Sustainable Water Management Strategy for Specialty Crop Expansion in the Sacramento Valley:

Task 1 Report:

Regional Hydrogeologic Assessment for Recharge Feasibility

Prepared for
Sacramento Area Council of Governments

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EXECUTIVE SUMMARY

The Sacramento Area Council of Governments (SACOG) is an association of local governments in the six-county Sacramento Region of El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba counties (excluding the Tahoe Basin in Placer and El Dorado counties) and the 22 cities therein. SACOG provides planning and funding for the region and serves as a forum for the study and resolution of regional issues. SACOG prepares the region's long range plan which considers both transportation and land use. Through the lens of rural planning, SACOG has actively engaged in a Rural-Urban Connections Strategy (RUCS) Program that has studied ways to enhance rural economies and natural assets. The RUCS Program includes a scenario analysis modeling tool that links a parcel-level crop map with environmental and economic factors, including a comprehensive profile of per acre operational cost and return metrics for each crop.

The study described in this report looks at how new agricultural crops and markets coupled with improved irrigation techniques will support new specialty crop acreage in the SACOG area. While new and improved irrigation techniques can result in better crop yields and decreased water demands, increases in irrigation efficiency also result in reduced groundwater recharge from irrigation return flows.

SACOG received grant funding from the California Department of Food and Agriculture (CDFA) to evaluate the feasibility of recharging groundwater on agricultural lands within the SACOG portion of the Sacramento Valley to benefit specialty crop production. The primary goal of the project is to bring together a broad range of different factors impacting groundwater recharge and infiltration and to identify areas across the region that are most suited for strategic flooding of specialty crop fields; in other words, areas that will most efficiently and effectively facilitate recharge, while minimizing cost to the specialty crop producer. Ultimately, this feasibility information will be incorporated into SACOG's RUCS model to evaluate the potential benefits of recharging groundwater on agricultural land for the benefit of specialty crops.

TASK 1 – HYDROGEOLOGIC ASSESSMENT AND CONCEPTUAL MODEL

Existing hydrogeologic information for the Sacramento and San Joaquin Valley portion of the SACOG area was reviewed, and a summary conceptual model focused on identifying the key factors relevant to groundwater recharge feasibility was prepared. This high-level review of an area of approximately 3,000 square miles included the following specific tasks:

1. Review and summary of hydrogeologic characteristics of the region.
2. Review and summary of geological suitability for groundwater recharge.
3. General estimation of agricultural water use.
4. Documentation of groundwater elevations and depths.
5. Recommendations for the hydrogeologic factors to be developed for recharge feasibility assessment.

The regional hydrogeological conceptual model is a simplified representation of the groundwater system including the geology, water quality, extent, and flow of groundwater. This review of the hydrogeological components was intended to provide a regional conceptualization of the hydrogeologic factors important to assessing recharge in the Sacramento and San Joaquin Valley portion of the SACOG area and provide datasets to use in spatial recharge feasibility assessment tools. The following recommendations for the application of these information and data to the evaluation of recharge suitability in the Study Area were developed from Task 1 work:

1. Develop indexed geographic coverages of vertical and horizontal hydraulic conductivity for application to the combined recharge suitability index.
2. Develop indexed geographic coverages of unsaturated aquifer thickness from the depth to groundwater datasets presented in this report.
3. Consider developing geographic water use coverage for agriculture. These data were not available for this assessment but may be useful for targeting recharge in the future.

TASK 2 – SUMMARY OF REGIONAL WATER CONVEYANCE INFRASTRUCTURE AND HYDROLOGY

Task 2 focused on recent trends and shifts in irrigation conveyance systems and techniques, including conversion of surface irrigation systems to pressurized systems low-flow systems. This evaluation included the following components:

1. Spatial evaluation of irrigation system types by location
2. General evaluation of changes in irrigation systems in the last 25 years
3. Analysis and summary of applied water by irrigation type and specialty crop
4. Estimation of yields supported by applied water
5. Where possible, determination of water source used for irrigation
6. Where possible, documentation of changes to groundwater recharge that have occurred as a result of conversion to pressurized irrigation techniques

Quantitative and qualitative information on the availability of water from an irrigation water supply and conveyance perspective was compiled to inform scenario development for the RUCS model.

The majority of districts are predominately using surface/gravity irrigation; however, specialty crops may not reflect this proportion. Approximately 20 percent of the land area in the study area has changed from surface irrigation methods to low-flow irrigation methods in the last 25 years. Estimated applied water for each specialty crop within the SACOG region based on 2014 land use mapping was calculated for each primary irrigation type. Typical yield values for each specialty crop were also compiled for this report; however, there is little research on the impact of increasing applied water. Preliminary survey information from field agronomists and farmers in the San Joaquin Valley was used to estimate recharge water in excess of crop water demand that could be applied at different periods of the year/crop cycle. Surface water availability information was reviewed for irrigation districts within the SACOG region which have specialty crops and where groundwater recharge potential was evaluated; however, this information varied by district and was only closely reviewed for areas where groundwater recharge suitability was feasible.

TASK 3 - RECHARGE-SPECIFIC CONCEPTUAL MODEL

Task 3 focused on evaluating groundwater recharge suitability relative to subsurface characteristics, surface soil properties, and crop type, and includes the following components:

1. Identification and description of recharge suitability factors and criteria used to assess infiltration.
2. Application of groundwater suitability index
3. Evaluation of specialty crops' influence on infiltration rates.
4. Development of per acre metrics for groundwater recharge potential by soil and specialty crop types.
5. Evaluation of nutrient load to groundwater potential from surface flooding on specialty crops

The main objective of this work is to apply an index and overlay method, using GIS, to determine a cumulative recharge suitability score for each field in the SACOG area, and develop ratings of good, fair and poor for groundwater recharge suitability. The results are supplemented and supported by narrative and/or qualitative information on the suitability of crops, soil, and hydrogeologic regions for recharge, and the availability and supply of irrigation water throughout the Study Area.

Good and fair ratings for hydrogeologic, soil and crop suitability converge in the southern portion of Sacramento County, central portion of Yolo County, along the Sutter Buttes, and near the intersection of Yuba, Placer, and Sutter counties. The total acreage of good ratings in the final recharge index is 32,179 during wet conditions and 42,345 acres during dry conditions. Approximately 37% of the fields with good ratings are idle while the remainder are primarily almonds, walnuts, grapes, plums, prunes, or apricots. Throughout the study area, specialty crop fields with good overall potential for recharge are limited and scattered compared to the total specialty crop acreage. Surface water suitability was not included in this evaluation at this time because of the scarcity of information available on surface water availability, though water supply and infrastructure were discussed in stakeholder meetings in Task 4.

TASK 4 – STAKEHOLDER ENGAGEMENT

Stakeholder engagement included seven meetings in total. Project updates were provided to stakeholders at three Northern California Water Association meetings in June 2017, December 2017 and June 2018. At the remaining four meetings, stakeholders were convened to present technical findings and receive feedback on these findings and other perceptions about groundwater recharge strategies. Attendees included local growers, water district/provider staff, and local planning entities. The stakeholder meetings were held in three targeted areas where groundwater recharge suitability was dominantly good, relative to other areas in the SACOG region. Groundwater conditions, current recharge activities, potential recharge preferences, and challenges with recharge differed in all three areas. Table 1 is a comparison of these factors in the three target areas.

Table 1. Comparison of Groundwater Recharge Considerations in SACOG Region Areas with Good Recharge Potential

Target Area	Groundwater Conditions	Current Recharge	Potential Recharge	Concerns & Barriers	Opportunities
Yuba/Sutter /Placer Counties Corner	• Generally good high natural recharge on rice fields • Limited aquifer capacity to store additional water except in western Placer county.	• Little active recharge other than winter flooding of rice fields	• Possibly on orchards in western Placer county; recently increased in acreage and increased water demand	• Growers and irrigation districts do not perceive urgent need for recharge • Relatively good groundwater conditions • Preference for selling available surface water out of the area.	• Local groundwater agencies are involved in broader region-wide effort to sustain groundwater levels, including groundwater banking
South Sacramento County	• High incidence of overdraft in aquifer overall • Cones of depression in specific areas	• No active recharge • Pilot studies are beginning because growers see need	• Grape vineyards have the highest potential, and are currently being studied	• Infrastructure to convey surface water is lacking • Area is reliant on groundwater • New infrastructure will be expensive	• Growers see need for recharge and are taking the lead • GSAs will ultimately be able to negotiate incentives to maximize recharge at lowest cost.
Yolo County	• Generally good • Some cones of depression in urban areas that are being corrected.	• Some active recharge using winter diversion through unlined canals	• Various non-crop land sites and farmland have potential to expand total recharge quantities if water can be obtained.	• Cost of regulatory permitting for new diversions; expansion of permanent crops is increasing water demand	• Water supplies are available • Several cropland and non-cropland opportunities exist in the area

TASK 5– SCENARIO DEVELOPMENT

SACOG ran the RUCS modeling tool on the following four scenarios, informed by technical information developed in Tasks 1, 2 and 3, and stakeholder knowledge and perceptions collected in Task 4:

- **Base Case - Recharge flooding with 2014 land use crops**
  - Establishes how much additional water volume could achieve with current (2014) cropping and land use patterns, through implementation of an on-farm recharge program throughout the region
  - Limited to only fields with good or fair soil and hydrogeologic suitability
  - Estimated recharge potential of a winter recharge-flooding program
- **Expanding flood tolerant specialty crops on idle lands**
  - Estimates the potential groundwater recharge benefits if idle cropland in areas with 'good' or 'fair' surface and subsurface suitability were to grow flooding-tolerant specialty crops
  - Crops are expanded in acreage based on their relative proportion in the base case and are allocated based on cropping production factors
- **Recharge flooding with specialty crop expansion**
  - Estimates the potential groundwater recharge benefits if all cropland in areas with 'good' or 'fair' surface and subsurface suitability were converted to grow flooding-tolerant specialty crops
  - Crops are expanded in acreage based on their relative proportion in the entire base case geography
- **Fallowing for recharge under SGMA plans**
  - Fallows 10 percent of the non-specialty crops grown on land with 'good' or 'fair' recharge potential (converting these lands to 'idle')
  - Fallowed lands would be managed as dedicated winter recharge sites to provide additional recharge capacity

The scenario analysis from the RUCS tool showed that in the base case, the annual specialty crops – which make up less than half of recharge acreage but are responsible for nearly three quarters of total potential recharge – provide a more robust opportunity for recharge, as compared with permanent specialty crops, such as orchards or vineyards. Annual specialty crop growers are able to flood their crops during winter months, when crops are not in the ground, so these growers are better able to apply recharge water liberally, without concern for harming their trees or vine stock.

In the idle conversion scenario, recharge capacity fell 44 percent when idle lands were replaced by specialty crops due to the increase in perennial crops which are more restricted in their recharge capacity compared to idle land. However, the conversion from idle land to specialty crops provides significant economic advantages including 15 percent higher return on investment. It also still provides some opportunity for recharge, with the scenario results showing estimated on-farm recharge potential still exceeded irrigated demand by 35 percent.

The non-specialty conversion scenario showed that the addition of more specialty crop acreage increased return on investment by 20 percent compared to the base case; however, this also came with an increase in labor cost. The scenario also showed increased recharge capacity with nearly 125,000 additional acres of recharge potential, which could yield up to an additional 3.4 million acre-feet of water each season. While adding specialty crop acreage increases returns, the irrigation water demand is 'hardened', decreasing flexibility for farmers to fallow crops when water supplies are limited or spike. This increased demand makes recharge efforts that much more critical when surplus water is available.

The 10 percent non-specialty crop fallowing scenario had the most modest change to the base case of any of the scenarios analyzed. This scenario is a strategy that stakeholders on the ground are considering as a measure to improve groundwater supply and reliability for existing and future specialty crop production. Fallowing 13,900 acres of non-specialty crop land brought modest decreases in overall returns, compared with the base case. Despite the small economic impact, this scenario helps to reduce irrigated water demand by nearly 20,000 acre-feet per year and provides an additional 16 percent, or 334,000 acre-feet, of recharge volume.

The scenario results show that annual specialty crops grown on suitable soils provide the greatest recharge potential of the identified specialty crops; however – with the exception of tomatoes – these crops do not currently represent a significant acreage in the region. While crop constraints limit the recharge capacity of orchard and vineyard crops, compared with annual specialty crops, these croplands are still able to generate recharge. The permanent water demand of established orchard and vineyard crops make recharge even more important. With full grower participation and adequate water supply, the region's growers could restore twice as much water as their crops would need for irrigation. This study highlights the potential for specialty crop growers to improve the reliability of their groundwater supplies.

REGIONAL HYDROGEOLOGIC ASSESSMENT FOR RECHARGE FEASIBILITY

SACRAMENTO AREA COUNCIL OF GOVERNMENTS (SACOG)

September 2017

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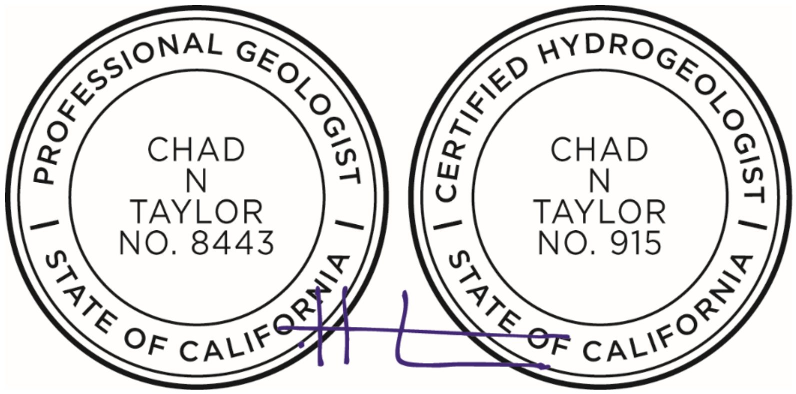

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1. INTRODUCTION

The Sacramento Area Council of Governments (SACOG) is an association of local governments in the six-county Sacramento Region of El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba counties (excludes the Tahoe Basin in Placer and El Dorado counties) and the 22 cities therein. SACOG provides planning and funding for the region and serves as a forum for the study and resolution of regional issues. SACOG prepares the region's long range plan which considers both transportation and land use. Through lens of rural planning, SACOG has actively engaged in a Rural Urban Connections Strategy Program that has studied ways to enhance rural economies and natural assets. This latest study looks at how new agricultural crops and markets coupled with improved irrigation techniques will support new specialty crop acreage in the SACOG area. While new and improved irrigation techniques can result in better crop yields and decreased water demands, increases in irrigation efficiency also result in reduced groundwater recharge from irrigation return flows.

SACOG has requested and received grant funding from the California Department of Food and Agriculture (CDFA) to evaluate the feasibility of recharging groundwater on specialty crop agricultural lands within the SACOG portion of the Sacramento Valley. The first phase of this feasibility study is to conduct a review of the hydrogeologic setting of the Sacramento Valley portion of the SACOG area to identify the hydrologic and hydrogeologic components important to assessing the feasibility of recharging groundwater on agricultural land. The primary goal of the project is to bring together a broad range of different factors impacting groundwater recharge and infiltration and to identify areas across the region that are most suited for strategic flooding of specialty crop fields; in other words, areas that will most efficiently and effectively facilitate recharge, while minimizing cost to the specialty crop producer. Ultimately, this feasibility information will be incorporated into SACOG's existing Rural Urban Connection Strategy (RUCS) model to provide a resource that can be used to evaluate the potential benefits of recharging groundwater on agricultural land.

The first task of this project is to review existing hydrogeologic information for the Sacramento and San Joaquin Valley portion of the SACOG area and prepare a summary conceptual model focused on identifying the key factors relevant to groundwater recharge feasibility. This task is a high-level review of the Sacramento and San Joaquin Valley portion of the SACOG counties, an area of approximately 3,000 square miles. This task includes the following:

6. Review and summary of hydrogeologic characteristics of the region.
7. Review and summary of geological suitability for groundwater recharge.
8. General estimation of agricultural water use.
9. Documentation of groundwater elevations and depths.
10. Recommendations for the hydrogeologic factors to be developed for recharge feasibility assessment.

The regional hydrogeological conceptual model is a simplified representation of the groundwater system including the geology, water quality, extent, and flow of groundwater. This review of the hydrogeological components is intended to provide a regional conceptualization of the hydrogeologic factors important to assessing recharge in the Sacramento and San Joaquin Valley portion of the SACOG area and provide datasets to use in spatial recharge feasibility assessment tools. The results of the hydrogeologic assessment for recharge feasibility in the Sacramento and San Joaquin Valley portion of the SACOG area are presented below.

2. STUDY AREA

As noted above, SACOG includes all of the six counties of El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba. Five of these counties include portions of the Sacramento Valley Groundwater Basin (DWR 2003 and 2016), with El Dorado County standing out as the only SACOG County not overlying portions of the Sacramento or San Joaquin Valley Groundwater Basin (Figure 1). Within the SACOG portion of the Sacramento Valley are all or part of nine individual groundwater subbasins of the Sacramento Valley Groundwater Basin. In addition, there is a single subbasin of the San Joaquin Valley Groundwater Basin in southeastern Sacramento County. Groundwater basins in California are defined by the California Department of Water Resources (DWR). The geographic boundaries of groundwater basins are defined by the areal extent of unconsolidated to semi-consolidated sedimentary deposits, and subbasins are internal basin divisions defined by hydrogeologic and jurisdictional boundaries. Not all areas of the SACOG counties are covered by groundwater basins or subbasins, as shown for portions of Yolo, Sutter, Yuba, Placer, and Sacramento Counties and all of El Dorado County on Figure 1. The SACOG area also includes a large portion of the lower Sacramento River hydrologic region. This represents a significant range of groundwater aquifers and a large watershed with a great deal of hydrogeologic and hydrologic variation.

The regional hydrogeologic assessment includes the Sacramento and San Joaquin Valley Groundwater Basin areas within the SACOG counties (Study Area). Including all the area covered by the groundwater basins in the study area is necessary to allow the hydrogeological conceptual assessment to consider and incorporate the large-scale features and groundwater flow within the natural boundaries of the groundwater basin. The Study Area is shown on Figure 2. This Study Area covers an area of over 2,800 square miles, which is equivalent to almost 1.8 million acres.

The surface water assessment component of this study (to follow in later tasks) need not include the entirety of the watersheds or even the groundwater basin areas associated with the surface water bodies, but should rather focus on discharge rates, diversions, historical use, and potential supply availability. A more focused study area to facilitate a near field scale assessment of surface water availability and use will be used for the surface water assessment task.

2.1. PHYSICAL SETTING

The Study Area covers approximately the southern half of the Sacramento Valley length. The Sacramento Valley is the area of the Central Valley of California north of the Sacramento–San Joaquin River Delta covering all or parts of ten counties in Northern California. The Sacramento Valley is bounded by the Northern Coast Range to the west, the Klamath Mountains to the north, the northern Sierra Nevada Mountains to the east, and the Sacramento–San Joaquin River Delta on the south. The Sacramento Valley is primarily flat grasslands that become lusher on the east side of the valley adjacent to the Sierra Nevada.

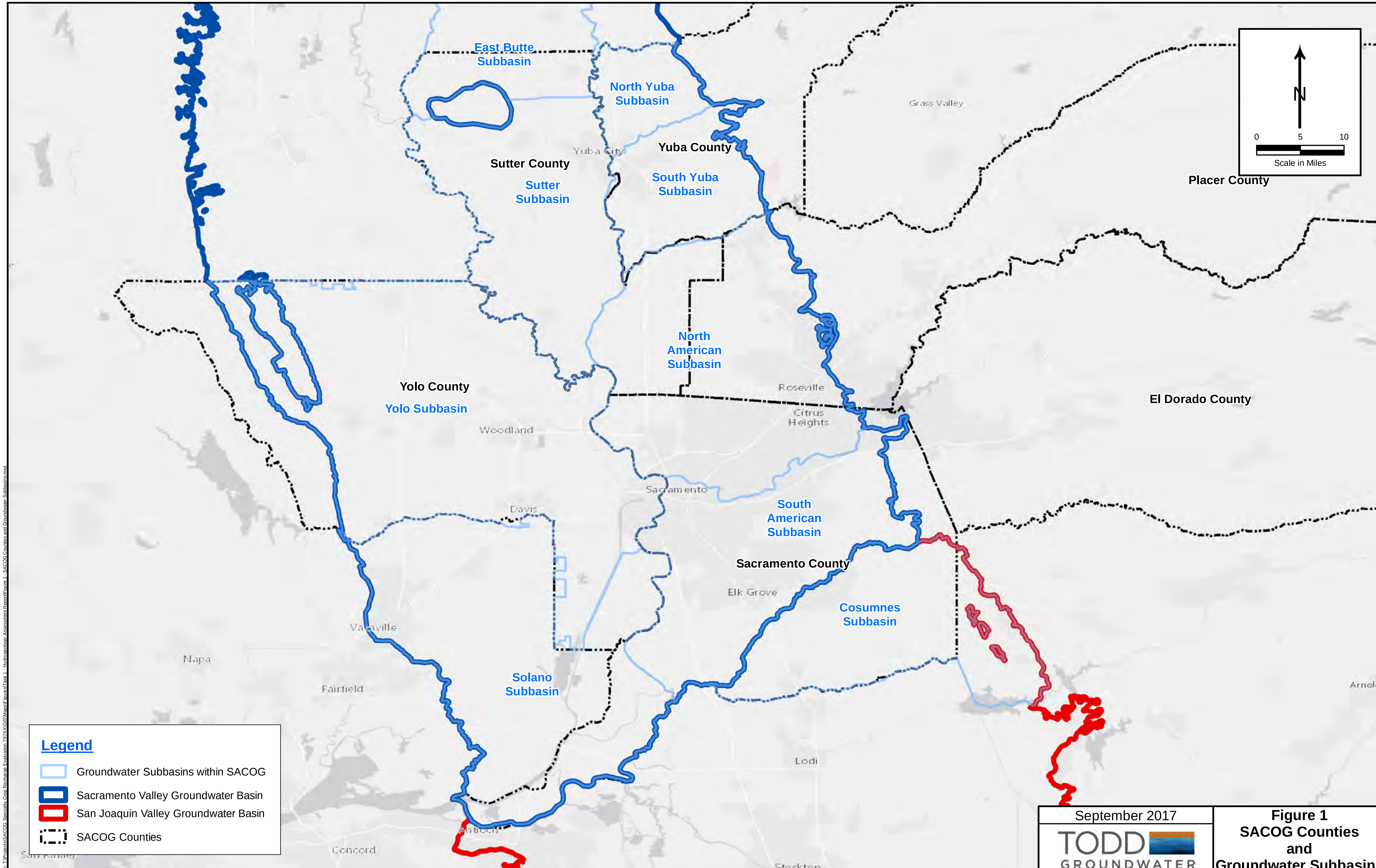

Figure 1
SACOG Counties and Groundwater Subbasins

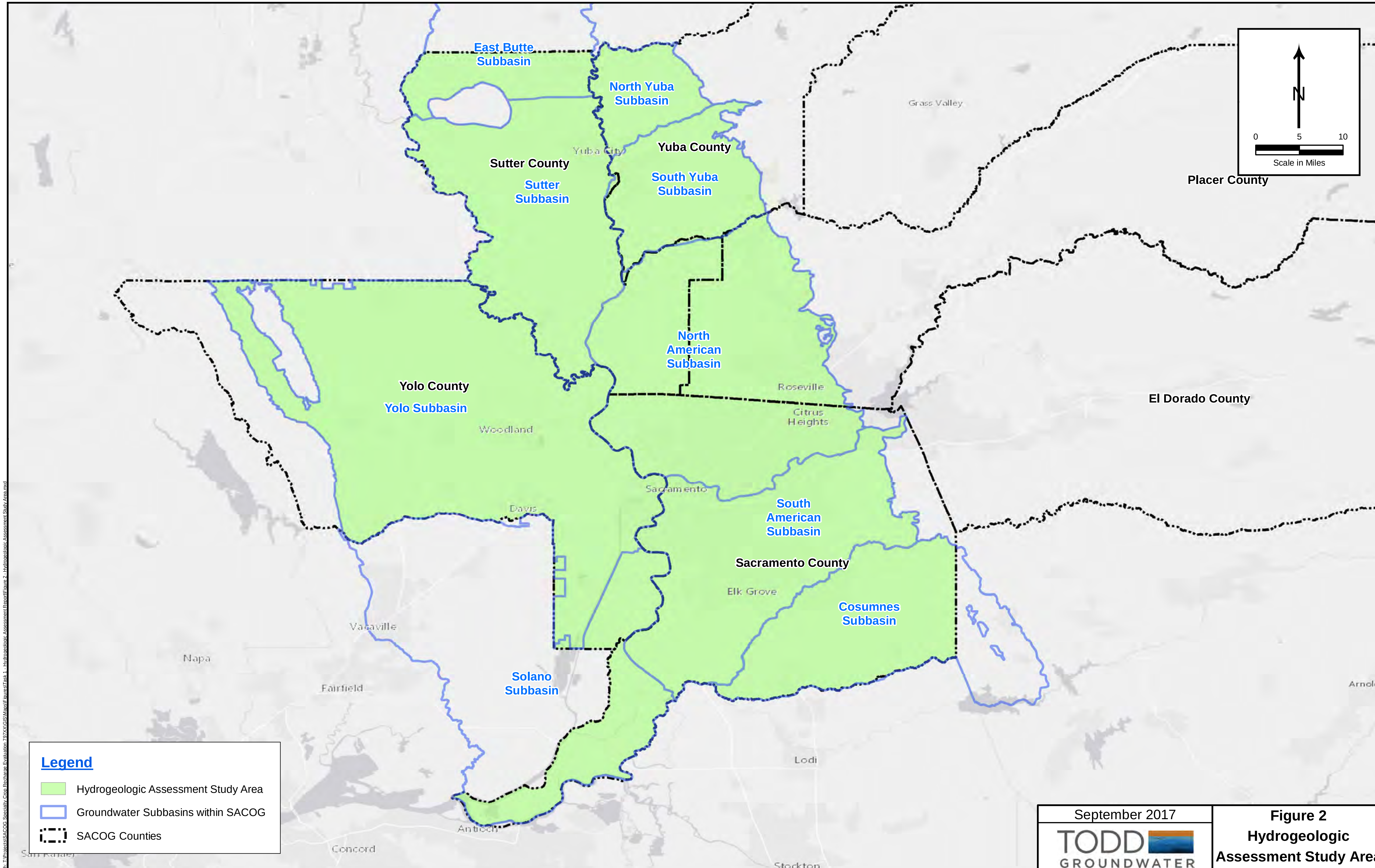

Figure 2
Hydrogeologic Assessment Study Area

The main drainage in the Study Area is the Sacramento River, and the river and its tributaries define the geography of most of the Study Area. The Sacramento River and its tributaries originate and drain the mountain ranges surrounding the Sacramento Valley. These river systems have shaped much of the geography and geology of the Sacramento Valley and they provide a significant source of water for agricultural, municipal, industrial recreational, and environmental uses.

2.1.1. Climate and Precipitation

The Study Area is characterized by cool, moist winters and hot, dry summers. The mean annual temperature from 1982 through 2017 is approximately 60.6 degrees Fahrenheit, and summer highs frequently exceed 90 degrees Fahrenheit in the central part of the Study Area (Davis Station, CIMIS 2017). Average precipitation in the central part of the Study Area is about 15.2 inches per year, mainly October through April (Davis Station, CIMIS 2017). However, precipitation ranges from 12.1 inches per year in the southwestern portion of Sacramento County (Twitchell Island) to over 25 inches per year in the eastern foothills where elevations begin to rise rapidly from the valley floor.

Long-term precipitation isohyets (contours) for the region from the PRISM Climate Group (PRISM 2017) are shown on Figure 3. Given the high temperatures, the average annual evapotranspiration (ET) rate is also high. Annual average ET in the central portion of the Study Area exceeds 58 inches per year (Davis Station, CIMIS 2017). While rainfall is concentrated in relatively low-ET winter months, soil conditions result in much of the valley-floor precipitation evaporating or being taken up by plants. It is assumed only a small portion of groundwater recharge originates directly from deep percolation of precipitation, due to high ET and low rainfall.

2.1.2. Surface Water Hydrology

As noted above, the primary surface water feature in the Study Area is the Sacramento River and its tributaries. These tributaries include the American River, Feather River, and others as shown on Figure 4. Other rivers and creeks flowing through the Study Area, such as the Mokelumne River to the southeast and the Putah Creek to the west, are not tributary to the Sacramento River (Figure 4). Most of the rivers and creeks flowing through the Study Area are dammed or otherwise controlled for flood protection and water supply purposes. These rivers and creeks provide a significant source of water for agricultural and municipal uses both within the Study Area and in other areas of the state. In addition to direct water supply, river and creek flow is also the primary source of groundwater recharge in the Study Area (Davids 2014). The Sacramento Groundwater Authority (SGA) has reported the water quality of the Sacramento and American Rivers to be excellent; diversions for drinking water supply require direct filtration but no other form of treatment before being used (SGA, 2008). Further assessment of surface water hydrology, natural and controlled discharge rates, historical agricultural water availability from surface water, and potential recharge water availability will be assessed in later portions of this project.

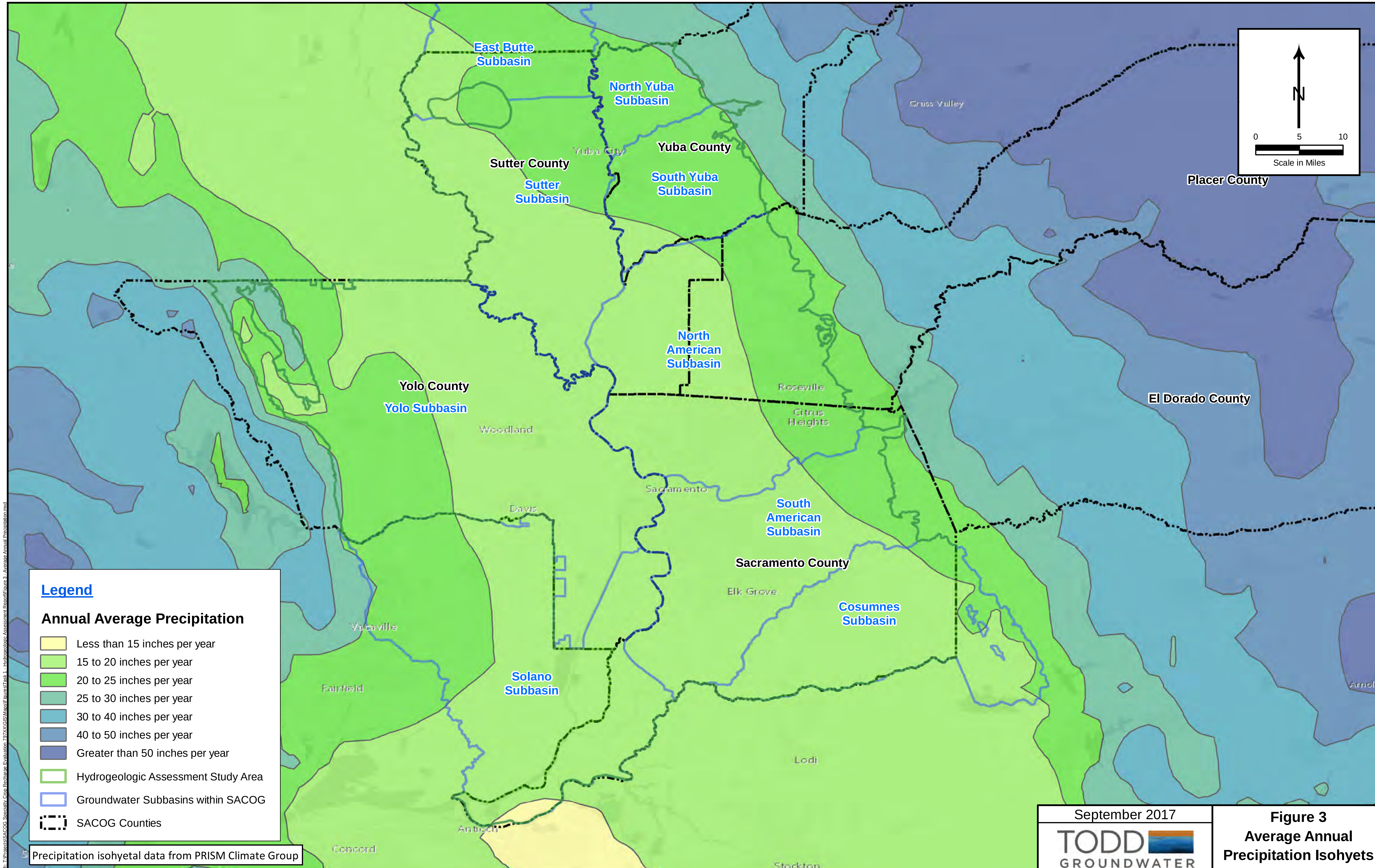

Figure 3
Average Annual Precipitation Isohyets

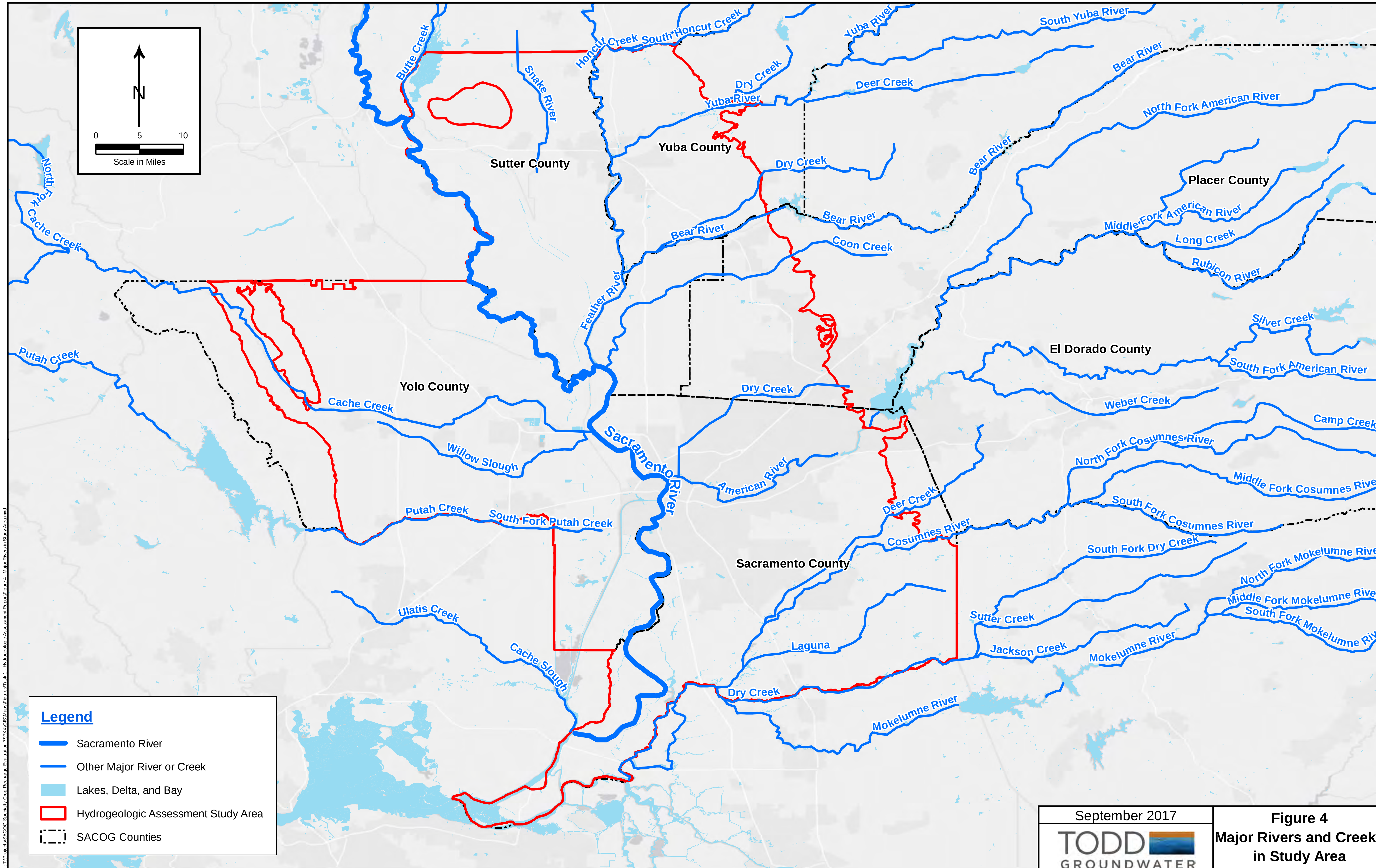

Figure 4
Major Rivers and Creeks in Study Area

3. HYDROGEOLOGY

The Study Area overlies a large part of the Sacramento Valley Groundwater Basin and a small part of the San Joaquin Groundwater Basin. These groundwater basins are part of the Central Valley of California, a long structural trough filled with more than 4,000 feet of marine and continental sediments. The continental sediments represent a variety of depositional environments including river and stream deposits (fluvial), delta deposits (deltaic), lake deposits (lacustrine), and alluvial fan sequences and form an alluvial wedge that generally thickens to the west across the valley.

Surficial geology of the Study Area is shown on Figure 5 (USGS 2007). The Study Area is characterized by a relatively flat alluvial plain surrounded by the dissected uplands of the Northern Coast Ranges to the west, the northern Sacramento Valley to the north, the northern Sierra Nevada to the east, and the Sacramento-San Joaquin Delta and northern San Joaquin Valley to the south. The most notable geologic feature in the Study Area is the Sutter Buttes, a Pliocene aged volcanic plug that rises 2,000 feet above the valley floor in the northern portion of the Study Area.

Some geologic features may result in restrictions to groundwater recharge and flow. These include the Mehrten Formation, a sequence of Miocene to Pliocene aged volcanics that can restrict the vertical movement of groundwater, and faulting and folding in older sedimentary units in the western Study Area (Olmstead and Davis 1961). Groundwater flow is generally from north to south and from the mountains on the periphery toward the center of the Study Area.

3.1. GROUNDWATER BASINS

The Study Area includes all or part of nine groundwater subbasins. The mapped extents of these subbasins are determined by the DWR. In general, groundwater basins are defined by the areal extent of unconsolidated to semi-consolidated sedimentary deposits. A simplified geologic map showing these surficial geologic differentiations is included on Figure 6. Subbasin divisions of groundwater basins may be created based on hydrogeologic or jurisdictional boundaries. Most of the boundaries between subbasins in the Study Area are based on the presence of hydrogeologic or hydrologic features, such as major rivers, most notably the Sacramento River. Summary descriptions of the geographic extents of each of the subbasins are presented below:

East Butte Subbasin
The northernmost groundwater basin in the SACOG area is East Butte. Only the southernmost portion of the 267,457 acre subbasin is within the Study Area, and it is bounded by Butte Creek to the west, the Sutter Buttes to the south, and the Feather River to the east. Managed groundwater recharge has been successful in this subbasin in the area south of Thermalito Afterbay (DWR 2003).

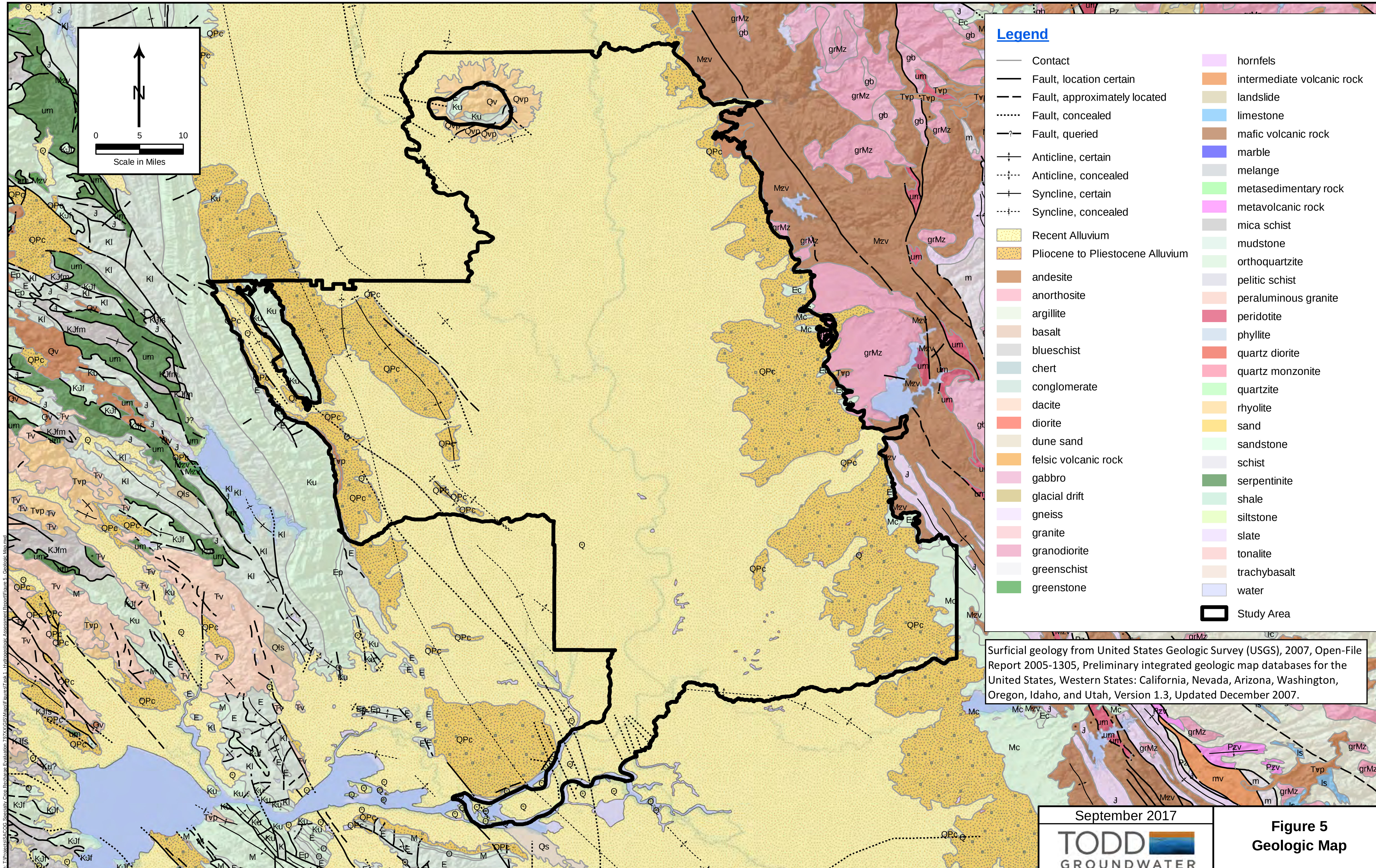

Figure 5
Geologic Map

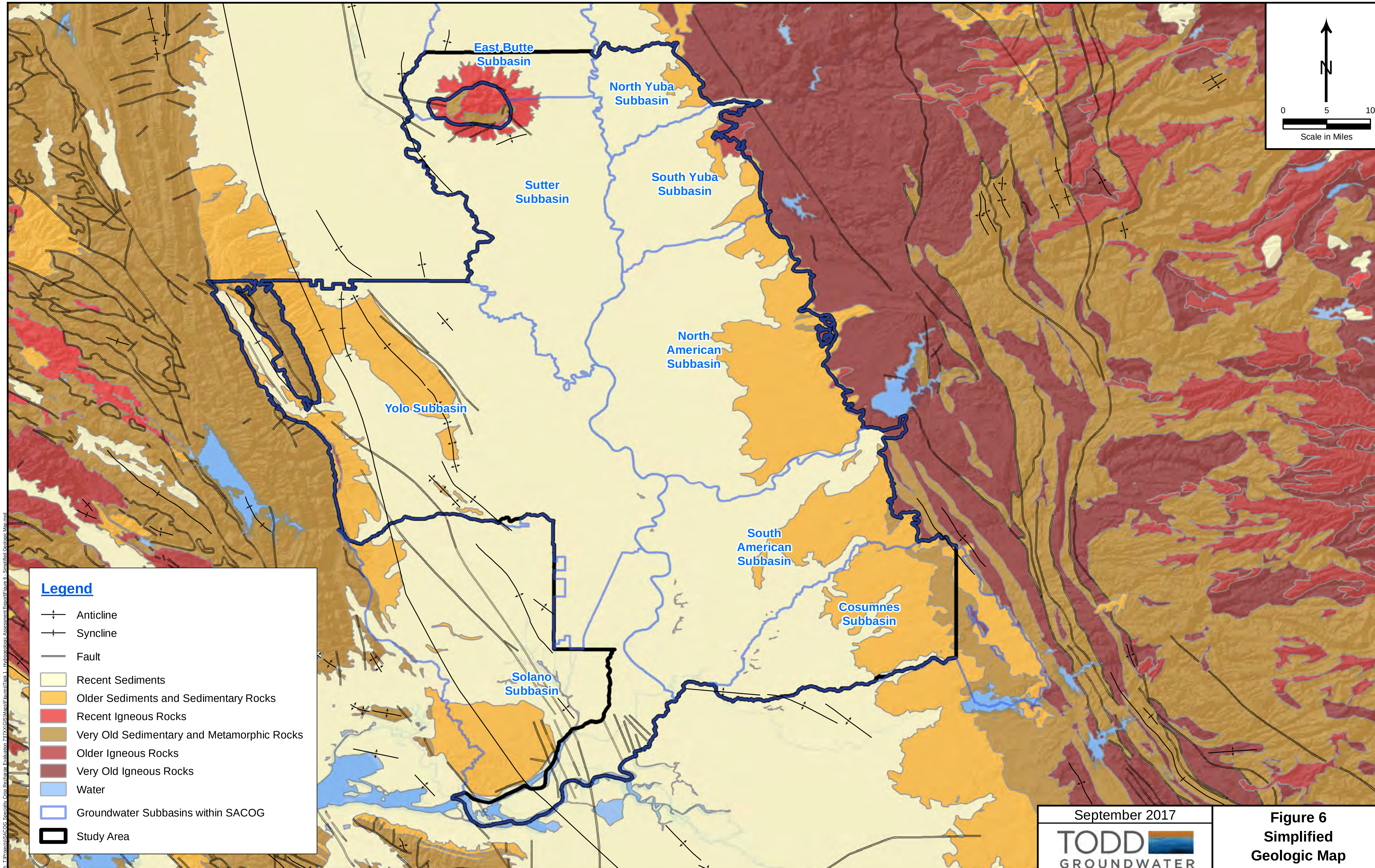

Figure 6
Simplified Geologic Map

Sutter Subbasin
The Sutter subbasin encompasses 233,086 acres in the northern portion of the Study Area. The subbasin is bound on the north by the Sutter Buttes and extends from the Sacramento River in the west to the Feather River on the east.

North Yuba Subbasin
The North Yuba subbasin is in the northeastern corner of the Study Area. This subbasin is 56,456 acres in area and bound by the Feather River on the west, South Honcut Creek on the north, the Yuba River on the south, and the consolidated rocks of the Sierra Nevada foothills in the east (Figures 4 and 6).

South Yuba Subbasin
Located just south of the North Yuba subbasin is the 109,661 acre South Yuba subbasin. This subbasin is bound by the Yuba River in the north, the feather river to the west and the consolidated rocks of the Sierra Nevada foothills on the east (Figures 4 and 6).

Yolo Subbasin
The Yolo subbasin is 504,201 acres extending over most of Yolo County. This area was previously divided into multiple smaller subbasins including Cache Creek, Upper Cache-Putah, Plainfield Ridge, Lower Cache-Putah, and Colusa, which were all combined to form the Yolo subbasin. The subbasin is bound on the north by Cache Creek, east by the Sacramento River, south by Putah creek, and west by the consolidated rocks of the Coast Range (Figures 4 and 6).

Solano Subbasin
The southwestern portion of Sacramento County and the southwestern portion of Yolo County overlies the Solano subbasin, which extends outside the Study Area into Solano County. The subbasin is 390,500 acres and is bound by the Putah Creek in the north, the Sacramento River in the east, and San Joaquin River to the south.

North American Subbasin
The North American subbasin underlies northern Sacramento county, western Placer County, and southeastern Sutter County. The 342,265 acre subbasin extends from the American River in the south to the Bear River in the north. It is bounded on the west by the Sacramento River and terminates in the east at the edge of the mapped sedimentary materials that comprise the water-bearing aquifer (Figure 6).

South American Subbasin
The 248,435 acre South American subbasin is located in central Sacramento County. The American River, Cosumnes River, and Sacramento River form the basin's northern, southern, and western boundaries respectively. The subbasin includes much of the Sacramento metropolitan area and extends eastward to the Sierra Nevada foothills to the edge of the mapped sedimentary materials (Figure 6).

Cosumnes Subbasin
The Cosumnes subbasin is in the southeastern portion of Sacramento County and is the only SACOG subbasin in the San Joaquin Groundwater Basin system. Located in the southeastern Study Area, it is bound by the Cosumnes River to the north, Dry Creek to the south, and the consolidated rocks of the Sierra Nevada foothills to the east (Figure 6). The subbasin is 210,276 acres with aquifer units extending up to 2,500 feet deep in some areas.

3.2. WATER BEARING AQUIFER UNITS

The aquifer units of the Study Area have been described in numerous previously completed studies including nearly 20 groundwater management plans, and numerous local investigations and studies. Most of these studies were completed for limited areas that do not encompass the entire Study Area and there is often disagreement between individual studies with regard to the names and composition of aquifer units. Nonetheless, two studies cover the entire study area and describe aquifer units in a consistent manner. These are Bulletin 118 from DWR (2003) and the United States Geological Survey report, *Geologic Features and Ground-Water Storage Capacity of the Sacramento Valley California,* by Olmstead and Davis (1961). A summary of the aquifer units present in the Study Area is presented below:

Recent Stream and Channel Deposits
The most recent deposits in most of the Study Area are Holocene stream channel and basin deposits. The thickness (depth) of these deposits varies widely from approximately 1 to 80 feet. These deposits are moderately to highly permeable and can be present to varying degrees throughout low-lying portions of the Study Area.

Quaternary Alluvium
Alluvial fan deposits are composed of loosely compacted silt, sand, gravel, and lesser amounts of clay from the Sierra Nevada and Coast Ranges. Sometimes recent stream and channel deposits are grouped into this category. The combined thickness of all younger alluvial deposits is about 100 feet and the deposits are generally coincident with the water table. In some places hardpan and claypan soils have developed and form an impermeable barrier that could reduce recharge feasibility.

Pleistocene Older Alluvium (Pleistocene Victor, Turlock Lake, or Modesto Formations)
Older alluvium occurs in much of the eastern Study Area (Butte, North American, South American, and Yuba subbasins). These materials are sometimes referred to by formation names including Victor, Turlock Lake, or Modesto for local discussion purposes. Older alluvium can be up to 100 feet thick underlying younger alluvium. These materials are generally considered to be moderately permeable.

Pliocene Tuscan Formation

The Tuscan Formation is found primarily in the northeastern portion of Study Area. This formation is fairly permeable, but does contain beds of tuff (a rock type formed by the consolidation of volcanic ash) and breccia (a rock type consisting of angular fragments consolidated together) that can form local aquitards (Olmstead and Davis 1961).

Pliocene Tehama Formation

The Tehama Formation is found in the western portion of the Study Area in the Butte, Yolo, and Solana subbasins. The Tehama formation in Butte County makes up a significant portion of the groundwater aquifer on the west side of the subbasin (CDM 2004). The formation ranges in thickness from 1,500 feet to 2,500 feet and has limited surface exposure occurring only on the western edge of the subbasin along the Coast Range. The Tehama consists of moderately compacted silt, clay, and silty sand, with variable permeability (Olmstead and Davis 1961).

Pliocene Laguna Formation

The Laguna Formation is a moderately consolidated layer comprised largely of fine grained materials and some cemented materials with local areas of low permeability. The formation ranges in thickness from 400 to 1,000 feet in the Study area (DWR 2003).

Miocene-Pliocene Mehrten Formation

The Mehrten is a sequence of fragmented volcanic rocks and sedimentary units. There is limited surface exposure of this formation; it crops out only along the eastern margin of the Study Area (Figure 5). The sand and gravel intervals are highly permeable but the volcanic tuff breccia components of the formation can act as confining layers. The thickness of the formation ranges from 200 to 1,200 feet (DWR 2003). This formation is sometimes referred to as the Sutter or Valley Springs Formation (Olmstead and Davis 1961).

3.3. AQUIFER CHARACTERISTICS RELATED TO RECHARGE

The key elements of hydrogeology for assessing relative groundwater recharge potential and benefits include:

- Vertical groundwater flow potential, which is a represented by vertical hydraulic conductivity, a description and measurement of the capacity of a porous media to transmit water vertically.
- Relative permeability, which is commonly represented by horizontal hydraulic conductivity, a measurement of the capacity of a porous media to transmit water horizontally.
- Presence of vertical boundaries to flow (aquitards), which are often the result of low permeability geologic units separating higher permeability units.

Available data on these aquifer characteristics were reviewed from multiple available previously completed studies, including groundwater management plans (GWMPs), DWR Bulletin 118, geologic maps, and other previously completed studies. Most of the available sources of information include narrative descriptions of aquifer characteristics, but very few include quantitative aquifer parameters that can be used to compare the relative recharge feasibility across the Study Area. The best available source for quantitative aquifer information covering the entire Study Area is the Central Valley Hydrologic Model (CVHM), which is a numerical groundwater model developed by the United States Geological Survey (Faunt 2009). While the CVHM is a good source of information relating to regional hydrogeology, it is a large-scale model populated with aquifer parameter data based on calibration to a limited set of aquifer characteristics and groundwater elevations. As a result, the aquifer parameters in the CVHM may not perfectly capture small-scale hydrogeologic features of complexity. A summary description of the CVHM and the methods used to develop and apply aquifer parameters to it is presented in Appendix A.

3.3.1. Horizontal and Vertical Hydraulic Conductivity in the Study Area

Hydraulic conductivity is a measure of the capacity of a porous media to transmit water. Groundwater aquifers generally have higher capacity to transmit water horizontally than vertically, so hydraulic conductivity is separated into horizontal and vertical components when modeling natural systems.

Horizontal and vertical hydraulic conductivity for the shallow aquifer materials throughout the Study Area are shown on Figures 7 and 8, respectively. These conductivity values are from the first two layers of the calibrated CVHM, representing approximately the upper 150 feet of aquifer materials. The first two layers were selected because they represent the elevation range within which shallow groundwater is generally found in the Study Area. Therefore, the first two layers best represent the horizontal and vertical hydraulic conductivities relevant to groundwater recharge.

When water enters a groundwater system, the rate at which it moves laterally is governed by horizontal hydraulic conductivity and the rate at which it moves vertically is governed by the vertical hydraulic conductivity. Water recharged in a discrete location will infiltrate more rapidly in areas with higher vertical hydraulic conductivity, making vertical hydraulic conductivity an important factor in managed recharge feasibility. When large volumes of water are recharged in discrete locations, there is a tendency for groundwater mounds to develop beneath the recharge areas. This can lead to decreased recharge rates or rejection of recharge water. However, water moves laterally away from a recharge source in areas with higher horizontal hydraulic conductivity. Therefore, it is important to also consider relative horizontal hydraulic conductivity when selecting recharge locations.

3.3.2. Aquitards

Aquitards are local or regional units of low permeability that limit vertical flow of groundwater. No regional aquitards that would impede the vertical flow of recharged water have been identified in the Study Area. However, hardpan and claypan soils have developed and form impermeable barriers to vertical flow that may reduce recharge feasibility in young alluvium sediments. These shallow low permeability features are included and represented in soils maps, and evaluation of the effect of these materials on recharge feasibility will be considered in future tasks. Additionally, the tuff breccia units in the Tuscan and Mehrten formations can act as aquitards. The Tuscan Formation may be within the upper 100 feet of ground surface in some locations in the Study Area while the Mehrten Formation is generally much deeper except at the east and west margins of the Study Area. However, no consistent mapping of the horizontal or vertical extents of the units that act as aquitards within the Tuscan or Mehrten formations was identified during this review.

3.3.3. Other Geologic Features that May Reduce Recharge Feasibility

In the western Study Area within the Yolo subbasin, there are fold and fault geologic features that affect groundwater flow and should be considered when assessing recharge feasibility. The most prominent of these features is an anticlinal ridge expressed as the Dunnigan Hills and Plainfield Ridge which bisect the basin, impeding flow west to east (DWR 2003). There is also significant faulting in this area that may impact horizontal groundwater flow. These features are shown on Figures 5 and 6.

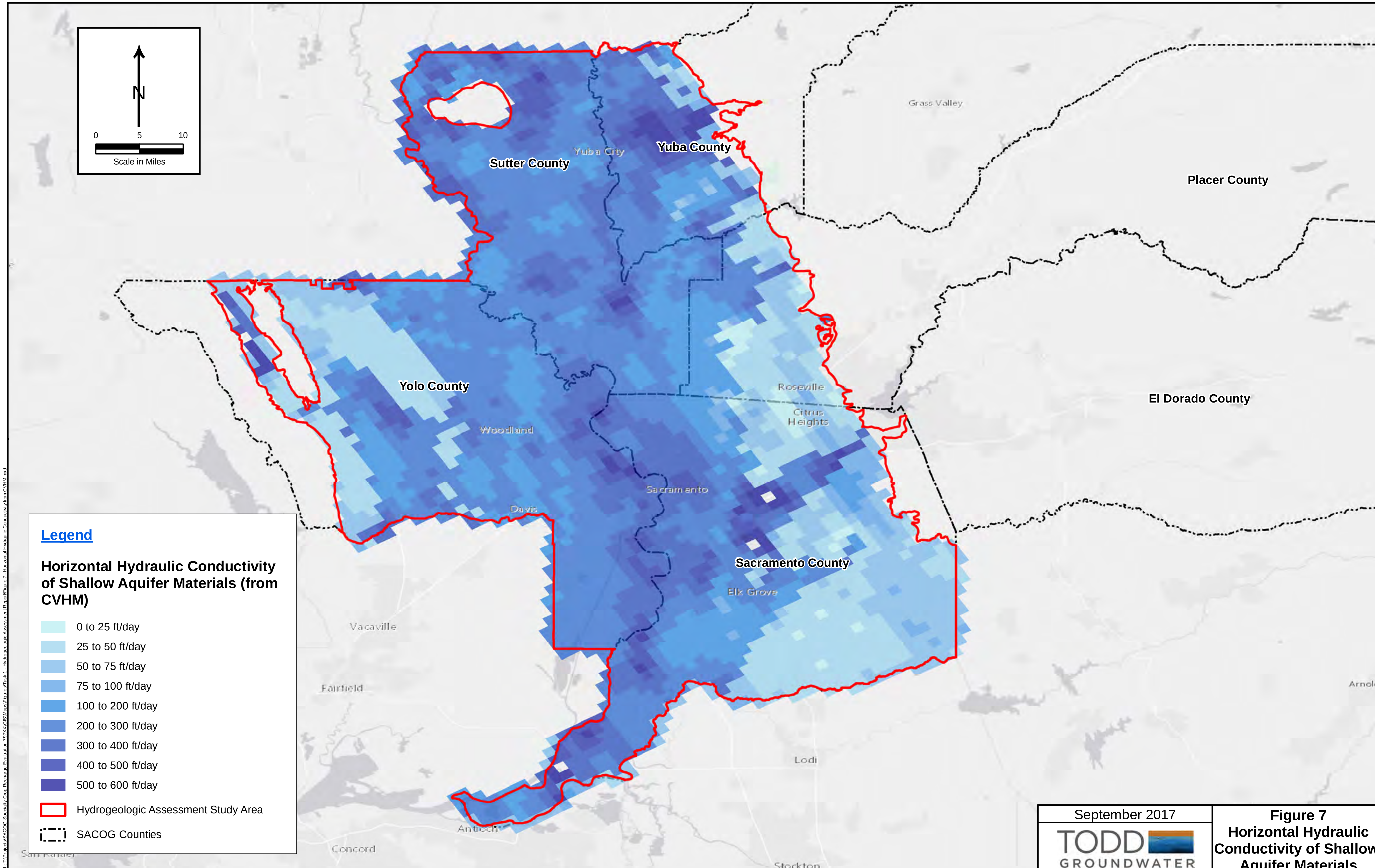
N
0
5
10
Scale in Miles
Grass Valley
Placer County
Yuba City
Yuba County
Sutter County
Yolo County
Woodland
Roseville
Citrus Heights
El Dorado County
Sacramento
Davis
Sacramento County
Elk Grove
Vacaville
Fairfield
Lodi
Arnold
Antioch
Concord
Stockton
Legend
Horizontal Hydraulic Conductivity of Shallow Aquifer Materials (from CVHM)
0 to 25 ft/day
25 to 50 ft/day
50 to 75 ft/day
75 to 100 ft/day
100 to 200 ft/day
200 to 300 ft/day
300 to 400 ft/day
400 to 500 ft/day
500 to 600 ft/day
Hydrogeologic Assessment Study Area
SACOG Counties
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Figure 7
Horizontal Hydraulic Conductivity of Shallow Aquifer Materials

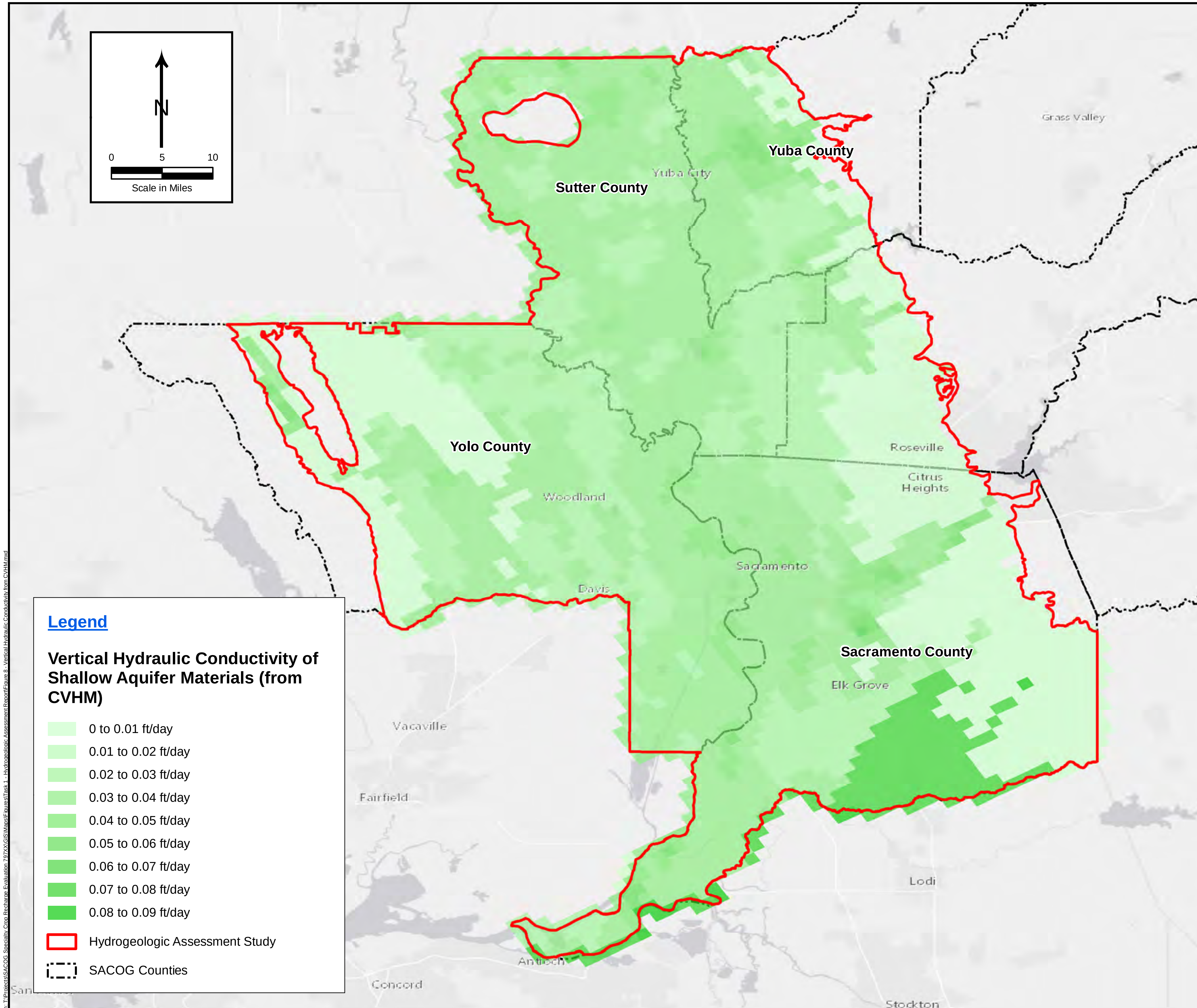

Figure 8
Vertical Hydraulic Conductivity of Shallow Aquifer Materials

4. GROUNDWATER ELEVATIONS AND DEPTH TO WATER

Groundwater elevation data were collected and compiled from DWR through the California Statewide Groundwater Elevation Monitoring (CASGEM) program and Water Data Library and from the USGS through the National Water Information System (NWIS). In total, groundwater elevation data were available for over 3,500 wells in and around the Study Area. This represents all the wells that have ever been monitored by these two agencies, but not all wells are still being monitored. Of the 3,500 total wells, over 1,000 are still actively monitored. Groundwater elevation data from these wells were compiled into a unified database and reviewed to assess groundwater elevation trends by subbasin, prepare selected groundwater surface contour maps, and estimate Study Area-wide depth to water.

4.1. GROUNDWATER TRENDS

Historical groundwater elevation data from the available records were evaluated to identify trends in groundwater conditions within each subbasin in the Study Area. The wells with the longest and most consistent records were reviewed to identify trends in each subbasin. These records showed wide variation in both short and long term trends within each subbasin. However, there were some patterns of trends in groundwater conditions. Wells representing these patterns within each subbasin were identified and are presented on Figures 9 through 15. A brief description of trends in each of the Study Area subbasins follows:

East Butte Subbasin
The hydrograph for 18N-03E-18F1 in Figure 9 shows the general trend in the East Butte subbasin. All the long-term hydrographs available for the subbasin show similar stable groundwater conditions from the 1950s through 2010. Water levels vary seasonally by five to ten feet, reflecting seasonal pumping and recharge cycles. The magnitude of these seasonal changes increased during the recent drought period.

North Yuba Subbasin
Figure 10 shows a hydrograph representing the long-term records in the North Yuba subbasin. The seasonal variation in this hydrograph is 10 to 20 feet, with higher elevations in the spring and lower elevations in fall. Groundwater elevations declined during the drought in the early 1990s drought and have remained low since. The recent drought resulted in further declines in groundwater elevations in the North Yuba subbasin.

South Yuba Subbasin
Figure 10 also shows a representative hydrograph from the South Yuba subbasin. This hydrograph shows a consistent decrease in groundwater elevations through the early 1980s, followed by increasing elevations through 2006. The recent drought resulted in brief elevation declines in 2010 and 2016. Groundwater elevations appear to have recovered quickly following these brief declines.

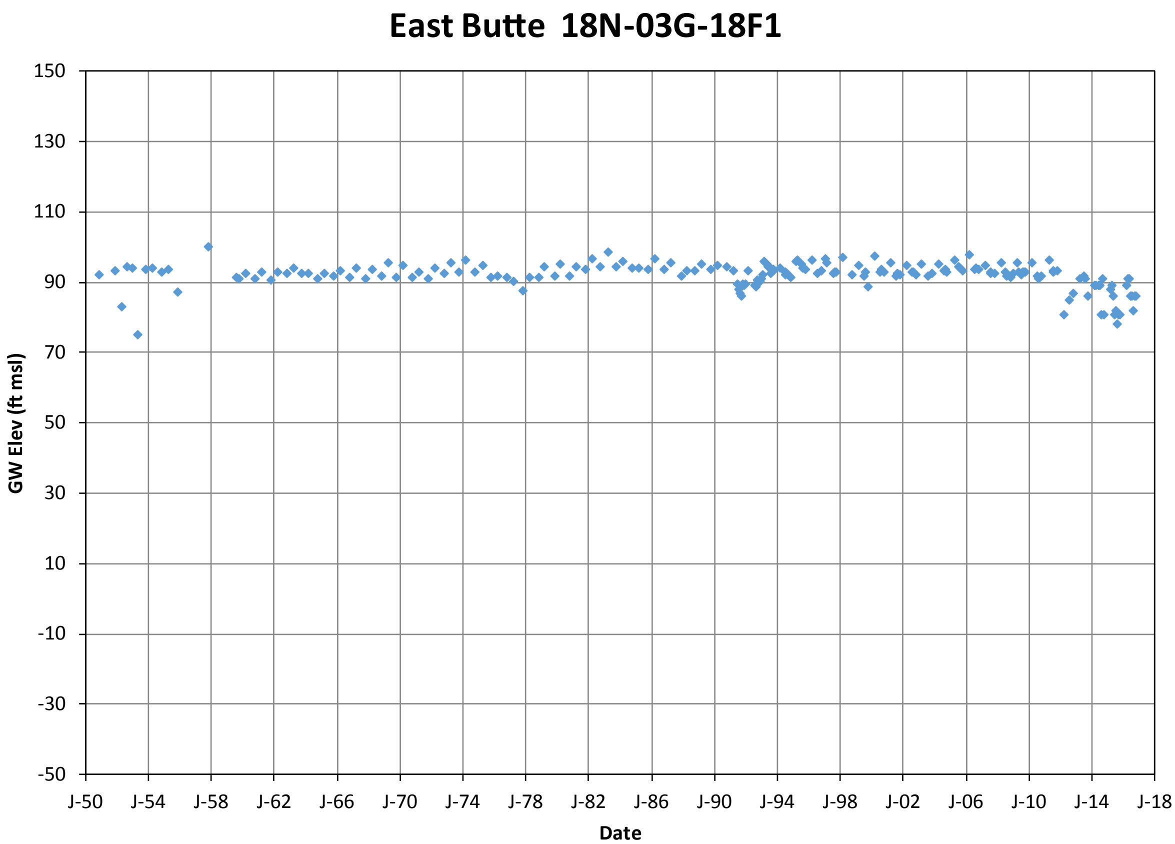

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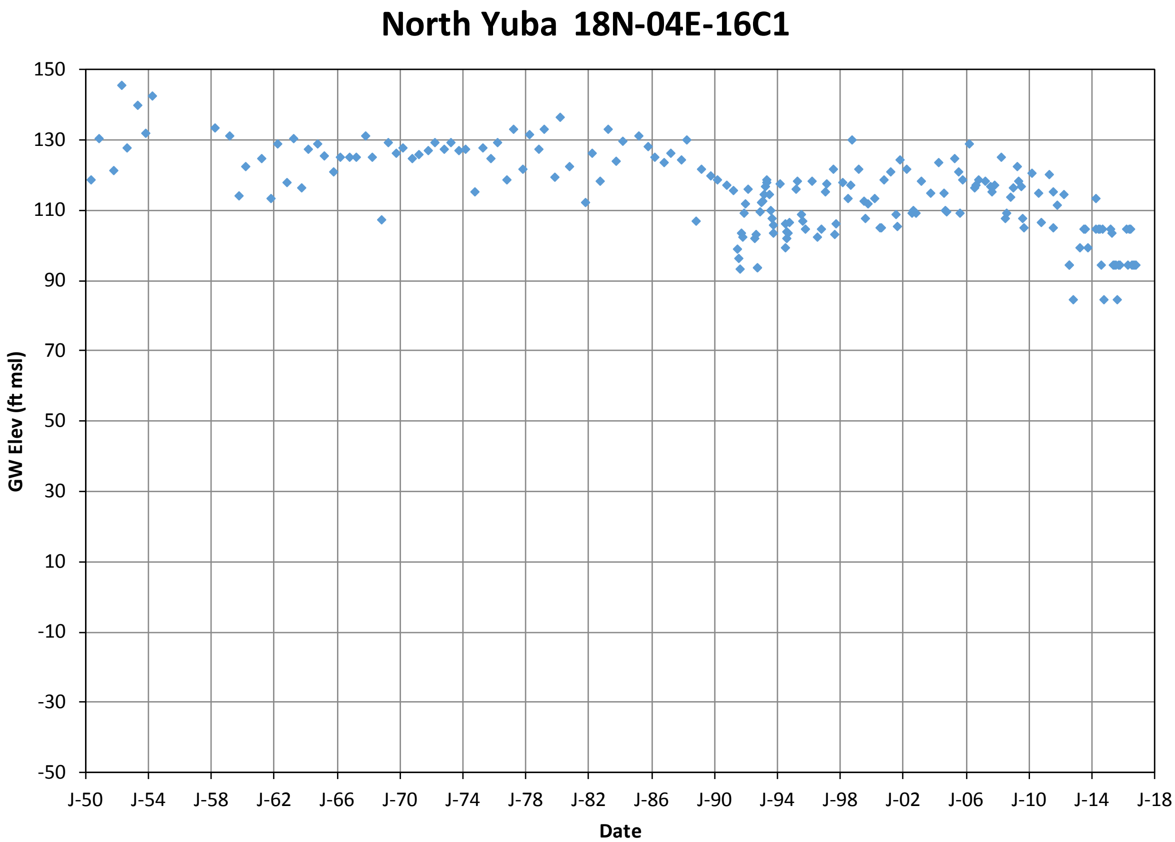
Figure 9
Hydrograph for East Butte Subbasin



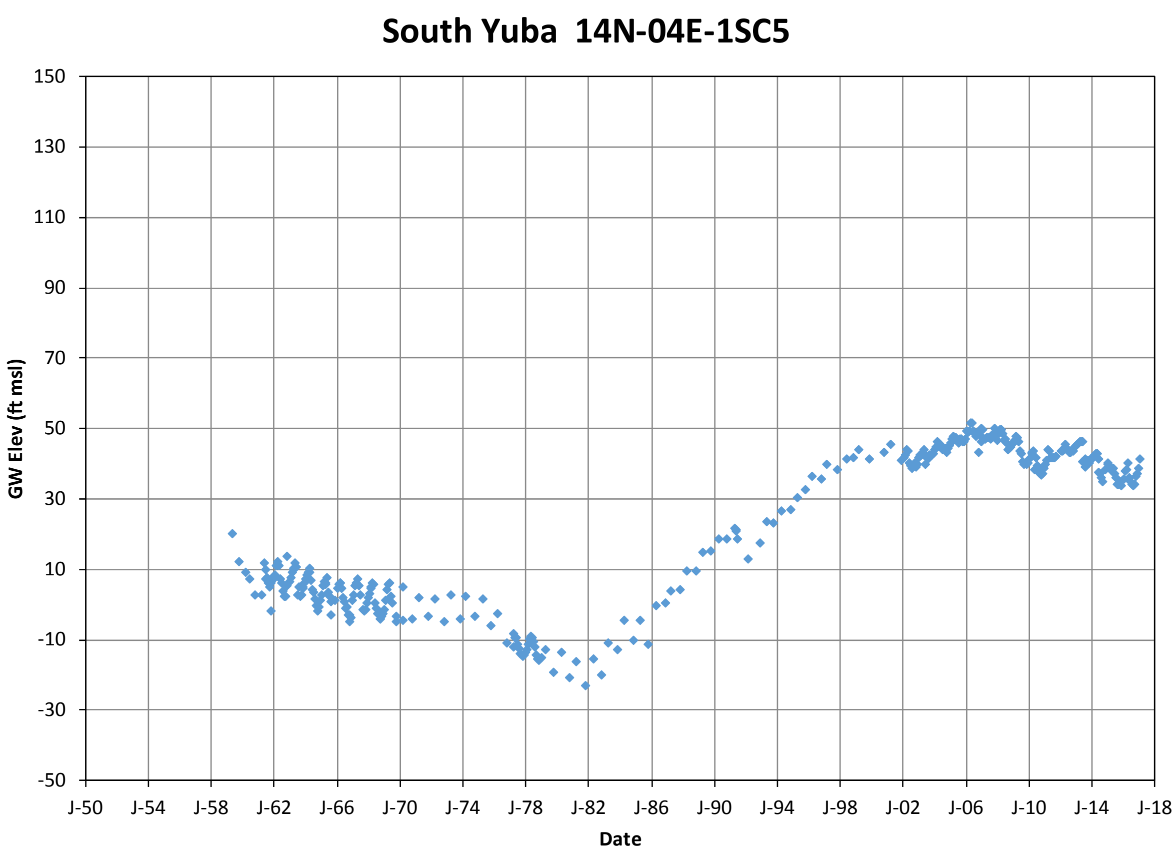


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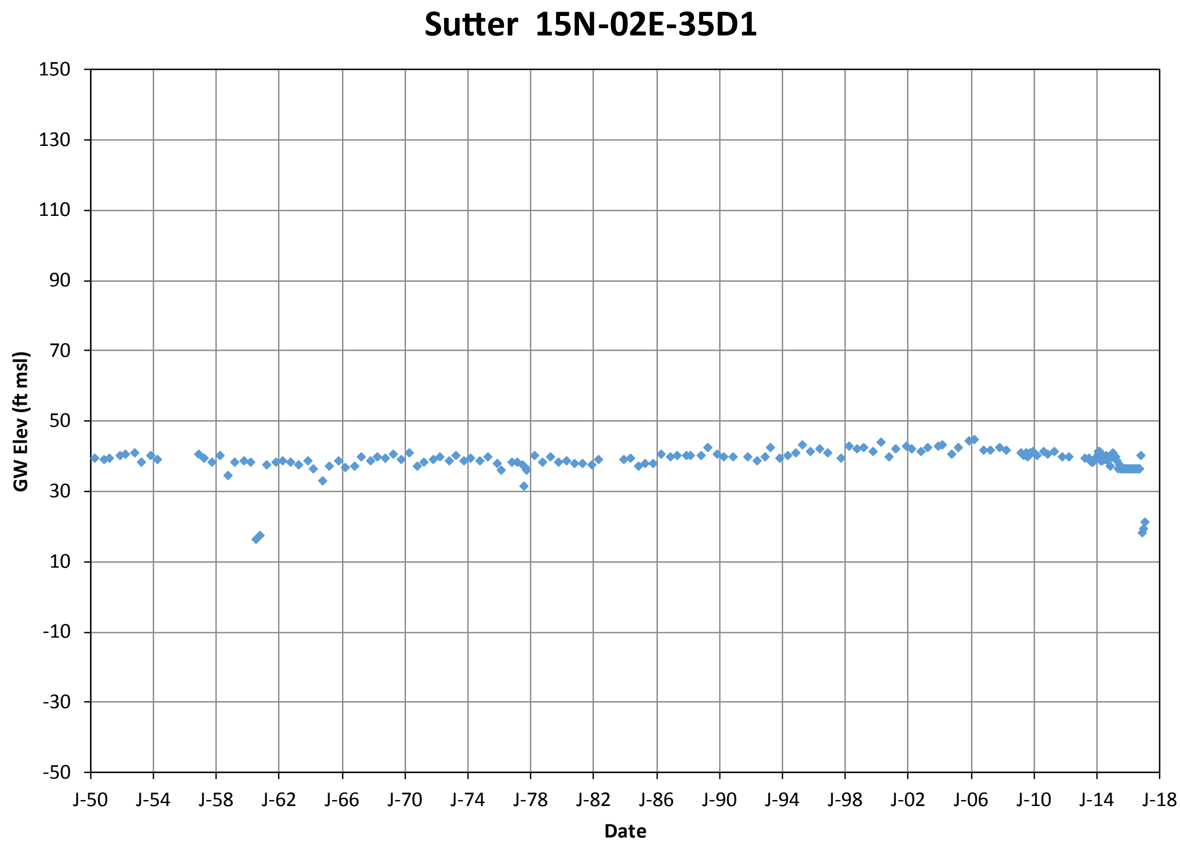
Figure 10
Hydrographs for Yuba Subbasins



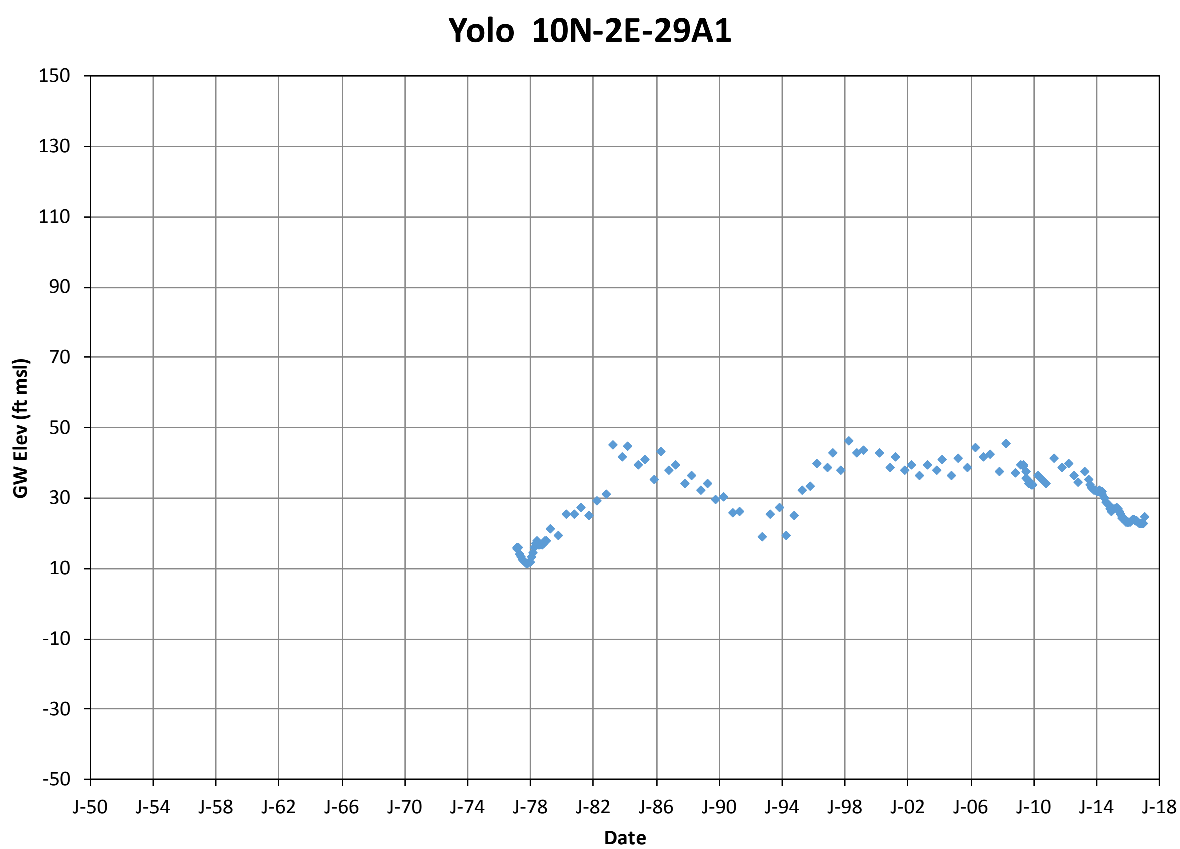


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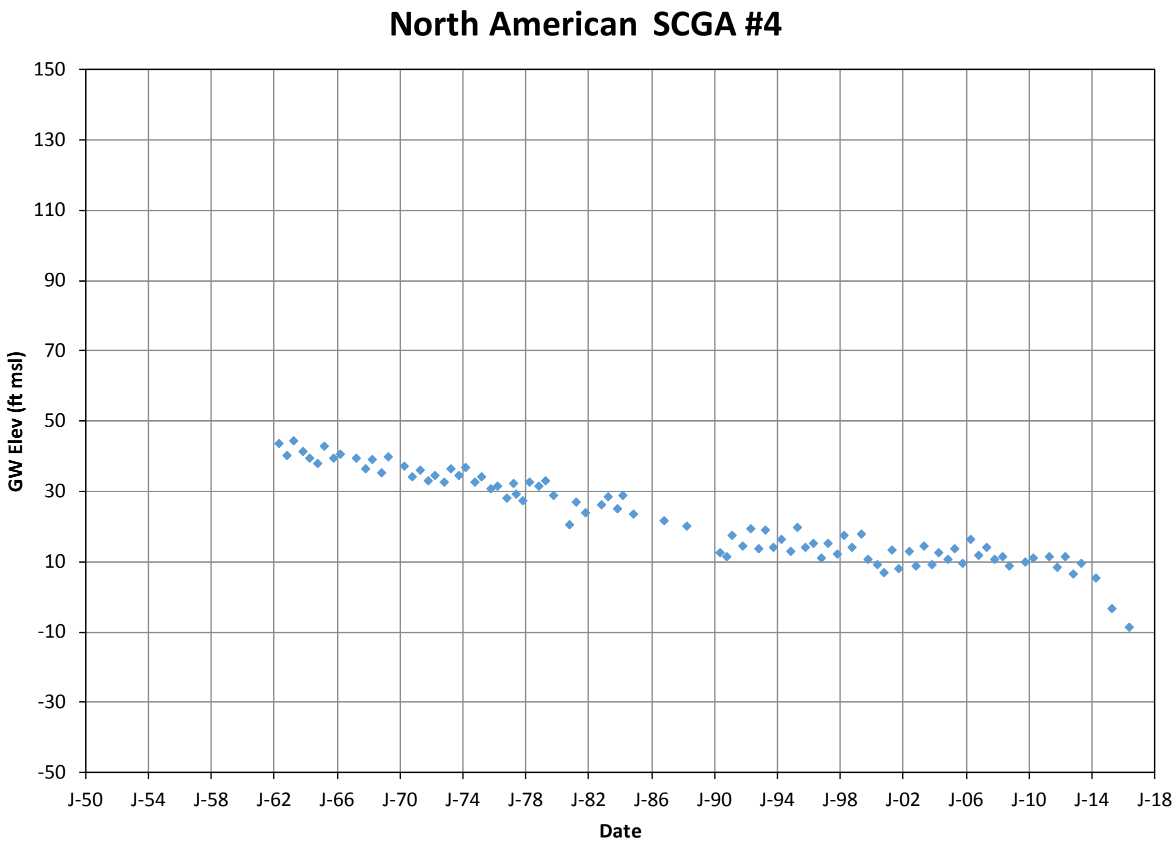
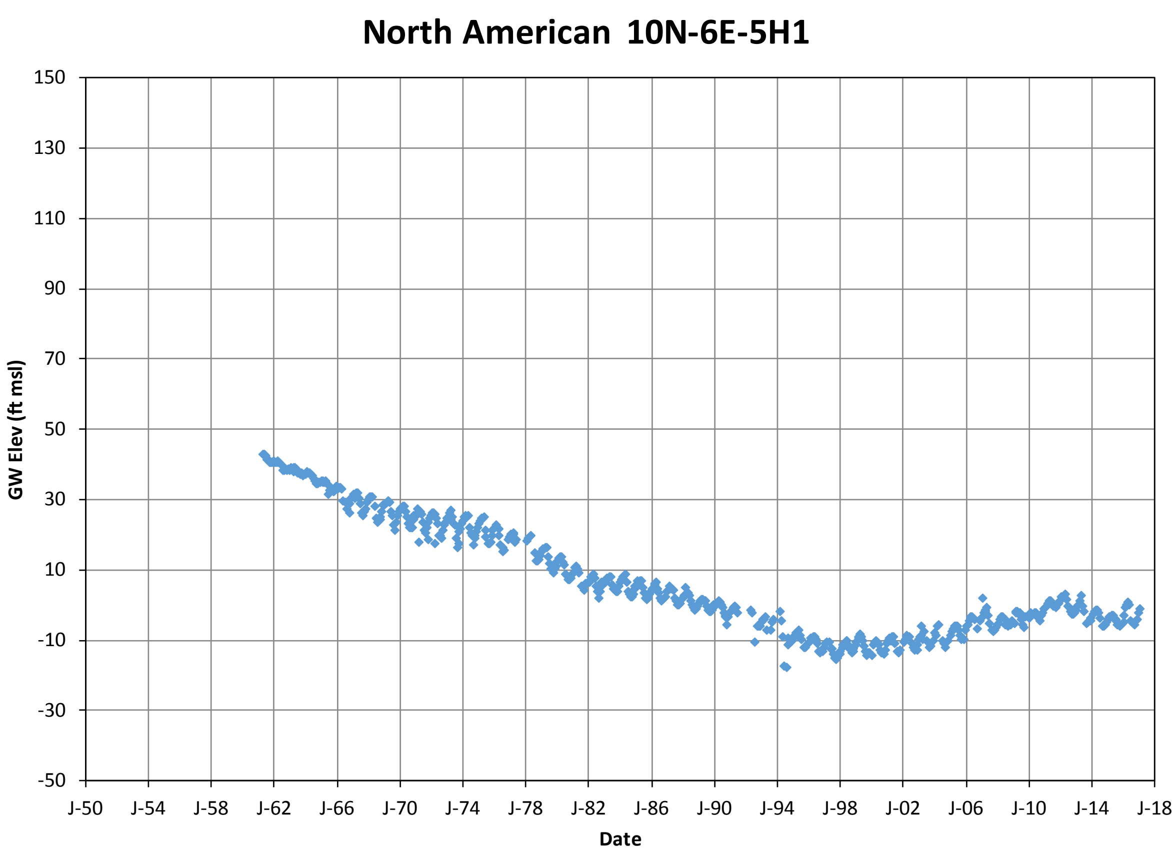
Figure 11
Hydrographs for Sutter and Yolo Subbasins





September 2017	Figure 12 Hydrographs for North American Subbasin
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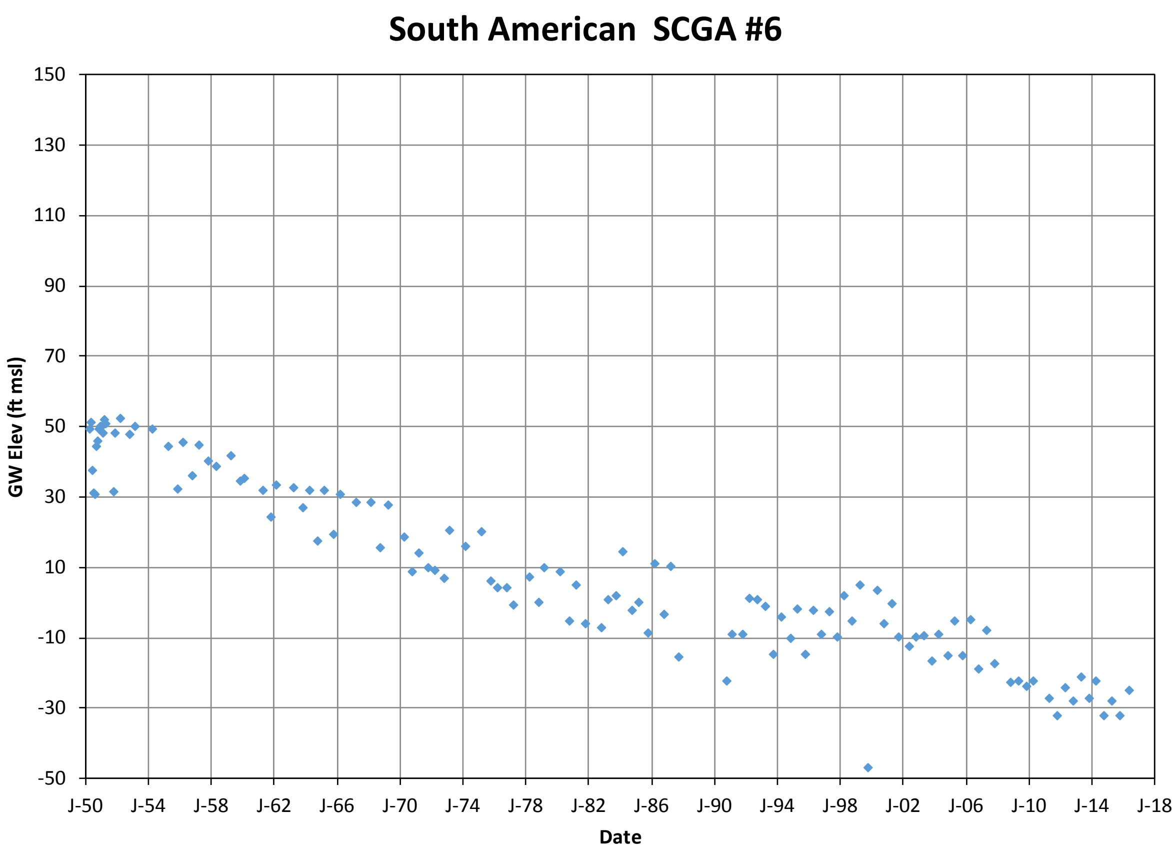
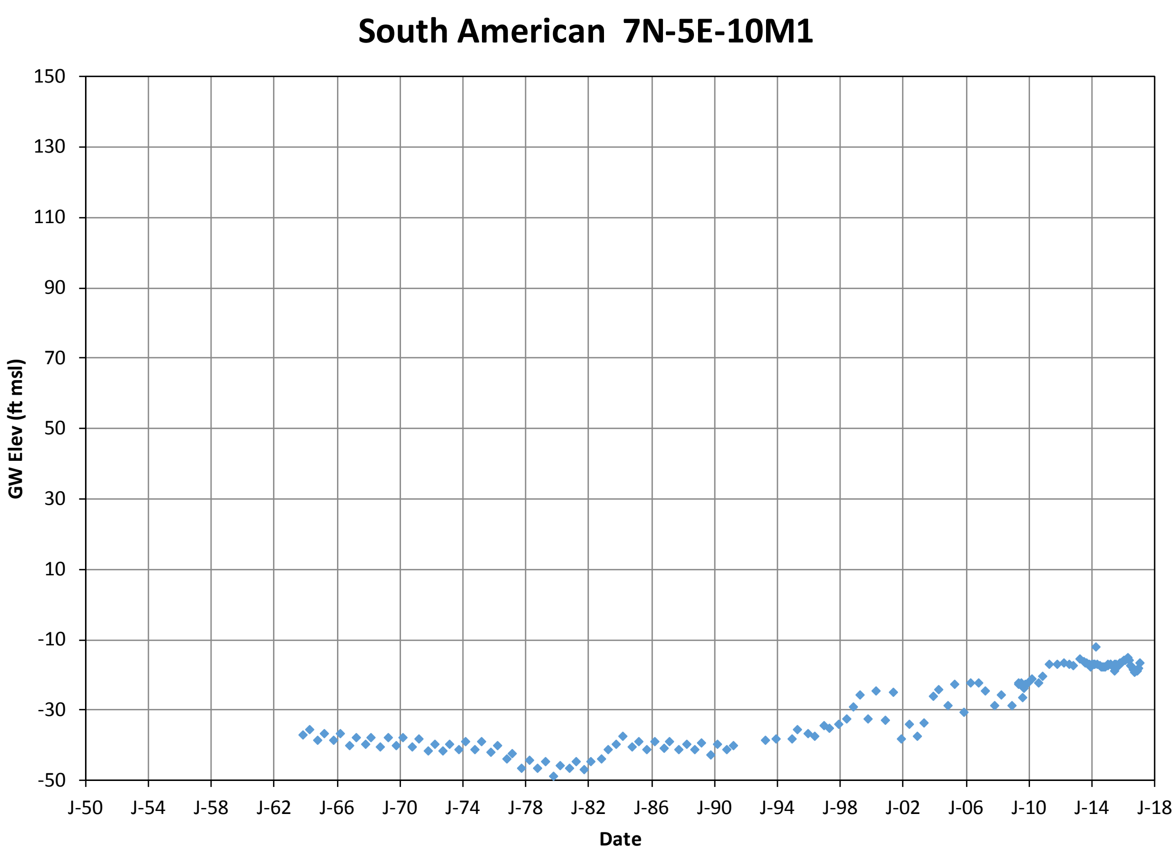
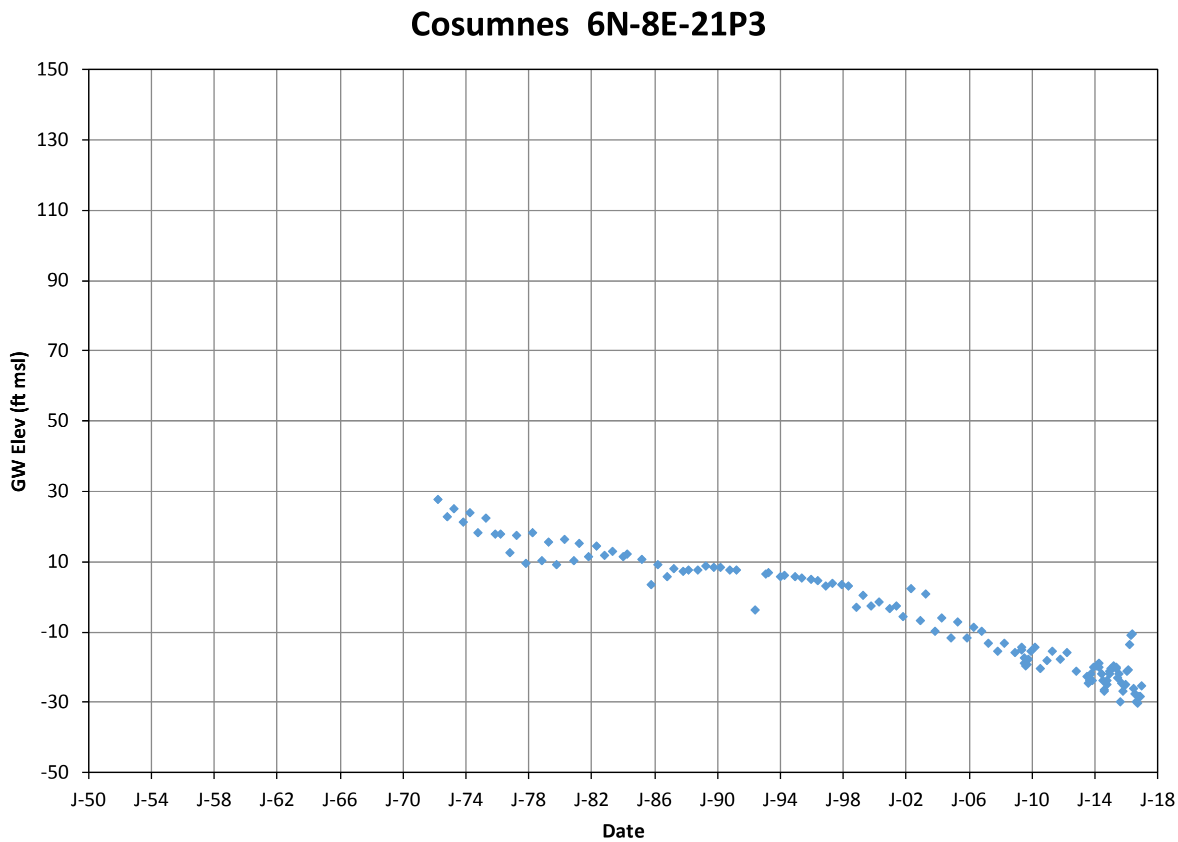




September 2017 TODD GROUNDWATER	**Figure 13** **Hydrographs for South American Subbasin**



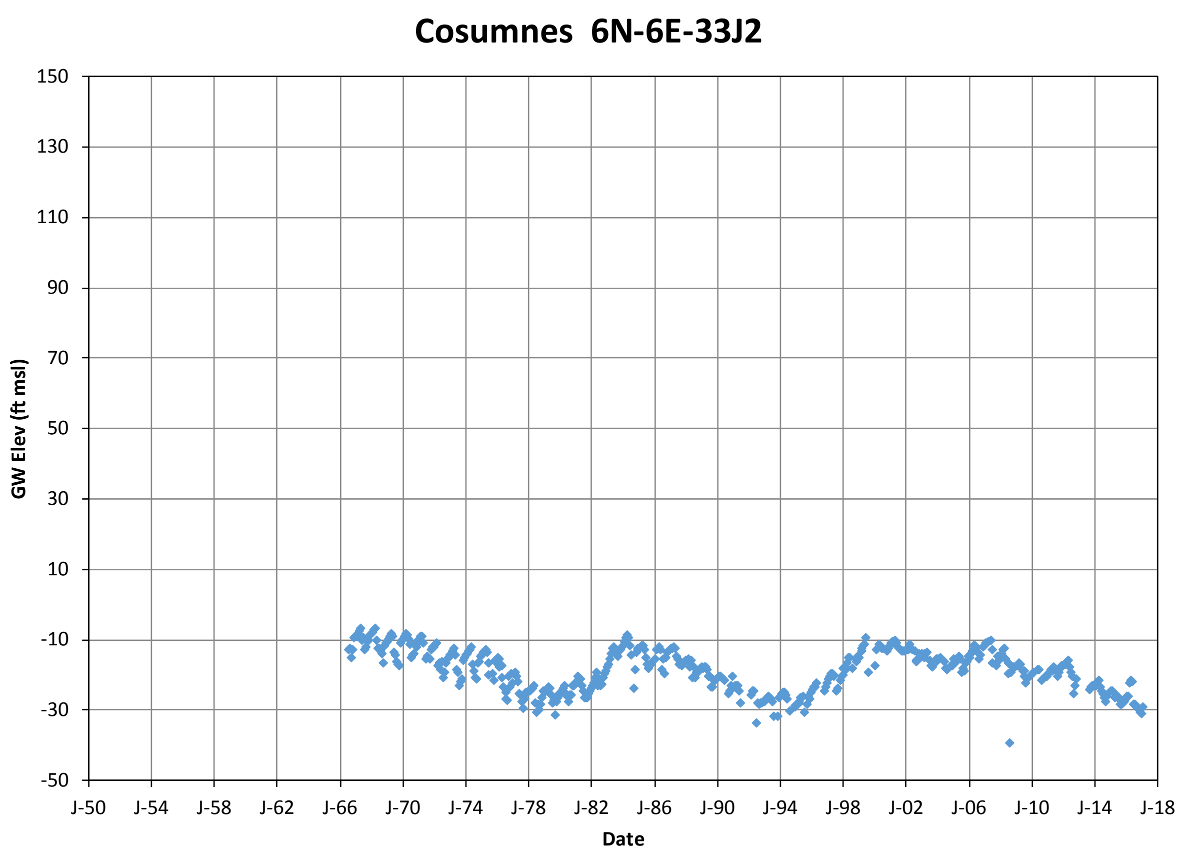


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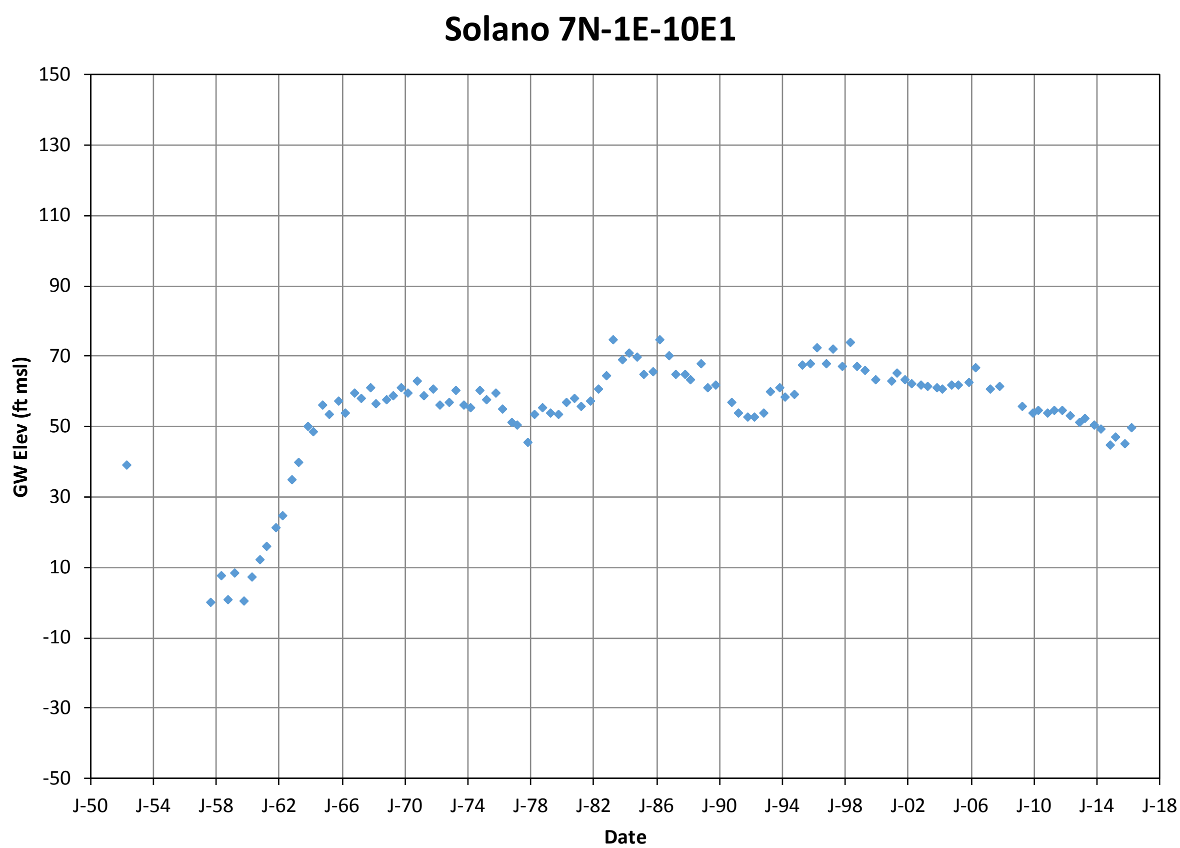
Figure 14
Hydrographs for Cosumnes Subbasin



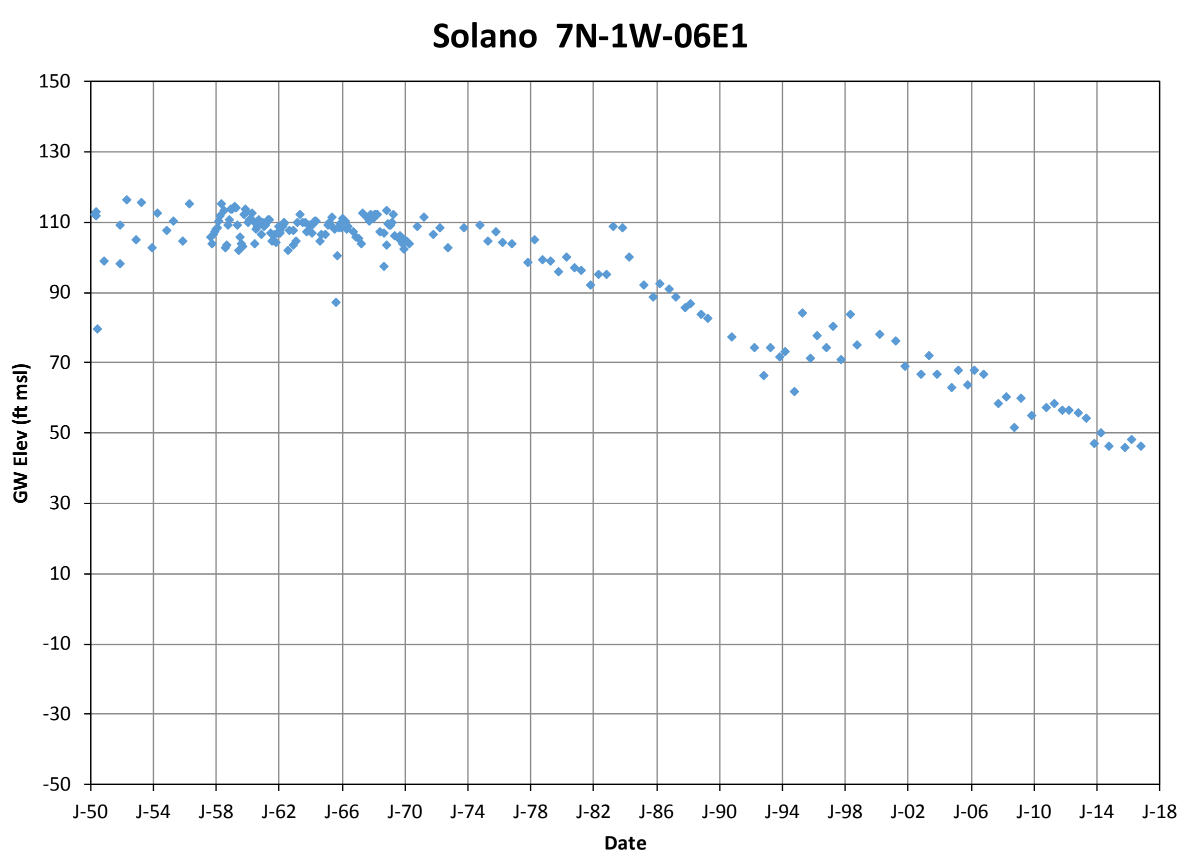


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Figure 15
Hydrographs for Solano Subbasin

Sutter Subbasin

Figure 11 shows long-term hydrographs from wells in the Sutter subbasin. Groundwater elevations in these wells are relatively consistent. The seasonal variation in elevation in this subbasin is relatively small, as were declines during the drought periods in the late 1970s, early 1990s, and 2012 through 2016. These declines are generally less than 5 feet, and elevations recover quickly following seasonal and drought-related declines.

Yolo Subbasin

Figure 11 also shows a long-term hydrograph for the Yolo subbasin. Groundwater elevations in this subbasin generally vary by 20 to 40 feet, with declines during drought conditions and recovery following for approximately the next five years. The effects of the most recent drought appear similar to those that occurred during the drought of the early 1990s.

North American Subbasin

The North American subbasin long-term hydrographs are shown in Figure 12. These two wells both show groundwater elevation generally declining through 1998. While the groundwater elevations in one well begins to recover the other remains stable. These variations may be due to the proximity to the river and availability of recharge.

South American Subbasin

The two hydrographs for the South American subbasin in Figure 13 show very different trends. One well shows a slightly declining trend from the 1950s, while the second shows an increasing trend from the 1980s. Both hydrographs show similar elevations for 2016.

Cosumnes Subbasin

Figure 14 shows two trends from the Cosumnes subbasin. The first of these wells shows a consistent decline from the late 1970s through today. The second well on Figure 14 shows a different trend present in the subbasin, which is a cyclical pattern of decline and recovery during and following droughts.

Solano Subbasin

The long-term hydrographs from the Solano subbasin also show two distinct trends (Figure 15). One well shows a consistent decline from the later 1970s through the present, while others show a cycle of decline and recovery during and then following droughts. However, groundwater elevations in wells showing both trends have declined 15 to 20 feet over the past 10 years.

In addition to assessing trends in groundwater in each subbasin, the groundwater elevation data were also reviewed alongside climatological data to identify recent time periods representing wet and dry conditions. This review and assessment identified spring 2012 as a recent wet period and fall 2016 as a recent dry period.

4.2. GROUNDWATER SURFACE ELEVATIONS AND FLOW

All available groundwater elevation records for spring 2012 and fall 2016 from wells in and around the Study Area were used to create groundwater surface elevation contours. Maps showing spring 2012 (a recent wet time) and fall 2016 (a recent dry time) groundwater elevation contours are shown on Figures 16 and 17, respectively. These maps are intended to show Study Area-wide groundwater elevation surfaces and they may not be representative of local groundwater conditions in some portions of the Study Area. The groundwater elevation contour maps generally show groundwater flow from north to south and from the periphery of the Study Area towards the center and the Sacramento River. There are localized groundwater depressions indicated in both the wet and dry period contour maps. These localized depressions are more prevalent in the dry period groundwater surface.

4.3. DEPTH TO GROUNDWATER

The wet and dry period groundwater elevation surface datasets described above were used to calculate Study-Area-wide depth to groundwater surfaces. Depth to groundwater was calculated for the entire Study Area by subtracting the gridded groundwater elevation surfaces from a ground surface elevation grid. The resulting depth to groundwater surfaces are shown on Figures 18 and 19 for the spring of 2012 and fall of 2016, respectively.

Depth to groundwater is equivalent to the thickness of the unsaturated zone. Locations where groundwater is close to the ground surface are generally considered less favorable for groundwater recharge because the thin unsaturated zone presents limited available storage capacity. Generally, areas where groundwater is within 20 to 50 feet or shallower are not recommended for managed groundwater recharge unless field tests show very high infiltration rates and transmissive capacity. The depth to water surfaces on Figures 18 and 19 are presented with a color ramp where groundwater within 20 feet of ground surface is red and deeper groundwater is shown as shades of blue. These maps show that groundwater is within 20 feet of the ground surface in large portions of the Study Area.

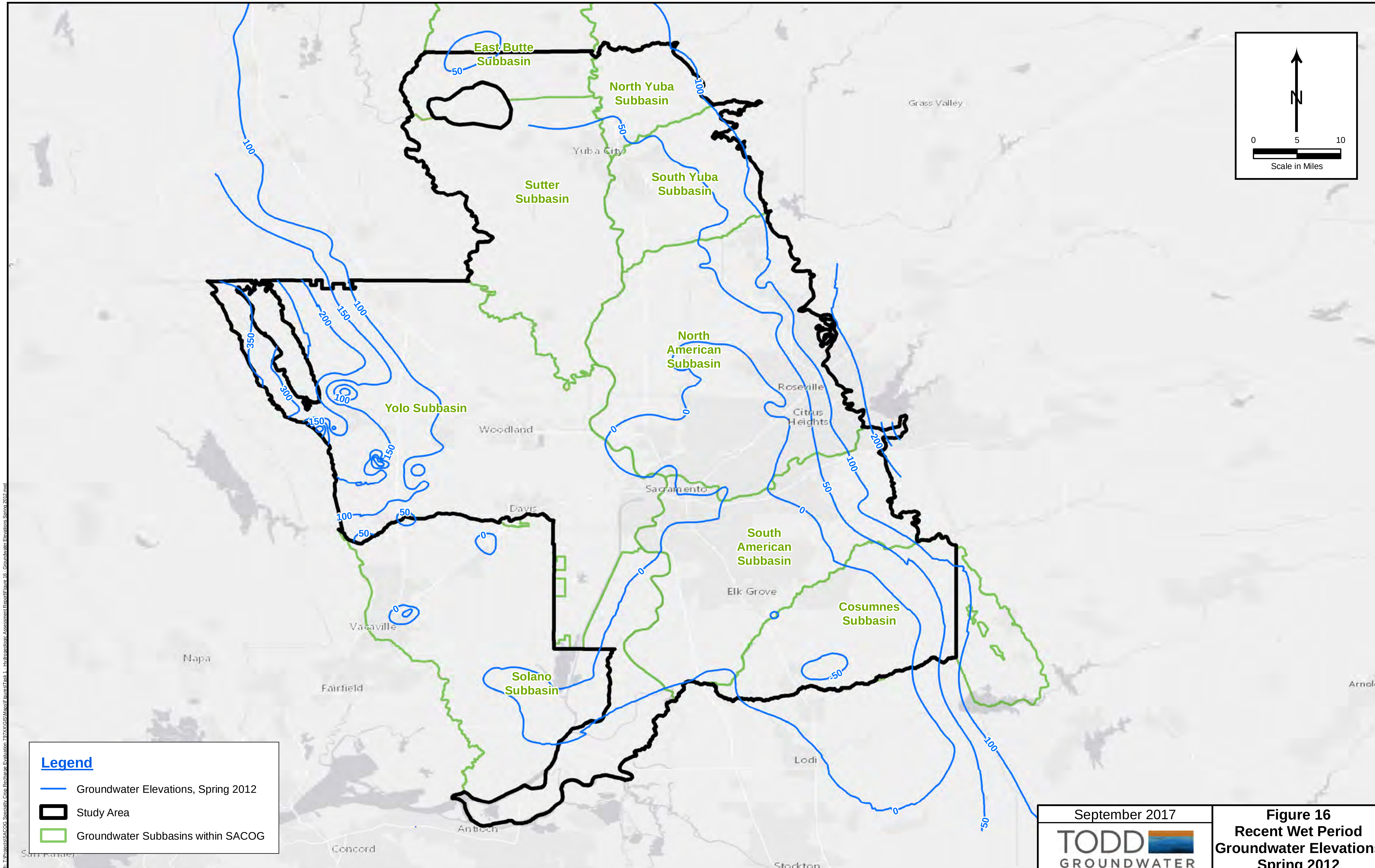

Figure 16
Recent Wet Period Groundwater Elevations Spring 2012

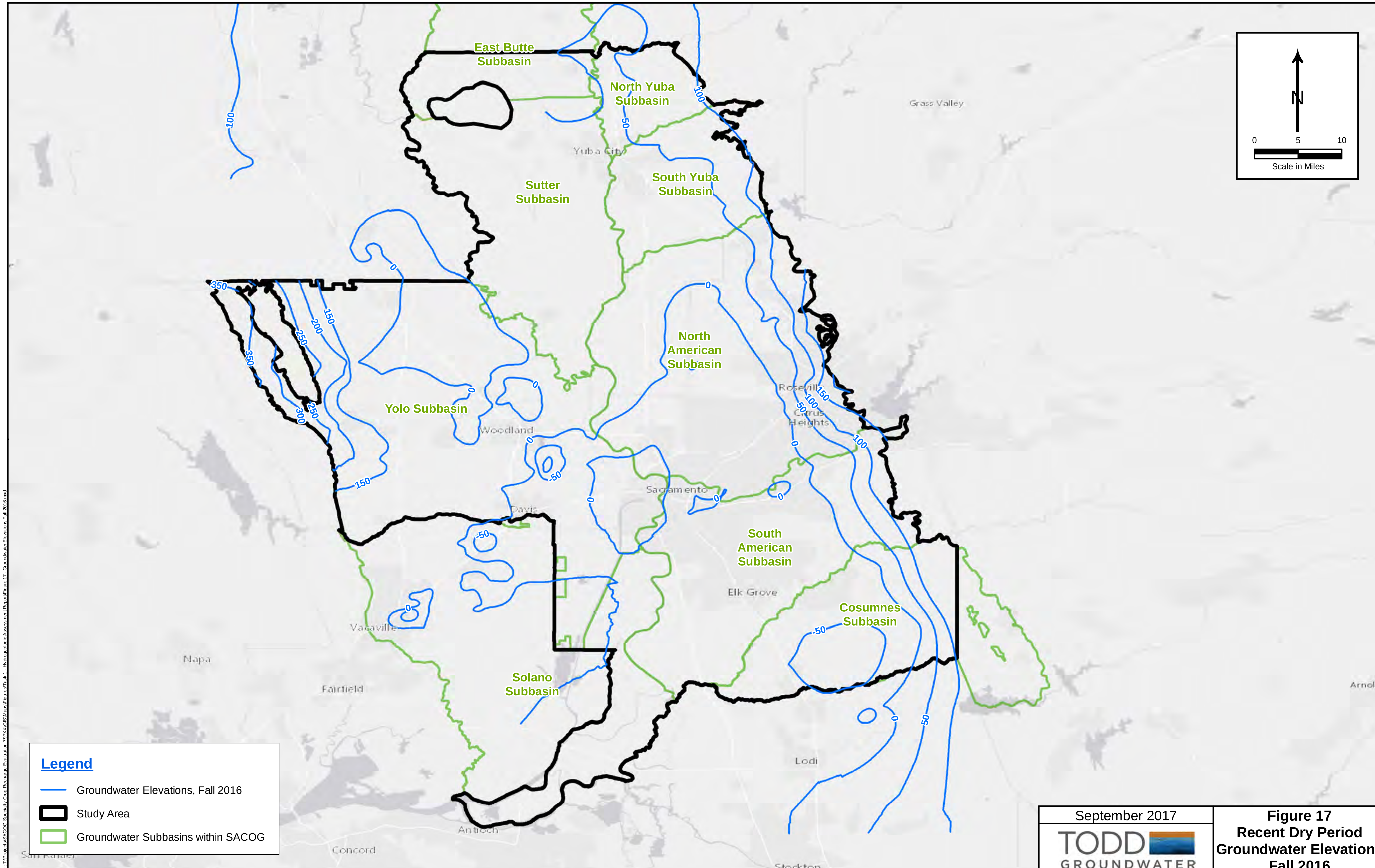

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Figure 17
Recent Dry Period Groundwater Elevations Fall 2016

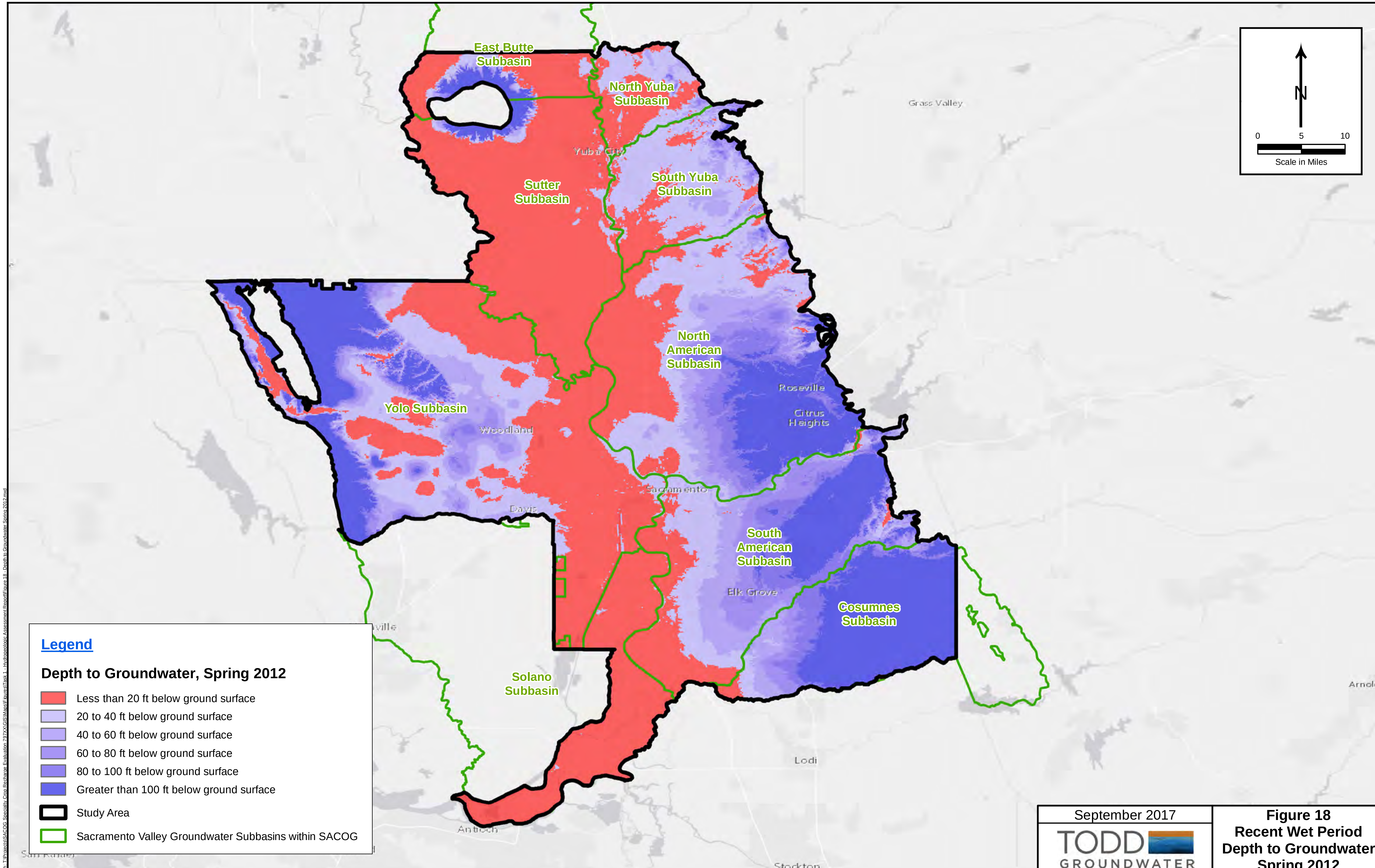

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Figure 18
Recent Wet Period Depth to Groundwater Spring 2012

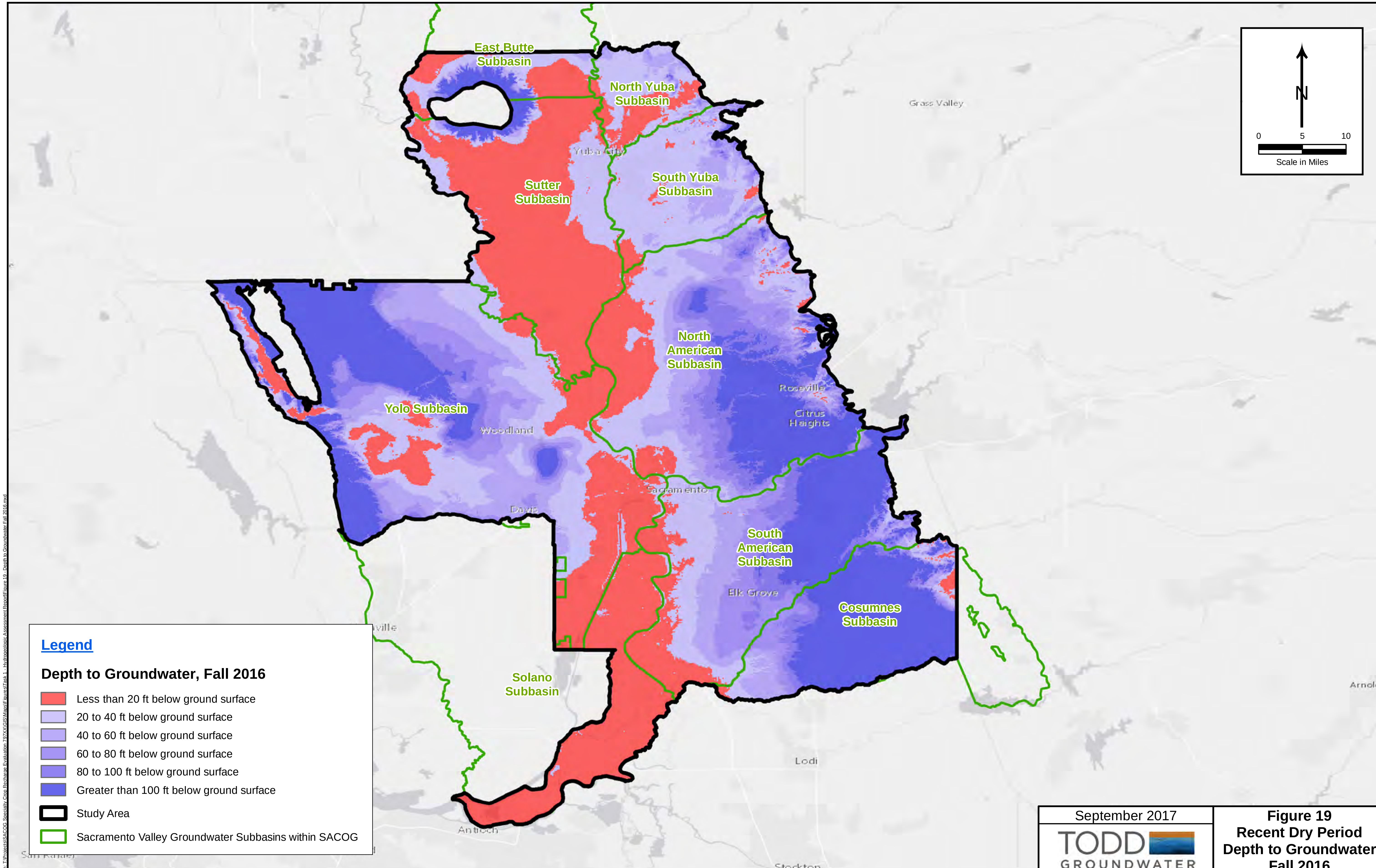

Figure 19
Recent Dry Period Depth to Groundwater Fall 2016

5. WATER QUALITY

A review of readily available groundwater quality information was completed as part of this hydrogeologic assessment. Publicly available data from the State Department of Water Resources Division of Drinking Water (SWRCB-DDW) and the Regional Water Quality Control Board (RWQCB) were reviewed. Water quality in most of the Study Area is generally good, which is important because recharging in areas of poor water quality or soil contamination can spread these undesirable conditions more widely.

Total dissolved solids (TDS) is a good indicator of the natural salinity of groundwater and it can also be an indicator of anthropogenic impacts (e.g., infiltration of urban runoff, agricultural return flows, and wastewater disposal). TDS in most of the Study Area is below the agricultural standard of 500 milligrams per liter (mg/L, parts per million). However, portions of the southern Sutter subbasin and areas along the Sacramento River in the North American subbasin do show elevated concentrations of TDS. There are also localized areas of high arsenic in the southeastern portion of the Solano subbasin. Other water quality parameters are generally well below regulatory guidelines.

Despite this generally good background water quality, there are numerous small-scale and some large-scale anthropogenic sources of groundwater contamination within the Study Area. The most common small-scale impairment is associated with leaking underground storage tanks, but there are also listed and monitored soil and groundwater contamination cases associated with landfills, cleaners, and small industrial sites. Information on sites that are currently monitored by the RWQCB are available on GeoTracker (SWRCB 2017). A list of the number of small-scale soil and groundwater contamination sites in each of the Study Area counties follows:

- Butte 493 sites
- Sacramento 1,989 sites
- Sutter 226 sites
- Yolo 510 sites
- Yuba 185 sites (includes higher elevation areas of the County)
- Placer 721 sites (includes higher elevation areas of the County)

There are also several large-scale contamination sites in the Study Area. These include the Aerojet Superfund site in the North American and South American subbasins. Other larger sites with water quality impairments include McClellan Air Force Base and Union Pacific Rail Yard in the North American subbasin and Kiefer Boulevard Landfill, PG&E sites, and Southern Pacific in the South American subbasin.

Localized areas of poor quality water are not automatically problematic for groundwater recharge. Salts and TDS for example are naturally occurring and highly soluble, and dilution with higher quality water may represent viable management for areas with saline groundwater. One way to dilute saline groundwater is to introduce low TDS water through managed recharge. However, most anthropogenic and some naturally occurring contaminants do not dilute as readily as do salts and TDS. Therefore, it is not advisable to recharge on or near sites of known anthropogenic or highly soluble natural water contamination. Assessment of the presence of this type of potential groundwater contamination should be a part of all field scale evaluations of recharge potential.

6. CONCEPTUAL WATER BALANCE

While a detailed water balance is not needed to assess recharge capabilities, a brief discussion of inflows and outflows has been prepared to illustrate how the groundwater system in the Study Area functions. Summary descriptions of the groundwater inflows and outflows in the Study Area are presented below.

6.1.1. Groundwater Inflows

Groundwater inflows are all those sources of water that flow in to a groundwater system. These include the natural and anthropogenic sources of recharge and return flows that make up groundwater supplies.

- Recharge from Surface Water Infiltration – This is the largest source of recharge to the subbasins within the Study Area. Recharge from surface water sources enters groundwater through the bed and banks of rivers and creeks when they flow through permeable aquifer units with available capacity. Surface water recharge also occurs during flooding events, when flood waters spread out and infiltrate over larger areas. Recharge from surface water sources can be limited by local high groundwater conditions near surface water bodies.

- Agricultural Return Flows – This inflow component accounts for the portion of irrigation water that is applied in excess of the water demands of a crop. The portion of applied water that results in return flow is a function of irrigation management practices and irrigation efficiency. Irrigation management and efficiency can vary widely in a geographic area depending on crop type and management practices. Older, less efficient irrigation methods like flood irrigation frequently lead to larger volumes of irrigation return flows. This can be beneficial to groundwater if the crops in question were irrigated with sources of water other than groundwater.

- Natural Recharge – Natural recharge is generally considered to be the portion of precipitation in excess of ET demand in a given area. Some portion of this excess percolates to groundwater. This can be a significant source of recharge water over large areas like the Study Area even when ET is high in comparison to precipitation, because of its broad distribution.

- Municipal Return Flows – Some water supplied to municipal users is applied to urban irrigation and other recreational uses. Many of these uses result in return flows to groundwater. On average Californians use 30 to 60 percent of their municipal water supply outdoors in some capacity (Save Our Water 2017); a portion of this percolates to groundwater.

- Subsurface Inflow – Water flowing into a groundwater system from another groundwater source is considered subsurface inflow. This is typically difficult to quantify because it depends on subsurface hydrogeologic conditions. There is likely a significant quantity of subsurface inflow entering the Study Area from the northern portion of the Sacramento Groundwater Basin.

6.1.2. Groundwater Outflows

Groundwater outflows represent all uses and losses of water in a groundwater system. As with most groundwater systems, the primary outflows in the Study Area are pumping to meet water demands.

- Agricultural Groundwater Pumping - Agricultural water demand in the Study Area is met from a combination of surface water and groundwater supplies. Groundwater pumping makes up 29 percent of agricultural water use in the Study Area (DWR 2013). However, agricultural demand is by far the largest use of water in the Study Area, so even with this relatively low percentage of total agricultural supply, agricultural groundwater pumping is still by far the largest outflow in the Study Area.
- Municipal Groundwater Pumping –Many cities, towns, and unincorporated areas within the Study Area rely on groundwater to supply municipal water demand. Groundwater makes up approximately 54 percent of the water supplies for municipal users in the Study Area (DWR 2013). Municipal pumping is more geographically focused than agricultural pumping due to the centralized nature of cities and towns.
- Subsurface Outflow – Like subsurface inflow, subsurface outflow is groundwater leaving an area through the subsurface. This is likely a relatively small volume of water in the Study Area.
- Surface Outflow – Groundwater outflow to streams occurs mostly along lower elevation reaches of streams and supports baseflow. While variable along a stream and through time (seasonally and long-term), it is the basis for groundwater-dependent ecosystems, the maintenance of which is a groundwater sustainability indicator.

6.1.3. Estimates of Major Inflows and Outflows

Estimates of the major inflows and outflows to groundwater have been prepared for some of the subbasins in the Study Area by DWR (2003). The estimates presented in Table 1 are somewhat dated and should be viewed as approximations for comparison purposes only. These estimates do indicate a disparity between inflows and outflows for most of the subbasins in the Study Area; in most cases, far more water is pumped than enters the systems via recharge and return flows. Development of additional recharge opportunities for these subbasins would help alleviate this disparity.

Table 1. Estimated Water Balance Summary

From DWR Bulletin 118 (DWR 2003), all values in Acre-Feet per Year

		Inflows		Outflows		
Basin Number	Subbasin Name	Natural Recharge	Agricultural Irrigation Return Flow	Agricultural Groundwater Pumping	Municipal Groundwater Pumping	Other Groundwater Pumping
5-021.59	East Butte	Not Available	126,000	104,000	75,500	1,300
5-021.60	North Yuba	51,100	13,900	65,800	9,000	Not Available
5-021.61	South Yuba	53,700	26,000	93,400	6,000	Not Available
5-021.62	Sutter	40,000	22,100	171,400	3,900	Not Available
5-021.64	North American	83,800	29,800	289,100	109,900	Not Available
5-021.65	South American	257,168	Not Available	162,954	68,058	Not Available
5-021.67	Yolo	Not Available	Not Available	Not Available	Not Available	Not Available
5-022.16	Cosumnes	269,518	Not Available	94,198	35,063	Not Available
5-021.66	Solano	Not Available	Not Available	Not Available	Not Available	Not Available

7. ESTIMATED AGRICULTURAL WATER USE

As shown in the estimated water balances, agricultural pumping is the most significant outflow from the groundwater basin. Groundwater makes up approximately 30-50 percent of source water for agricultural irrigation (DWR 2013).

Land IQ estimated the total agricultural water use for each groundwater basin within the SACOG study area, documented in Appendix A. Land use data developed by Land IQ for DWR was organized by the subbasins shown in Figure 20. While acknowledging the broad diversity of crops, the major crops for each of these subbasins include:

- East Butte – rice, almonds, walnuts, stone fruit
- North Yuba Subbasin -rice, walnuts
- South Yuba Subbasin -rice, mixed pasture, walnuts
- Sutter Subbasin – rice, walnuts, truck crops
- Yolo Subbasin- alfalfa, almonds, rice, tomatoes
- North American Subbasin – rice, alfalfa, mixed pasture

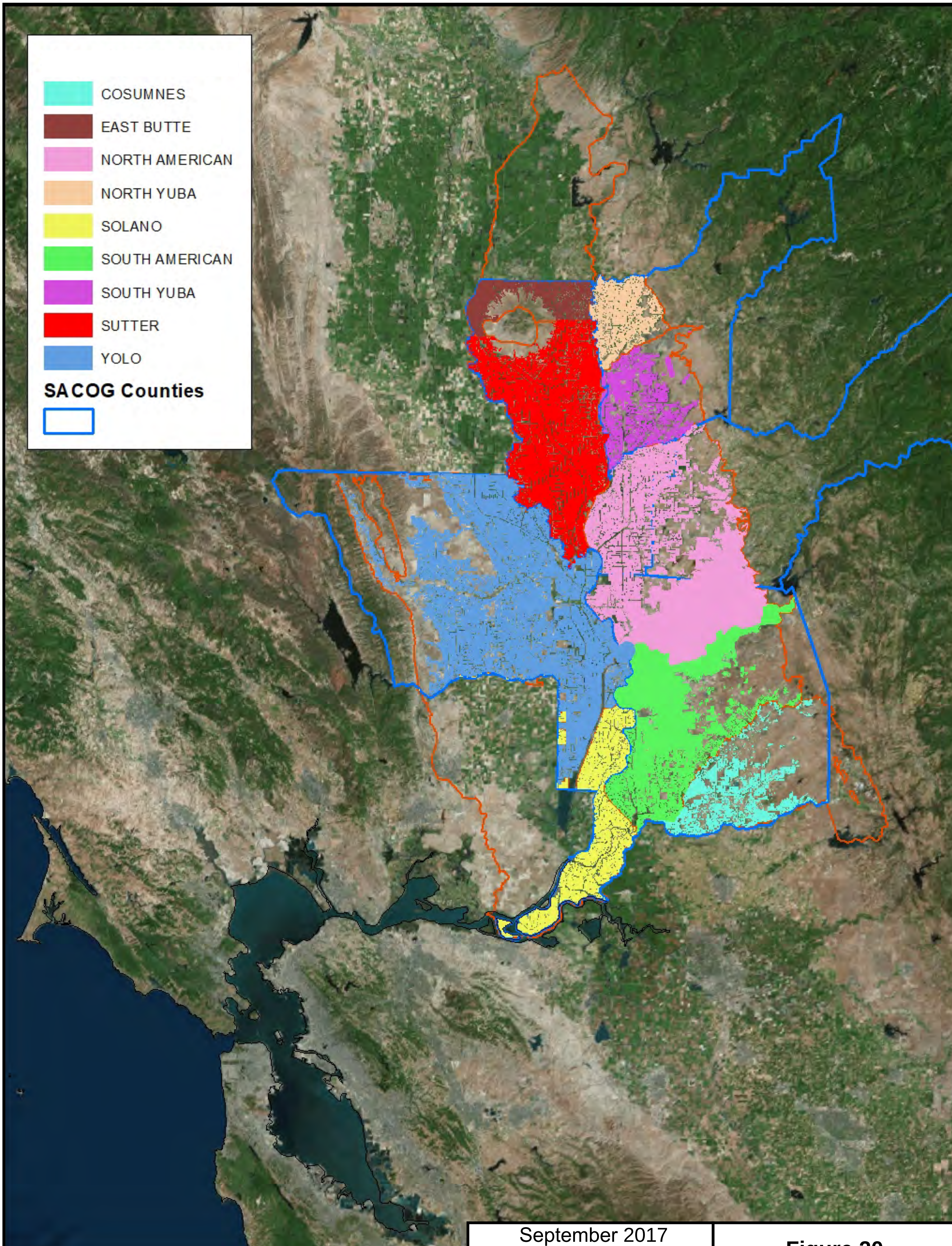

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Figure 20
Agricultural Areas with Study Area

- South American Subbasin – alfalfa, corn, grapes
- Cosumnes Subbasin – rice, grapes, mixed pasture
- Solano Subbasin – alfalfa, grapes, corn

Land IQ calculated the water demand for 45 different crop types based on the evapotranspiration (ET) needs of the specific crop, taking into account irrigation efficiency and effective precipitation in order to estimate applied water per acre. The ET needs of a crop can be estimated as ETc = Kc * ETo, where ETc is the ET demand of the crop, Kc is the crop coefficient, and ETo is the reference ET of the geographic area, either measured or observed. Both the crop coefficient and the ETo vary daily and thus the water demand of the crop also varies daily (DWR 2005).

Weather data were required to spatially estimate reference evapotranspiration (ETo) using the Penman-Monteith equation. The daily Penman-Monteith equation requires daily minimum and maximum temperatures, solar radiation, dewpoint temperature, and wind speed to calculate ETo. Data were downloaded from the California Irrigation Management Information System (CIMIS), which has a network of well-maintained weather monitoring stations across the state. Data were downloaded for nine stations of interest from 2014 to mid-2015.

Each crop type has a unique growing season and growth curve. Crop coefficient (Kc) values scale ETo values to estimate crop water use. For these purposes, Kc values have been taken from the Consumptive Use Program PLUS (CUP+; Orang, Matyac, & Snyder 2009) and from FAO56 (Allen, Pereira, Raes, & Smith 1998). CUP+ was developed at UC Davis with crop coefficients representative of the area.

Because irrigation is not 100 percent efficient, water is applied in excess of the ET demand. Irrigation efficiency, the percent of applied water needed beyond the ET demand of the crop, can vary significantly depending on several factors including geographic setting, irrigation method, and crop types. Land IQ varied the Irrigation Efficiency (IE) by irrigation type ranging from 64 to 84.5 percent efficient. Applied water that is in surplus of the ET demand of the crop (Applied Water less Consumptive Use) would percolate to the groundwater aquifer as agricultural return flow.

The agricultural use is met by both surface water deliveries and groundwater pumping. Surface water diversions and deliveries vary for each agricultural water use area. Areas that heavily rely on groundwater to meet irrigation demands on a field basis would benefit from increased groundwater recharge.

Table 2. Consumptive Use and Applied Water for SACOG Sub Basins

Sub Basin	Consumptive Use (Acre-Feet)	Applied Water (Acre-Feet)
COSUMNES	1,293,995	1,760,575
EAST BUTTE	802,603	1,094,803
NORTH AMERICAN	3,777,265	5,674,417
NORTH YUBA	1,590,149	2,310,879
SOLANO	2,783,619	3,878,165
SOUTH AMERICAN	1,572,243	2,160,820
SOUTH YUBA	1,894,221	2,710,116
SUTTER	5,870,235	8,381,365
YOLO	8,851,590	12,204,625
SUM	**28,435,920**	**40,175,766**

8. POTENTIAL EFFECTS OF CLIMATE CHANGE

Groundwater in the Study Area could be influenced by changes in precipitation, runoff, and snowmelt volumes and/or timing associated with climate change. As noted previously, flows from these sources serve to recharge the subbasins in the Study Area. Climate change models do not all agree on what changes in precipitation volumes or timing may occur within the Sacramento Valley watersheds. Some models predict warmer and wetter conditions, while others predict drier conditions as compared to historical average climate conditions (Joyce et al. 2006). However, most climate models agree that there will be increased precipitation as rain and earlier runoff peaks in streams.

These climate predictions significantly affect the hydrologic conditions in the Study Area. Streamflow and rainfall are the primary mechanisms through which the groundwater in the Study Area is recharged. Changes in the volume and timing of runoff and rainfall has the potential to result in earlier peaks and shorter periods of sustained summer streamflow. In streams without dams and storage, these conditions change the timing and volume of water available for natural recharge because flows are highest when groundwater levels are also high and then flows may recede before groundwater levels decline. This can reduce the percentage of water that infiltrates as recharge. Models of the effects of climate change on water supplies in the Sacramento Valley also indicate that crop water demands may increase due to longer growing seasons and warmer climate and that the changes in surface water supply volumes and timing may result in increased groundwater use (Joyce et al. 2006). However, these studies also indicate that reasonable management strategies to mitigate the effects of these changes are available and can be implemented in the Sacramento Valley.

9. RECOMMENDATIONS FOR RECHARGE FEASIBILITY ASSESSMENT

The review and development of the hydrogeologic assessment presented above has produced information and data that will be important for further assessment of recharge feasibility in the Study Area. The following presents recommendations for the application of these information and data to the evaluation of recharge suitability in the Study Area:

4. Develop indexed geographic coverages of vertical and horizontal hydraulic conductivity for application to the combined recharge suitability index.
    a. Hydraulic conductivity values should be divided into reasonable increments and assigned integer values to facilitate combination with other indexed recharge feasibility parameters.
    b. Vertical hydraulic conductivity should be weighted higher than horizontal hydraulic conductivity by a factor of 2 to 1.
    c. There is no need to include a separate coverage representing restrictive geologic materials as expressed in surficial geology in the recharge feasibility index; the affected areas are represented in the horizontal hydraulic conductivity coverage.
5. Develop indexed geographic coverages of unsaturated aquifer thickness from the depth to groundwater datasets presented in this report.
    a. Separate unsaturated thickness coverage should be prepared for wet (spring after a period of higher than average precipitation) and dry (fall after a period of lower than average precipitation) conditions.
    b. These individual datasets should then be developed into separate wet condition and dry condition versions of the combined recharge feasibility index. This will allow SACOG to evaluate the range of groundwater elevation conditions when reviewing recharge feasibility for specific locations.
    c. There is no need to include separate indexed coverage of fold and fault related horizontal flow restrictions; these features are represented in the depth to groundwater/unsaturated zone thickness coverages.
6. Consider developing geographic water use coverage for agriculture. These data were not available for this assessment but may be useful for targeting recharge in the future.

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APPENDIX A

Summary Description of the Central Valley Hydrologic Model

CENTRAL VALLEY HYDROLOGIC MODEL (CVHM)

The model domain of CVHM encompasses the alluvial deposits of the entire Central Valley extending from the Cascade Ranges on the north to the Tehachapi Mountains on the south, and bounded on the east by the Sierra Nevada and on the west by the Coast Ranges. The only outlet for this entire area is through the narrow Carquinez Strait, part of the tidal estuary of the Sacramento-San Joaquin River Delta. To create enough detail to be practical for water-management decisions, the aquifer was divided spatially into 20,000 model cells with a uniform horizontal discretization of one square mile oriented parallel to the valley axis at 34 degrees west of north (Faunt 2009).

The vertical discretization of the model into layers and the distribution of aquifer parameters throughout the model domain were informed by a textural analysis of subsurface sediments throughout the Central Valley aquifer. Texture is defined as the percentage of coarse-grained sediment within a specified subsurface depth interval (Laudon and Belitz 1991). The textural analysis was completed by evaluating lithologic drillers' logs from nearly 8,500 wells throughout the Central Valley (nearly 1,700 of which were in or near the Study Area) to identify the coarse-grained fraction in depth increments of 50 feet. The resulting texture values were then interpolated to the mile-square model cells using a three dimensional variogram model (Faunt 2009).

The texture data were interpolated to the model grid in two stages. In the first stage, the texture was estimated for each of the 50-ft thick layers. In the second stage, the resulting estimates were aggregated vertically into 10 model layers. Although the lateral spacing stayed the same throughout the model, the thickness of each model layer increases with depth. Aquifer parameters of hydraulic conductivity and storage were distributed over the CVHM domain using the texture data and geographically-specific multipliers for hydraulic conductivity of the coarse and fine-grained fractions. These aquifer parameter values were then modified during model calibration to better match local groundwater elevation observations. The calibrated CVHM includes horizontal and vertical hydraulic conductivity values for every cell in the model (i.e., every active mile-square cell in every layer). The post-calibration horizontal and vertical hydraulic conductivities from the CVHM represent the best available dataset for assessing the relative feasibility of recharge throughout the Study Area.

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APPENDIX B

Calculation of Consumptive Use for SACOG Subbasins, Land IQ, August 14, 2017

CALCULATION OF CONSUMPTIVE USE FOR SACOG SUBBASINS

PREPARED FOR: Todd Groundwater

PREPARED BY: Stephanie Tillman/Land IQ

Christopher Stall/Land IQ

DATE: August, 14 2017

INTRODUCTION

To calculate consumptive use (CU) and applied water (SW) across nine sub basins and six counties in California for Sacramento Area Council of Governments (SACOG), multiple sources of data were utilized to accurately assess and verify the estimate. The FAO Penman-Monteith (PM) equation was used to calculate daily evapotranspiration.

- Step 1 – Crop Acreage Distribution
- Step 2 – Weather Data
- Step 3 – Crop Growth Characteristics
- Step 4 – Irrigation Adjustment

STEP 1 – CROP ACREAGE DISTRIBUTION

Land IQ completed 2014 state wide crop mapping for the California Department of Water Resources in 2016. This data set was used to create a crop acreage distribution for the Study Area. Crops within the nine subbasins (Consumnes, East Butte, North American, North Yuba, Solano, South American, South Yuba, Sutter, and Yolo) and also within the five counties of interest (Sutter, Yuba, Yolo, Placer and Sacramento) were selected as a subset of the state wide crop mapping (Figure 1). Tabular data was exported and acreage by subbasin was calculated (Appendix A).

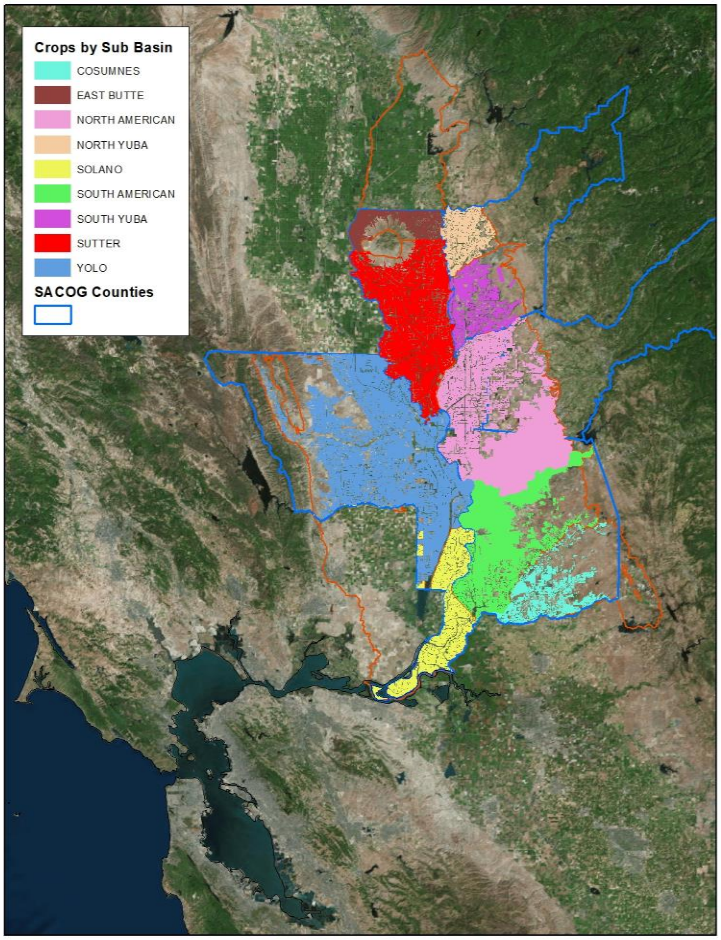

Figure 1. Crop Acreage Distribution in SACOG Sub Basins

STEP 2 – WEATHER DATA

Weather data was required to spatially estimate reference evapotranspiration (ETo). The daily PM equation requires daily minimum and maximum temperatures, solar radiation, dewpoint temperature, and wind speed to calculate ETo. The California Irrigation Management Information System (CIMIS) has a network of well-maintained weather monitoring stations across the state. Data was downloaded for stations of interest from 2014 to mid-2015 (Figure 2).

There were nine weather stations that were within the Study Area (Table 1). Each sub basin had a weather station assigned to all fields within its boundary. Data gaps were less than or equal to 5 days and were filed with a linear interpolation.

Table 1. Weather Stations Near/Within Study Area

CIMIS Station ID	Latitude	Longitude
006_Davis	38.54	-121.78
012_Durham	39.61	-121.82
121_Dixon	38.42	-121.79
131_Fair Oaks	38.65	-121.22
139_Winters	38.50	-121.98
140_Twitchell Island	38.12	-121.67
212_Hastings Tract East	38.28	-121.74
226_Woodland	38.67	-121.81
235_Verona	38.80	-121.61

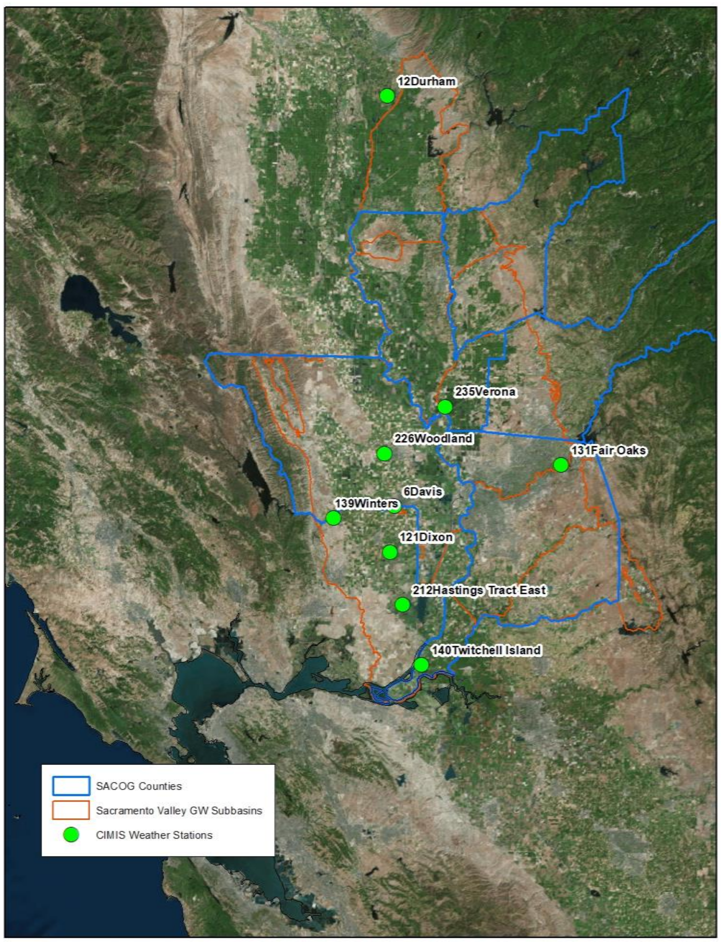

Figure 2. CIMIS Weather Stations

STEP 3 – CROP GROWTH CHARACTERISTICS

Each crop category has a unique growing season and growth curve. Crop coefficient (Kc) values scale ETo values to estimate crop water use. For these purposes, Kc values have been taken from the Consumptive Use Program PLUS (CUP+; Orang, Matyac, & Snyder, 2009) and from FAO56 (Allen, Pereira, Raes, & Smith, 1998). CUP+ was developed at UC Davis with crop coefficients representative of the area.

A sensitivity analysis was completed for consumptive use comparisons between the PM model run for 2014 and ITRC values (ITRC, 2003) for a "Typical" year. Individual crop Kc values and growing season dates can be found in Appendix B.

STEP 4 – IRRIGATION ADJUSTMENT

Irrigation type is important to accurately assign because it is the conversion factor from CU to AW. Irrigation type was assigned by crop from the "Survey of Irrigation Methods in California in 2010" (Tindula, Orang, & Snyder, 2013). This survey provides the type of irrigation for twenty different crop categories. Irrigation efficiencies (IE) were then applied to each type of irrigation to calculate a weighted efficiency per crop.

To ensure accuracy of IE assumptions, these values were compared with the spatial study completed by UC Davis (Sandoval-Solis, et al., 2013). They spatially summarized IE by crop in different regions of the state. An average IE was calculated between the DWR survey method and the UC Davis spatial IE method.

RESULTS

Once ETo has been calculated, and the Kc values have been applied to calculate consumptive use for each crop, AW can be determined. Applied water is determined by dividing the CU for the crop by the percent IE. Applied water was then summed by sub basin and is reported in Table 2.

Table 2. Consumptive Use and Applied Water for SACOG Sub Basins

Sub Basin	Consumptive Use (Acre-Feet)	Applied Water (Acre-Feet)
COSUMNES	1,293,995	1,760,575
EAST BUTTE	802,603	1,094,803
NORTH AMERICAN	3,777,265	5,674,417
NORTH YUBA	1,590,149	2,310,879
SOLANO	2,783,619	3,878,165
SOUTH AMERICAN	1,572,243	2,160,820
SOUTH YUBA	1,894,221	2,710,116
SUTTER	5,870,235	8,381,365
YOLO	8,851,590	12,204,625
SUM	28,435,920	40,175,766

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APPENDIX A- CROP ACREAGE BY SUB BASIN

Crop	COSUMNES	EAST BUTTE	NORTH AMERICAN	NORTH YUBA	SOLANO	SOUTH AMERICAN	SOUTH YUBA	SUTTER	YOLO	Sum
Alfalfa and Alfalfa Mixtures	3,028	337	4,627	101	13,110	4,896	491	2,163	27,431	56,183
Almonds	156	3,970	23	432	9	-	697	2,872	23,340	31,499
Apples	13	1	-	1	549	88	-	52	27	731
Beans (Dry)	157	-	454	-	132	284	-	7,406	899	9,333
Bush Berries	2	-	-	-	22	-	-	2	10	35
Carrots	9	-	-	-	437	-	-	4	154	603
Cherries	25	-	5	-	1,246	346	141	-	7	1,770
Citrus	-	-	32	10	1	18	19	20	135	234
Corn, Sorghum and Sudan	4,872	58	1,583	-	17,988	7,812	1,234	3,929	6,826	44,302
Cotton	-	-	-	-	-	-	-	462	-	462
Dates	-	-	-	-	-	-	-	-	6	6
Flowers, Nursery and Christmas Tree Farms	50	-	41	-	5	33	-	490	96	714
Grapes	15,064	41	45	-	14,032	12,782	3	42	8,133	50,142
Kiwis	-	118	-	222	19	-	76	31	-	465
Lettuce/Leafy Greens	-	-	36	-	67	-	-	-	-	102
Melons, Squash and Cucumbers	13	17	364	2	415	410	347	2,548	4,591	8,706
Miscellaneous Deciduous	24	24	152	100	62	37	779	220	568	1,965
Miscellaneous Field Crops	5	-	-	-	77	8	-	-	899	989
Miscellaneous Grain and Hay	1,305	79	1,211	47	1,034	1,476	147	492	2,937	8,729
Miscellaneous Grasses	757	41	1,269	3	1,011	535	46	328	1,155	5,145
Miscellaneous Subtropical Fruits	-	-	-	-	-	-	9	-	90	99
Miscellaneous Truck Crops	134	7	72	36	244	775	10	241	1,822	3,342
Mixed Pasture	8,293	578	5,437	795	8,956	7,896	5,058	1,105	9,927	48,046
Olives	54	507	67	139	-	31	58	399	3,209	4,464
Onions and Garlic	-	6	18	-	106	50	-	65	1,299	1,544
Peaches/Nectarines	-	1,718	168	2,270	-	-	817	5,522	67	10,562
Pears	-	-	2	-	3,179	2,003	172	-	4	5,359
Peppers	-	-	-	-	3	-	-	-	286	289
Pistachios	5	8	246	1	-	39	2	4	460	767
Plums, Prunes and Apricots	-	3,045	1,242	3,999	8	1	4,498	12,577	1,829	27,199
Pomegranates	9	15	-	33	16	1	-	27	6	108
Potatoes and Sweet Potatoes	-	-	-	-	-	-	-	-	12	12
Rice	-	5,677	56,037	20,404	573	696	17,291	51,751	24,231	176,659
Safflower	23	-	204	-	3,222	294	72	1,122	5,536	10,473
Strawberries	9	3	22	6	7	76	-	1	12	137
Sunflowers	-	99	627	-	6	81	136	9,289	17,880	28,117
Tomatoes	305	-	108	-	2,432	2,177	-	10,771	37,937	53,729
Walnuts	692	3,984	9,447	6,265	136	236	9,259	20,216	15,320	65,556
Wheat	1,263	74	1,031	-	2,658	1,426	143	3,025	6,026	15,646
Wild Rice	-	45	279	204	-	-	-	88	1,615	2,232
Young Perennials	48	463	275	614	98	-	775	2,966	1,337	6,577
Sum	36,314	20,915	85,122	35,685	71,860	44,507	42,281	140,232	206,117	683,032

Appendix B- Crop Coefficients and Growing Season Dates

CropType	SeasonB	SeasonC	SeasonD	KcAB	KcCd	KcE	StartDate	EndDate
Alfalfa and Alfalfa Mixtures (CUP+)	25	50	75	1	1	1	1-Jan	31-Dec
Almonds (CUP+)	0	50	90	0.55	1.2	0.65	1-Mar	15-Oct
Apples (CUP+)	0	50	75	0.55	1.15	0.8	1-Apr	15-Nov
Beans (Dry) (CUP+)	24	40	91	0.2	1	0.1	15-Jun	30-Sep
Bush Berries	12.5	33.33	87.5	0.3	1.05	0.5	1-Mar	1-Nov
Carrots (CUP+)	20	50	83	0.85	0.95	0.8	15-Jan	15-May
Cherries (CUP+)	0	50	75	0.55	1.15	0.8	1-Apr	15-Nov
Citrus (CUP+)	0	33	67	1	1	1	1-Jan	31-Dec
Corn, Sorghum and Sudan	20	46.7	80	0.3	1.2	0.6	1-Apr	30-Aug
Cotton (CUP+)	15	25	85	0.35	1	0.5	15-May	15-Oct
Dates (CUP+)	0	33	67	0.95	0.95	0.95	1-Jan	31-Dec
Flowers, Nursery and Christmas Tree Farms (CUP+)	0	33	67	1.15	1.15	1.15	1-Jan	31-Dec
Grapes (CUP+)	0	25	75	0.45	0.8	0.35	1-Apr	1-Nov
Kiwis (CUP+)	0	22	67	0.35	1.1	0.8	1-May	31-Oct
Lettuce/Leafy Greens (CUP+)	32	80	90	0.4	1	1	15-May	15-Jul
Melons, Squash and Cucumbers	25	60	85	0.5	1	0.8	15-Apr	24-Jul
Melons, Squash and Cucumbers	21	50	83	0.6	1	0.6	15-Apr	31-Jul
Mixed Pasture (CUP+)	25	50	75	0.95	0.95	0.95	1-Jan	31-Dec
Olives (CUP+)	0	33	67	0.9	0.9	0.9	1-Jan	31-Dec
Onions and Garlic	9.5	26.2	78.6	1.025	0.725	0.35	1-Jan	30-Jul
Peaches/Nectarines (CUP+)	0	50	90	0.55	1.2	0.65	1-Apr	15-Oct
Pears (CUP+)	0	50	75	0.55	1.15	0.8	1-Apr	15-Nov
Peppers (CUP+)	23	86	90	0.3	1.05	1.05	1-Mar	31-Aug
Pistachios (CUP+)	0	50	80	0.4	1.1	0.5	1-Mar	1-Nov
Plums, Prunes and Apricots (CUP+)	0	50	90	0.55	1.15	0.65	1-Apr	15-Oct
Pomegranates (CUP+)	0	50	75	0.55	1.15	0.8	1-Apr	15-Nov
Potatoes and Sweet Potatoes (CUP+)	20	45	78	0.7	1.15	0.5	15-Apr	15-Aug
Rice	16.7	33.3	77.8	1.05	1.2	0.75	1-May	31-Oct
Safflower (CUP+)	17	45	80	0.2	1.05	0.25	1-Apr	31-Aug
Strawberries (CUP+)	15	45	80	0.4	1.05	0.7	1-May	30-Sep
Sunflowers (CUP+)	20	45	80	0.2	1.05	0.4	1-May	10-Sep
Tomatoes (CUP+)	25	50	80	0.2	1.2	0.6	1-Apr	31-Aug
Walnuts (CUP+)	0	50	75	0.55	1.2	0.8	1-Apr	15-Nov
Wheat	11.1	44.4	83.3	0.7	1.15	0.325	1-Dec	30-May
Wild Rice	16.7	33.3	77.8	1.05	1.2	0.75	1-May	31-Oct
Wild Rice (CUP+)	20	26	86	1.2	1	0.5	15-May	15-Oct