APPENDIX 6.D. GROUNDWATER MODEL DOCUMENTATION

Prepared as part of the

Joint Groundwater Sustainability Plan
Madera Subbasin

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LIST OF ABBREVIATIONS

3D	Three-Dimensional
AF	Acre-Feet
AN	Above Normal
BMP	Best Management Practice
BN	Below Normal
C	Critical
C2VSim	California Central Valley Groundwater-Surface Water Simulation Model
C2VSim-CG	California Central Valley Groundwater-Surface Water Simulation Model – Coarse Grid
C2VSim-FG Beta2	California Central Valley Groundwater-Surface Water Simulation Model – Fine Grid
CDEC	California Data Exchange Center
CIMIS	California Irrigation Management Information System
CVHM	Central Valley Hydrologic Model
CVP	Central Valley Project
CWD	Chowchilla Water District
D	Dry
DWR	California Department of Water Resources
ET	Evapotranspiration
ET_a	Actual ET
ET_c	Crop ET
ET_o	Grass Reference ET
ET_r	Alfalfa Reference ET
ET_{ref}	Reference Crop Evapotranspiration
eWRIMS	SWRCB Electronic Water Rights Information Management System
ft/d	Feet Per Day
GDE	Groundwater Dependent Ecosystem
GFWD	Gravelly Ford Water District
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
GWS	Groundwater System
HCM	Hydrogeologic Conceptual Model
IDC	Integrated Water Flow Model Demand Calculator
IWFM	Integrated Water Flow Model
Kh	Horizontal Hydraulic Conductivity
Kv	Vertical Hydraulic Conductivity
MA	Management Area
MC	Madera County
MCSim	Madera-Chowchilla Groundwater-Surface Water Simulation Model
MID	Madera Irrigation District
Model	Numerical Groundwater Flow Model
MWD	Madera Water District
NOAA NCEI	National Oceanic and Atmospheric Administration National Centers for Environmental Information

NRCS	United States Department of Agriculture Natural Resources Conservation Service
PM	Penman-Monteith
PRISM	Parameter Elevation Regression on Independent Slopes Model
RCWD	Root Creek Water District
SEBAL	Surface Energy Balance Algorithm for Land
SGMA	Sustainable Groundwater Management Act of 2014
SJRRP	San Joaquin River Restoration Program
SLDMWA	San Luis & Delta-Mendota Water Authority
SS	Specific Storage
SVMWC	Sierra Vista Mutual Water Company
SWP	State Water Project
SWRCB	State Water Resources Control Board
SWS	Surface Water System
Sy	Specific Yield
T-ProGS	Transition Probability Geostatistical Software
TTWD	Triangle T Water District
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
W	Wet
WCR	Well Completion Report

1 INTRODUCTION

This report documents the development and calibration of the Madera-Chowchilla Groundwater-Surface Water Simulation Model (MCSim), a numerical groundwater flow model developed for the Madera and Chowchilla Subbasin areas to support preparation of Groundwater Sustainability Plans (GSPs) for both subbasins along with other future potential groundwater management and planning needs. This report includes a summary of the model platform, data sources, model development and calibration, and calibration results.

1.1 Background

To support preparation of GSPs for the Madera and Chowchilla Subbasins, four Groundwater Sustainability Agencies (GSAs) in the Madera Subbasin (Madera County, Madera Irrigation District, Madera Water District and City of Madera) and all GSAs in the Chowchilla Subbasin (Chowchilla Water District, Madera County, Triangle T Water District, and Sierra Vista Mutual Water Company) elected to pursue development of a numerical groundwater flow model to be able to satisfy GSP regulations requiring use of a numerical groundwater model, or equally effective approach, to evaluate projected water budget conditions and potential impacts to groundwater conditions and users from the GSP implementation. The development of MCSim is intended to support groundwater resources management activities associated with GSP development and implementation. MCSim utilizes data and the hydrogeologic conceptualization that are presented and described in the GSPs for the Madera and Chowchilla Subbasins and also incorporates data assembled as part of Data Collection and Analysis Reports prepared for both subbasins (DE & LSCE, 2017a; and DE & LSCE, 2017b) to improve the understanding of hydrologic processes and their relationship to key sustainability metrics within the Chowchilla and Madera Subbasins. MCSim provides a platform to evaluate potential outcomes and impacts from future management actions, projects, and adaptive management strategies through predictive modeling scenarios.

1.2 Objectives and Approach

Numerical groundwater models are structured tools developed to represent the physical basin setting and simulate groundwater flow processes by integrating a multitude of data (e.g. lithology, groundwater levels, surface water features, groundwater pumping, etc.) that compose the conceptualization of the natural geologic and hydrogeologic environment. MCSim was developed in a manner consistent with the Modeling Best Management Practices (BMP) guidance document prepared by the California Department of Water Resources (DWR) (DWR, 2016). The objective of MCSim is to simulate hydrologic processes and effectively estimate historical and projected future hydrologic conditions in the Chowchilla and Madera Subbasins related to groundwater dependent ecosystems (GDEs) and SGMA sustainability indicators relevant to the Chowchilla and Madera Subbasins including:

1. Lowering of Groundwater Levels
2. Reduction of Groundwater Storage
3. Depletion of Interconnected Surface Water

The development of MCSim involved starting with and evaluating the beta version (released 5/1/2018) of DWR's fine-grid version of the California Central Valley Groundwater-Surface Water Flow Model (C2VSim-FG Beta2) and eventually carving out a local model domain and conducting local refinements to the model structure (e.g., nodes, elements) and modifying or replacing inputs as needed to sufficiently and accurately simulate local conditions in the Madera and Chowchilla Subbasin areas within the model domain. C2VSim-FG Beta2 utilizes the most current version of the Integrated Water Flow Model (IWFM) code available at the time of the MCSim development. IWFM and C2VSim-FG Beta2 were selected as the modeling platform due to the versatility in simulating crop-water demands in the predominantly agricultural setting of the subbasins, groundwater surface-water interaction, the existing hydrologic inputs existing in the model for the time period through the end of water year 2015, and the ability to customize the existing C2VSim-FG Beta2 model to be more representative of local conditions in the area of the Madera and Chowchilla Subbasins. MCSim was refined from C2VSim-FG Beta2 and calibrated to a diverse set of available historical data using industry standard techniques. The version of the IWFM model code available at the time of MCSim development does not have the capability of directly simulating land subsidence or solute transport (groundwater quality), which are two additional sustainability indicators relevant to the Madera and Chowchilla Subbasins.

1.3 Report Organization

This report is organized into the following sections:

- Section 2: Model Code and Platform
- Section 3: Groundwater Flow Model Development
- Section 4: Groundwater Flow Model Results
- Section 5: Model Uncertainty and Limitations
- Section 6: Conclusions and Recommendations
- Section 7: References

2 MODEL CODE AND PLATFORM

The modeling code and platform utilized for MCSim are described below. As required by GSP regulations, the selected model code is in the public domain. The decision to select the model codes for the MCSim was based on providing Madera County with a modeling tool that can be used for GSP development with sufficient representation of local conditions, while utilizing to the extent possible, previous modeling tools available, including regional models. With this objective in mind, the model tools and platforms described below were determined to be most suitable for adaptation for use in GSP analyses.

2.1 Integrated Water Flow Model

IWFM is a quasi three-dimensional finite element modeling software that simulates groundwater, surface water, groundwater-surface water interaction, as well as other components of the hydrologic system (Dogrul et al., 2017). MCSim is developed using the IWFM Version 2015 (IWFM-2015) code, which couples a three-dimensional finite element groundwater simulation process with one-dimensional land surface, river, lake, unsaturated zone and small-stream watershed processes (Brush et al., 2016). A key feature of IWFM-2015 is its capability to simulate the water demand as a function of different land use and crop types, and compare it to the historical or projected amount of water supply (Dogrul et al., 2017). IWFM uses a model layering structure in which model layers represent aquifer zones that are assigned aquifer properties relating to both horizontal and vertical groundwater movement (e.g., horizontal and vertical hydraulic conductivity) and storage characteristics (e.g., specific yield, specific storage) with the option to associate an aquitard to each layer, although represented aquitards are assigned a more limited set of properties relating primarily to their role in vertical flow (e.g., vertical hydraulic conductivity).

The IWFM-2015 source code and additional information and documentation relating to the IWFM-2015 code is available from DWR at the link below:

http://baydeltaoffice.water.ca.gov/modeling/hydrology/IWFM/IWFM-2015/v2015_0_630/index_v2015_0_630.cfm

2.1.1 IWFM Demand Calculator

IWFM includes a stand-alone Integrated Water Flow Model Demand Calculator (IDC) that calculates water demands. Agricultural water demands are calculated in IDC based on climate, land use, soil properties, and irrigation method whereas urban demands are calculated based on population and per-capita water use. MCSim utilizes IDC to simulate root zone processes and water demands. The physically based IDC version 2015.0.0036 (DWR, 2015) is developed and maintained by DWR.

2.2 C2VSim-Fine Grid

The C2VSim-FG Beta2 model utilizes the IWFM-2015 code and represents a refinement of the previous C2VSim-Coarse Grid (C2VSim-CG) model. Refinements made in the development of C2VSim-FG Beta2 include a finer horizontal discretization, an updated aquifer layering scheme, updated precipitation data, and an extended simulation period through water year 2015 (DWR, 2018). C2VSim-CG had an average element size of approximately 15 square miles and the average element size for C2VSimFG Beta2 is about 0.6 square miles. The C2VSimFG Beta2 version available from DWR at the time of the initiation of modeling efforts to support GSP preparation in the Madera and Chowchilla, was not a calibrated model version. As of the date of this report (August 2019), a calibrated version of C2VSim-FG was not available.

3 GROUNDWATER FLOW MODEL DEVELOPMENT

This section describes the spatial and temporal (time-series) structure of the model and the input data that was utilized for model development. The model development process utilized data and information that was available at the time of model development and is described in greater detail in the GSP and previous Data Collection and Analysis reports (DE & LSCE, 2017a for Chowchilla, and DE & LSCE, 2017b for Madera).

3.1 MCSim – Historical Model

The MCSim historical model simulates the period from October 1985 through September 2015 at a monthly time step, with a calibration period of October 1988 through September 2015. Annual model time periods are based on water years defined as October 1 through September 30. The historical calibration model period extends from water years 1989 through 2015. Water years 1986 through 1988 are not included as part of the historical calibration period, but are simulated to allow the model some time to adjust to the specified initial conditions and spin-up prior to the calibration period starting in October 1988.

3.1.1 Model Grid

The MCSim grid was carved out of the regional C2VSim-FG Beta2 model domain. While MCSim focuses on the Chowchilla and Madera Subbasins, the model domain was extended outside the two subbasins to incorporate a buffer zone including area within the Merced, Delta-Mendota, and Kings Subbasins. The extent of the buffer zone was determined, using the C2VSimFG Beta2 regional model, by simulating pumping wells along the boundary of the Chowchilla and Madera Subbasins to determine the distance to a one-foot drawdown of groundwater levels. This MCSim domain was delineated with consideration of these drawdown distances (typically 5-10 miles from Chowchilla and Madera Subbasin boundaries). The MCSim domain, shown in **Figure 3-1**, encompasses a total of 847,624 acres. All C2VSim-FG Beta2 model features (e.g., nodes, elements, streams, layers) within this domain were initially included in MCSim with subsequent modifications and refinements made within MCSim to these model components, as described in this report.

3.1.1.1 Nodes and Elements

The MCSim grid contains 2,458 nodes and 2,632 elements (**Figure 3-1**). The X-Y coordinates for node locations are presented in the UTM Zone 10N, NAD83 (meters) projected coordinate system. While the number of nodes and elements within the MCSim domain were not altered from C2VSim-FG Beta2, the locations of some nodes and elements were modified to more accurately align with subbasin boundaries and streams. **Figure 3-2** highlights the modified nodes and elements in MCSim. **Table 3-1** presents MCSim grid characteristics.

Table 3-1. MCSim grid characteristics.

Nodes	2,458
Elements	2,632
Average Element Size (acres)	322
Minimum Element Size (acres)	10
Maximum Element Size (acres)	1,486
Subregions	16
Aquifer Layers	7
Aquitard Layers	3

3.1.1.2 Subregions

Model elements are grouped into subregions to assist in the summarization of model results and development of water budgets. MCSim includes 16 subregions (listed in **Table 3-2**). Subregions were delineated by subbasin, and also by GSA within the Chowchilla and Madera Subbasins. While subregions are used as the basis for summarizing model results, the model simulates hydrologic processes and conditions at the resolution of elements or nodes. **Figure 3-3** shows the delineation of subregions included within MCSim.

Table 3-2. Model Subregions within MCSim.

Subregion	Subbasin	GSA
1	Chowchilla	Chowchilla Water District
2	Chowchilla	Madera County - East
3	Chowchilla	Madera County - West
4	Chowchilla	Sierra Vista MWC - Madera County
5	Chowchilla	Sierra Vista MWC - Merced County
6	Chowchilla	Triangle T Water District
7	Madera	City of Madera
8	Madera	Madera County
9	Madera	Gravelly Ford Water District
10	Madera	Madera Irrigation District
11	Madera	Madera Water District
12	Madera	New Stone Water District
13	Madera	Root Creek Water District
14	Merced	
15	Delta-Mendota	
16	Kings	

3.1.1.3 Streams

MCSim includes 35 stream reaches composed of 657 stream nodes. Streams that were adapted from existing streams simulated in C2VSimFG Beta2 include Chowchilla River, Deadman's Creek, East Side Bypass/Chowchilla Bypass, Fresno River, Fresno Slough, and San Joaquin River. Some of the stream nodes were shifted to better align with the actual stream configuration. Streams added to MCSim that were not included in C2VSimFG Beta2 include Ash Slough, Berenda Creek, Berenda Slough, Cottonwood Creek, Dry Creek, Dutchman Creek, and Madera Canal. The stream network included in MCSim is shown in **Figure 3-4**.

3.1.1.4 Model Layers

A major modification in the adaptation of the C2VSim-FG Beta2 model for MCSim purposes was the refinement of the representation of the aquifer system through model layering. Within the MCSim domain, C2VSim-FG Beta2 delineates three aquifer layers and one aquitard layer; MCSim was refined to include seven aquifer layers and three aquitard layers corresponding with key hydrogeologic features identified in the Hydrogeologic Conceptual Model (HCM) for the subbasins. The aquifer system within MCSim is broken down into the Upper Aquifer (layer 1 through 3), the Lower Aquifer (layers 4 through 6), and a buffer layer (layer 7). The E-Clay unit (Corcoran Clay) of the Tulare Formation separates the Upper and Lower Aquifers, where present. Other less extensive clay units (e.g., A-Clay, C-Clay) of the Tulare Formation also exist in the area and were explicitly incorporated into the model as discrete model features (aquitard layers) or implicitly through assignment of hydraulic properties based on sediment texture as described below in section 3.1.4.1.

The Upper Aquifer is generally unconfined, except where the A-Clay and/or C-Clay are present. The top of the aquifer system is defined by the land surface. In general, Layer 1 extends approximately 50 feet below ground surface, or to the top of the A-Clay, where present. The A-Clay is included as the Layer 2 aquitard overlying the Layer 2 aquifer. The Layer 2 aquifer extends from the base of the A-Clay, where present, to the top of the C-Clay (or other comparable shallow clays), where present. The C-Clay is included as the Layer 3 aquitard overlying the Layer 3 aquifer. The Layer 3 aquifer extends from the base of the C-Clay, where present, to the top of the E-Clay (Corcoran Clay), where present. Where aquitard(s) are not present in the Upper Aquifer, the remaining Upper Aquifer thickness below Layer 1 is divided evenly between Layers 2 and 3.

The Corcoran Clay is modeled as the Layer 4 aquitard. This aquitard layer separates the Upper Aquifer from the Lower Aquifer. The depth, thickness, and extent of the Corcoran Clay is consistent with C2VSim-FG Beta2, and is based on mapping of the Corcoran Clay by Page (1986). Where the Corcoran Clay is not present, the below ground surface to the nearest occurrence of the Corcoran Clay was used to delineate the Upper and Lower aquifers.

The Lower Aquifer is confined where the Corcoran Clay is present, and is considered semi-confined outside of the Corcoran Clay extent. The thicknesses of the Layer 4 aquifer and Layers 5, and 6 are delineated as equal percentages (approximately 33 percent) of the total Lower Aquifer thickness to the base of freshwater. The base of the Lower Aquifer was generally kept consistent with the base of the Lower Aquifer in C2VSim-FG Beta2 model, but some modifications were made in MCSim to better align the base of the Lower Aquifer with the base of freshwater (Page, 1973).

Layer 7 extends from the base of freshwater to the base of continental deposits (Williamson et al., 1989) and is considered a buffer layer. Though included in MCSim, Layer 7, although simulated in the model, is treated as a low-conductivity zone below the base of freshwater and below the zone of any groundwater pumping. Layer 7 was preserved in MCSim, with an overall model thickness equal to that of C2VSim-FG Beta2.

Elevations and thicknesses of MCSim aquifer and aquitard layers are shown in **Figures 3-5** through **3-25**.

3.1.2 Land Surface System

The IWFM Land Surface Process, which includes the IDC, calculates a water budget for four land use categories: non-ponded agricultural crops, ponded agricultural crops (i.e., rice), native and riparian vegetation, and urban areas. The Land Surface Process calculates water demand at the surface, allocates water to meet demands, and routes excess water through the root zone (Brush et al., 2016). The development of land surface system input files is explained in this section.

3.1.2.1 Precipitation

Monthly precipitation time series data for water years 1922 through 2015 was extracted from C2VSim-FG Beta2. Precipitation rates were extracted for all elements and small watersheds included within MCSim. Precipitation data within both C2VSim-FG Beta2 and MCSim is based on Parameter Elevation Regression on Independent Slopes Model (PRISM) by the PRISM Climate Group at Oregon State University.

3.1.2.2 Evapotranspiration

Monthly evapotranspiration (ET) time series data was refined for water years 1973 through 2015. ET rates were developed for individual crop types and were refined based on observed data, as described in this section.

Weather Data
Weather data were obtained from the California Irrigation Management Information System (CIMIS) and National Oceanic and Atmospheric Administration National Centers for Environmental Information (NOAA NCEI). **Table 3-3** lists the stations and periods of record used for each station.

Table 3-3. Weather Data Time Series Summary.

Weather Station	Station Type	Start Date	End Date	Comment
Fresno State	CIMIS	Oct. 2, 1988	May 12, 1998	Used before Madera CIMIS station was installed.
Madera	CIMIS	May 13, 1998	Apr. 2, 2013	Moved eastward 2 miles in 2013 and renamed “Madera II.”
Madera II	CIMIS	Apr. 3, 2013	Dec. 31, 2015	
Madera	NOAA NCEI	Jan. 1, 1928	Dec. 31, 2017	Used for developing ET_{ref} timeseries for projected water budget period before CIMIS station data was available.

Daily time series data were evaluated following the quality control procedures described in the Chowchilla Subbasin GSP Appendix 2.F.f. to develop daily reference crop evapotranspiration (ET_{ref}) and precipitation records for both the Chowchilla and Madera Subbasins during the historical and projected water budget periods.

Reference Evapotranspiration Development

Daily reference crop evapotranspiration (ET_{ref}) was determined following the widely accepted standardized Penman-Monteith (PM) method, as described by the ASCE Task Committee Report on the Standardized Reference Evapotranspiration Equation (ASCE-EWRI, 2005). 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 California and was selected for this application. Daily ET_o values were calculated and provided as inputs to the IDC root zone model for simulating crop consumptive use requirements.

3.1.2.3 Land Use

To support water budget development for each Land Surface System water use sector, the IDC daily root zone water budget model was used to develop an accurate and consistent calculation of historical crop ET (ET_c) and other water budget components in the root zone. A daily root zone water budget is a generally accepted and widely used method to estimate effective rainfall (ASCE, 2016 and ASABE, 2007).

For developing the integrated Surface Water System (SWS) and Groundwater System (GWS) water budgets in the MCSim model, this daily IDC application was converted to a monthly application, recalibrated to equal monthly flows by each component in the SWS water budgets, and then integrated with MCSim. The IDC application thus served as the foundation for coupling the SWS water budget to the groundwater model used in GSP development.

IDC was used to develop time series estimates for the following water budget components:

- ET of applied water
- ET of precipitation
- Infiltration of applied water
- Infiltration of precipitation
- Uncollected surface runoff of applied water (estimated as negligible in the Chowchilla and Madera Subbasins)
- Uncollected surface runoff of precipitation
- Change in root zone storage

Details regarding the improved crop coefficients used by IDC for estimating ET are described in the Crop Water Use section below. Additional details regarding development of the full IDC root zone water budget, including major inputs, are provided in Chowchilla Subbasin GSP Appendix 2.F.g and Madera Subbasin GSP Appendix 2.H.h.

Crop Water Use (description of ET_c calculation by ET_o and crop coefficients; crop coefficient development using SEBAL)

The daily IDC root zone water budget application described above was used to develop an accurate and consistent calculation of historical ET_c using the widely accepted reference ET-crop coefficient method (ASCE, 2016). In this method, ET_o is adjusted to estimate ET_c of other crops using a crop coefficient unique to the individual crop type, growth characteristics, health, and other local conditions. 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 Chowchilla and Madera Subbasins, annual historical ET_c was computed for the IDC application using the quality controlled CIMIS ET_o and these local, remote sensing derived crop coefficients. The aforementioned IDC root zone model parsed these ET_c estimates into the ET of applied water and ET of precipitation estimates used in the Chowchilla Subbasin and Madera Subbasin water budgets.

3.1.3 Surface Water System

The IWFM Surface Water Process calculates a water budget along each stream reach between inflows and outflows, including stream-groundwater interactions (Brush et al., 2016). A steady-state period was used during the early years of the MCSim simulation period. Data from water year 2000 was used as a proxy for an average hydrology and was used for water years 1985-1988 surface water inflows and diversions. The development of surface water system input files is explained in this section.

3.1.3.1 Stream Characteristics

Stream bed parameters were taken from C2VSim-FG Beta2 for those stream nodes extracted from the C2VSim-FG Beta2 regional model. For additional stream nodes in MCSim, stream bed parameters were developed through review of soil properties and stream characteristics. Stream bed parameters, particularly stream bed conductivity and wetted perimeter, were further refined during the calibration process.

3.1.3.2 Inflows

Surface water inflows into the model domain are specified in MCSim for 10 stream reaches. Stream inflow locations are shown in **Figure 3-26**. Deadman’s Creek inflows were adapted from C2VSim-FG Beta2 inflow data. Fresno Slough inflows were generated in C2VSim-FG Beta2 by placing a stream flow hydrograph at the MCSim inflow node and using the resulting time series data for inflows to MCSim. Berenda Creek, Cottonwood Creek, and Dry Creek inflows were based off Madera Irrigation District (MID) Recorder data. Chowchilla River and Dutchman Creek inflows were developed from Chowchilla Water District (CWD) records. Fresno River, Madera Canal, and San Joaquin River inflows were based off of United States Geological Survey (USGS) gage data. More information regarding the development of surface inflow volumes is presented in **Table 3-4**.

Table 3-4. Summary of Historical Surface Water Inflows Development.

Waterway	Calculation/Estimation Technique	Information Sources
Berenda Creek	Calculated from MID recorder measurements adjusted upstream to the subbasin boundary for estimated seepage and evaporation	MID Recorder 13, USDA Natural Resources Conservation Service (NRCS) soil survey, Fresno State/Madera/Madera II CIMIS Stations
Chowchilla River	Reported Buchanan Dam irrigation and flood releases	United States Army Corps of Engineers (USACE) records, CWD records
Cottonwood Creek	Calculated from MID recorder measurements adjusted upstream to the subbasin boundary for estimated seepage and evaporation	MID Recorder 14, NRCS soil survey, Fresno State/Madera/Madera II CIMIS Stations
Deadman’s Creek	n/a	From C2VSim-FG Beta2
Dry Creek	Estimated as equal to Berenda Creek recorder measurements adjusted upstream to the subbasin boundary for estimated seepage and evaporation	MID Recorder 13, NRCS soil survey, Fresno State/Madera/Madera II CIMIS Stations

Waterway	Calculation/Estimation Technique	Information Sources
Berenda Creek	Calculated from MID recorder measurements adjusted upstream to the subbasin boundary for estimated seepage and evaporation	MID Recorder 13, USDA Natural Resources Conservation Service (NRCS) soil survey, Fresno State/Madera/Madera II CIMIS Stations
Dutchman Creek	Estimated as equal to Received Legrand water reported by CWD	CWD monthly water supply reports
Fresno River	Estimated as equal to USGS measurement site along Fresno River below Hidden Dam	USGS Site 11258000 (FRESNO R BL HIDDEN DAM NR DAULTON CA)
Fresno Slough	Extracted streamflow hydrograph at inflow point from C2VSim-FG Beta2 regional model	From C2VSim-FG Beta2
Madera Canal	Estimated as equal to USGS measurement site along Madera Canal near Friant	USGS Site 11249500 (MADERA CN A FRIANT CA)
San Joaquin River	Estimated as equal to USGS measurement site along San Joaquin River below Friant Dam	USGS Site 11251000 (SAN JOAQUIN R BL FRIANT CA)

3.1.3.3 Surface Water Diversions and Deliveries

Surface water diversions and deliveries are simulated in the model as diversions from a stream node with an assigned delivery destination (element group). A total of 65 surface water diversions are included in MCSim, with 18 adapted from C2VSim-FG Beta2 and 47 added to MCSim. Of the 47 additional MCSim diversions, 24 are agricultural diversions to CWD, Gravelly Ford Water District (GFWD), MID, Madera Water District (MWD), and Root Creek Water District (RCWD), and 23 are riparian diversions that are applied in Madera County (MC), MC-East, MC-West, MID, RCWD, Sierra Vista Mutual Water Company (SVMWC), and Triangle T Water District (TTWD). Diversion locations are shown in **Figure 3-27**. Diversion volumes adapted from C2VSim-FG Beta2 were adjusted fractionally based on the percentage of the original C2VSim-FG Beta2 delivery location included within the MCSim domain. These diversions occur primarily outside of the Chowchilla and Madera subbasins, but within the MCSim domain. Diversion volumes for the additional MCSim diversions were based on data reported by the United States Bureau of Reclamation (USBR), the State Water Resources Control Board (SWRCB), and local GSAs. More information regarding the development of diversion volumes is presented in **Table 3-5**.

Losses associated with surface water deliveries are defined as fractions of each surface water diversion within MCSim and remain constant throughout the simulation period. Recoverable losses occur as seepage of water from the delivery system prior to arrival at the delivery destination. Accordingly, the fraction of recoverable loss represents water that recharges from conveyance losses associated with surface water deliveries. Non-recoverable losses occur from evapotranspiration associated with surface water deliveries. The fraction of non-recoverable loss represents water that does not recharge and occurs as an output from the SWS. The remaining percentage of surface water diversions (after subtraction of recoverable and non-recoverable losses) is considered the delivery fraction. The initial recoverable loss fractions used in the model were determined based on the average conveyance losses for each GSA, as calculated in the SWS water budgets (Chowchilla Subbasin GSP Appendices 2.F and Madera Subbasin GSP Appendices 2.H) performed outside the groundwater model. The initial non-recoverable loss fractions were determined based on the average evapotranspiration losses for each GSA, as calculated in the SWS water budgets developed outside the groundwater model. Fractional losses and deliveries were further refined during the calibration process.

In MCSim surface water diversions are assigned to groups of elements for water delivery and recharge. A total of 54 unique surface water delivery groups and 56 recharge groups were utilized in MCSim. The surface water delivery and recharge groups included 19 groups adapted from C2VSim-FG Beta2 and 46 additional groups added to refine surface water deliveries within the Madera and Chowchilla Subbasin. The configuration and inputs associated with delivery and recharge groups adapted from C2VSim-FG Beta2 were not altered in MCSim; for refined surface water diversions and deliveries added into MCSim, delivery and recharge volumes were assigned to the entirety of the GSA receiving water, unless more specific data was available. Delivery groups for additional MCSim diversions were refined in CWD and MID based on delivery zone data provided for each GSA. Recharge groups were refined in CWD, GFWD, and MID based on locations of delivery conveyance systems. If a canal was present in a given element, recharge water was assigned to that element. Delivery locations for surface water deliveries are shown in **Appendix A, Figures A1** through **A65** of this model report.

Table 3-5. Summary of Historical Surface Water Diversions Development.

Diversion Number	Detailed Component	Calculation/Estimation Technique	Information Sources
DIV_1 - DIV_19	C2VSim-FG Beta2 diversions data file	n/a	From C2VSim-FG Beta2
DIV_20 - DIV_23	Chowchilla River and Berenda Slough Diversions to CWD	Sum of Buchanan Dam and Madera Canal irrigation releases diverted by CWD, plus additional flood releases diverted to meet reported CWD deliveries; apportioned to each waterway based on CWD STORM delivery records, GIS analysis, and historical operations (18% from Chowchilla River, 82% from Berenda Slough)	USBR Central Valley Project (CVP) delivery records, USACE records, CWD STORM delivery database, CWD monthly water supply reports
DIV_24	Flood Diversions to CWD for managed recharge	Reported deliveries during flood releases prior to the start of the irrigation season	CWD STORM delivery database
DIV_25 - DIV_28	Diversions to GFWD	Reported by GFWD	Gravelly Ford WD reports
DIV_29, DIV_65	Dry Creek Diversions to MWD	Measured by MID, MWD	MID STORM delivery database, MWD delivery records
DIV_30	Fresno River Diversions to MID	Closure of Fresno River Balance	USGS Site 11258000 (FRESNO R BL HIDDEN DAM NR DAULTON CA), USBR CVP delivery records, IDC root zone water budget, NRCS soils characteristics, CIMIS precipitation data, MID recorders, riparian deliveries.
DIV_31 - DIV_42	Madera Canal Diversions to MID	Reported in USBR CVP delivery records at Madera Canal Miles 6.1, 13.06, 22.95, 24.1, 26.8, 27.5, 28.38, 28.39, 28.64, 30.4, 30.5, 32.2	USBR CVP delivery records
DIV_43 - DIV_58	Riparian Deliveries to MID, MC, and RCWD	Reported by historical water rights and statements of diversion, estimated from streamflow and crop ET when records not available	SWRCB Electronic Water Rights Information Management System (eWRIMS), Holding Contracts

Diversion Number	Detailed Component	Calculation/Estimation Technique	Information Sources
DIV_59 - DIV_64	Water Rights Deliveries[1]	Reported riparian/appropriative/prescriptive water rights deliveries during flood releases and/or natural flood flows; estimated from streamflow and crop ET when records not available	CWD delivery records, eWRIMS, Fresno State/Madera/Madera II CIMIS Stations, land use data

[1] Includes riparian, appropriative, and prescriptive water rights deliveries during flood releases and/or natural flood flows along subbasin waterways.

3.1.3.4 Surface Water Bypasses

Surface water bypasses defined in the model simulate the movement of surface water between different waterways based on specified volumes or fractions. These bypasses can be used to simulate flood bypasses or water system operations. A total of eight surface water bypasses were included in MCSim. Two bypasses associated with moving surface water flows from the San Joaquin River into the Chowchilla Bypass and moving flows from the Chowchilla River into the East Side Bypass were initially adapted from C2VSim-FG Beta2. Six additional bypasses were added to MCSim as a means to simulate the operations of MID and CWD surface water distribution systems. More information regarding the development of bypass volumes is presented in **Table 3-6**. Bypass locations are shown in **Figure 3-28**.

Table 3-6. Summary of Historical Surface Water Bypasses Development.

Bypass Number	Detailed Component	Calculation/Estimation Technique	Information Sources
BYP_1	Chowchilla Bypass	Calculated from San Luis & Delta-Mendota Water Authority (SLDMWA) CBP station measurements adjusted downstream to the subbasin boundary for estimated seepage and evaporation	SLDMWA CBP station, NRCS soil survey, Fresno State/Madera/Madera II CIMIS Stations
BYP_2	C2VSim-FG Beta2 diversions data file	N/A	From C2VSim-FG Beta2
BYP_3 - BYP_4	Madera Canal Diversions to CWD	Reported in USBR CVP delivery records at Madera Canal Miles 33.6 and 35.6	USBR CVP delivery records
BYP_5	MID Deliveries to CWD	Measured by MID, CWD	MID STORM delivery database
BYP_6 - BYP_7	Chowchilla River and Berenda Slough Diversions to CWD	Sum of Buchanan Dam and Madera Canal irrigation releases diverted by CWD, plus additional flood releases diverted to meet reported CWD deliveries; apportioned to each waterway based on CWD STORM delivery records, GIS analysis, and historical operations (18% from Chowchilla River, 82% from Berenda Slough)	USBR CVP delivery records, USACE records, CWD STORM delivery database, CWD monthly water supply reports
BYP_8	Madera Canal Mile 18.8 Diversions to MID, Fresno River	Reported in USBR CVP delivery records at Madera Canal Mile 18.8	USBR CVP delivery records

[1] Includes riparian, appropriative, and prescriptive water rights deliveries during flood releases and/or natural flood flows along subbasin waterways.

3.1.4 Groundwater System

The IFWM Groundwater Flow Process balances subsurface inflows and outflows and manages groundwater storage within each element and layer (Brush et al., 2016). The development of groundwater system input files is explained in this section.

3.1.4.1 Aquifer Parameters

Because C2VSim-FG Beta2 was not a calibrated model and the basis for determining aquifer parameters in previous versions of C2VSim-CG were not characterized, aquifer parameters were defined in MCSim through subsurface lithologic textural analysis in conjunction with calibration of parameters based on texture. Aquifer parameters in MCSim are assigned to each node for each model layer, and were developed to represent subsurface hydrogeologic characteristics.

Lithologic Texture

Geostatistical modeling was developed using Transition Probability Geostatistical Software (T-ProGS) (Carle and Fogg, 1996; Carle and Fogg, 1997). TProGS is used to develop a conditional simulation of subsurface heterogeneity based on 3-D Markov chain models. Markov chain models are used to calculate the facies type at a given point given the occurrence of a facies type at another point and the specified probability of transitioning from one facies to another over a given distance.

Subsurface lithologic data were compiled from the existing texture database of lithologic log information developed by the USGS for the Central Valley Hydrologic Model (CVHM2) and supplemented with additional lithologic log information in areas of MCSim with missing or sparse data coverage in the CVHM2 database. Texture data were subdivided into 4 texture classes: clay, silt, sand or gravel. The borehole data were then discretized onto a 5-foot interval for analysis and incorporation into TProGS.

Each model domain was discretized into rectilinear cells with a 500-foot spacing in the horizontal direction and a 5-foot vertical spacing to conduct the sequential indicator simulation. The simulations were sequentially merged to develop a composite model (**Figure 3-29**). While TProGS can produce any number of equally probable simulations, one was selected to represent the subsurface geostatistical model used to develop the numerical groundwater model.

Assigning Aquifer Parameters

For setting of initial aquifer parameter values, results from the texture kriging were upscaled and mapped onto the model grid. The centroid of each texture cell was determined, and these points were assigned to MCSim model nodes using Thiessen polygons. Thiessen polygons were drawn around MCSim model nodes to define the area closest to each model node relative to other model nodes. All texture cell centroids within a given Thiessen polygon were assigned to the corresponding MCSim model node. Aquifer parameters for each MCSim model node and model layer were determined from analysis of the texture cell centroids within a given Thiessen polygon. Each vertical 5-ft interval for texture cells was assigned to a model layer. Initial aquifer parameter values (horizontal hydraulic conductivity (Kh), vertical hydraulic conductivity (Kv), specific yield (Sy), and specific storage (SS)) were set for each of the four texture categories (clay, silt, sand, gravel) assigned to each texture cell and five-foot vertical interval. Through an upscaling routine, aquifer parameters for individual texture cells and five-foot vertical interval were assigned to model nodes and layers. For upscaling of Kv, a harmonic mean of the specified values of Kv assigned for each texture class at 5-ft intervals was first calculated for each texture cell within each model layer. An arithmetic average of these resulting values by texture cell within each model node Thiessen polygon was calculated to represent the Kv value at each model node for each model layer. For upscaling of other aquifer parameters (Kh, Sy, SS) an arithmetic average of the vertical five-foot intervals within each model layer was calculated for each texture cell and then an arithmetic average of these resulting values was calculated for each model node Thiessen polygon for each model layer.

A fifth lithologic category was used to represent the occurrence of low-permeability materials associated with the basement complex within the MCSim model domain. Although the base of Layer 7 in the model was delineated to align with the base of continental deposits in many parts of the basin, because the contact between continental deposits and basement becomes steep along the eastern edge of the mode domain, in such areas MCSim simulated this contact through assignment of different aquifer parameters instead of through explicitly delineating this contact in the configuration of model layering. To achieve this, if a model layer was more than 50 percent below the mapped top of basement at a given model node, the node in that layer was designated as a basement complex node. Nodes designated as basement complex were assigned aquifer parameters associated with basement materials.

Calibration of Aquifer Parameters

Multipliers were selectively applied to aquifer parameters after the upscaling of lithology data to the model grid in an effort to improve representation of conceptual hydrogeologic elements in the model including the presence of different sedimentary geologic units in eastern parts of the model domain and also potential for greater consolidation and induration of materials with increasing depth and age. Two principal types of aquifer multiplier were applied: an eastern area multiplier and also depth decay factors. Both types of multipliers were applied by individual layer and parameter.

Existing geologic mapping in the model area indicates the presence of different geologic units in the eastern parts of the subbasin, including some more lithified formations consisting of sandstone, siltstone, and conglomerate. The eastern area multiplier was applied to nodes in the area of the model domain generally east of Highway 99, roughly aligned with the mapped contact between deposits of alluvium and the more consolidated formations to the east.

The depth decay factor was applied to layers in the lower aquifer to represent the increased consolidation and induration that is believed to exist in older geologic units that are at greater depth and have undergone compression and compaction because of the geostatic load at greater depth.

A very low depth decay factor was applied to Layer 7 consistent with the greater depth of the layer and because the layer is below the depth at which groundwater pumping occurs in the area. Few or no wells penetrate to depths below the top of Layer 7 because it is below the base of freshwater. As a result, no groundwater pumping occurs at such great depths and little lithologic information is available so Layer 7 was represented with low aquifer properties to reduce any effect the layer may have on simulated conditions within the upper model layers where groundwater is actively used. Layer 7 was not considered in water budget estimates developed using the model.

3.1.4.2 Boundary Conditions

MCSim utilizes General Head boundary conditions. Conductance was determined at each boundary node by layer. Conductance was calculated in each layer based on Kh, distance between boundary nodes, aquifer layer thickness, and the distance from the model boundary (set as 1,000-ft). Transient historical water level boundary conditions were developed by using the interpreted initial head conditions in 1985 and applying relative changes based on simulated water levels derived from the USGS CVHM model for each model time step for the period 1985 to 2015. Because CVHM only simulates conditions through 2002, substitute years based on similar water year conditions were used to extent the historical boundary condition data through 2015. A similar approach to developing boundary head conditions was evaluated using C2VSim-CG simulated water levels, but this approach was not as successful in achieving sufficient calibration, likely in part because of the coarser vertical and lateral resolution of the model. A calibrated version of C2VSimFG was not available at the time of this modeling effort.

3.1.4.3 Groundwater Pumping

Pumping within MCSim is determined by element and is calculated internally by the IDC to meet both agricultural and urban demands after available surface water deliveries have been accounted for. The vertical distribution of pumping by layer in MCSim was modified based on review of well construction information in DWR's database of Well Completion Reports (WCR) for wells within the model domain. Agricultural and urban pumping were distributed vertically based on well construction information data in DWR's WCR database for respective well types. The vertical distribution of pumping does not change over the historical simulation period and was adjusted to accommodate model layers going dry over the simulation period because of lowering water levels. In such cases, pumping was moved to deeper layers to simulate pumping from greater depths. Maps of the vertical distribution of agricultural pumping by layer are presented in **Figures 3-30 through 3-36** and for urban pumping by layer in **Figures 3-37 through 3-43**.

3.1.5 Small Watersheds

A total of 44 small watersheds were included in MCSim from C2VSim-FG Beta2 (**Figure 3-44**). **Table 3-7** summarizes the contributions of small watersheds to modeled streams. Modifications were made to C2VSim-FG Beta2 small watersheds to properly route water through the additional streams modeled in MCSim. Additionally, minor edits to the contributing acreage of small watersheds were made to adjust to modifications of elements along model boundary.

Table 3-7. Summary of Small Watersheds.

Stream fed by Small Watersheds	Count of Contributing Watersheds	Total Contributing Watershed Acreage
Berenda Creek	3	4,694
Cottonwood Creek	3	12,710
Deadman's Creek	4	17,131
Dry Creek	3	15,820
Dutchman Creek	2	3,335
Fresno River	3	2,174
Madera Canal	16	31,814
San Joaquin River	10	42,899
TOTAL	**44**	**130,577**

3.1.6 Initial Conditions

Initial conditions for MCSim were generated from simulated output from C2VSimCG and the C2VSim-FGC2VSim-FG Beta2 regional models for October 1985 in conjunction with mapped groundwater conditions based on observed groundwater levels and contour interpretation.C2VSim-FG. MCSim initial Conditions for the unsaturated zone and small watersheds were defined from simulated C2VSim-FGC2VSim-FG Beta2 conditions. Available historical groundwater level data were used to interpret groundwater elevations across the domain in Fall 1985 for use in representation of initial model water level (head) conditions. Initial groundwater level conditions were interpreted separately for the Upper and Lower Aquifers, in areas within the extent of the Corcoran Clay. Layers 1 through 3 were assigned initial head conditions representative of the Upper Aquifer and Layers 4 through 7 were assigned initial head conditions representative of the Lower Aquifer. Outside the extent of the Corcoran Clay, all layers were assigned the same initial head conditions from the interpreted unconfined groundwater surface. Initial water level conditions used in the historical MCSim runs are shown in **Figures 3-45** through **3-51**.

3.2 Model Calibration

As described above, MCSim was calibrated through trial and error. The calibration process focused on adjusting key model parameter values to improve the fit of simulated data to observed data. The key model parameters included in calibration were aquifer properties and streambed properties. Aquifer parameters adjusted during calibration included Kh, Kv, Ss, and Sy, which were specified for individual texture categories in the textural model and then upscaled to model nodes, and associated spatial adjustment factors to represent varying degrees of consolidation of aquifer materials at depth and by area. Streambed properties adjusted during the calibration included streambed conductivity and wetted perimeter. Model results were compared to observed groundwater levels and measured stream flows and SWS water budget estimates developed outside the model (Chowchilla Subbasin GSP Appendices 2.F and Madera Subbasin GSP Appendices 2.H). Observations used to constrain aquifer parameter values included approximately 9,000 groundwater level observations from 177 wells (**Figure 3-52**). Observations used to constrain stream bed parameters included approximately 1,800 stream flow measurements from 14 gage stations.

3.3 MCSim – Projected Model

MCSim was used to simulate projected future scenarios including under varying projects, management actions, and hydrology. The projected simulation period runs from WY 2016 through 2090 beginning on October 1, 2015 and ending September 30, 2090, at a monthly time step. Two distinct time periods exist in the future projected modeling: the implementation period (2020-2039), during which projects and management actions are enacted to bring the basin into sustainability, and the sustainability period (2040-2090), after which projects and management actions have been fully implemented. The development of the projected future scenarios in MCSim is described in this section.

3.3.1 Projected Hydrology

Future hydrology model inputs were projected into the future based on projected water year type and historical hydrology to achieve a future hydrologic period of 70 years that are representative and consistent with hydrology occurring over a historical 50-year period from 1965-2015. During the implementation period, an average climatic period was simulated by repeating the observed 10-year average climatic period from 2001-2010 twice for the 2020 to 2039 period. During the sustainability period, the 50-year climatic period from 1965-2015 is repeated. The projected water year type and assigned water years for use in future projections are shown in **Table 3-8**.

Table 3-8. Summary of Projected Water Years.

Water Year	Assigned Water Year	Water Year Type
1989	-	C
1990	-	C
1991	-	C
1992	-	C
1993	-	W
1994	-	C
1995	-	W
1996	-	W
1997	-	W
1998	-	W
1999	-	AN
2000	-	AN
2001	-	D
2002	-	D
2003	-	BN
2004	-	D
2005	-	W
2006	-	W
2007	-	C
2008	-	C
2009	-	BN
2010	-	AN
2011	-	W
2012	-	D
2013	-	C
2014	-	C
2015	-	C
2016	2016	D
2017	2017	W
2018	2018	AN
2019	1995	W
2020	2001	D
2021	2002	D
2022	2003	BN
2023	2004	D
2024	2005	W
2025	2006	W
2026	2007	C
2027	2008	C
2028	2009	BN
2029	2010	AN
2030	2001	D
2031	2002	D
2032	2003	BN
2033	2004	D
2034	2005	W
2035	2006	W
2036	2007	C
2037	2008	C
2038	2009	BN
2039	2010	AN
2040	1965	W
2041	1966	BN
2042	1967	W
2043	1968	D
2044	1969	W
2045	1970	AN
2046	1971	BN
2047	1972	D
2048	1973	AN
2049	1974	W
2050	1975	W
2051	1976	C
2052	1977	C
2053	1978	W
2054	1979	AN
2055	1980	W
2056	1981	D
2057	1982	W
2058	1983	W
2059	1984	AN
2060	1985	D
2061	1986	W
2062	1987	C
2063	1988	C
2064	1989	C
2065	1990	C
2066	1991	C
2067	1992	C
2068	1993	W
2069	1994	C
2070	1995	W
2071	1996	W
2072	1997	W
2073	1998	W
2074	1999	AN
2075	2000	AN
2076	2001	D
2077	2002	D
2078	2003	BN
2079	2004	D
2080	2005	W
2081	2006	W
2082	2007	C
2083	2008	C
2084	2009	BN
2085	2010	AN
2086	2011	W
2087	2012	D
2088	2013	C
2089	2014	C
2090	2015	C

Note: Water Year Type is based on the San Joaquin Valley Water Year Index and is classified into five types:

W	Wet
AN	Above Normal
BN	Below Normal
D	Dry
C	Critical

Climate change adjustments were also included in selected projected future scenarios to evaluate the potential influence of climate change on future conditions. The climate change factors applied are from the DWR CalSim II simulated volume projections based on State Water Project (SWP) and Central Valley

Project (CVP) operations under the 2030 mean climate change scenario (SGMA Data Viewer). For precipitation, evapotranspiration, and surface inflows for unimpaired waterways, historical data was adjusted by the CalSim II 2030 monthly streamflow change factors by water year type. For surface inflows for impaired waterways, the CalSim II projected reservoir outflows (assuming 2030 climate change) was used when available (1965-2003), or inflows were estimated as the average monthly CalSim II projected volume by water year type in other years (2004-2015). For inflows to the San Joaquin River and other waterways stemming from it (i.e., Madera Canal), the projected flows from a report on future supplies by the Friant Water Authority (Friant Water Authority, 2018) were used, considering San Joaquin River Restoration Program (SJRRP) implementation and the CalSim II 2030 climate change projections (1965-2003), or inflows were estimated based on the average monthly projected volume by water year type (2004-2015) included in the Friant Water Authority Report (Friant Water Authority, 2018). Additional information about climate change adjustments used in projected future scenarios is included in **Table 3-10** and **Table 3-12**.

3.3.2 Projected Future Scenarios

Four projected future scenarios were simulated to compare possible outcomes. These scenarios include: a Projected No Action scenario, a Projected No Action with Climate Change scenario, a Projected with Projects scenario, and a Projected with Projects and with Climate Change scenario. All four scenarios are simulated using historical climate data from an average period during the implementation period (2020-2039). The Projected No Action and Projected No Action with Climate Change scenarios use no flow boundary conditions, under which no subsurface flow is assumed to enter or exit the model domain along the model boundary. The Projected with Projects and Projected with Projects with Climate Change scenarios use boundary conditions that assume adjacent basins are also implementing projects. The Projected with Climate Change and Projected with Projects with Climate Change scenarios incorporate the 2030 mean climate change scenario adjustment for precipitation, ET, stream inflows, and surface water diversion volumes. All other model inputs are held constant across projected future scenarios.

The Projected with Projects scenario was chosen as the baseline future projected scenario. The Projected with Projects with Climate Change, Projected No Action, and Projected No Action with Climate Change model runs were chosen as sensitivity analysis scenarios. **Table 3-9** summarizes the differences between each projected future scenario.

Table 3-9. Summary of Projected Future Scenarios.

Scenario Conditions	Projected No Action	Projected No Action with Climate Change	Projected with Projects	Projected with Projects with Climate Change
Average Implementation Period	x	x	x	x
Climate Change Adjustment		x		x
Boundary Conditions - No Flow	x	x		
Boundary Conditions - Adjacent Basins Implementing Projects			x	x

3.3.3 Land Surface System

The development of land surface system datasets for projected future scenarios is described below.

3.3.3.1 Precipitation

Precipitation was updated for each element through September 2018 from PRISM. The precipitation amount in each future year was assumed to be equal to the amount in the historical water year assigned to that future year (**Table 3-8**). For scenarios with climate change adjustments, the historical precipitation amount was adjusted by using the CalSim II 2030 mean climate change scenario monthly water year type multiplier. Additional information about the development of projected precipitation rates is included in **Table 3-10**.

Table 3-10. Development of Projected Future Land Surface Process Components.

Water Budget Component	Without Climate Change Adjustments		With Climate Change Adjustments	
	Implementation Period	Sustainability Period	Implementation Period	Sustainability Period
	(2020-2039)	(2040-2090)	(2020-2039)	(2040-2090)
Precipitation	2001-2010 historical data (2020-2029 and 2030-2039)	1965-2015 historical data (2040-2090)	2001-2010 historical data (2020-2029 and 2030-2039) adjusted by CalSim II 2030 monthly change factors by water year type	1965-2015 historical data (2040-2090) adjusted by CalSim II 2030 monthly change factors by water year type
Evapotranspiration	2001-2010 historical data (2020-2029 and 2030-2039), assuming 2017 land use adjusted for projected urban area growth from 2017-2039	1965-2015 historical data, assuming 2017 land use adjusted for projected urban area growth from 2017-2070 (urban area constant from 2071-2090)	2001-2010 historical data (2020-2029 and 2030-2039) adjusted by CalSim II 2030 monthly change factors by water year type, assuming 2017 land use adjusted for projected urban area growth from 2017-2039	1965-2015 historical data (2040-2090) adjusted by CalSim II 2030 monthly change factors by water year type, assuming 2017 land use adjusted for projected urban area growth from 2017-2070 (urban area constant from 2071-2090)

3.3.3.2 Evapotranspiration

Evapotranspiration rates were also projected into the future based on historical data from the assigned water year corresponding to the projected water year (**Table 3-8**) and projected changes in land use (described in Section 3.3.3.3). Additional information about the development of projected ET rates is included in **Table 3-10**.

3.3.3.3 Land Use

No Action (Without Projects) Scenarios

Except in areas with urban growth, projected land use acreage in the Projected No Action scenarios was based on 2017 land use from DWR Land Use surveys and Land IQ results adjusted and interpolated through 2017 (Appendix 2.A.). In areas with urban growth, agricultural acreage decreases over time with urban expansion. Urban growth trends from 1989 through 2017 were first analyzed and urban growth percentages were developed to project urban expansion into the future. Starting from 2017, urban area was increased through 2070 using these urban growth percentages when non-urban land was available for conversion in a model element. Any remaining non-urban land was distributed among the other land uses in the element based on each non-urban land use's percentage of total non-urban area in the element in 2017. After 2070, urban acreage was held constant through 2090.

Projected urban population in the Projected No Action scenarios was developed based on review of observed population growth during water years 1989-2017. Projected urban population growth in the City of Chowchilla was estimated based on average 10-year population growth and projections for 2000-2040 from the City of Chowchilla Sphere of Influence Expansion & Municipal Service Review (Land Use Associates, 2011). Projected urban population growth in the City of Madera was estimated based on average 5-year population growth and review of the Madera Area Municipal Service Review and Sphere of Influence Update (Quad Knopf, 2018). An average annual percent change in total population of 0.8 percent per year was used to project urban population in City of Madera, City of Chowchilla, Firebaugh, and Mendota between water years 2016-2070. Projected urban population growth in the Root Creek Water District area was based on district-provided growth through 2040 and the same 0.8% average growth rate estimated for Chowchilla and Madera in other years. Estimated urban population in water years 2071-2090 was held constant at the estimated population in 2070. The monthly projected urban per capita water use between water years 2016 and 2090 was estimated to be the same as water year 2012.

With Projects Scenarios

Land use in the Projected with Projects scenarios is based on land use in the Projected No Action scenarios that is modified to incorporate reductions in non-ponded land use estimated to occur in response to demand management.

Demand management was simulated in MCSim by idling specified acreages of selected land uses each water year as estimated by the Madera County GSA Demand Management Simulation (Chowchilla Subbasin GSP Appendix 4.E.). Only the Madera County GSAs are planning demand management, so reduced land use only occurred in the Madera County GSAs. Water year 2020 land use was extracted from the Projected No Action land use dataset, and water years 2021-2070 land use was calculated by a percent change from the previous water year, starting in 2020 (see **Equation 1**). Idle acreage was used as a closure for each element in each water year.

$$\begin{array}{c}\text{water year n}\\ \text{land use for}\\ \text{each element}\end{array} = \begin{array}{c}\text{water year}\\ \text{n-1 land}\\ \text{use}\end{array} * \begin{array}{c}\text{(1 + percent change from}\\ \text{water year n-1 to}\\ \text{water year n)}\end{array} \qquad \textbf{Equation 1}$$

CWD, Madera County – East, Madera County – West, and Triangle T Water District in the Chowchilla subbasin and the Madera Irrigation District, and Madera County in the Madera Subbasin also had small reductions in land use as cropped area will be converted to recharge basins. Additional crop acreage was idled following the same percent change method described above. The water year in which additional demand management is implemented and the selection of crops to be idled varies by GSA and is described in **Table 3-11**.

Table 3-11. Additional Land Use Changes by GSA.

Subbasin	GSA	Change Year	Acres Idled	Crop Idled	Notes
Chowchilla	Chowchilla WD	2025	1,200	All crops in GSA	
Chowchilla	Madera County - East	2025	340	Largest crop by acreage in GSA	No elements with almonds idled
Chowchilla	Madera County - West	2025	880	Largest crop by acreage in GSA	
Chowchilla	Triangle T WD	2020	685	All crops in GSA	
Madera	Madera ID	2025	90	Grapes	Idled 90 ac grapes
Madera	Madera County	2025	3,200	Largest crop by acreage in GSA	

3.3.4 Surface Water System

The development of surface water system datasets for projected future scenarios is described below.

3.3.4.1 Stream Inflows

Stream inflow volumes were projected into the future based on historical data from the assigned water year corresponding to the projected water year (**Table 3-8**), with the exception of inflows to the San Joaquin River which were estimated from a report on future supplies by the Friant Water Authority (Friant Water Authority, 2018). For scenarios with climate change, a climate change adjustment was incorporated into the projections. Additional information about the development of projected stream inflows is included in **Table 3-12**.

Table 3-12. Development of Projected Future Surface Water System Components.

Water Budget Component	Without Climate Change Adjustments		With Climate Change Adjustments	
	Implementation Period	Sustainability Period	Implementation Period	Sustainability Period
	(2020-2039)	(2040-2090)	(2020-2039)	(2040-2090)
Surface Water Inflow - Unimpaired Streams	2001-2010 historical data (2020-2029 and 2030-2039)	1965-2015 historical data (2040-2090)	2001-2010 historical data (2020-2029 and 2030-2039) adjusted by CalSim II 2030 monthly streamflow change factors by water year type	1965-2015 historical data (2040-2090) adjusted by CalSim II 2030 monthly streamflow change factors by water year type

Water Budget Component	Without Climate Change Adjustments		With Climate Change Adjustments	
	Implementation Period	Sustainability Period	Implementation Period	Sustainability Period
	(2020-2039)	(2040-2090)	(2020-2039)	(2040-2090)
Surface Water Inflow - Chowchilla River (Buchanan Dam Releases)	2001-2010 historical data (2020-2029 and 2030-2039)	1965-2015 historical data (2040-2090)	2001-2010 data (2020-2029 and 2030-2039): 2001-2003 historical data adjusted by CalSim II 2030 climate change projections for Eastman Lake; 2004-2010 data estimated as the historical volume adjusted by the average monthly climate-adjusted volume by water year type	1965-2003 historical data (2040-2078) adjusted by CalSim II 2030 climate change projections for Eastman Lake; 2004-2015 data (2079-2090) estimated as the historical volume adjusted by the average monthly climate-adjusted volume by water year type
Surface Water Inflow - Fresno River (Hidden Dam Releases)	2001-2010 historical data (2020-2029 and 2030-2039)	1965-2015 historical data (2040-2090)	2001-2010 data (2020-2029 and 2030-2039): 2001-2003 historical data adjusted by CalSim II 2030 climate change projections for Hensley Lake; 2004-2010 data estimated as the historical volume adjusted by the average monthly climate-adjusted volume by water year type	1965-2003 historical data (2040-2078) adjusted by CalSim II 2030 climate change projections for Hensley Lake; 2004-2015 data (2079-2090) estimated as the historical volume adjusted by the average monthly climate-adjusted volume by water year type
Surface Water Inflow - San Joaquin River (Friant Dam Releases)	Estimated based on the Friant Water Authority Report* (same as the implementation period with climate change adjustments**, see right)	Estimated based on the Friant Water Authority Report* (same as the implementation period with climate change adjustments**, see right)	2001-2010 data (2020-2029 and 2030-2039): 2001-2003 data provided by Friant Water Authority Report*, considering the CalSim II 2030 climate change projections and implementation of the SJRRP; 2004-2010 data estimated as the historical volume adjusted by the average Friant Report volume by month and water year type	1965-2003 data (2040-2078) provided by Friant Water Authority Report*, considering the CalSim II 2030 climate change projections and implementation of the SJRRP; 2004-2015 data (2079-2090) estimated as the historical volume adjusted by the average Friant Report volume by month and water year type

Water Budget Component	Without Climate Change Adjustments		With Climate Change Adjustments	
	Implementation Period	Sustainability Period	Implementation Period	Sustainability Period
	(2020-2039)	(2040-2090)	(2020-2039)	(2040-2090)
Surface Water Inflow - Chowchilla Bypass	Estimated based on the historical monthly ratio of Chowchilla Bypass (CBP) and San Joaquin River (SJR) flows, with projected SJR inflow data provided by the Friant Water Authority Report* (same as the implementation period with climate change adjustments**, see right)	Estimated based on the historical monthly ratio of CBP and SJR flows, with projected SJR inflow data provided by the Friant Water Authority Report* (same as the implementation period with climate change adjustments**, see right)	2001-2010 data (2020-2029 and 2030-2039): 2001-2003: estimated based on the historical monthly ratio of CBP and SJR flows by water year type, with projected SJR inflow data provided by the Friant Water Authority Report*, considering the CalSim II 2030 climate change projections and implementation of the SJRRP; 2004-2010: estimated based on the historical monthly ratio of CBP to SJR flows by water year type, with average projected SJR inflows calculated from 1921-2003 by month and water year type	1965-2003 (2040-2078): estimated based on the historical monthly ratio of CBP to SJR flows by water year type, with projected SJR inflow data provided by the Friant Water Authority Report*, considering the CalSim II 2030 climate change projections and implementation of the SJRRP; 2004-2015 (2079-2090): estimated based on the historical monthly ratio of CBP to SJR flows by water year type, with average projected SJR inflows calculated by month and water year type
Diversions from Madera Canal	Estimated based on the Friant Water Authority Report* (same as the implementation period with climate change adjustments**, see right)	Estimated based on the Friant Water Authority Report* (same as the implementation period with climate change adjustments**, see right)	2001-2010 data (2020-2029 and 2030-2039): 2001-2003 data provided by Friant Water Authority Report*, considering the CalSim II 2030 climate change projections and implementation of the SJRRP; 2004-2010 data estimated as the historical volume adjusted by the average Friant Report climate change volume by month and water year type	1965-2003 data (2040-2078) provided by Friant Water Authority Report*, considering the CalSim II 2030 climate change projections and implementation of the SJRRP; 2004-2015 data (2079-2090) estimated as the historical volume adjusted by the average Friant Report climate change volume by month and water year type
Other Diversions/ Bypasses	2001-2010 historical data (2020-2029 and 2030-2039)	1965-2015 historical data (2040-2090)	2001-2010 historical data (2020-2029 and 2030-2039)***	1965-2015 historical data (2040-2090)***

* "Estimate of Future Friant Division Supplies for use in Groundwater Sustainability Plans, California," Friant Water Authority, 2018.

** Although the Friant Water Authority Report (or Friant Report) accounts for climate change, it is considered the best available estimate of projected Madera Canal deliveries under SJRRP. For comparison, projected Madera Canal deliveries under SJRRP were also estimated without account for climate change from the Steiner Report Kondolf Hydrograph (Steiner, 2005). These estimates were approximately equal to the Friant Report 2030 climate change adjusted deliveries. Thus, the Friant Report projections were used instead to maintain consistent assumptions in estimating Madera Canal deliveries across all projected simulations.

*** Historical volumes specified in the model to ensure that GSAs can use as much surface water as is available in a given time step up to the maximum historical surface water used.

3.3.4.2 Diversions

Surface water diversion volumes were projected into the future based on assigned water year corresponding to projected water year type, with the exception of diversions from the Madera Canal which were estimated from a report on future supplies by the Friant Water Authority (Friant Water Authority, 2018). For scenarios with climate change, a climate change adjustment was incorporated into the projections. Additional information the development of projected surface water diversions is included in **Table 3-12**.

3.3.4.3 Projects

Two main types of projects were simulated in MCSim. The first type of project delivers flood water or uncontrolled releases from the Madera Canal to recharge basins or farmer’s fields to increase groundwater recharge. The second type of project reduces groundwater pumping either by encouraging growers to use surface water rather than groundwater or by purchasing and importing additional surface water. Estimates of project configuration, cost and recharge were developed in close collaboration with each GSA. The objective of the projects (and demand management in the case of the Madera County GSA) is to increase recharge or reduce groundwater pumping a sufficient volume so groundwater pumping does not exceed the sustainable yield.

For recharge basins and flood managed aquifer recharge (flood-MAR) projects, diversion volumes were developed based on estimated recharge rates (four inches per day), the area flooded, and the water volumes available by water year type and month. For projects in which water is purchased and additional surface water is used by growers in lieu of groundwater, estimated diversion volumes were provided by the GSAs.

For projects using flood water, diversions were specified in the model as the maximum volumes that could be diverted and used by the projects. This ensured that projects could take as much water as was available in a given time step up to the maximum capacity of each project. Because maximum volumes were specified for each project, no climate change adjustment was applied to projects in the Projected with Projects with Climate Change scenario. Elements where recharge would occur were specified for each project. Additional surface water purchased, and additional surface water used by growers was assumed to be available to all elements in the GSA implementing the projects.

Project diversion locations are provided in **Figure 3-53.**

Diversion points were located downstream of historical diversions in order to prioritize historical diversions over project diversions. Project diversions were delivered to the entirety of the appropriate GSA, unless more detailed delivery information was provided for the project. Delivery locations for projects are shown in **Figures A-66 through A-111** of **Appendix A**.

Table 3-13. Summary of Projected Projects by GSA.

Subbasin	GSA	Project Name	Project Mechanism and Source of Information
Chowchilla	Chowchilla WD	CWD Recharge Basin	Estimated Average Annual Groundwater Basin Recharge Volume (AF, based on D. Welch analysis in Groundwater Basin Spreading Analysis 80 acres Scenario 4 2018 09 11 - dm)
Chowchilla	Chowchilla WD	CWD Additional Recharge Basin	Estimated Average Annual Groundwater Basin Recharge Volume (AF, based on 1989-2014 Historical Flood Releases and Assumptions Above)
Chowchilla	Chowchilla WD	CWD Flood-MAR	Estimated Average Annual On-Farm Recharge Volume (AF, based on 1989-2014 Historical Flood Releases and Assumptions Above)
Chowchilla	Chowchilla WD	Merced-Chowchilla Intertie	Estimated Average Annual Surface Water sold from Merced ID to Chowchilla WD (AF, based on San Joaquin River Restoration Program, Working Administrative Draft, Water Management Goal - Investment Strategy, Project 101 Chowchilla-Merced Intertie)
Chowchilla	Chowchilla WD	Madera Canal Capacity Increase	Estimated Average Annual Short duration flood waters delivered through increased capacity (AF, based on San Joaquin River Restoration Program, Working Administrative Draft, Water Management Goal - Investment Strategy, Project 114 Madera Canal Capacity Exp
Chowchilla	Chowchilla WD	Eastman Lake Enlargement	Estimated Average Annual Increased Buchanan Dam deliveries through increased capacity (AF, based on San Joaquin River Restoration Program, Working Administrative Draft, Water Management Goal - Investment Strategy, Project 105 Eastman Lake Enlargement)
Chowchilla	Madera Co.-East	Madera County Purchase, Chowchilla	Import of "other water" (high cost) into Eastern portion of Madera County GSA using Madera Canal (use for irrigation in lieu of pumping GW)
Chowchilla	Madera Co.-East	Madera County Flood Import, Chowchilla	Import of CVP "flood" water (215 or other) into Eastern portion of Madera GSA using Madera Canal (use recharge ponds, deep dry wells and Flood-MAR on crop land)
Chowchilla	Madera Co.-East	MC-East Flood-MAR	Estimated Average Annual On-Farm Recharge Volume (AF, based on 1989-2014 Historical Flood Releases and Assumptions Above)
Chowchilla	Madera Co.-West	Madera County Recharge Basin, Chowchilla	Estimated Average Annual Frequency Summary Table--Recharge Basins off Eastside Bypass--Flood Flows in W and AN
Chowchilla	Madera Co.-West	Red Top Joint Banking Project (Madera County)	Estimated Average Annual Frequency Summary Table--MARPO Red Top Joint Banking Project--7 new 20-CFS slant pump turnouts to flood recharge basins and fields

Subbasin	GSA	Project Name	Project Mechanism and Source of Information
Chowchilla	Madera Co.-West	Red Top Joint Banking Project (Ash) (Madera County)	Estimated Average Annual Frequency Summary Table--MARPO Red Top Joint Banking Project--CWD turnout replacement on Ash Slough--assume 20 CFS for 90 days in W years to flood recharge basins and fields
Chowchilla	Sierra Vista MWC	SVMWC Recharge Basin	Estimated Average Annual Frequency Summary Table--100 CFS per day to flood recharge basins
Chowchilla	Triangle T WD	Settlement Agreement	Estimated Average Annual Frequency Summary Table—TTWD Purchased contract water, based on settlement agreement with Exchange contractors
Chowchilla	Triangle T WD	Eastside Bypass Flood WR Application	Estimated Average Annual Frequency Summary Table--Eastside Bypass Flood WR Application--flood recharge basins and fields
Chowchilla	Triangle T WD	Red Top Joint Banking Project (TTWD)	Estimated Average Annual Frequency Summary Table--MARPO Red Top Joint Banking Project--5 new 20-CFS slant pump turnouts to flood recharge basins and fields
Chowchilla	Triangle T WD	Red Top Joint Banking Project (TTWD)	Estimated Average Annual Frequency Summary Table--MARPO Red Top Joint Banking Project--new 48-inch RCBC (60 to 150 CFS) off Eastside Bypass to Fresno River with capacity improvements to Grover Junction to flood recharge basins and fields
Madera	City of Madera	Berry Basin (City of Madera)	Berry Basin Project--Completed--Flood Flows and 215 water in W, AN and BN years
Madera	Gravelly Ford WD	GFWD Recharge Basin	Recharge Basin Project--Flood Flows and 215 water in W, AN and BN years
Madera	Madera County	Madera County Purchase, Madera	Import of "other water" (high cost) into Eastern portion of Madera County GSA using Madera Canal (use for irrigation in lieu of pumping GW)
Madera	Madera County	Madera County Flood Import, Madera	Import of CVP "flood" water (215 or other) into Eastern portion of Madera GSA using Madera Canal (use recharge ponds, deep dry wells and Flood-MAR on crop land)
Madera	Madera County	Madera County Recharge Basins, Madera	Recharge Basins off Chowchilla Bypass--Flood Flows in W and AN
Madera	Madera County	Madera County Additional Recharge	Additional Recharge of Chowchilla Bypass--Flood Flows in W and AN Water Years
Madera	Madera ID	MID Recharge Basin Rehabilitation	Estimated Average Annual Frequency Summary Table--MID Recharge Basin Rehabilitation Project--Existing Rehabilitated--Flood Flows and 215 water in W, AN and BN years, reduced volume in critical years is Hensley Lake water put in basins to reduce evaporation from Hensley Lake

Subbasin	GSA	Project Name	Project Mechanism and Source of Information
Madera	Madera ID	MID Pipeline Project	Estimated Average Annual Frequency Summary Table--MID Pipeline Project, Main I-Road 23 Project - 5900'--reduces evaporation and provides additional water to fields by lengthening the season
Madera	Madera ID	Ellis Basin	Estimated Average Annual Frequency Summary Table--Ellis Basin Project--Completed--Flood Flows and 215 water in W, AN and BN years
Madera	Madera ID	On-Farm Recharge Pilot Project	Estimated Average Annual Frequency Summary Table--On-Farm Recharge Project (Flood-MAR) Pilot Project
Madera	Madera ID	Berry Basin	Estimated Average Annual Frequency Summary Table--Berry Basin Project--Completed--Flood Flows and 215 water in W, AN and BN years
Madera	Madera ID	WaterSMART Pipeline Project	Estimated Average Annual Frequency Summary Table--WaterSMART Pipeline Project--reduces evaporation and provides additional water to fields by lengthening the season
Madera	Madera ID	WaterSMART SCADA Project	Estimated Average Annual Frequency Summary Table--WaterSMART SCADA Project--reduces evaporation and provides additional water to fields by lengthening the season
Madera	Madera ID	MID Recharge Basin Acquisition	Estimated Average Annual Frequency Summary Table--MID Recharge Basin Acquisition--22-acre Basin (Allende Basin) --Flood Flows and 215 water in W, AN and BN years, reduced volume in critical years is Hensley Lake water put in basins to reduce evaporation from Hensley Lake
Madera	Madera ID	MID Water Supply Development-Partnerships	Estimated Average Annual Frequency Summary Table--Water Supply Development-Partnerships
Madera	Madera ID	MID Recharge Basin Acquisition	Estimated Average Annual Frequency Summary Table--Recharge Basin Acquisition--locate, acquire and develop property for recharge--Flood Flows and 215 water in W, AN and BN years,
Madera	Madera ID	MID Water Supply Development-Partnerships Additional	Estimated Average Annual Frequency Summary Table--Water Supply Development-Partnerships Additional
Madera	Madera ID	MID Flood-MAR Enhanced Project	Estimated Average Annual Frequency Summary Table--Flood-MAR Enhanced Project
Madera	Madera ID	MID Incentive Programs	Estimated Average Annual Frequency Summary Table--Explore new fee structures and incentive-based programs Incentives to use surface water
Madera	Madera ID	MID Additional Recharge	Additional Recharge

Subbasin	GSA	Project Name	Project Mechanism and Source of Information
Madera	Madera WD	MWD Water Purchase	Madera Water District plans to purchase surface water in wet and above normal years to offset groundwater pumping during below normal, dry and critical years.
Madera	New Stone WD	Exercise of Appropriative Right	NSWD GSA has an appropriative water right along the Chowchilla Bypass (referred to as Eastside Bypass/Chowchilla Canal in permit) of 15,700 acre-feet/year (permit number 19615).
Madera	Root Creek WD	RCWD pipeline	Root Creek Water District--Surface Water delivered and applied through distribution system off MID Lateral 6.2
Madera	Root Creek WD	RCWD Surface Water Delivery Increase	Surface Water Delivery Increase from USBR Holding Contracts on San Joaquin River

3.3.4.4 Bypasses

Bypass volumes were projected into the future based on the water year type of the assigned historical year. The inflows to the Chowchilla Bypass from the San Joaquin River were estimated based on the historical monthly ratio of Chowchilla Bypass USGS stream gage (CBP) and projected San Joaquin River flows provided by a report on future supplies by the Friant Water Authority (Friant Water Authority, 2018). For scenarios with climate change, a climate change adjustment was incorporated into the projections. Additional information about the development of projected bypass volumes is included in **Table 3-12**.

3.3.5 Groundwater System

The development of groundwater system datasets for projected future scenarios is described below.

3.3.5.1 Boundary Conditions

Several different boundary head conditions were developed for use in evaluating potential future conditions in the projected future scenarios. Future boundary head conditions scenarios were developed for: 1) no subsurface flow boundary conditions, 2) continuation of the average historical trend in groundwater levels over the period 1989 to 2015, and 3) gradual ramping down of the average historical groundwater level trend over the implementation period (2020-2040) with long-term stable trends in groundwater levels from 2040 to 2070 and 2090. In developing the future groundwater head conditions, head conditions developed over the historical model base period from 1989 to 2015 were substituted based on similar water year types for the projected period. The relative changes in boundary head conditions from the base period were used to represent the appropriate trend in boundary head conditions to be represented at each boundary node. In scenarios in which the historical trend in boundary heads was ramped down over the implementation period and then set as stable for the sustainability period past 2040, adjustments were applied to achieve reductions in trend slopes in intervals of five years from 2020 to 2040 and then an adjustment to represent a zero long-term trend was applied for both the periods 2040 to 2070 and also 2070 to 2090.

In the future simulations, both the Projected No Action and Projected No Action with Climate Change scenarios assume no flow boundary conditions, under which no subsurface flow enters or exits the model domain along the model boundary. In the No Action scenarios, it is assumed that no subbasin is subject to SGMA, so levels continue to fall in neighboring subbasins also. In this situation, inflows probably remain about the same. To model this, a boundary condition of no subsurface inflow or outflow at the model boundary is assumed (approximately 5-10 miles outside Chowchilla and Madera Subbasin boundaries. The Projected with Projects and Projected with Projects with Climate Change scenarios utilize general head boundary conditions with the assumption that adjacent basins are also implementing projects and experience ramping down of historical groundwater level trends with generally stable water level conditions after 2040. The same conductance values from the Historical simulation period are also used for the projected future general head boundary conditions.

3.3.5.2 Groundwater Pumping

The pumping specifications used for the historical simulation period were retained for the duration of all projected simulations (2015-2090) except in the Western Management Area (MA) of Chowchilla Subbasin. Due to the general need to reduce pumping from the Lower Aquifer in many parts of the Western MA to mitigate for potential subsidence impacts, in projected scenarios much of the pumping that occurred from the Lower Aquifer in the Western MA under the historical simulations was shifted into the Upper Aquifer model layers for the projected simulations. As a result, in the Western MA approximately 90 percent of projected pumping occurs in the Upper Aquifer and 10 percent is in the Lower Aquifer. Maps of the vertical distribution of projected agricultural pumping by layer are presented in **Figures 3-54 through 3-60** and for projected urban pumping by layer in **Figures 3-61 through 3-67**.

3.3.6 Initial Conditions

Initial conditions for projected future simulation in MCSim were generated from the historical simulation in MCSim. Initial Conditions for the unsaturated zone, root zone, small watersheds, and groundwater levels were defined as the final conditions of the historical simulation in MCSim. Initial water levels are shown in **Figures 3-68 through 3-74**.

4 GROUNDWATER FLOW MODEL RESULTS

Calibrated parameter values for the historical model simulation as well as water budgets for both the historical and projected future scenarios in MCSim are presented in this section. Model calibration involves the adjustment of model parameters to achieve a model that simulates the observed hydrologic system as best possible. Model parameters adjusted during calibration include aquifer parameters, streambed parameters, and fractional conveyance losses. The final parameters for the calibrated model are presented in this section. Previous discussion of the calibration process and values was also presented in sections 3.1 and 3.2.

4.1 Aquifer Parameters

Initial aquifer parameter values assigned to each lithology texture categories (clay, silt, sand, gravel) were based on reported literature values. These values were further refined and adjusted during the calibration process. Final calibrated values for each of the texture categories are presented in **Table 4-1**. These parameter values were used in the upscaling routine to generate aquifer parameter values for each model node. The upscaling process was previously described in Section 3.1.4.1.

4.1.1 Hydraulic Conductivity

The calibrated horizontal hydraulic conductivity (Kh) values range from 0.49 feet per day (ft/d) for clay to 500 ft/d for gravel (**Table 4-1**). Calibrated Kh in clays and silts are higher than values reported in the literature because the lithologic categories in the model represent the dominant material type although, they often include a mixture of some coarser and more permeable deposits such as sand. The final Kh values in the calibrated model area shown by model layer in **Figures 4-1 through 4-7**. Calibrated vertical hydraulic conductivity (Kv) values range from 0.028 ft/d for clay to 268 ft/d for gravel (**Table 4-1**). Kv values for the aquitard layers were derived based on C2VSim-FG Beta2 values used for the Corcoran Clay (E-Clay) with some adjustments. Aquitard Kv values for the Corcoran Clay, E-Clay (Layer 4 aquitard) were assigned as the C2VSim-FG Beta2 value for E-Clay at that model node. Because of the interpreted reduced lateral and vertical continuity of the A-Clay and C-Clay units, aquitard Kv values representative of the A-Clay (Layer 2 aquitard) were assigned as 1.5 times C2VSim-FG Beta2 value for E-Clay at that model node and aquitard Kv values for the C-Clay (Layer 3 aquitard) were assigned as 2 times C2VSim-FG Beta2 value for E-Clay at that model node. The Kv values in the calibrated model are shown by model layer in **Figures 4-8 through 4-17**.

4.1.2 Storage Coefficients

Final specific yield (Sy) values used in the calibrated model range from 0.03 for clay to 0.2 for both sand and gravel (**Table 4-1**). Final Sy values in the calibrated model by layer are shown in **Figures 4-18 through 4-24**. Specific storage (Ss) values used in the calibrated model range from 1.64 x 10^{-6} ft^{-1} for gravel to 1.39 x 10^{-5} ft^{-1} for clay (**Table 4-1**). Final calibrated Ss values by model layer are shown in **Figures 4-25 through 4-31**. The calibrated Ss term incorporates elastic storage, inelastic storage, and the compressibility of water. The C2VSim-FG Beta2 model available for use in development of the MCSim model and at the time of this model report, does not currently include the capability to simulate land subsidence. With the inclusion of a subsidence component in future versions of IWFM, which will account for the inelastic storage component, the Ss term can be refined in future versions of MCSim to include only elastic storage.

Table 4-1. Summary of Calibrated Aquifer Parameter Values.

		Aquifer Parameters			
		Horizontal Conductivity (Kh)	**Specific Storage (Ss)**	**Specific Yield (Sy)**	**Vertical Conductivity (Kv)**
Lithology Type	**Gravel**	500	1.64E-06	0.2	268
	Sand	300	2.44E-06	0.2	35
	Silt	5	3.68E-06	0.1	0.06
	Clay	0.49	1.39E-05	0.03	0.028
	Basement	0.005	2.40E-06	0.025	5.00E-03
Units		ft/d	ft^{-1}	-	ft/d
Eastern Area Consolidation Factor	**Layer 1**	0.5	1	1	0.5
	Layer 2	0.5	1	1	0.5
	Layer 3	0.5	1	1	0.5
	Layer 4	0.5	1	0.5	0.5
	Layer 5	0.5	1	0.5	0.5
	Layer 6	0.5	1	0.5	0.5
Depth Decay Factor	**Layer 1**	1	1	1	1
	Layer 2	1	1	1	1
	Layer 3	1	1	1	1
	Layer 4	0.4	0.6	0.6	0.4
	Layer 5	0.2	0.4	0.6	0.2
	Layer 6	0.2	0.2	0.6	0.2
	Layer 7	0.00001	0.00001	0.00001	0.00001

4.1.3 Groundwater Levels

A subset of the 2,377 wells that have observed groundwater levels in the study area was selected for model calibration. Wells were selected to provide a broad representation of the model domain based on the spatial distribution, availability of associated well construction information, depth zone of well completion (e.g., Upper Aquifer, Lower Aquifer), and period of record of available water level data. A total of 177 wells were selected to be used in calibration of MCSim with a total of 8,928 water level observations during the calibration period. Simulated and observed groundwater elevations were compared over the 1988 through 2015 calibration period. Well hydrographs of simulated and observed groundwater elevations used for model calibration are included in **Appendix B**.

To quantify model fit between the simulated and observed groundwater levels, residual (simulated minus observed) groundwater levels were calculated for each well. To summarize calibration results, a single model layer was selected to compare to observed water levels. In some cases, a well is constructed across multiple model layers, or no construction details were available to determine where the well was screened. In these cases, a single model layer was chosen for each well based on a qualitative review of the hydrograph.

A histogram of residual groundwater elevations for all observations is shown in **Figure 4-32**. Residual groundwater levels range from -184 feet to 171 feet, with 41 percent of simulated groundwater elevations within 10 feet of observed and 73 percent of simulated groundwater elevations within 20 feet of observed. A review of average residual groundwater elevations by well (**Figure 4-33**) shows that 92 wells, or 52 percent of total, have an average residual groundwater elevation within 10 feet of observed, while 131 wells, or 74 percent of total, have an average residual groundwater elevation within 20 feet of observed. Average residual groundwater elevations by well range from -97 feet to 46 feet.

The relation between observed and simulated groundwater elevations is shown by layer in **Figure 4-34**. Points plotting above 1-to-1 correlation line represent observations where MCSim is simulating higher than observed groundwater elevations, while points plotting below the 1-to-1 correlation line represent observations where MCSim simulating lower than observed groundwater elevations. In general, points are plotting close to the 1-to-1 correlation line, indicating a good model fit.

The relationship between residual and observed groundwater elevations is shown by layer in **Figure 4-35**. This figure shows that the model generally predicts water levels close to observed in the Upper Aquifer. The model tends to predict higher than observed levels at lower observed groundwater elevations, while the model tends to predict lower than observed levels at higher observed groundwater elevations in the Lower Aquifer, particularly in Layer 4.

The spatial distribution of residual errors in the simulated levels are presented in **Figure 4-36**. Chowchilla Subbasin is generally well calibrated. Madera Subbasin is also generally well calibrated; however, residuals tend to increase in the eastern portion of the subbasin and along subbasin boundaries. The spatial distribution of residual errors in the simulated levels by layer are presented in **Figure 4-37**. The greatest residuals are generally observed in the Lower Aquifer. Layer 4 is generally well calibrated in the western portions of Chowchilla and Madera Subbasins, but residuals tend to increase in the eastern portions of the Subbasins. Layer 5 is generally well calibrated in both Chowchilla and Madera Subbasins, with the exception of the southwestern border of Madera Subbasin and along the Chowchilla Bypass in Chowchilla Subbasin.

4.1.4 Stream Flow

Observed stream flow was compared to simulated stream flow at 12 locations (**Figure 4-38**). Observed stream flow data were available from 16 stations for these 12 locations from the USGS and California Data Exchange Center (CDEC). Hydrographs of observed versus simulated stream flows are available in **Appendix C**. In general, simulated stream flows closely match observed stream flows, where data are available.

Because observed stream flow data were only available along the San Joaquin River, stream seepage estimates developed outside the model for ungaged waterways were also used to inform the calibration of stream flow along modeled stream reaches where observed data are not available. **Table 4-2** presents a comparison of the average annual residual (simulated minus estimated values) for stream seepage values for all simulated streams in the model domain.

Table 4-2. Summary of Residual Average Annual Stream Seepage.

	Water Year Type						
	W	AN	BN	D	C	Total	
Madera Subbasin	-5,555	-3,970	-6,034	-5,321	-6,312	-5,660	AF/month
Chowchilla Subbasin	9,220	3,177	-57	908	1,235	3,673	AF/month
MCSim	1,161	-721	-3,317	-2,489	-2,882	-1,418	AF/month

4.1.5 Groundwater Pumping

Over the historical model period, on average 20 percent of pumping occurred in the Upper Aquifer and 80 percent occurred in the Lower Aquifer within the Chowchilla Subbasin. Pumping shifts toward greater Upper Aquifer pumping during the projected model period, with an average of 35 percent in the Upper Aquifer and 65 percent in the Lower Aquifer during the Implementation Period (2020-2039), and an average of 34 percent in the Upper Aquifer and 66 percent in the Lower Aquifer during the Sustainability Period (2040-2090).

In accordance with the need to reduce pumping from the Lower Aquifer in many parts of the Western MA of the Chowchilla Subbasin to mitigate for potential subsidence impacts, much of the pumping that occurred from the Lower Aquifer in the Western MA under the historical simulations was shifted into the Upper Aquifer model layers for the projected simulations. Over the historical model period, on average 48 percent of pumping occurred in the Upper Aquifer and 52 percent occurred in the Lower Aquifer within the Western MA. During the projected model period, there was an average of 86 percent of total pumping in the Upper Aquifer and 14 percent in the Lower Aquifer during the Implementation Period (2020-2039), and an average of 87 percent of total pumping in the Upper Aquifer and 13 percent in the Lower Aquifer during the Sustainability Period (2040-2090). This shift results in an average of about 0.25 AF/ac per year of pumping from the Lower Aquifer within the Western MA in the projected simulation.

Over the historical model period, on average 30 percent of pumping occurred in the Upper Aquifer and 70 percent occurred in the Lower Aquifer within the Madera Subbasin. Pumping remains essentially constant during the projected model period, with an average of 27 percent in the Upper Aquifer and 73 percent in the Lower Aquifer during the Implementation Period (2020-2039), and an average of 28 percent in the Upper Aquifer and 72 percent in the Lower Aquifer during the Sustainability Period (2040-2090).

4.2 Water Budget

Separate groundwater budgets were generated for both the Chowchilla and Madera Subbasins for each of the model simulations. Water budget results are presented in the following sections.

4.2.1 Historical Period, 1989-2015

The water budget during the historical calibration period simulation was calculated for the 1989-2015 water years from October 1, 1988 through September 30, 2015.

Table 4-3. Summary of Historical and Projected Groundwater Pumping in MCSim.

		Madera Subbasin	Chowchilla Subbasin	Western MA (Chowchilla)	
		348,953	145,684	45,079	ac
Historical Period (1989-2015)	Upper	143,632	51,414	46,338	AF/yr
	Lower	336,667	209,813	50,651	AF/yr
	Upper	0.41	0.35	1.03	AF/ac/yr
	Lower	0.96	1.44	1.12	AF/ac/yr
	Upper	30%	20%	48%	%
	Lower	70%	80%	52%	%
Implementation Period (2020-2039)	Upper	133,197	96,471	91,994	AF/yr
	Lower	358,569	180,187	15,016	AF/yr
	Upper	0.38	0.66	2.04	AF/ac/yr
	Lower	1.03	1.24	0.33	AF/ac/yr
	Upper	27%	35%	86%	%
	Lower	73%	65%	14%	%
Sustainability Period (2040-2090)	Upper	124,775	84,773	79,721	AF/yr
	Lower	322,587	163,701	11,665	AF/yr
	Upper	0.36	0.58	1.77	AF/ac/yr
	Lower	0.92	1.12	0.26	AF/ac/yr
	Upper	28%	34%	87%	%
	Lower	72%	66%	13%	%

4.2.1.1 Chowchilla Subbasin

Change in groundwater storage shows an overall decrease of approximately 976,000 acre-feet (AF) over the 28-year period or an average decrease of about 36,000 AF per year. Net stream seepage, which includes in-channel seepage and conveyance losses, accounts for an average recharge of about 57,000 AF per year. Deep percolation accounts for an average recharge of about 120,000 AF per year. Groundwater pumping accounts for an average discharge of about 261,000 AF per year. Net subsurface inflow accounts for an average of about 49,000 AF per year with approximately 17,000 AF per year of net inflow from Madera Subbasin, 5,000 AF per year of net inflow from Merced Subbasin, and 27,000 AF per year of net inflow from Delta-Mendota Subbasin. There is significant uncertainty in subsurface inflow/outflow estimates because these calculations depend on a variety of factors inside and outside the subbasin.

Detailed historical water budget results for Chowchilla Subbasin are presented in **Appendix D.1.a.** and **Appendix D.1.c.**, and groundwater elevation hydrographs at select wells are included in **Appendix B**.

4.2.1.2 Madera Subbasin

Change in groundwater storage shows an overall decrease of approximately 1,250,000 AF over the 28-year period or an average decrease of about 46,000 AF per year. Net stream seepage, which includes in-channel seepage and conveyance losses, accounts for an average recharge of about 140,000 AF per year. Deep percolation accounts for an average recharge of about 223,000 AF per year. Groundwater pumping accounts for an average discharge of about 480,000 AF per year. Net subsurface inflow accounts for an average of about 70,000 AF per year with approximately 17,000 AF per year of net outflow to Chowchilla Subbasin, 60 AF per year of net inflow from Merced Subbasin, 22,000 AF per year of net inflow from Delta-Mendota Subbasin, and 65,000 AF per year of net inflow from Kings Subbasin. There is significant uncertainty in subsurface inflow/outflow estimates because these calculations depend on a variety of factors inside and outside the subbasin.

Detailed historical water budget results for Chowchilla Subbasin are presented in **Appendix D.1.b.** and **Appendix D.1.d.**, and groundwater elevation hydrographs at select wells are included in **Appendix B**.

4.2.2 Implementation Period, 2020-2039

The water budget during the implementation period simulation was calculated for the 2020-2039 water years from October 1, 2019 through September 30, 2039.

4.2.2.1 Chowchilla Subbasin

Projected with Projects

Change in groundwater storage shows an overall decrease of approximately 347,000 AF over the 20-year period or an average decrease of about 17,000 AF per year. Net stream seepage, which includes in-channel seepage, conveyance losses and project recharge, accounts for an average recharge of about 81,000 AF per year. Deep percolation accounts for an average recharge of about 112,000 AF per year. Groundwater pumping accounts for an average discharge of about 277,000 AF per year. Net subsurface inflow accounts for an average of about 66,000 AF per year with approximately 25,000 AF per year of net inflow from Madera Subbasin, 2,000 AF per year of net outflow to Merced Subbasin, and 43,000 AF per year of net inflow from Delta-Mendota Subbasin.

Detailed projected with projects water budget results for Chowchilla Subbasin are presented in **Appendix D.2.a.** and **Appendix D.2.c.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.1**.

Projected with Projects, with Climate Change

Change in groundwater storage shows an overall decrease of approximately 730,000 AF over the 20-year period or an average decrease of about 36,000 AF per year. Net stream seepage, which includes in-channel seepage, conveyance losses and project recharge, accounts for an average recharge of about 90,000 AF per year. Deep percolation accounts for an average recharge of about 114,000 AF per year. Groundwater pumping accounts for an average discharge of about 318,000 AF per year. Net subsurface inflow accounts for an average of about 77,000 AF per year with approximately 25,000 AF per year of net inflow from Madera Subbasin, 14,000 AF per year of net inflow from Merced Subbasin, and 39,000 AF per year of net inflow from Delta-Mendota Subbasin.

Detailed projected with projects with climate change water budget results for Chowchilla Subbasin are presented in **Appendix D.3.a.** and **Appendix D.3.c.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.2**.

Projected No Action

Change in groundwater storage shows an overall decrease of approximately 1,150,000 AF over the 20-year period or an average decrease of about 57,000 AF per year. Net stream seepage, which includes in-channel seepage and conveyance losses, accounts for an average recharge of about 61,000 AF per year. Deep percolation accounts for an average recharge of about 111,000 AF per year. Groundwater pumping accounts for an average discharge of about 303,000 AF per year. Net subsurface inflow accounts for an average of about 73,000 AF per year with approximately 36,000 AF per year of net inflow from Madera Subbasin, 13,000 AF per year of net outflow to Merced Subbasin, and 50,000 AF per year of net inflow from Delta-Mendota Subbasin.

Detailed projected water budget results for Chowchilla Subbasin are presented in **Appendix D.4.a.** and **Appendix D.4.c.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.3**.

Projected No Action, with Climate Change

Change in groundwater storage shows an overall decrease of approximately 1,730,000 AF over the 20-year period or an average decrease of about 87,000 AF per year. Net stream seepage, which includes in-channel seepage and conveyance losses, accounts for an average recharge of about 54,000 AF per year. Deep percolation accounts for an average recharge of about 110,000 AF per year. Groundwater pumping accounts for an average discharge of about 344,000 AF per year. Net subsurface inflow accounts for an average of about 93,000 AF per year with approximately 37,000 AF per year of net inflow from Madera Subbasin, 1,400 AF per year of net inflow from Merced Subbasin, and 55,000 AF per year of net inflow from Delta-Mendota Subbasin.

Detailed projected with climate change water budget results for Chowchilla Subbasin are presented in **Appendix D.5.a.** and **Appendix D.5.c.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.4**.

4.2.2.2 Madera Subbasin

Projected with Projects

Change in groundwater storage shows an overall decrease of approximately 634,000 AF over the 20-year period or an average decrease of about 32,000 AF per year. Net stream seepage, which includes in-channel seepage, conveyance losses, and project recharge, accounts for an average recharge of about 166,000 AF per year. Deep percolation accounts for an average recharge of about 199,000 AF per year. Groundwater pumping accounts for an average discharge of about 492,000 AF per year. Net subsurface inflow accounts for an average of about 95,000 AF per year with approximately 25,000 AF per year of net outflow to Chowchilla Subbasin, 60 AF per year of net inflow from Merced Subbasin, 41,000 AF per year of net inflow from Delta-Mendota Subbasin, and 80,000 AF per year of net inflow from Kings Subbasin.

Detailed projected with projects water budget results for Madera Subbasin are presented in **Appendix D.2.b.** and **Appendix D.2.d.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.1**.

Projected with Projects, with Climate Change

Change in groundwater storage shows an overall decrease of approximately 1,200,000 AF over the 20-year period or an average decrease of about 61,000 AF per year. Net stream seepage, which includes in-channel seepage, conveyance losses, and project recharge, accounts for an average recharge of about 162,000 AF per year. Deep percolation accounts for an average recharge of about 199,000 AF per year. Groundwater pumping accounts for an average discharge of about 530,000 AF per year. Net subsurface inflow accounts for an average of about 109,000 AF per year with approximately 25,000 AF per year of net outflow to Chowchilla Subbasin, 60 AF per year of net inflow from Merced Subbasin, 46,000 AF per year of net inflow from Delta-Mendota Subbasin, and 88,000 AF per year of net inflow from Kings Subbasin.

Detailed projected with projects with climate change water budget results for Madera Subbasin are presented in **Appendix D.3.b.** and **Appendix D.3.d.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.2**.

Projected No Action

Change in groundwater storage shows an overall decrease of approximately 2,040,000 AF over the 20-year period or an average decrease of about 102,000 AF per year. Net stream seepage, which includes in-channel seepage and conveyance losses, accounts for an average recharge of about 144,000 AF per year. Deep percolation accounts for an average recharge of about 192,000 AF per year. Groundwater pumping accounts for an average discharge of about 546,000 AF per year. Net subsurface inflow accounts for an average of about 107,000 AF per year with approximately 36,000 AF per year of net outflow to Chowchilla Subbasin, 60 AF per year of net inflow from Merced Subbasin, 63,000 AF per year of net inflow from Delta-Mendota Subbasin, and 81,000 AF per year of net inflow from Kings Subbasin.

Detailed projected water budget results for Madera Subbasin are presented in **Appendix D.4.b.** and **Appendix D.4.d.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.3**.

Projected No Action, with Climate Change

Change in groundwater storage shows an overall decrease of approximately 2,810,000 AF over the 20-year period or an average decrease of about 140,000 AF per year. Net stream seepage, which includes in-channel seepage and conveyance losses, accounts for an average recharge of about 130,000 AF per year. Deep percolation accounts for an average recharge of about 193,000 AF per year. Groundwater pumping accounts for an average discharge of about 585,000 AF per year. Net subsurface inflow accounts for an average of about 122,000 AF per year with approximately 37,000 AF per year of net outflow to Chowchilla Subbasin, 60 AF per year of net inflow from Merced Subbasin, 74,000 AF per year of net inflow from Delta-Mendota Subbasin, and 85,000 AF per year of net inflow from Kings Subbasin.

Detailed projected with climate change water budget results for Madera Subbasin are presented in **Appendix D.5.b.** and **Appendix D.5.d.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.4**.

4.2.3 Sustainability Period, 2040-2090

The water budget during the sustainability period simulation was calculated for the 2040-2090 water years from October 1, 2039 through September 30, 2090.

4.2.3.1 Chowchilla Subbasin

Projected with Projects

Change in groundwater storage shows an overall increase of approximately 124,000 AF over the 50-year period or an average increase of about 2,400 AF per year. Net stream seepage, which includes in-channel seepage, conveyance losses and project recharge, accounts for an average recharge of about 120,000 AF per year. Deep percolation accounts for an average recharge of about 121,000 AF per year. Groundwater pumping accounts for an average discharge of about 121,000 AF per year. Net subsurface inflow accounts for an average of about 9,700 AF per year with approximately 30,000 AF per year of net inflow from Madera Subbasin, 41,000 AF per year of net outflow to Merced Subbasin, and 21,000 AF per year of net inflow from Delta-Mendota Subbasin.

Detailed projected with projects water budget results for Chowchilla Subbasin are presented in **Appendix D.2.a.** and **Appendix D.2.c.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.1**.

Projected with Projects, with Climate Change

Change in groundwater storage shows an overall increase of approximately 115,000 AF over the 50-year period or an average increase of about 2,200 AF per year. Net stream seepage, which includes in-channel seepage, conveyance losses and project recharge, accounts for an average recharge of about 134,000 AF per year. Deep percolation accounts for an average recharge of about 123,000 AF per year. Groundwater pumping accounts for an average discharge of about 276,000 AF per year. Net subsurface inflow accounts for an average of about 21,000 AF per year with approximately 28,000 AF per year of net inflow from Madera Subbasin, 27,000 AF per year of net outflow to Merced Subbasin, and 20,000 AF per year of net inflow from Delta-Mendota Subbasin.

Detailed projected with projects with climate change water budget results for Chowchilla Subbasin are presented in **Appendix D.3.a.** and **Appendix D.3.c.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.2**.

Projected No Action

Change in groundwater storage shows an overall decrease of approximately 2,125,000 AF over the 50-year period or an average decrease of about 42,000 AF per year. Net stream seepage, which includes in-channel seepage and conveyance losses, accounts for an average recharge of about 67,000 AF per year. Deep percolation accounts for an average recharge of about 117,000 AF per year. Groundwater pumping accounts for an average discharge of about 298,000 AF per year. Net subsurface inflow accounts for an average of about 71,000 AF per year with approximately 46,000 AF per year of net inflow from Madera Subbasin, 18,000 AF per year of net outflow to Merced Subbasin, and 44,000 AF per year of net inflow from Delta-Mendota Subbasin.

Detailed projected water budget results for Chowchilla Subbasin are presented in **Appendix D.4.a.** and **Appendix D.4.c.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.3**.

Projected No Action, with Climate Change

Change in groundwater storage shows an overall decrease of approximately 1,970,000 AF over the 50-year period or an average decrease of about 39,000 AF per year. Net stream seepage, which includes in-channel seepage and conveyance losses, accounts for an average recharge of about 69,000 AF per year. Deep percolation accounts for an average recharge of about 115,000 AF per year. Groundwater pumping accounts for an average discharge of about 314,000 AF per year. Net subsurface inflow accounts for an average of about 91,000 AF per year with approximately 44,000 AF per year of net inflow from Madera Subbasin, 7,000 AF per year of net outflow to Merced Subbasin, and 54,000 AF per year of net inflow from Delta-Mendota Subbasin.

Detailed projected with climate change water budget results for Chowchilla Subbasin are presented in **Appendix D.5.a.** and **Appendix D.5.c.**, and groundwater elevation hydrographs at select wells are included in **Appendix E.4**.

4.2.3.2 Madera Subbasin

Projected with Projects

Change in groundwater storage shows an overall increase of approximately 523,000 AF over the 50-year period or an average increase of about 10,000 AF per year. Net stream seepage, which includes in-channel seepage conveyance losses, and project recharge, accounts for an average recharge of about 217,000 AF per year. Deep percolation accounts for an average recharge of about 219,000 AF per year. Groundwater pumping accounts for an average discharge of about 447,000 AF per year. Net subsurface inflow accounts for an average of about 21,000 AF per year with approximately 30,000 AF per year of net outflow to Chowchilla Subbasin, 20 AF per year of net inflow from Merced Subbasin, 6,000 AF per year of net inflow from Delta-Mendota Subbasin, and 45,000 AF per year of net inflow from Kings Subbasin.

Detailed projected with projects water budget results for Madera Subbasin are presented in **Appendix D.2.b.** and **Appendix D.2.d.**, and groundwater elevation hydrographs for select wells are included in **Appendix E.1**.

Projected with Projects, with Climate Change

Change in groundwater storage shows an overall increase of approximately 493,000 AF over the 50-year period or an average increase of about 10,000 AF per year. Net stream seepage, which includes in-channel seepage conveyance losses, and project recharge, accounts for an average recharge of about 228,000 AF per year. Deep percolation accounts for an average recharge of about 219,000 AF per year. Groundwater pumping accounts for an average discharge of about 479,000 AF per year. Net subsurface inflow accounts for an average of about 41,000 AF per year with approximately 28,000 AF per year of net outflow to Chowchilla Subbasin, 20 AF per year of net inflow from Merced Subbasin, 12,000 AF per year of net inflow from Delta-Mendota Subbasin, and 57,000 AF per year of net inflow from Kings Subbasin.

Detailed projected with projects with climate change water budget results for Madera Subbasin are presented in **Appendix D.3.b.** and **Appendix D.3.d.**, and groundwater elevation hydrographs are included in **Appendix E.2**.

Projected No Action

Change in groundwater storage shows an overall decrease of approximately 3,095,000 AF over the 50-year period or an average decrease of about 61,000 AF per year. Net stream seepage, which includes in-channel seepage and conveyance losses, accounts for an average recharge of about 162,000 AF per year. Deep percolation accounts for an average recharge of about 217,000 AF per year. Groundwater pumping accounts for an average discharge of about 548,000 AF per year. Net subsurface inflow accounts for an average of about 108,000 AF per year with approximately 46,000 AF per year of net outflow to Chowchilla Subbasin, 40 AF per year of net inflow from Merced Subbasin, 82,000 AF per year of net inflow from Delta-Mendota Subbasin, and 72,000 AF per year of net inflow from Kings Subbasin.

Detailed projected water budget results for Madera Subbasin are presented in **Appendix D.4.b.** and **Appendix D.4.d.**, and groundwater elevation hydrographs are included in **Appendix E.3**.

Projected No Action, with Climate Change

Change in groundwater storage shows an overall decrease of approximately 3,080,000 AF over the 50-year period or an average decrease of about 60,000 AF per year. Net stream seepage, which includes in-channel seepage and conveyance losses, accounts for an average recharge of about 158,000 AF per year. Deep percolation accounts for an average recharge of about 214,000 AF per year. Groundwater pumping accounts for an average discharge of about 565,000 AF per year. Net subsurface inflow accounts for an average of about 131,000 AF per year with approximately 44,000 AF per year of net outflow to Chowchilla Subbasin, 40 AF per year of net inflow from Merced Subbasin, 98,000 AF per year of net inflow from Delta-Mendota Subbasin, and 77,000 AF per year of net inflow from Kings Subbasin.

Detailed projected with climate change water budget results for Madera Subbasin are presented in **Appendix D.5.b.** and **Appendix D.5.d.**, and groundwater elevation hydrographs are included in **Appendix E.4**.

5 MODEL UNCERTAINTY AND LIMITATIONS

Any groundwater flow model is a simplification of the natural environment, and therefore has recognized limitations. For this reason, uncertainty exists in the ability of any numerical model to completely represent groundwater flow. Some of the uncertainty is associated with limitations in available data. Considerable effort was made to reduce model uncertainty by using measured values as model inputs whenever available, and by conducting quality assurance and quality control assessments of data that were obtained. Where limited data exist to develop input values for parameters or other inputs with high uncertainty, a conservative approach to assigning input values was followed.

The finding and conclusions of this study are focused on a Subbasin scale and use of the model for site-specific analysis should be conducted with an understanding that representation of local site-specific conditions may be approximate and should be verified with local site-specific investigations. The flow model was developed in a manner consistent with the level of care and skill normally exercised by professionals practicing under similar conditions in the area. There is no warranty, expressed or implied, that this modeling study has considered or addresses all hydrogeological, hydrological, environmental, geotechnical or other characteristics and properties associated with the subject model domain and the simulated system.

6 CONCLUSIONS AND RECOMMENDATIONS

Based on the calibration of MCSim to historical conditions for the calibration period from water year 1989 to 2015 and accompanying assessment of model sensitivity, the MCSim groundwater flow model is suitable for use as a tool to support management of water resources within the Madera and Chowchilla Subbasins.

6.1 Conclusions

MCSim provides a useful tool for evaluating a wide variety of future scenarios and inform the decision-making process to achieve and maintain sustainable groundwater management in both the Madera and Chowchilla Subbasins. A numerical model can be a convenient and cost-efficient tool for providing insights into groundwater responses to various perturbations including natural variability and change, and also changes associated with management decisions or other humanmade conditions. However, as with any other modeling tool, information obtained from a numerical model also has a level of uncertainty, especially for long-term predictions or forecasts. The level of uncertainty associated with model simulations are likely to increase the more the scenarios extend beyond the range of historical conditions and processes over which the model was calibrated, such as for long-term predictive scenarios or predictive scenarios with extreme alterations to the hydrologic conditions.

6.2 Recommendations

Future and ongoing updates to MCSim will be valuable for improving the model performance and verifying the accuracy of the model predictions. Using data from the ongoing monitoring efforts and forthcoming GSP monitoring, MCSim should be updated periodically, including through extending of the model period and associated inputs. Although the frequency of conducting model updates may depend on a variety of factors, including evaluation of the model performance in predicting future conditions, such an update could initially be considered every five years. This frequency of model update should be adequate and cost effective to test and improve MCSim periodically with new site-specific and monitoring information. Groundwater elevations, groundwater pumping, rainfall, and stream discharge should be collected on an ongoing basis, to the extent possible, at intervals of at least monthly for pumpage, rainfall, and streamflow, and less frequently (semi-annually at least) for groundwater levels. The new groundwater data should be compared with the respective model simulation results so that the flow model can be verified into the future. If the differences between the measured groundwater data and MCSim’s predicted results are significant, adjustment and modification may be applied to the model input parameters.

MCSim has been calibrated and verified. It adheres closely to site-specific observed data so that model input parameters are reasonable and appropriate especially within the Chowchilla and Madera Subbasins. Additional model revisions should be conducted in areas outside the Chowchilla and Madera Subbasins as that data is obtained from adjacent GSAs.

Further refinement to MCSim should be made by addressing key data gaps. Upon release of a calibrated C2VSimFG model, an evaluation should be done to incorporate any relevant aspects of the model into MCSim, as appropriate and necessary. In particular, a calibrated land subsidence simulation package should be incorporated into MCSim. This capability is anticipated with the future release of the calibrated C2VSimFG model. Updates to aquifer parameters (and model layering if needed) can be made through refinement of the depth of basement materials in the eastern model area and incorporation of lithologic information developed from new monitoring well construction efforts anticipated for completion by 2020. Through upcoming GSP-related monitoring, additional groundwater level data can be used to refine boundary condition water levels and improve model calibration. Additional improvements to model calibration can be made by the potential linking of additional well construction information to calibration wells, incorporation of additional stream flow data on ungaged streams, and refinements to the simulation of surface water distribution systems. Further refinements to MCSim can be made by extending the historical base period and ongoing updating of model calibration in preparation for 5-year GSP status/update report.

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