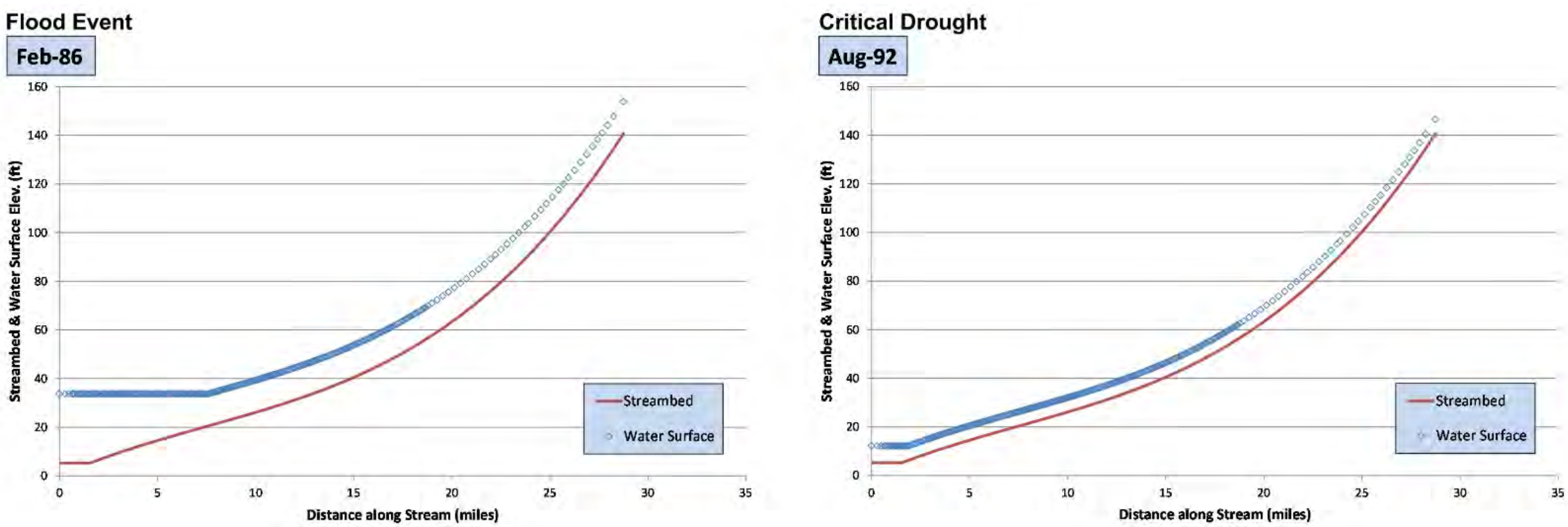

Figure 19
American River Water Surface Elevation during Flood Event and Drought
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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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:

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

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:

$$Q_{outflow} = 0 \quad (8)$$

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):

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

Where:

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

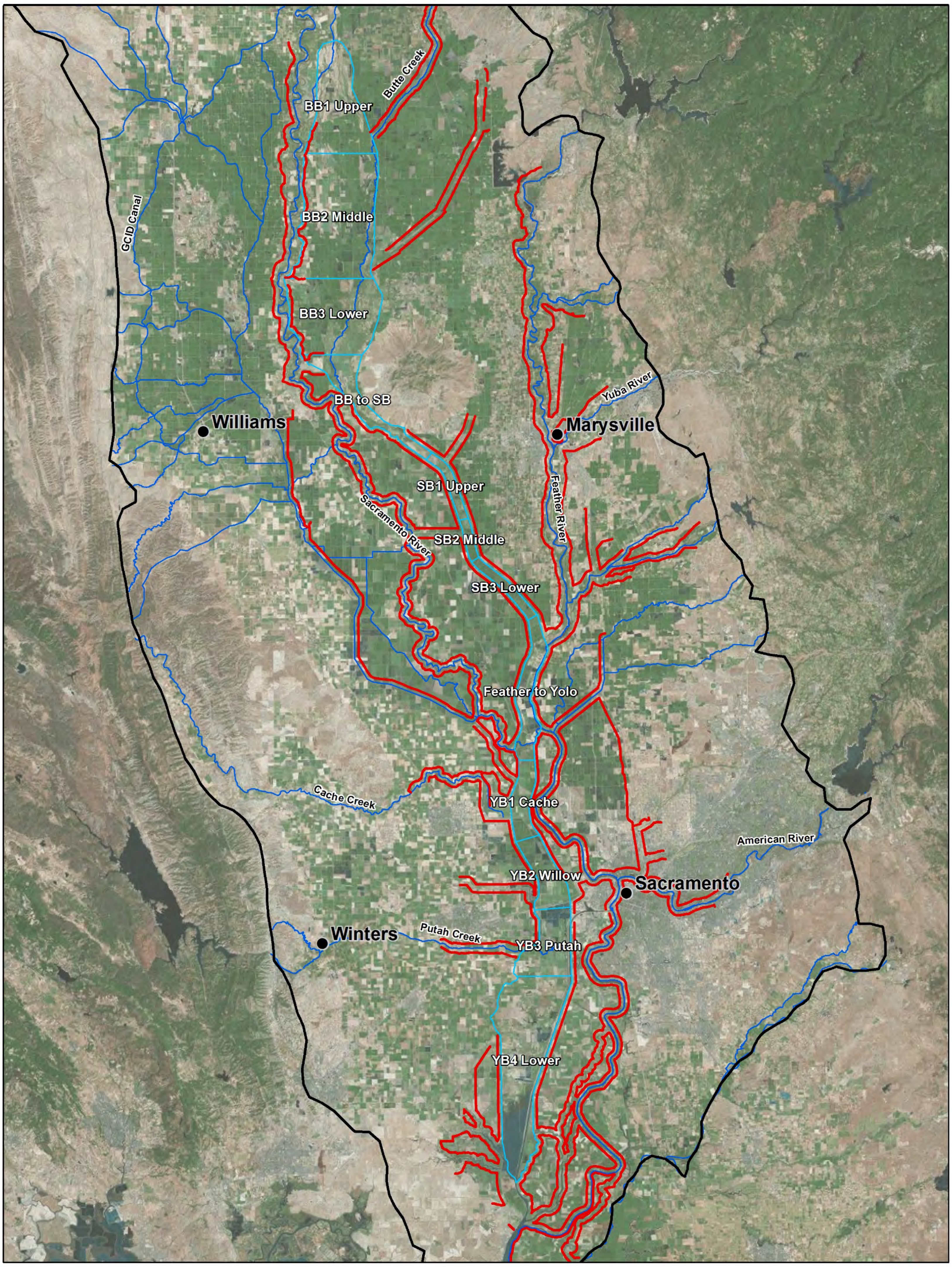
The process that was used to estimate the quantity of subsurface inflow, otherwise known as mountain-front recharge, is summarized as follows:

[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



LEGEND

- City
- Major Stream
- Flood Bypass
- Levee
- 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 20
Flood Bypass Areas and Subareas
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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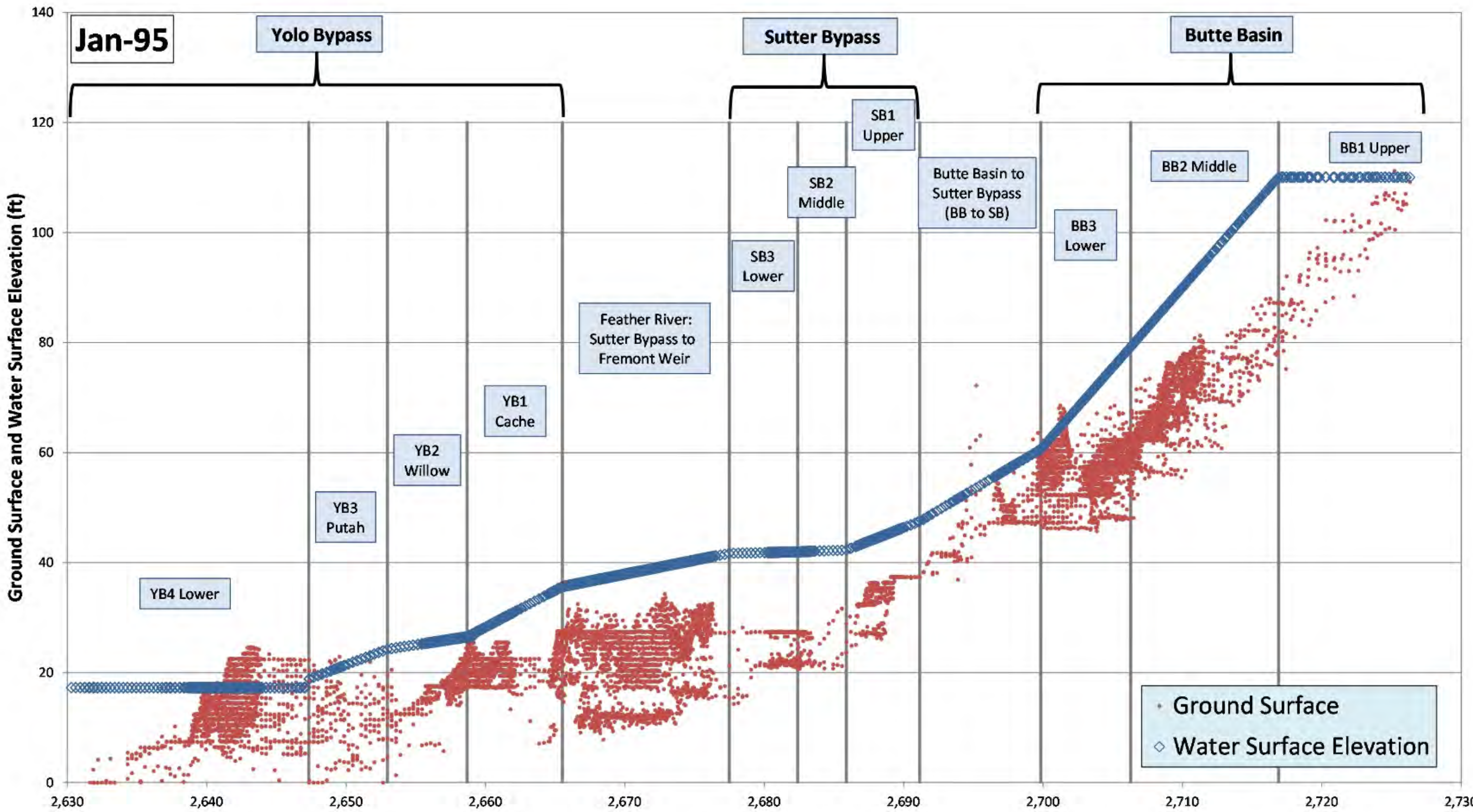

Figure 21
Flood Bypass Area Ground Surface and Water Surface Elevation
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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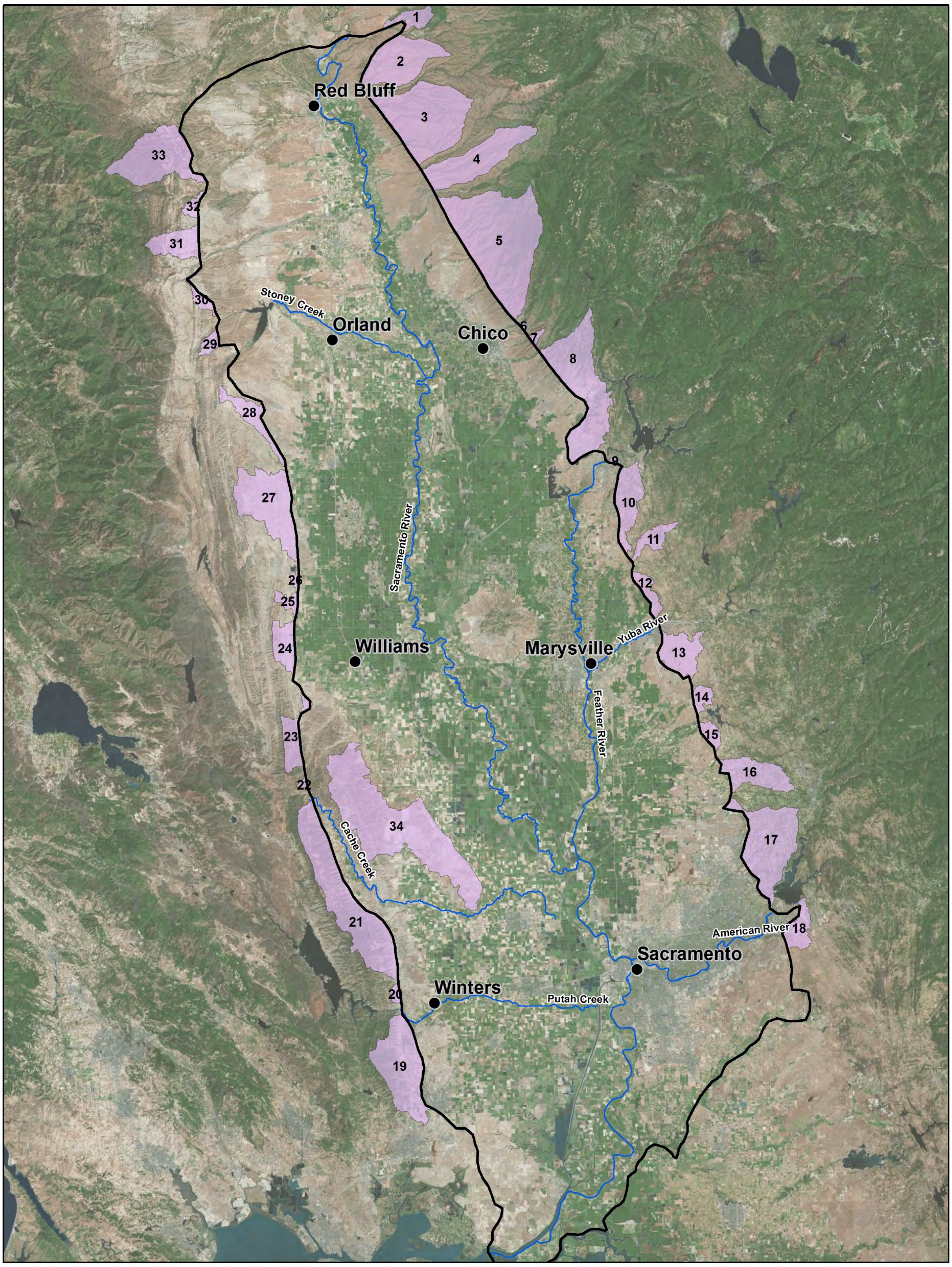

LEGEND

- 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

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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.

[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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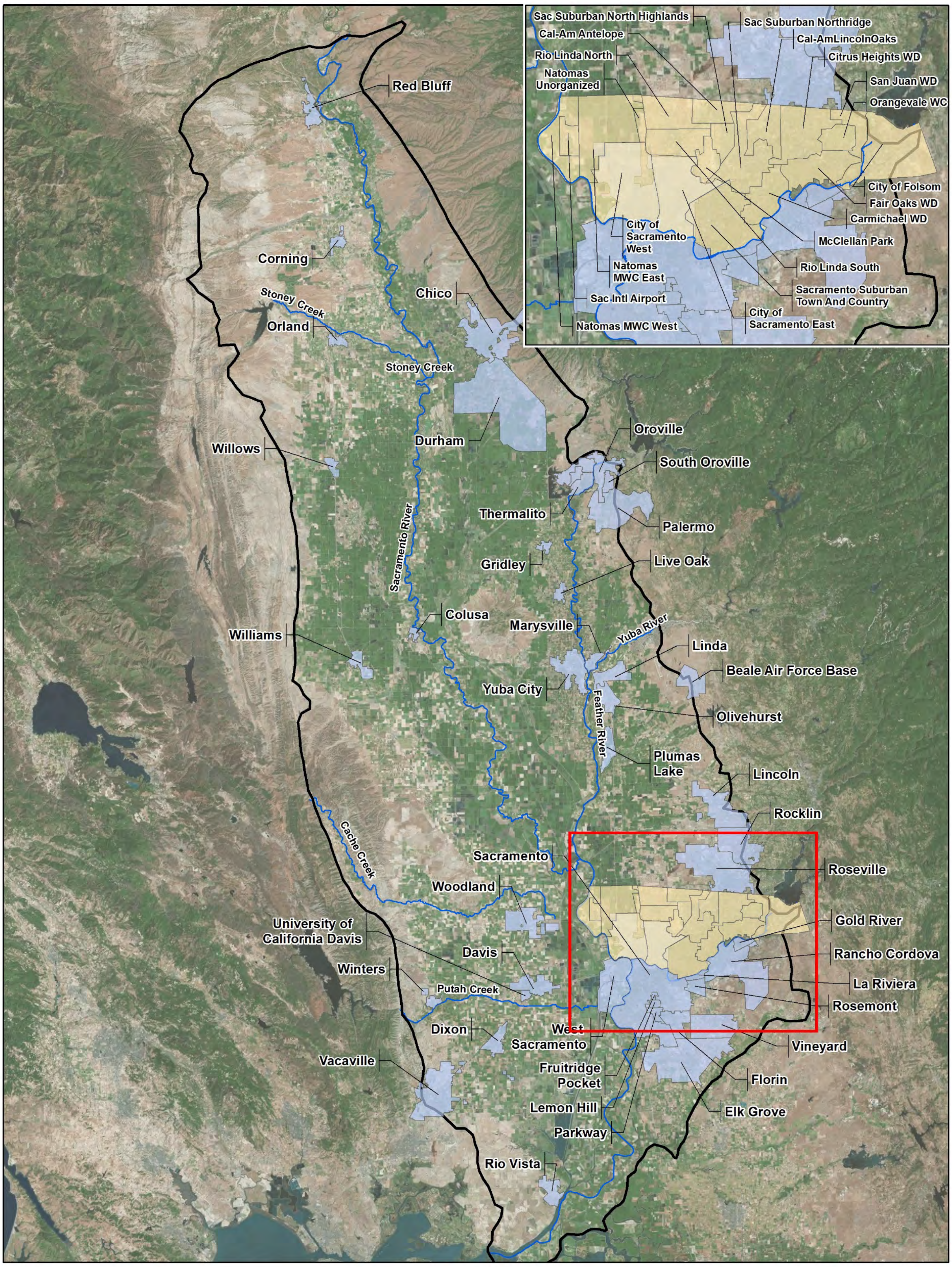

LEGEND

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

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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
	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.

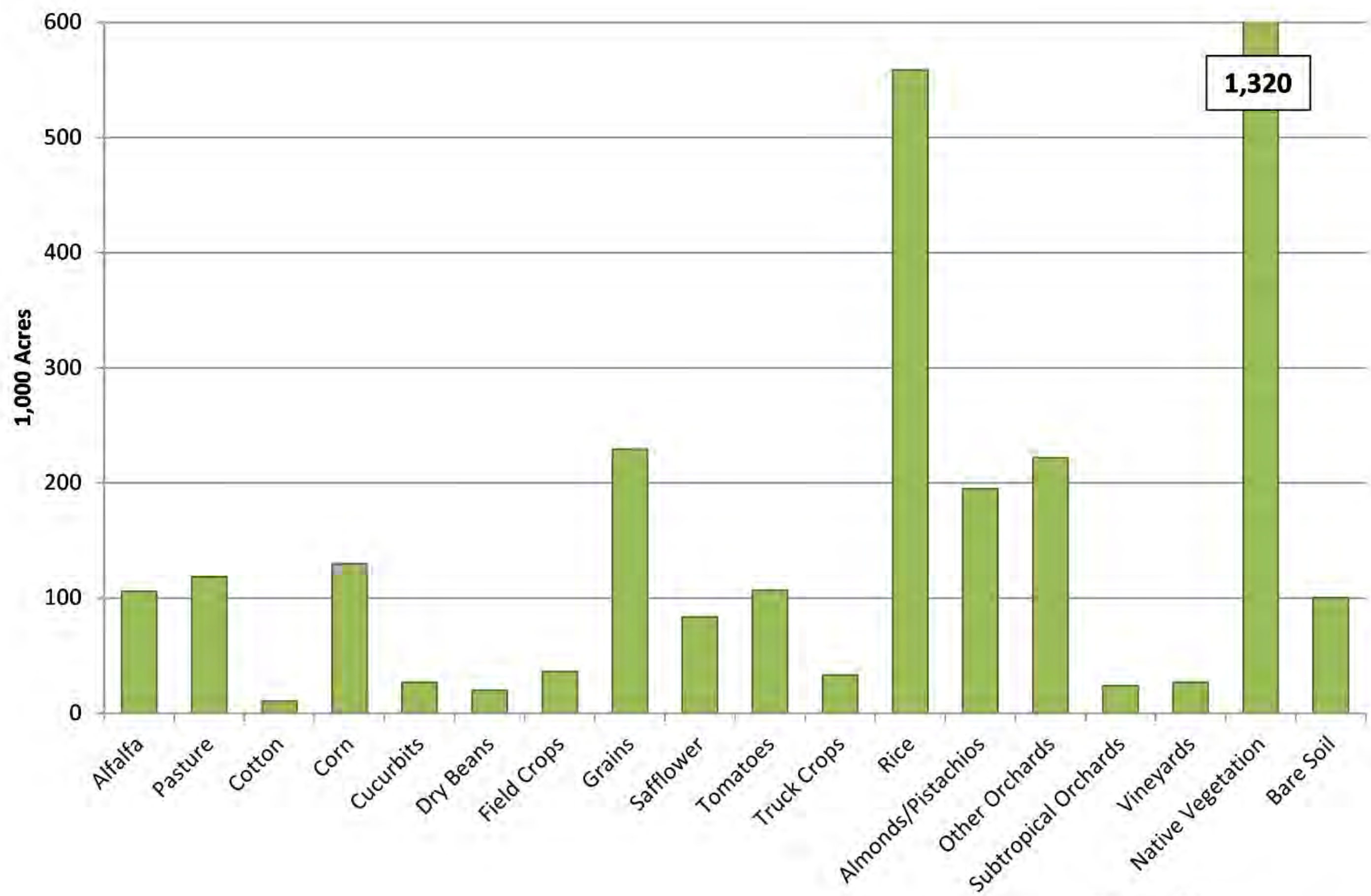


Figure 24
SACFEM2013 Land Use Data
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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.

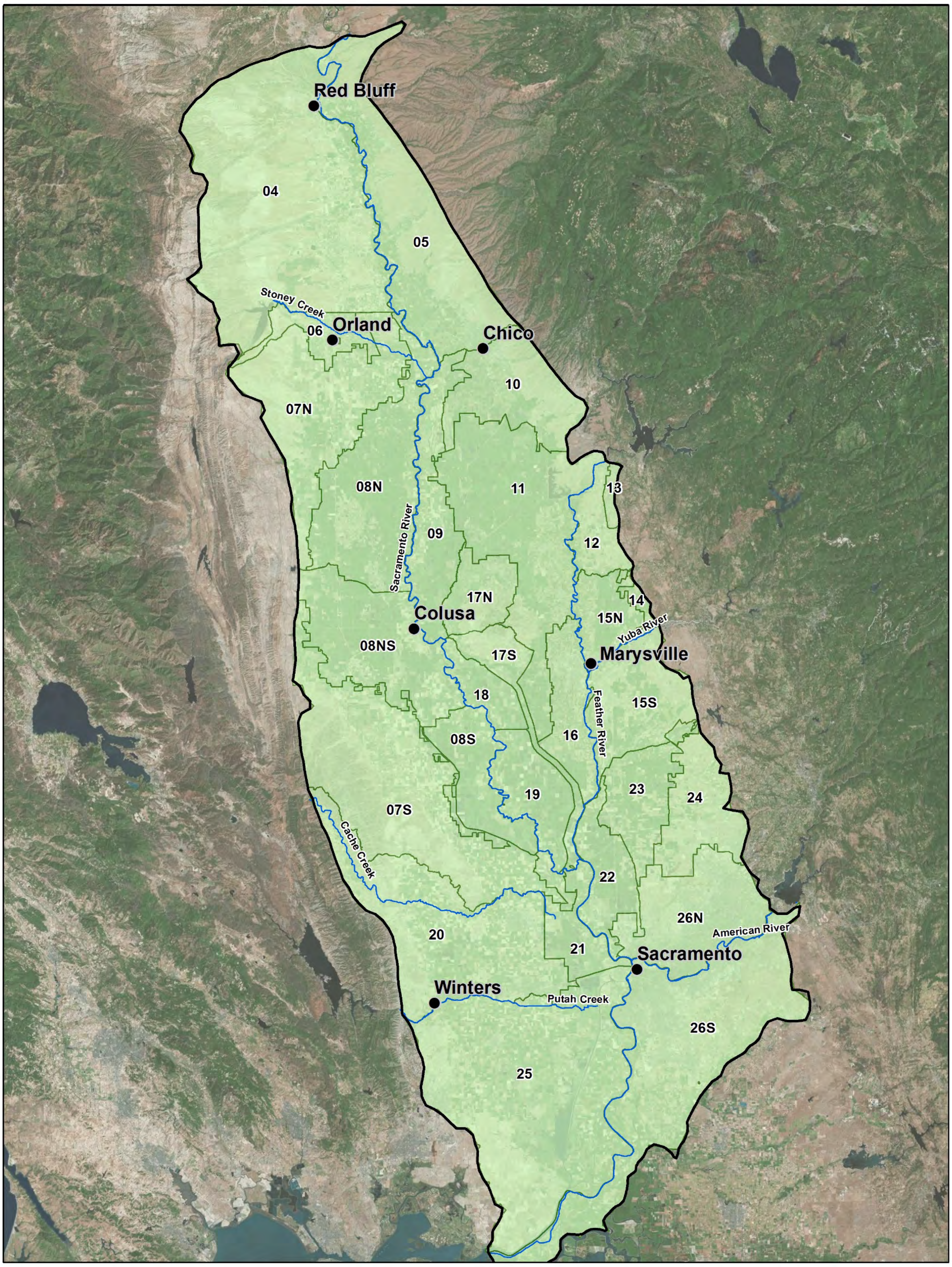
Water Budget Areas. Land use, water source, and soils data are then joined with boundaries of water budget areas (WBAs) within the SVGB. The SVGB was previously disaggregated into WBAs for the purpose of developing water budgets and inputs to other models such as CALSIM III. WBAs were defined by irrigation 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

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

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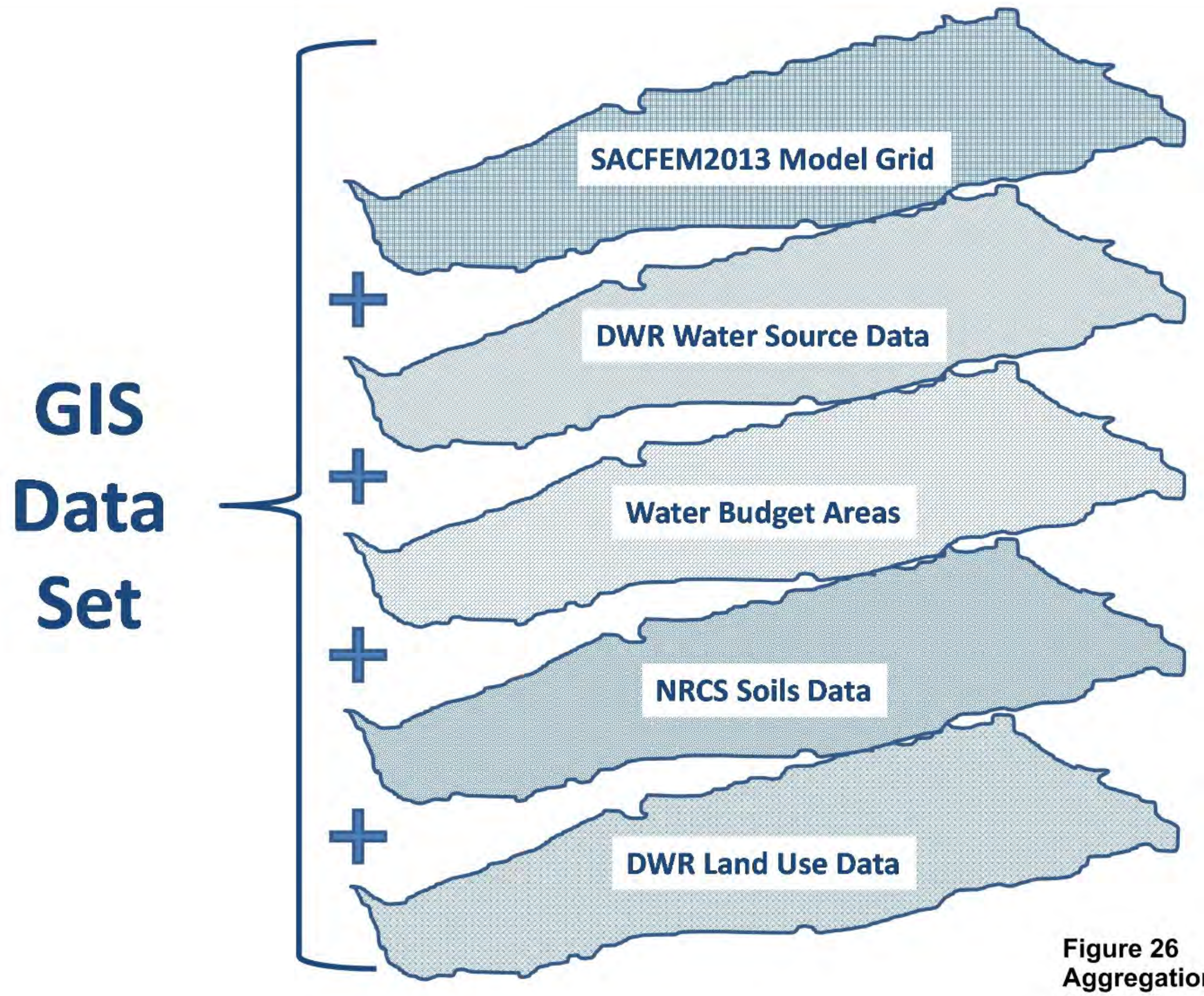


Figure 26
Aggregation of GIS Datasets for Agricultural Water Budgets
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL
MBK ENGINEERS

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.

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

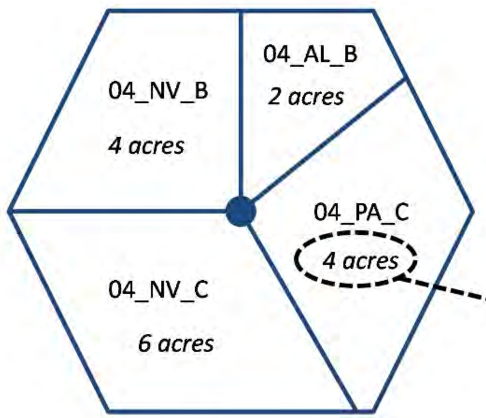
Many nodes include areas that are met from both groundwater and non-groundwater sources, areas of different crops and soils and, therefore different AWD or different pumping percentage. Groundwater pumping is calculated separately for each area and summed for the node each month.

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

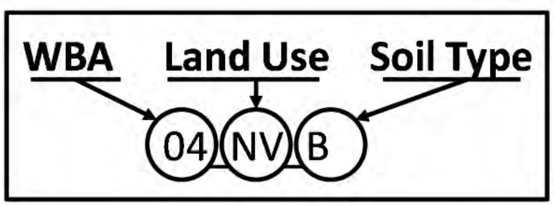
GIS Data Set for Nodal Area



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.

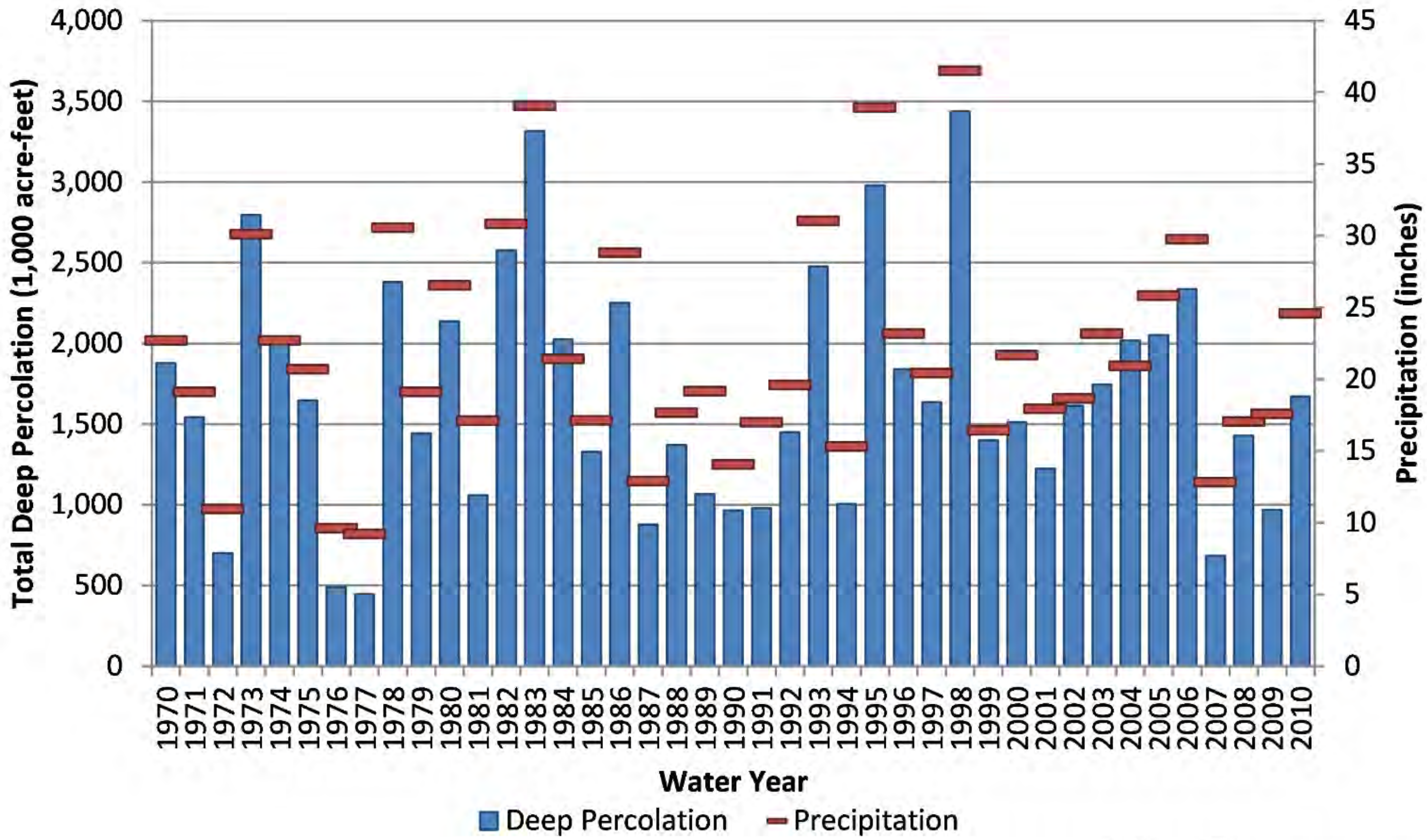

Figure 28
Annual Deep Percolation from Agricultural and Native Vegetation Areas

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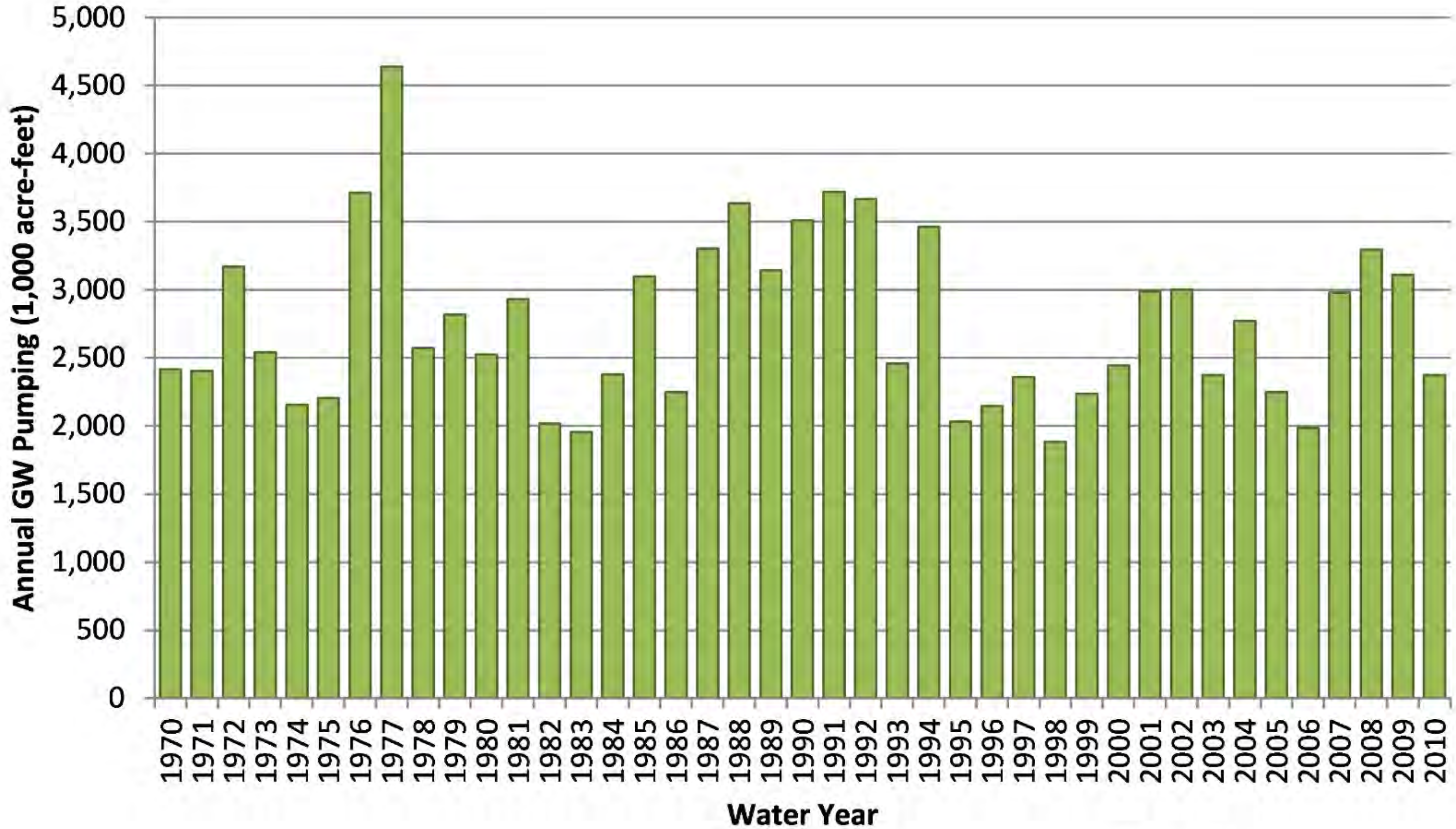

Figure 29
Annual Agricultural Groundwater Pumping

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MBK ENGINEERS