Appendix 2-J

Tehama Integrated Hydrologic Model
Documentation Report

Tehama County

Sustainable Groundwater
Management Act

Groundwater Sustainability Plan

Tehama IHM Model Documentation

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AF	acre-feet
ASCE	American Society of Civil Engineers
BMP	Best Management Practices
CDEC	California Data Exchange Center
C2VSim	Central Valley Groundwater-Surface Water Simulation Model
CIMIS	California Irrigation Management Information System
CSS	Composite Scaled Sensitivity
CVP	Central Valley Project
DWR	California Department of Water Resources
ET	Evapotranspiration
Et_a	Actual Evapotranspiration
ET_{aw}	Evapotranspiration of Applied Water
ET_c	Crop Evapotranspiration
ET_o	Daily reference ET
ET_{pr}	Evapotranspiration of Precipitation
Et_r	Alfalfa Reference Evapotranspiration
eWRIMS	Electronic Water Rights Information Management System
ft/d	Feet Per Day
GDE	Groundwater Dependent Ecosystems
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
GWS	Groundwater System
IDC	Irrigation Demand Calculator
IWFM	Integrated Water Flow Model
Kh	Horizontal Hydraulic Conductivity
Kv	Vertical Hydraulic Conductivity
MAE	Mean of Absolute Residual Error
ME	Residual Error
METRIC	Mapping Evapotranspiration at High Resolution using Internalized Calibration
NRMSE	Normalized Root Mean of Squared Residual Error
PM	Penman-Monteith
PMAs	Projects and Management Actions
PRISM	Parameter Elevation Regression on Independent Slopes Model
R	Linear Correlation Coefficient
RMSE	Root Mean of Squared Residual Error
SEBAL	Surface Energy Balance Algorithm for Land
SGMA	Sustainable Groundwater Management Act
Ss	Specific Storage
SVSim	Sacramento Valley Groundwater-Surface Water Simulation Model
SWRCB	State Water Resources Control Board
SWS	Surface Water System
Sy	Specific Yield
TAF	Thousand Acre-Feet

Tehama IHM	Tehama Integrated Hydrologic Model
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
VIC	Variable Infiltration Capacity
WCR	Well Completion Report
WD	Water District

1. INTRODUCTION

This report documents the development and calibration of the Tehama Integrated Hydrologic Model (Tehama IHM), a numerical groundwater flow model developed for four groundwater subbasins (Antelope, Bowman, Los Molinos, and Red Bluff) within Tehama County to support preparation of the Groundwater Sustainability Plans (GSPs) for the County, 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, model scenarios, and model results.

1.1. Background

To support GSP preparation the Tehama County Flood Control and Water Conservation District Groundwater Sustainability Agency (GSA) developed a numerical groundwater flow model covering the Antelope, Bowman, Los Molinos, and Red Bluff Subbasins to address GSP regulations requiring use of a numerical groundwater model, or equally effective approach, to evaluate historical and projected water budget conditions and potential impacts to groundwater conditions and users from the GSP implementation while also providing a broader tool for use in groundwater management decisions in the Subbasins. The development of Tehama IHM is intended primarily to support groundwater resources management activities associated with GSP development and implementation but is also envisioned as a tool that will also support water resources management activities less related to the GSP. Tehama IHM utilizes data and the hydrogeologic conceptualization that are presented and described in the four subbasin GSPs for to improve the understanding of hydrologic processes and their relationship to key sustainability metrics within the subbasins. Tehama IHM 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 many data types (e.g., lithology, groundwater levels, surface water features, groundwater pumping) that represent the conceptualization of the hydrogeologic setting and processes. Tehama IHM 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 Tehama IHM is to simulate hydrologic processes and effectively estimate historical and projected hydrologic conditions in the four subbasins related to Sustainable Groundwater Management Act (SGMA) sustainability indicators relevant to Tehama County including:

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

The development of Tehama IHM involved starting with and evaluating the beta version of DWR's Sacramento Valley Groundwater-Surface Water Simulation Model (SVSim) (release data April 29, 2020; DWR, 2020) 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 Tehama County areas within the model domain. SVSim utilizes the most current version of the Integrated Water Flow Model (IWFM) code available at the time of the Tehama IHM development. IWFM and SVSim 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 SVSim model to be more representative of local conditions in the area of Tehama County. Tehama IHM was refined from SVSim and calibrated to a diverse set of available historical data using industry standard techniques.

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: Sensitivity Analysis
- Section 6: Model Uncertainty and Limitations
- Section 7: Conclusions and Recommendations
- Section 8: References

2. MODEL CODE AND PLATFORM

The modeling code and platform utilized for Tehama IHM 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 Tehama IHM was based on providing Tehama 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). Tehama IHM 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:

https://water.ca.gov/Library/Modeling-and-Analysis/Modeling-Platforms/Integrated-Water-Flow-Model

2.1.1. IWFM Demand Calculator

IWFM includes a stand-alone Integrated Water Flow Model Irrigation 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. Tehama IHM utilizes IDC to simulate root zone processes and water demands. The physically based IDC version 2015.0.88 (released August 25, 2020) is developed and maintained by DWR.

2.2. SVSim

The SVSim model utilizes the IWFM-2015 code and represents a refinement of the previous California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) coarse grid (CG) and fine grid (FG) models. Refinements made in the development of SVSim include a finer horizontal discretization, an updated aquifer layering scheme, updated hydrogeology, and an extended simulation period through water year 2015 (DWR, 2020). When compared with C2VSim, SVSim improves the simulation of stream-groundwater interaction with thinner shallow model layers and a finer grid adjacent to waterways (DWR, 2020). The SVSim version available from DWR at the time of the initiation of modeling efforts to support GSP preparation in Tehama County was not a calibrated model version. In January 2021, a calibrated Version 1.0 release of SVSim was made available to the public through the California Natural Resources

Agency Open Data website (https://data.cnra.ca.gov/dataset/svsim) and was reviewed and considered during the development of the Tehama IHM. The SVSim Version 1.0 was subsequently removed from the Open Data website and as of the date of this report (September 2021), a calibrated version of SVSim is no longer 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 Subbasin GSPs.

3.1. Tehama IHM – Historical Model Simulation

The Tehama IHM historical model simulates the period from October 1985 through September 2019 at a monthly time step, with a calibration period of October 1989 through September 2018. Water years, as opposed to calendar years, are used as the time unit for defining analysis, following the DWR standard water year period (October 1 through September 30). Unless otherwise noted, all years referenced in this report are water years. The historical model calibration period extends from water years 1990 through 2018. Water years 1985 through 1989 are not included as part of the historical calibration period, but are simulated to allow the model sufficient time to adjust to the specified initial conditions and spin-up prior to the calibration period starting in October 1989.

3.1.1. Historical Base Period Selection

In accordance with GSP Regulations, the historical water budget for the Subbasins must quantify all required water budget components starting with the most recently available information and extending back a minimum of 10 years, or as is sufficient to calibrate and reduce the uncertainty of the water budget (23 CCR § 354.18(c)(2)(B)). The historical water budget period effectively represents long-term average hydrologic conditions and enables evaluation of the effects of historical hydrologic conditions and water demands on the water budget and groundwater conditions within the Subbasins over a period representative of long-term hydrologic conditions.

The historical water budget period was selected to evaluate conditions over discrete representative periods considering the following criteria: Sacramento Valley water year type; long-term mean annual water supply; inclusion of both wet and dry periods, antecedent dry conditions, adequate data availability; and inclusion of current hydrologic, cultural, and water management conditions in the Subbasins. The availability of historical data for use in developing model inputs is greatly increased for years since 1990 in the Subbasins.

Based on these criteria, the historical water budget period and model calibration period was selected as water years 1990-2018 (29 years) using historical hydrologic, climate, water supply, and land use data. The period from 1990-2018 is consistent with long-term average historical hydrologic conditions in the Subbasins as illustrated in **Table 3-1**. Further information and discussion of the historical water budget period, including discussion of historical hydrology and the historical base period selection considerations, are presented in **Section 2.3** of the Subbasin GSPs.

Table 3-1. Sacramento Valley Water Year Type Classification of the Historical Water Budget Period (1990-2018)

Sacramento Valley Water Year Type	Abbreviation	Number of Years, 1990-2018	Average Water Year Index	Average Precipitation	Percent Total Years, 1990-2018
Wet	W	8	11.87	28.8	28%
Above Normal	AN	4	8.55	28.1	14%
Below Normal	BN	5	7.07	21.0	17%
Dry	D	5	5.98	17.2	17%
Critical	C	7	4.48	17.1	24%
	Total	**29**	**7.78**	**22.5**	**100%**

Note: Water Year Type is based on the Sacramento Valley Water Year Index and is classified into five types: Wet (W) ≥9.2; Above Normal (AN) 7.8-9.2; Below Normal (BN) 6.5-7.8; Dry (D) 5.4-6.5; Critical (C) ≤5.4. Precipitation data is based on Red Bluff Municipal Airport station (NOAA station ID USW00024216).

3.1.2. Model Configuration

The Tehama IHM grid of nodes and elements was carved out of the regional SVSim model domain. While Tehama IHM focuses on the Antelope, Bowman, Los Molinos, and Red Bluff Subbasins, the model domain was extended outside the Subbasins to incorporate a buffer that includes area within the Corning, Vina, Anderson, Millville, South Battle Creek, Bend, and Colusa Subbasins. The extent of the buffer is approximately five miles outside of Tehama County, or to the extent of the SVSim model where that extent is less than five miles outside the County. The appropriate extent of the buffer was determined using DWR's C2VSimFG model (DWR, 2021), a calibrated regional model, by testing the radius of influence from pumping wells. The Tehama IHM domain, shown in **Figure 3-1**, encompasses a total of 942,227 acres. All SVSim model features (e.g., nodes, elements, streams, layers) within this domain were initially included in Tehama IHM with subsequent modifications and refinements made within Tehama IHM to these model components, as described in later sections of this report.

3.1.2.1. Nodes and Elements

The Tehama IHM grid contains 5,209 nodes and 5,398 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 Tehama IHM domain were not altered from SVSim, the locations of some nodes and elements were modified to more accurately align with added streams being simulated in Tehama IHM. **Figure 3-2** highlights the modified nodes and elements in Tehama IHM. **Table 3-2** presents Tehama IHM grid characteristics.

Table 3-2. Tehama IHM Grid Characteristics

Nodes	5,209
Elements	5,398
Average Element Size (acres)	*175*
Minimum Element Size (acres)	*0.72*
Maximum Element Size (acres)	*2,122*
Subregions	4
Aquifer Layers	9

3.1.2.2. Model Subregions

Model elements are grouped into subregions to assist in the summarization of model results and development of water budgets. Tehama IHM includes four subregions (listed in **Table 3-3**). Subregions were delineated by subbasin. 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 extent of the different subregions delineated in Tehama IHM.

Table 3-3. Model Subregions within Tehama IHM

Subregion Name	Actual Acreage	Modeled Acreage
Antelope Subbasin	19,091	19,057
Bowman Subbasin	122,534	122,760
Los Molinos Subbasin	99,422	99,351
Red Bluff Subbasin	271,794	272,155

3.1.2.3. Streams

Tehama IHM includes 29 stream reaches composed of 599 stream nodes. Most of the streams explicitly simulated in Tehama IHM were streams included in SVSim. Streams that were adapted from existing streams simulated in SVSim include Antelope Creek Group, Battle Creek, Cottonwood Creek, Deer Creek Group, Elder Creek, Glenn-Colusa Canal, Mill Creek, Paynes Creek, Sacramento River, Stoney Creek, and Thomes Creek. Streams added to Tehama IHM that were not included in SVSim include Dye Creek and Red Bank Creek. Some of the model nodes were shifted to better align with the actual stream configuration of added streams. The entire stream network included in Tehama IHM is shown in **Figure 3-4**.

3.1.2.4. Model Layers

No adjustments to the layering scheme from SVSim were made in the development of Tehama IHM. Tehama IHM includes a total of nine model layers; in the IWFM model code, model layers can be subdivided into aquifer layers and aquitard layers for representation of different hydrogeologic characteristics within a single model layer. None of the model layers specifically included simulation of an aquitard layer, although finer-grained zones with potential to impede vertical flow in ways similar to an aquitard were simulated in accordance with the HCM (**Section 2.2 of the GSPs**) and available sediment texture data. **Table 3-4** presents the average thickness of each model layer in Tehama IHM. The uppermost layers are thin in order to better represent surface water-groundwater interaction. As described in the HCM presented in **Section 2.2 of the GSP**, the Subbasin has two primary aquifers: an unconfined to semi-confined Upper Aquifer and a confined to semi-confined Lower Aquifer. In general, model layers 1 through 5 correspond with the Upper Aquifer and layers 6 through 9 correspond with the Lower Aquifer. Further information about the local geology in the Tehama County Subbasins is presented in **Section 2.2 of the Subbasin GSPs**.

Table 3-4. Average Thicknesses of Tehama IHM Layers

Average Model Layer Thickness (feet)	
Layer 1	35
Layer 2	35
Layer 3	40
Layer 4	58
Layer 5	129
Layer 6	193
Layer 7	129
Layer 8	193
Layer 9	515

Elevations and thicknesses of each of the Tehama IHM model layers are shown in **Figures 3-5** through **3-23.**

3.1.3. Land Surface System Inputs

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 built on previous water budget data and analyses related to surface water system water budgets available for some areas of the Subbasins and was expanded to represent the entire Subbasins and a longer analysis period. The development of the land surface system model input files is described in the following section with additional detail provided in **Section 2.3 of the GSPs**.

3.1.3.1. Precipitation

For water years 1985-2019, monthly precipitation data for all elements and small watersheds in Tehama IHM were derived from the Parameter Elevation Regression on Independent Slopes Model (PRISM) system, which is operated by the PRISM Climate Group at Oregon State University. PRISM combines weather and climate data from various monitoring station networks, applies a range of modeling techniques, and develops gridded spatial climate parameter datasets for grid cells across the United States at a spatial resolution of four kilometers (NACSE, 2021). Building on previous water budget analysis work, monthly precipitation data sets were downloaded for the coordinates nearest the centroid of each element or watershed in Tehama IHM. The monthly data sets were quality controlled and provided as model inputs for the nearest corresponding element or small watershed. PRISM gridded precipitation data were extracted and interpolated, as needed, for each element in the Tehama IHM model domain, and for the centroid of each small watershed upgradient to the Tehama IHM model domain. Precipitation inflows to each small watershed were calculated as the monthly precipitation depth derived from PRISM data, applied over the total area of that small watershed.

3.1.3.2. Evapotranspiration

Monthly evapotranspiration (ET) time series data were refined for water years 1985 through 2019. Monthly ET rates were developed for individual crop types using the best available science, as described in this section.

3.1.3.2.1 Reference Evapotranspiration Development

Daily reference ET (ET_o) values for calendar years 1985-2019 were based on measured weather data obtained from the California Irrigation Management Information System (CIMIS) "Gerber" station (CIMIS station ID 008) and "Gerber South" station (station ID 222). Data from the Gerber CIMIS station were used to represent average ET_o in the Tehama County Subbasins. The Gerber CIMIS station was used because of its long period of record and generally high-quality data compared to other CIMIS stations located in or near Tehama County. When the Gerber CIMIS station became inactive in 2014, data were obtained from the Gerber South CIMIS station. Daily time series data were evaluated following standard quality control procedures recommended by the American Society of Civil Engineers (ASCE) and others (Allen, 1996; Allen et al, 1998; Allen et al, 2005; ASCE, 2016).

For any days when quality control procedures resulted in refinements to any weather data, daily ET_o values were 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. For any days when quality control procedures did not result in refinements to weather data, ET_o values reported by the station were used directly. The combined daily ET_o time series record was used to calculate crop evapotranspiration inputs for all years in the Tehama IHM historical scenario.

3.1.3.2.2 Crop Evapotranspiration Development

Crop evapotranspiration (ET_c), or crop consumptive use, represents the volume of water that is lost to the atmosphere through both evaporation from soil and transpiration from crop surfaces. ET_c time series data are provided as inputs to the Tehama IHM. As part of the internal model processes, the Tehama IHM apportions these ET_c values between ET_{pr} and ET_{aw} by water use sector (based on land use type), as required by the GSP Regulations.

ET_c for each crop and land use class in the Tehama County Subbasins was calculated using the "crop coefficient – reference crop ET" methodology. In this method, daily ET_o values are adjusted to represent the unique and varying daily ET_c rates of other specific crops throughout their growing seasons using specific crop coefficient curves. Daily crop coefficient curves for major crops, native vegetation, and urban areas were derived using spatial land use data, daily ET_o values, and actual ET (ET_a) estimates determined from satellite imagery using two remote sensing surface energy balance models – the Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen, et al. 2005) and Mapping Evapotranspiration at High Resolution using Internalized Calibration (METRIC) (Allen, et al. 2007a). SEBAL and METRIC estimates of ET_a account for actual, observed conditions in the Tehama County Subbasins that affect crop consumptive use, such as salinity, deficit irrigation, disease, fertilization, immature permanent crops, and crop canopy structure, and other factors. Studies by Bastiaanssen et al. (2005), Allen et al. (2007b, 2011), Thoreson et al. (2009), and others have found that when performed by an expert analyst, seasonal ET_a estimates by these models are expected to be within five percent of actual ET determined using other reliable methods.

Spatially distributed ET_a results were available with spatial cropping data for 2009 (SEBAL) and 2017 (METRIC). Crop coefficient curves developed using 2009 SEBAL results were used to calculate ET_c values during water years 1983-2014, and crop coefficient curves developed using 2017 METRIC results were used to calculate ET_c values during water years 2015-2019.

3.1.3.3. Land Use

Characterizing historical land use is foundational for accurately quantifying how and where water is beneficially used. Land use areas are also used to distinguish the water use sector in which water is consumed, as required by the GSP Regulations. In the Tehama County Subbasins, water use sectors include agricultural, urban, and native vegetation land uses. The urban water use sector covers all urban, residential, industrial, and semi-agricultural land uses. See **Section 2.1 of the Subbasin GSPs** for more detail on land use in the Subbasins.

In the Antelope Subbasin, on average, agricultural, urban, and native vegetation land uses covered approximately 8,900 acres, 1,900 acres, and 8,300 acres, respectively, between 1990 and 2018. The total acreage of each water use sector has remained relatively steady over time, with only a slight increase in native vegetation corresponding with a slight decrease in agricultural area during the late 2000s and early 2010s. Historically, a majority of the agricultural area in the Antelope Subbasin has been comprised of orchards (primarily walnuts, prunes, and almonds) and pasture, with varying acreage of grain and hay crops over time. The overall orchard acreage has generally increased since the early 2000s. **Figure 3-24** summarizes annual land use over the historical period (1990-2018) in the Antelope Subbasin.

In the Bowman Subbasin, on average, agricultural, urban, and native vegetation land uses covered an average of 5,800 acres, 1,500 acres, and 115,100 acres, respectively, between 1990 and 2018. Since 1990, approximately 1,200 acres of native vegetation in the Bowman Subbasin has been converted to agricultural and urban land uses. Historically, irrigated pasture has been the predominant agricultural land use in the Bowman Subbasin. Other irrigated crops include mainly alfalfa, grain, and various orchard crops, especially walnuts, almonds, and prunes. Flood irrigation is typically used to support pasture, alfalfa, and grain crops in the Bowman Subbasin. **Figure 3-25** summarizes annual land use over the historical period (1990-2018) in the Bowman Subbasin.

In the Los Molinos Subbasin, on average, agricultural, urban, and native vegetation land uses covered approximately 18,200 acres, 1,600 acres, and 79,500 acres, respectively, between 1990 and 2018. The total area of each water use sector has remained relatively constant over time, though slight expansion of urban land uses in the 1990s coincided with a similar decrease in agricultural acreage. Historically, a majority of the agricultural area in the Los Molinos Subbasin has been comprised of pasture and various orchard crops, especially walnuts and prunes. The total area used to cultivate these primary crops has remained relatively constant over time, though the composition of orchard crops has shifted in recent years, with decreased acreage of prunes and increased acreage of walnuts. Slight decreases in agricultural land use have instead resulted from loss of other irrigated crop areas, such as alfalfa, grain, and safflower. **Figure 3-26** summarizes annual land use over the historical period (1990-2018) in the Los Molinos Subbasin.

In the Red Bluff Subbasin, on average, agricultural, urban, and native vegetation land uses covered approximately 36,000 acres, 6,400 acres, and 229,500 acres, respectively, between 1990 and 2018. Since 1990, the total area of native vegetation has decreased by approximately 10,000 acres, corresponding with a similar increase in agricultural acreage. Historically, a majority of the agricultural area in the Red Bluff Subbasin has been comprised of pasture, grain, and various orchard crops. Since the early 2000s, irrigated agricultural areas within the Red Bluff Subbasin have expanded, primarily due to increases in orchard acreage, especially walnuts and almonds. **Figure 3-27** summarizes annual land use over the historical period (1990-2018) in the Red Bluff Subbasin.

3.1.4. Surface Water System Inputs

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). The development of surface water system input files is explained in this section.

3.1.4.1. Stream Characteristics

Stream bed parameters were taken from SVSim for those stream nodes extracted from the SVSim regional model. For additional stream nodes in Tehama IHM, stream bed parameters were developed through review of stream characteristics of similar water features represented in SVSim and those characteristics were adopted for the new stream segments, as appropriate, using professional judgement and local knowledge of stream characteristics. Stream bed parameters, particularly stream bed conductivity, were further refined during the calibration process.

3.1.4.2. Surface Water Inflows

Surface water inflows into the model domain were specified in Tehama IHM for 16 surface water inflow locations shown in **Figure 3-28.** Surface water inflows to Tehama IHM were taken from SVSim or developed from data reported by the United States Geological Survey (USGS) or the United States Army Corps of Engineers (USACE), or some adjustment or correlation of these sources as noted in **Table 3-5**. Streamflow gage data were used to quantify surface water inflows, where available, through water year 2019.

Table 3-5. Information Sources to Quantify Surface Water Inflows

Waterway	Information Source
Antelope Creek	Correlation with USGS Gage 11381500
Battle Creek	USGS Gage 11376550
Black Butte Releases to Stony Creek	BLB report from USACE
Cottonwood Creek (North Fork, Middle Fork, South Fork)	SVSim inputs
Deer Creek	Correlation with USGS Gage 11383500
Dye Creek	SVSim inputs for small watershed 325
Elder Creek	USGS Gage 11379500
Mill Creek	USGS Gage 11381500
Paynes Creek (and Sevenmile Creek)	Correlation with USGS Gage 11381500
Red Bank Creek	USGS Gage 11379500 (assumed to be same as Elder Creek)
Sacramento River	SVSim inputs, adjusted to Tehama IHM model domain boundary
Stony Creek (North Fork, South Fork)	SVSim inputs
Thomes Creek	Correlation with USGS Gage 11376000

The primary surface water inflow to the Tehama IHM model domain is the Sacramento River, which flows along the boundaries of all four Subbasins. A regional SVSim model was run to adjust the Sacramento River inflows from the upstream inflow point simulated in the SVSim model domain to the inflow point in the Tehama IHM model domain.

Two additional stream reaches were added to the Tehama IHM representing inflows to Red Bank Creek and Dye Creek. Neither reach was discretely modeled in SVSim, though Dye Creek was taken to be equivalent to SVSim small watershed inflow 325. The Dye Creek inflow therefore replaced small watershed inflow 325.

3.1.4.3. Surface Water Diversions and Deliveries

Surface water diversions and deliveries were simulated in the model as diversions from a stream node with an assigned delivery destination (referred to as the element group). A total of 50 surface water diversions are included in Tehama IHM, with 30 adapted from SVSim and 20 newly added or revised in Tehama IHM. Diversion locations are shown in **Figure 3-29**. **Table 3-6** summarizes the data sources and used to quantify diversions and spillage within the four Subbasins in the Tehama IHM model domain.

Diversions and spillage of supply that is used within the four Subbasins are generally quantified based on outside data sources, including: delivery records reported by the United States Bureau of Reclamation (USBR), groundwater management or water planning documents developed by water agencies, and publicly available records maintained by the State Water Resources Control Board (SWRCB) in the

Electronic Water Rights Information Management System (eWRIMS). For water agencies without available spillage data, the percent spillage was estimated based on the conveyance system type (canal versus pipe), and the assumption that systems of adjacent suppliers or suppliers with similar systems have the same average spillage fraction.

Diversions of supply used outside the subbasins are generally assumed to be equal to diversions data specified in SVSim. Those diversions specified in SVSim that were retained unchanged, or with only slight area modifications in the Tehama IHM model domain are identified in **Table 3-6.**

Deliveries are generally calculated by Tehama IHM as the water supply used to meet simulated crop water demands, after accounting for seepage, evaporation, and spillage of the diverted supply.

For agencies that span portions of more than one subbasin, diversions, deliveries, and losses are also distributed across the relevant subbasins.

Table 3-6. Information Sources to Quantify Diversions and Spillage Within the Four Subbasins.[1]

Water Agency	Volume Specified		Delivery Location in Tehama IHM Domain Relative to Four Subbasins					Information Source	Note
	Diversion	Spillage	Antelope	Bowman	Los Molinos	Red Bluff	Outside		
Rio Alto Water District	X			X				USBR CVP delivery records (Sacramento River)	No reported volume in historical water budget period, not listed as CVP contractor in 2016.
Anderson-Cottonwood Irrigation District	X	X		X			X	USBR CVP delivery records (Sacramento River)	Service area boundaries partly overlie the Bowman Subbasin, areas in the Tehama IHM model domain but outside the subbasins, and areas outside the model domain; prorated diversion to percent irrigated area in the model domain; CVP delivery records available 1997-2019, estimated by average monthly volume earlier; Spillage fraction from 2012 Sacramento Valley Regional Water Management Plan, estimated to be similar in all years
Stanford Vina Ranch Irrigation	X	X			X			South Main Diversion: Water Data Library Site A04330 "SVWC Deer Creek South Diversion near Vina"; Cone Kimball and North Main Diversion: Tehama Regional Water Supply Inventory	South Main diversion records available 2002-2005, estimated in other years by correlation with Deer Creek Irrigation District diversion; Cone Kimball and North Main diversions estimated from relative fractions given in Table 4-9 of Tehama County Water Inventory and Analysis Report, estimated to be similar in all years; Spillage fraction estimated to be similar to Deer Creek Irrigation District
Deer Creek Irrigation District	X	X			X			Diversions: Water Data Library Site A43100 "DCID Deer Creek Diversion near Vina"; Spillage: 2011 Deer Creek Irrigation District	Diversion records available 1999-2016, estimated average monthly volume in other years; Spillage fraction from 2006-2007 water balance analysis, average estimated to be similar in all years

Water Agency	Volume Specified		Delivery Location in Tehama IHM Domain Relative to Four Subbasins					Information Source	Note
	Diversion	Spillage	Antelope	Bowman	Los Molinos	Red Bluff	Outside		
								Long Term System Improvements Feasibility Study	
Los Molinos Mutual Water Company	X	X	X		X			Upper Diversion and East Ditch Diversion: Los Molinos Mutual Water Company 2018 Northside Water Use Efficiency Master Plan; Ward Diversion: Los Molinos Mutual Water Company Southside Service Area Water Budget Results and Analysis	Diversion and spillage volumes based on Northside and Southside water budgets (2010-2017), diversions estimated by average monthly volume in other years, average spillage estimated to be similar in all years
Proberta Water District	X	X				X		USBR CVP delivery records (Corning Canal deliveries)	Volume of total CVP deliveries prorated based on contract amount; District has a piped conveyance system with approximately zero spillage, seepage, or evaporation.
Corning Water District	X	X					X	USBR CVP delivery records (Corning Canal deliveries)	Volume of total CVP deliveries prorated based on contract amount; District has a piped conveyance system with approximately zero spillage, seepage, or evaporation.
Thomes Creek Water District	X	X				X	X	USBR CVP delivery records (Corning Canal deliveries, prorated based on contract amount)	Volume of total CVP deliveries prorated based on contract amount; Spillage fraction estimated to be similar to Deer Creek Irrigation District
Thomes Creek Water Users Association	X						X	eWRIMS (S022584)	Diversion data in 2014, 2016-2019, estimated by average monthly volume in other years; Spillage estimated to

Water Agency	Volume Specified		Delivery Location in Tehama IHM Domain Relative to Four Subbasins					Information Source	Note
	Diversion	Spillage	Antelope	Bowman	Los Molinos	Red Bluff	Outside		
									occur through runoff (estimated zero spillage fraction; outside Subbasins)
Kirkwood Water District	X						X	USBR CVP delivery records (Tehama-Colusa Canal deliveries)	Spillage estimated to occur through runoff (estimated zero spillage fraction; outside Subbasins)
Edwards Ranch	X	X	X					eWRIMS (S003134, S016326)	Diversion data when available, estimated by average monthly volume in other years; Spillage fraction estimated to be similar to Los Molinos Mutual Water Company (northside)
The Nature Conservancy	X	X	X		X			eWRIMS (S020690, S028341, S028342, S028354)	Diversions are assumed to be applied to the Los Molinos Mutual Water Company service area; Diversion data when available, estimated by average monthly volume in other years; Spillage fraction estimated to be similar to Los Molinos Mutual Water Company (northside)
J.B. Unlimited, Inc.	X		X					USBR CVP delivery records (Sacramento River)	Diversion estimated by contract amount; Spillage estimated to be zero (Direct diverter, estimated to occur through runoff)
Leviathan, Inc.	X			X				USBR CVP delivery records (Sacramento River)	Diversion estimated by contract amount; Spillage estimated to be zero (Direct diverter, estimated to occur through runoff)
Micke, Daniel and Nina	X		X					USBR CVP delivery records (Sacramento River)	Diversion estimated by contract amount; Spillage estimated to be zero (Direct diverter, estimated to occur through runoff)
Sacramento River RM 273 to misc.	X			X			X	SVSim Div ID 14	Volume and specifications unchanged from SVSim (misc. diversions of relatively small volume mainly outside

Water Agency	Volume Specified		Delivery Location in Tehama IHM Domain Relative to Four Subbasins					Information Source	Note
	Diversion	Spillage	Antelope	Bowman	Los Molinos	Red Bluff	Outside		
Ag diverters (03_NA)									Bowman Subbasin; assumed that SVSim data were the best available)
Cottonwood Creek to misc. Ag diverters (02_NA)	X			X			X	SVSim Div ID 16	Volume and specifications unchanged from SVSim (misc. diversions of relatively small volume; assumed that SVSim data were the best available)
Elder Creek riparian diversions for Ag (04_NA)	X					X		SVSim Div ID 27	Volume and specifications unchanged from SVSim (misc. diversions of relatively small volume; assumed that SVSim data were the best available)
Tehama-Colusa Canal Losses (Import)	X					X	X	SVSim Div ID 35	Volume and specifications unchanged from SVSim (misc. canal losses; assumed that SVSim data were the best available)

[1] Other diversions specified in SVSim that are outside the four subbasins, but inside the Tehama IHM model domain, are retained with the same monthly volumes and specifications as established in SVSim, except those that are duplicates of diversions specified in this table.

3.1.4.4. 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. Twenty surface water bypasses were included in Tehama IHM. These bypasses represent conveyance losses from surface water diversions.

3.1.5. Groundwater System Inputs

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.

3.1.5.1. Aquifer Parameters

At the time of the commencement of GSP analyses in the Subbasins, SVSim was not available in a calibrated form. Therefore, aquifer parameters were defined in Tehama IHM through subsurface lithologic textural analysis in conjunction with calibration of parameters based on texture. Aquifer parameters in Tehama IHM are assigned to each node for each model layer and were developed to represent subsurface hydrogeologic characteristics.

3.1.5.1.1 Lithologic Texture Data

A lithologic texture model was developed using borehole lithology data from 672 Well Completion Reports (WCRs) located within the model domain. Lithology and texture data for 615 of these well WCRs were obtained from the textural dataset developed utilized for SVSim and available from DWR, which included considerable textural data from the US Geological Survey (USGS) Central Valley Hydrologic Model (CVHM). Texture data were compiled from an additional 57 wells selected to fill spatial (lateral and vertical) gaps in the SVSim textural dataset using information available in WCRs. Textural classification of additionally compiled lithology data (i.e., identifying coarse or fine-grained texture categories based on lithological descriptions given in WCRs) was performed following procedures used by DWR and USGS in developing the initial textural dataset using lookup tables for classifying lithology descriptions by texture. Consistent with the approach by DWR in developing the SVSim textural dataset, the texture of “top soil” description given in WCRs was determined using the Natural Resources Conservation Service SSURGO soils data.

Translating the point textural dataset to a continuous textural model for use in Tehama IHM was done by assigning values for the percent coarse at each textural borehole datapoint to each model layer penetrated by the borehole and then interpolating percent coarse by layer across the entire model domain. In this process, the intervals of fine and coarse-grained textured sediments were calculated for model layers at each WCR location and the thickness-weighted percentage of coarse-grained materials within each model layer were estimated. Using values for percent coarse-grained materials by model layer at each borehole point, spatially continuous datasets representing the percentage of coarse-grained materials were developed for each model layer through point interpolation methods. Interpolation was performed using ordinary kriging interpolation tool in the ESRI ArcGIS software package, which applies a semivariogram approach. An appropriate semivariogram model was selected through exploration of the data. The resulting kriged spatial distribution of percent coarse by model layer is shown in **Figures 3-30** through **3-38**. During model development and calibration, aquifer parameters were assigned to model nodes and layers using parameter values specified for both the fine and coarse end members and relating these to the percent coarse values developed from the textural model. The process used to assign and calibrate aquifer parameters in the model based on the percent coarse values are described in the discussions of model calibration in **Section 3.2** of this document.

3.1.5.1.2 Aquifer Parameter Zones

To better represent the geology within the Tehama IHM domain, a set of aquifer parameter zones were developed to enable for more refined assignment of aquifer parameters based on the lithologic texture values, especially recognizing that aquifer properties for similar textured materials (based on the textural model) may differ by geologic formation. Informed by the HCM, four zones (Alluvium, Tehama Formation, Tuscan Formation, and Non-Tehama/Non-Tuscan Zone) were delineated for using multipliers applied to parameter values derived from the textural data. The extents of the different geologic units used to delineate aquifer parameter zones are shown in **Figures 3-39** through **3-42**.

The alluvium zone is present in layers 1 and 2. The extent of this zone was developed after review of surficial geology maps. The Tehama Formation, Tuscan Formation, and Non-Tehama/Non-Tuscan Zone are present in all model layers. Maps illustrating the assignment of nodes to parameter zones within layers 1 and 2 are presented in **Figure 3-43**, and within layers 3 through 9 are presented in **Figure 3-44**. The discussion of the calibration of aquifer parameters using the parameter zones described above, and the results of the model calibration, are presented in **Sections 3.2 and 4.7** below.

3.1.5.2. Boundary Conditions

Tehama IHM utilizes time-varying general head boundary conditions to simulate groundwater levels and fluxes at the extent of the model domain. A map of nodes where general head boundary conditions were specified in the model is presented in **Figure 3-45**. In specifying general head boundary conditions, hydraulic conductance was estimated at each boundary node by layer based on average horizontal hydraulic conductivity (Kh), cross-sectional area associated with each boundary node (product of distance between nodes and saturated layer thickness), and the distance from the model boundary (set as 1,000-feet). Transient historical water level boundary conditions were developed by using the interpreted initial head conditions in 1985 and applying relative changes for each model time step based on simulated water levels from the calibrated version of SVSim provided by DWR for each model time step for the period 1985 to 2015. Because the available version of SVSim only simulates conditions through 2015, substitute years based on similar water year conditions were used to extend the simulated heads in SVSim through 2019 using relative water levels changes. Some additional refinements were made to the boundary conditions after comparing modeled water levels to observed data.

3.1.5.3. Groundwater Pumping

Pumping within Tehama IHM is primarily determined by element based on land use characteristics and simulated demand 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 Tehama IHM was modified from SVSim based on review of well construction information in DWR's WCR database for wells within the model domain. Agricultural and urban pumping were distributed vertically based on well construction information data in DWR's Online System for Well Completion Reports (OSWCR) for respective well types. In an effort to represent wells that are likely or potentially active in the model area, WCRs classified as well constructions (as opposed to well destructions) since 1970 in the OSWCR database were used to assign the vertical distribution of pumping in Tehama IHM.

The vertical distribution of pumping does not change over the historical simulation period. Maps of the vertical distribution of agricultural pumping by layer are presented in **Figures 3-46** through **3-54** and for urban pumping by layer in **Figures 3-55** through **3-63**.

3.1.6. Small Watersheds

A total of 33 small watersheds were included in Tehama IHM from SVSim. **Table 3-7** summarizes the contributions of small watersheds to modeled streams. Modifications were made to SVSim small watersheds to properly route water through the additional streams modeled in Tehama IHM. Nodes receiving small watershed contributions are shown in **Figure 3-64**.

Table 3-7. Summary of Tehama IHM Small Watersheds

Streams Fed by Small Watersheds	Count of Contributing Watersheds	Total Contributing Watershed Acreage
Antelope Creek Group	7	34,861
Cottonwood Creek	1	1,904
Elder Creek	3	2,645
Mill Creek	1	272
Paynes Creek	2	3,021
Sacramento River	15	120,921
Thomes Creek	4	16,055
TOTAL	**33**	**179,679**

3.1.7. Initial Conditions

Initial groundwater levels conditions for Tehama IHM were generated from mapped groundwater conditions based on groundwater level contours developed from observed data in conjunction with simulated water level output from SVSim regional model for October 1984, which represents the start of the historical model period. 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. The Upper Aquifer (Layers 1 through 5) were assigned initial head conditions from the interpreted observed groundwater surface. Initial heads in the Lower Aquifer (Layers 6 through 9) were then assigned by applying an offset to the observed groundwater levels based on observed offsets between depths from nested monitoring wells. Initial water level conditions used in the historical Tehama IHM runs are shown in **Figures 3-65** through **3-73**. All other initial conditions (e.g., soil moisture) were specified using the simulated conditions in October 1984 from SVSim.

3.2. Model Calibration

Tehama IHM was calibrated using a trial and error approach in conjunction with utilization of automated calibration and parameter estimation techniques involving application of UCODE-2014, an inverse modeling computer code developed by the US Geological Survey. Automated techniques were used at stages during the calibration to explore model sensitivity and inform the trial and error calibration efforts.

The calibration process focused on adjusting key model parameter values to improve the fit of simulated historical groundwater levels and streamflows to observed (measured) data. The key model parameters included in calibration were aquifer properties and streambed properties.

Aquifer parameters were developed by assigning end member values to the percent coarse-grained materials in the textural model described in **Section 3.1.5.1.1** of this report. Texture end member values are the aquifer parameter values at the two ends of the percent coarse spectrum, either 100% (coarse) or 0% (fine). The equations used to calculate the aquifer parameter values for each node and layer from the specified end-member values are presented below. For aquifer parameter zones where a multiplier was included in the calibration, the multiplier was applied to the parameter values resulting from calculations using these equations. The equations used for estimating aquifer parameters from textural model information are consistent with the methods used and described in development of the hydrogeologic conceptual model and model parameterization for SVSim (DWR, 2020).

Horizontal hydraulic conductivity (Kh) is calculated using the following equation:

$$Kh = (PCT * ({Kh_{C0}}^{pKh}) + (1 - PCT) * ({Kh_{F0}}^{pKh}))^{\frac{1}{pKh}}$$

Where: PCT is the percent coarse

Kh_{C0} is the Kh end member of coarse materials

Kh_{F0} is the Kh end member of fine materials

pKh is the power law empirical parameter for Kh

Vertical hydraulic conductivity (Kv) end members are calculated through application of an anisotropy ratio (Kv / Kh) to the Kh endmember values. The Kv value at each node and layer is then calculated using the following equation:

$$Kv = (PCT * ({Kv_{C0}}^{pKv}) + (1 - PCT) * ({Kv_{F0}}^{pKv}))^{\frac{1}{pKv}}$$

Where: PCT is the percent coarse

Kv_{C0} is the Kv end member of coarse materials

Kv_{F0} is the Kv end member of fine materials

pKv is the power law empirical parameter for Kv

Specific storage (Ss) is calculated using the following equation:

$$Ss = PCT * Ss_C + (1 - PCT) * Ss_F$$

Where: PCT is the percent coarse

Ss_C is the Ss end member of coarse materials

Ss_F is the Ss end member of fine materials

Specific yield (Sy) is calculated using the following equation:

$$SY = PCT * Sy_C + (1 - PCT) * Sy_F$$

Where: PCT is the percent coarse

Sy_C is the Sy end member of coarse materials

Sy_F is the Sy end member of fine materials

Calibrated end member values are presented in **Section 4.9** of this report.

Observations used in the calibration of aquifer parameters included approximately 7,900 groundwater level observations from 93 wells across the model domain selected based on historical data record, well construction, and spatial representation (lateral and vertical distribution) (**Figure 3-74**).

Streambed properties adjusted during the calibration included streambed conductivity. Observations used to constrain stream bed parameters included approximately 3,900 stream flow measurements from 12 gage stations (**Figure 3-75**). The results of the model calibration are presented and discussed in **Section 4.8** below.

3.3. Tehama IHM – Projected Model Simulations

The projected model simulations are intended to evaluate the effects of anticipated future conditions of hydrology, water supply availability, and water demand on the Tehama County Subbasins water budget and groundwater conditions over a 51-year GSP planning period from WY 2022 through 2072 starting October 1, 2022 and ending September 30, 2072. The projected model scenarios incorporate consideration of potential climate change and water supply availability scenarios and evaluation of the need for and benefit of any projects and management actions to be implemented in the Subbasins to maintain or achieve sustainability. The projected model scenarios use hydrologic conditions representative of the most recent 50 years of hydrology in the Subbasins, with adjustments applied in scenarios for evaluating the water budgets under climate change and/or altered water supply and demand conditions. The entire projected simulation period runs from WY 2020 through 2072, on a monthly time step, although the 51-year GSP planning period evaluated in the projected modeling covers water years 2022 through 2072. The development of the projected scenarios in Tehama IHM is described in the following sections.

3.3.1. Projected Hydrology Selection and Development

Establishing a sequence of projected hydrology is key to the development of the projected model scenarios. Future hydrology model inputs were developed based on review and consideration of the recent 51 years of hydrology for 1969-2019 and utilization of a hydrologic sequence that replicates the hydrologic patterns and trends over this period. Because of the availability of higher quality data and characterization of conditions in the Subbasins during the most recent 29 years spanning the historical base period (1990-2018), the projected analyses used surrogate years from the historical period to construct a future hydrology and analysis period representative and consistent with hydrologic conditions over the 51-year period from 1969 to 2019. Surrogate years from the historical period were assigned to represent 51 years of future hydrology based on 1) the Sacramento Valley water year index from DWR for each year and 2) mimicking variability (wet and dry) in the historical precipitation conditions in the Subbasins and replicating precipitation consistent with the annual average historical precipitation.

The projected water year type and assigned surrogate water years for use in developing the projected hydrology are shown in **Table 3-8a.** The frequency of water year types used in the projected hydrology is representative of the 51 years of hydrology for the period 1969-2019 and includes approximately equal proportions of water years with above normal (wet and above normal; 49%) and below normal (below normal, dry, critical; 51%) hydrologic conditions (**Table 3-8b**). **Figures 3-76 and 3-77** show graphs of the precipitation cumulative departure from the mean based on data at the Red Bluff and Orland Stations, respectively, over the projected period. The overall averages and cumulative departure curves highlight how closely the projected hydrology (using surrogate years) mimics the recent 51-year period. The average annual precipitation in the projected simulation period is 22.9 inches at the Red Bluff Municipal Airport station (**Table 3-8b**), similar but slightly below the average annual precipitation over the 51-year historical period from 1969 through 2019 of 23.3 inches at the Red Bluff Municipal Airport station. For comparison, the average annual precipitation over the historical water budget period of 1990-2018 is 22.5 inches based on measurements at the Red Bluff Municipal Airport station (**Table 3-1b**).

Table 3-8a. Summary of Projected Water Years in Tehama IHM

Simulation WY	WY Type	WY Index
1991	C	4.21
1992	C	4.06
1993	AN	8.54
1994	C	5.02
1995	W	12.89
1996	W	10.26
1997	W	10.82
1998	W	13.31
1999	W	9.8
2000	AN	8.94
2001	D	5.76
2002	D	6.35
2003	AN	8.21
2004	BN	7.51
2005	AN	8.49
2006	W	13.2
2007	D	6.19
2008	C	5.16
2009	D	5.78
2010	BN	7.08
2011	W	10.54
2012	BN	6.89
2013	D	5.83
2014	C	4.07
2015	C	4
2016	BN	6.71
2017	W	14.14
2018	BN	7.14
2019	W	10.34

Simulation WY	Surrogate WY	WY Type	WY Index
2020*	2007	D	6.19
2021*	2014	C	4.07
2022	2019	W	10.34
2023	1996	W	10.26
2024	1996	W	10.26
2025	2018	BN	7.14
2026	1993	AN	8.54
2027	2006	W	13.2
2028	1999	W	9.8
2029	2008	C	5.16
2030	2014	C	4.07
2031	1993	AN	8.54
2032	2012	BN	6.89
2033	2000	AN	8.94
2034	2002	D	6.35
2035	2006	W	13.2
2036	1998	W	13.31
2037	1996	W	10.26
2038	2002	D	6.35
2039	1996	W	10.26
2040	2001	D	5.76
2041	1990	C	4.81
2042	2007	D	6.19
2043	1994	C	5.02
2044	1994	C	5.02
2045	1992	C	4.06
2046	1993	AN	8.54

Simulation WY	Surrogate WY	WY Type	WY Index
2047	1994	C	5.02
2048	1995	W	12.89
2049	1996	W	10.26
2050	1997	W	10.82
2051	1998	W	13.31
2052	1999	W	9.8
2053	2000	AN	8.94
2054	2001	D	5.76
2055	2002	D	6.35
2056	2003	AN	8.21
2057	2004	BN	7.51
2058	2005	AN	8.49
2059	2006	W	13.2
2060	2007	D	6.19
2061	2008	C	5.16
2062	2009	D	5.78
2063	2010	BN	7.08
2064	2011	W	10.54
2065	2012	BN	6.89
2066	2013	D	5.83
2067	2014	C	4.07
2068	2015	C	4
2069	2016	BN	6.71
2070	2017	W	14.14
2071	2018	BN	7.14
2072	2019	W	10.34

*Years 2020-2021 were used to span the transitional period between the historical model period 1990-2019 and the projected model period 2022-2072.

Table 3-8b. Sacramento Valley Water Year Type Classification of the Projected Water Budget Period (2022-2072)

Sacramento Valley Water Year Type	Abbreviation	Number of Years, 2022-2072	Average Water Year Index	Average Precipitation	Percent Total Years, 2022-2072
Wet	W	18	11.46	27.9	35%
Above Normal	AN	7	8.60	29.3	14%
Below Normal	BN	7	7.05	19.7	14%
Dry	D	9	6.06	17.4	18%
Critical	C	10	4.64	16.6	20%
	Total	**51**	**8.17**	**22.9**	**100%**

3.3.2. Climate Change Adjustments

Climate change adjustments were also included in selected projected scenarios to evaluate the potential influence of climate change on future conditions. Adjustments to the projected hydrology were performed following DWR's Resource Guide on climate change in GSP development (DWR, 2018) using climate change adjustment factors provided by DWR for use in developing GSPs through the DWR SGMA Data Viewer (https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#waterbudget). Using the DWR-provided climate adjustment factors, adjustments were made to ET, precipitation, and surface water inflow model inputs to account for the potential effects of 2030 mean (or central tendency) and 2070 mean (or central tendency) climate change conditions. The climate change adjustment factors provided by DWR were calculated from data developed for the Variable Infiltration Capacity (VIC) model as described in the DWR Resource Guide and on the SGMA Data Viewer.

For ET and precipitation adjustments, monthly change factors were averaged across the VIC grids in the Tehama IHM model domain and applied to the individual precipitation and ET inputs. For surface water inflow adjustments, monthly streamflow change factors were summarized from the HUC 8 watershed covering the majority of the Tehama IHM model domain and applied to individual surface water inflows in the model.

For each of the model inputs adjusted in the climate change scenarios (e.g., ET, precipitation, surface water inflow), the baseline projected inputs were multiplied by the 2030 or 2070 change factors corresponding to the specific historical year that was used as a surrogate year in the projected simulations. Because climate change factors were only provided for historical years through 2011, the average factors (by water year type) for the period provided were applied to historical years after 2011. The average change factors applied by model input and water year type in the 2030 and 2070 climate change scenarios are presented in **Table 3-9**. As indicated in **Table 3-9**, on average the climate change adjustments tend to increase ET, increase precipitation, and increase stream inflow volumes by varying degrees. From a water budget standpoint, increases in ET will tend to increase the water demands (outflows), whereas increases to precipitation and stream inflows will tend to increase water supplies (inflows).

Table 3-9. Climate Change Adjustment Change Factors by Data Type and Water Year Type in Tehama IHM

	No Adjustment	Climate Change 2030	Climate Change 2070
	Evapotranspiration		
Wet (W)	1.00	1.04	1.09
Above Normal (AN)	1.00	1.04	1.09
Below Normal (BN)	1.00	1.04	1.09
Dry (D)	1.00	1.04	1.08
Critical (C)	1.00	1.04	1.09
TOTAL	**1.00**	**1.04**	**1.09**
	Precipitation		
Wet (W)	1.00	1.04	1.07
Above Normal (AN)	1.00	1.02	1.06
Below Normal (BN)	1.00	1.05	1.05
Dry (D)	1.00	1.05	1.05
Critical (C)	1.00	1.04	1.06
TOTAL	**1.00**	**1.04**	**1.06**
	Stream Inflow		
Wet (W)	1.00	1.04	1.12
Above Normal (AN)	1.00	1.01	1.04
Below Normal (BN)	1.00	1.03	1.06
Dry (D)	1.00	1.06	1.07
Critical (C)	1.00	1.02	1.05
TOTAL	**1.00**	**1.04**	**1.09**

3.3.3. Overview of Projected Scenarios

Multiple projected model scenarios were developed to compare potential outcomes and evaluate the future sustainability of the Subbasins. These scenarios include two baseline projected scenarios, one with a current land use condition and another with future land use conditions. Additional scenarios were developed with each of the baseline projected scenarios with both 2030 and 2070 climate change conditions. Lastly, a projected model scenario was developed to evaluate the benefits of potential projects and management actions. **Table 3-10** outlines the different model scenarios evaluated, including seven projected scenarios in addition to the historical base period model scenario. The projected current land use scenarios assume a static land use condition based on 2018 land use conditions. The projected future land use scenarios also assume a static land use condition based on a projected land use condition in 2072 reflective of anticipated land use changes within the four Subbasins. The projected scenarios with different climate change scenarios incorporate either the 2030 mean or the 2070 mean climate change condition adjustments for precipitation, ET, stream inflows, and surface water diversion volumes in accordance with guidance provided by DWR.

Table 3-10. Summary of Tehama IHM Projected Scenarios

Scenario #	Model Scenario Name/Description	Time Period (Water Years)	Land Use Conditions	Climate Change	Projects
	Historical/Calibration	1990-2018	Historical (Transient)	None	No
1	Projected (Current Land Use)	2022-2072	Current (2018)	None	No
2	Projected (Future Land Use)	2022-2072	Future (2072)	None	No
3	Projected (Current Land Use) with 2030 Climate Change	2022-2072	Current (2018)	2030	No
4	Projected (Future Land Use) with 2030 Climate Change	2022-2072	Future (2072)	2070	No
5	Projected (Current Land Use) with 2070 Climate Change	2022-2072	Current (2018)	2070	No
6	Projected (Future Land Use) with 2070 Climate Change	2022-2072	Future (2072)	2070	No
7	Projected (Future Land Use) with Projects and 2070 Climate Change	2022-2072	Future (2072)	2070	Yes

3.3.4. Land Surface System Inputs

The development of land surface system inputs for the projected model scenarios is described below.

3.3.4.1. Precipitation

The precipitation inputs for the projected simulation period were developed through use of surrogate years from the historical model as described in **Section 3.3.1** and presented in **Table 3-8a.** As described in **Section 3.3.2**, for scenarios including climate change, precipitation inputs were modified using the climate change adjustment factors for 2030 and 2070 central tendency climate change conditions using the guidance and adjustment factors provided by DWR.

3.3.4.2. Evapotranspiration

The evapotranspiration inputs for the projected simulation period were developed through use of surrogate years from the historical model as described in **Section 3.3.1** and presented in **Table 3-8a.** As described in **Section 3.3.2**, for scenarios including climate change, precipitation inputs were modified using the climate change adjustment factors for 2030 and 2070 central tendency climate change conditions using the guidance and adjustment factors provided by DWR.

3.3.4.3. Land Use

Characterizing projected land use is foundational for predicting how and where water is beneficially used in future scenarios. Land use areas are also used to distinguish the water use sector in which water is consumed. In Tehama County, water use sectors include agricultural, urban, and native vegetation land uses. The urban water use sector covers all urban, residential, industrial, and semi-agricultural land uses. The projected scenarios include two different land use conditions: a current land use condition representative of 2018 conditions held constant over the entire simulation period and a static future land use condition based on land use change anticipated to occur in Tehama County over a 50-year planning horizon and reflecting land use conditions estimated to exist in 2072. In the projected model simulations, the land use conditions outside of Tehama County are assumed to stay as they are represented in 2018 in the historical model simulation.

3.3.4.3.1 Current Land Use Scenarios

Projected scenarios with current land use conditions include a static land use condition based on 2018 conditions.

Figure 3-78 illustrates the unchanging land use areas over the projected period (2022-2072) in the Antelope Subbasin. In the current land use scenario, agricultural, urban, and native vegetation land uses covered approximately 9,100 acres, 1,900 acres, and 8,000 acres, respectively. A majority of the agricultural area in the Antelope Subbasin is comprised of deciduous crops, pasture, and grain crops.

Figure 3-79 illustrates the unchanging land use areas over the projected period (2022-2072) in the Bowman Subbasin. In the current land use scenario, agricultural, urban, and native vegetation land uses covered approximately 6,100 acres, 1,900 acres, and 115,000 acres, respectively. A majority of the agricultural area in the Bowman Subbasin is comprised of pasture and grain crops.

Figure 3-80 illustrates the unchanging land use areas over the projected period (2022-2072) in the Los Molinos Subbasin. In the current land use scenario, agricultural, urban, and native vegetation land uses covered approximately 18,000 acres, 1,600 acres, and 79,000 acres, respectively. A majority of the agricultural area in the Los Molinos Subbasin is comprised of pasture and various orchard crops.

Figure 3-81 illustrates the unchanging land use areas over the projected period (2022-2072) in the Red Bluff Subbasin. In the current land use scenario, agricultural, urban, and native vegetation land uses covered approximately 46,000 acres, 7,000 acres, and 207,000 acres, respectively. A majority of the agricultural area in the Red Bluff Subbasin is comprised of pasture, grain, and various orchard crops.

3.3.4.3.2 Future Land Use Scenarios

The projected scenarios with future land use conditions include a static land use condition based on anticipated changes by the Subbasins in the future. The future land use conditions were developed through discussion with local stakeholders and consultation with the Tehama County Planning Department. The future land use conditions include increases in urban area reflecting expansion of urban areas focused around each urban center with native vegetation and idle cropland areas decreasing by similar amounts within all of Tehama County. In Red Bluff, there was also an increase in almonds within orchard areas.

Figure 3-82 presents the annual land use areas over the projected period (2022-2072) in the Antelope Subbasin. In the future land use scenario, there is an increase in urban acreage with a corresponding decrease in native vegetation, and relatively no change in agricultural acreage.

Figure 3-83 presents the annual land use areas over the projected period (2022-2072) in the Bowman Subbasin. In the future land use scenario, there is a very slight increase in urban acreage with a corresponding decrease in native vegetation, but overall, there is relatively no change.

Figure 3-84 presents the annual land use areas over the projected period (2022-2072) in the Los Molinos Subbasin. In the future land use scenario, there is a very slight increase in urban acreage with a corresponding decrease in native vegetation, but overall, there is relatively no change.

Figure 3-85 presents the annual land use areas over the projected period (2022-2072) in the Red Bluff Subbasin. In the future land use scenario, there is an increase in agricultural area, specifically almonds and pistachios, with a corresponding decrease in urban acreage and native vegetation.

3.3.5. Surface Water System Inputs

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

3.3.5.1. Stream Inflows

The stream inflow volumes in each future year was assumed to be equal to the amount in the historical water year assigned to that future year (**Table 3-8a**). For scenarios with climate change adjustments, the historical stream inflow volumes were adjusted by using the CalSim II 2030 mean or 2070 mean climate change scenario monthly water year type multiplier.

3.3.5.2. Surface Water Diversions and Deliveries

The diversion volumes of each projected year were assigned by considering the diversion volumes from the associated historical year (**Table 3-8a**). For all diversions where historical data suggest the diversion was continuously active throughout the historical model period, the volume of water diverted in the projected year was assigned based on the associated historical year. For any surface water diversions that ceased diverting during the historical period 1990 through 2019, the volumes associated with these diversions were assumed to be zero for the entire projected period. The historical time-series data for each surface water diversion were evaluated and if a long period without any diversions occurred at the end of the period of available historical data, the diversion was assumed to be discontinued and assigned zero diversions for the entirety of the projected model period.

3.3.6. Groundwater System Inputs

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

3.3.6.1. Boundary Conditions

As described above in **Section 3.3.1**, the hydrology for the 51-year projected simulations mimics the hydrology of the historical period from 1969 through 2019 and the model inputs were developed using comparable surrogate years from the historical model period (1990-2019). The groundwater level of year 2019 was used as the initial groundwater head in boundaries for the prediction run. The groundwater levels of general head boundary condition for the predictive analysis were developed by using the associated historical boundary heads for each predictive year. For the last 31 years (2042-2072) of the projected model period , the general head boundary conditions were modified to represent long-term stability in general head conditions around the model domain. This is intended to reflect the expected achievement or maintenance of sustainable groundwater conditions around the extent of the model resulting from the implementation of groundwater management efforts associated with GSPs and elimination of any chronically declining trends in water levels.

3.3.6.2. Groundwater Pumping

The pumping specification inputs for all projected simulations used the same pumping specifications as the historical simulation, described in **Section 3.1.5.3**.

3.3.7. Initial Conditions

Initial conditions used for projected simulations starting in 2020 utilized the final conditions from the historical model at the end of 2019. The initial conditions included use of the final conditions of the historical simulation period for the unsaturated zone, root zone, small watersheds, and groundwater levels. Initial groundwater levels are shown in **Figures 3-86** through **3-94** by model layer**.**

3.3.8. Simulation of Potential Projects and Management Actions

Projects and management actions (PMAs) were developed to achieve and maintain the Red Bluff Subbasin sustainability goal by 2042 and avoid undesirable results over the GSP planning and implementation horizon. PMAs developed for implementation would help to achieve and maintain groundwater sustainability while supporting other local goals. These PMAs include a project that would divert available surface water from Thomes and Elder Creek onto fields in the Subbasin for direct or in-lieu recharge benefits, and an in-lieu recharge project that would expand use of existing Central Valley Project (CVP) contract supplies in Proberta Water District (WD) and Thomes Creek WD. Other PMAs developed for implementation include a proposed grower education program, a proposed multi-benefit groundwater recharge project that would supply groundwater recharge and provide habitat for migrating shorebirds, a proposed pump restoration project in El Camino Irrigation District, and two projects aimed at invasive species removal along various waterways in the Red Bluff Subbasin.

A projected simulation was conducted to evaluate the potential benefits that might occur from implementation of various project concepts. Stream diversions were added to the model in order to simulate the recharge projects along Thomes and Elder Creeks, while existing diversions were modified in order to simulate the recharge projects in Proberta WD and Thomes Creek WD. Additionally, in order to simulate a management action related to well permitting, all new agricultural pumping in the Red Bluff Subbasin was shifted from the Upper Aquifer to the Lower Aquifer. Maps of the vertical distribution of agricultural pumping by layer in with projects scenario are presented in **Figures 3-95** through **3-103**.

Additional detail about the projects and management actions implemented in the Red Bluff Subbasin are included in the **Red Bluff GSP Chapter 4**.

4. GROUNDWATER FLOW MODEL RESULTS

This section presents the results of Tehama IHM. Results presented in this section include Subbasin water budgets, groundwater levels, and streamflows for various scenarios, and calibrated aquifer parameters. The water budget results presented in this section are rounded to two significant digits consistent with the typical uncertainty associated with the methods and sources used in the analysis. Water budget component results may not sum to the totals presented because of rounding.

4.1. Antelope Subbasin

The following section summarizes the analyses and results relating to the Antelope Subbasin. Detailed water budget results for each of the individual model scenarios are presented in **Appendix A**.

4.1.1. Historical Water Budget Results

Annual inflows, outflows, and change in surface water system (SWS) root zone storage during the historical water budget period (1990-2018) are summarized in **Table 4-1**. Of particular note in the historical SWS water budget results are the volumes of groundwater discharge to surface water that make up a large part of the Subbasin SWS inflows. Over the historical period, groundwater discharge to surface water averaged a little over 53 thousand acre-feet (taf) per year. Surface water inflows and precipitation also represent larger SWS inflow components averaging about 43 taf per year and 41 taf per year, respectively. Groundwater extraction and uptake represent a smaller SWS inflow in the Subbasin averaging about 15 taf per year over the historical water budget period.

Among the outflows from the Subbasin SWS, surface water outflow makes up a large fraction of the total Subbasin SWS outflows. The surface water outflows total about 89 taf per year on average. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for ET of precipitation averaging about 25 taf per year and average ET of applied water totaling about 19 taf per year on average. All other outflow components from the SWS are relatively smaller. The outflow of deep percolation of precipitation and applied water to the groundwater system (GWS) are about 7.2 and 4.6 taf per year, respectively, and infiltration (seepage) of surface water to the GWS totals about 4.9 taf per year on average. ET of groundwater uptake averages about 1.5 taf per year and evaporation from surface water averages about 150 af per year over the historical water budget period.

Table 4-1. Antelope Subbasin Historical Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (1990-2018)
Inflows	Surface Water Inflow	43,000
	Precipitation	41,000
	Groundwater Extraction	15,000
	Groundwater Discharge	53,000
Outflows	Surface Water Outflow	89,000
	ET of Applied Water	19,000
	ET of Groundwater Uptake	1,500
	ET of Precipitation	25,000
	Evaporation	150
	Deep Percolation of Applied Water	4,500
	Deep Percolation of Precipitation	7,200
	Infiltration of Surface Water	4,900
Annual Change in Root Zone Storage		**-88**

Summarized results for major components of the historical water budget as they relate to the GWS are presented in **Table 4-2**. Among the outflows from the Subbasin GWS, groundwater pumping makes up the largest fraction of the total GWS outflows (on average -13 taf per year). Highly negative net seepage values (on average -48 taf per year) represent net groundwater discharging to surface water features and leaving the GWS. Deep percolation is the largest net inflow component averaging about 12 taf per year. Positive net subsurface flows (on average 50 taf per year) represent the combined subsurface inflows from adjacent subbasins and upland areas. Groundwater (root water) uptake directly from shallow groundwater (on average -1.5 taf per year) represents a smaller outflow from the GWS. Overall, the water budget results for the 29-year historic period indicate a cumulative change in groundwater storage of about -7 taf, which equals an average annual change in groundwater storage of only about -610 acre-feet (af) per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about 0.77 af per acre on average over the 29 years and an annual decrease of less than 0.07 af per acre across the entire Subbasin (approximately 9,130 acres).

Detailed results for each of the individual water budget components in the historical water budget are presented in **Appendix A-1**.

Table 4-2. Antelope Subbasin Historical Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (1990-2018)
Total Net Seepage	-48,000
Deep Percolation	12,000
Groundwater Pumping	-13,000
Groundwater Uptake	-1,500
Total Net Subsurface Flows	50,000
Annual Change in Groundwater Storage	**-610**

4.1.2. Projected (Current Land Use) Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the projected (current land use) water budget period (2022-2072) are summarized in **Table 4-3**. Of particular note in the projected (current land use) SWS water budget results are the volume of surface water inflows that makes up a large part of the Subbasin SWS inflows. Over the projected (current land use) period, surface water inflows average about 43 taf per year. Precipitation also represents a large SWS inflow component averaging about 43 taf per year. Groundwater extraction and groundwater discharge to surface water represent relatively smaller SWS inflows in the Subbasin averaging about 16 and 43 taf per year, respectively over the projected (current land use) water budget period.

Among the outflows from the Subbasin SWS, surface water outflow makes up a large fraction of the total Subbasin SWS outflows. The surface water outflows total about 81 taf per year on average. ET of applied water and ET of precipitation also represent large SWS outflow components, averaging about 20 taf and 26 taf, respectively, per year. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for deep percolation of applied water averaging about 4.2 taf per year. The outflows of deep percolation of precipitation and infiltration (seepage) of surface water are about 7.2 and 4.9 taf per year on average, respectively. ET of groundwater uptake averages about 1.2 taf per year and evaporation from surface water averages about 150 af per year over the projected (current land use) water budget period.

Table 4-3. Antelope Subbasin Projected (Current Land Use) Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (2022-2072)
Inflows	Surface Water Inflow	43,000
	Precipitation	43,000
	Groundwater Extraction	16,000
	Groundwater Discharge	43,000
Outflows	Surface Water Outflow	81,000
	ET of Applied Water	20,000
	ET of Groundwater Uptake	1,200
	ET of Precipitation	26,000
	Evaporation	150
	Deep Percolation of Applied Water	4,200
	Deep Percolation of Precipitation	7,200
	Infiltration of Surface Water	4,900
Annual Change in Root Zone Storage		**5**

Summarized results for major components of the projected (current land use) water budget as they relate to the GWS are presented in **Table 4-4**. The positive net subsurface flows (on average 42 taf per year) represent the combined subsurface flows from adjacent subbasins and upland areas and deep percolation represents another large net inflow averaging about 11 taf per year. The large negative net seepage values (on average -38 taf per year) represent net stream seepage to groundwater and groundwater pumping (on average -15 taf per year) is another large outflow from the GWS. Groundwater (root water) uptake directly from shallow groundwater (on average -1.2 taf per year) represents a smaller outflow from the GWS. Overall, the water budget results for the 51-year projected (current land use) period indicate a cumulative change in groundwater storage of about -15 taf, which equals an average annual change in groundwater storage of only about -290 af per year. These change in storage estimates equate to total decreases in storage in the Subbasin of about 0.03 af per acre on average over the 51 years and an annual decrease of less than 0.002 af per acre across the entire Subbasin (approximately 9,130 acres).

Detailed results for each of the individual water budget components in the projected (current land use) water budget are presented in **Appendix A-2**.

Table 4-4. Antelope Subbasin Projected (Current Land Use) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	-38,000
Deep Percolation	11,000
Groundwater Pumping	-15,000
Groundwater Uptake	-1,200
Total Net Subsurface Flows	42,000
Annual Change in Groundwater Storage	**-290**

4.1.3. Projected (Future Land Use) Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the projected (future land use) water budget period (2022-2072) are summarized in **Table 4-5**. Of particular note in the projected (future land use) SWS water budget results are the volume of surface water inflows and precipitation that make up a large part of the Subbasin SWS inflows. Over the projected (future land use) period, surface water inflows and precipitation each average about 43 taf per year. Groundwater Discharge to surface water also represents a large SWS inflow component averaging about 33 taf per year. Groundwater represents a relatively smaller SWS inflow in the Subbasin averaging about 16 taf per year over the projected (future land use) water budget period.

Among the outflows from the Subbasin SWS, surface water outflow makes up a large fraction of the total Subbasin SWS outflows. The surface water outflows total about 72 taf per year on average, a value that corresponds with the large volumes of surface water inflow. ET of applied water and ET of precipitation also represent large SWS outflow components, averaging about 20 taf and 26 taf, respectively, per year. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for deep percolation of precipitation averaging about 7 taf per year. The outflows of deep percolation of applied water and infiltration (seepage) of surface water are about 4.2 and 4.9 taf per year on average, respectively. Evaporation from surface water averages about 150 af per year over the projected (future land use) water budget period.

Table 4-5. Antelope Subbasin Projected (Future Land Use) Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (2022-2072)
Inflows	Surface Water Inflow	43,000
	Precipitation	43,000
	Groundwater Extraction	16,000
	Groundwater Discharge	33,000
Outflows	Surface Water Outflow	72,000
	ET of Applied Water	20,000
	ET of Groundwater Uptake	820
	ET of Precipitation	26,000
	Evaporation	150
	Deep Percolation of Applied Water	4,200
	Deep Percolation of Precipitation	7,100
	Infiltration of Surface Water	4,900
Annual Change in Root Zone Storage		**5**

Summarized results for major components of the projected (future land use) water budget as they relate to the GWS are presented in **Table 4-6**. Among the outflows from the Subbasin GWS, net seepage makes up the largest fraction of the total GWS outflows (on average -28 taf per year). Net seepage represents net groundwater discharging to surface waterways and leaving the GWS. Groundwater pumping additionally makes up a large portion of GWS outflows (on average -15 taf per year). Positive net subsurface flows and deep percolation are the largest net inflow components averaging about 33 and 11 taf per year, respectively. Groundwater (root water) uptake directly from shallow groundwater (on average -820 af per year) represents a smaller outflow from the GWS. Overall, the water budget results for the 51-year projected (future land use) period indicate a cumulative change in groundwater storage of about -17 taf, which equals an average annual change in groundwater storage of only about -330 af per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about 0.9 af per acre on average over the 51 years and an annual decrease of about 0.02 af per acre across the entire Subbasin (approximately 19,040 acres).

Detailed results for each of the individual water budget components in the projected (future land use) water budget are presented in **Appendix A-3**.

Table 4-6. Antelope Subbasin Projected (Future Land Use) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	-28,000
Deep Percolation	11,000
Groundwater Pumping	-15,000
Groundwater Uptake	-820
Total Net Subsurface Flows	33,000
Annual Change in Groundwater Storage	**-330**

4.1.4. Projected (Current Land Use) with Climate Change Water Budget Results

A comparison of the major components of the projected (current land use) with climate change water budget as they relate to the GWS are presented in **Table 4-7**. Net seepage becomes less negative under climate change scenarios, indicating less groundwater flow to SWS. Deep percolation and net subsurface flows remain nearly unchanged under climate change scenarios. Groundwater pumping increases under climate change scenarios, becoming a greater outflow from the groundwater system. Groundwater uptake remains nearly unchanged under climate change scenarios.

Detailed results for each of the individual water budget components in the projected (current land use) with climate change (2030) water budget are presented in **Appendix A-4**. Detailed results for each of the individual water budget components in the projected (current land use) with climate change (2070) water budget are presented in **Appendix A-5**.

Table 4-7. Comparison of Antelope Subbasin Projected (Current Land Use) Groundwater System Annual Water Budgets with Climate Change Adjustments (acre-feet)

GWS Water Budget Component	Projected (Current Land Use)		
	Baseline Scenario	Climate Change (2030)	Climate Change (2070)
Total Net Seepage	-38,000	-36,000	-33,000
Deep Percolation	11,000	12,000	11,000
Groundwater Pumping	-15,000	-16,000	-17,000
Groundwater Uptake	-1,200	-1,200	-1,100
Total Net Subsurface Flows	42,000	42,000	39,000
Annual Groundwater Storage Change	**-290**	**-300**	**-340**

4.1.5. Projected (Future Land Use) with Climate Change Water Budget Results

A comparison of the major components of the projected (future land use) with climate change water budget as they relate to the GWS are presented in **Table 4-8**. Overall, the climate change scenarios to not appear to change the overall Subbasin GWS water budget in a considerable way. Net seepage becomes less negative under climate change scenarios, indicating a reduction of the net volume of groundwater discharging to the surface waters. Deep percolation remains nearly unchanged under climate change scenarios. Net subsurface flows to the Subbasin decrease slightly under climate change scenarios, primarily a result of reduced subsurface inflows from Red Bluff Subbasin. Groundwater extractions increase vary slightly under climate change scenarios, becoming a greater outflow from the groundwater system.

Detailed results for each of the individual water budget components in the projected (future land use) with climate change (2030) water budget are presented in **Appendix A-6**. Detailed results for each of the individual water budget components in the projected (future land use) with climate change (2070) water budget are presented in **Appendix A-7**.

Table 4-8. Comparison of Antelope Subbasin Projected (Future Land Use) Groundwater System Annual Water Budgets with Climate Change Adjustments (acre-feet)

GWS Water Budget Component	Projected (Future Land Use)		
	Baseline Scenario	Climate Change (2030)	Climate Change (2070)
Total Net Seepage	-28,000	-26,000	-22,000
Deep Percolation	11,000	11,000	11,000
Groundwater Pumping	-15,000	-16,000	-18,000
Groundwater Uptake	-820	-830	-810
Total Net Subsurface Flows	33,000	32,000	29,000
Annual Groundwater Storage Change	**-330**	**-340**	**-390**

Note: positive values indicate inflows/increasing storage, negative values indicate outflows/decreasing storage.

4.1.6. Projected (Future Land Use) with Projects and Climate Change Water Budget Results

Summarized results for major components of the projected (future land use) with projects and climate change (2070) water budget as they relate to the GWS are presented in **Table 4-9**. Among the outflows from the Subbasin GWS, net seepage makes up the largest fraction of the total GWS outflows (on average -22 taf per year). Net seepage represents net groundwater discharging to surface waterways and leaving the GWS. Groundwater pumping additionally makes up a large portion of GWS outflows (on average -18 taf per year). Positive net subsurface flows and deep percolation are the largest net inflow components averaging about 29 and 11 taf per year, respectively. Groundwater (root water) uptake directly from shallow groundwater (on average -820 af per year) represents a smaller outflow from the GWS. Overall, the water budget results for the 51-year projected (future land use) with projects and climate change (2070) period indicate a cumulative change in groundwater storage of about -19 taf, which equals an average annual change in groundwater storage of only about -380 af per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about -1.0 af per acre on average over the 51 years and an annual decrease of about -0.02 af per acre across the entire Subbasin (approximately 19,040 acres).

Detailed results for each of the individual water budget components in the projected (future land use) with projects and climate change (2070) water budget are presented in **Appendix A-8**.

Table 4-9. Antelope Subbasin Projected (Future Land Use) with Projects and Climate Change (2070) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	-22,000
Deep Percolation	11,000
Groundwater Pumping	-18,000
Groundwater Uptake	-820
Total Net Subsurface Flows	29,000
Annual Change in Groundwater Storage	**-380**

4.2. Bowman Subbasin

The following section summarizes the analyses and results relating to the historical scenario for the Bowman Subbasin. Detailed water budget results for each of the individual model scenarios are presented in **Appendix B**.

4.2.1. Historical Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the historical water budget period (1990-2018) are summarized in **Table 4-10**. Of particular note in the historical SWS water budget results are the volume of precipitation that makes up a large part of the Subbasin SWS inflows averaging about 290 taf per year over the historical period. By comparison, other SWS inflows in the Subbasin are relatively smaller. Surface water inflows average about 81 taf per year. Groundwater extraction and uptake represents a relatively small SWS inflow averaging about 9.1 taf per year, and groundwater discharge to surface water is negligible over the historical water budget period.

Among the outflows from the Subbasin SWS, ET of precipitation makes up a large fraction of the total Subbasin SWS outflows averaging about 160 taf per year over the historical period. The surface water outflows total about 110 taf per year on average. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for deep percolation of precipitation about 44 taf per year and infiltration (seepage) of surface water about 43 taf per year on average. ET of applied water and deep percolation of applied water are about 11 and 8.6 taf per year on average, respectively. The outflows of ET of groundwater uptake and evaporation from surface water average about 3.0 and 0.7 taf per year, respectively.

Table 4-10. Bowman Subbasin Historical Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (1990-2018)
Inflows	Surface Water Inflow	81,000
	Precipitation	290,000
	Groundwater Extraction	9,100
	Groundwater Discharge	0
Outflows	Surface Water Outflow	110,000
	ET of Applied Water	11,000
	ET of Groundwater Uptake	3,000
	ET of Precipitation	160,000
	Evaporation	700
	Deep Percolation of Applied Water	8,600
	Deep Percolation of Precipitation	44,000
	Infiltration of Surface Water	43,000
Annual Change in Root Zone Storage		**-870**

Summarized results for major components of the historical water budget as they relate to the GWS are presented in **Table 4-11**. Deep percolation represents the largest inflow averaging nearly 53 taf per year while net seepage represents an inflow of about 43 taf per year. Net subsurface flows (combined subsurface flows with adjacent subbasins and upland areas) represent the largest net outflow totaling about -88 taf per year of outflow from the Bowman Subbasin on average. Groundwater pumping (on average -6.1 taf per year) and groundwater (root water) uptake directly from shallow groundwater (on average -3.0 taf per year) represent smaller outflows from the GWS. Overall, the water budget results for the 29-year historical period indicate a cumulative change in groundwater storage of about -50 taf, which equals an average annual change in groundwater storage of only about -1.7 taf per year. These changes in storage estimates equate to total decreases in storage in the Subbasin of about -0.41 af per acre over the 29 years and an annual decrease of less than -0.01 af per acre across the entire Subbasin (approximately 122,425 acres).

Detailed results for each of the individual water budget components in the historical water budget are presented in **Appendix B-1**.

Table 4-11. Bowman Subbasin Historical Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (1990-2018)
Total Net Seepage	43,000
Deep Percolation	53,000
Groundwater Pumping	-6,100
Groundwater Uptake	-3,000
Total Net Subsurface Flows	-88,000
Annual Change in Groundwater Storage	**-1,700**

4.2.2. Projected (Current Land Use) Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the projected (current land use) water budget period (2022-2072) are summarized in **Table 4-12**. Of particular note in the projected (current land use) SWS water budget results is the volume of precipitation that makes up the largest part of the Subbasin SWS inflows averaging about 300 taf per year over the projected period. By comparison, other SWS inflows in the Subbasin are relatively smaller. Surface water inflows average about 83 taf per year. Groundwater extraction and uptake represents a relatively small SWS inflow averaging about 9.1 taf per year, and groundwater discharge to surface water is negligible over the projected (current land use) water budget period.

Among the outflows from the Subbasin SWS, ET of precipitation makes up a large fraction of the total Subbasin SWS outflows averaging about 160 taf per year over the projected (current land use) period. The surface water outflows total about 120 taf per year on average. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for each deep percolation of precipitation totaling about 46 taf per year and infiltration (seepage) of surface water totaling about 43 taf per year, on average. ET of applied water and deep percolation of applied water are about 11 and 7.3 taf per year on average, respectively. The outflows of ET of groundwater uptake and evaporation from surface water average about 2.9 and 0.85 taf per year, respectively.

Table 4-12. Bowman Subbasin Projected (Current Land Use) Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (2022-2072)
Inflows	Surface Water Inflow	83,000
	Precipitation	300,000
	Groundwater Extraction	9,100
	Groundwater Discharge	0
Outflows	Surface Water Outflow	120,000
	ET of Applied Water	11,000
	ET of Groundwater Uptake	2,900
	ET of Precipitation	160,000
	Evaporation	850
	Deep Percolation of Applied Water	7,300
	Deep Percolation of Precipitation	46,000
	Infiltration of Surface Water	46,000
Annual Change in Root Zone Storage		**-69**

Summarized results for major components of the projected (current land use) water budget as they relate to the GWS are presented in **Table 4-13**. Deep percolation represents the largest inflow averaging nearly 53 taf per year while net seepage represents an inflow of about 46 taf per year. Net subsurface flows (combined subsurface flows with adjacent subbasins and upland areas) represent the largest net outflow totaling about -90 taf per year of outflow from the Bowman Subbasin on average. Groundwater pumping (on average -6.2 taf per year) and groundwater (root water) uptake directly from shallow groundwater (on average -2.9 taf per year) represent smaller outflows from the GWS. Overall, the water budget results for the 51-year projected (current land use) period indicate a cumulative change in groundwater storage of about -11 taf, which equals an average annual change in groundwater storage of about -0.2 taf per year. These changes in storage estimates equate to total decreases in storage in the Subbasin of about -0.09 af per acre over the 51 years and an annual decrease of -0.002 af per acre across the entire Subbasin (approximately 122,425 acres).

Detailed results for each of the individual water budget components in the projected (current land use) water budget are presented in **Appendix B-2**.

Table 4-13. Bowman Subbasin Projected (Current Land Use) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	46,000
Deep Percolation	53,000
Groundwater Pumping	-6,200
Groundwater Uptake	-2,900
Total Net Subsurface Flows	-90,000
Annual Change in Groundwater Storage	**-210**

4.2.3. Projected (Future Land Use) Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the projected (future land use) water budget period (2022-2072) are summarized in **Table 4-14**. Of particular note in the projected (future land use) SWS water budget results is the volume of precipitation that makes up the largest part of the Subbasin SWS inflows averaging about 300 taf per year over the projected period. By comparison, other SWS inflows in the Subbasin are relatively smaller. Surface water inflows average about 83 taf per year. Groundwater extraction and uptake represents a relatively small SWS inflow averaging about 9.2 taf per year, and groundwater discharge to surface water is negligible over the projected (future land use) water budget period.

Among the outflows from the Subbasin SWS, ET of precipitation makes up a large fraction of the total Subbasin SWS outflows averaging about 160 taf per year over the projected (future land use) period. The surface water outflows total about 120 taf per year on average. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for infiltration (seepage) of surface water and deep percolation of precipitation totaling about 47 taf and 46 taf per year on average, respectively. ET of applied water and deep percolation of applied water are about 11 and 7.3 taf per year on average, respectively. The outflows of ET of groundwater uptake and evaporation from surface water average about 2.8 and 0.85 taf per year, respectively.

Table 4-14. Bowman Subbasin Projected (Future Land Use) Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (2022-2072)
Inflows	Surface Water Inflow	83,000
	Precipitation	300,000
	Groundwater Extraction	9,200
	Groundwater Discharge	0
Outflows	Surface Water Outflow	120,000
	ET of Applied Water	11,000
	ET of Groundwater Uptake	2,800
	ET of Precipitation	160,000
	Evaporation	850
	Deep Percolation of Applied Water	7,300
	Deep Percolation of Precipitation	46,000
	Infiltration of Surface Water	47,000
Annual Change in Root Zone Storage		**-70**

Summarized results for major components of the projected (future land use) water budget as they relate to the GWS are presented in **Table 4-15**. Deep percolation represents the largest inflow averaging nearly 53 taf per year while net seepage represents an inflow of about 47 taf per year. Net subsurface flows (combined subsurface flows with adjacent subbasins and upland areas) represent the largest net outflow totaling about -91 taf per year of outflow from the Bowman Subbasin on average. Groundwater pumping (on average -6.4 taf per year) and groundwater (root water) uptake directly from shallow groundwater (on average -2.8 taf per year) represent smaller outflows from the GWS. Overall, the water budget results for the 51-year projected (future land use) period indicate a cumulative change in groundwater storage of about -15 taf, which equals an average annual change in groundwater storage of about -0.30 taf per year. These changes in storage estimates equate to total decreases in storage in the Subbasin of about -0.13 af per acre over the 51 years and an annual decrease of -0.002 af per acre across the entire Subbasin (approximately 122,425 acres).

Detailed results for each of the individual water budget components in the projected (future land use) water budget are presented in **Appendix B-3**.

Table 4-15. Bowman Subbasin Projected (Future Land Use) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	47,000
Deep Percolation	53,000
Groundwater Pumping	-6,400
Groundwater Uptake	-2,800
Total Net Subsurface Flows	-91,000
Annual Change in Groundwater Storage	**-300**

4.2.4. Projected (Current Land Use) with Climate Change Water Budget Results

A comparison of the major components of the projected (current land use) with climate change water budget as they relate to the GWS are presented in **Table 4-16**. Net seepage increases under climate change scenarios, indicating greater stream seepage to groundwater. Deep percolation and net subsurface flows remain nearly unchanged under climate change scenarios. Groundwater pumping increases under climate change scenarios, becoming a greater outflow from the groundwater system. Groundwater uptake remains nearly unchanged under climate change scenarios.

Detailed results for each of the individual water budget components in the projected (current land use) with climate change (2030) water budget are presented in **Appendix B-4**. Detailed results for each of the individual water budget components in the projected (current land use) with climate change (2070) water budget are presented in **Appendix B-5**.

Table 4-16. Comparison of Bowman Subbasin Projected (Current Land Use) Groundwater System Annual Water Budgets with Climate Change Adjustments (acre-feet)

GWS Water Budget Component	Projected (Current Land Use)		
	Baseline Scenario	Climate Change (2030)	Climate Change (2070)
Total Net Seepage	46,000	47,000	48,000
Deep Percolation	53,000	53,000	51,000
Groundwater Pumping	-6,200	-6,400	-6,900
Groundwater Uptake	-2,900	-2,900	-2,900
Total Net Subsurface Flows	-90,000	-91,000	-89,000
Annual Groundwater Storage Change	**-210**	**-240**	**-420**

4.2.5. Projected (Future Land Use) with Climate Change Water Budget Results

A comparison of the major components of the projected (future land use) with climate change water budget as they relate to the GWS are presented in **Table 4-17**. Overall, the climate change scenarios do not appear to change the overall Subbasin GWS water budget in a considerable way. Net seepage increases under both 2030 and 2070 climate change scenarios and deep percolation decreases by a small amount. Net subsurface flows also do not change much under climate change scenarios. Groundwater pumping increases slightly under climate change scenarios. Groundwater uptake remains nearly unchanged under climate change scenarios.

Detailed results for each of the individual water budget components in the projected (future land use) with climate change (2030) water budget are presented in **Appendix B-6**. Detailed results for each of the individual water budget components in the projected (future land use) with climate change (2070) water budget are presented in **Appendix B-7**.

Table 4-17. Comparison of Bowman Subbasin Projected (Future Land Use) Groundwater System Annual Water Budgets with Climate Change Adjustments (acre-feet)

GWS Water Budget Component	Projected (Future Land Use)		
	Baseline Scenario	Climate Change (2030)	Climate Change (2070)
Total Net Seepage	47,000	48,000	49,000
Deep Percolation	53,000	53,000	51,000
Groundwater Pumping	-6,400	-6,600	-7,100
Groundwater Uptake	-2,800	-2,800	-2,800
Total Net Subsurface Flows	-91,000	-92,000	-90,000
Annual Groundwater Storage Change	**-300**	**-340**	**-530**

Note: positive values indicate inflows/increasing storage, negative values indicate outflows/decreasing storage.

4.2.6. Projected (Future Land Use) with Projects and Climate Change Water Budget Results

Summarized results for major components of the projected (future land use) with projects and climate change (2070) water budget as they relate to the GWS are presented in **Table 4-18**. Deep percolation represents the largest inflow averaging nearly 51 taf per year while net seepage represents an inflow of about 49 taf per year. Net subsurface flows (combined subsurface flows with adjacent subbasins and upland areas) represent the largest net outflow totaling about -91 taf per year of outflow from the Bowman Subbasin on average. Groundwater pumping (on average -7.1 taf per year) and groundwater (root water) uptake directly from shallow groundwater (on average -2.8 taf per year) represent smaller outflows from the GWS. Overall, the water budget results for the 51-year projected (future land use) with projects and climate change (2070) period indicate a cumulative change in groundwater storage of about -27 taf, which equals an average annual change in groundwater storage of about -530 af per year. These changes in storage estimates equate to decreases in storage in the Subbasin of about -0.22 af per acre over the 51 years and an annual decrease of about -0.004 af per acre across the entire Subbasin (approximately 122,425 acres).

Detailed results for each of the individual water budget components in the projected (future land use) with projects and climate change (2070) water budget are presented in **Appendix B-8**.

Table 4-18. Bowman Subbasin Projected (Future Land Use) with Projects and Climate Change (2070) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	49,000
Deep Percolation	51,000
Groundwater Pumping	-7,100
Groundwater Uptake	-2,800
Total Net Subsurface Flows	-91,000
Annual Change in Groundwater Storage	**-530**

4.3. Los Molinos Subbasin

The following section summarizes the analyses and results relating to the historical scenario for the Los Molinos Subbasin. Detailed water budget results for each of the individual model scenarios are presented in **Appendix C**.

4.3.1. Historical Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the historical water budget period (1990-2018) are summarized in **Table 4-19**. Of particular note in the historical SWS water budget results are the volumes of surface water inflows that make up a large part of the Subbasin SWS inflows. Over the historical period, surface water inflows to surface water averaged about 630 taf per year. Precipitation also represents a large SWS inflow component averaging about 210 taf per year. Groundwater extraction and uptake represent a small SWS inflow in the Subbasin averaging about 33 taf per year over the historical water budget period. Groundwater discharge to surface water represents a smaller SWS inflow averaging about 2 taf per year.

Among the outflows from the Subbasin SWS, surface water outflow makes up a large fraction of the total Subbasin SWS outflows. The surface water outflows total about 620 taf per year on average. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for ET of precipitation about 120 taf per year and deep percolation of precipitation totaling about 39 taf per year on average. The outflow of ET of applied water, infiltration (seepage) of surface water, and ET of groundwater uptake are about 36, 35 and 17 taf per year on average, respectively. The outflows of deep percolation of applied water and evaporation from surface water are about 15 and 2.1 taf per year, respectively.

Table 4-19. Los Molinos Subbasin Historical Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (1990-2018)
Inflows	Surface Water Inflow	630,000
	Precipitation	210,000
	Groundwater Extraction	33,000
	Groundwater Discharge	2,000
Outflows	Surface Water Outflow	620,000
	ET of Applied Water	36,000
	ET of Groundwater Uptake	17,000
	ET of Precipitation	120,000
	Evaporation	2,100
	Deep Percolation of Applied Water	15,000
	Deep Percolation of Precipitation	39,000
	Infiltration of Surface Water	35,000
Annual Change in Root Zone Storage		**-630**

Summarized results for major components of the historical water budget as they relate to the GWS are presented in **Table 4-20**. The positive net seepage values (on average 33 taf per year) and deep percolation values (on average 54 taf per year) represent the major inflows to the GWS. The net subsurface flows average about -56 taf per year represent the combined net subsurface outflows from the Subbasin to adjacent subbasins. Groundwater (root water) uptake directly from shallow groundwater (on average -17 taf per year) and groundwater pumping (on average -16 taf per year) are somewhat smaller outflows from the GWS. Overall, the water budget results for the 29-year historic period indicate a cumulative change in groundwater storage of about -74 taf, which equals an average annual decrease in groundwater storage of approximately -2.5 taf per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about -0.74 af per acre over the 29 years and an annual decrease of about -0.03 af per acre across the entire Subbasin (approximately 99,000 acres).

Detailed results for each of the individual water budget components in the historical water budget are presented in **Appendix C-1**.

Table 4-20. Los Molinos Subbasin Historical Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (1990-2018)
Total Net Seepage	33,000
Deep Percolation	54,000
Groundwater Pumping	-16,000
Groundwater Uptake	-17,000
Total Net Subsurface Flows	-56,000
Annual Change in Groundwater Storage	**-2,500**

4.3.2. Projected (Current Land Use) Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the projected (current land use) water budget period (2022-2072) are summarized in **Table 4-21**. Of particular note in the projected (current land use) SWS water budget results are the volumes of surface water inflows that make up a large part of the Subbasin SWS inflows. Over the projected (current land use) period, surface water inflows to surface water averaged about 650 taf per year. Precipitation also represents a large SWS inflow component averaging about 220 taf per year. Groundwater extraction and uptake represent a small SWS inflow in the Subbasin averaging about 27 taf per year over the projected (current land use) water budget period. Groundwater discharge to surface water is negligible throughout the projected (current land use) period.

Among the outflows from the Subbasin SWS, surface water outflow makes up a large fraction of the total Subbasin SWS outflows. The surface water outflows total about 610 taf per year on average. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for ET of precipitation about 120 taf per year and infiltration (seepage) of surface water totaling about 59 taf per year on average. The outflow of ET of applied water, deep percolation of precipitation, and deep percolation of applied water are about 41, 38 and 14 taf per year on average, respectively. The outflows of ET of groundwater uptake and evaporation from surface water are about 7.3 and 2.2 taf per year, respectively.

Table 4-21. Los Molinos Subbasin Projected (Current Land Use) Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (2022-2072)
Inflows	Surface Water Inflow	650,000
	Precipitation	220,000
	Groundwater Extraction	27,000
	Groundwater Discharge	0
Outflows	Surface Water Outflow	610,000
	ET of Applied Water	41,000
	ET of Groundwater Uptake	7,300
	ET of Precipitation	120,000
	Evaporation	2,200
	Deep Percolation of Applied Water	14,000
	Deep Percolation of Precipitation	38,000
	Infiltration of Surface Water	59,000
Annual Change in Root Zone Storage		**24**

Summarized results for major components of the projected (current land use) water budget as they relate to the GWS are presented in **Table 4-22**. The positive net seepage values (on average 59 taf per year) and deep percolation values (on average 52 taf per year) represent the major inflows to the GWS. The net subsurface flows average about -86 taf per year represent the combined net subsurface outflows from the Subbasin to adjacent subbasins. Groundwater pumping (on average -20 taf per year) and groundwater (root water) uptake directly from shallow groundwater (on average -7.3 taf per year) are somewhat smaller outflows from the GWS. Overall, the water budget results for the 51-year projected (current land use) period indicate a cumulative change in groundwater storage of about -93 taf, which equals an average annual decrease in groundwater storage of approximately -1.8 taf per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about -0.94 af per acre over the 51 years and an annual decrease of about -0.02 af per acre across the entire Subbasin (approximately 99,000 acres).

Detailed results for each of the individual water budget components in the projected (current land use) water budget are presented in **Appendix C-2**.

Table 4-22. Los Molinos Subbasin Projected (Current Land Use) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	59,000
Deep Percolation	52,000
Groundwater Pumping	-20,000
Groundwater Uptake	-7,300
Total Net Subsurface Flows	-86,000
Annual Change in Groundwater Storage	**-1,800**

4.3.3. Projected (Future Land Use) Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the projected (future land use) water budget period (2022-2072) are summarized in **Table 4-23**. Of particular note in the historical SWS water budget results are the volumes of surface water inflows that make up a large part of the Subbasin SWS inflows. Over the projected (future land use) period, surface water inflows to surface water averaged about 650 taf per year. Precipitation also represents a large SWS inflow component averaging about 220 taf per year. Groundwater extraction and uptake represent a small SWS inflow in the Subbasin averaging about 27 taf per year over the projected (current land use) water budget period. Groundwater discharge to surface water is negligible throughout the projected (current land use) period.

Among the outflows from the Subbasin SWS, surface water outflow makes up a large fraction of the total Subbasin SWS outflows. The surface water outflows total about 610 taf per year on average. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for ET of precipitation about 120 taf per year and infiltration (seepage) of surface water totaling about 63 taf per year on average. The outflow of ET of applied water, deep percolation of precipitation, and deep percolation of applied water are about 42, 38 and 14 taf per year on average, respectively. The outflows of ET of groundwater uptake and evaporation from surface water are about 6.1 and 2.2 taf per year, respectively.

Table 4-23. Los Molinos Subbasin Projected (Future Land Use) Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (2022-2072)
Inflows	Surface Water Inflow	650,000
	Precipitation	220,000
	Groundwater Extraction	27,000
	Groundwater Discharge	0
Outflows	Surface Water Outflow	610,000
	ET of Applied Water	42,000
	ET of Groundwater Uptake	6,100
	ET of Precipitation	120,000
	Evaporation	2,200
	Deep Percolation of Applied Water	14,000
	Deep Percolation of Precipitation	38,000
	Infiltration of Surface Water	63,000
Annual Change in Root Zone Storage		**25**

Summarized results for major components of the projected (future land use) water budget as they relate to the GWS are presented in **Table 4-24**. The positive net seepage values (on average 63 taf per year) and deep percolation values (on average 51 taf per year) represent the major inflows to the GWS. The net subsurface flows average about -89 taf per year represent the combined net subsurface outflows from the Subbasin to adjacent subbasins. Groundwater pumping (on average -21 taf per year) and groundwater (root water) uptake directly from shallow groundwater (on average -6.1 taf per year) are somewhat smaller outflows from the GWS. Overall, the water budget results for the 51-year projected (future land use) period indicate a cumulative change in groundwater storage of about -100 taf, which equals an average annual decrease in groundwater storage of approximately -2.0 taf per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about 1.0 af per acre over the 51 years and an annual decrease of about -0.02 af per acre across the entire Subbasin (approximately 99,000 acres).

Detailed results for each of the individual water budget components in the projected (future land use) water budget are presented in **Appendix C-3**.

Table 4-24. Los Molinos Subbasin Projected (Future Land Use) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	63,000
Deep Percolation	51,000
Groundwater Pumping	-21,000
Groundwater Uptake	-6,100
Total Net Subsurface Flows	-89,000
Annual Change in Groundwater Storage	**-2,000**

4.3.4. Projected (Current Land Use) with Climate Change Water Budget Results

A comparison of the major components of the projected (current land use) with climate change water budget as they relate to the GWS are presented in **Table 4-25**. Net seepage increases under climate change scenarios, indicating greater stream seepage to groundwater. Deep percolation and net subsurface flows decrease slightly under climate change scenarios. Groundwater pumping increases slightly under climate change scenarios, but the overall water budget results suggest that annual change in storage is only very slightly more negative under the climate change scenarios.

Detailed results for each of the individual water budget components in the projected (current land use) with climate change (2030) water budget are presented in **Appendix C-4**. Detailed results for each of the individual water budget components in the projected (current land use) with climate change (2070) water budget are presented in **Appendix C-5**.

Table 4-25. Comparison of Los Molinos Subbasin Projected (Current Land Use) Groundwater System Annual Water Budgets with Climate Change Adjustments (acre-feet)

GWS Water Budget Component	Projected (Current Land Use)		
	Baseline Scenario	Climate Change (2030)	Climate Change (2070)
Total Net Seepage	59,000	62,000	67,000
Deep Percolation	52,000	52,000	50,000
Groundwater Pumping	-20,000	-22,000	-24,000
Groundwater Uptake	-7,300	-7,100	-6,400
Total Net Subsurface Flows	-86,000	-87,000	-88,000
Annual Groundwater Storage Change	**-1,800**	**-1,900**	**-2,100**

4.3.5. Projected (Future Land Use) with Climate Change Water Budget Results

A comparison of the major components of the projected (future land use) with climate change water budget as they relate to the GWS are presented in **Table 4-26**. Overall, the climate change scenarios do not appear to change the overall Subbasin GWS water budget in a considerable way. Net seepage increases under climate change scenarios, indicating greater stream seepage to groundwater. Deep percolation and net subsurface flows decrease slightly under climate change scenarios. Groundwater pumping under climate change scenarios, but the overall change in storage is only slightly more negative under the climate change scenarios.

Detailed results for each of the individual water budget components in the projected (future land use) with climate change (2030) water budget are presented in **Appendix C-6**. Detailed results for each of the individual water budget components in the projected (future land use) with climate change (2070) water budget are presented in **Appendix C-7**.

Table 4-26. Comparison of Los Molinos Subbasin Projected (Future Land Use) Groundwater System Annual Water Budgets with Climate Change Adjustments (acre-feet)

GWS Water Budget Component	Projected (Future Land Use)		
	Baseline Scenario	Climate Change (2030)	Climate Change (2070)
Total Net Seepage	63,000	66,000	71,000
Deep Percolation	51,000	51,000	49,000
Groundwater Pumping	-21,000	-22,000	-25,000
Groundwater Uptake	-6,100	-5,900	-5,100
Total Net Subsurface Flows	-89,000	-91,000	-92,000
Annual Groundwater Storage Change	**-2,000**	**-2,100**	**-2,300**

Note: positive values indicate inflows/increasing storage, negative values indicate outflows/decreasing storage.

4.3.6. Projected (Future Land Use) with Projects and Climate Change Water Budget Results

Summarized results for major components of the projected (future land use) with projects and climate change (2070) water budget as they relate to the GWS are presented in **Table 4-27**. The positive net seepage values (on average 70 taf per year) and deep percolation values (on average 49 taf per year) represent the major inflows to the GWS. The net subsurface flows average about -92 taf per year represent the combined net subsurface outflows from the Subbasin to adjacent subbasins.

Groundwater pumping (on average -25 taf per year) and groundwater (root water) uptake directly from shallow groundwater (on average -5.2 taf per year) are somewhat smaller outflows from the GWS. Overall, the water budget results for the 51-year projected (future land use) with projects and climate change (2070) period indicate a cumulative change in groundwater storage of about -120 taf, which equals an average annual decrease in groundwater storage of approximately -2.3 taf per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about -1.2 af per acre over the 51 years and an annual decrease of about -0.02 af per acre across the entire Subbasin (approximately 99,000 acres).

Detailed results for each of the individual water budget components in the projected (future land use) with projects and climate change (2070) water budget are presented in **Appendix C-8**.

Table 4-27. Los Molinos Subbasin Projected (Future Land Use) with Projects and Climate Change (2070) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	70,000
Deep Percolation	49,000
Groundwater Pumping	-25,000
Groundwater Uptake	-5,200
Total Net Subsurface Flows	-92,000
Annual Change in Groundwater Storage	**-2,300**

4.4. Red Bluff Subbasin

The following section summarizes the analyses and results relating to the historical scenario for the Red Bluff Subbasin. Detailed water budget results for each of the individual model scenarios are presented in **Appendix D**.

4.4.1. Historical Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the historical water budget period (1990-2018) are summarized in **Table 4-28**. Of particular note in the historical SWS water budget results are the volume of precipitation that makes up a large part of the Subbasin SWS inflows. Over the historical period, precipitation to surface water averaged about 580 taf per year. Surface water inflows and groundwater extraction and uptake also represent large SWS inflow components averaging about 120 and 90 taf per year, respectively. Groundwater discharge to surface water represents a relatively smaller SWS inflow in the Subbasin, averaging about 42 taf per year over the historical water budget period.

Among the outflows from the Subbasin SWS, ET of precipitation and surface water outflow make up large fractions of the total Subbasin SWS outflows. ET of precipitation averages about 350 taf per year, while surface water outflows total about 340 taf per year on average. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for ET of applied water and deep percolation of precipitation averaging about 61 and 55 taf per year, respectively. The outflows of deep percolation of applied water, ET of groundwater uptake and infiltration (seepage) of surface water are about 15, 9.7, and 2.4 taf per year on average, respectively. Evaporation from surface water averages about 0.7 taf per year over the historical water budget period.

Table 4-28. Red Bluff Subbasin Historical Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (1990-2018)
Inflows	Surface Water Inflow	120,000
	Precipitation	580,000
	Groundwater Extraction	90,000
	Groundwater Discharge	42,000
Outflows	Surface Water Outflow	340,000
	ET of Applied Water	61,000
	ET of Groundwater Uptake	9,700
	ET of Precipitation	350,000
	Evaporation	680
	Deep Percolation of Applied Water	15,000
	Deep Percolation of Precipitation	55,000
	Infiltration of Surface Water	2,400
Annual Change in Root Zone Storage		**-1,600**

Summarized results for major components of the historical water budget as they relate to the GWS are presented in **Table 4-29**. Among the outflows from the Subbasin GWS, groundwater pumping makes up the largest fraction of the total GWS outflows (on average -80 taf per year). Highly negative net seepage values (on average -39 taf per year) represent net groundwater discharging to surface waterways and leaving the GWS. Groundwater (root water) uptake directly from shallow groundwater (on average -9.7 taf per year) represents a smaller outflow from the GWS. Deep percolation is the largest net inflow component averaging about 70 taf per year. Positive net subsurface flows (on average 49 taf per year) represent the combined subsurface inflows from adjacent subbasins and upland areas. Overall, the water budget results for the 29-year historic period indicate a cumulative change in groundwater storage of about -310 taf, which equals an average annual change in groundwater storage of only about -11 taf per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about 1.1 af per acre on average over the 29 years and an annual decrease of less than 0.04 af per acre across the entire Subbasin (approximately 272,000 acres).

Detailed results for each of the individual water budget components in the historical water budget are presented in **Appendix D-1**.

Table 4-29. Red Bluff Subbasin Historical Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (1990-2018)
Total Net Seepage	-39,000
Deep Percolation	70,000
Groundwater Pumping	-80,000
Groundwater Uptake	-9,700
Total Net Subsurface Flows	49,000
Annual Change in Groundwater Storage	**-11,000**

4.4.2. Projected (Current Land Use) Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the projected (current land use) water budget period (2022-2072) are summarized in **Table 4-30**. Of particular note in the projected (current land use) SWS water budget results are the volume of precipitation that makes up a large part of the Subbasin SWS inflows (average about 600 taf per year over the projected period). Surface water inflows and groundwater extraction also represent large SWS inflow components averaging about 120 and 100 taf per year, respectively. Groundwater discharge to surface water is a relatively smaller SWS inflow in the Subbasin averaging about 26 taf per year over the projected (current land use) water budget period.

Among the outflows from the Subbasin SWS, ET of precipitation and surface water outflow make up large fractions of the total Subbasin SWS outflows. ET of precipitation averages about 360 taf per year, while surface water outflows total about 330 taf per year on average. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for ET of applied water and deep percolation of precipitation averaging about 80 taf and 54 taf per year, respectively. The outflows of deep percolation of applied water, ET of groundwater uptake and infiltration (seepage) of surface water are about 13, 6.3, and 4.5 taf per year on average, respectively. Evaporation from surface water averages about 0.9 taf per year over the projected (current land use) water budget period.

Table 4-30. Red Bluff Subbasin Projected (Current Land Use) Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (2022-2072)
Inflows	Surface Water Inflow	120,000
	Precipitation	600,000
	Groundwater Extraction	100,000
	Groundwater Discharge	26,000
Outflows	Surface Water Outflow	330,000
	ET of Applied Water	80,000
	ET of Groundwater Uptake	6,300
	ET of Precipitation	360,000
	Evaporation	910
	Deep Percolation of Applied Water	13,000
	Deep Percolation of Precipitation	54,000
	Infiltration of Surface Water	4,500
Annual Change in Root Zone Storage		**-46**

Summarized results for major components of the projected (current land use) water budget as they relate to the GWS are presented in **Table 4-31**. Among the outflows from the Subbasin GWS, groundwater pumping makes up the largest fraction of the total GWS outflows (on average -94 taf per year). Highly negative net seepage values (on average -21 taf per year) represent net groundwater discharging to surface waterways and leaving the GWS. Groundwater (root water) uptake directly from shallow groundwater (on average -6.3 taf per year) represents a smaller outflow from the GWS. Deep percolation is the largest net inflow component averaging about 67 taf per year. Positive net subsurface flows (on average 53 taf per year) represent the combined subsurface inflows from adjacent subbasins and upland areas. Overall, the water budget results for the 51-year projected (current land use) period indicate a cumulative change in groundwater storage of about -94 taf, which equals an average annual change in groundwater storage of only about -1.8 taf per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about 0.34 af per acre on average over the 51 years and an annual decrease of less than 0.01 af per acre across the entire Subbasin (approximately 272,000 acres).

Detailed results for each of the individual water budget components in the projected (current land use) water budget are presented in **Appendix D-2**.

Table 4-31. Red Bluff Subbasin Projected (Current Land Use) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	-21,000
Deep Percolation	67,000
Groundwater Pumping	-94,000
Groundwater Uptake	-6,300
Total Net Subsurface Flows	53,000
Annual Change in Groundwater Storage	**-1,800**

4.4.3. Projected (Future Land Use) Water Budget Results

Annual inflows, outflows, and change in SWS root zone storage during the projected (future land use) water budget period (2022-2072) are summarized in **Table 4-32**. Of particular note in the projected (future land use) SWS water budget results are the volume of precipitation that makes up a large part of the Subbasin SWS inflows (average about 600 taf over the projected period). Groundwater extraction and surface water inflows also represent large SWS inflow components averaging about 140 and 120 taf per year, respectively. Groundwater discharge to surface water is a relatively smaller SWS inflow in the Subbasin averaging about 16 taf per year over the projected (future land use) water budget period.

Among the outflows from the Subbasin SWS, ET of precipitation and surface water outflow make up large fractions of the total Subbasin SWS outflows. ET of precipitation averages about 360 taf per year, while surface water outflows total about 330 taf per year on average. By comparison, other SWS outflows in the Subbasin are relatively smaller, with values for ET of applied water and deep percolation of precipitation averaging about 110 and 51 taf per year, respectively. The outflows of deep percolation of applied water, infiltration (seepage) of surface water, and ET of groundwater uptake are about 17, 7.1, and 4.8 taf per year on average, respectively. Evaporation from surface water averages about 0.97 taf per year over the projected (current land use) water budget period.

Table 4-32. Red Bluff Subbasin Projected (Future Land Use) Surface System Annual Water Budget Summary (acre-feet)

Water Budget Component		Average (2022-2072)
Inflows	Surface Water Inflow	120,000
	Precipitation	600,000
	Groundwater Extraction	140,000
	Groundwater Discharge	16,000
Outflows	Surface Water Outflow	330,000
	ET of Applied Water	110,000
	ET of Groundwater Uptake	4,800
	ET of Precipitation	360,000
	Evaporation	970
	Deep Percolation of Applied Water	17,000
	Deep Percolation of Precipitation	51,000
	Infiltration of Surface Water	7,100
Annual Change in Root Zone Storage		**-50**

Summarized results for major components of the projected (future land use) water budget as they relate to the GWS are presented in **Table 4-33**. Among the outflows from the Subbasin GWS, groundwater pumping makes up the largest fraction of the total GWS outflows (on average -130 taf per year). Negative net seepage values (on average -9.3 taf per year) represent net groundwater discharging to surface waterways and leaving the GWS. Groundwater (root water) uptake directly from shallow groundwater (on average -4.8 taf per year) represents a smaller outflow from the GWS. Positive net subsurface flows and deep percolation are the largest net inflow components averaging about 74 and 68 taf per year, respectively. Overall, the water budget results for the 51-year projected (future land use) period indicate a cumulative change in groundwater storage of about -150 taf, which equals an average annual change in groundwater storage of only about -2.9 taf per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about 0.54 af per acre on average over the 51 years and an annual decrease of about 0.01 af per acre across the entire Subbasin (approximately 272,000 acres).

Detailed results for each of the individual water budget components in the projected (future land use) water budget are presented in **Appendix D-3**.

Table 4-33. Red Bluff Subbasin Projected (Future Land Use) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	-9,300
Deep Percolation	68,000
Groundwater Pumping	-130,000
Groundwater Uptake	-4,800
Total Net Subsurface Flows	74,000
Annual Change in Groundwater Storage	**-2,900**

4.4.4. Projected (Current Land Use) with Climate Change Water Budget Results

A comparison of the major components of the projected (current land use) with climate change water budget as they relate to the GWS are presented in **Table 4-34**. Net seepage becomes less negative under climate change scenarios, indicating less groundwater discharge to streams. Deep percolation decreases slightly, while net subsurface flows increase slightly under climate change scenarios. Groundwater pumping increases under climate change scenarios, becoming a greater outflow from the groundwater system. Overall, the annual change in groundwater storage becomes more negative under climate change scenarios.

Detailed results for each of the individual water budget components in the projected (current land use) with climate change (2030) water budget are presented in **Appendix D-4**. Detailed results for each of the individual water budget components in the projected (current land use) with climate change (2070) water budget are presented in **Appendix D-5**.

Table 4-34. Comparison of Red Bluff Subbasin Projected (Current Land Use) Groundwater System Annual Water Budgets with Climate Change Adjustments (acre-feet)

GWS Water Budget Component	Projected (Current Land Use)		
	Baseline Scenario	Climate Change (2030)	Climate Change (2070)
Total Net Seepage	-21,000	-18,000	-12,000
Deep Percolation	67,000	67,000	64,000
Groundwater Pumping	-94,000	-99,000	-110,000
Groundwater Uptake	-6,300	-6,200	-5,500
Total Net Subsurface Flows	53,000	54,000	56,000
Annual Groundwater Storage Change	**-1,800**	**-1,900**	**-2,400**

4.4.5. Projected (Future Land Use) with Climate Change Water Budget Results

A comparison of the major components of the projected (future land use) with climate change water budget as they relate to the GWS are presented in **Table 4-35**. Net seepage becomes less negative under 2030 climate change scenario indicating a reduction of groundwater discharge to streams. Net seepage becomes slightly positive under 2070 climate change scenario indicating seepage from surface water to groundwater. Deep percolation decreases slightly under climate change scenarios, while net subsurface flows increase slightly under climate change scenarios. Groundwater pumping increases under climate change scenarios, becoming a greater outflow from the groundwater system. Overall, the annual change in groundwater storage becomes more negative under climate change scenarios.

Detailed results for each of the individual water budget components in the projected (future land use) with climate change (2030) water budget are presented in **Appendix D-6**. Detailed results for each of the individual water budget components in the projected (future land use) with climate change (2070) water budget are presented in **Appendix D-7**.

Table 4-35. Comparison of Red Bluff Subbasin Projected (Future Land Use) Groundwater System Annual Water Budgets with Climate Change Adjustments (acre-feet)

GWS Water Budget Component	Projected (Future Land Use)		
	Baseline Scenario	Climate Change (2030)	Climate Change (2070)
Total Net Seepage	-9,300	-6,000	830
Deep Percolation	68,000	68,000	66,000
Groundwater Pumping	-130,000	-140,000	-150,000
Groundwater Uptake	-4,800	-4,600	-4,100
Total Net Subsurface Flows	74,000	77,000	80,000
Annual Groundwater Storage Change	**-2,900**	**-3,000**	**-4,100**

Note: positive values indicate inflows/increasing storage, negative values indicate outflows/decreasing storage.

4.4.6. Projected (Future Land Use) with Projects and Climate Change Water Budget Results

Summarized results for major components of the projected (future land use) with projects and climate change (2070) water budget as they relate to the GWS are presented in **Table 4-36**. Among the outflows from the Subbasin SWS, groundwater pumping makes up the largest fraction of the total SWS outflows (on average -150 taf per year). Groundwater (root water) uptake directly from shallow groundwater (on average -4.8 taf per year) represents a smaller outflow from the GWS. Positive net subsurface flows and deep percolation are the largest net inflow components averaging about 74 and 68 taf per year, respectively. Net seepage values (on average 0.3 taf per year) represents a smaller inflow to the GWS. Overall, the water budget results for the 51-year projected (future land use) with projects and climate change (2070) period indicate a cumulative change in groundwater storage of about -180 taf, which equals an average annual change in groundwater storage of only about -3.5 taf per year. This change in storage estimates equate to total decreases in storage in the Subbasin of about -0.66 af per acre on average over the 51 years and an annual decrease of about -0.01 af per acre across the entire Subbasin (approximately 272,000 acres).

Detailed results for each of the individual water budget components in the projected (future land use) with projects and climate change (2070) water budget are presented in **Appendix D-8**.

Table 4-36. Red Bluff Subbasin Projected (Future Land Use) with Projects and Climate Change (2070) Groundwater System Annual Water Budget Summary (acre-feet)

Water Budget Component	Average (2022-2072)
Total Net Seepage	300
Deep Percolation	67,000
Groundwater Pumping	-150,000
Groundwater Uptake	-4,300
Total Net Subsurface Flows	79,000
Annual Change in Groundwater Storage	**-3,500**

4.5. Summary of Subbasin Water Budget Results by Aquifer Zone

This section provides a summary comparison of the Subbasin water budget results for the different historical and projected conditions evaluated, including by primary aquifer zone.

4.5.1. Antelope Subbasin

Table 4-37 provides a summary comparison of the Antelope Subbasin water budget results for the different historical and projected conditions evaluated, including by primary aquifer zone. Net seepage becomes less negative in the projected scenarios as compared to the historical scenario, indicating less groundwater discharge to streams. The decrease in groundwater discharge to streams is greatest in the climate change scenarios which correlated with higher surface water inflows occurring under the climate change scenarios. Deep percolation from the SWS to the GWS is relatively stable between the historical and projected scenarios, but decreases slightly under the climate change scenarios. Net subsurface flows decrease in the projected scenarios as compared to the historical scenario, indicating decreased inflows to the Subbasin. These subsurface inflows decrease slightly under climate change scenarios. Groundwater pumping increases slightly in the projected scenarios as compared to the historical scenario and increases only modestly under climate change scenarios. Overall, all historical and projected water budgets suggest decreases in groundwater storage by varying magnitudes. The projected changes in storage are likely within the range of uncertainty in the water budget estimates.

As presented in **Table 4-37**, groundwater pumping in the Antelope Subbasin occurs primarily from the Upper Aquifer and historically averaged about 15 taf per year from the Upper Aquifer; in projected water budget scenarios, average groundwater pumping from the Upper Aquifer is estimated to range between 16 and 18 taf per year, depending on the water budget scenario. In the historical water budget period, groundwater pumping from the Lower Aquifer was estimated to average about 27 af per year; under projected water budget scenarios groundwater pumping from the Lower Aquifer is estimated to average between 36 and 45 af per year, depending on the water budget scenario.

Net subsurface flows in the Subbasin occur primarily from the Upper Aquifer and historically averaged about 51 taf per year of inflow to the Upper Aquifer; in projected water budget scenarios, average net subsurface flows to the Upper Aquifer are estimated to range between 29 and 42 taf per year of inflow, depending on the water budget scenario. All subsurface flows are inflows the Upper Aquifer along all boundaries. Net subsurface flows from the Red Bluff Subbasin were historically inflows to the Upper Aquifer, but shift to outflows in the projected (future land use) scenarios.

In the historical water budget period, net subsurface flows to the Lower Aquifer were estimated to average about 260 af per year of outflows; under projected water budget scenarios net subsurface flows to the Lower Aquifer are estimated to average between 99 and 140 af per year of outflows, depending on the water budget scenario. The majority of net subsurface inflows to the Lower Aquifer come from the Red Bluff Subbasin and Bend Subbasin. The majority of net subsurface outflows from the Lower Aquifer are to the Los Molinos Subbasin and to the Upper Aquifer.

The average change in groundwater storage within each of the two primary aquifers in the Subbasin are very minor under all historical and projected water budget scenarios. The water budget results suggest that slight decreases in groundwater storage are projected to occur in the Upper and Lower Aquifers, depending on the projected water budget scenario. The projected changes in storage are likely within the range of uncertainty in the water budget estimates.

Table 4-37. Comparison of Antelope Subbasin GWS Water Budgets (acre-feet)

GWS Water Budget Component	Historical	Projected (Current Land Use)			Projected (Future Land Use)		
		No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)	No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)
Upper Aquifer							
Net Seepage	-48,000	-38,000	-36,000	-33,000	-28,000	-26,000	-22,000
Deep Percolation	12,000	11,000	12,000	11,000	11,000	11,000	11,000
Groundwater Extraction	-15,000	-16,000	-17,000	-18,000	-16,000	-17,000	-18,000
Net Subsurface Flows	51,000	42,000	42,000	39,000	33,000	32,000	29,000
Horizontal flow from (+)/to (-) Los Molinos Subbasin	12,000	9,900	9,800	9,200	8,900	8,700	8,100
Horizontal flow from (+)/to (-) Red Bluff Subbasin	3,500	1,200	980	430	-2,500	-2,900	-3,700
Horizontal flow from (+)/to (-) Bend Subbasin	2,000	2,100	2,100	2,200	2,200	2,200	2,300
Vertical flow from (+)/to (-) Lower Aquifer	34,000	29,000	29,000	27,000	24,000	23,000	22,000
Annual Groundwater Storage Change	**-330**	**-160**	**-160**	**-180**	**-170**	**-180**	**-200**
Lower Aquifer							

GWS Water Budget Component	Historical	Projected (Current Land Use)			Projected (Future Land Use)		
		No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)	No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)
Net Seepage	0	0	0	0	0	0	0
Deep Percolation	0	0	0	0	0	0	0
Groundwater Extraction	-27	-36	-39	-45	-36	-39	-45
Net Subsurface Flows	-260	-99	-100	-110	-120	-120	-140
Horizontal flow from (+)/to (-) Los Molinos Subbasin	-6,900	-7,000	-7,000	-7,100	-6,200	-6,200	-6,200
Horizontal flow from (+)/to (-) Red Bluff Subbasin	22,000	17,000	16,000	15,000	10,000	9,700	8,100
Horizontal flow from (+)/to (-) Bend Subbasin	18,000	19,000	19,000	19,000	20,000	20,000	20,000
Vertical flow from (+)/to (-) Upper Aquifer	-34,000	-29,000	-29,000	-27,000	-24,000	-23,000	-22,000
Annual Groundwater Storage Change	**-290**	**-130**	**-140**	**-160**	**-160**	**-160**	**-180**
Entire Groundwater System							
Net Seepage	-48,000	-38,000	-36,000	-33,000	-28,000	-26,000	-22,000
Deep Percolation	12,000	11,000	12,000	11,000	11,000	11,000	11,000
Groundwater Extraction	-15,000	-16,000	-17,000	-18,000	-16,000	-17,000	-18,000
Net Subsurface Flows	50,000	42,000	42,000	39,000	33,000	32,000	29,000
Horizontal flow from (+)/to (-) Los Molinos Subbasin	4,700	2,900	2,800	2,100	2,600	2,600	1,900
Horizontal flow from (+)/to (-) Red Bluff Subbasin	25,000	18,000	17,000	15,000	8,000	6,800	4,400
Horizontal flow from (+)/to (-) Bend Subbasin	20,000	21,000	21,000	21,000	22,000	22,000	22,000
Annual Groundwater Storage Change	**-610**	**-290**	**-300**	**-340**	**-330**	**-340**	**-390**

4.5.2. Bowman Subbasin

Table 4-38 provides a summary comparison of the Bowman Subbasin water budget results for the different historical and projected conditions evaluated, including by primary aquifer zone. Net seepage increases in the projected scenarios as compared to the historical scenario, indicating greater stream seepage to groundwater. The increases in stream seepage are greatest in the climate change scenarios which correlated with higher surface water inflows occurring under the climate change scenarios. Deep percolation from the SWS to the GWS is relatively stable between the historical and projected scenarios, but decreases slightly under the climate change scenarios. Net subsurface flows become slightly more negative in the projected scenarios as compared to the historical scenario, indicating greater outflows from the Subbasin. These subsurface outflows vary slightly under climate change scenarios. Groundwater pumping increases slightly in the projected scenarios as compared to the historical scenario, and increases under climate change scenarios. Overall, all historical and projected water budgets suggest decreases in groundwater storage by varying magnitudes. The projected changes in storage are likely within the range of uncertainty in the water budget estimates.

As presented in **Table 4-38**, groundwater pumping in the Bowman Subbasin occurs primarily from the Upper Aquifer and historically averaged about 6.9 taf per year from the Upper Aquifer; in projected water budget scenarios, average groundwater pumping from the Upper Aquifer is estimated to range between 7.1 and 7.6 taf per year, depending on the water budget scenario. In the historical water budget period, groundwater pumping from the Lower Aquifer was estimated to average about 2.2 af per year; under projected water budget scenarios groundwater pumping from the Lower Aquifer is estimated to average between 2 and 2.3 af per year, depending on the water budget scenario.

Net subsurface flows in the Subbasin occur primarily from the Upper Aquifer and historically averaged about 89 taf per year of outflow from the Upper Aquifer; in projected water budget scenarios, average net subsurface flows from the Upper Aquifer are estimated to range between 91 and 94 taf per year of outflow, depending on the water budget scenario. The majority of net subsurface inflows to the Upper Aquifer come from the Anderson Subbasin and South Battle Creek Subbasin. The majority of net subsurface outflows from the Upper Aquifer are to the Red Bluff Subbasin and to the Lower Aquifer.

In the historical water budget period, net subsurface flows to the Lower Aquifer were estimated to average about 1.1 taf per year of inflows; under projected water budget scenarios net subsurface flows to the Lower Aquifer are estimated to average between 2.1 and 2.2 taf per year of inflows, depending on the water budget scenario. The majority of net subsurface inflows to the Lower Aquifer come from the Anderson Subbasin, South Battle Creek Subbasin, and Upper Aquifer. The majority of net subsurface outflows from the Lower Aquifer are to the Red Bluff Subbasin.

The average change in groundwater storage within each of the two primary aquifers in the Subbasin are very minor under all historical and projected water budget scenarios. The water budget results suggest that slight decreases in groundwater storage are projected to occur in the Upper and Lower Aquifers, depending on the projected water budget scenario. The projected changes in storage are likely within the range of uncertainty in the water budget estimates.

Table 4-38. Comparison of Bowman Subbasin GWS Water Budgets (acre-feet)

GWS Water Budget Component	Historical	Projected (Current Land Use)			Projected (Future Land Use)		
		No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)	No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)
Upper Aquifer							
Net Seepage	43,000	46,000	47,000	48,000	47,000	48,000	49,000
Deep Percolation	53,000	53,000	53,000	51,000	53,000	53,000	51,000
Groundwater Extraction	-6,900	-7,100	-7,300	-7,600	-7,100	-7,300	-7,600
Net Subsurface Flows	-89,000	-92,000	-93,000	-91,000	-94,000	-94,000	-93,000
Horizontal flow from (+)/to (-) Red Bluff Subbasin	-10,000	-11,000	-11,000	-11,000	-11,000	-11,000	-11,000
Horizontal flow from (+)/to (-) Anderson Subbasin	960	1,200	1,200	1,400	1,200	1,300	1,400
Horizontal flow from (+)/to (-) South Battle Creek Subbasin	4,200	4,400	4,500	4,500	4,600	4,600	4,600
Vertical flow from (+)/ to (-) Lower Aquifer	-84,000	-87,000	-88,000	-87,000	-89,000	-89,000	-88,000
Annual Groundwater Storage Change	**-620**	**-320**	**-330**	**-380**	**-340**	**-350**	**-400**
Lower Aquifer							
Net Seepage	0	0	0	0	0	0	0
Deep Percolation	0	0	0	0	0	0	0
Groundwater Extraction	-2,200	-2,000	-2,100	-2,200	-2,100	-2,200	-2,300
Net Subsurface Flows	1,100	2,100	2,200	2,100	2,200	2,200	2,100
Horizontal flow from (+)/to (-) Red Bluff Subbasin	-110,000	-110,000	-110,000	-110,000	-110,000	-110,000	-110,000
Horizontal flow from (+)/to (-) Anderson Subbasin	21,000	21,000	21,000	21,000	22,000	22,000	22,000
Horizontal flow from (+)/to (-) South Battle Creek Subbasin	5,300	5,800	5,900	5,900	6,200	6,200	6,300
Vertical flow from (+)/to (-) Upper Aquifer	84,000	87,000	88,000	87,000	89,000	89,000	88,000
Annual Groundwater Storage Change	**-1,100**	**110**	**91**	**-33**	**35**	**11**	**-120**

GWS Water Budget Component	Historical	Projected (Current Land Use)			Projected (Future Land Use)		
		No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)	No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)
Entire Groundwater System							
Net Seepage	43,000	46,000	47,000	48,000	47,000	48,000	49,000
Deep Percolation	53,000	53,000	53,000	51,000	53,000	53,000	51,000
Groundwater Extraction	-9,100	-9,100	-9,300	-9,800	-9,200	-9,500	-9,900
Net Subsurface Flows	-88,000	-90,000	-91,000	-89,000	-91,000	-92,000	-90,000
Horizontal flow from (+)/to (-) Red Bluff Subbasin	-120,000	-120,000	-120,000	-120,000	-130,000	-130,000	-130,000
Horizontal flow from (+)/to (-) Anderson Subbasin	22,000	22,000	22,000	23,000	23,000	23,000	24,000
Horizontal flow from (+)/to (-) South Battle Creek Subbasin	9,400	10,000	10,000	10,000	11,000	11,000	11,000
Annual Groundwater Storage Change	**-1,700**	**-210**	**-240**	**-420**	**-300**	**-340**	**-530**

4.5.3. Los Molinos Subbasin

Table 4-39 provides a summary comparison of the Los Molinos Subbasin water budget results for the different historical and projected conditions evaluated, including by primary aquifer zone. Net seepage increases in the projected scenarios as compared to the historical scenario, indicating greater stream seepage to groundwater. The increases in stream seepage are greatest in the climate change scenarios which correlated with higher surface water inflows occurring under the climate change scenarios. Deep percolation from the SWS to the GWS decreases in the projected scenarios as compared to the historical scenario, and decreases slightly under the climate change scenarios. Net subsurface flows become more negative in the projected scenarios as compared to the historical scenario, indicating greater outflows from the Subbasin. These subsurface outflows become more negative under climate change scenarios. Groundwater pumping decreases slightly in the projected scenarios as compared to the historical scenario, and increases under climate change scenarios. Overall, all historical and projected water budgets suggest decreases in groundwater storage by varying magnitudes.

As presented in **Table 4-39**, groundwater pumping in the Los Molinos Subbasin occurs primarily from the Upper Aquifer and historically averaged about 30 taf per year from the Upper Aquifer; in projected water budget scenarios, average groundwater pumping from the Upper Aquifer is estimated to range between 24 and 27 taf per year, depending on the water budget scenario. In the historical water budget period, groundwater pumping from the Lower Aquifer was estimated to average about 2.7 af per year; under projected water budget scenarios groundwater pumping from the Lower Aquifer is estimated to average between 3.2 and 3.7 af per year, depending on the water budget scenario.

Net subsurface flows in the Subbasin occur primarily from the Upper Aquifer and historically averaged about 57 taf per year of outflow from the Upper Aquifer; in projected water budget scenarios, average net subsurface flows from the Upper Aquifer are estimated to range between 88 and 95 taf per year of outflow, depending on the water budget scenario. All subsurface flows from the Upper Aquifer are outflows from the Los Molinos Subbasin.

In the historical water budget period, net subsurface flows to the Lower Aquifer were estimated to average about 2.7 taf per year of inflows; under projected water budget scenarios net subsurface flows to the Lower Aquifer are estimated to average between 3.2 and 3.7 taf per year of inflows, depending on the water budget scenario. The majority of net subsurface inflows to the Lower Aquifer come from the Antelope Subbasin, Red Bluff Subbasin, and Upper Aquifer. The majority of net subsurface outflows from the Lower Aquifer are to the Corning Subbasin and Vina Subbasin.

The average change in groundwater storage within each of the two primary aquifers in the Subbasin are very minor under all historical and projected water budget scenarios. The water budget results suggest that slight decreases in groundwater storage are projected to occur in the Upper and Lower Aquifers, depending on the projected water budget scenario.

Table 4-39. Comparison of Los Molinos Subbasin GWS Water Budgets (acre-feet)

GWS Water Budget Component	Historical	Projected (Current Land Use)			Projected (Future Land Use)		
		No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)	No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)
Upper Aquifer							
Net Seepage	33,000	59,000	62,000	67,000	63,000	66,000	71,000
Deep Percolation	54,000	52,000	52,000	50,000	51,000	51,000	49,000
Groundwater Extraction	-30,000	-24,000	-25,000	-27,000	-24,000	-25,000	-26,000
Net Subsurface Flows	-57,000	-88,000	-90,000	-91,000	-92,000	-93,000	-95,000
Horizontal flow from (+)/to (-) Antelope Subbasin	-12,000	-9,900	-9,800	-9,200	-8,900	-8,700	-8,100
Horizontal flow from (+)/to (-) Red Bluff Subbasin	-3,200	-2,400	-2,500	-2,500	-2,900	-3,000	-3,000
Horizontal flow from (+)/to (-) Corning Subbasin	-390	-3,200	-3,400	-3,900	-3,500	-3,800	-4,300
Horizontal flow from (+)/to (-) Vina Subbasin	-13,000	-16,000	-16,000	-16,000	-16,000	-16,000	-16,000
Vertical flow from (+)/to (-) Lower Aquifer	-30,000	-58,000	-59,000	-61,000	-62,000	-63,000	-65,000
Annual Groundwater Storage Change	**-1,100**	**-1,100**	**-1,100**	**-1,300**	**-1,200**	**-1,200**	**-1,400**

GWS Water Budget Component	Historical	Projected (Current Land Use)			Projected (Future Land Use)		
		No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)	No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)
Lower Aquifer							
Net Seepage	0	0	0	0	0	0	0
Deep Percolation	0	0	0	0	0	0	0
Groundwater Extraction	-2,700	-3,200	-3,400	-3,700	-3,200	-3,400	-3,700
Net Subsurface Flows	1,300	2,500	2,700	2,800	2,400	2,600	2,700
Horizontal flow from (+)/to (-) Antelope Subbasin	6,900	7,000	7,000	7,100	6,200	6,200	6,200
Horizontal flow from (+)/to (-) Red Bluff Subbasin	5,400	3,300	2,900	2,100	870	320	-620
Horizontal flow from (+)/to (-) Corning Subbasin	840	-4,000	-4,500	-5,400	-5,100	-5,700	-6,700
Horizontal flow from (+)/to (-) Vina Subbasin	-43,000	-62,000	-63,000	-63,000	-62,000	-62,000	-62,000
Vertical flow from (+)/to (-) Upper Aquifer	30,000	58,000	59,000	61,000	62,000	63,000	65,000
Annual Groundwater Storage Change	**-1,400**	**-730**	**-760**	**-860**	**-810**	**-850**	**-960**
Entire Groundwater System							
Net Seepage	33,000	59,000	62,000	67,000	63,000	66,000	71,000
Deep Percolation	54,000	52,000	52,000	50,000	51,000	51,000	49,000
Groundwater Extraction	-33,000	-27,000	-29,000	-31,000	-27,000	-28,000	-30,000
Net Subsurface Flows	-56,000	-86,000	-87,000	-88,000	-89,000	-91,000	-92,000
Horizontal flow from (+)/to (-) Antelope Subbasin	-4,700	-2,900	-2,800	-2,100	-2,600	-2,600	-1,900
Horizontal flow from (+)/to (-) Red Bluff Subbasin	2,200	880	390	-360	-2,000	-2,600	-3,700
Horizontal flow from (+)/to (-) Corning Subbasin	450	-7,100	-7,900	-9,300	-8,700	-9,600	-11,000
Horizontal flow from (+)/to (-) Vina Subbasin	-56,000	-79,000	-79,000	-79,000	-78,000	-78,000	-78,000
Annual Groundwater Storage Change	**-2,500**	**-1,800**	**-1,900**	**-2,100**	**-2,000**	**-2,100**	**-2,300**

4.5.4. Red Bluff Subbasin

Table 4-40 provides a summary comparison of the Red Bluff Subbasin water budget results for the different historical and projected conditions evaluated, including by primary aquifer zone. Net seepage becomes less negative in the projected scenarios as compared to the historical scenario, indicating less groundwater discharge to streams. The decreases in groundwater discharge to streams are greatest in the climate change scenarios which correlated with higher surface water inflows occurring under the climate change scenarios. Deep percolation from the SWS to the GWS decreases between the historical and projected scenarios, and decreases slightly under the climate change scenarios. Net subsurface flows increase in the projected scenarios as compared to the historical scenario, indicating greater inflows to the Subbasin. These subsurface inflows increase under climate change scenarios. Groundwater pumping increases in the projected scenarios as compared to the historical scenario, and increases under climate change scenarios. Overall, all historical and projected water budgets suggest decreases in groundwater storage by varying magnitudes.

As presented in **Table 4-40**, groundwater pumping in the Red Bluff Subbasin occurs primarily from the Upper Aquifer and historically averaged about 78 taf per year from the Upper Aquifer; in projected water budget scenarios, average groundwater pumping from the Upper Aquifer is estimated to range between 84 and 130 taf per year, depending on the water budget scenario. In the historical water budget period, groundwater pumping from the Lower Aquifer was estimated to average about 12 af per year; under projected water budget scenarios groundwater pumping from the Lower Aquifer is estimated to average between 16 and 21 af per year, depending on the water budget scenario.

Net subsurface flows in the Subbasin occur primarily from the Upper Aquifer and historically averaged about 43 taf per year of inflow from the Upper Aquifer; in projected water budget scenarios, average net subsurface flows from the Upper Aquifer are estimated to range between 39 and 62 taf per year of inflow, depending on the water budget scenario. The majority of net subsurface inflows to the Upper Aquifer come from the Bowman Subbasin, Los Molinos Subbasin, South Battle Creek Subbasin, and the Lower Aquifer. The majority of net subsurface outflows from the Upper Aquifer are to the Corning Subbasin and to the Bend Subbasin. Net subsurface flows from the Antelope Subbasin were historically outflows to the Upper Aquifer, but shift to inflows in the projected (future land use) scenarios.

In the historical water budget period, net subsurface flows to the Lower Aquifer were estimated to average about 5.3 taf per year of inflows; under projected water budget scenarios net subsurface flows to the Lower Aquifer are estimated to average between 15 and 18 taf per year of inflows, depending on the water budget scenario. The majority of net subsurface inflows to the Lower Aquifer come from the Bowman Subbasin and South Battle Creek Subbasin. The majority of net subsurface outflows from the Lower Aquifer are to the Antelope Subbasin, Los Molinos Subbasin, Corning Subbasin, and Bend Subbasin, and Upper Aquifer.

The average change in groundwater storage within each of the two primary aquifers in the Subbasin are very minor under all historical and projected water budget scenarios. The water budget results suggest that slight decreases in groundwater storage are projected to occur in the Upper and Lower Aquifers, depending on the projected water budget scenario.

Table 4-40. Comparison of Red Bluff Subbasin GWS Water Budgets (acre-feet)

GWS Water Budget Component	Historical	Projected (Current Land Use)			Projected (Future Land Use)		
		No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)	No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)
Upper Aquifer							
Net Seepage	-39,000	-21,000	-18,000	-12,000	-9,300	-6,000	830
Deep Percolation	70,000	67,000	67,000	64,000	68,000	68,000	66,000
Groundwater Extraction	-78,000	-84,000	-88,000	-93,000	-120,000	-120,000	-130,000
Net Subsurface Flows	43,000	39,000	39,000	40,000	58,000	59,000	62,000
Horizontal flow from (+)/to (-) Antelope Subbasin	-3,500	-1,200	-980	-430	2,500	2,900	3,700
Horizontal flow from (+)/to (-) Bowman Subbasin	10,000	11,000	11,000	11,000	11,000	11,000	11,000
Horizontal flow from (+)/to (-) Los Molinos Subbasin	3,200	2,400	2,500	2,500	2,900	3,000	3,000
Horizontal flow from (+)/to (-) Corning Subbasin	-4,700	-5,800	-5,900	-5,900	-4,300	-4,300	-4,200
Horizontal flow from (+)/to (-) Bend Subbasin	-3,900	-3,700	-3,700	-3,700	-3,500	-3,500	-3,400
Horizontal flow from (+)/to (-) South Battle Creek Subbasin	660	670	670	660	670	670	660
Vertical flow from (+)/to (-) Lower Aquifer	41,000	35,000	35,000	36,000	48,000	49,000	51,000
Annual Groundwater Storage Change	**-3,500**	**-510**	**-560**	**-750**	**-740**	**-810**	**-1,000**
Lower Aquifer							
Net Seepage	0	0	0	0	0	0	0
Deep Percolation	0	0	0	0	0	0	0
Groundwater Extraction	-12,000	-16,000	-17,000	-18,000	-19,000	-20,000	-21,000
Net Subsurface Flows	5,300	15,000	15,000	16,000	16,000	17,000	18,000
Horizontal flow from (+)/to (-) Antelope Subbasin	-22,000	-17,000	-16,000	-15,000	-10,000	-9,700	-8,100

GWS Water Budget Component	Historical	Projected (Current Land Use)			Projected (Future Land Use)		
		No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)	No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)
Horizontal flow from (+)/to (-) Bowman Subbasin	110,000	110,000	110,000	110,000	110,000	110,000	110,000
Horizontal flow from (+)/to (-) Los Molinos Subbasin	-5,400	-3,300	-2,900	-2,100	-870	-320	620
Horizontal flow from (+)/to (-) Corning Subbasin	-23,000	-30,000	-30,000	-31,000	-27,000	-27,000	-27,000
Horizontal flow from (+)/to (-) Bend Subbasin	-14,000	-14,000	-14,000	-13,000	-13,000	-13,000	-13,000
Horizontal flow from (+)/to (-) South Battle Creek Subbasin	850	860	860	860	860	870	860
Vertical flow from (+)/to (-) Upper Aquifer	-41,000	-35,000	-35,000	-36,000	-48,000	-49,000	-51,000
Annual Groundwater Storage Change	**-7,100**	**-1,300**	**-1,400**	**-1,700**	**-2,100**	**-2,200**	**-2,600**
Entire Groundwater System							
Net Seepage	-39,000	-21,000	-18,000	-12,000	-9,300	-6,000	830
Deep Percolation	70,000	67,000	67,000	64,000	68,000	68,000	66,000
Groundwater Extraction	-90,000	-100,000	-100,000	-110,000	-140,000	-140,000	-150,000
Net Subsurface Flows	49,000	53,000	54,000	56,000	74,000	77,000	80,000
Horizontal flow from (+)/to (-) Antelope Subbasin	-25,000	-18,000	-17,000	-15,000	-8,000	-6,800	-4,400
Horizontal flow from (+)/to (-) Bowman Subbasin	120,000	120,000	120,000	120,000	130,000	130,000	130,000
Horizontal flow from (+)/to (-) Los Molinos Subbasin	-2,200	-880	-390	360	2,000	2,600	3,700
Horizontal flow from (+)/to (-) Corning Subbasin	-28,000	-36,000	-36,000	-37,000	-31,000	-31,000	-31,000
Horizontal flow from (+)/to (-) Bend Subbasin	-18,000	-17,000	-17,000	-17,000	-16,000	-16,000	-16,000

GWS Water Budget Component	Historical	Projected (Current Land Use)			Projected (Future Land Use)		
		No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)	No Climate Adjust-ment	Climate Change (2030)	Climate Change (2070)
Horizontal flow from (+)/to (-) South Battle Creek Subbasin	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Annual Groundwater Storage Change	**-11,000**	**-1,800**	**-1,900**	**-2,400**	**-2,900**	**-3,000**	**-3,600**

4.6. Modeled Groundwater Levels

A number of wells were selected to evaluate simulated groundwater elevations within Tehama IHM. Wells with constructions data and a long period of record were selected to provide good horizontal and vertical spatial representation and to represent various aquifer parameter zones. Hydrographs of simulated groundwater elevations are presented in **Appendix E**. In general, water levels in the projected (current land use) and projected (future land use) scenarios follow the same trends as the historical scenario. In the climate change scenarios, water levels begin showing slight declines over the projected period. Maps of historical simulated groundwater elevation for key time periods are presented in **Appendix F**.

4.7. Modeled Streamflows

A number of stream nodes were selected to evaluate simulated streamflows within Tehama IHM. These nodes represent flows through Antelope Creek Group, Cottonwood Creek , Deer Creek Group, Dye Creek, Elder Creek, Mill Creek, Red Bank Creek, Sacramento River, and Thomes Creek. Hydrographs of historical simulated streamflows are presented in **Appendix G**. In general, average monthly flows in the projected (current land use) and projected (future land use) scenarios are slightly increased in the winter and spring months and relatively unchanged in the summer and fall months. In general, average monthly flows in the winter months are significantly increased during the winter months under climate change scenarios. Flows are decreased slightly in the spring to early summer months and are relatively unchanged in the late summer through fall months under climate change scenarios.

4.8. Model Calibration Results

Model calibration was achieved through comparison of observed groundwater levels and measured stream flows to model results. Observations used to constrain aquifer parameter values included approximately 7,900 groundwater level observations from 93 wells. Observations used to constrain stream bed parameters included approximately 3,900 stream flow measurements from 12 gage stations.

Calibration quality quantifies the ability of the groundwater model to simulate observed groundwater levels. These results are evaluated with respect to fit statistics outlined by Anderson and Woessner (2002). More qualitative measures of model fit are also commonly used to evaluate model calibration quality and included in the model results.

4.8.1. Statistical Measures of Model Fit

Model calibration was evaluated through five common residual error statistics used to characterize model fit. These include the mean of residual error (ME), mean of absolute residual error (MAE), root mean of squared residual error ($RMSE$), Normalized RMSE ($NRMSE$), and linear correlation coefficient (R). The residual error here is calculated by subtracting the observed value from the simulated value at a specific physical location and time.

The mean of residual error (ME) is a measure of the general model tendency to overestimate (+) or underestimate (-) measured values. In general, it is a quantification of the model bias given by:

$$ME = \frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)$$

Where: N is the total number of observations

y_i is the ith observed value

$\hat{y}_i$ is the ith simulated value of a model dependent variable

The mean absolute residual errors (MAE) is more robust to represent the goodness of fit as no individual errors will be canceled in the estimation as ME. The MAE estimates the average magnitude of the error between modeled and observed values and is defined as:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|(y_i - \hat{y}_i)|$$

The root mean of squared residual error ($RMSE$) is defined as the square root of the second moment of the differences between observed and simulated error. Since the error between each observed and simulated value is squared, larger errors tend to have a greater impact on the value of the $RMSE$, therefore RMSE is generally more sensitive to outliers than the MAE.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^{2}}$$

The normalized root mean squared error ($NRMSE$) is calculated to account for the scale dependency of the $RMSE$ and is a measure of the $RMSE$ divided by the range of observations (Anderson and Woessner, 2002).

The linear correlation coefficient (R) is defined in the following equations:

$$R = \frac{COV(y, \hat{y})}{\sigma_y . \sigma_{\hat{y}}}$$

Where: $COV(y, \hat{y}_i)$ is the covariance between the observed (y) and simulated ($\hat{y}$) values

σ_y is the standard deviation of the observed values

$\sigma_{\hat{y}}$ is the standard deviation of the simulated values

The value of R lies between 1 (perfect linear correlation) and -1 (perfect linear correlation in the opposite direction). Usually, simulated and observed quantity is plotted in a scatter diagram to represent the model calibration results graphically with associated linear correlation coefficient R.

There are no uniform calibration standards used to determine an acceptable calibration of a groundwater flow model (Anderson and Woessner, 2002; Anderson et al., 2015). Summary statistics, such as those discussed in this section, should be used to evaluate the fit of simulated values to observed data and to minimize the error between these values (Murray-Darling Basin Commission, 2001; ASTM, 2008). For the purposes of calibrating Tehama IHM, calibration targets were set to minimize the model error to within 10% of the range of observed values.

4.8.2. Groundwater Level Calibration

A subset of the approximately 2,400 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, and period of record of available water level data. A total of 93 wells were selected to be used in calibration of Tehama IHM with a total of 7,913 water level observations during the calibration period. Simulated and observed groundwater elevations were compared over the 1990 through 2018 calibration period. 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.

Groundwater level calibration statistics are presented in **Table 4-41**. As stated in **Section 4.7.1**, the calibration targets for Solano IHM were set to minimize the model error to within 10% of the range of observed values. Observed groundwater level measurements used for calibration range from 44 to 499 feet, therefore an acceptable *RMSE* for Solano IHM would be 45 feet.

The final calibrated *RMSE* was 21.6 feet, resulting in a *NRMSE* of 5%, well within acceptable limits. The calculated *MAE* is 13.6 ft, a small value when compared to the range of observed groundwater levels in the model domain (**Figure 4-1**). The calculated *ME* (-0.97 ft) indicates that the model tends to simulate slightly lower groundwater levels than observed (under-predict) by an average of about 1 foot. The relation between observed and simulated groundwater elevations is shown by layer in **Figure 4-2**. Points plotting above 1-to-1 correlation line represent observations where Tehama IHM is simulating higher than observed groundwater elevations, while points plotting below the 1-to-1 correlation line represent observations where Tehama IHM simulating lower than observed groundwater elevations. In general, while points are plotting close to the 1-to-1 correlation line (R = 0.98), the model tends to under simulate water levels at higher observed groundwater elevations. Groundwater hydrographs of simulated and observed groundwater elevations used for model calibration are included in **Appendix H.**

Table 4-41. Groundwater Level Calibration Statistics

Calibration Statistic	Result	Target
Mean of Residual Error (ME)	-0.97 feet	-
Mean Absolute Residual Error (MAE)	13.6 feet	-
Root Mean of Squared Residual Error (RMSE)	21.6 feet	45 feet
Normalized Root Mean of Squared Residual Error (NRMSE)	5%	10%
Linear Correlation Coefficient (R)	0.98	1

The spatial distribution of residual errors in the simulated levels are presented in **Figure 4-3**. Tehama IHM is generally well calibrated. Residuals tend to be randomly distributed, indicating no clear bias in the model. The spatial distribution of residual errors in the simulated levels by layer are presented in **Figure 4-4**. Residuals are randomly distributed by layer, indicating no clear vertical bias in the model.

4.8.3. Streamflow Calibration

Observed stream flow was compared to simulated stream flow at 12 locations. Observed stream flow data were available from the California Data Exchange Center (CDEC) and the USGS. Hydrographs of observed versus simulated stream flows are available in **Appendix I**. In general, simulated stream flows generally match observed stream flows, where data are available. Streambed parameters were adjusted during the calibration process. The final streambed conductance values, by node, are shown in **Figure 4-5.**

4.9. Aquifer Parameters

Initial aquifer parameter values assigned to each aquifer parameter zone were based on reported literature values. These values were further refined and adjusted during the calibration process. Final calibrated values for each of the parameter zones are presented in **Table 4-42**. These parameter values were applied to the percent coarse textural model to generate aquifer parameter values for each model node in each model layer.

Table 4-42. Summary of Tehama IHM Calibrated Aquifer Parameters

<table>
<tr><th></th><th></th><th>Horizontal Hydraulic Conductivity (feet/day)</th><th>Vertical Hydraulic Conductivity (feet/day)</th><th>Specific Yield (-)</th><th>Specific Storage (feet^{-1})</th><th>Anisotropy Ratio (Kv/Kh)</th></tr>
<tr><td rowspan="2">Percent Coarse End Member Values</td><td>Fine</td><td>5</td><td>-</td><td>0.01</td><td>1.00E-04</td><td rowspan="2">0.25</td></tr>
<tr><td>Coarse</td><td>550</td><td>-</td><td>0.2</td><td>1.00E-06</td></tr>
<tr><td rowspan="4">Zone Multipliers</td><td>Alluvium</td><td>1</td><td>1</td><td>1</td><td>1</td><td rowspan="4"></td></tr>
<tr><td>Tuscan Formation</td><td>0.6</td><td>0.75</td><td>0.6</td><td>0.6</td></tr>
<tr><td>Tehama Formation</td><td>0.35</td><td>0.15</td><td>0.25</td><td>0.25</td></tr>
<tr><td>Non-Tuscan/Non-Tehama Zone</td><td>0.5</td><td>0.4</td><td>0.5</td><td>0.5</td></tr>
</table>

NOTE: Power law empirical parameter for KH (pKh) = 1.00; for KV (pKv) = -0.62

4.9.1. Hydraulic Conductivity

The calibrated horizontal hydraulic conductivity (Kh) values range from 3.66 feet per day (ft/d) in layer 4 to 446.45 ft/d in layer 2 (**Table 4-43**). The final Kh values in the calibrated model area shown by model layer in **Figures 4-6** through **4-14**. Calibrated vertical hydraulic conductivity (Kv) values range from 0.19 ft/d in layer 4 to 13.02 ft/d in layer 2 (**Table 4-43**). The Kv values in the calibrated model are shown by model layer in **Figures 4-15** through **4-23**.

Table 4-43. Summary of Tehama IHM Calibrated Hydraulic Conductivity

	Horizontal Hydraulic Conductivity (feet/day)			Vertical Hydraulic Conductivity (feet/day)		
Model Layer	Minimum	Maximum	Average	Minimum	Maximum	Average
1	13.20	419.20	159.43	0.21	9.67	2.22
2	5.57	446.45	130.07	0.19	13.02	1.99
3	9.38	222.09	79.01	0.20	4.74	1.02
4	3.66	166.50	75.63	0.19	2.63	0.89
5	11.29	199.20	66.32	0.20	3.62	0.82
6	11.29	199.20	61.01	0.20	3.62	0.77
7	15.10	225.36	84.07	0.21	4.94	1.07
8	24.64	228.63	73.27	0.23	5.16	0.90
9	9.38	107.64	39.00	0.20	1.68	0.62
Total	**3.66**	**446.45**	**85.31**	**0.19**	**13.02**	**1.14**

4.9.2. Storage Coefficients

Final calibrated specific yield (Sy) values range from 0.003 in layers 2 and 4 to 0.164 in layer 2 (**Table 4-44**). The final Sy values in the calibrated model area shown by model layer in **Figures 4-24** through **4-32**. Calibrated specific storage (Ss) values range from 6.69E-06 ft^{-1} in layer 2 to 9.70E-05 ft^{-1} in layer 2 (**Table 4-44**). The Ss values in the calibrated model are shown by model layer in **Figures 4-33** through **4-41**.

Table 4-44. Summary of Tehama IHM Calibrated Storage Coefficients

	Specific Yield (-)			Specific Storage ($feet^{-1}$)		
Model Layer	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**
1	0.005	0.154	0.059	7.68E-06	9.21E-05	3.67E-05
2	0.003	0.164	0.049	6.69E-06	9.70E-05	4.19E-05
3	0.004	0.082	0.029	8.42E-06	5.41E-05	2.69E-05
4	0.003	0.063	0.027	1.02E-05	5.47E-05	2.77E-05
5	0.005	0.074	0.024	1.39E-05	5.64E-05	2.92E-05
6	0.005	0.074	0.022	1.44E-05	5.64E-05	3.01E-05
7	0.006	0.084	0.030	1.04E-05	5.52E-05	2.62E-05
8	0.008	0.085	0.026	9.41E-06	4.87E-05	2.82E-05
9	0.004	0.042	0.015	1.71E-05	5.70E-05	3.40E-05
Total	**0.003**	**0.164**	**0.031**	**6.69E-06**	**9.70E-05**	**3.12E-05**

5. SENSITIVITY ANALYSIS AND MODEL UNCERTAINTY

5.1. Sensitivity Analysis

A model response or prediction depends on the governing equations it solves, the mechanisms and structure of the model, and the values of the model parameters. Sensitivity analysis is a means of evaluating model uncertainty due to parameter estimates by systematically altering one of the model parameters and examining the associated change in the model response. After the groundwater flow model was calibrated, a quantitative sensitivity analysis was performed using the flow model parameters that were most uncertain and likely to affect the flow simulation results. The calibrated flow model was used as the baseline simulation and sensitivity simulations were compared with those of the baseline simulation at all observation points. Model sensitivity was evaluated for model parameters using UCODE-2014. The basis of a model parameters sensitivity was based on groundwater elevation observations given a 1% parameter value perturbation. Sensitivity was evaluated through the Composite Scaled Sensitivity (CSS) statistic described by Hill and Tiedman (2007).

Sensitivity of simulated groundwater elevations to parameter perturbation are presented in **Figure 5-1**. The CSS statistic shows the model is most sensitive to the Horizontal Hydraulic Conductivity of Coarse Materials (KHC) parameter within the aquifer system defined in **Table 4-43**.

5.2. Model Uncertainty and Limitations

All groundwater flow models are a simplification of the natural environment, and therefore have uncertainty and limitations that are important to recognize. 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.

Uncertainty associated with water budget results estimated using the Tehama IHM depends in part on the model inputs relating to the surface water system with additional sources of uncertainty associated with model inputs relating to the groundwater system, including aquifer and streambed properties, specification of boundary conditions, and other factors. The uncertainty estimates associated with surface water system water budget components that are also inputs or outputs of the groundwater system water budget are noted in **Section 2.3 of the GSPs**. Recognizing the uncertainty of the surface water system water budget components, the overall uncertainty of other water budget components simulated for the groundwater system, including subsurface flows, groundwater discharging to surface water, and change in groundwater storage are estimated to be in the range of 10 to 30 percent. These groundwater system water budget components are subject to slightly higher uncertainty as they incorporate uncertainty in the surface water system water inflows and outflows with additional uncertainty resulting from limitations in available input data and simplification required in modeling of the subsurface heterogeneity. However, the uncertainty in the groundwater system water budget derived from a numerical model such as the Tehama IHM depends to a considerable degree on the calibration of the model and can vary by location and depth within the Subbasin. The Tehama IHM is a product of local refinement and improvements made to the SVSim model. The Tehama IHM simulates the integrated groundwater and surface water systems and metrics relating to the calibration of the model indicate the model is reasonably well calibrated in accordance with generally accepted professional guidelines and is sufficient for GSP-related applications.

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

Based on the calibration of Tehama IHM using historical conditions over the calibration period from water year 1990 to 2018 and accompanying assessment of model sensitivity, the Tehama IHM groundwater flow model is suitable for use as a tool for analyses to support development and implementation of the Tehama County Subbasins' GSP and other water resource management interests within the Tehama County Subbasins.

Tehama IHM 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 the Tehama County 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 likely increases 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.

Future and ongoing updates to Tehama IHM will be valuable for improving the model performance and evaluating the accuracy of the model predictions. Using data from the ongoing historical monitoring efforts and forthcoming GSP monitoring, Tehama IHM 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, trends in projected hydrology, and intended model applications, 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 Tehama IHM periodically with new site-specific and monitoring information. In accordance with monitoring and reporting requirements associated with the GSP, high-quality groundwater elevation, pumping, surface water deliveries, ET, and stream discharge data will especially benefit the future improvement of the model. New groundwater observation data should be compared with simulated model results to assess the performance of the model in predictive applications. If the differences between the measured groundwater data and Tehama IHM's predicted results are significant, adjustment and modification may be applied to the model input parameters.

Further refinement to Tehama IHM should be made by addressing key data gaps. Upon release of a calibrated SVSim model, an evaluation should be done to consider the benefits of incorporating any relevant aspects from the calibrated SVSim into the Tehama IHM. 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 Solano IHM can be made by keeping the historical model simulations current through periodic updating of the model and review of model calibration in preparation for 5-year GSP update reports. Additional model revisions should be conducted in areas outside the Tehama County Subbasins as such data are obtained from adjacent Subbasins and determined to be beneficial in the evaluation of conditions within the Tehama County Subbasins.

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