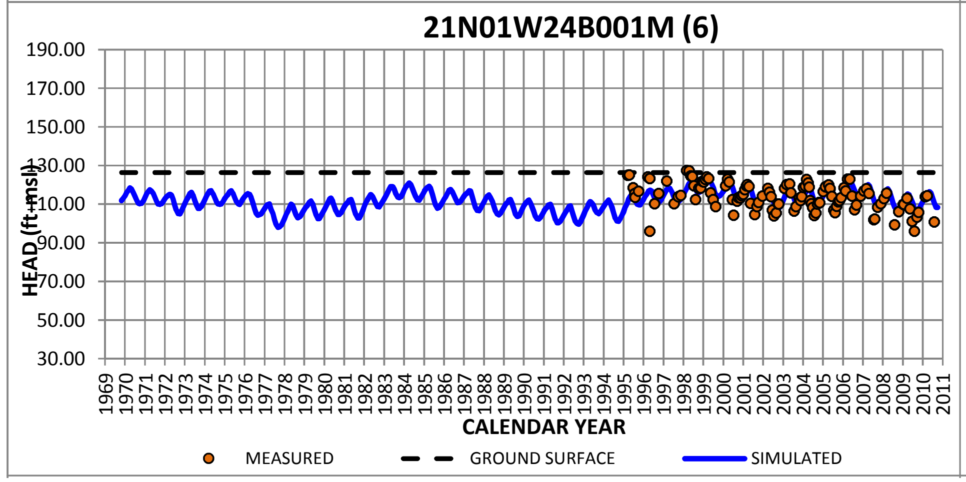
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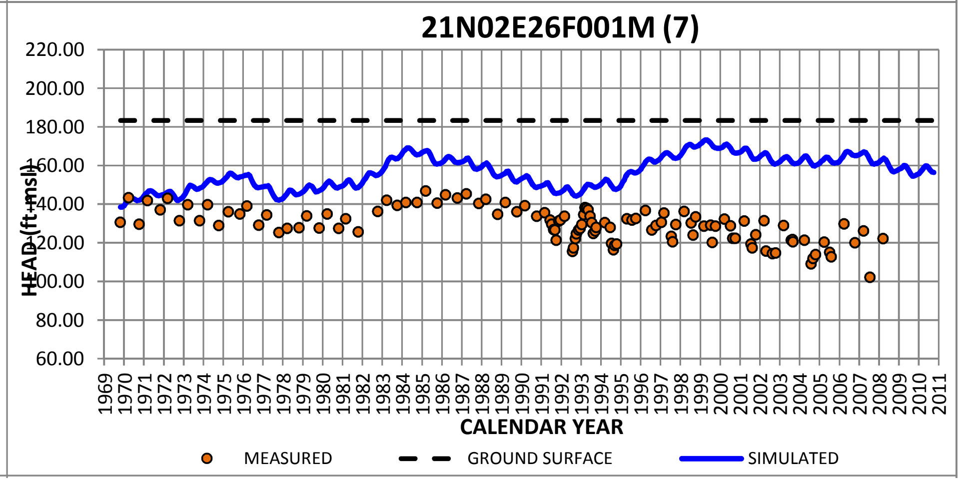
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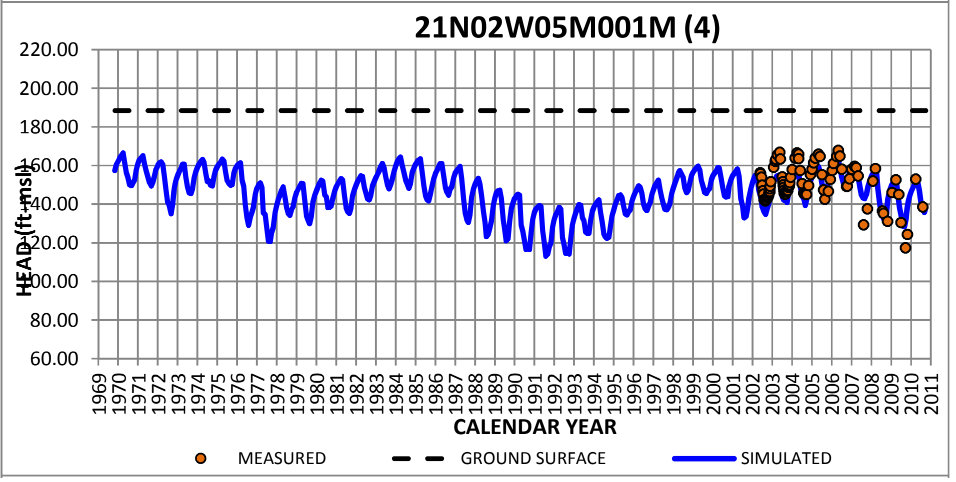
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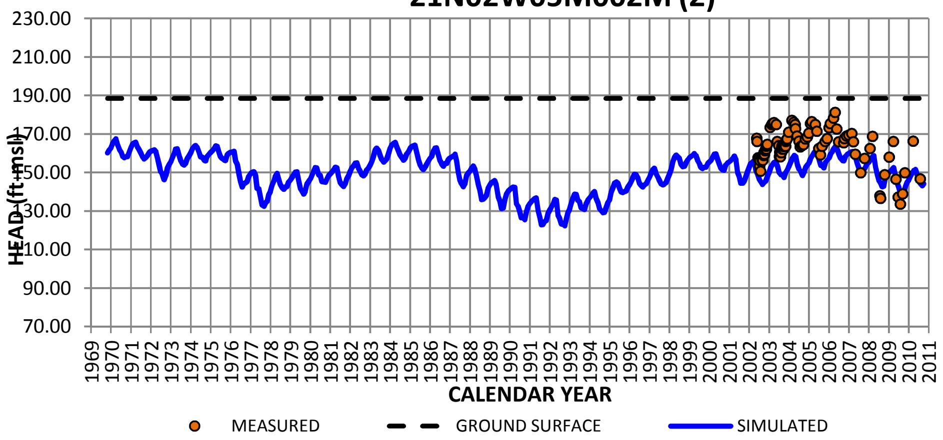

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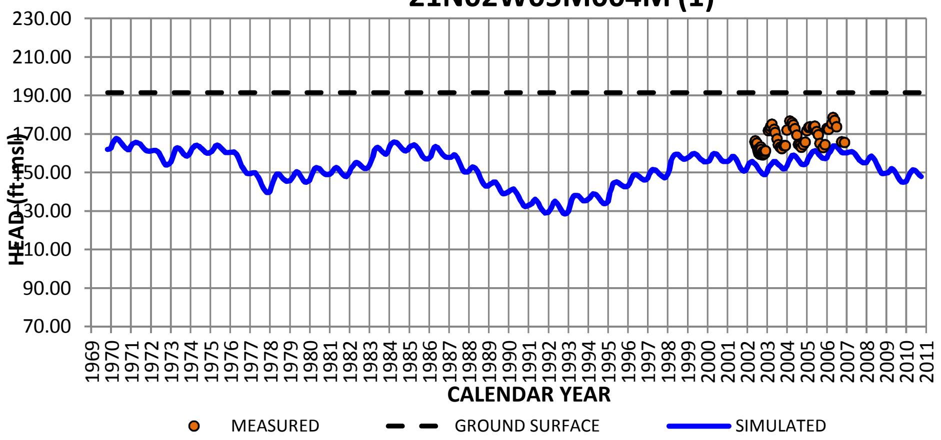

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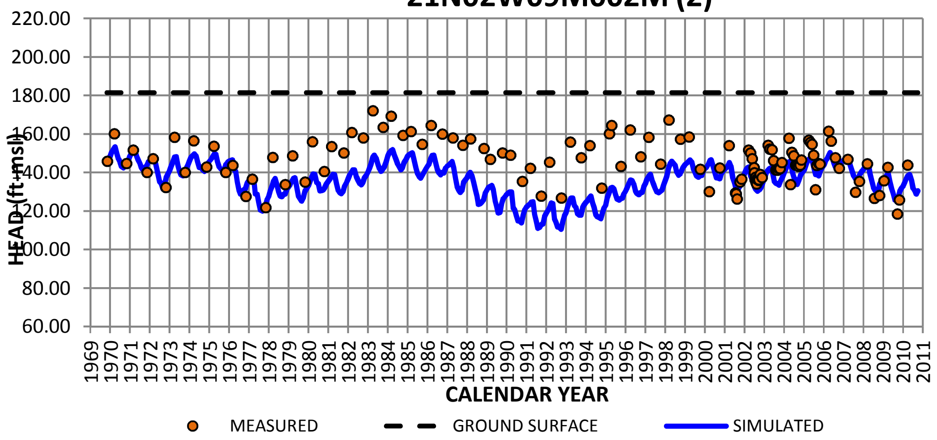

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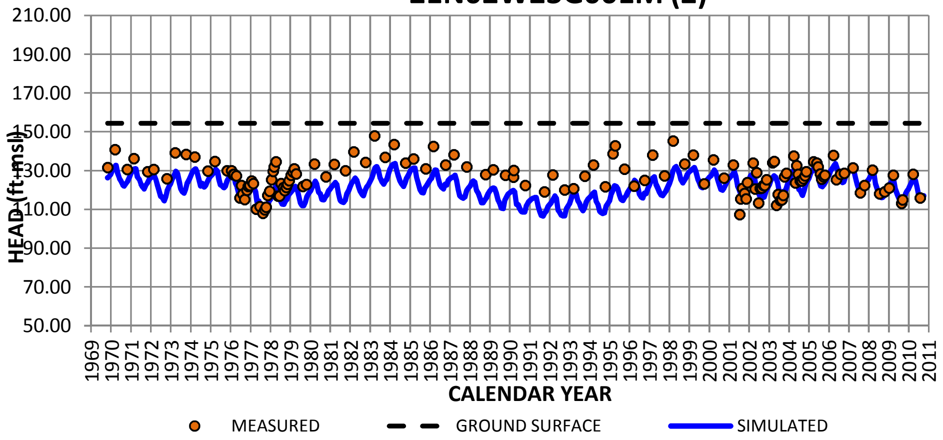

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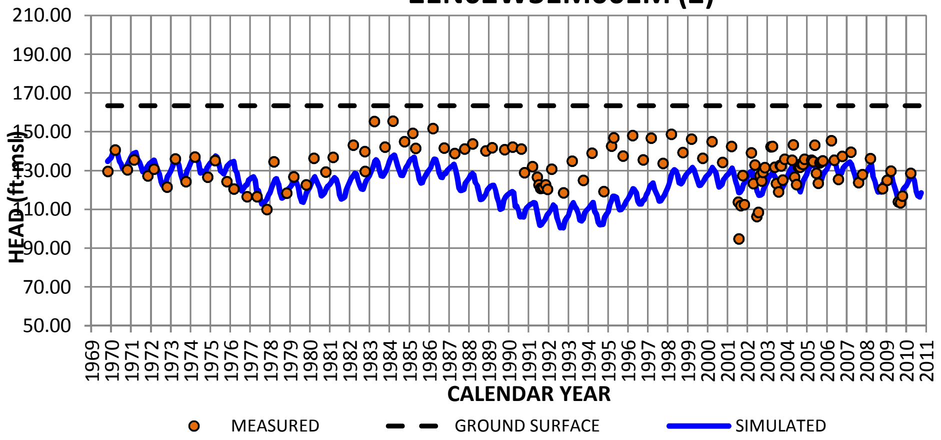

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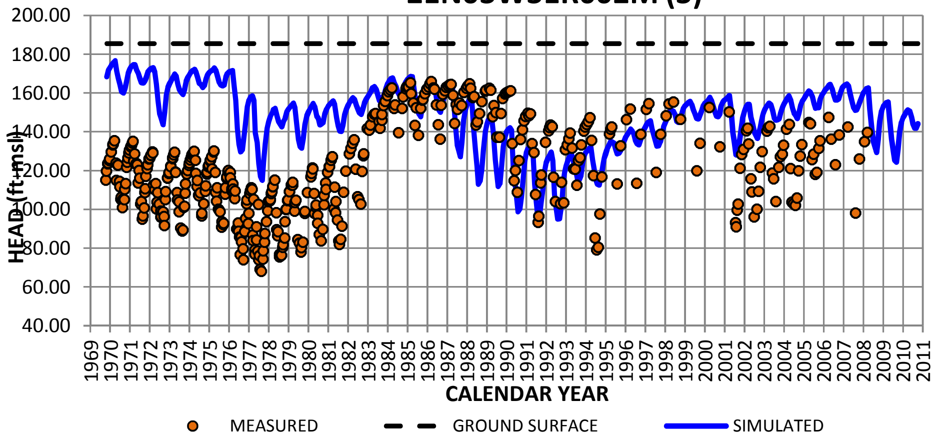

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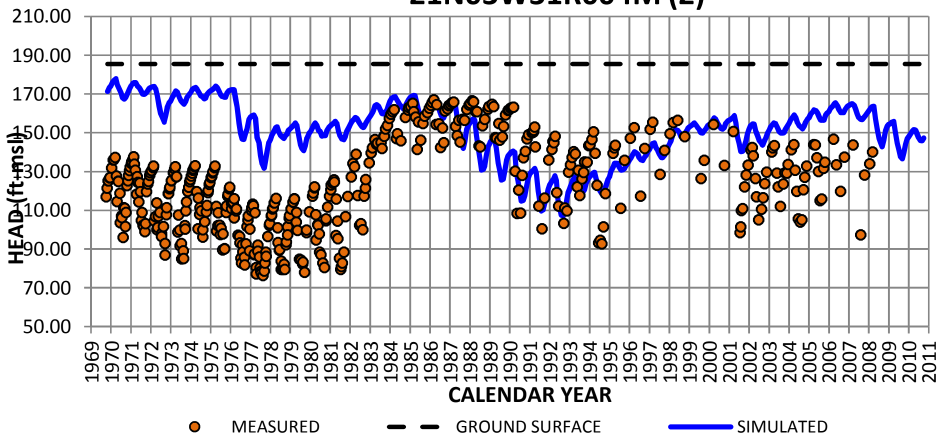

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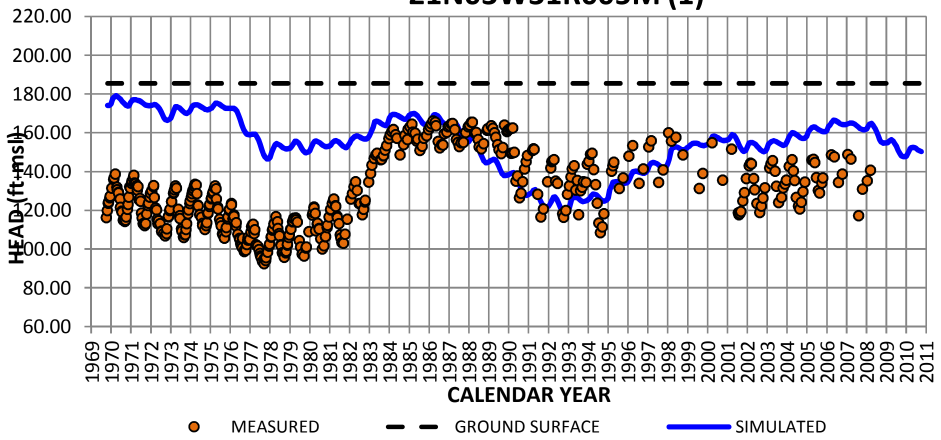

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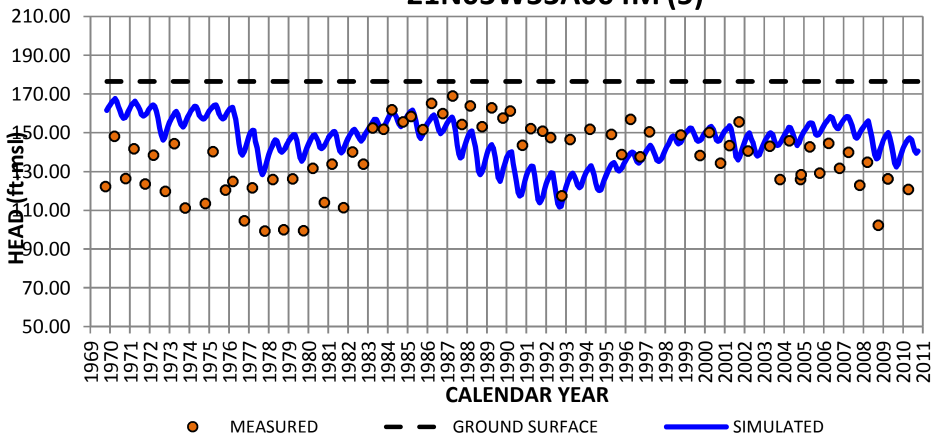

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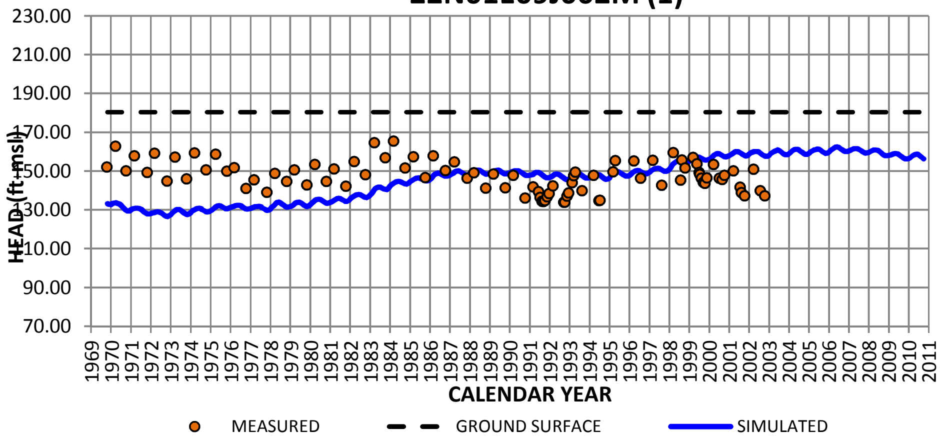

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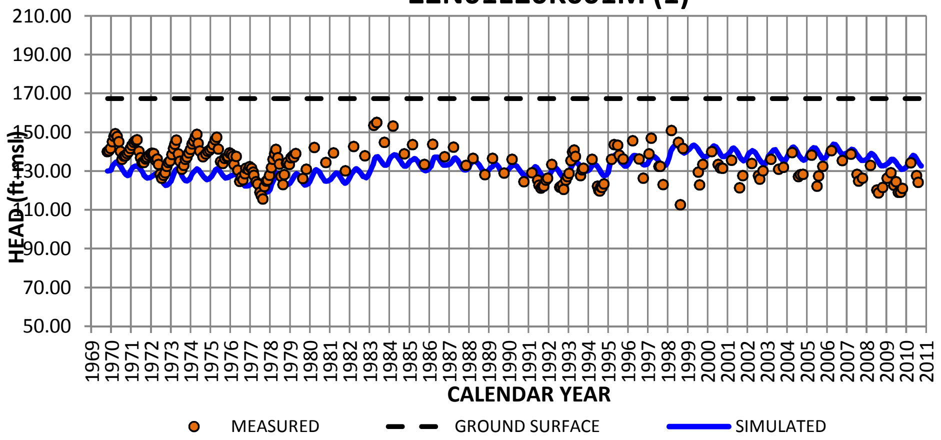

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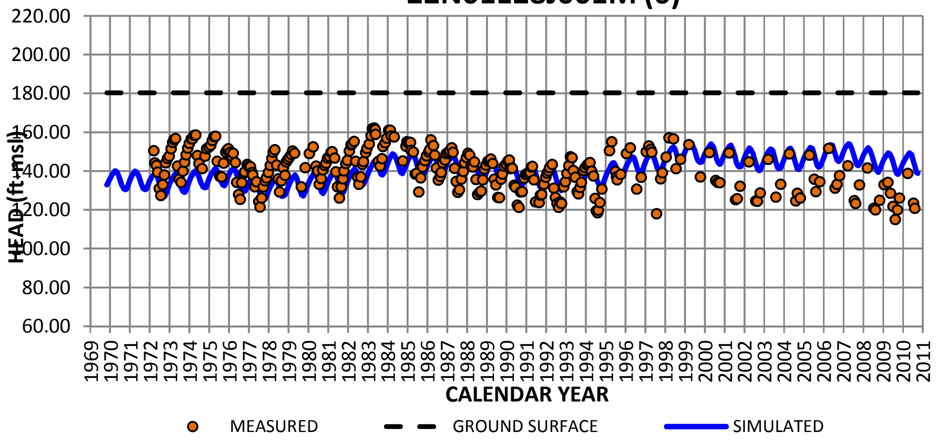

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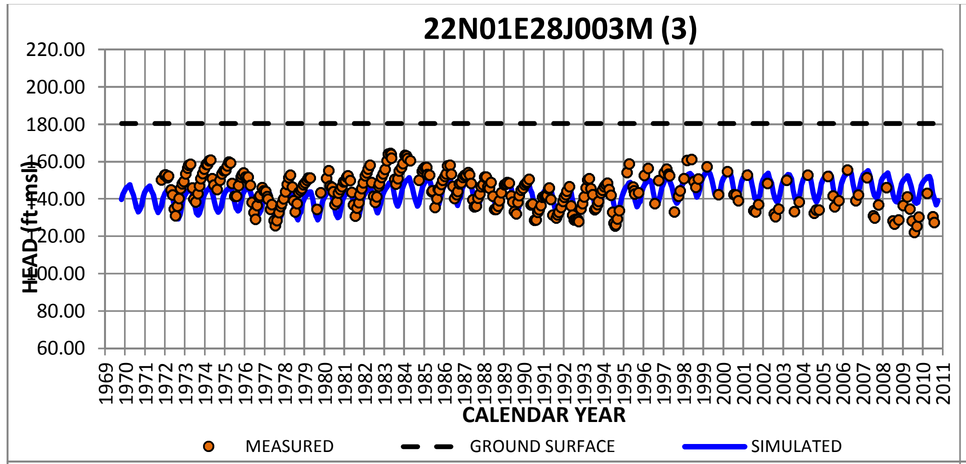

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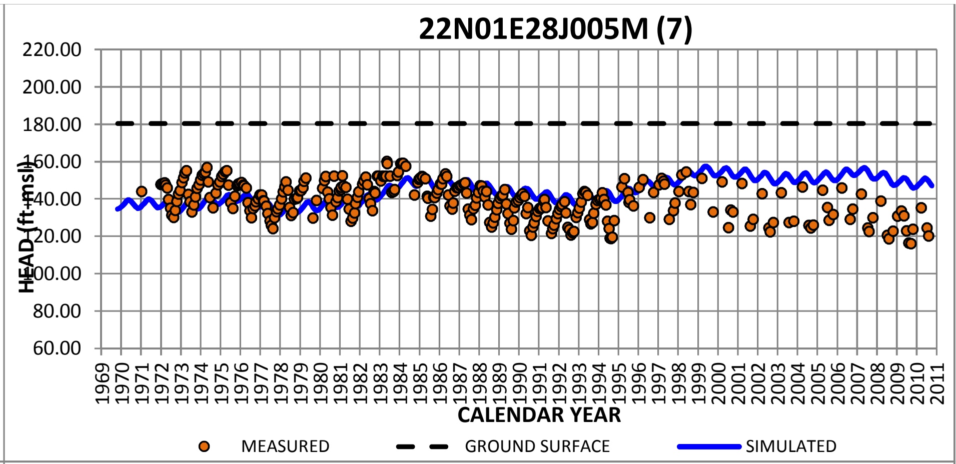

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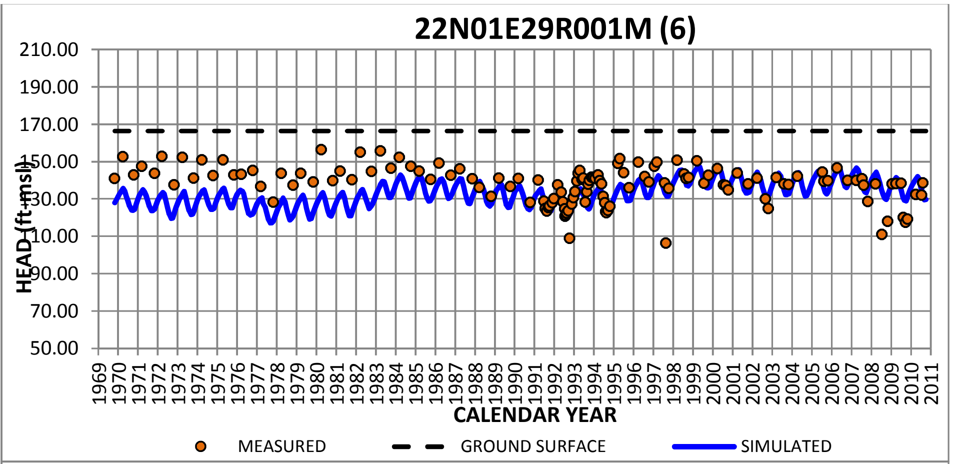

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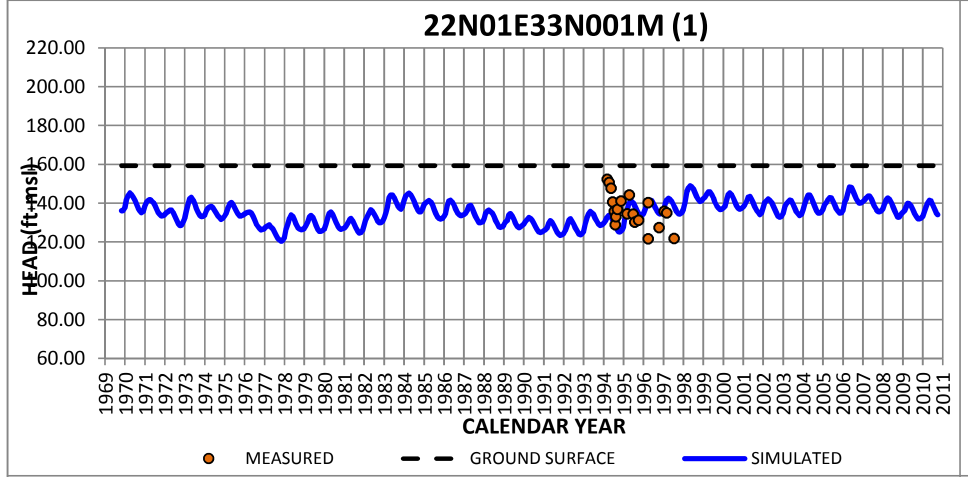

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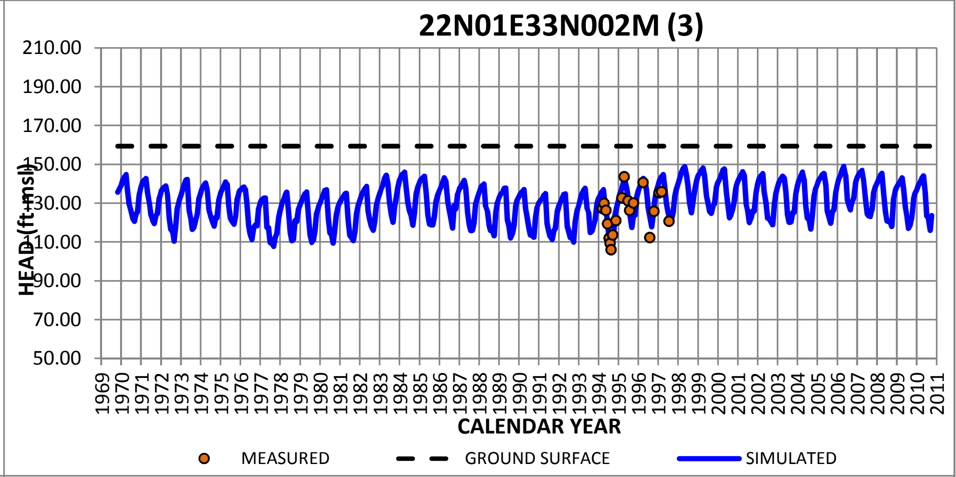

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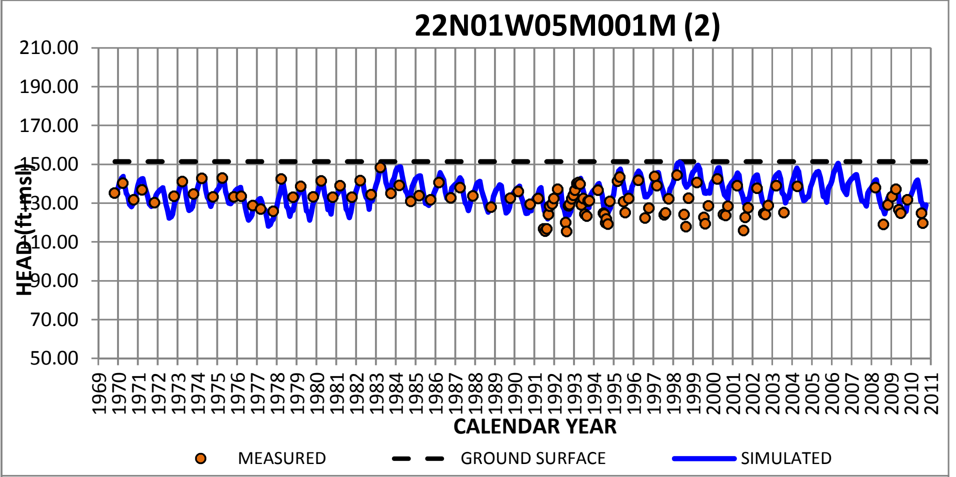

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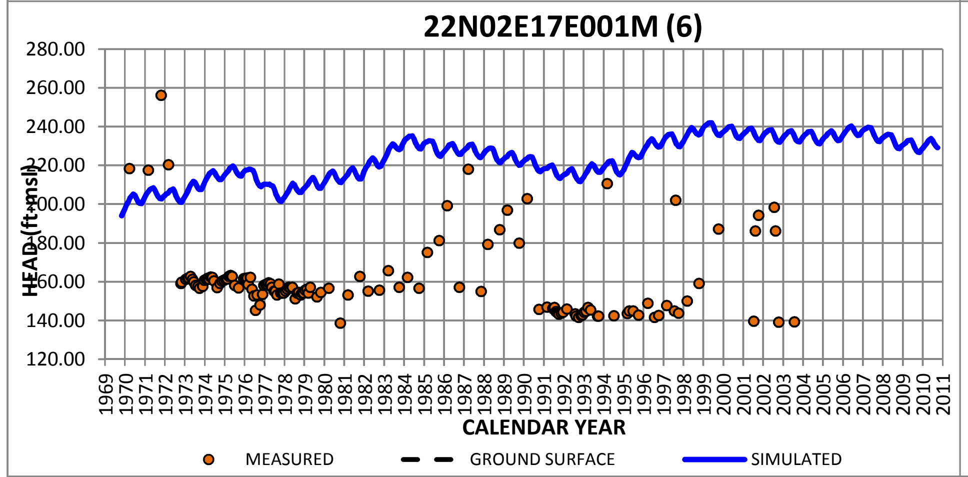

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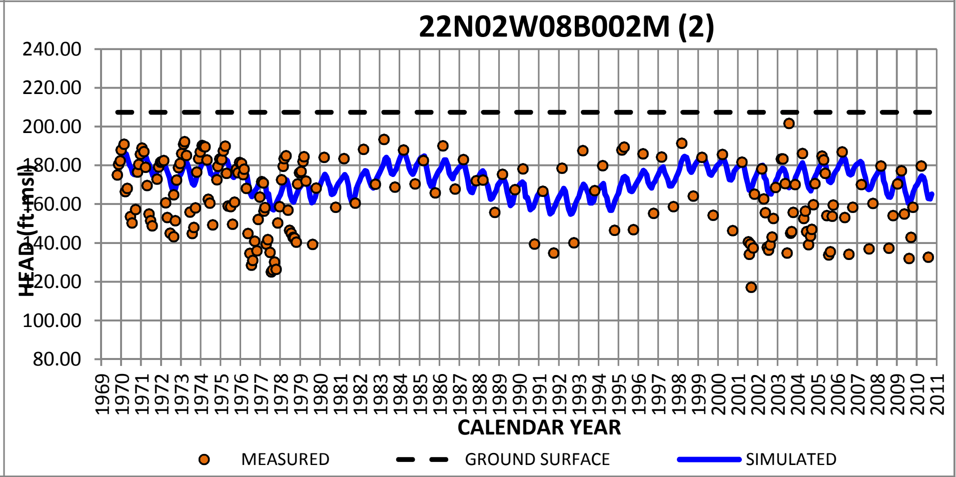

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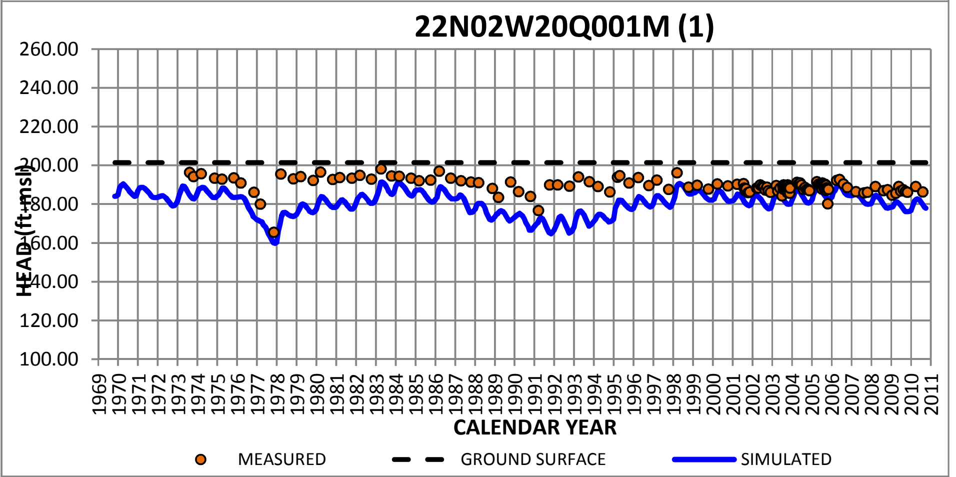

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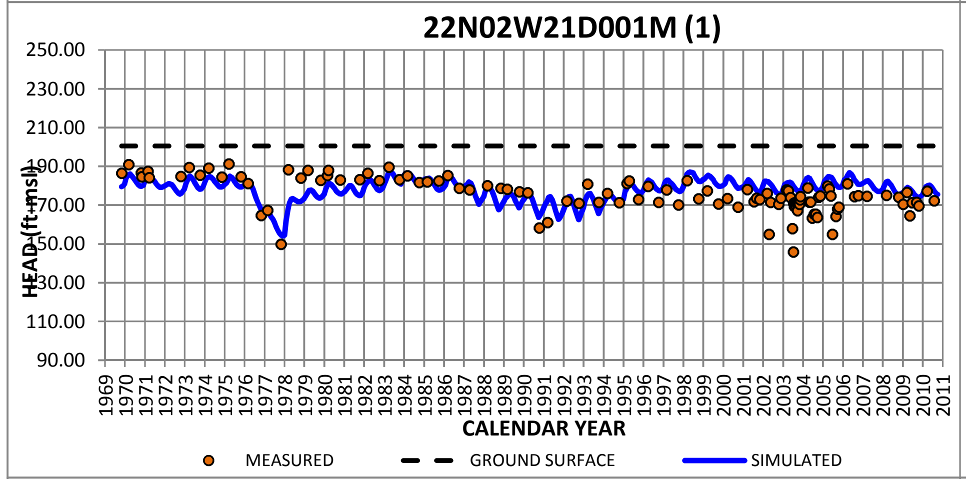

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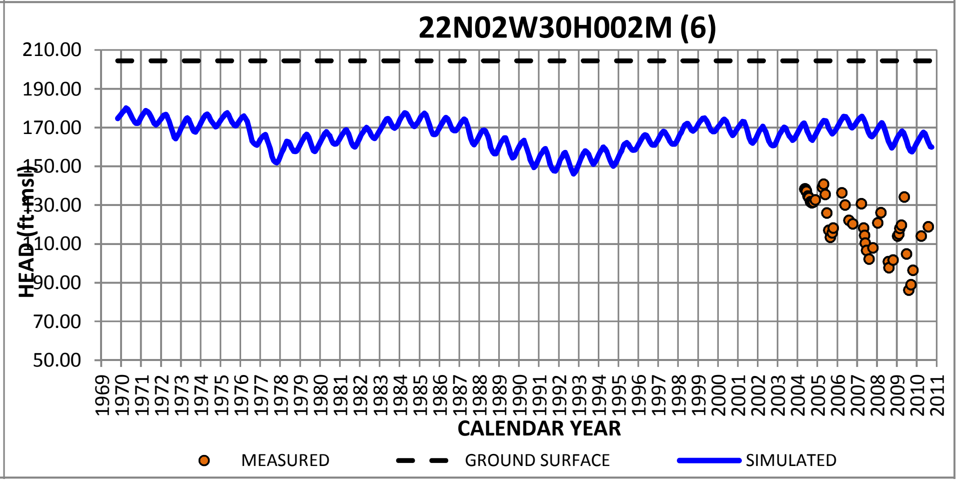

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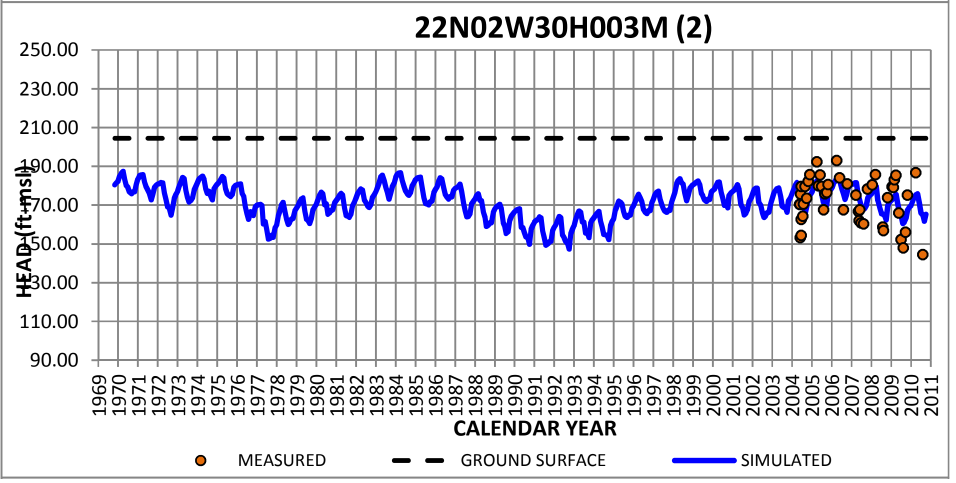

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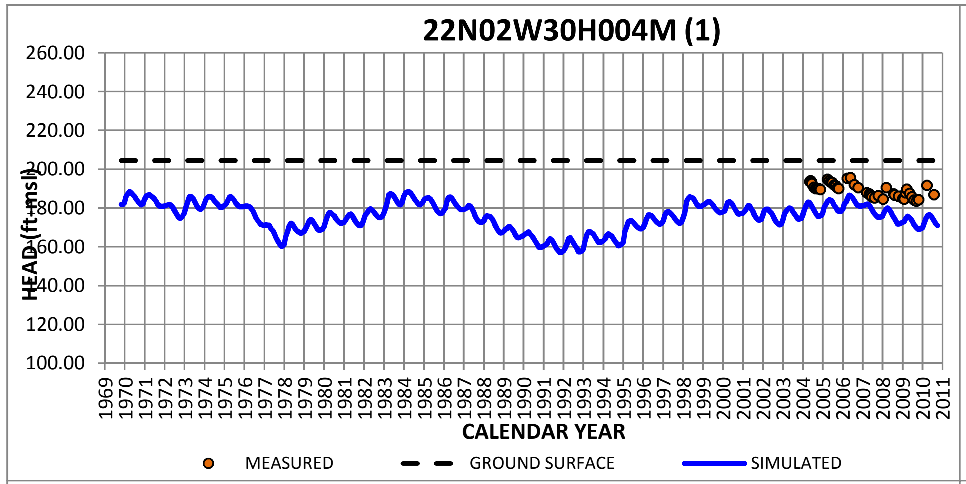
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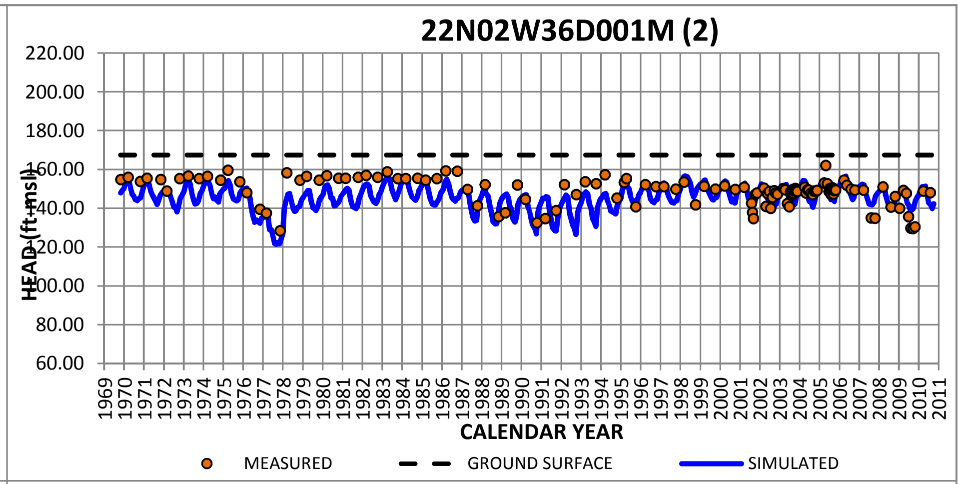
MEASURED
GROUND SURFACE
SIMULATED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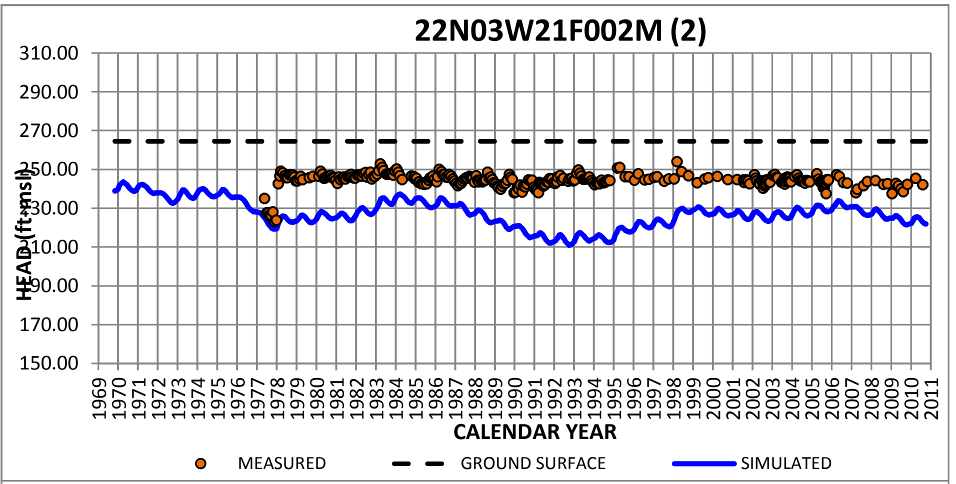
MEASURED
GROUND SURFACE
SIMULATED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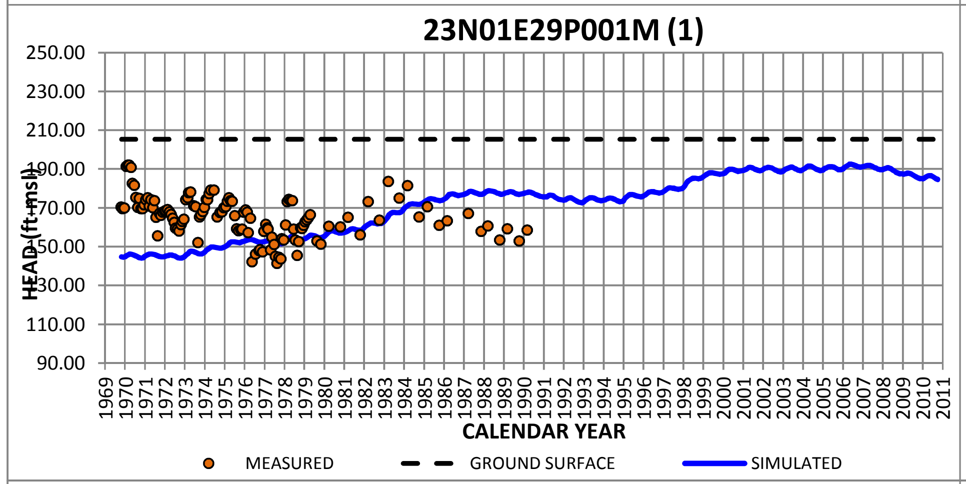
MEASURED
GROUND SURFACE
SIMULATED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CALENDAR YEAR
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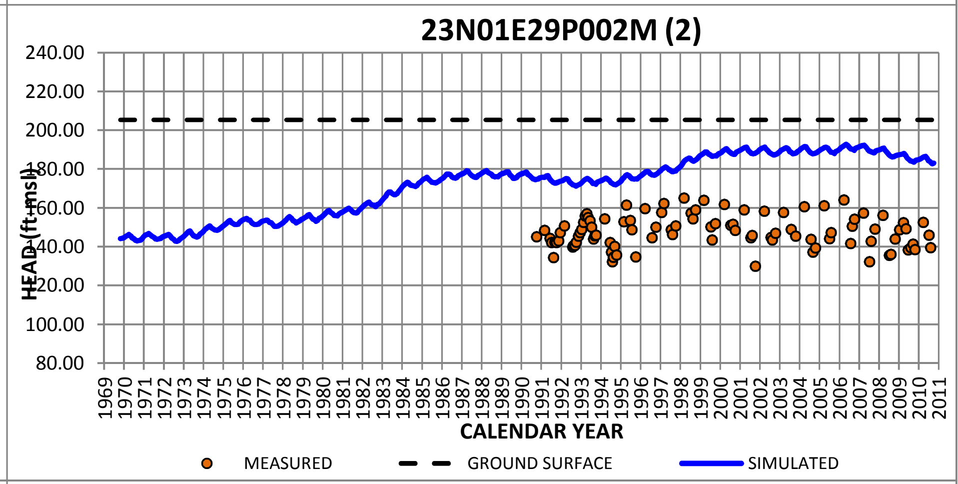
MEASURED
GROUND SURFACE
SIMULATED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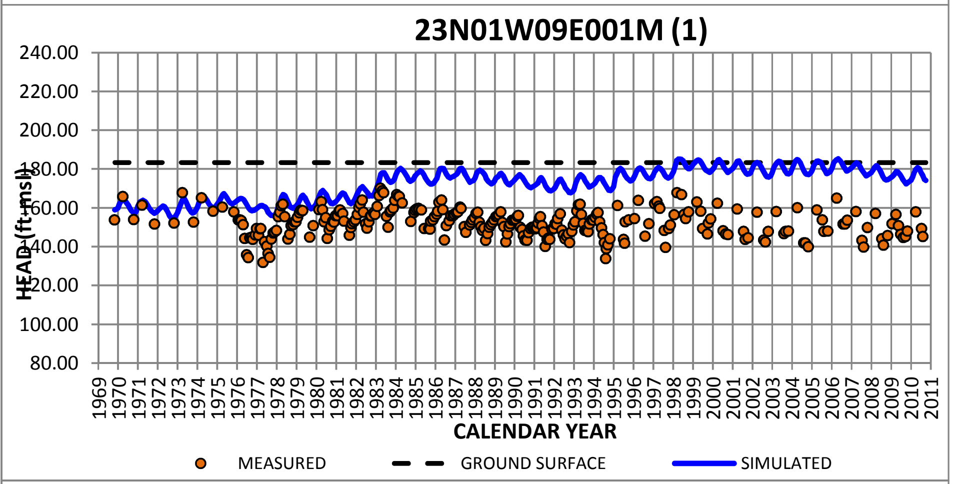
MEASURED
GROUND SURFACE
SIMULATED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MEASURED
GROUND SURFACE
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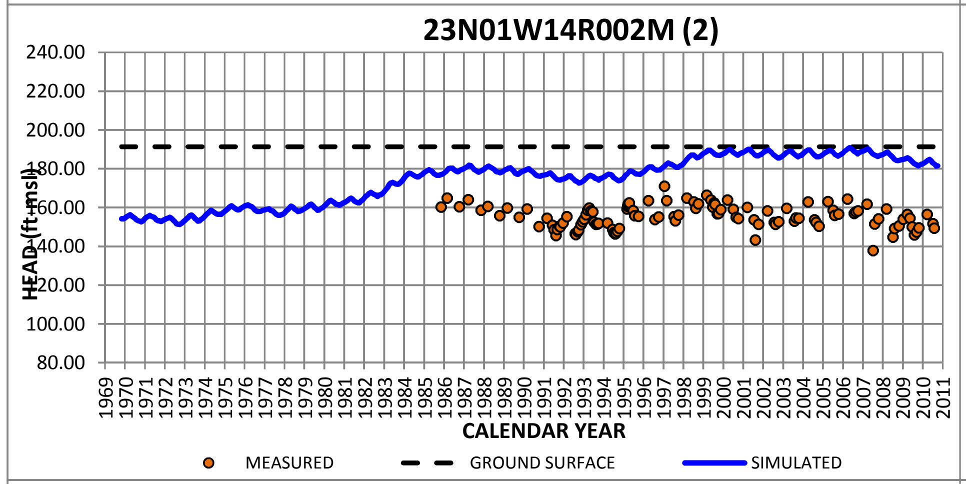
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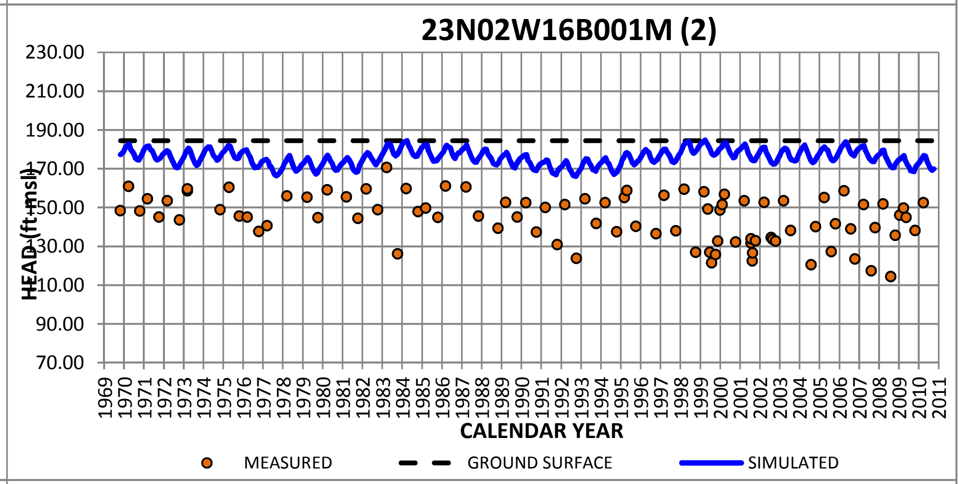
MEASURED
GROUND SURFACE
SIMULATED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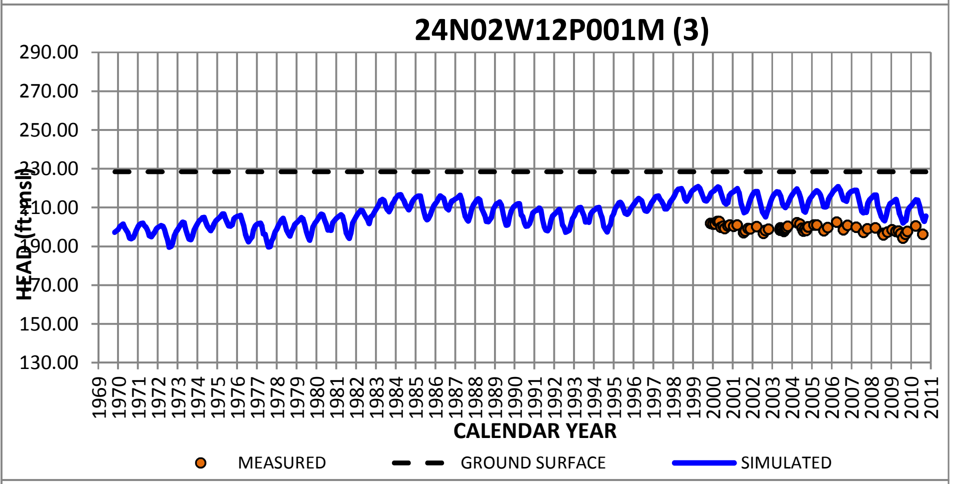
MEASURED
GROUND SURFACE
SIMULATED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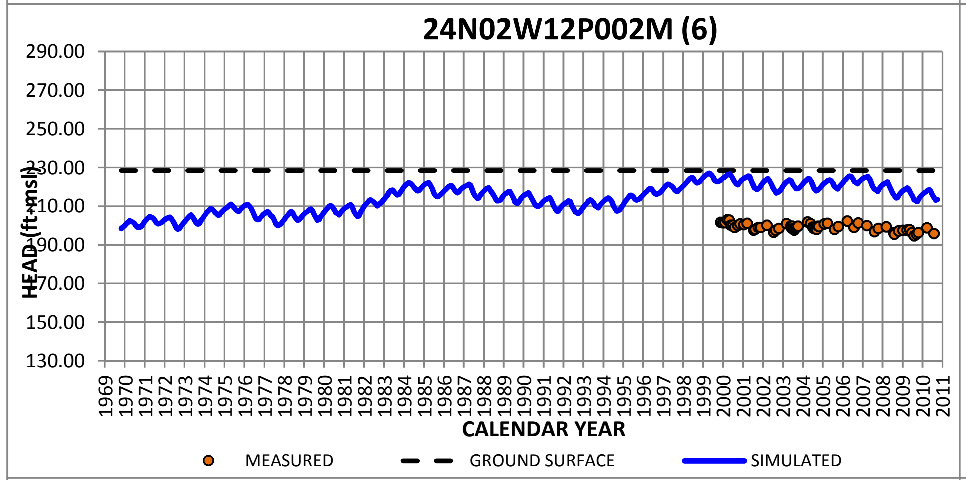
MEASURED
GROUND SURFACE
SIMULATED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CALENDAR YEAR
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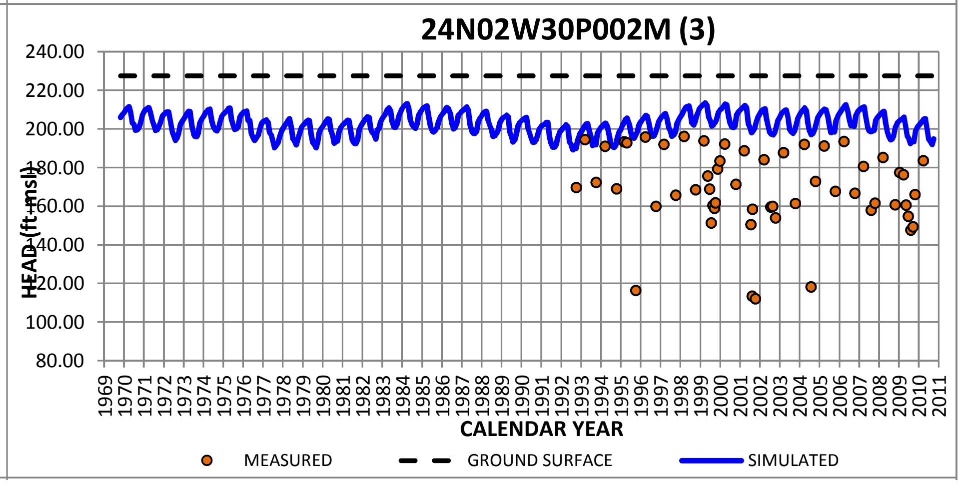
MEASURED
GROUND SURFACE
SIMULATED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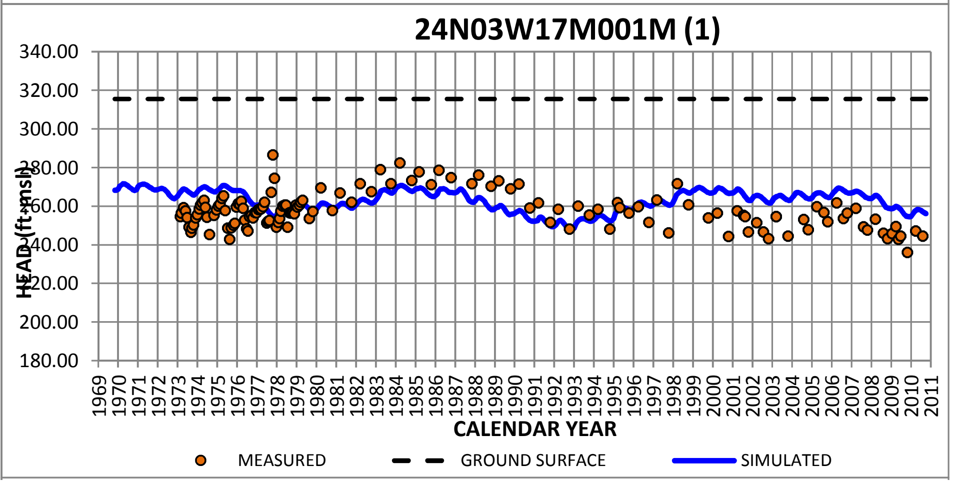
MEASURED
GROUND SURFACE
SIMULATED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CALENDAR YEAR
1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
MEASURED
GROUND SURFACE
SIMULATED

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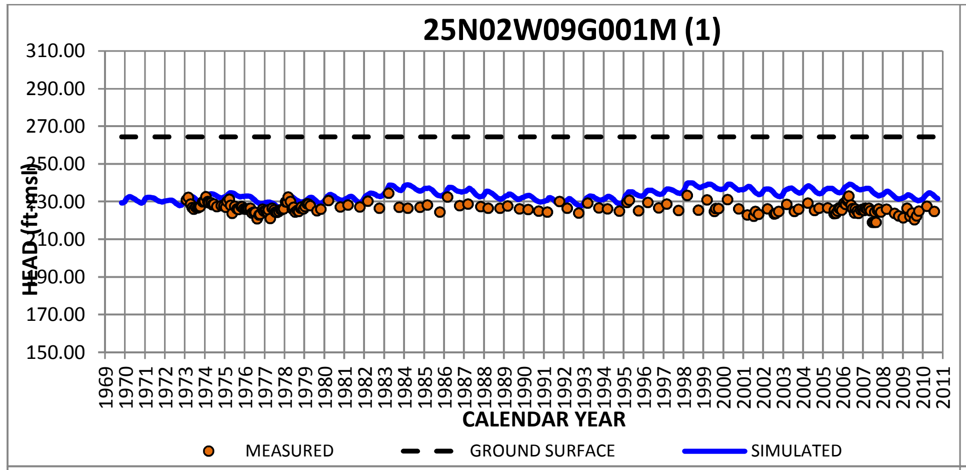
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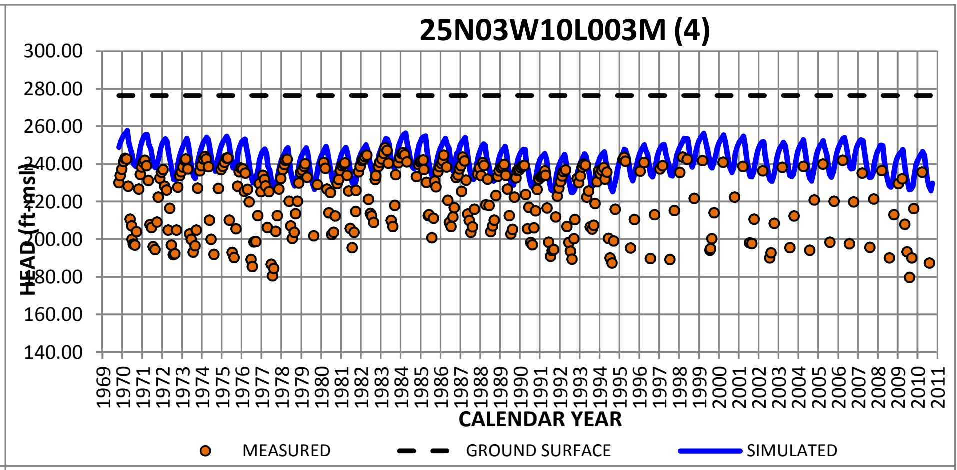
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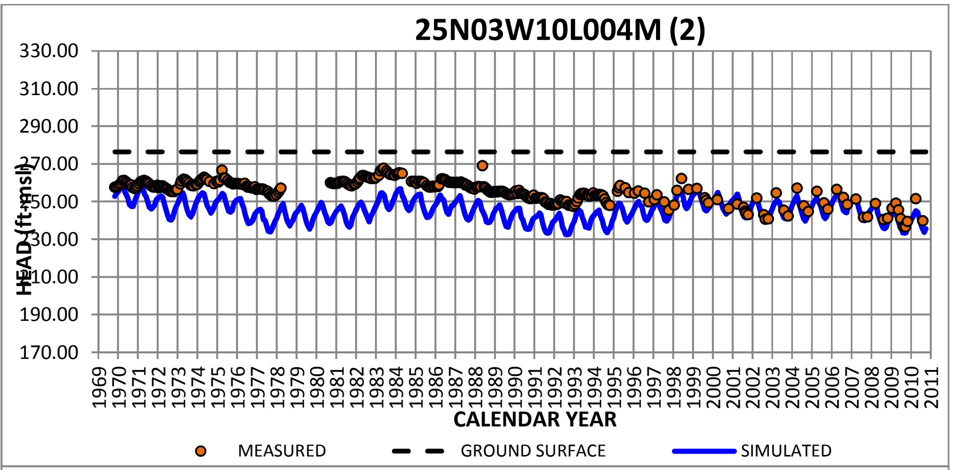
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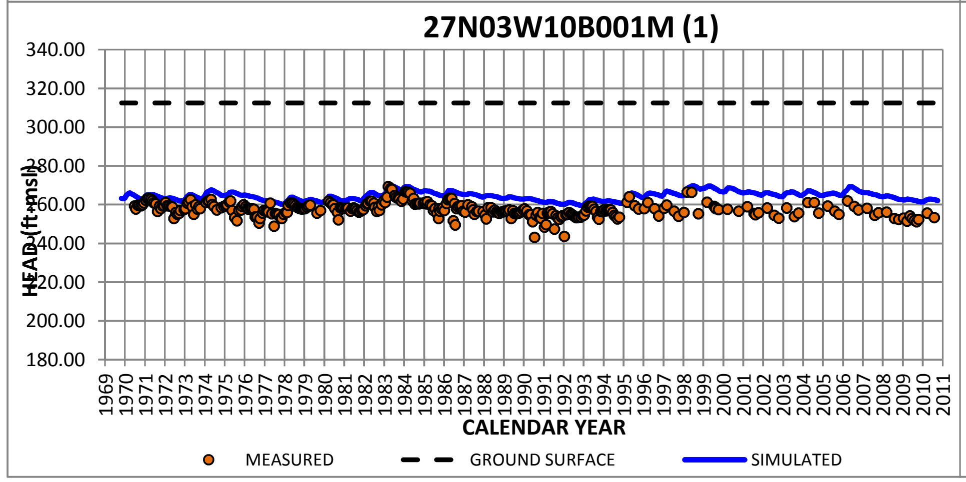
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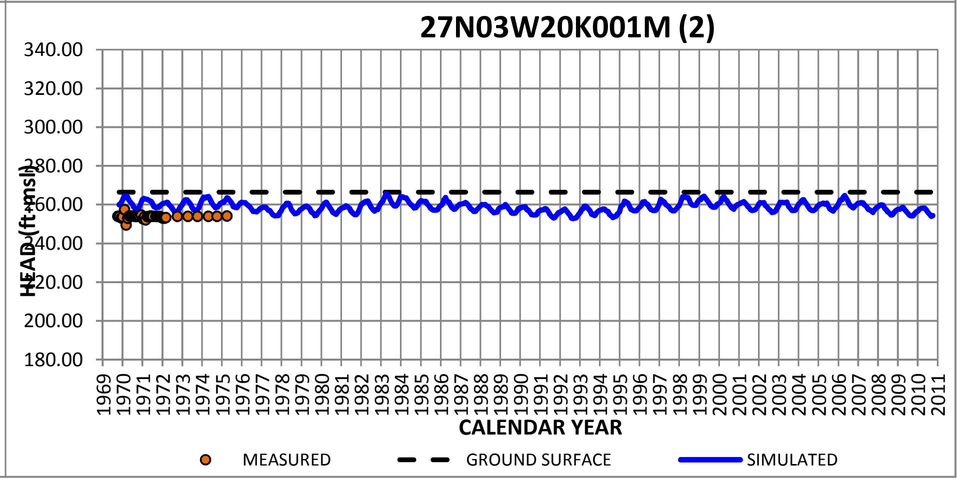
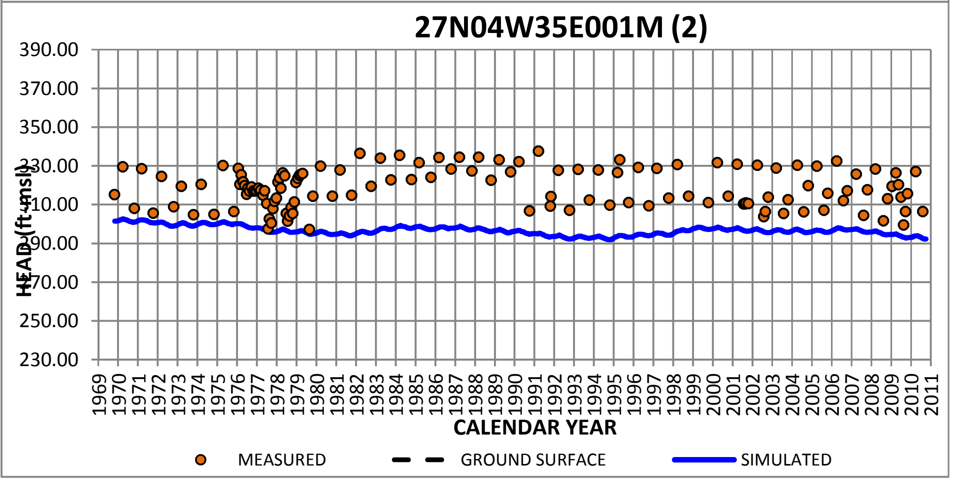

27N03W20K001M (2)


27N04W35E001M (2)

Appendix D
SACFEM2013.feb File

```
rem**************************************************************
rem        BEGIN SIMULATION
rem**************************************************************
LOAD
  h1=zero.par
  h2=zero.par
  h3=zero.par
  h4=zero.par
  h5=zero.par
  h6=zero.par
  h7=zero.par
  q1=zero.par
  q2=zero.par
  q3=zero.par
  q4=zero.par
  q5=zero.par
  q6=zero.par
  q7=zero.par
rem**********assign Transmissivity Values**********
LOAD
x3=SACFEM_v2_Kh_1_mpd_120313.par
x4=SACFEM_v2_Kh_2-5_mpd_120313.par
x5=SACFEM_v2_Kh_6-7_mpd_120313.par
EVAL
t1=mt1*x3
t2=mt2*x4
t3=mt3*x4
t4=mt4*x4
t5=mt5*x4
t6=mt6*x5
t7=mt7*x5
SAVE
t1=Trans.t1
t2=Trans.t2
t3=Trans.t3
```

```
t4=Trans.t4
t5=Trans.t5
t6=Trans.t6
t7=Trans.t7
rem**********assign vertical resistance values **********
LOAD
x6=SACFEM_v2_KhKv_Ratio_500.par
EVAL
c2=50*mt1^2/2/t1+x6*mt2^2/2/t2
c3=x6*mt2^2/2/t2+x6*mt3^2/2/t3
c4=x6*mt3^2/2/t3+x6*mt4^2/2/t4
c5=x6*mt4^2/2/t4+x6*mt5^2/2/t5
c6=x6*mt5^2/2/t5+x6*mt6^2/2/t6
c7=x6*mt6^2/2/t6+x6*mt7^2/2/t7
rem**********load extra register files **********
LOAD
x1=SACFEM_v2_GSE_Combined_mNAVD88_120313.par
x8=SACFEM_v2_WL1_042314.par
rem**********open ftq files**********
LOAD
lb=SACFEM_v2_all.lb
open-q all=all.ftq upper=1 lower=7
rem**********open ftq files for Water Budget Areas**********
LOAD
lb=SACFEM_v2_WBAs_121013.lb
open-q
WBA_2=WBA_2.ftq upper=1 lower=7
WBA_3=WBA_3.ftq upper=1 lower=7
WBA_4=WBA_4.ftq upper=1 lower=7
WBA_5=WBA_5.ftq upper=1 lower=7
WBA_6=WBA_6.ftq upper=1 lower=7
WBA_9=WBA_9.ftq upper=1 lower=7
WBA_10=WBA_10.ftq upper=1 lower=7
WBA_11=WBA_11.ftq upper=1 lower=7
WBA_12=WBA_12.ftq upper=1 lower=7
```

```
WBA_13=WBA_13.ftq upper=1 lower=7
WBA_14=WBA_14.ftq upper=1 lower=7
WBA_16=WBA_16.ftq upper=1 lower=7
WBA_18=WBA_18.ftq upper=1 lower=7
WBA_19=WBA_19.ftq upper=1 lower=7
WBA_20=WBA_20.ftq upper=1 lower=7
WBA_21=WBA_21.ftq upper=1 lower=7
WBA_22=WBA_22.ftq upper=1 lower=7
WBA_23=WBA_23.ftq upper=1 lower=7
WBA_24=WBA_24.ftq upper=1 lower=7
WBA_25=WBA_25.ftq upper=1 lower=7
WBA_27=WBA_27.ftq upper=1 lower=7
WBA_07N=WBA_07N.ftq upper=1 lower=7
WBA_07S=WBA_07S.ftq upper=1 lower=7
WBA_08N=WBA_08N.ftq upper=1 lower=7
WBA_08NS=WBA_08NS.ftq upper=1 lower=7
WBA_08S=WBA_08S.ftq upper=1 lower=7
WBA_15N=WBA_15N.ftq upper=1 lower=7
WBA_15S=WBA_15S.ftq upper=1 lower=7
WBA_17N=WBA_17N.ftq upper=1 lower=7
WBA_17S=WBA_17S.ftq upper=1 lower=7
WBA_26N=WBA_26N.ftq upper=1 lower=7
WBA_26S=WBA_26S.ftq upper=1 lower=7
no_WBA_North=no_WBA_North.ftq upper=1 lower=7
no_WBA_South=no_WBA_South.ftq upper=1 lower=7
rem**********open ftq files for streams**********
LOAD
lb=SACFEM_v2_Streams_FTQ_042314.lb
open-q
AMERICAN_RIV=AMERICAN_RIV.ftq upper=1 lower=1
ANTELOPE_CR=ANTELOPE_CR.ftq upper=1 lower=1
AUBURN_RAVINE=AUBURN_RAVINE.ftq upper=1 lower=1
BEAR_RIV=BEAR_RIV.ftq upper=1 lower=1
BIG_CHICO_CR=BIG_CHICO_CR.ftq upper=1 lower=1
BLACK_BUTTE_RESERVOIR=BLACK_BUTTE_RESERVOIR.ftq upper=1 lower=1
```

```
BUTTE_BYPASS=BUTTE_BYPASS.ftq upper=1 lower=1
BUTTE_CR=BUTTE_CR.ftq upper=1 lower=1
CACHE_CR=CACHE_CR.ftq upper=1 lower=1
COLUSA_BD=COLUSA_BD.ftq upper=1 lower=1
CONSUMNES_RIV=CONSUMNES_RIV.ftq upper=1 lower=1
COON_CR=COON_CR.ftq upper=1 lower=1
CORTINA_CR=CORTINA_CR.ftq upper=1 lower=1
DEER_CR_BUTTECO=DEER_CR_BUTTECO.ftq upper=1 lower=1
DEER_CR_CONSUMNES=DEER_CR_CONSUMNES.ftq upper=1 lower=1
DRY_CR_PUTAH=DRY_CR_PUTAH.ftq upper=1 lower=1
DRY_CR_YUBA=DRY_CR_YUBA.ftq upper=1 lower=1
EASTSIDE_CROSS_CANAL=EASTSIDE_CROSS_CANAL.ftq upper=1 lower=1
ELDER_CR=ELDER_CR.ftq upper=1 lower=1
FEATHER_RIV=FEATHER_RIV.ftq upper=1 lower=1
FRENCH_CR=FRENCH_CR.ftq upper=1 lower=1
FRESHWATER_CR=FRESHWATER_CR.ftq upper=1 lower=1
FUNKS_CR=FUNKS_CR.ftq upper=1 lower=1
GCID_CANAL=GCID_CANAL.ftq upper=1 lower=1
HONCUT_CR=HONCUT_CR.ftq upper=1 lower=1
LITTLE_CHICO_CR=LITTLE_CHICO_CR.ftq upper=1 lower=1
LURLINE_CR=LURLINE_CR.ftq upper=1 lower=1
MILL_CR_BUTTECO=MILL_CR_BUTTECO.ftq upper=1 lower=1
MILL_CR_THOMES=MILL_CR_THOMES.ftq upper=1 lower=1
MOKELUMNE_RIV=MOKELUMNE_RIV.ftq upper=1 lower=1
N_HONCUT_CR=N_HONCUT_CR.ftq upper=1 lower=1
NF_WALKER_CR=NF_WALKER_CR.ftq upper=1 lower=1
PAYNES_CR=PAYNES_CR.ftq upper=1 lower=1
PUTAH_CR=PUTAH_CR.ftq upper=1 lower=1
RD108_MAIN_DRAIN=RD108_MAIN_DRAIN.ftq upper=1 lower=1
S_HONCUT_CR=S_HONCUT_CR.ftq upper=1 lower=1
SACRAMENTO_RIV=SACRAMENTO_RIV.ftq upper=1 lower=1
SALT_RIV=SALT_RIV.ftq upper=1 lower=1
SAN_JOAQUIN_RIV=SAN_JOAQUIN_RIV.ftq upper=1 lower=1
SAND_CR=SAND_CR.ftq upper=1 lower=1
SEVENMILE_CR=SEVENMILE_CR.ftq upper=1 lower=1
```

```
SF_WILLOW_CR=SF_WILLOW_CR.ftq upper=1 lower=1
SPRING_VALLEY_CR=SPRING_VALLEY_CR.ftq upper=1 lower=1
STONE_CORRAL_CR=STONE_CORRAL_CR.ftq upper=1 lower=1
STONEY_CR=STONEY_CR.ftq upper=1 lower=1
SUTTER_BYPASS=SUTTER_BYPASS.ftq upper=1 lower=1
SYCAMORE_SLOUGH_LOWER=SYCAMORE_SLOUGH_LOWER.ftq upper=1 lower=1
SYCAMORE_SLOUGH_UPPER=SYCAMORE_SLOUGH_UPPER.ftq upper=1 lower=1
THERMALITO=THERMALITO.ftq upper=1 lower=1
THOMES_CR=THOMES_CR.ftq upper=1 lower=1
WALKER_CR=WALKER_CR.ftq upper=1 lower=1
WILKINS_SLOUGH_CANAL=WILKINS_SLOUGH_CANAL.ftq upper=1 lower=1
WILLOW_CR=WILLOW_CR.ftq upper=1 lower=1
WILSON_CR=WILSON_CR.ftq upper=1 lower=1
YOLO_BYPASS=YOLO_BYPASS.ftq upper=1 lower=1
YUBA_RIV=YUBA_RIV.ftq upper=1 lower=1
********open fth for WDL wells********
load
lb=SACFEM_v2_WDL_Wells.lb
open-h
^=WDL_Hydrographs.fth upper=1 lower=7
********assign initial heads********
load
h1=SACFEM_v2_09_86_Initial.h1
h2=SACFEM_v2_09_86_Initial.h2
h3=SACFEM_v2_09_86_Initial.h3
h4=SACFEM_v2_09_86_Initial.h4
h5=SACFEM_v2_09_86_Initial.h5
h6=SACFEM_v2_09_86_Initial.h6
h7=SACFEM_v2_09_86_Initial.h7


rem***********************************************
rem	BEGIN TRANSIENT SIMULATION
rem***********************************************
```

```
rem*************assign mountain-front recharge**********
LOAD
lb =SACFEM_v2_VoidPolygons2013_v2.lb
q1=zero.par
q2=zero.par
q3=zero.par
q4=zero.par
q5=zero.par
q6=zero.par
q7=zero.par
EVAL
x22=8071480 label=1
x22=35050083 label=2
x22=80605692 label=3
x22=76028964 label=4
x22=229983341 label=5
x22=949454 label=6
x22=3220633 label=7
x22=111833985 label=8
x22=897801 label=9
x22=22812497 label=10
x22=9639695 label=11
x22=6424725 label=12
x22=15522224 label=13
x22=4100614 label=14
x22=3571035 label=15
x22=20167473 label=16
x22=42791390 label=17
x22=9736556 label=18
x22=44503920 label=19
x22=2034253 label=20
x22=56249042 label=21
x22=776695 label=22
x22=7543586 label=23
```

```
x22=5209652 label=24
x22=1555595 label=25
x22=501520 label=26
x22=17635217 label=27
x22=5532887 label=28
x22=2311739 label=29
x22=2613399 label=30
x22=12198098 label=31
x22=2633584 label=32
x22=43738528 label=33
x22=57825106 label=34
rem*************adjust mountain-front recharge**********
LOAD
x23=SACFEM_v2_MtnFront_L_Factor_2013_v2.par
EVAL
x22=p*0.030*0.50/31 label=1
x22=p*0.030*0.50/31 label=2
x22=p*0.030*0.50/31 label=3
x22=p*0.030*0.50/31 label=4
x22=p*0.030*0.50/31 label=5
x22=p*0.030*1.00/31 label=6
x22=p*0.030*1.00/31 label=7
x22=p*0.030*1.00/31 label=8
x22=p*0.030*1.00/31 label=9
x22=p*0.030*1.00/31 label=10
x22=p*0.030*1.00/31 label=11
x22=p*0.030*1.00/31 label=12
x22=p*0.030*1.00/31 label=13
x22=p*0.030*1.50/31 label=14
x22=p*0.030*1.50/31 label=15
x22=p*0.030*1.50/31 label=16
x22=p*0.030*0.50/31 label=17
x22=p*0.030*0.50/31 label=18
x22=p*0.030*1.50/31 label=19
x22=p*0.030*1.00/31 label=20
```

```
x22=p*0.030*1.00/31 label=21
x22=p*0.030*1.50/31 label=22
x22=p*0.030*1.50/31 label=23
x22=p*0.030*1.00/31 label=24
x22=p*0.030*1.00/31 label=25
x22=p*0.030*1.00/31 label=26
x22=p*0.030*1.00/31 label=27
x22=p*0.030*1.00/31 label=28
x22=p*0.030*1.00/31 label=29
x22=p*0.030*1.00/31 label=30
x22=p*0.030*1.00/31 label=31
x22=p*0.030*1.00/31 label=32
x22=p*0.030*1.00/31 label=33
x22=p*0.030*1.00/31 label=34
q1=x22*x23*-1
Save Q1=10_69.q1

rem*************Normal/Wet Water Year**********
LOAD
storativity=SACFEM_v2.sto
wl1=SACFEM_v2_WL1_042314.par
dh1=SACFEM_v2_GSE_Combined_mNAVD88_120313.par
PPN=10_69.ppn
WH1=10_69.wh1
WC1=10_69.wc1
DC1=10_69.dc1
Q1=10_69.q1
Q2=10_69.q2
Q3=10_69.q3
Q4=10_69.q4

TIME
  days=31
  steps=1
```

```
RUN
  itmin=50
  itmax=600
  relax=0
  error=0.005
  m3error=1

SAVE
  h1=10_69.h1
  h2=10_69.h2
  h3=10_69.h3
  h4=10_69.h4
  h5=10_69.h5
  h6=10_69.h6
  h7=10_69.h7

rem*************assign mountain-front recharge**********
LOAD
lb =SACFEM_v2_VoidPolygons2013_v2.lb
q1=zero.par
q2=zero.par
q3=zero.par
q4=zero.par
q5=zero.par
q6=zero.par
q7=zero.par
EVAL
x22=8071480 label=1
x22=35050083 label=2
x22=80605692 label=3
x22=76028964 label=4
x22=229983341 label=5
x22=949454 label=6
x22=3220633 label=7
x22=111833985 label=8
```

```
x22=897801 label=9
x22=22812497 label=10
x22=9639695 label=11
x22=6424725 label=12
x22=15522224 label=13
x22=4100614 label=14
x22=3571035 label=15
x22=20167473 label=16
x22=42791390 label=17
x22=9736556 label=18
x22=44503920 label=19
x22=2034253 label=20
x22=56249042 label=21
x22=776695 label=22
x22=7543586 label=23
x22=5209652 label=24
x22=1555595 label=25
x22=501520 label=26
x22=17635217 label=27
x22=5532887 label=28
x22=2311739 label=29
x22=2613399 label=30
x22=12198098 label=31
x22=2633584 label=32
x22=43738528 label=33
x22=57825106 label=34
rem*************adjust mountain-front recharge**********
LOAD
x23=SACFEM_v2_MtnFront_L_Factor_2013_v2.par
EVAL
x22=p*0.049*0.50/30 label=1
x22=p*0.049*0.50/30 label=2
x22=p*0.049*0.50/30 label=3
x22=p*0.049*0.50/30 label=4
x22=p*0.049*0.50/30 label=5
```

```
x22=p*0.049*1.00/30 label=6
x22=p*0.049*1.00/30 label=7
x22=p*0.049*1.00/30 label=8
x22=p*0.049*1.00/30 label=9
x22=p*0.049*1.00/30 label=10
x22=p*0.049*1.00/30 label=11
x22=p*0.049*1.00/30 label=12
x22=p*0.049*1.00/30 label=13
x22=p*0.049*1.50/30 label=14
x22=p*0.049*1.50/30 label=15
x22=p*0.049*1.50/30 label=16
x22=p*0.049*0.50/30 label=17
x22=p*0.049*0.50/30 label=18
x22=p*0.049*1.50/30 label=19
x22=p*0.049*1.00/30 label=20
x22=p*0.049*1.00/30 label=21
x22=p*0.049*1.50/30 label=22
x22=p*0.049*1.50/30 label=23
x22=p*0.049*1.00/30 label=24
x22=p*0.049*1.00/30 label=25
x22=p*0.049*1.00/30 label=26
x22=p*0.049*1.00/30 label=27
x22=p*0.049*1.00/30 label=28
x22=p*0.049*1.00/30 label=29
x22=p*0.049*1.00/30 label=30
x22=p*0.049*1.00/30 label=31
x22=p*0.049*1.00/30 label=32
x22=p*0.049*1.00/30 label=33
x22=p*0.049*1.00/30 label=34
q1=x22*x23*-1
Save Q1=11_69.q1

rem*************Normal/Wet Water Year**********
LOAD
PPN=11_69.ppn
```

```
WH1=11_69.wh1
WC1=11_69.wc1
DC1=11_69.dc1
Q1=11_69.q1
Q2=11_69.q2
Q3=11_69.q3
Q4=11_69.q4

TIME
  days=30
  steps=1

RUN
  itmin=50
  itmax=600
  relax=0
  error=0.005
  m3error=1

SAVE
  h1=11_69.h1
  h2=11_69.h2
  h3=11_69.h3
  h4=11_69.h4
  h5=11_69.h5
  h6=11_69.h6
  h7=11_69.h7

rem*************assign mountain-front recharge**********
LOAD
lb =SACFEM_v2_VoidPolygons2013_v2.lb
q1=zero.par
q2=zero.par
q3=zero.par
q4=zero.par
```

```
q5=zero.par
q6=zero.par
q7=zero.par
EVAL
x22=8071480 label=1
x22=35050083 label=2
x22=80605692 label=3
x22=76028964 label=4
x22=229983341 label=5
x22=949454 label=6
x22=3220633 label=7
x22=111833985 label=8
x22=897801 label=9
x22=22812497 label=10
x22=9639695 label=11
x22=6424725 label=12
x22=15522224 label=13
x22=4100614 label=14
x22=3571035 label=15
x22=20167473 label=16
x22=42791390 label=17
x22=9736556 label=18
x22=44503920 label=19
x22=2034253 label=20
x22=56249042 label=21
x22=776695 label=22
x22=7543586 label=23
x22=5209652 label=24
x22=1555595 label=25
x22=501520 label=26
x22=17635217 label=27
x22=5532887 label=28
x22=2311739 label=29
x22=2613399 label=30
x22=12198098 label=31
```

```
x22=2633584 label=32
x22=43738528 label=33
x22=57825106 label=34
rem*************adjust mountain-front recharge**********
LOAD
x23=SACFEM_v2_MtnFront_L_Factor_2013_v2.par
EVAL
x22=p*0.102*0.50/31 label=1
x22=p*0.102*0.50/31 label=2
x22=p*0.102*0.50/31 label=3
x22=p*0.102*0.50/31 label=4
x22=p*0.102*0.50/31 label=5
x22=p*0.102*1.00/31 label=6
x22=p*0.102*1.00/31 label=7
x22=p*0.102*1.00/31 label=8
x22=p*0.102*1.00/31 label=9
x22=p*0.102*1.00/31 label=10
x22=p*0.102*1.00/31 label=11
x22=p*0.102*1.00/31 label=12
x22=p*0.102*1.00/31 label=13
x22=p*0.102*1.50/31 label=14
x22=p*0.102*1.50/31 label=15
x22=p*0.102*1.50/31 label=16
x22=p*0.102*0.50/31 label=17
x22=p*0.102*0.50/31 label=18
x22=p*0.102*1.50/31 label=19
x22=p*0.102*1.00/31 label=20
x22=p*0.102*1.00/31 label=21
x22=p*0.102*1.50/31 label=22
x22=p*0.102*1.50/31 label=23
x22=p*0.102*1.00/31 label=24
x22=p*0.102*1.00/31 label=25
x22=p*0.102*1.00/31 label=26
x22=p*0.102*1.00/31 label=27
x22=p*0.102*1.00/31 label=28
```

```
x22=p*0.102*1.00/31 label=29
x22=p*0.102*1.00/31 label=30
x22=p*0.102*1.00/31 label=31
x22=p*0.102*1.00/31 label=32
x22=p*0.102*1.00/31 label=33
x22=p*0.102*1.00/31 label=34
q1=x22*x23*-1
Save Q1=12_69.q1

rem*************Normal/Wet Water Year**********
LOAD
PPN=12_69.ppn
WH1=12_69.wh1
WC1=12_69.wc1
DC1=12_69.dc1
Q1=12_69.q1
Q2=12_69.q2
Q3=12_69.q3
Q4=12_69.q4

TIME
  days=31
  steps=1

RUN
  itmin=50
  itmax=600
  relax=0
  error=0.005
  m3error=1

SAVE
  h1=12_69.h1
  h2=12_69.h2
  h3=12_69.h3
```

```
  h4=12_69.h4
  h5=12_69.h5
  h6=12_69.h6
  h7=12_69.h7

rem*************assign mountain-front recharge**********
LOAD
lb =SACFEM_v2_VoidPolygons2013_v2.lb
q1=zero.par
q2=zero.par
q3=zero.par
q4=zero.par
q5=zero.par
q6=zero.par
q7=zero.par
EVAL
x22=8540053 label=1
x22=37478822 label=2
x22=84904385 label=3
x22=77394633 label=4
x22=232419920 label=5
x22=887594 label=6
x22=3023540 label=7
x22=105745704 label=8
x22=867913 label=9
x22=21415694 label=10
x22=9077969 label=11
x22=5757600 label=12
x22=13543439 label=13
x22=3414958 label=14
x22=2899943 label=15
x22=17517225 label=16
x22=35852152 label=17
x22=8297912 label=18
x22=46602663 label=19
```

```
x22=2184550 label=20
x22=59413680 label=21
x22=798035 label=22
x22=7919410 label=23
x22=5539452 label=24
x22=1670086 label=25
x22=545398 label=26
x22=19199301 label=27
x22=6086705 label=28
x22=2445877 label=29
x22=2748554 label=30
x22=13039352 label=31
x22=2866293 label=32
x22=51790487 label=33
x22=55248914 label=34
rem*************adjust mountain-front recharge**********
LOAD
x23=SACFEM_v2_MtnFront_L_Factor_2013_v2.par
EVAL
x22=p*0.142*0.50/31 label=1
x22=p*0.142*0.50/31 label=2
x22=p*0.142*0.50/31 label=3
x22=p*0.142*0.50/31 label=4
x22=p*0.142*0.50/31 label=5
x22=p*0.142*1.00/31 label=6
x22=p*0.142*1.00/31 label=7
x22=p*0.142*1.00/31 label=8
x22=p*0.142*1.00/31 label=9
x22=p*0.142*1.00/31 label=10
x22=p*0.142*1.00/31 label=11
x22=p*0.142*1.00/31 label=12
x22=p*0.142*1.00/31 label=13
x22=p*0.142*1.50/31 label=14
x22=p*0.142*1.50/31 label=15
x22=p*0.142*1.50/31 label=16
```

```
x22=p*0.142*0.50/31 label=17
x22=p*0.142*0.50/31 label=18
x22=p*0.142*1.50/31 label=19
x22=p*0.142*1.00/31 label=20
x22=p*0.142*1.00/31 label=21
x22=p*0.142*1.50/31 label=22
x22=p*0.142*1.50/31 label=23
x22=p*0.142*1.00/31 label=24
x22=p*0.142*1.00/31 label=25
x22=p*0.142*1.00/31 label=26
x22=p*0.142*1.00/31 label=27
x22=p*0.142*1.00/31 label=28
x22=p*0.142*1.00/31 label=29
x22=p*0.142*1.00/31 label=30
x22=p*0.142*1.00/31 label=31
x22=p*0.142*1.00/31 label=32
x22=p*0.142*1.00/31 label=33
x22=p*0.142*1.00/31 label=34
q1=x22*x23*-1
Save Q1=01_70.q1

rem*************Normal/Wet Water Year**********
LOAD
PPN=01_70.ppn
WH1=01_70.wh1
WC1=01_70.wc1
DC1=01_70.dc1
Q1=01_70.q1
Q2=01_70.q2
Q3=01_70.q3
Q4=01_70.q4

TIME
  days=31
  steps=1
```

```
RUN
 itmin=50
 itmax=600
 relax=0
 error=0.005
 m3error=1

SAVE
 h1=01_70.h1
 h2=01_70.h2
 h3=01_70.h3
 h4=01_70.h4
 h5=01_70.h5
 h6=01_70.h6
 h7=01_70.h7

rem*************assign mountain-front recharge**********
LOAD
lb =SACFEM_v2_VoidPolygons2013_v2.lb
q1=zero.par
q2=zero.par
q3=zero.par
q4=zero.par
q5=zero.par
q6=zero.par
q7=zero.par
EVAL
x22=8540053 label=1
x22=37478822 label=2
x22=84904385 label=3
x22=77394633 label=4
x22=232419920 label=5
x22=887594 label=6
x22=3023540 label=7
```

```
x22=105745704 label=8
x22=867913 label=9
x22=21415694 label=10
x22=9077969 label=11
x22=5757600 label=12
x22=13543439 label=13
x22=3414958 label=14
x22=2899943 label=15
x22=17517225 label=16
x22=35852152 label=17
x22=8297912 label=18
x22=46602663 label=19
x22=2184550 label=20
x22=59413680 label=21
x22=798035 label=22
x22=7919410 label=23
x22=5539452 label=24
x22=1670086 label=25
x22=545398 label=26
x22=19199301 label=27
x22=6086705 label=28
x22=2445877 label=29
x22=2748554 label=30
x22=13039352 label=31
x22=2866293 label=32
x22=51790487 label=33
x22=55248914 label=34
rem*************adjust mountain-front recharge**********
LOAD
x23=SACFEM_v2_MtnFront_L_Factor_2013_v2.par
EVAL
x22=p*0.152*0.50/28 label=1
x22=p*0.152*0.50/28 label=2
x22=p*0.152*0.50/28 label=3
x22=p*0.152*0.50/28 label=4
```

```
x22=p*0.152*0.50/28 label=5
x22=p*0.152*1.00/28 label=6
x22=p*0.152*1.00/28 label=7
x22=p*0.152*1.00/28 label=8
x22=p*0.152*1.00/28 label=9
x22=p*0.152*1.00/28 label=10
x22=p*0.152*1.00/28 label=11
x22=p*0.152*1.00/28 label=12
x22=p*0.152*1.00/28 label=13
x22=p*0.152*1.50/28 label=14
x22=p*0.152*1.50/28 label=15
x22=p*0.152*1.50/28 label=16
x22=p*0.152*0.50/28 label=17
x22=p*0.152*0.50/28 label=18
x22=p*0.152*1.50/28 label=19
x22=p*0.152*1.00/28 label=20
x22=p*0.152*1.00/28 label=21
x22=p*0.152*1.50/28 label=22
x22=p*0.152*1.50/28 label=23
x22=p*0.152*1.00/28 label=24
x22=p*0.152*1.00/28 label=25
x22=p*0.152*1.00/28 label=26
x22=p*0.152*1.00/28 label=27
x22=p*0.152*1.00/28 label=28
x22=p*0.152*1.00/28 label=29
x22=p*0.152*1.00/28 label=30
x22=p*0.152*1.00/28 label=31
x22=p*0.152*1.00/28 label=32
x22=p*0.152*1.00/28 label=33
x22=p*0.152*1.00/28 label=34
q1=x22*x23*-1
Save Q1=02_70.q1

rem*************Normal/Wet Water Year**********
LOAD
```

```
PPN=02_70.ppn
WH1=02_70.wh1
WC1=02_70.wc1
DC1=02_70.dc1
Q1=02_70.q1
Q2=02_70.q2
Q3=02_70.q3
Q4=02_70.q4

TIME
  days=28
  steps=1

RUN
  itmin=50
  itmax=600
  relax=0
  error=0.005
  m3error=1

SAVE
  h1=02_70.h1
  h2=02_70.h2
  h3=02_70.h3
  h4=02_70.h4
  h5=02_70.h5
  h6=02_70.h6
  h7=02_70.h7
```

<<THE LOOPING PORTION OF SACFEM2013.FEB CONTINUES FOLLOWING SIMILAR SYNTAX AS THE PRECEDING STRESS PERIODS THROUGH SEPTEMBER 2010.>>