TECHNICAL MEMORANDUM

PEER REVIEW OF SACRAMENTO VALLEY FINITE ELEMENT GROUNDWATER MODEL (SACFEM)

Prepared for:

U.S. Bureau of Reclamation

In Response to the Request of

The Sacramento Valley Water Management Agreement Management Committee

Prepared by: WRIME

October 2011

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AWWA	American Water Works Association
C2VSIM	Central Valley Groundwater and Surface Water Simulation Model
CDEC	California Data Exchange Center
CVP	Central Valley Project
DWR	California Department of Water Resources
DSA	Depletion Study Areas
EIR	Environmental Impact Report
IDC	IWMF Demand Calculator
IGSM	Integrated Groundwater and Surface water Model
IWFM	Integrated Water Flow Model
IWRIS	Integrated Water Resources Information System
NRCS	Natural Resources Conservation Service
Reclamation	U.S. Bureau of Reclamation
SacFEM	Sacramento Valley Finite Element Groundwater Model
SacIGSM	Sacramento County Integrated Groundwater and Surface water Model
SVWMP	Sacramento Valley Water Management Program
SWP	State Water Project
TM	Technical Memorandum
USGS	U. S. Geological Survey
WRIME	Water Resources and Information Management Engineering, Inc.

Peer Review
of
Sacramento Valley Finite Element Groundwater Model (SacFEM)

Technical Memorandum

October 2011

1. INTRODUCTION

A peer review of Sacramento Valley Finite Element Groundwater Model (SacFEM) was performed by WRIME, Inc. This Technical Memorandum (TM) presents the results of this peer review. The TM includes a summary of the peer review objectives and approach, SacFEM development objectives, peer review of SacFEM components and calibration, adequacy of SacFEM to be applied to its intended uses, and peer review recommendations.

1.1 PEER REVIEW OBJECTIVE

The objective of the SacFEM peer review was to ensure that the SacFEM is an appropriate tool capable of its intended uses; is technically appropriate and defensible, and is not limited by deficiencies or flaws that would render its results invalid for the intended applications.

The scope of work for the SacFEM peer review included the following tasks:

- Review of SacFEM documentation
- Review of conceptual model elements
- Review and assessment of SacFEM files and model operation:
  - Model areas, grid, layering
  - Input parameters
  - Calibration
- Preparation of Technical Memorandum to present:
  - Peer review conclusions in regard to:
    - Validity of SacFEM as reflective of Sacramento Valley
    - Ability to replicate historical conditions
    - Sufficiency of calibration period length
  - SacFEM applicability and its adequacy to be used for its intended applications.

1.2 Purpose of SacFEM Development

SacFEM was primarily developed as a numerical tool to estimate the impact of conjunctive water management projects on surface water and groundwater resources within the Sacramento Valley. More specifically, SacFEM will be used as a tool for the purpose of conducting impact analysis of Sacramento Valley's groundwater resources at regional and local levels, as part of the Sacramento Valley Water Management Program (SVWMP).

SacFEM covers all of the Sacramento Valley and incorporates detailed surface water processes. SacFEM has greater spatial resolution in project areas and areas with potential impacts to groundwater levels and stream flows.

SacFEM uses the proprietary MicroFEM model (Hemker, 1997) for simulation of groundwater flow and the **I**WFM **D**emand **C**alculator model (IDC) for simulation of land surface processes. IWFM is the **I**ntegrated **W**ater **F**low **M**odel that was developed by the California Department of Water Resources (DWR) in 2010. SacFEM links the groundwater model with the surface water budget and root zone model (i.e., IDC model) to estimate deep percolation and agricultural pumping on a node by node basis from 1970 through 2003.

A brief documentation of SacFEM is available (Lawson, 2009) and was reviewed as part of this peer review.

1.3 SacFEM Peer Review Process

This section presents the peer review approach, review team, outline of SacFEM review, and categories of recommendations for improvement of the model.

1.3.1 Peer Review Approach

The SacFEM peer review, a transparent and collaborative process, was targeted to address the main objective of the peer review, i.e., the adequacy of SacFEM to be used for the impact analyses of the SVWMP. As such, the peer review of SacFEM did not cover all aspects of the model, but only the components necessary to provide a recommendation for adequacy of SacFEM to be used for the SVWMP.

The following items were addressed in the SacFEM peer review:

- MicroFEM code is proprietary and was not reviewed.
- Accuracy of SacFEM input data, such as precipitation data, were not verified against the data sources.
- Estimated data and/or parameters, such as deep percolation rates, were compared against other available data and/or models, when available.
- IDC model results were reviewed.
- IDC model pre & post-processing routines were not available and not reviewed.
- Spatial data, such as hydrologic soil types and surface water availability information from the IDC model and/or SacFEM, were reviewed and used to verify model results.
- SacFEM simulations were performed to verify calibration results.

The peer review was closely coordinated with the SacFEM developer, Peter Lawson of CH2M HILL, and the IDC application team, Lee Bergfeld and Walter Bourez of MBK. Additionally, three workshops were held during the peer review process to share the results with the U.S. Bureau of Reclamation (Reclamation), DWR and other stakeholders.

1.3.2 Peer Review Management Team

The SacFEM peer review process was guided by a management team consisting of Tim Rust and Brad Hubbard of Reclamation, Bob Niblack of DWR, and Joe Scalmanini of Luhdorff & Scalmanini Consulting Engineers (LSCE). Additionally, the guidelines and results of the SacFEM peer review were reviewed by technical representatives from the stakeholders.

1.3.3 Peer Review Team

The peer review of SacFEM was conducted by a three-member panel of professional modeling and water resources experts, as follows:

- **Ali Taghavi**, Ph.D., P.E., Project Manager. Dr. Taghavi is an expert in water resources planning and hydrologic modeling. He is the co-author of several integrated hydrologic models, such as the Integrated Ground and Surface water Model, as well as system operations models.
- **Graham Fogg**, Ph.D., Professor of Hydrogeology at the University of California, Davis. Dr. Fogg has numerous years of experience in modeling in the Sacramento Valley.
- **Saquib Najmus**, Ph.D., P.E., Dr. Najmus is the author of the Hydrologic Modeling chapter and the Groundwater Development section of the Water Resources Planning Manual of the American Water Works Association (AWWA).

The Peer Review Panel was supported by a technical analysis team. The technical analysis team was responsible for running the model, analyzing the input and output files, evaluating the calibration results, and preparing the graphs and tables of findings from the peer review. The members of the technical analysis team are:

- **Reza Namvar**, Ph.D., P.E., Modeling expert with more than years of experience in groundwater and surface water modeling.
- **Mesut Cayar**, Ph.D., P.E., Modeling expert with significant experience in groundwater and surface water modeling.
- **Jon Traum**, P.E., Modeling expert with significant experience in land and water use data, model data development, and analysis, and model calibration.

1.3.4 Peer Review Outline

In order to address the objectives of the SacFEM peer review, the following components of SacFEM were reviewed:

- Model Grid
- Model Layers
- Aquifer Properties
- Land Surface Processes
- Land use/Crop Acreage
- Agricultural Groundwater Pumping
- Urban Groundwater Pumping

- Deep Percolation
- Stream Gain/Loss Calculation
- Mountain Front Recharge
- Model Calibration

The details of the review of each component are provided in Sections 2 and 3.

1.3.5 Recommendation Tiers

During the peer review process, several issues were identified that needed to be addressed for SacFEM to become an acceptable model for its intended application. The identified issues were grouped into three recommendation tiers with decreasing significance. The recommendation tiers are as follows:

- **Tier 1** – Findings that require model revisions and modification before SacFEM is acceptable for its intended use. The Peer Review Panel strongly recommends addressing these findings to help ensure defensible simulation results from SacFEM.
- **Tier 2** – Findings that do not require model revisions for application of SacFEM for its intended use. However, these enhancements will strengthen model defensibility. The Peer Review Panel recommends the implementation of these findings, subject to schedule and budget.
- **Tier 3** – Findings that would improve SacFEM feature and capabilities, but do not necessarily add to the accuracy of the model for its intended use.

Specific recommendations for each component of SacFEM are provided in the corresponding subsection of Sections 2 and 3. These recommendations are summarized in Section 5.

2. SACFEM FEATURES

This section provides a brief description, review and analysis, and recommendations of several components of SacFEM. Only the model components that were specified in Subsection 1.3.3 were reviewed and are presented in this section.

2.1 Model Codes Used for Development of SacFEM

SacFEM was developed using MicroFEM. MicroFEM is a proprietary code and only a limited assessment of its capabilities was conducted as part of this peer review. The IDC model was used to calculate the land surface and root zone processes. The results of the IDC model were imported into SacFEM. Reviewing the selection process of MicroFEM and IDC models for development of SacFEM and evaluation of the theoretical framework of these two models were not part of the scope of this peer review and were not reviewed.

MicroFEM is a finite element model and is similar to the MODFLOW model which simulates the saturated groundwater flow. MicroFEM's user interface includes several post processors that were used for the development of SacFEM.

The IDC model was originally a part of DWR's IWFM model. DWR has recently released the IDC model as a stand-alone model for calculation of land surface and root zone processes. The IDC model calculates agricultural and urban demand and estimates the deep percolation rates of applied water and precipitation. SacFEM developers used multiple GIS and Excel pre and post processors for the IDC model. The IDC model and its pre and post processors were not reviewed as part of this peer review.

IDC version 2.0b (DWR, 2007) was used to estimate the agricultural water demand, agricultural groundwater pumping, and deep percolation rates for each node of SacFEM. Results of IDC model were incorporated into the SacFEM input data files. Figure 1 illustrates a schematic of the IDC model and SacFEM simulation process.

Extensive spatial information was used for the IDC model to estimate the agricultural groundwater pumping and deep percolation rates. The spatial information used for the IDC model included:

- Land use/crop pattern
- Sources of irrigation water
- Surface water availability
- Seniority of water rights
- Spatial distribution of rain
- Hydrologic soil types

2.2 MODEL DOMAIN

The SacFEM domain coincides with the lateral extent of the freshwater aquifer within the Sacramento Valley Groundwater Basin. The SacFEM domain boundary is consistent with the freshwater boundary map available in the literature (DWR, 1978; and Page, 1986).

2.3 MODEL GRID

The SacFEM grid was configured to support evaluation of potential conjunctive water management projects associated with the SVWMP. It consists of 120,761 nodes and 241,001 elements (Figure 2). Nodal spacing varies from 325 feet (ft) to 8,200 ft. Finer node spacing is used near most of proposed project areas, project well pumping areas, and major rivers (Figure 3).

A comparison of SVWMP and the 2009 Drought Water Bank project wells locations with the SacFEM grid indicate that most project wells are located in the fine node spacing parts of the grid (Figures 2 and 3). However, Water Bank project wells in Sacramento County, east of Highway 50, are located in the coarse node spacing part of the grid (Figure 3). The coarser node spacing in this area does not support refined estimates of the effects of the Water Bank project in the Sacramento area. Project wells in the Sacramento area are recommended to be excluded, or the SacFEM grid needs to be refined in the Sacramento area for evaluation of the impact of conjunctive use projects.

Fine grid size sets the expectation that the supporting data is very detailed. However, fine grid resolution in project areas requires more accurate calibration targets and increases expectations on accuracy of model results, which may be beyond the precision of supporting data.

The assessment of the SacFEM grid is summarized below:

1. The grid is well sized for most project areas, other than the Sacramento area.

2. Fine grid size in project areas sets high expectations on accuracy of model results beyond the precision of supporting data.
3. Supporting data should have enough resolution on temporal and spatial resolution to provide sufficient level of accuracy for the simulation in the fine grid areas.
4. Fine grid size in the project areas increases the need for detailed or finer discretized input data, but not necessarily a higher level of calibration.

2.4 Land Surface and Root Zone Processes

Estimations of agricultural pumping and deep percolation of precipitation and applied water are, in part, based on the land use conditions. Land use changes during the calibration period of regional models will have a significant impact on groundwater pumping and deep percolation. Conversion of agricultural lands to urban areas or changes in cropping patterns will result in changes in timing and location of groundwater pumping and deep percolation.

2.4.1 Land Use

SacFEM and the IDC model use land use data for estimation of groundwater pumping and deep percolation during the 1970-2003 calibration period (Figure 4). The land use and cropping data are from DWR field surveys from several different years spanning from 1994 through 2003 (Table 1), and are assumed to represent approximately the 2005 level of development. It is assumed that no significant land use changes have occurred during the 1970-2003 period. However, other historical land use survey data are available from DWR for 1967, 1980, 1993, and 2000.

The use of only the 2005 level of development results in mismatch of the long-term changes in groundwater elevations in several calibration wells. The increase in urban areas will result in changes in groundwater pumping and elevation. This is evident in simulated groundwater elevations in calibration wells in the vicinity of the cities of Sacramento, Woodland, and Chico.

Additional historical land use information is recommended to be used for SacFEM and the IDC model to improve model calibration and obtain a better match of the long-term trends in groundwater elevation. Historical land use is not needed for analyzing the proposed projects; however, if SacFEM is better calibrated, it will have an improved estimate of the effects of the conjunctive use projects.

2.4.2 Crop Acreage

SacFEM and the IDC model use only the 2005 level of development crop mix data for the 1970-2003 calibration period (Figure 5). Similar to land use data, it is assumed that no significant changes to crop acreages have occurred during this period. Other historical land use survey and crop acreage data are available for 1967, 1980, 1993, and 2000. Figure 6 and Table 2 compare crop acreages and crop mix distribution of the Central Valley Groundwater and Surface Water Simulation Model (C2VSIM) with SacFEM crop acreage data. Alfalfa and pasture acreage reduced from a total of 25.1% in 1967 to 11.4% in 2005. Rice acreage varied from 25.2% in 1967 to 32.3% in 2000. Orchard acreage varied from 16.4% in 1980 to 24.4% in 1993.

Historical land use and cropping patterns for 1970-2003 indicate major changes in crop mix over time. These changes affect the historical estimates of agricultural water demand, agricultural groundwater pumping, and deep percolation. It is recommended to use historical crop acreage data for improved calibration of SacFEM and IDC models. A better calibrated SacFEM will have an improved estimate of the long-term trends in groundwater elevation as a result of future conjunctive use projects.

2.4.3 Agricultural Groundwater Pumping

Agricultural groundwater pumping of a farm is set to be equal to agricultural demand of the farm minus surface water delivery to the farm. Agricultural demand was calculated by the IDC model and the surface water delivery data was obtained from the CalSim-II model. Common Model Package version 8D at an existing level of development was used as the baseline CalSim-II simulation.

Agricultural demand was calculated based on the 2005 level of development land use and crop acreages, evapotranspiration, irrigation efficiency, and precipitation data (Figure 1). Infiltration rates are from the daily IDC model from MWH and DWR. Soil types data are from Natural Resources Conservation Service (NRCS).

Surface water availability information is based on surface water delivery calculations by the CalSim-II model on a monthly basis and reflects regulatory requirements of the Central Valley Project (CVP) and State Water Project (SWP) in place in 2008/2009. Seniority of water rights is incorporated in CalSim-II calculations of surface water deliveries. CalSim-II results were not available to compare with historical surface water deliveries; however, the surface water deliveries used for SacFEM are not representative of historical conditions for calibration purposes. Figure 7 presents the sources of water for agricultural areas in the Sacramento Valley.

Agricultural water demand estimates vary based on hydrological conditions. As a result, agricultural groundwater pumping estimates are highest in dry years and lowest in wet years. Groundwater pumping distributions for normal, dry, and wet hydrological conditions are presented in Figures 8, 9, and 10, respectively. The groundwater pumping maps for years 1976 (Figure 8) and 2000 (Figure 9) show excessive pumping in some areas where surface water appears to be available (Figures 7). In contrast, groundwater pumping distribution for 1983 (Figure 10) is consistent with the water supply mix map (Figure 7). Some of the areas with excessive pumping are marked on Figures 8 and 9.

Updating the land use and crop acreage data for historical conditions will result in changes in agricultural demand rates. It is recommended to verify the agricultural demand calculations against the update of the land use and crop acreage data. It is recommended to use available historical surface water delivery data for calculation of historical agricultural groundwater pumping. Historical agricultural groundwater pumping rates should be re-estimated based on historical agricultural demand and surface water delivery data.

2.4.4 Urban Groundwater Pumping

Urban groundwater pumping rates for municipal areas with a population greater than 5,000 were estimated based on 2000 Census data. It was assumed that the water consumption rate is 250 gallons per capita per day. However, higher per capita rates were used by SacFEM for

Chico and northern Sacramento County municipal areas to match the observed groundwater elevations. Municipal areas with a population of less than 5,000 were assumed to have insignificant groundwater pumping. The methodology for estimation of urban groundwater pumping does not consider the historical changes in urban water demand.

SacFEM estimates of urban groundwater pumping are compared to urban groundwater pumping data from two recent modeling reports (Table 3). SacFEM urban groundwater pumping estimates are significantly lower than the pumping data provided in the Sacramento County Integrated Groundwater and Surface water Model (SacIGSM) report. As a result, SacFEM estimates of groundwater pumping in this area were artificially increased to match the observed groundwater elevations. It is recommended to use historical municipal groundwater pumping data where actual data is available from local water purveyors.

2.4.5 Deep Percolation

The general methodology of SacFEM for estimation of deep percolation consists of two major steps of calculating deep percolation by IDC model for each model cell and then using the calculated IDC model deep percolation rates in SacFEM for various developed and undeveloped areas (Figure 1). This methodology is comparable to other regional groundwater models. However, due to using approximate input data for the parameters of the IDC model, the resulting deep percolation estimates are excessive. The estimated deep percolation rates by the IDC model were significantly modified to match the observed groundwater elevations during SacFEM calibration.

Deep percolation rate, in part, depends on hydrological soil types (Figure 1). Soil type A has the highest deep percolation rates and soil types D has the lowest deep percolation rates for the same precipitation rates. Distribution of hydrological soil types in the Sacramento Valley is presented in Figure 11. Distribution of the IDC model deep percolation rates from precipitation is presented in Figure 12. Estimates of deep percolation rates from precipitation are excessive, as high as 45 inches per year in some areas. Additionally, distribution of deep percolation from precipitation is not consistent with soil type and precipitation distribution.

Distribution of the IDC model deep percolation rates from applied water is presented in Figure 13. The IDC model estimates excessive deep percolation rates from applied water and the distribution of deep percolation is not consistent with soil type. Distribution of the IDC model total deep percolation rates from precipitation and applied water is presented in Figure 14. The IDC model estimates excessive deep percolation rates, as high as 45 inches per year, with a distribution that is not consistent with soil type and surface water distribution.

Because the IDC model deep percolation rates are significantly excessive, these rates were reduced for most parts of the model area before incorporating in SacFEM input data files. However, reduction factors are not uniformly distributed over the model area. High IDC deep percolation rates were further increased in specific areas before incorporating in SacFEM input data files. Annual deep percolation rates for the IDC model and SacFEM for the entire model area for 1970 to 2003 are shown in Figure 15. Average annual deep percolation volumes, rates, and reduction ratios factors by Depletion Study Areas (DSAs) are presented in Table 4. The distribution of deep percolation reduction factors is presented in Figure 16. The distribution of SacFEM total deep percolation rates is presented in Figure 17.

Reduction of the IDC model deep percolation rates in much of the model areas is reasonable; however, increasing deep percolation rates in specific areas results in significantly excessive deep percolation rates. More importantly, some of the excessive deep percolation areas correspond to project areas.

SacFEM final deep percolation rates are not supported by the fundamental IDC model methodology and parameters, resulting in a disconnect between the IDC model and SacFEM. It is recommended to incorporate a feedback loop between the IDC model and SacFEM deep percolation estimation with an appropriate convergence level between the two models (Figure 18). It is further recommended to make appropriate adjustments in the IDC model parameters on a monthly basis to develop revised deep percolation estimates for SacFEM. Because SacFEM deep percolation factors are not consistent with distribution of other data sets, it should be ensured that agricultural demand, groundwater pumping, and deep percolation estimates are supported by historical land use, crop mix, and agricultural practices.

2.6 STREAM-AQUIFER INTERACTION

Stream-aquifer interaction simulation is a major component of SacFEM and plays an important role in the simulation of ofSVWMP.

The stream network of SacFEM consists of 37 major and minor streams in the Sacramento Valley (Figure 19). SacFEM uses the wadi concept of MicroFEM for simulation of streams and stream-aquifer interaction (Figure 20). The wadi methodology uses two types of streams, coupled and de-coupled streams, for representation of rivers and streams and stream-aquifer interaction. Streams are represented in wadi by streambed thickness and time-series data of stream stage. The flow exchanged between streams and aquifers is a function of head difference between groundwater elevation and stream stage and streambed resistance. Streambed resistance in turn is a function of streambed thickness, layer 1 thickness, and hydraulic conductivities of streambed and layer 1. A uniform streambed thickness of 3.3 feet is used for all streams simulated by SacFEM. Streambed vertical hydraulic conductivities were based on the streambed deposits expected, given the stream size.

There are limited site-specific stream stage data available for smaller streams, but SacFEM assumes stream stages remain constant and do not change during the historical and scenarios simulations. Stream stage data used in SacFEM were extracted from existing base maps and U.S. Geological Survey (USGS) topo quad sheets. Stream-aquifer interaction is a function of wetting and drying conditions for smaller streams and average stream stage for larger rivers.

The assumption of constant stream stages results in stream-aquifer interaction to depend on streambed resistance and groundwater level changes over time. SacFEM uses two sets of lower and higher streambed resistances for irrigation and non-irrigation seasons, respectively. SacFEM uses this methodology to represent changes in the stream stages and does not reflect an actual physical change in the streambed conditions. Streambed resistances for different hydrological conditions are provided below:

- Dry/below normal year
    - Lower resistance for July-November (Irrigation season)
    - Higher resistance for Dec-June (Non-Irrigation season)
- Normal/wet year
    - Lower resistance for Aug-Oct (Irrigation season)

- Higher resistance for Nov-July (Non-Irrigation season)

SacFEM stream gains and losses were compared to hydrological conditions of normal, dry and wet years. SacFEM total annual stream gains and losses for the entire model area are presented in Figure 21. SacFEM estimates higher stream losses in dry years such as 1976 and 1977, and lower stream losses in wet years such as 1983.

SacFEM stream gains and losses for several segments of major streams were compared to stream water budget estimates of the USGS water budgets study for several streams in Central Valley for 1970 to 1977 (Mullen and Nady, 1985). The USGS study does not provide any stream water budget estimates for 1978 and later years. Figure 22 presents the selected stream reaches for comparison of stream gains and losses estimates of SacFEM and the USGS water budget analysis. The evaluated reaches include sections of the Feather River, Stony Creek, and Yuba River. Comparison of stream gain and loss estimates is provided below.

Feather River – A comparison of stream gains and loss estimates by SacFEM and the USGS study for Feather River at Oroville and Yuba City is presented in Figure 23. The USGS study shows this reach as a gaining and losing reach of Feather River; however, SacFEM consistently shows losses. SacFEM over estimates stream losses in the dry years of 1976 and 1977.

Yuba River – Stream gains and losses for Yuba River below Englebright Dam near Marysville are shown in Figure 24. The USGS study shows this reach as a gaining and losing reach; however, SacFEM shows losses consistently. SacFEM shows significant stream loses in 1977, while there were near zero flows in 1977.

Feather River – Estimates of net stream gains and losses for Feather River below Shanghai Bend and at Nicolaus are provided in Figure 25. The USGS study estimates this section of Feather River as a gaining reach, while SacFEM consistently shows losses. SacFEM losses are overestimated in dry years.

Stony Creek – Stream gains and losses for Stony Creek below Black Butte Dam are compared in Figure 26. The USGS study and SacFEM show that this is a losing stream year round; however, SacFEM losses are consistently overestimated. There were near zero flows in 1972 and 1976-1977, but SacFEM estimates of stream losses are highest for these years.

In the absence of stream stage data, adjustments of streambed resistances during the calibration process are used by some modeling efforts to fine tune the stream-aquifer interaction. However, for SacFEM the surface water stage fluctuations and groundwater level fluctuations are large enough to make a difference in stream gains and losses calculations and show that the assumption of constant stream stage is not valid. It is recommended that SacFEM use temporally varied stream stages on a monthly time step based on monthly streamflows. It is also recommended that the variable stream stages of regulated streams be revised for each SacFEM application scenario. Adjustment of streambed resistances may be used during SacFEM calibration after the stream stage data are incorporated in SacFEM input data files.

2.7 Model Layers and Aquifer Hydraulic Conductivity

Total SacFEM thickness consists of the total saturated aquifer thickness, as defined with the groundwater elevation contour map of the year 2000 at the top, and the base of the freshwater at the bottom. The SacFEM layers were developed to assess the effects of groundwater pumping on shallow features such as wetlands and streams as well as to assign pumping stresses to layers representing the major producing zones within the aquifer system. SacFEM is also used to investigate groundwater pumping from the lower Tuscan aquifer. SacFEM thickness is divided into seven (7) layers, with thickness of each layer set to a constant percentage of total model thickness.

The contour map of the base of the freshwater, bottom of Layer 7, and SacFEM cross sections were compared with the DWR (1978) map of the base of the freshwater. The DWR map is also based on the Berkstresser (1973) work. The comparison showed that the thickness of the SacFEM is comparable to that of the DWR (1978) map of the base of the freshwater.

SacFEM aquifer hydraulic conductivities are based on screen intervals and estimated transmissivity values obtained from DWR specific capacity data (1,100 values) (Lawson, 2009). Local level adjustments of aquifer properties may be needed when addressing local calibration issues. Vertical hydraulic conductivities are kept constant and the same between all layers and do not reflect the vertical stratification of other groundwater models covering parts or all of Sacramento Valley.

3. SACFEM CALIBRATION

SacFEM was calibrated for a steady state condition of year 2000 groundwater elevations and 34 years of transient conditions of 1970 to 2003 (Lawson, 2009). The calibration period of 1970 to 2003 is representative of the long-term hydrologic conditions and contains several wet and dry cycles. Steady state calibration was not available for this peer review. This section provides the review of SacFEM transient calibration.

3.1 CALIBRATION WELLS

Calibration wells were selected from a set of wells with available well construction information and a relatively large number of records. Measured groundwater elevation data from sixty five (65) calibration wells were used for transient calibration of SacFEM. Out of the 65 selected calibration wells, groundwater elevation data from forty one (41) wells cover the 1970 to 2003 calibration period and are referred to as long-term wells. The remaining twenty four (24) calibration wells only cover ten years or less of the calibration period, and are referred to as short-term wells. Figure 27 presents the locations of the SacFEM calibration wells. Calibration wells cover most of the model area; however, some of the project areas are not represented.

3.2 CALIBRATION HYDROGRAPHS

The matching status of the SacFEM calibration wells is provided in Table 5 and the scattergram of Figure 28. The long-term trend is not matched in twelve (12) out of the 41 long-term calibration wells. Seven (7) of the long-term calibration wells are in the vicinity of the urban areas of Sacramento, Woodland, and Chico.

There are more than 20 feet of differences between observed and simulated groundwater elevations for sixteen (16) of the 24 short-term calibration wells. Approximately half of the short-term calibration wells are located in western Placer and southern Sutter Counties, and more than 20 feet of head differences is obtained for each of these short-term calibration wells. Additionally, there are very limited long-term calibration wells in this area.

Six (6) representative calibration wells were selected to present the calibration status of SacFEM for different sections of the Sacramento Valley (Figure 29). An acceptable match is obtained for Calibration Well 51 in the Tuscan Formation in Central Butte County (Figure 30). There are no surface water supplies available for this area and groundwater is used to meet the agricultural and urban demands. The urban area is Chico and the agricultural area consists mostly of orchards. High streambed resistance is used for adjacent streams in normal/wet conditions.

Simulated groundwater elevations for Calibration Well 43 are approximately 20 feet below observed groundwater elevations (Figure 31). This well is in an agricultural area with rice as the dominant crop. Water demand is met by surface water supply, with no groundwater pumping. High streambed resistances are used for nearby rivers and streams.

Calibration Well 40 has simulated groundwater elevations that are approximately 30 feet below the observed groundwater elevations (Figure 32). This well is also in an agricultural area with rice as the dominant crop. Water demand is met by surface water supply and low groundwater pumping. High streambed resistances are used for nearby rivers and streams.

Recent trends in water levels are matched by Well 25; however, the simulated groundwater elevations are approximately 40 feet lower than the observed values (Figure 33). This well is in an agricultural area with orchards as the dominant crop. Water demand is met by surface water supply, with no groundwater pumping. Mixed streambed resistances are used for nearby rivers and streams.

A good match of simulated and observed groundwater elevations is obtained for Well 16 (Figure 34). This well is in an agricultural area with tomatoes and grain as the dominant crops. There are no surface water supplies for this area and the water demand is met by groundwater pumping. Deep percolation is significantly increased in this area, which results in higher inflows. In contrast, high streambed resistances are used for nearby streams and rivers, which results in lower stream groundwater recharge and less inflow to this area. The high deep percolation and low stream groundwater recharge at this location will need to be revisited, subsequent to incorporation of the peer review recommendations provided in Section 2.

The long-term trend of observed groundwater elevations is not matched by Well 12 (Figure 35). Simulated groundwater elevations are approximately 40 feet higher than the observed values. This well is in the urban area of Sacramento. High streambed resistances are used for the nearby American River. Approximately 80,000 acre-feet of urban groundwater pumping in this area is not included in SacFEM. As a result groundwater levels are significantly higher than the observed values.

Review of the representative and other calibration hydrographs reveals that significant calibration issues exists in areas that rely mostly on surface water. This is mainly due to the issues of SacFEM's estimation of stream-aquifer interaction. Calibration quality improves in areas that rely mostly on groundwater.

3.3 ADDITIONAL CALIBRATION WELLS

SacFEM covers a very large area with significant variations in hydrogeology, land use, water supplies, and stream-aquifer interactions. Use of additional calibration wells for SacFEM will improve the calibration status of the model. Figure 36 shows numerous wells in DWR's **I**ntegrated **W**ater **R**esources **I**nformation **S**ystem (IWRIS), which has more than 150 records.

Groundwater elevation of these wells was reviewed and a set of 108 wells was selected, which could be added to the SacFEM calibration wells to improve the calibration quality of the model in western Placer, southern Sutter and Yuba Counties (Figure 37). These areas are of special interest as a significant number of SVWMP and 2009 Drought Water Bank projects wells are located in this area.

It is recommended to include additional calibration wells in SacFEM to improve its calibration quality. These wells could be used for re-calibration of SacFEM with a focus on the fine grid areas and areas with significant stream-aquifer interactions.

4. PEER-REVIEW SUMMARY

The SacFEM peer review was performed to ensure that the SacFEM is an appropriate tool capable of its intended uses, including simulation of SVMWP projects. In order to address SacFEM applicability and its adequacy to be used for its objectives and purposes, as specified in Section 1.3.5, the findings of this peer review were grouped in three tiers and are presented in the following subsections.

4.1 TIER 1 FINDINGS – REQUIRED REVISIONS

The required revisions for SacFEM as Tier 1 findings are as follows:

1. **Include Historical Land Use and Crop Mix Data** - SacFEM calibration does not include historical land use and crop mix data. As a result, estimates of agricultural demand, groundwater pumping, and deep percolation for historical period are not representative of historical conditions.
2. **Verify CalSim-II and Historical Surface Water Delivery Data** - SacFEM uses surface water delivery data from CalSim-II simulations. These do not necessarily reflect the historical level of deliveries and as such, reflects on the estimates of groundwater pumping in the IDC model.
3. **Re-estimate agricultural groundwater pumping** – Agricultural groundwater pumping should be re-estimated once historical land and water use data are used for SacFEM calibration.
4. **Make Deep Percolation Estimates between the IDC Model and SacFEM Consistent** – Estimates of deep percolation based on land and water use processes are modified by SacFEM during calibration resulting in a disconnect between physical processes and calibration.
5. **Correct Stream Gain/Loss Simulation** - Stream-aquifer interaction uses static stage for all minor and major streams, resulting in erroneous calculation of stream gains/losses during much of the years, especially during extreme hydrologic conditions.
6. **Calibration Improvements**:
   a. Improvements in Existing Calibration Points – SacFEM is not calibrated to the existing calibration wells at a satisfactory level.
   b. Higher Accuracy in Refined Grid Area – SacFEM quality of calibration in the refined model area does not meet the requirements of the refined model grid.
   c. Expansion of Calibration Points – SacFEM does not include calibration wells at the strategic locations, such as the foothills or some of the project areas.

7. **Documentation on SacFEM and the IDC Model** – Model documentation, with appropriate level of detail on data collection, analysis, and input data preparation should be developed.

4.2 Tier 2 Findings – Model Enhancements

The enhancements for SacFEM as Tier 2 findings are as follows:

1. **Include Municipal Pumping Records** – Pumping in much of the urban areas is not reflective of the actual groundwater pumping data available from local water purveyors. In particular, SacFEM groundwater pumping in northern Sacramento County is significantly less than the data available from water purveyors. If SacFEM is used for project analysis in Sacramento County, then municipal pumping records for Sacramento County should be used.
2. **Vertical Hydraulic Conductivities** – Vertical hydraulic conductivity values are kept constant and the same for all layers. This does not reflect the vertical stratification of other regional models of the Sacramento Valley.
3. **Verification of Calibrated Aquifer Properties and Model Layering** – SacFEM aquifer properties and model layering should be verified with other field data and/or other regional/local models.

4.3 Tier 3 Findings – Model Improvements

The improvements for SacFEM as Tier 3 finding is follows:

1. **Refined Grid in Sacramento County –** SacFEM does not represent projects in the Sacramento area with refined grid. Refined grid should be used for this area, should SacFEM be used for project analysis in Sacramento County.

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Table 1. Land use data used for IDC and SacFEM

County	Survey Year
Butte	1999
Colusa	2003
Glenn	2003
Placer	1994
Sacramento	2000
Shasta	1995
San Joaquin	1996
Solano	1994
Sutter	1998
Tehama	1999
Yolo	1997
Yuba	1995

Table 2. Crop Mix Distribution

Crop/Land Use Type	C2VSIM				SacFEM
	1967	1980	1993	2000	2005
Grain	2.6%	15.3%	12.3%	7.1%	13.0%
Rice	25.2%	27.1%	26.1%	32.3%	28.4%
Cotton	0.0%	0.0%	0.0%	1.0%	0.7%
Sugat Beets	4.8%	4.0%	2.9%	0.5%	1.2%
Field Crops	14.6%	14.2%	14.3%	12.1%	14.9%
Alfalfa	8.9%	4.4%	5.6%	5.3%	4.9%
Pasture	16.2%	9.5%	8.4%	6.7%	6.5%
Tomatoes	4.7%	5.6%	6.5%	5.9%	6.6%
Truck Crops	3.1%	2.5%	3.9%	2.6%	2.5%
Orchard	19.1%	16.4%	18.7%	24.4%	19.9%
Vineyards	0.7%	1.0%	1.2%	2.2%	1.4%
Ag Total	100.0%	100.0%	100.0%	100.0%	100.0%

Note: C2VSIM = Central Valley Groundwater and Surface Water Simulation Model (C2VSIM)

Table 3. Comparison of SacFEM, SacIGSM, and YoloIGSM Urban Groundwater Pumping Rates (acre-feet/year)

References: WRIME, 2006 and WRIME, 2007

Urban Areas		SacFEM	SacIGSM (2004)	YoloIGSM (2000)
Davis		**13,510**		**14,920**
Woodland		**11,010**		**17,310**
Winters		**1,370**		**1,550**
Northern Sacramento County				
	Rio Linda	4,690		
	North Highlands & Foothills Farms	23,710		
	Subtotal	**28,400**	**113,590**	
Southern Sacramento County				
	Laguna & Elk Grove	50,760		
	Floring & Parkway	34,930		
	Rosemont & La Riveara	19,990		
	Subtotal	**105,680**	**106,810**	

Table 4. Average Annual Deep Percolation Rates and Reduction Factors by DSA Areas

Table : Average Annual Deep Percolation by DSA Areas

DSA	Area (Acres)	IDC Deep Percolation		SacFEM Deep Percolation		Ratio
		Volume (AF/year)	Rate (in/year)	Volume (AF/year)	Rate (in/year)	(SacFEM/IDC)
10	683,729	765,757	13.44	198,260	3.48	0.26
12	677,323	599,817	10.63	370,164	6.56	0.62
15	354,440	318,242	10.77	213,011	7.21	0.67
69	602,031	578,410	11.53	352,925	7.03	0.61
65	487,619	566,025	13.93	266,338	6.55	0.47
70	341,186	236,738	8.33	136,460	4.80	0.58
59	173,653	116,052	8.02	19,525	1.35	0.17
55	277,061	302,360	13.10	128,972	5.59	0.43
Average	**449,630**	**435,425**	**11.22**	**210,707**	**5.32**	**0.47**
Total	**3,597,042**	**3,483,401**	**89.74**	**1,685,653**	**42.57**	**3.80**

Table 5. Matching Status of SacFEM Calibration Wells

SacFEM Layer	Wells with sufficient data for 1970-2003 period			Wells with 10 years or less data for 1970-2003 period			Total Number of Wells per SacFEM layers
	Match	No Match	Subtotal	Match	No Match	Subtotal	
Column No.→	(1)	(2)	(3) = (1) + (2)	(4)	(5)	(6)= (4) + (5)	(7) = (3) + (6)
1	13	7	20	1	1	2	22
2	8	3	11	1	2	3	14
3	3	2	5	3	3	6	11
4	3	0	3	2	3	5	8
5	1	0	1	1	3	4	5
6	0	0	0	0	2	2	2
7	1	0	1	0	2	2	3
Total	**28**	**12**	**41**	**8**	**16**	**24**	**65**

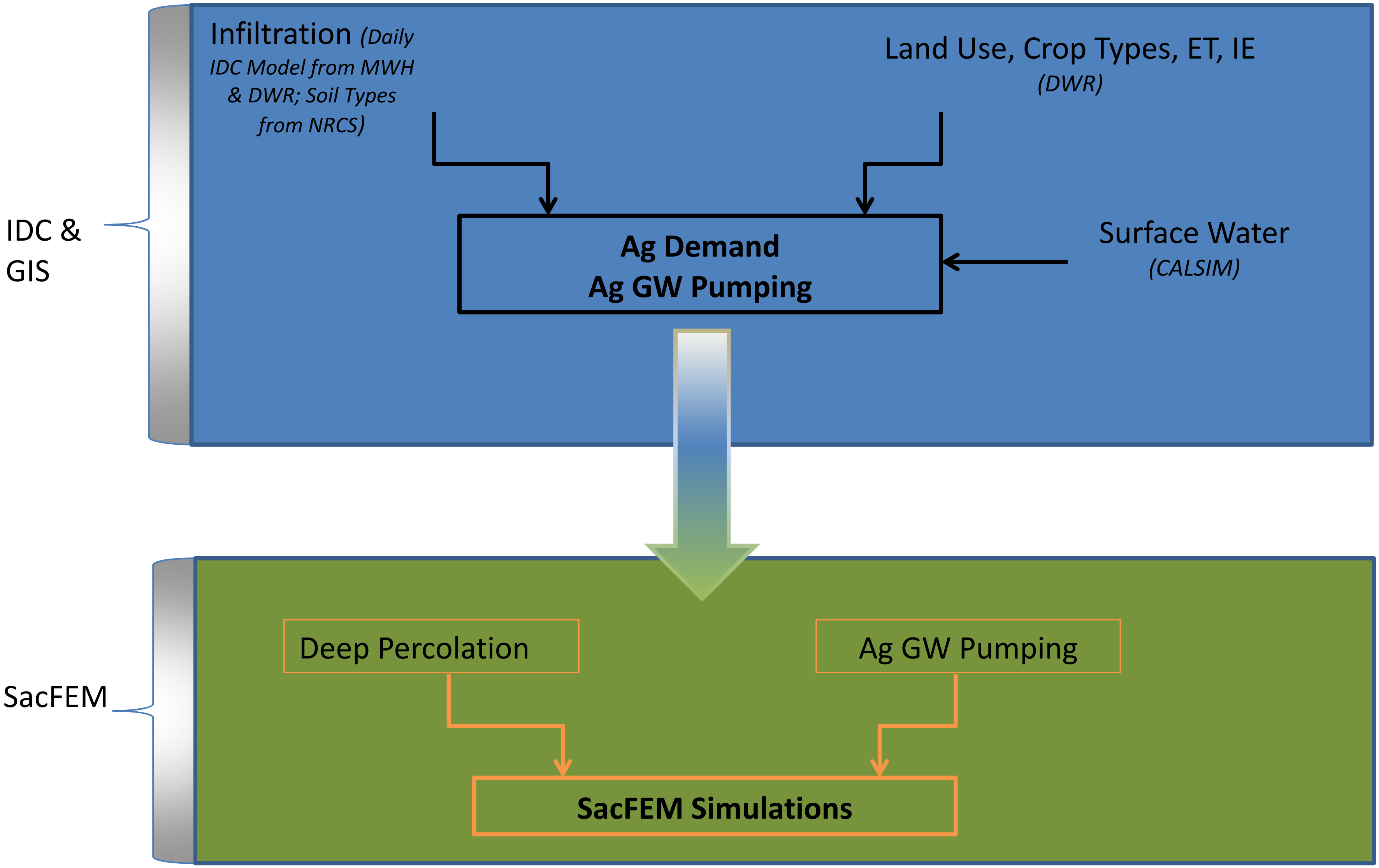

Figure 1. IDC and SacFEM Simulation Process

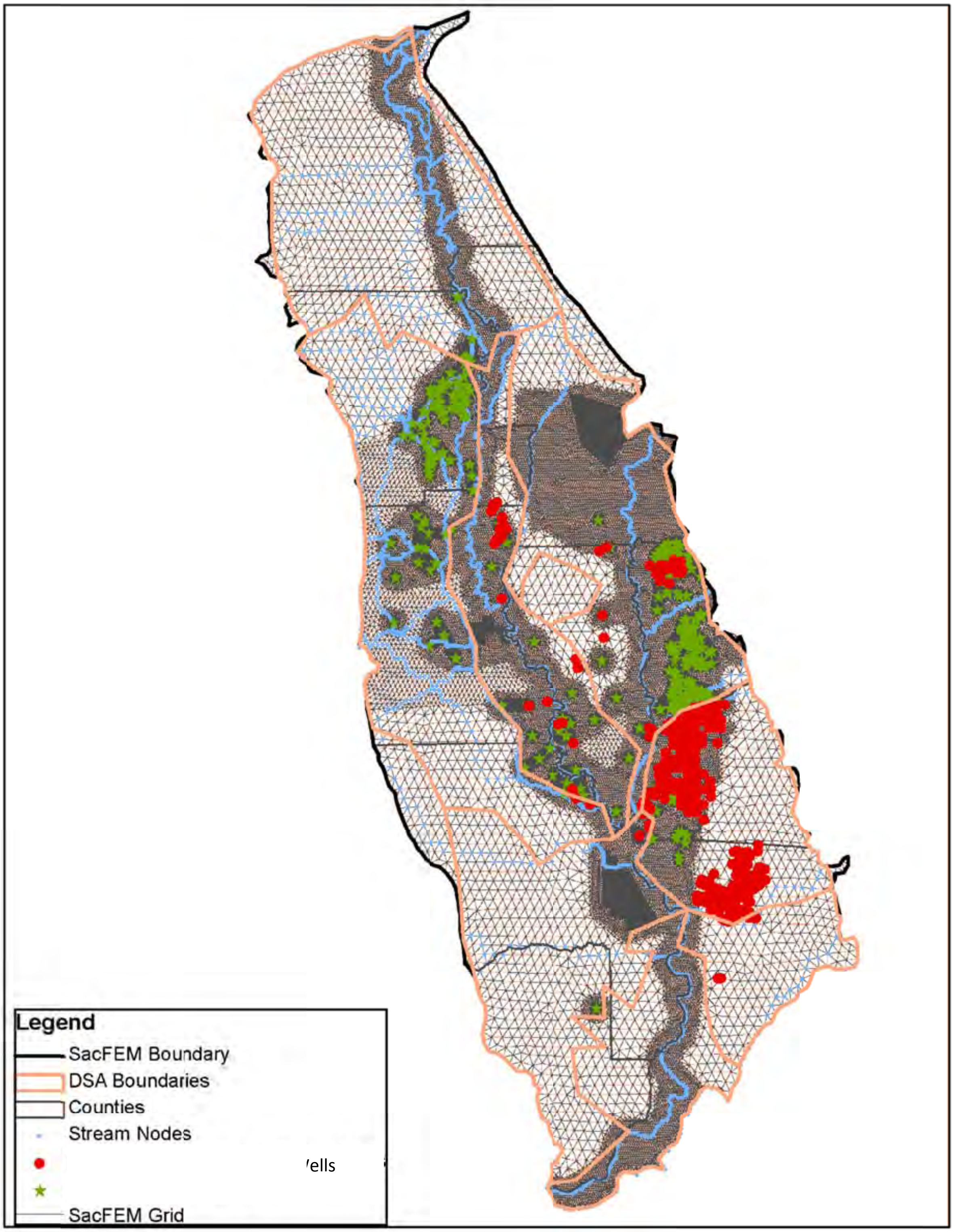

Figure 2. SacFEM Grid

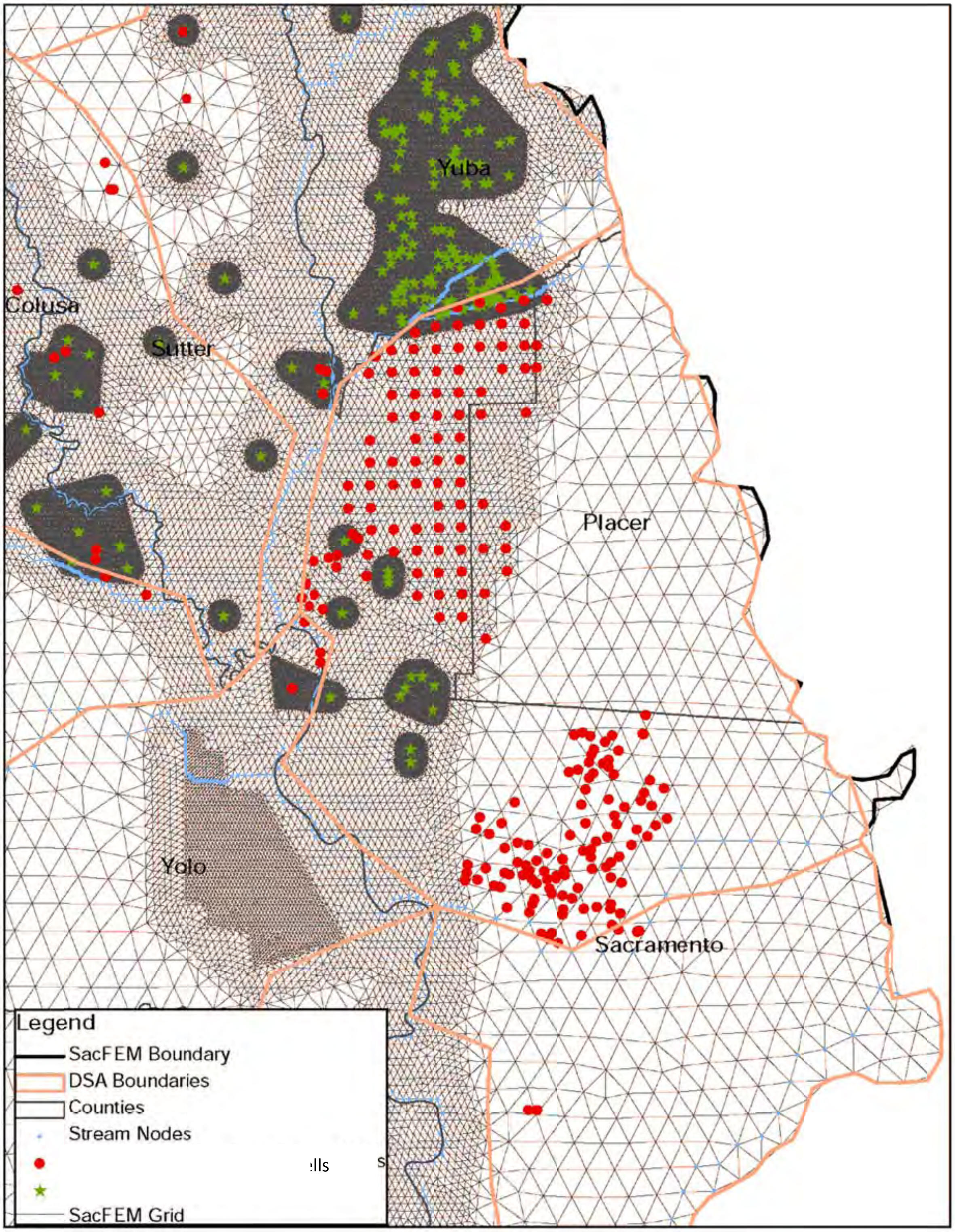

Figure 3. SacFEM Grid Resolutions in Project Areas

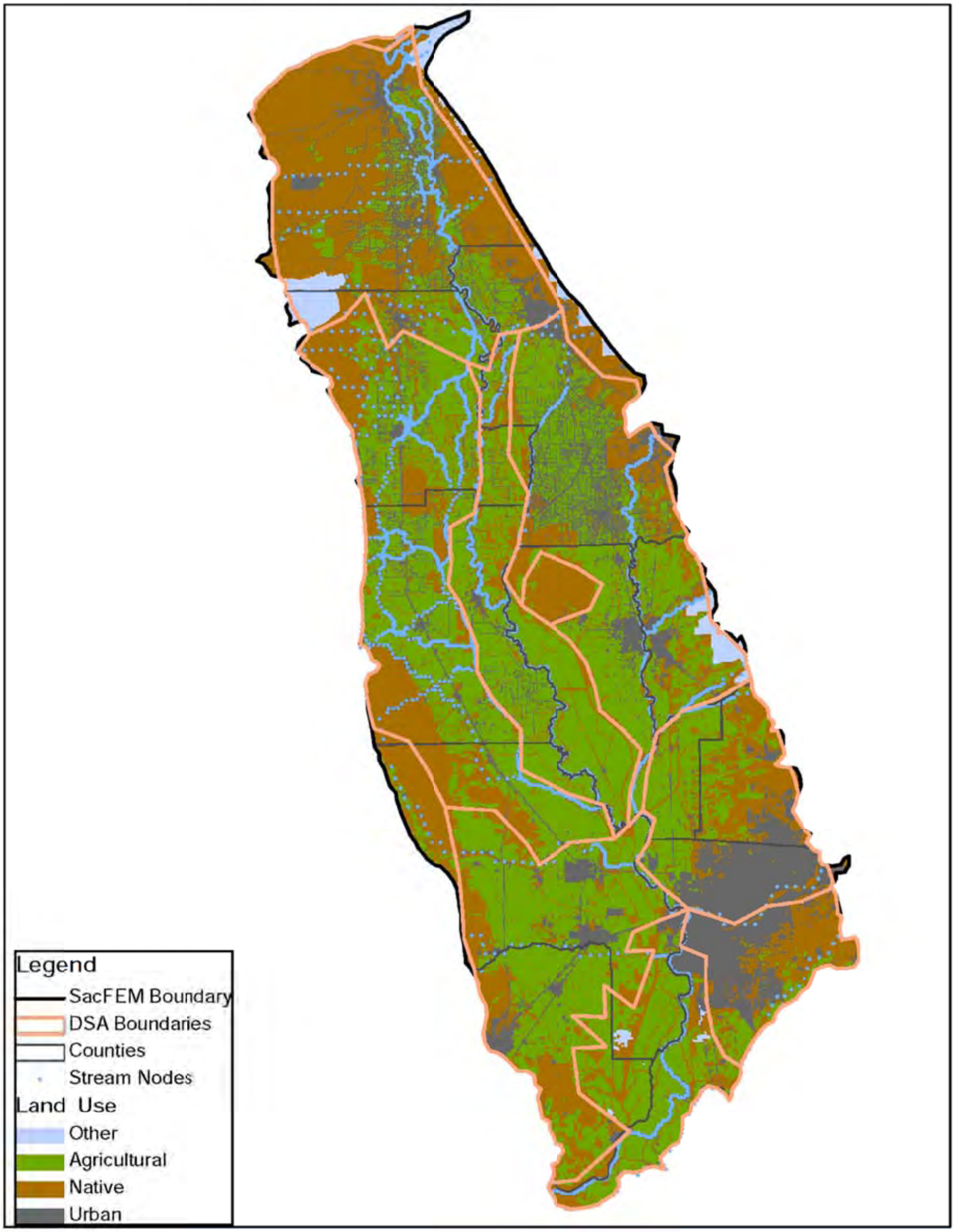

Figure 4. 2005 Land Use

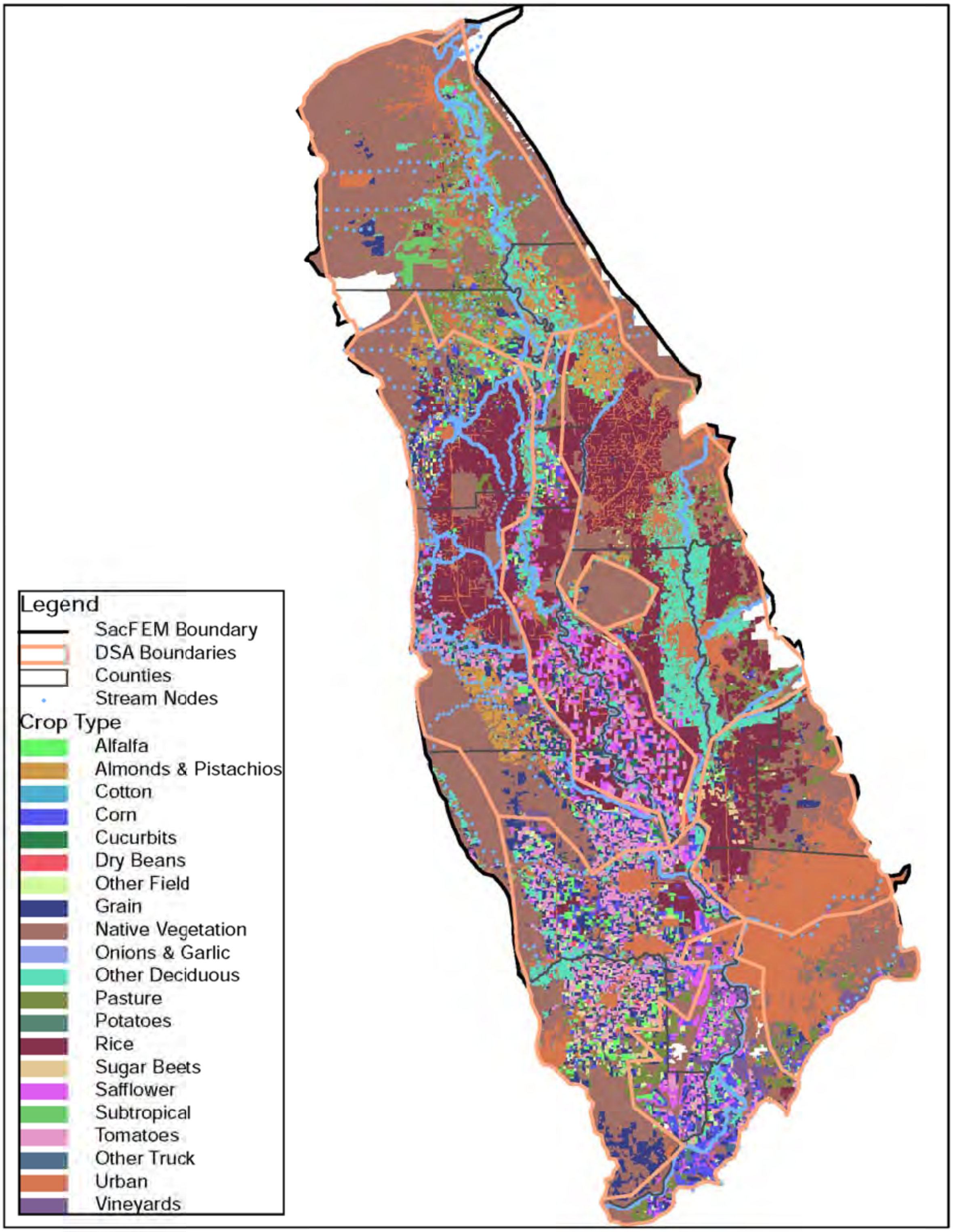

Figure 5. 2005 Crop Acreage

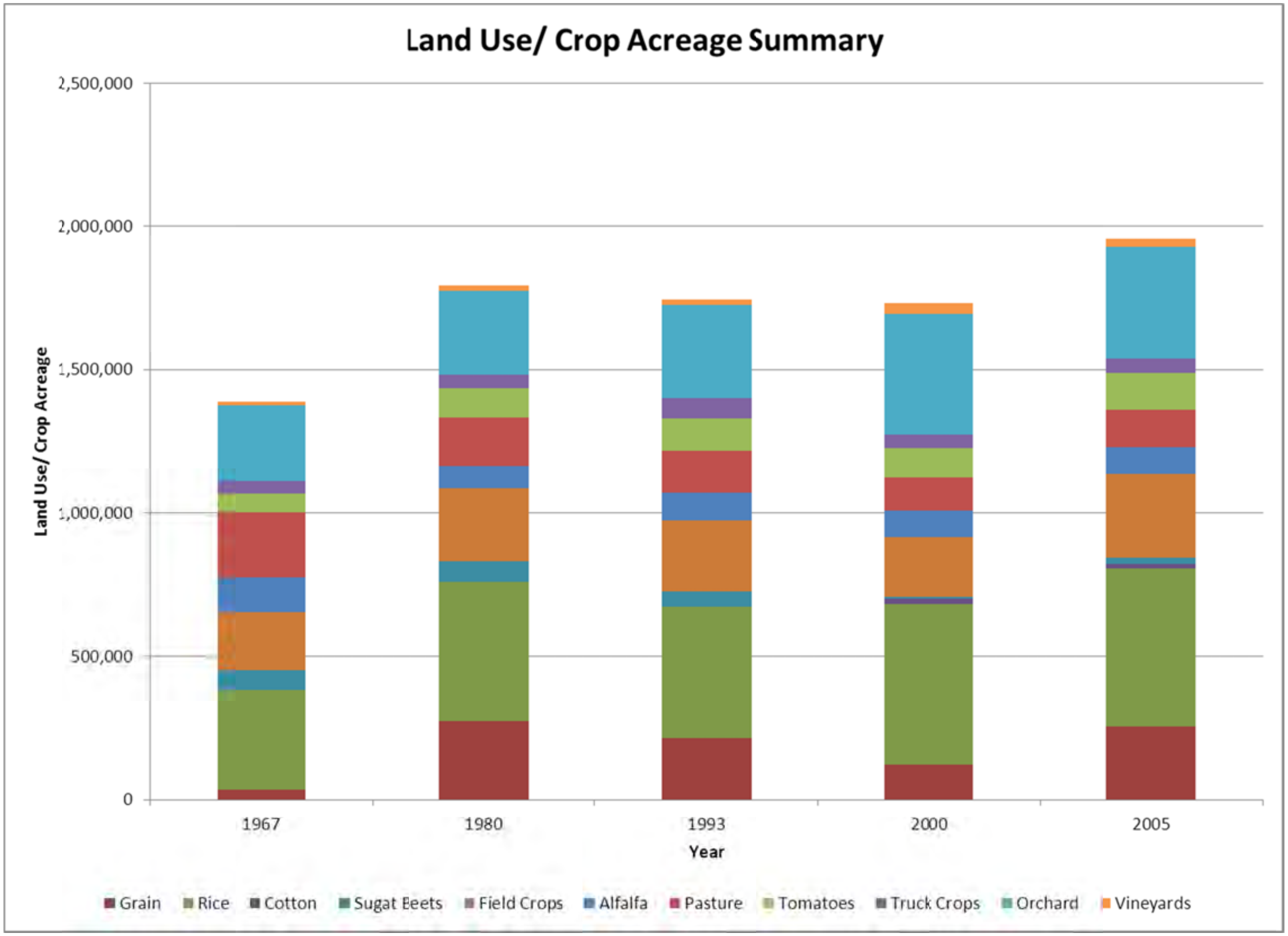

Figure 6. Historical Crop Average

Notes:
-1967, 1980, 1993, and 2000 Crop acreage data source:Central Valley Groundwater and Surface Water Simulation Model (C2VSIM).
-2005 crop acreage data source: SacFEM model.

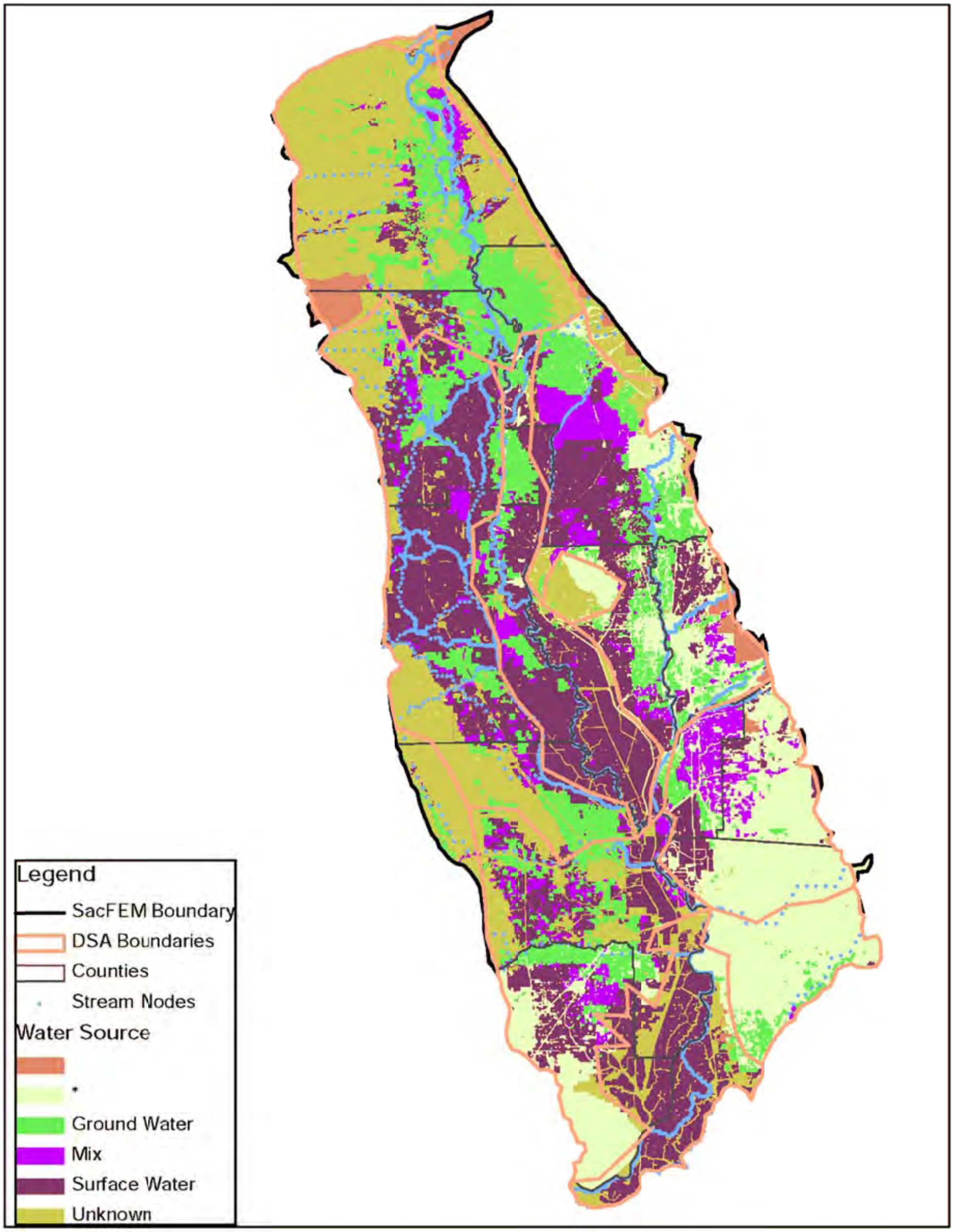

Figure 7. Sources of Water for Agricultural Areas in Sacramento Valley

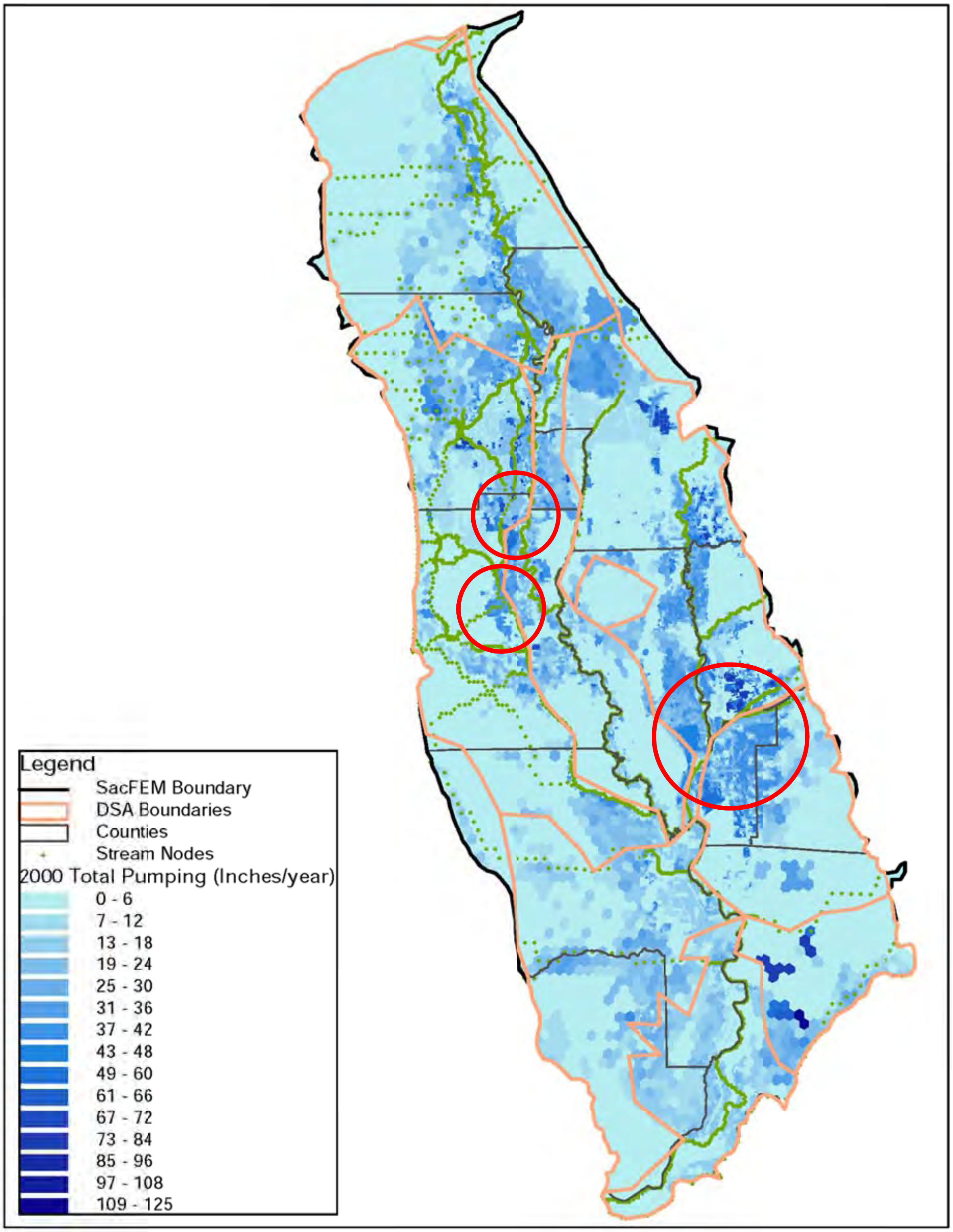

Figure 8. Groundwater Pumping for 2000 (normal hydrological conditions).

(Some of the areas with excessive groundwater pumping are identified with red circles.)

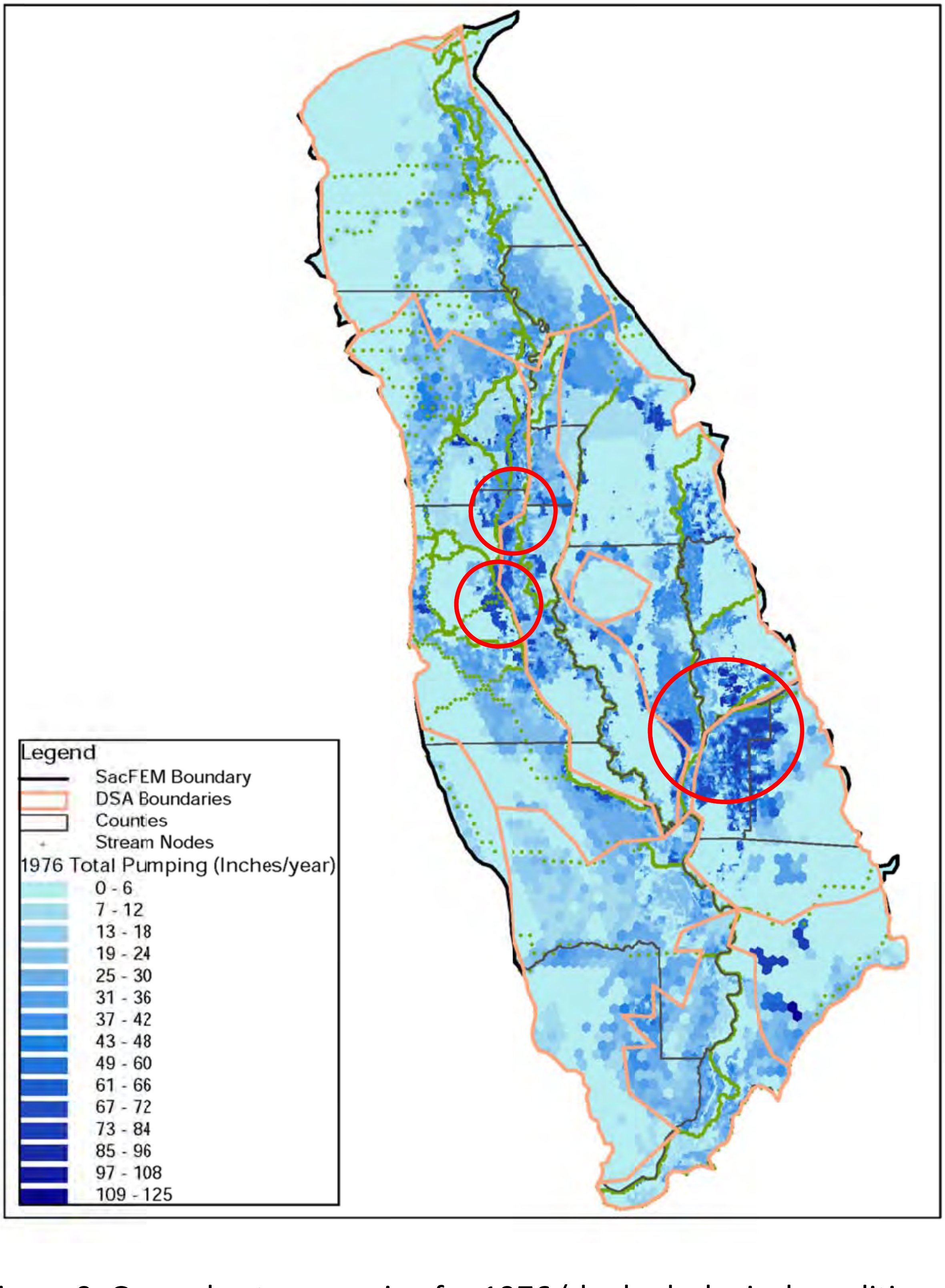

Figure 9. Groundwater pumping for 1976 (dry hydrological conditions).
(Some of the areas with excessive groundwater pumping are identified with red circles.)

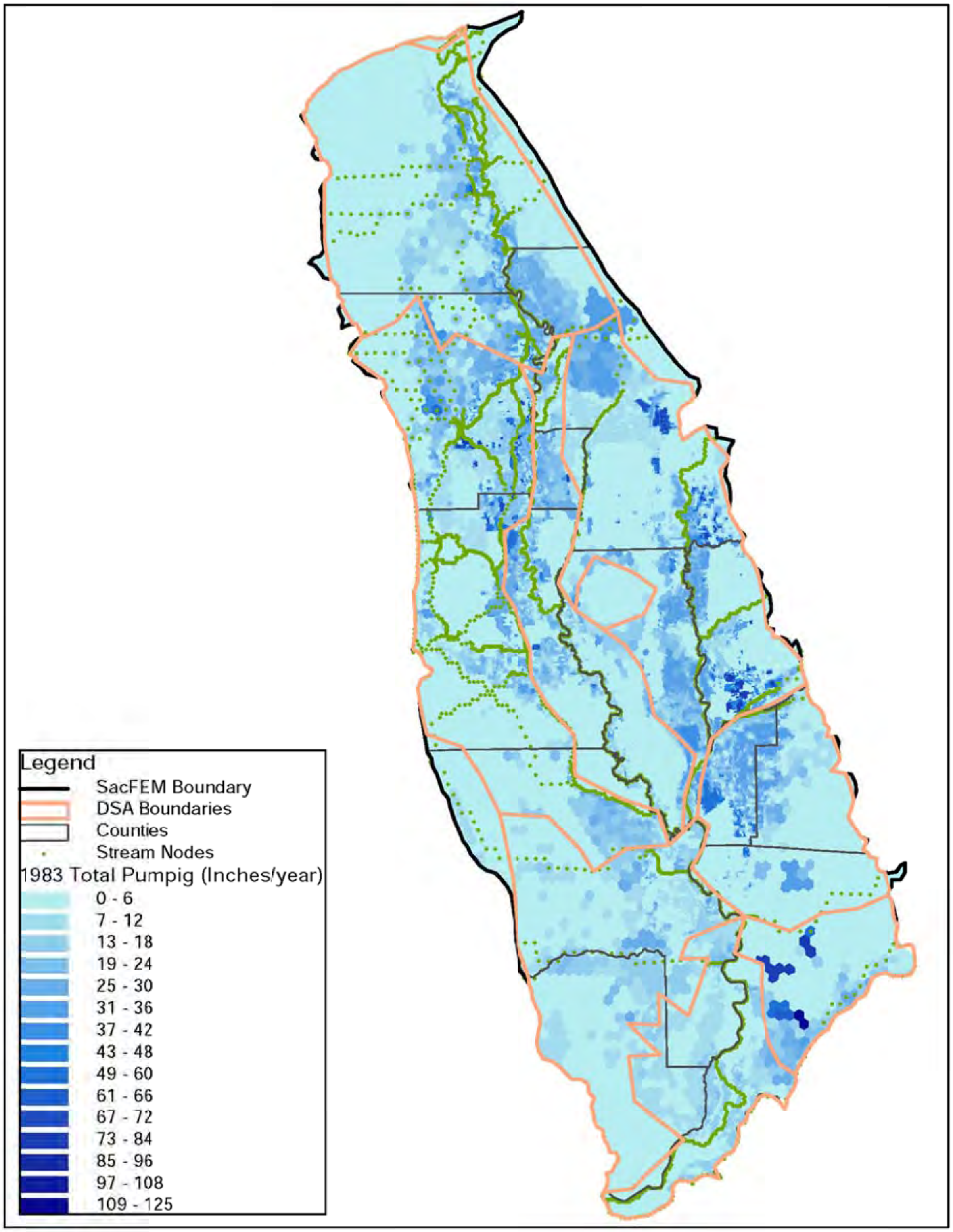

Figure 10. Groundwater pumping for 1983 (wet hydrological conditions).

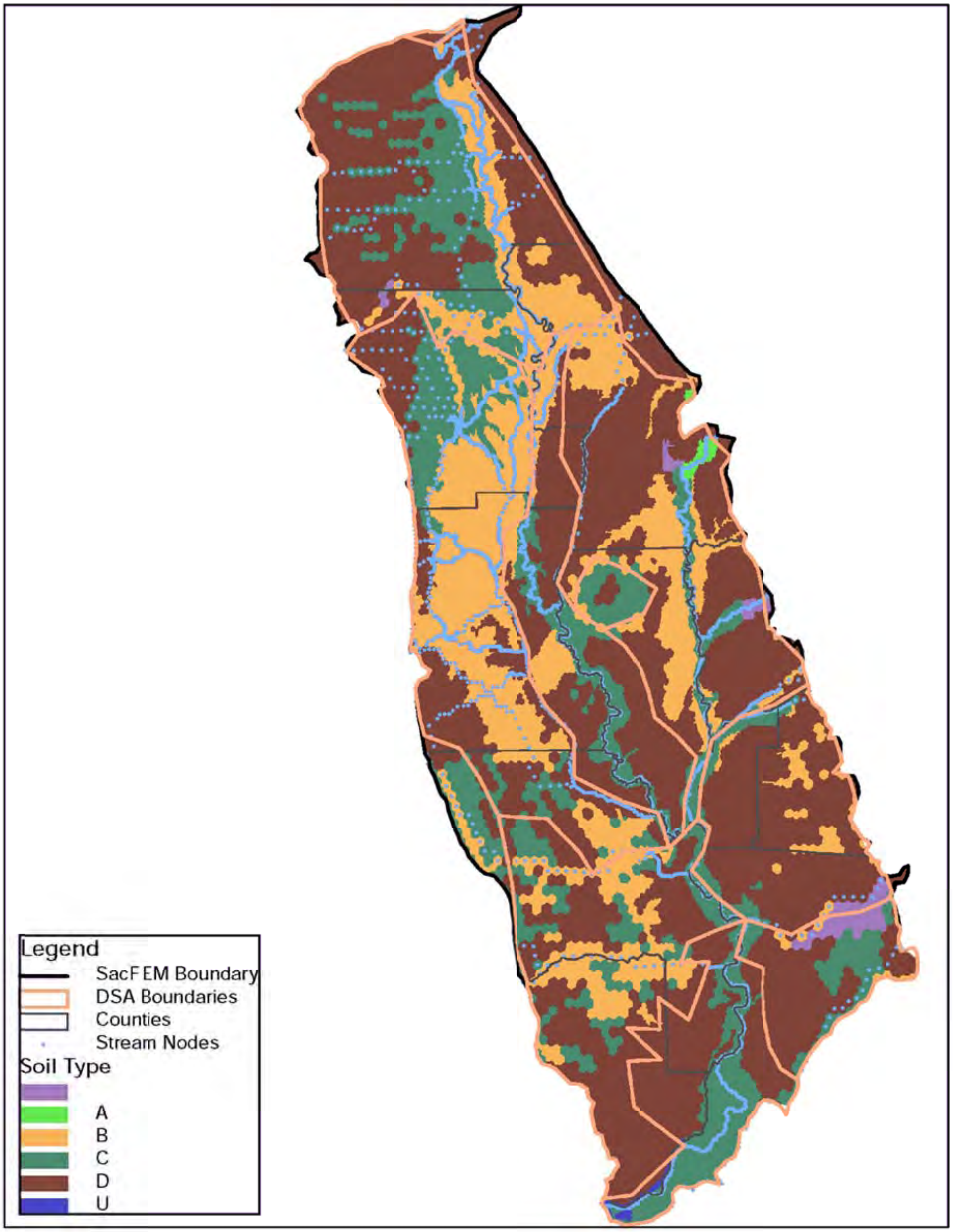

Figure 11. Hydrological Soil Types in Sacramento Valley

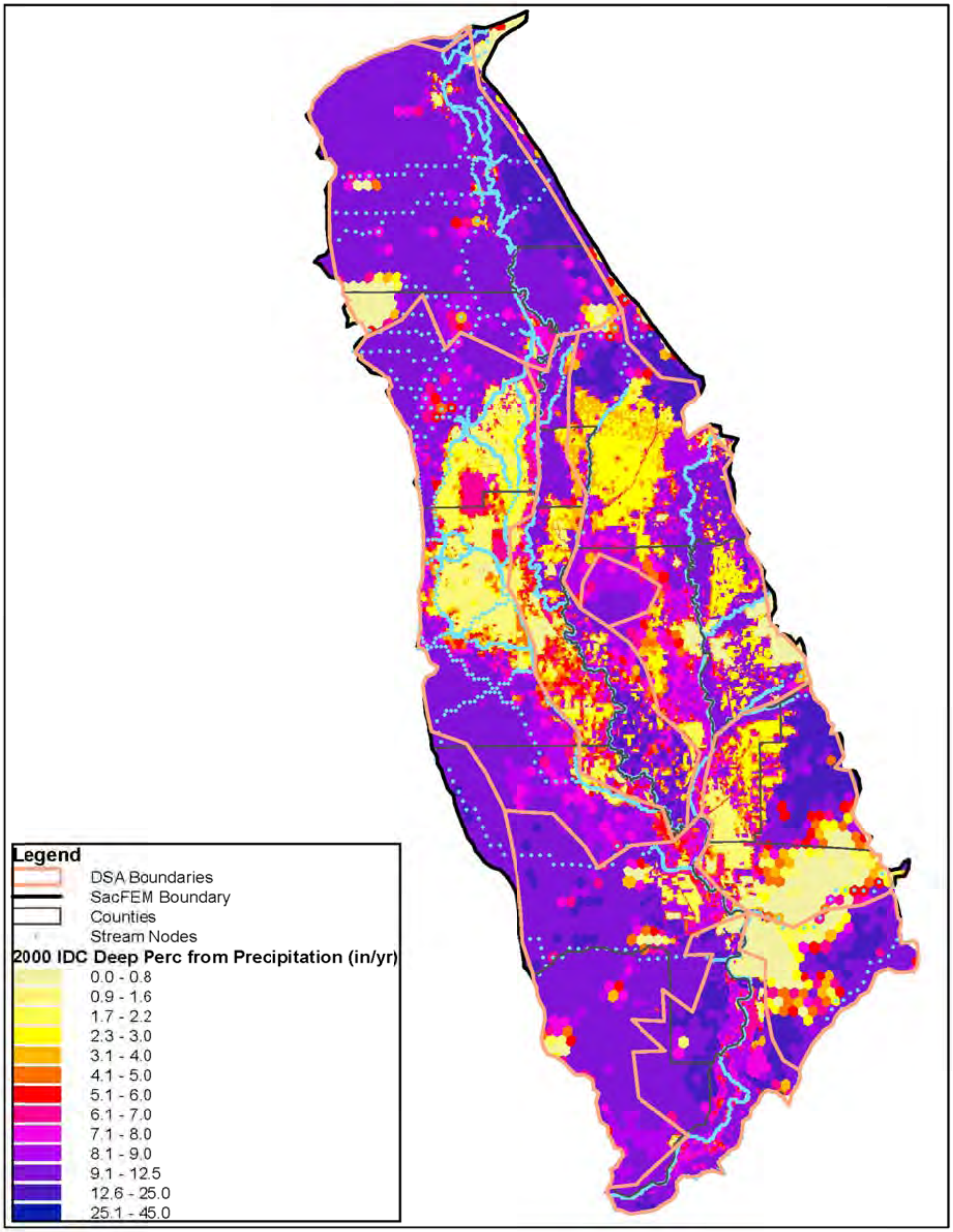

Figure 12. Distribution of IDC Deep Percolation Rates from Precipitation

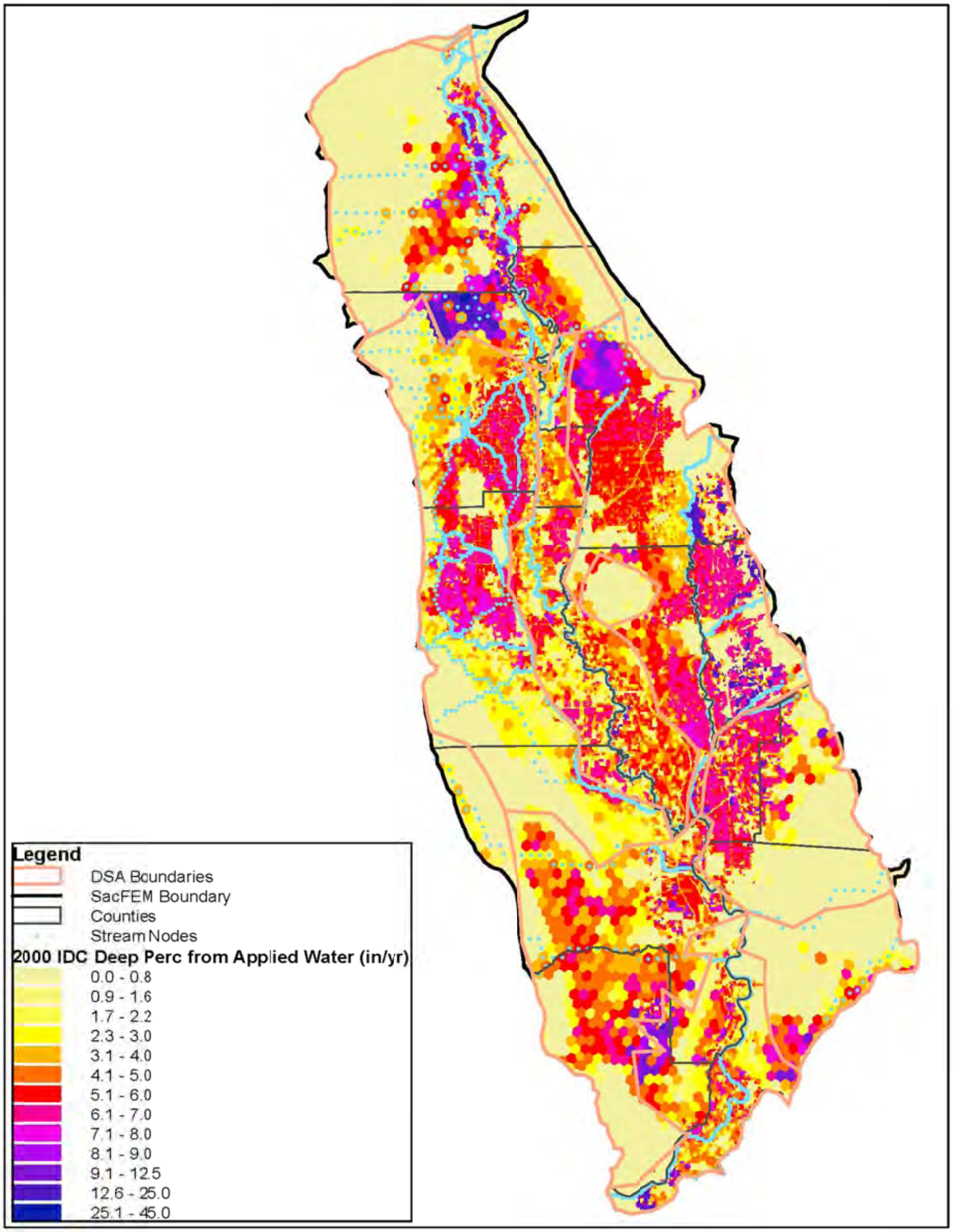

Figure 13. Distribution of ICD Deep Percolation Rates from Applied Water

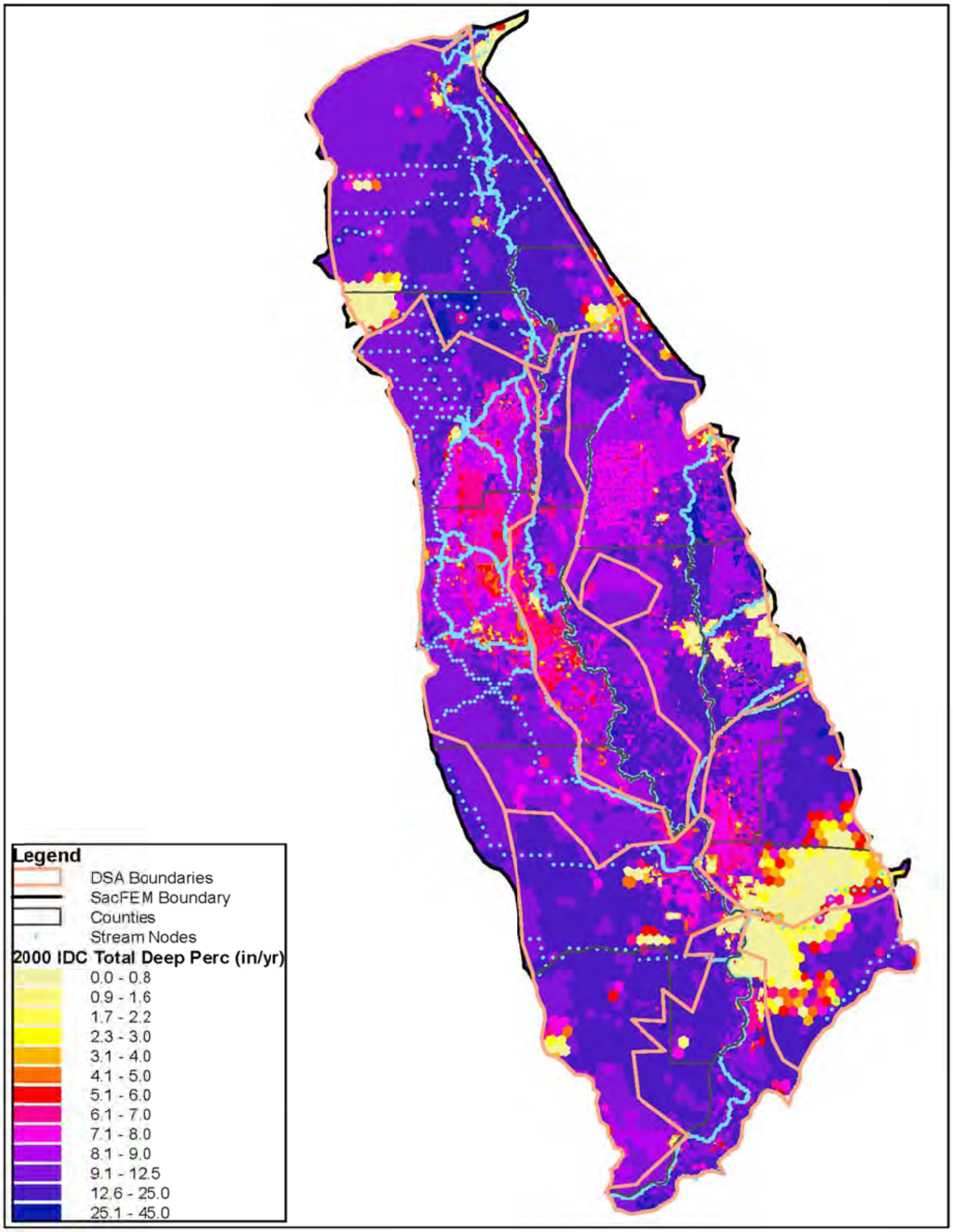

Figure 14.Distribution of IDC Total Deep Percolation Rates from Precipitation and Applied Water

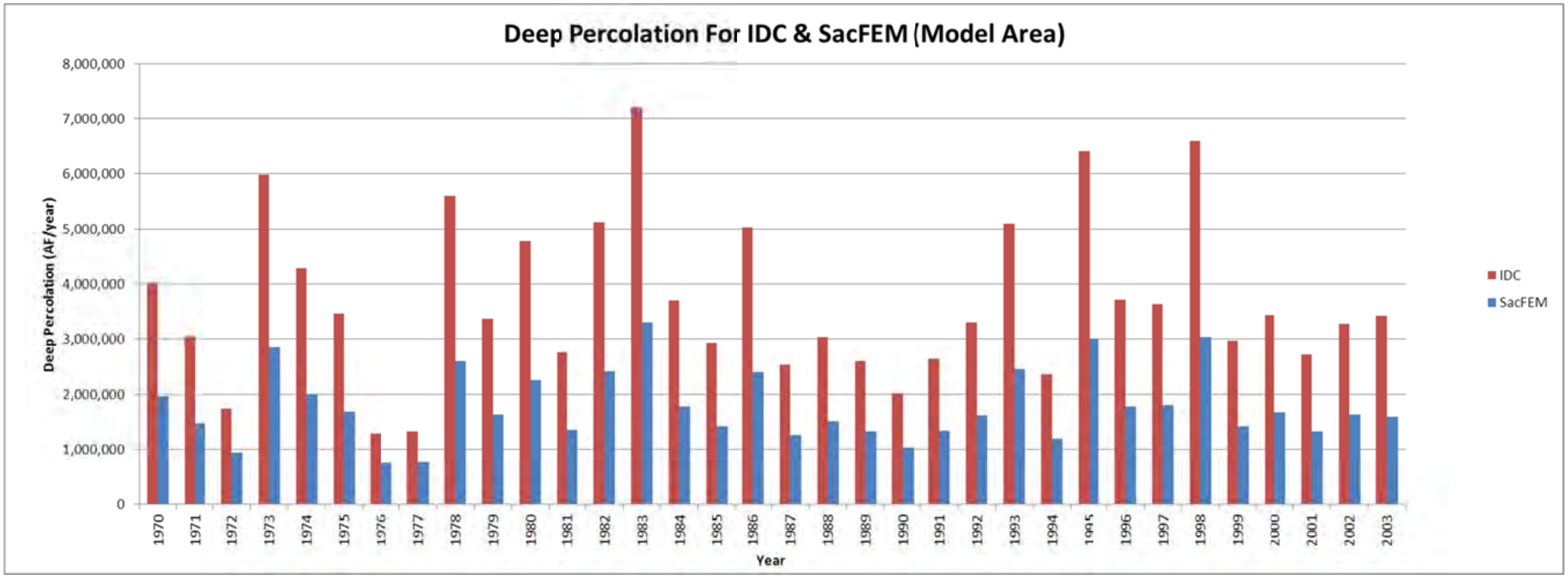

Figure 15. Annual Deep Percolation Rates for IDC and SacFEM for Entire Model Area

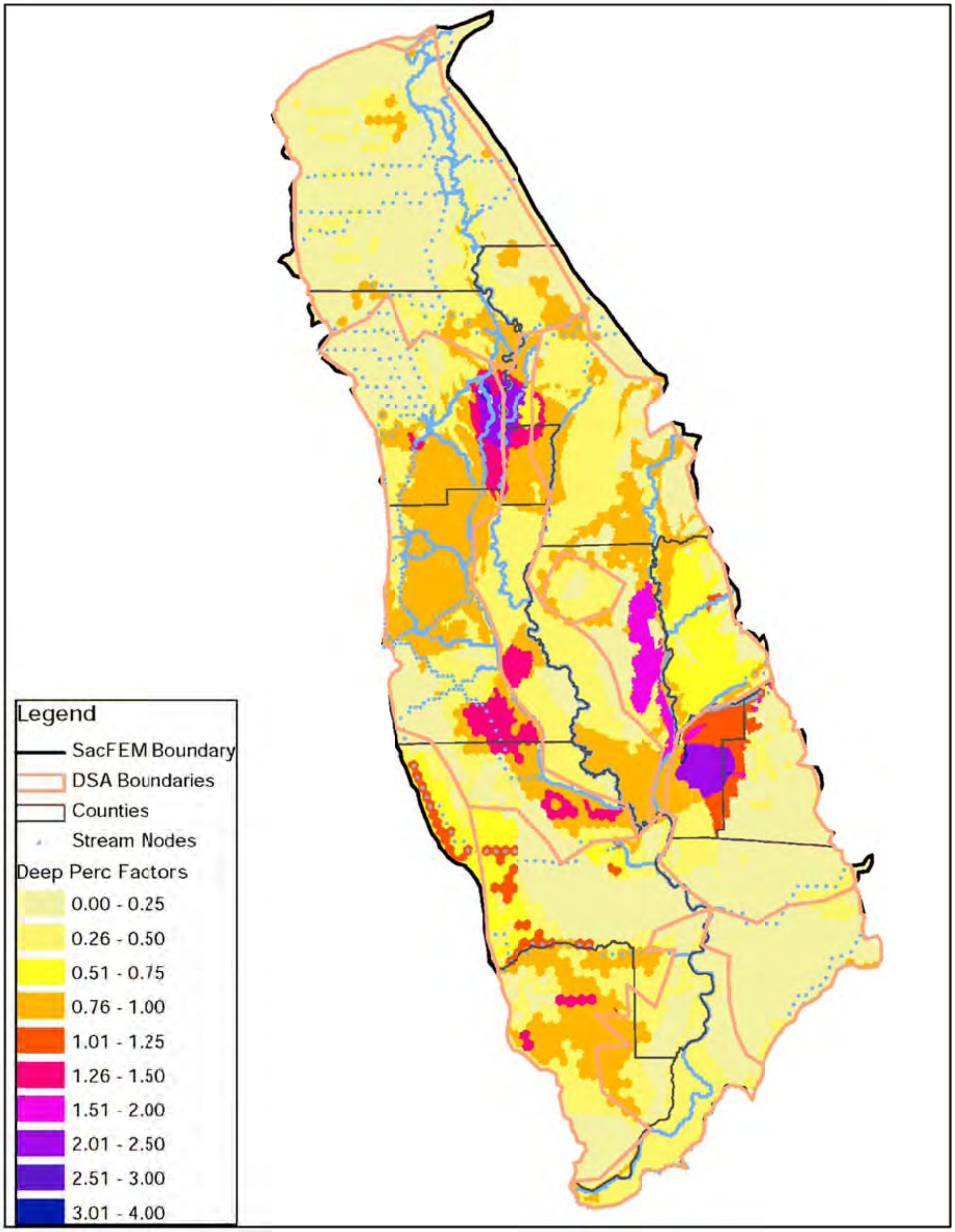

Figure 16. Distribution of Deep Percolation Reduction Factors

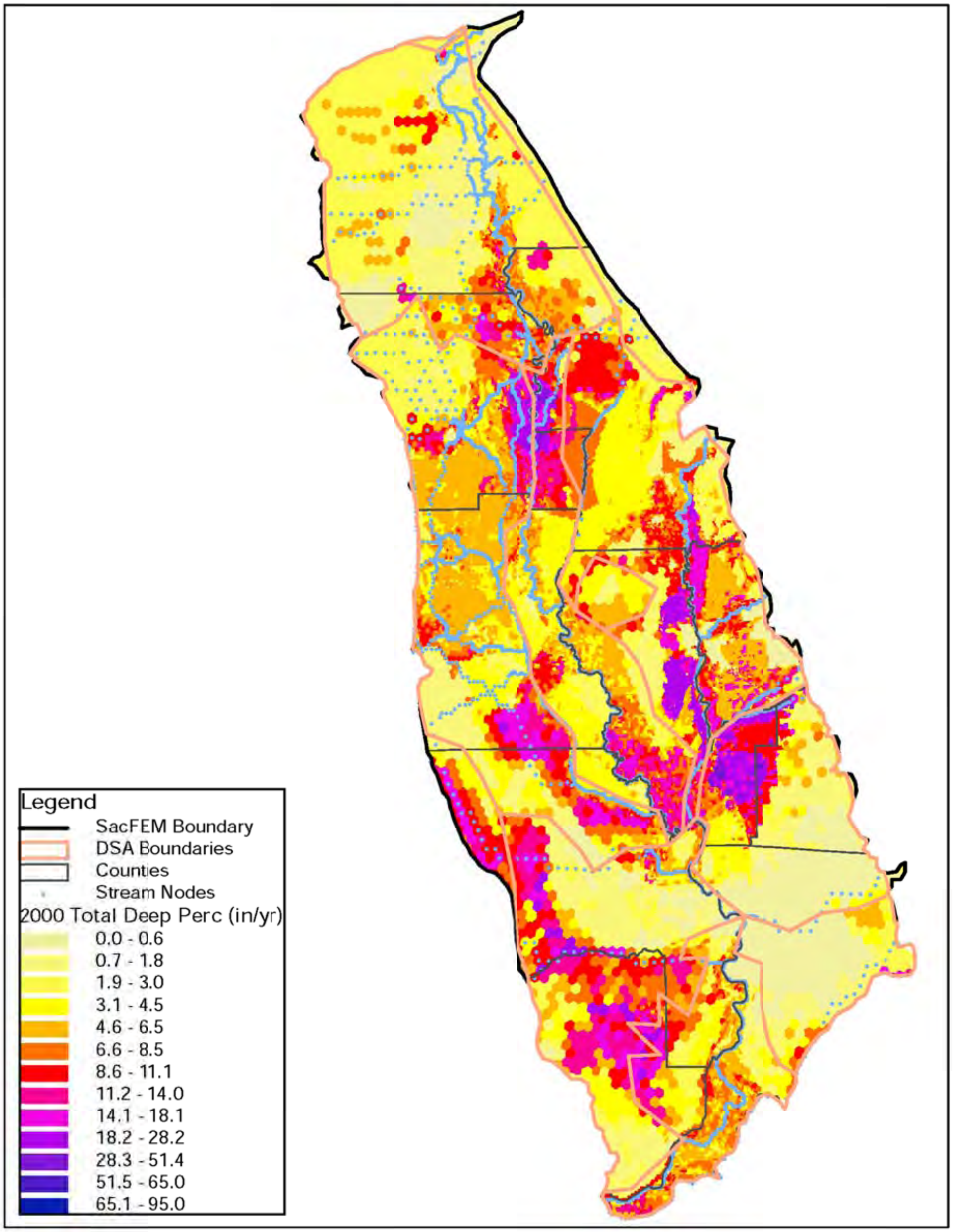

Figure 17. Distribution of SacFEM Deep Percolation Rates

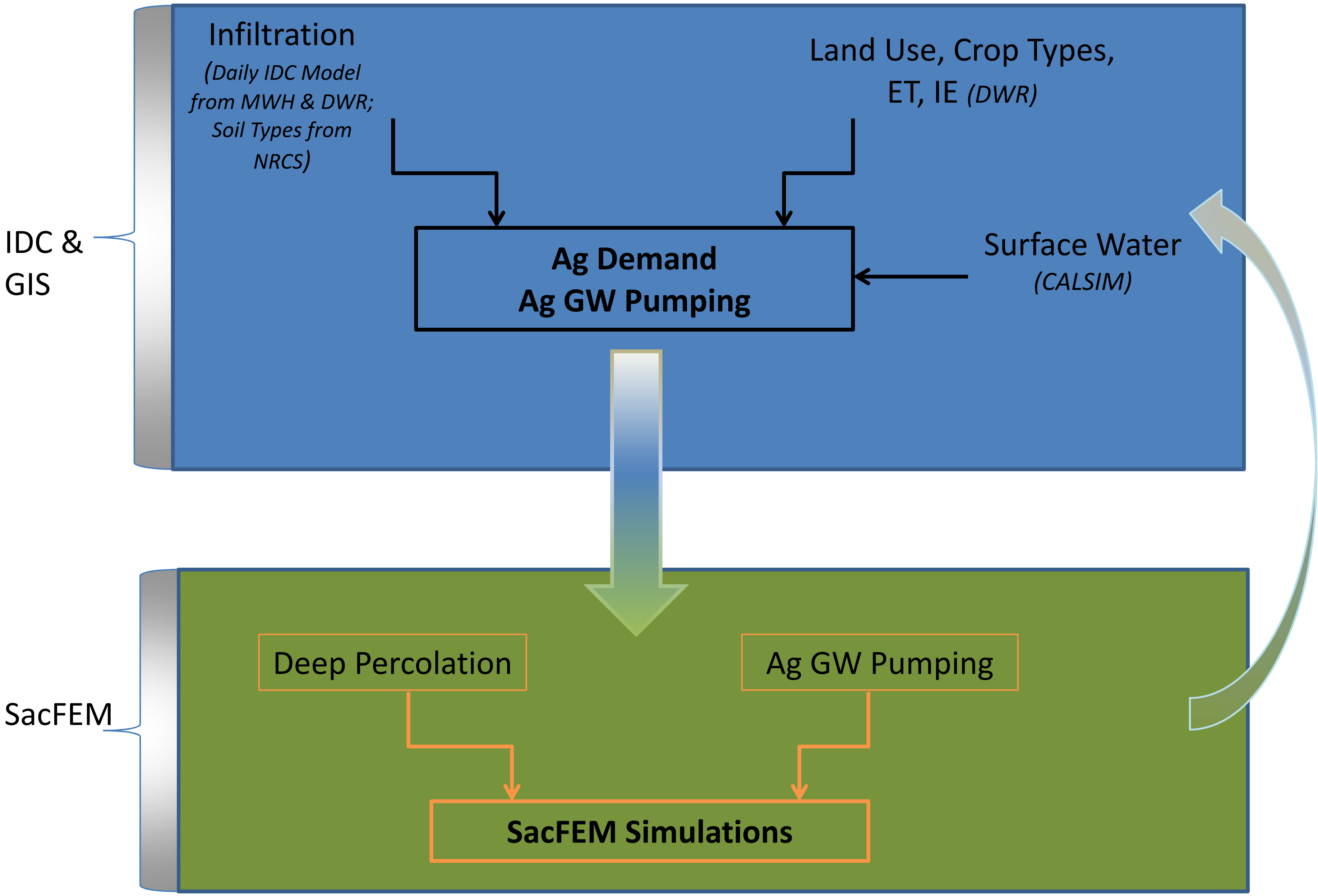

Figure 18. Feedback Loop between IDC and SacFEM Deep Percolation Estimation

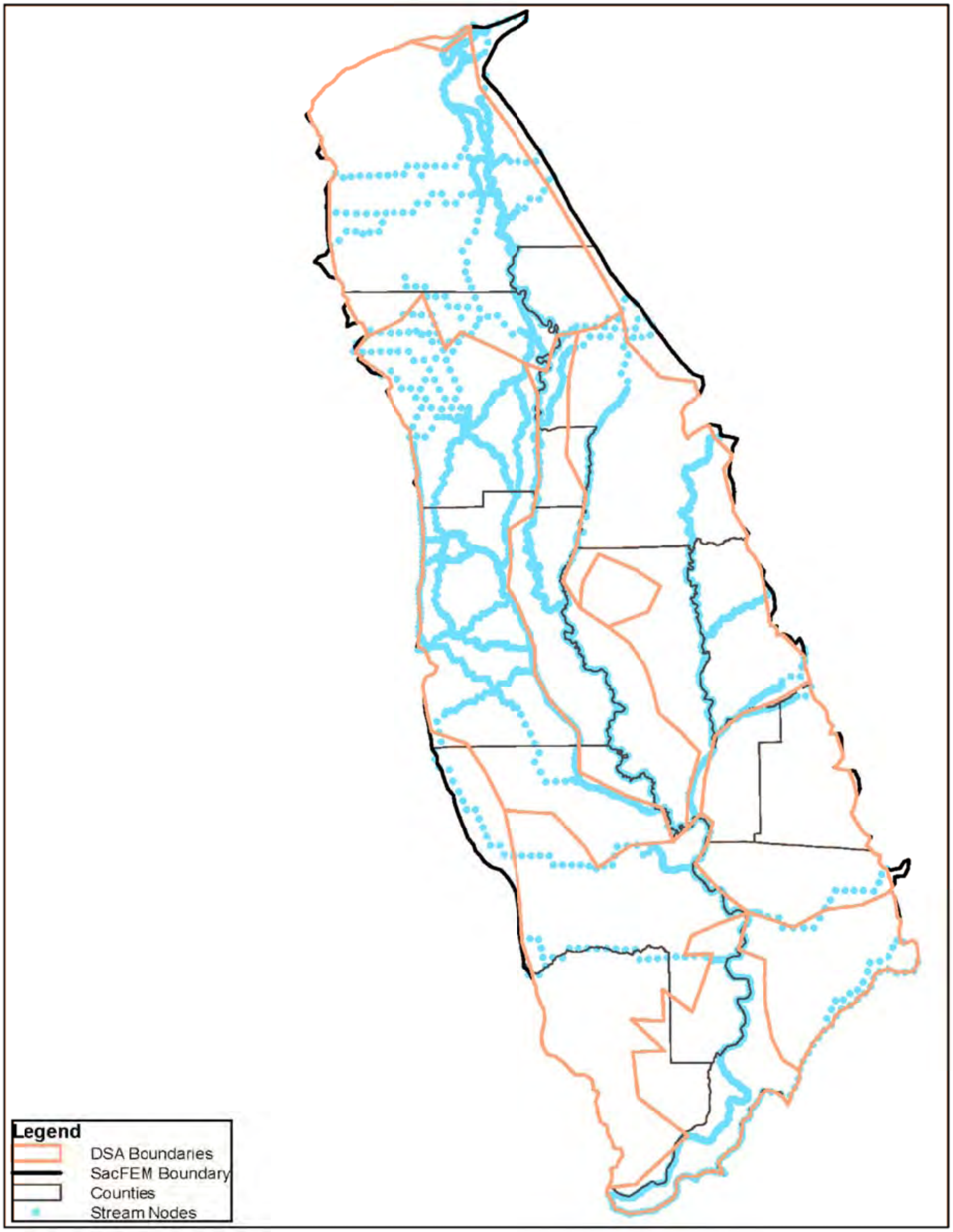

Figure 19. SacFEM Stream Network

- Coupled Streams

  $Q = (H_{stream} - H_{gw})/R$

  R = streambed resistance

  R = f(streambed thickness, Layer 1 thickness, $1/K_{streambed}$, $1/K_{layer1}$

- De-coupled Streams

  $Q = (H_{stream} – H_{stream\ Bottom})/R$

- Stream stage assumed constant
- GW level changes over time

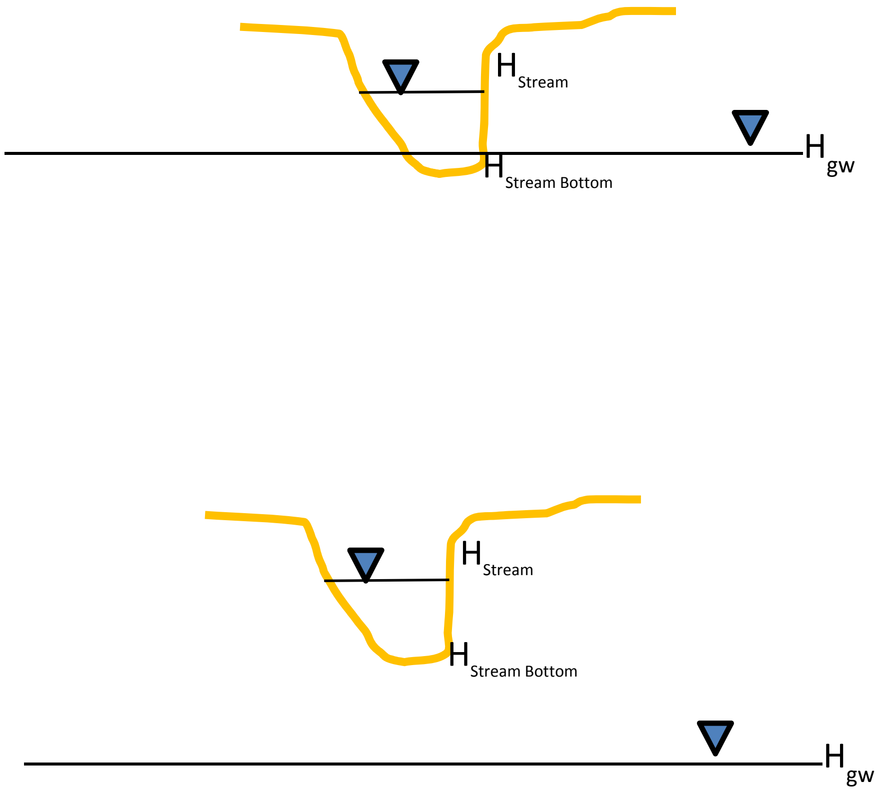

Figure 20. SacFEM Stream Gain/Loss Simulation

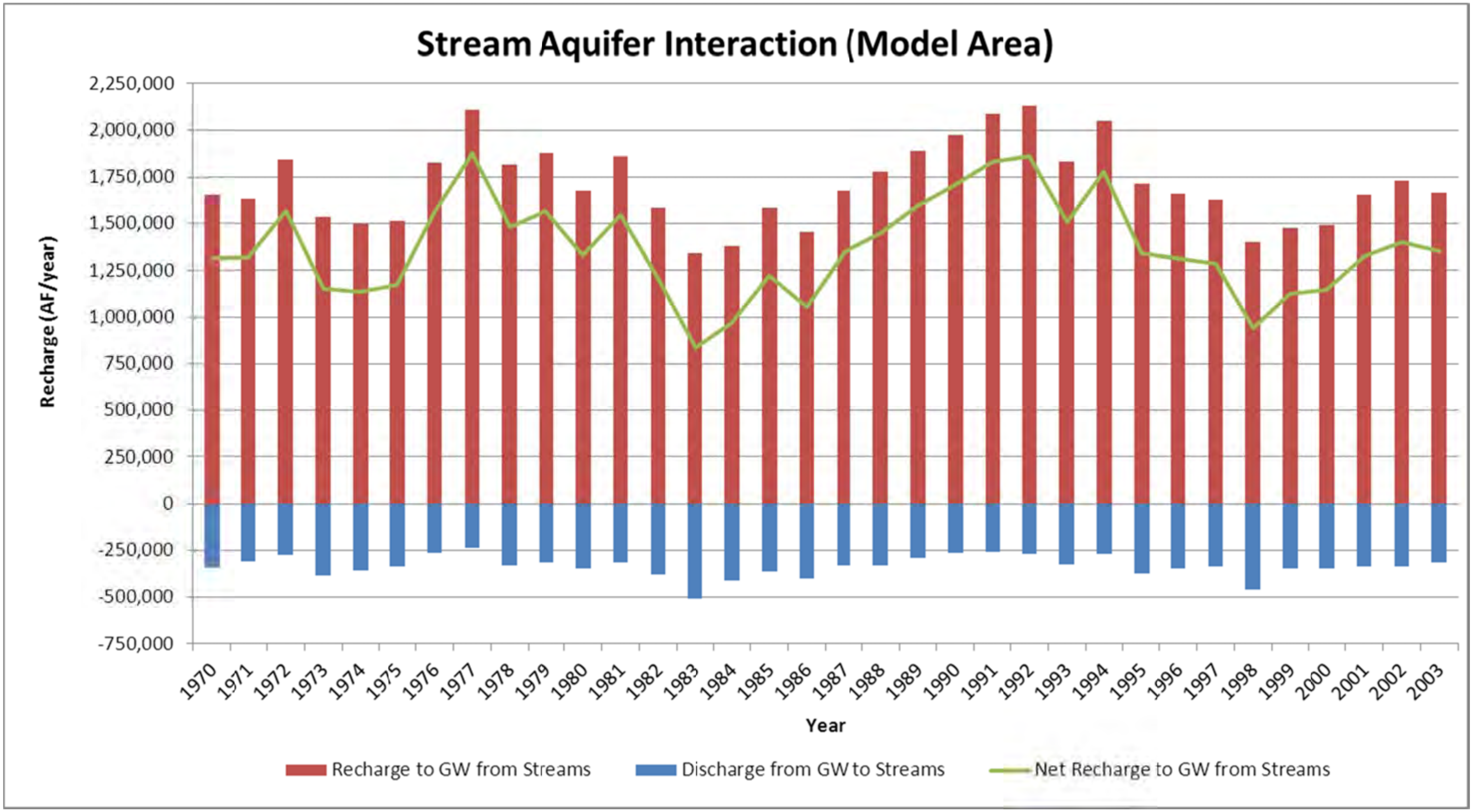

Figure 21. SacFEM Total Annual Stream Gains/Losses

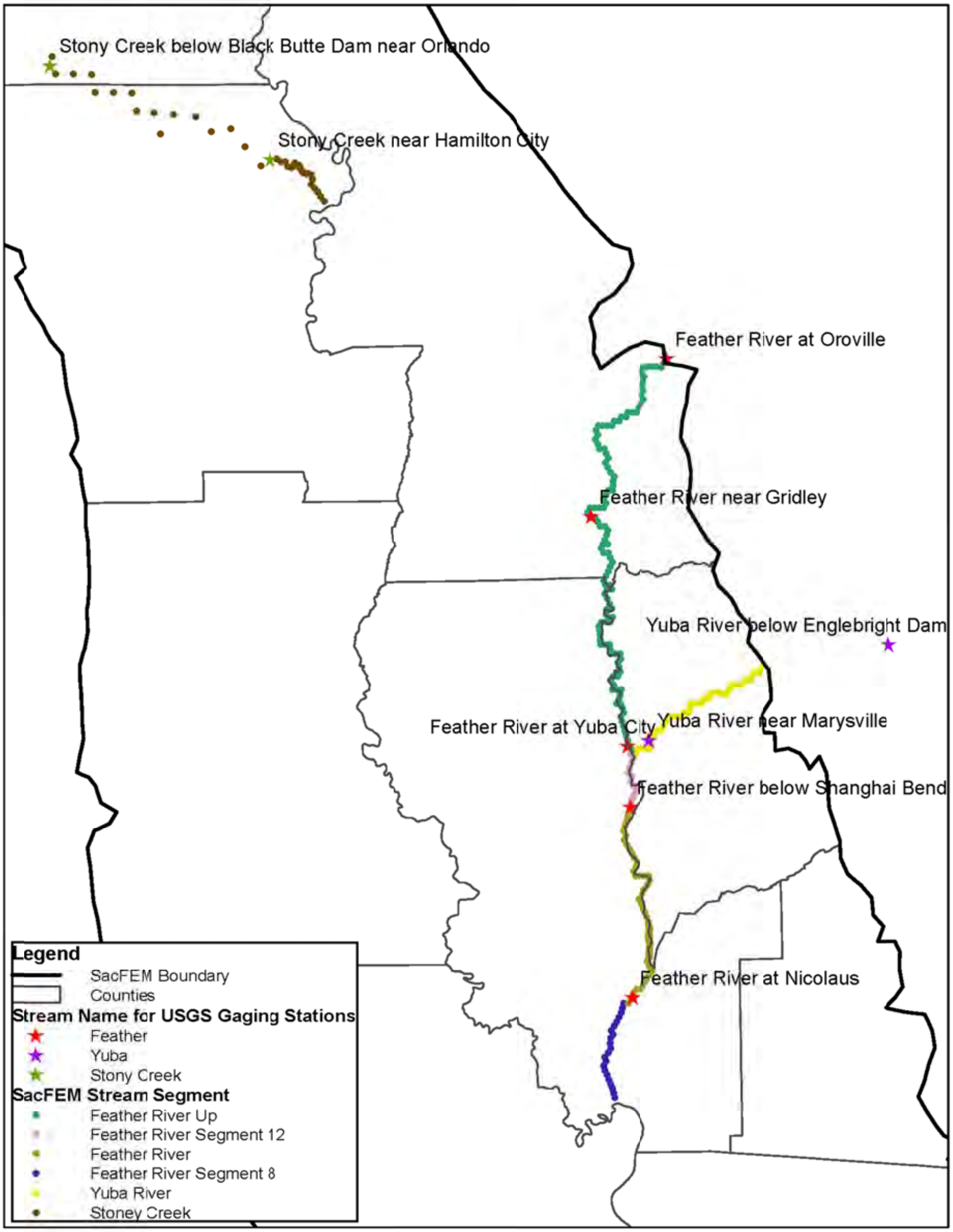

Figure 22. Selected Stream Reaches for Stream Gain/Loss Water Budget Analysis

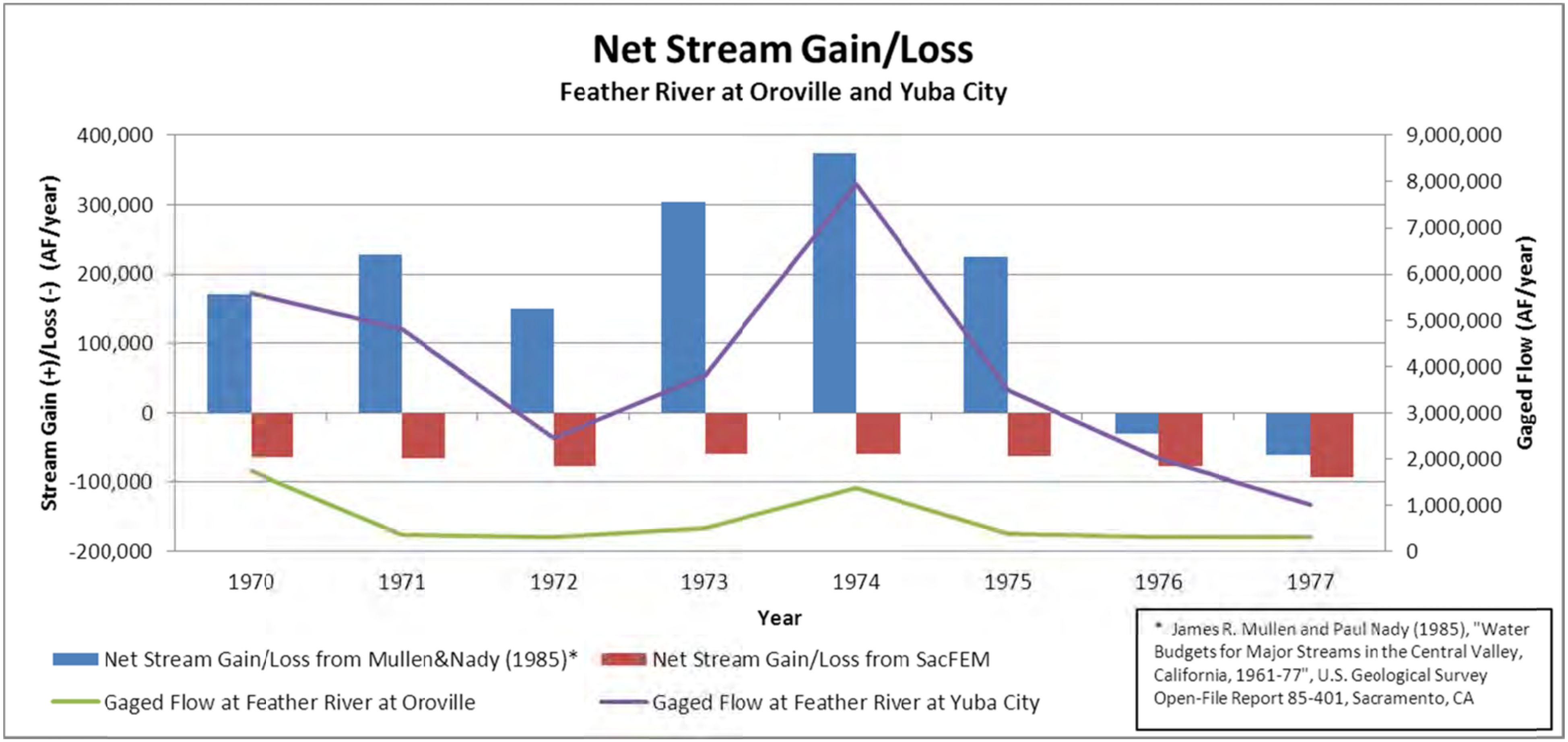

Figure 23. Net Stream Gain/Loss for Feather River at Oroville and Yuba City

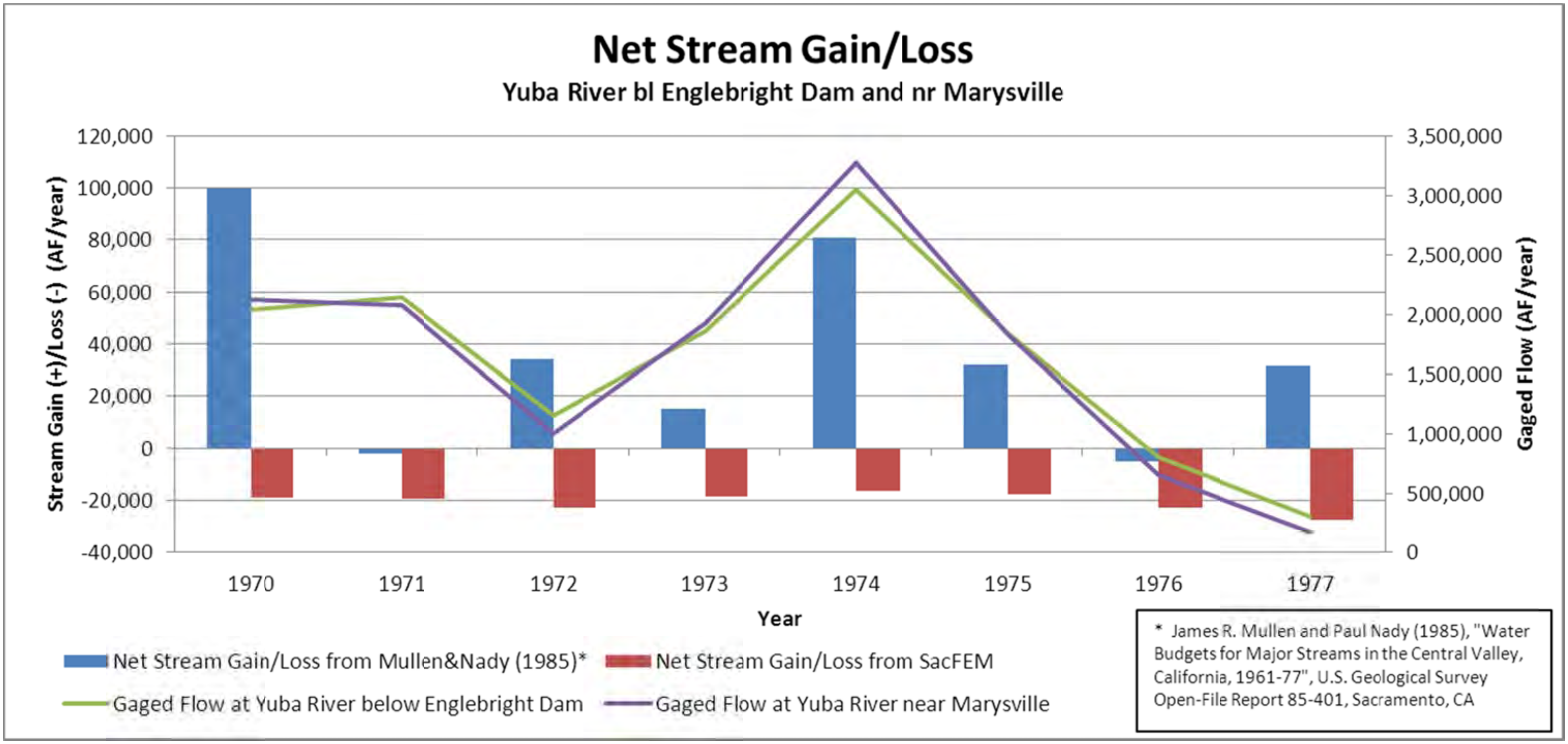

Figure 24. Net Stream Gain/Loss for Yuba River below Englebright Dam and Near Marysville

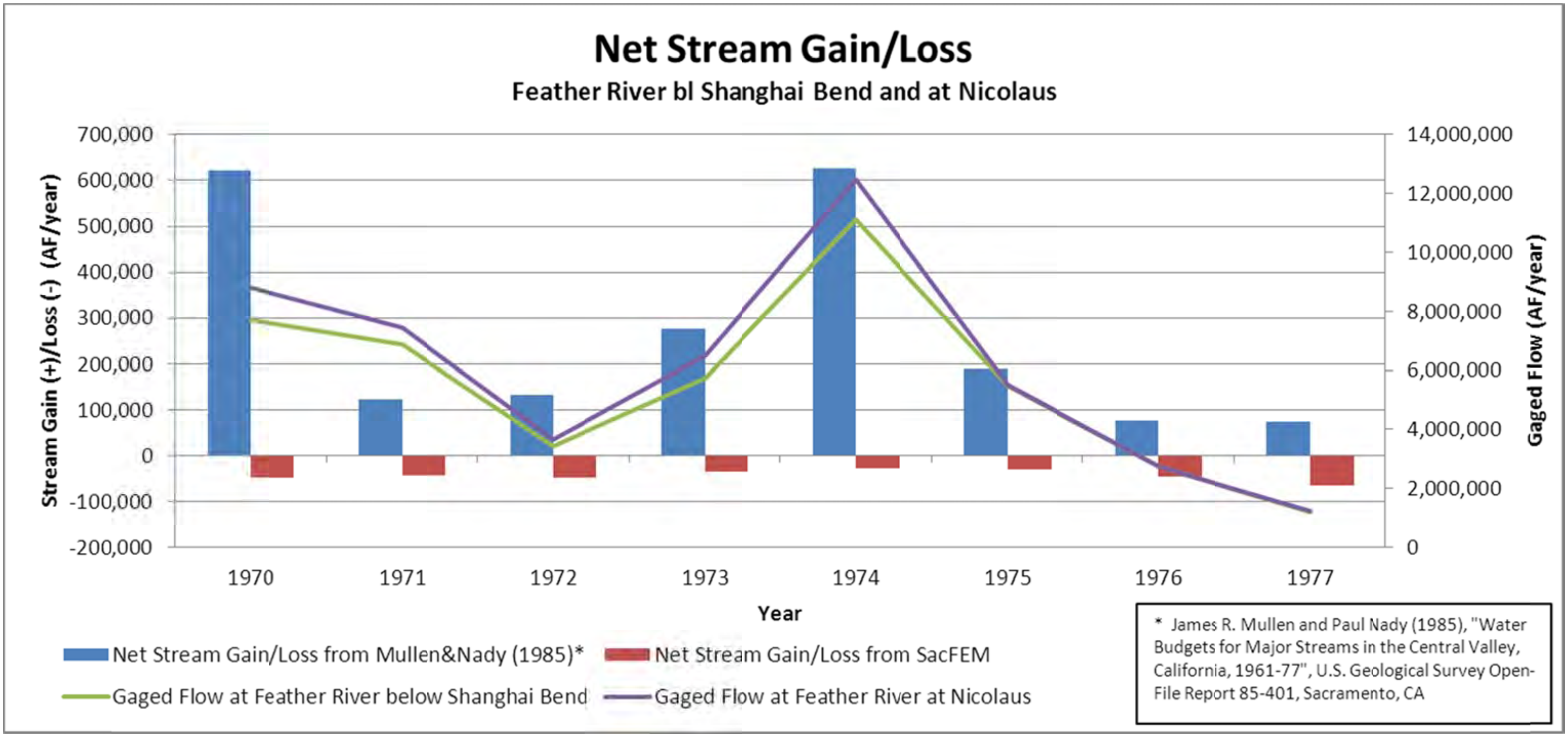

Figure 25. Net Stream Gain/Loss for Feather River Below Shanghai Bend and at Nicolaus

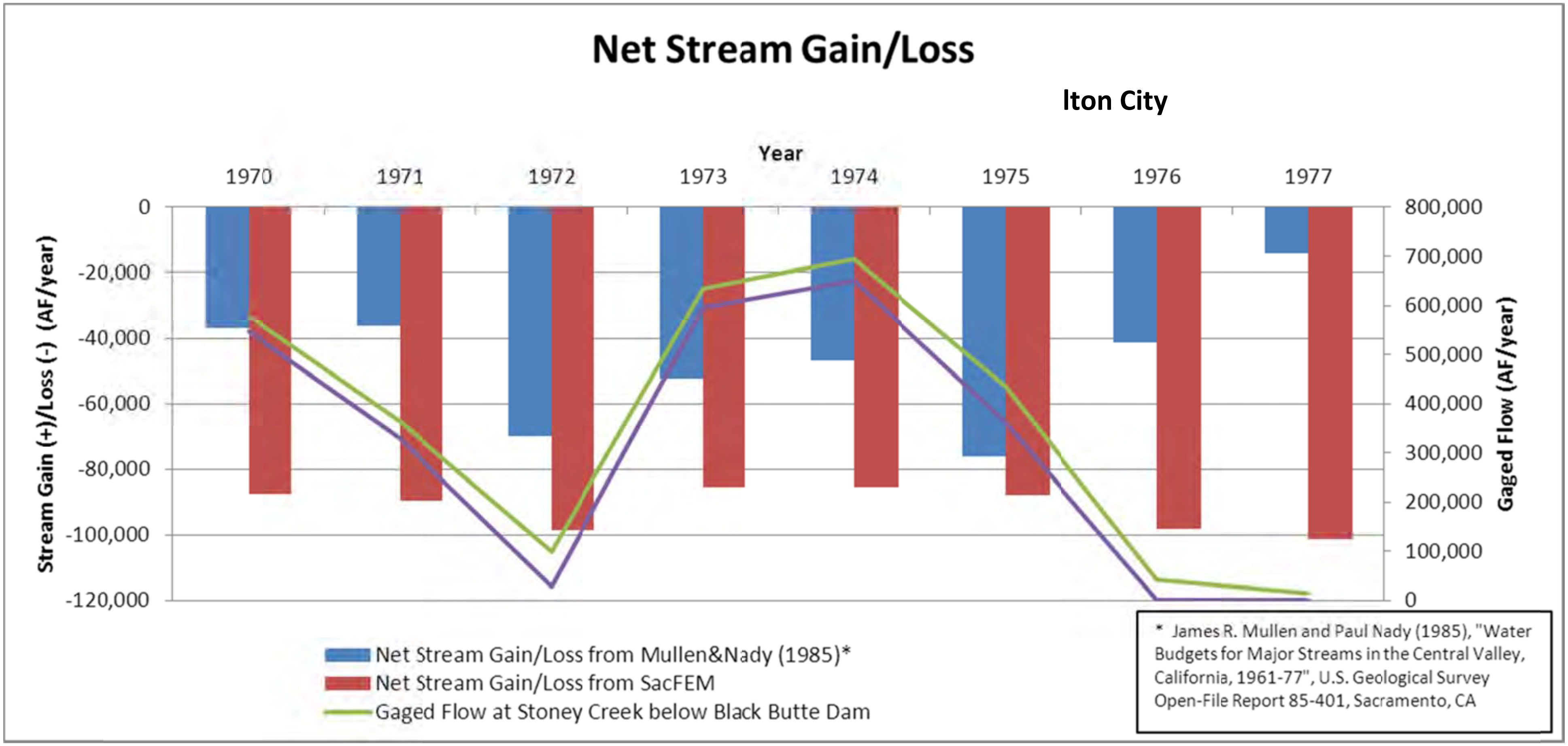

Figure 26. Net Stream Gain/Loss for Stony Creek below Black Butte Dam and Near Hamilton City

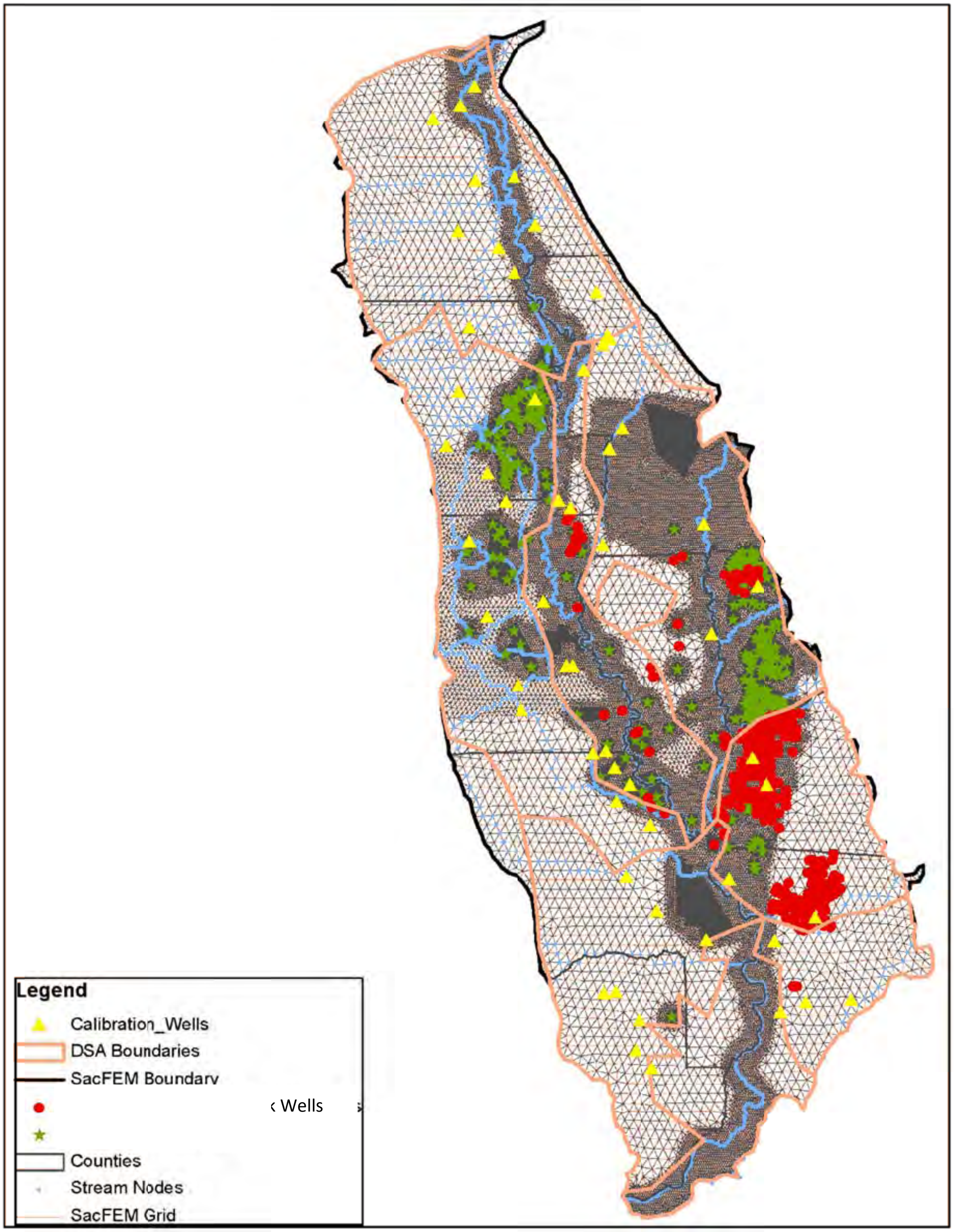

Figure 27. SacFEM Calibration and Project Wells

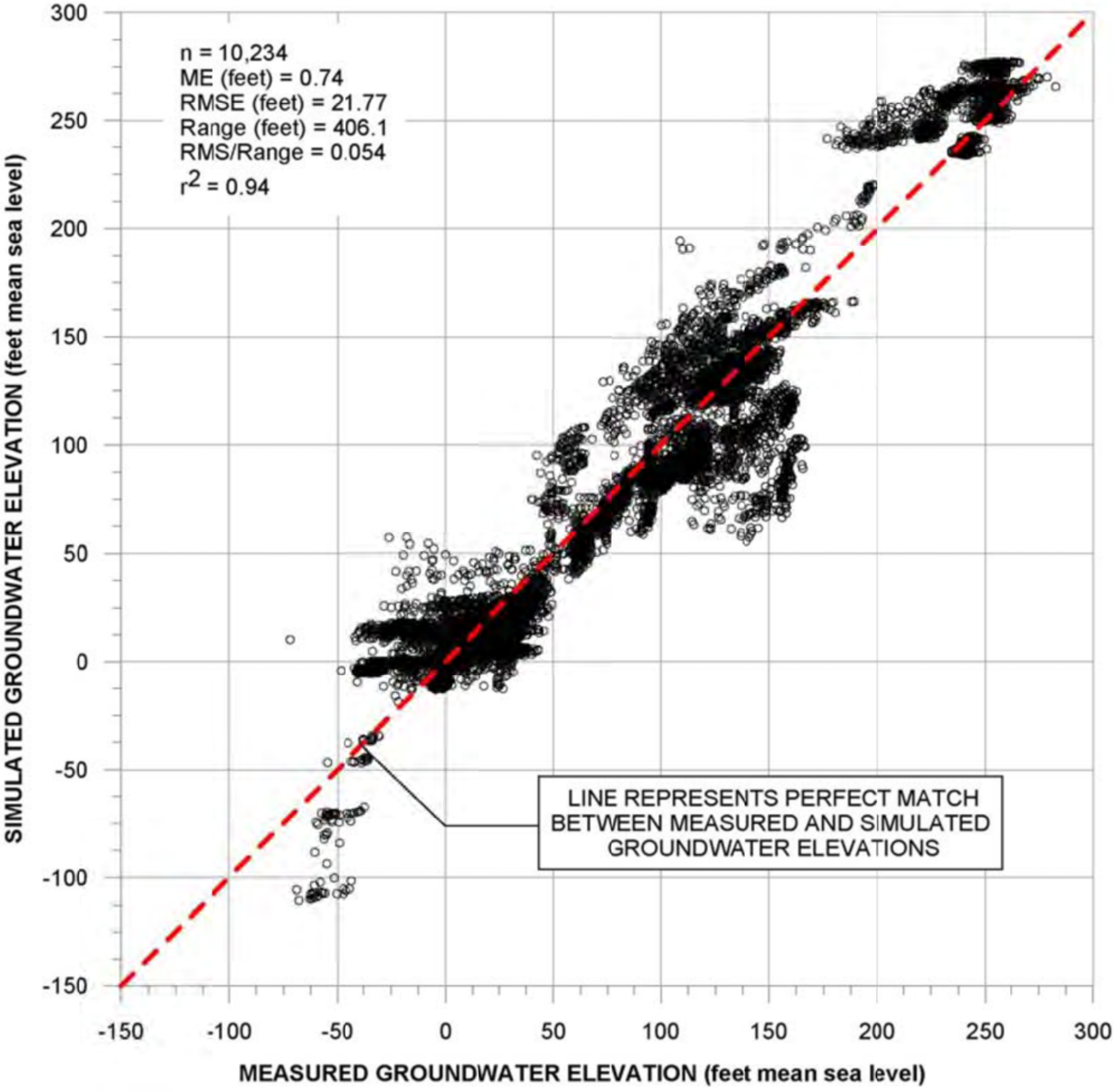

Figure 28. SacFEM Transient Calibration Scattergram from SacFEM Documentation (Lawson, 2009).

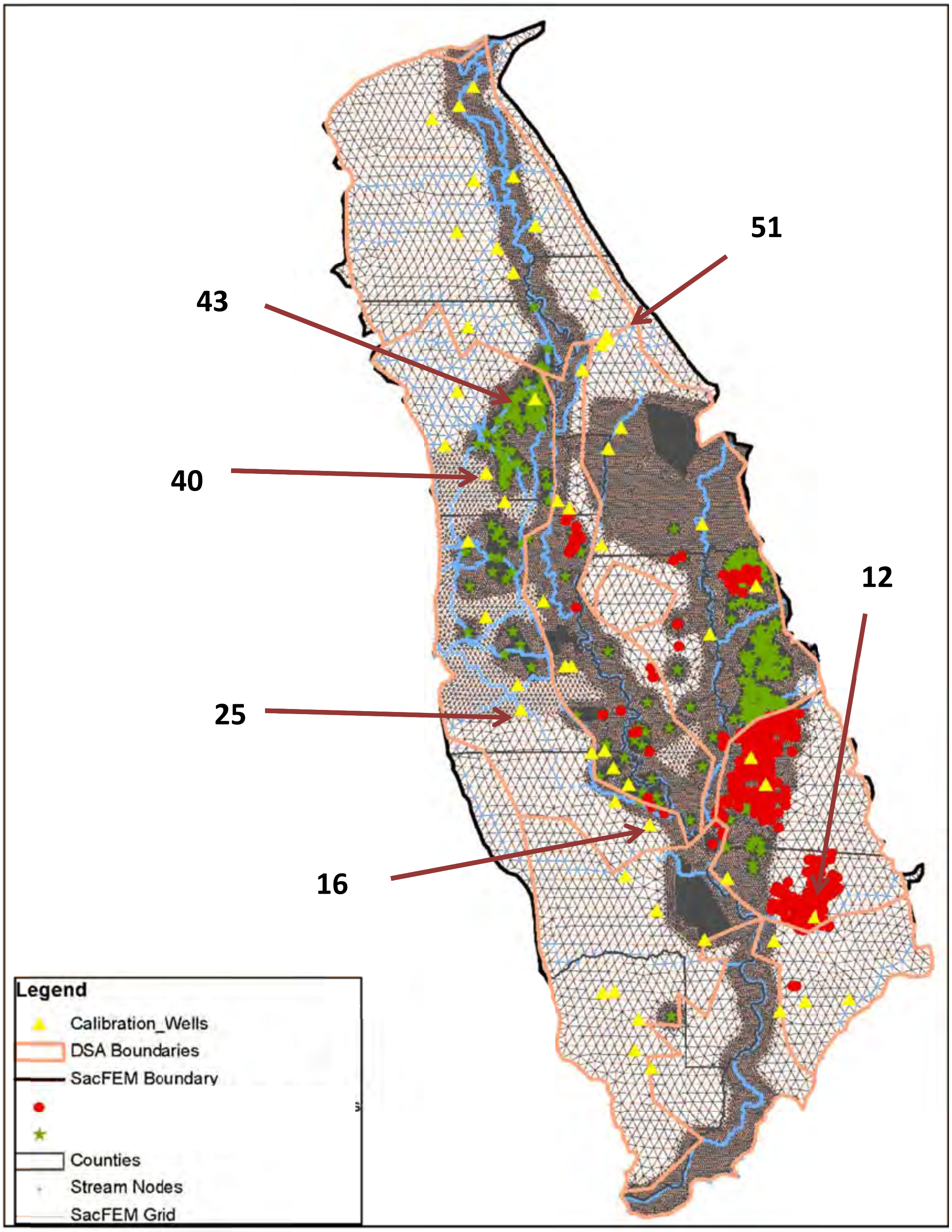

Figure 29. Representative SacFEM Calibration Wells

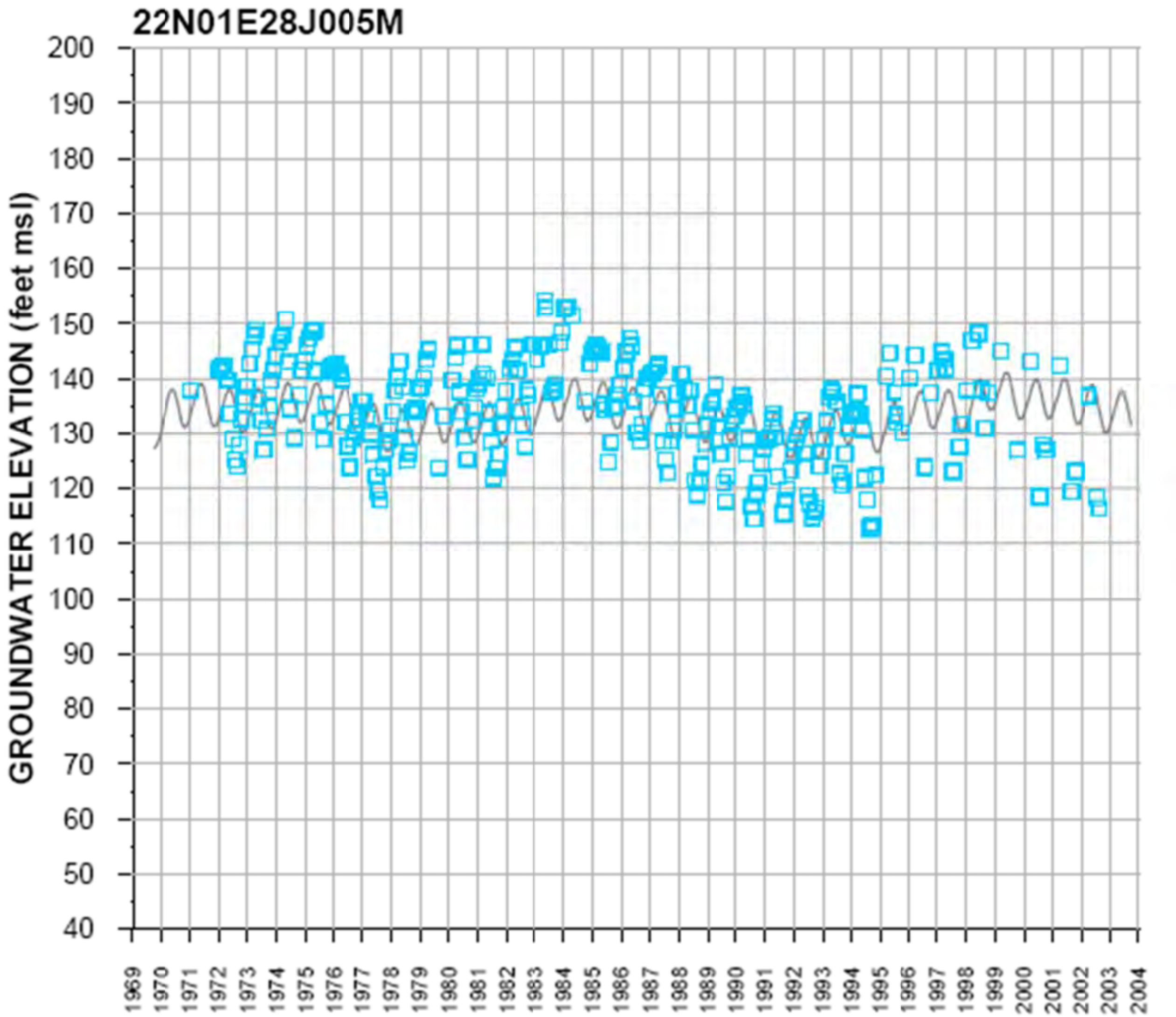

Figure 30. Transient Calibration Hydrograph for Well 51
(Layer 7) – Central Butte County, East of Sacramento River
(Blue markers and grey line represent observed and simulated groundwater elevations, respectively)

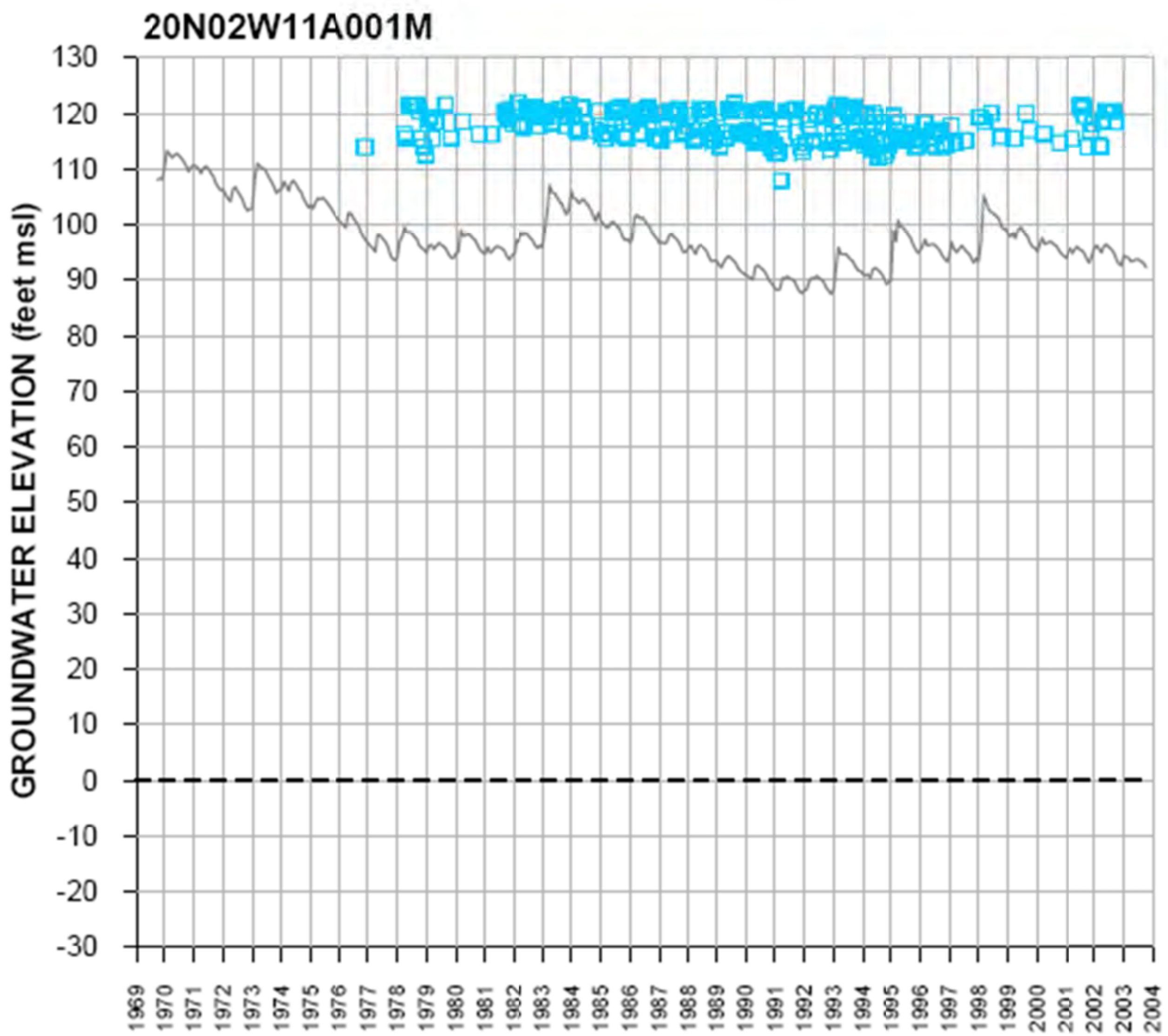

Figure 31. Transient Calibration Hydrograph for Well 43
(Layer 1) – Central Glenn County, West of Sacramento River
(Blue markers and grey line represent observed and simulated groundwater elevations, respectively)

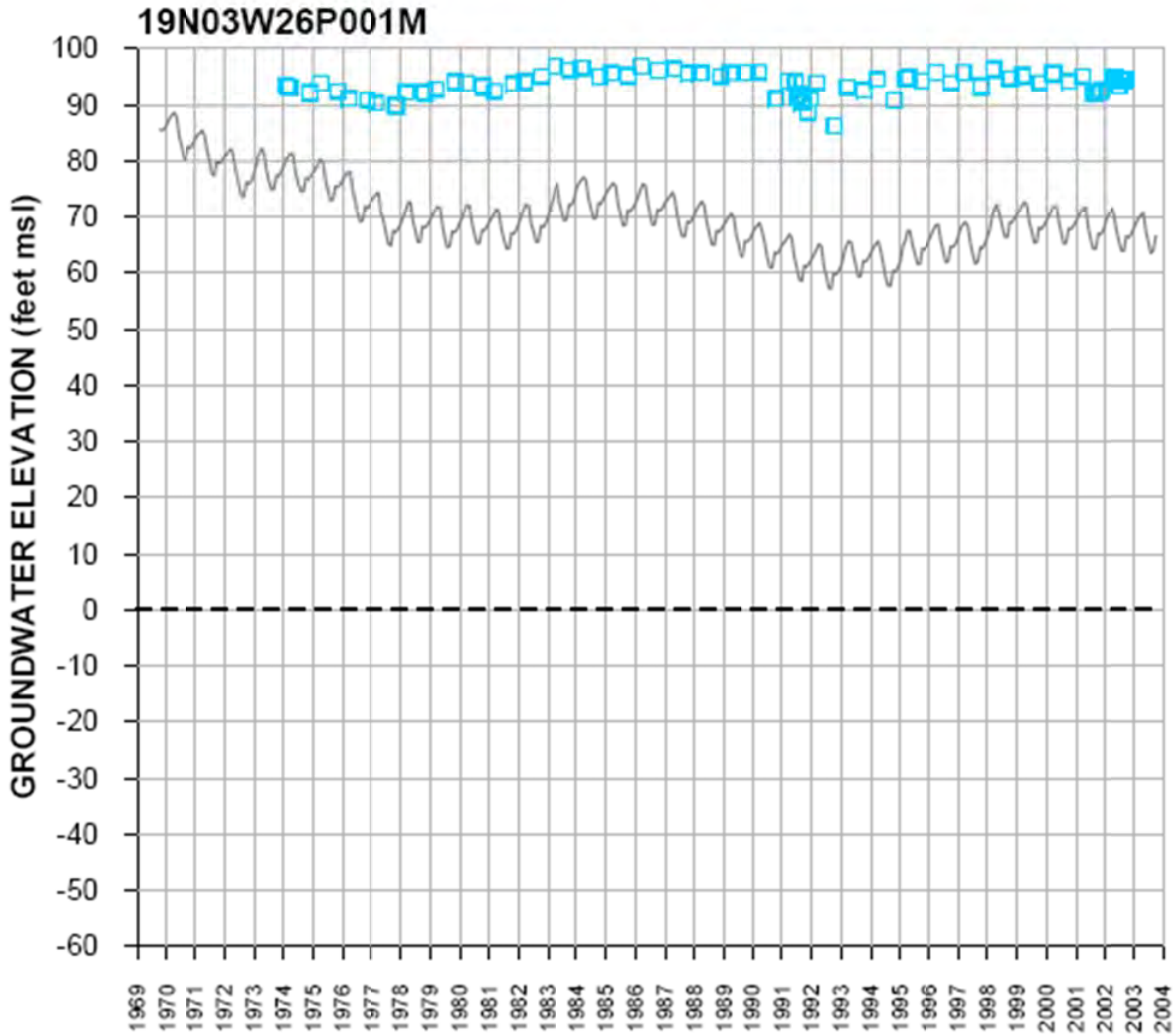

Figure 32. Transient Calibration Hydrograph for Well 40
(Layer 3) – Southern Glenn County, West of Sacramento River
(Blue markers and grey line represent observed and simulated groundwater elevations, respectively)

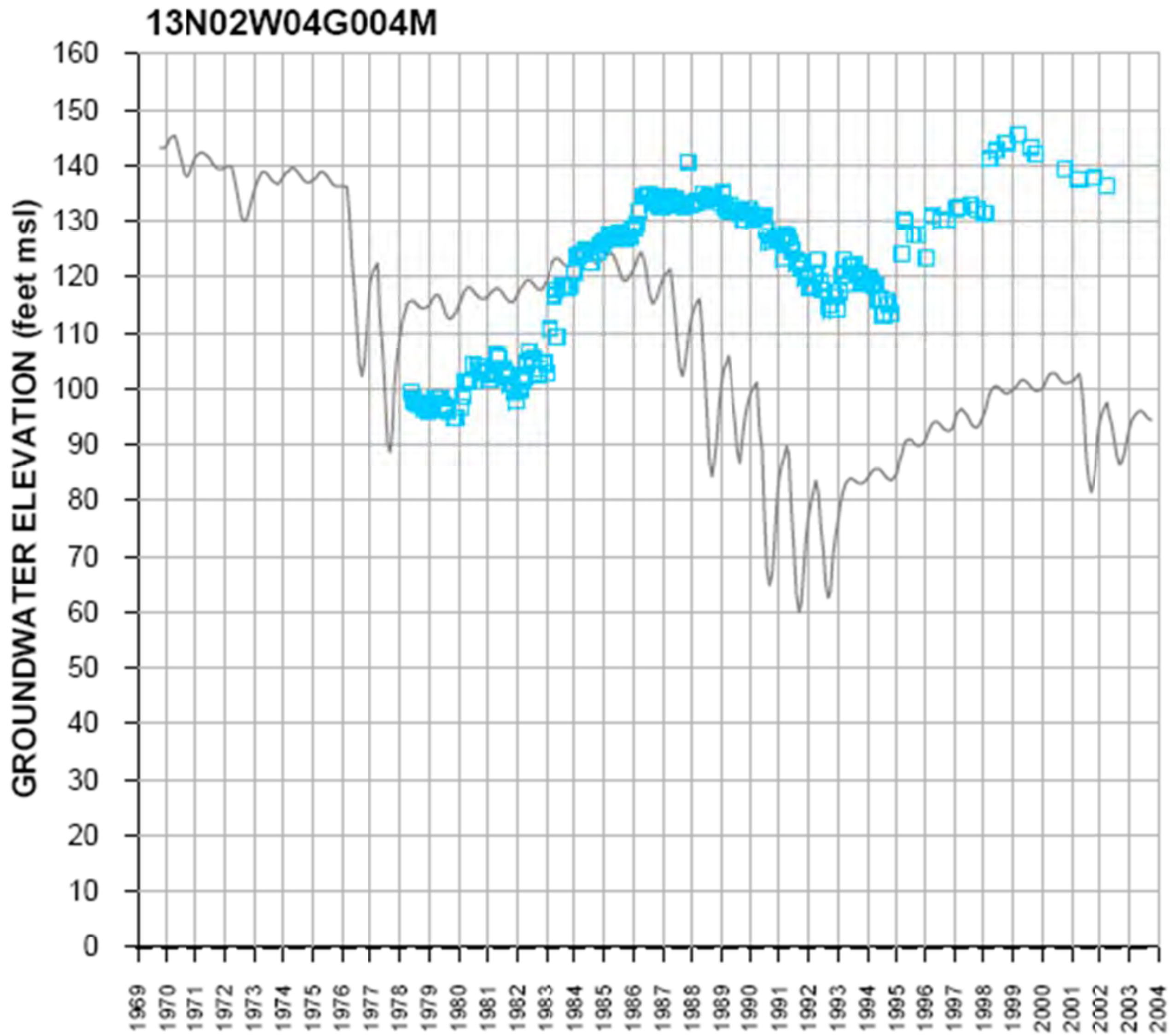

Figure 33. Transient Calibration Hydrograph for Well 25
(Layer 2) – Southern Colusa County, West of Sacramento River
(Blue markers and grey line represent observed and simulated groundwater elevations, respectively)

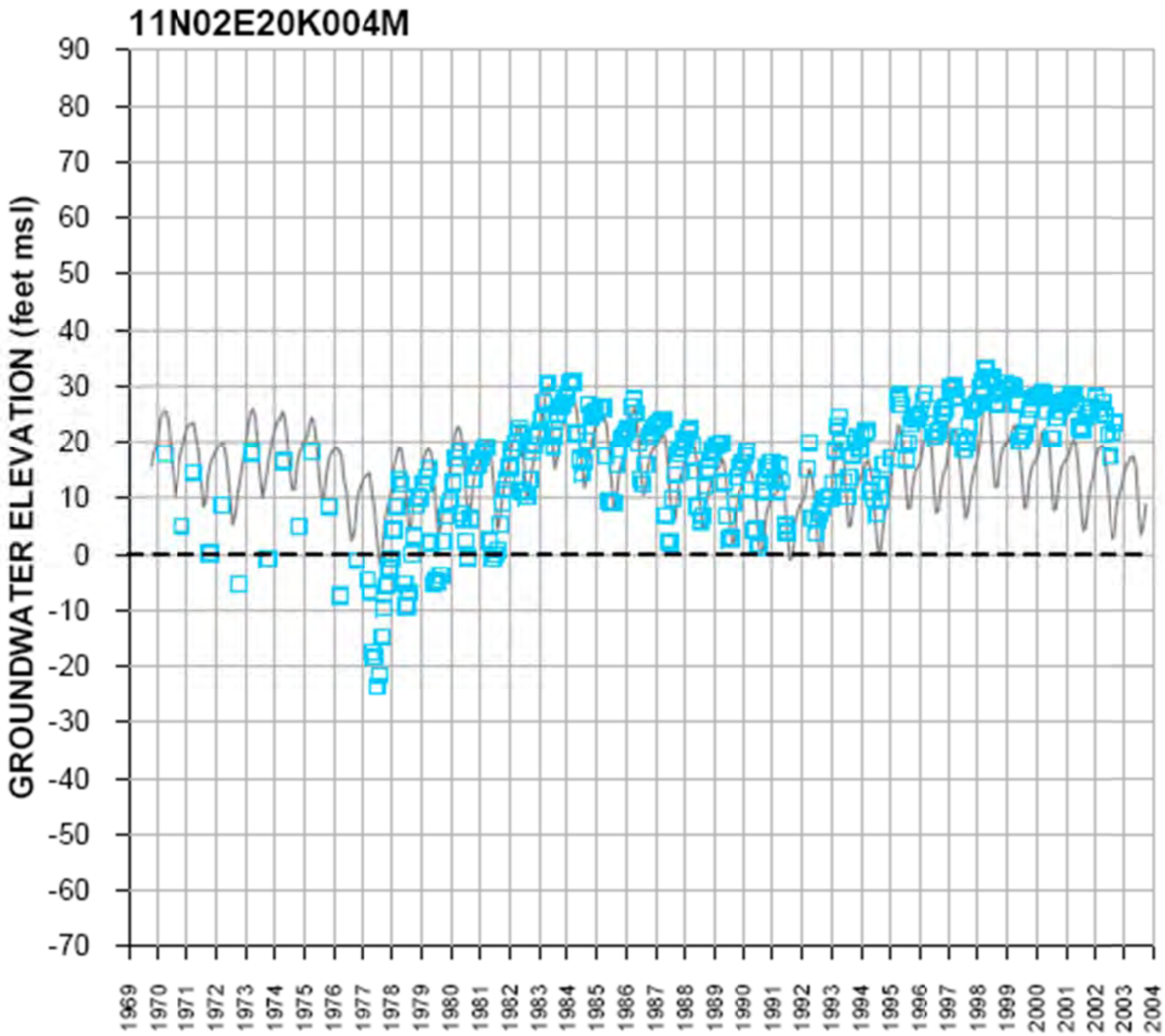

Figure 34. Transient Calibration Hydrograph for Well 16
(Layer 2) – Yolo County, West of Sacramento River
(Blue markers and grey line represent observed and simulated groundwater elevations, respectively)

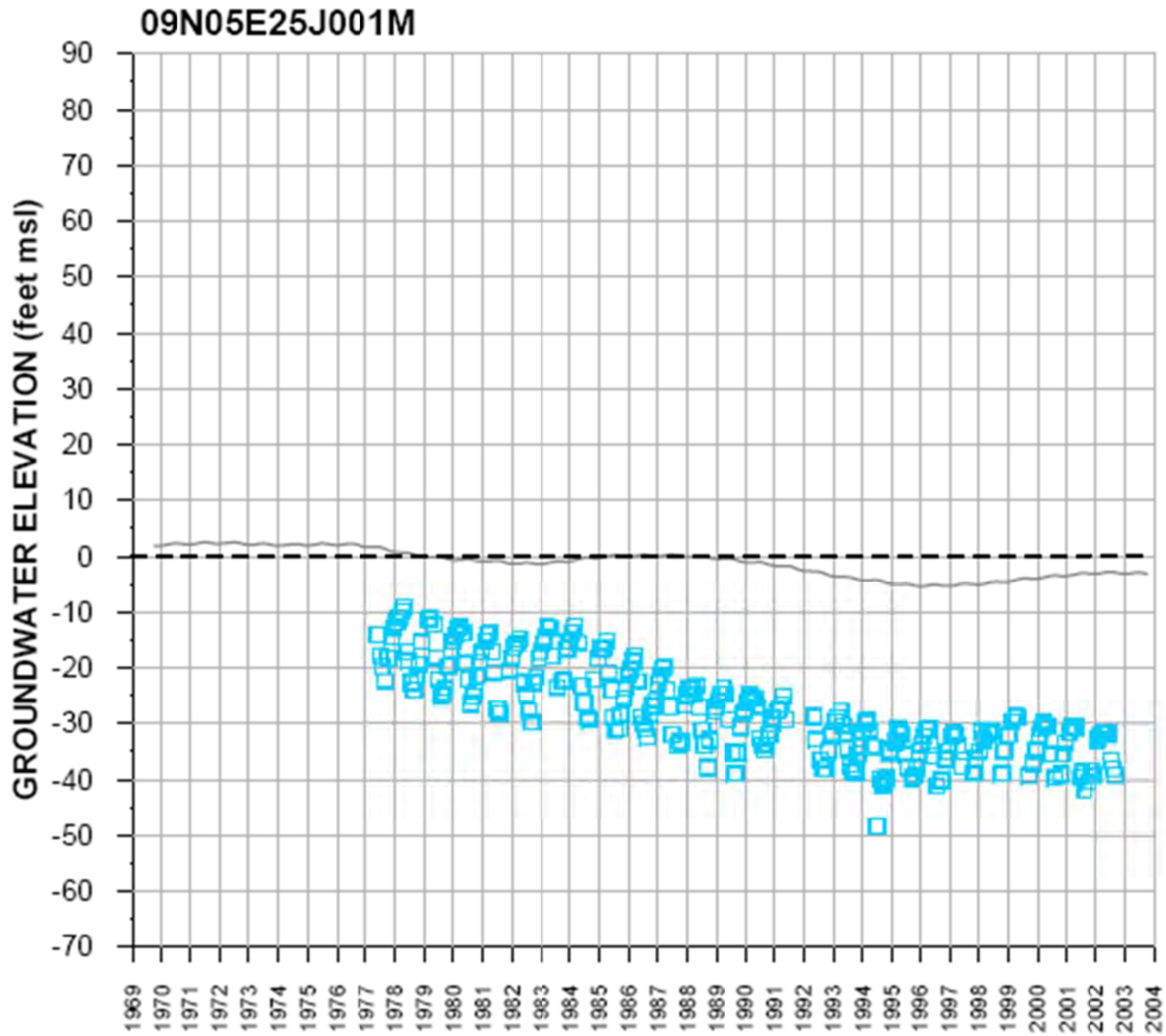

Figure 35. Transient Calibration Hydrograph for Well 12
(Layer 1) – Central Sacramento County, North of American River
(Blue markers and grey line represent observed and simulated groundwater elevations, respectively)

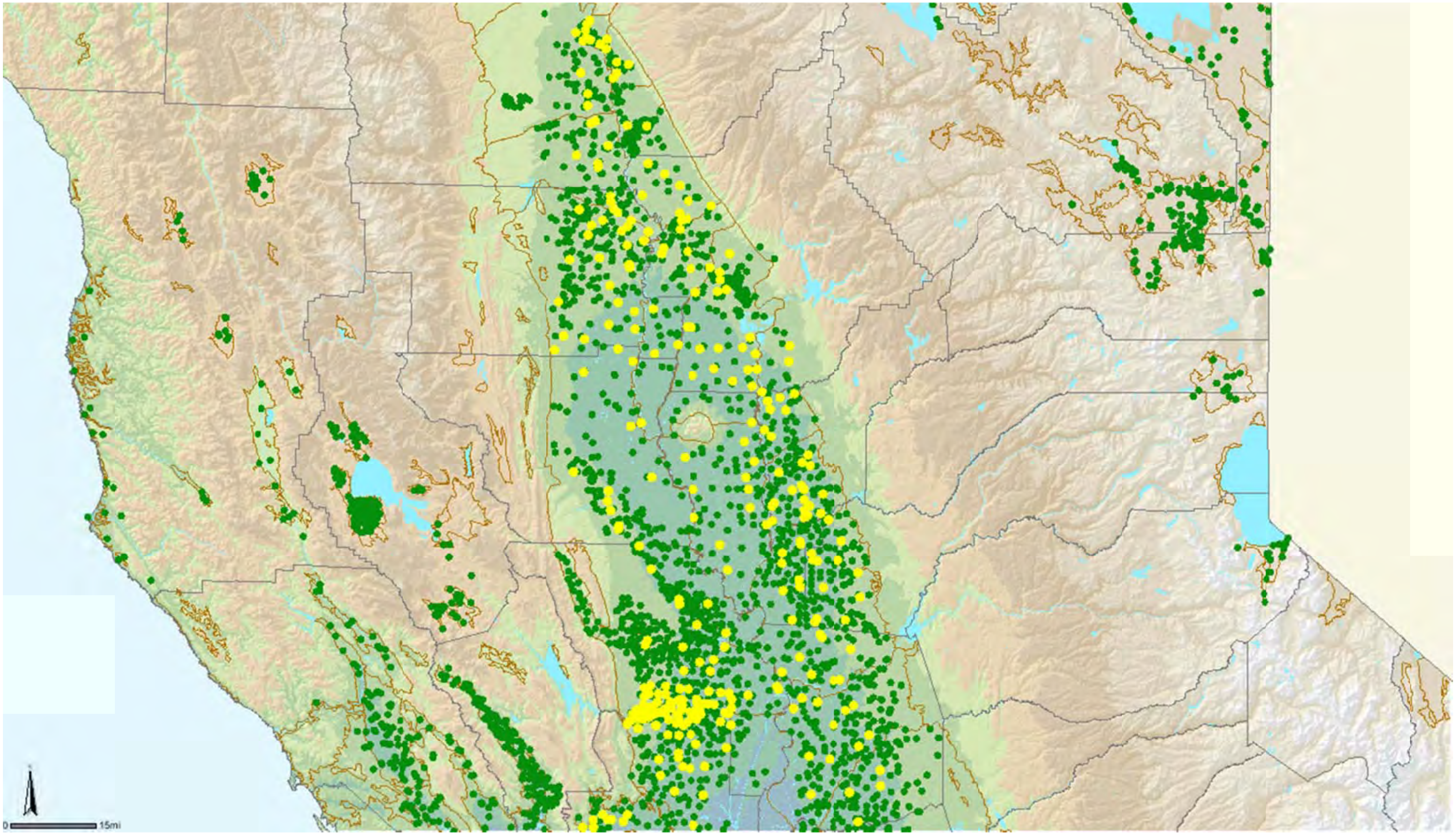

Figure 36. Available Groundwater Elevation Data from IWRIS
(Yellow Markers are Wells with More Than 150 Records)

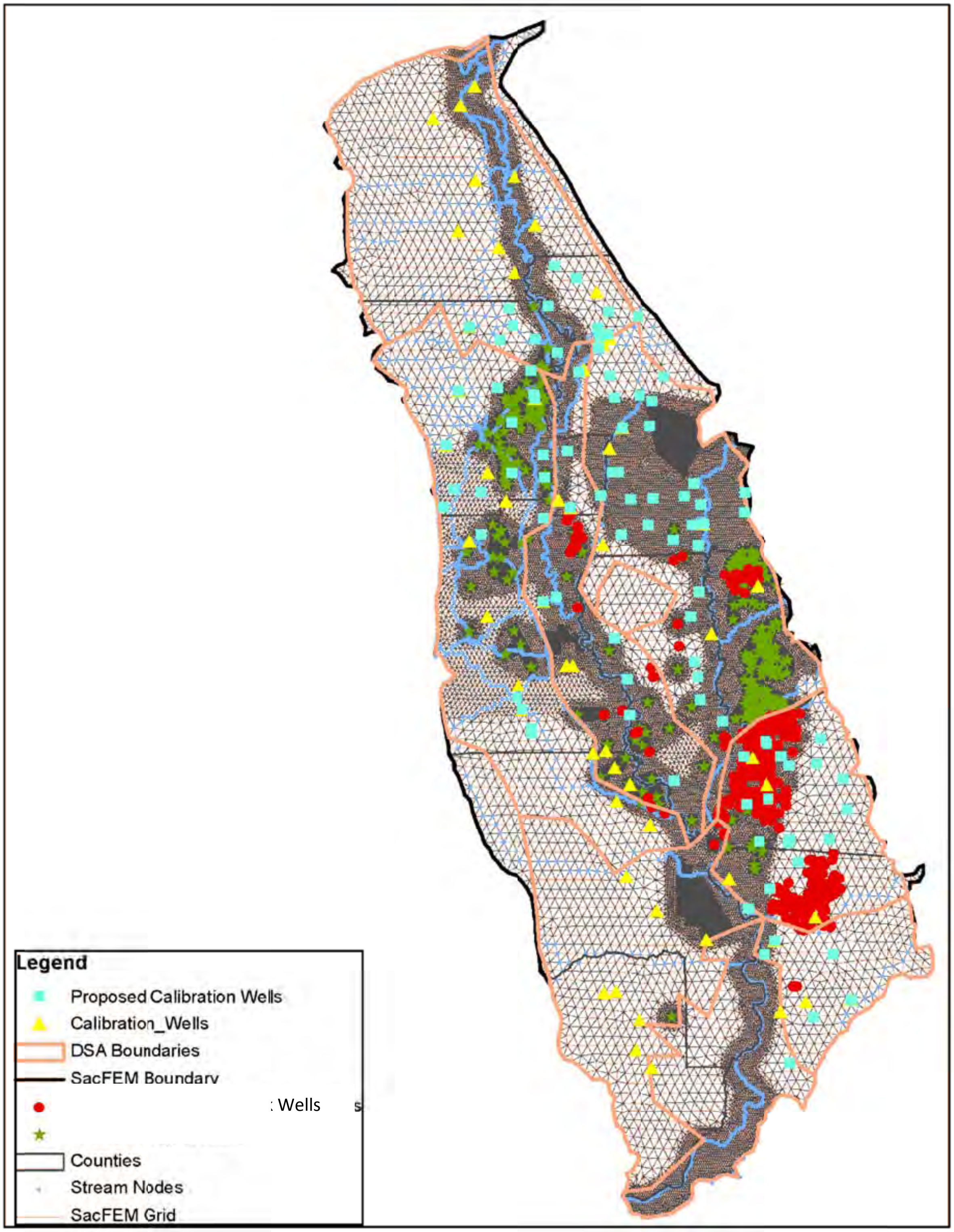

Figure 37. Proposed Calibration Wells