5. WATER BUDGETS

Water budgets are a critical component of understanding and evaluating a groundwater basin's sustainability. This chapter discusses the:

- General background on water budgets, the basis of the selected water budgets (historical, current conditions, projected conditions), and their components
- Average annual Subbasin- and area[1]-wide stream, land and water use, and groundwater budgets summarized in tabular format
- Results and insights from the water budget for the historical, current conditions, and projected conditions budgets with supporting figures
- Projected water budget under climate change conditions, including climate change methodology and resulting impacts on the Subbasin
- Sustainable yield assumptions and resulting water budgets
- Discussion of the importance of hydrologic variability on the water budgets and the range of change in groundwater storage for the Projected Conditions, Climate Change scenario, and Sustainable Yield scenario for each water year type.

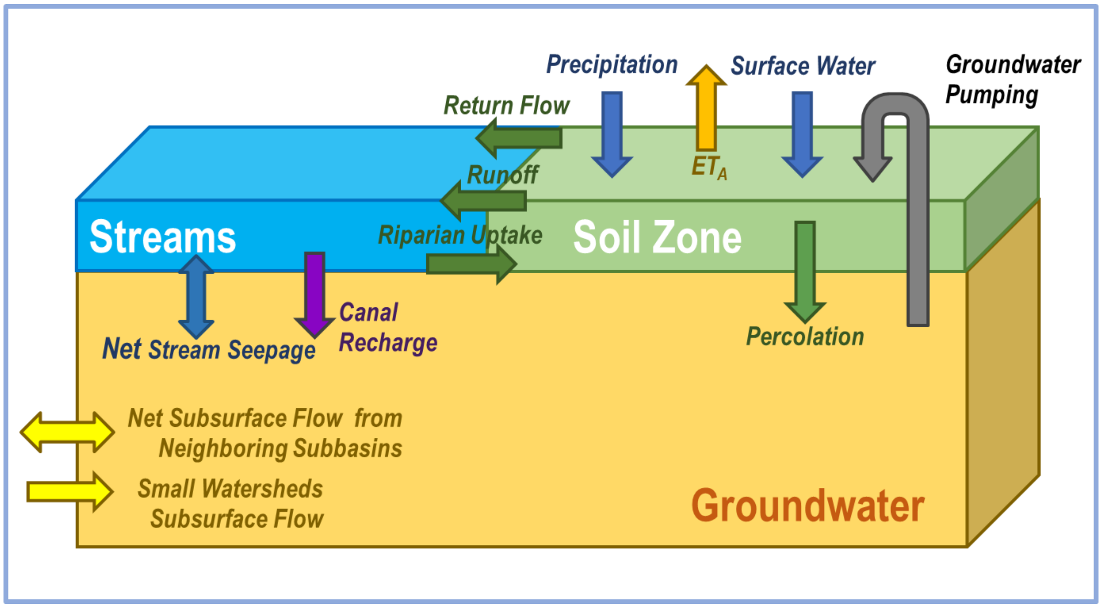
5.1. WATER BUDGET INFORMATION

Comprehensive hydrologic water budgets were developed to provide a quantitative understanding of water entering (inflows) and leaving (outflows) the Modesto Subbasin and are a requirement of the GSP regulations. Water budgets are provided for the three interconnected systems that define the overall hydrologic balance in the Modesto Subbasin - the land surface system, the stream and river system, and the groundwater system. Water entering and leaving each one of the physical systems, and water movement among the systems are a combination of natural processes and anthropogenic conditions. **Figure 5-1** highlights the main water budget components and interconnectivity of stream, surface, and groundwater components used in this analysis.

The values presented in the water budget provide hydrologic information on the historical, current, and projected conditions of the Modesto Subbasin relating to water demand, water supply, land use, population, climate change, groundwater and surface water interaction, and subsurface groundwater flow. An understanding of these impacts can assist in management of the Subbasin by identifying the scale of different water uses, highlighting potential risks presented by each condition, and identifying potential opportunities to improve water supply conditions and use of resources.

[1] The term "area" herein represents the four main subdivisions of the Modesto Subbasin discussed in this report – Modesto Irrigation District, Oakdale Irrigation District, Non-District East, and Non-District West. The establishment of these zones as Management Areas is discussed in **Section 6.2**.

Figure 5-1: Generalized Water Budget Diagram



The water budgets presented below reflect the interconnected movement of water through the land surface system (the soil zone), the stream system, and the groundwater system. Together, these systems and their interactions comprise the integrated water resources system which represents the comprehensive water cycle for the Subbasin. This comprehensive water budget is consistent with SGMA, GSP regulations, best management practices (BMPs), and recommendations in the Handbook for Water Budget Development published by the DWR (2020).

Water budgets can also be developed at different temporal scales. Daily water budgets can be used to demonstrate diurnal variation in the temperature and water use for agriculture and/or stream flows to assess implications on the fisheries and wildlife. Monthly water budgets are typically used to demonstrate variability in agricultural water demand during the irrigation season, or monthly and seasonal variability in surface water supply and/or groundwater pumping. The water budget for the Modesto Subbasin were developed on monthly intervals, though are presented on an annual basis in this report for presentation purposes and to facilitate their incorporation into policy decisions.

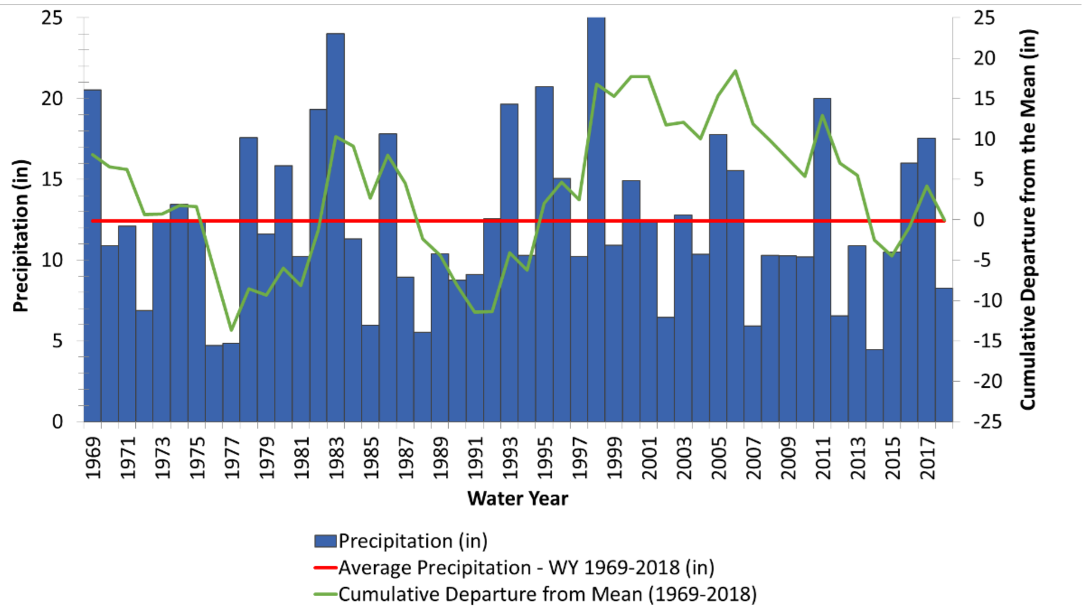
GSP regulations require that three sets of annual water budgets be developed, each reflecting the hydrology under historical, current, and projected levels of urban and agricultural development. Water budgets are developed to capture long-term conditions, which are assessed by averaging hydrologic conditions over several different timeframes. The historical water budgets reflect the average hydrology over a 25-year period (1991-2015), while current conditions are represented by a recent average year from the historical period (2010), and projected conditions are represented by the average of a 50-year hydrologic period. This provides opportunities to incorporate dry years and drought conditions, wet periods, and normal periods. By incorporating these varied conditions into the water budgets, the system can be analyzed in the short- and long-terms, allowing for assessment of the system response to certain hydrologic conditions (e.g., drought) and for assessment of broader system averages. The following subsection provides additional detail on identification of hydrologic periods.

5.1.1. Identification of Hydrologic Periods

Hydrologic periods were selected to meet the needs of developing historical, current, and projected water budgets. The GSP regulations require that the projected conditions are assessed over a 50-year hydrologic period to represent long-term hydrologic conditions. Precipitation data for the Modesto Subbasin were used to identify hydrologic periods that are representative of wet and dry periods and long-term average conditions needed for water budget analyses.

Rainfall data for the Subbasin is derived from the detailed database provided by the Precipitation-Elevation Regressions on Independent Slopes Model (PRISM) dataset. This data set is commonly used by DWR and other organizations for mapping the spatial and temporal distribution of precipitation throughout the state. DWR uses PRISM for the California Simulation of Evapotranspiration of Applied Water (CALSIMETAW) model, which is a major source of estimates of ET of applied water (ETAW) throughout the state. Periods with a balance of wet and dry intervals were identified by evaluating the cumulative departure from mean precipitation. **Figure 5-2** shows the annual precipitation and cumulative departure from the mean for the Modesto Subbasin. While the annual rainfall and precipitation data provides information on annual variability of rainfall over the course of the planning period, the cumulative departure from mean is indicative of long-term trends in Subbasin precipitation. In this context, the rising limbs of the cumulative departure line indicate short-term and long-term wet periods (e.g., 1978-83 and 1992-98), while falling limbs indicate short and long dry periods (e.g., 1976-77 and 2011-15). For the Modesto Subbasin water budget analysis, rainfall and water supply and demand conditions are available for the period October 1968 to September 2018 (WY 1969-2018), with an average annual rainfall of 12.4 inches. For the historical water budget analysis, the period WY 1991-2015 (average annual precipitation of 12.6 inches) is used, which coincides with the period for which the C2VSimTM model is calibrated, and for which the historical water demand and supplies have been confirmed. These periods of record meet the GSP regulatory requirement of at least 10 years for the historical water budget analysis. For the projected water budget purposes, the full period of WY 1969-2018 is used, which provides a 50-year record as required by GSP regulations.

Figure 5-2: 50-Year Historical Precipitation and Cumulative Departure from Mean Precipitation, Modesto Subbasin, California



5.1.2. Usage of C2VSimTM and Associated Data in Water Budget Development

Water budgets were developed utilizing C2VSimTM, a fully integrated surface and groundwater flow model covering the entire Central Valley. This version of C2VSim is based on the C2VSimFG-BETA2 model released by DWR. To support the GSP, C2VSimTM was developed and refined with a focus on land and water use operational data for both the Modesto and Turlock Subbasins. C2VSimTM, a quasi-three-dimensional finite element model, was developed using the Integrated Water Flow Model (IWFM) 2015 software package to simulate the relevant hydrologic processes prevailing in the model domain. The C2VSimTM integrates the groundwater aquifer with the surface hydrologic system and land surface processes and operations. Using data from federal, state, and local resources, the C2VSimTM was calibrated for the hydrologic period of October 1991 to September 2015 by comparing simulated evapotranspiration, groundwater levels, and streamflow records with historical observed records. Development of the model involved the study and analyses of hydrogeologic conditions, agricultural and urban water demands, agricultural and urban water supplies, and an evaluation of regional water quality conditions. Additional information on the data used to develop C2VSimTM is included in **Appendix C**.

All integrated hydrologic models contain assumptions and some level of uncertainty. They are decision support tools used to better understand complex interactive systems. Sources of model uncertainty include heterogeneity in hydrogeologic properties and stratigraphy, quality of historical data, projections of future land use, hydrology, operational data, and climatic conditions.

C2VSimTM has been calibrated and validated. The data and assumptions for Modesto and Turlock Subbasins were developed in a collaborative manner with the respective districts and are based on best available data and science. Projections of future land use and water demands were based on the most recent planning documents prepared by agencies in the Subbasin. In its current form, the model represents the best available data for the Subbasin. As additional information is collected during GSP implementation, the model will be updated to reflect the newly available resources. Efforts to address Subbasin data gaps will improve information available for the model.

With the C2VSimTM as the underlying framework, model simulations were developed to allow for the estimation of water budgets. Four model simulations were used to develop the water budgets for historical, current, projected, and climate change conditions, which are discussed in detail below:

The **historical water budget** is based on a simulation of historical conditions in the Modesto Subbasin (1991-2015).

The **current water budget** is based on an average year (2010) of the historical simulation that incorporates current irrigation and operational practices.

The **projected water budget** is based on a simulation of future land and water use over the historical hydrologic conditions.

The **climate change water budget** is based on the projected water budget under 2070 climate conditions and is discussed in **Section 5.2**.

The **sustainable yield water budget** is based on the projected water budget refined to meet SGMA sustainability criteria and is discussed in **Section 5.3**

5.1.3. Water Budget Definitions and Assumptions

Definitions and assumptions for the historical, current, and projected water budgets are provided below. These assumptions are summarized in **Table 5-1**.

5.1.3.1. Historical Water Budget

The historical water budget is intended to evaluate availability and reliability of past surface water supply deliveries, aquifer response to water supply, and demand trends relative to WY type. The historical calibration of the C2VSimTM reflects the historical conditions in the Modesto Subbasin through the 2015 water year. The hydrologic period of WY 1991 through 2015 is selected for the GSP historical water budget because it provides a period of representative hydrology while capturing recent operations within the Subbasin. The period WY 1991 through 2015 has an average annual precipitation of approximately 12.6 inches, slightly higher than the long-term average of 12.4 inches observed for the 50-year projected hydrologic period of WY 1969-2018. Both periods include the recent WY 2012-2015 drought, the wetter years of WY 1998 and 2010-2011, and periods of normal precipitation.

5.1.3.2. Current Water Budget

The current conditions water budget uses recent historical conditions. The 2010 water year was selected to represent current conditions because it was the last normal water year before the 2012-2015 drought. It represents the current level of development within the Subbasin and reflects current agricultural irrigation practices, land use patterns, surface water operations, and urban water usage under non-drought conditions.

5.1.3.3. Projected Water Budget

The projected water budget is intended to assess the hydrologic systems of the Subbasin under the projected agricultural and urban demand, water supply, and operational conditions over the next 50-years. The Projected Conditions Baseline scenario applies projected future land and water use conditions to the 50-year hydrologic period of WY 1969-2018. The Projected Condition Baseline assumes urban population and land use expansion based on each municipality's 2015 Urban Water Management Plan. Under projected conditions, agricultural land is held constant at 2015 cropping patters except where urban expansion pulls acreage out of production. Furthermore, under projected conditions, the consumptive use factor (CUF), or the ratio of evapotranspiration per unit of applied water, was increased relative to the historical to simulate modernization of irrigation management and technologies within the Subbasin.

The Projected Conditions Baseline includes the following conditions:

- Hydrologic period:
  - WY 1969-2018 (50-year hydrology)
- River flow is based on:
  - Tuolumne River: Tuolumne River System (TRS) operations model
  - Stanislaus River: Average monthly values by water year type
  - San Joaquin River: CalSim II baseline operations
- Land use is based on:
  - 2015 agricultural land use and cropping patterns held constant
  - Urban land use expansion based on 2015 UWMP
- Agricultural water demand is based on:
  - IWFM estimates based on current land use and refined CUF
- Surface water deliveries are based on data from:
  - Modesto ID – Tuolumne River System (TRS) operations model
  - Oakdale ID – Historical monthly average by water year type
  - Subbasin Riparian Users – Historical monthly average by water year type
- Urban water demand is based on:
  - 2015 Urban Water Management Plans (UWMPs)
  - Continuation of historical population trends, while meeting 2020 State of California GPCD goals.
- Urban water supply is based on:

- Expanded surface water deliveries from MID to the City of Modesto
- Projected urban groundwater production based on 2015 UWMPs distributed to existing wells

Table 5-1: Summary of Groundwater Budget Assumptions

Water Budget Type	Historical	Current	Projected
Tool	C2VSimTM	C2VSimTM	C2VSimTM
Scenario	Historical Simulation	Current Conditions Baseline	Projected Conditions Baseline
Hydrologic Years	WY 1991-2015	WY 2010	WY 1969-2018
Level of Development	Historical Records	WY 2010	General Plan buildout
Agricultural Demand	Historical Records	WY 2010	Projected based on refined 2015 land use and modern irrigation practices
Urban Demand	Historical Records	WY 2010	Projected based on local UWMP data and historical population growth
Water Supplies	Historical Records	WY 2010	Projected based on local operations modeling and historical trends

5.1.4. Water Budget Estimates

The primary components of the stream system, presented at the Subbasin scale, are:

- Inflows:
  - Stream inflows into the Tuolumne River and Stanislaus River at the boundary of the model and San Joaquin River inflows at upstream of the confluence of the Tuolumne and San Joaquin River (bounding the Modesto Subbasin)
  - Tributary inflows from surface water contributions from small watersheds
  - Total stream gain from the groundwater system
  - Surface runoff from precipitation to the stream system
  - Return flow of applied water to the stream system
- Outflows:
  - San Joaquin River flow downstream of the Stanislaus River confluence

- Surface water supplies diverted from the stream system to meet agricultural or urban demand downstream of La Grange Dam.
- Stream seepage to the groundwater system
- Uptake of river water from native or riparian vegetation along the stream bed

The primary components of the land surface system, presented for each water budget zone, include:

- Supplies:
  - Precipitation
  - Surface water supplies
  - Groundwater supplies
  - Uptake of river water from native or riparian vegetation along the stream bed
- Demands:
  - Evapotranspiration
  - Surface runoff of precipitation to the stream system
  - Return flow of applied water to the stream system
  - Percolation of water to the groundwater system
  - Land surface system balance

The primary components of the groundwater system, presented at the Subbasin scale, are:

- Inflows:
  - Percolation of water from the land surface system
  - Groundwater gains from stream system
  - Subsurface inflow from neighboring subbasins and the foothills
- Outflows:
  - Groundwater discharge to the stream system
  - Groundwater production (pumping)
  - Subsurface outflow to neighboring subbasins
  - Change in groundwater in storage - negative values represent a depletion of storage

The estimated water budgets are provided below in **Table 5-2** through **Table 5-8** for the historical, current, and projected water budgets. The land surface water budgets are presented for the entire Subbasin and for each water budget zone (Modesto Irrigation District managed zone (Modesto), Oakdale South, NDE, and Non-District West). Each of these zones represent the geographic area shown in **Figure 5-3** and include all sectors, including agricultural, industrial, municipal, and domestic water users. These zones have been used to develop *Management Areas* (as defined in the GSP regulations) based primarily on the availability of surface water sources. These Management Areas, along with the justification and rationale for each, are presented in **Section 6.2** on Sustainable Management Criteria.

Developing operational water budgets for the land surface system has allowed the GSAs to better quantify how varying anthropogenic processes have affected and will continue to affect the aquifer system. In contrast, the stream and groundwater system budgets are presented at the subbasin scale, to best target the GSA's sustainability goals and metrics.

Figure 5-3: Water Budget Zones

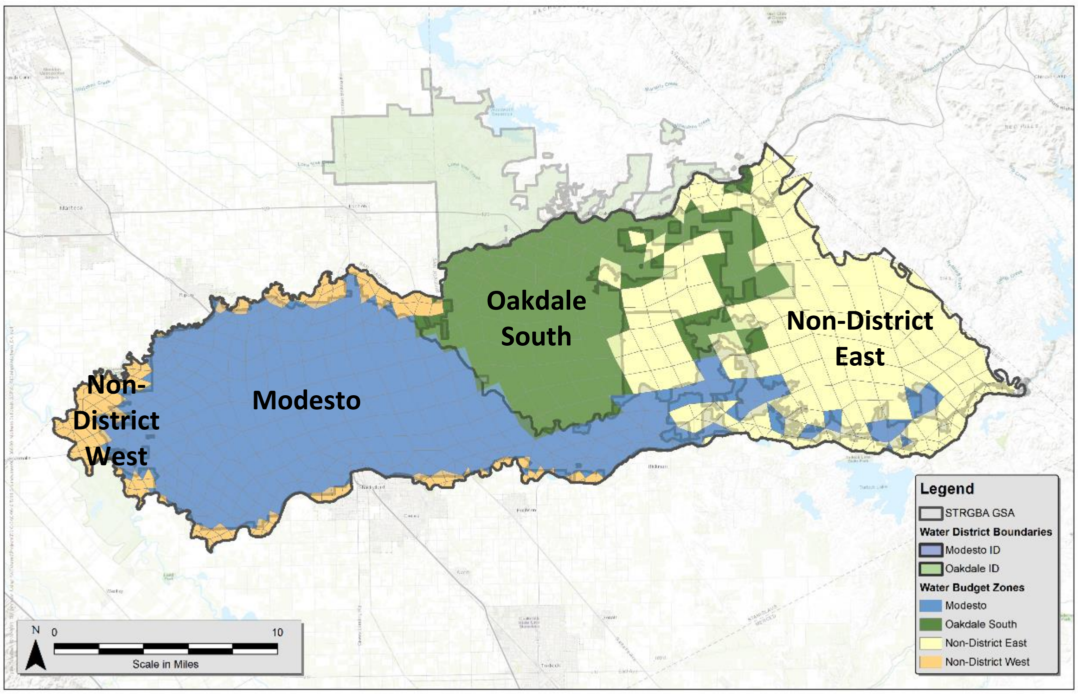


Table 5-2: Average Annual Water Budget – Stream Systems, Modesto Subbasin (AFY)

Component	Historical Condition Water Budget	Current Condition Water Budget	Projected Condition Water Budget
Hydrologic Period	WY 1991- 2015	WY 2010	Hydrology from WY 1969 - 2018
Stream Inflows	2,547,000	1,625,000	2,650,000
Stanislaus River	520,000	320,000	536,000
Tuolumne River	742,000	593,000	812,000
San Joaquin River	1,285,000	711,000	1,302,000
Tributary Inflow[1]	6,000	-	6,000
Stream Gain from Groundwater	207,000	167,000	104,000
Modesto Subbasin	100,000	80,000	50,000
Stanislaus River - South[2]	35,000	27,000	12,000
Tuolumne River - North	51,000	39,000	27,000
San Joaquin River - East	15,000	13,000	11,000
Other Subbasins	108,000	88,000	54,000
Stanislaus River – North	37,000	30,000	12,000
Tuolumne River - South	56,000	44,000	31,000
San Joaquin River - West	15,000	14,000	11,000
Surface Runoff to the Stream System[3]	57,000	35,000	60,000
Return Flow to Stream System[3]	104,000	97,000	113,000
Total Inflow	**2,922,000**	**1,923,000**	**2,934,000**
San Joaquin River Outflows	2,770,000	1,745,000	2,717,000
Diverted Surface Water[4]	43,000	47,000	33,000
Stream Seepage to Groundwater	74,000	95,000	146,000
Modesto Subbasin	40,000	51,000	76,000
Stanislaus River - South	19,000	20,000	36,000
Tuolumne River - North	20,000	30,000	38,000
San Joaquin River - East	1,000	-	2,000
Other Subbasins	34,000	44,000	71,000
Stanislaus River - North	13,000	14,000	31,000
Tuolumne River - South	20,000	30,000	38,000
San Joaquin River - West	1,000	-	2,000
Native & Riparian Uptake from Streams	35,000	37,000	37,000
Total Outflow	**2,922,000**	**1,923,000**	**2,934,000**

Note: sub-categories may not sum together due to rounding error

[1] Tributary inflow includes surface water contributions from small watersheds

[2] Represents the location of the Modesto Subbasin relative to the stream, i.e., "South" represents the gains/losses of that stream to the Modesto Subbasin where as "North" represents the gains/losses of that stream to the Eastern San Joaquin Subbasin.

[3] Includes runoff/return flow from all subbasins adjacent to the stream system, not just the Modesto Subbasin.

[4] Some surface water diversions are upstream of the Tuolumne River or Stanislaus River inflows and thus not included in this stream system (streams and canals) water budget.

Table 5-3: Average Annual Water Budget – Land Surface System, Modesto Subbasin (AFY)

Component	Historical Condition Water Budget	Current Condition Water Budget	Projected Condition Water Budget
Hydrologic Period	WY 1991- 2015	WY 2010	Hydrology from WY 1969 - 2018
Agricultural Areas Precipitation	147,000	122,000	139,000
Agricultural Water Supply	513,000	611,000	497,000
Agency Surface Water	264,000	250,000	241,000
Agency Groundwater	26,000	15,000	25,000
Private Groundwater	222,000	345,000	229,000
Urban Areas Precipitation	32,000	26,000	38,000
Urban Water Supply	89,000	88,000	111,000
Groundwater	63,000	56,000	60,000
Surface Water	26,000	32,000	51,000
Native Areas Precipitation	92,000	78,000	92,000
Native Uptake from Stream	20,000	20,000	22,000
Total Supplies	**892,000**	**945,000**	**900,000**
Agricultural ET	368,000	416,000	402,000
Agricultural ET of Precipitation	80,000	73,000	82,000
Agricultural ET of Surface Water	149,000	143,000	159,000
Agricultural ET of Agency Groundwater	14,000	8,000	16,000
Agricultural ET of Private Groundwater	125,000	192,000	146,000
Agricultural Percolation	246,000	236,000	201,000
Agricultural Percolation of Precipitation	57,000	39,000	45,000
Agricultural Percolation of Surface Water	99,000	83,000	75,000
Agricultural Percolation of Agency Groundwater	10,000	5,000	8,000
Agricultural Percolation of Private Groundwater	81,000	110,000	73,000
Agricultural Runoff & Return Flow	35,000	31,000	31,000
Urban Runoff & Return Flow	74,000	68,000	91,000
Urban ET	28,000	27,000	38,000
Urban Percolation	18,000	17,000	20,000
Native Runoff	12,000	5,000	12,000
Native ET	91,000	88,000	95,000
Native Percolation	8,000	3,000	7,000
Total Demands	**879,000**	**892,000**	**898,000**
Land Surface System Balance	13,000	53,000	2,000
Land Surface System Balance (% of supplies)	1.5%	5.6%	0.2%

Note: sub-categories may not sum together due to rounding error

Table 5-4: Average Annual Water Budget – Land Surface System, Modesto Area (AFY)

Component	Historical Condition Water Budget	Current Condition Water Budget	Projected Condition Water Budget
Hydrologic Period	WY 1991- 2015	WY 2010	Hydrology from WY 1969 - 2018
Agricultural Areas Precipitation	73,000	58,000	65,000
Agricultural Water Supply	281,000	315,000	244,000
Agency Surface Water	125,000	121,000	106,000
Agency Groundwater	22,000	11,000	21,000
Private Groundwater	135,000	183,000	117,000
Urban Areas Precipitation	26,000	21,000	32,000
Urban Water Supply	73,000	72,000	96,000
Groundwater	47,000	40,000	45,000
Surface Water	26,000	32,000	51,000
Native Areas Precipitation	11,000	9,000	11,000
Native Uptake from Stream	5,000	5,000	5,000
Total Supplies	**468,000**	**481,000**	**453,000**
Agricultural ET	193,000	210,000	195,000
Agricultural ET of Precipitation	38,000	34,000	38,000
Agricultural ET of Surface Water	69,000	68,000	68,000
Agricultural ET of Agency Groundwater	12,000	6,000	14,000
Agricultural ET of Private Groundwater	74,000	103,000	75,000
Agricultural Percolation	136,000	137,000	97,000
Agricultural Percolation of Precipitation	29,000	21,000	21,000
Agricultural Percolation of Surface Water	48,000	44,000	33,000
Agricultural Percolation of Agency Groundwater	8,000	4,000	6,000
Agricultural Percolation of Private Groundwater	51,000	67,000	36,000
Agricultural Runoff & Return Flow	20,000	18,000	16,000
Urban Runoff & Return Flow	61,000	56,000	78,000
Urban ET	22,000	21,000	31,000
Urban Percolation	16,000	16,000	19,000
Native Runoff	1,000	-	1,000
Native ET	14,000	13,000	14,000
Native Percolation	1,000	1,000	1,000
Total Demands	**463,000**	**471,000**	**453,000**
Land Surface System Balance	6,000	10,000	1,000
Land Surface System Balance (% of supplies)	1.2%	2.1%	0.1%

Note: sub-categories may not sum together due to rounding error

Table 5-5: Average Annual Water Budget – Land Surface System, Oakdale South Area (AFY)

Component	Historical Condition Water Budget	Current Condition Water Budget	Projected Condition Water Budget
Hydrologic Period	WY 1991- 2015	WY 2010	Hydrology from WY 1969 - 2018
Agricultural Areas Precipitation	46,000	40,000	45,000
Agricultural Water Supply	150,000	174,000	143,000
Agency Surface Water	120,000	109,000	121,000
Agency Groundwater	4,000	4,000	4,000
Private Groundwater	26,000	61,000	18,000
Urban Areas Precipitation	4,000	3,000	4,000
Urban Water Supply	11,000	12,000	9,000
Groundwater	11,000	12,000	9,000
Surface Water	-	-	-
Native Areas Precipitation	13,000	10,000	13,000
Native Uptake from Stream	2,000	2,000	2,000
Total Supplies	**225,000**	**241,000**	**217,000**
Agricultural ET	112,000	125,000	124,000
Agricultural ET of Precipitation	25,000	24,000	27,000
Agricultural ET of Surface Water	69,000	63,000	81,000
Agricultural ET of Agency Groundwater	2,000	2,000	3,000
Agricultural ET of Private Groundwater	15,000	36,000	12,000
Agricultural Percolation	72,000	59,000	57,000
Agricultural Percolation of Precipitation	17,000	11,000	14,000
Agricultural Percolation of Surface Water	45,000	30,000	37,000
Agricultural Percolation of Agency Groundwater	1,000	1,000	1,000
Agricultural Percolation of Private Groundwater	9,000	17,000	5,000
Agricultural Runoff & Return Flow	8,000	6,000	7,000
Urban Runoff & Return Flow	9,000	9,000	8,000
Urban ET	4,000	4,000	5,000
Urban Percolation	2,000	1,000	1,000
Native Runoff	2,000	1,000	2,000
Native ET	12,000	11,000	12,000
Native Percolation	1,000	1,000	1,000
Total Demands	**221,000**	**217,000**	**217,000**
Land Surface System Balance	4,000	24,000	-
Land Surface System Balance (% of supplies)	1.7%	9.8%	0.0%

Note: sub-categories may not sum together due to rounding error

Table 5-6: Average Annual Water Budget – Land Surface System, Non-District East (AFY)

Component	Historical Condition Water Budget	Current Condition Water Budget	Projected Condition Water Budget
Hydrologic Period	WY 1991- 2015	WY 2010	Hydrology from WY 1969 - 2018
Agricultural Areas Precipitation	19,000	16,000	19,000
Agricultural Water Supply	48,000	84,000	81,000
Agency Surface Water	-	-	-
Agency Groundwater	-	-	-
Private Groundwater	48,000	84,000	81,000
Urban Areas Precipitation	-	-	-
Urban Water Supply	-	-	-
Groundwater	-	-	-
Surface Water	-	-	-
Native Areas Precipitation	65,000	57,000	65,000
Native Uptake from Stream	6,000	6,000	7,000
Total Supplies	**137,000**	**163,000**	**173,000**
Agricultural ET	37,000	54,000	60,000
Agricultural ET of Precipitation	11,000	11,000	10,000
Agricultural ET of Surface Water	-	-	-
Agricultural ET of Agency Groundwater	-	-	-
Agricultural ET of Private Groundwater	26,000	43,000	50,000
Agricultural Percolation	22,000	23,000	34,000
Agricultural Percolation of Precipitation	7,000	4,000	7,000
Agricultural Percolation of Surface Water	-	-	-
Agricultural Percolation of Agency Groundwater	-	-	-
Agricultural Percolation of Private Groundwater	16,000	19,000	27,000
Agricultural Runoff & Return Flow	5,000	5,000	6,000
Urban Runoff & Return Flow	-	-	-
Urban ET	-	-	-
Urban Percolation	-	-	-
Native Runoff	9,000	4,000	9,000
Native ET	56,000	54,000	58,000
Native Percolation	5,000	2,000	5,000
Total Demands	**134,000**	**142,000**	**171,000**
Land Surface System Balance	4,000	21,000	1,000
Land Surface System Balance (% of supplies)	2.6%	13.1%	0.8%

Note: sub-categories may not sum together due to rounding error

Table 5-7: Average Annual Water Budget – Land Surface System, Non-District West (AFY)

Component	Historical Condition Water Budget	Current Condition Water Budget	Projected Condition Water Budget
Hydrologic Period	WY 1991- 2015	WY 2010	Hydrology from WY 1969 - 2018
Agricultural Areas Precipitation	10,000	8,000	10,000
Agricultural Water Supply	35,000	38,000	29,000
Agency Surface Water	19,000	20,000	15,000
Agency Groundwater	-	-	-
Private Groundwater	15,000	17,000	14,000
Urban Areas Precipitation	2,000	2,000	2,000
Urban Water Supply	5,000	4,000	6,000
Groundwater	5,000	4,000	6,000
Surface Water	-	-	-
Native Areas Precipitation	3,000	2,000	3,000
Native Uptake from Stream	7,000	7,000	8,000
Total Supplies	**61,000**	**61,000**	**57,000**
Agricultural ET	26,000	27,000	24,000
Agricultural ET of Precipitation	6,000	5,000	6,000
Agricultural ET of Surface Water	11,000	12,000	9,000
Agricultural ET of Agency Groundwater	-	-	-
Agricultural ET of Private Groundwater	9,000	10,000	9,000
Agricultural Percolation	16,000	18,000	13,000
Agricultural Percolation of Precipitation	4,000	3,000	3,000
Agricultural Percolation of Surface Water	7,000	8,000	5,000
Agricultural Percolation of Agency Groundwater	-	-	-
Agricultural Percolation of Private Groundwater	5,000	7,000	4,000
Agricultural Runoff & Return Flow	3,000	2,000	2,000
Urban Runoff & Return Flow	4,000	3,000	5,000
Urban ET	2,000	2,000	3,000
Urban Percolation	-	-	-
Native Runoff	-	-	-
Native ET	10,000	10,000	11,000
Native Percolation	-	-	-
Total Demands	**61,000**	**62,000**	**57,000**
Land Surface System Balance	-	(2,000)	-
Land Surface System Balance (% of supplies)	0.7%	-2.5%	-0.2%

Note: sub-categories may not sum together due to rounding error

Table 5-8: Average Annual Water Budget – Groundwater System, Modesto Subbasin (AFY)

Component	Historical Condition Water Budget	Current Condition Water Budget	Projected Condition Water Budget
Hydrologic Period	WY 1991- 2015	WY 2010	Hydrology from WY 1969 - 2018
Gain from Stream	40,000	51,000	76,000
Gain from Stanislaus River	19,000	20,000	36,000
Gain from Tuolumne River	20,000	30,000	38,000
Gain from San Joaquin River	1,000	-	2,000
Canal & Reservoir Recharge	49,000	47,000	47,000
Deep Percolation	272,000	257,000	228,000
Subsurface Inflow	80,000	79,000	77,000
Flow from the Sierra Nevada Foothills	9,000	5,000	9,000
Eastern San Joaquin Subbasin Inflows	8,000	9,000	28,000
Turlock Subbasin Inflows	30,000	34,000	33,000
Delta Mendota Subbasin Inflows	33,000	31,000	7,000
Total Inflow	**440,000**	**434,000**	**428,000**
Discharge to Stream	100,000	80,000	50,000
Discharge to Stanislaus River	35,000	27,000	12,000
Discharge to Tuolumne River	51,000	39,000	27,000
Discharge to San Joaquin River	15,000	13,000	11,000
Subsurface Outflow	73,000	63,000	75,000
Eastern San Joaquin Subbasin Outflows	6,000	5,000	35,000
Turlock Subbasin Outflows	32,000	24,000	34,000
Delta Mendota Subbasin Outflows	36,000	35,000	6,000
Groundwater Production	311,000	416,000	314,000
Agency Ag. Groundwater Production	26,000	15,000	25,000
Private Ag. Groundwater Production	222,000	345,000	229,000
Urban Groundwater Production	63,000	56,000	60,000
Total Outflow	**483,000**	**559,000**	**438,000**
Change in Groundwater in Storage	(43,000)	(125,000)	(11,000)

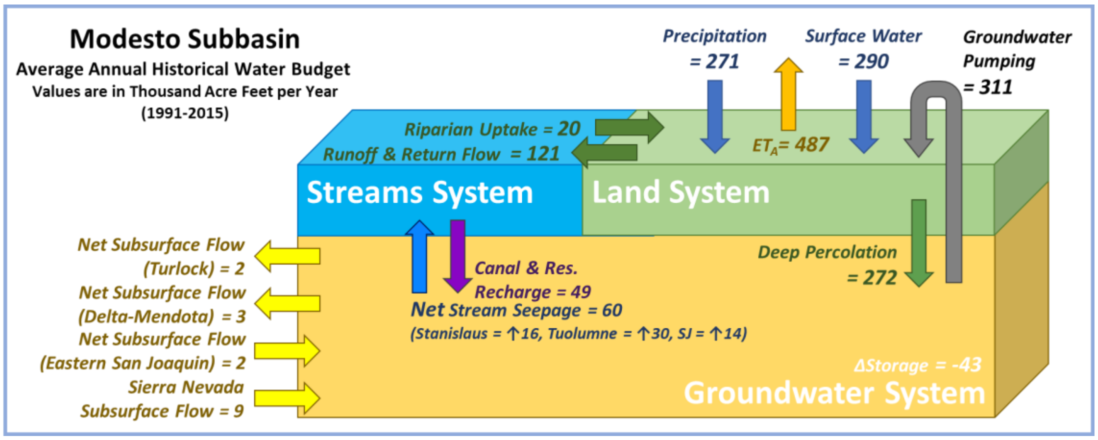
Note: sub-categories may not sum together due to rounding error

5.1.4.1. Historical Water Budget

The historical water budget is a quantitative evaluation of the historical surface and groundwater supply covering the 25-year period from WY 1991 to 2015. This period was selected as the representative hydrologic period as it reflects the most recent basin operations and has similar average precipitation compared to a longer historical period (WY 1969-2018). The goal of the water budget analysis is to characterize the water supply and demand, while summarizing the accounting of water demand and supply components and their changes within each area, and the Subbasin as a whole.

Figure 5-4 below shows the average annual water budget components for the entirety of the Modesto Subbasin and the interaction between the land surface, stream, and groundwater systems for the historical simulation.

Figure 5-4: Average Annual Historical Water Budget – Modesto Subbasin

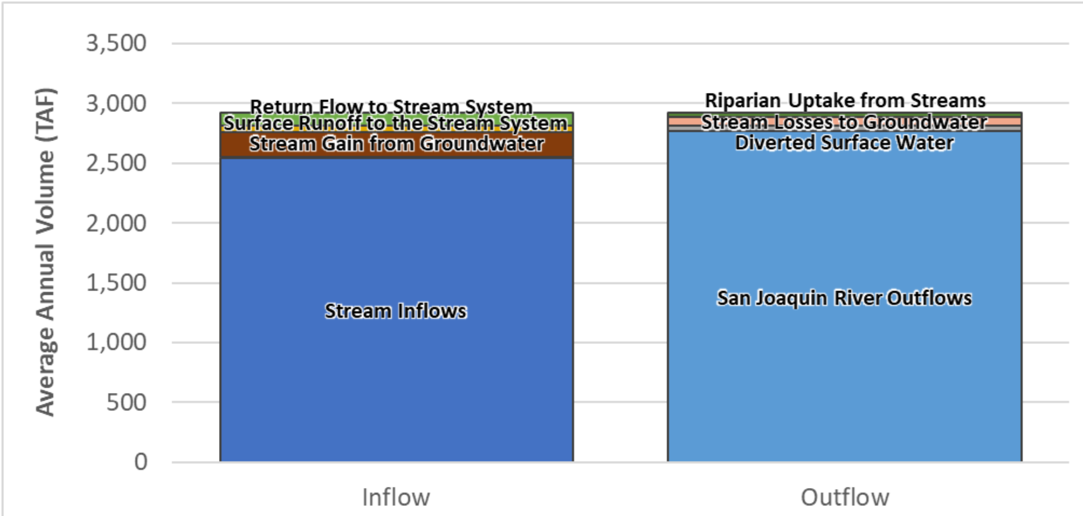


Note: sub-categories may not sum together due to rounding error

The existing stream system supplies multiple water users and agencies in the Modesto Subbasin, including Modesto ID, Oakdale ID, and riparian diverter along each of the major rivers. Analysis of the stream system accounts for potentially significant effects related to both natural interactions and managed operations of adjacent subbasins. Therefore, the water budget in **Table 5-2** above and **Figure 5-5**, shown below, provides average annual quantities of surface and canal system flows within the Modesto Subbasin, plus estimates of interactions with adjoining subbasins. Average annual surface water inflow to the streams adjacent to the Subbasin is estimated to be 2,921,000 AFY. Most of these flows enter the stream system through inflows from regulated reservoirs and river courses, with an average of 742,000 AFY from the Tuolumne, 520,000 AFY from the Stanislaus, and 1,285,000 AFY from the San Joaquin Rivers, respectively. Other stream system inflows include inflow from tributary watersheds (6,000 AFY), surface runoff from precipitation (57,000 AFY), return flow from applied water (104,000 AFY), and gain from groundwater (207,000 AFY).

Outflows from the Modesto Subbasin stream system total 2,922,000 AFY and include stream losses to the groundwater system (74,000 AFY), surface water diversions (43,000 AFY), and riparian uptake (35,000 AFY). Most outflows from the stream system are San Joaquin River flows, which discharge from the Modesto Subbasin downstream of its confluence with the Stanislaus River at an average of 2,770,000 AFY. Note that surface water diversions for Oakdale and Modesto Irrigation Districts occur from reservoirs upstream of the Subbasin boundaries and are not included in the stream-system budget.

Figure 5-5: Historical Average Annual Water Budget – Stream Systems, Modesto Subbasin



The land surface system of the Modesto Subbasin, shown in **Table 5-3** and in **Figure 5-6**, represents the demand and supplies in the Modesto Subbasin and in each zone. During the historical period, total average annual water supplies to the Modesto Subbasin is estimated at 892,000 AFY, consisting of precipitation (271,000 AFY), surface water deliveries (290,000 AFY), and groundwater supplies (312,000 AFY), as well as water uptake by riparian vegetation along the river courses (20,000 AFY). Surface water supplies are provided primarily through Modesto ID's and Oakdale ID's canal networks to growers in the districts, with some riparian surface water diversions in the Non-District West. Each of these areas supplement their surface water with some groundwater production to meet their agricultural and urban demand, whereas the NDE areas rely primarily on groundwater production for its agricultural supplies.

Average annual water demand in the Modesto Subbasin totals 879,000 AFY, and is comprised of agricultural crops, urban landscaping, and native evapotranspiration (487,000 AFY), surface runoff and return flow to the stream system (121,000 AFY), and deep percolation (272,000 AFY). **Figure 5-7** shows the annual volumes of major agricultural water demand and supply components throughout the historical water budget period. The surface water supply in this water budget is reflective of the applied water thus does not include operational return flow or canal seepage.

Figure 5-8 shows the annual supply and demand for municipal and private domestic water use in the Modesto Subbasin.

Figure 5-6: Historical Average Annual Water Budget – Land Surface System, Modesto Subbasin

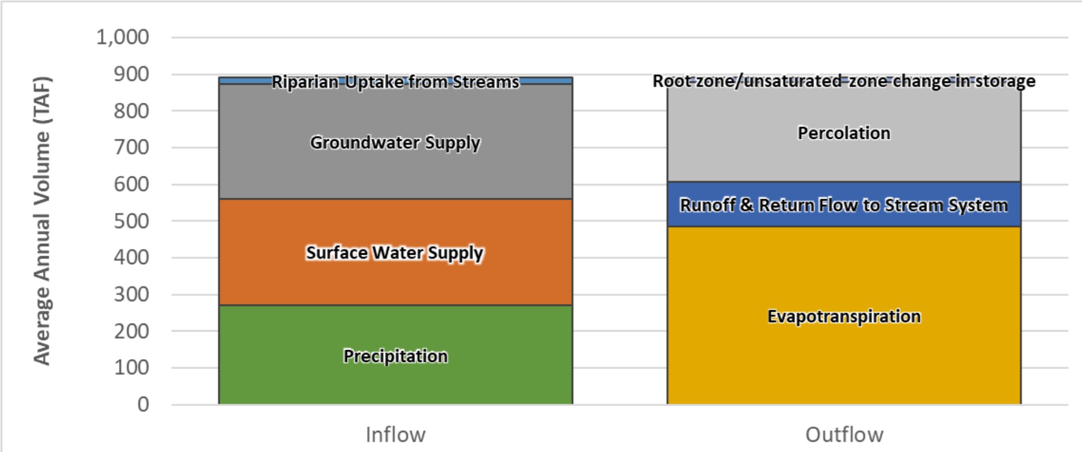


Figure 5-7: Historical Annual Water Budget – Agricultural Land Surface System, Modesto Subbasin

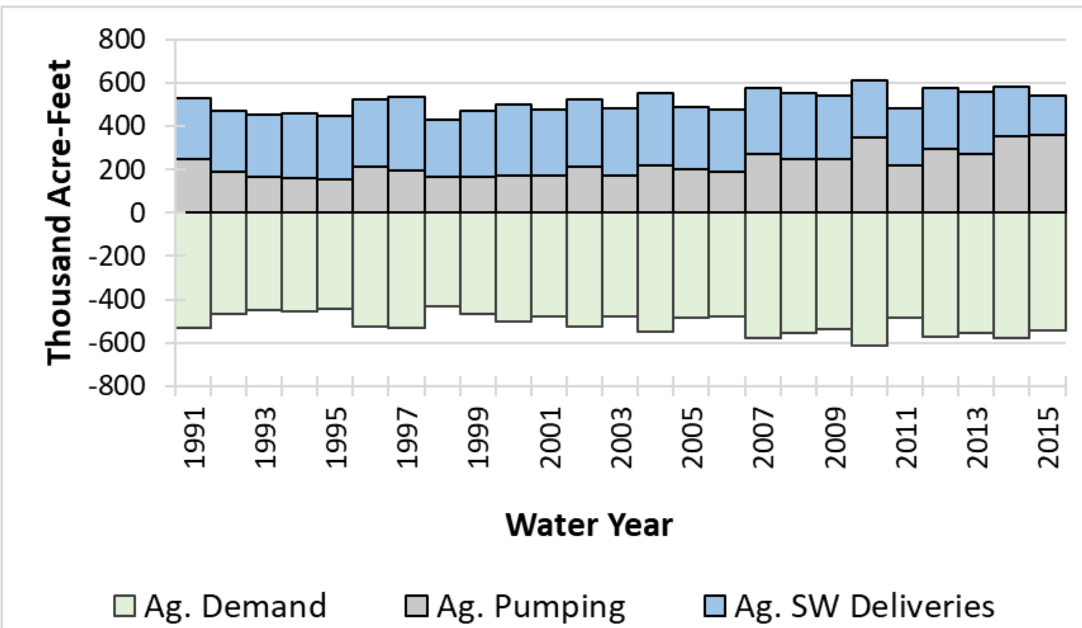


Figure 5-8: Historical Annual Water Budget – Urban Land Surface System, Modesto Subbasin

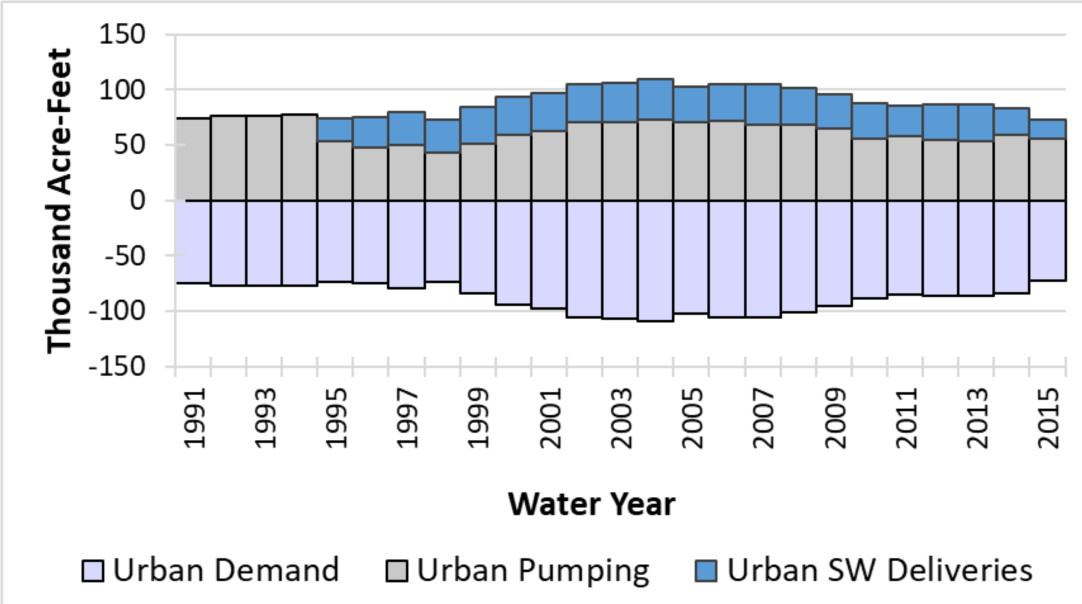


Table 5-8 highlights the major flow components of the Modesto Subbasin's groundwater system. As shown in this table, the aquifer receives approximately 440,000 AFY of inflows each year, which consist of recharge from streams (40,000 AFY), seepage from canals and reservoirs (49,000 AFY), deep percolation from precipitation and applied water (272,000 AFY), as well as subsurface inflows from the Sierra Nevada foothills and the neighboring subbasins of Eastern San Joaquin, Delta-Mendota, and Turlock (80,000 AFY combined).

Table 5-8 also shows the outflows from the Modesto Subbasin. On average, the outflows exceed the inflows in the Subbasin. The largest component of outflow from the groundwater system is groundwater pumping (311,000 AFY), followed by discharge to streams (100,000 AFY), and subsurface outflow to the neighboring subbasins (73,000 AFY).

In conjunction with the land surface budgets presented for each water budget area, a net-recharge analysis was preformed to better understand the relationship of water supply conditions and recharge to the groundwater system. This analysis is documented below, both at the Subbasin level and for each water budget area.

Figure 5-9 shows the total annual groundwater pumped from, and the subsequent recharge to the Modesto Subbasin. In this figure, groundwater pumping represents the combination of groundwater extracted for both agricultural and urban use for each year during the historical period. Recharge into the aquifer system includes both deep percolation from the land system and direct recharge from the canal and reservoir system. The deep percolation in this figure includes recharge from percolated precipitation, agricultural applied water, outdoor irrigation from municipal and rural domestic users.

Figure 5-10 shows the net-recharge in the Modesto Subbasin and is based on the annual balance from the previous figure. This figure indicates that during the historical period, the Subbasin has trended increasingly toward net extraction, but has on average experienced net recharge. This is both indicative of local hydrology and increasing demand on the aquifer system. Over the 25-year historical period, the Modesto Subbasin has seen a large increase in both urban demand and agricultural production. Over time, increases in groundwater production has further stressed the subbasin leading to more consistently negative values, or net extractions. Furthermore, through the 2012-2015 drought, the subbasin experienced a greater net-extraction from the aquifer system corresponding to reduced surface water supply, whereas in periods of wetter or normal operations, the Subbasin has historically been a net-contributor to the groundwater system.

Figure 5-11 through **Figure 5-18** show similar trends conditions for each water budget area. The Oakdale South water budget zone (**Figure 5-14**) has predominately experienced net recharge, while the NDE zone has predominately experienced net extraction (**Figure 5-16**). The Modesto water budget zone and the Non-District West zone experience more variable conditions trending in near-balance (**Figure 5-12** and **Figure 5-18**, respectively). Over the historical period, all zones have trended increasingly toward net extraction due to increased water demand from all sectors and drought conditions at the end of the period.

Overall, the Modesto Subbasin's groundwater system has experienced long term (25-year) decline in storage averaging 43,000 AFY as shown in **Figure 5-19**. This decline is more heavily weighted to the end of the study period due to increased stresses relating to both local hydrology, and water demand as shown in **Figure 20**. **Figure 20** also shows the temporal breakdown of the groundwater budget and highlights the intensifying decline of groundwater in storage in recent years, particularly under drought conditions where groundwater production has increased to a long-term high.

The historical inflows and outflows to the Modesto Subbasin change with hydrologic conditions. In wet years, precipitation and increased surface water availability reduces the need for groundwater use. However, in dry years, more groundwater is pumped to meet the demand not met by surface water or precipitation. This leads to an increase in groundwater in storage in wet years and a decrease in dry years. These trends are shown in **Table 5-9**, which provides average historical water supply and demand by water year type.

Figure 5-9: Groundwater Recharge and Extraction – Modesto Subbasin

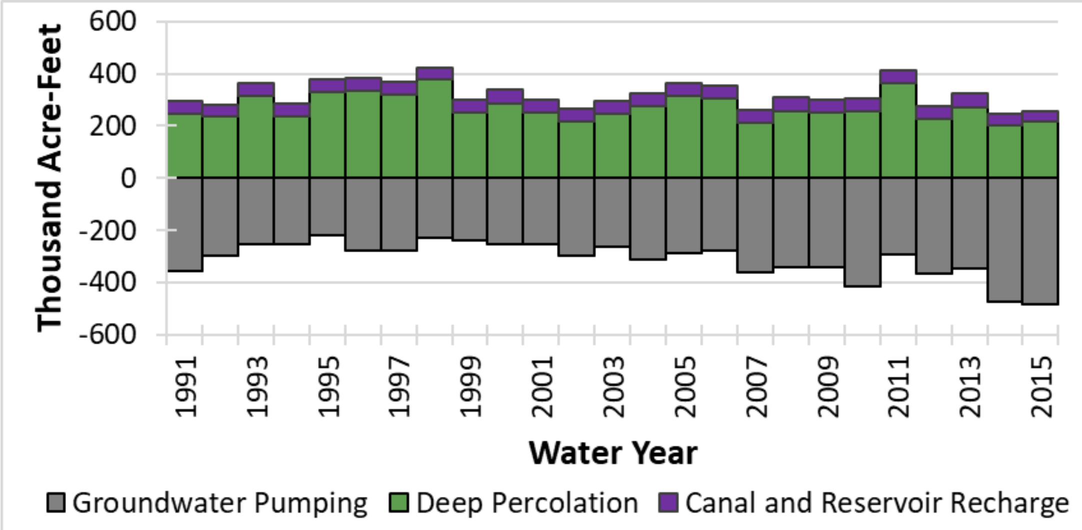


Figure 5-10: Net Recharge – Modesto Subbasin

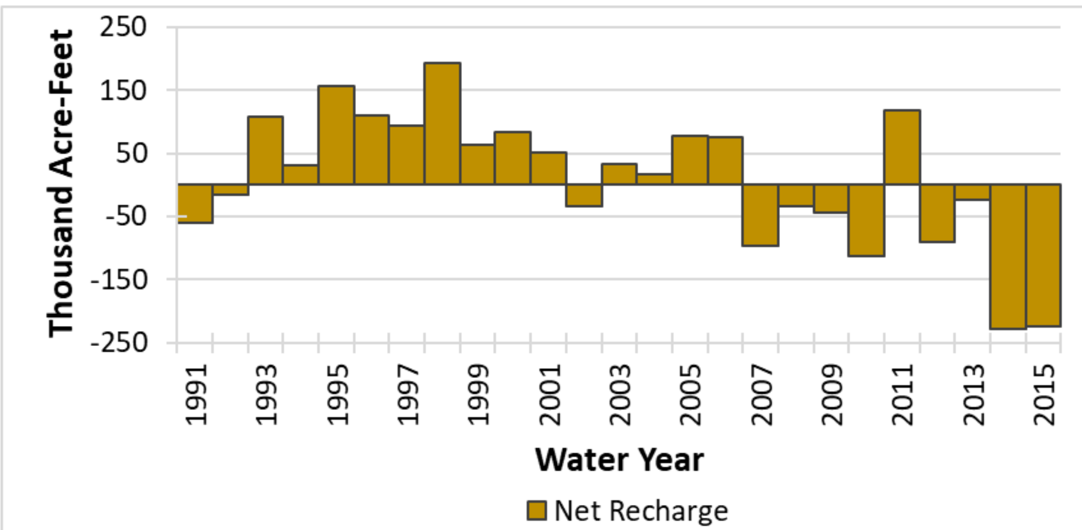


Figure 5-11: Groundwater Recharge and Extraction – Modesto Zone

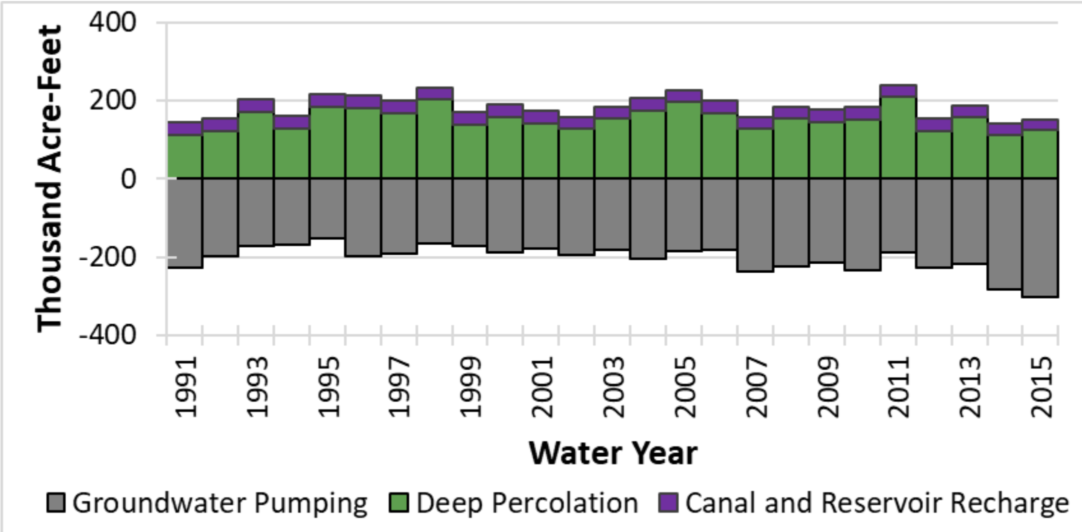


Figure 5-12: Net Recharge – Modesto Zone

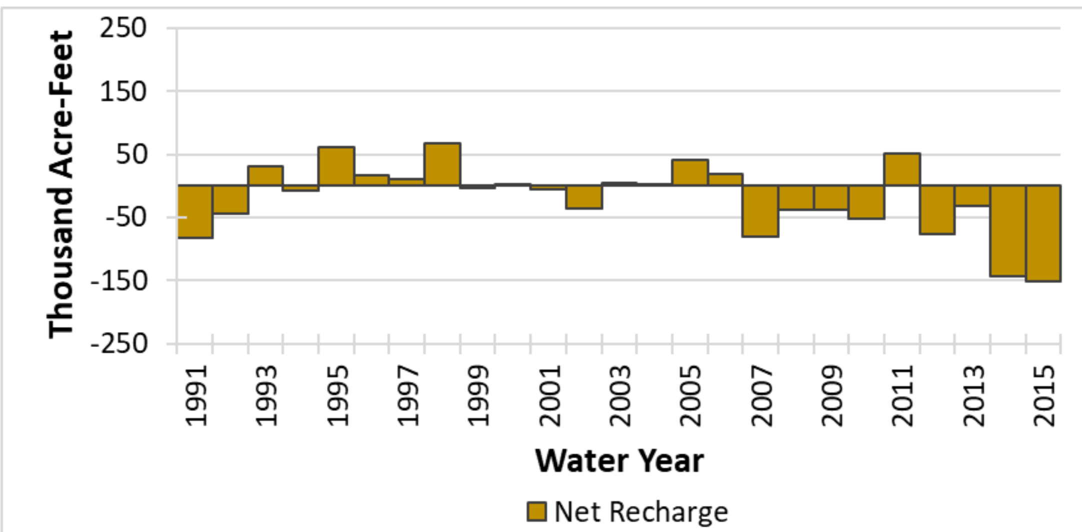


Figure 5-13: Groundwater Recharge and Extraction – Oakdale South Zone

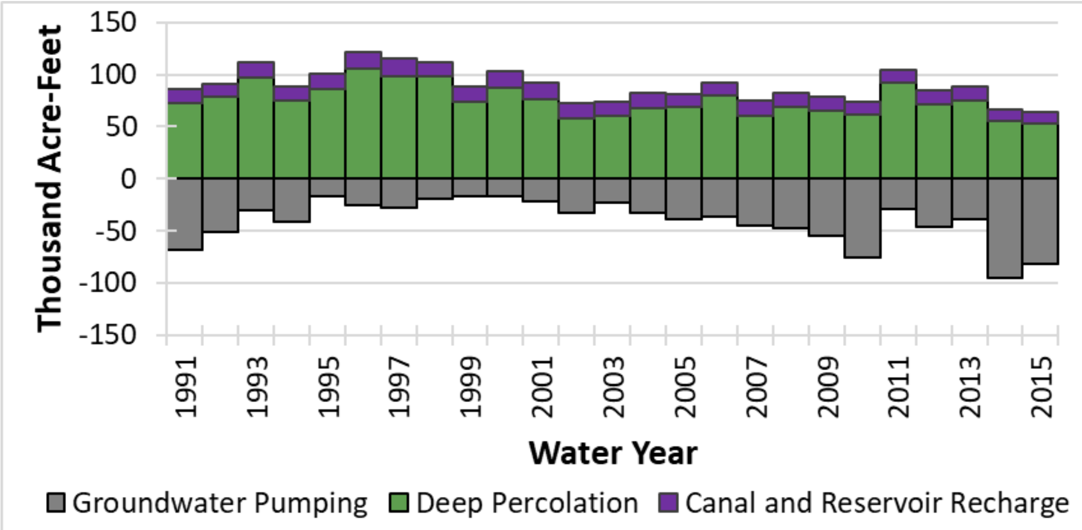


Figure 5-14: Net Recharge – Oakdale South Zone

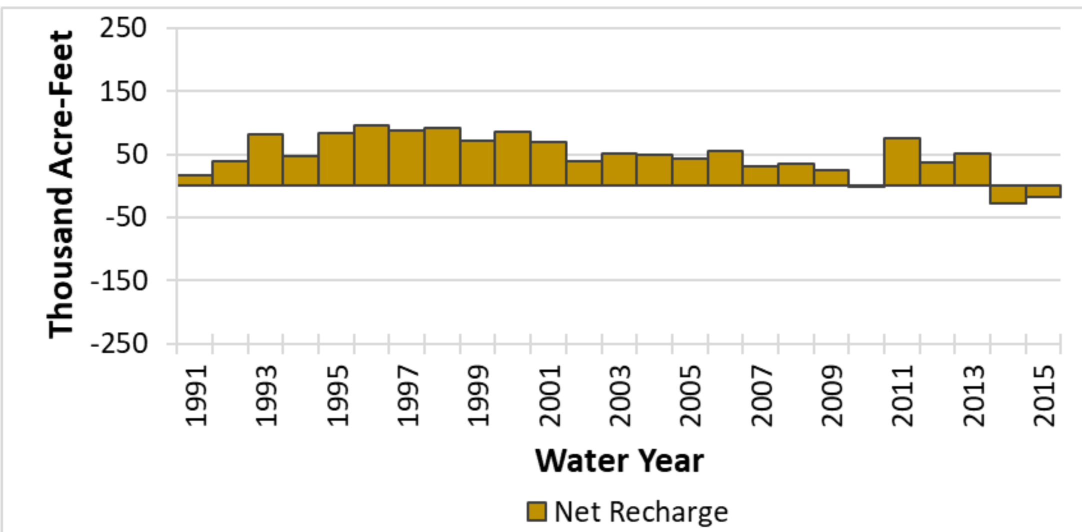


Figure 5-15: Groundwater Recharge and Extraction – Non-District East Zone

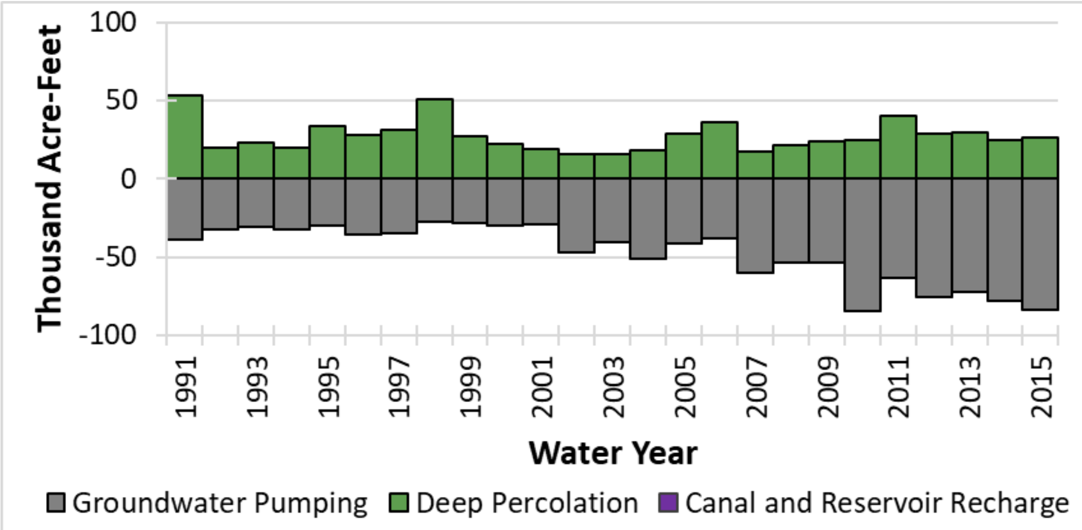


Figure 5-16: Net Recharge – Non-District East Zone

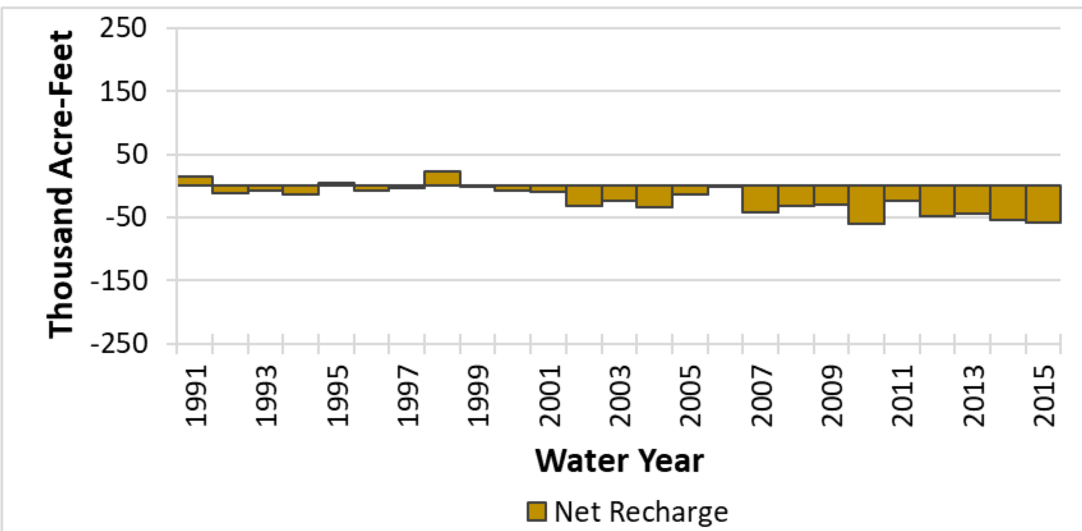


Figure 5-17: Groundwater Recharge and Extraction – Non-District West Area

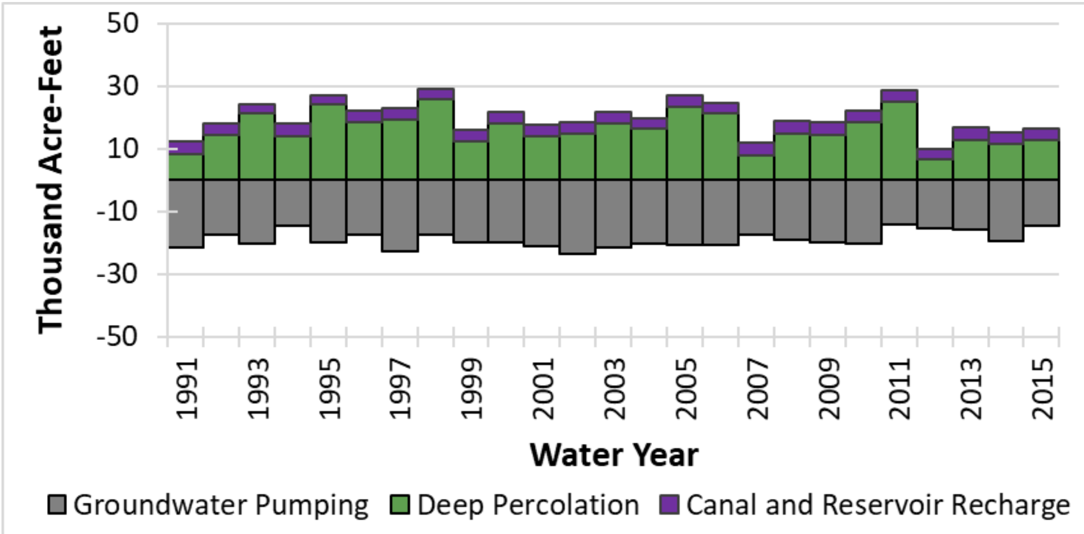


Figure 5-18: Net Recharge – Non-District West Area

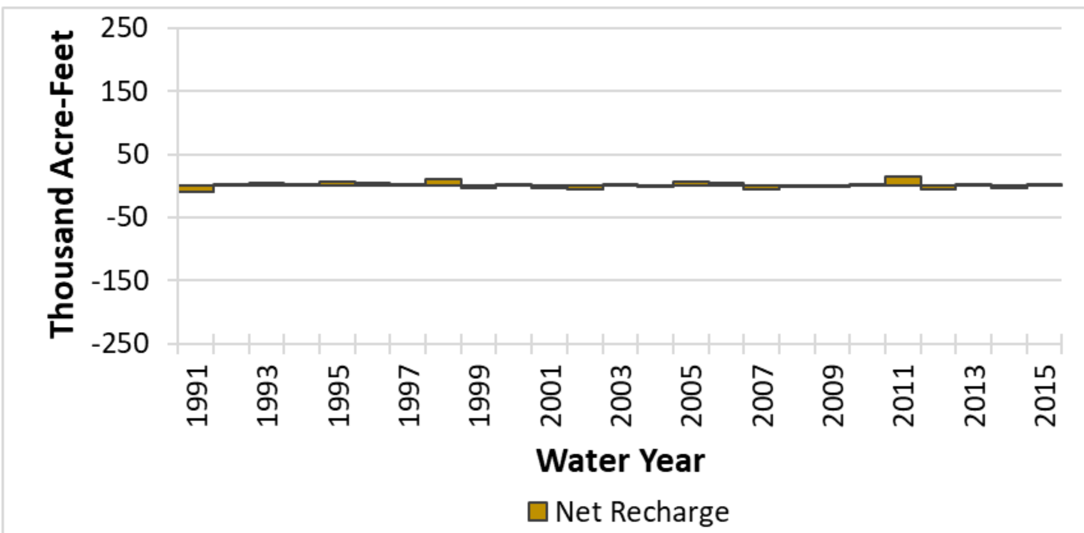


Figure 5-19: Historical Average Annual Water Budget – Groundwater System, Modesto Subbasin

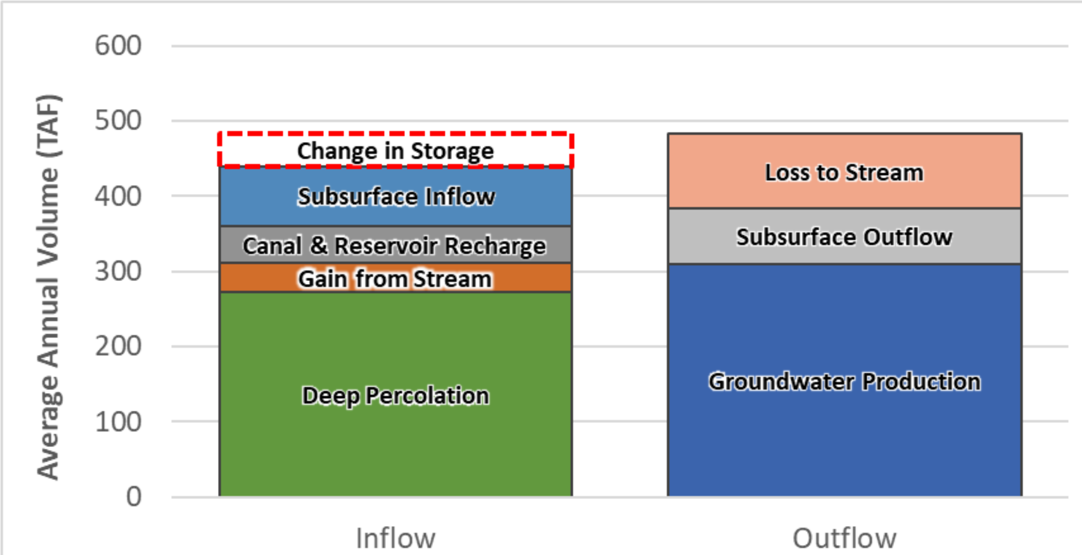
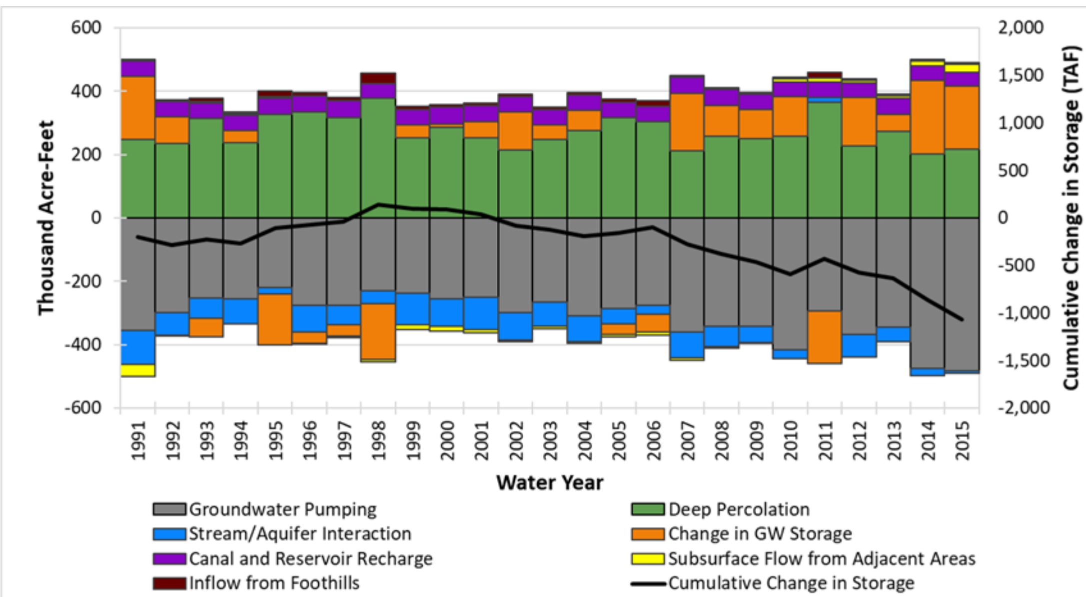


Figure 5-20: Historical Annual Water Budget – Groundwater System, Modesto Subbasin



*On **Figure 20**, positive numbers indicate inflows into the Subbasin aquifer, while negative numbers indicate outflows from the Subbasin aquifer.*

Table 5-9: Water Supply and Demand Budget by Year Type (AFY)

Component	Water Year Type (San Joaquin River Index)					
	Wet	Above Normal	Below Normal	Dry	Critical	Average
Agricultural Demand	479,000	526,000	511,000	532,000	533,000	516,000
Urban Demand	84,000	89,000	101,000	100,000	85,000	92,000
Total Water Demand	563,000	615,000	612,000	632,000	618,000	608,000
Total Surface Water Supply	317,000	332,000	335,000	342,000	289,000	323,000
Agricultural	292,000	299,000	302,000	308,000	271,000	294,000
Urban	25,000	33,000	33,000	34,000	18,000	29,000
Total Groundwater Supply	246,000	283,000	277,000	290,000	329,000	285,000
Agricultural	187,000	227,000	209,000	225,000	262,000	222,000
Urban	59,000	56,000	68,000	65,000	67,000	63,000
Total Water Supply	563,000	615,000	612,000	632,000	618,000	608,000
Change in GW Storage	90,000	-59,000	-69,000	-96,000	-136,000	-43,000

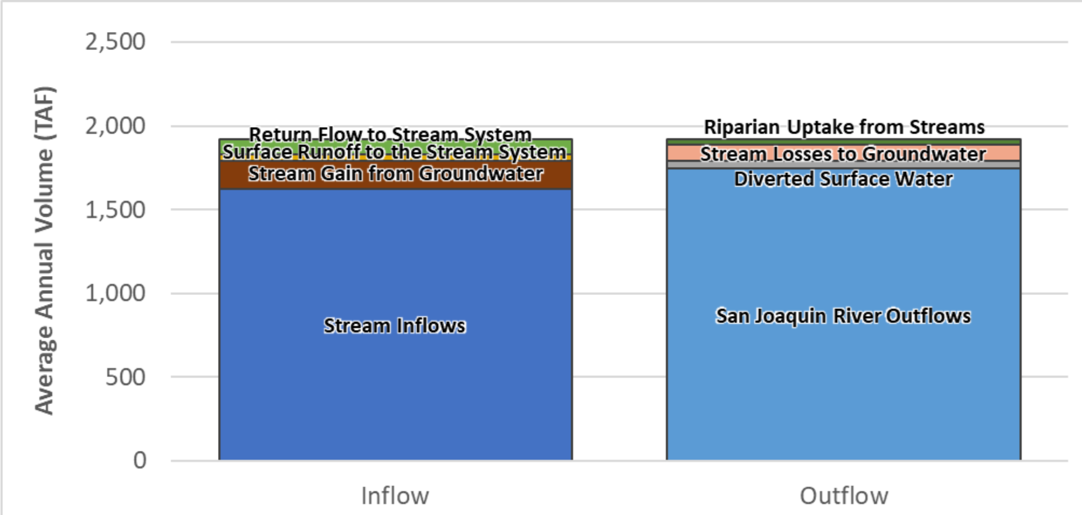
Notes: sub-categories may not sum together due to rounding error
All values in Table 5-9 are from WYs 1991-2015

5.1.4.2. Current Water Budget

The current water budget quantifies inflows to and outflows from the basin under existing conditions. The 2010 water year was selected to represent current conditions because it reflects an average, non-drought water supply with existing land use and water demand.

Table 5-2 and **Figure 5-21** summarize the average annual inflows and outflows of the Current Conditions Baseline in the Modesto Subbasin stream system. Under current conditions, inflows to the stream system total 1,923,000 AFY with 1,625,000 AFY coming directly as inflow to the Stanislaus, Tuolumne, and San Joaquin Rivers, 35,000 AFY is the result of surface runoff from precipitation, 97,000 AFY of return flow from applied water, and 167,000 AFY of groundwater contributions. In contrast to stream inflow, stream system outflows under current conditions include an average of 47,000 AFY of surface water diversions for agricultural use, 95,000 AFY of discharge to the groundwater system, 37,000 AFY of direct uptake by riparian vegetation, and 1,745,000 AFY of downstream outflows in the San Joaquin River.

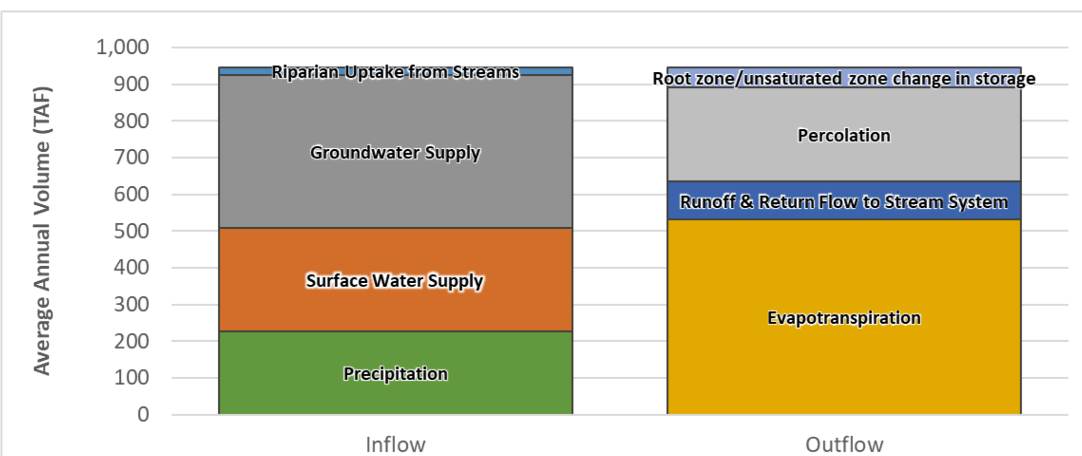
Figure 5-21: Current Conditions Annual Water Budget – Stream Systems, Modesto Subbasin



The land surface system water supply under Current Conditions, shown in **Table 5-3** and in **Figure 5-22**, is estimated using 2010 cropping patterns as the Subbasin experienced significant changes due to the 2012-2015 drought. Under the current Conditions Baseline the average annual water supply is estimated to be 945,000 AFY, including 226,000 AFY of precipitation, 699,000 AFY of surface and groundwater supply for irrigation and urban use (282,000 AFY of surface water and 417,000 AFY of groundwater), and 20,000 AFY of riparian uptake from the stream system.

The total water demand is estimated to be 892,000 AFY, which includes evapotranspiration (531,000 AFY), surface runoff and return flow to the stream system (105,000 AFY), and deep percolation (257,000 AFY). **Figure 5-22** summarizes the average annual current condition supplies and demands in the land surface budget for the Modesto Subbasin.

Figure 5-22: Current Conditions Average Annual Water Budget – Land Surface System, Modesto Subbasin

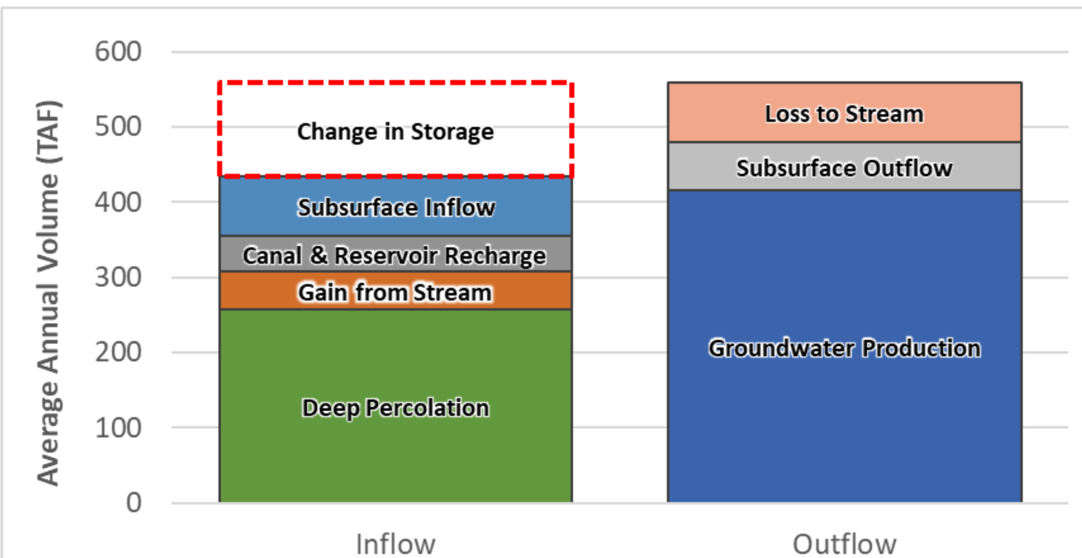


The groundwater system budget for current conditions baseline indicates an average annual inflow of 434,000 AFY, including 257,000 AFY of deep percolation, 47,000 AFY of canal and reservoir seepage, 51,000 AFY from stream seepage, and total subsurface inflows of 79,000 AFY.

Analysis of the groundwater system budget indicates that the system's average annual outflows exceed its inflows under current conditions, resulting in a net reduction in groundwater in storage. As under historical conditions, groundwater production (416,000 AFY) remains the largest component of groundwater discharge, with subsurface outflows (63,000 AFY) and discharge to the stream system (80,000 AFY) bringing the total system outflows to 559,000 AFY annually. Operational water budgets and net-groundwater interaction under current conditions remain like those of the historical period, based on the 2010 water year. On a Subbasin-wide scale, the groundwater in storage deficit under the current conditions baseline is approximately 125,000 AFY.

Figure 5-23 and **Table 5-8** summarize the average current conditions groundwater inflows and outflows in the Modesto Subbasin.

Figure 5-23: Current Conditions Average Annual Water Budget – Groundwater System, Modesto Subbasin



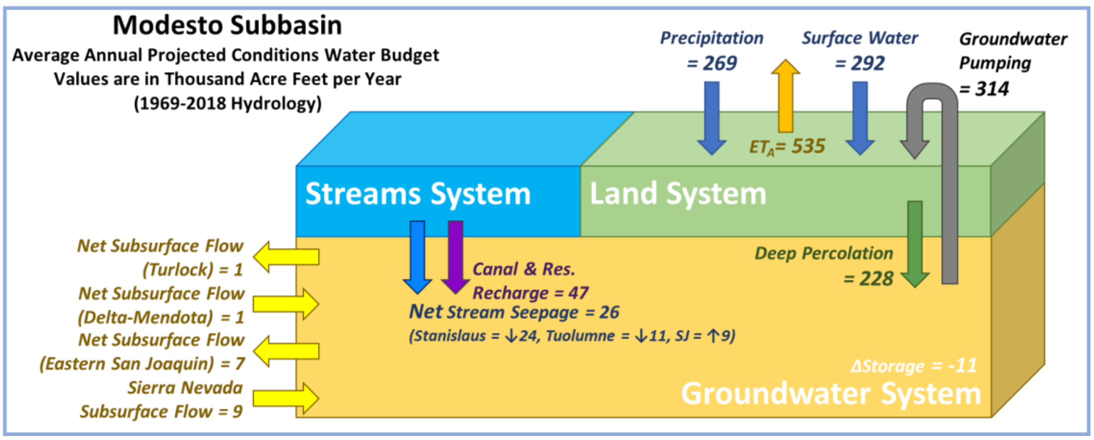
5.1.4.3. Projected Water Budget

The projected water budget provides an estimate of supplies and demands as defined under the projected conditions baseline listed above, including land use operations and their impact ~~to~~on the aquifer system. The projected conditions baseline is a version of C2VSimTM and was used to evaluate the water budget using projected operations in conjunction with the 50-year hydrologic period, 1969 to 2018. This hydrologic period has an average precipitation similar to the long-term average over the Subbasin. Within this 50-year period, there is variability in hydrologic conditions which allows the model to simulate different stresses.

Development of the projected water demand is based on the population growth trends reported in the 2015 UWMPs and the land use, evapotranspiration, and crop coefficient information from the Modesto ID and Oakdale ID 2015 AWMPs. Projected Tuolumne River inflows to the groundwater Subbasin and surface water supplies are determined through a combination of historical trends and the Tuolumne River System (TRS) operations model. Additional information about model development and inputs are detailed in the C2VSimTM Model Development Technical Memo in **Appendix C**.

Figure 5-24 shows the water budget schematic for the Modesto Subbasin with average annual projected values for each component.

Figure 5-24: Average Annual Projected Conditions Water Budget – Modesto Subbasin



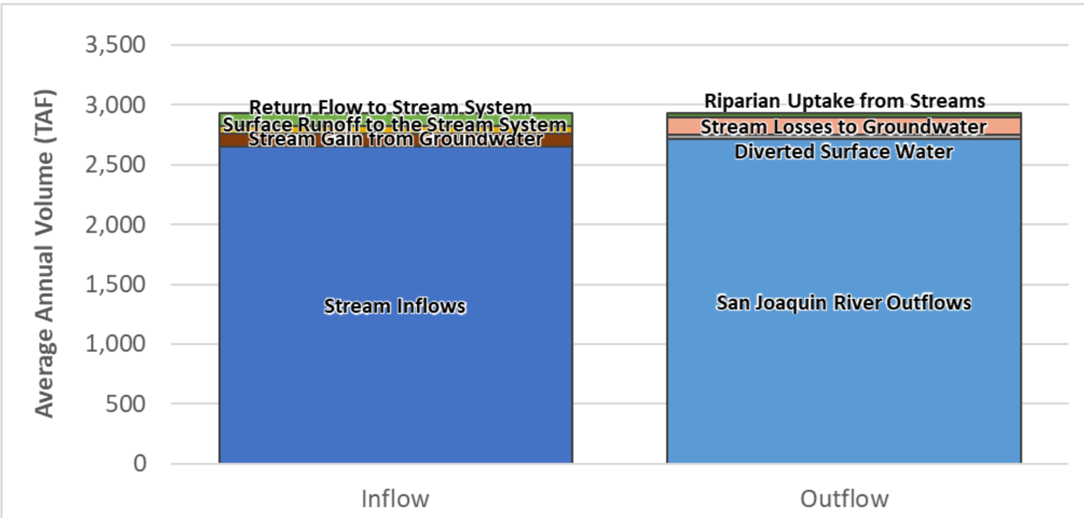
Note: sub-categories may not sum together due to rounding error

As shown in **Table 5-2**, average annual surface water inflows to the Modesto Subbasin's stream system total an average of 2,934,000 AFY. As with the historical and current conditions water budgets, stream inflows from the Stanislaus, Tuolumne, and San Joaquin Rivers comprise most of the inflows, averaging 2,650,000 AFY. Other inflows include contributions from tributaries (6,000 AY), gain from the aquifer (104,000 AFY), surface runoff from precipitation (60,000 AFY), and return flow from applied water to the stream system (113,000 AFY).

Under projected conditions, volumes of surface water diverted from Modesto Subbasin's stream system are lower than under historical conditions, down to 33,000 AFY from 43,000 AFY. Reduced diversion volumes under projected conditions are due to reduced demand by riparian users resulting from projected increases in irrigation efficiency. Other stream system outflows include seepage to the aquifer system (146,000 AFY), direct uptake by native vegetation (37,000 AFY), and San Joaquin River outflows downstream of the Tuolumne River confluence (2,717,000 AFY).

Groundwater levels are predicted to be further reduced under projected conditions than under historical conditions, and thus the 86,000 AFY reduction in net contribution from the aquifer[2] to the stream system matches the expected trend. Under such a decrease in aquifer contribution, streams in Modesto Subbasin transition from average net gaining streams to net losing streams. Therefore, under historical conditions, aquifers on average recharge streams, but under projected conditions, streams on average, recharge the aquifer. **Figure 5-25** summarizes the average projected inflows and outflows in the Modesto Subbasin surface water network.

Figure 5-25: Projected Conditions Average Annual Water Budget – Stream Systems, Modesto Subbasin



The land surface water budget for the Projected Conditions Baseline is shown on **Table 5-3** and has average annual supplies of 900,000 AFY. Supplies are comprised of precipitation (270,000 AFY), applied surface water (293,000 AFY), applied groundwater (315,000 AFY), and riparian uptake from streams (22,000 AFY). Demands total 898,000 AFY and are comprised of evapotranspiration (536,000 AFY), surface runoff and return flow (134,000 AFY) to the stream system, and deep percolation (228,000 AFY).

Urban supplies and demands increase relative to historical conditions due to forecasted population growth. Additionally, agricultural demand (evapotranspiration) is higher because agricultural land use is assumed to be at the historical high, reflecting more developed acres than average historical conditions. However, there is less percolation out of the root zone and agricultural return flow because of the projected improvements in irrigation efficiency (e.g., drip irrigation). The lower runoff in the projected conditions baseline compared to the historical scenario is driven by lower precipitation. There are no projected changes to soil

[2] Net contribution from the aquifer includes stream gains and losses within and outside of the Modesto Subbasin – any region adjacent to the Stanislaus River, Tuolumne River, and San Joaquin River.

characteristics (i.e., curve number or soil parameters) between the historical and projected conditions baseline scenarios.

A summary of these flows can be seen below in **Figure 5-26** though

Figure 5-28. **Figure 5-27** and

Figure 5-28 show the annual change in the land surface water budget components through the simulation period.

Figure 5-26: Projected Conditions Average Annual Water Budget – Land Surface System, Modesto Subbasin

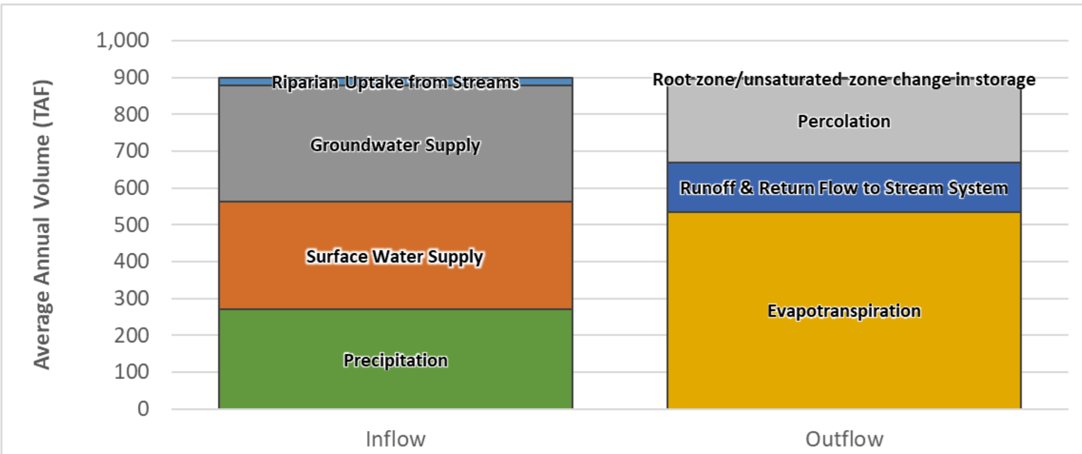


Figure 5-27: Projected Conditions Annual Water Budget – Agricultural Land Surface System, Modesto Subbasin

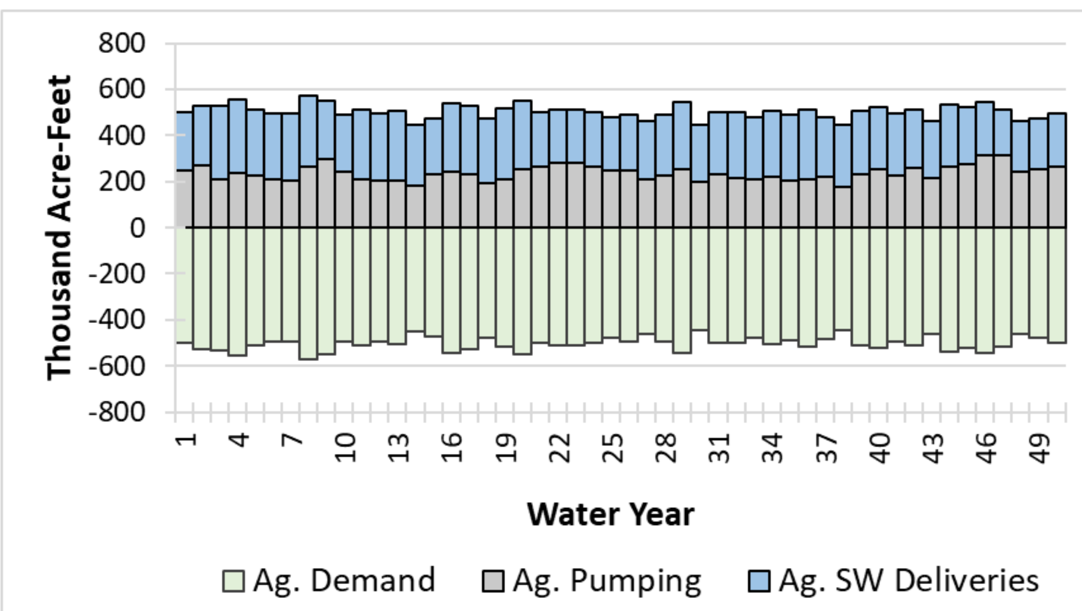
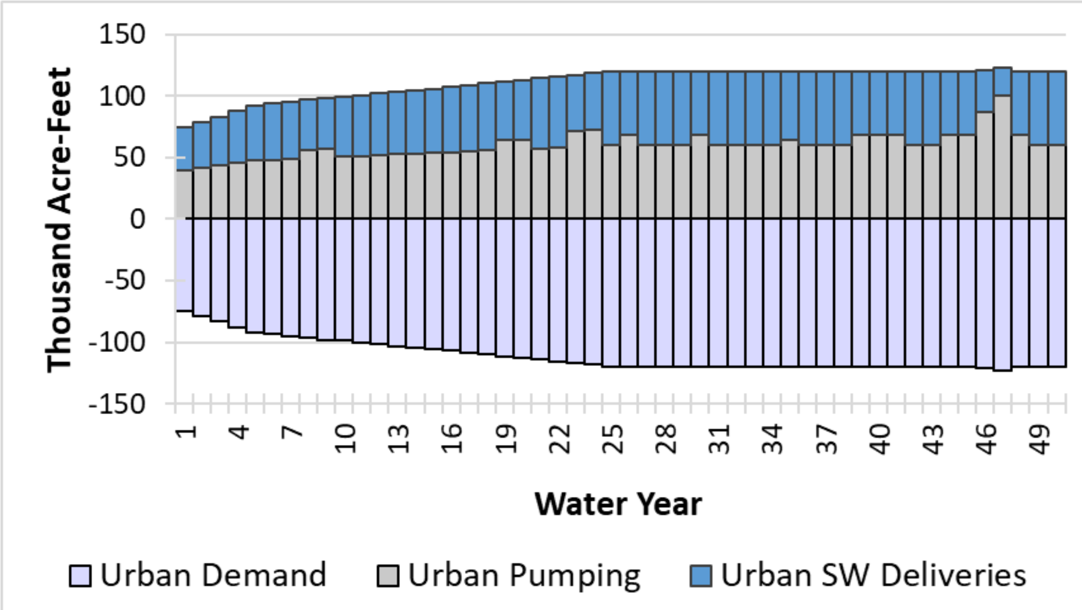


Figure 5-28: Projected Conditions Annual Water Budget – Urban Land Surface System, Modesto Subbasin



Anticipated growth in the Projected Conditions Baseline slightly increases groundwater production (314,000 AFY), compared to historical pumping. Subsurface outflows to neighboring subbasins (75,000 AF) and stream gain from groundwater (50,000 AFY) bring the total Subbasin discharges to 438,000 AFY.

Under projected conditions, the groundwater system of the Modesto Subbasin experiences an average of 428,000 AFY of inflows each year, of which 228,000 AFY is from deep percolation of rainfall and applied water. As previously mentioned, deep percolation from applied water is lower than under historical conditions because of projected increases in irrigation efficiency. Other inflows to the groundwater system consist of recharge from stream seepage (76,000 AFY), seepage from conveyance canals and reservoirs (47,000 AFY), and subsurface inflows from the Sierra Nevada foothills and neighboring subbasins of Eastern San Joaquin, Delta-Mendota, and Turlock (77,000 AFY combined). A summary of annual averages of the Modesto Subbasin groundwater system is provided on **Table 5-8**.

Under the projected conditions the groundwater system outflows are greater than the system inflows, resulting in an average annual groundwater in storage deficit of 11,000 AFY. While an average groundwater in storage decline of 11,000 AFY is significantly less than historical depletion (43,000 AFY), the decline is buffered by the net gain of 86,000 AFY of seepage from the stream system. This change in the projected groundwater conditions and stream-aquifer interactions are considered significant and unreasonable, which affects groundwater sustainability of the Subbasin.

An analysis of net recharge in the Projected Conditions model was performed for Modesto Subbasin and for each water budget area. **Figure 5-29** shows the total groundwater production and land-surface recharge each year under the projected conditions scenario. Additionally, the net-groundwater under projected conditions, shown in **Figure 5-30**, is predominantly negative, meaning that on average, the subbasin is a net-extractor. This continuation of historical trends reflects the relationship between the Subbasin's increased groundwater demand and declining storage.

Figure 5-31 through **Figure 5-38** show similar surface-to-groundwater operations and net-interaction to the historical water budgets. Under the projected conditions baseline, the Oakdale South water budget area maintains a constant net-contribution to the aquifer system while the Non-District West continues to be variable conditions and the NDE continues to be a net-extractor. The Modesto water budget area shows the greatest variance from the historical water budget, being predominantly a net-extractor under projected conditions. This is due to both changes in agricultural operations, combined with growing populations in the urban centers. **Figure** 5-39 summarizes the average projected groundwater inflows and outflows in the Modesto Subbasin, while **Figure 5-40** shows the annual change in each component of the groundwater budget plus cumulative change in storage throughout the simulation period. Based on this figure, Modesto Subbasin is projected to experience approximately 11,000 AFY of storage decline under projected conditions, leading to cumulative reduction of approximately 530,000 AFY of groundwater in storage over the 50-year planning horizon.

Table 5-10 shows the minimum, maximum and averages numbers by Water Year Type for the groundwater budget components in the Projected Conditions scenario. The net change in groundwater storage indicates a maximum increase in storage of 167,000 AF in a wet year and a worst-case scenario decrease in storage of 161,600 AF in a critically dry year. These ranges highlight the effect of hydrologic conditions over the Subbasin when analyzing individual years. Even within the same Water Year types there are significant ranges of values which reflects different starting conditions on which each individual year is analyzed.

Table 5-10. Average and Range of annual values for components of the Projected Conditions Groundwater Budget by Water Year Type (AFY)

Component		Wet	Above Normal	Below Normal	Dry	Critical
Net Stream Seepage (+)	Min	13,700	800	-2,900	-16,300	-23,200
	Avg	48,700	15,700	18,100	5,000	17,300
	Max	107,200	38,700	37,500	53,500	49,700
Canal and Reservoir Recharge (+)	Min	45,200	46,900	45,700	45,100	43,500
	Avg	47,100	48,400	47,800	48,300	46,200
	Max	48,600	49,600	50,100	50,000	48,800
Deep Percolation (+)	Min	224,200	201,800	191,000	177,500	160,500
	Avg	280,600	234,600	204,200	204,500	181,300
	Max	344,800	266,400	229,900	235,200	212,700
Net Subsurface Flows (+)	Min	-8,100	-18,800	-6,200	-13,300	-18,900
	Avg	8,500	-5,300	3,400	-2,500	800
	Max	30,000	8,500	20,900	25,500	24,600
Groundwater Pumping (-)	Min	249,600	274,500	271,500	266,700	303,700
	Avg	287,700	302,200	304,400	297,700	364,100
	Max	327,700	332,100	345,500	346,900	439,100
Change in Groundwater Storage	***Min***	***12,800***	***-57,200***	***-46,300***	***-91,200***	***-161,600***
	Avg	***97,300***	***-8,700***	***-30,900***	***-42,300***	***-118,500***
	Max	***167,100***	***42,700***	***-600***	***37,200***	***-49,400***

Figure 5-29: Projected Conditions Groundwater Recharge and Extraction – Modesto Subbasin

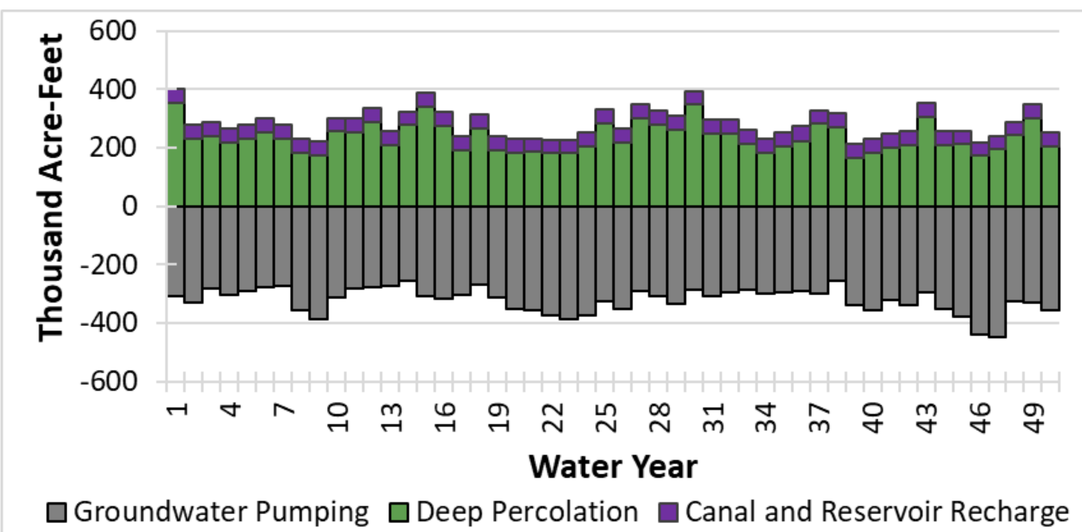


Figure 5-30: Projected Conditions Net Recharge – Modesto Subbasin

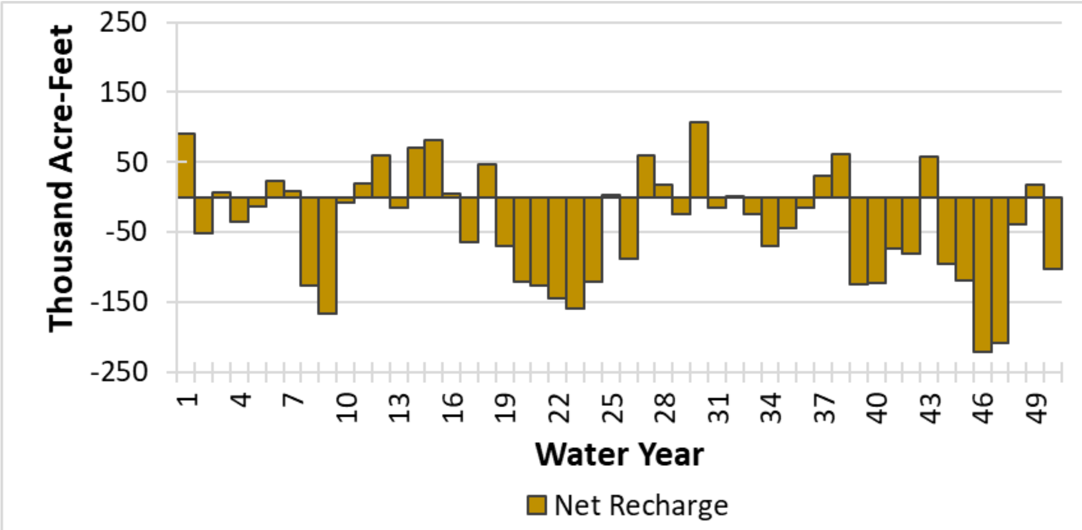


Figure 5-31: Projected Conditions Groundwater Recharge and Extraction – Modesto Zone

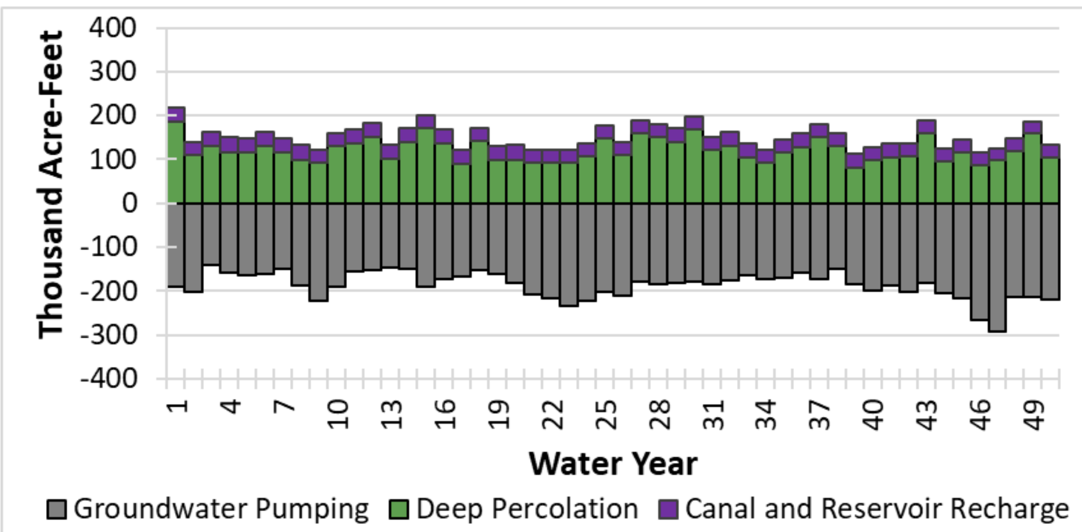


Figure 5-32: Projected Conditions Net Recharge – Modesto Zone

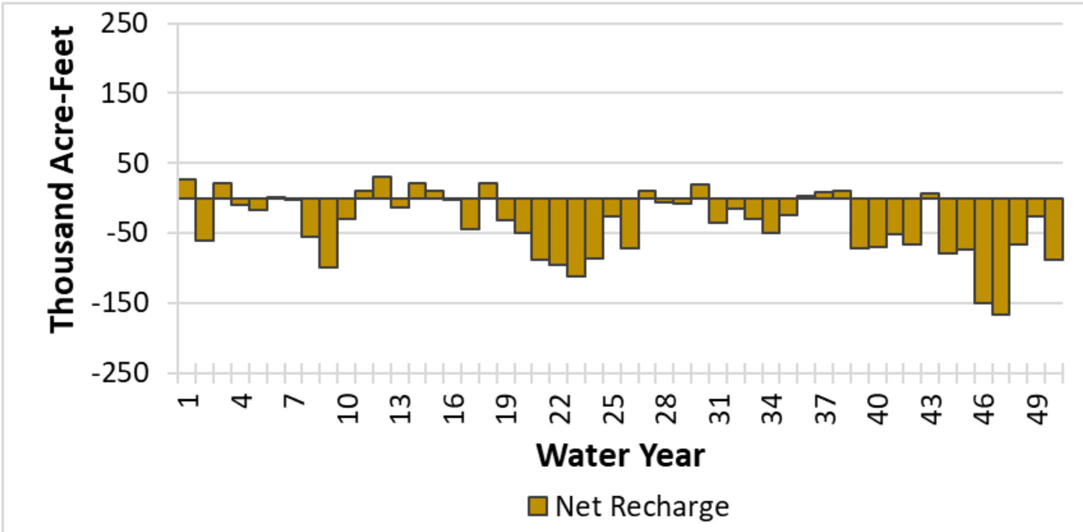


Figure 5-33: Projected Conditions Groundwater Recharge and Extraction – Oakdale South Zone

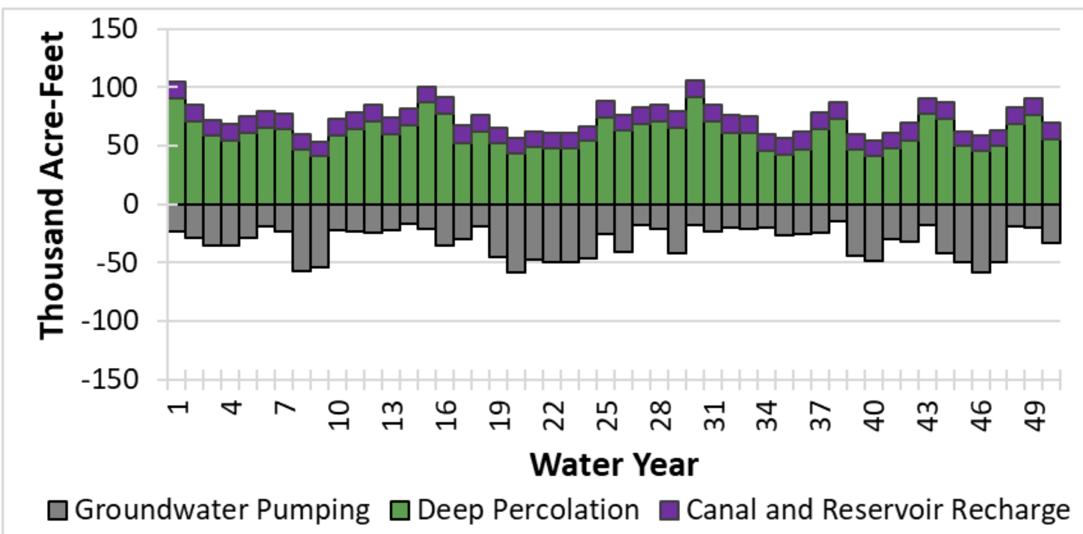


Figure 5-34: Projected Conditions Net Recharge – Oakdale South Zone

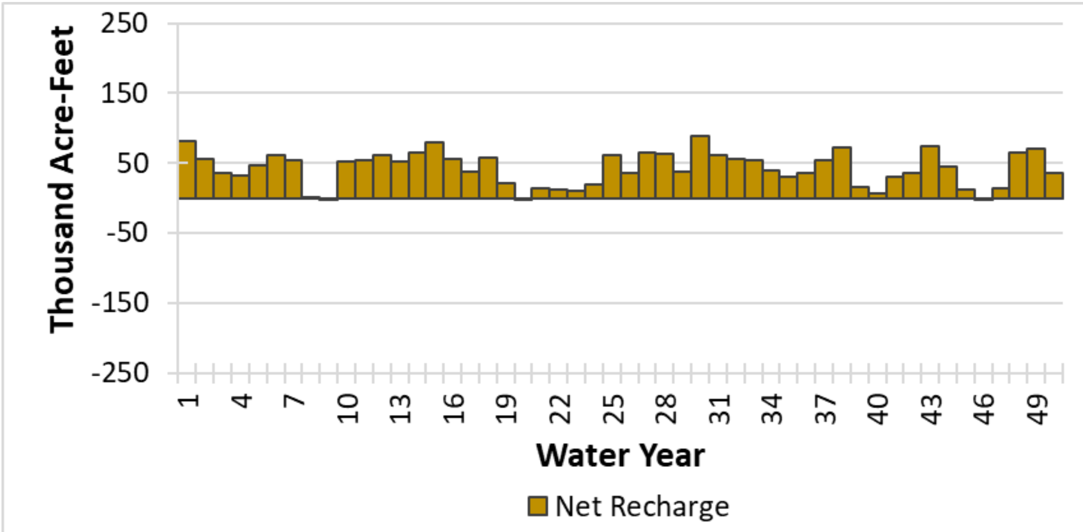


Figure 5-35: Groundwater Recharge and Extraction – Non-District East Area

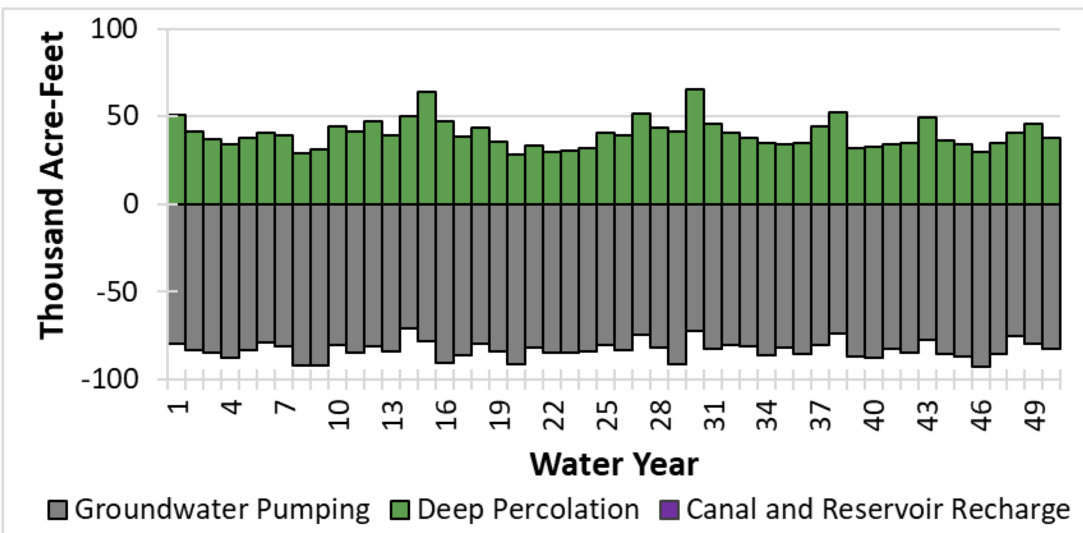


Figure 5-36: Net Recharge – Non-District East Area

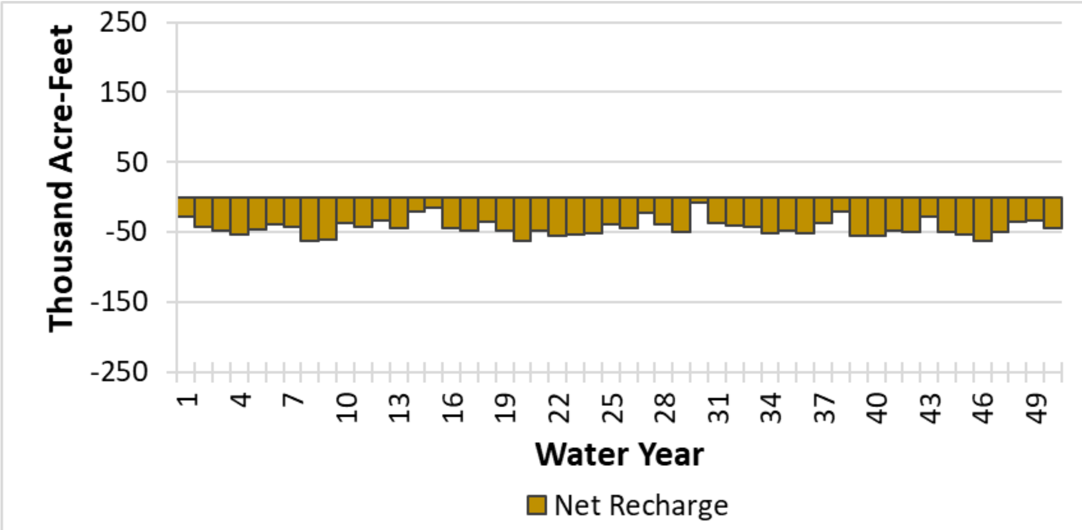


Figure 5-37: Groundwater Recharge and Extraction – Non-District West Zone

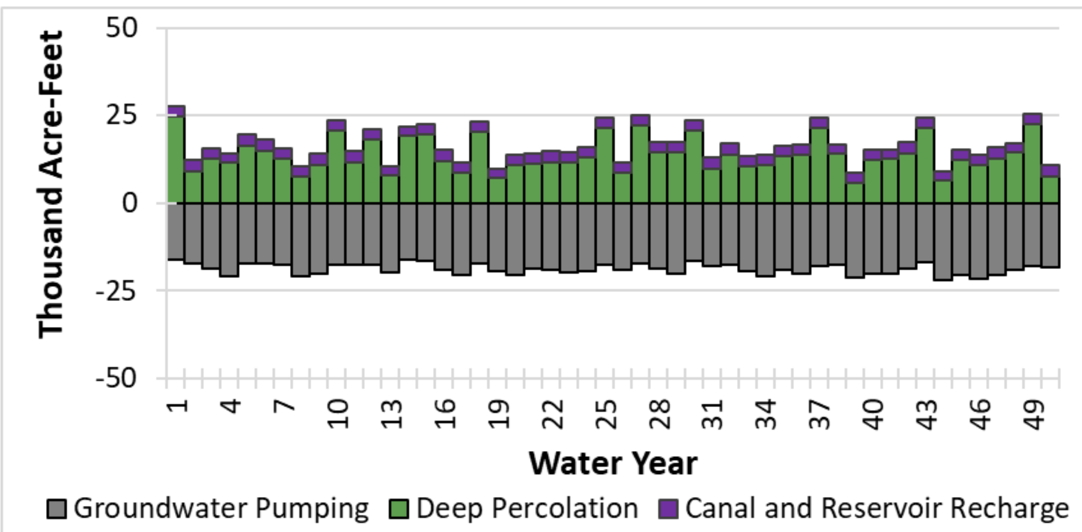


Figure 5-38: Net Recharge – Non-District West Zone

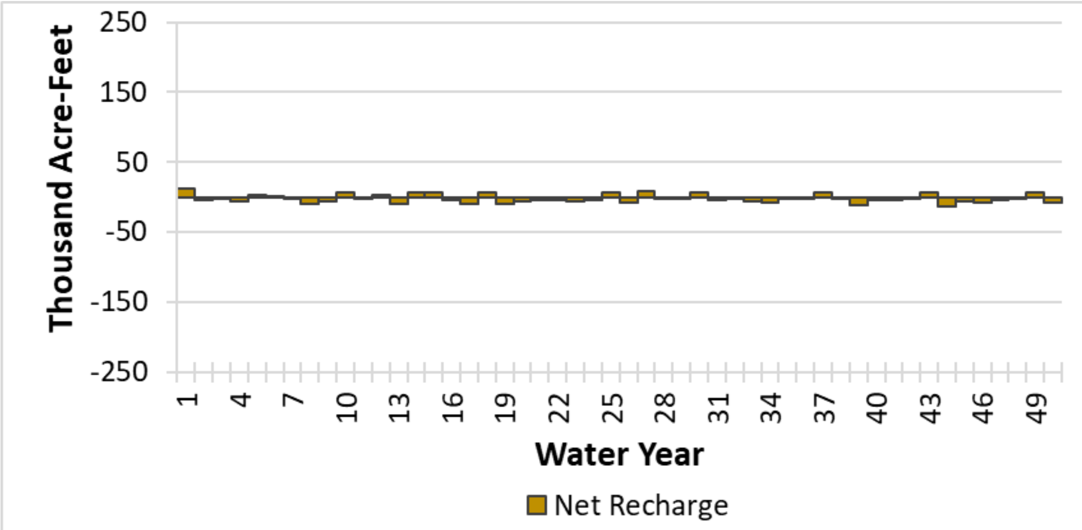


Figure 5-39: Projected Conditions Average Annual Water Budget – Groundwater System, Modesto Subbasin

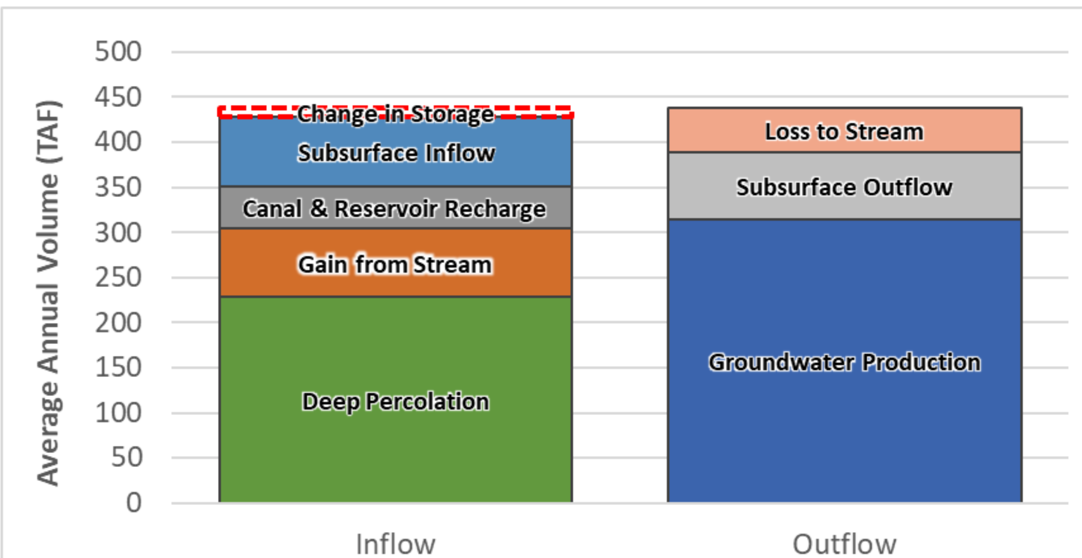
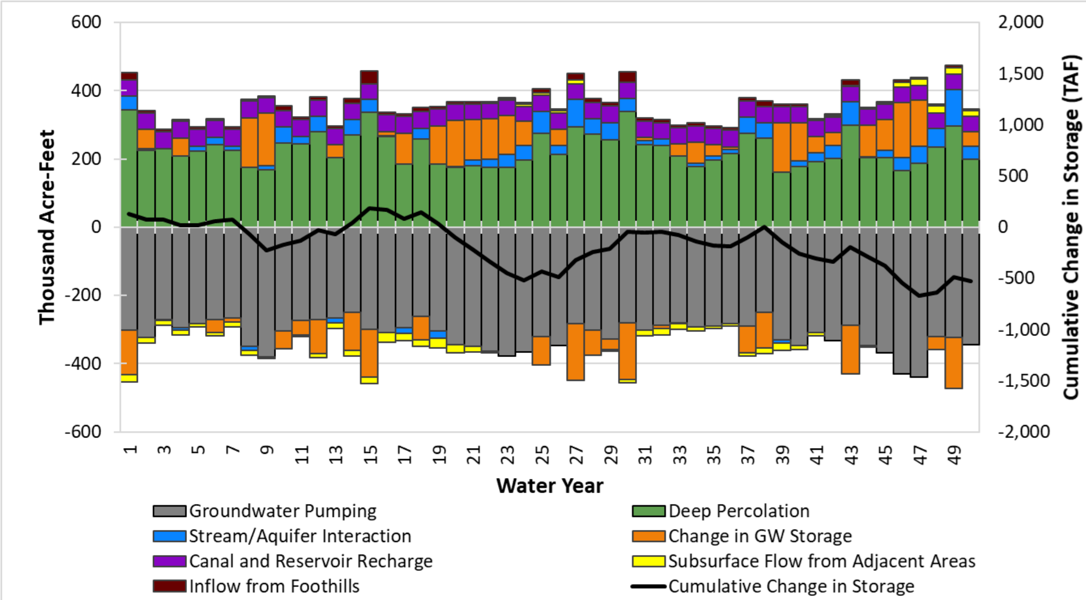


Figure 5-40: Projected Conditions Annual Water Budget – Groundwater System, Modesto Subbasin



5.2. CLIMATE CHANGE ANALYSIS

5.2.1. Regulatory Background

SGMA requires consideration of uncertainties associated with climate change in the development of GSPs. Consistent with §354.18(d)(3) and §354.18(e) of the SGMA Regulations, analyses for the Modesto GSP evaluated the projected water budget with and without climate change conditions.

5.2.2. DWR Guidance

Climate change analysis and the associated methods, tools, forecasted datasets, and the predictions of greenhouse gas concentrations in the atmosphere are continually evolving. The approach developed for this GSP is based on the methodology in DWR's guidance document (DWR, 2018b), which, in combination with Subbasin-specific modeling tools, was deemed to be the most appropriate information for evaluating climate change in the Modesto Subbasin GSP. The following resources from DWR were used in the climate change analysis:

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

SGMA Data Viewer provides the location for which the climate change forecasts datasets[3] were downloaded for the Modesto Subbasin (DWR, 2019b). The guidance document details the approach, development, applications, and limitations of the datasets available from the SGMA Data Viewer (DWR, 2018b). The Water Budget BMP describes in greater detail how DWR recommends projected water budgets be computed (DWR, 2016a). The Desktop IWFM Tools (DWR, 2018c) are available to calculate the projected precipitation and evapotranspiration inputs under climate change conditions.

The methods suggested by DWR in the above resources were used, with modifications where appropriate, to ensure the resolution would be reasonable for the Modesto Subbasin and align with the assumptions of the C2VSimTM. **Figure 5-41** shows the overall process developed for the Modesto GSP consistent with the Climate Change Resource Guide (DWR, 2018b) and describes workflow beginning with baseline projected conditions to perturbed 2070 conditions for the projected model run. For this analysis, it is assumed that the projected climate change conditions for 2070 central tendency is used.

Figure 5-41: Modesto GSP Climate Change Analysis Process

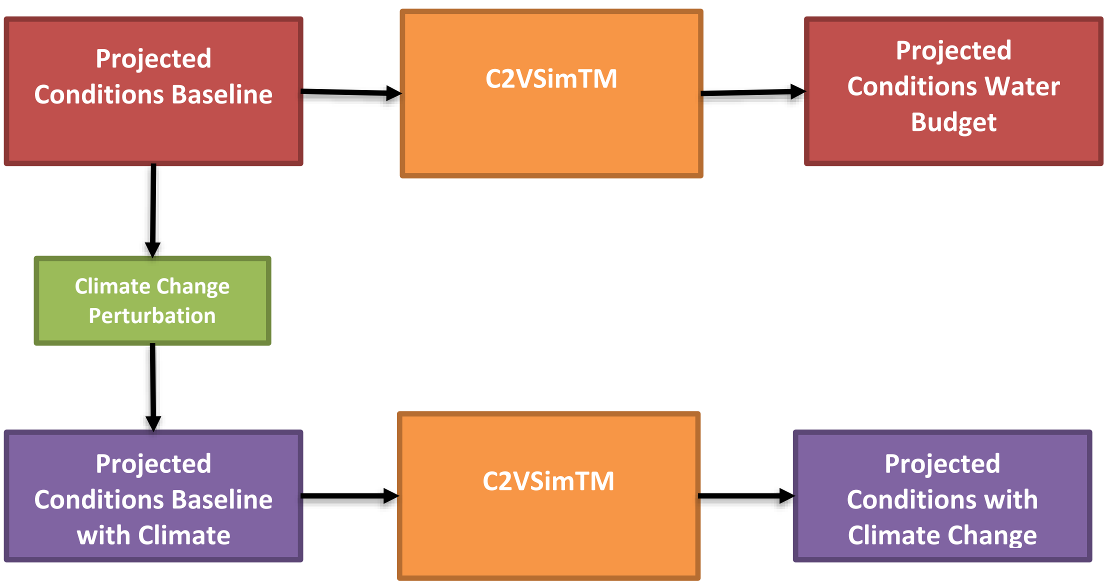


Table 5-10 summarizes the forecasted variable datasets provided by DWR that were used to carry out the climate change analysis. The "VIC" model (Variable Infiltration Capacity) referred to in **Table 5-10** is the hydrologic model used by DWR to estimate unimpaired flows in upper watersheds. "Unimpaired" streamflow refers to the natural streamflow produced by a watershed, without modifications to streamflow from reservoir regulations, diversions, and other operations. On the other hand, "impaired" streamflow referred to in **Table 5-10** is DWR's terminology for streams whose flow is impacted by ongoing water operations and

[3] In the industry, climate change impacted variable forecasts are sometimes referred to as "data" and their collections are called "datasets." Calling forecasted variable values "data" can be misleading, so this document tries to be explicit when referring to data (historical data) vs. forecasts or model outputs.

upstream regulations, such as diversions, deliveries, and reservoir storage. Flows on these streams are simulated using the CalSim II model results from the DWR baseline model. For Modesto Subbasin GSP, stream inflow and surface water deliveries to MID and OID were utilized from the CalSim II baseline model results. The San Joaquin River flows were also based on the results of CalSim II baseline model from DWR. All timeseries shown in **Table 5-10** use a monthly timestep. **Section 5.2.3** includes further description of the methodology, datasets, and results.

Table 5-11: DWR-Provided Climate Change Datasets

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

5.2.3. Climate Change Methodology

Climate change affects precipitation, streamflow, evapotranspiration and, for coastal aquifers, sea level rise, which in turn have impacts on the aquifer system. For the Modesto Subbasin, sea level rise is not relevant and not considered in this analysis. The method for perturbing the streamflow, precipitation, and evapotranspiration input files is described in the following sections. The late-century, 2070 central tendency climate scenario was evaluated in this analysis, consistent with DWR guidance (DWR, 2018b).

DWR combined 10 global climate models (GCMs) for two different representative climate pathways (RCPs) to generate the central tendency scenarios in the datasets used in this analysis. The “local analogs” method (LOCA) was used to downscale these 20 different climate projections to a scale usable for California (DWR, 2018b). DWR provides datasets for two future climate periods: 2030 and 2070. For 2030, there is one set of central tendency datasets available. For 2070, DWR has provided one central tendency scenario and two extreme scenarios: one that is drier with extreme warming and one that is wetter with moderate warming.

The 2070 central tendency projection serves to assess impacts of climate change over the long-term planning and implementation period and was therefore selected as the most appropriate scenario under which to assess in the Modesto GSP.

5.2.3.1. Streamflow under Climate Change

Hydrological forecasts for streamflow under various climate change scenarios are available from DWR as either a flow-based timeseries or a series of perturbation factors applicable to local data. DWR simulated volumetric flow in most regional surface water bodies by utilizing the Water Resource Integrated Modeling System (WRIMS, formally named CalSim II). While river flows and surface water diversions in the Tuolumne, Stanislaus, and San Joaquin Rivers are simulated in CalSim II, there are significant variations when compared to local historical data. Due to the uncertainty in CalSim II-simulated reservoir operations, flows from CalSim II provided by the state are not used directly in the Modesto GSP climate change analysis. Instead, relative perturbation factors were used to derive surface water inflows and diversions for analysis with the C2VSimTM.

The major streams entering the Modesto Subbasin are the Tuolumne River and Stanislaus River. All rivers are regulated and there are no unimpaired rivers or creeks that contribute significantly to the basin.

CalSim II estimated flows for point locations on the Tuolumne River and Stanislaus River were downloaded from DWR. The key flows obtained from CalSim II include:

- **Tuolumne River:** La Grange Outflow
- **Stanislaus River:** Goodwin Outflow

The San Joaquin River inflow was not adjusted in the climate change analysis because the Friant Dam is located far from the Modesto Subbasin and subbasins that are upstream of the Modesto Subbasin can have significant impacts on stream accretions/depletions, diversions, and operations. As these upstream impacts which are outside of the Modesto Subbasin cannot be captured without detailed analysis of projected flows under climate change conditions, the San Joaquin River flows are assumed to be same as the projected baseline conditions. This would not have a significant impact on the climate change analysis for the Modesto Subbasin, as majority of the surface water supplies, and interaction of surface and groundwater systems take place within Subbasins and along Tuolumne and Stanislaus Rivers.

The streamflow data extracted from CalSim II represent projected hydrology with climate change based on reservoir outflow, operational constraints, and diversions and deliveries of water for the State Water Project and the Central Valley Project. CalSim II data from WY 1965 to WY 2003 was available. For WY 2004 to WY 2018, streamflow data was synthesized based on similar year methodology, and used flows from WY 1965 to WY 2003 and the DWR San Joaquin Valley water year type (CDEC, 2018). (For example, the streamflow for October 2009 was calculated as the average of the October 1966 and October 1971 streamflow because these are all the Below Normal water years between WY 1965 and WY 2003.)

CalSim II outputs are considered more appropriate for regulated streams than streamflow derived using the unimpaired flow adjustment factors because CalSim II accounts for reservoir operations. As expected, streamflow simulated in CalSim II and those derived using the unimpaired flow adjustment factors did not present similar trends, particularly in dry years. DWR-provided unimpaired flow change factors do not account for variations in the operation of the reservoirs that would result from climate change conditions. The CalSim II flows, however, were also not considered completely appropriate for local conditions so a method was derived to compute change factors from CalSim II flows, as described below.

Using DWR's method of deriving the precipitation and evapotranspiration factors as a guide, a hybrid approach was derived to improve upon the discrepancy between the CalSim II and local models while accounting for some change in reservoir operations. In this approach, change factors are generated from the difference between each simulated future climate change CalSim II scenario (i.e., 2070) and the "without climate change" baseline CalSim II run. This "without climate change" baseline run is the CalSim II 1995 Historical Detrended simulation run provided through personal communication from DWR. The change perturbation factors are bounded by a maximum of 5 and minimum 0.2. For the purposes of simplicity, this method is referred to throughout the rest of the document as CalSim II Generated Perturbation Factors (CGPF). The generated change factors are then used to perturb the regulated baseline river inflows:

- Tuolumne River – CGPF multiplied by the projected conditions baseline for the Tuolumne River which is based on Tuolumne River System (TRS) operations model
- Stanislaus River – CGPF multiplied by the projected conditions baseline for the Stanislaus River which is based on historical trends and local hydrology

As previously discussed, the San Joaquin River flows were not perturbed due to the much larger tributary areas of the San Joaquin River that are outside the Modesto Subbasin. The CGPF method presents limitations given that the resulting flows are not directly obtained from an operations model. The actual mass balance on the reservoirs is not tracked in the estimates of the flows and, instead, the method relies on CalSim II tracking that storage and managing the reservoir based on the appropriate rule curves.

Figure 5-42 through **Figure 5-49** provide a comparison of projected conditions baseline and the CGPF method described above. Exceedance curves are included for each of the CGPF flows against the projected conditions baseline.

Figure 5-42: Tuolumne River Hydrograph

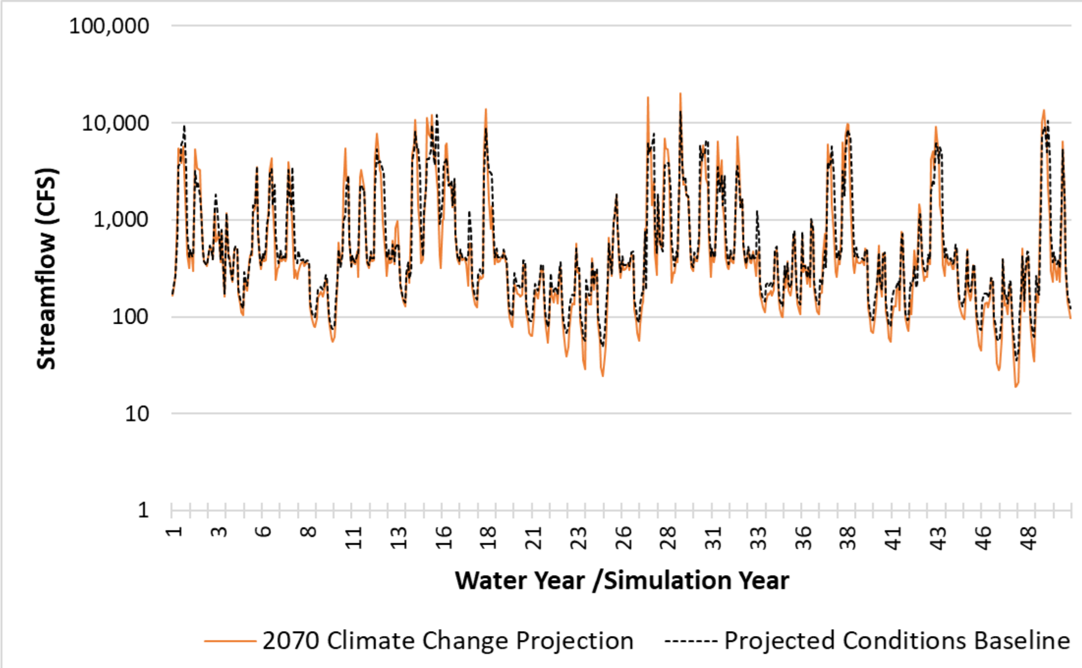


Figure 5-43: Tuolumne River Exceedance Curve

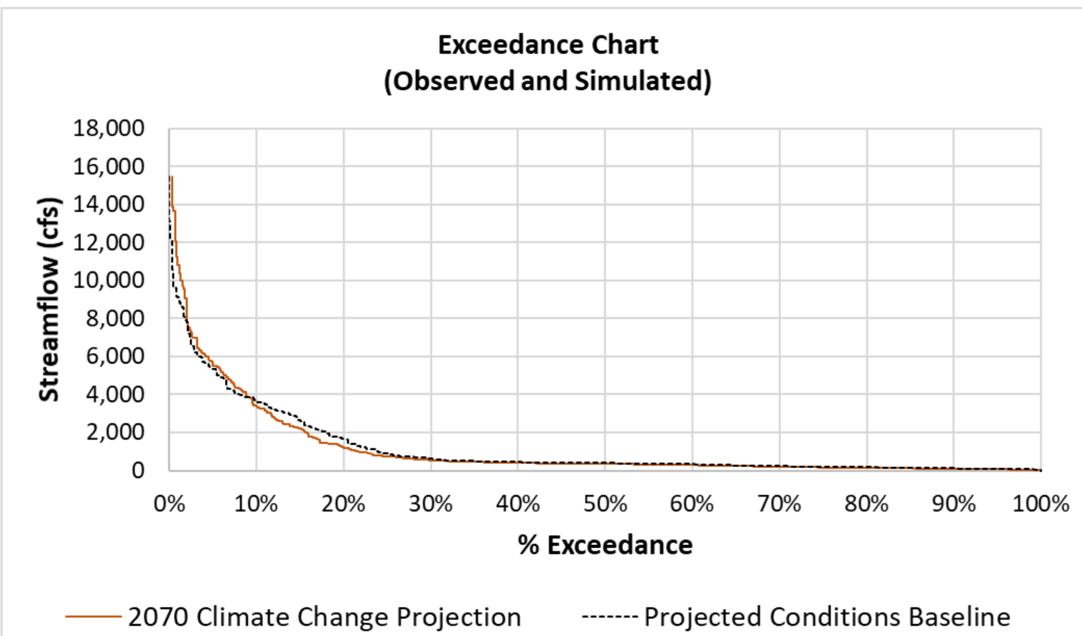


Figure 5-44: Stanislaus River Hydrograph

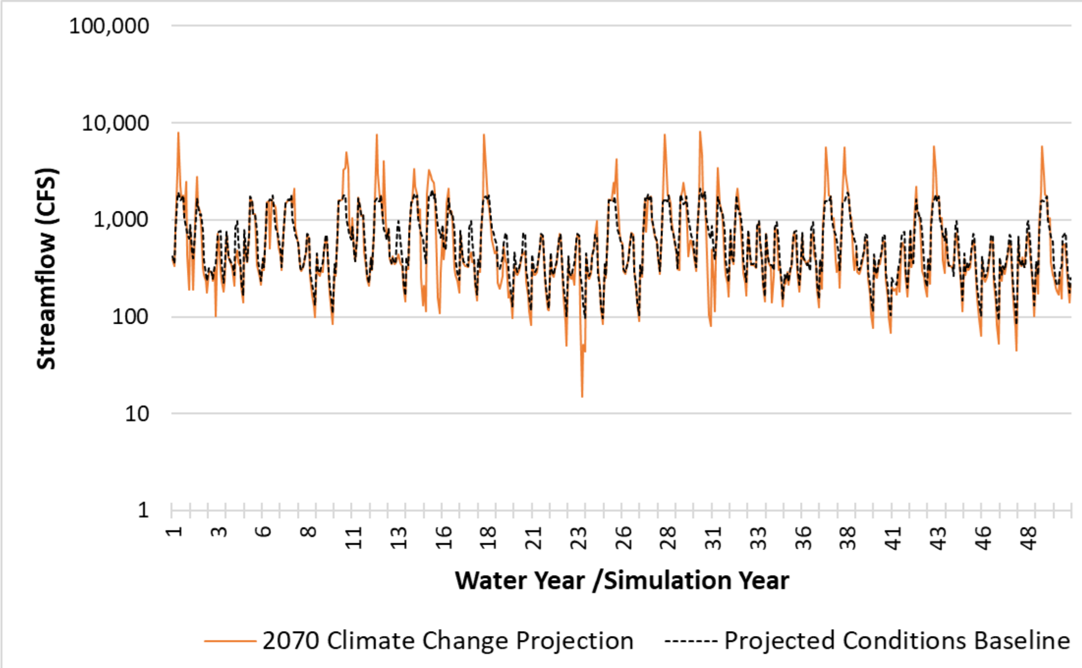
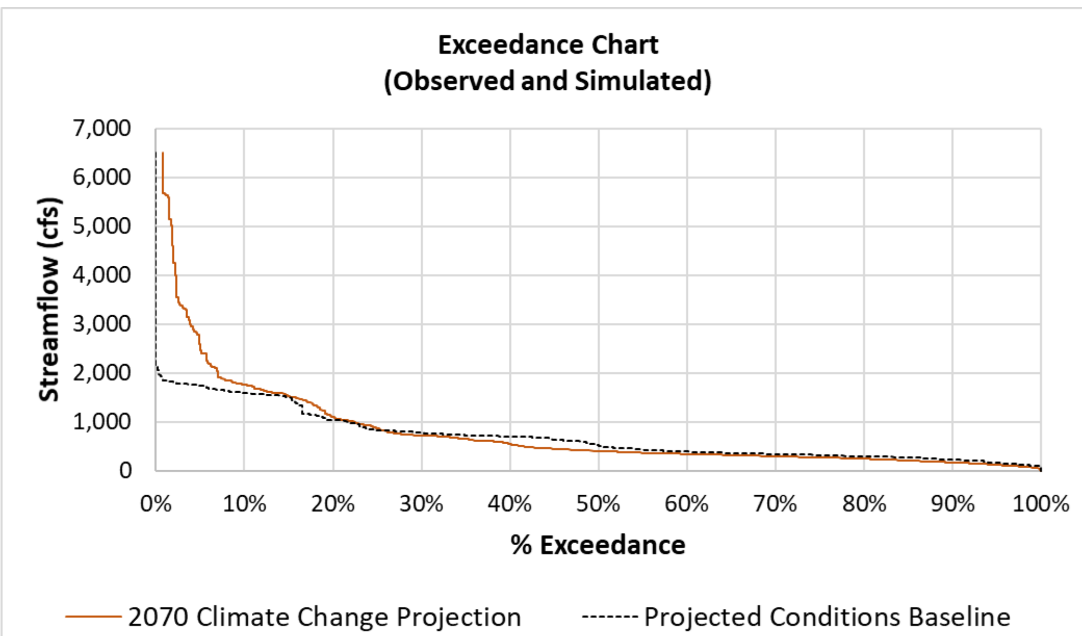


Figure 5-45: Stanislaus River Exceedance Curve



5.2.3.2. Precipitation and Evapotranspiration under Climate Change

Projected precipitation and evapotranspiration (ET) change factors provided by DWR were calculated using a climate period analysis based on historical precipitation and ET from January 1915 to December 2011 (DWR, 2018b). The Variable Infiltration Capacity (VIC) hydrologic model was used by DWR to simulate land-surface atmosphere exchanges of moisture and energy on a six-kilometer grid. Model output includes both precipitation and reference evapotranspiration change factors. The change factors provided by DWR were calculated as a ratio of a variable under a "future scenario" divided by a baseline. The baseline data is the 1995 Historical Template Detrended scenario by the VIC model through GCM downscaling. The "future scenario" corresponds to VIC outputs of the simulation of future conditions using GCM forecasted hydroclimatic variables as inputs. These change factors are thus a simple perturbation factor that corresponds to the ratio of a future with climate change divided by the past without it. Change factors are available on a monthly time step and spatially defined by the VIC model grid. Supplemental tables with the time series of perturbation factors are available by DWR for each grid cell. DWR has made accessible a Desktop GIS tool for both IWFM and MODFLOW to process these change factors (DWR, 2018c).

5.2.3.2.1. Applying Change Factors to Precipitation

DWR change factors were multiplied by projected conditions baseline precipitation to generate projected precipitation under the 2070 central tendency future scenario using the Desktop IWFM GIS tool (DWR, 2018c). The tool calculates an area weighted precipitation change factor for each model grid geometry. This model grid geometry was generated based on polygons built around the PRISM nodes that are within the model area.

However, the DWR tool only includes change factors through 2011. The remaining seven years of the time series were synthesized according to historically comparable water years (i.e., wet years were synthesized based on a wet year within the available time frame of the DWR tool). The perturbation factor from the corresponding month of the comparable year was applied to the baseline of the missing years (2012-2018) to generate projected values. Months with no precipitation in the baseline were assumed a monthly precipitation of 1 mm under climate change to account for increased precipitation that cannot be calculated from a baseline of 0 mm for these synthesized years. The comparable years that were used can be found in **Table 5-121**.

Table 5-12: Comparable Water Years (Precipitation)

Missing Water Year	Comparable Water Year
2012	1968
2013	2007
2014	2002
2015	1971
2016	1981
2017	1993
2018	1987

The resulting perturbed precipitation values and the baseline precipitation values for the representative historical period can be found in **Figure 5-46** below. The exceedance plot for these two times series can be found in **Figure 5-47**.

Figure 5-46: Perturbed Precipitation Under Climate Change

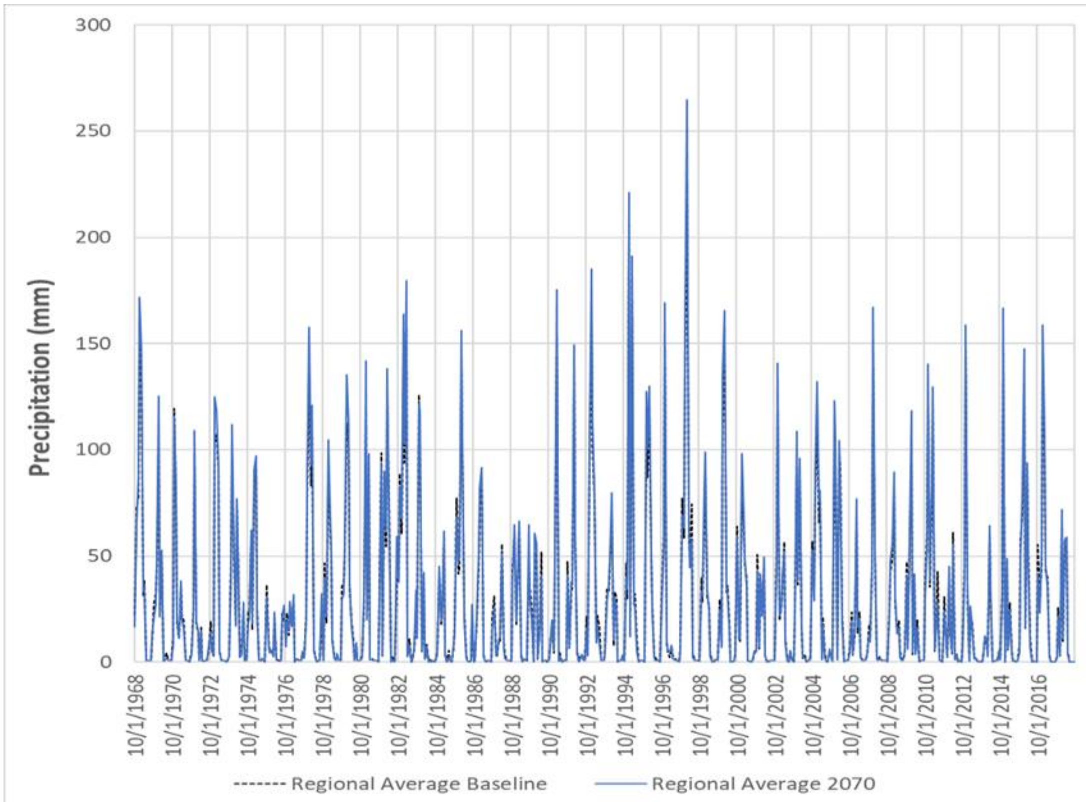


Figure 5-47: Perturbed Precipitation Exceedance Curve

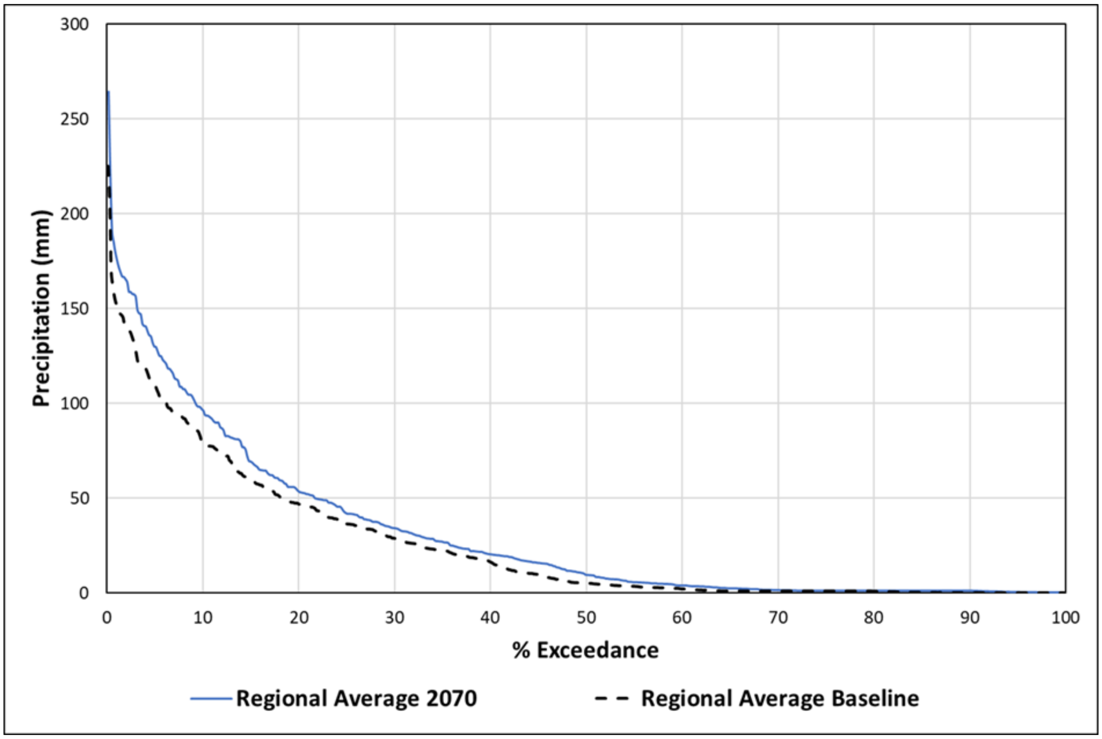


Figure 5-48 shows the difference between the regional average under 2070 climate change conditions and the regional average under projected conditions baseline plotted against different amounts of projected monthly precipitation. The average was taken across the area of the Modesto Subbasin.

Figure 5-48: Variation from Baseline of Perturbed Precipitation

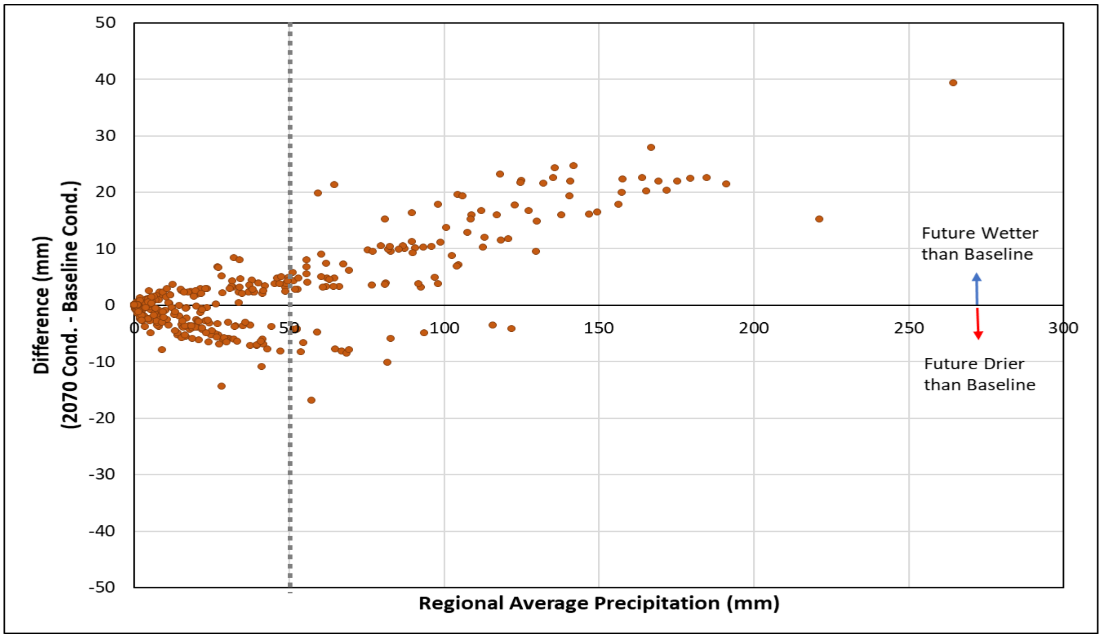
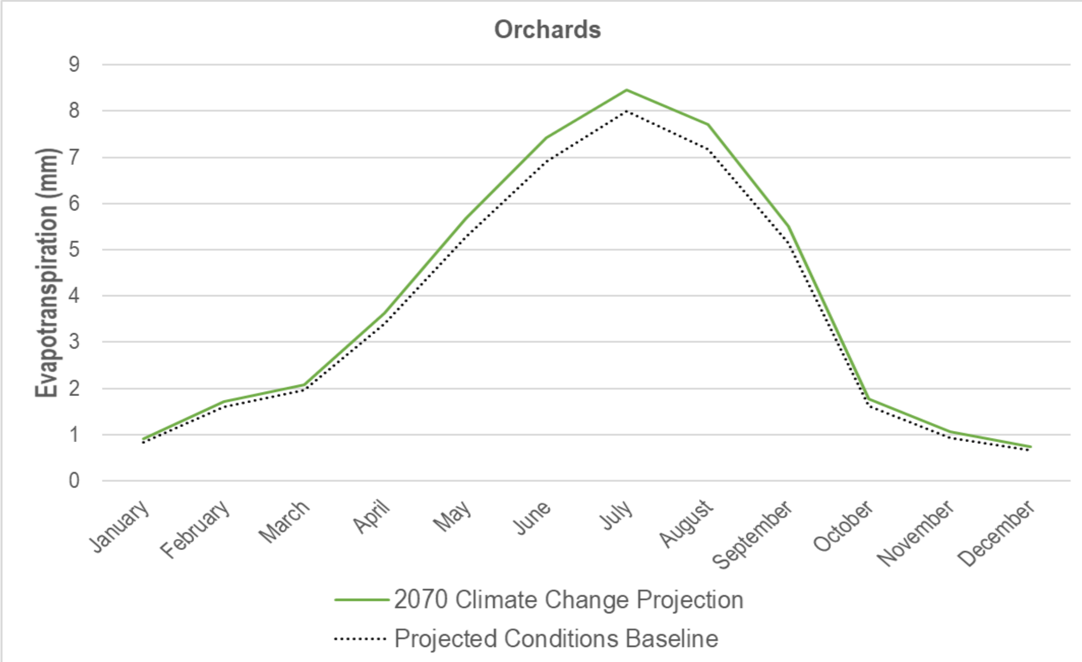


Figure 5-48 demonstrates that in 2070 with climate change added, in low precipitation months, there is approximately equal probability that the month will be wetter or drier than projected conditions baseline. However, under climate change, the 2070 conditions will be wetter in months with precipitation above approximately 50 mm, indicated by the vertical gray dashed line. Therefore, under climate change conditions (in the scenario selected for the GSP), we can see that the occurrence of low precipitation months will likely not change significantly, but the higher precipitation months are predicted to be wetter overall than the projected conditions baseline.

5.2.3.2.2. Applying Change Factors to Evapotranspiration

Potential ET in the Modesto Subbasin is aggregated to one of twenty-five land use categories but does not vary spatially. DWR provides change factors for ET in the same spatially distributed manner as precipitation, as described above. However, to match the level of discretization with the C2VSimTM, an average ET change factor was calculated across all VIC grid cells within the Modesto Subbasin boundary. Therefore, the tool to process ET provided by DWR was not needed or used. Change factors provided by DWR for November 1, 1964, through December 1, 2011, were averaged. This average ET change factor was then applied to the baseline ET time series for each crop type. Because the same ET change factor was applied over the entire baseline, no synthesis was required in this analysis. Refinement to the simulated evapotranspiration of orchards under 2070 climate conditions is shown in **Figure 5-49** below as an example. For 2070, the average change factor is 1.08.

Figure 5-49: Monthly ET for Sample Crops



5.2.3.3. Modesto Subbasin Water Budget Under Climate Change

A climate change scenario was developed for the C2VSimTM to evaluate the hydrological impacts under these conditions. The analysis was based on the projected conditions baseline with climate change perturbed inputs for streamflow, precipitation, and ET. Results are presented below in **Table 5-12** though **Table 5-14**.

Under the climate change scenario, the average annual volume of evapotranspiration is over six percent higher than the projected conditions baseline, increasing from 536,000 AFY to 568,000 AFY. Due to changes to local hydrology, the average annual surface water availability is projected to decrease by 1.6 percent from 293,000 AFY to 288,000 AFY.[4] As a result of less surface water and increased agricultural demands, private groundwater production is simulated to increase by approximately 14 percent, from 230,000 AFY to 262,000 AFY. Under climate change conditions, depletion in aquifer storage is expected to increase by more than half to an average annual rate of 17,000 AFY, from 11,000 AFY in the projected conditions baseline. This has an impact on the stream system and the net difference in stream-aquifer interactions, drawing 46,000 AFY on average from streamflow to the aquifer.

A graphical representation of simulated changes to evapotranspiration, surface deliveries, and groundwater pumping are presented in **Figure 5-50** though **Figure 5-52** below, and

[4] There are various approaches to estimating the effects of climate change on local hydrology. The 2070 Central Tendency used in this GSP according to DWR guidelines for GSP submittal may differ from local studies or certain Flood-MAR scenarios.

complete water budgets for the climate change scenario are shown in **Figure 5-53** though **Figure 5-55**.

Figure 5-50: Simulated Changes in Evapotranspiration due to Climate Change (Scenario minus Baseline)

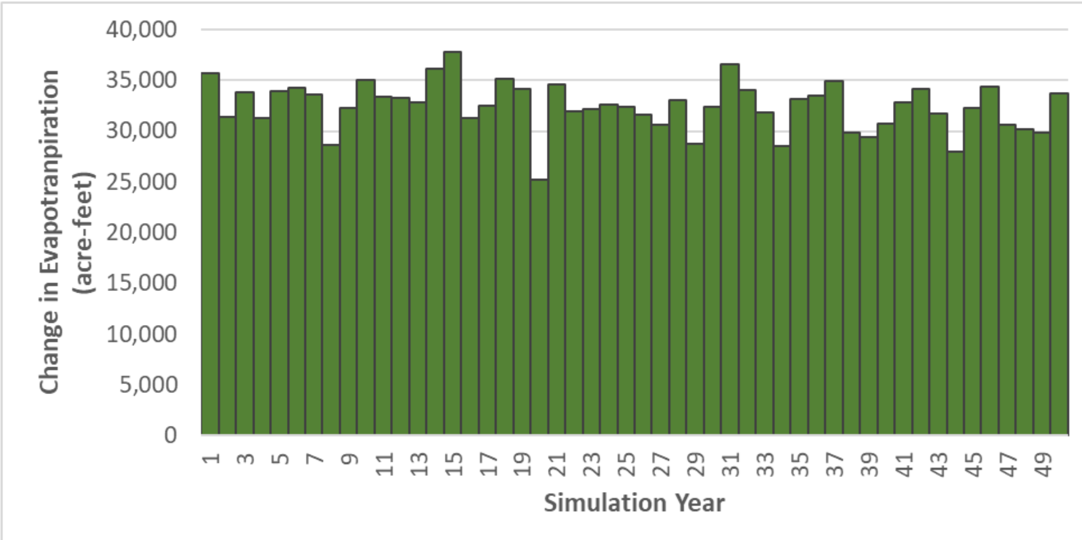


Figure 5-51: Simulated Changes in Surface Water Supplies due to Climate Change (Scenario minus Baseline)

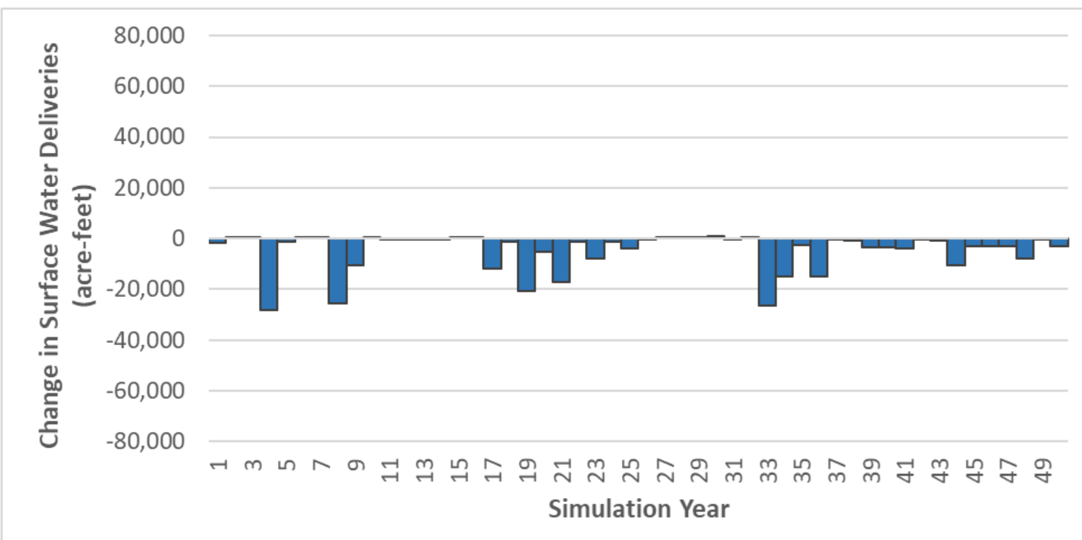


Figure 5-52: Simulated Changes in Groundwater Production due to Climate Change (Scenario minus Baseline)

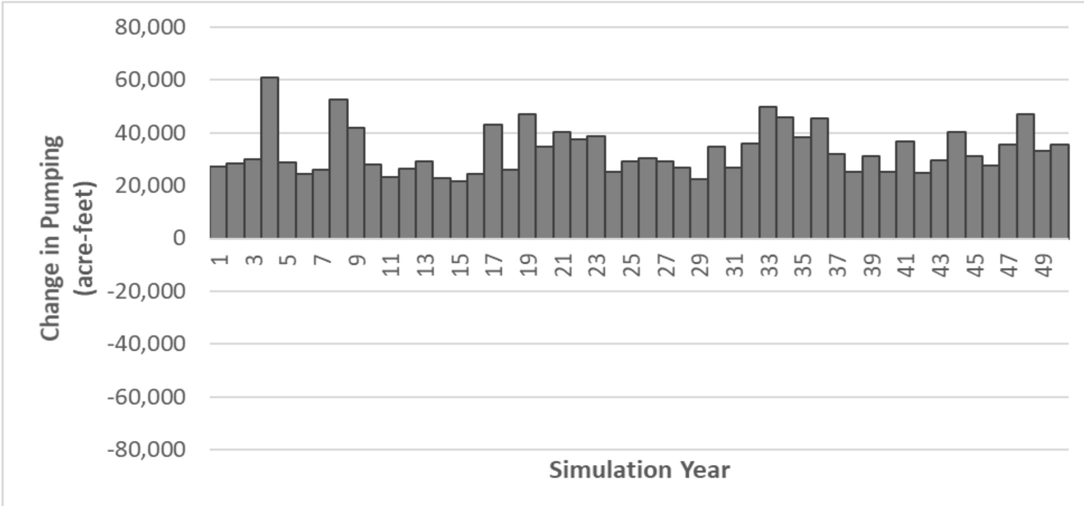


Figure 5-53: Agricultural Land and Water Use Budget – C2VSimTM Climate Change Scenario

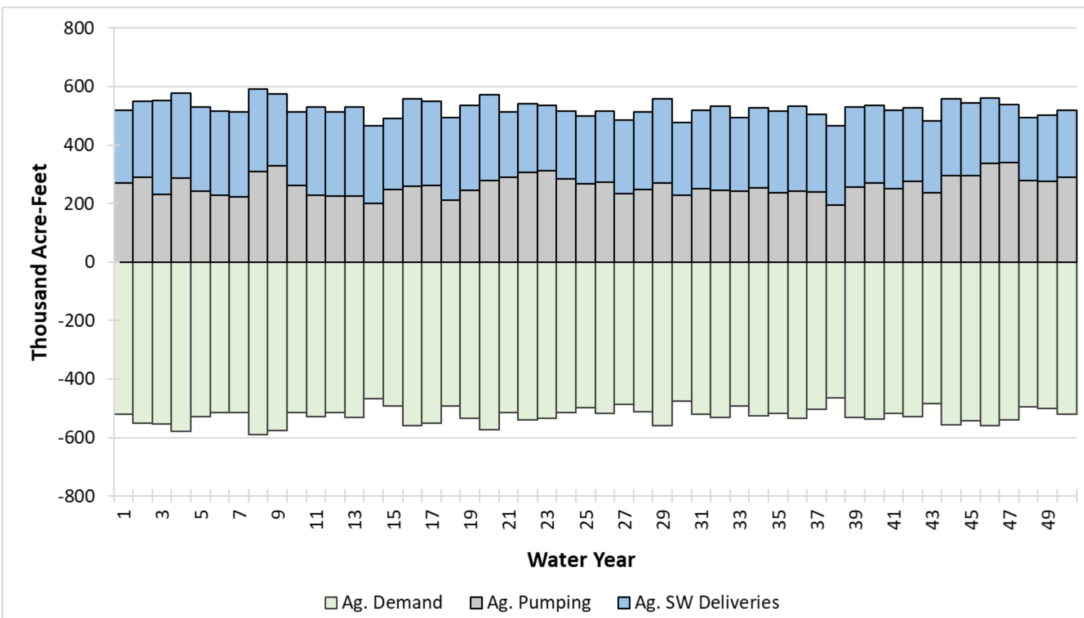


Figure 5-54: Urban Land and Water Use Budget – C2VSimTM Climate Change Scenario

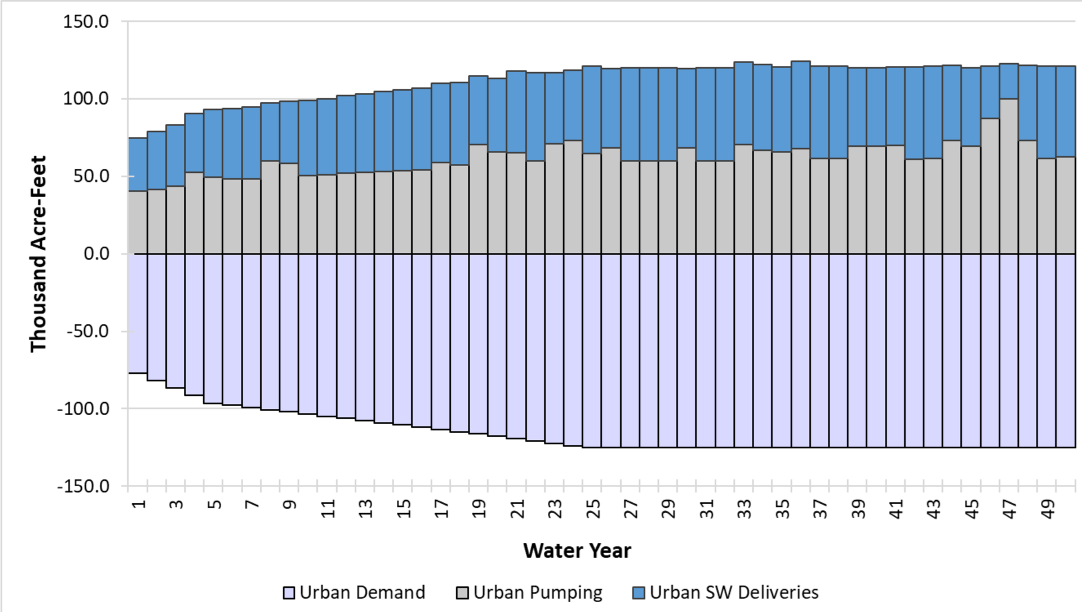


Figure 5-55: Groundwater Budget – C2VSimTM Climate Change Scenario

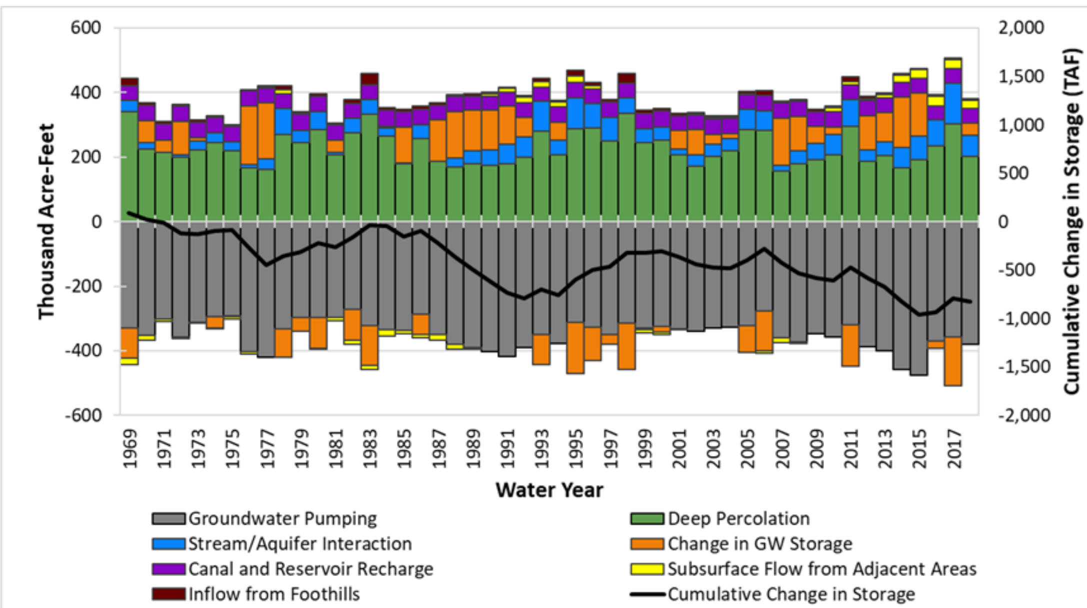


Table 5-~~12:~~ -13: Average Annual Water Budget Under Climate Change – Stream Systems, Modesto Subbasin (AFY)

Component	Projected Condition Water Budget	Climate Change Water Budget
Hydrologic Period	WY 1969 - 2018	WY 1969 - 2018
Stream Inflows	2,650,000	2,739,000
Stanislaus River	536,000	626,000
Tuolumne River	812,000	818,000
San Joaquin River	1,302,000	1,295,000
Tributary Inflow[1]	6,000	5,000
Stream Gain from Groundwater	104,000	96,000
Modesto Subbasin	50,000	45,000
Stanislaus River – South[2]	12,000	13,000
Tuolumne River - North	27,000	22,000
San Joaquin River - East	11,000	11,000
Other Subbasins	54,000	50,000
Stanislaus River - North	12,000	13,000
Tuolumne River - South	31,000	27,000
San Joaquin River - West	11,000	11,000
Surface Runoff to the Stream System[3]	60,000	72,000
Return Flow to Stream System[3]	113,000	114,000
Total Inflow	**2,934,000**	**3,025,000**
San Joaquin River Outflows	2,717,000	2,774,000
Diverted Surface Water[4]	33,000	33,000
Stream Seepage to Groundwater	146,000	177,000
Modesto Subbasin	76,000	91,000
Stanislaus River - South	36,000	44,000
Tuolumne River - North	38,000	45,000
San Joaquin River - East	2,000	2,000
Other Subbasins	71,000	86,000
Stanislaus River - North	31,000	39,000
Tuolumne River – South	38,000	45,000
San Joaquin River - West	2,000	2,000
Native & Riparian Uptake from Streams	37,000	41,000
Total Outflow	**2,934,000**	**3,025,000**

Note: sub-categories may not sum together due to rounding error

1 Tributary inflow include surface water contributions from small watersheds
2 Represents the location of the Modesto Subbasin relative to the stream, i.e., "North" represents the gains/losses of that stream to the Modesto Subbasin to the North.
3 Includes runoff/return flow from all subbasins adjacent to the stream system, not just the Modesto Subbasin.
4 Some surface water diversions are upstream of the Tuolumne River or Stanislaus River inflows and thus not included in this stream and canal water budget.

Table 5-~~13:~~ -14: Average Annual Water Budget Under Climate Change – Land Surface System, Modesto Subbasin (AFY)

Component	Projected Condition Water Budget	Climate Change Water Budget
Hydrologic Period	WY 1969 - 2018	WY 1969 - 2018
Agricultural Areas Precipitation	139,000	147,000
Agricultural Water Supply	497,000	525,000
Agency Surface Water	241,000	238,000
Agency Groundwater	25,000	25,000
Private Groundwater	230,000	262,000
Urban Areas Precipitation	38,000	40,000
Urban Water Supply	111,000	112,000
Groundwater	60,000	62,000
Surface Water	51,000	50,000
Native Areas Precipitation	92,000	97,000
Native & Riparian Uptake from Stream	22,000	24,000
Total Supplies	**900,000**	**945,000**
Agricultural ET	402,000	430,000
Agricultural ET of Precipitation	82,000	84,000
Agricultural ET of Surface Water	159,000	160,000
Agricultural ET of Agency Groundwater	16,000	17,000
Agricultural ET of Private Groundwater	146,000	170,000
Agricultural Percolation	201,000	202,000
Agricultural Percolation of Precipitation	45,000	46,000
Agricultural Percolation of Surface Water	75,000	70,000
Agricultural Percolation of Agency Groundwater	8,000	7,000
Agricultural Percolation of Private Groundwater	73,000	79,000
Agricultural Runoff & Return Flow	31,000	36,000
Urban Runoff & Return Flow	91,000	93,000
Urban ET	38,000	40,000
Urban Percolation	20,000	19,000
Native Runoff	12,000	15,000
Native ET	95,000	98,000
Native Percolation	7,000	8,000
Total Demands	**898,000**	**941,000**
Land Surface System Balance	2,000	4,000
Land Surface System Balance (% of supplies)	0.2%	0.4%

Note: sub-categories may not sum together due to rounding error

Table 5-~~14:~~ -15: Average Annual Water Budget Under Climate Change – Groundwater System, Modesto Subbasin (AFY)

Component	Projected Condition Water Budget	Climate Change Water Budget
Hydrologic Period	WY 1969 - 2018	WY 1969 - 2018
Gain from Stream	76,000	91,000
Gain from Stanislaus River	36,000	44,000
Gain from Tuolumne River	38,000	45,000
Gain from San Joaquin River	2,000	2,000
Canal & Reservoir Recharge	47,000	47,000
Deep Percolation	228,000	229,000
Subsurface Inflow	77,000	80,000
Flow from the Sierra Nevada Foothills	9,000	8,000
Eastern San Joaquin Subbasin Inflows	28,000	8,000
Turlock Subbasin Inflows	33,000	33,000
Delta Mendota Subbasin Inflows	7,000	32,000
Total Inflow	**428,000**	**446,000**
Discharge to Stream	50,000	45,000
Discharge to Stanislaus River	12,000	13,000
Discharge to Tuolumne River	27,000	22,000
Discharge to San Joaquin River	11,000	11,000
Subsurface Outflow	75,000	70,000
Eastern San Joaquin Subbasin Outflows	35,000	5,000
Turlock Subbasin Outflows	34,000	31,000
Delta Mendota Subbasin Outflows	6,000	35,000
Groundwater Production	314,000	347,000
Agency Ag. Groundwater Production	25,000	25,000
Private Ag. Groundwater Production	229,000	260,000
Urban Groundwater Production	60,000	62,000
Total Outflow	**438,000**	**463,000**
Change in Groundwater in Storage	(11,000)	(17,000)

Note: sub-categories may not sum together due to rounding error

Table 5-166 shows the minimum, maximum and averages numbers by Water Year Type for the groundwater budget components in the Climate Change scenario. The net change in groundwater storage indicates a maximum increase in storage of 157,800 AF in a wet year and a worst-case scenario decrease in storage of 183,200 AF in a critically dry year. Compared to the Projected Conditions, there is more groundwater storage loss as a result of higher temperatures and evapotranspiration rates, and less precipitation.

Table 5-16. Average and Range of annual values for components of Groundwater Budget by Water Year Type under the Climate Change Scenario (AFY)

Component		Wet	Above Normal	Below Normal	Dry	Critical
Net Stream Seepage (+)	Min	27,900	20,600	400	1,100	200
	Avg	63,200	37,400	38,200	27,500	40,300
	Max	125,400	62,300	65,000	79,400	73,100
Canal and Reservoir Recharge (+)	Min	43,900	46,900	45,200	43,700	43,100
	Avg	47,000	48,300	47,400	46,500	45,200
	Max	48,700	49,500	50,100	49,400	47,800
Deep Percolation (+)	Min	218,700	206,700	193,000	171,600	156,500
	Avg	284,300	237,200	203,000	201,000	180,400
	Max	339,400	264,900	214,800	235,800	206,300
Net Subsurface Flows (+)	Min	-200	-11,700	-2,000	-5,200	-10,500
	Avg	15,200	1,000	11,400	6,800	9,100
	Max	39,200	17,000	30,800	34,300	32,100
Groundwater Pumping (-)	Min	272,300	297,700	301,600	296,000	350,800
	Avg	315,000	329,700	339,600	342,900	399,800
	Max	357,300	357,000	380,900	387,300	474,800
Change in Groundwater Storage	***Min***	***3,500***	***-67,600***	***-51,800***	***-111,500***	***-183,200***
	Avg	***94,700***	***-5,800***	***-39,500***	***-61,100***	***-124,800***
	Max	***157,800***	***41,700***	***-31,100***	***24,200***	***-57,300***

5.2.3.4. Opportunities for Future Refinement

The climate change approach developed for this GSP is based on the methodology in DWR's guidance document (DWR, 2018b) and uses "best available information" related to climate change in the Modesto Subbasin. There are limitations and uncertainties associated with the analysis. One important limitation is that CalSim II does not fully simulate local surface water operations. Thus, the analysis conducted for this GSP may not fully reflect how surface and groundwater basin operations would respond to the changes in water demand and availability caused by climate change. For this first GSP iteration, use of a regional model and the perturbation factor approach were deemed appropriate given the uncertainties in the climate change analysis.

A recommendation for future refinements of this analysis is utilization of the local surface water operations model, the Tuolumne Reservoir Simulation (TRS) model. Use of this model would allow for greater resolution in the simulation of Tuolumne River flows and surface water supply based on local management. Additionally, utilization of TRS will allow for analysis of the localized climate conditions effecting snowpack and its implications on reservoir operations and streamflow. Further monitoring and adaptive management should be considered for the next update of the GSP along with improvements in DWR's climate change data.

5.3. SUSTAINABLE YIELD ESTIMATE

Sustainable yield is defined for SGMA purposes as "the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result." (CWC §10721(w)). Sustainable yield for the Modesto Subbasin was calculated through development of a C2VSimTM scenario in which the long-term (50-year) SGMA sustainability indicators are met either directly or by groundwater levels as a proxy as outlined in **Chapter 6: Sustainable Management Criteria**.

- **Reduction of Groundwater in Storage –** An Undesirable result is defined as significant and unreasonable reduction of groundwater in storage that would occur if the volume of groundwater supply is at risk of depletion and is not accessible for beneficial use, or if the Subbasin remains in a condition of long-term overdraft based on projected water use and average hydrologic conditions. in a manner that cannot be readily managed or mitigated.
- **Chronic Lowering of Groundwater Levels** – Undesirable results are defined as significant and unreasonable groundwater level declines – either due to multi-year droughts or due to chronic declines where groundwater is the sole supply – such that water supply wells are adversely impacted in a manner that cannot be readily managed or mitigated.
- **Depletion of Interconnected Surface Water –** An Undesirable Result is defined as significant and unreasonable adverse impacts to the beneficial uses of surface water caused by groundwater extraction.

The sustainable yield water budget is based on the Projected Conditions Baseline and is analyzed by reducing groundwater production through changes in the agricultural demand of the net groundwater extractors in Modesto Subbasin. Net-contributing and net-extracting users in the Subbasin are divided into the two groups shown in **Figure 5-56**. Group 1 users predominately rely on both surface and groundwater, while users in Group 2 predominantly rely on groundwater.

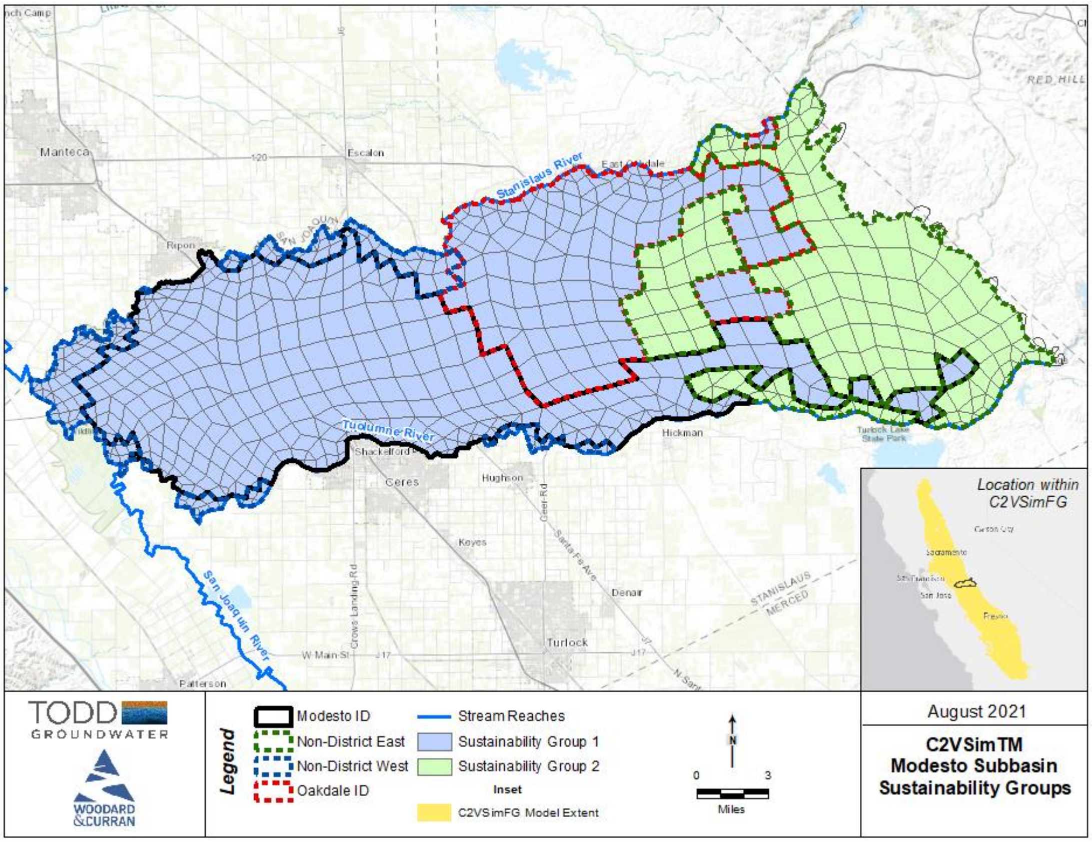
Group 1: Surface and Groundwater Users

- Modesto Irrigation District
- Oakdale Irrigation District
- Non-District West (riparian surface water users)

Group 2: Groundwater Only Users

- Non-District East

Figure 5-56: Modesto Subbasin Sustainability Groups



The Sustainable Yield Scenario varies from the Projected Conditions Baseline in its volume of agricultural water demand. These demands were reduced by decreasing agricultural land use via a global reduction in projected cropped acreage at the element level.

The sustainable yield water budget is intended to estimate future supply, demand, and aquifer response in the Modesto Subbasin under sustainable conditions achieved with a demand reduction scenario. To meet the goals set forth by the sustainability indicators listed above, Group 2 agricultural users would need to reduce demand by 58-percent from the projected baseline levels. This reduction in groundwater usage results in a sustainable yield of approximately 267,000 acre-feet per year for the Subbasin.

The methodology for reducing Subbasin-wide pumping to estimate sustainable yield is developed solely to estimate the subbasin's sustainable yield and is not intended to prescribe or describe how pumping would be reduced in the basin during GSP implementation to achieve sustainability. The reduction of groundwater demand to sustainable levels would be implemented in close coordination among the various Subbasin zones. The groundwater demand reduction is only one and/or part of the overall management actions that would result in groundwater sustainability within the Subbasin; factors such as water rights, beneficial uses, needs, and human right to water should also be considered. The status of plans for implementing management actions related to pumping reductions is further discussed in **Chapter 8 - Projects and Management Actions**.

Table 5-15 provides a detailed listing of the water flow components of the Modesto Subbasin's groundwater system for the historical, projected conditions baseline and sustainable yield conditions. To achieve sustainability and maintain minimum groundwater level thresholds, the Subbasin needs to experience an average annual net gain of groundwater in storage of 11,000 AFY. These conditions are met through 213,000 AFY of deep percolation, 47,000 AFY of canal and reservoir recharge, and 20,000 AFY of net subsurface inflow from the Sierra Nevada foothills and the neighboring Turlock, Delta-Mendota, and Eastern San Joaquin Subbasins. Outflows from the subbasin include 266,000 AFY of pumping and 14,000 AFY of net groundwater discharge to the surface water bodies. The major flow components are represented graphically in **Figure 5-57** and **Figure 5-58**, on an annual and average annual basis.

Figure 5-59 and **Figure 5-60** show the groundwater recharge and extraction and net recharge for the Modesto Subbasin. Under sustainable conditions, the Modesto Subbasin is expected to maintain an average net extraction of 7,000 AFY, compared to a net extraction of 39,000 AFY under projected conditions. This reduction in net extraction is attributed to the reduction of groundwater pumping, which is reduced from 314,000 AFY under the Baseline to 267,000 AFY under sustainable yield, combined with an overall reduction in percolation of agricultural applied water of 14,000 AFY between the two scenarios.

Table 5-~~15:~~ -17: Sustainable Yield Average Annual Water Budget Groundwater System – Modesto Subbasin

Component	Projected Conditions	Sustainable Conditions
Hydrologic Period	Hydrology from WY 1969 - 2018	Hydrology from WY 1969 - 2018
Gain from Stream	76,000	58,000
Gain from Stanislaus River	36,000	27,000
Gain from Tuolumne River	38,000	29,000
Gain from San Joaquin River	2,000	1,000
Canal & Reservoir Recharge	47,000	47,000
Deep Percolation	228,000	213,000
Subsurface Inflow	77,000	83,000
Flow from the Sierra Nevada Foothills	9,000	9,000
Eastern San Joaquin Subbasin Inflows	28,000	9,000
Turlock Subbasin Inflows	33,000	29,000
Delta Mendota Subbasin Inflows	7,000	37,000
Total Inflow	**428,000**	**401,000**
Discharge to Stream	50,000	71,000
Discharge to Stanislaus River	12,000	18,000
Discharge to Tuolumne River	27,000	40,000
Discharge to San Joaquin River	11,000	14,000
Subsurface Outflow	75,000	63,000
Eastern San Joaquin Subbasin Outflows	35,000	4,000
Turlock Subbasin Outflows	34,000	30,000
Delta Mendota Subbasin Outflows	6,000	30,000
Groundwater Production	314,000	267,000
Agency Ag. Groundwater Production	25,000	25,000
Private Ag. Groundwater Production	229,000	181,000
Urban Groundwater Production	60,000	60,000
Total Outflow	**438,000**	**401,000**
Change in Groundwater in Storage	(11,000)	-

Note: sub-categories may not sum together due to rounding error

Table 5-188 shows the minimum, maximum and averages numbers by Water Year Type for the groundwater budget components in the Sustainable Yield scenario. The net change in groundwater storage indicates a maximum increase in storage of 194,100 AF in a wet year and a worst-case scenario decrease in storage of 150,400 AF in a critically dry year. Compared with the Projected Conditions, there is a greater increase in groundwater storage as a result of the reduction in water demand.

Table 5-18. Average and Range of annual values for components of Groundwater Budget Under the Sustainable Yield by Water Year Type (AFY)

Component		Wet	Above Normal	Below Normal	Dry	Critical
Net Stream Seepage (+)	Min	-14,900	-39,500	-33,400	-56,200	-62,700
	Avg	8,800	-20,200	-20,400	-34,700	-22,500
	Max	55,600	-8,400	-8,400	9,000	6,500
Canal and Reservoir Recharge (+)	Min	45,200	46,900	45,700	45,100	43,500
	Avg	47,100	48,400	47,800	48,300	46,200
	Max	48,600	49,600	50,100	50,000	48,800
Deep Percolation (+)	Min	211,100	184,800	172,900	158,700	144,400
	Avg	264,900	221,200	190,000	187,700	165,300
	Max	348,900	250,200	227,900	214,500	192,300
Net Subsurface Flows (+)	Min	9,000	100	12,700	5,400	-200
	Avg	26,900	13,100	21,900	15,500	18,700
	Max	48,000	26,900	39,700	43,600	42,800
Groundwater Pumping (-)	Min	208,900	226,400	223,400	218,800	255,900
	Avg	242,800	254,300	257,600	249,900	314,800
	Max	279,300	284,100	298,900	298,300	390,900
Change in Groundwater Storage	***Min***	***34,300***	***-33,800***	***-44,800***	***-88,200***	***-150,400***
	Avg	***105,000***	***8,300***	***-18,200***	***-33,200***	***-107,200***
	Max	***194,100***	***57,900***	***46,000***	***33,000***	***-46,400***

Figure 5-57: Sustainable Yield Average Annual Water Budget Groundwater System – Modesto Subbasin

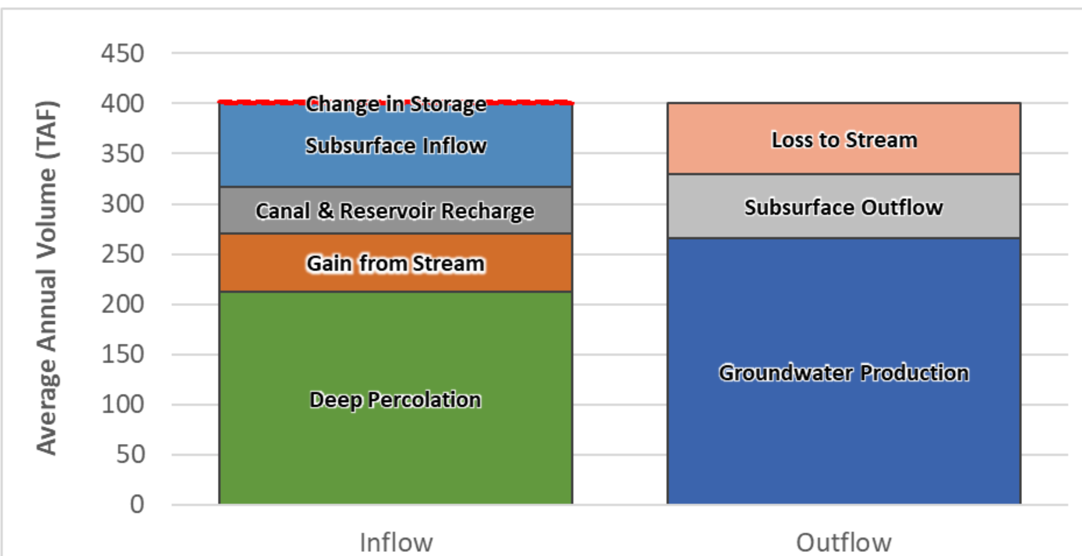


Figure 5-58: Sustainable Yield Water Budget Groundwater System – Modesto Subbasin

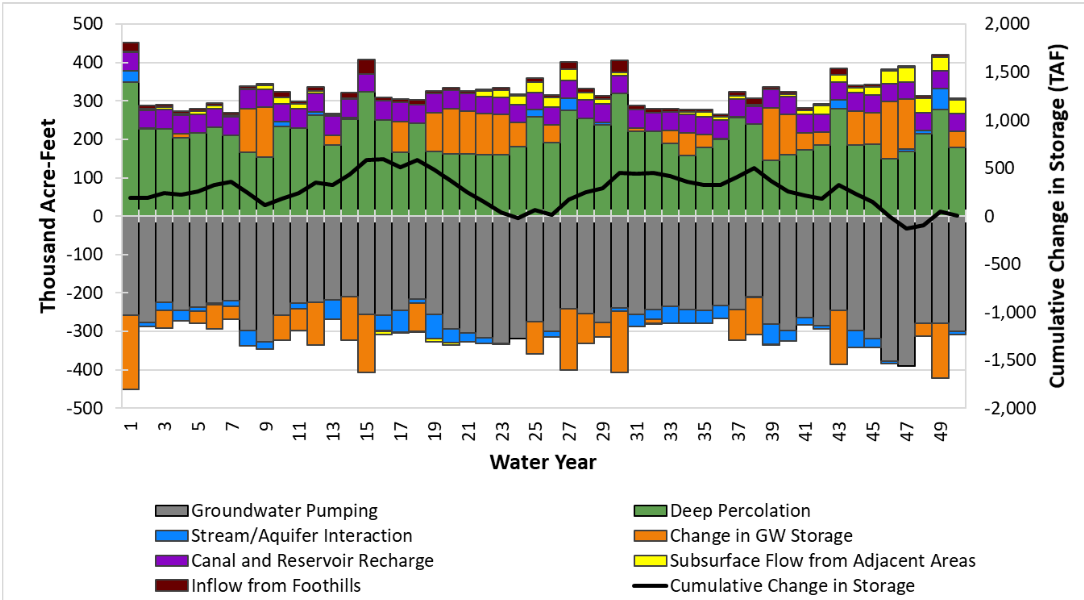


Figure 5-59: Sustainable Yield Water Budget Groundwater Recharge and Extraction – Modesto Subbasin

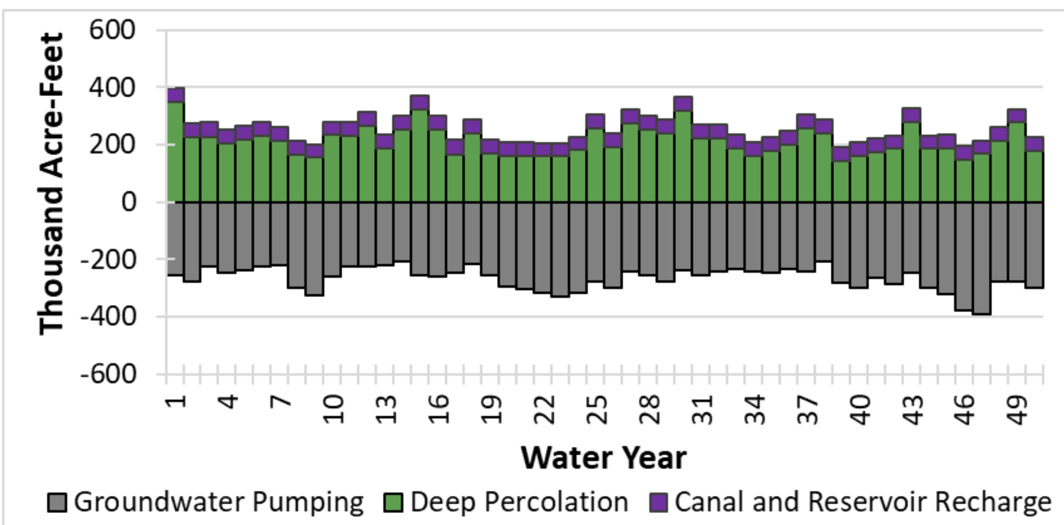
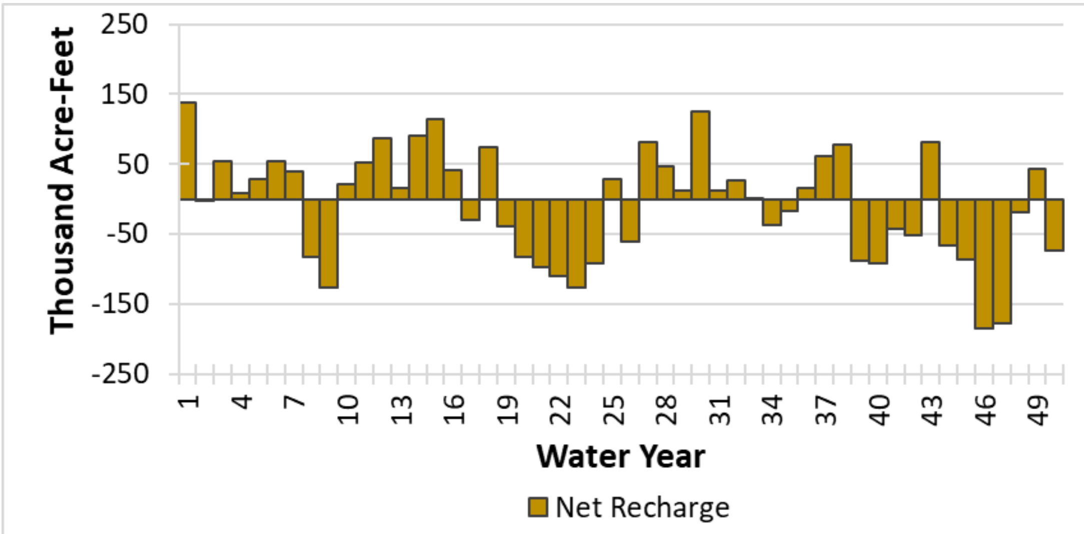


Figure 5-60: Sustainable Yield Water Budget Net Recharge – Modesto Subbasin



SUMMARY

The sustainable yield of the Modesto Subbasin is developed by methodically reducing groundwater demand for the net groundwater extractors (Sustainability Group 2) in the Subbasin. The goal of this groundwater demand reduction is to reduce groundwater pumping to a level that would result in no undesirable results if continued in the long-term. The presence of undesirable results is evaluated by analyzing sustainability indicators produced by the numerical model, including groundwater in storage, groundwater levels, and interconnected stream systems. It is assumed that by using groundwater levels as proxy for other applicable sustainability indicators (i.e., groundwater quality and land subsidence), the sustainable yield would address all applicable sustainability indicators in the Modesto Subbasin.

This analysis results in a sustainable yield of 267,000 AFY for the Modesto Subbasin.

The sustainable yield is based on the current and latest data and information for the ~~subbasin~~Subbasin. It is expected that the sustainable yield estimate would be updated for the next GSP update in 2027, as additional data and information become available on the operation of the Subbasin, implementation of projects and management actions, groundwater levels, storage, and quality, and as updates to the tools and technology, such as updates to the integrated numerical model are implemented.