Water Supply and Balance to Water Budget: Merced Basin Pilot Study

California Water Plan Update 2023

Supporting Document

Technical Report

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Acronyms and Abbreviations

AWMP	agricultural water management plan
C2VSim	California Central Valley Groundwater-Surface Water Simulation Model
Cal-SIMETAW	California Simulation of Evapotranspiration of Applied Water
CDEC	California Data Exchange Center
DAUCO	detailed analysis units by county
Delta	Sacramento-San Joaquin Delta
DWR	California Department of Water Resources
ETAW	evapotranspiration of applied water
GSP	Groundwater sustainability plan
HUC	hydrologic unit code
NRCS	Natural Resources Conservation Service
NRO	DWR's Northern Region Office
PA	planning area
SGMA	Sustainable Groundwater Management Act

SWAM	Surface Water Allocation Model
taf	thousand acre-feet
USGS	U.S. Geological Survey
UWMP	urban water management plan

Executive Summary

Since 1998, the California Water Plan's Water Supply and Balance Team has collected, compiled, and maintained water supply and balance data to characterize current conditions subject to California Water Code 10004. The water supply and balance data are gathered for management activities that primarily occur on the land surface, and thus the data mostly represent a water balance of the land system. The draft *Handbook for Water Budget Development: With or Without Models* (Water Budget Handbook) introduces an integrated systems approach with three interacting systems – land, surface water, and groundwater – for developing a comprehensive water budget. The purpose of this pilot study is to explore how the water supply and balance data can transition to a comprehensive water budget, consistent with the Water Budget Handbook's standardized accounting templates.

The water supply and balance to water budget pilot study was conducted in two parts. During the first part of the project, the California Department of Water Resources (DWR) developed an initial mapping from water supply and balance components to the water budget components, consistent with the common vocabulary and water accounting templates in the Water Budget Handbook. This mapping was accomplished by reviewing definitions of water supply and balance components and identifying corresponding components in the Water Budget Handbook. Part 2 of the project involved verifying and updating the initial mapping, reviewing notes on potential modifications to the system, identifying additional required modifications, and estimating missing water budget components that would balance the land, surface, and groundwater systems.

The Merced basin was chosen for this pilot study because DWR has several other pilot studies being conducted for the Merced basin and could have supporting data available for filling data gaps or validation. The study area consists of Water Plan Planning Areas 607, 608, and 609, which include the areas east of the San Joaquin River, approximately from Stockton to Fresno. Data used for the pilot study was for the period from October 2013 to September 2014 (Water Year 2014) as Water Year 2014 data were the most recent data available from the California Water Plan when this study was initiated. A systematic mapping between the water supply and balance data, and the water budget schematic was undertaken to develop water budgets for the land, surface water, and the groundwater systems.

The water balance to water budget pilot study in the Merced basin provides a detailed methodology for mapping water supply and balance data to the water accounting templates. The process exposed some limitations in both the water supply and balance data, and the water accounting templates. Specifically, the water supply and balance data account for most, but not all, land system components. While surface water and groundwater used by the land system are well accounted, there are not enough surface water and groundwater components accounted for in the water supply and balance data to complete a water budget for those systems. Without supplemental information from other sources, the accuracy of water supply and balance data related to the surface water and groundwater systems cannot be assessed, and even with those additional data sources a satisfactory balance could not be obtained. The water accounting templates also have deficiencies. They generally assume a single standalone water budget zone and do not have sufficient components for routing water that flows outside of the system boundaries but does not go to a stream or a designated use. The accounting templates also do not deal with water budget zones where streams lie on, or outside of, the boundary of a water budget zone. And finally, groundwater interactions that do not involve direct use or recharge, such as the injection of groundwater to create a salinity barrier, or percolation that goes to unusable groundwater layers, could not be sufficiently identified by the water accounting templates in their current forms.

The Merced basin pilot study highlighted several challenges for transitioning from water supply and balance data to comprehensive water accounting. The following recommendations are made to help overcome the challenges in a systematic way.

1. Expand the Merced basin pilot study to refine the water budgets developed in the pilot study by reviewing, assessing, and using available data and information from annual reports submitted for groundwater sustainability plans (GSPs) within the Merced basin, California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), agricultural water management plans (AWMPs), urban water management plans (UWMPs), and other locally available data and information. The goal will be to close the loop and generate a complete water accounting for the basin by adding all other available data to the water supply and balance data.
2. Conduct additional pilot studies in selected hydrologic regions of the state that consider regional variability, data availability, and organizational capacity. These additional pilot studies will be conducted to provide a comprehensive water accounting based on the water budget information compiled in California Water Plan, California's Groundwater, GSPs, C2VSim, AWMPs,

UWMPs, and other water management activities to the standardized water accounting templates and common vocabulary Water Budget Handbook.

3. Develop a roadmap for developing basin, watershed, regional, and statewide water budgets.
4. Refine the groundwater system in the water budget schematic to account for saline intrusion and potential saline intrusion barriers to reduce or prevent the saline intrusion by installing and operating dedicated groundwater injection wells.
5. Refine the groundwater system in the water budget schematic to account for the complex interactions in a multilayered groundwater system.

1. Introduction

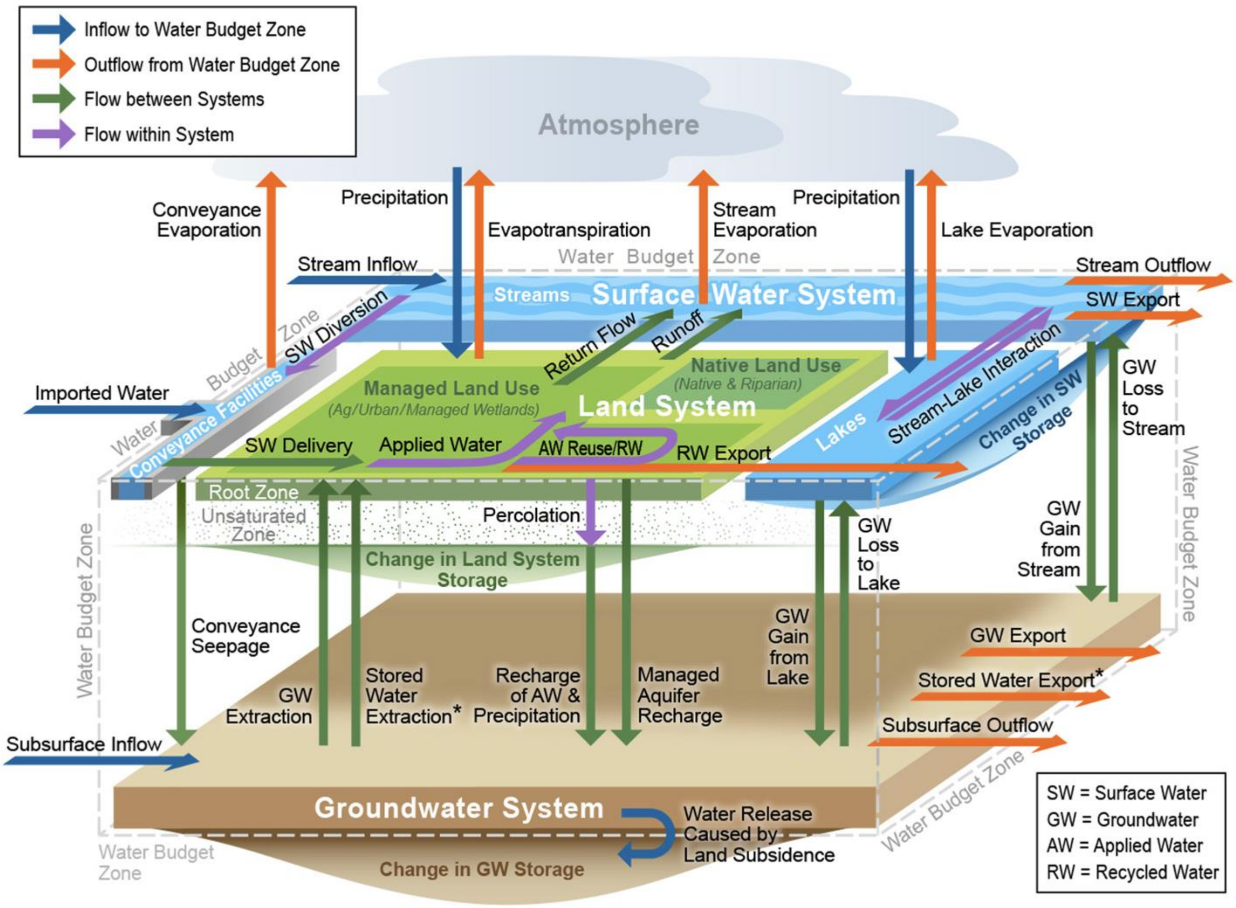
Since 1998, the California Water Plan's Water Supply and Balance Team has collected, compiled, and maintained water supply and balance data to characterize current conditions subject to California Water Code 10004. The water supply and balance data are gathered for management activities that primarily occur on the land surface, and thus, the data mostly represent a water balance of the land system. The draft *Handbook for Water Budget Development: With or Without Models* (Water Budget Handbook) (California Department of Water Resources 2020) introduces an integrated systems approach with three interacting systems – land, surface water, and groundwater – for developing a comprehensive water budget. The purpose of this pilot study is to explore how the water supply and balance data can transition to a comprehensive water budget, consistent with the Water Budget Handbook's standardized accounting templates.

A systematic mapping can be conducted of the water budget information compiled as part of California Water Plan updates, California Groundwater updates, groundwater sustainability plans (GSPs) as part of Sustainable Groundwater Management Act (SGMA) implementation, and other water management activities to the comprehensive water accounting described in the Water Budget Handbook. This allows the resulting data to provide an improved understanding of the inflows, outflows, and change in storage at the groundwater basin and regional scales. This water budget information will also inform actions in California's *Water Resilience Portfolio* that include assessments of water budgets and water accounting on a statewide and regional basis.

1.1 Water Budget Handbook

The Water Budget Handbook provides a systems-based three-dimensional conceptual schematic of water budget components with associated common vocabulary; standardized water accounting templates to organize and present inflows and outflows for the land, surface water, and groundwater systems; decision trees to streamline selection of a modeling or non-modeling approach for water budget development; case studies demonstrating development of water budgets with and without a model; and a compilation of relevant data sources with tips and practical advice on how to use the sources to develop estimates of various water budget components. The three-dimensional water budget schematic from the handbook that depicts the movements of water over the entire hydrologic cycle is shown in Figure 1.

Figure 1 Total Water Budget Schematic



1.2 Water Supply and Balance

The California Water Plan water supply and balance data provide an accounting of water that enters and leaves the state, and how it is used and exchanged between the regions. The water supply and balance data provide water use estimates and sources of supply information for a continuous 21-year period (1998–2018). Subsequent years will continue to be compiled and released with each update of the California Water Plan. The data is compiled by the detailed analysis units by county (DAUCO) scale which are analysis areas developed by combining watershed boundaries and jurisdictional boundaries. DAUCO are represented by a unique five-digit number with the first three digits representing the detailed analysis unit and the last two digits representing the county number. For example, DAUCO 20539 is the portion of DAU 205 that occurs in county 39, San Joaquin County. There are nearly 500 DAUCO in California. The water supply and balances are focused primarily on management actions which occur on the land surface, with a limited amount of groundwater and surfaces water system information tracked as well.

1.3 Study Approach

The water supply and balance to water budget pilot study was conducted in two parts. During the first part of the project, DWR developed an initial mapping from water supply and balance components to the water budget components, consistent with the common vocabulary and water accounting templates in the Water Budget Handbook. This mapping was accomplished by reviewing definitions of water supply and balance components and identifying corresponding components in the Water Budget Handbook. For example, the term “runoff” from the water supply and balance data may not have mapped to “runoff” in the water budget handbook because of differences in definition. The initial effort by DWR resulted in a mapping of 95 percent of the water supply and balance data.

Part 2 of the project involved verifying and updating the initial mapping, reviewing notes on potential modifications to the system, identifying additional required modifications, and estimating missing water budget components that would balance the land, surface, and groundwater systems.

2. Pilot Study Area and Data Used

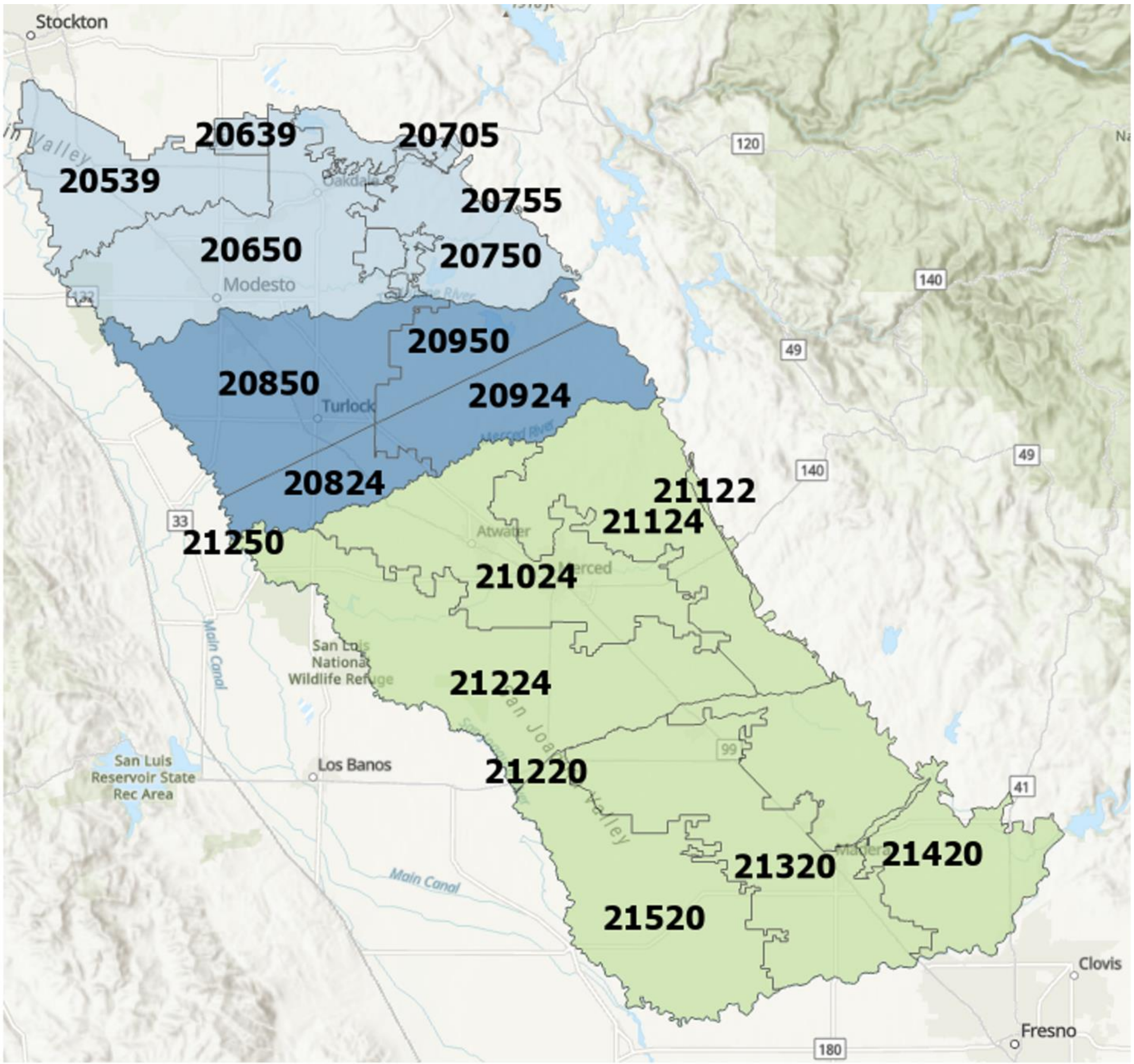
The Merced basin was chosen for this pilot study because DWR has several other pilot studies being conducted for the Merced basin and could have supporting data available for filling data gaps or validation. The study area consists of Water Plan Planning Areas (PAs) 607, 608, and 609, which include the areas east of the San Joaquin River, approximately from Stockton to Fresno as shown in Figure 2. The figure also includes the DAUCO in the area. Some DAUCO shown are slivers (e.g., 20755 and 21122). They do not have any significant water activity in them and were excluded from this analysis.

Data used for the pilot study was for the period from October 2013 to September 2014 (Water Year 2014) as Water Year 2014 data were the most recent data available from the Water Plan when this study was initiated. Additional water years (2002–2013) were explored to see if they made any difference in the results, but because the primary purpose of this investigation was to accurately map from the water supply and balance data to the water accounting templates, a single year was deemed sufficient for this investigation. More years would provide a better check on the accuracy of the water supply and balance data; but, no year-specific effects were seen in the mapping that would have caused a change in how a water budget component was mapped.

In addition to the water supply and balance data, the following additional, supplemental data sources were used:

- California Simulation of Evapotranspiration of Applied Water (Cal-SIMETAW).
- U.S. Geological Survey runoff data.
- Soil data and curve number from Natural Resources Conservation Service.
- National Land Cover Database.
- River balance sheets from DWR’s South Central Region Office.
- California Data Exchange Center stream gauges.
- C2VSIM Fine Grid v 1.01.

Figure 2 The Water Supply and Balance to Water Budget Pilot Study Area



For the purposes of this pilot project, PA 607 is made up of DAUCO 20539, 20639, 20650, and 20750. PA 608 is made up of DAUCO 20824, 20850, 20924, and 20950. PA 609 is made up of DAUCO 21024, 21124, 21224, 21320, 21420, and 21520. The model area includes the San Joaquin River, Merced River, Tuolumne River, Stanislaus River, Bear Creek, Dry Creek, and several minor rivers.

3. Review of Water Budget Schematic

Before delving into the details of the mapping between the water supply and balance data and the water budget, the water budget schematic was reassessed to determine if any fundamental changes to the schematic were required. While the water budget schematic, the common vocabulary, and the standardized water accounting templates were developed to depict the movement of all water across the entire hydrologic cycle, some water budget components were combined or simplified for the ease of depiction. When the hydrologic cycle water budget is applied in practice, the need to refine and further detail out portions of the schematic and accounting became necessary. The following refinements were identified to better align the water budget schematic with the water supply and balance data.

1. Add a flow within the system component called conveyance return flows to refer to water that is diverted off the surface water system into conveyance facilities but is ultimately returned to the surface water system. From a mass balance perspective, the water remains in the surface water system, but the volumes must be tracked separately to maintain consistency with diversion records. When trying to trace conveyance return flows in the water supply and balance data, the only way these flows can be tracked in the water accounting templates is to trace the flows from the surface water system to the land system back to the surface water system. This resulted in an overcomplicated representation of this component. An option was to add a separate term for conveyance return flow to the water accounting templates that remains as an internal flow in the surface water system.
2. Update the recycled water export component to a more generic land surface export term. While the groundwater and surface water systems both have an export component to move water from the system and deliver to a different water budget zone, the land system did not have an equivalent component. As such, flows originating from the land system that end up outside the water budget zone have no way of being accounted. The more generic land surface export component can comprise subcomponents for recycled water export; return flow to another region; runoff to another region; wastewater; deep percolation to Nevada, Oregon, and Mexico; runoff and return flow to the ocean; and wastewater export into the ocean as well as other land surface exports not specified here.
3. The land system storage component needs to be either expanded to include snowpack within the region to ensure an appropriate mass balance that

includes all forms of precipitation, or a new component must be included to account for snowpack.

4. The conveyance seepage component could be misleading. All other terms that go from the land system to the groundwater system are referred to as recharge; additionally, seepage can be used to refer to lateral flows out of a conveyance structure that meet evapotranspiration demands areas adjacent to the canal. Thus, the conveyance seepage component in the water accounting template should be renamed conveyance recharge.
5. The surface water delivery component may need to be generalized or clarified to include any flows going from the surface water system to the land system, such as water seeping or spilling laterally out of a canal.
6. The water accounting template does not account for water used to produce energy. While this could be accounted for by “applying” the water to the land surface generically and routing consumed water through evapotranspiration, a more robust accounting of water for energy production might be desirable.
7. Wastewater produced within a region may need to be tracked for verification or other purposes. A flow within a system could be added to the land system to account for wastewater produced within the region so that wastewater can be more accurately routed. Similarly, it may be important when identifying imported flows to add a subcomponent for imported wastewater that is not immediately available as a supply until treated or recharged.
8. In the future, it could be beneficial to evaluate the necessity of adding terms related specifically to water going to unrecoverable areas, such as a saline aquifer. While this situation was not occurring within the pilot project area, the team concluded that there is a need to track water injected into the ground to form salinity barriers and other seawater and groundwater interactions.

On completion of the review of the water budget schematic, a systematic mapping between the water supply and balance data, and the water budget schematic was undertaken to develop water budgets for the land, surface water, and the groundwater systems.

4. Land System

The Water Budget Handbook defines the land system as the portion of the water budget zone that includes the land surface and the unsaturated zone that extends vertically to the top of the groundwater system (i.e., water table). The land system water budget is an analysis of the land system's inflows and outflows within a water budget zone, including the change in storage in the land surface and the unsaturated zone. It accounts for the exchange of water over the land surface resulting from the various native and managed land use activities (e.g., urban, agricultural, and managed wetlands), movement of water through the unsaturated zone including infiltration into the root zone and subsequent percolation, and the exchange of water with the atmosphere, surface water systems and groundwater systems.

Inflows to the land system include precipitation onto the land surface, groundwater extraction, and surface water diversions from rivers and streams. Outflows from the land system include rainfall-runoff; agricultural, urban, and managed wetlands return flows to the surface-water system; managed aquifer recharge and recharge of applied water and precipitation to the groundwater system; and evapotranspiration to the atmosphere. The change in land system storage consists of change in ponded water storage (not streams, lakes, or conveyance facilities) on the land surface as well as the change in soil moisture storage in the unsaturated zone, including the root zone. The change in storage in lakes and streams is included in the change in surface-water storage.

The following sections detail the cross-mapping and calculations for each term in the land system budget. A tabular representation of this mapping is included in Appendix A.

4.1 Inflows

4.1.1 Precipitation

Precipitation is not available in the water supply and balance data. Rather, the water portfolio only tracks agricultural effective precipitation. To develop a more comprehensive water budget, precipitation values for each DAUCO were obtained from the California Simulation of Evapotranspiration of Applied Water (Cal-SIMETAW) model. The Cal-SIMETAW model provides agricultural water use estimates used in the water supply and balance data. Cal-SIMETAW uses data from the monthly Parameter-elevation Relationships on Independent Slopes Model (PRISM) climate data and daily U.S. National Climatic Data Center climate station data to cover California with a 4×4-kilometer grid.

4.1.2 Groundwater Extraction

The groundwater extraction values in the water supply and balance data are a combination of measured and estimated groundwater that were pumped for use in the agriculture, urban and managed wetlands sectors. For example, many urban water utilities report groundwater extractions to the State Water Resources Control Board; but, there are self-supplied urban and non-urban water users who rely on groundwater wells but who may not be required to report the amount of groundwater pumped. Groundwater extraction is also used as a closure term for each of the water use sectors when the pumping data are not available or cannot be reasonably estimated. The closure term is calculated as the difference between the total water use estimate, and the total surface water supplies plus reuse. Note that DWR’s Northern Region Office (NRO) utilizes land use surveys that include water source mapping, irrigation methods, and crop type to estimate groundwater pumping for the agricultural sector. Surface water supplies are reported for agricultural, urban, and managed wetlands. State and federal agencies have provided pumping data for managed wetlands to NRO.

Groundwater extraction comprises the following water supply and balance components:

- Groundwater Extraction: Unadjudicated – Agriculture.
- Groundwater Extraction: Unadjudicated – Urban.
- Groundwater Extraction: Unadjudicated – Managed Wetlands.
- Groundwater Extraction: Adjudicated – Agriculture.
- Groundwater Extraction: Adjudicated – Urban.
- Groundwater Extraction: Adjudicated – Managed Wetlands.
- Groundwater Extraction: Banked – Agriculture.
- Groundwater Extraction: Banked – Urban.
- Groundwater Extraction: Banked – Managed Wetlands.

Unadjudicated Groundwater extraction is included in the first three items of the list because, theoretically, it represents a groundwater extraction. When such data are available, they represent the amount of groundwater extraction used. But, in some locations where groundwater extraction is not measured, and water source is not identified, unadjudicated groundwater extraction can be used as a closure term in the water supply and balance data.

4.1.3 Surface Water Delivery

Surface water deliveries could not be mapped directly from water supply and balance data but could be calculated from surface water diversions minus losses. The losses include conveyance seepage, conveyance deep percolation, and conveyance evaporation.

As surface water delivery is the primary mechanism for conveying water from the surface water system to the land system, it includes the water supply and balance component, conveyance seepage. Conveyance seepage represents water that leaves the canal system laterally and helps to meet nearby evapotranspiration needs; it is assumed to be a reuse term. Surface water delivery conveyance seepage includes the following water supply and balance components:

- Conveyance Seepage: Agriculture.
- Conveyance Seepage: Urban.
- Conveyance Seepage: Managed Wetlands.

4.2 Flows within System

4.2.1 Applied Water

Applied water comprises the following water supply and balance components:

- Applied Water: Agriculture.
- Applied Water: Urban.
- Applied Water: Managed Wetlands.
- Applied Water: Residential Use – Single Family – Interior – Urban.
- Applied Water: Residential Use – Single Family – Exterior – Urban.
- Applied Water: Residential Use – Multi-Family – Interior – Urban.
- Applied Water: Residential Use – Multi-Family – Exterior – Urban.
- Applied Water: Commercial Use – Urban.
- Applied Water: Industrial Use – Urban.
- Applied Water: Urban Large Landscape – Urban.
- Applied Water: Energy Production – Urban.
- Applied Water: Groundwater Recharge – Urban.

4.2.2 Applied Water Reuse

Applied water reuse comprises the following water supply and balance components:

- Reuse of Return Flows within DAU/County: Agriculture.
- Reuse of Return Flows within DAU/County: Managed Wetlands.
- Reuse of Return Flows within DAU/County: Urban.

4.2.3 Recycled Water

In the water supply and balance data, recycled water is tabulated in the DAUCO where it is used; this may or may not be the DAUCO where it was generated (treated). Recycled water comprises the following water supply and balance components:

- Urban Wastewater Recycling: Urban.
- Urban Desalination: Urban.

4.2.4 Wastewater

Wastewater is the total amount of urban interior water use that is estimated to go into either a sewer system or septic tank. Wastewater comprises the following water supply and balance component:

- Urban Wastewater Produced: Urban.

Wastewater is not a water budget component; but, because this component could not be reconciled to any of the existing water accounting terms, it was included separately for the purposes of this study. For more information on recommendations for updates to the water accounting templates, see Section 7, "Recommendations."

4.3 Outflows

4.3.1 Evapotranspiration and Evaporation

Evapotranspiration comprises the following water supply and balance components:

- Return Flows Evaporation and Evapotranspiration: Agriculture.
- Effective Precipitation: Agriculture.
- Evapotranspiration of Applied Water: Agriculture.
- Evapotranspiration of Applied Water: Managed Wetlands.
- Evapotranspiration of Applied Water: Urban.
- Evaporation and Evapotranspiration of Groundwater Recharge: Agriculture.
- Return Flows Evaporation and Evapotranspiration: Managed Wetlands.

- Evaporation and Evapotranspiration of Groundwater Recharge: Urban.
- Evaporation and Evapotranspiration of Wastewater: Urban.
- Return Flows Evaporation and Evapotranspiration: Urban.
- Evaporation and Evapotranspiration from Unirrigated Agriculture.

Evapotranspiration from unirrigated agriculture is not explicitly included in the water supply and balance data, but is calculated as a closure term to balance total precipitation and the tracked evaporation values. This component is calculated as the difference between total precipitation and effective precipitation, and recharge of precipitation. While this calculation was used for the simplicity in the pilot study, a more accurate representation would need to consider that some of the precipitation becomes the change in storage in the land surface and the unsaturated zone.

4.3.2 Recycled Water Export

Recycled water export is not available in the water supply and balance data.

4.3.3 Managed Aquifer Recharge

Managed aquifer recharge comprises the following water supply and balance components:

- Deep Percolation of Groundwater Recharge: Agriculture.
- Deep Percolation of Groundwater Recharge: Managed Wetlands.
- Deep Percolation of Groundwater Recharge: Urban.

4.3.4 Recharge of Applied Water

Recharge of applied water comprises the following water supply and balance terms:

- Deep Percolation of Applied Water: Agriculture.
- Deep Percolation of Applied Water: Managed Wetlands.
- Deep Percolation of Applied Water: Urban.
- Deep Percolation to Oregon: Agriculture.
- Deep Percolation to Nevada: Agriculture.
- Deep Percolation to Mexico: Agriculture.
- Deep Percolation to Oregon: Managed Wetlands.
- Deep Percolation to Nevada: Managed Wetlands.
- Deep Percolation to Mexico: Managed Wetlands.
- Deep Percolation to Oregon: Urban.

- Deep Percolation to Nevada: Urban.
- Deep Percolation to Mexico: Urban.
- Deep Percolation of Applied Water to Salt Sink: Agriculture.
- Deep Percolation of Applied Water to Salt Sink: Managed Wetlands.
- Deep Percolation of Applied Water to Salt Sink: Urban.

Deep percolation of water to a salt sink is considered non-recoverable water in the water supply and balance data. It might need to be tracked differently in the future if the Water Budget Handbook schematic includes separate tracking of saline water.

4.3.5 Recharge of Precipitation

Recharge of precipitation is not available in the water supply and balance data and is assumed to be 5 percent of total precipitation. A 2019 study on climate and groundwater recharge variability in southern California showed statewide, long-term average recharge to be
4.2 percent of average annual precipitation (Manna 2019). A 2011 study on recharge in fractured rock aquifers east of San Diego County showed recharge to be about 5 percent of precipitation (Durbin 2019; Winas and Huntley 2011).

While these numbers were used for expediency in the pilot study, recharge of precipitation is variable throughout California based upon the type of surface cover, subsurface characteristics, and the intensity of rainfall. Future studies should account for local conditions when estimating recharge of precipitation.

4.3.6 Return Flow

Return flow comprises the following water supply and balance components:

- Return Flow to Developed Supply (Other DAUCO within PA): Agriculture.
- Return Flow to Developed Supply (Other PA): Agriculture.
- Return Flow to Developed Supply (Other Region): Agriculture.
- Return Flow to Developed Supply (Other DAUCO within PA): Managed Wetlands.
- Return Flow to Developed Supply (Other PA): Managed Wetlands.
- Return Flow to Developed Supply (Other Region): Managed Wetlands.
- Return Flow to Developed Supply (Other DAUCO within PA): Urban.
- Return Flow to Developed Supply (Other PA): Urban.
- Return Flow to Developed Supply (Other Region): Urban.

- Return Flow to Oregon: Agriculture.
- Return Flow to Nevada: Agriculture.
- Return Flow to Mexico: Agriculture.
- Return Flow to Oregon: Managed Wetlands.
- Return Flow to Nevada: Managed Wetlands.
- Return Flow to Mexico: Managed Wetlands.
- Return Flow to Oregon: Urban.
- Return Flow to Nevada: Urban.
- Return Flow to Mexico: Urban.
- Return Flow to Salt Sink: Agriculture.
- Return Flow to Salt Sink: Managed Wetlands.
- Return Flow to Salt Sink: Urban.
- Return Flow for Delta Outflow: Agriculture.
- Return Flow for Delta Outflow: Managed Wetlands.
- Return Flow for Delta Outflow: Urban.

While these components are called return flows, functionally they directly flow out of the system. Some might return to the river shortly before flowing out, but most do not. It was not possible to identify from the data which ones did or did not return to the surface water system before leaving the DAUCO. For that reason, the choice was made to route these flows out of the system directly from the land system. In a future update of the water accounting template, these components maybe included in land system export. Only reuse of return flows from the water supply and balance data matched what the water accounting template defines as return flow, but that component also includes reuse numbers and thus was already accounted for the data in Section 4.2.2, “Applied Water Reuse.”

4.3.7 Runoff

Runoff of precipitation is not available in the water supply and balance data. Runoff is calculated based on the precipitation values obtained from Cal-SIMETAW.

Using the daily precipitation values and the Natural Resources Conservation Service (NRCS) curve number method, runoff estimates were developed for each DAUCO. Curve numbers were estimated based on land use type. This method proved to be inadequate for a regional analysis. The curve number method is used to estimate the approximate amount of direct runoff from a rainfall event in a particular area. The method also requires precipitation to exceed the initial abstraction or the amount of water before runoff. To account for this limitation, only precipitation events more than 0.5 inches were considered in the analysis. As a result, only events above a certain threshold were used to identify runoff. Runoff from different land cover types were then summed to develop a single runoff number for each DAUCO. The outcome of this calculation process shows that approximately 8.6 percent of the precipitation became runoff for the study area, with individual DAUCOs ranging from 6.8 percent to 10.6 percent.

Runoff was also evaluated using U.S. Geological Survey (USGS) methodology to estimate runoff by hydrologic unit code. The USGS methodology provides monthly calculations of runoff percentage by hydrologic unit code (HUC) 8 and coarser scales. Monthly runoff percentages for each DAU were assigned based on the HUC6 watershed in which the DAUCO resides. The runoff percentages from USGS were used to calculate the total runoff that occurs within each DAU, using the total precipitation for each month along with the area of each DAU. Analysis of the region using HUC6 runoff percentages yielded more reasonable estimates than HUC8. Using runoff percentages for HUC8 resulted in some extremely high estimates in the range of 30 percent to 40 percent in some DAUCOs, which appeared to be unreasonably high. This could be caused by spatial differences between DAUCO and HUC8 which could overemphasize more localized effects. But, using HUC6 runoff percentages yielded an average runoff percentage of 9.7 percent across the region, with individual DAUCOs ranging from 8.5 percent to 11.3 percent.

Based on the analysis using both the USGS runoff estimates and the NRCS curve number method, a flat 10 percent was used to estimate runoff for the study area to complete the water budget calculations.

4.4 Discussion of Mass Balance and Explanation of Discrepancies

The detailed inflow and outflow sheets of the water supply and balance data include footnotes describing routing, but the routing information does not carry over to the summarized water balance sheets used in the analysis. Without an intended destination or path of conveyance for the return flow water volume estimates in the water balance sheets, it is unknown if the water flows into a water body or directly to the land system in a neighboring or far away water budget zone. This is important for water flowing from one DAUCO to another in the same PA or one in a different PA.

Initial balances using only the water supply and balance data were not as close as initially expected; PA 607 had a mass balance error of -239 thousand acre-feet (taf), PA 608 had a mass balance error of -390 taf, PA 609 had a mass balance error of -193 taf.

With the addition of precipitation (from Cal-SIMETAW), runoff, and recharge of precipitation (from related hand calculations) the mass balance error improves somewhat: PA 607 had a mass balance error of -35 taf, PA 608 had a mass balance error of -237 taf, PA 609 had a mass balance error of 141 taf. Reviewing the DAUCO values, some of the values appear to have significant mass balance errors. For example, in PA 607, DAUCO 20650 applies a combined total of 578 taf of water, but only receives surface water deliveries and groundwater extraction equaling 388 taf. In PA 608, DAUCO 20850 applies a combined total of 571 taf of water, but only receives surface water deliveries and groundwater extraction equaling 336 taf.

Additionally, because the water supply and balance does not do any tracking of precipitation data directly, unirrigated agriculture is not tracked either, but it would consume precipitation and some soil moisture from the land surface. There was not enough information to make an approximation of evapotranspiration of unirrigated agriculture for this pilot study, which means that any water consumed by unirrigated agriculture would contribute to the mass balance error.

5. Surface Water System

The Water Budget Handbook defines the surface water system as the portion of the water budget zone that includes streams, conveyance facilities, diversion ditches, lakes, and reservoirs that are part of the water supply system for meeting agricultural, urban, and managed wetlands applied water demands.

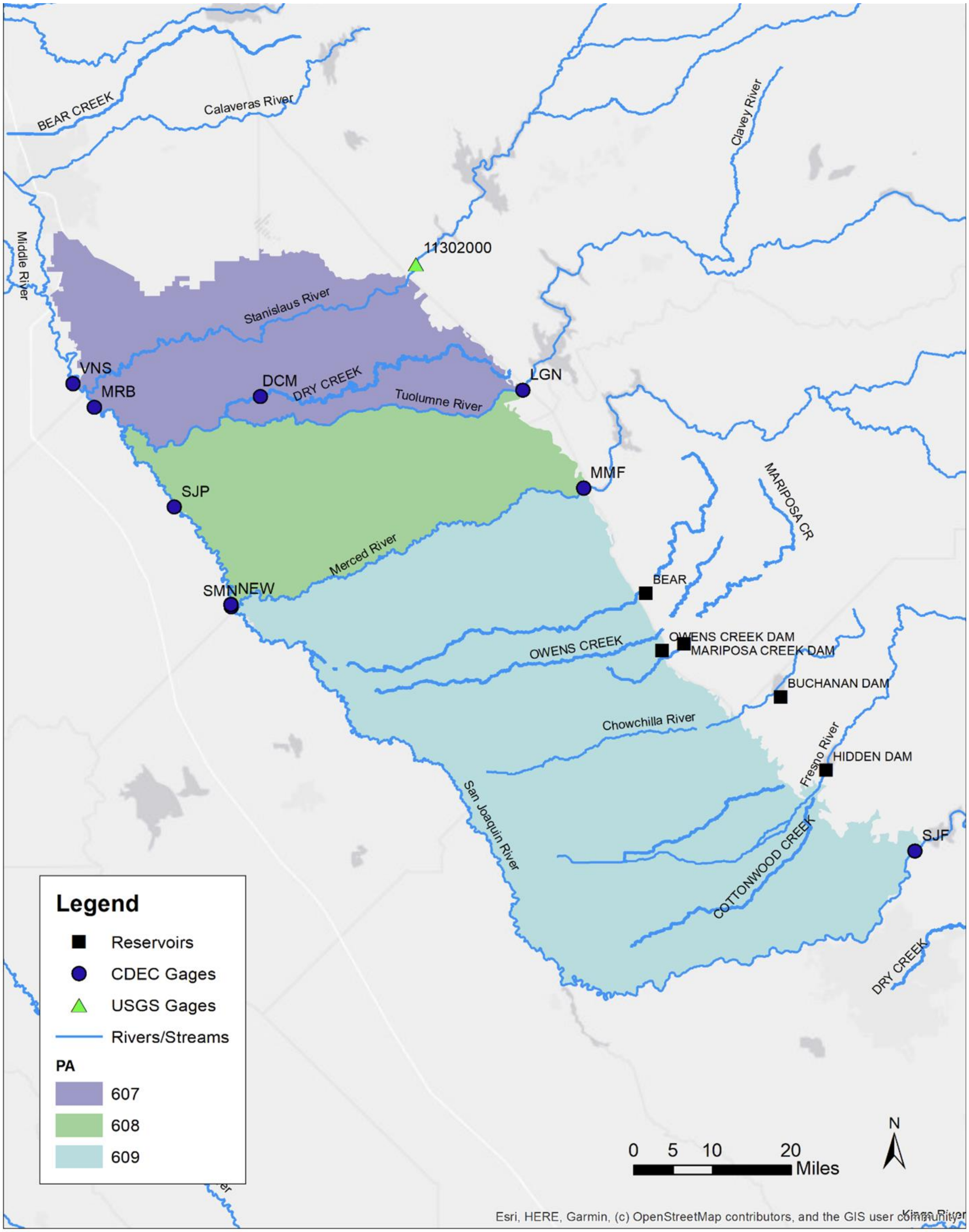
The surface water budget is an analysis of inflows to and outflows from the surface water system within a water budget zone, including the change in surface water storage. Inflows to the surface water system include stream flows and imported water entering the water budget zone, precipitation onto the surface water body, rainfall-runoff and return flow contributions from the land system, and gain from the groundwater system. Outflows from the surface water system include stream flows and surface water exports leaving the water budget zone, surface water deliveries to the land system, conveyance seepage and streamflow loss to the groundwater system, and lake evaporation to the atmosphere. The change in surface water storage includes change of storage in lakes and large streams.

The water supply and balance team evaluates water balances for developed water supply and use. Water budget components are presented in the context of agricultural, urban, and managed wetland supplies and demands. Flows are tracked for instream flow requirements, wild and scenic rivers, and Sacramento-San Joaquin Delta (Delta) outflows. Within each sector, water use is tracked for applied water as well as evapotranspiration, return flows, deep percolation and additional considerations for urban uses (recycled water and desalination). Each sector of water use is also tracked for the water's final destination. Supplies are split into several generalized categories: local supplies, return flows, local imports, groundwater extraction, desalination, deliveries from various projects, and water transfers (although water transfer amounts and destinations are not noted in water supply and balance data). Each category is further subdivided by water use and source (for example, a specific project, within a planning area versus outside a planning area) Natural processes such as precipitation and runoff are not explicitly captured in the water supply and balance data.

While the water supply and balance data are adequate for conducting the land system balance, and to some extent includes the primary components in the groundwater system balance, the surface water system balance is more difficult to achieve. Using water budget components directly from the water supply and balance data is not sufficient for balancing the surface water system. Many components of the surface water balance are not included as part of the water portfolio and those that are included are often presented at too coarse a spatial scale to properly trace to the source. Detailed information regarding inflows, outflows, diversions, return flows, and spills are not directly linked to a managed supply or demand and are left out of the water supply and balance data. While major streams and some tributaries are captured, not all tributaries and local creeks are reflected in the data. Surface water data in the water plan presented at a DAUCO scale and is not represented for individual streams. Furthermore, the challenge of accounting for streams on the boundary of a water budget zone is even more pronounced in the data because of the aggregation of terms to DAUCOs and hydrologic regions.

An initial attempt was made to balance the surface water system using gauged surface water flows from USGS and California Data Exchange Center (CDEC) gauges. Figure 3 depicts the major surface water features in the study area as well as relevant stream gauges from USGS and CDEC. Starting upstream and moving downstream, surface water flows for the major streams were obtained for Water Year 2014 and used for balancing the surface water system in the planning area. For streams on the boundary of the planning area, the stream was included in the balance of both sides to avoid having to arbitrarily split the stream in two. During this exercise, two primary issues emerged. The first was availability of streamflow data. Not all the surface water features in the region had stream gauges to work with. The available stream gauges were not necessarily situated in the best location relative to the planning area boundaries. Without a gauge at each end of the water budget zone, portions of each stream go unaccounted for and manual calculations must be made to estimate what occurs between the end of the water budget zone and the stream gauge. This leads to the second issue of not having diversions, runoff, or any other surface water components available at the stream resolution in the water supply and balance data. Without knowing exactly where along the streams, or in some cases not knowing which streams, the water budget needs to be accounted, it becomes impossible to balance the system. The lack of sufficient stream gauging is not a result of deficiencies in water supply and balance data or procedures used, but rather a general limitation of insufficient gauged stream data to support a robust water accounting throughout California.

Figure 3 Streams and Gauges in the Pilot Study Area



Behind the water supply and balance data, more detailed estimates of surface water flows, diversions, and spills that are balanced for individual stream reaches are included in river balance sheets. Each river balance sheet provides a balance for the river reach, moving upstream to downstream and documenting diversions, spills, and tributary inflows between stream gauges. Gauged flow values are taken from USGS and CDEC gauges. Diversions for riparian uses were estimated, other diversions were typically gauged. It is not documented where the spills originate. Tributary inflows are often from gauges. The difference between inflows and outflows between each gauge is attributed to a seepage term. Because this is a closure term, it includes stream-aquifer interaction as well as ungauged runoff and return flows (separate from the spills), and potentially ungauged and unmonitored diversions. Without a way to separate the stream-aquifer interaction component, these numbers were designated mass balance errors rather than assigned to the stream-aquifer interaction components of the water balance. Riparian diversions are estimated using regression analysis. The seepage term is used as a closure term for the river balances. These datasets were utilized to achieve more accurate surface water system balances for the pilot study area. Individual river balance sheets for the San Joaquin, Tuolumne, Merced, and Stanislaus rivers were provided by DWR's South Central Region Office to balance the surface water flows in the study area. Additionally, an aggregated spreadsheet, Surface Water Allocation Model (SWAM), summarizing the total diversions from each river system to each DAUCO was used for linking the individual river spreadsheets to the summarized water balances as well as filling in data gaps for diversions from minor streams that do not have their own individual balances.

5.1 Inflows

5.1.1 Imported Water

Imported Water comprises the following water supply and balance components:

- Colorado River Deliveries: Agriculture.
- Colorado River Deliveries: Managed Wetlands.
- Colorado River Deliveries: Urban.
- State Water Project Deliveries: Agriculture.
- State Water Project Deliveries: Managed Wetlands.
- State Water Project Deliveries: Urban.
- Central Valley Project: Base Deliveries: Agriculture.
- Central Valley Project: Base Deliveries: Managed Wetlands.
- Central Valley Project: Base Deliveries: Urban.

- Central Valley Project: Project Deliveries: Agriculture.
- Central Valley Project: Project Deliveries: Managed Wetlands.
- Central Valley Project: Project Deliveries: Urban.
- Other Federal Deliveries: Agriculture.
- Other Federal Deliveries: Managed Wetlands.
- Other Federal Deliveries: Urban.
- Ocean Desalination: Agriculture.
- Ocean Desalination: Managed Wetlands.
- Ocean Desalination: Urban.
- Water from Refineries: Agriculture.
- Water from Refineries: Managed Wetlands.
- Water from Refineries: Urban.
- Water Transfers – Regional: Agriculture.
- Water Transfers – Regional: Managed Wetlands.
- Water Transfers – Regional: Urban.
- Inter-basin Water Transfers: Agriculture.
- Inter-basin Water Transfers: Managed Wetlands.
- Inter-basin Water Transfers: Urban.
- Local Imports: Agriculture.
- Local Imports: Managed Wetlands.
- Local Imports: Urban.
- Return Flow from Other DAUCO within PA: Agriculture.
- Return Flow from Other DAUCO within PA: Managed Wetlands.
- Return Flow from Other DAUCO within PA: Urban.
- Return Flow from Other PA: Agriculture.
- Return Flow from Other PA: Managed Wetlands.
- Return Flow from Other PA: Urban.
- Return Flow from Other Region: Agriculture.
- Return Flow from Other Region: Managed Wetlands.
- Return Flow from Other Region: Urban.

Note: The team was not able to map from the river balance sheets to the appropriate term in the water supply and balance data, so for the final 12 terms in the list above, the team opted to use the numbers derived from the river balance sheets instead of the analogous water supply and balance terms.

As noted previously, while the water supply and balance data account for the total volume of surface water deliveries to an area, it does not track the origin of the water with respect to which streams or where along a stream the water is diverted. Without the additional details in the river balance sheets maintained by DWR's region offices, it is not possible to separate surface water deliveries into local diversions versus imported water. Using the river balance sheets and knowing approximately where diversions occur allows identification of imported and exported water components. Surface water deliveries originating from streams outside the water budget zone are tagged as imported water.

5.1.2 Precipitation on Lakes

Precipitation on lakes is not available in the water supply and balance data.

5.1.3 Stream Inflow

Stream inflows and outflows are not explicitly included in the water supply and balance data but are used in developing the river balance spreadsheets. Flows at gauges at the inflow and outflow points for streams in each planning area can be used to assign stream inflows and outflows for the surface water balance. These are available in the river balance spreadsheets as well as directly from USGS or DWR's CDEC network.

Data to support comprehensive accounting of inflows and outflows are typically only available for major streams. Minor streams that also flow into the water budget zone are not explicitly accounted. In some cases, the minor streams are a tributary to the major streams, so some of the flows might be captured in the river balance data. In other cases, the stream might terminate somewhere in the middle of the water budget zone and go unaccounted.

5.1.4 Groundwater Loss to Lake

Groundwater lake interactions are not available in the water supply and balance data.

5.1.5 Groundwater Loss to Stream

Stream-aquifer interaction is not explicitly included in the water supply and balance data. The river balance spreadsheets include a "seepage term." But the seepage is used as a closure term within the river balance and includes not only stream-aquifer interaction but also runoff, return flow, evaporation, ungauged diversions, and others.

Using it as the stream aquifer-interaction value in the water budget balance could mask additional sources of error that exist in the rest of the surface water data.

5.1.6 Return Flow

As none of the return flow items from the water supply and balance data represent flows that would normally return to the river, and instead represent flows that would leave the water budget zone, they were routed out of the zone through the land surface. For more information on the water supply and balance return flows routed out from the land surface directly, see Section 4.3.6, "Return Flow."

Since the water supply and balance data did not have sufficient information on return flows, the river balance spreadsheets provided by the South Central Region Office (SCRO) were consulted. The river balance spreadsheets do include a spills component, but that term does not capture all the runoff and return flow that occurs in an area. Th spills components are operational flows that might fall under conveyance return flows and are used to balance individual stream reaches but are not explicitly included in the water supply and balance data. Additionally, rivers along the boundary of a water budget zone have uncertainties related to the volumes of runoff and return flow associated with them.

5.1.7 Runoff

Described in Section 4.3.6, "Return Flow," and Section 5.1.6, "Return Flow."

5.2 Flow within System

5.2.1 Stream-Lake Interaction

Stream-lake interactions are not available in the water supply and balance data.

5.2.2 Surface Water Diversion

Surface water diversion comprises the following water supply and balance components:

- Colorado River Deliveries: Agriculture.
- Colorado River Deliveries: Managed Wetlands.
- Colorado River Deliveries: Urban.
- State Water Project Deliveries: Agriculture.
- State Water Project Deliveries: Managed Wetlands.

- State Water Project Deliveries: Urban.
- Central Valley Project: Base Deliveries: Agriculture.
- Central Valley Project: Base Deliveries: Managed Wetlands.
- Central Valley Project: Base Deliveries: Urban.
- Central Valley Project: Project Deliveries: Agriculture.
- Central Valley Project: Project Deliveries: Managed Wetlands.
- Central Valley Project: Project Deliveries: Urban.
- Other Federal Deliveries: Agriculture.
- Other Federal Deliveries: Managed Wetlands.
- Other Federal Deliveries: Urban.
- Ocean Desalination: Agriculture.
- Ocean Desalination: Managed Wetlands.
- Ocean Desalination: Urban.
- Water from Refineries: Agriculture.
- Water from Refineries: Managed Wetlands.
- Water from Refineries: Urban.
- Water Transfers – Regional: Agriculture.
- Water Transfers – Regional: Managed Wetlands.
- Water Transfers – Regional: Urban.
- Inter-basin Water Transfers: Agriculture.
- Inter-basin Water Transfers: Managed Wetlands.
- Inter-basin Water Transfers: Urban.
- Local Supplies: Agriculture.
- Local Supplies: Managed Wetlands.
- Local Supplies: Urban.
- Local Imports: Agriculture.
- Local Imports: Managed Wetlands.
- Local Imports: Urban.

These flows can also be obtained from the river balance spreadsheets. Surface water diversions in the river balance spreadsheets track both the origin (stream reach and location between gauges) and destination (DAU). Diversions to DAUs within the water budget zone represent surface water diversions.

Note: These flows are tracked for accounting purposes but have already been accounted for in the calculations of imported water.

5.3 Outflows

5.3.1 Conveyance Evaporation

Conveyance Evaporation comprises the following water supply and balance components:

- Conveyance Evaporation and Evapotranspiration of Applied Water (ETAW): Agriculture.
- Conveyance Evaporation and ETAW: Managed Wetlands.
- Conveyance Evaporation and ETAW: Urban.

5.3.2 Lake Evaporation

Lake evaporation comprise the following water supply and balance components:

- Evaporation from Lakes.
- Evaporation from Reservoirs.

These components are only tracked at the hydrologic region scale and are not available at the planning area or DAUCO level.

5.3.3 Stream Evaporation

Steam evaporation is not available in the water supply and balance data.

5.3.4 Stream Outflow

Stream outflow comprises the following water supply and balance components:

- Return Flow to Salt Sink: Agriculture.
- Return Flow for Delta Outflow: Agriculture.
- Conveyance Return Flow to Oregon: Agriculture.
- Conveyance Return Flow to Nevada: Agriculture.
- Conveyance Return Flow to Mexico: Agriculture.
- Conveyance Return Flows to Salt Sink: Agriculture.
- Conveyance Return Flow for Delta Outflow: Agriculture.
- Conveyance Return Flow to Developed Supply (Other DAUCO within PA): Agriculture.

- Conveyance Return Flow to Developed Supply (Other PA): Agriculture.
- Conveyance Return Flow to Developed Supply (Other Region): Agriculture.
- Conveyance Return Flow to Oregon: Managed Wetlands.
- Conveyance Return Flow to Nevada: Managed Wetlands.
- Conveyance Return Flow to Mexico: Managed Wetlands.
- Conveyance Return Flows to Salt Sink: Managed Wetlands.
- Conveyance Return Flow for Delta Outflow: Managed Wetlands.
- Conveyance Return Flow to Developed Supply (Other DAUCO within PA): Managed Wetlands.
- Conveyance Return Flow to Developed Supply (Other PA): Managed Wetlands.
- Conveyance Return Flow to Developed Supply (Other Region): Managed Wetlands.
- Return Flow to Salt Sink: Managed Wetlands.
- Return Flow for Delta Outflow: Managed Wetlands.
- Return Flow to Salt Sink: Urban.
- Return Flow for Delta Outflow: Urban.
- Conveyance Return Flow to Oregon: Urban.
- Conveyance Return Flow to Nevada: Urban.
- Conveyance Return Flow to Mexico: Urban.
- Conveyance Return Flows to Salt Sink: Urban.
- Conveyance Return Flow for Delta Outflow: Urban.
- Conveyance Return Flow to Developed Supply (Other DAUCO within PA): Urban.
- Conveyance Return Flow to Developed Supply (Other PA): Urban.
- Conveyance Return Flow to Developed Supply (Other Region): Urban.

Stream inflows and outflows are not available in the water supply and balance data but are used in developing the river balance spreadsheets. The above components all could theoretically represent stream outflows, but these components do not account for the full water flows in a region. Instead, flows at gauges at the inflow and outflow points for streams in each planning area can be used to assign stream inflows and outflows for the surface water system balance. These data are available in the river balance spreadsheets as well as directly from USGS or DWR's CDEC network.

5.3.5 Export

While the water supply and balance data do account for the total volume of surface water deliveries to an area, it does not track the origin of the water with respect to which stream or where along a stream the water is diverted. Without that level of detail, there is no way to know how much water is leaving a zone as exported water. Using the river balance spreadsheets and knowing approximately where diversions occur allows for identifying imported and exported water components. Water diverted off a stream within the water budget zone, but delivered to outside the water budget zone, are tagged as exported water.

5.3.6 Surface Water Delivery

Surface water delivery could not be mapped directly from water supply and balance data but could be calculated from surface water diversions minus losses.

5.3.7 Conveyance Percolation

Conveyance percolation comprises the following water supply and balance terms:

- Conveyance Deep Percolation to Oregon: Agriculture.
- Conveyance Deep Percolation to Nevada: Agriculture.
- Conveyance Deep Percolation to Mexico: Agriculture.
- Conveyance Deep Percolation: Agriculture.
- Conveyance Deep Percolation to Salt Sink: Agriculture.
- Conveyance Deep Percolation to Oregon: Managed Wetlands.
- Conveyance Deep Percolation to Nevada: Managed Wetlands.
- Conveyance Deep Percolation to Mexico: Managed Wetlands.
- Conveyance Deep Percolation: Managed Wetlands.
- Conveyance Deep Percolation to Salt Sink: Managed Wetlands.
- Conveyance Deep Percolation to Oregon: Urban.
- Conveyance Deep Percolation to Nevada: Urban.
- Conveyance Deep Percolation to Mexico: Urban.
- Conveyance Deep Percolation: Urban.
- Conveyance Deep Percolation to Salt Sink: Urban.

5.3.8 Conveyance Seepage

Conveyance seepage comprises the following water supply and balance terms:

- Conveyance Seepage: Agriculture.
- Conveyance Seepage: Managed Wetlands.
- Conveyance Seepage: Urban.

5.3.9 Groundwater Gain from Lake

Groundwater lake interactions are not available in the water supply and balance data.

5.3.10 Groundwater Gain from Stream

See Section 5.1.5, "Groundwater Loss to Stream."

5.4 Discussion of mass balance and explanation of discrepancies

Initial water budgets using only the water supply and balance data were not balanced, but that was expected as these data do not track stream inflows and outflows, but rather focuses on the land surface. PA 607 had a mass balance error of -284 taf, PA 608 had a mass balance error of +124 taf, PA 609 had a mass balance error of -327 taf.

With the addition of stream gauged inflow and outflow data, as well as diversion and seepage data from the river balance spreadsheets, the mass balance errors became: PA 607 had a mass balance error of -161 taf, PA 608 had a mass balance error of +218 taf, PA 609 had a mass balance error of +335 taf. After including additional data in the analysis, these systems are still not sufficiently balanced at the planning area level. Additional work on understanding the mismatch of mapping of river balance sheet data to water supply and balance data may help to close this gap. Additional stream gauges at key locations throughout the planning areas would also help to reduce this uncertainty.

5.5 Discussion of River Balance Sheets

The river balance sheets include a file specific to each stream in the region (e.g., a file for the Merced River) as well as a SWAM spreadsheet that aggregates information from each of the streams into DAU totals (the spreadsheets still use DAU not DAUCO but include the county name). The process for feeding data from the SWAM spreadsheet to the water supply and balance data was not known by the team. This section attempts to walk through the data in each of the sheets to better understand potential sources of error.

The river balance sheets include calculations of mass balances for each river segment between gauges. The sheets call out these mass balance errors as seepage. Seepage is not quantified and is a possible explanation for the discrepancies. Additionally, the seepage term can be positive or negative, indicating that it may be a quantification of a gaining or losing stream-aquifer interaction.

But there could be other explanations for these discrepancies, including runoff from parts of the river not including in the planning area of interest (e.g., west side of the San Joaquin River), return flows or diversions that are not explicitly quantified (e.g., riparian diversions are not measured but rather estimated using a regression analysis), and potential inaccuracies in reported data. For those reason, rather than referring to this term as seepage, it will be referred to as mass balance error between each segment of the stream.

Finally, the team did not understand why gauge data listed in the river balance sheets did not match similar gauge data pulled by the team from USGS or DWR's CDEC. This could be a result of the water supply and balance data being gathered closer to the events and did not benefit from any corrections on the gauges or of gauges in similar stream locations showing different readings.

5.4.1 PA 607 Balance

Starting in PA607, the planning area is bounded by the Tuolumne River to the south and San Joaquin River to the west. The Stanislaus River and Dry Creek both flow into the area. No river balance spreadsheets were available for Dry Creek, but balances were available for the other three streams.

The Stanislaus River balances well and is the easiest stream to account for in PA607. All spills originate from within the planning area and all diversions off the river serve the planning area. Overall, the mass balance error for Stanislaus is 1.2 taf. The only complexity for the Stanislaus River is a diversion to Oakdale Irrigation District that occurs off the river but upstream of the first stream gauge location. For the purposes of the water budget, this volume would either need to be assigned as an import or included both in the diversion volume and to the inflow volume to avoid double counting.

The Tuolumne River is on the boundary of PA607 and PA608. The river is included in the surface water system budget for both planning areas. Diversions and spills are accounted for separately between the two planning areas. Between two stream-gauge locations, there is a mass balance difference of 44 taf, indicating riparian diversions could potentially be underestimated. Furthermore, there are two diversions that occur upstream of the first stream gauge and are treated as imports for the purposes of the water budget. Diversions include 193 taf through the Modesto Canal for use in DAU 206 (in PA 607) and 359 taf through the Turlock Canal for use in DAU 208 (PA 608). Additionally, there is a spill from Modesto Irrigation District in the river spreadsheet that is not included in the balance equation in the SWAM sheet; but, this volume is 1.7 taf in 2014, so it likely does not have a significant effect on the overall water budget.

Dry Creek does not have a river balance sheet. It drains into the Tuolumne River and these volumes are captured in the Tuolumne River balance as one of the tributary inflows.

The San Joaquin River balance is the most complicated of the three river balance sheets for the planning area. There are some additional points of uncertainty in this balance because of flows and diversions that occur outside the reach associated with the planning area. Overall, the San Joaquin River balance shows a mass balance difference of 111 taf.

Closer inspection reveals that there are disconnects in the surface water components of the water supply and balance data. Aggregating individual diversions in the river spreadsheets by planning area yields a total of 458 taf in surface water deliveries. The water supply and balance data show a total of 490 taf in diversions, a 32 taf difference from the river balances between the two.

Comparing the deliveries by DAU from the SWAM spreadsheet to those in water supply and balance data reveal significant differences. DAU 205 has 40 taf worth of diversion in the SWAM spreadsheet versus 193 taf in the water balance spreadsheet. DAU 206 has 415 taf in the SWAM spreadsheet versus 294 taf in the water balance spreadsheet. DAU 207 is consistent with 1 taf in both.

5.4.2 PA 608 Balance

A similar comparison was conducted for PA 608. The Tuolumne River bounds the planning area to the north and consists of the same balances as previously described in PA 607. The Merced River runs along the southern boundary of the planning area.

Diversions off the Merced River go into PA 608 and PA 609. The Merced River sheet balances well, with a mass balance error of 2.7 taf in 2014. Diversions totaling 14.6 taf occur upstream of the first gauge and 281 taf is exported to PA 609 (from the PA 608 perspective).

The San Joaquin River again provides the greatest source of uncertainty. For PA 608, the river balance for the San Joaquin River is conducted between the Newman and Maze Road Bridge gauges. The Newman gauge is immediately upstream of the confluence of the Merced and San Joaquin rivers. But, similar to the problem in PA 608, there is no gauge at the confluence of the San Joaquin and Tuolumne rivers. Maze Road Bridge is upstream of the confluence and may include diversions, spills, runoff, and return flow, which could influence the overall balance. The mass balance error for this reach of the San Joaquin River is significant, with a difference of 126 taf between inflows and outflows.

Similar to PA 607, the stream reach budgets were checked against the SWAM spreadsheets and the water supply and balance data. PA 608 diversions match those in the SWAM spreadsheet; but those diversions do not match similar terms in the water supply and balance data. In the water supply and balance data, DAU 208 and DAU 209 have 109 taf and 78 taf in local deliveries, respectively. The SWAM spreadsheet shows 399 taf being delivered to DAU 208 and 78 taf to DAU 209. The diversion from the Tuolumne River is seemingly unaccounted for in the balance.

5.4.3 PA 609 Balance

A water balance was also conducted for PA 609 using the same approach as the other two planning areas. PA 609 is bounded by the Merced River to the north and by the San Joaquin River to the west and south. Numerous tributaries enter the planning area from the foothills in the east but there are no river balance sheets associated with them, although some data about the tributaries are tabulated in the SWAM sheet. CDEC and USGS gauges at the upstream end indicate that flows in these tributaries is relatively small. The SWAM sheets seem to contain some data for these tributaries, but it was unclear where the data originated because there was no associated river balance sheet.

The Merced River water balance is described above for PA 608. Overall, the river balances well with a very small mass balance error. The San Joaquin River, again, has the greatest source of uncertainty. Between the upstream point below Friant Dam and the downstream point after the confluence with the Merced River, the San

Joaquin River has a mass balance error of
450 taf, indicating there are significant data gaps for this area. The San Joaquin River is balanced across five gauges in PA 608. Between the most upstream point at Friant Dam and the first gauge at Gravelly Ford, the flow drops from 470 taf to 327 taf. The only thing that is estimated to occur in this stretch is a riparian diversion of 18.5 taf, resulting in a mass balance error of 124.5 taf between the two points. Between Gravelly Ford and the Chowchilla Bypass, the measured San Joaquin River flow drops from 327 taf to 252 taf, with no measured or estimated diversions occurring in that stretch. This accounts for an additional 75 taf of water unaccounted for. Between the Chowchilla Bypass and the community of Stevinson, the measured San Joaquin River flow drops from 252 taf to 9 taf with one diversion of 6 taf in between, resulting in a 237 taf mass balance error. Finally, between Stevinson and the confluence with the Merced River, the river balance spreadsheet estimates a mass balance error of 22 taf. While large portions of these mass balance errors could be attributed to stream-aquifer interaction, they could also be attributed to a variety of other water budget terms, including unmeasured diversions. More data are needed to refine these balances. Additional points of uncertainty in PA 609 exist in that the gauge data checked by the team from USGS or DWR's CDEC for the San Joaquin River did not match those in the river balance sheets and the data in the river balance sheets did not appear to match similar terms in the water supply and balance data.

6. Groundwater System

The Water Budget Handbook defines the groundwater system as the portion of the water budget zone that extends vertically from the base of the unsaturated zone (water table) to the bottom of the basin within the water budget zone; it can include one or more principal aquifers and represents the physical extent of the water budget zone used to quantify the volume of groundwater stored.

The groundwater budget is an analysis of inflows to and outflows from the groundwater system within a water budget zone, including the change in groundwater storage. Inflows to the groundwater system include subsurface groundwater flow entering the water budget zone, conveyance seepage from the surface water system, recharge of applied water and precipitation percolating downward through the unsaturated zone, and managed aquifer recharge from the land system. Outflows from the groundwater system primarily include groundwater and stored water extraction through wells, losses to the surface water system, and subsurface groundwater flow, as well as groundwater and stored water exports leaving the water budget zone. The change in groundwater storage includes change in storage in aquifers resulting from changes in groundwater levels.

6.1 Inflows

6.1.1 Subsurface Inflow

Subsurface inflow is not available in the water supply and balance data. For the purposes of completing a water budget, zbudget data from C2VSIM version 1.01 was processed and compiled to obtain numbers for subsurface inflow.

6.1.2 Water Release caused by Land Subsidence

Water release caused by land subsidence is not available in the water supply and balance data. For the purposes of completing a water budget, zbudget data from C2VSIM version 1.01 was processed and compiled to obtain numbers for water release caused by land subsidence.

6.1.3 Conveyance Percolation

Conveyance percolation comprises the following water supply and balance components:

- Conveyance Deep Percolation to Oregon: Agriculture.

- Conveyance Deep Percolation to Nevada: Agriculture.
- Conveyance Deep Percolation to Mexico: Agriculture.
- Conveyance Deep Percolation: Agriculture.
- Conveyance Deep Percolation to Salt Sink: Agriculture.
- Conveyance Deep Percolation to Oregon: Urban.
- Conveyance Deep Percolation to Nevada: Urban.
- Conveyance Deep Percolation to Mexico: Urban.
- Conveyance Deep Percolation to Oregon: Managed Wetlands.
- Conveyance Deep Percolation to Nevada: Managed Wetlands.
- Conveyance Deep Percolation to Mexico: Managed Wetlands.
- Conveyance Deep Percolation: Managed Wetlands.
- Conveyance Deep Percolation to Salt Sink: Managed Wetlands.
- Conveyance Deep Percolation: Urban.
- Conveyance Deep Percolation to Salt Sink: Urban.

6.1.4 Managed Aquifer Recharge

Managed aquifer recharge comprises the following water supply and balance components:

- Deep Percolation of Groundwater Recharge: Agriculture.
- Deep Percolation of Groundwater Recharge: Managed Wetlands.
- Deep Percolation of Groundwater Recharge: Urban.

6.1.5 Recharge of Applied Water

Recharge of applied water comprises the following water supply and balance components:

- Deep Percolation of Applied Water: Agriculture.
- Deep Percolation of Applied Water to Salt Sink: Agriculture.
- Deep Percolation to Oregon: Agriculture.
- Deep Percolation to Nevada: Agriculture.
- Deep Percolation to Mexico: Agriculture.
- Deep Percolation of Applied Water: Managed Wetlands.
- Deep Percolation of Applied Water to Salt Sink: Managed Wetlands.
- Deep Percolation to Oregon: Managed Wetlands.
- Deep Percolation to Nevada: Managed Wetlands.

- Deep Percolation to Mexico: Managed Wetlands.
- Deep Percolation of Applied Water: Urban.
- Deep Percolation of Applied Water to Salt Sink: Urban.
- Deep Percolation to Oregon: Urban.
- Deep Percolation to Nevada: Urban.
- Deep Percolation to Mexico: Urban.

6.1.6 Recharge of Precipitation

See Section 4.3.5, "Recharge of Precipitation" for the description of recharge of precipitation.

6.1.7 Groundwater Gain from Stream

See Section 5.1.5, "Groundwater Loss to Stream."

6.2 Flow Between Systems

There are no flow between systems identified in the water accounting template for the groundwater system.

6.3 Outflows

6.3.1 Subsurface Outflow

Subsurface outflow comprises of the following water supply and balance components:

- Conveyance Deep Percolation to Oregon: Agriculture.
- Conveyance Deep Percolation to Nevada: Agriculture.
- Conveyance Deep Percolation to Mexico: Agriculture.
- Deep Percolation to Oregon: Agriculture.
- Deep Percolation to Nevada: Agriculture.
- Deep Percolation to Mexico: Agriculture.
- Conveyance Deep Percolation to Oregon: Managed Wetlands.
- Conveyance Deep Percolation to Nevada: Managed Wetlands.
- Conveyance Deep Percolation to Mexico: Managed Wetlands.
- Deep Percolation to Oregon: Managed Wetlands.
- Deep Percolation to Nevada: Managed Wetlands.

- Deep Percolation to Mexico: Managed Wetlands.
- Deep Percolation to Oregon: Urban.
- Deep Percolation to Nevada: Urban.
- Deep Percolation to Mexico: Urban.
- Conveyance Deep Percolation to Oregon: Urban.
- Conveyance Deep Percolation to Nevada: Urban.
- Conveyance Deep Percolation to Mexico: Urban.

Although the items shown in this list potentially contribute to subsurface outflow, all values were null because the planning areas analyzed are not adjacent to California borders. The water supply and balance data do not have other subsurface outflow information. For the purposes of completing a water budget, zbudget data from C2VSIM version 1.01 was processed and compiled to obtain numbers for subsurface outflow.

6.3.2 Groundwater Extraction

Recharge of applied water comprises the following water supply and balance components:

- Groundwater Extraction – Unadjudicated: Agriculture.
- Groundwater Extraction – Unadjudicated: Managed Wetlands.
- Groundwater Extraction – Unadjudicated: Urban.
- Groundwater Extraction – Adjudicated: Agriculture.
- Groundwater Extraction – Adjudicated: Managed Wetlands.
- Groundwater Extraction – Adjudicated: Urban.

6.3.3 Stored Water Extraction

Recharge of applied water comprises the following water supply and balance components:

- Groundwater Extraction: Banked –Agriculture.
- Groundwater Extraction: Banked – Managed Wetlands.
- Groundwater Extraction: Banked – Urban.

6.3.4 Groundwater Loss to Stream

See Section 5.1.5, "Groundwater Loss to Stream."

6.4 Discussion of Mass Balance and Possible Explanation of Discrepancies

Initial balance errors using the water supply and balance data were significant: PA 607 had a mass balance error of -267 taf, PA 608 had a mass balance error of -598 taf, PA 609 had a mass balance error of -1,635 taf.

With the addition of the subsurface flow, release of water resulting from subsidence, and change in groundwater storage components from C2VSim, the mass balance errors were much smaller: PA 607 had a mass balance error of 4 taf, PA 608 had a mass balance error of -169 taf, PA 609 had a mass balance error of -29 taf. The addition of C2VSim data brings the balances closer together. But it cannot be said that the water supply and balance data accurately represent the groundwater conditions in the area because of the water budget components discussed above that are not included.

7. Conclusion and Recommendations

The water balance to water budget pilot study in the Merced basin provides a detailed methodology for mapping water supply and balance data to the water accounting templates. The process exposed some limitations in the water supply and balance data and in the water accounting templates. Specifically, the water supply and balance data account for most, but not all, land system components. While surface water and groundwater used by the land system are well accounted, there are not enough surface water and groundwater components accounted for in the water supply and balance data to complete a water budget for those systems. Without supplemental information from other sources (stream gauges, river balance sheets, and C2VSim) the accuracy of water supply and balance data related to the surface water and groundwater systems cannot be assessed; even with those additional data sources a satisfactory balance could not be obtained. The water accounting templates also have deficiencies because they generally assume a single standalone water budget zone and do not have sufficient components for routing water that flows outside of the system boundaries, but do not go to a stream or a designated use. The accounting templates also do not deal with water budget zones where streams lie on, or outside of, the boundary of a water budget zone. And finally, groundwater interactions that do not involve direct use or recharge, such as the injection of groundwater to create a salinity barrier, or percolation that goes to unusable groundwater layers, could not be sufficiently identified by the water accounting templates in their current forms.

7.1 Recommendations for Improvements to the Water Supply and Balance Data

While the water supply and balance data are the most comprehensive statewide water dataset that exists, it is still insufficient to develop a complete water budget as it focuses only on developed water supply and use, generally focused on the land system. The following recommendations are made to substantively improve the utility of the water supply and balance data for water accounting:

- Boundaries of the water supply and balance data should be revisited to include streams within the area rather than on boundaries when possible.
  - If streams cannot be incorporated into the area for better tracking, stream balance sheets, such as those maintained by the South Central Region Office, should be incorporated into the water supply and balance data.
- Precipitation and runoff data are available from Cal-SIMETAW and used in

various steps of the balance but are not utilized by the final balances in the water supply and balance data. These data should be incorporated into water balances.

- Groundwater representation in the water supply and balance data are insufficient to characterize groundwater systems. While groundwater extraction is estimated by the water supply and balance data, other important groundwater interactions are not available which prevents accurately balancing the groundwater system. Additional groundwater information should be incorporated into the water supply and balance data. One potential source that could be considered for this purpose is the groundwater sustainability plan annual reports and integrated groundwater and surface water models developed for the area of interest.

7.2 Recommendations for Improvements to the Water Budget Accounting Template

As discussed in Section 3, the water budget accounting templates were also evaluated for how well they captured the water supply and balance data. Most of the water supply and balance data could be mapped into the water accounting templates. But, to ensure consistency with the water supply and balance data, the following components of the water accounting templates may need to be addressed:

- Update the surface water delivery term to account for additional components such as intentional conveyance seepage and imported waste waters.
- Add a conveyance return flow component for water that is diverted off the surface water system into conveyance facilities but ultimately returns to the surface water system.
- Update the recycled water export component to a more generic land system export component.
- Revisit wastewater tracking to account for wastewater produced within a region, including when wastewater does not go to applied water reuse or recycled water.
- Clarify accounting of snowpack.
- Rename existing conveyance seepage component to conveyance recharge component.
- Add optional tracking for water used to produce energy.

7.3 Recommendations for Future Work

The Merced basin pilot study highlighted several challenges for transitioning from water supply and balance data to comprehensive water accounting. The following recommendations are made to help overcome the challenges in a systematic way.

1. Expand the Merced basin pilot study to refine the water budgets developed in the pilot study by reviewing, assessing, and using available data and information from annual reports submitted for GSPs within the Merced basin, C2VSim, AWMPs, UWMPs, and other locally available data and information. The goal will be to close the loop for a complete water accounting of the basin by adding all other available data to the water supply and balance data.
2. Conduct additional pilot studies in selected California hydrologic regions. The studies should consider regional variability, data availability, and organizational capacity. These additional pilot studies will be conducted to provide a comprehensive water accounting based on the water budget information compiled in California Water Plan, California's Groundwater, GSPs, C2VSim, AWMPs, UWMPs, and other water management activities to the standardized water accounting templates and common vocabulary of the Water Budget Handbook.
3. Develop a roadmap for developing basin, watershed, regional, and statewide water budgets.
4. Refine the groundwater system in the water budget schematic to account for saline intrusion and potential saline intrusion barriers to reduce or prevent the saline intrusion by installing and operating dedicated groundwater injection wells.
5. Refine the groundwater system in the water budget schematic to account for the complex interactions in a multilayered groundwater system.

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Appendix A. Main Balance Spreadsheet

Appendix A is an extensive Excel spreadsheet with supporting data for this Pilot Project is available on the CNRA Open Data Platform at the following link: Water Balance to Water Budget Pilot Project Data - Datasets - California Natural Resources Agency Open Data (https://data.cnra.ca.gov/dataset/b85e0357-314f-4f22-ad5e-703a511b53a8?).

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