Draft American River Watershed Resilience Pilot Water Budget

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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 American River Watershed Resilience Pilot (ARWRP). This 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. This water budget was developed to be consistent with guidance from the non-modeling approach outlined in the *Handbook for Water Budget Development* (DWR 2020).

2. Data Sources

The data sources used to develop the water budget for the ARWRP are described in this section. The water budget parameters that each of these data sources informed are summarized in Table 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 bullets. 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 used to characterize water budget components for lower watershed areas within the ARWRP planning boundary.
- **CalSim 3 Report**: CalSim 3 has been collaboratively developed by the California Department of Water Resources (DWR) and US Bureau of Reclamation (USBR) 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, additional land use and demand information, groundwater pumping, 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.

- **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.
- **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.
- **Cosumnes-South American-North American (CoSANA) Integrated Water Resources Model**: The CoSANA model is built on the Integrated Water Flow Model (IWFM) framework and has been used to support Groundwater Sustainability Agency (GSA) 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 several groundwater-specific components to both improve quantification and provide a basis for comparison between estimated values. Additional information related to comparisons are highlighted in Section 4.4.
- **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 was 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 is incorporated in this water budget.

Table 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	
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	
Inflow	▪ DCR Simulations	▪ Valley Floor Areas	North American and South American regions receive 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 deep percolation components
Tailwater	▪ CalSimHydro	▪ Valley Floor Areas	Applied water return flow
Urban Demand	▪ CalSimHydro	▪ Valley Floor Areas	Demands partitioned between surface water and groundwater components

Parameter	Data Sources	Geographic Area	Notes
Wastewater	- CalSimHydro	- Valley Floor Areas	Urban demand return flow
Deep Percolation	- CalSimHydro - CoSANA	- Valley Floor Areas	
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 to be consistent with the guidance included in DWR's *Handbook for Water Budget Development*. However, limitations of this water budget exist and are 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.
- Spatial coverage of available data does not extend across the entirety of the ARWRP 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. 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 ensure 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 that 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 ARWRP 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.

4. Methodology

The following subsections describe the approach used to develop the water budget spreadsheet tool for the ARWRP. 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 ARWRP 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. First, the Upper Coon-Upper Auburn and portions of the Lower Sacramento HUC-8 watersheds were merged to create the "North American" region. Second, the portions of the Lower Sacramento and Upper Mokelumne HUC-8 watersheds that overlap with the ARWRP planning boundary were merged to create the "South American" region. The North American, South

American, and Cosumnes groundwater basins were trimmed to align with the extent of the ARWRP 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 1 and Figure 2, respectively).

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

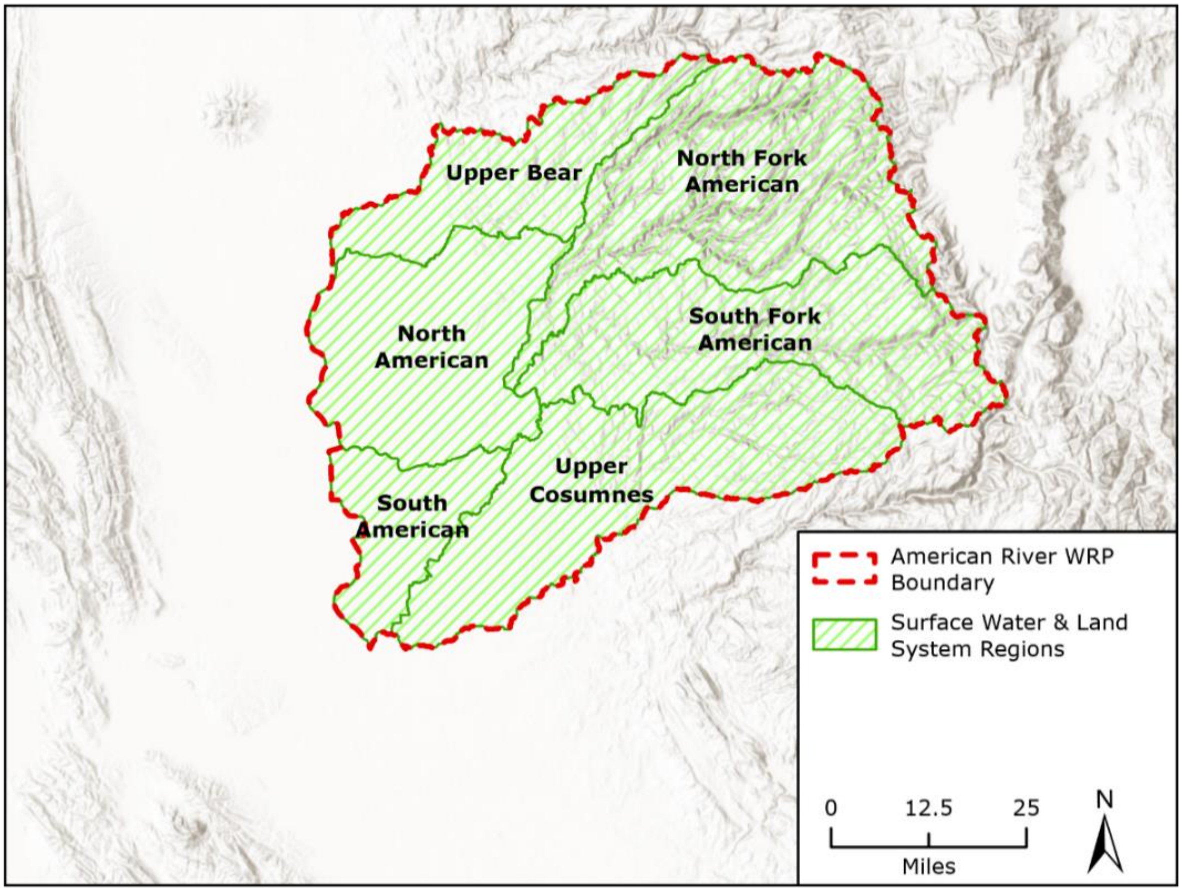
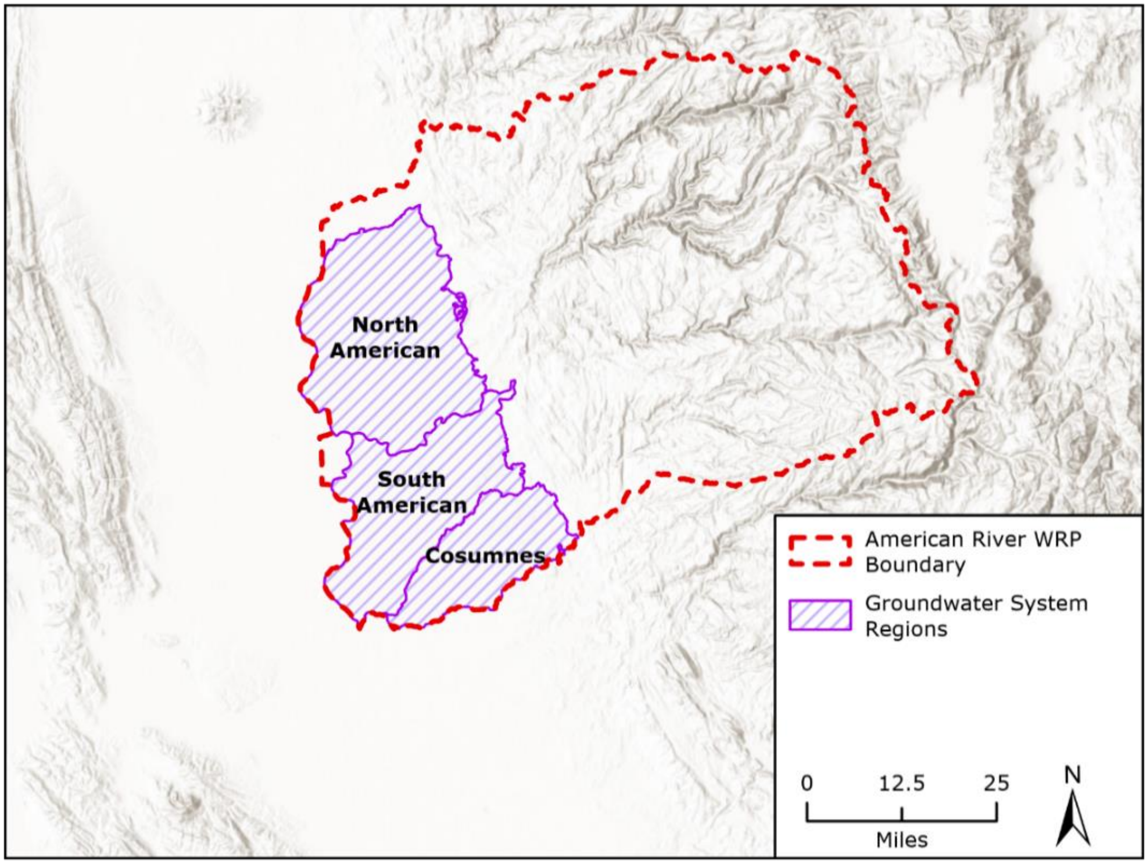


Figure 2. Overview of Groundwater System Water Budget Spatial Delineation



Polygons for CalSim 3 WBAs and upper watersheds were compiled to assess timeseries dataset coverage within the ARWRP planning boundary (Figure 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 and 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 ARWRP 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 3. CalSim 3 Water Budget Areas and Upper Watersheds

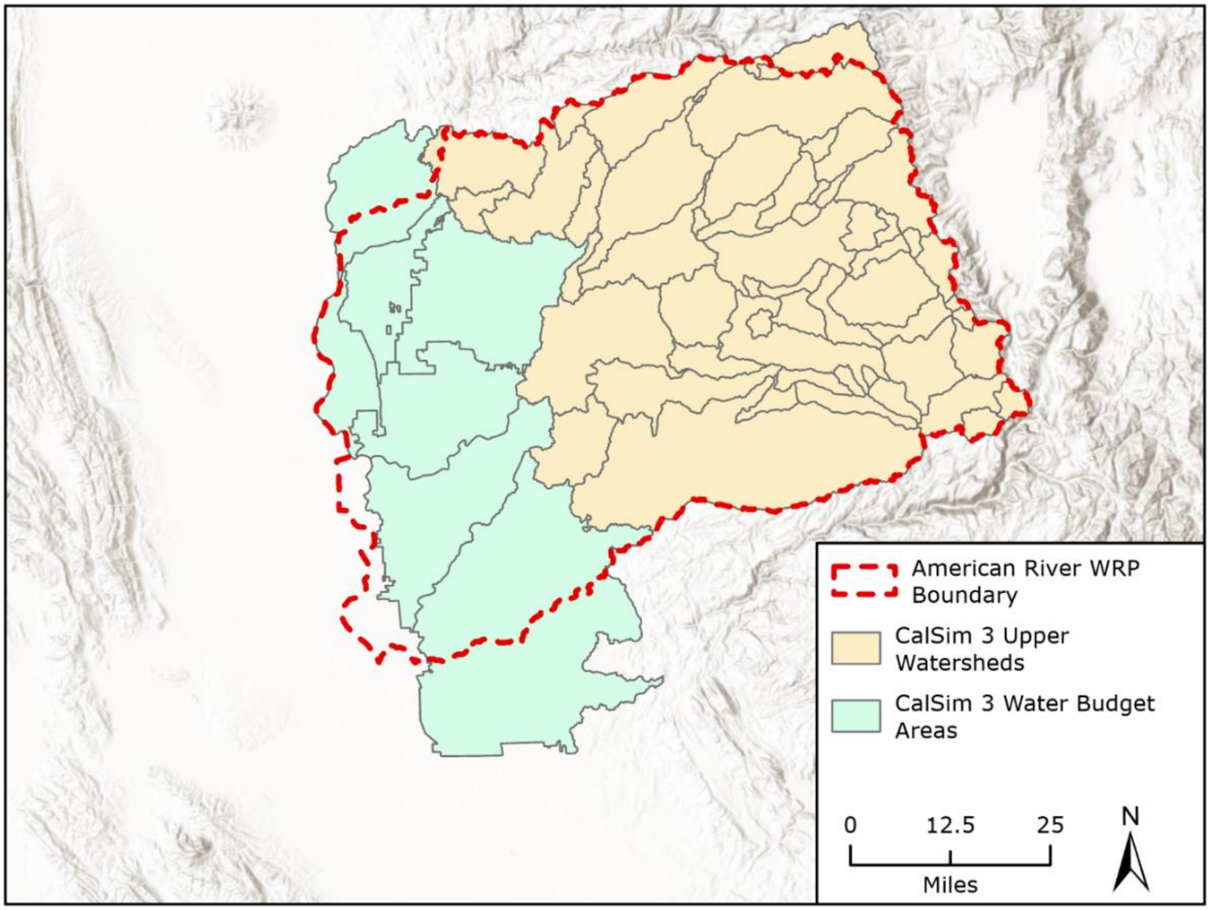


Figure 4. Alignment Between CalSim 3 Polygons and Water Budget Regions (Surface Water and Land)

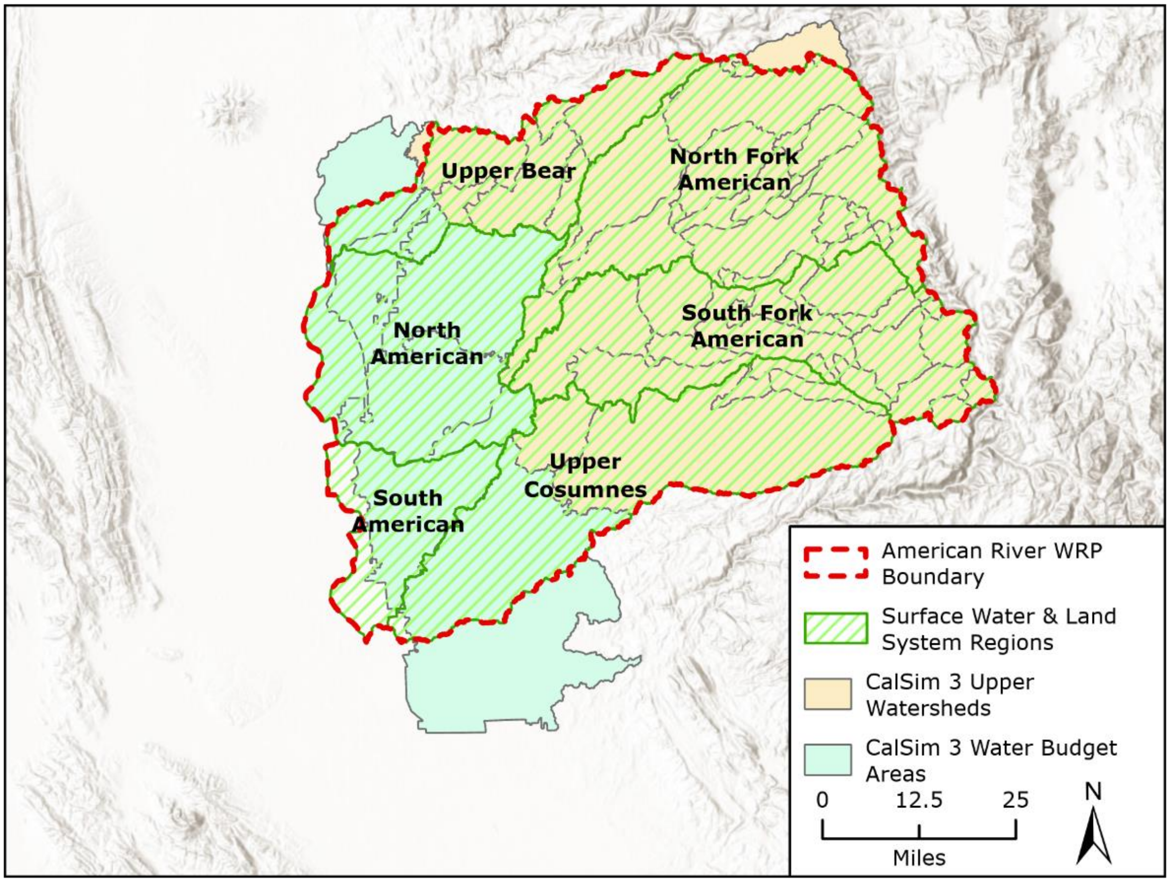
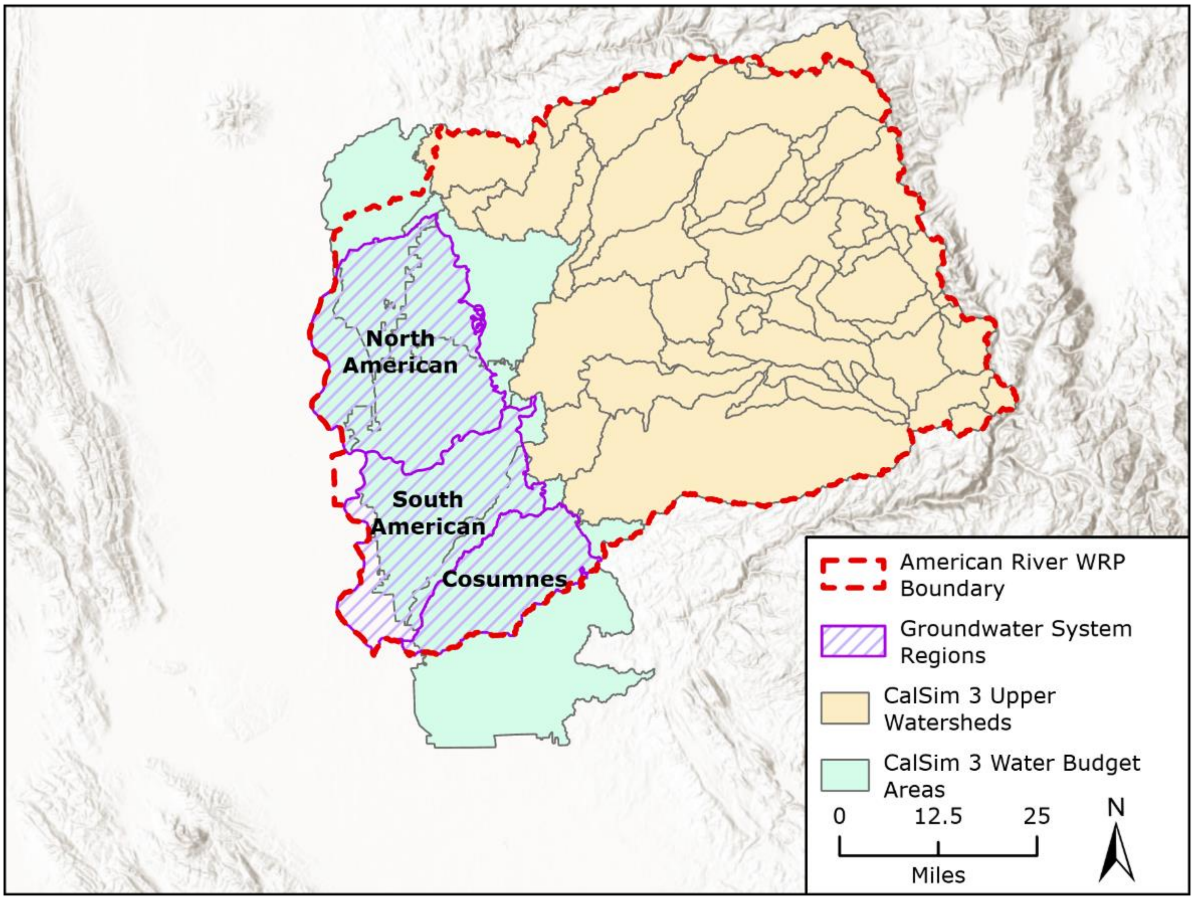


Figure 5. Alignment Between CalSim 3 Polygons and Water Budget Regions (Groundwater)



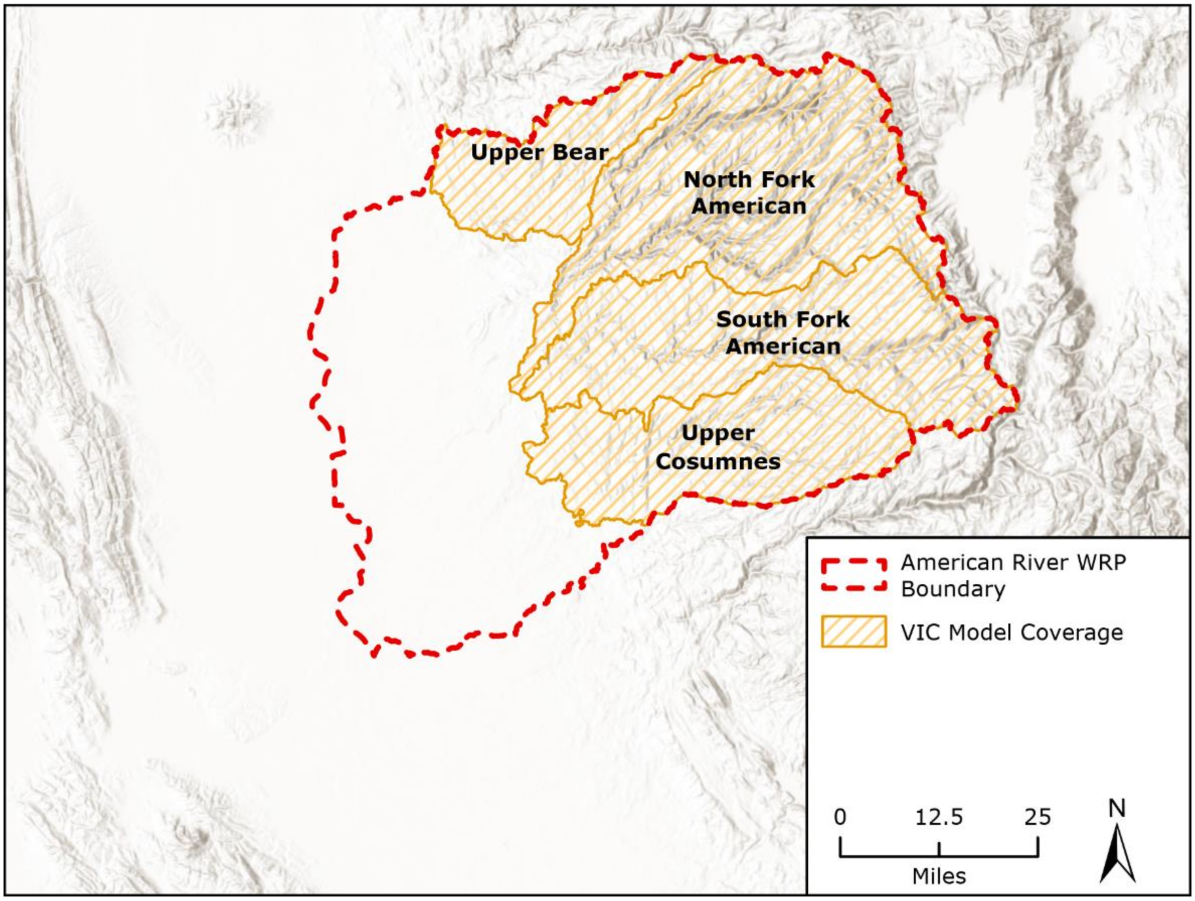
4.2 Upper Watershed Areas

The following subsections detail the approach used to characterize water budget components for upper watershed areas (yellow polygons on Figure 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 et 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 6.

Figure 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, 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 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. CalSim 3 reservoir evaporation monthly timeseries for the period of water years 1922 through 2021 were incorporated for the following reservoirs in upper watershed areas:

- 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)

4.2.6 Inflow

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

4.2.7 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.

4.2.8 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 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 above, 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 reservoir in the valley floor area: 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 ARWRP planning boundary were 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 ARWRP 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) and 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 ARWRP 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% deep percolation 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 and were therefore 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.

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

Deep percolation represents outflows from the surface water system into the groundwater system. Monthly deep percolation 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 deep percolation 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 ARWRP 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 (noting 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 1.1, 3.37, and 1.2 thousand acre-feet (TAF) per month, respectively.

As highlighted previously herein, CoSANA model outputs provide a more robust spatial representation of historical groundwater budgets within the ARWRP planning area. However, given that the variables are not derived from the same land system and surface water system components, there are some differences in estimated groundwater system variables. Further discussion on apparent differences between annual averages over the full period of available CoSANA outputs is included for each subbasin in the following bullets:

- 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.
    - **Deep Percolation**: Values are fairly consistent with CalSimHydro-based results, with only an 8 TAF annual average difference between the two approaches.
    - **Surface Water-Groundwater Interaction**: CalSim 3-based approach overestimates annual streamflow gains by 20 TAF, on average, compared to CoSANA outputs, but covers a larger spatial domain.
- South American Subbasin
    - **Groundwater Pumping**: 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 deep percolation outputs are 96 TAF higher, on average, between 1970 and 2019.
    - **Deep Percolation**: Annual CoSANA groundwater pumping outputs are 50 TAF higher, on average, between 1970 and 2019. Considerations noted above for groundwater pumping are relevant here.
    - **Surface Water-Groundwater Interaction**: Annual CoSANA net subsurface inflow outputs are 86 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.
  - **Deep Percolation**: Annual deep percolation 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 nearly identical to those estimated from the CalSim 3-based approach.

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:

- 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 Demand Diversions + Reservoir Evaporation + Streamflow Losses
- Land System
  - **Inflows**: Precipitation + Applied Water + Urban Demand
  - **Outflows**: Evapotranspiration + Surface Runoff (and Baseflow, where relevant) + Deep Percolation + Evaporative Conveyance Losses + Deep Percolation Conveyance Losses + Operational Spill Conveyance Losses + Lateral Flow Conveyance Losses + Tailwater + Wastewater
- Groundwater System
  - **Inflows**: Deep Percolation + Deep Percolation Conveyance Gains + Streamflow Gain
  - **Inflows (CoSANA Only)**: Deep Percolation + Streamflow Gains + Subsurface Inflow
  - **Outflows**: Applied Water Pumping + Urban Demand Pumping + Streamflow Loss
  - **Outflows (CoSANA Only)**: Total Groundwater Pumping + Streamflow Losses + Subsurface Outflow

5. Findings and Results

Figures7 through 10 present water budgets between water years 1981 through 2021 for the land, surface water, and groundwater systems, as well as total inflows and outflows across the ARWRP 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 the following 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. Pie charts that display annual averages of individual water budget components across the same period for each system are displayed in Figures 11 through 14.

Figure 7. ARWRP Total Historical Water Budget between Water Years 1981 to 2021

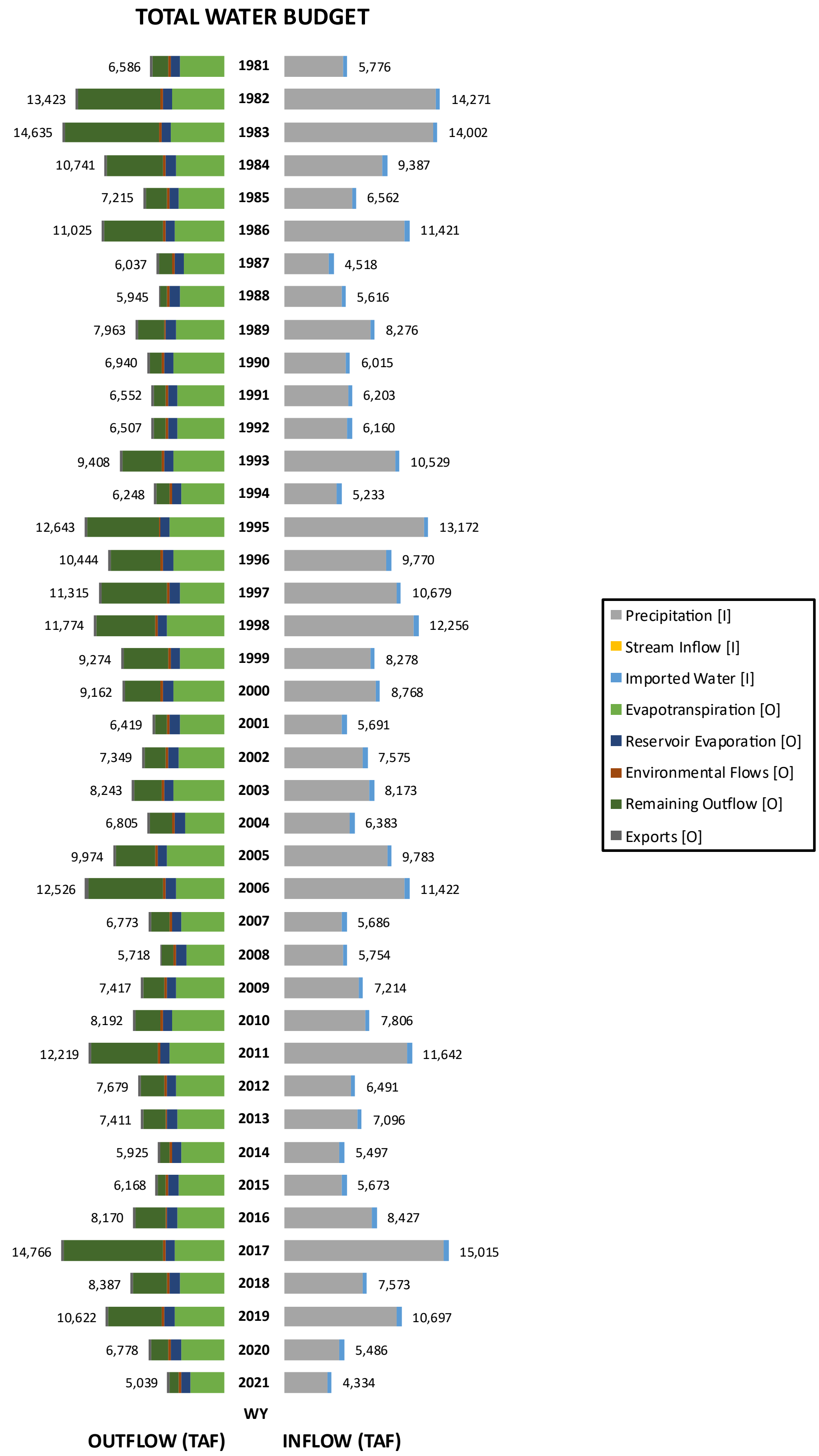


Figure 8. ARWRP Total Historical Surface Water System Budget between Water Years 1981 to 2021

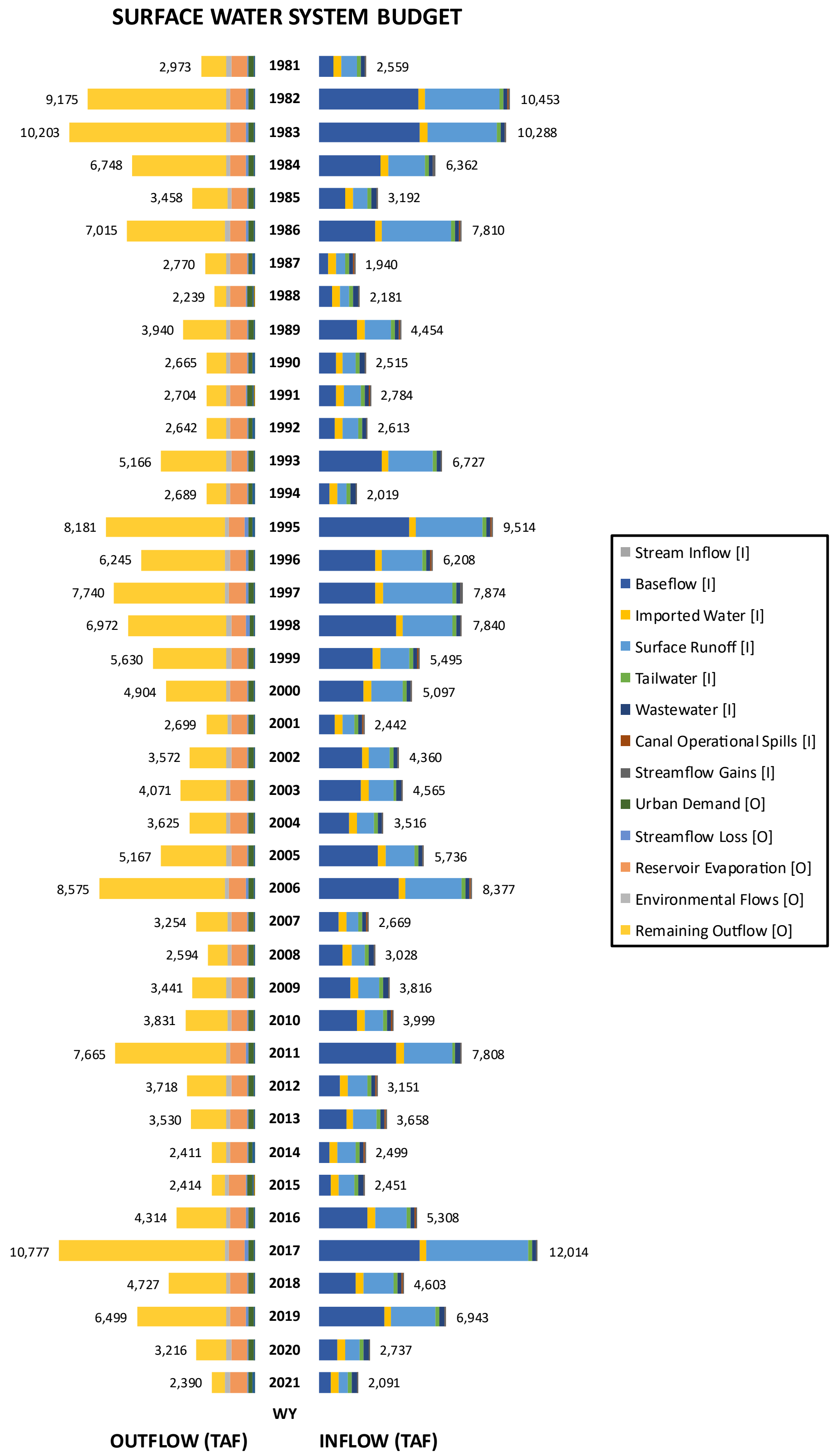


Figure 9. ARWRP Total Historical Land System Water Budget between Water Years 1981 to 2021

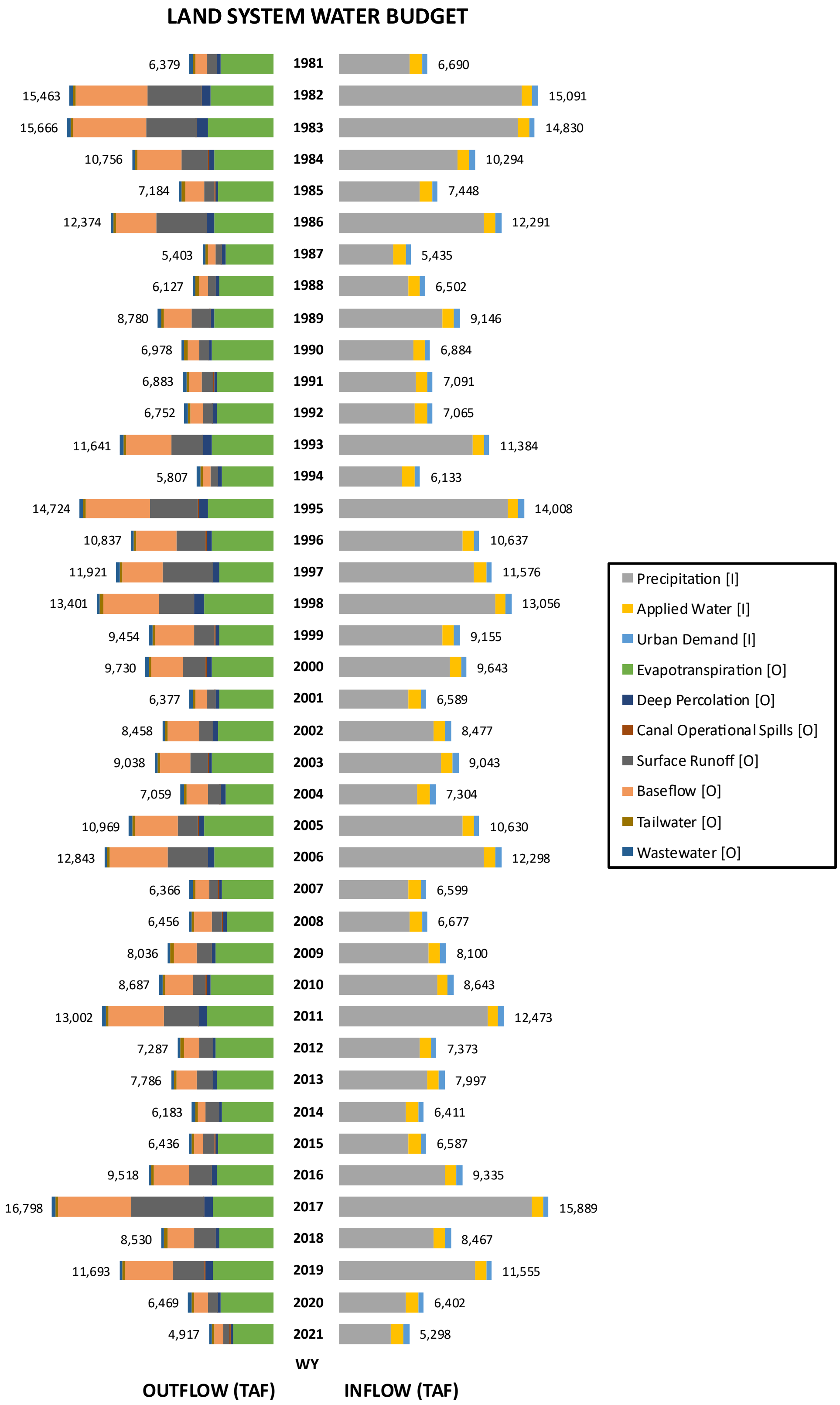


Figure 10. ARWRP Total Historical Groundwater System Budget between Water Years 1981 to 2021

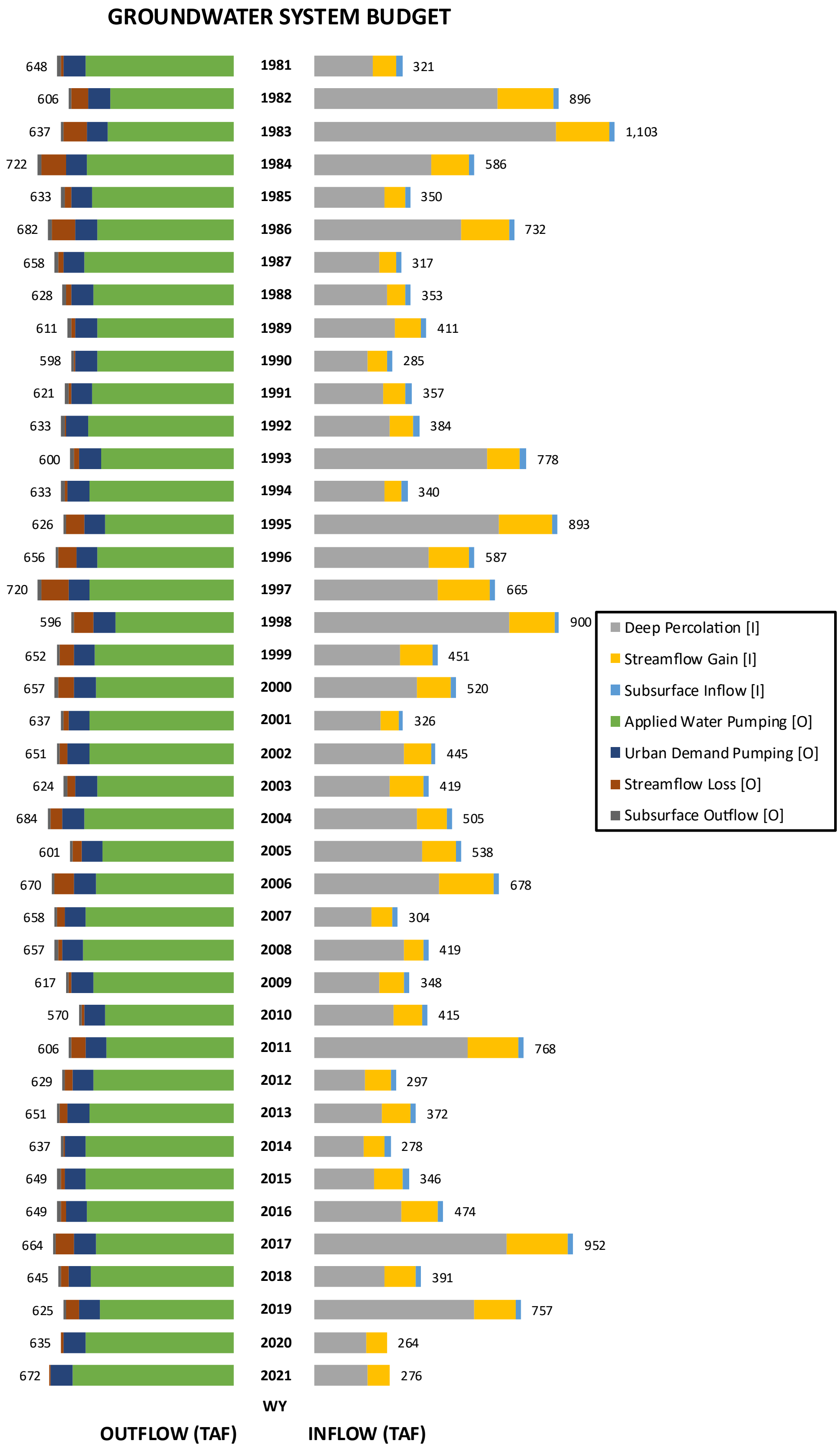


Figure 11. Annual Average Total Water Budget between Water Years 1981 to 2021 (TAF)

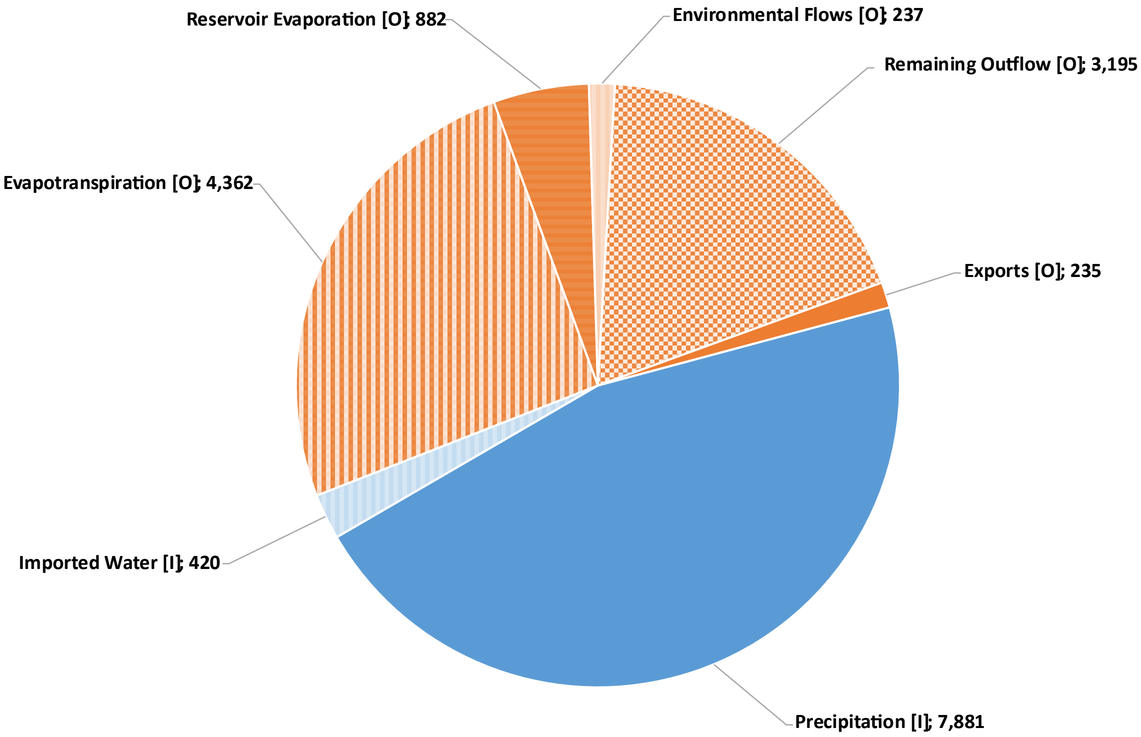


Figure 12. Annual Average Surface Water System Budget between Water Years 1981 to 2021 (TAF)

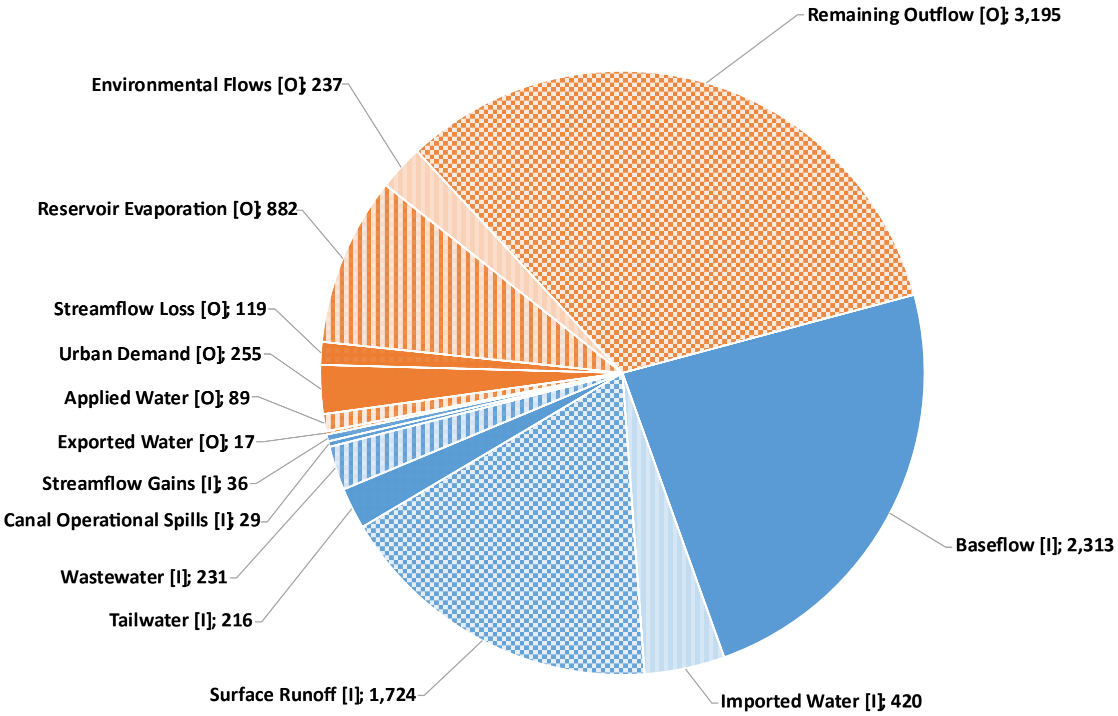


Figure 13. Annual Average Land System Water Budget between Water Years 1981 to 2021 (TAF)

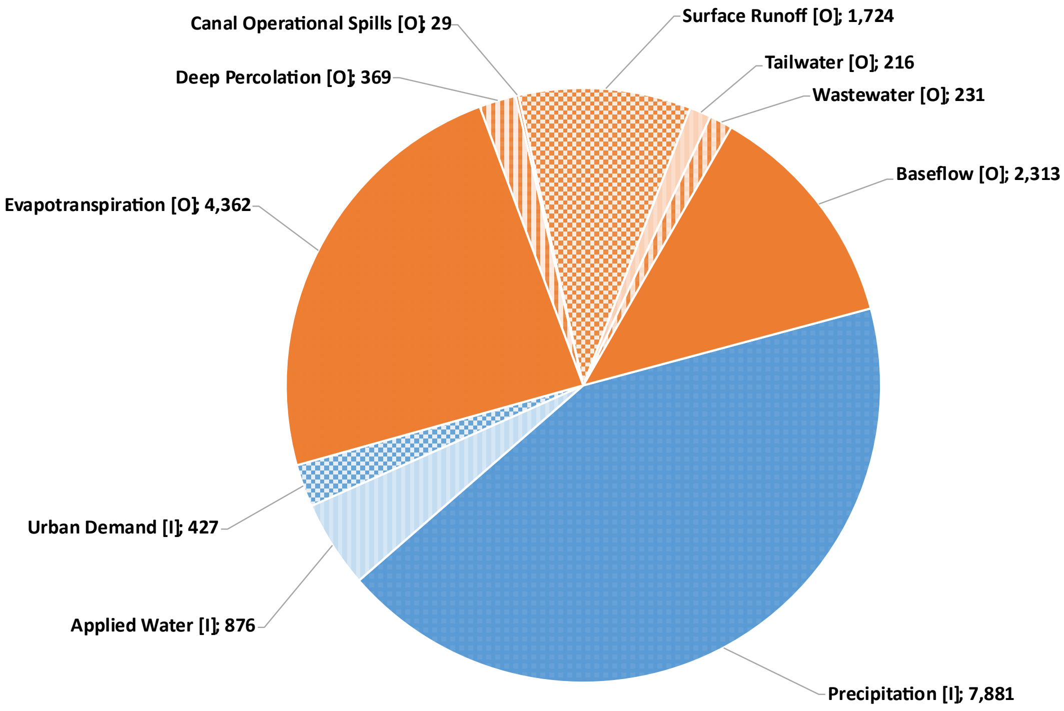
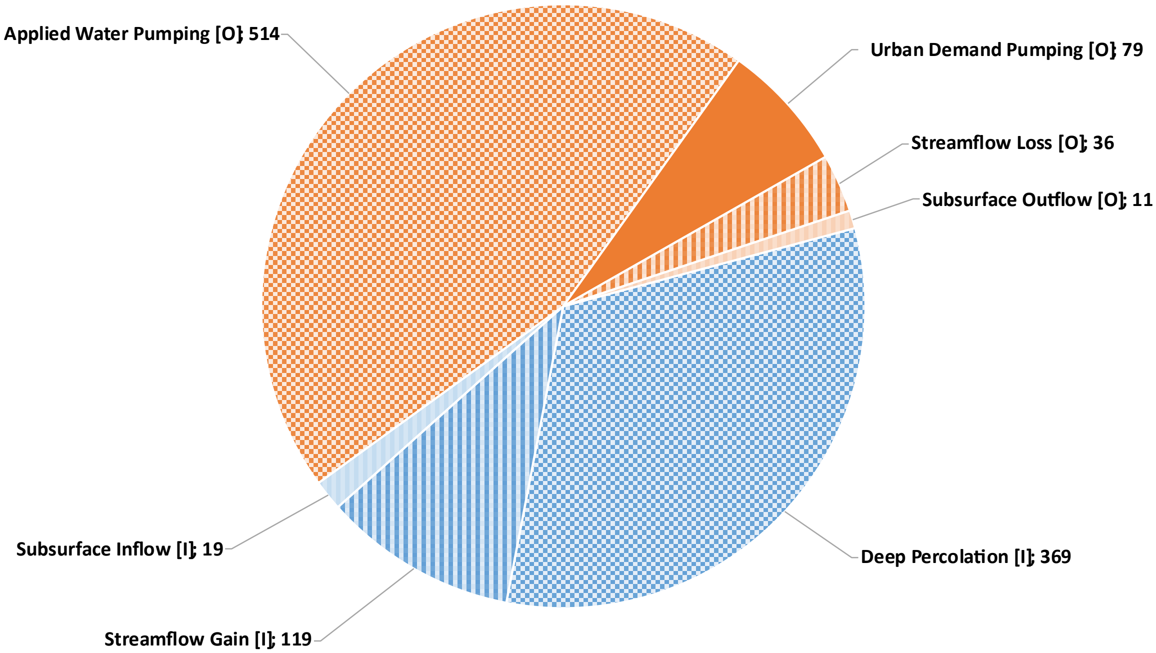


Figure 14. Annual Average Groundwater System Budget between Water Years 1981 to 2021 (TAF)



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