Appendix I
Historical Water Budget

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Project name: Regional Water Authority Watersheds Resilience Pilot

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1. Purpose

This technical memorandum (TM) highlights the development process and assumptions used for constructing a water budget spreadsheet tool for the Regional Water Authority (RWA) Watersheds Resilience Pilot (WRP). The water budget provides a means to visualize and assess the current distribution of inflows, consumptive uses, imports, exports, and other factors that affect water supplies within the planning area for the RWA WRP (Figure 1-1).

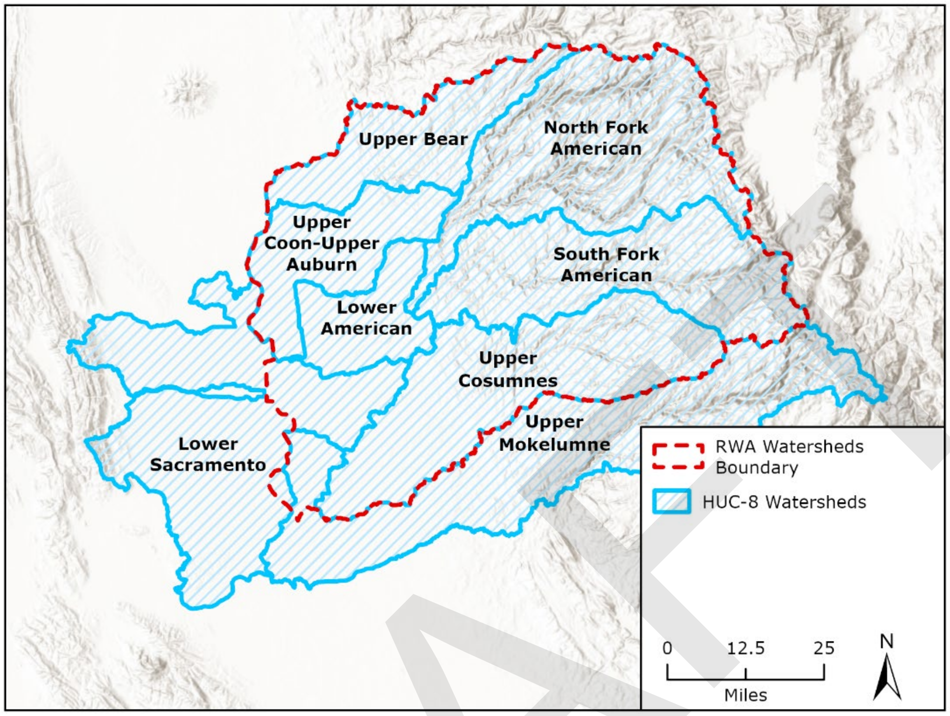
The water budget supports the historical assessment component of characterizing the existing state of the watershed and how climatological and extreme weather events have evolved over time. Understanding these trends is an important factor in identifying current vulnerabilities within the RWA watersheds (i.e., Bear River, American River, and Cosumnes River watersheds) and how evolution of these trends may influence water management needs in the future. The water budget offers some insight into how simulated hydrologic conditions over the last 100 years (water years 1922 through 2021) have influenced the relative contribution of individual water-related components across the planning area. As such, a discussion of key takeaways is presented to highlight observable trends and considerations for the broader historical assessment component of this effort.

The water budget was developed consistent with guidance from the non-modeling approach outlined in the *Handbook for Water Budget Development* (DWR 2020). The water budget is organized around three interconnected systems: the land system, the surface water system, and the groundwater system.

1. **The land system** represents what happens to water once it reaches the land surface, including soils, vegetation, agricultural lands, and urban landscapes. Here, precipitation and applied water are partitioned into evapotranspiration (the primary consumptive use); surface runoff and baseflow that move to rivers and streams; and deep percolation (DP) that recharges aquifers, with soil moisture serving as short-term storage.
2. **The surface water system** includes rivers, streams, lakes, and reservoirs that convey and temporarily store water. It receives runoff and stream inflows; supports environmental flows and diversions; and may lose water to evaporation or seepage into groundwater.
3. **The groundwater system** consists of aquifers that store water below ground, Aquifers are replenished by DP and stream seepage, while water leaves through pumping, discharge to streams, or subsurface outflow to adjacent basins.

Together, these three systems provide a structured framework for accounting for all water entering, leaving, and being stored within a basin, verifying that inflows minus outflows equal changes in storage.

Figure 1-1 RWA WRP Planning Area with Overlapping HUC-8 Watersheds



2. Data Sources

The data sources used to develop the water budget for the RWA WRP are described in the following bullets. The water budget parameters that each of these informed are summarized in Table 2-1.

- **CalSimHydro**: The coverage area for CalSim 3 is divided into three types of areas: rim watersheds, valley floor water budget areas (WBAs), and Delta subregions. CalSimHydro provides the surface hydrologic modeling for the WBAs within CalSim 3; these are described in further detail in the following sections. CalSimHydro consists of four hydrologic models: Daily Curve Number Runoff Model, Integrated Demand Calculator for CalSim 3, rice water use model, and refuge water use model. More information is provided in the *CalSimHydro Reference Manual* (DWR 2017). Outputs from CalSimHydro have been utilized to characterize water budget components for lower watershed areas within the RWA WRP planning boundary. CalSimHydro is the primary dataset for this water budget and is used to represent the majority of parameters in valley floor areas. CalSimHydro was used because of its readily available nature and frequent use in California Department of Water Resources (DWR) and US Bureau of Reclamation (Reclamation) planning studies and long-term operations-related efforts.
- **CalSim 3 Report**: CalSim 3 has been collaboratively developed by DWR and Reclamation to represent State Water Project and Central Valley Project operations. The *CalSim 3 Report* describes the development approach for CalSim 3 as well as the structure and assumptions for individual modeling components such as the WBAs (DWR 2022). Some of this information has been leveraged to expand on the CalSimHydro outputs to better characterize certain considerations within the water budget spreadsheet tool. These include conveyance losses, points of diversion, crop coefficients, groundwater pumping, additional land use and demand information, and more.

- **CalSim 3 Reservoir Evaporation**: In addition to assumptions and information leveraged from the *CalSim 3 Report*, reservoir evaporation monthly timeseries datasets have been collected to characterize evaporative losses in upper watersheds and valley floor areas. Reservoir evaporation is primarily applied to reservoirs in upper watersheds, with the exception of Lake Natoma.
- **CalSim 3 2023 Delivery Capability Report (DCR) Historical Climate Simulations**: CalSim 3 model outputs from the Final 2023 DCR were used to represent inflows, outflows, minimum instream flows, and surface water exports, where necessary (CNRA 2024). Outputs from the CalSim 3 groundwater dynamic link library (DLL) were also used to characterize surface water-groundwater interaction and compare pumping volumes calculated from CalSimHydro. Because CalSimHydro outputs are an input to CalSim 3, assumptions between these datasets remain consistent.
- **Variable Infiltration Capacity (VIC) Model**: To further represent water budget components in upper watersheds, outputs from VIC simulations have been utilized to describe baseflow, surface runoff, and evapotranspiration. These components are described in further detail in Section 4.2. CalSimHydro data does not extend to upper watershed areas; VIC simulations are able to fill this gap to represent certain water budget parameters. However, the VIC simulations used for this water budget do not include urban or applied water-related demand parameters. For the purposes of this water budget, it is assumed that limited urban or applied water uses are present in these areas.
- **Cosumnes-South American-North American (CoSANA) Integrated Water Resources Model**: The CoSANA model is built on the Integrated Water Flow Model framework and has been used to support Groundwater Sustainability Agency planning in the Cosumnes, South American, and North American subbasins (Woodard & Curran 2021). Outputs from the CoSANA model have been integrated into the water budget for selected groundwater-specific components to improve quantification and provide a basis for comparison between estimated values. Additional information related to comparisons is highlighted in Section 4.4. For accounting results presented in Section 5, the only CoSANA-produced values that are utilized are subsurface inflows and outflows. These two terms were not quantified through any other data source. For all other instances, CoSANA data were used for comparison with calculated groundwater.
- **Extended Livneh et al. (2013) Dataset**: Livneh et al. (2013, updated thereafter) daily historical meteorology data at 1/16th degree (roughly 6 kilometers or 3.75 miles) spatial resolution for the period 1915 through 2015 were extended using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) daily historical meteorology data from 2016 through 2021. The extended daily historical precipitation, minimum and maximum temperatures data were adjusted based on PRISM monthly data (Daly et al. 1994) to correct biases found in the period of interest. Only the precipitation data from this dataset are incorporated in this water budget.

Table 2-1. Water Budget Parameters and Corresponding Data Sources

Parameter	Data Sources	Geographic Area	Notes
Precipitation	▪ Extended Livneh et al. Dataset ▪ CalSimHydro	▪ Upper Watershed Areas ▪ Valley Floor Areas	
Evapotranspiration	▪ VIC ▪ CalSimHydro	▪ Upper Watershed Areas ▪ Valley Floor Areas	

Parameter	Data Sources	Geographic Area	Notes
Surface Runoff	▪ VIC ▪ CalSimHydro	▪ Upper Watershed Areas ▪ Valley Floor Areas	
Reservoir Evaporation	CalSim 3	▪ Upper Watershed Areas ▪ Valley Floor Areas	
Baseflow	VIC	Upper Watershed Areas	
Upper Watershed Subsurface Gains and Losses	VIC	Upper Watershed Areas	Calculated as precipitation minus surface runoff, baseflow, and evapotranspiration
Inflow	DCR Simulations	Valley Floor Areas	North American and South American regions receiving inflows from the North Fork American and South Fork American regions
Outflow	▪ DCR Simulations	▪ Upper Watershed Areas ▪ Valley Floor Areas	
Environmental Flows	▪ DCR Simulations	▪ Upper Watershed Areas ▪ Valley Floor Areas	Includes minimum instream flows and mitigation flows
Exports	DCR Simulations	Valley Floor Areas	
Applied Water	CalSimHydro	Valley Floor Areas	Demands partitioned between surface water and groundwater components
Evapotranspiration of Applied Water	CalSimHydro	Valley Floor Areas	Subset of total evapotranspiration
Conveyance Losses	CalSim 3 Report	Valley Floor Areas	Only[a] applied to applied water; includes return flow, evaporation, and DP components
Tailwater	CalSimHydro	Valley Floor Areas	Applied water return flow
Urban Demand	CalSimHydro	Valley Floor Areas	Demands partitioned between surface water and groundwater components; referred to as urban surface water diversions, urban deliveries, and urban pumping for surface water, land, and groundwater systems
Wastewater	CalSimHydro	Valley Floor Areas	Urban demand return flow
DP	▪ CalSimHydro ▪ CoSANA	Valley Floor Areas	

Parameter	Data Sources	Geographic Area	Notes
Surface Water-Groundwater Interaction	▪ DCR Simulations ▪ CoSANA	Valley Floor Areas	
Groundwater Pumping	▪ DCR Simulations ▪ CoSANA	Valley Floor Areas	Only used for comparison between calculated groundwater pumping to meet applied water and urban demands
Subsurface Inflows and Outflows	CoSANA	Valley Floor Areas	

[a] One conveyance loss factor is applied to a single demand unit for urban demand, consistent with documentation noted in the CalSim 3 Report. This is considered a return flow.

3. Limitations

This water budget was developed consistent with the guidance included in DWR's *Handbook for Water Budget Development*. However, limitations of this water budget exist, as follows:

- This water budget characterizes a range of budget parameters under historical hydrologic conditions between water years 1922 and 2021; these hydrologic conditions are simulated and may not represent exact regulatory and operational conditions during the entirety of this time period.
- While not every parameter noted in the *Handbook for Water Budget Development* is included in this water budget, a variety of datasets were leveraged to characterize as many of these parameters as possible. As such, total accounting between all parameters may be unbalanced in some cases due to the mixing of these various datasets and differing assumptions. Correction factors have been implemented for the individual surface water, land, and groundwater systems to adjust for biases and balancing errors in input datasets. These correction factors have been primarily applied to terms that flow in or out of a given system rather than between systems (e.g., DP). As such, outflow, reservoir evaporation, and evapotranspiration volumes have been adjusted for some systems to balance uncharacteristic imbalances between inflows and outflows. Surface water-groundwater interaction and subsurface inflows and outflows volumes have also been scaled up to better represent quantities included in Groundwater Sustainability Plan documents for the North American, South American, and Cosumnes subbasins. Due to this approach, the total water budgets for each system can propagate errors or overrepresentations of a given component. Additional calibration of water budget factors could be investigated to improve balancing across total water budget-related terms.
- Spatial coverage of available data does not extend across the entirety of the RWA WRP in all cases. This is particularly notable for CalSimHydro data for the South American Region. As such, budget parameters for this region may be an underestimate in some cases. Based on missing area, roughly 30% of the overall South American Region is excluded from the water budget. As such, it could be assumed that groundwater demands, evapotranspiration, DP, precipitation, runoff, and other return flows for the South American Region are likely to be higher in reality than calculated values depending on land use and land cover. Surface water demands are likely to rely on the Sacramento River for this area; therefore, they would be excluded. See Figures 3 and 4 for more information.
- Groundwater-related parameters calculated through this water budget do not follow the exact spatial extents displayed on Figure 2 to confirm consistency in accounting between the land and surface water

systems. Comparisons with CoSANA model outputs reveal that the North American and Cosumnes groundwater regions overestimate budget parameters in some cases, and the South American groundwater region underestimates budget parameters. Additional discussion on these considerations is noted in the following bullet.

- Several of the water budget parameters included in the land system are aligned to the extent of the RWA WRP planning area through an area weighted approach. However, the applied water, urban demand, tailwater, and wastewater parameters use a point of diversion-based routing approach to limit volumes of water included in the water budget. Because these two approaches rely on the same set of data (i.e., CalSimHydro) that includes its own water volume conservation at a differing spatial extent, the approaches employed by this water budget likely result in imbalances among parameters. This could be mitigated by applying the same scaling factors to all CalSimHydro parameters; however, such consistency has not been implemented at this time. The correction factors described herein generally adjust for these inconsistencies in budgeting for individual systems but may result in some errors at the total water budget level.

4. Methodology

The following subsections describe the approach used to develop the water budget spreadsheet tool for the RWA WRP. At a high level, the water budget has been separated into surface water, land, and groundwater system regions, aligning with the approach described in DWR's Water Budget Handbook. For this effort, surface water and land systems share the same spatial domain; the groundwater system has its own spatial extent.

4.1 Structure

To adequately assess the inflows, demands, and other uses within the RWA WRP planning boundary, the water budget was largely delineated according to US Geological Survey (USGS) hydrologic unit code (HUC) 8 watersheds and Bulletin 118 groundwater basins. However, a few adjustments were incorporated to simplify the number of individual regions.

1. First, the Upper Coon-Upper Auburn and portions of the Lower Sacramento HUC 8 watersheds were merged to create the "North American" region.
2. Second, the portions of the Lower Sacramento and Upper Mokelumne HUC 8 watersheds that overlap with the RWA WRP planning boundary were merged to create the "South American" region.
3. The North American, South American, and Cosumnes groundwater basins were trimmed to align with the extent of the RWA WRP planning area. Note that the Cosumnes groundwater basin was the only Bulletin 118 basin with a largely differing extent; the North American and South American basins are largely intact.

The modified HUC-8 watersheds were used to represent the surface water and land systems, while the trimmed Bulletin 118 basins were used to represent the groundwater system (Figure 4-1 and Figure 4-2, respectively).

Figure 4-1. Overview of Surface Water and Land Systems Water Budget Spatial Delineation

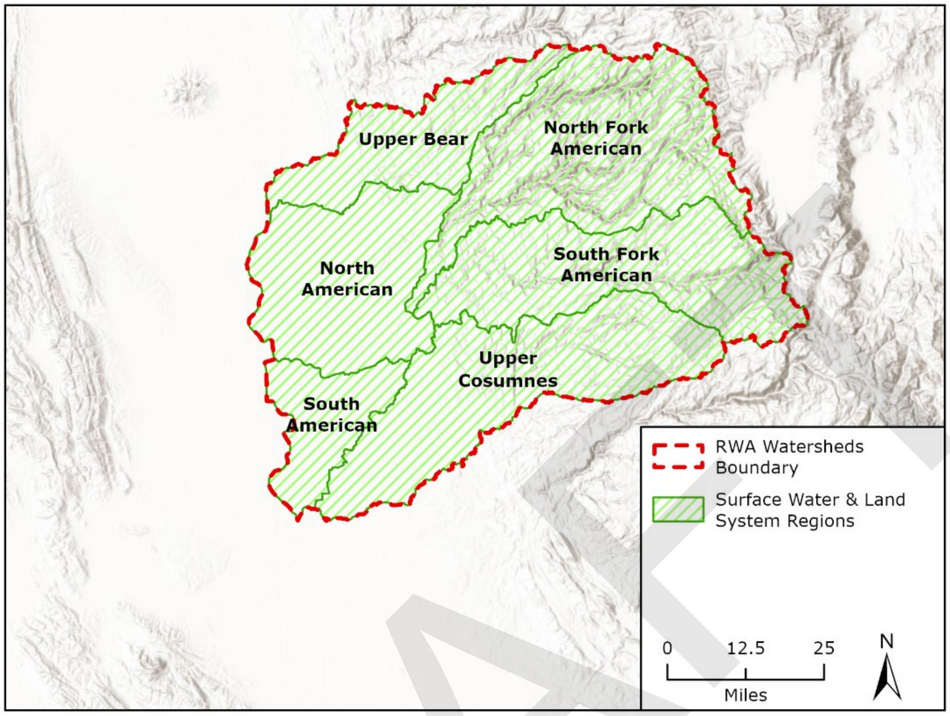
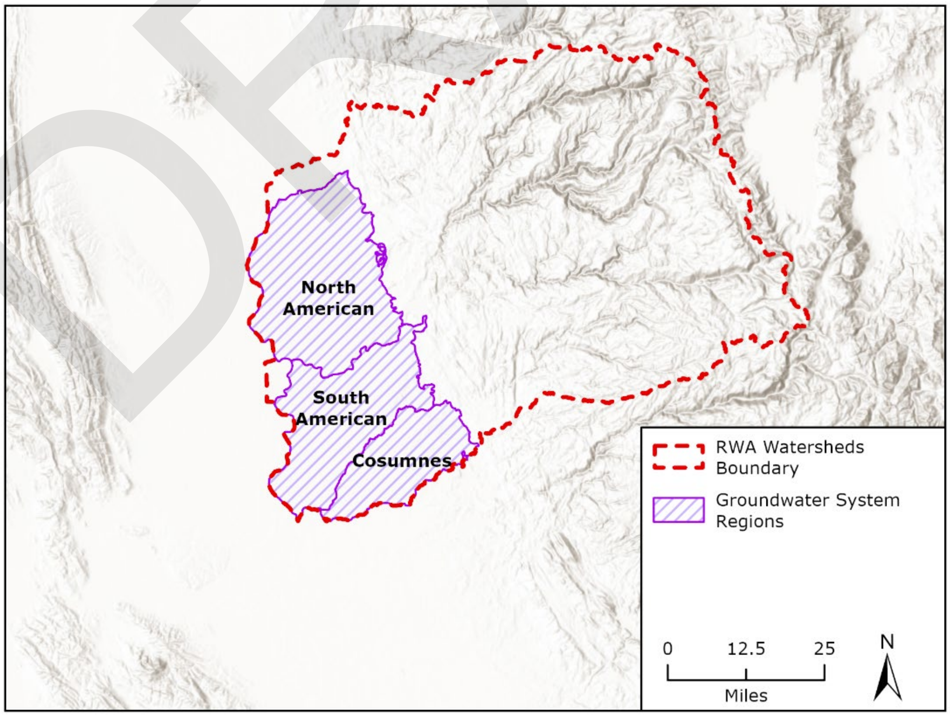


Figure 4-2. Overview of Groundwater System Water Budget Spatial Delineation



Polygons for CalSim 3 WBAs and upper watersheds were compiled to assess timeseries dataset coverage within the RWA WRP planning boundary (Figure 4-3). Overlap between the CalSim 3 polygons and the water budget regions were also assessed to determine how well datasets align with the desired structure of the water budget (Figures 4-4 and 4-5). While the upper watersheds generally align with the water budget boundaries, the CalSim 3 WBAs have been delineated based on similarities to individual demand units that comprise each WBA. As such, the defined boundaries for these areas do not align well with each water budget region in some cases. To resolve this misalignment, various spatial analyses were conducted for the WBAs to partition available datasets to better align with the water budget regions. It is important to note that valley floor areas beyond the defined extents of the groundwater system are considered in water budgeting purposes such that interactions between the surface water and land systems are maintained and water does not disappear from accounting. For example, while only a small portion of the northern-most WBA intersects with the North American basin, all of the groundwater-related components for the WBA are assumed to originate or travel to this subbasin. Furthermore, if the total portion of overlapping area between a given surface water and land system region and a groundwater region has, for example, 25% overlap with one subbasin and 75% overlap with another subbasin, all groundwater-related components are partitioned accordingly. Similarly, portions of the groundwater system within the RWA WRP planning boundary that do not overlap with a given WBA (primarily for the South American basin) are excluded from any surface water and land system interactions. To address this misalignment, CoSANA model comparisons have been incorporated to provide a better spatial representation of the Bulletin 118 basins while acknowledging that full budgeting alignment between WBAs is not met.

Figure 4-3. CalSim 3 Water Budget Areas and Upper Watersheds

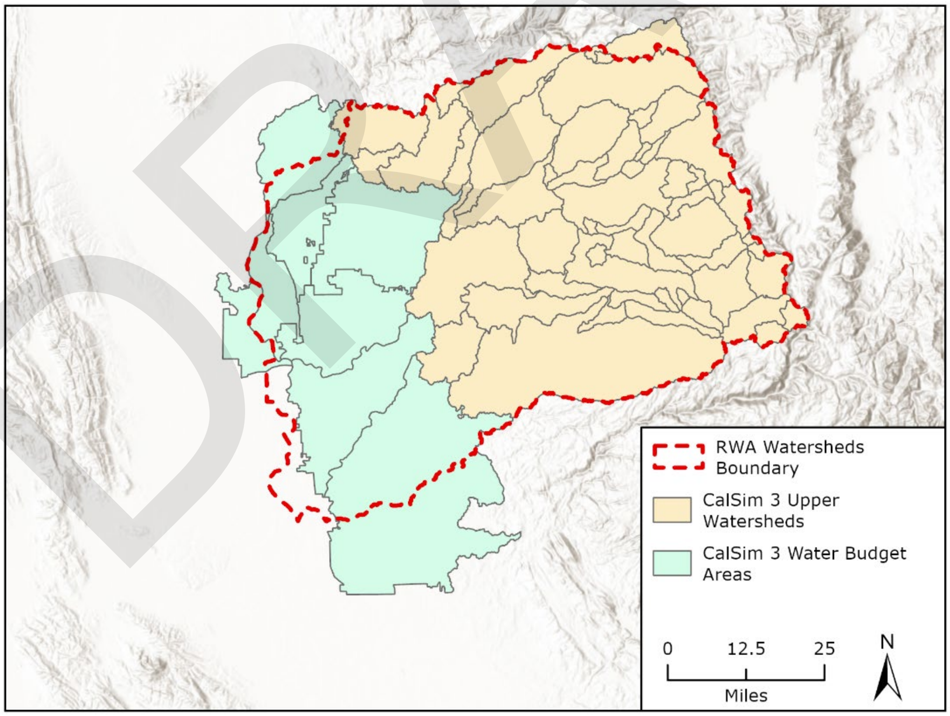


Figure 4-4. Alignment Between CalSim 3 Polygons and Water Budget Regions (Surface Water and Land)

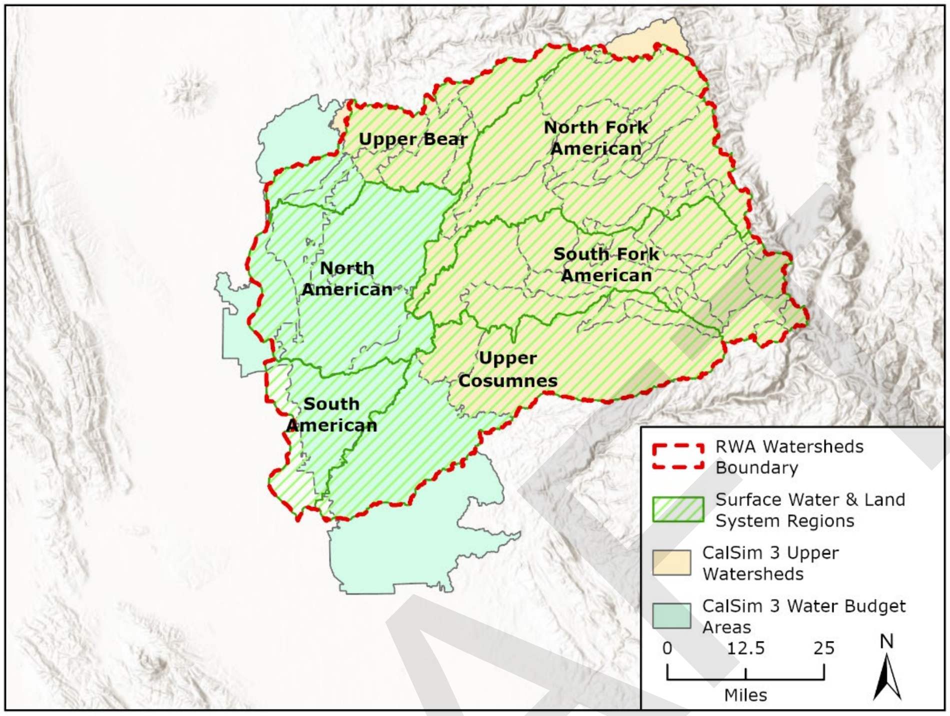
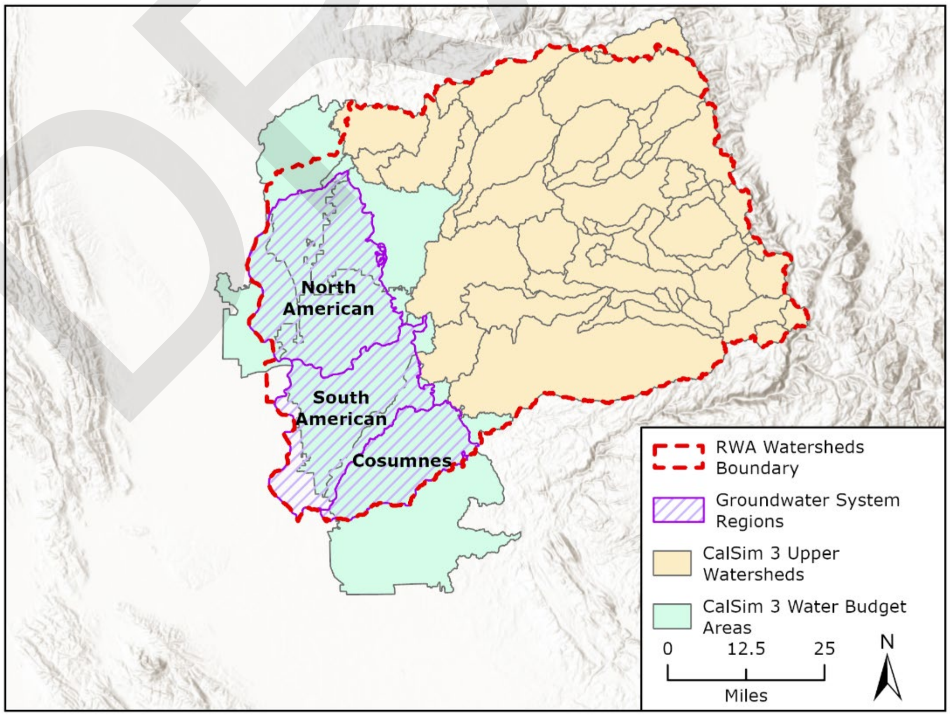


Figure 4-5. Alignment Between CalSim 3 Polygons and Water Budget Regions (Groundwater)



4.1.1 System Connections

The following tables provide an overview of individual water budget parameters within each system and how they connect to other systems. For full accounting equations, refer to Section 4.5. Table 4-1 details surface water system connections, while Table 4-2 provides land system connections, and Table 4-3 details groundwater system connections Tables 4-4 and 4-5 provide additional insight into how surface water and land system volumes are routed to the groundwater system. In general, most input data is provided at the WBA-level as it originates from CalSimHydro. These values are determined by partitioning the overlapping area between selected surface polygons and a Bulletin 118 groundwater basin of interest, as described previously. All relevant terms from the surface water or land systems are then routed to a destination basin using the percentages assigned in Tables 4-4 and 4-5. Finally, Table 4-6 summarizes total water budget connections.

Table 4-1. Surface Water System Connections

Term	Type	Destination	Connecting System
Stream Inflow	Inflow	Into System	N/A
Imported Water	Inflow	Into System	N/A
Surface Runoff	Inflow	Between Systems	Land System
Baseflow	Inflow	Between Systems	Land System
Tailwater	Inflow	Between Systems	Land System
Wastewater	Inflow	Between Systems	Land System
Operational Spill Conveyance Gain	Inflow	Between Systems	Land System
Lateral Flow Conveyance Gain	Inflow	Between Systems	Land System
Streamflow Gain	Inflow	Between Systems	Groundwater System
Stream Outflow	Outflow	Out of System	N/A
Environmental Flows	Outflow	Out of System	N/A
Exported Water	Outflow	Out of System	N/A
Applied Water Diversions	Outflow	Between Systems	Land System
Urban Surface Water Diversions	Outflow	Between Systems	Land System
Reservoir Evaporation	Outflow	Out of System	N/A
Streamflow Losses	Outflow	Between Systems	Groundwater System

Table 4-2. Land System Connections

Term	Type	Destination	Connecting System
Precipitation	Inflow	Into System	N/A
Applied Water	Inflow	Between Systems	Surface Water System, Groundwater System
Urban Deliveries	Inflow	Between Systems	Surface Water System, Groundwater System
Upper Watershed Subsurface Gains	Inflow	Into System	N/A
Evapotranspiration	Outflow	Out of System	N/A
Surface Runoff	Outflow	Between Systems	Surface Water System
Baseflow	Outflow	Between Systems	Surface Water System
DP	Outflow	Between Systems	Groundwater System
Evaporative Conveyance Losses	Outflow	Out of System	N/A
DP Conveyance Losses	Outflow	Between Systems	Groundwater System
Operational Spill Conveyance Gain	Outflow	Between Systems	Surface Water System
Lateral Flow Conveyance Gain	Outflow	Between Systems	Surface Water System
Tailwater	Outflow	Between Systems	Surface Water System
Wastewater	Outflow	Between Systems	Surface Water System
Upper Watershed Subsurface Losses	Outflow	Out of System	N/A

Table 4-3. Groundwater System Connections

Term	Type	Destination	Connecting System
DP	Inflow	Between Systems	Land System
DP Conveyance Gains	Inflow	Between Systems	Land System
Streamflow Gain	Inflow	Between Systems	Surface Water System
Subsurface Inflow	Inflow	Into System	N/A
Applied Water Pumping	Outflow	Between Systems	Land System
Urban Pumping	Outflow	Between Systems	Land System
Streamflow Loss	Outflow	Between Systems	Surface Water System
Subsurface Outflow	Outflow	Out of System	N/A

Table 4-4. Groundwater Connections to Water Budget Areas from CalSimHydro

CalSimHydro Water Budget Area	North American Subbasin	South American Subbasin	Cosumnes Subbasin
15S	100%	0%	0%
21	97.7%	2.3%	0%
22	100%	0%	0%
23	100%	0%	0%
24	100%	0%	0%
26N	99.9%	0.1%	0%
26S	0%	21.7%	78.3%
60N	97.7%	2.3%	0%

Table 4-5. Groundwater Connections to Surface Water and Land Systems

Region	North American Subbasin	South American Subbasin	Cosumnes Subbasin
Upper Bear	100%	0%	0%
North American	92.5%	7.5%	0%
South American	0%	100%	0%
Upper Cosumnes	0%	21.3%	78.7%

Table 4-6. Total Water Budget Connections

Term	Type	Destination	Connecting System
Precipitation	Inflow	Into System	N/A
Stream Inflows	Inflow	Into System	N/A
Imported Water	Inflow	Into System	N/A
Subsurface Inflow	Inflow	Into System	N/A
Upper Watershed Subsurface Gains	Inflow	Into System	N/A
Evapotranspiration	Outflow	Out of System	N/A
Evaporative Conveyance Losses	Outflow	Out of System	N/A
Reservoir Evaporation	Outflow	Out of System	N/A
Stream Outflow	Outflow	Out of System	N/A
Environmental Flows	Outflow	Out of System	N/A
Exported Water	Outflow	Out of System	N/A
Subsurface Outflow	Outflow	Out of System	N/A
Upper Watershed Subsurface Losses	Outflow	Out of System	N/A

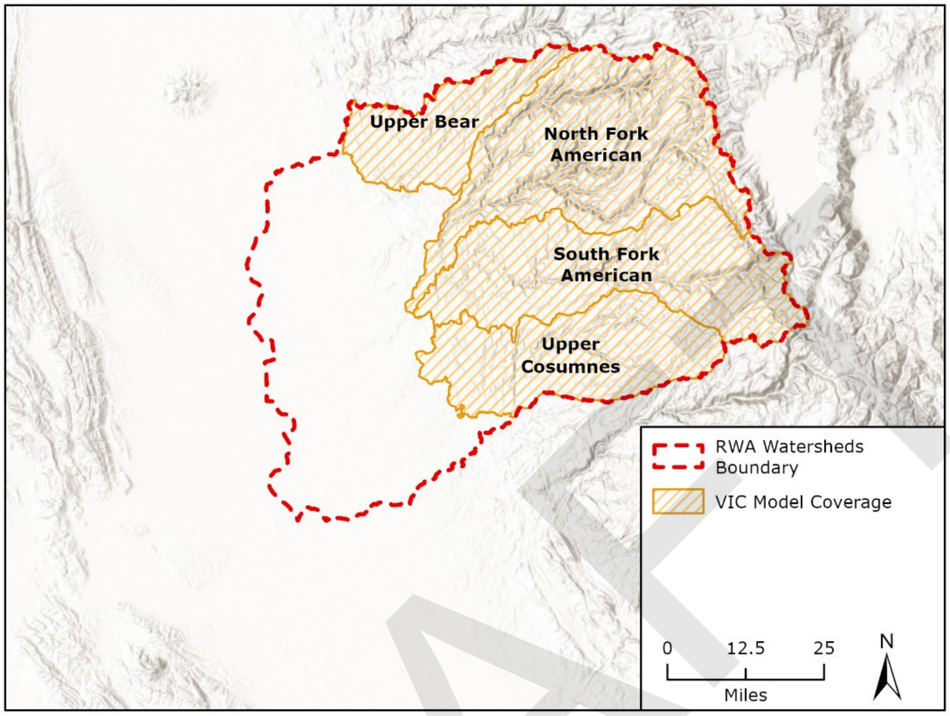
4.2 Upper Watershed Areas

The following subsections detail the approach used to characterize water budget components for upper watershed areas (yellow polygons on Figure 4-3). Consumptive uses in these areas are assumed to be largely captured through evapotranspiration; no groundwater interaction was incorporated in these areas. Water budget terms for upper watershed areas are estimated through modeled outputs and are not measured.

4.2.1 Precipitation

The extended Livneh at al. (2013) dataset was used to estimate precipitation volumes in upper watershed areas for the period of January 1915 through December 2021. Individual timeseries were generated for relevant areas in the Upper Bear and Upper Cosumnes regions, as well as the entirety of the North Fork American and South Fork American regions. The Livneh dataset is used as an input for the VIC model. As such, coverage of this dataset aligns with that of the VIC model displayed on Figure 4-6.

Figure 4-6. VIC Model Coverage



4.2.2 Evapotranspiration

VIC model simulations were used to estimate evapotranspiration volumes in upper watershed areas for the period of January 1915 through December 2021. Individual outputs were generated for relevant areas in the Upper Bear and Upper Cosumnes regions, as well as the entirety of the North Fork American and South Fork American regions.

4.2.3 Surface Runoff

VIC model simulations were used to estimate surface volumes in upper watershed areas for the period of January 1915 through December 2021. Individual outputs were generated for relevant areas in the Upper Bear and Upper Cosumnes regions, as well as the entirety of the North Fork American and South Fork American regions.

4.2.4 Baseflow

VIC model simulations were used to estimate baseflow volumes in upper watershed areas for the period of January 1915 through December 2021. Baseflow is the portion of the streamflow that is sustained between precipitation events and fed to streams by delayed pathways. Baseflow is the sustained flow of a stream in the absence of direct runoff (DWR 2024). Individual outputs were generated for relevant areas in the Upper Bear and Upper Cosumnes regions, as well as the entirety of the North Fork American and South Fork American regions.

4.2.5 Upper Watershed Subsurface Gains and Losses

Upper watershed subsurface gains and losses were calculated to balance precipitation and VIC model simulations in the upper watershed areas. Subsurface gains (negative results) and losses (positive results) in these areas are calculated as precipitation minus surface water, evapotranspiration, and baseflow.

4.2.6 Reservoir Evaporation

Reservoir evaporation is assumed to be a subset of evapotranspiration and is only considered for surface water regions. Evapotranspiration volumes reflected in land systems are adjusted to exclude this component. CalSim3 reservoir evaporation monthly timeseries for the period of water years 1922 through 2021 were incorporated for the following reservoirs in upper watershed areas as noted:

- Folsom Lake (South Fork American & North Fork American)
- Camp Far West Reservoir (Upper Bear)
- French Meadows Reservoir (North Fork American)
- Hell Hole Reservoir (North Fork American)
- Look Lake (North Fork American)
- Lake Valley Reservoir (North Fork American)
- Stumpy Meadows Reservoir (North Fork American)
- Union Valley Reservoir (South Fork American)
- Ice House Reservoir (South Fork American)
- Lake Aloha (South Fork American)
- Caples Lake (South Fork American)
- Silver Lake (South Fork American)
- Jenkinson Lake (Upper Cosumnes)
- Rollins Reservoir (Upper Bear)
- Lake Combie (Upper Bear)
- Gerle Creek Reservoir (North Fork American)
- Rancho Murieta Reservoirs (Upper Cosumnes)

4.2.7 Inflow

Because the upper watershed areas are the headwaters for this water budget, no inflows are considered in these areas.

4.2.8 Outflow

The North Fork American and South Fork American are the only water budget regions that are exclusively represented by upper watershed areas. As such, they are the only regions that include outflows for this area. DCR simulations were used to characterize spills from Folsom Lake into the North American (and South American) regions. Monthly Folsom Lake releases for the period of water years 1922 through 2021 were split evenly between the North Fork American and South Fork American regions to represent outflow from these regions.

4.2.9 Environmental Flows

For this water budget, environmental flows consider minimum instream flows and mitigation flows. Flows related to temperature requirements are assumed to be captured in outflow terms. Both minimum instream flows and mitigation flows do not influence overall water balances; they are considered for informational purposes only at relevant outflow locations. Similar to the outflows described previously, environmental flows are only considered for the North Fork American and South Fork American regions in upper watershed regions. While Folsom Lake does not include a minimum instream flow or mitigation flow parameter for releases, the immediately downstream Lake Natoma does. As such, the reported environmental flows from the North Fork American and South Fork American regions utilize Lake Natoma minimum instream flow and mitigation flow requirement releases. This requirement is split evenly between both regions.

4.3 Valley Floor Areas

The following subsections detail the approach used to characterize water budget components for valley floor areas (green polygons on Figure 4-2). Consumptive uses in these areas are far more prevalent than the upper watershed areas. As such, additional complexities are incorporated in the water budget to appropriately represent these interactions. Water budget terms for valley floor areas are estimated through modeled outputs and are not measured.

4.3.1 Precipitation

Monthly precipitation timeseries data for each WBA are available from CalSimHydro for the period of water years 1922 through 2021. Precipitation values from each WBA were partitioned to individual, overlapping water budget regions using an area-weighted approach.

4.3.2 Evapotranspiration

Monthly evapotranspiration timeseries data for each WBA are available from CalSimHydro for the period of water years 1922 through 2021. Evapotranspiration values from each WBA were partitioned to individual, overlapping water budget regions using an area-weighted approach.

4.3.3 Surface Runoff

Monthly surface runoff timeseries data for each WBA are available from CalSimHydro for the period of water years 1922 through 2021. Surface runoff values from each WBA were partitioned to individual, overlapping water budget regions using an area-weighted approach.

4.3.4 Reservoir Evaporation

As noted previously, reservoir evaporation is assumed to be a subset of evapotranspiration and is only considered for surface water regions. CalSim 3 reservoir evaporation monthly timeseries for the period of water years 1922 through 2021 were incorporated for the following reservoirs in valley floor areas as noted: Lake Natoma (North American).

4.3.5 Inflow

Inflows in valley floor areas are linked to outflows from upper watershed areas. As such, the only inflows considered in this water budget are those from the North Fork American and South Fork American. While the North American region is slightly upstream of the South American region, monthly DCR-simulated releases from Folsom Lake are divided equally between these two regions.

4.3.6 Outflow

Outflows are considered for the Upper Bear, North American, South American, and Upper Cosumnes regions using monthly DCR-simulated flows. The furthest downstream CalSim node within the RWA WRP planning boundary was selected to represent outflows for these regions. Furthermore, outflows from the American River to the Sacramento River were divided evenly between the North American and South American regions. Selected CalSim nodes for the Bear River, American River, and Cosumnes River are C_BRR004, C_AMR004, and C_CSM005, respectively.

4.3.7 Environmental Flows

Monthly DCR-simulated environmental flows (i.e., minimum instream flows and mitigation flows) are only relevant for the Bear River and American River. The American River has minimum instream flow and mitigation flow outputs at the same node selected to represent outflows; however, the closest relevant location for the Bear River is slightly upstream and only includes minimum instream flow requirements (C_BRR017). Monthly timeseries for these two locations were used to represent environmental flow requirements for the Upper Bear, North American, and South American regions. Environmental flows for the American River were divided evenly between the North and South American regions.

4.3.8 Applied Water

Monthly applied water timeseries data for each demand unit within each WBA are available from CalSimHydro for the period of water years 1922 through 2021. Applied water data is divided into three categories: applied water for rice, applied water for other crops, and applied water for wetlands. Because some demand units within a given WBA divert water from sources outside of the RWA WRP planning area (e.g., Sacramento River), not all applied water uses are consumptive within the bounds of the water budget. As such, applied water volumes for each demand unit were screened based on identified points of diversion in the *CalSim 3 Report*. From this, applied water can be categorized as water entering the system from outside the water budget boundary (i.e., imports) as well as consumptive uses from within the water budget boundary. Furthermore, for points of diversion within a given water budget region, these can be assigned without needing an area-weighted approach for specific demand unit applied water volumes. However, for non-district demand units (i.e., those without a point of diversion listed), an area-weighted approach was applied to partition applied water to a given water budget region.

To estimate the role that groundwater supplies play in meeting applied water demands, minimum groundwater pumping ratios identified in the *CalSim 3 Report* for each agricultural demand unit were utilized. These ratios were used to partition applied water demands into surface water (or land system) and groundwater components. In some cases, these ratios were modified to align with the reported availability of water supplies in the *CalSim 3 Report* (i.e., either surface water, groundwater, or a mix of the two) or better align with other sources of groundwater pumping information.

The *CalSim 3 Report* also provides assumptions related to conveyance losses. Rather than investigate the conveyance efficiency of all infrastructure within the RWA WRP boundary, medium efficiency values were selected from the *CalSim 3 Report*. These include the following as percentages of surface water diversions:

- 5% lateral flow loss factor (assumed to be a return flow)
- 6% DP loss factor (assumed to be additive to groundwater storage)
- 3% operational spill factor (assumed to be a return flow)
- 1% evaporative loss factor

These volumes were assumed to be additive to simulated applied water demands; therefore, they were re-assigned to either surface water diversions, groundwater pumping, or imported water to appropriately balance volumes.

CalSimHydro also includes monthly evapotranspiration volumes per WBA from the applied water itself, not losses that occur through conveyance. These timeseries have also been incorporated into the water budget for valley floor areas as a subset of total evapotranspiration.

In addition to applied water, CalSimHydro provides monthly timeseries data for tailwater for each demand unit within each WBA. This is considered to be a return flow from applied water use. Simulated tailwater volumes were first screened based on the total amount of applicable applied water for each demand unit (i.e., applied water within the water budget boundary) before applying an area-weighted approach to assign volumes to a given water budget region.

4.3.9 Urban Demand

Monthly urban demand timeseries data for each demand unit within each WBA are available from CalSimHydro for the period of water years 1922 through 2021. The *CalSim 3 Report* includes annual totals for public supported and self-supported (i.e., through groundwater supplies). In addition, groundwater pumping fractions are identified that can be used to partition public-supported urban demand into surface water and groundwater components. The same point of diversion-based approach described for applied water was also applied for surface-based urban demand. No conveyance losses were applied for urban demand for most demand units; the *CalSim 3 Report* only notes a single 3% loss factor for a single demand unit (Folsom Lake Shoreline). This has been incorporated into the analysis and is considered a return flow. For clarity, urban demand is referred to as urban surface water diversions; urban deliveries; and urban pumping for surface water, land, and groundwater systems. This is consistent with the figures presented in Section 5.

Similar to tailwater, CalSimHydro provides monthly timeseries data for wastewater for each demand unit within each WBA. This is also considered to be a return flow. Simulated wastewater volumes were first screened based on the total amount of applicable urban water for each demand unit (i.e., urban demand-specific water within the water budget boundary) before applying an area-weighted approach to assign volumes to a given water budget region.

4.3.10 Exports

Exports were estimated using the CalSim 3 schematic and DCR-simulated diversions. The Folsom South Canal was the only source of identified exports within the water budget area. Surface water deliveries for areas beyond the water budget boundary were compiled for the period of water years 1922 through 2021. The source of these exports was assumed to be the North American region.

4.3.11 Deep Percolation

DP represents outflows from the surface water system into the groundwater system. Monthly DP timeseries data for each WBA are available from CalSimHydro for the period of water years 1922 through 2021. From the perspective of the land system, the values from each WBA were partitioned to individual, overlapping water budget regions using an area weighted approach. A similar weighting approach was used to partition these volumes to the groundwater system as well.

CoSANA model outputs for DP for each groundwater subbasin are available at the monthly scale for the period of water years 1970 through 2019. Area weighting was applied to timeseries data to exclude portions of subbasins that extend beyond the RWA WRP planning area.

4.3.12 Surface Water-Groundwater Interaction

The groundwater DLL within the 2023 DCR CalSim 3 model includes a monthly surface water-groundwater interaction parameter for each WBA (note that the notation for these areas is slightly different in the water budget spreadsheet) for the period of water years 1922 through 2021. Values were separated into positive (i.e., losing stream) and negative (i.e., gaining stream) components. Next, an area weighted approach was used to partition flows across either surface water system or groundwater system regions.

CoSANA model outputs for streamflow gains and losses for each groundwater subbasin are available at the monthly scale for the period of water years 1970 through 2019. No area weighting was applied to timeseries data; streamflow gains and losses are incorporated as-is for each groundwater subbasin. It is assumed that the largest contributors to streamflow are captured within the water budget footprint.

4.3.13 Subsurface Inflows and Outflows

CoSANA model outputs for subsurface inflows and outflows for each groundwater subbasin are available at the monthly scale for the period of water years 1970 through 2019. No area weighting was applied to timeseries data; inflows and outflows are incorporated as-is for each groundwater subbasin.

4.4 Groundwater Comparison

The groundwater DLL within the 2023 DCR CalSim 3 model also includes a total groundwater pumping parameter. This parameter was incorporated into the water budget spreadsheet for comparison purposes. From this comparison, the minimum groundwater pumping ratios were increased, where relevant, to better align calculated values with DCR-simulated results. On average, calculated values for the North American, South American, and Cosumnes subbasins differ from simulated values by approximately 1.6, 3.4, and 1.2 thousand acre-feet (TAF) per month, respectively.

As highlighted herein, CoSANA model outputs provide a more robust spatial representation of historical groundwater budgets within the RWA WRP planning area due to its focus on the Bulletin 118 basins. However, there are differences in estimated groundwater system variables, given that the variables are not derived from the same land system and surface water system components, differing underlying model assumptions, and varying spatial extents. Additionally, the groundwater-focused terms included in this water budget are largely calculated through spatial analyses and post-processing of model outputs from CalSimHydro and other sources. Further discussion on apparent differences between annual averages over the full period of available CoSANA outputs is included for each subbasin, as follows:

- North American Subbasin
  - **Groundwater Pumping**: CalSimHydro-based approach overestimates annual groundwater extraction by 43 TAF, on average, compared to CoSANA outputs, but covers a larger spatial domain.
  - **DP**: Values are fairly consistent with CalSimHydro-based results, with only an 11 TAF annual average difference between the two approaches.
  - **Surface Water-Groundwater Interaction**: CalSim 3-based approach overestimates annual streamflow gains by 44 TAF, on average, compared to CoSANA outputs, but covers a larger spatial domain.
- South American Subbasin
  - **Groundwater Pumping**: Annual CoSANA groundwater pumping outputs are 96 TAF higher, on average, between 1970 and 2019. Considerations noted above for groundwater pumping are relevant here.
  - **DP**: The South American Subbasin is only partially covered in the CalSimHydro-based approach. As such, estimates appear to be significantly underestimated when compared to CoSANA outputs. Annual CoSANA DP outputs are 50 TAF higher, on average, between 1970 and 2019.
  - **Surface Water-Groundwater Interaction**: Annual CoSANA net subsurface inflow outputs are 60 TAF higher, on average, between 1970 and 2019. This is a significant departure from the CalSim 3-based approach. However, this is likely due to the influence of the Sacramento River; this is excluded from the CalSim 3-based approach.
- Cosumnes Subbasin
  - **Groundwater Pumping**: Annual groundwater extraction quantities appear to be overestimated in the CalSimHydro-based approach (35 TAF). However, the CoSANA footprint covers a smaller spatial domain.
  - **DP**: Annual DP quantities appear to be slightly overestimated in the CalSimHydro-based approach (14 TAF). However, the CoSANA footprint covers a smaller spatial domain.
  - **Surface Water-Groundwater Interaction**: Annual CoSANA outputs are 19 TAF and 5 TAF higher for streamflow losses and gains estimated from the CalSim 3-based approach, respectively.

Figures 4-7 through 4-12 provide additional information on parameter-specific comparisons between calculated variables and CoSANA outputs. Note that subsurface inflows and outflows between adjacent groundwater basins are excluded from these figures because there is no calculated basis for comparison.

Figure 4-7. Deep Percolation Comparison

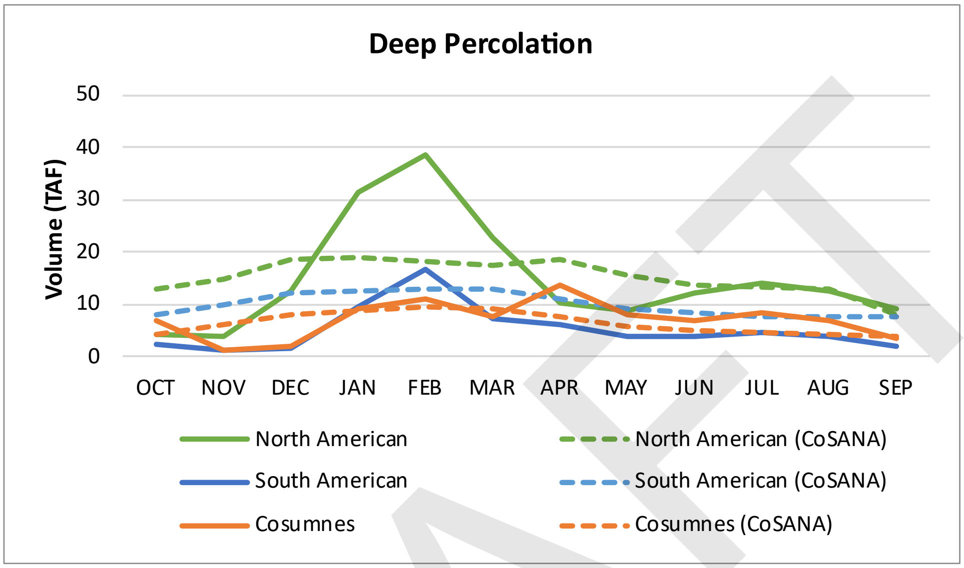


Figure 4-8. Streamflow Gain Comparison

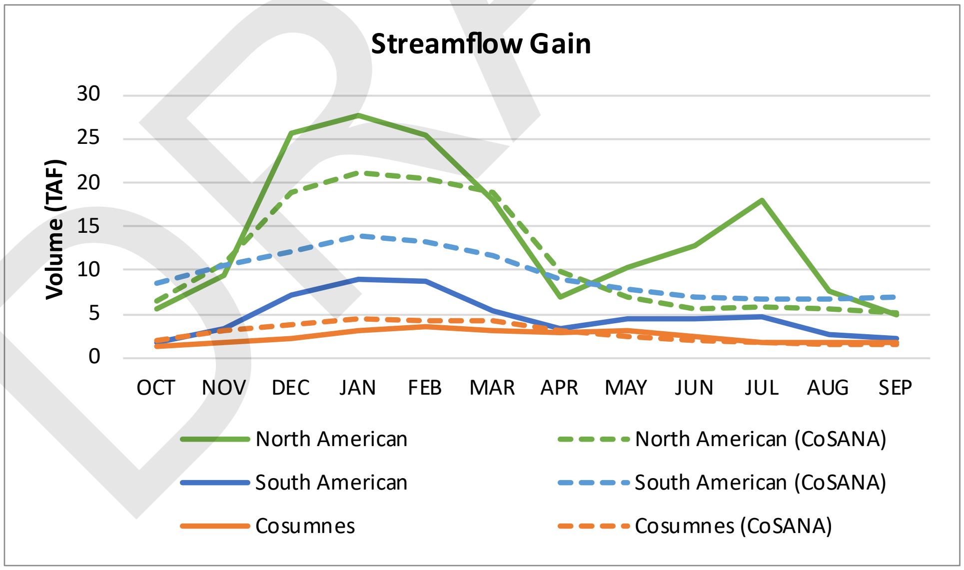


Figure 4-9. Streamflow Loss Comparison

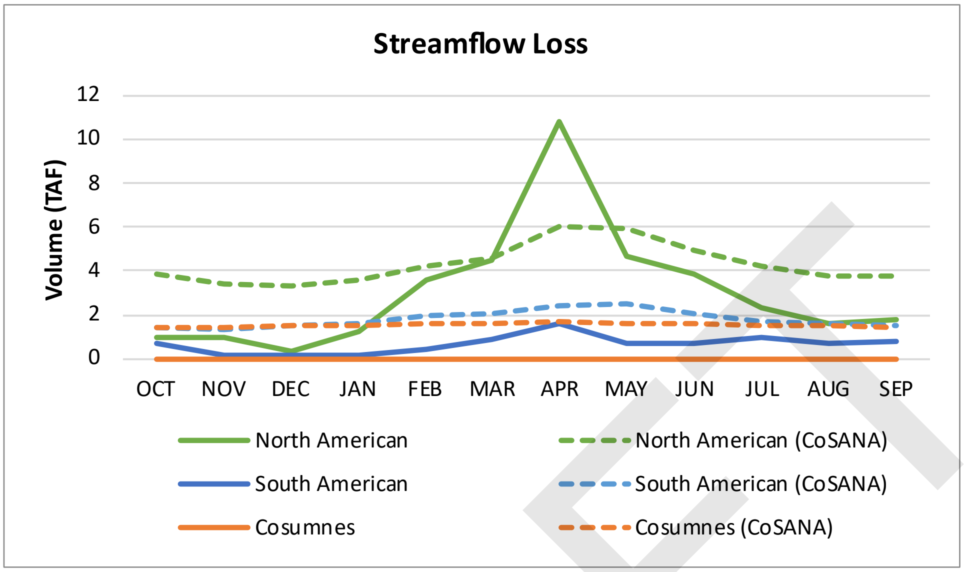


Figure 4-10. Groundwater Production Comparison (calculated versus CoSANA)

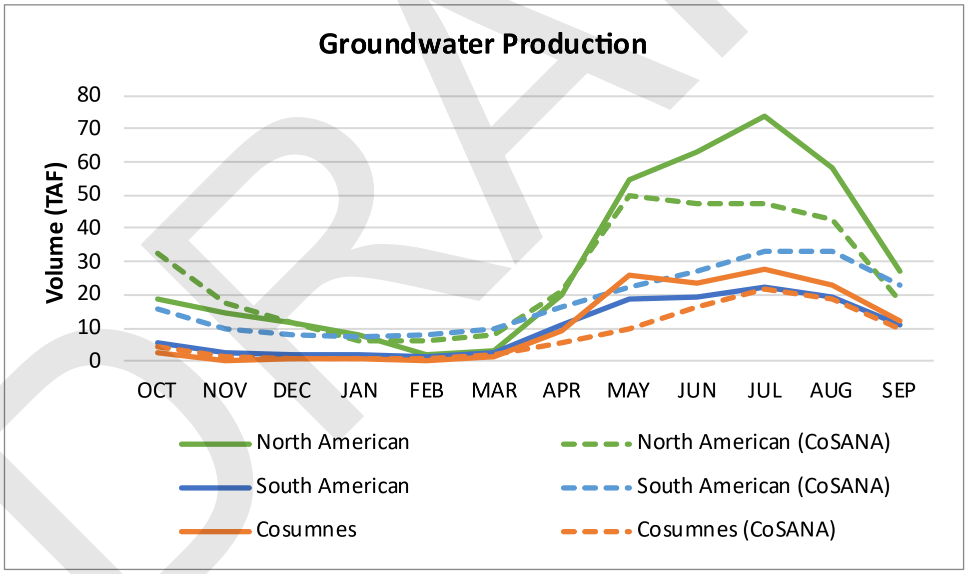


Figure 4-11. Groundwater Production Comparison (calculated versus CalSim 3)

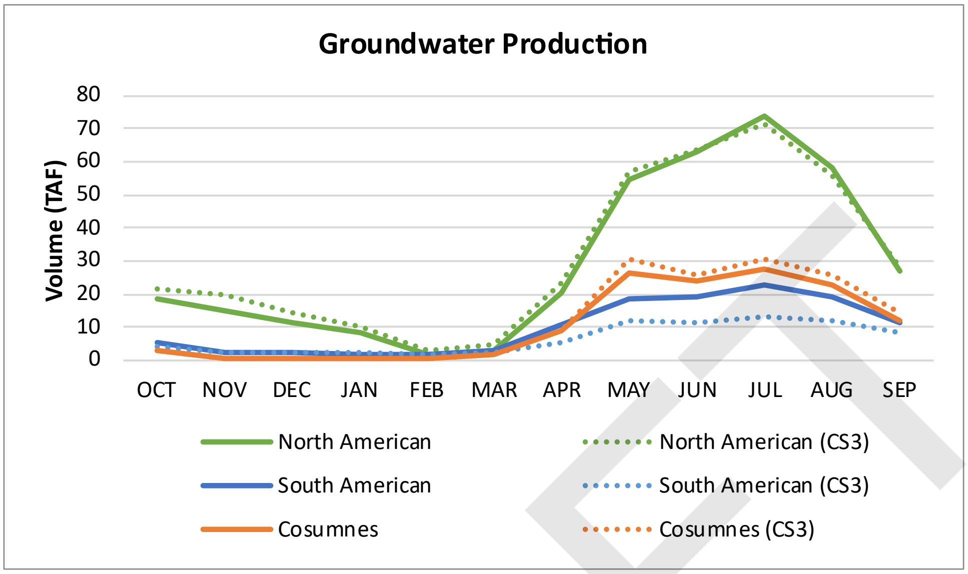
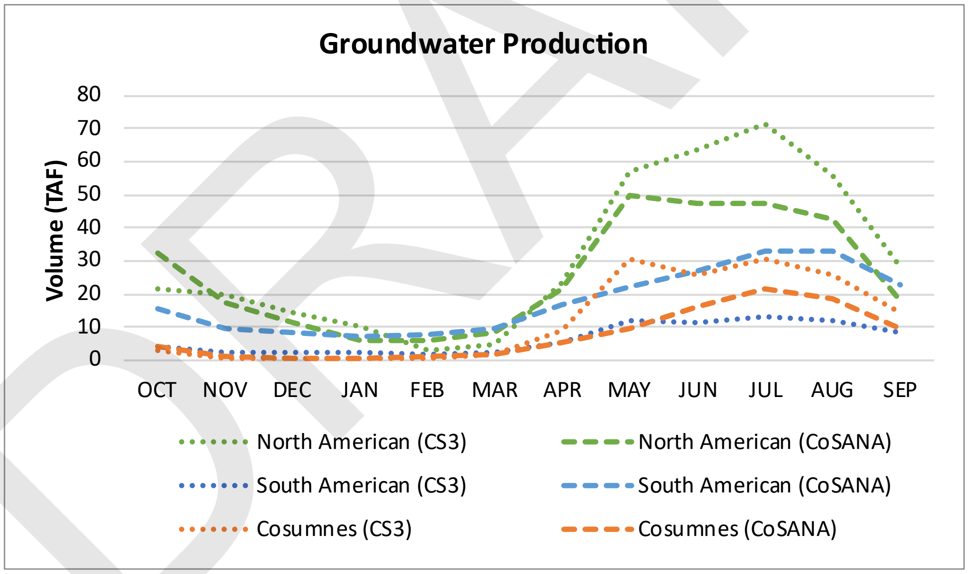


Figure 4-12. Groundwater Production Comparison (CalSim 3 versus CoSANA)



4.5 Water Budget Equations

The following equations (largely informed by the *Handbook for Water Budget Development*) are used to estimate the net change (i.e., inflows minus outflows) in storage within a given water budget region over a selected period of time. Note that this change in storage can also be interpreted as a measure of uncertainty of mass balancing (i.e., accounting) between inflows and outflows. In most cases, inflows and outflows for each year are not perfectly balanced across systems. Additionally, for systems such as the groundwater system, change in storage can be used to assess long-term trends in aquifer supplies, for example:

- Surface Water System
  - **Inflows**: Stream Inflow + Imported Water + Runoff (and Baseflow, where relevant) + Tailwater + Wastewater + Operational Spill Conveyance Gain + Lateral Flow Conveyance Gain + Streamflow Gain
  - **Outflows**: Stream Outflow + Exported Water + Applied Water Diversions + Urban Surface Water Diversions + Reservoir Evaporation + Streamflow Losses + Environmental Flows
  - **Change in Surface Water Storage**: Total Surface Water Inflows – Total Surface Water Outflows
- Land System
  - **Inflows**: Precipitation + Applied Water + Urban Deliveries + Upper Watershed Subsurface Gains
  - **Outflows**: Evapotranspiration + Surface Runoff (and Baseflow, where relevant) + DP + Evaporative Conveyance Losses + DP Conveyance Losses + Operational Spill Conveyance Losses + Lateral Flow Conveyance Losses + Tailwater + Wastewater + Upper Watershed Subsurface Losses
  - **Change in Land System Storage**: Total Land System Inflows – Total Land System Outflows
- Groundwater System
  - **Inflows**: DP + DP Conveyance Gains + Streamflow Gain + Subsurface Inflow
  - **Inflows (CoSANA Only)**: DP + Streamflow Gains + Subsurface Inflow
  - **Outflows**: Applied Water Pumping + Urban Pumping + Streamflow Loss + Subsurface Outflow
  - **Outflows (CoSANA Only)**: Total Groundwater Pumping + Streamflow Losses + Subsurface Outflow
  - **Change in Groundwater System Storage**: Total Groundwater System Inflows – Total Groundwater System Outflows
- Total Water Budget
  - **Inflows**: Precipitation + Stream Inflows + Imported Water + Subsurface Inflow + Upper Watershed Subsurface Gains
  - **Outflows**: Evapotranspiration + Evaporative Conveyance Losses + Reservoir Evaporation + Stream Outflow + Environmental Flows + Exported Water + Subsurface Outflow + Upper Watershed Subsurface Losses
  - **Change in Total Water Budget Storage**: Total Water Budget Inflows – Total Water Budget Outflows

5. Findings and Results

This section highlights outputs from the RWA WRP water budget and discusses key findings based on observable trends. Additional figures not presented in this section can be generated via the accompanying spreadsheet. For simplicity, most discussion is focused at the overall RWA WRP planning area level (rather than focusing on individual contributing watersheds).

5.1 Discussion

- **Annual Trends**: The surface water and land systems show a general balance between inflows and outflows between water years 1979 and 2019. The groundwater system shows increasing aquifer storage totaling roughly 25 TAF per year on average. The total water budget shows some minor imbalance between inflows and outflows, primarily as a result of the limitations described in Section 3. Inflows for the surface water system are primarily dominated by surface runoff and baseflow as a result of corresponding outflows from the land system. Precipitation drives the majority of inflows into the overall (i.e., total) water budget; evapotranspiration and stream outflows are the largest contributor to overall outflows across the planning area. Groundwater system regions are largely supplied through subsurface gains as a result of interactions between surface water as well as DP received through the land system. Groundwater outflows are primarily dominated by withdrawals to support agricultural production.
- **Annual Trends by Water Year Type**: Total inflows for the surface water and land systems generally correspond to the shift in precipitation (and resulting surface runoff and baseflow) between wet, above normal, below normal, dry, and critically dry water years. Total surface water system outflows decrease as riverine outflows decrease under reduced water availability. Total outflows for the land system are reduced, as less precipitation is available to drive evapotranspiration processes, DP, surface runoff, and return flows. These considerations are carried through to the total water budget, which is largely driven by precipitation, evapotranspiration, and riverine outflow across the planning area. For the groundwater system, total outflows are generally static between each water year type; this is likely attributed to increased groundwater production to compensate for decreased surface water in dry and critically dry years. Groundwater system inflows decrease from wet to critically dry years in accordance with reduced surface water flows and a reduction in land system precipitation that would have resulted in DP.
- **Monthly Trends**: At the monthly scale, surface water inflows generally peak in the early to mid-spring in accordance with the timing of runoff. For the North and South American regions, inflows peak in February and again in late spring, corresponding with Folsom Lake releases. This pattern is mirrored in the monthly outflow distribution for the North Fork and South Fork American regions. For the Upper Cosumnes Region, the timing of inflows and outflows generally mirrors runoff regimes due to the unregulated nature of the watershed. For the land system, each region generally follows the same pattern for total inflows and outflows as a result of the timing and magnitude of precipitation and upper watershed subsurface gains (inflows) and the combination of evapotranspiration, surface runoff, baseflow, and upper watershed subsurface losses (outflows). The increases noted for the North American Region in the summer months are attributed to a peak in applied water and urban deliveries during these months. Total groundwater system inflow trends somewhat mirror patterns displayed for the surface water and land systems. Each groundwater region appears to be sustained through surface water interaction in winter and summer months in conjunction with DP in the winter. Total outflows peak in summer months when groundwater production is at its highest point and begin to taper off toward the winter. As noted herein, because the total water budget is largely comprised of land system components, monthly average patterns generally align with trends presented for the land system.

However, influence of the surface water system can be noted when examining total water budget outflow due to the prevalence of the stream outflow term.

- **Changes in Storage**: Changes in storage for the land system show large increases (roughly 350 TAF) during above normal water years and decreases in storage of about 125 TAF in wet years. These decreases may be attributed to some of the limitations noted previously or could be primarily driven as a result of higher stream outflow volumes during these years. Monthly patterns indicate that much of the seasonal gain in storage occurs in late winter and early spring, with reductions in storage occurring during summer months. Changes in land system storage decrease from wet water years to dry water years (approximately 40 TAF gain to 40 TAF loss), with the majority of gains and losses in storage primarily occurring during below normal, dry, and critically dry water years, respectively. This variation is likely due to imbalances between precipitation and evapotranspiration during these water years.

  At the monthly scale, gains occur during winter months alongside the arrival of precipitation and losses occur in late spring and early summer in conjunction with the timing of runoff and peak evapotranspiration. Gains in aquifer storage are primarily driven by above normal (roughly 225 TAF) and wet (75 TAF) water years when more precipitation is available for DP and streamflow volumes are higher. Decreases in aquifer storage (just below 200 TAF annually) occur in below normal, dry, and critically dry years. Similar to the land system, increases in aquifer storage occur during the winter and early spring. Decreases in aquifer storage occur across the summer corresponding with peaks in groundwater production. Cumulatively, the surface water and land systems are roughly balanced over the full simulation period. Increases and decreases in land system storage appear to follow the cadence of individual water year types due to the influence of precipitation on inflows. Cumulative groundwater system storage shows a decline leading up to 1970, followed by a general increase toward 2021. The reason for this shift over time is because subsurface inflows and outflows from outside the RWA WRP are not represented until 1970, when the CoSANA dataset begins. As such, it can be assumed that cumulative groundwater trends would not show a deficit by 2021.

5.2 Land System

The historical record shows two distinct behavioral patterns among land system components: climate-driven variability and relatively steady human-driven demand. Precipitation is the primary driver of variability in the land system. In wet years, higher precipitation leads to sharp increases in surface runoff, baseflow, and DP. These years expand the overall volume of water moving through the land system, resulting in greater recharge to groundwater and larger contributions to surface water flows. Conversely, during drought years, precipitation declines substantially, which directly reduces runoff and recharge. DP, an important source of groundwater replenishment, declines markedly in dry periods. Upper watershed subsurface gains and losses also fluctuate with hydrologic conditions. In short, the ‘natural’ components of the land system respond immediately and proportionally to wet and dry cycles.

Applied water deliveries (agricultural irrigation) and urban deliveries are comparatively stable from year to year. While there may be modest adjustments, the demand signal remains consistent relative to the swings in precipitation. Similarly, evapotranspiration, although influenced by climate, remains persistently large across all year types because crops, landscapes, and natural vegetation continue to require water even during drought. Return flows such as tailwater and wastewater also remain relatively consistent, reflecting steady patterns of water use.

The contrast between highly variable natural inflows and relatively steady human demand has important consequences:

- **Groundwater becomes the balancing mechanism:** When precipitation and runoff decline during droughts but agricultural and urban demands remain relatively constant, the system compensates by increasing groundwater pumping. This reinforces groundwater's role as a drought buffer.
- **Recharge depends heavily on wet years:** Because DP rises significantly in wet years and falls sharply in dry years, long-term groundwater sustainability depends on the frequency and magnitude of wet and above-normal years. Fewer wet years under future climate conditions could reduce recharge opportunities.
- **Evapotranspiration drives consumptive use regardless of hydrologic condition:** ET remains the largest outflow component in nearly all years. This means that even when precipitation declines, consumptive use does not decline proportionally, increasing stress on stored supplies.
- **System throughput expands and contracts with climate:** In wet years, total inflows and outflows both increase with more water moves through the system. In drought years, the total "size" of the water budget contracts, but fixed demands remain, tightening the balance.
- **Resilience is conditional:** Historically, the land system has remained broadly balanced over time, with inflows roughly matching outflows. However, this balance is achieved through the interplay of wet-year recharge and dry-year groundwater reliance. If drought frequency increases or recharge windows shorten, that balance could erode.

5.3 Surface Water System

The historical surface water budget shows that stream outflow leaving the basin represents the dominant fate of surface water inflows. In most years, total inflows to the surface water system, comprised primarily of surface runoff, baseflow, and upstream stream inflows, are closely matched by total outflows. Within that balance, stream outflow consistently accounts for the largest share.

On average, roughly two-thirds to three-quarters of total surface water inflows ultimately leave the basin as stream outflow to downstream receiving waters. In wet years, when runoff and baseflow increase substantially, stream outflow increases proportionally and may represent an even larger share of total inflows. In dry years, total inflows shrink significantly, but stream outflow remains the primary outflow component, although its relative share may decline slightly as fixed obligations such as environmental flows and diversions represent a larger percentage of the reduced supply.

Storage gains and losses vary from year to year. Wet years show significant reservoir storage gains as inflows exceed releases. Dry years show storage drawdown as reservoirs are used to meet downstream demands and environmental requirements. Therefore, reservoir operations serve as a balancing mechanism between wet and dry periods.

Outflow components, other than streamflow outflows, are comparatively stable, including environmental flows (minimum instream and mitigation releases), urban surface water diversions, reservoir evaporation, and streamflow losses. These components do not fluctuate as dramatically as natural inflows. Environmental flows are driven by regulatory requirements. Urban diversions reflect steady municipal demand. Evaporation reflects reservoir surface area rather than precipitation variability. During drought years, these steady obligations represent a larger proportion of the total available supply (i.e., as inflows shrink, fixed requirements consume a greater share of the system).

5.4 Groundwater System

Groundwater inflows are primarily driven by DP from the land system, supplemented by streamflow gains and subsurface inflows from adjacent areas. Recharge varies significantly from year to year, increasing sharply in wet years when precipitation and runoff are abundant and declining during drought periods. In contrast, groundwater outflows, which are dominated by agricultural pumping, remain comparatively steady and often increase during dry years when surface water supplies are reduced. Urban pumping represents a smaller, more stable portion of total withdrawals.

As a result, groundwater storage tends to rise in wet and above-normal years and decline during extended dry periods. This cyclical pattern highlights the role of groundwater as a buffering system that compensates for climate variability, absorbing excess water in wet years and supplying additional water during drought. Long-term sustainability therefore depends on the frequency and magnitude of recharge years relative to sustained pumping demands.

5.5 Key Findings

- Precipitation variability drives runoff, recharge, and overall system performance. Planning assumptions must account for increasing hydrologic volatility.
- The American River basin is significant contributor of surface flows to the downstream areas via the Sacramento River and the Delta, with most inflow leaving as stream outflow. Therefore, local resilience is not constrained by total annual volume but depends on storage and timing.
- Storage gains in wet years and drawdown in dry years highlight the importance of flexible, adaptive reservoir management.
- Evapotranspiration and human demands do not decline proportionally during drought, increasing stress on stored supplies.
- Environmental flow requirements and steady municipal demands consume a larger share of reduced supplies in dry years.
- Most aquifer replenishment occurs in wet and above-normal years. Policies that capture and store excess water during these periods are critical.
- Long-term balance depends on sufficient recharge years. A shift toward more frequent drought could erode historical stability.

5.6 Historical Water Budgets

Figures 5-1 through 5-4 present water budgets between water years 1979 through 2019 for the land, surface water, and groundwater systems, as well as total inflows and outflows across the RWA WRP planning area. Water budgets for individual sub-regions within the planning area as well as extended time frames (beyond 40 years) can be viewed in the companion spreadsheet tool for this memorandum. Note that in some cases, the parameters shown in these figures have been consolidated or adjusted for simplicity or insight into specific components (e.g., evapotranspiration represents the sum of evapotranspiration and evaporative conveyance losses). Additionally, parameters that represent inflows and outflows are denoted by [I] and [O] in the legend, respectively.

Figure 5-1. RWA WRP Total Historical Surface Water System Budget between Water Years 1979-2019

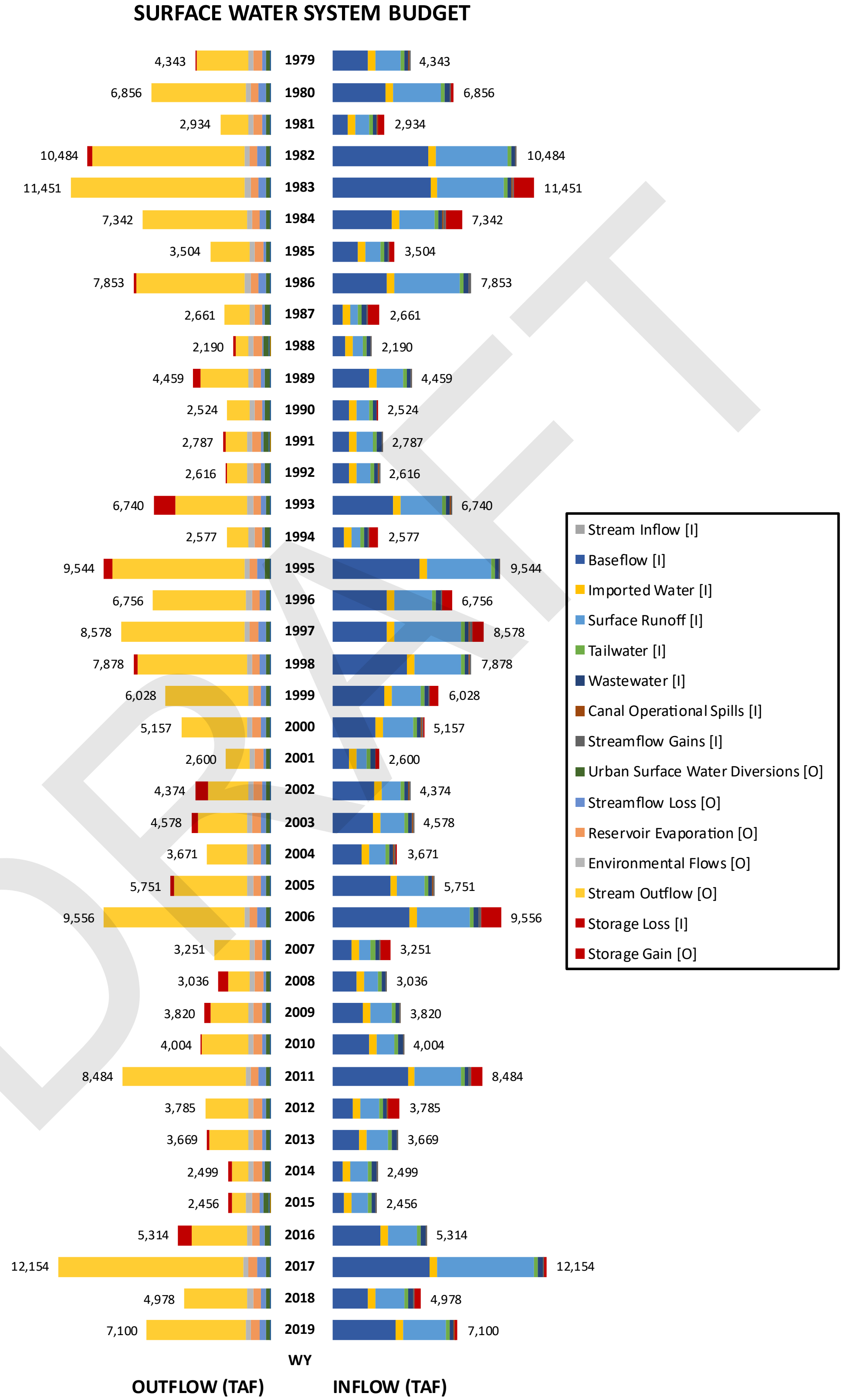


Figure 5-2. RWA WRP Total Historical Land System Water Budget between Water Years 1979-2019

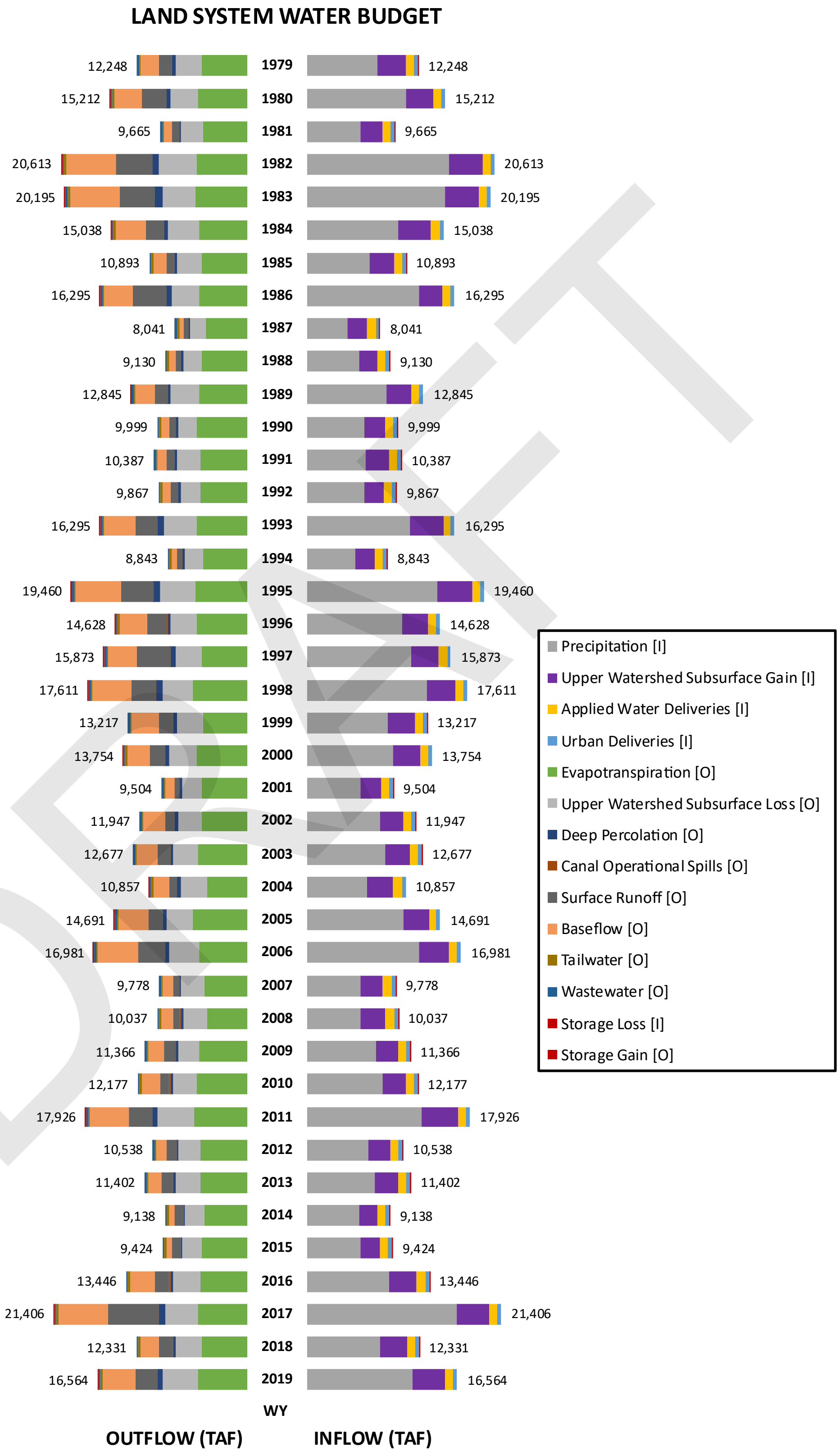


Figure 5-3. RWA WRP Total Historical Groundwater System Budget between Water Years 1979-2019

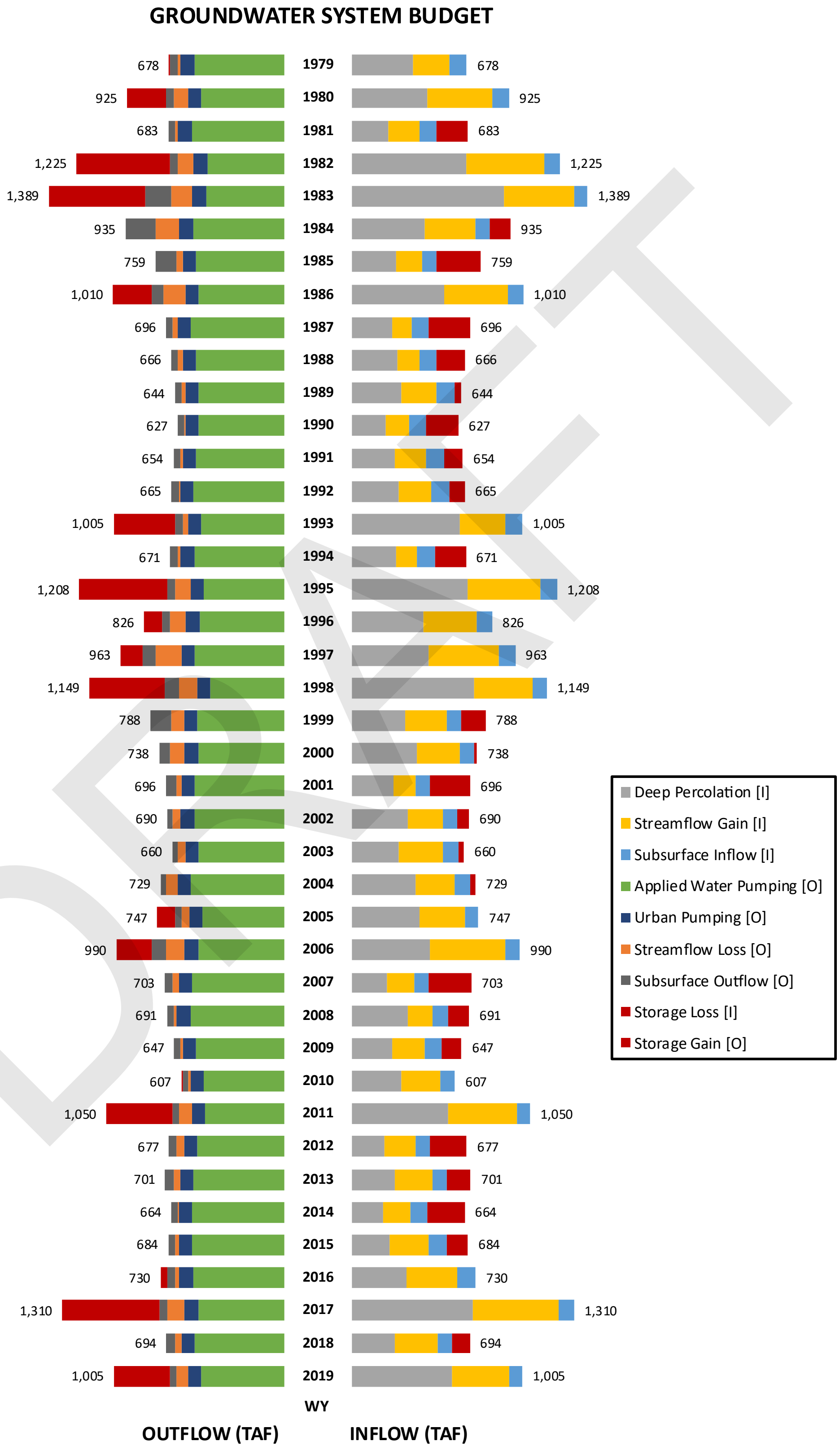
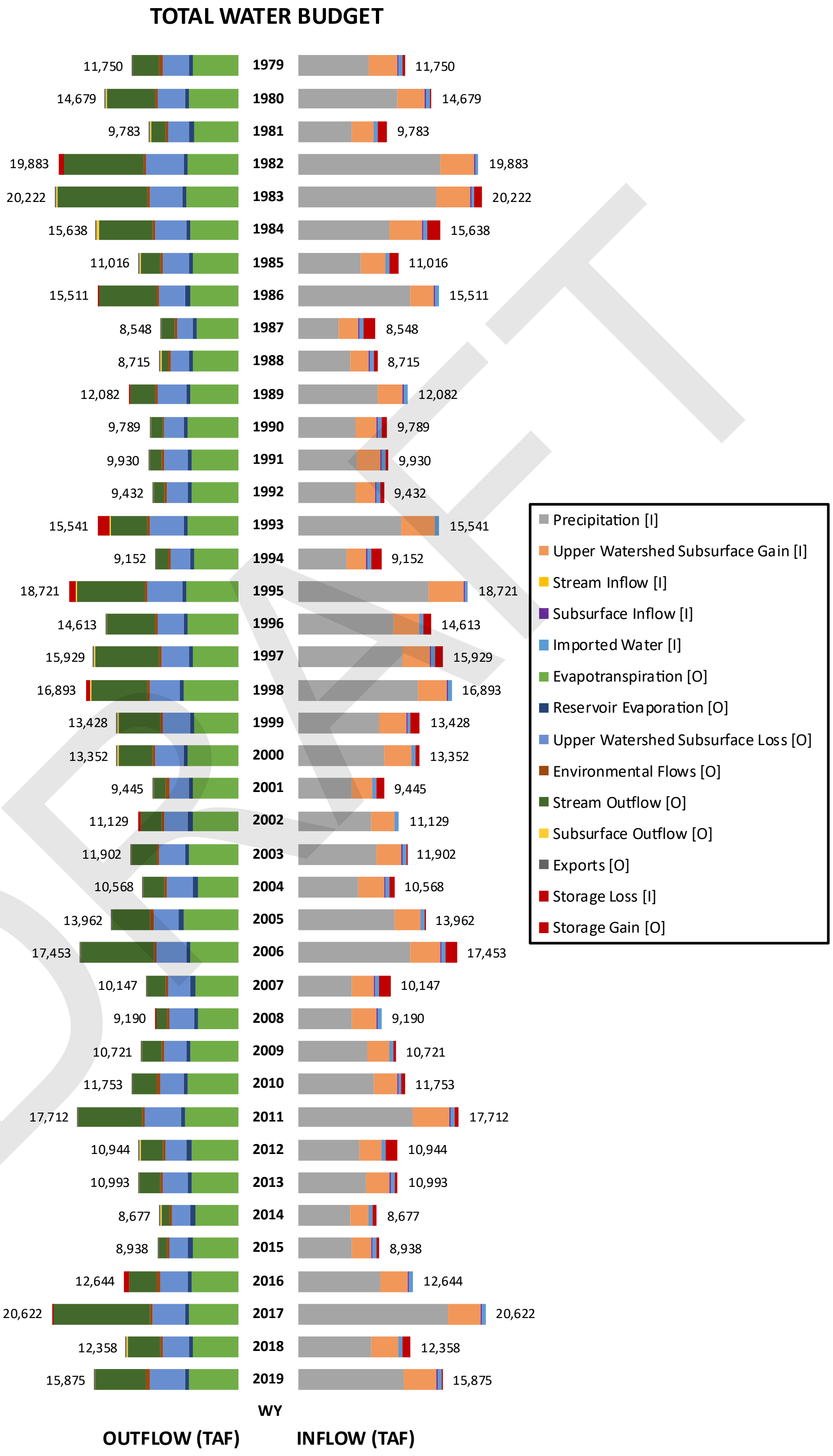


Figure 5-4. RWA WRP Total Historical Water Budget between Water Years 1979-2019



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Attachment A: Tabulated Historical Water Budget Results

Introduction

This attachment provides tabulated water budget results for Figures 5-1 through 5-4. Results are presented in units of thousand acre-feet (TAF) for individual water budget components and are provided for each water year between 1979 through 2019. Tables for inflows and outflows are provided separately for the surface water, land, and groundwater systems as well as total inflows and outflows across the Regional Water Authority (RWA) Watersheds Resilience Pilot. Additional outputs and extended timeseries are provided in the accompanying spreadsheet.

Caution should be taken when using historical water budget results due to the limitations described in Section 3. Results are best suited for evaluating trends in historical hydrologic patterns rather than determining the exact volumes of specific water budget components. It is likely that water budget results differ from real-world observations in several places.

Surface Water System

Table A-1. Total Historical Surface Water System Budget Inflows between Water Years 1979-2019 (TAF)

Water Year	Baseflow	Imported Water	Surface Runoff	Tailwater	Wastewater	Canal Operational Spills	Streamflow Gains	Storage Loss
1979	1985	424	1439	218	231	29	17	0
1980	3020	404	2751	215	231	28	82	126
1981	820	432	815	219	231	30	16	371
1982	5453	392	4080	211	231	27	90	0
1983	5560	395	3783	211	231	27	127	1117
1984	3347	426	2020	218	231	30	138	932
1985	1428	420	843	218	231	29	37	298
1986	3061	415	3769	219	231	29	130	0
1987	517	431	491	220	231	30	31	710
1988	710	418	559	215	231	29	28	0
1989	2077	414	1471	216	231	28	22	0
1990	910	415	711	215	231	28	7	7
1991	940	421	939	215	231	29	12	0
1992	895	429	803	219	231	30	9	0
1993	3421	406	2408	214	231	28	32	0
1994	598	427	504	218	231	30	17	552
1995	4930	399	3653	212	231	27	92	0
1996	3054	415	2200	215	231	29	97	516

Water Year	Baseflow	Imported Water	Surface Runoff	Tailwater	Wastewater	Canal Operational Spills	Streamflow Gains	Storage Loss
1997	3079	419	3800	217	231	29	147	656
1998	4239	387	2677	211	231	26	108	0
1999	2944	412	1611	217	231	28	79	507
2000	2424	413	1724	217	231	28	88	31
2001	893	424	629	218	231	29	28	148
2002	2335	424	1093	217	231	30	44	0
2003	2286	411	1363	214	231	28	46	0
2004	1661	430	900	221	231	30	64	135
2005	3256	405	1573	213	231	28	46	0
2006	4350	417	3063	214	231	29	107	1145
2007	1048	434	679	221	231	30	38	570
2008	1329	433	772	219	231	30	22	0
2009	1727	422	1182	216	231	29	12	0
2010	2083	399	1039	212	231	27	13	0
2011	4252	398	2639	211	231	27	74	653
2012	1149	424	1077	214	231	29	39	622
2013	1475	426	1250	219	231	30	40	0
2014	542	435	1039	219	231	30	3	0
2015	639	430	890	219	231	30	17	0
2016	2680	428	1704	218	231	30	24	0
2017	5501	414	5559	216	231	29	101	104

Water Year	Baseflow	Imported Water	Surface Runoff	Tailwater	Wastewater	Canal Operational Spills	Streamflow Gains	Storage Loss
2018	2018	424	1656	216	231	29	41	362
2019	3570	411	2443	216	231	28	66	135

Table A-2. Total Historical Surface Water System Budget Outflows between Water Years 1979-2019 (TAF)

Water Year	Urban Surface Water Diversions	Streamflow Loss	Reservoir Evaporation	Environmental Flows	Stream Outflow	Storage Gain
1979	255	214	474	309	2931	64
1980	255	385	459	310	5359	0
1981	255	179	487	285	1632	0
1982	255	456	453	289	8714	232
1983	255	418	446	309	9936	0
1984	255	296	476	309	5910	0
1985	255	152	468	307	2229	0
1986	255	380	473	309	6179	167
1987	255	117	487	296	1371	0
1988	255	128	478	289	688	161
1989	255	207	474	289	2707	411
1990	255	138	478	278	1243	0
1991	255	185	464	288	1258	153
1992	255	192	495	300	1148	100

Water Year	Urban Surface Water Diversions	Streamflow Loss	Reservoir Evaporation	Environmental Flows	Stream Outflow	Storage Gain
1993	255	265	465	290	4127	1249
1994	255	126	483	296	1279	0
1995	255	429	444	290	7545	453
1996	255	315	484	310	5302	0
1997	255	414	481	310	7024	0
1998	255	347	434	309	6187	262
1999	255	245	453	310	4673	0
2000	255	259	483	309	3758	0
2001	255	129	482	308	1331	0
2002	255	202	480	309	2279	754
2003	255	264	470	310	2805	382
2004	255	226	493	308	2291	0
2005	255	270	457	309	4172	200
2006	255	449	467	309	7983	0
2007	255	158	483	286	1971	0
2008	255	140	479	289	1227	548
2009	255	188	476	309	2156	343
2010	255	227	448	309	2662	15
2011	255	405	441	309	6986	0
2012	255	191	472	310	2464	0
2013	255	223	480	292	2220	105

Water Year	Urban Surface Water Diversions	Streamflow Loss	Reservoir Evaporation	Environmental Flows	Stream Outflow	Storage Gain
2014	255	167	487	276	935	240
2015	255	232	478	305	832	177
2016	255	301	483	289	3098	785
2017	255	507	466	309	10524	0
2018	255	246	478	307	3598	0
2019	255	336	466	310	5643	0

Land System

Table A-3. Total Historical Land System Budget Inflows between Water Years 1979-2019 (TAF)

Water Year	Precipitation	Upper Watershed Subsurface Gain	Applied Water Deliveries	Urban Deliveries	Storage Loss
1979	7751	3163	898	427	9
1980	10950	3002	833	427	0
1981	5976	2310	921	427	31
1982	15614	3787	786	427	0
1983	15209	3762	797	427	0
1984	10118	3585	908	427	0
1985	6856	2720	880	427	11
1986	12329	2680	860	427	0
1987	4524	2110	923	427	57
1988	5715	2085	878	427	26
1989	8753	2807	858	427	0
1990	6270	2371	858	427	74
1991	6428	2634	883	427	15
1992	6332	2175	908	427	25
1993	11345	3688	836	427	0
1994	5374	2108	902	427	32
1995	14436	3788	810	427	0
1996	10481	2864	856	427	0

Water Year	Precipitation	Upper Watershed Subsurface Gain	Applied Water Deliveries	Urban Deliveries	Storage Loss
1997	11548	3008	890	427	0
1998	13276	3149	760	427	0
1999	8914	3007	863	427	6
2000	9423	3041	863	427	0
2001	5909	2232	896	427	40
2002	8013	2602	900	427	6
2003	8653	2723	855	427	20
2004	6636	2869	925	427	0
2005	10652	2787	826	427	0
2006	12425	3261	868	427	0
2007	5948	2449	922	427	32
2008	5937	2723	931	427	19
2009	7621	2414	883	427	22
2010	8304	2615	811	427	20
2011	12717	3978	804	427	0
2012	6816	2375	879	427	41
2013	7458	2610	902	427	6
2014	5722	2017	923	427	49
2015	5881	2158	918	427	40
2016	9093	3013	911	427	2

Water Year	Precipitation	Upper Watershed Subsurface Gain	Applied Water Deliveries	Urban Deliveries	Storage Loss
2017	16556	3560	862	427	0
2018	8053	2951	893	427	7
2019	11584	3710	843	427	0

Table A-4. Total Historical Land System Budget Outflows between Water Years 1979-2019 (TAF)

Water Year	Evapotranspiration	Upper Watershed Subsurface Loss	Deep Percolation	Canal Operational Spills	Surface Runoff	Baseflow	Tailwater	Wastewater	Storage Gain
1979	5037	2948	360	29	1439	1985	218	231	0
1980	5484	3014	444	28	2751	3020	215	231	26
1981	4969	2363	217	30	815	820	219	231	0
1982	5666	4163	678	27	4080	5453	211	231	105
1983	5832	3548	895	27	3783	5560	211	231	110
1984	5388	3372	430	30	2020	3347	218	231	2
1985	5072	2813	260	29	843	1428	218	231	0
1986	5436	2957	543	29	3769	3061	219	231	51
1987	4599	1714	239	30	491	517	220	231	0
1988	5028	2090	269	29	559	710	215	231	0
1989	5378	3111	294	28	1471	2077	216	231	38

Water Year	Evapotranspiration	Upper Watershed Subsurface Loss	Deep Percolation	Canal Operational Spills	Surface Runoff	Baseflow	Tailwater	Wastewater	Storage Gain
1990	5602	2104	198	28	711	910	215	231	0
1991	5169	2613	251	29	939	940	215	231	0
1992	5241	2172	276	30	803	895	219	231	0
1993	5602	3690	638	28	2408	3421	214	231	63
1994	4887	2117	258	30	504	598	218	231	0
1995	5858	3791	680	27	3653	4930	212	231	78
1996	5616	2855	421	29	2200	3054	215	231	8
1997	5031	2998	456	29	3800	3079	217	231	32
1998	6152	3267	720	26	2677	4239	211	231	89
1999	4978	2890	318	28	1611	2944	217	231	0
2000	5653	3081	380	28	1724	2424	217	231	15
2001	5048	2211	244	29	629	893	218	231	0
2002	5138	2573	331	29	1093	2335	217	231	0
2003	5543	2737	276	28	1363	2286	214	231	0
2004	4577	2859	378	30	900	1661	221	231	1
2005	6154	2833	397	28	1573	3256	213	231	6
2006	5392	3216	458	29	3063	4350	214	231	28
2007	4868	2492	209	30	679	1048	221	231	0
2008	4455	2670	331	30	772	1329	219	231	0
2009	5319	2421	241	29	1182	1727	216	231	0

Water Year	Evapotranspiration	Upper Watershed Subsurface Loss	Deep Percolation	Canal Operational Spills	Surface Runoff	Baseflow	Tailwater	Wastewater	Storage Gain
2010	5672	2623	292	27	1039	2083	212	231	0
2011	5937	3999	567	27	2639	4252	211	231	63
2012	5302	2347	189	29	1077	1149	214	231	0
2013	5253	2695	250	30	1250	1475	219	231	0
2014	4867	2028	181	30	1039	542	219	231	0
2015	5132	2064	219	30	890	639	219	231	0
2016	5253	3012	319	30	1704	2680	218	231	0
2017	5452	3623	711	29	5559	5501	216	231	85
2018	5037	2888	256	29	1656	2018	216	231	0
2019	5520	3892	588	28	2443	3570	216	231	76

Groundwater System

Table A-5. Total Historical Groundwater System Budget Inflows between Water Years 1979-2019 (TAF)

Water Year	Deep Percolation	Streamflow Gain	Subsurface Inflow	Storage Loss
1979	360	214	104	0
1980	444	385	96	0
1981	217	179	100	187
1982	678	456	90	0
1983	895	418	76	0
1984	430	296	83	126
1985	260	152	87	259
1986	543	380	88	0
1987	239	117	97	244
1988	269	128	103	166
1989	294	207	108	36
1990	198	138	100	191
1991	251	185	111	107
1992	276	192	108	88
1993	638	265	102	0
1994	258	126	103	184
1995	680	429	99	0
1996	421	315	90	0
1997	456	414	94	0

Water Year	Deep Percolation	Streamflow Gain	Subsurface Inflow	Storage Loss
1998	720	347	82	0
1999	318	245	82	143
2000	380	259	83	16
2001	244	129	85	238
2002	331	202	90	67
2003	276	264	88	32
2004	378	226	90	35
2005	397	270	80	0
2006	458	449	82	0
2007	209	158	85	252
2008	331	140	96	123
2009	241	188	100	119
2010	292	227	89	0
2011	567	405	78	0
2012	189	191	77	221
2013	250	223	86	142
2014	181	167	98	218
2015	219	232	109	124
2016	319	301	110	0
2017	711	507	92	0
2018	256	246	86	106
2019	588	336	81	0

Table A-6. Total Historical Groundwater System Budget Outflows between Water Years 1979-2019 (TAF)

Water Year	Applied Water Pumping	Urban Pumping	Streamflow Loss	Subsurface Outflow	Storage Gain
1979	531	79	17	47	4
1980	487	79	82	51	227
1981	544	79	16	43	0
1982	454	79	90	48	553
1983	462	79	127	148	573
1984	539	79	138	179	0
1985	518	79	37	124	0
1986	503	79	130	67	231
1987	547	79	31	39	0
1988	517	79	28	40	0
1989	502	79	22	41	0
1990	502	79	7	39	0
1991	519	79	12	43	0
1992	535	79	9	42	0
1993	488	79	32	43	363
1994	531	79	17	44	0
1995	471	79	92	43	523
1996	500	79	97	43	106
1997	528	79	147	81	128
1998	435	79	108	84	443

Water Year	Applied Water Pumping	Urban Pumping	Streamflow Loss	Subsurface Outflow	Storage Gain
1999	509	79	79	120	0
2000	507	79	88	63	0
2001	528	79	28	61	0
2002	531	79	44	35	0
2003	501	79	46	34	0
2004	550	79	64	35	0
2005	480	79	46	34	108
2006	507	79	107	83	213
2007	543	79	38	43	0
2008	552	79	22	37	0
2009	517	79	12	38	0
2010	471	79	13	36	7
2011	466	79	74	36	396
2012	513	79	39	46	0
2013	532	79	40	49	0
2014	544	79	3	38	0
2015	543	79	17	44	0
2016	538	79	24	46	43
2017	506	79	101	45	579
2018	525	79	41	48	0
2019	490	79	66	41	329

Total Water Budget

Table A-7. Total Historical Water Budget Inflows between Water Years 1979-2019 (TAF)

Water Year	Precipitation	Upper Watershed Subsurface Gain	Subsurface Inflow	Imported Water	Storage Loss
1979	7751	3163	104	424	310
1980	10950	3002	96	404	226
1981	5976	2310	100	432	965
1982	15614	3787	90	392	0
1983	15209	3762	76	395	779
1984	10118	3585	83	426	1426
1985	6856	2720	87	420	934
1986	12329	2680	88	415	0
1987	4524	2110	97	431	1386
1988	5715	2085	103	418	394
1989	8753	2807	108	414	0
1990	6270	2371	100	415	634
1991	6428	2634	111	421	336
1992	6332	2175	108	429	387
1993	11345	3688	102	406	0
1994	5374	2108	103	427	1139
1995	14436	3788	99	399	0
1996	10481	2864	90	415	762

Water Year	Precipitation	Upper Watershed Subsurface Gain	Subsurface Inflow	Imported Water	Storage Loss
1997	11548	3008	94	419	860
1998	13276	3149	82	387	0
1999	8914	3007	82	412	1014
2000	9423	3041	83	413	391
2001	5909	2232	85	424	795
2002	8013	2602	90	424	0
2003	8653	2723	88	411	28
2004	6636	2869	90	430	543
2005	10652	2787	80	405	39
2006	12425	3261	82	417	1267
2007	5948	2449	85	434	1231
2008	5937	2723	96	433	0
2009	7621	2414	100	422	165
2010	8304	2615	89	399	345
2011	12717	3978	78	398	541
2012	6816	2375	77	424	1252
2013	7458	2610	86	426	413
2014	5722	2017	98	435	405
2015	5881	2158	109	430	361
2016	9093	3013	110	428	0

Water Year	Precipitation	Upper Watershed Subsurface Gain	Subsurface Inflow	Imported Water	Storage Loss
2017	16556	3560	92	414	0
2018	8053	2951	86	424	844
2019	11584	3710	81	411	89

Table A-8. Total Historical Water Budget Outflows between Water Years 1979-2019 (TAF)

Water Year	Evapotranspiration	Reservoir Evaporation	Upper Watershed Subsurface Loss	Environmental Flows	Stream Outflow	Subsurface Outflow	Exports	Storage Gain
1979	5037	474	2948	309	2931	47	3	0
1980	5484	459	3014	310	5359	51	3	0
1981	4969	487	2363	285	1632	43	3	0
1982	5666	453	4163	289	8714	48	3	548
1983	5832	446	3548	309	9936	148	3	0
1984	5388	476	3372	309	5910	179	3	0
1985	5072	468	2813	307	2229	124	3	0
1986	5436	473	2957	309	6179	67	3	87
1987	4599	487	1714	296	1371	39	42	0
1988	5028	478	2090	289	688	40	101	0
1989	5378	474	3111	289	2707	41	28	53

Water Year	Evapotranspiration	Reservoir Evaporation	Upper Watershed Subsurface Loss	Environmental Flows	Stream Outflow	Subsurface Outflow	Exports	Storage Gain
1990	5602	478	2104	278	1243	39	45	0
1991	5169	464	2613	288	1258	43	94	0
1992	5241	495	2172	300	1148	42	35	0
1993	5602	465	3690	290	4127	43	3	1321
1994	4887	483	2117	296	1279	44	45	0
1995	5858	444	3791	290	7545	43	45	706
1996	5616	484	2855	310	5302	43	3	0
1997	5031	481	2998	310	7024	81	3	0
1998	6152	434	3267	309	6187	84	3	456
1999	4978	453	2890	310	4673	120	3	0
2000	5653	483	3081	309	3758	63	3	0
2001	5048	482	2211	308	1331	61	3	0
2002	5138	480	2573	309	2279	35	3	312
2003	5543	470	2737	310	2805	34	4	0
2004	4577	493	2859	308	2291	35	3	0
2005	6154	457	2833	309	4172	34	3	0
2006	5392	467	3216	309	7983	83	3	0
2007	4868	483	2492	286	1971	43	3	0
2008	4455	479	2670	289	1227	37	3	30
2009	5319	476	2421	309	2156	38	3	0

Water Year	Evapotranspiration	Reservoir Evaporation	Upper Watershed Subsurface Loss	Environmental Flows	Stream Outflow	Subsurface Outflow	Exports	Storage Gain
2010	5672	448	2623	309	2662	36	3	0
2011	5937	441	3999	309	6986	36	3	0
2012	5302	472	2347	310	2464	46	3	0
2013	5253	480	2695	292	2220	49	3	0
2014	4867	487	2028	276	935	38	45	0
2015	5132	478	2064	305	832	44	83	0
2016	5253	483	3012	289	3098	46	11	454
2017	5452	466	3623	309	10524	45	3	200
2018	5037	478	2888	307	3598	48	3	0
2019	5520	466	3892	310	5643	41	3	0