TECHNICAL MEMORANDUM:

MADERA SUBBASIN

Sustainable Groundwater Management Act (SGMA)

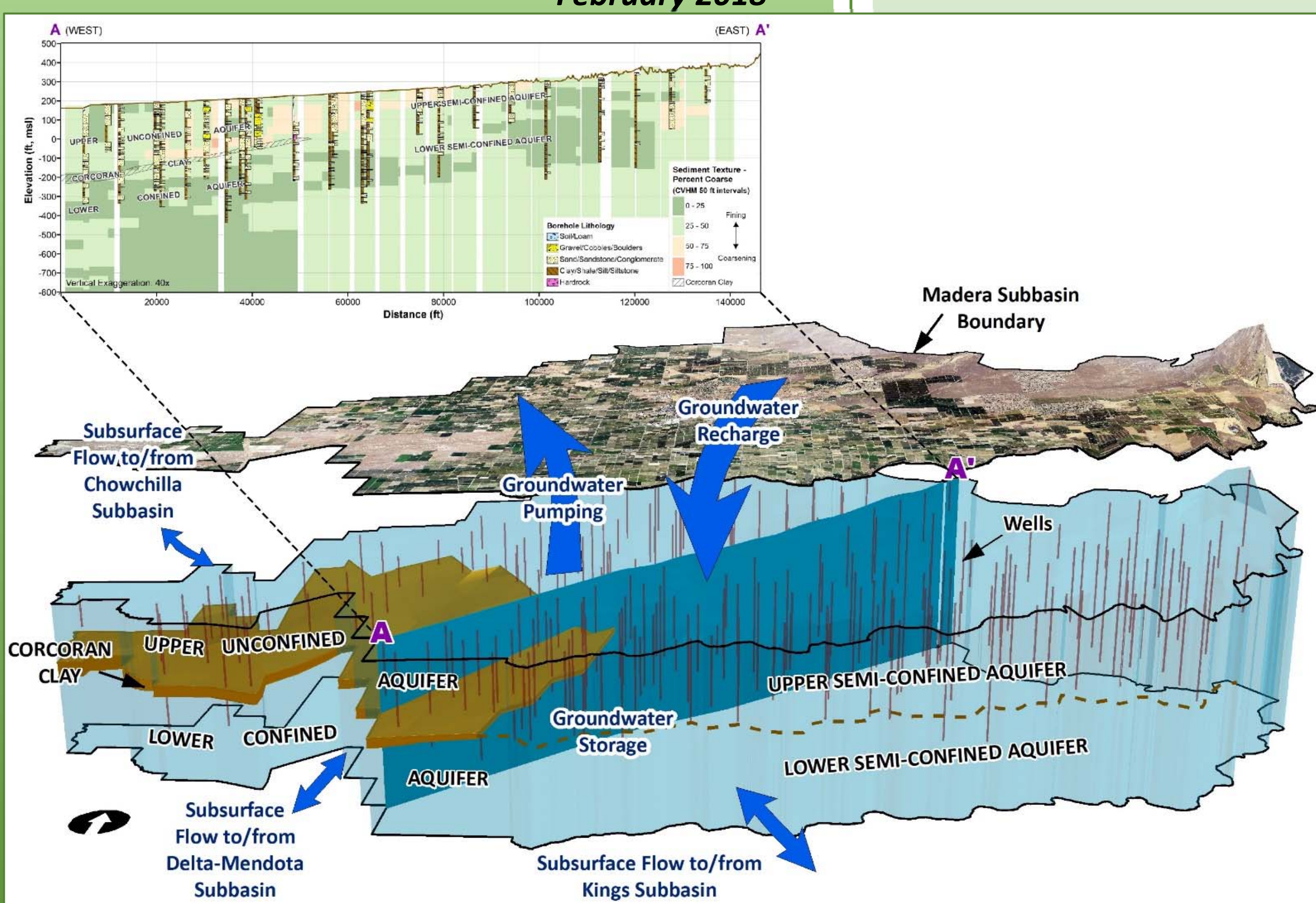
DRAFT PRELIMINARY BASIN BOUNDARY WATER BUDGET

February 2018

Prepared by

DAVIDS ENGINEERING, INC

LUHDORFF & SCALMANINI CONSULTING ENGINEERS



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Prepared For

Madera Subbasin Coordinating Committee

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DAVIDS ENGINEERING, INC

and

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LIST OF ABBREVIATIONS

above normal (AN)

acre-feet/year (AFY)

actual ET (ET_a)

air temperature (T_a)

alfalfa reference (ET_r)

Automatic Weather Stations (AWS)

below normal (BN)

Best Management Practice (BMP)

California Central Valley Groundwater-Surface Water Simulation Model (C2VSim)

California Data Exchange Center (CDEC)

California Department of Water Resources (DWR)

California Irrigation Management Information System (CIMIS)

Central Valley Hydrologic Model (CVHM)

Central Valley Project (CVP)

Chowchilla Water District (CWD)

Confidence Interval (CI)

critical (C)

crop ET (ET_c)

cubic feet per second (cfs)

Davids Engineering (DE)

dry (D)

ET of applied water (ET_{aw})

ET of precipitation (ET_{pr})

evapotranspiration (ET)

geographic information system (GIS)

grass reference (ET_o)

Gravelly Ford (GRF)

Gravelly Ford Water District (GFWD)

groundwater dependent ecosystems (GDEs)

Groundwater Management Plan (GMP)

Groundwater Sustainability Agencies (GSA)

Groundwater Sustainability Plan (GSP)

groundwater system (GWS)

hydraulic conductivity (Kh)

Hydrogeologic Conceptual Model (HCM)

Integrated Water Flow Model (IWFM)

Integrated Water Flow Model Demand Calculator (IDC)

Luhdorff & Scalmanini Consulting Engineers (LSCE)

Madera Irrigation District (MID)

Madera Water District (MWD)

New Stone Water District (NSWD)

Penman-Monteith (PM)

published coarse-grid version of C2VSim, Version R374 (C2VSim-CG)

reference crop evapotranspiration (ET_{ref})

relative humidity (RH)

Root Creek Water District (RCWD)

San Joaquin Valley (SJV)

solar radiation (R_s)

specific yield (Sy)

State Water Resources Control Board (SWRCB)

Surface Energy Balance Algorithm for Land (SEBAL)

surface water system (SWS)

Sustainable Groundwater Management Act of 2014 (SGMA)

This Technical Memorandum (TM)

U.S. Bureau of Reclamation (USBR)

U.S. Department of Agriculture (USDA)

United States Geological Survey (USGS)

Water Data Library (WDL)

wet (W)

wind speed (W_s)

EXECUTIVE SUMMARY

Introduction

The Madera Subbasin covers about 346,600 acres in Madera County. Seven Groundwater Sustainability Agencies (GSAs) have formed to cover the subbasin in its entirety (**Figure ES-1**). Groundwater and surface water are critical resources that support agriculture and other economic activities in the subbasin. Groundwater is particularly important because it is relied upon to a significant extent in all years, and serves as the main supply source in periods when surface water supplies are limited. Thus, the sustainable management of groundwater is important to the long-term prosperity of Madera County's various communities. The Sustainable Groundwater Management Act of 2014 (SGMA) allows for local control of groundwater resources while requiring sustainable management of these resources.

The purpose of this investigation was to develop a preliminary water budget for the subbasin as a whole according to DWR's Groundwater Sustainability Plan (GSP) regulations. This is referred to as the subbasin boundary water budget. The subbasin boundary water budget is based on historical data and is useful because it provides insights into the magnitude of the historical imbalance (or overdraft) of the subbasin. This is turn provides preliminary insights into the nature and scale of potential management actions and/or projects that may be necessary to achieve sustainable groundwater management according to SGMA. Additionally, this work supports initial discussion of delineation of potential management areas.

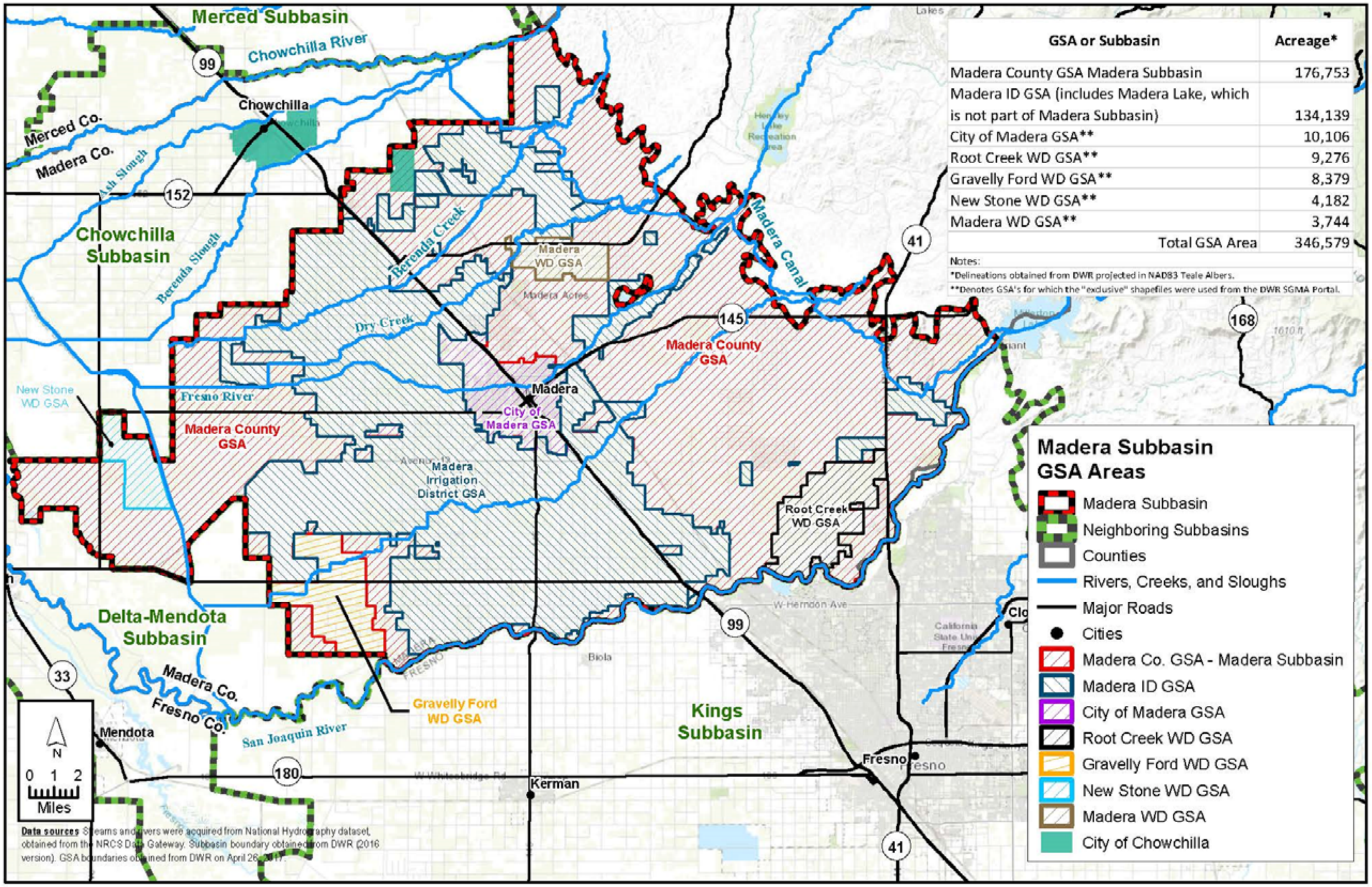
Water Budget Conceptual Model

A water budget is defined as a complete accounting of all water flowing into and out of a defined volume (e.g., a subbasin) over a specified period of time. The conceptual model (or structure) for the Madera Subbasin water budget developed for this investigation is consistent with the GSP Regulations and adheres to sound water budget principles and practices (DWR, 2016).

The lateral extent of the basin is defined by the subbasin boundaries provided on DWR's groundwater information website (DWR, 2017). The vertical boundaries of the subbasin are the land surface on top and the base of fresh water (Page, 1973) as the bottom of the basin as discussed in the preliminary Hydrogeologic Conceptual Model (HCM) developed during previous data collection and analysis efforts conducted by DE and LSCE (2017). The vertical extent of the basin is subdivided into a surface water system (SWS) and the underlying groundwater system (GWS), with separate but related water budgets prepared for each that together represent the overall subbasin water budget.

A conceptual representation of the Madera Subbasin boundary water budget is represented in **Figure ES-2**. Boundary inflows include precipitation, surface water inflows (in various canals and streams), and boundary watercourse seepage and groundwater inflows from adjoining subbasins. Outflows include evapotranspiration (ET), surface water outflows (in various canals and streams), and groundwater outflows. Also represented in Figure ES-2 are groundwater recharge and extraction, which are "internal" flows between theSWS and GWS. Subbasin boundary inflows and outflows must be quantified according to Section §354.18(b) of the GSP Regulations. This was done on a monthly time step for the period 1989 through 2015, including accounting for changes in storage within each time step, such as changes in water stored in the root zone (Equation ES-1).

$$\text{Inflows} - \text{Outflows} = \text{Change in Storage (monthly time step)} \qquad \text{[ES-1]}$$



GSA or Subbasin	Acreage*
Madera County GSA Madera Subbasin	176,753
Madera ID GSA (includes Madera Lake, which is not part of Madera Subbasin)	134,139
City of Madera GSA**	10,106
Root Creek WD GSA**	9,276
Gravelly Ford WD GSA**	8,379
New Stone WD GSA**	4,182
Madera WD GSA**	3,744
Total GSA Area	346,579

Notes:
*Delineations obtained from DWR projected in NAD83 Teale Albers.
**Denotes GSA's for which the "exclusive" shapefiles were used from the DWR SGMA Portal.

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FIGURE ES-1
Preliminary Madera Subbasin GSA Map

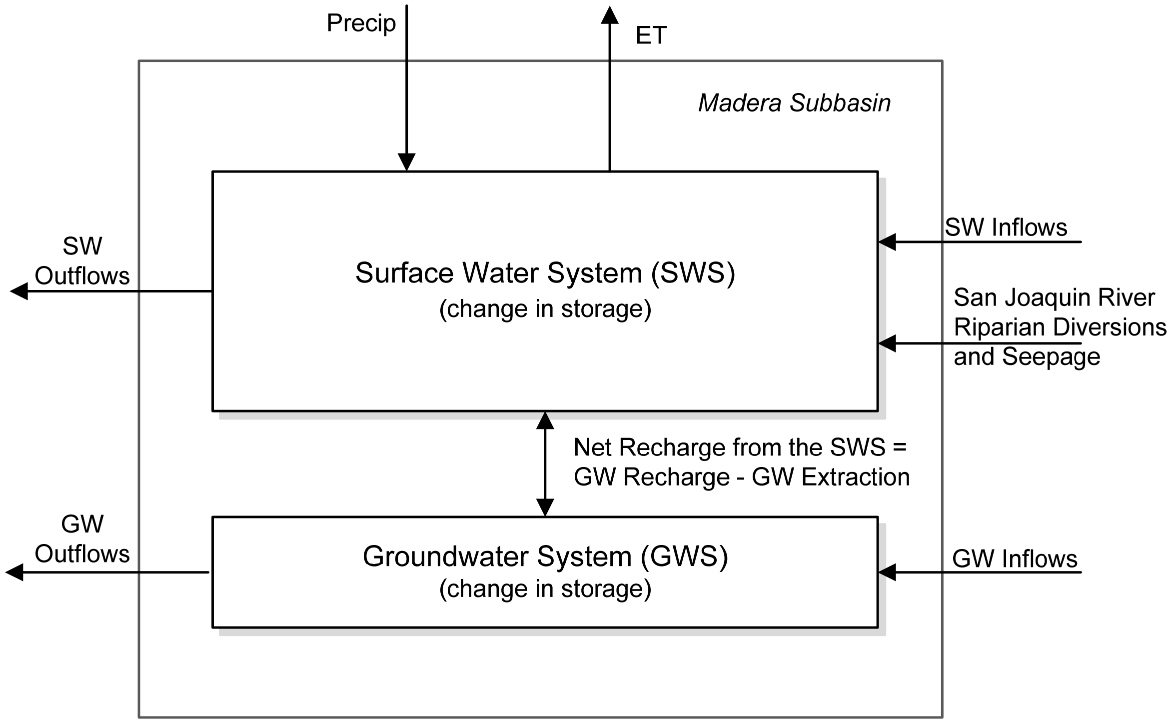

FIGURE ES-2
Preliminary Basin Boundary Water Budget Diagram

Separate but related water budgets were prepared for the SWS and GWS. Each budget and associated methodologies and results are documented in the body of this report. Preliminary estimates of subbasin overdraft derived from the SWS and GWS water budgets are briefly described in the following sections. Additionally, discussion of potential management areas is presented.

Preliminary Sustainable Yield Estimates for the Subbasin

This report estimates an initial Preliminary Sustainable Yield across the entire Madera Subbasin and does not quantify local variability, including the variability between the different GSAs. The preliminary sustainable yield for the overall Madera Subbasin will change once a more detailed analysis is performed. The GSP will quantify local variability among the individual GSAs.

Sustainable yield is defined as the maximum quantity of water, calculated over a base period representative of long-term conditions (in this case 1989 through 2015) in the subbasin, including accounting for any temporary water surpluses, that can be withdrawn annually from a groundwater supply without causing an undesirable result (CA Water Code 10721). According to DWR's recently released Sustainable Management Criteria BMP (DWR, 2017), "Sustainable yield estimates are part of the SGMA's required basinwide water budget" and "a single value of sustainable yield must be calculated basinwide."

For this preliminary analysis, three calculation methods were used to estimate sustainable yield in the Madera Subbasin. The three methods use different combinations of SWS and GWS water budget results to calculate sustainable yield. These preliminary sustainable yield estimates do not include an evaluation of the spatial distribution of pumping and recharge within the subbasin in relation to sustainability indicators. More detailed analyses will be performed during preparation of the GSP to provide this essential additional detail.

The results of all three sustainable yield calculations are similar in magnitude as indicated in **Table ES-1**. The first method is based on subtracting historical change in groundwater storage from historical pumping, indicating an average sustainable yield of slightly more than 300,000 acre-feet annually. The second method is based on summing the total inflow to the GWS, indicating a sustainable yield of slightly less than 300,000 acre-feet. Finally, the third method is based on numerical modeling of the subbasin in which water demands are reduced until extraction (pumping) from the subbasin is balanced by recharge. This method also indicates a sustainable yield of slightly more than 300,000 acre-feet. The second and third methods each depend on the water budget results and therefore may not be completely independent. These results will be refined during GSP development.

Table ES-1
Preliminary Summary of Sustainable Yield Calculation Results

Quantification Method	Average Volume (AF)*	Estimated Confidence Interval (CI) (percent)	CI Source	Average minus CI (AF)	Average plus CI (AF)
GW pumping and GW Change in Storage	301,500	16%	Calculation	253,900	349,100
Total Inflows to GWS	298,200	28%	Calculation	214,900	382,400
"Simulation" of Reduced Demand	303,100	20%	Professional Judgement.	242,500	363,700

*1989 through 2014

Based on these preliminary results, which represent recent historical conditions and reflect the 410,000 to 420,000 acre-feet of groundwater extractions occurring on average annually in the subbasin, it is estimated that groundwater recharge would need to be increased by approximately 110,000 to 120,000 acre-feet annually to achieve sustainable operation of the groundwater system. Alternatively, some combination of increased groundwater recharge and decreased groundwater pumping and water consumption totaling to approximately 110,000 to 120,000 acre-feet annually would be needed to achieve sustainable operation of the groundwater system. This preliminary estimate assumes that all other water budget parameters (namely surface water supplies and GWS inflows and outflows) would remain the same in the future as they were during the period of analysis. More detailed analysis during GSP preparation will assess the reasonableness and validity of these assumptions, taking into account climate change and other possible changes.

Potential Management Areas

Potential management areas were considered in terms of hydrogeologic features and jurisdictional boundaries, and some options are presented. Based on review of the preliminary HCM, the key hydrogeologic features of Madera Subbasin include the extent of Corcoran Clay and the extent and magnitude of historical subsidence. The key jurisdictional boundaries to consider are the GSA boundaries. Regardless of the ultimate decision made by the GSAs regarding boundaries for management areas, individual SWS water budgets are planned for each GSA to provide greater insight on water inflows and outflows at the GSA boundary scale.

One potential option to consider for management areas that involves consideration of both hydrogeologic factors and GSA boundaries would involve delineation of three management areas in the western, central, and eastern portions of the subbasin (**Figure ES-3**). The western management area would encompass the area where Corcoran Clay is present and the area of the subbasin most impacted by historical subsidence. GSAs in the western area include all Gravelly Ford Water District (GFWD), all of New Stone Water District (NSWD), portions of Madera County, and portions of Madera Irrigation District (MID). The central management area would be immediately east of the Corcoran Clay and has shown minimal historical subsidence. The City of Madera GSA is entirely contained in the central area, but the majority of the central area is occupied by the MID GSA. The potential eastern area is far removed from the Corcoran Clay and any significant subsidence concerns. It includes all of Madera Water District GSA and Root Creek Water District GSA, but the majority of the eastern area lands are part of Madera County GSA.

A second potential option is to have management areas based solely on GSA boundaries with no consideration of hydrogeologic factors. This option would result in non-contiguous management areas given the nature of GSA boundaries. However, using GSA boundaries to delineate management areas would allow each GSA to have a better understanding of its own particular Basin Setting (e.g., geologic conditions, water budget, groundwater conditions). The recommended next step in the management area development process is further discussion among the GSAs regarding advantages and disadvantages of the two options described.

Limitations of This Preliminary Analysis

The main limitation of this preliminary basinwide analysis is that it does not account for all undesirable results and does not consider potential localized undesirable effects. An additional limitation is the reliance at this preliminary stage of investigation on the coarse grid Central Valley groundwater model, and its somewhat dated period of analysis, to estimate changes in groundwater storage, and groundwater inflows and outflows. During GSP development a finer grid local model will be developed that will consider all undesirable and localized undesirable results as required by the GSP regulations.

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.

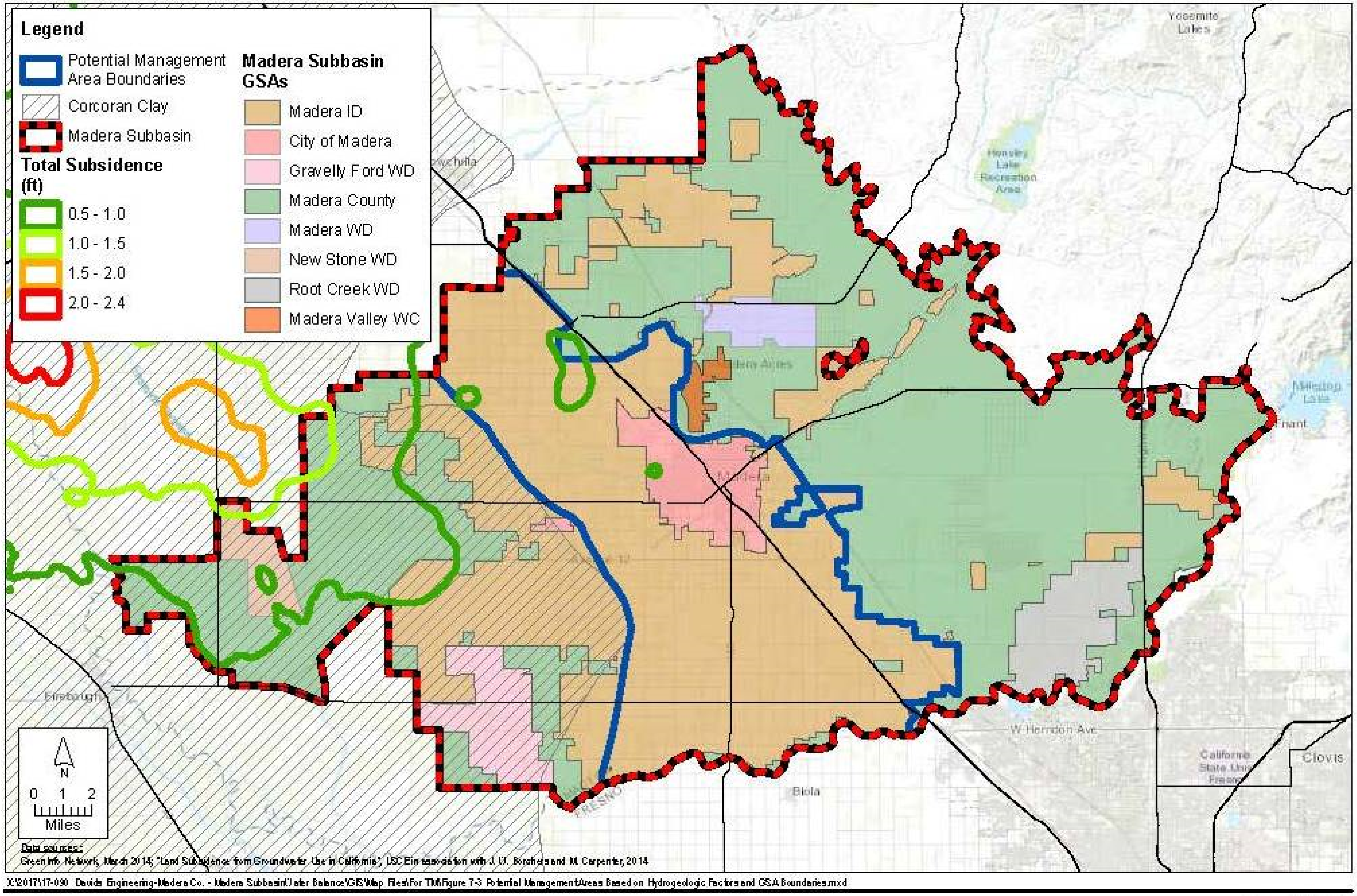

FIGURE ES-3
Preliminary Potential Management Areas Based on Hydrogeologic Factors and GSA Boundaries

1 INTRODUCTION

Agriculture is an important economic driver in the Madera area and groundwater represents an important source of supply for agricultural, municipal, domestic and industrial uses in the Madera Subbasin. Thus, the sustainable management of groundwater is important for the long-term prosperity of the community. The Sustainable Groundwater Management Act (SGMA) allows for local control of groundwater resources while requiring sustainable management of these resources.

The Madera Subbasin covers approximately 346,600 acres, all within Madera County. Seven Groundwater Sustainability Agencies (GSA) have formed to cover the subbasin (**Figure 1-1**). The largest of these is the Madera County GSA covering about 176,800 acres. The Madera Irrigation District (MID) GSA covers about 134,100 acres in Madera County. The remainder of the subbasin is covered by five additional GSAs, including the City of Madera GSA, Root Creek Water District (RCWD) GSA, Gravelly Ford Water District (GFWD) GSA, New Stone Water District (NSWD) GSA, and Madera Water District (MWD) GSA, each individually covering areas between about 3,700 and 10,000 acres.

The Madera Subbasin has been identified by the California Department of Water Resources (DWR) as a critically overdrafted subbasin. Davids Engineering (DE) and Luhdorff & Scalmanini Consulting Engineers (LSCE) recently completed the Sustainable Groundwater Management Act (SGMA) Data Collection and Analysis project for the Madera Subbasin Coordinating Committee. This technical memorandum (TM) documents another task identified by the Madera Subbasin Coordinating Committee as an initial step towards addressing SGMA requirements and the development of a Groundwater Sustainability Plan (GSP). The Committee requested that the DE and LSCE Team complete selected tasks identified during the Data Collection and Analysis Project, including completion of a basin boundary water budget and development of a preliminary basin-wide estimate of sustainable yield. Importantly, the water budget and sustainable yield estimates are preliminary and do not include assessment of undesirable results as required by the GSP regulations. Furthermore, the boundary water budget represents the subbasin in aggregate and therefore the preliminary estimate of sustainable yield does not account for possible localized undesirable results within the subbasin. The objectives of this study are to conduct an initial evaluation of the available data relating to water budget components within the Madera Subbasin and to prepare preliminary assessments of sustainable yield and potential management areas to support future analyses to be conducted as part of development of a GSP for the Madera Subbasin.

DWR has recently published guidance and Best Management Practice (BMP) documents related to the development of GSPs (DWR, 2016). The GSP Annotated Outline includes four distinct components for the Basin Setting section: Hydrogeologic Conceptual Model (HCM), Current and Historical Groundwater Conditions, Water Budget Information, and Management Areas. This TM documents a systematic process to prepare and analyze data relating to the historical water budget, sustainable yield and evaluation of potential options for management areas for the Madera Subbasin.

This TM includes sections describing the conceptual water budget, water budget analysis period, water budget data sources and data acquired, boundary water budget assembly, groundwater storage change calculations, groundwater inflow and outflow calculations, the boundary water budget assembly, a preliminary sustainable yield analysis, and a preliminary delineation of management areas. The methods of analysis, results and, importantly, limitations of the aggregated water budget, preliminary sustainable yield and potential management areas for the Madera Subbasin area are presented to help inform more detailed water budget analyses and the more detailed sustainable yield analysis (including consideration of undesirable results) to be conducted as part of the GSP development.

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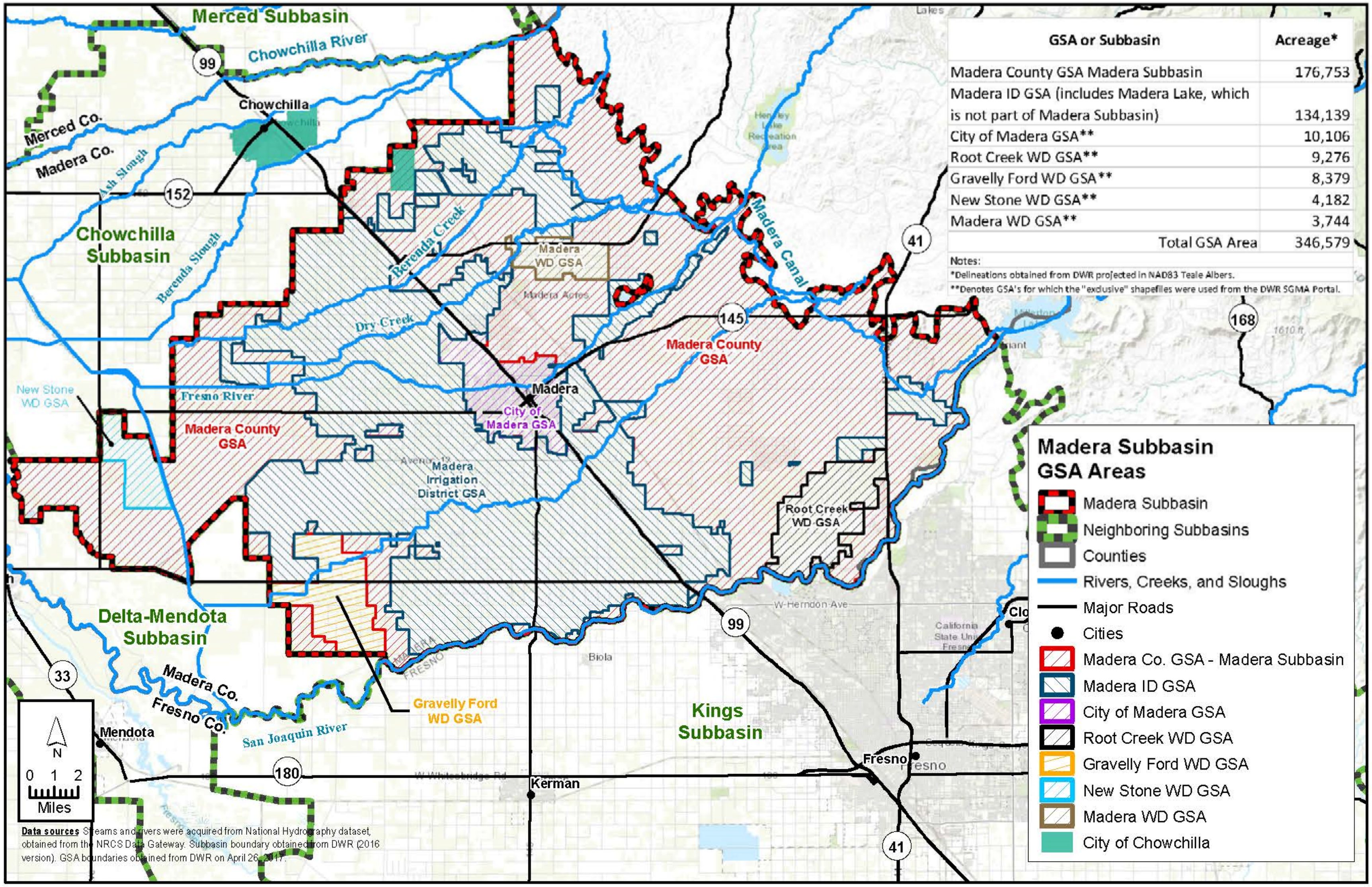

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FIGURE 1-1
Preliminary Madera Subbasin GSA Map

2 WATER BUDGET CONCEPTUAL MODEL

A water budget is defined as a complete accounting of all water flowing into and out of a defined volume (e.g., a subbasin) over a specified period of time. The conceptual model (or structure) for the Madera Subbasin water budget was developed during previous data collection and analysis efforts conducted by DE and LSCE (2017) and is consistent with the GSP Regulations and adheres to sound water budget principles and practices described in the Water Budget BMP (DWR, 2016).

The lateral extent of the basin is defined by the subbasin boundaries provided in the recent DWR Bulletin 118 update (DWR, 2016). The vertical boundaries of the subbasin are the land surface on top and the definable bottom of the basin. The definable bottom was established as part of developing the preliminary HCM during previous data collection and analysis efforts conducted by DE and LSCE (2017). The vertical extent of the basin is subdivided into a surface water system (SWS) and groundwater system (GWS), with separate but related water budgets prepared for each that together represent the overall subbasin water budget.

The SWS represents the land surface down to the bottom of plant root zone, within the lateral boundaries of the basin. The GWS extends from the bottom of the root zone to the definable bottom of the subbasin, within the lateral boundaries of the basin. The SWS basin boundary water budget was completed on a monthly time step and calendar year[1] annual results are provided in Section 5.

The SWS is further subdivided into water use sectors identified in the GSP regulations. Water use sectors are defined in the GSP Regulations as “categories of water demand based on the general land uses to which the water is applied, including urban, industrial, agricultural, managed wetlands, managed recharge, and native vegetation.” Water budgets for each water use sector in the subbasin will be added to the water budget during GSP development.

Subbasin boundary inflows and outflows must be quantified according to Section §354.18(b) of the GSP Regulations. Inflows and outflows may cross the subbasin boundary, or may represent exchanges of water between the SWS and the underlying GWS. The Madera Subbasin boundary water budget is represented in **Figure 2-1.** Boundary inflows include precipitation, surface water inflows (in various canals and streams), boundary watercourse seepage and groundwater inflows from adjoining subbasins. Outflows include evapotranspiration (ET), surface water outflows (in various canals and streams), and groundwater outflows. Also represented in Figure 2-1 are groundwater recharge and extraction, which are “internal” flows between the SWS and GWS. Net recharge from the SWS from the GWS is defined as groundwater recharge minus groundwater extraction, and is useful for understanding and analyzing the combined effects of land surface processes on the underlying GWS. Basin boundary inflows and outflows are quantified on a monthly basis, including accounting for any changes in storage, such as changes is water stored in the root zone (Equation 2-1).

Inflows – Outflows = Change in Storage (monthly time step) [2-1]

[1] Calendar years represent the agricultural irrigation season better than water years.

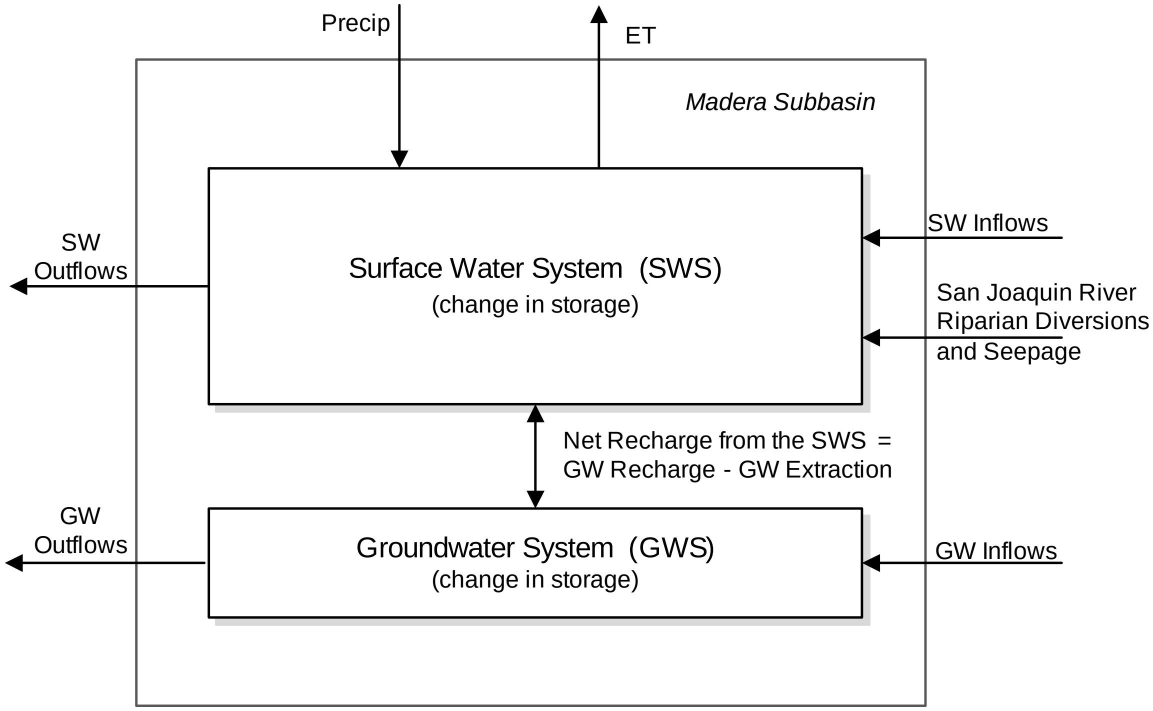


FIGURE 2-1
Preliminary Basin Boundary Water Budget Diagram

A slightly more detailed representation of the conceptual budget from DWR's water budget BMP document (DWR 2017) is shown in **Figure 2-2**. It is conceptually identical to **Figure 2-1**, but illustrates the various inflows and outflows comprising recharge, extraction and discharge from the GWS.

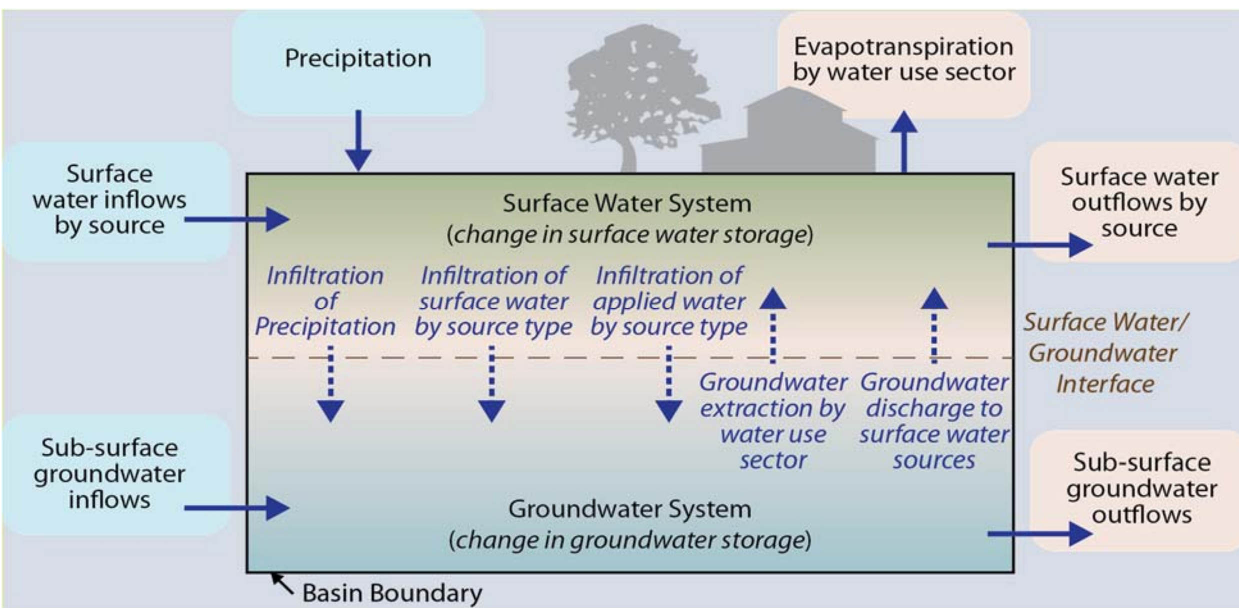


FIGURE 2-2
Preliminary Basin Boundary Water Budget
(Source: DWR Water Budget BMP (2016))

The time period of analysis selected for the water budget analysis is discussed in Section 3. The specific components of SWS inflows and outflows, and the data available and calculation methodology for each component are described in Section 4, with water budget results presented in Section 5. Quantification of GWS inflows and outflows is described in Section 6. Inflows and outflows were calculated independently using measurements and other data, or calculated as the water budget closure term.

3 WATER BUDGET ANALYSIS PERIOD

In accordance with GSP regulations, a base period must be selected so that the analysis of sustainable yield is performed for a representative period, with minimal bias that might result from the selection of an overly wet or dry period, while recognizing changes in other conditions including land use and water demands. The base period should be selected considering the following criteria: long-term mean annual water supply; inclusion of both wet and dry periods, antecedent dry conditions, adequate data availability; and inclusion of current hydrologic, cultural, and water management conditions in the basin. To develop a preliminary base period to be used for sustainability analyses during GSP development, only historical precipitation records for the area were evaluated.

Precipitation provides an indication of the long-term mean water supply and potential for natural groundwater recharge. Monthly precipitation records acquired from the Western Regional Climate Center for a station in Madera (Station 045233) were analyzed for the period 1928 through 2016. This station provides a longer record than the CIMIS weather stations described in Section 4. A plot with annual precipitation, mean annual precipitation, and cumulative departure[2] from mean annual precipitation was developed for the Madera station (**Figure 3-1).**

Notable on this plot is the long-term overall average period from the late 1920s through the late-1970s (overall flat cumulative departure curve), followed by a somewhat wet period during the late-1970s and early-1980s, dry late-1980s, wet 1990s, overall average from late 1990s through 2011, and recently a dry period from 2012 through 2015. The period of 1989 through 2015 is a relatively balanced climatic period with a similar number of wet and dry years and some prolonged periods of wet, dry, and average conditions and represents a reasonable base period for conducting sustainability analyses. Nevertheless, the net negative slope of the cumulative departure curve over this period suggests that precipitation inputs to the subbasin over the 1989 through 2015 period were slightly below average (relative to the entire 1928 through 2015 period average).

Antecedent (i.e., prior or left-over year) dry conditions minimize differences in groundwater in the unsaturated zone at the beginning and at the end of a study period. Given that the measure of water in the unsaturated zone is nearly impossible to determine, particularly at the scale of a groundwater subbasin, selection of a base period with relatively dry conditions antecedent to the beginning and end of the period of record is preferable because any water stored in the unsaturated zone is minimized. In this case, the proposed base period from 1989 through 2015 begins in a dry year with one additional prior dry year and ends in a dry year with several prior dry years.

The available hydrologic and land and water use data over the period are sufficient to calculate the various parameters used to analyze groundwater conditions as related to the groundwater budget and sustainability (e.g., precipitation, streamflow, land uses, groundwater pumping, groundwater levels, and imported water sources). Lastly, the proposed base period ends near the present time, and therefore can be used to assess groundwater conditions as they currently exist. Given these criteria, the base period of 1989 through 2015, is considered to be appropriate for assessing groundwater conditions with minimal bias introduced from land use changes or imbalances due to wet or dry conditions. Although the evaluation of the precipitation data at Madera suggest that 1989 through 2015 represents a good base period of 27 years for conducting GSP analyses, additional consideration with respect to the base

[2] Cumulative departure curves are useful to illustrate long-term rainfall characteristics and trends during drier or wetter periods relative to the mean annual precipitation. Downward slopes of the cumulative departure curve represent drier periods relative to the mean, while upward slopes represent a wetter period relative to the mean.

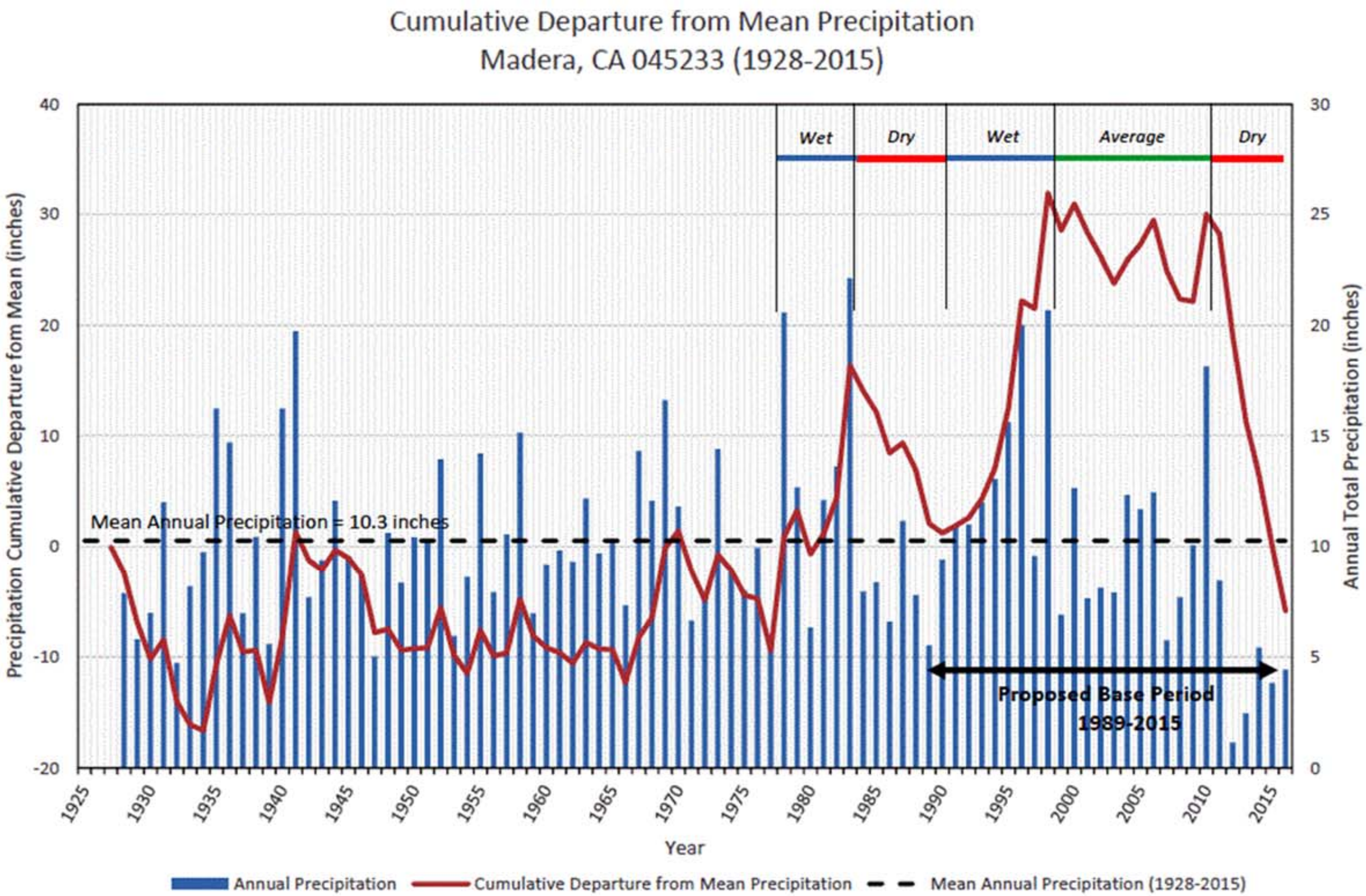
period should be given during the GSP development as additional data review is conducted. In particular, consideration should be given to the patterns of CVP supplies and to local supplies from Hensley Lake, which may or may not be strongly correlated with local precipitation. Ultimately, the GSP base period may be selected based on some combination of these and/or other factors to define a period that is normal for the subbasin from a water budget perspective.

The GSP regulations also specify that sustainability analyses be conducted on at least an annual time step. However, a monthly time step is recommended to support evaluation of sustainability indicators, and potential projects and management actions. These sustainability evaluations, which may include analyses involving hydrologic modeling, will require data and analyses at a time step sufficient to assess seasonal conditions and trends within an annual interval in addition to long-term trends spanning years.

The analysis period selected for this initial water budget evaluation is based on a combination of the historical climatic conditions and availability of data suitable for use in conducting the different analyses of the water budget components. During review of groundwater level data needed to calculate change in groundwater storage from observed conditions, it became apparent that 1989 through 2014 would be a more appropriate analysis period for this effort because of the relative sparsity of groundwater level data (and therefore diminished quality of resulting groundwater level interpretations) available for 2015. Therefore, the analysis results discussed below are based on analysis of the period 1989 through 2014, although data and calculations of water budget components were also assembled for 2015, to the extent that suitable data exist. Based on the cumulative departure curve (**Figure 3-1**) used to choose time periods for analysis, using 2014 as the last year still provides a balanced hydrologic time period for the analysis. Therefore, groundwater elevation contours were produced for spring of 2014, and used for change in groundwater levels and change in storage calculations.

The GSP regulations require that evaluation of water budgets under projected future conditions utilize 50 years of historical hydrology (precipitation, evapotranspiration and streamflow) information. Evaluation of projected future water budgets for the Madera Subbasin was not part of this analysis and will be conducted as part of future GSP development efforts.

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.



(Precipitation data from Western Regional Climate Center, 2017)

FIGURE 3-1
Preliminary Cumulative Departure from Mean Precipitation

4 WATER BUDGET DATASETS

This section describes the data sources, quality control and calculations completed to develop the main time series datasets required to develop the SWS water budget. The datasets include surface water inflows and outflows, meteorological data used to compute reference crop evapotranspiration (ET_{ref}), land use and cropping patterns, crop water use (evapotranspiration, or ET), surface water diversions, applied surface water volumes, and groundwater pumping volumes. Each of these datasets is described below.

4.1 Surface Water Inflows and Outflows

4.1.1 Madera Canal

Inflow data for the Madera Canal were assembled from measurements collected by the United States Geological Survey (USGS) for the "MADERA CN A FRIANT CA" site. This site is located near the town of Friant, California is also referred to by its USGS site number: 11249500. This site measures the flow in the Madera Canal just downstream of the diversion point from Millerton Lake near the north end of Friant Dam. This water is used to irrigate lands in the Madera and Chowchilla Subbasins. Daily records of discharge in cubic feet per second (cfs) were downloaded for the full period of available records, from October 1, 1948 through September 30, 2016. These 68 years of records were summarized into monthly and annual volumes.

The Madera Canal enters the Madera Subbasin at its southeastern corner, runs northwesterly along the eastern subbasin boundary, and leaves the subbasin almost 32 miles to the northwest. Located along the canal are delivery points to irrigation distribution infrastructure and irrigated lands within the Madera Subbasin. The USGS inflow measurement site described above is located 0.58 miles outside of the subbasin boundary. More information about this site is available at: https://waterdata.usgs.gov/nwis/inventory/?site_no=11249500&agency_cd=USGS.

Outflow data for the Madera Canal were assembled from records provided by MID for the years 1973-2016 using the data from operating reports of Class 1 and Class 2 Deliveries to MID and Chowchilla Water District (CWD). These data were assembled into monthly and annual volumes.

Irrigation deliveries from the Madera Canal to the MID distribution system and in some cases directly to MID irrigated lands were compiled into monthly and annual volumes using data provided by MID. These deliveries were included as surface water inflow into the Madera Subbasin.

Using the USGS Madera Canal inflow data and the irrigation deliveries to MID and to CWD, a monthly water budget for the Madera Canal was prepared to estimate seepage from the canal. For this preliminary seepage estimate, canal evaporation was assumed to be negligible. Seepage estimates for the Madera Canal prepared for the Madera Canal Capacity Restoration Feasibility Study (USBR 2016) were also reviewed. For this preliminary water budget, the seepage estimate of 5,400 acre-feet for the full canal length was multiplied by 87 percent, the percent of the canal length in, or on the boundary, of the Madera Subbasin.

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.

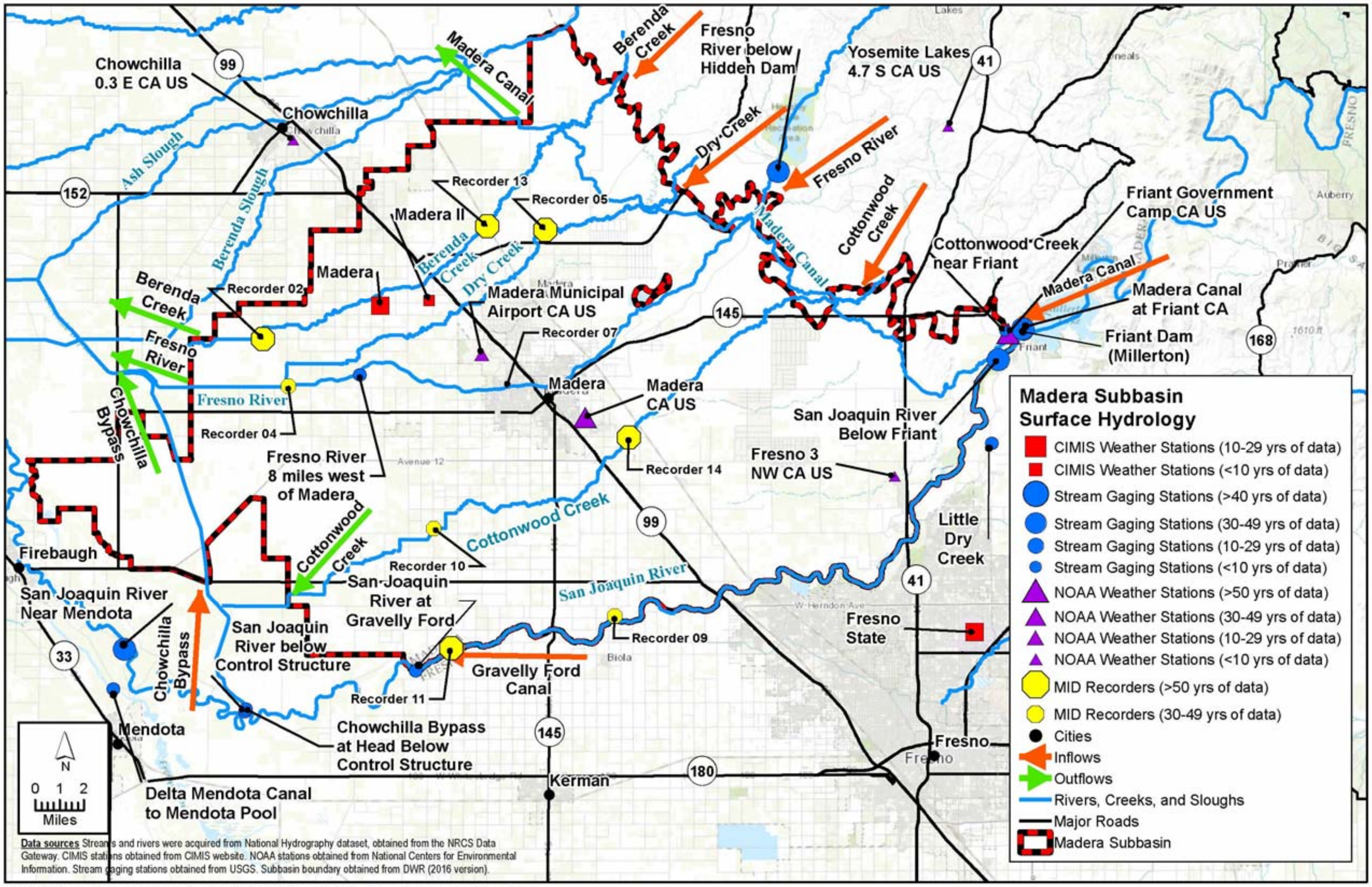


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FIGURE 4-1
Preliminary Madera Subbasin Inflows and Outflows

4.1.2 Cottonwood Creek

Inflow data for Cottonwood Creek were assembled from records provided by MID. MID has installed a number of recorders within the district infrastructure that record flows at key inflow and outflow points. One of these points is Recorder 14: Cottonwood Creek Head, which records historical inflows. The recorder is located along the creek just a few miles southeast of Madera, CA in Madera County. Average daily flow volumes were provided by MID for the years 1970-2016, and summarized into monthly and annual volumes.

Cottonwood Creek enters the Madera Subbasin along its eastern boundary, and continues for approximately 34 miles through the subbasin until it exits along the southwestern subbasin boundary. During the irrigation season, just over 18 miles of the creek are used as part of the irrigation distribution system. The measurement point of Recorder 14 is approximately 11 miles from the eastern boundary of the subbasin. The measured flows at this point have been used as an estimate of the flows entering the Madera Subbasin; for this preliminary water budget, no adjustment for seepage loss from the portion of the canal outside the subbasin has been completed. Additionally, Gravelly Ford Water District diverts water from Cottonwood Creek downstream of MID Recorder 10 under water right Application A0230231 Permit # 016060.

4.1.3 Fresno River

Inflow data for the Fresno River were assembled from records provided by both the USGS and the DWR's California Data Exchange Center (CDEC). The USGS site named "FRESNO R BL HIDDEN DAM NR DAULTON CA," is located near Daulton, CA in Madera County, approximately 1 mile downstream of Hidden Dam on the Fresno River. The site is also referred to by its USGS site number: 11258000. This site measures discharge in the Fresno River at this point and has discharge records for the period October1941 through October 1990. The CDEC site, Hidden Dam (Hensley), is also located near Daulton, CA in Madera County just downstream of Hidden Dam. This site also measures the discharge of the reservoir in the Fresno River and has records for October 1993 through present. Data sets from both sites were downloaded and summarized into monthly and annual volumes.

The Fresno River enters the Madera Subbasin along its eastern boundary and exits along its western boundary. The total distance of the river within the subbasin boundaries is approximately 27 miles. During the irrigation season, about 10 miles of the river are used as part of the irrigation water distribution system. The inflow measurement points are approximately 2 miles upstream of the subbasin boundary. The measured flows at this point were used as an estimate of the flows entering the Madera Subbasin. Additional information about this site can be found by visiting https://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=HID or https://waterdata.usgs.gov/nwis/inventory/?site_no=11258000&agency_cd=USGS.

Outflow data for the Fresno River was assembled from records provided by MID for "Recorder 4: Fresno River Rd. 16." This recorder measures flow in the Fresno River where it exits the MID service area, approximately 10 miles directly west of the City Madera. Average monthly and daily flow volumes were provided by MID for the years 1951-2017. From these records, monthly and annual summaries of volumes were compiled. This measurement point is approximately 4 miles inside of the subbasin boundary. In this preliminary water budget, the measured flows at this point were used as an estimate of the flows leaving the Madera Subbasin, without adjustment for seepage loss from the portion of the river inside the subbasin but downstream of the outflow measurement point. On rare occasions, Fresno River flows may be diverted up Dry Creek to satisfy irrigation demands. Historical information documenting when these infrequent diversions occurred is unavailable. These flows will be further investigated during GSP development.

4.1.4 Dry Creek

Inflow data for Dry Creek were assembled from records provided by MID. Another recorder within their system, "Recorder 5: Dry Creek Head Flood Water," is located along Dry Creek approximately 7 miles north of the City of Madera. Average daily flow values were provided by MID for the years 1966 through 2017, which were summarized into monthly and annual flow volumes.

Dry Creek enters the Madera Subbasin along the eastern border, between the Fresno River and Berenda Creek. It travels for a distance of approximately 24 miles before its confluence with the Fresno River before the Fresno River reaches the subbasin boundary. About 21 of the 24 miles of this waterway are used as part of the irrigation distribution system during the irrigation system. The measured flows at Recorder 5, approximately 8.5 miles inside the boundary of the subbasin, were used as an estimate of the flows entering the Madera Subbasin; For this preliminary water budget no adjustment for seepage loss from the portion of the creek inside the subbasin but upstream of the inflow measurement point was completed. Dry Creek joins the Fresno River before the measurement at MID Recorder 4. Therefore, Dry Creek outflow is usually included in the Fresno River outflow measurement. However, sometimes during flood conditions, the Sallaberry Canal often conveys Dry Creek flows out of the Subbasin without passing through Recorder 4 in the Fresno River. This outflow will be included with an estimate of the flows during GSP development.

4.1.5 Chowchilla Bypass

The Chowchilla Canal Bypass is located along the southern edge of the Madera Subbasin. It is a flood control channel operated via gates along the San Joaquin River that are opened to divert flow into the bypass when flow in the San Joaquin River would exceed the river's downstream capacity. The bypass may remain dry for extended periods of time until needed to convey flood flows and provide flood protection. At other times of the year, water may remain ponded in some of the lower-lying areas. Because of these characteristics and the fact that this site is operated on an as-needed basis, there may be significant times during the record of flow that there is no water flowing through the channel. Records like this are denoted as "Below the Rating Table" in the DWR's CDEC and were replaced with 0 before proceeding with the compilation of monthly and annual volumes.

Inflow data for Chowchilla Bypass at head Below Control Structure were assembled using a combination of CDEC records and DWR's Water Data Library (WDL) records. WDL provided data for the years 1982-1991, and CDEC provided data for the years 1997-2017. Daily average flow values were summarized as monthly and annual volumes for this site.

The Chowchilla Bypass enters the Madera Subbasin along the southwestern border, traverses the Subbasin for approximately 5 miles, and exits the subbasin boundary and enters the Chowchilla Subbasin. It flows intermittently, only when flows in the San Joaquin River are above flood stage. Shortly after exiting the subbasin boundary, the Fresno River flows into the Bypass. At this point it becomes the Eastside Bypass. There is no measurement point for flows leaving the Madera subbasin in the Chowchilla Bypass. Seepage and evaporation losses from the Chowchilla Bypass for the five mile length in the Madera Subbasin have been assumed to be negligible for this preliminary water budget. To track the Chowchilla Bypass flows, the measured flows at the Chowchilla Bypass at head Below

Control Structure have been used as an estimate of the flows entering the Madera Subbasin and leaving the Madera Subbasin, without adjustment for seepage loss.

4.1.6 Berenda Creek

Inflow data for Berenda Creek were assembled from records provided by MID. Another recorder within their system, "Recorder 13: Berenda Creek Head," is located along Berenda Creek approximately 7.5 miles north of the City of Madera. Average daily flow values were provided by MID for the years 1970 through 2017, and summarized into monthly and annual flow volumes.

Berenda Creek enters the Madera Subbasin along the northeastern subbasin boundary, between the Chowchilla River and Dry Creek. It continues southwesterly for a distance of approximately 28 miles before exiting the subbasin boundary just north of the Fresno River. During the irrigation season, approximately 7.5 miles of this waterway are used as part of the irrigation distribution system. The inflow measurement point is almost 13 miles inside the boundary of the subbasin, as measured along the course of the creek. In this preliminary water budget, the measured flows at this point have been used as an estimate of the flows entering the Madera Subbasin, without adjustment for seepage loss from the portion of the creek within the subbasin but upstream of the inflow measurement point.

Outflow data for Berenda Creek were assembled from records provided by MID for "Recorder 2: Berenda Creek Spill," located along Berenda Creek approximately 8.5 miles south of the City of Chowchilla. Monthly and daily flow volumes were provided by MID for the years 1966 through 2017, and were compiled into monthly and annual volume summaries.

Berenda Creek exits the Madera Subbasin along its western edge, just north of the Fresno River. The measurement point for this recorder is just over 3 miles upstream of the subbasin boundary. In this preliminary water budget, the measured flows at this point have been used as an estimate of the flows leaving the Madera Subbasin, without adjustment for seepage loss from the portion of the creek inside the subbasin but upstream of the inflow measurement point.

4.1.7 San Joaquin River

Inflow data for the San Joaquin River were assembled from records provided by the USGS. The site, called "SAN JOAQUIN R BL FRIANT CA," is located near the town of Friant in Fresno County, approximately 2 miles downstream of the Friant Dam. This site is also referred to by its site number: 11251000. The site measures flows released from Millerton Lake. Discharge records are available for nearly 110 years, from 1911 to the present. Daily data was downloaded and summarized into monthly and annual volumes.

The San Joaquin River runs southwesterly from Millerton Lake north of the northern edge of the City of Fresno, then travels westward toward the City of Mendota, forming the southern Madera Subbasin boundary. It exits the subbasin approximately 8 miles northwest of the City of Kerman. The total length of the river along the subbasin boundary is nearly 40 miles. The San Joaquin River below Friant measurement point is 0.5 miles inside the subbasin boundary. Additional information about this site is available at: https://waterdata.usgs.gov/nwis/inventory/?site_no=11251000&agency_cd=USGS.

Outflow data for the San Joaquin River were assembled from records provided by CDEC. The site, named "San Joaquin River at Gravelly Ford (GRF)," is located in Madera County approximately 7.5 miles northwest of the town of Kerman. The site measures mean daily flow values with data available for the period from 6/27/1997-to the present. The data were downloaded and summarized as monthly and annual volumes.

The San Joaquin River leaves the Madera Subbasin boundary 0.7 miles downstream of this measurement point, and the Gravelly Ford Canal Pumped Diversion inflow is just over one mile upstream of the measurement site. More information about this site is available at: http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=GRF.

Based on a list of riparian diversions and estimates of capacity between Friant and Gravelly Ford (McBain & Trush, 2002), an estimate of the area irrigated was prepared. The almond applied water results from the root zone water budget described later in Section 5 was used with the area to estimate riparian diversions. During the GSP preparation, this estimate will be checked by totaling the cropped area riparian to the river from the land use analysis described in Section 5. Riparian deliveries are inflows to the basin and were included in the surface water inflows. Using the USGS San Joaquin River below Friant flow data, the inflow from Little Dry Creek, the Gravelly Ford discharge measurement site and the estimate of riparian diversions, a water budget for this reach of the San Joaquin River was completed to estimate the volume of river seepage. For this preliminary estimate of seepage, evaporation was assumed to be negligible. San Joaquin River seepage is an inflow to the GWS and is included in the infiltration of surface water. McBain & Trush (2002) also estimated San Joaquin River seepage. These estimates will be reviewed during the GSP development studies.

4.1.8 Gravelly Ford Canal

The Gravelly Ford Canal is pumped from the San Joaquin River at a site known as the "Gravelly Ford Pump Diversion." The Gravelly Ford Water District (GFWD) provided pumping volumes for the years 1989-2015. This pumping site is located along the San Joaquin River just over 1 mile upstream of the San Joaquin River at Gravelly Ford USGS measurement site. The records provided by GFWD were assembled into monthly and annual volumes.

4.1.9 Inflow and Outflow Data Quality Control

Quality control procedures were applied to identify data gaps and data values outside of plausible ranges. Data gaps were filled with estimates based on the water year index (http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST) developed by the DWR. DWR has categorized each water year since 1901 for both the Sacramento and San Joaquin Valleys into five year types based on estimated unimpaired runoff. DWR defines unimpaired runoff as "the natural water production of a river basin, unaltered by upstream diversions, storage, and export of water to or import of water from other basins." Each year is assigned one of the following five year types: wet (W), above normal (AN), below normal (BN), dry (D), and critical (C).

For months with missing data within the years 1989-2015, the average of that same month calculated using all the years with the same water year classification was used as an estimate for the flow in the missing month. When the number of years with available data for developing water year type monthly averages was less than five, the five water year types were grouped into simply "Wet" and "Dry" years. "Wet" years were defined as wet or above normal, and the "Dry" years were defined as below normal, dry, or critical.

4.2 Meteorological Data

4.2.1 ETo Results Summary

A scientifically sound and widely accepted method for determining consumptive use of irrigation water utilizes daily reference crop evapotranspiration (ET_{ref}) values calculated using the standardized Penman-Monteith (PM) method as described by the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005). The PM method requires measurements of the following meteorological (weather) parameters: incoming solar radiation (R_s), air temperature (T_a), relative humidity (RH) and wind speed (W_s), all at hourly or daily time steps. The task committee report standardizes the ASCE PM method for application to a full-cover alfalfa reference (ET_r) and to a clipped cool season grass reference (ET_o). The clipped cool season grass reference is widely used throughout the western United States and was selected for this application. Additionally, the Task Committee Report provides recommended methods for estimating required inputs to the standardized equation when measured data are missing.

Weather data from irrigated areas are needed to develop estimates of consumptive use of irrigation water. Automatic Weather Stations (AWS) provide measurements of R_s, T_a, RH and W_s over hourly or shorter periods used to compute ET_o. The California Irrigation Management Information System (CIMIS) weather stations meet these requirements and weather data was obtained and quality controlled to develop ET_{ref} and precipitation records for the Madera Subbasin for the period from 1989 through 2015. **Table 4-1** lists the stations and periods of record used.

Table 4-1
Preliminary Madera Subbasin Weather Data Time Series Summary for the Period 1989 through 2015

Weather Station	Start Date	End Date	Comment
Fresno State	Oct. 2, 1988	May 12, 1998	CIMIS. Before Madera was installed.
Madera	May 13, 1998	Apr. 2, 2013	CIMIS. Moved eastward 2 miles in 2013 and renamed “Madera II.”
Madera II	Apr. 3, 2013	Dec. 31, 2015	CIMIS

Weather data from each station were reviewed and corrected when necessary following accepted, scientific procedures (Allen et al., 1996; Allen et al., 1998; ASCE-EWRI, 2005; and ASCE, 2016). Daily data were checked using visual interpretation of time series graphs developed in spreadsheets. Quality control methods according to the guidelines specified in Appendix-D of the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005) were applied as necessary, as described in **Appendix A**.

The average water year ET_o for 1989 through 2015 was 55.34 inches and ranged from 50.64 inches in 1995 to 59.79 inches in 2004 (**Table 4-2).**

Table 4-2
Preliminary Weather Data Time Series Summary for the Period 1989 through 2015

Weather Station	Start Date	End Date	Average Water Year ET_o, inches	Minimum Water Year ET_o, inches	Maximum Water Year ET_o, inches
Fresno State	Oct. 2, 1988	May 12, 1998	55.13	50.64 (1995)	59.27 (1992)
Madera	May 13, 1998	Apr. 2, 2013	55.67	52.56 (2011)	59.79 (2004)
Madera II	Apr. 3, 2013	Dec. 31, 2015	55.51	53.79 (2014)	57.24 (2015)
Overall	Oct. 2, 1988	Dec. 31, 2015	55.34	50.64 (1995)	59.79 (2004)

Water year ET_o totals for the complete 1989 through 2015 period are included in **Appendix A**.

4.2.2 Precipitation Results Summary

Based on data from the same weather stations described above, the 27-year average water year precipitation from 1989 through 2015 was 10.11 inches, varying from 3.59 inches in 2014 to 19.62 inches in 1995 (**Table 4-3**).

Table 4-3
Preliminary Water Year Precipitation Statistics for 1989 through 2015

Weather Station	Start Date	End Date	Average Water Year Precipitation, inches	Minimum Water Year Precipitation, inches	Maximum Water Year Precipitation, inches
Fresno State	Oct. 2, 1988	May 12, 1998	12.76	9.14 (1994)	19.62 (1995)
Madera	May 13, 1998	Apr. 2, 2013	8.98	4.35 (2012	12.79 (2006)
Madera II	Apr. 3, 2013	Dec. 31, 2015	4.25	3.59 (2014)	4.90 (2015)
Overall	Oct. 2, 1988	Dec. 31, 2015	10.11	3.59 (2014)	19.62 (1995)

Water year precipitation totals for the complete 1989 through 2015 period are included in **Appendix A.**

4.3 Land Use

Accurate land use areas are required for determining consumptive use of irrigation water, or evapotranspiration (ET). The objective was to develop a Madera County-wide annual, spatial crop acreage dataset from which the crop areas in the Madera Subbasin, Madera County GSA in Madera Subbasin, MID GSA, RCWD GSA, Gravelly GFWD GSA, NSWD GSA and Madera City GSA were derived.

Data used to develop annual, county-wide spatial land use includes: (1) DWR spatial land use surveys for Madera County in 1995, 2001 and 2011, (2) Land IQ[3] remotely sensed land use data obtained through

[3] Land IQ is a firm that was contracted by DWR to use remote sensing methodologies to identify crops in fields.

DWR for 2014, and (3) Madera County Agricultural Commissioner annual crop production areas reported for 1989 through 2015. The following five steps were taken:

1.) Developed spatial land use coverages for 1995, 2001, 2011, and 2014. Made adjustments to the spatial coverage, including:
    a) Inserted 2011 DWR coverage for missing areas from 2014 LandIQ coverage (native, urban, water, & semi-agriculture land uses account for 86% of the missing area)
    b) Water surfaces were not included in the 1995 DWR survey; used the water area from 2001 for the 1995 DWR survey

2.) Calculated agricultural area:
    a) County data have idle equal to zero for all years--assumed county data do not include idle land
    b) Excluded idle from DWR agricultural totals--to be consistent with county totals
    c) Calculated the ratio of the DWR agricultural total area (not including idle lands) to county agricultural production area for years with DWR (or Land IQ) land use data
    d) Interpolated the ratio calculated in step (c) for missing years, extended trend or set at last values for years before first and after last county data

3.) Multiplied county agricultural acres for each crop by the ratio calculated in step 2 (c) to adjust county agricultural areas for each crop scaling each crop area in each year by an estimate of the difference between the areas in the DWR land use surveys and County Commissioner reports. This procedure assumes DWR areas are the most accurate.
    a) Interpolated native, semi-agriculture, urban, and water land uses between DWR years
    b) Calculated idle area as the remaining area (total DWR land use minus total cropped area)

4.) Reviewed calculated idle and crop area graphs to adjust individual annual cropped areas with abnormal crop area shifts based on judgment to eliminate calculated negative idle areas
    a) 1996 adjustments--replaced high miscellaneous truck areas with interpolated values between 1995 and 1997
    b) 2002, 2003, 2004 and 2005 adjustments--replaced high areas for mixed pasture and alfalfa between 2001 and 2011 DWR areas by interpolating areas between 2001 and 2011
    c) 2012 adjustments--replaced high miscellaneous deciduous, field and truck with interpolated value between 2011 and 2013

5.) Implemented the DWR Land Use interpolation tool to create annual spatial cropping data sets

4.4 Crop Water Use

A daily root zone water budget model using improved crop coefficients[4] was used to develop an accurate and consistent calculation of historical crop ET (ET_c) and parse ET_c into ET from applied water (ET_{aw}) and ET from precipitation (ET_{pr}). A daily root zone water budget is a generally accepted and widely used method to estimate effective rainfall (ASCE, 2015 and ASABE, 2007). The physically-based Integrated Water Flow Model Demand Calculator (IDC) version 2015.0.0036 (DWR, 2015) was used to calculate the

[4] Derived from actual ET estimated by a Surface Energy Balance Algorithm for Land (SEBAL) remotely sensed energy balance for the 2009 irrigation season.

daily root zone water budget. IDC is the root zone component of the DWR Integrated Water Flow Model (IWFM). In this application, IDC was used independently of IWFM. However, this IDC application will be the foundation for coupling the water budget to the groundwater model, likely C2VSIM that will be used for GSP development.

The improved crop coefficients were derived from actual ET (ET_a) estimated by the Surface Energy Balance Algorithm for Land (SEBAL) for 2009. Remotely sensed energy balance ET results account for soil salinity, deficit irrigation, disease, poor plant stands, and other stress factors that affect crop ET. Studies by Bastiaanssen, et al. (2005), Allen, et al. (2007 and 2011), Thoreson, et al. (2009) and others have found that when performed by an expert analyst, seasonal ET_a estimates produced by SEBAL are within plus or minus five percent of actual crop ET. For crops grown in the Madera Subbasin, annual historic ET_c computed using the quality controlled CIMIS ET_o and improved crop coefficients are provided in **Table 4-4.**

Table 4-4
Preliminary Average Annual Acreages and Annual Evapotranspiration Rates for Madera Subbasin, 1989 to 2015

Crop	Acres	ET_c (in)	ET_{pr} (in)	ET_{aw} (in)
Native Vegetation	98,199	7.5	7.5	0
Grapes	79,409	26.7	6.6	20
Almonds	38,304	41.6	7.1	34.5
Pistachios	21,856	32.3	7.5	24.8
Idle	11,690	6.5	6.5	0
Miscellaneous Deciduous	10,860	30.4	8.3	22.1
Miscellaneous Field Crops	9,907	30.9	6.4	24.5
Alfalfa	8,865	38.6	7.5	31
Grain and Hay Crops	7,857	7.7	7.7	0
Corn (double cropped)	7,380	34.3	5.6	28.7
Mixed Pasture	7,059	28.7	6.7	22
Citrus and Subtropical	6,534	40.3	7.6	32.7
Semi agricultural	4,345	13.9	6.7	7.2
Miscellaneous Vegetables	2,711	30.4	5.2	25.2
Walnuts	1,045	33.9	7.2	26.7

IDC was used to develop the following time series outputs which are then used with surface water delivery to develop groundwater pumping estimates.

- ET of precipitation (ET_{pr}); and
- ET of applied water (ET_{aw}).

IDC files were developed for a stand-alone, daily time step IDC application. (These inputs will be reviewed and revised to generate input files that can be used when IDC and IWFM are operated in an integrated model to simulate the combined SWS and GWS.) Additional details and values for the other major inputs to IDC are provided in Appendix B.

4.5 Surface Water Diversions

Irrigation diversions from the Madera Canal to the MID distribution system and in some cases directly to MID irrigated lands were compiled into monthly and annual volumes using data provided by MID. These deliveries represent surface water inflow to the Madera Subbasin and surface water diversions into the MID distribution system.

Inflow data for the Fresno River were obtained from the USGS site, called "FRESNO R BL HIDDEN DAM NR DAULTON CA," located near Daulton and the nearby CDEC site, Hidden Dam (Hensley). The measured flows at this point have been used as an estimate of surface water diversions to MID from Hensley Lake on the Fresno River.

Pumped surface water diversions from the San Joaquin River to the Gravelly Ford Water District were provided for the years 1989 through 2015 by the Gravelly Ford Water District.

4.6 Applied Surface Water

A preliminary estimate of applied surface water was developed by multiplying the surface water diversions described above by an estimated distribution system efficiency of 65 percent. The 65 percent estimate is based on the estimates of distribution system losses described in the MID 2012 Water Management Plan. Delivery data exported from MID's delivery database program for recent years was received during preparation of this report. This data will be reviewed during GSP development and used to prepare a water budget for the MID distribution system and agricultural water use sector, resulting in a refined estimate of applied surface water.

4.7 Groundwater Pumping

A preliminary estimate of urban groundwater pumping was developed by dividing the ET_{aw} for the urban areas by an assumed efficiency of 75 percent. Indoor non-consumptive uses were not estimated in this preliminary basin boundary water budget because return flow from the indoor non-consumptive uses is treated and returned to the groundwater system. A preliminary estimate of agricultural pumping was developed by dividing the estimated ET_{aw} for the agricultural lands by an assumed on-farm efficiency of 75 percent and subtracting the total volume of applied water. The total estimated groundwater pumping volume is the sum of the estimated urban groundwater pumping volume and the estimated agricultural pumping volume. Note that the urban pumping volume is assumed to include the groundwater volume pumped by the semi-agricultural and rural domestic areas. Groundwater pumping volumes for recent years were received from the City of Madera. These pumping volumes are being reviewed and will be used to refine these groundwater pumping estimates during GSP development.

5 SURFACE SYSTEM WATER BUDGET ANALYSIS

The Madera Subbasin conceptual water budget model was previously presented and discussed in Section 2. It is structured to include separate but related water budgets for the SWS and for the underlying GWS. The SWS budget is presented and discussed in this section. It was prepared for the proposed base period from 1989 through 2015 discussed in Section 3.

5.1 Surface Water System Inflows and Outflows

Surface water inflows include: Cottonwood, Dry and Berenda Creeks; the Chowchilla Bypass; riparian diversions from the San Joaquin River; GFWD's pumped diversion from the San Joaquin River; Hidden Dam Flood Releases to the Fresno River and CVP Releases to Madera ID; and Madera Canal CVP Releases to Madera ID (**Table 5-1**). The inflows in the creeks, the Fresno River and the bypass vary widely from critical to wet years. The three creeks together vary from a few hundred acre-feet in dry years to about 30,000 acre-feet in wet years. The Chowchilla Bypass carries flood flows, so the flows vary from zero in dry years to approximately976,900 acre-feet in wet years. In the wet years, most of the inflow is winter and spring flood flows that pass through the basin.

Surface water outflows include: Cottonwood and Berenda Creeks; the Fresno River and the Chowchilla Bypass (**Table 5-2**). The outflows in the creeks, the river and the bypass vary widely from critical to wet years. The two creeks together vary from a few hundred acre-feet in dry years to about 24,000 acre-feet in wet years. The Chowchilla Bypass carries flood flows, so the flows vary from zero in below normal, dry and critical years to approximately976,900 acre-feet in wet years.

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.

Table 5-1
Preliminary Annual Averages of Surface Water Inflows from 1989 through 2015

Year	Year Type*	Cottonwood Creek	Dry Creek	Berenda Creek	Chowchilla Bypass	San Joaquin River (Riparian Diversions)	San Joaquin River (GFWD Pumped Diversion)	Hidden Dam (Flood Releases and CVP Release to Madera ID)	Madera Canal (CVP Release to Madera ID)	SW Inflows Total
1989	C	0	0	0	0	5,634	0	16,417	94,920	116,971
1990	C	0	0	0	0	5,634	0	9,933	68,119	83,686
1991	C	2,858	746	746	0	5,634	0	20,389	93,362	123,735
1992	C	796	504	504	0	5,634	0	20,389	79,160	106,987
1993	W	18,420	6,022	6,022	681,197	5,634	3,956	8,977	252,083	982,310
1994	C	0	0	0	0	5,634	0	29,937	88,559	124,130
1995	W	24,318	7,187	7,187	681,197	5,634	6,423	155,385	193,473	1,080,804
1996	W	17,575	5,132	5,132	681,197	5,634	6,423	131,066	198,868	1,051,027
1997	W	20,260	9,329	9,329	675,797	5,634	6,423	183,333	199,350	1,109,455
1998	W	24,332	14,270	14,270	627,013	5,634	1,701	185,273	109,419	981,911
1999	AN	103	0	0	42,640	5,634	1,701	58,900	132,853	241,831
2000	AN	12,341	2,283	2,283	13,100	5,634	8,005	79,602	146,663	269,910
2001	D	197	145	145	0	5,634	3,707	41,463	118,534	169,825
2002	D	89	268	268	0	5,634	6,082	23,986	120,231	156,558
2003	BN	0	0	0	0	5,634	8,444	28,374	142,762	185,214
2004	D	0	0	0	0	5,634	5,350	21,124	125,145	157,253
2005	W	8,833	7,226	7,226	270,420	5,634	9,061	98,330	129,071	535,800
2006	W	3,779	7,226	7,226	976,859	5,634	7,911	169,298	135,681	1,313,613
2007	C	0	139	139	0	5,634	0	56,286	93,492	155,689
2008	C	1,207	139	139	0	5,634	4,233	52,440	106,069	169,860
2009	BN	0	0	0	0	5,634	1,701	14,119	138,468	159,921
2010	AN	8,435	1,350	1,350	0	5,634	4,859	63,115	184,453	269,195
2011	W	10,788	7,226	7,226	855,897	5,634	2,878	182,740	179,953	1,252,341
2012	D	0	137	137	0	5,634	0	29,860	86,480	122,247

Year	Year Type*	Cottonwood Creek	Dry Creek	Berenda Creek	Chowchilla Bypass	San Joaquin River (Riparian Diversions)	San Joaquin River (GFWD Pumped Diversion)	Hidden Dam (Flood Releases and CVP Release to Madera ID)	Madera Canal (CVP Release to Madera ID)	SW Inflows Total
2013	C	0	139	139	0	5,634	0	26,623	71,204	103,738
2014	C	0	139	139	0	5,634	0	3,416	19,187	28,514
2015	C	0	139	139	0	5,634	0	1,621	7,982	15,514
W average		16,038	7,952	7,952	681,197	5,634	5,597	139,300	174,737	1,038,408
AN average		6,960	1,211	1,211	18,580	5,634	4,855	67,206	154,656	260,312
BN average		0	0	0	0	5,634	5,073	21,246	140,615	185,214
D average		72	137	137	0	5,634	3,785	29,108	112,598	151,471
C average		486	194	194	0	5,634	423	23,745	72,205	102,882
1989-2015 average		5,716	2,583	2,583	203,901	5,634	3,291	63,422	122,798	409,927
1989-2014 average		5,936	2,677	2,677	211,743	5,634	3,418	65,799	127,214	425,097
1989-2015 average, %		1.4%	0.6%	0.6%	49.7%	1.4%	0.8%	15.5%	30.0%	100.0%
1989-2014 average, %		1.4%	0.6%	0.6%	49.8%	1.3%	0.8%	15.5%	29.9%	100.0%

* The SJV water year index classifies each water year into one of five types: (1) Wet (W), (2) Above Normal (AN), (3) Below Normal (BN), (4) Dry (D) and (5) Critical (C)

Table 5-2
Preliminary Annual Averages of Surface Water Outflows from 1989 through 2015

Year	Year Type*	Cottonwood Creek	Berenda Creek	Fresno River	Chowchilla Bypass	SW Outflows Total
1989	C	646	12	0	0	658
1990	C	426	19	0	0	445
1991	C	2,472	798	0	0	3,270
1992	C	660	541	0	0	1,201
1993	W	20,800	3,805	74,081	681,197	779,883
1994	C	195	335	0	0	530
1995	W	20,961	9,330	136,293	681,197	847,781
1996	W	18,288	6,447	107,884	681,197	813,816
1997	W	23,133	10,562	149,847	675,797	859,339
1998	W	30,439	13,335	226,273	627,013	897,060
1999	AN	6,636	1,823	3,900	42,640	54,999
2000	AN	18,103	3,326	24,093	13,100	58,622
2001	D	2,922	1,106	1,299	0	5,327
2002	D	1,975	939	0	0	2,914
2003	BN	3,311	974	0	0	4,285
2004	D	2,528	565	0	0	3,093
2005	W	13,323	6,035	33,517	270,420	323,294
2006	W	14,252	6,409	134,809	976,859	1,132,329
2007	C	2,538	426	651	0	3,615
2008	C	1,444	630	0	0	2,074
2009	BN	2,174	1,442	0	0	3,616
2010	AN	8,081	2,227	18,868	0	29,176
2011	W	15,420	6,266	122,432	855,897	1,000,014
2012	D	604	478	3,817	0	4,899
2013	C	520	201	603	0	1,323
2014	C	528	196	0	0	723
2015	C	0	46	39	0	85
W average		19,577	7,774	123,142	681,197	831,689
AN average		10,940	2,459	15,620	18,580	47,599
BN average		2,743	1,208	0	0	4,285
D average		2,007	772	1,279	0	4,058
C average		943	320	129	0	1,392
1989-2015 average		7,866	2,899	38,459	203,901	253,125
1989-2014 average		8,168	3,009	39,937	211,743	262,857

* The SJV water year index classifies each water year into one of five types: (1) Wet (W), (2) Above Normal (AN), (3) Below Normal (BN), (4) Dry (D) and (5) Critical (C)

5.2 Surface Water System Budget

The calendar year annual volumes for each basin boundary inflow and outflow are provided in **Table 5-3** along with the year type based on DWR's San Joaquin Valley[5] (SJV) water year index. The SJV water year index classifies each water year into one of five types: (1) Wet (W), (2) Above Normal (AN), (3) Below Normal (BN), (4) Dry (D) and (5) Critical (C). As expected, the surface water inflows vary widely from critical to wet years with a minimum of just over 15,500 acre-feet in 2015 and a maximum of just over 1.30 million acre-feet in 2006. In the wet years, most of the inflow is winter and spring flood flows that pass through the basin. The boundary watercourse seepage inflow includes seepage from the San Joaquin River and the Madera Canal and is estimated to vary from 52,300 acre-feet in 2006 to 83,400 acre-feet in 2014. Precipitation varies from just over 90,000 acre-feet in 2013 to just under 550,000 acre-feet in 1996. In contrast, the ET outflow from the basin is relatively constant (**Figure 5-1**) varying from 588,000 acre-feet in 1989 to 718,000 acre-feet in 2015. Surface water outflows vary widely from 85 acre-feet in 2015 to just over 1.13 million acre-feet in 2006.

Net recharge from the SWS (net flow from the SWS to the GWS) averaged -152,300 acre-feet over the proposed 1989 through 2015 base period based on the basin boundary SWS budget and -140,800 acre-feet from 1989 to 2014. Net recharge from the SWS was positive in three wet years (1995, 1996 and 2010) indicating that in these three years groundwater recharge was greater than groundwater extraction. The average net recharge from the SWS in the eight wet years was about -12,700 acre-feet. In contrast, the average net recharge from the SWS in the 10 critical years was about 250,500 acre-feet.

Table 5-4 lists each inflow and outflow represented in the SWS budget, indicating for each the quantification method, its typical flow volume based on the 1989 through 2014 annual averages, and its estimated confidence interval (CI) expressed as a percent. As indicated, estimated confidence intervals vary by inflow and outflow from 5 to 53 percent of the estimated value, with uncertainties generally being less for measured inflows and outflows and greater for estimated inflows and outflows. The estimated uncertainty of the closure term is provided, calculated based on the concept of propagation of random errors as described by (Clemmens, A.J. and C.M. Burt, 1997).

The confidence intervals for the inflows and outflows from the basin boundary water budget ranged from ten percent on the measured inflows and outflows, respectively (**Table 5-4**). The individual confidence intervals for each inflow and outflow were combined statistically, resulting in a CI of plus or minus 53 percent on net recharge from the SWS, the closure term.

[5] Water year runoff, index, and water year type information for the San Joaquin Valley was retrieved from DWR's website: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST, accessed 9/29/2017.

Table 5-3
Preliminary Surface Water System Budget (1989 through 2015) in Acre-Feet

Year	Year Type*	SW Inflows Total (a)	Boundary Watercourse Seepage Inflow (b)	Precipitation (c)	ET (d)	SW Outflows Total (e)	Net Recharge from the SWS ((a+b+c)-(d+e))
1989	C	116,971	57,214	237,218	588,582	658	-177,838
1990	C	83,686	63,469	321,214	645,723	445	-177,799
1991	C	123,735	62,006	366,399	613,517	3,270	-64,648
1992	C	106,987	64,758	335,986	695,156	1,201	-188,626
1993	W	982,310	67,534	399,998	670,194	779,883	-235
1994	C	124,130	64,673	299,491	648,040	530	-160,276
1995	W	1,080,804	67,534	533,233	638,749	847,781	195,041
1996	W	1,051,027	66,973	549,164	691,880	813,816	161,467
1997	W	1,109,455	67,534	274,003	690,782	859,339	-99,129
1998	W	981,911	67,534	389,859	620,780	897,060	-78,536
1999	AN	241,831	55,623	160,172	612,876	54,999	-210,249
2000	AN	269,910	60,220	362,633	675,732	58,622	-41,592
2001	D	169,825	52,865	368,426	716,250	5,327	-130,461
2002	D	156,558	60,532	234,900	696,867	2,914	-247,791
2003	BN	185,214	67,990	210,860	681,557	4,285	-221,779
2004	D	157,253	62,094	241,272	709,242	3,093	-251,715
2005	W	535,800	73,331	286,746	672,224	323,294	-99,641
2006	W	1,313,613	52,340	357,129	674,540	1,132,329	-83,786
2007	C	155,689	62,963	148,876	659,085	3,615	-295,171
2008	C	169,860	59,893	222,445	687,430	2,074	-237,306
2009	BN	159,921	68,717	227,949	651,562	3,616	-198,592
2010	AN	269,195	72,264	403,762	664,157	29,176	51,886
2011	W	1,252,341	59,715	282,691	688,087	1,000,014	-93,353
2012	D	122,247	62,730	215,784	653,949	4,899	-258,088
2013	C	103,738	77,386	91,527	667,312	1,323	-395,984
2014	C	28,514	83,360	188,847	656,837	723	-356,840
2015	C	15,514	82,159	170,020	717,872	85	-450,264
W average		1,038,408	65,312	384,103	668,405	831,689	-12,272
AN average		260,312	62,702	308,856	650,922	47,599	-66,652
BN average		172,567	67,990	219,404	666,560	3,951	-221,779
D average		151,471	59,555	265,095	694,077	4,058	-222,014
C average		102,882	67,788	238,202	657,955	1,392	-250,475
1989-2015 average		409,927	65,312	291,874	666,259	253,125	-152,271
1989-2014 average		425,097	64,664	296,561	664,274	262,857	-140,809

* The SJV water year index classifies each water year into one of five types: (1) Wet (W), (2) Above Normal (AN), (3) Below Normal (BN), (4) Dry (D) and (5) Critical (C)

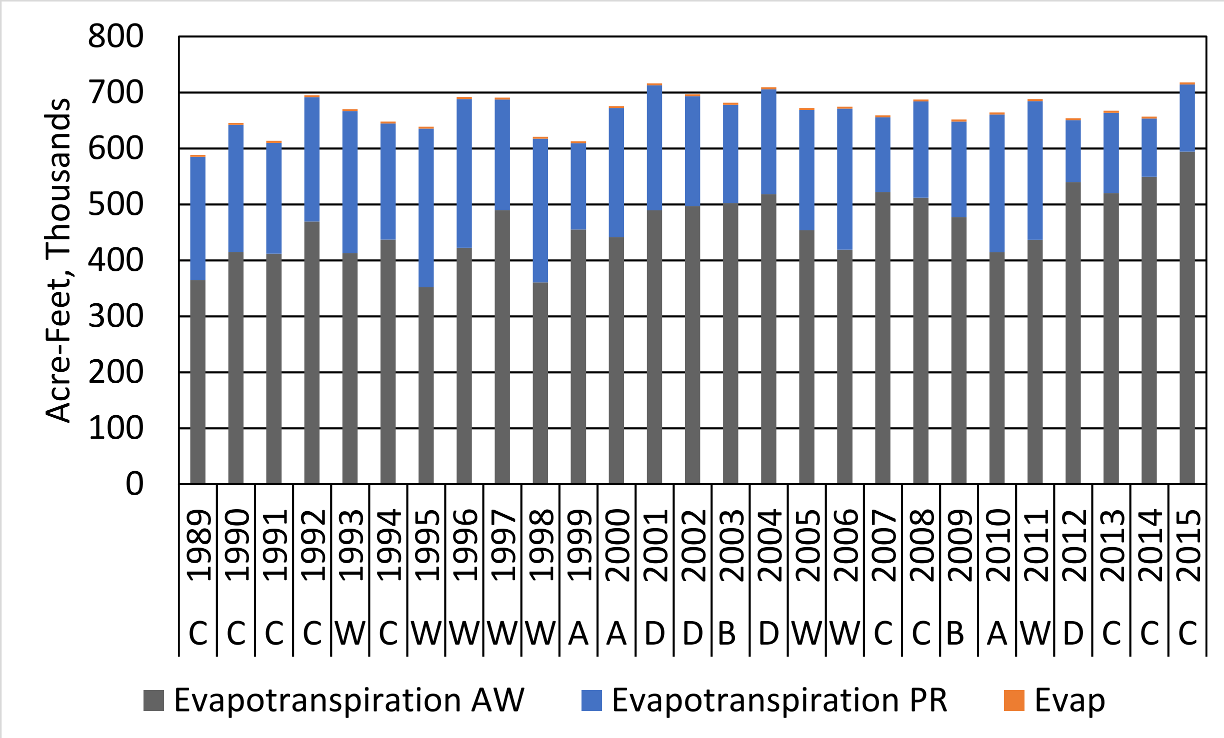


FIGURE 5-1
Preliminary Annual Evapotranspiration[6] from 1989 through 2015

Table 5-4
Preliminary Measured Inflows and Outflows from the Surface Water System

Inflow/Outflow	Quantification Method	Typical Volume (AF)*	Estimated CI (percent)	CI Source
SW Inflows Total	Measurement	425,100	5%	Professional Judgement.
Boundary Watercourse Seepage Inflow	Calculation	64,700	25%	Professional Judgement.
Precipitation	Calculation	296,600	20%	Professional Judgement.
ET	Calculation	664,300	5%	Professional Judgement.
SW Outflows Total	Measurement	262,900	5%	Professional Judgement.
Net recharge from the SWS	Closure	**-140,800**	53%	Calculation

[6] Includes evapotranspiration of applied water (AW) and precipitation (PR) and evaporation (Evap).

To better understand the exchanges between the surface water system and the groundwater system and provide more detailed results for use in the estimation of sustainable yield, the net recharge from the SWS was divided into various components consistent with the DWR water budget BMP (DWR, 2016).

Groundwater extraction averaged 426,900 acre-feet over the 1989 to 2015 period (**Table 5-5**) based on the volume needed to meet ET_{aw} demands given available information, surface water deliveries and estimates of irrigation application efficiencies as described in Section 4. The annual volumes for each surface water-groundwater inflow and outflow except the groundwater discharge to surface water sources[7] are provided along with the year type according to DWR's San Joaquin Valley water year index. As expected, the infiltration of precipitation varies widely from critical to wet years with a minimum of about 14,000 acre-feet in 2014 and a maximum of just over 185,700 acre-feet in 1995. Groundwater extraction also varies widely, but with the higher values associated with the critically dry years, from just under 700,000 acre-feet in 2015 to just under 130,000 acre-feet in 1995. Infiltration of surface water includes estimates of infiltration, or seepage, from canals, streams and creeks and the San Joaquin River and Madera Canal. Volumes range from just over 48,000 acre-feet in 1989 to just over 262,000 acre-feet in 1996. In contrast the infiltration of applied water is relatively constant varying from about 71,000 acre-feet in 2010 to 113,000 acre-feet in 1997. Interestingly, the minimum and maximum annual values of infiltration of applied water occurred in wet and above normal years, respectively. The infiltration of applied water depends primarily on the applied water volumes which are higher in wet years. However, in some years, the distribution of precipitation leads to reduced application of applied water. The total infiltration of applied water is estimated based on the difference between applied water and ET_{aw} (assuming runoff of applied water is negligible), however, the monthly and annual distributions are based on IDC root zone water budget results. The infiltration of precipitation is also based on IDC root zone water budget results. These results will be refined during GSP development.

During GSP development, the SWS water budgets inside the basin boundary will be prepared for the rivers and streams, irrigation distribution system, and the agriculture, native, urban, industrial and managed recharge will be completed and results reviewed in the context of the overall basin boundary balance. The additional detail from these budgets will lead to refinements in the inflow and outflow volumes presented in **Table 5-1** and the components of the inflows and outflows in **Table 5-2**, such as infiltration of surface water and infiltration of groundwater, will also be reported.

[7] Assumed to be zero pending more detailed surface water groundwater interaction analyses to be performed during GSP development.

Table 5-5
Preliminary Annual Volumes of Surface Water System and Groundwater System Exchanges (1989 through 2015) in Acre-Feet

Year	Year Type*	Groundwater Extraction (a)	Infiltration of Precipitation (b)	Infiltration of Surface Water** (a+d-b-c)	Infiltration of Applied Water (c)	Net Recharge from the SWS (from Table 4-2) (d)
1989	C	360,547	48,200	48,310	86,200	-177,838
1990	C	450,234	47,256	133,527	91,652	-177,799
1991	C	395,822	73,737	157,258	100,179	-64,648
1992	C	501,932	42,261	167,865	103,179	-188,626
1993	W	325,152	96,409	129,666	98,842	-235
1994	C	424,144	38,480	134,833	90,555	-160,276
1995	W	223,292	130,267	200,457	87,609	195,041
1996	W	301,196	93,311	261,996	107,357	161,467
1997	W	428,890	85,587	130,981	113,194	-99,129
1998	W	377,639	99,114	117,058	82,931	-78,536
1999	AN	402,602	23,080	84,986	84,286	-210,249
2000	AN	326,305	53,838	141,614	89,261	-41,592
2001	D	445,418	42,999	178,721	93,237	-130,461
2002	D	478,336	35,383	101,957	93,205	-247,791
2003	BN	446,050	26,488	115,106	82,677	-221,779
2004	D	479,742	28,460	105,930	93,637	-251,715
2005	W	376,776	39,221	161,419	76,495	-99,641
2006	W	351,733	63,942	122,781	81,224	-83,786
2007	C	491,923	14,954	101,264	80,533	-295,171
2008	C	479,242	28,228	132,343	81,365	-237,306
2009	BN	427,383	21,732	135,410	71,650	-198,592
2010	AN	294,958	60,118	215,303	71,423	51,886
2011	W	306,088	61,806	72,729	78,199	-93,353
2012	D	546,584	21,131	180,738	86,626	-258,088
2013	C	548,336	21,266	52,775	78,311	-395,984
2014	C	639,440	14,036	190,317	78,246	-356,840
2015	C	697,697	16,413	149,544	81,477	-450,264
W average		336,346	83,707	149,636	90,731	-12,272
AN average		341,288	45,679	147,301	81,657	-66,652
BN average		436,716	24,110	115,106	77,163	-221,779
D average		487,520	31,993	141,837	91,676	-222,014
C average		498,932	34,483	126,804	87,170	-250,475
1989-2015 average		426,943	49,175	137,959	87,539	-152,271
1989-2014 average		416,529	50,435	137,513	87,772	-140,809

* The SJV water year index classifies each water year into one of five types: (1) Wet (W), (2) Above Normal (AN), (3) Below Normal (BN), (4) Dry (D) and (5) Critical (C)

**Includes Seepage Inflows (San Joaquin River and Madera Canal)

6 GROUNDWATER SYSTEM WATER BUDGET ANALYSIS

The overall water budget for the groundwater system includes inputs from the surface layer, groundwater storage change, and the net of groundwater inflows and outflows. The groundwater system inputs from the surface layer are described and quantified above in Section 5. This section of the report includes description and quantification of groundwater storage change and groundwater inflows and outflows. Two different approaches were utilized to quantify groundwater storage change and inflows/outflows: a calculation approach based on measured groundwater levels and analytical equations, and a numerical modeling based method. The overall approaches are described in Section 6.1, results for groundwater storage change calculations are provided in Section 6.2, and groundwater inflow/outflow calculations are provided in Section 6.3.

6.1 Approach to Estimating Change in Groundwater Storage and Subsurface Lateral Flows

A calculation/analytical method and numerical modeling method were used to evaluate changes in groundwater storage and subsurface flows to and from the Madera Subbasin over the entire analysis period and for three hydrologic periods[8] as follows:

1) Entire Analysis Period, 1989-2014;
2) Wet Period, 1990-1998;
3) Average Period, 1999-2010;
4) Dry Period, 2011-2014.

The wet, average, and dry hydrologic periods were identified using historical precipitation data measured at Madera as discussed in Section 4 and as documented in earlier SGMA-related work (DE and LSCE, 2017). The overall approaches for the groundwater storage and inflow/outflow calculations are described below.

6.1.1 Calculation Analysis Method

An analytical approach to calculating the change in groundwater storage within the Madera Subbasin and subsurface lateral flows into or out of the Subbasin over the analysis period is described in the following paragraphs. Calculation of the change in groundwater storage and subsurface flows both rely on representations of measured groundwater elevations in and around the Subbasin.

Groundwater Storage Change

A review of groundwater elevation contour maps produced by DWR for the Madera Subbasin found a lack of spatial coverage and completeness for the years of interest in this analysis. The groundwater elevation contour maps available from DWR were not available in geographic information system (GIS) data formats until 2011, and of the contour maps since 2011, coverage and completeness is highly variable from year to year. As a result, new groundwater elevation contour maps were constructed for the periods of interest in this analysis. Water level data obtained from DWR, USGS, and Geotracker-GAMA as part of the previous data collection effort for the Madera Subbasin (DE and LSCE, 2017) were

[8] Due to limited availability of spring 2015 groundwater level data, 2015 was not included in the GWS analyses.

utilized for generating contour maps. Wells were selected for analysis if sufficient construction details were available to determine if the well was located within the Upper Aquifer, or if no construction details were available but the well had historically been used by DWR to generate groundwater elevation contour maps. Wells historically used by DWR to generate groundwater elevation contour maps that were determined to be composite or Lower Aquifer wells were not used for analysis.

The change in storage evaluation was based on spring water levels. Of the wells selected for analysis, the maximum groundwater elevation measurement observed from January to May of each year was selected for contouring. If water level measurements were available during the months of March or April, these measurements were selected preferably over other months. This method of choosing water level measurements was adapted from the methods used by DWR to produce their groundwater elevation contour maps. Groundwater level data were processed in GIS using inverse distance weighting (IDW) interpolation to generate groundwater elevation contours.

Data for spring of 2015 was extremely sparse. As a result, the groundwater elevation contours had a high level of uncertainty and were likely inaccurate. To mitigate this data gap, data for the spring of 2014 were used as the end year for the analysis period as described in Section 3.

Due to a lack of data, it was not possible to generate groundwater elevation contour maps for the Lower Aquifer. A combination of a lack of Lower Aquifer wells and very short periods of record for available Lower Aquifer wells resulted in significant data gaps. Therefore, groundwater storage change for the Lower Aquifer was not quantified by the analytical/calculation method.

Change in storage for the Upper Aquifer was calculated for the analysis time period and the wet/average/dry time periods using GIS. Change in storage was calculated on a cell-by-cell basis, using 100-meter by 100-meter cells. The following equation was used to calculate change in storage (Equation 6-1):

$$\text{Change in Storage} = \text{Average Groundwater Elevation Change} \times \text{Specific Yield} \times \text{Cell Area} \qquad [6\text{-}1]$$

Various estimates of specific yield within the Madera Subbasin were used for analysis. The distributions of specific yield throughout the Subbasin obtained from C2VSim and CVHM models are shown in **Figures 6-1 and 6-2**, respectively. Model estimates are representative of Upper Aquifer properties. Additionally, estimates of specific yield were obtained for the Madera Subbasin from DWR's Bulletin 118 (10.4 percent, or 0.104) and for all of Madera County (0.13) from the Madera Regional Groundwater Management Plan (GMP) (Provost & Pritchard, 2014). Estimates of specific yield were applied either on a cell-by-cell basis (C2VSim and CVHM) or uniformly across the entire Subbasin (DWR and GMP).

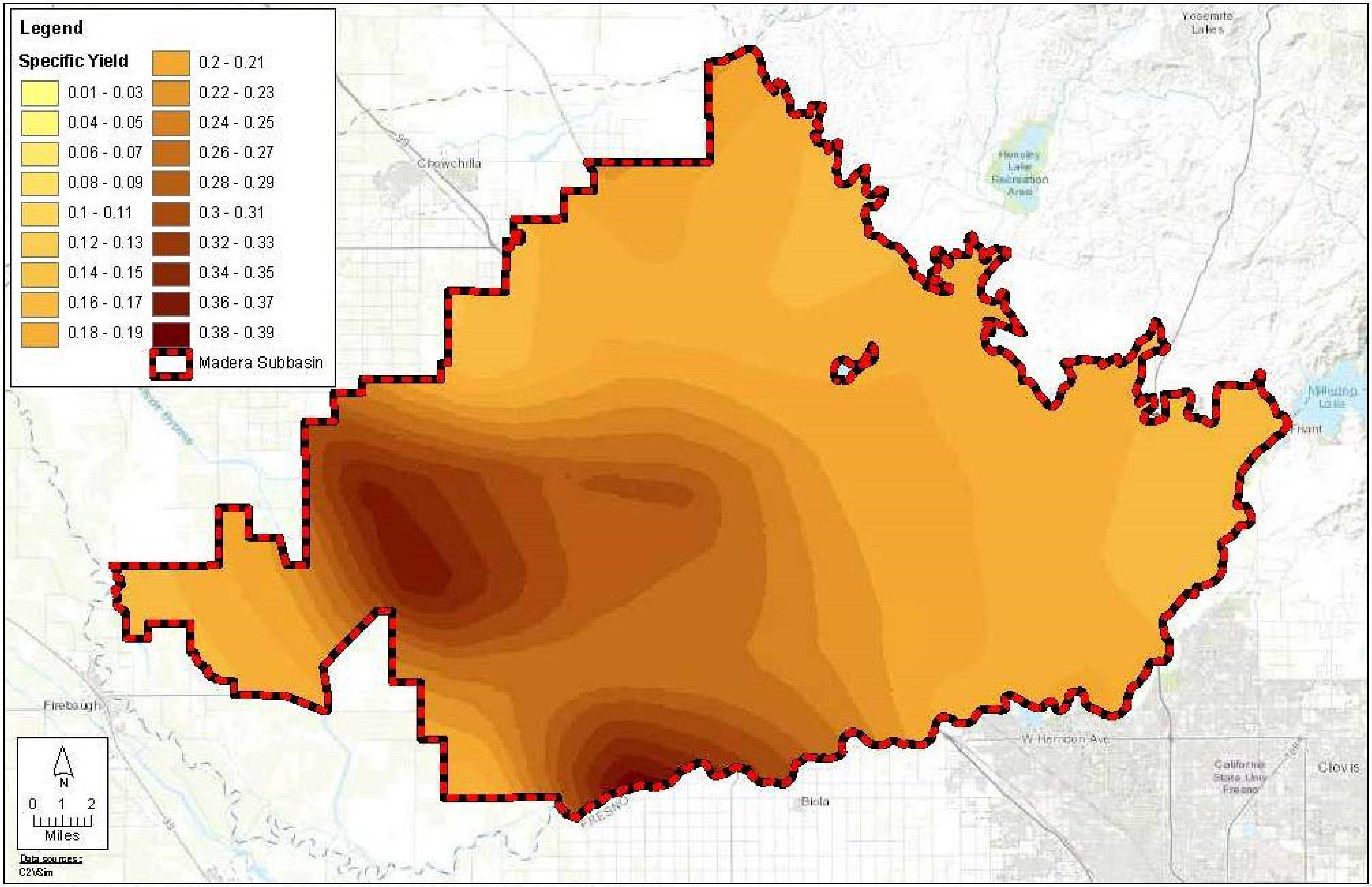
Groundwater Inflows/Outflows

The subsurface lateral flow along the Madera Subbasin boundary was calculated using an analytical approach to evaluate the annual net groundwater inflow/outflow to the Subbasin for comparison to estimates derived from the numerical model.

The groundwater elevation contours created for the change in storage calculations for each year identified as the start or end of the overall analysis period and wet/average/dry time periods were used for the inflow/outflow calculations (**Appendix C**). Estimates of aquifer parameters were obtained from C2VSim and CVHM. **Figures 6-3 and 6-4** show the range of horizontal hydraulic conductivity (Kh) values.

Figures 6-5 and 6-6 show the thickness of the Upper Aquifer, calculated by subtracting the bottom elevation of the Upper Aquifer (obtained from the models) from the groundwater elevation contours for various years.

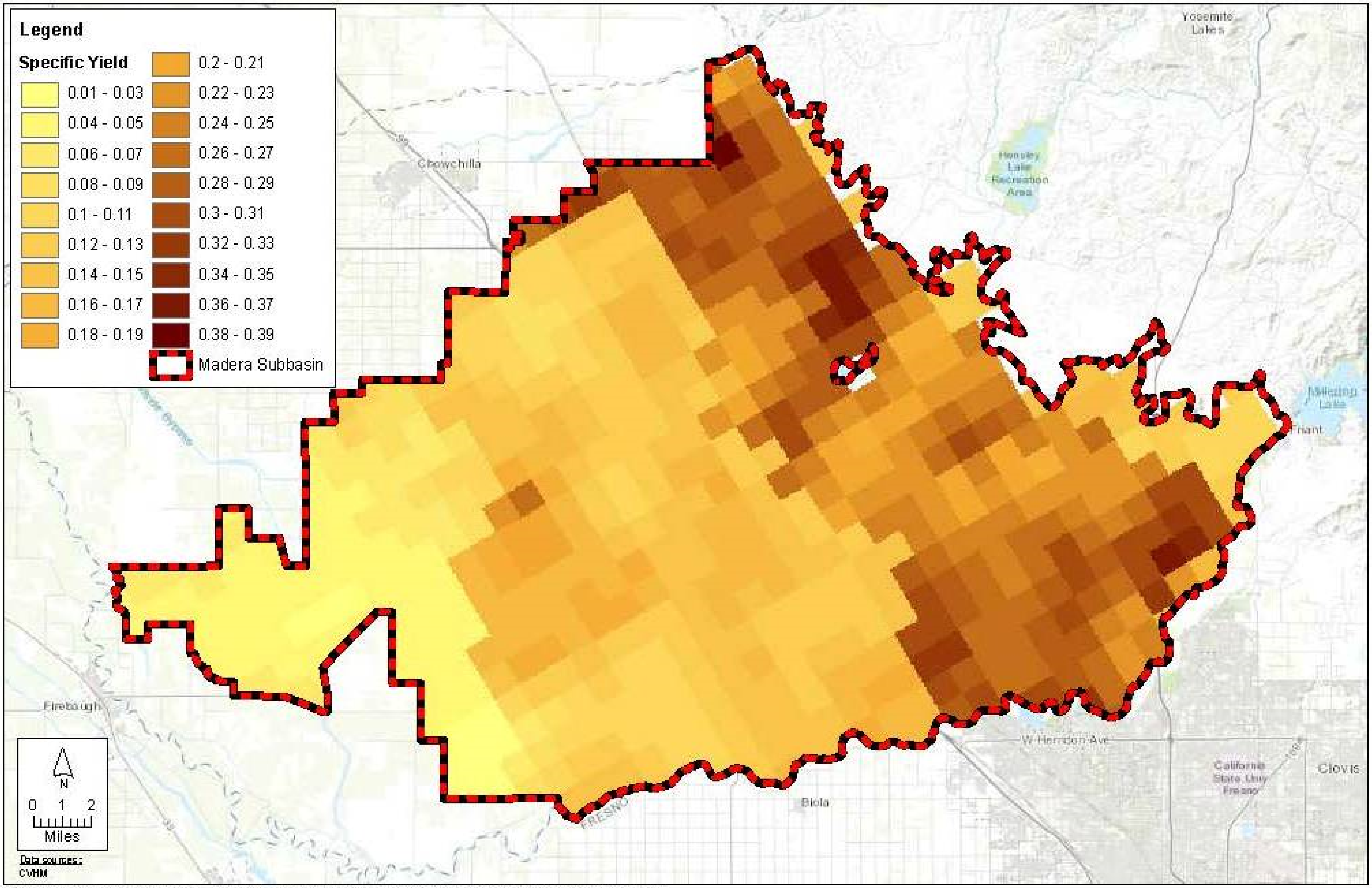
DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.



X:\2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 5-1 Specific Yield, Upper Aquifer (C2VSim).mxd

FIGURE 6-1
Preliminary Specific Yields, Upper Aquifer (C2VSim)

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.



X:\2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 5-2 Specific Yield, Upper Aquifer (CVHM).mxd

FIGURE 6-2
Preliminary Specific Yields, Upper Aquifer (CVHM)

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.

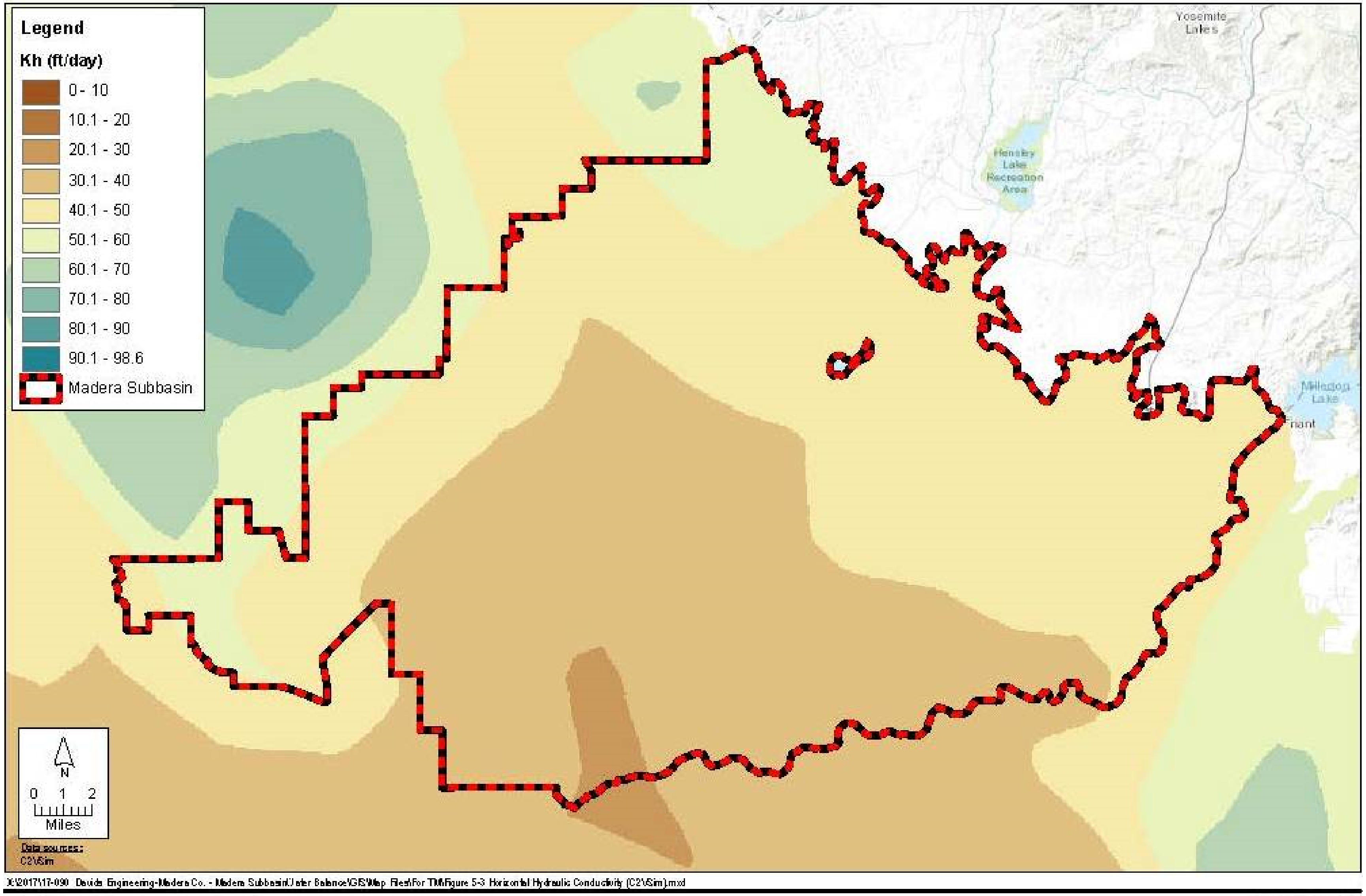
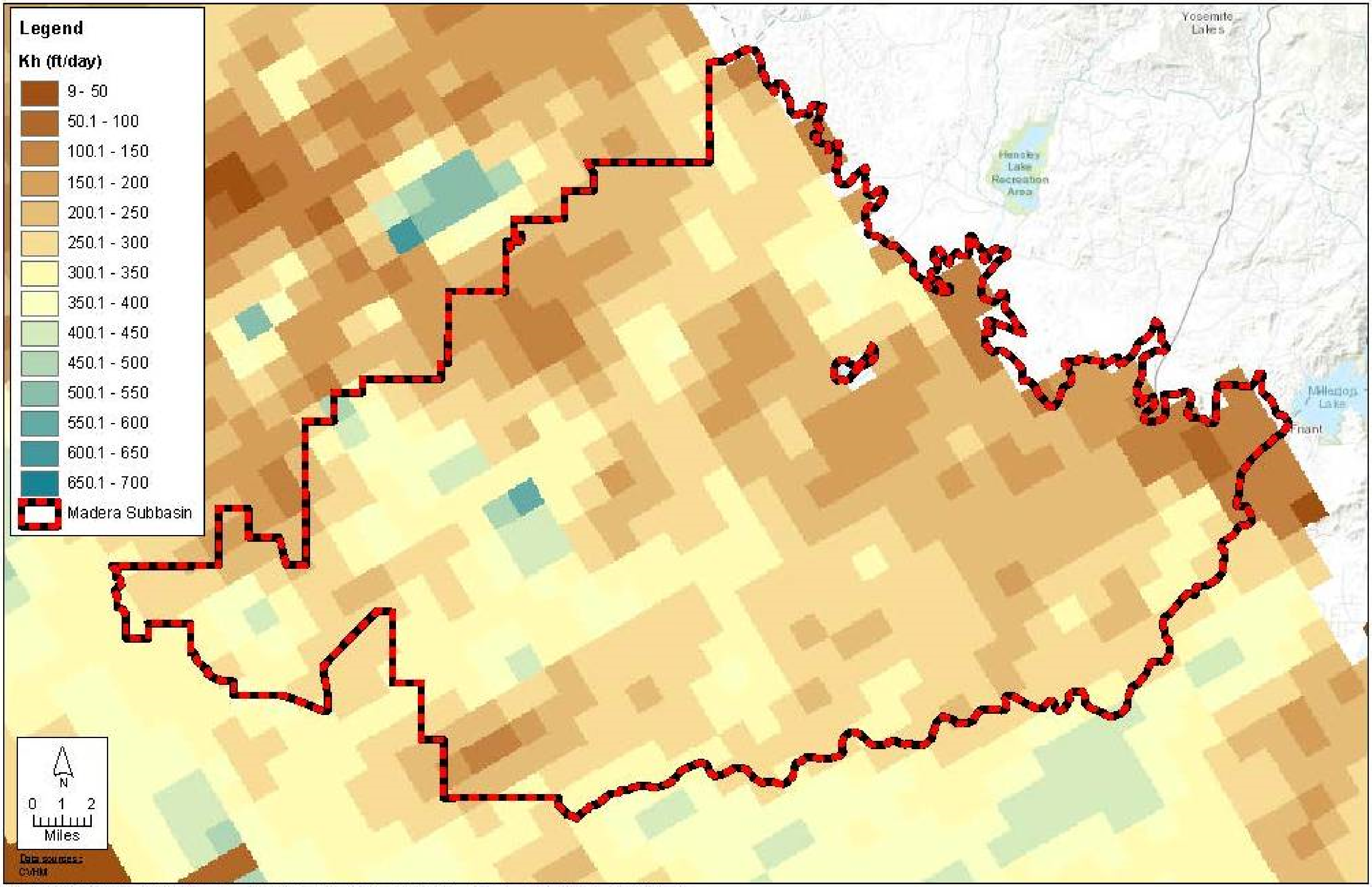


FIGURE 6-3
Preliminary Horizontal Hydraulic Conductivity (C2VSim)

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.



X:\2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 5-4 Horizontal Hydraulic Conductivity (CVHM).mxd

FIGURE 6-4
Preliminary Horizontal Hydraulic Conductivity (CVHM)

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.

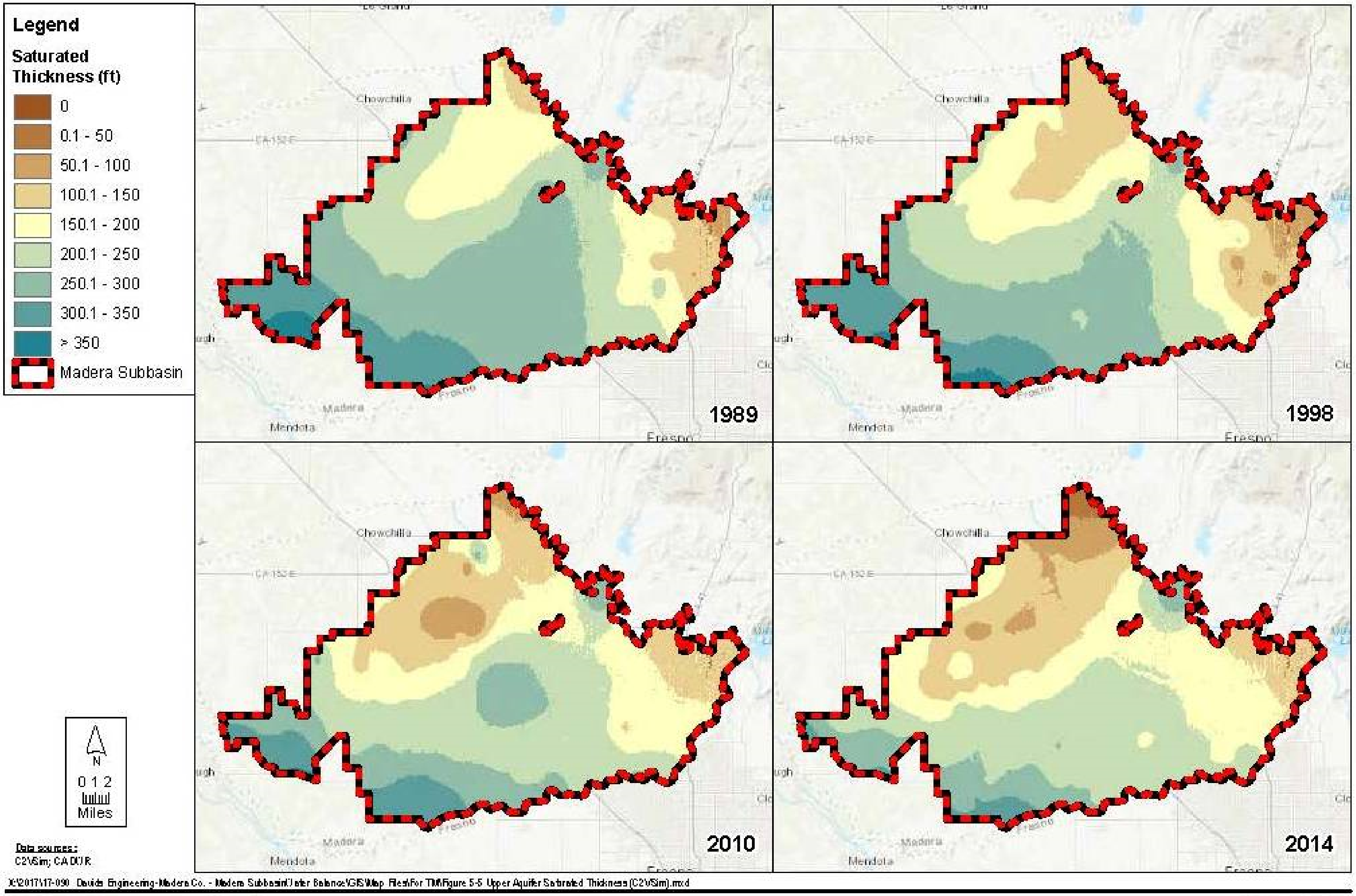
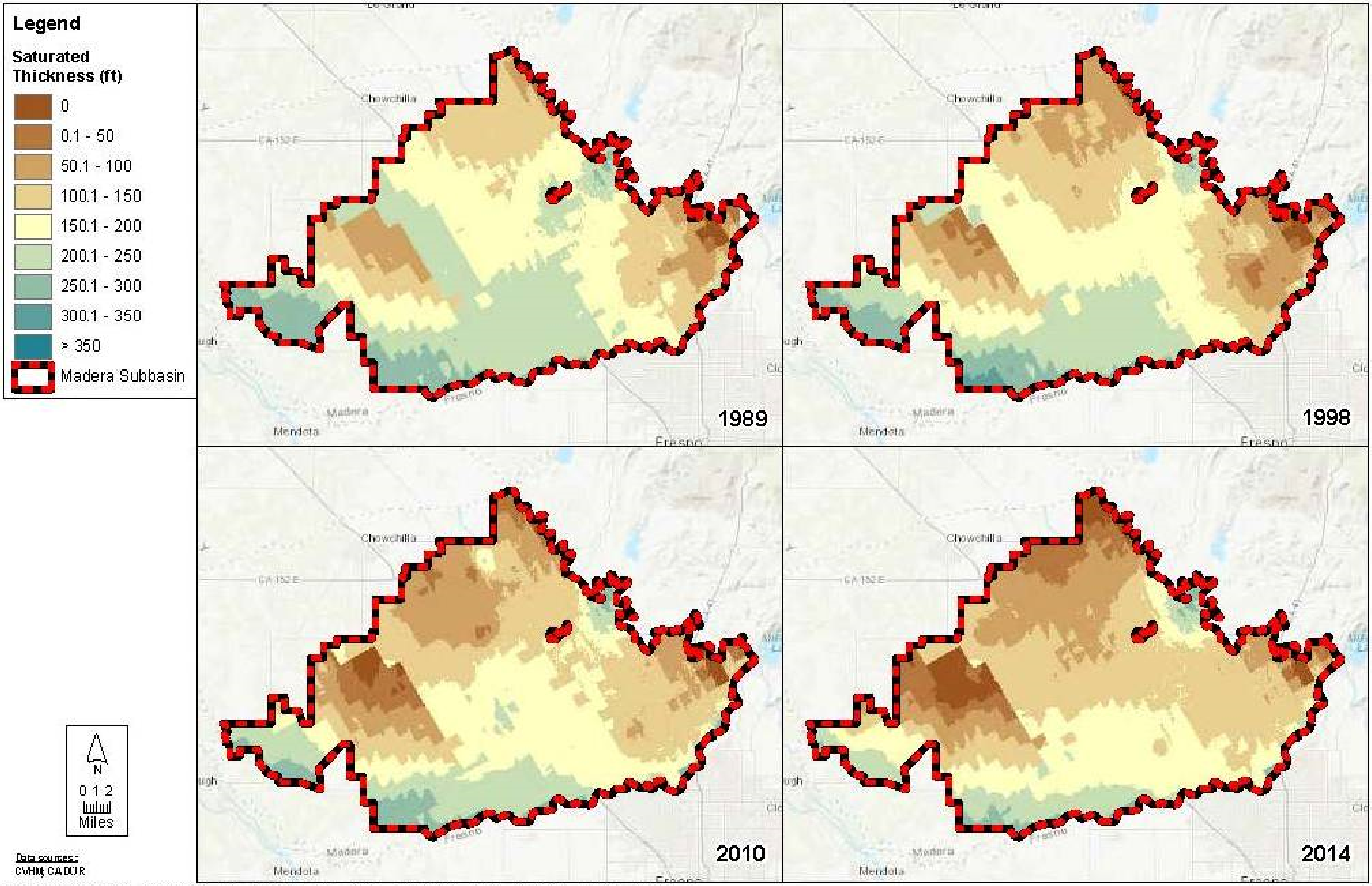


FIGURE 6-5
Preliminary Upper Aquifer Saturated Thickness (C2VSim)

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.



X:\2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 5-6 Upper Aquifer Saturated Thickness (CVHM).mxd

FIGURE 6-6
Preliminary Upper Aquifer Saturated Thickness (CVHM)

A multi-step approach was taken to estimate subsurface inflow/outflow along the Subbasin boundary. First, the Subbasin boundary was broken up into 2-mile segments. The eastern boundary of the Madera Subbasin was excluded from analysis, as it is not bordered by a DWR Bulletin 118 identified groundwater basin. At the mid-point of each segment, a point was placed on each side of the boundary at a distance of 1-mile from the boundary (see **Figure 6-7** for point pair alignment). The groundwater elevation at each year for analysis was then determined at each point. Based on this information, the change in head and hydraulic gradient between each point pair was calculated.

Next, a 1-mile buffer was drawn around each boundary segment. The minimum, maximum, and average Kh estimates within these buffer zones were determined and applied to each segment, using both C2VSim and CVHM Kh distributions (**Figures 6-3 and 6-4**). The average Upper Aquifer thickness within each buffer zone was also applied to the corresponding boundary segment (**Figures 6-5 and 6-6**). The saturated thickness was then calculated by subtracting the depth to water at each segment midpoint for each time period from the average aquifer thickness of that segment.

Finally, subsurface inflow/outflow was calculated using Darcy's Law (Equation 6-2):

$$Q = -kA\frac{dh}{dL} \qquad [6\text{-}2]$$

where *k* is the horizontal hydraulic conductivity estimate from the C2VSim and CVHM models; *A* is the cross-sectional area of flow, determined by multiplying the segment length (2-miles) by the saturated thickness; and dh/dL is the hydraulic gradient calculated between each point pair.

6.1.2 Regional Model-Based Analysis Approach

Model-simulated results were obtained from available regional groundwater models to provide independent estimates of change in groundwater storage and subsurface inflows and outflows for the Madera Subbasin for comparison with calculated/analytical based values described above. Two main regional groundwater models exist that were considered for this purpose: 1) the Central Valley Hydrologic Model (CVHM) developed by the US Geological Survey (Faunt et al., 2009) and the coarse-grid version of the California Central Valley Groundwater-Surface Water Simulation Model Version R374 (C2VSim-CG) developed by DWR (Brush et al., 2016). Because the simulation period for CVHM only extends through 2002, whereas C2VSim-CG extends through 2009, C2VSim-CG was selected for conducting this analysis.

C2VSim-CG was used to evaluate simulated changes in groundwater storage within and subsurface flows to and from the Madera Subbasin over the entire analysis period and for three hydrologic periods as follows:

1) Entire Analysis Period, 1989-2014;
2) Wet Period, 1990-1998;
3) Average Period, 1999-2010;
4) Dry Period, 2011-2014.

The wet, average, and dry hydrologic periods were identified using historical precipitation data measured at Madera as discussed in Section 3 and as documented in earlier SGMA-related work (DE and LSCE, 2017).

The published coarse-grid version of C2VSim, Version R374 (C2VSim-CG) (DWR, 2016) was reviewed and model results for all groundwater budget components were post-processed to evaluate model-based estimates for the analysis time period 1989 to 2014. Although the focus of the analysis was estimating change in groundwater storage and subsurface flows to and from the Subbasin, additional water budget components were also extracted from C2VSim-CG and reviewed during the analysis. However, only the water budget components relating to the estimation of groundwater storage and subsurface flows are directly presented and discussed in this document. The estimated values for all simulated water budget components based on the analysis approach described above are presented in **Appendix D**.

The original published C2VSim-CG model output data were post-processed for this effort for the collection of model elements that represent the Madera Subbasin. Because of recent modifications to the boundary of the Madera Subbasin, the elements selected to represent the Madera Subbasin in this analysis were slightly different from those used in previously published model result summaries for the Subbasin, which were based on the subbasin boundaries defined at the time of publication of the DWR's model datasets. As a result, a configuration of model elements that better represents the modified Madera Subbasin boundary were selected (**Figure 6-8**), and the originally published model results were post-processed to derive water budget values for an area that better represents the modified Subbasin area. In conducting this analysis, no changes were made to the actual C2VSim-CG model inputs or outputs.

C2VSim has three model layers representing a total of three aquifer zones and three aquitards, which overlie each of the modeled aquifer zones. Within the Madera Subbasin Layer 1 in the C2VSim model represents the Upper Aquifer and Layers 2 and 3 together represent the Lower Aquifer zone, which is separated from Layer 1 by the Layer 2 aquitard, representing the Corcoran Clay unit (where present). Within the Madera Subbasin, Layer 1 (Upper Aquifer) has a saturated thickness as indicated on **Figures 6-5 and 6-6**. The Layer 2 aquitard, which represents the Corcoran Clay where it exists in the western portion of the Madera Subbasin, ranges in thickness from 1 foot to 75 feet, with an average thickness of about 20 feet, where present. The combined thickness of Layers 2 and 3 (Lower Aquifer) averages about 640 feet within the Madera Subbasin. Model results were evaluated separately for the Upper and Lower Aquifers, and also for the entire model thickness.

Because the simulation period for C2VSim-CG ends in 2009, simulated water budget results from select years during the simulation period were substituted to best represent the years 2010 to 2014. The years selected for use in this substitution were identified from previously simulated years with similar hydrologic conditions. In order to estimate groundwater budget components for 2010 to 2015, water year index numbers and water year types were used to find years with similar hydrologic conditions. The water year index and water year type are based on DWR's runoff and water year index values for the San Joaquin Valley (SJV)[9]. The water year index number and water year type were the main focus for selecting similar years in the past, but other considerations were also taken into account: 1) preference was put on years closer to the present to better represent current land use conditions, and 2) preceding year's hydrologic conditions (e.g., if wet years precede dry years, look for similar years in the past with wet years preceding dry years). **Table 6-1** presents the years and water year index information used to estimate water years 2010 to 2015.

[9] Water year runoff, index, and water year type information for the San Joaquin Valley was retrieved from DWR's website: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST, accessed 9/29/2017.

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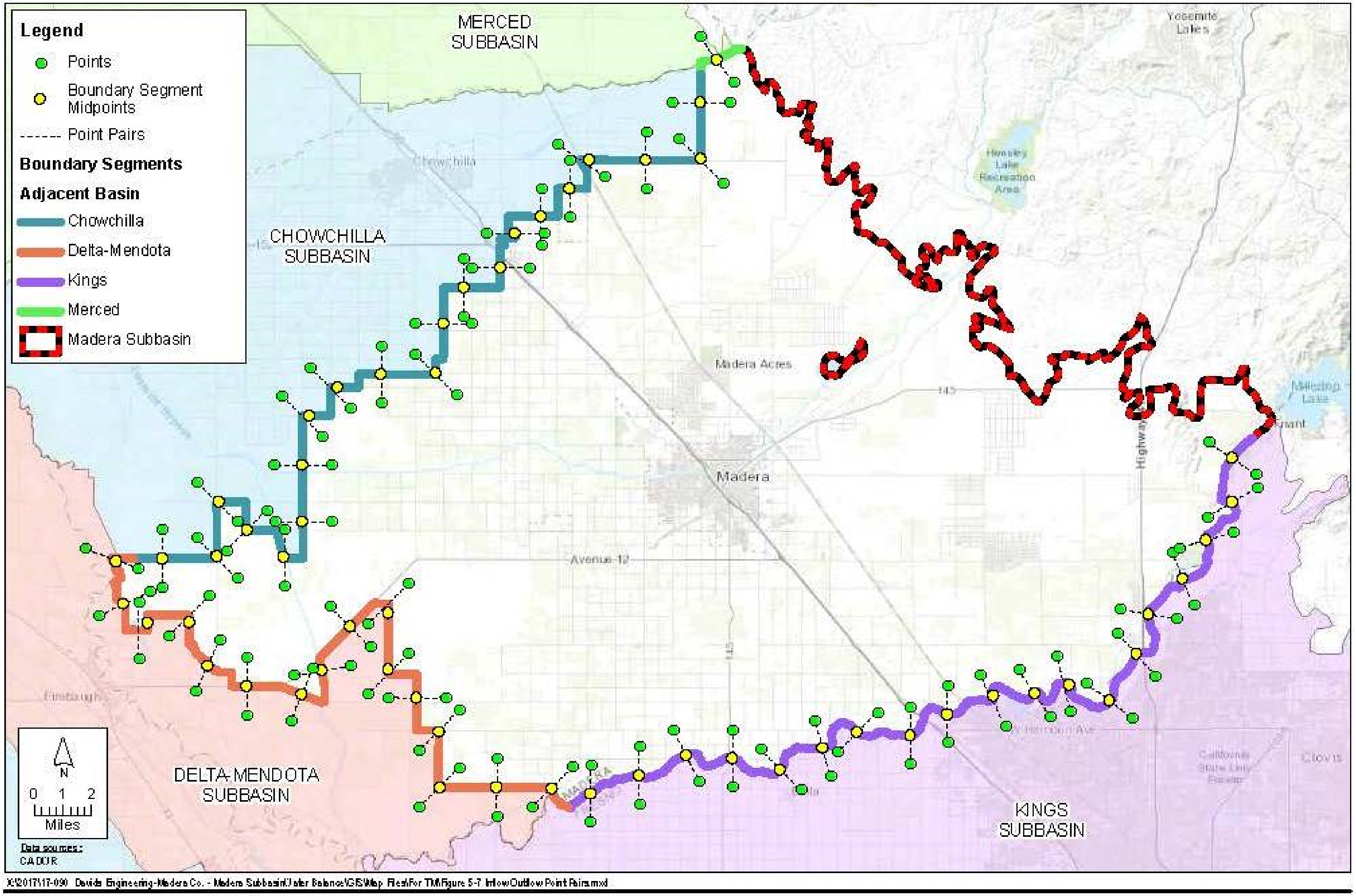

FIGURE 6-7
Preliminary Inflow/Outflow Point Pairs & Adjacent Groundwater Subbasins

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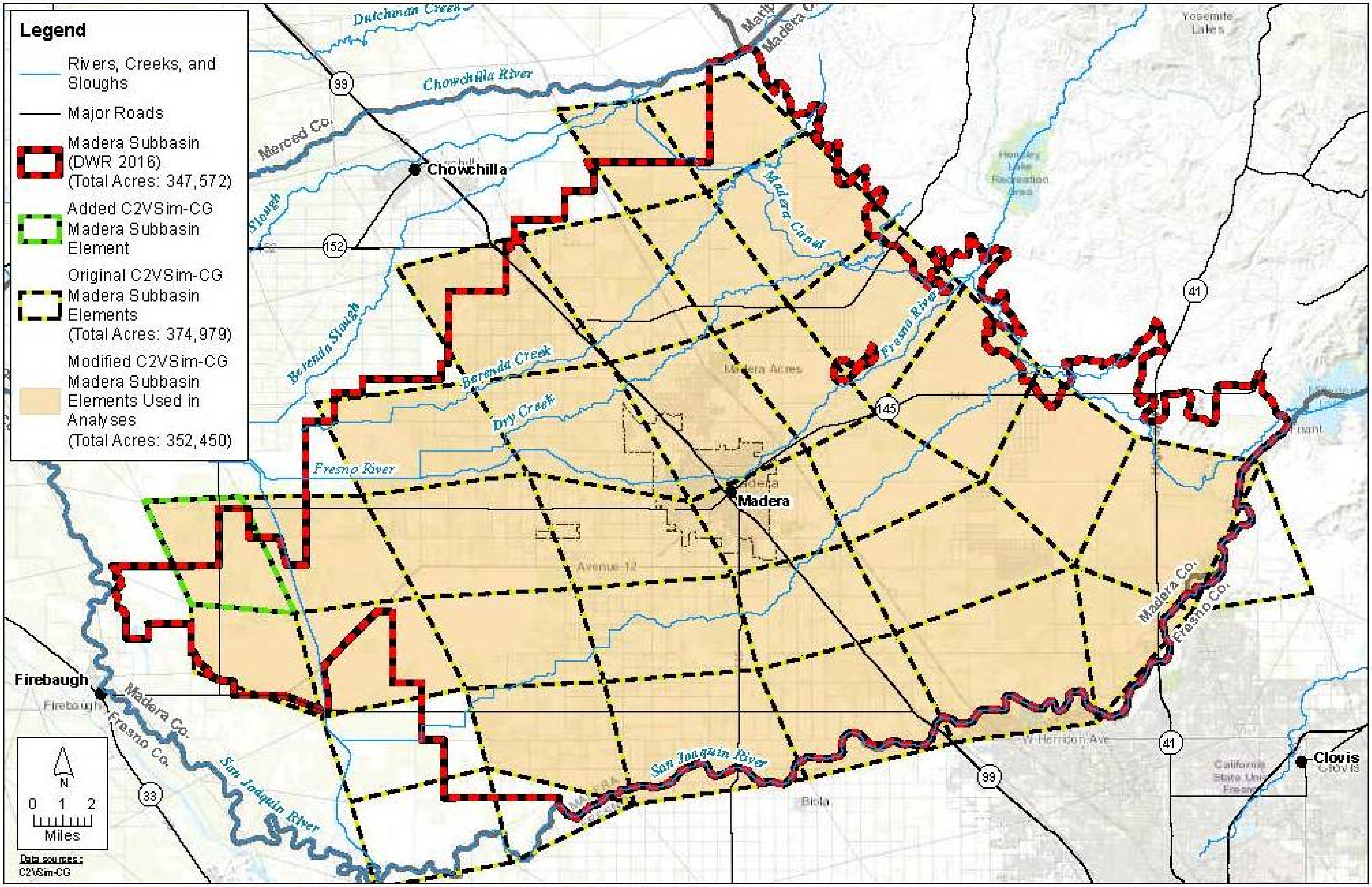


X:\2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 5-8 Modified Madera Subbasin C2VSim Model Boundaries.mxd

FIGURE 6-8
Preliminary Modified Madera Subbasin C2VSim-CG Model Boundaries for Water Budget Analyses

Table 6-1
Preliminary Hydrologic Conditions for Selection of Substitute Model Years to Use for 2010 through 2014

Water Year for Estimating	Water Year Index (SJV)	Water Year Type (SJV)	Preceding Hydrologic Condition	Substitute Year Used	Substitute Year's Water Year Index (SJV)	Substitute Year's Water Year Type (SJV)	Substitute Year's Preceding Hydrologic Conditions
2010	3.55	AN	Two years of C (critical) then BN (below normal)	1999	3.59	AN	Wet conditions[1]
2011	5.58	W	Above Normal (AN)	1998	5.65	W	Wet conditions
2012	2.18	D	A year of AN (above normal) and then a wet year (W)	2001	2.2	D	Wet and above normal conditions
2013	1.71	C	Dry year (D)	1989	1.96	C	Critically dry years
2014	1.16	C	Dry year and critical year	1990	1.51	C	Critically dry years
Abbreviations: C – Critical; W – Wet; D – Dry; BN – Below Normal; AN – Above Normal							

[1] Preceding conditions for substituting year 2010 were hard to match from the available simulated years because there are very little above normal hydrologic years. Simulation year 1999 was used as a substitute year for 2010 because of its very similar water year index.

6.2 Change in Groundwater Storage

The results of the groundwater storage change calculations described above are provided in this section for both the analytical/calculation and numerical approaches.

6.2.1 Calculated Change in Groundwater Storage

Groundwater elevation contour maps were produced for each year identified above as the start or end of a time period for analysis (**Appendix C**). The groundwater elevation contour maps were then evaluated in GIS to determine the total groundwater elevation change over each period that was analyzed (**Appendix E and Table 6-2**). These maps represent groundwater levels in the Upper Aquifer, with positive values indicating increased groundwater levels over the time period, and negative values indicating a decrease in groundwater levels over the time period. Groundwater elevation generally declines during each time period. During the analysis period, water levels decline in the northern and western portions of the Subbasin, and increase in the southeastern portion of the Subbasin. During the Wet Period, water levels increase along the San Joaquin River at the southern boundary, and decrease in the northern portion of the Subbasin, as well as in a localized area in the southeastern portion of the Subbasin. During the Average Period, water levels generally declined throughout the Subbasin, with increased water levels observed in localized areas in the northern and southeastern portions of the Subbasin. During the Dry Period, water levels declined in the central and southern portions of the Subbasin, and increased in the northern portion and in localized areas in the southern portion of the Subbasin.

Table 6-2
Preliminary Summary of Total Groundwater Elevation Change (ft)

	Analysis Period	Wet Period	Average Period	Dry Period
	1989-2014	**1990-1998**	**1999-2010**	**2011-2014**
Minimum	-151	-117	-86	-97
Maximum	62	54	99	64
Average	-50	-12	-15	-12

The average annual groundwater elevation change over the duration of each time period was also calculated. As seen in **Table 6-3**, water levels generally declined annually during each time period. Annual groundwater level change does not vary widely across the Subbasin during the Base, Wet, and Average Periods (**Appendix E**), with the exception of a localized area in the southeastern portion of the Subbasin during the Wet Period. Annual water level change is spatially highly variable during the Dry Period (**Appendix E**), with extremes in both increasing and decreasing trends observed. Groundwater level changes over the analysis period are shown in **Figure 6-9**.

Results of the change in storage calculations using each specific yield estimate are summarized in **Table 6-4**. Positive values indicate an increase in storage, while negative values indicate a decline in storage. Groundwater storage is shown to be declining during each time period using each specific yield estimate. The greatest loss of storage occurs during the Dry Period, while smaller storage losses occur during Wet and Average Periods.

The change in groundwater storage calculated from the C2VSim specific yield estimate is much higher than the change in groundwater storage calculated with the other specific yield estimates. Additionally, the most spatially variable change in storage within the Subbasin during a given time period is observed when using the C2VSim specific yield estimate. This is the result of the high spatial variability of specific yield values obtained from this model (**Figure 6-1**).

Table 6-3
Preliminary Summary of Annual Groundwater Elevation Change (ft)

	Analysis Period	Wet Period	Average Period	Dry Period
	1989-2014	1990-1998	1999-2010	2011-2014
Minimum	-6.1	-14.6	-7.8	-32.2
Maximum	2.5	6.7	9.0	21.4
Average	-2.0	-1.5	-1.4	-4.0

NOTE: Average annual groundwater elevation change is calculated based on the cumulative groundwater change over the specific hydrologic period, and divided over the number of years in each hydrologic period. The minimum and maximum values are for local areas within the basin with the greatest groundwater elevation change over the specific hydrologic period listed.

Table 6-4
Preliminary Summary of Calculated Results for Annual Change in Groundwater Storage (AFY)

Specific Yield (sy)Estimate	Analysis Period	Wet Period	Average Period	Dry Period
	1989-2014	1990-1998	1999-2010	2011-2014
C2VSim	-160,398	-103,073	-126,875	-358,755
CVHM	-99,212	-107,480	-43,246	-158,242
DWR	-71,368	-53,510	-50,600	-143,466
GMP	-89,210	-66,887	-63,262	-179,333
Average	*-105,047*	*-82,738*	*-70,996*	*-209,949*

6.2.2 Model-Based Evaluation of Change in Storage

C2VSim-CG simulates groundwater storage and change in storage as separate water budget components: groundwater storage within the effective aquifer pore space (specific yield/specific storage) and groundwater storage change relating to elastic and inelastic subsidence (compaction/expansion of the solid matrix). In this analysis, the groundwater storage and storage change results for C2VSim-CG are presented with a focus on the combined total of groundwater stored (and storage change) within effective aquifer pore space and change in groundwater storage relating to subsidence. Because substitute years were used to extend the analysis period through 2014, the changes in storage presented for the analysis years 2010 to 2014 should be considered with appropriate caution. In general, results suggest that in the Madera Subbasin, changes in groundwater storage relating to subsidence are very small relative to the total changes in groundwater storage.

The annual changes in simulated groundwater storage over different time periods, including the entire analysis period and wet, average, and dry hydrologic periods, are summarized in **Table 6-5** based on C2VSim-CG water budget output data for model elements contained in the Madera Subbasin. Negative values for change in storage indicate decreasing groundwater storage (declining groundwater levels) **Figure 6-9**. The variability in these values highlights some of the potential uncertainty in estimated groundwater storage change using C2VSim-CG simulated output. Based on evaluation of C2VSim-CG results, the average change in groundwater storage within the Madera Subbasin over the entire analysis period is estimated at about -96,000 acre-feet/year (AFY) with annual values ranging from a storage increase of about 151,000 to a storage decrease 265,000 acre-feet. Annual declines in groundwater storage values during the average hydrologic period were slightly greater (-123,000 AFY) than over the entire analysis period. The average change in storage during the wet hydrologic period is estimated to decrease about 37,000 AFY, representing considerably less annual decline than the average period, whereas the average change in storage during the dry hydrologic period is estimated to decrease approximately 115,000 AFY.

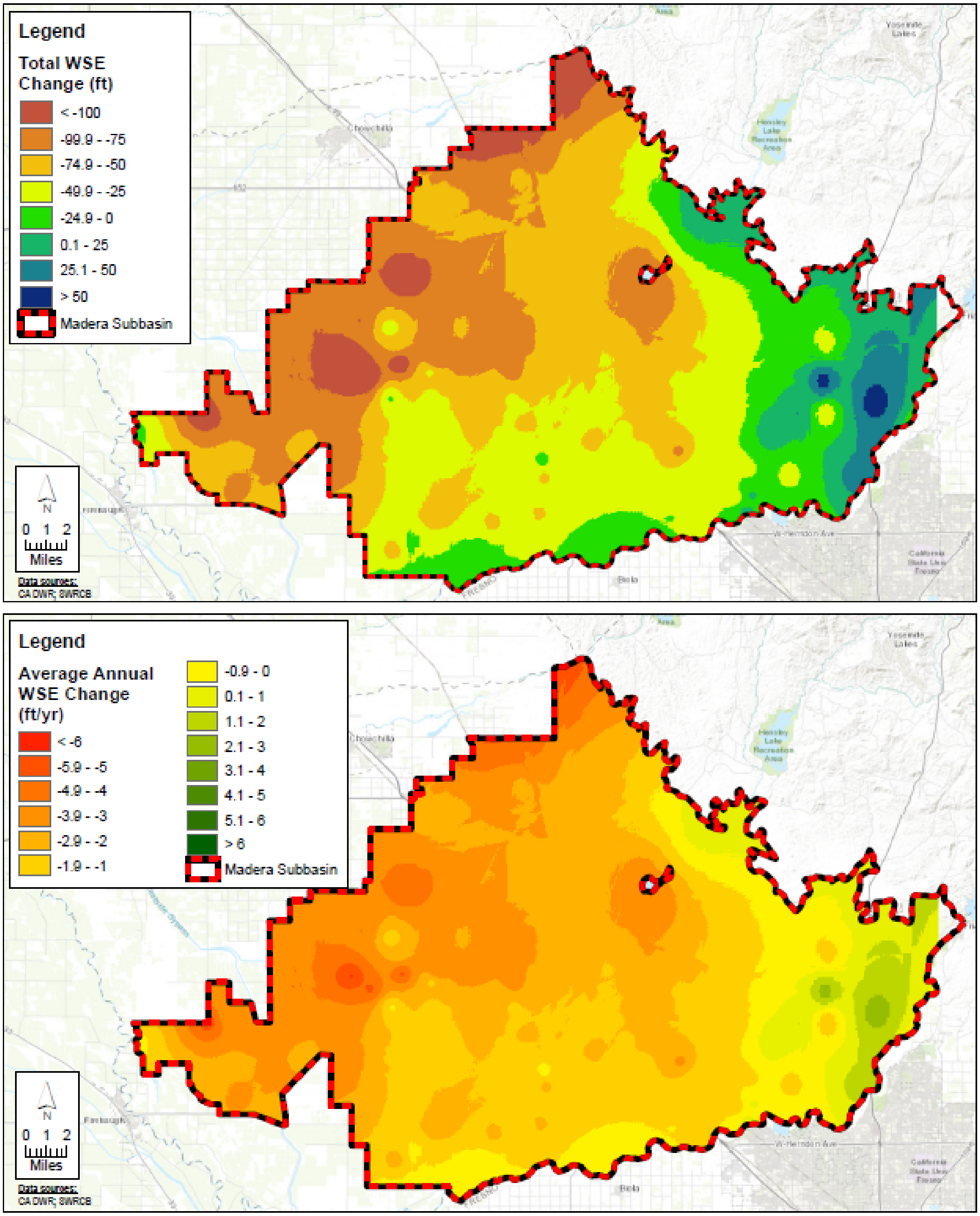
The range of estimated change in storage values based on C2VSim-CG results are also presented individually for the Upper Aquifer (C2VSim layer 1) and the Lower Aquifer (C2VSim layers 2 and 3). By separating the water budget components by model layer, it is also possible to evaluate how groundwater storage is changing within different parts of the groundwater system. As illustrated in **Figures 6-10 and 6-11**, the Upper Aquifer (C2VSim Layer 1) has experienced most of the groundwater depletion over the analysis period. The model results suggest that most of the change in storage during all analysis periods occurred in the Upper Aquifer, which is unconfined. The simulated change in storage in the Lower Aquifer appears to be relatively small and has been on the order of 10 percent of total storage change. However, it is possible that deeper wells drilled recently in the area may not be captured by the C2VSim-CG model period, which ends in 2009. The results by aquifer exhibit similar temporal trends in storage change although the volume of change estimated within the Upper Aquifer is considerably greater than in the Lower Aquifer. Over the entire analysis period on average the groundwater storage decreased by about 88,000 AFY in the Upper Aquifer and by about 8,000 AFY in the Lower Aquifer. During the wet period, results suggest there was an overall slight increase in storage in the Lower Aquifer of approximately 700 AFY.

Time-series results for annual and cumulative change in groundwater storage (**Figures 6-10 and 6-11)** also show how overall annual groundwater storage depletion in the Madera Subbasin tends to be less during wet periods when compared to average and dry periods. Although the analysis of groundwater storage based on C2VSim-CG model results suggests that there was a considerable net decrease in groundwater storage in the Madera Subbasin over the analysis period, there are individual years over this period during which there is a net increase in groundwater storage, particularly during the wet hydrologic period. According to the C2VSim-CG water budget output, water years during which groundwater storage was replenished include 1993, 1995, 1997, 1998, 2005, 2006, and 2011 (as represented by results for water year 1998 in C2VSim-CG).

Table 6-5
Preliminary Summary of Model-Based Results for Annual Change in Groundwater Storage (AFY)

Water Year	Entire Madera Subbasin	Upper Aquifer	Lower Aquifer
1989	-220,975	-199,207	-21,768
1990	-264,899	-228,245	-36,654
1991	-194,820	-184,290	-10,530
1992	-181,470	-173,104	-8,366
1993	56,927	7,600	49,327
1994	-116,731	-97,426	-19,305
1995	67,099	53,049	14,050
1996	-1,589	-4,972	3,383
1997	151,554	167,598	-16,044
1998	149,080	118,782	30,297
1999	-151,509	-116,565	-34,944
2000	-82,356	-80,997	-1,358
2001	-122,389	-114,417	-7,972
2002	-169,325	-148,970	-20,355
2003	-149,616	-140,547	-9,068
2004	-159,355	-148,055	-11,300
2005	13,548	-12,974	26,522
2006	50,676	41,002	9,675
2007	-155,423	-128,770	-26,653
2008	-214,765	-171,515	-43,250
2009	-186,469	-183,597	-2,872
2010 (1999)*	-151,509	-116,565	-34,944
2011 (1998)*	149,080	118,782	30,297
2012 (2001)*	-122,389	-114,417	-7,972
2013 (1989)*	-220,975	-199,207	-21,768
2014 (1990)*	-264,899	-228,245	-36,654
ANALYSIS PERIOD (1989-2014)			
Average	-95,904	-87,895	-8,009
Minimum	-264,899	-228,245	-43,250
Maximum	151,554	167,598	49,327
WET PERIOD (1990-1998)			
Average	-37,205	-37,890	684
Minimum	-264,899	-228,245	-36,654
Maximum	151,554	167,598	49,327
AVERAGE PERIOD (1999-2010)			
Average	-123,208	-110,164	-13,044
Minimum	-214,765	-183,597	-43,250
Maximum	50,676	41,002	26,522
DRY PERIOD (2011-2014)			
Average	-114,796	-105,771	-9,024
Minimum	-264,899	-228,245	-36,654
Maximum	149,080	118,782	30,297

**Results presented for years 2010-2014 are from substituted years indicated in parentheses.*



X:\2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 6-9 Calculated GWL Change over Analysis Period (1989-2014).mxd

FIGURE 6-9
Preliminary Calculated Groundwater Level Change over Analysis Period (1989-2014)

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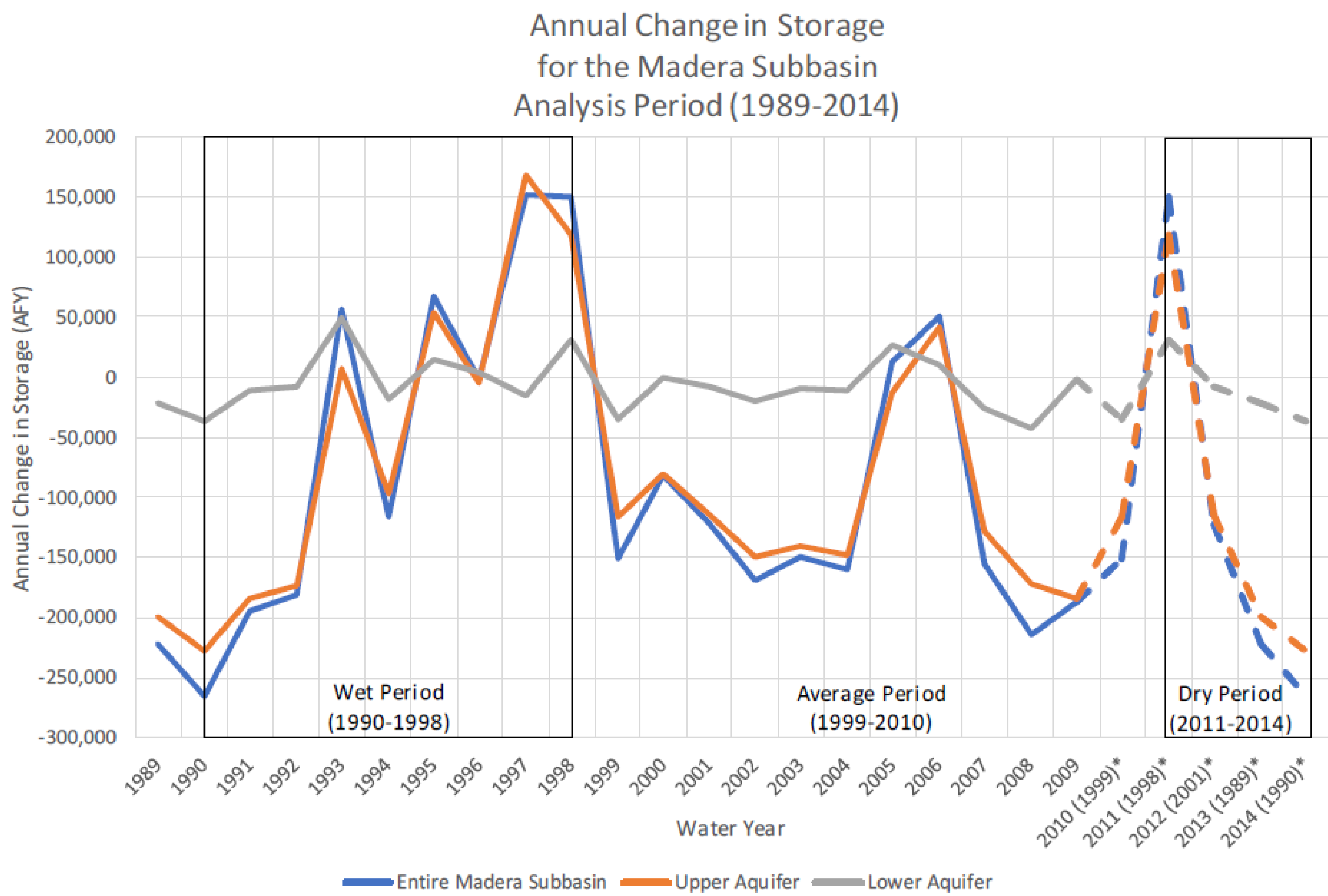
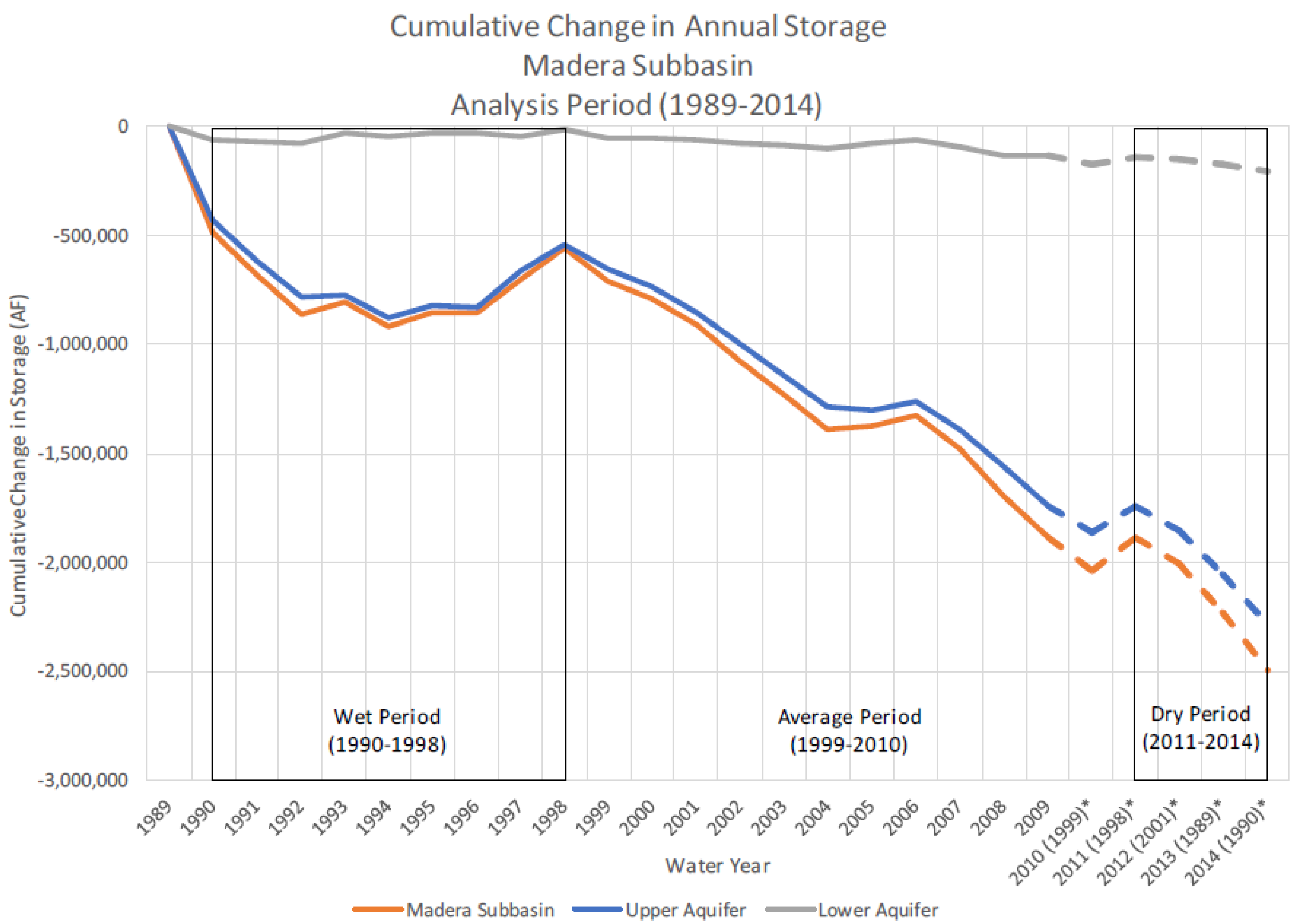


**Results presented for years 2010-2014 are from substitue years indicated in parentheses.*
NOTE: Negative change in storage values indicate storage depletion; positive change in storage values indicate storage replenishment.
The C2VSim-CG simulation period ends in 2009; dashed lines are used for 2010-2014 where results for substitued years are presented.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 5-9 Model-Based Results for Annual Change in Storage.mxd

FIGURE 6-10
Preliminary Model-Based Results for Annual Change in Storage



**Results presented for years 2010-2014 are from substitue years indicated in parentheses.*
NOTE: Negative change in storage values indicate storage depletion; positive change in storage values indicate storage replenishment.
The C2VSim-CG simulation period ends in 2009; dashed lines are used for 2010-2014 where results for substitued years are presented.

2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 6-10 Model-Based Results for Cumulative Change in Annual Storage.mxd

FIGURE 6-11
Preliminary Model-Based Results for Cumulative Change in Annual Storage

6.2.3 Summary of Change in Groundwater Storage Analysis

A summary of the results from the calculations of change in groundwater storage and model-based results for change in groundwater storage are summarized in **Table 6-6**. Although calculations of changes in groundwater storage over the analysis period were only possible for the Upper Aquifer because of limitations in available groundwater level data, the range of values from the calculated results are comparable to the model-based results for change in storage in the Upper Aquifer. The average annual calculated change in storage in the Upper Aquifer ranges between -70,000 to -160,000 AFY (average of -105,000 AFY) depending on the specific yield (Sy) aquifer properties applied, whereas the model-based results suggest an annual change in storage in the Upper Aquifer of about -88,000 AFY. Model-based results for change in groundwater storage in the Lower Aquifer suggest much lower numbers than in the Upper Aquifer with average annual values of -8,000 AFY over the analysis period. Based on the combined evaluation of calculated and C2VSim-CG model-based results for change in groundwater storage, the overall historical change in groundwater storage in the Madera Subbasin over the analysis period 1989-2014 is estimated be in the range of -110,000 to -120,000 AFY. This groundwater storage change estimate is based upon the calculated/analytical approach value of 105,000 AFY for the Upper Aquifer and the model-based value of 8,000 AFY for the Lower Aquifer.

Previous estimates of groundwater storage change for Madera County include DWR (1992), Todd (2002), and Provost & Pritchard (2014). DWR (1992) estimated groundwater storage decline from 1970 to 1990 to be 74,115 AFY. Todd (2002) calculated a groundwater storage decline of 68,338 AFY for the period from 1990 to 1998. For the Madera County area included in the analysis (not including areas of Root Creek Water District, Madera Water District, Aliso Water District, or Columbia Canal Company) plus the area of Merced County included in Chowchilla Water District, groundwater storage between 1980 and 2011 was estimated to have declined at an average rate of 143,000 AFY over the 31-year period.

While the above-cited previous studies quantified groundwater storage change for different time periods and different areas compared to the current estimate provided in this report, the results of the current study are generally consistent with previous study results.

6.3 Subsurface Lateral Flows

6.3.1 Calculated Subsurface Lateral Flows

Subsurface flow was calculated at each segment along the Subbasin boundary for 1989, 1990, 1998, 1999, 2010, 2011, and 2014. Positive values indicate inflows to Madera Subbasin, while negative values indicate outflows from Madera Subbasin. The net subsurface flow was calculated by summing the results of all the segments. A comparison of the results using each Kh distribution is shown in **Figure 6-12**, and summarized in **Tables 6-7 and 6-8.** A net inflow to Madera Subbasin was calculated for each time period for each estimate. The net inflow values calculated using CVHM estimates are significantly higher than those calculated using C2VSim estimates due to the Kh values from CVHM being almost an order of magnitude higher than those from C2VSim (see **Figures 6-3 and 6-4**). The C2VSim model K values appear to be more reasonable for Madera Subbasin than CVHM model K values based on comparison to available aquifer parameter data. In addition, C2VSim was developed by DWR, which may make it more acceptable to them.

Table 6-6
Preliminary Summary of Calculated and Model-Based Results of Change in Groundwater Storage (AFY)

Source	Estimate	Sy Estimate	Analysis Period 1989-2014	Wet Period 1990-1998	Average Period 1999-2010	Dry Period 2011-2014
Calculated	Average Annual Upper Aquifer	*C2VSim*	-160,398	-103,073	-126,875	-358,755
		CVHM	-99,212	-107,480	-43,246	-158,242
		DWR	-71,368	-53,510	-50,600	-143,466
		GMP	-89,210	-66,887	-63,262	-179,333
		Average	-105,047	-82,738	-70,996	-209,949
Model-Based	Average Annual Upper Aquifer		-87,895	-37,890	-110,164	-105,771
	Average Annual Lower Aquifer		-8,009	684	-13,044	-9,024
	Total		-95,904	-37,205	-123,208	-114,796
Overall Estimated Change in Groundwater Storage from Groundwater System Analyses Over Analysis Period[10]			**-110,000 to -120,000 AFY**			

[10] The overall estimated storage change of -110,000 to -120,000 AFY is based on the average of the calculated methods for the Upper Aquifer plus the average model-derived value for the Lower Aquifer.

Table 6-7
Preliminary Summary of Calculated Results for Annual Subsurface Lateral Flow (C2VSim Kh Estimates)

Model: C2VSim		Net	*Adjacent Subbasin*			
			Chowchilla	**Delta-Mendota**	**Kings**	**Merced**
Miles along Boundary:		**114[1]**	**42**	**32**	**38[2]**	**2[3]**
Kh Est.	***Year***	**AFY**	**AFY**	**AFY**	**AFY**	**AFY**
Average	1989	24,083	5,831	1,673	16,103	475
Average	1990	33,129	7,142	8,305	17,682	*No Data*
Average	1998	52,008	10,250	10,026	30,978	755
Average	1999	55,376	17,068	4,418	33,360	530
Average	2010	32,729	-8,079	10,187	31,604	-984
Average	2011	30,297	9,365	3,321	17,977	-365
Average	2014	33,562	-1,097	22,335	12,612	-287
Minimum	1989	22,654	5,562	1,140	15,497	452
Minimum	1990	30,893	6,722	7,135	17,036	*No Data*
Minimum	1998	48,709	9,715	8,816	29,461	718
Minimum	1999	51,941	16,167	3,695	31,574	504
Minimum	2010	30,861	-7,170	8,805	30,161	-936
Minimum	2011	27,933	8,903	2,439	16,938	-347
Minimum	2014	31,068	-1,057	20,334	12,065	-273
Maximum	1989	25,600	6,281	1,922	16,906	490
Maximum	1990	35,133	7,605	9,017	18,512	*No Data*
Maximum	1998	55,128	11,002	10,665	32,682	779
Maximum	1999	59,026	18,394	4,796	35,287	547
Maximum	2010	33,622	-9,258	10,783	33,112	-1,016
Maximum	2011	32,014	9,912	3,574	18,904	-377
Maximum	2014	35,242	-1,453	23,845	13,147	-297

NOTE:
Negative lateral flow values indicate outflows; Positive lateral flow values indicate inflows.
[1] Miles along Boundary = 110 in 1989, 108 in 1990 due to lack of water level data
[2] Miles along Boundary = 34 in 1989 and 1991 due to lack of water level data
[3] Miles along Boundary = 0 in 1990 due to lack of water level data

Table 6-8
Preliminary Summary of Calculated Results for Annual Subsurface Lateral Flow (CVHM Kh Estimates)

Model: CVHM		Net	*Adjacent Subbasin*			
			Chowchilla	Delta-Mendota	Kings	Merced
Miles along Boundary:		114[1]	42	32	38[2]	2[3]
Kh Est.	*Year*	AFY	AFY	AFY	AFY	AFY
Average	1989	147,614	16,869	6,367	123,140	1,238
Average	1990	200,089	21,121	38,589	140,380	*No Data*
Average	1998	304,774	28,436	53,041	221,480	1,817
Average	1999	299,810	42,276	21,338	234,969	1,227
Average	2010	264,091	-20,426	51,396	234,847	-1,725
Average	2011	166,534	21,821	13,207	131,603	-98
Average	2014	223,337	-3,637	124,988	101,694	291
Minimum	1989	107,236	10,781	4,483	91,366	607
Minimum	1990	151,952	13,048	32,199	106,705	*No Data*
Minimum	1998	233,245	19,646	44,750	167,959	891
Minimum	1999	230,630	30,032	21,201	178,795	602
Minimum	2010	210,861	-15,606	42,549	184,764	-846
Minimum	2011	137,823	16,261	16,625	104,986	-48
Minimum	2014	168,525	-5,064	92,341	81,105	143
Maximum	1989	187,817	24,421	7,202	154,327	1,867
Maximum	1990	250,912	33,164	43,387	174,361	*No Data*
Maximum	1998	386,277	43,328	58,690	281,518	2,741
Maximum	1999	383,327	59,508	21,882	360,086	1,850
Maximum	2010	325,916	-23,259	58,813	292,963	-2,601
Maximum	2011	212,188	37,830	11,420	163,085	-148
Maximum	2014	263,037	711	140,143	121,745	439

NOTE:
Negative lateral flow values indicate outflows; Positive lateral flow values indicate inflows.
[1] Miles along Boundary = 110 in 1989, 108 in 1990 due to lack of water level data
[2] Miles along Boundary = 34 in 1989 and 1991 due to lack of water level data
[3] Miles along Boundary = 0 in 1990 due to lack of water level data

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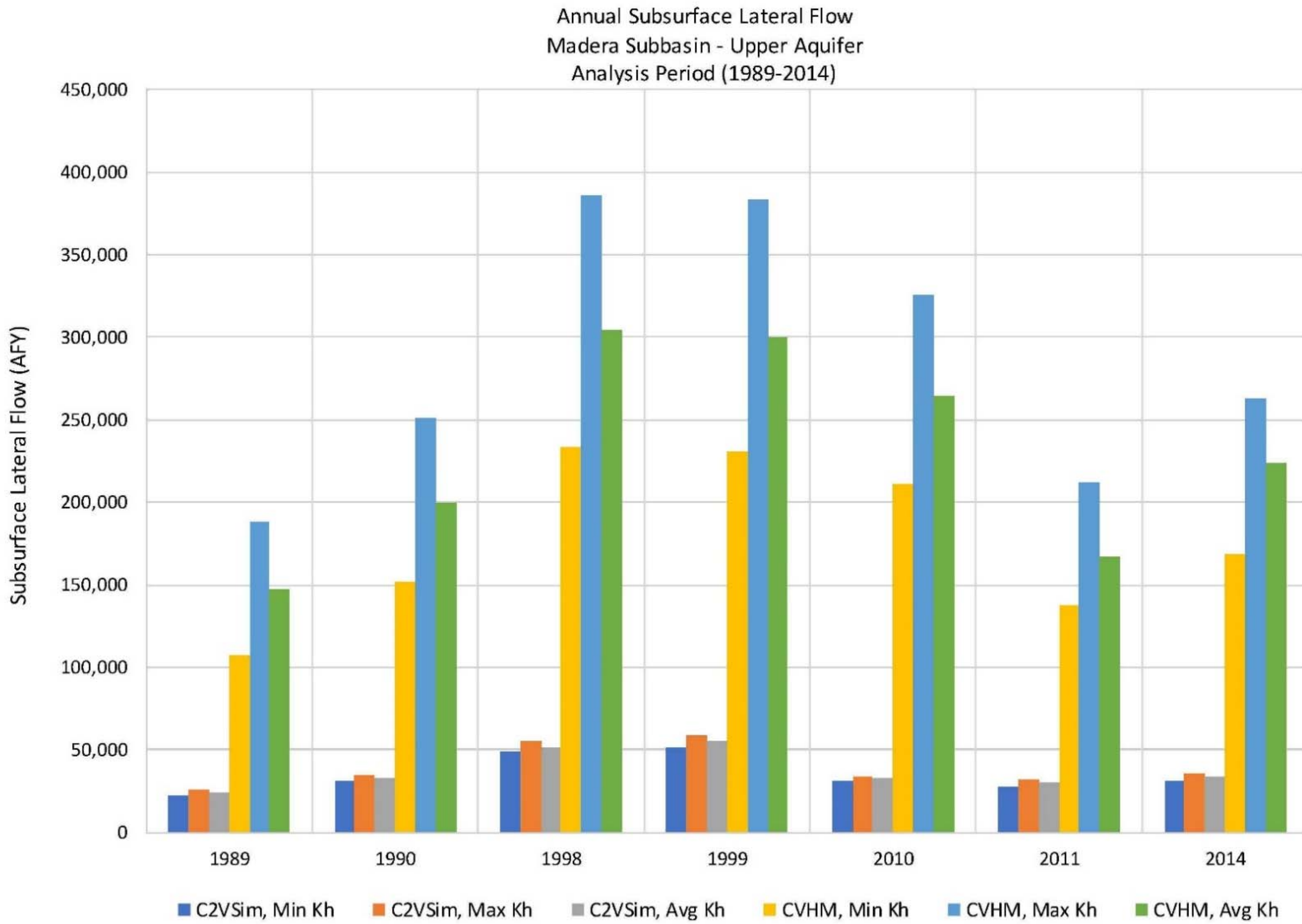

NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 5-11 Calculated Results for Annual Subsurface Lateral Flow.mxd

FIGURE 6-12
Preliminary Calculated Results for Annual Subsurface Lateral Flow

The net subsurface flow from adjacent subbasins was calculated by summing the results of all segments along a particular subbasin boundary. **Figure 6-13** shows the net flow from the Chowchilla Subbasin. Lateral flow along this boundary is generally an inflow to the Madera Subbasin, with the exception of 2010 and 2014. **Figure 6-14** shows the net flow from the Delta-Mendota Subbasin. Lateral flow along this boundary is shown to be an inflow to the Madera Subbasin. **Figure 6-15** shows the net flow from the Kings Subbasin. Lateral flow along this boundary is shown to be an inflow to the Madera Subbasin. **Figure 6-16** shows the net flow from the Merced Subbasin. Lateral flow along this boundary was an inflow to the Madera Subbasin in 1989, 1998, and 1999, and an outflow from the Madera Subbasin in 2010, 2011, and 2014.

The highest rate of inflow to the Madera Subbasin comes from the Kings Subbasin. However, the rate of flow from the Kings Subbasin may be an overestimate influenced by stream recharge. The border of the Madera and Kings Subbasins follows the path of the San Joaquin River, a known source of recharge to groundwater in the area. The Chowchilla Subbasin is also observed to contribute a high amount of inflow to the Madera Subbasin, except in 2010 and 2014 when there is an outflow from Madera Subbasin. The Merced Subbasin has a much lower contribution of lateral flow to the Madera Subbasin due to its limited shared boundary.

6.3.2 Model-Based Evaluation of Subsurface Lateral Flows

Subsurface groundwater flow to and from the Madera Subbasin occurs as lateral flow from adjacent subbasins, and also from the watersheds outside the Subbasin to the east (**Figure 6-17**). C2VSim-CG results were processed to individually evaluate subsurface flow between the Madera Subbasin and Chowchilla Subbasin and the Merced Subbasin to the north, the Delta-Mendota Subbasin to the west, and the Kings Subbasin to the south. Additionally, subsurface inflows resulting from small watershed contributions in C2VSim-CG were also summarized and evaluated. Small watershed contributions represent the subsurface inflow from surrounding small watersheds to the east of the Madera Subbasin and are comprised of separate inflow components which enter the Subbasin as subsurface flow resulting from small watershed baseflow and small watershed percolation.

Over the entire analysis period (1989-2014) there is a net subsurface lateral inflow between the Madera Subbasin and the neighboring subbasins, though there is a consistent outflow of groundwater between the Madera Subbasin and the Chowchilla Subbasin over the analysis period (**Table 6-9 and Figure 6-18**). The largest annual subsurface lateral flow typically occurs between the Madera Subbasin and the Kings Subbasin as an inflow to Madera Subbasin. The subsurface inflows from the Merced and Delta-Mendota Subbasins are considerably less with the individual inflows from these subbasins averaging about one tenth of the subsurface inflows from the Kings Subbasin. **Figures 6-18 to 6-20** illustrate the annual lateral inflows and outflows from neighboring subbasins over the analysis period for the entire Madera Subbasin, the Upper Aquifer, and the Lower Aquifer. The total subsurface lateral flow between adjacent subbasins over the entire analysis period (1989-2014) ranges from net inflows of 10,168 AFY (during water year 1994) to 38,856 AFY (in 2008), with an average of 22,503 AFY (**Table 6-9**). During the wet period, total subsurface lateral inflows from adjacent subbasins were generally less with net inflows from 10,168 AFY to 29,131 AFY and an overall average inflow of 16,808 AFY. During the average hydrologic period total subsurface lateral flows range from net inflows of 22,425 AFY to 38,856 AFY with an average inflow of 28,696 AFY while during the dry period, total subsurface lateral flows range from net inflows of 14,086 AFY to 23,056 AFY, with an average inflow of 18,512 AFY.

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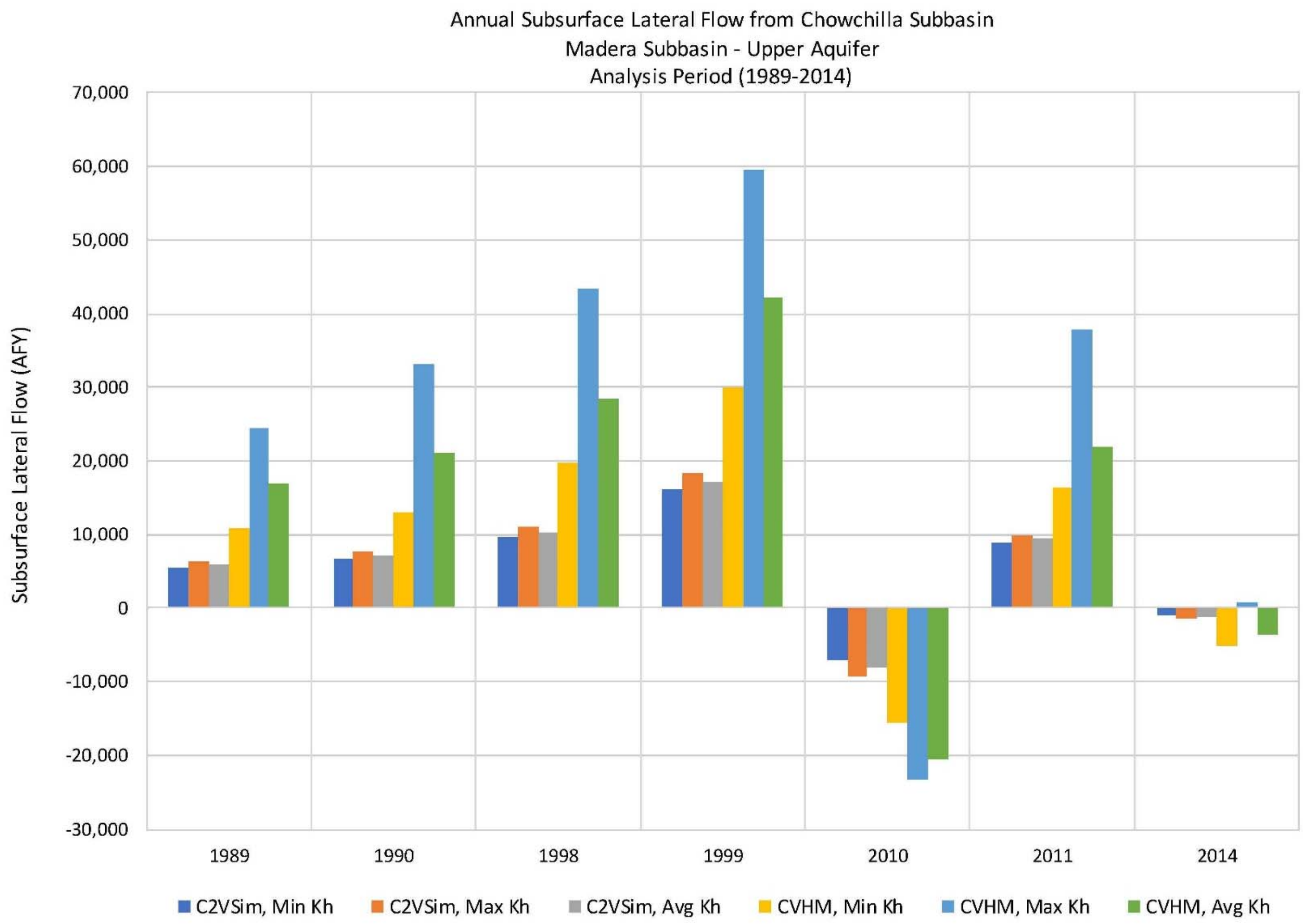

NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure 5-12 Calculated Results for Annual Subsurface Lateral Flow from Chowchilla Subbasin.mxd

FIGURE 6-13
Preliminary Calculated Results for Annual Subsurface Lateral Flow from Chowchilla Subbasin

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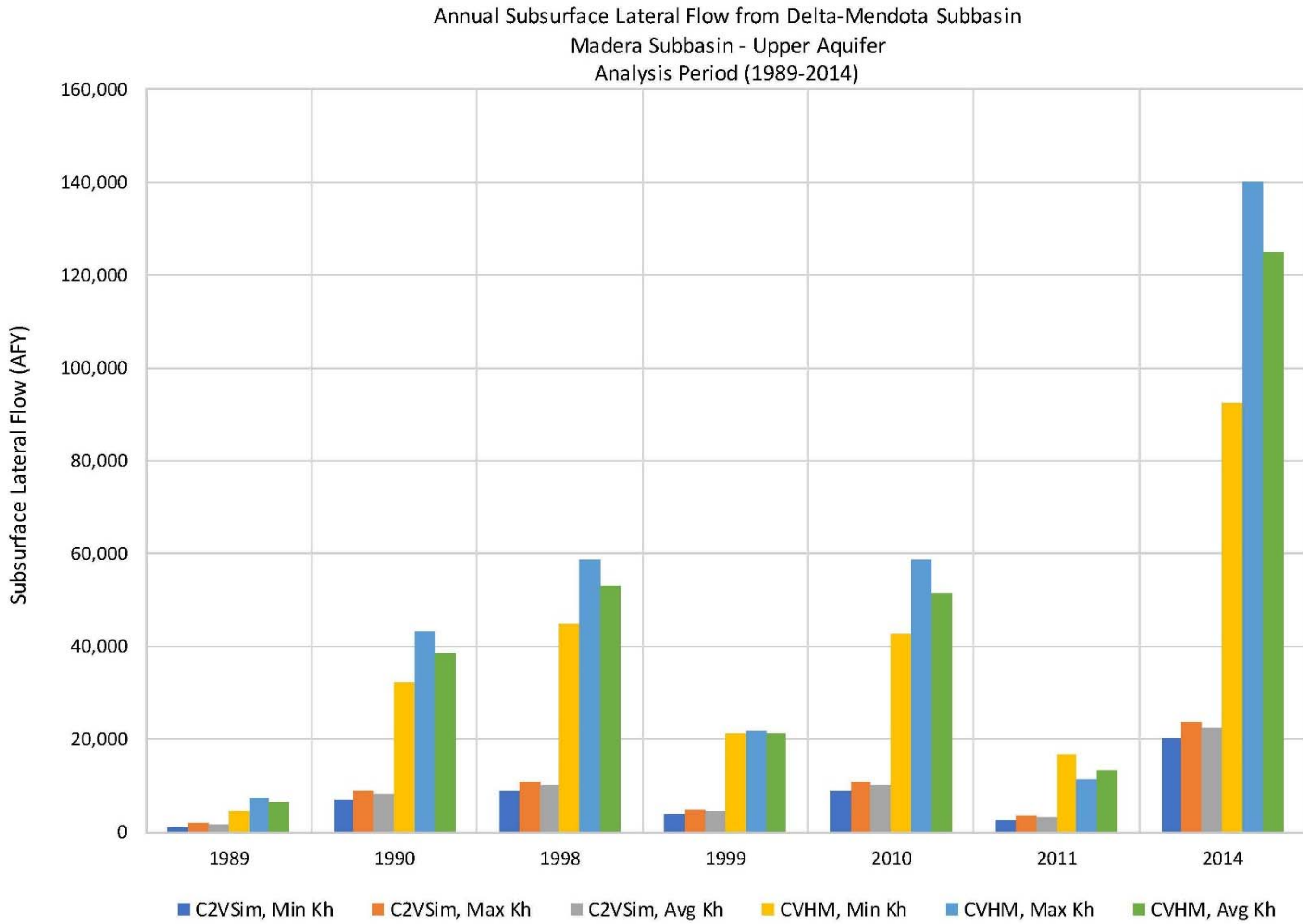

NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 5-13 Calculated Results for Annual Subsurface Lateral Flow from Delta-Mendota Subbasin.mxd

FIGURE 6-14
Preliminary Calculated Results for Annual Subsurface Lateral Flow from Delta-Mendota Subbasin

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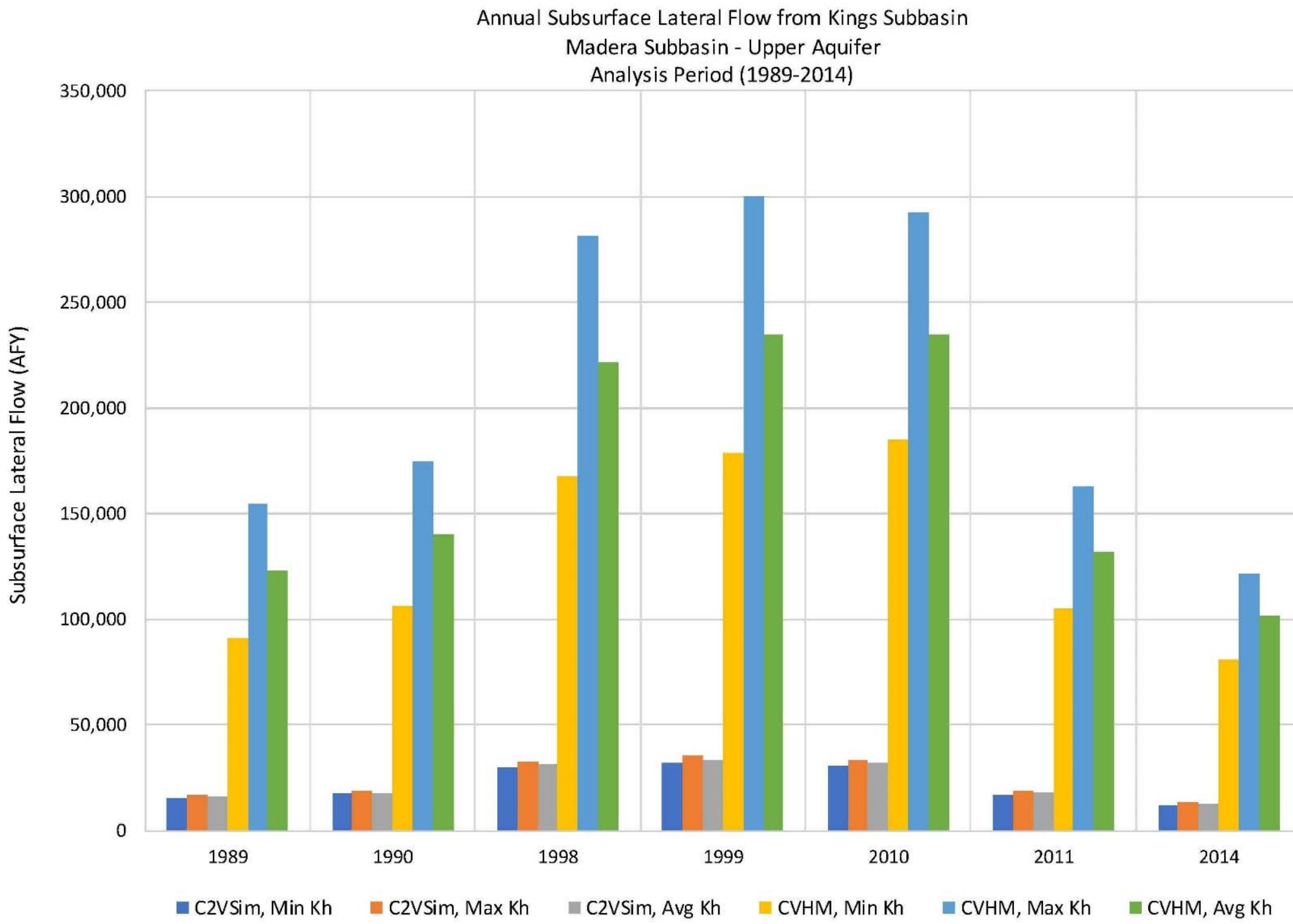

NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure 5-14 Calculated Results for Annual Subsurface Lateral Flow from Kings Subbasin.mxd

FIGURE 6-15
Preliminary Calculated Results for Annual Subsurface Lateral Flow from Kings Subbasin

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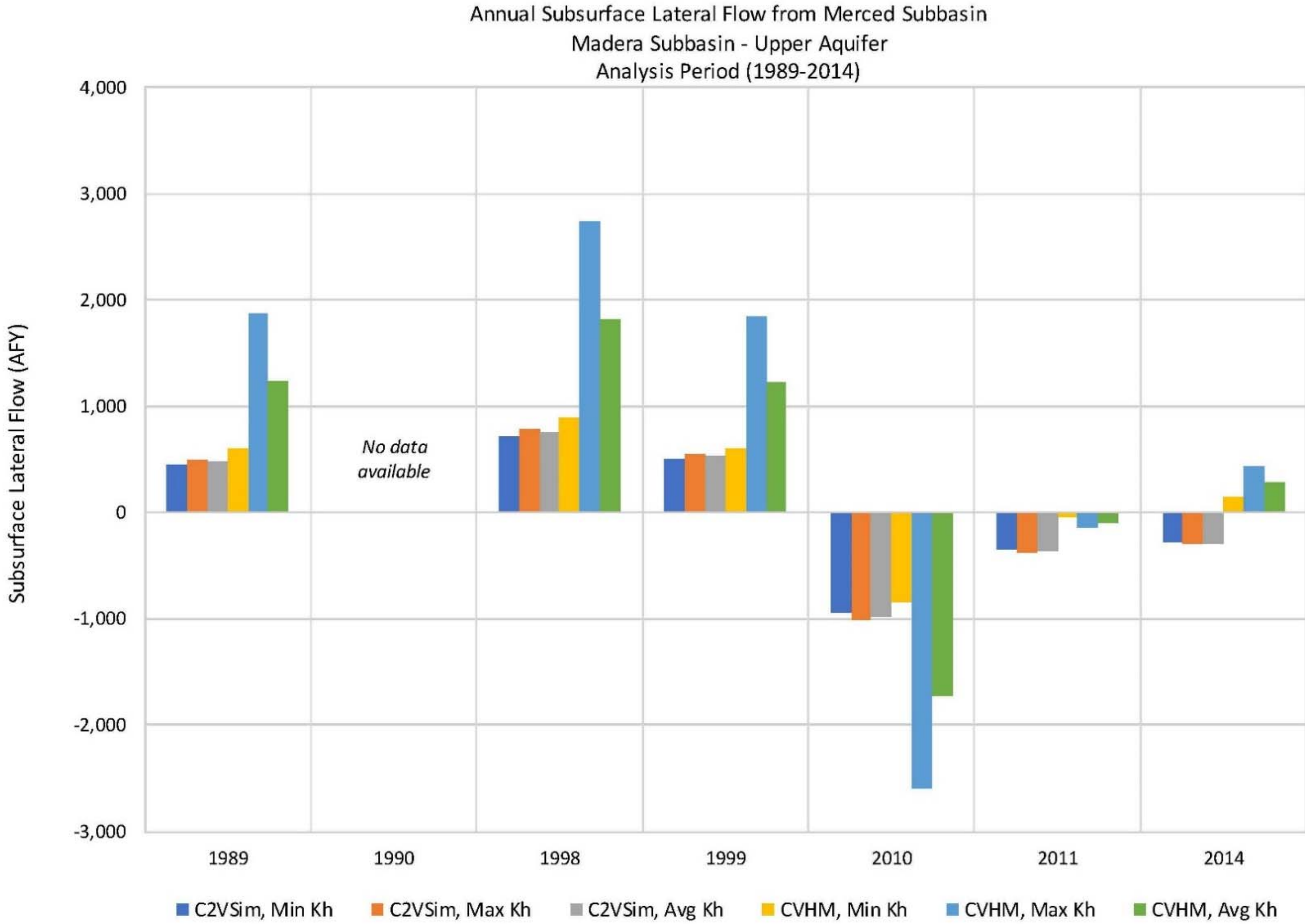

NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure 5-15 Calculated Results for Annual Subsurface Lateral Flow from Merced Subbasin.mxd

FIGURE 6-16
Preliminary Calculated Results for Annual Subsurface Lateral Flow from Merced Subbasin

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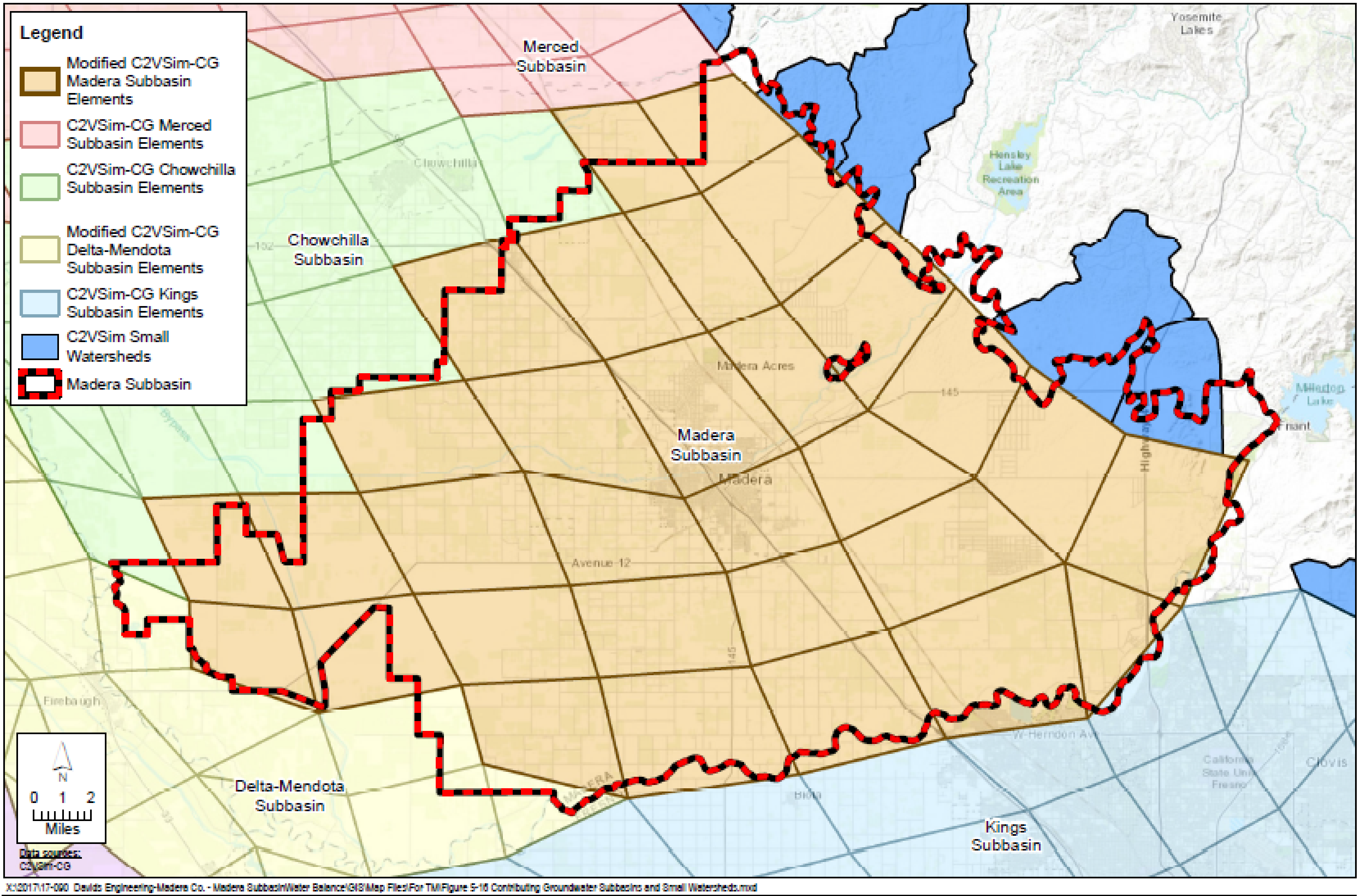
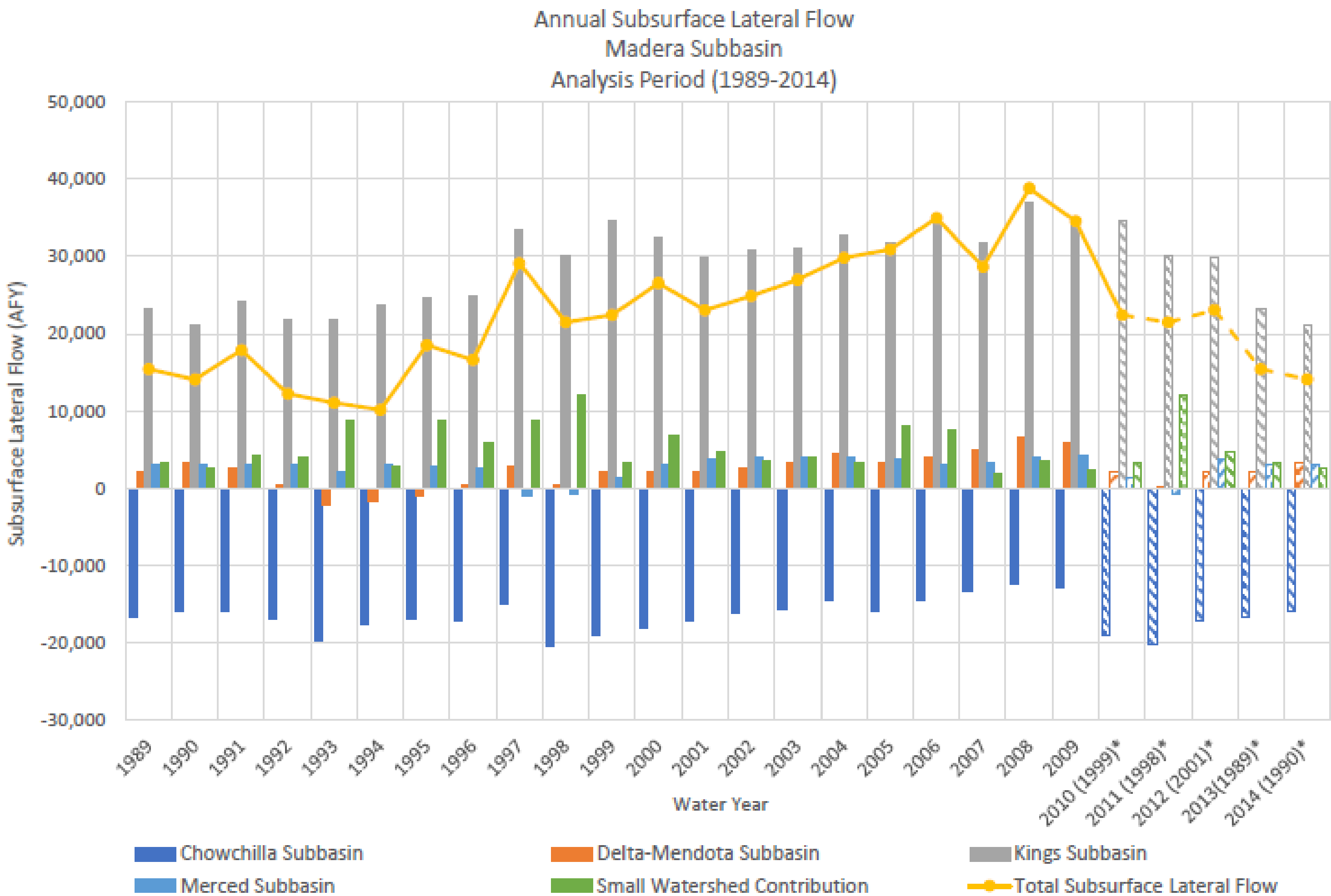


FIGURE 6-17
Preliminary Contributing Groundwater Subbasins and Small Watersheds



**Results presented for years 2010-2014 are from substitue years indicated in parentheses.*
NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.
The C2VSim-CG simulation period ends in 2009; dashed lines are used for 2010-2014 where results for substitued years are presented.

FIGURE 6-18
Preliminary Model-Based Results for Annual Subsurface Lateral Flow

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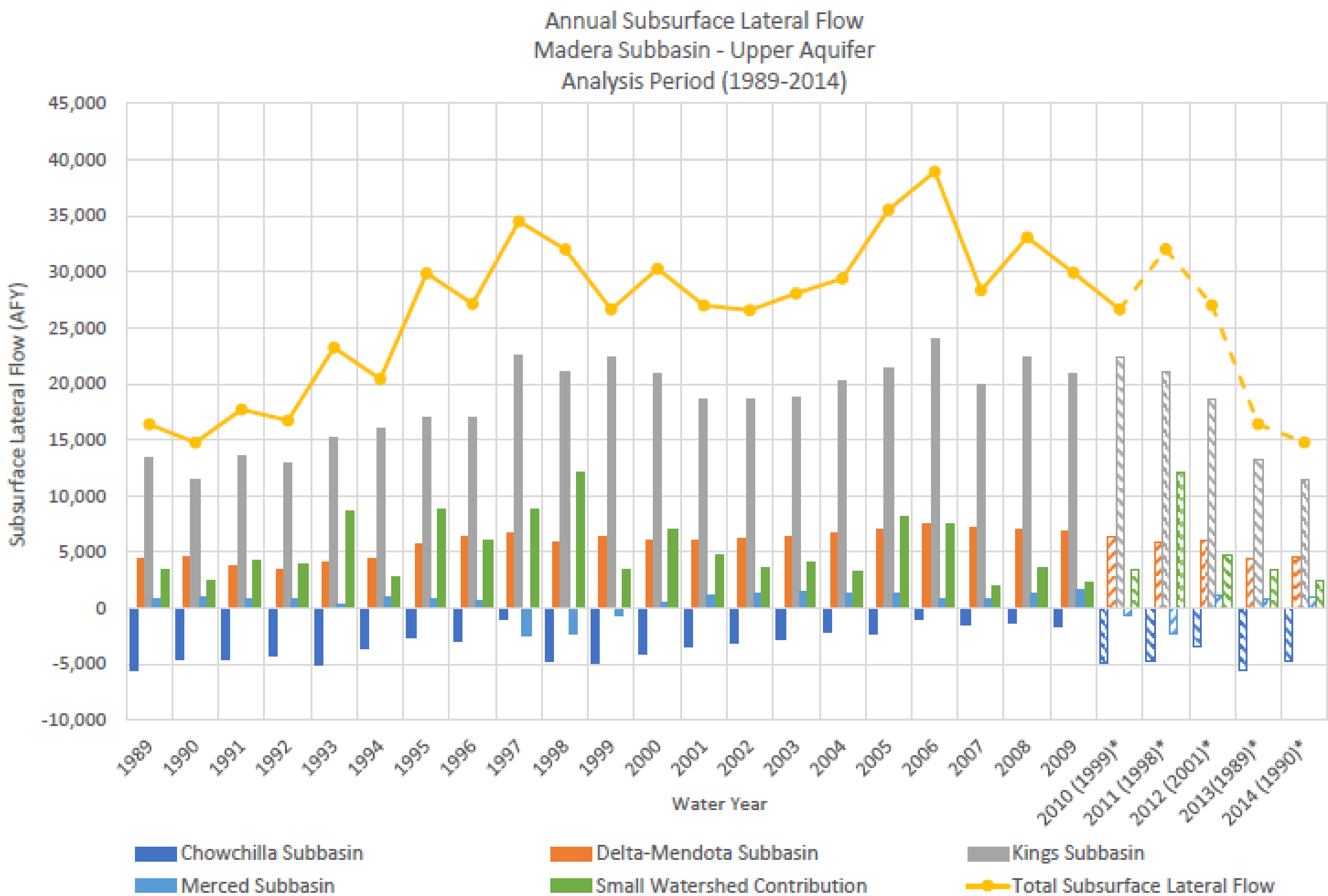

**Results presented for years 2010-2014 are from substitue years indicated in parentheses.*
NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.
The C2VSim-CG simulation period ends in 2009; dashed lines are used for 2010-2014 where results for substitued years are presented.

FIGURE 6-19
Preliminary Model-Based Results for Annual Subsurface Lateral Flow - Upper Aquifer

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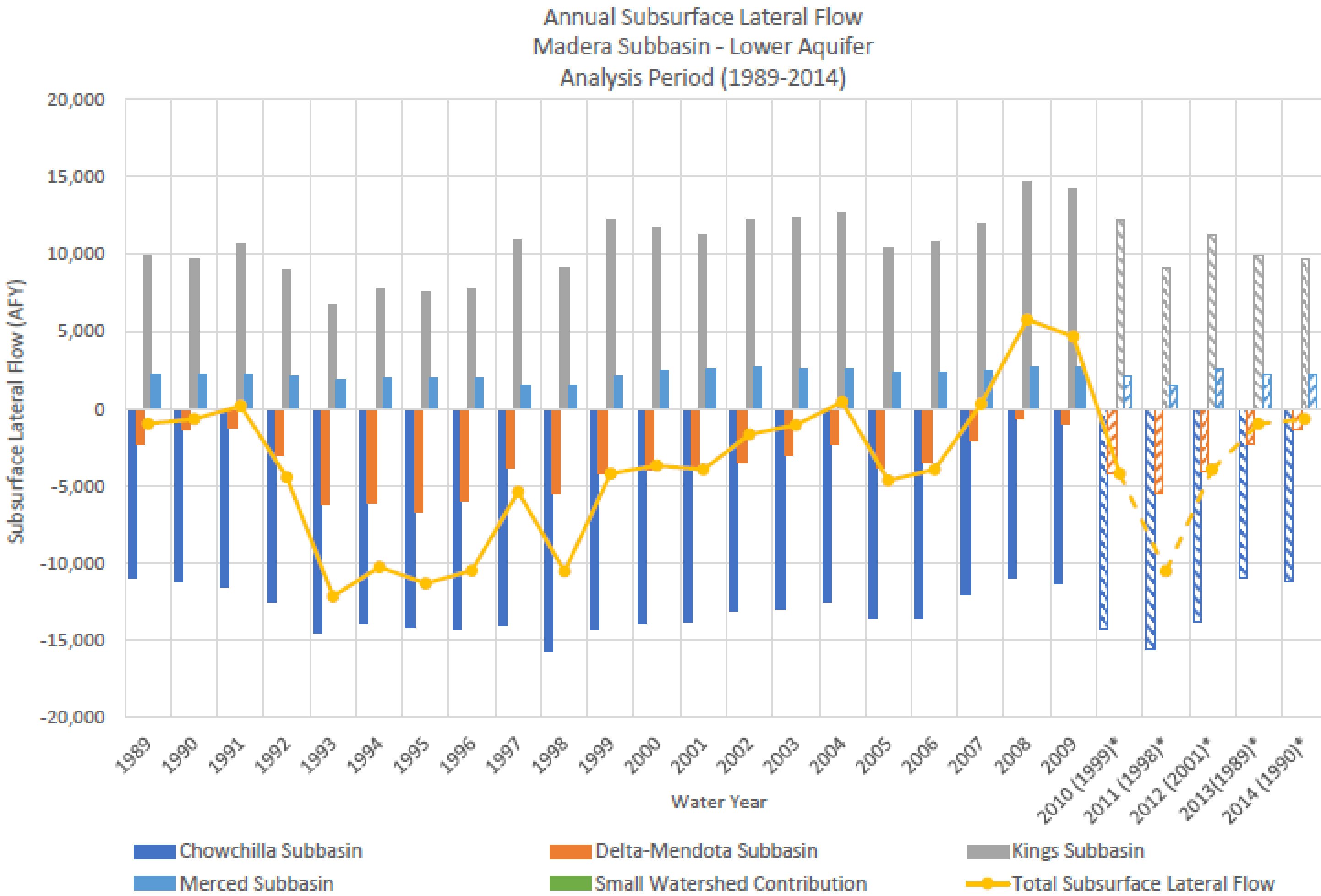

**Results presented for years 2010-2014 are from substitue years indicated in parentheses.*
NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.
The C2VSim-CG simulation period ends in 2009; dashed lines are used for 2010-2014 where results for substitued years are presented.

FIGURE 6-20
Preliminary Model-Based Results for Annual Subsurface Lateral Flow - Lower Aquifer

Table 6-9
Preliminary Summary ofC2VSim Model-Based Results for Annual Subsurface Lateral Flow (AFY)

Water Year	Chowchilla Subbasin	Delta-Mendota Subbasin	Kings Subbasin	Merced Subbasin	Small Watershed Contribution	Total Lateral Flow
1989	-16,560	2,219	23,232	3,161	3,358	15,410
1990	-15,904	3,204	21,148	3,155	2,483	14,086
1991	-16,026	2,521	24,200	3,001	4,190	17,885
1992	-16,788	347	21,768	2,999	3,932	12,257
1993	-19,698	-2,052	21,909	2,196	8,715	11,069
1994	-17,604	-1,767	23,797	2,951	2,791	10,168
1995	-16,813	-951	24,645	2,860	8,817	18,558
1996	-17,165	334	24,807	2,675	5,986	16,637
1997	-15,088	2,851	33,512	-956	8,812	29,131
1998	-20,319	321	30,182	-798	12,098	21,485
1999	-19,080	2,157	34,573	1,375	3,400	22,425
2000	-18,011	2,061	32,589	2,999	6,961	26,598
2001	-17,227	2,035	29,804	3,701	4,753	23,066
2002	-16,130	2,638	30,786	4,027	3,603	24,924
2003	-15,648	3,334	31,114	4,083	4,136	27,020
2004	-14,612	4,404	32,846	3,921	3,290	29,848
2005	-15,856	3,203	31,750	3,675	8,143	30,915
2006	-14,433	3,982	34,714	3,169	7,572	35,004
2007	-13,423	5,082	31,804	3,310	1,892	28,664
2008	-12,289	6,488	36,997	4,055	3,605	38,856
2009	-12,916	5,826	35,122	4,273	2,296	34,601
2010 (1999)*	-19,080	2,157	34,573	1,375	3,400	22,425
2011 (1998)*	-20,319	321	30,182	-798	12,098	21,485
2012 (2001)*	-17,227	2,035	29,804	3,701	4,753	23,066
2013 (1989)*	-16,560	2,219	23,232	3,161	3,358	15,410
2014 (1990)*	-15,904	3,204	21,148	3,155	2,483	14,086
ANALYSIS PERIOD (1989-2014)						
Average	-16,565	2,237	28,855	2,709	5,266	22,503
Minimum	-20,319	-2,052	21,148	-956	1,892	10,168
Maximum	-12,289	6,488	36,997	4,273	12,098	38,856
WET PERIOD (1990-1998)						
Average	-17,267	534	25,107	2,009	6,425	16,808
Minimum	-20,319	-2,052	21,148	-956	2,483	10,168
Maximum	-15,088	3,204	33,512	3,155	12,098	29,131
AVERAGE PERIOD (1999-2010)						
Average	-15,725	3,614	33,056	3,330	4,421	28,696
Minimum	-19,080	2,035	29,804	1,375	1,892	22,425
Maximum	-12,289	6,488	36,997	4,273	8,143	38,856
DRY PERIOD (2011-2014)						
Average	-17,503	1,945	26,092	2,305	5,673	18,512
Minimum	-20,319	321	21,148	-798	2,483	14,086
Maximum	-15,904	3,204	30,182	3,701	12,098	23,066

*Results presented for years 2010-2014 are from substitute years indicated in parentheses.

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Based on an evaluation of the C2VSim-CG results, the subsurface lateral flow in the Upper Aquifer consistently occurs as an inflow throughout the analysis period and is dominated by inflow from the Kings Subbasin (**Figure 6-19**). Inflow from the Delta-Mendota Subbasin also occurs within the Upper Zone, but it is typically much less than from the Kings Subbasin. Subsurface lateral flows between the Madera and Chowchilla Subbasins typically occur as outflows within the Upper Aquifer. On average, a very small amount of subsurface lateral inflow comes from the Merced Subbasin within the Upper Aquifer; and during some years (e.g., 1997, 1998, 1999), the flow between the Madera and Merced Subbasin occurs as an outflow from the Madera Subbasin.

Over the entire analysis period there is a net subsurface lateral inflow to the Madera Subbasin within the Upper Aquifer averaging about 26,000 AFY and ranging from about 14,000 AFY to about 39,000 AFY. During the wet hydrologic period, subsurface lateral flow in the Upper Aquifer averaged a net inflow of nearly 24,000 AFY with values ranging from approximately 15,000 AFY to 35,000 AFY. During the dry period, subsurface lateral flows in the Upper Aquifer ranged from net inflows of about 14,000 AFY to 32,000 AFY with an overall average of nearly 23,000 AFY. During the average hydrologic period, subsurface lateral flow in the Upper Aquifer occurred as generally higher net inflows to the Madera Subbasin with inflows ranging from about 27,000 AFY to 39,000 AFY and averaging nearly 30,000 AFY.

The subsurface lateral flow in the Lower Aquifer is typically a net outflow from the Madera Subbasin; however, over the analysis period, subsurface lateral flows in the Lower Aquifer between the Madera Subbasin and the Kings and Merced Subbasins both occur as net inflows to the Madera Subbasin (**Figure 6-20**). In contrast, subsurface lateral flow in the Lower Aquifer between the Madera and Chowchilla Subbasins generally represents a considerable outflow component from the Madera Subbasin, while the Delta-Mendota Subbasin also typically receives outflow from the Madera Subbasin in the Lower Aquifer, although at much lesser rates than Chowchilla Subbasin. Annual subsurface lateral flow in the Lower Aquifer averages about 3,800 AFY of outflow over the analysis period with a range of about 12,000 AFY of outflow to about 6,000 AFY of inflow. During the wet hydrologic period subsurface lateral flow in the Lower Aquifer was always negative indicating outflow, with an average outflow from the Madera Subbasin of about 7,200 AFY. Over the average and dry hydrologic periods, the subsurface lateral flow in the Lower Aquifer represented on average a small outflow from the Madera Subbasin of about 1,300 and 4,000 AFY, respectively. Within each of these hydrologic periods, there was considerable variability in magnitude and nature (inflow versus outflow) of the subsurface lateral flow values in the Lower Aquifer (**Figure 6-20**).

Subsurface inflows to the Madera Subbasin from small watershed contributions average about 5,300 AFY over the analysis period and range from about 2,000 to 12,000 AFY. Small watershed contributions are highest during the wet period (averaging 6,400 AFY) with lower subsurface inflows from small watershed contributions during the dry (about 5,700 AFY) and average (about 4,400 AFY) hydrologic periods (**Figure 6-21**). All of the subsurface inflows from small watershed contributions occur within the Upper Aquifer.

6.3.3 Summary of Subsurface Lateral Flows Analysis

Because of the variable quality and timing of available groundwater level data highlighted above, and the resulting potential for biasing subsurface lateral flow calculations based on discrete snapshots of groundwater level conditions, the model-based results derived from C2VSim-CG were considered as more likely to represent reasonable estimates of subsurface lateral flows. Additionally, the model-based results account for simulated subsurface lateral flows from adjacent small watersheds, which are difficult to estimate using the calculation method based on groundwater levels. Considering the challenges with implementing the calculation method in conjunction with the model-based results for subsurface lateral flows from the adjacent subbasins and the adjacent watersheds to the east, the overall historical subsurface lateral flows to and from the Madera Subbasin over the analysis period 1989-2014 are estimated be in the range of 20,000 to 25,000 AFY as net inflow to the Subbasin. As noted above, this represents an estimate of the aggregate historical net subsurface lateral flow into the Subbasin over the analysis period, although the subsurface lateral flows across the Subbasin boundary vary spatially and occur as both inflow and outflow exchanges with the different adjacent subbasins. It is also important to note that the subsurface lateral flow estimates presented are based on the analysis period 1989 to 2014 during which approximately -110,000 to -120,000 AFY of change in groundwater storage is estimated to have occurred. The depletion of this groundwater storage and the associated declines in groundwater levels over this period influence the historical subsurface flows. Under conditions of no change in groundwater storage, subsurface lateral flows would likely be different.

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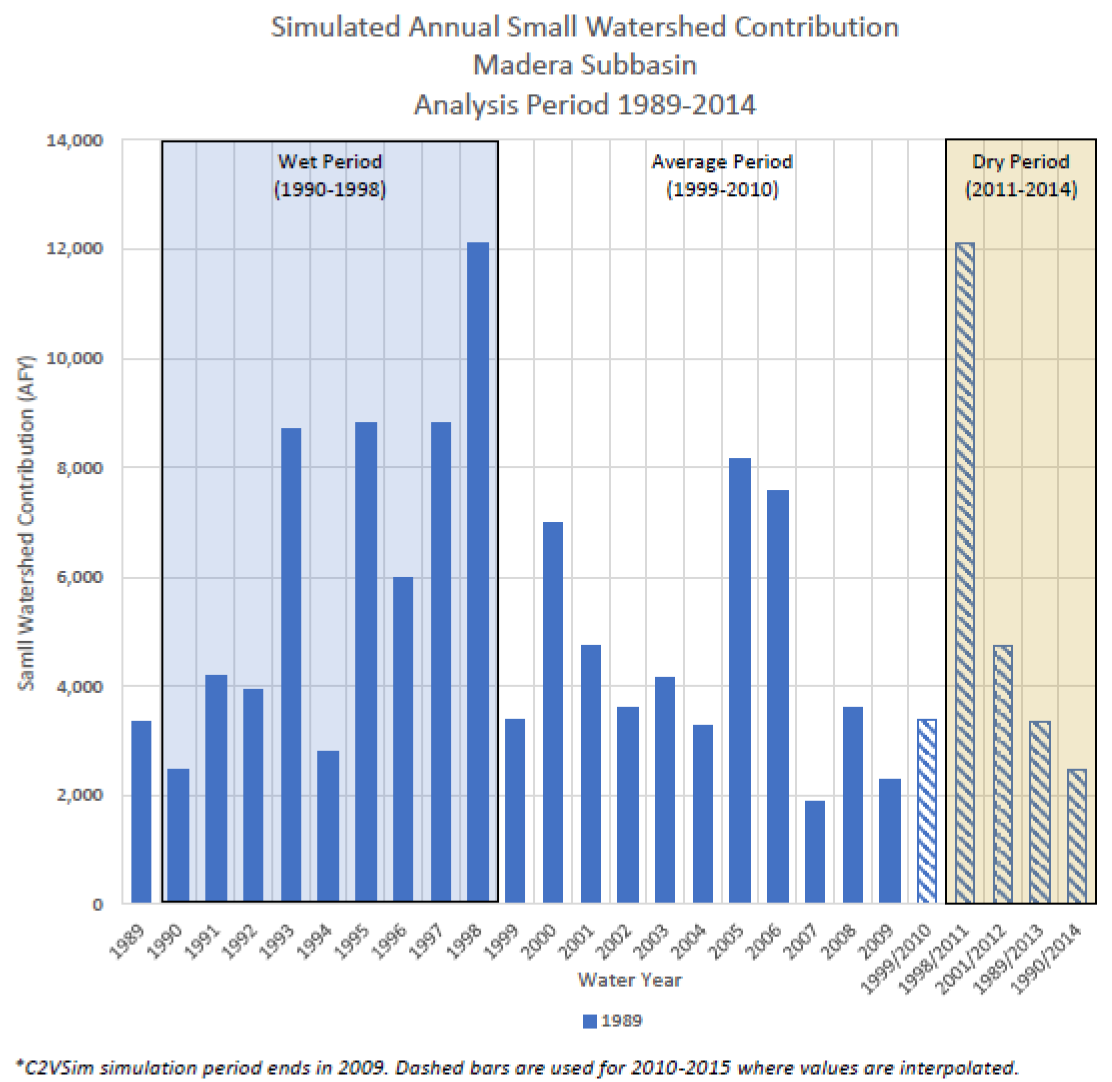

FIGURE 6-21
Preliminary Simulated Annual Small Watershed Contribution

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7 PRELIMINARY SUSTAINABLE YIELD ESTIMATES

This report estimates an initial Preliminary Sustainable Yield across the entire Madera Subbasin and does not quantify local variability, including the variability between the different GSAs. The preliminary sustainable yield for the overall Madera Subbasin will change once a more detailed analysis is performed. The GSP will quantify local variability among the individual GSAs.

Following completion of the water budget, preliminary estimates of sustainable subbasin pumping, or subbasin sustainable yield, were developed. The sustainable yield estimate derived from this analysis should be considered preliminary, as it does not fully account for surface water – groundwater interactions, groundwater dependent ecosystems (GDEs), and other SGMA-required components into the sustainable yield assessment. The sustainable yield assessment is largely based on the balance of recharge versus discharge components in conjunction with groundwater storage change estimates for the subbasin as a whole. In other words, undesirable results for sustainability indicators not accounted for in this preliminary analysis may lead to a lower sustainable yield estimate. While preliminary, this initial sustainable yield assessment does provide important initial insights regarding the magnitude of existing groundwater overdraft, and the scale of potential projects that may be needed to ultimately achieve sustainable subbasin operations.

The GSP Regulations require the water budget to quantify the sustainable yield for the basin. Sustainable yield under SGMA is defined 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” (CA Water Code 10721). According to DWR’s recently released Sustainable Management Criteria BMP (DWR, 2017), “Sustainable yield estimates are part of the SGMA’s required basinwide water budget” and “a single value of sustainable yield must be calculated basinwide.”

The applicable sustainability indicators for Madera Subbasin relative to undesirable results include groundwater levels, groundwater storage, subsidence, groundwater quality, and surface water depletion/GDEs. The evaluation of undesirable results will require more in-depth analysis during GSP development. Additionally, the preliminary sustainable yield estimate provided in this report does not include evaluation of the spatial distribution of pumping and recharge in relation to sustainability indicators.

Preliminary sustainable yield estimates that do not include an evaluation of the spatial distribution of pumping in relation to sustainability indicators were calculated using three methods. Each method used a different combination of water budget results.

The first methodology calculated sustainable yield as the water budget average annual groundwater pumping over the 1989 through 2014 analysis period minus the average annual change in groundwater storage over the same time period. The average annual change in groundwater storage was calculated independently from the water budget by using specific yield estimates and the observed changes in groundwater levels described in Section 6. Applying judgement based on experience with similar water budgets, confidence intervals were estimated for the input values and a confidence interval (CI) was calculated (Clemmens and Burt, 1997) for the preliminary sustainable yield resulting in a 95 percent CI between 253,900 and 349,100 AFY (**Table 7-1**).

Table 7-1
Preliminary Sustainable Yield Calculated from Groundwater Pumping and Change in Groundwater Storage

Inflow/Outflow	Quantification Method	Average Volume (AF)*	Estimated CI (percent)	*CI Source*	Average minus CI (AF)	Average plus CI (AF)
Average annual groundwater pumping	Calculation	416,500	10%	Professional Judgement.	374,900	458,200
Average annual change in groundwater storage	Calculation & model-derived value for the Lower Aquifer	115,000	20%	Professional Judgement.	92,000	138,000
Sustainable Yield	Calculation	**301,500**	16%	Calculation	**253,900**	**349,100**

*1989 through 2014

The second method totals all the groundwater inflows including groundwater inflows from the surface water system and the net groundwater inflow across the lateral boundaries of the groundwater system. This is the sum of the annual averages over the 1989 through 2014 analysis period of the total infiltration of precipitation (often referred to as deep percolation of precipitation), total infiltration of surface water by source type (often referred to as seepage from lakes, streams, rivers and canals), and total infiltration of applied water by source type (often referred to as deep percolation of applied water from surface water and groundwater) net groundwater inflows. Again, applying judgement based on experience with similar water budgets, confidence intervals were estimated for the input values and a CI was calculated (Clemmens and Burt, 1997) for the preliminary sustainable yield estimate resulting in a 95 percent CI between 214,900 and 382,400 AFY (**Table 7-2**).

Table 7-2
Preliminary Sustainable Yield Calculated from Estimated Groundwater Inflows

Inflow	Quantification Method	Average Volume (AF)*	Estimated CI (percent)	*CI Source*	Average minus CI (AF)	Average plus CI (AF)
Average Infiltration of Precipitation	Calculation	50,400	25%	Professional Judgement.	37,800	63,000
Average Infiltration of Surface Water**	Calculation	137,500	50%	Professional Judgement.	68,800	206,300
Average Infiltration of Applied Water	Calculation	87,800	50%	Professional Judgement.	43,900	131,700
Average net lateral Inflow to GWS	Calculation	22,500	50%	Professional Judgement.	11,300	33,800
Sustainable Yield	Calculation	**298,200**	28%	Calculation	**214,900**	**382,400**

*1989 through2014

** Includes seepage inflows from the San Joaquin River and Madera Canal

The third method reduced the ET_{aw} proportionately across all months, crops and years until the net groundwater recharge from the SWS discussed in the water budget section was increased to an average annual value of zero. The reduction in ET_{aw} resulted in a reduction in average annual groundwater pumping that increased the net groundwater recharge from the SWS. Again, applying judgement based on experience with similar water budgets, confidence intervals were estimated for the input values and a CI was calculated (Clemmens and Burt, 1997) for the preliminary sustainable yield resulting in a 95 percent CI between 242,500 and 363,700 AFY (**Table 7-3**).

Table 7-3
Preliminary Sustainable Yield Calculated from Simulation for Net Recharge from the SWS Equal to Zero

Inflow/Outflow	Quantification Method	Average Volume (AF)*	Estimated CI (percent)	CI Source	Average minus CI (AF)	Average plus CI (AF)
Sustainable Yield**	Calculation	**303,100**	20%	Professional Judgement.	**242,500**	**363,700**

*1989 through 2014
**Estimated average annual groundwater pumping with net recharge from the SWS equal to zero

The results of all three methods are similar in magnitude with the first method having the smallest CI (**Table 7-4**). The second and third methods depend on the water budget results and thus, may not be completely independent. These results will be refined during the upcoming GSP development. This discussion re-emphasizes the importance of including all the inflow and outflow volumes as accurate as economically possible.

Table 7-4
Preliminary Summary of Sustainable Yield Calculation Results

Quantification Method	Average Volume (AF)*	Estimated CI (percent)	CI Source	Average minus CI (AF)	Average plus CI (AF)
GW pumping and GW Change in Storage	301,500	16%	Calculation	253,900	349,100
Total Inflows to GWS	298,200	28%	Calculation	214,900	382,400
"Simulation" of Reduced Demand	303,100	20%	Professional Judgement.	242,500	363,700

*1989-2014

8 POTENTIAL MANAGEMENT AREAS

Potential management areas were considered in relation to hydrogeologic features and jurisdictional boundaries, and some options are presented. Based on review of the preliminary HCM, the key hydrogeologic features of Madera Subbasin include the extent of Corcoran Clay and the extent/magnitude of historical subsidence. The key jurisdictional boundaries to consider are the GSA boundaries. It should be noted that regardless of the ultimate decision made by the GSAs regarding boundaries for management areas, individual water budgets can be conducted for each GSA to provide greater insight on water inflows and outflows at the GSA boundary scale.

The extent of Corcoran Clay is limited to approximately the western third of Madera Subbasin (**Figure 8-1**). The presence of the Corcoran Clay is significant with respect to potential for subsidence and confinement of the Lower Aquifer. These factors may be important in terms of sustainability indicators and the nature of projects and/or management actions that may ultimately be required to reach sustainable yield. In terms of sustainability indicators, potential for future subsidence is likely to require more attention in areas where Corcoran Clay is present. Lower Aquifer confinement may influence the viability of certain projects and/or management actions.

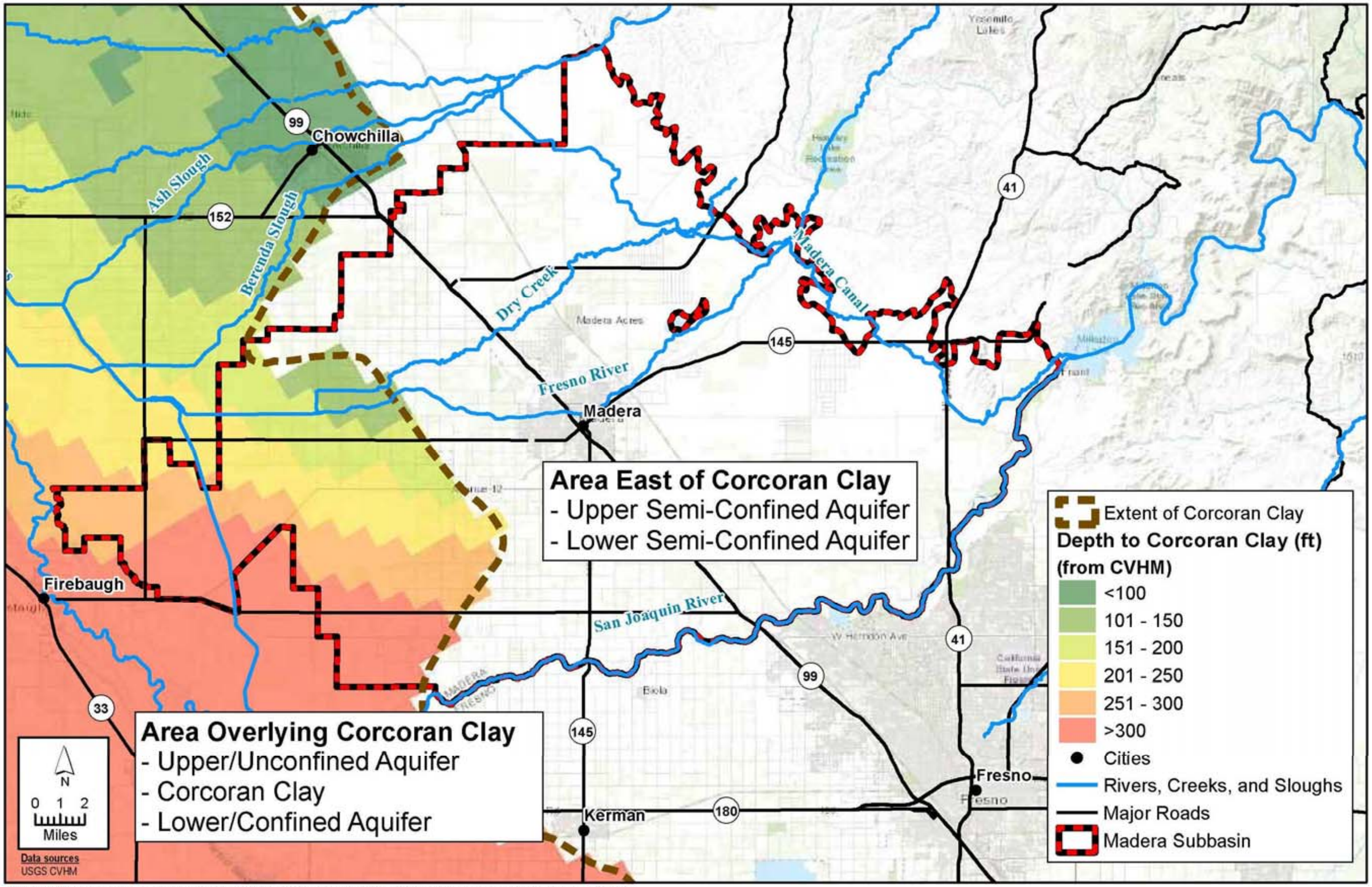
The distribution and magnitude of recent subsidence is shown on **Figure 8-2**. It is a function of both the presence of Corcoran Clay and the center of recent subsidence being to the northwest in the Chowchilla Subbasin. LSCE, Borchers, and Carpenter (2014) note that this has resulted in some recent subsidence of 0.5 to 1 foot in the northwestern most portion of the Madera Subbasin. The main cause of the subsidence appears to be groundwater pumping in the western portion of Chowchilla Subbasin; however, it is not known if groundwater pumping in the northwest portion of Madera Subbasin is a contributing factor.

One potential option to consider for management areas that involves consideration of both hydrogeologic factors and GSA boundaries would involve delineation of three management areas in the western, central, and eastern portions of the subbasin (**Figure 8-3**). The western management area would encompass the area where Corcoran Clay is present and the area of the subbasin most impacted by historical subsidence. GSAs in the western area include all of Gravelly Ford WD, all of New Stone WD, portions of Madera County, and portions of MID. The central management area would be immediately east of the Corcoran Clay and has shown minimal historical subsidence. The City of Madera GSA is entirely contained in the central area, but the majority of the central area is occupied by the MID GSA. The potential eastern area is far removed from the Corcoran Clay and any significant subsidence concerns. It includes all of Madera WD GSA and Root Creek WD GSA, but the majority of the eastern area lands are part of Madera County GSA.

A second potential option is to have management areas based solely on GSA boundaries with no consideration of hydrogeologic factors (**Figure 8-4**). This option would result in non-contiguous management areas given the nature of GSA boundaries. The potential advantages of using GSA boundaries to delineate management areas include: each GSA will have a better understanding of its own particular Basin Setting (e.g., geologic conditions, water budget, groundwater conditions), responsibilities for the overall basin water budget deficit will be clearer (although this could be accomplished regardless of selected management areas), each GSA will have primary responsibility for establishing and monitoring its minimum thresholds and measurable objectives, and each GSA could potentially to focus on projects/management actions most suited to its management area. The potential disadvantages of using GSA boundaries to delineate management areas include: more challenges in establishing a representative monitoring network (e.g., may require a greater number of monitoring wells), need for monitoring and establishment of minimum thresholds for certain sustainability indicators (e.g., subsidence) in some portions of a management area but not in other portions of the same management area, and greater influence from adjacent management areas on the smaller portions of a given management area (e.g., monitoring results for sustainability indicators for one management area may be largely dependent on groundwater management in adjacent management areas).

There are other potential options for development of management areas, such as further subdivision of the three management areas under Option 1. However, it is suggested that the next step in the management area development process is further discussion among the GSAs regarding whether management areas might be designated other than strictly along lines of GSA boundaries (Option 2).

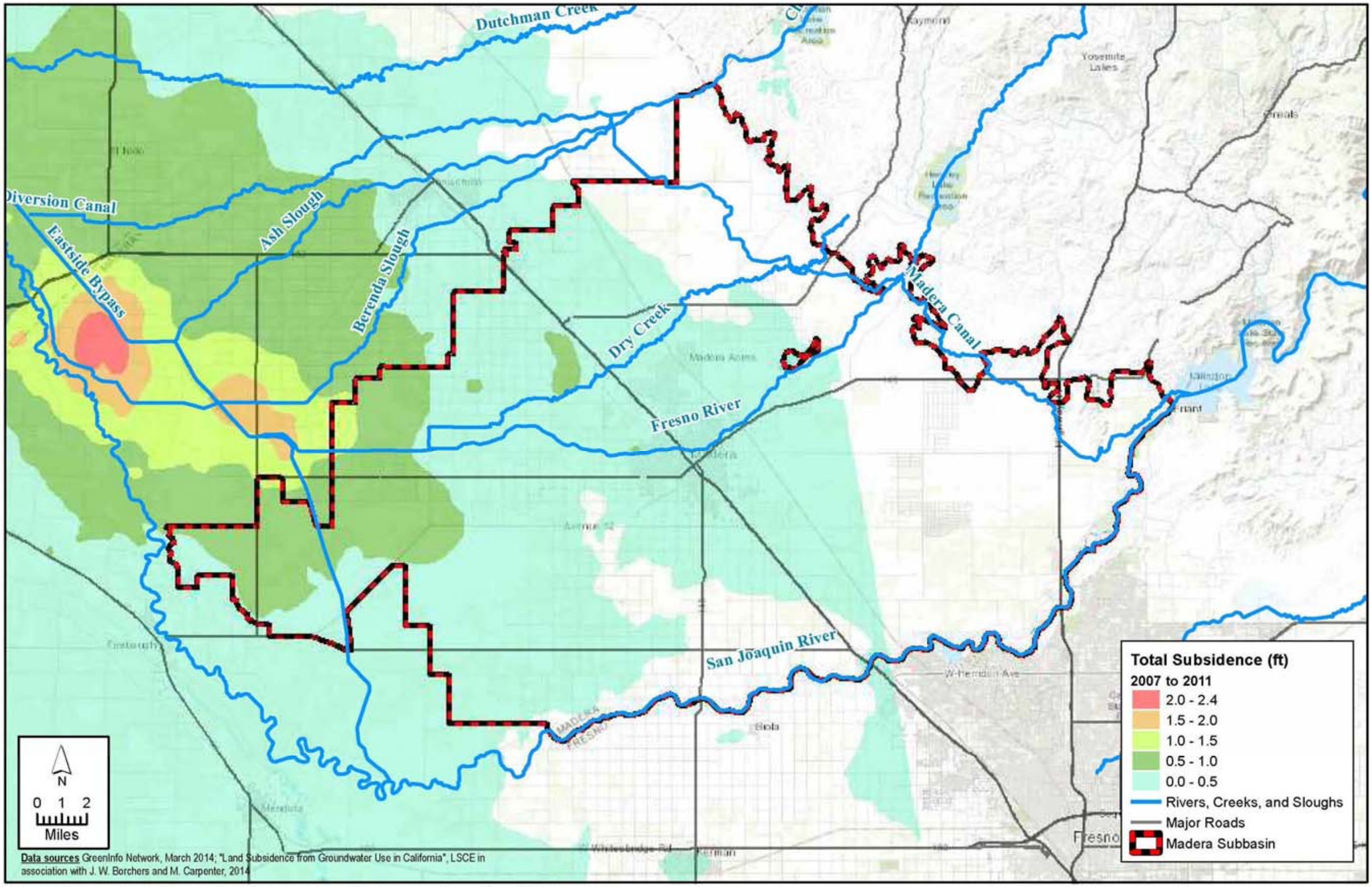
DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure 7-1 Depth to Top of Corcoran Clay.mxd

FIGURE 8-1
Preliminary Depth to Top of Corcoran Clay

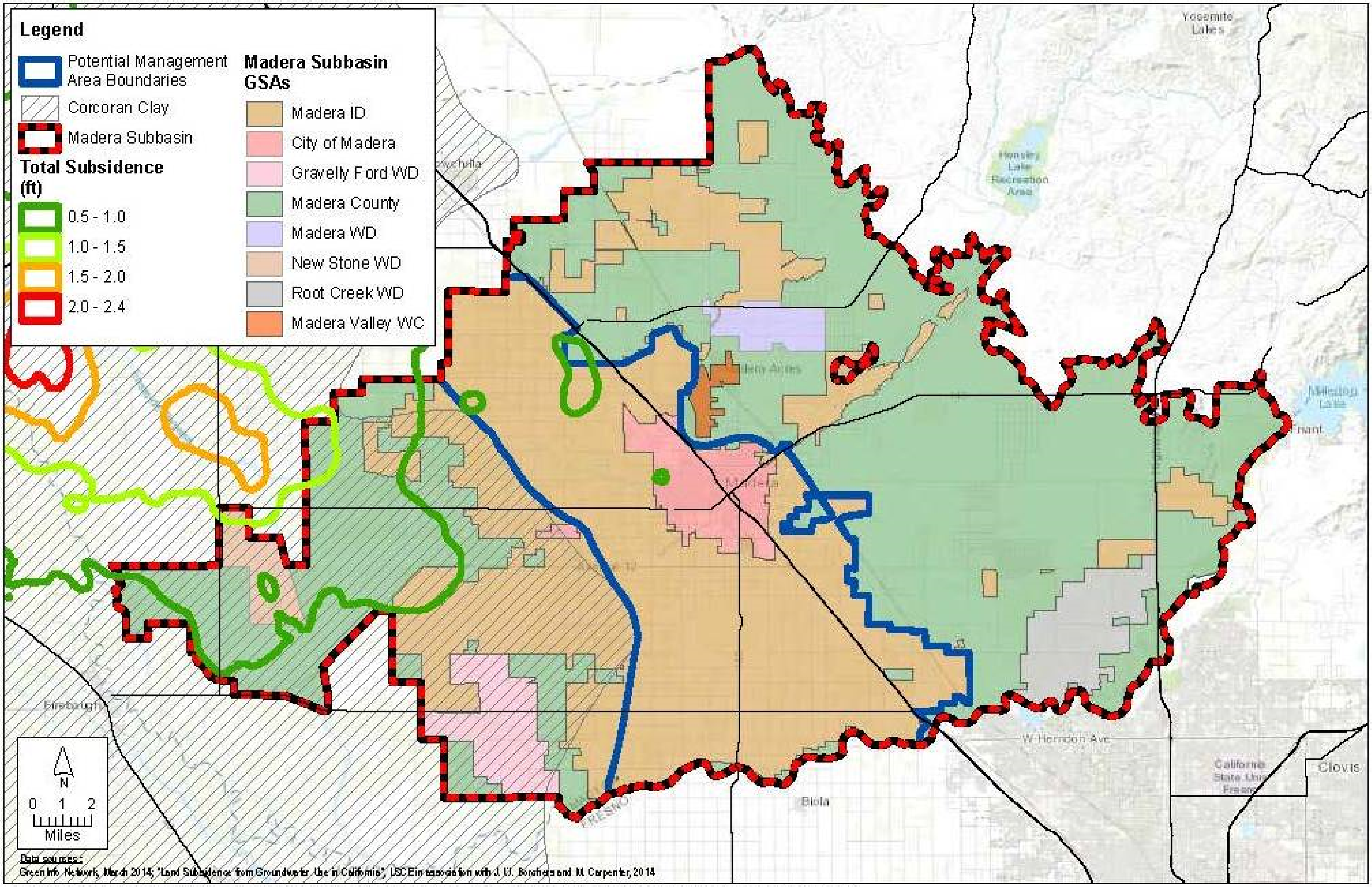
DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure 7-2 Map of Land Subsidence.mxd

FIGURE 8-2
Preliminary Map of Land Subsidence: 2007 through 2011

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.



X:\2017\17-090 Davids Engineering-Madera Co. - Madera Subbasin\Water Balance\GIS\Map Files\For TM\Figure 7-3 Potential Management Areas Based on Hydrogeologic Factors and GSA Boundaries.mxd

FIGURE 8-3
Preliminary Potential Management Areas Based on Hydrogeologic Factors and GSA Boundaries

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.

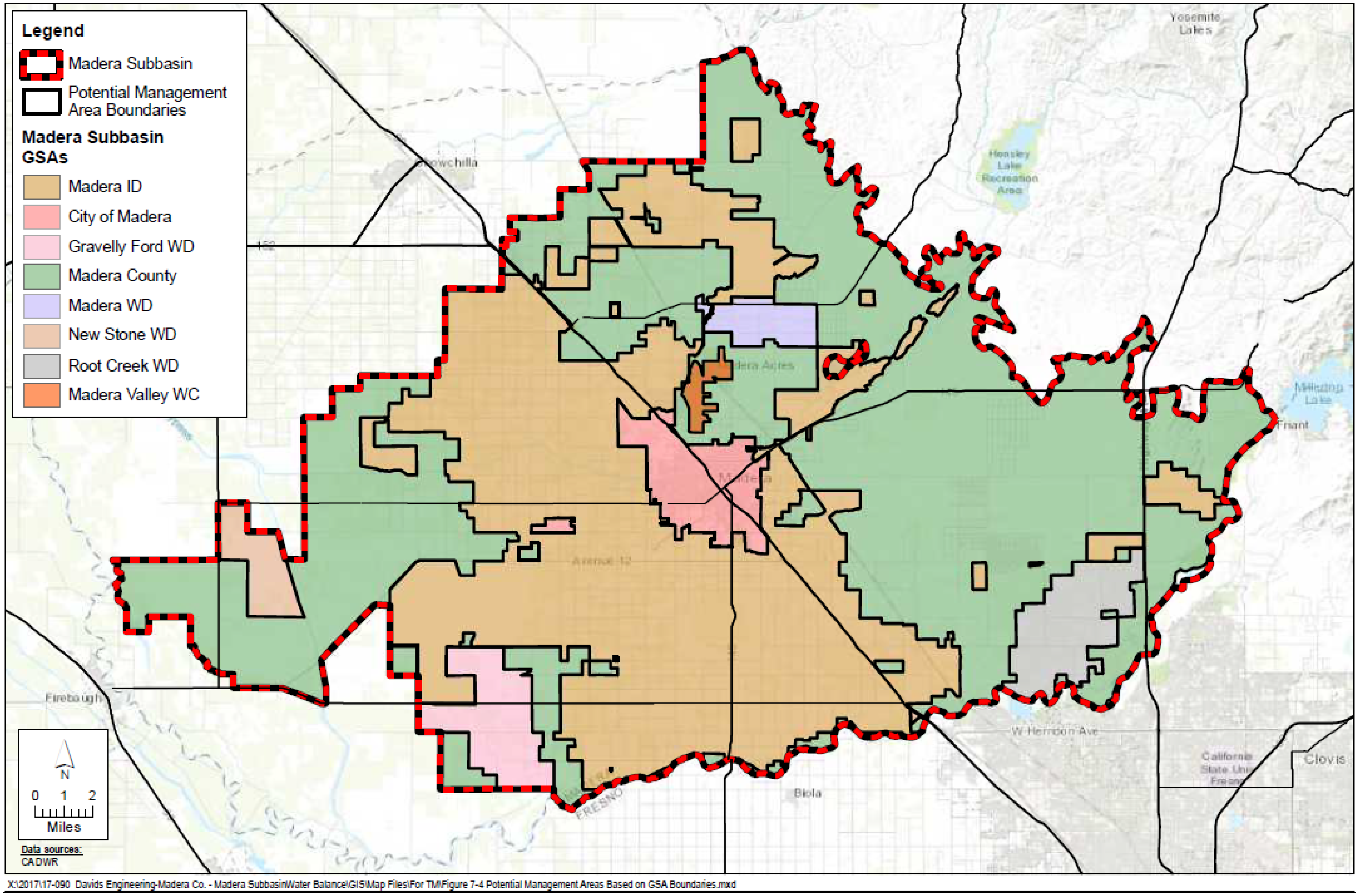


FIGURE 8-4
Preliminary Potential Management Areas Based on GSA Boundaries

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Appendix A

Daily Reference Evapotranspiration and Precipitation Quality Control

November 2017

Purpose

The purpose of this report is to describe the development of daily reference evapotranspiration (ET_{ref}) and precipitation values for water years 1989 through 2015 for use to determine consumptive use of irrigation water. The Study Area is the Madera groundwater basin.

This report describes the methodology for developing ET_{ref} and precipitation records, the results and the findings.

Methodology

Scientifically sound and widely accepted methods for determining consumptive use of irrigation water utilize daily ET_{ref} determined using the standardized Penman-Monteith (PM) method as described by the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005). The PM method requires measurements of incoming solar radiation (R_s), air temperature (T_a), relative humidity (RH) and wind speed (W_s) at hourly or daily time steps. The task committee report standardizes the ASCE PM method for application to a full-cover alfalfa reference (ET_r) and to a clipped cool season grass reference (ET_o). The clipped cool season grass reference is widely used throughout the western United States and was selected for this application. Additionally, the Task Committee Report provides recommended methods for estimating required inputs to the standardized equation when measured data are unavailable. The remainder of this section describes an inventory of weather stations and available data, weather data quality control (QC), and the methods used to estimate ET_o.

Weather Data Inventory

Weather data from irrigated areas are needed to develop estimates of consumptive use of irrigation water. Automatic Weather Stations (AWS) provide measurements of R_s, T_a, RH and W_s over hourly or shorter periods used to compute ET_o. AWS data are often available from state extension services and weather station networks. Prior to the advent of the AWS, National Oceanic and Atmospheric Administration (NOAA) stations recorded daily minimum and maximum air temperatures and daily precipitation. Data from these NOAA stations are available from the National Centers for Environmental Information (NCEI) formerly National Climatic Data Center (NCDC).

In recent years, several gridded climate data sets have become available for public use. Daymet and PRISM (Parameter-elevation Relationships on Independent Slopes Model) are two of the more well-known data sets. The gridded estimates are developed by a collection of algorithms that interpolate and extrapolate from daily meteorological observations at available weather stations. Generally, the gridded estimates do not include all necessary parameters to calculate ET_o. PRISM[11] provides estimates for precipitation, daily maximum air temperature, daily minimum air temperature and daily average

[11] http://www.prism.oregonstate.edu/ accessed on November 2017.

dewpoint temperature by interpolating between weather stations based on the physiographic similarity of the station to the grid cell.

For developing ET_o values to use in determining crop water depletions, the weather data used must represent irrigated agriculture. This is because ET from irrigated areas in arid regions is generally lower than that from surrounding not irrigated areas. The evaporation process tends to both cool and humidify the near-surface boundary layer over irrigated fields. This cooling and humidifying effect tends to reduce ET rates, including the reference ET estimate, and should be considered when calculating reference ET. Weather stations used to develop the gridded data are from both irrigated and not irrigated areas. For this reason, AWS inside the irrigated area are the preferred source for weather data to calculate ET_o for use in determining consumptive use of irrigation water.

A complete inventory of weather stations both inside and near irrigated areas was conducted to select the most appropriate weather station, or stations, for the historical crop water consumptive use analysis.

Weather Data Quality Control

Accurate estimation of consumptive use of irrigation water requires accurate and representative weather data. Weather data from each station were reviewed and corrected when necessary, following accepted, scientific procedures (Allen, et al 1996, Allen, et al, 1998, ASCE-EWRI, 2005 and ASCE, 2016). Daily data obtained for the AWS stations were quality checked using spreadsheets and graphs of weather data parameters for analysis and application of quality control methods according to the guidelines specified in Appendix-D of the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005). Quality control procedures applied to R_s, T_a, RH and W_s are briefly described in the following sections.

Solar Radiation

Solar radiation data were quality controlled by plotting measured R_s and computed clear sky envelopes of solar radiation on cloudless days (R_{so}) for hourly or daily time steps (Allen, et al 1996, Allen, et al, 1998, ASCE-EWRI, 2005 and ASCE, 2016). Recommended equations for R_{so} that include the influence of sun angle, turbidity, atmospheric thickness, and precipitable water were used. The measured R_s should reach the clear sky envelope on cloud-free days. On cloudy or hazy days, the measured R_s will not reach the clear sky envelope. Measured R_s values that consistently fall above or below the curve indicate improper calibration or other problems, such as the presence of dust, bird droppings or something else on the sensor. Values for R_s that were found to be consistently above or below R_{so} on clear days were adjusted by dividing R_s by the average value of R_s/R_{so} on clear days at intervals of 60-day groupings for daily data and 30-day periods for hourly data. The values resulting from these adjustments were carefully reviewed for reasonableness of the adjustments.

Air Temperature

Air temperature is the simplest weather parameter to measure and the parameter most likely to be of high quality (Allen, et al 1996, Allen, et al, 1998, ASCE-EWRI, 2005 and ASCE, 2016). Nevertheless, daily maximum and minimum air temperatures were plotted together vs. time, and the extreme values were compared against historical extremes. Temperatures that consistently exceed the recorded extremes for a region may indicate a problem with the sensor or environment and may need to be adjusted based on air temperatures collected at a nearby station.

Relative Humidity

Daily maximum and minimum relative humidity values were plotted and examined for values chronically lower than five to ten percent and values that were consistently over 100 percent (Allen, et al 1996, Allen, et al, 1998, ASCE-EWRI, 2005 and ASCE, 2016). Additionally, relative humidity was checked on days having recorded rainfall to confirm that the measured maximum RH values approached 90 to 100 percent. Where necessary, reasonable adjustments such as setting all values above 100 percent equal to 100 percent were made.

Wind Speed

Wind speed records were plotted and visually inspected for consistently low wind speed values (Allen, et al 1996, Allen, et al, 1998, ASCE-EWRI, 2005 and ASCE, 2016). Low wind speeds can indicate dirty or worn anemometer bearings that lead to failure of the anemometer. Any period of more than thirty days with wind speeds below 1.0 meters per second was compared to available nearby stations and, if the wind speed at the nearby station did not indicate a period of unusually low wind speeds, adjusted based on the nearby station.

Results

This section describes the results of an inventory of weather stations and available data, weather data quality control, and ET_o estimates.

Weather Station Inventory

Table A-1 lists the stations and time periods used for the Madera Subbasin weather data.

Table A-1. Madera Subbasin Weather Data Time Series Summary for the period 1989 through 2015

Weather Station	Start Date	End Date	Comment
Fresno State (#80)	Oct. 2, 1988	May 12, 1998	AWS. Before Madera was installed.
Madera (#145)	May 13, 1998	Apr. 2, 2013	AWS. Moved East 2 miles and renamed “Madera II”
Madera II (#188)	Apr. 3, 2013	Dec. 31, 2015	AWS

Weather Data Quality Control

Hourly checks and necessary adjustments performed on AWS station data and daily checks are described in the following sections. However, the following sections only include examples of common data adjustments observed in the quality-controlling process. A complete list of adjustments can be found in Attachment A.

Solar Radiation

CIMIS AWS solar radiation data were generally of good quality, but it was apparent that some records required adjustment to fall within reasonable bounds. Two different types of quality control were performed on the solar radiation data. First, there are time periods in certain years where there is an obvious drop or rise in solar radiation values which cause them to fall significantly above or below the expected values. One instance of an unreasonable, sudden drop in solar radiation occurred in 1996 at the Madera CIMIS station. This is displayed in Figure A-1 below. This data was then adjusted up by a factor of 1.08, and the calibrated data is displayed in Figure A-2 below.

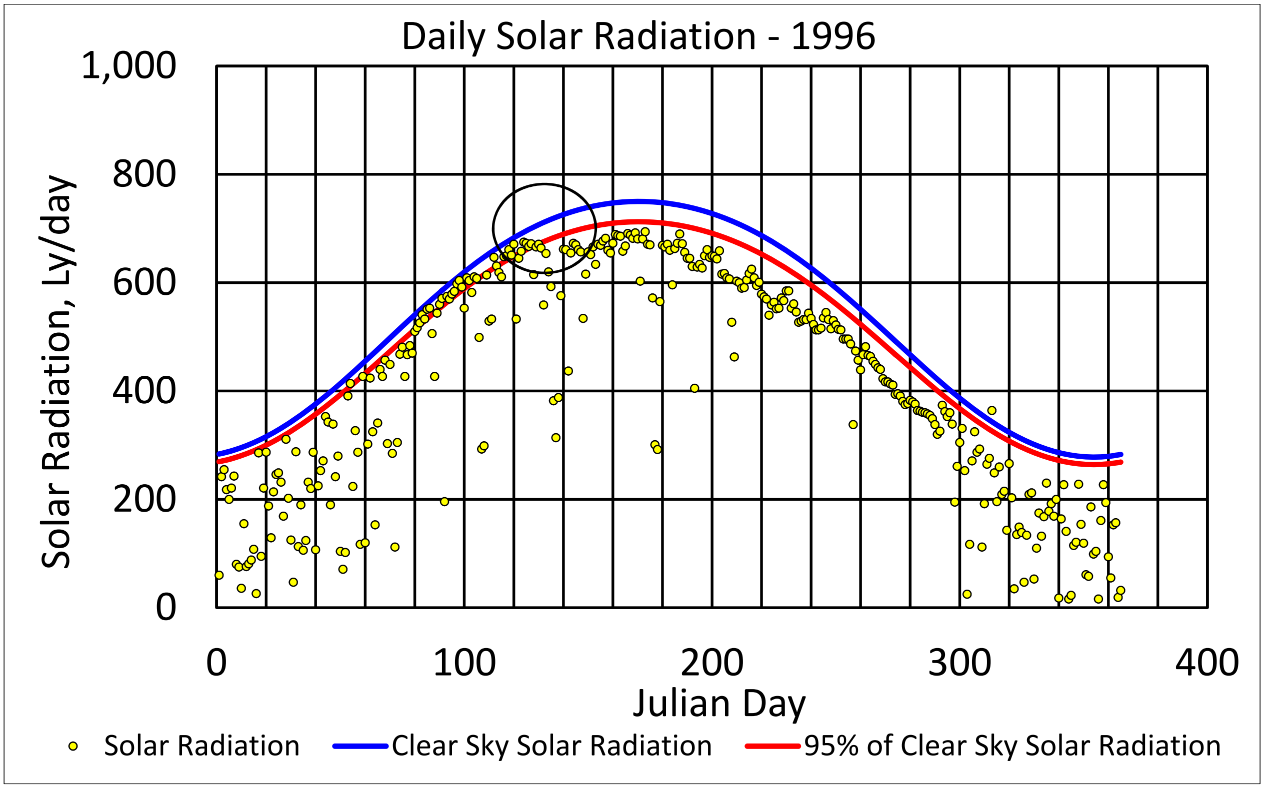

Figure A-1: Daily Solar Radiation (Ly/day) for Madera CIMIS station (#145) for 1996 before QC

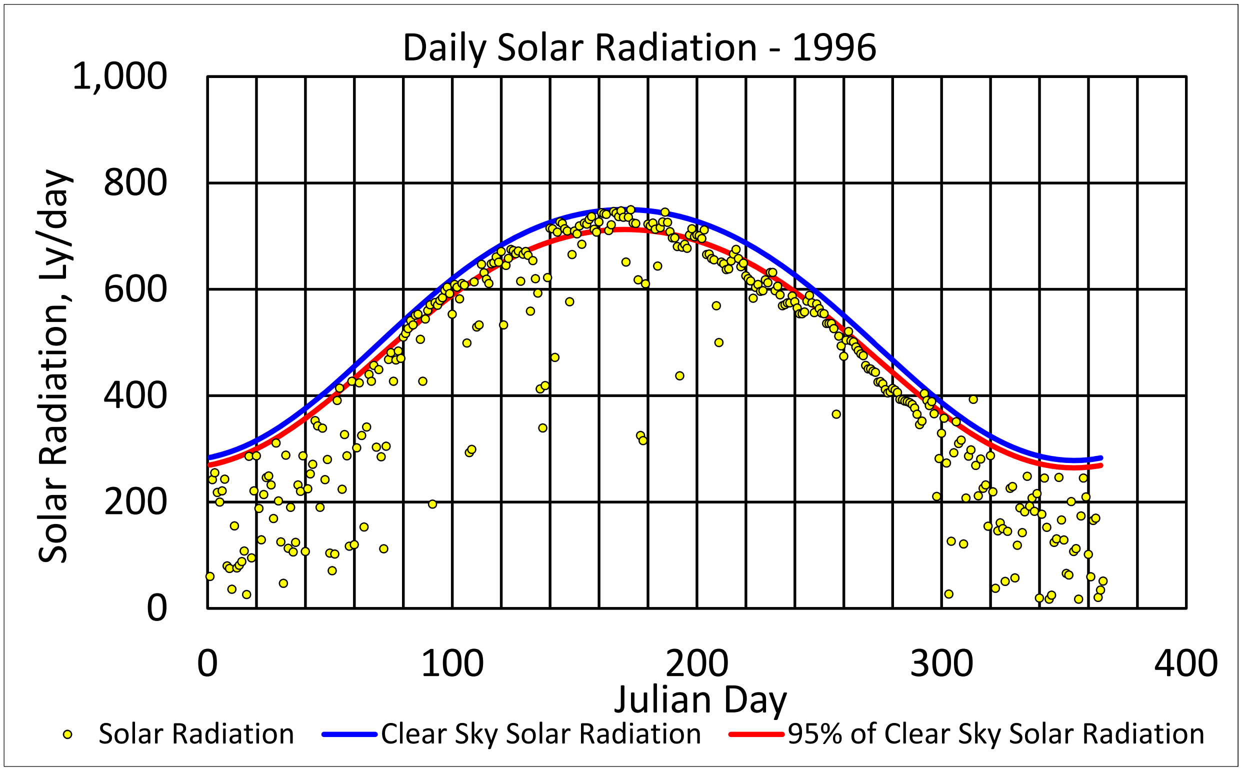

Figure A-2: Daily Solar Radiation (Ly/day) for Madera CIMIS station (#145) for 1996 after QC

Air Temperature

For the most part, CIMIS AWS air temperature data were consistent and followed expected values and behavior. However, adjustments were applied to some data points to more closely reflect the expected temperatures within the seasons for each year. There were two common problems observed within this parameter: missing data points and minimum temperatures automatically being assigned a value of 32 degrees Fahrenheit. The latter is made obvious by the season in which the data points reside, and the difference between this point and those immediately before and after. Examples of both issues are displayed in Figure A-3. Missing data points were filled in with a value of the corresponding parameter from a nearby CIMIS station. The same process was applied to the points that were automatically set to 32 degrees Fahrenheit. The adjusted data can be observed in Figure A-4.

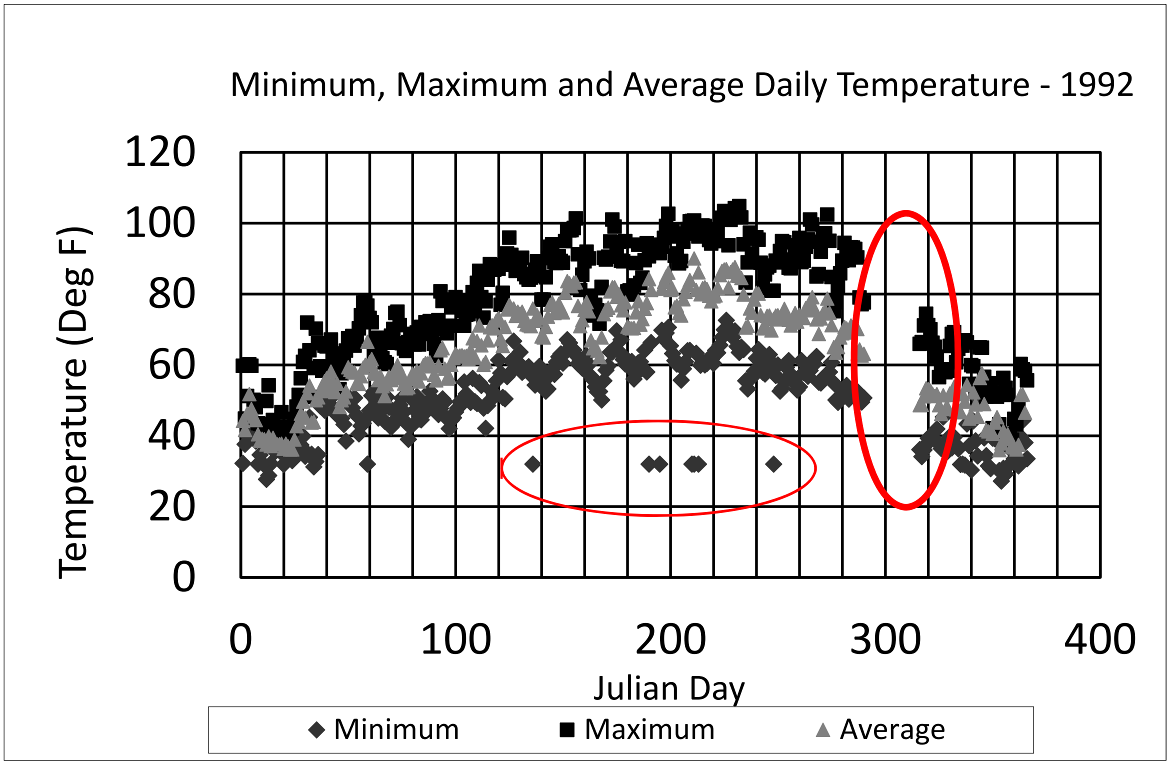

Figure A-3: Average, Maximum, and Minimum Daily Temperatures (DegF) for Fresno State CIMIS station (#80) for 1992 before QC

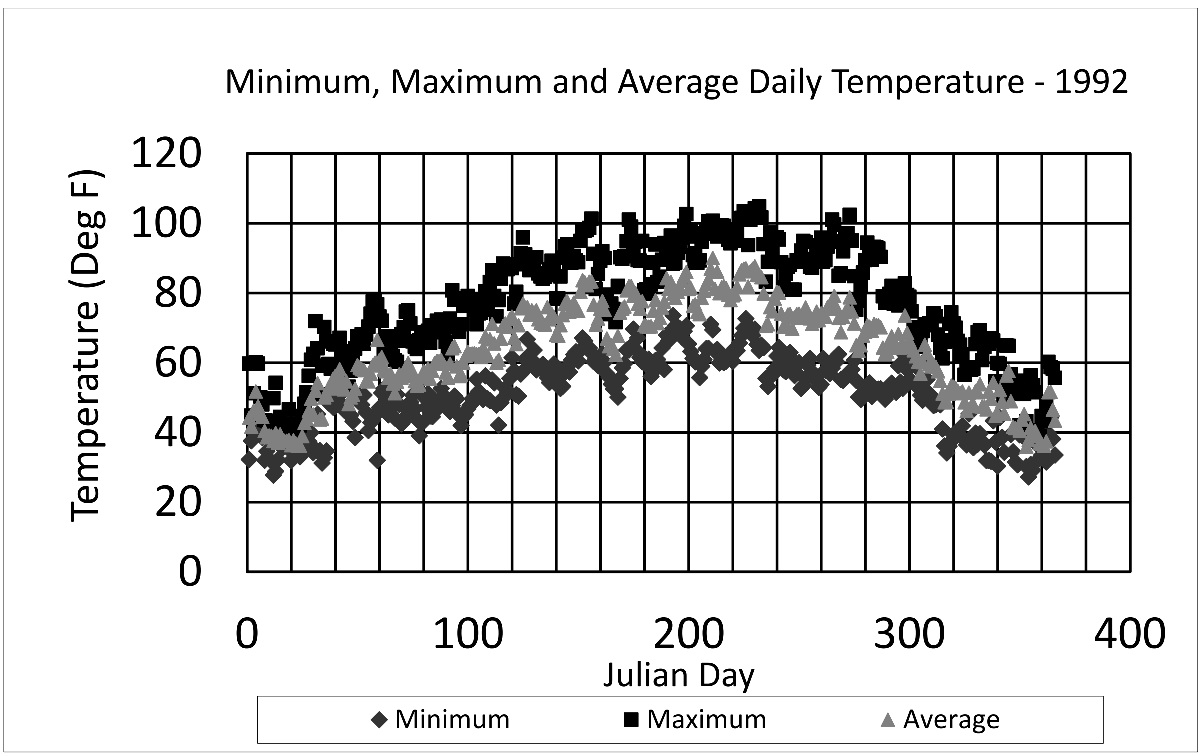

Figure A-4: Average, Maximum, and Minimum Daily Temperatures (DegF) for Fresno State CIMIS station (#80) for 1992 after QC

Relative Humidity

CIMIS AWS Relative Humidity (RH) data was analyzed for all of the time period and station combinations listed in Table A-1 above and the necessary adjustments were made. Maximum RH at night commonly approaches 60% during the summer period and 100% during the winter period. When values fall significantly below this expected range of values (Figure A-5), it can be concluded that the RH sensor is in need of calibration or to be replaced and the data need to be adjusted. In years when this trend was observed, such as for the Madera station in 2005, the data was adjusted (Figure A-6).

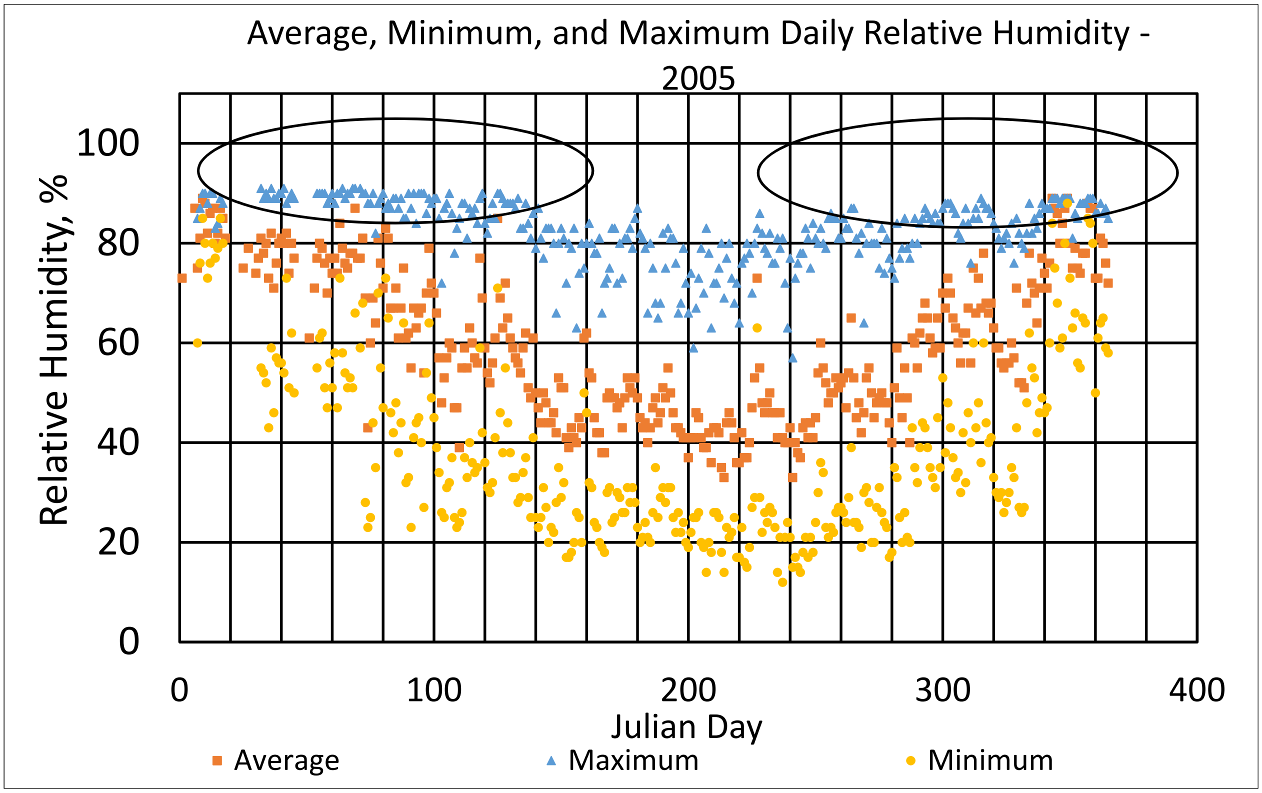

Figure A-5: Average, Max., and Min. Daily Temperature (DegF) for Madera CIMIS station (#145) for 2005 before QC

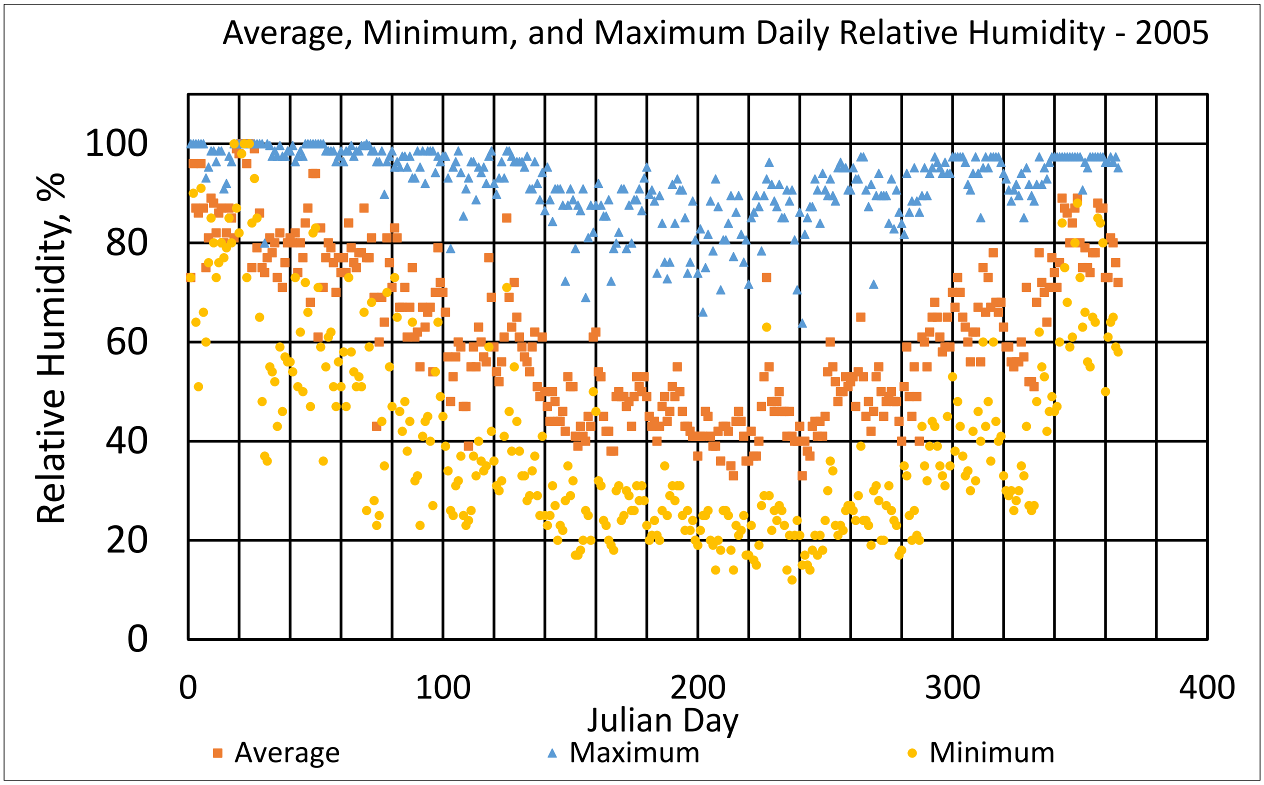

Figure A-6: Average, Max., and Min. Daily Temperature (DegF) for Madera CIMIS station (#145) for 2005 after QC

Wind Speed

CIMIS AWS wind speed data were generally reasonable and usually followed expected ranges and patterns, with lower values during nighttime and higher values during the day. To calculate ET_o, all hourly wind speed values less than 0.5 m/s were set to 0.5 m/s, following the recommendation in ASCE-EWRI (2005), Appendix E, to represent a floor on wind movement and equilibrium boundary layer stability effects in the Penman-Monteith equation. A graphical example of this quality-control as it is applied to Madera windspeed data in the year 2000, can be observed in Figures A-7 (unadjusted data) and A-8 (adjusted data).

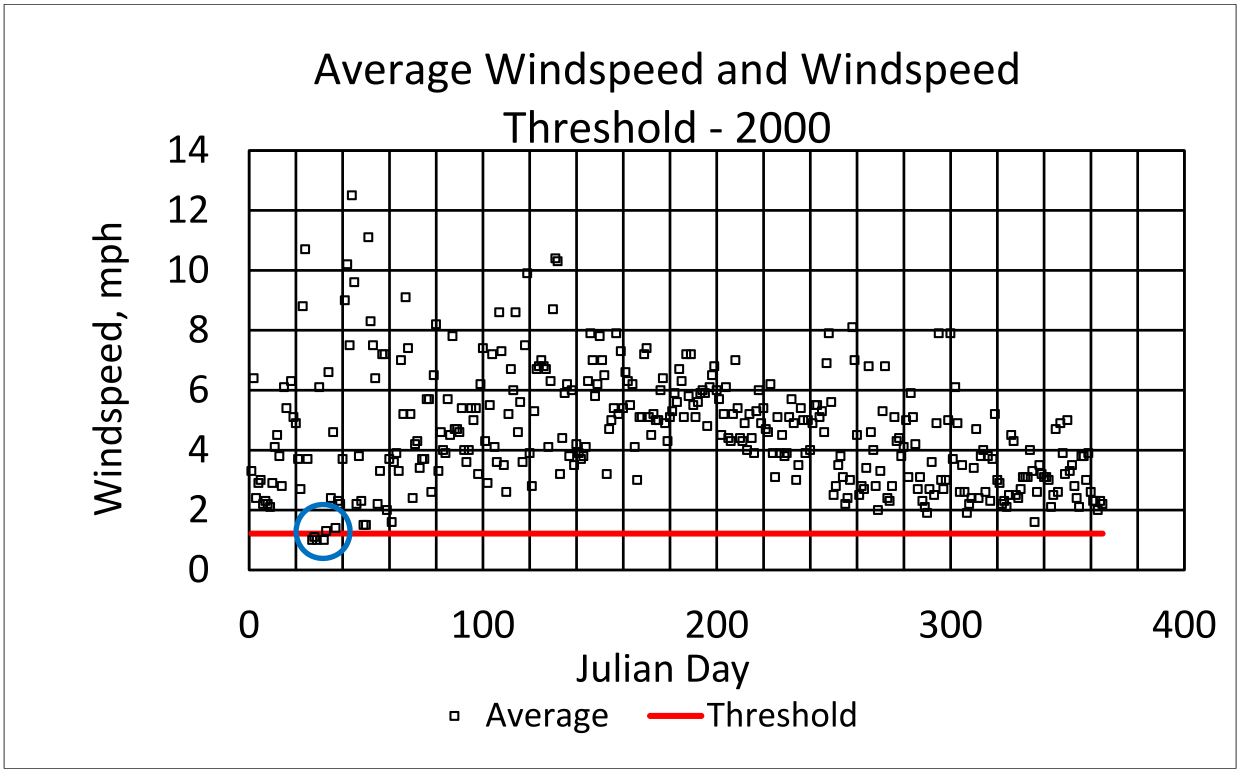

Figure A-7: Average Windspeed (mph) for Madera CIMIS station (#145) for 2000 before quality-controlling

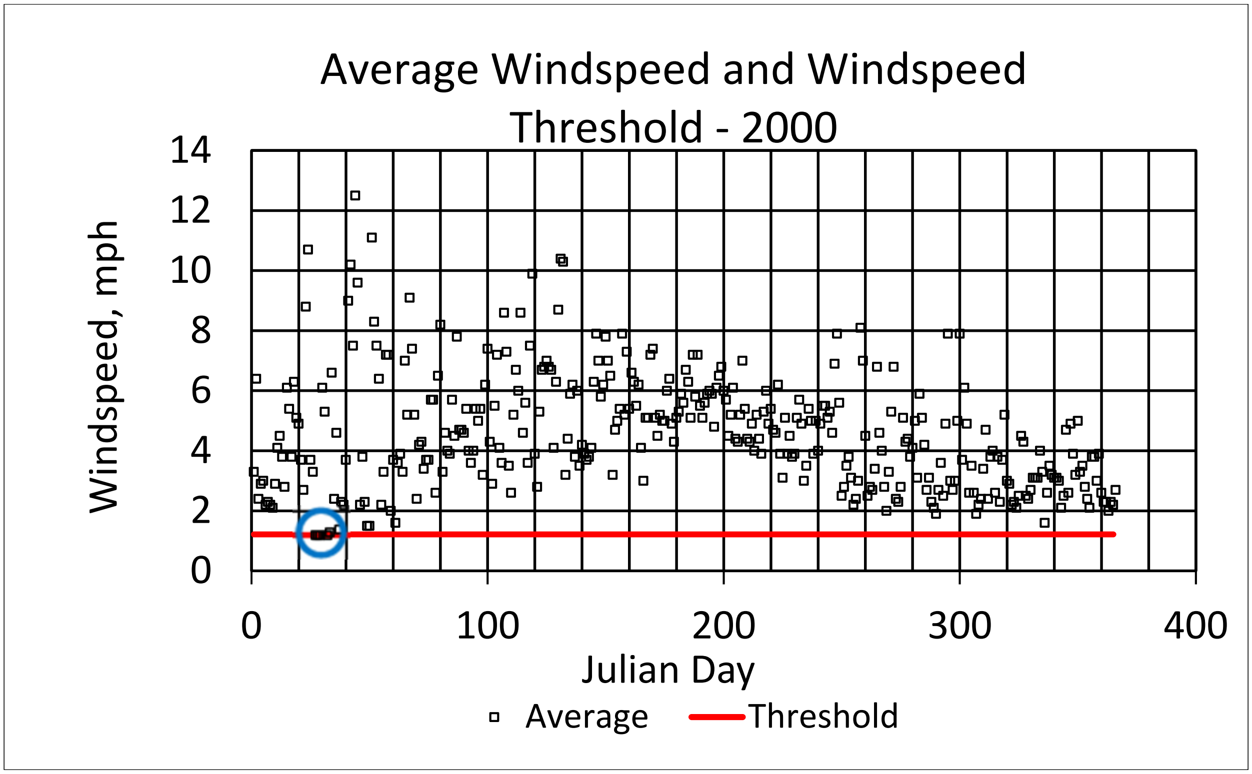

Figure A-8: Average Windspeed (mph) for Madera CIMIS station (#145) for 2000 after quality-controlling

ET_o Results Summary

The average water year ET_o for 1989 through 2015 was 55.34 inches and ranged from 50.64 inches in 1995 to 59.79 inches in 2004. This indicates that the differences in the average ET_o values computed from the weather data collected at the various stations (Table A-2) is most likely due to natural and expected variability in the record.

Table A-2. Weather Data Time Series Summary for the period 1989 through 2015

Weather Station	Start Date	End Date	Average Water Year ET_o, inches	Minimum Water Year ET_o, inches	Maximum Water Year ET_o, inches
Fresno State	Oct. 1, 1988	May 12, 1998	55.13	50.64 (1995)	59.27 (1992)
Madera	May 13, 1998	Apr. 2, 2013	55.67	52.56 (2011)	59.79 (2004)
Madera II	Apr. 3, 2013	Dec. 31, 2015	55.51	53.79 (2014)	57.24 (2015)
Overall	Oct. 2, 1988	Dec. 31, 2015	55.34	50.64	59.79

Water year ET_o totals for the complete 1989 through 2015 period are included in Appendix A.

Precipitation Results Summary

The 26-year average water year precipitation from 1989 through 2015, was 10.11 inches, varying from 3.59 inches in 2014 to 19.62 inches in 1995 (Table A-3).

Table A-3. Water Year Precipitation Statistics for 1989 through 2015

Weather Station	Start Date	End Date	Average Water Year Rainfall, inches	Minimum Water Year Rainfall, inches	Maximum Water Year Rainfall, inches
Fresno State	Oct. 1, 1988	May 12, 1998	12.76	9.14 (1994)	19.62 (1995)
Madera	May 13, 1998	Apr. 2, 2013	8.98	4.35 (2012	12.79 (2006)
Madera II	Apr. 3, 2013	Dec. 31, 2015	4.25	3.59 (2014)	4.90 (2015)
Overall	Oct. 2, 1988	Dec. 31, 2015	10.11	3.59 (2014)	19.62 (1995)

Water year rainfall totals for the complete 1989 through 2015 period are included in Attachment B.

FINDINGS

All weather stations in the Madera Subbasin are located in agricultural areas. Quality control and quality assessment protocols were followed with review of hourly data and necessary adjustments performed on AWS data and daily checks and necessary adjustments performed on NOAA data. In conclusion, the time period was of such duration that at some point each parameter needed some adjustment. Minor adjustments to short periods of the wind data were necessary at all three sites. Air temperature data were mostly acceptable with the exception of multiple errors in the minimum temperature values for individual points within each site. Regarding both solar radiation and relative humidity for each site, erroneous trends were noticed and corrected, though the adjustment factors generally remained minimal (under 5%).

The average water year ET_o for 1989 through 2015 was 55.34 inches. The 26-year average precipitation from 1989 to 2015, was 10.11 inches.

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Allen, R.G., Walter. I. A., Elliot, R., Howell, T., Itenfisu, D., Jensen, M. 2005. *"The ASCE Standardized Reference Evapotranspiration Equation."* Publication, American Society of Civil Engineers.

Attachment A. List of Quality Control Adjustments Completed

Madera II Weather Station data:

Air Temperature:

2013: bad minimum temperature for 4-2, 10-7, 11-12,

2014: bad minimum temperature on 3-10, 4-7, 11-10, 11-12,

2015: bad minimum temperature on 3-9, 12-8,

2016: bad minimum temperature on 2-26, 5-27, 10-18,

Solar Radiation:

2013: data values need replacement on 4-2, 7-2, 7-5, 8-12, 9-4, 9-11, 9-17,

2014: 1% increase until 6-29, 4% increase the rest of the year, data values need replacement on 3-10, 4-3, 4-7, 6-4, 6-6, 8-12, 9-4, 9-8, 10-22, 11-10, 11-14

2015: 2% increase all year, data values need replacement on 2-9, 3-9, 7-8, 8-17, 9-16, 11-13

Relative Humidity:

2013: increase data up 3% all year (from 4-2 when station starts through the end of year)

2014: apply 3% increase for first half of year

2015: good

Windspeed*:

2013-2015: Good

Fresno State Weather Station data:

Air Temperature:

1989: missing average air temperature for 1-1 and 1-2, 10-13, missing all data for 10-12

1990: missing/bad data for 3-26 and 3-27, missing all data from 8-20 through 9-1

1991: bad data point on 3-8, missing data on 10-18 through 10-21 and 12-23

1992: missing data from 7-10 through 7-13 and from 10-17 through 11-10, data points need replacement on 5-15, 7-8, 7-13, 7-28, 7-29, 7-31, 9-4, 11-6, and 12-1

1993: bad minimum temperature readings on 2-1, 3-23, 4-21, 5-21, 6-25, 7-2, 9-10, and 10-29

1994: bad minimum temperature readings on 5-20, 7-18, 9-9, missing average temperature on 1-3

1995: all good

1996: bad minimum temperature on 4-30, 11-8, 12-31

1997: bad minimum temperature on 7-29, 4-1, 4-18, 10-2, and 10-10

1998: bad minimum temperature on 7-17, 8-17, bad average temp on 9-4

1999: bad minimum temperature on 4-10, 10-15, missing minimum temperature on 6-11, 7-23, 9-22, bad average temperature on 2-25, 3-1

2000: bad minimum temperature values on 4-12, 5-2, 5-16, 10-20,

2001: bad minimum temperature values on 4-10, 5-31, and 10-12

2002: bad minimum temperature values on 2-25, 4-30, 5-28,

2003: bad minimum temperature values on 3-11,

Solar Radiation:

1989: Good

1990: Good

1991: Adjust data down 9% from 5-30 through 6-7

1992: data points need replacement on 5-15, 7-13, 7-29, 7-31, 9-4, 12-1; adjust all data for this year up 2.5%

1993: data points need replacement on 2-1, 5-21, 6-25, 7-2, 9-10, 10-29

1994: data points need replacement on 7-18

1995: adjust data down 1%

1996: Adjust data up 8% from 5-15 on

1997: Adjust data up 8% until 4-1, then no adjustment; data points need replacement on 4-1, 4-18, 7-29

1998: data points need replacement on 5-1, 7-17, 11-25, adjust data down 2% from 5-9 through 7-1

1999: data points need replacement for 4-23, 6-11, 7-23, moved data up 5% from beginning until 8-10, move data up 7% from 8-10 until 9-2, then move data up 12% for the rest of the year

Relative Humidity:

1989: good

1990: move data up 1% for the whole year

1991: move data up 4% from 9-21 through end of the year

1992: move data up 1% all year

1993: Good

1994: Good

1995: Good

1996: Good

1997: Good

1998: Good

1999: Good

Windspeed*:

1989-1999: Good

Madera Weather Station Data:

Air temperature:

1998: Bad minimum temperature on 10-1,

1999: bad minimum temperature on 4-23,

2000: bad minimum temperature on 3-7, 10-2,

2001: bad minimum temperature on 10-11,

2002: bad minimum temperature on 4-15, 4-22, 2-27,

2003: bad minimum temperature on 3-2, 4-8, 5-12, 10-29,

2004: bad minimum temperature on 4-21, 12-5, 12-9,

2005: bad minimum temperature on 1-6, 1-12, 1-31, 4-20,

2006: bad minimum temperature on 2-6,

2007: bad average temperature on 1-1,

2008: bad minimum temperature on 4-14,

2009: bad minimum temperature on 1-16, 3-13,

2010: bad minimum temperature on 1-27,

2011: bad minimum temperatures on 1-22 through 2-1, 2-16, 3-17, 4-14, bad average temperature on 11-29,

2012: bad minimum temperature on 5-9, 2-6, 2-28, 1-23,

2013: good through 4-2 (end of record)

Solar Radiation:

1998: Data points need replacement on 8-26, 12-23, 12-31,

1999: Data points need replacement on 4-2, 4-23, 6-11, 7-2, 9-7, move all data up 3.5%,

2000: move data down 1% until 6-6, and then move data up 1% through the rest of the year

2001: data points need replacement on 7-20, 8-13, 8-15, 9-10, move data up 3% until 5-10, then move data up 4% until 7-11, then unadjusted data through the end of the year

2002: move all data down 1.5%, data points need replacement on 8-21, 8-24, 8-25,

2003: From 7-15 on, move data up 3.5%, data points need replacement on 3-10, 4-8, 5-12, 7-10, 8-14,

2004: data points need replacement on 6-18, 7-19, 8-18, move all data up 2.5%,

2005: data points need replacement on 2-22, 3-15, move all data up 4%

2006: move data up 10% until 6-19, and then move data up 14% through the end of the year

2007: data points need replacement on 8-16, move data down 3% until 5-2, and then move data down 8% until 8-14, then move data up 3% for the rest of the year,

2008: move data up 13% until 4-13, then move data down 12% through the end of the year, 2009: move data down 6% until 6-7, then move data down 2% for the rest of the year, data points need replacement on 6-16, 6-19, 8-7, 8-10,

2010: move data up 2% for the year, data points need replacement on 1-27, 11-24,

2011: move data up 3.5% until 5-25, then move data down 6% until end of year, data points need replacement on 7-18, 9-7, 11-2,

2012: replace data from 4-29 through 5-7, and on 3-19, 5-9, 6-5, 6-6, move data up 5% from 5-14 through the end of the year,

2013: data points need replacement from 3-29 through 4-2

Relative Humidity:

1998: good

1999: apply 2% increase to the second half of the year

2000: apply 2% increase to first half of year, and 3% increase to second half of year

2001: apply 3% increase to first half of year, and 4% increase to second half of year

2002: apply 4% increase all year

2003: apply 4% increase to first half of year, and 6.5% increase to second half of year

2004: apply 7% increase to first half of year, and 8.5% increase to second half of year

2005: apply 9.5% increase to first half of year, and 12% increase to second half of year

2006: apply % increase until 6-9, then no adjustment factor

2007: good

2008: good

2009: apply 2% increase all year

2010: apply 2% increase all year

2011: apply 2% increase all year

2012: apply 1% increase all year

2013: Good

Windspeed*:

1998-2013: Good

*Windspeed values that fell below the threshold may have been replaced with replacement stations data but are not listed here because they were not replaced in the manual review QC process.

Attachment B. Annual ET_o and Precipitation Results

Table AB-1. Water Year ET_o and Precipitation Results

Water Year	ET_o, inches	Precip, inches
1989	52.68	11.96
1990	55.16	11.15
1991	54.96	11.65
1992	59.27	9.52
1993	55.29	16.13
1994	55.75	9.14
1995	50.64	19.62
1996	55.76	11.99
1997	56.63	13.70
1998	53.05	16.55
1999	52.63	6.68
2000	55.02	10.89
2001	56.16	10.16
2002	56.07	9.22
2003	55.42	8.10
2004	59.79	6.73
2005	53.94	11.61
2006	55.44	12.79
2007	57.25	5.18
2008	57.36	7.87
2009	57.62	7.11
2010	53.24	12.21
2011	52.56	12.78
2012	56.89	4.35
2013	54.50	7.35
2014	53.79	3.59
2015	57.24	4.90

Appendix B

Madera Subbasin Daily Time Step IDC Root Zone Model Inputs to Support Madera Subbasin Boundary Water Budget (1989-2015)

January 2018

OVERVIEW

The water budget uses available data and estimates to develop an accurate accounting of all water inflows and outflows from the Madera Subbasin. The information supporting the water balance for 1989 through 2015 has been assembled to complete a preliminary Madera Subbasin water budget. As part of water budget development, the stand-alone root zone water budget modeling tool that is linked to the Integrated Water Flow Model (IWFM) developed and maintained by the California Department of Water Resources (DWR) is used to partition ET into ET from applied water and ET from precipitation. This stand-alone version of the root zone model is known as the IWFM Demand Calculator (IDC). The root zone water budget included with IWFM is designed such that it can be used as a stand-alone model to complete the root zone water balance for agricultural, urban, and native lands. IDC was used to develop the following time series outputs which are then combined with surface water delivery and groundwater pumping information to complete the subbasin boundary water budget and provide estimates of the infiltration of precipitation and runoff of precipitation:

- ET of precipitation (ET_{pr});
- ET of applied water (ET_{aw}); and
- Deep percolation of precipitation (DP_{pr})
- Uncollected surface runoff of precipitation (RO_{pr})

IDC files were developed for a stand-alone, daily time step IDC application and these inputs may not directly translate into IDC files that can be used with IDC when it is integrated with IWFM. Thus, the IWFM results for the surface layer for the Madera Subbasin area should be carefully reviewed and IDC Model parameters may require some adjustment to align the results with the farmed lands water balance results. In particular, IDC was not calibrated to ensure estimated applied water demands match historical deliveries and pumping.

Inputs to the IDC root zone model provided include:

- Daily crop evapotranspiration (ET_c) representing actual ET (as compared to potential ET) for each crop from January 1, 1985 through December 31, 2015 developed by multiplying reference ET (ET_o) by the appropriate crop coefficient.
- Daily precipitation (P_r) from January 1, 1985 through December 31, 2015.
- Rooting depth for each crop, or crop group
- Other model parameters for the crops and crop groups simulated
- Soil properties for each soil texture simulated

IDC MODEL SETUP

The IDC Model uses a daily time step to compute ET_{aw} and ET_{pr} for the Madera Subbasin agricultural water budget. The model is set up as a unitized model (as compared to a spatial model) that provides per acre results by specifying one unique crop-soil-runoff combination per element with the area of each element set to 10,000 acres. To allow crop-soil-runoff combinations to be added in future years, 50 elements comprised of 114 nodes were configured in the model. The crop-soil-runoff combinations are described in the following sections. The input files provided were used with the IWFM Version 2015.0.0036, Root Zone Component Version 4.0 (DWR, 2015).

Weather Inputs

Evapotranspiration Inputs

Daily reference ET (ET_o) values used for 1985 through 2015 are based on measured weather data from three California Irrigation Management Information System (CIMIS) stations (Table B-1). Measured weather parameters supporting daily ET_o calculations were quality controlled following standard procedures (ASCE-EWRI, 2005) to produce a high quality daily ET_o time series for use with crop coefficients to develop the ET time series for each crop as described in Appendix A.

Table B-1. Madera Subbasin Weather Data Time Series Summary for the period 1989 – 2015.

Weather Station	Start Date	End Date	Comment
Fresno State (#80)	Jan. 1, 1985	May 12, 1998	CIMIS. Before Madera was installed.
Madera (#145)	May 13, 1998	Apr. 2, 2013	CIMIS. Moved East 2 miles and renamed "Madera II"
Madera II (#188)	Apr. 3, 2013	Dec. 31, 2015	CIMIS

Crop coefficients were derived using ET_o values described in the previous paragraph and actual ET (ET_a) estimates from remotely sensed surface energy balance results from Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen, et al. 2005). Spatially distributed ET_a results were available with spatial cropping data for 2009. SEBAL results account for effects of salinity, deficit irrigation, disease, fertilization, immature permanent crops, crop canopy structure, and any other factors resulting in differences between potential and actual crop ET. Studies by Bastiaanssen et al. (2005), Allen et al. (2007, 2011), Thoreson et al. (2009), and others have found that when performed by an expert analyst, seasonal ET_a estimates by these models are expected to be within five percent of actual ET determined using other, reliable methods. For crops grown in the Madera Subbasin, annual ET_a computed using the quality controlled CIMIS ET_o and crop coefficients are provided in Table B-2.

Table B-2. Average Acreages and Annual Evapotranspiration Rates for Madera Subbasin, 1989 to 2015

Crop	Acres	ET_c (in)	ET_{pr} (in)	ET_{aw} (in)
Alfalfa	8,865	38.6	7.5	31.0
Almonds	38,304	41.6	7.1	34.5
Citrus and Subtropical	6,534	40.3	7.6	32.7
Corn (double cropped)	7,380	34.3	5.6	28.7
Grain and Hay Crops	7,857	7.7	7.7	0.0
Grapes	79,409	26.7	6.6	20.0
Idle	11,690	6.5	6.5	0.0
Miscellaneous Deciduous	10,860	30.4	8.3	22.1
Miscellaneous Field Crops	9,907	30.9	6.4	24.5
Miscellaneous Vegetables	2,711	30.4	5.2	25.2
Mixed Pasture	7,059	28.7	6.7	22.0
Native	98,199	7.5	7.5	0.0
Pistachios	21,856	32.3	7.5	24.8
Semiagricultural	4,345	13.9	6.7	7.2
Urban	28,029	14.1	6.7	7.4
Walnuts	1,045	33.9	7.2	26.7
Water	3,521	48.5	6.5	42.0

Precipitation Inputs

Precipitation values are from the three CIMIS stations (Table B-1) for 1985 through 2015 and average 10.1 inches per water year over the 1989 through 2015 period. The precipitation records were carefully reviewed and standard quality control procedures (ASCE-EWRI, 2005) were applied as described in Appendix A.

Land Use Inputs and Parameters

Land Use

Annual land use was estimated based primarily on spatially distributed crop information from DWR Land Use surveys in 1995, 2001 and 2011 and the Land IQ[12] remote sensing based crop identification for 2014. County Agriculture Commission crop areas were used to interpolate between years with spatial crop information available. Cropped lands in the District were assigned to one of seventeen land use groups. These land use groups along with average acres over the 1989 through 2015 period were previously listed in Table B-2.

The following five steps were used to develop the Madera County-wide annual, spatial land use dataset.

1.) Developed spatial land use coverages for 1995, 2001, 2011, and 2014. Made adjustments to the spatial coverage, including:

[12] Land IQ is a firm that was contracted by DWR to use remote sensing methodologies to identify crops in fields.

   a) Filled missing area from LandIQ coverage with 2011 DWR coverage (Native, Urban, Water, & Semiag account for 86% of the missing area)
   b) Water surfaces were not included in the 1995 DWR survey; used the water area from 2001 for the 1995 DWR survey.

2.) Calculated agricultural area:

   a) County data has idle equal to zero for all years--assume county data does not include idle land
   b) Exclude idle from DWR agricultural totals--to be consistent with county totals
   c) Calculate the ratio of the DWR agricultural total area (not including idle lands) to county agricultural production area for years with DWR (or Land IQ) land use data
   d) Interpolate the ratio calculated in step (c) for missing years, extend trend or set at last values for years before first and after last county data

3.) Multiplied county agricultural acres for each crop by the ratio calculated in in step 2 (c) to adjust county agricultural areas for each crop scaling each crop area in each year by an estimate of the difference between the areas in the DWR land use surveys and County Commissioner reports. This procedure assumes DWR areas are the most accurate.

   a) Interpolate native, semiag, urban, and water land uses between DWR years.
   b) Calculate idle area as the remaining area (total DWR land use minus total cropped area)

4.) Reviewed calculated idle and crop area graphs and adjust individual annual cropped areas with abnormal crop area shifts based on judgement to eliminate calculated negative idle areas

   a) 1996 adjustments--replace high miscellaneous truck areas with interpolated values between 1995 and 1997
   b) 2002, 2003, 2004 and 2005 adjustments--replace high areas for mixed pasture and alfalfa between 2001 and 2011 DWR areas by interpolating areas between 2001 and 2011.
   c) 2012 adjustments--replace high miscellaneous deciduous, field and truck with interpolated value between 2011 and 2013

5.) Implemented the DWR Land Use interpolation tool to create annual spatial cropping data sets.

Complete land use areas for the entire subbasin for 1989 through 2015 are provide in Attachment A.

Root Depth

The IDC model was set up to simulate the aforementioned seven crop groups. Root depths for each crop group were estimated primarily from Allen, et al. (1998) with consideration given for local conditions. A list of the crops and rooting depths are provided in Table B-3. IDC provides an option that models root growth as the season progresses for annual crops. For this application, all crops were modeled with constant root depths.

Table B-3. Root Depths Used in IDC Model

Crop	Root Depth, ft
Alfalfa	6.0
Almonds	4.0
Citrus and Subtropical	4.0
Corn (double crop)	3.5
Grain and Hay Crops	3.5
Grapes	4.0
Idle	3.0
Miscellaneous Deciduous	4.0
Miscellaneous Field Crops	3.5
Miscellaneous Vegetable Crops	2.5
Mixed Pasture	3.0
Native	6.0
Pistachios	4.0
Semi-agricultural	4.0
Urban	4.0
Walnuts	6.0
Water	4.0

Runoff Curve Numbers

The IDC uses a modified version of the SCS curve number (SCS-CN) method to compute runoff of precipitation. A curve number for each crop and soil type is required as input to the model. Curve numbers are used as described in the National Engineering Handbook Part 630[13] (USDA, 2004, 2007) based on land use or cover type, treatments (straight rows, bare soil, etc.), hydrologic condition (good was used), and hydrologic soil group. An area weighted average curve number for each land use-soil type combination was calculated based on the area in each hydrologic soil group and is presented in Table B-4. The total area of each soil group within the Madera Subbasin was estimated from the NRCS SSURGO database and is described in a later section.

[13] Table 1. Runoff curve numbers for agricultural lands.

DRAFT PRELIMINARY ANALYSES AND RESULTS TO BE REFINED DURING GSP DEVELOPMENT.

Table B-4. Curve Number Used to Represent Runoff Conditions in Madera Subbasin

Soil Group	Alfalfa	Almonds	Citrus and Subtropical	Corn	Grain and Hay Crops	Grapes	Idle	Miscellaneous Deciduous	Miscellaneous. Field Crops	Miscellaneous Vegetable Crops	Mixed Pasture	Native	Pistachios	Semiag	Urban	Walnuts	Water
clay - clay loam (30, 30, 40)	78	79	79	89	87	79	94	79	89	89	78	78	79	86	86	79	89
clay (20, 30, 50)	78	79	79	89	87	79	94	79	89	89	78	78	79	86	86	79	89
clay (30, 20, 50)	78	79	79	89	87	79	94	79	89	89	78	78	79	86	86	79	89
clay loam (30, 40, 30)	74	75	75	87	84	75	92	75	87	87	74	74	75	83	83	75	87
clay loam (40, 30, 30)	77	78	78	88	86	78	94	78	88	88	77	77	78	85	85	78	88
loam (40, 40, 20)	69	70	70	84	82	70	90	70	84	84	69	69	70	81	81	70	84
loam (50, 30, 20)	73	74	74	86	84	74	92	74	86	86	73	73	74	83	83	74	86
loamy sand (80, 20, 0)	31	33	33	67	63	33	77	33	67	67	31	31	33	59	59	33	67
sand (100, 0, 0)	60	61	61	80	77	61	87	61	80	80	60	60	61	76	76	61	80
sandy clay loam (50, 20, 30)	78	79	79	89	87	79	94	79	89	89	78	78	79	86	86	79	89
sandy clay loam (60, 10, 30)	78	79	79	89	87	79	94	79	89	89	78	78	79	86	86	79	89
sandy loam - sandy clay loam (60, 20, 20)	64	65	65	81	79	65	89	65	81	81	64	64	65	78	78	65	81
sandy loam - sandy clay loam (70, 10, 20)	77	78	78	88	86	78	93	78	88	88	77	77	78	85	85	78	88
sandy loam (70, 20, 10)	61	61	61	80	77	61	87	61	80	80	61	61	61	76	76	61	80
sandy loam (80, 10, 10)	41	42	42	71	68	42	80	42	71	71	41	41	42	65	65	42	71
silty clay loam (20, 50, 30)	58	58	58	78	75	58	86	58	78	78	58	58	58	74	74	58	78

Irrigation Period

The irrigation period determines the cropped and non-cropped periods for each crop. One represents a cropping period and IDC calculates applied water demand for the period. Zero represents a non-cropping period and IDC does not compute applied water demand for this period. In this application the irrigation period was set to one between March and October for all crop groups except Idle. For Idle lands, the irrigation period was set to zero for all months. Different irrigation periods can be defined for different land use types if necessary. In this case, the irrigation season was selected to roughly correspond with the irrigation season in the Madera Subbasin.

Minimum Soil Moisture

The minimum soil moisture value for each particular crop corresponds to the moisture content at the Management Allowable Depletion (MAD) specified for that crop. Management Allowed Depletion (MAD) is defined as the desired soil water deficit at the time of irrigation and can vary with growth stage (ASABE, 2007). The MAD is often set as the percent of total available moisture that the crop can withdraw without suffering stress or yield loss. Water stress is estimated within the IDC model when the percent of total available moisture exceeds 50 percent. The IDC Model allows different values to be input for different crops and different crop stages. Values for the minimum soil moisture were set to 50 percent for all crops at all growth stages to prevent stress from occurring in the simulation. It is important to note here that the crop coefficients, as described previously, are developed from remotely sensed energy balance ET data and thus already include ET reductions that may have occurred due to water stress or other factors.

Agricultural Water Supply Requirement (Target Soil Moisture Fraction)

Water supplied to each crop can either be calculated within the simulation or provided as input to the model. The agricultural water supply requirement data file allows a time series of agricultural demands to be specified for some or all of the crops as a model input. This feature was not used in this simulation. Irrigation is simulated when the soil moisture reaches the minimum soil moisture as described in the previous paragraph. The irrigation applied water volume during the cropped season, as specified by the irrigation period, is calculated as the volume required to return the soil moisture to the target soil moisture plus applied water that becomes return flow as specified by the return flow and minimum deep percolation fraction. For this model application, the return flow from irrigation and minimum deep percolation fraction are set to zero as described in the following paragraphs. The target soil moisture in the model is field capacity.

Reuse and Return Flow

For this simulation, irrigation water return flow and reuse fractions have been set to zero in the IDC model. Return flow and reuse are internal flow paths and thus not included in the Subbasin boundary water budget.

Minimum Deep Percolation Fraction

The minimum deep percolation fraction, defined as a fraction of “infiltrated” applied water, is used to simulate the practice of applying additional water to leach salts from the root zone. Because of the high-quality water and soil in the study area, applying additional water to leach salts is not a common practice, so the minimum deep percolation factor was set equal to zero for all crops. This factor also can be set independently for each crop. Even though the minimum deep percolation factor is set to zero, IDC does simulate and separately track deep percolation of precipitation and applied water. However, only the IDC simulated deep percolation of precipitation is used in the Subbasin water budget. Deep percolation of applied water is calculated as a closure term in the Subbasin water budget.

Initial Soil Moisture

In many years, sufficient precipitation occurs during the winter months to fill the root zone to field capacity. Thus, the initial soil moisture was set to field capacity. The IDC model runs for the Subbasin water budget were started in 1985, four years before the first year in the water budget period to minimize any potential effect from incorrectly specifying the initial soil moisture value.

Soil Inputs

Soil textural classes and associated hydraulic parameters for soils within the Madera Subbasin were estimated from the Soil Survey Geographic (SSURGO) database (Soil Survey Staff, 2014) for use in IDC. The SSURGO database contains information about soils in the United States collected by the National Cooperative Soil Survey (NCSS). The United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), formerly known as the Soil Conservation Service (SCS), organizes the NCSS and publishes soil surveys. Sandy clay loam and sandy loam textured soils together underlie nearly 77 percent of the area inside the Madera Subbasin, respectively (Table B-5). The IDC model includes sixteen soil textures representing the majority of the Madera Subbasin. Together these soil types cover approximately 98 percent of the Madera Subbasin area.

For each texture class, initial soil hydraulic properties were estimated based on pedotransfer functions reported by Saxton and Rawls (2006) and refined to provide drainage from saturation to field capacity within a reasonable amount of time and to predict minimal gravitational drainage once field capacity was reached (Table B-6). The following five soil parameters are inputs to the IDC Model:

1) Permanent Wilting Point (PWP), dimensionless
2) Field Capacity (FC), dimensionless
3) Total Porosity (ϕ), dimensionless
4) Pore Size Distribution Index (λ), dimensionless
5) Saturated Hydraulic Conductivity (K_{sat}) in feet per day (ft/day)

Table B-5. Soil Textures by Area

Soil Group	Acres	% of Area
sandy loam (70, 20, 10)*	63,719	18.3%
sandy loam - sandy clay loam (60, 20, 20)*	57,912	16.7%
sandy clay loam (50, 20, 30)*	57,242	16.5%
sandy loam - sandy clay loam (70, 10, 20)*	40,910	11.8%
sandy clay loam (60, 10, 30)*	40,235	11.6%
loam (50, 30, 20)*	34,360	9.9%
loamy sand (80, 20, 0)*	13,067	3.8%
silty clay loam (20, 50, 30)*	6,866	2.0%
sandy loam (80, 10, 10)*	6,812	2.0%
clay loam (40, 30, 30)*	5,533	1.6%
clay loam (30, 40, 30)*	3,452	1.0%
clay (20, 30, 50)*	2,462	0.7%
loam (40, 40, 20)*	2,399	0.7%
sand (100, 0, 0)*	2,203	0.6%
clay - clay loam (30, 30, 40)*	1,681	0.5%
clay (30, 20, 50)*	1,043	0.3%
sand (90, 10, 0)	670	0.2%
sandy loam (60, 30, 10)	639	0.2%
sandy clay (50, 10, 40)	521	0.1%
silt loam - loam (40, 50, 10)	430	0.1%
loamy sand (90, 0, 10)	421	0.1%
silt loam - loam (30, 50, 20)	253	0.1%
clay - clay loam (40, 20, 40)	107	0.0%
silt loam (30, 60, 10)	92	0.0%
Other (i.e., water, urban, etc.)	4,432	1.3%
Total	347,461	100%

*Soil texture represented in the IDC model.

Table B-6. Soil Texture with IDC Model Parameters

Soil Group	PWP	FC	ϕ	λ	K_{sat} (ft/d)
sandy loam (70, 20, 10)	0.07	0.15	0.38	0.42	19.00
sandy loam - sandy clay loam (60, 20, 20)	0.11	0.20	0.38	0.26	14.00
sandy clay loam (50, 20, 30)	0.16	0.27	0.40	0.17	4.00
sandy loam - sandy clay loam (70, 10, 20)	0.09	0.17	0.38	0.33	16.00
sandy clay loam (60, 10, 30)	0.15	0.24	0.39	0.20	6.00
loam (50, 30, 20)	0.11	0.23	0.39	0.22	7.20
loamy sand (80, 20, 0)	0.01	0.07	0.40	1.20	31.00
silty clay loam (20, 50, 30)	0.16	0.32	0.42	0.14	0.80
sandy loam (80, 10, 10)	0.03	0.10	0.39	0.74	25.50
clay loam (40, 30, 30)	0.18	0.30	0.41	0.19	0.60
clay loam (30, 40, 30)	0.19	0.33	0.42	0.16	0.49
loam (40, 40, 20)	0.13	0.26	0.40	0.18	3.50
sand (100, 0, 0)	0.01	0.04	0.42	4.50	35.50
clay (20, 30, 50)	0.30	0.43	0.49	0.13	0.08
clay - clay loam (30, 30, 40)	0.24	0.37	0.45	0.13	0.24
clay (30, 20, 50)	0.27	0.40	0.47	0.12	0.13

References

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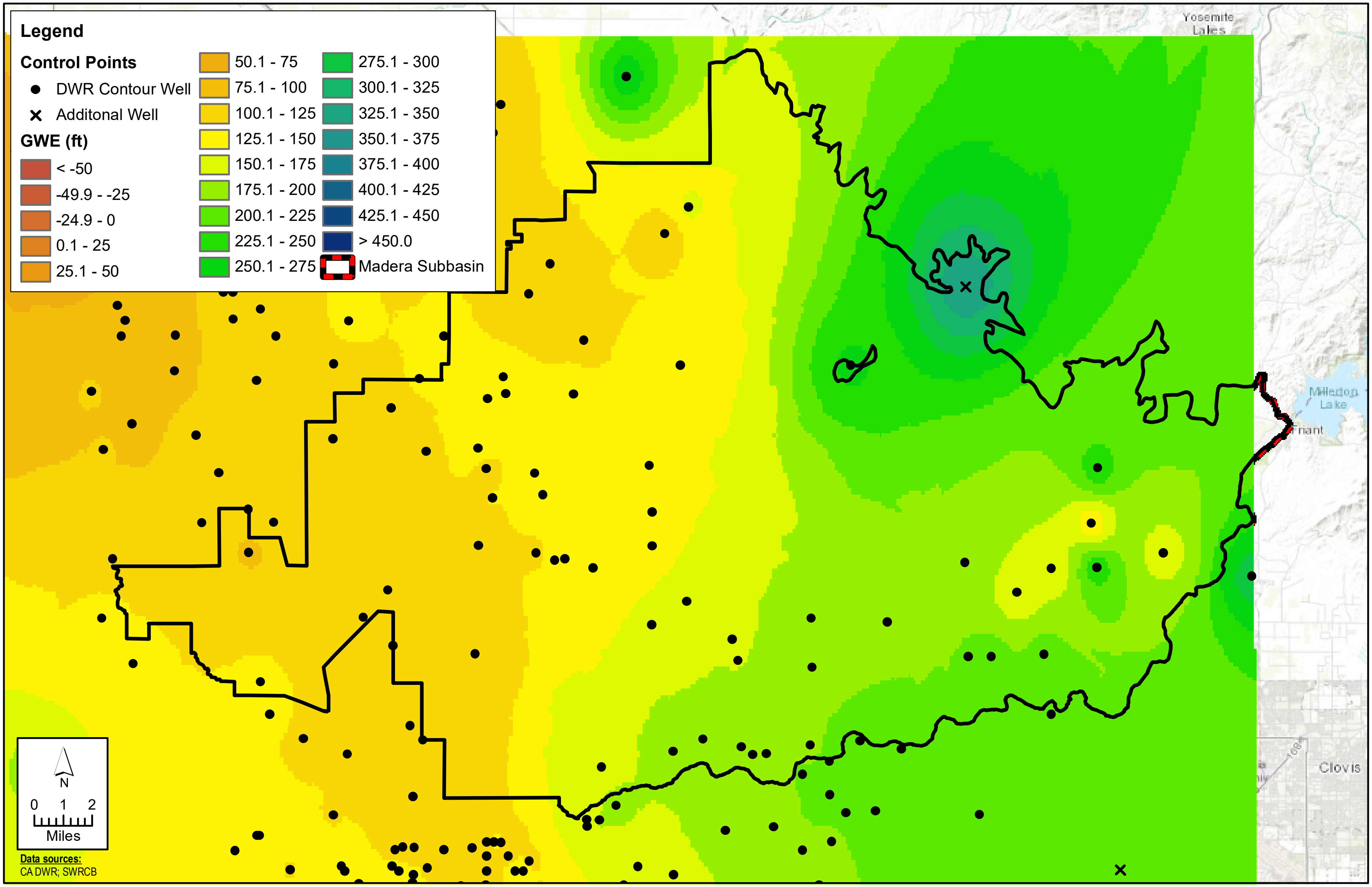
Attachment A. Land Use Areas in Acres in the Madera Subbasin for 1989 through 2015.

Year	Alfalfa	Almonds	Citrus and Subtropical	Corn	Grain and Hay Crops	Grapes	Idle	Miscellaneous Deciduous	Miscellaneous Field Crops	Miscellaneous Vegetable Crops	Mixed Pasture	Native	Pistachios	Semi agricultural	Urban	Walnuts	Water	Total	Farmed	Developed	Orchards	Pasture and Alfalfa
1989	10,247	21,774	6,059	5,244	5,524	69,599	32,682	9,048	17,109	1,213	19,748	103,472	14,103	3,547	23,175	1,258	3,113	346,915	213,608	26,722	46,183	29,995
1990	10,480	23,087	6,252	4,656	7,152	70,045	25,448	9,695	18,063	2,071	20,397	103,053	15,063	3,556	23,446	1,353	3,096	346,913	213,762	27,002	49,198	30,877
1991	10,532	24,348	6,917	4,377	5,270	71,677	19,864	10,153	19,944	2,004	21,883	102,690	15,458	3,563	23,707	1,445	3,083	346,915	213,872	27,270	51,405	32,415
1992	10,233	25,589	6,908	4,852	6,288	74,617	15,702	10,381	19,097	2,255	21,153	102,120	15,988	3,572	23,959	1,161	3,040	346,914	214,223	27,531	53,118	31,386
1993	10,576	26,804	7,018	5,177	6,242	75,812	17,125	10,926	19,204	2,648	15,725	101,680	16,301	3,584	24,206	855	3,029	346,915	214,415	27,790	54,887	26,302
1994	11,041	28,005	7,178	5,024	5,754	79,171	17,564	11,778	18,033	4,175	10,208	101,120	16,036	3,594	24,456	778	2,999	346,914	214,746	28,050	56,598	21,248
1995 (DWR)	10,768	29,184	6,588	5,469	12,625	79,946	10,610	15,697	17,507	1,358	5,255	100,597	18,967	3,602	24,707	1,061	2,975	346,915	215,034	28,309	64,908	16,023
1996	12,432	29,925	7,414	7,464	7,323	83,421	5,655	14,119	21,466	2,498	5,153	100,203	17,480	3,619	24,967	800	2,972	346,911	215,150	28,586	62,323	17,585
1997	12,986	30,668	7,470	5,331	7,721	85,937	8,101	15,118	14,815	3,132	5,050	99,807	18,127	3,637	25,227	819	2,970	346,916	215,274	28,864	64,732	18,036
1998	11,102	31,409	6,595	6,302	4,804	86,550	14,645	14,497	12,466	2,403	4,948	99,413	18,761	3,655	25,486	908	2,967	346,911	215,390	29,141	65,575	16,050
1999	10,966	32,149	2,933	6,603	2,238	92,547	15,008	14,674	10,588	2,234	4,845	99,019	19,740	3,672	25,746	985	2,964	346,914	215,512	29,418	67,549	15,812
2000	10,469	32,890	7,335	7,043	7,420	95,933	345	15,385	10,812	1,254	4,743	98,624	20,856	3,690	26,005	1,146	2,962	346,912	215,631	29,695	70,277	15,212
2001 (DWR)	9,245	33,633	6,869	6,552	12,366	89,433	3,079	14,194	12,507	1,254	4,640	98,229	20,639	3,708	26,265	1,344	2,959	346,916	215,754	29,973	69,810	13,885
2002	8,979	34,319	7,419	8,235	8,201	92,162	4,415	14,041	8,084	1,622	4,416	98,045	22,140	3,898	26,948	872	3,118	346,915	214,905	30,847	71,372	13,395
2003	8,712	35,384	7,065	8,533	6,792	89,406	6,699	13,085	8,087	2,023	4,192	97,861	23,151	4,089	27,632	926	3,278	346,915	214,056	31,721	72,546	12,904
2004	8,445	35,892	6,502	8,601	7,073	87,306	6,503	11,754	8,921	3,086	3,968	97,676	24,015	4,280	28,315	1,140	3,437	346,914	213,206	32,595	72,801	12,413
2005	8,178	36,046	7,222	7,833	8,852	85,048	8,191	11,750	7,599	2,860	3,744	97,492	23,939	4,471	29,000	1,095	3,597	346,915	212,355	33,471	72,829	11,922
2006	7,911	38,707	6,706	8,508	8,418	81,567	12,761	9,161	5,443	3,781	3,519	97,307	23,947	4,662	29,684	1,076	3,756	346,914	211,505	34,345	72,890	11,431
2007	7,645	39,911	6,949	10,034	7,240	81,384	11,953	9,150	3,665	3,859	3,296	97,123	24,421	4,852	30,367	1,151	3,916	346,915	210,657	35,219	74,632	10,940
2008	7,378	41,064	6,480	11,320	8,864	82,085	13,679	6,938	944	1,482	3,071	96,939	25,551	5,043	31,050	952	4,075	346,915	209,808	36,093	74,505	10,450
2009	7,111	41,546	5,726	8,301	7,876	77,002	21,696	7,196	124	2,679	2,847	96,754	25,970	5,233	31,736	882	4,234	346,914	208,956	36,969	75,595	9,958
2010	6,844	48,708	5,932	8,781	10,825	74,372	11,635	7,105	1,542	2,889	2,623	96,570	25,965	5,424	32,419	887	4,394	346,914	208,107	37,843	82,665	9,468
2011 (DWR)	6,578	53,266	8,776	8,587	10,834	68,138	3,064	11,497	3,416	3,034	2,399	96,386	26,628	5,615	33,102	1,041	4,553	346,916	207,259	38,717	92,432	8,977
2012	5,964	56,471	4,816	11,373	9,991	67,293	6,471	8,122	2,306	3,519	4,035	94,293	28,094	5,615	33,230	850	4,468	346,912	209,306	38,845	93,537	9,999
2013	5,185	61,557	4,222	10,852	10,240	66,445	9,746	4,885	835	3,945	2,989	92,195	29,564	5,615	33,358	896	4,383	346,912	211,362	38,973	96,902	8,175
2014 (LandIQ)	4,451	65,089	8,237	6,909	6,722	65,600	8,198	7,267	3,989	2,324	2,279	90,102	31,030	5,615	33,485	1,319	4,298	346,915	213,415	39,100	104,705	6,730
2015	4,440	74,821	4,499	6,918	9,091	67,498	4,181	5,045	409	7,459	3,114	87,588	27,070	5,682	33,668	1,172	4,257	346,913	215,718	39,351	108,109	7,555
Average	8,848	38,231	6,522	7,366	7,842	79,259	11,667	10,839	9,888	2,706	7,046	98,013	21,815	4,337	27,976	1,043	3,515	346,914	213,074	32,313	71,929	15,894

Appendix C
Subbasin Inflow/Outflow Calculations



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure C-1 Groundwater Elevation - Spring 1989.mxd

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FIGURE C-1

Preliminary Groundwater Elevation - Spring 1989

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget

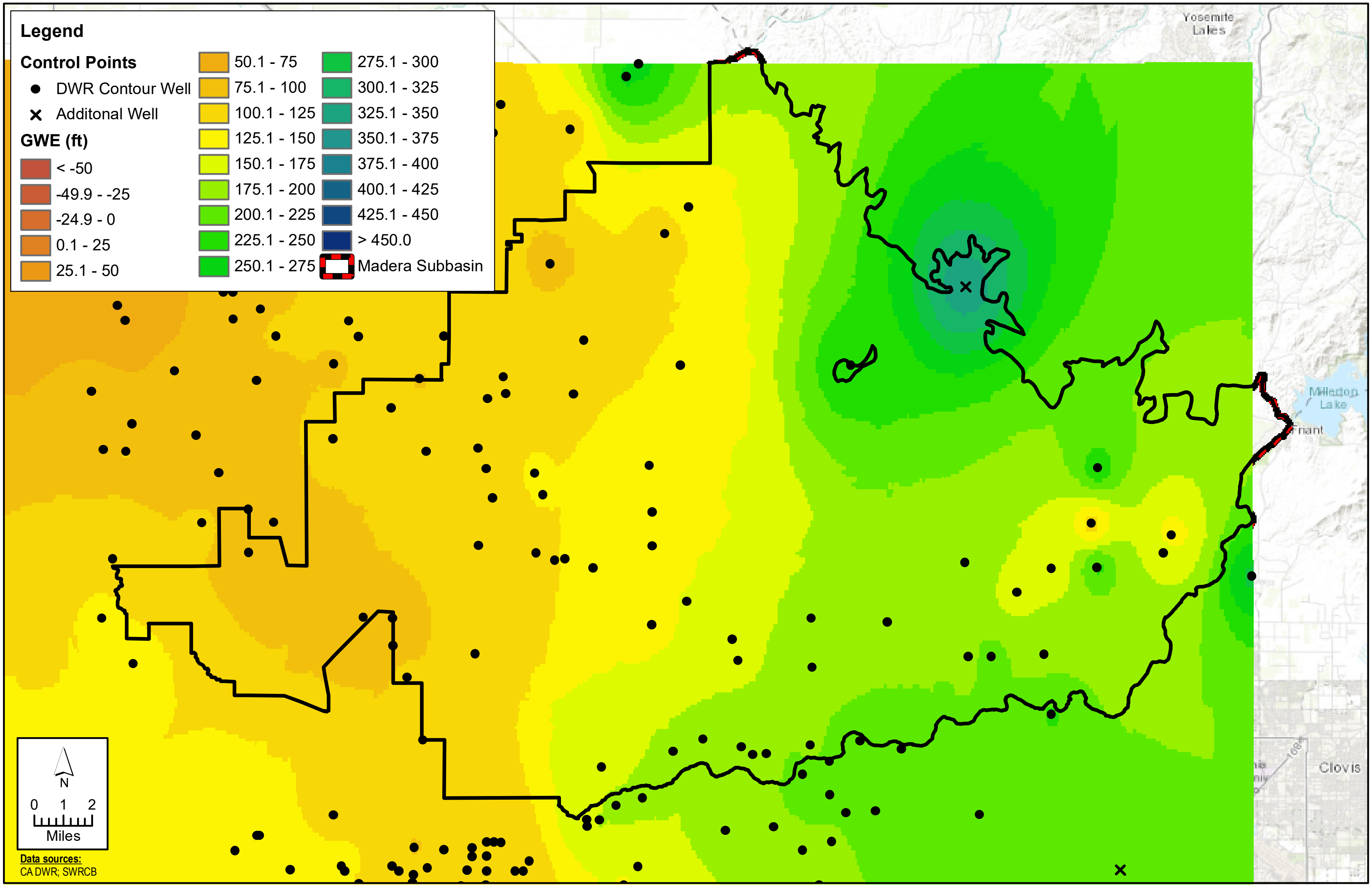

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FIGURE C-2

Preliminary Groundwater Elevation - Spring 1990

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget

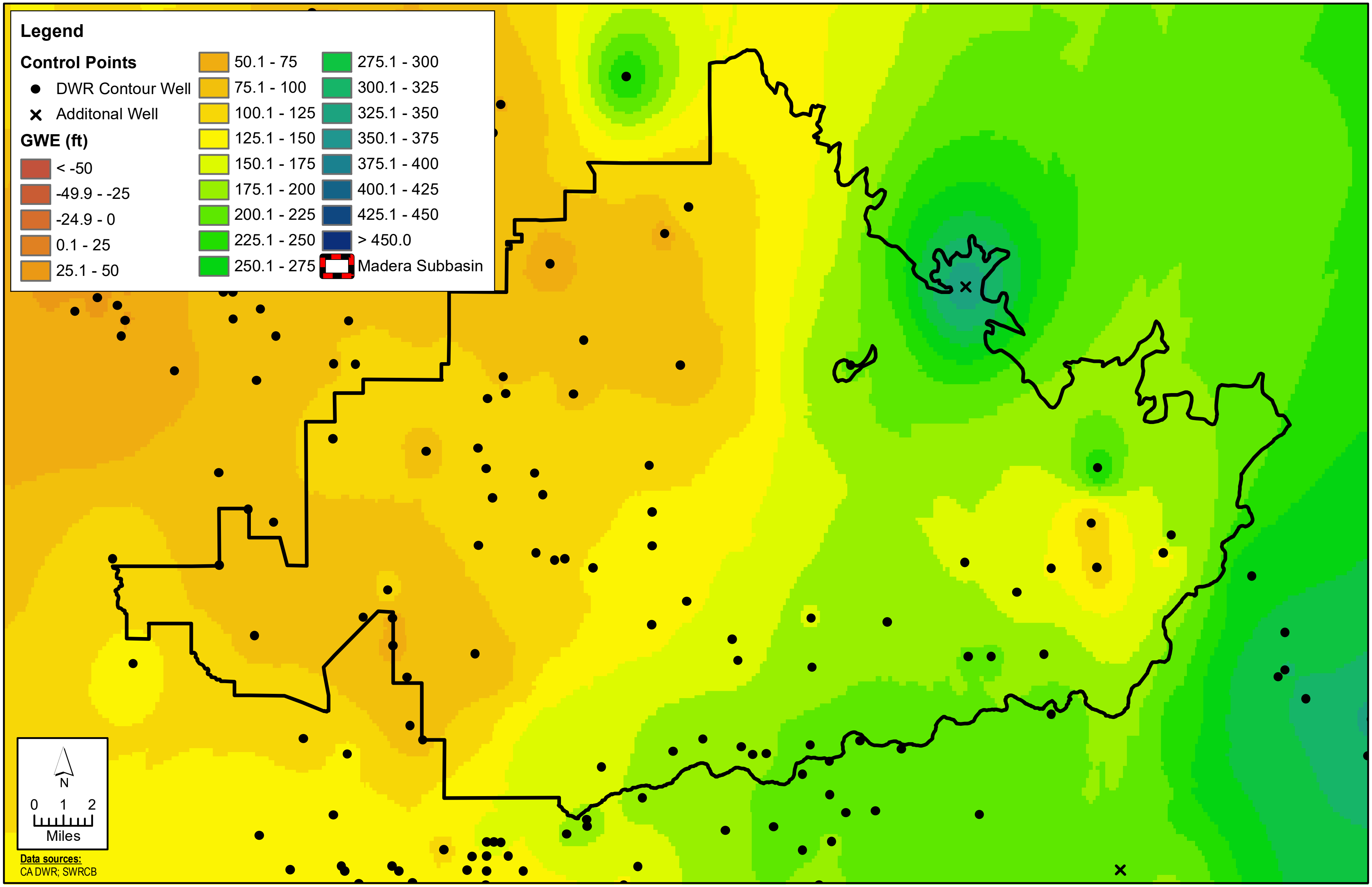

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FIGURE C-3

Preliminary Groundwater Elevation - Spring 1998

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget

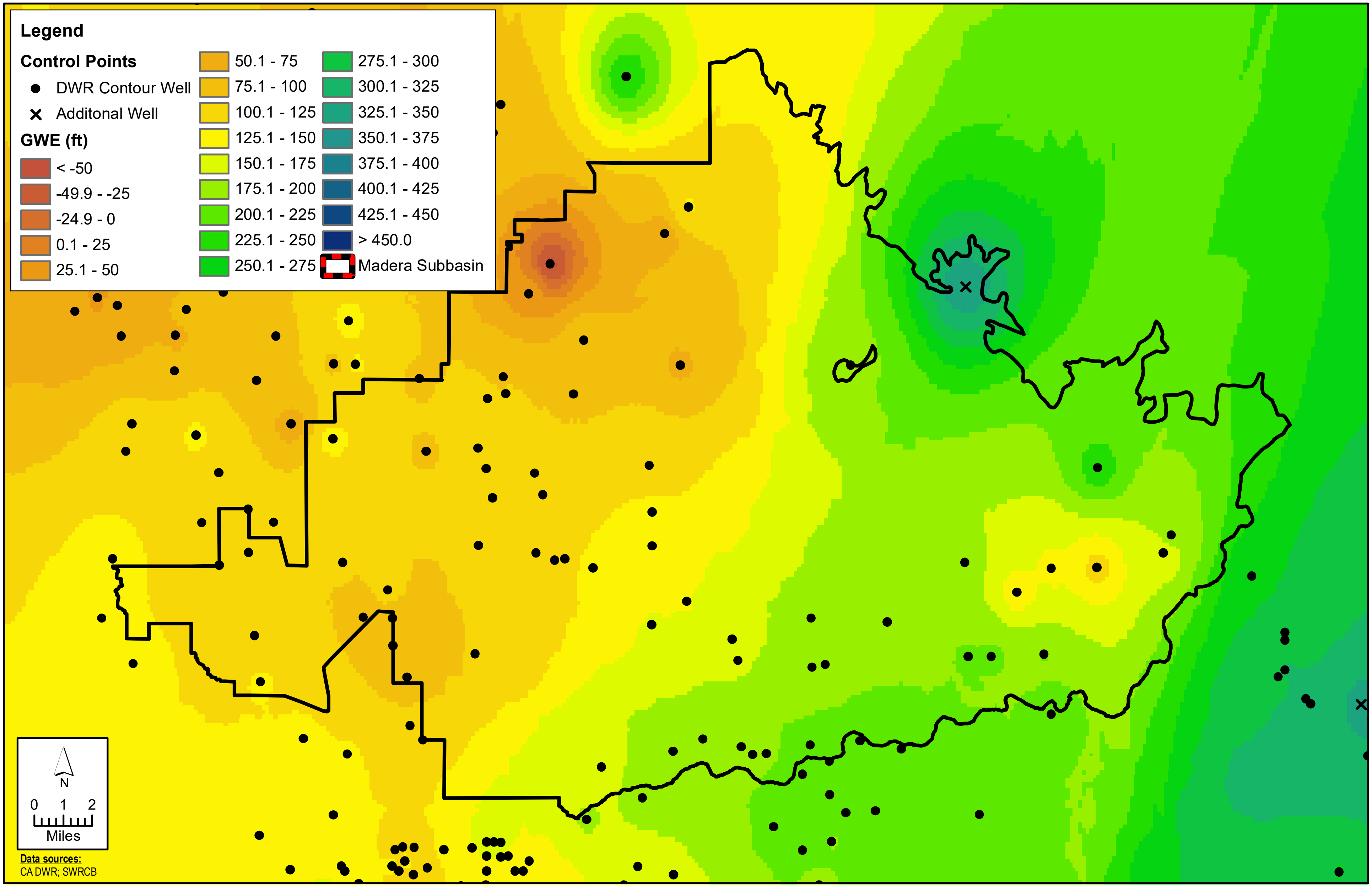

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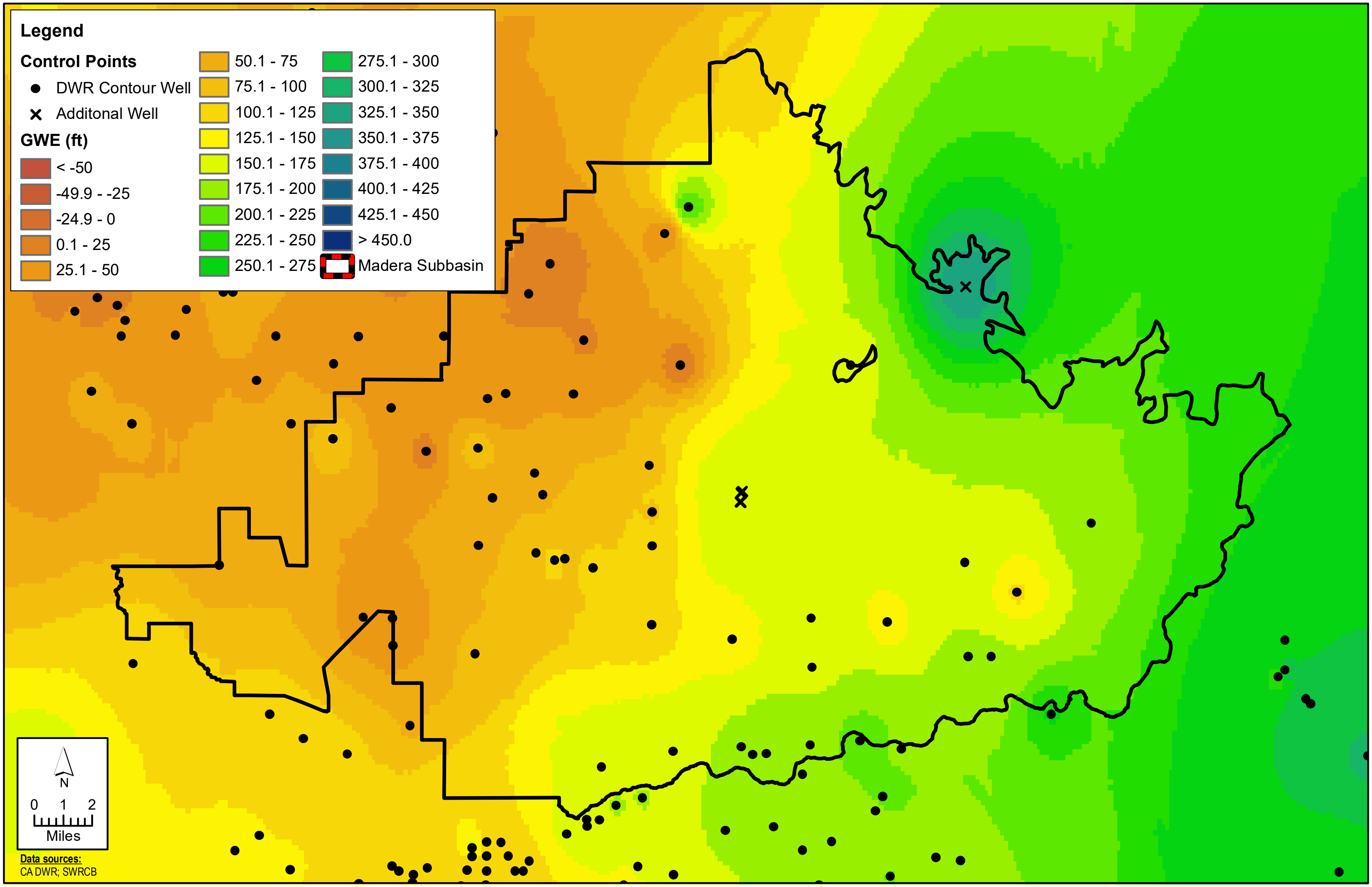
FIGURE C-4

Preliminary Groundwater Elevation - Spring 1999

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure C-5 Groundwater Elevation - Spring 2010.mxd

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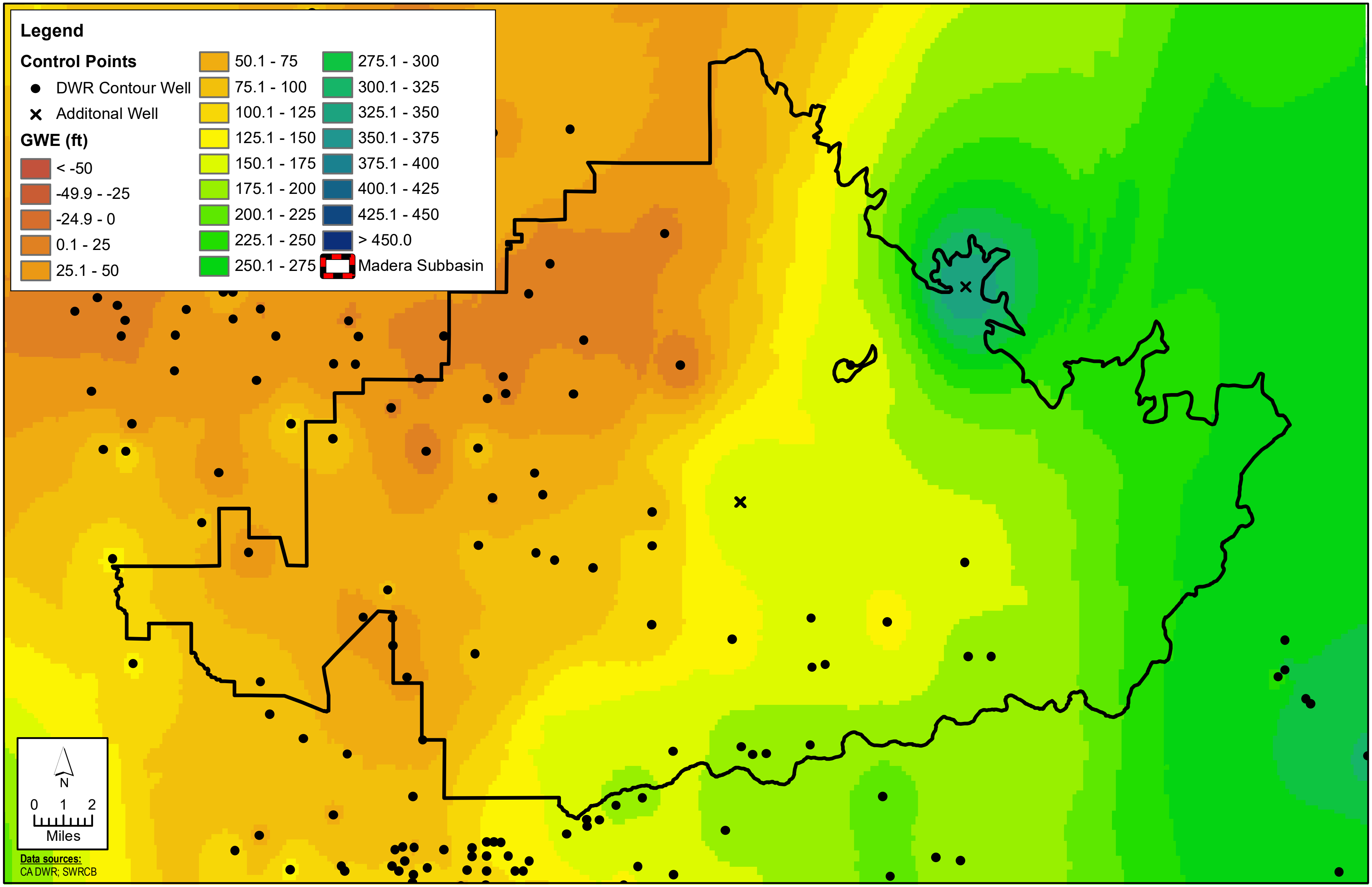
FIGURE C-5

Preliminary Groundwater Elevation - Spring 2010

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure C-6 Groundwater Elevation - Spring 2011.mxd

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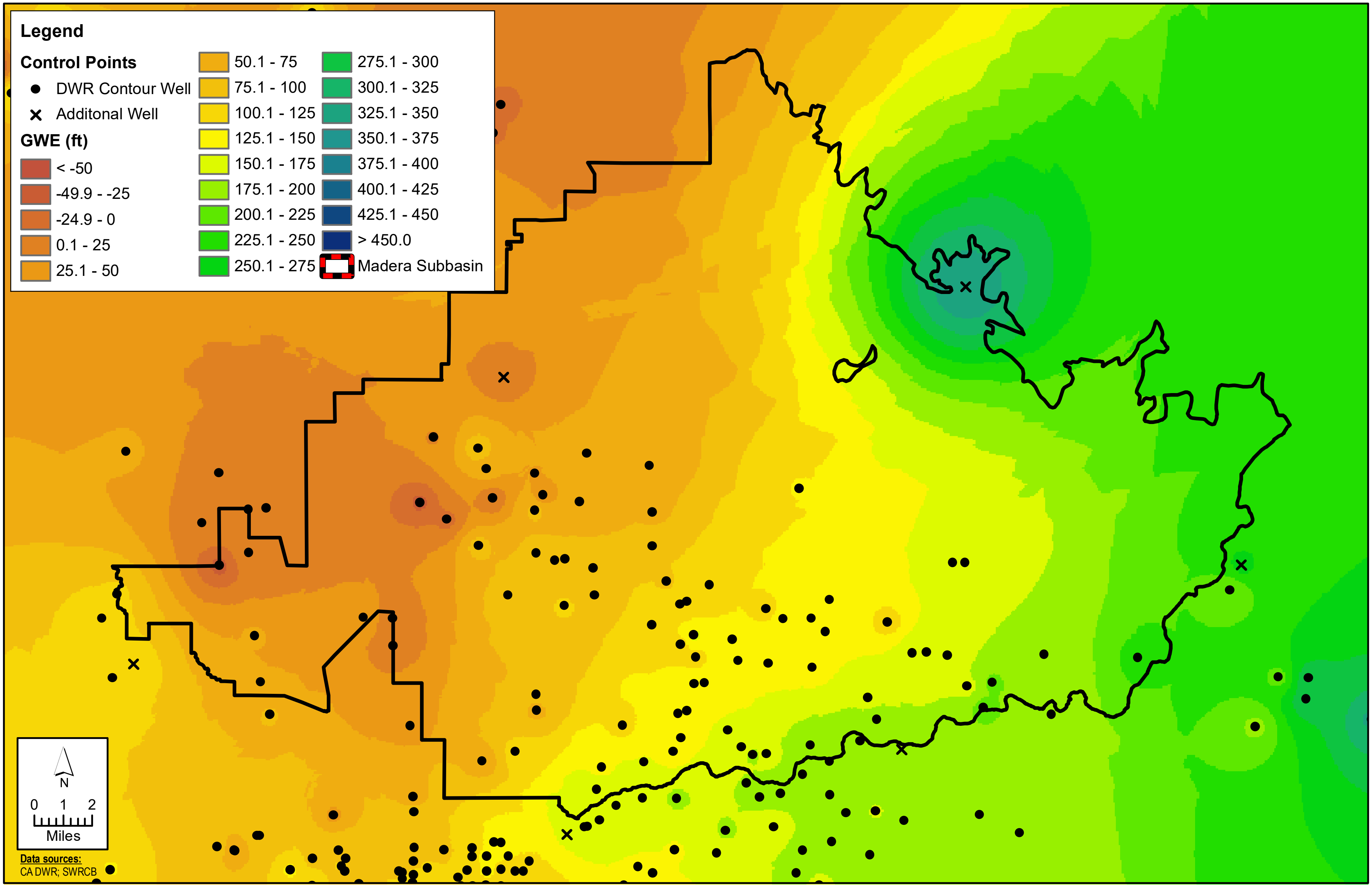
FIGURE C-6

Preliminary Groundwater Elevation - Spring 2011

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure C-7 Groundwater Elevation - Spring 2014.mxd

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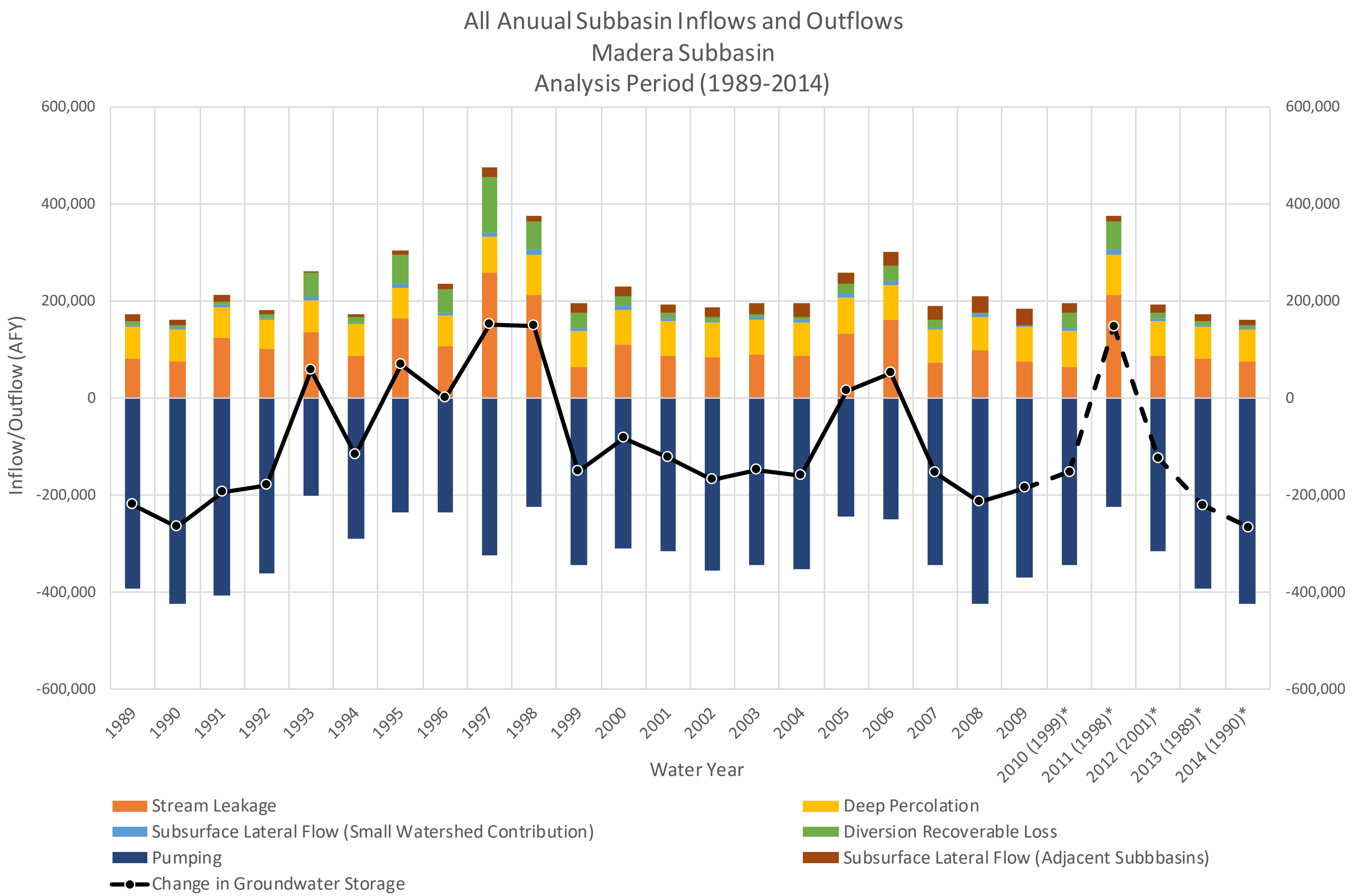
FIGURE C-7

Preliminary Groundwater Elevation - Spring 2014

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget

Appendix D
Estimated Values for All Simulated Water Budget Components Based on the Analysis Approach



**Results presented for years 2010-2014 are from substitue years indicated in parentheses.*
NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.
The C2VSim-CG simulation period ends in 2009; dashed lines are used for 2010-2014 where results for substitued years are presented.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure D-1 Model-Based Results for All Annual Subbasin Inflows and Outflows.mxd

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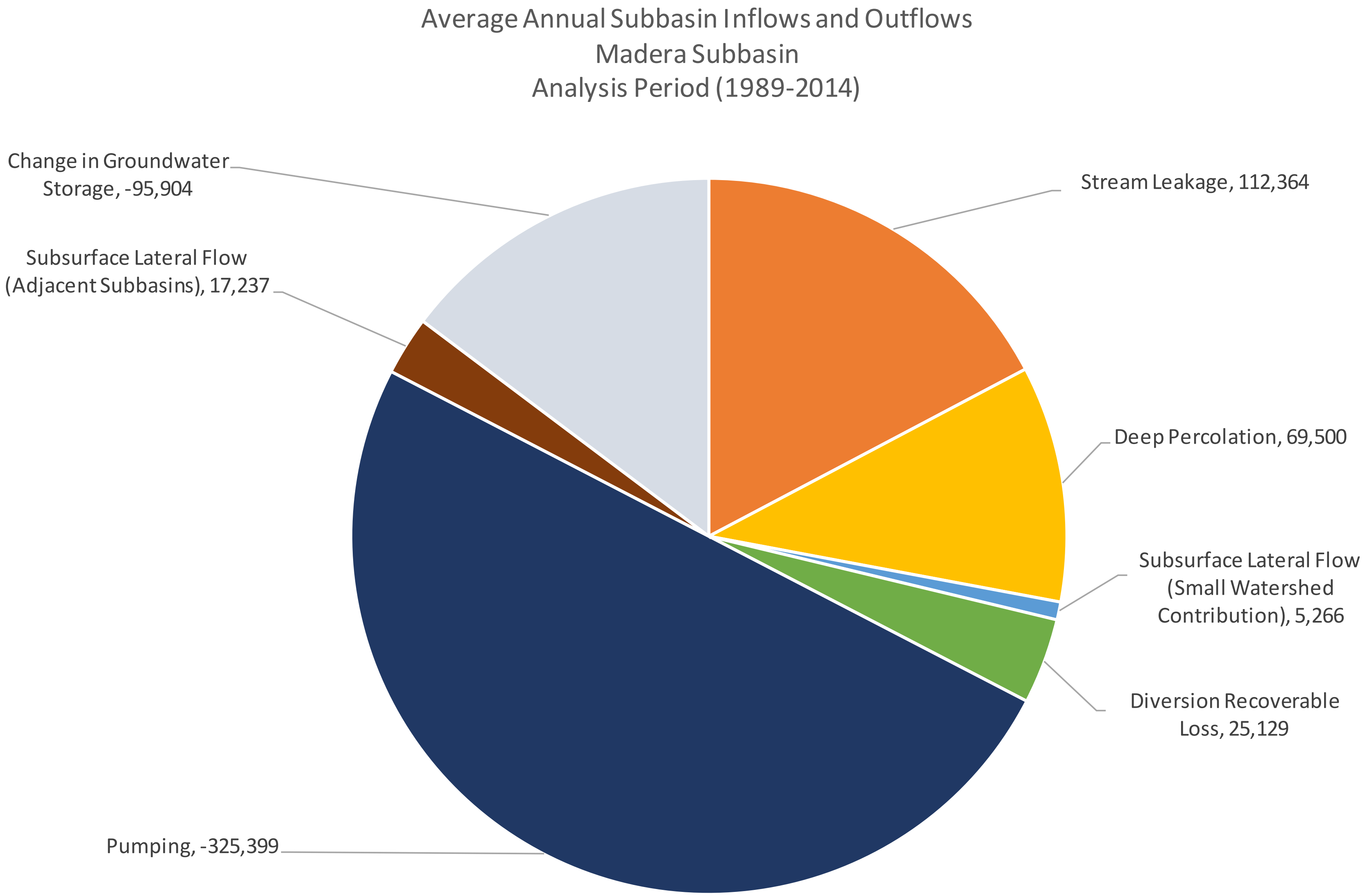
FIGURE D-1

Preliminary Model-Based Results for All Annual Subbasin Inflows and Outflows

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.
Change in Groundwater Storage term does not represent an inflow or outflow to basin, rather represents the difference between inflows and outflows.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure D-2 Model-Based Results for Average Annual Subbasin Inflows and Outflows.mxd

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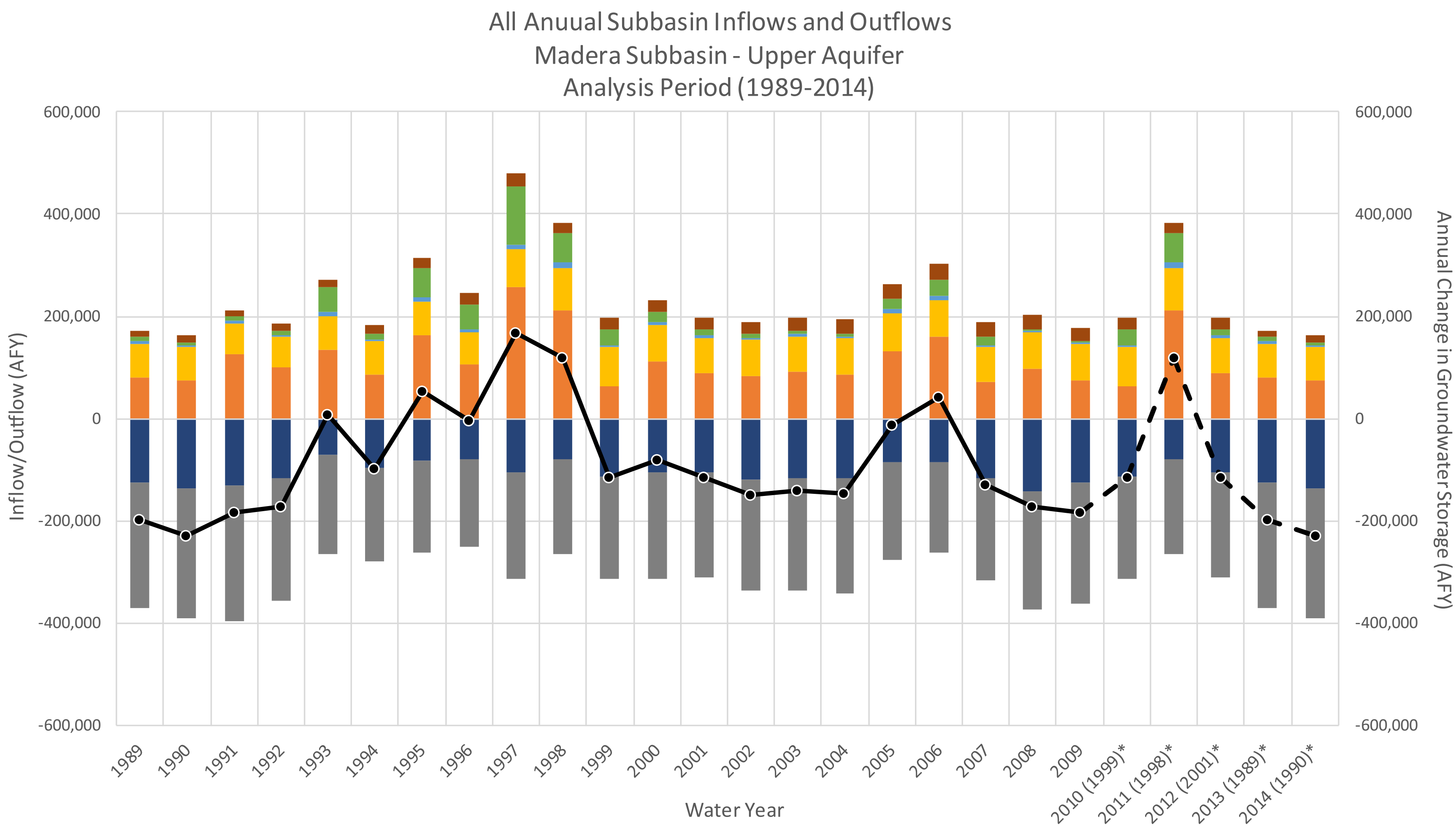
FIGURE D-2

Preliminary Model-Based Results for Average Annual Subbasin Inflows and Outflows

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



**Results presented for years 2010-2014 are from substitue years indicated in parentheses.*
NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.
The C2VSim-CG simulation period ends in 2009; dashed lines are used for 2010-2014 where results for substitued years are presented.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure D-3 Model-Based Results for All Annual Subbasin Inflows and Outflows - Upper Aquifer.mxd

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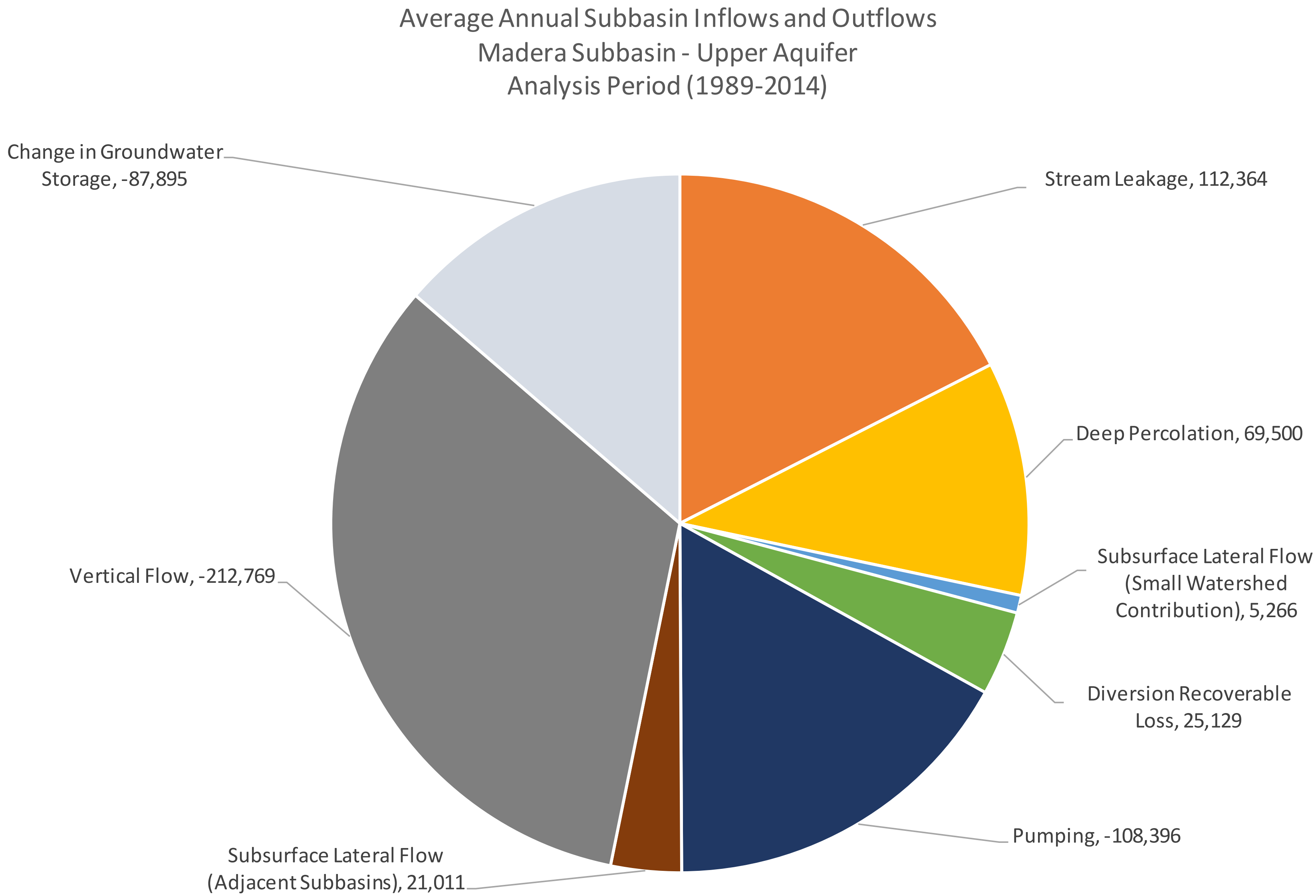
FIGURE D-3
Preliminary Model-Based Results for All Annual Subbasin Inflows and Outflows Upper Aquifer

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.
Change in Groundwater Storage term does not represent an inflow or outflow to basin, rather represents the difference between inflows and outflows.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure D-4 Model-Based Results for Average Annual Subbasin Inflows and Outflows - Upper Aquifer.mxd

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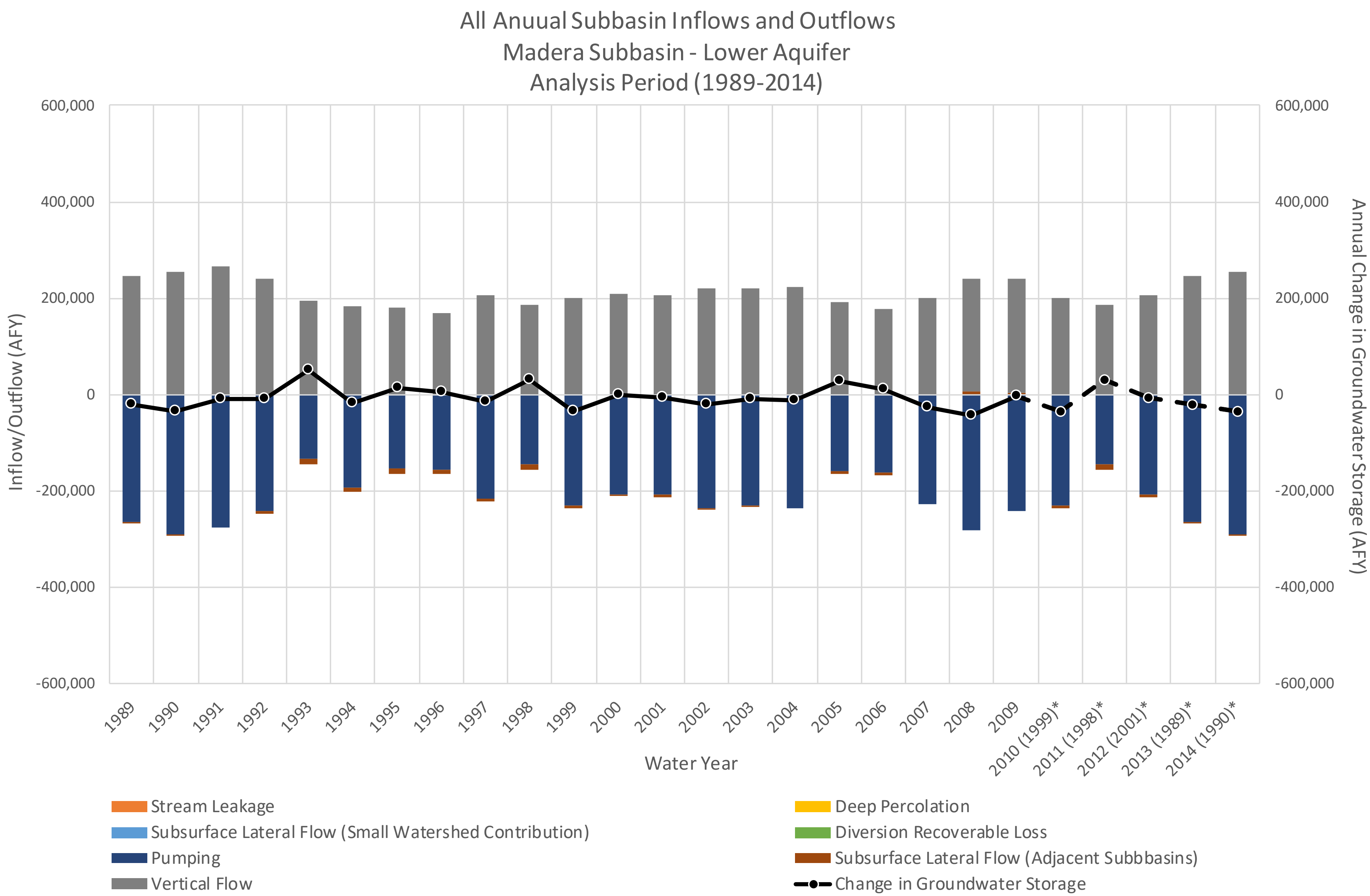
FIGURE D-4
Preliminary Model-Based Results for Average Annual Subbasin Inflows and Outflows Upper Aquifer

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



**Results presented for years 2010-2014 are from substitue years indicated in parentheses.*

NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows. Subsurface lateral flows from small watershed contributions are limited to Upper Aquifer. The C2VSim-CG simulation period ends in 2009; dashed lines are used for 2010-2014 where results for substitued years are presented.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure D-5 Model-Based Results for All Annual Subbasin Inflows and Outflows - Lower Aquifer.mxd

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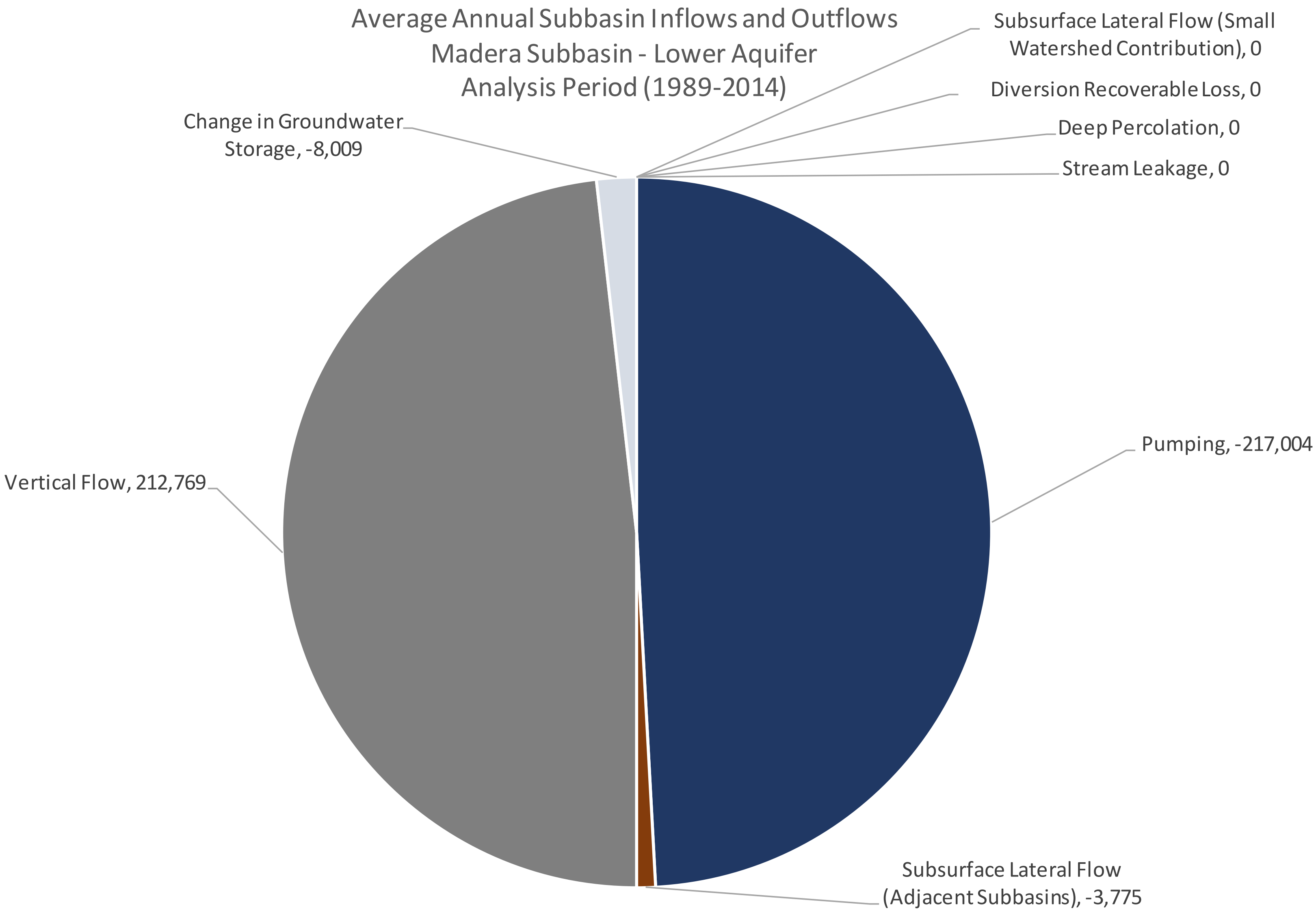
FIGURE D-5
Preliminary Model-Based Results for All Annual Subbasin Inflows and Outflows Lower Aquifer

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



NOTE: Negative lateral flow values indicate outflow; positive lateral flow values indicate inflows.
Change in Groundwater Storage term does not represent an inflow or outflow to basin, rather represents the difference between inflows and outflows.

X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure D-6 Model-Based Results for Average Annual Subbasin Inflows and Outflows - Lower Aquifer.mxd

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FIGURE D-6
Preliminary Model-Based Results for Average Annual Subbasin Inflows and Outflows Lower Aquifer

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget

Table D-1 Model-Based Results for Water Budget Components for the Entire Madera Subbasin (AFY)

	Change in Groundwater Storage				Groundwater Recharge						Groundwater Pumping			Subsurface Lateral Flow				
						Small Watershed Contribution												
Water Year	Specific Storage/ Specific Yield	Subsidence	Total Change in Groundwater Storage	Stream Leakage	Deep Percolation	Small Watershed Baseflow	Small Watershed Percolation	Total Small Watershed Contribution	Diversion Recoverable Loss	Total Groundwater Recharge	Agricultural Pumping	Urban Pumping	Total Groundwater Pumping	Chowchilla Subbasin	Delta-Mendota Subbasin	Kings Subbasin	Merced Subbasin	Total Subsurface Lateral Flow
1989	-215,434	-5,540	-220,975	80,148	66,920	595	2,763	3,358	8,595	78,873	-379,083	-12,965	-392,047	-16,560	2,219	23,232	3,161	12,052
1990	-257,031	-7,868	-264,899	75,669	64,956	526	1,958	2,483	6,420	73,860	-412,551	-13,480	-426,031	-15,904	3,204	21,148	3,155	11,603
1991	-187,012	-7,808	-194,820	124,795	61,660	465	3,725	4,190	8,115	73,965	-392,233	-15,041	-407,274	-16,026	2,521	24,200	3,001	13,695
1992	-176,622	-4,847	-181,470	100,253	60,038	411	3,521	3,932	7,507	71,476	-347,029	-14,495	-361,524	-16,788	347	21,768	2,999	8,325
1993	56,318	609	56,927	135,145	64,730	467	8,247	8,715	49,195	122,639	-189,984	-13,228	-203,212	-19,698	-2,052	21,909	2,196	2,355
1994	-115,581	-1,150	-116,731	86,963	64,409	462	2,329	2,791	11,655	78,855	-274,986	-14,940	-289,926	-17,604	-1,767	23,797	2,951	7,377
1995	67,014	85	67,099	163,798	63,480	538	8,279	8,817	57,588	129,885	-220,182	-16,142	-236,324	-16,813	-951	24,645	2,860	9,740
1996	-1,516	-73	-1,589	105,056	64,195	563	5,423	5,986	48,537	118,718	-221,431	-14,582	-236,014	-17,165	334	24,807	2,675	10,651
1997	152,602	-1,049	151,554	258,214	73,578	795	8,017	8,812	114,880	197,270	-310,280	-13,970	-324,250	-15,088	2,851	33,512	-956	20,319
1998	148,543	537	149,080	211,640	82,736	1,093	11,006	12,098	57,589	152,423	-207,952	-16,417	-224,369	-20,319	321	30,182	-798	9,386
1999	-149,701	-1,808	-151,509	64,447	74,572	1,125	2,276	3,400	32,125	110,097	-329,156	-15,922	-345,078	-19,080	2,157	34,573	1,375	19,025
2000	-81,330	-1,026	-82,356	110,423	71,255	994	5,967	6,961	20,586	98,802	-295,208	-16,010	-311,218	-18,011	2,061	32,589	2,999	19,637
2001	-120,847	-1,543	-122,389	87,724	69,595	878	3,875	4,753	12,651	86,999	-298,277	-17,148	-315,425	-17,227	2,035	29,804	3,701	18,313
2002	-165,654	-3,671	-169,325	83,842	70,288	776	2,827	3,603	7,826	81,716	-338,555	-17,649	-356,204	-16,130	2,638	30,786	4,027	21,321
2003	-146,428	-3,188	-149,616	90,429	70,856	686	3,450	4,136	7,146	82,138	-326,837	-18,229	-345,067	-15,648	3,334	31,114	4,083	22,883
2004	-155,522	-3,833	-159,355	86,837	69,039	606	2,683	3,290	7,866	80,194	-334,979	-17,966	-352,944	-14,612	4,404	32,846	3,921	26,558
2005	13,495	53	13,548	132,461	72,982	536	7,607	8,143	21,612	102,737	-227,065	-17,357	-244,422	-15,856	3,203	31,750	3,675	22,772
2006	50,718	-42	50,676	160,874	71,669	474	7,098	7,572	32,700	111,941	-232,850	-16,721	-249,571	-14,433	3,982	34,714	3,169	27,432
2007	-153,497	-1,926	-155,423	71,897	68,718	419	1,473	1,892	18,783	89,393	-323,444	-20,041	-343,485	-13,423	5,082	31,804	3,310	26,773
2008	-206,467	-8,298	-214,765	96,785	70,862	370	3,235	3,605	2,697	77,165	-402,053	-21,914	-423,966	-12,289	6,488	36,997	4,055	35,251
2009	-180,977	-5,492	-186,469	74,427	71,680	327	1,969	2,296	1,899	75,875	-346,676	-22,401	-369,077	-12,916	5,826	35,122	4,273	32,305
2010 (1999)*	-149,701	-1,808	-151,509	64,447	74,572	1,125	2,276	3,400	32,125	110,097	-329,156	-15,922	-345,078	-19,080	2,157	34,573	1,375	19,025
2011 (1998)*	148,543	537	149,080	211,640	82,736	1,093	11,006	12,098	57,589	152,423	-207,952	-16,417	-224,369	-20,319	321	30,182	-798	9,386
2012 (2001)*	-120,847	-1,543	-122,389	87,724	69,595	878	3,875	4,753	12,651	86,999	-298,277	-17,148	-315,425	-17,227	2,035	29,804	3,701	18,313
2013 (1989)*	-215,434	-5,540	-220,975	80,148	66,920	595	2,763	3,358	8,595	78,873	-379,083	-12,965	-392,047	-16,560	2,219	23,232	3,161	12,052
2014 (1990)*	-257,031	-7,868	-264,899	75,669	64,956	526	1,958	2,483	6,420	73,860	-412,551	-13,480	-426,031	-15,904	3,204	21,148	3,155	11,603
ANALYSIS PERIOD (1989-2014)																		
Average	-93,054	-2,850	-95,904	112,364	69,500	666	4,600	5,266	25,129	99,895	-309,147	-16,252	-325,399	-16,565	2,237	28,855	2,709	17,237
Minimum	-257,031	-8,298	-264,899	64,447	60,038	327	1,473	1,892	1,899	71,476	-412,551	-22,401	-426,031	-20,319	-2,052	21,148	-956	2,355
Maximum	152,602	609	151,554	258,214	82,736	1,125	11,006	12,098	114,880	197,270	-189,984	-12,965	-203,212	-12,289	6,488	36,997	4,273	35,251
WET PERIOD (1990-1998)																		
Average	-34,809	-2,396	-37,205	140,170	66,642	591	5,834	6,425	40,165	113,232	-286,292	-14,699	-300,992	-17,267	534	25,108	2,009	10,383
Minimum	-257,031	-7,868	-264,899	75,669	60,038	411	1,958	2,483	6,420	71,476	-412,551	-16,417	-426,031	-20,319	-2,052	21,148	-956	2,355
Maximum	152,602	609	151,554	258,214	82,736	1,093	11,006	12,098	114,880	197,270	-189,984	-13,228	-203,212	-15,088	3,204	33,512	3,155	20,319
AVERAGE PERIOD (1999-2010)																		
Average	-120,493	-2,715	-123,208	93,716	71,341	693	3,728	4,421	16,501	92,263	-315,355	-18,107	-333,461	-15,725	3,614	33,056	3,330	24,275
Minimum	-206,467	-8,298	-214,765	64,447	68,718	327	1,473	1,892	1,899	75,875	-402,053	-22,401	-423,966	-19,080	2,035	29,804	1,375	18,313
Maximum	50,718	53	50,676	160,874	74,572	1,125	7,607	8,143	32,700	111,941	-227,065	-15,922	-244,422	-12,289	6,488	36,997	4,273	35,251
DRY PERIOD (2011-2014)																		
Average	-111,192	-3,604	-114,796	113,795	71,052	773	4,901	5,673	21,314	98,039	-324,466	-15,003	-339,468	-17,503	1,945	26,092	2,305	12,839
Minimum	-257,031	-7,868	-264,899	75,669	64,956	526	1,958	2,483	6,420	73,860	-412,551	-17,148	-426,031	-20,319	321	21,148	-798	9,386
Maximum	148,543	537	149,080	211,640	82,736	1,093	11,006	12,098	57,589	152,423	-207,952	-12,965	-224,369	-15,904	3,204	30,182	3,701	18,313

*Results presented for years 2010-2014 are from substitute years indicated in parentheses.

Table D-2 Model-Based Results for Water Budget Components for the Upper Aquifer of the Madera Subbasin (AFY)

	Change in Groundwater Storage				Groundwater Recharge							Groundwater Pumping			Subsurface Lateral Flow					
						Small Watershed Contribution													
Water Year	Specific Storage/ Specific Yield	Subsidence	Total Change in Groundwater Storage	Stream Leakage	Deep Percolation	Small Watershed Baseflow	Small Watershed Percolation	Total Small Watershed Contribution	Diversion Recoverable Loss	Total Groundwater Recharge	Agricultural Pumping	Urban Pumping	Total Groundwater Pumping	Chowchilla Subbasin	Delta-Mendota Subbasin	Kings Subbasin	Merced Subbasin	Total Subsurface Lateral Flow	Vertical Flow (Downward)
1989	-199,008	-198	-199,207	80,148	66,920	595	2,763	3,358	8,595	78,873	-112,984	-12,965	-125,949	-5,612	4,461	13,294	880	13,023	-245,301
1990	-227,939	-306	-228,245	75,669	64,956	526	1,958	2,483	6,420	73,860	-122,960	-13,480	-136,440	-4,667	4,576	11,446	907	12,262	-253,596
1991	-183,589	-701	-184,290	124,795	61,660	465	3,725	4,190	8,115	73,965	-116,905	-15,041	-131,946	-4,538	3,761	13,492	784	13,500	-264,603
1992	-172,260	-843	-173,104	100,253	60,038	411	3,521	3,932	7,507	71,476	-103,432	-14,495	-117,927	-4,279	3356	12,824	869	12,771	-239,676
1993	7,866	-266	7,600	135,145	64,730	467	8,247	8,715	49,195	122,639	-56,625	-13,228	-69,853	-5,137	4,136	15,133	372	14,504	-194,835
1994	-96,888	-538	-97,426	86,963	64,409	462	2,329	2,791	11,655	78,855	-81,960	-14,940	-96,900	-3,667	4,327	16,003	970	17,633	-183,976
1995	53,157	-109	53,049	163,798	63,480	538	8,279	8,817	57,588	129,885	-65,626	-16,142	-81,768	-2,619	5766	17,053	859	21,060	-179,926
1996	-4,863	-109	-4,972	105,056	64,195	563	5,423	5,986	48,537	118,718	-65,999	-14,582	-80,581	-2,920	6344	17,003	710	21,138	-169,303
1997	167,633	-35	167,598	258,214	73,578	795	8,017	8,812	114,880	197,270	-92,481	-13,970	-106,451	-1,042	6,679	22,580	-2520	25,697	-207,133
1998	118,754	29	118,782	211,640	82,736	1,093	11,006	12,098	57,589	152,423	-61,982	-16,417	-78,399	-4,679	5841	21,011	-2261	19,912	-186,794
1999	-116,376	-189	-116,565	64,447	74,572	1,125	2,276	3,400	32,125	110,097	-98,108	-15,922	-114,030	-4,834	6,337	22,421	-695	23,228	-200,307
2000	-80,661	-336	-80,997	110,423	71,255	994	5,967	6,961	20,586	98,802	-87,990	-16,010	-104,000	-4,151	6,042	20,881	547	23,319	-209,542
2001	-113,838	-579	-114,417	87,724	69,595	878	3,875	4,753	12,651	86,999	-88,905	-17,148	-106,053	-3,482	6,041	18,593	1,097	22,248	-205,335
2002	-147,915	-1,055	-148,970	83,842	70,288	776	2,827	3,603	7,826	81,716	-100,911	-17,649	-118,560	-3,094	6,122	18,593	1,344	22,965	-218,932
2003	-139,456	-1,091	-140,547	90,429	70,856	686	3,450	4,136	7,146	82,138	-97,419	-18,229	-115,648	-2,717	6,379	18,827	1,445	23,934	-221,401
2004	-146,713	-1,342	-148,055	86,837	69,039	606	2,683	3,290	7,866	80,194	-99,846	-17,966	-117,811	-2,134	6,681	20,191	1,371	26,109	-223,383
2005	-12,558	-416	-12,974	132,461	72,982	536	7,607	8,143	21,612	102,737	-67,680	-17,357	-85,037	-2,266	7,013	21,318	1,344	27,409	-190,543
2006	41,223	-221	41,002	160,874	71,669	474	7,098	7,572	32,700	111,941	-69,404	-16,721	-86,126	-913	7,432	23,993	856	31,368	-177,055
2007	-127,766	-1,004	-128,770	71,897	68,718	419	1,473	1,892	18,783	89,393	-96,407	-20,041	-116,449	-1,416	7,125	19,872	872	26,454	-200,064
2008	-169,644	-1,871	-171,515	96,785	70,862	370	3,235	3,605	2,697	77,165	-119,838	-21,914	-141,751	-1,343	7,093	22,339	1,377	29,466	-233,180
2009	-181,532	-2,065	-183,597	74,427	71,680	327	1,969	2,296	1,899	75,875	-103,332	-22,401	-125,733	-1,621	6,820	20,860	1,563	27,622	-235,789
2010 (1999)*	-116,376	-189	-116,565	64,447	74,572	1,125	2,276	3,400	32,125	110,097	-98,108	-15,922	-114,030	-4,834	6,337	22,421	-695	23,228	-200,307
2011 (1998)*	118,754	29	118,782	211,640	82,736	1,093	11,006	12,098	57,589	152,423	-61,982	-16,417	-78,399	-4,679	5841	21,011	-2261	19,912	-186,794
2012 (2001)*	-113,838	-579	-114,417	87,724	69,595	878	3,875	4,753	12,651	86,999	-88,905	-17,148	-106,053	-3,482	6,041	18,593	1,097	22,248	-205,335
2013 (1989)*	-199,008	-198	-199,207	80,148	66,920	595	2,763	3,358	8,595	78,873	-112,984	-12,965	-125,949	-5,612	4,461	13,294	880	13,023	-245,301
2014 (1990)*	-227,939	-306	-228,245	75,669	64,956	526	1,958	2,483	6,420	73,860	-122,960	-13,480	-136,440	-4,667	4,576	11,446	907	12,262	-253,596
ANALYSIS PERIOD (1989-2014)																			
Average	-87,338	-557	-87,895	112,364	69,500	666	4,600	5,266	25,129	99,895	-92,144	-16,252	-108,396	-3,477	5,753	18,250	485	21,011	-212,770
Minimum	227,939	2,065	228,245	-64,447	-60,038	-327	-1,473	-1,892	-1,899	-71,476	122,960	22,401	141,751	5,612	-3,356	-11,446	2,520	-12,262	264,603
Maximum	167,633	29	167,598	258,214	82,736	1,125	11,006	12,098	114,880	197,270	-56,625	-12,965	-69,853	-913	7,432	23,993	1,563	31,368	-169,303
WET PERIOD (1990-1998)																			
Average	-37,570	-320	-37,890	140,170	66,642	591	5,834	6,425	40,165	113,232	-85,330	-14,699	-100,029	-3,728	4,976	16,283	77	17,609	-208,871
Minimum	-227,939	-843	-228,245	75,669	60,038	411	1,958	2,483	6,420	71,476	-122,960	-16,417	-136,440	-5,137	3,356	11,446	-2,520	12,262	-264,603
Maximum	167,633	29	167,598	258,214	82,736	1,093	11,006	12,098	114,880	197,270	-56,625	-13,228	-69,853	-1,042	6,679	22,580	970	25,697	-169,303
AVERAGE PERIOD (1999-2010)																			
Average	-109,301	-863	-110,164	93,716	71,341	693	3,728	4,421	16,501	92,263	-93,996	-18,107	-112,102	-2,734	6,619	20,859	869	25,613	-209,653
Minimum	-181,532	-2,065	-183,597	64,447	68,718	327	1,473	1,892	1,899	75,875	-119,838	-22,401	-141,751	-4,834	6,041	18,593	-695	22,248	-235,789
Maximum	41,223	-189	41,002	160,874	74,572	1,125	7,607	8,143	32,700	111,941	-67,680	-15,922	-85,037	-913	7,432	23,993	1,563	31,368	-177,055
DRY PERIOD (2011-2014)																			
Average	-105,508	-264	-105,772	113,795	71,052	773	4,901	5,673	21,314	98,039	-96,708	-15,003	-111,710	-4,610	5,230	16,086	156	16,861	-222,757
Minimum	-227,939	-579	-228,245	75,669	64,956	526	1,958	2,483	6,420	73,860	-122,960	-17,148	-136,440	-5,612	4,461	11,446	-2,261	12,262	-253,596
Maximum	118,754	29	118,782	211,640	82,736	1,093	11,006	12,098	57,589	152,423	-61,982	-12,965	-78,399	-3,482	6,041	21,011	1,097	22,248	-186,794

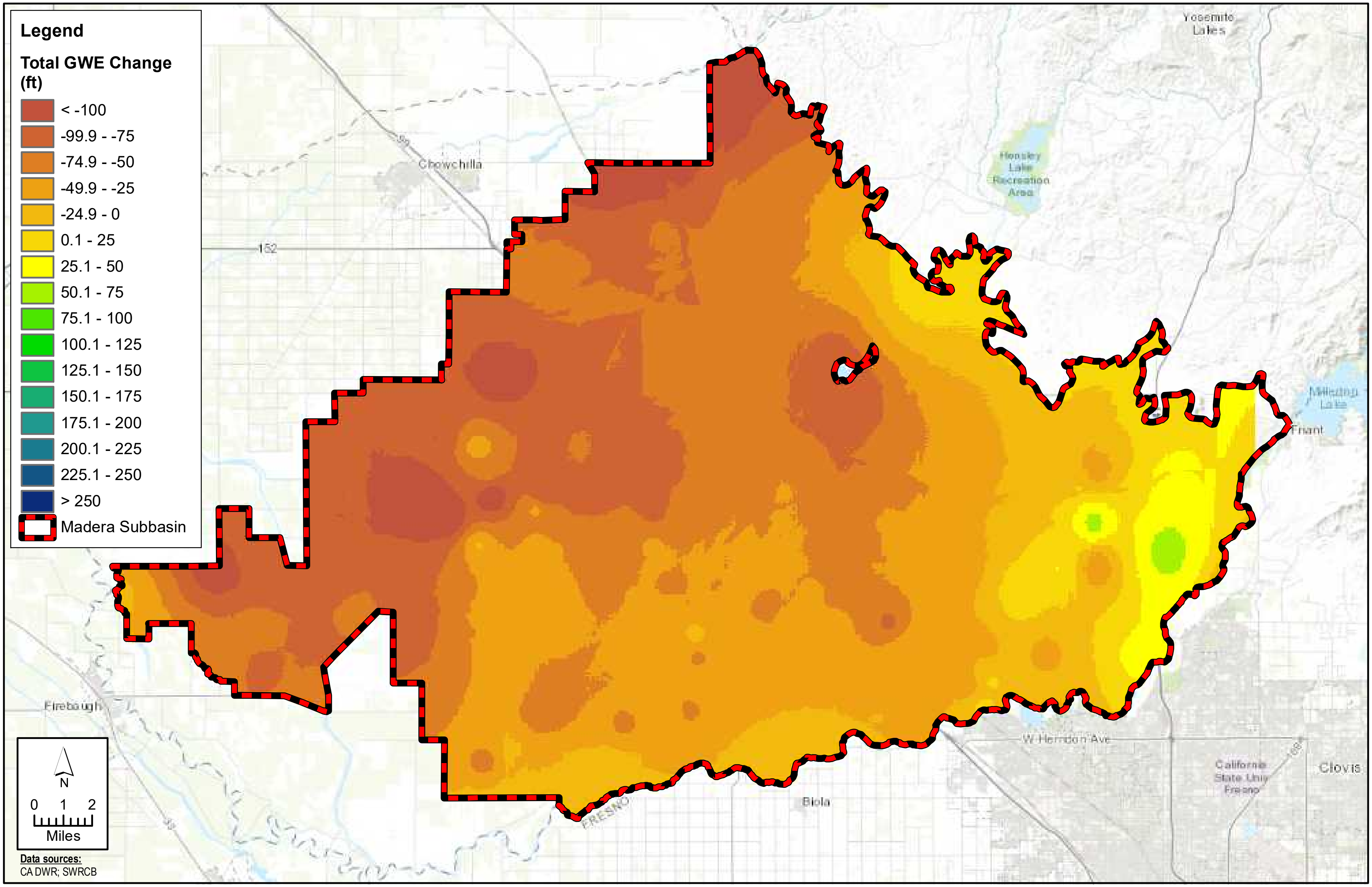
*Results presented for years 2010-2014 are from substitute years indicated in parentheses.

Table D-3 Model-Based Results for Water Budget Components for the Lower Aquifer of the Madera Subbasin (AFY)

	Change in Groundwater Storage				Groundwater Recharge						Groundwater Pumping			Subsurface Lateral Flow					
Water Year	Specific Storage/ Specific Yield	Subsidence	Total Change in Groundwater Storage	Stream Leakage	Deep Percolation	Small Watershed Contribution: Small Watershed Baseflow	Small Watershed Contribution: Small Watershed Percolation	Small Watershed Contribution: Total Small Watershed Contribution	Diversion Recoverable Loss	Total Groundwater Recharge	Agricultural Pumping	Urban Pumping	Total Groundwater Pumping	Chowchilla Subbasin	Delta-Mendota Subbasin	Kings Subbasin	Merced Subbasin	Total Subsurface Lateral Flow	Vertical Flow (Downward)
1989	-16,426	-5,342	-21,768	0	0	0	0	0	0	0	-266,098	0	-266,098	-10,948	-2,242	9,938	2,281	-971	245,301
1990	-29,092	-7,562	-36,654	0	0	0	0	0	0	0	-289,591	0	-289,591	-11,237	-1,371	9,702	2,247	-659	253,596
1991	-3,423	-7,106	-10,530	0	0	0	0	0	0	0	-275,328	0	-275,328	-11,489	-1,241	10,708	2,217	195	264,603
1992	-4,362	-4,004	-8,366	0	0	0	0	0	0	0	-243,597	0	-243,597	-12,509	-3009	8,943	2,130	-4,446	239,676
1993	48,452	875	49,327	0	0	0	0	0	0	0	-133,359	0	-133,359	-14,561	-6,188	6,776	1,824	-12,149	194,835
1994	-18,693	-612	-19,305	0	0	0	0	0	0	0	-193,025	0	-193,025	-13,938	-6,093	7,794	1,981	-10,256	183,976
1995	13,856	194	14,050	0	0	0	0	0	0	0	-154,556	0	-154,556	-14,194	-6718	7,591	2,001	-11,319	179,926
1996	3,347	36	3,383	0	0	0	0	0	0	0	-155,432	0	-155,432	-14,245	-6011	7,804	1,964	-10,487	169,303
1997	-15,030	-1,014	-16,044	0	0	0	0	0	0	0	-217,798	0	-217,798	-14,047	-3,828	10,933	1563	-5,378	207,133
1998	29,789	508	30,297	0	0	0	0	0	0	0	-145,970	0	-145,970	-15,640	-5520	9,171	1463	-10,526	186,794
1999	-33,325	-1,620	-34,944	0	0	0	0	0	0	0	-231,047	0	-231,047	-14,245	-4,180	12,152	2,069	-4,204	200,307
2000	-668	-690	-1,358	0	0	0	0	0	0	0	-207,218	0	-207,218	-13,860	-3,981	11,708	2,452	-3,682	209,542
2001	-7,009	-963	-7,972	0	0	0	0	0	0	0	-209,372	0	-209,372	-13,745	-4,006	11,211	2,604	-3,936	205,335
2002	-17,739	-2,617	-20,355	0	0	0	0	0	0	0	-237,644	0	-237,644	-13,036	-3,483	12,193	2,683	-1,644	218,932
2003	-6,971	-2,097	-9,068	0	0	0	0	0	0	0	-229,418	0	-229,418	-12,931	-3,045	12,288	2,638	-1,051	221,401
2004	-8,809	-2,491	-11,300	0	0	0	0	0	0	0	-235,133	0	-235,133	-12,478	-2,277	12,655	2,550	450	223,383
2005	26,052	469	26,522	0	0	0	0	0	0	0	-159,385	0	-159,385	-13,589	-3,810	10,432	2,331	-4,637	190,543
2006	9,495	180	9,675	0	0	0	0	0	0	0	-163,445	0	-163,445	-13,520	-3,450	10,722	2,313	-3,936	177,055
2007	-25,731	-922	-26,653	0	0	0	0	0	0	0	-227,037	0	-227,037	-12,007	-2,044	11,932	2,438	319	200,064
2008	-36,823	-6,427	-43,250	0	0	0	0	0	0	0	-282,215	0	-282,215	-10,947	-604	14,658	2,678	5,784	233,180
2009	554	-3,427	-2,872	0	0	0	0	0	0	0	-243,344	0	-243,344	-11,295	-994	14,262	2,709	4,682	235,789
2010 (1999)*	-33,325	-1,620	-34,944	0	0	0	0	0	0	0	-231,047	0	-231,047	-14,245	-4,180	12,152	2,069	-4,204	200,307
2011 (1998)*	29,789	508	30,297	0	0	0	0	0	0	0	-145,970	0	-145,970	-15,640	-5520	9,171	1463	-10,526	186,794
2012 (2001)*	-7,009	-963	-7,972	0	0	0	0	0	0	0	-209,372	0	-209,372	-13,745	-4,006	11,211	2,604	-3,936	205,335
2013 (1989)*	-16,426	-5,342	-21,768	0	0	0	0	0	0	0	-266,098	0	-266,098	-10,948	-2,242	9,938	2,281	-971	245,301
2014 (1990)*	-29,092	-7,562	-36,654	0	0	0	0	0	0	0	-289,591	0	-289,591	-11,237	-1,371	9,702	2,247	-659	253,596
ANALYSIS PERIOD (1989-2014)																			
Average	-5,716	-2,293	-8,009	0	0	0	0	0	0	0	-217,003	0	-217,003	-13,088	-3,516	10,606	2,223	-3,775	212,769
Minimum	-36,823	-7,562	-43,250	0	0	0	0	0	0	0	-289,591	0	-289,591	-15,640	-6,718	6,776	1,463	-12,149	169,303
Maximum	48,452	875	49,327	0	0	0	0	0	0	0	-133,359	0	-133,359	-10,947	-604	14,658	2,709	5,784	264,603
WET PERIOD (1990-1998)																			
Average	2,760	-2,076	684	0	0	0	0	0	0	0	-200,962	0	-200,962	-13,540	-4,442	8,825	1,932	-7,225	208,871
Minimum	-29,092	-7,562	-36,654	0	0	0	0	0	0	0	-289,591	0	-289,591	-15,640	-6,718	6,776	1,463	-12,149	169,303
Maximum	48,452	875	49,327	0	0	0	0	0	0	0	-133,359	0	-133,359	-11,237	-1,241	10,933	2,247	195	264,603
AVERAGE PERIOD (1999-2010)																			
Average	-11,192	-1,852	-13,043	0	0	0	0	0	0	0	-221,359	0	-221,359	-12,992	-3,005	12,197	2,461	-1,338	209,653
Minimum	-36,823	-6,427	-43,250	0	0	0	0	0	0	0	-282,215	0	-282,215	-14,245	-4,180	10,432	2,069	-4,637	177,055
Maximum	26,052	469	26,522	0	0	0	0	0	0	0	-159,385	0	-159,385	-10,947	-604	14,658	2,709	5,784	235,789
DRY PERIOD (2011-2014)																			
Average	-5,685	-3,340	-9,024	0	0	0	0	0	0	0	-227,758	0	-227,758	-12,893	-3,285	10,006	2,149	-4,023	222,756
Minimum	-29,092	-7,562	-36,654	0	0	0	0	0	0	0	-289,591	0	-289,591	-15,640	-5,520	9,171	1,463	-10,526	186,794
Maximum	29,789	508	30,297	0	0	0	0	0	0	0	-145,970	0	-145,970	-10,948	-1,371	11,211	2,604	-659	253,596

*Results presented for years 2010-2014 are from substitute years indicated in parentheses.

Appendix E
Annual Groundwater Level Change



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure E-1 Total GWE Change - Base Period (1989-2014).mxd

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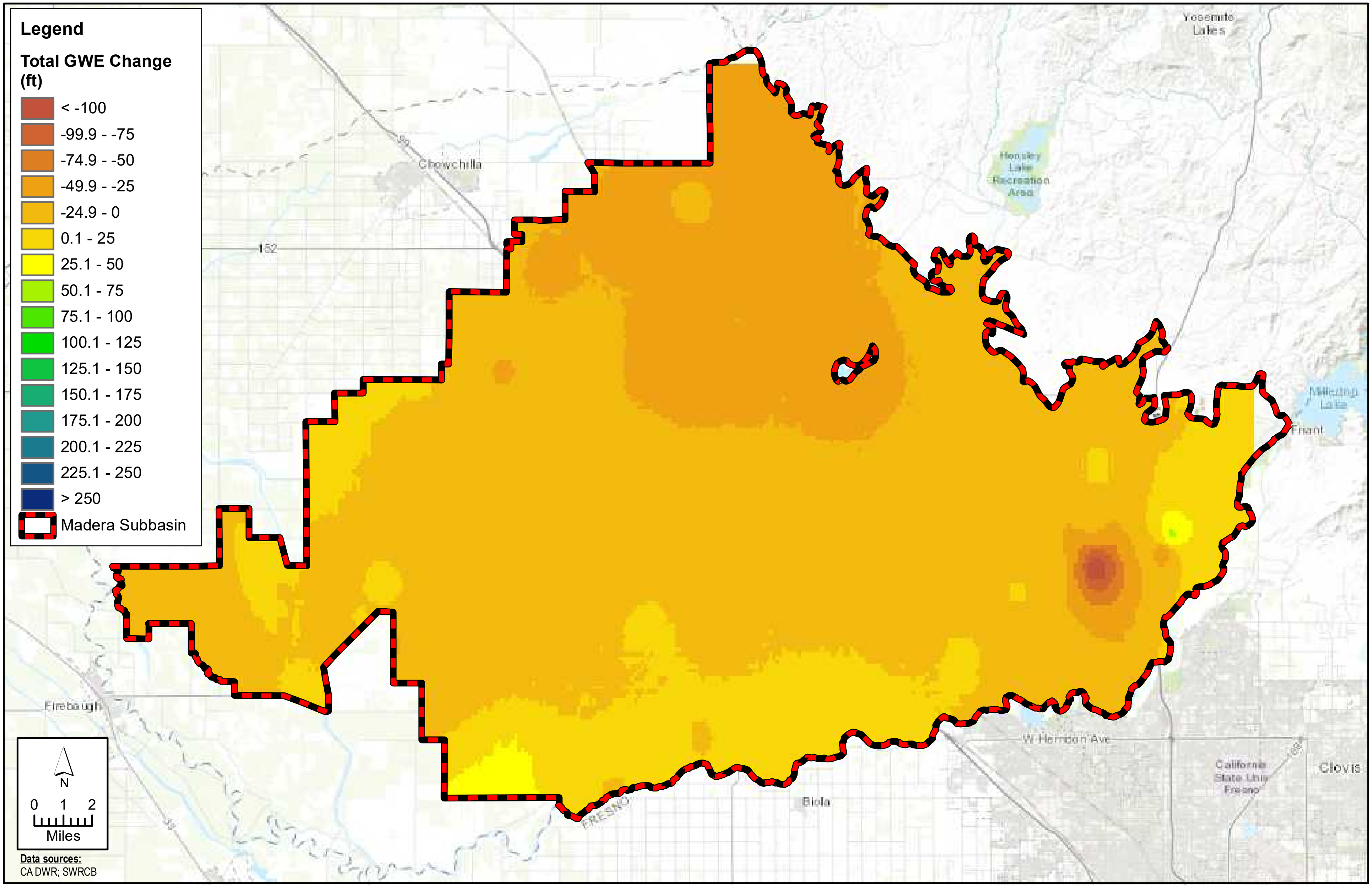
FIGURE E-1

Total Preliminary Groundwater Elevation Change - Base Period (1989-2014)

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure E-2 Total GWE Change - Wet Period (1990-1998).mxd

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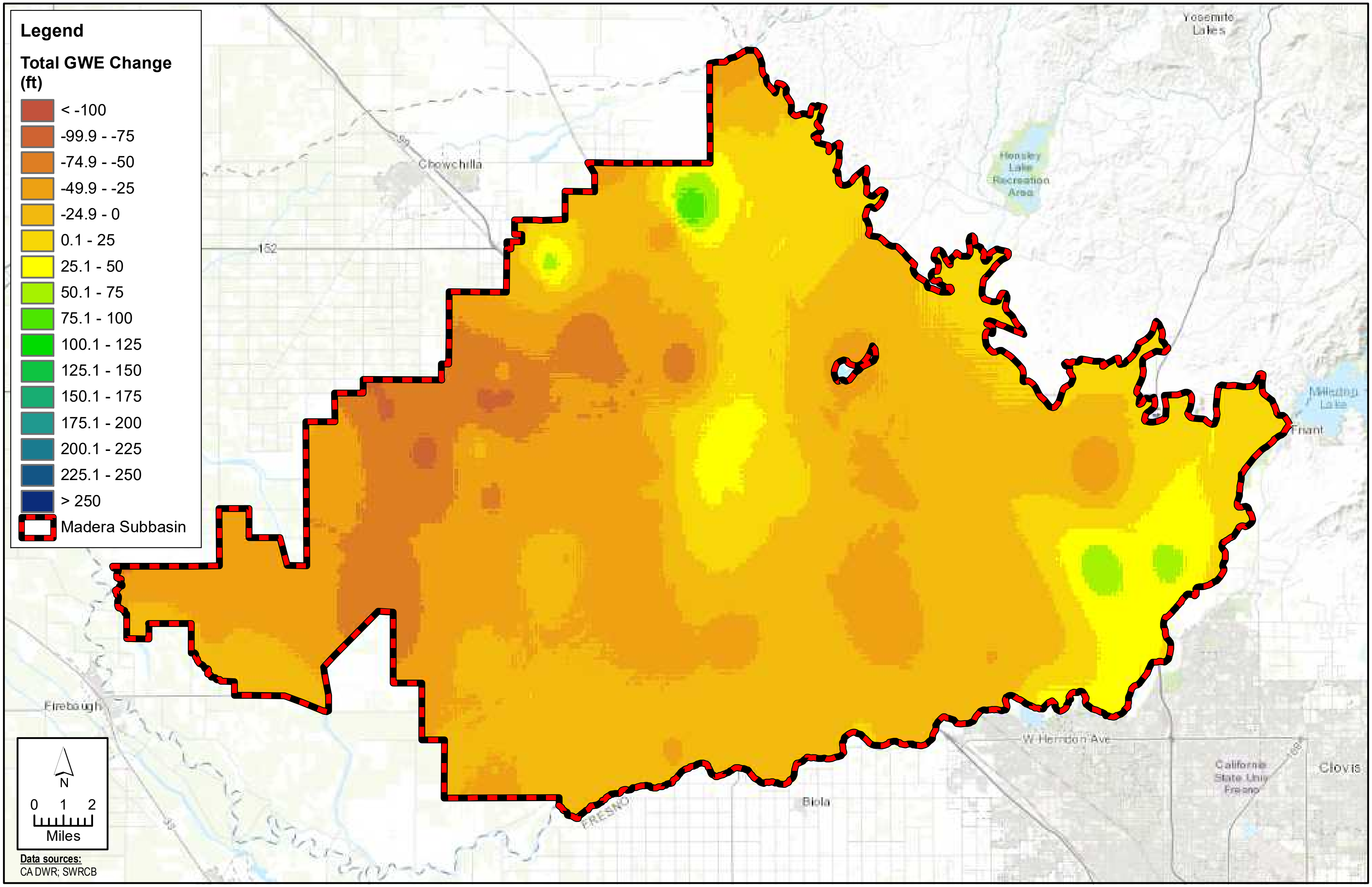
FIGURE E-2

Total Preliminary Groundwater Elevation Change - Wet Period (1990-1998)

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure E-3 Total GWE Change - Average Period (1999-2010).mxd

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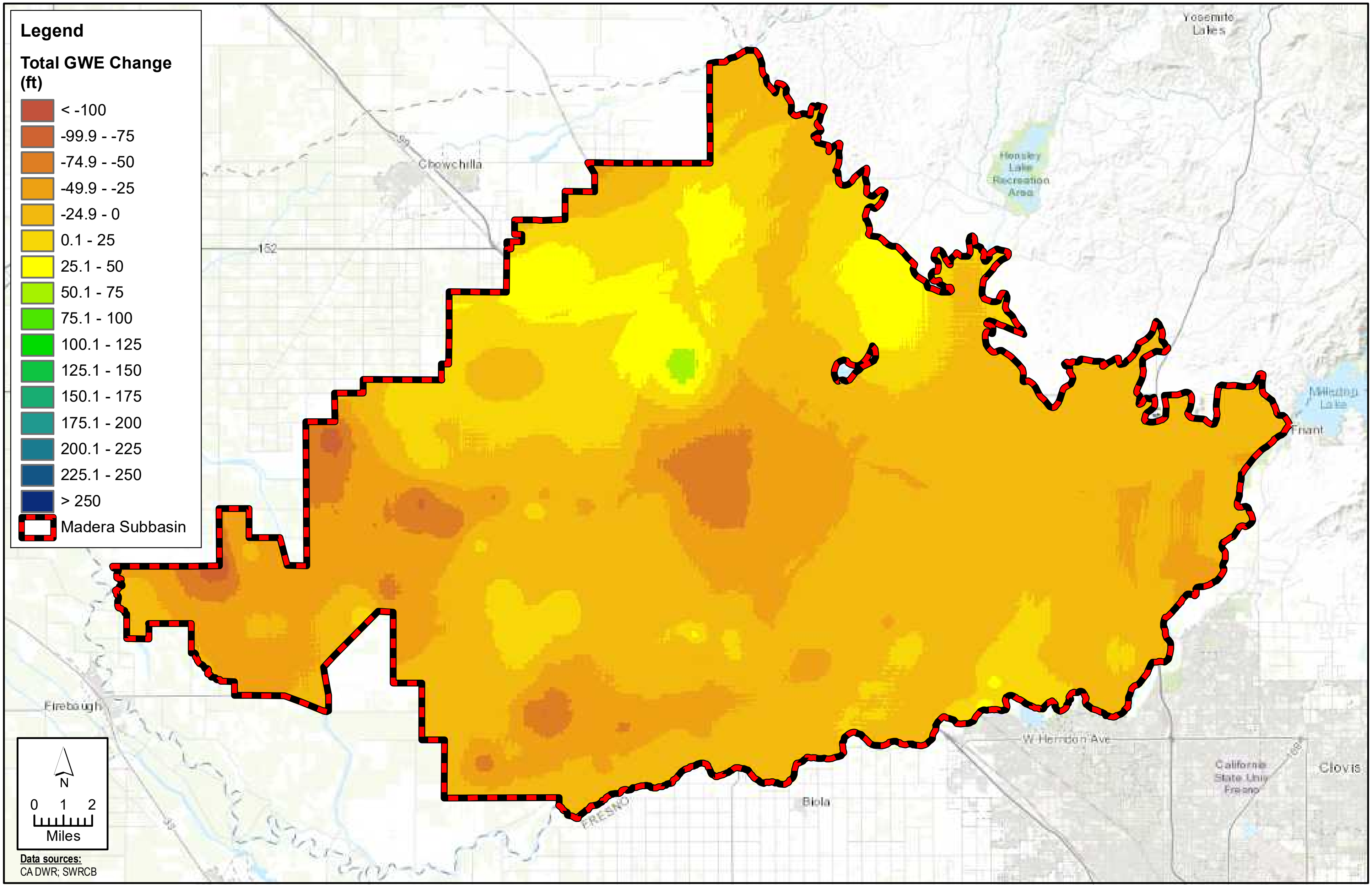
FIGURE E-3

Total Preliminary Groundwater Elevation Change - Average Period (1999-2010)

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure E-4 Total GWE Change - Dry Period (2011-2014).mxd

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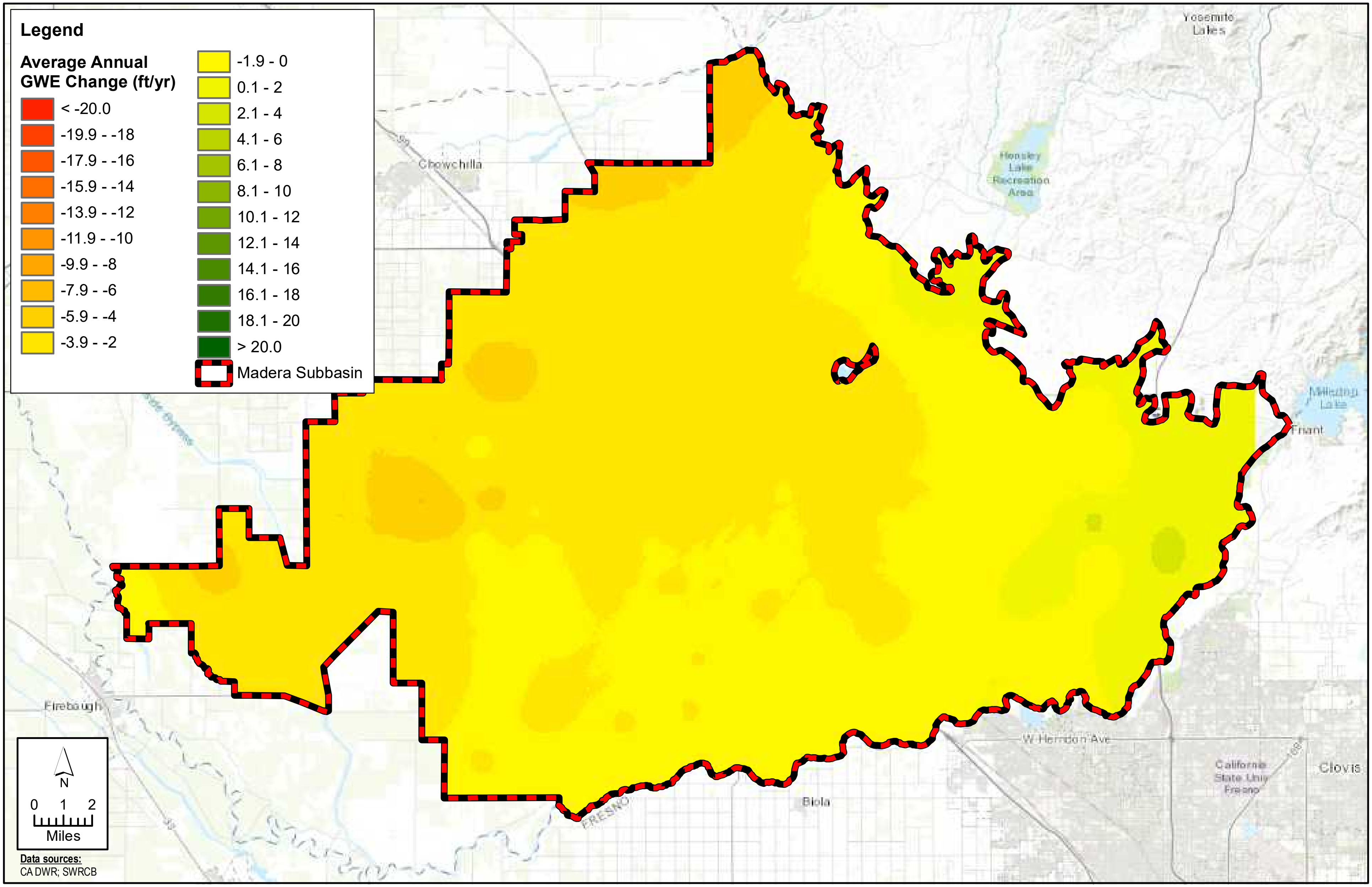
FIGURE E-4

Total Preliminary Groundwater Elevation Change - Dry Period (2011-2014)

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure E-5 Average Annual GWE Change - Base Period (1989-2014).mxd

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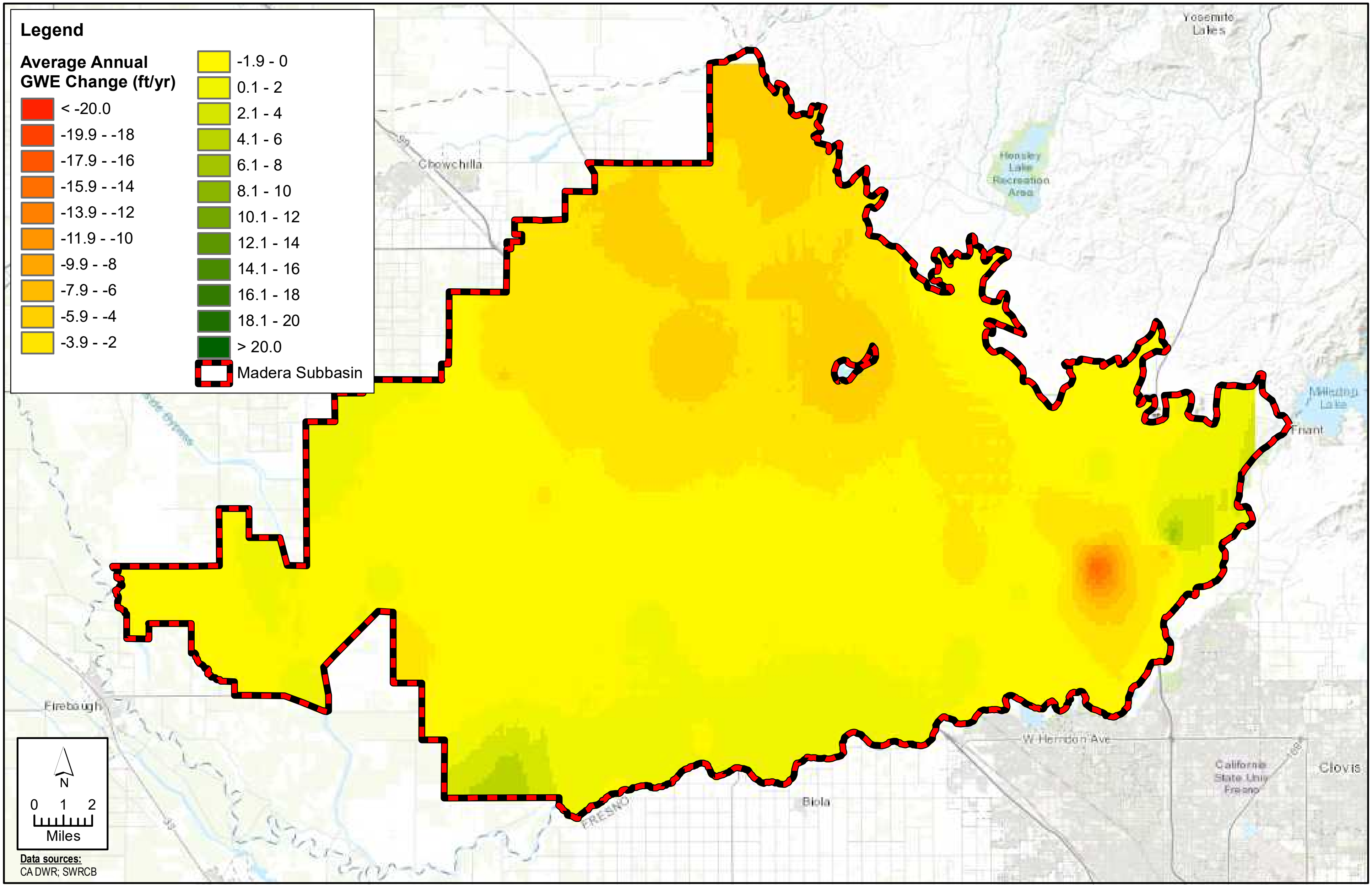
FIGURE E-5

Average Preliminary Annual Groundwater Elevation Change - Base Period (1989-2014)

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure E-6 Average Annual GWE Change - Wet Period (1990-1998).mxd

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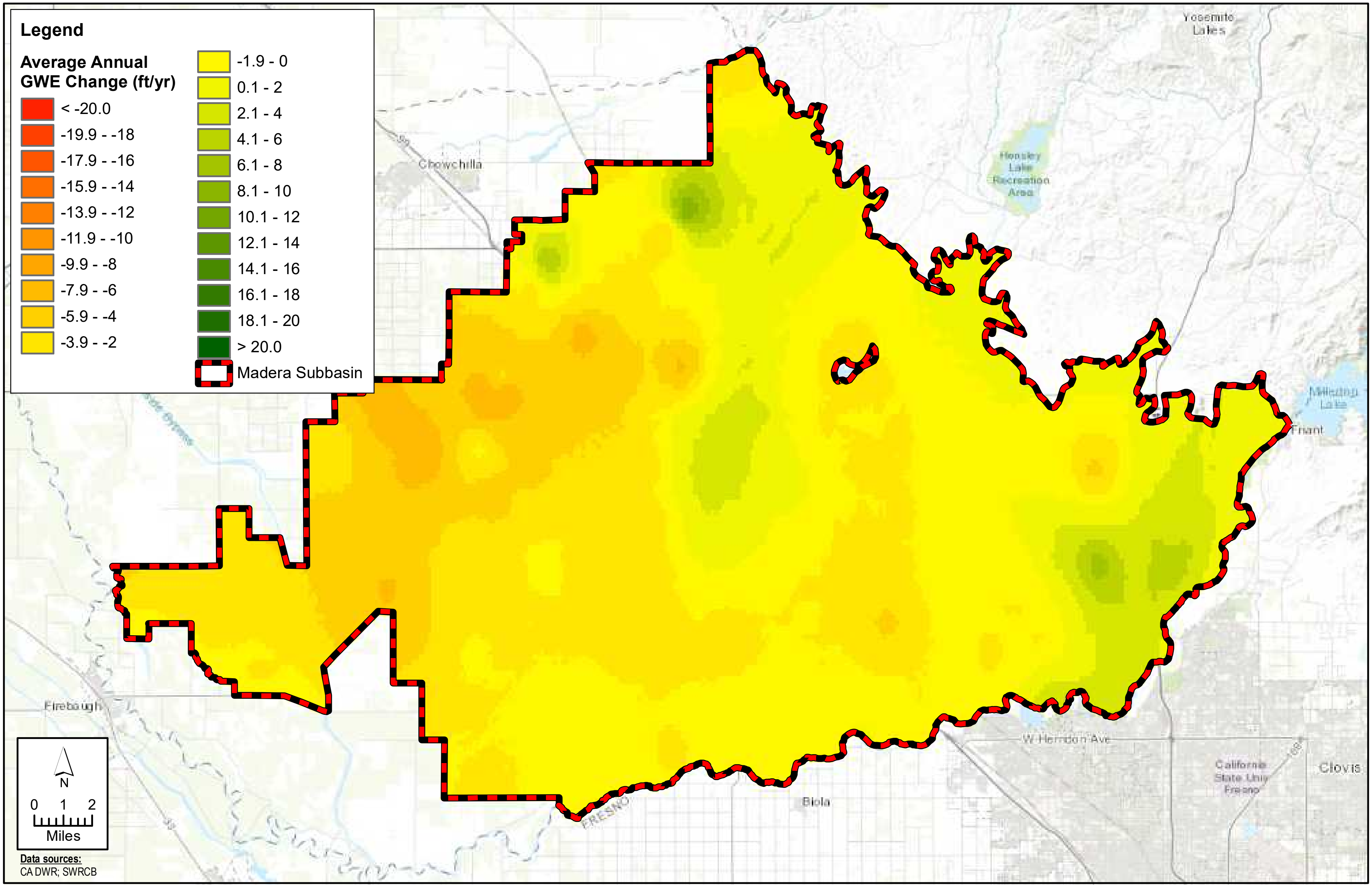
FIGURE E-6

Average Preliminary Annual Groundwater Elevation Change - Wet Period (1990-1998)

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure E-7 Average Annual GWE Change - Average Period (1999-2010).mxd

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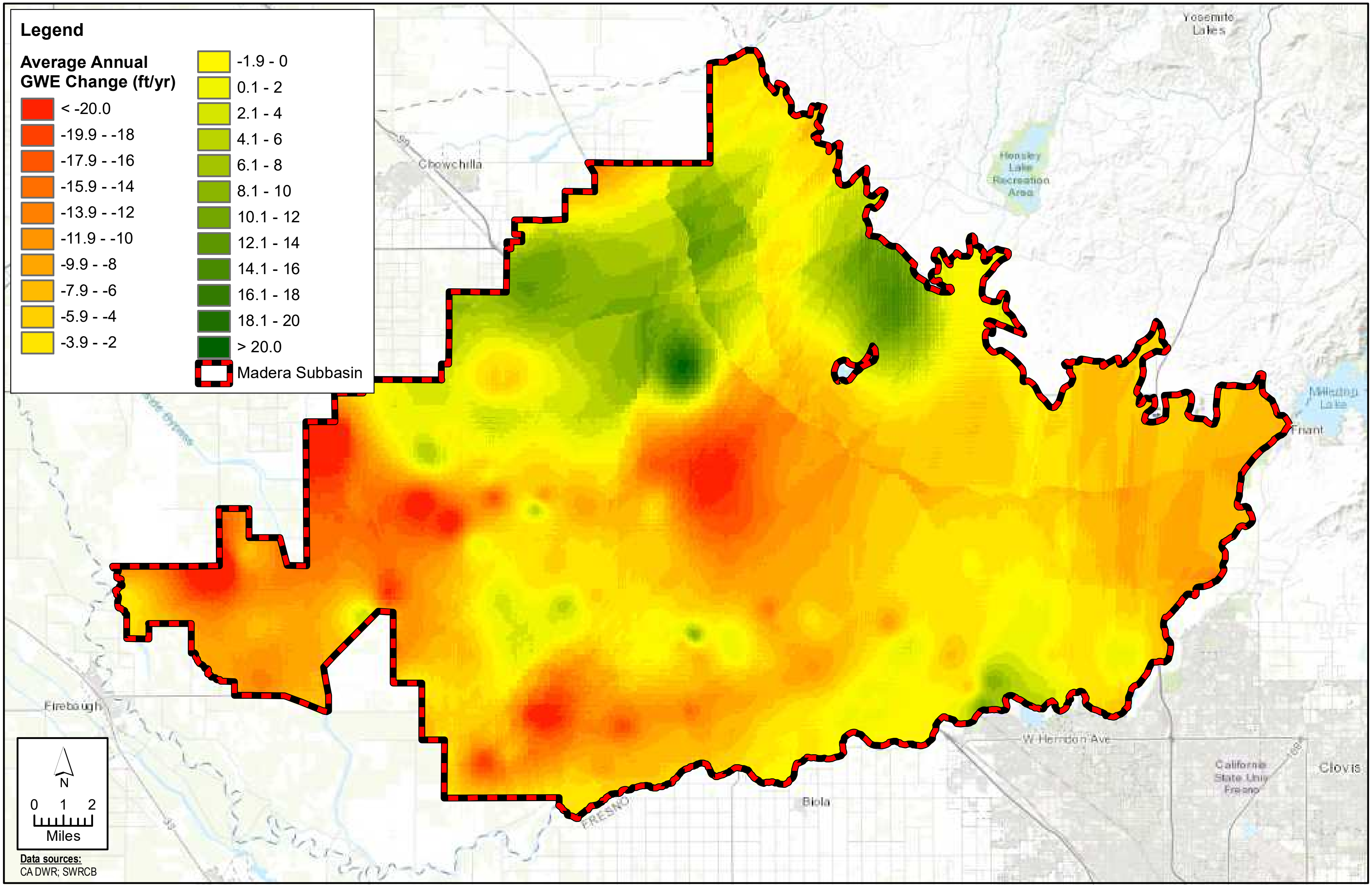
FIGURE E-7

Average Preliminary Annual Groundwater Elevation Change - Average Period (1999-2010)

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget



X:\2017\17-090 Davids Engineering-Madera Co. - Madera SubbasinWater Balance\GIS\Map Files\For TM\Figure E-8 Average Annual GWE Change - Dry Period (2011-2014).mxd

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FIGURE E-8

Average Preliminary Annual Groundwater Elevation Change - Dry Period (2011-2014)

Madera County: Madera Subbasin
SGMA Basin Boundary Water Budget