# TECHNICAL MEMORANDUM

## Stanislaus County Hydrologic Model: Development and Forecast Modeling
## Stanislaus County, California

December 20, 2017

*Prepared under direction and supervision of:*

*Mike Tietze, PG, CEG, CHG*
*Principal Engineering Geologist*

## TABLE OF CONTENTS PAGE

**LIST OF TABLES**



**LIST OF FIGURES**

**LIST OF APPENDICES**

**LIST OF ACRONYMS AND ABBREVIATIONS**

| | |
|---|---|
| AF | acre feet |
| AFY | acre feet per year |
| APA | Agricultural Preservation Alliance |
| AWMP | Agricultural Water Management Plan |
| $^{o}$C | Degrees Celsius |
| C2VSim | California Central Valley Groundwater-Surface Water Simulation |
| CASGEM | California Statewide Groundwater Elevation Monitoring |
| CDEC | California Data Exchange Center |
| CEQA | California Environmental Quality Act |
| CVHM | Central Valley Hydrologic Model |
| DEM | digital elevation model |
| DWR | California's Department of Water Resources |
| FERC | Federal Energy Regulatory Commission |
| ft | foot |
| GDE | groundwater dependent ecosystem |
| GSA | Groundwater Sustainability Agencies |
| GSP | Groundwater Sustainability Plan |
| IWFM | Integrated Water Flow Model |
| JJ&A | Jacobson James & Associates, Inc. |
| MERSTAN | Merced-Stanislaus |
| MSR | Municipal Service Review |
| NWIS | National Water Information System |
| Ordinance | Stanislaus County Groundwater Ordinance |
| PEIR | Programmatic Environmental Impact Report |
| PEST | Parameter Estimation |
| PRISM | Parameter-elevation Regressions on Independent Slopes Model |
| SCHM | Stanislaus County Hydrologic Model |
| SGMA | Sustainable Groundwater Management Act |
| SSJID | South San Joaquin Irrigation District |
| SJVGB | San Joaquin Valley Groundwater Basin |
| SLDMWMA | San Luis and Delta-Mendota Water Management Authority |

| | |
|---|---|
| SLDMWUA | San Luis and Delta-Mendota Water Users Authority |
| STRGBA | Stanislaus and Tuolumne Rivers Groundwater Basin Association |
| SWRA | Stanislaus Regional Water Authority |
| TAC | Stanislaus County's Technical Advisory Committee |
| TGBA | Turlock Groundwater Basin Association |
| TID | Turlock Irrigation District |
| TM | Technical Memorandum: Stanislaus County Hydrologic Model: Development and Forecast Modeling |
| USGS | United States Geological Survey |
| UWMP | Urban Water Management Plan |
| WAC | Stanislaus County's Water Advisory Committee |
| WY | water year |
| % | percent |

# 1.0 INTRODUCTION

## 1.1 Project Background

Stanislaus County adopted a Groundwater Ordinance in November 2014 (Chapter 9.37 of the County Code, hereinafter, the "Ordinance") that codifies requirements, prohibitions, and exemptions intended to help promote sustainable groundwater extraction in unincorporated areas of the county. The Ordinance prohibits the unsustainable extraction of groundwater and makes issuing well construction permits discretionary for new wells that are not exempt from this prohibition. The ordinance does not apply to incorporated areas of the county. Exemptions apply to water districts operating under a functional groundwater management plan and their rate payers. Applications for non-exempt wells must include substantial evidence that they will not withdraw groundwater unsustainably. After an unincorporated area adopts a Groundwater Sustainability Plan (GSP) pursuant to California's Sustainable Groundwater Management Act (SGMA), it becomes exempt from this requirement, and the sustainable management of new wells will follow the SGMA-mandated process by which a Groundwater Sustainability Agency (GSA) advises the county whether the proposed new well complies with the GSP and extracts groundwater sustainably. Upon receiving such an assessment, the county would issue a well construction permit on a ministerial basis. However, after GSPs are adopted, the county can also require holders of permits for wells it reasonably concludes are withdrawing groundwater unsustainably to provide substantial evidence that continued operation of such wells does not constitute unsustainable extraction, and has the authority to regulate future groundwater extraction from such wells. Given that GSAs have the primary responsibility for regulation of sustainable groundwater extraction under SGMA, it is unlikely that the county would ever exercise this authority under the Ordinance, but it exists as a backstop to help assure sustainable groundwater management.

As the lead agency under the California Environmental Quality Act (CEQA), Stanislaus County is voluntarily preparing a Programmatic Environmental Impact Report for Discretionary Well Permitting and Management under the Stanislaus County Groundwater Ordinance (the PEIR) to evaluate the broad-scale environmental impacts of issuing discretionary well permits and regulating potentially unsustainable wells under the Ordinance. The purpose of the PEIR is to develop a more robust basis for managing these discretionary programs and streamline the application and review process for new well permits. The PEIR may also inform future groundwater management policy alternatives and, if necessary, identify program-level mitigation measures.

As part of this effort, a hydrologic model (the Stanislaus County Hydrologic Model or SCHM) has been developed to help characterize the affected groundwater environment and facilitate evaluation of potential environmental effects associated with the permitting of discretionary wells, and other reasonably foreseeable groundwater management actions and trends. The development of the SCHM and its application to identification of reasonably foreseeable groundwater conditions and hydrologic impacts of Ordinance implementation are discussed in this Technical Memorandum (the TM).

## 1.2 Objectives

The PEIR will evaluate the effects of permitting new discretionary wells under the Ordinance, primarily before GSPs are adopted, and of regulating wells from which the County has reason to believe that groundwater is being extracted unsustainably after GSPs are adopted. The PEIR, and by extension the SCHM, is therefore intended to support the following major objectives:

1. Evaluation of hydrologic and water supply impacts at a programmatic level, such as regional drawdown, groundwater storage depletion, surface water depletion, effects on groundwater-dependent ecosystems (GDEs), water quality, land subsidence, and ability to meet future water demands; as well as non-hydrologic, indirect, and cumulative impacts;

2. Development of a Tier I document that can be used to refine the County's well permitting program, streamline the well permit application process and help facilitate the transition to groundwater management under SGMA; and

3. Gathering and evaluating information that will be relevant to Groundwater Sustainability Agencies (GSAs) in their early stages of planning for compliance with the SGMA, including technical data compilation and analysis that will assist GSP development.

Development of the SCHM serves as a key tool to meet the objectives of the PEIR, and therefore is guided by the following additional objectives:

1. Extensive groundwater basin characterization and modeling has been completed in the County by the United States Geological Survey (USGS), California's Department of Water Resources (DWR), Stanislaus and Tuolumne Rivers Groundwater Basin Association (STRGBA), Turlock Groundwater Basin Association (TGBA), and other stakeholders. The SCHM does not duplicate this work, and to the extent possible, leverages previous work for the model-development effort.

2. The SCHM supports a programmatic-level assessment of potential impacts associated with permitting wells under the Ordinance. The specific locations, completion details, and pumping rates of these wells are not yet known.

3. Several water management programs with significant implications for the Stanislaus County area are in the early stages of development at this time, and their outcomes and potential effects on groundwater resources are not known. The potential effects of these programs will be discussed in the PEIR, but because their outcomes are uncertain and evaluation would be speculative, they will not be addressed in the modeling evaluation. These include (1) implementation of the GSPs that will not be developed until 2020 or 2022; (2) proposed requirements for unimpaired flow on the Stanislaus, Tuolumne and Merced Rivers to support proposed amendments to Bay-Delta Water Quality Control Plan of the State Water Resources Control Board; and (3) relicensing of Modesto Irrigation District and Turlock Irrigation District (TID) hydroelectric projects on the Stanislaus and Tuolumne Rivers by the Federal Energy Regulatory Commission (FERC).

4. To support impact assessment, in light of the above objectives, the following specific modeling objectives were adopted in development of the SCHM and defining the forecast scenarios that were used in impact assessment:

    - The model was developed to include the entirety of the County and, at the request of stakeholders in the Turlock Groundwater Basin who were interested in using the model as a preliminary evaluation tool, the entirety of the Turlock Groundwater Subbasin, including the portion that extends into Merced County. Collectively, these areas are referred to as the Study Area.

    - Boundary locations and boundary conditions were determined with the goal of minimizing the size of the model, to the extent possible, while not introducing artificial boundary effects within the Study Area.

    - The model was developed to be able to evaluate issues related to groundwater levels, flow, boundary conditions, inter-basin underflow, and groundwater-surface water-interactions at a level of detail sufficient to recognize potential issues for programmatic impact assessment. As such, it was developed to be generally more detailed and locally accurate than existing regional models developed by the USGS and the DWR,[1] but a subbasin scale model capable of accurately predicting head elevations was not necessary to meet the objectives of this project.

    - A superposition approach was considered appropriate to meet the objectives of evaluating impacts at a program level. As explained further in Section 3.1.1, in a superposition approach differences between a baseline and forecast condition are compared without the need to accurately simulate the actual baseline or predicted heads, since these are essentially subtracted out. This approach is widely used in impact assessment, and tends to reduce the effect of model uncertainty on model outputs.

    - Extensive data compilation was undertaken, but it is believed that significant additional data exist that were not obtained from stakeholders, and/or were not able to be compiled within the limitations of the project. This means that while the model is sufficiently detailed and accurate to meet the objectives of a program-level impact analysis, further refinement is possible and necessary for construction of subbasin-scale models to support GSP development.

    - Improvements in model calibration can be achieved by varying a number of different parameters in non-unique ways; however, when the data used to build a model are uncertain, more "precise" calibration will not necessarily mean a model is a more "accurate" representation of the actual hydrogeologic system. In recognition of this fact, model calibration was continued as long as it was supported by available data or justified by a

[1] Specifically, the Central Valley Hydrologic Model (CVHM) and the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), respectively. See USGS, 2009 and DWR, 2013b.

conceptual model of how the aquifer should behave. Further calibration was not considered prudent at this point, or necessary to meet the model objectives.

## 1.3 Acknowledgements

Development of the SCHM was partially funded by a grant from the DWR under the Sustainable Groundwater Planning Grant program, which was approved by voters in the state as part of Proposition 1 in November 2014. Local matching funds were provided by the following entities:

| | | |
|---|---|---|
| Stanislaus County | City of Patterson | Oakdale Irrigation District |
| Rock Creek Water District | City of Modesto | City of Newman |
| Eastside Water District | City of Hughson | City of Turlock |
| City of Waterford | City of Riverbank | Modesto Irrigation District |
| City of Ceres | Agricultural Preservation Alliance | West Stanislaus Irrigation District |
| City of Oakdale | Patterson Irrigation District | Turlock Irrigation District |

The following people provided key input into development of the SCHM:

- Bob Abrams was instrumental in developing the model concept, acted as lead modeler in the early phases of model development, and provided guidance and supervision throughout the modeling process;
- Gerry O'Neil assisted with the development of model inputs for municipal wells, evaluation of water budgets, and adjustment of boundary heads;
- Nick Anchor, Juliet Hutchins and Claudia Corona compiled and evaluated the data on which the model is based and constructed the model;
- Surface water hydrology, precipitation and climate data were evaluated and provided by Sujoy Roy, PhD and John Rathe of Tetra Tech;
- Advice, guidance and review regarding the hydrogeologic setting and modeling approach were provided by Stephen Carlton of Tetra Tech;
- Charlie Brush and Can Dogrul of the DWR's Groundwater Modeling Branch provided invaluable assistance during construction of the model; and
- Walter Ward, Stanislaus County Water Resources Manager, provided key direction and review, and facilitated coordination of the work with the local groundwater management community.

## 1.4 Stakeholder Engagement and Outreach

To meet the modeling objectives and facilitate a collaborative and transparent process, coordination with regional water management agencies and other stakeholders was conducted. The County engaged in regular communications and shared regional data with Participating Stakeholders and via the Water Advisory Committee (WAC) and Technical Advisory Committee (TAC). Two regional modeling workshops were convened to discuss the project with regional stakeholders from areas within the model domain and adjacent areas in San Joaquin and Merced Counties. Additional outreach, consultation, and data exchange occurred as requested by individual stakeholders to facilitate regional coordination, data sharing, dialog regarding issues, opportunities, data gaps, and priorities important to groundwater management planning. An online repository of available data relevant to groundwater modeling and management in the region was shared with participating stakeholders and is publicly available.

## 1.5 Organization

This TM includes the following sections:

- Section 1, Introduction, which presents the project background, identifies objectives, provides acknowledgements, and stakeholder engagement and outreach activities.
- Section 2, Hydrogeologic Setting and Background, which summarizes information regarding the groundwater subbasins underlying the county that is pertinent to understanding the hydrogeology of the County as it pertains to the SCHM.
- Section 3, Model Development, which describes the approach taken to develop the SCHM, including the concept and approach, code selection, discretization, boundaries, sources and sinks, parameterization, time period, initial conditions, and historical water budget inputs.
- Section 4, Calibration, which summarizes the approach and methods used to calibrate the SCHM, including development of calibration datasets, adjustments to the model water budget, diversions, loss factors, land-use-based water budget data, small watersheds, streambed conductance, lateral and vertical hydraulic conductivity, and discusses the results.
- Section 5, Sensitivity Analysis, which evaluates the sensitivity of model response to changes in aquifer lateral hydraulic conductivity, aquitard vertical hydraulic conductivity, aquifer storage coefficients, and evapotranspiration.
- Section 6, Model Forecasts, which summarizes the approach used in applying the model to forecasting future groundwater conditions, and discusses the results of four future scenarios, including high demand increase, low demand increase, discretionary well permitting under the Ordinance, and enhanced recharge.
- Section 7, Conclusions and Recommendations, which summarizes the conclusions and recommendations resulting from development, calibration and application of the SCHM.
- Section 8, References, which lists the references cited in the TM.

# 2.0 HYDROGEOLOGIC SETTING AND BACKGROUND

## 2.1 Overview

### 2.1.1 Water Use in the SCHM

Stanislaus County relies on the conjunctive use of surface water and groundwater to meet a variety of water demands. The Stanislaus and Tuolumne Rivers are an important agricultural and municipal water supply sources to the county via diversions that occur under senior water rights held by Modesto Irrigation District, Oakdale Irrigation District and Turlock Irrigation District (Figure 2-1). These districts deliver water to their agricultural and municipal customers through locally developed and financed water projects. Several public water agencies also divert at least a portion of the water they deliver from the San Joaquin River, for example El Solyo Water District, Patterson Irrigation District and Westside Irrigation District. Additional riparian and appropriative water rights holders near these rivers divert water for local use. The California Aqueduct and Delta Mendota Canal skirt the western edge of the San Joaquin Valley and also provide water to several public water agencies, for example Central California Irrigation District, Del Puerto Water District, Oak Flat Water District, Patterson Irrigation District and Westside Irrigation District.

Groundwater is the predominant source of municipal water in the county, although surface water makes up a growing percentage of the municipal water supply, and additional projects to provide surface water for municipal use are being planned. Throughout most of the county, groundwater is used conjunctively with surface water as an irrigation water supply. Generally, in areas that receive surface water deliveries, groundwater is used as a supplemental irrigation supply during times of surface water shortage. This conjunctive use pattern, combined with deep percolation of applied water to recharge groundwater supplies, has resulted in generally stable groundwater levels over the long term. A few areas rely primarily on groundwater as an irrigation water supply. These areas include, for example, Eastin Water District, Eastside Water District and the unincorporated areas of the county that are located outside of the boundaries of existing public water agencies. Groundwater resources in these areas are more vulnerable to long term stress and depletion; however, enhanced groundwater recharge and other means of relieving stress on groundwater resources are being investigated in these areas.

Due to regulatory restrictions associated with pumping water through the Sacramento-San Joaquin Delta and recent drought conditions, surface water deliveries from the state and federal water projects to water agencies west of the San Joaquin River have been significantly less than their contract allocations. For example, during the last seven years, Del Puerto Water District received 10 percent (%) (2009), 80% (2010), 45% (2011), 40% (2012), 20% (2013), 0% (2014), and 0% (2015) of its contract allocation. In addition, irrigation districts east of the San Joaquin River have not been able to deliver their full allocations during the drought. The affected water districts have actively engaged in local, regional, and statewide efforts to secure additional water supplies as needed to help meet customer demand; however, in some cases landowners have relied on the fallowing of productive lands or turned to groundwater for irrigation supplies, where available.

### 2.1.2 Groundwater Hydrology

Stanislaus County is underlain by the Delta-Mendota, Eastern San Joaquin, Modesto, and Turlock groundwater subbasins of the San Joaquin Valley Groundwater Basin, as shown in Figure 2-2. Data regarding the groundwater subbasins in Stanislaus County is summarized in Table 2-1, below.

**Table 2-1: Summary of Stanislaus County Groundwater Subbasins**

| Groundwater Subbasin (DWR Basin Number) | Approximate Area | CASGEM Priority | Critical Overdraft Listing |
|---|---|---|---|
| Eastern San Joaquin Subbasin (5-22.01) | 1,105 mi$^2$ (707,000 acres, including areas outside the county) | High | Listed |
| Modesto Subbasin (5-22.02) | 385 mi$^2$ (247,00 acres, entirely within the county) | High | No |
| Turlock Subbasin (5-22.03) | 542 mi$^2$ (347,000 acres, including areas outside the county) | High | No |
| Delta-Mendota Subbasin (5-22.07) | 1,170 mi$^2$ (747,000 acres, including areas outside county) | High | Listed |

Sources:
California Department of Water Resources (DWR), 2003. *California's Groundwater, Bulletin 118.* Last update for Eastern San Joaquin, Turlock, and Delta-Mendota Subbasins: 2006; Modesto Subbasin: 2004.
DWR. 2016. *Water Management Planning Tool.* Website: http://water.ca.gov/groundwater/boundaries.cfm. Accessed July 12, 2017.

Groundwater in most of the county has been sustainably managed for many years through conjunctive use with surface water under groundwater management plans that are being implemented by the San Luis and Delta-Mendota Water Users Authority (SLDMWUA), the STRGBA, and the TGBA. Nevertheless, all four subbasins have experienced storage depletion and other stresses resulting from conditions of drought. Particular current concerns include new groundwater demand to supply the conversion of rangeland to irrigated agricultural production in the eastern portion of the county, and increased reliance on groundwater in the western portion of the county in areas where surface water deliveries have been curtailed due to the drought and changing surface water allocations. In addition, the Eastern San Joaquin Subbasin and the Delta-

Mendota Subbasin, portions of which underlie the county, are designated as critically overdrafted[2] by the DWR as a result of overdraft conditions and subsidence outside the county.

## 2.2 Understanding of Hydrogeologic Setting

Aquifer systems in the San Joaquin Valley Groundwater Basin (SJVGB) consist mostly of continental sediments derived from erosion of the Sierra Nevada to the east and the Coast Ranges to the west, and deposited in the valley. The alluvial aquifer system, much of which occurs as fan deposits, consists of a complex set of interbedded aquifers and aquitards that function regionally as a single water-yielding system. The aquifers are relatively thick, with the upper approximately 800 feet providing the primary source of groundwater supply in the area. Aquifer materials consist of gravel and sand, which become increasingly interbedded with fine-grained silt, clay, and lakebed deposits toward the center of the valley. Regionally, the aquifer system of the SJVGB can be divided into an upper unconfined to semi-confined aquifer system, a series of geographically extensive confining clay layers, and a deep confined aquifer system that occupies the central portions of the basin. Toward the center of the valley, the distal, finer-grained facies of the alluvial deposits are interfingered and interbedded with flood plain and basin deposits. Buried river-channel deposits occur in the alluvial fan deposits at the margins of the valley and along Pleistocene and modern river courses (DWR, 2013a).

The principal water-bearing formations on the east side of SJVGB include the semi-consolidated to consolidated Mehrten Formation (Miocene-Pliocene), the semi-consolidated to unconsolidated Turlock Lake Formation (Plio-Pleistocene),[3] the unconsolidated Riverbank and Modesto Formations (Pleistocene), and the overlying unconsolidated Holocene Alluvium and Basin Deposits. These sedimentary deposits dip gently westward and increase in thickness with distance from the Sierra Nevada foothills and from north to south along the valley axis. Aquifers in these deposits tend to be unconfined to semi-confined near the valley margin, grading to semi-confined and confined near the valley axis (USGS, 2004b; DWR, 2013a).

The principal water-bearing formation on the west side of the SJVGB is the Plio-Pleistocene Tulare Formation, which increases in thickness eastward away from the Coast Range to a maximum thickness of approximately 1,400 feet near the valley axis (SLDMWUA, 2011). The Tulare Formation consists of alluvial deposits separated by a series of fine-grained lacustrine deposits. It is broadly separated into an upper unconfined to semi-confined aquifer and a lower confined aquifer. The unconfined and confined aquifer systems are separated by a regionally extensive lacustrine unit in the upper Tulare Formation known as the Corcoran Clay, which is important throughout the SJVGB (USGS, 2004b; DWR, 2013a).[4]

[2] The DWR has adopted the following definition of critical overdraft: "A basin is subject to critical conditions of overdraft when continuation of present water management practices would probably result in significant adverse overdraft-related environmental, social, or economic impacts" (DWR Bulletin 118-80).

[3] Some workers have mapped the Turlock Lake Formation as transitioning to the Plio-Pleistocene Laguna Formation north of Oakdale.

[4] The Corcoran Clay is also reported as a member of the Turlock Lake Formation, which is coeval and interfingered with the Tulare Formation near the center of the SJVGB (USGS, 2004b).

### 2.2.1 Eastern San Joaquin Groundwater Subbasin

The Eastern San Joaquin Groundwater (SJGW) Subbasin underlies the "northern triangle" of Stanislaus County. Topographically, this area is characterized by low, rolling hills on the eastern flank of the San Joaquin Valley. It is bounded to the south by the Stanislaus River and to the east by low-permeability bedrock formations of the Sierra Nevada. To the north and west it extends outside the county boundaries into San Joaquin County. A small portion of the Eastern SJGW Subbasin also extends into Calaveras County to the east. Woodward Reservoir is located in the south-central portion of the northern triangle, and the Calaveras River is located near its northern apex.

Groundwater in this portion of the subbasin occurs primarily in the Mehrten Formation under unconfined to semi-confined conditions. The southeastern portion of this area is also underlain by the Turlock Lake, Laguna, and Riverbank Formations, and by valley-fill alluvium near the Stanislaus River. These units supply more limited quantities of groundwater. The Stanislaus River in this area is groundwater-connected and includes both gaining and losing reaches (USGS, 2004b; SWRCB, 2012).

A portion of the area southwest of Woodward Reservoir is served by surface water from the Oakdale Irrigation District; however, groundwater is the primary water source for most of the remaining portion of the Eastern SJGW Subbasin that underlies the County. Most high-capacity irrigation wells in the area are completed in the Mehrten Formation; whereas the Turlock Lake Formation, Riverbank Formation, and valley-fill alluvium primarily serve as the water supply for lower-capacity and domestic wells.

The lack of current surface-water supply options in the eastern portions of the County, coupled with agricultural land conversion trends that are served almost exclusively by local groundwater extraction, have placed significant stress on groundwater resources in the portion of the Eastern SJGW Subbasin underlying the County. Because economic pressures toward land conversion to predominantly permanent crops are ongoing, these groundwater stresses may be expected to continue. Groundwater monitoring data are limited in this area; however, information compiled by the County suggests that groundwater levels have fallen in some areas by tens of feet in recent years. At this time, available data are insufficient to assess long-term trends in much of this area.

In 2015, the County registered with the DWR to be the California Statewide Groundwater Elevation Monitoring (CASGEM) monitoring entity for that portion of the Eastern SJGW Subbasin that lies within the County's boundaries, and submitted a monitoring plan that was accepted by DWR. Stanislaus County is coordinating monitoring activities in this area with Oakdale Irrigation District, Rock Creek Water District, and private land owners. The public agencies involved in groundwater management within the eastern portion of the Eastern San Joaquin Groundwater Subbasin, including the northern triangle area, have formed the Eastside San Joaquin Groundwater Sustainability Agency to address compliance with the SGMA. The locations of water agencies in this effort are shown in Figure 2-1.

### 2.2.2 Modesto Groundwater Subbasin

The Modesto Subbasin is bounded to the south by the Tuolumne River, to the north by the Stanislaus River, to the west by the San Joaquin River, and to the east by low-permeability bedrock formations of the Sierra Nevada. The subbasin lies entirely within the County. Topography ranges from gently rolling hills in the eastern portion of the subbasin to alluvial plains in the central and western portions. Modesto Reservoir is located in the rolling topography in the eastern portion of the subbasin, near the contact between the Mehrten Formation and the younger alluvial formations.

Groundwater in the eastern portion of the subbasin occurs primarily in the Mehrten, Turlock Lake, Riverbank, and Modesto formations under unconfined to semi-confined conditions. In the central and western portions of the subbasin, an unconfined to semi-confined aquifer system occurs above the Corcoran Clay in the Modesto and Riverbank Formations and Holocene alluvial deposits. Confined aquifers occur in the Turlock Lake Formation and Mehrten Formation below the Corcoran Clay. Groundwater production wells are completed in both the confined and unconfined aquifer systems. The Stanislaus and Tuolumne Rivers are groundwater-connected, and include both gaining and losing reaches (USGS, 2015; TGBA, 2008).

Agricultural water demand in the central and western portions of the subbasin are primarily served by surface-water deliveries from Modesto Irrigation District and Oakdale Irrigation District, and to a lesser extent by groundwater extraction. Municipal water demand is met with a combination of surface water and groundwater supplied by the Cities of Modesto, Oakdale, Riverbank, and Waterford. The central and western portions of the Modesto Subbasin have a history of successful conjunctive use of groundwater and surface water that spans several decades, as evidenced by long-term well hydrographs indicating groundwater levels have generally recovered after periods of drought. The eastern portion of the subbasin is served almost exclusively by groundwater derived from the Mehrten Formation. Recent groundwater-level declines in portions of the basin that have been monitored under the CASGEM program.

As discussed above, the lack of current surface-water supply options in the eastern portions of the subbasin, coupled with agricultural land conversion trends that are served almost exclusively by local groundwater extraction, have placed significant stress on groundwater resources in the Modesto Subbasin. Because economic pressures toward land conversion to predominantly permanent crops are ongoing, these groundwater stresses may be expected to continue. Groundwater monitoring data are limited in the eastern portion of the County. At this time, available data are insufficient to assess long-term trends in much of this area.

Additional stress on the entire subbasin may occur if, as is currently proposed, the state mandates minimum unimpaired flow requirements for the Stanislaus and Tuolumne Rivers as part of the Bay-Delta Water Quality Control Plan Amendment process. Under these conditions, it is anticipated that less water will be available for diversion to meet existing agricultural and municipal water demands. The shortfall in demand is expected to be met through additional groundwater pumping. This scenario will potentially result in significant additional stress throughout the subbasin.

The Stanislaus and Tuolumne Rivers Groundwater Basin Association (STRGBA) is registered with the DWR to be the CASGEM monitoring entity for the Modesto Subbasin. This group, consisting of the Cities of Modesto, Riverbank, Waterford and Oakdale, as well as Oakdale Irrigation District (OID), Modesto Irrigation District (MID) and Stanislaus County, has recently organized to form the STRGBA GSA to address compliance with the SGMA. The locations of water agencies in this effort are shown in Figure 2-1. Stanislaus County coordinates groundwater-related activities in the subbasin with these entities, and shares information with them through direct communication and via the WAC and TAC, and as a member of the GSA.

### 2.2.3 Turlock Groundwater Subbasin

Turlock Subbasin is bounded to the south by Merced River, to the north by Tuolumne River, to the west by San Joaquin River, and to the east by low-permeability bedrock formations of the Sierra Nevada; the subbasin extends southward from Stanislaus County into Merced County (Figure 2-1). Topography ranges from gently rolling hills in the eastern subbasin to alluvial plains in the central and western portions. Turlock Lake is located in the rolling topography in the eastern portion of the subbasin.

Similar to the Modesto Subbasin, groundwater in the eastern portion of the Turlock Subbasin occurs mainly in the Mehrten, Turlock Lake, Riverbank, and Modesto formations under unconfined to semi-confined conditions. An unconfined to semi-confined aquifer system occurs in the central and western portions of the subbasin in the Modesto and Riverbank Formations and Holocene alluvial deposits overlying the Corcoran Clay, and confined aquifers occur in the Turlock Lake Formation and Mehrten Formation below the Corcoran Clay. Groundwater production wells are completed in both the confined and unconfined aquifer systems. The Tuolumne River is groundwater-connected and includes both gaining and losing reaches (SWRCB, 2012; TGBA, 2008).

Agricultural water demand in the western and central portions of the subbasin is served primarily by surface-water deliveries from Turlock Irrigation District and to a lesser extent by groundwater extraction. Within Eastside Irrigation District, irrigation water demand is met entirely by groundwater pumping. Municipal water demand is met via groundwater supplied by the Cities of Turlock, Ceres, Hughson and Delhi, and the Denair Community Services District. New projects are proposed that would increase reliance on conjunctive use of groundwater and surface water. The central and western portions of the basin have a history of successful agricultural conjunctive use of groundwater and surface water that spans several decades, as evidenced by long-term well hydrographs indicating groundwater levels have recovered after periods of drought. The eastern portion of the subbasin is served almost exclusively by groundwater from the Mehrten Formation and overlying alluvial aquifers. Recent groundwater-level declines in portions of the basin that have been monitored under the CASGEM program.

As discussed above, the lack of current surface-water supply options in the eastern portions of the subbasin, coupled with agricultural land conversion trends that are served almost exclusively by local groundwater extraction, has placed significant stress on groundwater resources in the Turlock Subbasin. Because economic pressures toward land conversion to predominantly permanent crops are ongoing, this groundwater stress may be expected to continue. Groundwater monitoring data in the vicinity of Eastside

Irrigation District indicate groundwater-level declines of over 40 feet within the last 10 years with a resulting groundwater gradient reversal near the Tuolumne River (TGBA, 2008). Data are limited further east, and at this time, available data are insufficient to assess long-term trends.

Additional stress on the entire subbasin may occur if, as is currently proposed, the state mandates minimum unimpaired flow requirements for the Stanislaus and Tuolumne Rivers as part of the Bay-Delta Water Quality Control Plan Amendment process. Under these conditions, it is anticipated that less water will be available for diversion to meet existing agricultural and municipal water demands. The shortfall in demand is expected to be met through additional groundwater pumping. This scenario will potentially result in significant additional groundwater stress throughout the subbasin.

The Turlock Groundwater Basin Association (TGBA) is registered with the DWR to be the CASGEM monitoring entity for the Turlock Subbasin. The western members of this group, consisting of the Cities of Turlock, Modesto, Ceres, Hughson and Waterford, as well as Turlock Irrigation District (TID), Delhi County Water District, Hilmar County Water District, Stevinson Water District, Merced Irrigation District, Merced County, Stanislaus County, Keyes Community Services District and Denair Community Services District have recently organized to form the West Turlock Subbasin GSA to address compliance with the SGMA. The eastern members of TGBA, including Eastside Water District (EWD), Ballico Cortez Water District, Merced Irrigation District, Merced County, Stanislaus County and the City of Turlock have formed the East Turlock Subbasin GSA. The locations of water agencies in this effort are shown in Figure 2-1. Stanislaus County coordinates groundwater-related activities in the subbasin with these entities, and shares information with them through direct communication and via the WAC and TAC, and as a member of the GSAs in the subbasin.

### 2.2.4 Delta Mendota Groundwater Subbasin

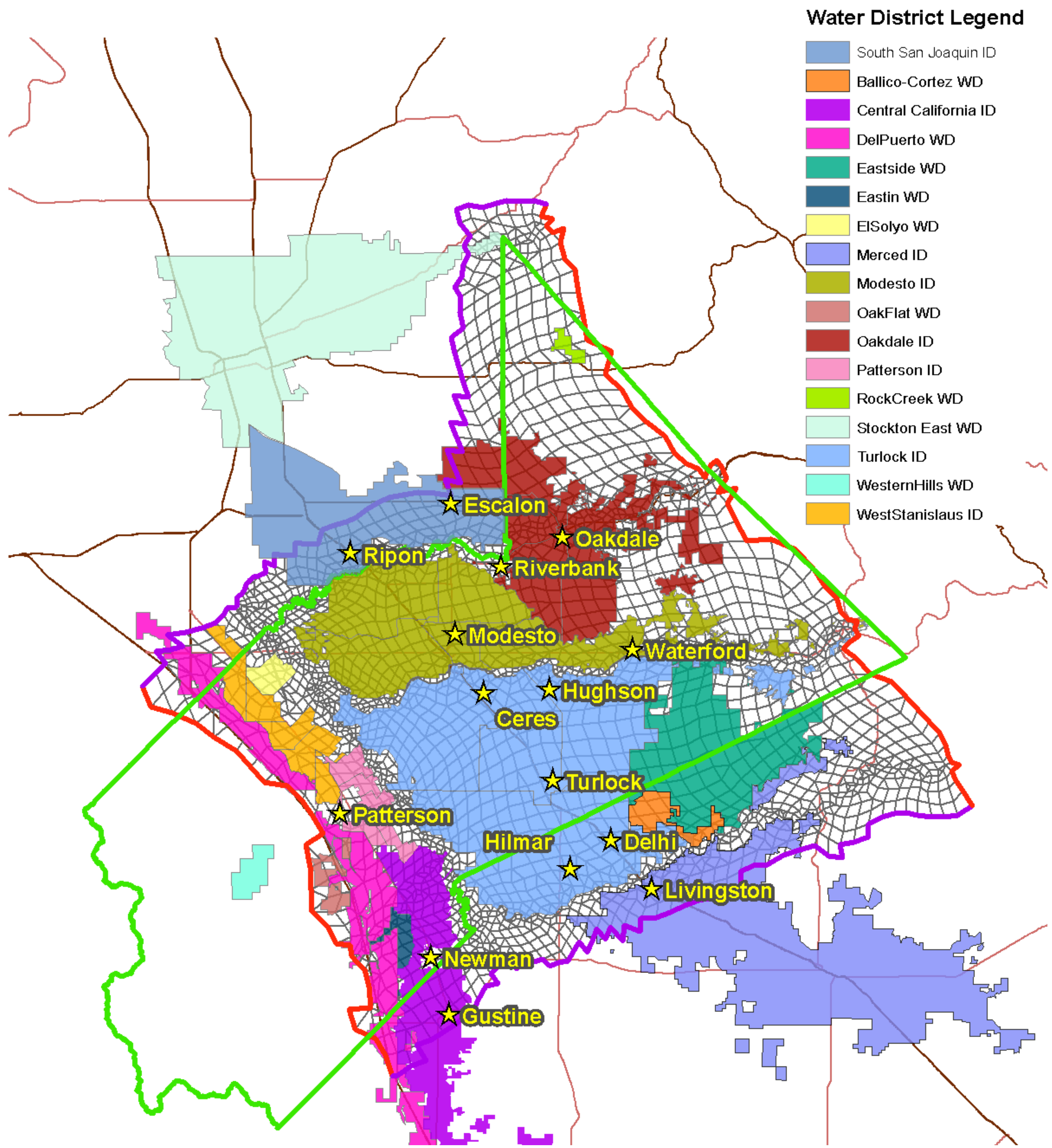
Within Stanislaus County, the Delta Mendota Subbasin is bounded to the east by the San Joaquin River and to the west by low-permeability bedrock formations of the Coast Ranges. The subbasin extends southward from the northern boundary of Stanislaus County along the west side of San Joaquin Valley for approximately 80 miles, and crosses a total of five counties. The western margin of the subbasin consists of low hills and dissected alluvial fans at the foot of the Coast Range. A short distance to the east, elevations drop off into alluvial and flood plains associated with the San Joaquin River. The Delta Mendota Canal and California Aqueduct run along the western margin of the subbasin.

Groundwater in the Delta Mendota Subbasin occurs in the Tulare Formation and overlying Holocene Alluvium. The top of the Corcoran Clay occurs at depths of approximately 100 to 300 feet below ground surface (bgs) in this area, and extends from near the western margin of the subbasin to beneath the San Joaquin River. Near the western margin of the subbasin, the Corcoran Clay divides the Tulare Formation into an upper aquifer system that is unconfined to semi-confined and a lower aquifer system that is confined. The Tulare Formation extends to a depth of over 1,000 feet and includes other lacustrine clay units; however, the Corcoran Clay is the most prominent and continuous (DWR, 2013). Groundwater production wells are completed in both the unconfined and confined aquifer systems; however, most high-capacity wells extend into the confined aquifer system, beneath the Corcoran Clay. Portions of the San Joaquin River are groundwater-connected (SWRCB, 2015).

Land use overlying the Delta Mendota Subbasin is primarily agricultural, with agricultural water demand served by surface-water deliveries from Del Puerto Water District, West Stanislaus Irrigation District, and Central California Irrigation District (one of the San Joaquin Exchange Contractors), supplemented by groundwater extraction. Municipal water demand for the City of Patterson is met using groundwater.

DWR has included the Delta Mendota Subbasin on the list of critically overdrafted basins, largely due to subsidence reported outside Stanislaus County to the south (DWR, 2015a). Nevertheless, the unreliability of surface-water deliveries from the State and Federal water projects has resulted in an increase in agricultural and municipal groundwater demand. This trend is expected to continue in the future as climatic variability and environmental flow requirements continue to affect the reliability of surface-water deliveries. Groundwater levels have fallen over 40 feet in the last 10 years in the southern portion of the Delta Mendota Subbasin in Stanislaus County. In addition, active subsidence of 1 to 2.5 inches has been reported at a continuous survey station near Patterson (DWR, 2015b). DWR has designated the Delta Mendota Subbasin as having a high potential for future subsidence.

Groundwater monitoring and management in the Delta Mendota Subbasin have been implemented through the San Luis & Delta Mendota Water Users Authority (SLDMWUA), of which Del Puerto Water District, West Stanislaus Irrigation District, Patterson Irrigation District, and Central California Irrigation District are members. Water management entities within the portion of the Delta-Mendota Subbasin that lies in the SCHM have formed five separate GSAs to implement compliance with the SGMA. These include the City of Patterson, Patterson Irrigation District, Del Puerto Water District, West Stanislaus Irrigation District, and the Northwestern Delta-Mendota GSA, which consists of several cooperating entities. The locations of water agencies in these efforts are shown in Figure 2-1. Stanislaus County coordinates groundwater-related activities in the subbasin with these entities, and shares information with them through direct communication and via the WAC and TAC.




Notes:
ID = irrigation district
WD = water district

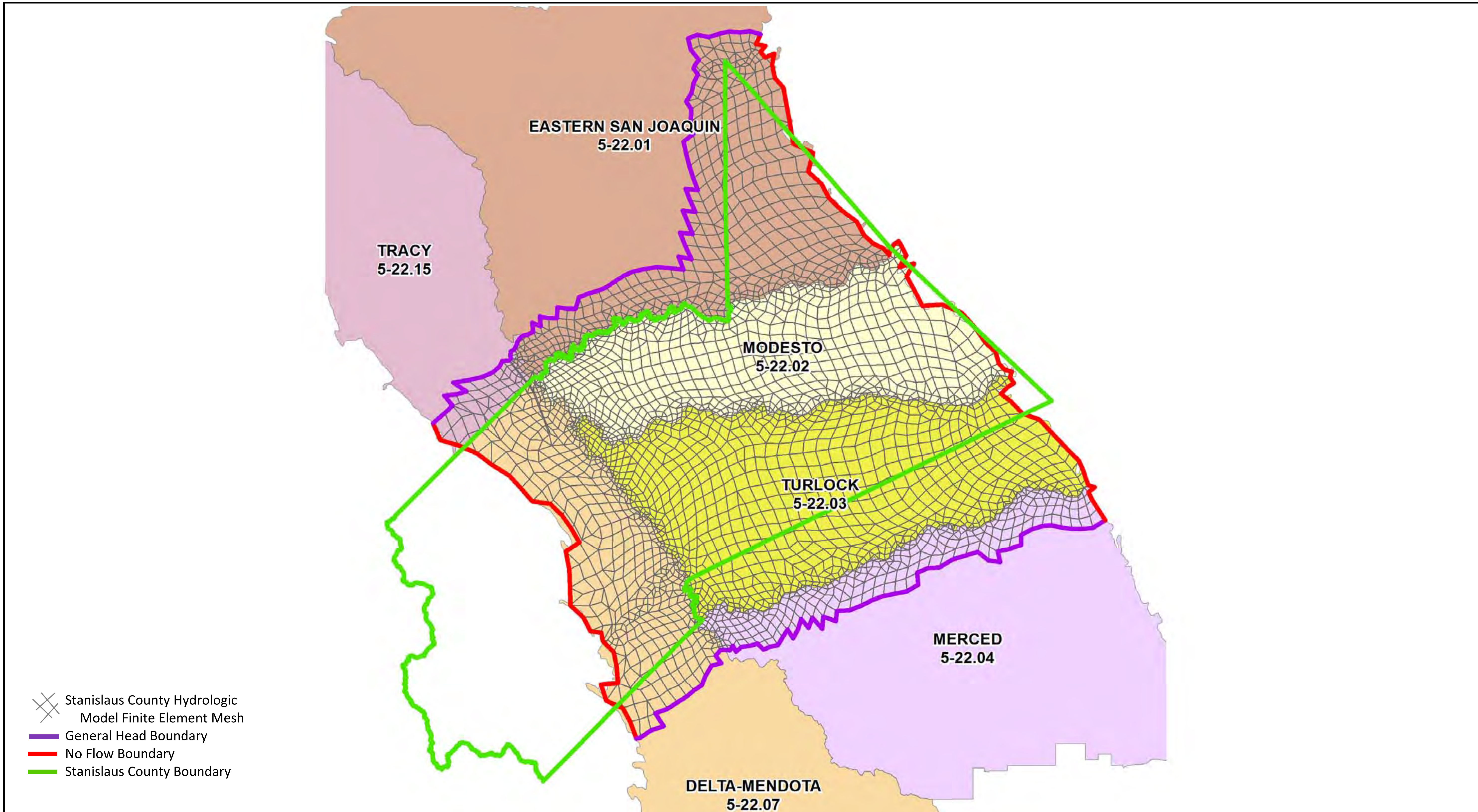
JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| *STANCO.002* | *11/17/17* | *JH* | *MT* |

*FIGURE 2-1*

***Locations of Irrigation and Water Districts within SCHM Study Area***




JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/10/17 | JH | MT |

*FIGURE 2-2*

***Groundwater Subbasins and SCHM Discretization***

# 3.0 MODEL DEVELOPMENT

## 3.1 Model Conceptualization and General Approach

### 3.1.1 Approach

Development of the SCHM followed the general groundwater model development steps laid out by Anderson and Woessner (2002), in general conformance with the Modeling Plan (JJ&A, 2016b):

- A conceptual model was developed based on the conceptual understanding summarized below in Section 3.1.2.
- An existing model and modeling code were selected for development of the SCHM as discussed further in Section 3.2, consistent with Modeling Objective 4 (Section 1.2).
- The model grid, boundary, and initial conditions were selected based on the conceptual model and available information from prior modeling in the County, as discussed in Section 3.3 through 3.8.
- The model was calibrated, and the accuracy of simulation results was improved by analyzing the calibration results and identifying aquifer parameters and inputs that needed to be modified or additional processes that needed to be considered or refined. This was achieved by implementation of iterative calibration and sensitivity analysis.
- The calibrated model was used to predict changes in groundwater elevation, storage, and flow as a result of implementing discretionary well permitting under the Ordinance as well as a reasonable range of water demand changes based on future groundwater demand projections.

Consistent with the modeling objectives described in Section 1.2, a superposition modeling approach was used for impact assessment. Superposition or impact modeling is a robust modeling approach which focuses on evaluation of drawdown as opposed to actual hydraulic head, and allows the modeler to focus more on the evaluation of the changes introduced by a project, rather than the simulation of past or future groundwater levels (Reilly, Franke and Bennett, 1987). The use of superposition modeling in hydrogeologic literature is well established, and this approach has been widely used to evaluate the impacts of water supply pumping. The SCHM consists of (1) a calibrated historical model that simulates groundwater and surface water conditions from Water Year (WY) 2000 to WY 2015,[5] (2) a baseline forecast model and a set of forecast scenarios from WY 2016 to WY 2042 to establish the aquifer response under a reasonable range of possible water management scenarios,[6] and to evaluate the effects of groundwater withdrawal from new wells that will potentially be permitted under the Ordinance.

---

[5] This time period includes a range of climatic/groundwater conditions, which is necessary for meaningful model calibration.

[6] Although 2042 represents the time when all groundwater sub-basins within the County must be managed sustainably as defined in SGMA, and is thus an appropriate time frame for the PEIR impact evaluation, the specific requirements of GSPs necessary to achieve this objective remain to be developed. GSAs to be formed within the County by June 2017 will be vested with the responsibility of developing GSPs. As such, the specific groundwater management strategies necessary to achieve sustainable groundwater management under SGMA are not considered reasonably foreseeable at this time, and will not be evaluated in the PEIR.

### 3.1.2 Conceptual Understanding

The conceptual model for construction of the SCHM consists of the principal components summarized below.

- The area of interest for this study is the portion of the San Joaquin Valley Groundwater Basin that underlies the County. This area includes all of the Modesto Subbasin and portions of the Eastern San Joaquin and Delta Mendota Subbasins. In addition, all of the Turlock Subbasin, including portions that lie in Merced County to the south, is included in the Study Area (Figure 2-1).
- Low permeability bedrock of the Sierra Nevada and the Diablo Range from the eastern and western boundaries of the basin, respectively.
- A series of broad, coalescing alluvial fans along the western slope of the Sierra Nevada foothills contain aquifers with unconfined to semi-confined conditions and represent a recharge zone (forebay) for deeper confined aquifers closer to the center of the basin. In the eastern portion of this area, Miocene fluvio-volcanic deposits of the Mehrten Formation contain productive aquifers, but the presence of well-developed duripan soils limits local recharge.
- A narrow band of alluvial fans along the eastern margin of the Diablo Range behaves in a similar fashion, functions as a region for local mountain-front recharge, and contains aquifers with unconfined to semi-confined conditions.
- A central region with an upper unconfined to semi-confined aquifer system that is separated by the Corcoran Clay from an underlying confined aquifer system underlies the center of the basin, where deposits from the Sierra Nevada and the Coast Range interfinger.
- The freshwater-bearing valley-fill sediments are underlain by marine sedimentary deposits that contain brackish water at depths between about 900 to 1,500 feet below ground surface.
- Groundwater-connected streams and rivers, including the Stanislaus, Tuolumne, and Merced Rivers, enter the basin from the east and merge with the groundwater-connected San Joaquin River, which flows northward along the valley axis. The Calaveras River crosses the northern triangle portion of the SCHM.
- Reservoirs along the Stanislaus and Tuolumne River are located in the proximal alluvial fan areas near the eastern margin of the basin.
- Groundwater flow, in the absence of groundwater pumping, is generally away from the Sierra Nevada on the east and the Diablo Range on the west, toward the San Joaquin River in the center of the valley, and northward along the San Joaquin River out of the County.

## 3.2 Modeling Code Selection

### 3.2.1 Available Models

Several existing groundwater flow models have been developed that cover all or portions of Stanislaus County and are pertinent to the proposed modeling effort:

- The Merced-Stanislaus (MERSTAN) model was developed by USGS in 2015, and covers portions of three of the four groundwater subbasins in the County (Phillips, S.P. *et al*, 2015). It encompasses an area of about 1,000 square miles centered on the Cities of Modesto and Turlock and was developed using the MODFLOW-OWHM modeling code.
- The more generalized regional Central Valley Hydrologic Model (CVHM) developed by USGS includes all of the groundwater subbasins in the County (USGS, 2009 and 2017). The current version of CVHM was also developed using the MODFLOW-OWHM code and is currently being updated.
- The California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) was developed by DWR with the Integrated Water Flow Model (IWFM) code to evaluate groundwater and surface water management issues in the Central Valley and delta (DWR, 2013b and 2016a). The model comes in both a coarse grid version and a fine grid beta version, with the fine grid beta version improved to support evaluation of groundwater flow at a local scale. The model is currently being updated and is expected to be released in late 2017 or early 2018; however, some land use and other data utilized for the updates have been made available by the DWR.
- A three-dimensional finite element model was prepared for the Turlock Subbasin by Timothy J. Durbin as a consultant for TGBA and TID using a customized version of the FEMFLOW3D modeling code (the TID Model) (Durbin, 2008). This model was recently used by TGBA for a study in the eastern Turlock Subbasin. FEMFLOW3D is a proprietary modeling code.
- In support of its Aquifer Characterization and Recharge Project, the City of Modesto has developed a city-wide groundwater flow model with the USGS MODFLOW code, using the GMS modeling platform (the Modesto Model) (Todd and RMC, 2016). The model was extracted from the MERSTAN model to evaluate groundwater flow on a more localized level. The underlying lithology and discretization of the MERSTAN model were not changed.

### 3.2.2 Model and Code Selection

Consistent with the modeling objectives discussed in Section 1.2, the existing available models were evaluated to determine if one of them could be used as a starting point for construction of the SCHM. The MERSTAN, TID and Modesto models are not able, by themselves, to meet the modeling objectives, as they do not cover all of Stanislaus County. In addition, the TID model is based on a proprietary modeling code and therefore is not consistent with DWR guidance for development of models that would support GSPs (DWR, 2016b). Data from these models may be used to refine the SCHM, but they were not considered suitable as a starting point for model construction. The CVHM and the fine grid version of C2VSim (C2VSim-FG) are both suitable starting points for development of a model that would meet the objectives discussed in Section 1.2, and were evaluated in greater detail in the Modeling Plan (JJ&A, 2016a).

Although based on different modeling codes, C2VSim-FG and CVHM have many similarities, and use some of the same data. Both models were constructed with the objectives of understanding the water budget of the Central Valley, including groundwater/surface water interactions, irrigation demand, and changes in groundwater levels and storage. In addition, both models provide a basis for continued investigations at the local scale via the development of "child" models based on regional "parent" analysis. Of these two models, C2VSim was selected as the starting point for development of the SCHM for the following reasons:

- Planned use of C2VSim by DWR to evaluate the compliance of GSPs with the requirements of SGMA;
- It was anticipated that ongoing efforts by DWR would result in a greater level of support and beta data availability than the CVHM;
- Compatibility with the CalSim and CalLite surface water models and related diversion data;
- Compatibility with groundwater modeling efforts to the north and south of the SCHM in San Joaquin and Merced Counties, which are developing models based on the C2VSim modeling code, IWFM; and
- CVHM has limited options for pre- and post-processing tools that are publicly available; whereas, several Excel and GIS pre- and post-processing tools are available for C2VSim.

When the decision was made to select C2VSim as the starting point for development of the SCHM, it was expected that a calibrated update to the C2VSim-CG model would be released in early 2017, and an updated beta version of C2VSim-FG would also be available. Both models were to be upgraded to the latest version of the IWFM modeling code (IWFM version 2015), which includes several significant improvements over the previous version, IWFM 3.02. Unfortunately, DWR's updates of C2VSim took longer than originally anticipated, and are now expected to be released in late 2017 or early 2018, as of the date of this report. Therefore, the SCHM was constructed using the previously released beta version of C2VSim-FG, which is based on the IWFM 3.02 modeling code and includes historical data through WY 2009. DWR was able to make available several IWFM-formatted datasets, including updated precipitation data and land use data based on updated crop surveys with data through WY 2015, which were able to be incorporated into the SCHM.

## 3.3 Model Discretization

### 3.3.1 Finite Element Mesh

The finite element mesh for the SCHM was extracted from the C2VSim-FG model and is shown in Figure 2-1. The mesh includes a total of 3,105 elements and 2,923 nodes, which average approximately 0.6 miles across and range in size from 17 to approximately 1,500 acres within the SCHM domain. The extracted finite element mesh for the SCHM covers Stanislaus County and the entirety of the Turlock Subbasin in Stanislaus and Merced Counties. The mesh extends approximately 3 miles outside the boundaries of the primary model area in order to provide a buffer zone that decreases the potential for boundary effects to influence model results in the primary area of interest.

### 3.3.2 Water Budget Subregions

IWFM 3.02 utilizes water budget subregions for input of certain water budget data, including surface water diversions and land use data (e.g., crop types). In order to accept updated land use data provided by DWR, the model domain was therefore subdivided in 108 subregions to correspond approximately with the C2VSim coarse grid elements for which the land use data were provided. The subregions are shown graphically in Figure 3-1.

### 3.3.3 Layering

The SCHM retained the layering scheme of the current C2VSim model, that is, a three-layer system with a vertical conductance pseudo-layer to simulate the Corcoran Clay at the top of Model Layer 2. These layers may be described as follows:

- Layer 1 extends from the ground surface to a depth of 202 to 1,005 feet, and represents the uppermost unconfined to semi-confined aquifer system.
- Layer 2 underlies Layer 1 and ranges in thickness from 16 to 647 feet. It represents the semi-confined to confined aquifer system that underlies the basin at depth to the east and west of the Corcoran Clay subcrop area, and the lower, confined aquifer system below the Corcoran Clay.
- A vertical conductance pseudo-layer is defined at the top of Layer 2 to represent the Corcoran Clay. The vertical conductance of the layer is defined by a hydraulic conductivity multiplied by a thickness, which is set to the interpreted thickness of the Corcoran Clay where it is present, and to zero (providing no impedance) where it is not. The extent of the Corcoran Clay layer is shown on Figure 3-2.
- Layer 3 underlies Layer 2 and represents a regional deep aquifer that ranges in thickness from 30 to 1,572 feet and overlies the interpreted base of fresh water in the area. This layer is penetrated by few wells in the area, and its properties are therefore poorly documented.

## 3.4 Model Boundaries

The following boundary conditions were assigned, as shown in Figure 2-1:

- Similar to the C2VSim-FG model, the eastern and western boundaries of the model were designated as no flow boundaries along the contact between the valley-fill alluvium and relatively impermeable formations exposed in the foothills of the Sierra Nevada and the Diablo Range.
- The northern and southern model boundaries were designated as general-head boundaries, which require designation of a general head and distance to the general head. Variable flow may occur across these boundaries depending on variations in simulated hydraulic gradients over time. Time-series head values for these boundaries were initially assigned based on heads extracted from beta version of the C2VSim-FG model for WY 1991 to WY 2009. Boundary heads for WY 2010 to WY 2015 were duplicated from C2VSim data for years with similar hydrologic characteristics. These boundary heads were updated during the model calibration process as discussed in Section 4.3.1.3. The distance to the general heads was set at 1 meter.

## 3.5 Sources and Sinks

Sources and sinks were modeled as follows:

- Rivers and streams, including Merced River, Orestimba Creek, Calaveras River, Stanislaus River and Tuolumne River, were simulated using river nodes as shown in Figure 3-3. River boundary cells are a head-dependent boundary condition that allows water to enter or exit the river according to the head difference between the groundwater elevation and the surface water elevation, and in proportion to the hydraulic conductivity and thickness of the stream bed layer, which is represented by a conductance term. The stream bed conductance values from C2VSim were initially adopted for use in the model, and updated during the calibration process as discussed in Section 4.3.3.
- Small watersheds that are tributary to the model were adopted from C2VSim and refined as described in Section 3.9.3.3. They were further updated and refined during the calibration process as described in Section 4.3.2.
- Reservoirs were simulated using recharge nodes with 100 percent recoverable losses (i.e., all seepage losses remain within the model) in the footprints of the reservoirs shown in Figure 3-3. Additional information regarding the assigned recharge rates at these nodes is provided in Section 3.9.3.4. The diversion for Turlock Lake was adjusted during the calibration process to 33 percent recoverable and 67 percent non-recoverable losses.
- There are no tile drains in the current version of C2VSim within the domain of the SCHM. Tile drains are reported to be located in some areas of shallow groundwater near the San Joaquin River within TID; however, they are a relatively small component of the water budgets and information regarding the drain depths and locations was not readily available, so they were not incorporated into the model. These could be added at a later date if data regarding drain elevations and conductance values is obtained.
- Municipal pumping wells were added based on data provided by municipal water agencies or obtained from Urban Water Management Plans (UWMPs), Municipal Service Reviews (MSRs) and other sources as described in Table 3-1. The locations of these wells are shown on Figure 3-4. Additional information regarding development of the municipal pumping component of the model groundwater budget is described in Section 3.9.4.1.
- Rural domestic pumping was evaluated using the methodology described in Section 3.9.4.2, and a single surrogate well was defined in each of the 108 water-budget subregions in Layer 1 to simulate this component of the regional groundwater demand. The locations of these wells are shown on Figure 3-4.
- Recharge elements are designated in C2VSim to receive urban return flow, recoverable diversion losses, and recharge from small watershed stream inflows. These nodes were retained, except that recharge nodes for small watersheds were updated and refined during the model calibration process as described in Section 4.3.2.

## 3.6 Parameterization

The model was originally extracted with the aquifer parameter values assigned by C2VSim, which were then updated as follows:

- Spatial data (xyz) regarding the distribution of hydraulic conductivity in the MERSTAN model were extracted from that model and uploaded into the SCHM. Parameter data for the inactive portions of the MERSTAN model west of the San Joaquin River were not used, as USGS staff indicated that the data in this area were not subjected to the same level of geostatistical analysis as data east of the river, and were therefore less reliable.[7] The MERSTAN model includes 16 layers, which were assigned as follows:
    - Hydraulic conductivity values from MERSTAN Layers 1 through 7 were assigned to SCHM Layer 1;
    - Hydraulic conductivity values from MERSTAN Layer 8 represent the Corcoran Clay, and were not used;
    - Hydraulic conductivity values form MERSTAN Layers 9 through 13 were assigned to SCHM Layer 2; and
    - Hydraulic conductivity values from MERSTAN Layers 14 through 16 were assigned to SCHM Layer 3

  The hydraulic conductivities at each model node were calculated using the standard formulas for calculation of effective vertical and lateral hydraulic conductivities of heterogeneous layered systems as follows:
    - Lateral hydraulic conductivity was calculated using the following formula:

$$\boldsymbol{K_x = \sum_{i=1}^{n} \frac{k_i d_i}{d}}$$

    - Vertical hydraulic conductivity was calculated using the following formula:

$$\boldsymbol{K_z = \sum_{i=1}^{n} \frac{d}{\frac{d_i}{K_i}}}$$

- Hydraulic conductivity data estimated from 30 specific capacity tests performed on wells in the eastern foothills area of the County were used to update and adjust hydraulic conductivity values in areas east of the MERSTAN model domain using a modified nearest-neighbor geospatial analysis technique.
- Hydraulic conductivity data estimated from 23 specific capacity and aquifer pumping tests west of the San Joaquin River were similarly used to update and adjust hydraulic conductivity values in that area using a modified nearest neighbor geospatial analysis technique.

[7] Steve Phillips, USGS, personal communication, July 2017.

- The vertical hydraulic conductivity and thickness of the Corcoran Clay were used to calculate the conductance term assigned to aquitard at the top of Layer 2. To do this, the lateral extent and thickness of the Corcoran Clay reported by the USGS was used (USGS, 2012), as shown in Figure 3-2. The vertical hydraulic conductivity of the Corcoran Clay within the SCHM is not well characterized, but a reasonable range based on the literature is approximately $6.2 \times 10^{-4}$ to $3.0 \times 10^{-6}$ ft/day (USGS, 2004b; USGS, 2009). A uniform vertical hydraulic conductivity of $1 \times 10^{-5}$ feet/day was applied to the Corcoran Clay based on these values, and then adjusted as appropriate during calibration as discussed in Section 4.3.5.
- Targeted changes to the initial lateral and vertical hydraulic conductivity assignments were made during the calibration process as described in Section 4.3.4.
- The SCHM retained the aquifer specific yield, specific storage, elastic and inelastic storage coefficients, interbed thickness, minimum interbed thickness, and precompaction hydraulic head incorporated in C2VSim.

To help illustrate the above described parameterization process, the initial distribution of lateral hydraulic conductivity in SCHM Layer 1 in relation to the MERSTAN model domain, and the locations of wells for which hydraulic conductivity data were calculated is shown in Figure 3-5.

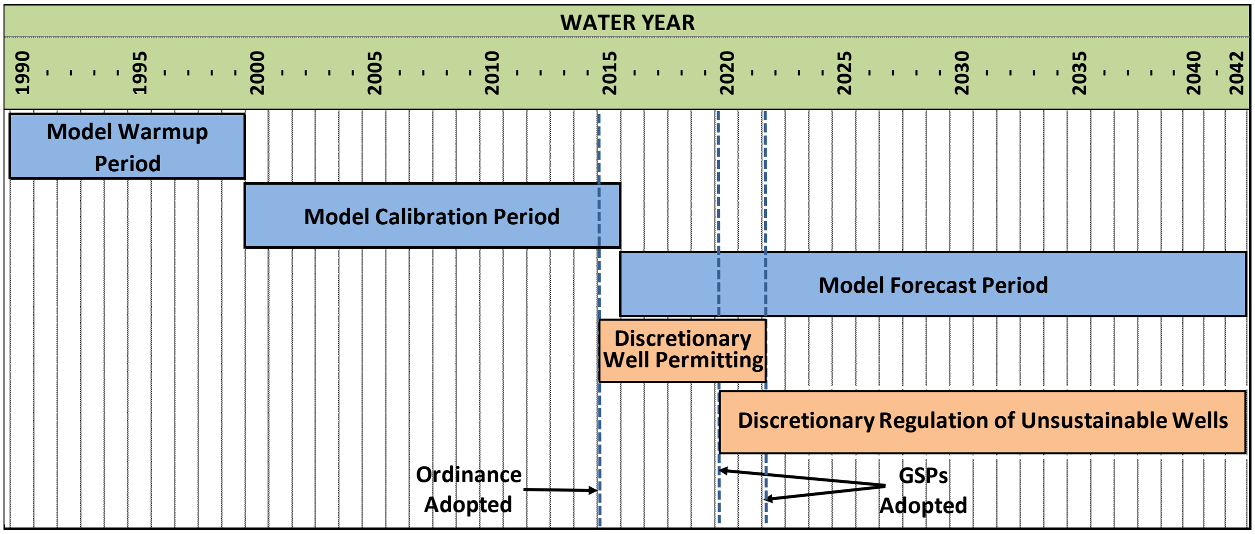
## 3.7 Model Time Period

The Ordinance was adopted in November of 2014, and the primary period of interest to be evaluated using the SCHM covers the time that discretionary well permits will be issued in unincorporated, non-district lands prior to adoption of GSPs. Adoption and implementation of GSPs will take place in the Delta Mendota and Eastern San Joaquin Subbasins beginning in 2020, and in the Modesto and Turlock Subbasins beginning in 2022. Achievement of sustainable groundwater management is required throughout the basins within 20 years after GSPs are adopted, or in 2040 and 2042, respectively. During this time, wells determined by the County to be operated unsustainably may be regulated under the Ordinance.

Based on this information, the temporal simulation periods of the model may be subdivided as shown graphically in Figure 3-6 and as described below:

- A model "warm up period" was established from WY 1991 to WY 1999 to allow the model to reach conditions that are consistent with historical water budget inputs;
- A calibration or history matching period of WY2000 to WY2015 was selected, and includes a selection of wet, dry and normal hydrologic years to allow for a robust calibration process;
- A forecast period extending from WY 2016 to WY 2042 was established to run forward simulations capable of assessing reasonably foreseeable water management and climatic trends, and evaluating the impacts of issuing discretionary well permits under the Ordinance.

**Figure 3-6: Timeline for Well Permitting Requirements Evaluated in the SCHM**




## 3.8 Initial Conditions

Starting heads for the model were initially extracted for October of 1990 (the beginning of WY 1991) after running the existing version of C2VSim from 1921 to 1990. The use of a warmup period makes the model less sensitive to the choice of initial heads. Nevertheless, after the water budget adjustments during the calibration process (Section 4.3.1), WY 1999 model heads were substituted as the initial WY 1991 heads because these were generally more closely aligned with observed heads as seen in the calibration wells reported for the model warmup period (WY 1991 to WY 1999). Historical Water Budget Data

Water budget data for the model calibration (history match) period were compiled from several sources as follows:

- The water budget data from C2VSim-FG were initially retained in the SCHM and updated when more reliable data were deemed to be available;
- Updated land use and precipitation data from WY 1991 through WY 2015 were provided by DWR from its work in updating C2VSim and were incorporated into the SCHM;
- Municipal water budget data provided by municipal water purveyors and/or data from UWMPS, MSRs and other plans and reports were incorporated into the model as described in Table 3-1 and in Sections 3.9.4.1;
- Diversion data from C2VSim were re-allocated from the six water budget subregions defined in C2VSim to the 108 water budget subregions defined in the SCHM, and updated based on information provided by agricultural water purveyors and/or data from Agricultural Water Management Plans (AWMPs), MSRs and other plans and reports as described in Table 3-2 and in Section 4.3.1.1;

- Agricultural land use and water budget data provided by agricultural water purveyors and/or data from AWMPs, MSRs and other plans and reports were used as described in Table 3-3 to refine model cropping data, the diversions listed in Table 3-2 and the diversion recoverable and non-recoverable losses (Table 3-4), allocation loss and cropping data as further described in Sections 3.9.4.3 and 4.3.1.2;
- Agricultural land use data provided by the Stanislaus County Agricultural Commissioner for non-district areas in the eastern portion of the SCHM were incorporated during the model calibration process as described in Section 4.3.1.2;
- Small watershed recharge locations and rates were refined to scale small watersheds split across the model boundaries, and were adjusted during the calibration process as discussed in Section 4.3.2;
- Stream inflows were updated for WY 2010 through WY 2015 using gaging station data; and
- River conductance values were adjusted to change the surface-groundwater interaction in some reaches during the calibration process as discussed in Section 4.3.3.

### 3.8.1 Precipitation

Updated precipitation data were obtained from DWR for WY 1991 through WY 2015 in a gridded dataset that was applied to the 108 water-budget subregions defined in the SCHM. The data were derived by DWR using the Parameter-elevation Regressions on Independent Slopes Model (PRISM), which is a climate analysis system that uses point data, a digital elevation model (DEM), and other spatial datasets to generate gridded estimates of annual, monthly and event-based climatic parameters (Daly et al., 1997 and 2004).

### 3.8.2 Stream Inflows

The major stream inflows into the SCHM were developed as follows:

- River inflows (Rim Inflows) for the Stanislaus River, Tuolumne River, Merced River, Calaveras River, and Orestimba Creek were adopted from C2VSim for WY 1991 through WY 2009, and derived from the USGS gaging station flow data for the C2VSim-assigned gaging stations for WY 2010 through WY 2015; and
- River inflows for the San Joaquin River were defined using the C2VSim river node at the river's entry point into the SCHM for WY 1991 through WY 2009; for WY 2010 through WY 2015, inflows were extrapolated based on USGS gaging station data for the San Joaquin River at Newman which were scaled based on pre-2010 correlation with the SCHM inflow data.

### 3.8.3 Recharge

Recharge, or deep percolation, is calculated in IWFM 3.02 by routing excess water from land surface processes such as land use (agricultural, urban, native vegetation or riparian), precipitation, irrigation, conveyance losses, runoff, return flow and surface water, as infiltration into a root-zone model, from which it is routed downward through the vadose zone model and into groundwater based on soil moisture content and field capacity (or directly into groundwater when it is shallow enough) (DWR, 2013c). The land surface, root zone and vadose zone processes are controlled by a number of sub-processes, water budget and soil property variables that can be defined in the model input files. The reader is referred to the document DWR 2013b for a more complete discussion regarding the model's approach to the generation and routing of recharge.

#### 3.8.3.1 Areal Recharge from Precipitation

Areal infiltration into the root zone in IWFM 3.02 is calculated on a subregional level based on precipitation, soil properties and designated elemental land use. Precipitation inputs into the SCHM were updated based on data provided by the DWR as described in Section 3.9.1. The remaining factors used by the surface and land use processes, root zone model and vadose zone model to calculate areal recharge were adopted unchanged from C2VSim.

#### 3.8.3.2 Streams

Recharge from streams (or discharge to streams) in IWFM 3.02 is governed by defined streambed geometry and conductance terms at each stream node, stream flows and the surface and groundwater hydrology modeled at the stream (i.e., whether the stream is gaining, losing, or disconnected from direct groundwater interaction). Stream flows in the SCHM were simulated as discussed in Section 3.9.2. The conductance terms consist of a streambed thickness and hydraulic conductivity. Streambed conductance values in C2VSim were adopted in the SCHM, and then adjusted for some reaches as discussed in Section 4.3.3.

#### 3.8.3.3 Small Watersheds

Inflow into the model from tributary watersheds that are not modeled as streams is simulated in IWFM using "small watersheds" for which runoff, underflow in, and recharge at designated recharge nodes are simulated. C2VSim includes 18 small watersheds that are tributary to the SCHM, some of which are also tributary to portions of C2VSim that fall outside the SCHM model domain. The input data for the overlapping small watersheds was scaled based on the portion of the watersheds tributary to the SCHM model domain, and the C2VSim data for the small watersheds was adopted unchanged into the SCHM. Changes to the number of specifications of recharge nodes for some of the small watersheds were made during the calibration process as described in Section 4.3.2.

#### 3.8.3.4 Reservoirs

Three reservoirs in the eastern Stanislaus County serve to provide off-stream storage for water to be delivered for agricultural and municipal use: Modesto Reservoir and Turlock Lake, which receive water diverted from the Tuolumne River, and Woodward Reservoir, which receives water diverted from the Stanislaus River. These reservoirs are located in the low foothills of the Sierra Nevada near the contact between the Mehrten and Turlock Lake Formations, which include relatively permeable sands, and the reservoirs therefore are a significant source of local recharge. C2VSim does not simulate these reservoirs, so they were added by designating recharge nodes with 100 % recoverable losses (i.e., all of the water stays within the model) within the footprints of the reservoirs that receive water imports from outside the model in proportion to the estimated seepage losses, as described in Section 3.5. Losses for Turlock Lake were adjusted during the calibration process. Recharge from these reservoirs was estimated using the following approach:

- Annual seepage losses from Woodward Reservoir from 1994 through 2014 were taken from a water balance table provided in the 2015 AWMP for South San Joaquin Irrigation District (SSJID) (Davids Engineering, 2015). Values for 1990 to 1993 and 2015 were substituted from similar hydrologic years in the available record. In the absence of specific data, seepage was assumed to be a constant value during each month of any given year.
- Monthly seepage losses for Turlock Lake were calculated from lake inflow, outflow and storage data provided by TID, subtracting evaporation losses. Evaporation losses were calculated by scaling annual evaporation losses reported for Woodward Reservoir (Davids Engineering, 2015) based on the relative size of the free water surface areas of the reservoirs at average high-water levels, distributed based on reported monthly potential evapotranspiration.
- Monthly seepage losses for Modesto Reservoir were calculated from lake inflow and outflow data provided by Modesto Irrigation District, and storage data from California Data Exchange Center (CDEC), subtracting evaporation losses. Evaporation losses were calculated by scaling annual evaporation losses reported for Woodward Reservoir (Davids Engineering, 2015) based on the relative size of the free water surface areas of the reservoirs at average high-water levels, distributed based on reported monthly potential evapotranspiration.

#### 3.8.3.5 Urban Deep Percolation

Urban deep percolation is derived from diversion conveyance losses, urban landscape irrigation, wastewater return flows and precipitation. Infiltration into the root zone model is controlled by a number of factors that can be defined in the model inputs (indoor vs. outdoor water use fractions, urban evapotranspiration, percent of impervious materials, designated return flow and recharge fractions, etc.). From the root zone model, infiltration is routed through a vadose zone model and into groundwater depending on soil properties and antecedent moisture conditions. Urban deep percolation as a function of urban supply therefore varies from year to year in the model. Refining these variables was beyond the scope of this project. They were therefore adopted unchanged from C2VSim, and could be refined during future modeling efforts.

#### 3.8.3.6 Agricultural Deep Percolation

Similar to urban deep percolation, agricultural deep percolation is calculated by the model based on a complex series of interactions between land use, water supply, evapotranspiration, irrigation efficiency, drainage, applied water and soil conditions. Similar to urban deep percolation, agricultural infiltration is routed from the root zone model through a vadose zone model and into groundwater depending on soil properties and antecedent moisture conditions. Agricultural deep percolation as a function of applied water therefore varies by location and from year to year in the model. Refining these variables was beyond the scope of this project. They were therefore adopted unchanged from C2VSim, and could be refined during future modeling efforts. WALT: Same comment applies here.

### 3.8.4 Pumpage

#### 3.8.4.1 Municipal Pumping

Municipal pumping in IWFM 3.02 can either be designated by entering pumping well specifications or by entering a municipal demand and allowing the model to calculate pumping based on the difference between available surface water diversions and demand. C2VSim identified centrally located surrogate wells for each urban area to simulate municipal groundwater pumping. For the SCHM, municipal pumping was specified by entering well data. The approach used is summarized in Table 3-1 and included the following steps:

- The locations of 218 municipal wells reported by municipal water purveyors or identified from UWMPs, MSRs or other planning documents were entered into the model;
- Completion depths and screen intervals were added for the wells when available, or were estimated based on nearby supply wells when they were not available;
- The locations and completion details of four surrogate wells used in C2VSim to simulate municipal groundwater pumping in four cities located within the buffer zone outside the primary model area (Escalon, Ripon, Gustine and Livingston) were retained; and
- Annual and monthly municipal groundwater pumping was specified based on information reported by municipal water purveyors, and/or data from UWMPs, MSRs or other planning documents, augmented by information regarding population trends, as summarized in Table 3-1.

#### 3.8.4.2 Rural Domestic Pumping

Rural domestic pumping was assumed to occur from Model Layer 1 and was estimated using the following geospatial analysis approach:

- Rural domestic pumping was assumed to occur in each water budget subregion with land falling outside the cities and community service districts included in the SCHM;
- The intersection between the areas identified as having rural domestic water demand and Census 2000 tracts was used to estimate the number of households reliant on rural domestic pumping for their water supply in that year;
- A default water demand of 0.5 acre-feet per year (AFY) was assumed for each rural domestic household (Water Research Foundation, 2016), and was decreased by 38% to account for return flows from landscape irrigation and wastewater disposal to septic systems (Aquacraft, 2011); and
- The rural domestic water demand was adjusted for the model period prior to and following 2000 based on rural population trends reported in the Stanislaus County General Plan Housing Element (Michael Baker International, 2016).

### 3.8.4.3 Agricultural Pumping

Agricultural pumping is calculated by IWFM 3.02 based on the difference between the total irrigation water demand and the amount of surface water and precipitation available to meet the demand. The resulting agricultural pumpage is applied on an elemental basis. The irrigation water demand is calculated by the model for each subregion based on designated land use, crop type, evapotranspiration, irrigation efficiency and soil properties. The following approach was used to calculate agricultural pumping in the SCHM:

- Land use data from DWR crop surveys was provided by DWR through WY 2015 and entered into the input files for each SCHM subregion;
- Crop types were adjusted from C2VSim/IWFM 2015 data (which is the format provided by DWR) to correlate with the crop types available in C2VSim/IWFM 3.02;
- Evapotranspiration, irrigation efficiencies, and soil properties were adopted unchanged from C2VSim;
- Diversions and diversion losses were determined based on data provided by irrigation districts or available from AWMPs, MSRs and various planning documents using the process described in Tables 3-2, 3-3 and 3-4; and
- Diversions, diversion losses and crop data were adjusted during the calibration process based on comparison between modelled and reported farm gate water deliveries and groundwater pumping as described in Table 3-3 and Section 4.3.1.1.

| Jurisdiction | Groundwater Subbasin | Water Supply Source | Description | Groundwater | | |
|---|---|---|---|---|---|---|
| | | | | Well Location Data Source | Well Completion Data Source | Groundwater Pumping Data Source |
| Ballico CSD | Turlock | Groundwater | One well serves a population of approximately 400 via 70 connections. | -- | -- | Use data for 2000-2006 in TGBGMP and extrapolate for other years based on population trends. |
| Ceres | Turlock | Groundwater | 15 potable and 11 non-potable wells serve a population of approximately 48,000 via 11,300 connections. | Map in 2016 1,2,3-TCP Feasibility Study; 11 wells coordinates in Modesto LGA Model inputs. | Modesto LGA Model input file | City-provided spreadsheet: 2001-2015 monthly pumping by well. |
| Crows Landing CSD | Delta-Mendota | Groundwater | Two wells serve a population of approximately 500 via 140 connections. | Map from City | Logs from City | Aggregated monthly data 2013-2015 provided by CSD, extrapolate other years 2000 based on population trends. |
| Delhi County WD | Turlock | Groundwater | Four wells serve a population of approximately 7,800 via 2,400 connections. | -- | -- | Use data for 2000-2006 in TGBGMP and extrapolate for other years based on population trends. |
| Denair CSD | Turlock | Groundwater | Four wells and one standby well serve a population of approximately 3,200 via 1,400 connections. | -- | -- | Use data for 2000-2006 in TGBGMP and extrapolate for other years based on population trends. |
| Escalon | Eastern San Joaquin | Groundwater | Four wells serving population of approximately 8,800. | Use C2VSim data | Use C2VSim data | Use data from C2VSim for 1990-2000; |
| Gustine | Delta-Mendota | | | Use C2VSim data | Use C2VSim data | Use data from C2VSim for 1990-2000; |
| Hilmar County WD | Turlock | Groundwater | Four wells serve a population of approximately 4,850 via 1,570 connections. | -- | -- | Use data provided by RMC or extrapolate from MAGPI Model based on population, compare to 2000-2006 graph in TGBGMP. |
| Hughson | Turlock | Groundwater | 3 active and 2 standby wells serving a population of approximately 6,100 with 2,000 connections. | Ground-truthed City data and Modesto LGA Model inputs. | In Modesto LGA Model input file | Average aggregated annual for 2000 and 2005 in 2005 UWMP; extrapolate other years based on population. |
| Industrial Pumping | All | Groundwater | Some food processing and other industrial facilties in the area utilize their own water supply wells. | Not provided | Not provided | Assume included in C2VSim elemental M&I pumping. |
| Keyes CSD | Turlock | Groundwater | Four wells serve a population of approximately 4,800 via 1,500 connections. | Latitude/Longitude provided via email | SRF application indicates 200-800 ft screen. | Aggregated annual pumping graph for 2000-2006 in TGBGMP; Spreadsheet with monthly pumping by well 2007-2015; Extrapolate other years based on population. |
| Knights Ferry CSD | Modesto | Surface Water | Surface water delivered by an OID diversion from the Stanislaus River. | -- | -- | -- |
| Livingston | Merced | Groundwater | Eight wells serving population of approximately 14,000. | Use C2VSim data | Use C2VSim data | Use data from C2VSim for 1990-2000; |
| Modesto | Modesto Turlock | 60% Groundwater 40% Surface Water | 88 wells plus surface water serve a population of approximately 260,000 via 75,000 connections (2015), including several "service island" systems (Grayson, Turlock, Del Rio, Empire, Hickman). | GIS files provided by City | Spreadsheet provided by City. | Spreadsheet: 2000-2015 monthly by well |
| Monterey Park CSD | Modesto | Groundwater | 2 wells serve a population of approximately 200 via 50 connections. | Assume center of CSD | Assume Model Layer 1 | Assume included in C2VSim elemental M&I pumping. |
| Newman | Delta-Mendota | Groundwater | 3 active and 1 standby wells serving a population of approx 11,000 with approx 3,300 connections. | Map and WCRs | WCRs | 2013-2015 City data, interpolated to 2010 using UWMP data, and 2000 based on population. |
| Oakdale | Modesto Eastern San Joaquin | Groundwater | 9 wells serve a population of approximately 22,000 Via 7,700 connections. | Map in 2015 WMP | 2015 WMP (well depths only) | 2000-2014 Aggregated annual pumping in MSR; extrapolate to 2015 based on population. |
| Patterson | Delta-Mendota | Groundwater | 7 wells and 2 non-potable wells serving a population of approx 22,600 with approx 6,300 service connections. | Map from City | Arambel Business Park WSA | 2012-2015 Tabulated monthly pumping by well provided by city; extrapolate backward based on aggregated annual data in 2015 UWMP (various tables). |
| Ripon | Eastern San Joaquin | Groundwater | 8 groundwater serving population of approximately 18,100 | Use C2VSim data | Use C2VSim data | Use data from C2VSim for 1990-2000; |
| Riverbank | Modesto | Groundwater | 10 wells serve a population of 23,000 via 6,800 connections. | Map in 2010 UWMP or Nolte 2007 WMP | 2010 UWMP | Aggregated annual pumping for 2000-2013 2010 UWMP; apporationed based on monthly pumping by well for 2006 in Nolte 2007; extrapolated forward based on population. |
| Riverdale Park CSD | Modesto | Groundwater | 1 well serves a population of approximately 300 via 180 connections. | Not provided | Not provided | Assume included in C2VSim elemental M&I pumping. |
| Turlock | Turlock | TID Surface Water and Groundwater | 20 active, 1 standby and 4 non-potable wells plus surface water serve a population of approximately 70,000 via 18,500 connections. | Determine from addresses in spreadsheet. | Interpret from casing and seal depths in spreadsheet | 2000-2015 monthly aggregated pumping in city spreadsheet equally apportioned. |



JACOBSON | JAMES
& associates, inc

| Jurisdiction | Groundwater Subbasin | Water Supply Source | Description | Groundwater | | |
|---|---|---|---|---|---|---|
| | | | | Well Location Data Source | Well Completion Data Source | Groundwater Pumping Data Source |
| Waterford | Modesto | Groundwater | Three systems serve a population of approximately 10,000: Two adjacent systems (Waterford and River Pointe) with 8 wells serve 2,400 connections; Hickman with 2 wells serves 180 connections. | Maps in 2016 WMP | 2016 WMP Well depth table | Calculate from data in 2016 WMP and extrapolate based on population. |
| Westley CSD | Delta-Mendota | Groundwater | Groundwater purchased from Hillview Homes: 2 wells serve a population of approximately 70. | NA | NA | Assume included in C2VSim elemental M&I pumping. |

Notes:
C2VSim = California Central Valley Groundwater-Surface Water Simulation Model
CSD = Community Services District
ft = foot
GIS = geographic information system
KMZ = keyhole markup language (geographic annotation for two-dimensional maps and three-dimensional Earth browsers)
LGA = Local Groundwater Assistance
MAGPI = Merced Area Groundwater Pool Interest
M&I = municipal and industrial
MSR = Municipal Service Review
RMC = RMC Water and Environment
SRF = Safe Drinking Water State Revolving Fund
1,2,3-Trichloropropane
TGBGMP = Turlock Groundwater Basin Groundwater Management Plan
TID = Turlock Irrigation District
UWMP = Urban Water Management Plan
WCR = well completion report
WD = Water District
WMP = Water Master Plan
WSA = Water Supply Assessment
% = percent
-- = not available/not applicable

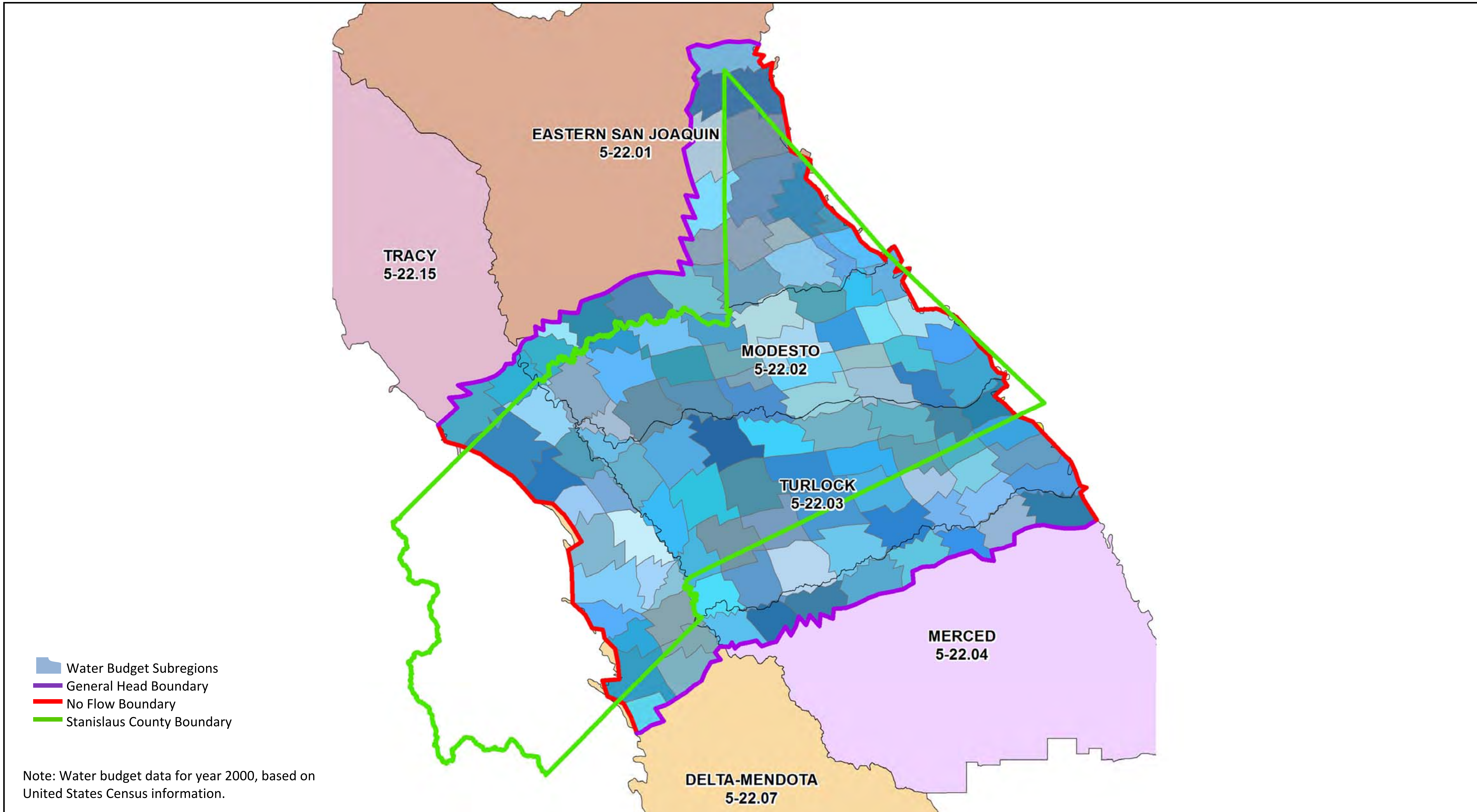
References:
City of Patterson, 2012. *Water Supply Assessment for Arambel Business Park/KDN Retail Center Final Draft.* April.
Nolte Associates, Inc., 2007. *City of Riverbank Water Supply Study and Water Master Plan. Volume I.* Prepared for City of Riverbank. November.
Provost & Pritchard Consulting Group, 2016. *City of Ceres 1,2,3-TCP Mitigation Feasibiilty Study.* Prepared for City of Ceres. August 22.

| C2VSim Diversion ID | SCHM Diversion ID | C2VSim Diversion Name | Water District(s)/Area Receiving Water Deliveries | Approach for Calculating Diversions for Historical Model Period (WY1990 - WY2015) | Approach for Calculating Diversions for Forecast Model Period (WY2016 - WY2042) |
|---|---|---|---|---|---|
| 85 | 1 | Calaveras River | SEWD | Use reported diversions from New Hogan Reservoir for 2013-2015 in Table 7 of the SEWD AWMP. For 1990-2012, calculate the fraction of the 2014 Diversion 85 volume in each year, and multiply it by the 2014 delivery reported in the AWMP. Multiply all diversions by 0.09 based on the percentage of the SEWD service territory within the model domain. Calculate monthly delivery fraction using reported average monthly deliveries reported for OID. | Use historical year data in the order specified in Table 3. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 1990, respectively). |
| 93 | 2 | Sacramento-San Joaquin Delta to SWP | Oak Flat Water District | Use reported 2006 - 2015 diversions reported in 2016 Municipal Service Review. Calculate 1990-2005 diversions by multiplying the maximum district allocation by reported historical SWP deliveries. Calculate monthly delivery fraction using reported average deliveries reported for DPWD. | Use historical year data in the order specified in Table 3. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 94 | 3 | Stanislaus River to South San Joaquin Canal for Agriculture | SEWD | Use reported diversions from New Melones Reservoir for 2013-2015 in Table 7 of the SEWD AWMP. For 1990-2012,calculate the fraction of the 2014 Diversion 85 volume in each year, and multiply it by the 2014 delivery reported in the AWMP. Multiply all diversions by 0.09 based on the percentage of the SEWD service territory within the model domain. Calculate monthly delivery fraction using reported average monthly deliveries reported for OID. | Use historical year data in the order specified in Table 3. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 94 | 3 | Stanislaus River to South San Joaquin Canal for Agriculture | SSJID | Use reported 1994-2014 releases from Woodward Reservoir in Table 14 of the SSJID AWMP. For 1990-1993 and 2015, calculate the fraction of the 2014 Diversion 94 volume in each year, and multiply it by the 2014 delivery reported in the AWMP. Multiply all diversions by 0.51 based on the percentage of the SSJID service territory within the model domain. Calculate monthly delivery fraction using reported average monthly deliveries reported for OID. | Use historical year data in the order specified in Table 3. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 95 | 4 | Stanislaus River to South San Joaquin Canal for M&I | City of Ripon | Use 0 for 1990-1998, 0.5 TAF for 1999-2005, 1 TAF for 2006-2010, 1.5 TAF for 2011-2015. Calculate monthly delivery fraction using reported average monthly deliveries reported for OID. | Use historical year data in the order specified in Table 3. For historical years 1983-1987, use 0. |
| 96 | 5 | Stanislaus River to Oakdale Canal for Agriculture | OID | Use data from OID-provided spreadsheet "OID Hist Use - DW & Surface H2O_1990 to 2016.xls", adjusted for 98% of service territory in SCHM. Calculate monthly delivery fraction using reported average monthly deliveries reported for OID. | Use historical year data in the order specified in Table 3. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 98 | 6 | Stanislaus River riparian for Agriculture | Non-district parcels near Stanislaus River | Use C2VSim diversions unchanged. | Use historical C2VSim Diversion 98 data in the order specified in Table 3. |
| 100 | 7 | Tuolumne River to Modesto Canal | Primary diversion to Modesto Reservoir for Modesto Irrigation District and City of Modesto | Use C2VSim diversions multiplied by 0.93 to match reported farm gate deliveries for Diversion 101 and reasonable losses. | Use historical C2VSim Diversion 100 data in the order specified in Table 3, multiplied by 0.93. |
| 101 | 8 | Modesto Canal for Agriculture | Modesto Irrigation District | Calculate based on difference between adjused Diversion 100 after lossses minus Diversion 102 ([Diversion 100 x 0.93] - Diversion 102). Calculate monthly delivery fraction using reported average monthly deliveries reported for OID. | Use historical year data in the order specified in Table 3. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset during which surface water deliveries were made (1995, 1996, 2004, 2005, and 2007, respectively). |
| 102 | 9 | Modesto Canal for M&I | City of Modesto | Use 2000-2015 "MID" data from City-provided spreadsheet titled "Modesto Monthly system flow totals 2000-2017.xls" and multiply by 1.06. For 1995 to 1999, use 35,616. For 1994, use 15,710. Assume constant puming rate throughout each year. | Use historical year data in the order specified in Table 3. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset during which surface water deliveries were made (1995, 1996, 2004, 2005, and 2007, respectively). |
| 103 | 10 | Tuolumne River right bank riparian diversions for Agriculture | Non-district parcels near Tuolumne River right bank | Use C2VSim monthly diversions unchanged. | Use historical C2VSim data in the order specified in Table 3. |
| 105 | 11 | Tuolumne River left bank riparian diversions for Agriculture | Non-district parcels near Tuolumne River left bank | Use C2VSim monthly diversions unchanged. | Use historical C2VSim data in the order specified in Table 3. |
| 107 | 12 | Tuolumne River to Turlock Canal | Primary diversion to Turlock Lake for TID | Use C2VSim Diversion 107 multiplied by 0.90. | Use adjusted historical C2VSim Diversion 107 data in the order specified in Table 3. |
| 108 | 13 | Turlock Canal for Agriculture | TID | Use unadjusted C2VSim Diversion 107 minus 13%. Distribute in proportional to farm gate delivery data provided by TID. | Use adjusted historical C2VSim Diversion 107 data in the order specified in Table 3. |
| 110 | 14 | Merced River to Merced ID Northside Canal for Agriculture | Merced Irrigation District north of Merced River | Use 2010 to 2015 data from Table 5-15 in the Merced ID AWMP multiplied by the fraction of the Merced ID service territory located north of the Merced River. Apply average monthly OID delivery fractions. For 1990 to 2009, use C2VSim monthly diversions unchanged. | Use historical year data in the order specified in Table 3. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |

| C2VSim Diversion ID | SCHM Diversion ID | C2VSim Diversion Name | Water District(s)/Area Receiving Water Deliveries | Approach for Calculating Diversions for Historical Model Period (WY1990 - WY2015) | Approach for Calculating Diversions for Forecast Model Period (WY2016 - WY2042) |
|---|---|---|---|---|---|
| 112 | 15 | Merced River right bank riparian diversions for Agriculture | Non-district parcels near Merced River right bank | Use C2VSim monthly diversions unchanged. | Use historical C2VSim data in the order specified in Table 3. |
| 114 | 16 | Merced River left bank riparian diversions for Agriculture | Non-district parcels near Merced River left bank | Use C2VSim monthly diversions unchanged. | Use historical C2VSim data in the order specified in Table 3. |
| 116 | 17 | Merced River to Merced ID Main Canal for Agriculture | Merced Irrigation District south of Merced River | Use 2010 to 2015 data from Table 5-15 in the Merced ID AWMP multiplied by the fraction of the Merced ID service territory located south of the Merced River, plus Stevinson Water District deliveries. Apply average monthly OID delivery fractions. For 1990 to 2009, use C2VSim monthly diversions unchanged. Apply Stevinson Water District diversion to model subregion that corresponds with their territory. | Use historical year data in the order specified in Figure 6-1. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 128 | 18 | San Joaquin River riparian diversions, Fremont Ford to Vernalis, to Subregion 10 for Agriculture | Non-district parcels near San Joaquin River left bank | Assume same as right bank diversions, which are C2VSim Diversion 129 + Diversion 130. | Use historical year data in the order specified in Figure 6-1 For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 128 | 18 | San Joaquin River riparian diversions, Fremont Ford to Vernalis, to Subregion 10 for Agriculture | PID | Use 2001 to 2010 data from the "Local Water" column in Table 8 of the PID AWMP. For 1990 to 2000 and 2011 to 2013, use the 2001-2010 average. For 2014 and 2015, use half the average. Apply monthly delivery fractions reported in the 2008 DPWD AWMP. | Use historical year data in the order specified in Figure 6-1 For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 128 | 18 | San Joaquin River riparian diversions, Fremont Ford to Vernalis, to Subregion 10 for Agriculture | El Solyo Water District | For 2008-2015, use EWRIMS data. For 1990 to 2007, use average of 2008 to 2013 EWRIMS data. Apply monthly delivery fractions reported in the 2008 DPWD AWMP. | Use historical year data in the order specified in Figure 6-1 For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 128 | 18 | San Joaquin River riparian diversions, Fremont Ford to Vernalis, to Subregion 10 for Agriculture | West San Joaquin Irrigation District | For 2012 to 2015, use diversion data from WSID tab of comparison spreadsheet (J31:J34). For 1990 to 2011, refer "WSID Reports 2015.xls" in the data library. In the Water Delivery tab: From Total Diverted, subtract CVP. Apply monthly delivery fractions reported in the 2008 DPWD AWMP. | Use historical year data in the order specified in Figure 6-1 For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 129 | 19 | San Joaquin River riparian diversions, Fremont Ford to Vernalis, to Subregion 11 for Agriculture | Non-district parcels near San Joaquin River in Turlock Subbasin, right bank | Use C2VSim monthly diversions unchanged. | Use historical C2VSim data in the order specified in Figure 6-1. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 130 | 20 | San Joaquin River riparian diversions, Fremont Ford to Vernalis, to Subregion 12 for Agriculture | Non-district parcels near San Joaquin River in Modesto and Eastern San Joaquin Subbasins, right bank | Use C2VSim monthly diversions unchanged. | Use historical C2VSim data in the order specified in Figure 6-1. For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 171 | 21 | Delta Mendota Canal to Subregion 9 for Agriculture | Del Puerto Irrigation District in San Joaquin County | Use 1999 to 2015 diversions reported in 2016 MSR and and multiply by 0.07 (model area in C2VSim SR 9). For 1990 to 1998, use average of 1999-2015. Apply monthly delivery fractions reported in the 2008 DPWD AWMP. | Use historical year data in the order specified in Figure 6-1 For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 172 | 22 | Delta Mendota Canal to Subregion 10 for Agriculture | Del Puerto Irrigation District in Stanislaus County | Use 1999 to 2015 diversions reported in 2016 MSR and and multiply by 0.63 (model area in C2VSim SR 10). For 1990 to 1998, use average of 1999-2015. Apply monthly delivery fractions reported in the 2008 DPWD AWMP. | Use historical year data in the order specified in Figure 6-1 For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 172 | 22 | Delta Mendota Canal to Subregion 10 for Agriculture | WSJID | Use 2001 to 2010 Federal Agriculture Water from Table 8 of WSJID AWMP. For 2011 to 2013 and 2015, use 3,000 AF. For 2015, use 0. For 1990 to 2000, use 6,000. Apply monthly delivery fractions reported in the 2008 DPWD AWMP. | Use historical year data in the order specified in Figure 6-1 For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |
| 177 | 23 | Mendota Pool to Subregion 10 for Agriculture | CCID | For 2010 to 2015, use CCID reported CVP allocation multiplied by the fraction of the district area in the SCHM. For 1990 to 2009, use the value for 2010. Apply monthly delivery fractions reported in the 2008 DPWD AWMP. | Use historical year data in the order specified in Figure 6-1 For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |

| C2VSim Diversion ID | SCHM Diversion ID | C2VSim Diversion Name | Water District(s)/Area Receiving Water Deliveries | Approach for Calculating Diversions for Historical Model Period (WY1990 - WY2015) | Approach for Calculating Diversions for Forecast Model Period (WY2016 - WY2042) |
|---|---|---|---|---|---|
| N/A | 24 | Not in C2VSim - Rock Creek Water District | Rock Creek Water District | Use diversion data from EWRIMS. Calculate monthly delivery fraction using reported average monthly deliveries reported for OID. | Use historical year data in the order specified in Figure 6-1 For historical years 1983-1987, use years of the same hydrologic year type from the historical model dataset (1995, 1996, 2004, 2005 and 2007, respectively). |

Notes:
AF = acre foot
AWMP = Agricultural Water Management Plan
C2VSim = California Central Valley Groundwater-Surface Water Simulation Model
CVP = Central Valley Project
DPWD = Del Puerto Water District
EWRIMS = Electronic Water Right Information Management System
ID = identification
M & I = Municipal and Industrial
MID = Modesto Irrigation District
MSR = Municipal Service Review
N/A = not applicable
OID = Oakdale Irrigation District
PID = Patterson Irrigation District
SCHM = Stanislaus County Hydrologic Model
SEWD = Stockton East Water District
SSJID = South San Joaquin Irrigation District
SWP = State Water Project
TAF = thousand acre foot
TID = Turlock Irrigation District
WSJID = West San Joaquin Irrigation District
WY = water year




Note: Water budget data for year 2000, based on United States Census information.

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/10/17 | JH | MT |

*FIGURE 3-1*

***Water Budget Subregions within SCHM***

| Jurisdiction | Groundwater Subbasin | Water Source | Description | Approach to Initial Model Inputs and Calibration | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Irrigated Acreage and Crop Types | Surface Water Diversions | Diversion Losses | Groundwater Pumping | Well Data | Soil Conditions | Other Considerations |
| Central California Irrigation District | Delta-Mendota | CCID delivers CVP water (as a San Joaquin River Exchange Contractor) and groundwater, which is augmented by private groundwater pumping. | CCID serves approximately 560 customers in a service territory of 143,400 acres, of which 20,000 acres are in western Stanislaus County, via a system of ditches and canals. CVP allocations average 510,000 AFY, but can be significantly less during drought years. | DWR crop survey data (developed for C2VSim updates and provided by DWR in 2017) applied to water budget subregions in SCHM. | Use reported allocation data in CCID spreadsheet for 2010 to 2015; Use 2010 value for earlier years. Multiply by 22% for fraction of district within the model. | Estimated seepage and evaporation losses based on reported delivery fractions in WSID and OID AWMPs. | Allow model to calculate | Use elemental pumping to simulate private and district pumping (district well data available but not be entered as private well data are not available). | C2VSim | |
| Del Puerto Water District | Delta-Mendota | DPWD delivers CVP water, which is augmented by private groundwater pumping. | DPWD is contracted to deliver up to 140,210 AFY to 147 retail customers with 44,000 irrigable acres in a 53,000 acre service area, mostly in Stanislaus County, via a system of ditches and canals. | Use DWR 2017 crop survey data; compare to 2008 irrigated acreage reported in 2011 AWMP. | Use 1999 to 2015 diversions reported in 2016 MSR and and multiply by the fraction of district within each subregion. For 1990 to 1998, use average of 1999-2015 data. | Estimated seepage and evaporation losses based on reported delivery fractions in WSID and OID AWMPs. | Allow model to calculate; Compare to 2008 private pumping reported in 2011 AWMP and adjust irrigated acreage as needed. | None reported, use elemental pumping | C2VSim | Incidental M&I deliveries of 3 AF/month; Slow rate of conversion to M&I use lands, especially in Patterson. |
| Eastin Water District | Delta-Mendota | Groundwater | At this time, water within the 3,520-acre district is provided entirely by private groundwater pumping. | DWR 2017 crop survey data | None | NA | Allow model to calculate; compare to KDSA 2000 | Unknown, use elemental pumping | C2VSim | No population growth expected per 2016 MSR. |
| Eastside Water District | Turlock | Groundwater | At this time, water within the approximately 54,000-acre district is provided primarily by private groundwater pumping, with minor deliveries of TID surface water in years when surplus water is avaialble | DWR 2017 crop survey data; adjusted using rangeland conversion rate in east Stanislaus County reported by County Agricultural Commissioner in 2000 to 2015. | None | NA | Allow model to calculate, check against Durbin 2003 and Todd 2016 Water Budget and adjust irrigated acreage as needed. | Unknown, use elemental pumping | C2VSim | |
| El Solyo Water District | Delta-Mendota | San Joaquin River water, augmented by private groundwater. | ESWD delivers water to agricultural customers in a 4,060-acre service area through a system of canals and ditches. | DWR crop survey data | For 2008-2015, use EWRIMS data. For 1990 to 2007, use average of 2008 to 2013 EWRIMS data. | Estimated seepage and evaporation losses based on reported delivery fractions in WSID and OID AWMPs. | Allow model to calculate | Unknown, use elemental pumping | C2VSim | No population growth expected per 2016 MSR. |

| Jurisdiction | Groundwater Subbasin | Water Source | Description | Approach to Initial Model Inputs and Calibration | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Irrigated Acreage and Crop Types | Surface Water Diversions | Diversion Losses | Groundwater Pumping | Well Data | Soil Conditions | Other Considerations |
| Modesto Irrigation District | Modesto | Modesto ID delivers Tuolumne River water and groundwater, which is augmented to some extent by private groundwater pumping. | Modesto ID serves approximately 3,100 retail agricultural irrigation customers on 60,000 acres of irrigable land in a service territory of approximately 101,700 acres via a system of ditches and canals. In addition, the district delivers wholesale domestic water to the City of Modesto. | DWR crop survey data; Compare to irrigated acreage and crop water demand in 2015 AWMP. | Calculate based on C2VSim Diversion 100 minus deliveries to City of Modesto; Compare to 2000-2015 data in summary provided by Modesto ID and 2010-2014 data in 2015 AWMP. Adjust deliveries to subregions based on data in USGS, 2004. | Estimated seepage and evaporation losses based on difference between reported diversions and farm gate deliveries, adjusted by 20% to account for possible reporting bias. | Allow model to calculate; compare to data in 2015 AWMP and adjust irrigated acreage as needed. | District well data available, but private well data unknown, use elemental pumping. | C2VSim | Modesto ID delivers municipal supply to Modesto; See Modesto UWMP for estimated demand growth over time. |
| Oak Flat Water District | Delta-Mendota | OFWD delivers SWP water, which is augmented by private groundwater pumping. | OFWD is contracted to deliver up to 5,700 AFY to 2,158 irrigable acres in a 4,537 acre service area via a system of ditches and canals. | DWR crop survey data. | Use reported 2006 - 2015 diversions reported in 2016 MSR. Calculate 1990-2005 diversions by multiplying the maximum allocation by reported SWP delivery fractions. | Estimated seepage and evaporation losses based on reported delivery fractions in WSID and OID AWMPs. | Allow model to calculate | Unknown, use elemental pumping | C2VSim | No population growth expected per 2016 MSR. |
| Oakdale Irrigation District | Modesto Eastern San Joaquin | OID delivers Stanislaus River water, drainage water and groundwater, which is augmented to some extent by private groundwater pumping. | OID serves approximately 2,900 retail agricultural irrigation customers and nine domestic water systems in a service territory of approximately 73,660 acres via a system of ditches and canals. | DWR crop survey data; Compare to tabulated data for 2009-2015 in district crop reports | Use data reported in OID-provided spreadsheet. | Estimated seepage and evaporation losses based on reported delivery fractions calculated from OID data. | Allow model to calculate. Compare to data in 2015 AWMP and 2000 to 2015 spreadsheet data and adjust irrigated areage as needed. | District well data available, but private well data unknown, use elemental pumping. | C2VSim | |
| Patterson Irrigation District | Delta-Mendota | PID delivers CVP, reclaimed drainage, groundwater and San Joaquin River Water, which is augmented by private groundwater pumping. | PID serves approximately 725 retail customsers in a 13,150 acre service area via a system of ditches and canals. | DWR crop survey data; Compare to irrigated acres and crop water demand reported in 2016 AWMP | Use 2001 to 2010 data from AWMP; For 1990 to 2000 and 2011 to 2013, use the 2001-2010 average; For 2014 and 2015, use half the average. | Estimated seepage and evaporation losses based on reported delivery fractions in WSID and OID AWMPs. | Allow model to calculate. Compare to groundwater pumping reported in 2016 AWMP and adjust irrigated areage as needed. | None reported, use elemental pumping | C2VSim | Growth of the City of Patterson is expected to result in decreased acreage served |



JACOBSON | JAMES
& associates, inc

| Jurisdiction | Groundwater Subbasin | Water Source | Description | Approach to Initial Model Inputs and Calibration | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Irrigated Acreage and Crop Types | Surface Water Diversions | Diversion Losses | Groundwater Pumping | Well Data | Soil Conditions | Other Considerations |
| Rock Creek Water District | Eastern San Joaquin | RCWD delivers surface water from the Salt Spring Reservoir in Calaveras County, which is augmented by private groundwater pumping. | RCWD serves four retail customers in a service territory of 1,844 acres via a canal from Salt Springs Reservoir. | DWR crop survey data | Use EWRIMS data | Estimated seepage and evaporation losses based on reported delivery fractions in WSID and OID AWMPs. | Allow model to calculate. | None reported, use elemental pumping | C2VSim | No population growth expected |
| Turlock Irrigation District | Turlock | TID delivers Tuolumne River water and groundwater, which is augmented to some extent by private groundwater pumping. | TID serves approximately 5,800 retail agricultural irrigation customers on 150,000 acres of irrigable land in a service territory of approximately 196,500 acres via system of ditches and canals. In addition, the district delivers domestic water to the community of La Grange. | DWR crop survey data, compare to crop data provided by district. | Use Calsim Diversion 107 data after accounting for losses; Distribute in accordance with reported subregional farm gate deliveries reported by district. | Use C2VSim data for primary diversion, adjust using professional judment during calibration process; Calculate diversion losses for ag deliveries based on TID provided data. | Allow model to calculate, compare to spreadsheet data provided by district and adjust irrigated acreage and crop water demand as appropriate. | None reported, use elemental pumping | C2VSim, compare to IDC data files provided by district. | |
| West Stanislaus Irrigation District | Delta-Mendota | WSID delivers water from the San Joaquin River, CVP and groundwater, which is augmented by private groundwater pumping. | WSID serves 83 retail customers in a 21,774 acre service territory via a system of ditches and canals. WSID also sells water to the 2,203 acres in the White Lake area, north of Grayson. | DWR crop survey data, compare to district crop data for 2015 and irrigated acreage for 2000-2015. | CalSim, allocated proportionally. Compare to spreadsheet data for 2000 - 2015 and water budgets from 2009 and 2014 AWMPs. | Estimated seepage and evaporation losses based on reported delivery fractions in WSID AWMP. | Allow model to calculate, compare to spreadsheet data provided by district for 2015, and to 2009 and 2014 AWMPs. | Some district well data available, but private well data unknown, use elemental pumping. | C2VSim | Growth in Grayson, Westley and Patterson will decrease irrigated acreage. |
| Ballico-Cortez Water District | Turlock | Groundwater | At this time, water within the approximately 6,700-acre district is provided primarily by private groundwater pumping, with minor deliveries of TID surface water in years when surplus water is avaialble. | DWR 2017 crop survey data; adjusted using rangeland conversion rate in east Stanislaus County reported by County Agricultural Commissioner in 2000 to 2015. | None | NA | Allow model to calculate, check against Durbin 2003 and Todd 2016 Water Budget and adjust irrigated acreage as appropriate. | Unknown, use elemental pumping | C2VSim | |



JACOBSON | JAMES & associates, inc

| Jurisdiction | Groundwater Subbasin | Water Source | Description | Approach to Initial Model Inputs and Calibration | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Irrigated Acreage and Crop Types | Surface Water Diversions | Diversion Losses | Groundwater Pumping | Well Data | Soil Conditions | Other Considerations |
| Merced Irrigation District | Turlock | Merced ID delivers Merced River water and groundwater, which is augmented by private groundwater pumping. | Merced ID delivers up to 310,000 AFY to 2,200 retail customers with 110,000 irrigable acres in a 164,000 acre service area, via a system of ditches and canals. Approximately 10,000 acres of Merced ID's service territory overlies the Turlock Subbasin in Merced County. | DWR crop survey data, compare to 2016 AWMP | Use 2010 to 2015 data from 2016 AWMP for Northside Canal and Main Canal, and multiply by the fraction of Merced ID service area for each canal within SCHM. For 1990 to 2009, use C2VSim diversions. Allocate Stevinson Water District deliveries to the corresponding subregions. | Calculate seepage and evaporation losses based on data in the 2016 AWMP and adjust using professional judgment during the calibration process. | Allow model to calculate, compare to Durbin 2003 Water Budget and 2016 AWMP and adjust irrigated acreage and crop demand as appropriate | Unknown, use elemental pumping | C2VSim | |

Notes:
AF = acre foot
AFY = acre foot per year
AWMP = Agricultural Water Management Plan
C2VSim = California Central Valley Groundwater Surface Water Simulation Model
CalSim = formal name for Water Resource Integrated Modeling System (WRIMS model engine or WRIMS)
CCID = Central California Irrigation District
CVP = Central Valley Project
DPWD = Del Puerto Water District
DWR = California Department of Water Resources
ESWD = El Solyo Water District
EWRIMS = Electronic Water Rights Information System
IDC = Irrigation Demand Calculator
ID = Irrigation District
KDSA = Kenneth D. Schmidt and Associates
M&I = Municipal and Industrial
MSR = Municipal Service Review
NA = not available
OFWD = Oak Flat Water District
OID = Oakdale Water District
RCWD = Rock Creek Water District
SCHM = Stanislaus County Hydrologic Model
SWP = State Water Project
TID = Turlock Irrigation District
USGS = United States Geological Survey
UWMP = Urban Water Management Plan
WSID = West Stanislaus Irrigation District
% = percent

References:
Timothy J. Durbin, Inc., 2003. *Turlock Groundwater Basin Water Budget 1952 - 2002.* Prepared for Turlock Groundwater Basin Association. December.
KDSA, 2000. *Groundwater Conditions in and near the Eastin Water District.* Prepared for Central California Irrigation District and Eastin Water District. February.
Todd Groundwater, 2016. *Final Report Hydrogeological Characterization of the Eastern Turlock Subbasin.* March.
USGS, 2004. *Hydrogeologic Characterization of the Modesto Area, San Joaquin Valley, California.* Scientific Investigations Report 2004-5232.

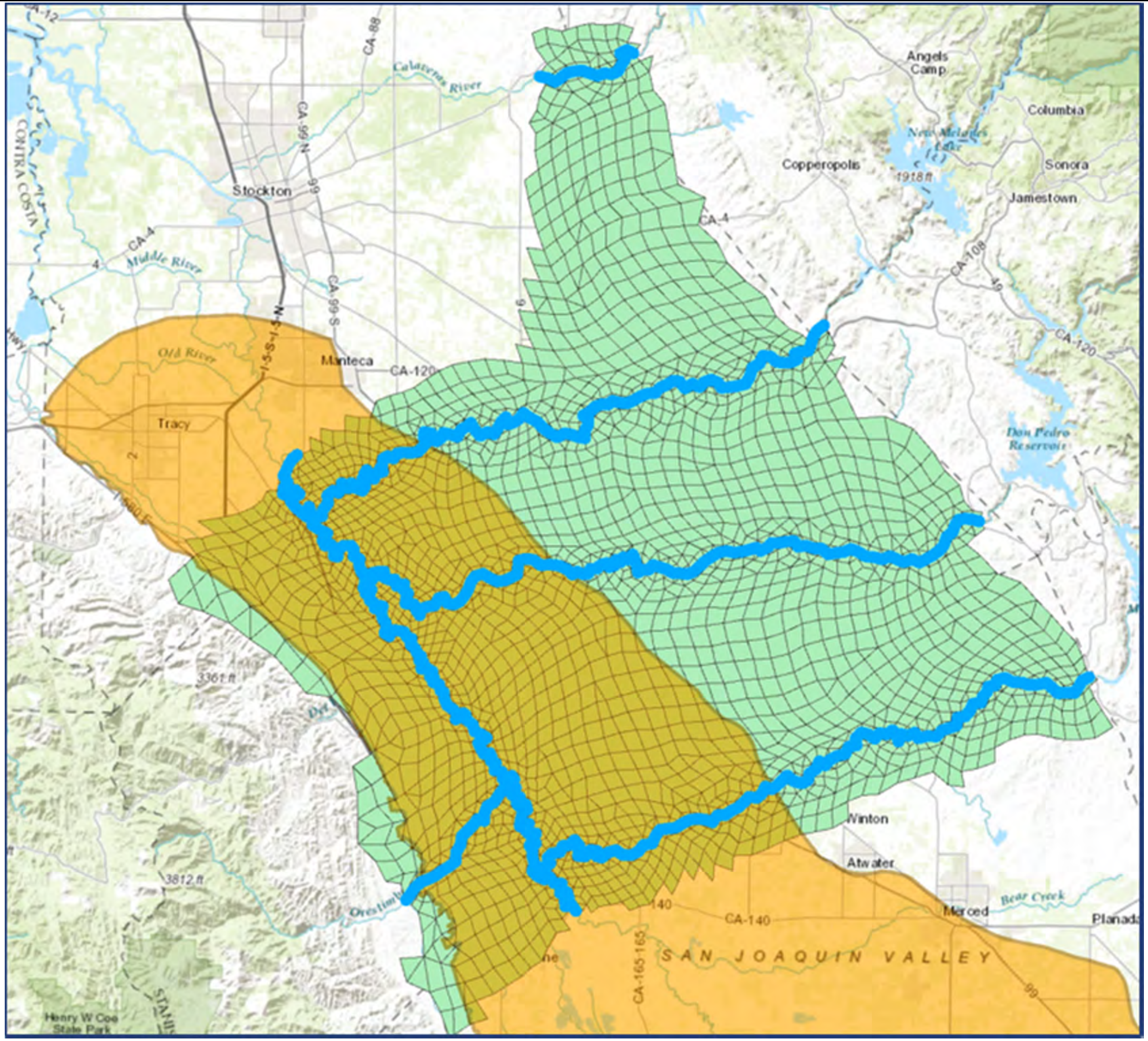
**TABLE 3-4**
**SUMMARY OF SCHM DIVERSION LOSS FRACTIONS**
**Stanislaus County Hydrologic Model: Development and Forecast Modeling**
Stanislaus County, California

| C2VSim Diversion ID | SCHM Diversion ID | Description | Recoverable Loss Fraction[a] | Non-Recoverable Loss Fraction[b] | Comments |
|---|---|---|---|---|---|
| 85 | 1 | Calaveras River | 0.15 | 0.32 | Calculated from SEWD data |
| 93 | 2 | Sacramento-San Joaquin Delta to SWP | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| 94 | 3 | Stanislaus River to South San Joaquin Canal for Ag | 0.12 | 0.06 | Calculated from SSJID data |
| 95 | 4 | Stanislaus River to South San Joaquin Canal for M&I | 0.9 | 0.1 | Professional judgment based on SSJID delivery to recharge basins in Ripon |
| 96 | 5 | Stanislaus River to Oakdale Canal for Agriculture | 0.1 | 0.01 | Calculated from OID data |
| 98 | 6 | Stanislaus River riparian for Agriculture | 0.15 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| 100 | 7 | Tuolumne River to Modesto Canal | 0.02 | 0.01 | Adjusted from C2Vsim values during calibration to reflect more reasonable loss factors based on available data |
| 101 | 8 | Modesto Canal for Agriculture | 0.15 | 0.15 | Calculated from Modesto Irrigation District data |
| 102 | 9 | Modesto Canal for M&I | 0.05 | 0.01 | From C2VSim |
| 103 | 10 | Tuolumne River right bank riparian diversions for Agriculture | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| 105 | 11 | Tuolumne River left bank riparian diversions for Agriculture | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| 107 | 12 | Tuolumne River to Turlock Canal | 0.02 | 0.01 | Adjusted from C2Vsim values during calibration to reflect more reasonable loss factors based on available data |
| 108 | 13 | Turlock Canal for Agriculture | 0.08 | 0.05 | Calculated from TID data |
| 110 | 14 | Merced River to Merced Irrigation District Northside Canal for Agriculture | 0.1 | 0.22 | Calculated from Merced Irrigation District data and adjusted during calibration based on professional experience regarding farm gate delivery reporting |
| 112 | 15 | Merced River right bank riparian diversions for Agriculture | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| 114 | 16 | Merced River left bank riparian diversions for Agriculture | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| 116 | 17 | Merced River to Merced Irrigation District Main Canal for Agriculture | 0.1 | 0.22 | Calculated from Merced Irrigation District data and adjusted during calibration based on professional experience regarding farm gate delivery reporting |
| 128 | 18 | San Joaquin River riparian diversions, Fremont Ford to Vernalis, to Subregion 10 for Agriculture | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| 129 | 19 | San Joaquin River riparian diversions, Fremont Ford to Vernalis, to Subregion 11 for Agriculture | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| 130 | 20 | San Joaquin River riparian diversions, Fremont Ford to Vernalis, to Subregion 12 for Agriculture | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |

**TABLE 3-4**
**SUMMARY OF SCHM DIVERSION LOSS FRACTIONS**
**Stanislaus County Hydrologic Model: Development and Forecast Modeling**
**Stanislaus County, California**

| C2VSim Diversion ID | SCHM Diversion ID | Description | Recoverable Loss Fraction[a] | Non-Recoverable Loss Fraction[b] | Comments |
|---|---|---|---|---|---|
| 171 | 21 | Delta Mendota Canal to Subregion 9 for Agriculture | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| 172 | 21 | Delta Mendota Canal to Subregion 10 for Agriculture | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| 177 | 21 | Mendota Pool to Subregion 10 for Agriculture | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |
| N/A | 22 | Rock Creek Water District | 0.1 | 0.03 | Assumed default based on reported typical loss fractions reported in WSID and OID AWMPs and C2VSim |

Notes:
[a] Recoverable losses include deep percolation and recharge.
[b] Non-Recoverable losses include evaporation and spills exiting the model.
AWMP = Agricultural Water Management Plan
C2VSim = California Central Valley Groundwater-Surface Water Simulation Model
ID = identification
M&I = Municipal and Industrial
OID = Oakdale Irrigation District
SCHM = Stanislaus County Hydrologic Model
SEWD = Stockton East Water District
SSJID = South San Joaquin Irrigation District
SWP = State Water Project
TID = Turlock Irrigation District
WSID = West San Joaquin Irrigation District




Stanislaus County Hydrologic Model Finite Element Mesh

River Nodes

Corcoran Clay

Note:
Corcoran Clay source: USGS, 2012. *Extent of Corcoran Clay modified from Page (1986) for the Central Valley Hydrologic Model (CVHM):* https://water.usgs.gov/GIS/metadata/usgswrd/XML/pp1766_corcoran_clay_extent.

Map Source: Esri, HERE, DeLorme, Tom Tom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, OpenStreetMap contributors, and the GIS User Community

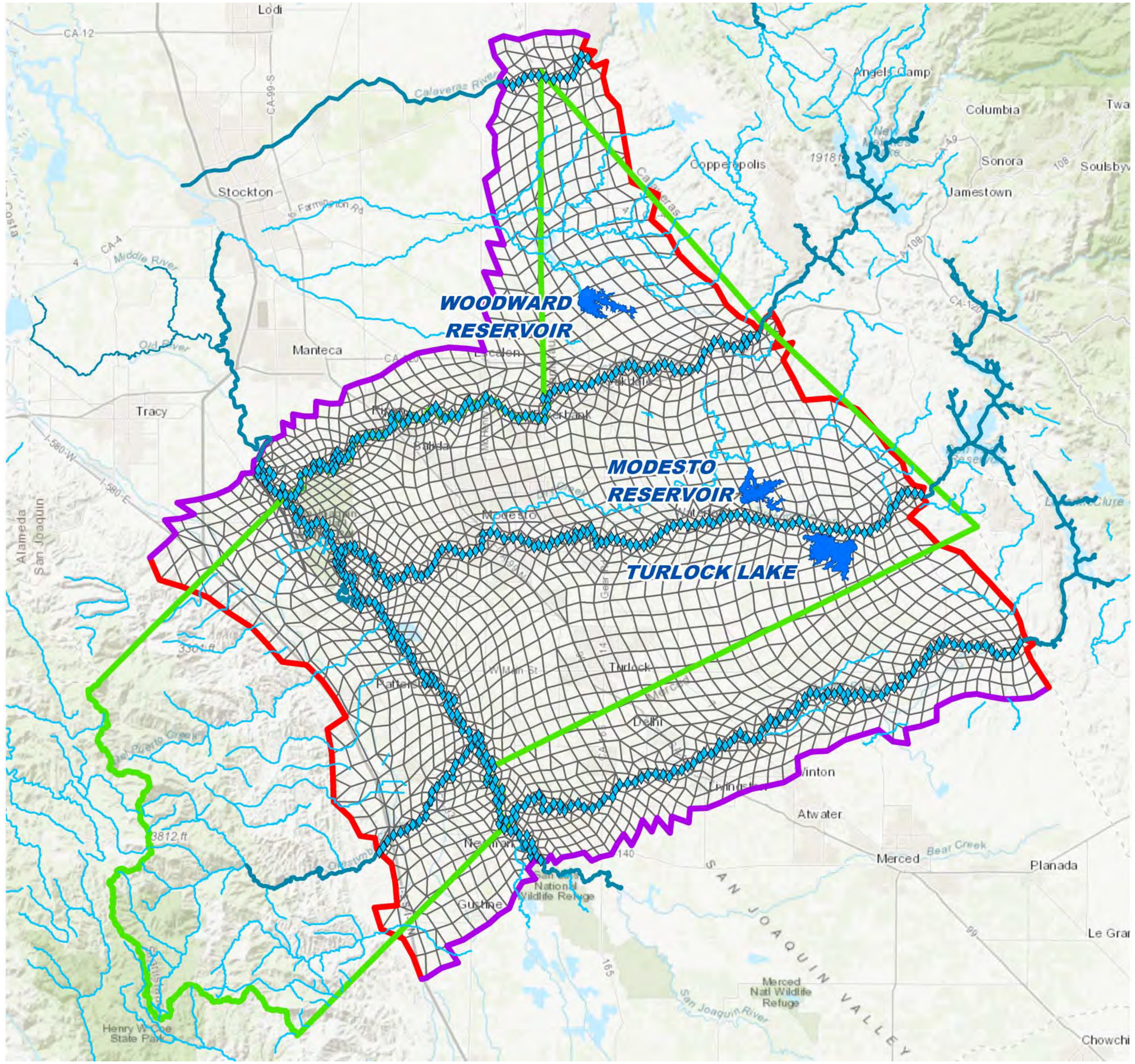
JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/16/17 | JH | MT |

*FIGURE 3-2*

***Corcoran Clay Extent in SCHM***




Stanislaus County Hydrologic Model Finite Element Mesh
River Nodes
General Head Boundary
No Flow Boundary
Stanislaus County Boundary

Map Source: Esri, HERE, DeLorme, Tom Tom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, OpenStreetMap contributors, and the GIS User Community

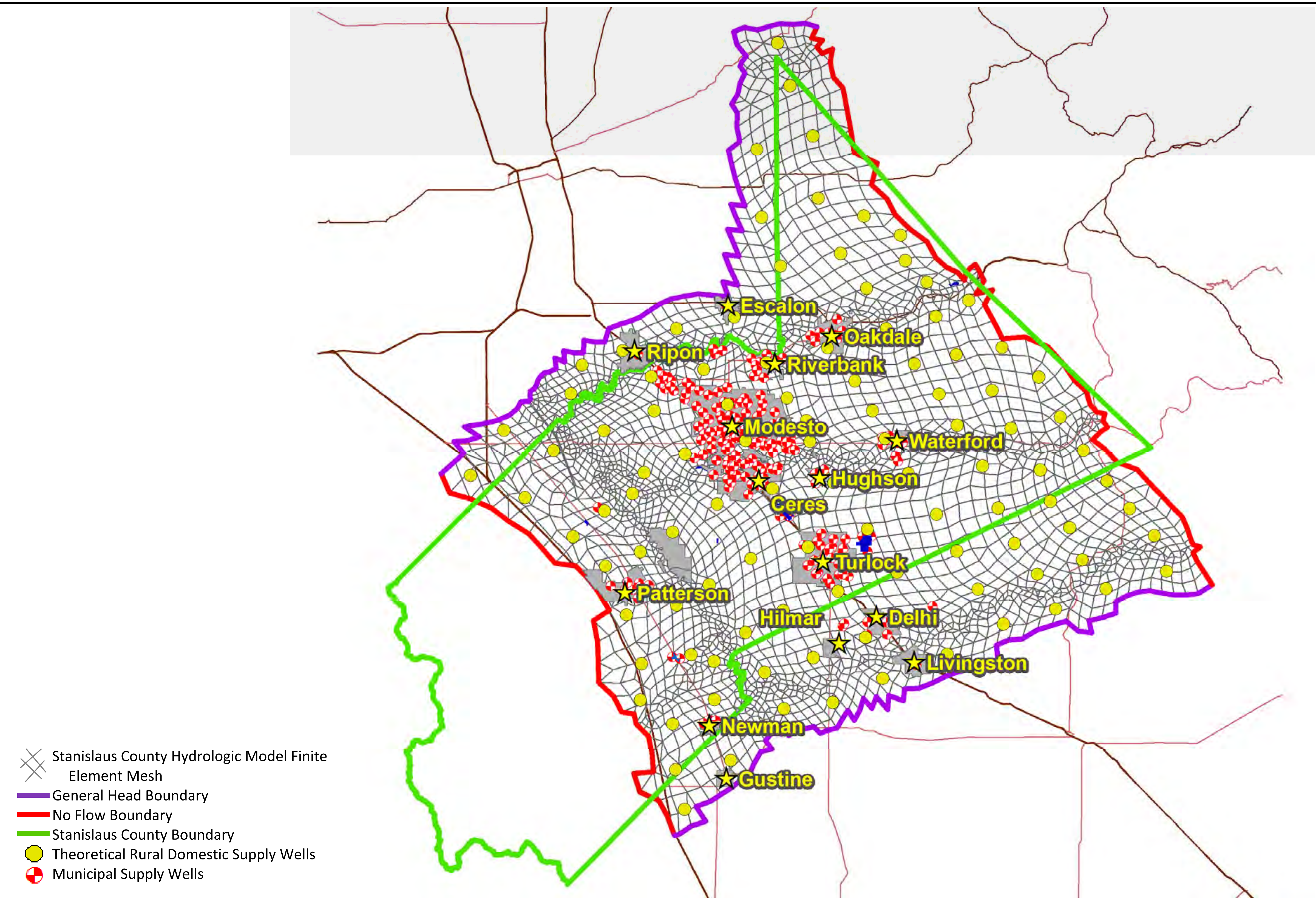
JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/17/17 | JH | MT |

*FIGURE 3-3*

***Surface Water Hydrologic Features within SCHM***



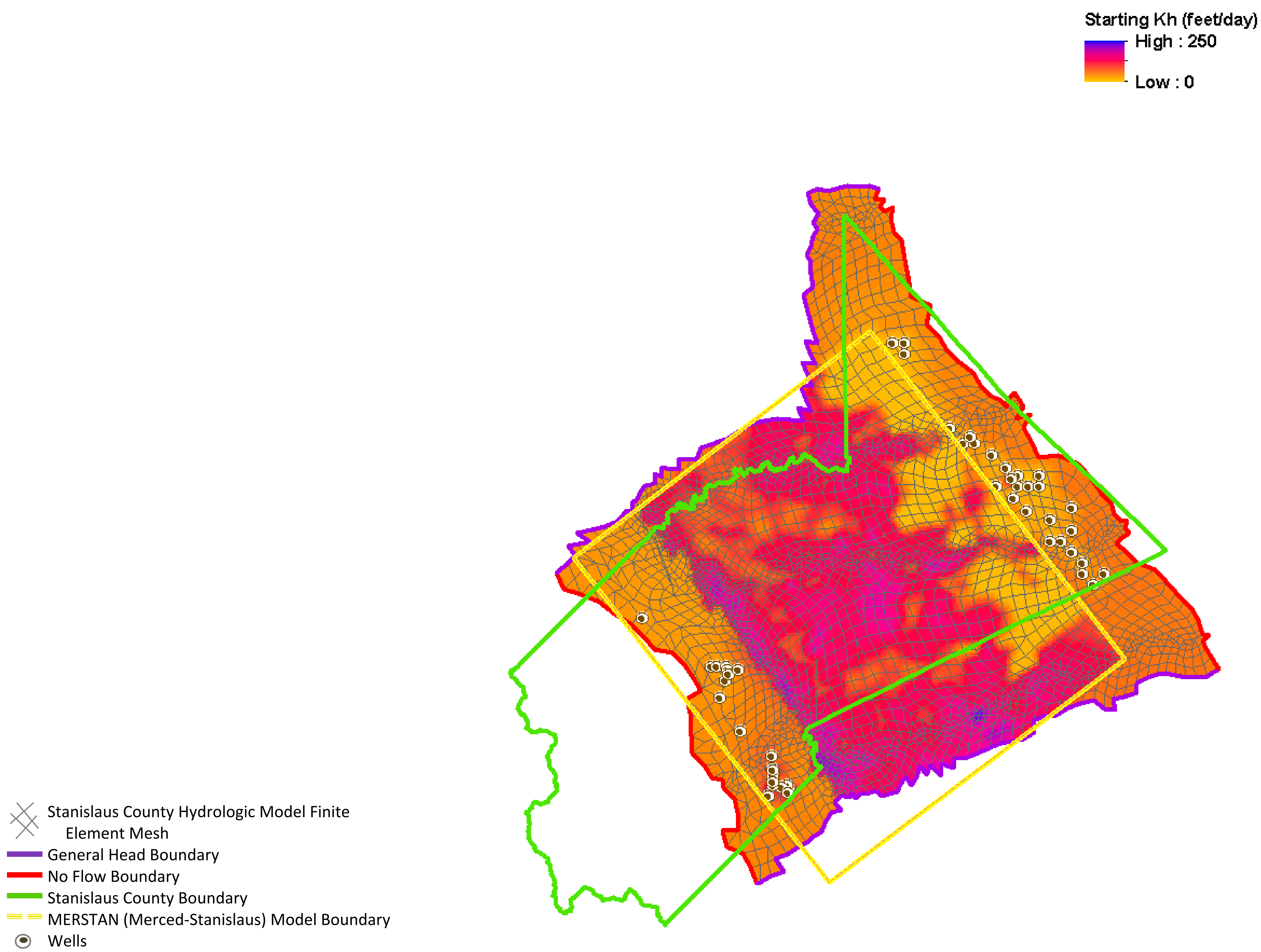

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/10/17 | JH | MT |

*FIGURE 3-4*

***Location of Municipal Supply Wells and Theoretical Rural Domestic Supply Wells within SCHM***




JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/17/17 | JH | MT |

*FIGURE 3-5*

***Development of Starting Hydraulic Conductivity for SCHM Layer 1***

# 4.0 CALIBRATION

## 4.1 Approach

Calibration of model parameters and inputs is an important and necessary step to improve a model's reliability to predict future conditions. The amount of effort that is appropriate for calibrating a groundwater flow model depends on its intended use (USGS, 2004a). In addition, because the response of a groundwater flow model to introduced stresses is a result of the interaction between a complex series of model inputs and parameters, a variety of adjustments may result in improved model calibration, but not all of them are necessarily realistic. Thus, it is possible to improve a model's calibration response without necessarily making it better reflect the actual conditions it is intended to simulate. For these reasons, the calibration effort focused on making manual adjustments to the model inputs and architecture, and it was decided to forego automated calibration using the Parameter Estimation (PEST) software package, which will not necessarily result in a unique solution. The following approach was taken to calibrate the SCHM:

- Because the current application of the SCHM is to evaluate the broad programmatic effects of groundwater well permitting using a superposition approach, the level of calibration judged to be appropriate is more limited than for a model used to evaluate the more localized effects of specific projects, or to develop sub-basin scale criteria for sustainable groundwater management as part of a GSP. Should more detailed application be required in the future, additional data refinement and calibration could be performed in specific areas of interest.
- Extensive local data have been compiled for construction of the SCHM; however, as discussed in Section 1.2, substantial uncertainties remain and much additional data are likely available to inform and refine future modeling efforts. For this reason, calibration efforts were focused on making changes that were consistent with our understanding of the model hydrogeology and water budget, and on documenting the remaining opportunities for additional refinement and calibration in the future. Calibration activities therefore focused on the following tasks:
    - Adjustments to the model water budget were made when comparison between the model water budget and data provided by local districts or available in water management plans indicated a discrepancy that needed correction.
    - Adjustments to model boundary conditions were implemented where significant discrepancies were observed between boundary heads extracted from C2VSim and near-boundary calibration wells.
    - Adjustments to aquifer parameters (lateral and vertical hydraulic conductivity) were made in an iterative fashion in areas where a bias in calibration results was observed, and where those adjustments were consistent with specific conceptual model refinements, i.e., where there was a specific hydrogeologic rationale for making the changes.

- Adjustments to streambed conductance and recharge distribution from small watersheds were made where surface water flow and groundwater level data indicated a discrepancy that could be related to surface/groundwater interaction.

## 4.2 Calibration Datasets

The following dataset of calibration wells and gaging stations was assembled to support the calibration process. Locations of these calibration points are shown on Figure 4-1.

- Sixty-three (63) calibration wells designed in C2VSim within the SCHM model domain were adopted as calibration wells for the model. Groundwater elevation data for these wells after WY 2009 (the current cutoff date in C2VSim) were obtained from the CASGEM database to complete the calibration dataset for these wells.
- One hundred one (101) additional calibration wells were selected from the CASGEM database for use in portions of the SCHM domain that were under-represented in the C2VSim calibration dataset.
- Seven gaging stations were selected from the USGS National Water Information System (NWIS) to represent inflows and outflows from the model along the major streams.

Each calibration well was evaluated for data quality and assigned to a particular model layer or layers. In a limited number of cases, data labeled as questionable by CASGEM were removed when individual data points appeared to be anomalous, but in most cases, all of the water level data were retained. At each well, predicted water levels in Model Layers 1 and 2 were compared to measured water levels, and the results were evaluated in relation to well depth and screen interval (when reported) and to data from nearby wells. In a number of cases, it was found that wells that penetrated to a completion depth within the deeper aquifer system (Layer 2) nevertheless displayed water levels that were more representative of the shallow aquifer system (Layer 1). This was especially the case in areas where groundwater levels in the upper aquifer system are significantly higher than in the deeper aquifer system, suggesting that the well screens or gravel packs are cross connecting the two aquifer systems and the hydraulic signal from the upper aquifer is dominating groundwater levels in the well. In such cases, the wells were assigned to Layer 1. Thirteen calibration (13) calibration wells were considered representative of groundwater levels in both Layers 1 and 2, and are designated and compared as separate wells in the calibration well data set.

## 4.3 Model Adjustments

### 4.3.1 Water Budget Adjustments

Because the water budget data compiled for development of the SCHM were considered the most reliable data for characterization of local conditions, the first step of model calibration consisted of comparing model water budget data to the compiled dataset, making adjustments where appropriate, and evaluating the effect of these changes on the groundwater level and surface water flow calibration results. Information regarding municipal surface water deliveries and groundwater pumping was considered reliable as entered into the model using the procedure summarized in Table 3-1, so efforts were focused primarily on refinement and calibration of the agricultural water budget using the procedure summarized in Table 3-3. These initial calibration steps were conducted as described below, and resulted in a substantial improvement in model conformance with historical calibration well groundwater levels and trends.

#### 4.3.1.1 Water Diversions and Deliveries

Surface water deliveries ascribed in the SCHM to each of the 17 water and irrigation and districts shown on Figure 2-1 were compared to data obtained from the districts or compiled from AWMPs, MSRs and other plans and reports as outlined in Table 3-3. This process was conducted iteratively, and effects on model calibration were evaluated at each step. Where discrepancies were noted, the diversions were adjusted, redistributed between the assigned water budget subareas, and/or the loss factors for the diversions were adjusted such that farm gate deliveries more closely approximated reported values. Consistent with the approach taken by the USGS to recent updates of the MERSTAN model, loss factors for some districts were adjusted downward when warranted by calibration data in order to compensate for the potential underestimation of deliveries.[8] For Modesto Irrigation District, water deliveries were allocated throughout the district's service areas in proportion to the delivery fractions reported in the USGS documentation for the MERSTAN model (USGS, 2004b). For TID, water deliveries were allocated throughout the district's service areas based on data provided by the district. The TID dataset was considered the most extensive and reliable provided, and after this initial calibration step, surface water deliveries in the SCHM were approximately 98% of reported farm gate deliveries. The final diversion and diversion loss values adopted in the SCHM are summarized in Tables 3-2 and 3-4, respectively.

#### 4.3.1.2 Land Use-Based Water Budget Data

The second step in the calibration process consisted of comparing the groundwater pumping calculated by the model in each water and irrigation district to reported pumping data obtained from the districts or compiled from AWMPs, MSRs and other plans and reports as outlined in Table 3-3. This process was conducted iteratively, and effects on model calibration were evaluated at each step. Where discrepancies were noted, the irrigated acreage and in some cases crop types were adjusted to align the pumping more closely with the reported values. The most extensive changes during this step were made in the eastern, foothill portion of the model, and changes were made in consideration of aerial imagery that confirmed changes in cropping patterns, and a geospatial analysis cropping trends in eastern, non-district lands provided by the Stanislaus County Agricultural Commissioner (Appendix A).

#### 4.3.1.3 Initial and Boundary Heads

After implementation of refinements to the diversions and cropping were made, the assigned heads for the time-dependent head boundaries were adjusted to match nearby historical data as needed so as to minimize potential boundary effects. This was accomplished by examining data for calibration wells located near the

[8] Per personal communication from Stephen Phillips, USGS, in November 2017 with Walter Ward.

SCHM northern and southern general head boundaries, and interpolating boundary node head elevations based on nearby spatial and temporal water level data. The resulting adjusted boundary heads were loaded into the model files.

### 4.3.2 Reservoirs and Small Watersheds

After the initial calibration steps, it was found that predicted groundwater levels near and downgradient of Turlock Lake were consistently higher than calibration well groundwater levels. Since the calculated leakage from Turlock Lake was significantly higher than leakage rates reported and calculated for Woodward and Modesto Reservoirs, it was decided to decrease the recoverable losses from Turlock Lake from 100% to 33%. This change improved the calibration for wells in this region.

Recharge from small watersheds was adjusted in areas where, based on calibration results, the known hydrology and hydrogeology of the area, and professional judgment, recharge had either been over or underestimated. This primarily consisted of increasing recharge in proximal alluvial fan areas along the Diablo range near the western no-flow boundary of the model, and in the northern triangle area of the County, where local investigations have indicated that recharge from small streams is more prominent than was reflected in the existing version of C2VSim (JJ&A, 2016a and 2017a). In addition, recharge from small streams along the southeastern no-flow boundary of the model appeared to be overestimated when compared to similar areas further north. In order to adjust recharge form small watersheds, recharge nodes within the model domain were added or moved as deemed appropriate based on local scale geology, and the maximum recharge assigned to the nodes was altered (increased or decreased, as appropriate). This process was conducted iteratively, and effects on model calibration were evaluated at each step.

### 4.3.3 Streambed Conductance

Next, stream discharge predicted by the model at river nodes corresponding to the calibration gaging stations was compared to actual gaging station data. Adjustments were made to the hydraulic conductivity term of the streambed conductance in groundwater-connected reaches upstream of gaging stations where a bias was observed between actual and predicted data. This process was conducted iteratively, and the effects on model calibration were evaluated at each step.

### 4.3.4 Aquifer Hydraulic Conductivity

As a final calibration step, targeted manual changes were made to the model hydraulic conductivity of Layers 1 and/or 2. These changes were implemented in areas where a bias was noted in the model to either under- or over-predict groundwater levels, and a rational hydrogeologic explanation could be made to justify the adjustment that did not contradict the findings of prior studies. Within the portion of the SCHM where hydraulic conductivities were extracted from the MERSTAN model (which were based on extensive and detailed geostatistical evaluation of aquifer textural data), care was taken to target changes to follow areas where the prior analysis could have produced a bias (such as through end-point scaling of permeability) and not to randomly make changes simply based on calibration results. Changes were broadly applied to aquifer vertical hydraulic conductivity, which was more poorly constrained by data. Outside the area of the MERSTAN model, changes to the initial model hydraulic conductivity were more liberally applied based on calibration data, with care being taken that they follow the local hydrogeologic conceptual understanding and match conditions in the adjacent MERSTAN area. This process was conducted iteratively, and effects on model calibration were evaluated at each step. It was clearly evident that the effect of hydraulic conductivity on model performance was both locally and regionally complex, and that multiple adjustments could result in "improved" model calibration, without necessarily being a better representation of actual aquifer conditions. It was therefore decided that less focus would be based on parameter adjustment than on water budget adjustment during the calibration process. For this reason, calibration was continued only until the objectives for use of the model for programmatic impact assessment under the PEIR were met. Automated calibration using PEST was not performed, and iterative parameter calibration was limited pending the collection of additional data by workers involved in GSP development that would help to guide the direction of further calibration.

### 4.3.5 Aquitard Vertical Hydraulic Conductivity

The vertical permeability of the regional Corcoran Clay aquitard and its local variation are poorly understood in the SCHM area and has a profound effect on local groundwater flow patterns. Permeability can vary locally and can be changed by artificial penetrations such as composite wells, absence of well seals, damaged wells, or cross connections created by unsealed boreholes. Adjustments were made to the Corcoran Clay vertical permeability where calibration data indicated that either more or less vertical flow across this aquitard may be locally occurring than represented by the assumed uniform hydraulic conductivity in the SCHM. This process was conducted iteratively, and effects on model calibration were evaluated at each step. Similar to aquifer hydraulic conductivity, it was evident that the effect of aquitard hydraulic conductivity on model performance was both locally and regionally complex, that multiple combinations of adjustments could result in the same "improvements" in model calibration. Adjustment of this parameter was therefore focused on the objective of using the model as a programmatic impact assessment tool for the PEIR.

## 4.4 Calibration Results

### 4.4.1 Groundwater Level Calibration Results

Figures 4-2 and 4-3 show plots of the measured vs. the predicted water levels and the residual vs. the measured water levels in each calibration well, respectively. The plots on Figure 4-2 clearly show a clustering of results near the 1:1 correlation line, indicating that at many times and locations the model results are well aligned with historical results. Overall, more points tend to fall below the lines, indicating a slight overall bias of the model to under-predict heads. The clustering of points in bands reflects a bias to either over or under-predict that is associated with particular areas in the model. The biases in these areas could likely be corrected through additional investigation into local conditions and refinement of the model. At some calibration wells, the model under or overpredicts actual heads by several tens of feet. Calibration statistics for the final calibrated model are summarized in Table 4-1, below.

**Table 4-1: Summary of Calibration Statistics**

| Calibration Statistic | Layer 1 Value | Layer 2 Value |
|---|---|---|
| Residual Mean | 3.89 feet (ft) | 7.37 ft |
| Residual Standard Deviation | 19.59 ft | 26.24 ft |
| Mean Absolute Error | 13.26 ft | 22.57 ft |
| Mean Error | 3.90 ft | 7.37 ft |
| Minimum Residual | -117.05 ft | -114.73 ft |
| Maximum Residual | 76.26 ft | 78.56 ft |
| Range in Target Heads | 236.76 ft | 236.76 ft |
| (Standard Deviation) / (Range) | 8.4 % | 11.1 % |
| (Mean Absolute Error) / (Range) | 5.6 % | 9.5 % |
| (Mean Error) / Range | 1.6 % | 3.1 % |
| Nash-Sutcliffe Coefficient | 0.60 | 0.34 |

Appropriate calibration goals vary with the type of model and its application (Anderson and Woessner, 2002). A model that requires a high degree of accuracy in predicting actual heads and flow will require a higher degree of calibration; whereas, a lower degree of calibration is often acceptable for model that is used in superposition mode. This is especially true when the degree of resolution of the model is lower, such as when a model is used to assess program level changes caused by different scenarios. In all cases, the limitations of a model must be known in order to properly use the model and interpret its results. Generally accepted goals for Standard Deviation/Range and Absolute Mean Error/Range are approximately 10%, and a generally acceptable goal for Mean Error/Range is 5%. Nash-Sutcliffe values greater than 0.5 are generally considered acceptable, values less than 0.5 may be acceptable depending on the model application, and values greater than 0 indicate that calibrated model input values are better predictors of conditions than regional averages (Anderson and Woessner, 2002). The above statistics indicate that the model calibration may be considered acceptable for the evaluation of program-level impacts using a superposition approach, which is the primary application of this model (Section 1.2). Quantitative water budget results, predicted heads and stream flows derived from this version of the SCHM and presented in this TM should be considered indicative based on the known limitations of the model. Other objectives, such as development of sustainable groundwater management criteria, or evaluating the effects of specific projects, may require a greater degree of model refinement and calibration, and potentially a more refined model grid. Such refinements could be targeted at the model subareas where more rigorous data are needed.

### 4.4.2 Stream Discharge Calibration Results

A comparison of predicted stream discharge and corresponding measurements at the seven selected calibration gaging stations (Table 4-2) is provided in Figures 4-4 and 4-5. As shown in the figure, the predicted and observed stream flows at the gaging stations are closely correlated, with the following exceptions:

- Discharge on the Tuolumne River at the Modesto gaging station is somewhat overpredicted by the model during low flow periods, indicating that groundwater discharge to the river may also be overpredicted.
- At the gaging station on Orestimba Creek, which is located near its confluence with the San Joaquin River, the model significantly under-predicts flow. This is due to the fact that in this area model heads in Layer 1 are under-predicted relative to measured groundwater levels at nearby calibration wells, and as a result the stream is modeled as being disconnected from the groundwater table. Data from nearby calibration wells suggests that in fact Orestimba Creek is groundwater connected and gaining in its middle and lower reaches. This was accepted as a model limitation that should be addressed during future modeling efforts when additional data are available or evaluations conducted to select the appropriate approach to improving the calibration.

## 4.5 Calibrated Historical Model Results

### 4.5.1 Hydraulic Conductivity

The final lateral hydraulic conductivity distribution for Model Layers 1, 2, and 3 is shown in Figure 4-6. The model retains many of the characteristics of the original hydraulic conductivity distribution extracted from the MERSTAN with local adjustments, and more significant refinements to the original C2VSim hydraulic conductivity outside the MERSTAN model domain boundaries and west of the San Joaquin River. In general, areas of higher hydraulic conductivity are concentrated in Layer 1 near the current river corridors.

### 4.5.2 Groundwater Levels and Flow

Simulated groundwater level elevations for Model Layers 1 and 2 are shown for 2000 and 2015 in Figure 4-7 and Figure 4-8, respectively. Groundwater levels and flow directions are generally consistent with historical maps available from DWR through the Groundwater Information Center Interactive Mapping Application (DWR, 2017b). In general, groundwater flows away from the Sierra Nevada and the Diablo Range toward the San Joaquin River, and then northward along the valley axis. A prominent cone of depression is evident in the eastern Turlock Subbasin. Contours near the major streams in the Study area suggest both gaining and losing reaches where prior studies have generally determined they should be located (USGS, 2004b and 2015).

### 4.5.3 Groundwater Budget

The final, calibrated model diversions are summarized in Tables 3-2 and 3-4, and the water budget for WY 2000, 2005, 2010 and 2015, broken down by subbasin, is summarized in Table 4-3. As noted above, these water budget data should be considered indicative and preliminary; however, the following key observations may be made:

- Both increases and decreases in simulated groundwater storage were observed in the Study Area during the historical evaluation period of the model (WY 2000 to WY 2015). Simulated storage changes are related to variations in hydrologic conditions, the amount of surface water available for irrigation, and the amount of groundwater pumping. As expected, the greatest storage depletions were observed in 2015, at the height of the recent drought.
- Simulated groundwater recharge from streams has generally increased (groundwater discharge to streams has decreased) in the Modesto and Turlock Subbasins. This is consistent with data summarized in Table 4-4, which indicates that simulated groundwater discharge to the Merced, Stanislaus and Tuolumne Rivers is decreasing over time.
- There is a decrease in simulated deep percolation over time across the Study Area.
- A decrease in simulated net underflow into the Turlock Subbasin is evident over time, as discussed in greater detail in Section 4.5.4, below.
- There is an increase in simulated net underflow over time out of the portion of the Eastern San Joaquin Subbasin that lies within the SCHM. A portion of this increase may be related to flow southward into the Modesto Subbasin, as discussed in greater detail in Section 4.5.4, below, but a portion may also be associated with underflow across the county boundary to the west out of the Study Area.
- Simulated agricultural pumping accounts for 80 to 89% of groundwater extraction in the Study Area, and has been variable and dependent on the amount of surface water available for irrigation. The highest agricultural pumping rates were observed at the height of the recent drought during WY 2015. No clear trends are evident, except in the Eastern San Joaquin Subbasin, where a steady increase in agricultural pumping is evident. This trend is consistent with conversion of rangeland to irrigated agriculture in the eastern foothill area of the model during this time period.
- Simulated municipal pumping accounts for 9 to 18% of groundwater extraction in the Study Area, with more limited variability in actual pumping rates than agricultural pumping rates (approximately 90,000 to 110,000 AFY). Pumping rates were generally lowest in 2015, likely due to the effect of water conservation measures that were implemented during the drought.
- Simulated rural domestic pumping accounts for just 1 to 2% of total groundwater extraction in the Study Area, and was modeled to increase with increasing rural population over time.

### 4.5.4 Interbasin Flows

Interbasin flows simulated between the subbasins that underlie the SCHM domain in WY 2000, 2005, 2010 and 2015 are summarized in Table 4-5. As noted above, these water budget data should be considered indicative and preliminary; however, the following key observations may be made:

- Turlock Subbasin. Underflow into the Turlock Subbasin occurs from the Merced Subbasin to the south and the Modesto Subbasin to the north. Simulated underflow from the Merced Subbasin decreases over time, and the net direction of simulated underflow in Layer 1 reverses direction from northward to southward between WY 2010 and WY 2015. Simulated underflow southward into the Turlock Subbasin from the Modesto Subbasin is variable and does not display a distinct trend, although the rate is greatest in WY 2015, at the height of the recent drought. Simulated underflow out of the Turlock Subbasin is less than underflow in, occurs to the Delta-Mendota Subbasin to the west, and displays a generally increasing trend over time.
- Modesto Subbasin. Underflow into the Modesto Subbasin occurs from the Eastern San Joaquin Subbasin to the north. Simulated underflow from the Eastern San Joaquin Subbasin decreases over time in Layer 1, but does not display a distinct trend in Layer 2. Simulated underflow out of the Modesto Subbasin is greater than underflow in, and occurs to the Turlock Subbasin to the south and the Delta-Mendota Subbasin to the west. Distinct trends in the rate of underflow out of the subbasin are not evident, but the greatest rate of underflow out was simulated in WY 2015, at the height of the recent drought.
- Delta-Mendota Subbasin. Underflow into the portion of the Delta-Mendota Subbasin in the Study Area is simulated to occur in Layer 1 primarily from the Modesto and Turlock Subasins to the east. In Layer 2, underflow into the subbasin is simulated to occur primarily from the Modesto and Turlock Subbasins to the east, and the Tracy Subbasin to the north. It should be noted that there are few calibration wells in the SCHM in the northern portion of the Delta-Mendota Subbasin, so that groundwater levels and flow directions in the confined aquifer system in this area may need further confirmation and the model may require refinement before drawing conclusions regarding cross boundary flows between the Delta-Mendota and Tracy Subbasins. Simulated underflow into the Delta-Mendota Subbasin from the Turlock and Modesto Subbasins displays a generally increasing trend over time. The SCHM does not simulate any significant outflow from the Delta-Mendota Subbasin.
- Eastern San Joaquin Subbasin. The SCHM does not simulate any significant underflow into the portion of the Eastern San Joaquin Subbasin in the Study Area. Underflow out of the portion of the Eastern San Joaquin Subbasin in the Study Area is simulated to occur primarily into the Modesto Subbasin to the south. The simulated rate of underflow out is variable, but generally increasing over time.

**TABLE 4-2**
**NWIS GAGING STATION SUMMARY**
**Stanislaus County Hydrologic Model: Development and Forecast Modeling**
**Stanislaus County, California**

| Gaging Station ID | Station Name | USGS Code | Elevation | Latitude | Longitude | Nearby City |
|---|---|---|---|---|---|---|
| NEW | SAN JOAQUIN RIVER NEAR NEWMAN | 11274000 | 90 | 37.3504944 | -120.97715 | NEWMAN |
| VNS | SAN JOAQUIN RIVER NEAR VERNALIS | 11303500 | 35 | 37.6760406 | -121.26633 | MODESTO |
| OCL | ORESTIMBA CK AT RIVER RD NR CROWS LNDG | 11274538 | 65 | 37.4135475 | -121.01604 | CROWS LANDING |
| MOD | TUOLUMNE RIVER AT MODESTO | 11290000 | 90 | 37.6272222 | -120.98333 | MODESTO |
| LGN | TUOLUMNE R BLW LA GRANGE DAM NR LA GRANG | 11289650 | 170 | 37.6663208 | -120.44214 | LA GRANGE |
| RIP | STANISLAUS RIVER AT RIPON | 11303000 | 73 | 37.7296524 | -121.1105 | RIPON |
| FFB[a] | SAN JOAQUIN R AT FREMONT FORD BRIDGE | 11261500 | -- | 37.31 | -120.93 | STEVINSON |

Notes:
[a] Gaging Station ID made for purposes of this project, since USGS did not have an ID for this station.
ID = identification
NWIS = National Water Information System
-- = not available

**TABLE 4-3**
**HISTORICAL WATER BUDGET SUMMARY**
**Stanislaus County Hydrologic Model: Development and Forecast Modeling**
**Stanislaus County, California**

| Subbasin | Groundwater Budget Component | Water Budget (acre-feet) | | | |
|---|---|---|---|---|---|
| | | WY 2000 | WY 2005 | WY 2010 | WY 2015 |
| Delta-Mendota Subbasin (within Stanislaus County) | Recharge from Diversion Losses | 10,547 | 9,488 | 11,147 | 6,444 |
| | Net Inflow from (+) or Discharge to (-) Streams | (29,475) | 4,376 | (3,864) | (22,346) |
| | Deep Percolation to Groundwater | 67,311 | 61,418 | 50,278 | 36,694 |
| | Net Underflow In (+)/Out (-) | 81,771 | 87,392 | 77,470 | 115,884 |
| | Agricutrual Pumping | (127,880) | (116,935) | (85,345) | (233,864) |
| | Municipal Pumping | (4,788) | (6,038) | (6,394) | (5,644) |
| | Rural Domestic Pumping | (1,371) | (1,394) | (1,416) | (1,467) |
| | Change in Storage | (3,885) | 38,276 | 41,826 | (103,399) |
| Eastern San Joaquin Subbasin (within Stanislaus County) | Recharge from Diversion Losses | 24,054 | 22,847 | 24,393 | 18,783 |
| | Net Inflow from (+) or Discharge to (-) Streams | 31,547 | 35,358 | 37,407 | 45,762 |
| | Deep Percolation to Groundwater | 5,406 | 4,430 | 3,684 | 3,363 |
| | Net Underflow In (+)/Out (-) | (30,743) | (29,520) | (34,644) | (35,972) |
| | Agricultural Pumping | (15,605) | (23,729) | (30,489) | (66,315) |
| | Municipal Pumping | 0 | 0 | 0 | 0 |
| | Rural Domestic Pumping | (721) | (731) | (744) | (770) |
| | Change in Storage | 13,940 | 8,654 | (391) | (35,149) |
| Modesto Subbasin | Recharge from Diversion Losses | 87,929 | 89,008 | 58,427 | 48,250 |
| | Net Inflow from (+) or Discharge to (-) Streams | (95,648) | (57,089) | (37,691) | (410) |
| | Deep Percolation to Groundwater | 217,823 | 220,820 | 175,652 | 127,100 |
| | Net Underflow In (+)/Out (-) | (94,378) | (82,764) | (89,335) | (88,920) |
| | Agricultural Pumping | (54,557) | (56,333) | (53,410) | (170,892) |
| | Municipal Pumping | (48,696) | (54,394) | (45,268) | (45,968) |
| | Rural Domestic Pumping | (5,492) | (5,580) | (5,673) | (5,870) |
| | Change in Storage | 6,981 | 53,667 | 2,702 | (136,711) |
| Turlock Subbasin | Recharge from Diversion Losses | 99,026 | 117,519 | 78,750 | 50,478 |
| | Net Inflow from (+) or Discharge to (-) Streams | (110,378) | (35,190) | 7,689 | 16,058 |
| | Deep Percolation to Groundwater | 203,485 | 213,196 | 173,297 | 127,576 |
| | Net Underflow In (+)/Out (-) | 203,262 | 184,370 | 117,343 | 74,319 |
| | Agricultural Pumping | (337,533) | (289,579) | (277,113) | (405,274) |
| | Municipal Pumping | (45,825) | (47,978) | (44,238) | (38,199) |
| | Rural Domestic Pumping | (5,667) | (5,853) | (5,853) | (6,058) |
| | Change in Storage | 6,369 | 136,580 | 49,874 | (181,102) |
| Grand Total SCHM Primary Focus Area | Recharge from Diversion Losses | 221,557 | 238,861 | 172,716 | 123,954 |
| | Net Inflow from (+) or Discharge to (-) Streams | (203,954) | (52,546) | 3,540 | 39,064 |
| | Deep Percolation to Groundwater | 494,024 | 499,864 | 402,912 | 294,733 |
| | Net Underflow In (+)/Out (-) | 159,912 | 159,478 | 70,834 | 65,310 |
| | Agricultural Pumping | (535,574) | (486,577) | (446,357) | (876,345) |
| | Municipal Pumping | (99,309) | (108,410) | (95,899) | (89,812) |
| | Rural Domestic Pumping | (13,251) | (13,558) | (13,686) | (14,164) |
| | Change in Storage | 23,405 | 237,177 | 94,012 | (456,361) |

Notes:
SCHM = Stanislaus County Hydrologic Model
WY = water year

**TABLE 4-4**
**HISTORICAL STREAMFLOW GAIN/LOSS**
**Stanislaus County Hydrologic Model: Development and Forecast Modeling**
**Stanislaus County, California**

| Stream Reach | Gain/Loss from Groundwater (acre-feet/year) [1] | | | |
|---|---|---|---|---|
| | WY 2000 | WY 2005 | WY 2010 | WY 2015 |
| Merced River | 10,929 | (49,573) | (117,162) | (122,373) |
| Orestimba Creek [2] | (10,477) | (20,986) | (18,053) | (5,827) |
| San Joaquin River | 79,513 | 33,288 | 43,864 | 60,340 |
| Stanislaus River | (2,820) | (9,329) | (35,801) | (85,214) |
| Tuolumne River | 156,597 | 101,418 | 76,181 | 40,841 |

Notes:
[1] Based on the level of model calibration, streamflow gain/loss values should be considered indicative.
[2] Hydrograph calibration for Orestimba Creek is relatively poor; therefore the results for this stream should not be considered indicative.
WY = water year

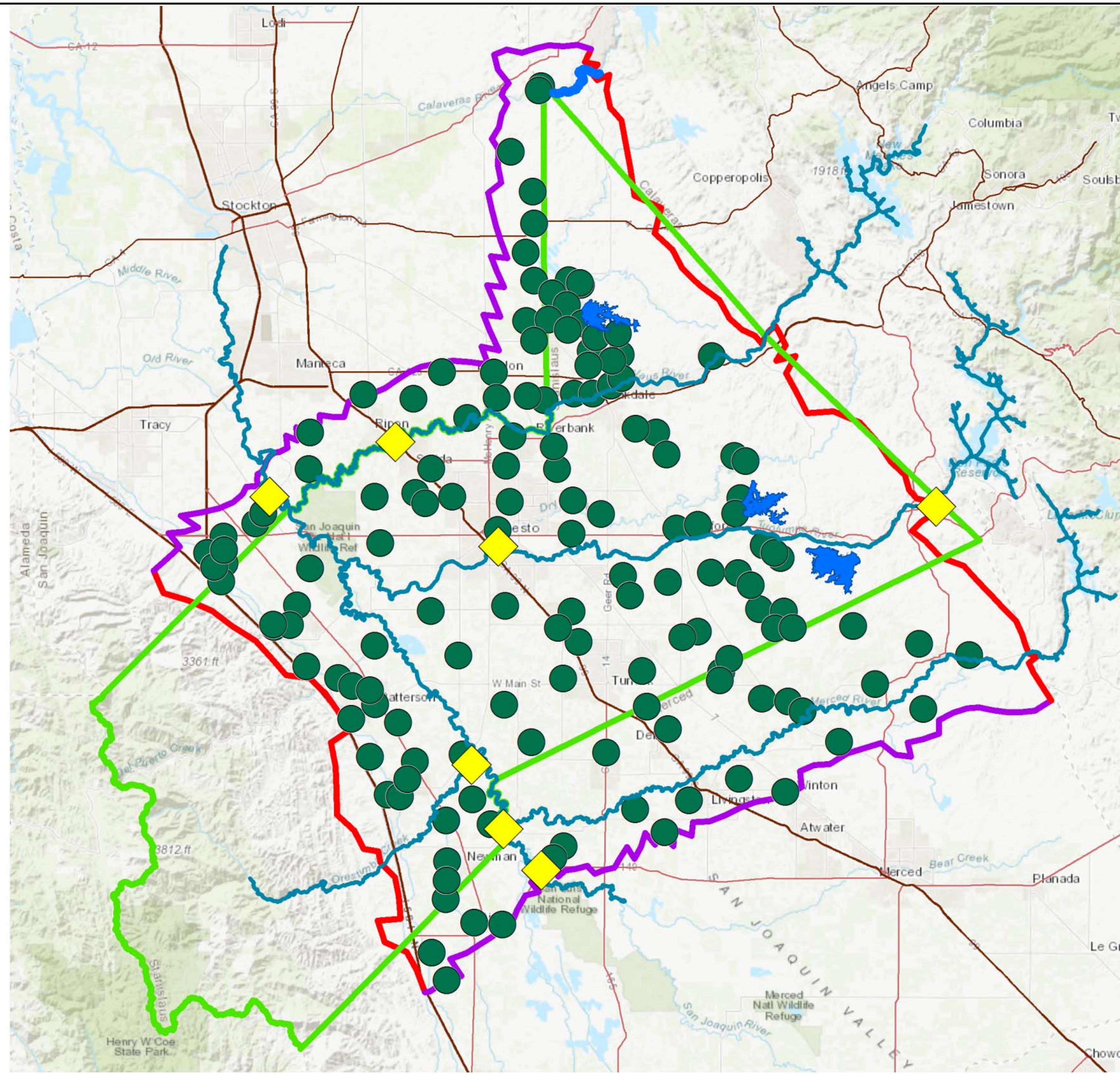
| LAYER 1 (by WY) | | | | | | |
|---|---|---|---|---|---|---|
| *2000* | | | | | | |
| Flow From | Flow To (AC-FT) | | | | | |
| Subbasin Name | MERCED | TURLOCK | DELTA-MENDOTA | MODESTO | TRACY | EASTERN SAN JOAQUIN |
| MERCED | -- | 42,219 | -- | -- | -- | -- |
| TURLOCK | -- | -- | 7,340 | -- | -- | -- |
| DELTA-MENDOTA | 4,178 | -- | -- | -- | 69 | -- |
| MODESTO | -- | 18,722 | 2,230 | -- | -- | -- |
| TRACY | -- | -- | -- | -- | -- | -- |
| EASTERN SAN JOAQUIN | -- | -- | -- | 2,097 | 1,730 | -- |
| *2005* | | | | | | |
| Flow From | Flow To (AC-FT) | | | | | |
| Subbasin Name | MERCED | TURLOCK | DELTA-MENDOTA | MODESTO | TRACY | EASTERN SAN JOAQUIN |
| MERCED | -- | 31,585 | -- | -- | -- | -- |
| TURLOCK | -- | -- | 10,229 | -- | -- | -- |
| DELTA-MENDOTA | 1,189 | -- | -- | -- | -- | -- |
| MODESTO | -- | 20,759 | 1,780 | -- | -- | -- |
| TRACY | -- | -- | 192 | -- | -- | -- |
| EASTERN SAN JOAQUIN | -- | -- | -- | 4,960 | 1,962 | -- |
| *2010* | | | | | | |
| Flow From | Flow To (AC-FT) | | | | | |
| Subbasin Name | MERCED | TURLOCK | DELTA-MENDOTA | MODESTO | TRACY | EASTERN SAN JOAQUIN |
| MERCED | -- | 1,871 | 523 | -- | -- | -- |
| TURLOCK | -- | -- | 11,665 | -- | -- | -- |
| DELTA-MENDOTA | -- | -- | -- | -- | -- | -- |
| MODESTO | -- | 22,155 | 1,767 | -- | -- | -- |
| TRACY | -- | -- | 59 | -- | -- | -- |
| EASTERN SAN JOAQUIN | -- | -- | -- | 3,743 | 1,910 | -- |
| *2015* | | | | | | |
| Flow From | Flow To (AC-FT) | | | | | |
| Subbasin Name | MERCED | TURLOCK | DELTA-MENDOTA | MODESTO | TRACY | EASTERN SAN JOAQUIN |
| MERCED | -- | -- | -- | -- | -- | -- |
| TURLOCK | 30,451 | -- | 14,174 | -- | -- | -- |
| DELTA-MENDOTA | 1,154 | -- | -- | -- | -- | -- |
| MODESTO | -- | 20,884 | 2,633 | -- | -- | -- |
| TRACY | -- | -- | 363 | -- | -- | -- |
| EASTERN SAN JOAQUIN | -- | -- | -- | 5,181 | 3,060 | -- |

| LAYER 2 (by WY) | | | | | | |
|---|---|---|---|---|---|---|
| *2000* | | | | | | |
| Flow From | Flow To (AC-FT) | | | | | |
| Subbasin Name | MERCED | TURLOCK | DELTA-MENDOTA | MODESTO | TRACY | EASTERN SAN JOAQUIN |
| MERCED | -- | 28,225 | -- | -- | -- | -- |
| TURLOCK | -- | -- | 8,026 | -- | -- | -- |
| DELTA-MENDOTA | 86 | -- | -- | -- | -- | -- |
| MODESTO | -- | 50,295 | 9,093 | -- | -- | -- |
| TRACY | -- | -- | 17,420 | -- | -- | -- |
| EASTERN SAN JOAQUIN | -- | -- | -- | 13,170 | 2,018 | -- |
| *2005* | | | | | | |
| Flow From | Flow To (AC-FT) | | | | | |
| Subbasin Name | MERCED | TURLOCK | DELTA-MENDOTA | MODESTO | TRACY | EASTERN SAN JOAQUIN |
| MERCED | -- | 26,432 | -- | -- | -- | -- |
| TURLOCK | -- | -- | 8,468 | -- | -- | -- |
| DELTA-MENDOTA | 516 | -- | -- | -- | -- | -- |
| MODESTO | -- | 47,942 | 9,477 | -- | -- | -- |
| TRACY | -- | -- | 20,505 | -- | -- | -- |
| EASTERN SAN JOAQUIN | -- | -- | -- | 13,167 | 197 | -- |
| *2010* | | | | | | |
| Flow From | Flow To (AC-FT) | | | | | |
| Subbasin Name | MERCED | TURLOCK | DELTA-MENDOTA | MODESTO | TRACY | EASTERN SAN JOAQUIN |
| MERCED | -- | 10,570 | 1,091 | -- | -- | -- |
| TURLOCK | -- | -- | 11,653 | -- | -- | -- |
| DELTA-MENDOTA | -- | -- | -- | -- | -- | -- |
| MODESTO | -- | 46,365 | 9,850 | -- | -- | -- |
| TRACY | -- | -- | 15,431 | -- | -- | -- |
| EASTERN SAN JOAQUIN | -- | -- | -- | 7,433 | 1,708 | -- |
| *2015* | | | | | | |
| Flow From | Flow To (AC-FT) | | | | | |
| Subbasin Name | MERCED | TURLOCK | DELTA-MENDOTA | MODESTO | TRACY | EASTERN SAN JOAQUIN |
| MERCED | -- | 2,575 | 2,343 | -- | -- | -- |
| TURLOCK | -- | -- | 18,026 | -- | -- | -- |
| DELTA-MENDOTA | -- | -- | -- | -- | -- | -- |
| MODESTO | -- | 54,142 | 16,225 | -- | -- | -- |
| TRACY | -- | -- | 31,620 | -- | -- | -- |
| EASTERN SAN JOAQUIN | -- | -- | -- | 18,533 | 3,796 | -- |

Notes:
AC-FT = acre feet
WY = water year



JACOBSON | JAMES & associates, inc




Map Source: Esri, HERE, DeLorme, Tom Tom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, OpenStreetMap contributors, and the GIS User Community

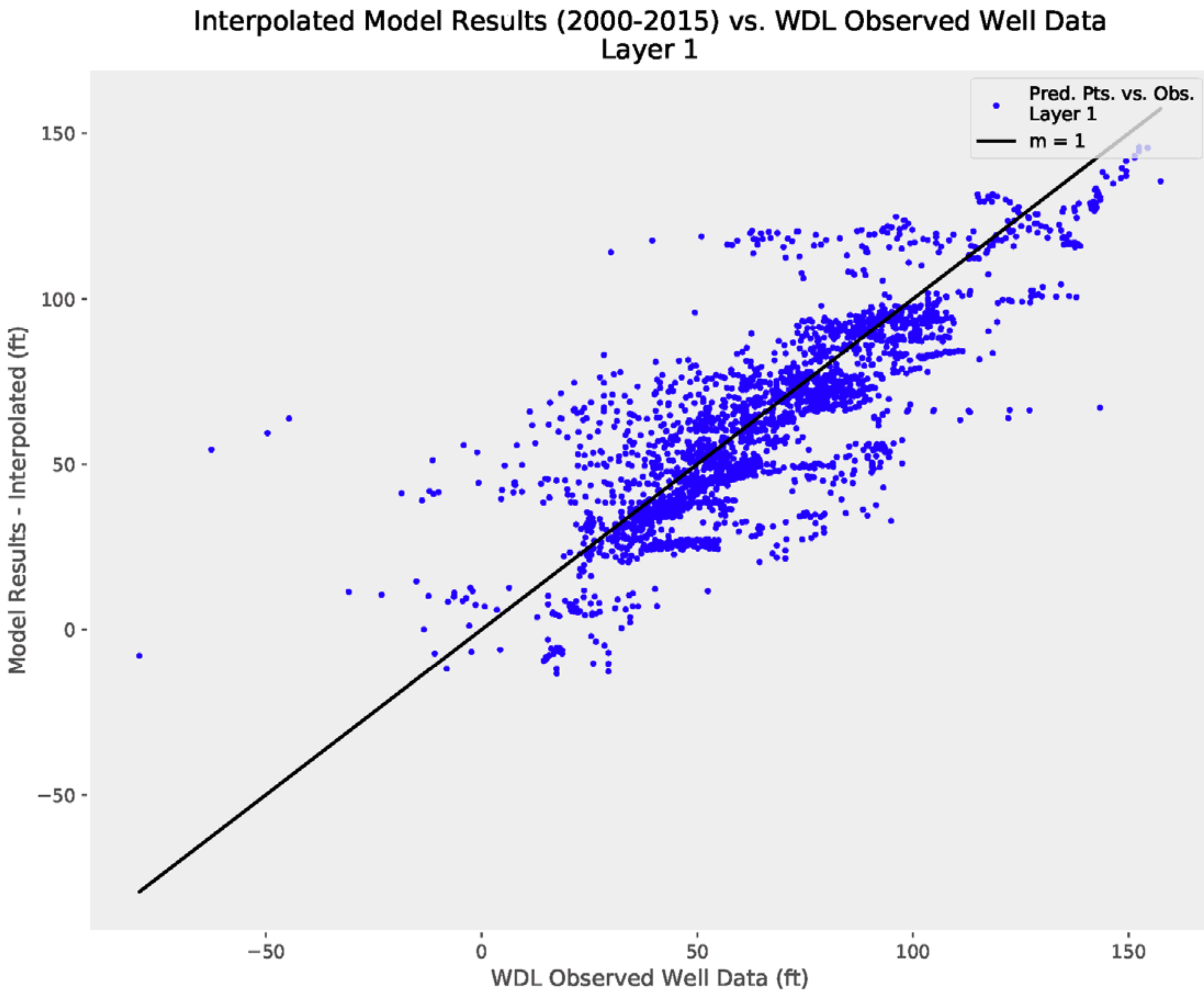
JACOBSON | JAMES & associates, inc

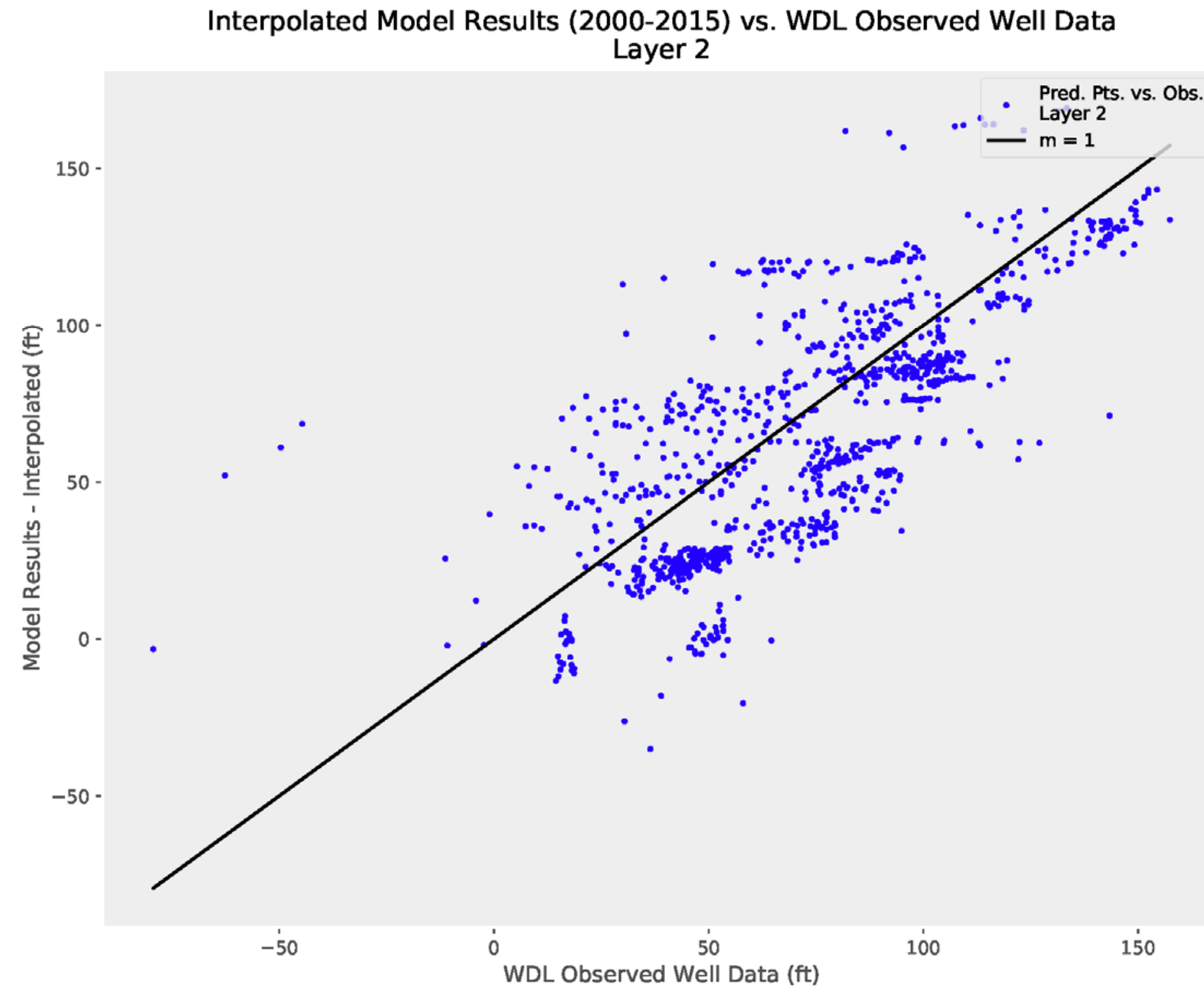
*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.001 | 11/10/17 | JH | MT |

*FIGURE 4-1*

***Locations of Calibration Gaging Stations and Calibration Wells within SCHM***




Notes:
ft = foot
WDL = Water Data Library
Modeled water level data were predicted monthly and interpolated to actual WDL measurement dates

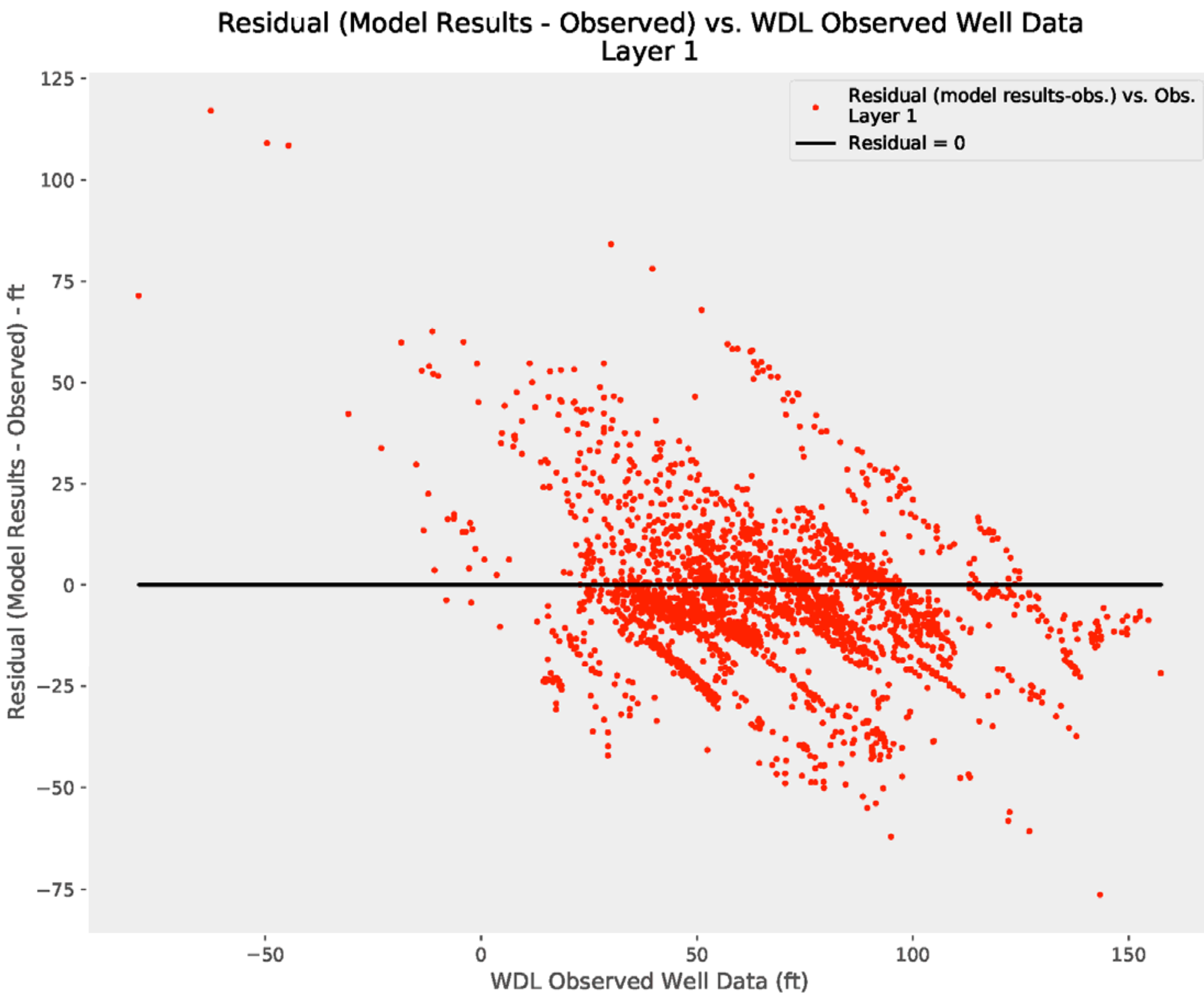
JACOBSON | JAMES & associates, inc

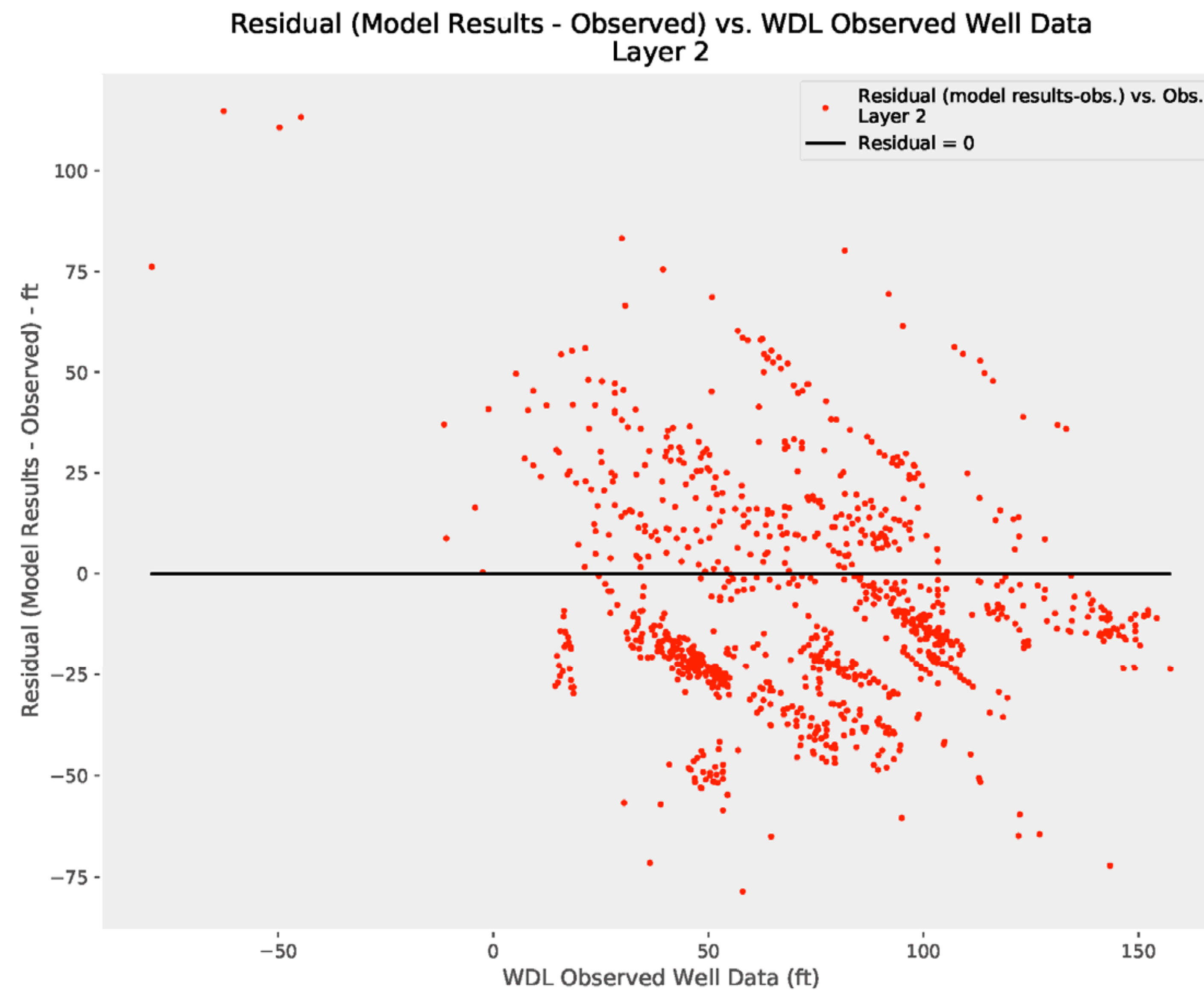
*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| *STANCO.002* | *11/17/17* | *JH* | *MT* |

*FIGURE 4-2*

***Measured versus Predicted Water Levels for SCHM Layers 1 and 2***




Notes:
ft = foot
WDL = Water Data Library
Modeled water level data were predicted monthly and interpolated to actual WDL measurement dates prior to calculating residuals

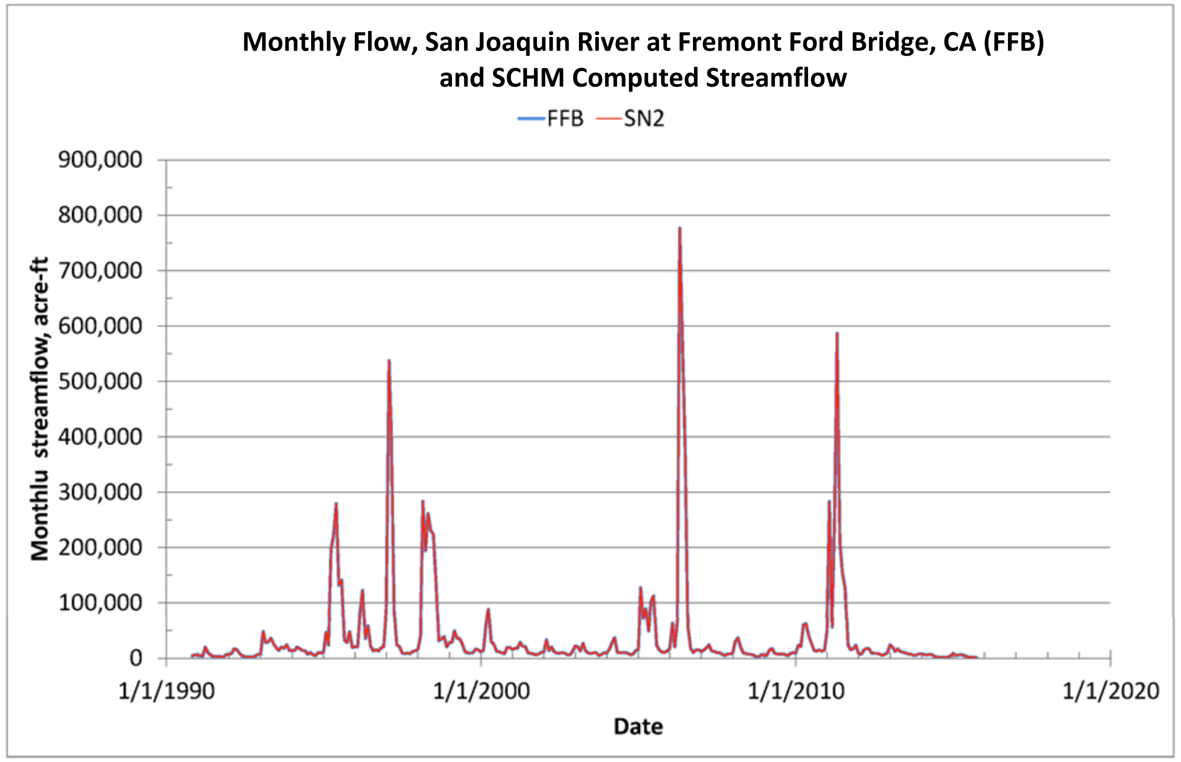
JACOBSON | JAMES
& associates, inc

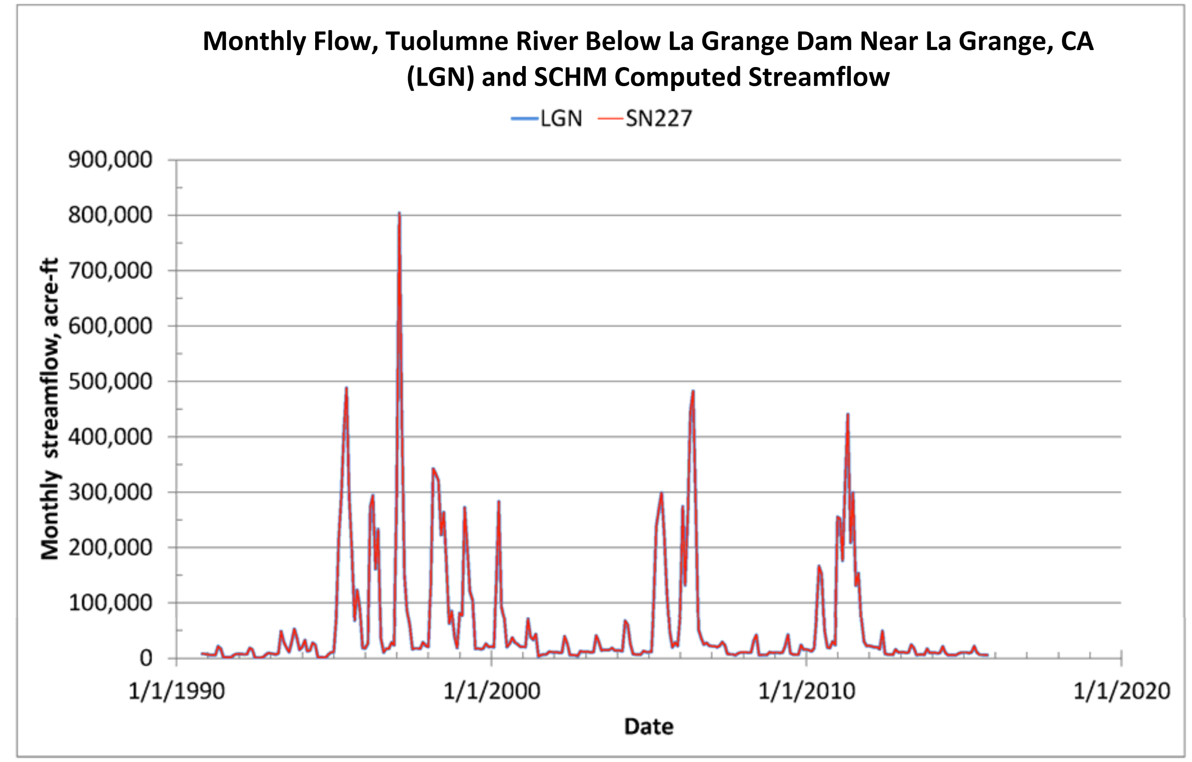
*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

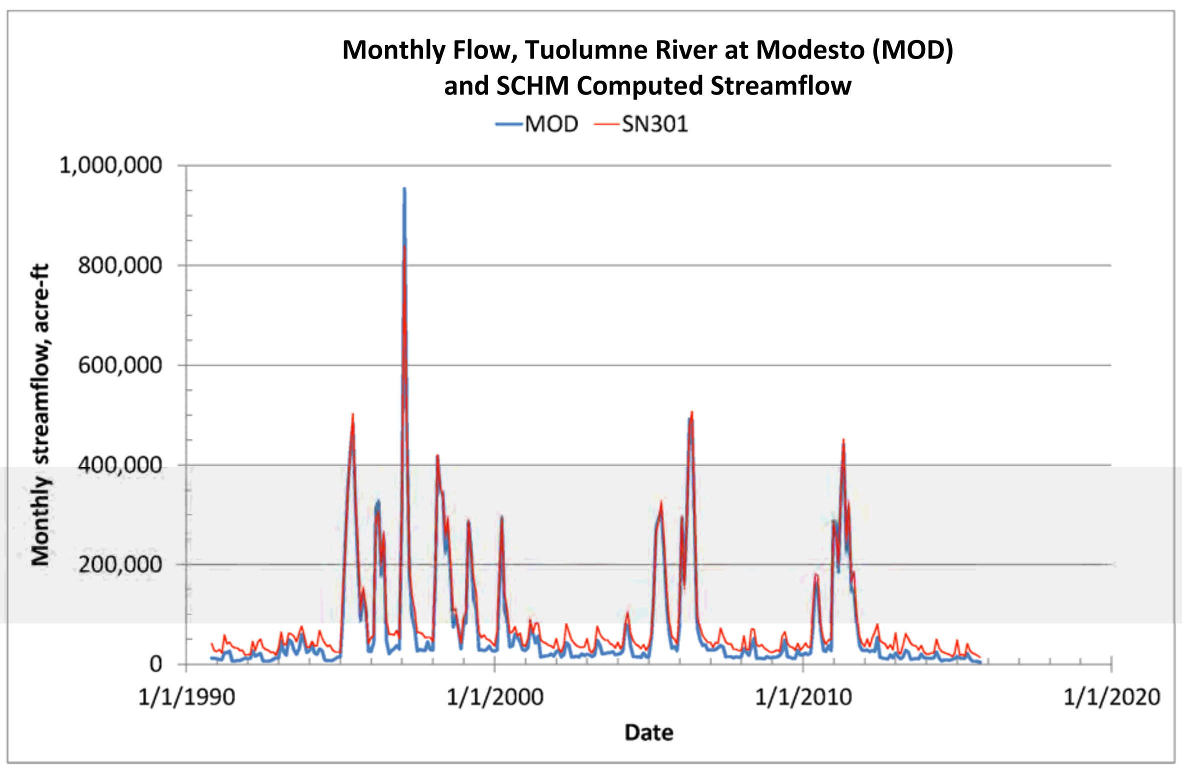
| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/17/17 | JH | MT |

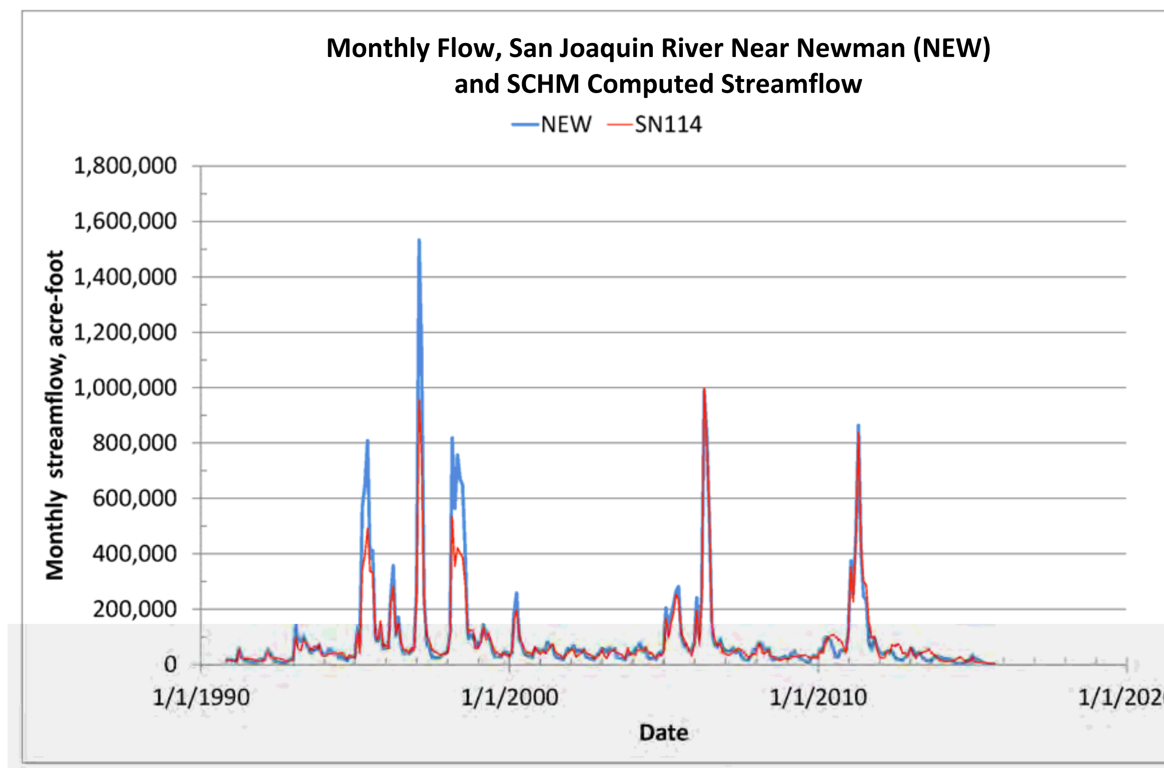
*FIGURE 4-3*

***Residual versus Predicted Water Levels for SCHM Layers 1 and 2***



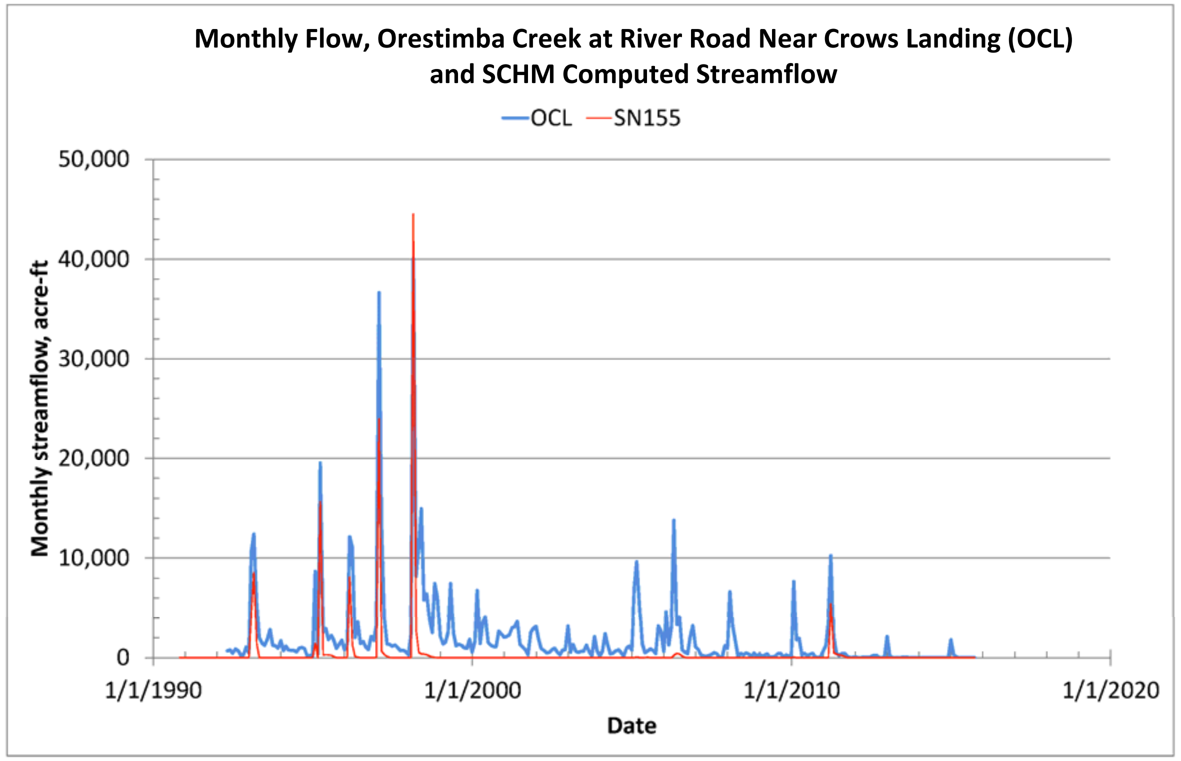

JACOBSON | JAMES
& associates, inc

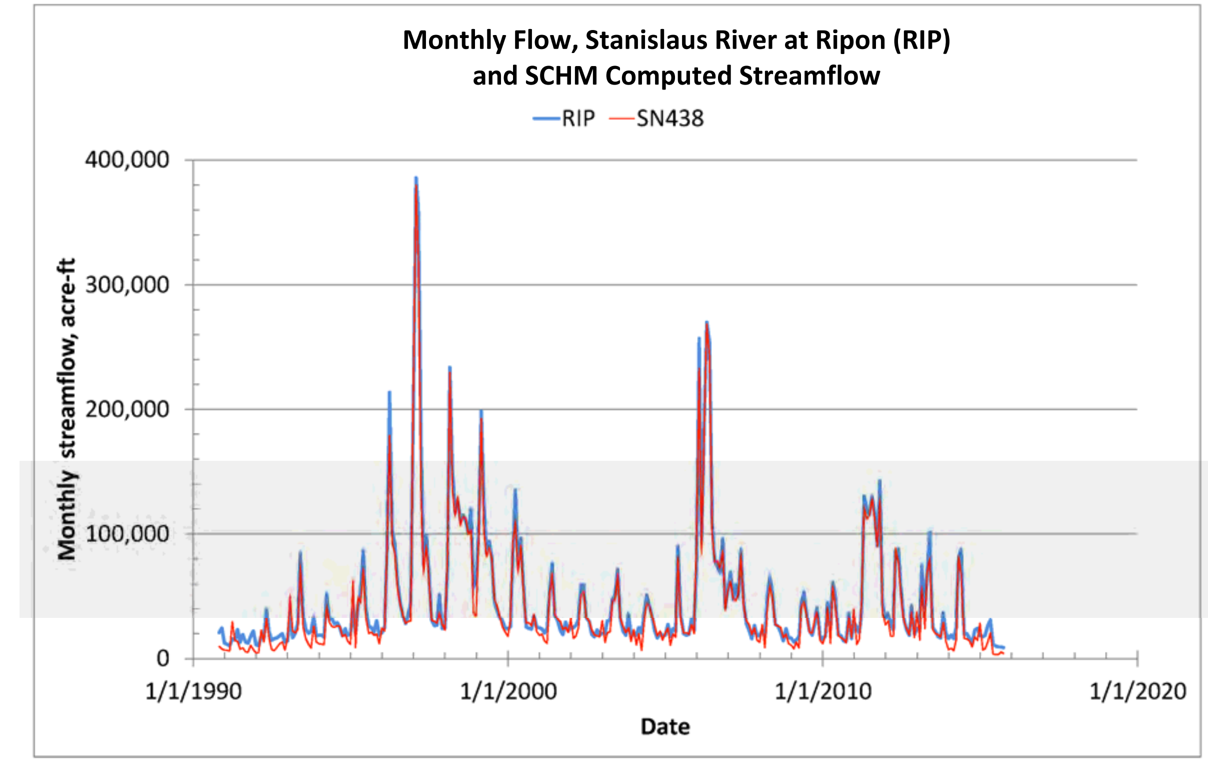
*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

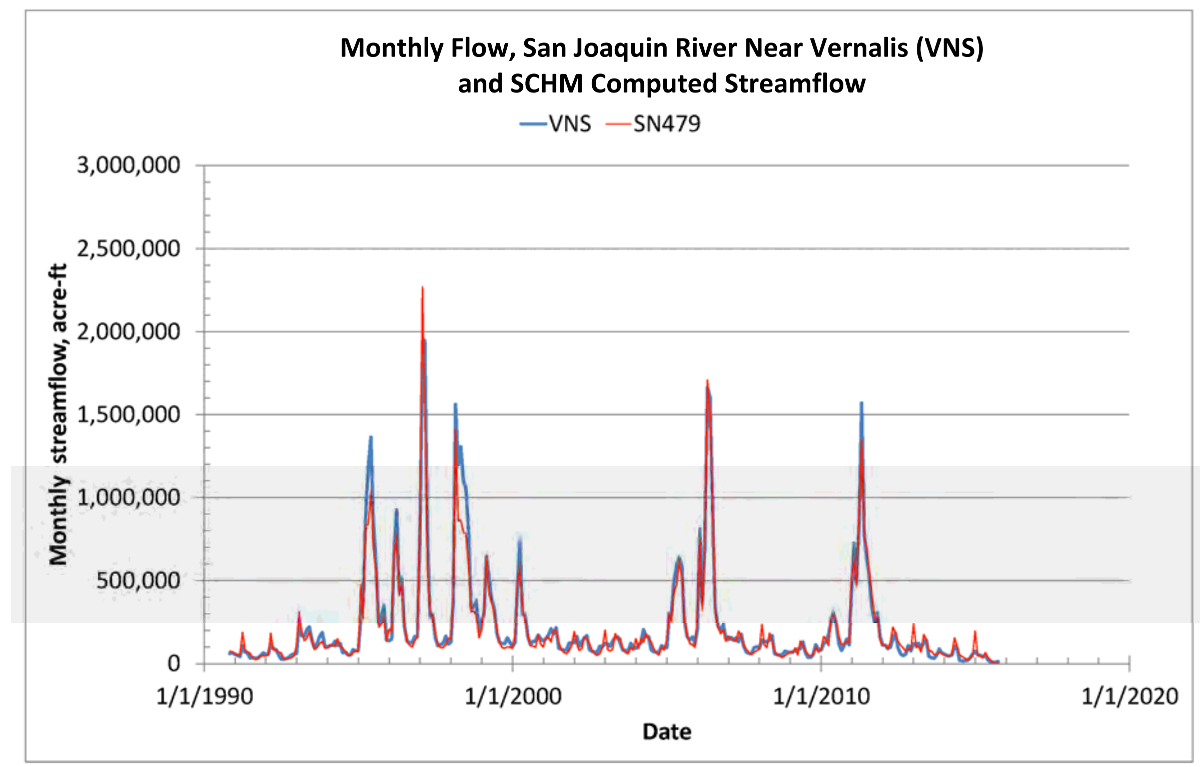
| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/28/17 | JH | MT |

*FIGURE 4-4*

***Monthly Streamflow at FFB, LGN, MOD, and NEW and SCHM Computed Streamflow***



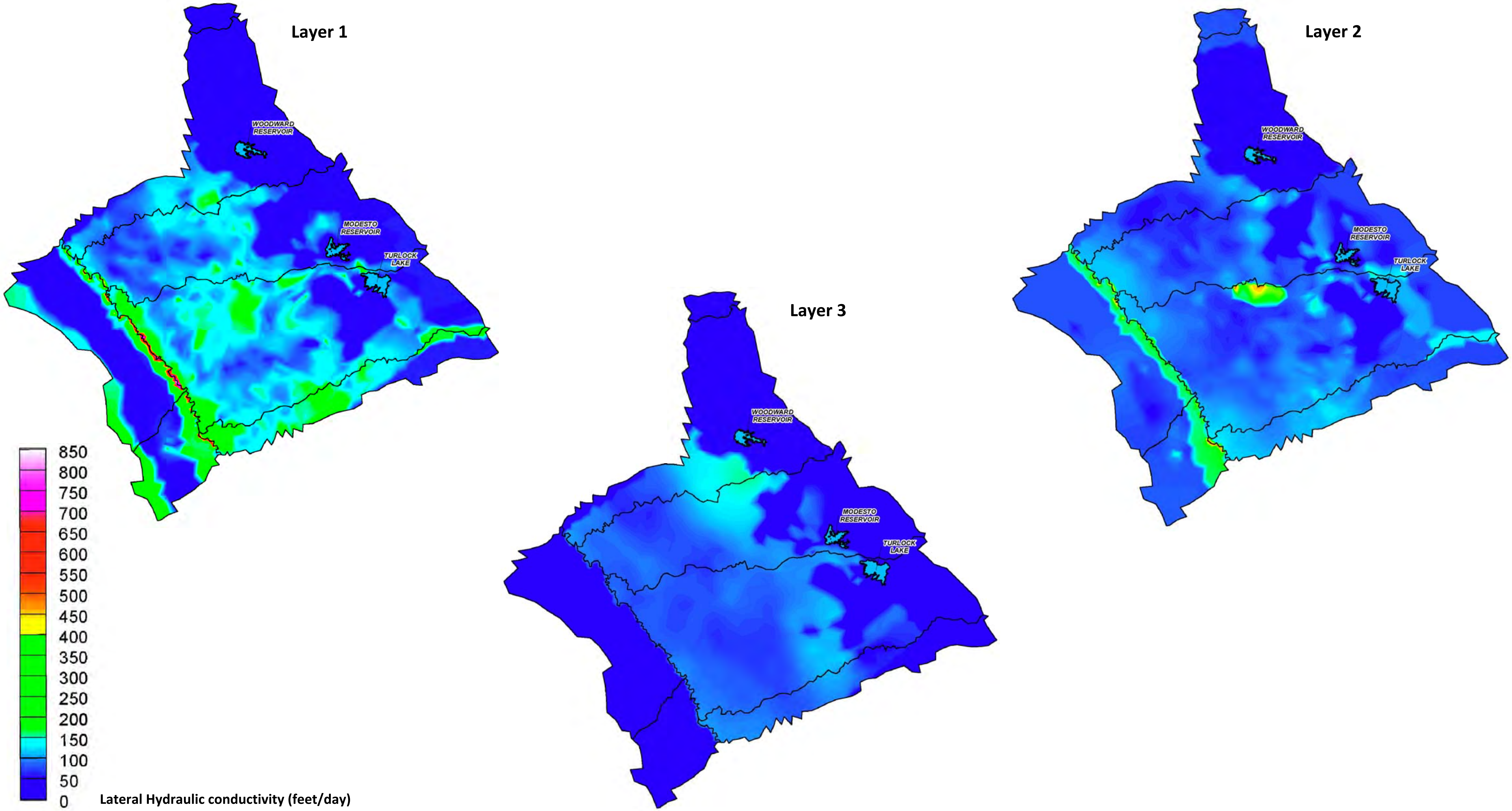

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| *STANCO.002* | *11/17/17* | *JH* | *MT* |

*FIGURE 4-5*

***Monthly Streamflow at OCL, RIP, and VNS and SCHM Computed Streamflow***



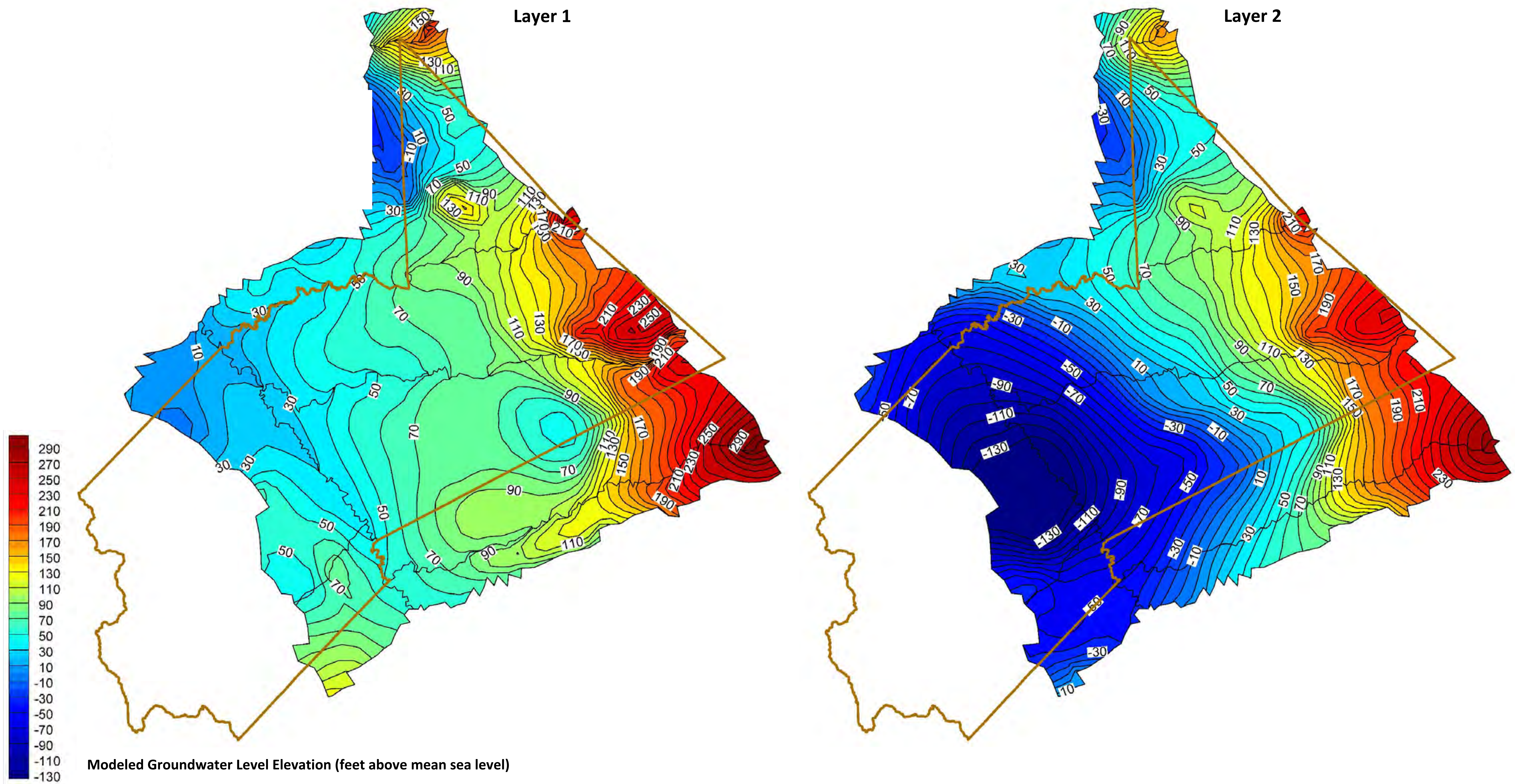

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/10/17 | JH | MT |

*FIGURE 4-6*

***Final Hydraulic Conductivity for SCHM Layers 1, 2, and 3***



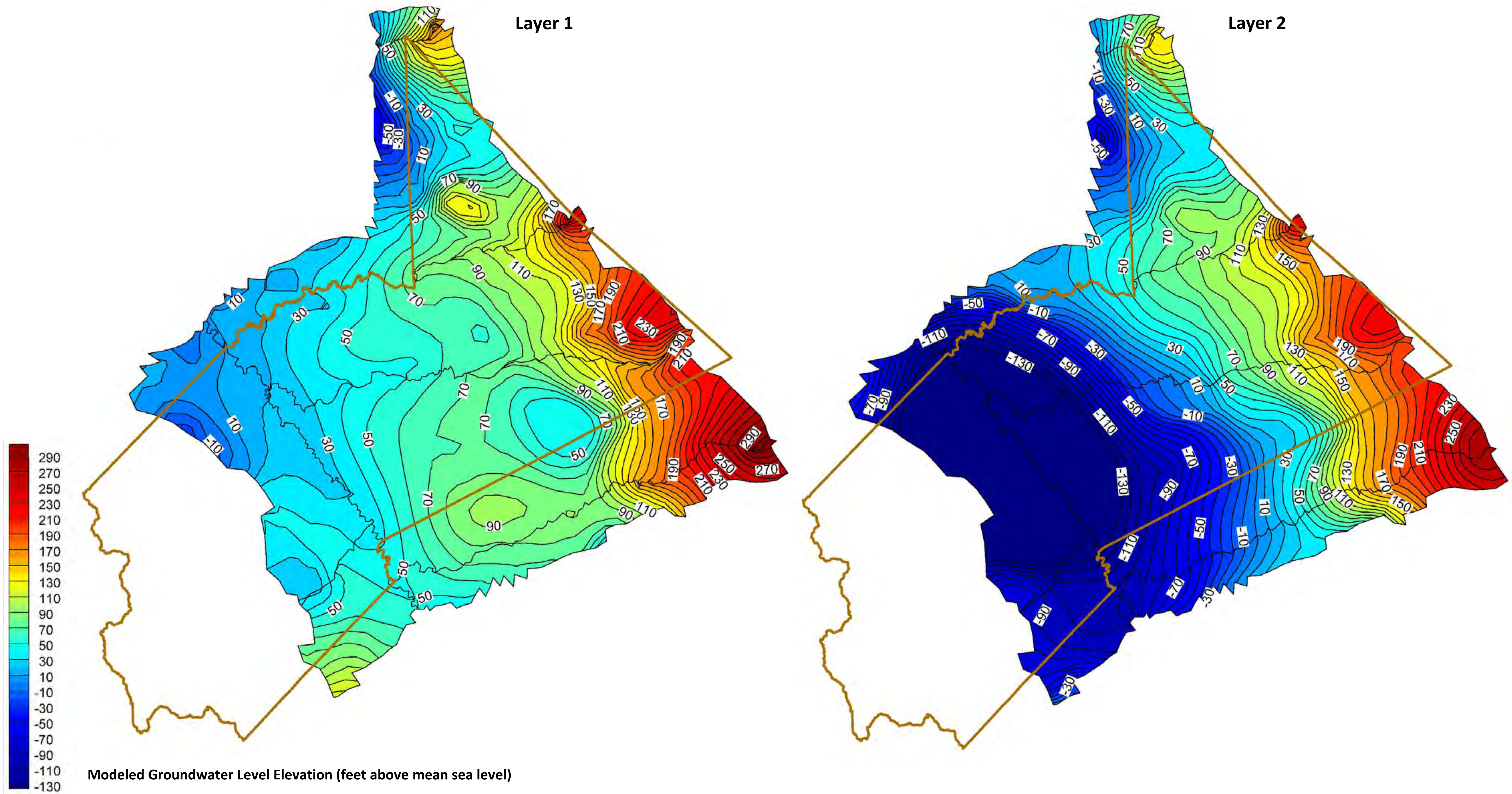

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/22/17 | JH | MT |

*FIGURE 4-7*

***Groundwater Level Elevations in SCHM Layers 1 and 2, September 2000***




JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/22/17 | JH | MT |

*FIGURE 4-8*

***Groundwater Level Elevations in SCHM Layers 1 and 2, September 2015***

# 5.0 SENSITIVITY ANALYSIS

In order to investigate the sensitivity of the SCHM to variations in key parameters and inputs, a sensitivity analysis was conducted by varying several key inputs as summarized in Table 5-1 below. The inputs were varied across a range of low and high values, and the resulting simulated heads for September 2015 in Model Layers 1 and 2 were compared the calibrated historical model. The purpose of this analysis was to provide perspective on the significance of potential data gaps in the construction and calibration of the model, and to help inform potential future model refinement efforts.

**Table 5-1: Sensitivity Analysis Input Parameters**

| Model Input | Range of Variation |
|---|---|
| Aquifer Layer Lateral Hydraulic Conductivity | Existing Value x 0.2; Existing Value x 5 |
| Storage Coefficients<br>- Specific Storage<br>- Specific Yield | <br>Existing Value x 0.1; Existing Value x 10<br>Existing Value x 0.1; Existing Value x 2 |
| Evapotranspiration | Existing Value x 0.5; Existing Value x 2 |
| Corcoran Clay Vertical Hydraulic Conductivity | Existing Value x 0.2; Existing Value x 5 |

It should be noted that the ranges of input values listed above do not necessarily reflect an expected or necessarily even a reasonable range in those parameters, but are a set of values intended to test the sensitivity of the model to potential variations. The results of the analysis are discussed in the following sections.

## 5.1 Aquifer Lateral Hydraulic Conductivity

The changes in simulated groundwater levels with decreased and increased model lateral hydraulic conductivity are shown in Figures 5-1 and 5-2, respectively. As shown in Figure 5-1, decreasing model lateral hydraulic conductivity has a significant but variable effect on simulated groundwater levels across the model domain, increasing them in some areas while decreasing them in others. These results support the observation that variations in hydraulic conductivity can affect model outcomes through multiple mechanisms. In some areas, the primary effect of decreasing the hydraulic conductivity appears to be to slow the flow of recharge away from an area and retain water in that part of the model, causing groundwater mounding. This is observed in portions of the eastern foothill area of the model near the Stanislaus, Tuolumne and Merced Rivers, as well as in Layer 1 beneath areas east of the San Joaquin River that are irrigated primarily through delivery of surface water. In other areas, lower hydraulic conductivity appears to result in greater drawdown associated with simulated model pumping. In these areas, drawdown may also be increased as a result of a slower rate of lateral groundwater inflow from recharge areas, such as in the cone of depression beneath the eastern Turlock Subbasin, and in most of Layer 2, away from the foothills. In addition, in some areas along the Diablo Range and the northern portion of the northeast model boundary, mountain front recharge from small watersheds appears to be infiltrated less effectively, causing a local decline in simulated groundwater levels.

As shown in Figure 5-2, increasing model lateral hydraulic conductivity also has a varying effect on simulated groundwater levels, which is generally opposite of the effect of decreasing hydraulic conductivity discussed above. With increased hydraulic conductivity, groundwater flows more readily away from recharge areas and to areas where groundwater is extracted, decreasing drawdown in those areas.

These results may be most useful when considering the results of extensive evaluation of sediment texture on hydraulic conductivity for the MERSTAN model (USGS, 2015). Regional adjustment of the end-point scaling used in this analysis could be investigated to provide improvements in regional model calibration during future refinements.

## 5.2 Storage Coefficients

The changes in simulated September 2015 groundwater level elevations with decreased and increased model storage coefficients (Specific Storage and Specific Yield) are shown in Figures 5-3 and 5-4 respectively. As shown in Figure 5-3, decreasing the model storage coefficients has the general effect of decreasing simulated heads, and can also be a significant effect on model results. This is especially true in Layer 2 in the west central portion of the model, which represents the confined aquifer system, and is consistent with less water being available to be removed from storage for each increment of drawdown. This portion of the model represents the model discharge area and reflects the cumulative effect of these changes throughout the model domain. As shown in Figure 5-4, increasing model lateral storage coefficients has the opposite effect, except in some isolated areas in the northeastern portion of the model domain. The reason for these local effects is not clear.

Local data regarding storage coefficients in the SCHM area are not widely available, and prior modeling efforts have relied largely on generalized information and the results of regional studies. The analysis above illustrates that the model could be refined if future model calibration efforts can rely on additional local field data from aquifer tests.

## 5.3 Evapotranspiration

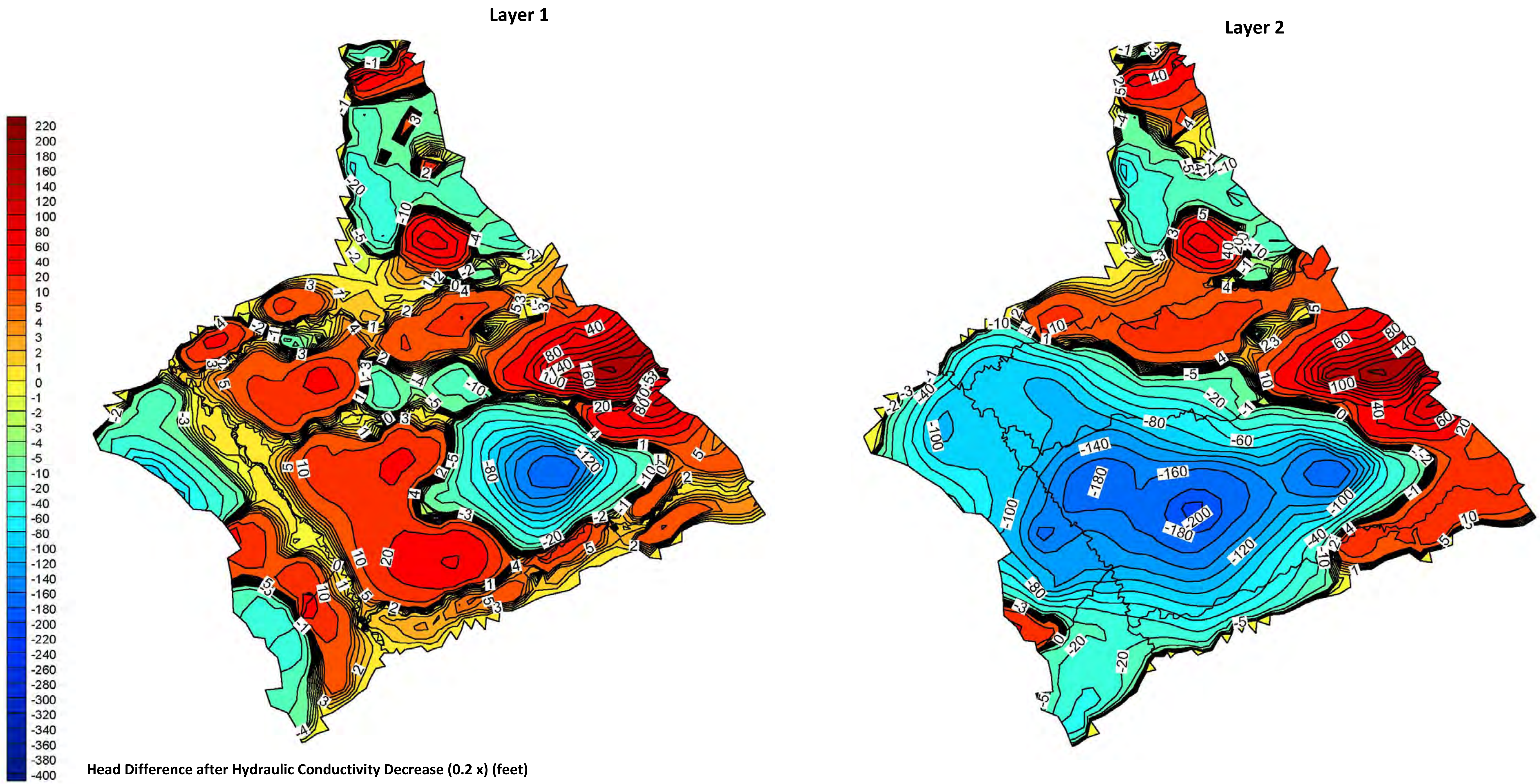
The changes in simulated September 2015 groundwater level elevations with decreased and increased model evapotranspiration are shown in Figures 5-5 and 5-6 respectively. As shown in Figure 5-5, decreasing the model evapotranspiration has the general effect of increasing simulated heads. This is true across the model domain in both Layers 1 and 2, but is most pronounced in the western portion of Layer 2 where the cumulative effects of more water being available for deep percolation throughout the model domain become more pronounced. As shown in Figure 5-6, increasing model evapotranspiration has the opposite effect, resulting in a decrease in heads across the model domain in both Layers 1 and 2. Similar to decreasing evapotranspiration, the cumulative effects of less deep percolation being available throughout the model domain become most pronounced in western portion of Layer 2.

These results reflect the fact that evapotranspiration from crops and natural vegetation is a significant component of the model water budget. DWR is undertaking efforts to refine its understanding of evapotranspiration in cropping in the region through several remote-sensing datasets. The results of these efforts were not available during development of the SCHM, but will be available to inform future modeling efforts.

## 5.4 Aquitard Vertical Hydraulic Conductivity

The changes in simulated September 2015 groundwater level elevations with decreased and increased Corcoran Clay vertical hydraulic conductivity are shown in Figures 5-7 and 5-8 respectively. As shown in Figure 5-7, decreasing the Corcoran Clay vertical hydraulic conductivity has the general effect of increasing simulated heads in Layer 1 and decreasing heads in Layer 2 beneath the Corcoran Clay subcrop area. This is because water is retained in the upper aquifer system and vertical leakance into the underlying confined aquifer system if impeded. This is effect is most pronounced in the western portion of the model, west of the San Joaquin River. As shown in Figure 5-8, increasing the vertical hydraulic conductivity has the opposite effect, resulting in a decrease in simulated heads in Layer 1 and an increase in simulated heads in Layer 2 beneath the Corcoran Clay subcrop area. This is because more water is allowed to leak vertically out of Layer 1 and into Layer 2 in this area.

These results illustrate the fact that the Corcoran Clay is a key regional hydrostratigraphic unit that affects not only the aquifer system's response to shallow and deep pumping, but also to the partition of the groundwater budget between the shallow and deep aquifer system. Local data regarding the vertical hydraulic conductivity of this unit are sparse, and prior modeling efforts have relied largely on regional studies or calibration results to assign values to this important parameter. The model could be refined through targeted evaluation of this important input parameter.



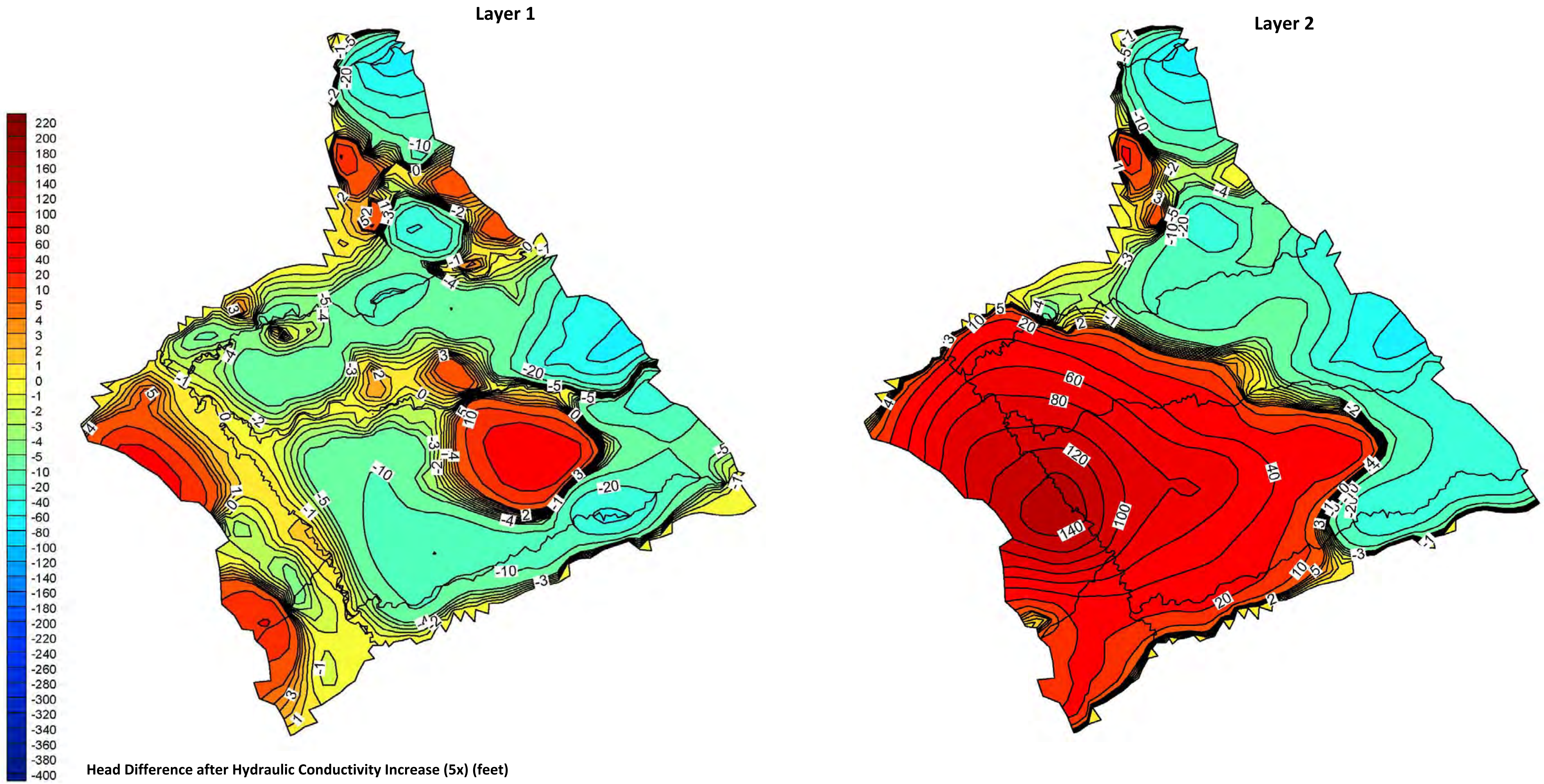

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/22/17 | JH | MT |

*FIGURE 5-1*

***Sensitivity Analysis Results: Decreased Lateral Hydraulic Conductivity***




**Head Difference after Hydraulic Conductivity Increase (5x) (feet)**

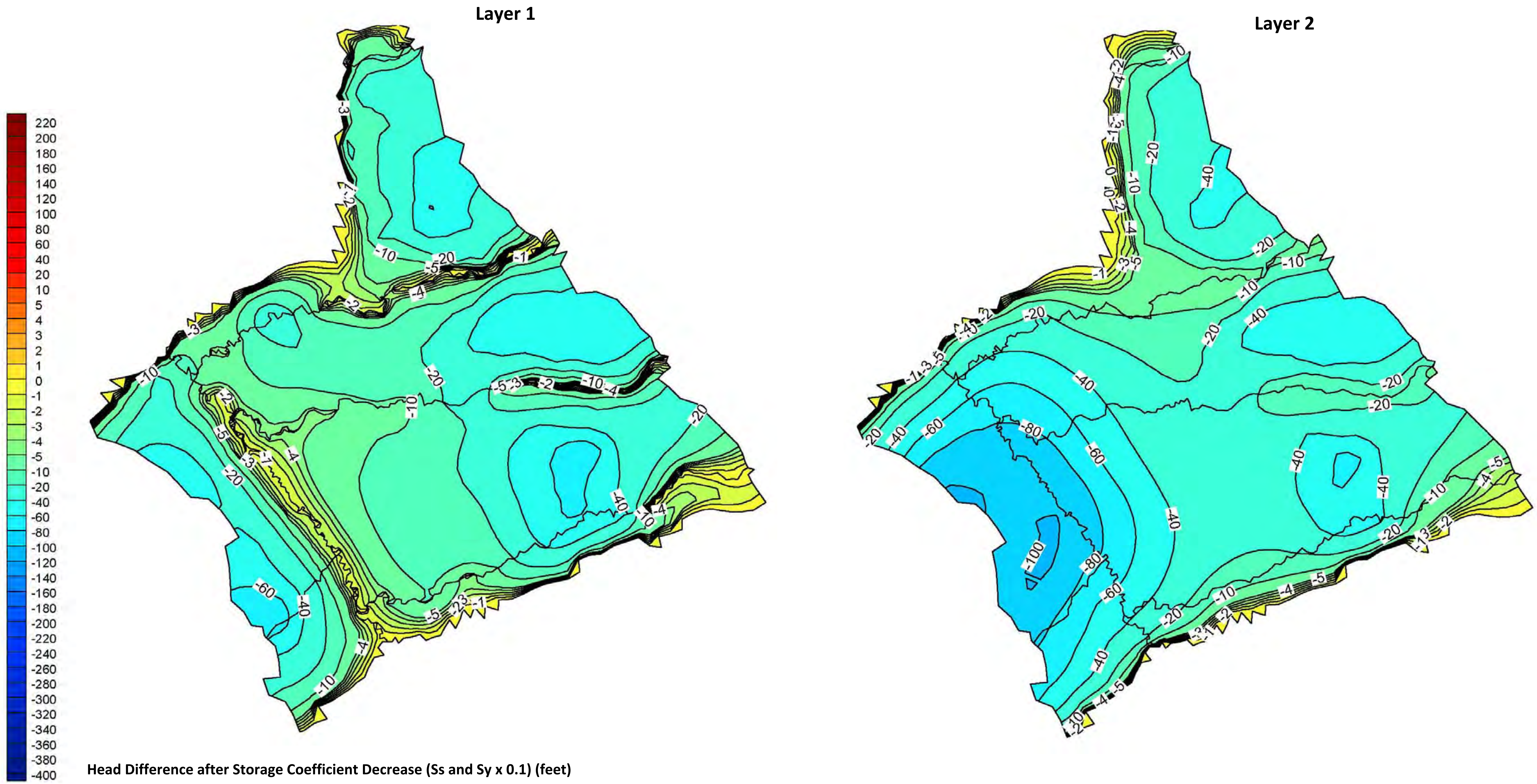
JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
| --- | --- | --- | --- |
| STANCO.002 | 11/22/17 | JH | MT |

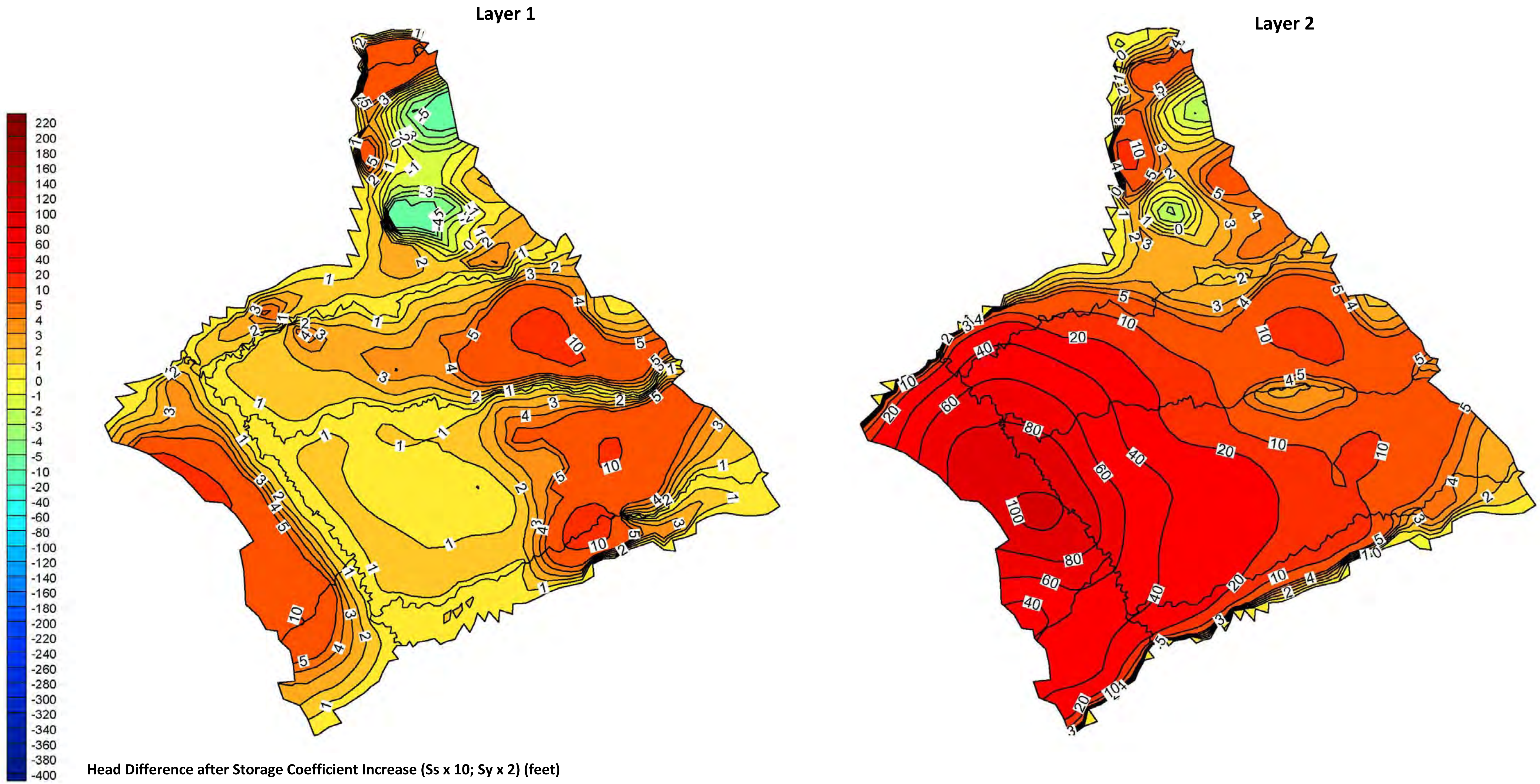
*FIGURE 5-2*

***Sensitivity Analysis Results:***
***Increased Lateral Hydraulic Conductivity***




**Head Difference after Storage Coefficient Decrease (Ss and Sy x 0.1) (feet)**

| | | | |
|---|---|---|---|
| JACOBSON \| JAMES & associates, inc | *Stanislaus County Hydrologic Model: Development and Forecasts*<br>*Stanislaus County, California* | | *FIGURE 5-3*<br>***Sensitivity Analysis Results: Decreased Storage Coefficients*** |
| PROJECT NO. *STANCO.002* | DATE *11/22/17* | DRAWN BY *JH* | APPR. BY *MT* |




**Head Difference after Storage Coefficient Increase (Ss x 10; Sy x 2) (feet)**

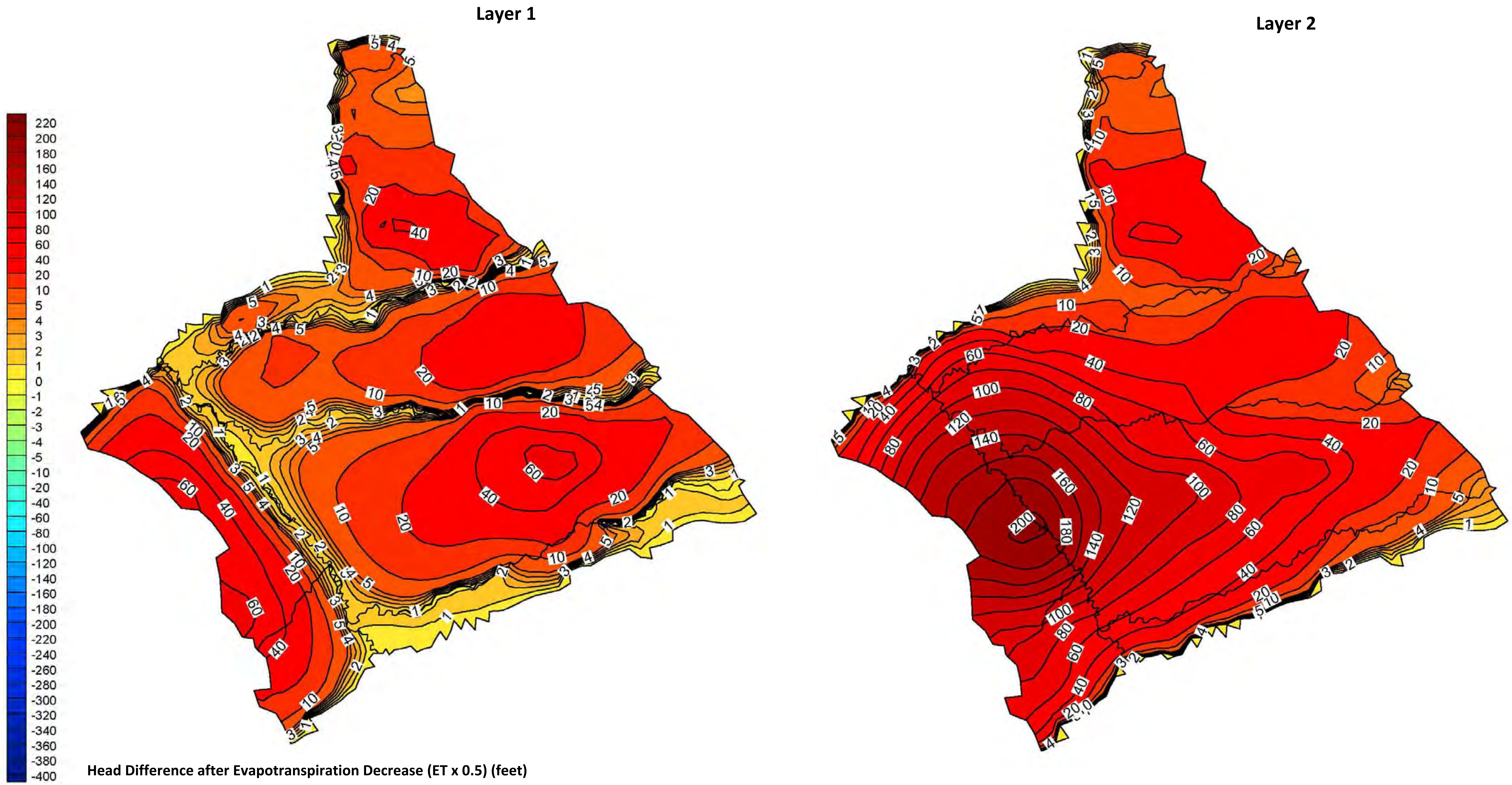
JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/22/17 | JH | MT |

*FIGURE 5-4*

***Sensitivity Analysis Results: Increased Storage Coefficients***




**Head Difference after Evapotranspiration Decrease (ET x 0.5) (feet)**

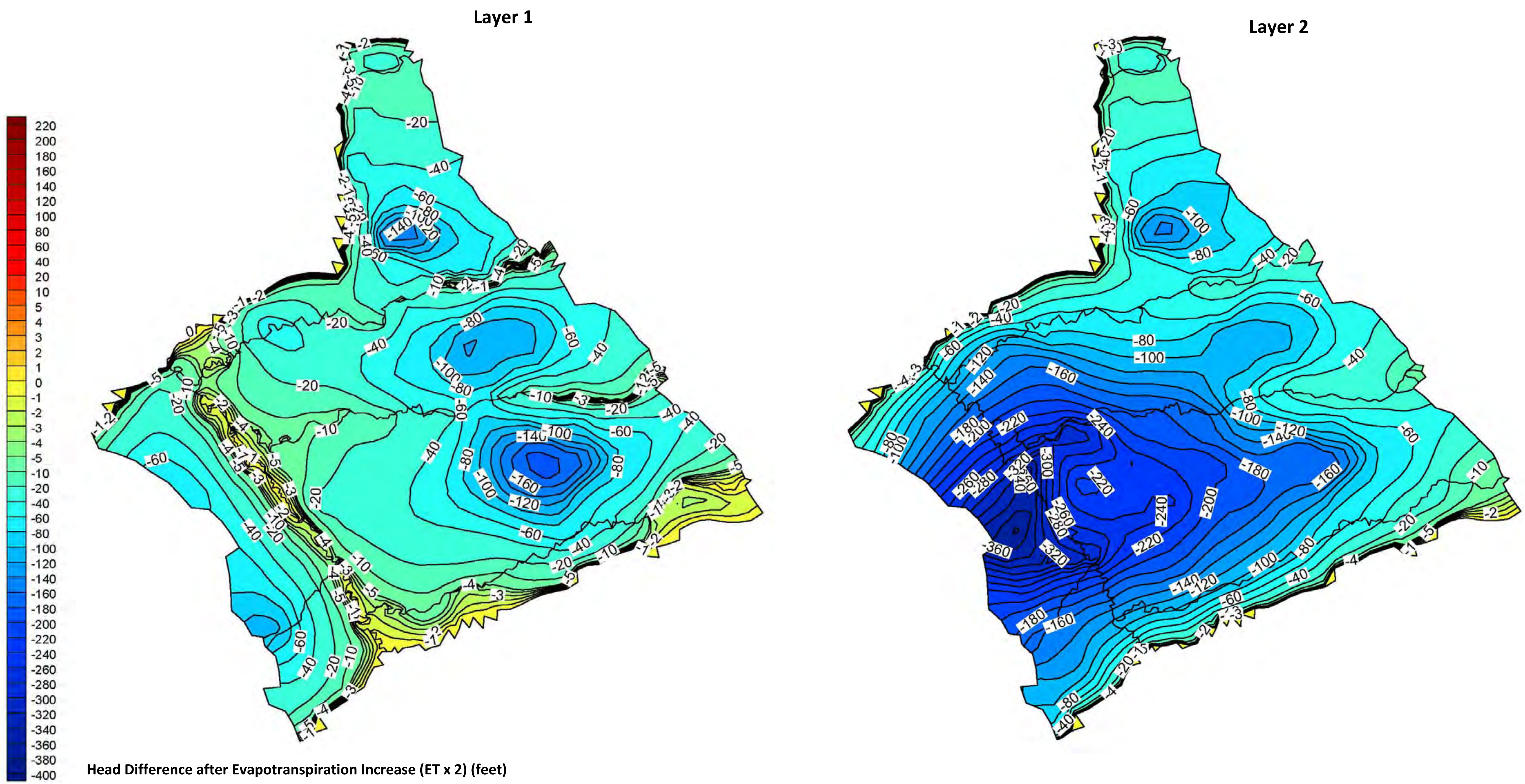
JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/22/17 | JH | MT |

*FIGURE 5-5*

***Sensitivity Analysis Results: Decreased Evapotranspiration***



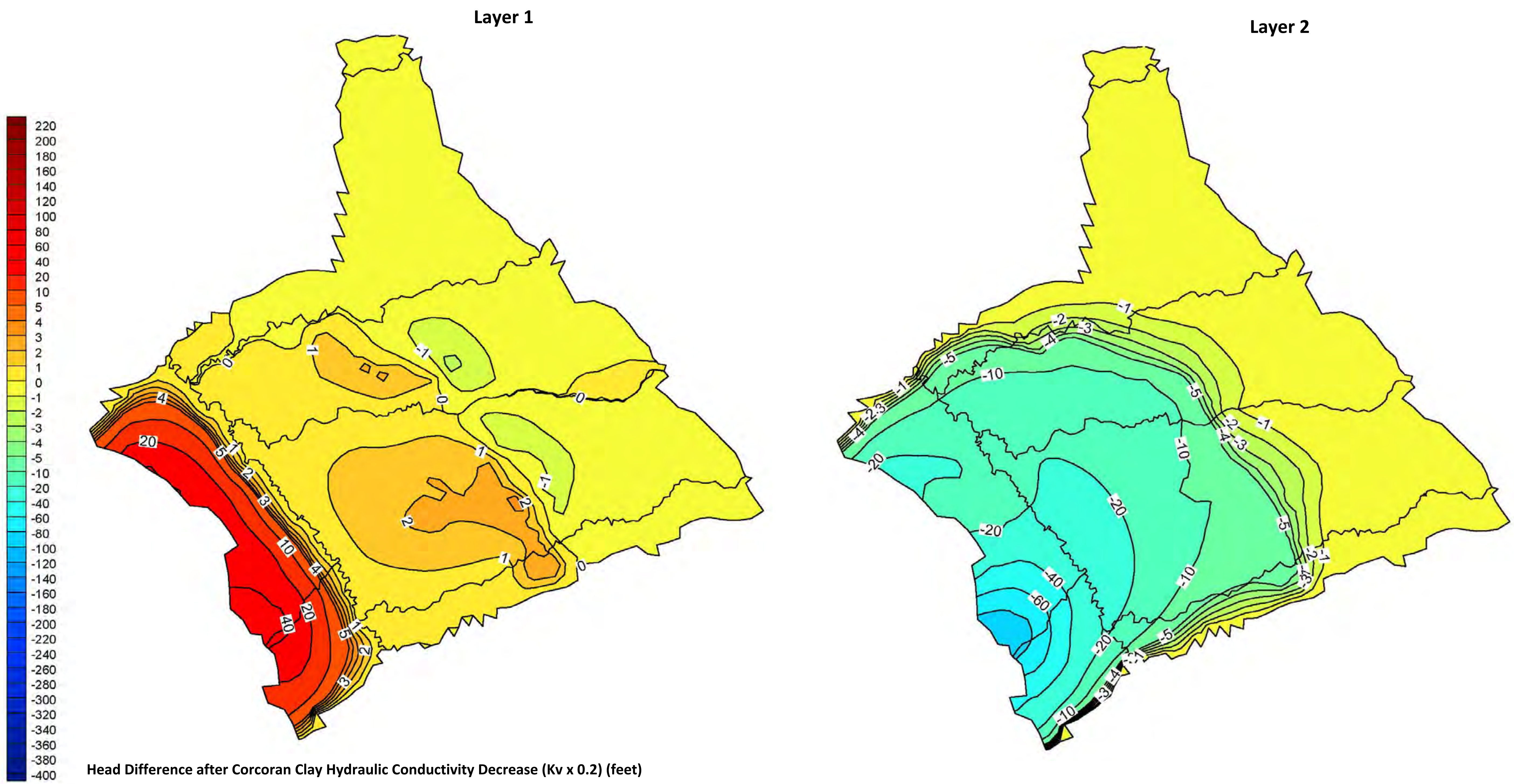

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/22/17 | JH | MT |

*FIGURE 5-6*

***Sensitivity Analysis Results: Increased Evapotranspiration***




**Head Difference after Corcoran Clay Hydraulic Conductivity Decrease (Kv x 0.2) (feet)**

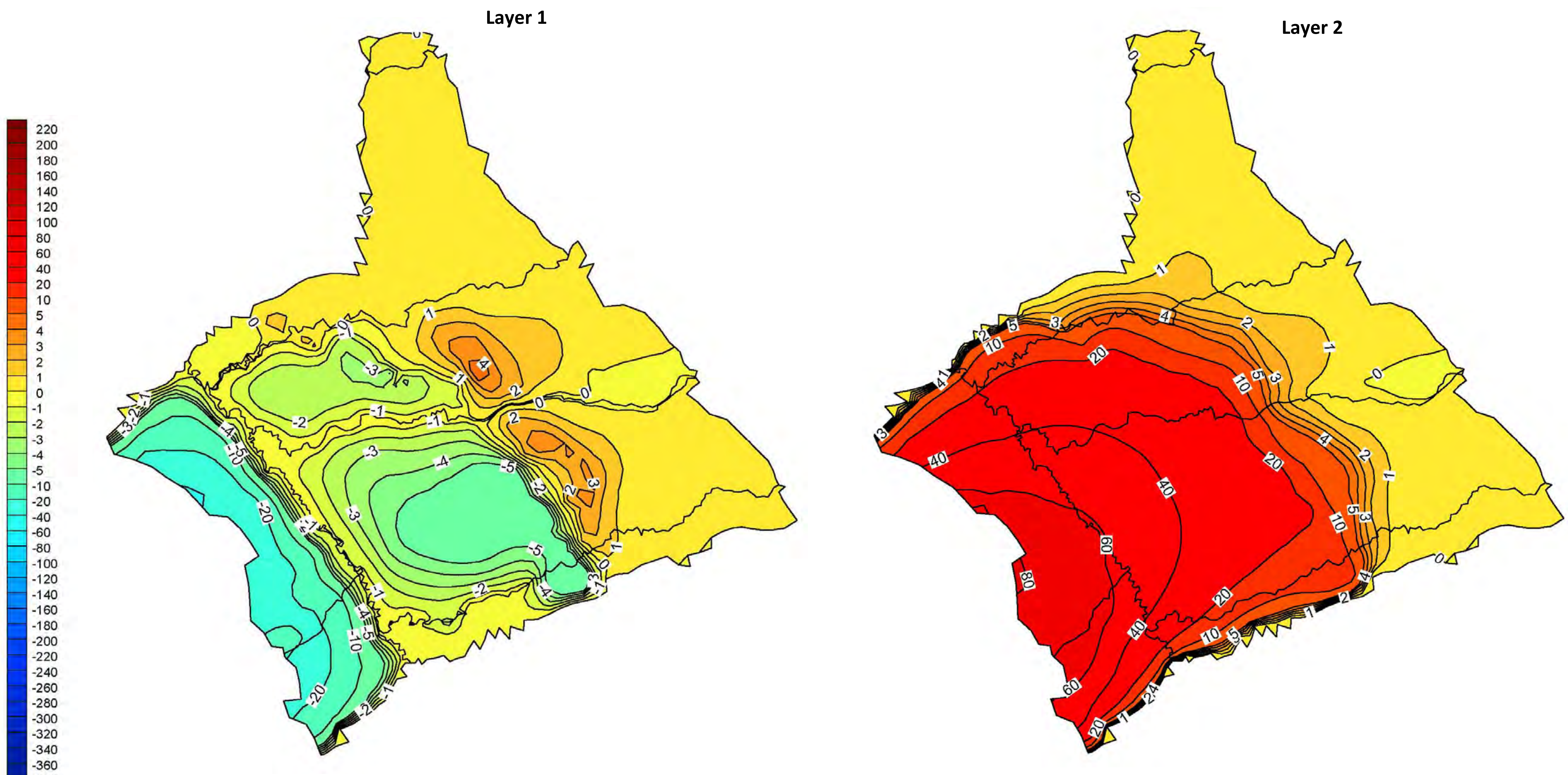
JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| *STANCO.002* | *11/22/17* | *JH* | *MT* |

*FIGURE 5-7*

***Sensitivity Analysis Results:***
***Decreased Aquitard Vertical Hydraulic Conductivity***




**Head Difference after Corcoran Clay Hydraulic Conductivity Increase (Kv x 5) (feet)**

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/22/17 | JH | MT |

*FIGURE 5-8*

***Sensitivity Analysis Results: Increased Aquitard Vertical Hydraulic Conductivity***

# 6.0 MODEL FORECASTS

## 6.1 Approach

Model forecasts were run from 2016 through 2042 to provide perspective on the effects of potential future groundwater management trends, and to evaluate the impacts of discretionary well permitting at a programmatic level. Several key uncertainties underlie these scenarios: (1) GSPs for the subbasins in the Study Area have not yet been prepared and, as such, sustainable yields and management criteria remain to be established; (2) Important water policy decisions that could profoundly affect groundwater management in the region are currently pending (SWRCB, 2016); and, (3) The actual locations of wells that will be permitted under the County's discretionary well permitting program are not known. For these reasons, it is important to note that the simulated scenarios described below are not deterministic, quantitative assessments, but are intended to provide perspective on the reasonable range of potential outcomes, and to inform the evaluation of whether a potential exists for significant impacts to result from the permitting of discretionary wells by the County. The scenarios evaluated in this study are described in Table 6-1. Additional details regarding the approach used and the results of the simulations are presented in Sections 6.2 through 6.6, below.

## 6.2 Scenario 1 – Baseline

Scenario 1 provides the basic hydrologic conditions for each of the subsequent scenarios, and is the baseline against which Scenarios 2 through 5 are compared to assess the changes produced by the scenario assumptions using a superposition approach. The following approach was used to construct this scenario.

- Scenario 1 includes a sequence of historical hydrologic years assembled to represent a reasonable sequence of future hydrologic conditions. The selected years and their hydrologic year type based on the San Joaquin Valley Water Year Hydrologic Classification Index (DWR, 2017a) are presented on Figure 6-1. The hydrologic data used includes surface water inflows, precipitation and temperature/ evapotranspiration. Gridded PRISM data (Daly et al., 2004) for precipitation, where a mix of real years were associated with corresponding model years, were prepared as input for the SCHM grid.
- Surface water diversions for the forecast hydrologic years were developed for the baseline scenario using the approach summarized in Table 3-2. When the historical hydrologic years used to develop the forecast sequence preceded WY 1991, a representative year between WY 1991 and WY 2015 with a similar hydrology for which diversions were developed was utilized to represent diversions.
- Climate change was incorporated into the baseline scenario by assuming similar precipitation as historical conditions, and allowing for an increase in temperature. The temperature increase was associated with an increase in evapotranspiration that was calculated in input into the model. Evapotranspiration changes resulted from a steady increase in temperature of 0.0355 degrees Celsius ($^{o}$C) per year from WY 2016 through WY 2042. The selected temperature ramp is based on an extrapolation using recent trends in historical data for California, over 1970-2006, using US Historical Climate Network and National Weather Service Cooperative Network data for the San Joaquin basin

(Cordero et al., 2011). The specific value is the mean statistically significant increase for the daily minimum and daily maximum temperature at individual stations. This temperature change was used to calculate corresponding evapotranspiration changes using a variation of the Penman Equation developed by Makkink (Makkink, 1957),[9] and to develop multipliers to adjust monthly evapotranspiration values in the model Evapotranspiration Data file of C2VSim.

- In order to allow Scenario 1 to be used as a baseline for the evaluation of potential future groundwater management and demand changes, the groundwater demand simulated in this scenario is based on the assumption that WY 2015 urban demand will continue, WY 2015 land use patterns will be maintained throughout the forecast period, and WY 2015 time-dependent boundary conditions will be maintained.

## 6.3 Scenario 2 – Reasonable Upper Bound Potential Demand Increase

The municipal water demand increase simulated in this scenario was developed using water demand forecasts contained in UWMPs developed for the region as summarized in Table 6-2. As summarized in this table, the average median annual urban water demand increase in the region is approximately 2.7%.[10] This factor was used for all cities except Modesto. For Modesto, the mean forecast demand increase through 2040 is 0.08%; however, this average includes an initial forecast demand decline, and a forecast increase of 0.4% per year was therefore applied. Rural domestic groundwater demand was assumed to increase in proportion to a rural population growth rate of approximately 1 percent per year.

It is reasonable to assume that any increase in urban water demand and delivery would be associated with a corresponding increase in recharge from urban return flows, and from retirement of agricultural demand as parcels are converted for urban use. For this scenario, it was assumed that the projected demand increase represents a reasonable maximum net pumping increase that includes any offsetting agricultural demand reduction, and the associated return flow and deep percolation were not explicitly modeled.

Also simulated in this scenario is an increase in agricultural groundwater demand resulting from the conversion of unincorporated rangeland in the eastern portion of the county to irrigated agricultural land. The forecast rate of agricultural land conversion in Scenario is based on the historical rate of rangeland conversion to permanent crops in the eastern portion of the County between 2000 and 2015 reported by the Stanislaus County Agricultural Commissioner (Appendix A). Based on this information, it is assumed that 3,100 acres per year of rangeland in this area is converted to orchard.

Drawdowns predicted in Layers 1 and 2 in 2022 and 2042 under Scenario 2 are shown graphically in Figures 6-2 and 6-3, and key water budget changes are summarized in Table 6-3. These results are presented as

[9] Tetra Tech performed a study comparing six different methods to calculate evapotranspiration based on changes in temperature alone. The method of Makkink provided the best correlation with measured values and was adopted for use in developing the SCHM.

[10] This average includes data from UWMPs that predate as well as postdate the requirements of SBX7-7 in order to develop a reasonable maximum urban demand growth scenario. As such, the estimate was not developed to explicitly simulate current municipal water conservation/demand reduction requirements.

changes relative to the baseline case (Scenario 1). Changes induced by increasing municipal and agricultural groundwater demand under this scenario include the following:

- Under this scenario, drawdown in Layer 1 (the shallow aquifer system) in the eastern foothills area of the SCHM is predicted to range from approximately 1 to 3 feet by 2022 and approximately 5 to 30 feet by 2042. The lateral expansion of drawdown cones is limited by the major groundwater-connected streams draining the foothills, including the Stanislaus, Tuolumne and Merced Rivers. This is consistent with an increase in the amount of streamflow lost to groundwater as shown in Table 6-3. Drawdown in Layer 2 (the deeper aquifer system) in the eastern portion of the SCHM is predicted to range from approximately 1 to 5 feet in 2022 and approximately 10 to 40 feet in 2042.

- Groundwater levels in Layer 1 beneath Turlock and Patterson are predicted to rise between 1 and 2 feet by 2042. The rise in groundwater levels occurs because municipal pumping in these areas occurs primarily from the deeper aquifer system (Layer 2); whereas deep percolation from urban water use will be a source of recharge to Layer 1. In reality, a greater amount of net recharge to the shallow aquifer system may occur as a result of the conversion of agricultural land to urban land, and the retirement of agricultural water demand.

- Cones of depression are predicted to form in Layer 1 beneath urban areas that rely more extensively on groundwater from the shallow aquifer system (e.g., Modesto, Riverbank, Hughson and Oakdale). Layer 1 groundwater levels are predicted to fall by approximately 1 to 3 feet beneath these cities by 2042.

- A broad cone of depression is predicted to form in Layer 2, centered approximately on the Cities of Turlock and Patterson. Drawdowns beneath Turlock are predicted to range from 1 to 4 feet by 2022, and 10 to 20 feet by 2042. Drawdowns beneath Patterson are predicted to exceed 1 foot by 2022, and to range from 5 to 10 feet by 2042.

- Consistent with the observation above regarding apparent streamflow depletion due to pumping under Scenario 2, forecast water budget data (Table 6-3) indicates net groundwater discharge to streams from the Eastern San Joaquin, Modesto and Turlock Subbasins is forecast to decrease several thousand AFY (approximately 0.6 & to 2 %) by 2022 and several tens of thousands AFY (approximately 4% to 13 %) by 2042, relative to the baseline case. Groundwater discharge from the Delta Mendota Subbasin to streams is not predicted to change significantly (less than 0.2 %).

- As summarized in Table 6-3, the cumulative groundwater storage change in the Eastern San Joaquin, Modesto and Turlock Subbasins is forecast to decrease several thousand AF (approximately 0.1 %) by 2022 and several tens of thousand AF (approximately 0.4 % to 1.8 %) by 2042, relative to the baseline case. Groundwater storage change in the Delta Mendota Subbasin is not predicted to vary significantly from the baseline change.

## 6.4 Scenario 3 – Reasonable Lower Bound Potential Demand Increase

The municipal water demand increase simulated in this scenario was developed using 25% of the water demand forecasts contained in UWMPs developed for the region (Table 6-2). Studies indicate that urban water demand forecasts often overestimate the actual amount of demand growth by incorporating conservative assumptions regarding population growth, demographic changes and the effectiveness of water conservation (Woodard, 2015). A demand increase of 0.7% per year was used for municipal pumping, with the exception of Modesto, where a demand increase of 0.1% per year was applied based on the average forecast data. Similar to Scenario 2, it was assumed that net pumping increase that includes any offsetting agricultural demand reduction, and the associated return flow and deep percolation were not explicitly modeled. Rural domestic groundwater demand was assumed to remain constant, consistent with general a general plan policy to discourage additional residential development in agricultural areas of the county.

Scenario 3 also simulated an increase in agricultural groundwater demand resulting from the conversion of unincorporated rangeland in the eastern portion of the county to irrigated agricultural land, at a rate of approximately 20% of the historical rate. In general, the rate of agricultural land conversion in the eastern portion of the County has slowed since adoption of the Groundwater Ordinance in late 2014, and the economic pressures on land conversion have moderated as the price of almonds has stabilized; however, it is reasonable to assume that some agricultural land conversion will continue to occur. Based on this information, it is assumed that 610 acres per year of rangeland in this area is converted to orchard.

Drawdowns predicted in Layers 1 and 2 in 2022 and 2042 under Scenario 3 are shown graphically in Figures 6-4 and 6-5, and key water budget changes are summarized in Table 6-3. These results are presented as changes relative to the baseline case (Scenario 1). Changes induced by increasing municipal and agricultural groundwater demand under this scenario include the following:

- Under this scenario, drawdown in Layer 1 (the shallow aquifer system) in the eastern foothills area of the SCHM is predicted to be less than 1 foot in 2022, and to range from approximately 1 to 5 feet by 2042. Groundwater mounding or drawdown in other areas of the model is not predicted to exceed 1 foot.
- Similar to Scenario 2, the lateral expansion of drawdown cones is limited by the major groundwater-connected streams draining the foothills, including the Stanislaus, Tuolumne and Merced Rivers; however, the amount of stream flow depletion is predicted to be much less (Table 6-3).
- In Layer 2, limited areas with approximately 1 foot of drawdown are predicted to form in the eastern portion of the SCHM by 2022. By 2042, more extensive drawdown ranging from 1 to 5 feet is predicted in this area.
- A broad cone of depression is predicted to form beneath Turlock in Layer 2, and to reach approximately 1 to 4 feet of drawdown by 2042.
- Consistent with the observation above regarding apparent streamflow depletion due to pumping under Scenario 3, forecast water budget data (Table 6-3) indicates net groundwater discharge to

streams from the Eastern San Joaquin, Modesto and Turlock Subbasins is forecast to decrease by about 1,000 AFY each (approximately 0.1 % to 0.4 %) by 2022 and several thousand AFY (approximately 0.7 % to 2.5 %) by 2042, relative to the baseline scenario. Groundwater discharge from the Delta Mendota Subbasin to streams is not predicted to change significantly from the baseline.

- As summarized in Table 6-3, the cumulative groundwater storage change in the Eastern San Joaquin, Modesto and Turlock Subbasins is forecast to decrease by about 1,000 AFY each by 2022 and several thousand AFY by 2042. Groundwater storage change in the Delta Mendota Subbasin is not predicted to vary significantly from the baseline.

## 6.5 Scenario 4 – Discretionary Well Permitting

Scenario 4 was constructed to evaluate the potential effects of permitting new discretionary wells under the County Groundwater Ordinance. This was accomplished by randomly selecting 10 model elements each year starting in 2018 for simulation of pumping from a new well that would theoretically be installed under the Ordinance. Ten wells per year is considered a reasonable maximum for this evaluation, based on the observation that only two discretionary wells have been processed for permitting during the first three years since the Ordinance was adopted in November 2014. Even if the rate of well permitting increases after adoption of the PEIR in early 2018, it appears unlikely that more than 10 wells per year will be permitted on average. Each well is assumed to extract approximately 400 AFY of groundwater from Layer 1 (Scenario 4a) or Layer 2 (Scenario 4b). The wells are assumed to be installed in unincorporated, non-district lands throughout the County from 2018 to 2020, and in unincorporated lands of the Modesto and Turlock Subbasin from 2021 to 2022, based on schedule mandated schedule for adoption of GSPs. The locations and installation years for the simulated wells are shown on Figure 6-6.

Drawdowns induced in Layers 1 and 2 in 2022 and 2042 are shown graphically in Figure 6-7 and 6-8 for Scenario 4a, and Figures 6-9 and 6-10 for Scenario 4b. Key water budget changes for Scenarios 4a and 4b are summarized in Table 6-3. These results are presented as changes relative to the baseline case.

Changes predicted to be induced by discretionary well permitting under Scenarios 4a (shallow wells) include the following:

- Cones of depression are predicted to develop in the eastern portion of the County in Layer 1, with drawdown ranging from 1 to 5 feet by 2022. By 2042 these cones of depression are predicted to expand and deepen to approximately 4 to 10 feet. The lateral expansion of drawdown cones is predicted to be limited by the Stanislaus and Tuolumne Rivers, from which the wells would derive at least some of their extracted groundwater, as summarized in Table 6-3. Smaller, local cones of depression are also predicted to form where wells are located in other areas of the County; however, these cones of are predicted to be more limited in size and depth, remaining between 1 and 2 feet in depth throughout the entire simulation. This distribution of drawdown is consistent with a greater degree of groundwater development and limited recharge in the eastern portion of the County.

- Drawdown in Layer 2 is predicted to be more muted. Predicted drawdown exceeding 1 foot is limited to the eastern portion of the County. In this area, several cones of depression are predicted to reach drawdowns from 1 to 3 feet. Similar to Layer 1, this drawdown is predicted to expend by 2042, and to range from 1 to 5 feet by that time.
- Consistent with the observation above regarding apparent streamflow depletion due to pumping under Scenario 4a, forecast water budget data (Table 6-3) indicates net groundwater discharge to streams from the Delta-Mendota, Eastern San Joaquin, Modesto and Turlock Subbasins is forecast to decrease by about 3,400, 1,400 to 9,000 and 2,900 AFY (approximately 0.6 % to 1.7 %), respectively, by 2022, and 4,000, 2,900, 13,000 and 3,100 AFY (approximately 0.6 % top 1 %), respectively, by 2042, relative to the baseline scenario.
- As summarized in Table 6-3, cumulative groundwater storage change in the Delta-Mendota, Eastern San Joaquin, Modesto and Turlock Subbasins is forecast to decrease by about 1,000 to 4,000 AF (approximately 0.1 % or less) by 2022. Storage depletion rates are forecast to decrease over time. By 2042, cumulative storage depletion in the Eastern San Joaquin Subbasin is predicted to be approximately 1,300 AFY (approximately 0.3 %) less than the baseline, and be essentially unchanged from the baseline in the other subbasins. In addition, the annual rate of storage change in the subbasins is predicted to be low (less than 0.01 %) with the basins remaining relatively stable.

Changes predicted to be induced by discretionary well permitting under Scenarios 4b (deeper wells) include the following:

- As expected, the development of cones of depression in the upper aquifer system (Layer 1) for Scenario 4b (deeper wells) is predicted to be more muted than under Scenario 4a. Cones of depression are predicted to develop in the eastern portion of the County with drawdown ranging from 1 to 3 feet by 2022 and 3 to 5 feet by 2042. As in Scenario 4a, lateral propagation of drawdown appears to be limited by the Stanislaus and Tuolumne Rivers. Smaller cones of depression up to between 1 and 2 feet in depth are predicted to form in the central portion of the County by 2022 but are not predicted to grow further in size.
- In the deeper aquifer system (Layer 2), drawdown is predicted to be somewhat more extensive under Scenario 4b. A series of depression cones under the eastern portion of the County is predicted to reach a depth of 2 to 5 feet by 2022 and 3 to 6 feet by 2042. In addition, a broad area of drawdown is predicted to form in the confined aquifer system beneath the western portion of the County and to reach a depth of approximately 5 feet in 2022. Although the area of drawdown is predicted to grow by 2042, it is not predicted to get deeper.
- As summarized in Table 6-3, streamflow depletion under this scenario is predicted to be similar to, or somewhat less than, streamflow depletion rates under Scenario 4a. Groundwater storage depletion rates are predicted to be generally similar for the two scenarios, although cumulative depletion, on average, is predicted to be higher for Scenario 4b.

## 6.6 Scenario 5 – Additional Surface Water Delivery

Scenario 5 evaluates the potential effect of additional surface water deliveries to offset municipal demand. This scenario was developed using the demand growth simulated in Scenario 2, and groundwater level changes were evaluated relative to Scenario 1. Additional surface water deliveries were simulated using the currently planned Stanislaus Regional Water Authority (SWRA) project as a surrogate. It should be noted that this evaluation is intended to provide perspective on the potential effects of conjunctive use projects to help meet municipal water demand in the region, but actual evaluation of the impacts and benefits of the SRWA will require more in-depth analysis. To construct the water demand inputs for this scenario, it was assumed that up to 5,700 AFY of Tuolumne River water will be supplied to the City of Ceres and up to 11,100 AFY will be supplied to the City of Turlock, beginning in 2022 (West Yost, 2017). The point of diversion will be just downstream of the Greer Road bridge. The minimum groundwater extraction rates assumed to be needed to maintain the water quality and functionality of existing supply wells is assumed to be 2 million gallons/day (MGD) in Ceres and 6.6 MGD in Turlock (West Yost, 2016). During the winter months (assumed to be December through March), as much of the demand as possible will be supplied from surface water and groundwater pumping will be decreased to minimum levels. During the rest of the year, groundwater pumping may be increased above minimum levels, if needed to meet peak demands.

Scenario 5 maintained an increase in agricultural groundwater demand resulting from the conversion of unincorporated rangeland in the eastern portion of the county to irrigated agricultural land, at a rate of 3,100 acres per year.

Drawdowns predicted in Layers 1 and 2 in 2022 and 2042 under Scenario 5 are shown graphically in Figures 6-11 and 6-12, and key water budget changes are summarized in Table 6-3. These results are presented as changes relative to the baseline case (Scenario 1). Changes induced by increasing municipal and agricultural water demand and adding conjunctive use to meet the municipal demand under this scenario include the following:

- Under this scenario, predicted drawdown in Layer 1 (the shallow aquifer system) and Layer 2 in the eastern foothills area of the SCHM remains essentially unchanged from Scenario 2. Drawdowns predicted in the Delta-Mendota Subbasin near the City of Patterson are somewhat muted compared to Scenario 2, but are generally similar.
- In the western Turlock Subbasin beneath Turlock, groundwater levels are predicted to rise up to 1 to 2 feet by 2022 and up to 5 feet by 2042. Beneath the City of Patterson, groundwater levels are predicted to rise between 1 and 2 feet by 2042. As would be expected, the groundwater level rise under this scenario is greater than under Scenario 2, which simulates reasonable maximum groundwater demand growth.
- Groundwater levels in Layer 2 beneath the western Turlock Subbasin are also predicted to rise initially, reaching up to 4 feet above the baseline case. By 2042, however, groundwater levels are predicted to fall to elevations that are up to 10 feet below the baseline case. This is compared to drawdowns under Scenario 2 in the range of 1 to 4 feet by 2022, and 10 to 20 feet by 2042. As such,

indicate that conjunctive use is predicted to result in less drawdown and greater water level recovery than would occur otherwise, on the order of approximately 5 to 10 feet under the simulated assumptions. In addition, the scenario illustrates that a demand-growth tipping point may exist beyond which drawdown will increase even under a conjunctive use scenario. In the simulation, this tipping point occurs between 2022 and 2042 under demand growth forecasts that are based on regional averages (2.7%), and are less than the demand growth forecasts contained in the Ceres and Turlock UWMPs (4.23 and 3.73% per year, respectively; see Table 6-2).

- Net groundwater discharge to streamflow is predicted to be similar to or decrease less than under Scenario 2. The change in streamflow discharge relative to the baseline case in the Delta-Mendota, Modesto and Turlock Subbasins is predicted to be approximately 1,000, 9,000 and 3,000 AFY (approximately 0.5 % to 0.8 %), respectively (Table 6-3). Net change in groundwater discharge to streamflow in the Eastern San Joaquin Subbasin is similar under both scenarios (approximately 2 %).

- Net annual and cumulative storage change is predicted to be similar under both scenarios for the Delta-Mendota, Eastern San Joaquin and Modesto Subbasins. Annual storage change in the Turlock Subbasin is predicted to be approximately 13,000 AFY less than Scenario 2 in 2022, and 1,000 AFY less in 2042. Under Scenario 5, cumulative storage depletion is predicted to be approximately 74,000 acre-feet (AF) less than Scenario 2 by 2022, and over 1,000,000 AF less by 2042. However, this is only a small change in percentage (0.04 % and 0.2 %, respectively) relative to Scenario 2.

| Scenario | Purpose | Description and Assumptions | Approach |
|---|---|---|---|
| Scenario 1 - Baseline | Establishes a baseline against which the other scenarios are compared. | Prepare a sequence years that will represent the hydrology dataset for forecasts. Use historical data to represent a representative sequence of normal, wet and dry years. Maintain 2015 groundwater demand and cropping patterns throughout the baseline forecast period. Incorporate climate change into the hydrology dataset by developing a temperature ramp based on published data and calculating the resulting evapotranspiration increases for input into the model. Use the resulting dataset as a comparison point for all of the subsequent scenarios. | Use the hydrology data series outlined in Figure 6-1 to simulate forecast hydrologic conditions. |
| | | | Use the approach outlined in Table 3-2 develop a diversion dataset. |
| | | | Escalate evapotranspiration using the Makkink method based on a temperature increase of 0.0355 °C/year. |
| | | | Maintain municipal and rural domestic demand at 2015 levels. |
| | | | Maintain 2015 cropping and land use patterns. |
| Scenario 2 – Reasonable Upper Bound Potential Demand Increase | Provide perspective on potential effects if agricultural groundwater demand grows at historical rates and municipal demand grows at rates forecast in UWMPs. This scenario is to represent an upper bound of reasonable demand growth. | Agricultural water demand is assumed to increase through the continued conversion of rangeland in the eastern foothill region at rates experienced from 2000 to 2015. Urban water demand is assumed to increase in accordance with water demand increases forecast in UWMPs, and to be offset to some degree with the conversion of remaining agricultural land to urban use. Rural domestic water demand is assumed to increase at forecast population growth rates in the Stanislaus County General Plan Housing Element. | Use the baseline data from Scenario 1 as a starting and comparison point. |
| | | | Increase municipal pumping by 2.7 %/year (median average UWMP demand increase) for all cities except Modesto. |
| | | | Increase municipal pumping in Modesto by 0.4%/year. |
| | | | Increase rural domestic pumping by 1%/year. |
| | | | Demand increase offset by land use conversion is captured in pumping rate adjustment. |
| | | | Convert Natural Vegetation land to Agricultural Land (orchards) in unincorporated, non-district areas, EWD and BCWD at a rate of 3,100 acres/year. |
| Scenario 3 – Reasonable Lower Bound Potential Demand Increase | Provide perspective on the effectiveness of limiting the expansion of groundwater extraction to decrease potential effects of agricultural and municipal groundwater demand increases. This scenarios is to represent a lower bound of reasonable demand growth. | Agricultural conversion in the east foothills is assumed to proceed at a rate that is approximately 20% of historical rates, consistent with recent slowdowns in the planting of new orchards in this area. Urban demand is assumed to increase at a rate that approximately 25% of forecast rates. This assumption assumes that UWMP demand forecasts may be overly conservative, that additional efficiency improvements will be implemented, and that some demand increase will be offset by urban development of agricultural land. In the case of Modesto, it is assumed that unused agricultural deliveries will be made available to meet municipal demand. Rural domestic demand is assumed not to grow, consistent with an existing General Plan policy to limit rural residential development. | Use the baseline data from Scenario 1 as a starting and comparison point. |
| | | | Increase municipal pumping by 0.7 %/year (25 % of median average UWMP demand increase) for all cities except Modesto. |
| | | | Increase municipal pumping in Modesto by 0.1%/year. |
| | | | Demand increase offset by land use conversion is captured in pumping rate adjustment. |
| | | | Convert Natural Vegetation land to Agricultural Land (orchards) in unincorporated, non-district areas, EWD and BCWD at a rate of 610 acres/year (20% of historical rate from 2000 to 2015). |
| Scenario 4a – Discretionary Well Permitting of Shallow Wells | Evaluate the potential effects of permitting new extraction wells subject to the Groundwater Ordinance on unincorporated, non-district lands within the County. | Add 10 new wells per year at randomly selected locations in unincorporated, non-district lands within the County between 2018 and 2020, then continue adding 10 wells per year from 2021 to 2022, but only in the Modesto and Turlock Subbasins. The timing of adding new wells is consistent with the time frame during which discretionary well permitting will occur prior to the adoption of GSPs in 2020 in the Eastern San Joaquin and Delta-Mendota Subbasins, and in 2022 in the Modesto and Turlock Subbasins. Ten wells per year are assumed to be added as an estimated upper bound assuming that the rate of discretionary well permitting will increase after completion of the PEIR. Note that since the Ordinance was adopted in November 2014, only two discretionary well permits have been processed; however, over 1,000 non-discretionary well permits were processed in the same time frame, indicating a back log of demand for well permits may exist. | Use the baseline data from Scenario 1 as a starting and comparison point. |
| | | | Add the wells shown in Figure 6-6, which were selected in the centers of randomly selected elements in unincorporated, non-district lands in the eastern foothills. |
| Scenario 4b – Discretionary Well Permitting of Deep Wells | | | Add the wells to either Model Layer 1 (Scenario 4a) or Model Layer 2 (Scenario 4b) in the sequence indicated on Figure 6-6. |
| | | | Specify pumping for the wells at a rate of 400 AFY (assuming a typical demand of 4 feet for a typical 100-acre orchard for each well). |
| Scenario 5 – Additional Surface Water Delivery | Evaluate the potential effectiveness of making additional surface water available to meet municipal water demand in the County. | Model delivery of additional surface water to Turlock and Ceres to simulate the general effect of projects such as the Stanislaus Regional Water Authority project on groundwater levels and budgets. Use Scenario 2 – Reasonable Upper Bound Potential Demand Increase as a starting point to compare effectiveness against. | Use the baseline data from Scenario 2 as a starting point and compare to Scenario 1. |
| | | | Model diversion of up to 5,600 AFY surface water from the Tuolumne River downstream of Geer Road to City of Ceres starting 2022 (West Yost, 2017), and decrease municipal pumping proportionally. Decrease well pumping to no less than 2 mgd and increase well pumping in April-November as needed to meet Scenario 2 demand (West Yost 2016). |
| | | | Model diversion of up to 11,100 AFY surface water from the Tuolumne River downstream of Geer Road to City of Turlock starting 2022 (West Yost, 2017), and decrease municipal pumping proportionally. Decrease well pumping to no less than 6.6 mgd and increase well pumping in April-November as needed to meet Scenario 2 demand (West Yost 2016). |

Notes:
AFY = acre foot per year
BCWD = Ballico-Cortez Water District
EWD = Eastside Water District
GSP = Groundwater Sustainability Plan
mgd = million gallon per day
PEIR = Programmatic Environmental Impact Report
UWMP = Urban Water Management Plan
°C = degree Celsius
% = percent

Sources:
West Yost, 2016. *Preliminary Phasing and Water Treatment Plant Sizing for the SRWA Surface Water Supply Project.* June 16.
West Yost, 2017. *Surface Water Supply Project, Initial Project Capacity, Estimated Cost and Rate Impacts.* Presentation for Stanislaus Regional Water Authority. August 3.

**TABLE 6-2**
**FORECAST URBAN WATER DEMANDS**
**Stanislaus County Hydrologic Model: Development and Forecast Modeling**
**Stanislaus County, California**

| Urban District | Year of UWMP | Total Water Demand (2016-2042) | | | Groundwater Demand (2016-2042) | | Annual Demand Increase per Five Year Increment | | Total Average Percent Increase |
|---|---|---|---|---|---|---|---|---|---|
| | | Year | MGY | AFY | MGY | AFY | AFY | Percent | Acre Feet |
| City of Ceres | 2015 | 2015 | 2,161 | 6,632 | 2,161 | 6,632 | -- | -- | -- |
| | | 2020 | 3,505 | 10,757 | 1,680 | 5,156 | -295 | -4.45% | -- |
| | | 2025 | 4,241 | 13,016 | 2,416 | 7,415 | 452 | 8.76% | -- |
| | | 2030 | 4,973 | 15,262 | 3,148 | 9,661 | 449 | 6.06% | -- |
| | | 2035 | 6,006 | 18,432 | 4,181 | 12,831 | 634 | 6.56% | 4.23% |
| City of Hughson | 2006 | 2015 | 1,022 | 3,136 | 1,022 | 3,136 | -- | -- | -- |
| | | 2020 | 1,314 | 4,033 | 1,314 | 4,033 | 179 | 5.72% | -- |
| | | 2025 | 1,661 | 5,097 | 1,661 | 5,097 | 213 | 5.28% | -- |
| | | 2030 | 1,661 | 5,097 | 1,661 | 5,097 | 0 | 0.00% | 3.67% |
| City of Livingston | 2016 | 2015 | 2,191 | 6,724 | 2,191 | 6,724 | -- | -- | -- |
| | | 2020 | 2,257 | 6,927 | 2,257 | 6,927 | 41 | 0.60% | -- |
| | | 2025 | 2,330 | 7,151 | 2,330 | 7,151 | 45 | 0.65% | -- |
| | | 2030 | 2,413 | 7,405 | 2,413 | 7,405 | 51 | 0.71% | -- |
| | | 2035 | 2,503 | 7,682 | 2,503 | 7,682 | 55 | 0.75% | -- |
| | | 2040 | 2,604 | 7,992 | 2,604 | 7,992 | 62 | 0.81% | 0.70% |
| City of Modesto | 2016 | 2015 | 22,645 | 47,459 | 10,451 | 32,058 | -- | -- | -- |
| | | 2020 | 22,645 | 69,464 | 8,040 | 24,664 | -1,479 | -4.61% | -- |
| | | 2025 | 24,418 | 74,902 | 8,596 | 26,369 | 341 | 1.38% | -- |
| | | 2030 | 26,191 | 80,340 | 9,152 | 28,073 | 341 | 1.29% | -- |
| | | 2035 | 27,964 | 85,778 | 9,708 | 29,778 | 341 | 1.21% | -- |
| | | 2040 | 29,736 | 91,216 | 10,263 | 31,483 | 341 | 1.15% | 0.08% |
| City of Newman | 2016 | 2015 | 893 | 2,741 | 893 | 2,741 | -- | -- | -- |
| | | 2020 | 1,111 | 3,410 | 1,111 | 3,410 | 134 | 4.88% | -- |
| | | 2025 | 1,234 | 3,787 | 1,234 | 3,787 | 75 | 2.21% | -- |
| | | 2030 | 1,380 | 4,235 | 1,380 | 4,235 | 90 | 2.37% | -- |
| | | 2035 | 1,535 | 4,711 | 1,535 | 4,711 | 95 | 2.25% | -- |
| | | 2040 | 1,705 | 5,233 | 1,705 | 5,233 | 104 | 2.21% | 2.78% |

**TABLE 6-2**
**FORECAST URBAN WATER DEMANDS**
**Stanislaus County Hydrologic Model: Development and Forecast Modeling**
**Stanislaus County, California**

| Urban District | Year of UWMP | Total Water Demand (2016-2042) | | | Groundwater Demand (2016-2042) | | Annual Demand Increase per Five Year Increment | | Total Average Percent Increase |
|---|---|---|---|---|---|---|---|---|---|
| | | Year | MGY | AFY | MGY | AFY | AFY | Percent | Acre Feet |
| City of Oakdale | 2015 (Water Master Plan) | 2015 | 1,532 | 4,700 | 1,532 | 4,700 | -- | -- | -- |
| | | 2020 | 1,369 | 4,200 | 1,369 | 4,200 | -100 | -2.13% | -- |
| | | 2025 | 1,467 | 4,500 | 1,467 | 4,500 | 60 | 1.43% | -- |
| | | 2030 | 1,549 | 4,750 | 1,549 | 4,750 | 50 | 1.11% | -- |
| | | 2035 | 1,614 | 4,950 | 1,614 | 4,950 | 40 | 0.84% | 0.31% |
| City of Patterson | 2016 | 2015 | 1,048 | 3,216 | 1,048 | 3,216 | -- | -- | -- |
| | | 2020 | 2,079 | 6,376 | 2,079 | 6,376 | 632 | 19.65% | -- |
| | | 2025 | 2,627 | 8,058 | 2,627 | 8,058 | 336 | 5.28% | -- |
| | | 2030 | 2,941 | 9,020 | 2,941 | 9,020 | 192 | 2.39% | -- |
| | | 2035 | 3,254 | 9,982 | 3,254 | 9,982 | 192 | 2.13% | -- |
| | | 2040 | 3,568 | 10,944 | 3,568 | 10,944 | 192 | 1.93% | 6.28% |
| City of Riverbank | 2014 | 2015 | 1,662 | 5,098 | 1,662 | 5,098 | -- | -- | -- |
| | | 2020 | 1,786 | 5,478 | 1,786 | 5,478 | 76 | 1.49% | -- |
| | | 2025 | 2,007 | 6,157 | 2,007 | 6,157 | 136 | 2.48% | -- |
| | | 2030 | 2,229 | 6,837 | 2,229 | 6,837 | 136 | 2.21% | -- |
| | | 2035 | 2,451 | 7,517 | 2,451 | 7,517 | 136 | 1.99% | 2.04% |
| City of Turlock | 2016 | 2015 | 5,675 | 17,417 | 5,675 | 17,417 | -- | -- | -- |
| | | 2020 | 8,462 | 25,970 | 8,462 | 25,970 | 1,711 | 9.82% | -- |
| | | 2025 | 9,394 | 28,830 | 9,394 | 28,830 | 572 | 2.20% | -- |
| | | 2030 | 10,432 | 32,016 | 10,432 | 32,016 | 637 | 2.21% | -- |
| | | 2035 | 11,586 | 35,557 | 11,586 | 35,557 | 708 | 2.21% | -- |
| | | 2040 | 12,870 | 39,498 | 12,870 | 39,498 | 788 | 2.22% | 3.73% |
| City of Waterford | 2016 (Water Master Plan) | 2015 | 456 | 1,400 | 456 | 1,400 | -- | -- | -- |
| | | 2020 | 548 | 1,680 | 548 | 1,680 | 56 | 4.00% | -- |
| | | 2025 | 639 | 1,960 | 639 | 1,960 | 56 | 3.33% | -- |
| | | 2030 | 694 | 2,128 | 694 | 2,128 | 34 | 1.71% | -- |

**TABLE 6-2**
**FORECAST URBAN WATER DEMANDS**
**Stanislaus County Hydrologic Model: Development and Forecast Modeling**
**Stanislaus County, California**

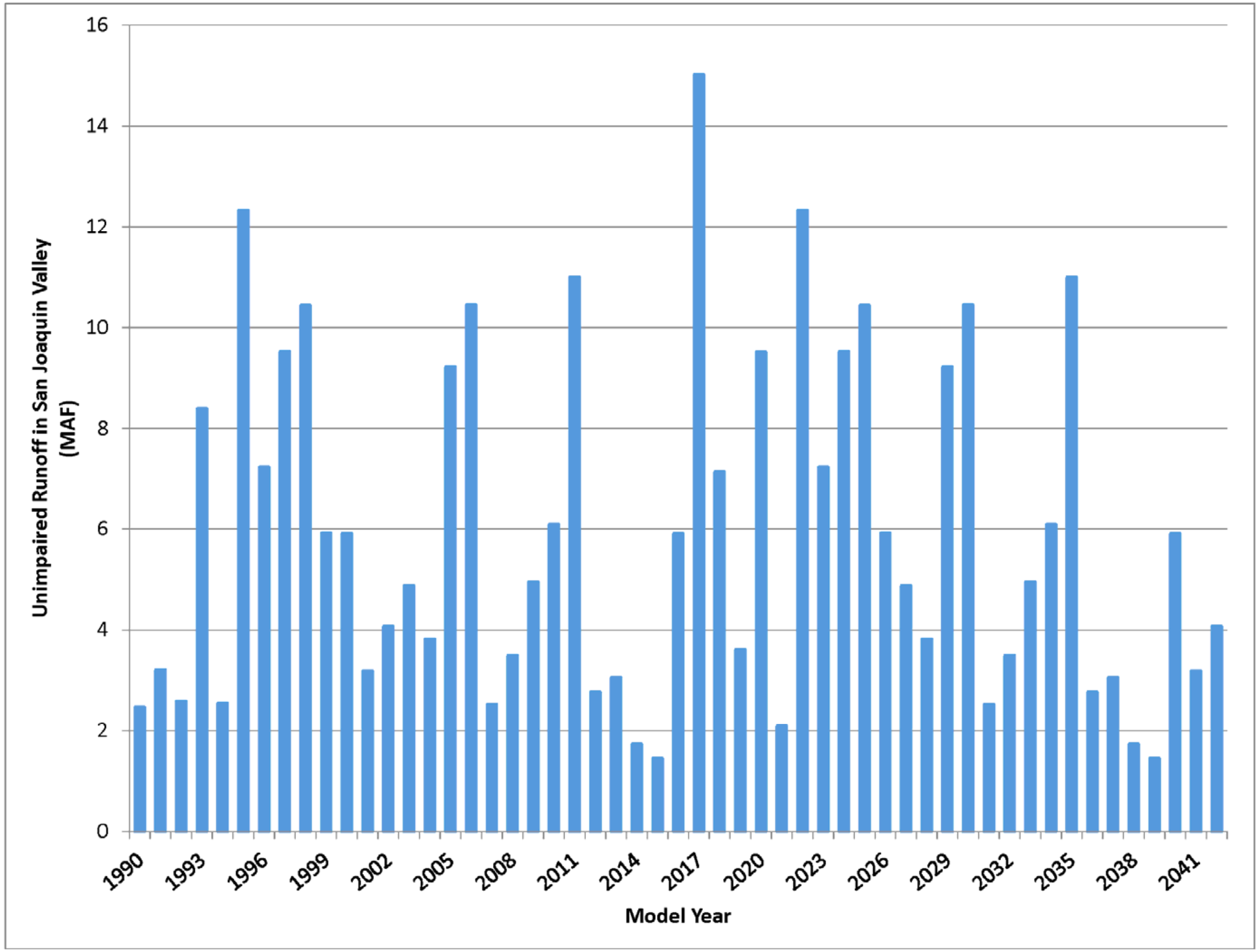
| Urban District | Year of UWMP | Total Water Demand (2016-2042) | | | Groundwater Demand (2016-2042) | | Annual Demand Increase per Five Year Increment | | Total Average Percent Increase |
|---|---|---|---|---|---|---|---|---|---|
| | | Year | MGY | AFY | MGY | AFY | AFY | Percent | Acre Feet |
| City of Waterford (continued) | 2016 (Water Master Plan) | 2035 | 767 | 2,352 | 767 | 2,352 | 45 | 2.11% | -- |
| | | 2040 | 840 | 2,576 | 840 | 2,576 | 45 | 1.90% | 2.61% |
| | | | | | | | | Average | 2.64% |
| | | | | | | | | Median Average | 2.70% |

Notes:
AFY = acre foot per year
MGY = million gsllon per year
UWMP = Urban Water Management Plan
% = percent

**TABLE 6-3**
**FORECAST SCENARIO GROUNDWATER BUDGET COMPARISON**
**Stanislaus County Hydrologic Model: Development and Forecast Modeling**
Stanislaus County, California

| Subbasin | Water Budget Component | Groundwater Budget Change Relative to Baseline in WY 2022 | | | | | Groundwater Budget Change Relative to Baseline in WY 2042 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Scenario 2 | Scenario 3 | Scenario 4a | Scenario 4b | Scenario 5 | Scenario 2 | Scenario 3 | Scenario 4a | Scenario 4b | Scenario 5 |
| Delta-Mendota | Change in Stream Gain from GW (AC-FT) | 72 | 39 | (3,390) | (1,525) | 86 | 682 | 174 | (3,964) | (1,948) | 1,528 |
| | Cumulative Storage Change (AC-FT) | (7,612) | (1,044) | (135,676) | (138,058) | (7,057) | (35,935) | (4,967) | (155,574) | (171,005) | (12,131) |
| | Annual Storage Change (AC-FT) | (63) | (7) | (837) | (1,031) | 95 | (479) | (52) | 29 | 52 | (469) |
| Eastern San Joaquin | Change in Stream Gain from GW (AC-FT) | (2,809) | (556) | (1,419) | (1,714) | (2,799) | (18,649) | (3,519) | (2,923) | (3,182) | (18,428) |
| | Cumulative Storage Change (AC-FT) | (255,244) | (48,244) | (175,725) | (162,065) | (255,201) | (3,433,006) | (627,837) | (636,517) | (549,882) | (3,430,237) |
| | Annual Storage Change (AC-FT) | (5,600) | (1,021) | (2,861) | (2,417) | (5,591) | (21,772) | (4,005) | (1,306) | (1,115) | (21,766) |
| Modesto | Change in Stream Gain from GW (AC-FT) | (9,413) | (1,851) | (8,963) | (7,163) | (6,714) | (57,614) | (10,973) | (13,068) | (11,411) | (48,206) |
| | Cumulative Storage Change (AC-FT) | (337,180) | (64,877) | (266,959) | (273,856) | (334,436) | (2,952,544) | (562,514) | (644,028) | (654,576) | (2,905,847) |
| | Annual Storage Change (AC-FT) | (6,690) | (1,277) | (4,420) | (4,597) | (6,203) | (17,992) | (3,422) | (268) | (245) | (17,970) |
| Turlock | Change in Stream Gain from GW (AC-FT) | (5,057) | (924) | (2,853) | (2,434) | (5,027) | (26,372) | (4,982) | (3,066) | (2,782) | (23,579) |
| | Cumulative Storage Change (AC-FT) | (331,978) | (62,373) | (315,628) | (340,189) | (257,691) | (2,217,507) | (425,147) | (363,417) | (417,594) | (1,191,660) |
| | Annual Storage Change (AC-FT) | (4,678) | (947) | (853) | (1,407) | 8,202 | (11,682) | (2,346) | (50) | (64) | (10,887) |

Notes:
AC-FT = acre feet
GW = groundwater
WY = water year




| Model Year (1990 – 2042) | Hydrology Data Year | Data Year Unimpaired Runoff in San Joaquin Valley (MAF) | Data Year Type | Climate Adjustment 2016 - 2042 (Temperature °C) |
|---|---|---|---|---|
| 1990 | 1990 | 2.46 | C | -- |
| 1991 | 1991 | 3.2 | C | -- |
| 1992 | 1992 | 2.58 | C | -- |
| 1993 | 1993 | 8.38 | W | -- |
| 1994 | 1994 | 2.54 | C | -- |
| 1995 | 1995 | 12.32 | W | -- |
| 1996 | 1996 | 7.22 | W | -- |
| 1997 | 1997 | 9.51 | W | -- |
| 1998 | 1998 | 10.43 | W | -- |
| 1999 | 1999 | 5.91 | AN | -- |
| 2000 | 2000 | 5.9 | AN | -- |
| 2001 | 2001 | 3.18 | D | -- |
| 2002 | 2002 | 4.06 | D | -- |
| 2003 | 2003 | 4.87 | BN | -- |
| 2004 | 2004 | 3.81 | D | -- |
| 2005 | 2005 | 9.21 | W | -- |
| 2006 | 2006 | 10.44 | W | -- |
| 2007 | 2007 | 2.51 | C | -- |
| 2008 | 2008 | 3.49 | C | -- |
| 2009 | 2009 | 4.94 | BN | -- |
| 2010 | 2010 | 6.08 | AN | -- |
| 2011 | 2011 | 10.99 | W | -- |
| 2012 | 2012 | 2.76 | D | -- |
| 2013 | 2013 | 3.05 | C | -- |
| 2014 | 2014 | 1.72 | C | -- |
| 2015 | 2015 | 1.44 | C | -- |
| 2016 | 2000 | 5.9 | AN | 0.0355 |
| 2017 | 1983 | 15.01 | W | 0.0710 |
| 2018 | 1984 | 7.13 | AN | 0.1065 |
| 2019 | 1985 | 3.6 | D | 0.1420 |
| 2020 | 1986 | 9.5 | W | 0.1775 |
| 2021 | 1987 | 2.08 | C | 0.2130 |
| 2022 | 1995 | 12.32 | W | 0.2485 |
| 2023 | 1996 | 7.22 | W | 0.2840 |
| 2024 | 1997 | 9.51 | W | 0.3195 |
| 2025 | 1998 | 10.43 | W | 0.3550 |
| 2026 | 1999 | 5.91 | AN | 0.3905 |
| 2027 | 2003 | 4.87 | BN | 0.4260 |
| 2028 | 2004 | 3.81 | D | 0.4615 |
| 2029 | 2005 | 9.21 | W | 0.4970 |
| 2030 | 2006 | 10.44 | W | 0.5325 |
| 2031 | 2007 | 2.51 | C | 0.5680 |
| 2032 | 2008 | 3.49 | C | 0.6035 |
| 2033 | 2009 | 4.94 | BN | 0.6390 |
| 2034 | 2010 | 6.08 | AN | 0.6745 |
| 2035 | 2011 | 10.99 | W | 0.7100 |
| 2036 | 2012 | 2.76 | D | 0.7455 |
| 2037 | 2013 | 3.05 | C | 0.7810 |
| 2038 | 2014 | 1.72 | C | 0.8165 |
| 2039 | 2015 | 1.44 | C | 0.8520 |
| 2040 | 2000 | 5.9 | AN | 0.8875 |
| 2041 | 2001 | 3.18 | D | 0.9230 |
| 2042 | 2002 | 4.06 | D | 0.9585 |

Notes:
AN = above normal    BN = below normal    C = critically dry    D = dry    MAF = million acre foot    °C = degree Celsius
Source: California Department of Water Resources, California Data Exchange Center. California Cooperative Snow Surveys.
Website: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST.

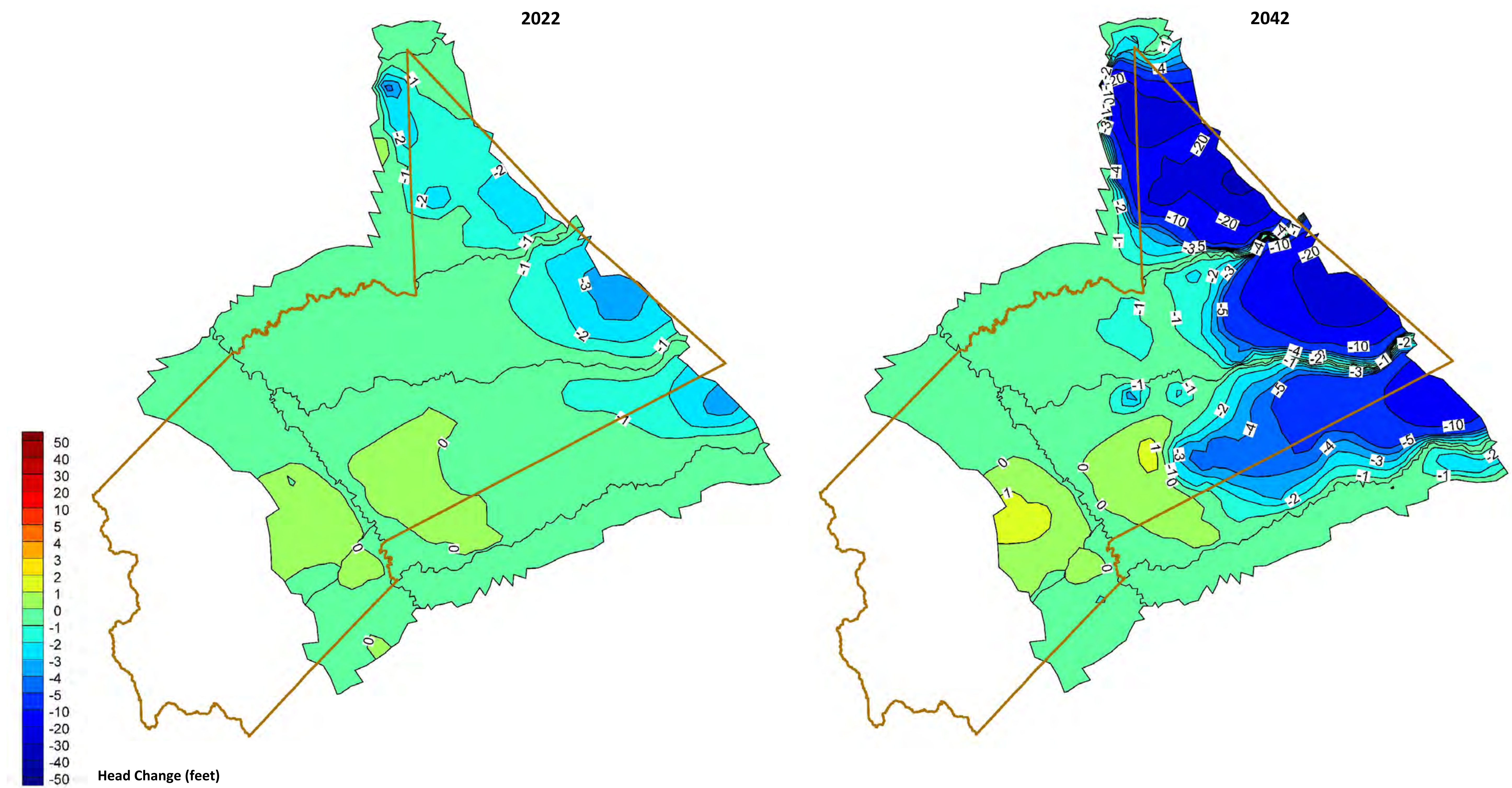
JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| *STANCO.002* | *10/24/17* | *JH* | *MT* |

*FIGURE 6-1*

**SCHM Forecast Hydrologic Data, 2016 - 2042**



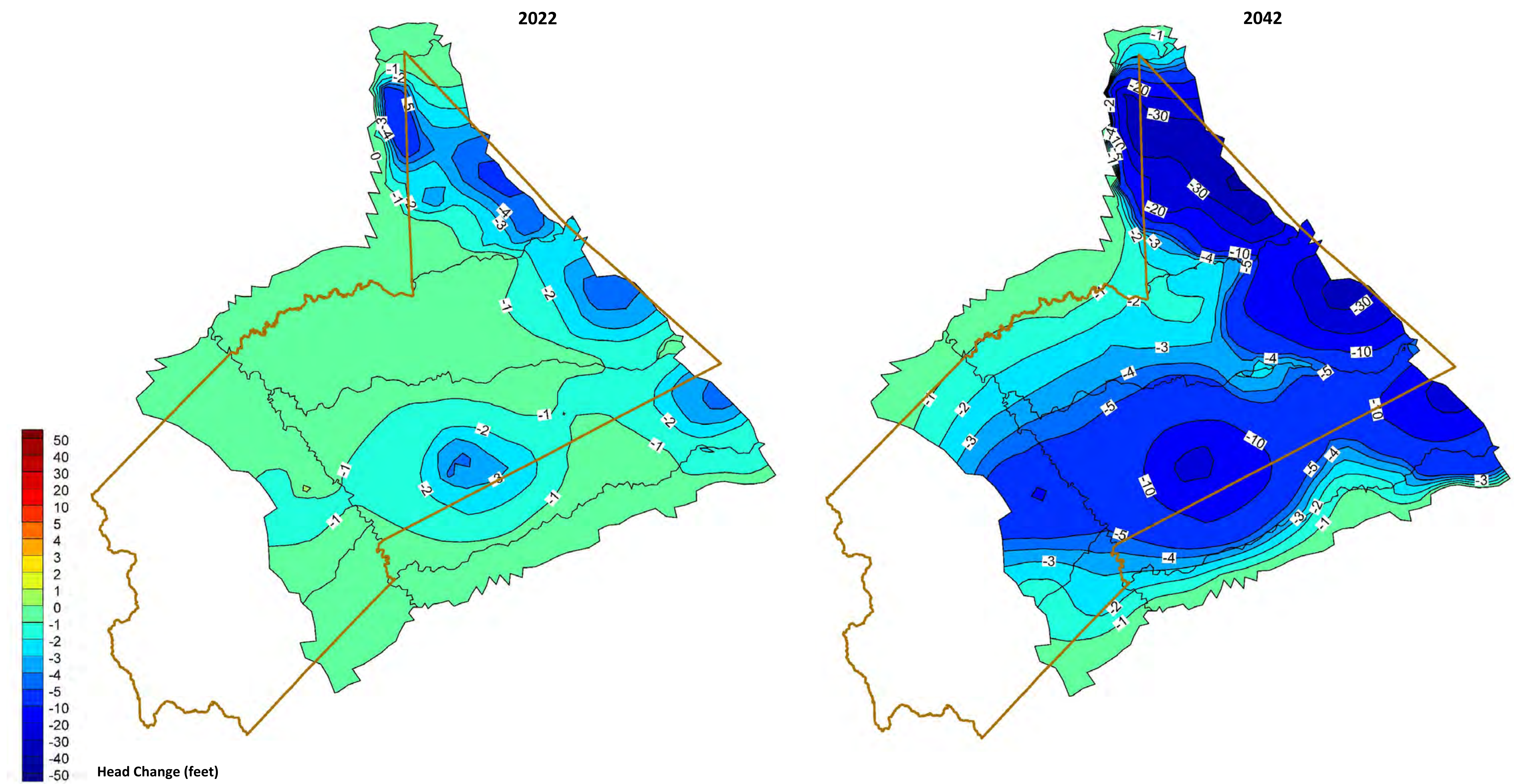

JACOBSON | JAMES
& associates, inc

Stanislaus County Hydrologic Model: Development and Forecasts
Stanislaus County, California

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/28/17 | JH | MT |

FIGURE 6-2

**Scenario 2 Head Change Predictions in SCHM Layer 1**



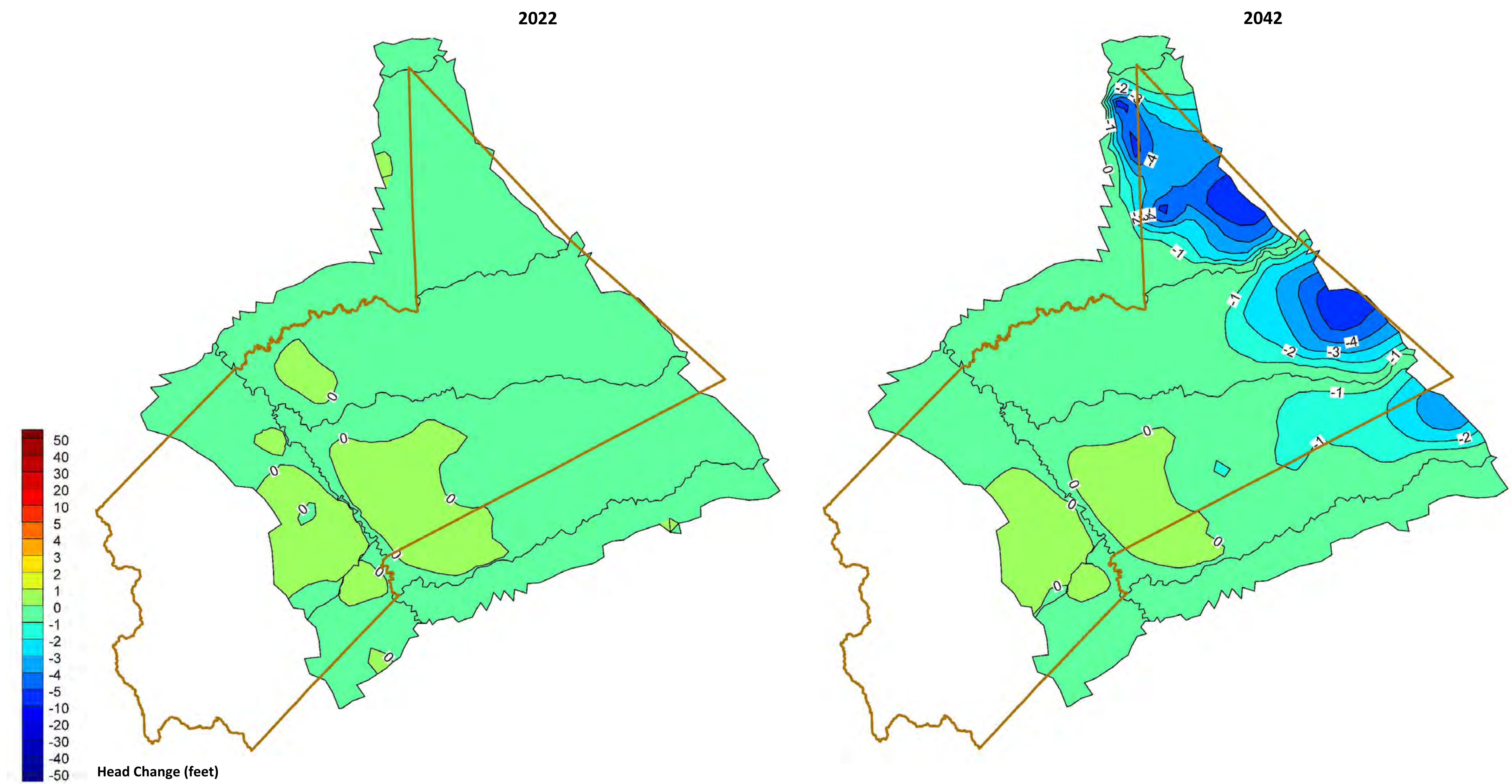

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/28/17 | JH | MT |

*FIGURE 6-3*

***Scenario 2 Head Change Predictions in SCHM Layer 2***



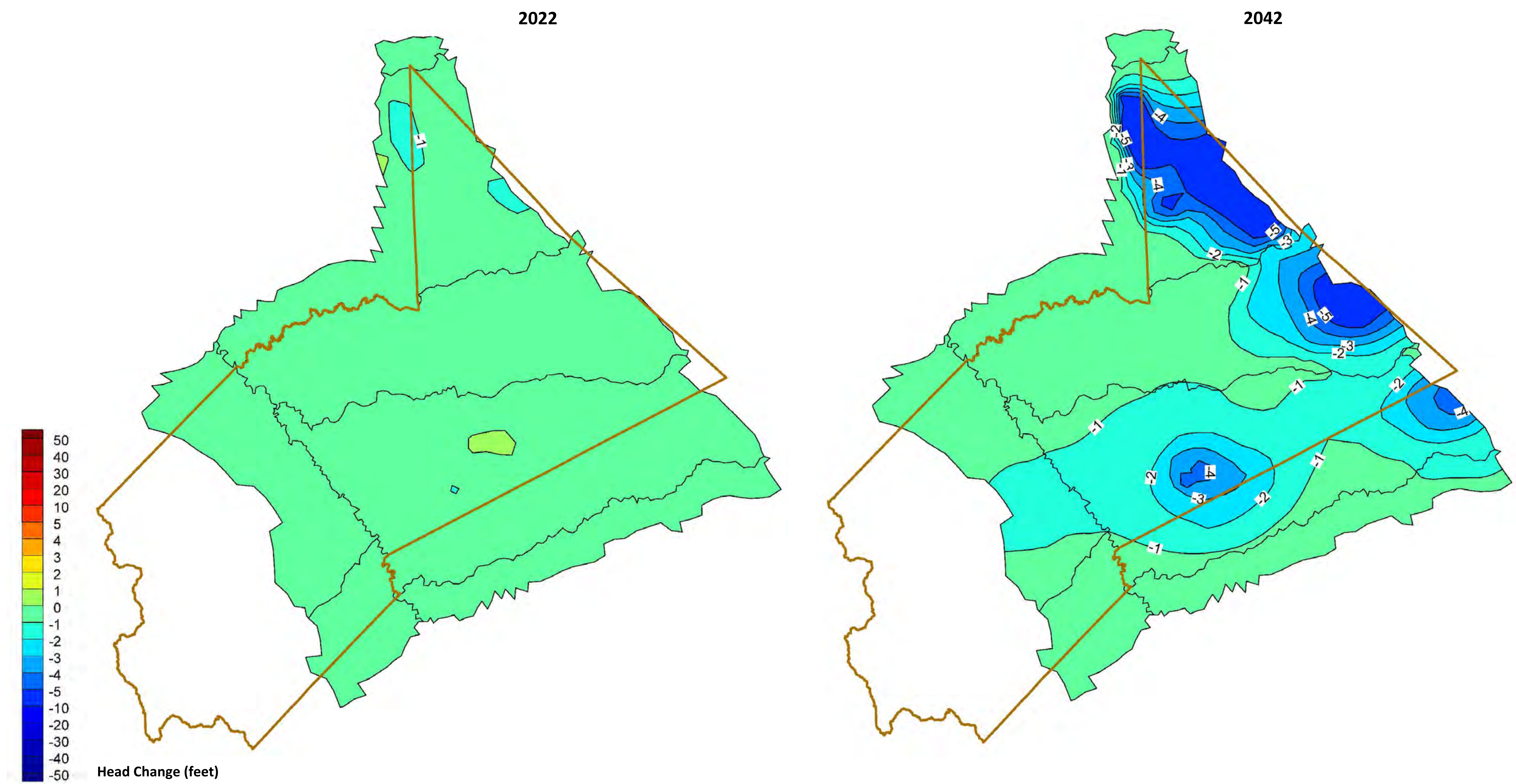

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/28/17 | JH | MT |

*FIGURE 6-4*

***Scenario 3 Head Change Predictions for SCHM Layer 1***



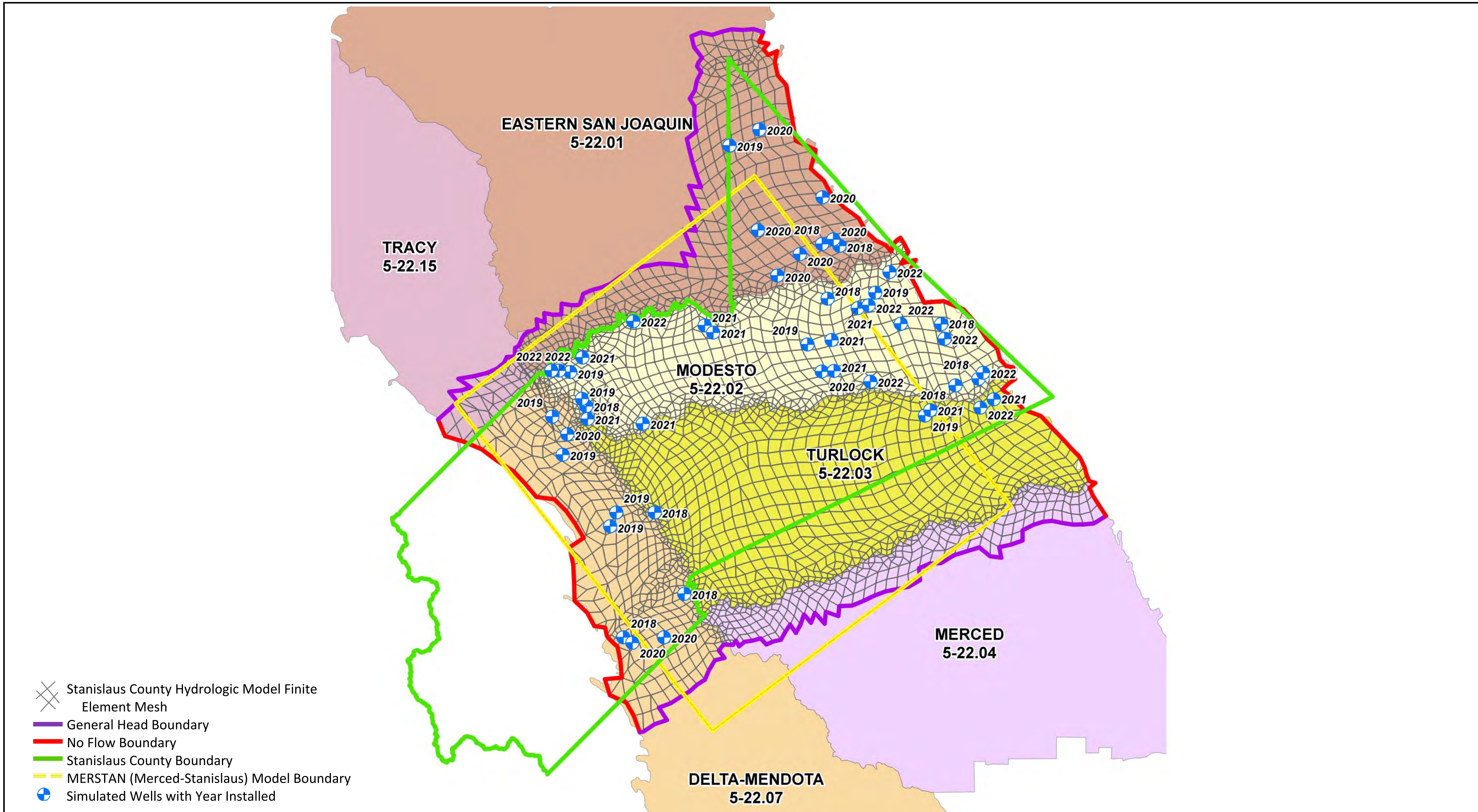

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/28/17 | JH | MT |

*FIGURE 6-5*

***Scenario 3 Head Change Predictions for SCHM Layer 2***



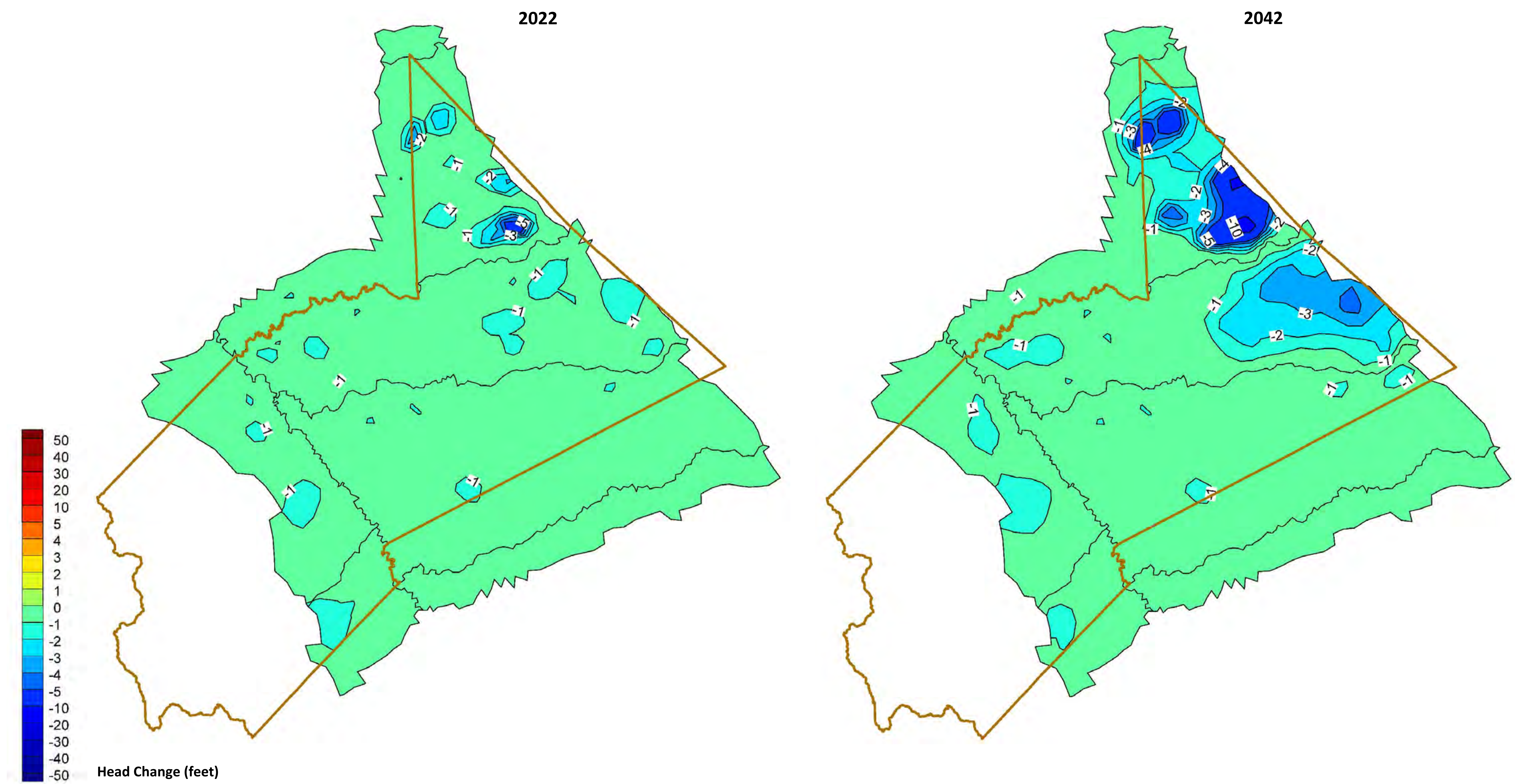

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/28/17 | JH | MT |

*FIGURE 6-6*

***Scenario 4a and 4b: Location of Simulated Wells and Year Installed***



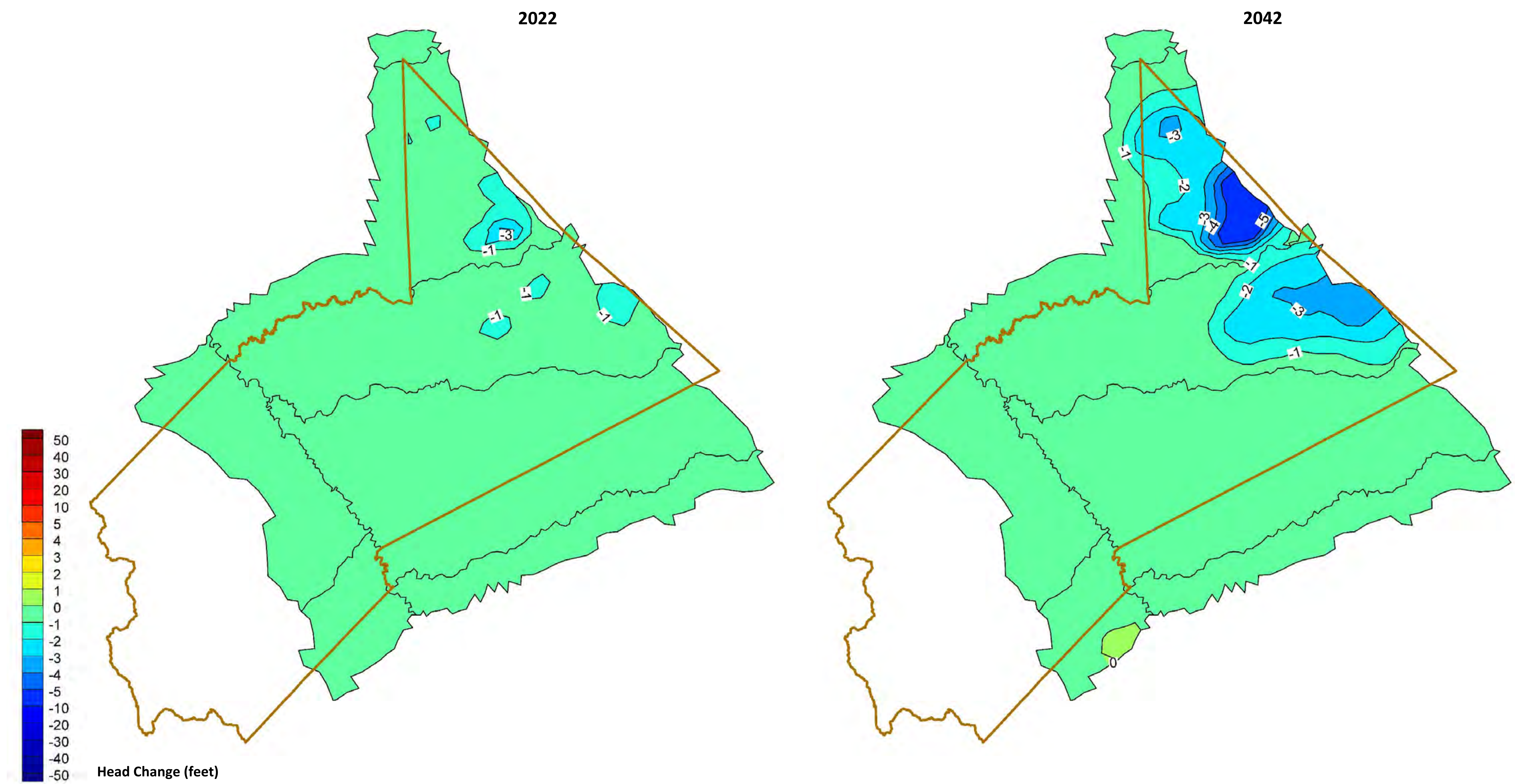

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/28/17 | JH | MT |

*FIGURE 6-7*

***Scenario 4a Head Change Predictions for SCHM Layer 1***



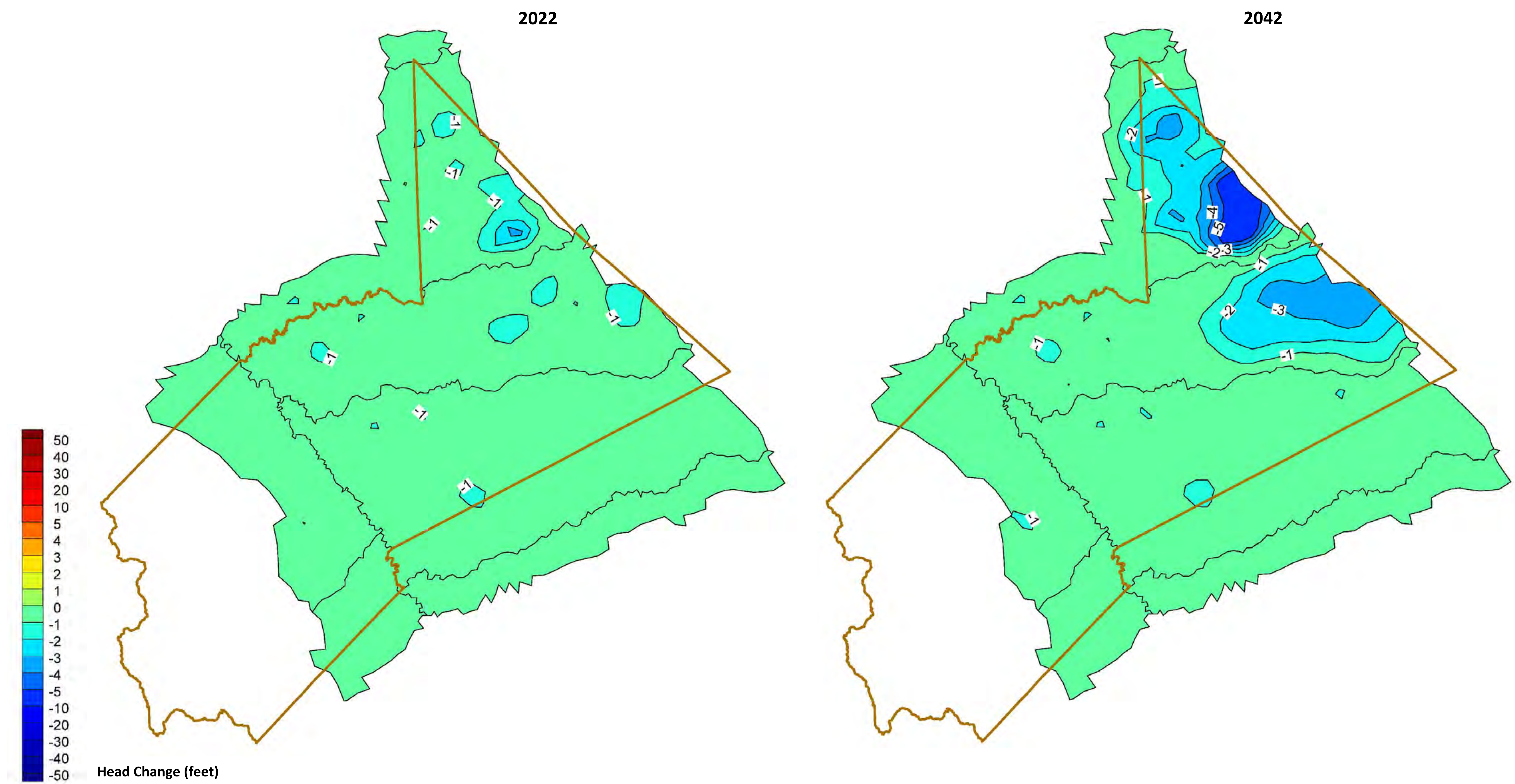

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/28/17 | JH | MT |

*FIGURE 6-8*

***Scenario 4a Head Change Predictions for SCHM Layer 2***



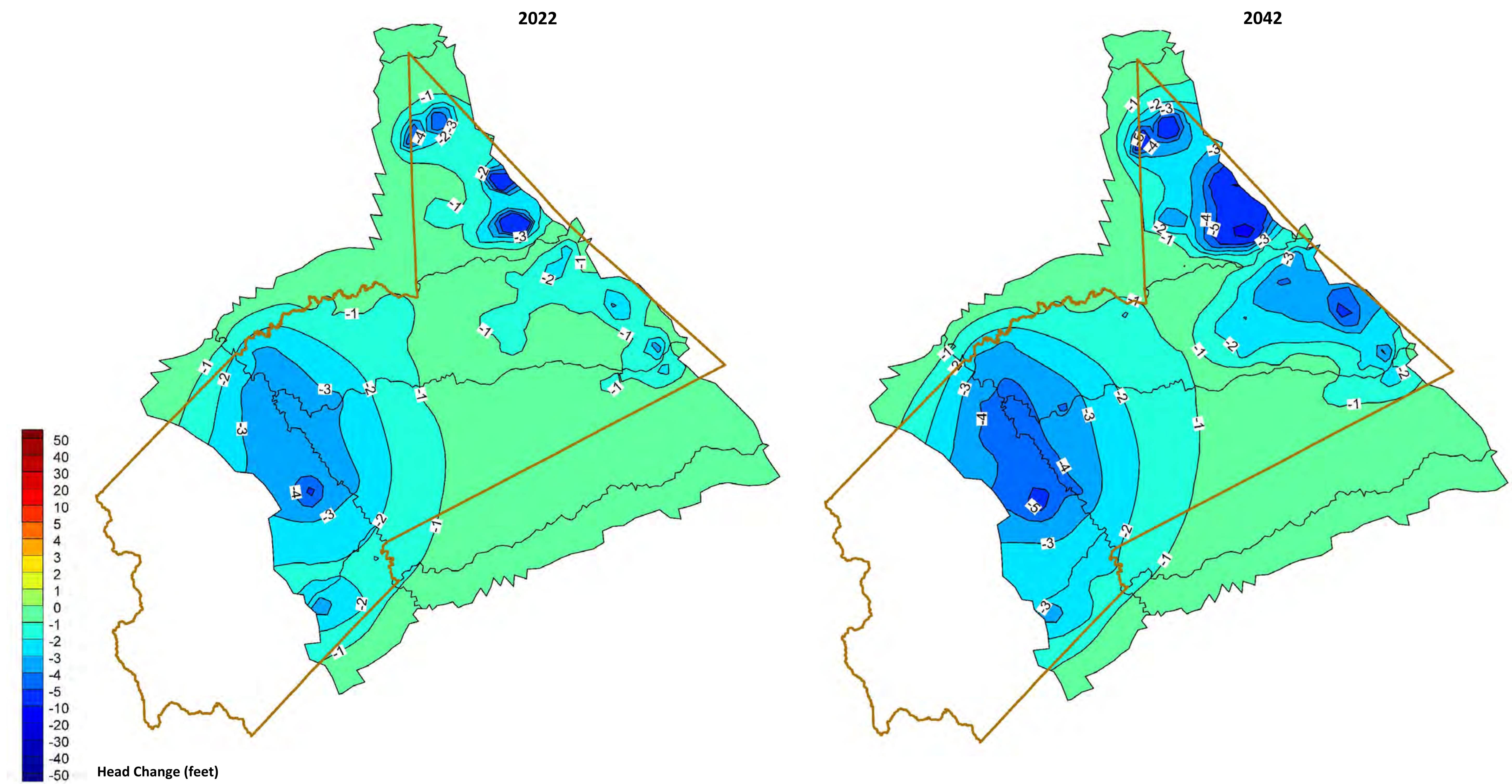

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| STANCO.002 | 11/28/17 | JH | MT |

*FIGURE 6-9*

***Scenario 4b Head Change Predictions for SCHM Layer 1***



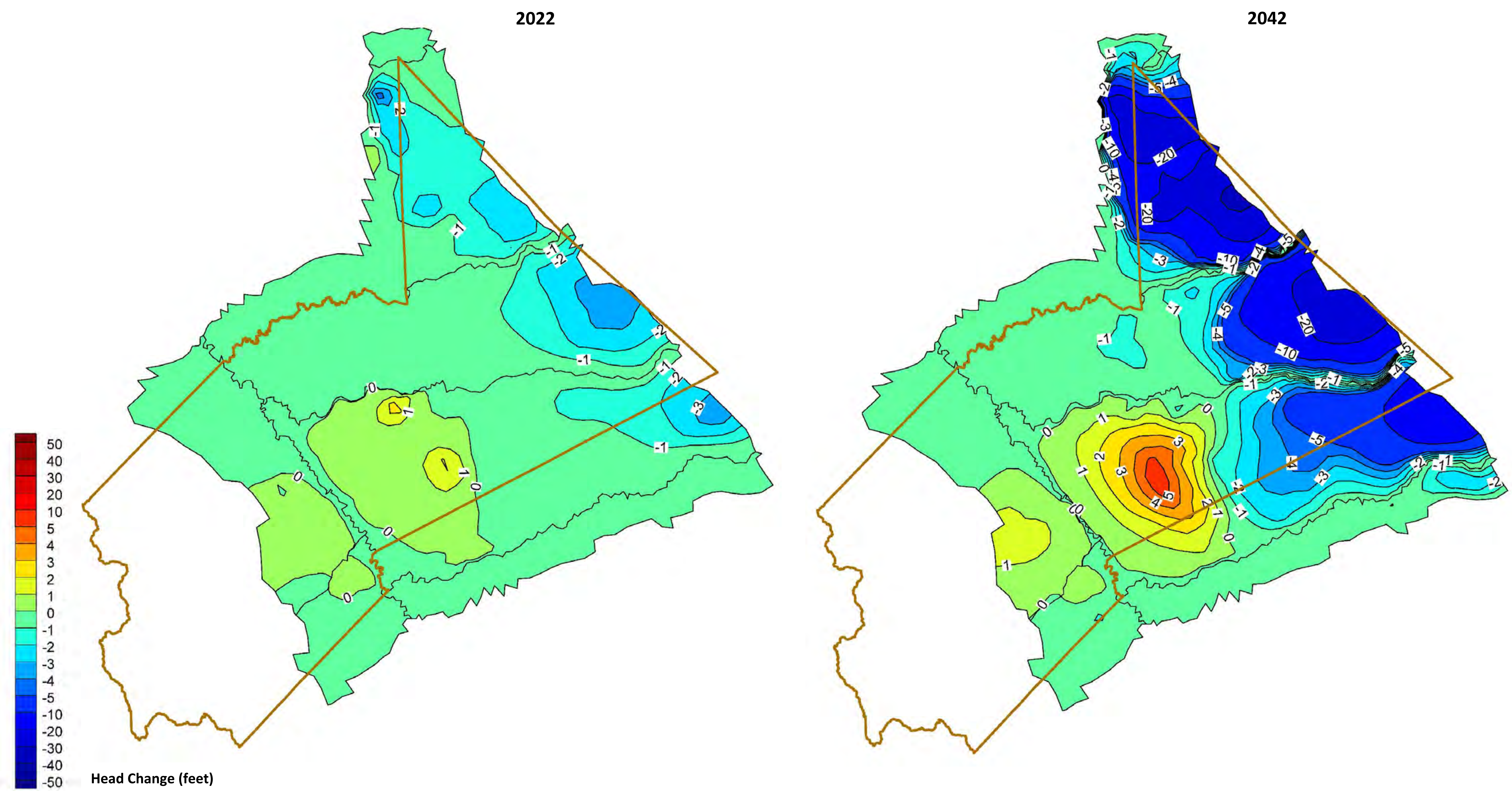

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| *STANCO.002* | *11/28/17* | *JH* | *MT* |

*FIGURE 6-10*

***Scenario 4b Head Change Predictions for SCHM Layer 2***



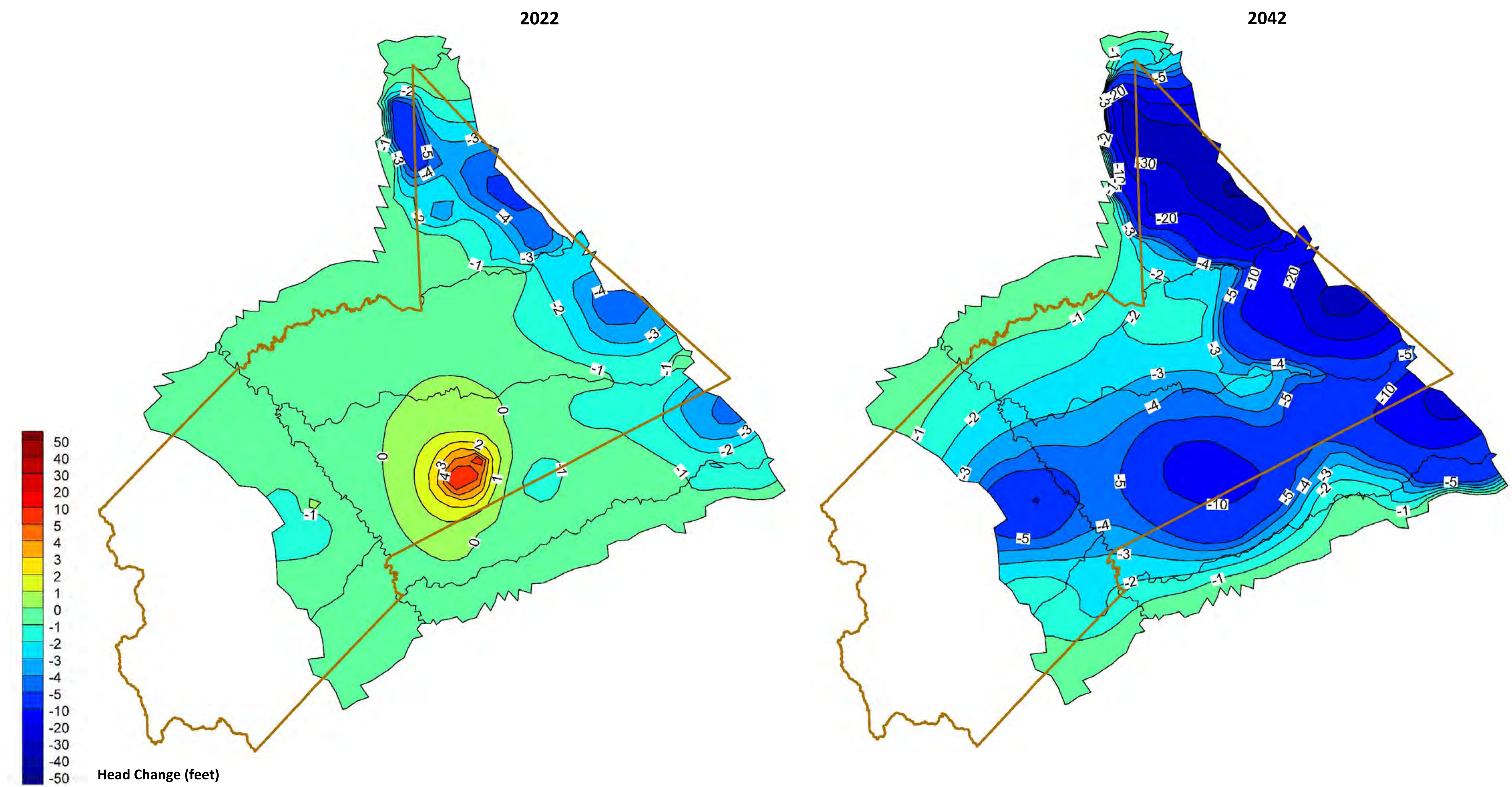

JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| *STANCO.002* | *11/28/17* | *JH* | *MT* |

*FIGURE 6-11*

***Scenario 5 Head Change Predictions for SCHM Layer 1***




JACOBSON | JAMES
& associates, inc

*Stanislaus County Hydrologic Model: Development and Forecasts*
*Stanislaus County, California*

| PROJECT NO. | DATE | DRAWN BY | APPR. BY |
|---|---|---|---|
| *STANCO.002* | *11/28/17* | *JH* | *MT* |

*FIGURE 6-12*

***Scenario 5 Head Change Predictions for SCHM Layer 2***

# 7.0 CONCLUSIONS AND RECOMMENDATIONS

The primary objectives of developing the SCHM were to provide a tool that may be used for evaluation of program-level impacts of implementing the County's discretionary well permitting program, and producing an incremental improvement in understanding and modeling of regional hydrogeologic conditions that builds on past efforts and can help inform future studies leading up to development of GSPs. The groundwater budget, cross boundary flow, and some head data produced by the SCHM should be considered preliminary and indicative; however, the forecast data are produced using a superposition approach that is adequate for the evaluation of program-level impacts to groundwater resources. As noted in the preceding sections, further refinement of groundwater modeling in the area will be needed to produce subbasin-scale models that can support the preparation of GSPs, or that are suitable for evaluation of groundwater and other hydrologic impacts associated with specific projects. This can be accomplished through the construction of new models, by updating the SCHM, or by creating more detailed "child" models within the SCHM domain that incorporate sufficient refinements to meet future modeling objectives. The construction, calibration and sensitivity testing of the SCHM, as well as its use to evaluate historical conditions and forecast future conditions, provides key information to identify and prioritize data needs and opportunities to support such activities. Key findings and recommendations are discussed below.

## 7.1 Principal Findings of Forecast Analysis

The modeling forecast analysis provided insights into changes in water budgets and groundwater levels that could occur throughout the County under a variety of scenarios and stresses. Both water budgets and groundwater levels are discussed in Section 6 and principal findings are summarized below. Table 7-1 provides a summary of the model forecast water budgets for the entire model area.

**Table 7-1a Modeling Forecast Water Budget Summary**

| **Combined All Subbasins** | **Groundwater Budget Change Relative to Baseline in WY 2022** | | | | |
|---|---|---|---|---|---|
| | **Scenario 2** Upper Bound Demand Increase | **Scenario 3** Lower Bound Demand Increase | **Scenario 4a** Discretionary Well Permitting Shallow Aquifer | **Scenario 4b** Discretionary Well Permitting Deep Aquifer | **Scenario 5** Additional Surface Water Delivery |
| Change in Stream Gain from GW (AC-FT) | (17,207) | (3,292) | (16,625) | (12,835) | (14,454) |
| Cumulative Storage Change (AC-FT) | (932,014) | (176,538) | (893,987) | (914,168) | (854,385) |
| Annual Storage Change (AC-FT) | (17,031) | (3,252) | (8,972) | (9,452) | (3,498) |

**Table 7-1b Modeling Forecast Water Budget Summary**

| Combined All Sub-Basins | Groundwater Budget Change Relative to Baseline in WY 2042 | | | | |
|---|---|---|---|---|---|
| | Scenario 2 Upper Bound Demand Increase | Scenario 3 Lower Bound Demand Increase | Scenario 4a Discretionary Well Permitting Shallow Aquifer | Scenario 4b Discretionary Well Permitting Deep Aquifer | Scenario 5 Additional Surface Water Delivery |
| Change in Stream Gain from GW (AC-FT) | (101,954) | (19,299) | (23,021) | (19,323) | (88,685) |
| Cumulative Storage Change (AC-FT) | (8,638,993) | (1,620,466) | (1,799,536) | (1,793,056) | (7,539,876) |
| Annual Storage Change (AC-FT) | (51,925) | (9,825) | (1,595) | (1,372) | (51,091) |

Principal conclusions from the SCHM forecast analysis include the following.

- Comparing water budgets over the short term (Table 7-1a through WY 2022), the reasonable lower bound demand increase scenario (Scenario 3) results in the least stream depletion and removes the least water from storage (cumulative and annual). Over the long term (Table 7-1b through WY 2042), decreased demand and the discretionary well permitting program (with wells in either the shallow aquifer [Scenario 4a] or deep aquifer [Scenario 4b] zones), water budget are similar and have significantly less impacts to stream depletion and groundwater storage compared to Scenario 2 (the reasonable upper bound demand increase scenario. The difference in streamflow and aquifer depletion simulated in Scenario 5 (additional surface water) decreases the effects of Scenario 2, and would compensate for a large percentage of Scenario 3 impacts.
- In all of the forecast scenarios except Scenario 4b (discretionary well permitting with addition of new wells in the deeper aquifer), increases in groundwater demand led to a greater drawdown response in the eastern foothills area of the model than in other locations. This was generally true in both Model Layer 1 and 2 (the shallow aquifer system and the deeper aquifer system), and appears to reflect a greater relative sensitivity of this area to groundwater stresses. Greater sensitivity to drawdown stresses in this area may result from less local recharge being available due to local soil conditions and a lack of surface water availability.
- A second area of the model where groundwater stresses appeared to result in greater drawdown is the north central area of the model in Model Layer 2 beneath the Corcoran Clay. This area displayed the greatest amount of drawdown in Scenario 4b, which evaluated the effects of permitting discretionary wells in the deeper aquifer. The area may be more susceptible to drawdown because it represents a terminal outflow point of the model, where water budget effects become cumulative, and because the strongly confined nature of the deeper aquifer system beneath the Corcoran Clay

results in greater drawdown per unit volume of water extracted. The historical model simulates a broad cone of depression in this area (Figures 4-7 and 4-8), as does C2VSim.

- Groundwater extraction in the western portion of the model and from the shallow aquifer system resulted in higher amounts of streamflow depletion than groundwater withdrawal from the deeper aquifer or in other areas. Nevertheless, the increases in streamflow depletion resulting from higher groundwater demand were relatively modest, and the amount of total streamflow depletion that was forecast was relatively modest and below the typical range of error of stream gaging stations (typically about +/- 5 %).
- Groundwater level drawdown from municipal pumping was greatest in cities that rely primarily on wells completed in the deeper aquifer system, such as Turlock. Increase in municipal demand in these areas were accompanied by a slight increase in shallow groundwater levels resulting from deep percolation of return flows, while groundwater extraction from the confined, deep aquifer system led to higher rates of drawdown than in other areas.
- The greatest amount of drawdown was predicted under Scenario 2 (reasonable upper bound potential demand increase), which is based on worst case assumptions regarding municipal, rural domestic and agricultural demand growth. Demand growth at the simulated rates has a low likelihood of ever being realized, but coupled with Scenario 3 (reasonable lower bound potential demand increase), which incorporates a more realistic demand growth scenario, provides a useful preliminary perspective for investigating the relationship between demand growth, drawdown, and sustainable yield.
- Scenario 5 (Scenario 2 with additional surface water delivery) illustrates the effectiveness of conjunctive use projects to help alleviate local drawdown. For perspective, the surface water supply rates simulated in this scenario appear capable of moderating the drawdown resulting from worst case demand growth (Scenario 2), and more than offset the drawdown associated with a more reasonable demand growth rate (Scenario 3). However, the volumes of surface water assumed to be supplied under Scenario 5 are relatively small compared to regional demand, and did little to offset streamflow or storage depletion at a subbasin level.

## 7.2 Principal Findings and Recommendations from Model Construction and Calibration

### 7.2.1 Selected Model Code and Scheduled Improvements

Updates to the DWR's C2VSim are being developed using the IWFM 2015 modeling code, which features an improved ability to apply water budget data, simulate demand, route deep percolation, and other key features. The USGS is also working to refine the CVHM and MERSTAN models. In addition, efforts are underway to develop improved cropping and evapotranspiration datasets. These efforts, which were in progress as the SCHM was being developed, will be available for use by future subbasin-scale modeling efforts needed to support GSP development. Finally, subbasin scale modeling efforts were in progress in the Eastern San Joaquin Subbasin to the north and west of the SCHM domain, and to the south of the SCHM in the Merced Subbasin. It is expected that the results of these efforts will be useful to better understanding water budget processes in the region and cross boundary flows into and out of these respective modeling areas.

### 7.2.2 Water Budgets

Efforts during construction of the SCHM focused on refinement of water budgets to a greater degree than refinement of model lithology or model calibration. Nevertheless, significant data needs and opportunities for further refinement of local and regional water budgets remain that were beyond of the scope of the current project to address. These include the following.

- Additional data likely exist regarding urban and agricultural water demand, well completions, surface water deliveries, system losses, tile drainage, return flows and system "spill", that were not provided by water districts or available from published plans. These data could be used as an input to improve understanding of regional, subbasin and local water budgets, and would serve as a primary data source to help guide future model calibration and refinement efforts.
- Refined datasets regarding historical cropping patterns and evapotranspiration based on improvements in remote sensing data application are being developed by DWR. As was stated in Section 4.5.3, agricultural pumping accounts for 80 to 89% of groundwater pumping in the County. Therefore, these data, coupled with comparison to data from the Agricultural Commissioner and field-level verification, provide a significant and necessary opportunity for model refinement. As illustrated by the results of the sensitivity analysis for evapotranspiration, accurate data regarding these key agricultural water budget inputs are essential to model accuracy and to producing meaningful calibration results. These data should be incorporated into future modeling efforts based on codes (such as IWFM 2015) with an improved capability of applying and simulating agricultural water budget processes.
- Urban water budgets in the SCHM were refined using updated historical demand data and well completion information, but urban water budget processes in the SCHM are based largely on *ad hoc* assumptions incorporated into the C2VSim that may be appropriate for regional modeling, but can be substantially refined for more local application. This includes information regarding system leakage, wastewater return flow, indoor vs. outdoor water use, storm drainage and urban evapotranspiration, among others. Refinements to the processes are available in IWFM 2015, and should be applied in tandem with investigation of refined urban water budgets.
- Industrial groundwater pumping data were not provided for the development of the SCHM. The approach taken to developing rural domestic groundwater demand inputs for the SCHM around urban fringes may compensate for this deficiency somewhat by estimating higher rural domestic demand in areas where the model water budget subregions overlap with both urban and rural census tracts. Industrial groundwater users in the region tend to be located in these urban fringe areas.

However, the extent of this effect has not been evaluated. If provided in the future, industrial groundwater demand data would be useful for developing a refined understanding of urban water budgets.

- Recharge from offstream storage reservoirs in eastern Stanislaus County is an important water budget component. C2VSim does not include these reservoirs, and recharge rates incorporated into MERSTAN were based on rough estimates. Recharge rates were developed for SCHM based on district-provided water balance data, but could likely be refined. A disparity existed between the recharge rates estimated for Woodward and Modesto Reservoir, and those estimated based on data provided for Turlock Lake, with the rates for Turlock Lake being several times higher even though the reservoirs are all of fairly similar size and located in similar geologic settings. During the calibration process, high water levels were noted in the vicinity of Turlock Lake and the recharge rate for this lake was therefore adjusted downward. It would be desirable to further investigate the actual recharge rates for these reservoirs, as the most complete water balance dataset among the three reservoirs was provided for Turlock Lake, and this adjustment was not based on a comparison to the other reservoir for which data was more limited, and local groundwater levels.

### 7.2.3 Measured and Simulated Groundwater Levels

Development of groundwater level calibration datasets and calibration of the SCHM revealed that the current CASGEM dataset, which does not differentiate monitoring data from different hydrostratigraphic zones, may lead to an overly simplified understanding of groundwater levels and flow. In many cases, we found that wells completed to total depths within Model Layer 2 had measured water levels that were more consistent with simulated and measured water levels in Model Layer 1. When considered together with data from other nearby wells, in many cases it appeared that this was a function of the well construction rather than an inaccuracy in the modeling results. Theoretically this is possible when deep wells cross-connect the upper and lower aquifer systems mixing water from the two zones due to annular flow, cross screening or damaged well casings, and vertical flow in the wells causes water levels within the well to be dominated by higher groundwater levels in the upper aquifer system. Further work is warranted to investigate groundwater levels in the shallow and confined aquifer systems, especially in the area underlain by the Corcoran Clay.

Historical groundwater level data in the eastern foothill region of the SCHM is, at present, relatively sparse, but efforts are underway by Stanislaus County and the Agricultural Preservation Alliance (APA) to compile additional data that can help inform future modeling efforts.

Based on the above observation and the simulate historical SCHM model results for Model Layer 1 and Model Layer 2, groundwater levels in the confined aquifer system beneath the Corcoran Clay may be deeper than has previously be recognized on a regional basis. However, the calibration data also indicate that the model has a bias toward underpredicting water levels in Model Layer 2. Model Layer 2 beneath the Corcoran Clay in the north-central portion of the County represents the most downgradient portion of the model domain, and be subject to the cumulative effects of all upstream model inputs, including any errors. Investigation of groundwater levels at discrete hydrostratigraphic intervals will be key to making meaningful improvements in model calibration and refining model accuracy.

### 7.2.4 Model Aquifer Parameters

The most sophisticated lithology dataset in the SCHM region stems from extensive work completed by the USGS for the MERSTAN model. Care was taken during calibration of the SCHM not to disregard this dataset and make widespread hydraulic conductivity adjustments in this area when other model inputs are not constrained at a similar level of detail. Outside the active MERSTAN domain to the east and to the west, a limited dataset of specific capacity and aquifer tests was utilized to update model hydraulic conductivity. Additional specific capacity test data are being compiled by Stanislaus APA for the eastern foothills area of the SCHM and will be available to help inform future modeling efforts. Similar data may be available for the Delta-Mendota Subbasin portion of the SCHM. Alternatively, well log data for these areas could be compiled and analyzed geostatistically to expand the MERSTAN geostatistical lithology model the edges of the groundwater basin.

The model sensitivity analysis indicates that lateral hydraulic conductivity, vertical hydraulic conductivity, and storage coefficients are all sensitive parameters, and the model could be improved through their refinement. The greatest variation noted in the sensitivity analysis was in response due to decreases in lateral hydraulic conductivity, which produced the greatest head decline below the Corcoran Clay in Layer 2, although Layer 1 was also sensitive to this parameter to a lesser degree. An unexpected result was the variation in effect from one location to another, especially in Layer 1. The same change produced increases and declines in groundwater levels in adjacent areas. The source of this variability should be further investigated in order to facilitate future changes to the model inputs.

Aquifer storage coefficients had a more uniform effect on groundwater levels, which was most pronounced in Layer 2. Relatively few data sources for aquifer storage coefficients exist within the SCHM domain. Additional data from aquifer tests may exist that were not considered in constructing the SCHM, and deriving additional data from future aquifer tests would help to constrain this important parameter and support more refined and meaningful model calibration.

The vertical hydraulic conductivity of the Corcoran Clay is a key parameter in terms of its influence on groundwater flow and levels, especially in Layer 2, yet little direct data exist to substantiate this property within the SCHM domain. Focused studies to help constrain this property on a subregional basis, laboratory analysis of cores, and/or carefully constructed aquifer testing would help to constrain this parameter and support more refined and meaningful model calibration.

# 8.0 REFERENCES

Aquacraft, 2011. *California Single Family Water Use Efficiency Study.* June.

Anderson, Mary P. and Woessner, W.W., 2002. *Applied Groundwater Modeling, Simulation of Flow and Advective Transport.* Academic Press.

Daly et al. 1997. *The Prism Approach to Mapping Precipitation and Temperature.*

Daly, C., Gibson, W.P., Doggett, M., Smith, J. and Taylor, G., 2004. *Up-to-date monthly climate maps for the conterminous United States.* In Proc., 14th AMS Conf. on Applied Climatology, 84th AMS Annual Meeting Combined Preprints, Amer. Meteorological Soc., Seattle, WA. January.

California Department of Water Resources (DWR), 2013a. California's Groundwater Update 2013, A Compilation of Enhanced Content for California Water Plan Update 2013, Chapter 8 – San Joaquin River Hydrologic Region. April.

DWR, 2013b. *Development and Calibration the California Central Valley Groundwater-. Surface Water Simulation Model (C2VSim), Version 3.02-CG.* DWR Technical Memorandum. June.

DWR, 2013c. *Integrated Water Flow Model Version 3.02, Theoretical Documentation.* October.

DWR, 2015a. Draft List of Critically Overdrafted Basins – August 6, 2015. August.

DWR, 2015b. Groundwater Information Center Interactive Mapping Application. Website: https://gis.water.ca.gov/app/gicima/. Last edited January 15, 2015. Accessed December, 2015.

DWR, 2016a. C2VSim: California Central Valley Groundwater-Surface Water Simulation Model. Website: http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm

DWR, 2016b. *Best Management Practices for the Sustainable Management of Groundwater: Modeling.* December.

DWR, 2017a. California Data Exchange Center. Website: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST

DWR, 2017b. Groundwater Information Center Interactive Map Application. Website: https://gis.water.ca.gov/app/gicima/

Cordero, E.C., Kessomkiat, W., Abatzoglou, J. and Mauget, S.A., 2011. *The identification of distinct patterns in California temperature trends.* Climatic change, 108(1), pp.357-382.

Davids Engineering, 2015. *2015 Agricultural Water Management Plan, South San Joaquin Irrigation District.* December.

Durbin, 2008. *Assessment of Future Groundwater Impacts due to Assumed Water-Use Changes, Turlock Groundwater Basin, California*. Prepared for the Turlock Groundwater Basin Association, September.

Jacobson James & Associates, Inc. (JJ&A), 2016a. *Groundwater Resources Impact Assessment, Crows Landing Industrial Business Park, Stanislaus County, California.* Prepared for Stanislaus County Division of Public Works. October.

JJ&A, 2016b. *Hydrologic Modeling Plan, Program Environmental Impact Report for Implementation of the Stanislaus County Groundwater Ordinance.* December.

JJ&A, 2017. *Draft Initial Study and Mitigated Negative Declaration, Well Permit Application 2017-117, Larry Gillum, Stanislaus County, California.* Prepared for Stanislaus County Department of Environmental Resources. October.

Makkink, G.F. 1957. *Testing the Penman formula by means of lysimeters.* J. Inst. of Water Eng. 11: 277-288.

Michael Baker International, 2016. *Stanislaus County 2015 – 2023 Housing Element Update.* April.

Phillips, S.P., Rewis, D.L., and Traum, J.A., 2015. *Hydrologic model of the Modesto Region, California, 1960–2004.* U.S. Geological Survey Scientific Investigations Report, 2015–5045, 69 p. Website:.

Reilly, Thomas E., Franke, O. Lehn, and Bennett, Gordon D., 1987. *The Principle of Superposition and its Application in Ground-Water Hydraulics.* U.S. Geological Survey Techniques of Water-Resources Investigations 03-B6.

State Water Resources Control Board (SWRCB), 2012. Draft Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the Bay-Delta: San Joaquin River Flows and Southern Delta Water Quality. December.

SWRCB, 2015. *A Guide for Private Domestic Well Owners.* Website: http://www.waterboards.ca.gov/gama/docs/wellowner_guide.pdf. Accessed September 14, 2016.

SWRCB, 2016. *Draft Revised Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the Bay-Delta: San Joaquin River Flows and Southern Delta Water Quality.* September 15.

San Luis & Delta Mendota Water Use Authority (SLDMWUA), 2011. Groundwater Management Plan for the Northern Agencies in the Delta Mendota Canal Service Area. November.

Todd Groundwater and RMC Groundwater and Environment (Todd and RMC), 2016. *Groundwater Characterization and Recharge Study, Modesto LGA Project.* Prepared for the City of Modesto. June.

Turlock Groundwater Basin Association (TGBA), 2008. Turlock Groundwater Basin Groundwater Management Plan. March.

United States Geological Survey (USGS), 2004a. *Guidelines for Evaluating Ground-Water Flow Models.* Scientific Investigations Report 2004-5038.

USGS, 2004b. *Hydrogeologic Characterization of the Modesto Area, San Joaquin Valley, California.* Scientific Investigations Report 2004-5232.

USGS, 2009. *Groundwater Availability of the Central Valley Aquifer.* California: U.S. Geological Survey Professional Paper 1766.

USGS, 2012. *Extent of Corcoran Clay modified from Page (1986) for the Central Valley Hydrologic Model (CVHM).* USGS Professional Paper 1766. Accessed at https://water.usgs.gov/GIS/metadata/usgswrd/XML/pp1766_corcoran_clay_extent.xml

USGS, 2015. *Hydrologic Model of the Modesto Region, California, 1960-2004.* Scientific Investigations Report 2015-5045.

USGS, 2017. Central Valley Hydrologic Model (CVHM). Website: http://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html

West Yost, 2016. *Preliminary Phasing and Water Treatment Plant Sizing for the SRWA Surface Water Supply Project.* June 16..

West Yost, 2017. *Surface Water Supply Project, Initial Project Capacity, Estimated Cost and Rate Impacts. Presentation to Stanislaus Regional Water Authority.* August 3.

Water Research Foundation, 2016. *Residential End Uses of Water, Version 2.* April.

Woodard, Gary, 2015. *The Surprising Slide in Domestic Demand: Be Careful What You Wish For.* Presentation at the Water Resources Research Center (WRRC), University of Arizona. March.

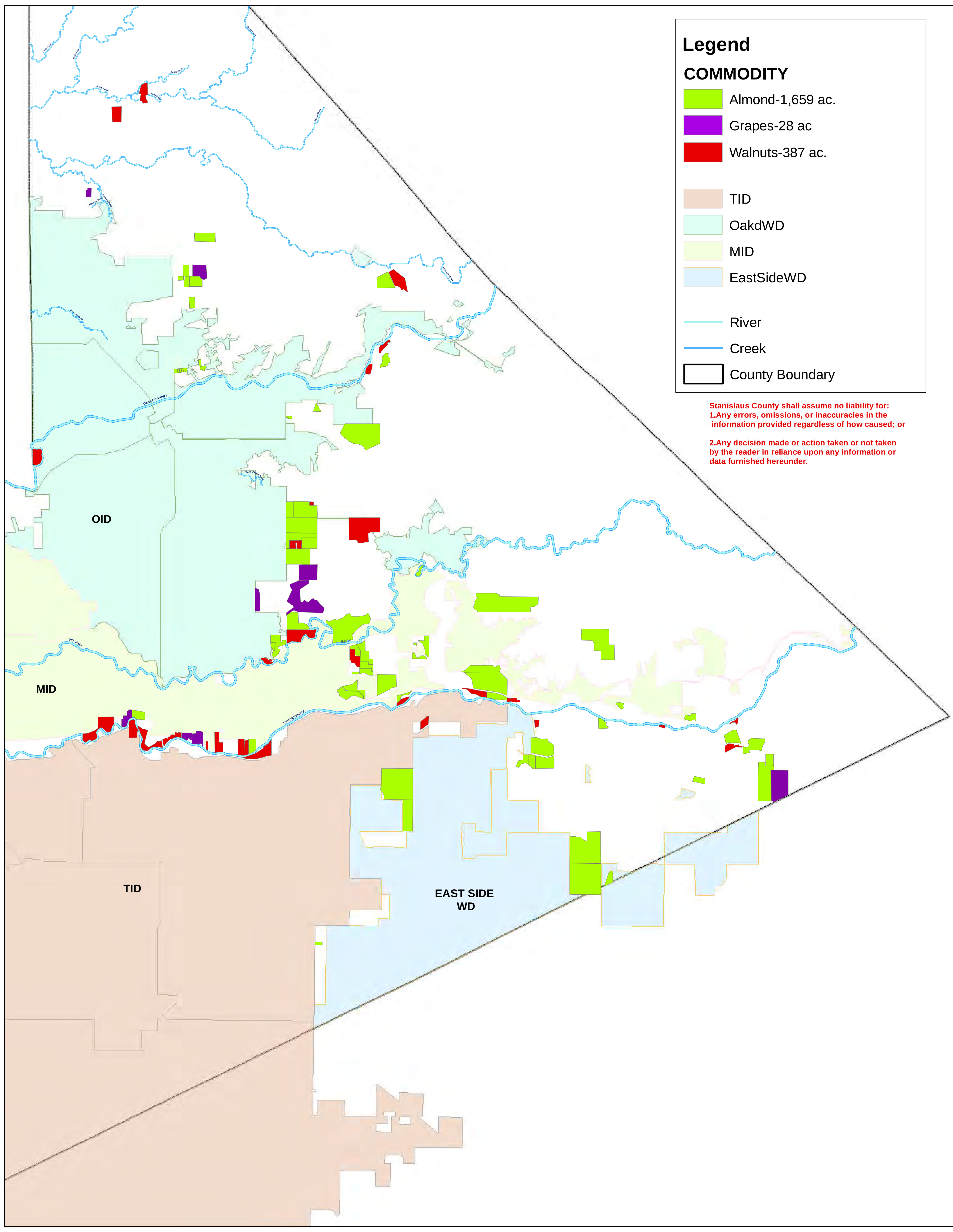
# APPENDIX A

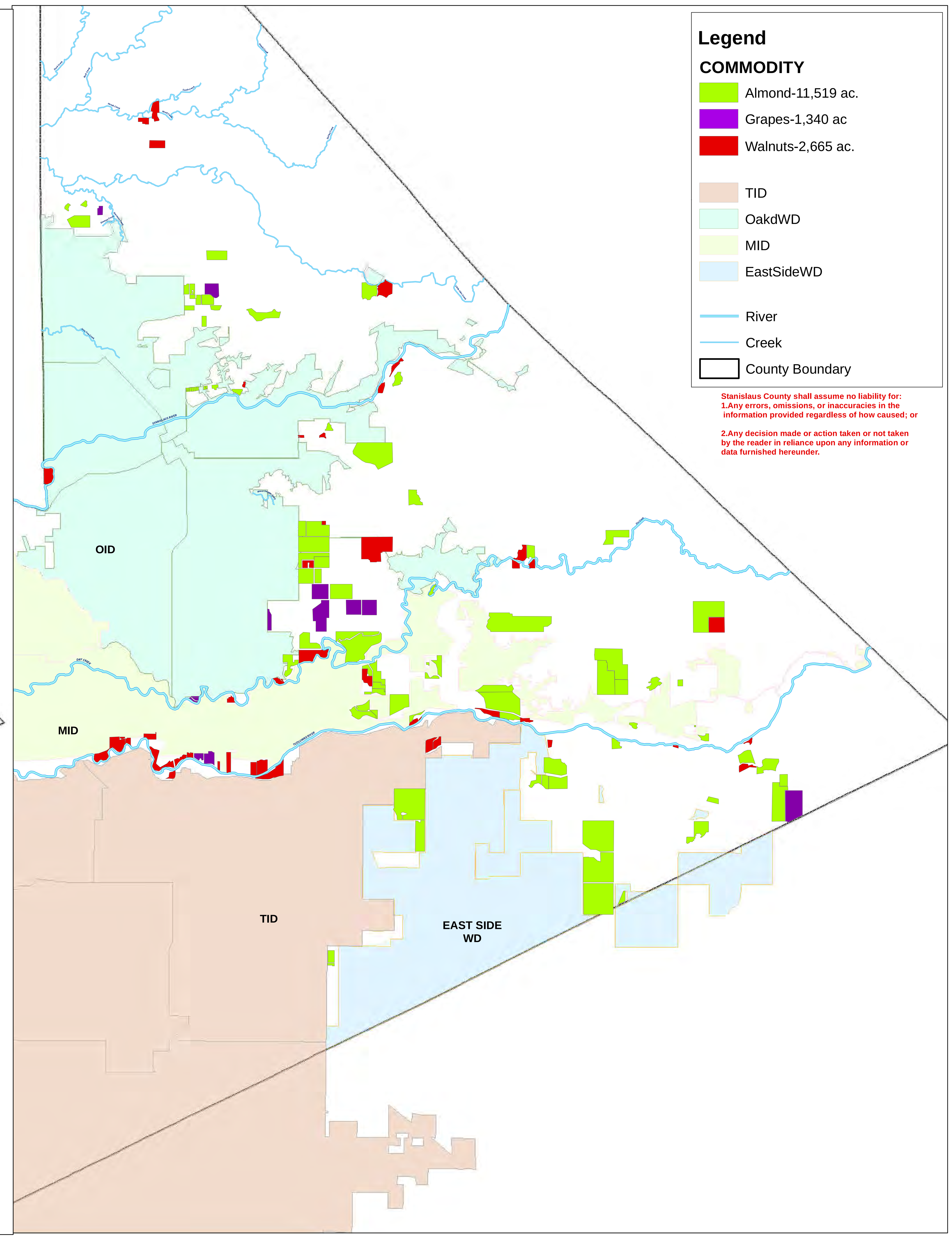
# DATA REGARDING CONVERSION OF NON-DISTRICT RANGELAND IN EASTERN STANISLAUS COUNTY TO PERMANENT CROPS FROM 2000 TO 2015

# 2001

DRAFT Copy

# 2005/2006




# 2010

DRAFT Copy

# 2015