Eastern San Joaquin Water Resources Model (ESJWRM)

AUGUST 2018

WOODARD & CURRAN

EASTERN SAN JOAQUIN WATER RESOURCES MODEL (ESJWRM)

Final Report

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Prepared by

WOODARD & CURRAN

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LIST OF ABBREVIATIONS

AF and AFY	Acre-Feet and Acre-Feet Per Year
ASTM	American Standard Testing Method
AWMP	Agricultural Water Management Plan
C2VSim	California Central Valley Groundwater-Surface Water Simulation Model
Cal Water	California Water Service Company Stockton District
CALSIMETAW	California Simulation of Evapotranspiration of Applied Water
CASGEM	California Statewide Groundwater Elevation Monitoring
CCWD	Calaveras County Water District
CDEC	California Data Exchange Center
CFS	Cubic Feet per Second
CIMIS	California Irrigation Management Information System
County	San Joaquin County
CSJWCD	Central San Joaquin Water Conservation District
CVHM	Central Valley Hydrologic Model
DEM	Digital Elevation Model
DWR	California Department of Water Resources
ESJ Subbasin	Eastern San Joaquin Groundwater Subbasin
ESJWRM	Eastern San Joaquin Water Resources Model
ET	Evapotranspiration
ETAW	Evapotranspiration of Applied Water
GBA	Eastern San Joaquin County Groundwater Basin Authority
GMS	Aquaveo Groundwater Modeling System
GPCD	Gallons Per Capita Per Day
GSA	Groundwater Sustainability Agency
GSE	Ground Surface Elevation
GSP	Groundwater Sustainability Plan
GWA	Eastern San Joaquin Groundwater Authority
IDC	IWFM Demand Calculator
IGSM	Integrated Groundwater and Surface Water Model
IRWMP	Integrated Regional Water Management Plan
IWFM	Integrated Water Flow Model
KH	Aquifer Hydraulic Conductivity
KV	Aquifer or Aquitard Vertical Hydraulic Conductivity
LCSD	Lockeford Community Services District
LCWD	Linden County Water District
MAF and MAFY	Million Acre-Feet and Million Acre-Feet Per Year
METRIC	Mapping Evapotranspiration at High Resolution with Internalized Calibration
NASS	National Agricultural Statistics Service
NRCS	Natural Resource Conservation Service
NSJWCD	North San Joaquin Water Conservation District
OID	Oakdale Irrigation District
OSWCR	Online System for Well Completion Reports
PRISM	Precipitation-Elevation Regressions on Independent Slopes Model

PSDI	Pore Size Distribution Index
RMS	Root Mean Square
SEWD	Stockton East Water District
SGMA	Sustainable Groundwater Management Act
SS	Aquifer Specific Storage
SSJID	South San Joaquin Irrigation District
SSURGO	Soil Survey Geographic Database
STATSGO2	Digital General Soil Map of the United States
SY	Aquifer Specific Yield
TAF and TAFY	Thousand Acre-Feet and Thousand Acre-Feet Per Year
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UWMP	Urban Water Management Plan
WDL	Water Data Library
WID	Woodbridge Irrigation District

ACKNOWLEDGEMENTS

In December 2015, San Joaquin County (County) applied for Proposition 1's Counties with Stressed Basins Grant and received approval for $499,900. With a fifty percent cost share with the California Department of Water Resources, the County executed a contract with Woodard & Curran (formerly RMC Water and Environment), on September 13, 2016 to begin work on a hydrologic model for the Eastern San Joaquin Groundwater Subbasin. The purpose of the resulting model, the Eastern San Joaquin Water Resources Model (ESJWRM), is to support activities in long-term management of the Eastern San Joaquin Subbasin at the local scale, specifically focusing on meeting the goals and requirements of the Sustainable Groundwater Management Act.

A technical committee provided quality assurance and technical support throughout the project, resulting in a groundwater model widely accepted by local shareholders and public agencies. The committee was an informal group consisting of technical representatives from local agencies, consultants with knowledge of the area, representatives for neighboring groundwater subbasins, Department of Water Resources (DWR) staff, and San Joaquin County personnel. Local agencies with consistent representation included San Joaquin County, Woodbridge Irrigation District, City of Lodi, North San Joaquin Water Conservation District, Lockeford Community Services District, Calaveras County Water District, City of Stockton, California Water Service Company Stockton District, Stockton East Water District, City of Lathrop, City of Manteca, South San Joaquin Irrigation District, City of Escalon, Oakdale Irrigation District, and Stanislaus County.

The Main Project Team included:

- Woodard & Curran (formerly RMC Water and Environment)
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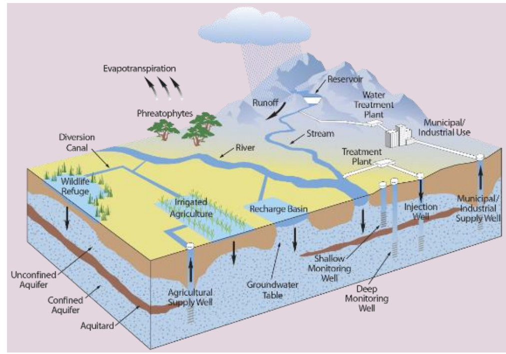
    - Jeanna Long, Data Management System Lead
    - Sara Miller, Project Engineer
- NV5

EXECUTIVE SUMMARY

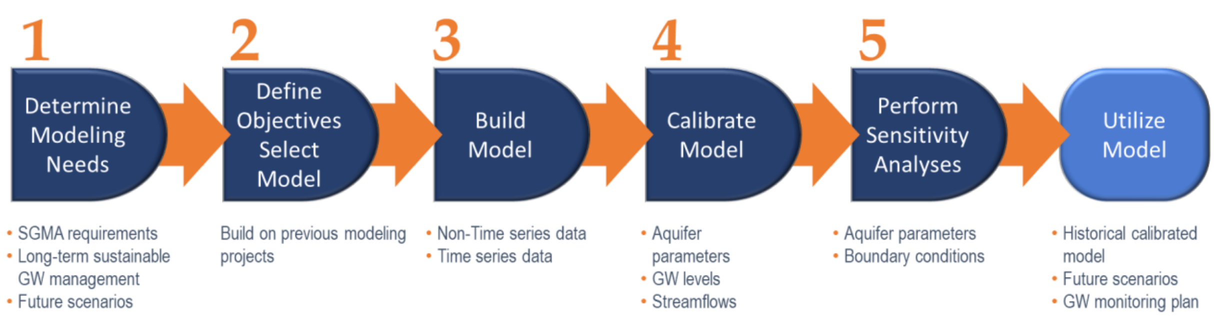
The Eastern San Joaquin Water Resources Model (ESJWRM) was developed to evaluate the surface water and groundwater resources in the Eastern San Joaquin Groundwater Subbasin (ESJ Subbasin) during recent historical hydrologic conditions. This period covers water years 1995 through 2015, and includes several above normal and wet years, as well as the most recent drought conditions. The model is designed to simulate the regional water resources conditions in the ESJ Subbasin, including the land surface processes, groundwater operations, stream and river systems, and the interaction between these resources.



Development of the ESJWRM occurred in an open and transparent process over approximately 24 months, starting in September 2016. Model development was a collaborative process between San Joaquin County staff, local water agencies, and Woodard & Curran, as consultant and developers of the model. The model was developed by partial funding from the Department of Water Resources (DWR), and as such, the DWR staff were engaged and collaborated in development of the model.

A technical committee provided quality assurance and technical support throughout the project, resulting in an integrated water resources model widely accepted by local shareholders and public agencies. The committee was an informal group consisting of technical representatives from local agencies, consultants with knowledge of the area, representatives from neighboring groundwater subbasins, DWR staff, and San Joaquin County personnel. Local agencies with consistent representation included San Joaquin County, Woodbridge Irrigation District, City of Lodi, North San Joaquin Water Conservation District, Lockeford Community Services District, Calaveras County Water District, City of Stockton, California Water Service Company Stockton District, Stockton East Water District, City of Lathrop, City of Manteca, South San Joaquin Irrigation District, City of Escalon, Oakdale Irrigation District, and Stanislaus County.

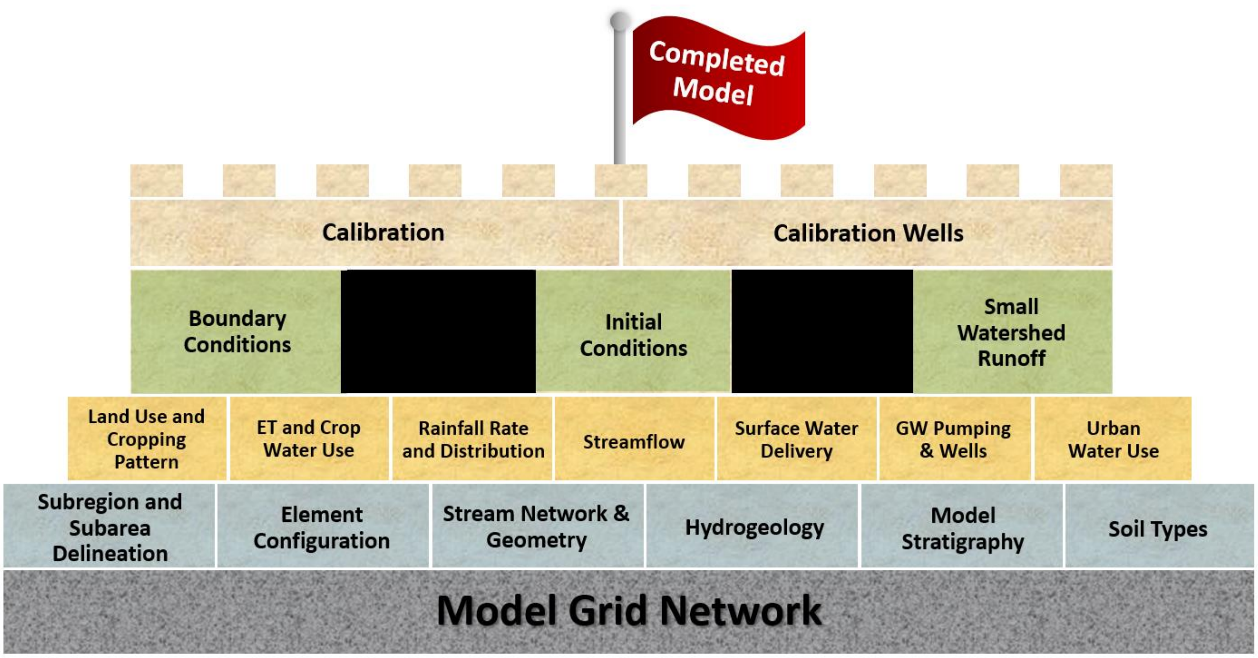
ESJWRM development followed a robust process as shown below. Modeling needs were established in early 2015, shortly after the passage of the Sustainable Groundwater Management Act (SGMA). Subsequently, modeling goals and objectives were discussed and established, and San Joaquin County was successful in securing funds through Proposition 1 to begin development of the model.



ESJWRM development required a significant amount of data and information, including hydrologic, hydrogeologic, topographic and soil conditions, land use and cropping patterns, urban and agricultural water demand, urban and agricultural water supplies, surface water conveyance and distribution systems, groundwater infrastructure and extraction, and irrigation practices. The following figure shows the type of data and information needed to develop the model. A collaborative process was followed to collect and analyze, fill data gaps, and develop proper assumptions for the use, context, and accuracy of the data, before analyzing and properly formatting the data for input in the model.

Once the model was constructed, appropriate state-of-the-art scientific and engineering protocols and guidelines were utilized to calibrate the model to ensure that:

- Water budgets generated by the model represent the regional and local understanding of the agricultural and urban entities represented in the model. The model-generated water budgets showing water demand and supply and the groundwater system are prepared and reported on both monthly and annual scales for urban and agricultural entities as well as at the subbasin scale.
- Monthly groundwater levels generated by the model at select observation wells throughout the subbasin closely follow the long-term annual trends and short-term seasonal fluctuations that are recorded and reported at the observation wells.
- Monthly streamflow generated by the model at select gauging stations closely follow the high and low flows as reported.

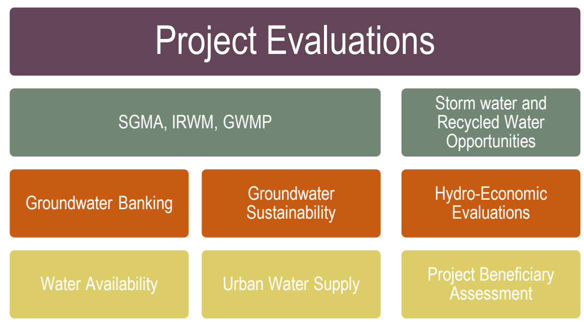


The calibrated ESJWRM provides detailed conditions of the ESJ Subbasin over the calibration period of water years 1996 through 2015. This calibrated model can be used for understanding subbasin characteristics and the effects of historical surface water and groundwater operations as well as irrigation practices or urban operations on the groundwater and surface water resources in the ESJ Subbasin. These include:

- Historical and current levels of development
- Subbasin operations under natural conditions
- Nature, extent, and rates of stream-aquifer interaction

- Effects and benefits of upstream regulation of rivers on the operations of the groundwater subbasin
- Effects of operations of regional water supply projects, including conjunctive use, on subbasin conditions
- Evaluation of water quality conditions in the subbasin

Additionally, the calibrated model can be used to develop baseline conditions representing projections of land use, population growth, water demand, and water supply conditions, as estimated based on local and regional planning activities. The baseline model, as a robust, defensible, and detailed tool, may be used for assessing the current and projected water resources conditions in the basin to support various local and regional planning projects and programs, such as the development and implementation of a Groundwater Sustainability Plan (GSP). ESJWRM may also be used to evaluate the effectiveness of different projects that may be proposed through the GSP development process. The fine scale of the model also provides the opportunity for individual Groundwater Sustainability Agencies (GSAs) to evaluate the effects of ESJ Subbasin conditions on smaller GSA areas.



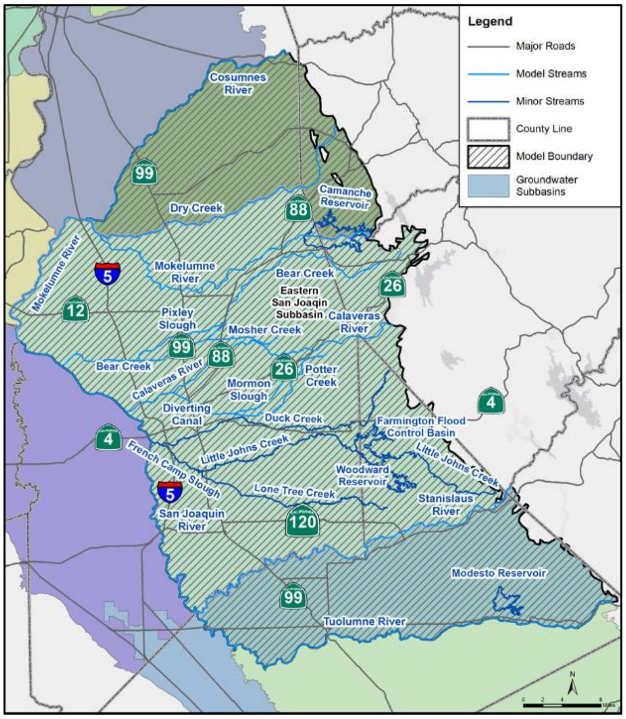
Some of the key features of the ESJWRM are as follows:

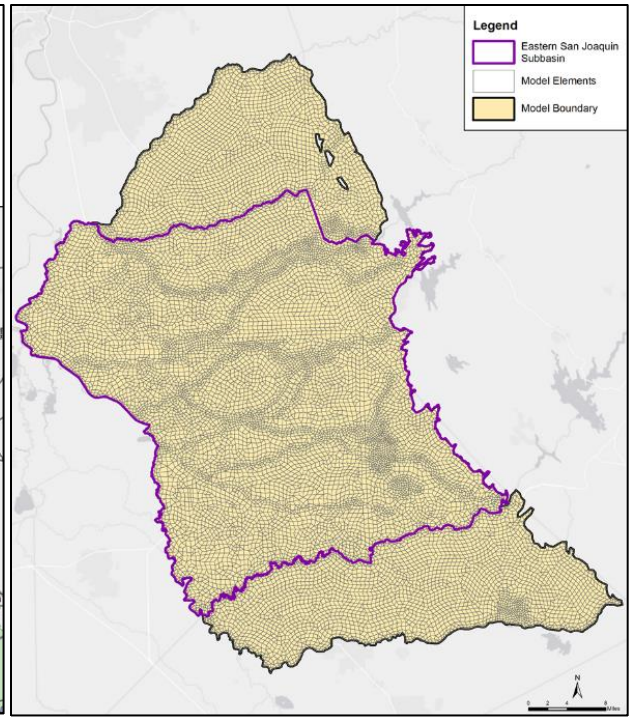
Model Platform

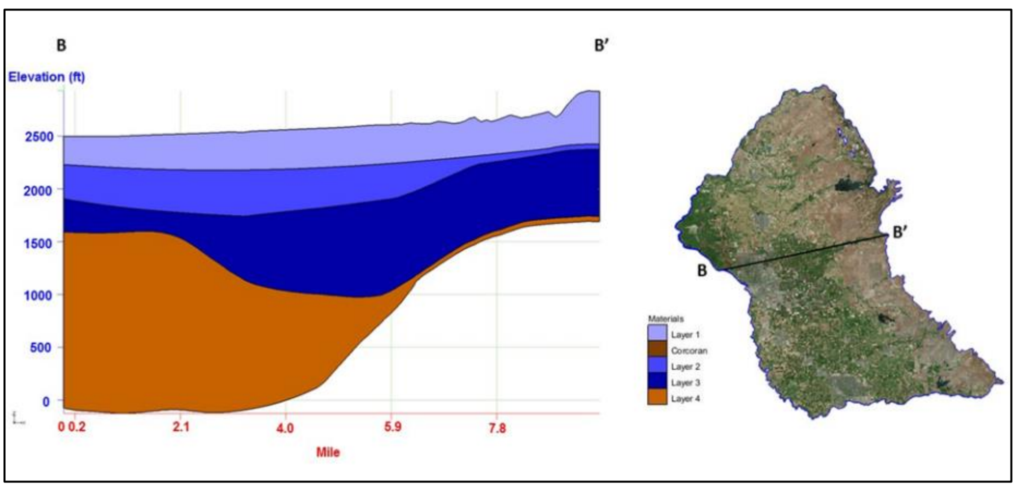
The model code platform is the DWR's Integrated Water Flow Model (IWFM-2015). This code platform was developed by DWR to simulate the integrated hydrologic conditions of a groundwater basin, with interactions between the surface water, groundwater, and stream system. The code platform has specific strengths in the calculation of agricultural water demand in a predominantly agricultural area, such as the Eastern San Joaquin Subbasin. The code platform is supported by the DWR modeling support staff for local and regional applications, including SGMA implementation.

Model Area

The model covers the entire area of the Eastern San Joaquin Groundwater Subbasin, as defined by DWR Bulletin 118, as well as the areas of the Modesto and Cosumnes Groundwater Subbasins (the basins immediately north and south of the ESJ Subbasin). The model area is subdivided into small units (elements). A comprehensive integrated hydrologic process and analysis is conducted at each model element, and surface water and groundwater flows are calculated and simulated across elements, and throughout the entire model area on a monthly time step, in such a way that mass balance is preserved every month. Additionally, each element represents the geologic and hydrogeologic conditions of the subsurface environment as represented by four model layers in a conceptual context.

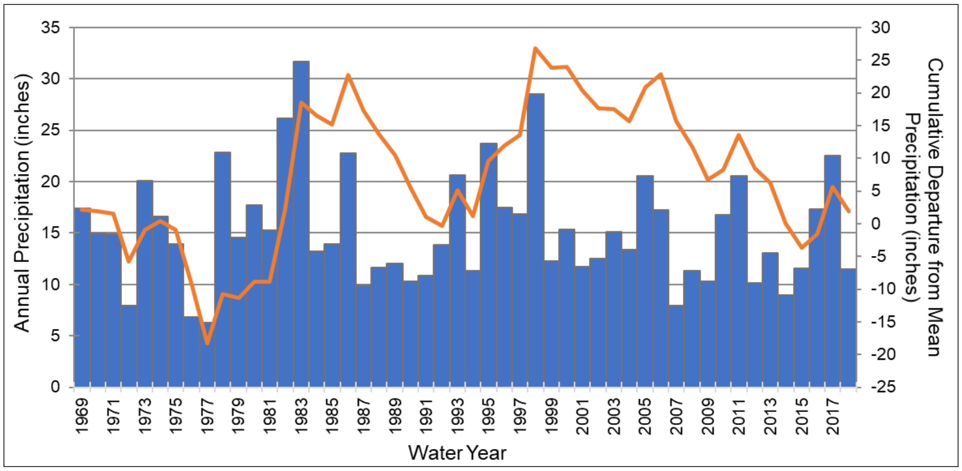


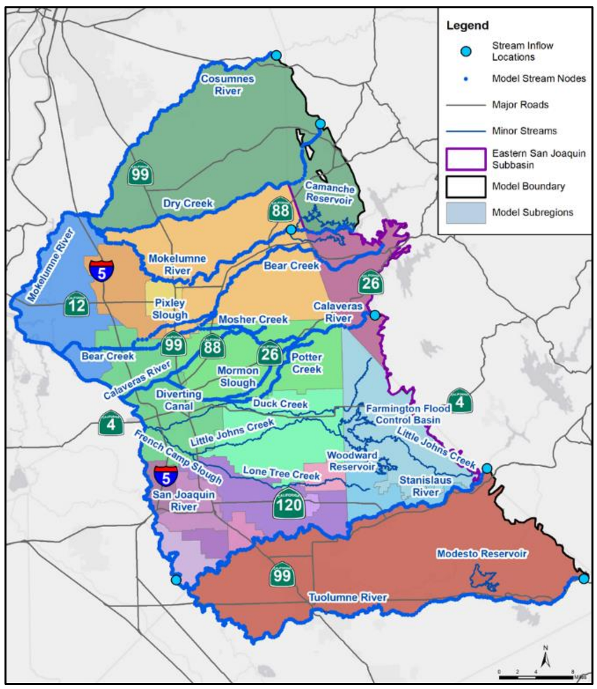




Hydrology

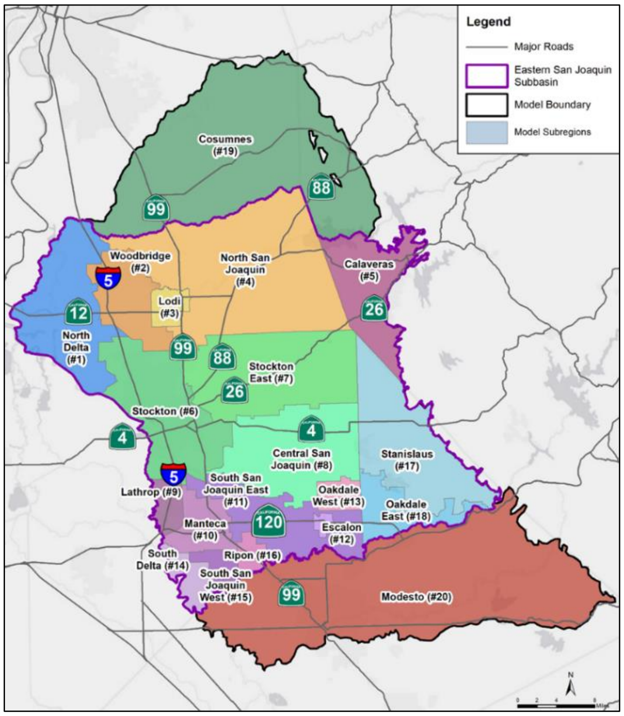
The model contains 50 years of hydrologic period (water years 1969 through 2018), which provides opportunities to assess the basin conditions during above normal, below normal, and drought periods. The model is calibrated during the period of 1996-2015, during which there are more robust and defensible data available for model calibration. In addition, the model includes major and minor rivers and creeks in the area and calculates stream-aquifer interaction along the major rivers and creeks. The minor creeks and canals represented in the model are used for conveyance of irrigation water and drainage.

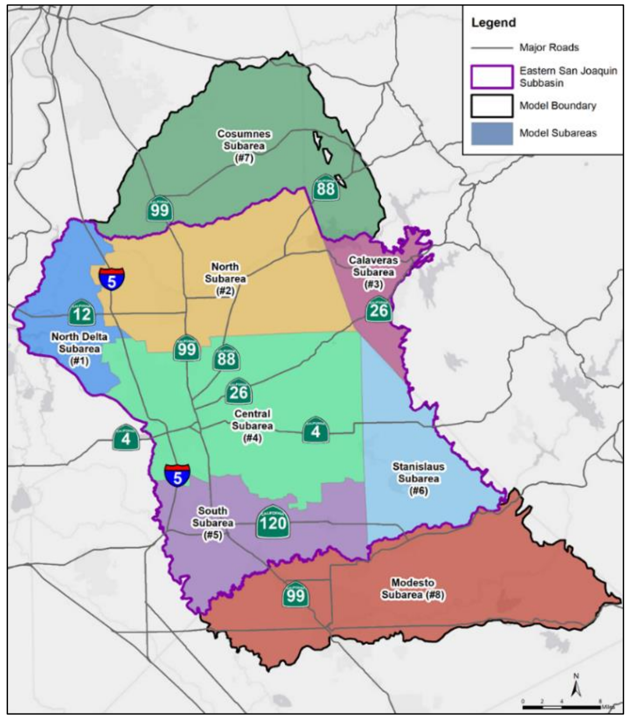




Model Subareas

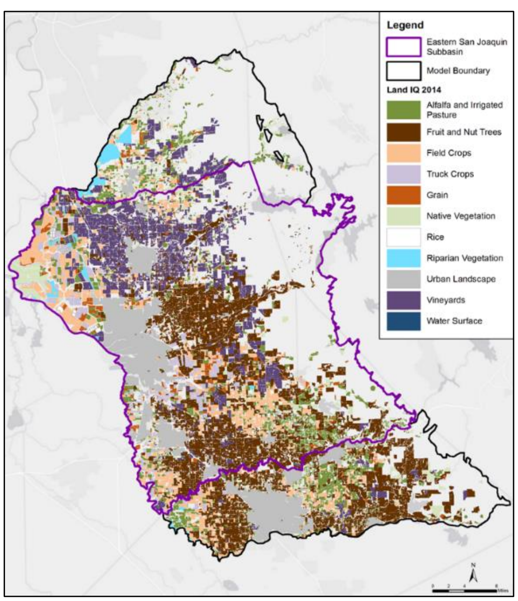
The model elements are aggregated into larger geographic areas, which represent individual agricultural and urban entities (Subregions) and larger planning areas (Subareas). These larger areas can be used to prepare model input data and to analyze model generated water budgets for planning purposes.

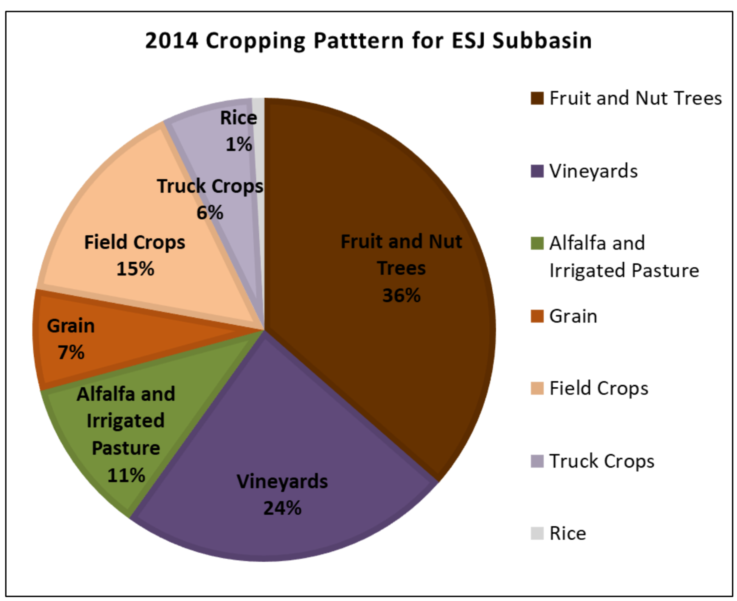




Land Use and Agricultural Cropping Pattern

A key data set used in the model is the distribution of land between agricultural, urban, native, and riparian land use categories, as well as acreages of major crops in the agricultural lands. This information is prepared and processed based on land use surveys prepared and reported by the DWR (DWR, 1993-2000), remote sensing data from the United States Department of Agriculture called CropScape (USDA NASS, 2007-2015), and the DWR Land IQ dataset (DWR, 2014). This information was compiled, analyzed, and evaluated for each model element; compared and cross-checked with data and information from the agricultural entities; and finalized for use in the model.

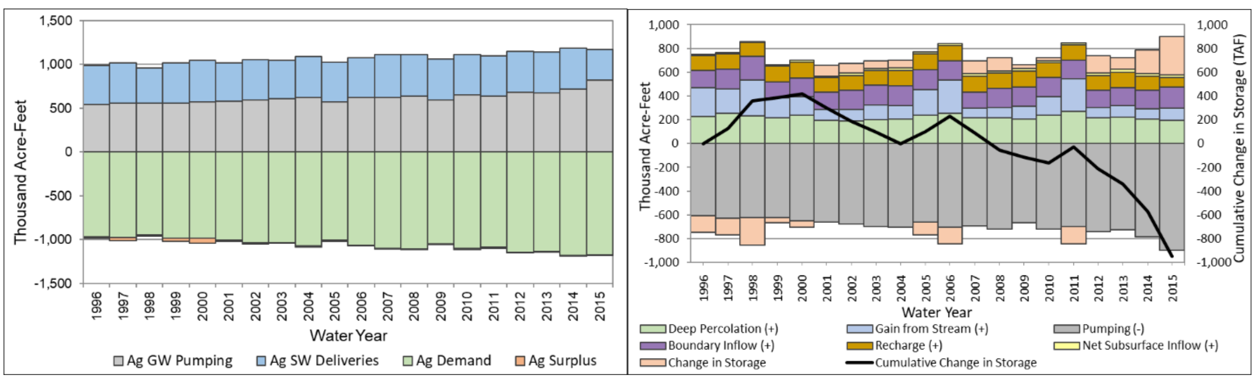




Water Budgets

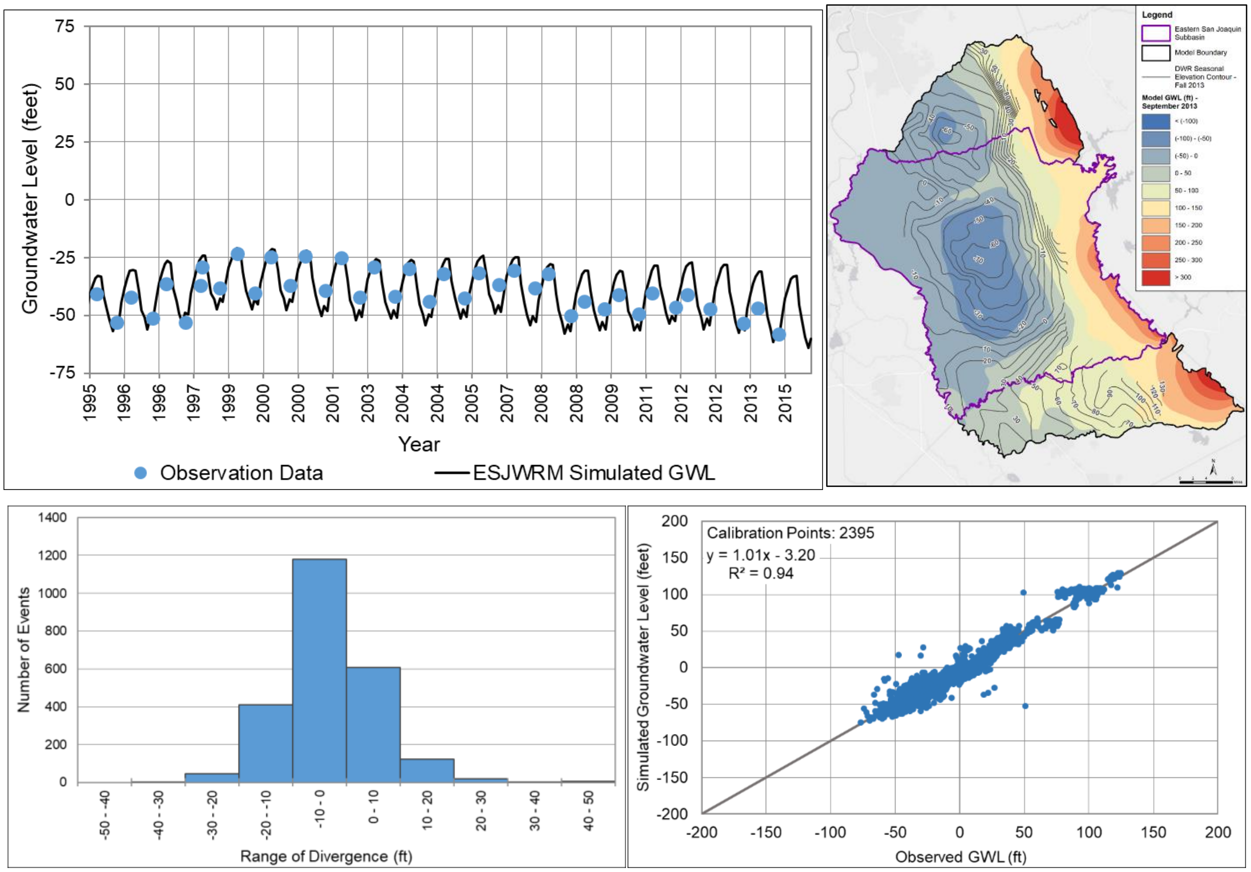
The model produces water budgets for land surface processes, including an estimate of urban and agricultural water demands, and water supplies. In addition, the model produces water budgets for the groundwater system, including groundwater pumping to meet irrigation demand and urban water needs, deep percolation from rainfall and irrigation applied water, subsurface flows from neighboring groundwater subbasins and the Sierra Nevada foothills, seepage from unlined conveyance canals, and flows between the stream and the aquifer system. The model can present this information on both a monthly and annual basis. Local operations data and information was collected from various water users and model parameters were adjusted to calibrate the model outcome to the reported values. Model calibration was conducted in an open and transparent process to ensure that the water budgets and model calibration results are properly representing the conditions of the groundwater basin to the extent that information is available.

An annual representation of the groundwater budget can reveal overall changes in groundwater storage, as depicted in the chart below. Uncertainties are inherent in every data set and calculation. Through a systematic sensitivity analysis, the range of impacts of uncertainties on model calculations was quantified. Knowledge of this range of uncertainties can assist in providing flexibility in decisions that rely on model results. The average annual depletions in groundwater storage for the historical period of 1996-2015 is estimated to be about 24,000 to 70,000 acre-feet per year (AFY), with an average depletion of 47,000 AFY.



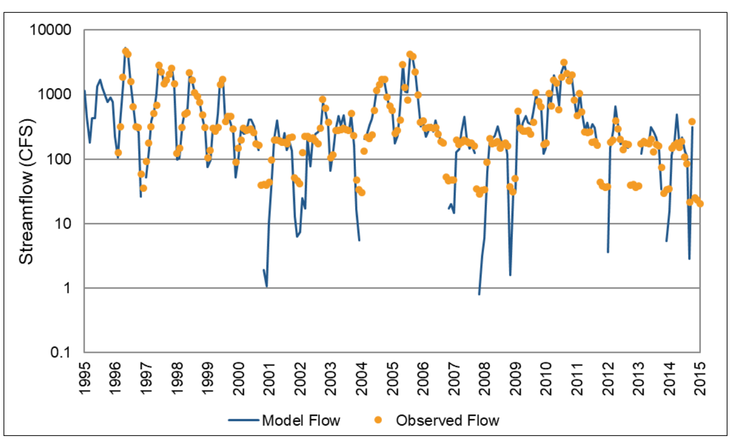
Groundwater Levels

The model-calculated groundwater levels are calibrated to observed groundwater levels at key wells over time. The typical goal of this calibration process is to adjust hydraulic parameters that influence the movement of groundwater such that the groundwater levels calculated by the model at the specific observation wells throughout the model area track short-term seasonal fluctuations and long-term trends as closely as possible. A typical model produced result is shown in the chart below. Once calibrated, the model produces regional groundwater levels for select points in time, as shown in the figure below. Model calibration statistics are represented in the following figures, which indicate that 75% of model calculated groundwater levels are within 10 feet of reported observations, and 97% are within 20 feet of reported observations. Given the uncertainties in the measurement of reported values, as well as uncertainties in model calculations, and expected calibration results for similar models as reported in the scientific communities, this statistic represents a very good model performance.



Streamflows

The model calculates flow of water in the stream system throughout the basin. Streamflows are subject to the diversion of water for beneficial agricultural uses or urban consumption, return flows from irrigation practices, runoff of rainfall, as well as gains and losses due to interaction with the groundwater system. The model stream system is calibrated to reported flows at the downstream gauging stations. The chart below shows the comparison between model calculated streamflow and gauge records on Mokelumne River at Woodbridge. The results indicate that the model is capable of simulating both the low and the high flows reasonably well.



Conclusions and Recommendations

The ESJWRM, in its current state, is a robust, comprehensive, defensible and well-established model for assessing the water resources in the ESJ Subbasin under historical and projected conditions. The following recommendations are to be considered for further refinements and enhancements of the model:

- **Continue engagement with local groundwater users and managers**. Continue working with local agencies and groundwater users in ESJ Subbasin to further understand the local operations of the groundwater system and improve representation of groundwater users in the ESJWRM.
- **Refinement of boundary flows**. The current boundary flows at the northern, western, and southern boundaries of the model area are based on an older version of the C2VSim with adjustments made based on initial groundwater levels assumed for the beginning of the model (October 1994). DWR is currently in the process of updating the C2VSIm model. Once the latest fine grid version (C2VSim-2015) is publicly available, boundary flows for the ESJ model area should be verified and updated, as necessary.
- **Enhance variability of potential evapotranspiration**. The current version of the IDC used for estimation of the consumptive use of crops in the ESJWRM uses monthly potential ET values that are the same for all years during the model period. Given that there may be annual variability in the potential ET data with possible effects on the annual estimation of crop water demand, it is recommended to use more detailed data with temporal variability to develop a full time series of ET values for use in the model.
- **Refine surface water deliveries in Cosumnes and Modesto Subbasins.** The surface water deliveries in the Cosumnes and Modesto Subbasins are currently at the subregion level and do not have the detailed spatial resolution of other areas within the ESJ Subbasin. This data may need to be verified and updated as modeling efforts in those subbasins progress to meet the requirements of SGMA.
- **Update C2VSim based on ESJWRM**. The fine grid version of C2VSim was developed by the DWR to evaluate the integrated surface water and groundwater conditions at a regional scale; whereas, the ESJWRM is capable of evaluation at the local scale. To increase the accuracy of regional groundwater conditions in the fine grid C2VSim, the County is encouraged to work with DWR to provide data and information for further refinement and update of C2VSim in the ESJWRM area.
- **Develop model update schedule**. In order to keep the ESJWRM up-to-date and current for analysis of water resources and especially for supporting SGMA implementation, it is recommended that the model be updated every 3 to 5 years. A possible update schedule can be kept consistent with the GSP updates, with a lead time of 2 to 3 years relative to the GSP update schedule.

1. INTRODUCTION

1.1 Goals of Model Development

The Eastern San Joaquin Water Resources Model (ESJWRM) was developed primarily to evaluate the current and recent historical groundwater conditions of the Eastern San Joaquin Groundwater Subbasin (ESJ Subbasin) and simulate various future condition scenarios as part of the Groundwater Sustainability Plan (GSP) preparation process under the Sustainable Groundwater Management Act (SGMA). ESJWRM will also be used to evaluate the effectiveness of different projects that may be proposed through the GSP development process. The fine scale of the model also provides the opportunity for individual Groundwater Sustainability Agencies (GSAs) to evaluate the effect of changing ESJ Subbasin conditions on smaller GSA areas.

1.2 Eastern San Joaquin Groundwater Subbasin

The ESJ Subbasin underlies portions of San Joaquin, Calaveras, and Stanislaus counties, with the majority of the area in San Joaquin County (Figure 1). San Joaquin County is located in the northeastern San Joaquin Valley and contains portions of the Sacramento-San Joaquin River Delta.

In 2014, the ESJ Subbasin was categorized as a high priority groundwater subbasin under the California Statewide Groundwater Elevation Monitoring (CASGEM) program. The ESJ Subbasin has been identified by the California Department of Water Resources (DWR) as critically overdrafted and is included in the List of Critically Overdrafted Basins finalized in January 2016. As a critically overdrafted subbasin, GSAs in the ESJ Subbasin must develop a GSP by January 31, 2020 that details how the ESJ Subbasin will be managed in a sustainable manner by 2040. The other groundwater subbasins immediately surrounding the ESJ Subbasin are not critically overdrafted except for the Delta-Mendota Subbasin (Figure 2).

The major municipalities in the ESJ Subbasin are the cities of Lodi, Stockton (including California Water Service Company Stockton District or Cal Water), Lathrop, Manteca, Ripon, and Escalon. The major agricultural water providers in the ESJ Subbasin include Woodbridge Irrigation District (WID), North San Joaquin Water Conservation District (NSJWCD), Stockton East Water District (SEWD), Central San Joaquin Water Conservation District (CSJWCD), South San Joaquin Irrigation District (SSJID), and Oakdale Irrigation District (OID). The major municipalities and agricultural water providers are all GSAs. Other agencies which supply water or have land use authority within the ESJ Subbasin and have been designated as GSA's are San Joaquin County, Stanislaus County (in combination with CCWD and Rock Creek Water District), Calaveras County Water District (CCWD), North and South Delta Water Agencies, Lockeford Community Services District (LCSD), and Linden County Water District (LCWD). The 17 GSAs covering ESJ Subbasin and their corresponding member agencies are listed in Table 1. The water purveyors are shown in Figure 3a and the GSAs are shown in Figure 3b.

Table 1: ESJ Subbasin GSAs and Member Agencies

GSA	Member Agency
Central Delta Water Agency	Central Delta Water Agency
Central San Joaquin Water Conservation District	Central San Joaquin Water Conservation District
City of Lathrop	City of Lathrop
City of Lodi	City of Lodi

GSA	Member Agency
City of Manteca	City of Manteca
City of Stockton	City of Stockton
Eastside San Joaquin GSA	Calaveras County Water District Stanislaus County Rock Creek Water District
Linden County Water District	Linden County Water District
Lockeford Community Services District	Lockeford Community Services District
North San Joaquin Water Conservation District	North San Joaquin Water Conservation District
Oakdale Irrigation District ESJ Subbasin GSA	Oakdale Irrigation District
San Joaquin County	San Joaquin County
San Joaquin County No. 2	San Joaquin County Cal Water
South Delta Water Agency	South Delta Water Agency
South San Joaquin GSA	South San Joaquin Irrigation District City of Ripon City of Escalon
Stockton East Water District	Stockton East Water District
Woodbridge Irrigation District	Woodbridge Irrigation District

1.3 Local Coordination

The development of the ESJWRM took place in an open and transparent process. The 17 GSAs of the ESJ Subbasin coordinate SGMA activities through the formation of the Eastern San Joaquin Groundwater Authority (GWA). The Eastern San Joaquin County Groundwater Basin Authority (GBA) was the organizational structure for agency coordination of water resources activities before SGMA regulations and the formation of the GWA. Many of the GBA/GWA agency members participated in a Technical Review Committee, which acted as the forum to review model input data and assumptions, as well as calibration results. The Technical Review Committee helped to facilitate major modeling decisions, provided input data, and reviewed results. The monthly Technical Review Committee meetings were open to all interested parties and generally consisted of technical representatives from local agencies, consultants with knowledge of the area, representatives for neighboring groundwater subbasins, DWR staff, and San Joaquin County personnel. Presentations given to this group are included in Appendix A and highlight major model configuration decisions, data analysis, and draft model results.

Local agencies with consistent representation at the Technical Review Committee meetings included San Joaquin County, WID, City of Lodi, NSJWCD, LCSD, CCWD, City of Stockton, Cal Water, SEWD, City of Lathrop, City of Manteca, SSJID, City of Escalon, OID, and Stanislaus County.

1.4 Model Platform

The ESJ Subbasin has been modeled since the mid-1980s. In 1993, as part of the Bureau of Reclamation's American River Watershed Investigation, an integrated model was developed based on the Integrated

Groundwater and Surface Water Model (IGSM) code. This model was developed in coordination with the San Joaquin County (County) and DWR and was used to analyze several conjunctive use programs and projects. In 2001, the San Joaquin County IGSM model was converted to a DYNFLOW platform (a proprietary finite element groundwater flow model) and was used for the County's Water Management Plan (CDM, 2008). The model originally simulated a period of October 1969 through September 1993 and was updated in 2007 for the Eastern San Joaquin Integrated Regional Water Management Plan (IRWMP) to simulate hydrologic conditions through September 2006. The proprietary nature of DYNFLOW makes the model not suitable to support subbasin analysis as part of GSP development per SGMA requirements.

With the award of Proposition 1's Counties with Stressed Basins Grant, the determination was made to combine data from the older models into a new, local-scale model using DWR's code that updated and replaced IGSM, called Integrated Water Flow Model (IWFM). IWFM is an open-source, finite element simulation code that supports triangular and quadrilateral elements (Dogrul et al., 2017a). It was specifically designated in GSP regulations as being supported by DWR for water budget development and SGMA compliance. It is also the code used for DWR's California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), the fine grid version of which is being refined and enhanced by DWR to support SGMA activities throughout the Central Valley at the regional scale (Brush et al., 2013). C2VSim was developed using the same methodology and source data as were ESJWRM's datasets. To maintain consistency, ESJWRM relies on C2VSim for many of its datasets.

The IWFM Demand Calculator (IDC) is the stand-alone root zone component of IWFM that simulates land surface and root zone flow processes (Dogrul et al., 2017b). It calculates agricultural and urban water demands using inputs including climate conditions, soil parameters, and land use types and distribution. It can be run separately or combined with IWFM. IDC data development and results in this documentation are included as part of all other IWFM datasets and results. The IDC major data pieces and draft results were initially presented in a February 1, 2018 Technical Memorandum (Appendix B).

At the October 26, 2016 Technical Review Committee meeting, the decision was made to keep the model domain the same as for the DYNFLOW model. The County's DYNFLOW model included the ESJ Subbasin, as well as the Cosumnes Subbasin to the north and the Modesto Subbasin to the south. The ESJ Subbasin is the primary model area and the secondary model area includes the Cosumnes and Modesto Subbasins. The physical model boundaries are included in Table 2 and shown in Figure 4.

Table 2: Physical Model Boundaries

Boundary	Entire Model	Primary Model Area (ESJ Subbasin)
North	Cosumnes River	Dry Creek and County Boundary (including Mokelumne River)
East	Sierra Nevada Foothills	Sierra Nevada Foothills
South	Tuolumne River	Stanislaus River
West	San Joaquin River	San Joaquin River

2. MODEL DEVELOPMENT

This section presents the source and analysis of input data used in the development of ESJWRM. This includes spatial and temporal information for hydrologic and hydrogeologic data sets included in the model, as well as physical parameters and assumptions.

2.1 Model Input Data

The historical ESJWRM simulates water years 1995 through 2015 (October 1, 1994 through September 30, 2015). All data and computations are performed on a monthly time step. IWFM model files and corresponding major data sources and report sections are referenced below in Table 3.

Table 3: ESJWRM Major Model Data

Major Data Category	Minor Data Category	Data Source	Report Section
Hydrogeological Data	Geologic Stratification	C2VSim	2.9
	Aquifer Parameters	USGS Texture Model	4.7
Stream Data	Stream Configuration	C2VSim & San Joaquin County	2.3
	Stream Inflow	USGS & USACE Stream Gauges	2.3
	Calibration Gauges	USGS & CDEC Stream Gauges	4.3
Hydrological Data	Precipitation	PRISM & CalSIMETAW	2.4
Agricultural Water Demand	Land Use	DWR CropScape Land IQ Ag Commissioner's Report Local Information	2.6
	Evapotranspiration	C2VSim METRIC Local Information	2.7
	Soil Properties	SSURGO & STATSGO2	2.5
Urban Water Demand	Population	U.S. Census Bureau & Local Information	3.2
	Per Capita Water Use	Local Information (UWMPs)	3.2
Water Supply	Groundwater Pumping	Local Information	3.3.2
	Surface Water Deliveries	Local Information	3.3.1
Other	Boundary Conditions	C2VSim & Local Information	2.11
	Initial Conditions	C2VSim	2.12
	Small Watersheds	C2VSim	2.10
	Calibration Wells	DWR & Local Information	4.5

The hydrologic period used to build the model data files was water years 1969 through 2018 (October 1, 1968 through September 30, 2018). This allows for future work to use a longer model run time using actual historical rainfall and stream inflow records.

2.2 Model Grid and Reporting Units

The finite element grid was developed using Aquaveo's Groundwater Modeling System (GMS) software. The grid includes quadrilateral and triangular elements based on selected input lines and control points. Features included in the development of the model grid are shown in Figure 5 and included:

- Groundwater subbasin boundaries
- Hydrologic and hydrogeologic features (i.e., major and minor streams, reservoirs/lakes, and outcroppings)
- City spheres of influence boundaries
- ESJ Subbasin GSA boundaries
- County boundaries
- Subsurface flow patterns
- Other boundaries

The model grid contains 16,054 elements and 15,302 nodes with an average element area of 76.5 acres (Figure 6). The average node spacing is 0.37 miles overall, ranging from about 0.28 miles near hydrologic features to 0.42 miles in other areas. There was a 0.75-mile buffer included around the streams to transition from the finer to coarser node spacing. Primary objectives during grid development were to maintain a manageable number of elements and nodes, to optimize resolution for data analysis, to contain a finer resolution along rivers to allow for better simulation of stream-aquifer interaction, to optimize the model run time, and to streamline model output.

The model elements are grouped into 20 model subregions that are used to organize input data for the model and report standard model output water budgets (Figure 7). Subregion borders were delineated using boundaries including city spheres of influence, water agencies, subbasin, and county lines. These subregions are aggregated into 8 larger units (model subareas), which are the primary units to present results and are used for basin-scale planning (Figure 8). ESJ Subbasin, the primary model area, is made up of 6 subareas and 18 subregions or a total of 772,377 acres (about 1,207 square miles). The entire ESJWRM area covers 1,228,194 acres (about 1,919 square miles). A description of model subregions, including the subarea they are part of and the number of model elements they contain, is in Table 4.

Table 4: Model Subregions and Subareas

Subregion Number	Subregion Name	Subarea Name and Number	Number of Elements
1	North Delta	North Delta Subarea (#1)	872
2	Woodbridge	North Subarea (#2)	485
3	Lodi		104
4	North San Joaquin		1,969

Subregion Number	Subregion Name	Subarea Name and Number	Number of Elements
5	Calaveras	Calaveras Subarea (#3)	664
6	Stockton	Central Subarea (#4)	1,074
7	Stockton East		1,314
8	Central San Joaquin		929
9	Lathrop	South Subarea (#5)	119
10	Manteca		224
11	South San Joaquin East		632
12	Escalon		33
13	Oakdale West		128
14	South Delta		254
15	South San Joaquin West		74
16	Ripon		86
17	Stanislaus	Stanislaus Subarea (#6)	1,312
18	Oakdale East		332
19	Cosumnes	Cosumnes Subarea (#7)	2,378
20	Modesto	Modesto Subarea (#8)	3,071

2.3 Stream Configuration and Stream Inflow

The model hydrology is represented by 25 model stream reaches, which are largely defined to start and/or end at confluences. Major streams include Cosumnes River, Dry Creek, Mokelumne River, Bear Creek, Calaveras River, Stanislaus River, Tuolumne River, and San Joaquin River (Figure 9). Many of these streams route water along connecting sloughs and canals, including Pixley Slough, Mosher Creek, Potter Creek, Mormon Slough, and Diverting Canal. As described in Section 2.2, the model grid was designed to include other hydrologic features such as major reservoirs or other important streams that may be simulated in ESJWRM in the future. Hydrologic features used during grid development (i.e., reservoirs and minor streams) include Camanche Reservoir, Duck Creek, Farmington Flood Control Basin, French Camp Slough, Little Johns Creek, Lone Tree Creek, Modesto Reservoir, Tracy Lakes, and Woodward Reservoir (Figure 5 and Figure 9). These hydrologic features represent important drainage and conveyance water courses in the model, while the model streams interactively simulate flows and stream-aquifer interaction at every model stream node.

The streams and creeks are represented in the model by 1674 stream nodes on a quarter-mile interval. The number of stream nodes and their refined resolution provide increased accuracy when depicting stream-groundwater interaction. Physical characteristics, including the stream invert elevation, channel width, and a stream flow rating table, were obtained from the closest C2VSim stream nodes and United States Geological Survey (USGS) Digital Elevations Models (DEM).

Time series of stream inflow data is available from 7 USGS and the United States Army Corps of Engineers (USACE) gauging stations. This data is consistent with C2VSim streamflow data (Brush, 2013). A table of stream input data and a map of available stream gauge locations may be found in Table 5 and Figure 9.

There was not sufficient data available for Bear Creek to generate a full time series record and it is only receiving runoff and/or drainage from nearby model elements.

Table 5: Summary of ESJWRM Stream Inflow Data

Stream	Stream Node	Source	Gauge Name	Period of Record	Average Annual Streamflow (acre-feet)
Cosumnes River	1	USGS	USGS 11335000: Cosumnes River at Michigan Bar, CA	October 1907 to present/ongoing	365,000
Dry Creek	140	USGS	Estimated in C2VSim by correlation with USGS 11329500: Dry Creek near Galt, CA	Not continuous October 1926 to December 1997	25,000
		USGS	Estimated in C2VSim by correlation with USGS 11335000: Cosumnes River at Michigan Bar, CA	Used October 1987 to September 1995 and January 1998 to present/ongoing	
Mokelumne River	290	USGS	USGS 11323500: Mokelumne River below Camanche Dam, CA	October 1904 to present/ongoing	525,000
Calaveras River	758	USGS	USGS 11308900: Calaveras River below New Hogan Dam near Valley Springs, CA	February 1961 to September 1990	151,000
		USACE	New Hogan Dam releases	October 1990 to present/ongoing	
Stanislaus River	1033	USGS	USGS 11302000: Stanislaus River below Goodwin Dam near Knights Ferry, CA	February 1957 to present/ongoing	575,000
Tuolumne River	1248	USGS	USGS 11289650: Tuolumne River below Lagrange Dam near Lagrange, CA	October 1970 to present/ongoing	835,000
San Joaquin River	1497	USGS	USGS 11303500: San Joaquin River near Vernalis, CA	October 1923 to present/ongoing	3,089,000

ESJWRM also specifies how water routes at forks in the rivers. Ten percent of Bear Creek flows through Pixley Slough before returning to Bear Creek, while 90% continues in Bear Creek. Eighty percent of Calaveras River flows through Mormon Slough and the Diverting Canal before returning to Calaveras River, while 20% continues in Calaveras River.

2.4 Precipitation

Rainfall data for the model area is derived from the PRISM (Precipitation-Elevation Regressions on Independent Slopes Model) database used in the DWR's CALSIMETAW (California Simulation of Evapotranspiration of Applied Water) model. The database contains daily precipitation data from October 1, 1921 on a 4-kilometer grid throughout the model area. ESJWRM has monthly rainfall data defined for every model element in order to preserve the spatial distribution of the monthly rainfall. Each of the model elements was mapped to the nearest of 364 available PRISM reference nodes, uniformly distributed across the model domain. The resulting average annual precipitation is shown in Figure 10.

Figure 11 shows the annual rainfall in the model area and the cumulative departure from mean, which is an indication of long-term rainfall trends in the area. The minimum precipitation during the simulation period was in water year 2007 with 8.0 inches, while the maximum occurred in water year 1998 with 28.5 inches. The average precipitation was 15.1 inches, with 9 above average and 12 below average simulation years.

2.5 Root Zone Soil Parameters

The soil properties specified in the model are field capacity, wilting point, total porosity, saturated hydraulic conductivity, and pore size distribution index (PSDI). A recent update to IWFM added the capability to specify a separate saturated hydraulic conductivity for areas covered by rice or wetlands, which prevents the overestimation of deep percolation during periods of ponded water. All the soil properties are used to determine the soil types and characteristics of each model element.

DWR's IWFM Soil Data Builder (DWR, 2017) was used in conjunction with the United States Department of Agriculture (USDA) Soil Survey Geographic Database (SSURGO) (USDA, 2017a) soil data to determine the five soil properties for each model element. The IWFM Soil Data Builder extracts the SSURGO data relevant to the model area (in this case, 6 counties) and associates it with each grid element. For ESJWRM elements where SSURGO data was incomplete, USDA's Digital General Soil Map of the United States (STATSGO2) data were used instead (USDA, 2017b). In total, a little over 3,500 elements (about 22% of all elements) used STATSGO2 data for at least one of the parameters. Editing of soil parameters is a standard part of IDC calibration and the final soil parameter values and their spatial distributions are discussed and shown in figures in Section 4.2.

Model elements are associated with the four hydrological soil groups according to their runoff potential and infiltration characteristics. ESJWRM elements with their corresponding hydrologic soil group are shown in Figure 12. The Natural Resource Conservation Service (NRCS) (USDA NRCS, 2009) defines these hydrological soil groups as follows:

- Group A – Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Some soils having loamy sand, sandy loam, loam or silt loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.
- Group B – Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures.

Some soils having loam, silt loam, silt, or sandy clay loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

- Group C – Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.
- Group D – Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential.

2.6 Land Use and Cropping Patterns

For the model to calculate water supply requirements, every model element needs to have land use defined for every year of the simulation. ESJWRM includes 23 irrigated crop categories and 4 general land use categories. All of the irrigated crop categories except for rice are simulated as non-ponded crops, meaning they are grown without standing water. Rice is simulated as both no decomposition (assumed 20% of total rice area) and flooded decomposition (assumed 80% of total rice area) to represent the current understanding of local growing practices. The general land use categories include urban landscape (e.g., residential areas, golf courses, and school fields), water surface (e.g., streams, lakes, and reservoirs), riparian vegetation (e.g., native vegetation located near surface water), and native vegetation. The irrigated crop categories were combined into 6 high-level groupings of crops with similar water use or irrigation practices. Table 6 lists the land use categories.

The crop categories are identical to those in C2VSim, except that ESJWRM breaks out almonds, cherries, pistachios, and walnuts as individual categories. This was done at the request of the Technical Review Committee based on the importance and amount of these crops in the ESJ Subbasin.

Spatial land use data was used to specify land use types and crop acreages for each model element for each year. The three major reference sources include DWR land use surveys, CropScape, and Land IQ. As crop categories were not consistent across all the land use data sources, individual mappings matched up each crop type to model land use category.

DWR conducts periodic land use surveys for each county that include over 70 different crop categories, as well as urban and native vegetation, for each parcel or field (DWR, 1993-2000). DWR land use surveys have high accuracy due to extensive ground truthing. For ESJWRM, the land use surveys by county were merged and assumed to represent water year 1995 in the model. The surveys used include:

1. San Joaquin County (1996)
2. Sacramento County (1993)
3. Amador County (1997)
4. Calaveras County (2000)
5. Stanislaus County (1996)

Data for water years 2007 through 2015 are from the USDA's remote sensing CropScape data (USDA NASS, 2007-2015). CropScape includes 256 land use categories that come from annual satellite imagery collected during the growing season on 30-meter by 30-meter pixels. Based on reports on the CropScape website, the level of accuracy for this data is about 85-97% for crop-specific land cover categories. Although this level of accuracy is relatively high, the accuracy varies depending on many factors, including the time of the satellite image, growing season timing, cloud cover, type of crop, and maturity state of the crop.

DWR retained Land IQ to develop a statewide assessment of agricultural land use in summer 2014. Land IQ used remote sensing methods to collect and process the data at the parcel scale, which was then ground truthed for a reported overall accuracy of 96.6% (DWR, 2014). In ESJWRM, this data was used as verification of CropScape 2014 data and, in some cases, as replacement or enhancement of the CropScape data. Land IQ did not include a native vegetation category, so any blank land was assumed to be native vegetation.

Table 6: Land Use Categories

<table>
<tr><th>Land Use Type</th><th>Model Category</th><th>Grouped Categories</th></tr>
<tr><td rowspan="7">Irrigated Crops</td><td>Almonds
Cherries
Citrus & Subtropical
Other Orchard
Pistachios
Walnuts</td><td>Fruit and Nut Trees</td></tr>
<tr><td>Vineyards</td><td>Vineyards</td></tr>
<tr><td>Alfalfa
Pasture</td><td>Alfalfa and Irrigated Pasture</td></tr>
<tr><td>Grain</td><td>Grain</td></tr>
<tr><td>Corn
Cotton
Dry Beans
Field Crops
Safflower
Sugar Beets</td><td>Field Crops</td></tr>
<tr><td>Cucurbits
Onion & Garlic
Potatoes
Tomato Fresh
Tomato Processing
Truck Crops</td><td>Truck Crops</td></tr>
<tr><td>Rice</td><td>Rice</td></tr>
<tr><td>Other Land Use</td><td colspan="2">Urban Landscape
Water Surface
Riparian Vegetation
Native Vegetation</td></tr>
</table>

Local data and knowledge was also utilized to refine and correct, when necessary, the cropping acreages developed based on the DWR land use surveys and CropScape years. To fill the gap between 1995 and 2007, all land use and crop categories were interpolated at the spatial resolution level of the model element. Thus, the geographic distribution of interpolated land use and cropping patterns are honored.

Consistent mappings were developed to link crop categories from the various data sources to model categories based on previous work done for C2VSim. Adjustments were made, as needed, at the element level to ensure that the land use and cropping pattern trends over time are reflective of local data. These adjustments were mostly based on local knowledge and information received from various entities, including irrigation districts, water districts, and municipalities.

Figure 13 and Figure 14 show the spatial distribution of the major land use categories in the ESJ Subbasin for 1995 and 2015. Figure 15 shows the annual trends of land use categories in the ESJ Subbasin.

Figure 16, Figure 17, and Figure 18 show the spatial distribution of the irrigated crops for 1995, 2014, and 2015. Figure 19a-19g show the annual cropping patterns, by high level categories, for the entire ESJ Subbasin and major model subareas.

Overall, land use trends from 1995 through 2015 show significant increases in total and irrigated agricultural acreage, with about 384,000 irrigated acres in ESJ Subbasin at the beginning of simulation and about 398,000 acres with agricultural production by 2015. This change from native to agricultural area brings additional stresses on the hydrological system, particularly as the majority of this increase comes from conversion to higher water permanent crops, particularly vineyards, almonds, and walnuts. This translates to a higher water requirement, largely provided either by groundwater or surface water, though changes in irrigation methods may mitigate some of the increased water need due to land use changes.

Not all the subareas show an increase in agricultural land; many remain relatively consistent through the entire simulation period. When there was a decrease in agricultural land, there was a compensating increase in urban land, indicating the expansion of urban areas.

2.7 Evapotranspiration

The crop evapotranspiration (ET) requirement is an important factor in agricultural demand estimation. Every ESJWRM land use category (except for water surface) plus small-stream watersheds must have average monthly values used for the entire simulation. To allow for spatial variability within the model, ET rates are also defined by model subregion.

The ET values are based on a variety of sources, including locally-developed data for the SSJID and the OID Agricultural Water Management Plans (AWMPs) (SJJID, 2015; OID, 2016) and averages for DWR's CIMIS (California Irrigation Management Information System) Zone 12 developed using the Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC) methodology, which is a remote-sensing based technology to estimate crop actual ET. Based on discussions with locals (pers. comm. Jennifer Spaletta representing NSJWCD and Bryan Thoreson representing SSJID), deficit irrigation of vineyards was simulated in ESJWRM with reference to the growing season ET values in the Lodi area (Prichard).

In IWFM, ET represents the net vertical water flux from the land surface and root zone through the upper model boundary. Figure 20 shows the range in annual evapotranspiration rates from the various sources for the 27 categories. Final model ET depends on the model subregion, with SSJID and OID using their locally-developed ET rates and the remainder of the model using the METRIC data.

2.8 Drainage

Surface water drainage (e.g., runoff from rainfall and excess applied water) for each model element is assigned to a stream node representing where the drainage ultimately flows to. These drainage patterns were delineated using the USGS Watershed Boundary Dataset for 12-digit hydrologic units, also called subwatersheds. Each 12-digit hydrologic unit located within the model boundaries was associated with the model stream node it ultimately drained into through both visual analysis as well as information provided on the subwatersheds. Elements falling within the hydrologic units were assigned to the model stream node indicating the ultimate surface water drainage direction. A total of 94 unique stream nodes receive surface water drainage in ESJWRM from 79 subwatersheds. Figure 21 shows these stream nodes and the subwatersheds mapped to the model elements.

2.9 Model Layering

The subsurface zone is characterized by four model layers (three freshwater aquifers and one saline aquifer) representing the different geology from the ground surface to the bedrock. A small portion of the southwestern part of the subbasin has a confining unit of Corcoran Clay. The layering extents and thicknesses are all consistent with C2VSim. Descriptions of each of the model layers are listed below, from top to bottom.

- Layer 1: Layer 1 represents the top unconfined portion of the aquifer. The ground surface elevation (GSE), or the top of Layer 1, comes from the USGS DEM at a resolution of 10 meters. The bottom of Layer 1 is defined as the top of Corcoran Clay where the confining unit exists or else as the bottom of Layer 1 in C2VSim. The layer thickness is limited by the stream invert elevation and ranges from 34 to 966 feet. The GSE is shown in Figure 22 and thickness of Layer 1 is shown in Figure 23.
- Aquitard 1: Corcoran Clay (i.e., E Clay) separates Layers 1 and 2 in a small portion of the southwest corner of the model. The extent, thickness, and depth of the Corcoran Clay originated from the Central Valley Hydrologic Model (CVHM) Spatial Database. The depth to the Corcoran Clay, ranging from 20 to 280 feet below the GSE, is shown in Figure 24 and the thickness of the Corcoran Clay, ranging from 10 to 160 feet, is in Figure 25.
- Layer 2: Layer 2 represents the primary pumping layer and is beneath the confining layer where Corcoran Clay exists. Layer 2 is principally bounded on the top by the bottom of Layer 1 or the bottom of Corcoran Clay (where it exists) and on the bottom by Layer 2 in C2VSim. The thickness of Layer 2, ranging from 50 to 540 feet, is in Figure 26.
- Layer 3: Layer 3 extends to the base of fresh water. Information used in developing the bottom of Layer 3 includes data from Steven Springhorn of DWR's North Central Regional Office, Christopher Olvera of DWR's South Central Regional Office, and Williamson et al. 1989. The thickness of Layer 3, ranging from 50 to 1,335 feet, is in Figure 27.
- Layer 4: Layer 4 consists of the saline water ranging from the base of fresh water to the base of continental deposits and is a current non-production zone. Information used in developing the bottom of Layer 4 includes Page's 1974 Base and Thickness of the Post Eocene Continental Deposits in the Sacramento Valley and the thickness of the aquifer developed by Williamson et al. 1989. The thickness of Layer 4, ranging from 50 to 2,250 feet, is in Figure 28.

Cross sections of the model layering in various locations across the model extent can be seen in Figure 29a-29f.

2.10 Small-Stream Watersheds

The inflow from the eastern boundary of the model (i.e., Sierra Nevada foothills) originates from both gauged and ungauged watersheds. The simulation of gauged watersheds (i.e., stream inflows into the model) was discussed in Section 2.3 and shown in Figure 9. The simulation of the ungauged watersheds is explained in this section.

Flow from ungauged small watersheds is estimated based on precipitation rates and characteristics assigned to each identified ungauged watershed. A portion of flow from the small watershed enters the model area as surface runoff and flows to simulated streams. The remaining small watershed inflow infiltrates to groundwater.

ESJWRM simulates the ungauged eastern inflow using 39 distinct small watersheds (Figure 30), consistent with those on the eastern boundary of C2VSim. These were delineated originally from the USGS Watershed Boundary Dataset.

All subsurface inflows from these small watersheds are routed to model Layer 1 along specified groundwater nodes (Figure 30), with a user-defined maximum percolation rate at each node. Excess flows that do not infiltrate to groundwater enter the simulated streams at user-specified locations (Figure 30) delineated using a similar methodology to the drainage pattern discussed above in Section 2.8. The hydrologic conditions of these small watersheds used to estimate the subsurface and surface flows are represented using site-specific parameters (e.g., precipitation, surface layer soil parameters, runoff coefficient) based on C2VSim.

2.11 Boundary Conditions

As discussed in the previous section, inflows along the eastern boundary are represented using small watersheds. Boundary conditions define the subsurface inflows from all other boundaries of the model (i.e., northern, western, and southern), as well as areas with known groundwater levels.

Time series general head boundary conditions representing groundwater levels outside of the model area were defined for 596 boundary nodes on the northern, western and southern limits (i.e., along Cosumnes, Mokelumne, San Joaquin, and Tuolumne Rivers). Groundwater flow at the model boundaries was quantified based on the groundwater gradient across the model boundary. The head inside the model area is simulated by ESJWRM and the head outside the model area is based on historical groundwater elevation data from DWR’s Water Data Library (WDL).

Additional groundwater boundary conditions were defined to simulate known groundwater elevations for the Sacramento-San Joaquin Delta and lakes or reservoirs (reservoir locations shown in Figure 5). ESJWRM specifies high groundwater levels at or near zero feet for 60 groundwater nodes representing the edges of the Sacramento-San Joaquin Delta. Using data available in C2VSim, seepage from Camanche Reservoir was represented by specifying the full time series of groundwater levels for the 270 groundwater nodes representing the reservoir. The other reservoirs in the model were not included in C2VSim, so did not have boundary conditions available to estimate reservoir seepage. Instead, Woodward Reservoir seepage is included as a stream diversion from Stanislaus River (see Section 3.3.1). Farmington Flood Control Basin is used primarily for flood control purposes. Any recharge is incidental to the operation of the dam and is currently not included in ESJWRM. Modesto Reservoir, as it is located outside of the focus area of ESJ Subbasin, was not simulated.

2.12 Initial Conditions

Groundwater heads for each model node and each layer at the beginning of the simulation (i.e., October 1, 1994) were developed using the DWR's WDL database and San Joaquin County's database of historical groundwater monitoring. Over 1,100 wells with data for Fall 1993, Fall 1994, or Fall 1995 were compiled and interpolated to create a raster representing initial groundwater levels for each model groundwater node. Due to the lack of information on well perforation and even depth for many of the WDL and San Joaquin County monitoring locations, the groundwater heads for each model layer are assumed to all begin at the same value. This assumption means the model needs about a year for groundwater levels to stabilize, so model results focus on water years 1996 through 2015 (a 20-year period). The initial conditions for ESJWRM representing October 1, 1994 are shown in Figure 31.

3. WATER SUPPLY AND DEMAND DATA

The following sections describe the data and methodology for the ESJWRM water demand and supply calculations. Agricultural and urban demand are calculated in the IDC portion of IWFM. Agricultural and urban supply are specified in IWFM's groundwater pumping and surface water diversion data.

3.1 Agricultural Water Demand

Agricultural water demand is the amount of irrigation water that is required to satisfy the crops evapotranspiration requirement. The IWFM Demand Calculator or IDC is designed to estimate the agricultural water demand for each model element through consumptive use methodology. The IDC calculations rely on model input data for historical crop acreage, irrigation practices (e.g., return and reuse fractions, irrigation period), soil moisture requirements, effective rainfall (the portion of rainfall available for crop consumptive use), crop evapotranspiration, and localized soil parameters. This data was compiled, analyzed, synthesized, and processed for input in ESJWRM.

Precipitation, land use, evapotranspiration, and soil properties are discussed in the relevant sections in Chapter 2. Irrigation period, using data from C2VSim, defines irrigation as either on or off for each crop and each month of the model simulation period. These were vetted and revised as necessary by the Technical Review Committee to better represent local practices in the ESJWRM area. Most trees are assumed irrigated from April through October (with almonds and pistachios from February through October), vineyards from May through October, most field crops from May through September, and most truck crops from April through September. Crops with irrigation assumed year-round include citrus and subtropical trees, irrigated pasture, alfalfa, and onions and garlic. Fractions to represent return flow (i.e., irrigation flow following the model drainage pattern discussed in Section 2.8) and reuse (i.e., the fraction of applied irrigation water to be reused for irrigation) are from C2VSim and are defined by subregion. For all ESJWRM, agricultural lands are given a 1% return flow and 1% reuse factor and urban landscape areas are assumed to have 15% return flow and 0% reuse.

3.2 Urban Water Use

IDC calculates urban demand based on per capita water use, population, and the breakdown of indoor versus outdoor water use by month. Figure 32 shows the annual population trends for each urban center. Figure 33 shows the annual per capita water use values of these urban centers used in the calculation of urban water demand.

Population and per capita water use for the major urban areas were largely provided directly by the urban areas or were obtained from the respective Urban Water Management Plans (UWMP). Additional annual population, including an estimate for rural urban areas, came from the United States Census Bureau and the California Department of Finance. Monthly per capita water use, commonly reported in gallons per capita per day (GPCD), was generally estimated for each urban entity using the annual population and monthly urban water use (provided by cities based on water delivery records). To estimate the urban water demand of rural domestic water areas, the average major urban area GPCD was combined with estimated rural population.

It was assumed that an annual average of 60% of urban water was used indoors and 40% was used outdoors. The monthly fractions entered into the model had the majority of urban water demand due to indoor activities from November through March and up to a maximum of 60% of urban water used outdoors for the remainder of the year.

The indoor/outdoor breakdown received concurrence from the urban water providers who attended the Technical Review Committee meetings. Population and per capita water use data were reviewed by the major urban areas and confirmed at the meetings (pers. comm. Kathryn Garcia from Lodi, Andrew Richle from Lodi, Michael Bolzowski from Cal Water, Greg Gibson from Lathrop, and Elba Mijango from Manteca).

3.3 Water Supply Summary

Both the agricultural and urban demands estimated by IDC are primarily met through the IWFM representation of surface water diversions and groundwater pumping. Other sources of water simulated in IWFM to meet demand include precipitation and existing moisture in the soil.

3.3.1 Surface Water

Historical surface water diversions for the simulation period were compiled from a combination of sources discussed in more detail in Section 3.4, including gauge data, water rights reports, UWMPs, AWMPs, and other sources. Some diversions were estimated based on historical demands. A summary of diversions simulated in the model is provided in Table 7, along with fractions for recoverable loss (i.e., percolation or canal seepage), non-recoverable loss (i.e., evaporation), and delivery (i.e., amount delivered is equal to the total amount minus the recoverable and non-recoverable losses).

The monthly data for all these diversions came from local agencies or C2VSim (Modesto Subbasin diversions and riparian diversions) as discussed in more detail in Section 3.4. Many diversions provide water across model subregions, so deliveries are assigned to a group of elements representing the delivery area. Diversions either are taken out of streams at specified model streams nodes or are imported into the model area (i.e., diversion location occurs upstream of stream inflow gauge). Figure 34 shows the stream nodes where diversions occurred.

Table 7: Summary of ESJWRM Surface Water Deliveries

ID	Description	Diversion Location	Delivery Area	Use	Fraction			Average Annual Diversion*** (acre-feet)	Data Source
					RL*	NL**	Delivery		
1	Mokelumne River to Woodbridge ID for Ag	Mokelumne River at Lodi Lake	Element group representing Woodbridge Irrigation District	Ag	30%	2%	68%	56,700	WID
2	Mokelumne River to City of Lodi (by agreement with Woodbridge ID)	Mokelumne River at Lodi Lake	Lodi Sphere of Influence	Urban	3%	1%	96%	5,000	WID

ID	Description	Diversion Location	Delivery Area	Use	Fraction			Average Annual Diversion*** (acre-feet)	Data Source
					RL*	NL**	Delivery		
3	Mokelumne River to City of Stockton for Delta Water Supply Project (by agreement with Woodbridge ID)	Mokelumne River at Lodi Lake	Element group representing Stockton area minus Cal Water	Urban	3%	1%	96%	5,400	WID
4	Mokelumne River to Contra Costa WD (by agreement with Woodbridge ID)	Mokelumne River at Lodi Lake	Export out of model	Urban	0%	0%	100%	2,000 (one year only)	WID
5	Mokelumne River to North San Joaquin WCD For Ag	Mokelumne River between Camanche Reservoir and Lodi Lake	Element group representing North San Joaquin WCD	Ag	10%	2%	88%	2,200	NSJWCD
6	Calaveras River to Bellota Pipeline to Stockton East WD WTP for M&I	Calaveras River at split with Mormon Slough	Stockton Sphere of Influence	Urban	3%	1%	96%	15,800	SEWD
7	Calaveras River to Calaveras County WD for Ag	Import (outside of ESJWRM)	Calaveras Subregion (Subregion 5)	Ag	9%	1%	90%	1,100	CCWD
8	Calaveras River to Stockton East WD for Ag	Calaveras River at split with Mormon Slough	Element group representing Stockton East Water District agricultural customers	Ag	40%	5%	55%	42,600	SEWD
9	Calaveras River to Farmington Groundwater Recharge Program	Calaveras River at split with Mormon Slough	Element group representing recharge locations	Ag	100%	0%	0%	1,300	SEWD
10	San Joaquin River at Empire Tract to City of Stockton for Delta Water Supply Project	San Joaquin River at Empire Tract just after junction with Bear Creek	Element group representing Stockton area minus Cal Water	Urban	3%	1%	96%	7,800	City of Stockton

ID	Description	Diversion Location	Delivery Area	Use	Fraction			Average Annual Diversion*** (acre-feet)	Data Source
					RL*	NL**	Delivery		
11	San Joaquin River to North Delta	San Joaquin River near North Delta Subregion	Element group representing North Delta	Ag	5%	1%	94%	107,000	Estimated by model
12	San Joaquin River to South Delta	San Joaquin River near South Delta Subregion	Element group representing South Delta	Ag	5%	1%	94%	14,200	Estimated by model
13	Farmington Reservoir via Lower Farmington Canal to Peters Pipeline to Stockton East WD WTP	Import (outside of ESJWRM)	Stockton Sphere of Influence	Urban	3%	1%	96%	33,300	SEWD
14	Farmington Reservoir via Lower Farmington Canal to Stockton East WD for Ag	Import (outside of ESJWRM)	Element group representing Stockton East Water District agricultural customers	Ag	15%	2%	83%	5,300	SEWD
15	Farmington Reservoir via Little Johns Creek and Lower Farmington Canal to Central San Joaquin WCD for Ag	Import (outside of ESJWRM)	Element group representing Central San Joaquin WCD	Ag	28%	2%	70%	38,800	SEWD
16	Stanislaus River to Farmington Groundwater Recharge Program	Import (outside of ESJWRM)	Element group representing recharge locations	Ag	100%	0%	0%	3,000	SEWD
17	Woodward Reservoir to South San Joaquin ID for Ag	Import (outside of ESJWRM)	Element group representing South San Joaquin ID minus Division 6	Ag	21%	6%	74%	195,300	SSJID
18	Stanislaus River at Goodwin Dam to Oakdale ID for Ag	Import (outside of ESJWRM)	Element group representing Oakdale ID	Ag	16%	1%	83%	111,100	OID

ID	Description	Diversion Location	Delivery Area	Use	Fraction			Average Annual Diversion*** (acre-feet)	Data Source
					RL*	NL**	Delivery		
19	Woodward Reservoir Seepage	Import (outside of ESJWRM)	Element group representing Woodward Reservoir	Ag	100%	0%	0%	17,500	SSJID
20	Woodward Reservoir to Nick C. DeGroot WTP to City of Manteca for M&I	Import (outside of ESJWRM)	Manteca Sphere of Influence	Urban	3%	1%	96%	6,300	AWMP/ UWMP
21	Woodward Reservoir to Nick C. DeGroot WTP to City of Escalon for M&I	Import (outside of ESJWRM)	Escalon Sphere of Influence	Urban	3%	1%	96%	0	AWMP/ UWMP
22	Woodward Reservoir to Nick C. DeGroot WTP to City of Lathrop for M&I	Import (outside of ESJWRM)	Lathrop Sphere of Influence	Urban	3%	1%	96%	1,100	AWMP/ UWMP
23	Woodward Reservoir to Nick C. DeGroot WTP to City of Ripon for M&I	Import (outside of ESJWRM)	Ripon Sphere of Influence	Urban	3%	1%	96%	0	AWMP/ UWMP
24	Tuolumne River to Modesto ID	Import (outside of ESJWRM)	Element group representing Modesto ID	Ag	15%	3%	82%	307,600	C2VSim
25	Tuolumne River to City of Modesto (via Modesto ID)	Import (outside of ESJWRM)	Element group representing City of Modesto	Urban	5%	1%	94%	30,600	C2VSim
26	Cosumnes River to Riparian for Ag	Along Cosumnes River near confluence with Mokelumne River	Element group representing riparian diverters	Ag	10%	2%	88%	4,300	C2VSim
27	Dry Creek to Riparian for Ag	Approximately midway along Dry Creek	Element group representing riparian diverters	Ag	10%	2%	88%	6,000	C2VSim

ID	Description	Diversion Location	Delivery Area	Use	Fraction			Average Annual Diversion*** (acre-feet)	Data Source
					RL*	NL**	Delivery		
28	Mokelumne River to Riparian for Ag	Approximately midway along Mokelumne River	Element group representing riparian diverters	Ag	10%	2%	88%	9,700	C2VSim
29	Calaveras River to Riparian for Ag	Calaveras River at split with Mormon Slough	Element group representing riparian diverters	Ag	10%	2%	88%	20,400	C2VSim
30	Stanislaus River to Riparian for Ag	Approximately midway along Stanislaus River	Element group representing riparian diverters	Ag	15%	3%	82%	20,700	C2VSim
31	Tuolumne River to Riparian for Ag	Approximately midway along Tuolumne River	Element group representing riparian diverters	Ag	15%	3%	82%	2,500	C2VSim
32	San Joaquin River to Riparian for Ag	San Joaquin River near confluence with Tuolumne River	Element group representing riparian diverters	Ag	15%	3%	82%	6,200	C2VSim
33	Woodward Reservoir to South San Joaquin ID Division 6 for Ag	Import (outside of ESJWRM)	Element group representing South San Joaquin ID Division 6	Ag	15%	2%	83%	5,200	SSJID

*RL = Recoverable Loss (canal seepage or recharge)
**NL = Non-Recoverable Loss (evaporation)
*** Averages calculated only for years with diversions occurring (i.e., non-zero average)

3.3.2 Groundwater Pumping

Groundwater pumping within ESJWRM is separated into well- or element-based pumping. The former largely includes district-operated wells that feed into the surface water supply network, while the latter includes estimated private groundwater pumping.

District pumping (or well pumping) is specified monthly throughout the simulation period. Data was provided by local agencies and included well locations, depths and perforations, use (agricultural or urban) and historical monthly pumping records. Table 8 lists the number of wells by type and agency included in ESJWRM. Figure 35 shows all the district pumping wells (separated by agricultural and municipal wells) in ESJWRM.

Table 8: Summary of ESJWRM Well Pumping

Agency	Number of Urban Pumping Wells	Number of Agricultural Pumping Wells	Average Annual Urban Pumping (acre-feet)	Average Annual Agricultural Pumping (acre-feet)
Cal Water	56	---	9,600	0
Escalon	4	---	1,400	0
Lathrop	6	---	2,200	0
Linden County WD	4	---	450	0
Lockeford CSD	4	---	530	0
Lodi	29	---	15,200	0
Manteca	15	31	9,500	1,300
Oakdale ID	---	24	0	5,800
Ripon	9	9	3,900	1,100
SEWD	5	---	3,100	0
SSJID	---	28	0	5,200
Stockton	37	---	9,300	0
Total Average Annual Pumping (acre-feet)			55,180	13,400

Private groundwater pumping quantities on an individual well basis are largely unknown, though aggregate estimates for private pumping are often included in planning documents (e.g., AWMPs, UWMPs, groundwater management plans). Therefore, private agricultural pumping in ESJWRM is estimated by IWFM on an element basis by assigning two virtual wells at the centroid of each model element. One well represents private agricultural pumping and one well represents rural residential pumping. These wells are used to calculate any additional pumping necessary to meet the agricultural and urban demand estimated by IDC for an element after district pumping and surface water has been distributed.

The perforation interval, which dictates the layers a simulated well extracts water from, were assigned separately to the agricultural and domestic (i.e., rural residential) wells. All agricultural wells were assumed to pump 40% from Layer 1 and 60% from Layer 2. Rural residential wells used a statistical analysis of perforation interval developed for C2VSim. Perforation interval data was compiled by DWR using data from the CASGEM and Online System for Well Completion Reports (OSWCR) databases. Simulated perforation intervals were assigned as the 5th and 95th percentiles of the well perforation interval data for each township/range block.

3.4 Water Supply Sources

This section provides a detailed description of the sources of water supply (both surface water and pumping) occurring in ESJWRM.

3.4.1 Delta Areas

The North Delta and South Delta Subregions (Subregion 1 and 14) are mostly assumed to cover the portion of the Sacramento-San Joaquin River Delta overlying the ESJ Subbasin. As discussed at the Technical Review Committee meetings, the majority of the agricultural water demand in these areas is known to be entirely served by surface water taken off the San Joaquin River. Therefore, almost all of the agricultural demand is assumed to be supplied by the San Joaquin River (Diversion #11 and #12 for North Delta and

South Delta, respectively). A small portion of the agricultural land is assumed to rely on groundwater via element pumping. All of the urban demand is supplied by small, private residential wells and is estimated in ESJWRM using element pumping.

Though Subregions 1 and 14 are assumed to represent the Delta, elements in Subregions 1 and 14 receive surface water from other diversions unrelated to the assumed riparian Delta diversions. A portion of WID's delivery area extends into Subregion 1 and is supplied by WID's diversion off the Mokelumne River (Diversion #1) as discussed in Section 3.4.2. Portions of other riparian diversions discussed in Section 3.4.19 extend into Subregions 1 and 14, specifically Dry Creek (Diversion #27) in Subregion 1 and San Joaquin River (Diversion #32) in Subregion 14.

3.4.2 Woodbridge Irrigation District

WID receives water from the Mokelumne River, which is provided to its agricultural customers through a distribution canal network or is sold to nearby municipalities. Through agreements, Lodi and Stockton use some of WID's surface water right beginning in water years 2013 and 2012, respectively (Diversion #2 and #3). In water year 2013, WID supplied Contra Costa Water District with a one-time transfer of 2,000 AF (acre-feet), represented by Diversion #4. Diversion #1 delivers water to the element group representing WID's service area, which spans portions of Subregion 1, most of Subregion 2, part of Subregion 3, and a small area of Subregion 6. The scale of the ESJWRM element grid is not refined enough to simulate deliveries on the parcel scale, so model elements may include parcels which do not in actuality receive surface water from WID.

Some of the agricultural demand (largely native landscape) adjacent to streams is met by the riparian diversion from Mokelumne River (Diversion #28) as discussed in Section 3.4.19. All remaining agricultural demand is estimated in ESJWRM as element pumping. All urban demand is likewise element pumping.

3.4.3 City of Lodi

The City of Lodi purchases surface water from WID, which it takes from the Mokelumne River adjacent to the city. Diversion #2 supplies part of the urban demand beginning in water year 2013, with all of the previous demand being met exclusively by groundwater. 29 municipal wells are simulated in the model, with at least 3 becoming inactive during the simulation period. Since Lodi began receiving surface water, its supply mix has steadily decreased its reliance on groundwater, from 100% of the urban demand in water year 2012 to 55% of the demand in water year 2015, with its increase in surface water use.

The agricultural land surrounding the current city boundaries is supplied by either WID on the west or NSJWCD to the east. Though the agricultural demand in these areas is small, WID's Diversion #1 or NSJWCD's Diversion #5, along with the riparian diversion from Mokelumne River (Diversion #28) (see Section 3.4.19), are able to supply some of the agricultural demand adjacent to Lodi. The city's wastewater treatment plant, located to the west of the city in Subregion #1, is surrounded by fields irrigated using recycled water from the treatment plant. Any additional agricultural or urban demand is estimated in ESJWRM as element pumping.

3.4.4 North San Joaquin Water Conservation District

NSJWCD receives water from the Mokelumne River, which is provided to its agricultural customers as Diversion #5. Historically, NSJWCD has not used its entire water right allotment and did not divert any water towards the end of the simulation (starting water year 2013).

Some of the agricultural demand adjacent to water is met by the riparian diversions from Dry Creek (Diversion #27) and Mokelumne River (Diversion #28) (see Section 3.4.19). Any additional agricultural demand is estimated in ESJWRM as element pumping, while small domestic urban demand is met by element pumping.

3.4.5 Lockeford Community Services District

LCSD is located within ESJWRM Subregion 4 and is surrounded by agricultural land under NSJWCD. LCSD has 4 municipal pumping wells used to meet all the urban demand generated by its customers. Some of the agricultural demand is met by the riparian diversion from Mokelumne River (Diversion #28) (see Section 3.4.19), while the remaining is met by element pumping.

3.4.6 Calaveras County

Only a small portion of Calaveras County extends into the ESJ Subbasin and the land is mostly unirrigated or native vegetation with small residential pockets and some irrigated agricultural parcels. CCWD uses a small amount of Calaveras River water for agricultural demand in the ESJ Subbasin (Diversion #7). Additional agricultural demand is met by the riparian diversion from Calaveras River (Diversion #29) (see Section 3.4.19) or element pumping. All the residential demand is met by element pumping.

3.4.7 Stockton Area

The Stockton area includes service areas of both the City of Stockton as well as Cal Water. San Joaquin County also manages water for several unincorporated areas in and around the city.

Both the City of Stockton and Cal Water purchase surface water for urban use from SEWD. The water originates from either the Calaveras or Stanislaus Rivers and is delivered to customers after treatment at the SEWD water treatment plant (Diversion #6 and Diversion #13). Additionally, Stockton began the Delta Water Supply Project in water year 2012 and built a water treatment plant, providing another source of surface water for the area from San Joaquin River at Empire Tract (Diversion #10) and Mokelumne River via agreement with WID (Diversion #3).

Stockton, Cal Water, and San Joaquin County maintain pumping wells for urban water use. Due to the scale of the element grid, many of the San Joaquin County areas were too small to be simulated separately from Stockton or Cal Water. Thus, San Joaquin County groundwater pumping is instead estimated by element pumping in ESJWRM. Stockton itself has 37 municipal wells in the area, though only about 14 are still active at the end of the simulation. Cal Water maintains a separate delivery area and operates 56 wells to meet urban demand, though only about 20 wells are active at the end of ESJWRM's historical simulation. Due to the complexity of the water supply in the area, the supply mix for urban water use in ESJWRM is difficult to separate by agency, though for the entire area is, on average, 70% surface water and 30% groundwater pumping with the reliance on groundwater decreasing toward the end of simulation due to the construction of the Delta Water Supply Project.

One riparian diversion from Calaveras River (Diversion #29) provides water to areas adjacent to the river (see Section 3.4.19). Additional agricultural demand may be met by surface water from WID (Diversion #1) where it extends into the northern part of the Stockton area or SEWD (Diversion #8 and Diversion #14). Any additional agricultural demand occurring in the area is supplied by the estimated element pumping.

3.4.8 Stockton East Water District

SEWD receives water from both Calaveras River (i.e., New Hogan Lake) and Stanislaus River (i.e., New Melones Lake) and sells water to its customers for both agricultural and municipal purposes. Agricultural water is delivered directly to customers scattered across the district area (model Subregions 6 and 7). Municipal water, as discussed in Section 3.4.7, is routed to SEWD's water treatment plant and is sold to the City of Stockton and Cal Water. Beginning in water year 2003, SEWD has operated groundwater recharge projects near its water treatment plant, utilizing water taken from both the Calaveras and Stanislaus Rivers.

In Table 7, SEWD's two urban diversions are Diversion #6 and Diversion #13, the two agricultural diversions are Diversion #8 and Diversion #14, and the two diversions used for recharge are Diversion #9 and Diversion #16. One riparian diversion from Calaveras River (Diversion #29) provides water to areas adjacent to the river (see Section 3.4.19). SEWD operates 5 urban pumping wells in the vicinity of the water treatment plant that are mixed with the surface water for use in the Stockton area and are utilized rarely (only during water year 2015 during the simulation period of ESJWRM). Any additional agricultural or urban demand is met by element pumping.

3.4.9 Linden County Water District

LCWD is located within ESJWRM Subregion 7 and is surrounded by agricultural land under SEWD. Though it receives no surface water, LCWD has 4 municipal pumping wells to meet all the urban demand generated by its customers. By the end of the simulation, only 2 of the wells are still active.

3.4.10 Central San Joaquin Water Conservation District

CSJWCD receives water from Stanislaus River (i.e., New Melones Lake) (Diversion #15) that is used for agricultural demand in model Subregion 8. Any additional agricultural demand is estimated as element pumping by ESJWRM. All the private residential urban demand is likewise calculated as element pumping.

3.4.11 South San Joaquin Irrigation District

SSJID's service area covers the agricultural lands around the cities of Manteca, Ripon, and Escalon. SSJID provides water to agricultural customers within the district using water from the Stanislaus River (taken out at Goodwin Dam) and then stored in Woodward Reservoir just east of the district's area in Stanislaus County. Diversion #17 represents the agricultural diversion from Woodward Reservoir that is delivered to SSJID's customers through its series of canals covering the district. Based on communication with SSJID, one portion of SSJID, Division 6 (formerly Division 9), began receiving more surface water beginning in water year 2011. An increase in surface water to Division 6 (near Ripon in Subregions 15 and 16) is simulated using Diversion #33. Diversion #19 represents the seepage from Woodward Reservoir as SSJID had monthly data estimating the groundwater recharge due to the reservoir. Diversion #30 simulates the riparian diverters along Stanislaus River (see Section 3.4.19).

SSJID maintains 28 agricultural wells located in and around the City of Manteca to augment their surface water supply. Any remaining agricultural demand in the district is met by element pumping estimated by ESJWRM.

The Nick C. DeGroot Water Treatment Plant located at Woodward Reservoir was constructed as part of the South County Water Supply Project through the collaboration of SSJID and the cities of Escalon, Lathrop, Manteca, and Tracy. Beginning in water year 2005, surface water deliveries from the treatment plant began to Lathrop, Manteca, and Tracy with Escalon deliveries to begin in the future (currently

Escalon's allotment is sold to Tracy). Ripon potentially may be added to the project at a later point. These deliveries are simulated in ESJWRM as Diversion #20 (Manteca), #21 (Escalon), #22 (Lathrop), and #23 (Ripon). Urban demand in these areas in discussed further in the relevant sections below. Any private residential demand estimated by ESJWRM in SSJID is met by element pumping.

3.4.12 City of Lathrop

Lathrop has 6 municipal pumping wells, one of which was inactive for the entire simulation period but may come back online for future use. The city began receiving surface water from the South County Water Supply Project in water year 2005 (Diversion #22) and will receive a higher allotment in future phases of the project.

Since Lathrop began receiving surface water and normalized for the drought, its supply mix has steadily decreased its reliance on groundwater, from 100% of the urban demand in water year 2004 to an average of 74% of the demand after the South County Water Supply Project began (ranging from 53% to 92% at the peak of the drought).

The small amount of agricultural demand in the vicinity of Lathrop is supplied by element pumping in ESJWRM. Recycled water is utilized for some fodder crop irrigation and will be incorporated in baseline runs of the model.

3.4.13 City of Manteca

Manteca has 15 active municipal wells that provide water for urban use and 31 active agricultural wells used to irrigate city landscaping. Agricultural land near the city is irrigated by SSJID's diversion from Stanislaus River (Diversion #17). Starting in water year 2005, Manteca began receiving water from the South County Water Supply Project (Diversion #20). Additional agricultural and urban demand not met by the mix of groundwater pumping and surface water supply is estimated in the model as element pumping.

Since Manteca began receiving surface water, its supply mix has steadily decreased its reliance on groundwater, from 100% of the urban demand before water year 2005 to an average of 62% of the demand after.

3.4.14 City of Ripon

Ripon has 9 municipal pumping wells, at least 5 of which remain active at the end of the historical simulation. In addition, Ripon has 3 agricultural wells used for the city's non-potable system and 6 non-potable wells owned by Nestle. The groundwater pumping is augmented by SSJID's diversion from Stanislaus River (Diversion #17) used for agricultural land surrounding the city. The city is currently not receiving surface water for municipal use from the South County Water Supply project, but may pursue that possibility in the future (Diversion #23). Currently, all the urban demand is met by groundwater pumping.

Adjacent to the Stanislaus River, some elements are receiving water for agricultural purposes from the Stanislaus River riparian diversion (Diversion #30) as discussed in Section 3.4.19.

3.4.15 City of Escalon

Escalon has 4 municipal pumping wells, at least 3 of which remain active at the end of the simulation. Starting in water year 2005, the city was eligible to receive water from the South County Water Supply Project (Diversion #21), but has yet to build the pipeline necessary to take advantage of the allotted surface water. Currently, Escalon sells its allotment to the City of Tracy (located in San Joaquin County but outside of the ESJ Subbasin).

Agricultural land near the city is irrigated by SSJID's diversion from Stanislaus River (Diversion #17) as discussed in Section 3.4.19. Any remaining agricultural demand is supplied using ESJWRM's element pumping estimates.

3.4.16 Oakdale Irrigation District

OID takes surface water from Stanislaus River at Goodwin Dam that splits from SSJID's water to go into OID's distribution system to supply to agricultural users (Diversion #18). The district's delivery area is spread between elements in ESJWRM Subregions 13, 18, and 20. Additional agricultural water comes from OID's 24 wells spread around the district's area.

3.4.17 Cosumnes Subbasin

As it is outside of the model focus area of ESJ Subbasin, the only diversions simulated in the Cosumnes Subbasin in ESJWRM are the riparian diversions from Cosumnes River (Diversion #26) and Dry Creek (Diversion #27) (see Section 3.4.19). Any additional agricultural or urban demands are met in the model by element pumping.

3.4.18 Modesto Subbasin

Three riparian diversions extend to elements in the Modesto Subbasin—Stanislaus River (Diversion #30), Tuolumne River (Diversion #31), and San Joaquin River (Diversion #32) (see Section 3.4.19). Additional agricultural surface water comes from the Tuolumne River to Modesto Irrigation District using data in C2VSim (Diversion #24). OID's delivery area extends into the Modesto Subbasin and receives a portion of OID's diversion off Stanislaus River (Diversion #18). Any remaining agricultural demand is supplied by ESJWRM-calculated element pumping.

Urban demand in the Modesto Subbasin is largely met using element pumping, except in the area of the City of Modesto, which receives surface water from Tuolumne River (via Modesto Irrigation District) in Diversion #25, with data from C2VSim.

3.4.19 Riparian Diverters

C2VSim includes surface water diversions to non-district riparian water users along simulated streams. This information (diversion volumes, locations, and delivery areas) was pulled from C2VSim and used to simulate riparian diversions in ESJWRM. These diversions are from Cosumnes River (Diversion #26), Dry Creek (Diversion #27), Mokelumne River (Diversion #28), Calaveras River (Diversion #29), Stanislaus River (Diversion #30), Tuolumne River (Diversion #31), and San Joaquin River (Diversion #32). The riparian lands receiving these diversions are shown in Figure 36.

4. MODEL CALIBRATION

The goals of model calibration are (1) to achieve a reasonable water budget for each component of the hydrologic cycle modeled (i.e., land and water use, soil moisture, stream flow, and groundwater) and (2) to maximize the agreement between simulated and observed groundwater levels at selected well locations and simulated and observed streamflow hydrographs at selected gauging stations. These objectives are achieved through verification of the model input data and adjustment of model parameters.

4.1 Model Calibration

Model calibration begins after data analysis and input data file development is completed. The calibration effort can be broken down into subsets that align with packages within the IWFM platform. As an integrated groundwater model, the results of each part of the simulation are dependent on one another. The model calibration can be considered a systematic process that includes the following activities:

- Calibrate hydrologic demand
- Calibrate surface water features
- Calibrate overall water budgets for the model area
- Calibrate simulated groundwater levels to observed groundwater levels
- Compare calibration performance with the calibration targets
- Conduct additional refinements to model as necessary

ESJWRM was calibrated to local data and knowledge, surface water flows, groundwater hydrographs, and groundwater contours. The sources used to check model results include local knowledge (mainly gathered during Technical Review Committee meetings), AWMPs, UWMPs, other local planning efforts, measured groundwater levels and contours, and observed streamflow data.

Due to uncertainty in the initial conditions, a one year “ramp up” period is included to allow groundwater levels to stabilize. Thus, the model calibration period for the ESJWRM is October 1995 through September 2015 or water years 1996 through 2015 (20 years).

4.2 Calibration of the IDC and Root-Zone Parameters

The goal of the IDC calibration process is to determine reasonable urban and agricultural demand and develop the components of a balanced root zone budget. IDC calibration serves as the foundation of the IWFM calibration as demand estimated translates directly to groundwater pumping, which is the primary stress on the groundwater system. This part of the calibration effort focused primarily on refining individual budget items while maintaining reasonable root zone parameters.

The calibrated IDC was used to estimate monthly agricultural water demand at each model element during the model hydrologic period. To adjust agricultural demand, elemental root zone parameters, particularly the soil hydraulic conductivity and the pore size distribution index, were adjusted in accordance with the hydrologic soil group and subregion. Spatial representation of these calibrated parameters is shown in Figure 37 though Figure 41. The IDC model was calibrated to agricultural water use values reported by irrigation districts in their AWMPs and then checked against local data with input from irrigation district representatives and consultants (pers. comm. Doug Heberle from WID, Jennifer Spaletta representing

NSJWCD, Tom Flinn from NSJWCD, Peter Martin from CCWD, Cathy Lee from SEWD, Manuel Verduzco from SEWD, Sam Bologna from SSJID, Peter Rietkerk from SSJID, Bryan Thoreson representing SSJID, Emily Sheldon from OID, Eric Thorburn from OID, and Byron Clark representing OID). Figure 42a-42n show the agricultural water demand, unit agricultural water use, and unit evapotranspiration of applied water (ETAW) estimates by the total ESJ Subbasin area and major subareas. Differences in the charts between the subregion and subareas is due the differences in cropping patterns and evapotranspiration rates, which drive the estimation of agricultural demand. The difference between the two unit water use columns provide an indication of the efficiency of agricultural practices in the subregion or subarea. Overall, the estimated agricultural demand reflects the same variability seen in irrigation practices and major crops from area to area within the ESJ Subbasin.

Figure 43a-43g show the model estimated annual urban demand for the total ESJ Subbasin area and subareas. Urban demand reflects the population and per capita water use defined for each urban area and estimated for the remaining rural residential areas.

4.3 Calibration of Surface Water Features

The ESJWRM simulates streamflow in 39 small watersheds and several major rivers and creeks across the model domain.

As discussed in Section 2.10, small watersheds are used to simulate inflows into the model from ungauged watersheds. The small watershed contributions are split between surface water runoff that enters the stream system, percolation that occurs during transport to the streams, and baseflow entering the groundwater system at the model boundary. Groundwater level hydrographs along the model boundary selected for groundwater level calibration (Section 4.5) were referenced to confirm and edit, as necessary, the various parameters of the small watersheds.

Streamflow calibration is primarily performed by comparing the simulated streamflow with local data from 11 stream gauges (Table 9 and Figure 44). Data for these gauges came from USGS or the California Data Exchange Center (CDEC). Two of these stream gauges (Mokelumne River below Camanche Dam and San Joaquin River near Vernalis) are duplicates of gauges used to estimate stream inflow into the model area and were not referenced for streamflow calibration and only verification of model setup.

Table 9: Summary of ESJWRM Stream Calibration Gauges

Stream	Stream Node	Agency	Gauge Name	Period of Record
Cosumnes River	98	USGS	USGS 11336000: Cosumnes River at McConnell, CA	October 1941 to October 1982
Dry Creek	222	USGS	USGS 11329500: Dry Creek near Galt, CA	October 1926 to December 1997
Mokelumne River*	290	USGS	USGS 11323500: Mokelumne River below Camanche Dam, CA	October 1904 to present/ongoing
Mokelumne River	382	USGS	USGS 11325500: Mokelumne River at Woodbridge, CA	June 1924 to present/ongoing
Mokelumne River	501	USGS	USGS 11336930: Mokelumne River at Andrus Island near Terminous, CA	July 2006 to present/ongoing

Stream	Stream Node	Agency	Gauge Name	Period of Record
Mormon Slough	876	USACE	CDEC MRS: Mormon Slough at Bellota	December 1997 to present/ongoing
Stanislaus River	1067	DWR	CDEC OBB: Stanislaus River at Orange Blossom Bridge	January 1993 to present/ongoing
Stanislaus River	1186	USGS	USGS 11303000: Stanislaus River at Ripon, CA	October 1940 to present/ongoing
Tuolumne River	1382	USGS	USGS 11290000: Tuolumne River at Modesto, CA	April 1940 to present/ongoing
San Joaquin River*	1497	USGS	USGS 11303500: San Joaquin River near Vernalis, CA	October 1923 to present/ongoing
San Joaquin River	1597	USGS	USGS 11304810: San Joaquin River below Garwood Bridge at Stockton, CA	December 1995 to present/ongoing

*Same as stream inflow gauge, so not used for calibration and included as verification of model setup

Stream flow calibration included refinement of the stream bed hydraulic conductivity originally from C2VSim (Figure 45). Simulated stream flows were compared with observed records and exceedance charts were also used to check the model performance when simulating high and low flows at each gauge location. Calibration results for select stream gauges are included in Figure 46a-46j.

4.4 Calibration of Water Budgets

The aim of the calibration process is to ensure the accurate representation of the hydrologic characteristics of the groundwater basin, confirmed through the analysis of the resulting water budgets. A water budget balances all supplies, demands, and any subsequent change in storage occurring within that specific portion of the hydrologic cycle. IWFM automatically outputs budgets at the subregion scale for processes involving groundwater, the surface layer, streams, the root zone, small watersheds, and the unsaturated zone. IWFM can output select budgets down to a single element or any specific grouping of elements.

During this step of the calibration process, model results are reviewed and summarized into monthly and annual (by water year) budgets. The most important budgets reviewed for calibration are the groundwater budget and the land and water use budget. After extensive budget analysis, key model datasets and parameters are adjusted, particularly groundwater aquifer parameters, to better match local budgets from AWMPs or other planning efforts. The ESJWRM water budget results are summarized in the following sections.

4.4.1 Land and Water Use Budget

The land and water use budget includes two different versions, agricultural and urban, and represents the balance of the IDC-calculated water demands with the water supplied. Both the agricultural and urban versions include the same components that make up the water balance:

- Inflows:
    - Demand (either agricultural or urban)
    - Surplus (if applicable)

- Outflows:
  - Groundwater pumping
  - Surface water deliveries
  - Shortage (if applicable)

The average annual water demand for the subbasin within the calibration period was 1.2 million acre-feet (MAF), consisting of approximately 1.1 MAF agricultural demand and 0.1 MAF urban demand. This demand was met by approximately an average annual of 0.50 MAF of surface water deliveries (0.45 MAF of agricultural and 0.05 MAF of urban deliveries) and was supplemented by approximately 0.69 MAF of groundwater production (0.62 MAF of agricultural and 0.07 MAF of urban pumping). The annual estimated land and water use budgets for the calibration period are presented in Figure 47a-47g and Figure 48a-48g, showing the agricultural and urban, respectively, demands and water supplies in the ESJ Subbasin and its component subareas. Due to uncertainties in the reported and estimated values of agricultural and urban water supplies, as well as respective estimates of the demands, there are some imbalances between the demand and supply values. These imbalances are shown as surplus or shortage and are typically less than 10% of the reported supplies, and within the margin of errors of the analysis.

4.4.2 Groundwater Budget

The primary components of the groundwater budget, corresponding to the major hydrologic processes affecting groundwater flow in the model area, are:

- Inflows:
  - Deep percolation (from rainfall and excess irrigation applied water)
  - Gain from stream (or recharge due to stream seepage)
  - Recharge (from other sources such as irrigation canal seepage and recharge ponds)
  - Boundary inflow (from outside the model area)
  - Subsurface inflow (from adjacent subregions)
- Outflows:
  - Groundwater pumping
  - Loss to stream (or outflow to streams and rivers)
  - Boundary outflow (to outside the model area)
  - Subsurface outflow (to adjacent subregions)
- Change in groundwater storage (either an inflow or outflow)

The groundwater budget consists of inflows to and outflows from the groundwater system. Figure 49a-49g show the annual components of the groundwater budget, including cumulative change in groundwater storage for ESJ Subbasin. Primary components of the groundwater budget are as follows: average annual groundwater pumping is estimated to be 0.70 MAF, which is offset by approximately 0.22 MAF of deep percolation from rainfall and applied water, net gain from stream of 0.15 MAF, recharge from conveyance and unlined canals of approximately 0.12 MAF, and a total net subsurface inflow of approximately 0.16 MAF from neighboring subbasins and foothills. The cumulative change in groundwater storage is calculated from the change in groundwater storage. Due to inherent uncertainties in data and assumptions used in the model, approximations used in representing physical features in the aquifer system, and uncertainties in the model calibration, all budget components have some degree of uncertainty. A sensitivity analysis was performed to estimate the sensitivity of the model results to the changes in each of the key model parameters. Given the overall range of uncertainties, the long-term average annual depletion in groundwater storage in ESJ Subbasin during the model historical period is estimated to range between 24 to 70 TAF, with an average of approximately 47 TAF per year.

4.5 Groundwater Level Calibration

Like streamflow calibration, the goal of groundwater level calibration is to achieve reasonable agreement between the simulated and observed values (in this case, groundwater levels at calibration wells). Within the ESJWRM, over 3,000 wells were evaluated for developing groundwater observation locations to track ESJWRM's calibration at both a regional and local scale. The records for these wells were obtained from San Joaquin County's monitoring database, DWR's CASGEM program, and local monitoring wells from the City of Lodi and Oakdale Irrigation District. The calibration wells were selected based on their period of record, spatial distribution across the model, representativeness of good indicators of model responses to the various stresses, availability of observation data, and trends of nearby wells. Though a working set of 160 wells was tentatively selected initially, this was narrowed to an ultimate set of 70 wells that are representative of the long-term conditions of groundwater levels both at a local and regional scale in ESJWRM. These 70 calibration wells are shown in Figure 50 with information tabulated in Appendix C.

Simulated groundwater levels are calibrated to observed levels through adjustments to hydrogeologic parameters or aquifer parameters including hydraulic conductivity, specific storage, and specific yield (discussed in Section 4.7). The goal of groundwater level calibration is to achieve the maximum agreement between simulated and observed groundwater elevations at calibration wells while maintaining reasonable values for aquifer parameters. The groundwater level calibration is performed in two stages:

- The initial calibration effort is focused on the regional scale to verify hydrogeological assumptions made during data development and confirm the accuracy of general groundwater flow vectors. During this iteration, simulated groundwater elevation trends, flow directions, and groundwater gradients are compared to measured data. DWR's groundwater level contours for spring and fall many years starting in the 2010s were used to evaluate ESJWRM's groundwater contours from matching time periods. Figure 51a-51d show the resulting ESJWRM groundwater level elevations (average of the top 2 layers of the model where most of the pumping in the subbasin occurs) compared to DWR contours for 4 different seasons and years: Spring 2011, Fall 2013, Spring 2015, and Fall 2015. Fall 2015 also represents the end of simulation groundwater levels.
- The second stage of calibration of groundwater levels is to compare the simulated and observed groundwater level at each calibration well. This comparison provides information on the overall model performance during the simulation period. The simulated groundwater elevations at the 70 calibration wells were compared with corresponding observed values for concurrence in long-term trends as well as seasonal fluctuations.

Discussed further in the next section (Section 4.6), the results of the groundwater level calibration indicate that the ESJWRM reasonably simulates the long-term hydrologic responses under various hydrologic conditions. Figure 52a-52r show a selection of calibration wells (1 representing each ESJ Subbasin model subregion or 18 wells) with their resulting groundwater level hydrographs. All 70 calibration well hydrographs are included in Appendix C.

4.6 Measurement of Calibration Status

The ESJWRM calibration status was measured using two metrics: the groundwater level trend and the relationship between simulated and observed groundwater levels. The statistics were evaluated to meet the American Standard Testing Method (ASTM) standard. In addition to quantifiable metrics, the ESJWRM calibration was evaluated by generating reasonable regional groundwater flow directions and producing realistic water budgets.

The "Standard Guide for Calibrating a Groundwater Flow Model Application" (ASTM D5981) states that "the acceptable residual should be a small fraction of the head difference between the highest and lowest heads across the site." The residual is defined as the simulated head minus the observed head. An analysis of all calibration water levels within the model indicated the presence of 200+ feet of water level changes. Using 10 percent as the "small fraction", the acceptable residual level would be 20 feet. Calibration goals for the groundwater level residuals were set such that no more than 10 percent of the observed groundwater levels would exceed the acceptable residual level of 20 feet.

- 75% of observed groundwater levels are within +/- 10 feet of its respective simulated values
- 97% of observed groundwater levels are within +/- 20 feet of its respective simulated values
- 99% of observed groundwater levels are within +/- 30 feet of its respective simulated values

The residual histogram for the ESJ Subbasin is shown in Figure 53. Additionally, a scatter plot of simulated versus observed values is shown in Figure 54.

4.7 Final Calibration Parameters

The initial aquifer parameters for the ESJWRM came from DWR's texture model values extracted to C2VSim coarse grid nodes. These coarse grid nodes formed a parametric grid covering the model area and reflected the scale at which parameters were adjusted throughout the calibration process. The grid was slightly modified to cover the entire ESJWRM model along the boundaries and additional nodes were added or moved within areas of the model to provide better control (Figure 55). The parameters resulting from the calibration process are listed in Table 10.

Table 10: Range of Aquifer Parameter Values

Stream	Layer 1	Layer 2	Layer 3	Layer 4
Horizontal Hydraulic Conductivity (ft/day)	11.5 – 72.7	6.4 – 44.8	1.1 – 4.6	1.8 – 5.2
Vertical Hydraulic Conductivity (ft/day)	0.005 – 0.14	0.004 – 0.07	0.004 – 0.05	0.004 – 0.15
Corcoran Clay Vertical Hydraulic Conductivity (ft/day)	3.6×10^{-4} – 1.5×10^{-3}	3.6×10^{-4} – 1.5×10^{-3}	3.6×10^{-4} – 1.5×10^{-3}	3.6×10^{-4} – 1.5×10^{-3}
Specific Storage (unitless)	8.55×10^{-5} – 1.57×10^{-4}	4.18×10^{-6} – 1.97×10^{-4}	4.21×10^{-6} – 2.05×10^{-4}	2.53×10^{-5} – 1.75×10^{-4}
Specific Yield (unitless)	0.04 - 0.10	0.04 – 0.09	0.04 – 0.09	0.05 – 0.09

Horizontal Hydraulic Conductivity – The hydraulic conductivity (KH) in the ESJWRM varies across the horizontal direction and across model layers. The fully calibrated values remain descriptive of the initial hydrogeologic analysis, range from 1.1 ft/day to 72.7 ft/day, and the spatial distribution is represented in Figure 56 through Figure 58.

Vertical Hydraulic Conductivity – Primarily a constraining factor across the Corcoran Clay in the small portion of the model underlain by it, the Vertical Hydraulic Conductivity (KV) facilitates the separation between the unconfined and confined aquifers within the ESJWRM. The KV values of the Corcoran aquitard is found to be less than one one-thousandth of the horizontal conductivity of the surrounding aquifer systems. For those parts of ESJWRM without Corcoran Clay, the KV controls the flow of groundwater between the materials making up the different modeled aquifer layers.

Specific Storage – Specific Storage (SS) is used to represent the available storage at nodes in a confined aquifer, where the hydraulic head is above the top of the aquifer. Specific Storage is the unit volume of water released or taken into storage per unit change in head. Calibrated specific storage values range from 4.18×10^{-6} to 2.05×10^{-4}, as shown in Figure 59 through Figure 61.

Specific Yield – Specific Yield (SY) is representative of the available storage in an unconfined aquifer and defined as the unit volume of volume released from the aquifer per unit change in head due to gravity. Calibrated specific storage values range from 0.04 to 0.10 and are shown in Figure 62 through Figure 64.

4.8 Sensitivity Analysis

Sensitivity analysis is an important step in the model development process. It is defined as "the study of distribution of dependent variables (e.g., groundwater elevations in a groundwater model) in response to changes in the distribution of independent variables, initial conditions, boundary conditions, and physical parameters" (AWWA, 2001). In general, a sensitivity analysis of an integrated groundwater and surface water model is performed for the following purposes:

- To test the robustness and stability of the model by establishing tolerance within which the model parameters can vary without significantly changing the model results;
- To understand the impact of inaccuracies in input data on model results (e.g., how model results can change because of a 10% error in the estimation of agricultural pumping); and
- To develop an understanding of the relative sensitivity of the components of the hydrologic cycle and data, so that an effective data collection and monitoring plan can be developed.

A sensitivity analysis was performed using the ESJWRM to assess the sensitivity of model results to specific model parameters and input data. Two different metrics were selected to measure the sensitivity of the ESJWRM. A sensitivity metric is a single number derived from the ESJWRM results and has a unique value for each model run corresponding to a given set of data or parameter value. The sensitivity metrics used here:

- Average groundwater elevation in the study areas, and
- Average root mean square (RMS) error aggregated from selected calibration wells.

Average groundwater elevation in the study areas is defined as a three-way average of simulated groundwater elevations at model nodes. The average is taken over the model layers, model nodes, and time.

This can be mathematically expressed by:

$$\overline{H} = \frac{1}{M}\sum_{K=1}^{M} H_k$$

Such that,

$$H_k = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{1}{L}\sum_{j=1}^{L} h_j\right]_i^k$$

Where,

M total number of simulation time steps,

H_k average head in the model area at k-th time step,

N number of model nodes,

L number of model layers in aquifer,

H_j groundwater elevation at layer j, and

i, j, k are indices for node, layer, and time, respectively.

The average RMS error at selected calibration wells is defined as the average of individual RMS error at each calibration well. The RMS error at a calibration well is defined as follows:

$$RMS_w = \sqrt{\left\{\frac{1}{N}\sum_{k=1}^{N_0}\left[h_{k,w}^0 - h_{k,w}^s\right]^2\right\}}$$

where,

N_0 is the number of observations at well k,

$h_{k,w}^0$ is the observed groundwater elevation at time step k, at well w,

$h_{k,w}^s$ is the simulated groundwater elevation at time step k, at well w.

4.8.1 Sensitivity Analysis Results

Adjustments of aquifer parameters, and the analysis the resulting groundwater head, was performed at all groundwater nodes within the model domain. Similarly, streambed conductance was analyzed at all model stream nodes. Sensitivity analyses were performed for the ESJWRM for the following parameters with results discussed below.

Horizontal Hydraulic Conductivity – The sensitivity of the ESJWRM to changes in hydraulic conductivity are presented in Figure 65 and Figure 66. Reduction of hydraulic conductivity to one-fourth of the calibrated value results in 10.13 feet higher groundwater levels in the model, whereas increases to hydraulic conductivity decrease the average groundwater levels by 2.05 feet. Changes to horizontal hydraulic conductivity have small impacts to RMS values.

Vertical Hydraulic Conductivity – The sensitivity of the ESJWRM to changes in vertical hydraulic conductivity are presented in Figure 67 and Figure 68. Reduction of this parameter to one-fourth of the calibrated value results in 10.34 feet higher groundwater levels in the model, whereas increases to the vertical hydraulic conductivity decrease the average groundwater levels by 4.80 feet. Changes to vertical hydraulic conductivity have very little impact on RMS values.

Specific Storage – The sensitivity of the ESJWRM to changes in specific storage are presented in Figure 69 and Figure 70. Reduction of specific storage to one-fourth of the calibrated value results in approximately 12.64 feet higher groundwater levels in the model, whereas increases to specific storage decrease the average groundwater levels by 1.49 feet. Changes to specific storage have very little impact on RMS values.

Specific Yield – The sensitivity of the ESJWRM to changes in specific yield are presented in Figure 71 and Figure 72. Reduction of specific yield to one-fourth of the calibrated value results in 11.67 feet higher groundwater levels in the model and increases to specific yield increase the average groundwater levels by 1.82 feet. Changes to specific yield have slight impacts to RMS values.

Streambed Conductance – The sensitivity of the ESJWRM to changes in streambed conductance are presented in Figure 73 and Figure 74. Reduction of conductance to one-fourth of the calibrated value results in 8.09 feet higher groundwater levels in the model, whereas increases to conductance decrease the average groundwater levels by 5.09 feet. Changes to streambed conductance have slight impacts to RMS values.

The results of the sensitivity analysis for the ESJWRM indicate that the model is a stable model and the system responds in the expected manner because of changes in aquifer parameters and other input data.

5. CONCLUSIONS AND RECOMMENDATIONS

The ESJWRM, in its current state, is a robust, comprehensive, defensible and well-established model for assessing the water resources in the ESJ Subbasin under historical and projected conditions. The following recommendations are to be considered for further refinements and enhancements of the model:

- **Continue engagement with local groundwater users and managers**. Continue working with local agencies and groundwater users in ESJ Subbasin to further understand the local operations of the groundwater system and improve representation of groundwater users in the ESJWRM.
- **Refinement of boundary flows**. The current boundary flows at the northern, western, and southern boundaries of the model area are based on an older version of the C2VSim with adjustments made based on initial groundwater levels assumed for the beginning of the model (October 1994). DWR is currently in the process of updating the C2VSIm model. Once the latest fine grid version (C2VSim-2015) is publicly available, boundary flows for the ESJ model area should be verified and updated, as necessary.
- **Enhance variability of potential evapotranspiration**. The current version of the IDC used for estimation of the consumptive use of crops in the ESJWRM uses monthly potential ET values that are the same for all years during the model period. Given that there may be annual variability in the potential ET data with possible effects on the annual estimation of crop water demand, it is recommended to use more detailed data with temporal variability to develop a full time series of ET values for use in the model.
- **Refine surface water deliveries in Cosumnes and Modesto Subbasins.** The surface water deliveries in the Cosumnes and Modesto Subbasins are currently at the subregion level and do not have the detailed spatial resolution of other areas within the ESJ Subbasin. This data may need to be verified and updated as modeling efforts in those subbasins progress to meet the requirements of SGMA.
- **Update C2VSim based on ESJWRM**. The fine grid version of C2VSim was developed by the DWR to evaluate the integrated surface water and groundwater conditions at a regional scale; whereas, the ESJWRM is capable of evaluation at the local scale. To increase the accuracy of regional groundwater conditions in the fine grid C2VSim, the County is encouraged to work with DWR to provide data and information for further refinement and update of C2VSim in the ESJWRM area.
- **Develop model update schedule**. In order to keep the ESJWRM up-to-date and current for analysis of water resources and especially for supporting SGMA implementation, it is recommended that the model be updated every 3 to 5 years. A possible update schedule can be kept consistent with the GSP updates, with a lead time of 2 to 3 years relative to the GSP update schedule.

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FIGURES

Figure 1: ESJ Subbasin with County Lines

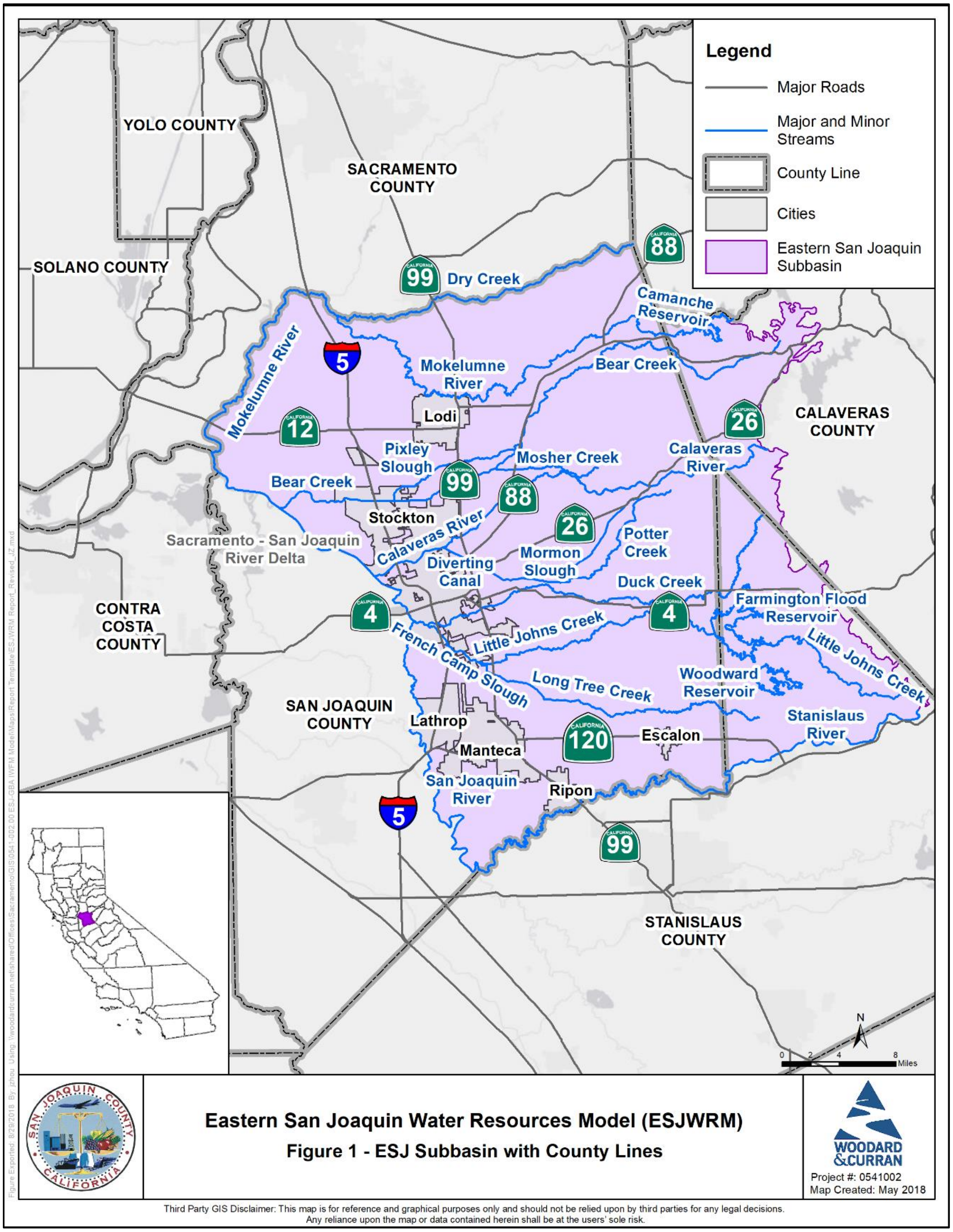

Figure 2: Groundwater Subbasins

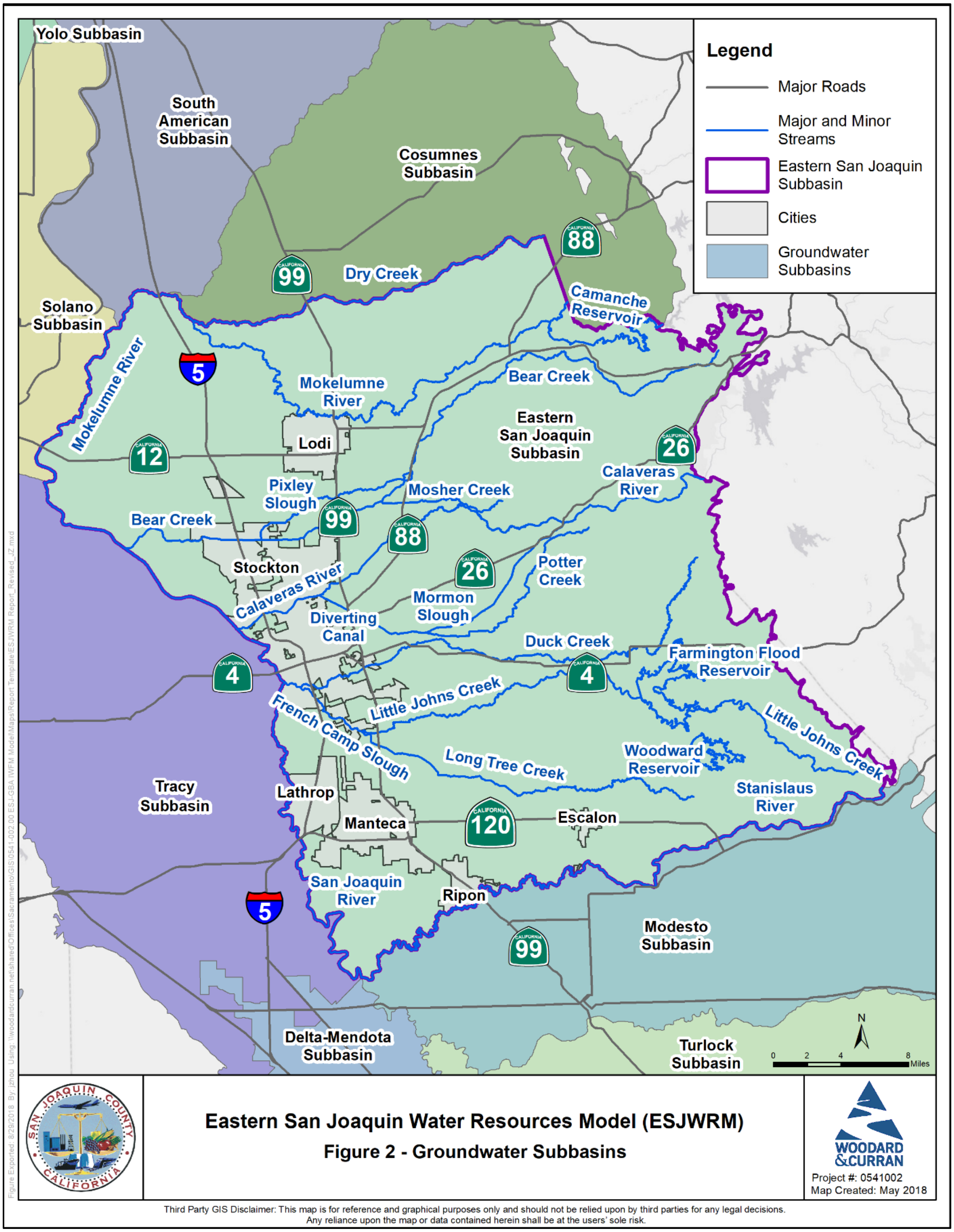

Figure 3a: ESJ Subbasin Major Water Purveyors

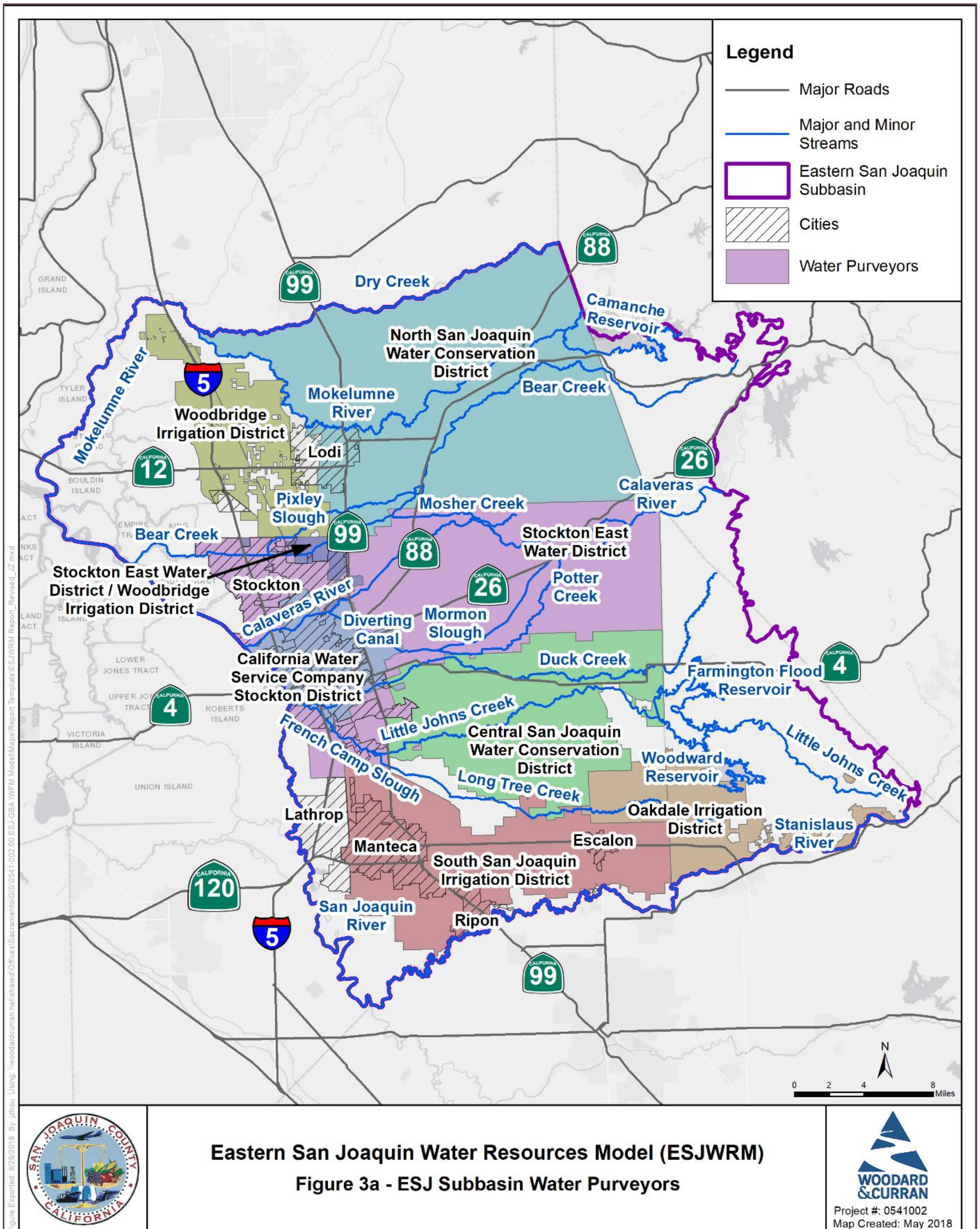

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Figure 3b: ESJ Subbasin Groundwater Sustainability Agencies

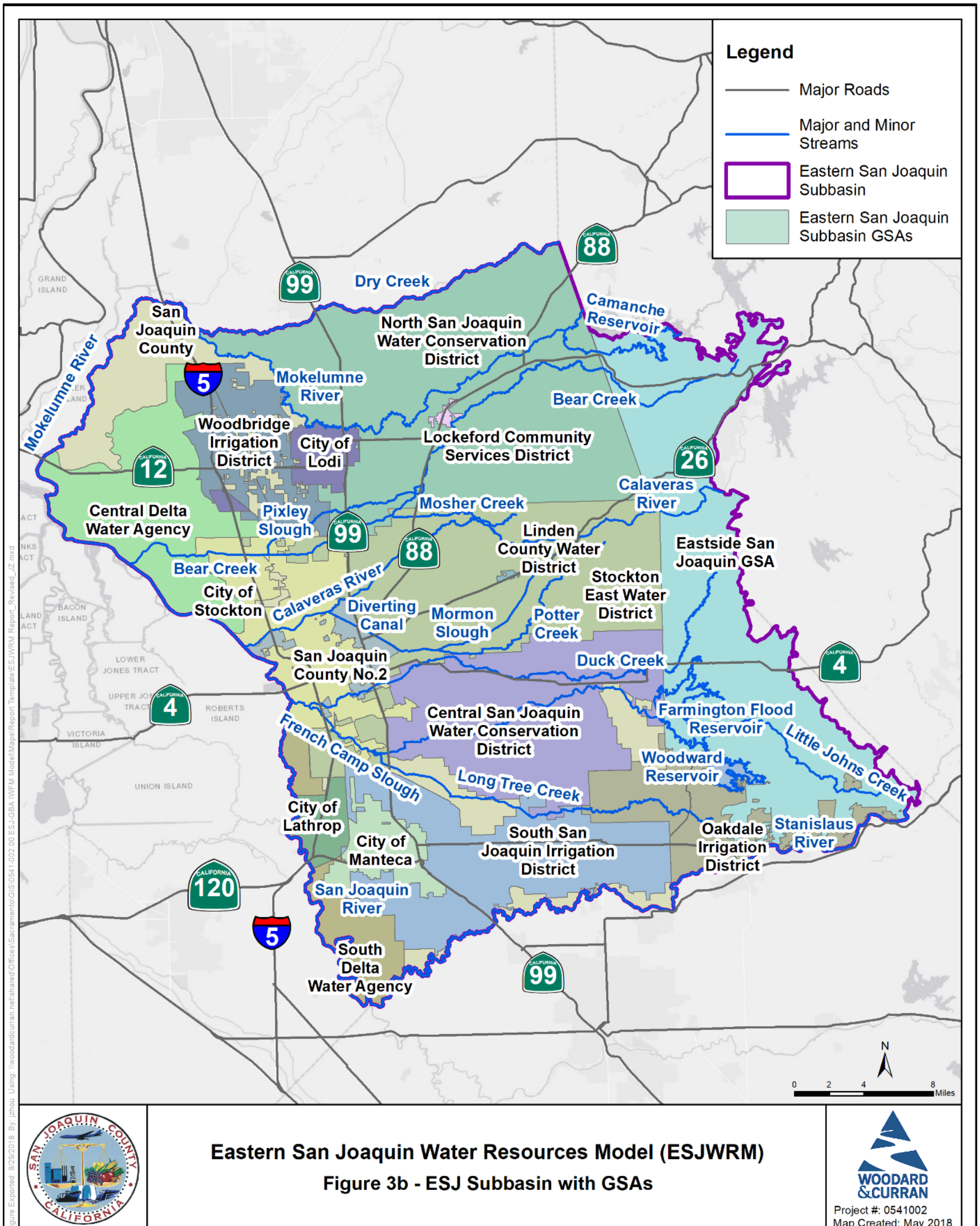

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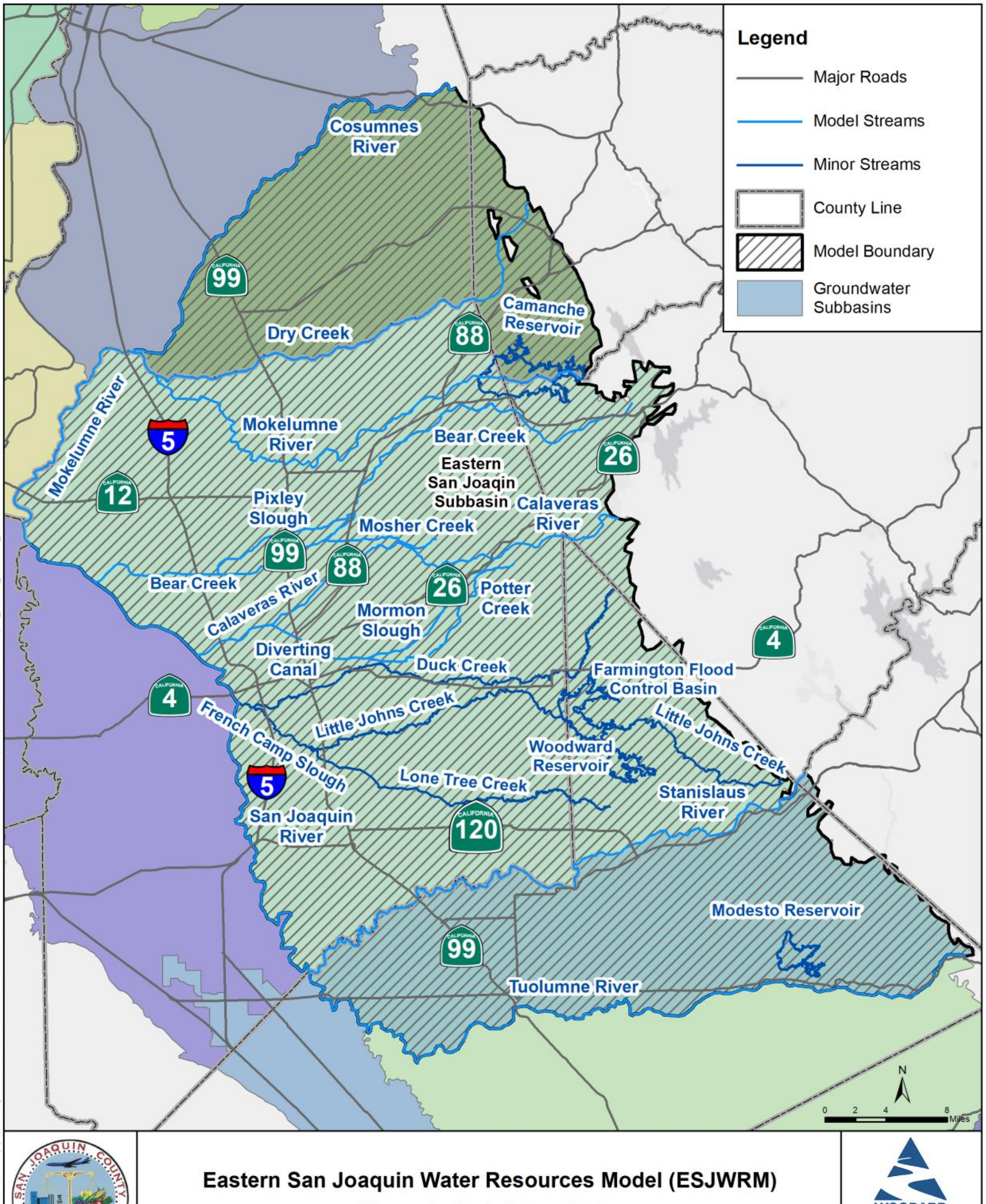
Figure 4: ESJWRM Boundaries



Eastern San Joaquin Water Resources Model (ESJWRM)

Figure 4 - Model Boundaries

WOODARD &CURRAN

Project #: 0541002
Map Created: May 2018

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Figure 5: ESJWRM Grid Development Features

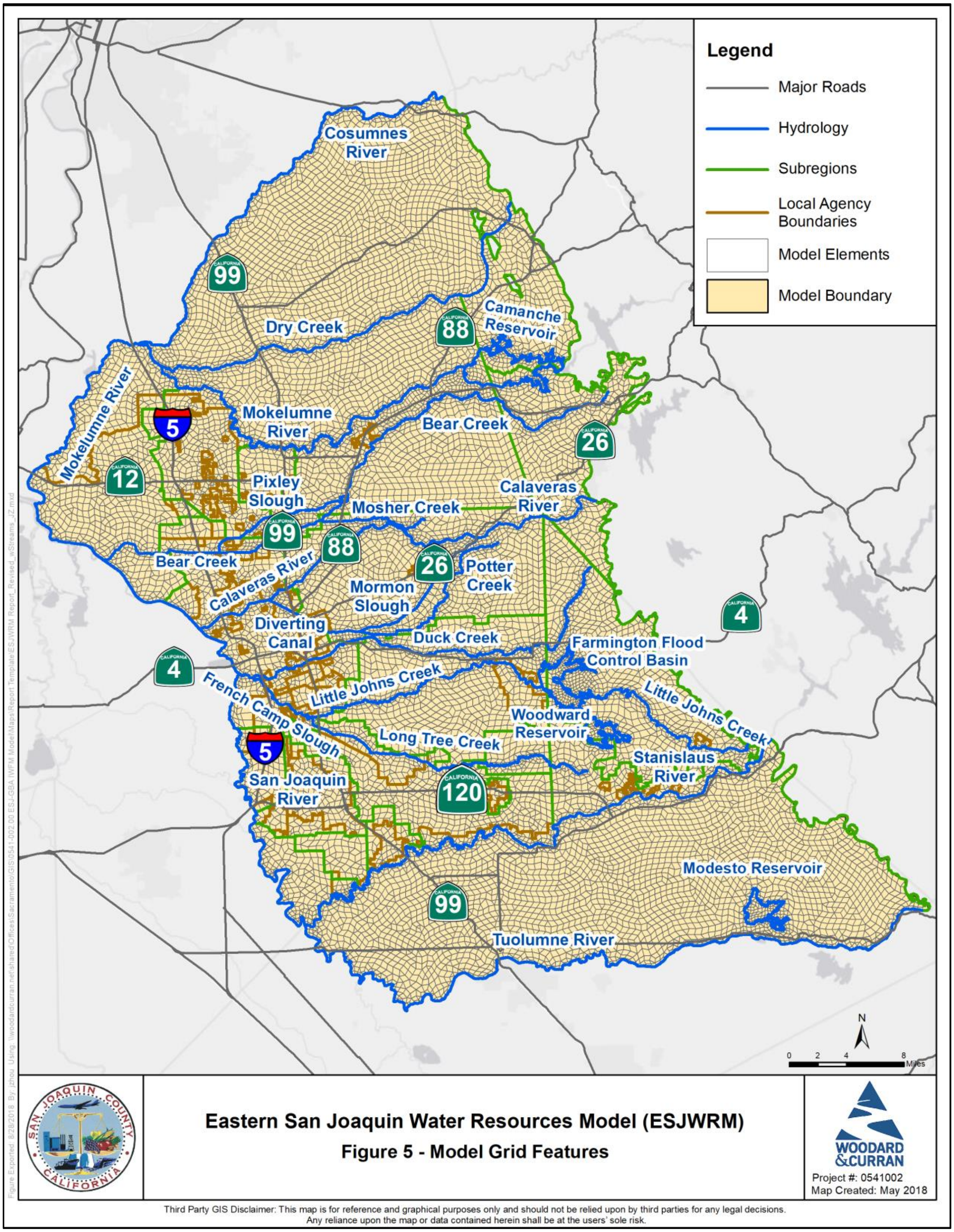

Figure 6: ESJWRM Elements

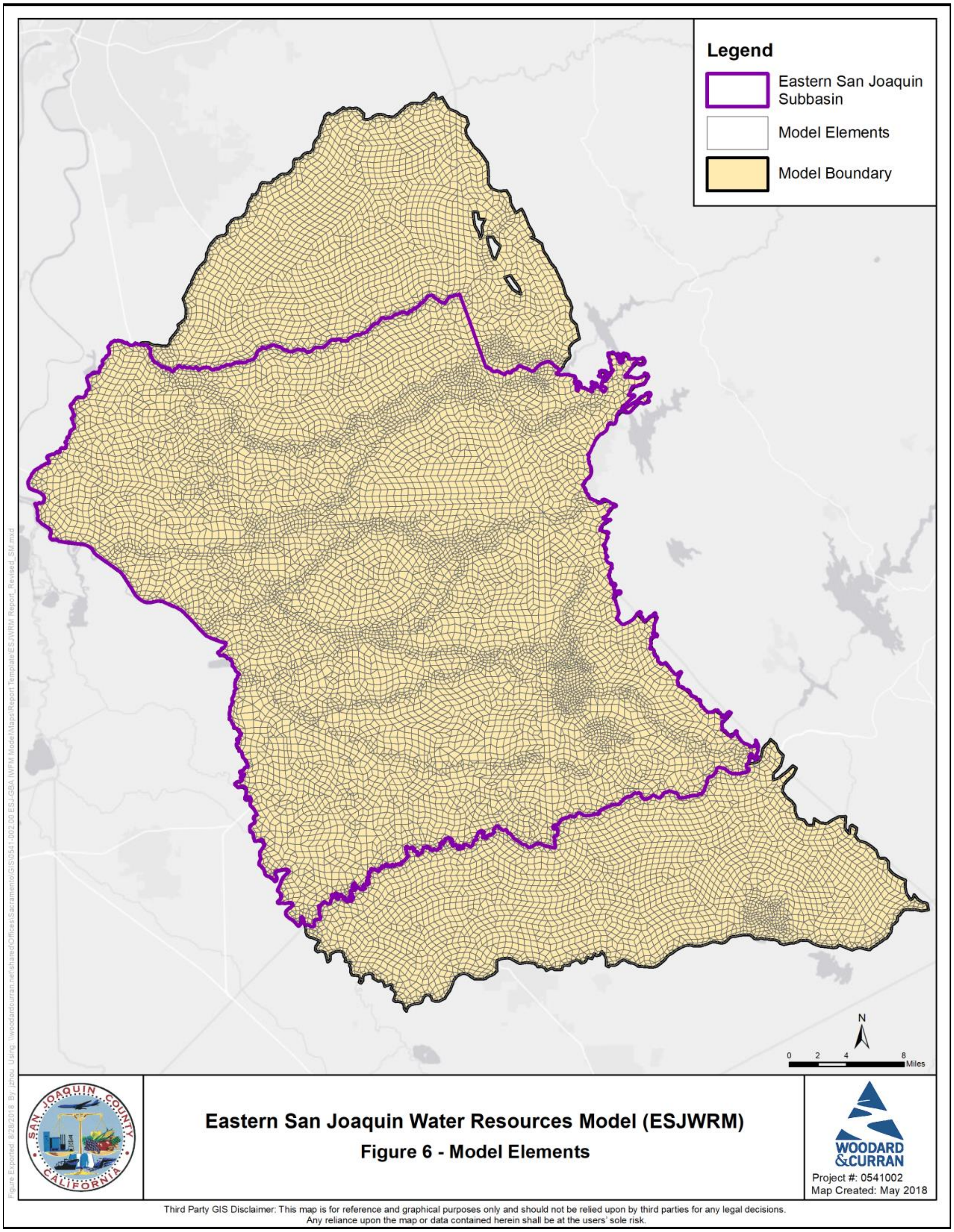

Figure 7: ESJWRM Subregions

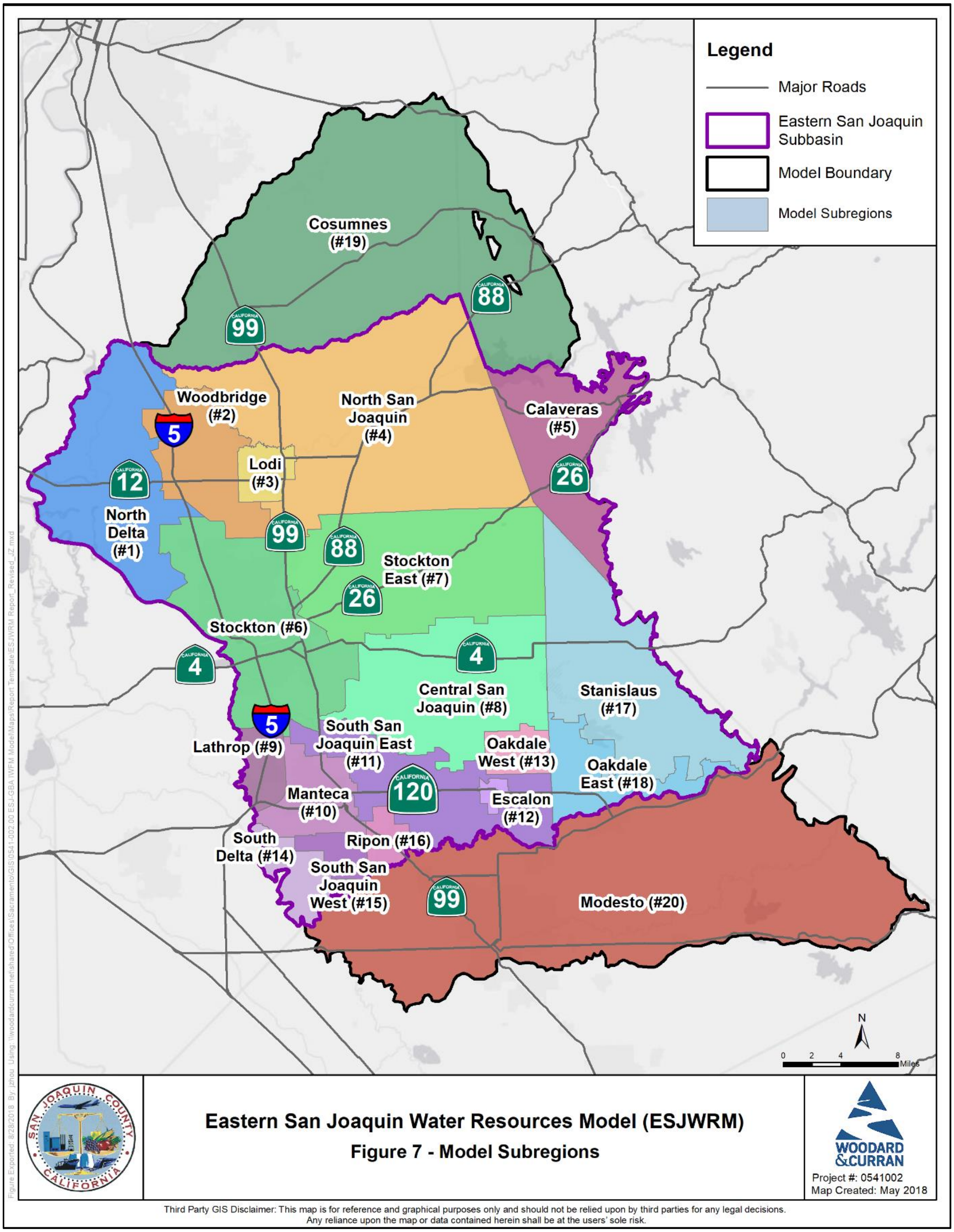

Figure 8: ESJWRM Subareas

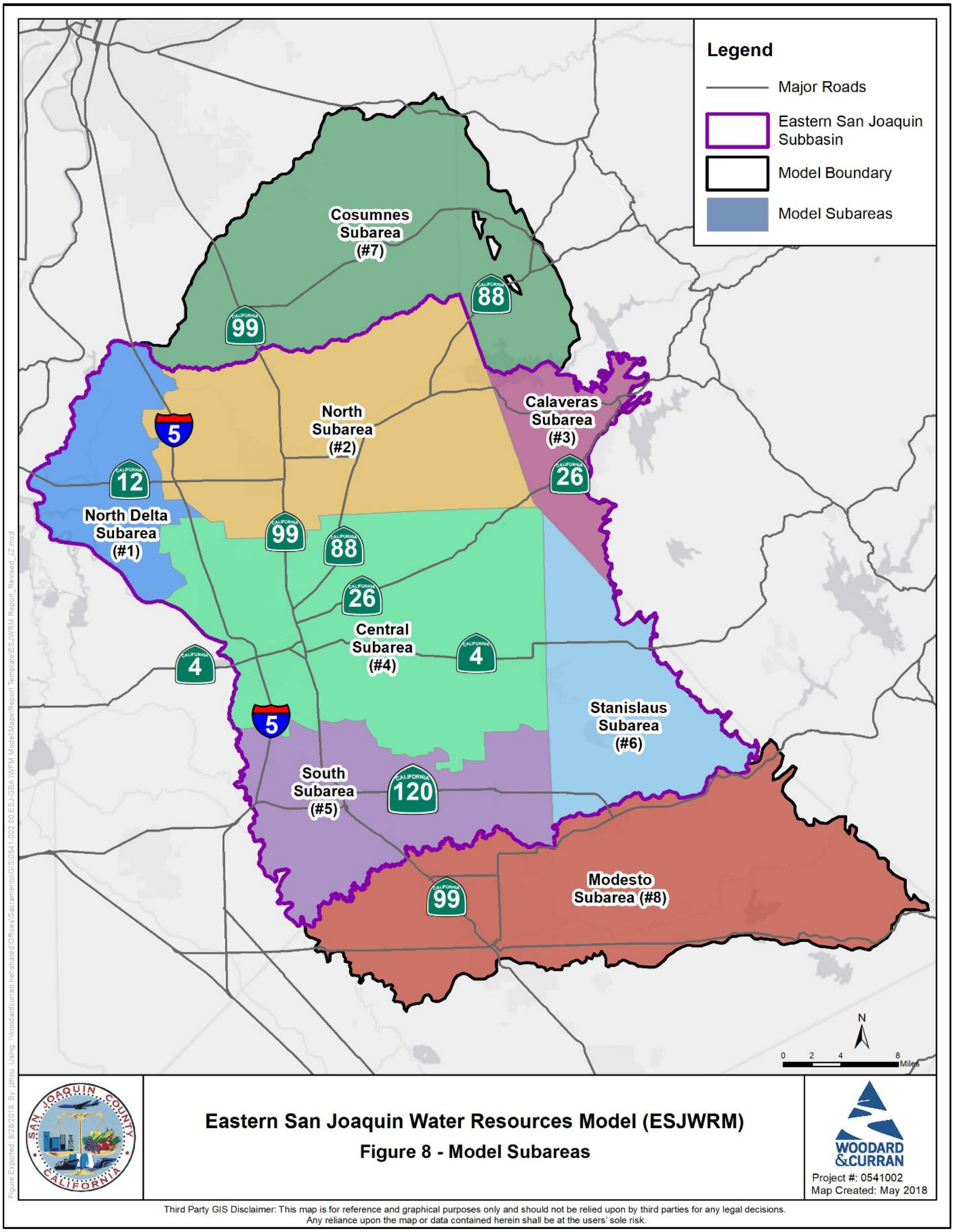

Figure 9: ESJWRM Streams and Stream Inflow Locations

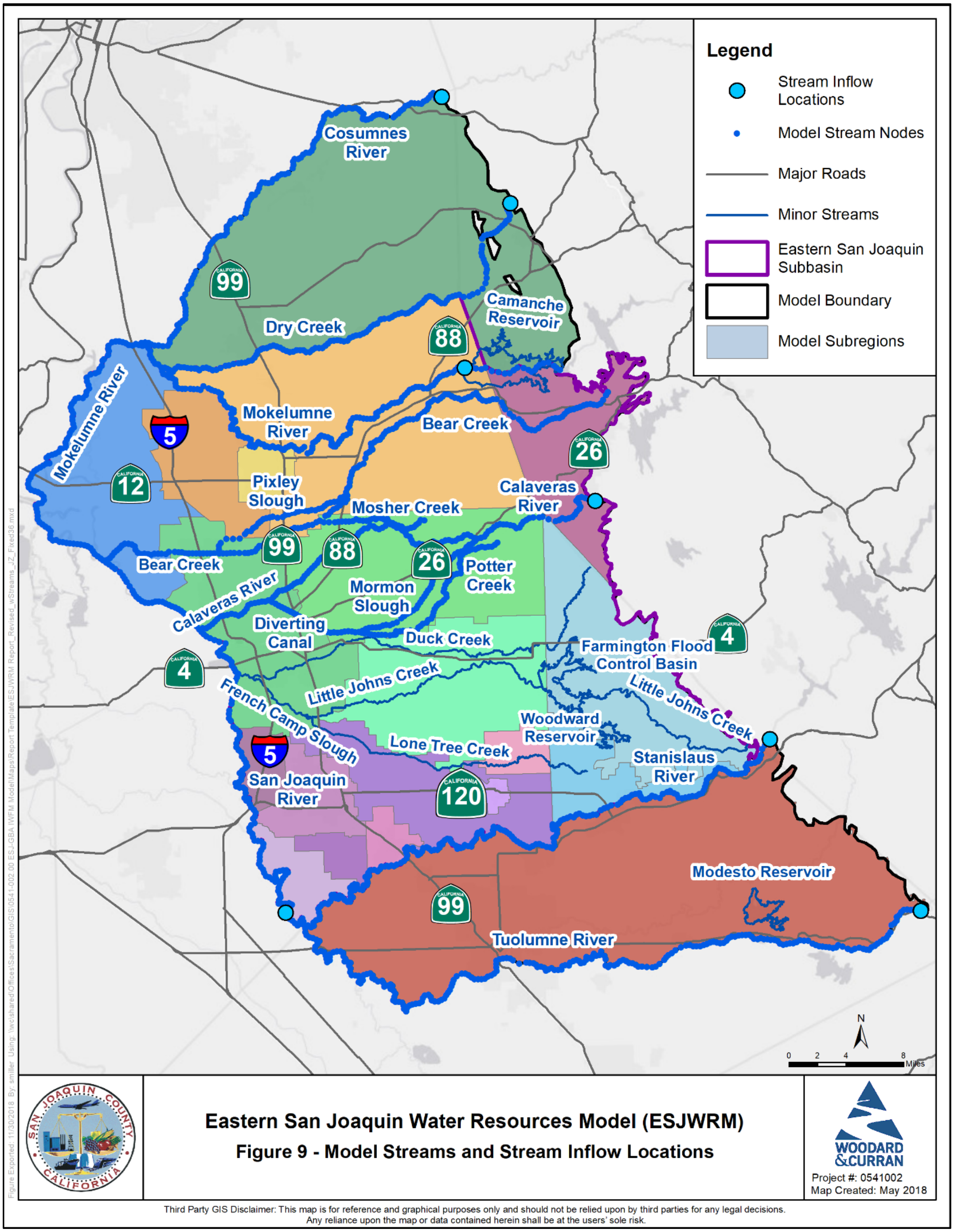

Figure 10: ESJWRM Average Annual Precipitation

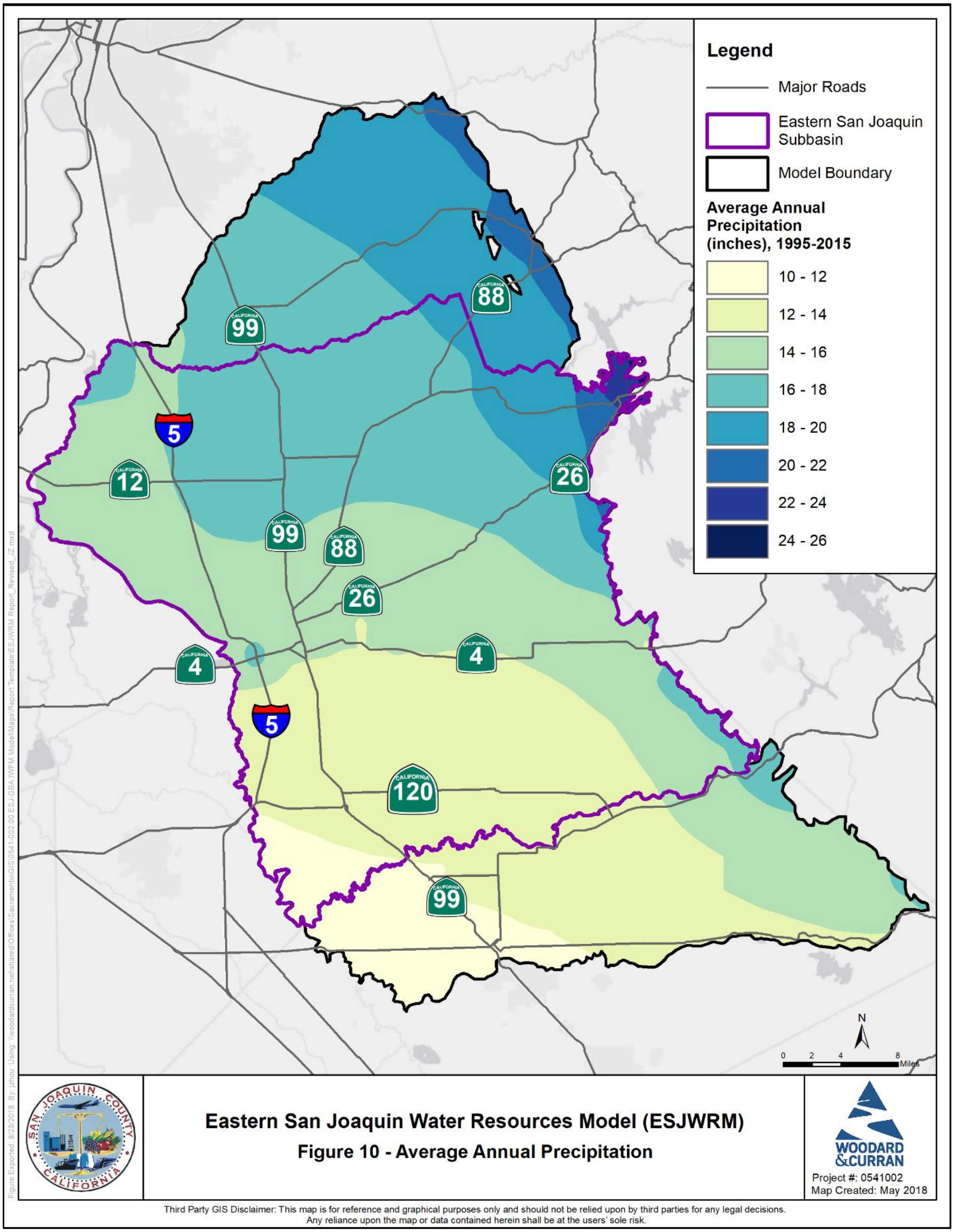

Figure 11: ESJWRM Annual Rainfall

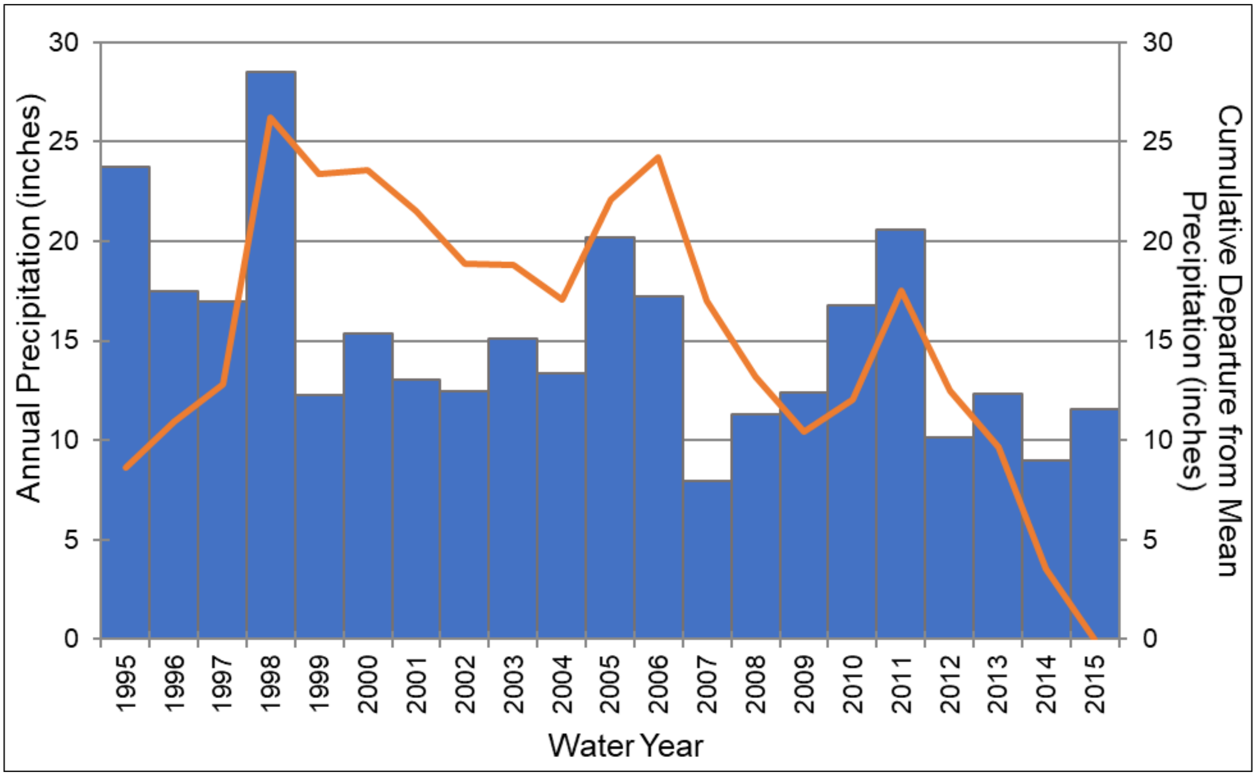

Figure 12: ESJWRM Hydrologic Soil Group

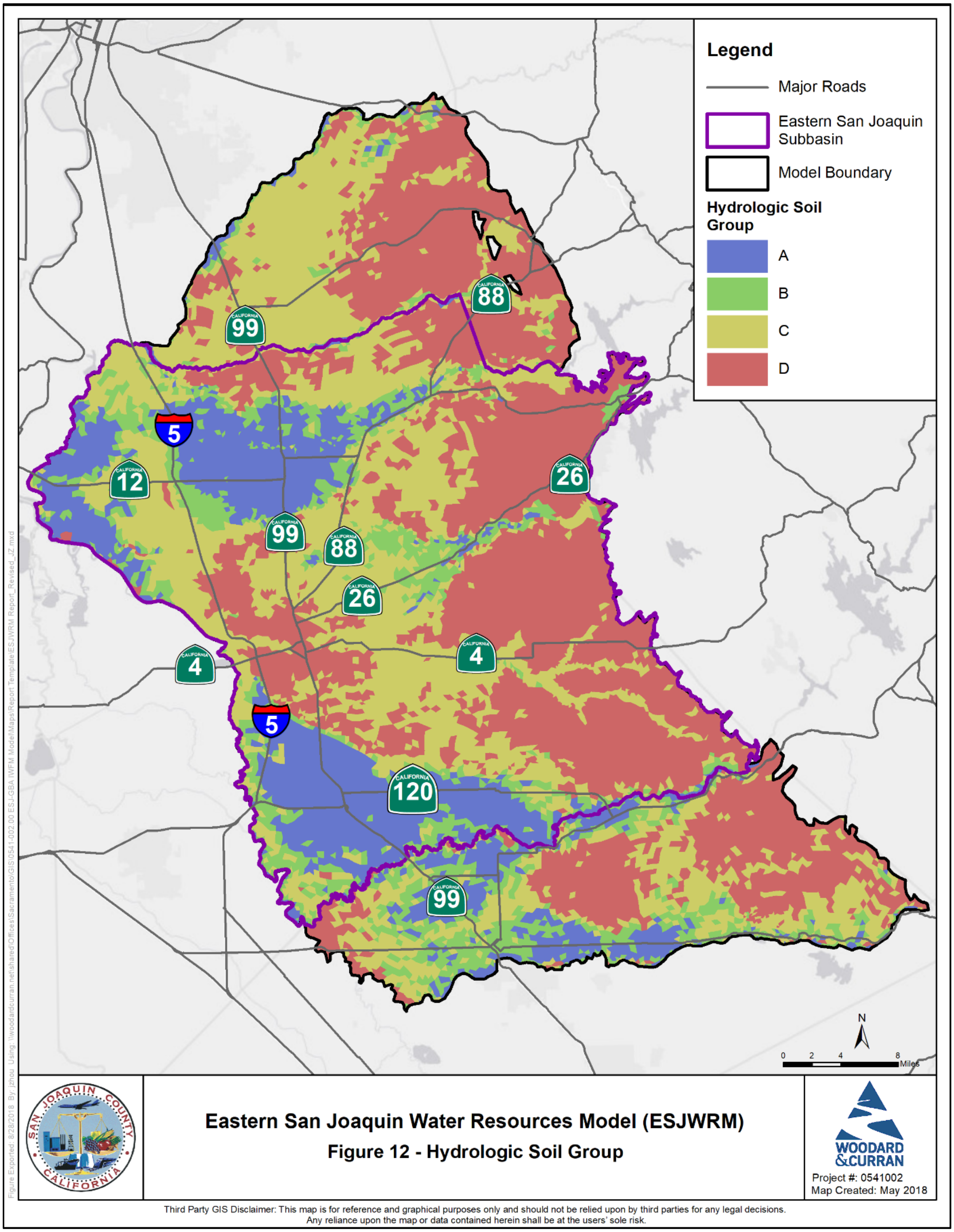

Figure 13: ESJWRM General Land Use in 1995 DWR Land Use Survey

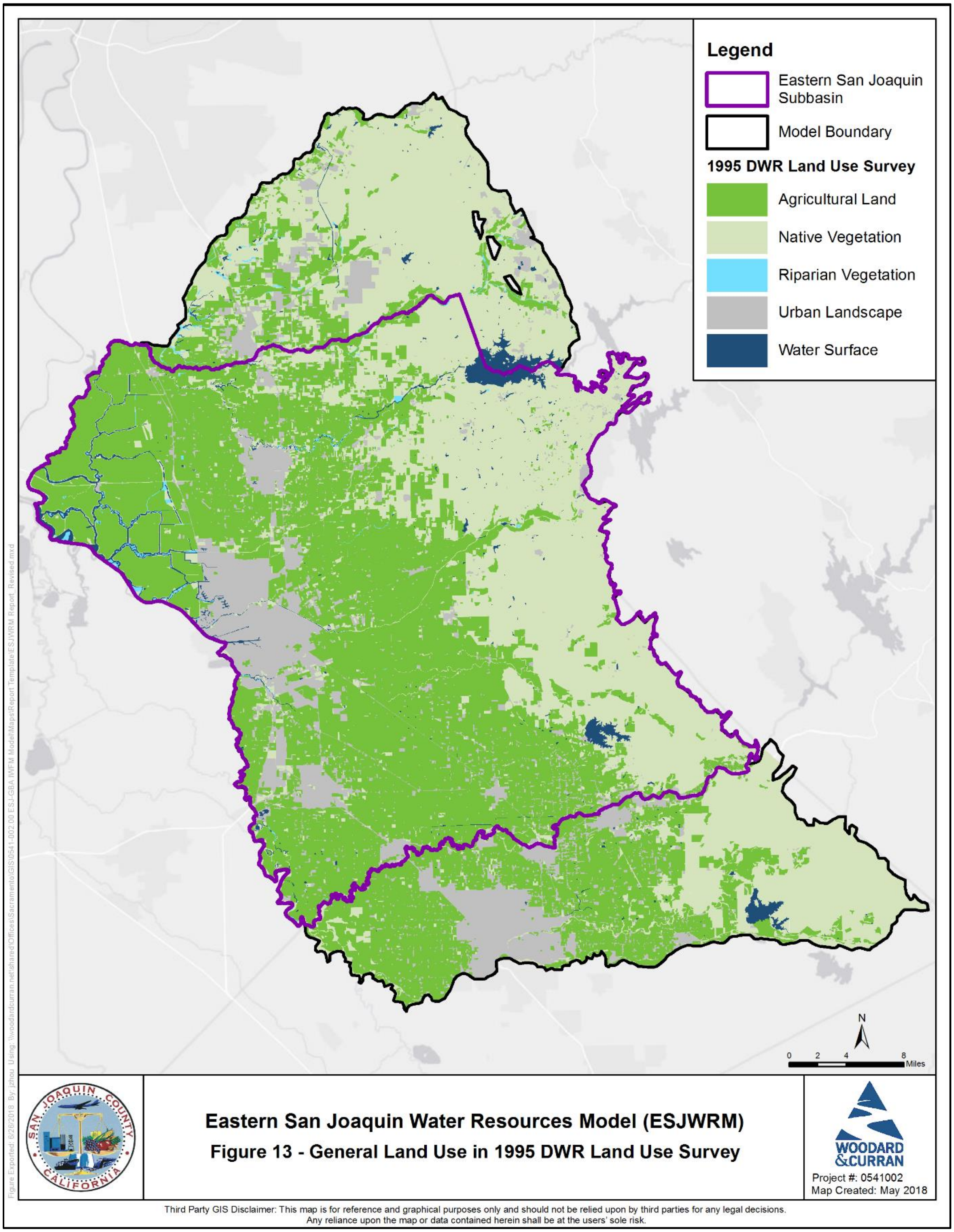

Figure 14: ESJWRM General Land Use in 2015 CropScape

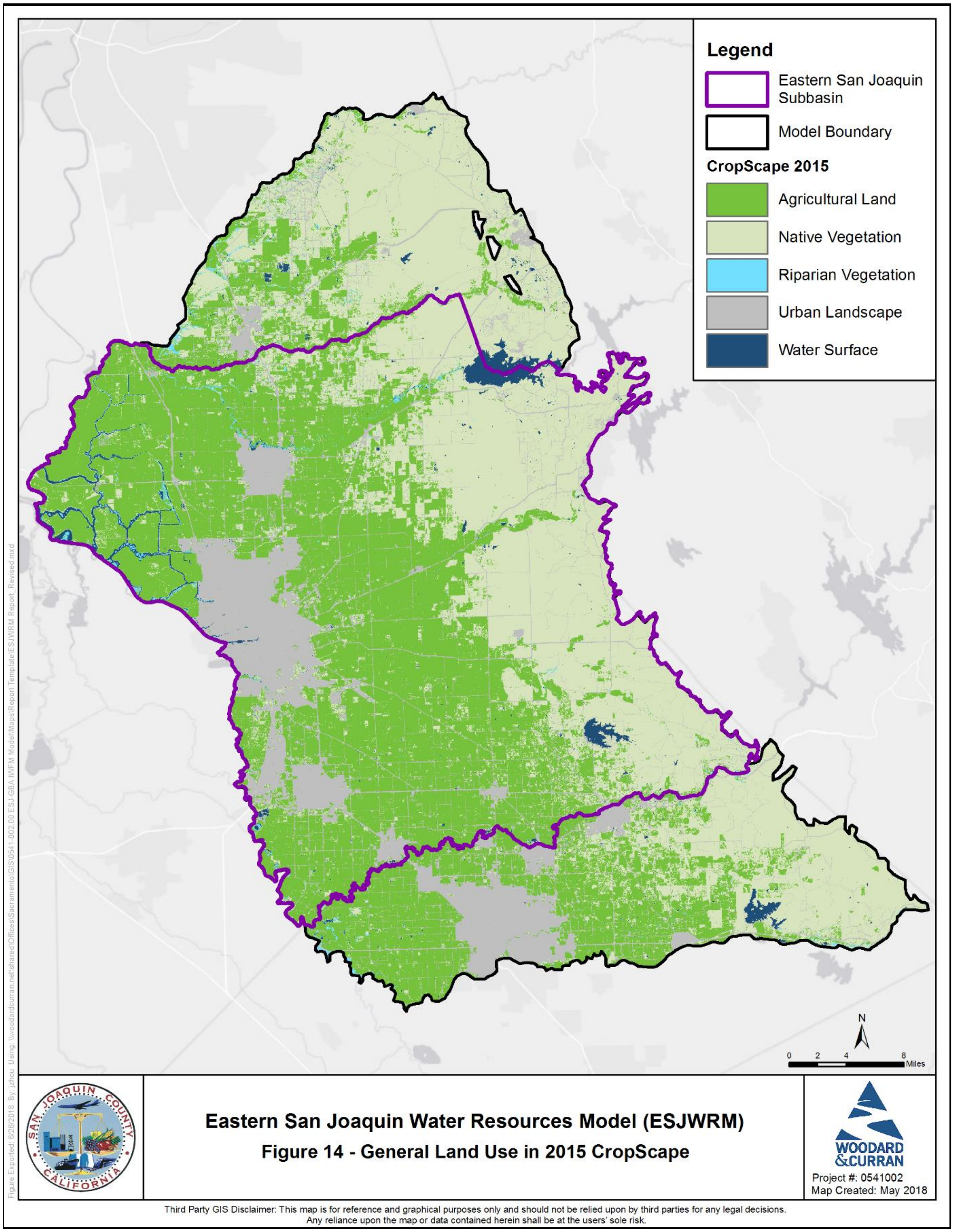

Figure 15: ESJWRM ESJ Subbasin Annual General Land Use

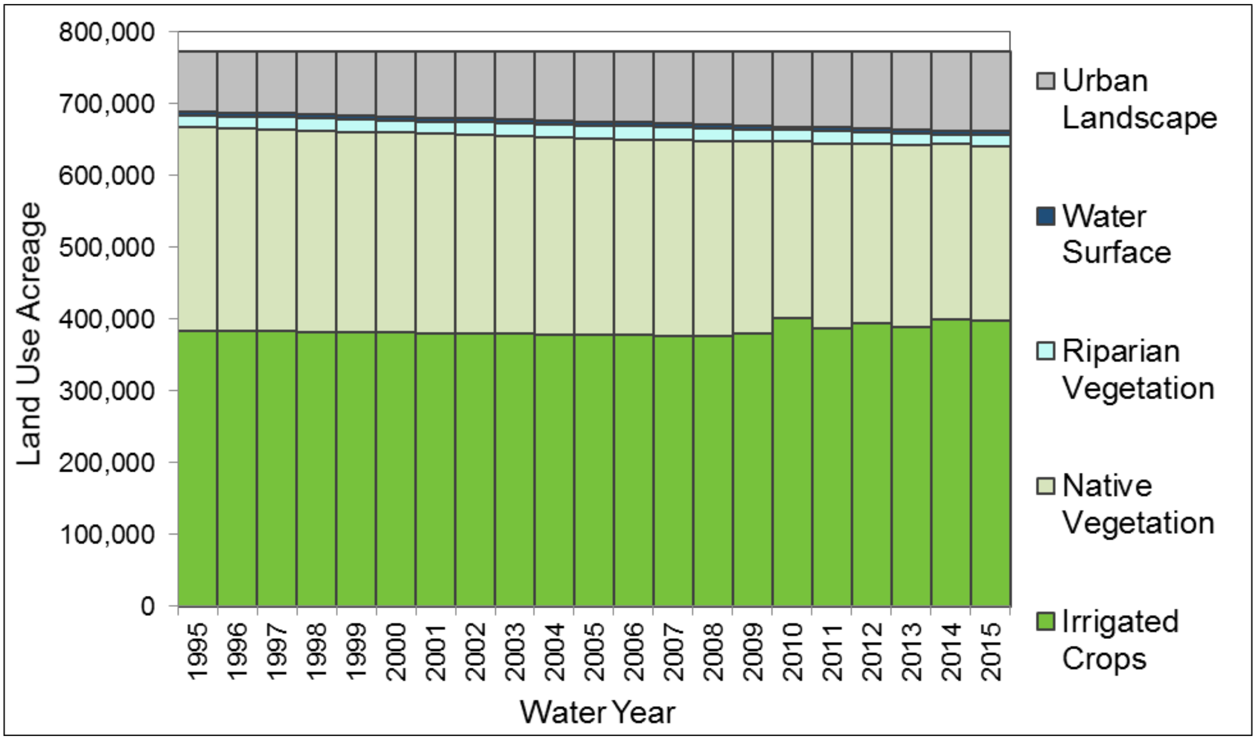

Figure 16: ESJWRM Cropping Pattern in 1995 DWR Land Use Survey

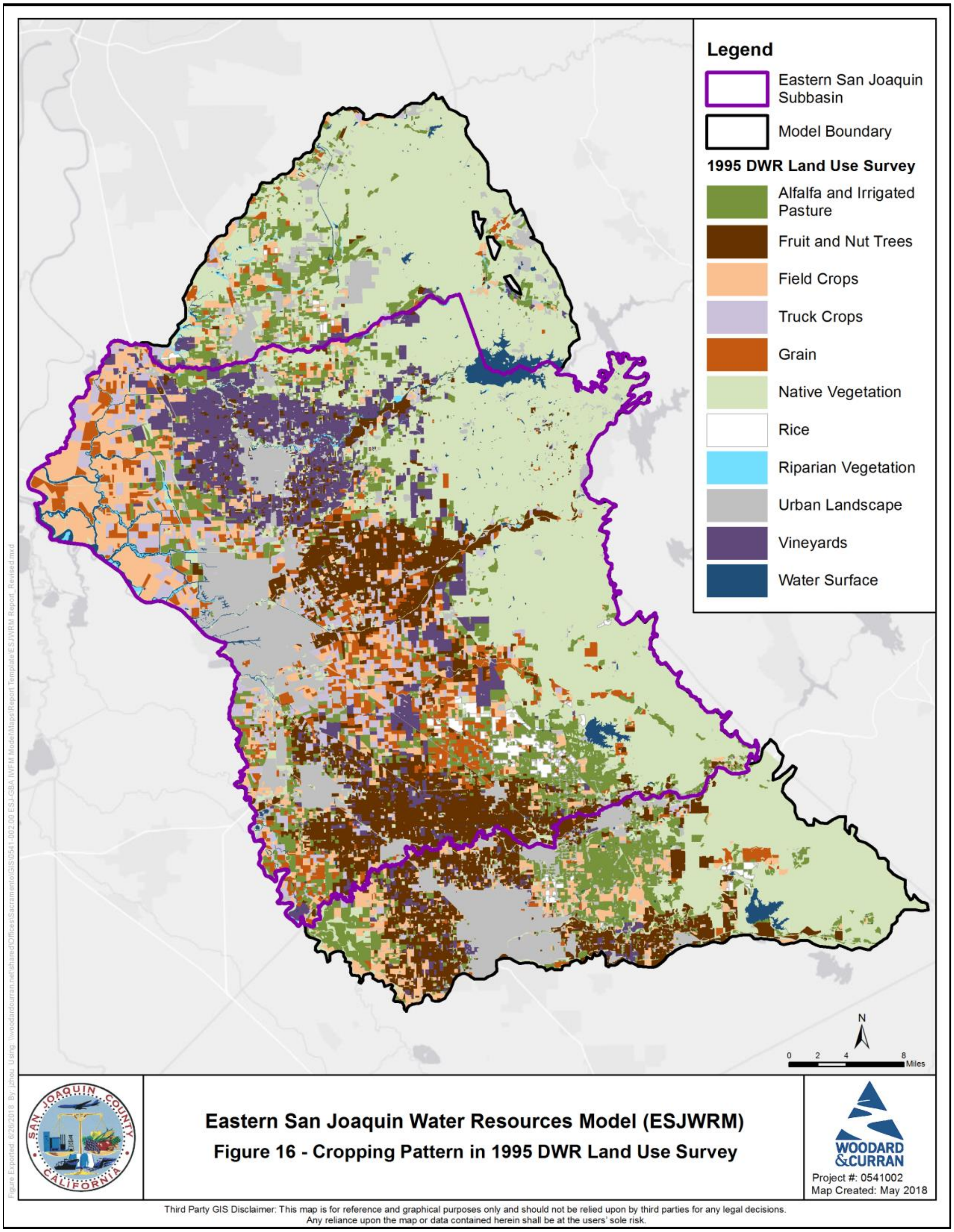

Figure 17: ESJWRM Cropping Pattern in 2014 Land IQ

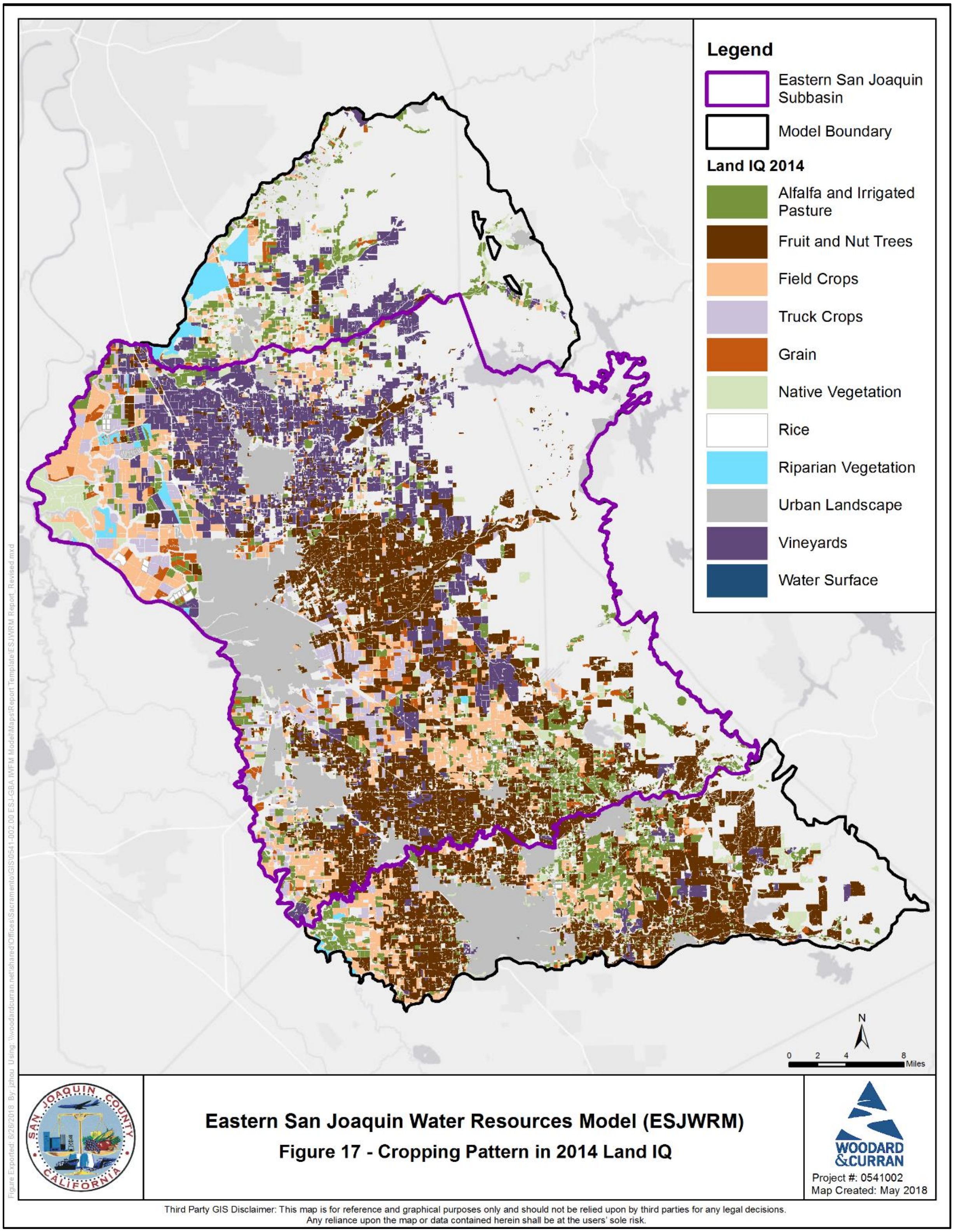

Figure 18: ESJWRM Cropping Pattern in 2015 CropScape

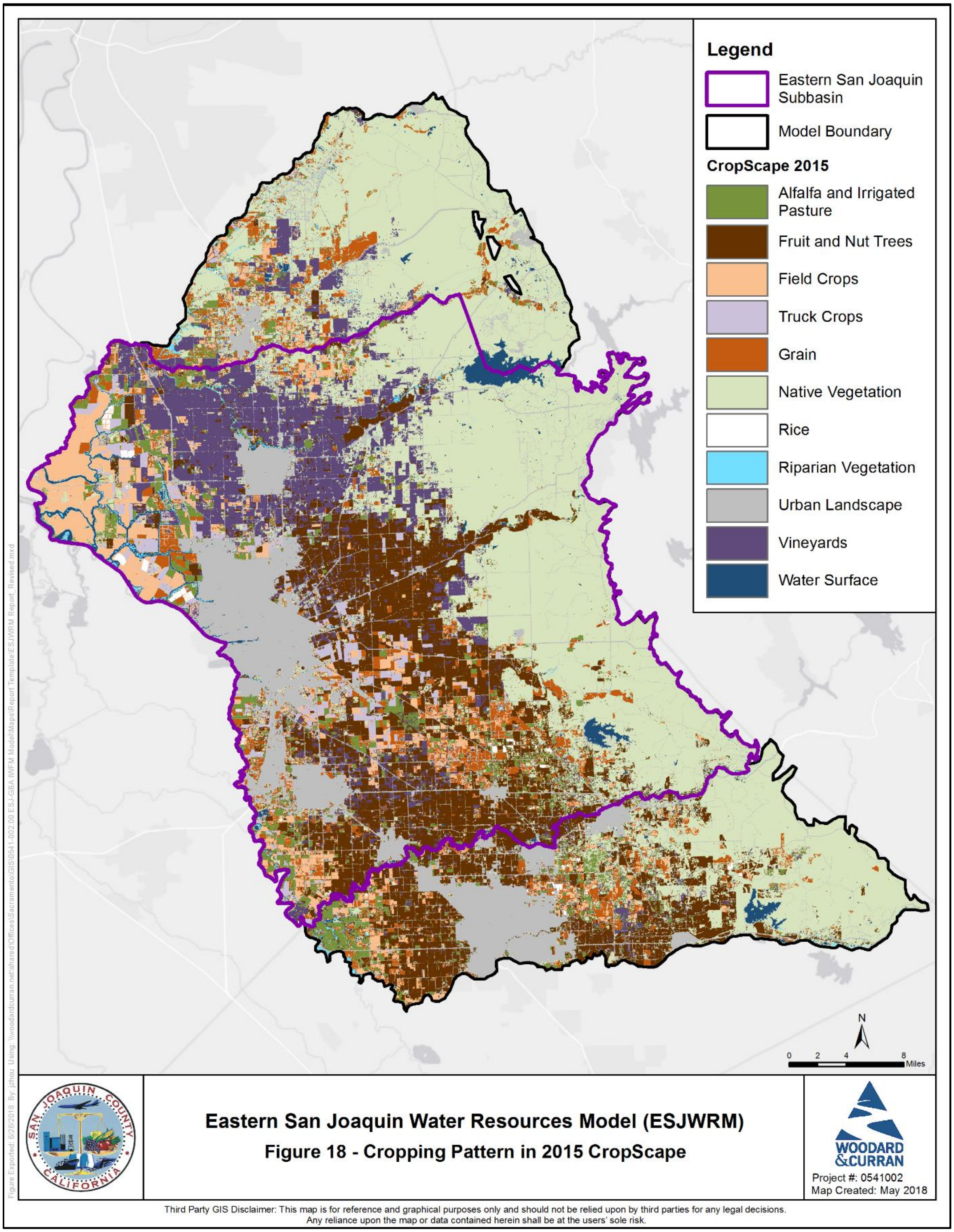

Figure 19a: ESJWRM Annual Cropping Pattern – Eastern San Joaquin Subbasin

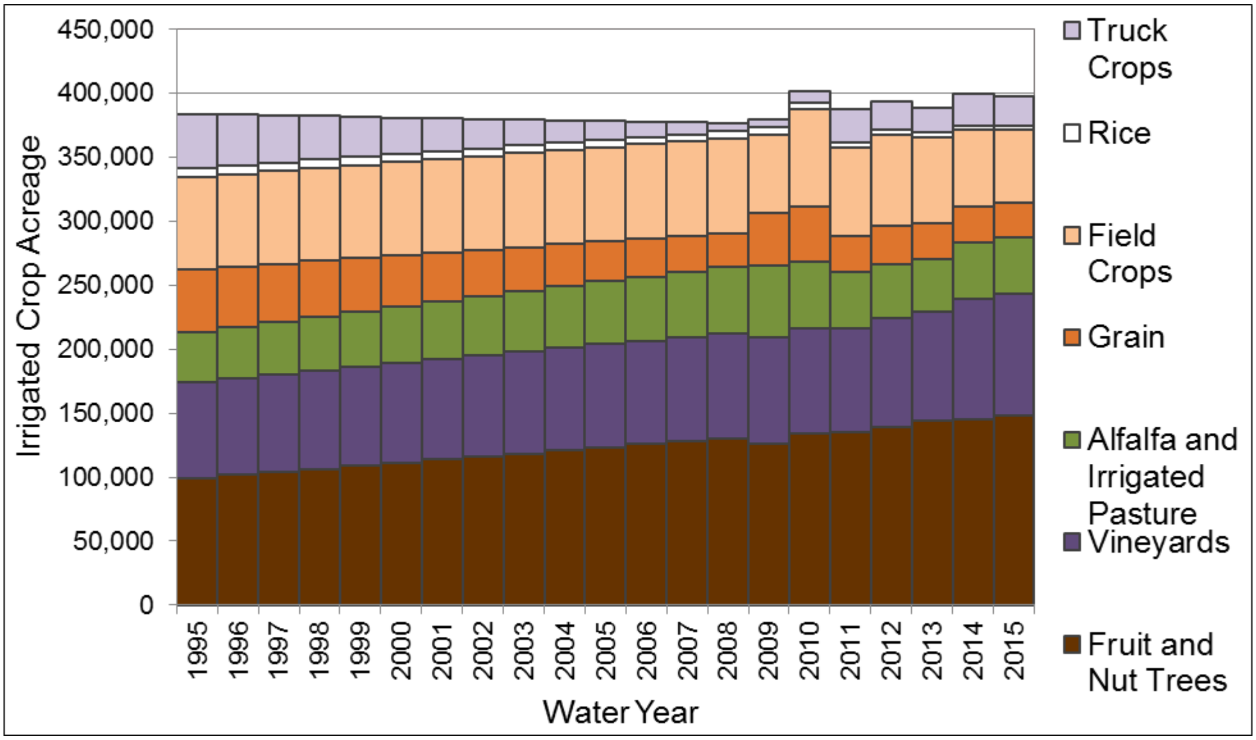

Figure 19b: ESJWRM Annual Cropping Pattern – Subarea 1 (North Delta Subarea)

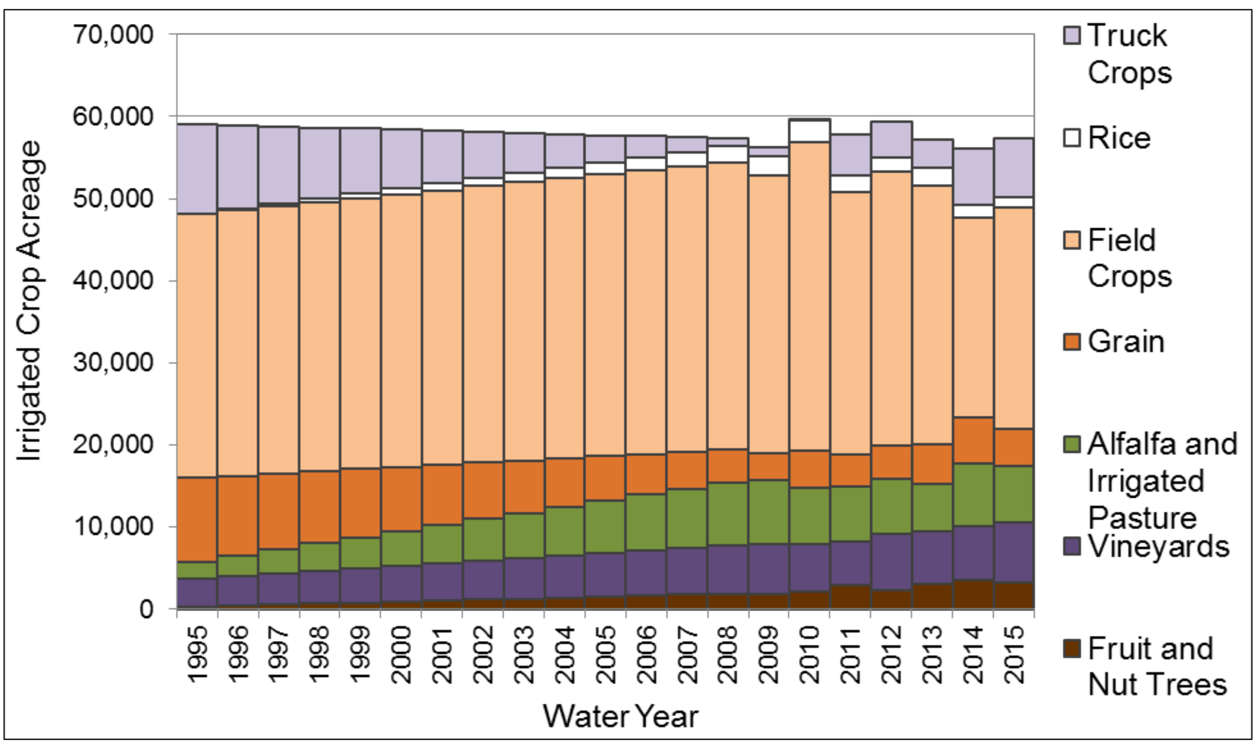

Figure 19c: ESJWRM Annual Cropping Pattern – Subarea 2 (North Subarea)

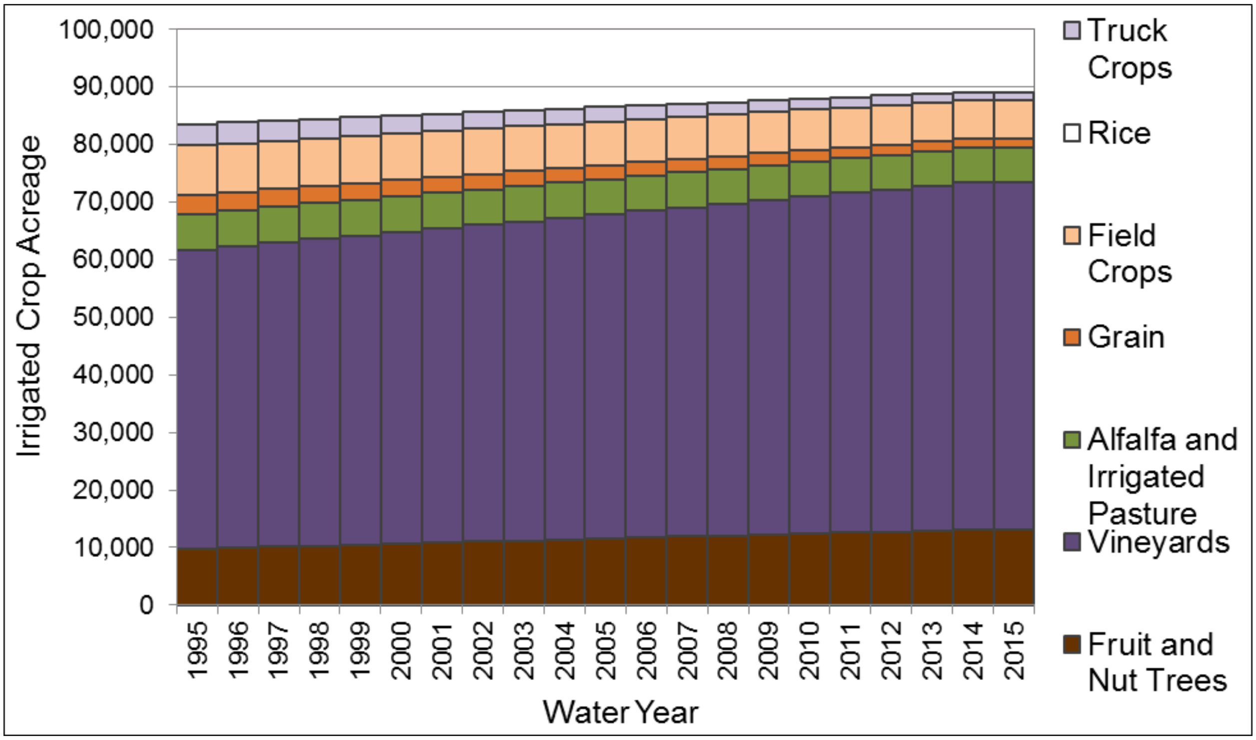

Figure 19d: ESJWRM Annual Cropping Pattern – Subarea 3 (Calaveras Subarea)

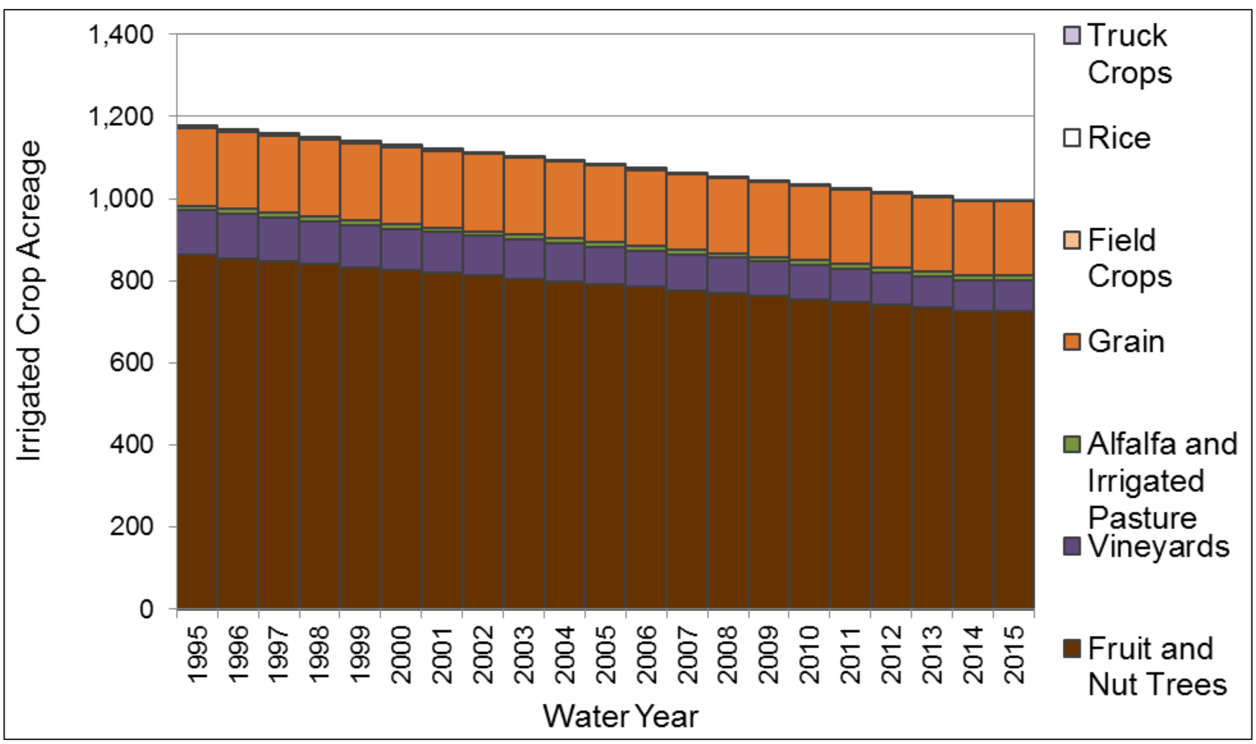

Figure 19e: ESJWRM Annual Cropping Pattern – Subarea 4 (Central Subarea)

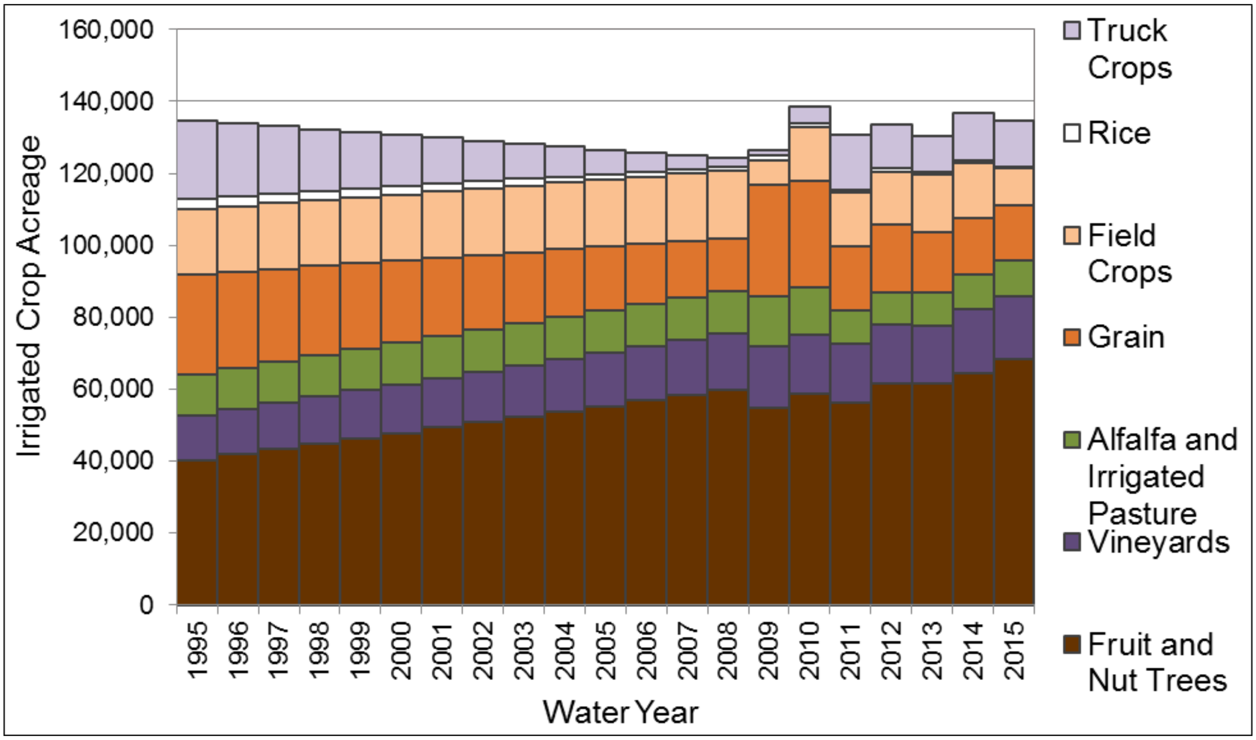

Figure 19f: ESJWRM Annual Cropping Pattern – Subarea 5 (South Subarea)

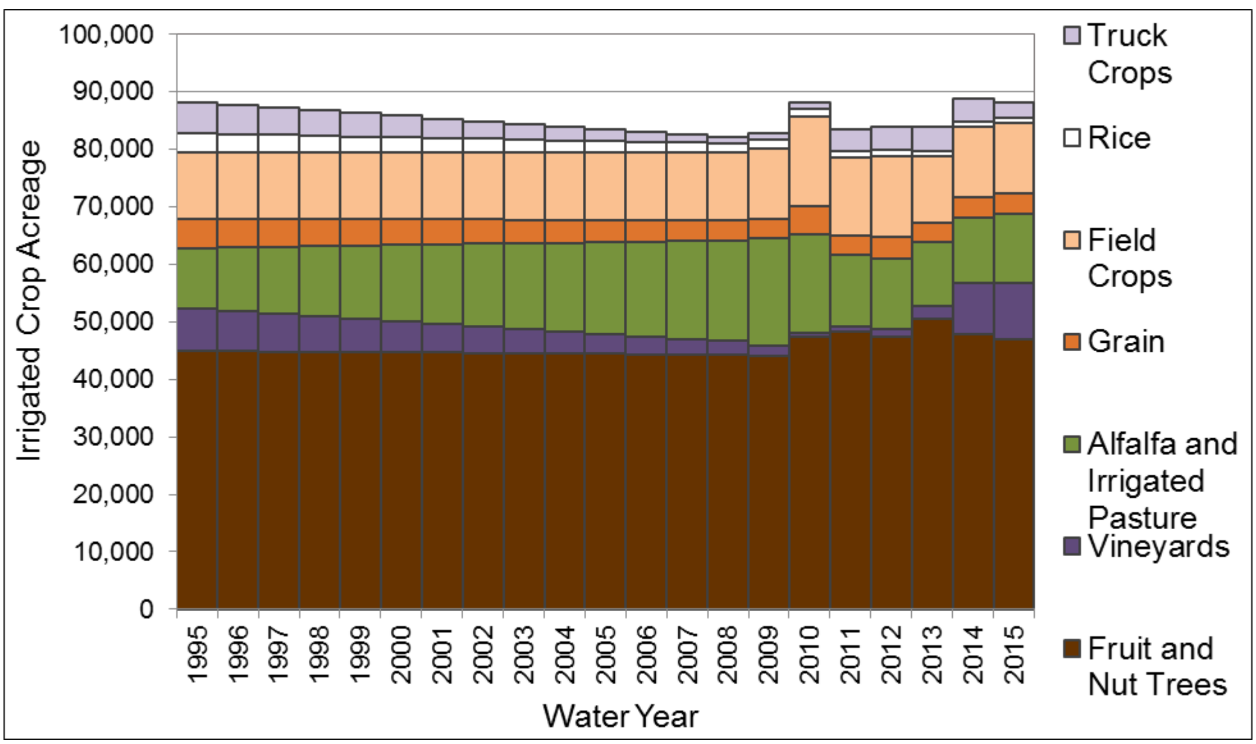

Figure 19g: ESJWRM Annual Cropping Pattern – Subarea 6 (Stanislaus Subarea)

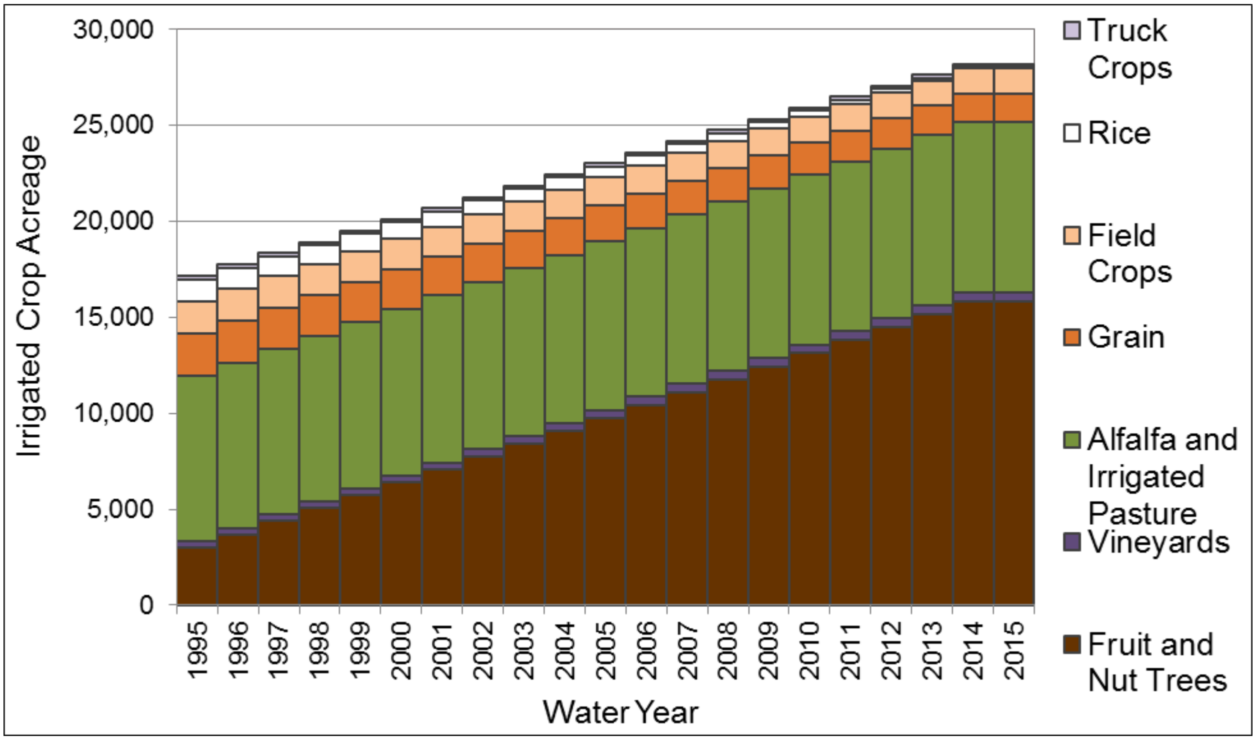

Figure 20: ESJWRM Annual Evapotranspiration

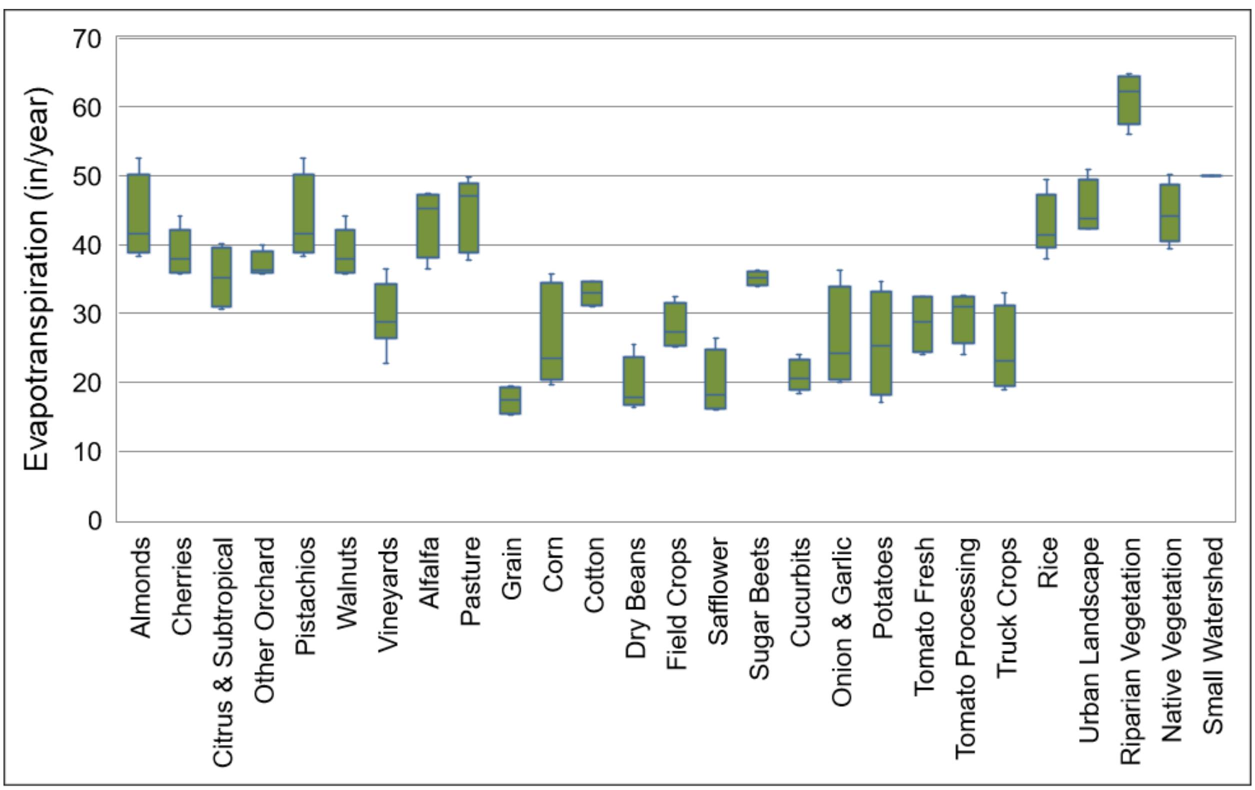

Figure 21: ESJWRM Surface Water Drainage Watersheds

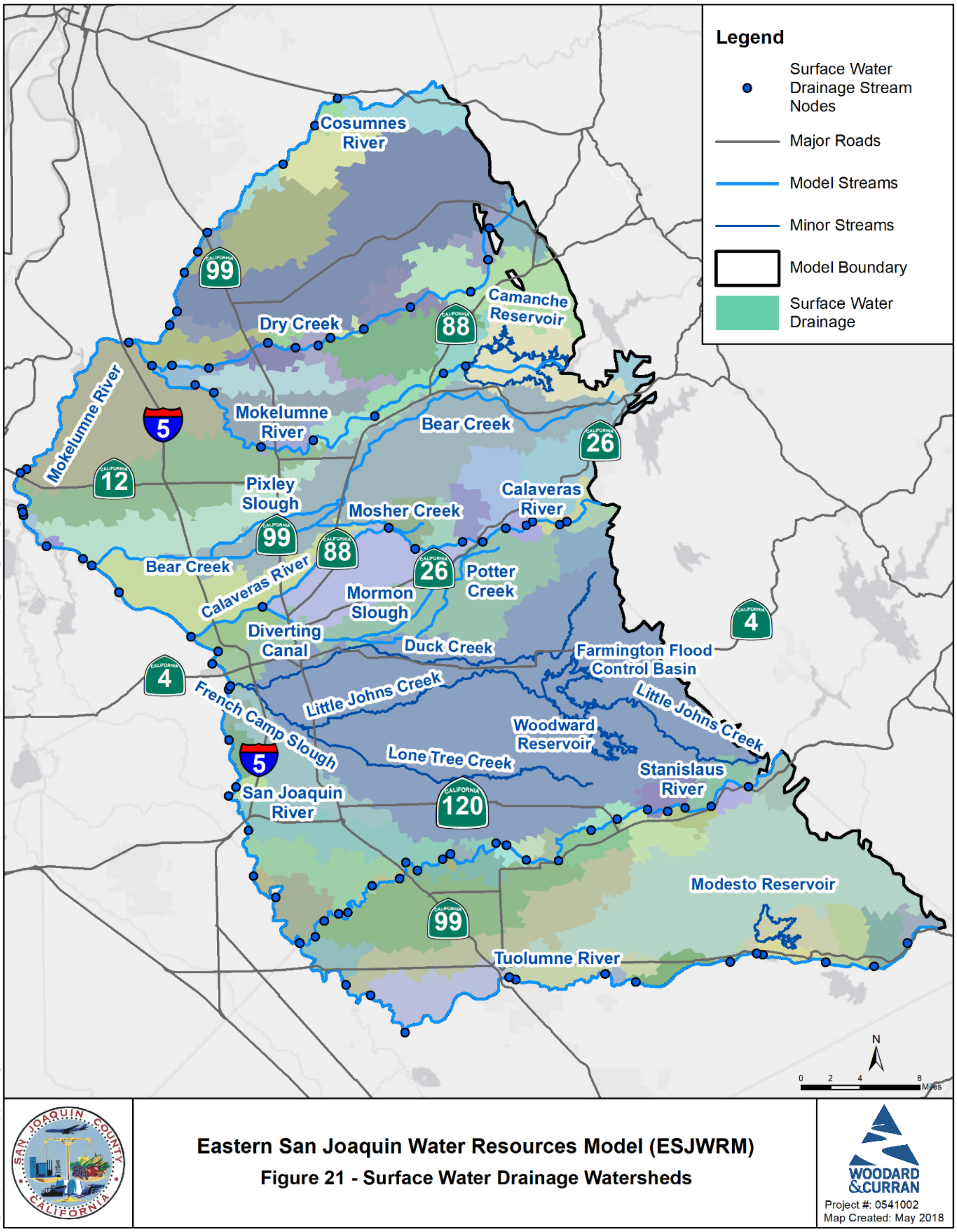

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Figure 22: ESJWRM Ground Surface Elevation

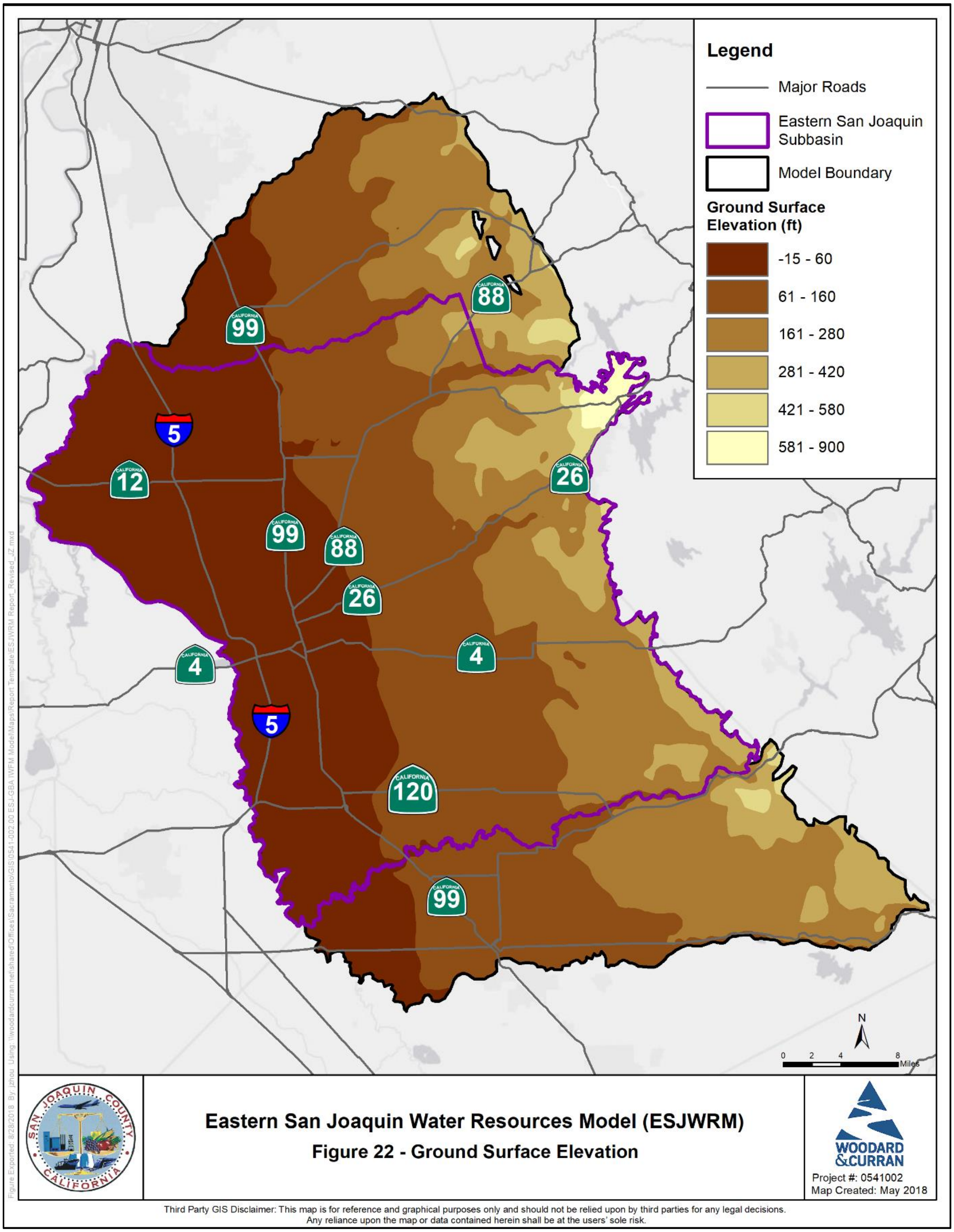


Figure 23: ESJWRM Layer 1 Thickness

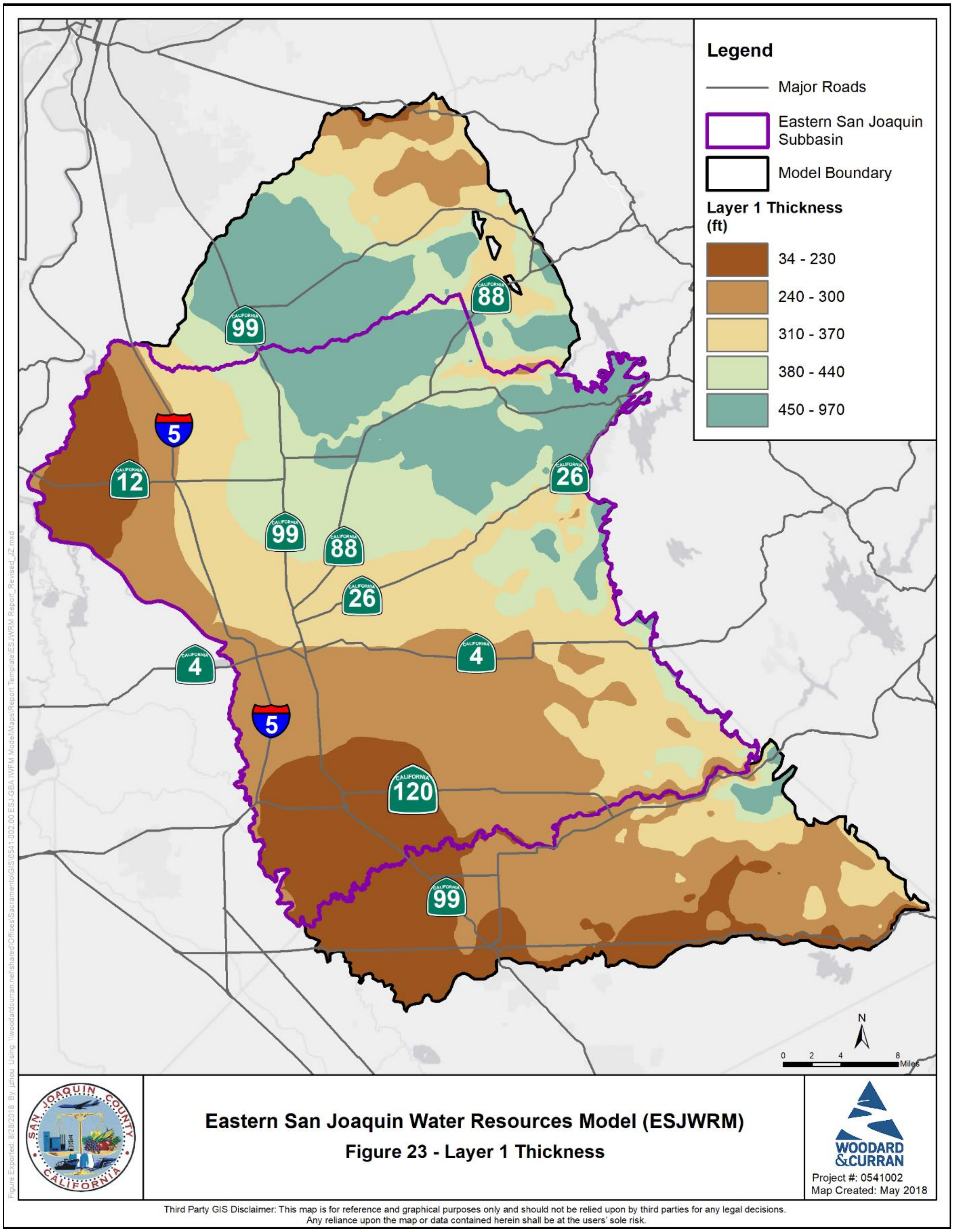


Figure 24: ESJWRM Corcoran Clay Depth to Top

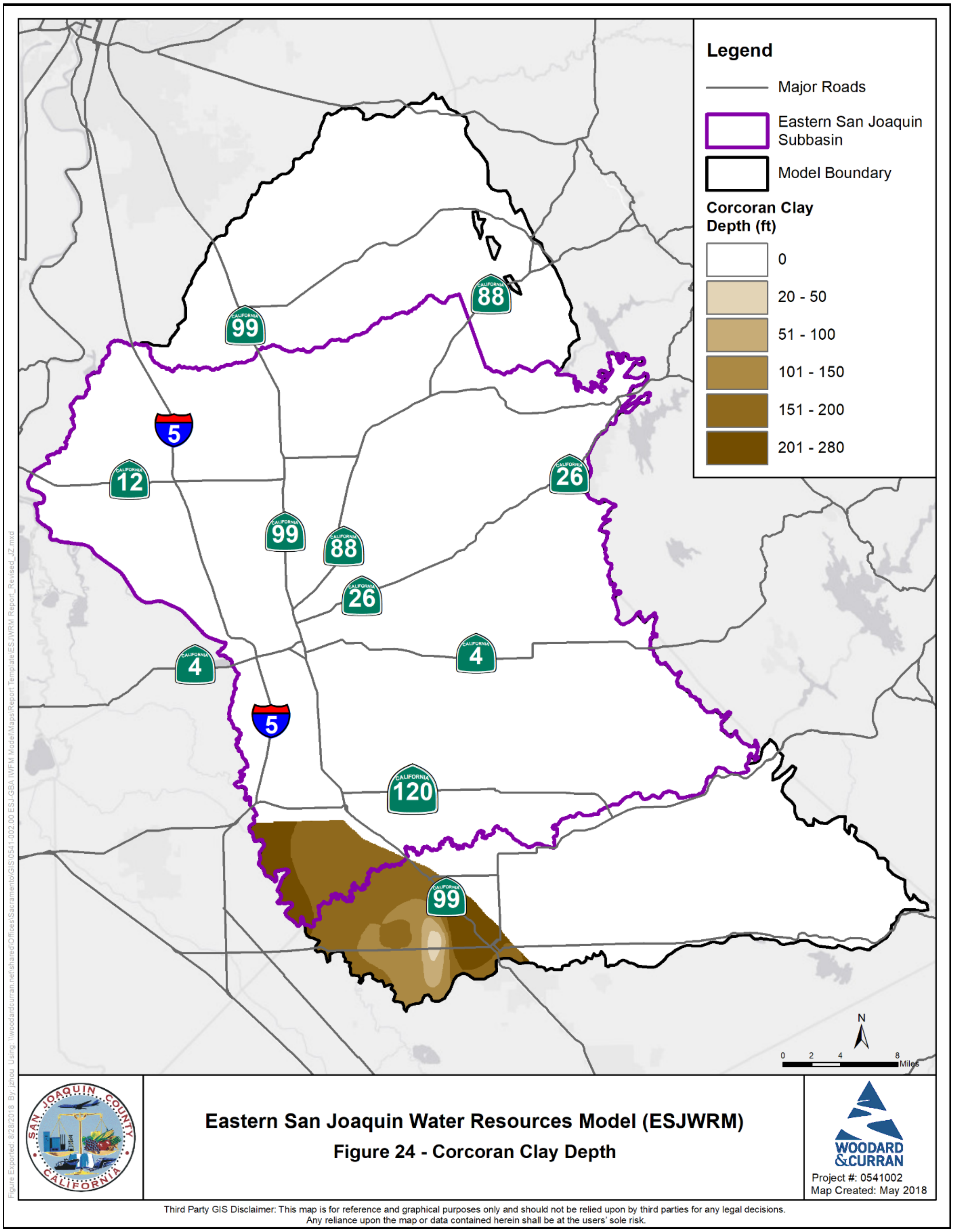


Figure 25: ESJWRM Corcoran Clay Thickness

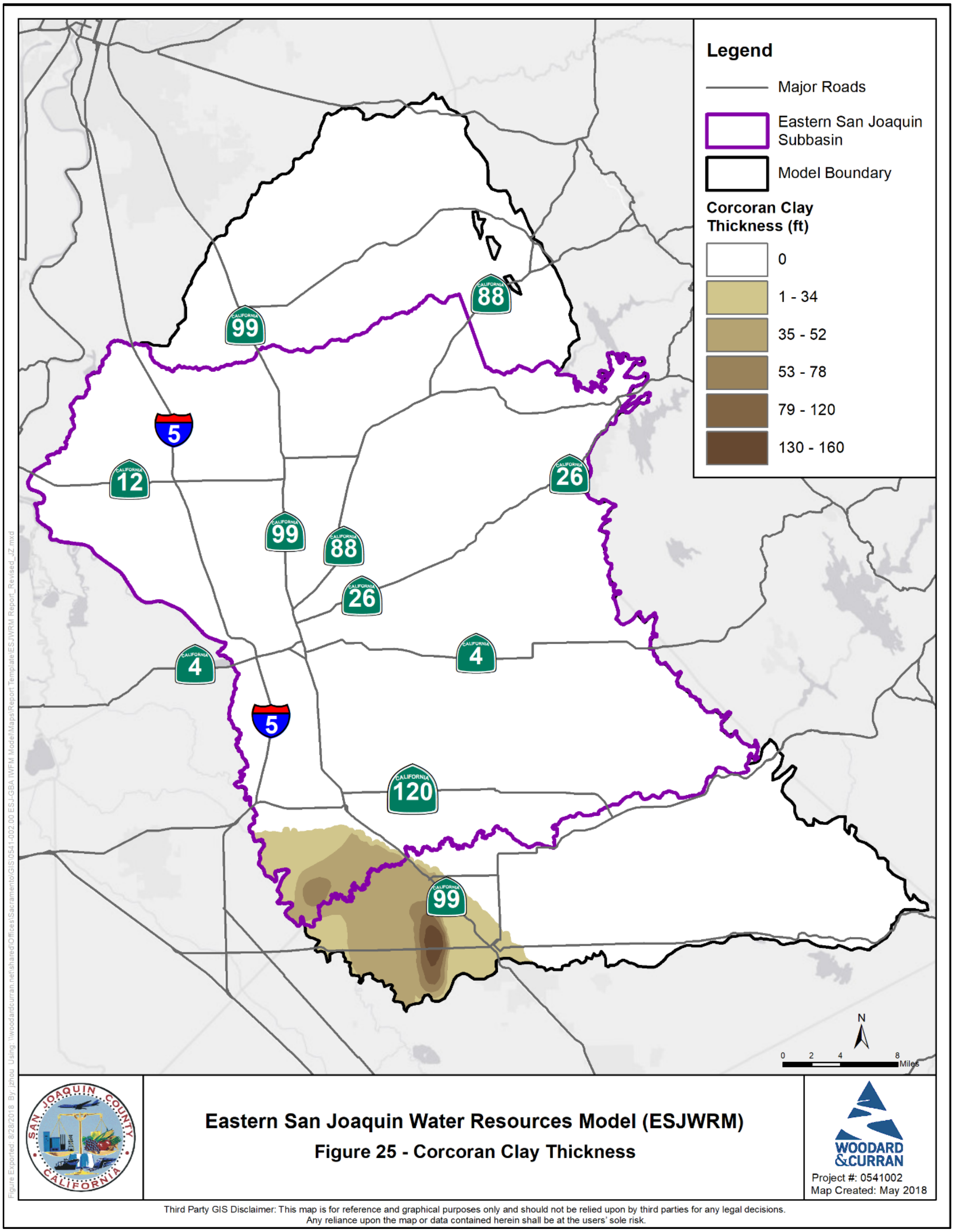


Figure 26: ESJWRM Layer 2 Thickness

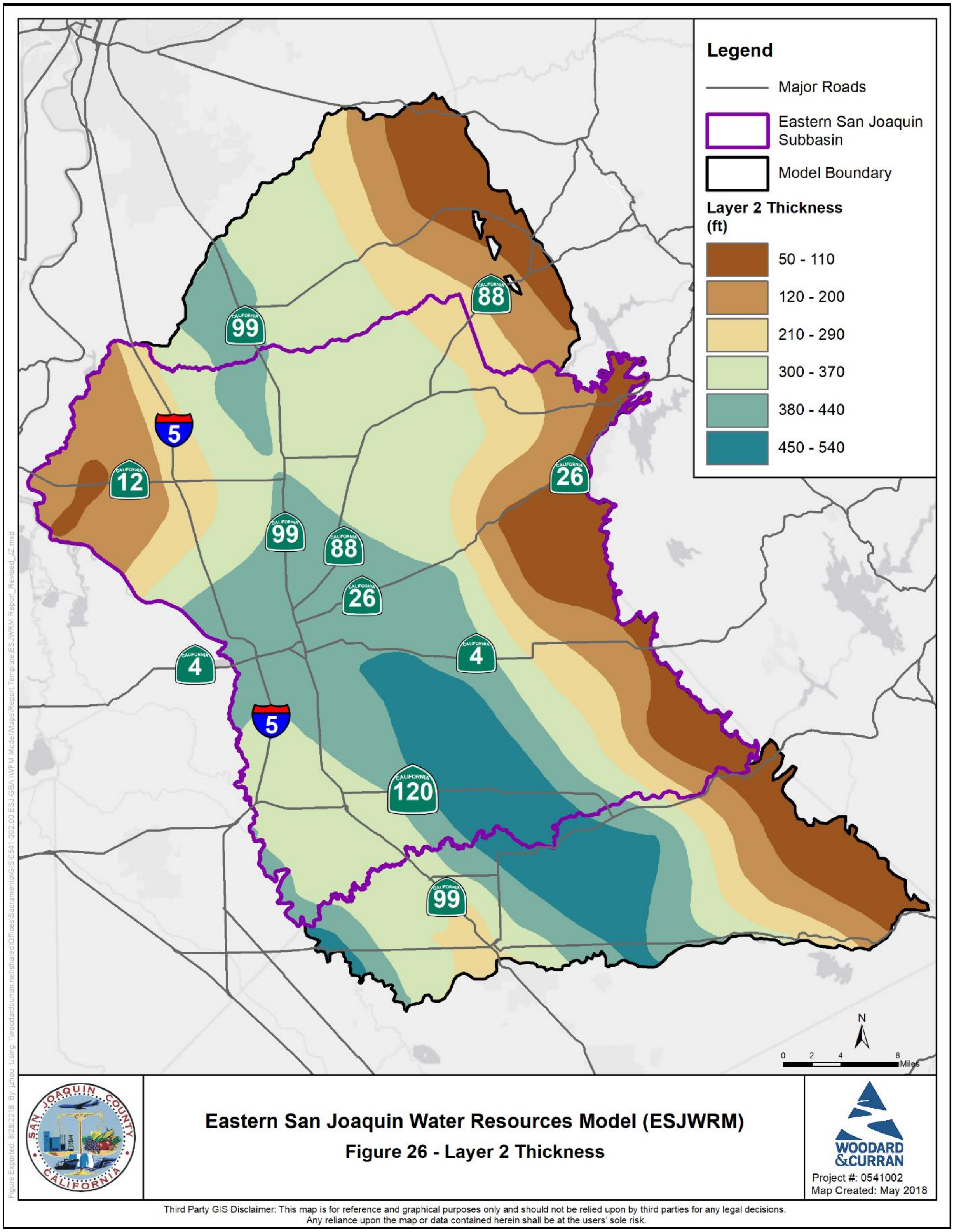
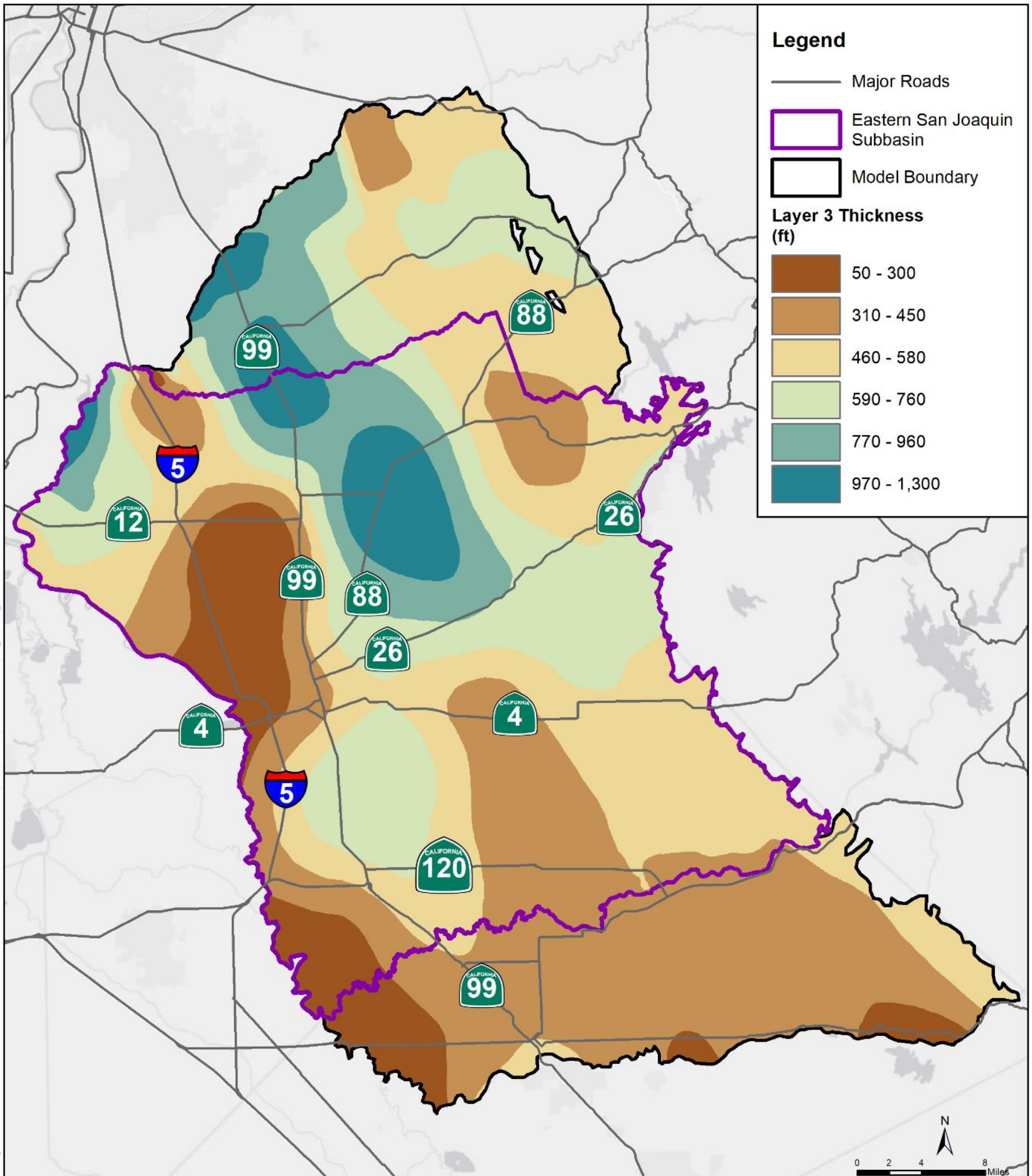


Figure 27: ESJWRM Layer 3 Thickness



Eastern San Joaquin Water Resources Model (ESJWRM)

Figure 27 - Layer 3 Thickness

Project #: 0541002
Map Created: May 2018

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Figure 28: ESJWRM Layer 4 Thickness

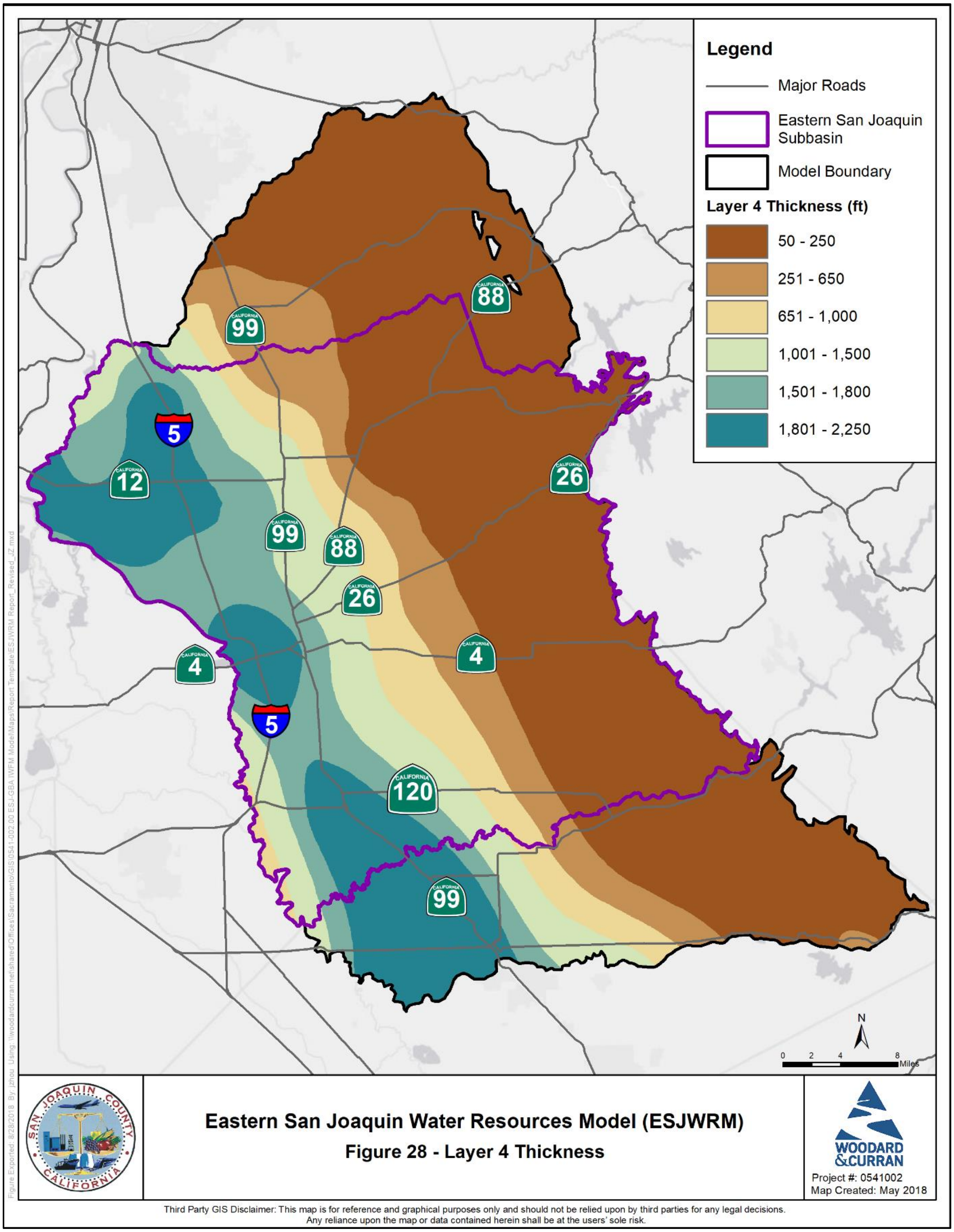

Figure 29a: ESJWRM Cross Section A - A’

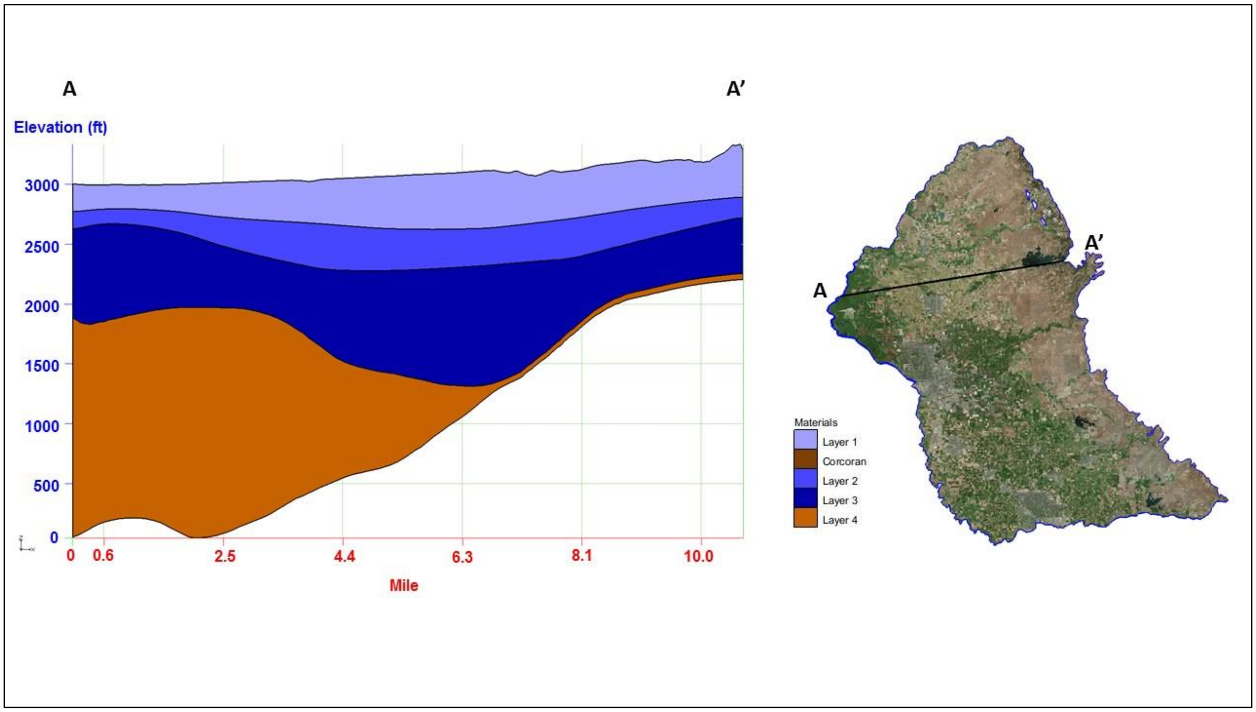

Figure 29b: ESJWRM Cross Section B - B’

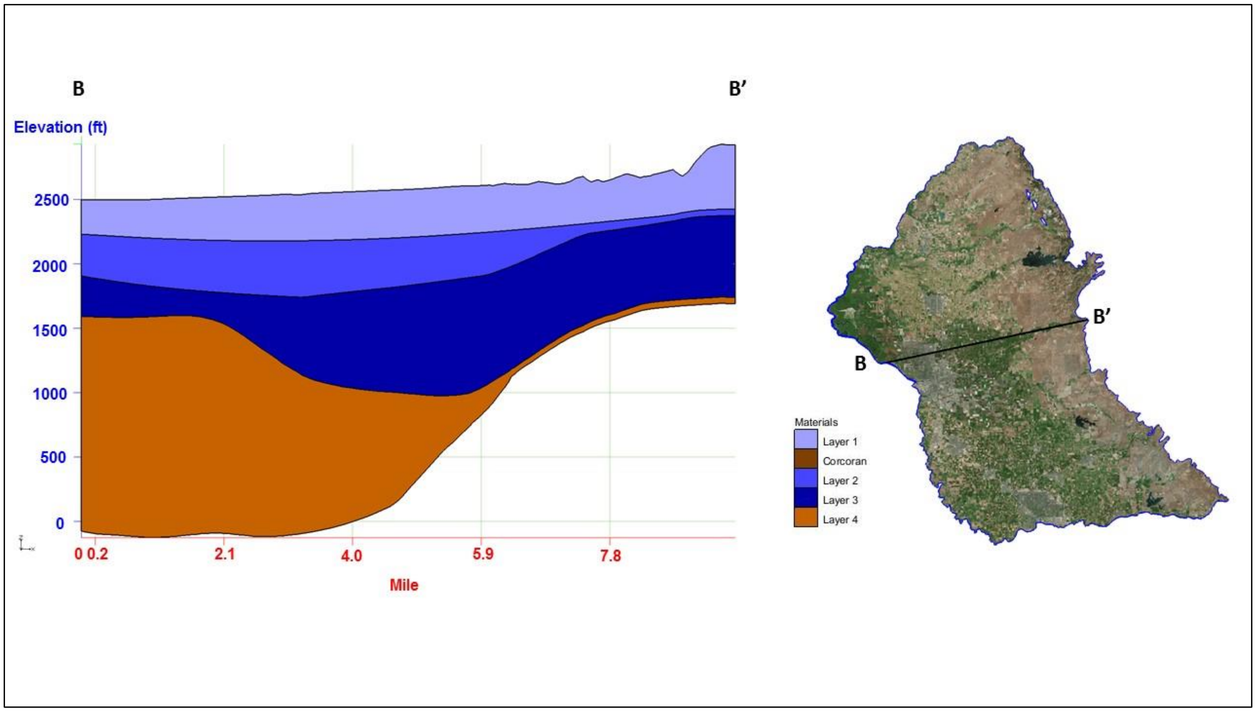

Figure 29c: ESJWRM Cross Section C - C'

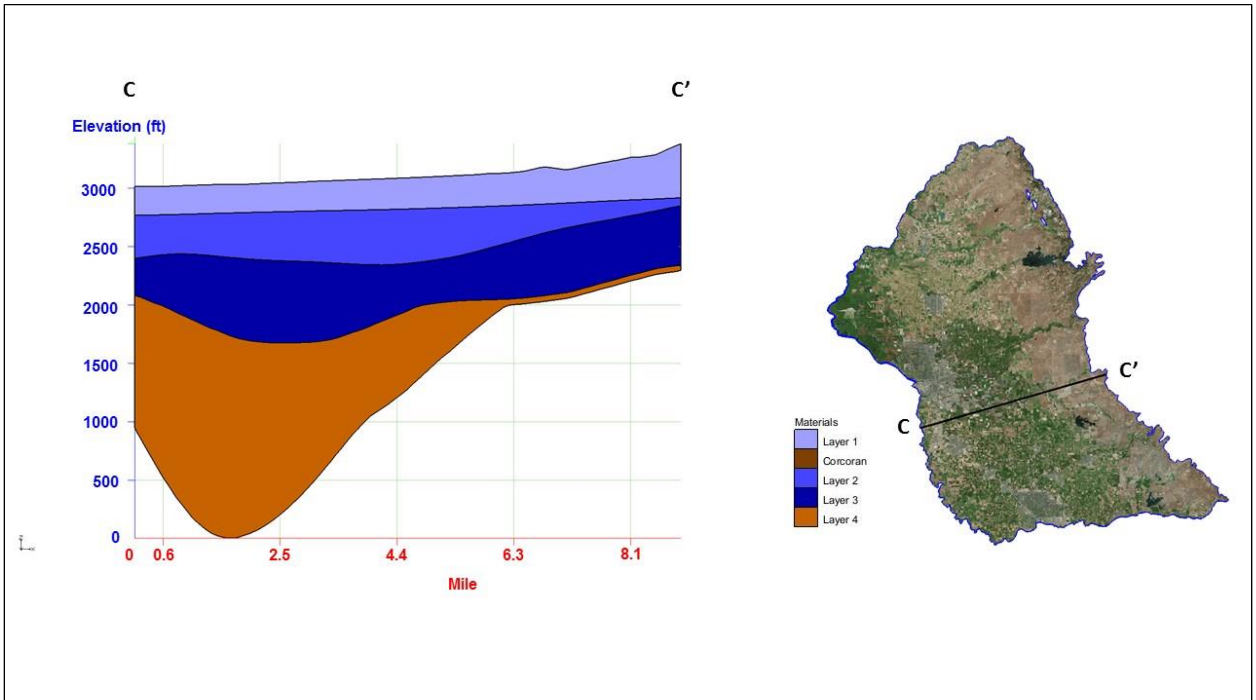

Figure 29d: ESJWRM Cross Section D - D'

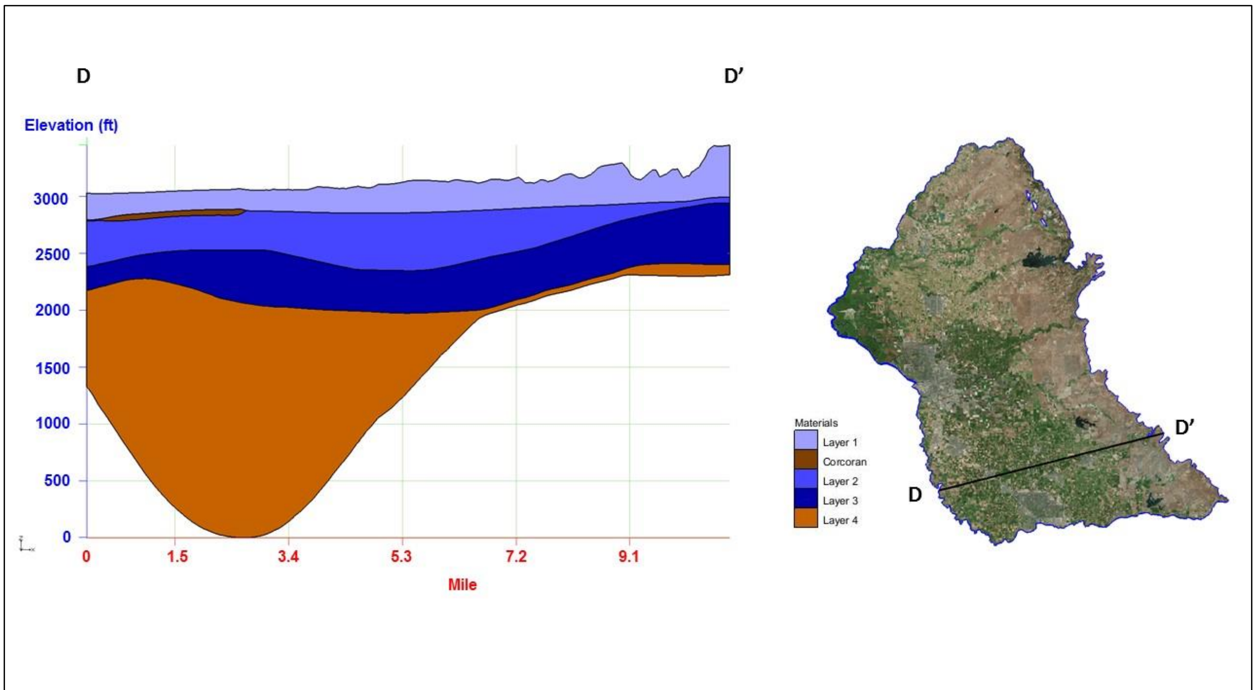

Figure 29e: ESJWRM Cross Section E - E’

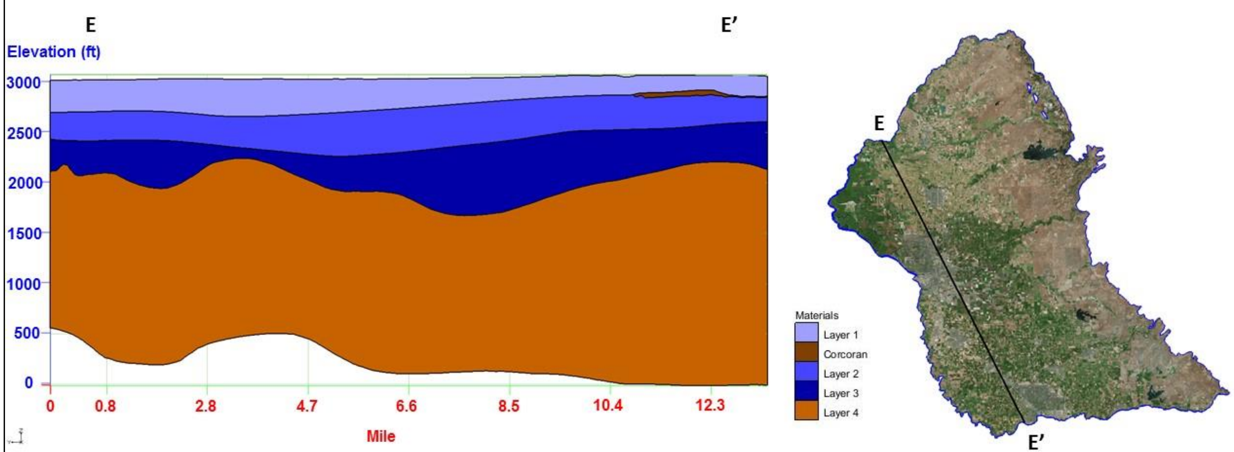

Figure 29f: ESJWRM Cross Section F - F’

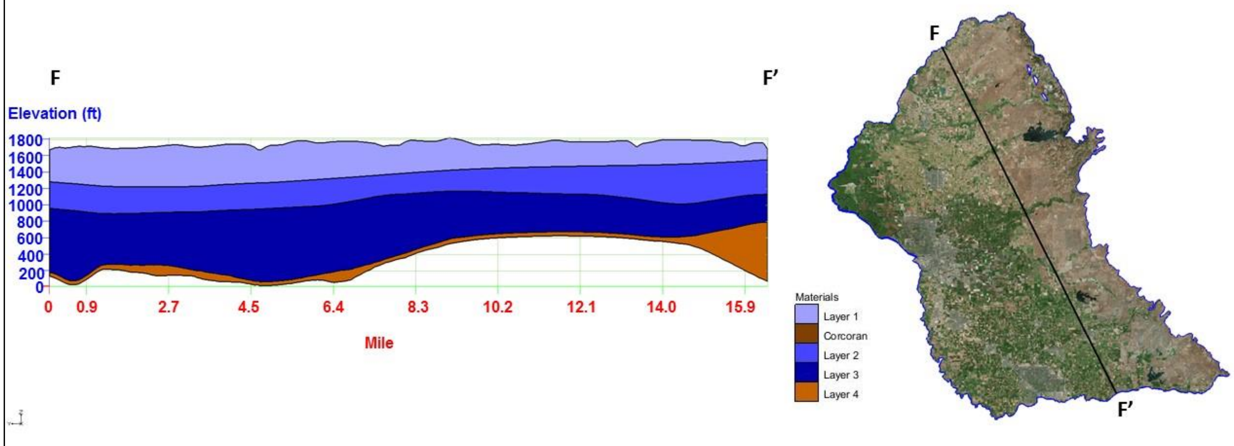

Figure 30: ESJWRM Small Watersheds

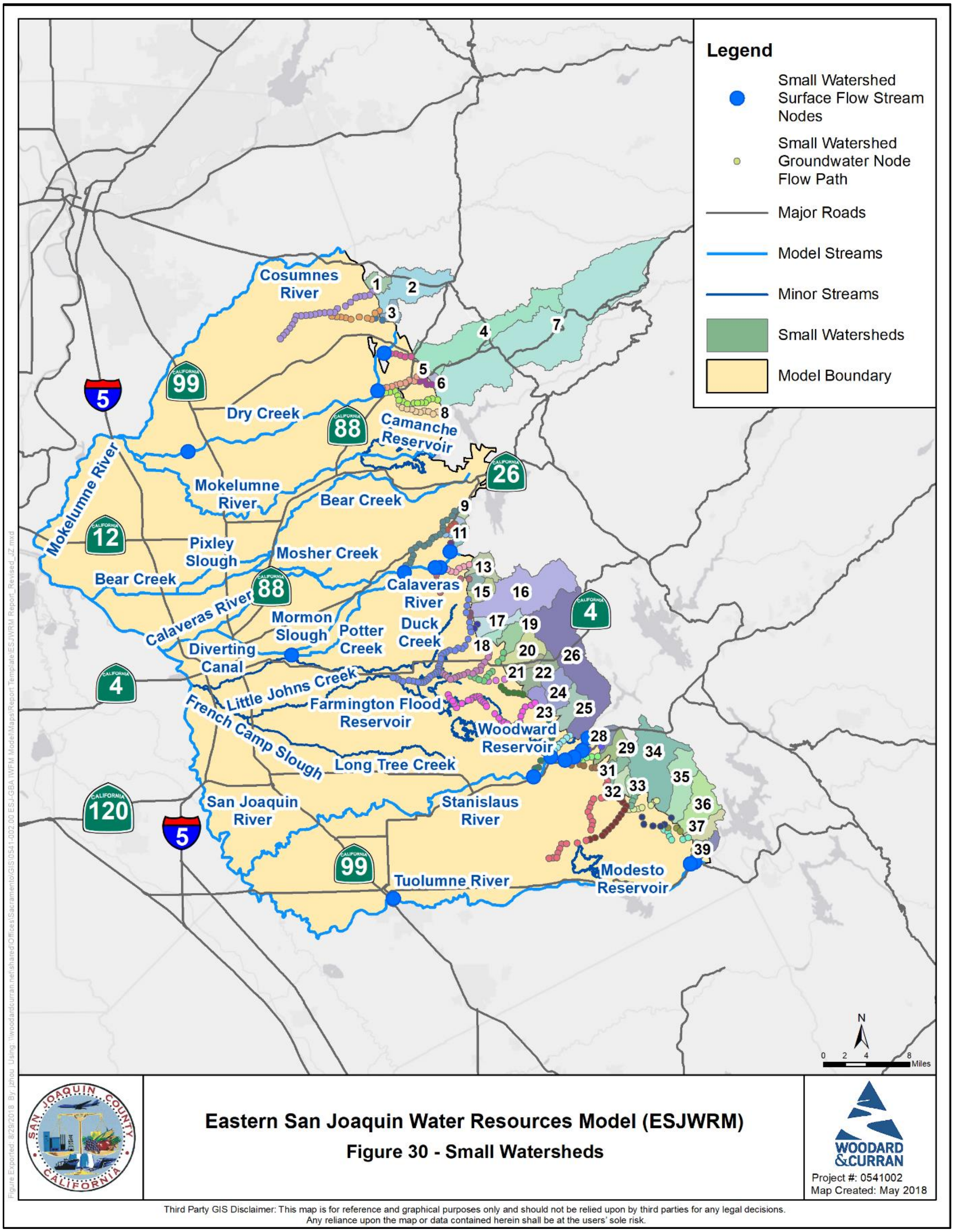

Figure 31: ESJWRM Initial GW Levels (Fall 1994)

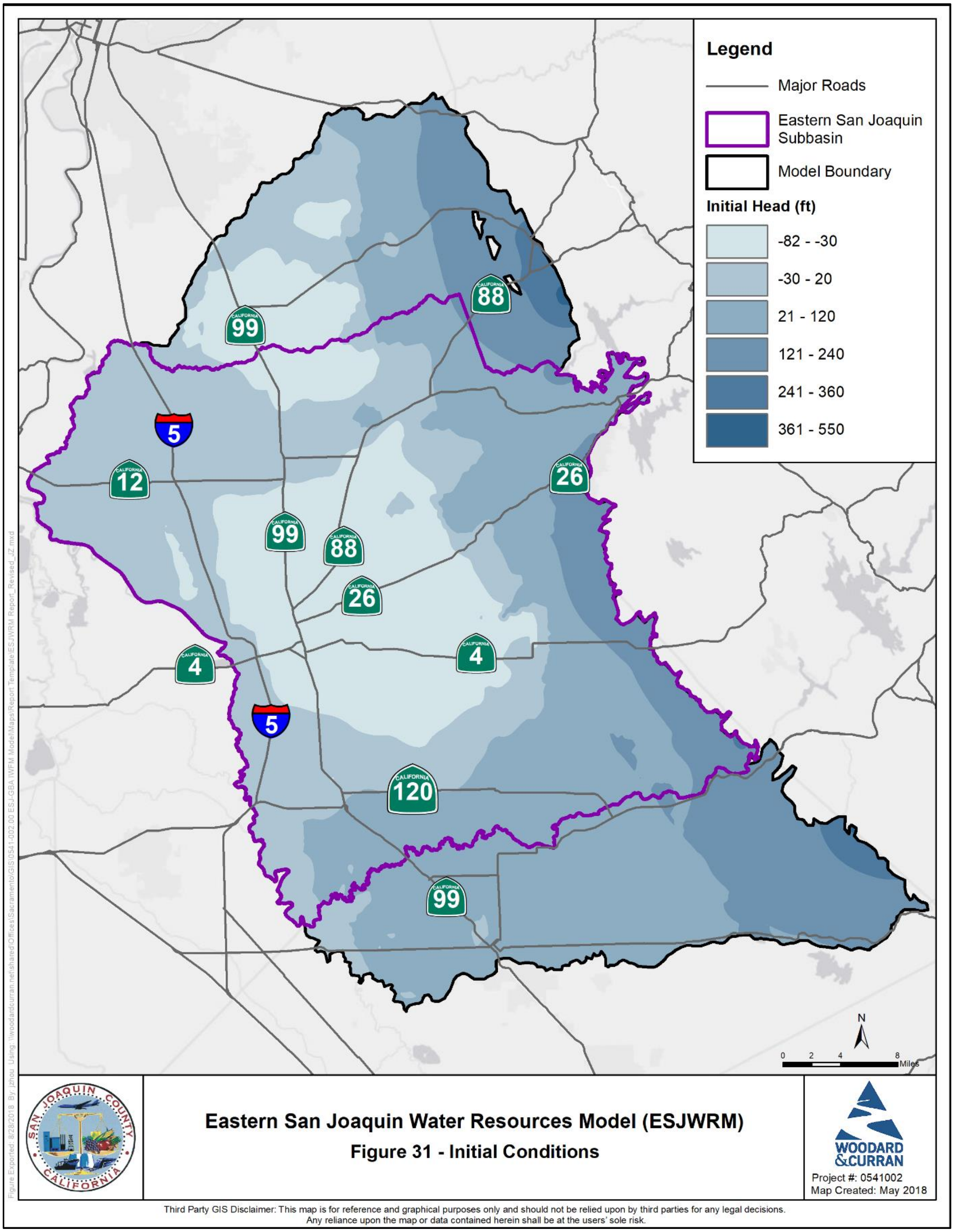

Figure 32: ESJWRM Annual Population by Urban Center

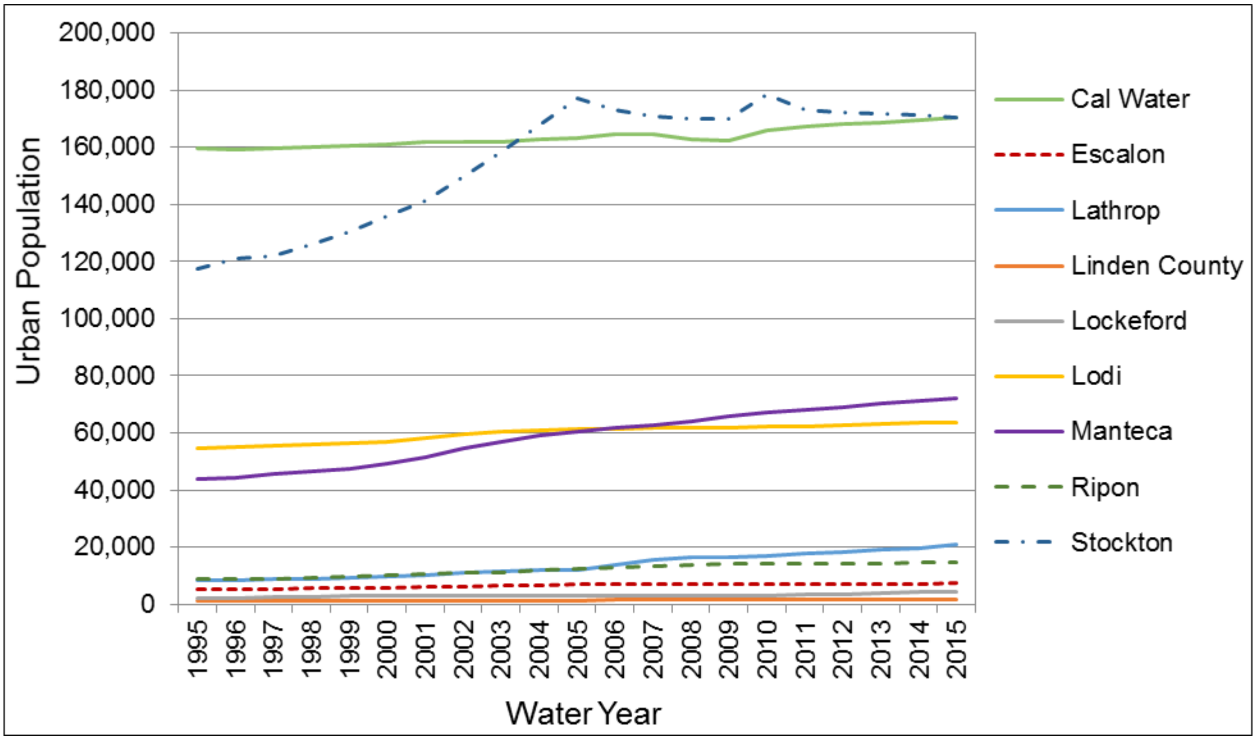

Figure 33: ESJWRM Annual Per Capita Water Use by Urban Center

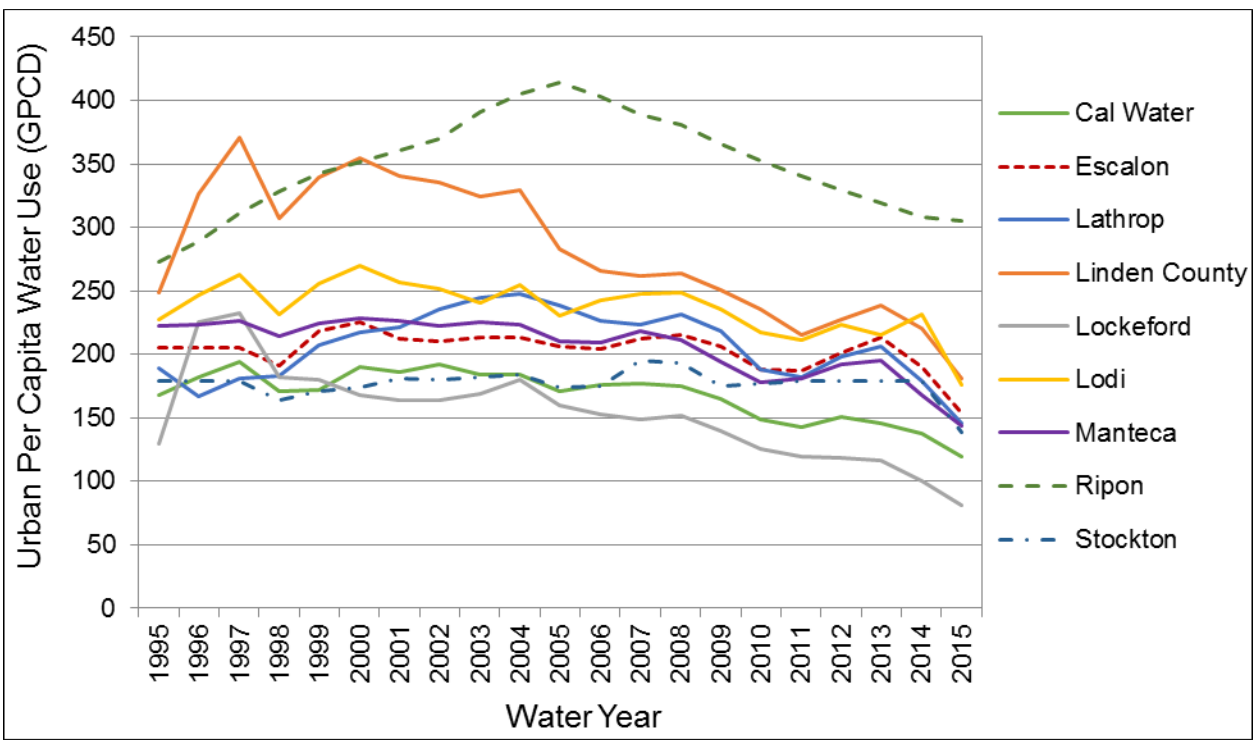

Figure 34: ESJWRM Surface Water Diversion Locations

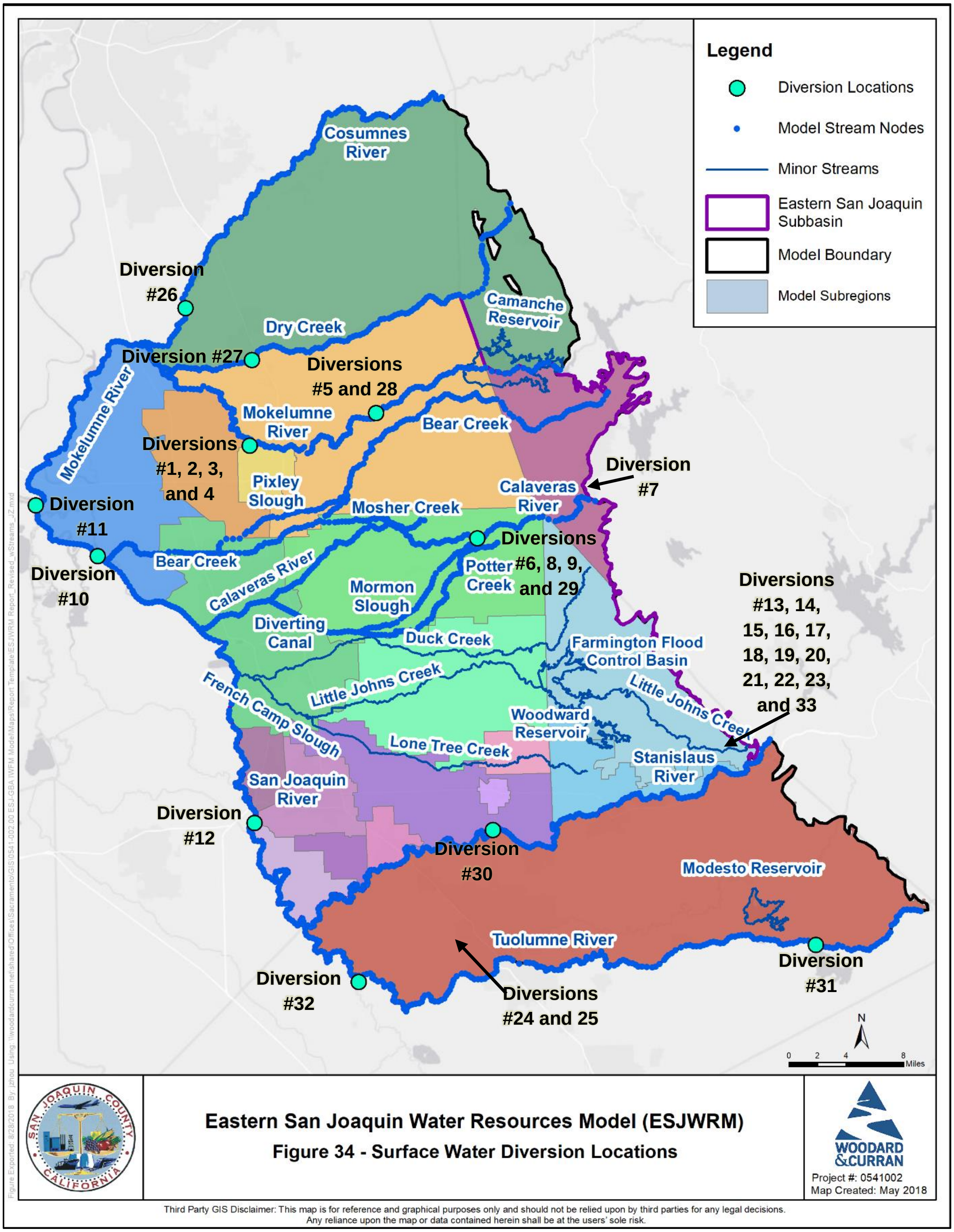

Figure 35: ESJWRM Groundwater Production Wells

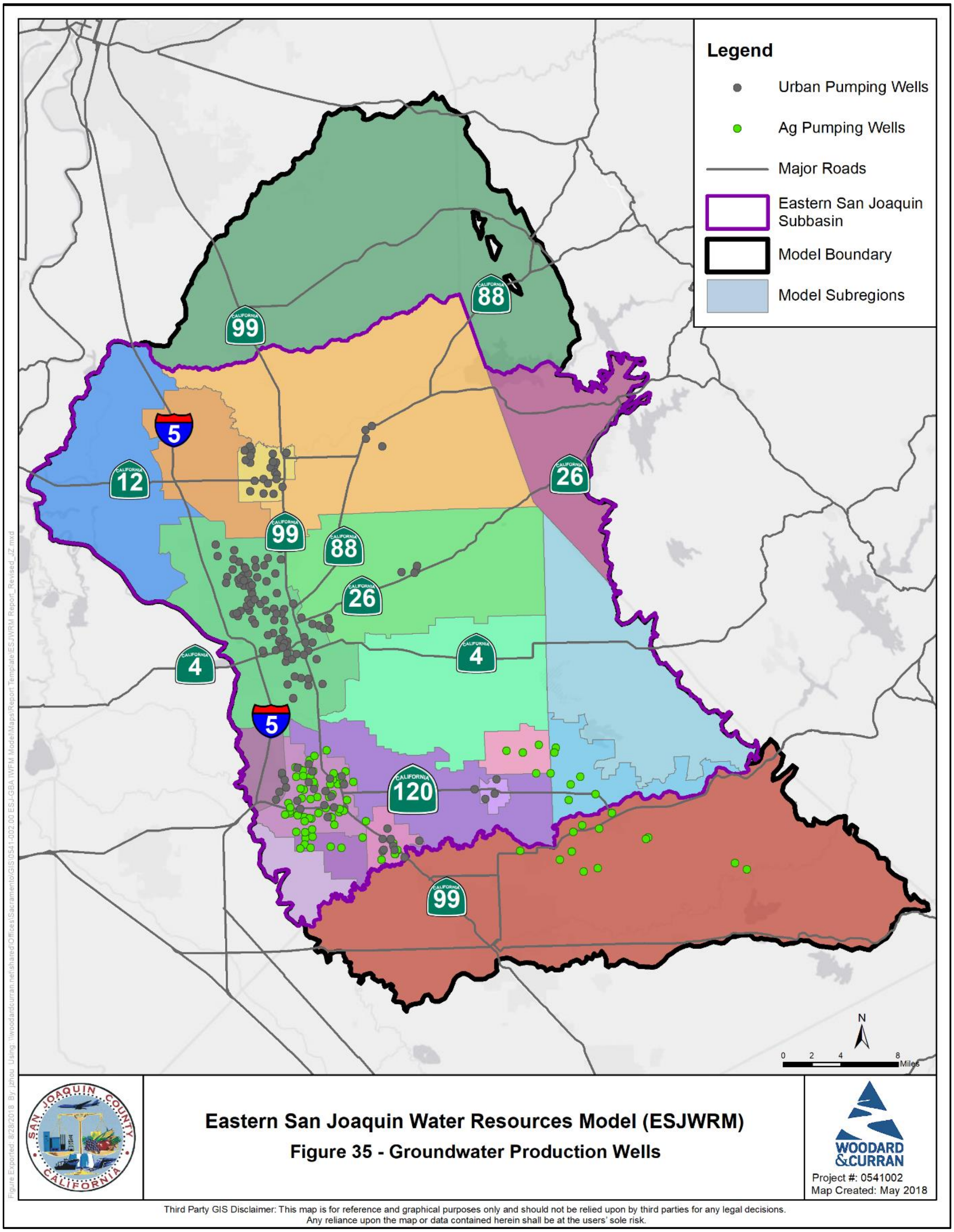

Figure 36: ESJWRM Riparian Surface Water Diversion Areas

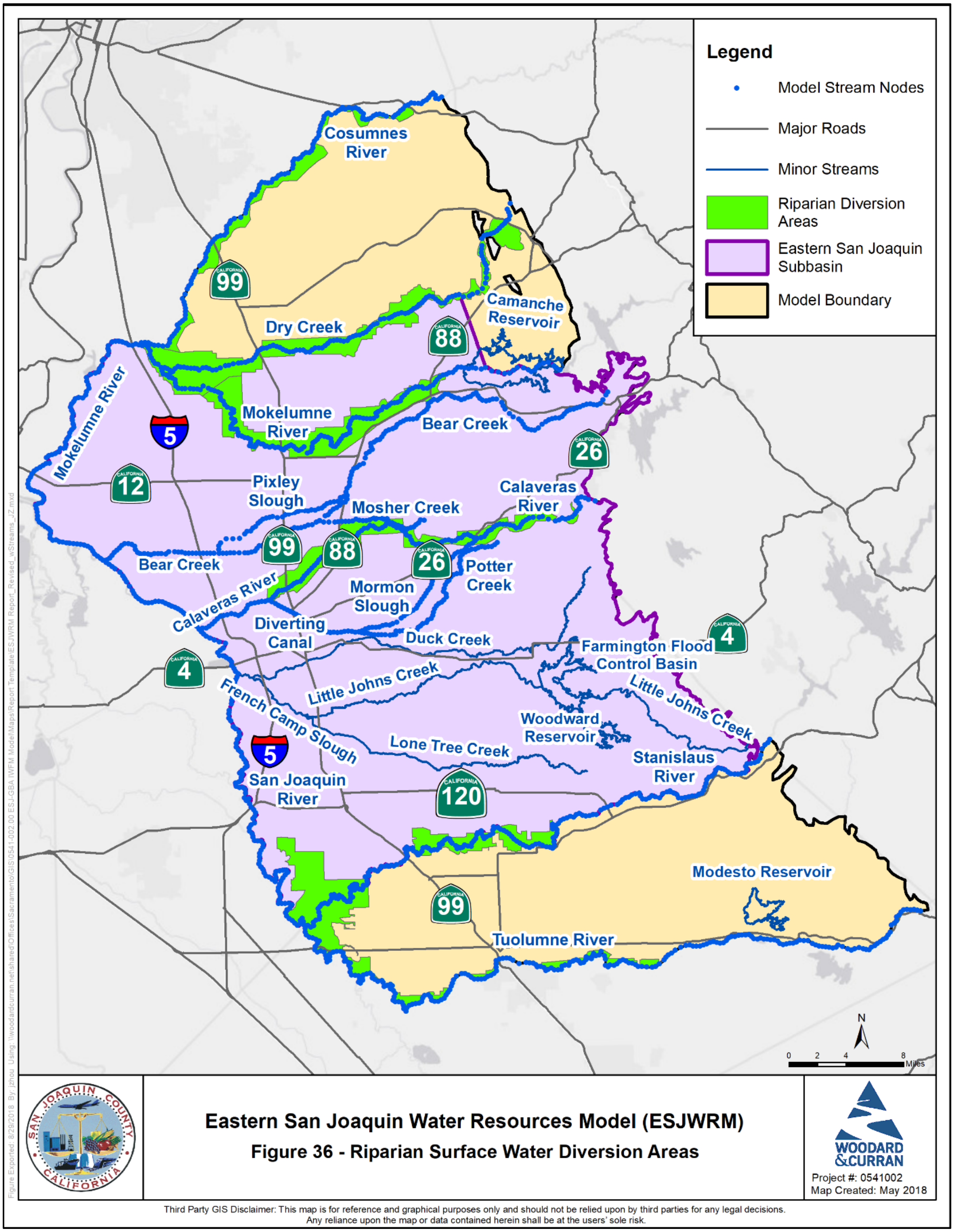

Figure 37: ESJWRM Field Capacity

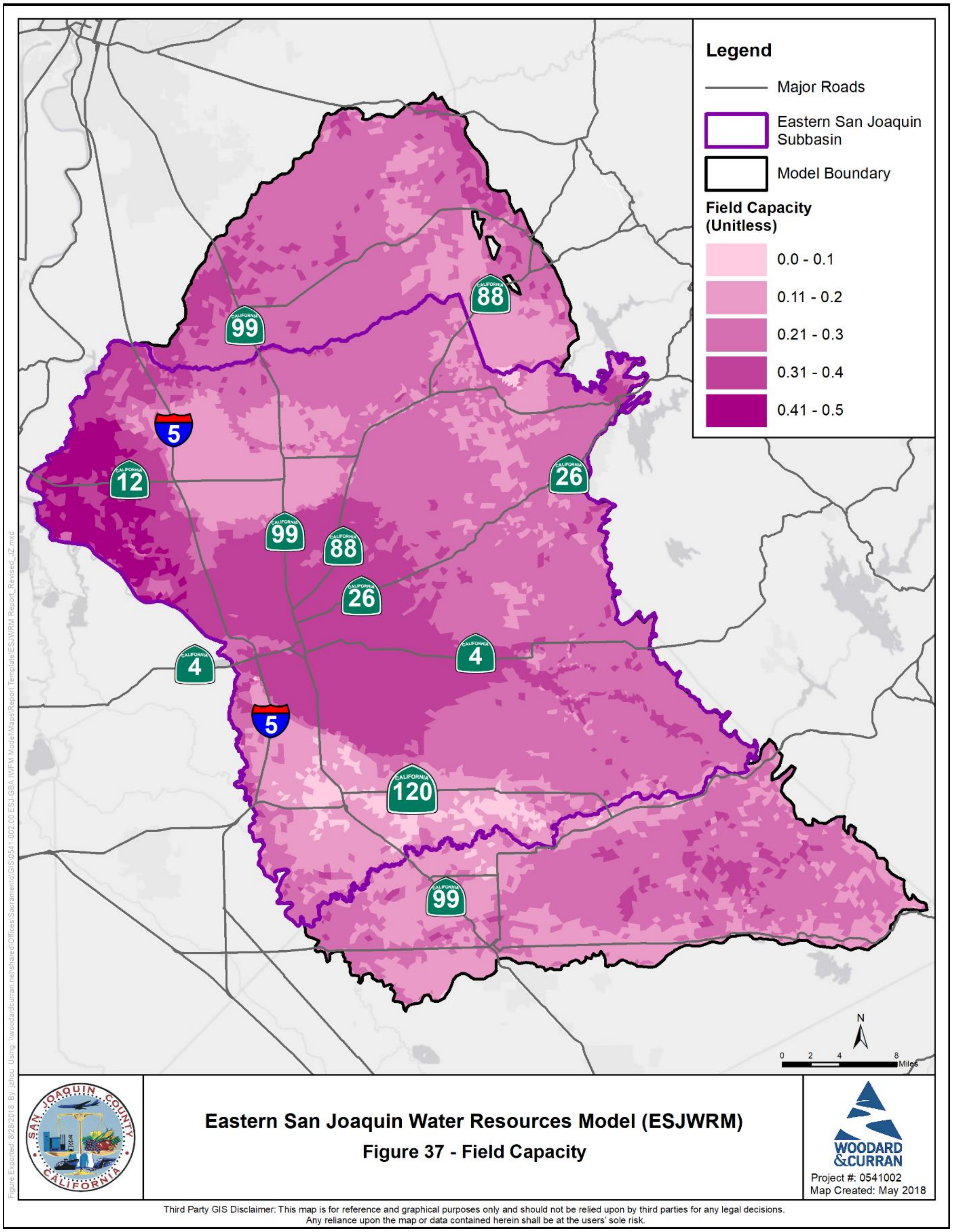

Figure 38: ESJWRM Wilting Point

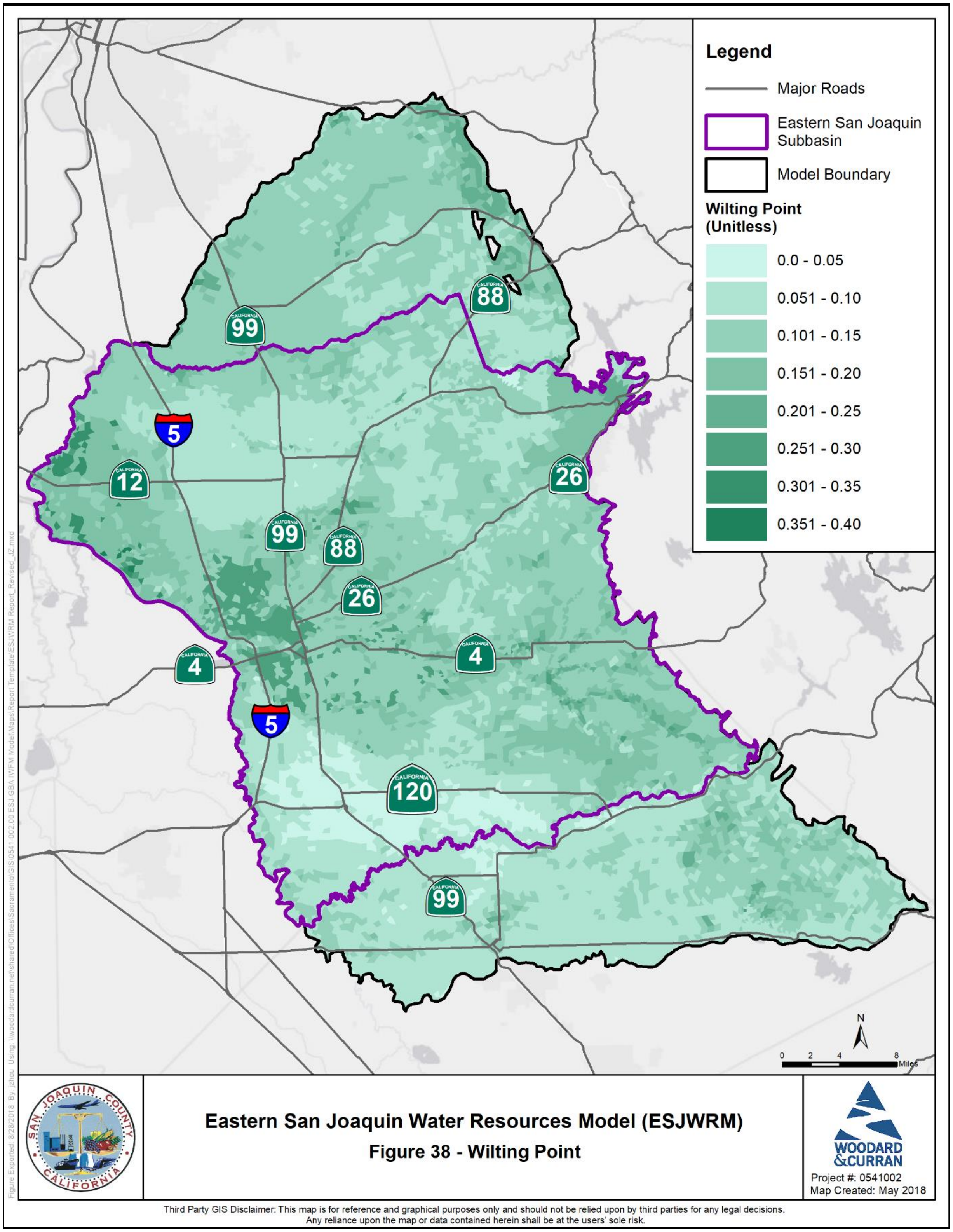

Figure 39: ESJWRM Total Porosity

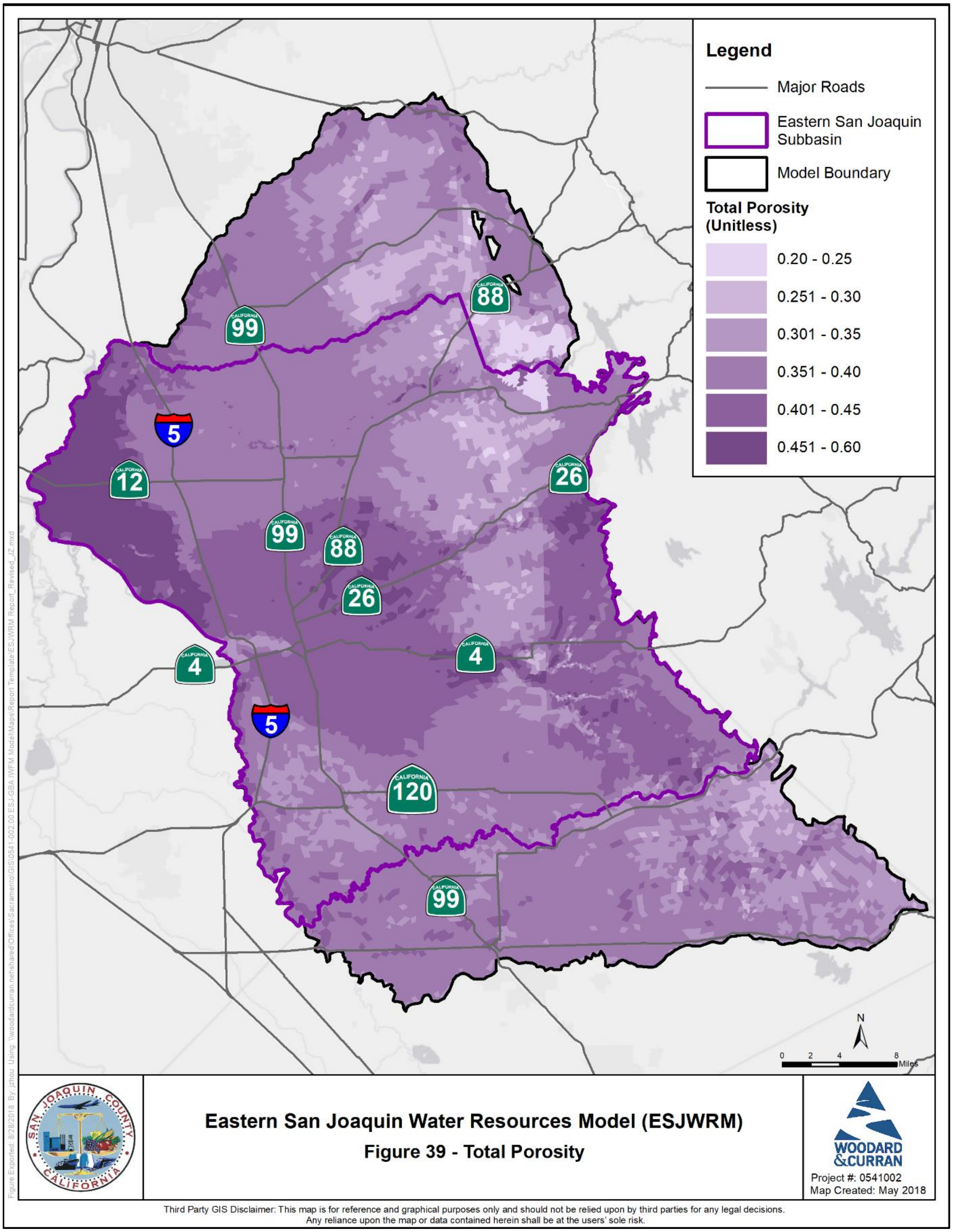

Figure 40: ESJWRM Saturated Hydraulic Conductivity

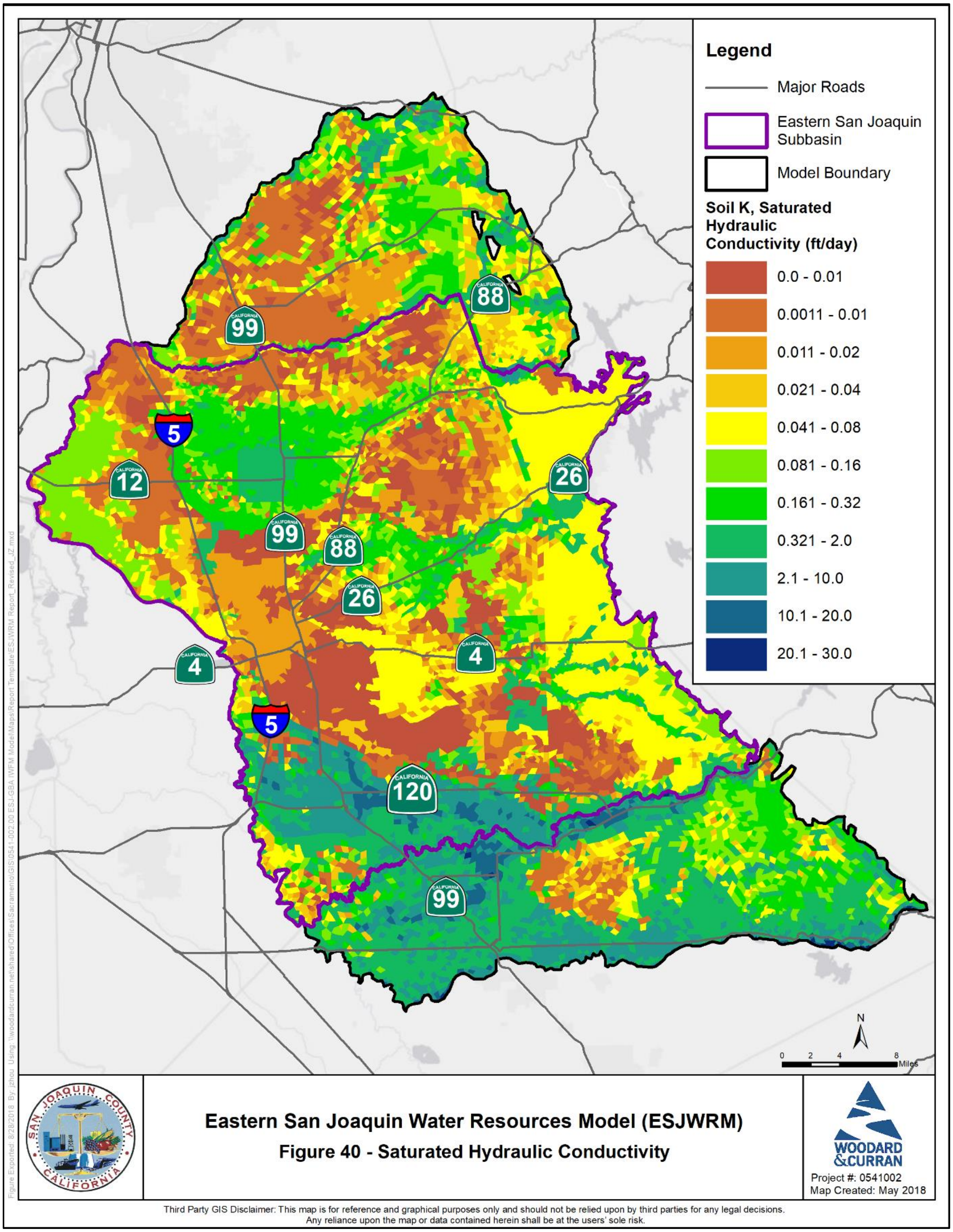

Figure 41: ESJWRM Pore Size Distribution Index

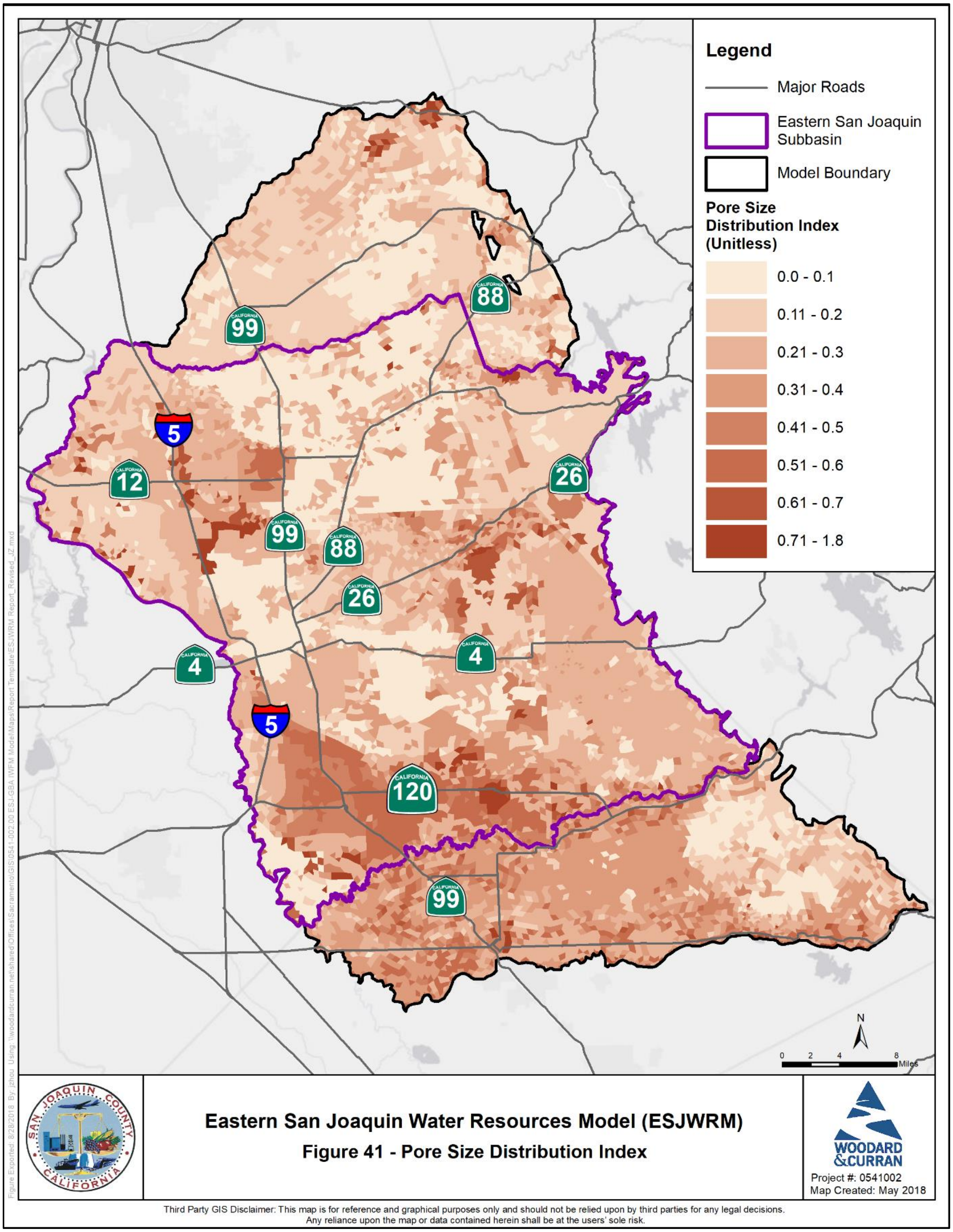

Figure 42a: ESJWRM Agricultural Water Demand – Eastern San Joaquin Subbasin

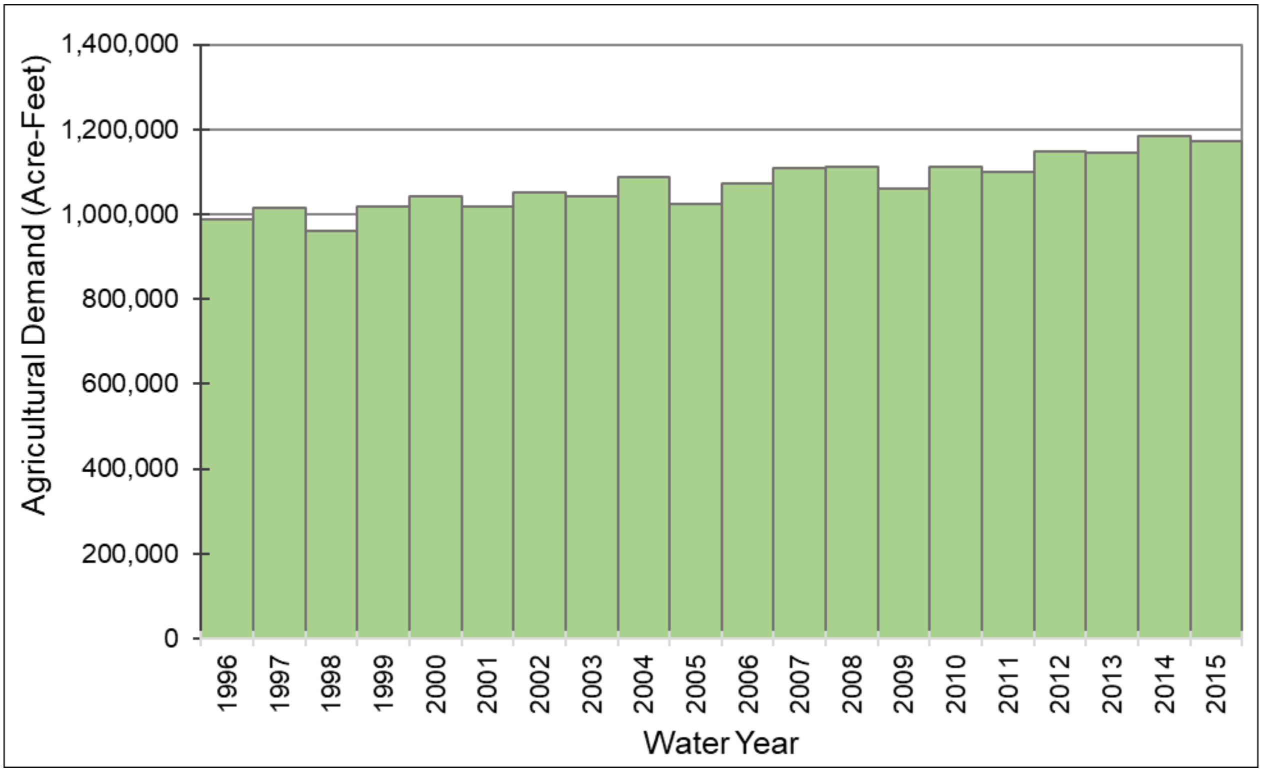

Figure 42b: ESJWRM Unit Agricultural Water Use and ETAW – Eastern San Joaquin Subbasin

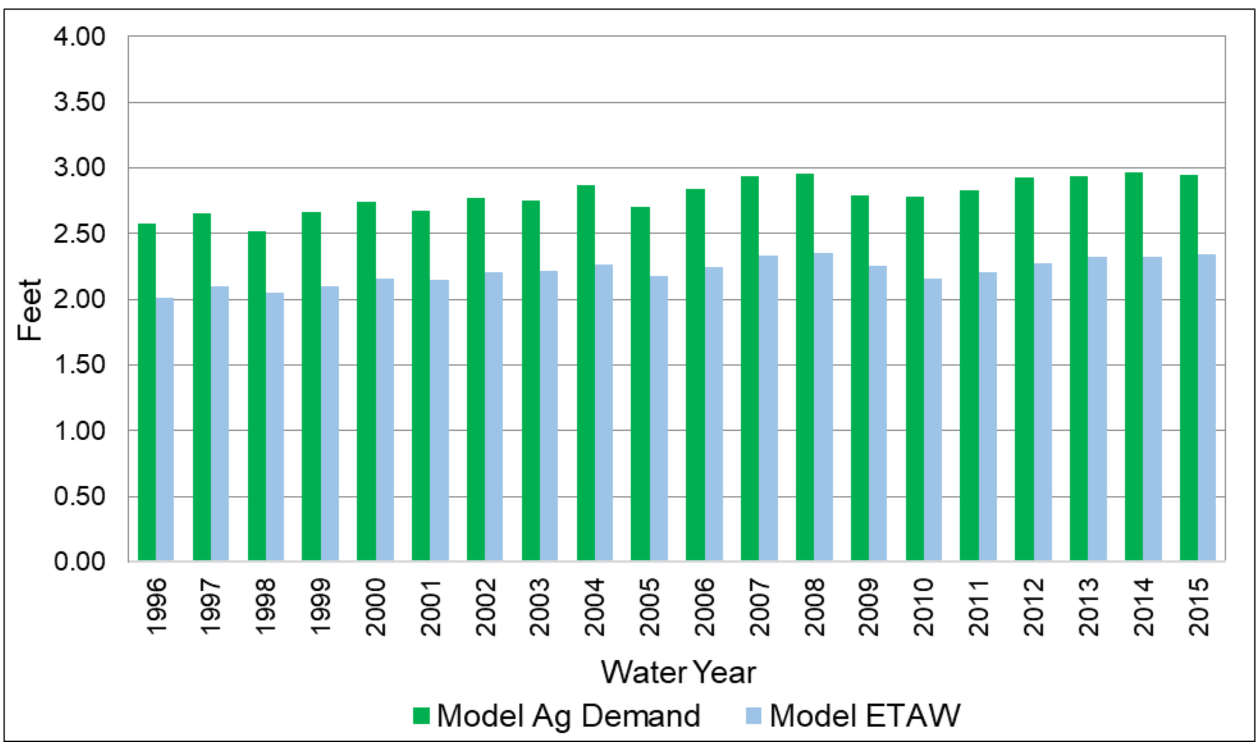

Figure 42c: ESJWRM Agricultural Water Demand – Subarea 1 (North Delta Subarea)

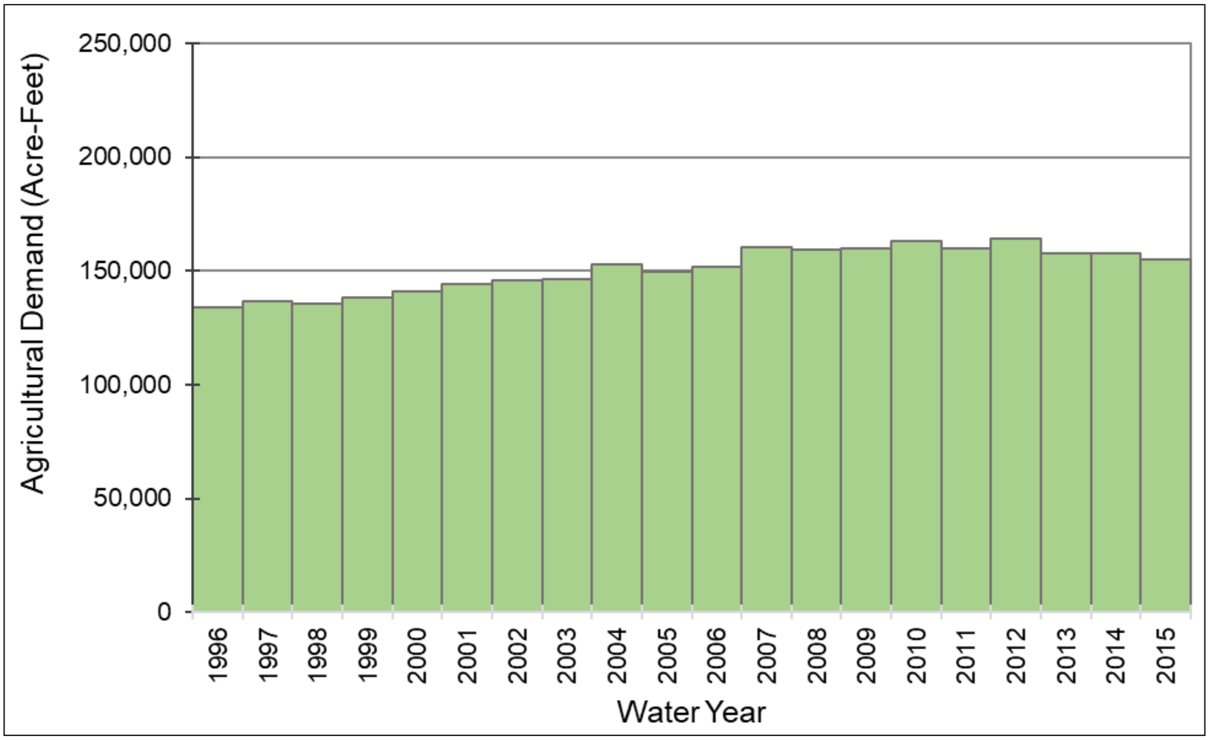

Figure 42d: ESJWRM Unit Agricultural Water Use and ETAW – Subarea 1 (North Delta Subarea)

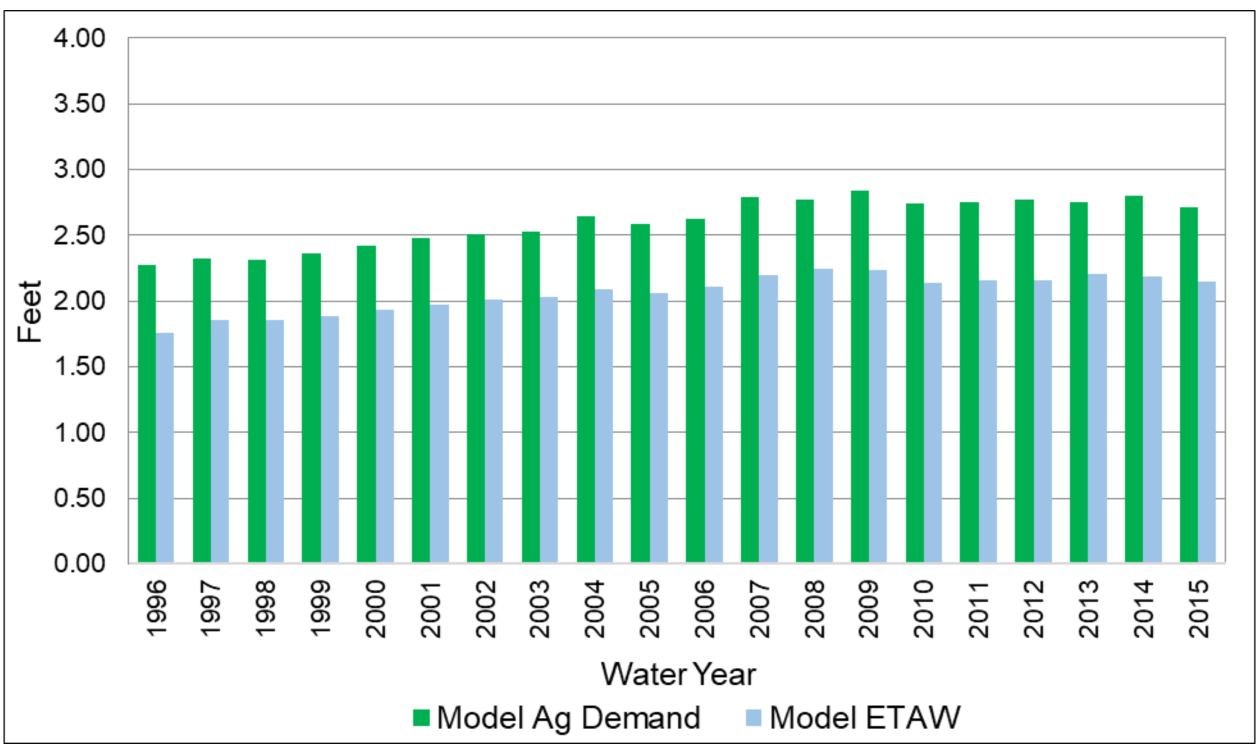

Figure 42e: ESJWRM Agricultural Water Demand – Subarea 2 (North Subarea)

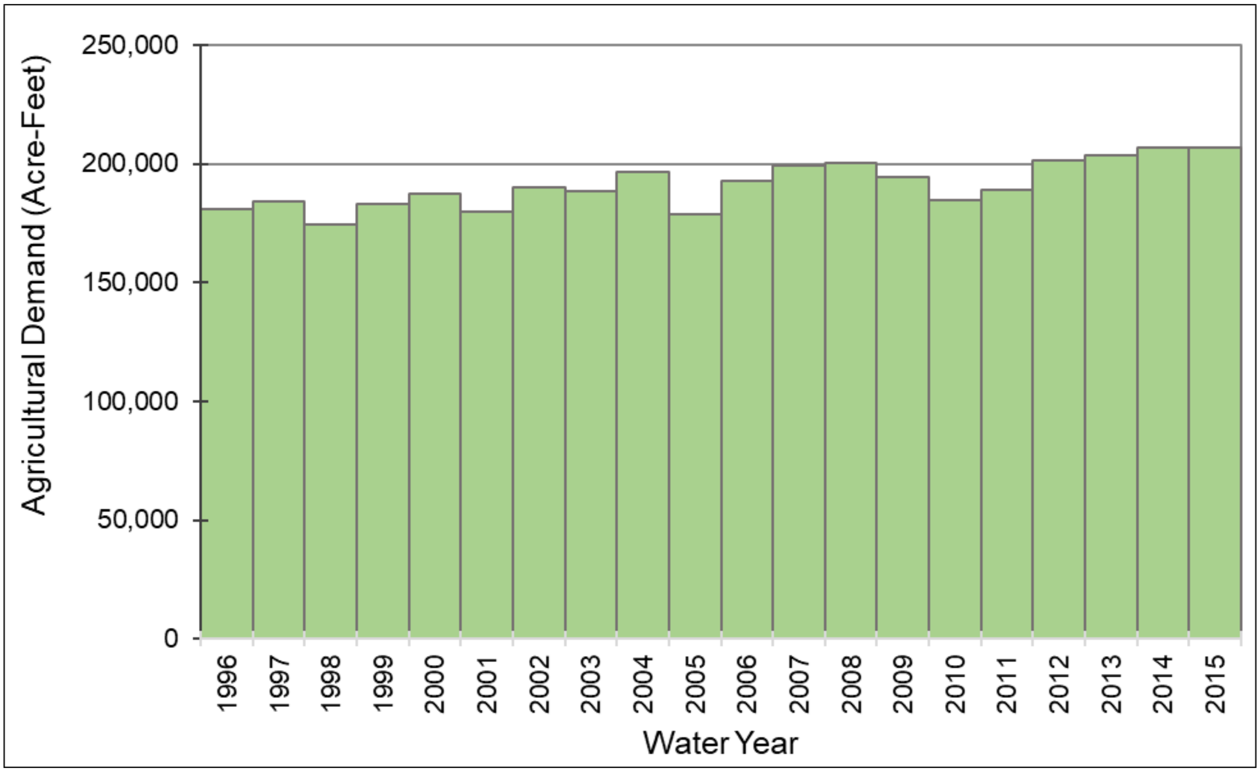

Figure 42f: ESJWRM Unit Agricultural Water Use and ETAW – Subarea 2 (North Subarea)

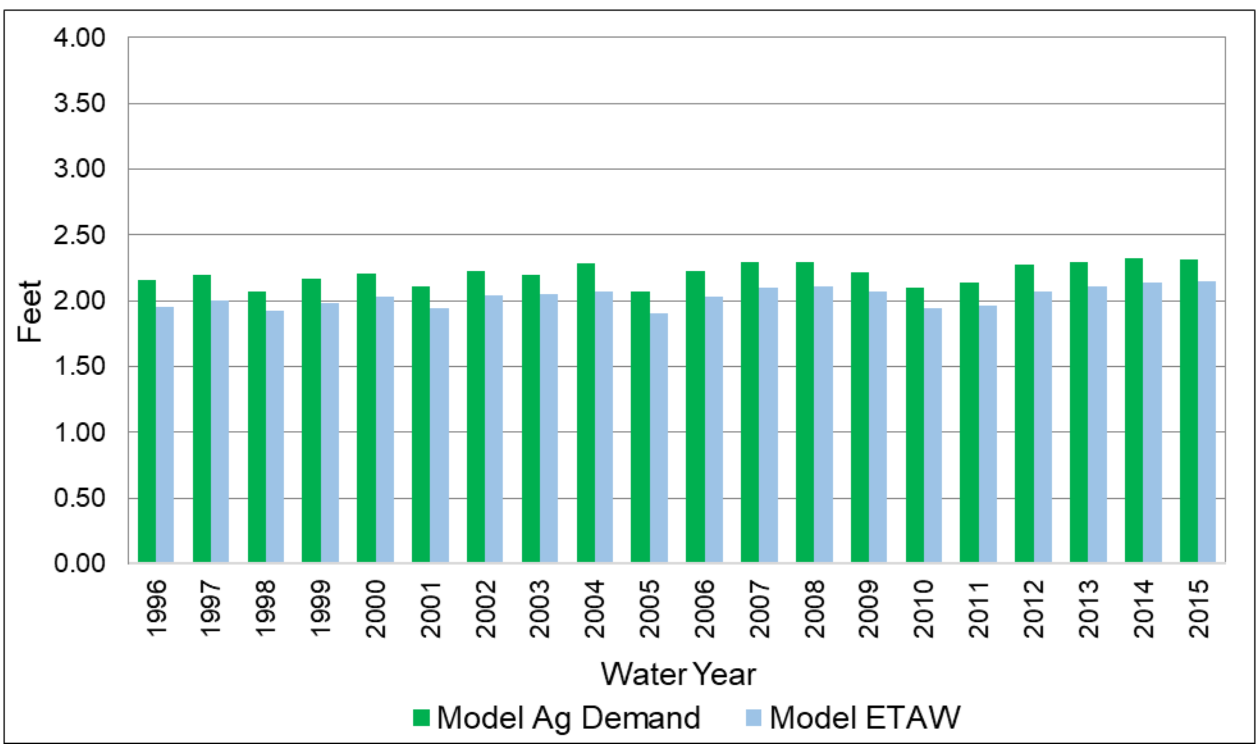

Figure 42g: ESJWRM Agricultural Water Demand – Subarea 3 (Calaveras Subarea)

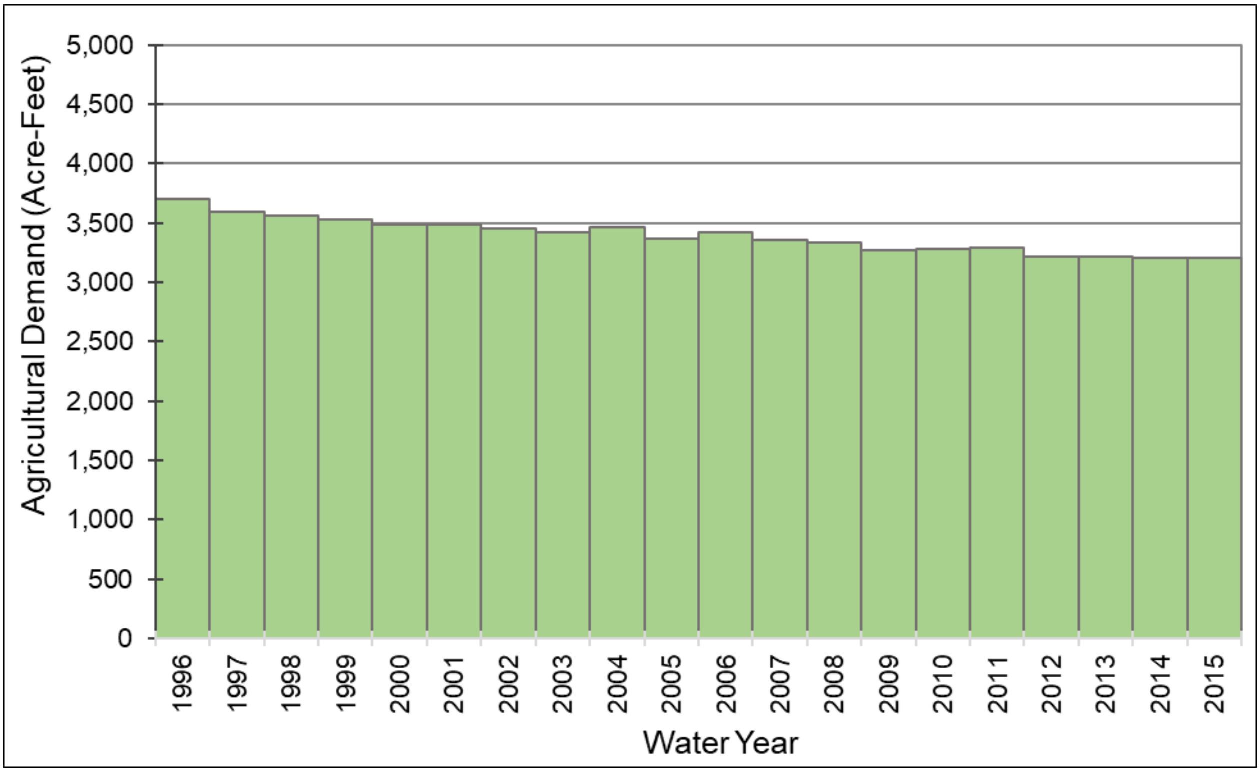

Figure 42h: ESJWRM Unit Agricultural Water Use and ETAW – Subarea 3 (Calaveras Subarea)

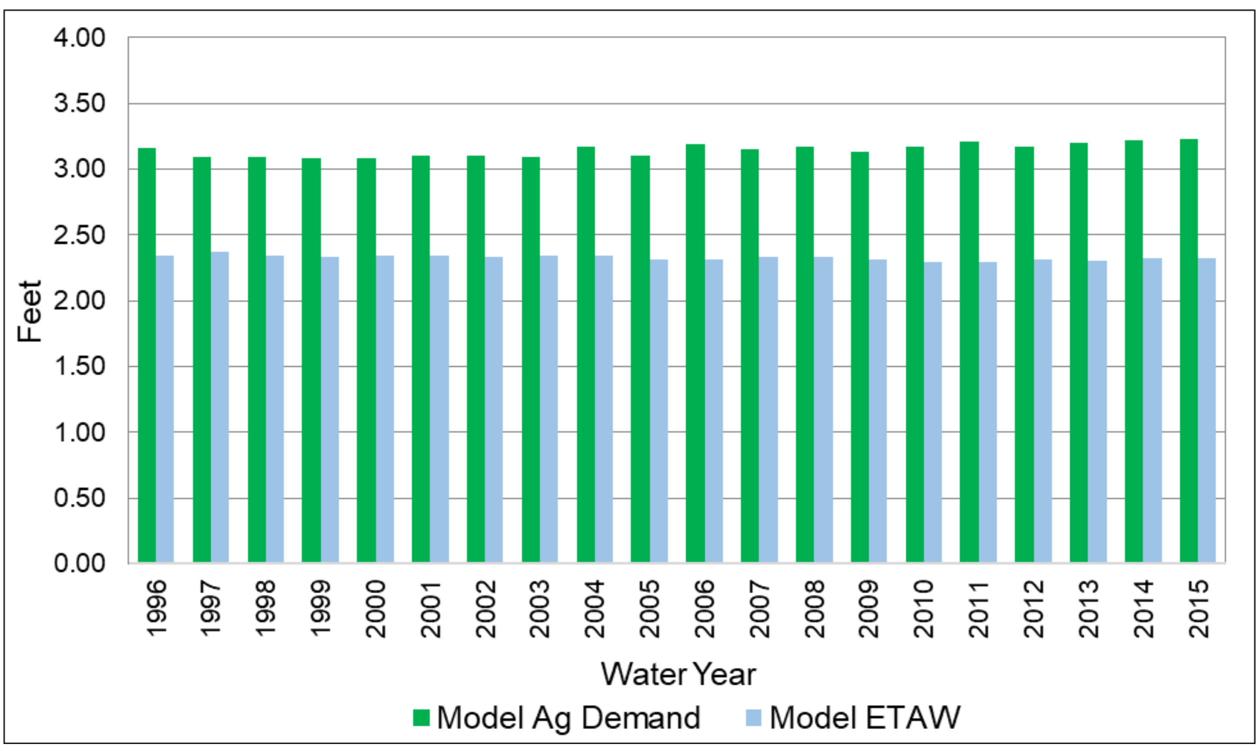

Figure 42i: ESJWRM Agricultural Water Demand – Subarea 4 (Central Subarea)

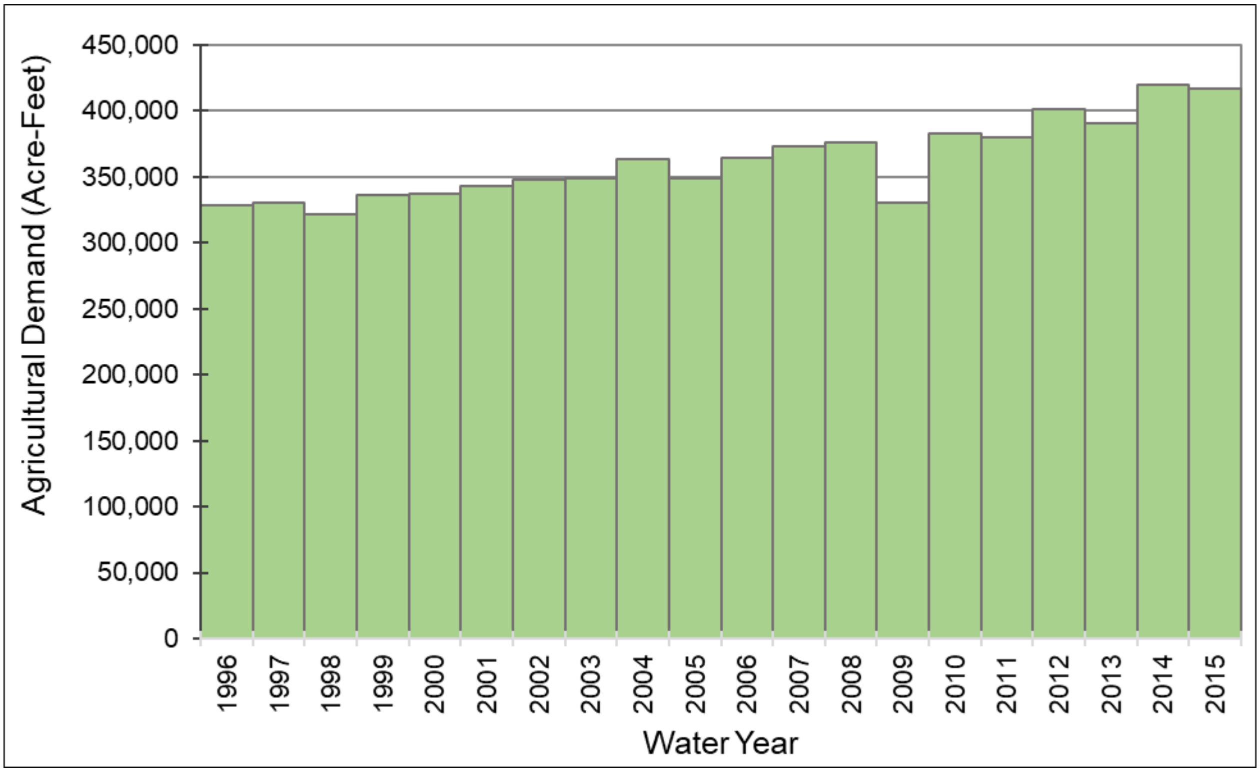

Figure 42j: ESJWRM Unit Agricultural Water Use and ETAW – Subarea 4 (Central Subarea)

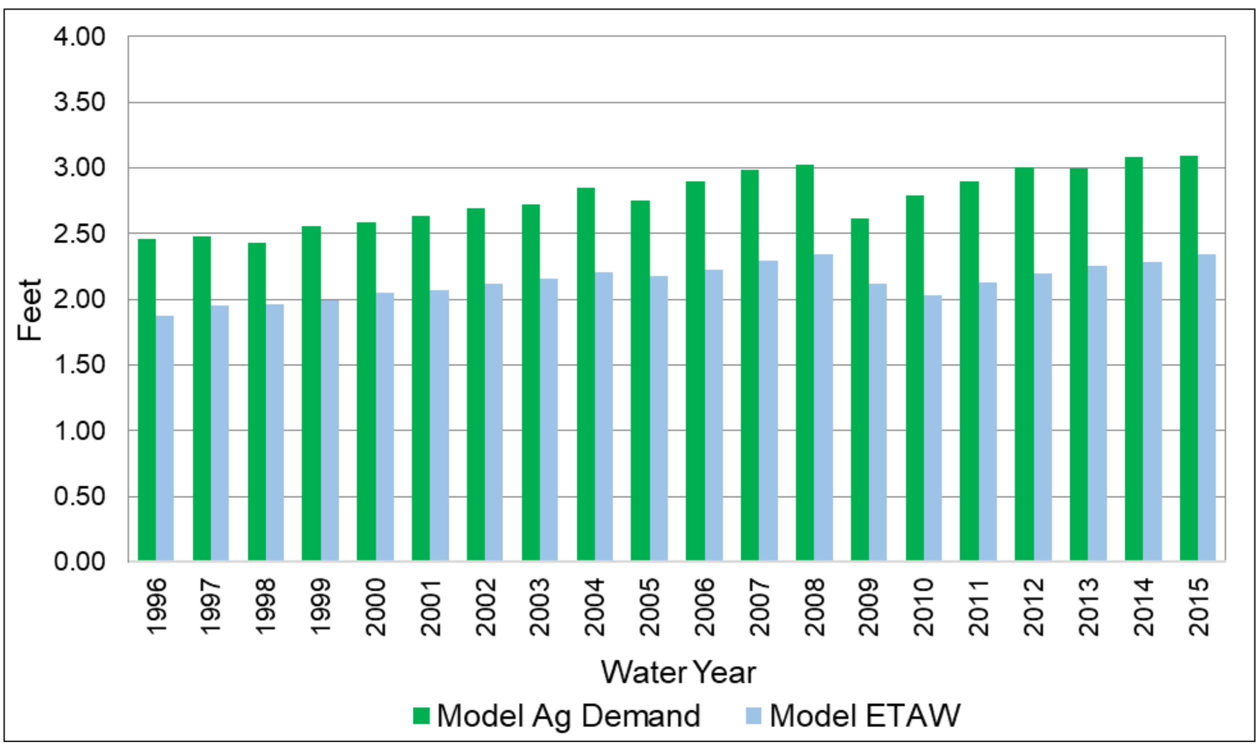

Figure 42k: ESJWRM Agricultural Water Demand – Subarea 5 (South Subarea)

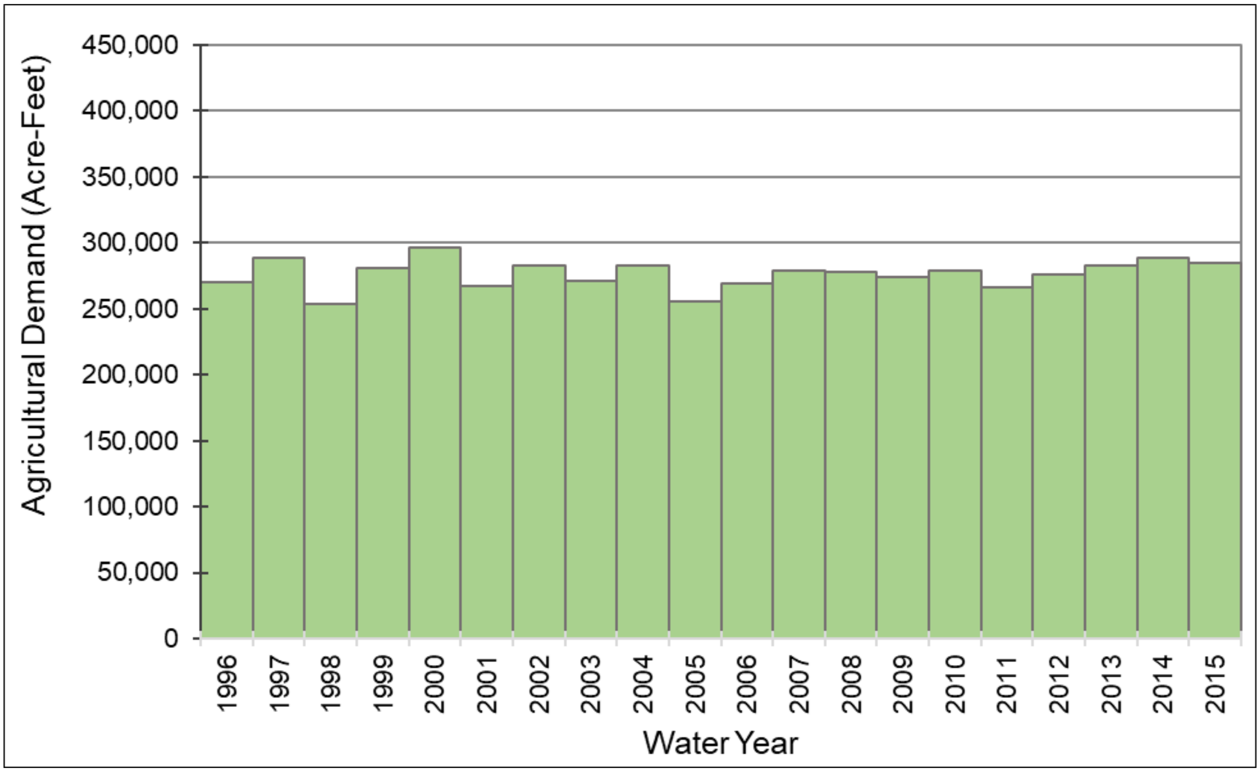

Figure 42l: ESJWRM Unit Agricultural Water Use and ETAW – Subarea 5 (South Subarea)

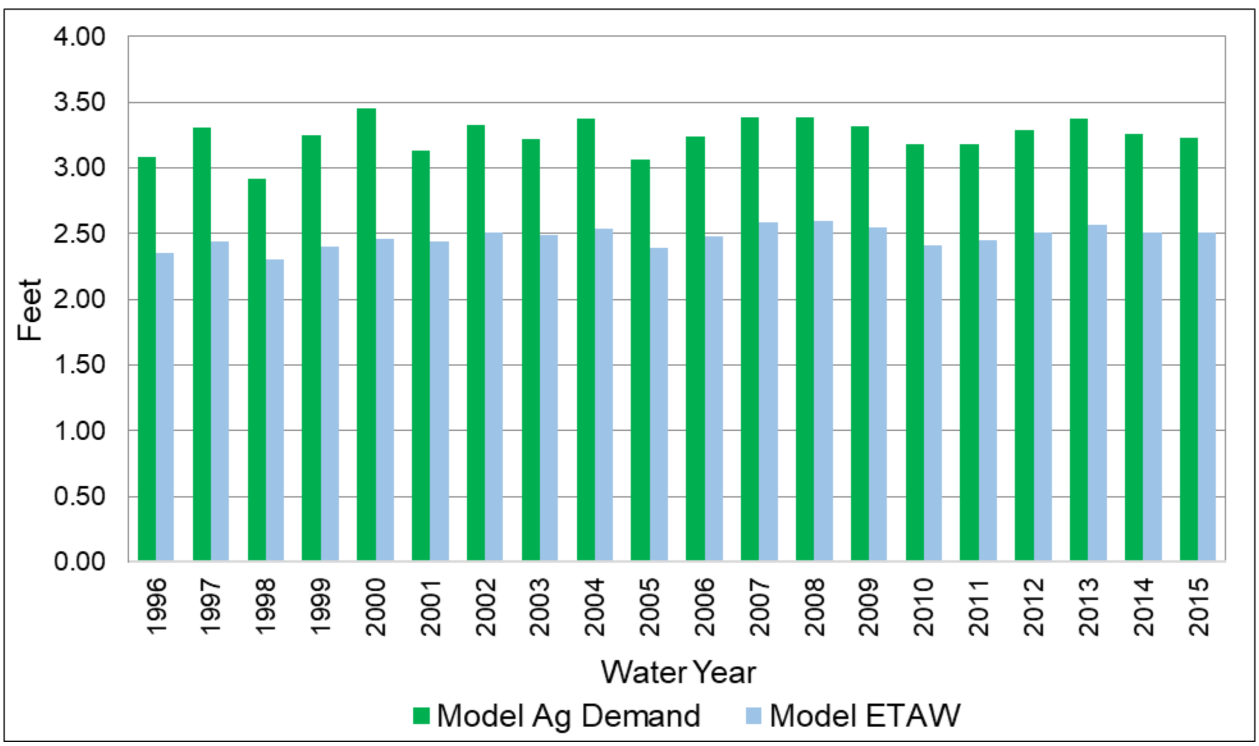

Figure 42m: ESJWRM Agricultural Water Demand – Subarea 6 (Stanislaus Subarea)

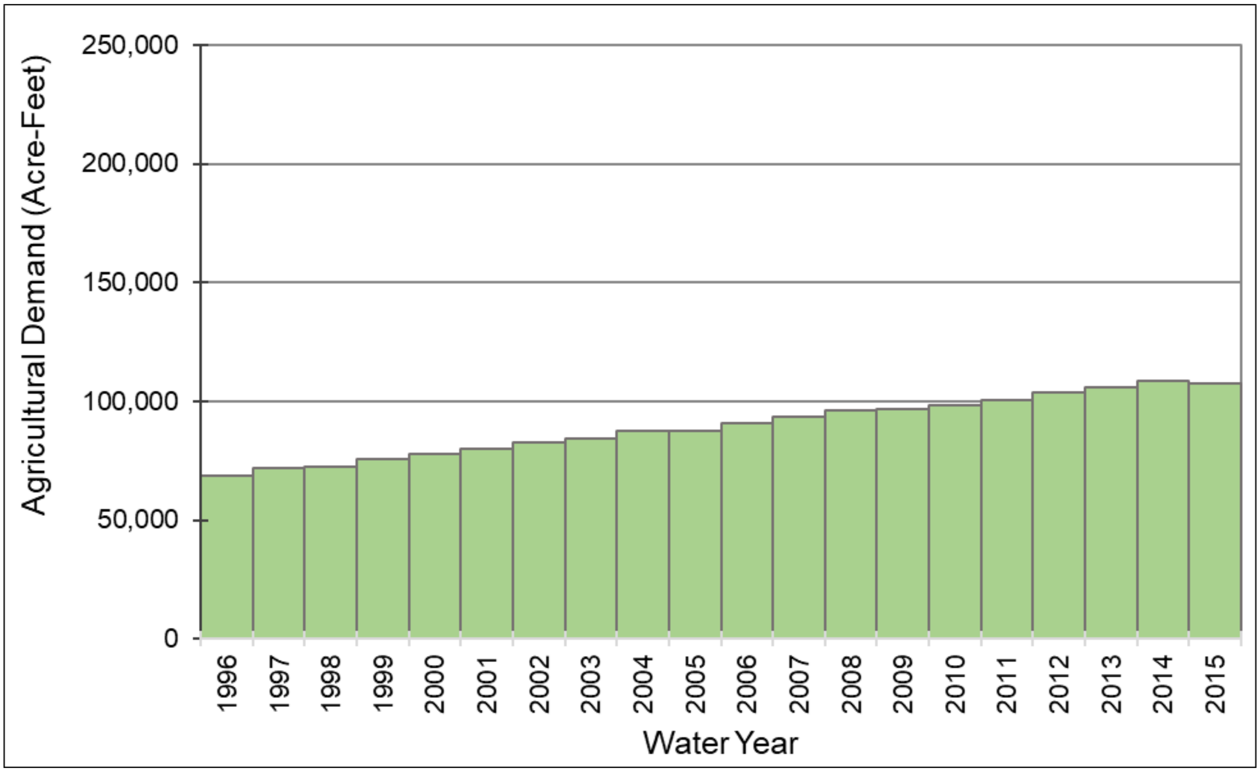

Figure 42n: ESJWRM Unit Agricultural Water Use and ETAW – Subarea 6 (Stanislaus Subarea)

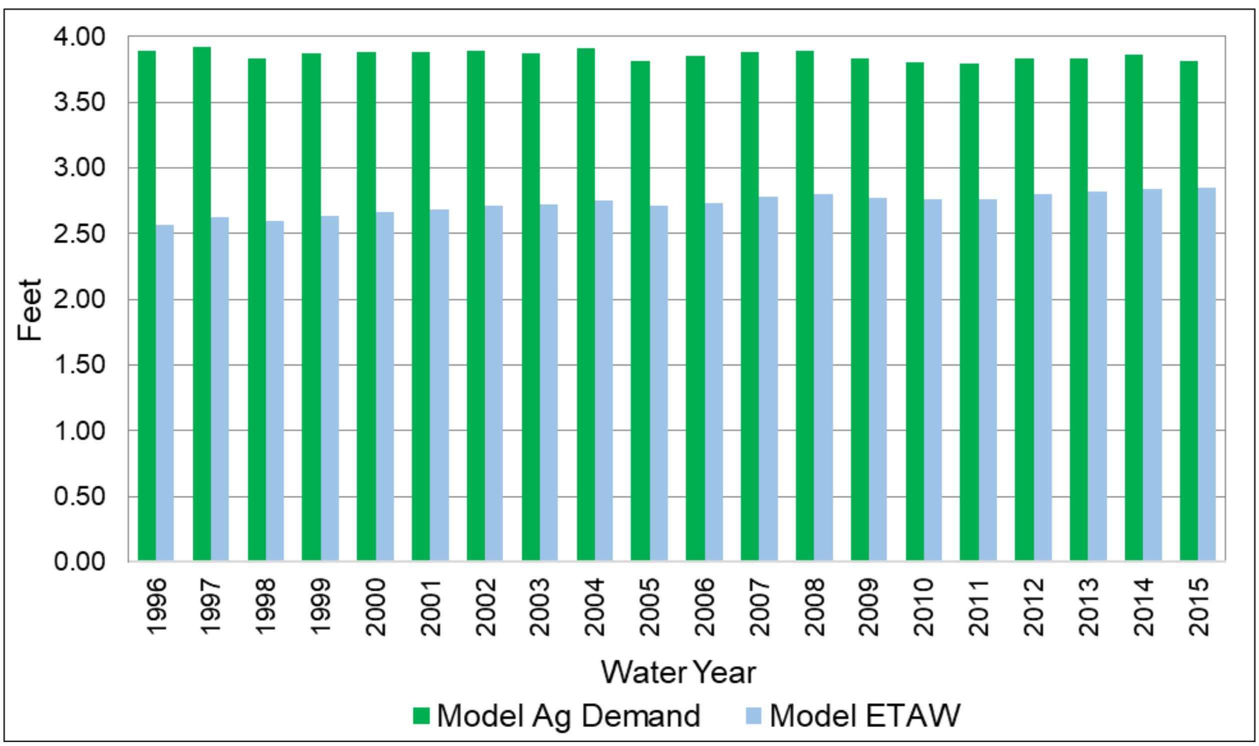

Figure 43a: ESJWRM Urban Water Demand – Eastern San Joaquin Subbasin

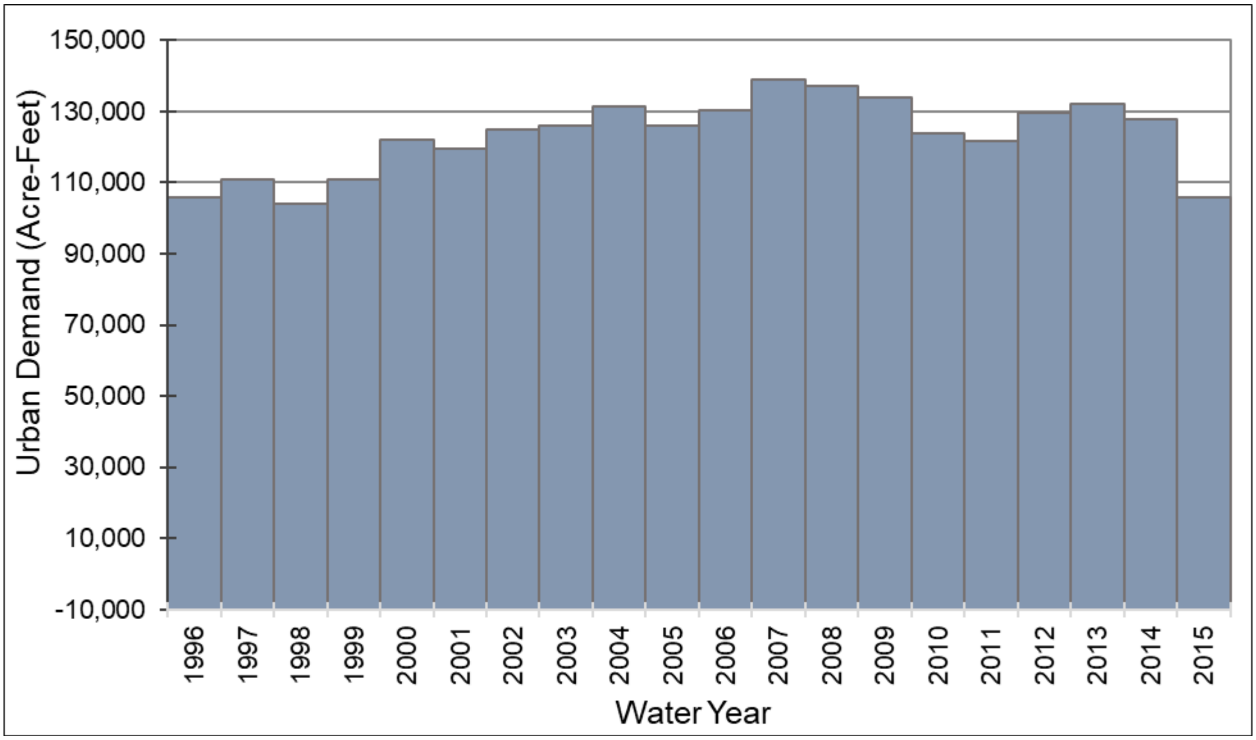

Figure 43b: ESJWRM Urban Water Demand – Subarea 1 (North Delta Subarea)

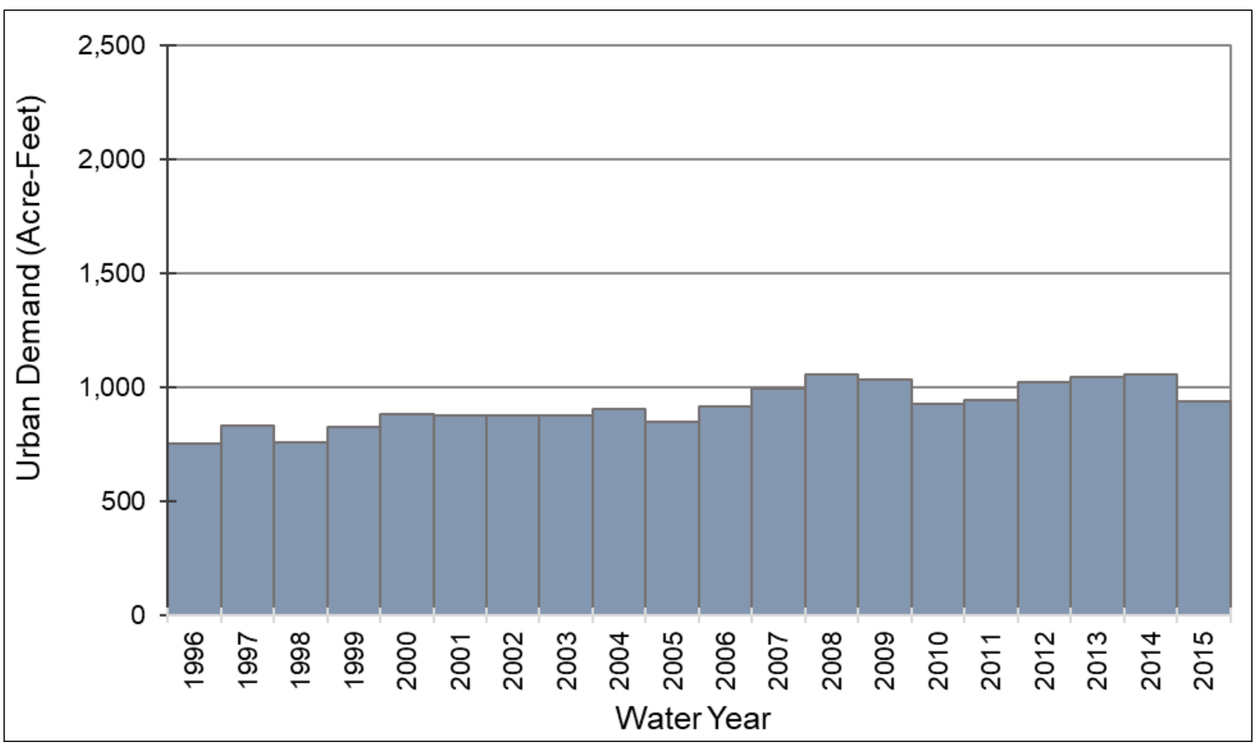

Figure 43c: ESJWRM Urban Water Demand – Subarea 2 (North Subarea)

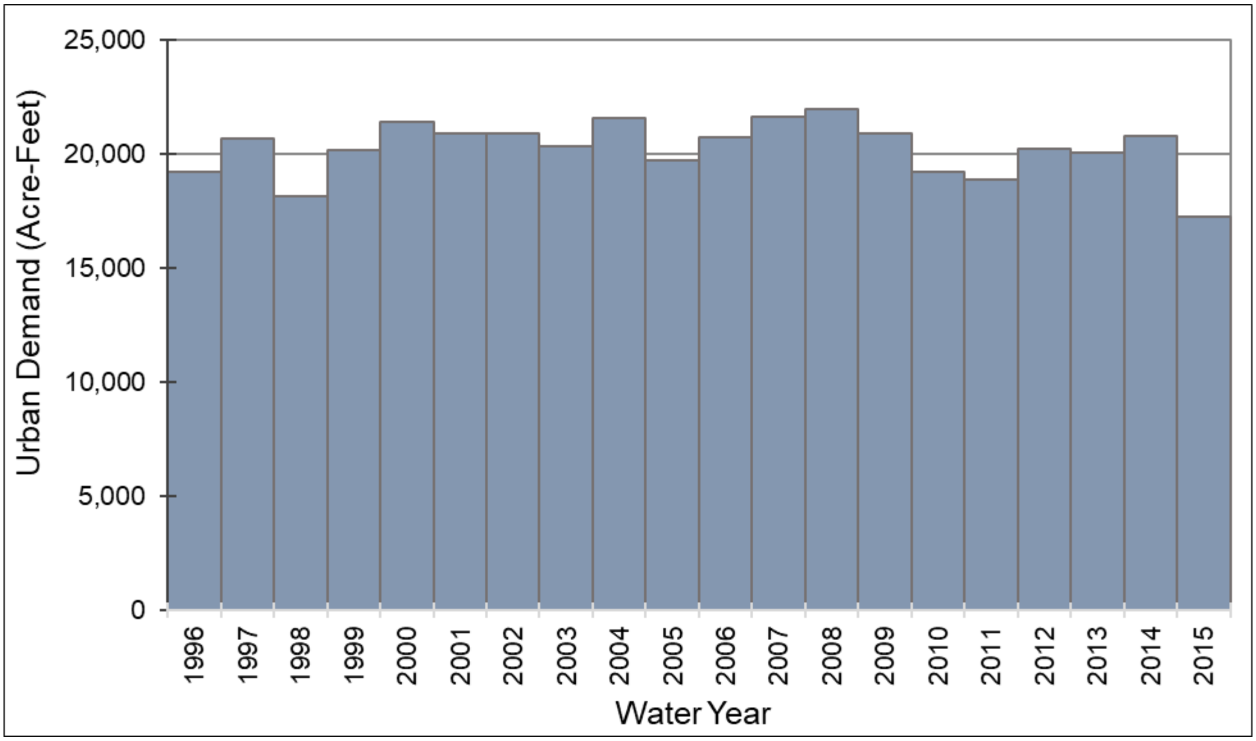

Figure 43d: ESJWRM Urban Water Demand – Subarea 3 (Calaveras Subarea)

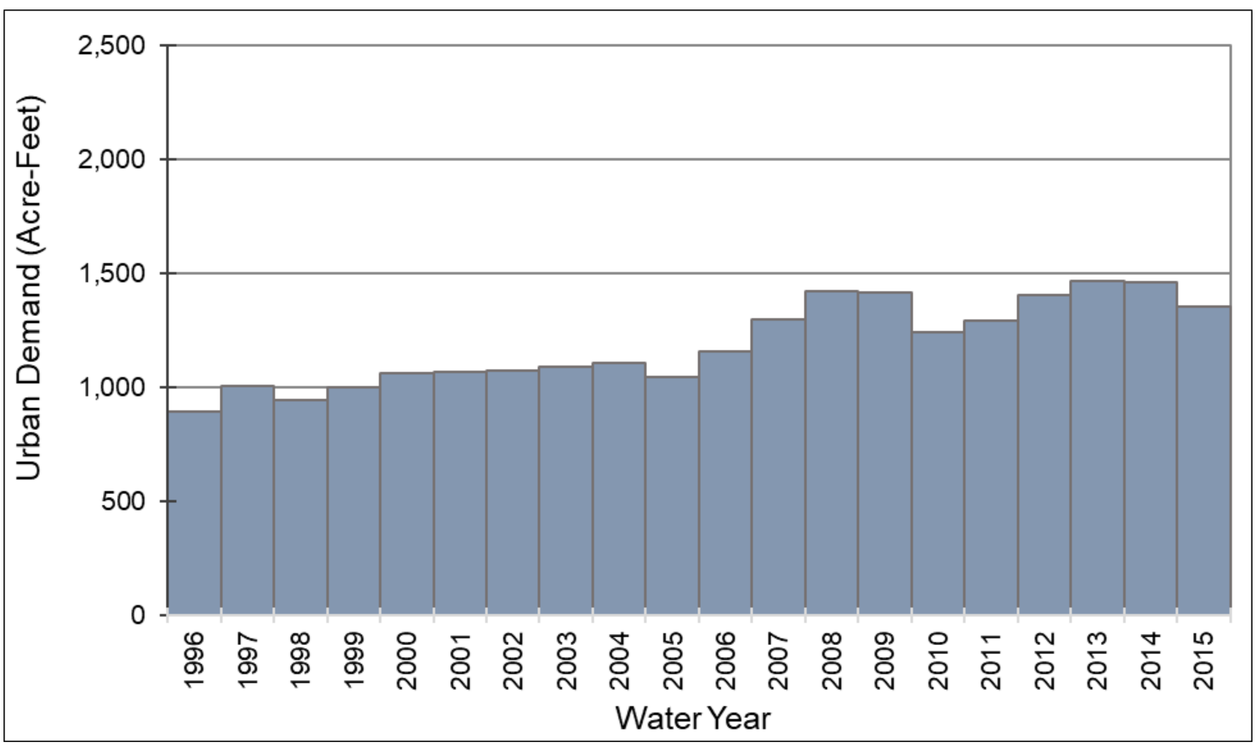

Figure 43e: ESJWRM Urban Water Demand – Subarea 4 (Central Subarea)

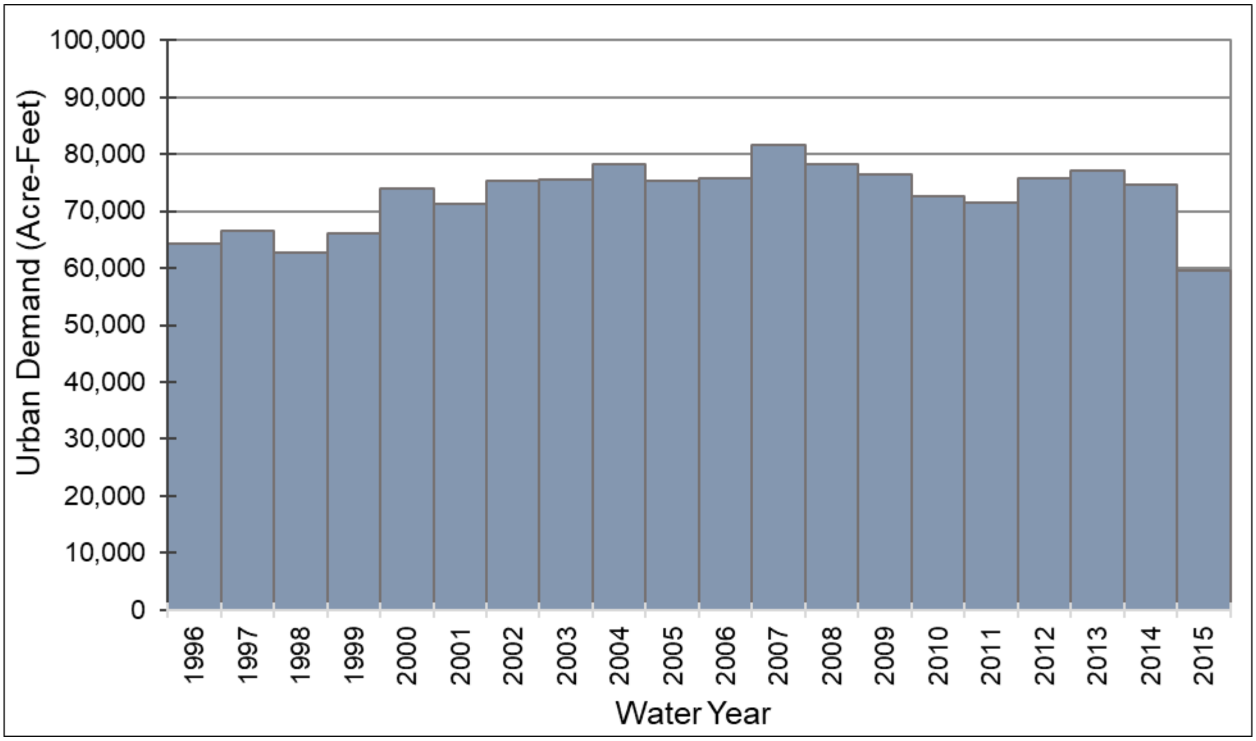

Figure 43f: ESJWRM Urban Water Demand – Subarea 5 (South Subarea)

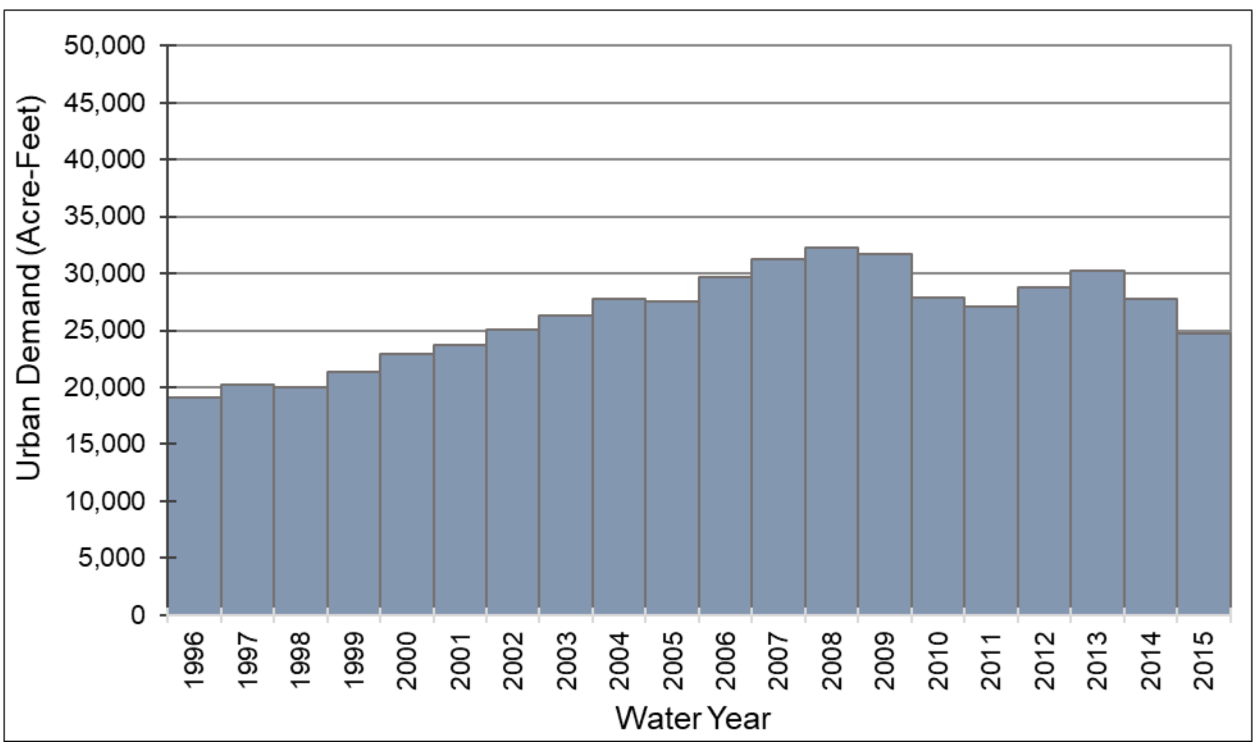

Figure 43g: ESJWRM Urban Water Demand – Subarea 6 (Stanislaus Subarea)

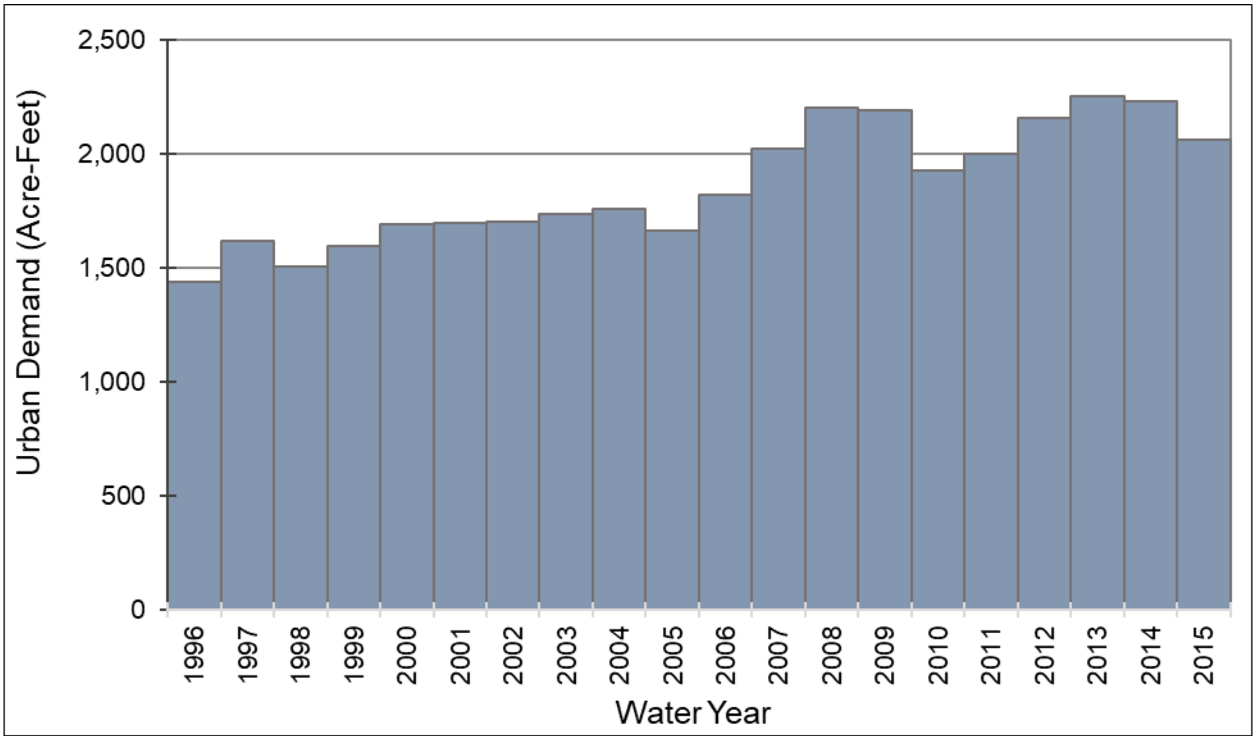

Figure 44: ESJWRM Stream Calibration Gauges

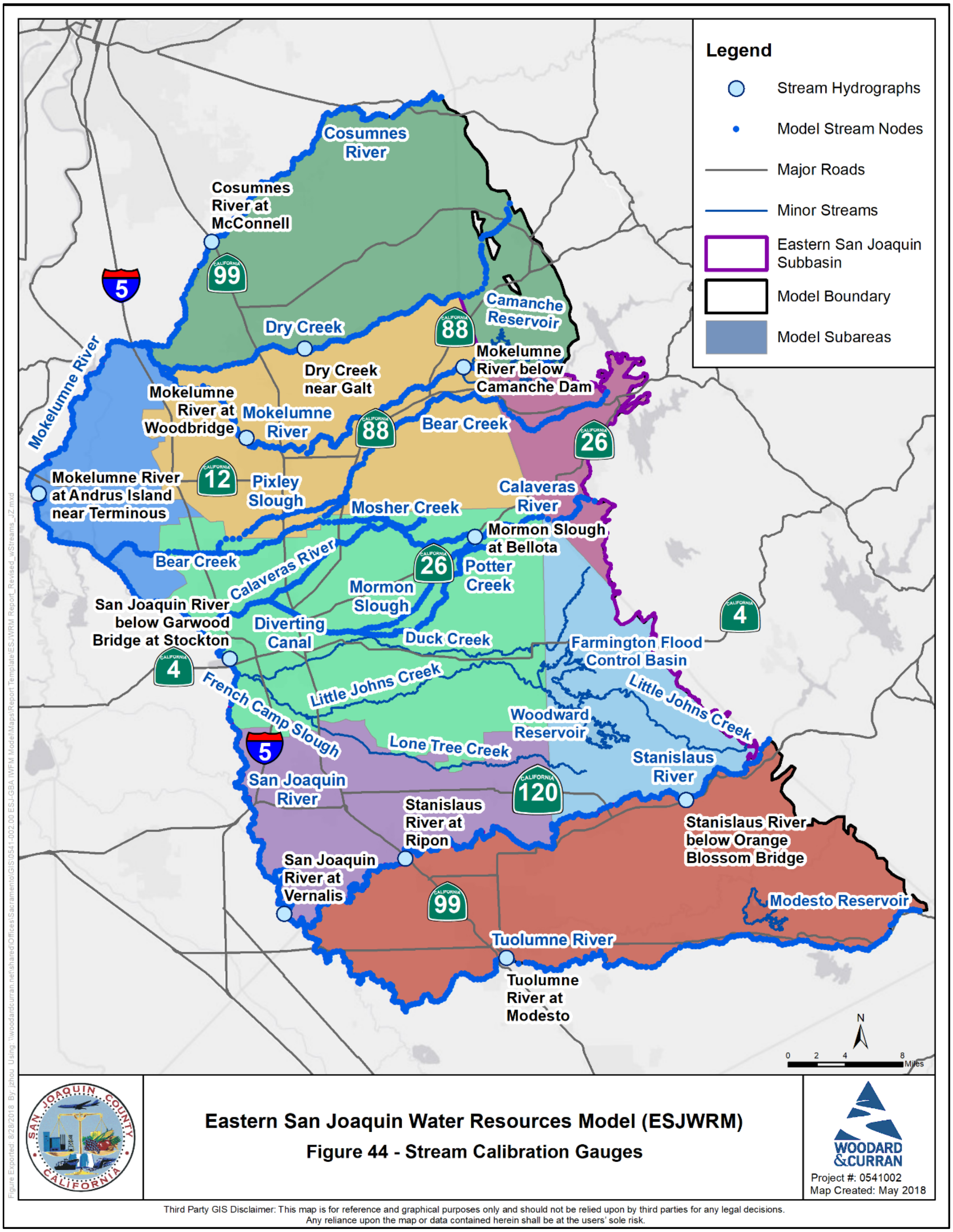

Figure 45: ESJWRM Stream Bed Hydraulic Conductivity

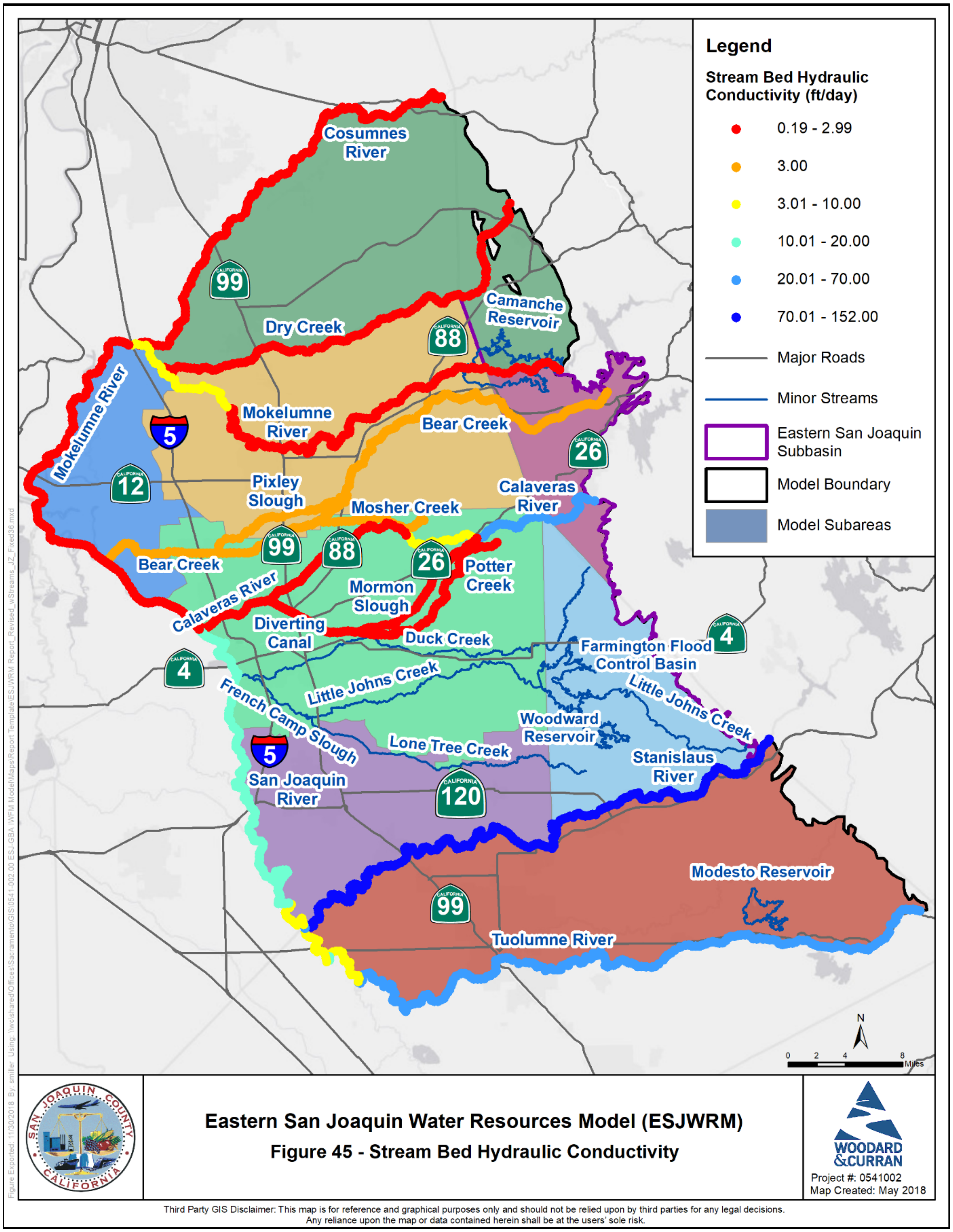

Figure 46a: ESJWRM Stream Calibration Gauges Streamflow – Dry Creek near Galt

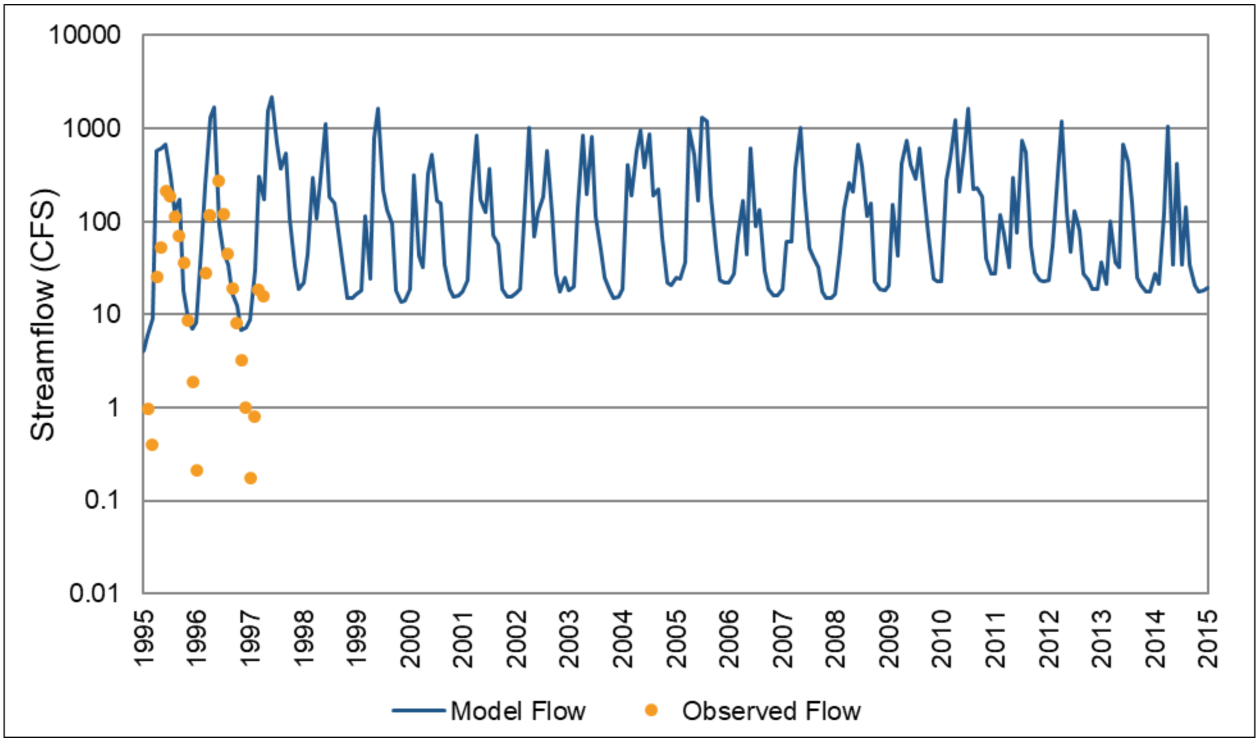

Figure 46b: ESJWRM Stream Calibration Gauges Exceedance – Dry Creek near Galt

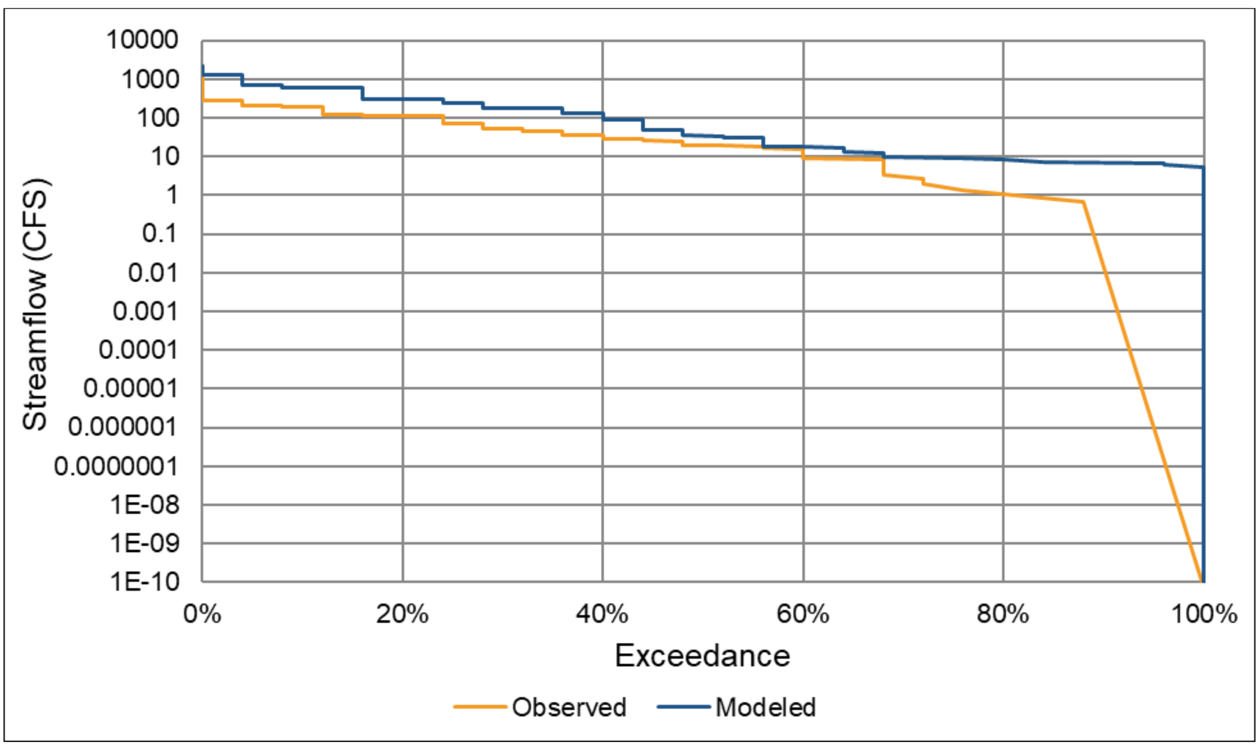

Figure 46c: ESJWRM Stream Calibration Gauges Streamflow – Mokelumne River at Woodbridge

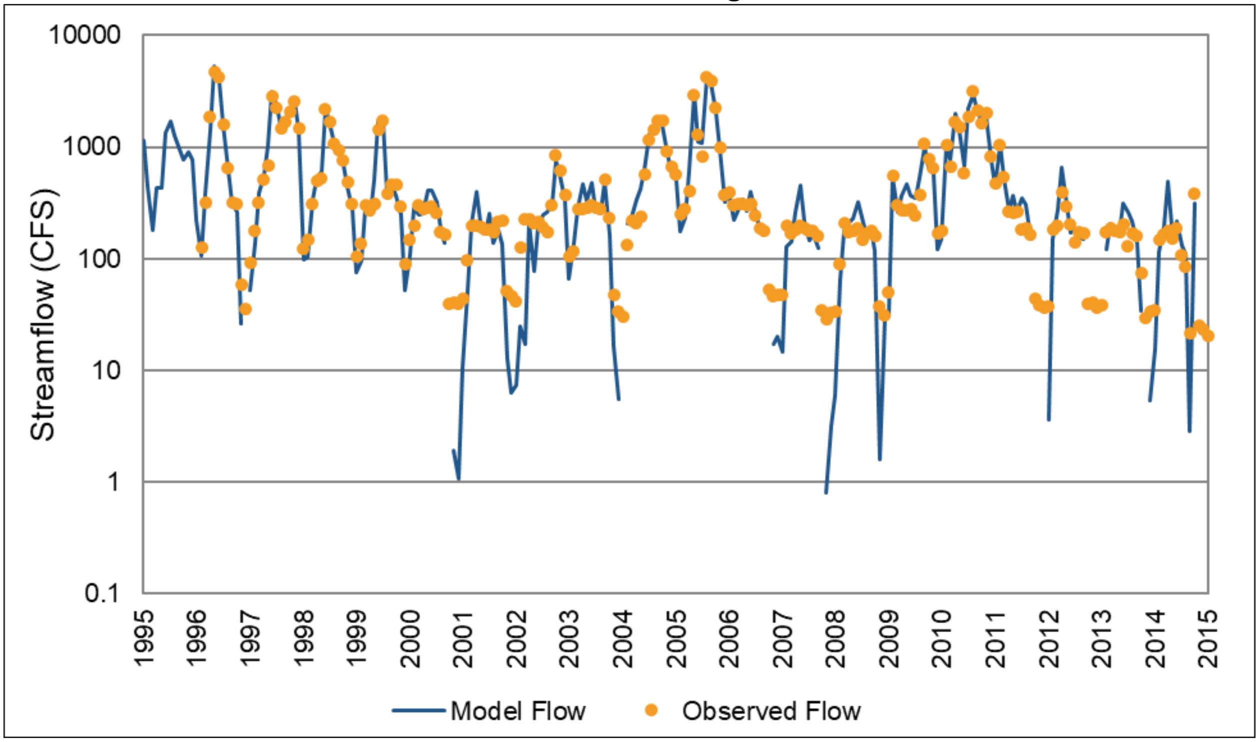

Figure 46d: ESJWRM Stream Calibration Gauges Exceedance – Mokelumne River at Woodbridge

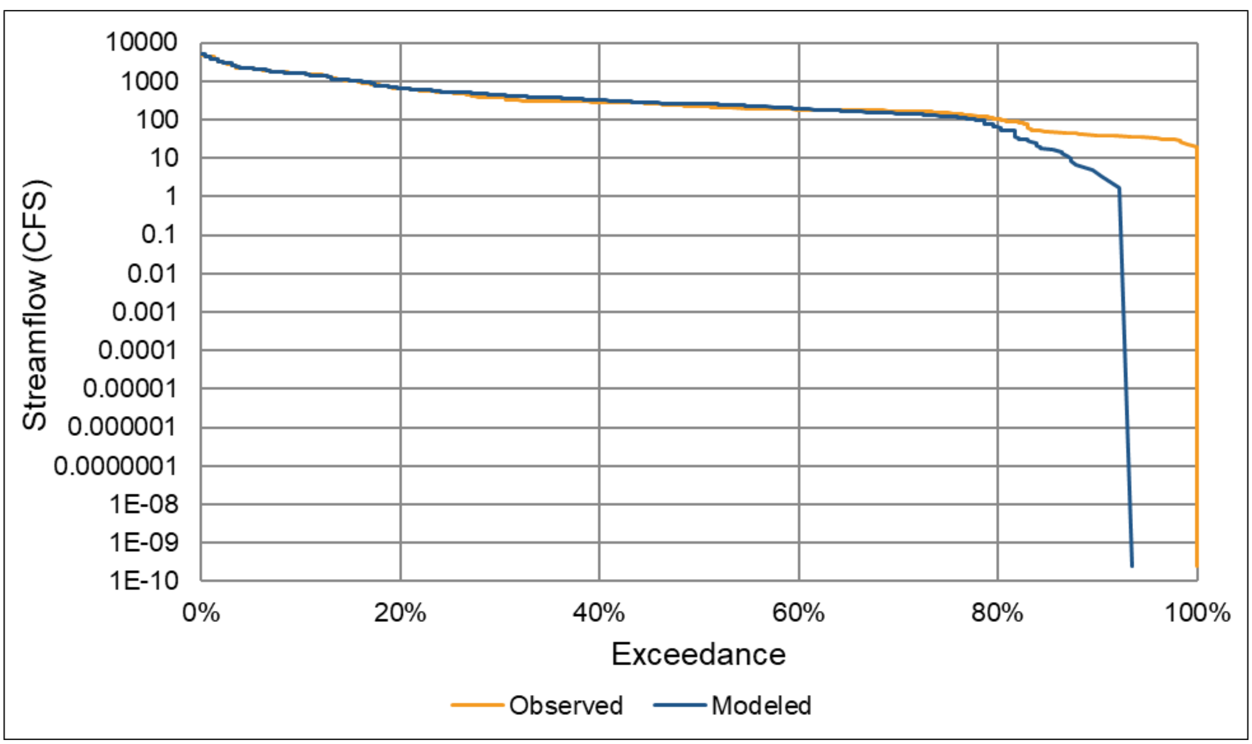

Figure 46e: ESJWRM Stream Calibration Gauges Streamflow – Mormon Slough at Bellota

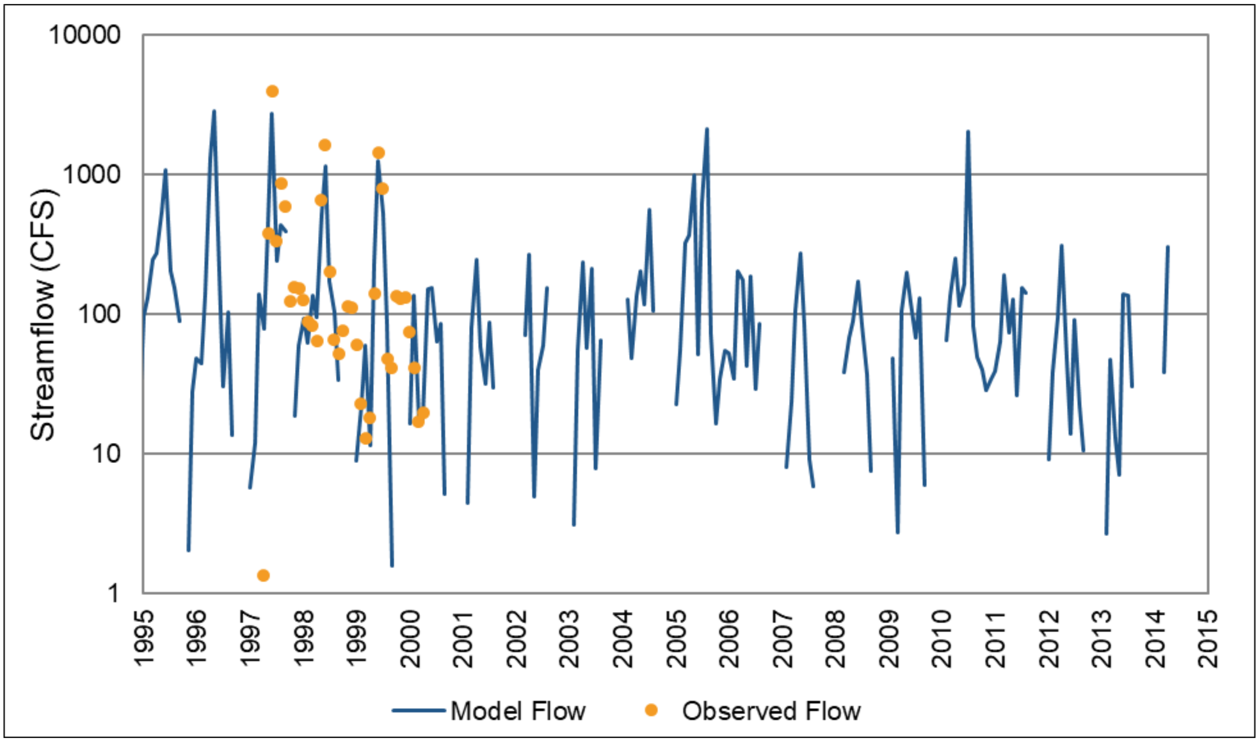

Figure 46f: ESJWRM Stream Calibration Gauges Exceedance – Mormon Slough at Bellota

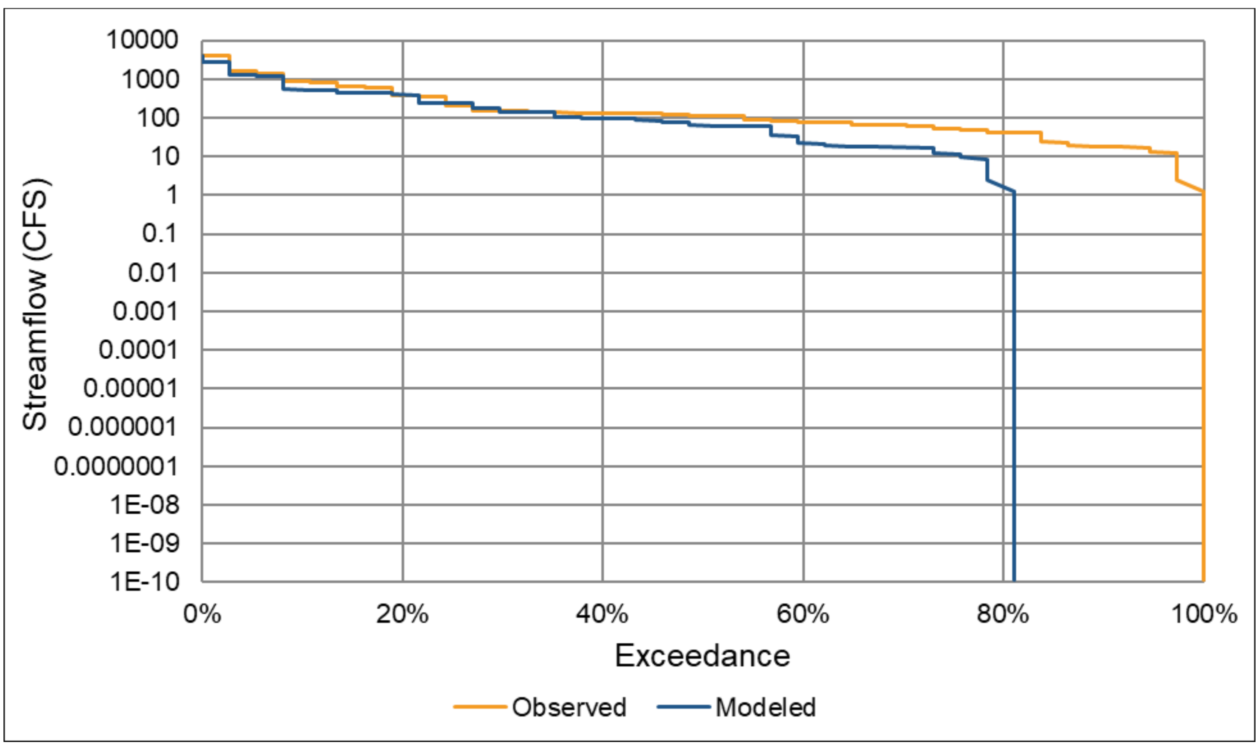

Figure 46g: ESJWRM Stream Calibration Gauges Streamflow – Stanislaus River below Orange Blossom Bridge

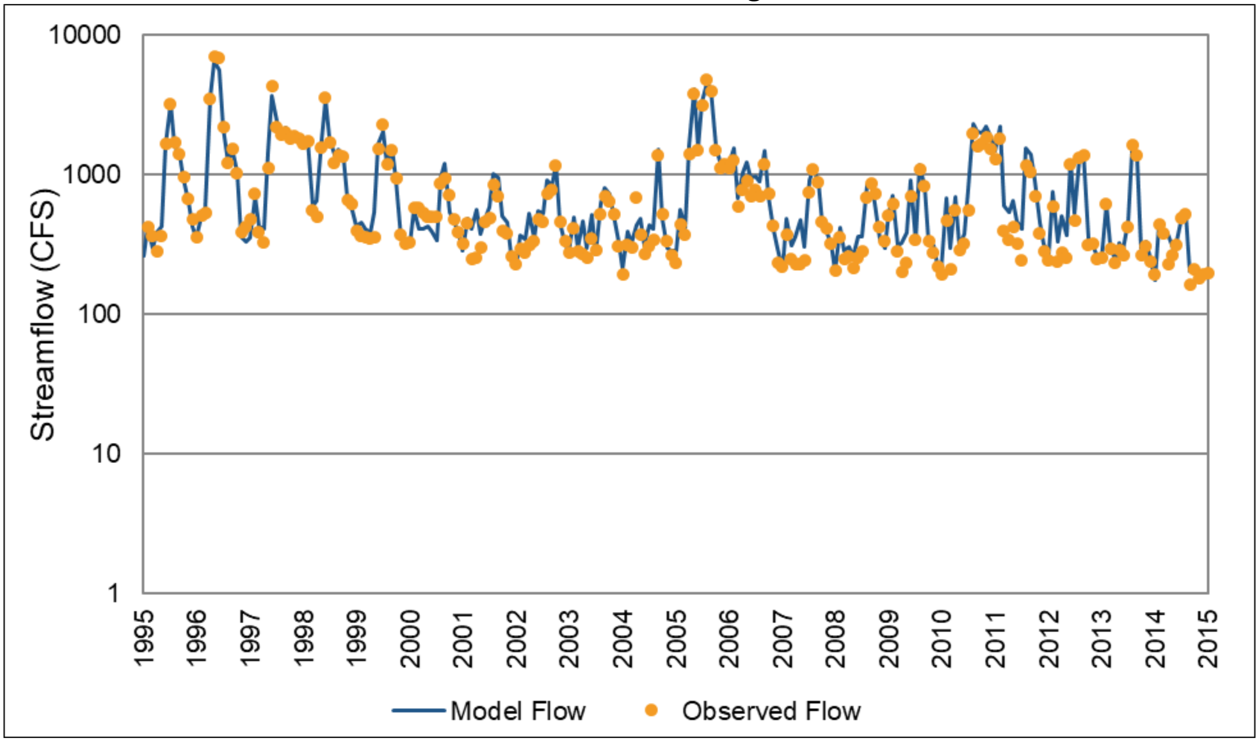

Figure 46h: ESJWRM Stream Calibration Gauges Exceedance – Stanislaus River below Orange Blossom Bridge

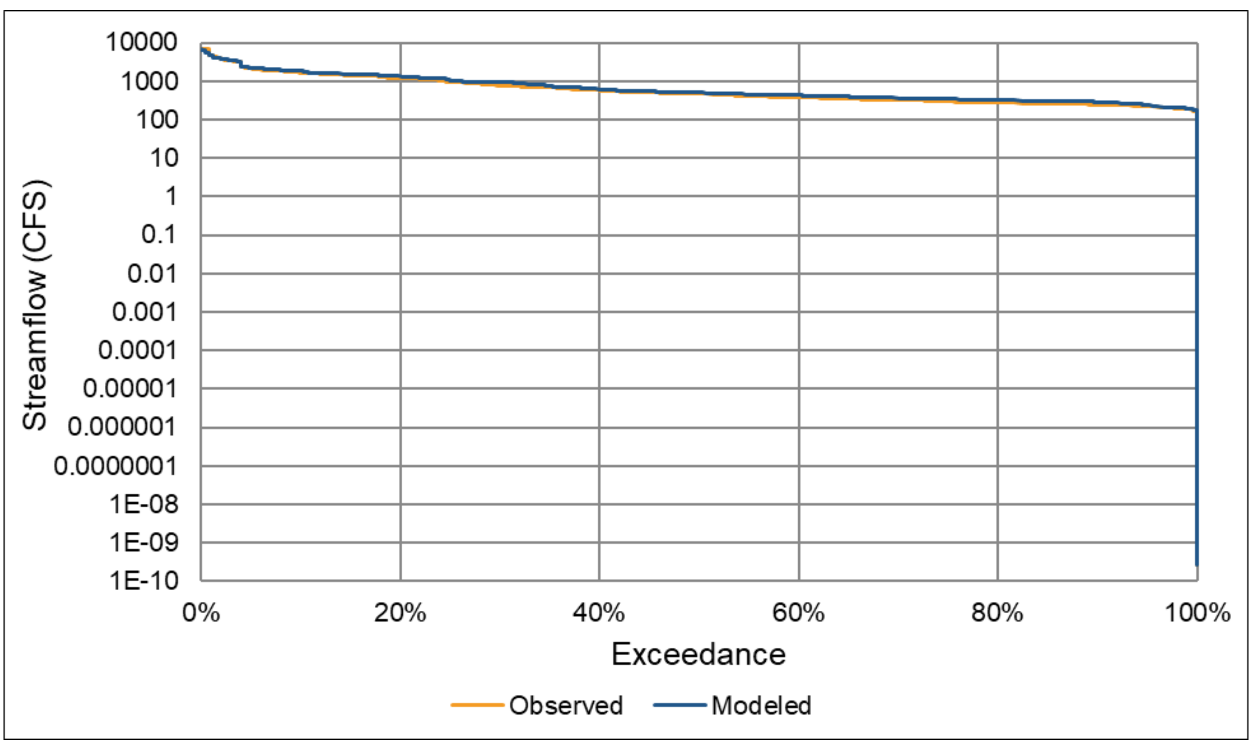

Figure 46i: ESJWRM Stream Calibration Gauges Streamflow – San Joaquin River below Garwood Bridge at Stockton

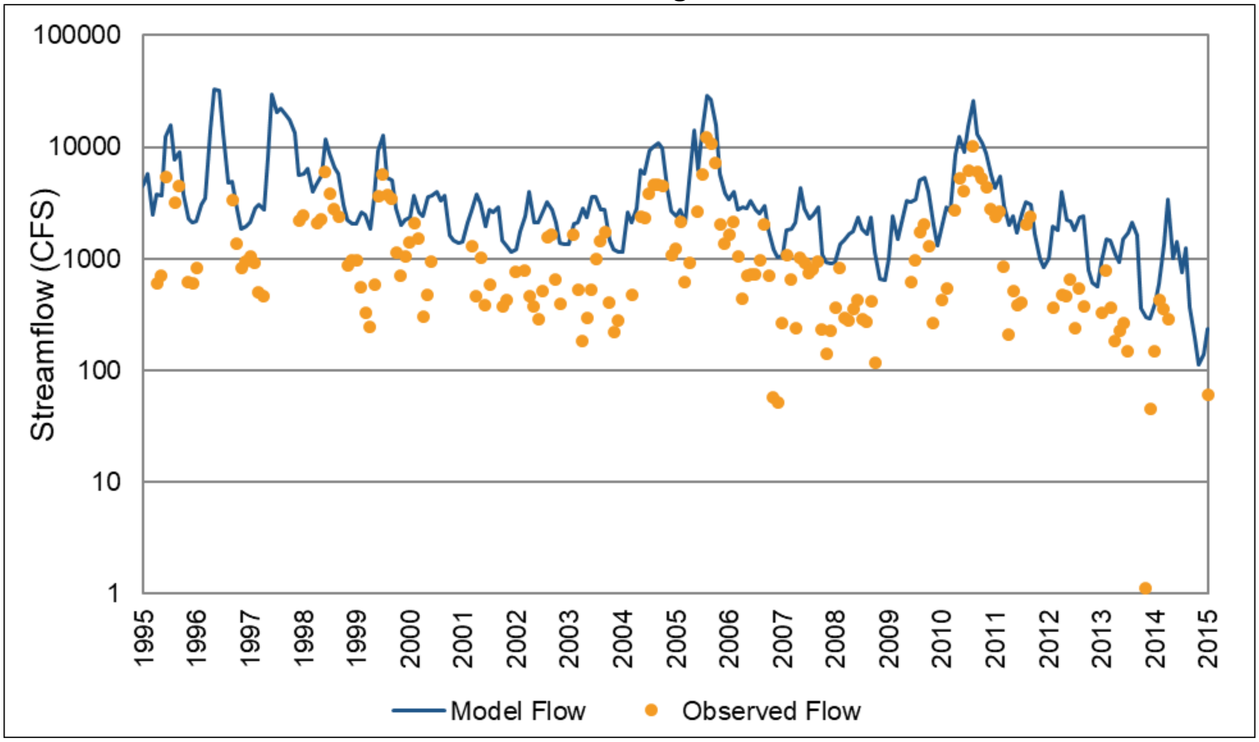

Figure 46j: ESJWRM Stream Calibration Gauges Exceedance – San Joaquin River below Garwood Bridge at Stockton

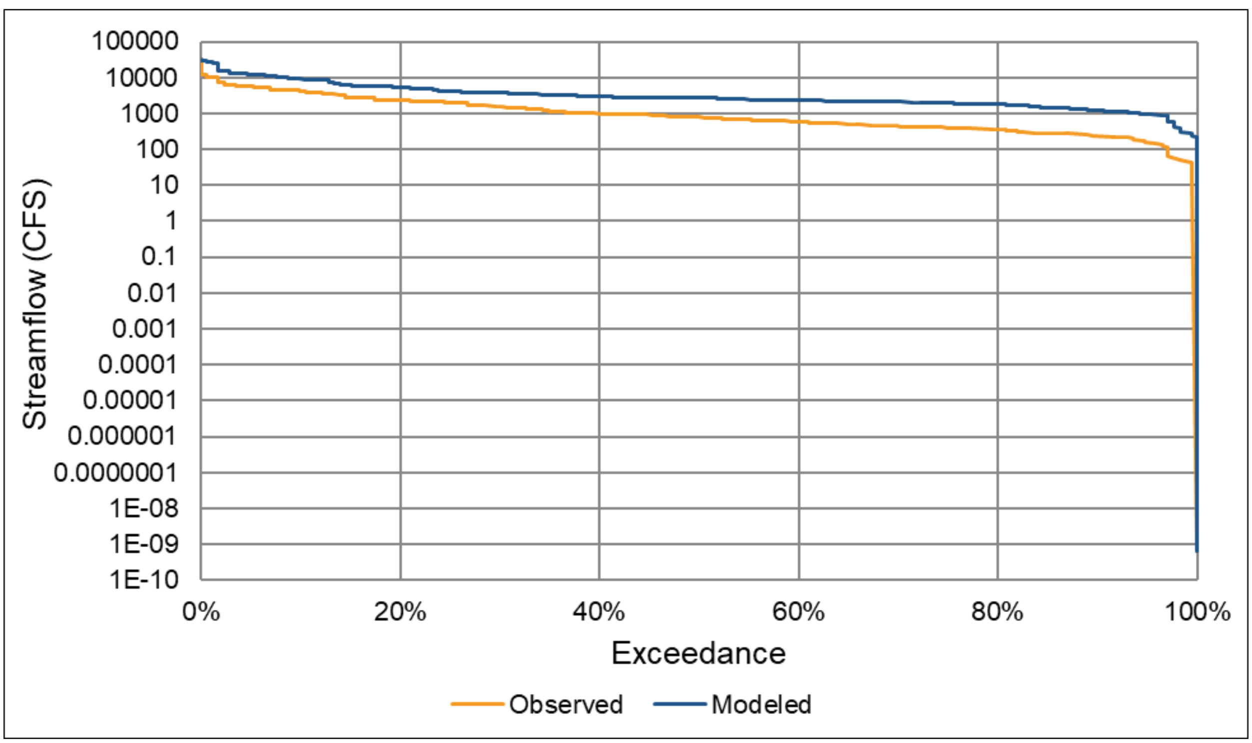

Figure 47a: ESJWRM Agricultural Land and Water Use Budget – Eastern San Joaquin Subbasin

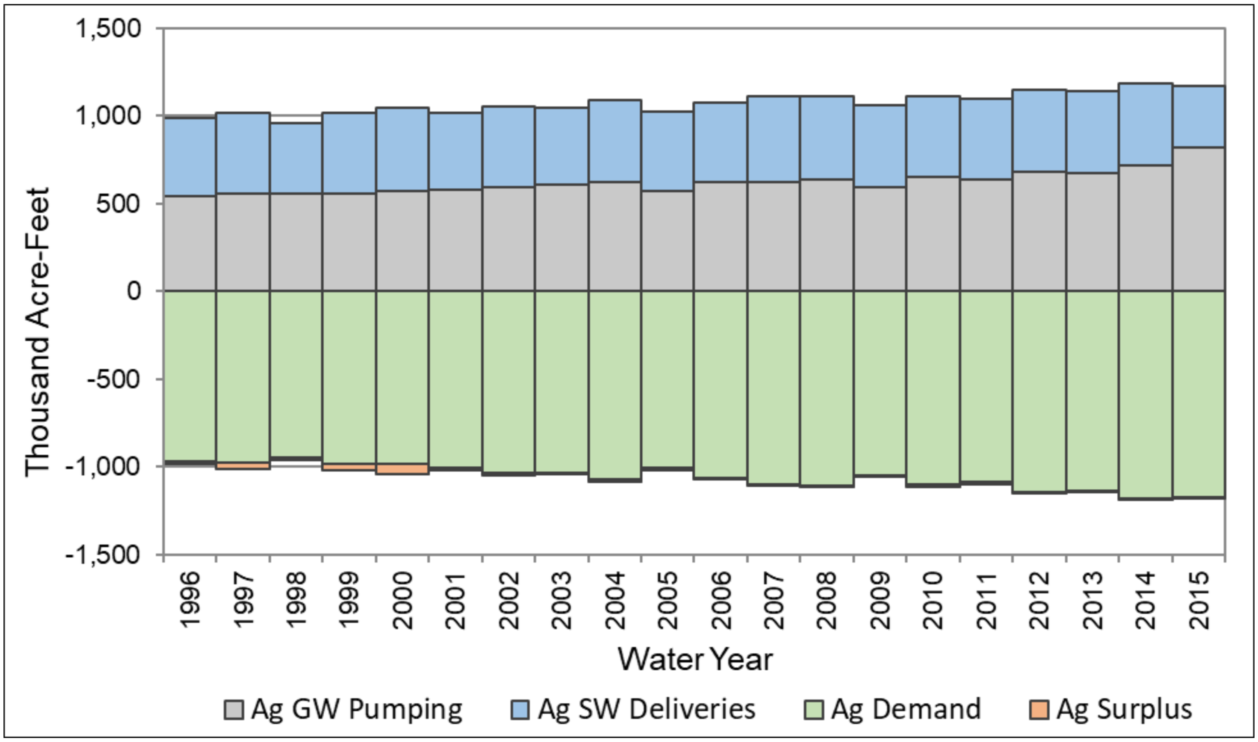

Figure 47b: ESJWRM Agricultural Land and Water Use Budget – Subarea 1 (North Delta Subarea)

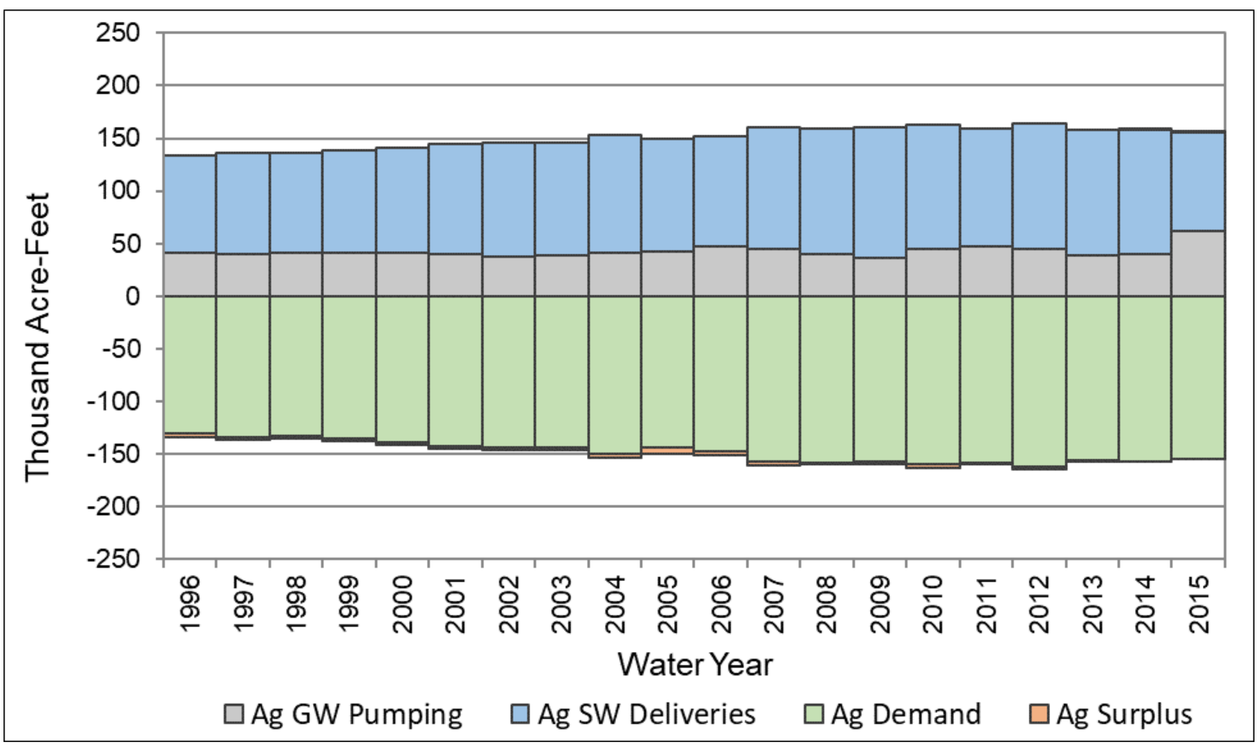

Figure 47c: ESJWRM Agricultural Land and Water Use Budget – Subarea 2 (North Subarea)

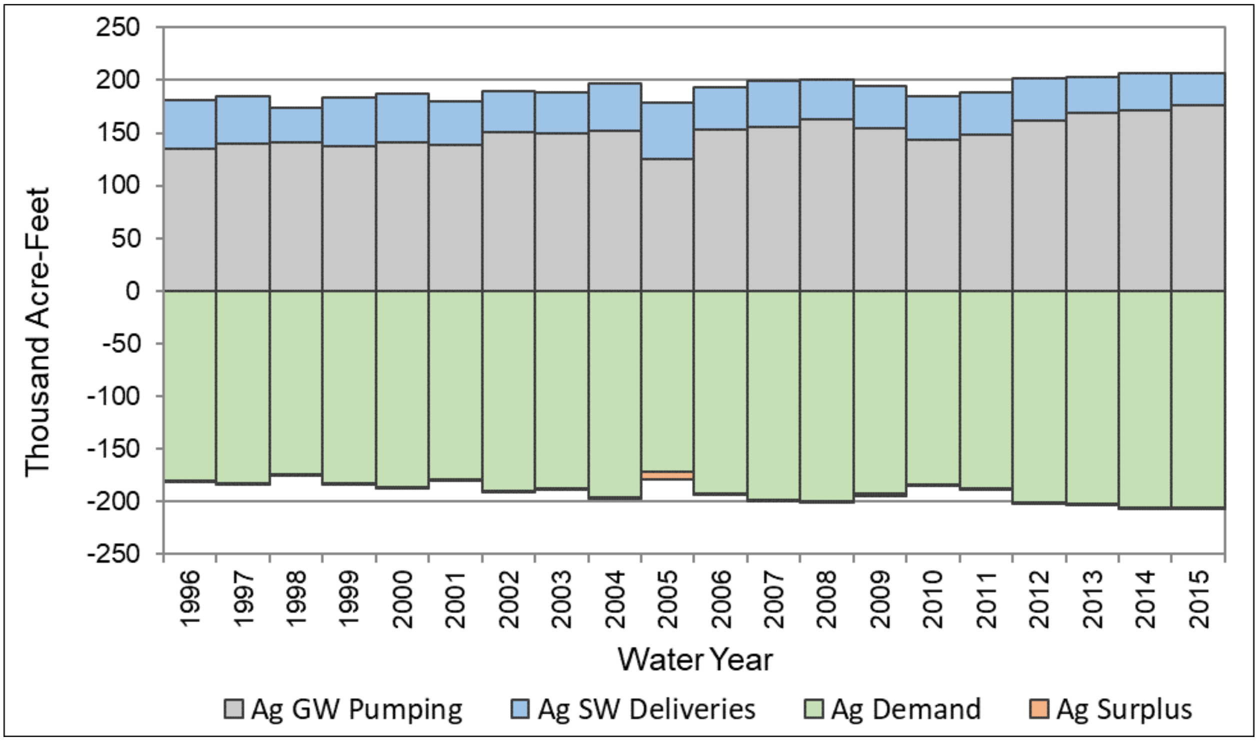

Figure 47d: ESJWRM Agricultural Land and Water Use Budget – Subarea 3 (Calaveras Subarea)

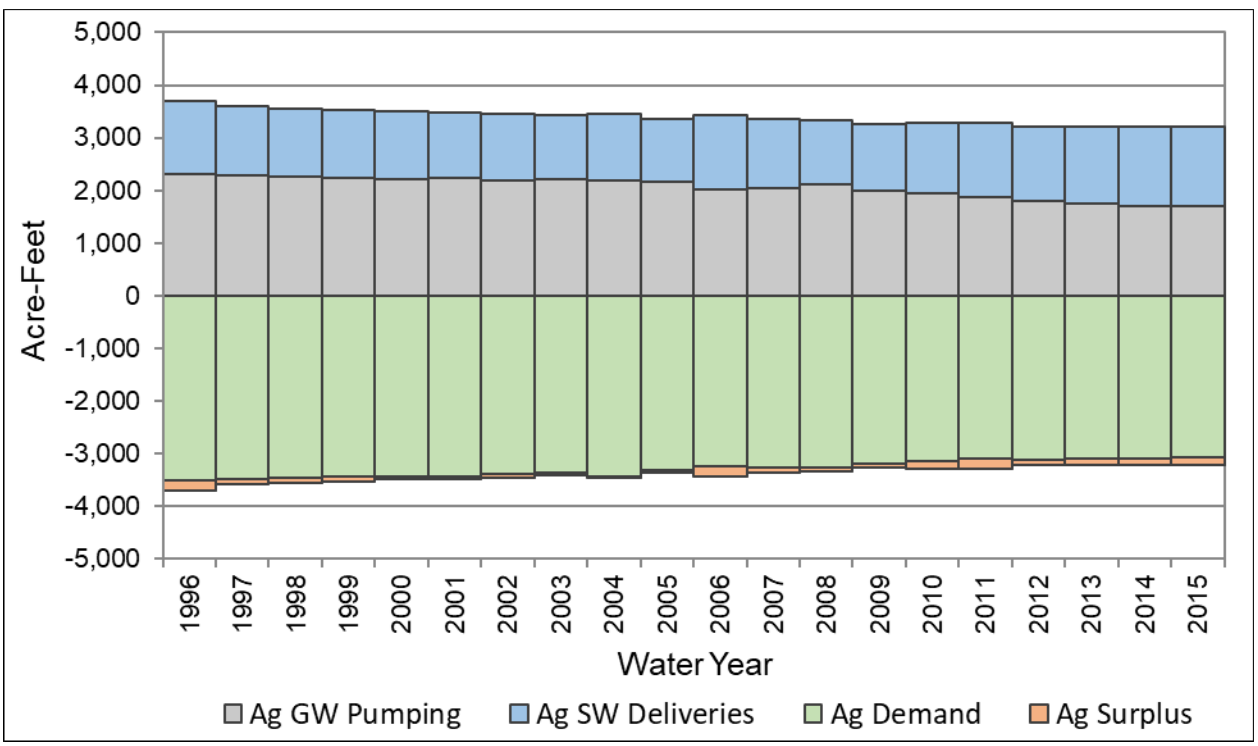

Figure 47e: ESJWRM Agricultural Land and Water Use Budget – Subarea 4 (Central Subarea)

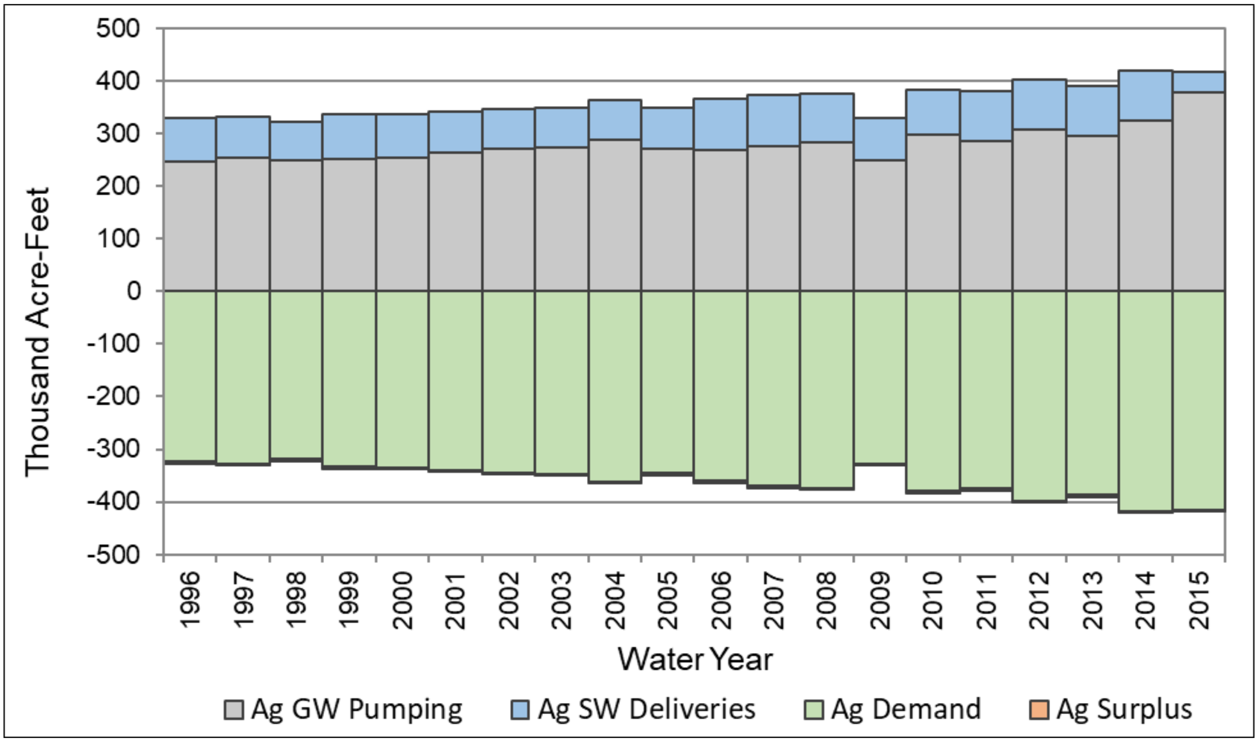

Figure 47f: ESJWRM Agricultural Land and Water Use Budget – Subarea 5 (South Subarea)

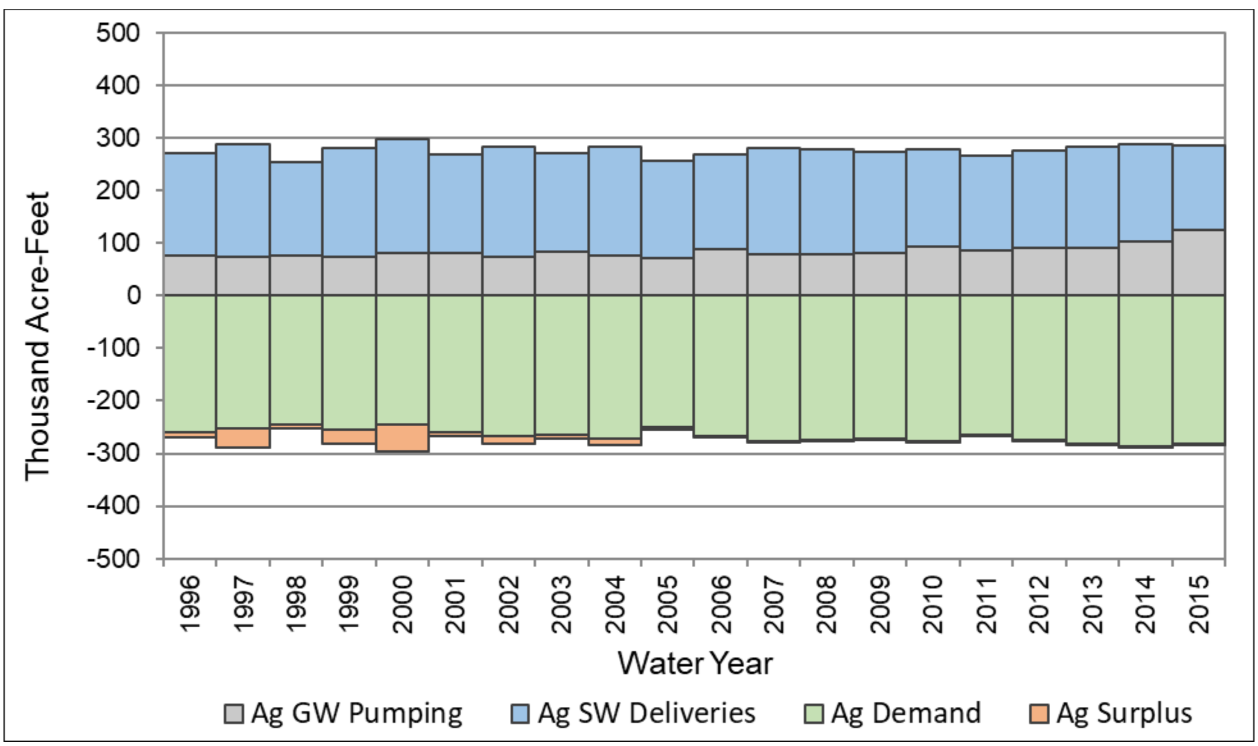

Figure 47g: ESJWRM Agricultural Land and Water Use Budget – Subarea 6 (Stanislaus Subarea)

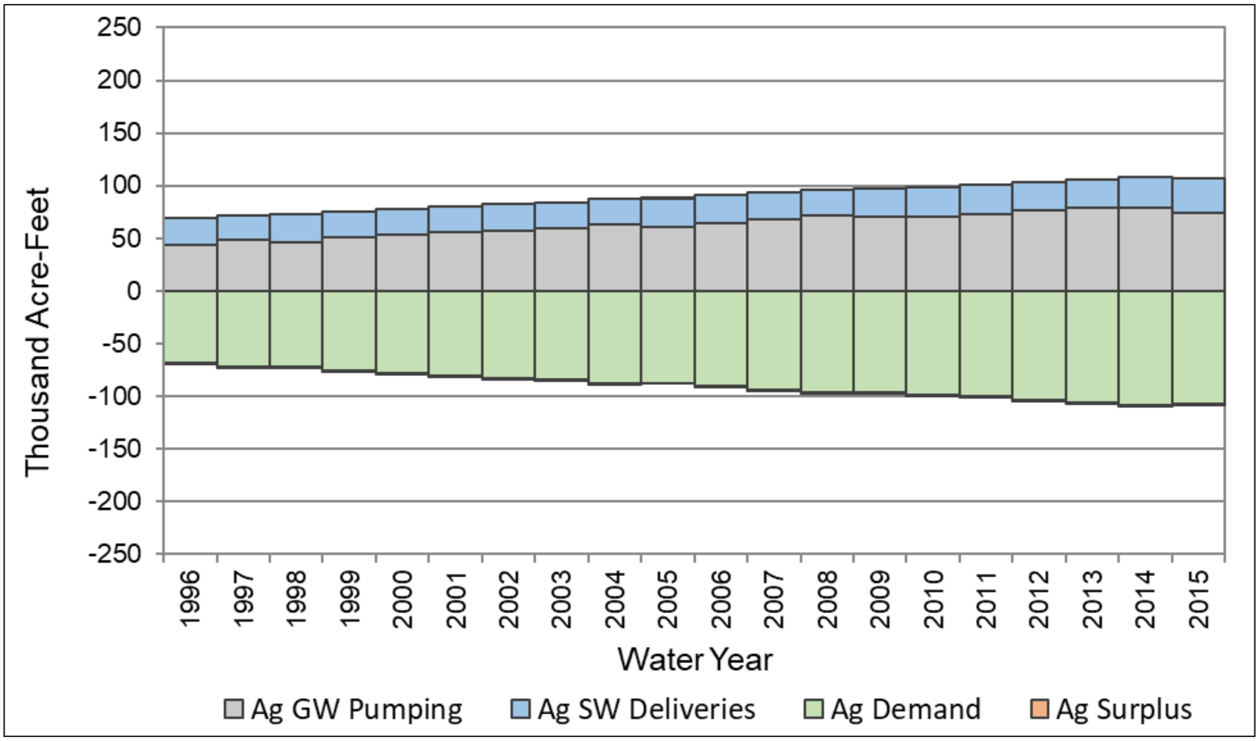

Figure 48a: ESJWRM Urban Land and Water Use Budget – Eastern San Joaquin Subbasin

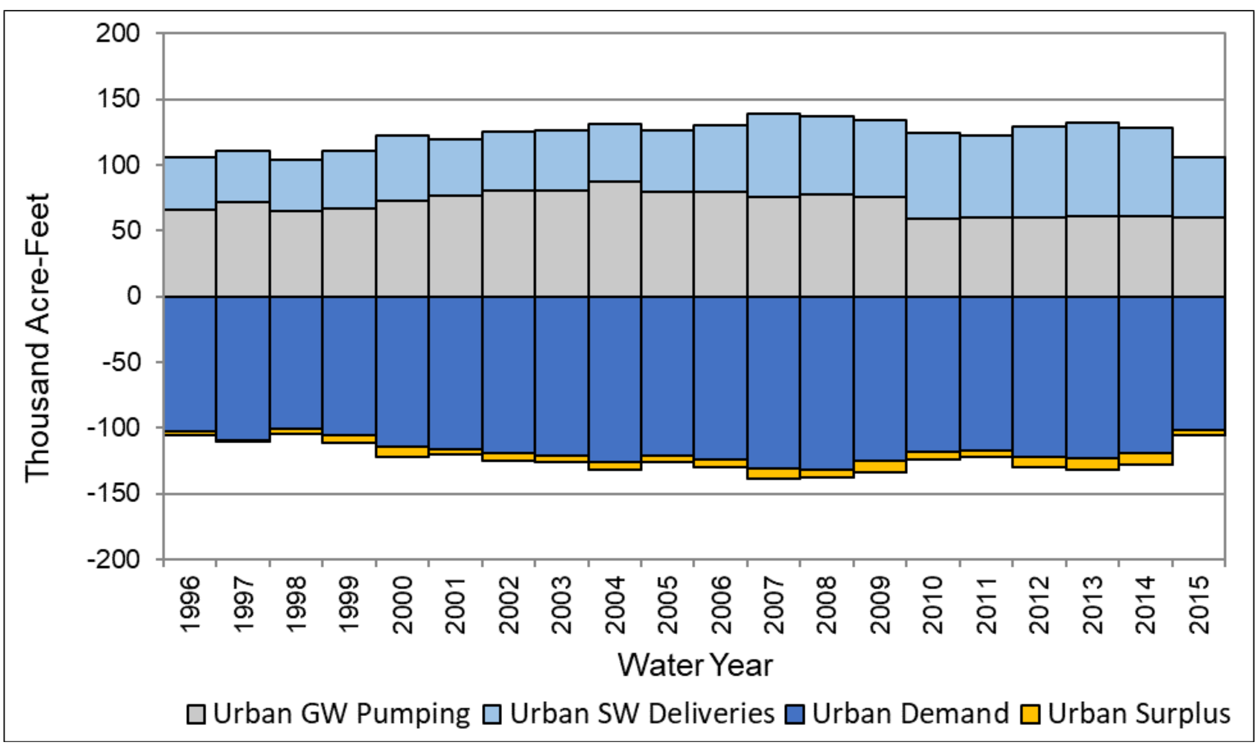

Figure 48b: ESJWRM Urban Land and Water Use Budget – Subarea 1 (North Delta Subarea)

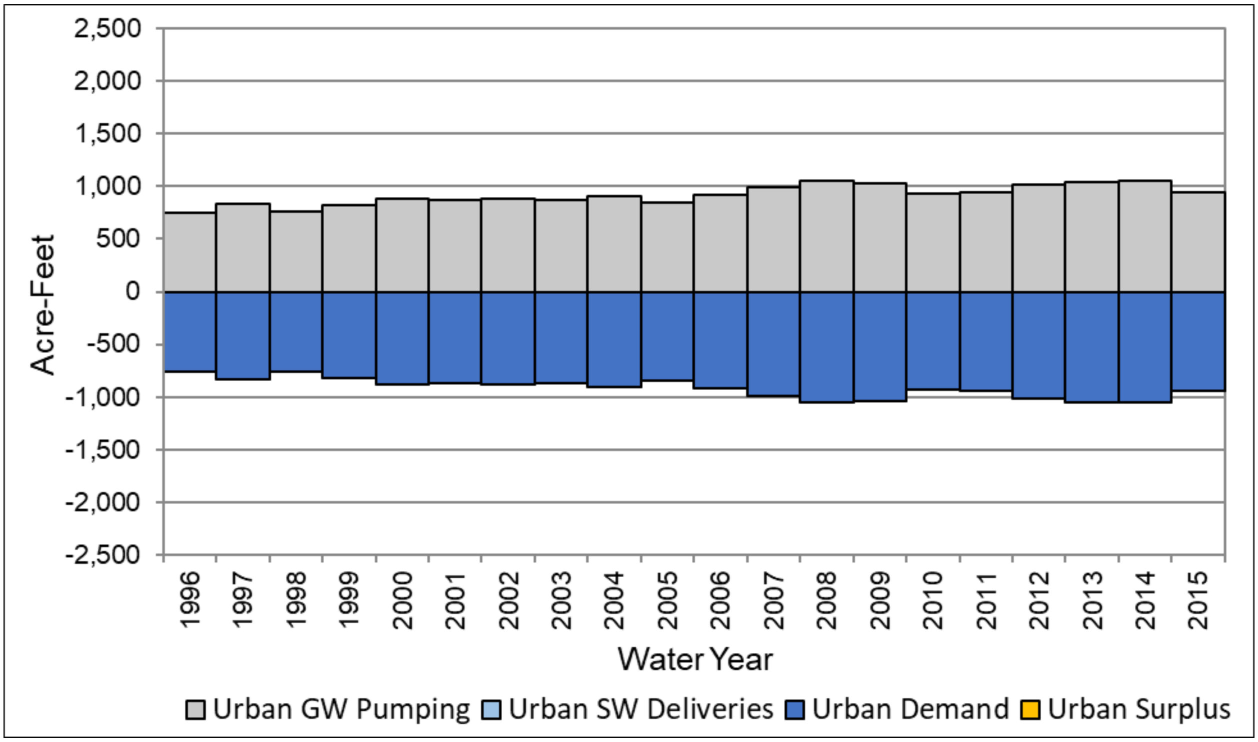

Figure 48c: ESJWRM Urban Land and Water Use Budget – Subarea 2 (North Subarea)

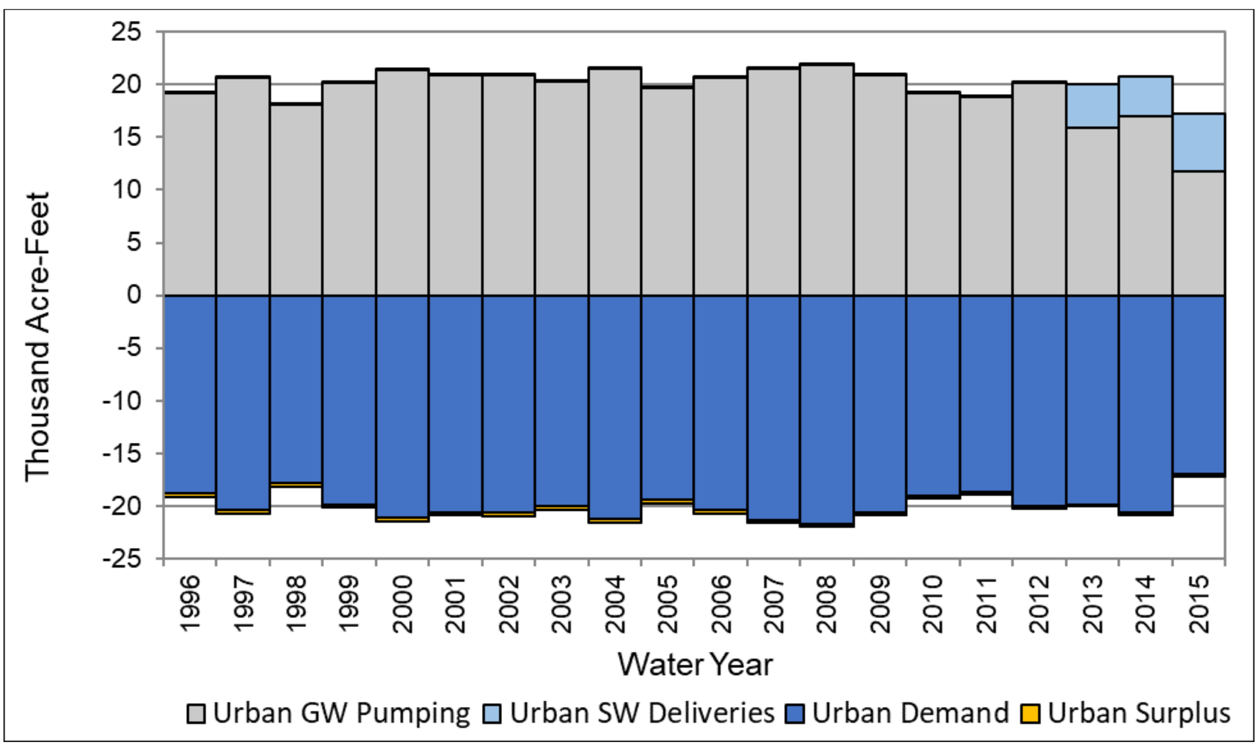

Figure 48d: ESJWRM Urban Land and Water Use Budget – Subarea 3 (Calaveras Subarea)

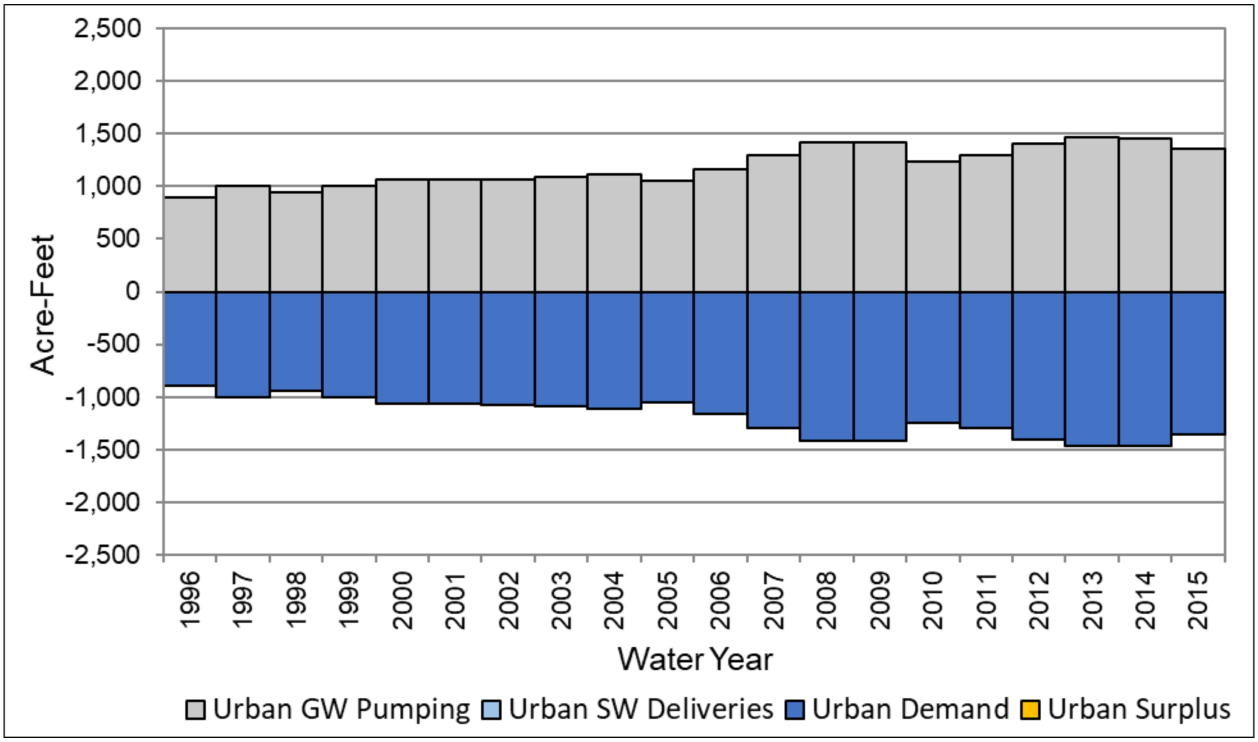

Figure 48e: ESJWRM Urban Land and Water Use Budget – Subarea 4 (Central Subarea)

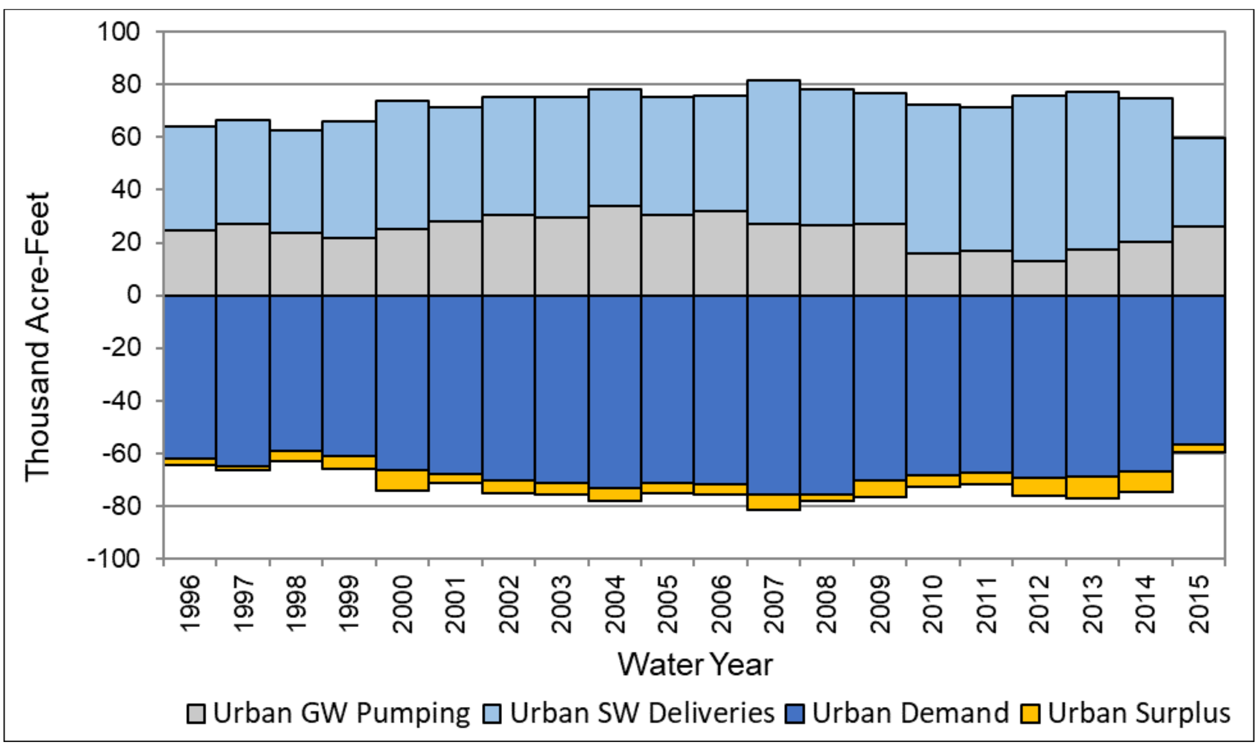

Figure 48f: ESJWRM Urban Land and Water Use Budget – Subarea 5 (South Subarea)

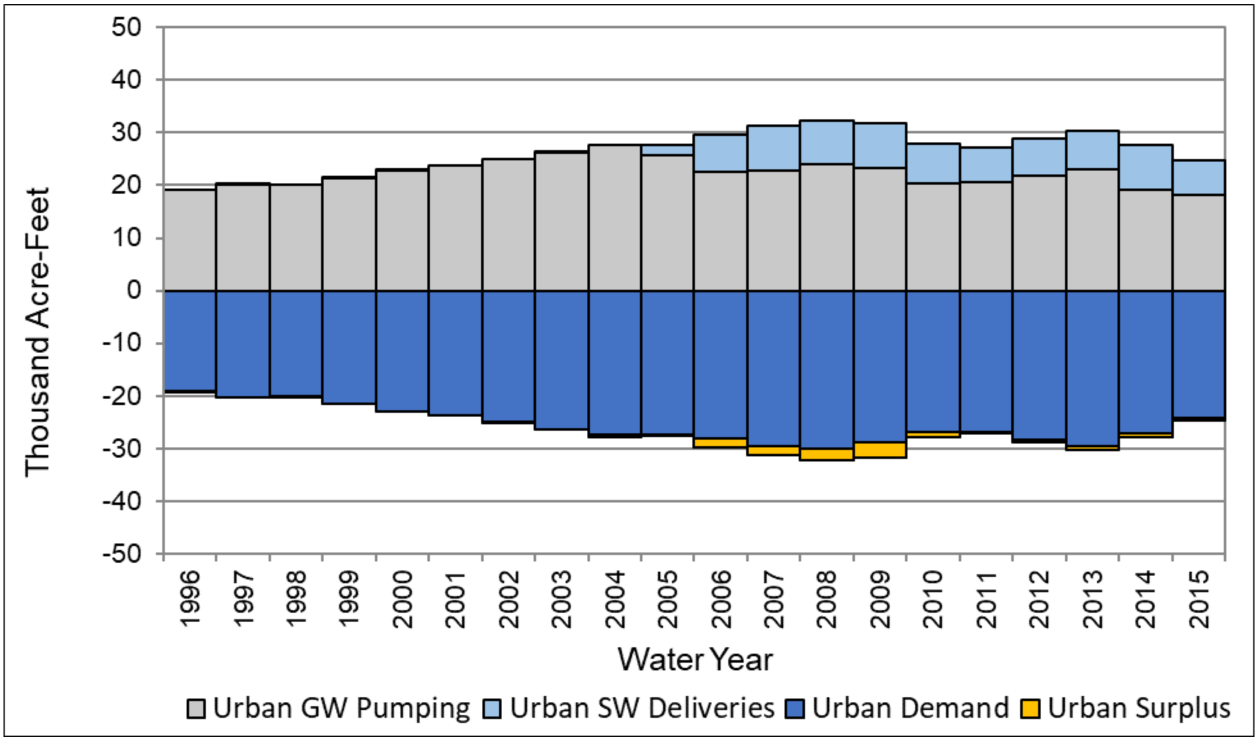

Figure 48g: ESJWRM Urban Land and Water Use Budget – Subarea 6 (Stanislaus Subarea)

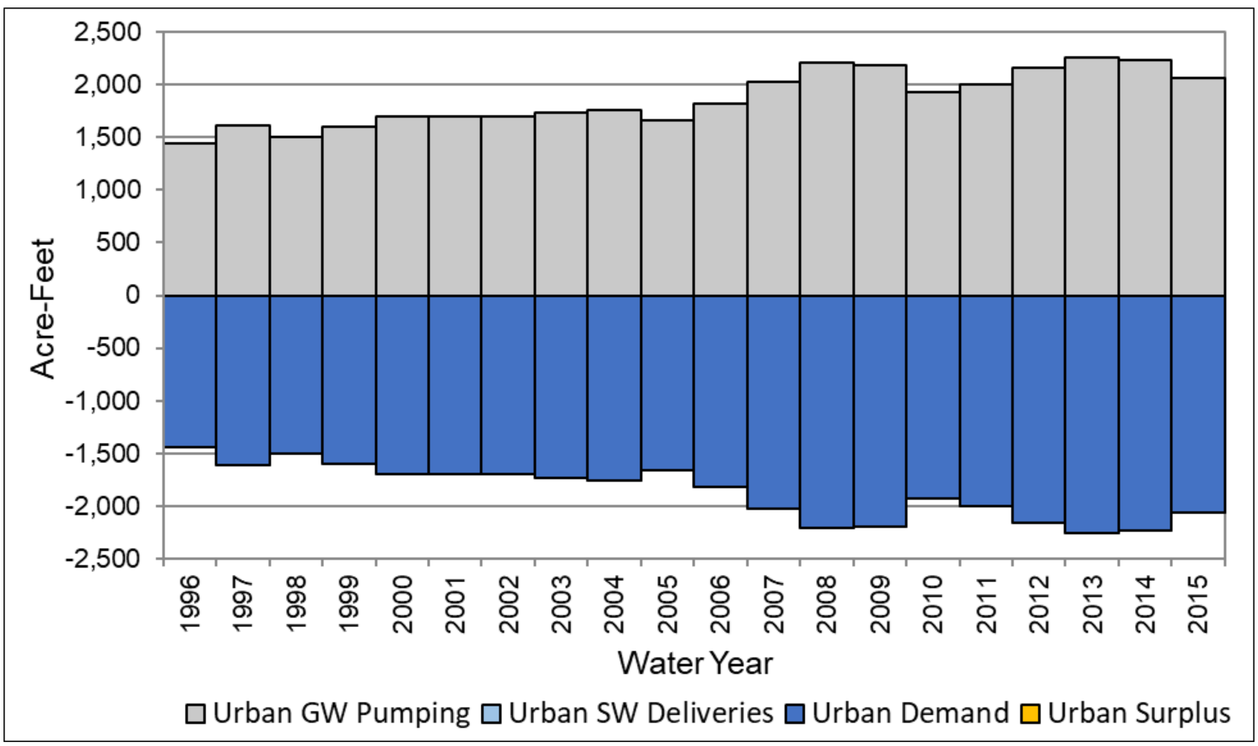

Figure 49a: ESJWRM Groundwater Budget – Eastern San Joaquin Subbasin

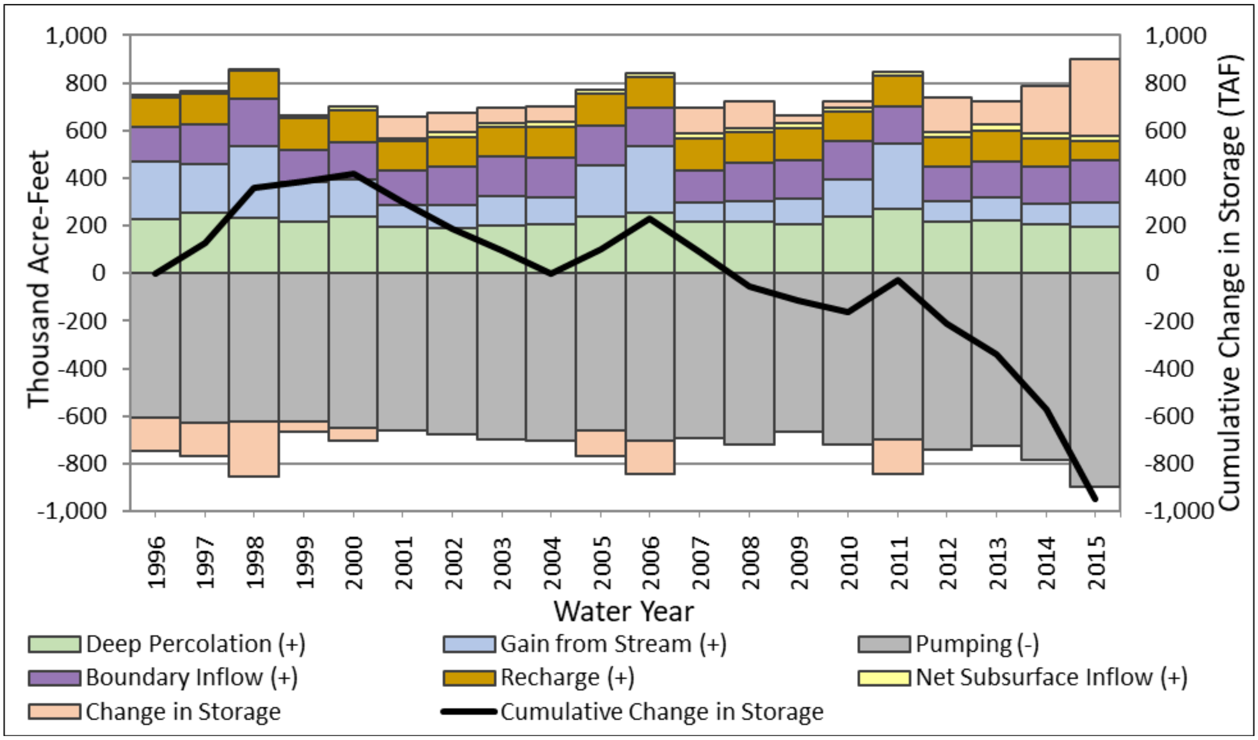

Figure 49b: ESJWRM Groundwater Budget – Subarea 1 (North Delta Subarea)

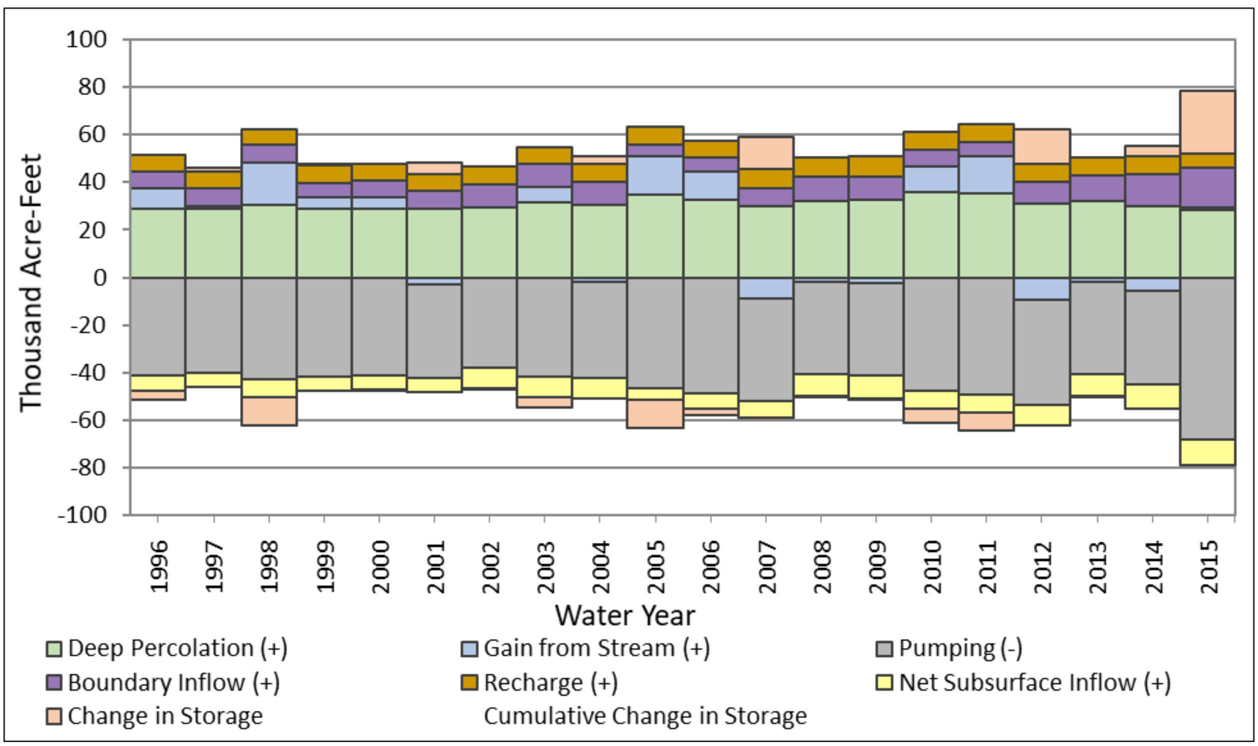

Figure 49c: ESJWRM Groundwater Budget – Subarea 2 (North Subarea)

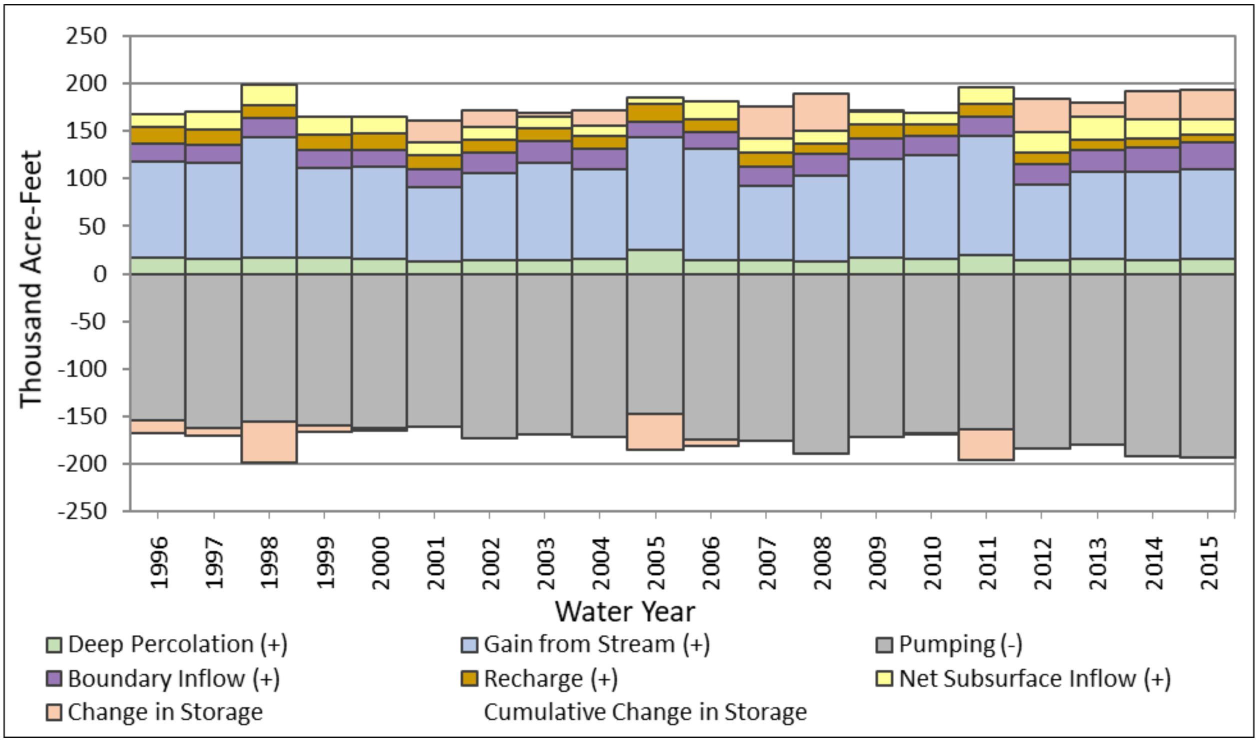

Figure 49d: ESJWRM Groundwater Budget – Subarea 3 (Calaveras Subarea)

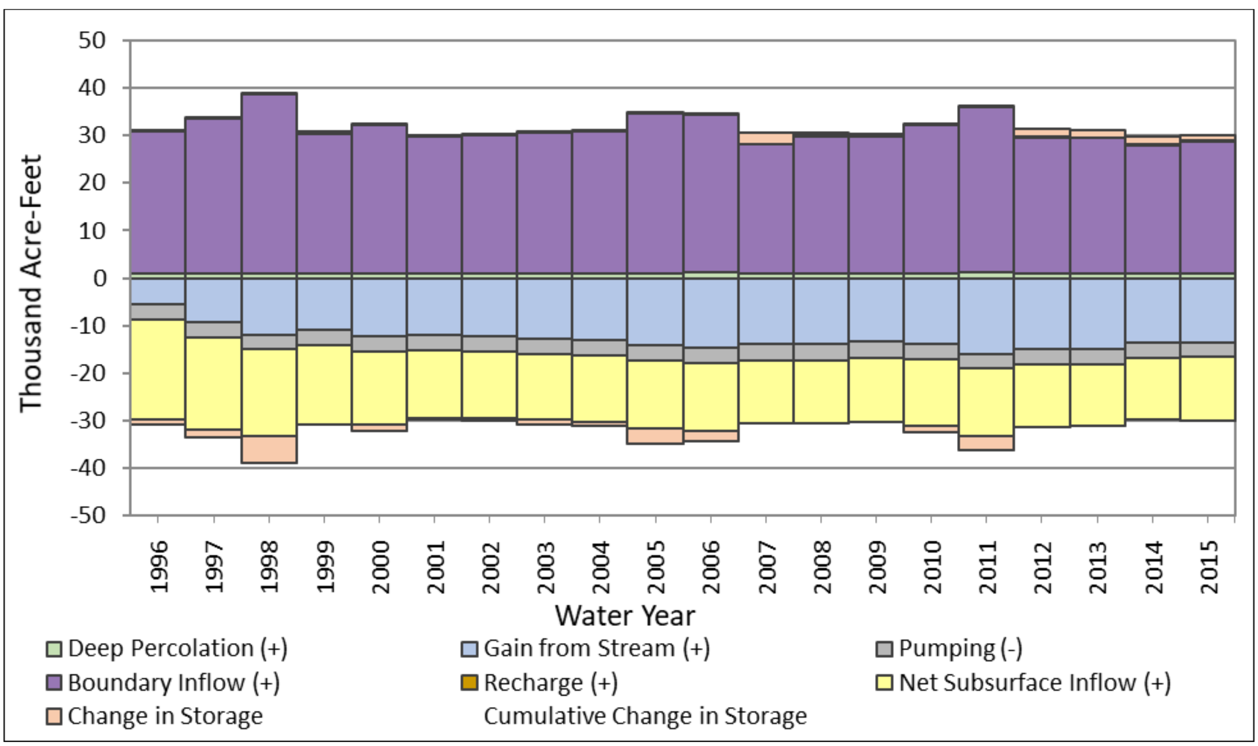

Figure 49e: ESJWRM Groundwater Budget – Subarea 4 (Central Subarea)

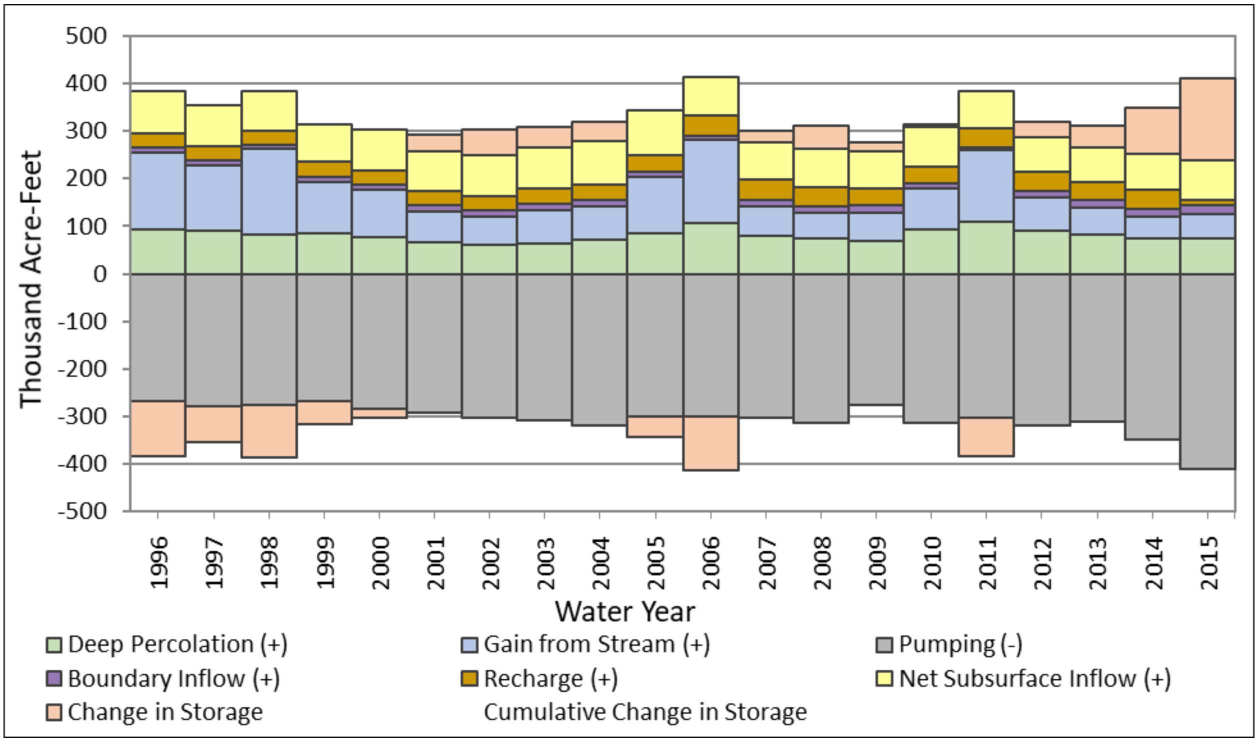

Figure 49f: ESJWRM Groundwater Budget – Subarea 5 (South Subarea)

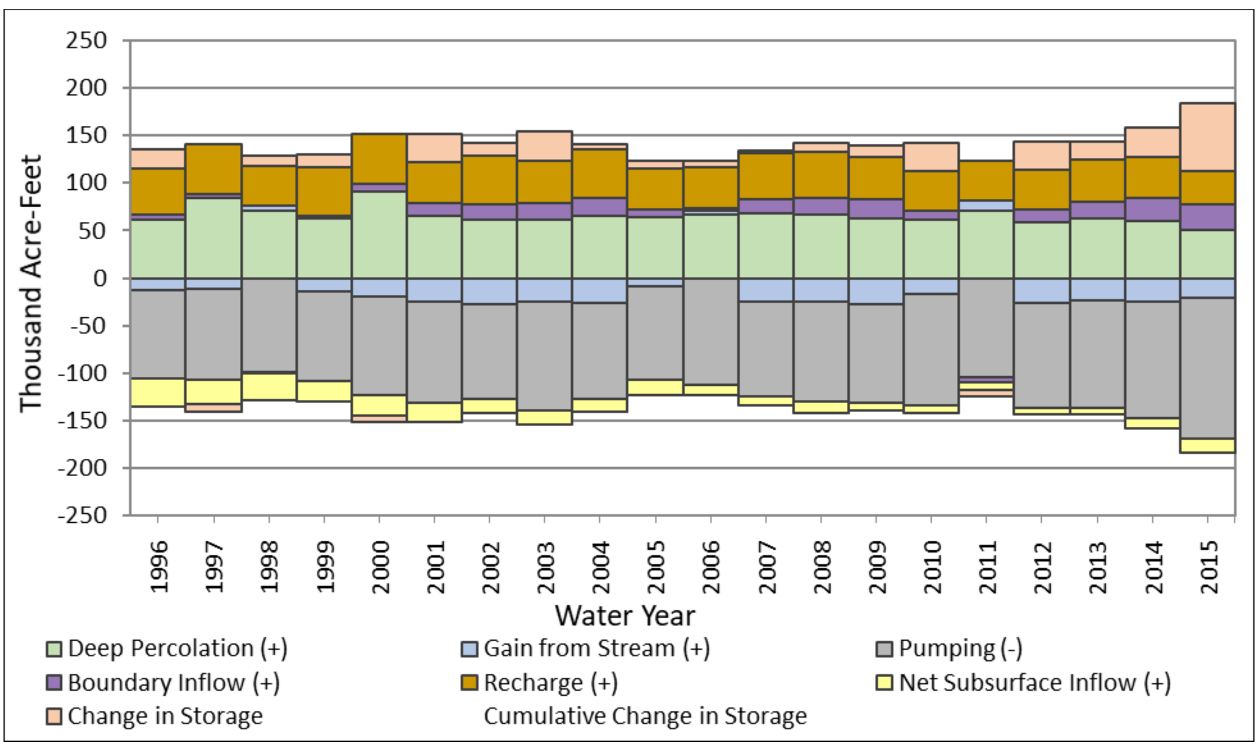

Figure 49g: ESJWRM Groundwater Budget – Subarea 6 (Stanislaus Subarea)

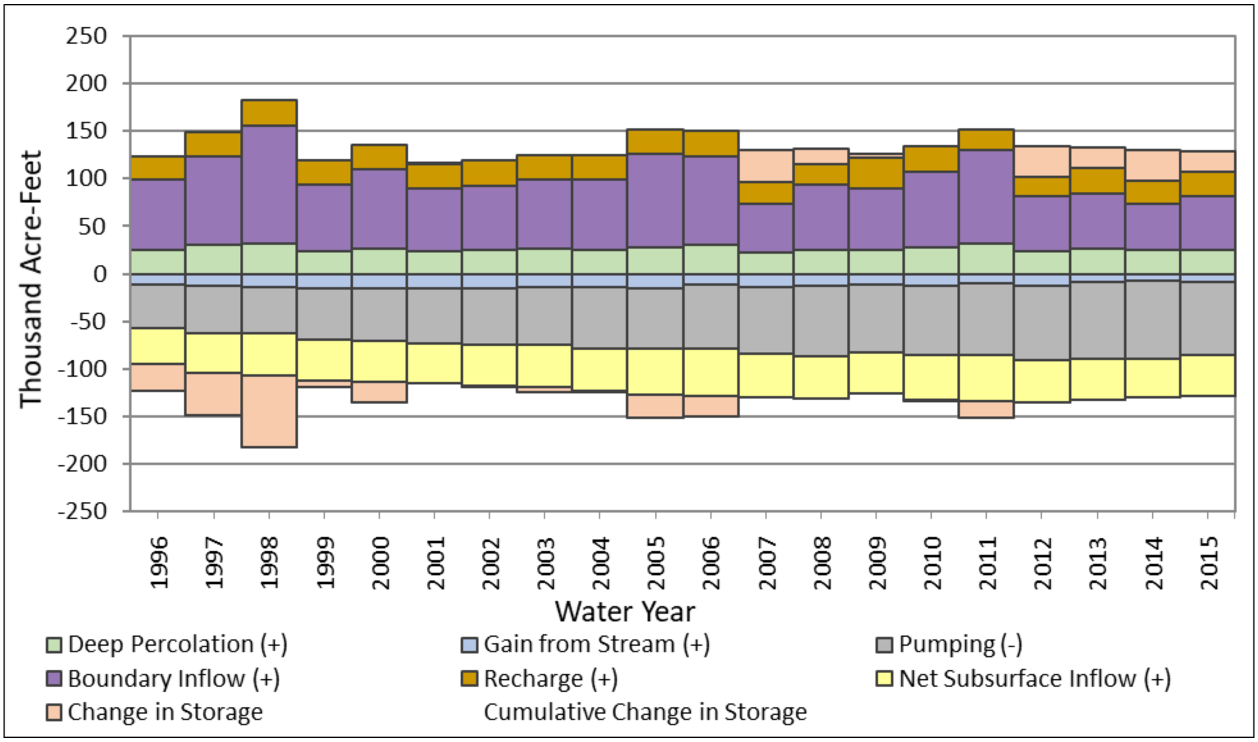

Figure 50: ESJWRM Groundwater Level Calibration Wells

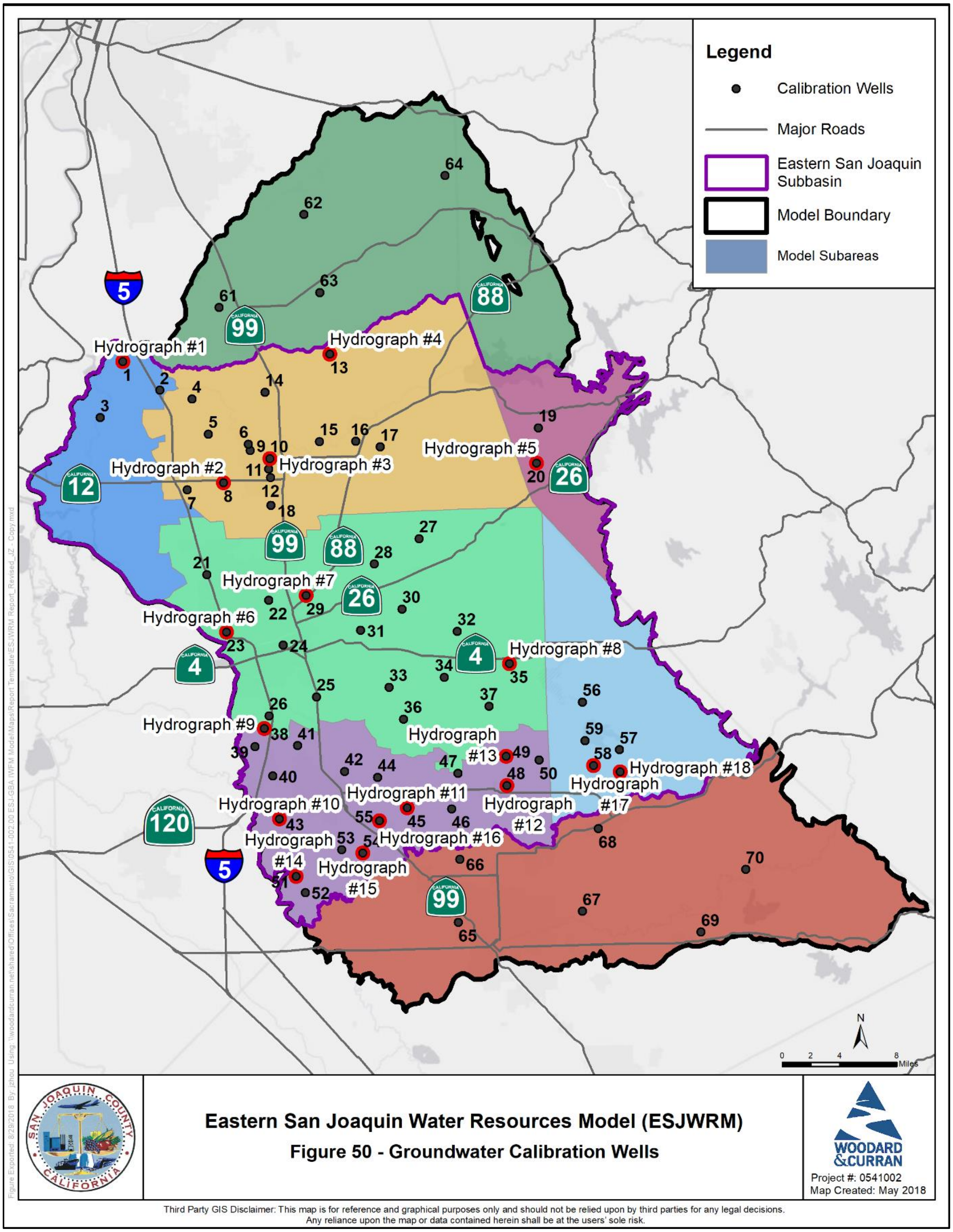

Figure 51a: ESJWRM Groundwater Level Contours (Fall 2015)

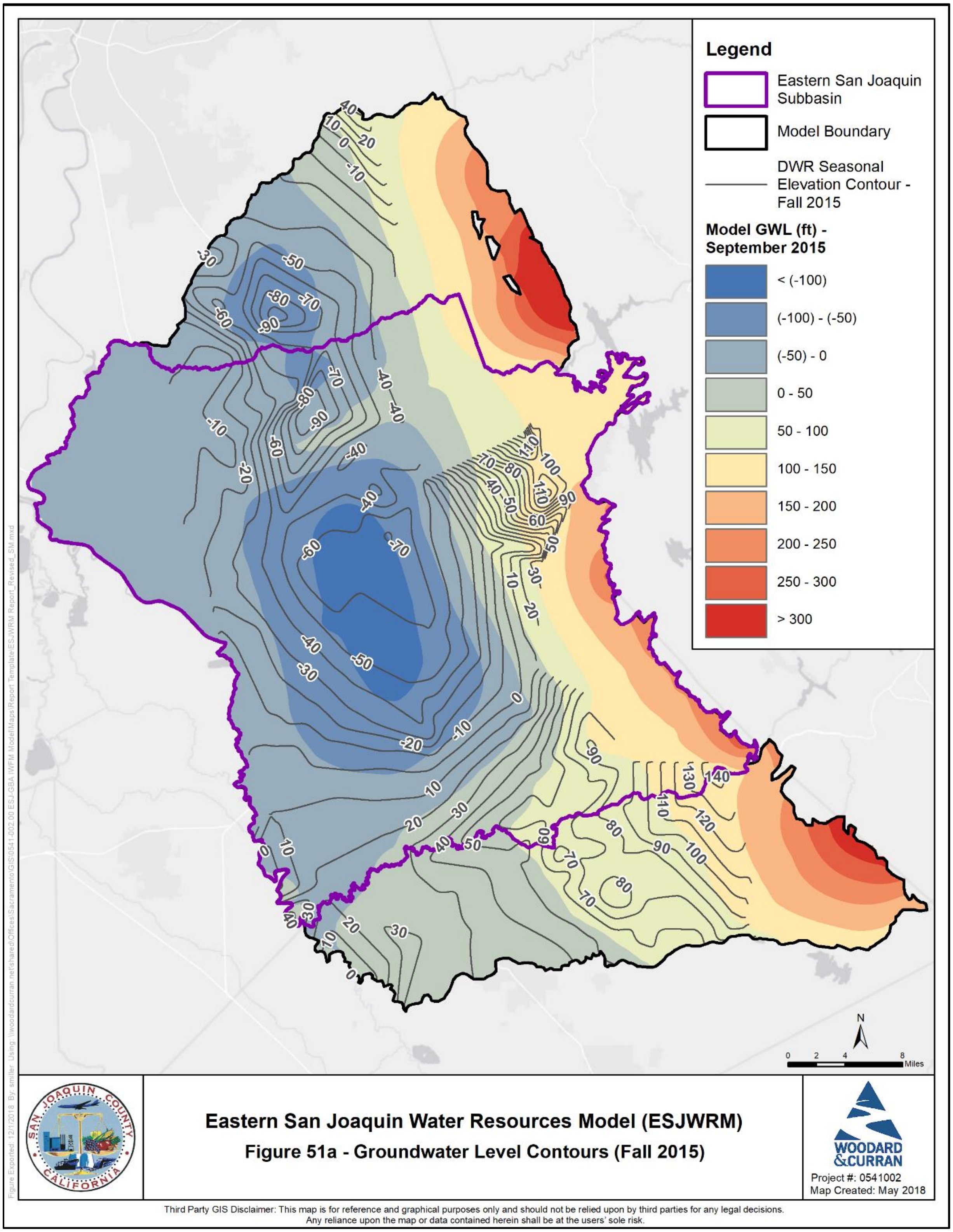

Figure 51b: ESJWRM Groundwater Level Contours (Spring 2015)

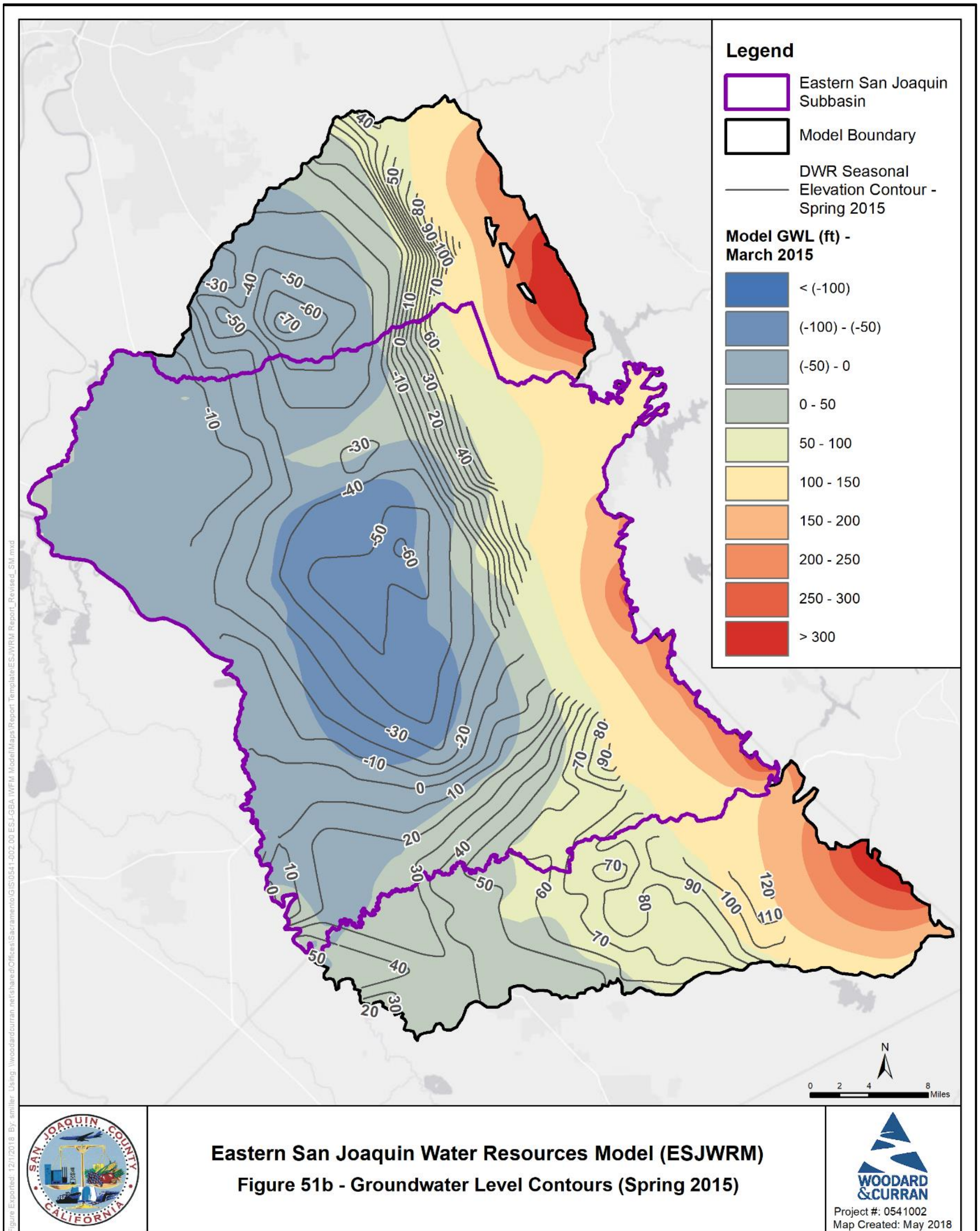

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Figure 51c: ESJWRM Groundwater Level Contours (Fall 2013)

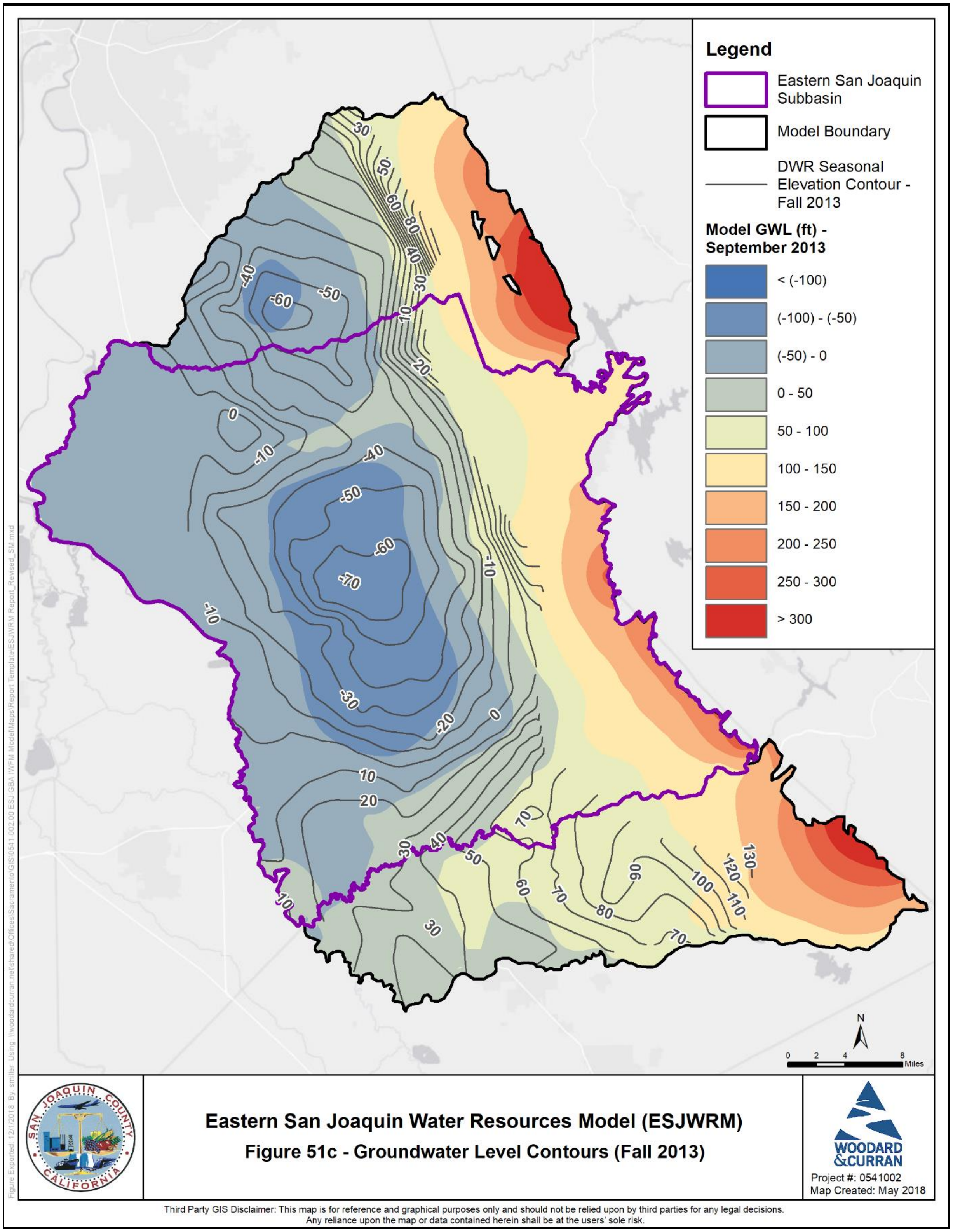

Figure 51d: ESJWRM Groundwater Level Contours (Spring 2011)

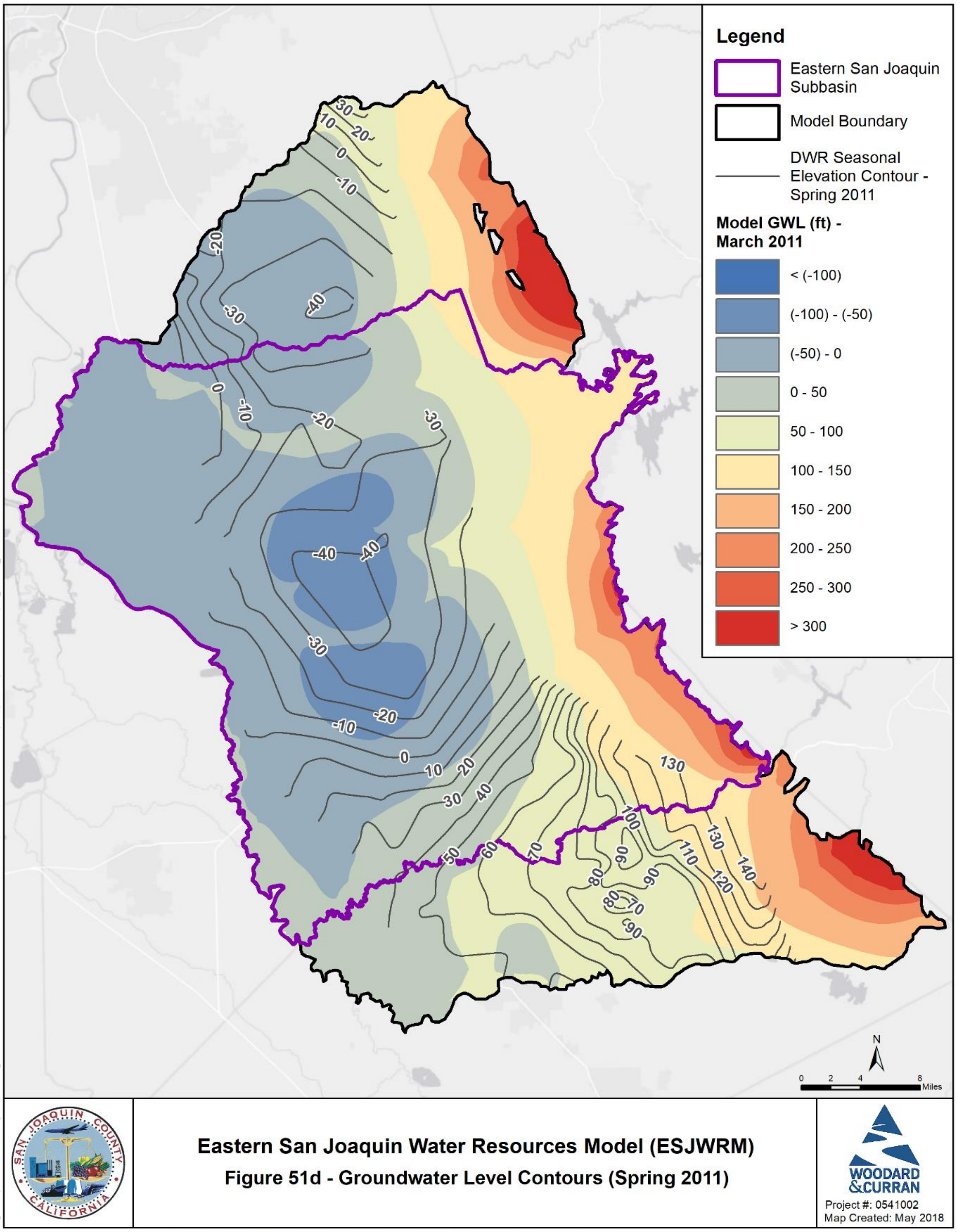

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Figure 52a: ESJWRM Groundwater Level Hydrograph – Hydrograph #1

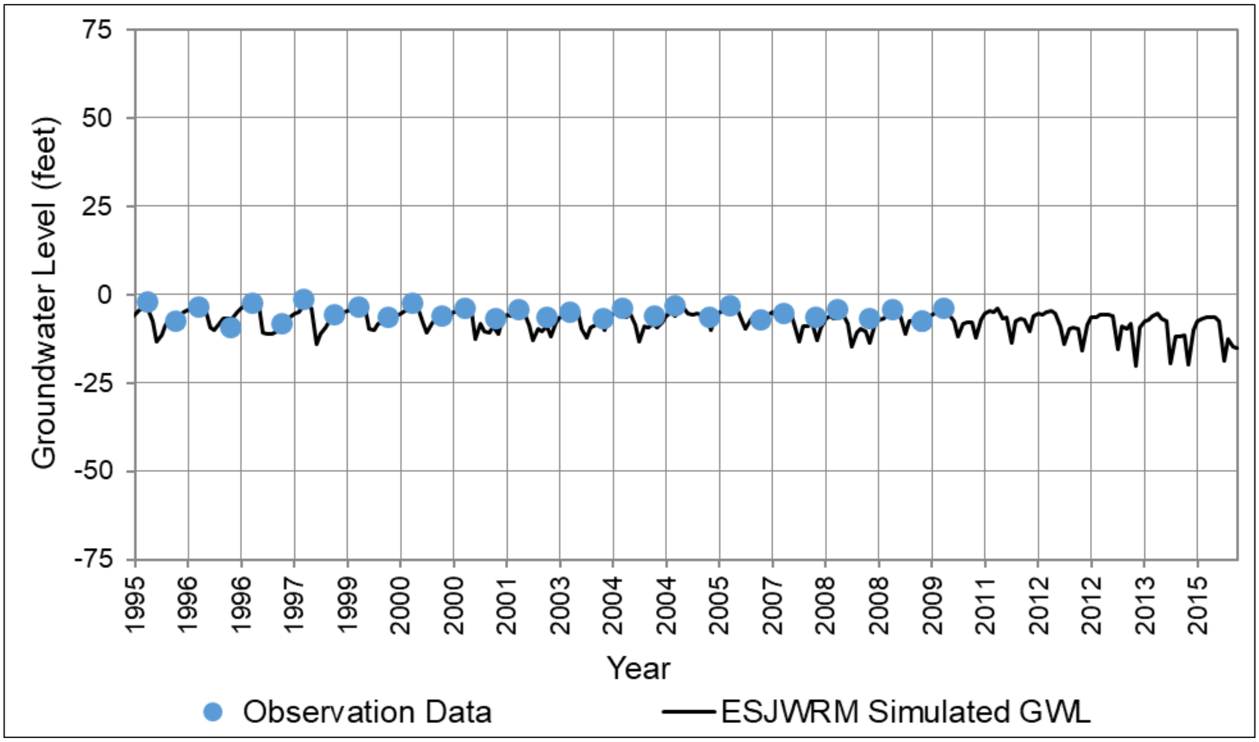

Figure 52b: ESJWRM Groundwater Level Hydrograph – Hydrograph #2

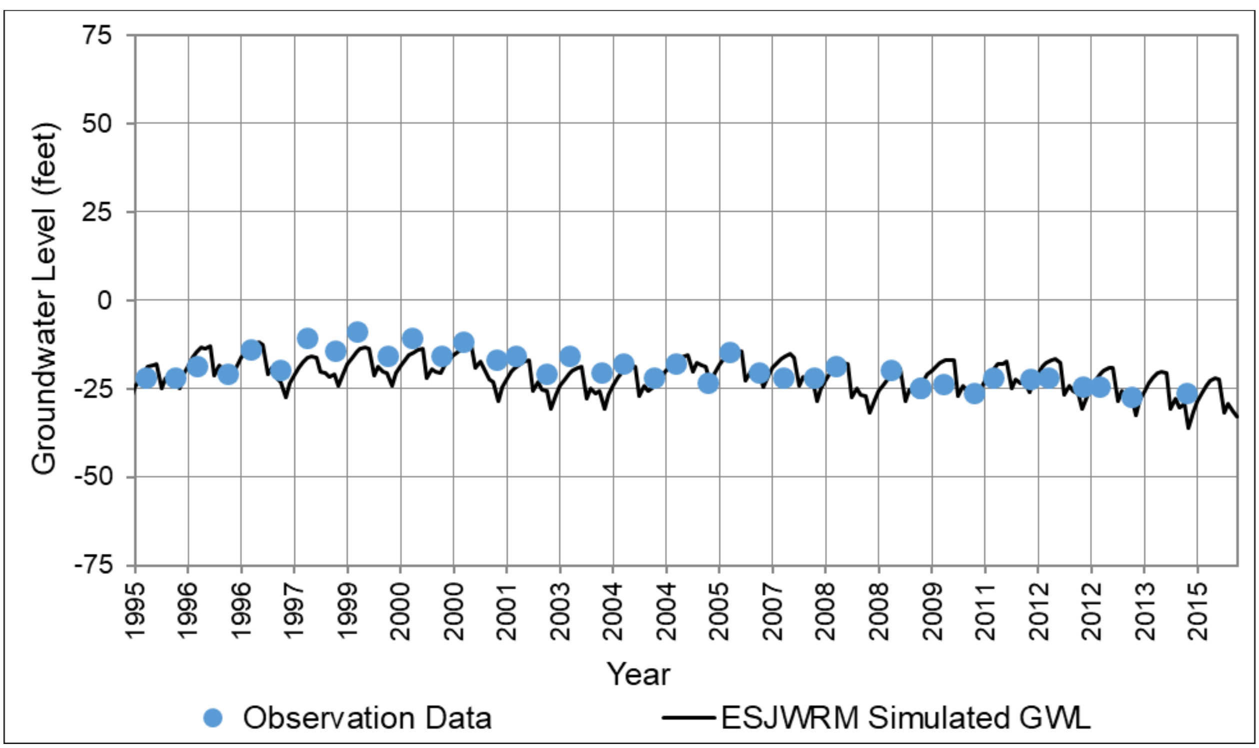

Figure 52c: ESJWRM Groundwater Level Hydrograph – Hydrograph #3

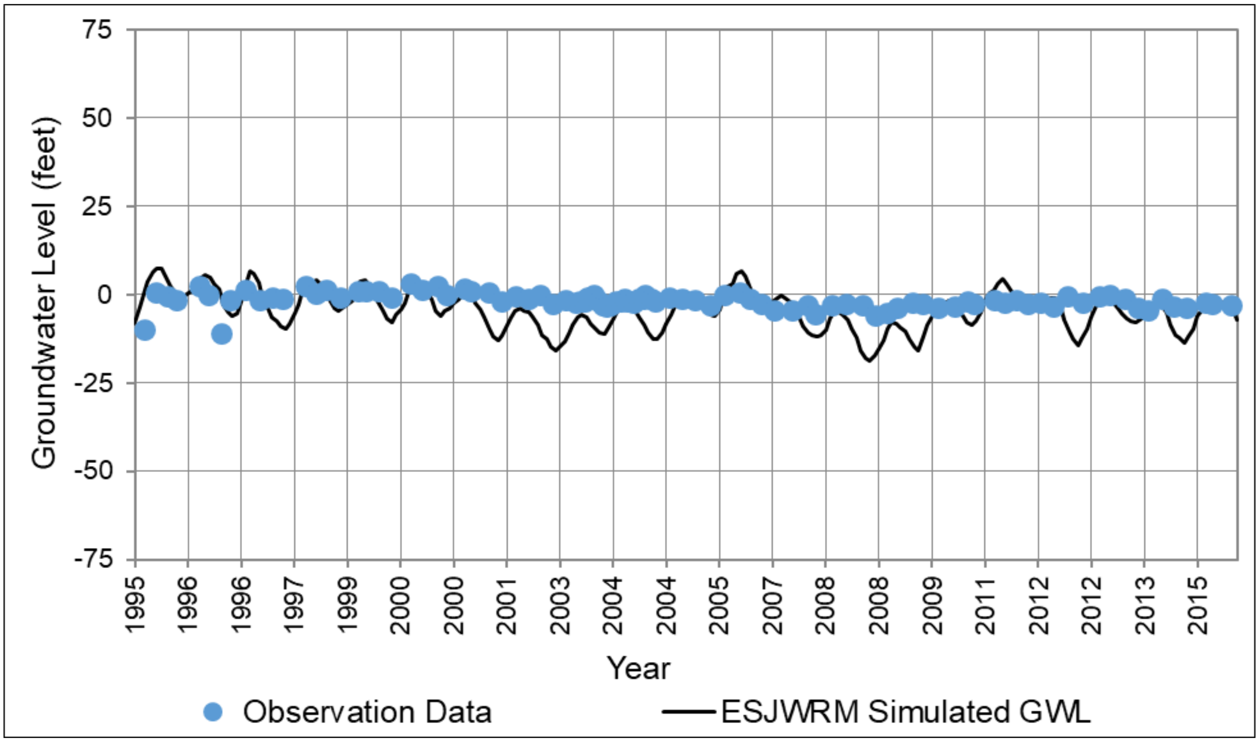

Figure 52d: ESJWRM Groundwater Level Hydrograph – Hydrograph #4

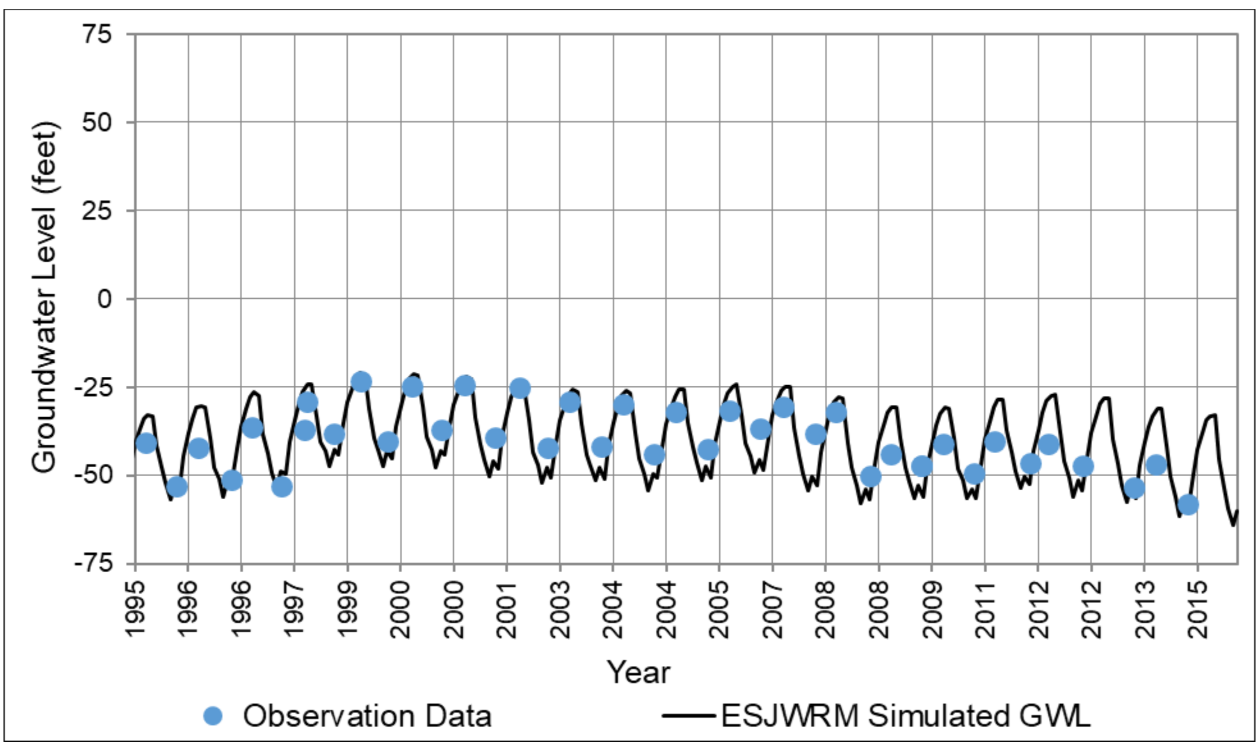

Figure 52e: ESJWRM Groundwater Level Hydrograph – Hydrograph #5

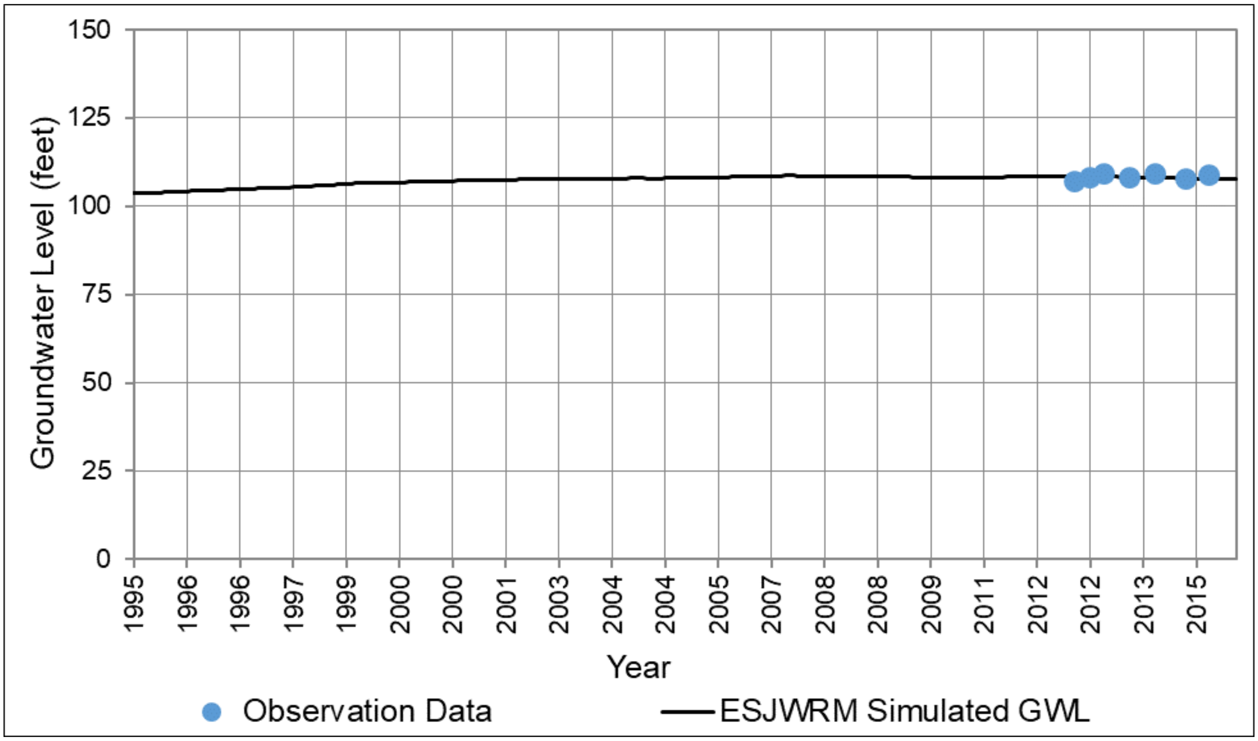

Figure 52f: ESJWRM Groundwater Level Hydrograph – Hydrograph #6

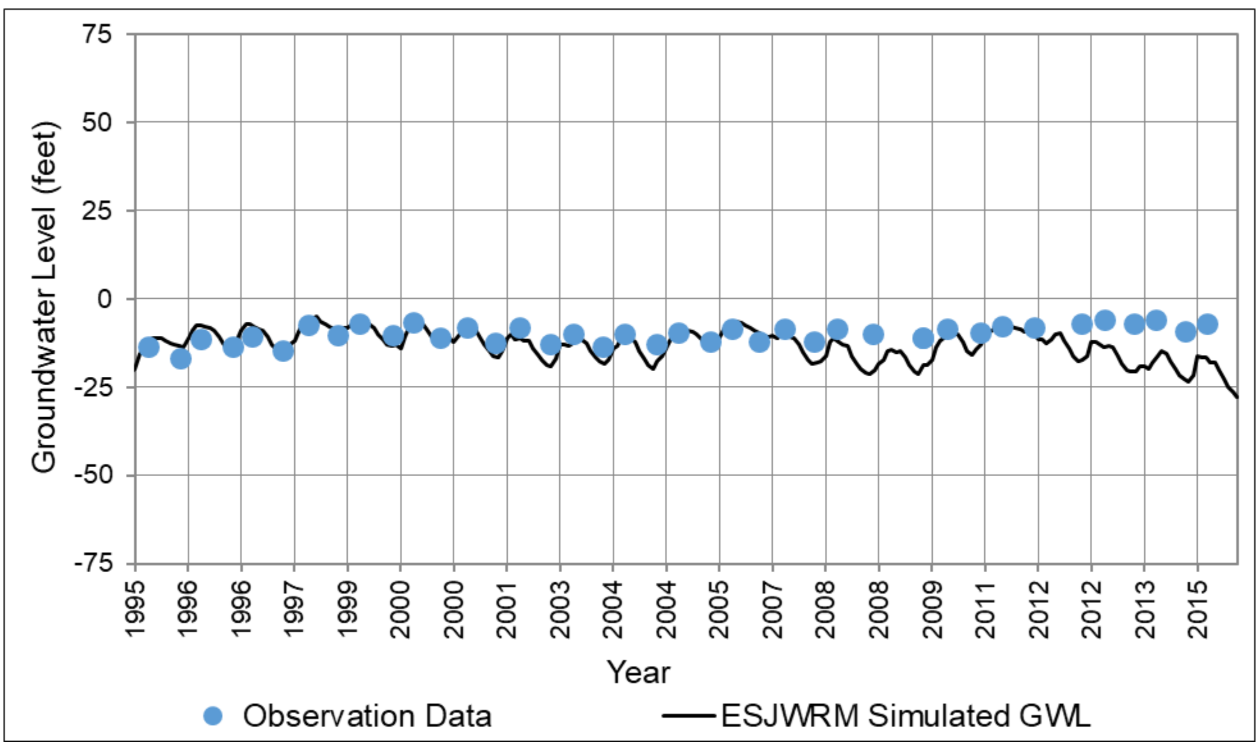

Figure 52g: ESJWRM Groundwater Level Hydrograph – Hydrograph #7

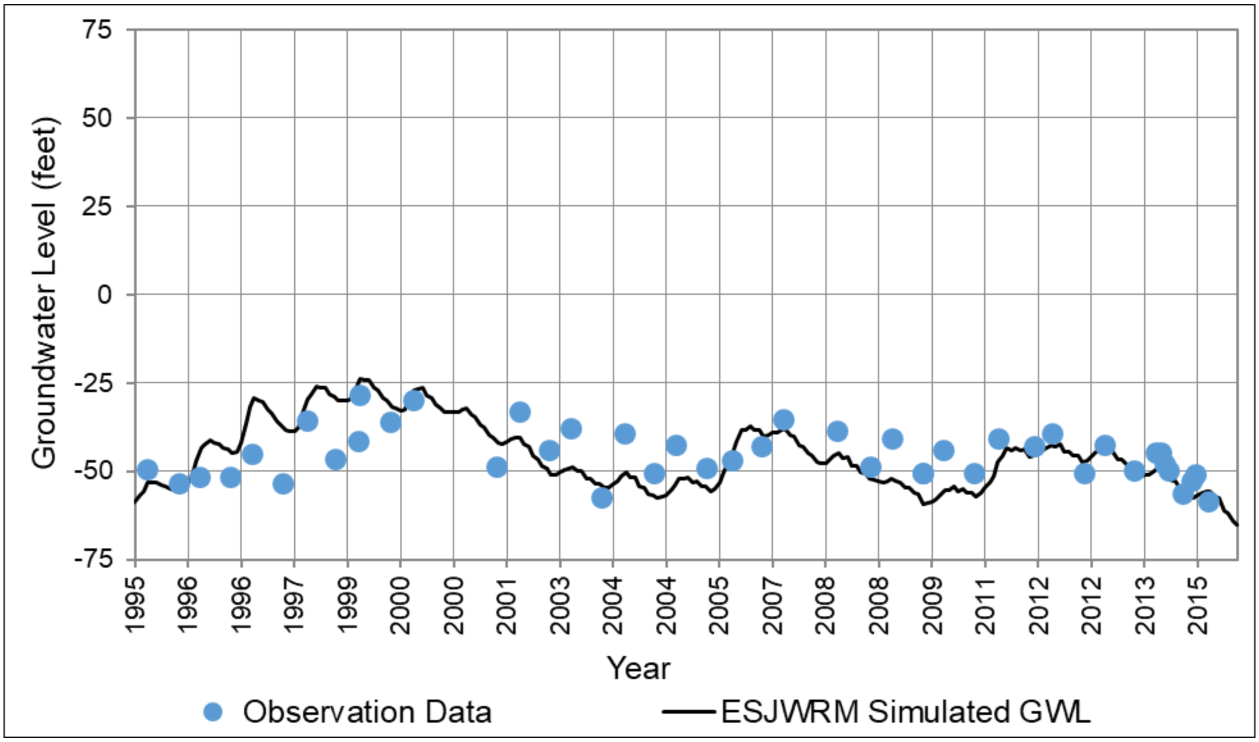

Figure 52h: ESJWRM Groundwater Level Hydrograph – Hydrograph #8

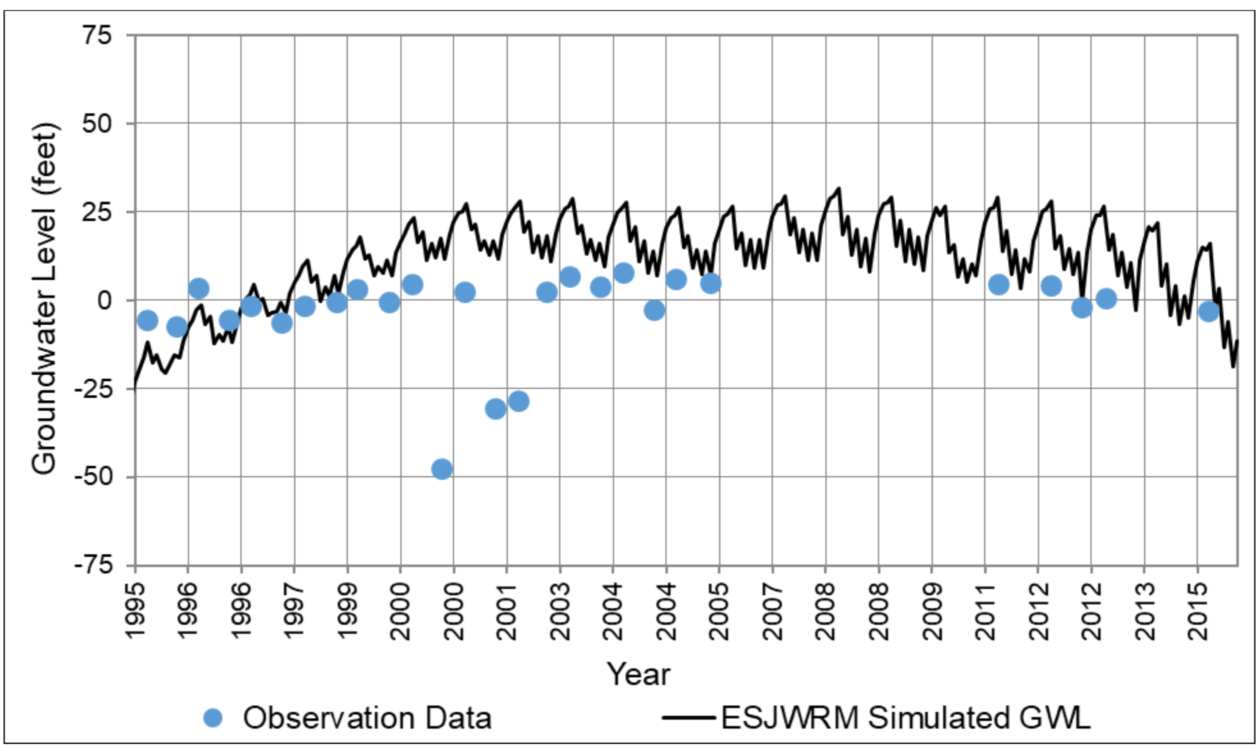

Figure 52i: ESJWRM Groundwater Level Hydrograph – Hydrograph #9

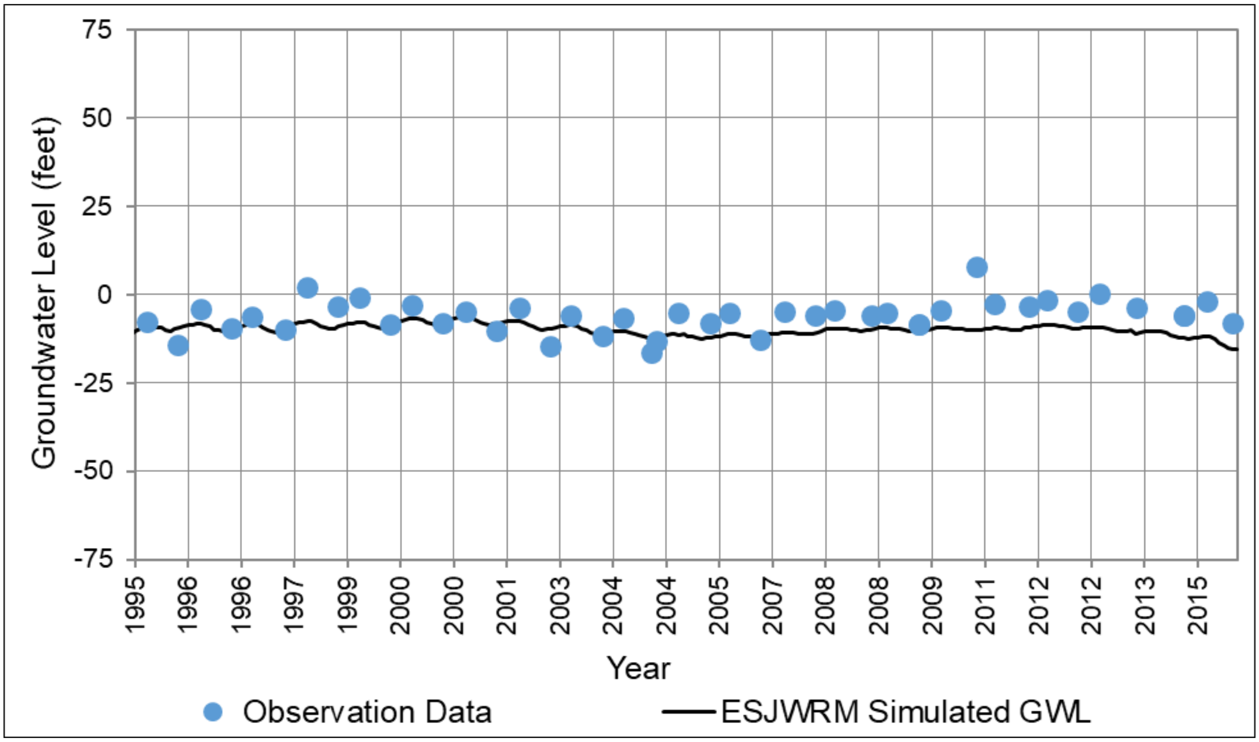

Figure 52j: ESJWRM Groundwater Level Hydrograph – Hydrograph #10

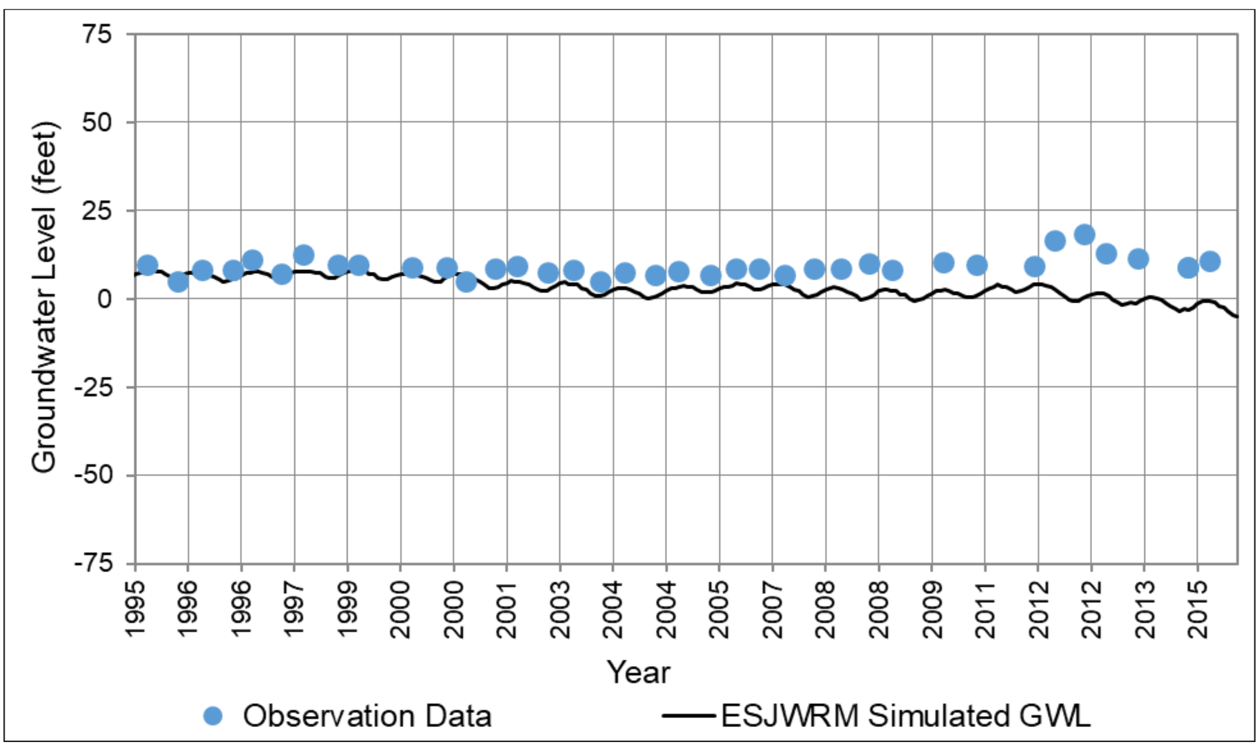

Figure 52k: ESJWRM Groundwater Level Hydrograph – Hydrograph #11

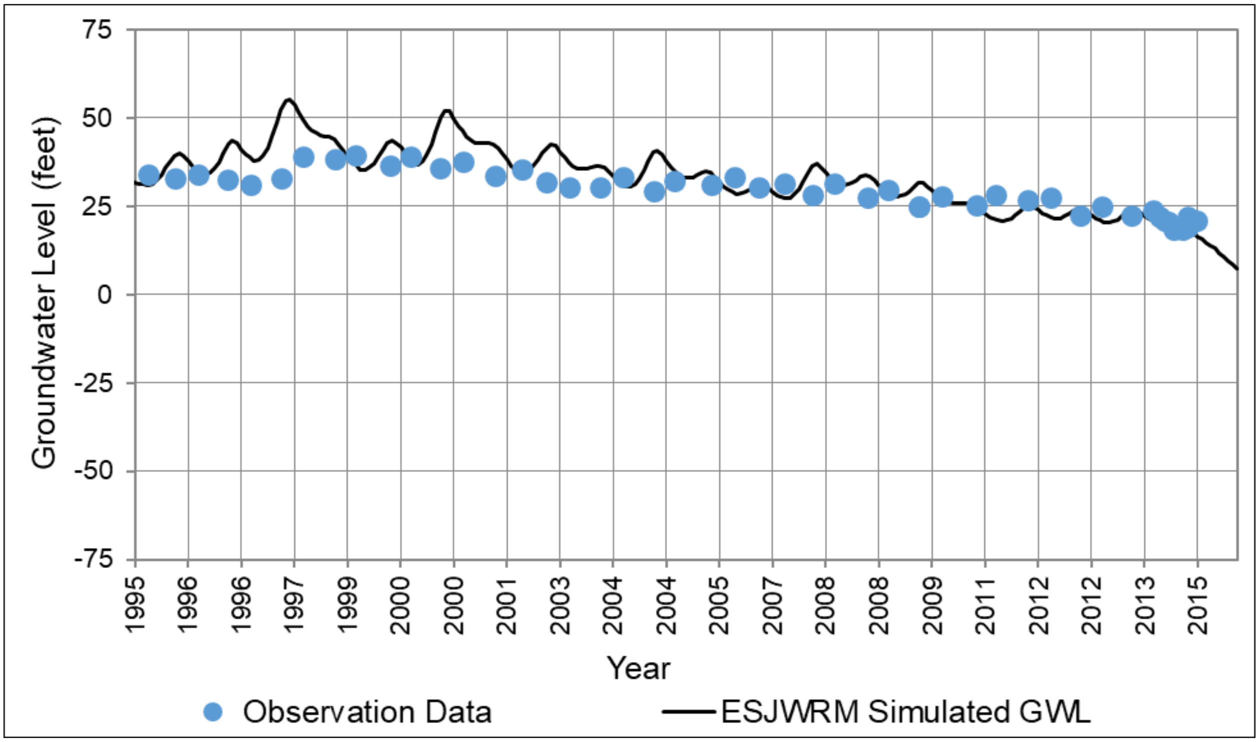

Figure 52l: ESJWRM Groundwater Level Hydrograph – Hydrograph #12

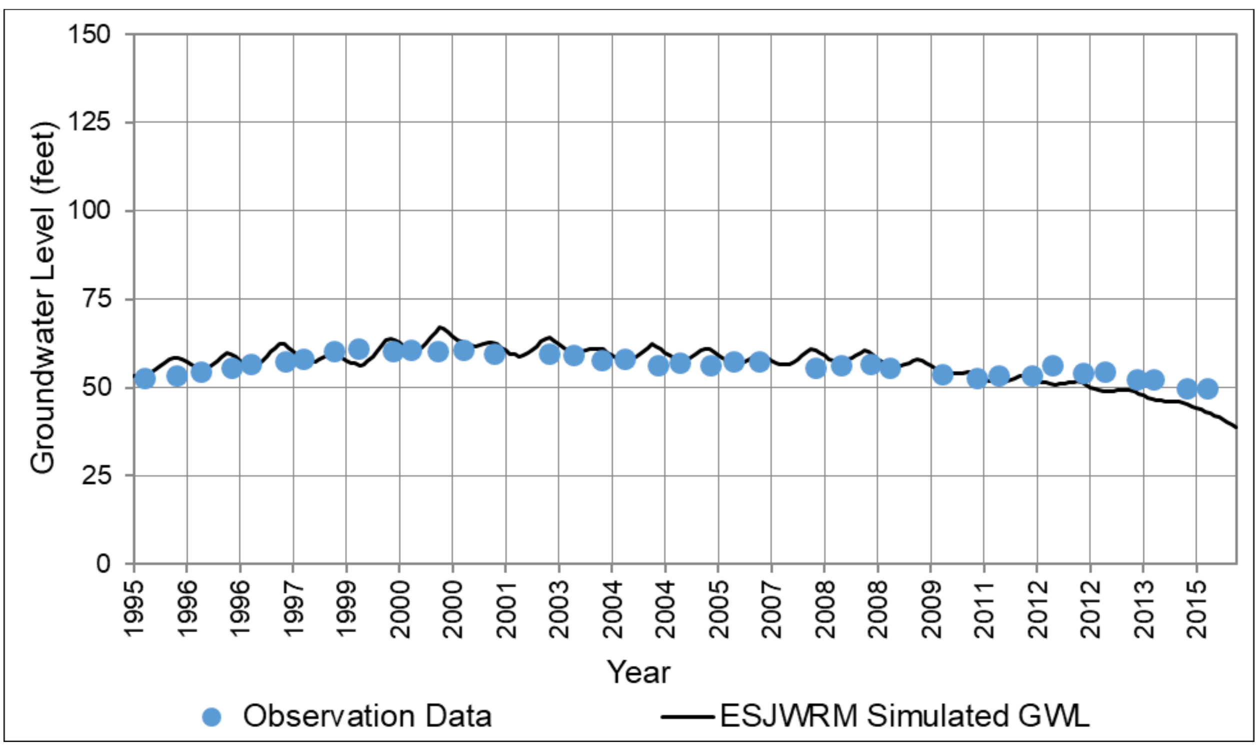

Figure 52m: ESJWRM Groundwater Level Hydrograph – Hydrograph #13

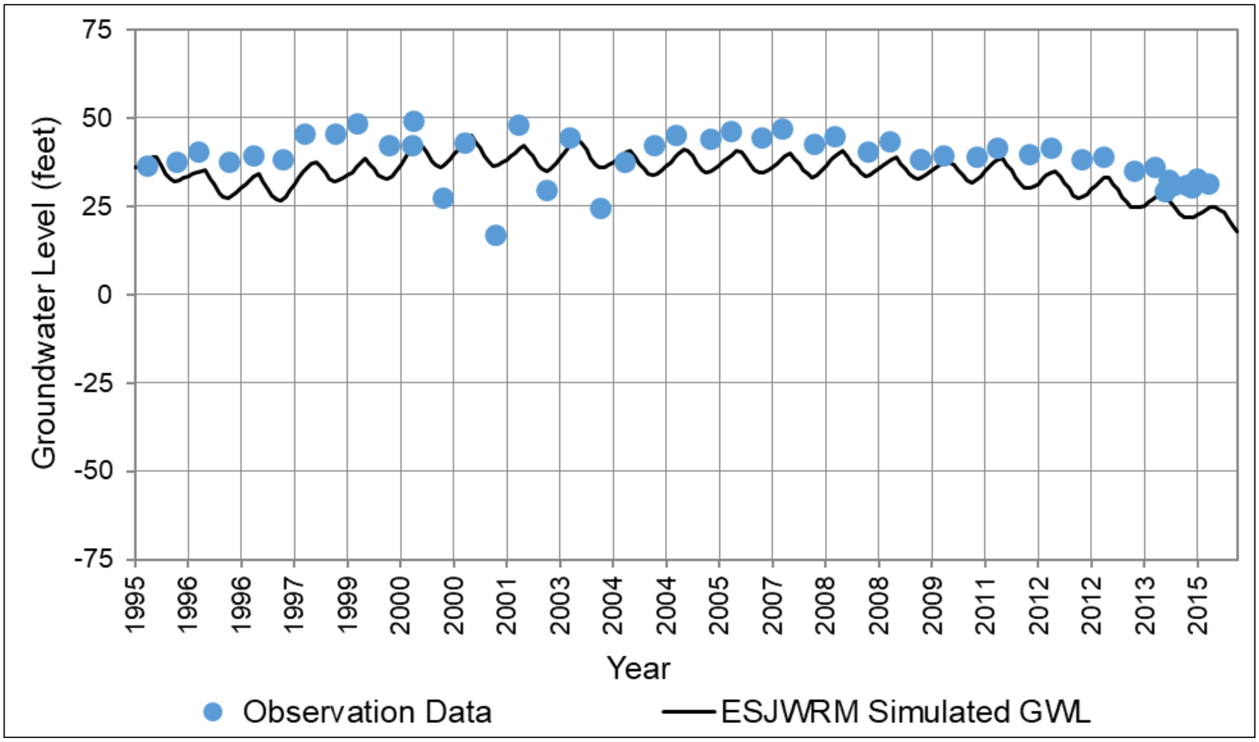

Figure 52n: ESJWRM Groundwater Level Hydrograph – Hydrograph #14

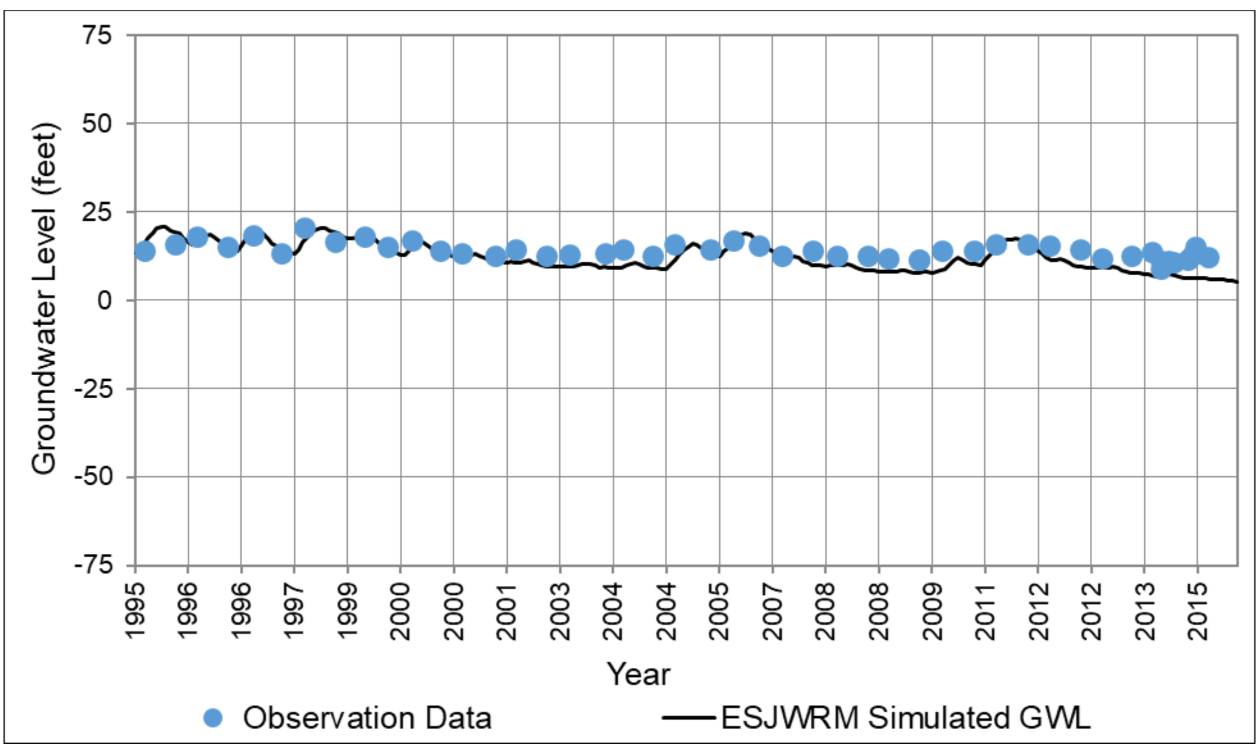

Figure 52o: ESJWRM Groundwater Level Hydrograph – Hydrograph #15

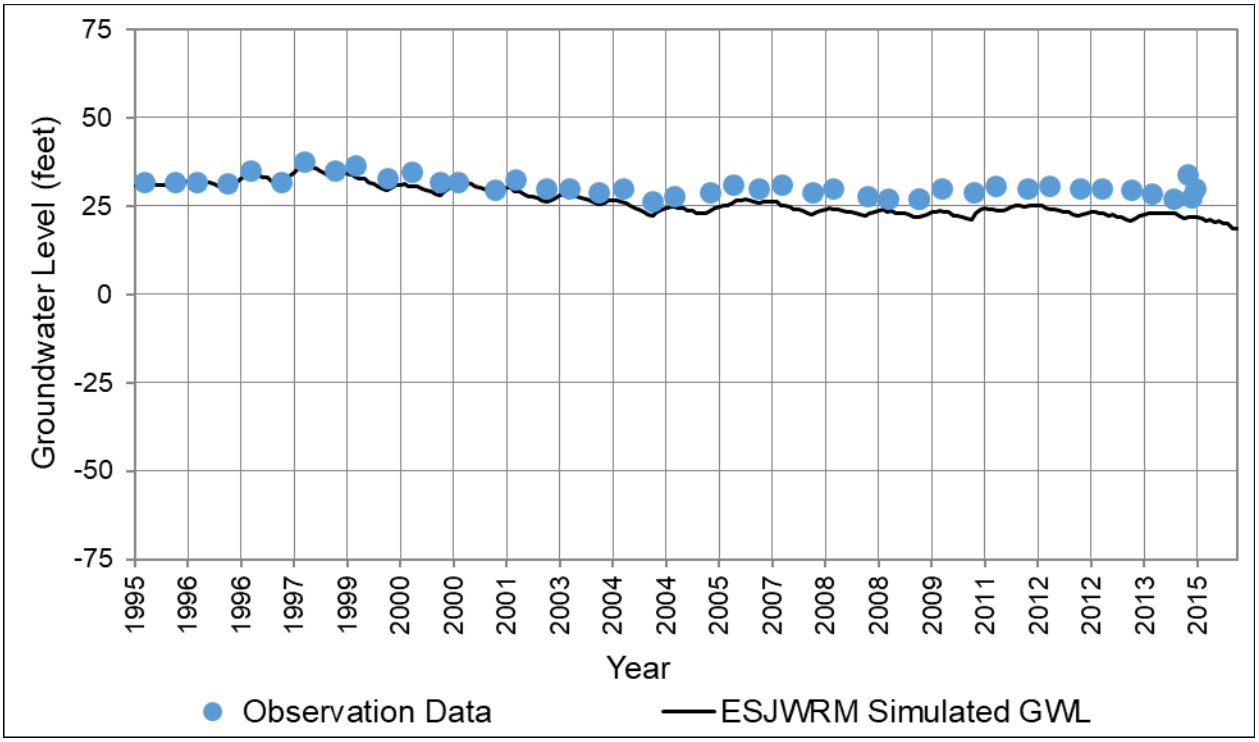

Figure 52p: ESJWRM Groundwater Level Hydrograph – Hydrograph #16

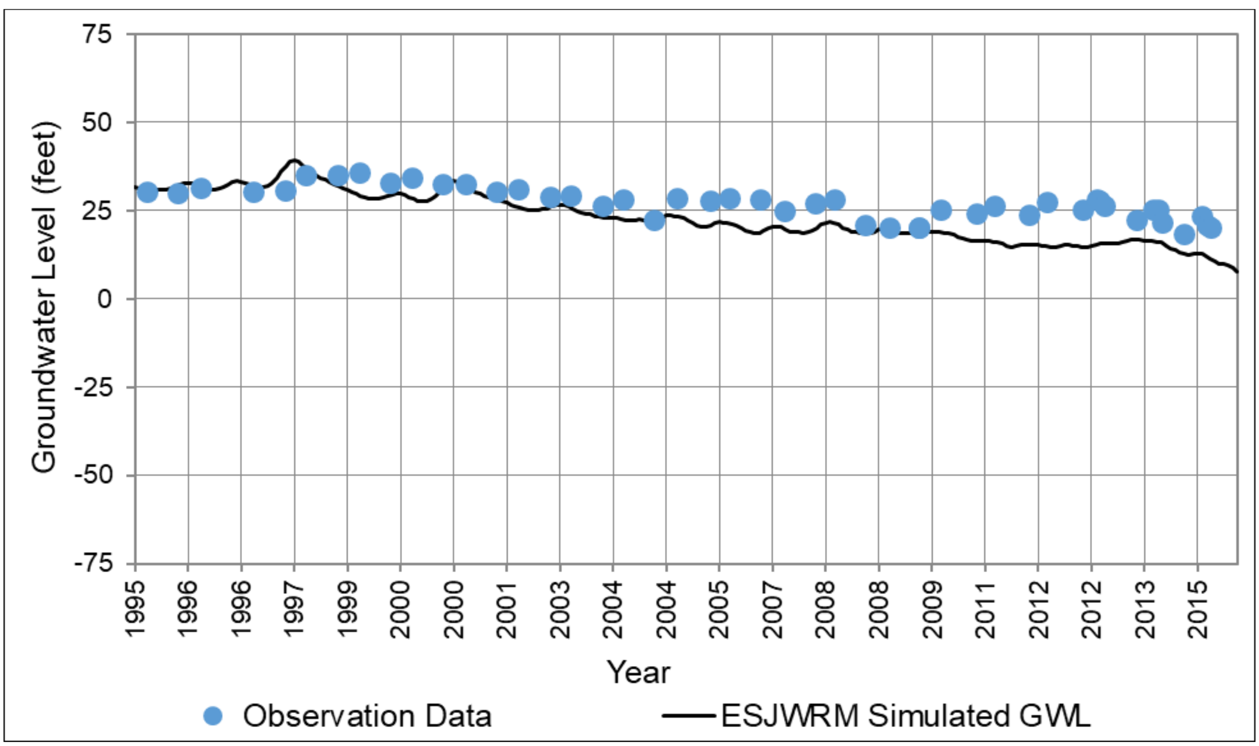

Figure 52q: ESJWRM Groundwater Level Hydrograph – Hydrograph #17

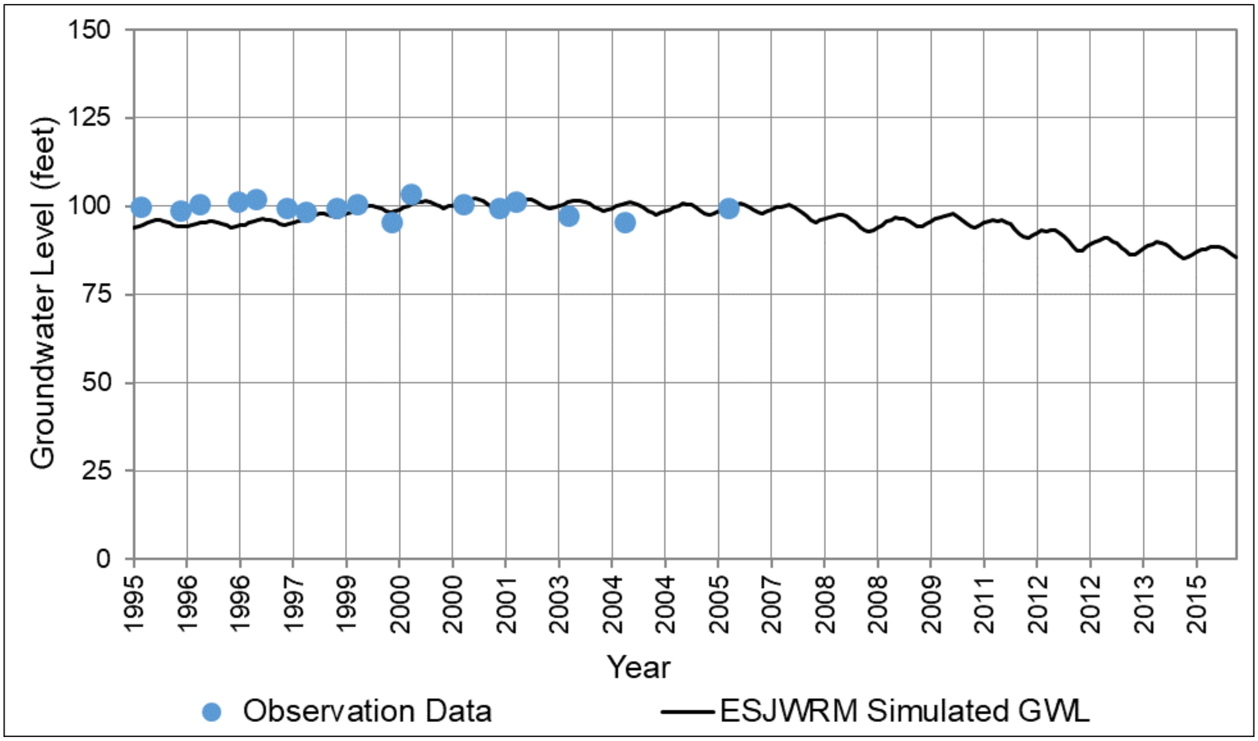

Figure 52r: ESJWRM Groundwater Level Hydrograph – Hydrograph #18

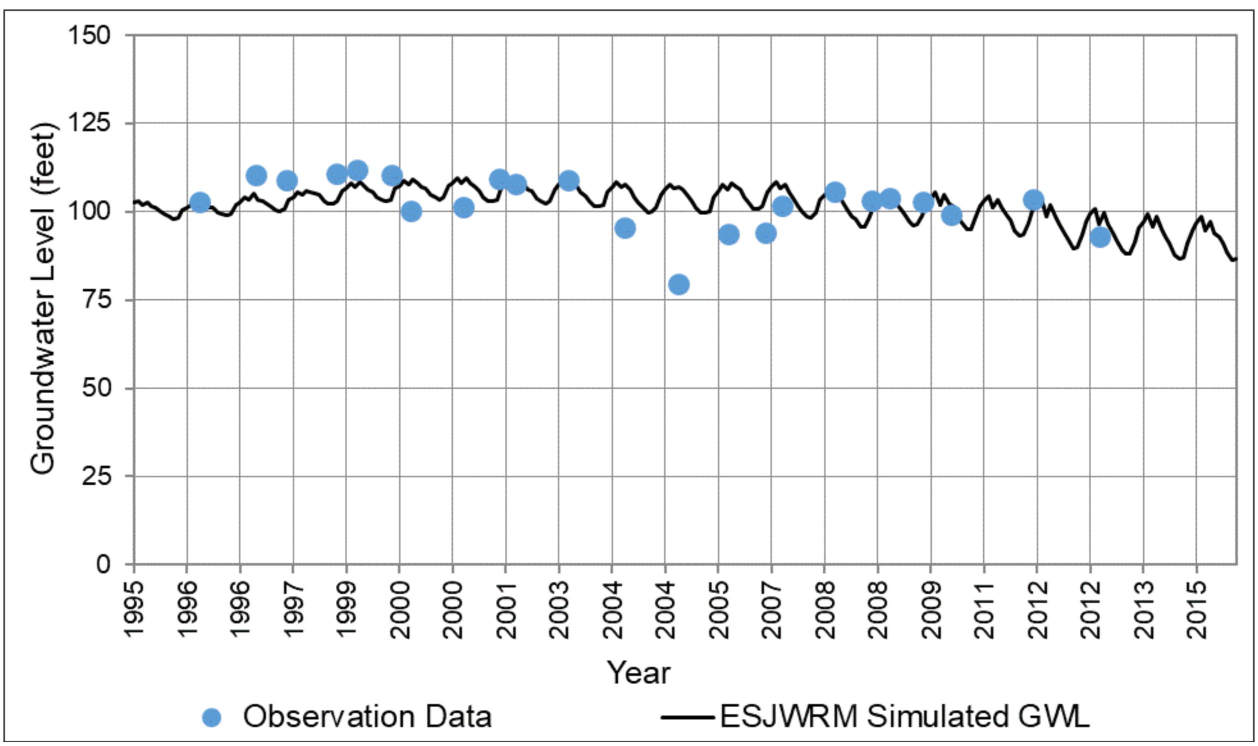

Figure 53: ESJWRM ESJ Subbasin Groundwater Level Histogram

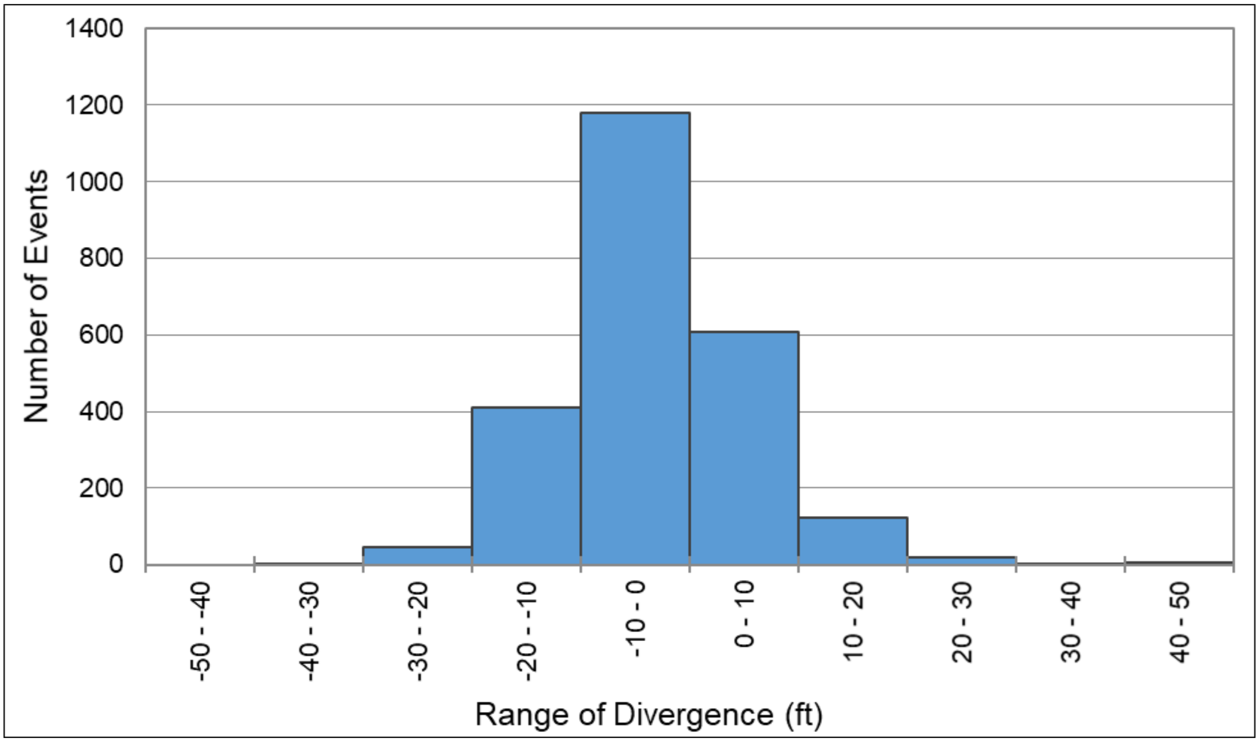

Figure 54: ESJWRM ESJ Subbasin Groundwater Level Scatter Plot

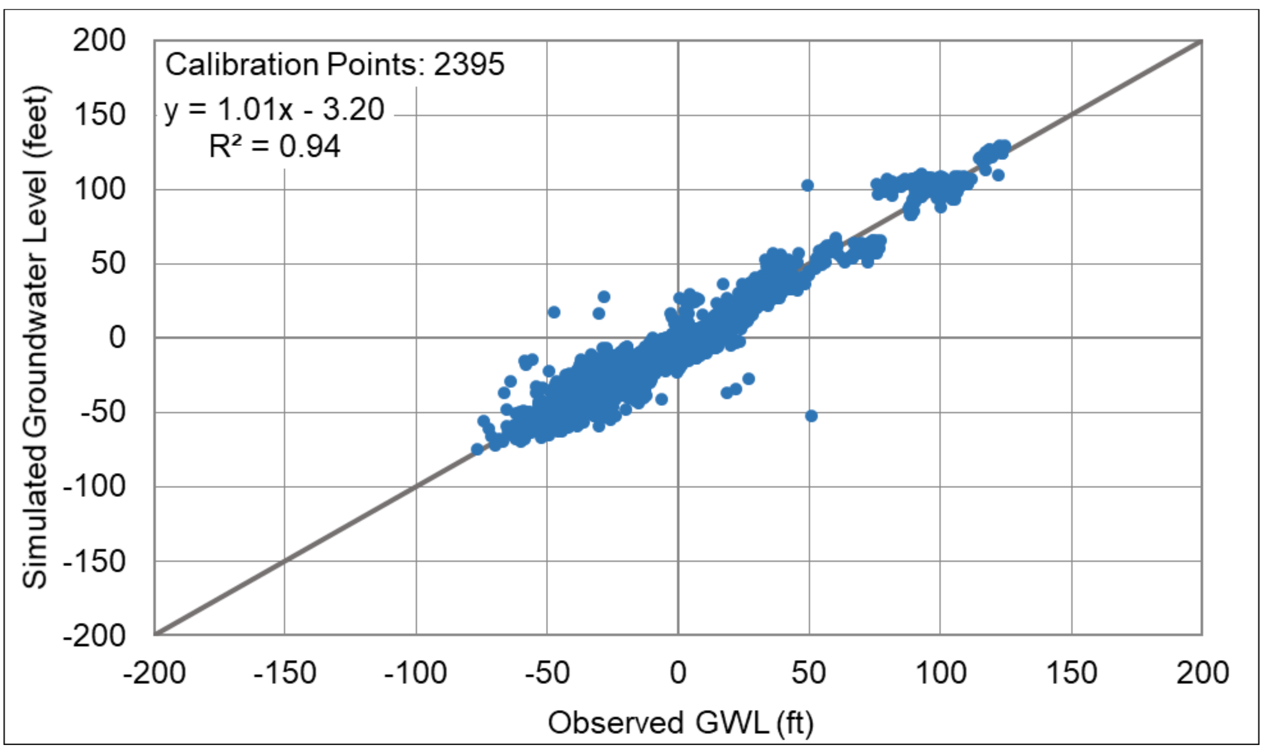

Figure 55: ESJWRM Parametric Grid

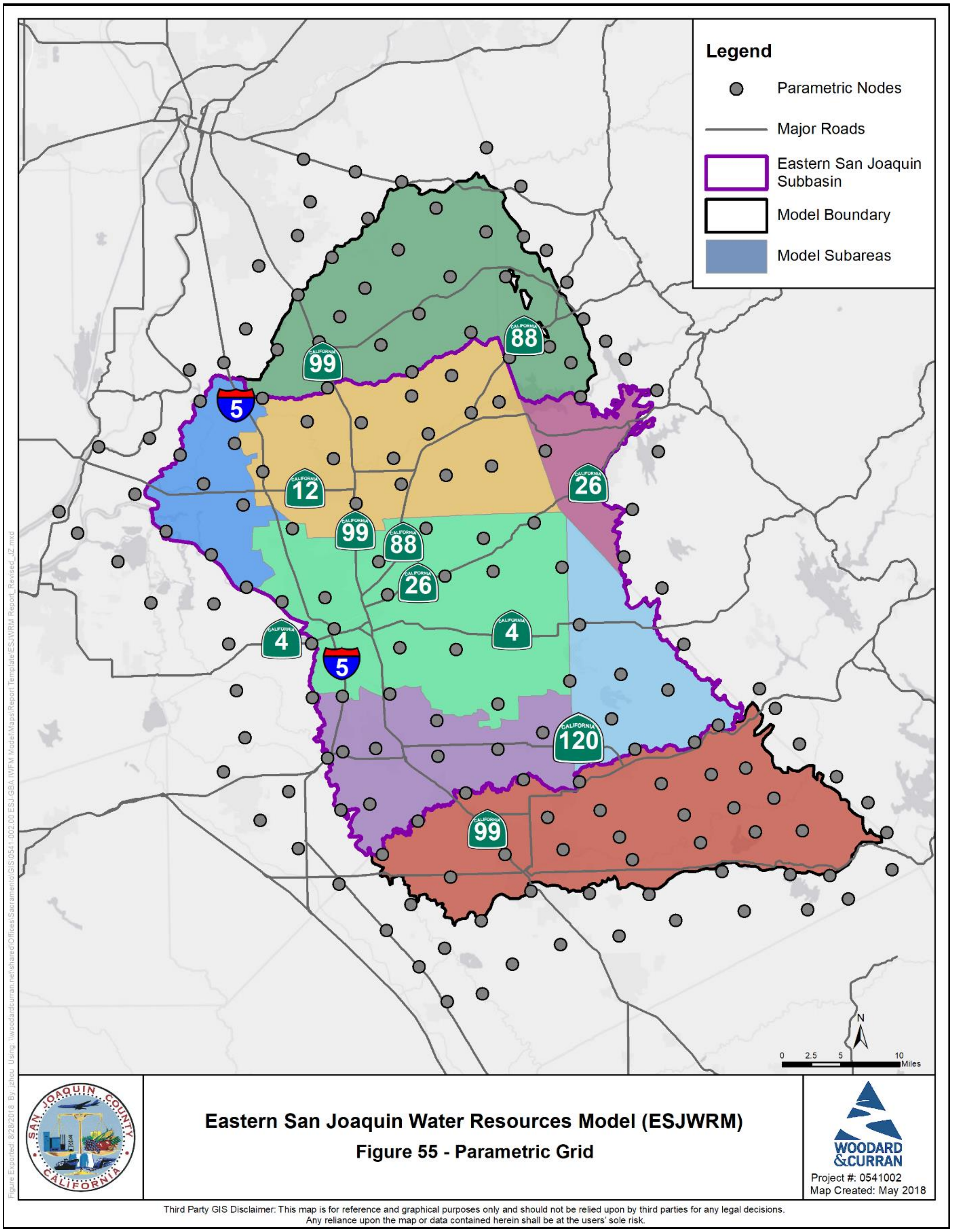

Figure 56: ESJWRM Layer 1 Horizontal Hydraulic Conductivity

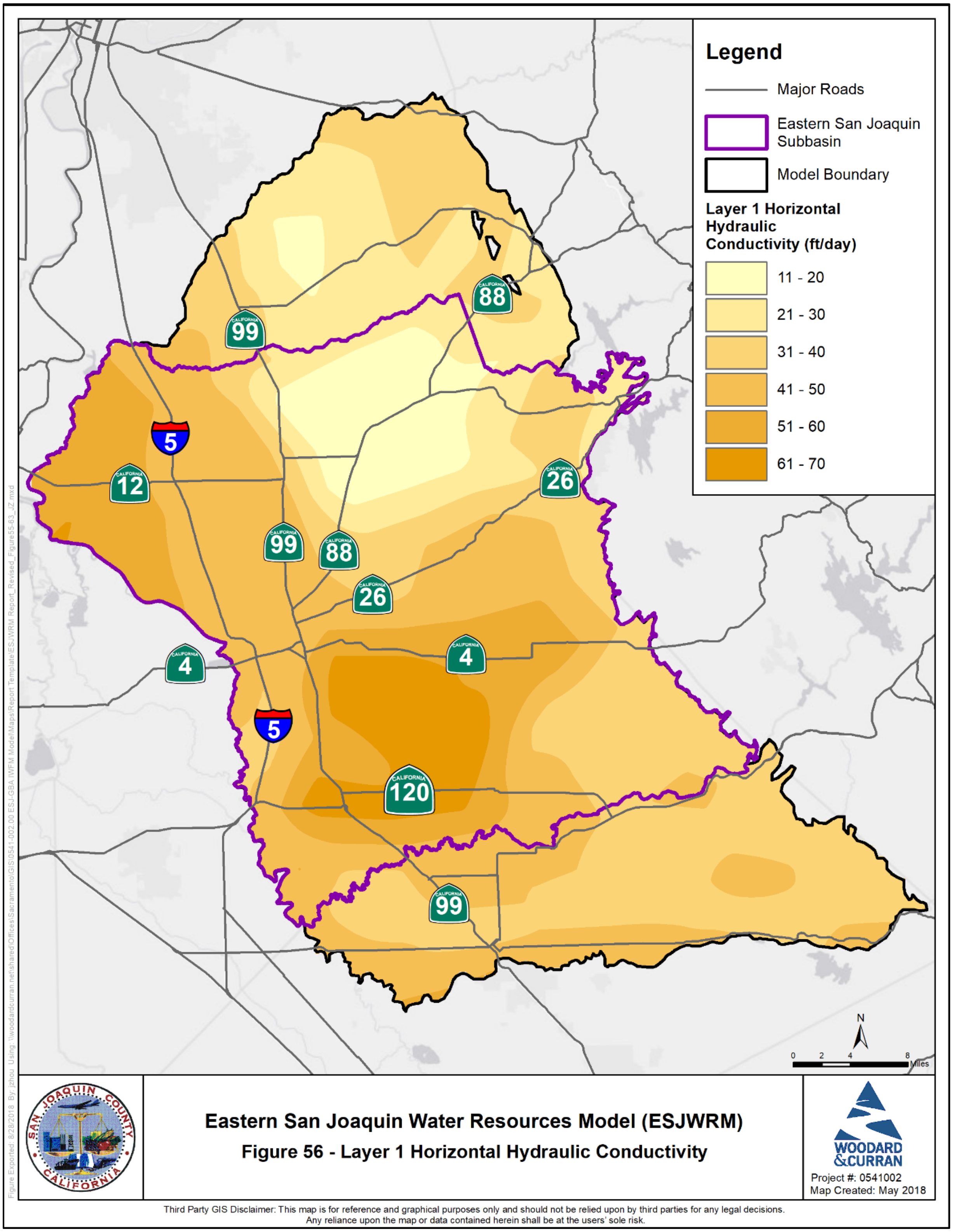

Figure 57: ESJWRM Layer 2 Horizontal Hydraulic Conductivity

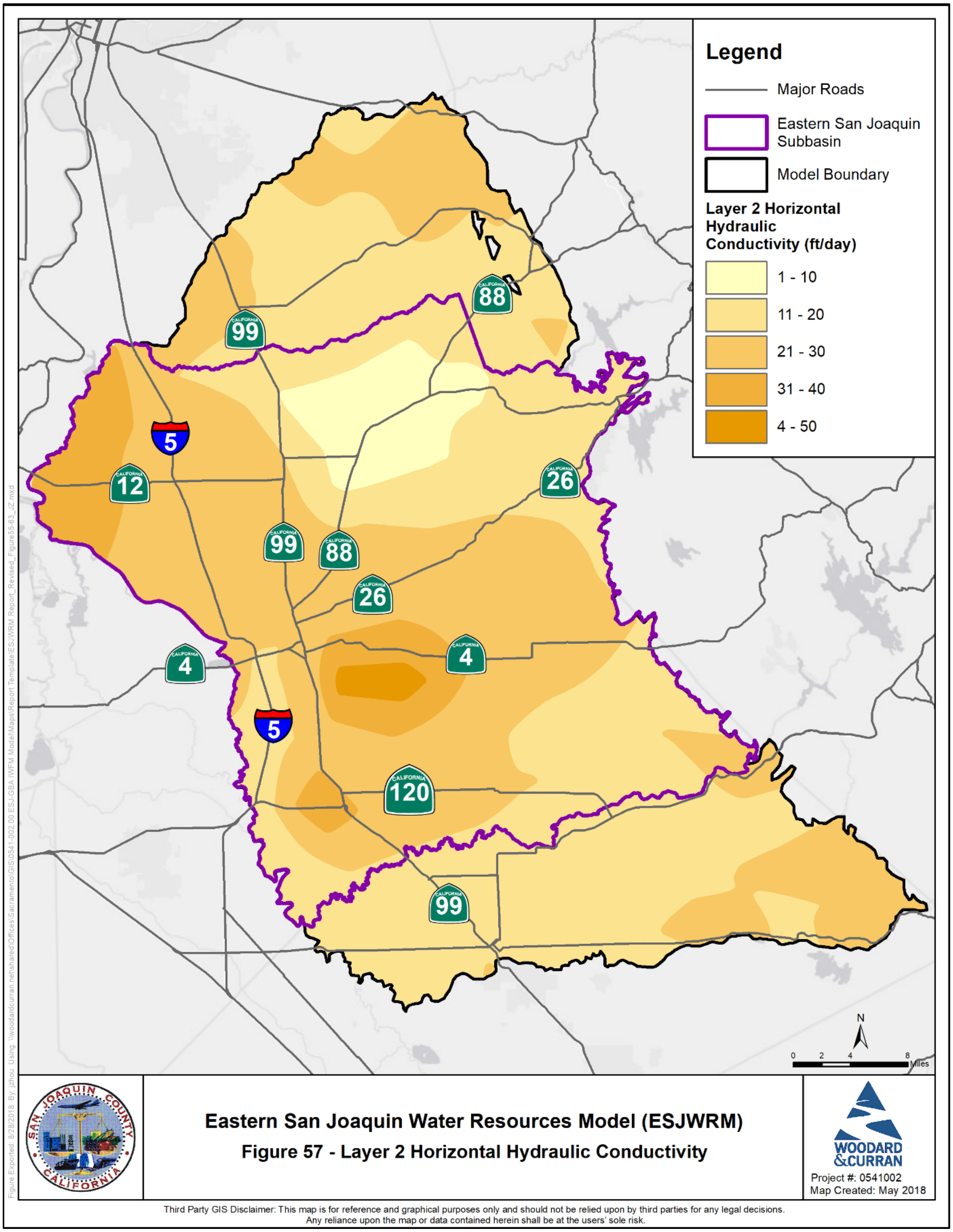

Figure 58: ESJWRM Layer 3 Horizontal Hydraulic Conductivity

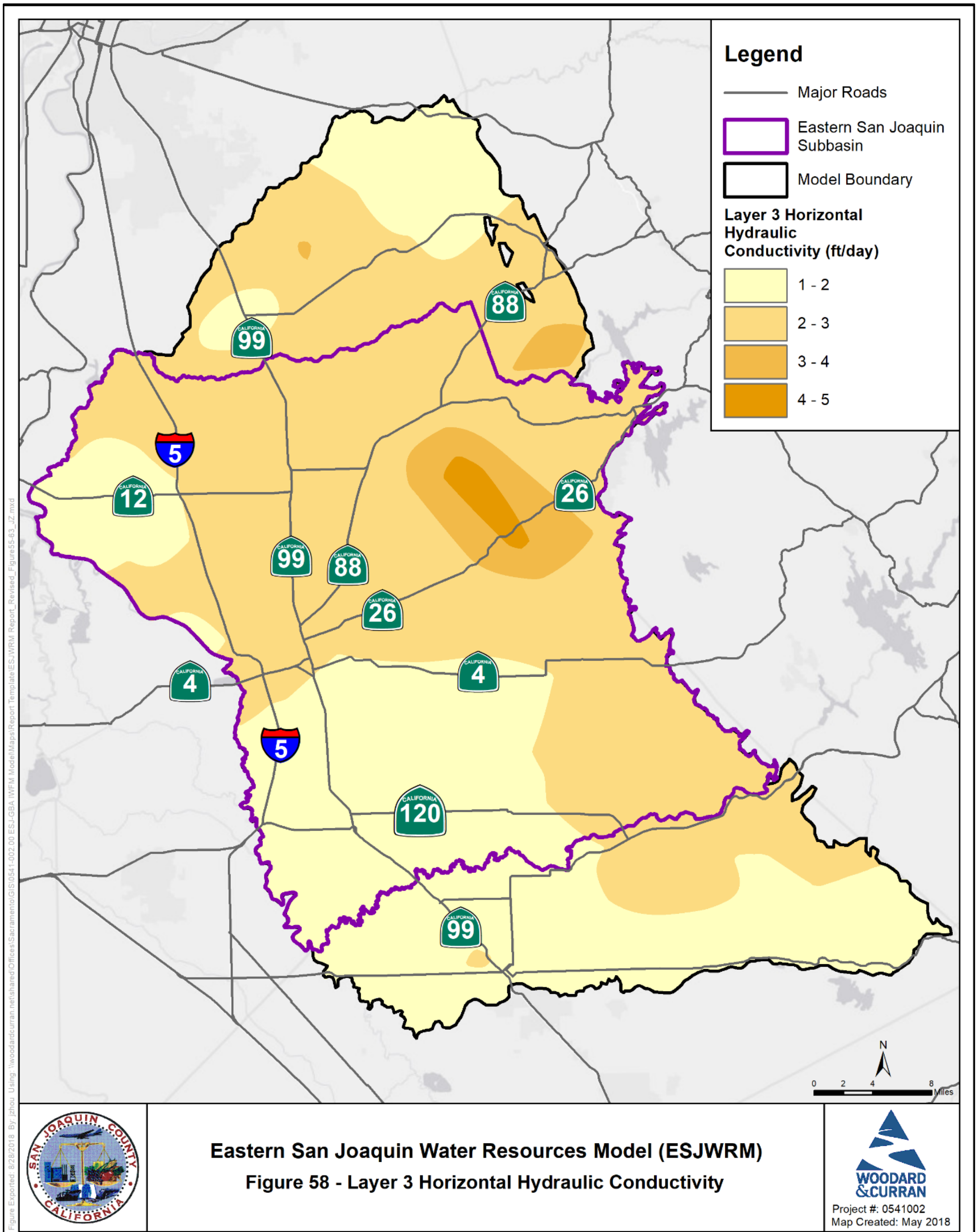

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Figure 59: ESJWRM Layer 1 Specific Storage

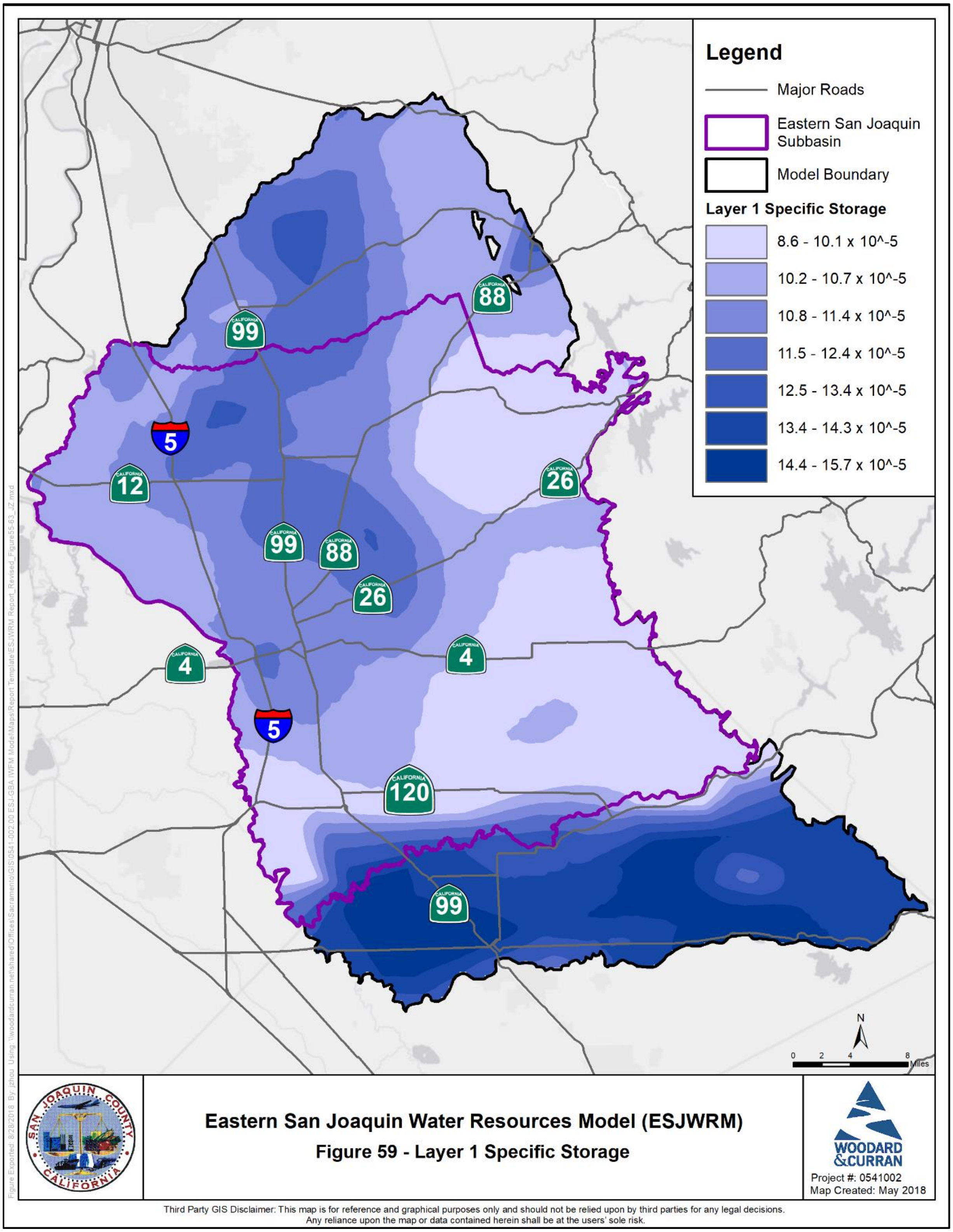

Figure 60: ESJWRM Layer 2 Specific Storage

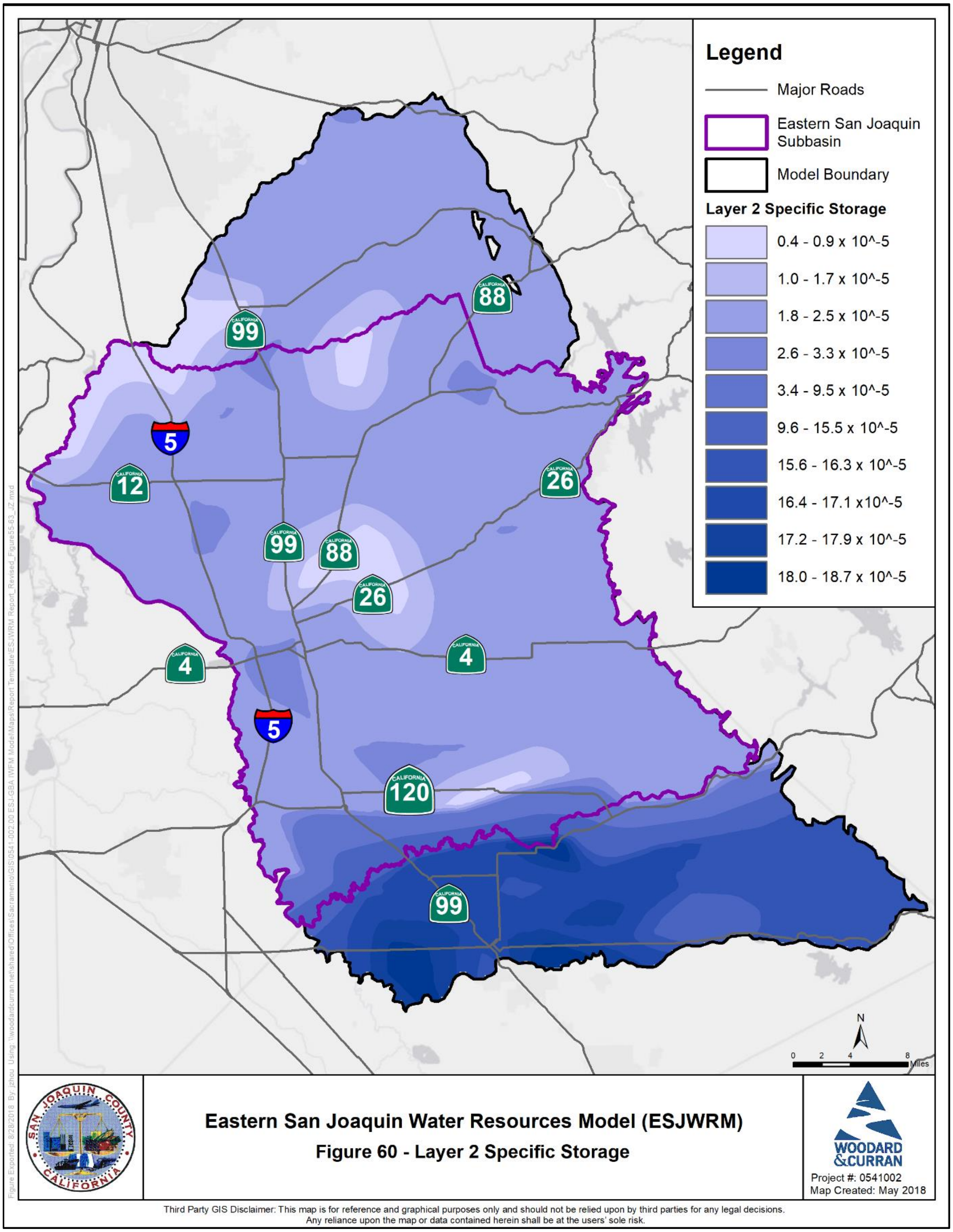

Figure 61: ESJWRM Layer 3 Specific Storage

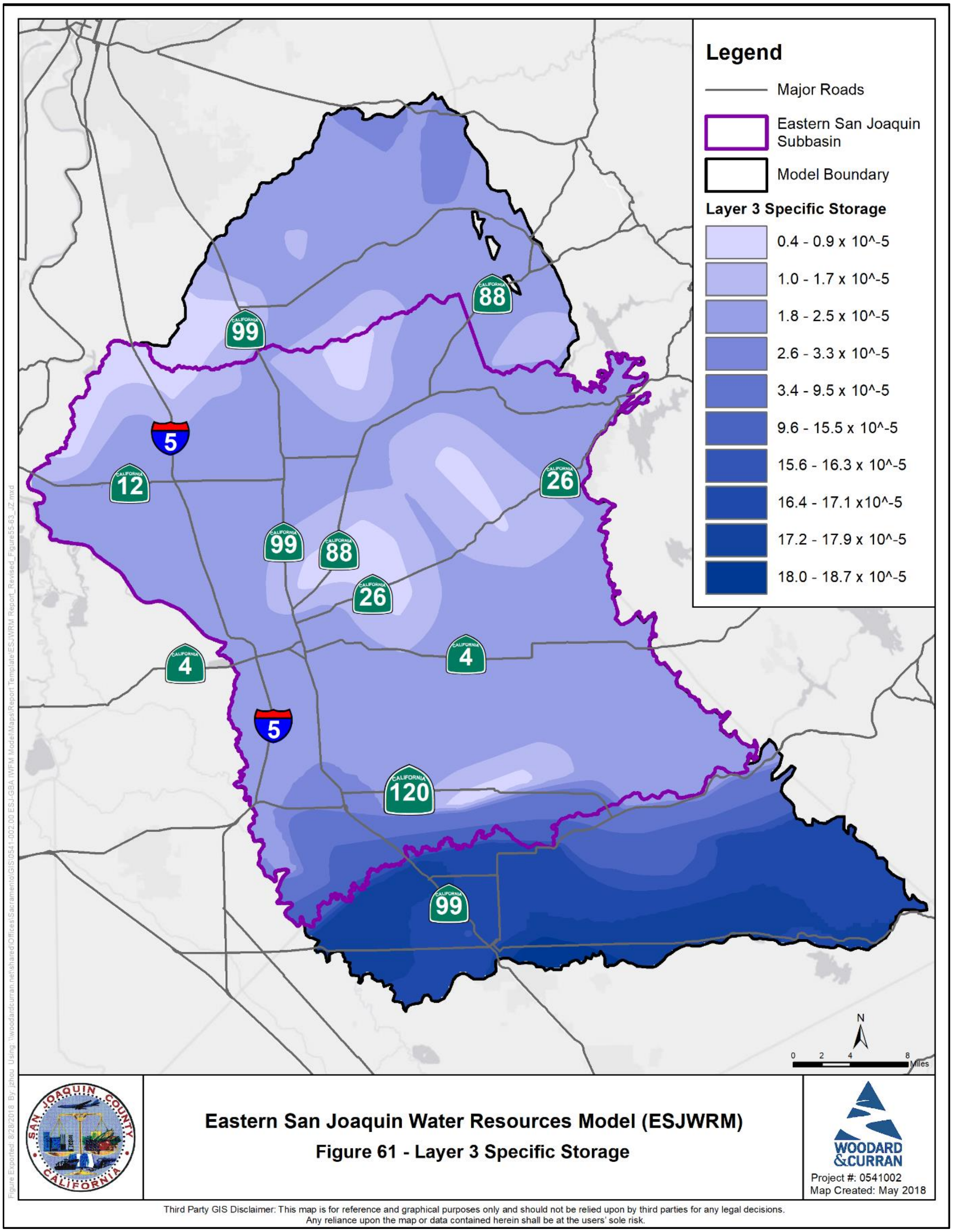

Figure 62: ESJWRM Layer 1 Specific Yield

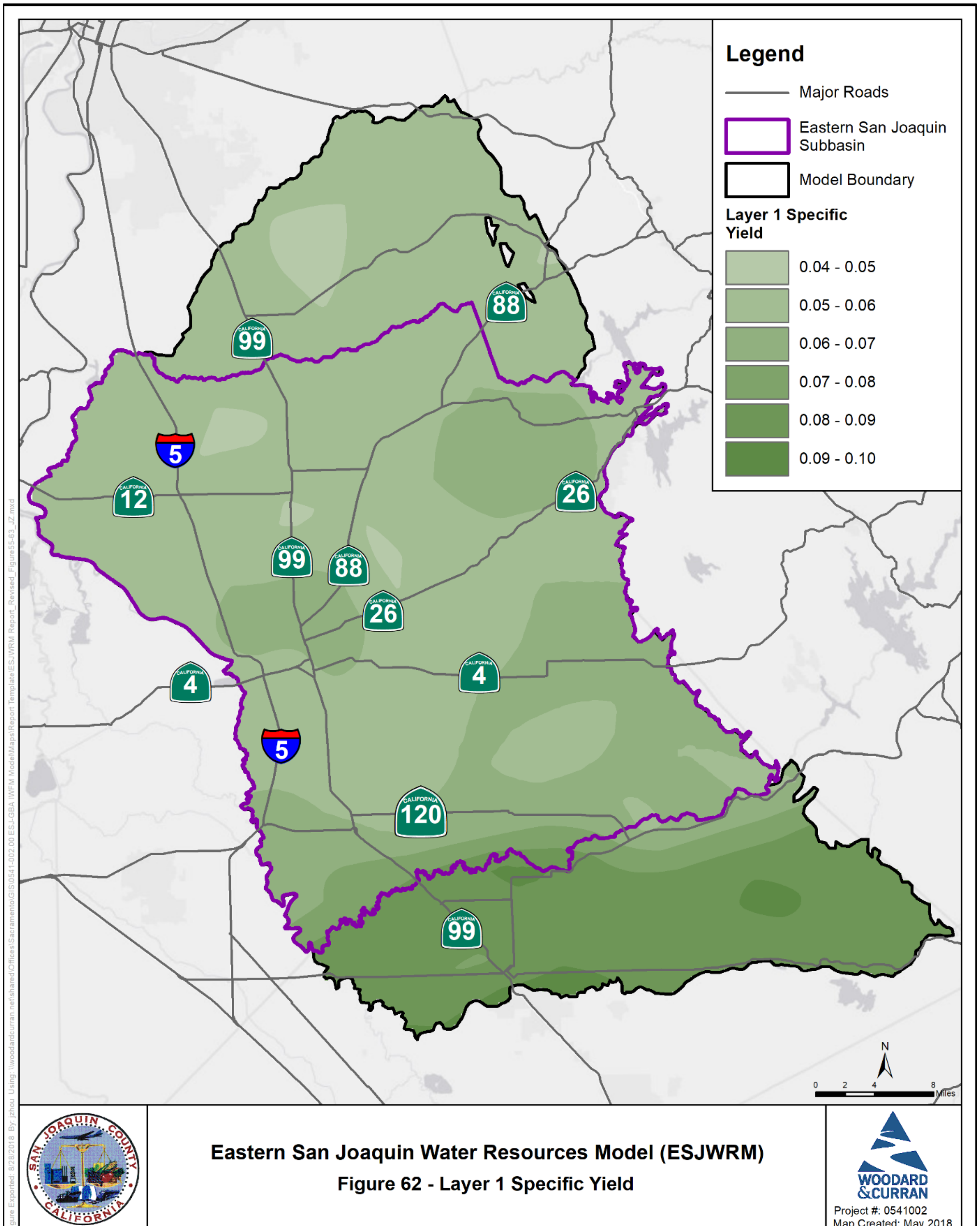

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Figure 63: ESJWRM Layer 2 Specific Yield

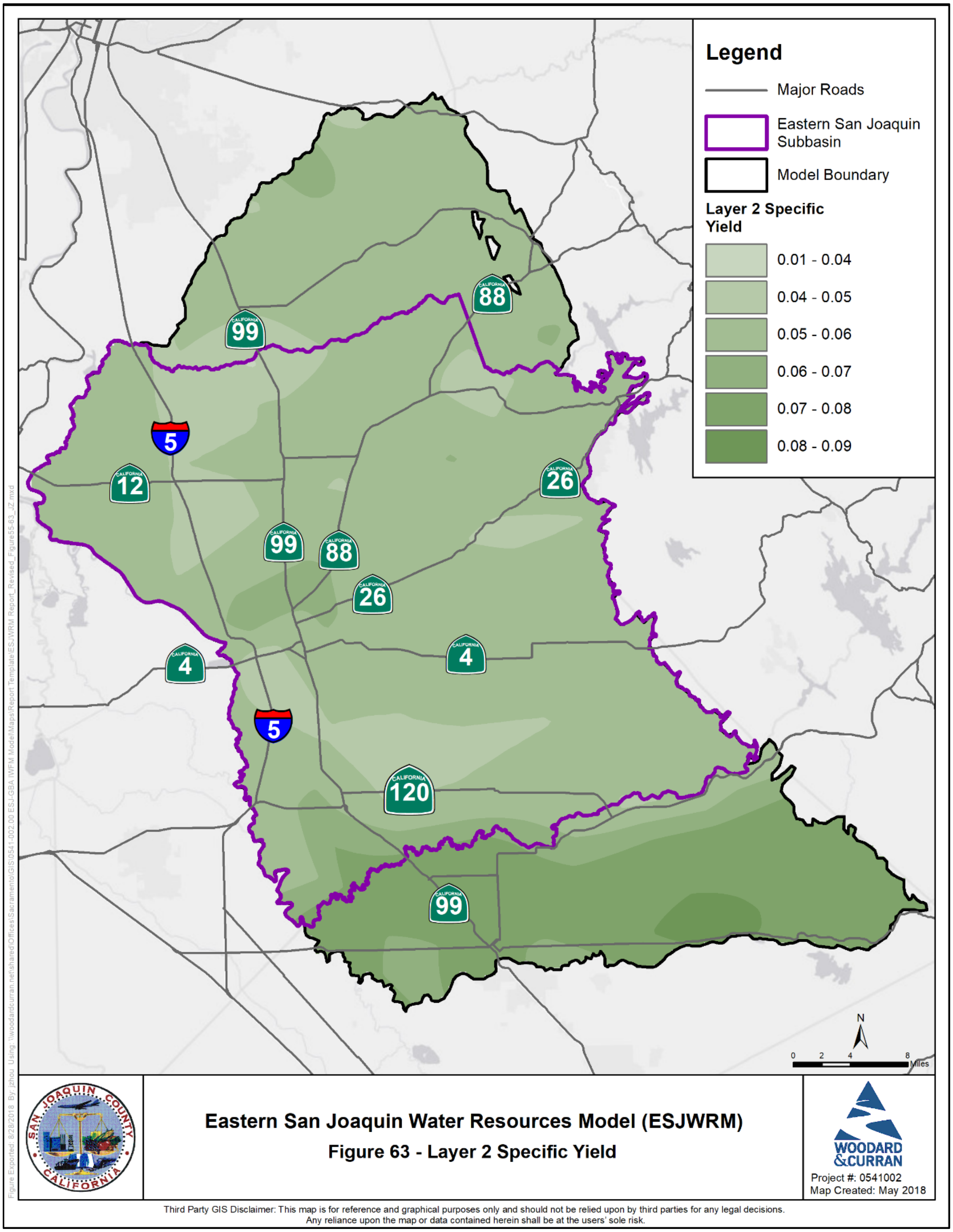


Figure 64: ESJWRM Layer 3 Specific Yield

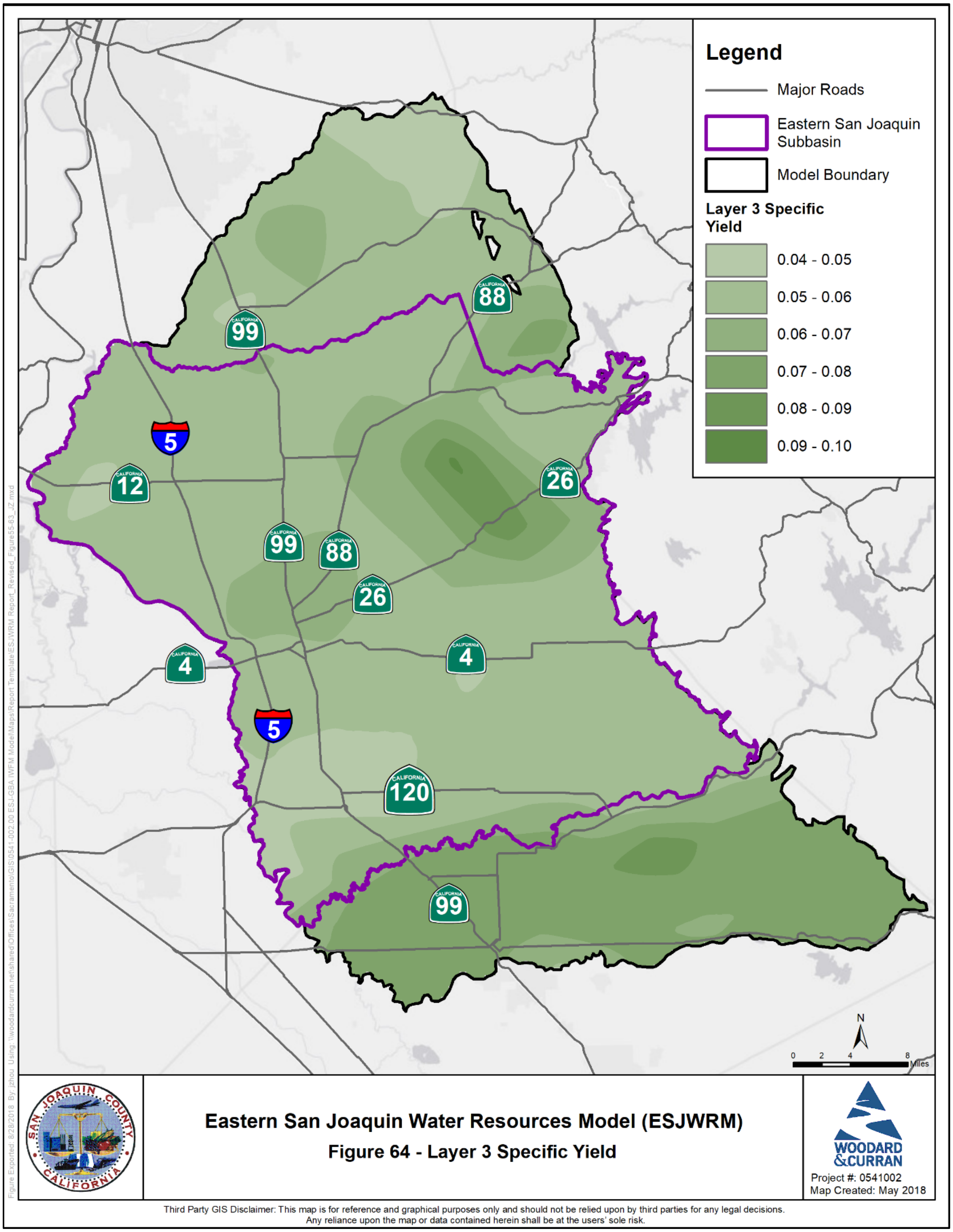


Figure 65: ESJWRM Sensitivity Analysis of Horizontal Hydraulic Conductivity – Difference in Average Groundwater Elevation (feet)

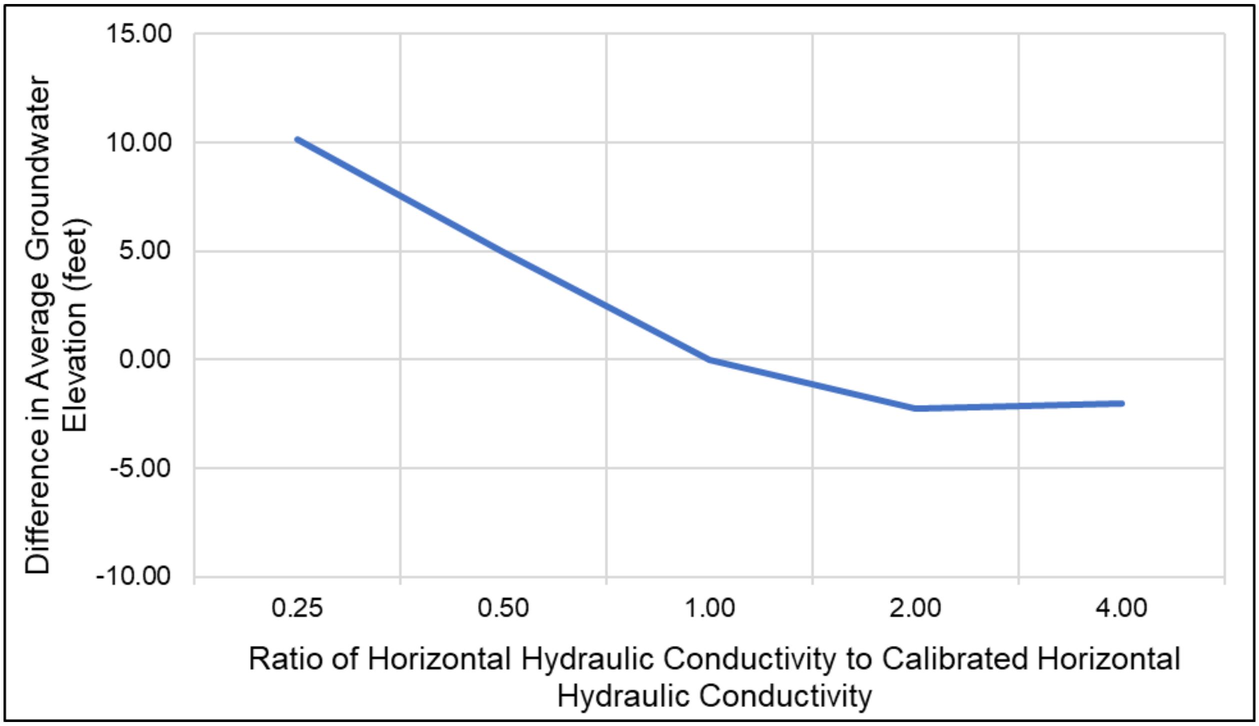


Figure 66: ESJWRM Sensitivity Analysis of Horizontal Hydraulic Conductivity – Relative Root Mean Square Error

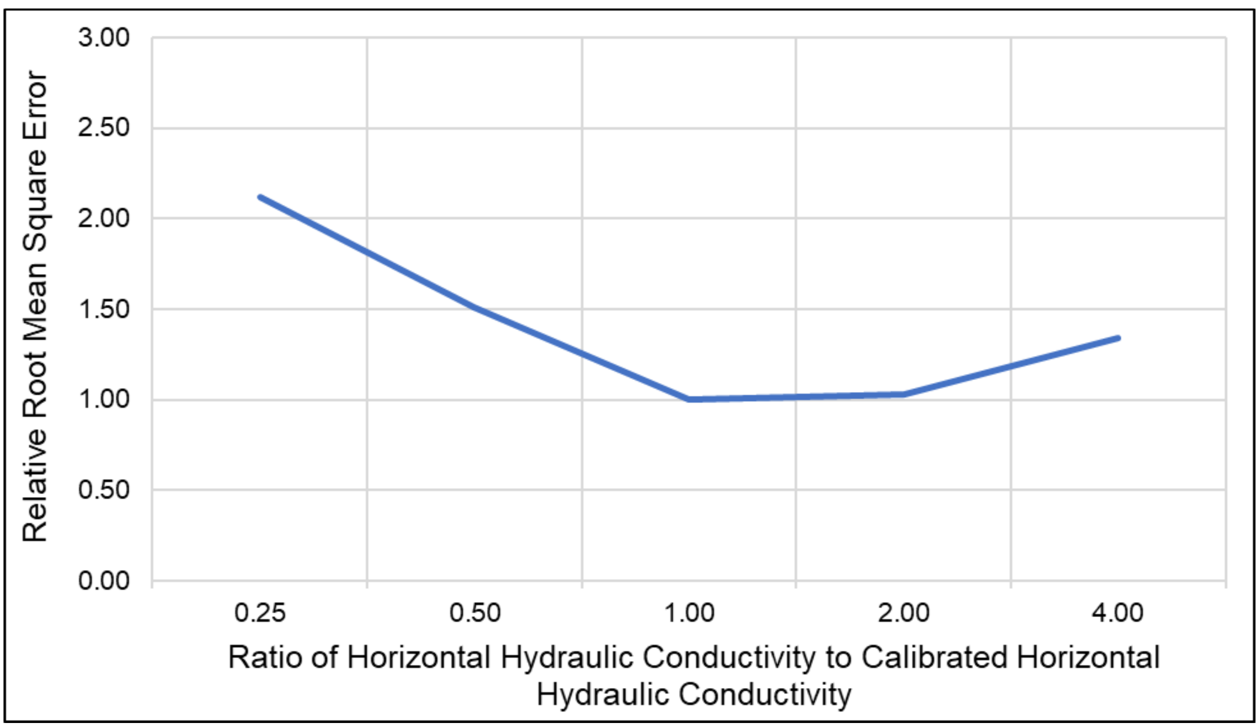


Figure 67: ESJWRM Sensitivity Analysis of Vertical Hydraulic Conductivity – Difference in Average Groundwater Elevation (feet)

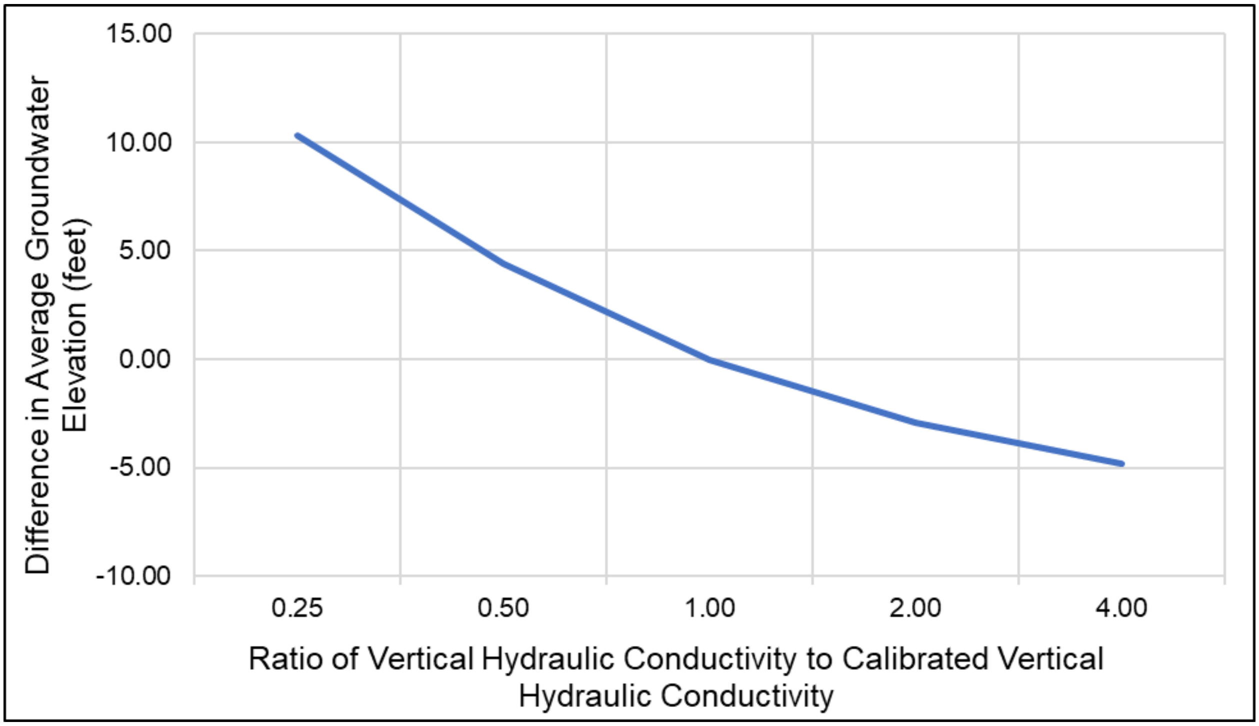


Figure 68: ESJWRM Sensitivity Analysis of Vertical Hydraulic Conductivity – Relative Root Mean Square Error

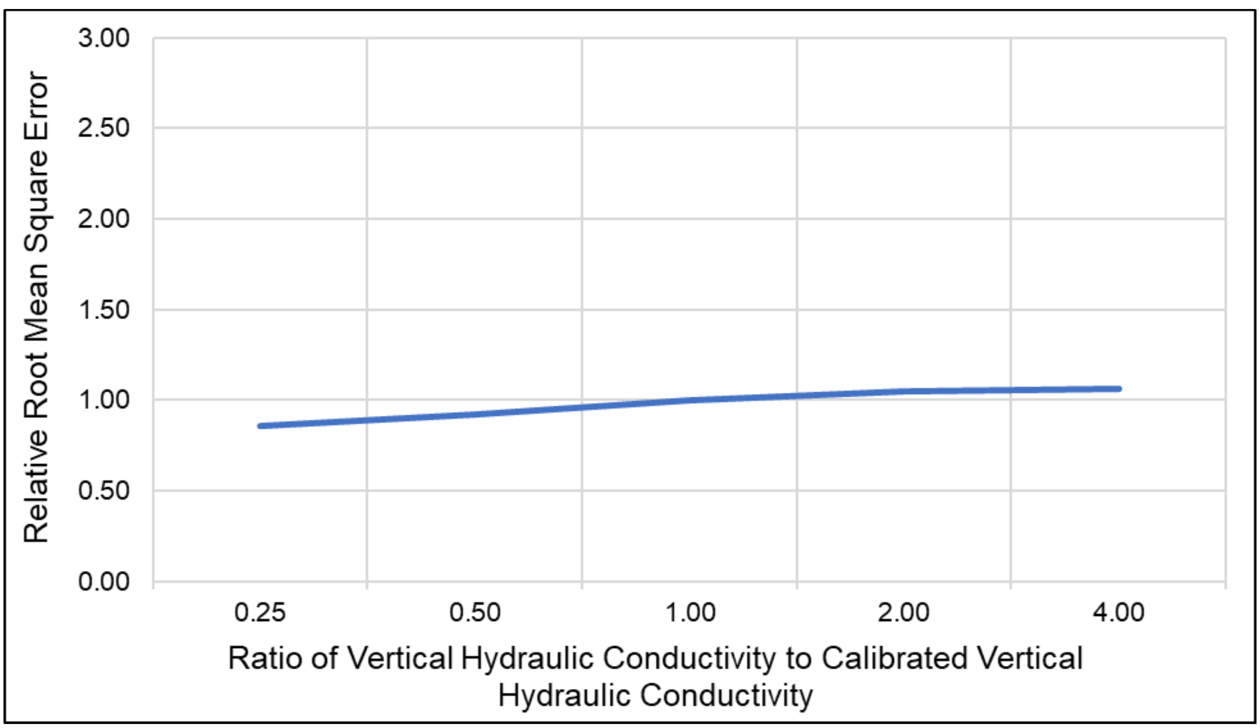


Figure 69: ESJWRM Sensitivity Analysis of Specific Storage – Difference in Average Groundwater Elevation (feet)

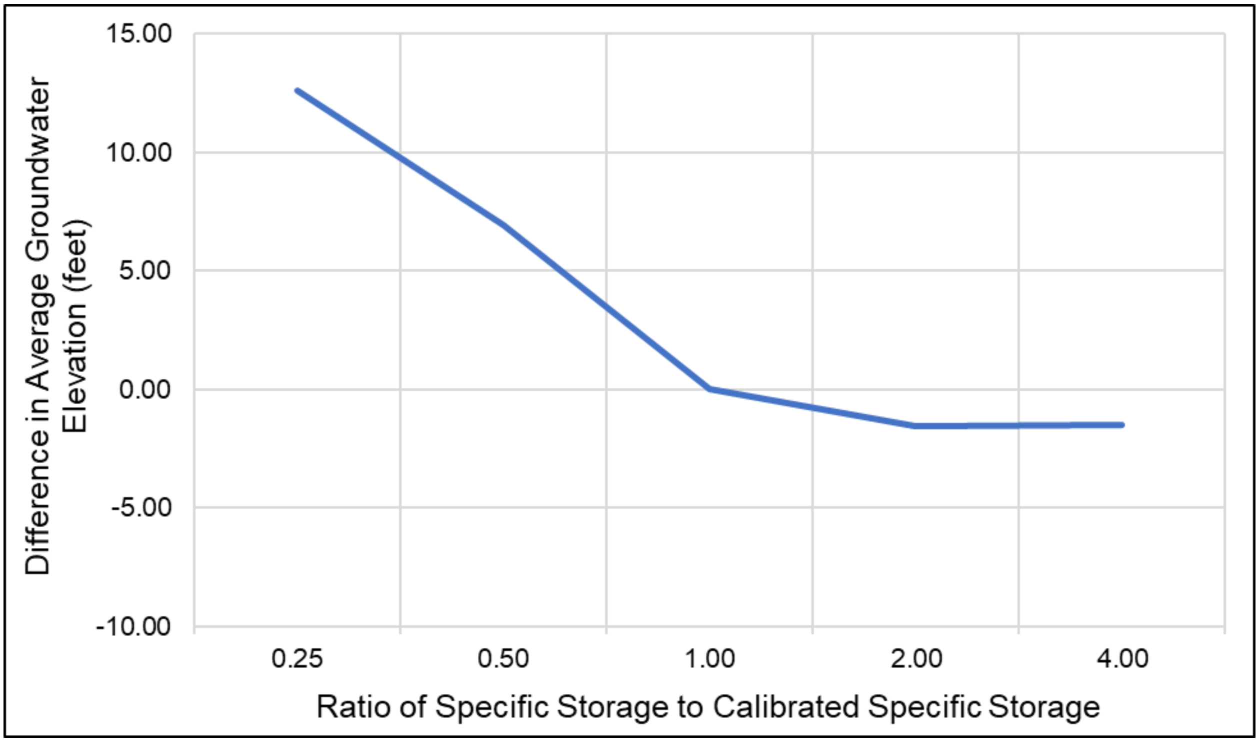


Figure 70: ESJWRM Sensitivity Analysis of Specific Storage – Relative Root Mean Square Error

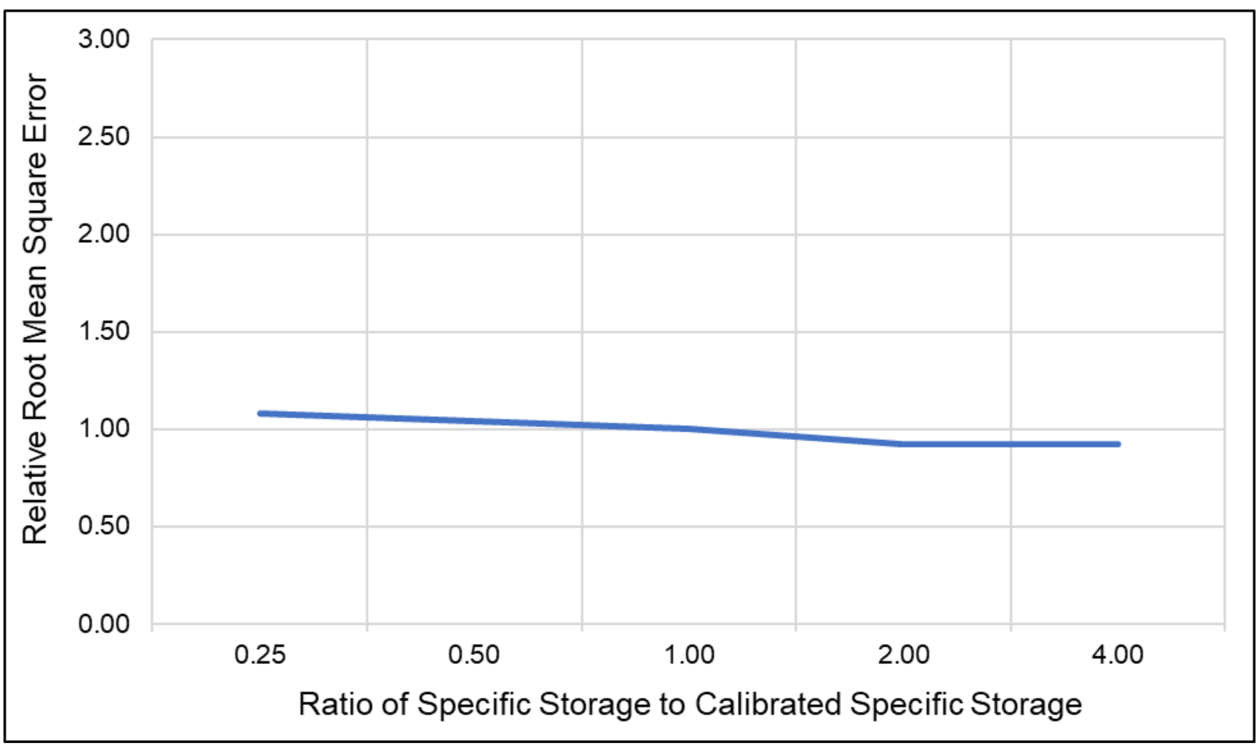


Figure 71: ESJWRM Sensitivity Analysis of Specific Yield – Difference in Average Groundwater Elevation (feet)

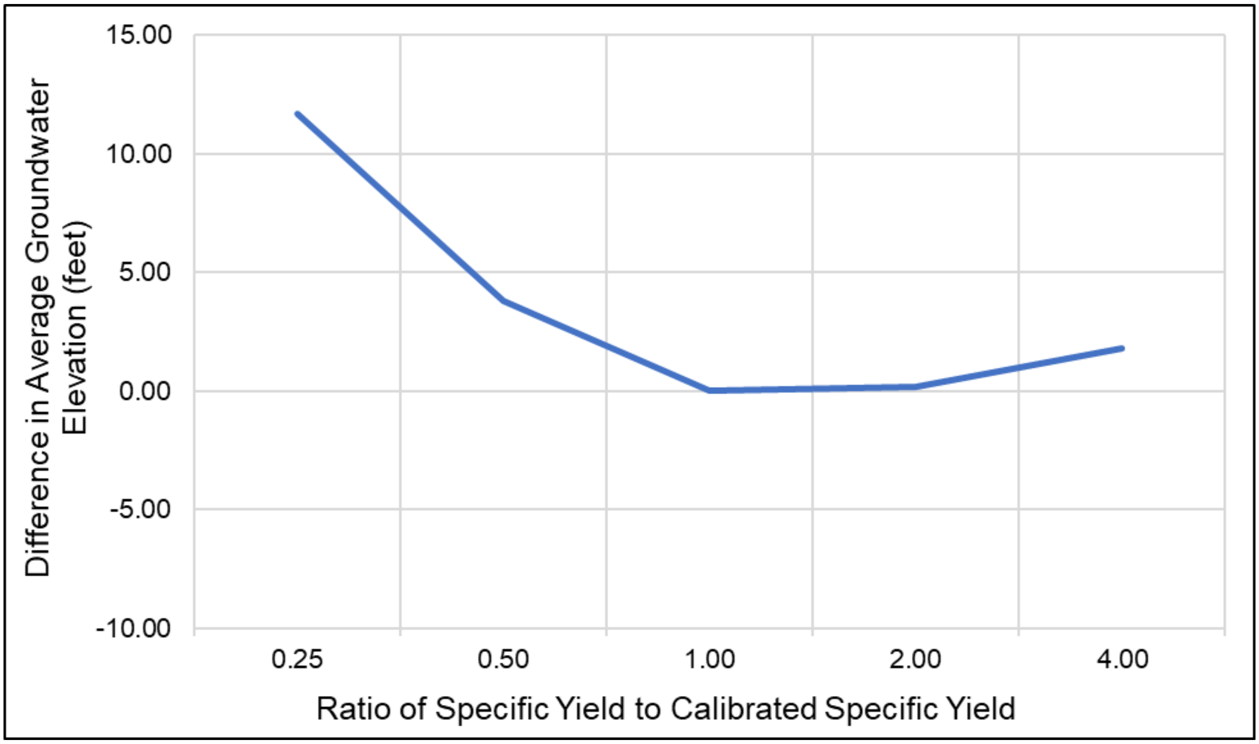


Figure 72: ESJWRM Sensitivity Analysis of Specific Yield – Relative Root Mean Square Error

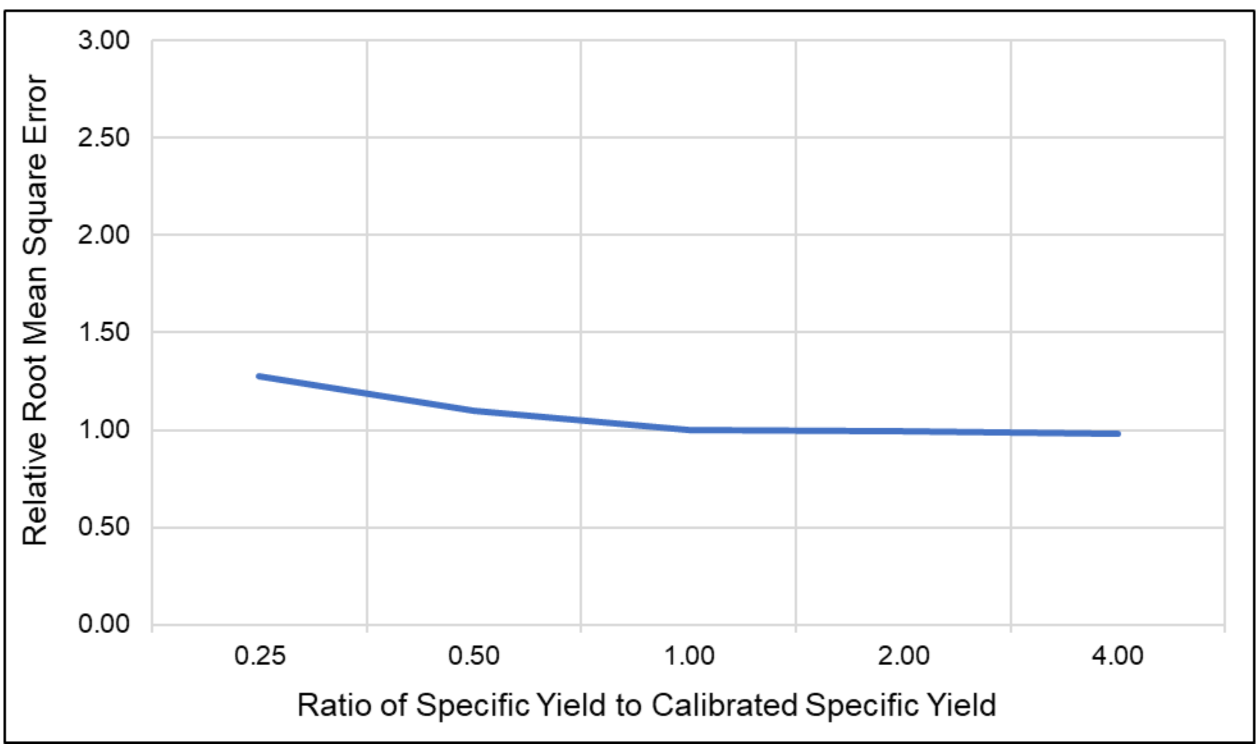


Figure 73: ESJWRM Sensitivity Analysis of Streambed Conductance – Difference in Average Groundwater Elevation (feet)

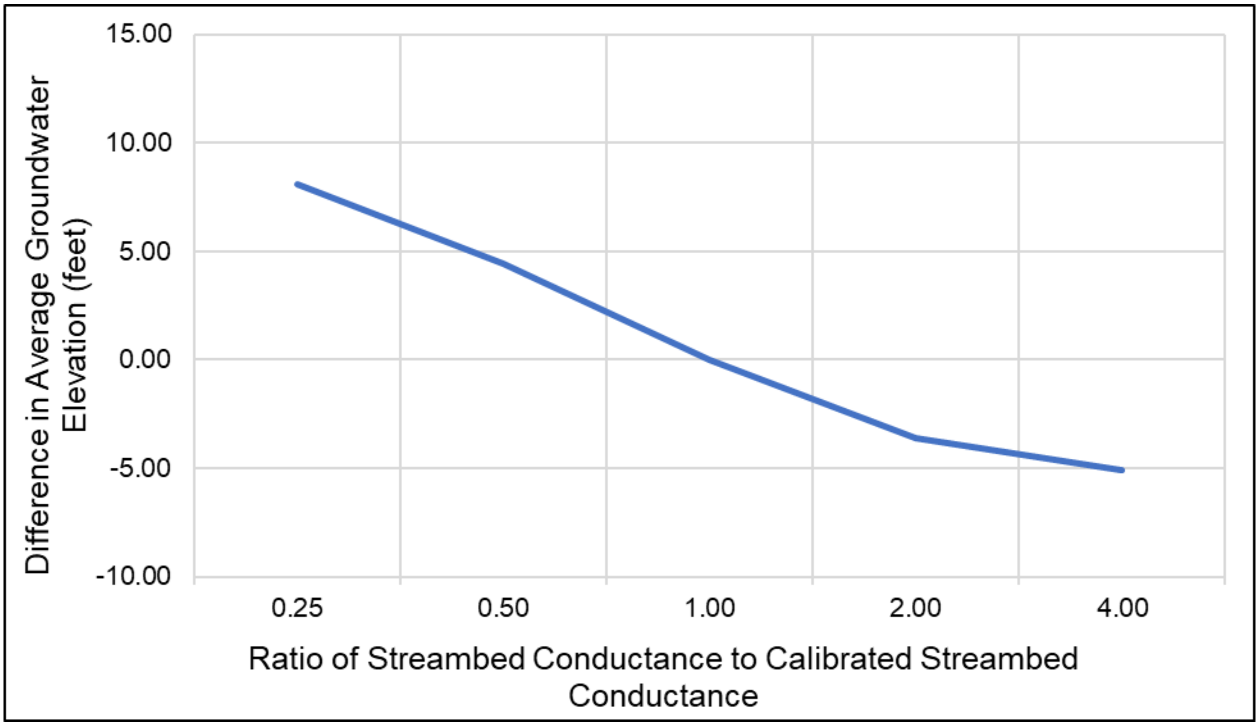
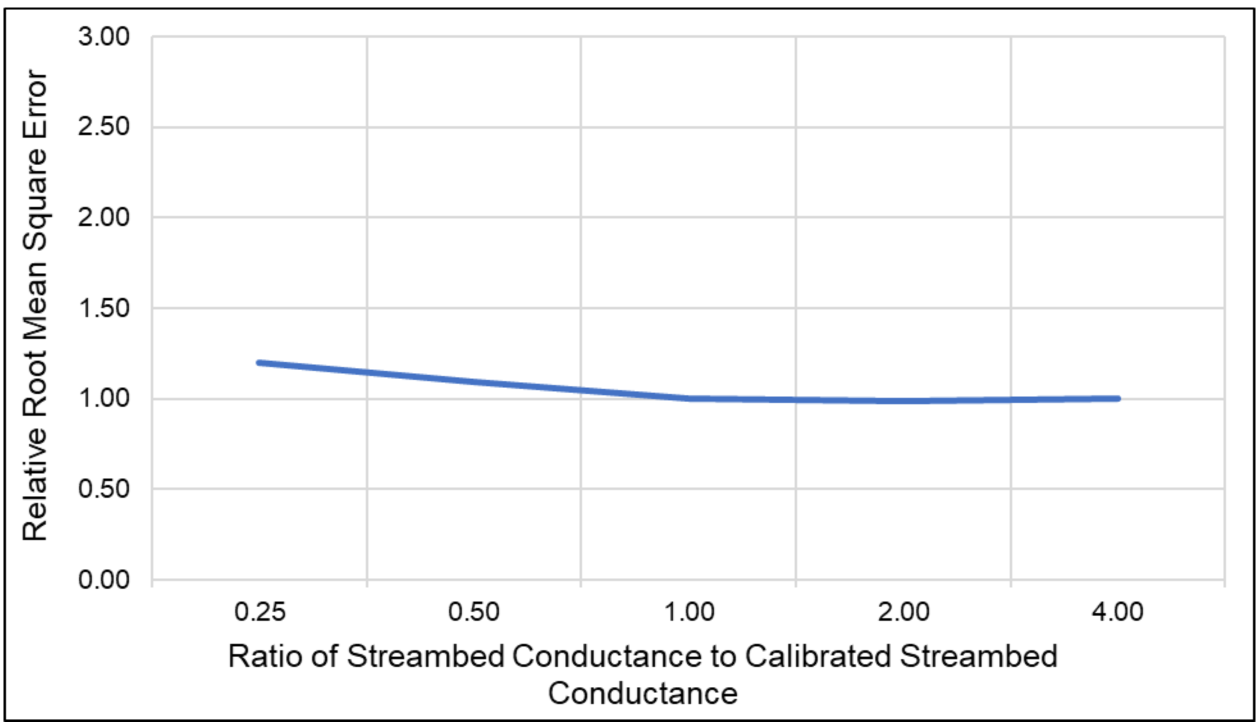


Figure 74: ESJWRM Sensitivity Analysis of Streambed Conductance – Relative Root Mean Square Error



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