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.

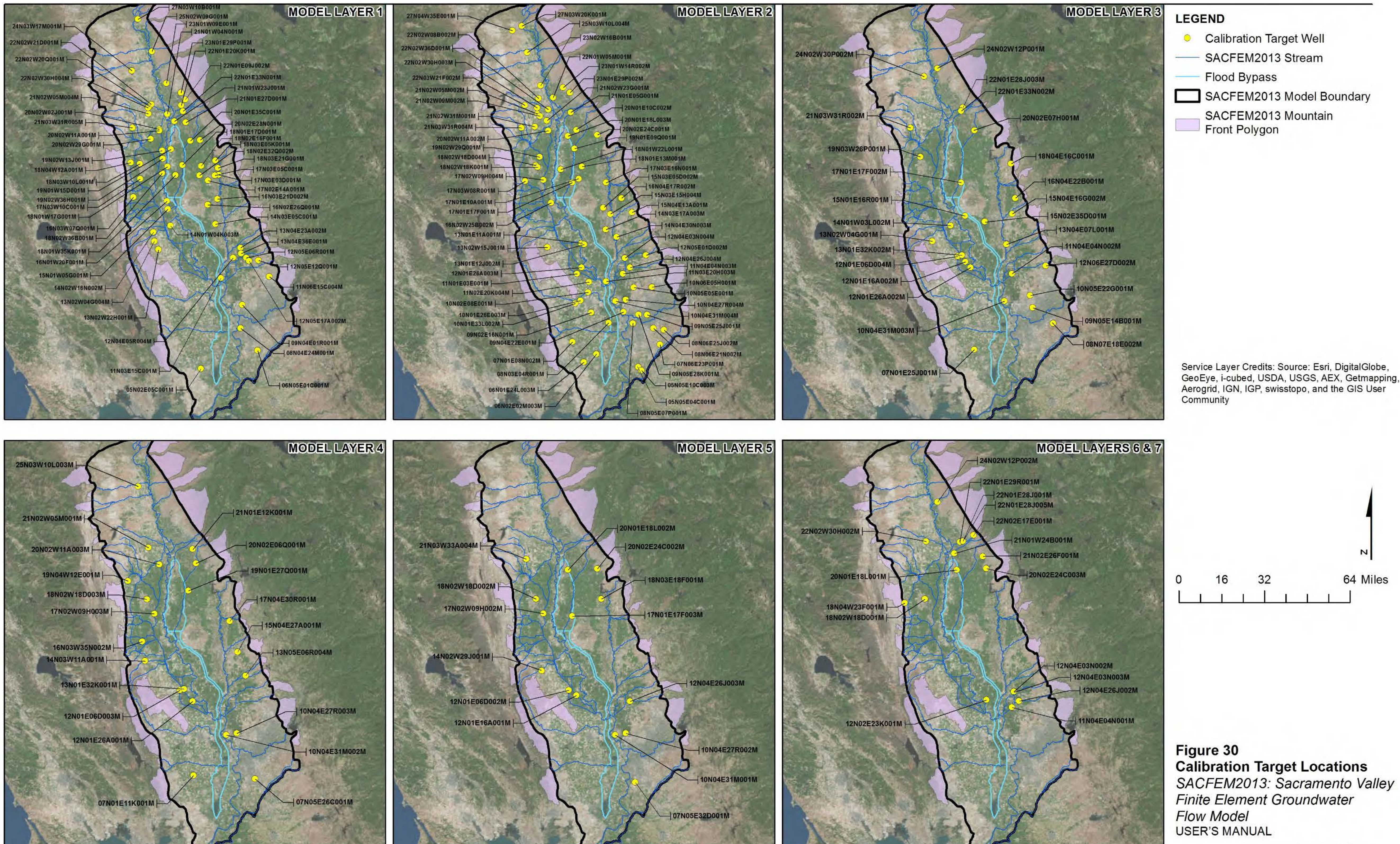

Figure 30
Calibration Target Locations
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
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Figure 31 is a scatter plot of individual simulated-versus-target head values. The summary statistics for data presented on Figure 31 and defined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

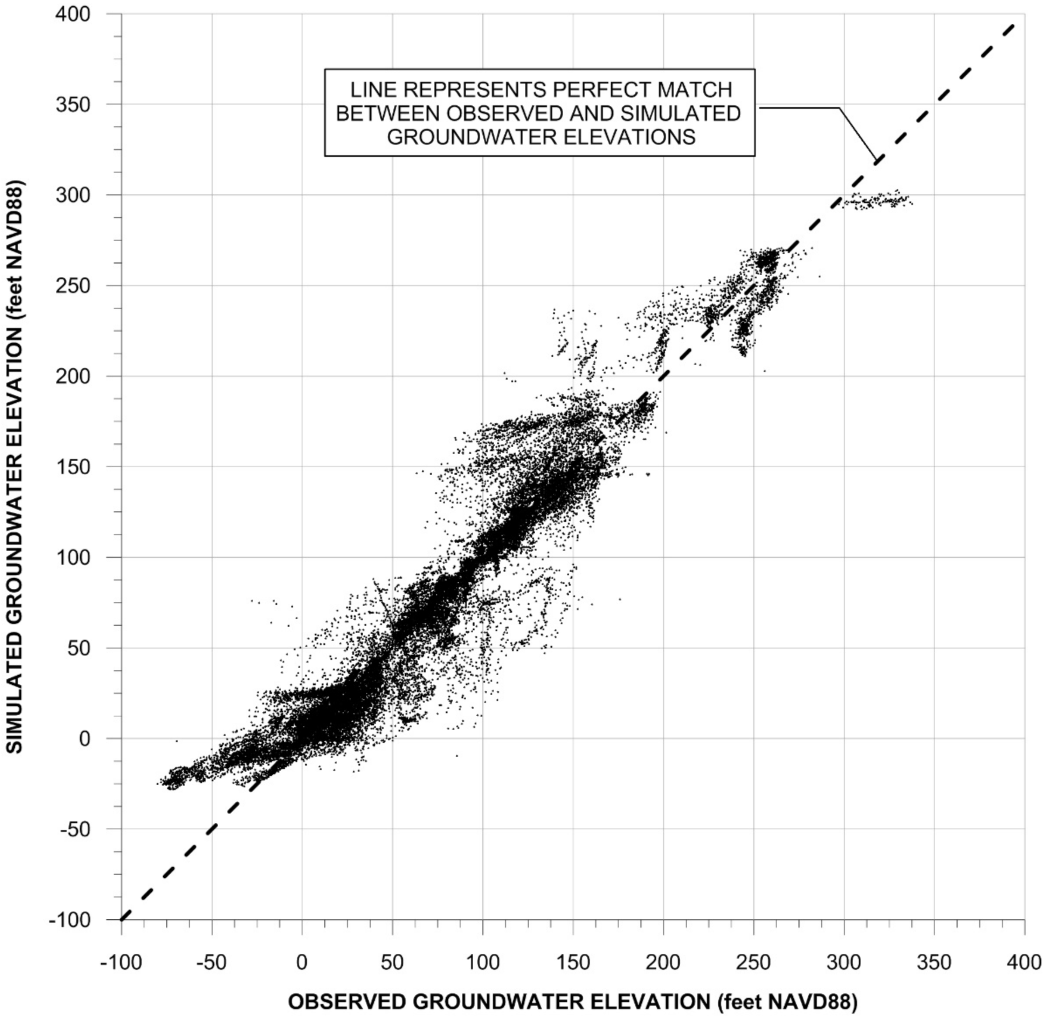
The ME value of 1.6 feet indicates that SACFEM2013 slightly over-predicted heads throughout the domain, as shown by the positive value. However, the ME, RMSE, and RMSE/Range are relatively small, particularly given the scale of the model domain. Additionally, as shown on Figure 31, there is a strong 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

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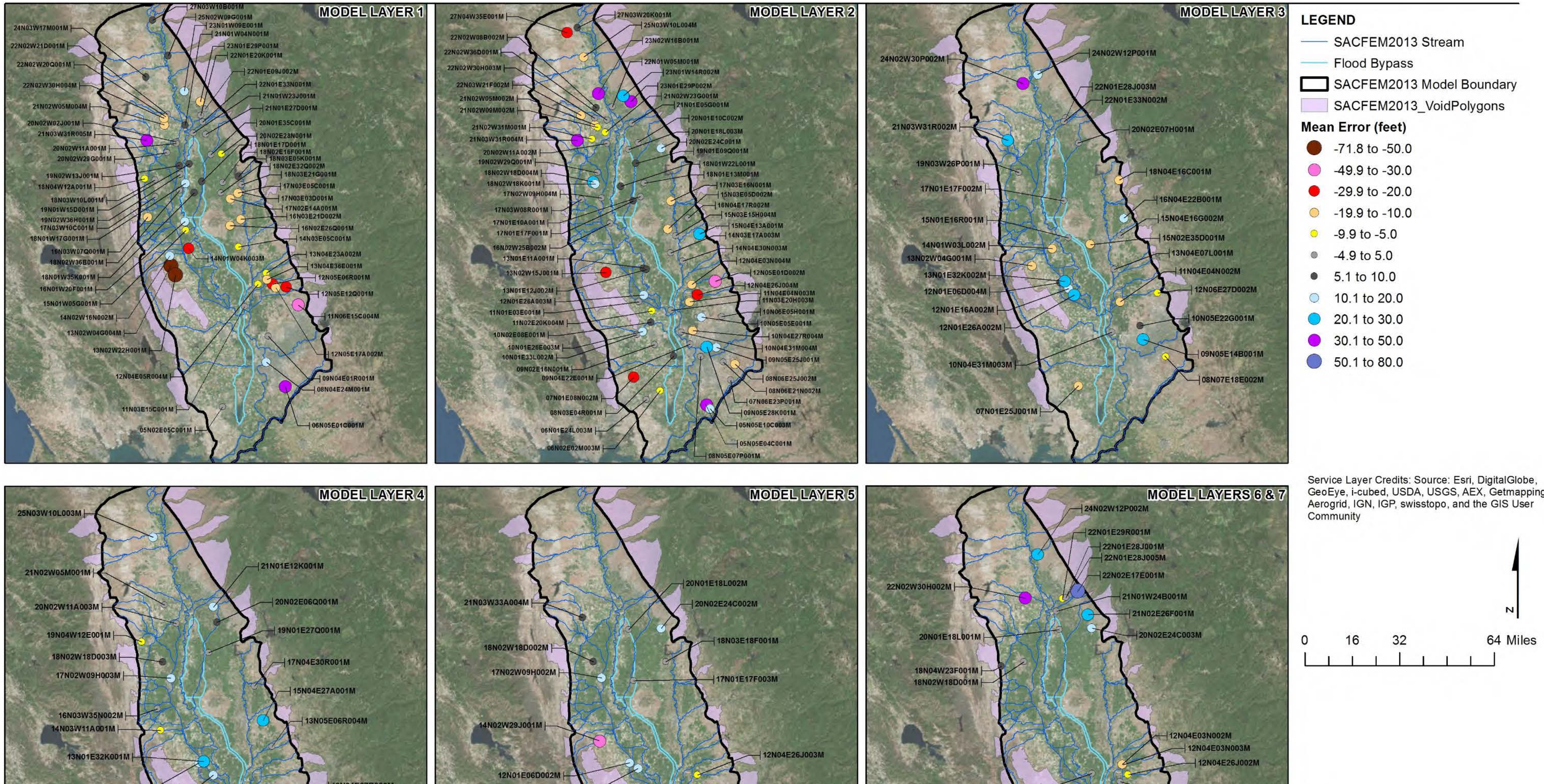

Figure 32
Simulated Mean Error in Groundwater Elevation
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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

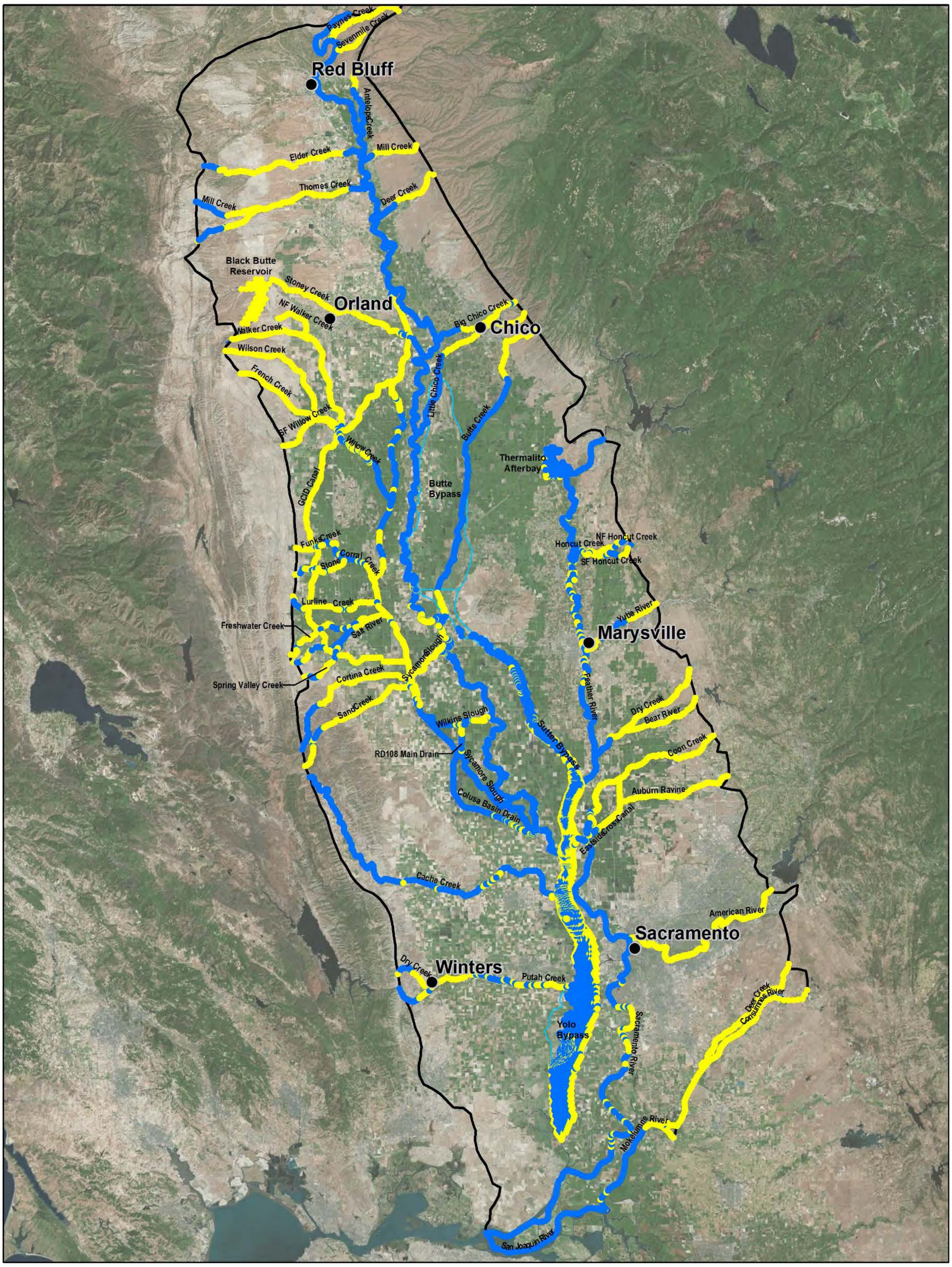
4.3.2 Human Errors

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.



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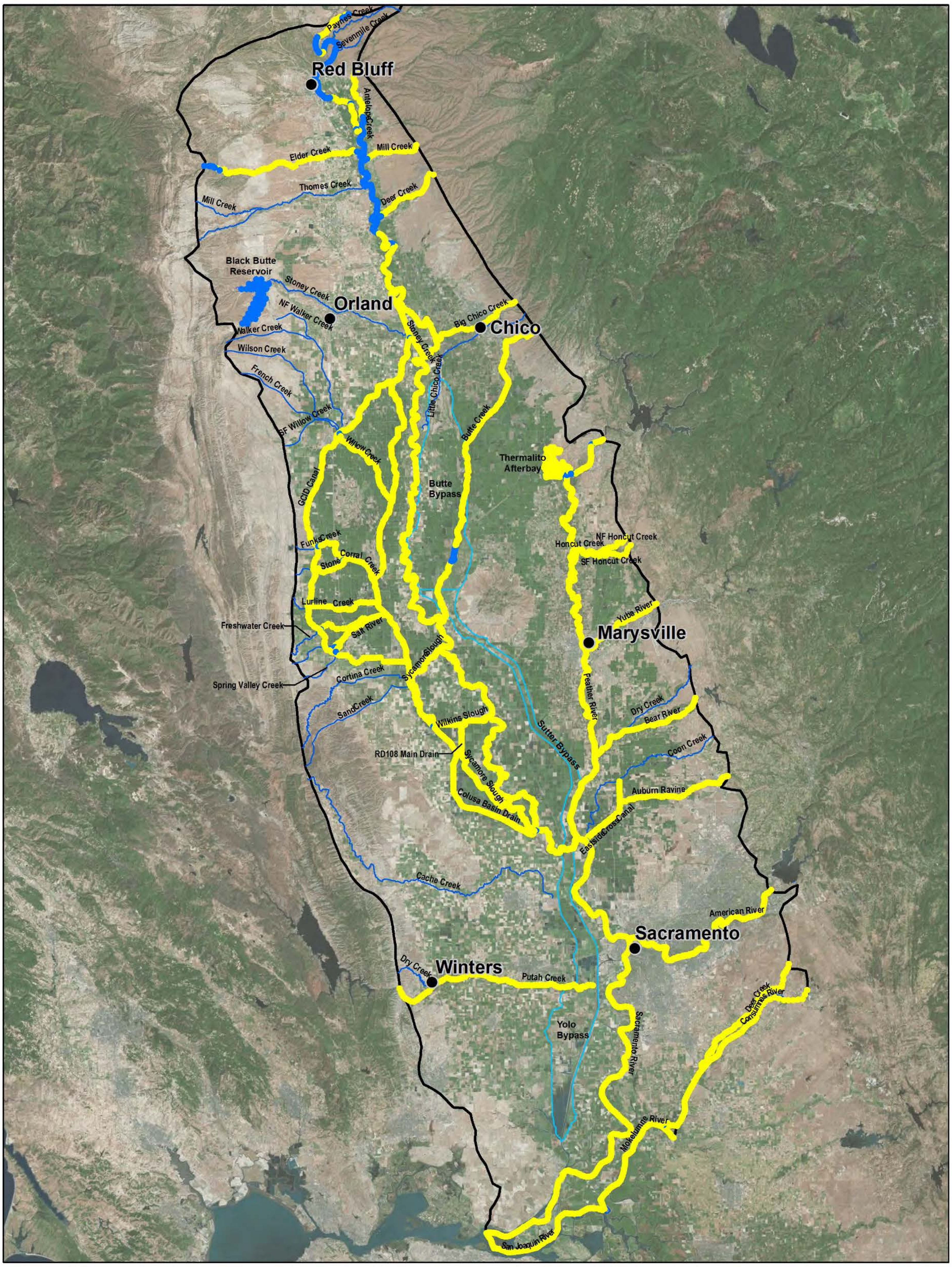

LEGEND

- 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

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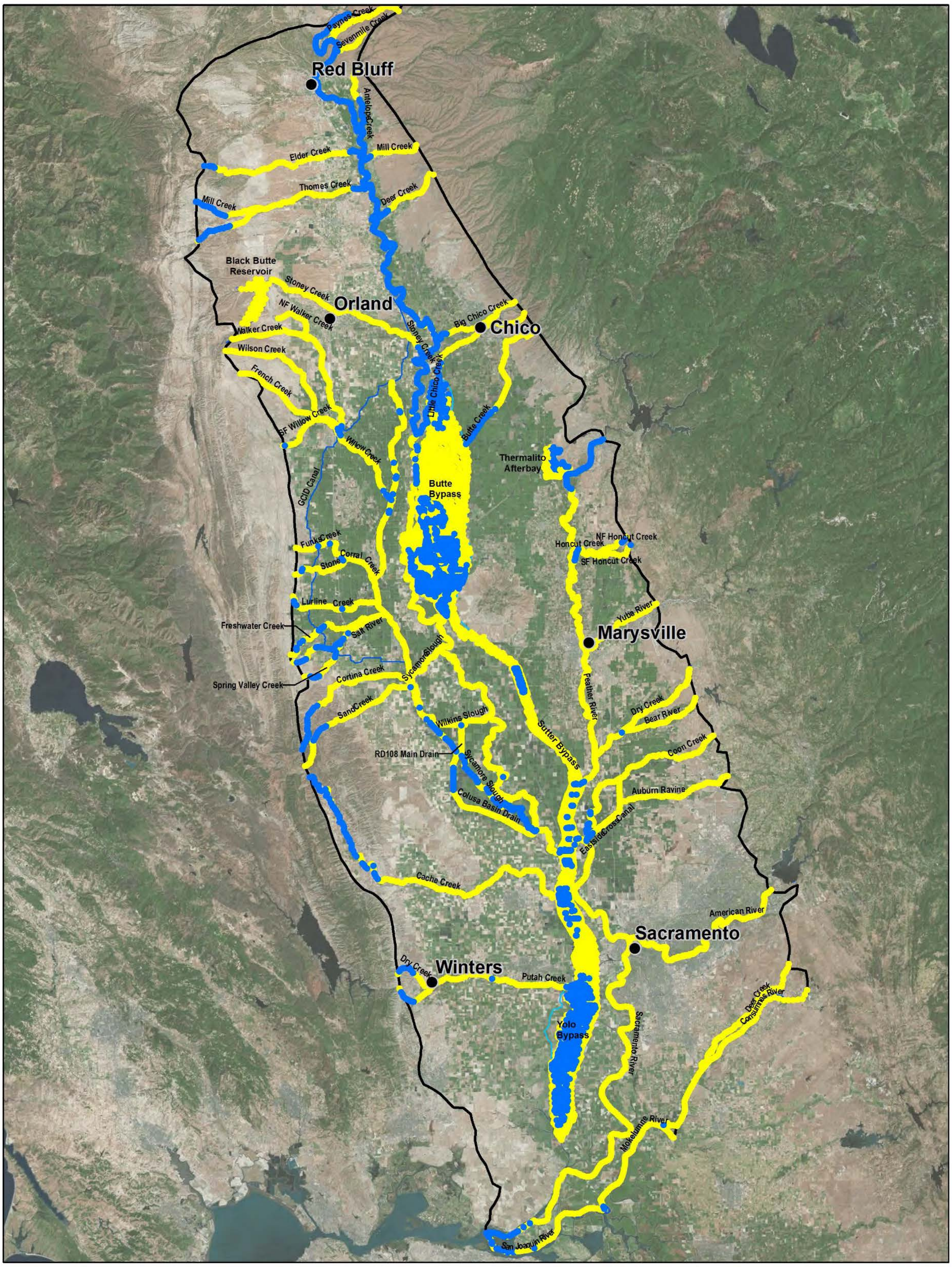

LEGEND

- ● 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

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0 6 12 24 Miles

Figure 35
Distribution of Simulated Stream Gain and Loss; January 1983
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
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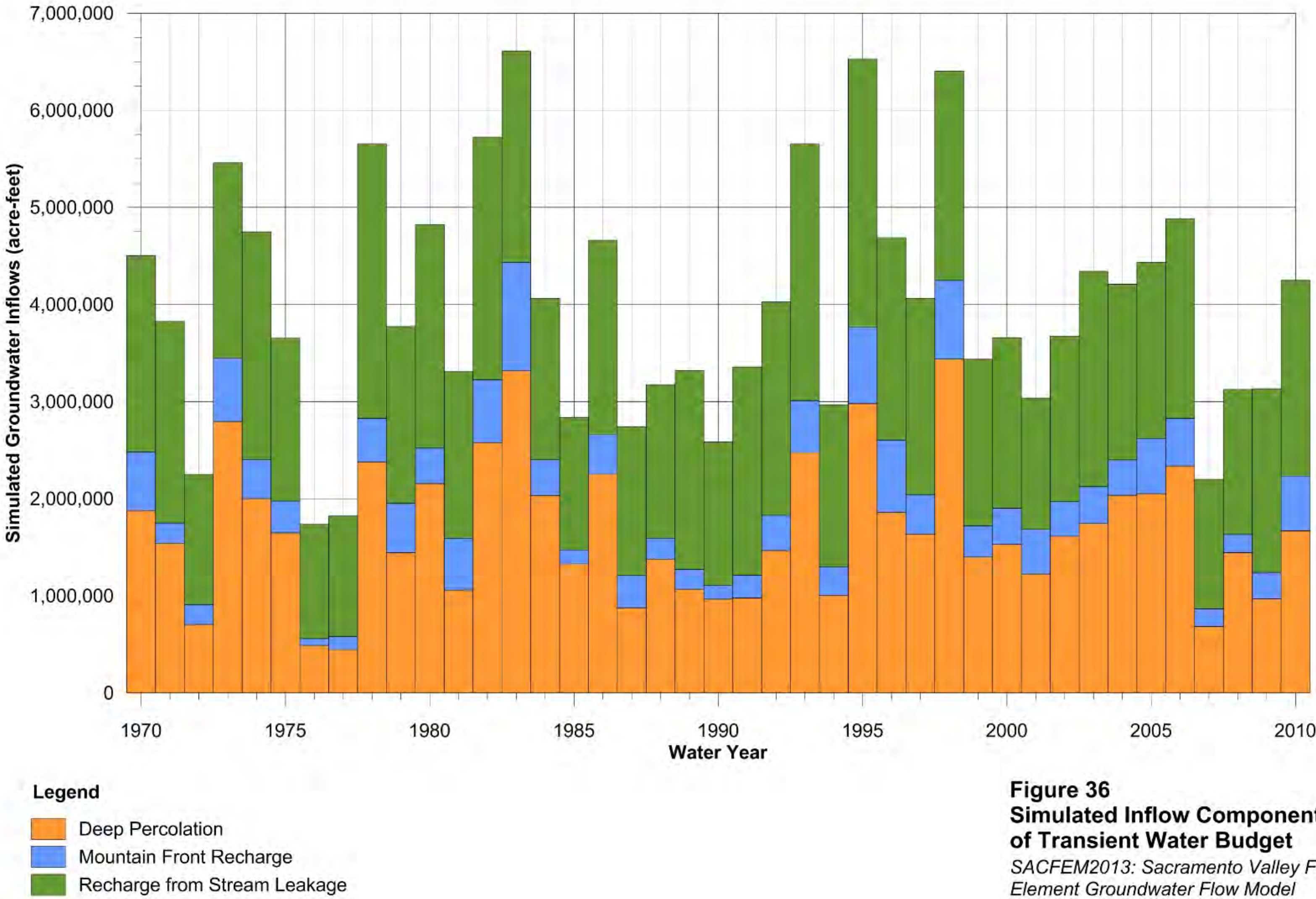
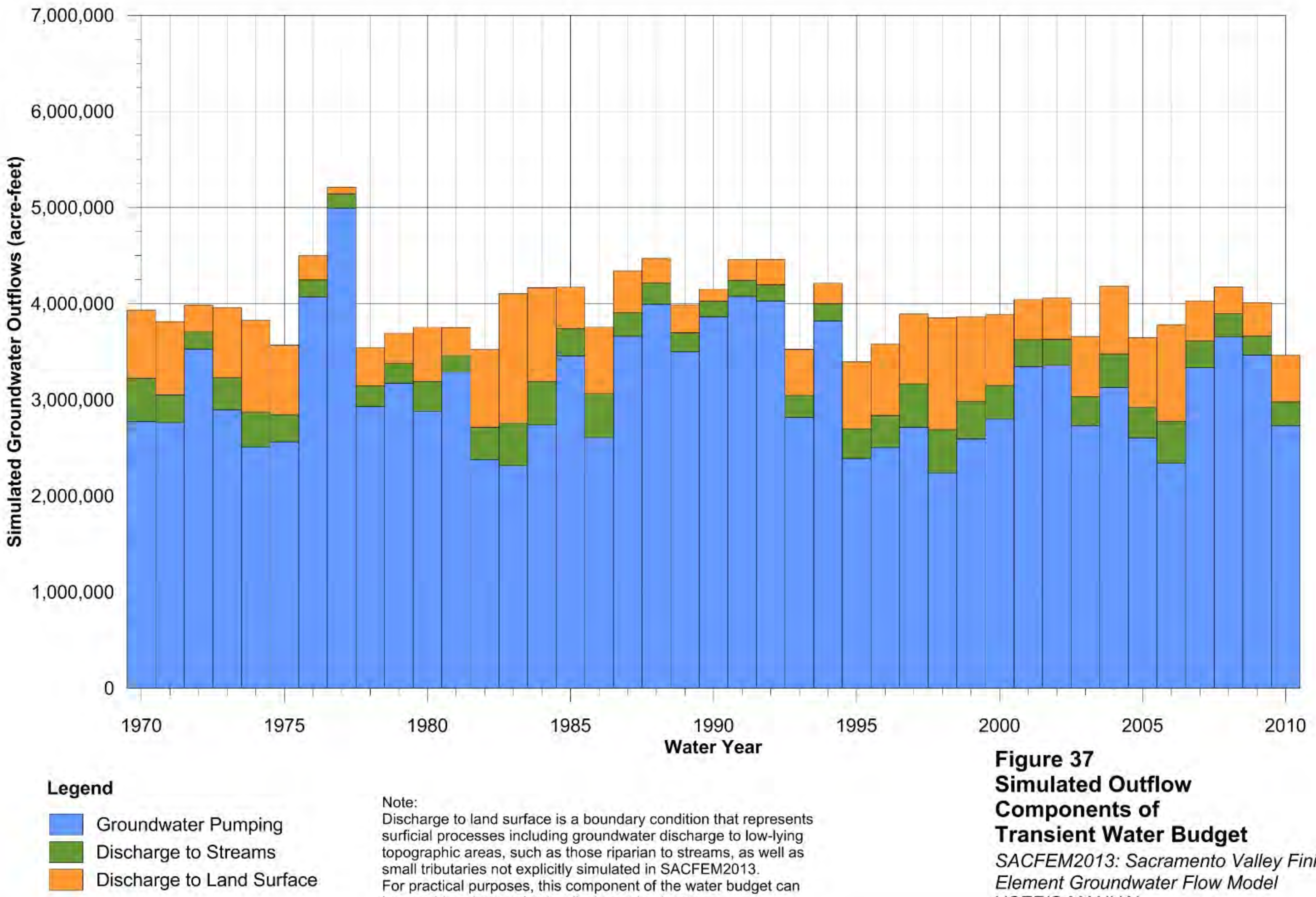


Figure 36
Simulated Inflow Components of Transient Water Budget
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL



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

CH2MHILL.

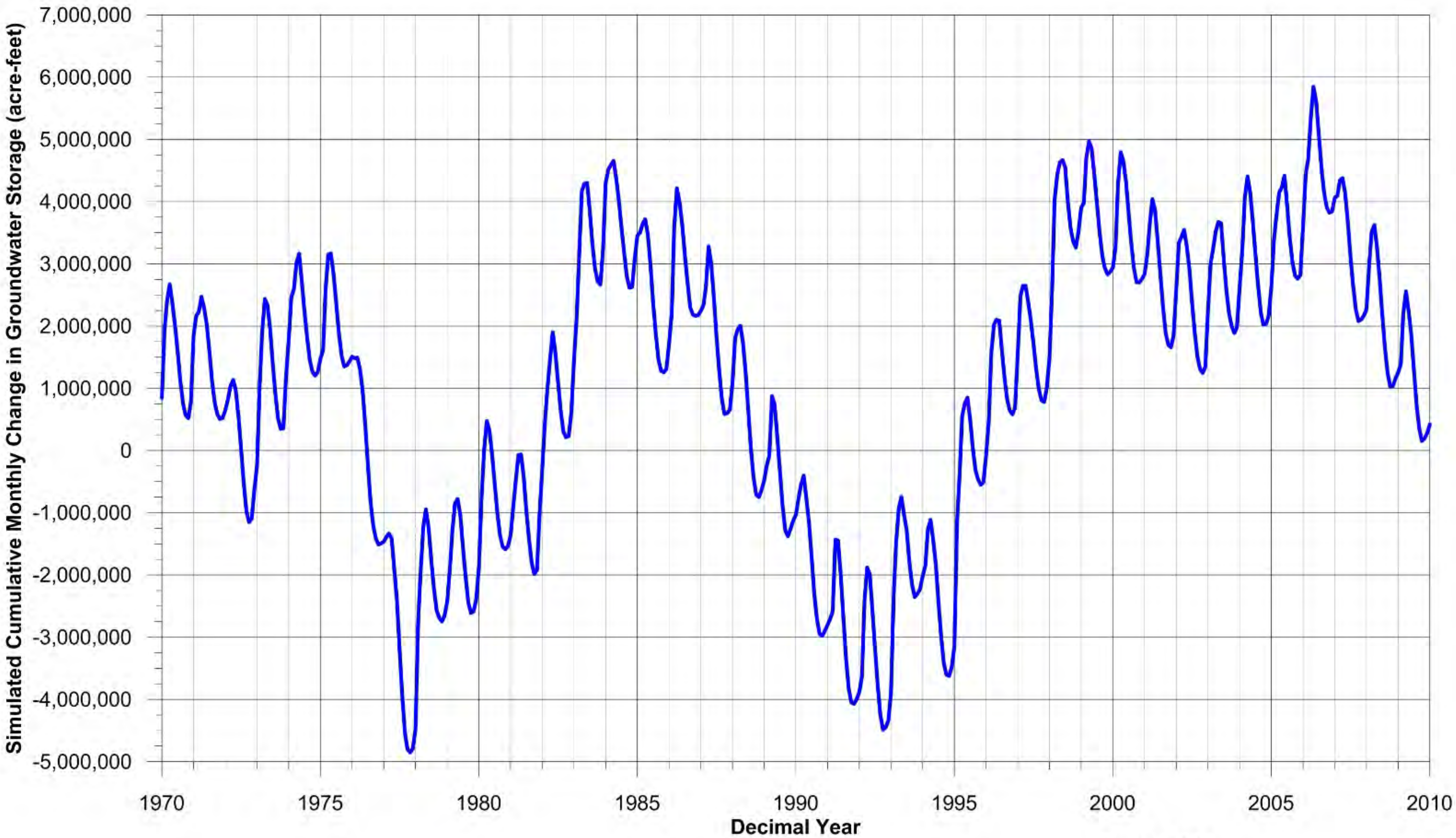


Figure 38
Simulated Cumulative Monthly Change in Groundwater Storage
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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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.

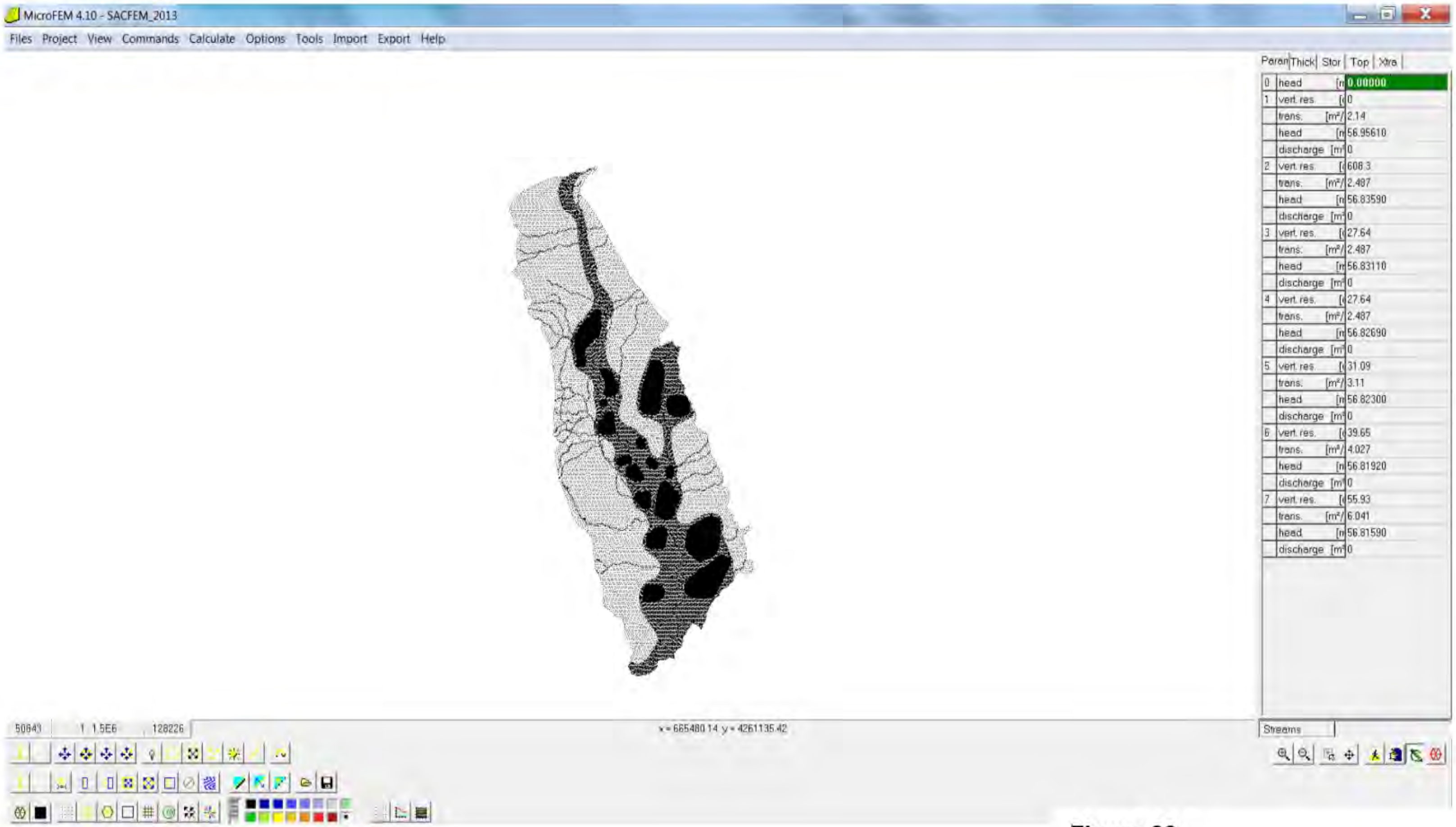


Figure 39
View of SACFEM2013.fpr via MicroFEM Interface

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

CH2MHILL.

FIGURE 40

MicroFEM Project Manager, Main Window

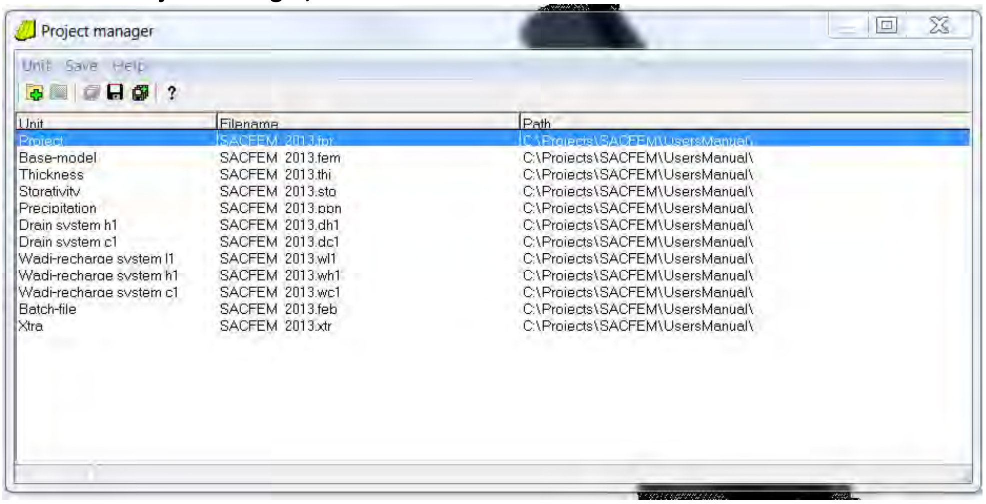
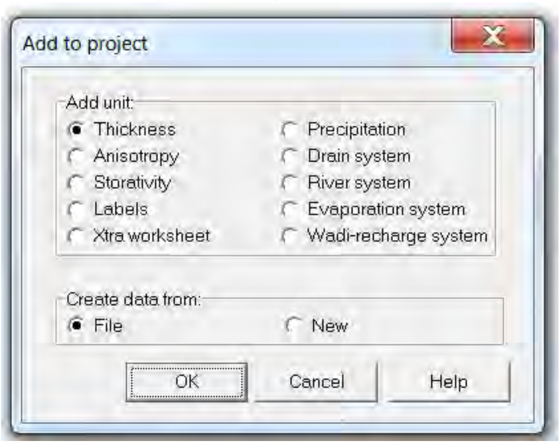


FIGURE 41

MicroFEM Project Manager, Load File Window



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

Parar | Thick | Stor | Top | Xtra

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

Parar | Thick | Stor | Top | Xtra

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

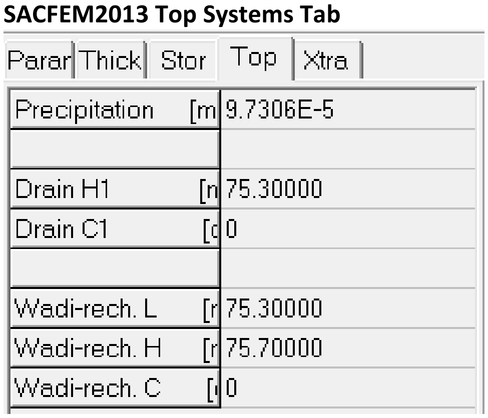
5.1.4 SACFEM2013 Top Systems ("Top" Tab)

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



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.

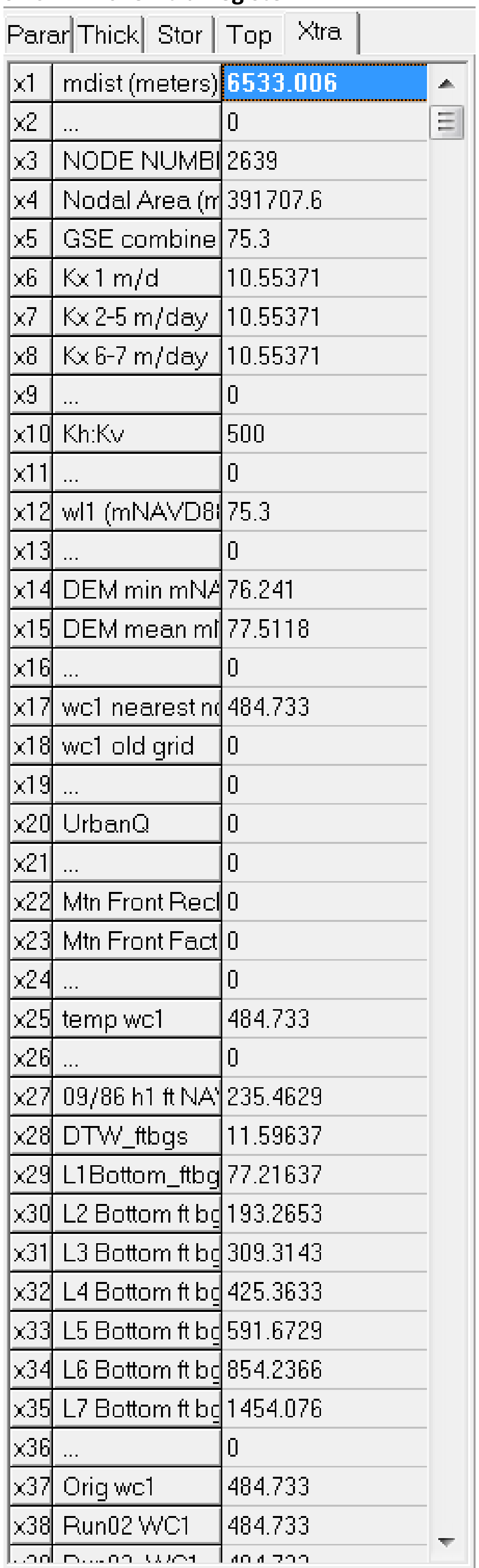
5.1.5 SACFEM2013 Extra Register ("Xtra" Tab)

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



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

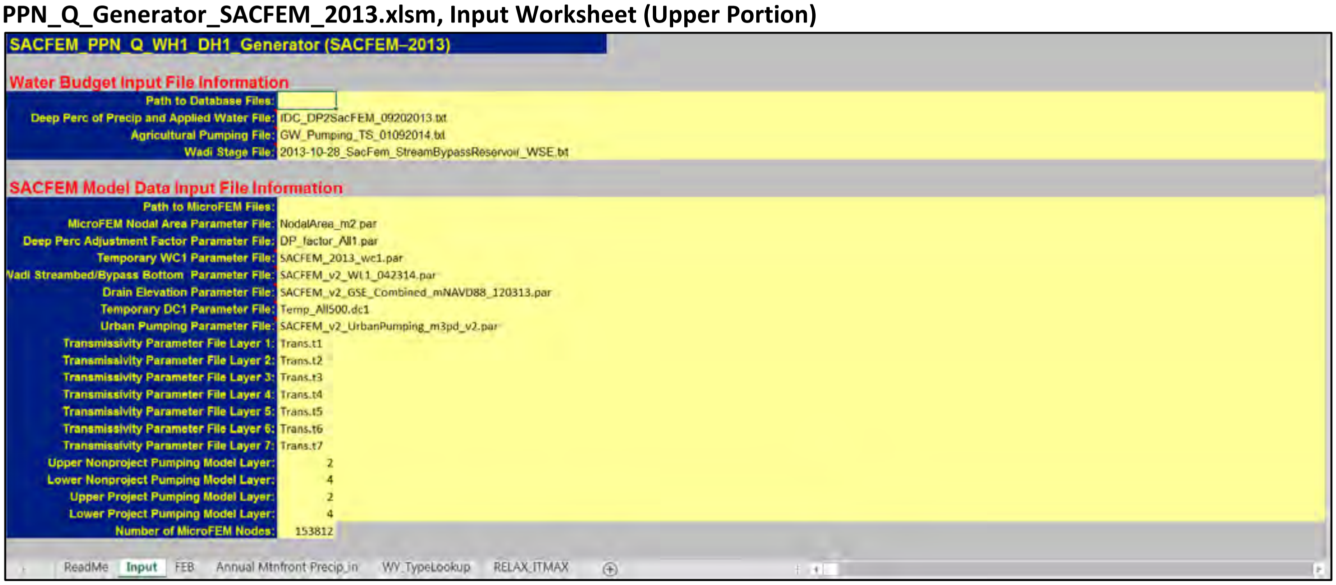
This portion of the worksheets (see Figure 46) directs the macros to generate the SACFEM2013 parameter files necessary for the various calculations and conversions. The first line is where the user inputs the file path to the parameter files. The necessary parameter files include the following:

- **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)



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

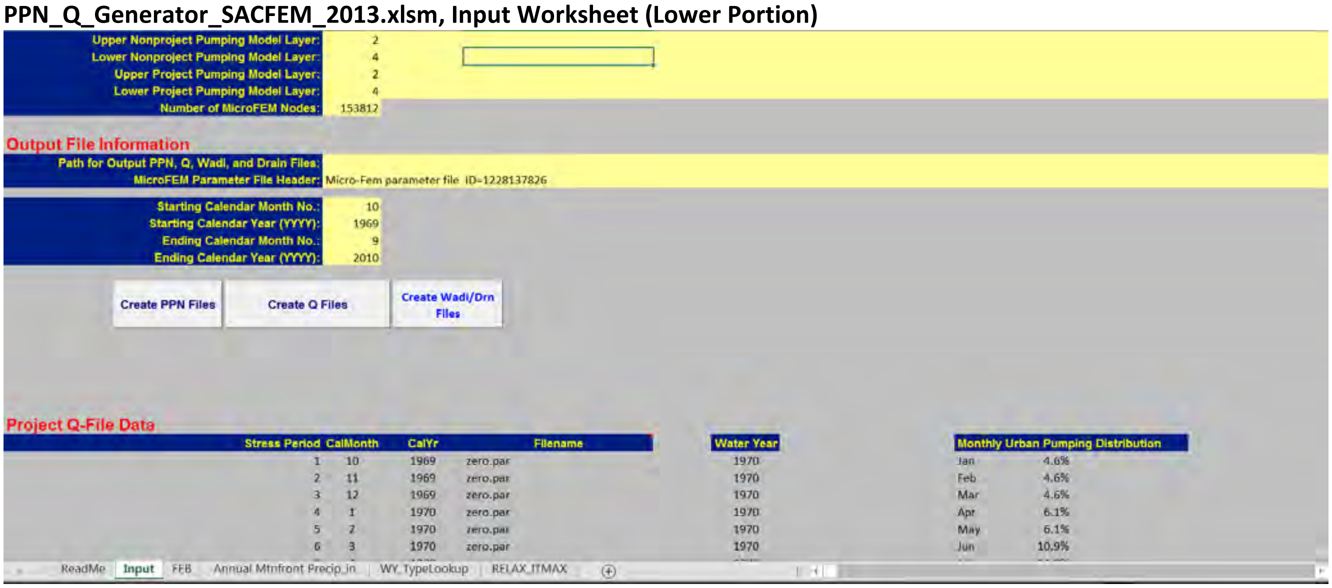
This section of the worksheet (see Figure 47) provides the macros to generate the output file information. The first row is where the user inputs the file path to the folder where all SACFEM2013 input files created by the macros will be stored. The next row is where the user specifies the MicroFEM header 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)



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:

$$Factor = \frac{T_2}{T_2 + T_3 + T_4} \quad (12)$$

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

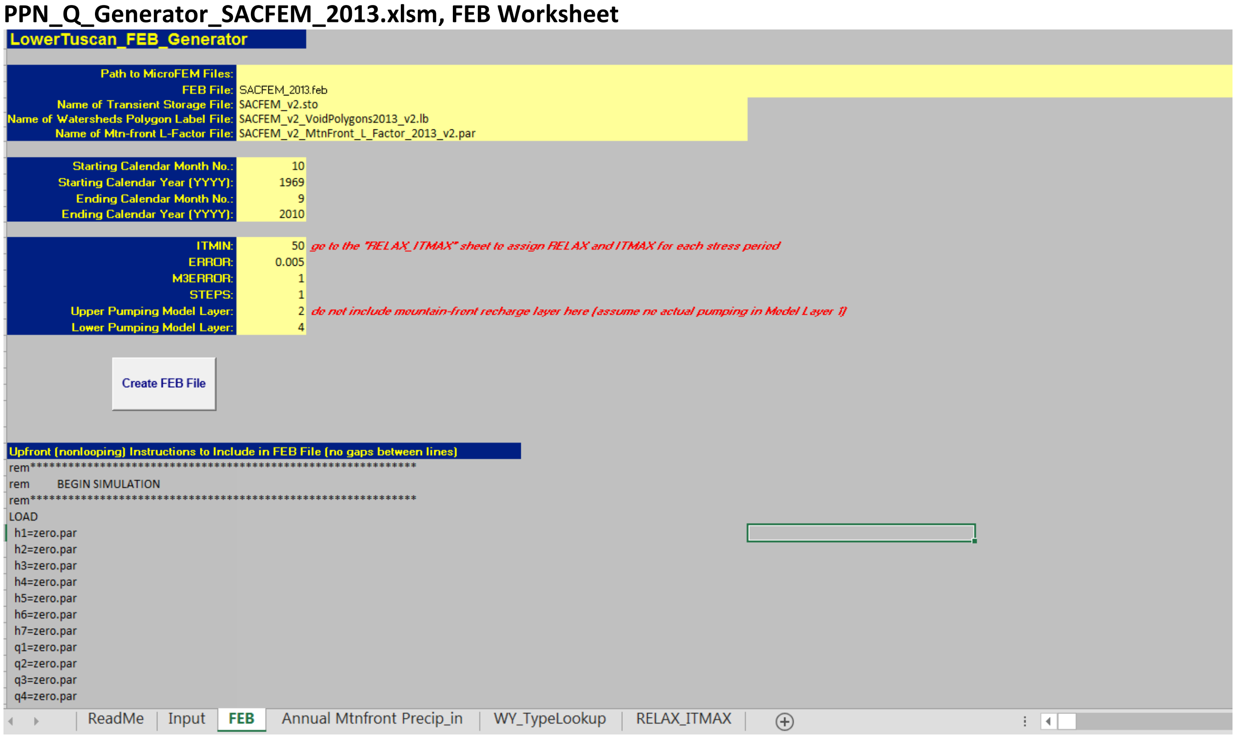
The FEB worksheet of the pre-processing utility contains one macro that is used to generate the batch file (*.feb) that runs the transient SACFEM2013 simulation. The SACFEM_2013.feb file is included as Appendix D for reference and is discussed in detail in Section 5.3.

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



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 (m³)											
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
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

Source: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

ReadMe | Input | FEB | Annual Mtnfront Precip_in | WY_TypeLookup | RELAX_ITMAX

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 (m³)	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

ReadMe | Input | FEB | Annual Mtnfront Precip_in | WY_TypeLookup | RELAX_ITMAX

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

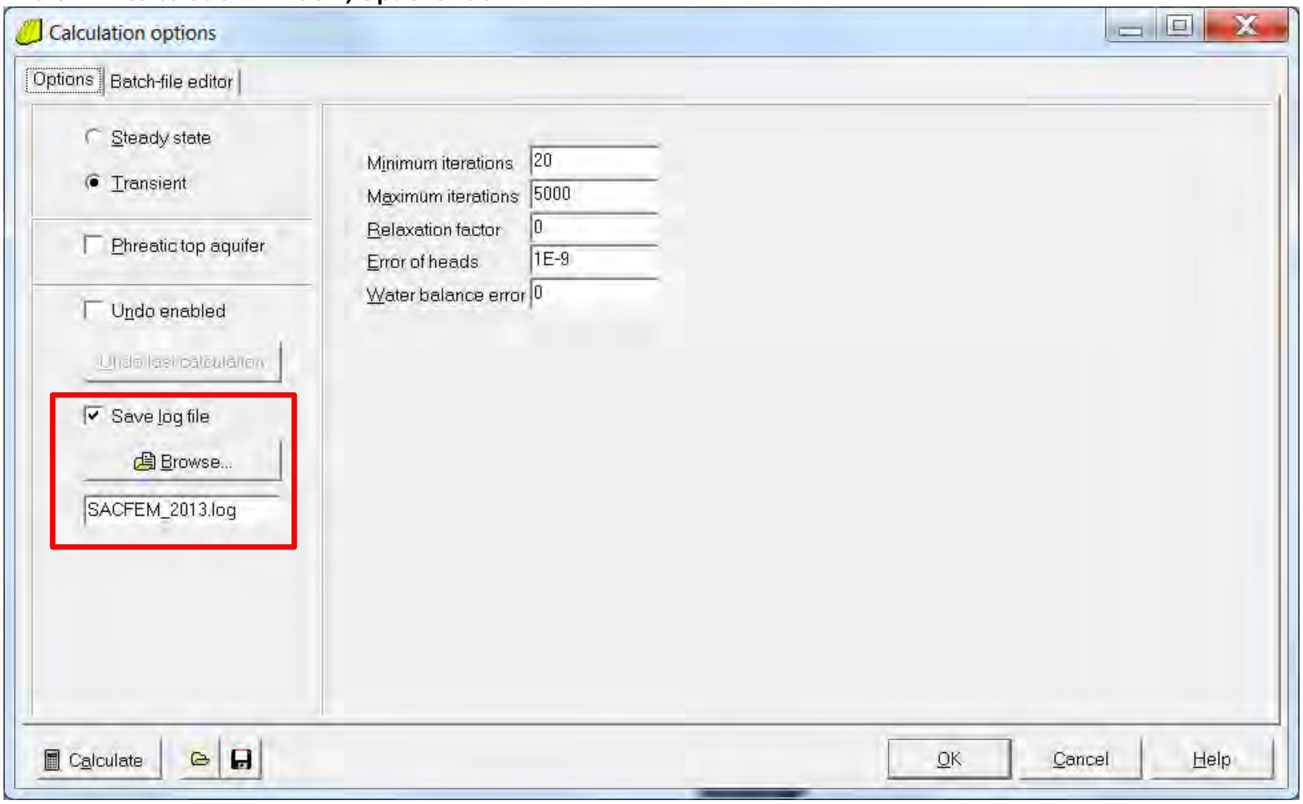
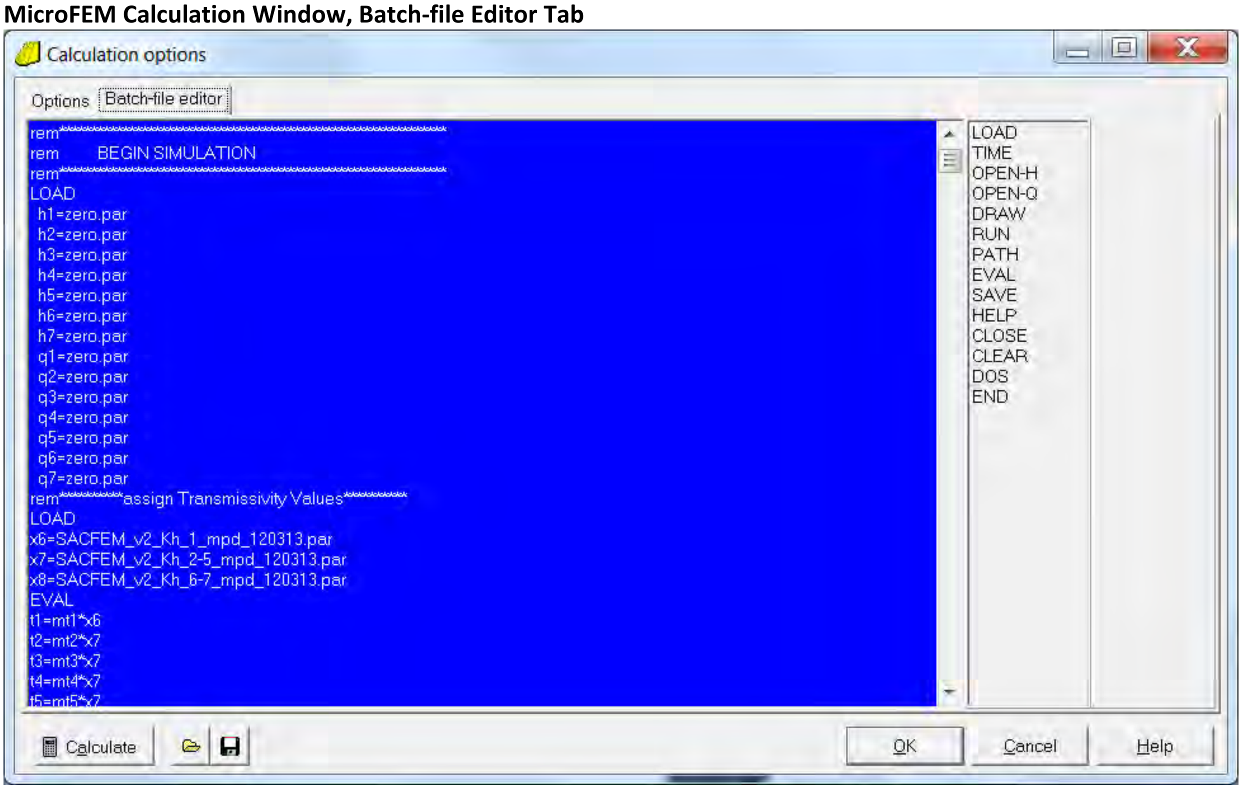


FIGURE 53
MicroFEM Calculation Window, Batch-file Editor Tab



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:

$$t1 = mt1 \times x3 \quad (13)$$

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:

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

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

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

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

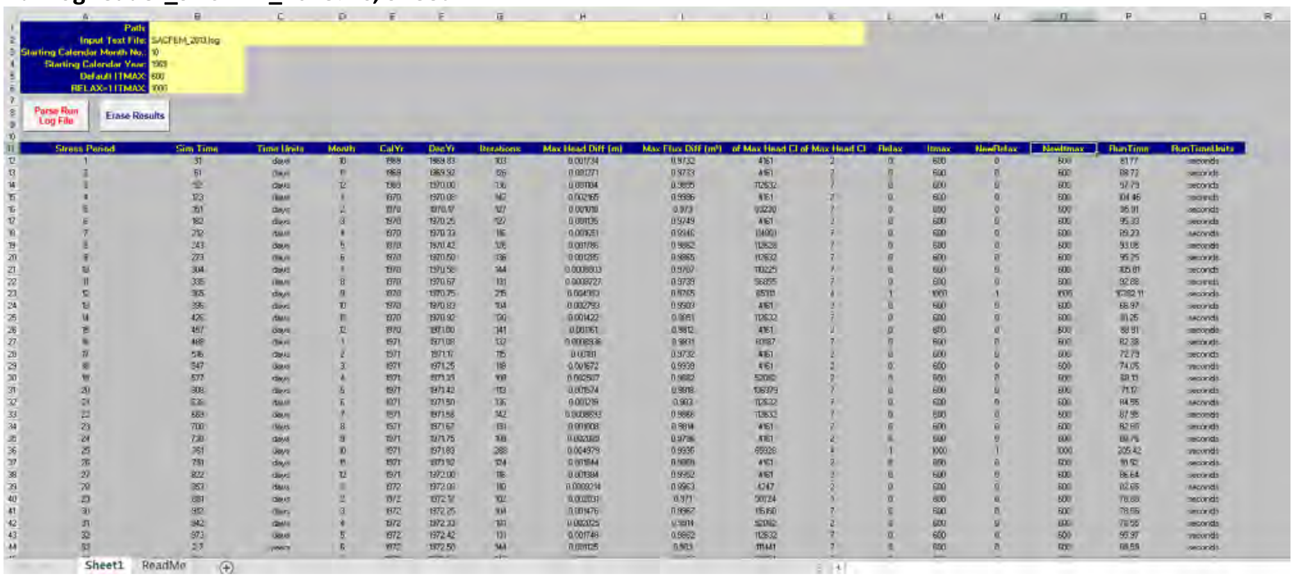
The SACFEM2013 run log reader summarizes the simulation information for each stress period from the *.log file. The user inputs SACFEM2013 file information in the first six rows including: path in *.log file, file name (including extension), starting month (calendar month), starting year (calendar year), 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

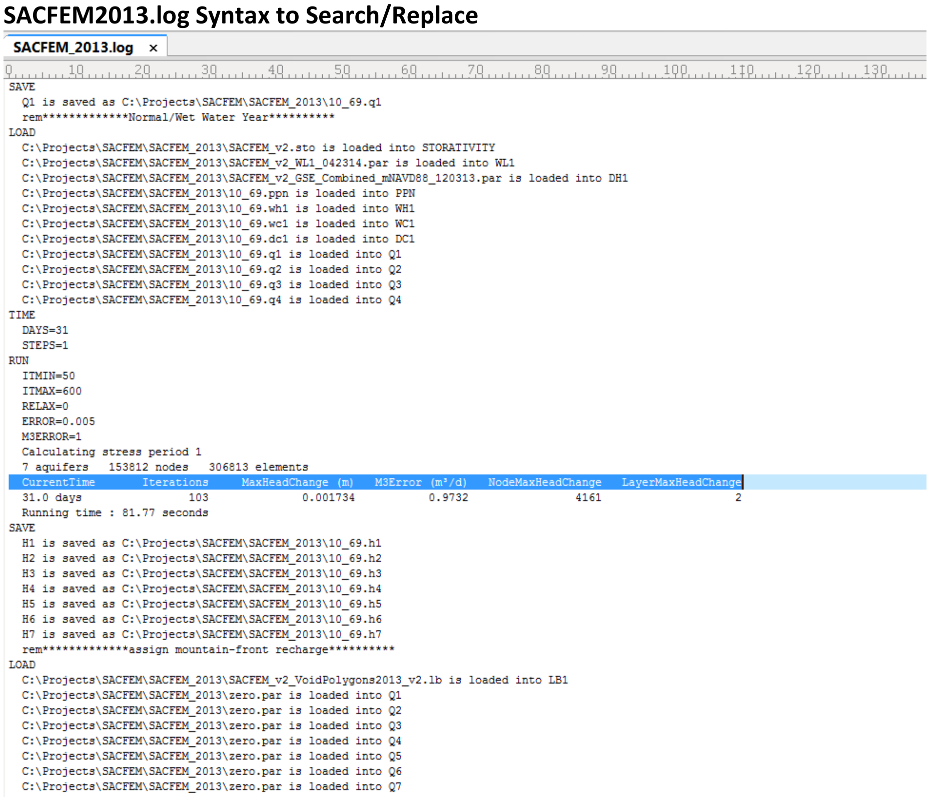
RunLogReader_SACFEM_2013.xls, Sheet 1



*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

```
ReadFTH.inp
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

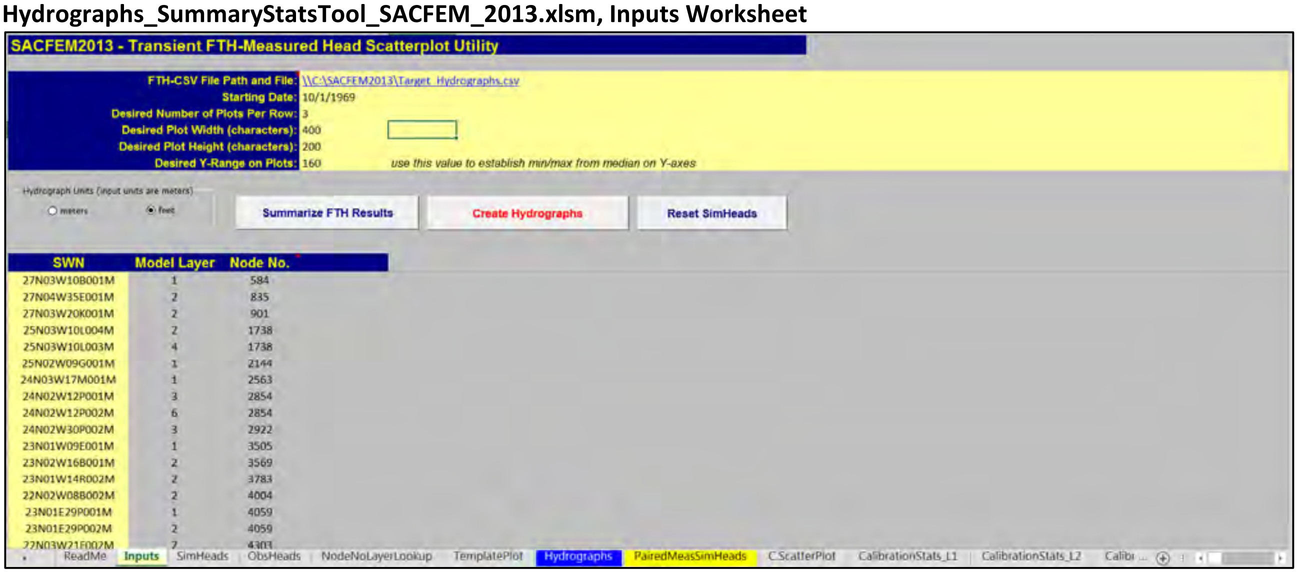
Below the user-specified information is a toggle box for the desired output units as well as buttons for each of the macros. The last section of the "*Inputs*" worksheet contains the list of calibration targets, including SWN, SACFEM2013 model layer, and SACFEM2013 model node number. The list should 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

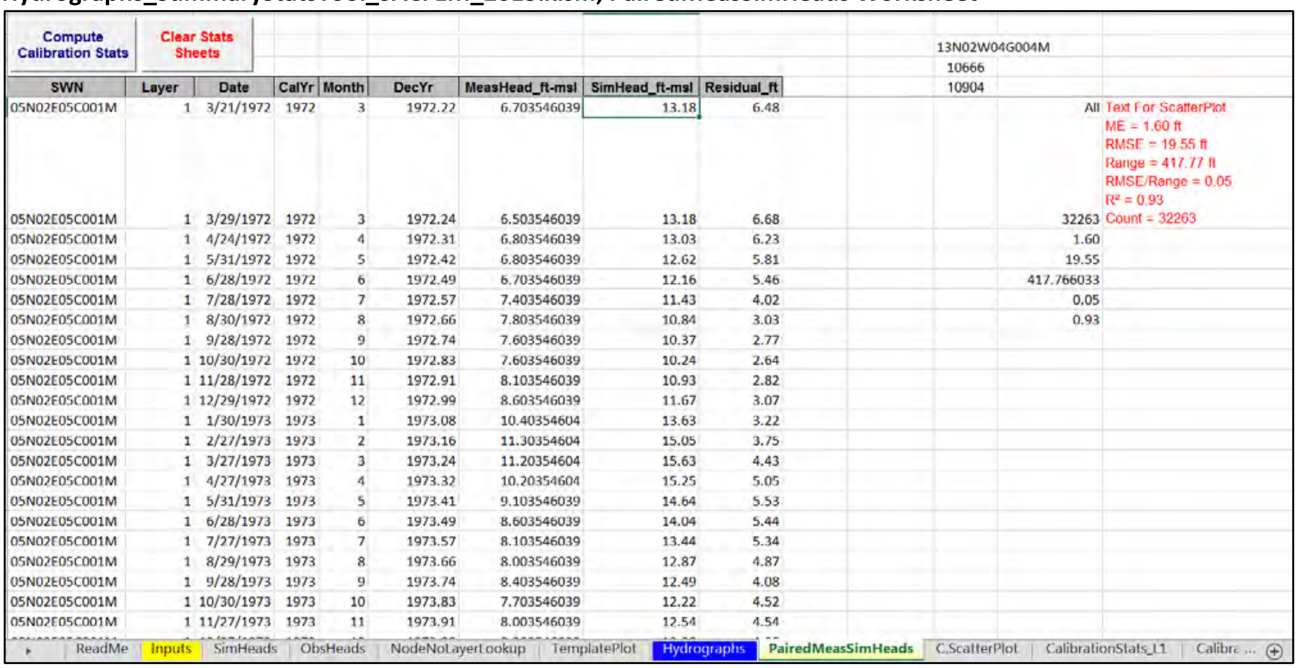


5.5.2.3 PairedMeasSimHeads Worksheet

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:

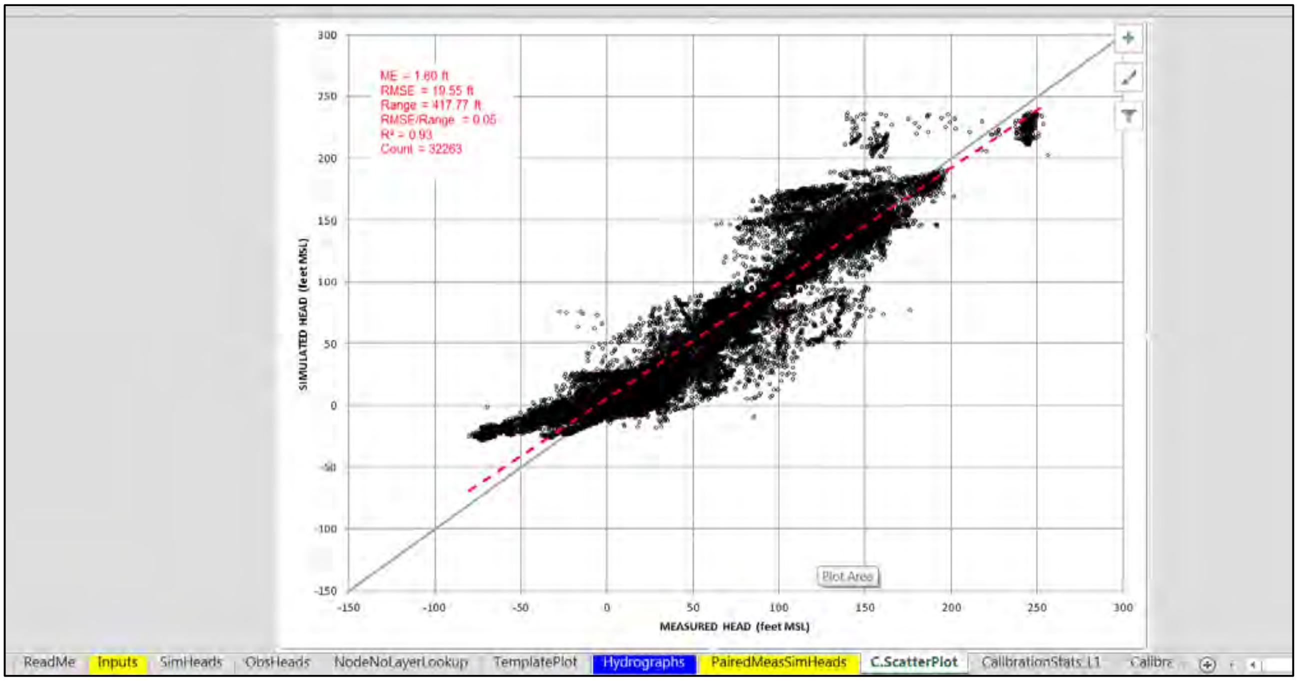
- For each measured groundwater elevation on the “ObsHeads” worksheet, the macro pairs a quasi-contemporaneous simulated groundwater elevation from the “SimHeads” worksheet. The macro interpolates the simulated groundwater elevation data between stress periods to matches the date of the measured groundwater 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
											ME = 1.60 ft
											RMSE = 19.55 ft
											Range = 417.77 ft
											RMSE/Range = 0.05
											R² = 0.93
05N02E05C001M	1	3/29/1972	1972	3	1972.24	6.503546039	13.18	6.68		32263	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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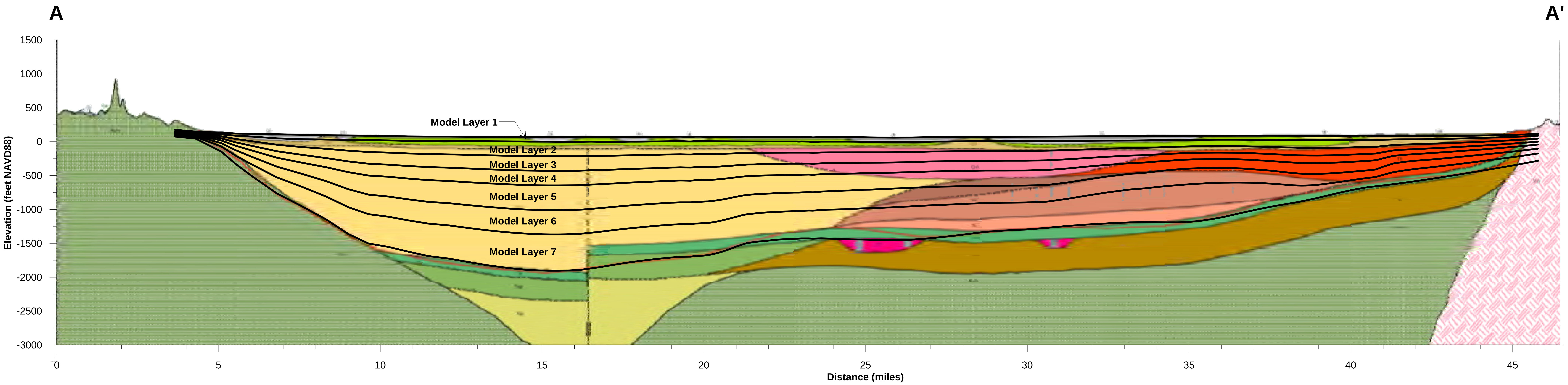

- **Qa** — **Alluvium** (Holocene)-Includes surficial alluvium and stream channel deposits of unweathered gravel, sand and silt, maximum thickness 80 ft. *(adapted from Helley & Harwood, 1985)*.
- **Qh** — **Basin Deposits** (Holocene)-Fine-grained silt and clay derived from adjacent mountain ranges, 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)*.
- **Qtb** — **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

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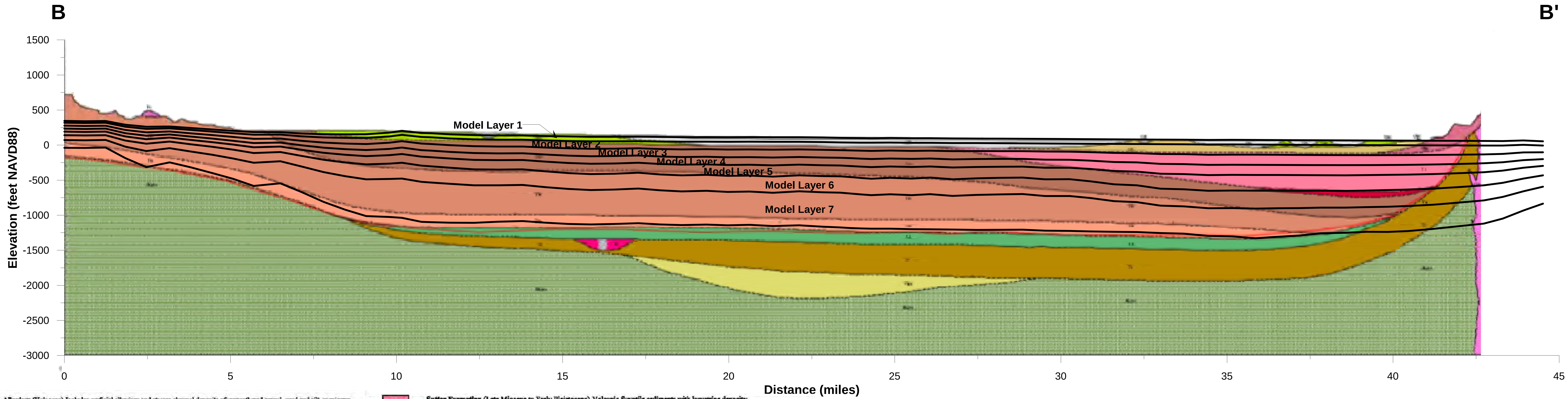

Qa	**Alluvium** (Holocene)-Includes surficial alluvium and stream channel deposits of unweathered gravel, sand and silt, maximum thickness 80 ft. *(adapted from Helley & Harwood, 1985)*.
Qb	**Basin Deposits** (Holocene)-Fine-grained silt and clay derived from adjacent mountain ranges, maximum thickness up to 200 ft. *(adapted from Helley & Harwood, 1985)*.
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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)*.
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Qtm	**Tuff Breccia** (Plio-Pleistocene)-Tuff breccia forming outer ring surrounding the Sutter Buttes *(adapted from Helley & Harwood, 1985)*.
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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)*.
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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)*.
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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)*.
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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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