Eastern San Joaquin Subbasin Groundwater Sustainability Plan

Draft Deliverable 2

June 2019

TABLE OF CONTENTS

SECTION **PAGE NO.**

List of Tables

List of Figures

ACRONYMS

1,2,3-TCP	1,2,3-Trichloropropane
AB	Assembly Bill
ACP	agricultural conservation program
AF	acre-feet
AF/year	acre-feet per year
ALOS	Advanced Land Observing Satellite
AN	Above normal
AWMPs	Agricultural Water Management Plans
BHC	benzene hexachloride
BMP	best management practice
BN	Below normal
B.P.	before present
BTEX	benzene, toluene, ethylbenzene, and xylenes
Cal Water	California Water Services Company Stockton District
California State Parks	California Department of Parks and Recreation
CALSIMETAW	California Simulation of Evapotranspiration of Applied Water
CASGEM	California Statewide Groundwater Elevation Monitoring
CCR	Consumer Confidence Reporting
CCWD	Calaveras County Water District
CDEC	California Data Exchange Center
CDPH	California Department of Public Health
CDPR	California Department of Pesticide Regulation
CEDEN	California Environmental Data Exchange Network
cfs	cubic feet per second
CGPF	CalSim II Generated Perturbation Factors
CNRA	California Natural Resources Agency
CSJWCD	Central San Joaquin Water Conservation District
CVRWQCB	Central Valley Regional Water Quality Control Board
CWC	California Water Code
DBCP	1,2-birobmo-3-chloropropane
DDW	Division of Drinking Water
DMS	data management system
DOGGR	Division of Oil, Gas, and Geothermal Resources
DPR	Department of Pesticide Regulations
DTSC	Department of Toxic Substances Control
DWR	Department of Water Resources
ED	Economic Development
EDB	ethylene dibromide
ESJWQC	East San Joaquin Water Quality Coalition
ESJWRM	Eastern San Joaquin Water Resources Model

ETo	evapotranspiration
EWMPs	efficient water management practices
FB	Financing and Budgeting
GAMA	groundwater ambient monitoring and assessment
GBA	Groundwater Basin Authority
GDE	groundwater dependent ecosystem
GICIMA	Groundwater Information Center Interactive Mapping Application
GIS	Geographic Information System
GMP	Groundwater Management Plan
gpm	gallons per minute
GPS	Global Positioning System
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
GWA	Groundwater Authority
GWA Board	Groundwater Authority Board of Directors
HCM	Hydrogeologic Conceptual Model
ICU Program	Integrated Conjunctive Use Program
IGC	Inter-governmental Coordination
ILRP	Irrigated Lands Regulatory Program
InSAR	Interferometric Synthetic Aperture Radar
IRGMP	Integrated Regional Groundwater Management Plan
IRWMP	Integrated Regional Water Management Plan
IWFM	Integrated Water Flow Model
JP	Joint Partnerships
JPA	Joint Powers Agreement
LLNL	Lawrence Livermore National Laboratory
LU	land use
Ma	millions of years ago
MAC	Mokelumne-Amador-Calaveras
MAF	million acre-feet
MAR	managed aquifer recharge
MCL	maximum contaminant level
mg/L	milligrams per liter
MokeWISE	Mokelumne Watershed Interregional Sustainability Evaluation
MS	Microsoft
MTBE	methyl tertiary-butyl ether
MUD	Municipal Utilities Department
MWH	Montgomery Watson Harza
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NCCAG	natural communities commonly associated with groundwater

NDWA	North Delta Water Agency
NRCS	Natural Resource Conservation Service
NSJWCD	North San Joaquin Water Conservation District
NWIS	National Water Information System
OID	Oakdale Irrigation District
OSWCR	Online System for Well Completion Reports
PCE	perchloroethylene
PDF	portable document format
PFIP	Public Facilities Implementation Plan
PFOA	perfluorooctantoic acid
PFOS	perfluorooctanesulfonic acid
PG&E	Pacific Gas and Electric Company
PI	Public Information
PRISM	Precipitation-Elevation Regressions on Independent Slopes Model
PS	persistent scatter
PSP	Plans, Strategies, and Programs
PSR	Planning Studies and Reports
RDR	Regulation and Development Review
RWQCB	Regional Water Quality Control Board
SB	Senate Bill
SCDER	Stanislaus County Department of Environmental Resources
SCWSP	South County Water Supply Program
SDWA	South Delta Water Agency
SEWD	Stockton East Water District
SGMA	the Sustainable Groundwater Management Act
SJC	San Joaquin County
SJCFCWCD	San Joaquin County Flood Control and Water Conservation District
SJRRP	San Joaquin River Restoration Program
SJV	San Joaquin Valley
SMCL	secondary maximum contaminant levels
SO	Services and Operations
SRA	State Recreation Area
SS	specific storage
SSJID	South San Joaquin Irrigation District
State ID	State Well Numbering System identification
SVRA	State Vehicular Recreation Area
SWRCB	State Water Resources Control Board
SY	specific yield
TCE	trichloroethene
TDS	total dissolved solids
TNC	The Nature Conservancy

UNAVCO	University NAVSTAR Consortium
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USFW	United States Fish & Wildlife Service
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
UWMPs	Urban Water Management Plans
VAMP	Vernalis Adaptative Management Plan
VIC	Variable Infiltration Capacity
VOC	volatile organic compound
WDL	Water Data Library
WDR	Waste Discharge Requirement
WID	Woodbridge Irrigation District
Workgroup	Groundwater Sustainability Workgroup

This document includes the working drafts of the Water Budget and the Current and Historical Conditions sections of Chapter 3: Basin Setting that will be included as part of the Eastern San Joaquin Subbasin Groundwater Sustainability Plan (Eastern San Joaquin GSP). These sections satisfy §354.18 and §354.16 of the Sustainable Groundwater Management Act (SGMA) Regulations, respectively. The Basin Settings chapter contains three main subsections:

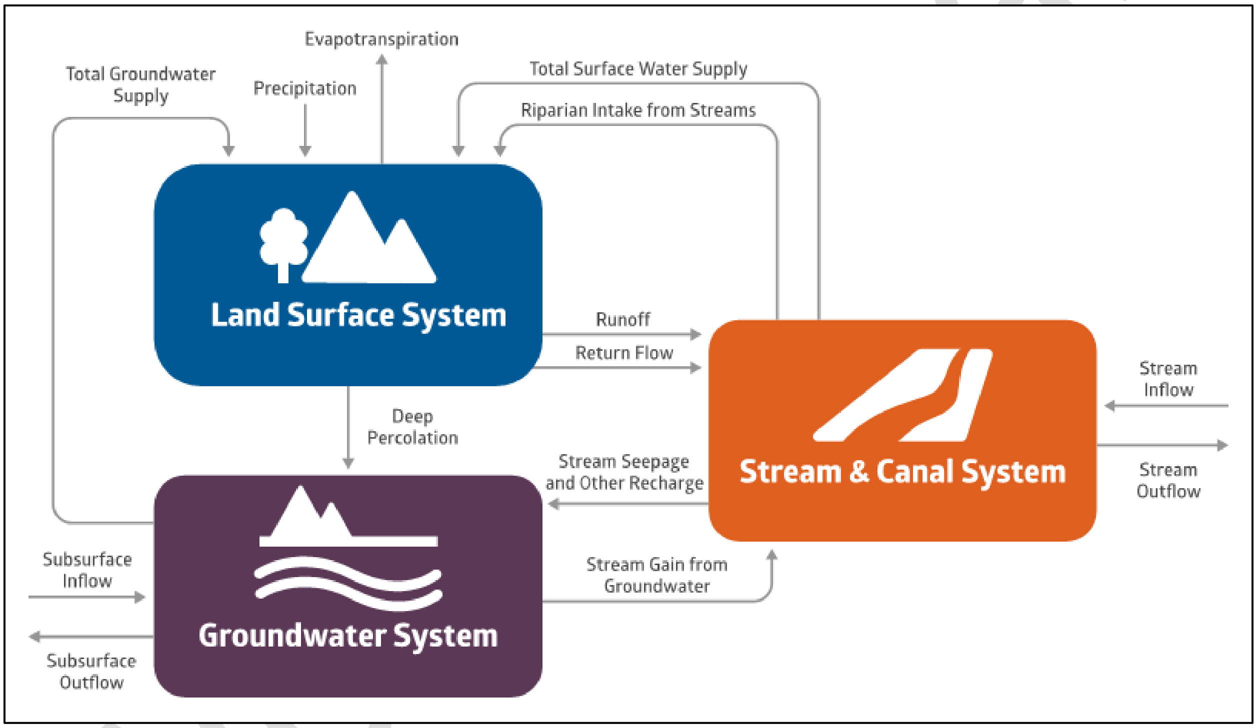
- **Hydrogeologic Conceptual Model –** This section provides the geologic information needed to understand the framework in which water moves through the basin. It focuses on geologic formations, aquifers, structural features, and topography.
- **Current and Historical Conditions –** This section describes and presents groundwater trends, levels, hydrographs and level contour maps; estimates changes in groundwater storage; identifies groundwater quality issues; and addresses subsidence and surface water interconnection.
- **Water Budget –** This section provides information used in water budget development, discusses how the budget was calculated, and provides water budget estimates for historical conditions, current conditions, and projected conditions.

3.3 WATER BUDGETS

3.3.1 Water Budget Background Information

Water budgets are developed to provide a quantitative account of water entering and leaving the Eastern San Joaquin Subbasin. Water entering and leaving the Subbasin includes flows at the surface and in the subsurface environment. Water enters and leaves due to natural conditions, such as precipitation and streamflow, and/or through human activities, such as groundwater pumping or recharge from applied water. Additionally, interconnection between the groundwater system and rivers/streams accounts for other components of the water budget. Figure 3-1 depicts the major components of a water budget and their interconnection as presented in the context of stream, land surface, and groundwater systems.

Figure 3-1: Generalized Water Budget Diagram



Quantities presented for the water budget components of the Eastern San Joaquin Subbasin provide information on historical, current, and projected conditions as they relate to hydrology, water demand, water supply, land use, population, climate variability, groundwater and surface water interaction, and groundwater flow. This information can assist in the management of the Subbasin by identifying the relationship between different components affecting the water budget in the Subbasin, which provides context in the development and implementation of strategies and policies to achieve Subbasin groundwater sustainability conditions. Water budget quantities presented are based on the simulation results from the Eastern San Joaquin Water Resources Model (ESJWRM).

The ESJWRM was developed to be the main analysis tool supporting the development of the GSP for the Subbasin. The ESJWRM is a quasi-three-dimensional finite element model developed using the Integrated Water Flow Model (IWFM) simulation code (Dogrul et al., 2017). Using data from Federal, State, and local resources, the ESJWRM was calibrated for the 20-year hydrologic period of October 1995 to September 2015 (water years 1996 through 2015) by comparing simulated groundwater levels and streamflow records with historical observed records. Development of the model involved the study and analysis of hydrogeologic conditions, agricultural and urban water demands, agricultural and urban water supplies, and an evaluation of regional water quality conditions. ESJWRM development is documented in a report, "Eastern San Joaquin Water Resources Model (ESJWRM) Final Report," published in August 2018 and included in Appendix X.

Consistent with §354.18 of the Regulations (California Code of Regulations), the water budgets presented in this document encompass the combined surface and groundwater system of the Eastern San Joaquin Subbasin. The Subbasin water budget focuses on the full water year (12 months spanning October 1 of the previous year to September 30 of the year in question), with some consideration of monthly variability.

The Regulations require that the annual water budget quantify three different conditions: historical, current, and projected. Budgets are developed to capture typical conditions during these time periods. Typical conditions are developed through selecting historical hydrologic periods that incorporate droughts, wet periods, and normal periods. By incorporating these varied conditions within the budgets, the Subbasin is analyzed under certain hydrologic conditions, such as drought or very wet events, along with long-term averages. This Plan relies on historical hydrology to identify time periods for water budget analysis and uses the ESJWRM and associated data to develop the water budget and resulting budget estimates. The water budget components developed for the Eastern San Joaquin Subbasin are based upon estimates developed from historical and projected data as well as modeling assumptions. Because this process is new, and has been developed under time constraints, the water budget assumptions will be refined in the future, the water budget may change, and the conclusions and recommendations derived from the water budget may also change.

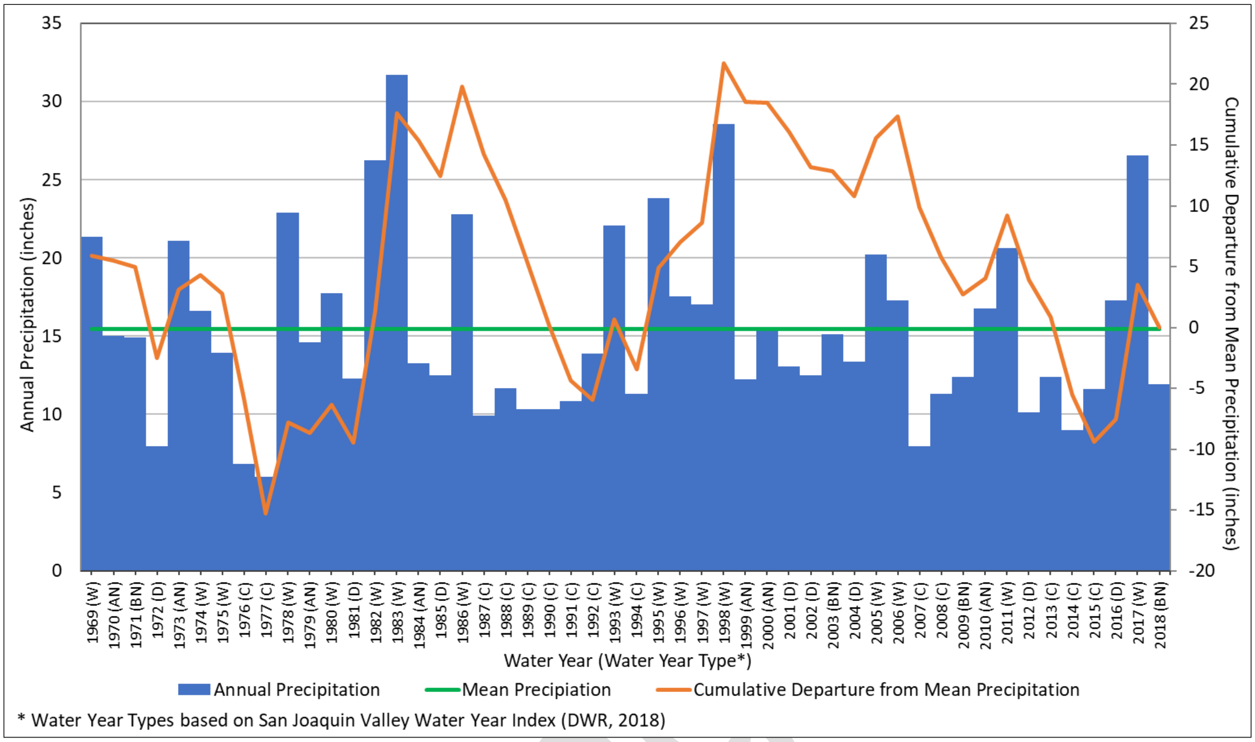
3.3.2 Identification of Hydrologic Periods

The historical hydrologic periods used in this Plan were selected to meet the requirements of developing historical, current, and projected water budgets. The Regulations require that the projected water budget reflect a 50-year hydrologic period in order to project how the Subbasin's land and groundwater systems may react under long-term average hydrologic conditions. Consistent with the Regulations, the 50-year historical record characterizes future conditions with respect to precipitation, evapotranspiration, and streamflow. Historical precipitation or rainfall in the Eastern San Joaquin Subbasin was used to identify a hydrologic period that would provide a representation of wet and dry periods and long-term average conditions needed for water budget analyses. Rainfall data for the Subbasin is derived from the PRISM (Precipitation-Elevation Regressions on Independent Slopes Model) dataset of the DWR's CALSIMETAW (California Simulation of Evapotranspiration of Applied Water) model. PRISM is a spatial estimation of rainfall data developed using monitoring network point data and interpolated using a variety of factors (NACSE, 2019).

Wet and dry hydrologic periods were identified by evaluating the cumulative departure from mean precipitation. Under this method, the long-term average precipitation is subtracted from annual precipitation within each water year to develop the departure from mean precipitation for each water year. Wet years have a positive departure and dry years have a negative departure; a year with exactly average precipitation would have zero departure. Starting at the first year analyzed, the departures are added cumulatively for each year. So, if the departure for Year 1 is 5 inches and the departure for Year 2 is -2 inches, the cumulative departure would be 5 inches for Year 1 and 3 inches (5 plus -2) for Year 2. Figure 3-2 graphically illustrates the cumulative departure of the spatially averaged rainfall within the Eastern San Joaquin Subbasin. The figure includes bars displaying annual precipitation for each water year from 1969 through 2018 and a horizontal line representing the mean precipitation of 15.4 inches. The cumulative departure from mean precipitation is based on these data sets and is displayed as a line that highlights wet periods with upward slopes (positive departure) and dry periods with downward slopes (negative departure). More severe events are shown by steeper slopes and greater changes. For example, the period from 1975 to 1977 illustrates a short period with dramatically dry conditions (6-inch decline per year in cumulative departure).

The PRISM estimates for rainfall in the Subbasin were confirmed by comparing the cumulative departure from mean precipitation results to the water year types in the San Joaquin Valley Water Year Hydrologic Classification (DWR, 2018), which classifies water years 1901 through 2017 as wet, above normal, below normal, dry, and critical based on inflows to major reservoirs or lakes. Wet (W) or Above Normal (AN) years show upward sloping cumulative departures, while Below Normal (BN), Dry (D), or Critical (C) water year types show downward trending cumulative departures (Figure 3-2).

Figure 3-2: 50-Year Historical Precipitation and Cumulative Departure from Mean Precipitation



* Water Year Types based on San Joaquin Valley Water Year Index (DWR, 2018)

3.3.3 Use of the ESJWRM and Associated Data in Water Budget Development

This Plan developed water budgets utilizing the ESJWRM, a fully integrated surface and groundwater flow model covering the Eastern San Joaquin Subbasin, as well as the Cosumnes Subbasin to the north and the Modesto Subbasin to the south. The adjacent subbasins were included in the ESJWRM boundaries to be consistent with past local modeling efforts and to better simulate boundary flows to/from the north and south of the Subbasin. This Plan provides a water budget for the Eastern San Joaquin Subbasin portion of the ESJWRM.

With the ESJWRM as the underlying framework, three model scenarios were developed representing historical, current, and projected conditions in the Eastern San Joaquin Subbasin, as discussed below:

- **Historical water budget** represents the historical model calibration period, which covers water years 1996 through 2015 (20 years).
- **Current water budget** represents estimated long-term average conditions of the Subbasin assuming that the current level of development and agricultural demand persists over a long-term period of hydrologic conditions (the 50-year period represented by water years 1969 through 2018).
- **Projected water budget** represents estimated long-term conditions of the Subbasin under the foreseeable future level of development over a long-term period of hydrologic conditions (the 50-year period represented by water years 1969 through 2018).

3.3.4 Water Budget Definitions and Assumptions

Definitions and assumptions for the historical, current, and projected water budgets are provided in the sections below and summarized in Table 3-1.

Table 3-1: Summary of Water Budget Assumptions (Historical, Current, and Projected Periods)

Water Budget Type	Historical	Current	Projected
Tool	ESJWRM	ESJWRM	ESJWRM
Scenario	Historical Calibration	Current Conditions	Projected Conditions
Hydrologic Years	Water Years 1996-2015	Water Years 1969-2018	Water Years 1969-2018
Level of Development[1]	Historical[5]	Current	General Plan or Sphere of Influence Buildout
Agricultural Demand[2]	Historical[5]	Current (2014)	Current (2014), less urban expansion
Urban Demand[3]	Historical[5]	Current (pre-drought)	Projected based on UWMP data
Water Supplies[4]	Historical[5]	Current	Projected based on local information

Notes:

[1] The level of development describes the footprint of the urban areas. Historical is the footprint in the historical model period (water years 1996-2015), current is the footprint at the end of the historical model period (water year 2015), and projected reflects the footprint after general plan or sphere of influence urban buildout (approximately water year 2040).

[2] Agricultural demand is based on historical cropping patterns and evapotranspiration rates. Current and projected agricultural cropping patterns are assumed to be consistent with DWR's statewide crop mapping of 2014, less any urban buildout in the projected conditions. Future evapotranspiration rates are assumed to remain the same as historical.

[3] Historical urban demand includes actual demand and population from UWMPs or other planning efforts. Current demand is assumed to represent demands at a pre-drought level (assumed water year 2013) and water year 2015 population. Projected demand uses projected demand and population from UWMPs or other planning efforts and uses numbers for a buildout level of development (approximately water year 2040).

[4] Historical water supplies rely on local district information and records. Projected water supplies were assumed for approximately water year 2040 and may include projects or expansions of supplies currently begun or with funding secured. Current water supplies represent water supplies averaging approximately water years 2012-2015 in the historical records.

[5] For more information on historical assumptions, see the published model report in Appendix X.

3.3.4.1 Assumptions Used in the Historical Water Budget

The historical water budget is intended to evaluate availability and reliability of past surface water supply deliveries, aquifer response to water supply, and demand trends relative to water year type. The historical calibration of the ESJWRM reflects the historical conditions in the Eastern San Joaquin Subbasin over water years 1996-2015. The hydrologic period has an average annual precipitation of approximately 14.7 inches and includes the recent 2012-2015 drought, the wetter years of 1996-2000, and periods of normal precipitation. Regulations require the use of a minimum of 10 years to develop the historical water budget. The entire historical calibration period of the ESJWRM was used to be inclusive of all the data used in developing the ESJWRM and to average over a broader range of different hydrologic conditions. The historical water budget applied an evolving level of development and agricultural demand throughout a 20-year historical hydrology.

Additional details of the data used in the development of the historical calibration can be found in the published model report in Appendix X.

The historical calibration includes the following:

- Hydrologic period: Water Years 1996-2015 (20-year hydrology)
- Stream Flows for Water Years 1996-2015:
    - Dry Creek: No streamflow gaging stations available for Dry Creek; as such, flow estimates from the DWR's California Central Valley surface and groundwater Model (C2VSim) was used (C2VSim-Fg Beta Release, DWR, May 2018)

    - Mokelumne River: Historical records from USGS (Mokelumne River below Camanche Dam, CA)
    - Calaveras River: New Hogan Dam releases
    - Stanislaus River: Historical records from USGS (Stanislaus River below Goodwin Dam near Knights Ferry, CA)
    - San Joaquin River: Historical records from USGS (San Joaquin River near Vernalis, CA)
- Reservoir Operations: Upstream reservoirs regulating streamflows into the Subbasin include Pardee and Camanche on the Mokelumne River; New Hogan on the Calaveras River; and New Melones, Tulloch, and Goodwin on the Stanislaus River. Streamflows entering the Subbasin are regulated releases from respective reservoirs. As such, no changes to the historical operations of the reservoirs are assumed. In addition, two other local reservoirs are included in the model: Woodward and Farmington. The model estimates seepage contributions from these reservoirs to the groundwater system. Water supply deliveries from these reservoirs are based on records provided by the agencies responsible for operation of these reservoirs.
- Land use and cropping patterns are based on the DWR land use surveys (assumed to represent water year 1995), USDA's remote sensing data from the CropScape library for 2007-2015, and the recent, comprehensive, and Subbasin-wide land use survey from DWR as prepared by Land IQ (2014). Local data and information were also utilized to refine and update the cropping patterns, as needed. To fill the gap between 1995 and 2007, all land use and crop categories were interpolated at the spatial resolution level of the model elements to simulate the geographic distribution of various crops.
- Urban water demand is calculated for all the urban areas in the model. Urban centers in Eastern San Joaquin Subbasin are City of Escalon, Linden, Lockeford, City of Lodi, City of Manteca, City of Ripon, and City of Stockton. Demands for other domestic areas are estimated based on rural population. Urban water demand is based on:
    - Urban water use from 2015 Urban Water Management Plans (Cal Water; CCWD, Cities of Lodi, Manteca, Ripon, and Stockton; SEWD; and SSJID) or municipal pumping records, used to calculate the per capita water use for each urban center.
    - Urban center population from Urban Water Management Plans, United States Census Bureau, or the California Department of Finance.
- Surface Water Deliveries:
    - Deliveries to agricultural areas: Obtained from agricultural entities in the Subbasin, including CSJWCD, NSJWCD, OID, SEWD, SSJID, and WID
    - Deliveries to urban areas: Cities of Lodi, Manteca, and Stockton (including Cal Water and City of Stockton service areas, and unincorporated San Joaquin County areas)
    - Recharge projects: SEWD's Farmington Groundwater Recharge Program
    - Riparian diversions: CCWD, Delta areas, and data from the California Central Valley Surface and Groundwater Model (C2VSim) for riparian diversions off major streams (Dry Creek, Mokelumne River, Calaveras River and related streams, Stanislaus River, San Joaquin River) (C2VSim-Fg Beta Release, DWR, May 2018)
- Groundwater Pumping:
    - District pumping for agricultural/landscape uses: City of Manteca, OID, City of Ripon, and SSJID
    - District pumping for urban uses: Cal Water, City of Escalon, Linden County WD, Lockeford CSD, City of Lodi, City of Manteca, City of Ripon, SEWD, and City of Stockton

   - Data on private pumping was not available, so private pumping was estimated as that which would be required to meet agricultural and rural residential water needs as calculated by the ESJWRM model based on consumptive use methodology (Refer to the ESJWRM documentation for details: Appendix X).

3.3.4.2 Assumptions Used in the Current Water Budget

To analyze the long-term effects of the current level of development on groundwater and surface water conditions and to most appropriately estimate current inflows and outflows for the Subbasin, a current conditions scenario using the ESJWRM was developed for use in estimating the current water budget. The current conditions scenario applies the recent level of development and agricultural demand to a 50-year historical hydrology. As discussed below, current conditions are not necessarily indicative of one year and are instead a compilation of data assumed representative of average recent conditions.

The current conditions scenario includes the following assumptions:

- Hydrologic Period: Water Years 1969-2018 (50-year hydrology)
- Stream Flows for Water Years 1969-2018:
   - Dry Creek: No streamflow gaging stations available for Dry Creek, as such, flow estimates from the DWR's C2VSim was used (C2VSim-Fg Beta Release, DWR, May 2018)
   - Mokelumne River: Historical records from USGS (Mokelumne River below Camanche Dam, CA)
   - Calaveras River: Historical records from USGS (Calaveras River below New Hogan Dam near Valley Springs, CA) and New Hogan Dam releases
   - Stanislaus River: Historical records from USGS (Stanislaus River below Goodwin Dam near Knights Ferry, CA)
   - San Joaquin River: Historical records from USGS (San Joaquin River near Vernalis, CA)
- Reservoir Operations: Upstream reservoirs regulating streamflows into the Subbasin include Pardee and Camanche on the Mokelumne River; New Hogan on the Calaveras River; and New Melones, Tulloch, and Goodwin on the Stanislaus River. Current condition scenario assumes that the historical operations of the reservoirs over the 50-year hydrologic records were in place and no changes are made.
- Land use and cropping patterns are based on the most recent, comprehensive, and Subbasin-wide land use survey from DWR as prepared by LandIQ (2014), with adjustments based on local information and input.
- Urban water demands are calculated for all the urban areas in the model. Urban centers in Eastern San Joaquin Subbasin are City of Escalon, Linden, Lockeford, City of Lodi, City of Manteca, City of Ripon, and City of Stockton. Demands for other domestic areas are estimated based on rural population. Urban water demand is based on:
   - Urban water use for 2013 from 2015 Urban Water Management Plans (Cal Water; CCWD, Cities of Lodi, Manteca, Ripon, and Stockton; SEWD; and SSJID) or municipal pumping records, used to calculate the per capita water use for each urban center under normal (pre-drought) water use conditions.
   - Urban center population from the 2015 Urban Water Management Plans, United States Census Bureau, or the California Department of Finance for 2015. No growth assumed during scenario.
- Surface water delivery data for the 50-year hydrologic period was estimated based on average values for similar water year types from the historical calibration, taking into consideration any changes to delivery volumes that occurred within the historical model. Diversion points and delivery areas were assumed to remain the same as the historical calibration. Surface water deliveries include:
   - Deliveries to agricultural areas: CSJWCD, NSJWCD, OID, SEWD, SSJID, and WID

  - Deliveries to urban areas: Cities of Lodi, Manteca, and Stockton (including Cal Water and City of Stockton service areas, and unincorporated San Joaquin County areas)
  - Recycling or recharge projects: Recycled water for Cities of Lodi and Manteca; SEWD's Farmington Groundwater Recharge Program; and NSJWCD's Tracy Lakes Recharge Project
  - Riparian: CCWD, Delta areas, and data from C2VSim for riparian diversions off major streams (Dry Creek, Mokelumne River, Calaveras River, Stanislaus River, and San Joaquin River)
- As private groundwater pumping was estimated by ESJWRM in the historical calibration, there is no local estimate of current private groundwater pumping. Therefore, groundwater pumping to meet agricultural and rural residential needs is calculated by the model based on meeting remaining demands after appropriate surface water delivery is made to respective areas. Demand in areas with no access to surface water is completely met by groundwater pumping.

3.3.4.3 Assumptions Used in the Projected Water Budget

The projected water budget is intended to assess the conditions of the Subbasin under future conditions of water supply and agricultural and urban demand, including quantification of uncertainties in the components. The projected conditions scenario applies future land and water use conditions and uses the 50-year hydrologic period of water years 1969-2018. Projections are assumed to represent a buildout level of development (approximately year 2040) and are represented using projected population, land use, and water demand and supply projections.

The projected conditions scenario includes the following conditions:

- Hydrologic Period: Water Years 1969-2018 (50-year hydrology)
- Stream Flows for Water Years 1969-2018:
  - Dry Creek: No streamflow gaging stations available for Dry Creek, as such, flow estimates from the DWR's C2VSim was used (C2VSim-Fg Beta Release, DWR, May 2018)
  - Mokelumne River: Historical records from USGS (Mokelumne River below Camanche Dam, CA)
  - Calaveras River: Historical records from USGS (Calaveras River below New Hogan Dam near Valley Springs, CA) and New Hogan Dam releases
  - Stanislaus River: Historical records from USGS (Stanislaus River below Goodwin Dam near Knights Ferry, CA)
  - San Joaquin River: Historical records from USGS (San Joaquin River near Vernalis, CA)
- Reservoir Operations: Upstream reservoirs regulating streamflows into the Subbasin include Pardee and Camanche on the Mokelumne River; New Hogan on the Calaveras River; and New Melones, Tulloch, and Goodwin on the Stanislaus River. Projected condition scenario assumes that the historical operations of the reservoirs over the 50-year hydrologic records were in place and no changes are made.
- Land use and cropping patterns are based on the most recent, comprehensive, and Subbasin-wide land use survey from DWR as prepared by LandIQ (2014), with adjustments based on local information and input. Urban areas expand to either the sphere of influence or general plan boundaries and are held constant during the simulation. Cropping acreage is reduced only where urban expansion occurs.
- Urban water demands are calculated for all the urban areas in the model. Urban centers in Eastern San Joaquin Subbasin are City of Escalon, Linden, Lockeford, City of Lodi, City of Manteca, City of Ripon, and City of Stockton. Demands for other domestic areas are estimated based on rural population. Urban water demand is based on:

    - Urban water use estimated from projections in the 2015 Urban Water Management Plans (Cal Water; CCWD, Cities of Lodi, Manteca, Ripon, and Stockton; SEWD; and SSJID) or municipal pumping records, used to calculate the per capita water use for each urban center in the future (approximately 2040).
    - Urban center population projections from the San Joaquin Council of Governments.
- Surface water delivery projections for the 50-year period was estimated based on the historical records of diversions by water year type, surface water rights or agreements, and potential planned changes/upgrades to the surface water diversion facilities. Surface water diversion estimates reflecting projected conditions using current available information and knowledge were provided to each GSA for review and comment and appropriate adjustments were made to the estimated record to reflect the surface water diversion projections for each entity. Surface water deliveries include:
    - Deliveries to agricultural areas: CSJWCD, NSJWCD, OID, SEWD, SSJID, and WID
    - Deliveries to urban areas: Cities of Lodi, Manteca, and Stockton (including Cal Water and City of Stockton service areas, and unincorporated San Joaquin County areas)
    - Recycling or recharge projects: Recycled water for Cities of Lodi and Manteca; SEWD's Farmington Groundwater Recharge Program; NSJWCD's Tracy Lakes Recharge Project; and NSJWCD's CALFED groundwater recharge project
    - Riparian: CCWD, Delta areas, and data from C2VSim for riparian diversions off major streams (Dry Creek, Mokelumne River, Calaveras River, Stanislaus River, and San Joaquin River)
- As private groundwater pumping was estimated by ESJWRM in the historical calibration, there is no local estimate of current private groundwater pumping. Therefore, groundwater pumping to meet agricultural and rural residential needs is calculated by the model based on meeting remaining demands after appropriate surface water delivery is made to respective areas. Demand in areas with no access to surface water is completely met by groundwater pumping.

3.3.5 Water Budget Estimates

The ESJWRM simulates the major hydrologic processes that affect the land surface, stream, and groundwater systems in the Eastern San Joaquin Subbasin. The major hydrologic processes can be represented by separate water budgets which detail inflows and outflows occurring at the stream level (budget on surface water flows occurring in the Subbasin), land surface level (budget balancing how demands on urban, agricultural, and native lands are met by rainfall, surface water deliveries, or groundwater pumping), and groundwater (budget detailing flows occurring within the groundwater aquifers of the Subbasin).

The primary components of the stream system are:

- Inflows:
    - Stream inflows
    - Stream gain from the groundwater system
    - Surface runoff to the stream system from precipitation
    - Return flow to stream system from irrigation water
- Outflows:
    - Stream outflows
    - Stream losses to groundwater
    - Surface water diversions

    - Riparian intake from streams

The primary components of the land surface system are:

- Inflows:
    - Precipitation
    - Surface water supplies to meet agricultural and urban uses
    - Groundwater pumping (groundwater supplies to meet agricultural and urban uses)
    - Riparian intake from streams
- Outflows:
    - Evapotranspiration
    - Surface runoff to the stream system
    - Return flow to the stream system
    - Deep percolation from precipitation, applied water (surface water and groundwater) for agricultural lands, and applied water (surface water and groundwater) for outdoor use in the urban areas

The primary components of the groundwater system are:

- Inflows:
    - Deep percolation from precipitation, applied water (surface water and groundwater) for agricultural lands, and applied water (surface water and groundwater) for outdoor use in the urban areas
    - Stream seepage (stream losses to groundwater)
    - Other recharge (including unlined canals/reservoir seepage, local tributaries seepage, and Managed Aquifer Recharge [MAR] projects)
    - Subsurface inflow
- Outflows:
    - Stream gain from the groundwater system
    - Groundwater pumping
    - Subsurface outflow
- Change in Groundwater Storage: This reflects average annual change in groundwater storage

The estimated water budgets for the historical, current conditions, and projected conditions scenarios are provided herein, with results summarized below in Table 3-2 through Table 3-4.

Table 3-2: Average Annual Water Budget – Stream System (AF/year)

Component	Historical Calibration (AF/year)	Current Conditions (AF/year)	Projected Conditions (AF/year)
Hydrologic Period	**Water Years 1996- 2015**	**50-Year Period**	**50-Year Period**
Inflows			
Stream Inflows[1]	4,066,000	3,949,000	3,952,000
Stream Gain from Groundwater[2]	202,000	209,000	212,000
Eastern San Joaquin Subbasin	107,000	109,000	114,000
Dry Creek	-	1,000	1,000
Mokelumne River	14,000	22,000	24,000
Calaveras River	14,000	15,000	16,000
Stanislaus River	41,000	31,000	29,000
San Joaquin River	29,000	30,000	30,000
Local Tributaries[3]	8,000	11,000	14,000
Other Subbasins[4]	95,000	100,000	98,000
Dry Creek	28,000	39,000	40,000
Mokelumne River	1,000	1,000	1,000
Stanislaus River	49,000	42,000	40,000
San Joaquin River	17,000	18,000	17,000
Runoff to the Stream System[5]	471,000	533,000	542,000
Return Flow to Stream System[6]	74,000	75,000	127,000
Total Inflow	**4,812,000**	**4,766,000**	**4,833,000**
Outflows			
Stream Outflows[7]	4,168,000	4,037,000	4,050,000
Stream Seepage[2]	303,000	375,000	381,000
Eastern San Joaquin Subbasin	262,000	317,000	318,000
Dry Creek	12,000	14,000	14,000
Mokelumne River	114,000	124,000	122,000
Calaveras River	91,000	105,000	102,000
Stanislaus River	13,000	35,000	39,000
San Joaquin River	28,000	36,000	36,000
Local Tributaries[3]	3,000	3,000	3,000
Other Subbasins[4]	41,000	58,000	63,000
Dry Creek	14,000	15,000	16,000
Mokelumne River	2,000	2,000	2,000
Stanislaus River	18,000	32,000	36,000
San Joaquin River	8,000	9,000	9,000
Surface Water Diversions[8]	301,000	323,000	370,000
Riparian Intake from Streams[9]	40,000	31,000	32,000
Total Outflow	**4,812,000**	**4,766,000**	**4,833,000**

Notes:

[1] Stream inflows into Eastern San Joaquin Subbasin include flows from Cosumnes River, Dry Creek, Mokelumne River, Calaveras River, Stanislaus River, San Joaquin River, and estimated tributary flows. Differences between historical and current/projected flows are due to differing hydrologic periods. Differences between current and projected flows are due to differences in flows simulated at Subbasin boundaries (such as from Cosumnes River and Dry Creek) and estimated tributary flows.

[2] Stream gain from groundwater and stream seepage represent the interaction of surface water and groundwater. Differences between the scenarios are related to differences in streamflows and long-term average groundwater elevations.

[3] Local tributaries include Bear Creek and related streams, Little Johns Creek, Duck Creek, and Lone Tree Creek.

[4] Other subbasins include the Cosumnes, Modesto, South American, Solano, East Contra Costa, and Tracy Subbasins. Stream-aquifer interaction with the other subbasins was included for streams on the boundaries of the Eastern San Joaquin Subbasin.

[5] Runoff to the stream system is due to precipitation. As urban areas are assumed to have greater runoff (e.g., more paved areas), the changes in runoff between the runs are due to differences in the urban areas in the scenarios, as well as the amount of precipitation occurring. The historical calibration, with both less precipitation and smaller urban areas, has a corresponding smaller runoff. The current condition uses urban areas at the end of the historical calibration, while the projected scenario includes urban buildout to sphere of influence or general plan boundaries and therefore has more runoff.

[6] Return flow to the stream system is due to applied water, either surface water or groundwater used for agricultural or municipal purposes. Differences between the scenarios is primarily related to the urban growth in the projected conditions scenario causing higher urban demand and therefore correspondingly higher applied water to meet that demand resulting in greater urban return flows (i.e., discharge of treated wastewater).

[7] Stream outflows occur at the edge of Eastern San Joaquin Subbasin at the confluence of the San Joaquin and Mokelumne Rivers.

[8] Surface water diversions shown in this table are the volumes of water taken directly off the river prior to any losses due to evaporation or canal seepage. These numbers do not include surface water directly diverted from simulated stream nodes (i.e., water taken off Stanislaus River occurs just upstream in the Subbasin). Differences between scenarios are due to differences in current and planned surface water diversions.

[9] Riparian intake from streams is the portion of the riparian vegetation evapotranspiration met by streamflows. Differences between scenarios may be due to availability of streamflows or extent of riparian vegetation, which may be affected by growth in urban areas.

Table 3-3: Average Annual Water Budget – Land Surface System (AF/year)

Component	Historical Calibration (AF/year)	Current Conditions (AF/year)	Projected Conditions (AF/year)
Hydrologic Period	**Water Years 1996- 2015**	**50-Year Period**	**50-Year Period**
Inflows			
Precipitation[1]	938,000	984,000	984,000
Total Surface Water Supply[2]	502,000	493,000	529,000
Agricultural	451,000	426,000	426,000
Urban and Industrial	51,000	67,000	103,000
Total Groundwater Supply[3]	692,000	851,000	801,000
Agricultural	624,000	788,000	680,000
Urban and Industrial	68,000	63,000	121,000
Riparian Intake from Streams[4]	28,000	23,000	24,000
Total Inflow	**2,161,000**	**2,352,000**	**2,338,000**
Outflows			
Evapotranspiration[5]	1,351,000	1,449,000	1,394,000
Agricultural	969,000	1,077,000	976,000
Municipal and Domestic	66,000	73,000	123,000
Refuge, Native, and Riparian	316,000	300,000	296,000
Runoff to the Stream System[6]	471,000	533,000	542,000
Return Flow to the Stream System[7]	74,000	75,000	127,000
Agricultural	2,000	2,000	2,000
Municipal and Domestic	72,000	73,000	125,000
Deep Percolation[8]	218,000	272,000	266,000
Precipitation	61,000	68,000	66,000
Applied Surface Water – Agricultural	59,000	65,000	64,000
Applied Surface Water – Urban and Industrial	7,000	10,000	15,000
Applied Groundwater – Agricultural	82,000	119,000	102,000
Applied Groundwater – Urban and Industrial	9,000	10,000	18,000
Other Flows[9]	47,000	23,000	8,000
Total Outflow	**2,161,000**	**2,352,000**	**2,338,000**

Notes:

[1] Precipitation is discussed in the identification of the hydrologic periods in 3.3.2. The current and projected conditions scenarios utilize the same 50 years of hydrology (water years 1969-2018) and have the same overall Subbasin precipitation, whereas the historical calibration has a shorter hydrologic period (20 years from 1996-2015) with less precipitation on average.

[2] Total surface water supply shown in this table is the volume of surface water diverted or transported to meet agricultural and urban demands minus estimated losses due to evaporation or canal seepage. Differences between scenarios are due to differences in current and planned surface water deliveries.

[3] Total groundwater supply in the scenarios is calculated based on meeting remaining demands after surface water deliveries occur. Differences in demand largely drive the amount of groundwater pumped.

[4] Riparian intake from streams is the portion of the riparian vegetation evapotranspiration met by streamflows. Differences between scenarios may be due to availability of streamflows or extent of riparian vegetation, which may be affected by growth in urban areas.

[5] Evapotranspiration is the demand required by agricultural land (i.e., crops); municipal and domestic areas (i.e., industrial and urban demands); and refuge, native and riparian areas. Differences in evapotranspiration are largely related to differences in urban areas between the scenarios and the loss of agricultural or native/riparian land as urban growth occurs.

[6] Runoff to the stream system is due to precipitation. As urban areas are assumed to have greater runoff (e.g., more paved areas), the changes in runoff between the runs are due to differences in the urban areas in the scenarios, as well as the amount of precipitation occurring. The historical calibration, with both less precipitation and smaller urban areas, has a corresponding

smaller runoff. The current condition uses urban areas at the end of the historical calibration, while the projected scenario includes urban buildout to sphere of influence or general plan boundaries and therefore has more runoff.

[7] Return flow to the stream system is due to applied water, either surface water or groundwater used for agricultural or municipal purposes. Differences between the scenarios is primarily related to the urban growth in the projected conditions scenario causing higher urban demand and therefore correspondingly higher applied water to meet that demand.

[8] Deep percolation is the amount of infiltrated water ultimately reaching the groundwater aquifer. The source of the water may be from precipitation or either applied surface water or groundwater used for agricultural or urban and industrial purposes. Differences between scenarios are related to differences between these sources of water and differences in the infiltration parameters related to land use.

[9] Other Flows captures the gains and losses due to land expansion and temporary storage in the root-zone and unsaturated (vadose) zones.

Table 3-4: Average Annual Water Budget – Groundwater System (AF/year)

Component	Historical Calibration (AF/year)	Current Conditions (AF/year)	Projected Conditions (AF/year)
Hydrologic Period	**Water Years 1996- 2015**	**50-Year Period**	**50-Year Period**
Inflows			
Deep Percolation[1]	218,000	272,000	266,000
Precipitation	61,000	68,000	66,000
Applied Surface Water – Agricultural	59,000	65,000	64,000
Applied Surface Water – Urban and Industrial	7,000	10,000	15,000
Applied Groundwater – Agricultural	82,000	119,000	102,000
Applied Groundwater – Urban and Industrial	9,000	10,000	18,000
Stream Seepage[2]	262,000	317,000	317,000
Dry Creek	12,000	14,000	14,000
Mokelumne River	114,000	124,000	122,000
Calaveras River	91,000	105,000	102,000
Stanislaus River	13,000	35,000	39,000
San Joaquin River	28,000	36,000	36,000
Local Tributaries[3]	3,000	3,000	2,000
Other Recharge[4]	160,000	158,000	164,000
Subsurface Inflow[5]	171,000	212,000	192,000
Cosumnes Subbasin	32,000	38,000	37,000
Sierra Nevada Mountains	55,000	58,000	59,000
Modesto Subbasin	25,000	41,000	33,000
South American Subbasin	4,000	4,000	3,000
Solano Subbasin	15,000	15,000	13,000
East Contra Costa Subbasin	6,000	7,000	7,000
Tracy Subbasin	35,000	48,000	41,000
Total Inflow	**811,000**	**959,000**	**939,000**
Outflows			
Groundwater Outflow to Streams[2]	107,000	109,000	114,000
Dry Creek	-	1,000	1,000
Mokelumne River	14,000	22,000	24,000
Calaveras River	14,000	15,000	16,000
Stanislaus River	41,000	31,000	29,000
San Joaquin River	29,000	30,000	30,000
Local Tributaries[3]	8,000	11,000	14,000
Groundwater Pumping[6]	692,000	851,000	801,000
Agricultural	624,000	788,000	680,000
Urban and Industrial	68,000	63,000	121,000
Subsurface Outflow[5]	53,000	47,000	58,000
Cosumnes Subbasin	18,000	15,000	18,000
Modesto Subbasin	19,000	18,000	25,000
South American Subbasin	-	-	-
Solano Subbasin	4,000	4,000	4,000
East Contra Costa Subbasin	2,000	2,000	2,000
Tracy Subbasin	9,000	8,000	8,000
Total Outflow	**852,000**	**1,007,000**	**973,000**
Change in Groundwater Storage	**(41,000)**	**(48,000)**	**(34,000)**

Notes:

[1] Deep percolation is the amount of infiltrated water ultimately reaching the groundwater aquifer. The source of the water may be from precipitation or either applied surface water or groundwater used for agricultural or urban and industrial purposes. Differences between scenarios are related to differences between these sources of water and differences in the infiltration parameters related to land use.

[2] Stream gain from groundwater and stream seepage represent the interaction of surface water and groundwater. Differences between the scenarios are related to differences in streamflows and long-term average groundwater elevations.

[3] Local Tributaries include Bear Creek and related streams, Little Johns Creek, Duck Creek, and Lone Tree Creek.

[4] Other Recharge includes unlined canals/reservoir seepage, local tributaries seepage, and managed aquifer recharge (MAR) projects.

[5] The goal of projecting interbasin flows is to maintain a reasonable balance between the neighboring groundwater subbasins. The resulting projected conditions scenario flows are within 10-15% of historical calibration flows, considered a reasonable range given the availability of projected land use, population, surface water delivery, and groundwater production data from areas outside of the Eastern San Joaquin Subbasin.

[6] Groundwater pumping is estimated by the ESJWRM based on the need for additional water to meet remaining demands after surface water deliveries occur. Differences in demand largely drive the amount of groundwater pumped.

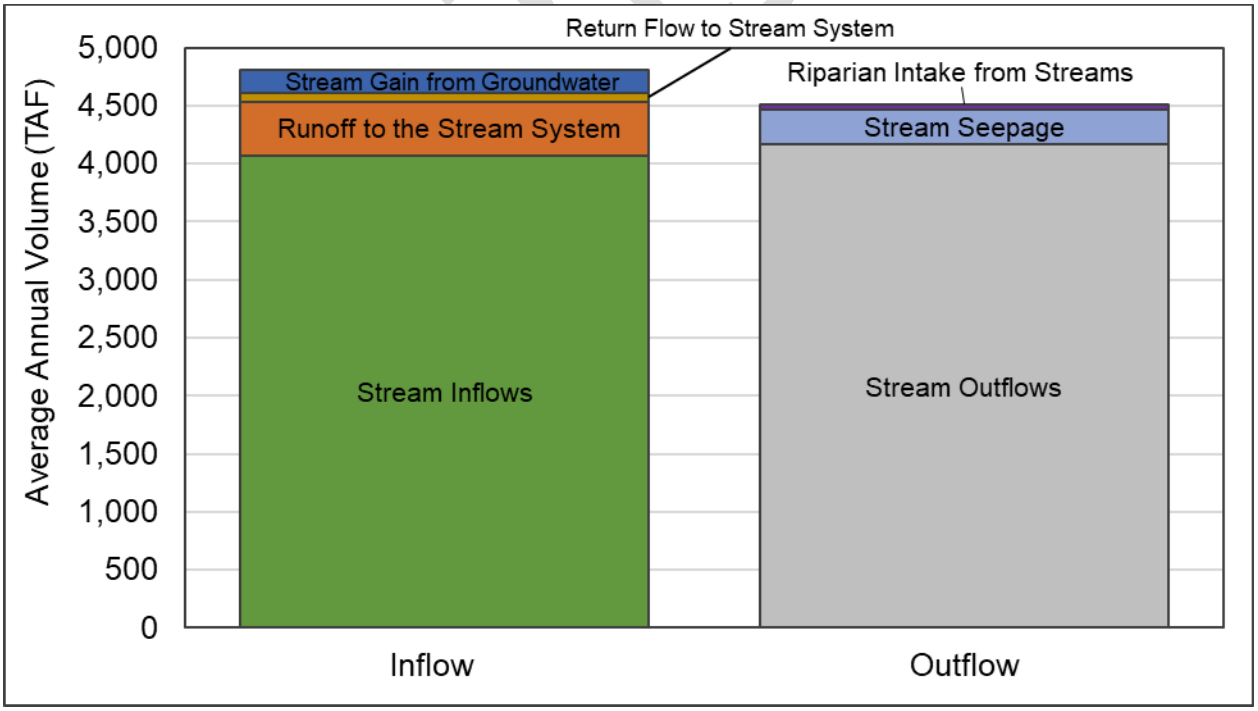
3.3.5.1 Historical Water Budget Estimates

The historical water budget is a quantitative tabulation of the historical surface and groundwater supply represented in the historical calibration of the ESJWRM covering the 20-year period of water years 1996-2015. The JPA selected this period as the representative hydrologic period to calibrate and reduce the uncertainty of the ESJWRM. Proper analysis and calibration of water budgets using the ESJWRM assures the hydrologic characteristics of the groundwater basin are well simulated. The historical calibration is discussed in detail in the historical model documentation in Appendix X. Per §354.18 of the Regulations, the water budget includes estimates for supply and demand, while summarizing flows within the Subbasin, including the movement of all primary sources of water such as rainfall, irrigation, streamflow, and subsurface flows.

The existing stream network supplies water to multiple agricultural water users and municipalities in the Eastern San Joaquin Subbasin. When analyzing the water budget for the stream system, it is important to note potentially significant effects resulting from the natural interactions and managed operations of adjacent groundwater subbasins for streams coinciding with the boundaries of the Subbasin (i.e., Dry Creek, portions of the Mokelumne River, San Joaquin River, and Stanislaus River). Because of these circumstances, the water budget presented in Table 3-1 and Figure 3-3 below not only quantifies surface water systems within the Subbasin, but also estimates of contributions from adjoining areas.

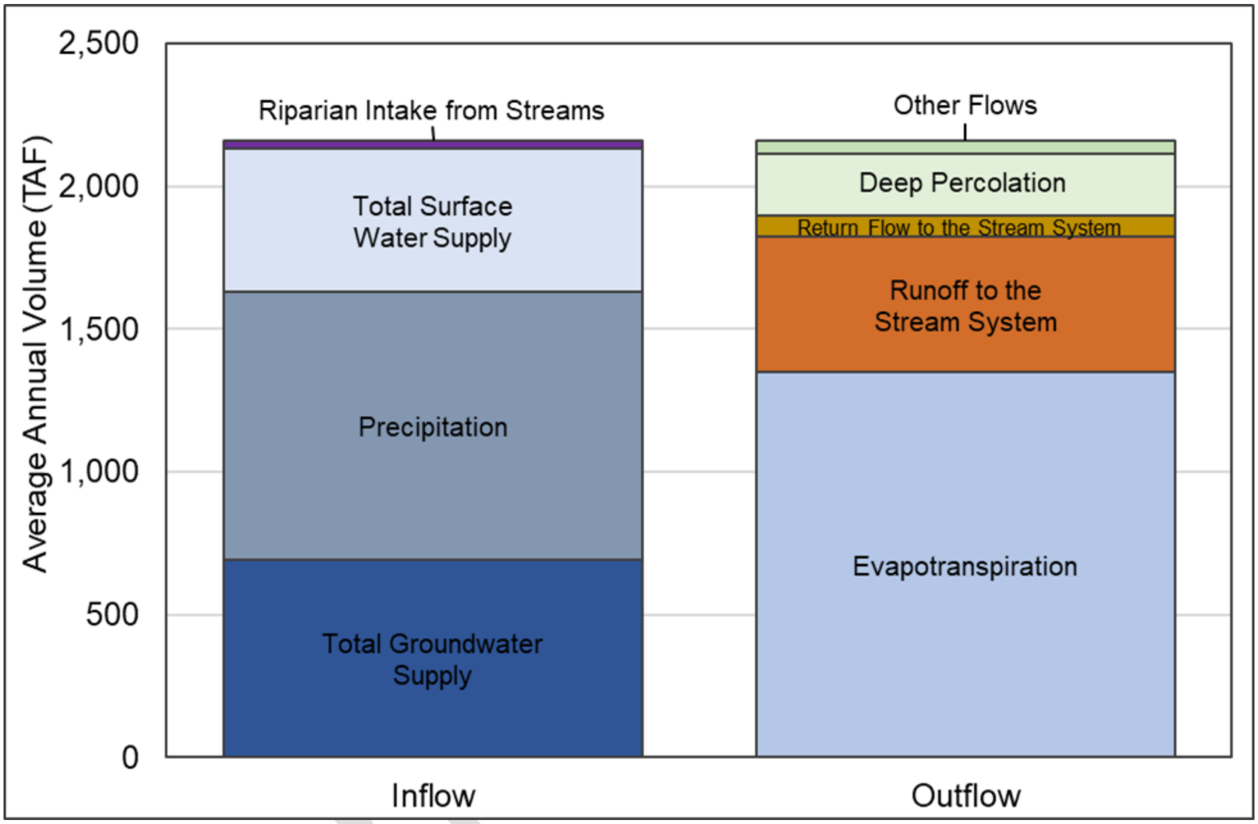
The stream system inflows through or along the Subbasin boundary simulated in the historical condition average 4.8 million acre-feet per year (MAF/year). The majority of these flows, almost 4.1 MAF/year, enter the Subbasin through upstream reservoir releases into major streams in the Subbasin. Three other surface water inflows are estimated stream gains from the groundwater system (202,000 AF/year), runoff of precipitation (471,000 AF/year), and return flow of applied water (74,000 AF/year). Outflows of the Eastern San Joaquin Subbasin stream system total 4.8 MAF/year and include downstream outflows leaving the Subbasin (almost 4.2 MAF/year), stream seepage to the groundwater system (303,000 AF/year), surface water diversions (301,000 AF/year), and riparian vegetation intake (40,000 AF/year).

Figure 3-3: Historical Average Annual Water Budget – Stream System



The land surface system water budget in the historical calibration of the Eastern San Joaquin Subbasin, shown below in Figure 3-4, estimates almost 2.2 MAF/year of inflows, a combination of precipitation (938,000 AF/year), surface water supply (502,000 AF/year), groundwater supply (692,000 AF/year), and riparian intake from streams (28,000 AF/year). The outflow from the land surface system in the historical calibration estimates evapotranspiration (close to 1.4 MAF/year), surface runoff of precipitation (471,000 AF/year), return flow of applied water (74,000 AF/year), deep percolation of precipitation or applied water (218,000 AF/year), and a small component representing other flows (47,000 AF/year), which includes uncertainties in other components due to land expansion and temporary storage in the root-zone and unsaturated (vadose) zones.

Figure 3-4: Historical Average Annual Water Budget – Land Surface System

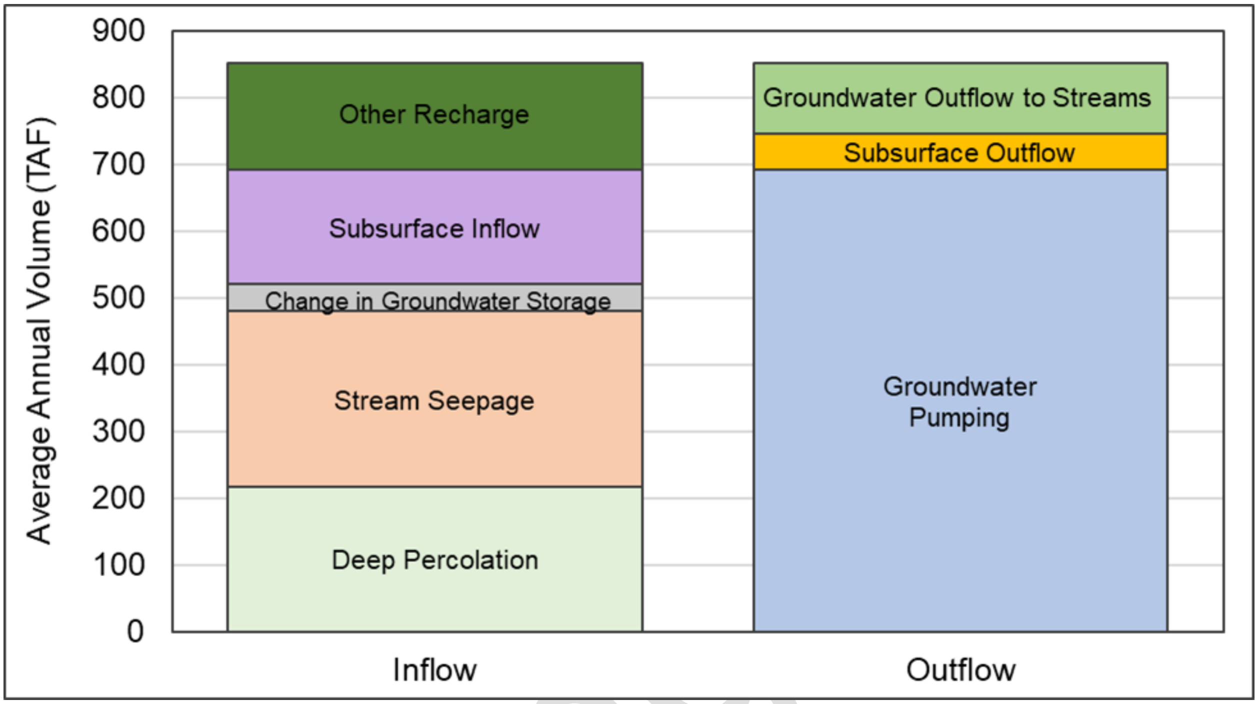


The groundwater system of the Eastern San Joaquin Subbasin includes 811,000 AF/year of inflows in the historical calibration (not including change in storage), of which 218,000 AF/year is deep percolation. There is also stream seepage (262,000 AF/year), other recharge (160,000 AF/year), and subsurface inflows (171,000 AF/year) from the Sierra Nevada Mountains and the neighboring groundwater subbasins of Cosumnes, Modesto, South American, Solano, East Contra Costa, and Tracy. On average, the inflows do not meet the entire groundwater demand. The primary outflow of the groundwater system is pumping (692,000 AF/year), followed by groundwater outflow to streams (107,000 AF/year), and subsurface outflow to the neighboring groundwater subbasins (53,000 AF/year).

The Eastern San Joaquin Subbasin average historical groundwater budget has greater outflows than inflows, leading to an estimated average annual decrease in groundwater storage of approximately 41,000 AF/year. Figure 3-5 summarizes the average historical calibration groundwater inflows and outflows of the Eastern San Joaquin Subbasin.

A groundwater overdraft estimate of 41,000 AF/year represents a refinement over previous efforts which have formerly estimated levels of overdraft for the Subbasin to be between 70,000 AF and 150,000 AF annually. Such previous efforts include the DWR's 2003 Bulletin 118 study and modeling conducting as part of the SJCFCWCD's 2001 Water Management Plan and presented in the 2004 Eastern San Joaquin Groundwater Basin Groundwater Management Plan. The analysis presented in this Plan represents the best available information to date. These estimates, which are the result of several years of collaboration between agencies prior to Plan development, utilize new data and modeling capabilities not captured in prior modeling efforts. Additionally, a portion of the reduction seen in the overdraft estimate may be due to a shift to surface water supplies that has occurred since the development of previous estimates. For additional discussion of refinements that occurred in the development of the ESJWRM, see Appendix X.

Figure 3-5: Historical Average Annual Water Budget Estimates – Groundwater System



Historical inflows and outflows change by water year type as defined by the San Joaquin Valley Water Year Hydrologic Classification (DWR, 2018). In wet years, precipitation meets more of the water demand and greater availability of surface water reduces the need for groundwater pumping. However, in dry years, more groundwater is pumped to meet the demand not met by surface water or precipitation. This may lead to an increase in groundwater storage in wet years and a decrease in dry years.

Table 3-5 breaks down the average historical water supply and demand by water year type.

During the historical calibration, the focus is on representing changing conditions and operations, such as new agricultural land or crop types, new surface water diversions, and population growth. When these changes occurred was oftentimes independent of the hydrologic conditions of the year in question; therefore, looking at supplies and demands averaged by water year type does not necessarily present clear results. Furthermore, the 20 years represented in the historical calibration do not include an equal number of each water year type, making averages less reliable to gather historical trends. As the projected conditions scenario considered the water year type in some of the model inputs and the 50-year hydrologic period allows for greater repetition of the water year types, the results presented in Table 3-6 are more consistent with the trends expected when averaging by water year type.

Table 3-5: Average Annual Values for Key Components of Historical Water Budget by Year Type

Component	Water Year Type (San Joaquin River Index)					
	Wet	Above Normal	Below Normal[1]	Dry	Critical	20-Year
Number of Years	**6**	**3**	**1**	**5**	**5**	**20**
Average Precipitation	**1,287,000**	**944,000**	**963,000**	**784,000**	**666,000**	**938,000**
Water Demand (AF/year)						
Ag Demand[2]	1,030,000	1,060,000	1,054,000	1,072,000	1,142,000	1,074,000
Urban Demand[3]	115,000	118,000	123,000	126,000	124,000	120,000
Total Demand	**1,145,000**	**1,178,000**	**1,177,000**	**1,198,000**	**1,266,000**	**1,194,000**
Water Supply (AF/year)						
Total Surface Water Supply[4]	491,000	518,000	479,000	510,000	504,000	502,000
Agricultural	446,000	466,000	435,000	458,000	445,000	451,000
Urban and Industrial	46,000	51,000	44,000	52,000	59,000	51,000
Total Groundwater Supply[5]	654,000	660,000	698,000	688,000	762,000	692,000
Agricultural	585,000	595,000	620,000	615,000	698,000	624,000
Urban and Industrial	68,000	65,000	78,000	73,000	64,000	68,000
Total Supply (AF/year)	**1,145,000**	**1,178,000**	**1,177,000**	**1,198,000**	**1,266,000**	**1,194,000**
Change in Groundwater Storage (AF/year)	**137,000**	**-3,000**	**-106,000**	**-120,000**	**-184,000**	**-41,000**

Notes:

[1] There was only one below normal water year in the historical calibration (water year 2003), so averages are just based on model results for that single water year. Since there weren't any more below normal years to use in the average, results for the below normal water year type do not follow expected trends.

[2] Agricultural demand is based on evapotranspiration by crop and the acreages by crop. As land use continually evolves over the historical calibration, averaging of the resulting agricultural demand is less a function of water year type and rather dependent more on when in the simulation that year type fell.

[3] Urban demand evolves in the historical calibration based on changes in population and water consumption. Due to these changes over the historical calibration period, averaging of the urban demand is less a function of water year type and rather dependent more on when in the simulation that year type fell.

[4] Total surface water supply is based on information received from local entities and varied historically based on when surface water rights or agreements occurred. As some entities received new surface water sources during the historical calibration period, averaging by water year type depends more on when the water year types occurred in the simulation.

[5] Total groundwater supply as estimated by the ESJWRM is a function of demand, precipitation, and surface water. Differences between water year types for groundwater pumping is more related to differences in these components.

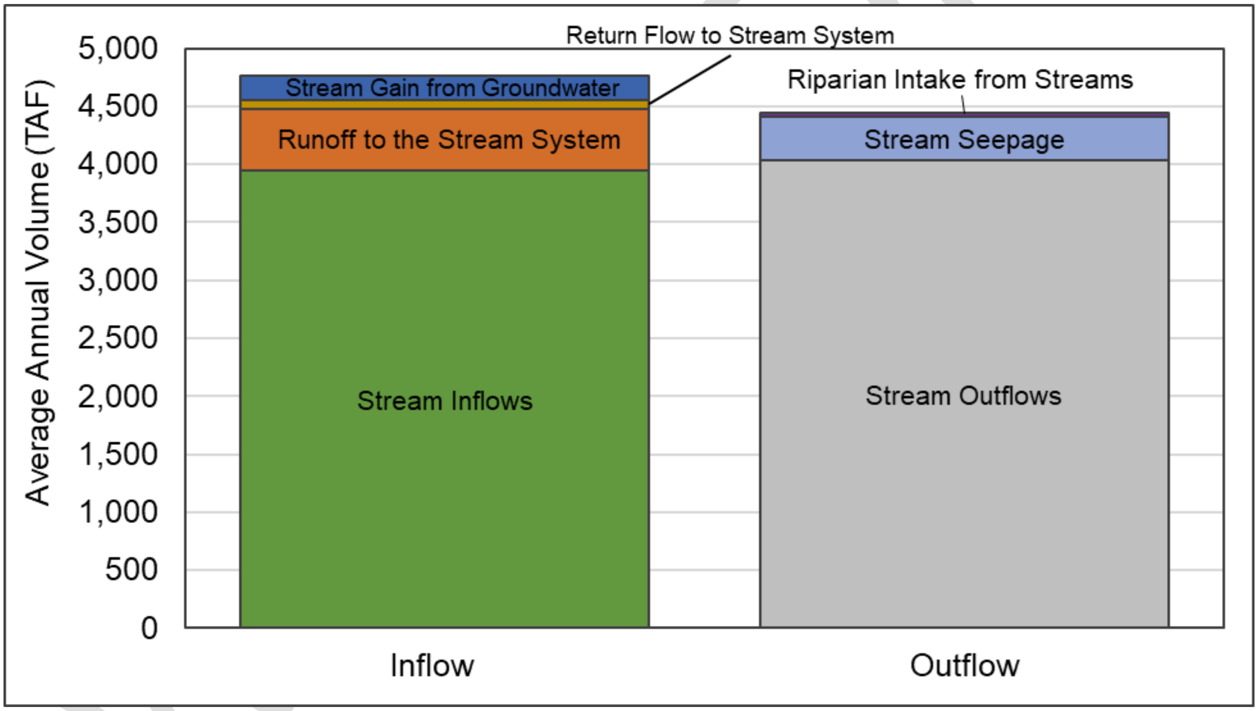
3.3.5.2 Current Water Budget Estimates

The current water budget quantifies inflows to and outflows from the basin using the most recent 50 years of hydrology, water supply, water demand, and land use information. By using a baseline approach with the ESJWRM, long-term hydrology is applied to the most recent water supply, water demand, and land use information to provide a robust estimate of the current water budget. These conditions are incorporated in the current conditions scenario of the ESJWRM.

The stream system in the current conditions scenario estimates 323,000 AF/year of surface water diversions occurring in the Subbasin from simulated streams. In addition, on average, over 4.0 MAF/year leaves the Subbasin's surface water system as downstream flow in the San Joaquin River and Mokelumne River, 375,000 AF/year is lost as stream seepage to the groundwater system, and 31,000 AF/year is used by riparian vegetation.

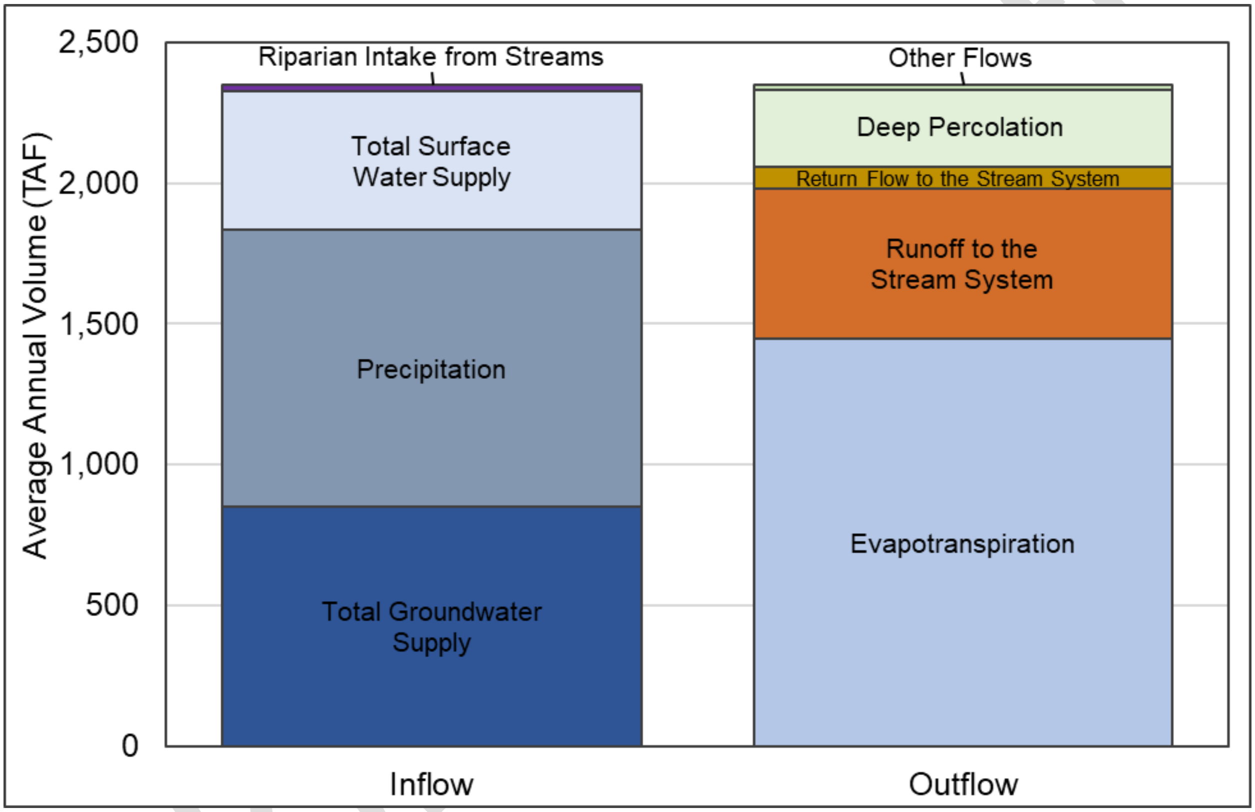
These demands are met by an estimated 3.9 MAF/year of local stream inflows, 533,000 AF/year of surface runoff of precipitation, 75,000 AF/year of return flow of applied water, and 209,000 AF/year of stream gain from groundwater. Figure 3-6 summarizes the average annual inflows and outflow of the current condition scenario in the Eastern San Joaquin Subbasin surface water network.

Figure 3-6: Current Average Annual Water Budget Estimates – Stream System



Based on 2014 cropping patterns and urban demands calculated using 2015 population and pre-drought (assumed 2013) per capita water use, over the 50-year hydrologic period, the current conditions land surface water budget simulates annual inflows of almost 2.4 MAF/year, including 984,000 AF/year of precipitation, 1.3 MAF/year of applied water (493,000 AF/year of surface water and 851,000 AF/year of groundwater), and 23,000 AF/year of riparian intake from the stream system. The almost 2.4 MAF/year of outflows include evapotranspiration (1.4 MAF/year), surface runoff to the stream system of precipitation (533,000 AF/year), return flow to the stream system of applied water (75,000 AF/year), deep percolation (272,000 AF/year), and other flows due to land expansion and temporary storage in the root-zone and vadose zones (23,000 AF/year). Figure 3-7 summarizes the average annual current condition inflows and outflows in the land surface budget for the Eastern San Joaquin Subbasin.

Figure 3-7: Current Average Annual Water Budget Estimates – Land Surface System

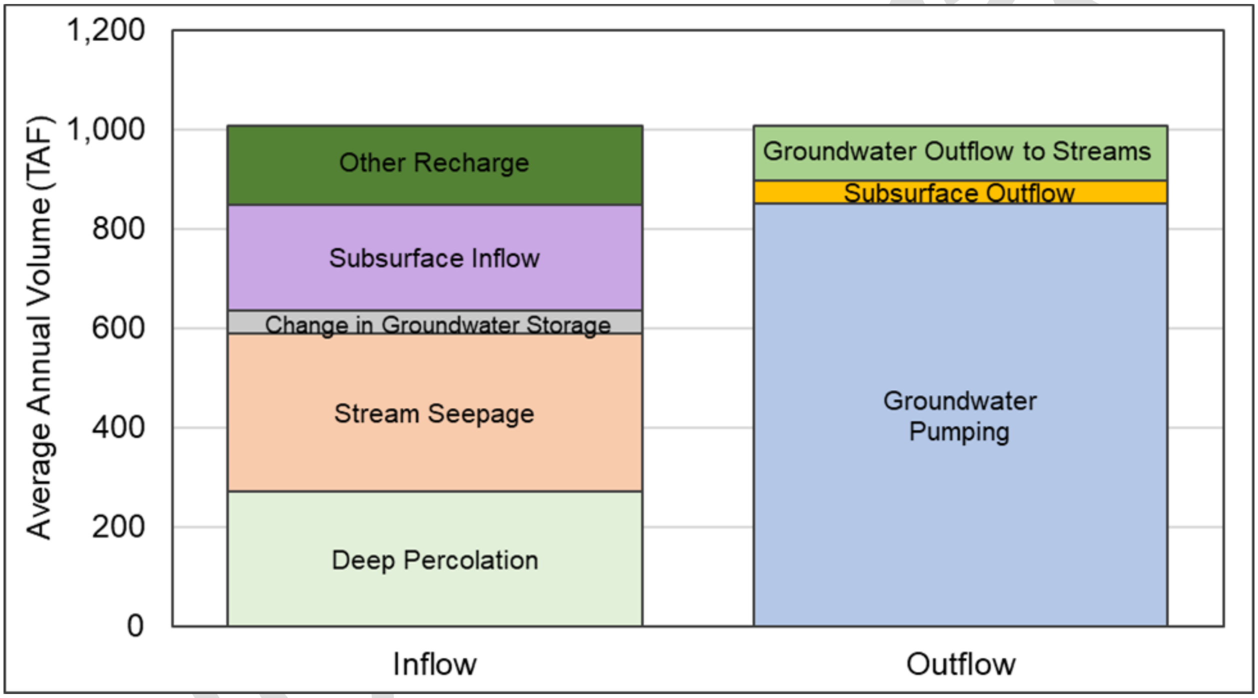


The current conditions scenario simulates 50 years of hydrology with initial conditions reflective of the start of the 2016 water year. Over the simulation, the current conditions groundwater system water budget simulates annual inflows of 959,000 AF/year, including 272,000 AF/year of deep percolation, 317,000 AF/year of stream seepage, 158,000 AF/year of other recharge (including canal and reservoir seepage and MAR projects), and subsurface inflows from surrounding subbasins and the Sierra Nevada Mountains totaling 212,000 AF/year.

Similar to the historical water budget, average aquifer outflows exceed the inflows under current conditions. Groundwater production (851,000 AF/year) remains the largest portion of aquifer discharge, with subsurface outflows to surrounding Subbasins (47,000 AF/year) and losses to the stream system (109,000 AF/year) bringing the total system outflows to over 1 MAF/year.

The Eastern San Joaquin Subbasin current conditions groundwater budget has greater outflows than inflows, resulting in an average annual deficit in groundwater storage of 48,000 AF/year. Figure 3-8 summarizes the average current conditions groundwater inflows and outflows in the Eastern San Joaquin Subbasin.

Figure 3-8: Current Average Annual Water Budget Estimates – Groundwater System



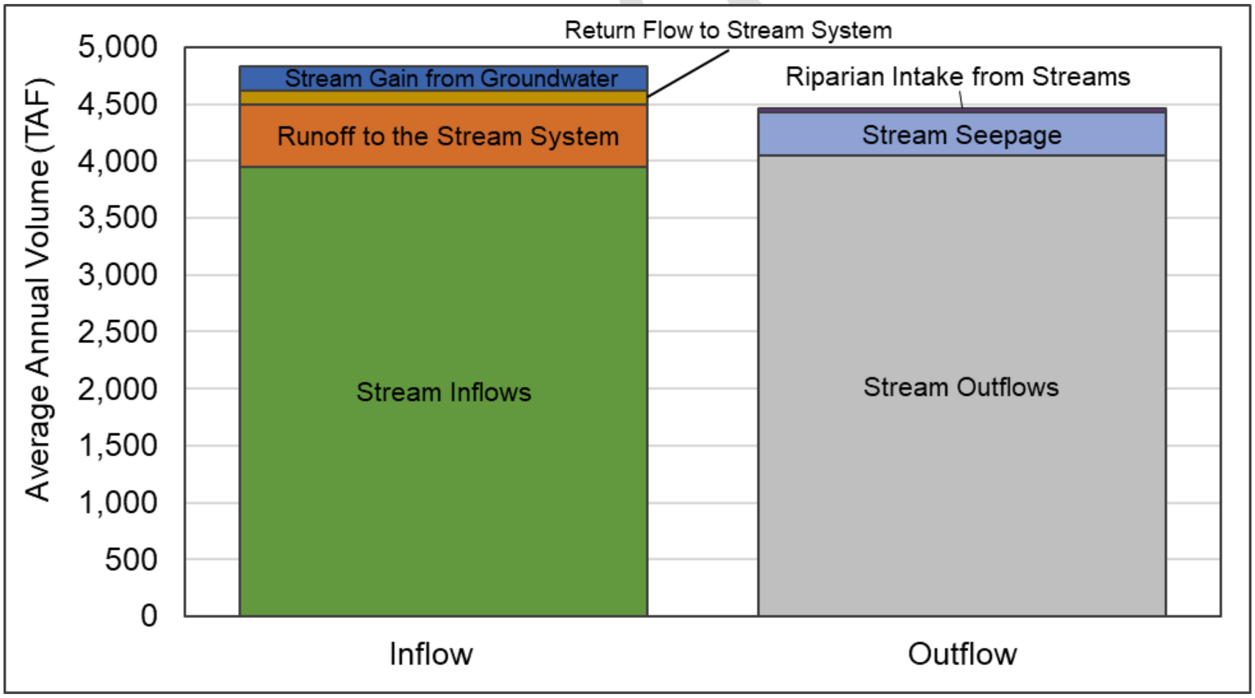
3.3.5.4 Projected Water Budget Estimates

The projected water budget is used to estimate future baseline conditions of supply, demand, and aquifer response to Plan implementation. The projected conditions scenario of the ESJWRM is used to evaluate the projected conditions water budget assuming a 2040 level of development and using hydrology from water years1969-2018.

Development of the projected water demand is based on population growth trends reported by the San Joaquin Council of Governments, urban per capita water use consistent with projections in 2015 UWMPs, and urban area expansion from general plans or sphere of influence boundaries. Due to the expansion of urban area in all the major municipalities, agricultural acreage is reduced by less than 40,000 acres. There is agricultural growth anticipated in the eastern areas of the Subbasin and potential conversion of existing agricultural land to permanent irrigated crops, but no reliable projections were available to include in the simulation; therefore, no additional agricultural land growth was added to the projected conditions scenario. An analysis of county agricultural reports can be performed to assess agricultural trends in future scenarios of the ESJWRM.

Average annual surface water inflows to the Eastern San Joaquin Subbasin's stream system total an average of over 4.8 MAF/year in the projected conditions scenario. Under projected conditions, stream inflows of almost 4.0 MAF/year are augmented by stream gains from groundwater of 212,000 AF/year and runoff of precipitation (542,000 AF/year) and return flow of applied water (127,000 AF/year) to the stream system. Of these volumes, it is anticipated that 370,000 AF/year will be distributed to local growers to meet agricultural demand as surface water diversions and the remaining amount will leave the system in the form of San Joaquin River and Mokelumne River outflows (over 4.0 MAF/year), stream seepage (380,000 AF/year), and riparian intake (32,000 AF/year). Figure 3-9 summarizes the average projected inflows and outflows in the Eastern San Joaquin Subbasin surface water network.

Figure 3-9: Projected Average Annual Water Budget Estimates – Stream System



The land surface water budget for the projected conditions scenario has annual average inflows and outflows of 2,338,000 AF/year. Inflows are comprised of precipitation (984,000 AF/year), surface water (529,000 AF/year), groundwater (801,000 AF/year), and riparian intake from streams (24,000 AF/year). The balance of this is the summation of average annual evapotranspiration (1,394,000 AF/year), surface runoff of precipitation (542,000 AF/year), return flow of applied water (127,000 AF/year), and deep percolation (266,000 AF/year). A summary of these flows can be seen below in Figure 3-10.

Figure 3-10: Projected Average Annual Water Budget Estimates – Land Surface System

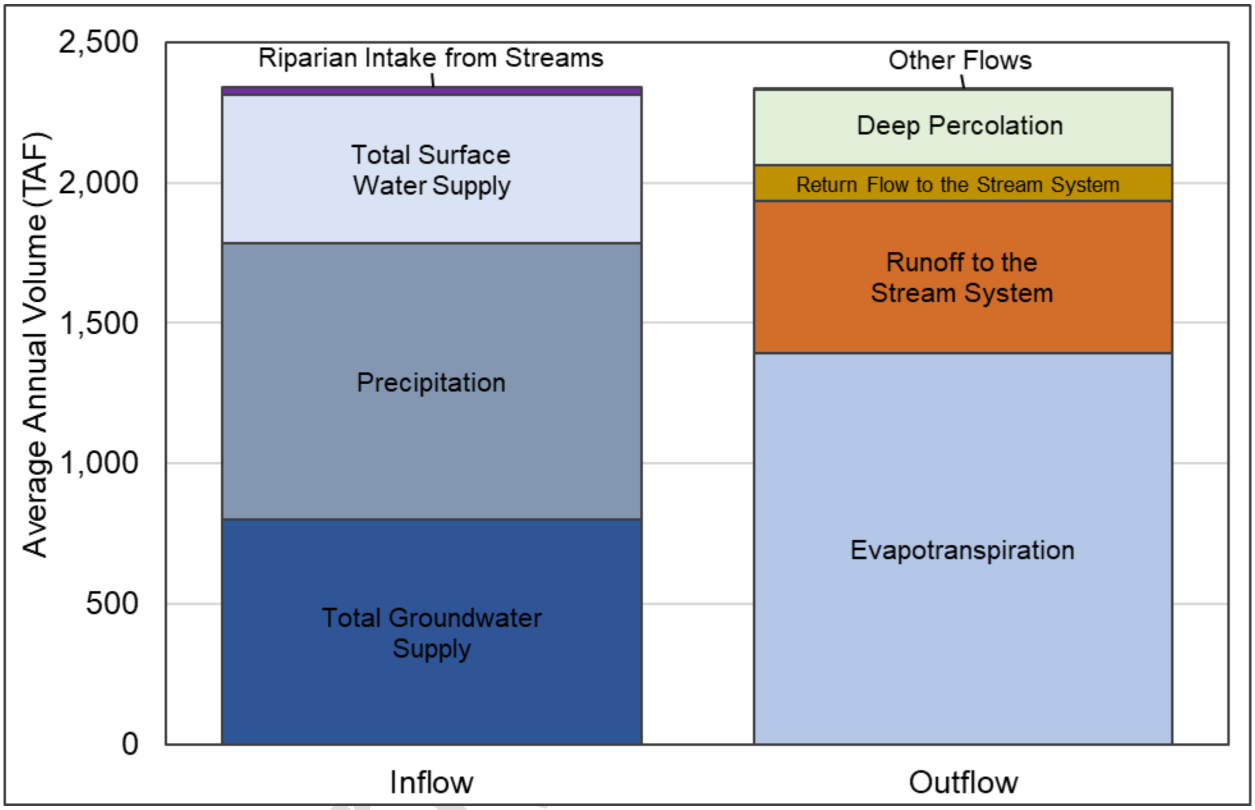
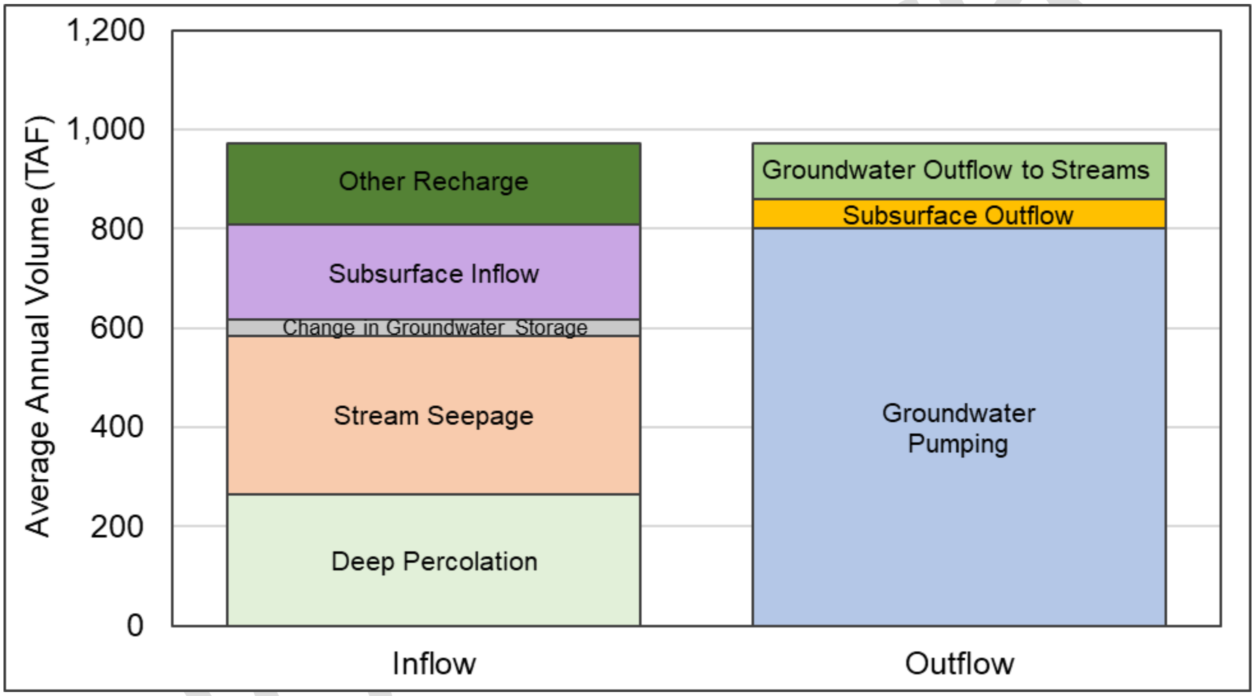


Figure 3-11 below shows how anticipated expansion in surface water supplies is reflected by decreases to groundwater production (801,000 AF/year) relative to current conditions estimates. Subsurface outflow to neighboring subbasins (58,000 AF/year) and stream gain from groundwater (114,000 AF/year) bring the total Subbasin discharges to 973,000 AF/year.

Under projected conditions, the groundwater system of the Eastern San Joaquin Subbasin experiences an average of 939,000 AF/year of inflows each year, of which 266,000 AF/year is deep percolation. There is also seepage from streams (317,000 AF/year), as well as other recharge which includes recharge from canals, reservoirs, and MAR projects (164,00 AF/year), and subsurface inflows (192,000 AF/year) from the Sierra Nevada Mountains and the neighboring subbasins of Cosumnes, Modesto, South American, Solano, East Contra Costa, and Tracy.

The projected water budget has greater outflows than inflows, resulting in an average annual deficit in groundwater storage of 34,000 AF/year. Figure 3-11 summarizes the average projected groundwater inflows and outflows in the Eastern San Joaquin Subbasin.

Figure 3-11: Projected Average Annual Water Budget Estimates – Groundwater System



As seen previously in

Table 3-5 for the historical calibration, Table 3-6 shows the projected conditions water demands, supplies, and change in groundwater storage averaged based on the San Joaquin Valley Water Year Hydrologic Classification or water year type (DWR, 2018). As expected, in wet years there is more precipitation and surface water to meets more of the water demand, reducing the need for groundwater pumping and increasing groundwater storage. However, in dry years, more groundwater is pumped to meet the demand not met by surface water or precipitation, which leads to a decrease of groundwater storage. Unlike the historical calibration, the 50-year period allows for enough of each water year type to calculate meaningful averages and the supplies and demands are largely unchanging except for differences based on water year type.

Table 3-6: Average Annual Values for Key Components of Projected Water Budget by Year Type

Component	Water Year Type (San Joaquin River Index)					
	Wet	Above Normal	Below Normal	Dry	Critical	20-Year
Number of Years	**17**	**7**	**4**	**8**	**14**	**50**
Average Precipitation	**1,376,000**	**987,000**	**866,000**	**790,000**	**652,000**	**984,000**
Water Demand (AF/year)						
Ag Demand	1,088,000	1,107,000	1,108,000	1,112,000	1,117,000	1,104,000
Urban Demand	230,000	228,000	225,000	225,000	222,000	226,000
Total Demand	**1,318,000**	**1,335,000**	**1,333,000**	**1,337,000**	**1,339,000**	**1,330,000**
Water Supply (AF/year)						
Total Surface Water Supply	565,000	559,000	518,000	507,000	488,000	529,000
Agricultural	450,000	446,000	416,000	408,000	395,000	426,000
Urban and Industrial	114,000	113,000	102,000	98,000	93,000	103,000
Total Groundwater Supply	753,000	776,000	815,000	830,000	851,000	801,000
Agricultural	639,000	662,000	693,000	705,000	725,000	681,000
Urban and Industrial	115,000	116,000	124,000	126,000	128,000	121,000
Total Supply (AF/year)	**1,318,000**	**1,335,000**	**1,333,000**	**1,337,000**	**1,339,000**	**1,330,000**
Change in Groundwater Storage (AF/year)	**185,000**	**20,000**	**-113,000**	**-164,000**	**-223,000**	**-34,000**

3.3.6 Sustainable Yield Estimate

Sustainable yield is defined for SGMA purposes as "the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result." (CWC §10721(w)). Sustainable yield for the Eastern San Joaquin Subbasin was calculated through development of an ESJWRM sustainable conditions scenario (model run) in which the goal was to generate a long-term (50-year) change in Subbasin groundwater storage of zero, a conservative approach, as a change in storage of greater than zero could occur without causing undesirable results. In order to account for the challenges of implementing the GSP, this Plan assumes future operations would remain consistent for a 25-year period and groundwater levels would continue to decline until 2040. From 2040, the 50 years of long-term hydrology was applied and various scenarios were run to see what level of groundwater production resulted in a long-term change in storage of, or very close to, zero. The sustainable conditions scenario is based on the projected conditions scenario (see Section 3.3.4.3, Table 3-4, and Figure 3-11) modified by lowering groundwater production across the model domain. The sustainable conditions scenario estimates future conditions of supply, demand, and the resulting aquifer response to implementation of sustainable conditions in the Subbasin.

There are uncertainties associated with projections in the ESJWRM scenarios due to the sequence of the hydrologic period, population projections, future cropping patterns, and irrigation practices and technologies, as well as uncertainties inherent in the representation of the physical groundwater and surface water system by the model. Therefore, to account for these uncertainties, a range of assumptions (from use of high-end estimates to low-end estimates) are used in running model scenarios to estimate the sustainable yield and a rough estimate of the adjustment that would be required to achieve the sustainable yield over the 50-year planning period. These assumptions will be honed over time in updates to this Plan.

The sustainable conditions scenario results in groundwater outflows almost equal to groundwater inflows, bringing the long-term (50-year) average change in groundwater storage to close to zero. Based on this analysis, the sustainable yield of the basin is 715,000 AF/year ± 10%.

In order to achieve a net-zero change in groundwater storage over a 50-year planning period, approximately 78,000 AF/year of direct or in lieu groundwater recharge and/or reduction in agricultural and urban groundwater pumping would need to be implemented in the Eastern San Joaquin Subbasin. This number is larger than the estimated annual overdraft of the projected conditions scenario due to the integrated nature of the groundwater subbasin. As efforts are made to reach sustainability in the Subbasin, flows to and from neighboring basins and flows to and from streams may be impacted, creating the need for additional recharge or pumping reduction greater than the overdrafted amount.

3.3.7 Climate Change Analysis

3.3.7.1 Regulatory Background

SGMA requires taking into consideration uncertainties associated with climate change in the development of GSPs.

Consistent with Section 354.18(d)(3) and Section 354.18(e) of the GSP Regulations, analyses for the Eastern San Joaquin Subbasin GSP evaluated the projected water budget with and without climate change conditions.

Section 354.18(d)(3) of the GSP Regulations states:

> **“***(d) The Agency shall utilize the following information provided, as available, by the Department pursuant to Section 353.2, or other data of comparable quality, to develop the water budget:*
> *(1) Historical water budget information for mean annual temperature, mean annual precipitation, water year type, and land use.*
> *(2) Current water budget information for temperature, water year type, evapotranspiration, and land use.*
> *(3) Projected water budget information for population, population growth,* ***climate change*** *[emphasis added]***,** *and sea level rise.***”**

Section 354.18(e) states:

> **“***(e) Each Plan shall rely on the best available information and best available science to quantify the water budget for the basin in order to provide an understanding of historical and projected hydrology, water demand, water supply, land use, population,* ***climate change*** *[emphasis added], sea level rise, groundwater and surface water interaction, and subsurface groundwater flow. If a numerical groundwater and surface water model is not used to quantify and evaluate the projected water budget conditions and the potential impacts to beneficial uses and users of groundwater, the Plan shall identify and describe an equally effective method, tool, or analytical model to evaluate projected water budget conditions.***”**

3.3.7.2 DWR Guidance

Climate change analysis is an area of continued evolution in terms of methods, tools, forecasted datasets, and the predictions of greenhouse gas concentrations in the atmosphere. The approach developed for this GSP is based on the methodology in DWR’s guidance document (DWR, 2018a). The “best available information” related to climate change in the Eastern San Joaquin Subbasin was deemed to be the information provided by DWR combined with basin-specific modeling tools. The following resources from DWR were used in the climate change analysis:

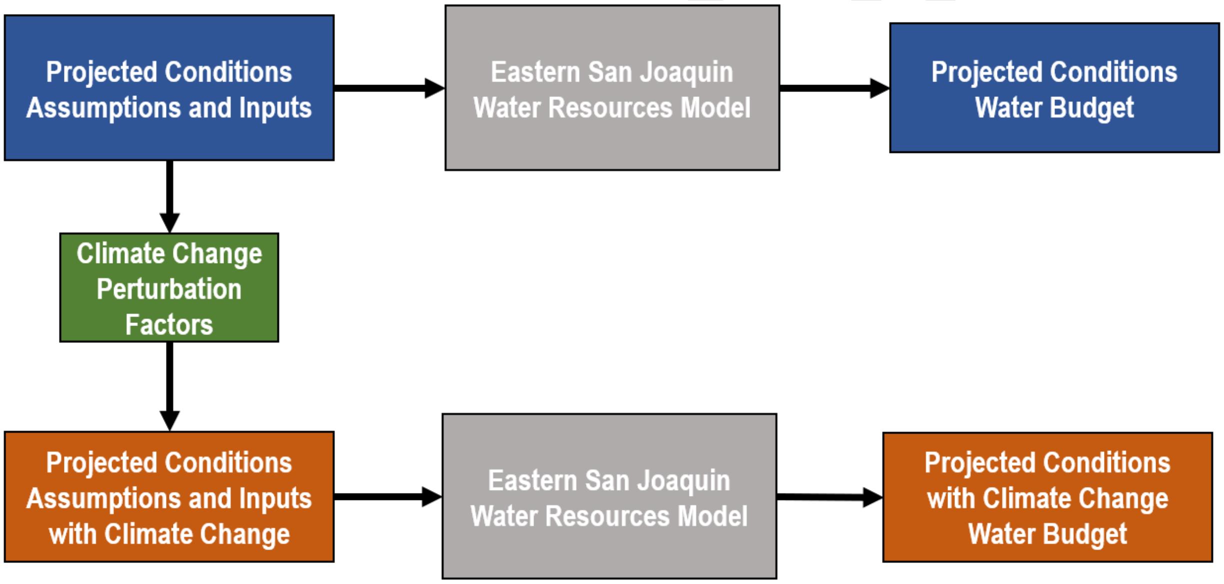
- SGMA Data Viewer

- Guidance for Climate Change Data Use During Sustainability Plan Development and Appendices (Guidance Document)
- Water Budget BMP
- Climate Change Desktop IWFM Tools

The SGMA Data Viewer is where the climate change forecast datasets are available for download (DWR, 2019). The guidance document details the approach, development, applications, and limitations of the datasets available from the SGMA Data Viewer (DWR, 2018a). The Water Budget BMP describes in greater detail how DWR recommends projected water budgets be computed (DWR, 2016). The Desktop IWFM Tools are available to calculate the projected precipitation and evapotranspiration inputs under climate change conditions (DWR, 2018b).

The methods suggested by DWR in the above resources were used, with modifications where needed, to ensure the resolution would be reasonable for the Eastern San Joaquin Subbasin and align with the assumptions of the ESJWRM. Figure 3-12 shows the overall process developed for the Subbasin consistent with the Climate Change Resource Guide (DWR, 2018c) and describes workflow beginning with projected conditions inputs and assumptions to perturbed 2070 conditions for the projected conditions.

Figure 3-12: Eastern San Joaquin Climate Change Analysis Process



The process described in Figure 3-12 of developing a projected water budget with and without climate change was discussed with DWR staff and is consistent with the regulations. Further, it enables the analysis to account for variability in demand and supply separate from the uncertainty associated with climate change forecasts.

Table 3-7 summarizes the forecasted variable datasets provided by DWR that were used to carry out the climate change analysis (DWR, 2019). The VIC (Variable Infiltration Capacity) model referred to in Table 3-7 is the fully mechanistic hydrologic model used by DWR to derive hydrographs under standard and climate change conditions. Section 1.2.2 includes further description of the model and other tools and datasets.

Table 3-7: DWR-Provided Datasets

Input Variable	DWR-Provided Dataset
Unimpaired Streamflow	Combined VIC model runoff and baseflow to generate change factors, provided by HUC 8 watershed geometry
Impaired Streamflow (Ongoing Operations)	CalSim II time series outputs
Precipitation	VIC model-generated GIS grid with associated change factor time series for each cell
Reference ET	VIC model-generated GIS grid with associated change factor time series for each cell

3.3.7.3 Climate Change Methodology

Accepted methods for estimating climate change impacts on groundwater are based on the assessment of impacts on the individual water resource system elements that directly link to groundwater. These elements include precipitation, streamflow, evapotranspiration and, for coastal aquifers, sea level rise as a boundary condition. For the Eastern San Joaquin Subbasin, sea level rise was not included.

The method for perturbing the streamflow, precipitation, and evapotranspiration input files is described in the following sections. A future scenario of 2070 climate forecasts was evaluated in this analysis, consistent with DWR guidance (DWR, 2018a). DWR combined 10 global climate models (GCMs) for two different representative climate pathways (RCPs) to generate the central tendency scenarios in the datasets used in this analysis. The “local analogs” method (LOCA) was used to downscale these 20 different climate projections to a scale usable for California (DWR, 2018a). The 2070 central tendency among these projections serves to assess impacts of climate change over the long-term planning and implementation period.

3.3.7.3.1 Streamflow under Climate Change

Hydrologic forecasts for streamflow under various climate change scenarios are available from DWR as either a flow-based timeseries or a series of perturbation factors applicable to local data. DWR simulates volumetric flow in most regional surface water bodies by utilizing the Water Resource Integrated Modeling System (WRIMS, formally named CalSim II). While river flows and surface water diversions in the Calaveras, San Joaquin, and Stanislaus Rivers are simulated in CalSim II, there are significant variations when compared to local historical data. Due to the uncertainty in reservoir operations, flows from CalSim II provided by the state are not used directly. Instead, relative perturbation factors were used to derive surface water inflows and diversions for use in ESJWRM.

Local tributaries and smaller streams within Eastern San Joaquin Subbasin are not simulated in CalSim II and must be simulated using adjustment factors developed by DWR for unregulated stream systems. Dry Creek flows were perturbed using this method. The resolution of these perturbation factors is at the HUC 8 watershed scale. CalSim II model runs are not available for the Mokelumne River, according to Appendix B, Table B-2 of DWR’s Climate Change Document (DWR, 2018a). Therefore, to keep as consistent as possible, Mokelumne River flows are considered “unimpaired” flow and the perturbation factor method was employed. The remaining streams simulated in the ESJWRM utilize the IWFM small watershed package, whose climate change impacts are calculated internally dependent on both precipitation and evapotranspiration refinement. Table 3-8 presents the impaired and unimpaired streams in the ESJWRM model for the Eastern San Joaquin Subbasin.

Table 3-8: Eastern San Joaquin Stream Inflows

Stream	Impaired	Unimpaired
Dry Creek		X
Mokelumne River		X
Calaveras River	X	
San Joaquin River	X	
Stanislaus River	X	

3.3.7.3.1.1 Unimpaired Flows

Change factors for unimpaired streams (Dry Creek and Mokelumne River) were downloaded from SGMA Data Viewer and multiplied by the projected conditions input streamflow data to calculated perturbed flows. DWR change factors are available through 2011; however, the model hydrologic period runs from WY 1969-2018. Flows for the remaining model years beyond 2011 were synthesized using the change factor from the most recent matching water year type in the available dataset. Water Year types are designated for each year based on the San Joaquin Valley Runoff WY year type index (DWR, 2017). DWR uses five designations ranging from driest to wettest conditions: Critical, Dry, Below Normal, Above Normal, and Wet. Table 3-9 below shows the year type designations used to synthesize the remaining years (2011-2018).

Table 3-9: San Joaquin Valley Water Year Type Designations

Water Year	Year Type
2003	Below Normal
2004	Dry
2005	Wet
2006	Wet
2007	Critical
2008	Critical
2009	Below Normal
2010	Above Normal
2011	Wet
2012	Dry
2013	Critical
2014	Critical
2015	Critical
2016	Dry
2017	Wet
2018	Below Normal

Figure 3-13 shows the perturbed time series against the projected condition scenario time series for Dry Creek and Figure 3-14 presents the exceedance probability curve. Figure 3-15 and Figure 3-16 show perturbed time series and exceedance curves for Mokelumne River. The exceedance curves are provided because they more clearly show the differences between the projected condition scenario and the with climate change scenario. Generally, flows under the climate change scenario are slightly higher.

Figure 3-13: Dry Creek Hydrograph

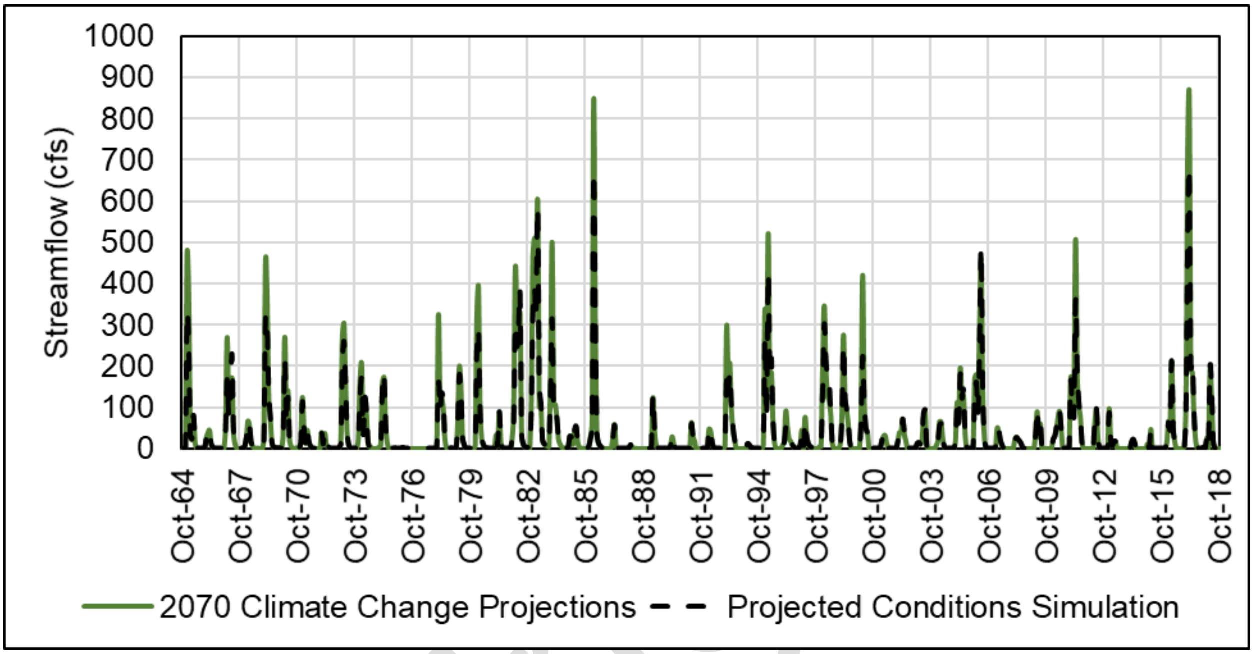


Figure 3-14: Dry Creek Exceedance Curve

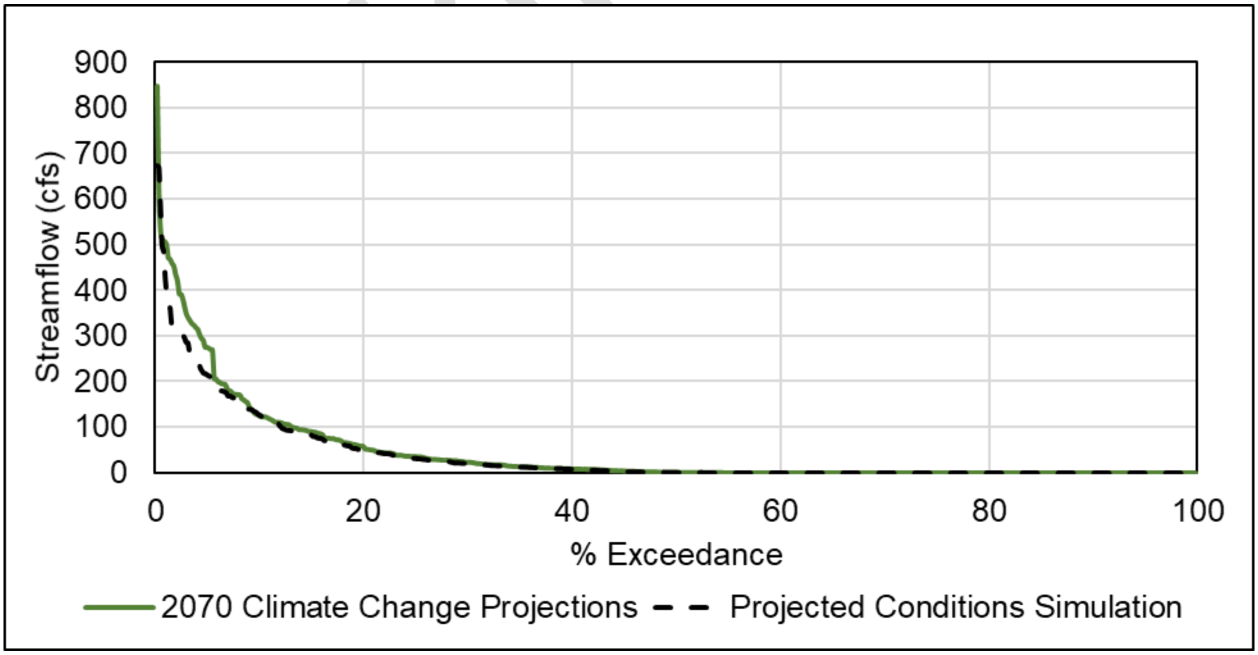


Figure 3-15: Mokelumne River Hydrograph

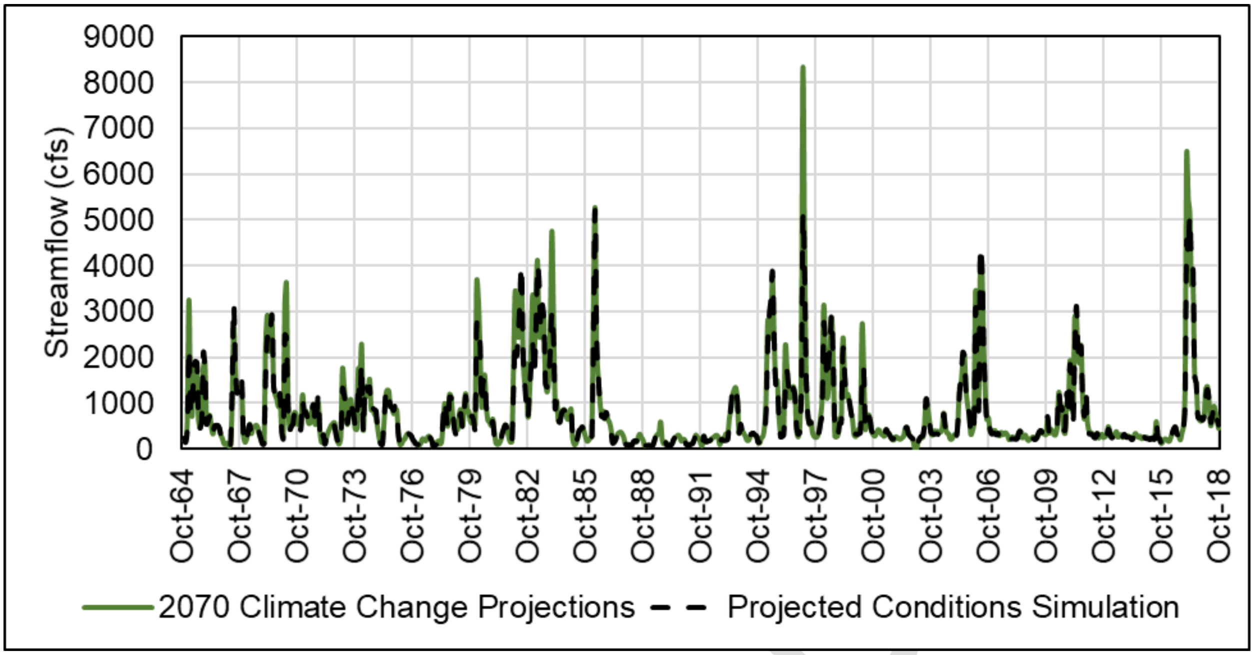
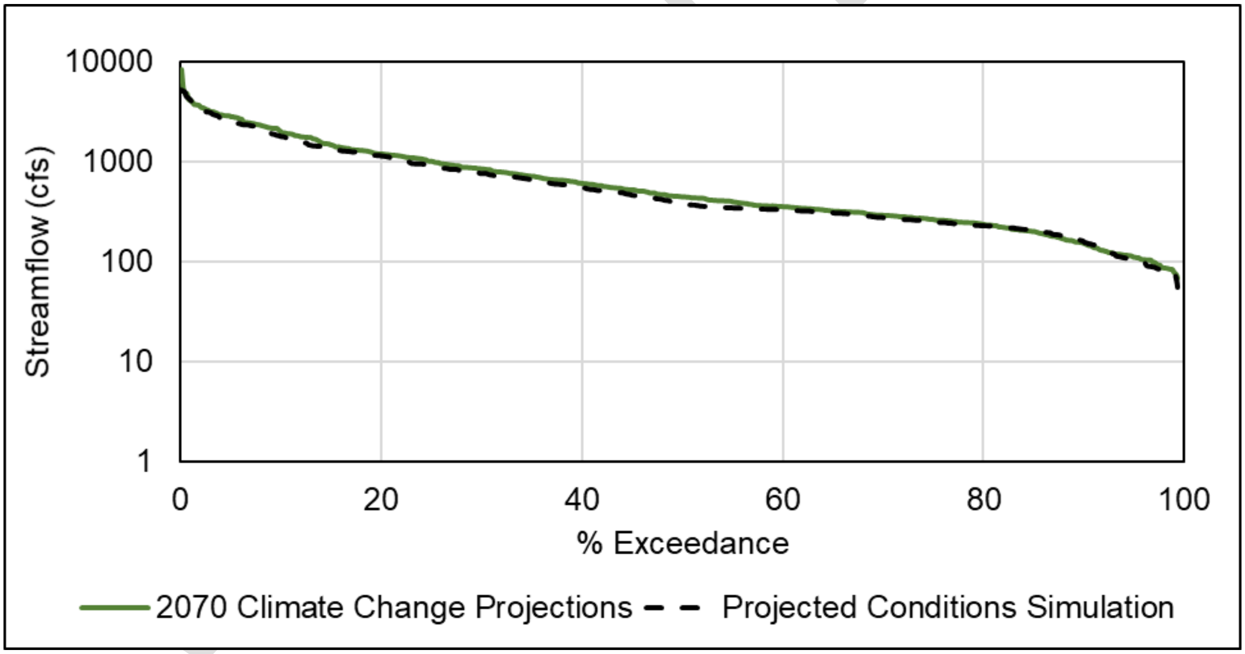


Figure 3-16: Mokelumne River Exceedance Curve



3.3.7.3.1.2 Impaired Flows

CalSim II-estimated flows for point locations on the Calaveras River, San Joaquin River, and Stanislaus River were downloaded from DWR. These points obtained from CalSim II include:

- Calaveras River: New Hogan Reservoir Outflow
- San Joaquin River: San Joaquin River at Vernalis
- Stanislaus River: New Melones Reservoir Outflow

These flows represent projected hydrology based on reservoir outflow, operational constraints, and diversions and deliveries of water for the State Water Project and the Central Valley Project. CalSim II data from WY 1969-2003 was available. For the years 2003-2018, streamflow was synthesized based on flows from WY 1969-2003 and the DWR year type index shown in Table 3 (DWR, 2017). For example, the total monthly streamflow for October 2003 was calculated as the average of the monthly streamflows from October 1966 and October 1971 because they are the same water year type.

CalSim II simulated flows were compared with flows generated using the DWR-provided unimpaired perturbation factors. Streamflow simulated in CalSim II and those derived using the unimpaired adjustment factors did not present similar trends, particularly in dry years, due to CalSim II's simulation of reservoir operations. DWR-provided unimpaired change factors do not account for variations in the operation of the reservoirs that would result from climate change conditions. Therefore, CalSim II outputs were considered a more appropriate starting dataset for regulated streams given that downstream flow is driven by surface water demand rather than natural flow.

The team explored a hybrid approach to improve upon the discrepancy between flows produced using CalSim II and perturbation factors, while accounting for some change in reservoir operations. In this approach, change factors are generated from the difference between the simulated future climate change CalSim II scenario for 2070 climate conditions and a "without climate change" CalSim II run. This "without climate change" run is the CalSim II 1995 Historical Detrended simulation run. The generated change factors from these two runs were then used to perturb the regulated river inflows simulated in the ESJWRM projected conditions scenario. For the purposes of simplicity, this method is referred to throughout the rest of the document as CalSim II Generated Perturbation Factors (CGPF). The CGPF method presents limitations given that the resulting flows are not directly obtained from an operations model. The actual mass balance on the reservoirs is not tracked in the estimates of the flows and, instead, the method relies on CalSim II tracking storage and managing the reservoir based on the appropriate rule curves.

Figure 3-17 through Figure 3-22 provide a comparison of project baseline condition and the results of the CGPF method described above. Exceedance curves are included for each of the CGPF flows against the project baseline flows.

Figure 3-17: Calaveras River Perturbed Hydrograph

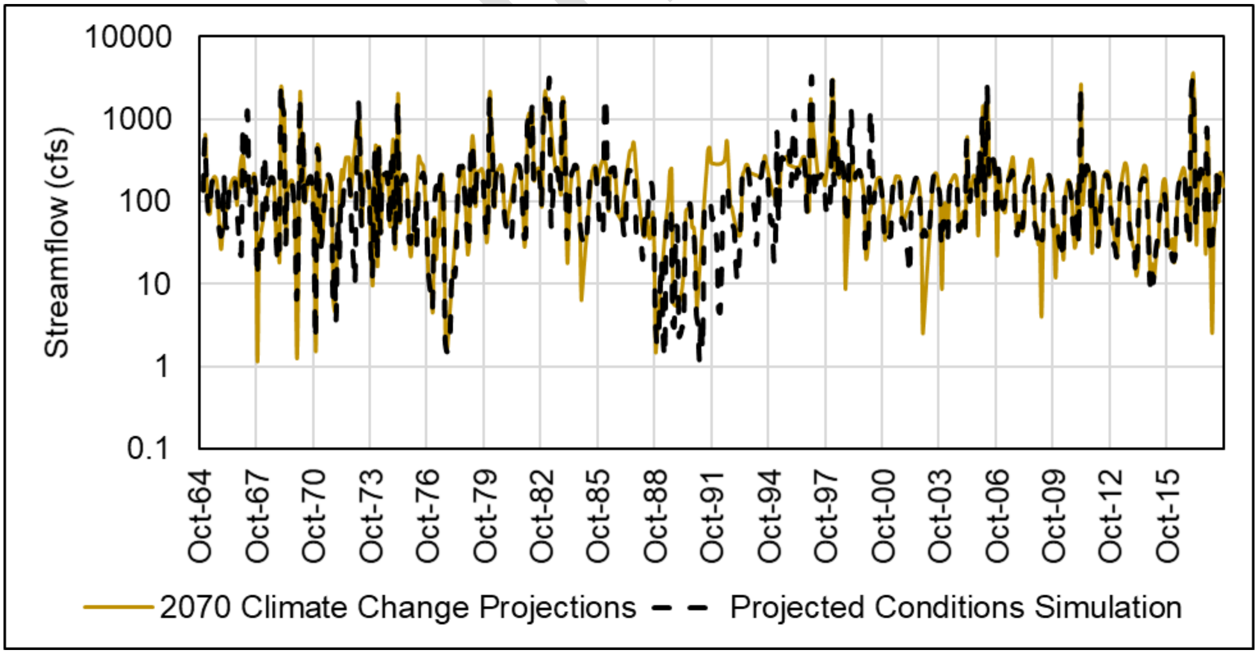


Figure 3-18: Calaveras River Exceedance Curve

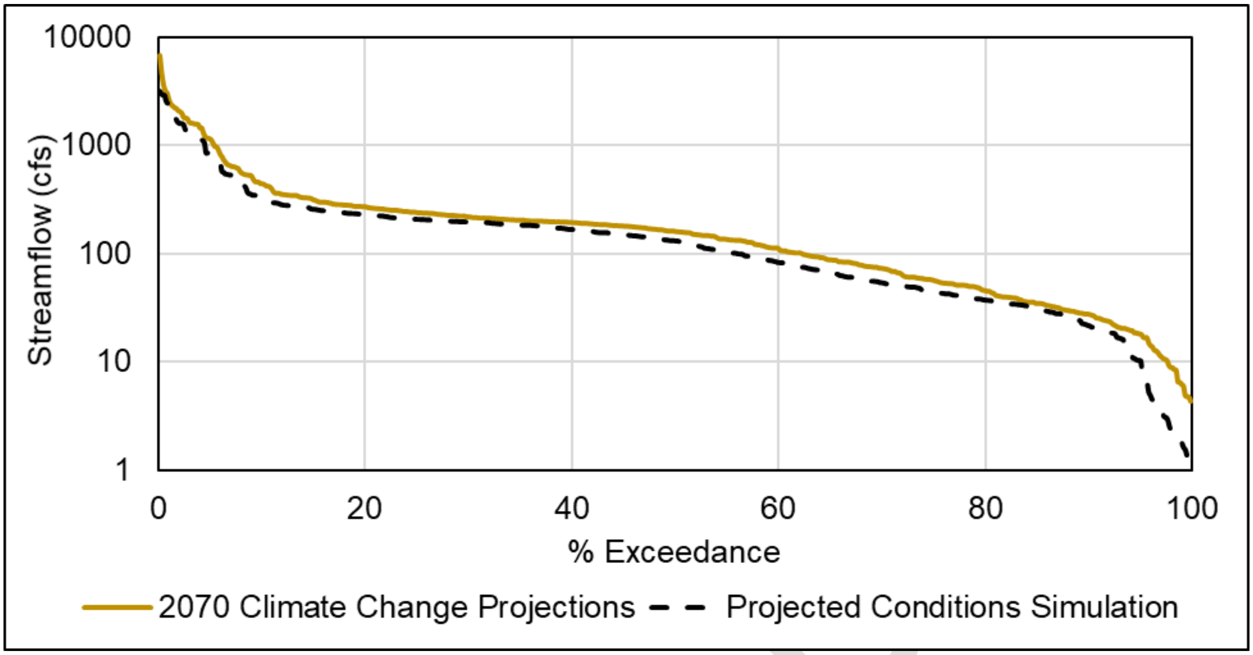


Figure 3-19: Stanislaus River Hydrograph

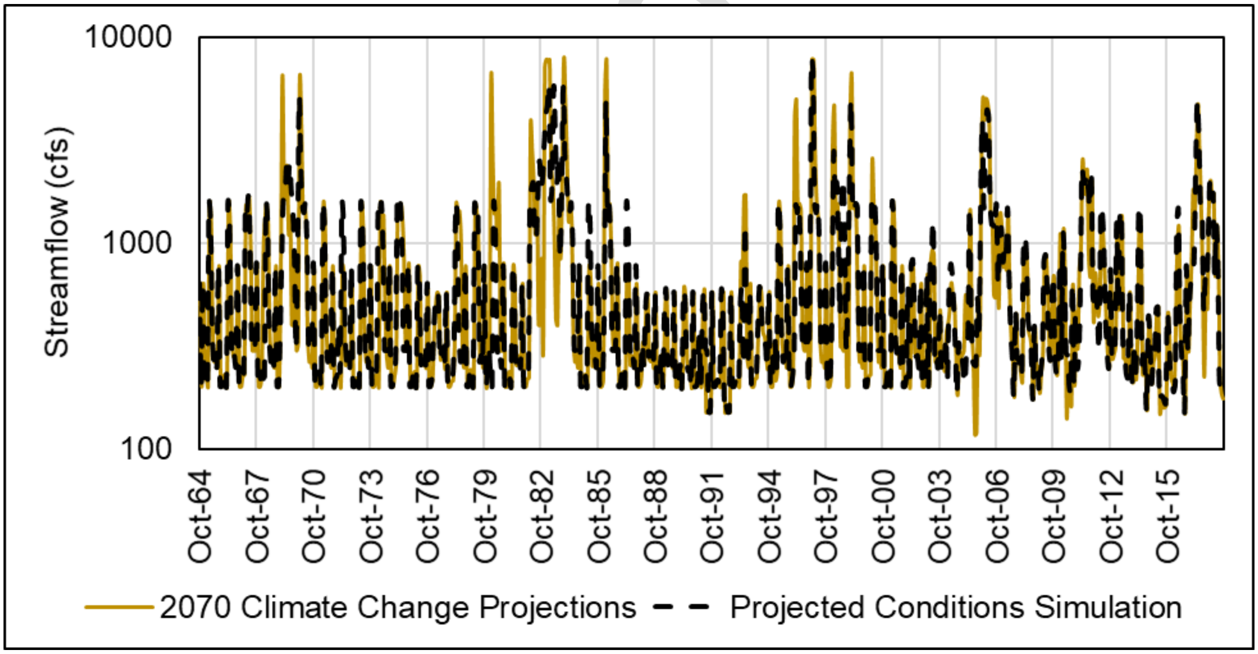


Figure 3-20: Stanislaus River Exceedance Curve

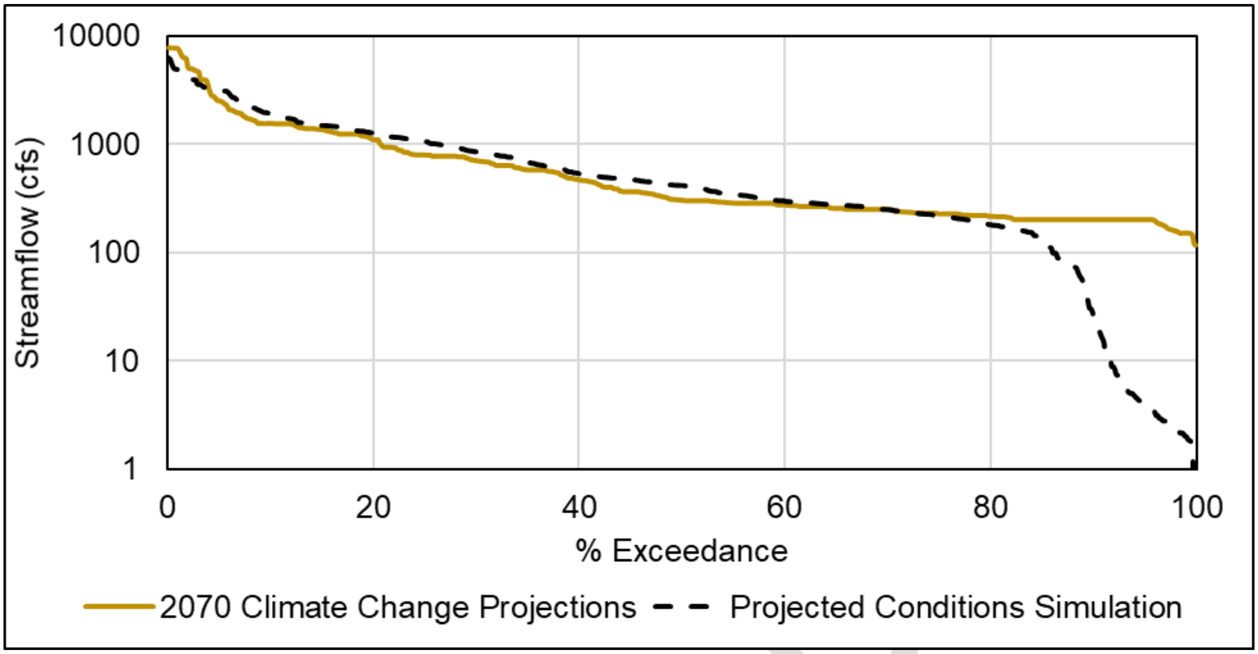


Figure 3-21: San Joaquin River Hydrograph

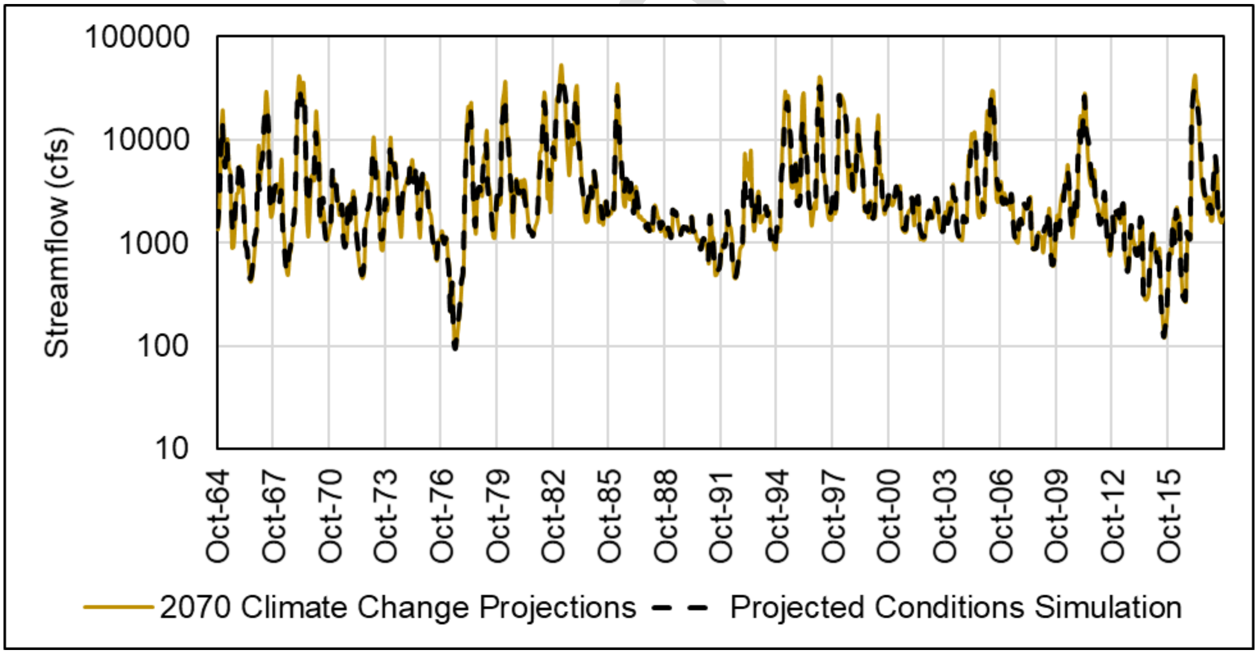
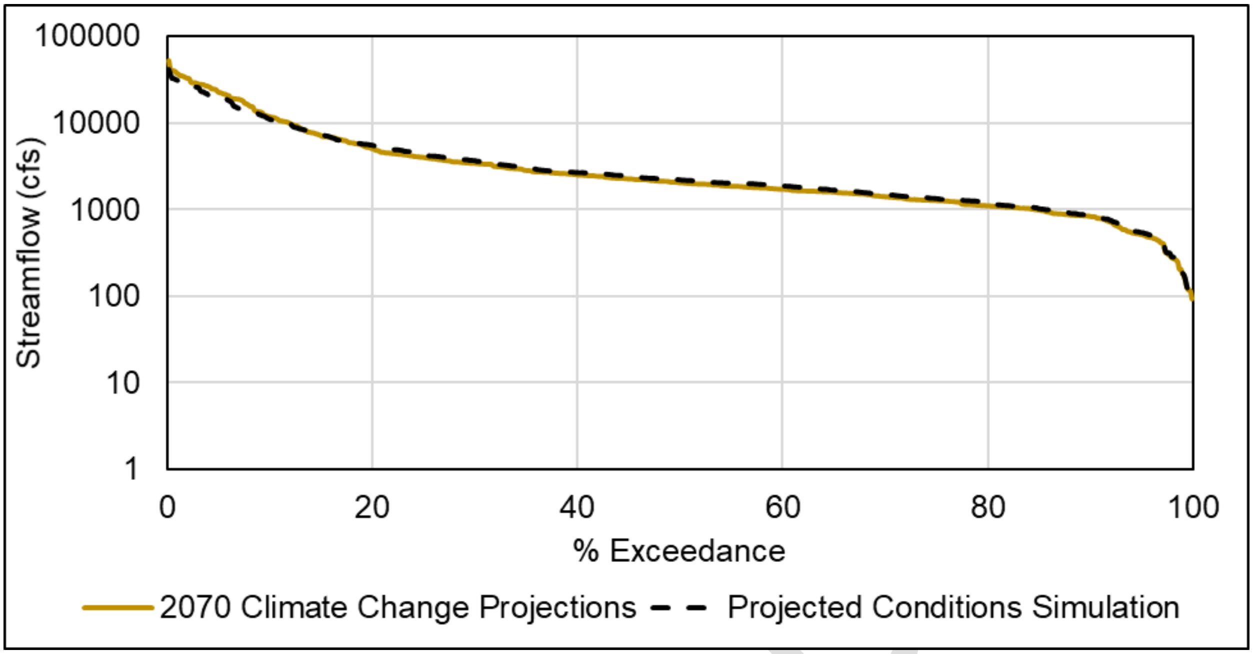


Figure 3-22: San Joaquin River Exceedance Curve



3.3.7.3.2 Precipitation and Evapotranspiration under Climate Change

Projected precipitation and ETo change factors were calculated using a climate period analysis based on historical precipitation and ETo from January 1915 to December 2011 (DWR, 2018a). DWR used a macroscale hydrologic model that solves the water balance of a watershed, called the VIC Model. Change factors provided by DWR were calculated as a ratio of the value of a variable under a “future scenario” divided by a baseline. That baseline data is the 1995 Historical Temperature Detrended scenario downscaled from GCM climate data. The “future scenario” corresponds to VIC outputs of the simulation of future conditions using GCM forecasted hydroclimatic variables as inputs. These change factors are thus a simple perturbation factor that corresponds to the ratio of a future with climate change divided by the past without it. Change factors are available on a monthly time step and spatially defined by the VIC model grid. Supplemental tables with the time series of perturbation factors are available from DWR for each grid cell. DWR has made accessible a Desktop GIS tool for both IWFM and MODFLOW to process these change factors (DWR, 2018b).

3.3.7.3.2.1 Applying Change Factors to Precipitation

DWR change factors were multiplied by historical precipitation to generate projected precipitation under the 2070 central tendency future scenario using the Desktop IWFM GIS tool (DWR, 2018b). The tool calculates an area weighted precipitation change factor for each model grid geometry. This model grid geometry was based on polygons generated around the PRISM nodes within the model region used to specify rainfall depths.

However, the DWR tool only includes change factors through 2011. The remaining 6 years of the time series were synthesized according to historically comparable water years. The perturbation factor from the corresponding month of the comparable year was applied to the baseline of the missing years (2012-2018) to generate projected values. Months with no precipitation in the baseline were assumed a monthly precipitation of 1mm under climate change to account for increased precipitation that cannot be calculated from a baseline of 0 mm for these synthesized years. The comparable years that were used can be found in Table 3-10. These comparable years were determined by comparing total San Joaquin Valley runoff, DWR year type index, and total annual Subbasin precipitation.

Table 3-10: Comparable Water Years (Precipitation)

Water Year Not Available in DWR Tool	Comparable Water Year
2012	2001
2013	1991
2014	1987
2015	1977
2016	2002
2017	1983
2018	1983

The resulting perturbed precipitation values and the baseline precipitation values for the representative historical period can be found in Figure 3-23. The exceedance plot for these two times series can be found in Figure 3-24.

Figure 3-23: Perturbed Precipitation Under Climate Change

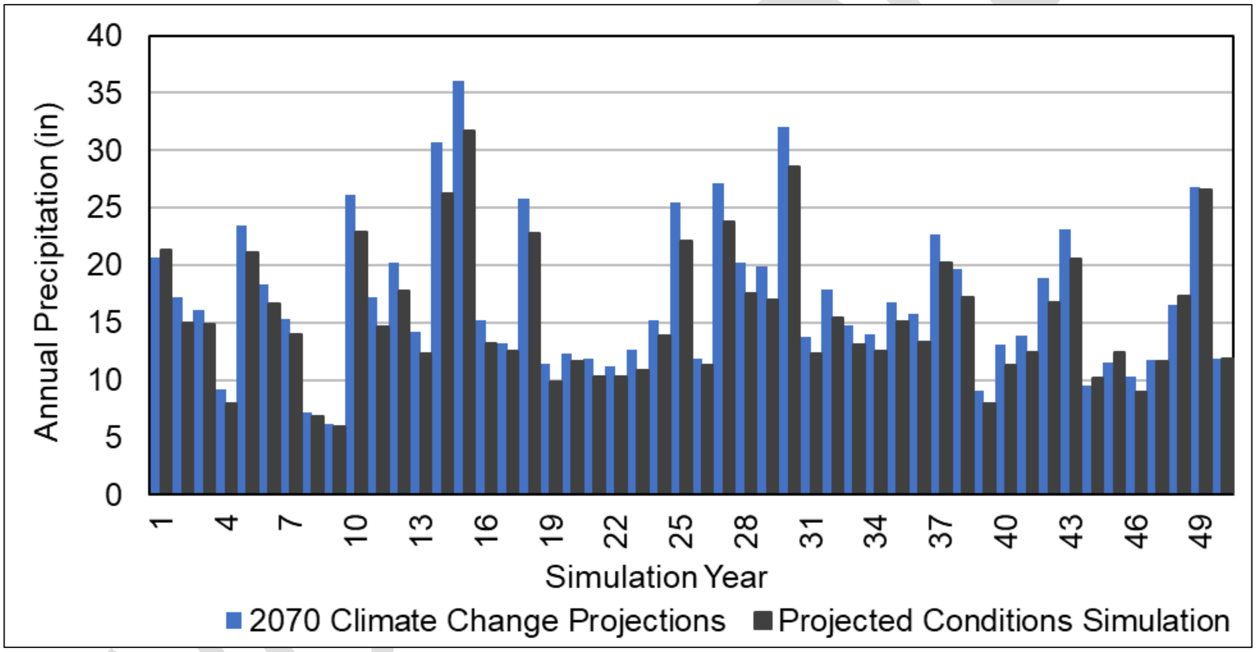
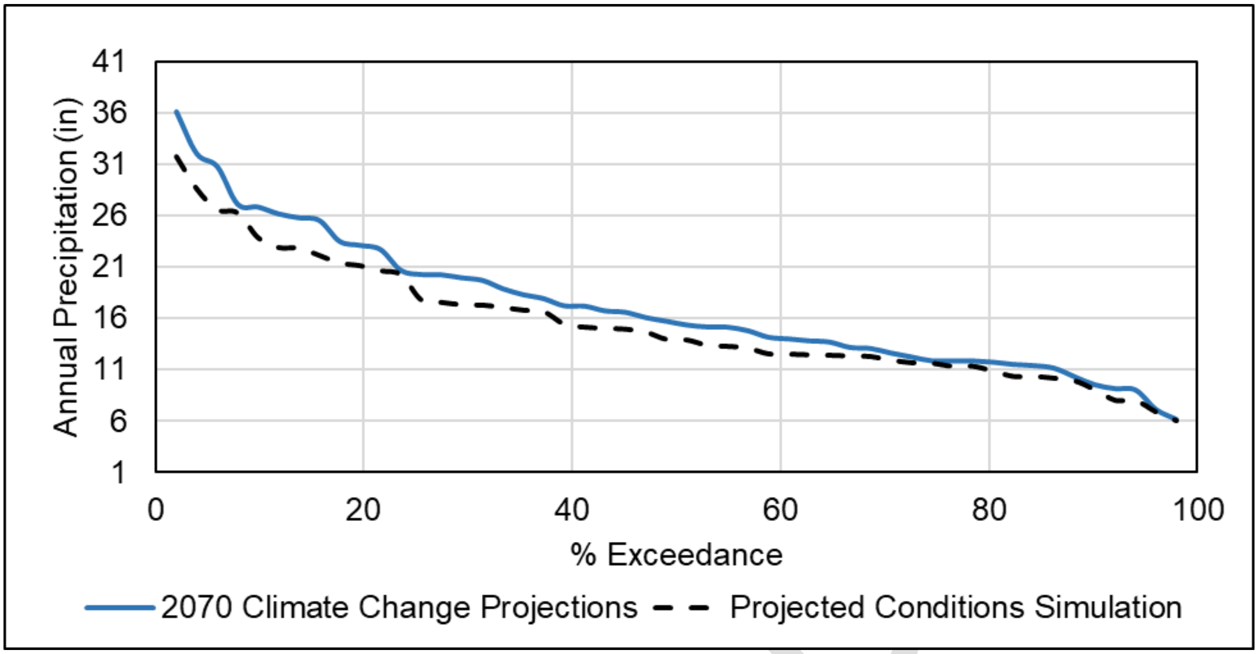


Figure 3-24: Perturbed Precipitation Exceedance Curve



3.3.7.3.2.2 Applying Change Factors to Evapotranspiration

Potential ETo in the basin varies geographically and by land use. DWR provides change factors for ETo that vary spatially based on the VIC model grid as described above. ETo in southern portions of the basin is generally higher than in northern portions for certain land use types, as reflected in the historical calibration of the ESJWRM. For the purposes of this analysis, a localized change factor of 1.084 was used for almonds, walnuts, cherries, pistachios, pasture crops, corn, and rice in the southern areas of the model and a regional ETo change factor of 1.082 was used for the remaining crops in the south and all crops in the northern portion. In this way, the level of discretization of ETo variation between the change factors and the modeled ETo is matched.

The tool provided by DWR to process ETo was not used because of the minimal spatial variation in ETo in the Subbasin. Change factors provided by DWR for November 1, 1964 through December 1, 2011 were averaged. This average ETo change factor was then applied to the historical ETo time series for each crop type. Because there is no interannual variability in ETo in ESJWRM, the same perturbed time series was applied across all simulation years. Refinement to the simulated evapotranspiration of almonds, walnuts, and cherries under 2070 climate conditions are shown in Figure 3-25 through Figure 3-28.

Figure 3-25: Monthly Evapotranspiration Variability for Almonds

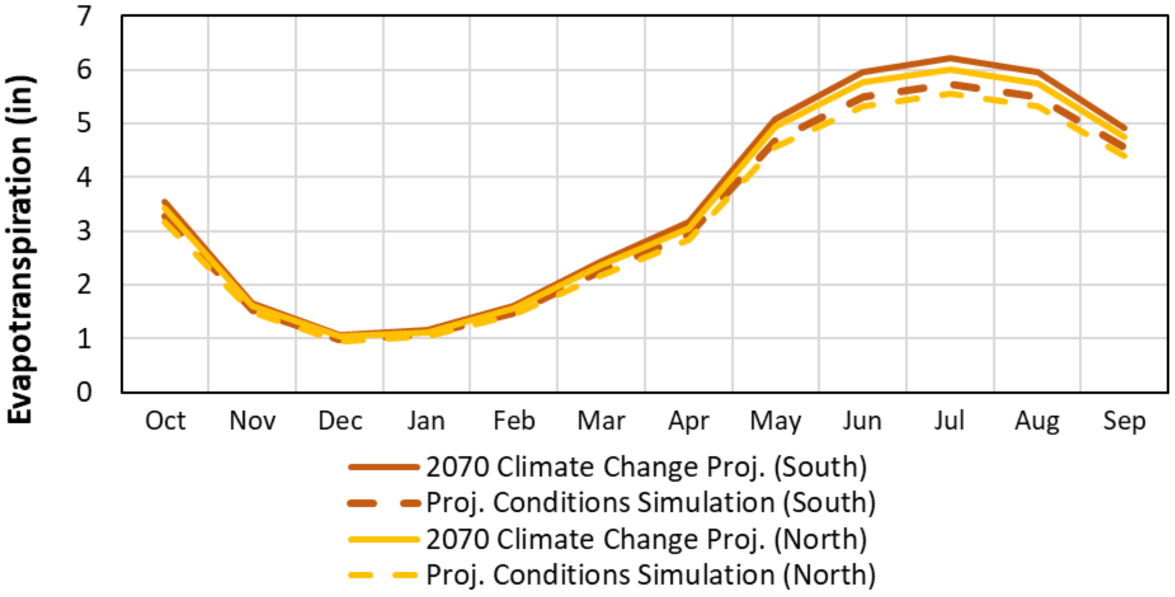


Figure 3-26: Monthly Evapotranspiration Variability for Walnuts

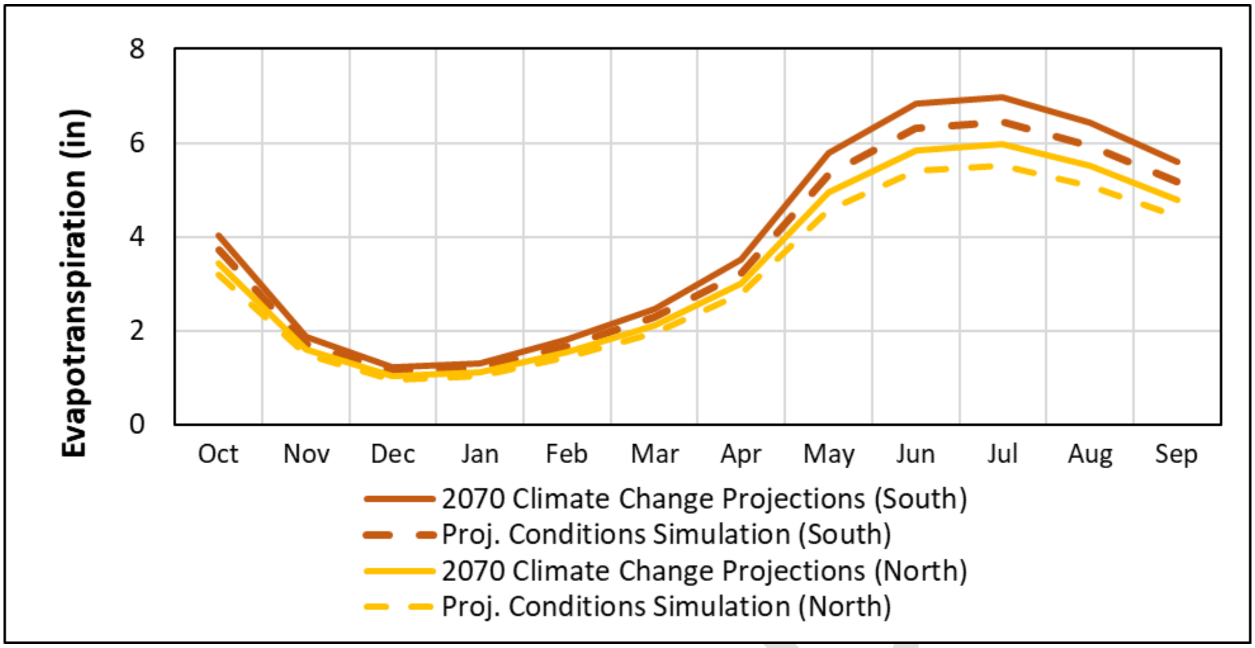


Figure 3-27: Monthly Evapotranspiration Variability for Cherries

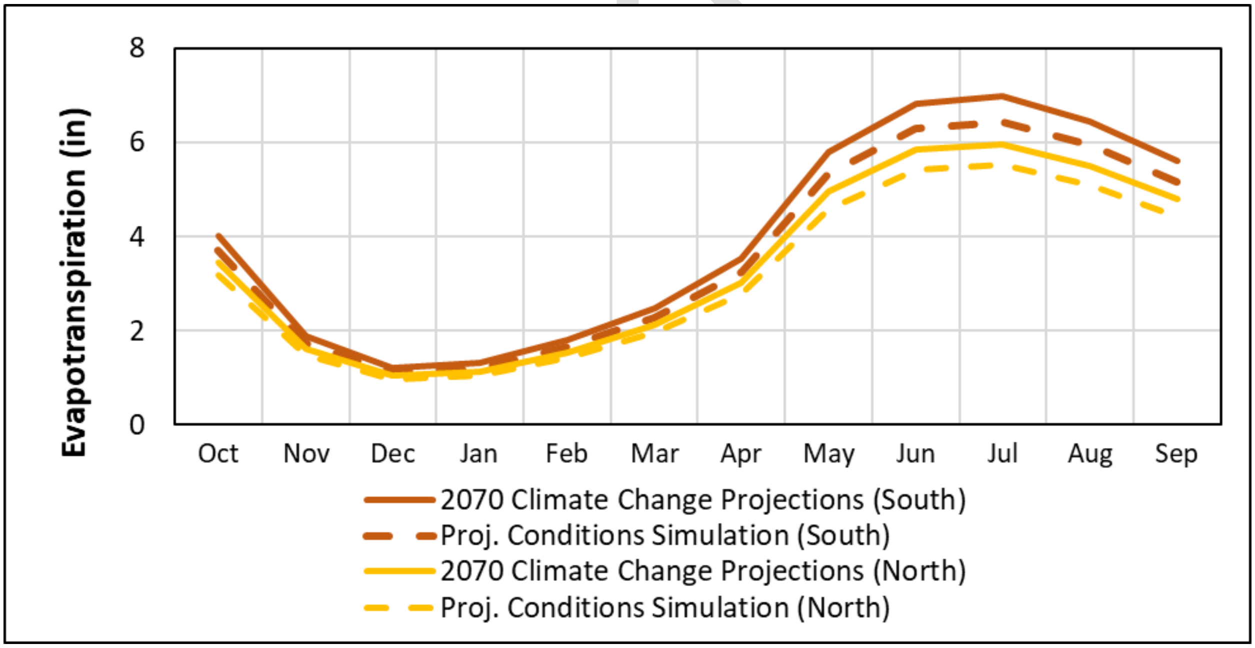
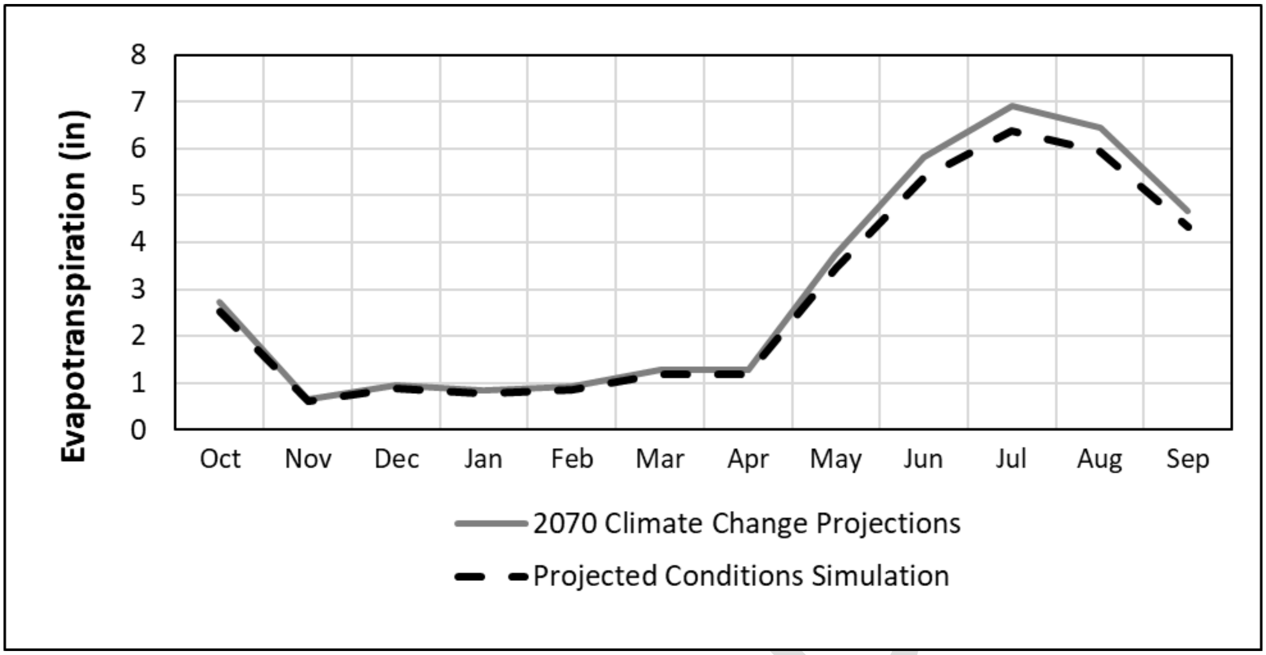


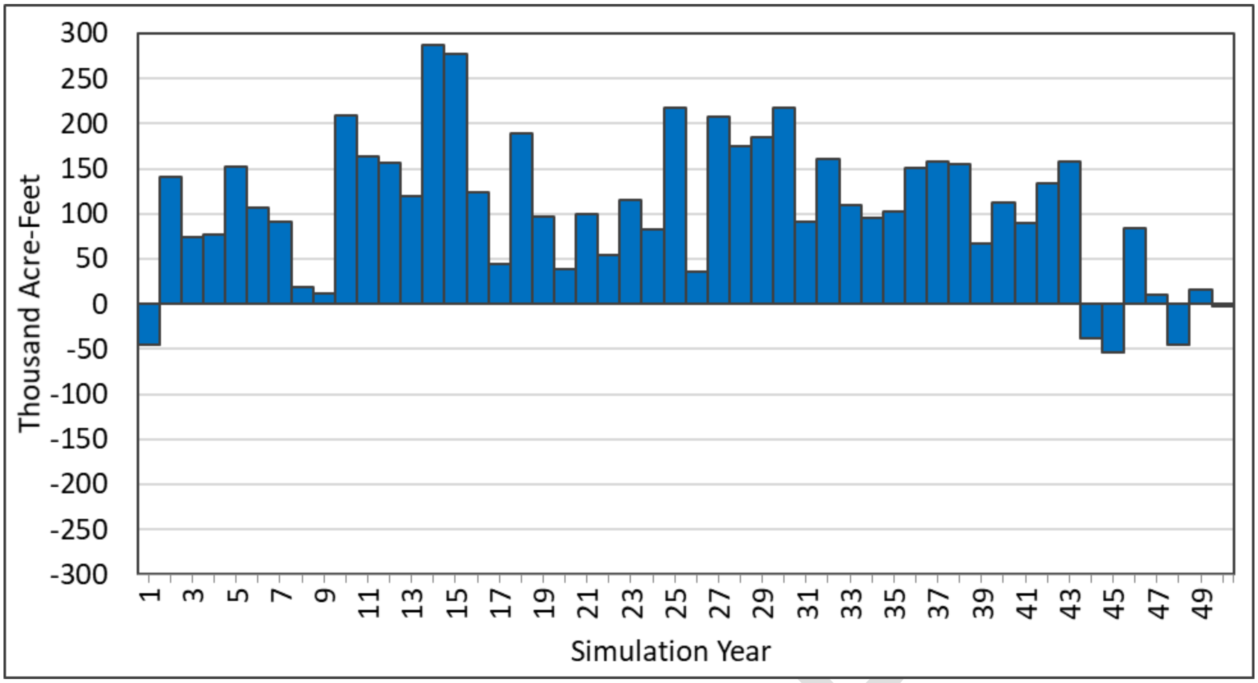
Figure 3-28: Monthly Evapotranspiration Variability for Vineyards



3.3.7.4 Eastern San Joaquin Water Budget Under Climate Change

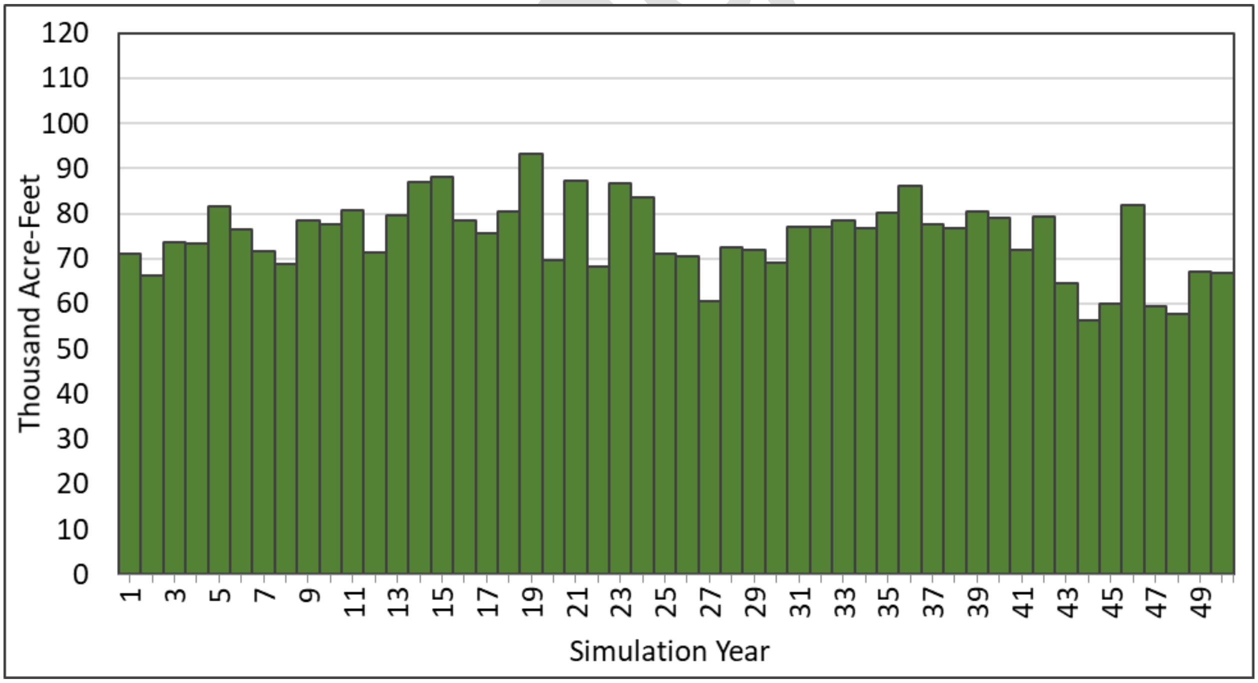
A climate change scenario was developed for the ESJWRM to evaluate the hydrological impacts under these climate change conditions. The analysis was based on the projected conditions scenario with climate change perturbed inputs for streamflow, precipitation, and ETo. Under the climate change scenario, the average annual precipitation is 11 percent higher than the projected conditions scenario, increasing from 984,000 AFY to 1,090,000 AFY. Similarly, the average annual volume of evapotranspiration is 6 percent higher than the projected conditions scenario, increasing to 1,476,000 AFY from 1,394,000 AFY. Despite there being higher flows in streams, the monthly timing of the flows meant that surface water diversions were not expected to change due to both availability of water in the stream and water rights agreements limiting diversion months. With a similar surface water supply and increased water demands under the climate change scenario, private groundwater production is simulated to increase approximately 11 percent, from 801,000 AFY to 887,000 AFY. Under climate change conditions, the depletion in aquifer storage is expected to increase by about 68 percent to an average annual storage change of 57,000 AFY, from 34,000 AFY in the projected conditions scenario. A graphical representation of simulated changes to precipitation, evapotranspiration, and groundwater pumping are presented in Figure 3-29 though Figure 3-31, and complete water budgets for the climate change scenario are shown in Figure 3-32 and Figure 3-33.

Figure 3-29: Simulated Changes in Precipitation due to Climate Change



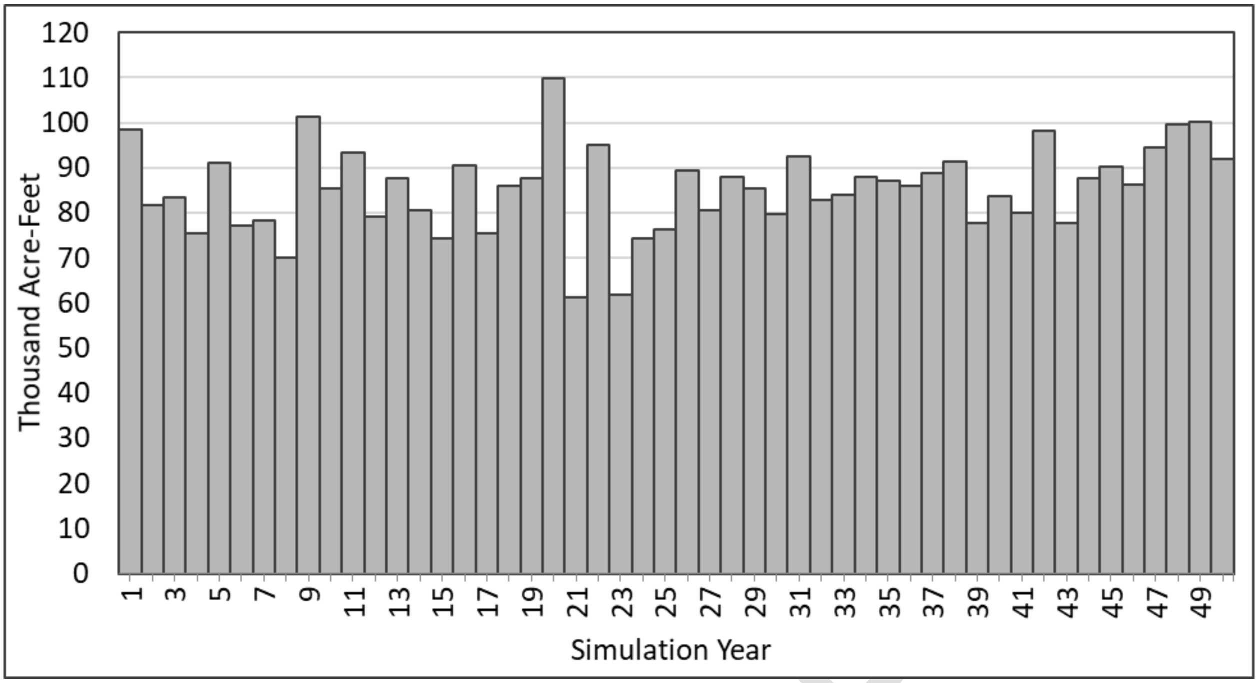
Note: Negative indicates projected conditions scenario value was larger and positive indicates climate change scenario was larger. As expected based on the analysis, the climate change scenario largely has more precipitation.

Figure 3-30: Simulated Changes in Evapotranspiration due to Climate Change



Note: Climate change scenario evapotranspiration is always larger than the projected conditions scenario for all simulated years.

Figure 3-31: Simulated Changes in Groundwater Production due to Climate Change



Note: Climate change scenario groundwater pumping or production is always larger than the projected conditions scenario for all simulated years.

Figure 3-32: Land and Water Use Budget – Climate Change Scenario

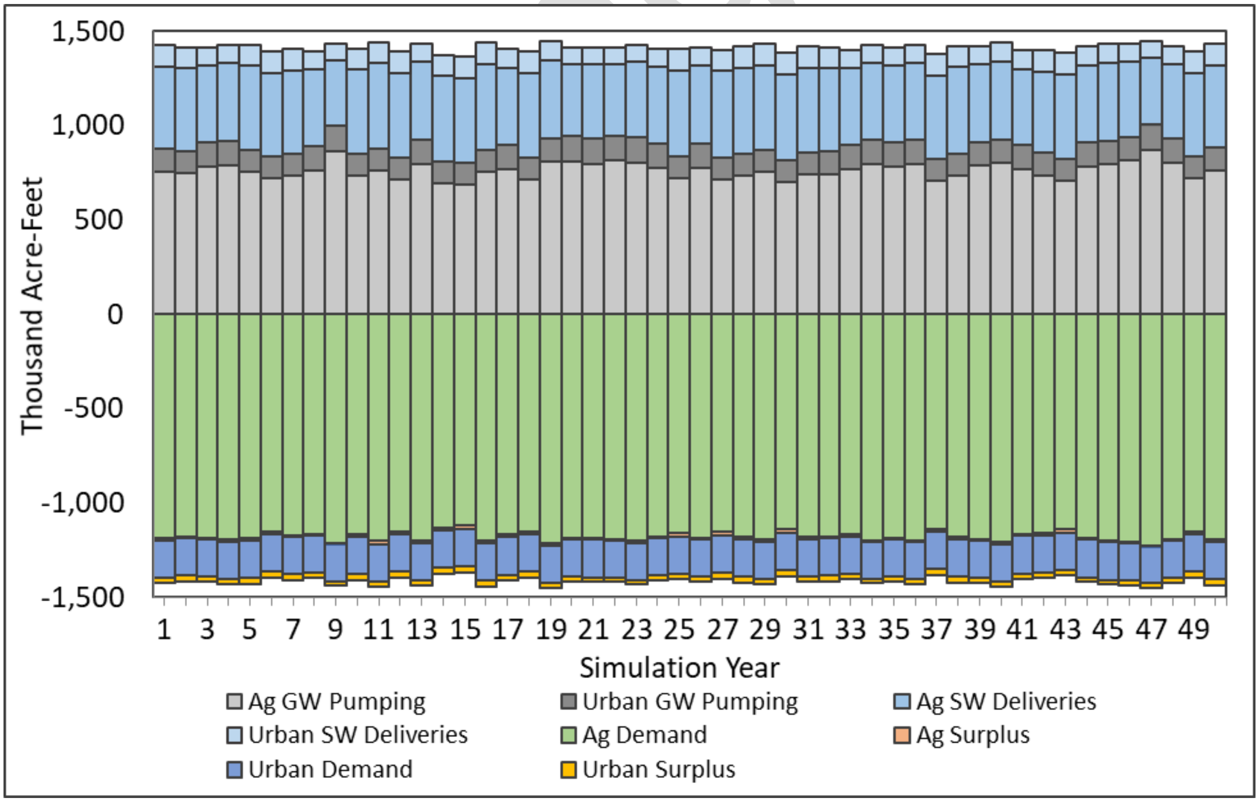
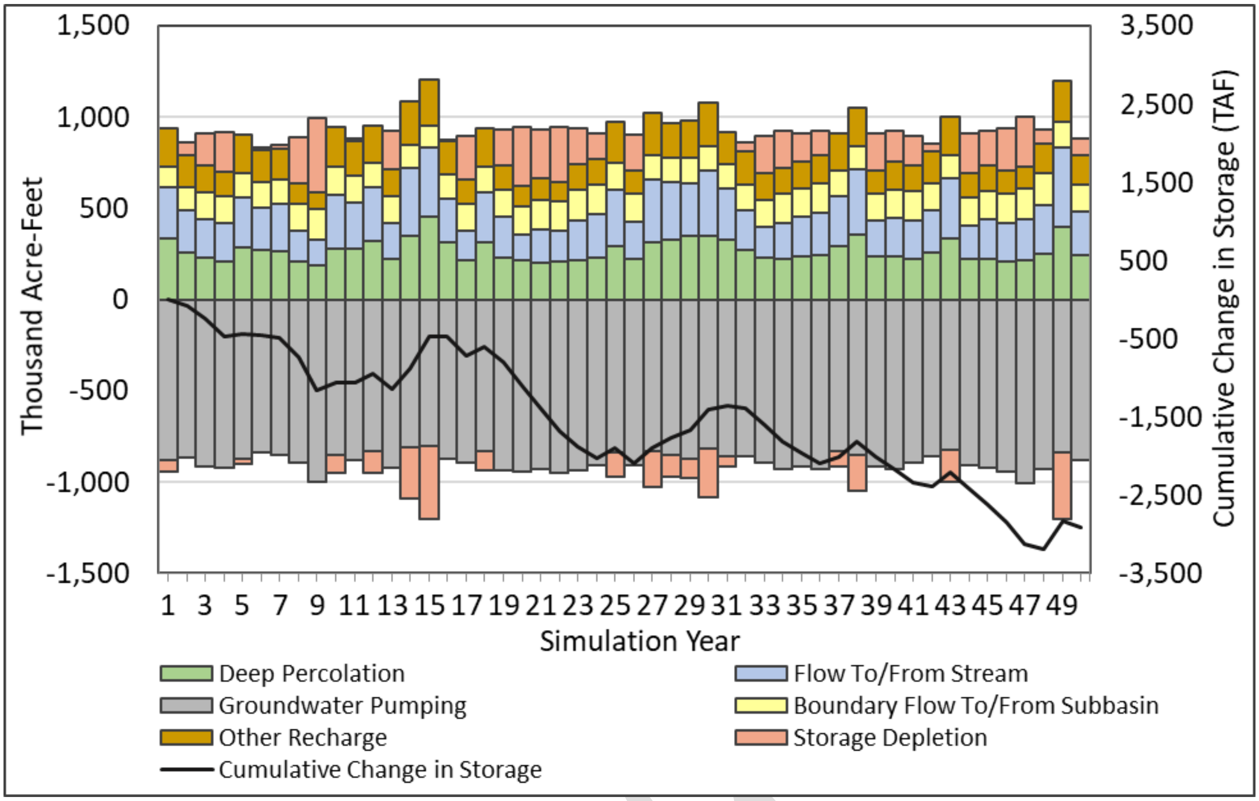


Figure 3-33: Groundwater Budget – Climate Change Scenario



3.3.7.5 Opportunities for Future Refinement

The approach developed for this GSP is based on the methodology in DWR's guidance document (DWR, 2018a) and uses "best available information" related to climate change in the Eastern San Joaquin Subbasin. There are limitations and uncertainties associated with the analysis. One important limitation is that CalSim II does not fully simulate local surface water operations. Thus, the analysis conducted for this GSP may not fully reflect how surface and groundwater basin operations would respond to the changes in water demand and availability caused by climate change. Despite the influence of operations from Pardee and Camanche Dams, Mokelumne flows are simulated under climate change as unimpaired flows in this analysis. This presents an opportunity in future efforts to improve the analysis to better project streamflow. However, for this GSP, use of a local model and the perturbation factor approach were deemed appropriate given the uncertainties in the climate change analysis.

3.4 CURRENT AND HISTORICAL GROUNDWATER CONDITIONS

This section describes the current and historical groundwater conditions in the Eastern San Joaquin Subbasin. As required by the GSP regulations, the groundwater conditions section includes:

- Definition of current groundwater conditions in the Subbasin
- Description of historical groundwater conditions in the Subbasin
- Description of the distribution, availability (storage), and quality of groundwater
- Identification of interactions between groundwater, surface water, groundwater dependent ecosystems, and subsidence

The groundwater conditions described in this section present the historical availability, quality, and distribution of groundwater which are the basis of this Plan's sustainable management criteria and monitoring network.

In the Eastern San Joaquin Subbasin, the two aspects of greatest focus historically have been groundwater elevation and, in some areas of the Subbasin, groundwater quality conditions. As discussed herein, a groundwater depression exists in the central portion of the Subbasin, while high groundwater levels characterize the west portion of the Subbasin. Additionally, there are elevated levels of salinity and nitrate in some areas, along with naturally occurring constituents commonly seen throughout Central Valley soil conditions. Detailed descriptions of these conditions are provided in the following sections as part of a discussion of the historical and current conditions for each of the six sustainability indicators:

- Groundwater Elevation (Section 3.4.1)
- Groundwater Storage (Section 3.4.2)
- Seawater Intrusion (Section 3.4.3)
- Groundwater Quality (Section 3.4.4)
- Land Subsidence (Section 3.4.5)
- Interconnected Surface Water (Section 3.4.6)

3.4.1 Groundwater Elevation

3.4.1.1 Historical Groundwater Elevations

Data sources for groundwater elevation are abundant in the Eastern San Joaquin Subbasin. As discussed in Section 3.1, the CASGEM and San Joaquin County databases constitute the groundwater level data used for this analysis. These sources provide a robust dataset of water levels going back to 1940.

To visually show long-term trends in groundwater elevations in the Eastern San Joaquin Subbasin, 10 wells with periods of record greater than 40 years and that are relatively evenly distributed across the Subbasin were selected from available data (see Figure 3-34). Long-term hydrographs prepared for these wells show that, throughout most of the Eastern San Joaquin Subbasin, groundwater elevations have declined over time.

Average groundwater level decline was quantified for 1996-2015. In Section 3.3 - Water Budgets, the Historical Water Budget uses 1996-2015 as a representative hydrologic period which includes an average annual precipitation of 14.7 inches, very close to the long-term average of 15.4 inches. The 1996-2015 period also includes the recent 2012-2015 drought, the wet years of 2010-2011, and periods of normal precipitation. Based on data from the 10 selected wells in Figure 3-34, the average groundwater level decline was -0.5 ft/year from 1996-2015. Hydrographs for wells numbered #2, #5, and #6 show the largest decrease in groundwater elevation. These wells are located to the east of the City of Stockton. Hydrograph #9, which corresponds to a well located on the north edge of the Subbasin, shows the least decrease in groundwater elevation from 1996-2015. Hydrograph #4 corresponds with a well located in the western side of the Subbasin and is the only well to show an increasing trend in groundwater elevations. The northeast corner of the Subbasin is an area without a nearby representative hydrograph and was identified as a data gap in the HCM Section.

Figure 3-34: Hydrographs of Selected Wells

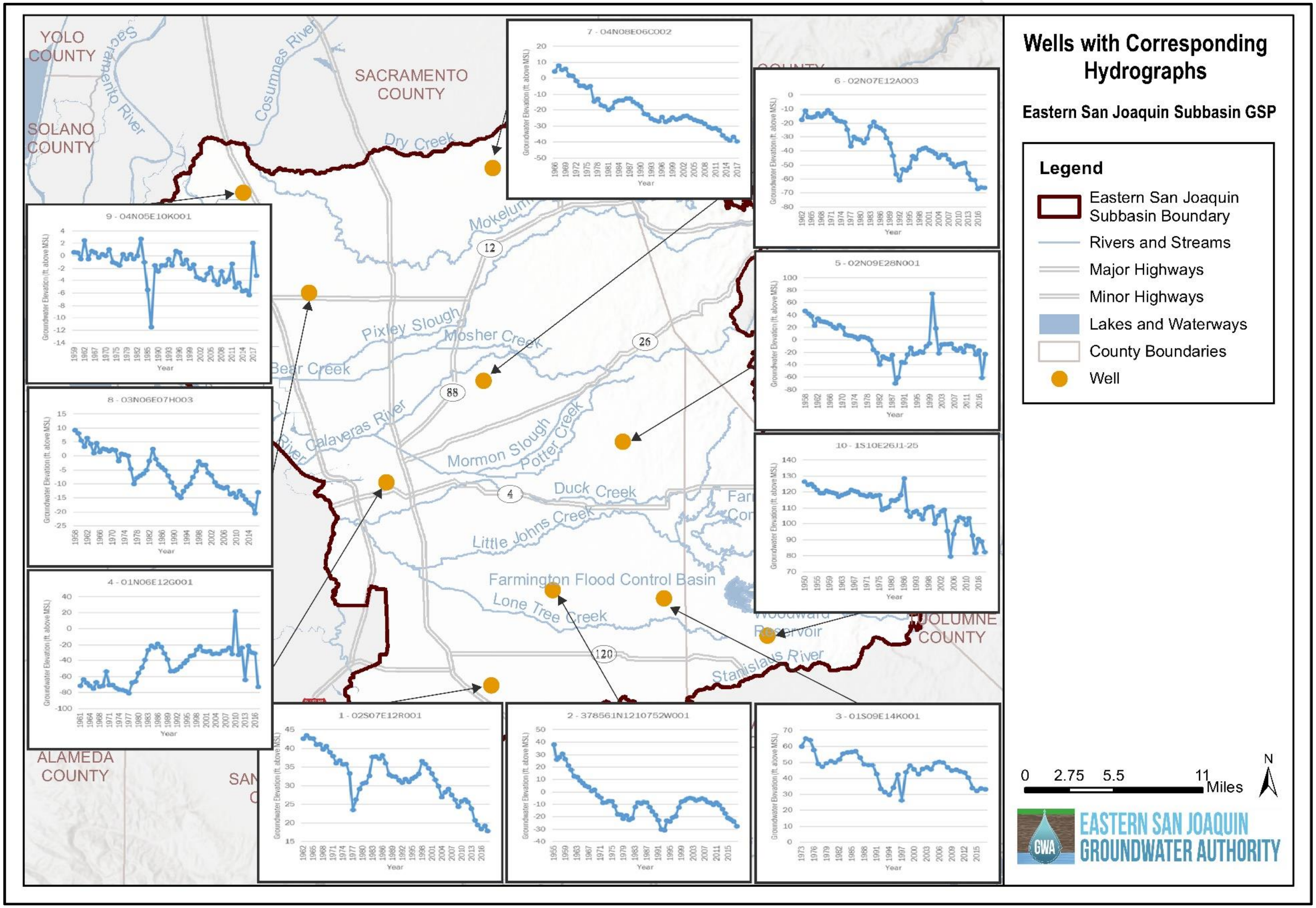
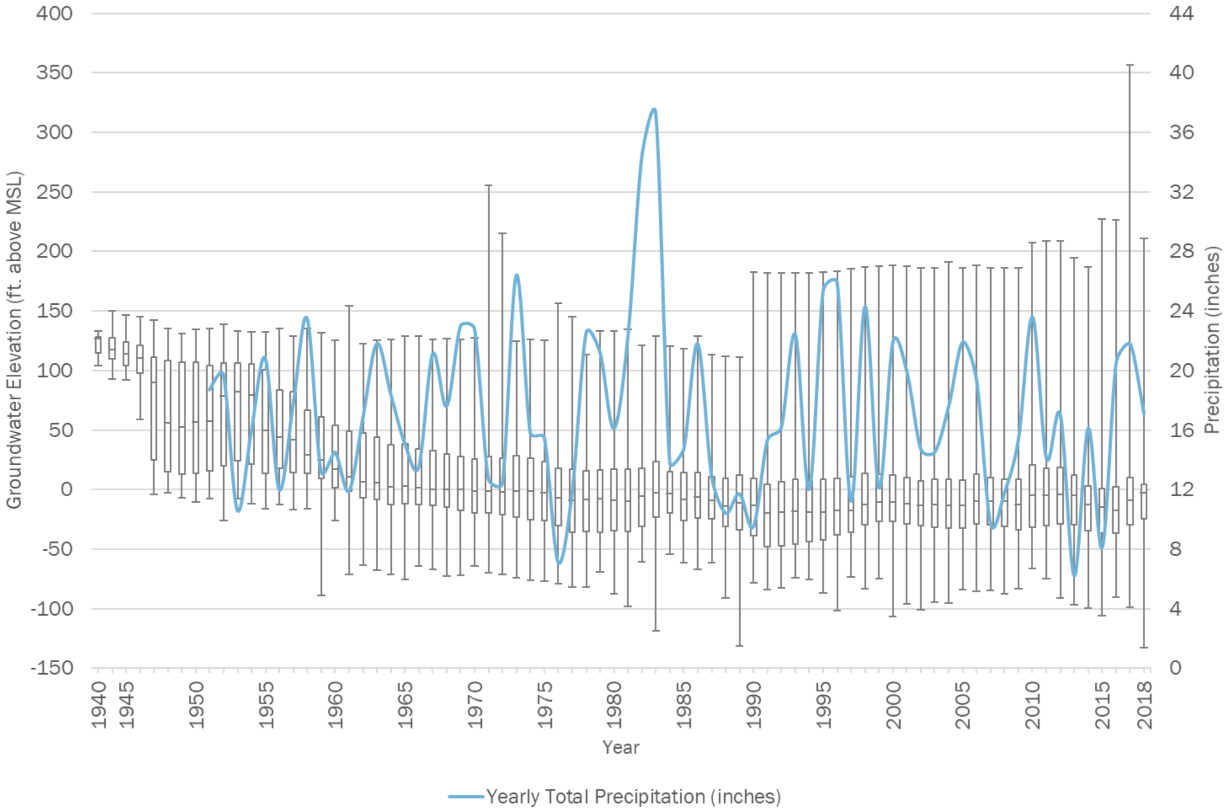


Figure 3-35 shows the distribution of the groundwater elevations from the CASGEM and San Joaquin County databases against average precipitation from several stations in the Subbasin, including one station located at Camp Pardee in Calaveras County, east of the Subbasin boundary. Figure 3-35 shows an overall decreasing trend in groundwater elevation levels with larger variability over time. The increasing variability comes partly due to a larger number of wells being sampled through time, but also reflects the growing difference between areas of groundwater depression and areas that show higher groundwater levels, such as the west portion of the Subbasin.

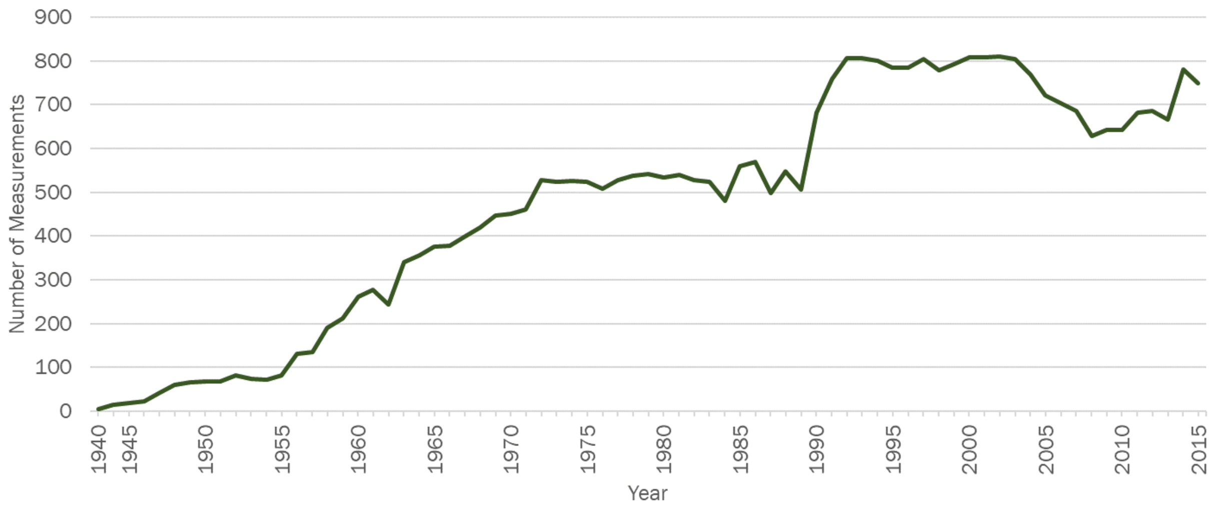
Periods of increases in groundwater elevation moderately correspond to the amount of precipitation in the Eastern San Joaquin Subbasin. A correlating trend can be seen with groundwater elevation increases in several hydrographs in the early 1980s and late 1990s, associated with periods of high precipitation.

Figure 3-35: Groundwater Elevation 1940-2018

(a) Box-and-Whisker Plot with Precipitation

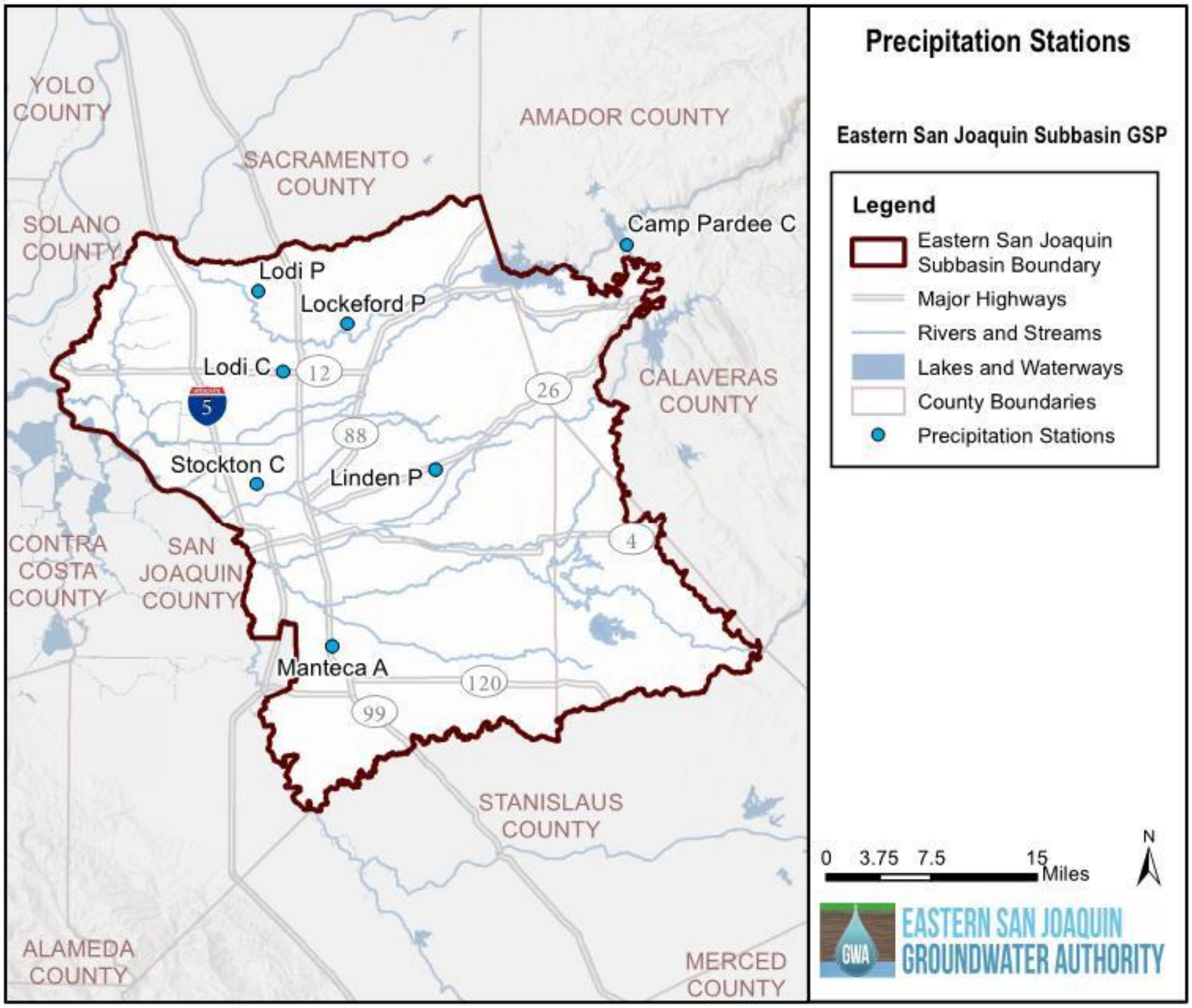


(b) Number of Groundwater Measurements



1. Each vertical bar in Figure 3-35 (a) represents the full range of groundwater level measurements recorded in a given year. The central gray box represents the middle 50% of measurements (ranging from the 25th percentile to the 75th percentile), with the horizontal line showing the median. The capped lines below and above the central box represent the minimum and maximum, respectively.
2. Precipitation monitoring depicted in Figure 3-35 (a) began in 1951.
3. The average annual precipitation line, presented in Figure 3-35 (b) is based on an average of data collected at 7 stations which are mapped in Figure 3-36.

Figure 3-36: Precipitation Stations



1. These stations are from California Irrigation Management Information System (CIMIS), National Oceanic and Atmospheric Administration (NOAA), or PestCast (University of California Statewide Integrated Pest Management Program [UC IPM] and Department of Pesticide Regulation [DPR]).

Additionally, extensive reports and research examining the groundwater conditions of the Central Valley are available from a variety of sources, including the USGS and DWR. These documents supplement the water level data provided by the CASGEM and San Joaquin County databases and were used to assess current and historical groundwater elevations.

USGS Water Supply Paper 780 – One of the earliest discussions of measured groundwater levels in the Eastern San Joaquin Subbasin is the USGS Water Supply Paper 780. The report details river stage of the Mokelumne River and the surrounding groundwater table from roughly 1900 to 1930. Groundwater levels in wells around the Mokelumne River varied, but mostly declined due to an increase in groundwater pumping. Even between years of minimal groundwater pumping, from 1927 to 1933, the water table decreased in elevation, most drastically in areas northeast and southeast of the City of Lodi (USGS, 1939).

DWR Bulletin 146 – DWR's Bulletin 146 (1967) discusses water levels and flow directions in the 1960s and earlier, which provides added historical context to current groundwater conditions. Figures 4 and 5 of Bulletin 146 show groundwater elevation in most of the Eastern San Joaquin Subbasin in Fall of 1950 and 1964, respectively. Both maps show groundwater levels at the lowest elevation underneath the City of Stockton, which is attributed to heavy groundwater pumping. This depression is attributed as causing groundwater from the Delta to flow toward the City of Stockton and is described as having relatively worse water quality. Barriers between the poorer quality water from the Delta, and higher quality water from the Sierra Nevada Mountains noted in previous studies around the City of Stockton are not apparent (DWR, 1967).

Williamsons 1989 – Groundwater conditions provided in the groundwater model report by Williamsons (1989) included horizontal and vertical flows. As depicted on Figure 14 of that report, a westerly groundwater flow direction that roughly parallels the ground surface in the Eastern San Joaquin Subbasin was confirmed. Estimates of groundwater elevations for before human development were provided. Vertical flow characteristics before considerable human development were characterized and mapped; artesian flow existed throughout the valley and in the western portion of the Eastern San Joaquin Subbasin. This is in contrast to current conditions, where artesian wells have not been currently observed in the Subbasin. At present, USGS nested monitoring wells confirm downward vertical flows (Williamsons, 1989).

3.4.1.2 Current Groundwater Elevations

Current groundwater elevation conditions, for the purposes of this Plan, have been characterized as First Quarter 2017 (most recent seasonal high) and Fourth Quarter 2017 (most recent seasonal low) groundwater elevation measurements. At the time of this report, these records constitute the most complete dataset. Groundwater elevations are mapped using the CASGEM dataset (including voluntarily monitored wells) and the San Joaquin County dataset.

Figure 3-37 and Figure 3-38 show the groundwater elevations for these periods. A pumping depression at the center of the Subbasin, east of the City of Stockton, exists during both of these periods. Groundwater generally flows from the outer edges of the Subbasin towards the depression in the middle of the Subbasin. Along the eastern side of the Subbasin, the lateral gradient ranges from approximately 21 ft/mi during the seasonal high and 16 ft/mi during the seasonal low. Along the western side of the Subbasin, the lateral gradient ranges from approximately 7 ft/mi during the seasonal high and 6 ft/mi during the seasonal low.

Figure 3-37: First Quarter 2017 Groundwater Elevation

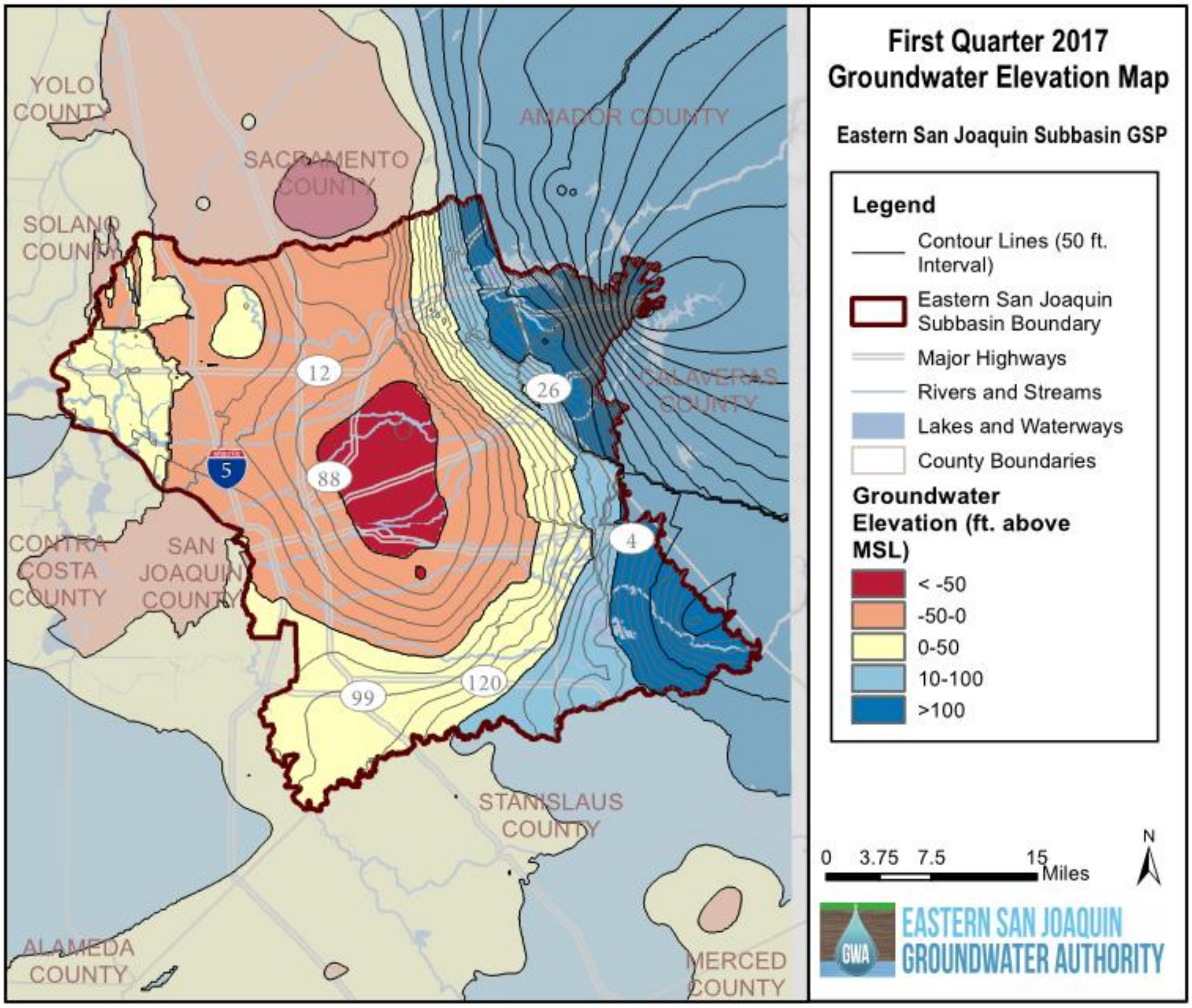
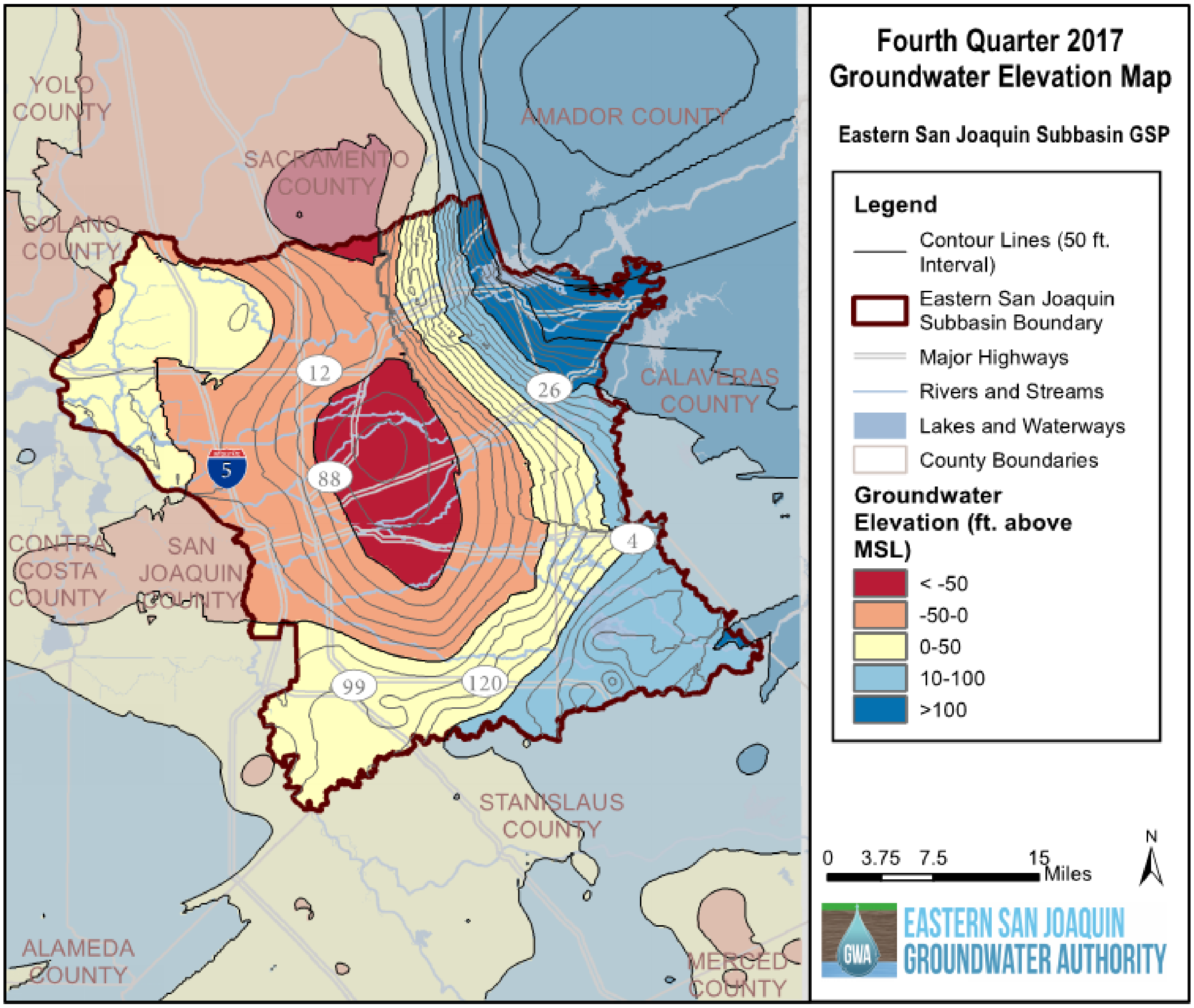


Figure 3-38: Fourth Quarter 2017 Groundwater Elevation



3.4.1.2.1 Vertical Gradients

A vertical gradient drives the movement of groundwater perpendicular to the ground surface and is typically measured by comparing the elevations of groundwater in clustered or nested wells, wells with multiple completions at different depths. If groundwater elevations in the shallower completions are higher than in the deeper completions, the gradient is identified as a downward gradient. A downward gradient is one where groundwater is moving downward through the subsurface. If groundwater elevations in the shallower completions are lower than in the deeper completions, the gradient is identified as an upward gradient. An upward gradient is one where groundwater is moving upward through the subsurface. If groundwater elevations are the same throughout the completions, there is no vertical gradient. Knowledge about vertical gradients is required by regulation and is useful for understanding how groundwater moves in the Subbasin.

Vertical flow characteristics before considerable human development are characterized and mapped by Williamsons (1989), showing that artesian flow existed in the western portion of the Eastern San Joaquin Subbasin. This contrasts with current conditions, where artesian wells have not been currently observed in the Subbasin. At present, USGS nested monitoring wells confirm downward vertical flows (Williamsons, 1989).

There are 16 multiple completion wells located in the Eastern San Joaquin Subbasin. The locations of the multiple completion wells are shown in Figure 3-39. The majority of these wells are located in the northwest portion of the Subbasin near cities of Stockton and Lodi. Hydrographs with groundwater elevations for each respective set of completion wells are shown in Figure 3-40 through Figure 3-49. 10 out of 16 sets of wells consistently show elevations in shallower completions that are higher than in the deeper completions which confirms the downward gradient. The remaining six sets of multiple completion wells are located in the City of Lodi and hydrographs are still being prepared.

Figure 3-39: Map of Multiple Completion Wells

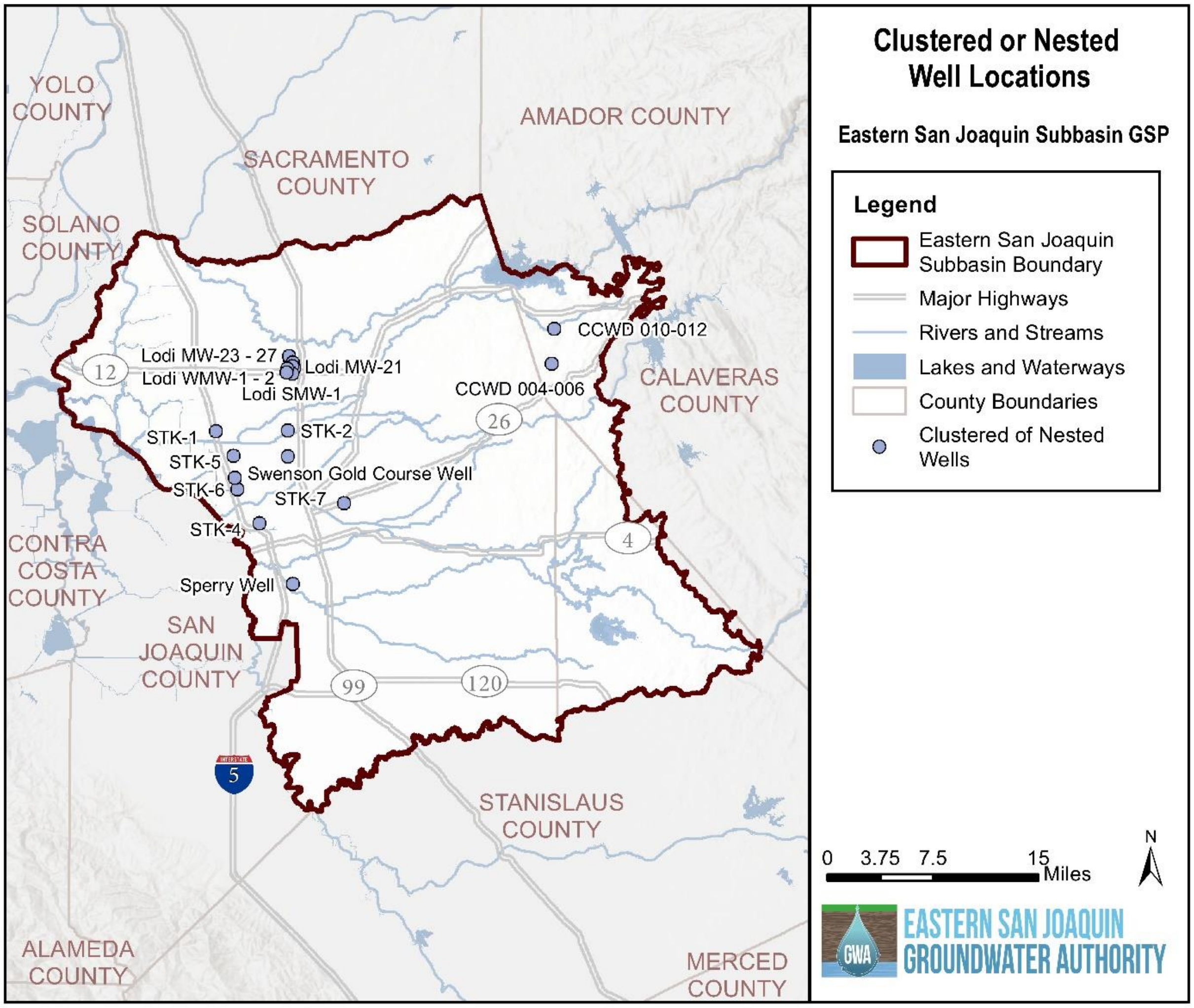


Figure 3-40: Nested Well Hydrographs: CCWD 004-006

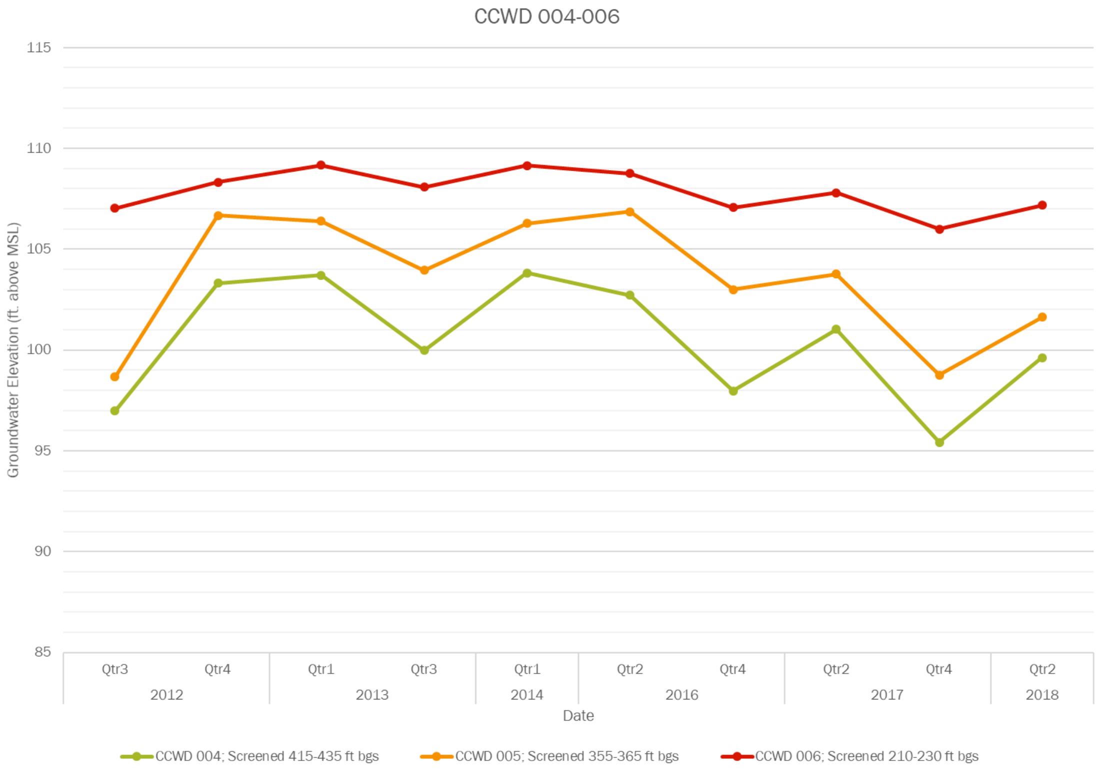


Figure 3-41: Nested Well Hydrographs: CCWD 010-012

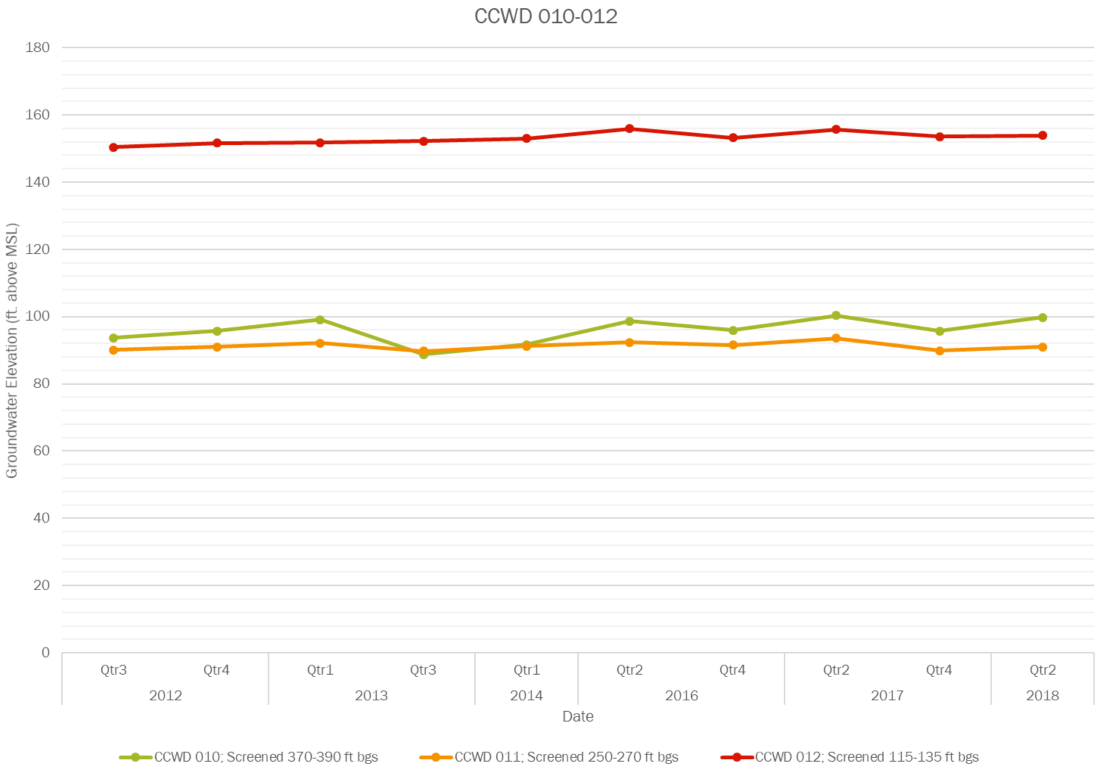


Figure 3-42: Nested Well Hydrographs: Sperry Well

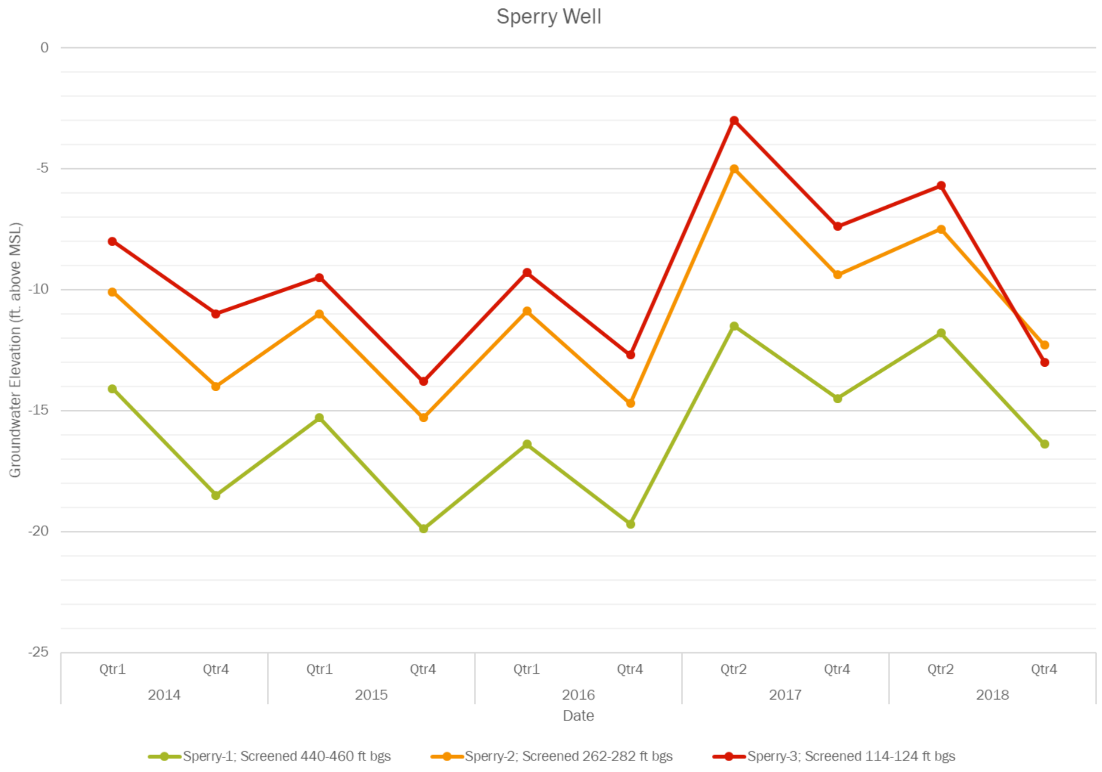


Figure 3-43: Nested Well Hydrographs: Swenson Golf Course

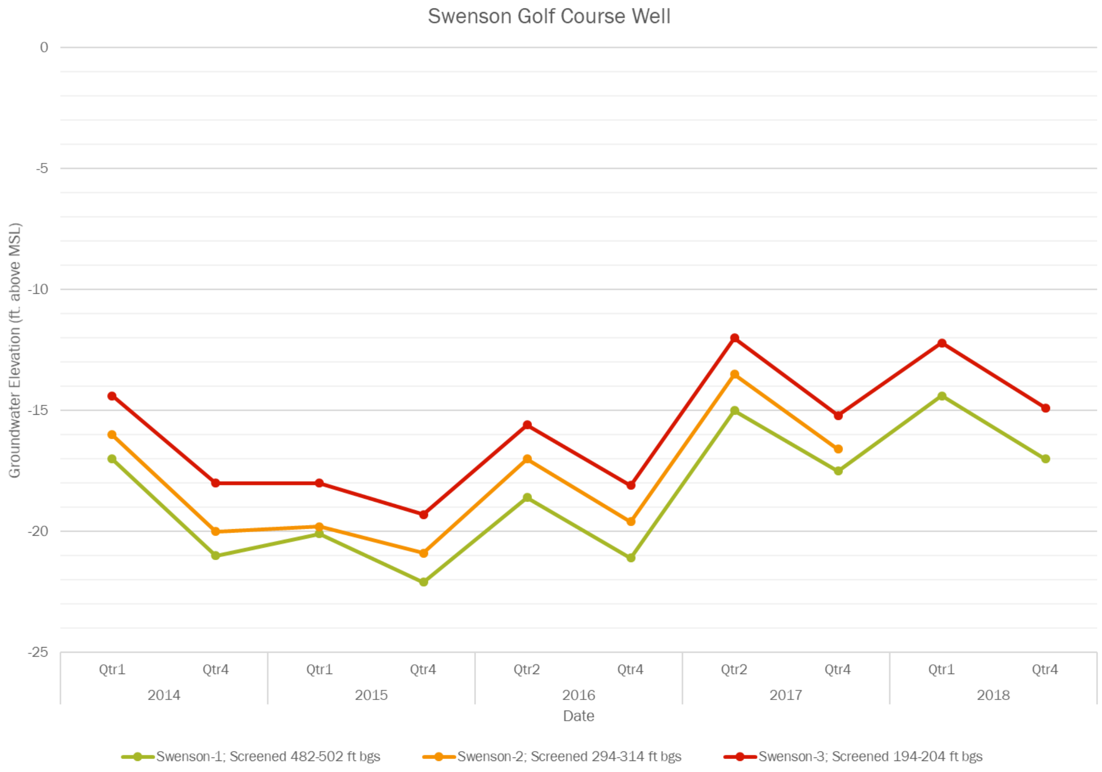


Figure 3-44: Nested Well Hydrographs: STK-1

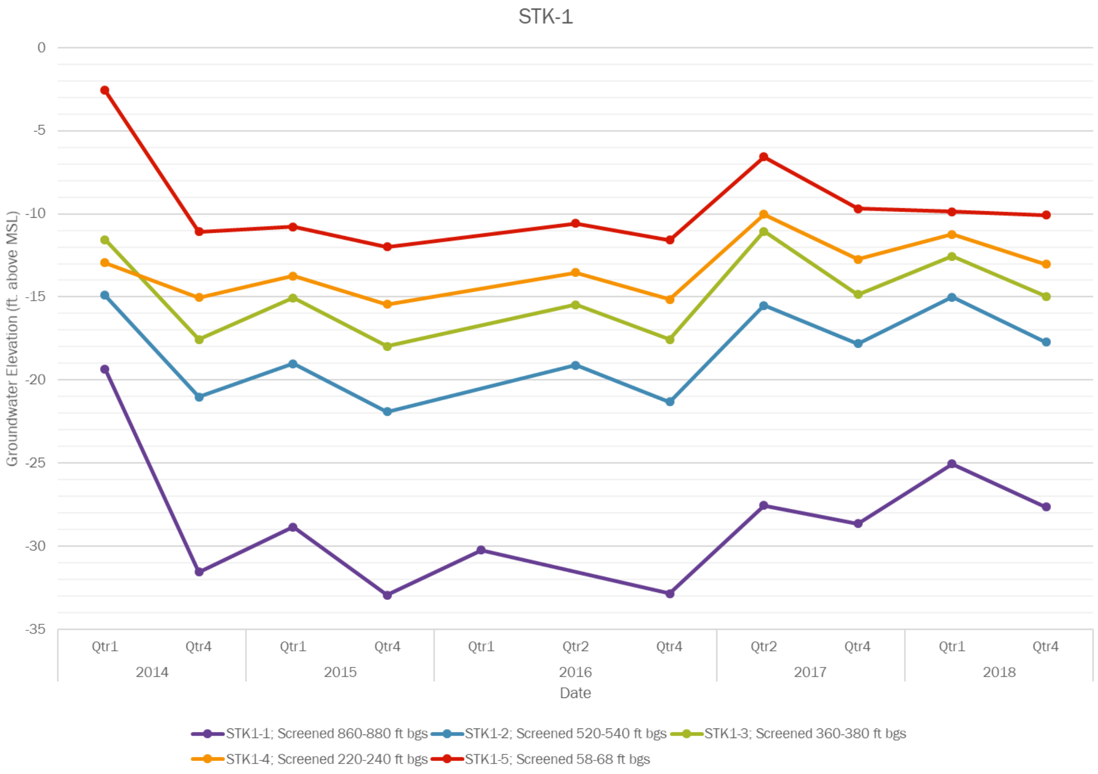


Figure 3-45: Nested Well Hydrographs: STK-2

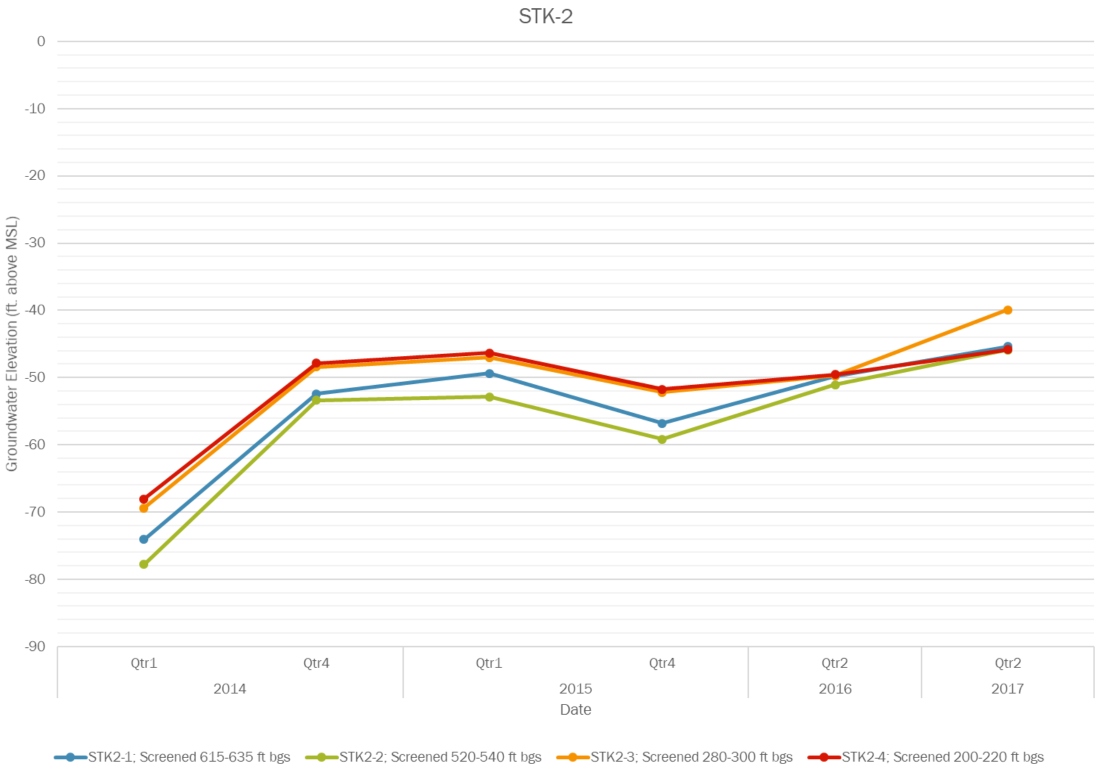


Figure 3-46: Nested Well Hydrographs: STK-4

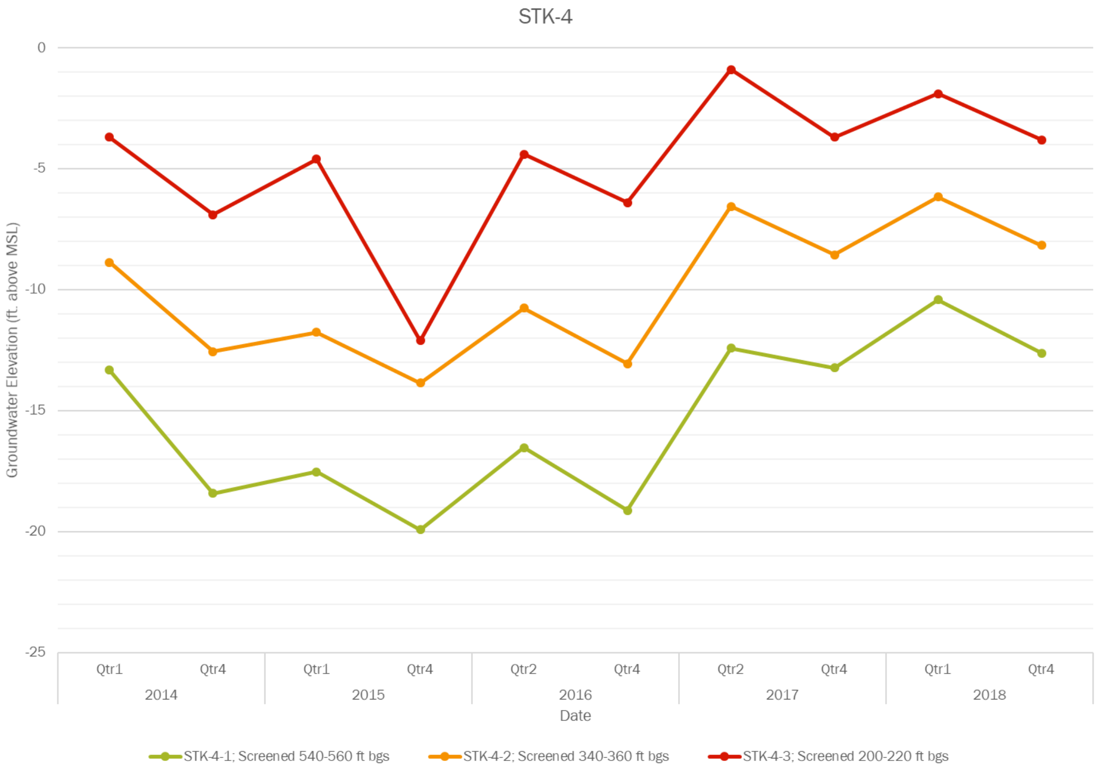


Figure 3-47: Nested Well Hydrographs: STK-5

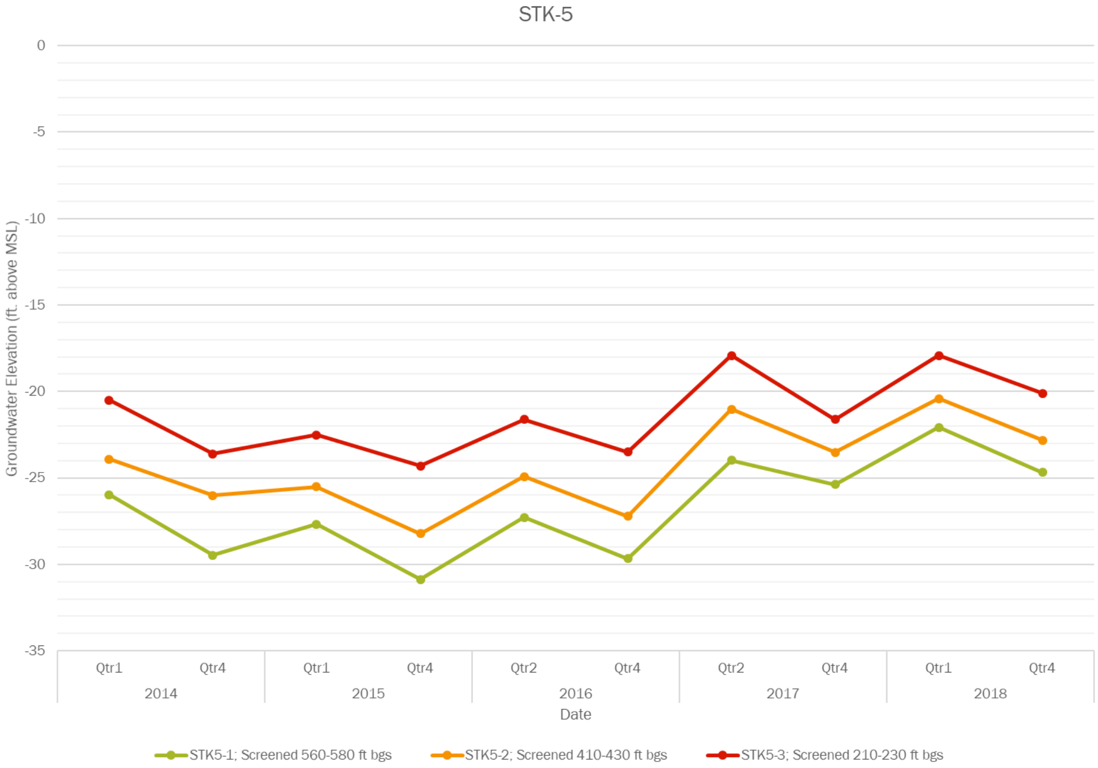


Figure 3-48: Nested Well Hydrographs: STK-6

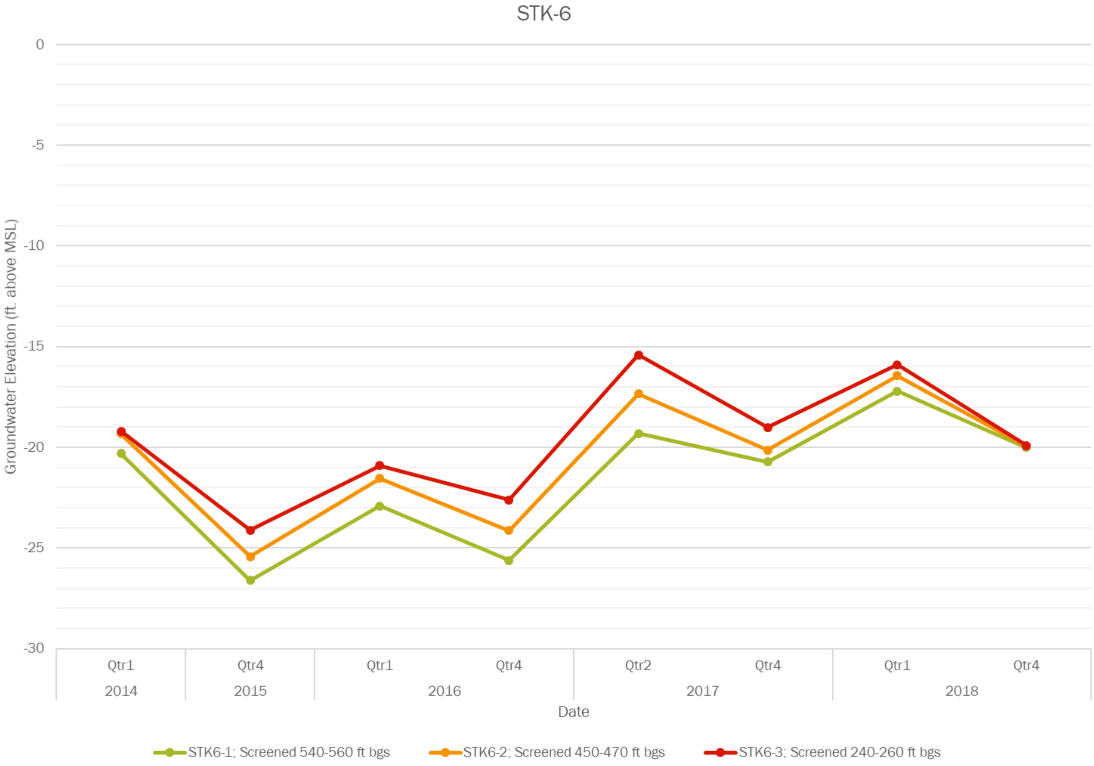
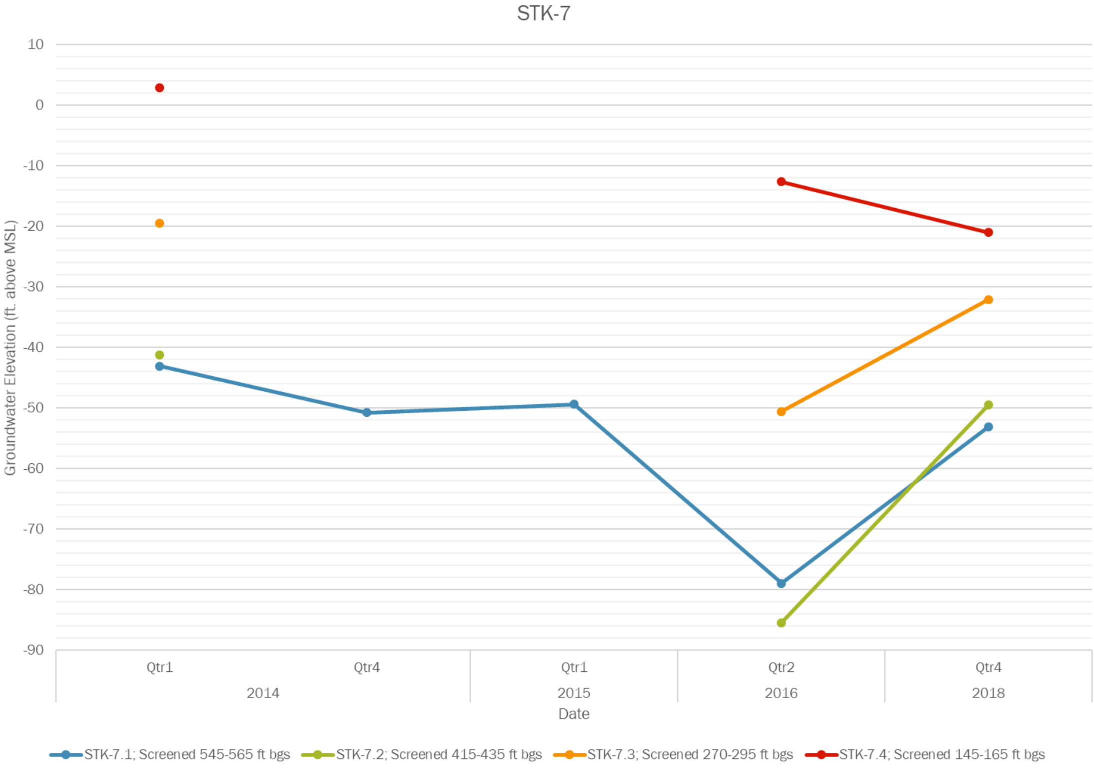


Figure 3-49: Nested Well Hydrographs: STK-7



3.4.2 Groundwater Storage

The ESJWRM was used to estimate historical change in storage of the Eastern San Joaquin Subbasin from 1995-2015.

Figure 3-50 shows annual total storage for the combined ESJWRM fresh groundwater layers (not including the deep saline layer). Figure 3-51 shows the cumulative change in storage against annual storage change and water year type. In 2015, the total fresh groundwater storage was estimated as 53.0 MAF and the cumulative change in storage over 1995-2015 was estimated as -0.91 MAF (-0.09%), or -0.05 MAF/year. An additional 75.0 MAF in Layer 4 of the model (not pictured) is saline water. More information about the layers of the ESJWRM and calculation of storage changes can be found in model documentation in Appendix X.

Figure 3-50: Historical Modeled Change in Storage

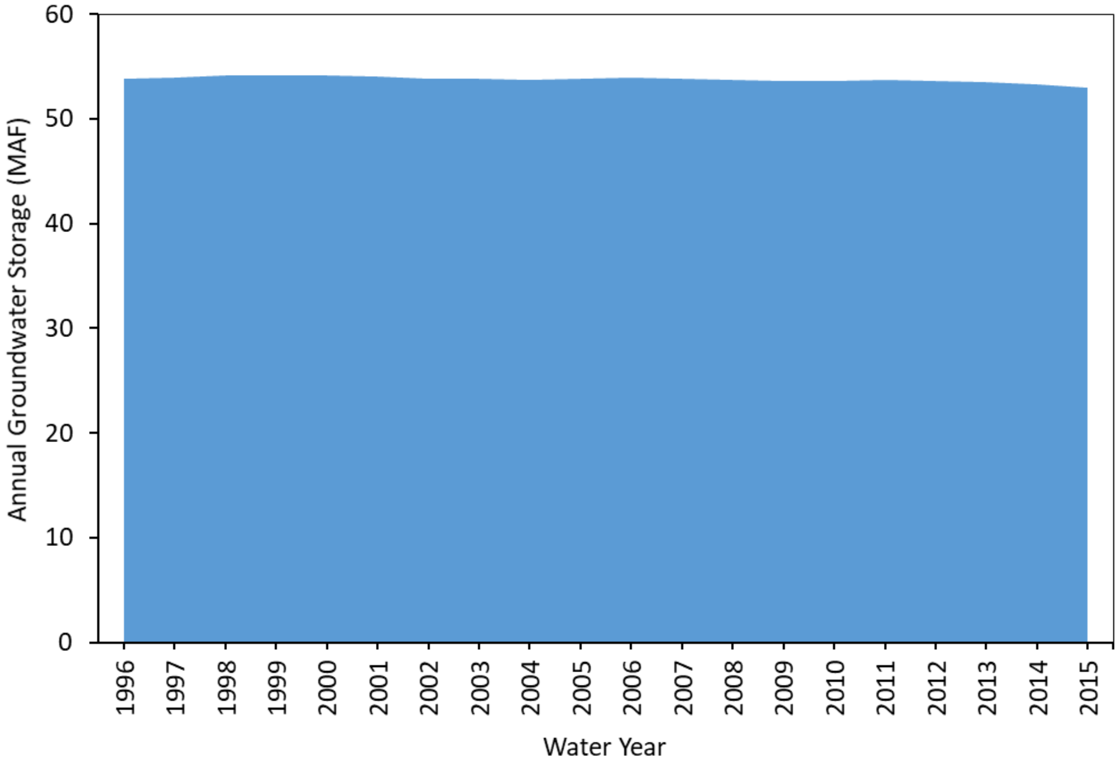
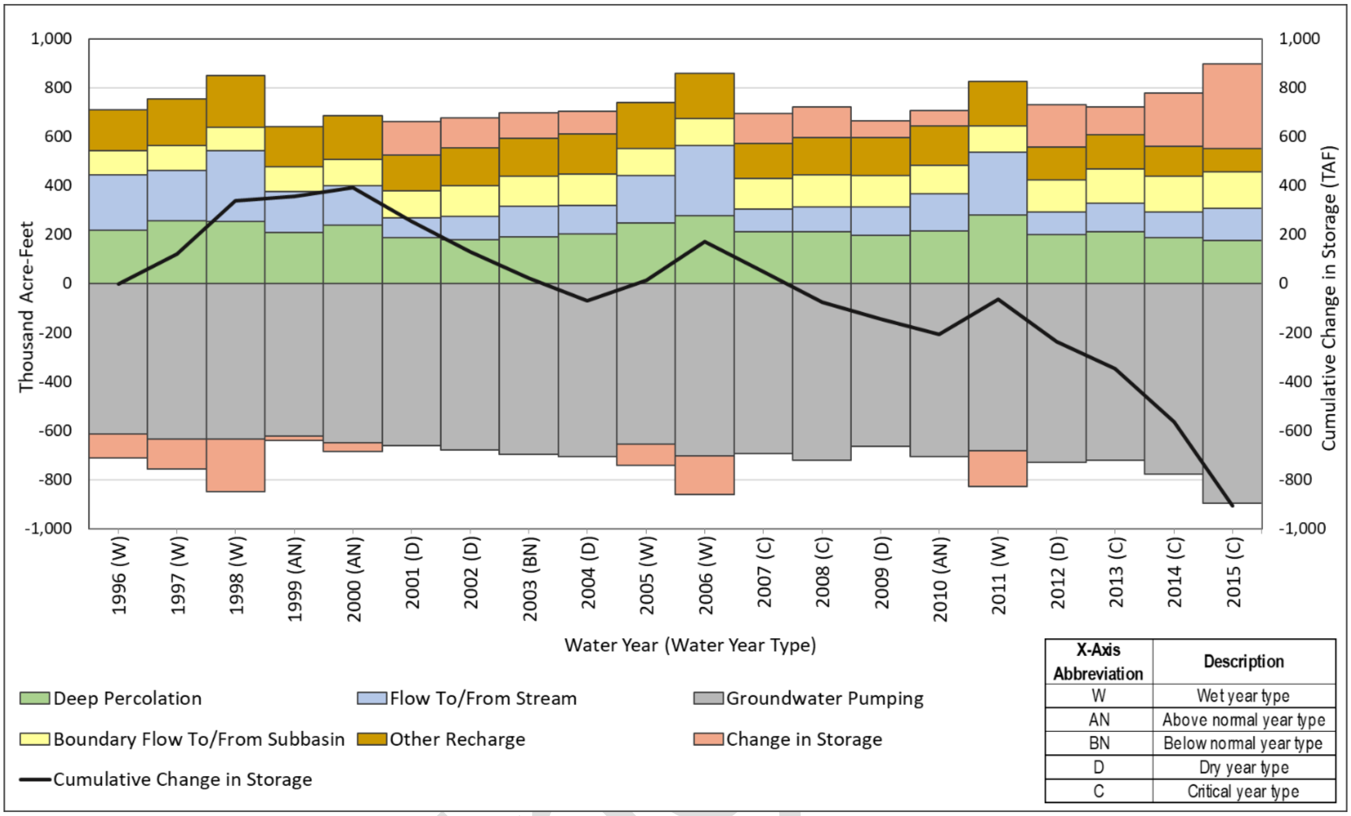


Figure 3-51: Historical Modeled Change in Annual Storage with Water Use and Year Type



X-Axis Abbreviation	Description
W	Wet year type
AN	Above normal year type
BN	Below normal year type
D	Dry year type
C	Critical year type

Notes:

1. Water Year Types based on San Joaquin Valley Water Year Index (DWR, 2018)
2. "Other Recharge" includes managed aquifer recharge, recharge from unlined canals and/or reservoirs, and recharge from ungauged watersheds.
3. "Change in Storage" is placed to balance the water budget. For instance, if annual outflows (-) are greater than inflows (+), there is a decrease in storage, but this would be shown on the positive side of the bar chart to balance out the increased outflows on the negative side of the bar chart.

3.4.3 Seawater Intrusion

The Eastern San Joaquin Subbasin is not in a coastal area and seawater intrusion is not present. While the Delta ecosystem evolved with a natural salinity cycle that brought brackish tidal water in from the San Francisco Bay, barriers are now in place between the Bay and the Delta to prevent the inland movement of seawater through the Delta. Current management practices maintain freshwater surface flows through a combination of hydraulic and physical barriers, and alternations to existing channels (Water Education Foundation). Portions of the Subbasin do, however, experience water quality issues related to salinity, which are addressed under the water quality section (Section 3.4.4.1). As described in Section 3.4.4.1, the sources of salinity in the Subbasin are due to other factors, and are not the result of seawater intrusion.

3.4.4 Groundwater Quality

While groundwater quality in the Eastern San Joaquin Subbasin is generally sufficient to meet beneficial uses, a number of constituents of concern are either currently impacting groundwater use or have the potential to impact it in the future. Depending on the water quality constituent, the source may be anthropogenic in origin or naturally occurring, and the issue may be widespread or localized.

The primary naturally occurring water quality constituents of concern are salinity and arsenic, while primary water quality constituents related to human activity include nitrates, salinity, and various point-source contaminants.

The sections herein provide information on the historical and current groundwater quality conditions for constituents including:

- Salinity (Section 3.4.4.1)
- Nitrate (Section 3.4.4.2)
- Arsenic (Section 3.4.4.3)
- Point-source contamination (Section 3.4.4.4), which includes petroleum hydrocarbons, solvents, and emerging contaminants

The EPA implements national primary drinking water regulations, which are a starting point for evaluating groundwater quality in a regulated toxicological context and for assessing impact to beneficial use. The EPA defines a Primary MCL or SMCL, for a variety of parameters. For the purposes of this GSP, comparing parameter concentrations to their MCL or SMCL is used as the basis for describing groundwater quality concerns in the Eastern San Joaquin Subbasin. Comparisons to the MCL or SMCL must be considered in context as the measured concentrations represent raw water, which may be treated or blended prior to delivery to meet the standard or may not be used for potable uses. Water quality is not known to have adversely affected beneficial uses of groundwater in the Eastern San Joaquin Subbasin, generally.

3.4.4.1 Salinity

As identified in prior planning efforts, and as referenced in Section 3.2 of this Plan, localized salinity issues are a concern for some areas of the Eastern San Joaquin Subbasin. Pumping in excess of recharge has resulted in declining aquifer water levels that have contributed to an increase of salinity in groundwater wells since the 1950s. As identified through isotopic typing, elevated salinity concentrations in the Subbasin are the result of natural processes and overlying land use activities (O'Leary et al., 2015). Within the Subbasin, there are three primary sources of salinity:

1. **San Joaquin Delta Sediments** – Naturally occurring soluble salts are emplaced in the San Joaquin Delta sediments from the evaporation of groundwater in discharge areas.

2. **Deep Deposits** – Saline groundwater in the Subbasin is principally the result of the migration of a naturally occurring deep saline water body which originates in regionally deposited marine sedimentary rocks that

underlie the San Joaquin Valley. This results in a saline aquifer underlying the freshwater aquifer and well pumping can result in upwelling saline brines into the freshwater aquifer.

3. **Irrigation Return Water** – Irrigation return water is excess surface and subsurface water that flows from an irrigated field following the application of irrigation water. Return water may include contaminants typical of agricultural practices (e.g., pesticides, herbicides), including those commonly high in salinity, and may act as a conduit delivering these contaminants to the surrounding watershed. Areas in the Subbasin with salinity resulting from irrigation return water do not commonly exceed chloride concentrations of 100 mg/L (O'Leary et al., 2015).

Salinity is a measure of the amount of dissolved particles and ions in water. Salinity can include several different ions, but the most common are chloride, sodium, nitrate, calcium, magnesium, bicarbonate, and sulfate. Chloride and TDS are two common ways to measure and analyze salinity. Each is described separately in the sections below.

3.4.4.1.1 Chloride

Chloride is one way to measure salinity and is reported as a concentration of the Cl^- ion that originates from the dissociation of salts in water. EPA's SMCL of 250 mg/L for chloride is a common approach to identifying poor water quality for this constituent. The SMCL is a Secondary Drinking Water Standard that is established for aesthetic reasons such as taste, odor, and color and is not based on public health concerns. The 250 mg/L value is "recommended" by SWRCB as a threshold below which chloride concentrations are desirable for a higher degree of consumer acceptance of drinking water. An "upper" limit of 500 mg/L is used to define a range above the "recommended" value where chloride concentration is acceptable if it is neither reasonable nor feasible to provide more suitable waters (SWRCB, 2006). Comparisons to the SMCL must be considered in context as the measured concentrations represent raw water, which may be treated or blended prior to delivery to meet the standard or may not be used for potable uses.

As shown in Figure 3-52, the majority of observed chloride concentrations above 250 mg/L occur on the western side of the Subbasin, with additional measurements above 250 mg/L scattered throughout San Joaquin County. As shown in Figure 3-53, the number of measurements with observed concentrations above 250 mg/L have decreased since the 1970s.

Figure 3-52: Chloride Concentration Greater Than 250 mg/L (1940s-2010s)

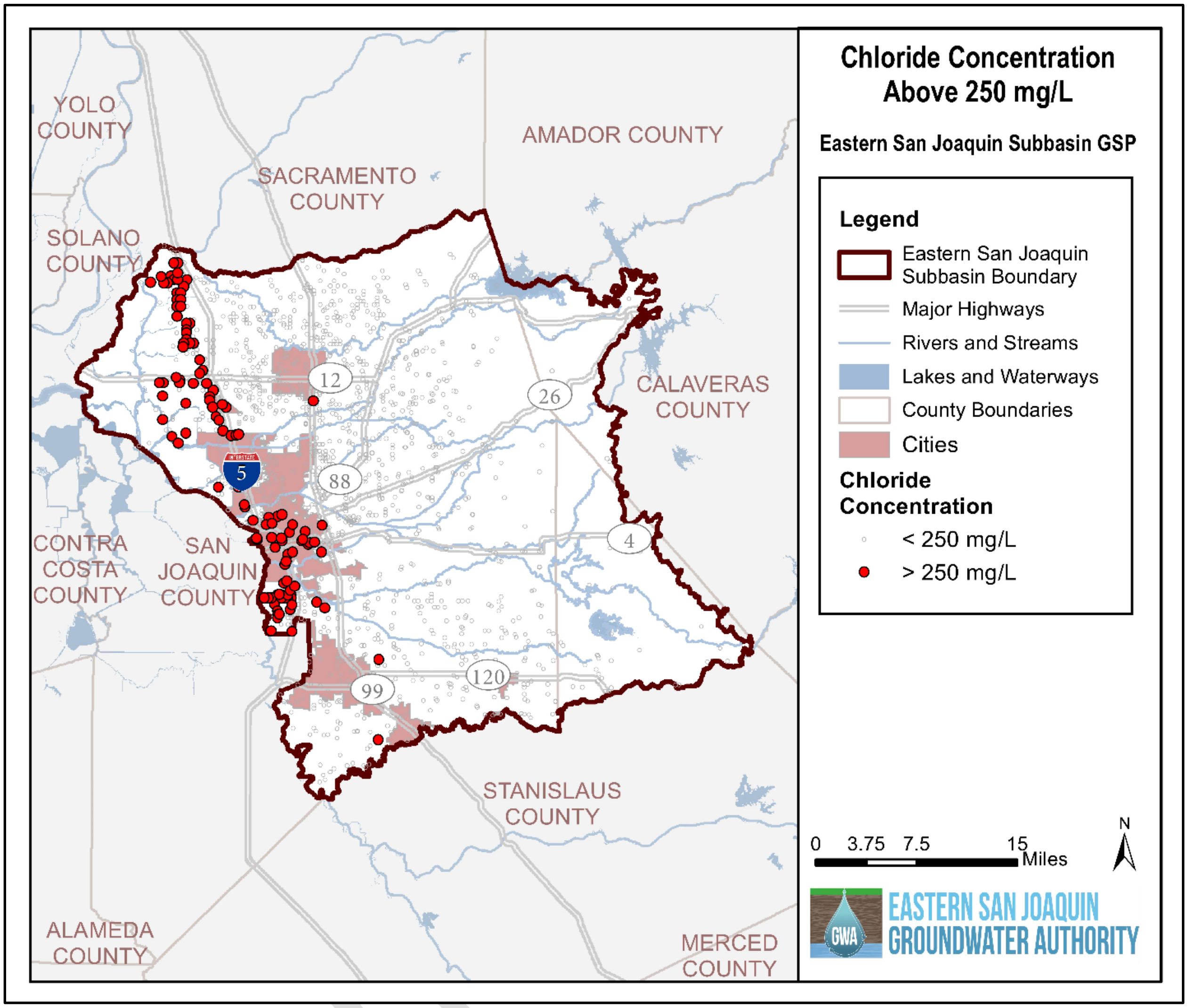


Figure 3-53: Chloride Concentration Above 250 mg/L by Decade

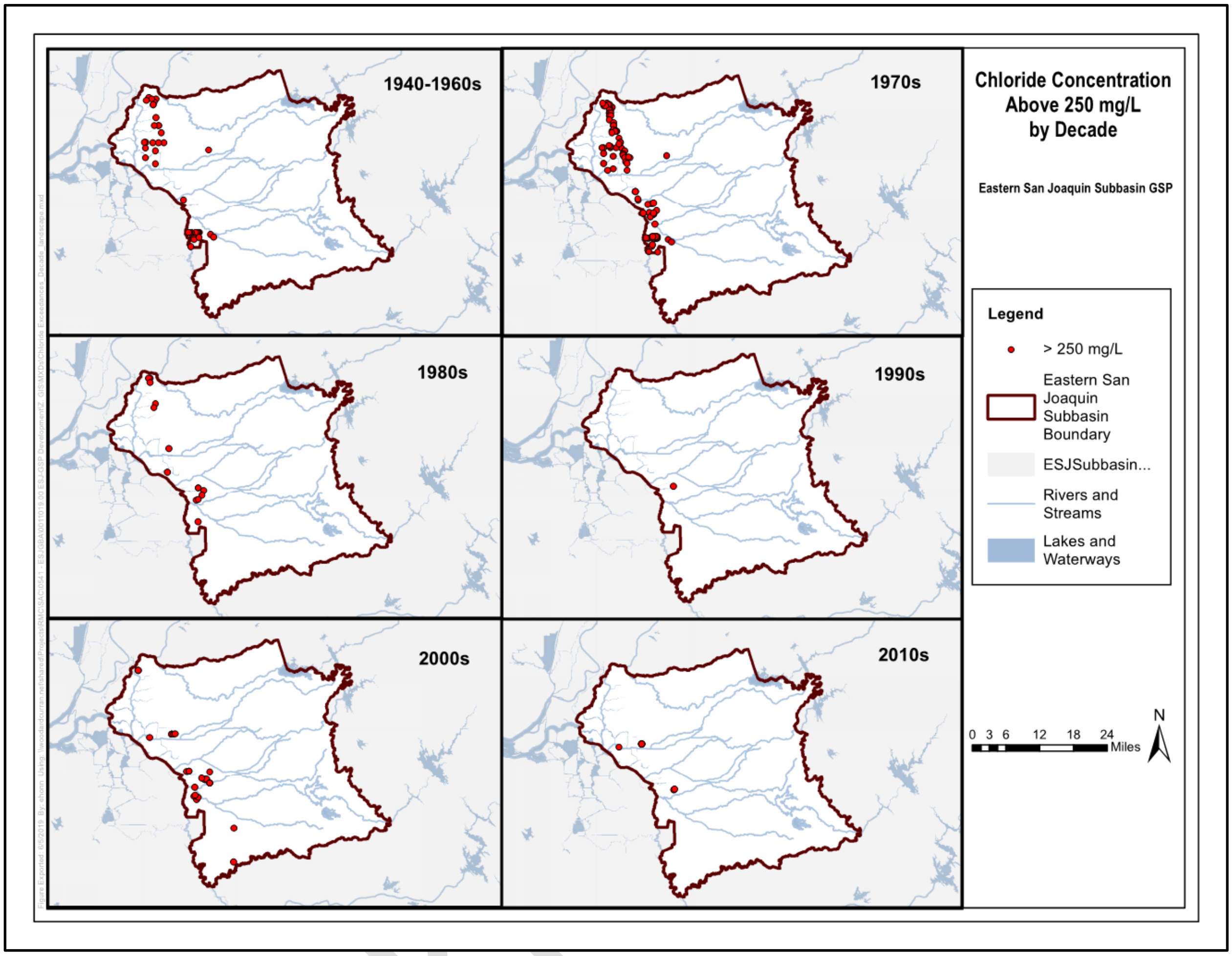


Table 3-11 shows occurrence of chloride measurements greater than 250 mg/L by decade. Chloride records have been observed above 250 mg/L both historically and recently. Sampling frequencies increased in the 1970s and 2000s.

Table 3-11: Summary of Chloride Data by Decade

Decade	Measurement Above 250 mg/L?		Range of Values (mg/L)				Total Number of Samples
	No	Yes	Minimum	Average	Median	Maximum	
1940	98%	2%	7.0	45.2	20.0	975	180
1950	93%	7%	2.3	89.4	25.0	3,750	699
1960	90%	10%	0.0	115.0	17.0	1,960	312
1970	90%	10%	1.8	85.9	19.0	3,310	1,780
1980	97%	3%	0.0	45.4	20.5	630	858
1990	99%	1%	0.0	31.2	19.0	533	663
2000	95%	5%	0.0	59.6	35.0	2,050	1,453
2010	97.5%	2.5%	0.0	34.8	39.0	2,050	986

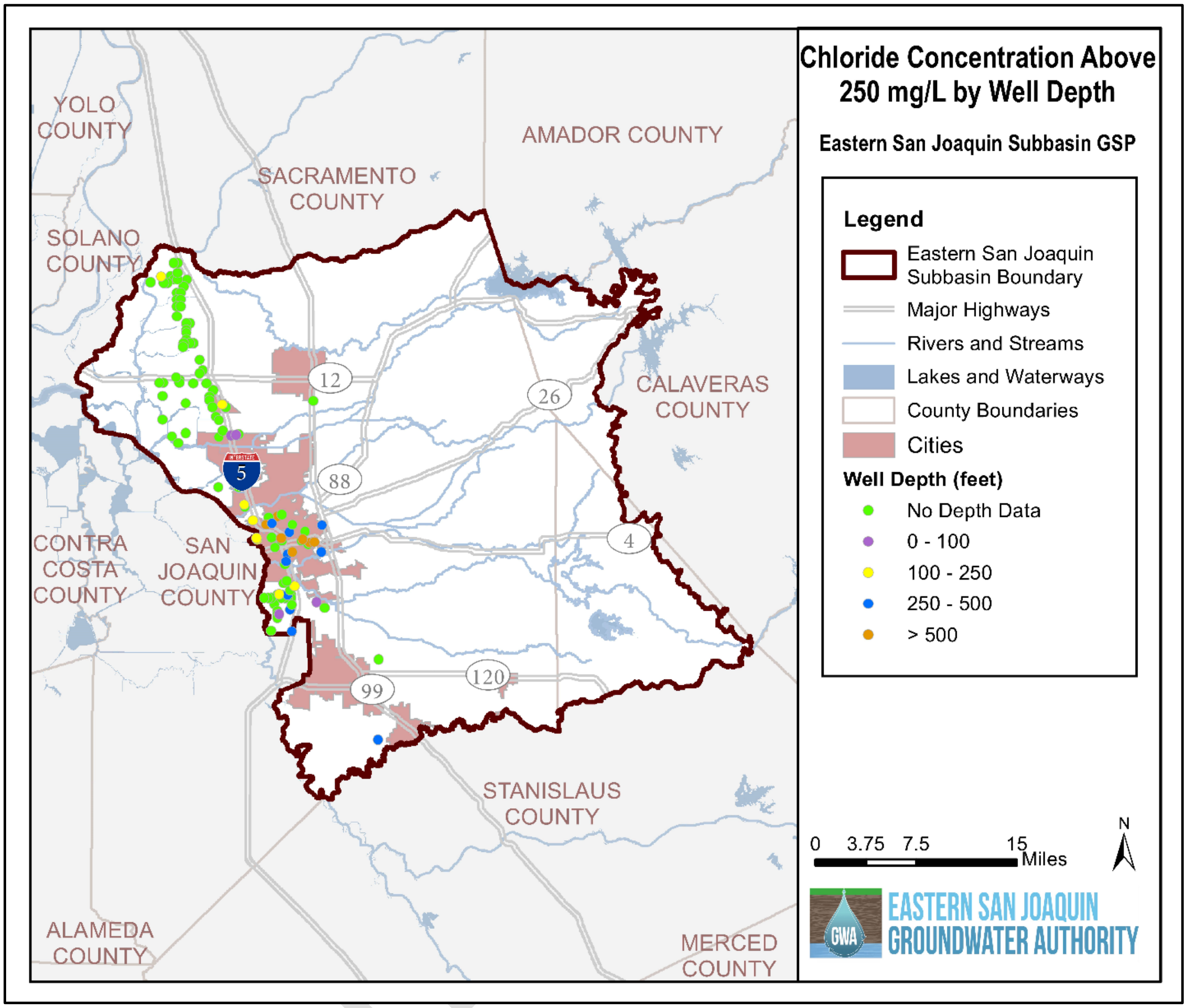
Table 3-12 shows chloride occurrences of concentrations greater than 250 mg/L by well depth. The highest proportion of readings above 250 mg/L occur in the shallowest wells, less than 100 feet deep (8 percent). The highest maximum value also occurred at this depth range (up to 2,050 mg/L).

Figure 3-54 shows the spatial distribution of chloride occurrences greater than 250 mg/L by well depth within the Subbasin.

Table 3-12: Summary of Chloride Data by Depth (1940s-2010s)

Depth (feet)	Measurement Above 250 mg/L?		Range of Values (mg/L)				Total Number of Samples
	No	Yes	Minimum	Average	Median	Maximum	
No Depth Data	92%	8%	0.0	82.5	20.0	3,750	3,566
0 - 100	92%	8%	0.8	73.5	60.0	2,050	239
100 - 250	97%	3%	1.0	44.2	36.0	1,400	1,215
250 - 500	98%	2%	0.0	32.4	16.0	1,100	1,487
> 500	95%	5%	2.7	62.1	15.6	1,940	424

Figure 3-54: Chloride Concentration Above 250 mg/L by Well Depth (1940s-2010s)



A lack of depth information presents a challenge to analyzing the vertical distribution of chloride measurements which would inform identification of chloride sources. Examples of depth information include total well construction depth or screened interval depths, which vary between wells. Some wells have construction depth but not screened interval depth, or vice versa. For this analysis, screened interval depth was used first, and if this information was not available, total depth was used. Approximately 4,600 of the almost 13,000 chloride measurements in the Eastern San Joaquin Subbasin are from wells lacking any construction or screen depth information. Roughly half of the measurements above 250 mg/L occur in the wells lacking depth data, which also show the highest range in values occurring above 250 mg/L. Identifying the source of high-chloride water in wells of various depths over time requires further analysis of geochemical data; depth-specific water quality was identified as a data gap in the HCM.

3.4.4.1.2 Total Dissolved Solids (TDS)

TDS is one way to measure salinity. It is a concentration of all dissolved substances remaining when water is evaporated away from a sample and is reported in mg/L. Recent TDS measurements show trends that match closely with the overall historical trends for chloride and highlight areas with elevated salinity concentrations in more recent years. Between 2015 and 2018, TDS concentrations in the Eastern San Joaquin Subbasin ranged from 35 to 2,500 mg/L. Spatially, the highest concentrations of TDS are found along the western margin of the Subbasin and the San Joaquin River and decrease significantly to the east, to typically less than 500 mg/L. TDS measurements, like chloride levels, are elevated near cities of Stockton and Manteca, and in the Lodi GSA near the White Slough Water Pollution Control Facility.

Figure 3-55 shows the maximum and Figure 3-56 shows the average TDS concentrations from 2015 to 2018 as compared to the SMCL lower limit of 500 mg/L and upper limit of 1,000 mg/L. The SMCL is established by the USEPA then adopted by the SWRCB. The SMCL is a Secondary Drinking Water Standard that is established for aesthetic reasons such as taste, odor, and color and is not based on public health concerns. The 500 mg/L value is "recommended" by SWRCB as a threshold below which TDS concentrations are desirable for a higher degree of consumer acceptance of drinking water. The "upper" limit is used to define a range above the "recommended" value where TDS concentration is acceptable if it is neither reasonable nor feasible to provide more suitable waters (SWRCB, 2006). Comparisons to the SMCL must be considered in context as the measured concentrations represent raw water, which may be treated or blended prior to delivery to meet the standard or may not be used for potable uses.

Figure 3-55: Maximum TDS Concentrations 2015-2018

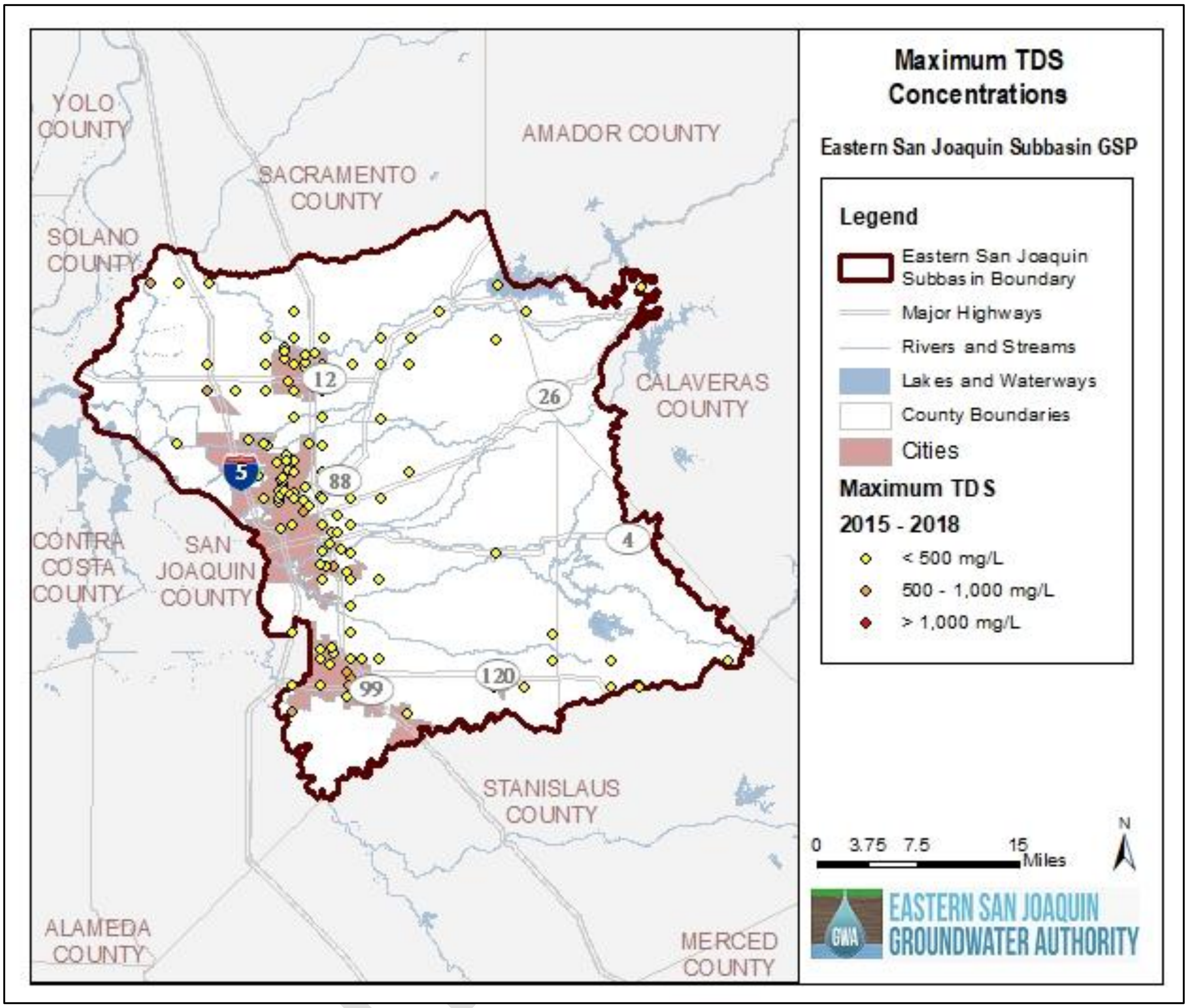
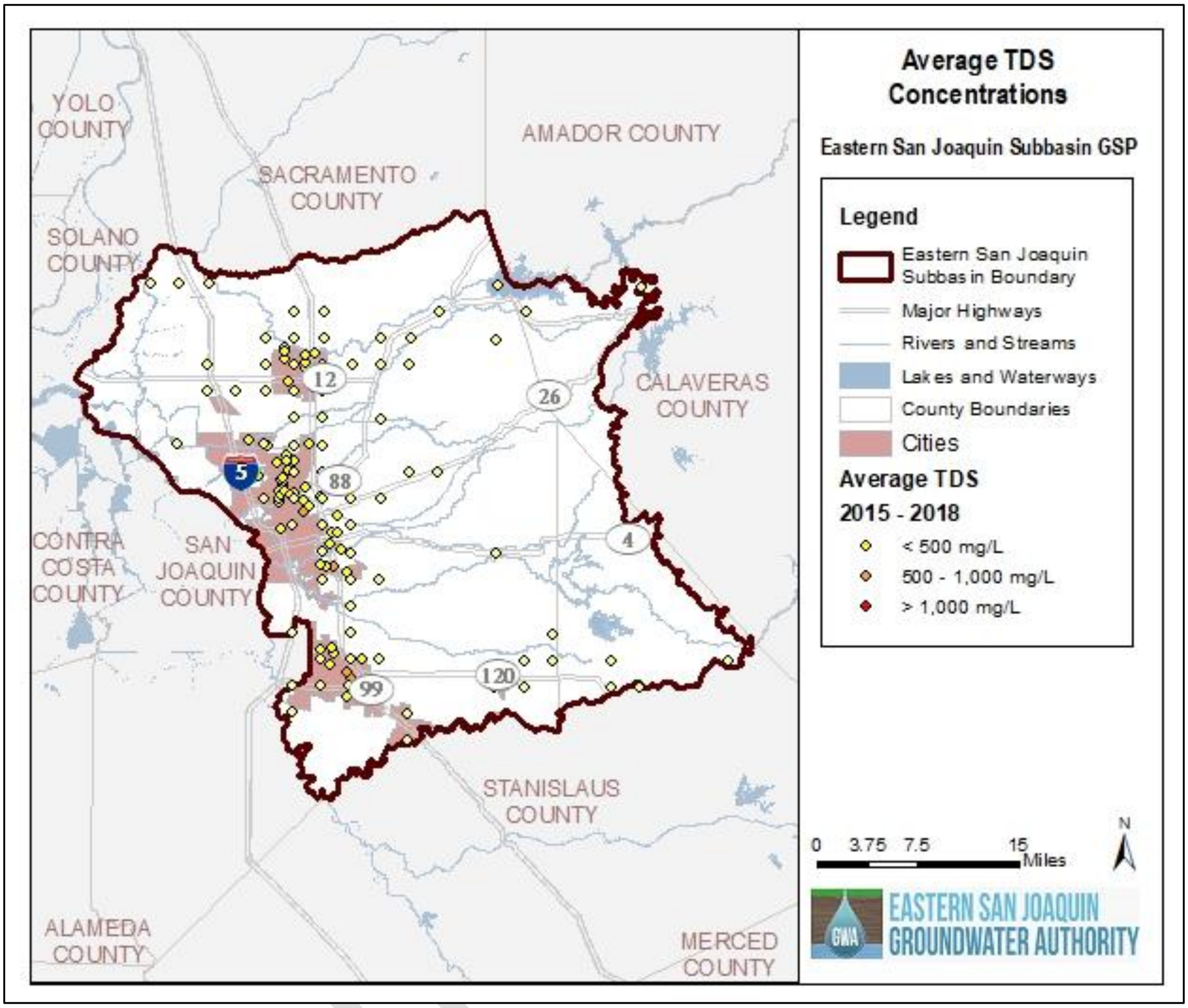


Figure 3-56: Average TDS Concentrations 2015-2018



Elevated TDS concentrations are apparent in very shallow groundwater in close proximity to the San Joaquin River, while deep wells (depths greater than 200 feet) typically have TDS concentrations below 500 mg/L. TDS trends by depth are summarized in Table 3-13.

Figure 3-57 shows the maximum TDS concentrations for shallow wells in the Eastern San Joaquin Subbasin from years 2015 to 2018, and Figure 3-58 shows the maximum TDS concentrations for deep wells in the same timeframe. As with chloride measurements, depth-dependent TDS data is not widely available. It was identified as a data gap in the HCM and will be a focus of the monitoring network for water quality, as described in the Monitoring Network section.

Table 3-13: Summary of TDS Data by Depth (2015-2018)

Depth (feet)	% Measurements in Range			Range of Values (mg/L)				Total Number of Samples
	< 500 mg/L	500 – 1000 mg/L	> 1,000 mg/L	Minimum	Average	Median	Maximum	
No Depth Data	90%	8%	2%	94	339	310	1,180	451
0 - 100	N/A							0
100 - 250	54%	46%	0%	280	438	480	540	13
250 - 500	93%	7%	0%	120	344	340	560	75
> 500	N/A							0

Figure 3-57: Maximum TDS Concentrations in Shallow Wells 2015-2018

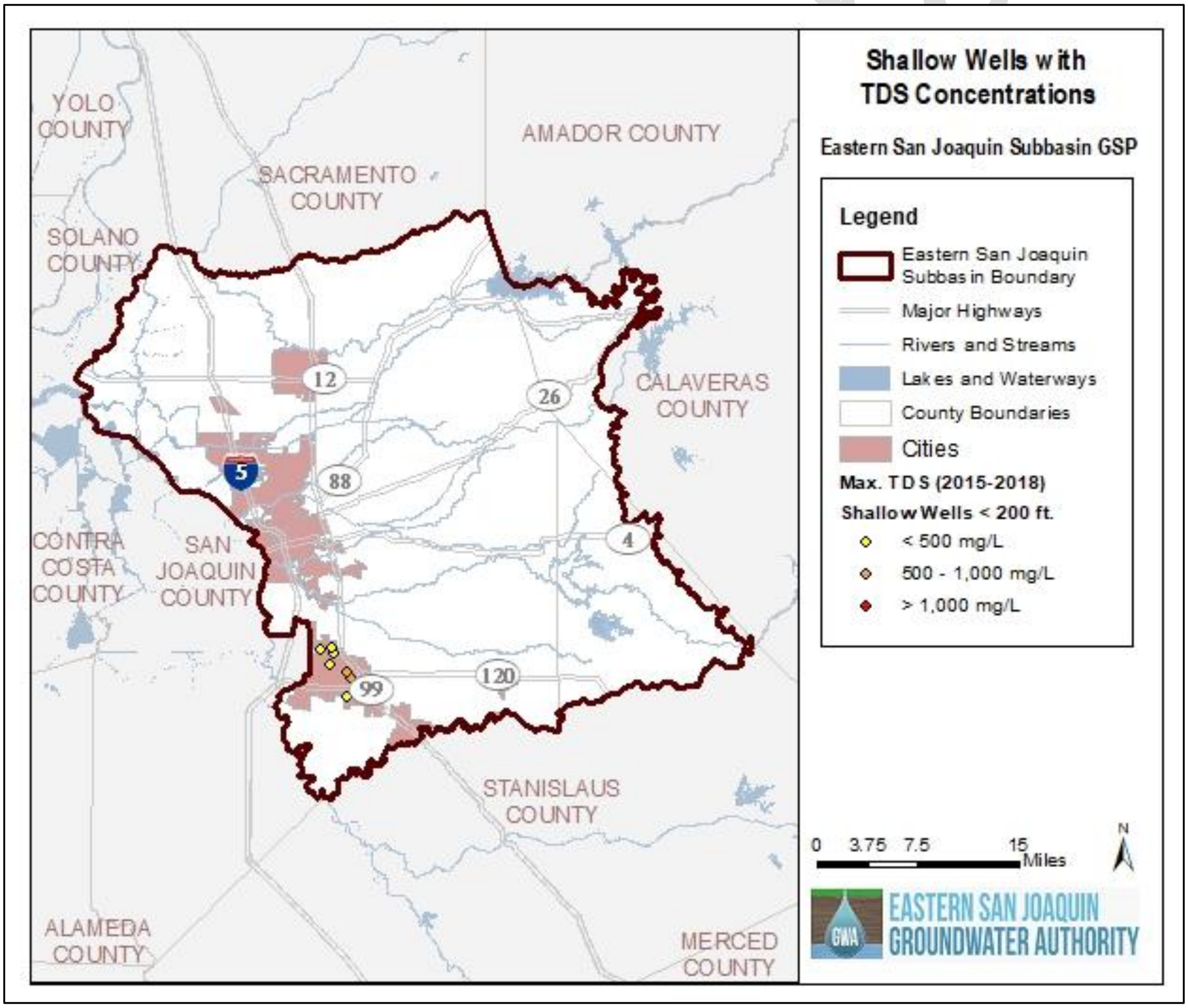
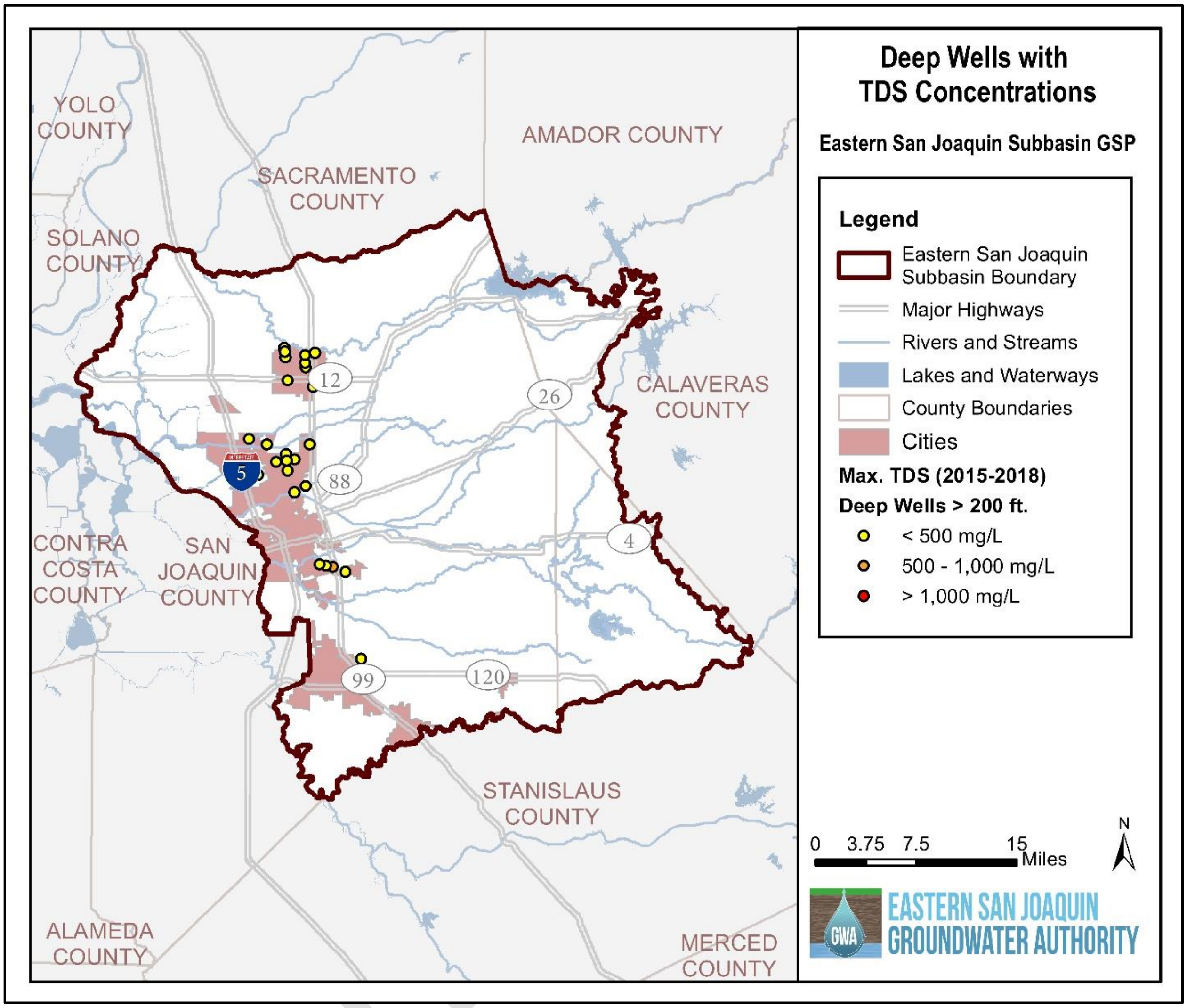


Figure 3-58: Maximum TDS Concentrations in Deep Wells 2015-2018



3.4.4.2 Nitrate

Nitrate is both naturally occurring and can be contributed a result of human activity. Nitrate can cause adverse human health effects. Anthropogenic sources of nitrate include fertilizers, septic systems, and animal feedlots. The EPA's MCL of 10 mg/L for Nitrate as N delimits high levels of nitrate for drinking water use. Many measured concentrations are above this value, both historically and recently. Comparisons to the MCL must be considered in context as the measured concentrations represent raw water, which may be treated or blended prior to delivery to meet the standard or may not be used for potable uses.

Table 3-14 provides the total number of nitrate values by decade and the percentage of those values greater than 10 mg/L. Although the total number of nitrate measurements has grown since 2000, the occurrence of concentrations greater than 10 mg/L has increased greater than what is proportional for this increase in sampling.

Table 3-14: Nitrate as N Concentrations by Decade

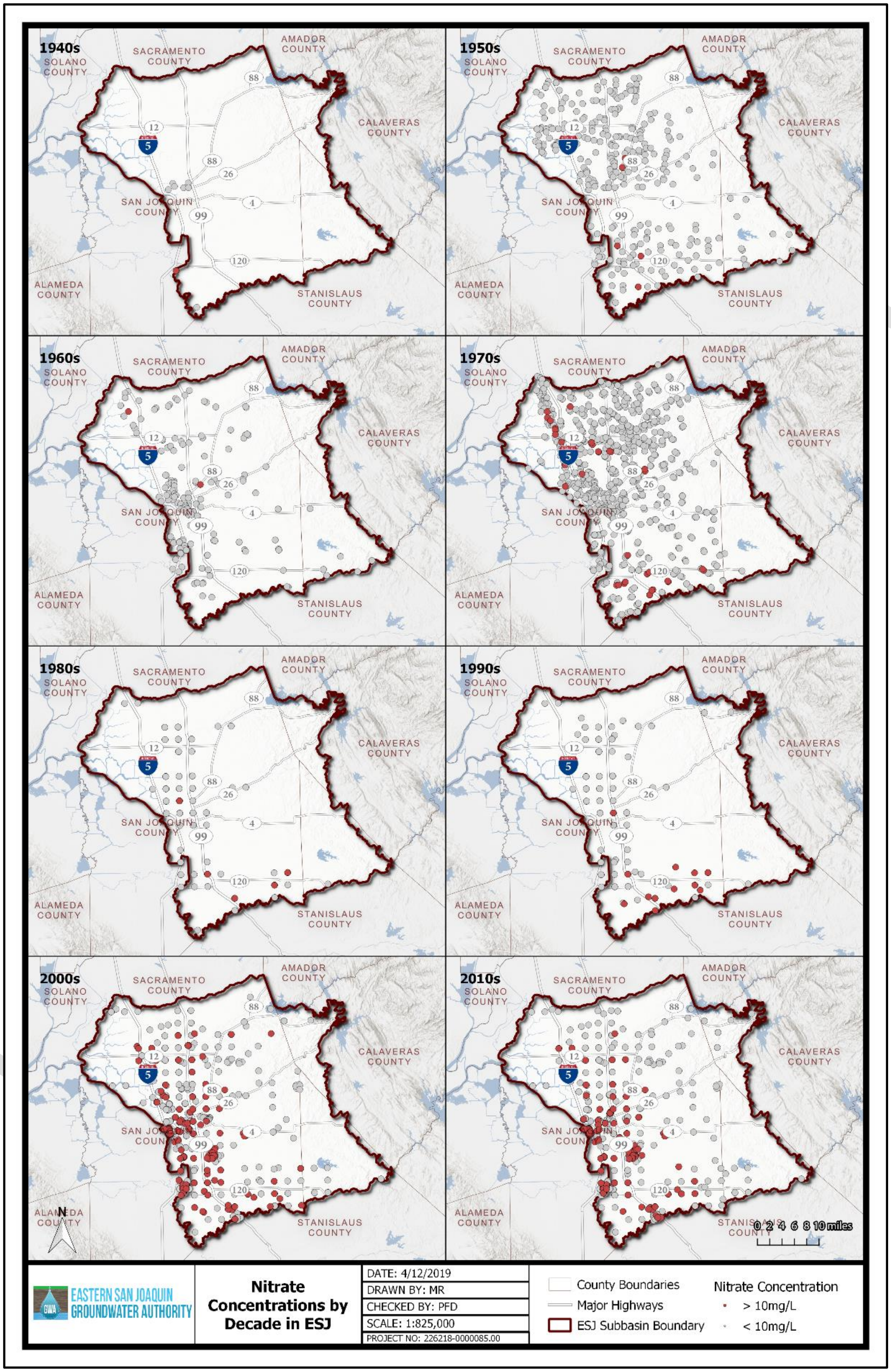
Decade	% of Measurements		Number of Nitrate Measurements
	<10 mg/L	>10 mg/L	
1940	88%	13%	8
1950	99%	1%	362
1960	99%	1%	240
1970	96%	4%	1,500
1980	95%	5%	420
1990	98%	2%	1,716
2000	87%	13%	9,679
2010	83%	17%	11,060

Figure 3-59 shows the historical spatial distribution of nitrate samples and detections by decade. During the 1940s, the earliest decade with nitrate measurements, very few records exist and no significant conclusions can be made from this timeframe. The 1950s and 1960s have larger datasets, but measurements above 10 mg/L during these decades are sporadic and localized. Nitrate concentrations during the 1970s show a significant number of measurements above 10 mg/L in the northwest portion of the Eastern San Joaquin Subbasin, adjacent to Interstate 5. The 1980s and 1990s show similar patterns of fewer records than the 1970s, primarily around the cities of Stockton, Lodi, and Manteca. Nitrate measurements above 10 mg/L are also located near the southern edge of the Eastern San Joaquin Subbasin, close to Highway 120. Although a much greater number of records exists for the 1990s than the 1980s, these decades have approximately the same spatial distribution. One possible explanation is similar wells were sampled during the 1980s and 1990s, but much more frequently in the 1990s. The 2000s and 2010s had both the greatest number of nitrate measurements and the largest number of measurements above 10 mg/L. Measurements above 10 mg/L during these decades follow previous trends: they are primarily between Highway 99 and Interstate 5, from Ripon to near Lodi.

Recent nitrate measurements above the MCL correspond to the overall historical trends and highlight areas with elevated Nitrate concentrations in more recent years. These areas include cities of Stockton and Ripon, areas of the Lodi GSA near the White Slough Pollution Control Facility, the N.A. Chaderjian Youth Correctional Facility, Republic Services Landfill on South Austin Road, and the Kruger and Sons, Inc. site off Highway 4 outside Farmington. Increased nitrate concentrations have not been found to be related to groundwater management activities in the Subbasin.

Section 2.2.1.2.6 of this Plan discusses IRLP and CV-SALTS, two existing regulatory programs for the monitoring and regulation of nitrate. Under the IRLP, the San Joaquin County and Delta Water Quality Coalition is required to test and potentially mitigate for nitrate in domestic wells. Additionally, the 2017 Salt and Nitrate Management Plan developed by CV-SALTS through the CVRWQCB identifies long-term nitrate management practices (CVRWQCB, 2017).

Figure 3-59: Nitrate as N Concentrations by Decade



3.4.4.3 Arsenic

Arsenic is ubiquitous in nature and is commonly found in drinking water sources in California. Determining the source of arsenic in groundwater is difficult because arsenic is both naturally occurring and used in human activities such as agriculture. Public health concerns about arsenic in drinking water related to its potential to cause adverse health effects are addressed through EPA's MCL, established at 10 µg/L.

Figure 3-60 shows the spatial distribution of arsenic concentrations contained in the GAMA database. From the 1970s to present, the total number and percentage of arsenic values above 10 µg/L has increased (see Table 3-15). The spatial distribution of measurements above 10 µg/L is similar to nitrate, largely between Interstate 5 and Highway 99, from Manteca to Lodi. The increased arsenic concentrations near urban areas are not necessarily indicative of contamination from these areas and may partially be due to the fact that arsenic measurements are more abundant in these urban areas; GAMA water quality records are rarely evenly distributed throughout the Subbasin for any constituent. Recent arsenic samples show measurements above 10 µg/L similar to the overall trends (see Figure 3-61). Measurements above 10 µg/L in years 2015, 2016, 2017, and 2018 are primarily located in cities of Stockton and Manteca, with fewer occurring around City of Lodi. Increased arsenic concentrations have not been found to be related to groundwater management activities in the Subbasin.

Figure 3-60: Arsenic Concentrations by Decade

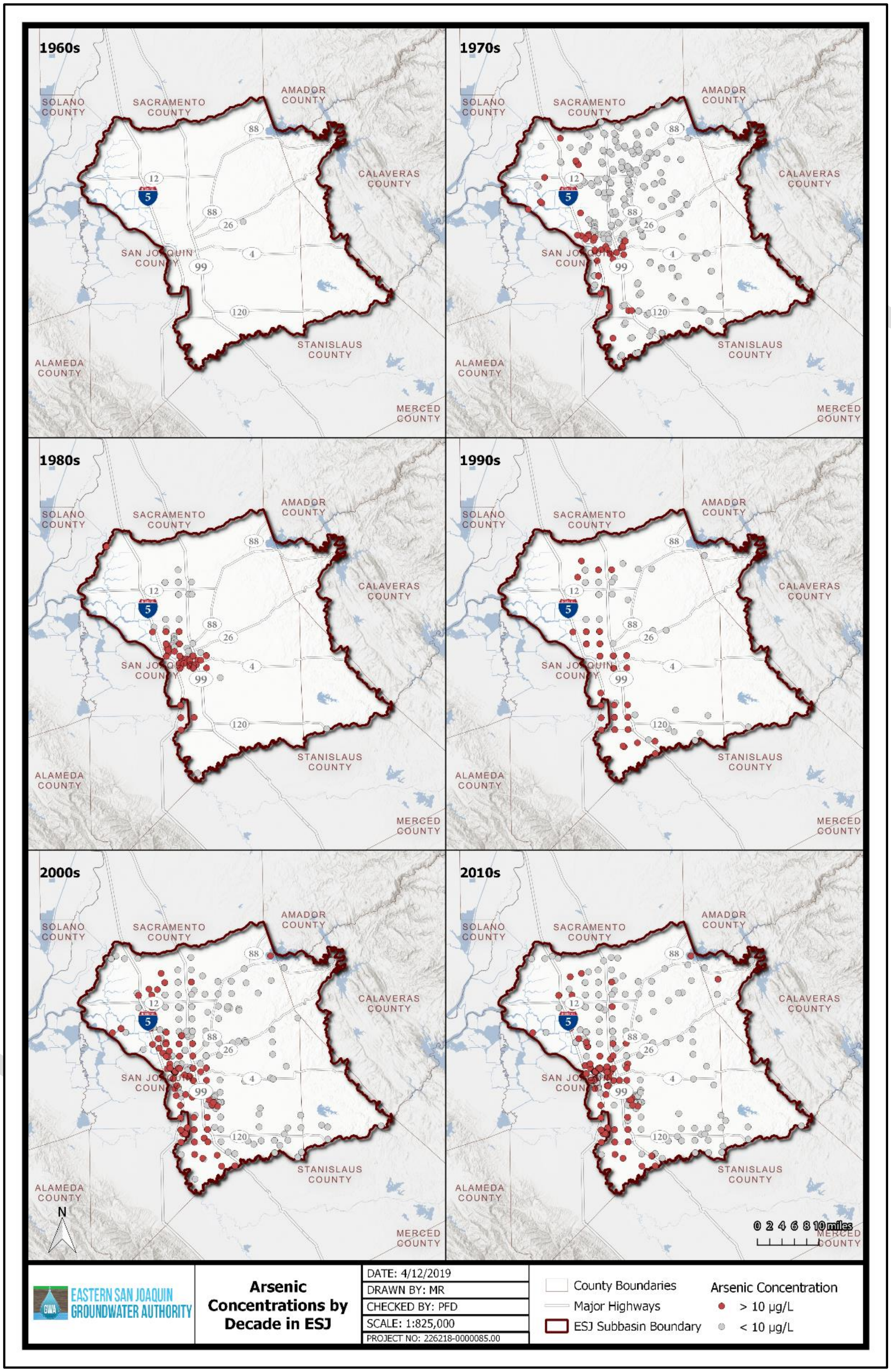
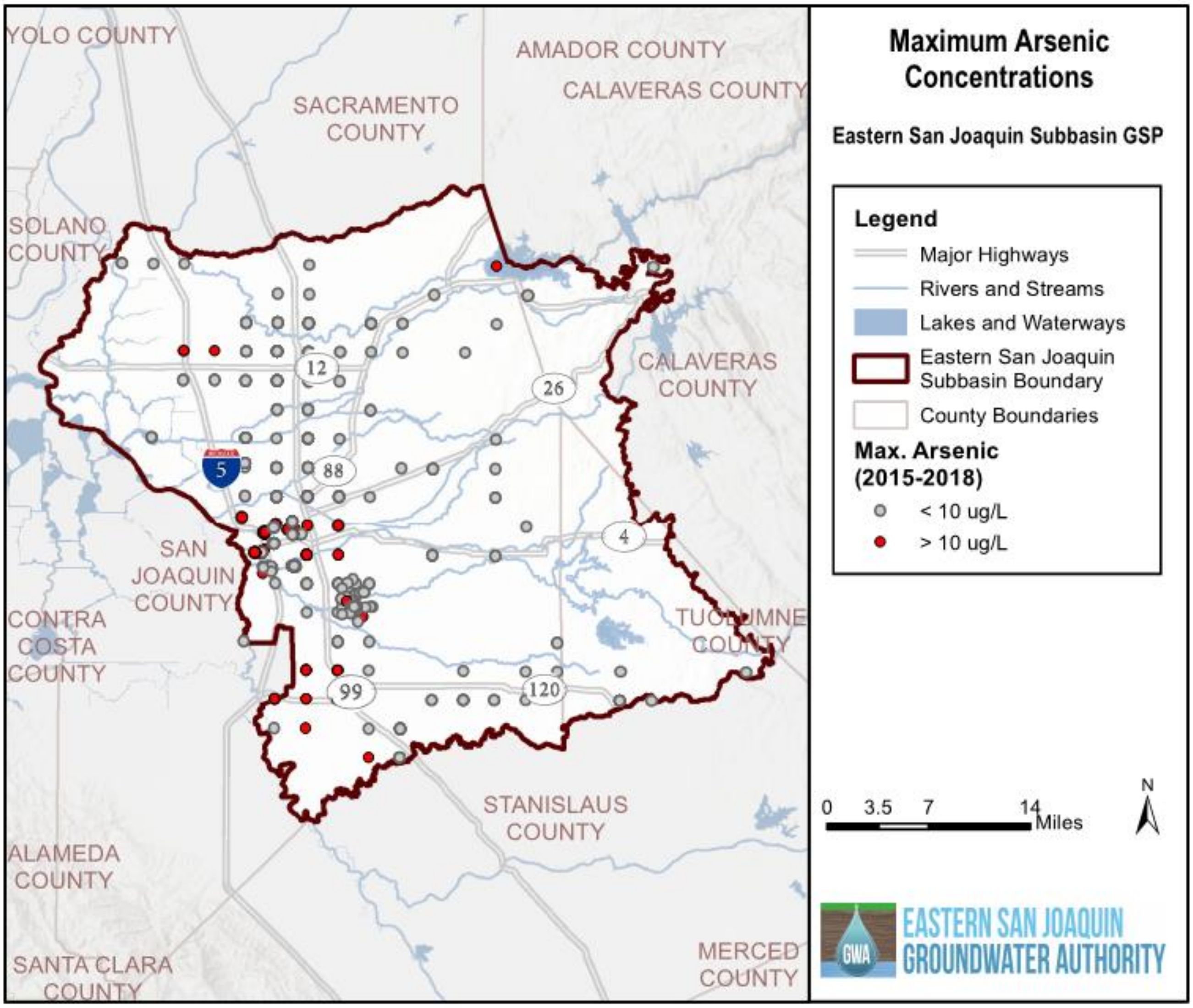


Table 3-15: Arsenic Values by Decade

Decade	% of Measurements		Number of Arsenic Measurements
	<10 ug/L	>10 ug/L	
1960	100%	0%	1
1970	86%	14%	339
1980	72%	28%	363
1990	72%	28%	645
2000	56%	44%	4,051
2010	48%	52%	5,109

Figure 3-61: Maximum Arsenic Concentrations 2015-2018



3.4.4.4 Point Sources

Point sources are discrete or discernable sources of pollutants which may introduce undesirable constituents into groundwater and may negatively impact water quality. In the Eastern San Joaquin Subbasin, point sources include leaking underground storage tanks, landfills, historical dry cleaners, and others. These sites are actively investigated and monitored within the Eastern San Joaquin Subbasin in response to these known or potential sources of groundwater contamination. The RWQCB, the DTSC, and the USEPA provide oversight of point source pollution through existing regulatory programs, including management of remedial action for point source contamination sites. Figure 3-62 shows the results of a query from both the RWQCB's GeoTracker database and the DTSC's EnviroStor database. GeoTracker documents contaminant concerns that the RWQCB is or has been working with site owners to remediate while EnviroStor is the DTSC's data management system to track known contamination sites undergoing cleanup, permitting, enforcement, and investigation efforts. As shown in Figure 3-62, there are 258 active sites within the Eastern San Joaquin Subbasin which are color-coded based on the site's constituent(s) of concern: fuels (gas and/or diesel); synthetic organics (pesticides, herbicides, insecticides, etc.); or a mix of constituents (multiple constituents such as heavy metals and pesticides). Most sites within the Eastern San Joaquin Subbasin are fuel sites (e.g., gas or diesel) that are under active investigation or remediation. Sites with the potential to cause plumes are mapped in Figure 3-63, which were identified by filtering for sites containing soluble and mobile constituents such as VOCs; BTEX; and/or petroleum hydrocarbons (gas or diesel). Point source contamination has not been found to be related to groundwater management activities in the Subbasin.

Specific point source sites and contaminants are discussed in the sections below.

Figure 3-62: Active Investigation and Remediation Sites

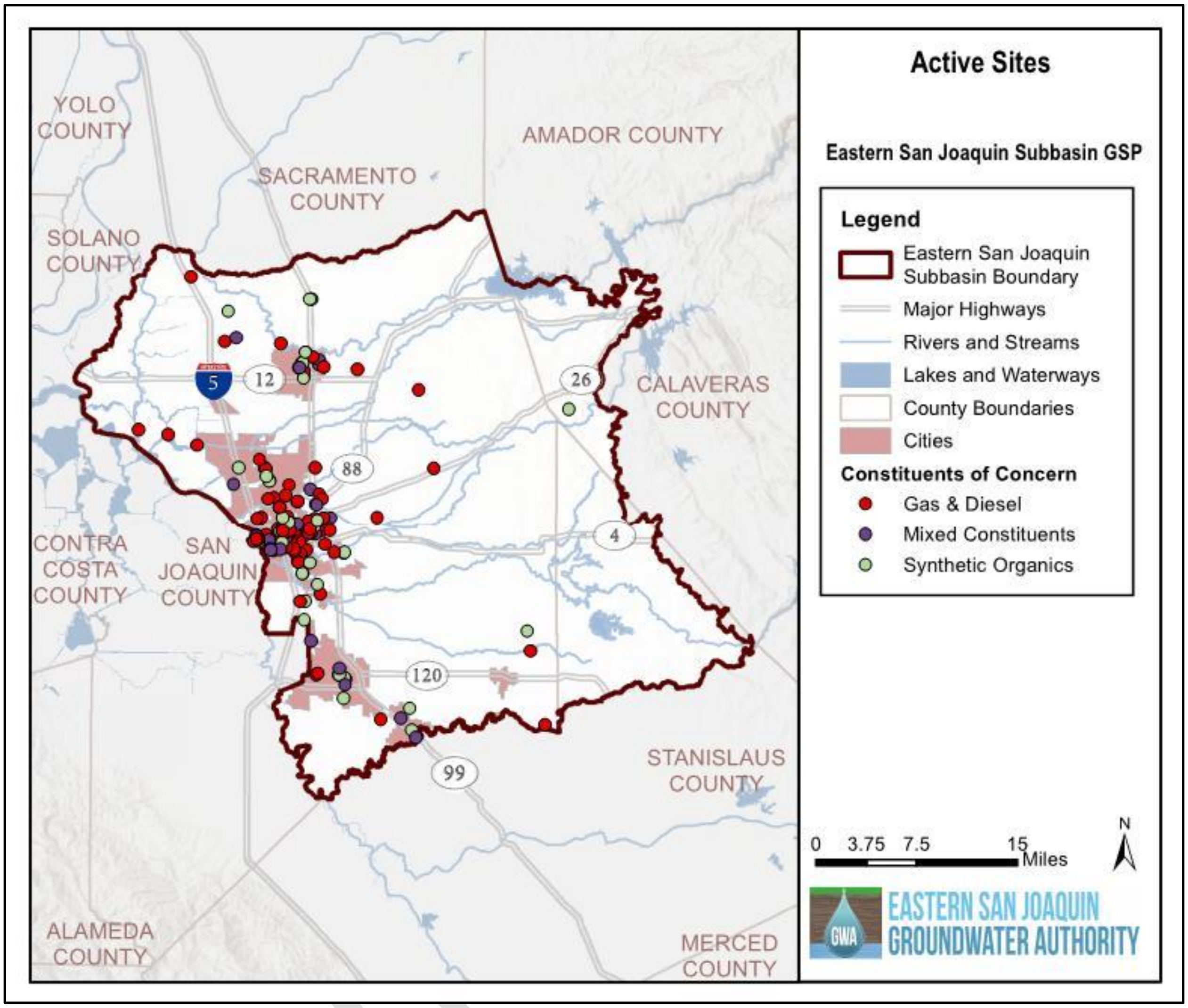
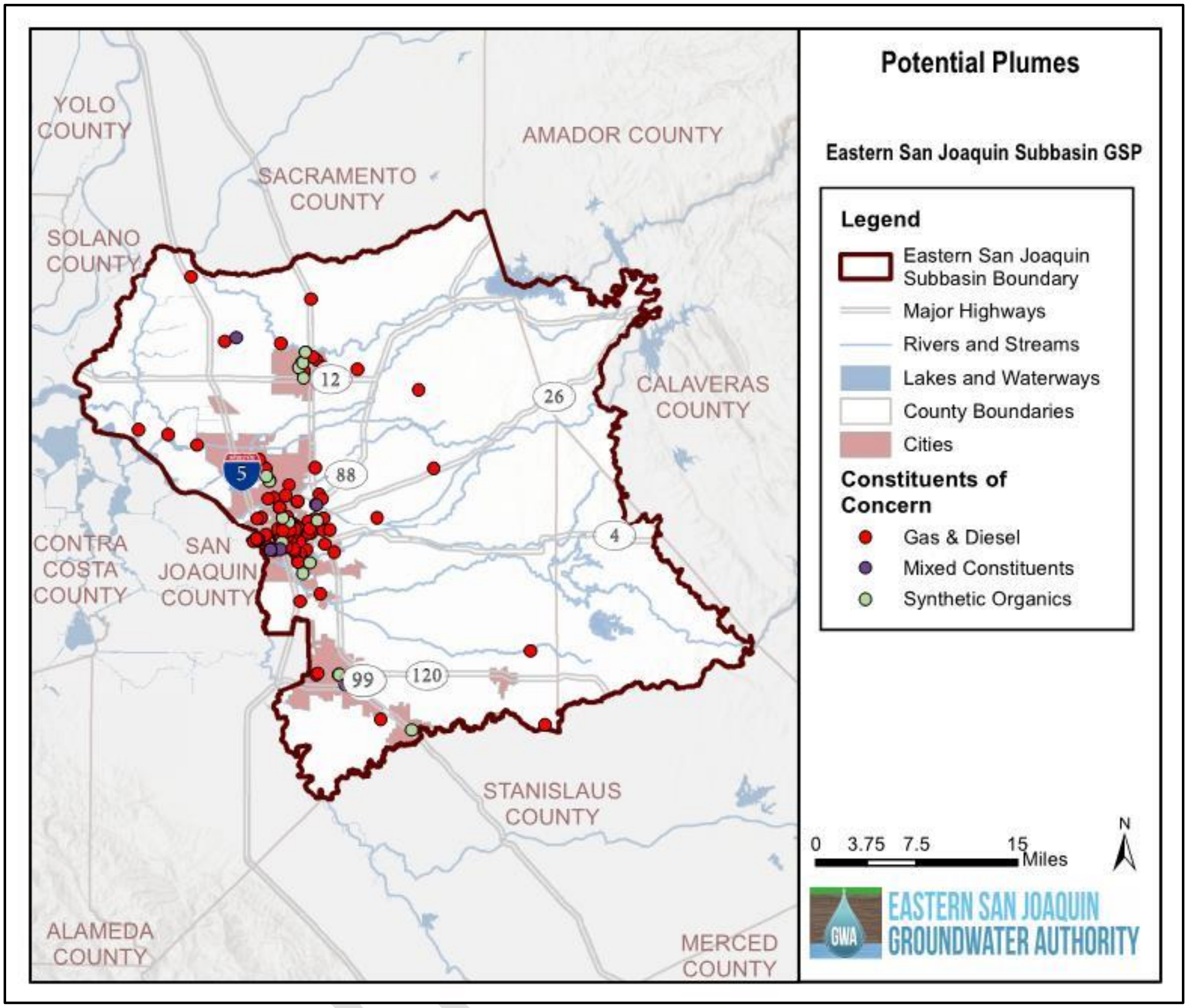


Figure 3-63: Active Sites with the Potential to Cause Plumes



3.4.4.4.1 Publicized Plumes in and near the Subbasin

As indicated above, the Eastern San Joaquin Subbasin has numerous open cleanup sites, including areas contaminated by chlorinated solvents, MtBE, pesticides and herbicides, and leaking underground storage tanks. Plume sites are often clustered around urban centers but are also found near sites where historical industrial or agricultural practices have released contaminants of concern. While other plumes exist in and around the Subbasin, three specific plumes have been highly publicized: the Lodi Plumes, the Sharpe Army Depot Plume, and the Occidental Chemical Corporation Plume

In the late 1980s, the City of Lodi discovered the chlorinated solvents PCE and TCE in drinking water supplies and pursued a groundwater investigation that revealed a series of five separate plume areas located in the northeastern portion of the City: the Northern, Western, Central, Southern, and Busy Bee plumes. The Busy Bee plume, named after a dry cleaner business that previously operated on the site, now has regulatory closure and with cleanup moving toward completion under CVRWQCB oversite (Water Resources Control Board, 2011).

Groundwater contamination plumes in the City of Lathrop, located just outside the Subbasin boundary, include the Sharpe Army Depot and Occidental Chemical Corporation sites. Contamination of groundwater at the Sharpe Army

Depot consists primarily of trichloroethene, tetrachloroethene, and cis-1,2-dichloroethene from historical industrial activities related to military activities. Due to concerns of potential contamination, the City abandoned City wells in the area. Three groundwater extraction and treatment systems are located at Sharpe Army Dept and are used to treat existing groundwater (City of Lathrop UWMP, 2015).

The Occidental Chemical Corporation Plume was discovered in the late 1970s and is the result of former leaking wastewater holding ponds containing pesticides and chemicals used for equipment cleaning by the Occidental Chemical Corporation. Contaminants of concern include the pesticides DBCP and EDB, 2,3,4,5-tetrahydrothiopene-1, 1-dioxide, sulfate, nitrate, chloride, lindane, and BHC (RWQCB, 2012). Since the discovery of these plumes in the 1980s, groundwater has been monitored and evaluated at these point source locations and has resulted in the removal of contaminant sources and the implementation of remedial activities such as the installation of groundwater extraction and remedial systems, implementation of a Salinity Reduction Plan, and mandated WDRs (RWQCB, 2012).

3.4.4.4.2 Petroleum Hydrocarbons

Approximately 134 sites in the Eastern San Joaquin Subbasin are identified as actively investigating or remediating an unauthorized release of petroleum hydrocarbons, according to the GeoTracker and EnviroStor databases. Of these sites, petroleum hydrocarbon constituents are most commonly fuels (diesel, gasoline, motor oil, or aviation fuel) and VOCs commonly added to fuels, including MTBE and BTEX constituents. Concentrations of petroleum hydrocarbons have not been modeled across the Subbasin; concentrations are local and site specific. A summary description of the aforementioned constituents is provided in Table 3-16 below:

Table 3-16: MCLs for Common Petroleum Hydrocarbons and MTBE

Constituent	Source	Primary MCL[1]
MTBE	Oxygenate commonly added to gasoline	13 µg/L
BTEX		
Benzene	Industrial solvent added to crude oil paint, varnish, and lacquer thinner	1 µg/L
Toluene	Aromatic hydrocarbon used in industrial feedstock, as a solvent, and to produce benzene and added to gasoline	15 µg/L
Ethylbenzene	Used as a solvent and added to fuel, asphalt, and naphthalene	300 µg/L
Xylenes	Naturally occurring in petroleum, coal and wood tar	1.750 mg/L

Notes:

[1] Source: (SWRCB, 2018)

3.4.4.4.3 Synthetic Organics

Approximately 47 sites in the Eastern San Joaquin Subbasin are identified as actively investigating or remediating an unauthorized release of synthetic organics, according to the GeoTracker and EnviroStor databases. Of these sites, pesticides, herbicides, fertilizer, and pesticides are the most common constituents. Other constituents include VOCs such as PCE and TCE. Concentrations of synthetic organics have not been modeled across the Subbasin; concentrations are local and site specific. For context, a brief description of the aforementioned VOCs is provided in Table 3-17.

Table 3-17: MCLs for Common Synthetic Organic Constituents

Constituent	Source	Primary MCL[1]
TCE	Used as a solvent in manufacturing facilities and dry cleaners	5 µg/L
PCE	Used as a solvent in manufacturing facilities, printing shops, and auto repair facilities	5 µg/L

Notes:

[1] Source: (SWRCB, 2018)

3.4.4.4.4 Mixed Constituents

Approximately 28 sites in the Eastern San Joaquin Subbasin are identified as actively investigating or remediating an unauthorized release of mixed constituents, according to the GeoTracker and EnviroStor databases. Sites with mixed constituents are those that include a release of more than one type of contaminant, such as a mix of heavy metals, diesel, inorganics, and/or organics. Of these sites, the most common constituents include a mixture of heavy metals (chromium, arsenic, and lead), inorganics, and solvents. The sources and primary MCL for many contaminants found in the 'mixed constituents' classification have been discussed throughout Section 3.4.4.

3.4.4.4.5 Emerging Contaminants

Many chemical and microbial constituents that have not historically been considered as contaminants are occasionally, and in some cases with increasing frequency, detected in groundwater. These newly recognized (or emerging) contaminants are commonly derived from municipal, agricultural, industrial wastewater, and domestic wastewater sources and pathways. These newly recognized contaminants are dispersed to the environment from domestic, commercial, and industrial uses of common household products and include caffeine, artificial sweeteners, pharmaceuticals, cleaning products, and other personal care products. Residual waste products of genetically modified organisms are also of potential concern. Several studies, such as by Watanabe et al. in 2010, have recently been published or are underway regarding the potential link between dairies and the occurrence of pharmaceuticals in shallow groundwater in the San Joaquin Valley.

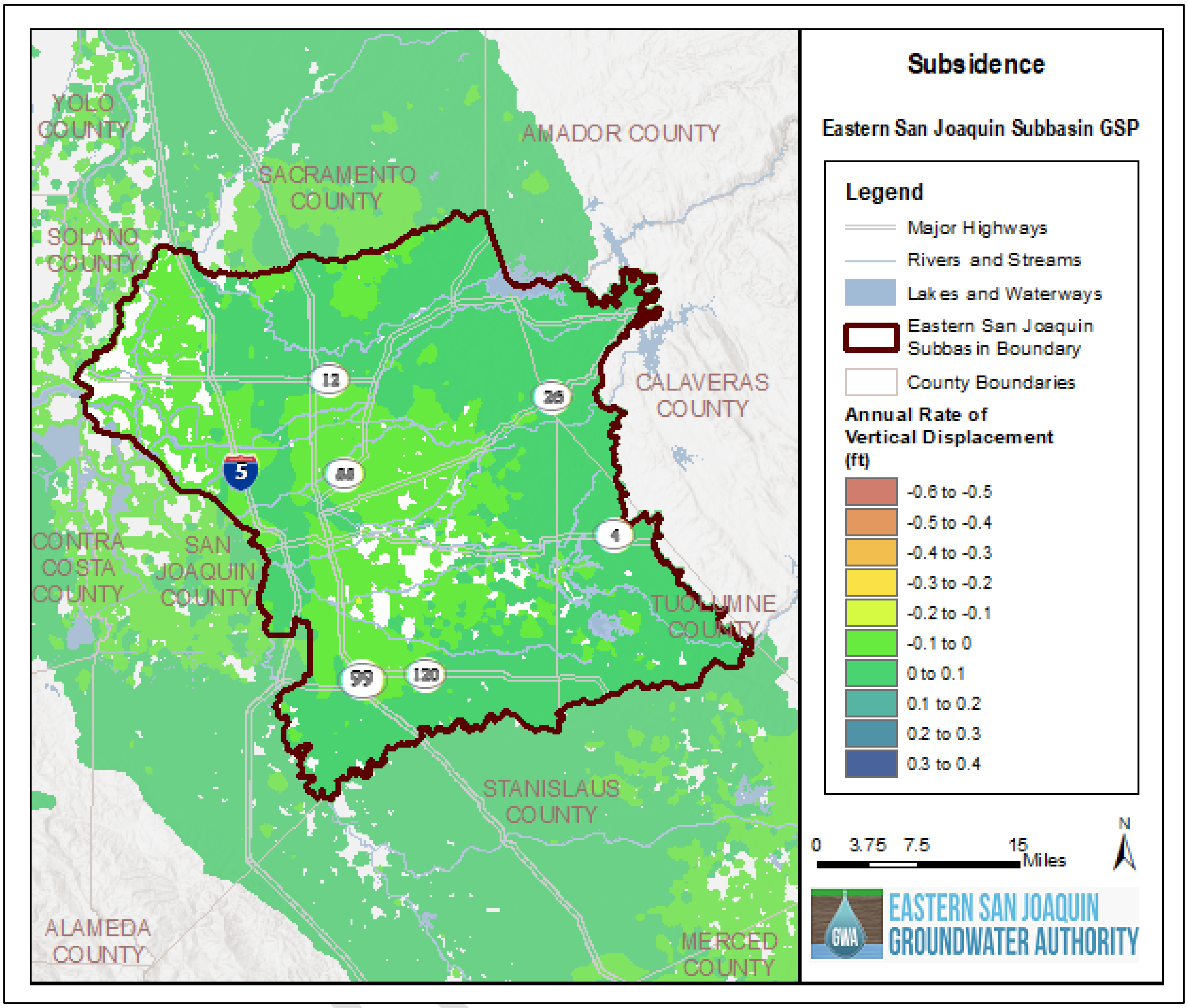
PFOS and PFOA are organic chemicals synthesized for water and lipid resistance, used in a wide variety of consumer products as well as fire-retarding foam and various industrial processes. These chemicals tend to accumulate in groundwater, though typically in a localized area in association with a specific facility, such as a factory or airfield (California Water Boards, 2018). There are currently no MCLs for PFOS or PFOA; however, the USEPA is moving forward with the MCL process for (USEPA, 2019). The USEPA has recommended municipalities notify customers at levels at or greater than 70 PPT in water supplies, and California's DDW has established notification levels at 13 PPT for PFROS and 14 PPT for PFOA (SWRCB, 2019). The MCL for 1,2,3-TCP is 0.005 ug/L and is regulated as of January 1, 2018. The solvent is typically found in industrial or hazardous waste sites (SWRCB, 2019).

Currently, data on PFOS, PFOA, and 1,2,3-TCP is limited in the Eastern San Joaquin Subbasin since these are emerging contaminants.

3.4.5 Land Subsidence

Subsidence has not historically been an area of concern in the Eastern San Joaquin Subbasin as there are no records of significant and unreasonable impacts from subsidence. Figure 3-64 shows regional subsidence produced from InSAR data. InSAR is a satellite-based method for showing ground-surface displacement over time. This figure illustrates that subsidence has historically been minimal in the Subbasin and surrounding areas (ranging from -0.1 to 0.1 feet of vertical displacement annually). See section 3.2.X for a discussion of the soils and clays within the Subbasin, including the extent of Corcoran Clay.

Figure 3-64: Subsidence (Annual Rate of Vertical Displacement)



3.4.6 Interconnected Surface Water Systems

Interconnected surface waters are surface water features that are hydraulically connected by a saturated zone to the groundwater system. In these systems, water table and surface water features intersect at the same elevations and locations. Interconnected surface waters may be either gaining or losing, wherein the surface water feature itself is either gaining water from the aquifer system or losing water to the aquifer system.

In the Eastern San Joaquin Subbasin, groundwater discharge from the aquifer is primarily through groundwater pumping. However, groundwater also discharges to streams where groundwater elevations are higher than the streambed. Figure 3-65 shows gaining streams in blue where groundwater discharges to rivers, losing streams in red where streams lose water to the groundwater system, and mixed streams (gaining or losing less than 75% of the time) in orange. This analysis was based on modeling results from the historical calibration of the ESJWRM for approximately 900 stream nodes in the Eastern San Joaquin Subbasin.

Stream connectivity was analyzed by comparing monthly groundwater elevations from the historical calibration of the ESJWRM to streambed elevations along the streams represented in ESJWRM. Shown in Figure 3-66 are locations where streams are interconnected at least 75% of the time (shown in blue) or disconnected (shown in green).

Figure 3-65: Losing and Gaining Streams

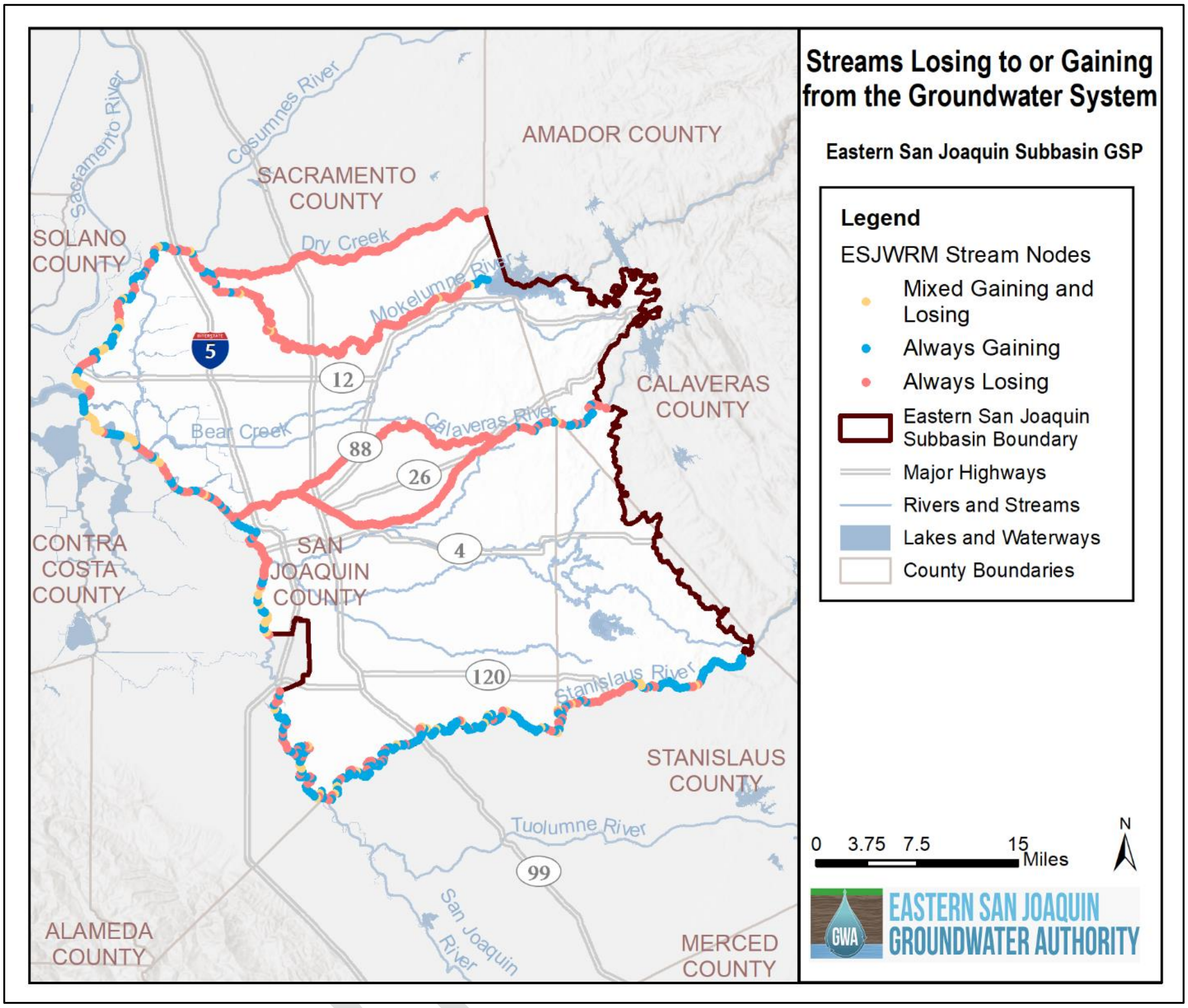
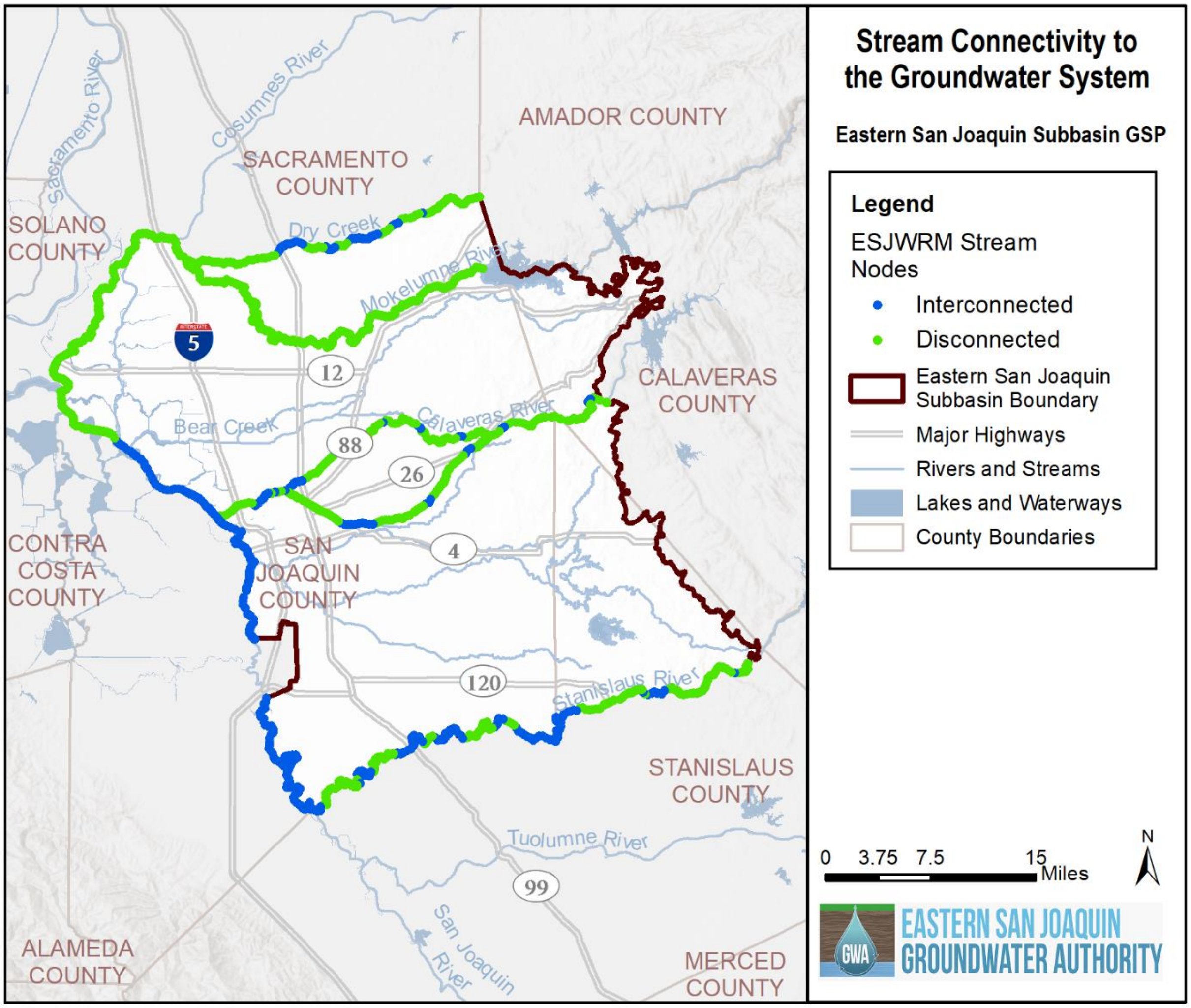


Figure 3-66: Interconnected and Disconnected Streams



3.4.7 Groundwater-Dependent Ecosystems

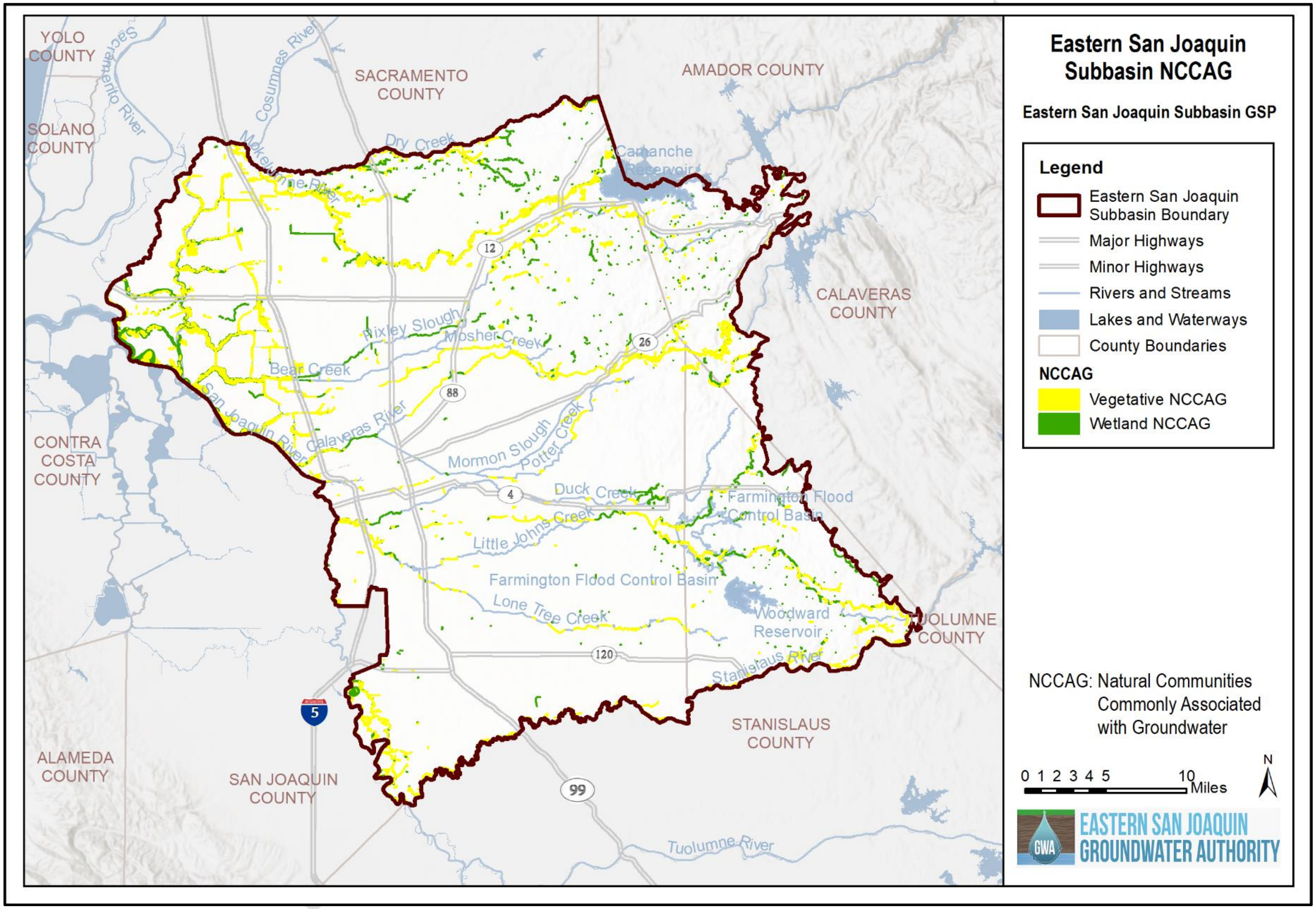
GDEs are defined in the GSP regulations as “ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface”. SGMA requires the identification of GDEs but does not require that sustainable management criteria be established to manage these areas.

GDEs exist where vegetation accesses shallow groundwater for survival; without the access to shallow groundwater, these plants would die. Thus, this Plan identifies GDEs within the Eastern San Joaquin Subbasin based on determining the areas where vegetation is dependent on groundwater

3.4.8 Methodology for GDE Identification

The NCCAG database was used as a starting point to identify natural communities within the Subbasin. The NCCAG database was developed from a working group comprised of DWR, CDFW, and TNC by reviewing publicly available state and federal agency datasets that mapped California vegetation, wetlands, springs, and seeps and by conducting a screening process to retain types and locations commonly known to be associated with groundwater. The results were compiled into the NCCAG database with two habitat classes defined. The first class includes wetland features commonly associated with the surface expression of groundwater under natural, unmodified conditions. The second class includes vegetation types commonly associated with the sub-surface presence of groundwater (phreatophytes). Figure 3-67 shows these two classes of NCCAG areas within the Eastern San Joaquin Subbasin.

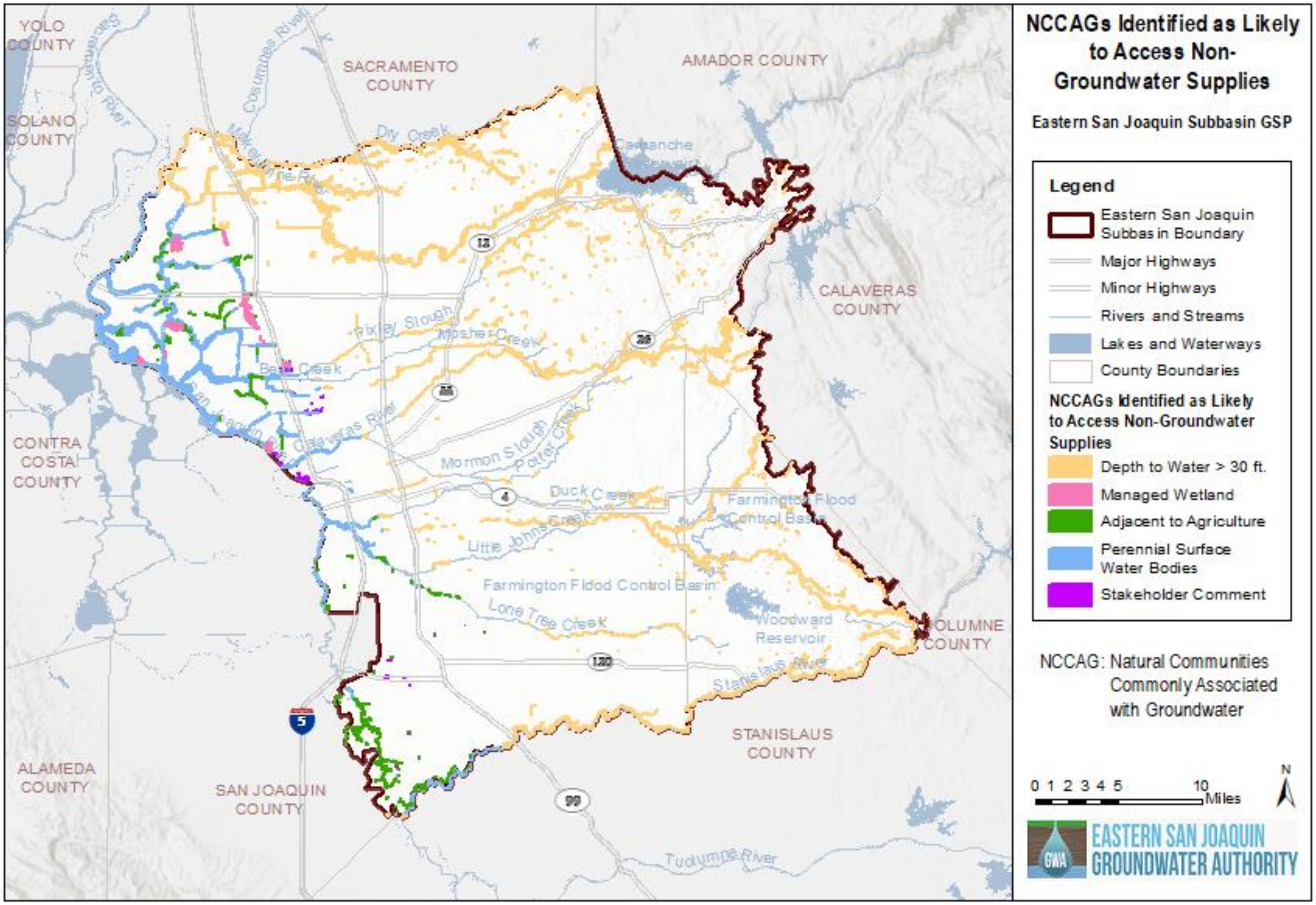
Figure 3-67: Natural Communities Commonly Associated with Groundwater (NCCAG)



This Plan identifies GDEs as NCCAG communities that are dependent on groundwater. The NCCAG database was refined to identify only communities without alternate water supplies. This was done by confirming sufficiently shallow groundwater levels and examining distance from alternative water supplies. This GSP does not consider communities without access to shallow groundwater and in close proximity to alternative water supplies to be groundwater dependent. Figure 3-68 shows the locations of NCCAGs that were excluded through this process.

The distinction between GDEs and other NCCAG areas is important from a management perspective, as no land use protections are conveyed through SGMA. Management of NCCAGs may require greater focus on land use or irrigation activities, whereas GDEs are expected to be more responsive to changes in groundwater management. The rigorous analysis to identify GDEs was developed to focus groundwater management activities on the most appropriate areas.

Figure 3-68: NCCAGs Identified as Likely to Access Non-groundwater Water Supplies



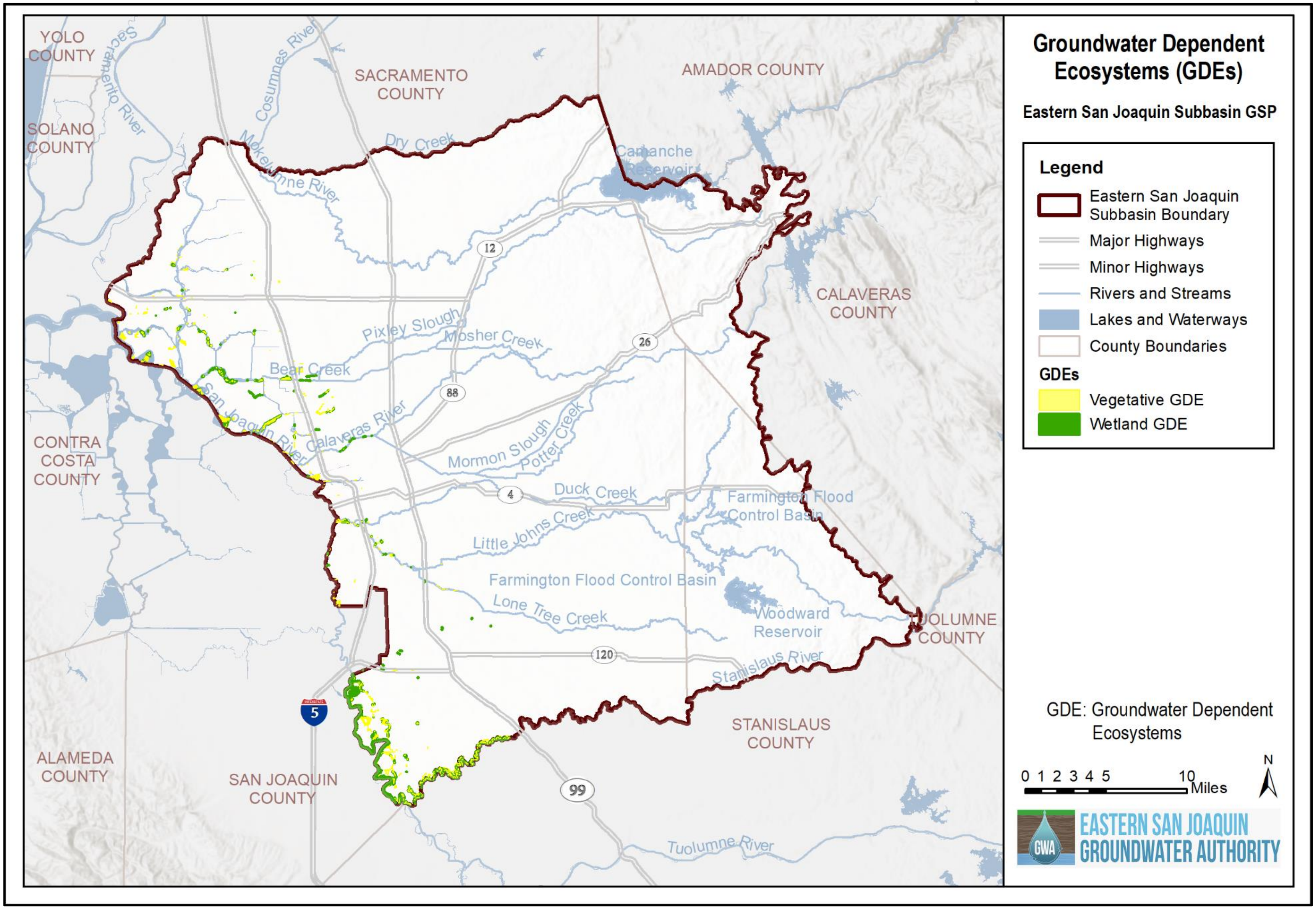
This Plan identifies GDEs as NCCAG-identified areas the meet all of the below criteria.

- **Areas with a depth to groundwater less than 30 feet** – Oak trees are considered the deepest-rooted plant in the region with a root zone of roughly 25 feet. Communities with zones where the depth to water in 2015 was less than 30 feet are classified as GDEs in this Plan because they are likely to be supported by groundwater. Even the 25-foot value is considered conservative, as this depth is unlikely to support recruitment of new oak seedlings. Communities in areas with groundwater deeper than 30 feet are assumed to be reliant on other water supplies and not dependent on groundwater. These communities are not considered GDEs and are labeled as "Depth to Water".
- **Areas without alternate water supplies** – In addition to having access to shallow groundwater, to be dependent on groundwater there must not be other available water supplies. Areas that are without supplemental water were considered for classification as GDEs. This was defined as areas that are:
    - At least 50 feet from irrigated agricultural lands – Irrigated agricultural lands are dependent on reliable water supplies to ensure a successful harvest, and surface water or deeper groundwater is used to irrigate crops in the Eastern San Joaquin Subbasin. Such irrigation benefits not only the crops, but also surrounding vegetation, regardless of the condition of the underlying aquifer. Areas farther than 50 feet from irrigated lands were assumed to be supported by groundwater, or water supplies other than agricultural irrigation water, and were considered for classification as GDEs. Areas likely dependent on water from irrigated fields are represented as NCCAG areas with access to non-groundwater water supplies. 50 feet was used to reflect non-ponded conditions in the fields.
    - At least 150 feet from managed wetlands that receive supplemental water – Managed wetlands receive supplemental water to support wildlife habitat. The wetlands were identified and reviewed with local water managers to verify supplemental water deliveries. Areas at least 150 feet from the managed wetlands are assumed to be unable to access the supplemental water and dependent on groundwater and were considered for classification as GDEs. Managed wetlands and areas within 150 feet of managed wetlands are not assumed to be dependent on groundwater, as they can access delivered water supplies regardless of the condition of the underlying aquifer. This Plan does not consider these areas as GDEs and are labeled as NCCAG areas with access to non-groundwater water supplies. 150 feet was used to reflect ponded conditions at the wetlands.
    - At least 150 feet from perennial surface water bodies – Perennial surface water bodies provide year-round water supplies that can be accessed by adjacent vegetation. These water bodies include much of the Delta; large, managed rivers; and smaller water bodies that flow throughout the summer due to agricultural deliveries or tailwater. Areas at least 150 feet from the perennial surface water bodies are assumed to be unable to access the water from the perennial surface water bodies and dependent on groundwater and were considered for classification as GDEs. Areas within 150 feet of these surface water bodies are not assumed to be dependent on groundwater, as they can access water from the river regardless of the condition of the underlying aquifer. These are labeled as NCCAG areas with access to non-groundwater water supplies. 150 feet was used to reflect open water conditions in the surface water bodies.

3.4.9 Areas Identified as GDEs

Following the methodology presented above, this Plan identifies several GDEs, primarily located along the western boundary of the Subbasin, in the Delta areas where groundwater is typically shallow. These areas are divided into two categories: vegetative GDEs and wetland GDEs, as shown in Figure 3-69.

Figure 3-69: Areas Identified as GDEs



The current and historical conditions discussed above are further expanded upon in the Sustainable Management Criteria chapter, and used to define measurable objectives, identify interim milestones, and establish undesirable results. Groundwater elevations and quality are targeted based on existing conditions, and existing programs lay the framework for monitoring associated with thresholds set for the GSP.