4 WATER BUDGETS

This section summarizes the estimated water budgets for the Subbasin, including information required by the GSP Regulations and other information supporting development of an effective sustainability plan. In accordance with the GSP Regulations §354.18, this water budget provides an accounting and assessment of the total annual volume of surface water and groundwater entering and leaving the subbasin, including historical, current, and projected water budget conditions, and the change in the volume of groundwater in storage. Water budgets are reported in graphical and tabular formats, where applicable. The Revised GSP addresses the current estimate of the annual change in storage related to overdraft. A complete and comprehensive water budget analysis for current and future conditions will be conducted as part of the 5-year Periodic Evaluation in January 2027.

4.1 Overview of Water Budget Development

The GSP Regulations require the development of a subbasin-wide groundwater budget, and a subbasin-wide surface water budget. In agricultural areas such as the Corning Subbasin, a land surface budget is an additional useful element to review to assess changes in water demands over time and evaluate the water demand versus water supply balance due to climatic variations and land use changes. The land surface budget also ties certain components together from the groundwater budget and the surface water budget, allowing identification of interim steps in water use.

The water budget descriptions are divided into 3 subsections: (1) historical water budgets, (2) current water budgets, and (3) projected water budgets. Within each subsection, a groundwater budget, a land surface budget, and a surface water budget are presented. Each water budget is described by providing a brief summary of key observations of trends over time, and relative contribution to the water budget by different components, to emphasize what portions of the water budget have the most and least influence on the water resources conditions in the Subbasin. A table summarizing the amount of water contributed by each component is provided in addition to a graphical representation of the water budget components over time, on an annual basis. Each subsection follows the same format.

Water budgets were developed using a modified version of the C2VSimFG Version 1.0, developed by DWR (DWR, 2020c). C2VSimFG is an integrated regional hydrologic model that simulates water movement through the land surface, surface water, and groundwater flow systems using the publicly available Integrated Water Flow Model (IWFM) software. The base C2VSimFG model was revised by the GSP Development Team to better represent local land and water use, and to develop more accurate water budgets in the Subbasin. An overview of model refinements implemented for this GSP is provided in Appendix 4A.

Before presenting the water budgets, a brief overview of the inflows and outflows pertaining to the Subbasin is provided.

4.1.1 Water Budget Area and Components

The water budget is an inventory of surface water and groundwater inflows (supplies) and outflows (demands) to and from the Subbasin. Some water budget components can be measured, such as streamflow at a gaging station or municipal groundwater pumping from a metered well. Other components of the water budget are simulated by the model, such as recharge from precipitation, agricultural groundwater pumping, and change of groundwater in storage. The change of groundwater in storage is calculated by the model from simulated inflows minus outflows and is associated with change in groundwater levels.

As described in Section 3-1, the Subbasin is bounded on its northern, southern, and eastern extents by Thomes Creek, Stony Creek, and the Sacramento River, respectively (Figure 4-1). Black Butte Lake also forms a portion of the southern boundary. The western boundary is defined by the westernmost edge of the Tehama Formation. The Subbasin's vertical boundary is defined by the bottom of the Tehama and Tuscan Formations, corresponding with the base of freshwater.

The water budgets for the Subbasin are calculated within the following boundaries:

- Lateral boundaries: The perimeter of the Corning Subbasin. For the purpose of surface water budgets, the surface water bodies constituting Subbasin boundaries are considered to be within the Subbasin.
- Bottom: The base of the model. This also includes simulation of an unpumped saline layer below the Subbasin, roughly representing portions of the Upper Princeton Valley Fill and Great Valley Sequence. The water budget is not sensitive to the exact definition of Subbasin bottom, because it is defined as a depth below which there is not significant inflow, outflow, or change in storage.
- Top: Above the ground surface, such that surface water is included in the water budget.

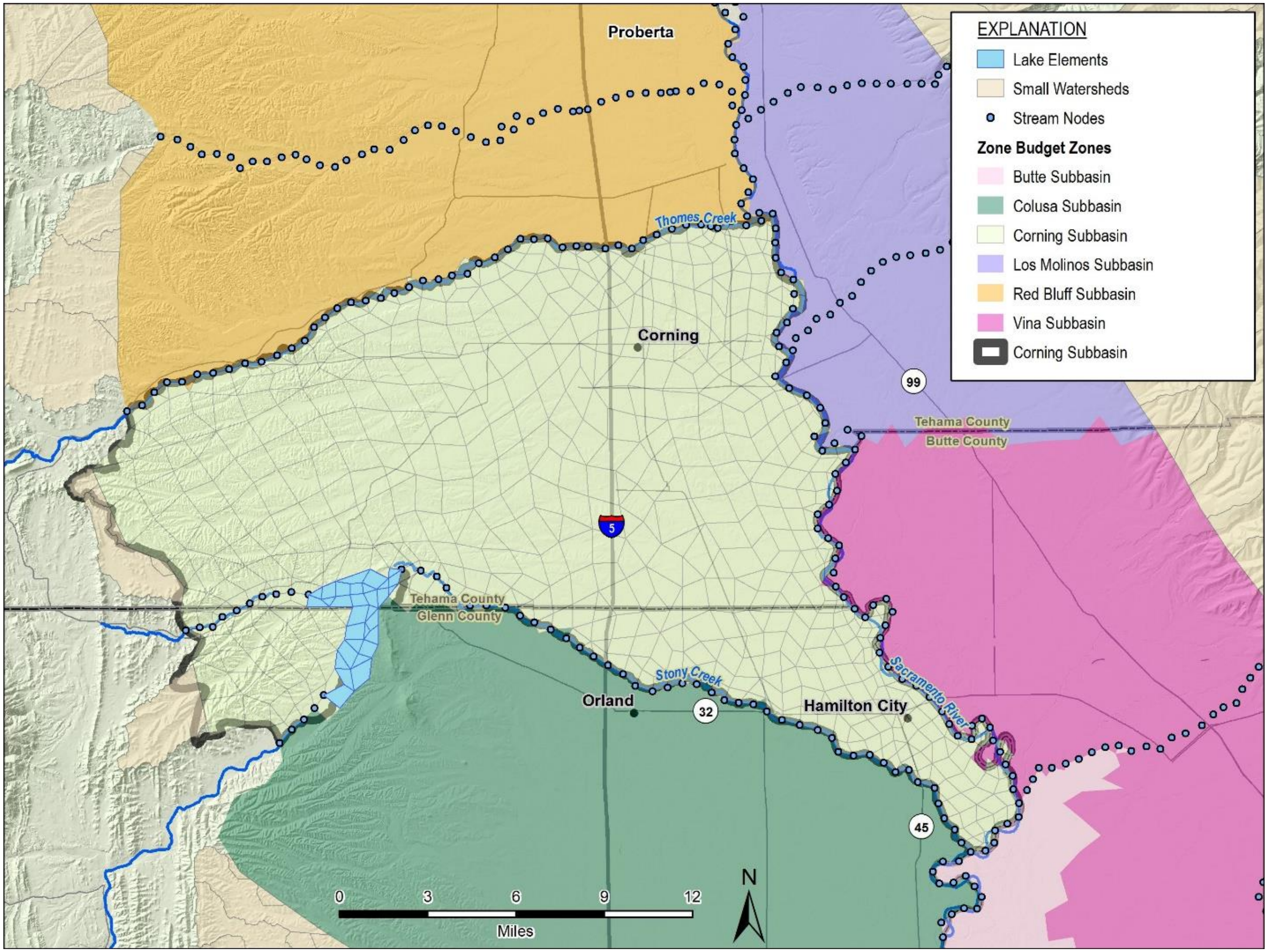

Figure 4-1. Corning Subbasin Water Budget Area

Figure 4-2 presents the general schematic diagram of the hydrologic cycle that is included in the water budget BMP (DWR, 2016c). Not all of the components represented in this graphic apply to the Corning Subbasin, and the specific components relevant to this GSP are presented in the subsections below.

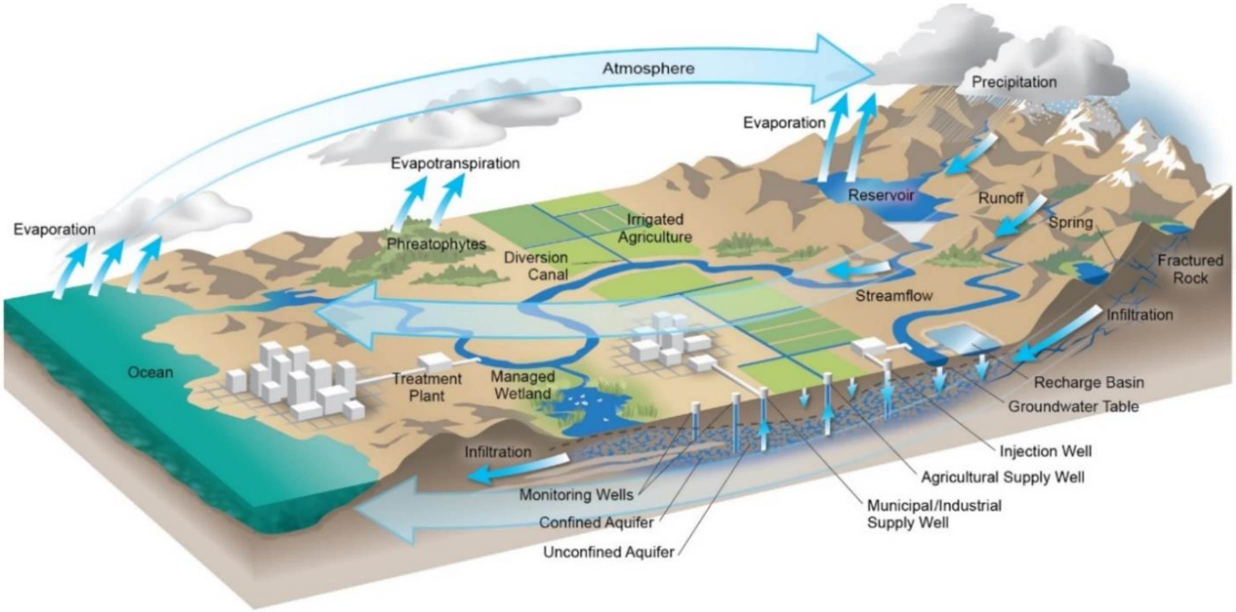

Figure 4-2. Schematic Hydrologic Cycle (DWR, 2016c)

During GSP development, technical coordination among Northern Sacramento Valley GSP Development Teams occurred to share information and understanding of HCMs, integrated hydrologic models, and water budgets. Specifically, teams compared simulated cross-boundary flows and stream-aquifer interaction flows to verify results for overlapping models. The neighboring models predict the same direction for net boundary flows between subbasins, and also generally predict similar gaining and losing conditions at streams that create subbasin boundaries. The flow values are within general orders of magnitude, but a more detailed review of model inputs, assumptions, and results will help further refine Subbasin and neighboring models, during GSP implementation, as further discussed in Section 8.

The subsections below describe the Subbasin water budgets including the simulated inflow and outflow components. The interaction of these water budget components is presented in Appendix 4B.

4.1.1.1 Groundwater Budget Components

The groundwater budget represents the Subbasin’s flow below the unsaturated zone and is developed by extracting groundwater budget components from the model over the Corning Subbasin zone budget area (Figure 4-1). Evaluation of the groundwater budget provides an understanding of subbasin-wide trends in groundwater use, flows between subbasins, and groundwater-surface water connection.

Groundwater budget components applicable in the Subbasin are summarized below and illustrated on Figure 4-3.

Groundwater Inflows:

- **Deep Percolation to Groundwater** - Recharge from precipitation or irrigation water applied at surface that percolates to groundwater in the saturated zone
- **Subsurface Inflow** - Inter-aquifer flow from neighboring Subbasins into the Subbasin
- **Inflow from Foothills** - Subsurface flow from small watershed aquifers west of the Subbasin to groundwater in the Subbasin
- **Recharge from Black Butte Lake** - Flow which percolates to groundwater from the bed of Black Butte Lake
- **Streambed Recharge** - Flow which percolates to groundwater from stream channels
- **Canal Leakage** – Flow which percolates to groundwater from unlined canals that cross the subbasin. Canal Leakage is simulated as a direct recharge amount to groundwater along the canal alignment. Therefore, it is grouped with Deep Percolation to Groundwater in water budget tables and figures. Any difference between Deep Percolation to Groundwater in the groundwater and land surface budgets thus reflects the inclusion of Canal Leakage

Groundwater Outflows:

- **Subsurface Outflow** - Inter-aquifer flow from the Subbasin to neighboring Subbasins
- **Agricultural Pumping** - Groundwater extracted from wells for use in agriculture irrigation
- **Urban and Domestic Pumping** - Groundwater extracted from wells for domestic and urban use
- **Groundwater Discharge to Streams** - Flow that discharges from groundwater into stream channels

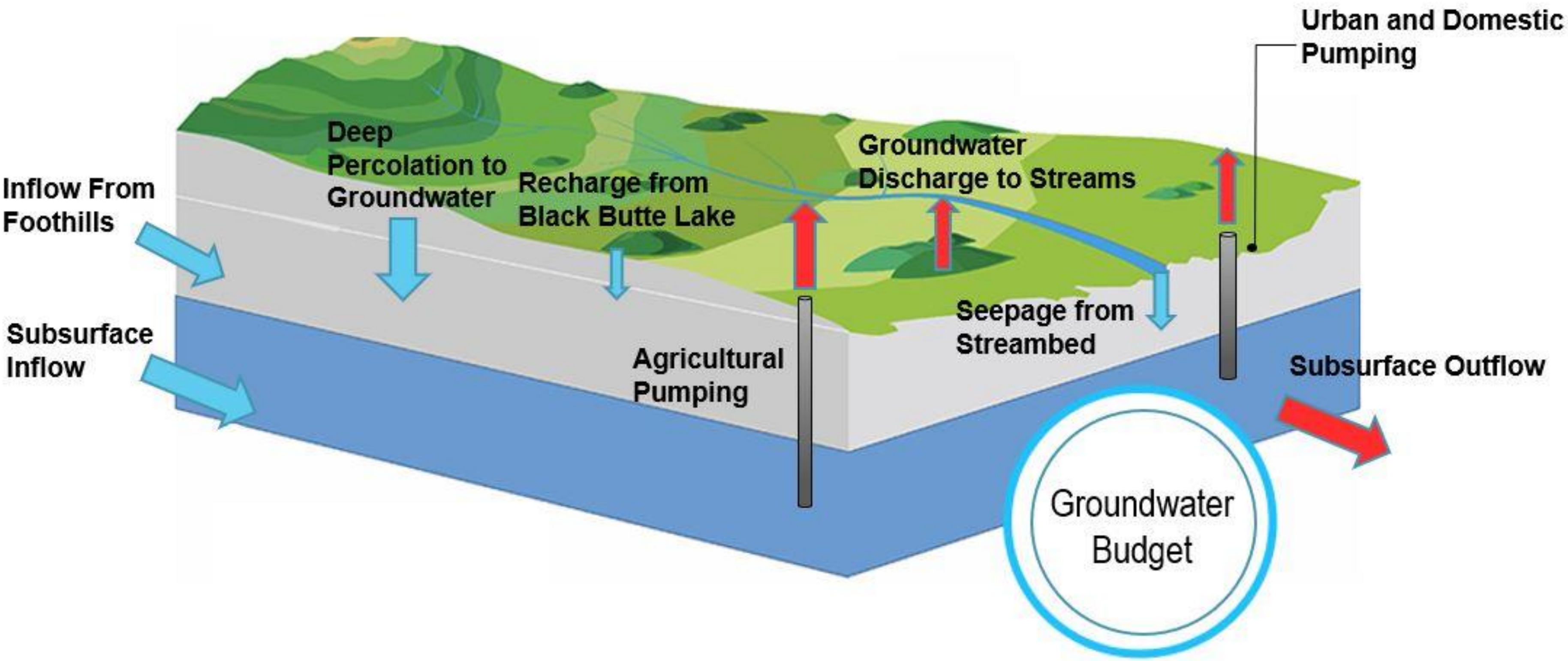

Figure 4-3. Illustration of Groundwater Budget Components

4.1.1.2 Land Surface Budget Components

The land surface budget simulates the Subbasin’s land surface system composed of the soil/land surface, root zone, and unsaturated zone. The land surface budget is developed by extracting land surface budget components from the historical model over the Corning Subbasin zone budget area (Figure 4-1). Evaluation of the land surface budget lends insight into trends in land and water use and the responsiveness of the surficial hydrologic system to inter-annual changes in precipitation.

Land surface budget components applicable in the Subbasin are summarized below and illustrated on Figure 4-4.

Land Surface Inflows:

- **Precipitation -** All precipitation that falls within the Subbasin
- **Applied Groundwater** - Water that is extracted from groundwater and applied to crops in the Subbasin
- **Applied Surface Water** - Water that is diverted from surface water bodies and canals (primarily the Corning Canal) and applied to crops in the Subbasin

Land Surface Outflows:

- **Deep Percolation to Groundwater** - Recharge from precipitation or water applied at surface that percolates to groundwater
- **Evapotranspiration** - Water transpired by crops and native vegetation or evaporated into the atmosphere
- **Overland Flow** - Precipitation that runs off the land surface into surface water bodies. Treated water from the City of Corning Wastewater Treatment Plant is released into the Sacramento River; however, this is not currently included in the model.
- **Irrigation Return Flow to Streams -** Applied agricultural water that runs off the land surface into surface water bodies

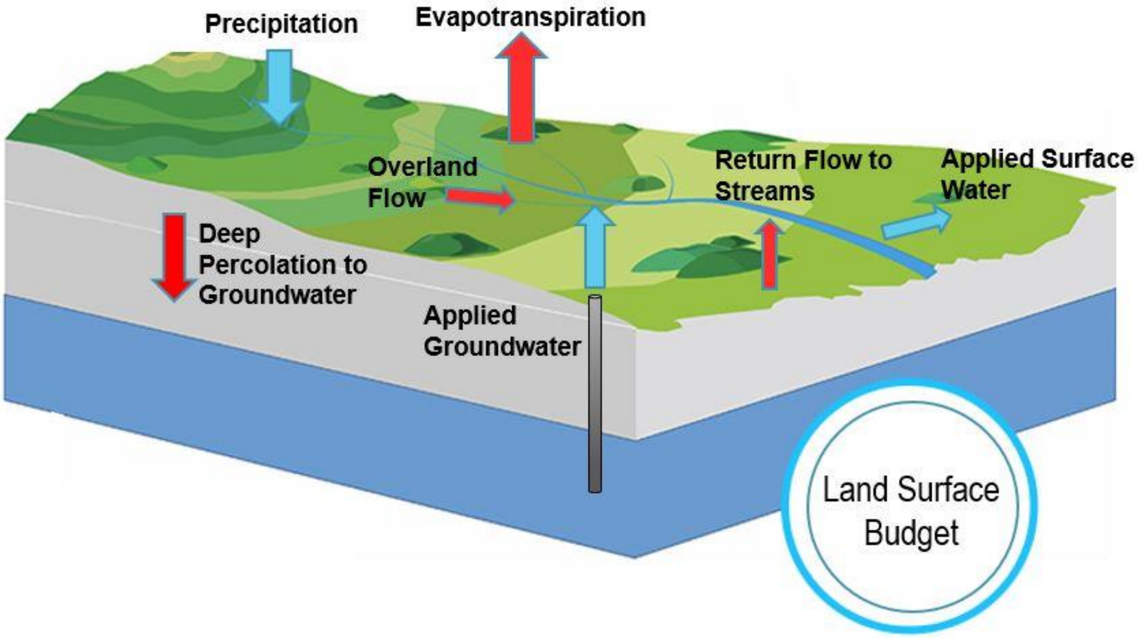

Figure 4-4. Illustration of Land Surface Budget Components

4.1.1.3 Surface Water Budget Components

A Subbasin-wide surface water budget encompassing the surface water bodies bounding and within the Subbasin is required in the GSP Regulations. The surface water budget is developed by extracting surface water budget components from the historical model over Thomes Creek, Stony Creek (including Black Butte Lake), and the Sacramento River, the 3 major streams within the Corning Subbasin (Figure 4-1 and Figure 3-17 in the HCM Section). Three individual stream surface water budgets are also presented, which detail the inflows and outflows for Thomes Creek, Stony Creek, and the Sacramento River. Evaluation of these surface water budgets increases understanding of Subbasin-wide trends in groundwater-surface water connection, surface water use, and the responsiveness of the surface water system to historical climatic variation.

Surface water budget components applicable in the Subbasin are summarized below.

Surface Water Inflows:

- **Inflow from Upstream of Subbasin** - Surface water inflow from major streams outside of the Subbasin into the Subbasin's streams

- **Inflow from Small Tributaries -** Surface water inflow from minor streams outside of the Subbasin into the Subbasin's streams
- **Groundwater Discharge to Streams -** Flow that discharges from groundwater into stream channels. The component of groundwater-surface water interaction where groundwater enters a stream under gaining conditions
- **Overland Flow to Streams** - Precipitation that runs off the land surface into surface water bodies
- **Irrigation Return Flow to Streams** - Applied agricultural water that runs off the land surface into surface water bodies

Surface Water Outflows:

- **Stream Outflow Outside of Subbasin** - Surface water outflow from the Subbasin. In the Corning Subbasin, all surface water flows out through the Sacramento River at the boundary with the Colusa and Butte Subbasins
- **Surface Water Diversions**- Water that is diverted from surface water bodies and applied to crops in the Subbasin
- **Streambed Recharge** - Flow which percolates down to groundwater from stream channels, also known as seepage from streambed. The component of groundwater-surface water interaction where streamflow percolates down to groundwater under losing conditions.
- **Diversion to Glenn-Colusa Canal** - Flow diverted into the Glenn-Colusa Canal (there is also a small diversion going to the M&T Ranch). Note that the Corning and Tehama Colusa Canals diversions are outside of the Corning Subbasin boundary, but are included within the NSac model.
- **Flood Bypass near M&T Ranch** - Flood bypass that diverts high flows from the Sacramento River left (west) bank into Butte Basin which eventually flow to Sutter Bypass.
- **Riparian Evapotranspiration** – Evapotranspiration of surface water by plants along riparian corridors
- **Recharge to Groundwater from Black Butte Lake –** Flow that percolates to groundwater from the bed of Black Butte Lake
- **Black Butte Lake Losses –** Other flow that leaves Black Butte Lake, including lake evapotranspiration and the diversion to the Orland Unit Project (OUP) southside canal that exports water to the Colusa Subbasin.

The difference between inflows and outflows is equal to the change in storage for all water budgets.

4.1.2 Model Assumptions and Limitations for Water Budget Development

Data sources and limitations for the water budget components described above are presented in Table 4-1. Data and interpretation uncertainty associated with the model is further discussed in Appendix 4A. The level of accuracy and certainty is highly variable between water budget components, depending largely on the quality of model input data or available calibration data. Water budget uncertainty may be reduced over time as GSP monitoring programs are implemented and the resulting data are used to check and improve the modeling tools and resulting water budgets. Incorporation of locally refined water budget information may also increase model simulation accuracy.

Table 4-1. Water Budget Components Data Sources and Limitations

Water Budget Component	Source of Model Input Data	Limitations
Land Surface Inflows		
Precipitation	Historical precipitation data as provided by the AN81m dataset from the PRISM	Precipitation is summarized over model element areas and may therefore not capture all variation over the element area
Applied Groundwater	Simulated using land use water demands and surface water applications	Groundwater pumping rates are not derived from measured pumping data. They are estimated from crop acreages, crop water demand estimates, and surface water delivery estimates. Land use was developed on an element scale, and crop water demand estimates were developed on a regional scale.
Applied Surface Water	Historical surface water diversion and delivery data	Derived from available historical records which are not always complete. Partitioning diversions to farm deliveries and losses is estimated.
Land Surface Outflows		
Deep percolation to groundwater	Simulated by model	Estimated, limited data for calibration
Evapotranspiration	Simulated using land use evapotranspiration coefficients	Regional evapotranspiration rates are used for broad crop categories. Actual on-farm rates may differ based on irrigation technology, management practices, crop age and density, and other factors
Overland Flow	Simulated by model	Estimated, limited data for calibration
Irrigation Return Flow to Streams	Simulated by model	Estimated, limited data for calibration
Surface Water Inflows		
Inflow from Upstream of Subbasin	Simulated by model using historical streamflow measurements at stream headwaters and simulated surface water budget components	Subject to limitations in available streamflow measurements and estimates of stream inflows from and outflows to adjacent lands. These include diversions, precipitation, evaporation, runoff, return flows, gains from groundwater, and seepage to groundwater
Inflow from Small Tributaries	Simulated by model	Estimated, there is no gauge data for inflows from the ephemeral streams discharging from upstream watersheds bordering the model
Groundwater Discharge to Streams	Simulated by model	Estimated, limited data for calibration
Overland Flow to Streams	Simulated by model	Estimated, limited data for calibration
Irrigation Return Flow to Streams	Simulated by model	Estimated, limited data for calibration

Water Budget Component	Source of Model Input Data	Limitations
Surface Water Outflows		
Downstream Outflow Outside of Subbasin	Simulated by model using historical streamflow measurements at stream headwaters and simulated surface water budget components	Subject to limitations in available streamflow measurements and estimates of stream inflows from and outflows to adjacent lands. These include diversions, precipitation, evaporation, runoff, return flows, gains from groundwater, and seepage to groundwater
Surface water diversions	Historical surface water diversion and delivery data	Derived from available historical records which are not always complete
Streambed Recharge	Simulated by model	Estimated, limited data for calibration
Black Butte Lake Losses	Simulated by model	Represents multiple lake loss components including lake evaporation and the diversion to the OUP southside canal. Including all uncertainty associated with these components.
Diversion to Glenn-Colusa Canal	Historical surface water diversion and delivery data	
Flood Bypass	Historical time series of bypass flows.	
Groundwater Inflows		
Deep Percolation to Groundwater	Simulated by model	Estimated, limited data for calibration.
Subsurface Inflow	Simulated by model	Subject to uncertainty in simulated heads and aquifer hydraulic properties
Inflow from Foothills	Simulated by model	DWR acknowledges current C2VSim boundary inflows from small watersheds may be too high in the North Sacramento Valley. Limited data is available
Recharge from Black Butte Lake	Simulated by model	Subject to uncertainty in simulated heads and lakebed hydraulic properties
Streambed Recharge	Simulated by model	Estimated, limited data for calibration
Groundwater Outflows		
Subsurface Outflow	Simulated by model	Estimated, limited data for calibration
Agricultural Pumping	Simulated using crop type, crop water demands, and surface water applications	Groundwater pumping rates and depths are not derived from measured pumping data. They are estimated from crop acreages, crop water demand estimates and surface water delivery estimates
Urban and Domestic Pumping	Simulated using urban water demands	Groundwater pumping rates are based on delivery data or on per-capita water use data applied to population data
Groundwater Discharge to Streams	Simulated by model	Estimated, limited data for calibration

4.1.3 Water Budget Time Frames

The GSP Regulations require water budgets for 3 different time frames, representing historical conditions, current conditions, and projected conditions. Although significant seasonal variation is simulated by the model (which operates on a monthly timestep), the GSP does not consider seasonal water budgets. All water budgets are developed for complete water years.

In accordance with the GSP Regulation 23 CCR §354.18(c), the GSP quantifies a current, historical, and projected water budget for the Subbasin, as follows:

- The historical water budget is intended to evaluate how past water supply availability has affected aquifer conditions and the ability of groundwater users to operate sustainably. GSP Regulations require that the historical water budget include at least the most recent 10 years of water budget information (depending on data availability).
- The current water budget is intended to allow the GSA and DWR to understand the existing supply, demand, and change in storage under the most recently available population, land use, and hydrologic conditions.
- The projected water budgets are intended to quantify the estimated future baseline conditions without implementation of GSP projects and management actions. The projected water budgets are based on information from the historical budget and include an assessment of uncertainty due to climate change. The projected water budgets estimate the future baseline conditions concerning hydrology, water demand, and surface water supply over a 50-year planning and implementation horizon. Historical trends in hydrologic conditions are used to project forward 50 years while considering projected climate change assumptions.

Figure4-5 summarizes the 3 timeframes for the water budgets developed for this GSP.

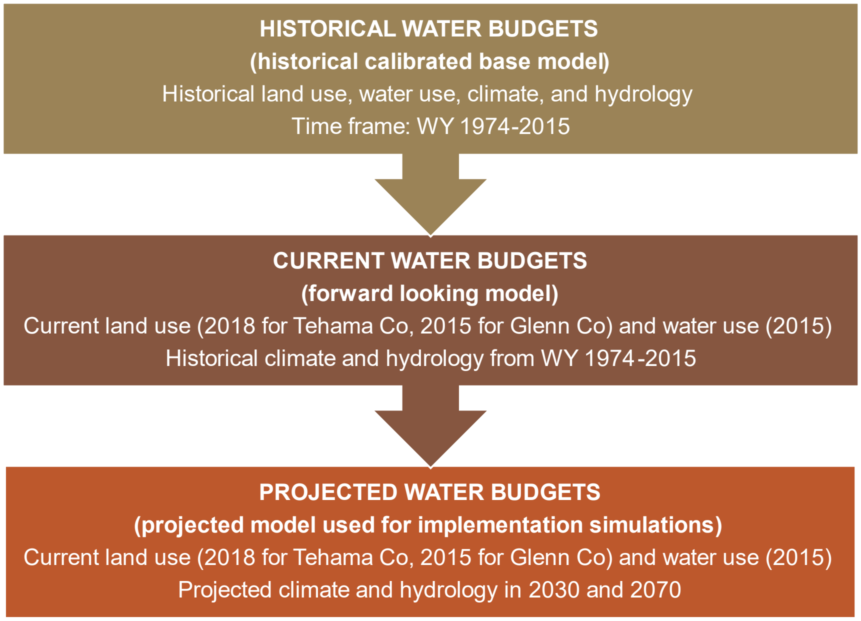

Figure 4-5. Summary of GSP-required Water Budget Time Frames

4.1.3.1 Historical Water Budgets

Historical conditions should go back to the most reliable historical data that are available for GSP development and water budgets calculations. For this GSP, the historical time frame is defined as WY 1974-2015 using historical land use, water use, climate, and hydrology, as simulated by the Northern Sacramento Valley portion of the calibrated C2VSimFG model (NSac model; Appendix 4A).

4.1.3.2 Current Water Budgets

Current conditions are generally the “most recent conditions” for which adequate data are available. Current conditions are not precisely defined by DWR but can include an average over a few recent years with various climatic and hydrologic conditions (for example, centered around the most recent drought in 2015, which is also the effective date of SGMA). Alternatively, current water budgets may represent current conditions with respect to land and water use, simulated over the historical climate and hydrologic conditions to better assess the variability of climate on what is understood as most recent land and water use. For this GSP, the current model time frame is a simulation of current land and water use conditions projected over 50 years into the future, using historical climate and hydrology, assuming no climate change or change in anthropogenic activity. The current time frame represents a current or recent Subbasin land and water use, while repeating the historical climate and hydrology to identify variations in the water budget due to climate with current water management. For this model simulation, the current land use in the Subbasin is represented by 2018 cropping (Land IQ, 2020) for the Tehama County portion, and 2015 land use (as represented currently in the available model) for the Glenn

County portion. Current surface water use was set for the entire simulation at 2015 applications for a conservative estimate of potential groundwater pumping. WY 2015 reflects a drought year with low to no surface water deliveries and associated increases in groundwater pumping. The model simulates groundwater pumping based on crop demand and availability of surface water (Appendix 4A). The Revised GSP addresses the current estimate of the annual change in storage related to overdraft. A complete and comprehensive water budget analysis for current and future conditions will be conducted as part of the 5-year Periodic Evaluation in January 2027.

4.1.3.3 Future Projected Water Budgets

Projected conditions should include a time frame of 50 years into the GSP planning and implementation horizon, including projected climate change, population, and land use changes. To simulate projected conditions, the current model as described above is used with climate change assumptions over a 50-year hydrologic projection. In summary, the projected model includes current land use (2015 and 2018) and water use (2015), while altering climate and hydrology to account for climate change, as projected around 2030 and 2070. As a result, 2 projected water budgets were developed for this GSP, using DWR 2030 and 2070 central tendency climate change projections. The Revised GSP addresses the current estimate of the annual change in storage related to overdraft. A complete and comprehensive water budget analysis for current and future conditions will be conducted as part of the 5-year Periodic Evaluation in January 2027.

As discussed in the DWR Guidance Document on climate change (DWR, 2018b):

The projected water budgets can be developed for 2 future conditions using a climate period analysis as follows:

- Water budget representing conditions at 2030 with uncertainty (i.e., using 50 years of historical record representative of the range of inter-annual variability as a baseline)
- Water budget representing conditions at 2070 with uncertainty (using the same 50-year period as for 2030)

These water budgets do not represent a specific 50-year projected future, but rather simulate approximate hydrologic conditions over a 50-year period that may occur in 2030, and approximate hydrologic conditions that may occur in 2070.

Projected water budgets, in addition to a review of sustainable management criteria, are useful to evaluate if sustainability will be maintained over the 50-year planning and implementation horizon. Projected future baseline conditions are then used to simulate potential projects and management actions in case sustainability criteria cannot be maintained with projected climate assumptions.

4.1.4 Key Water Budget Take-Aways

As described above, this GSP includes 3 types of water budgets (groundwater, surface water, and land surface budget) over 3 time periods: historical, current, and projected. Each water budget provides important information on relative contribution of each component to the overall water budget. When comparing the results from each of the 3 time frames, potential trends in water budget gains and losses can be established for future subbasin management. The pie charts shown on Figure 4-6 summarize average annual groundwater budget components for each simulated water budget time frame and help illustrate key differences between the time frames.

Key take-aways of the detailed water budgets in the Subbasin can be summarized as follows:

- As simulated over the entire historical period, it appears that the Corning Subbasin has not been subject to overdraft, as the change of groundwater in storage is positive, with simulated groundwater inflows exceeding simulated groundwater outflows; however, water levels have been dropping in the past 15 years in some areas, reflected in the decreasing change in storage value, which leads to a negative change in storage for the current water budget.

- The historical water budget is not the most critical to review for GSP implementation; rather, it gives an understanding of past behavior and interactions of various flow components. The water budgets provide background information that is complementary to the Basin Setting.

- The groundwater budget provides key information such as total groundwater pumping, and change in groundwater storage annually, and cumulatively over the full simulation period. The land surface budget provides information on the total water demand and relative use of surface water versus groundwater. The surface water budget primarily is used to assess stream depletions. In this Subbasin, streams are forming the boundary with other subbasins, and therefore, there are uncertainties in the stream depletion estimates due to actions within the Subbasin, as compared to neighboring subbasins.

- Cumulative and annual change in storage is slightly declining in the current water budget simulation compared to the historical water budget; therefore, if water management strategies remain the same as they are now, the Subbasin will continue to experience groundwater level and storage declines and an overall worsening of conditions compared to historical conditions.

- An increase in irrigated farmland and decrease in surface water deliveries causes groundwater pumping for irrigation to increase over time. Average annual agricultural pumping increased by about 20,700 AF from the historical

(132,300 AF/yr) to current simulation (153,000 AF/yr) and is projected to continue to increase in the future compared to current conditions, from 6,300 AF in 2030 (159,300 AF/yr) to 14,300 AF in 2070 (167,300 AF/yr). The simulated historical average annual change of groundwater in storage is 6,900 AF, which indicates a subbasin generally in balance over the historical time period. This is further evidenced by the calculated cumulative[39] gain in groundwater storage of 290,300 AF over the historical simulation period.

- The current water budget shows an average 5,800-AF decrease in annual change of groundwater in storage as compared to the historical time frame. This results in a cumulative change of groundwater in storage of 56,100 AF over the 50-year simulation period, down 234,200 AF from the historical groundwater budget, driven mainly by decreases in surface water availability and an increase in groundwater pumping. The Revised GSP includes a new estimate of the current water budget, overdraft of 31,200 AF/yr, and is described in Section 4.3.1.

- The projected water budgets result in an additional depletion of 700 AF of groundwater in storage per year on average in the 2030 simulation, and a depletion of 1,500 AF/yr on average in the 2070 simulation, as compared to simulated current conditions. These annual changes culminate in an additional 34,900 AF loss of groundwater in storage in the 2030 projection and an additional 75,800-AF loss in the 2070 projection as compared to simulated current conditions. The 2070 projected water budget results in a cumulative change in storage of -19,700 AF over the 50-year projected period, indicative of an imbalanced water budget. The Revised GSP provides a new estimate of the current overdraft, which is relevant to the future water budget. The Revised GSP future water budget should be recalculated with the numerical model, in the 5-year Periodic Evaluation. The model will be updated with current inputs, including the revised overdraft, updated water levels, updated parameters based on changes to the conceptual model, and updated climate change predictions. It was not possible to properly update and run the model in the 180-day-period allowed by DWR to revise the GSP.

- The current, 2030, and 2070 water budgets display increasingly less groundwater discharge to streams and more streambed recharge to groundwater, indicating that progressively lowered groundwater elevations in the future may draw more water from the Subbasin's streams, and contribute less groundwater baseflow in return.

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[39] total annual change in storage over the simulation time frame

- Overall observations regarding historical, current, and future baseline groundwater budgets:
    - Historical: Subbasin is generally in balance but the trend is downward in recent decades
    - Current (if all things stay the same): Somewhat declining trend in water levels due to increased pumping. Overall a bit worse than historical.
    - Projected baseline with climate change: The Subbasin begins to experience continual imbalance, particularly in the 2070 projection; will probably need to implement projects to maintain water levels.
- The projected future water budget is what the GSP uses to evaluate SMC, and which helps define the sustainable yield of the Subbasin.
- Revised simulated projected water budgets, incorporating changes in conditions as well as projects and management actions undertaken, along with sustainability indicator monitoring and SMC evaluation, will provide “proof” of continued sustainability during GSP implementation.

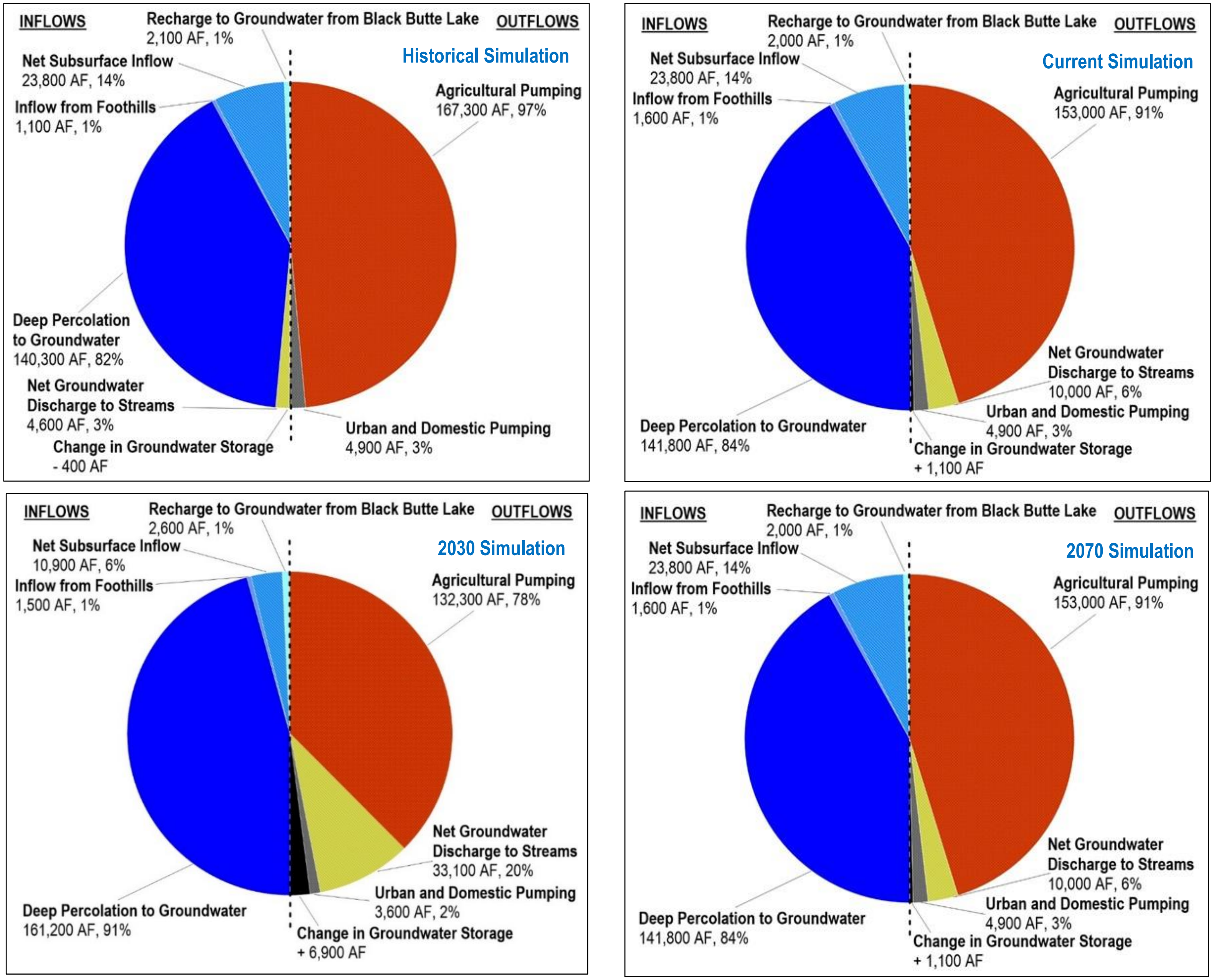

Figure 4-6. Groundwater Budget Pie Charts

4.2 Historical Water Budgets

4.2.1 Groundwater Budget

The complete historical annual groundwater budget is summarized in Table 4-2 and presented in time series on Figure 4-9 and Figure 4-10. Figure 4-7 highlights the groundwater budget inflow components, while Figure 4-8 presents outflows. Figure 4-9 displays all components of the groundwater budget, while Figure 4-10 groups components related to subsurface inflow and groundwater-surface water interaction to show net values into and out of the aquifer.

The historical groundwater budget is dominated by 4 primary components: deep percolation to groundwater, agricultural pumping, flow between groundwater and surface water, and inter-basin subsurface flow.

- Deep percolation represents 52% of total groundwater inflow in an average year, though the total volume varies significantly with climate, ranging from 50,700 to 292,600 AF/yr (Table 4-2; Figure 4-7).
- Agricultural pumping constitutes 43% of groundwater outflow, and similarly ranges from 85,200 to 132,300 AF/yr with variation largely dependent on climate, land use, and surface water use.
- Groundwater-surface water interaction occurs in both gaining and losing reaches across the Subbasin, as shown in Table 4-2 and detailed further in Section 4.2.3. Subbasin-wide streambed recharge comprises 16% of total groundwater inflows in an average year, while groundwater discharge to streams comprises 23% of total outflows in an average year. Subbasin-wide, a net volume of 33,100 AF of groundwater discharges into the Subbasin's streams in an average year (Table 4-2; Figure 4-8).
- Subsurface flows constitute 30% of total groundwater inflows and 28% of total groundwater outflows in an average year; on a net basis the Subbasin generally receives inflows from Red Bluff and Los Molinos Subbasins, and provides outflows to Vina and Colusa Subbasins (Table 4-2; Figure 4-11). The net subsurface flow to Butte Subbasin is negligible. These trends in subsurface flow occur largely due to Sacramento Valley-wide groundwater gradients that direct groundwater from north to south, and from west to east on the western side of the Sacramento River. Subsurface flows are also impacted by seasonal groundwater pumping occurring in agricultural areas.

Time series figures of the groundwater budget overlain on Sacramento Valley water year type classification support analysis of climatic and historical factors influencing the Subbasin's groundwater budget (Figure 4-9; Figure 4-10). Historical wet periods (namely 1981-1986 and 1994-2000) result in increased deep percolation to groundwater and reduced groundwater pumping due to associated increases in surface water use and reduced irrigation demands.

Likewise, the Subbasin is highly responsive to extended dry periods (namely 1975-1977, 1987-1993, and 2012-2016), largely driven by decreases in deep percolation to groundwater and increased reliance on groundwater extraction. The groundwater budget displays consistent net groundwater discharge to streams and net subsurface inflows over the historical period, though these net flows are relatively minor in contrast to deep percolation to groundwater and agricultural pumping (Figure 4-9).

The annual change of groundwater in storage fluctuates between -130,200 and 123,100 AF with an annual average of 6,900 AF, which shows a subbasin generally in balance over the historical time period. The Subbasin displays a cumulative[40] gain in groundwater storage of 290,300 AF over the historical simulation period. These periodic fluctuations illustrate the Subbasin's response to wet and dry periods and point towards a generally balanced groundwater budget over the historical period. Toward the tail end of the historical period (2011 onward) the Subbasin experiences 4 consecutive years of decline in annual groundwater storage, driven by both the recent statewide drought and changes in land and water use and availability across the Subbasin. The current water budget period (Section 4.3) and the discussion of water supply and reliability in Section 4.2.5 further examine the influence and implications of these recent trends.

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[40] total annual change in storage over the simulation time frame

Table 4-2. Historical Annual Groundwater Budget Summary

All values are in acre-feet, rounded to nearest 100 AF						
Component		Average	% Contribution *	Average in Critically Dry/Dry Years	Average in Below Normal/Above Normal Years	Average in Wet Years
Inflows	Deep Percolation to Groundwater	161,200	52%	116,350	176,100	212,600
	Streambed Recharge	51,100	16%	46,400	56,150	53,500
	Inflow from Colusa	17,700	6%	16,650	18,550	18,600
	Inflow from Red Bluff	44,500	14%	43,950	45,550	44,500
	Inflow from Butte	1,500	<1%	1,350	1,400	1,800
	Inflow from Los Molinos	21,300	7%	21,200	22,000	20,800
	Inflow from Vina	10,700	3%	21,200	22,000	20,800
	Inflow from Foothills	1,500	<1%	1,100	1,650	1,900
	Recharge to Groundwater from Black Butte Lake	2,600	1%	2,100	2,750	3,000
Outflows	Urban and Domestic Pumping	3,600	1%	3,650	3,850	3,500
	Agricultural Pumping	132,300	43%	141,400	127,700	122,600
	Outflow to Colusa	32,200	11%	32,350	31,450	32,200
	Outflow to Red Bluff	12,300	4%	11,750	12,050	13,500
	Outflow to Butte	1,500	0%	1,550	1,600	1,300
	Outflow to Los Molinos	12,900	4%	11,800	12,200	14,600
	Outflow to Vina	26,200	9%	25,000	25,650	28,200
	Groundwater Discharge to Streams	84,200	28%	70,250	83,900	104,400
Storage	Annual Change of Groundwater in Storage	6,900	-	-38,350	35,850	47,300
	Cumulative Change of Groundwater in Storage from WY 1974 to WY 2015	290,300	-	-	-	-

* Percent contribution of component to average total inflow/outflow. Small discrepancies between inflow minus outflow and change in storage may occur due to rounding.

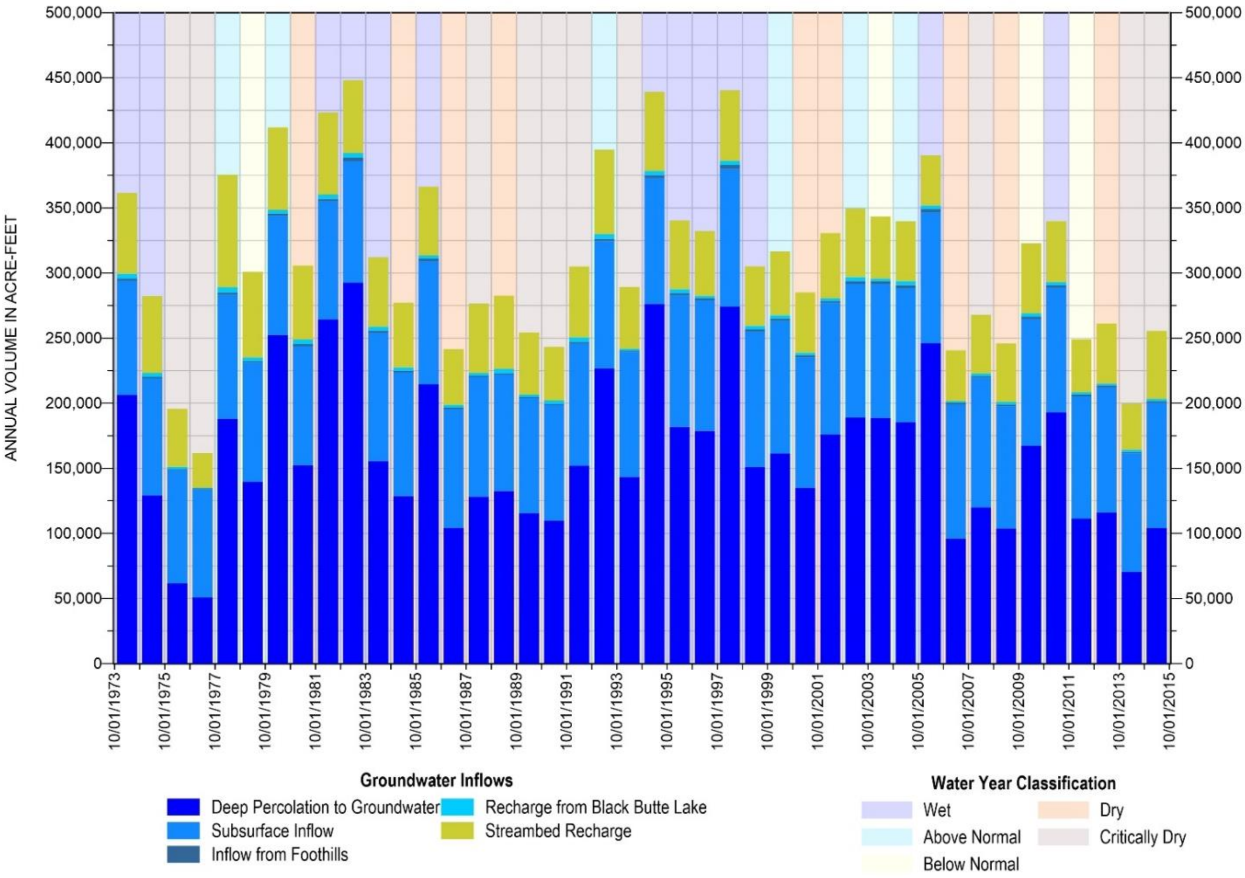


Figure 4-7. Historical Groundwater Budget Inflow

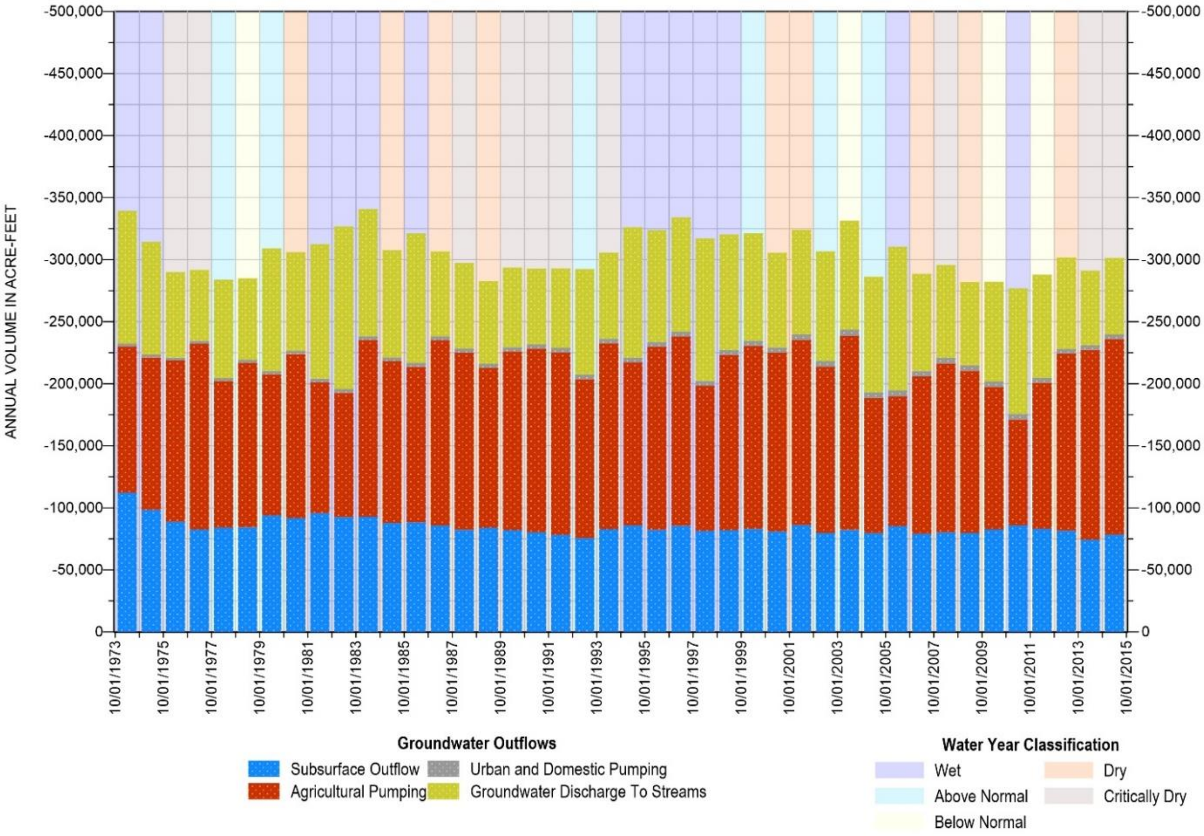


Figure 4-8. Historical Groundwater Budget Outflows

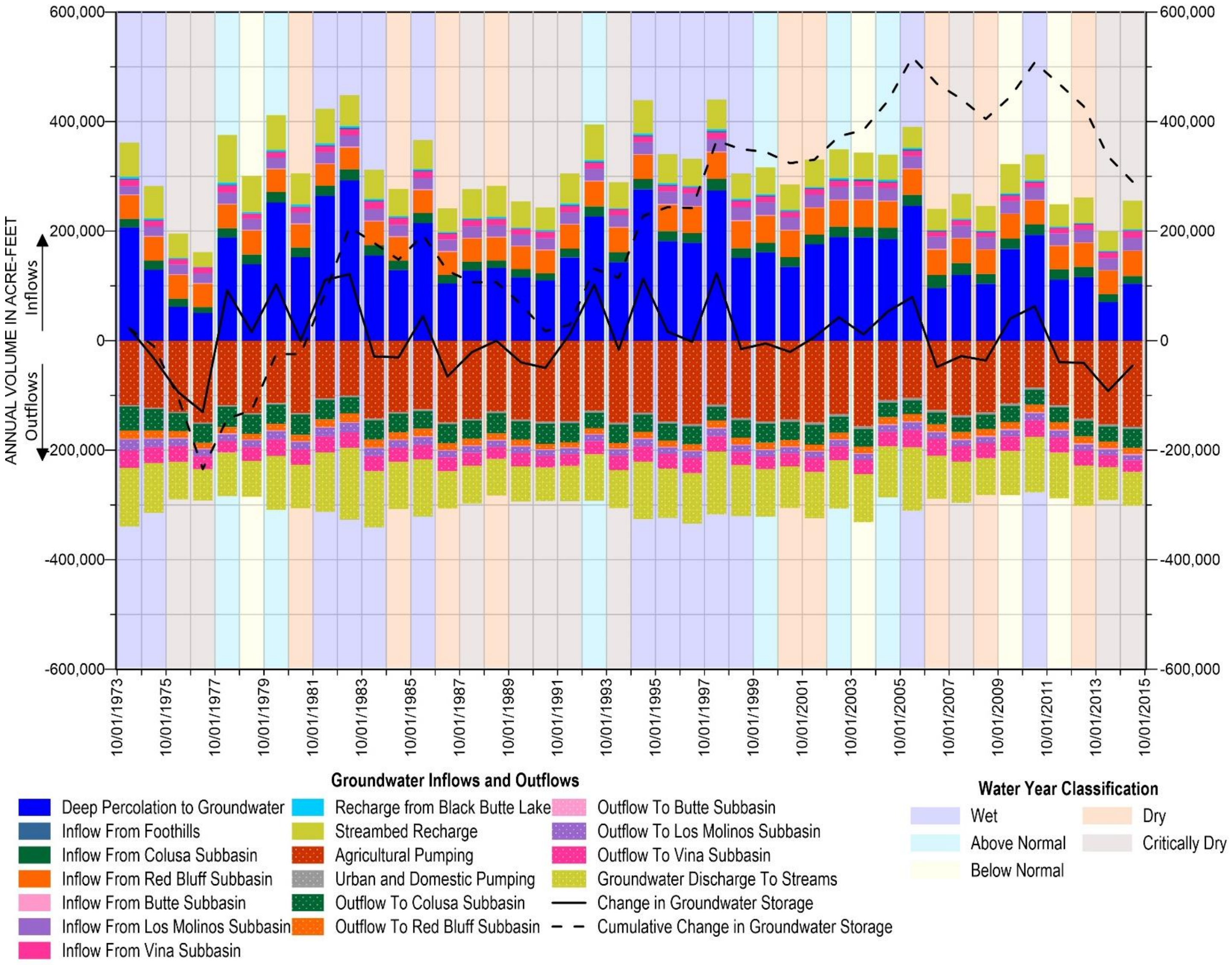


Figure 4-9. Historical Groundwater Budget

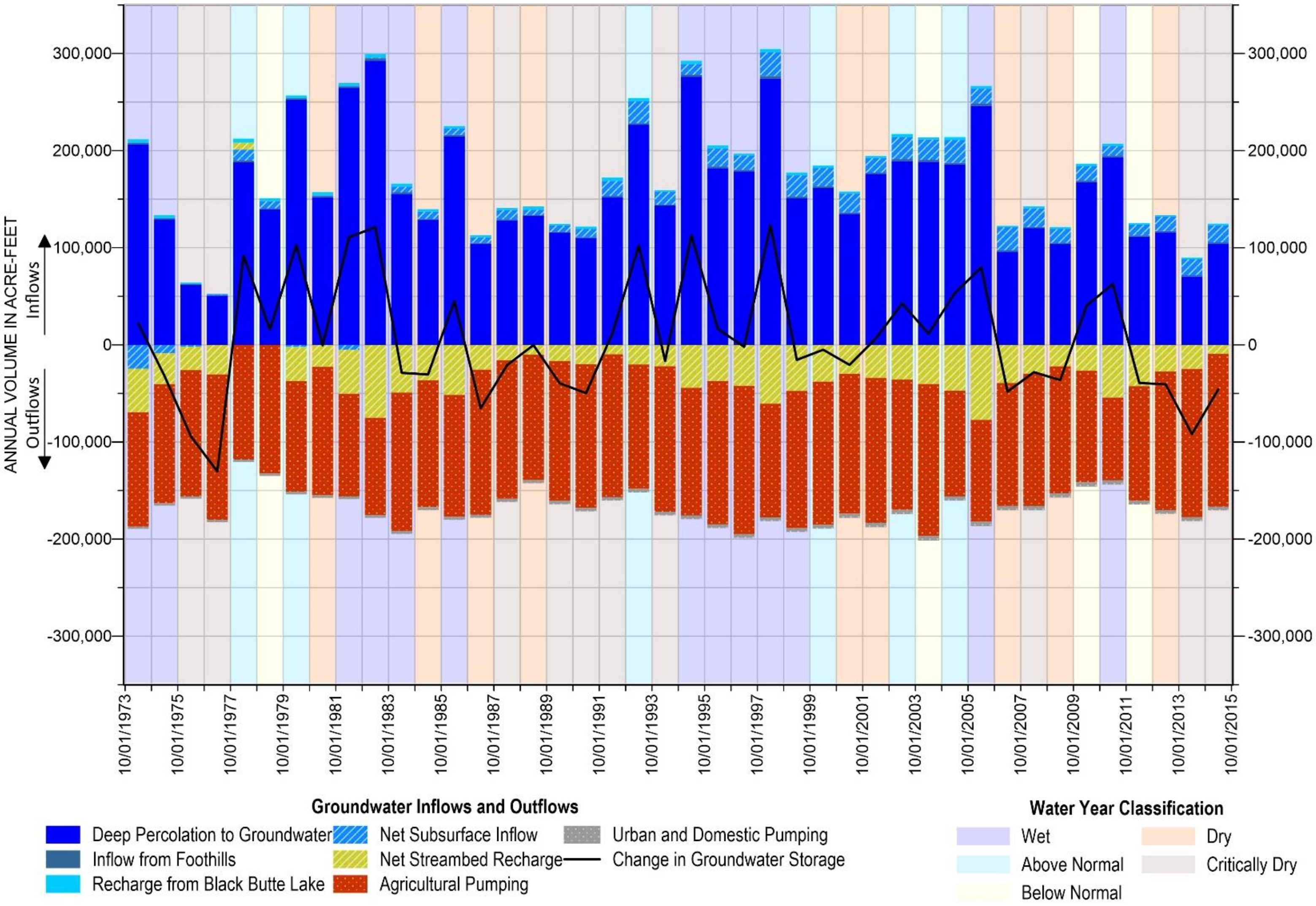


Figure 4-10. Historical Groundwater Budget of Net Flows

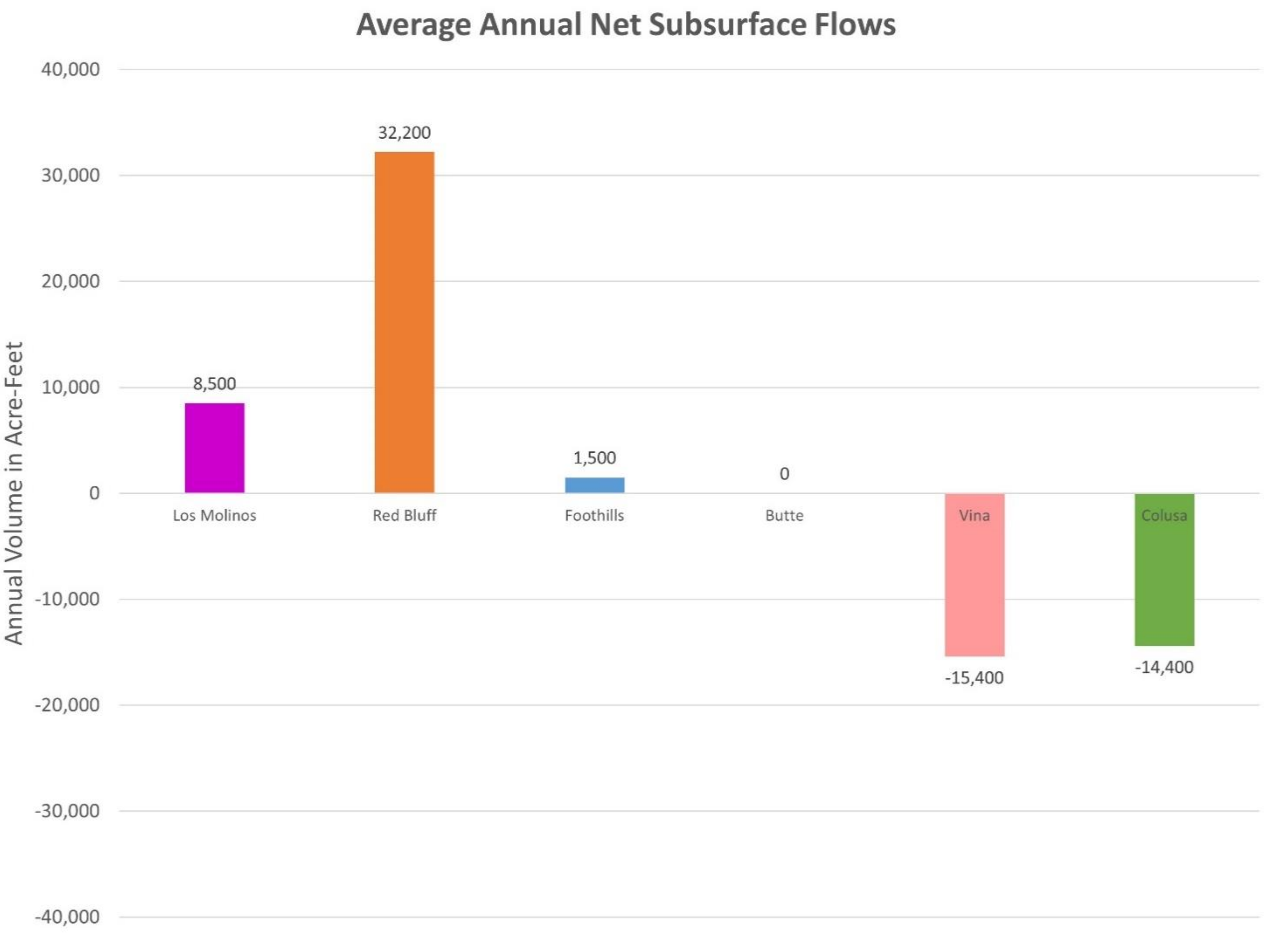


Figure 4-11. Historical Groundwater Budget Annual Average Net Subsurface Flows From Neighboring Subbasins

4.2.2 Land Surface Budget

The historical annual land surface budget is summarized in Table 4-3 and presented in time series on Figure 4-12.

Inflow to the land surface system is dominated by precipitation (63%), supplemented by applied groundwater (22%) and applied surface water (16%). Outflow from the land surface system is primarily from evapotranspiration (50%), deep percolation to groundwater (20%), and overland flow (22%) (Table 4-3; Figure 4-12). The land surface system is highly dependent on annual precipitation, with total flow correlating strongly with climate classification (Figure 4-12). Applied groundwater increases in dry years and decreases in wet years, related to increased groundwater demand during dry years. Applied surface water and irrigation return flows to streams generally display the opposite trend, associated with surface water use increasing in wet years and decreasing in dry years.

Over the historical period, particularly from 2011 onward, the volume of applied surface water has declined, correlated to both the recent statewide drought and more local decreases in surface water delivery within the Subbasin. These decreases in applied water, coupled with a large decrease in precipitation, bring about some of the lowest volumes of deep percolation to groundwater seen across the historical period.

Table 4-3. Historical Annual Land Surface Budget

All values are in acre-feet, rounded to nearest 100 AF					
	Component	**Min**	**Max**	**Average**	**% Contribution***
Inflows	Precipitation	189,200	829,800	391,800	65%
	Applied Groundwater	89,700	161,400	135,900	22%
	Applied Surface Water	36,600	114,300	79,000	13%
Outflows	Deep Percolation to Groundwater	48,500	287,100	157,000	26%
	Evapotranspiration	246,400	322,200	292,200	48%
	Overland Flow	15,600	449,100	136,000	22%
	Return Flow to Streams	12,100	28,800	19,900	3%
Storage	Change in Soil and Unsaturated Zone Storage	-69,800	52,400	1,700	

* Percent contribution of component to average total inflow/outflow. Small discrepancies between inflow minus outflow and change in storage may occur due to rounding.

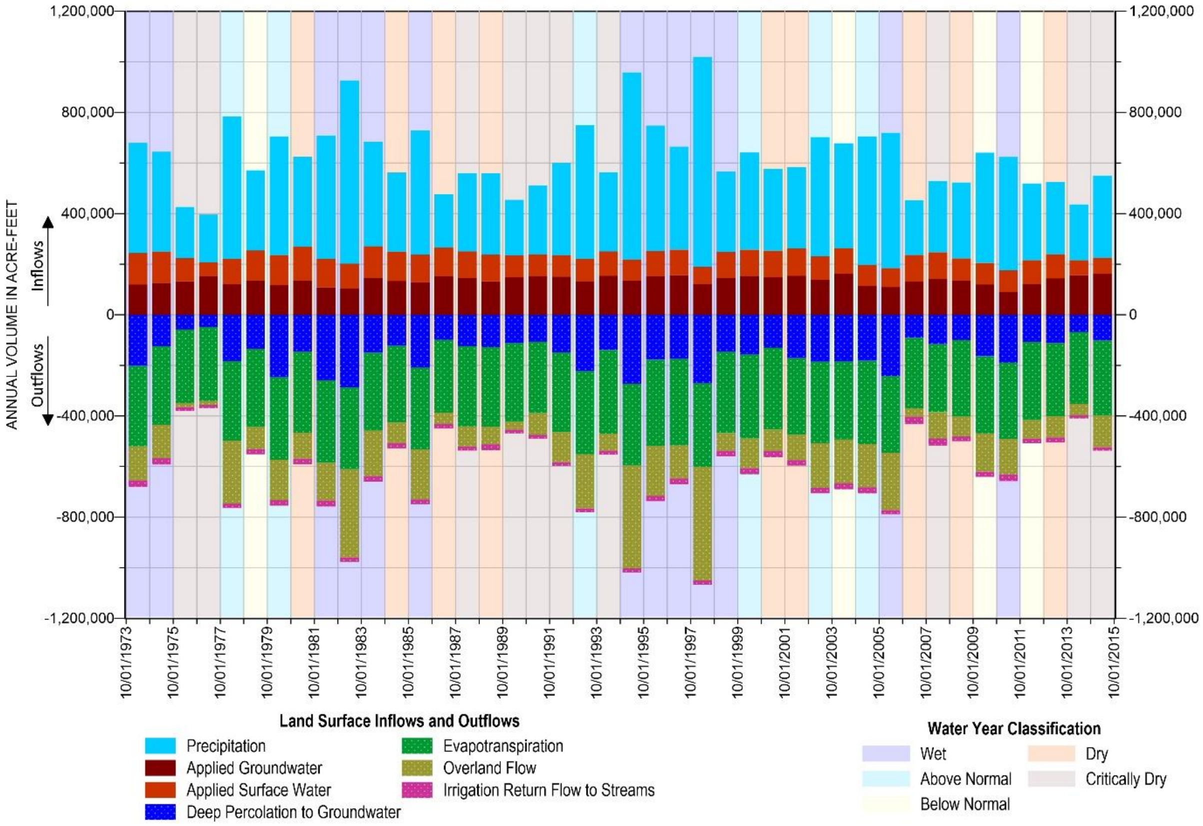


Figure 4-12. Historical Land Surface Budget

4.2.3 Surface Water Budget

The surface water budget includes inflows from and outflows to surface water bodies within the subbasin. Three major streams occur in the Subbasin at its north, east, and south boundaries with the neighboring subbasins: Thomes Creek, Sacramento River, and Stony Creek, respectively. Since these streams receive and provide flows from neighboring subbasins in addition to the Corning Subbasin, it is difficult to estimate a subbasin-specific surface water budget. Instead, the surface water budgets presented below include simulated flows for the entire stream systems as it passes within the Corning Subbasin, including flows from outside of the subbasin, for a complete balanced surface water budget overview, including recharge to groundwater and other losses on Black Butte Lake. Note that the groundwater budget only includes stream recharge for model nodes that fall within the Subbasin boundary (at their border).

In addition to the 3 major streams, numerous intermittent (ephemeral) streams cross the subbasin, originating from the Coastal Range foothills and discharging into the Sacramento River. These streams are not explicitly simulated in the integrated model. They provide overall flow to the system in the form of groundwater recharge and runoff to the Sacramento River, but these flow components are primarily represented in the land surface budget as small watershed inflow, and not presented here as part of the surface water budget.

Several canals also cross the subbasin to deliver surface water within the subbasin and to neighboring subbasins (See Section 3.1 for more details). Unlined canals, such as the Corning Canal, allow for some amount of leakage to groundwater through the dirt (unlined) canal bottom. To account for this leakage, a small amount of recharge is added to the model recharge component along the canal’s alignment. This recharge component is accounted for in the groundwater budget as deep percolation to groundwater, as the canals are not explicitly simulated as physical surface water features in the model. The Tehama Colusa Canal flows through the Corning Subbasin but is lined and does not provide significant recharge to groundwater. Similarly, the OUWUA surface water delivery system, which provides surface water in the southern portion of the Subbasin, is lined and does not represent significant recharge to the Subbasin.

Therefore, the historical surface water budget encompasses the 3 major streams bounding the Subbasin and is developed by extracting surface water budget components from the historical model over Thomes Creek, Stony Creek, and the Sacramento River within the Corning Subbasin (Figure 4-1). Stony Creek also includes an accounting of recharge to groundwater and other losses on Black Butte Lake. Evaluation of the surface water budget increases understanding of Subbasin-wide trends in groundwater-surface water connection, surface water use, and the responsiveness of the surface water system to historical climatic variation. The historical surface water budget is summarized in Table 4-4 and presented in time series on Figure 4-13 and Figure 4-14. Figure 4-13 displays all components of the surface water budget, while Figure 4-14 presents surface water inflow and outflow on a net basis to aid visualization of components otherwise dwarfed by upstream and downstream streamflows on Figure 4-13.

The vast majority (approximately 97%) of inflow to the surface water system is composed of inflow from areas outside of the Subbasin in the form of stream inflow from upstream of the Subbasin (96%) and inflow from small tributaries (1%). This inflow is supplemented by overland flow and groundwater discharge to streams, which constitute 2% and 1% of total inflow, respectively. Irrigation return flows to streams comprise another small percentage of inflow less than 1%. In an average year, approximately 91% of surface water inflow leaves via the Sacramento River. The remainder is diverted to the Glenn-Colusa Canal (7%), diverted by riparian water rights holders (1%), occurs as losses from Black Butte Lake (1%), enters groundwater as streambed recharge (<1%), or is evapotranspired along riparian corridors (<1%).

GSP Regulations require a total surface water budget over the entire subbasin. However, in this subbasin the total volume of flow in the Sacramento River far exceeds flows in Thomes and Stony Creeks, and therefore the Subbasin-wide surface water budget is numerically dominated by the Sacramento River. As such, stream-level surface water budgets are presented below for Thomes Creek, Stony Creek, and the Sacramento River separately, to better understand each river system’s hydrologic trends over time. To remain concise, this Subbasin-wide surface water budget is not presented for the current or projected model periods, which instead only show the stream-level surface water budgets.

Table 4-4. Historical Annual Surface Water Budget

All values are in acre-feet, rounded to nearest 100 AF					
Component		Minimum	Maximum	Average	% Contribution*
Inflows	Inflow from Upstream of Subbasin	5,335,000	23,384,400	10,993,400	96%
	Inflow from Small Tributaries	6,518	182,300	67,600	1%
	Overland Flow	22,200	761,700	235,800	2%
	Irrigation Return Flows to Streams	25,600	38,900	30,800	<1%
	Groundwater Discharge to Stream	55,400	166,700	90,400	1%
Outflows	Streambed Recharge	20,800	111,200	53,500	0%
	Downstream Outflow South of Subbasin	4,711,800	23,217,500	10,380,600	91%
	Riparian ET	26,700	43,800	36,400	<1%
	Surface water diversions	39,800	205,400	78,900	1%
	Diversion to Glenn-Colusa Canal and Bypass	540,000	1,028,800	787,100	7%
	Recharge to Groundwater from Black Butte Lake	13,800	19,500	17,800	<1%
	Black Butte Lake Losses	-7,800	119,500	63,700	1%

* Percent contribution of component to average total inflow/outflow. Small discrepancies between total inflow and outflow may occur due to rounding.

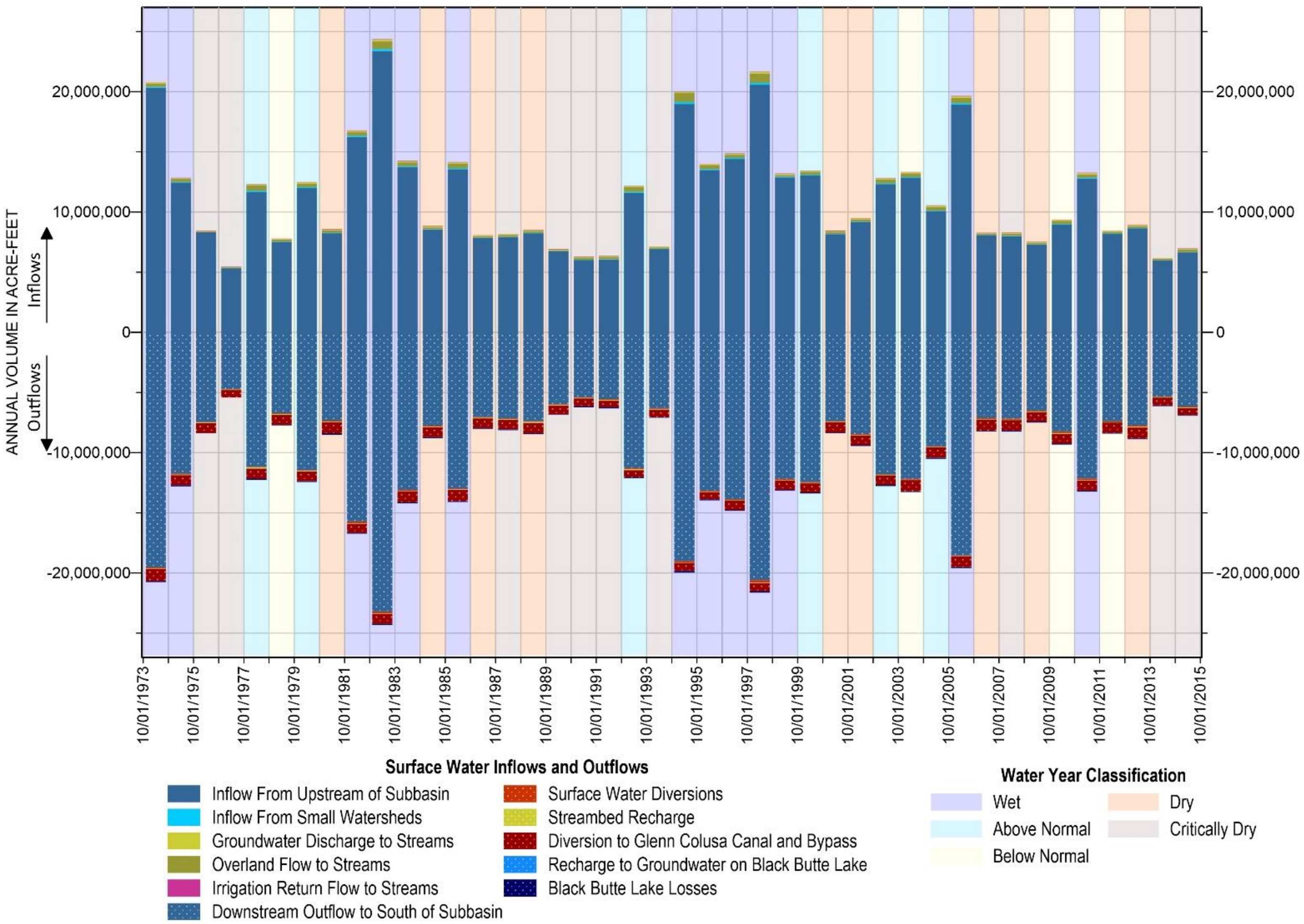
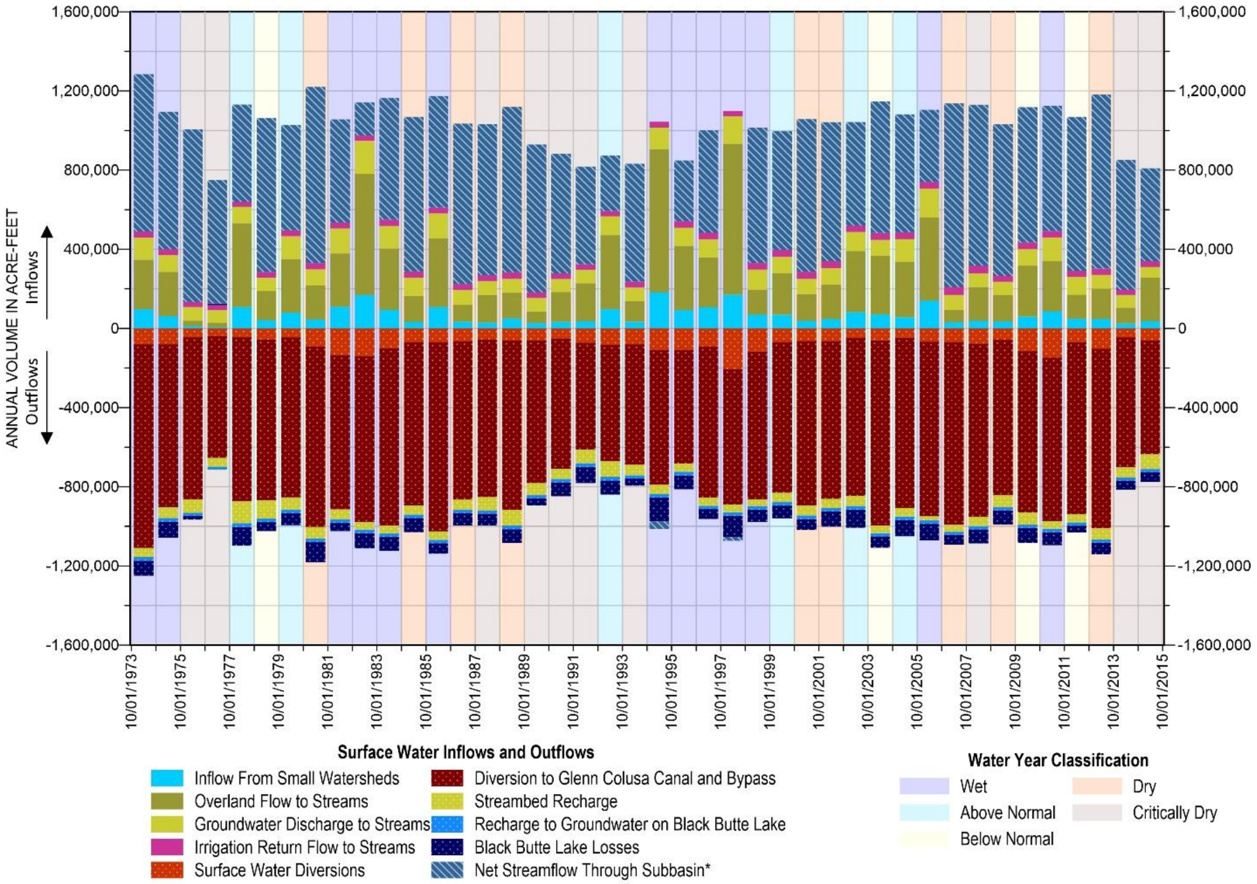


Figure 4-13. Historical Surface Water Budget



**Reflects upstream surface water inflows to Stony Creek, Thomes Creek and the Sacramento River, minus downstream surface water outflows in the Sacramento River*

Figure 4-14. Historical Surface Water Budget Net Flows

4.2.3.1 Sacramento River Budget

The historical Sacramento River budget is summarized in Table 4-5 and presented in time series on Figure 4-15. The vast majority of inflow to the Sacramento River arrives as inflow from areas outside of the Subbasin and small tributaries (97%), with the remaining 3% arriving from overland flow (2%), groundwater discharge to streams (1%) and irrigation return flows to streams (<1%). Outflows depart the Sacramento River primarily as downstream outflow (92%) and diversions to the Glenn-Colusa Canal (7%).

On a net basis, the Sacramento River is gaining from groundwater in all years, with the net gain smaller in dry years when groundwater elevations are lower. Agricultural diversions and diversions to the Glenn-Colusa Canal fluctuate inter-annually depending on climate, but generally remain consistent over the historical period.

Table 4-5. Sacramento River Historical Annual Surface Water Budget

All values are in acre-feet, rounded to nearest 100 AF					
	Component	Minimum	Maximum	Average	% Contribution*
Inflows	Inflow from Upstream of Basin	5,306,500	22,028,200	10,538,700	97%
	Inflow from Small Tributaries	6,518	139,200	56,800	<1%
	Overland Flow	18,300	615,500	194,800	2%
	Irrigation Return Flows to Streams	19,700	33,400	25,400	<1%
	Groundwater Discharge to Stream	54,400	145,900	88,700	1%
Outflows	Streambed Recharge	0	33,500	7,300	<1%
	Downstream Outflow South of Subbasin	4,710,600	21,953,100	10,067,200	92%
	Riparian ET	14,500	25,300	21,200	<1%
	Agricultural Diversions	6,400	31,700	21,500	<1%
	Flow to Glenn-Colusa Canal	540,000	922,500	759,200	7%
	Flow to Flood Bypass	0	240,700	28,000	<1%

* Percent contribution of component to average total inflow/outflow. Small discrepancies between total inflow and outflow may occur due to rounding.

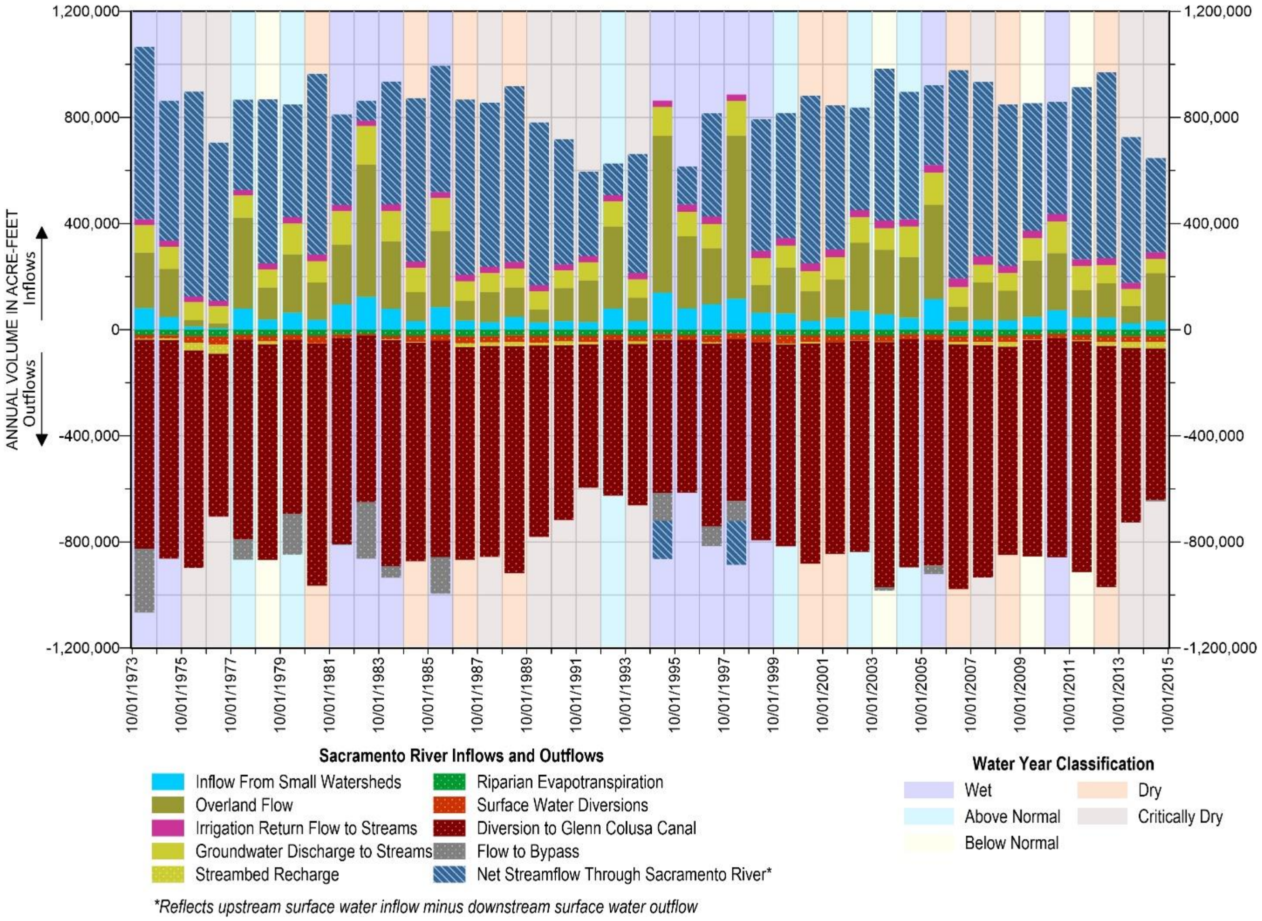


Figure 4-15. Sacramento River Historical Surface Water Budget

4.2.3.2 Stony Creek and Black Butte Lake Budget

The historical Stony Creek and Black Butte Lake budget is summarized in Table 4-6 and presented in time series on Figure 4-16. Most inflow to this system is composed of flow from areas outside of the Subbasin and small tributaries (95%), supplemented by overland flow (4%) and irrigation return flows to streams (1%). Stony Creek is losing on a net basis, with groundwater discharge to streams composing less than 1% of inflow, but roughly 4% of outflow. Stony Creek generally loses a larger volume of water as streambed recharge during dry years when groundwater elevations are lower. Black Butte Lake discharges roughly 17,800 AF to groundwater annually (4% of outflow).

Stony Creek is subject to significant surface water diversions (12%), providing significant volumes of irrigation water to OUWUA’s North district. These diversions fluctuate inter-annually with climate, but generally remain consistent over the historical period. During wet years, a larger volume is typically diverted given the larger amount of surface water available.

Table 4-6. Stony Creek and Black Butte Lake Historical Annual Surface Water Budget

All values are in acre-feet, rounded to nearest 100 AF					
Component		Minimum	Maximum	Average	% Contribution*
Inflows	Inflow from Upstream of Basin	21,900	1,412,700	450,000	94%
	Inflow from Small Tributaries	0	16,100	2,800	1%
	Overland Flow	3,200	70,500	21,500	4%
	Irrigation Return Flows to Streams	1,800	7,100	4,400	1%
	Groundwater Discharge to Stream	0	22,600	1,700	<1%
Outflows	Streambed Recharge	0	70,600	19,200	4%
	Downstream Outflow to Sacramento River	1,200	1,264,400	313,400	65%
	Riparian ET	6,000	13,600	10,500	2%
	Surface Water Diversions	7,900	181,100	55,900	12%
	Recharge to Groundwater from Black Butte Lake	13,800	19,500	17,800	4%
	Black Butte Lake Losses	-7,800	119,500	63,700	14%

* Percent contribution of component to average total inflow/outflow. Small discrepancies between total inflow and outflow may occur due to rounding.

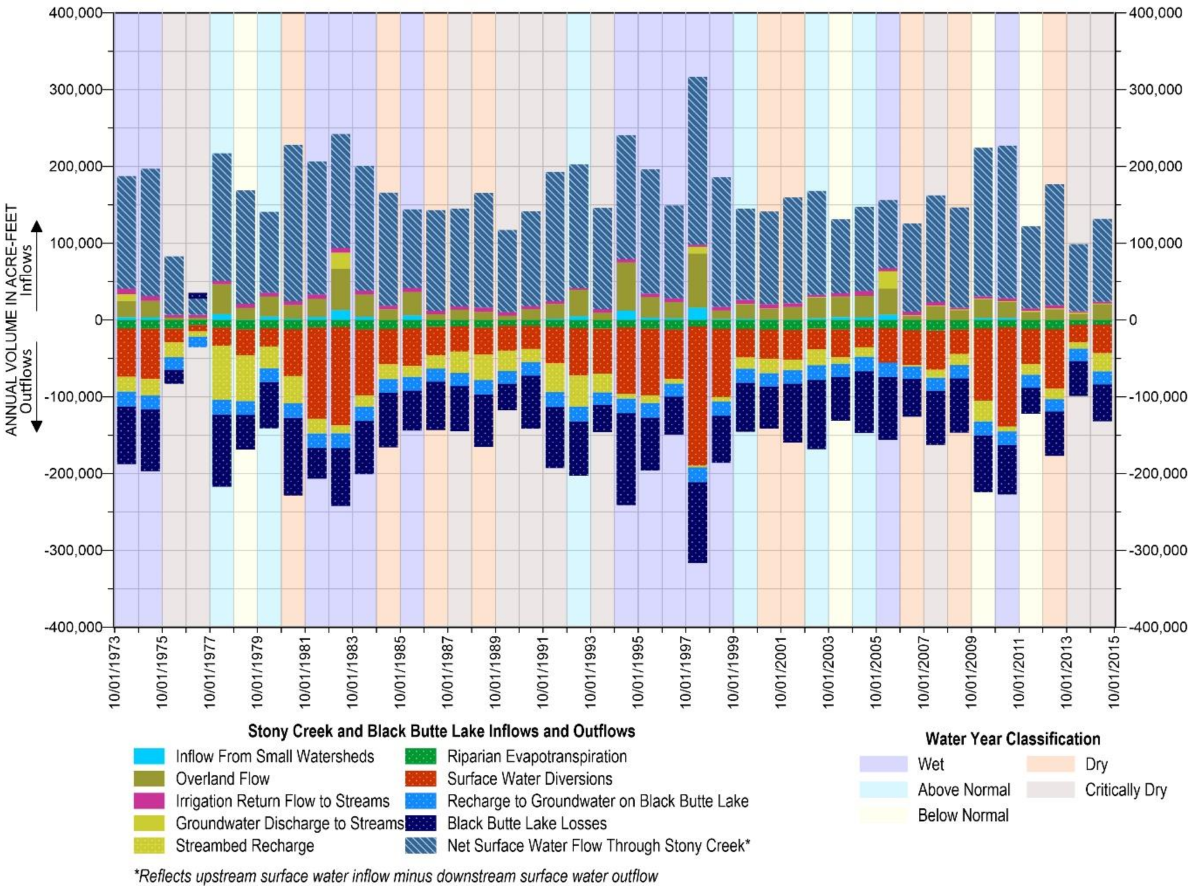


Figure 4-16. Stony Creek and Black Butte Lake Historical Surface Water Budget

4.2.3.3 Thomes Creek Budget

The historical Thomes Creek budget is summarized in Table 4-7and presented in time series on Figure 4-17**.** Most inflow to Thomes Creek is composed of flow from areas outside of the Subbasin and small tributaries (92%), supplemented by overland flow (8%) and irrigation return flows to streams (1%). Thomes Creek is a strongly losing stream, with no groundwater discharge to the stream in all years and streambed recharge composing 11% of total outflow. Streambed recharge to groundwater increases during wet years when total streamflow volume is higher.

Surface water diversions on Thomes Creek (1%), which provide water to Thomes Creek WD and minor riparian diversions, are in decline over the historical period. In response to the recent drought (WY 2013-2015), these diversions stop entirely, and there was no diversion on Thomes Creek during WY 2015.

Table 4-7. Thomes Creek Historical Surface Water Budget

All values are in acre-feet, rounded to nearest 100 AF					
Component		Minimum	Maximum	Average	% Contribution*
Inflows	Inflow from Upstream of Basin	15,600	567,600	226,700	89%
	Inflow from Small Tributaries	0	38,200	8,000	3%
	Overland Flow	800	75,600	19,500	8%
	Irrigation Return Flows to Streams	700	1,700	1,100	<1%
	Groundwater Discharge to Stream	0	0	0	0%
Outflows	Streambed Recharge	4,400	40,600	27,000	11%
	Downstream Outflow to Sacramento River	9,000	638,800	222,000	87%
	Riparian ET	3,600	6,300	4,700	2%
	Surface water diversions	0	4,200	1,500	1%

* Percent contribution of component to average total inflow/outflow. Small discrepancies between total inflow and outflow may occur due to rounding.

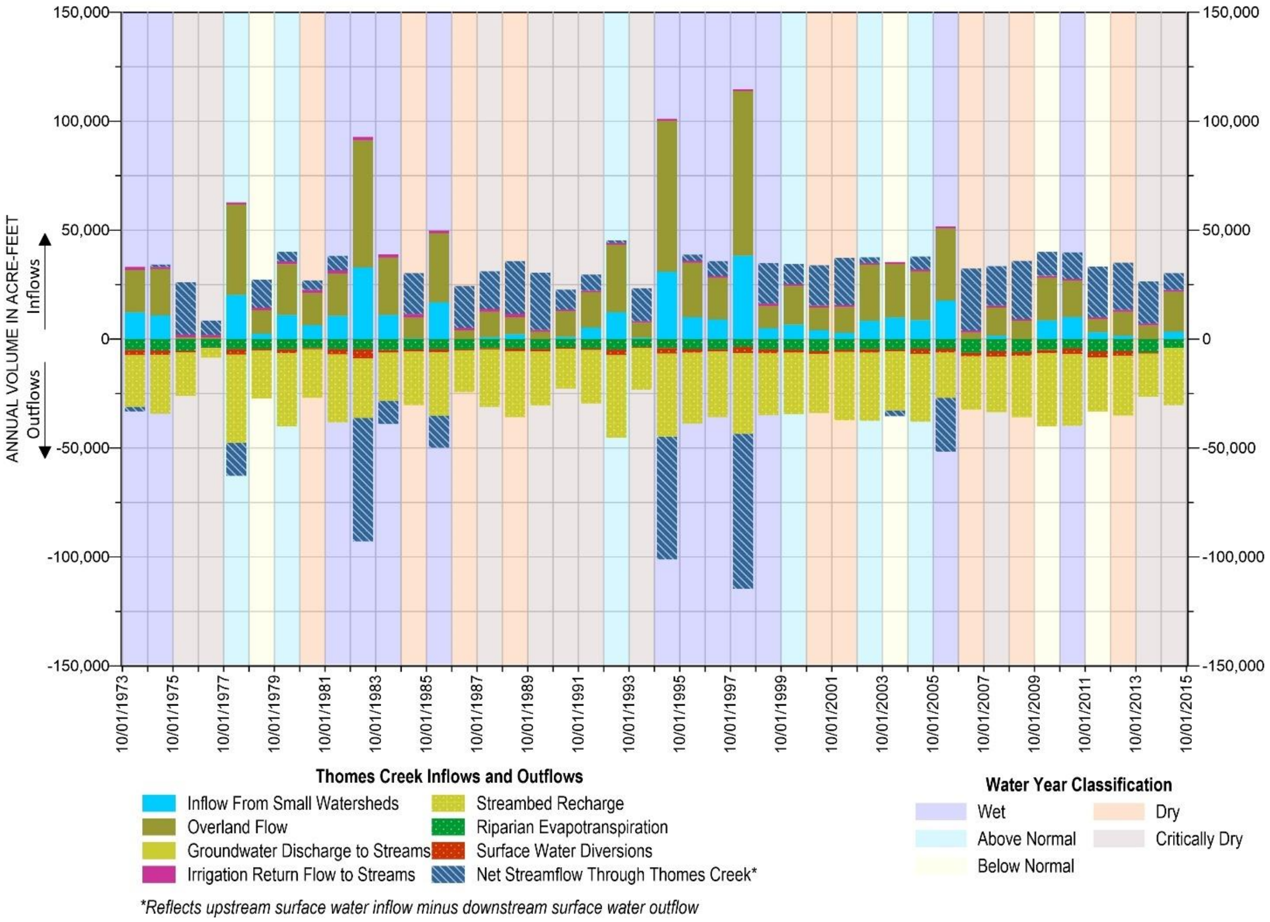


Figure 4-17. Thomes Creek Historical Surface Water Budget

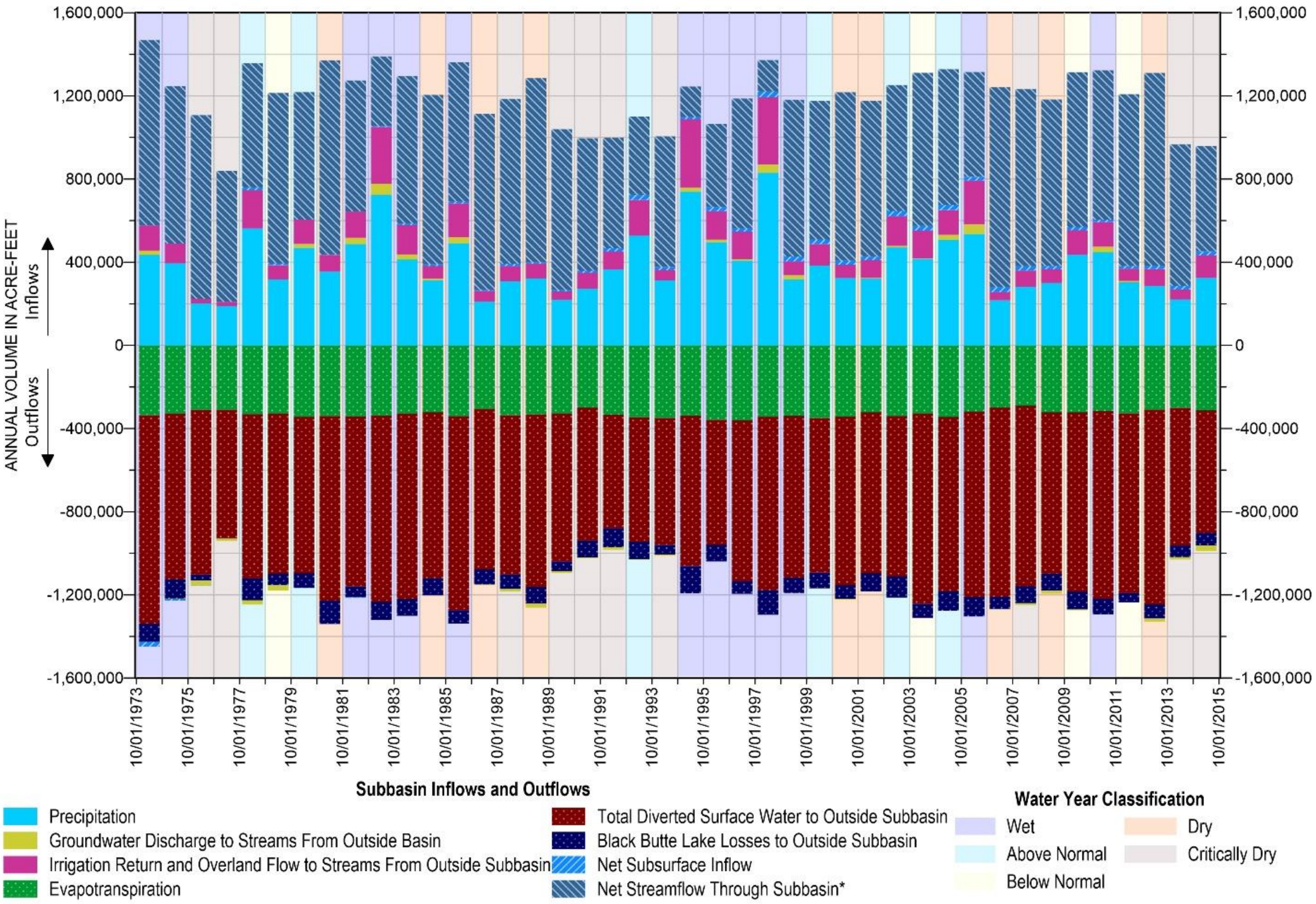
4.2.4 Subbasin Budget

A Subbasin-wide water budget is summarized in Table 4-8 and presented visually on Figure 4-18. As this water budget requires changes to budget component calculation to account for the total flow of water into and out of the Subbasin, additional explanation of components is provided in Table 4-8. An average of around 95% of total flow into the Subbasin arrives as Surface water inflow, stressing the importance of surface water in the Subbasin’s overall hydrology. Precipitation forms another 2% of inflow, with the remainder composed of groundwater-surface water interactions, overland flow, and subsurface inflows from areas outside of the Subbasin.

Surface water outflow through the Sacramento River composes roughly 89% of outflow on average, in addition to another 7% of flow that is diverted to areas outside of the Subbasin, of which a large portion enters the Glenn-Colusa Canal. The total change in Subbasin water storage is positive on average, indicating that the Subbasin has generally been in balance over the historical period. However, decreases in precipitation correlated with the recent statewide drought result in losses of total water storage.

Table 4-8. Subbasin Annual Water Budget Summary

All values are in acre-feet, rounded to nearest 100 AF			
	Component	**Average**	**Additional Explanation**
Inflows	Precipitation	391,800	Precipitation that falls on Subbasin
	Surface Water Inflow	11,061,000	Surface water that flows into Stony Creek, Thomes Creek, and the Sacramento River where they enter the Subbasin, plus flow from small watersheds
	Subsurface Inflow	97,100	Subsurface inflow into the Subbasin from neighboring subbasins and foothills
	Groundwater Discharge to Streams from Outside Subbasin	3,800	Net groundwater discharge into Stony Creek, Thomes Creek, and Sacramento River from neighboring Subbasins
	Overland Flow and irrigation return flow to Streams from Outside Subbasin	110,700	Overland flow and irrigation return flow into Stony Creek, Thomes Creek, and Sacramento River from neighboring Subbasins
Outflows	Evapotranspiration	328,600	Evapotranspiration that occurs on the Subbasin's land surface and riparian evapotranspiration along Stony Creek, Thomes Creek, and Sacramento River
	Surface Water Outflow	10,380,600	Surface water outflow where the Sacramento River leaves the Subbasin
	Subsurface Outflow	84,800	Subsurface outflow from the Subbasin into neighboring subbasins
	Losses on Black Butte Lake Outside of Subbasin	74,900	Losses on Black Butte Lake to areas outside of the Subbasin including groundwater recharge to Colusa Subbasin, ET, and diversions.
	Total Diverted Surface Water to Areas Outside of Subbasin	787,000	The total amount of surface water that is diverted from the Subbasin to neighboring areas, including diversions to Glenn-Colusa Canal and M&T bypass minus the amount of surface water that is imported into the Subbasin
Storage	Change in Subbasin Storage	8,500	A sum of the above inflows and outflows, generally reflecting an amount of water stored in groundwater and in the soil and unsaturated zone



**Reflects upstream surface water inflows to Stony Creek, Thomes Creek and the Sacramento River, minus downstream surface water outflows in the Sacramento River*

Figure 4-18. Historical Total Subbasin Water Budget

4.2.5 Subbasin Water Supply Reliability

4.2.5.1 Surface water supplies

As described in Section 3.1.8, surface water is available in the Subbasin for areas within managed water districts, which account for only 12% of the total Subbasin area. The total current irrigated agricultural acreage within the Subbasin is approximately 30% of the total Subbasin area, and approximately 40% of the irrigated area has access to surface water supplies. Other surface water supplies are from smaller riparian and appropriative water rights users along streams. The majority of the water supply source in the Subbasin comes from groundwater (Figure 4-12; Table 4-3).

Surface water deliveries from outside of the subbasin to Corning Subbasin water districts have decreased over the historical period, particularly in recent years (Figure 4-19). The model simulation period ends in 2015, at the height of the last major drought, and shows the proportion of surface water supplies versus groundwater supplies has decreased, similar to other historical dry periods. However, since many districts received zero water allocations in 2014 and 2015, surface water supplies declined severely in those 2 years, forcing growers to turn to groundwater to maintain their crops, in particular tree crops that have recently been more prominent in the Subbasin.

The total simulated volume of surface water application within the Subbasin varies over the historical period from roughly 40,000 to 120,000 AF/yr, dependent largely on precipitation and corresponding available surface water, in addition to land use trends. From 2013 onward, surface water application drops sharply, corresponding to a lack of available surface water in the recent statewide drought (Figure 4-19). Note that simulated surface water applications may not exactly match the actual surface water used, because of model approximations.

Figure 4-20 through Figure 4-23 display simulated groundwater and surface water use in the modeled application areas of Corning WD, Thomes Creek WD, Kirkwood WD, and OUWUA North, respectively. While long-term surface water use in OUWUA North has remained fairly consistent, the other 3 water districts have experienced large declines in surface water deliveries and increasing dependence on groundwater as the primary or sole source of water.

4.2.5.2 Groundwater supplies

Simulated groundwater use within the subbasin ranges across the historical period from around 80,000 AF to over 160,000 AF/yr, dependent on changes in land use, available surface water, and climatic variation (Figure 4-19). Groundwater applications have generally increased over the historical period, correlated primarily with increases in total irrigated agricultural land and local transitions from row crops and pasture to more permanent crops such as almonds, walnuts, and olives. Historical land use trends are described in more detail in the Plan Area Section 2.

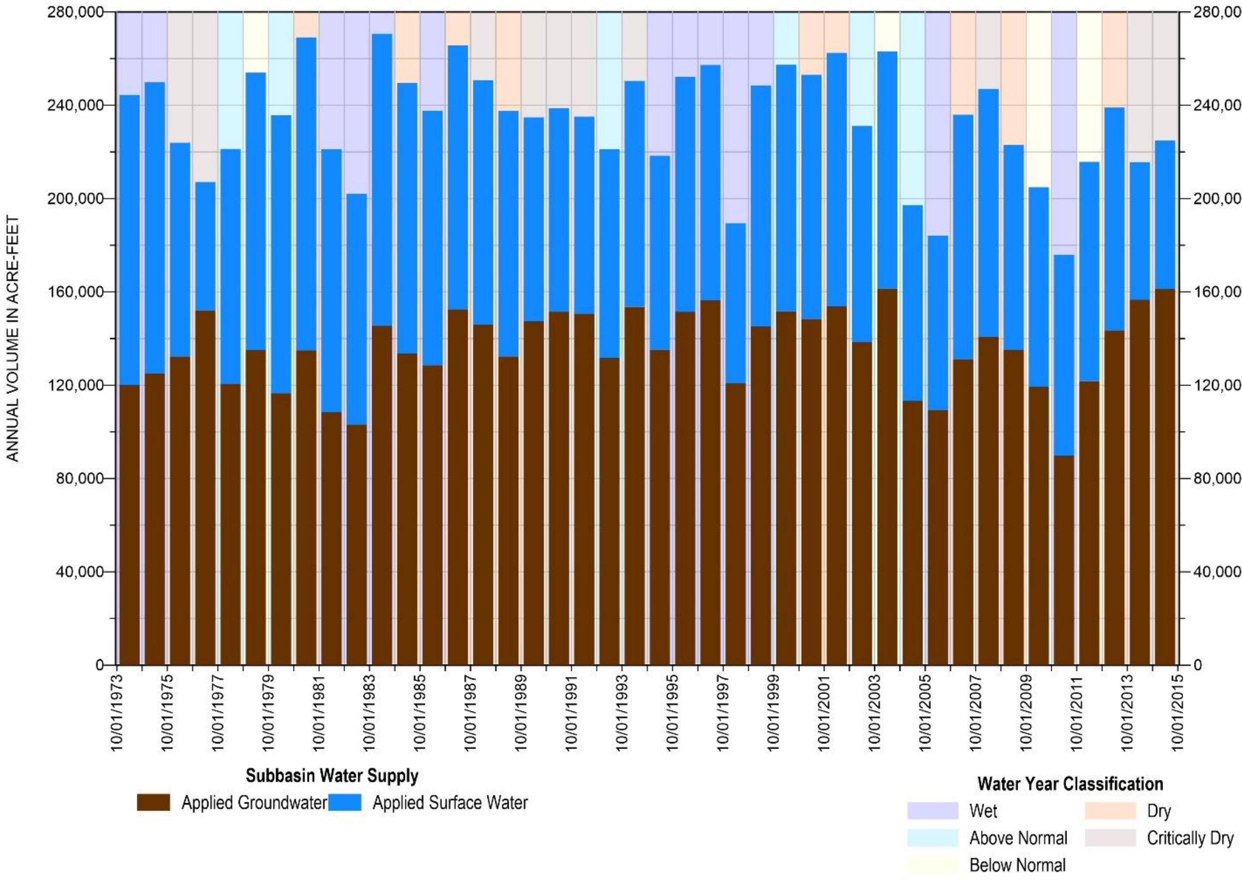


Figure 4-19. Subbasin Simulated Historical Applied Water Summary

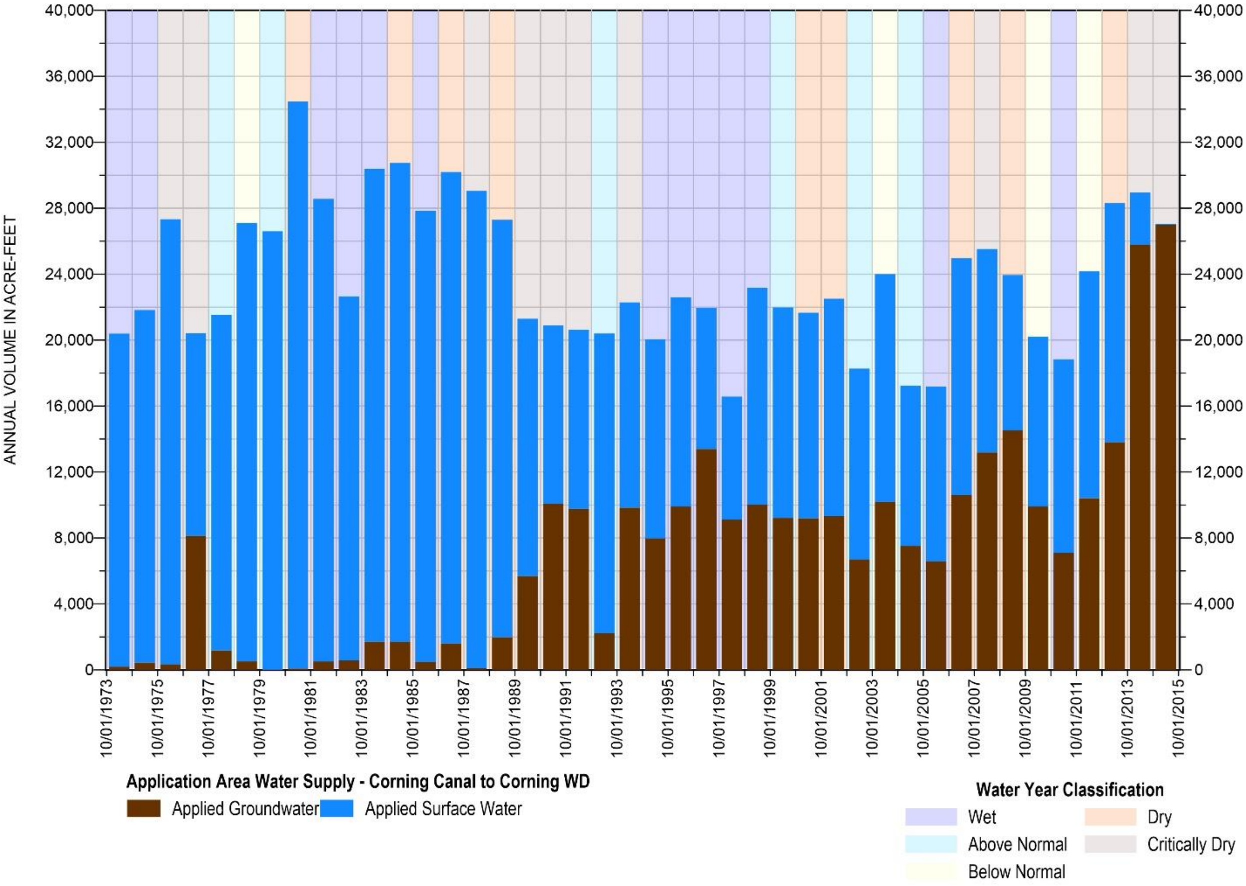


Figure 4-20. Application Area Simulated Water Supply, Corning Canal to Corning WD

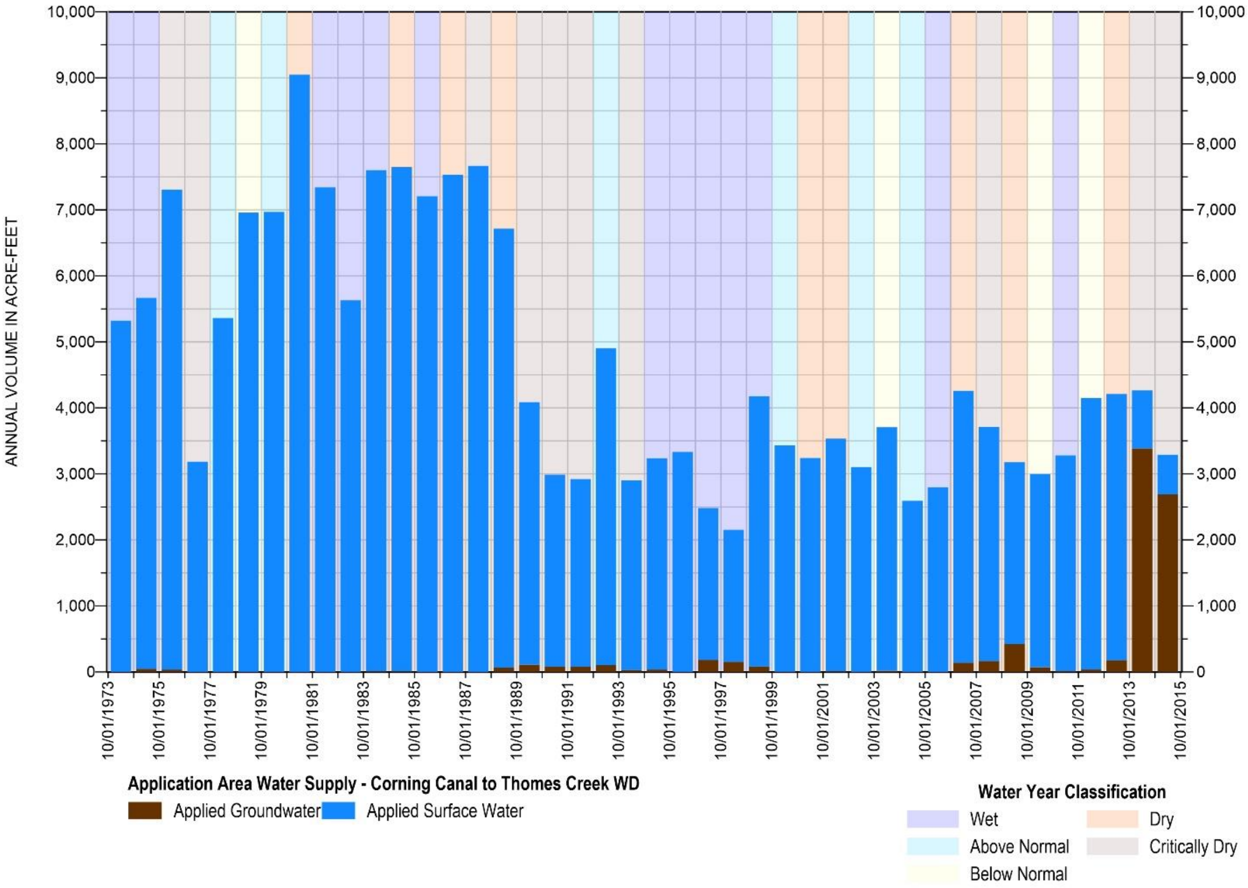


Figure 4-21. Application Area Simulated Water Supply, Corning Canal to Thomes Creek WD

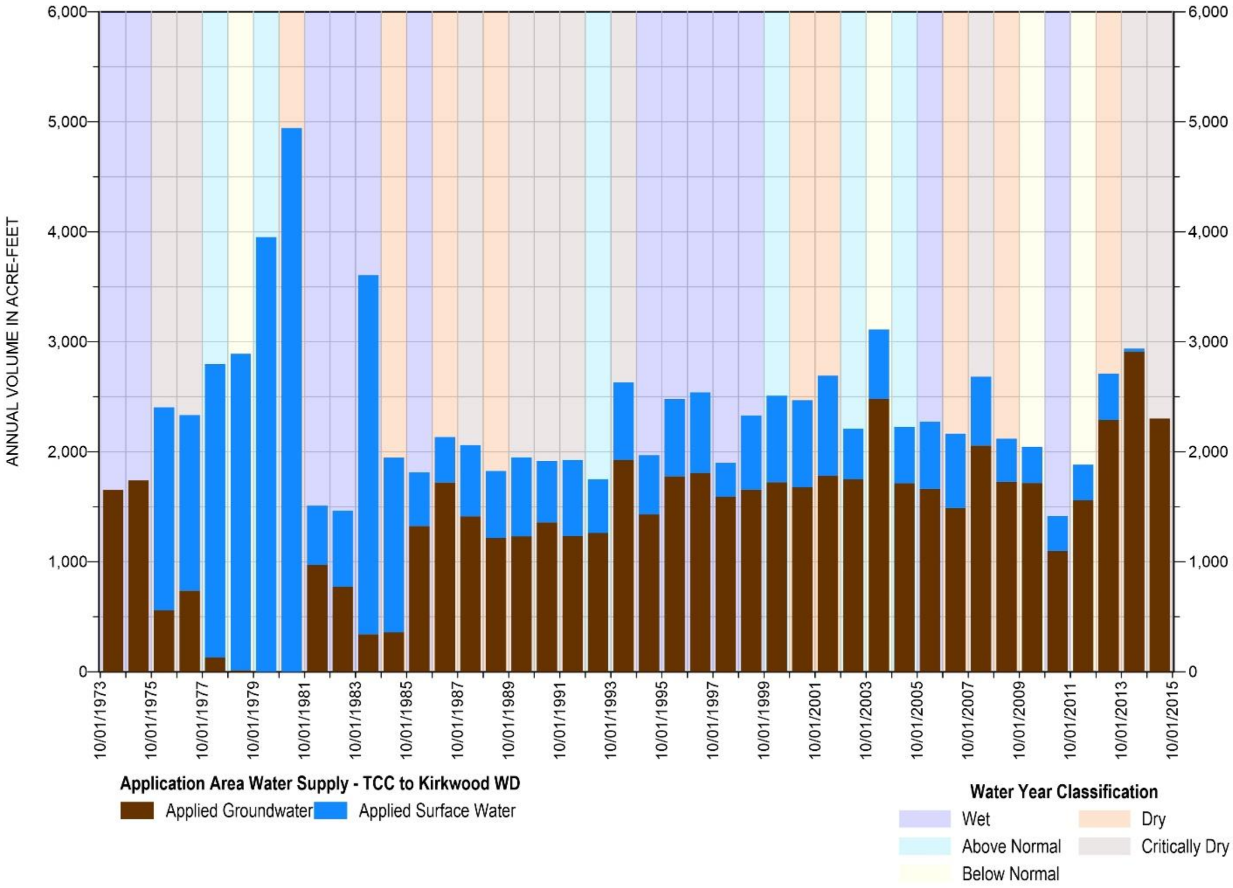


Figure 4-22. Application Area Simulated Water Supply, Tehama Colusa Canal to Kirkwood WD

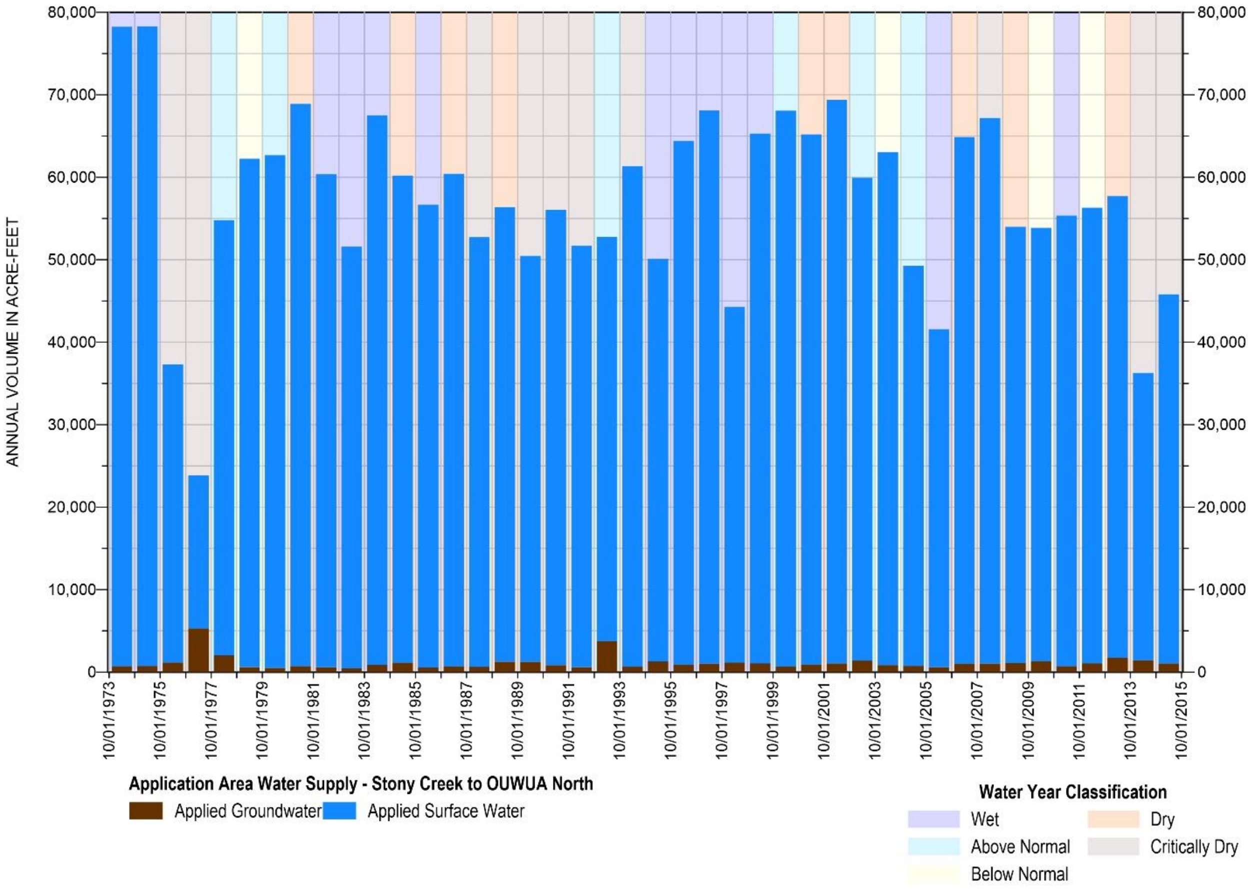


Figure 4-23. Application Area Simulated Water Supply, Stony Creek to OUWUA North

4.2.5.3 Recent Surface Water Supply Availability Challenges

Figure 4-24 through Figure 4-26 display recent historical records of surface water application for Corning WD, Thomes Creek WD, OUWUA's North District, and Kirkwood WD. These graphs help describe Subbasin surface water applications past the model's end date of WY 2015. While surface water application in Corning WD (Figure 4-24) and OUWUA North (Figure 4-27) have recovered since decadal lows seen around 2014-2015, applications remain generally lower than historical. Applications in Thomes Creek WD (Figure 4-25) and Kirkwood WD (Figure 4-26) dropped drastically during the drought and remain well below pre-drought levels.

The sections below provide a summary of surface water supplies from data collected from the Districts, as well as trends of surface water versus groundwater use.

4.2.5.3.1 Corning Water District

Corning Water District has adequate surface water supply with a good surface water contract amount that generally could satisfy the majority of the surface water supply needs of the district in wet and normal years (Table 4-9). However, in recent years, after the last drought, more growers have turned to groundwater, reducing the amount of surface water used within the district, and increasing the amount of groundwater use. In addition, the total CVP contract amount for the District, which was originally 23,000 AF/yr, decreased to 20,000 AF/yr in 2018 and then to 15,000 AF/yr in 2020, due to the District selling parts of their allocations.

Corning WD is able to work with other CVP users along the Tehama Colusa Canal to transfer water in and out of the district to manage surface water supply based on its growers' needs and to generate revenue (Table 4-9).

Table 4-9. Corning Water District Surface Water Contract Allocation

Year	Allocation %	Allocation Total AF	Transfer in (AF)	Transfer out (AF)	Actual Surface Water Used (AF)
2010	100%	23,000	0	0	10,811
2011	100%	23,000	0	0	10,554
2012	100%	23,000	0	29	14,550
2013	75%	17,250	0	982	13,461
2014	0%	0	1,063	0	1,063
2015	0%	0	688	0	688
2016	100%	23,000	0	0	9,166
2017	100%	23,000	0	0	9,901
2018	100%	20,000	0	0	8,987
2019	100%	20,000	0	0	8,077
2020	50%	7,500	200	0	7,700

Note: Since 2020, the District's total allocation is 15,000 AF/yr.

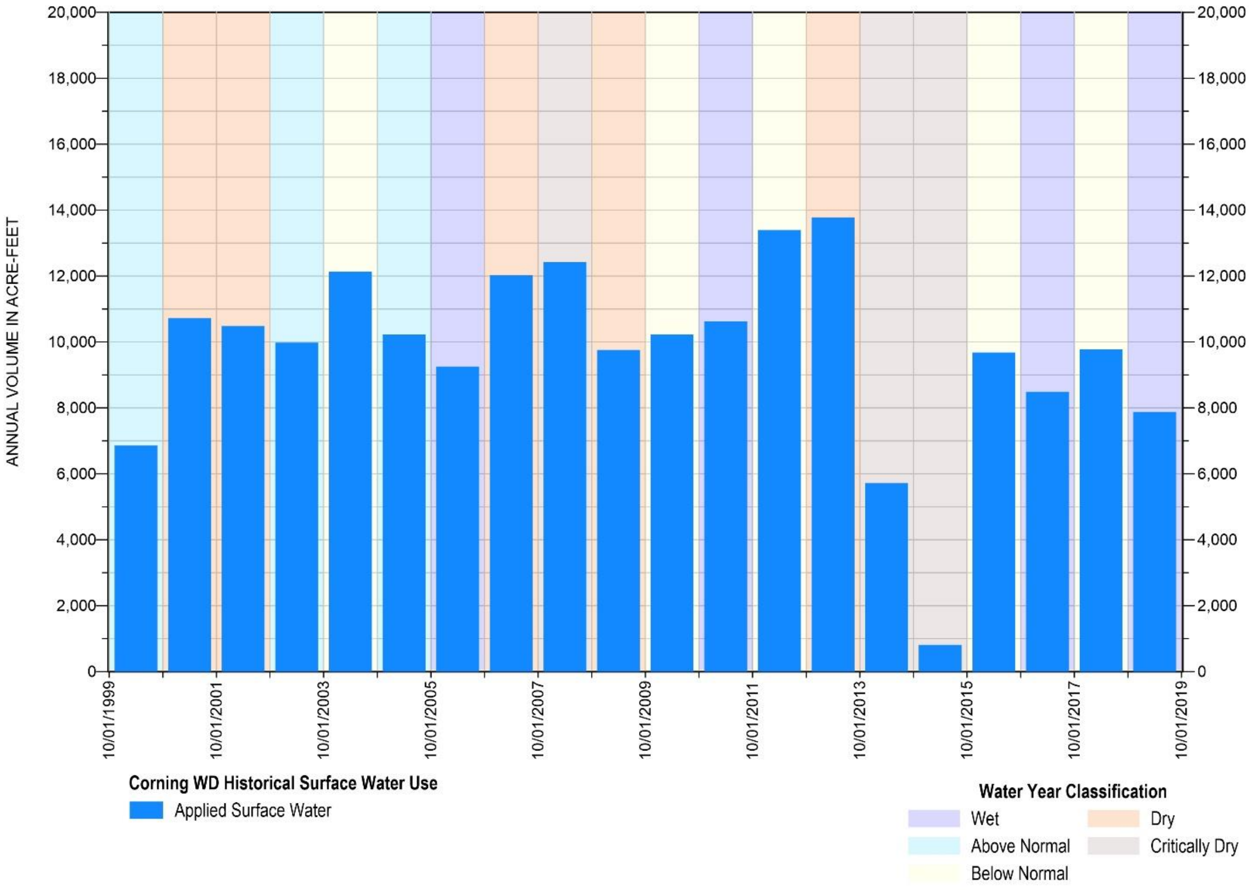


Figure 4-24. Corning WD Recent Surface Water Use, from Measured Data (Corning WD, 2020)

4.2.5.3.2 Thomes Creek Water District

Thomes Creek WD has drastically reduced its use of surface water since the 2012-2016 drought (Figure 4-25), when the District received zero surface water allocations, forcing growers with permanent crops to drill wells to pump groundwater. However, since the drought, growers have preferred to continue using groundwater instead of surface water, due to increased cost of surface water, and unreliability of surface water deliveries. Growers also made large investments in infrastructure to access groundwater supplies (well, irrigation system refinements, and related). As a result, groundwater use is more prominent within the District than in the past.

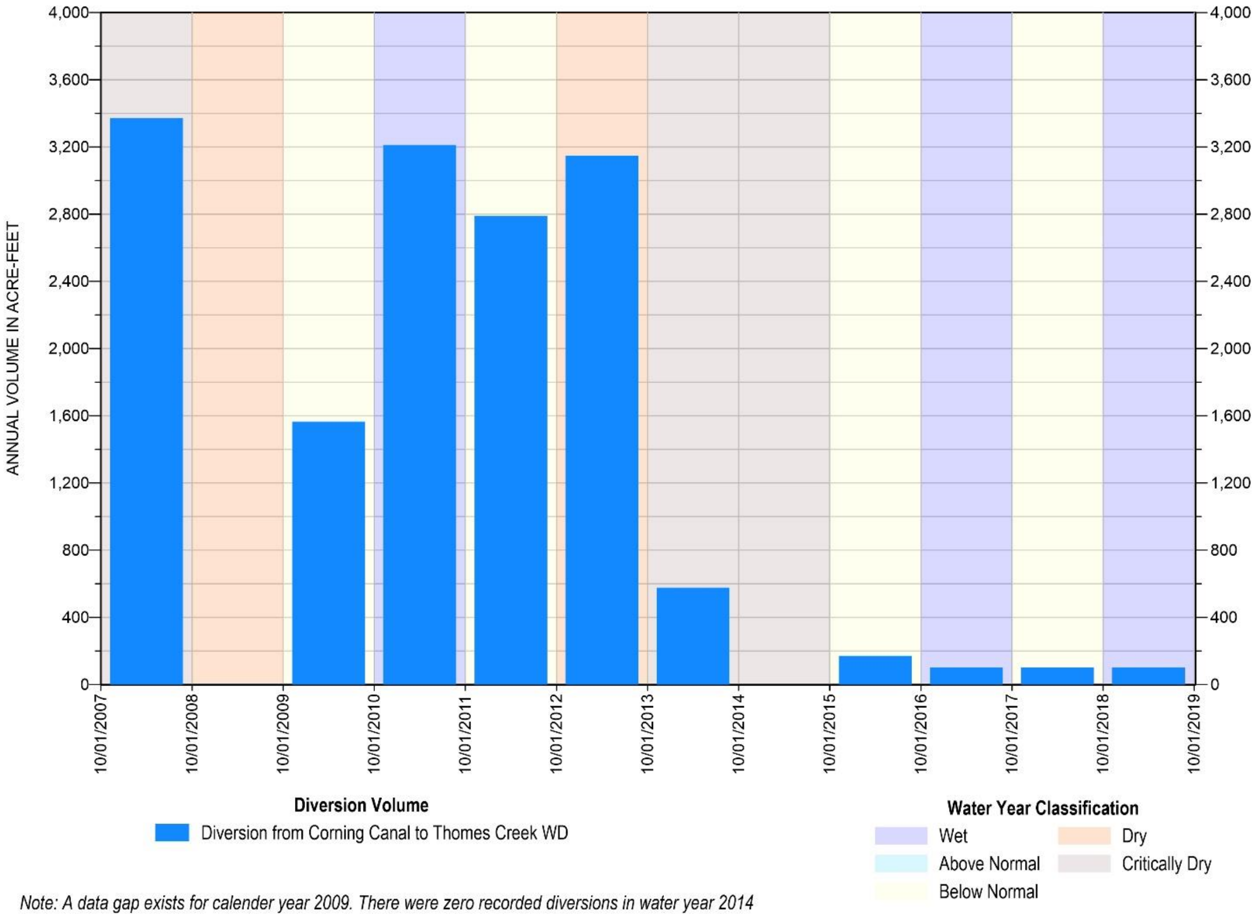


Figure 4-25. Thomes Creek WD Recent Surface Water Use, from Measured Data (Thomes Creek WD, 2020)

4.2.5.3.3 Kirkwood Water District

Kirkwood WD has stopped using surface water since the 2012-2016 drought (Figure 4-26), when the District received zero surface water allocations, forcing growers with permanent crops to drill wells to pump groundwater. However, since the drought, growers have preferred to continue using groundwater instead of surface water, due to increased cost of surface water, and unreliability of surface water deliveries. Growers also made large investments in infrastructure to access groundwater supplies (well, irrigation system refinements, and related). As a result, groundwater use is more prominent within the District than in the past.

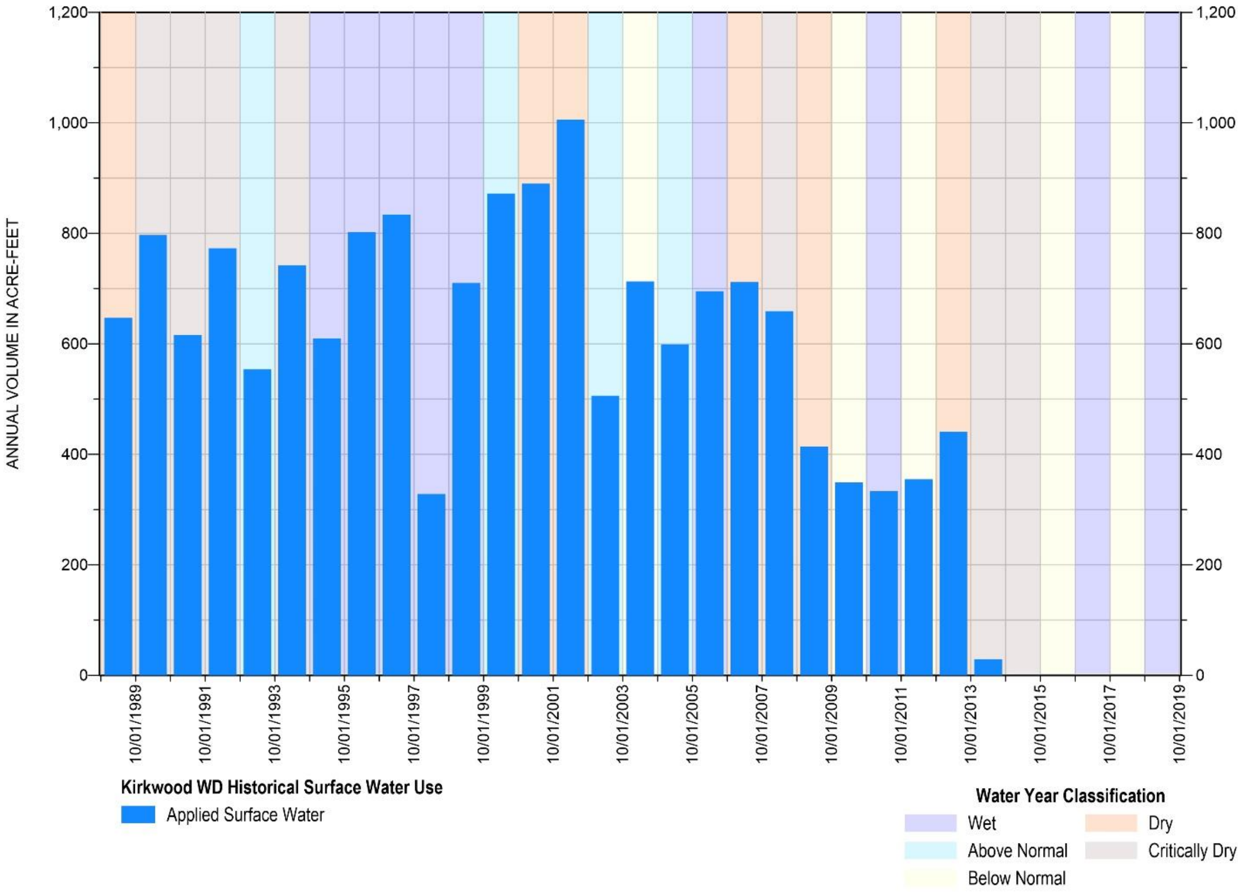


Figure 4-26. Kirkwood WD Recent Surface Water Use, from Measured Data (USBR, 2020)

4.2.5.3.4 Orland Unit Project (Northside)

Available surface water usage data from the Orland Unit Project's Northside service area presents consistent application of over 20,000 AF of surface water within the Subbasin since WY1993 (Figure 4-27). Total application volume is not strongly correlated with climate, and applications have ranged from around 23,000 to 47,000 AF since WY1993.

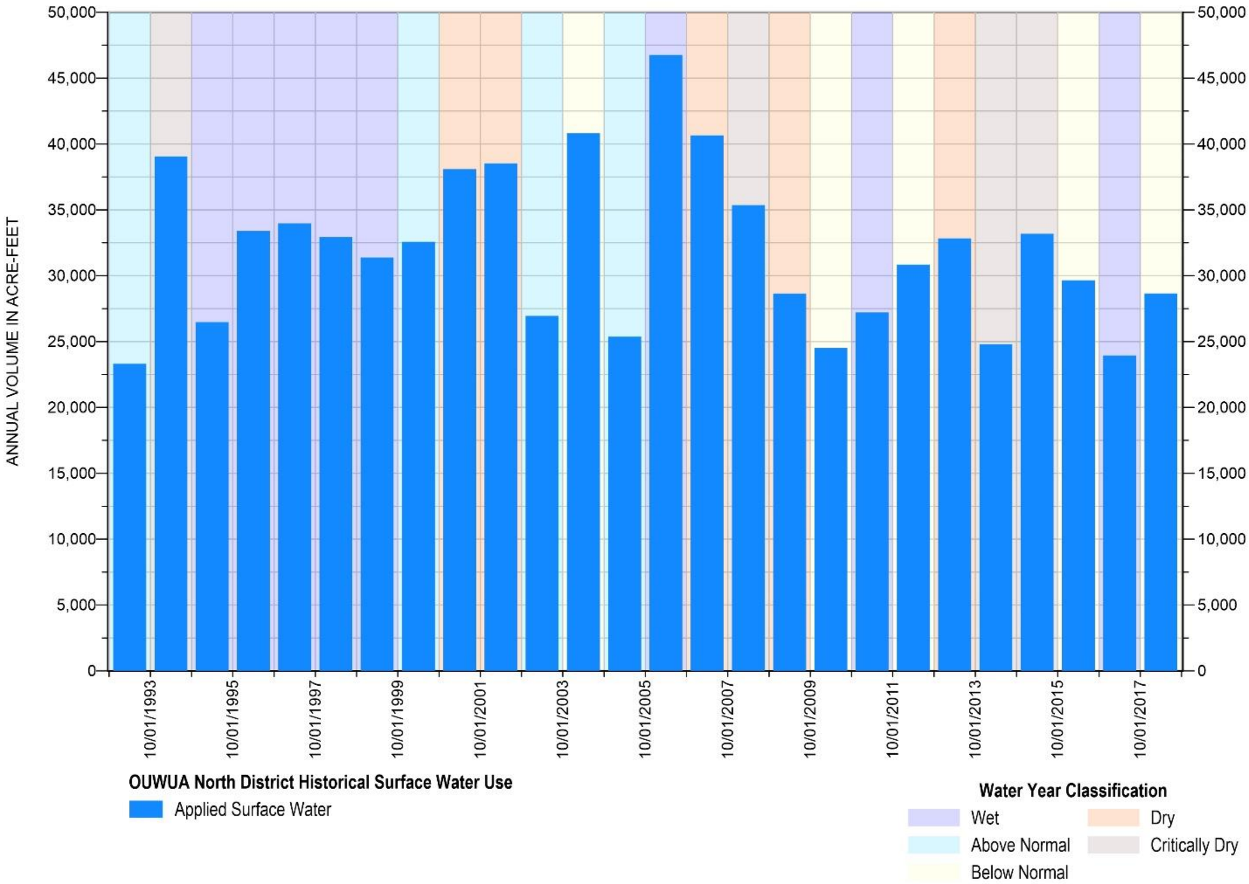


Figure 4-27. OUWUA North District Recent Surface Water Use, from Measured Data

4.3 Current Water Budgets

As described further in Section 4.4.3.2, the current model time frame is a simulation of current land and water use conditions, assuming no climate change or change in anthropogenic activity. The current time frame uses current land use (2018 for Tehama County and 2015 for Glenn County) and current surface water use (2015), while repeating the historical climate and hydrology. The historical climate and hydrology sequence are repeated over a 50-year period to bring the current timeframe out to 2066, to allow for more direct comparison with the projected water budgets timeframe. The historical 41 years of climate and hydrology from the calibrated model (representing WY1974-2015) was repeated for the projected period, and then the first 9 years of the historical period were repeated to create a 50-year projected time frame. The future projected water budgets described below follow the same time period, to facilitate direct comparison between current and projected conditions with climate change.

When compared to the historical groundwater simulation, inputs to the current model time frame are characterized largely by decreased surface water use and an increase in irrigated acreage, primarily in orchard crops. As WY 2015 was at the tail end of the recent statewide drought with mostly zero CVP allocations, surface water diversions were lower across the entire Northern Sacramento Valley than in recent earlier years.

4.3.1 Groundwater Budget

The current groundwater budget is summarized in Table 4-10 and presented in timeseries on Figure 4-28 and Figure 4-29. Major differences between the historical groundwater budget and the current groundwater budget include the following:

- A 19,400-AF decrease in average deep percolation to groundwater caused primarily by decreases in surface water applications.
- A 6,800-AF increase in average streambed recharge, and a 16,300-AF decrease in groundwater discharge to streams, driven by lower groundwater elevations near streams.
- A 20,700 AF increase in agricultural pumping driven by decreased surface water applications.
- A 5,800-AF decrease in average annual change of groundwater in storage largely attributable to the trends described above.

The above changes result in a cumulative change of groundwater in storage of 56,100 AF over the 50-year simulation period, down 234,200 AF from the historical groundwater budget, driven mainly by decreases in surface water availability. These results suggest that current land use and water use trends may not be sustainable if continued over another 43 years, absent of considerations of climate change.

This section addresses the first part of DWR's correction 1a stated below and projects and management actions are updated in Section 7. At the 5-year Periodic Evaluation the integrated surface water – groundwater model, SVSim or C2VSim will be updated and calibrated with new information that includes but is not limited to improvements to the conceptual model based on information from the AEM survey, and new geology, water level and well information, new water budget inputs, and updates to climate change predictions. The numerical model was not used in the revised GSP. The 5-year Periodic Evaluation in January 2027 will address current and future water budgets including overdraft based on the updated model.

> "Reevaluate the assessment of overdraft conditions in the Subbasin. Specifically, the GSAs should examine the assumptions that were used to develop the absence of historical and current overdraft and the projected overdraft estimates in the projected water budget considering the results vary greatly from the values reported in the recent annual report data. The assessment should include the latest information for the Subbasin to ensure the GSP includes the required projects and management actions to mitigate overdraft in the Subbasin."

The GSP documents annual change groundwater storage as a positive 6,900 acre-feet per year, however negative change in groundwater storage (i.e., overdraft) was reported for water year (WY) 2021 and WY 2022 of -100,000 acre-feet and -90,000 acre-feet, respectively. The water budget elements in the GSP were derived from the model up through WY 2015. The water budget elements and changes in groundwater storage (overdraft) were derived from an empirical method using measured groundwater elevation changes and aquifer storage coefficient for WY 2020-2023 as described in the annual reports. The significant difference in the values from 2019 compared to subsequent years is likely both a function of the method and hydrology with WY 2021 and WY 2022 both critically dry.

The Revised GSP provides a new estimate of current groundwater storage change, overdraft, and a basis for future overdraft predictions. The new estimate is not applicable to past overdraft estimates as it relies on recent data that cannot be applied to past conditions. This method was presented to DWR in consultation meetings. The method is to average annual groundwater storage values from the last five years that includes water years 2019 through 2023. This new estimate is -31,200 acre-feet per year. The annual storage changes for water years 2019 thru 2023, in order and (rounded to two significant digits) are 80,000 AF, -100,000 AF, -80,000 AF, -90,000 AF and 34,000 AF, therefore the average is the updated overdraft value of -31,200 AFY. These five years were Wet, Dry, Critically Dry, Critically Dry, and Wet, respectively. The range of years was selected to begin in 2019 based on land use changes that indicate an increase in water use from crops, mainly walnuts and almonds, and hence likely to influence future water use. There is uncertainty in the total recharge from projects once they are fully implemented (Section 7). Project listed in Tables 7-4 and 7-8 range from approximately 30,000 AF to approximately 55,000 AF. If fully realized, these projects may compensate for or even exceed the current estimate of overdraft.

Demand management may be required, until the recharge projects are fully implemented, if their total efficacy is less than estimated or recharge is limited in drought years.

The empirical method used in annual reports likely has less certainty than the numerical model. Regardless of the methodology, numerical modeling or empirical method, there is significant uncertainty in the overdraft value. The overdraft value is important for planning PMAs that are expected to compensate for overdraft and keep the subbasin on the path to sustainability. Monitoring of basin conditions through water levels and documented in annual reports should be the basis for determining the general magnitude of overdraft, if any, and the effectiveness of PMAs to compensate.

Given this new estimate of overdraft, Section 7 is updated to demonstrate feasible proposed projects and management actions to mitigate the overdraft, which addresses corrective action 1b.

Table 4-10. Current Groundwater Budget Summary

All values are in acre-feet, rounded to nearest 100 AF						
Component		Average	% Contribution*	Average in Critically Dry / Dry Years	Average in Below Normal / Above Normal Years	Average in Wet Years
Inflows	Deep Percolation to Groundwater	141,800	47%	98,900	157,700	175,800
	Streambed Recharge	57,900	19%	51,850	62,650	58,500
	Inflow from Colusa	14,500	5%	13,150	15,000	15,900
	Inflow from Red Bluff	48,100	16%	47,550	48,450	48,600
	Inflow from Butte	1,000	0%	850	950	1,100
	Inflow from Los Molinos	24,100	8%	24,100	24,300	24,000
	Inflow from Vina	12,300	4%	24,100	24,300	24,000
	Inflow from Foothills	1,600	1%	1,200	1,750	1,900
	Recharge to Groundwater from Black Butte Lake	2,000	1%	1,750	2,300	2,200
Outflows	Urban and Domestic Pumping	4,900	2%	4,900	4,900	4,900
	Agricultural Pumping	153,000	51%	164,100	147,750	145,000
	Outflow to Colusa	34,000	11%	34,850	34,100	31,700
	Outflow to Red Bluff	10,300	3%	10,050	10,300	11,000
	Outflow to Butte	2,300	1%	2,350	2,350	2,100
	Outflow to Los Molinos	9,600	3%	9,050	9,600	10,700
	Outflow to Vina	20,000	7%	19,000	19,900	21,400

All values are in acre-feet, rounded to nearest 100 AF						
	Component	Average	% Contribution*	Average in Critically Dry / Dry Years	Average in Below Normal / Above Normal Years	Average in Wet Years
	Groundwater Discharge to Streams	67,900	22%	57,350	69,250	80,900
Storage	Annual Change of Groundwater in Storage	1,100		-49,600	26,550	32,000
	Cumulative Change of Groundwater in Storage	56,100	-	-	-	-

* Percent contribution of component to average total inflow/outflow. Small discrepancies between inflow minus outflow and change in storage may occur due to rounding.

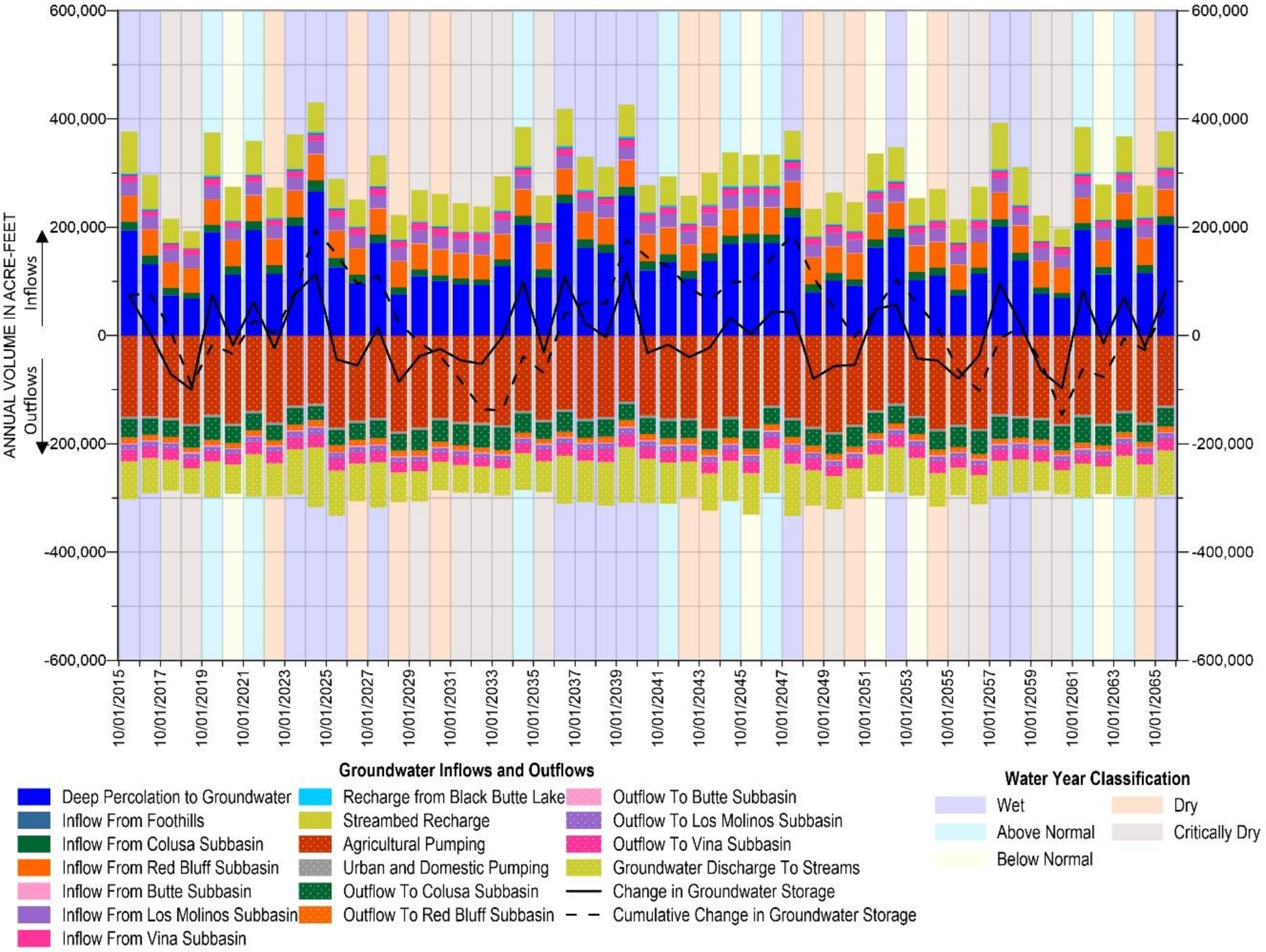


Figure 4-28. Current Groundwater Budget

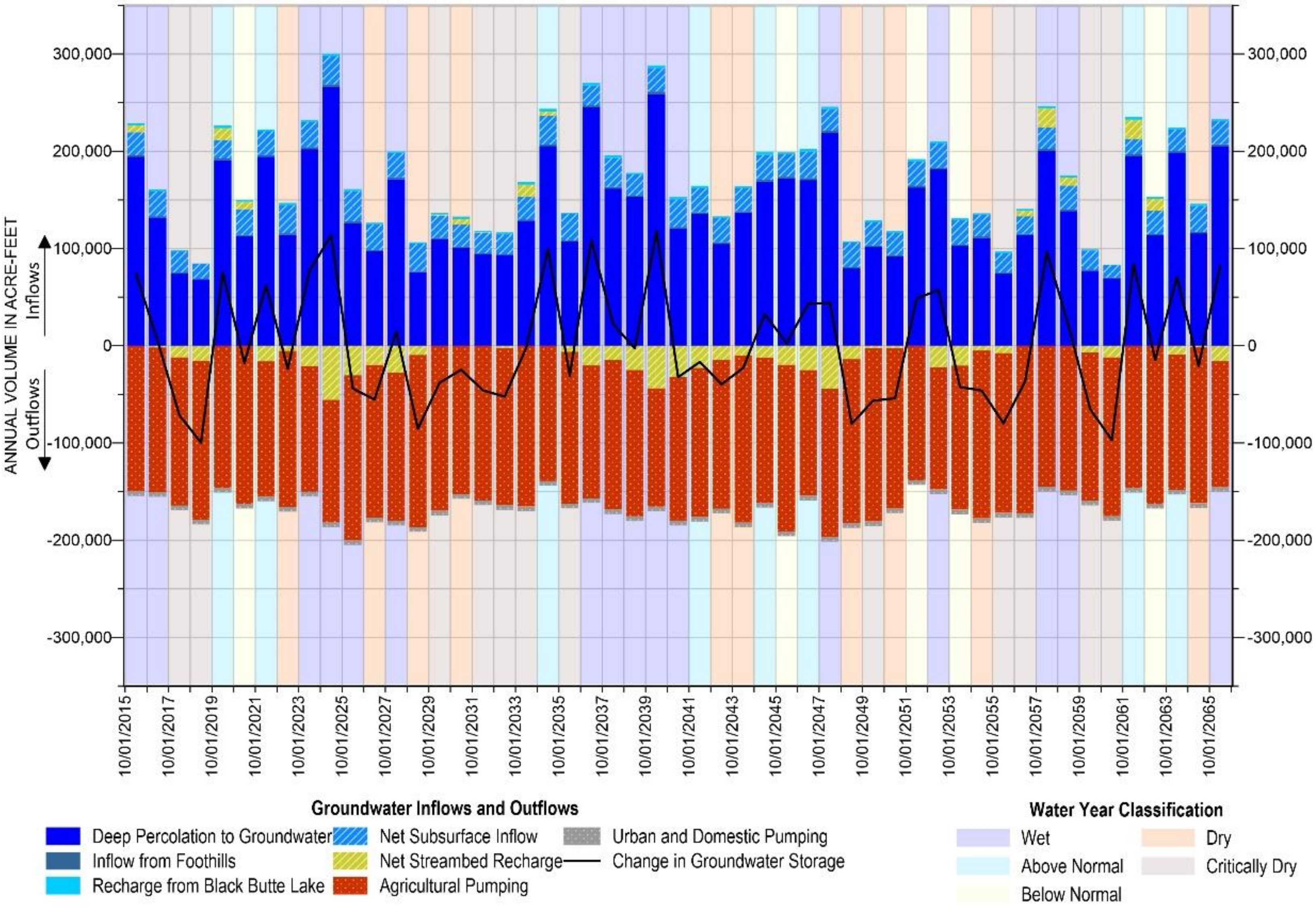


Figure 4-29. Current Groundwater Budget Net Flows

4.3.2 Land Surface Budget

The current land surface budget is summarized in Table 4-11 and presented in timeseries on Figure 4-30. Major differences between the historical land surface budget and the current land surface budget include the following:

- A 32,800-AF decrease in applied surface water, driven by the low diversion volumes in WY2015
- A 21,900-AF increase in average applied groundwater correlated with the above decrease in applied surface water and recent land use changes from 2015-2018 that increased the Subbasin's total irrigated acreage.
- A 17,700-AF decrease in deep percolation to groundwater attributable to lower volumes of total applied water and smaller decreases in overland flow and return flow to streams.

Overall, the current land surface budget compared to historical reflects a system with drastically decreased applied surface water, increased groundwater application, and decreased deep percolation to groundwater. As the current land surface budget incorporates low current (WY2015) surface water use, agricultural land use switches to groundwater as its primary source of water across much of the Subbasin. These trends are largely caused by the low diversion volumes present in WY 2015 that are incorporated into the current model period.

Table 4-11. Current Land Surface Budget

All values are in acre-feet, rounded to nearest 100 AF					
	Component	**Minimum**	**Maximum**	**Average**	**% Contribution***
Inflows	Precipitation	189,200	829,800	389,500	66%
	Applied Groundwater	126,400	182,800	157,800	27%
	Applied Surface Water	46,000	48,300	46,200	8%
Outflows	Deep Percolation to Groundwater	65,700	263,600	139,300	23%
	Evapotranspiration	272,900	323,200	302,100	51%
	Overland Flow	18,100	456,900	136,800	24%
	Return Flow to Streams	13,100	20,200	15,100	3%
Storage	Change in Soil and Unsaturated Zone Storage	-58,400	32,400	200	

* Percent contribution of component to average total inflow/outflow. Small discrepancies between inflow minus outflow and change in storage may occur due to rounding.

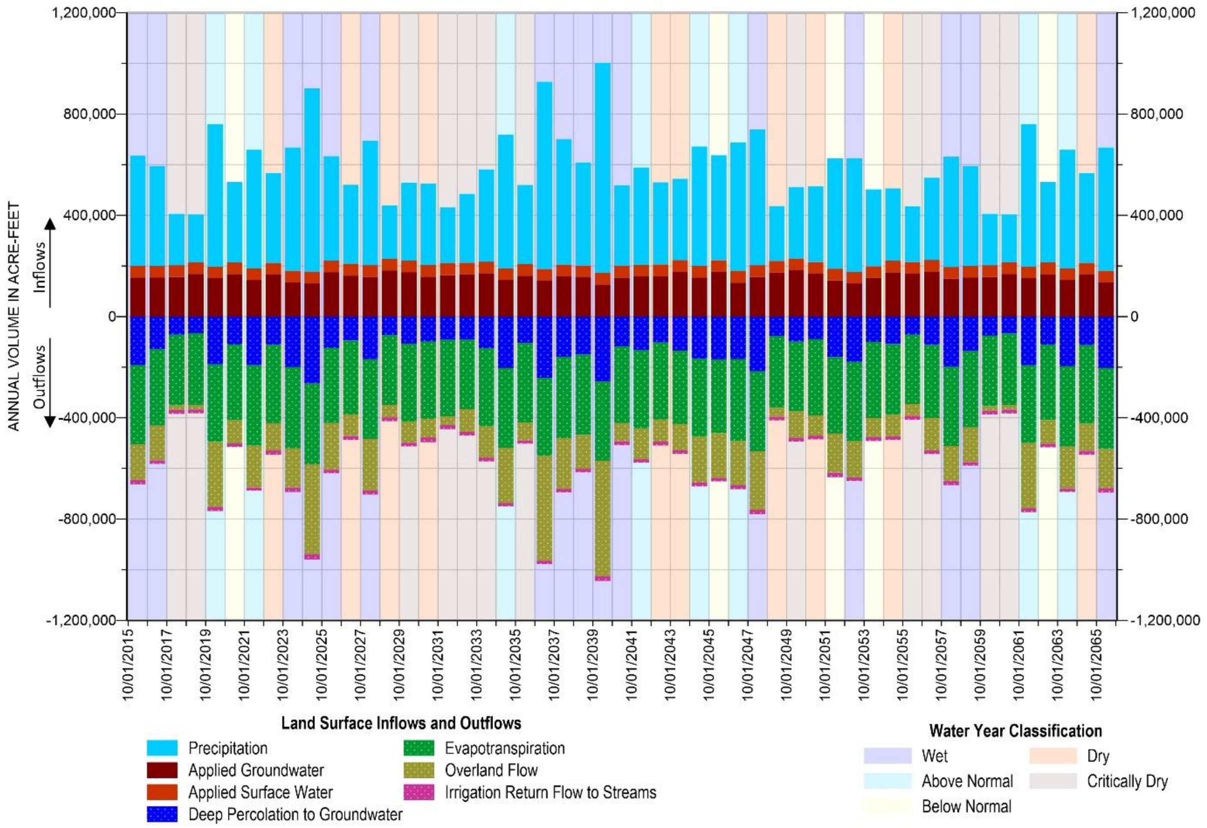


Figure 4-30. Current Land Surface Budget

4.3.3 Surface Water Budget

4.3.3.1 Sacramento River Budget

The current Sacramento River budget is summarized in Table 4-12Table 4-12 and presented in timeseries on Figure 4-31. Major differences in average annual components between the historical Sacramento River budget and the current Sacramento River budget include the following:

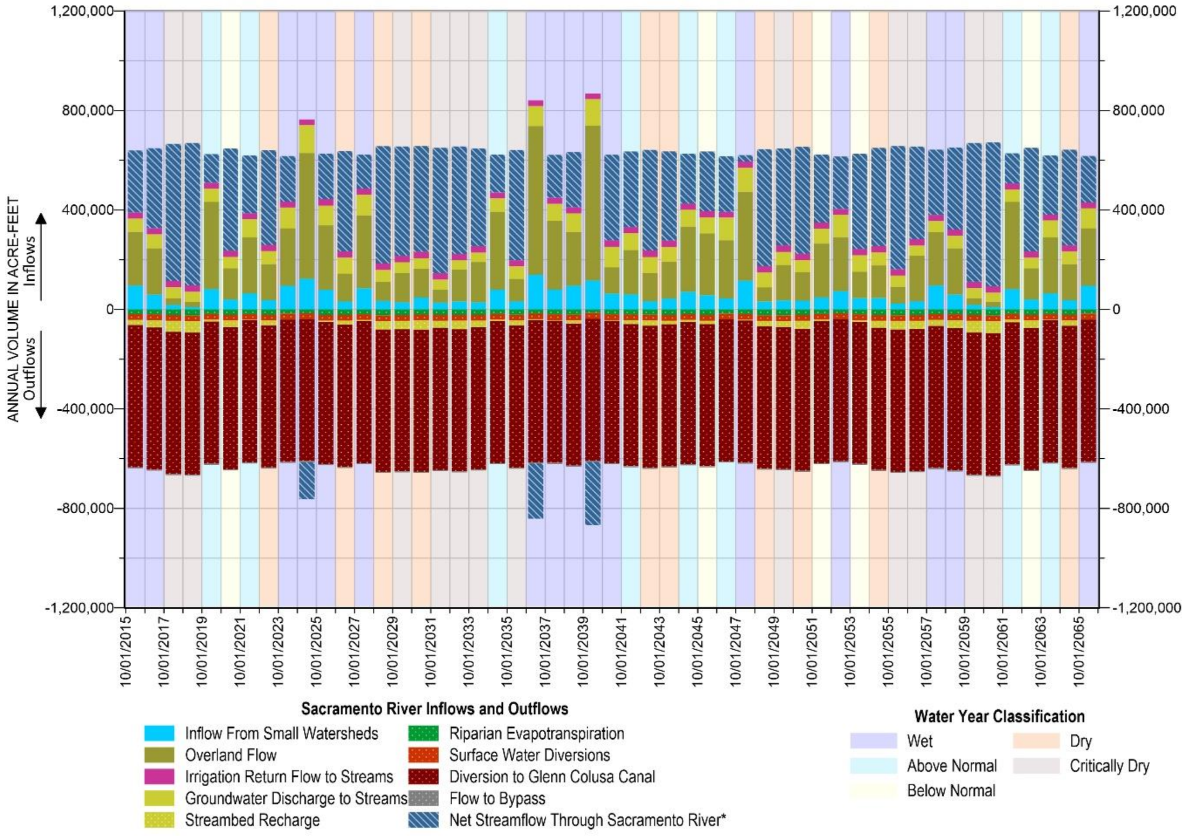
- A 27,500-AF decrease in groundwater discharge to streams and 11,200-AF increase in streambed recharge, potentially resulting from lowered groundwater levels and increased flow in the Sacramento River
- A 310,700 AF increase in inflow from upstream of basin, correlated with a decrease in diversions upstream of the Corning Subbasin
- A 188,000-AF decrease in flow to the Glenn-Colusa Canal

Overall, the current Sacramento River budget compared to the historical budget reflects a system with decreased diversions, increased total surface water flow, and decreased groundwater discharge to streams. Decreased diversions and increased total surface water flow result from the use of WY2015 diversions, which were low due to zero to minimal surface water allocations as a result of the recent statewide drought. Decreased diversions along the Sacramento River north of the Subbasin result in increased flow from upstream of the Subbasin.

Table 4-12. Current Sacramento River Surface Water Budget

All values are in acre-feet, rounded to nearest 100 AF					
Component		Minimum	Maximum	Average	% Contribution
Inflows	Inflow from Upstream of Basin	5,550,600	22,213,100	10,849,400	97%
	Inflow from Small Tributaries	9,811	139,200	57,400	1%
	Overland Flow	20,600	621,800	193,300	2%
	Irrigation Return Flows to Streams	21,800	26,400	24,600	<1%
	Groundwater Discharge to Stream	37,200	112,400	61,200	1%
Outflows	Streambed Recharge	0	49,300	18,500	<1%
	Downstream Outflow South of Subbasin	4,970,900	22,362,200	10,547,900	94%
	Riparian ET	14,200	24,100	20,400	<1%
	Surface water diversions	23,200	23,200	23,200	<1%
	Flow to Glenn-Colusa Canal	571,200	571,200	571,200	5%
	Flow to Bypass	4,700	254,400	4,700	<1%

* Percent contribution of component to average total inflow/outflow. Small discrepancies between total inflow and outflow occur due to rounding.



**Reflects upstream surface water inflow minus downstream surface water outflow*

Figure 4-31. Current Sacramento River Surface Water Budget

4.3.3.2 Stony Creek and Black Butte Lake Budget

The current Stony Creek budget is summarized in Table 4-13 and presented in timeseries on Figure 4-32. Major differences in average annual components between the historical Stony Creek budget and the current Stony Creek budget include the following:

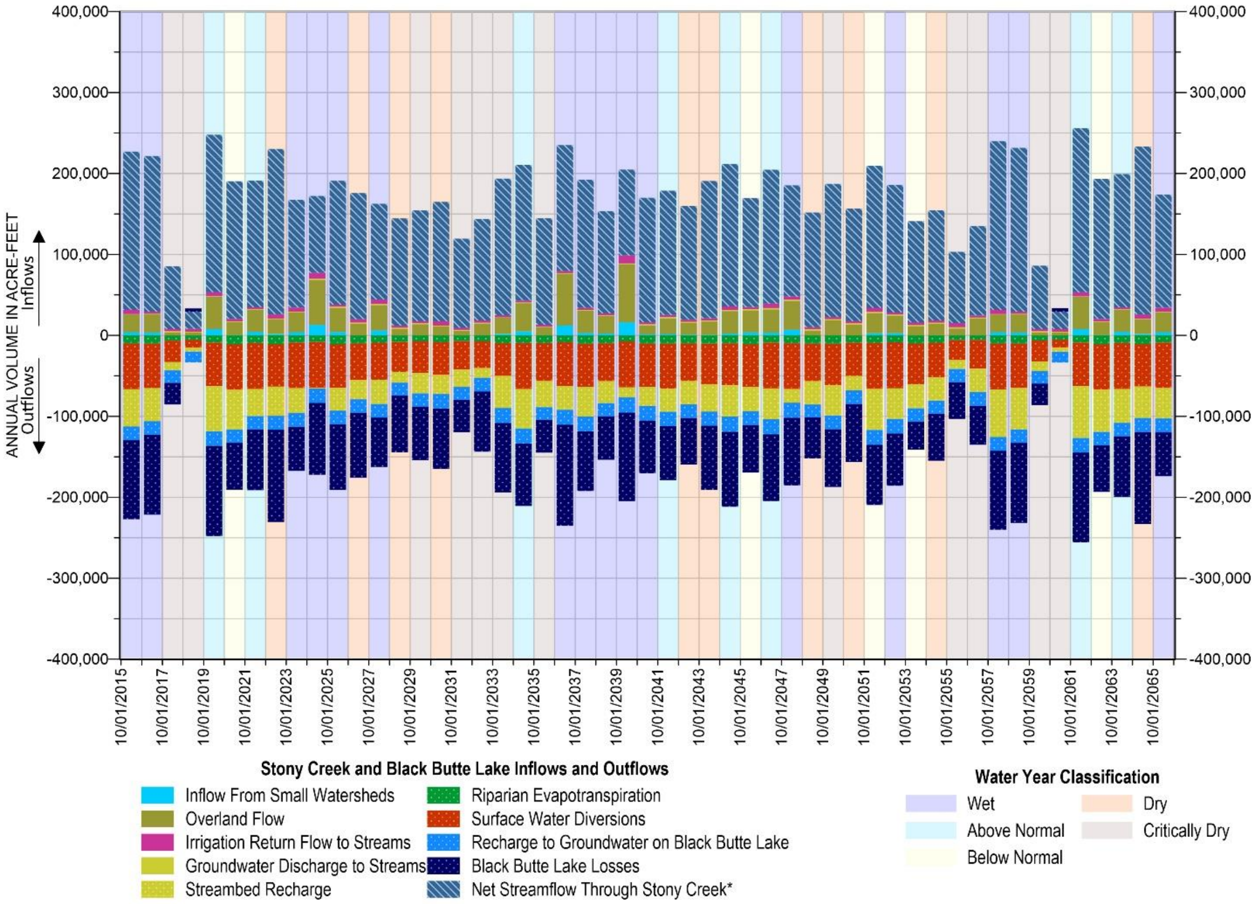
- A 11,900-AF increase in streambed recharge and a 500-AF decrease in groundwater discharge to streams resulting from lower groundwater elevations along Stony Creek.
- An 8,600-AF decrease in surface water diversions.
- An 800-AF decrease in irrigation return flows to streams attributable to decreased surface water application Subbasin-wide.

Overall, the current Stony Creek budget compared to the historical budget reflects a system with decreased overland flow and irrigation return flow contribution, decreased diversions, and decreased groundwater discharge to streams.

Table 4-13. Current Stony Creek and Black Butte Lake Water Budget

All values are in acre-feet, rounded to nearest 100 AF					
Component		Minimum	Maximum	Average	% Contribution*
Inflows	Inflow from Upstream of Basin	21,900	1,412,700	451,100	94%
	Inflow from Small Tributaries	0	16,100	2,800	1%
	Overland Flow	3,400	71,500	21,600	4%
	Irrigation Return Flows to Streams	2,400	9,800	3,600	1%
	Groundwater Discharge to Stream	300	2,100	1,200	<1%
Outflows	Streambed Recharge	900	64,200	31,100	6%
	Downstream Outflow to Sacramento River	700	1,317,800	306,100	64%
	Riparian ET	5,400	11,000	9,000	2%
	Surface water diversions	9,800	56,700	47,300	10%
	Recharge to Groundwater on Black Butte Lake	13,300	18,800	17,100	4%
	Black Butte Lake Losses	-4,200	124,800	69,800	15%

* Percent contribution of component to average total inflow/outflow. Small discrepancies between total inflow and outflow may occur due to rounding.



Reflects upstream surface water inflow minus downstream surface water outflow

Figure 4-32. Current Stony Creek and Black Butte Lake Water Budget

4.3.3.3 Thomes Creek Budget

The current Thomes Creek budget is summarized in Table 4-14 and presented in timeseries on Figure 4-33. Major differences in average annual components between the historical Thomes Creek budget and the current Thomes Creek budget include the following:

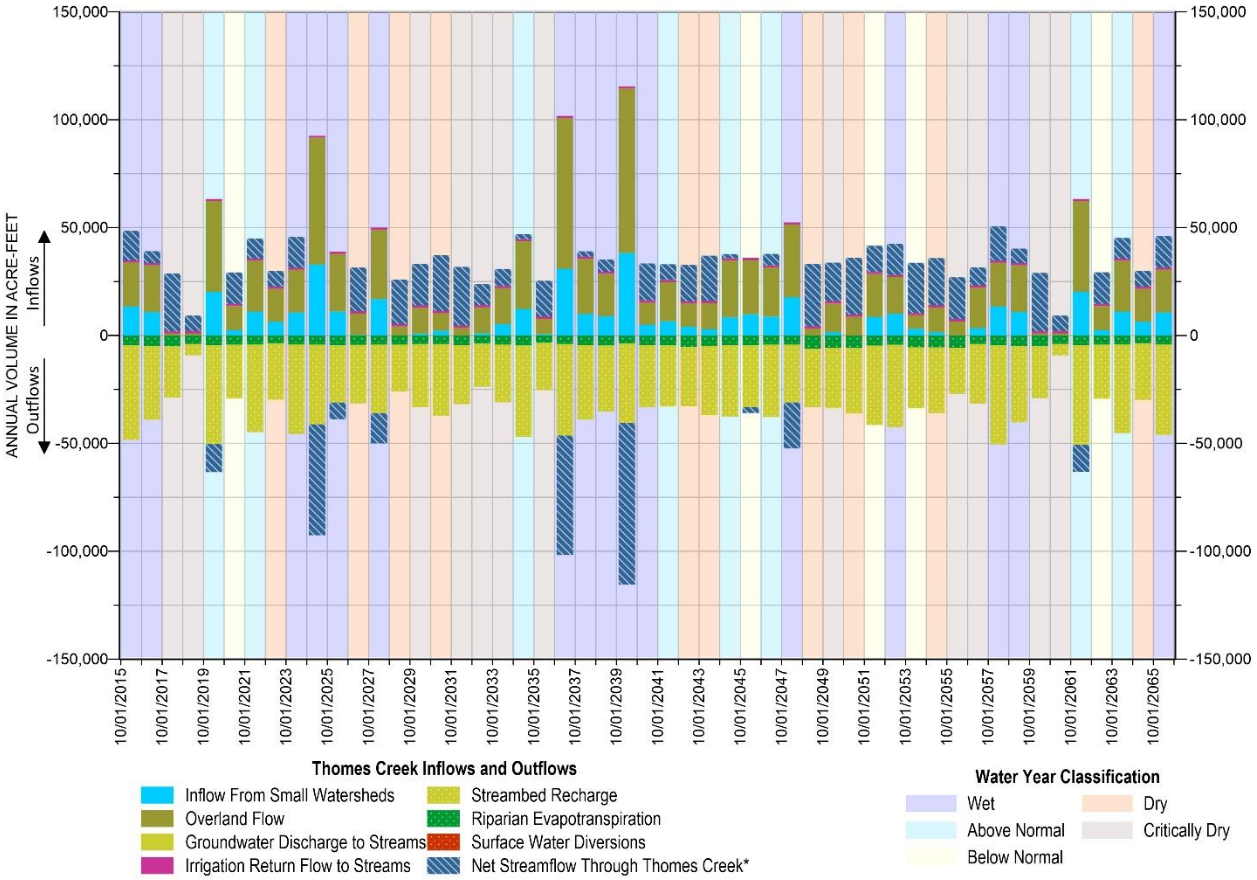
- A 1,500 decrease in surface water diversions, resulting in no surface water diversions on Thomes Creek over the entire current water budget
- A 3,800 -AF increase in streambed recharge resulting from lower groundwater elevations along Thomes Creek.
- A 1,400 AF decrease in downstream outflow to the Sacramento River largely attributable to Thomes Creek losing more volume to groundwater as it travels eastward.

Overall, the current Thomes Creek budget compared to the historical budget reflects an increasing losing steam with decreased total surface water flow, no surface water diversions, and increased discharge to groundwater. These trends likely result from lowered groundwater elevations along Thomes Creek correlated with decreased surface water applications and increased groundwater pumping.

Table 4-14. Current Thomes Creek Water Budget

All values are in acre-feet, rounded to nearest 100 AF					
Component		Minimum	Maximum	Average	% Contribution*
Inflows	Inflow from Upstream of Basin	15,600	567,600	227,500	89%
	Inflow from Small Tributaries	0	38,200	8,100	3%
	Overland Flow	900	76,400	19,400	8%
	Irrigation Return Flows to Streams	800	1,100	1,000	<1%
	Groundwater Discharge to Stream	0	0	0	0%
Outflows	Streambed Recharge	5,300	46,200	30,800	12%
	Downstream Outflow to Sacramento River	8,400	642,500	220,600	86%
	Riparian ET	3,500	6,100	4,500	2%
	Surface water diversions	0	0	0	0%

* Percent contribution of component to average total inflow/outflow. Small discrepancies between total inflow and outflow may occur due to rounding.



**Reflects upstream surface water inflow minus downstream surface water outflow*

Figure 4-33. Current Thomes Creek Water Budget Net Flows

4.4 Projected Water Budgets

Two projected water budgets are presented, one incorporating estimated 2030 climate change projections and one incorporating estimated 2070 climate change projections. Both climate projections represent central tendencies of climate change model projections for the years 2030 and 2070, respectively (DWR, 2018b). These projected water budgets represent 50 years of future conditions incorporating projected climate change. These projections do not simulate a specific 50-year projected future, but rather simulate approximate hydrologic conditions that may occur in 2030, and approximate hydrologic conditions that may occur in 2070.

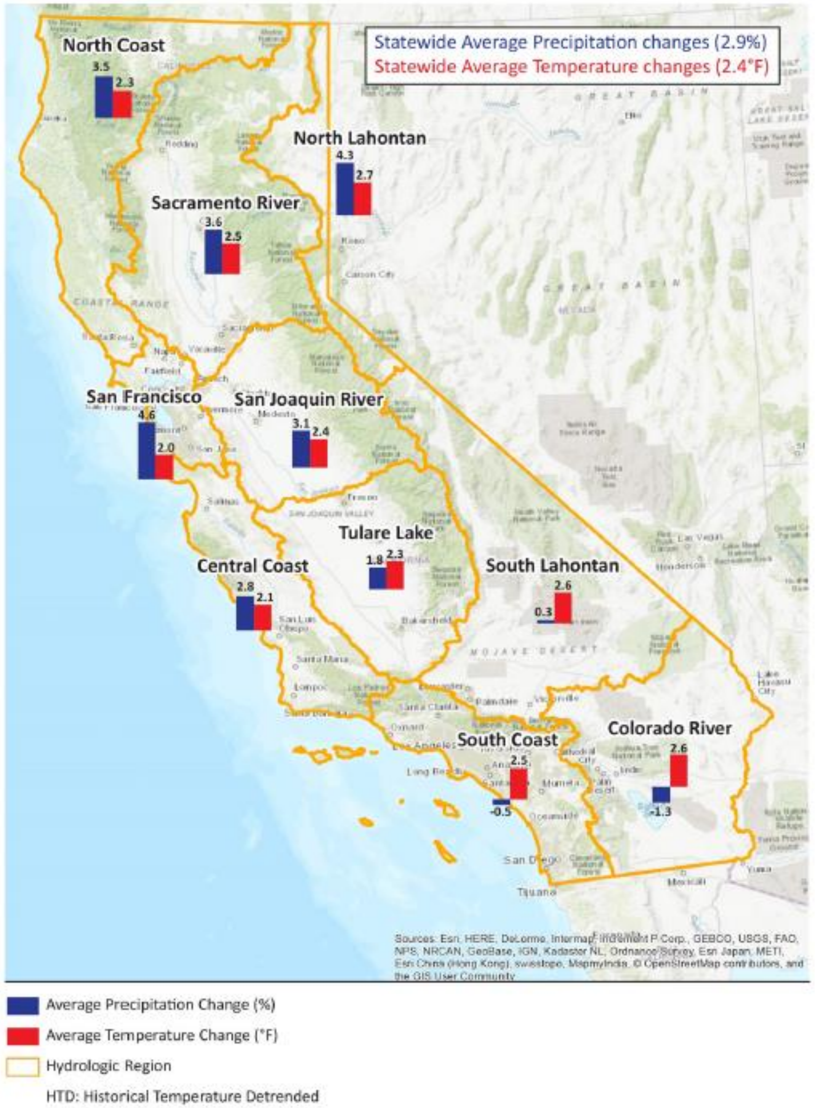
The climate change projections are based on the available climate change and projected hydrology data provided by DWR (DWR, 2018b). For this GSP, the projected time frame is defined as WY 2016-2066 with current land use (2018 in Tehama County, 2015 in Glenn County) and current surface water use (2015), while altering climate and hydrology to account for climate change as projected around 2030 and 2070.

Projected water budgets are useful to verify that sustainability will be achieved in the 20-year implementation period and maintained over the 50-year planning and implementation horizon.

The Revised GSP addresses the current estimate of the annual change in storage related to overdraft. A complete and comprehensive water budget analysis for current and future conditions will be conducted as part of the 5-year Periodic Evaluation in January 2027.

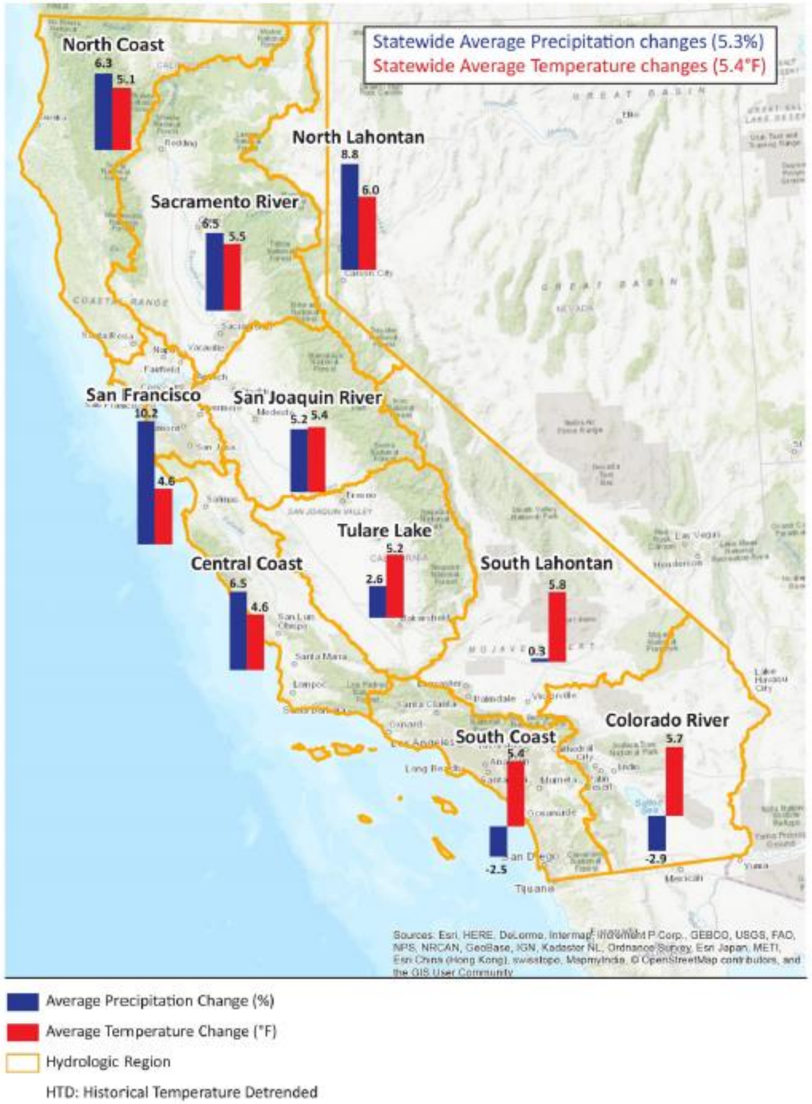
4.4.1 Method and Assumptions used to Develop Projected Water Budgets

Precipitation, evapotranspiration, stream inflow, and surface water diversions were adjusted for the 2030 and 2070 water budgets using publicly available DWR climate change and hydrology data and guidance (DWR, 2018b). In both scenarios, precipitation and ET are projected to increase in the Northern Sacramento Valley, with the 2070 period displaying larger increases in precipitation and ET Figure 4-34). A more detailed description of projected 2030 and 2070 scenario development is included in Appendix 4C.



Reference: Water Storage and Investment Program Technical Reference, California Water Commission, 2016.

Figure A-13. Projected Changes in Climate Conditions for 2030
Source: California Water Commission, 2016



Reference: Water Storage and Investment Program Technical Reference, California Water Commission, 2016.

Figure A-14. Projected Changes in Climate Conditions for 2070
Source: California Water Commission, 2016

Figure 4-34. Projected Precipitation and ET Changes at 2030 and 2070 [DWR, 2018b]

4.4.2 Projected 2030 and 2070 Groundwater Budgets

The projected 2030 and 2070 groundwater budgets are summarized in Table 4-15, along with average values from the current groundwater budget to facilitate comparison. Figure 4-35 through Figure 4-38 display the projected 2030 and 2070 groundwater budgets in time series.

Major differences between the current groundwater budget and the projected groundwater budgets incorporating climate change include the following, on an annual average basis:

- A 6,300-AF increase in agricultural pumping in the 2030 budget, and a 14,300-AF increase the 2070 budget. Agricultural pumping increases are driven largely by increased ET due to higher temperatures. As surface water applications are constant across all scenarios, increased ET exacerbates crop water demand, necessitating greater volumes of groundwater extraction.
- A 500-AF decrease in inflow from foothills in both 2030 and 2070 budgets, associated with increased ET in small watersheds west of the Subbasin. Increased ET decreases the amount of water percolating to groundwater in these small foothill watersheds, reducing the amount of flow reaching the Subbasin.
- A 3,000-AF increase in average streambed recharge to groundwater in the 2030 budget, and an 8,200-AF increase in the 2070 budget. Likewise, the 2030 budget projects a 2,400-AF decrease in groundwater discharge to streams, while the 2070 budget projects a 6,400-AF decrease. These changes are driven by lower groundwater elevations near streams.

Due in part to the trends discussed above, the projected water budgets result in an additional depletion of 700 AF of groundwater in storage per year on average in the 2030 simulation, and a depletion of 1,500 AF/yr on average in the 2070 simulation. These annual average changes culminate in an additional 34,900 AF loss of groundwater in storage in the 2030 projection and an additional 75,800-AF loss in the 2070 projection over the 50-year projected period.

Overall, as currently projected by available climate change datasets, trends in climate change will affect the Subbasin’s groundwater budget by increasing agricultural water demand, resulting in increased groundwater pumping, as it is anticipated that surface water availability will largely be the same as current without added projects. Therefore, more water is predicted to flow from streams to groundwater, resulting in less discharge from groundwater to streams. These changes are largely driven by increased ET, which increases crop water demand. It is likely that the increased precipitation in these projected datasets has a counterbalancing effect, reducing groundwater demand by increasing available water in the land surface system. However, the net effect results in increased water demand. Further, the increased seasonality associated with these datasets suggests an increased volume of precipitation in a narrower rainy season, which may not correspond with the growing season of many crops. Trends in land and surface water use not incorporated in these simulations, such as increases in total irrigated acreage or conversion from non-irrigated lands to orchards, may further exacerbate any changes associated with climate change and result in a less sustainable groundwater budget.

Table 4-15. Projected 2030 and 2070 Groundwater Budgets Summary

All values are in acre-feet, rounded to nearest 100 AF				
	Component	Current Average	2030 Average	2070 Average
Inflows	Deep Percolation to Groundwater	141,800	141,600	140,300
	Streambed Recharge	57,900	60,900	66,100
	Inflow from Colusa	14,500	14,900	14,300
	Inflow from Red Bluff	48,100	49,200	49,800
	Inflow from Butte	1,000	900	800
	Inflow from Los Molinos	24,100	24,500	25,000
	Inflow from Vina	12,300	12,100	12,600
	Inflow from Foothills	1,600	1,100	1,100
	Recharge to Groundwater from Black Butte Lake	2,000	2,100	2,100
Outflows	Urban and Domestic Pumping	4,900	4,900	4,900
	Agricultural Pumping	153,000	159,300	167,300
	Outflow to Colusa	34,000	34,800	37,400
	Outflow to Red Bluff	10,300	10,100	9,800
	Outflow to Butte	2,300	2,400	2,500
	Outflow to Los Molinos	9,600	9,300	8,900
	Outflow to Vina	20,000	20,300	20,100
	Groundwater Discharge to Streams	67,900	65,500	61,500
Storage	Annual Change of Groundwater in Storage	1,100	400	-400
	Cumulative Change of Groundwater in Storage over the 50-yr simulation period	56,100	21,200	-19,700

Small discrepancies between inflow minus outflow and change in storage may occur due to rounding.

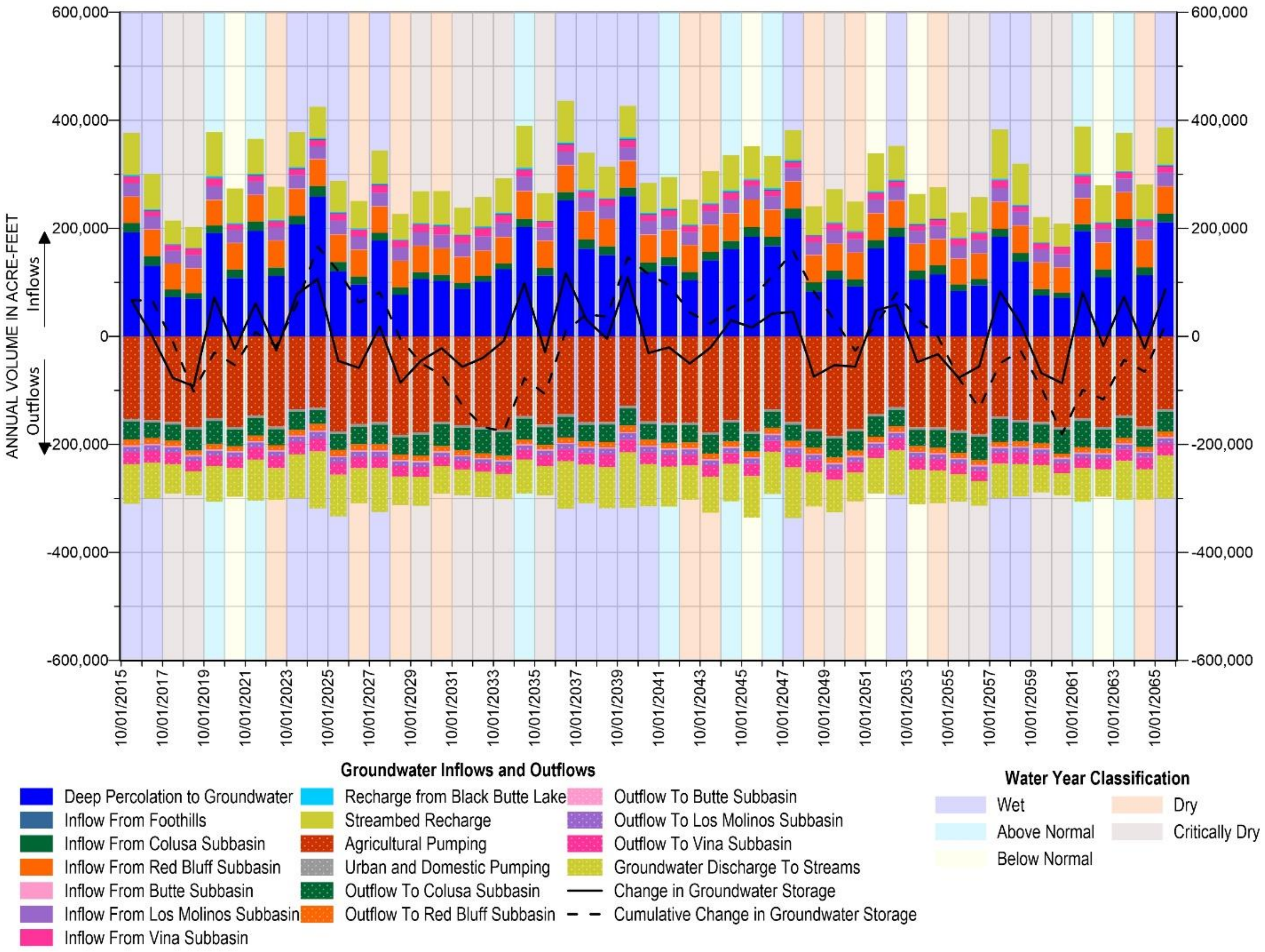


Figure 4-35. Projected 2030 Groundwater Budget

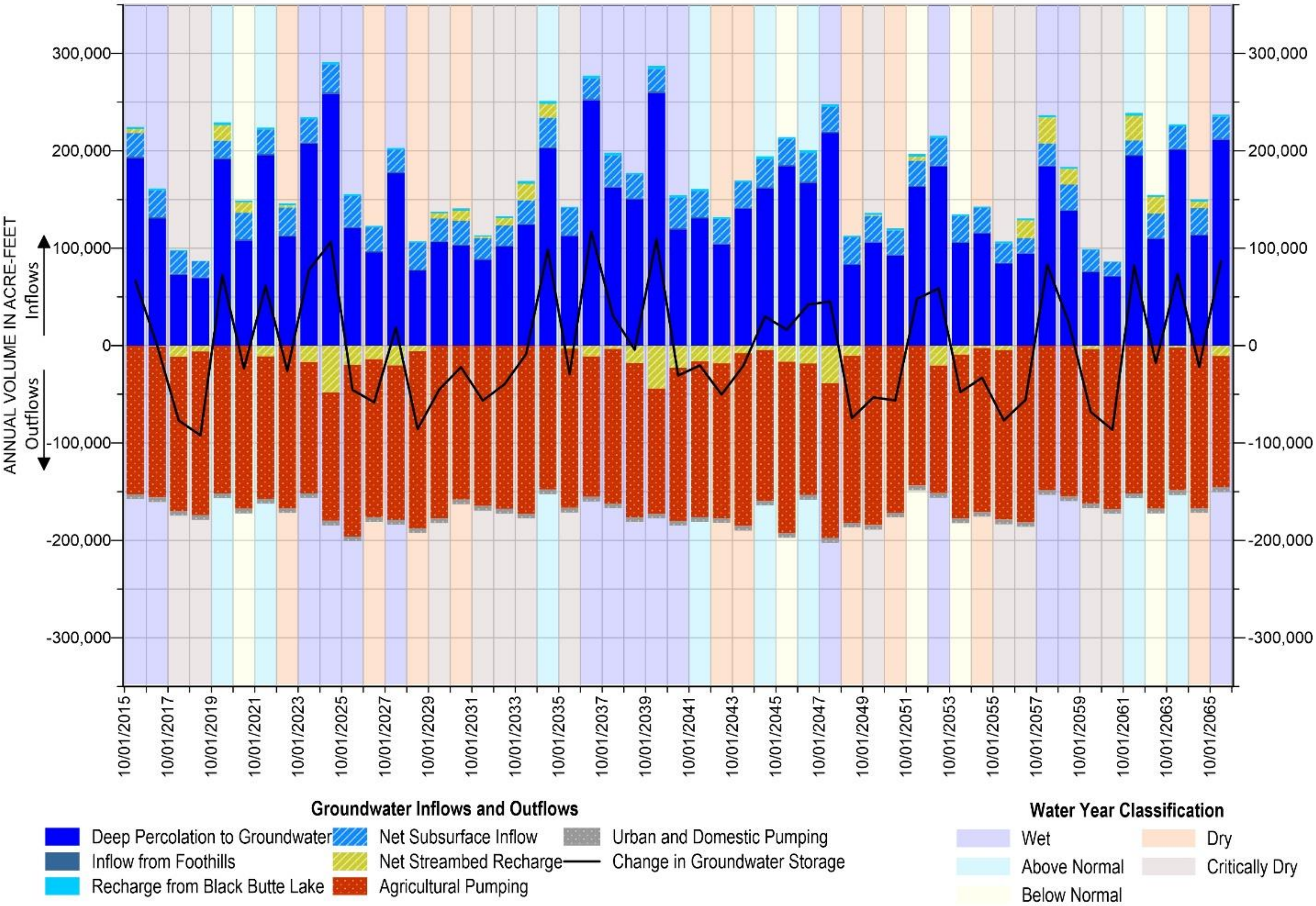


Figure 4-36. Projected 2030 Groundwater Budget Net Flows

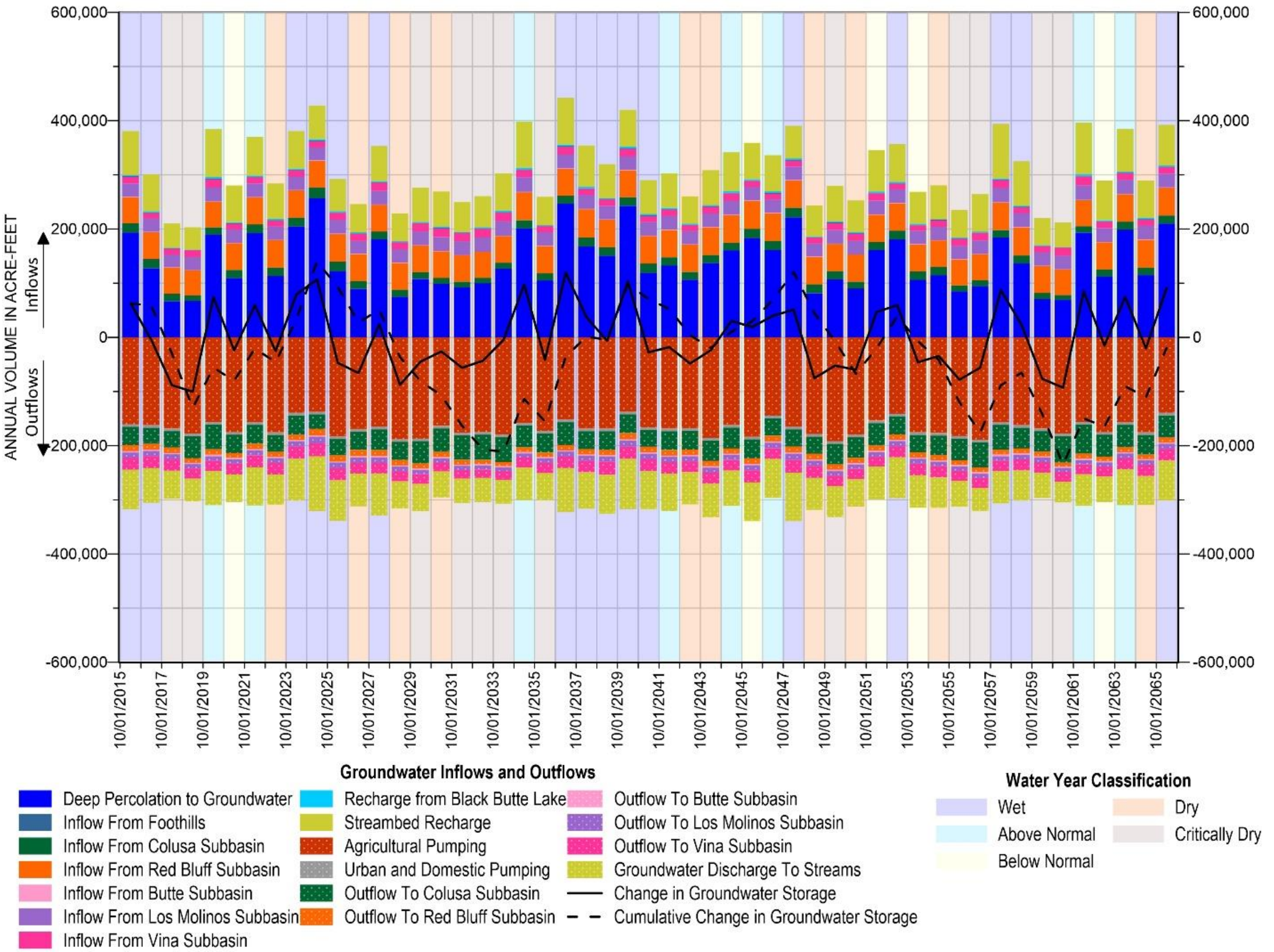


Figure 4-37. Projected 2070 Groundwater Budget

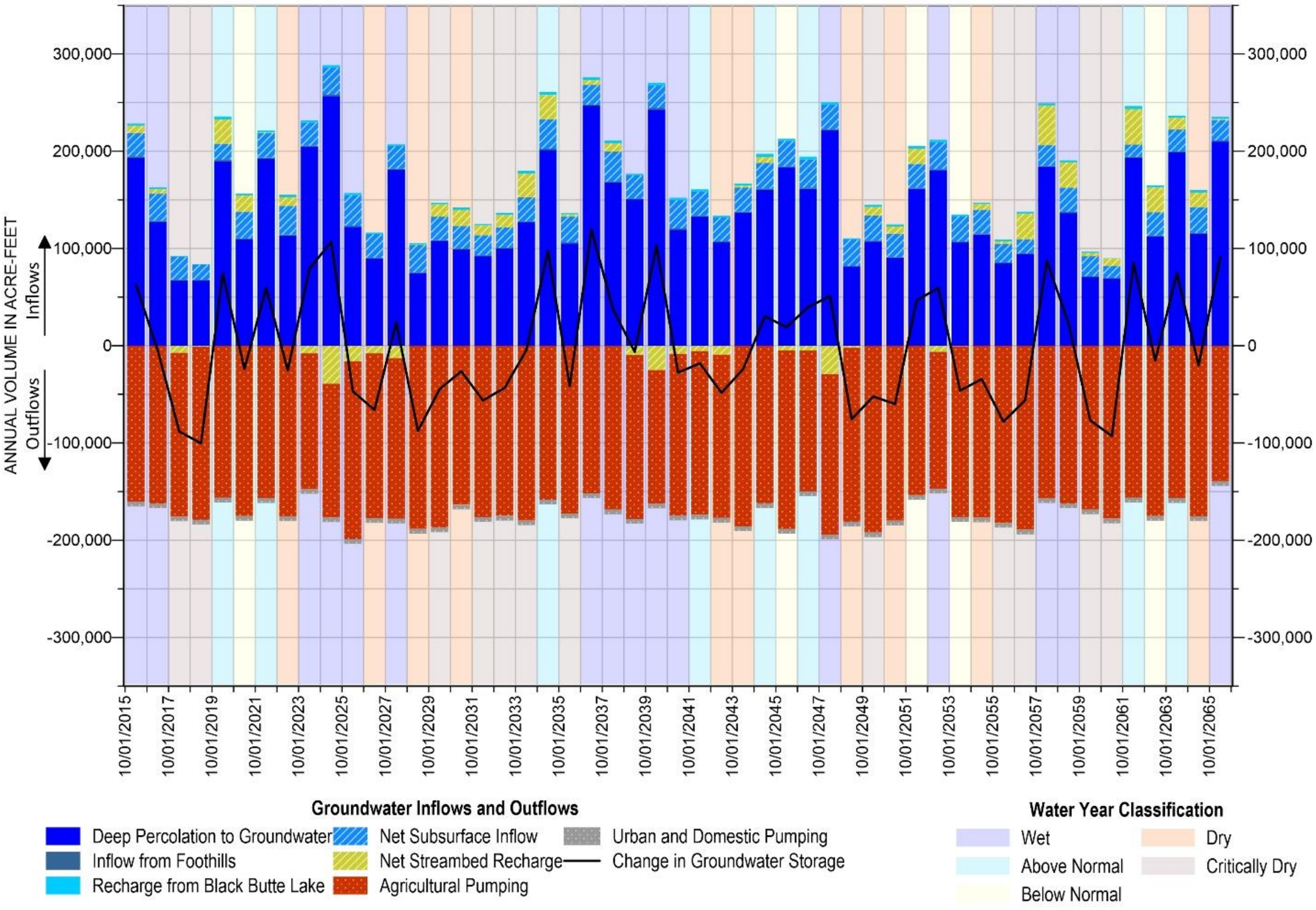


Figure 4-38. Projected 2070 Groundwater Budget Net Flows

4.4.3 Projected 2030 and 2070 Land Surface Budgets

The projected 2030 and 2070 land surface budgets are summarized in Table 4-16 and presented in time series on Figure 4-39 and Figure 4-40, respectively.

Major differences between the current land surface budget and the projected land surface budgets incorporating climate change include the following, on an annual average basis:

- A 10,500-AF increase in precipitation in the 2030 budget and a 24,200-AF increase in the 2070 budget.
- An 8,600-AF increase in ET in the 2030 budget and a 17,700-AF increase in the 2070 budget.
- An 8,200-AF increase in overland flow to streams in the 2030 budget and a 21,700-AF increase in the 2070 budget, driven by increased precipitation and potentially the concentration of storms in a shorter rainy season.
- A 6,300-AF increase in applied groundwater in the 2030 projection and a 14,300-AF increase in the 2070 projection, resulting from increased ET and associated increases in water demand.

As expected, the projected land surface budgets reflect a land surface system with increased precipitation, largely offset by increased evapotranspiration. Much of this increased precipitation runs off into the Subbasin’s water bodies as increased overland flow, which coupled with greater ET, results in negligible change in deep percolation to groundwater.

Examining the annual and cumulative change in soil and unsaturated zone storage, climate change factors do not appear to have a large effect on overall water storage in the Subbasin’s land surface system. However, climate change pressures on the land surface system cause ramifications in the groundwater budget, as evidenced by decreases in groundwater storage (Table 4-15, Figure 4-35).

Table 4-16. Projected 2030 and 2070 Land Surface Budgets Summary

All values are in acre-feet, rounded to nearest 100 AF				
Component		Current Average	2030 Average	2070 Average
Inflows	Precipitation	389,500	400,000	413,700
	Applied Groundwater	157,800	164,100	172,100
	Applied Surface Water	46,200	46,300	46,400
Outflows	Deep Percolation to Groundwater	139,300	139,100	137,800
	Evapotranspiration	302,100	310,700	319,800
	Overland Flow	136,800	145,000	158,500
	Return Flow to Streams	15,100	15,300	15,400
Storage	Change in Soil and Unsaturated Zone Storage	200	400	600

Small discrepancies between inflow minus outflow and change in storage may occur due to rounding.

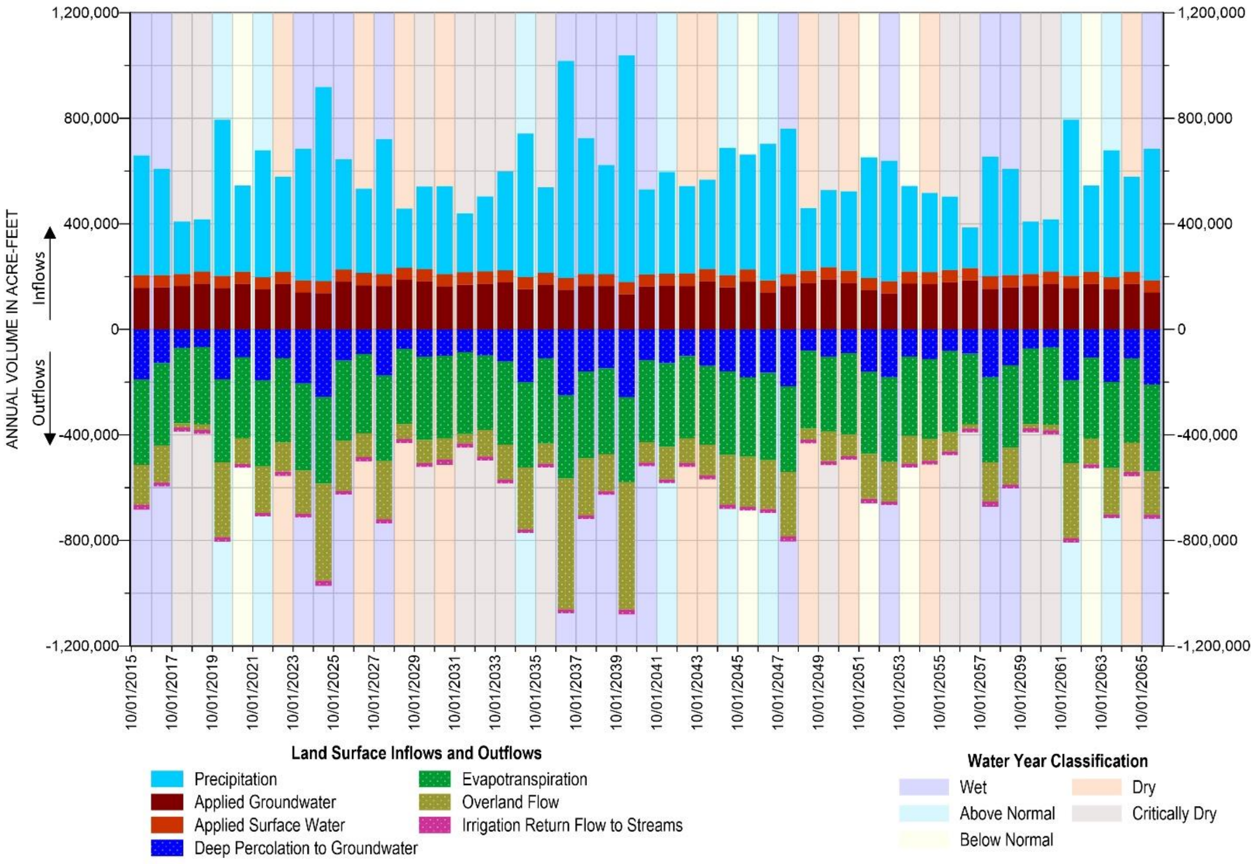


Figure 4-39. Projected 2030 Land Surface Budget

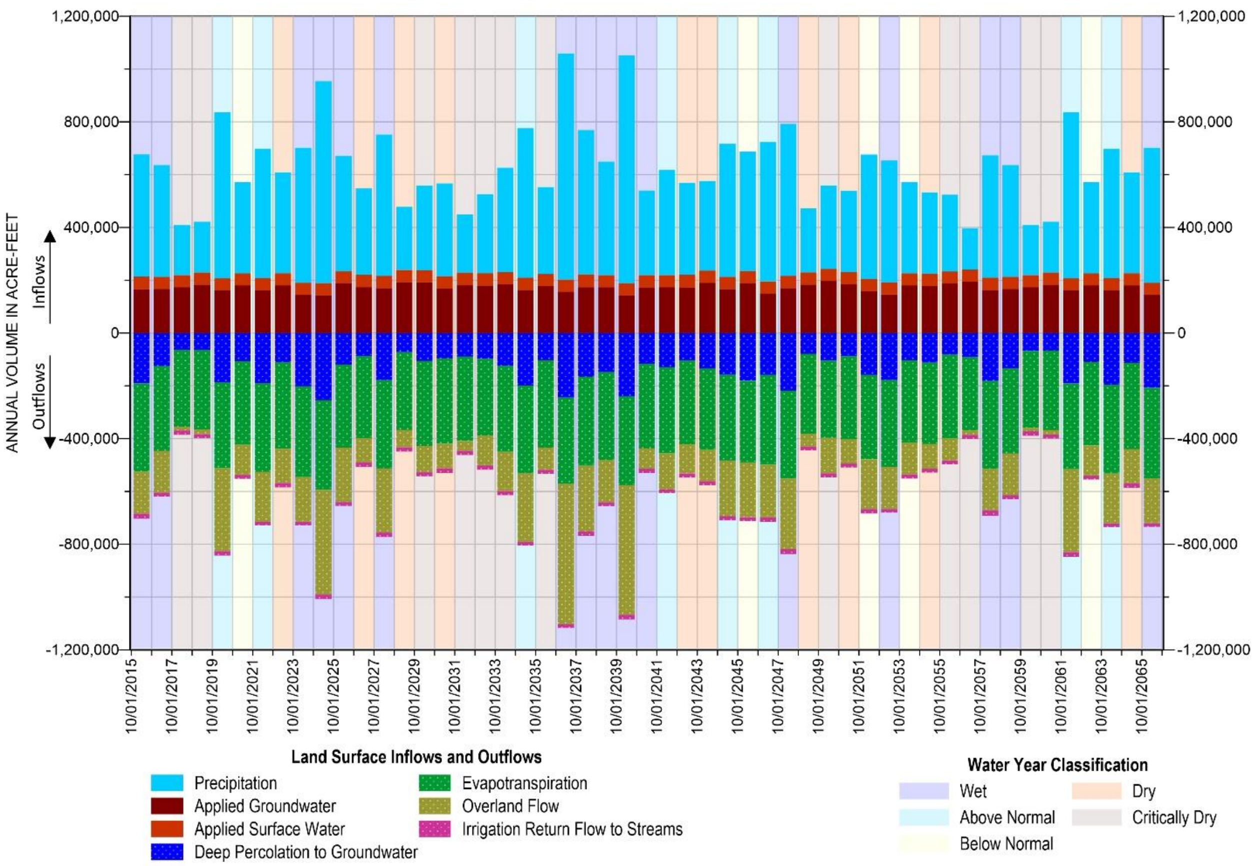


Figure 4-40. Projected 2070 Land Surface Budget

4.4.4 Projected 2030 and 2070 Surface Water Budgets

4.4.4.1 Sacramento River Budget

The projected 2030 and 2070 Sacramento River budgets are summarized in Table 4-17 and presented in time series on Figure 4-41 and Figure 4-42, respectively. Major differences in average annual components between the current Sacramento River budget and the projected Sacramento River budgets include the following:

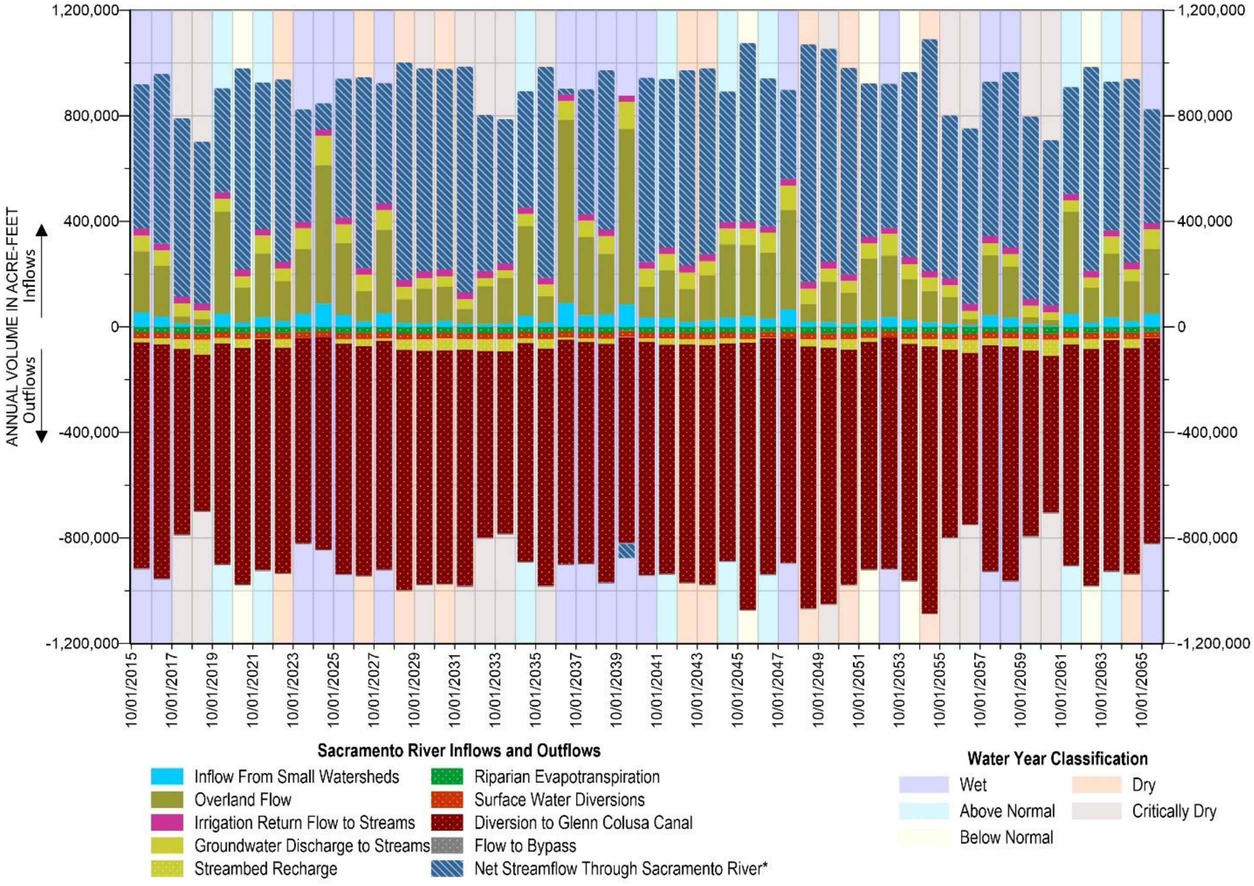
- Large increases in outflow to the Glenn-Colusa Canal in both scenarios, associated with the increased diversions in the projected simulations compared to low WY2015 water diversions in the current simulation.
- A 25,200-AF decrease in inflow from small watersheds in the 2030 simulation and a 24,000-AF decrease in the 2070 simulation. This change is likely resulting from increased ET in the areas outside of the Subbasin which reduces the annual amount of stream inflow. Increased precipitation and ET in both scenarios influence flow from outside of the Subbasin; while increased precipitation increases the total inflow volume, increased ET reduces the amount of flow that reaches the Subbasin.
- A 4,600-AF decrease in groundwater discharge to streams in the 2030 simulation and a 11,900-AF decrease in the 2070 simulation. Likewise, an up to 6,400-AF increase in streambed recharge in the 2030 projection and a 12,500-AF increase in the 2070 projection, driven by lower groundwater elevations along the Sacramento River.
- Increases in overland flow and riparian ET associated with increased precipitation and ET in the Subbasin in both scenarios.

As relevant to groundwater sustainability, the projected Sacramento River budgets display a large decrease in groundwater discharge to streams likely correlated with lower groundwater elevations along the Sacramento River. The projected climate change scenarios also result in less upstream inflow and small watershed inflow to the Sacramento River due to increased ET at the land surface. Increased surface water diversions to the Glenn-Colusa Canal are due to assumptions in the projected CALSIM model, which were used as inputs to the NSac projected scenarios models. Since under current conditions diversions were kept constant at 2015 values, this increase in diversions shows that projected diversions will be greater than the 2015 diversions, on average, considering the variation in projected climate.

Table 4-17. Projected 2030 and 2070 Sacramento River Surface Water Budgets

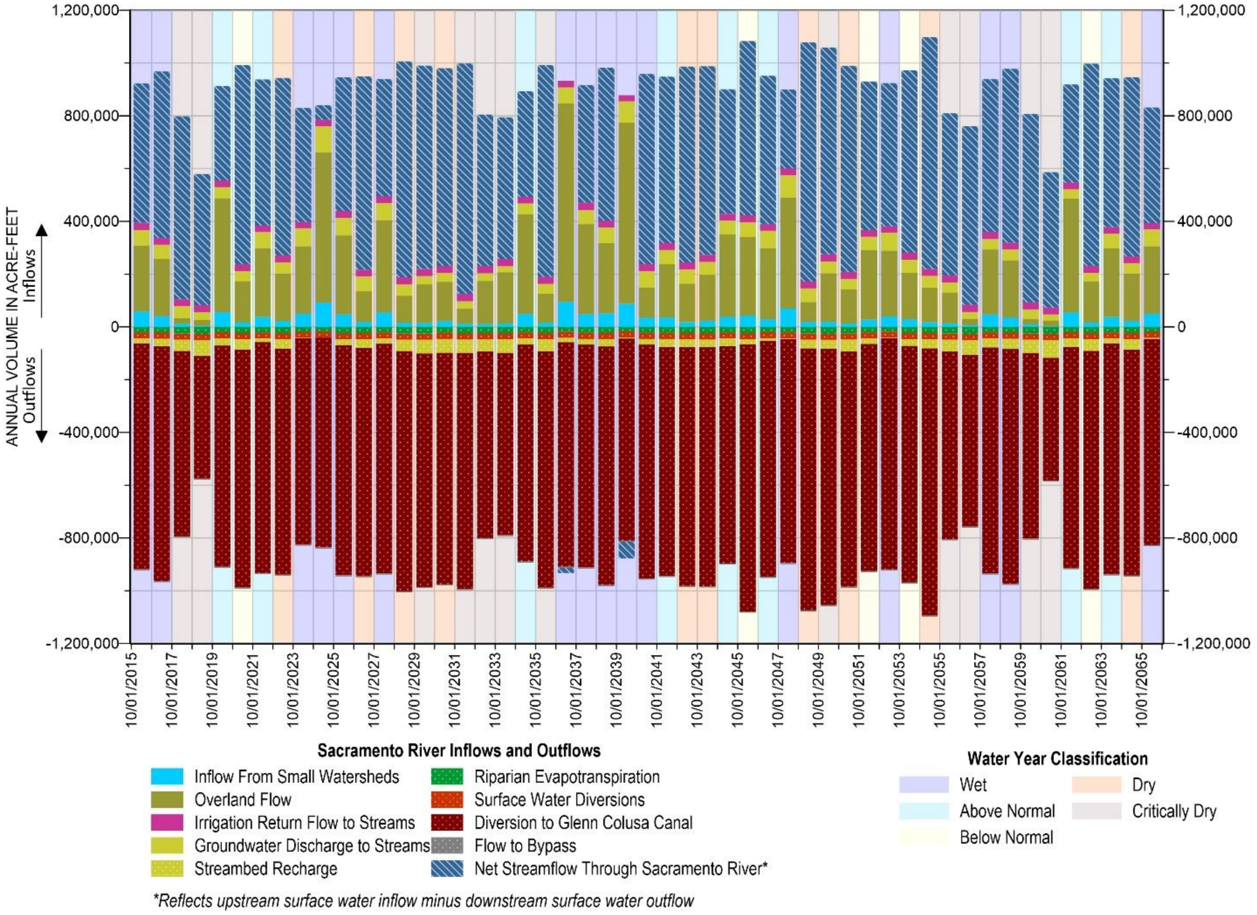
All values are in acre-feet, rounded to nearest 100 AF				
	Component	**Current Average**	**2030 Average**	**2070 Average**
Inflows	Inflow from Upstream of Basin	10,849,400	10,442,900	10,700,800
	Inflow from Small Watersheds	57,400	32,200	33,400
	Overland Flow	193,300	205,600	226,200
	Irrigation Return Flows to Streams	24,600	25,200	25,800
	Groundwater Discharge to Stream	61,200	56,600	49,300
Outflows	Streambed Recharge	18,500	24,900	31,000
	Downstream Outflow South of Subbasin	10,547,900	9,844,800	10,115,400
	Riparian ET	20,400	21,400	22,700
	Surface Water Diversions	23,200	23,200	23,200
	Flow to Glenn-Colusa Canal	571,200	843,600	838,600
	Flow to Bypass	4,700	4,700	4,700

Small discrepancies between total inflow and outflow may occur due to rounding.



**Reflects upstream surface water inflow minus downstream surface water outflow*

Figure 4-41. Projected 2030 Sacramento River Surface Water Budget



**Reflects upstream surface water inflow minus downstream surface water outflow*

Figure 4-42. Projected 2070 Sacramento River Surface Water Budget

4.4.4.2 Stony Creek and Black Butte Lake Budget

The projected 2030 and 2070 Stony Creek and Black Butte Lake budgets are summarized in Table 4-18 and presented in time series on Figure 4-43 and Figure 4-44, respectively. Major differences in average annual components between the current Stony Creek budget and the projected Stony Creek budgets include the following:

- A 3,500-AF increase in inflow from small watersheds in the 2030 budget and a 3,800-AF increase in the 2070 budget, resulting in increased precipitation in the small watersheds west of the Subbasin
- A 400-AF decrease in groundwater discharge to streams in the 2030 budget and a 600-AF decrease in the 2070 budget, resulting from lowered groundwater elevations along Stony Creek. The 2030 budget projects an 1,800-AF increase in streambed recharge, while the 2070 budget projects a 5,400-AF increase.
- Increases in overland flow to streams and riparian ET in both budgets, associated with increased precipitation and ET in the Subbasin

As seen in the Sacramento River budget, the projected scenarios indicate a shift towards increased losses to groundwater and decreased groundwater discharge to streams on Stony Creek. These trends are due to lower Subbasin-wide groundwater elevations, which are in turn driven by increased ET and increased groundwater pumping.

Table 4-18. Projected 2030 and 2070 Stony Creek and Black Butte Lake Water Budgets

All values are in acre-feet, rounded to nearest 100 AF				
	Component	Current Average	2030 Average	2070 Average
Inflows	Inflow from Upstream of Basin	451,100	442,300	447,800
	Inflow from Small Watersheds	2,800	6,300	6,600
	Overland Flow	21,600	22,900	25,100
	Irrigation Return Flows to Streams	3,600	3,500	3,400
	Groundwater Discharge to Stream	1,200	800	600
Outflows	Streambed Recharge	31,100	32,900	36,500
	Downstream Outflow to Sacramento River	306,100	312,300	339,000
	Riparian ET	9,000	9,200	9,400
	Surface Water Diversions	47,300	44,500	43,600
	Groundwater Recharge on Lake	17,100	17,100	17,100
	Black Butte Lake Losses	69,800	60,000	37,700

Small discrepancies between total inflow and outflow may occur due to rounding.

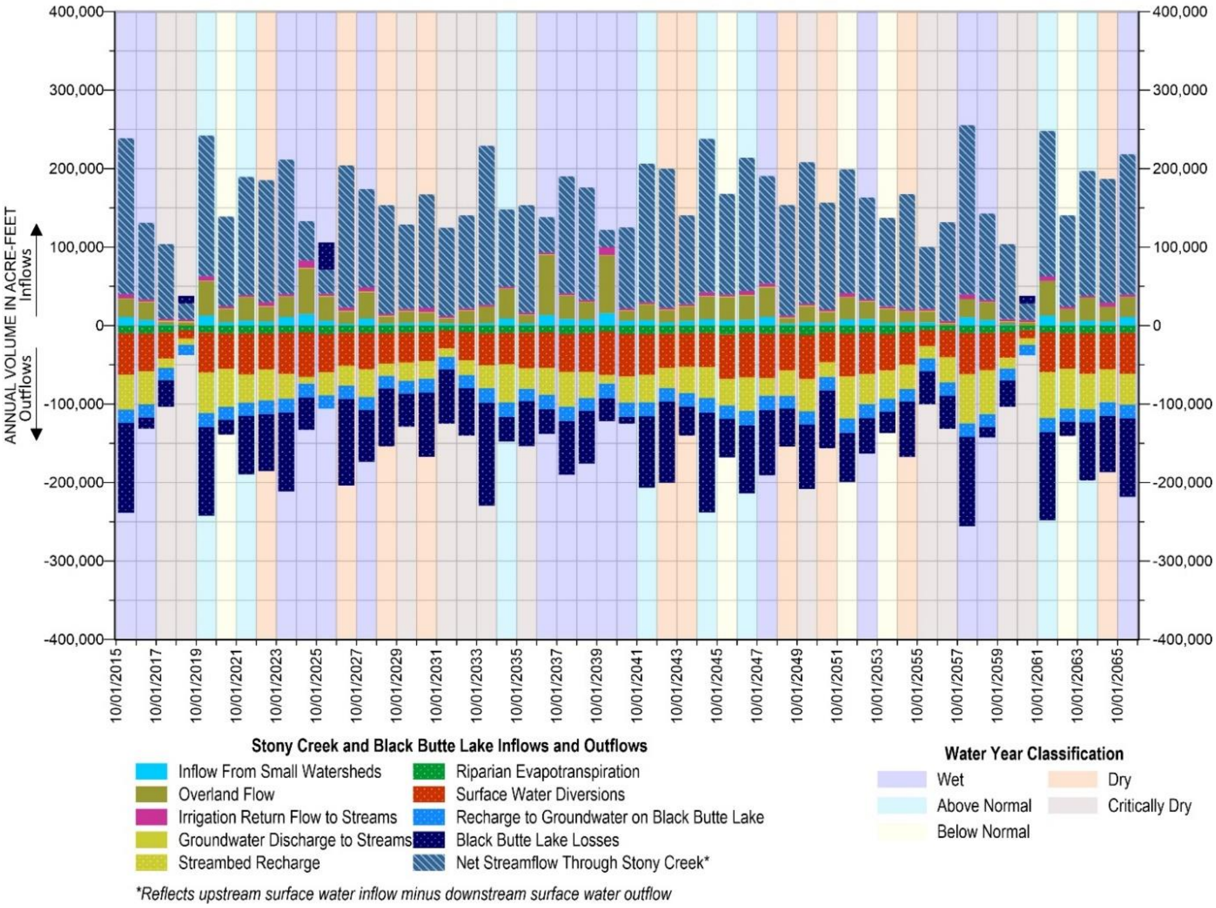
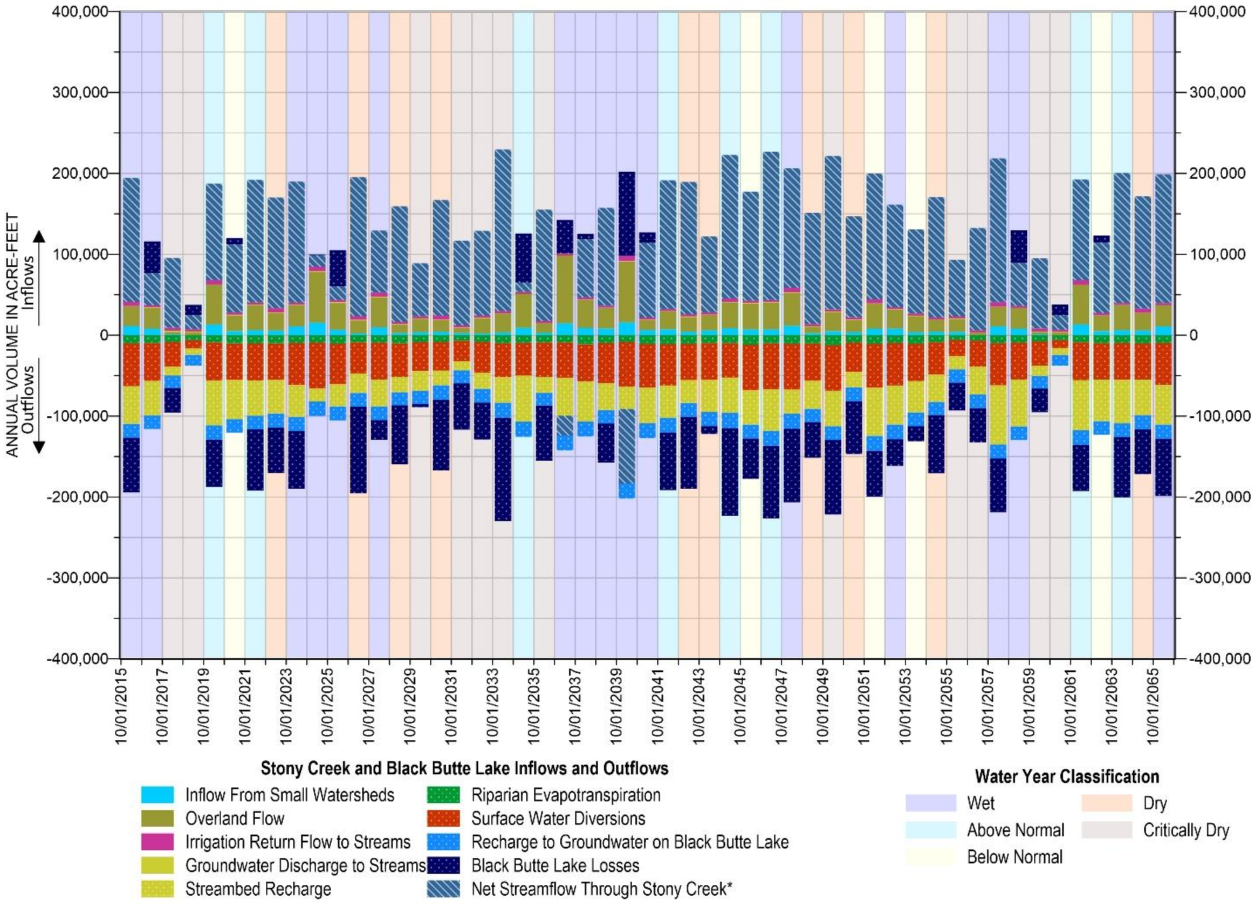


Figure 4-43. Projected 2030 Stony Creek and Black Butte Lake Water Budget



**Reflects upstream surface water inflow minus downstream surface water outflow*

Figure 4-44. Projected 2070 Stony Creek and Black Butte Lake Water Budget

4.4.4.3 Thomes Creek Budget

The projected 2030 and 2070 Thomes Creek budgets are summarized in Table 4-19 and presented in time series on Figure 4-45 and Figure 4-46, respectively. Major differences in average annual components between the current Thomes Creek budget and the projected Thomes Creek budgets include the following:

- Increased inflow from upstream of the Subbasin and from small watersheds in both budgets, resulting from increased precipitation in areas west of the Subbasin.
- A 100-AF increase in streambed recharge to groundwater in the 2030 budget, and an increase of 1,500 AF in the 2070 budget. In the current and both projected scenarios, Thomes Creek does not receive any groundwater discharge.
- Increases in overland flow to streams and riparian ET associated with increased precipitation and ET in the Subbasin.

The projected Thomes Creek water budgets reflect a stream with greater total surface flow and increased streambed recharge to groundwater. These predicted increases in streamflow are due to increased precipitation in the Subbasin and foothills to the west. In addition to greater streamflow, lower groundwater elevations along Thomes Creek influence the increases in streambed recharge.

Table 4-19. Projected 2030 and 2070 Thomes Creek Water Budgets Summary

All values are in acre-feet, rounded to nearest 100 AF				
	Component	**Current Average**	**2030 Average**	**2070 Average**
Inflows	Inflow from Upstream of Basin	227,500	224,800	245,200
	Inflow from Small Watersheds	8,100	13,300	14,300
	Overland Flow	19,400	20,900	23,400
	Irrigation Return Flows to Streams	1,000	1,000	1,100
	Groundwater Discharge to Stream	0	0	0
Outflows	Streambed Recharge	30,800	30,900	32,300
	Downstream Outflow to Sacramento River	220,600	224,500	246,800
	Riparian ET	4,500	4,600	4,800
	Surface Water Diversions	0	0	0

Small discrepancies between inflow minus outflow may occur due to rounding.

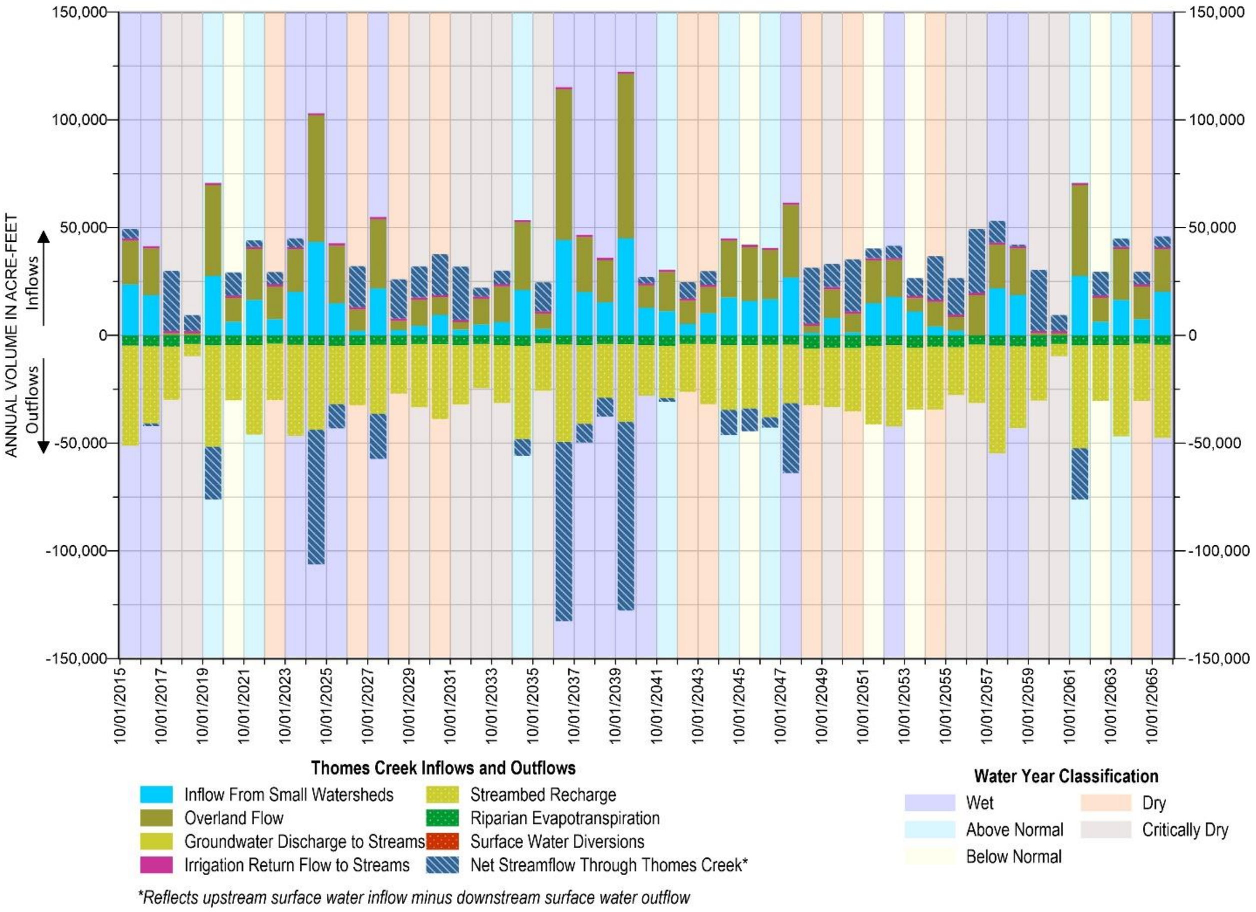
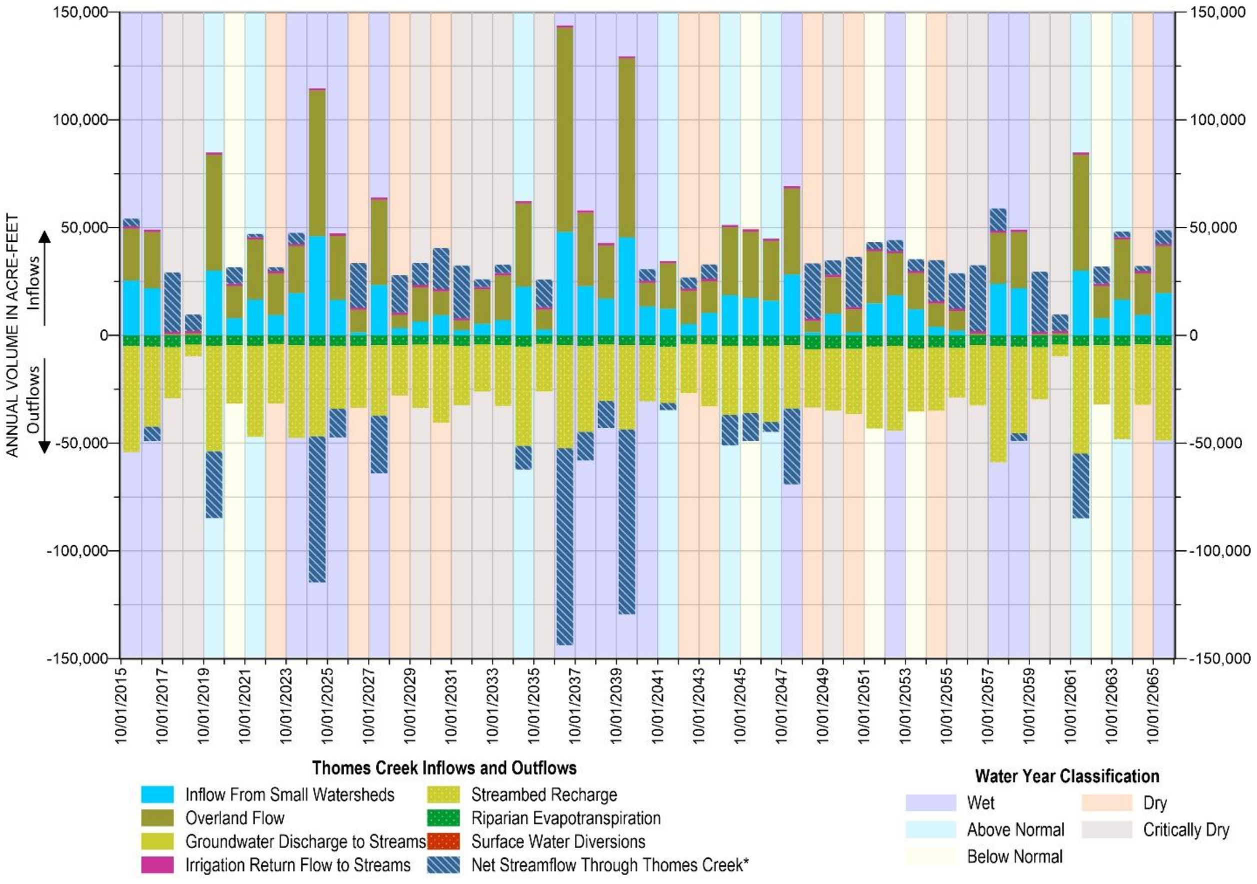


Figure 4-45. Projected 2030 Thomes Creek Water Budget



**Reflects upstream surface water inflow minus downstream surface water outflow*

Figure 4-46. Projected 2070 Thomes Creek Water Budget

4.4.5 Uncertainties in Projected Water Budget Simulations

While significant uncertainty exists regarding the prediction of atmospheric conditions, the 2030 and 2070 central tendency scenarios provided by DWR are considered best available science at the time the GSP was developed, and can be used to adequately describe likely future conditions for SGMA planning and implementation (DWR, 2018b). As described by DWR, there is an approximately equal likelihood that actual future conditions will be more stressful or less stressful than those described by the recommended scenarios, therefore these conditions provide a solid middle-ground on which to examine future groundwater sustainability with climate change. Further specifics regarding uncertainty in projected water budget simulations are described in the climate change guidance released by DWR (DWR, 2018b). As climate change science improves and newer data become available, DWR will release revised projected climate change datasets to be used in future GSP Periodic Evaluations.

4.4.6 Sustainable Yield

The sustainable yield of the Subbasin is an estimate of the quantity of groundwater that can be pumped on a long-term average annual basis without causing undesirable results. Basin-wide pumping within the sustainable yield estimate is neither a measure of, nor proof of, sustainability. Sustainability under SGMA is only demonstrated by avoiding undesirable results for the 6 sustainability indicators. However, estimates of sustainable yield using the current and projected simulations may prove useful in estimating the need for projects and management actions to help achieve and maintain sustainability.

The role of sustainable yield estimates in SGMA, as described in the Sustainable Management Criteria (SMC) BMP (DWR, 2017), are as follows:

> *"In general, the sustainable yield of a basin is the amount of groundwater that can be withdrawn annually without causing undesirable results. Sustainable yield is referenced in SGMA as part of the estimated basinwide water budget and as the outcome of avoiding undesirable results.*
>
> *Sustainable yield estimates are part of SGMA's required basinwide water budget. Section 354.18(b)(7) of the GSP Regulations requires that an estimate of the basin's sustainable yield be provided in the GSP (or in the coordination agreement for basins with multiple GSPs). A single value of sustainable yield must be calculated basinwide. This sustainable yield estimate can be helpful for estimating the projects and programs needed to achieve sustainability."*

Groundwater elevations simulated in the projected 2070 model scenario compared to minimum thresholds, indicate undesirable results are unlikely. Therefore, average annual pumping in the 2070 projected simulation can be used as an estimate of sustainable yield for the Subbasin. However, the 2070 groundwater budget indicates an average annual negative change in groundwater storage of 400 AF. Accordingly, this number is subtracted from average annual projected 2070 simulated pumping value (172,200 AF) to develop the sustainable yield, resulting in a sustainable yield of 171,800 AF of groundwater pumping per year. The Revised GSP addresses the current estimate of the annual change in storage related to overdraft. A complete and comprehensive water budget analysis for current and future conditions will be conducted as part of the 5-year Periodic Evaluation in January 2027. The GSA recognizes that the updated annual groundwater storage is negative and constitutes overdraft. This value of -31,200 AFY will affect the sustainable yield calculation downward. The recalculation of the sustainable yield will also be conducted as part of the 5-year Periodic Evaluation. Until that time, the 2070 simulated sustainable yield is 141,000 AF.

4.5 Summary

The water budgets calculated for different time frames provide a snapshot of overall groundwater conditions on a subbasin-wide scale for past, current, and potential future scenarios to help with groundwater sustainability planning.

The simulated historical groundwater budget indicates a mostly balanced budget with an overall positive annual average change of groundwater in storage, and a cumulative change of groundwater in storage that is increasing over time, indicating no overdraft. However, between 2012 and 2015, annual change in storage declined to negative values. This could be the start of declining groundwater in storage and overdraft could occur if this trend continues. The historical model only simulates subbasin conditions until 2015; however, based on the review of more recent groundwater elevation measurements, it is evident that groundwater levels continue to decline in some parts of the Subbasin (Section 3.2.2) since the 2012-2016 drought, and total recovery has not occurred such as in previous wet years following drought years. As a result, the simulated current groundwater budget indicates a decrease in average annual change in groundwater in storage compared to the historical time period, based on a continuation of increased groundwater pumping and a decrease in surface water use observed since the drought. This trend could be further exacerbated with projected climate change effects, as evidenced by the projected 2030 and 2070 scenarios which present increasingly lower average annual change in groundwater storage. The simulated current, 2030, and 2070 water budgets also display progressively less groundwater discharge to streams due to lowering groundwater levels, indicating that the Subbasin may draw more water from streams into groundwater given current land use, water use, and the influence of projected climate change. Therefore, it will be necessary to implement projects and management actions to halt this declining trend in groundwater levels and keep the Subbasin sustainable into the future. Water budget tables including annual component flow by water year are included in Appendix 4D for all tables presented here.