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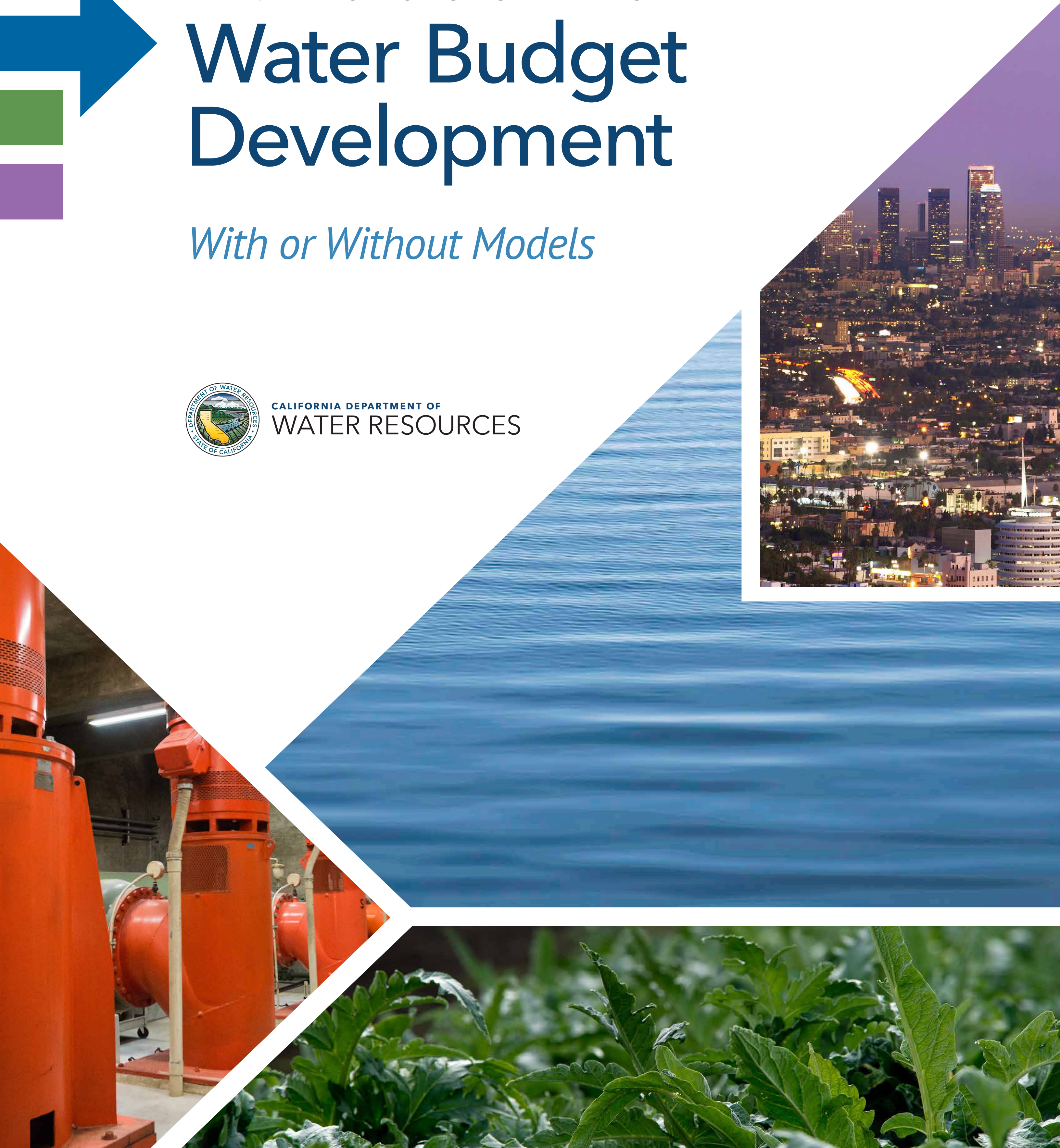
Handbook for Water Budget Development

With or Without Models

CALIFORNIA DEPARTMENT OF
WATER RESOURCES



Using This Handbook

- The "Handbook for Water Budget Development: With or Without Models" (Water Budget Handbook) provides a catalog of methods that a water agency may consider based on their basin setting, needs, availability of data and tools, and expertise. It is not prescriptive in what methods an agency should apply and does not impose requirements as to how a water budget should be developed for any compliance purposes. It serves as a technical resource that provides information on a suite of methods and data sources and is provided as technical assistance to parties interested in developing water budgets.
- The Sustainable Groundwater Management Act and Groundwater Sustainability Plan Regulations specify the requirements of a groundwater sustainability plan. While the Water Budget Handbook describes methods a groundwater sustainability agency may use to estimate water budgets, following these methods or any additional guidance in this handbook does not guarantee approval of the resulting groundwater sustainability plan.
- Water budgets developed using the methods and accounting template described in the Water Budget Handbook are not meant to satisfy the requirements for a water right application. Additional pertinent studies and data collection may be necessary to satisfy those requirements.
- The guidance and methods presented in the Water Budget Handbook can be used to support water planning decisions by resource managers as they assess potential actions to improve the water portfolio and sustainability within their management areas. Additional guidance and methods beyond those discussed in this handbook may be required for developing water budgets to support their decision making.
- The case studies for the modeling and non-modeling approaches are included as practical examples of applying the methods and models presented in the Water Budget Handbook. For a specific management area of interest, relevant data should be compiled for developing water budget estimates and additional work may be needed to confirm or refine the estimates to support water management decisions.
- The Data Resources Directory included in the Water Budget Handbook provides an organized inventory of relevant information, although it is not all-inclusive. In addition, some resources may be duplicative, covering the same information but in different formats or time scales. Users of the directory are responsible for independently verifying and understanding the applicability of the information provided.

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Foreword

Water is the essence of life for California. It touches everything from public health and safety to the environment and the economy. The state needs sustainable and resilient water resources so that all Californians have access to safe and reliable drinking water, its native plants and animals and their ecosystems thrive, and its farms and businesses are productive.

The management, protection, and efficient use of water is a shared responsibility of every Californian. Accurate accounting of the state's water resources is vital because a resource that is not measured cannot be managed. The California Water Code requires the development of water budgets to better account for the water entering and leaving a given area.

A water budget provides an understanding of historical conditions and how future changes to supply, demand, hydrology, population, land use, and climatic conditions may affect an area. Water agencies use water budgets for a variety of purposes, such as water supply planning and evaluating the effectiveness of water management actions.

Today, several factors are hindering the development of water budgets, including inconsistent definitions, nonstandard water accounting, poor documentation, inconsistent description of inter-basin flows, differing interpretation of model results, and widely dispersed data sources.

The "Handbook for Water Budget Development: With or Without Models" is a practical reference guide that addresses these challenges. It fills a significant gap by systematically presenting relevant information in a single publication. Its use will facilitate consistent development and communication of water budget information by diverse water management entities across the state.

The California Department of Water Resources believes that this comprehensive handbook will reduce the cost of water budget development and documentation for local and regional agencies. It will contribute to better communication and information exchange among those who manage and use water as a shared resource.

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Acronyms and Abbreviations

af/a	acre-feet per acre
af/y	acre-feet per year
BCM	U.S. Geologic Survey’s Basin Characterization Model
C2VSim	California Central Valley Groundwater Surface Water Simulation
CP	cultural practices
CDEC	California Data Exchange Center
CVHM	Central Valley Hydrologic Model
DAU	detailed analysis units
DAUCO	detailed analysis units by county
DEM	digital elevation model
DWR	California Department of Water Resources
ET	evapotranspiration
ETAW	evapotranspiration of applied water
GIS	geographic information system
GPCD	gallons per capita per day
GSA	groundwater sustainability agency
GSP	groundwater sustainability plan
HCM	hydrogeologic conceptual model
IDC	Integrated Water Flow Model Demand Calculator
ITRC	Irrigation Training and Research Center
IWFM	Integrated Water Flow Model

KRWA	Kings River Water Association
METRIC	Mapping Evapotranspiration at high Resolution with Internalized Calibration
MODFLOW-OWHM	MODFLOW One Water Hydrologic Flow Model
MODIS	Moderate Resolution Imaging Spectroradiometer
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
PRISM	Parameter-elevation Relationships on Independent Slopes Model
Reclamation	U.S. Bureau of Reclamation
RWQCB	Los Angeles Regional Water Quality Control Board
SEBAL	Surface Energy Balance Algorithms for Land
SGMA	Sustainable Groundwater Management Act
SIMS	Satellite Irrigation Management Support
SSEBop	Simplified Surface Energy Balance
State Water Board	State Water Resources Control Board
taf	thousand acre-feet
TOPS	Terrestrial Observation and Prediction System
UC	University of California
USGS	U.S. Geological Survey
WWTP	wastewater treatment plant

1. INTRODUCTION

1.1 PURPOSE AND NEED

The purpose of the Handbook for Water Budget Development: With or Without Models (Water Budget Handbook), prepared by the California Department of Water Resources (DWR), is to provide the California water resources community with a resource to develop water budgets for any geographic area and time period, using modeling and non-modeling approaches.

A water budget is a critical element of water management planning as it provides an understanding of historical conditions and how future changes to supply, demand, hydrology, population, land use, and climatic conditions will affect a geographic area. Water agencies may use water budgets for a variety of purposes, such as water supply planning, preparing feasibility studies, facilitating integrated water resources management, estimating and quantifying water resources, identifying data gaps, and forecasting optimum water management actions.

Water budget development is mandated by recent legislation in California. The Groundwater Sustainability Plan Regulations, adopted pursuant to the Sustainable Groundwater Management Act (SGMA) of California[1], requires all high- and medium-priority groundwater basins in California prepare a groundwater sustainability plan (GSP) that "…shall include a water budget for the basin that provides an accounting and assessment of the total annual volume of groundwater and surface water entering and leaving the basin, including historical, current and projected water budget conditions, and the change in the volume of water stored." Additionally, Assembly Bill 1668, passed in 2018, requires agricultural water management plans to include "an annual water budget based on the quantification of all inflow and outflow components for the service area of the agricultural water supplier."

A review of current hydrologic literature revealed that there is no single practical reference guide that is available for developing water budgets. To

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[1] AB 1739 (Dickinson), SB 1168 (Pavley), and SB 1319 (Pavley), collectively known as the Sustainable Groundwater Management Act (SGMA), September 16, 2014

support development of water budgets consistent with SGMA requirements, DWR published the Water Budget Best Management Practices (Water Budget BMP) in December 2016. The Water Budget BMP describes the fundamental water budget concepts and the relationships among different water budget components. The Water Budget Handbook systematically presents the existing, but unorganized, information on various methods and data sources for developing estimates of water budget components.

This Water Budget Handbook is not prescriptive in what methods a water agency should apply to develop water budgets; rather, the handbook provides a catalog of methods that an agency may consider based on its needs, data and tool availability, and expertise.

1.2 INNOVATIONS

The Water Budget Handbook is an innovation by itself in that it is the first-ever single-volume technical reference that explicitly describes how to develop water budgets with or without models. Other innovations in this Water Budget Handbook are:

1. First-ever **total water budget** with three-dimensional representation of water budget components and common vocabulary, which was vetted with various DWR programs, State Water Resources Control Board, U.S. Geological Survey, and academia (University of California [UC], Davis, UC San Diego, UC Merced) to facilitate understanding and communication.
2. **Decision tree** to streamline selection of a modeling or a non-modeling approach for water budget development.
3. **Water Budget Accounting Template** to organize and present inflows (credits) and outflows (debits) for the land system, the surface water system, and the groundwater system.
4. **Case studies** demonstrating development of water budgets with a model (modeling approach) and without a model (non-modeling approach).
5. First-ever compilation of relevant **key data sources** with tips and practical advice on how to use the sources to develop estimates of various water budget components.

1.3 TOTAL WATER BUDGET

Total water budget is a concept found in the California Water Code Section 10721: “an accounting of the total groundwater and surface water entering and leaving a basin including the changes in the amount of water stored.” The **total water budget** is a comprehensive accounting of all inflows to and outflows from the three interrelated and interacting systems in a water budget zone:

- Land system.
- Surface water system.
- Groundwater system.

A **water budget zone** represents any user-defined water management area, such as a watershed, groundwater basin, water district, groundwater sustainability agency (GSA), or other geographical area. The total water budget is developed from individual water budgets of each of the three systems mentioned above. A schematic representation of inflows and outflows in these systems within a water budget zone is presented in Figure 1-1. Flows entering and leaving the water budget zone are shown as blue and orange arrows, respectively; flows from one system to another are shown as green arrows, and internal flows within a system are shown as purple arrows. Definitions of the water budget components shown in Figure 1-1 are provided in Table 1-1. It should be noted that all components shown may not be applicable or relevant to a particular water budget zone depending on the geographic setting and water management operations. For example, there may not be any applied water reuse or recycled water in a water budget zone. Furthermore, data for some applicable and/or relevant water budget components may not be available separately; those components would need to be combined with related water budget components. For example, stored water extraction may not be tracked separately in a water budget zone; in such a case, total groundwater extraction will be used as a combined total of two components: (1) groundwater extraction, and (2) stored water extraction. The purpose of Figure 1-1 is not to prescribe the required components of the total water budget but to make the user of the Water Budget Handbook aware of various water budget components and their pathways among the land system, surface water system, and groundwater system within a water budget zone.

The three interacting systems — the land system, the surface water system, and the groundwater system — and the corresponding individual system water budgets that comprise the total water budget are described below.

1.3.1 Land System

The **land system** is 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 unsaturated zone (also known as vadose zone) is the portion of the subsurface that lies between the bottom of the land surface and the water table that defines the upper boundary of the groundwater system. It includes the root zone, which is the top layer of the unsaturated portion of the subsurface designated by the depth of the plant roots that draw moisture from the soil. The thickness of the unsaturated zone varies seasonally. The variation in thickness may be caused by groundwater pumping, water management practices, or climatic conditions. In areas with shallow groundwater conditions, the groundwater system may connect directly to the land surface, thus eliminating the unsaturated zone, allowing direct uptake of groundwater by plants, and potentially causing groundwater to discharge directly to the land surface through seeps, wetlands, or springs.

The **land system water budget** is an analysis of inflows to and outflows from the land system 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 as well as the surface water and the groundwater systems. The root zone and part of the unsaturated zone immediately below the root zone store infiltrated water for later transpiration or evaporation. The portion of the applied water and precipitation that percolates all the way to the water table becomes groundwater recharge. Water in the unsaturated zone (including water in the root zone) may move laterally down gradient and re-emerge in canals and streams without recharging into the groundwater system. This lateral shallow subsurface flow is also called interflow and may become applied water reuse to meet applied water demands on downslope agricultural lands within the water budget zone.

As shown in Figure 1-1, inflows to the land system include surface water diversions from rivers and streams (streams), groundwater extraction, and precipitation onto the land surface. In areas with a high groundwater table or where the subsurface geology causes outflow from the groundwater system to the land surface, additional inflows to the land system may come from capillary movement into the root zone or from direct outflow of groundwater onto the land surface through seeps, wetlands, or springs. Outflows from the land system include rainfall-runoff and 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, which includes the root zone. The change in storage in lakes and streams is included in the change in surface water storage.

1.3.2 Surface Water System

The **surface water system** is the portion of the water budget zone that includes streams, conveyance facilities and diversion ditches, and lakes and reservoirs (lakes) that are part of the water supply system for meeting agricultural, urban, and managed wetlands applied water demands.

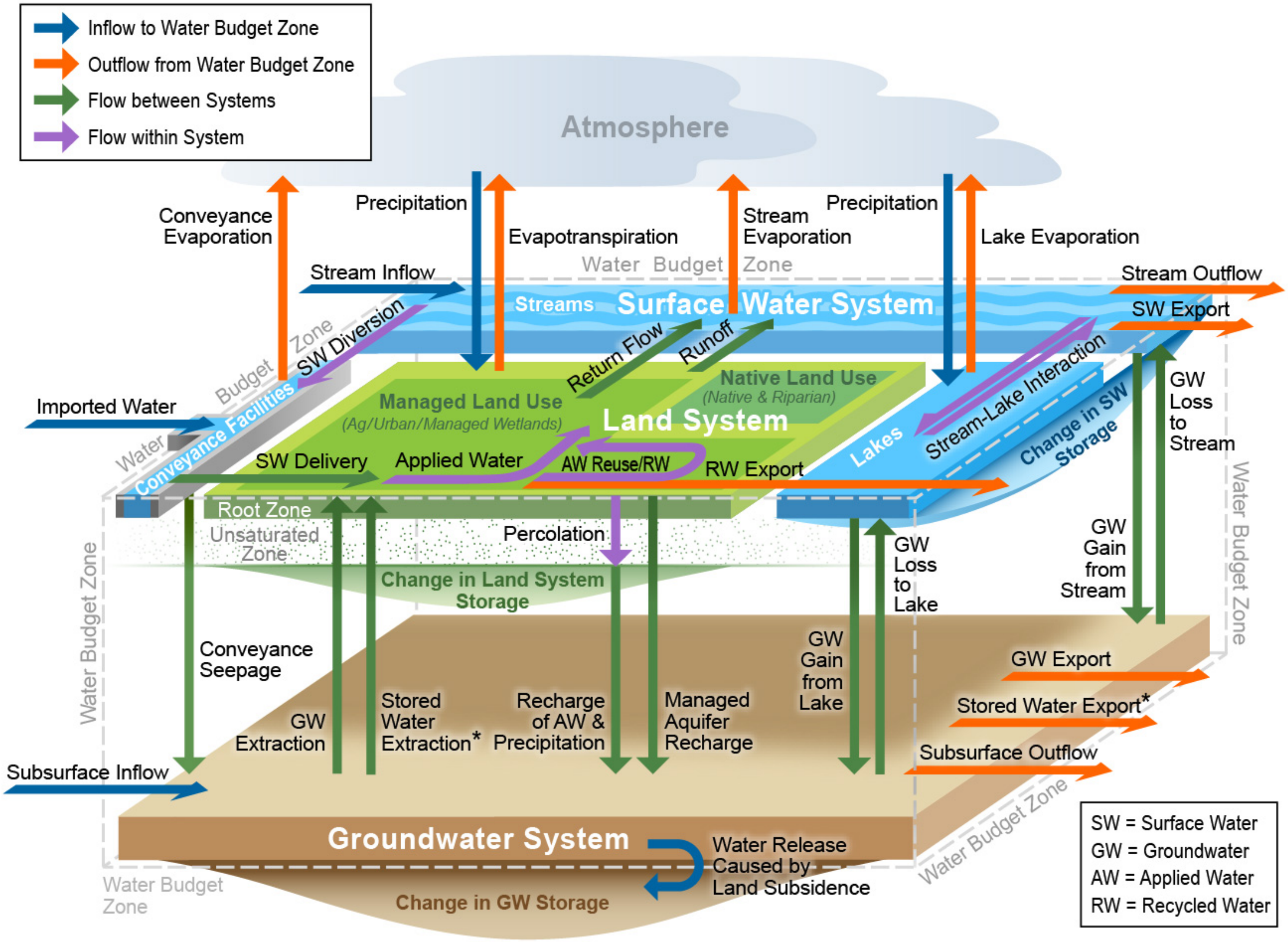
The **surface water budget** is an analysis of inflows to and outflows from the surface water system within a water budget zone, including the change in surface water storage. As shown in Figure 1-1, inflows to the surface water system include stream flows and imported water entering the water budget 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.

1.3.3 Groundwater System

The groundwater system is 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. As shown in Figure 1-1, 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. Additional outflows from the groundwater system may occur as a result of (1) shallow groundwater discharge from seeps, wetlands, and springs, and (2) evapotranspiration and bare soil evaporation when the capillary fringe of the water table rises to within the root zone or the soil surface.

Figure 1-1 Total Water Budget Schematic



*For clarification, see Table 1-1.

Table 1-1 Definitions of Total Water Budget Schematic Components Shown in Figure 1-1

Water Budget Component (Alphabetical)	**Definition**
Applied Water (AW)	Volume of water delivered to the intake of a city water system, a factory, a farm headgate, managed wetlands, or managed aquifer recharge; it includes all sources of supply (surface water, groundwater, applied water reuse, and recycled water).
Applied Water (AW) Reuse	Volume of applied water contributing to (1) lateral flow below the land surface that is influenced by impermeable layers and re-emerges as return flow for reuse in the land system, (2) tailwater available for reuse in the land system, or (3) a combination of both.
Change in Groundwater (GW) Storage	Net change in the volume of groundwater stored within the underlying aquifer of the water budget zone.
Change in Land System Storage	Net change in the volume of water stored within the land system, which includes ponded water on the land surface (not including streams, lakes, and conveyance facilities) and soil moisture within the unsaturated zone, which includes the root zone.
Change in Surface Water (SW) Storage	Net change in the volume of water stored within the surface water system, which includes lakes and reservoirs, streams, and conveyance facilities.
Conveyance Evaporation	Volume of water evaporated into the atmosphere from conveyance facilities, other than streams, during water delivery.
Conveyance Seepage	Volume of water recharged to the groundwater system from the conveyance facilities, other than streams, during water delivery.
Evapotranspiration	Volume of water entering the atmosphere through the combined process of evaporation from soil and plant surfaces and transpiration from plants.
Groundwater (GW) Export	Volume of groundwater pumped (extracted) from the underlying aquifer for use outside the water budget zone. It does not include groundwater extraction, stored water extraction, and stored water export.
Groundwater (GW) Extraction	Volume of groundwater pumped (extracted) from the underlying aquifer(s) for use within the water budget zone. It does not include groundwater export, stored water extraction, and stored water export.
Groundwater (GW) Gain from Lake	Volume of water entering the groundwater system from lakes and reservoirs.

Water Budget Component (Alphabetical)	**Definition**
Groundwater (GW) Gain from Stream	Volume of water entering the groundwater system from rivers and streams.
Groundwater (GW) Loss to Lake	Volume of water entering lakes and reservoirs from the groundwater system.
Groundwater (GW) Loss to Stream	Volume of water entering rivers and streams from the groundwater system.
Imported Water	Volume of water brought from outside the water budget zone for use within the water budget zone, such as State Water Project water, Central Valley Project water, water produced from desalination of ocean water, and water produced from desalination of deep groundwater from below the base of freshwater.
Lake Evaporation	Volume of evaporation from lakes and reservoirs.
Managed Aquifer Recharge	Volume of water intentionally added to the groundwater system as part of defined recharge and water banking programs through spreading basins, injection wells, and other means.
Percolation	Volume of applied water and precipitation that travels from the root zone to the unsaturated zone of the aquifer; this water then travels either vertically into the groundwater system or horizontally into the surface stream system.
Precipitation	Volume of water vapor that falls to the earth (land and surface water systems) as rain, snow, hail, or is formed on the earth as dew, and frost.
Recharge of Applied Water and Precipitation	Volume of applied water and precipitation that travels vertically through the soil/unsaturated zones and reaches the saturated zone of the aquifer (groundwater system).
Recycled Water (RW)	Volume of water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur within the water budget zone. It includes wastewater that is treated, stored, distributed, and reused or recirculated for beneficial uses.
Recycled Water (RW) Export	Volume of recycled water diverted from the land system within a water budget zone for use outside the zone.
Return Flow	Volume of applied water that is not consumptively used and flows to the surface water system. It includes treated wastewater discharges to the surface water system.

Water Budget Component (Alphabetical)	**Definition**
Runoff	Volume of water flowing into the surface water system within a water budget zone from precipitation over the land surface.
Stored Water Export*	Volume of groundwater pumped (extracted) from the underlying aquifer(s) through a defined recharge and extraction program for use outside the water budget zone. For example, a water bank with dedicated extraction wells can provide data for stored water export. It does not include stored water extraction, groundwater extraction, and groundwater export. Groundwater export and stored water export will be combined if stored water export amounts are unknown or are not separately measured. In such a case, the total volume of combined exports will be reported as groundwater export.
Stored Water Extraction*	Volume of groundwater pumped (extracted) from the underlying aquifer(s) through a defined recharge and extraction program for use within the water budget zone. For example, a water bank with dedicated extraction wells can provide data for stored water extraction. It does not include stored water export, groundwater extraction, and groundwater export. Groundwater extraction and stored water extraction will be combined if stored water extraction amounts are unknown or are not separately measured. In such a case, the total volume of combined extractions will be reported as groundwater extraction.
Stream Evaporation	Volume of water evaporated into the atmosphere from streams.
Stream Inflow	Volume of water entering through streams at the periphery of a water budget zone.
Stream Outflow	Volume of water leaving through streams at the periphery of a water budget zone.
Stream-Lake Interaction	Volume of water exchanged between streams and lakes.
Subsurface Inflow	Volume of water entering as groundwater into a water budget zone through its subsurface boundaries.
Subsurface Outflow	Volume of water leaving as groundwater from a water budget zone through its subsurface boundaries.
Surface Water (SW) Delivery	Volume of surface water delivered to a water budget zone. This does not equal the volume of surface water diversion and imported water because the latter also include conveyance seepage and evaporation during transport of the water.
Surface Water (SW) Diversion	Volume of water taken from the surface water system within a water budget zone for use within the zone.

Water Budget Component (Alphabetical)	**Definition**
Surface Water (SW) Export	Volume of water diverted from the surface water system within a water budget zone for use outside the zone.
Water Release Caused by Land Subsidence	Volume of water released to an aquifer on a one-time basis as a result of land subsidence, which is caused by the inelastic consolidation of porous fine-grained material.

1.4 WATER BUDGET ACCOUNTING TEMPLATE

Water budget accounting involves accounting of all inflows and outflows within each of the three systems, which aggregates into total water budget accounting. A template for water budget accounting will facilitate standardization, error checking, and correction of water budget estimates. Use of a standardized template will also result in improved communication and coordination with neighboring water agencies through consistent water budget accounting across boundaries and water budget zones. An example template is provided in Figure 1-2 through 1-5. The template is available in accessible Excel format on the Water Budget Handbook webpage. The standardized template applies to both modeling and non-modeling approaches discussed in Section 2, "Water Budget Development Process." The inflow and outflow components of the land, surface water, and groundwater systems are shown as credits (+) or debits (-) to facilitate proper accounting of different water budget components. The relationships of the components in a system with components in other systems are provided in the rightmost column of Figures 1-2 through 1-5.

Figure 1-2 Water Budget Accounting Template — Land System Water Budget

Color Key:

Blue	Inflow to Water Budget Zone
Orange	Outflow from Water Budget Zone
Green	Flow between Systems
Purple	Flow within Systems

LAND SYSTEM WATER BUDGET			
Flow Type	**Component**	**Credit(+)/ Debit(-)**	**Relationship with Other Systems**
Inflow	Precipitation on Land System	+	
Inflow	Surface Water Delivery	+	Equal to the *Surface Water Delivery* term in the surface water system outflow
Inflow	Groundwater Extraction	+	Equal to the *Groundwater Extraction* term in the groundwater system outflow
Inflow	Stored Water Extraction	+	Equal to the *Stored Water Extraction* term in the groundwater system outflow
Inflow	Applied Water Reuse/Recycled Water		
Inflow	Applied Water		Sum of *Surface Water Delivery* , *Groundwater Extraction* , *Stored Water Extraction* , and *Applied Water Reuse/Recycled Water*
Inflow	*Total Inflow*		*Precipitation* plus *Surface Water Delivery* plus *Groundwater Extraction* plus *Stored Water Extraction*
Outflow	Evapotranspiration	-	
Outflow	Runoff	-	Equal to the *Runoff* term in Surface Water System*
Outflow	Return Flow	-	Equal to the *Return Flow* term in Surface Water System*
Outflow	Recharge of Applied Water	-	Equal to the *Recharge of Applied Water* term in the groundwater system
Outflow	Recharge of Precipitation	-	Equal to the *Recharge of Precipitation* term in the groundwater system
Outflow	Managed Aquifer Recharge	-	Equal to the *Managed Aquifer Recharge* term in the groundwater system
Outflow	Recycled Water Export	-	
Outflow	*Total Outflow*		*Evapotranspiration* plus *Runoff* plus *Return Flow* plus *Recharge of Applied Water* plus *Recharge of Precipitation* plus Managed Aquifer Recharge *plus Recycled Water Export*
Storage Change	Change in Land System Storage		
Land System Mass Balance Error			

* For cases where the surface water system is outside the water budget zone, some of these components will require additional consideration to characterize correctly.

Figure 1-3 Water Budget Accounting Template — Surface Water System Water Budget

Color Key:

Blue	Inflow to Water Budget Zone
Orange	Outflow from Water Budget Zone
Green	Flow between Systems
Purple	Flow within Systems

SURFACE WATER SYSTEM WATER BUDGET

Flow Type	Component	Credit(+)/ Debit(-)	Relationship with Other Systems
Inflow	Stream Inflow	+	
Inflow	Imported Water	+	
Inflow	Precipitation on Lakes	+	
Inflow	Runoff	+	Equal to the *Runoff* term in land system*
Inflow	Return Flow	+	Equal to the *Return Flow* term in the land system*
Inflow	Stream Gain from Groundwater	+	Equal to the *Groundwater Loss to Stream* term in the groundwater system
Inflow	Lake Gain from Groundwater	+	Equal to the *Groundwater Loss to Lake* term in the groundwater system
Inflow	*Total Inflow*		*Stream Inflow* plus *Imported Water* plus *Precipitation on Lakes* plus *Runoff* plus *Return Flow* plus *Stream Gain from Groundwater* plus *Lake Gain from Groundwater*
Outflow	Stream Outflow	-	
Outflow	Surface Water Exports	-	
Outflow	Surface Water Diversions		*Surface Water Delivery* minus *Imported Water* plus *Conveyance Evaporation* plus *Conveyance Seepage*
Outflow	Conveyance Evaporation	-	
Outflow	Conveyance Seepage	-	Equal to the *Conveyance Seepage* term in the groundwater system
Outflow	Surface Water Delivery	-	Equal to the *Surface Water Delivery* term in land system
Outflow	Stream Loss to Groundwater	-	Equal to the *Gain from Stream* term in the groundwater system
Outflow	Lake Loss to Groundwater	-	Equal to the *Groundwater Gain from Lake* term in the groundwater system
Outflow	Lake Evaporation	-	
Outflow	Stream Evaporation	-	
Outflow	*Total Outflow*		*Stream Outflow* plus *Surface Water Exports* plus *Conveyance Evaporation* plus *Conveyance Seepage* plus *Surface Water Delivery* plus *Stream Loss to Groundwater* plus *Lake Loss to Groundwater* plus *Lake Evaporation plus Stream Evaporation*
Storage Change	Change in Surface Water Storage		
Surface Water System Mass Balance Error			

* For cases where the surface water system is outside the water budget zone, some of these components will require additional consideration to characterize correctly.

Figure 1-4 Water Budget Accounting Template — Groundwater System Water Budget

Color Key:

Blue	Inflow to Water Budget Zone
Orange	Outflow from Water Budget Zone
Green	Flow between Systems
Purple	Flow within Systems

GROUNDWATER SYSTEM WATER BUDGET			
Flow Type	**Component**	**Credit(+)/ Debit(-)**	**Relationship with Other Systems**
Inflow	Recharge of Applied Water	+	Equal to the *Recharge of Applied Water* term in the land system
Inflow	Recharge of Precipitation	+	Equal to the *Recharge of Precipitation* term in the land system
Inflow	Managed Aquifer Recharge	+	Equal to the *Managed Aquifer Recharge* term in the land system
Inflow	Groundwater Gain from Stream	+	Equal to the *Stream Loss to Groundwater* term in the surface water system
Inflow	Groundwater Gain from Lake	+	Equal to the *Lake Loss to Groundwater* term in the surface water system
Inflow	Conveyance Seepage	+	Equal to the *Conveyance Seepage* term in the surface water system
Inflow	Subsurface Inflow	+	
Inflow	Water Release Caused by Land Subsidence	+	
Inflow	*Total Inflow*		*Recharge of Applied Water plus Recharge of Precipitation plus Managed Aquifer Recharge plus Groundwater Gain from Stream plus Groundwater Gain from Lake plus Conveyance Seepage plus Subsurface Inflow plus Water Release Caused by Land Subsidence*
Outflow	Groundwater Extraction	-	Equal to the *Groundwater Extraction* term in the land system
Outflow	Stored Water Extraction	-	Equal to the *Stored Water Extraction* term in the land system
Outflow	Groundwater Loss to Stream	-	Equal to the *Stream Gain from Groundwater* term in the surface water system
Outflow	Groundwater Loss to Lake	-	Equal to the *Lake Gain from Groundwater* term in the surface water system
Outflow	Subsurface Outflow	-	
Outflow	Groundwater Export	-	
Outflow	Stored Water Export	-	
Outflow	*Total Outflow*		*Groundwater Extraction* plus *Stored Water Extraction* plus *Groundwater Loss to Stream* plus *Groundwater Loss to Lake* plus *Subsurface Outflow* plus *Groundwater Export* plus *Stored Water Export*
Storage Change	Change in Groundwater Storage		
Groundwater System Mass Balance Error			

Figure 1-5 Water Budget Accounting Template — Total Water Budget

Color Key:

Blue	Inflow to Water Budget Zone
Orange	Outflow from Water Budget Zone
Green	Flow between Systems
Purple	Flow within Systems

TOTAL WATER BUDGET

Flow Type	**Component**	**Credit(+)/ Debit(-)**	**Relationship with Other Systems**
Inflow	Precipitation on Land System	+	Equal to the *Precipitation* term in the land system
Inflow	Precipitation on Lakes	+	Equal to the *Precipitation on Lakes* term in the surface water system
Inflow	Stream Inflow	+	Equal to the *Stream Inflow* term in the surface water system
Inflow	Imported Water	+	Equal to the *Imported Water* term in the surface water system
Inflow	Subsurface Inflow	+	Equal to the *Subsurface Inflow* term in the groundwater system
Inflow	Water Release Caused by Land Subsidence	+	Equal to the *Water Release Caused by Land Subsidence* term in the groundwater system
Inflow	*Total Inflow*		*Precipitation on Land System* plus *Precipitation on Lakes* plus *Stream Inflow* plus *Imported Water* plus *Subsurface Inflow* plus *Water Release Caused by Land Subsidence*
Outflow	Evapotranspiration	-	Equal to the *Evapotranspiration* term in the land system
Outflow	Stream Evaporation	-	Equal to the *Stream Evaporation* term in the surface water system
Outflow	Lake Evaporation	-	Equal to the *Lake Evaporation* term in the surface water system
Outflow	Conveyance Evaporation	-	Equal to the *Conveyance Evaporation* term in the surface water system
Outflow	Stream Outflow	-	Equal to the *Stream Outflow* term in the surface water system
Outflow	Subsurface Outflow	-	Equal to the *Subsurface Outflow* term in the groundwater system
Outflow	Surface Water Export	-	Equal to the *Surface Water Export* term in surface water system
Outflow	Groundwater Export	-	Equal to the *Groundwater Export* term in the groundwater system
Outflow	Stored Water Export	-	Equal to the *Stored Water Export* term in the groundwater system
Outflow	Recycled Water Export	-	Equal to the *Recycled Water Export* term in the land system
Outflow	*Total Outflow*		*Evapotranspiration from Land System* plus *Stream Evaporation* plus *Lake Evaporation* plus *Conveyance Evaporation* plus *Stream Outflow* plus *Subsurface Outflow* plus *Surface Water Export* plus *Groundwater Export* plus *Stored Water Export* plus *Recycled Water Export*
Storage Change	Change in Total System Storage		
Total System Mass Balance Error			

2. WATER BUDGET DEVELOPMENT PROCESS

2.1 INTRODUCTION

To properly account for all water budget components under the wide range of circumstances faced by local agencies, a systematic process of identifying, classifying, verifying, summarizing, interpreting, and communicating water budget information is needed. The Water Budget Handbook attempts to respond to this need by defining consistent water budget components (Section 1) and documenting multiple methods for estimating and accounting the water budget components (Sections 3, 4 and 5). Section 2 identifies necessary considerations for water budget development and describes the decision process for selecting appropriate approaches based on needs and availability of data.

2.2 DIFFERENT WAYS OF DEVELOPING A TOTAL WATER BUDGET

A water budget can be developed using (1) a modeling approach and/or (2) a non-modeling approach. The **modeling approach** refers to using an integrated numerical model that includes simulation of processes in the land system, surface water system, and groundwater system at various time scales, such as daily, monthly, or annually. The **non-modeling approach** is an accounting method that uses a combination of assumptions, process equations, and available basic meteorological, hydrologic, and other related data to develop spatially and temporally lumped estimates of various water budget components. The modeling approach is the most comprehensive way of developing the total water budget for a water budget zone. But, development of a defensible integrated numerical model that is well calibrated and has stakeholders' buy-in requires considerable investment in data, tools, people, and process. The non-modeling approach is used in the absence of a robust, accepted integrated numerical model, or when a model may not be needed for estimating the required water budget components.

The non-modeling approach may be a relatively inexpensive way to understand the water budget within a water budget zone and assess whether development of a numerical model is needed to support evaluation of projects and management actions. Additionally, the non-modeling approach provides a preliminary means of developing water budgets and can serve as the fundamental building block toward the modeling approach over time as more data are collected and more tools are developed.

The application of the non-modeling approach helps identify data necessary for developing various water budget components. This Water Budget Handbook systematically presents a compendium of methods and data sources for estimating different water budget components using the non-modeling approach. The same or similar methods are sometimes also the basis for the subprocess models of land, surface water, and groundwater systems within an integrated numerical groundwater and surface water model. Similarly, data sources for water budget development used in the non-modeling approach may also be utilized in developing input data for numerical models and in calibrating and validating those models.

The detail required in a water budget depends on the questions a water agency intends to answer. A more detailed answer will likely require more data and more resources to develop and maintain a numerical model. A simple water budget developed through the non-modeling approach may not be capable of providing sound answers to certain questions that require a more complete understanding of the spatial and temporal scope of the water budget. In contrast, certain basin conditions may require less detail than others, where a non-modeling approach may be adequate for the purpose at hand.

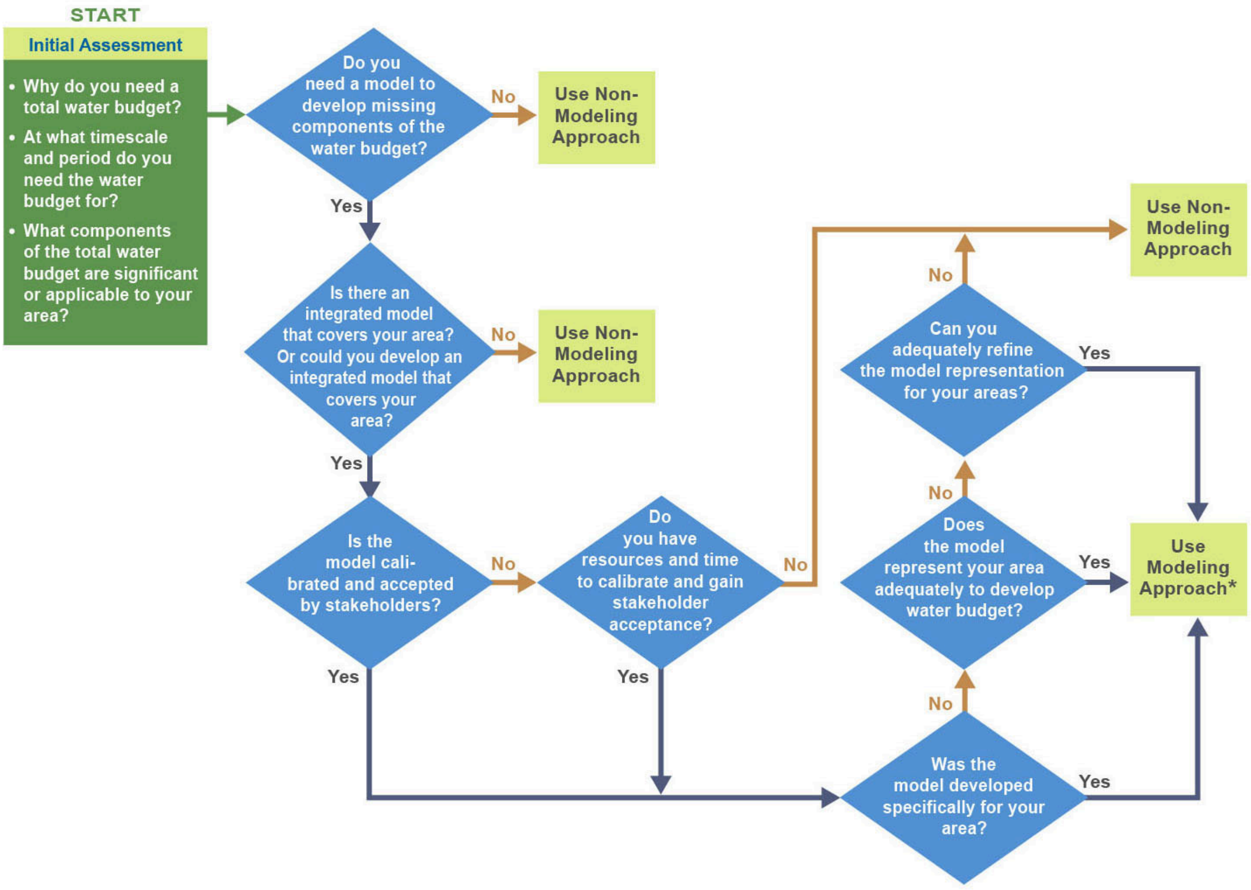
Similarly, although the non-modeling approach can be used to develop projected future water budgets under different management scenarios, the modeling approach is naturally well suited for simulating a range of future conditions. Another unique strength of the modeling approach is its ability to simulate the temporal and spatial aspects of groundwater movement in a detailed way that is not possible using the non-modeling approach. For example, a non-modeling approach may show water recharged as an accretion to groundwater storage, but not the distribution of the recharged water over space and time. In contrast, a numerical model which attempts to represent the physical hydrologic processes would capture this spatial and temporal aspect more accurately. Based on whether these additional capabilities provided by a numerical model are critical for a water agency to manage its basin may dictate its decision to invest in the development/refinement of a numerical model.

The modeling approach allows the evaluation of interdependencies associated with various water budget components, resulting in improved water budgets. Additionally, it facilitates the identification of the range of uncertainties inherent in various water budget components and provides a means to improve water budget estimations over time through collection of supplemental data to address those uncertainties. In the modeling approach, water budget components which have a higher level of certainty can be used to help validate or constrain estimates of the components that carry more uncertainty. For example, groundwater extraction and recharge, two of the largest groundwater budget components in irrigated California basins, have not been measured or reported in many locations. But if an integrated numerical model can both simulate historical fluctuations in groundwater levels and some fluxes that have also been measured (e.g., stream baseflows, conveyance facility flows), the model can reduce the actual uncertainty in the groundwater extraction and recharge numbers. As a result, a well calibrated model with sufficient data representing the physics of groundwater flow allows the use of the model to compute unknown water budget components from other, known or more reliably estimated water budget components and parameters. In such a case, the model helps fill in data gaps.

2.3 DETERMINATION OF WATER BUDGET DEVELOPMENT APPROACH

This Water Budget Handbook is intended to assist water managers, having different levels of data, capacities, and resources, in determining an approach (modeling or non-modeling) to develop a water budget. The decision tree in Figure 2-1 illustrates the logical steps for determining when to use the non-modeling approach and when to use the modeling approach. The significance of each water budget component in a water budget zone of interest should be assessed before embarking on a specific approach for water budget development. There are cases when a hybrid approach of the modeling approach and the non-modeling approach may be best suited for a water budget zone of interest depending on the status of data availability and model features.

Figure 2-1 Decision Tree for Water Budget Development Approach



*If all required water budget components are not available in the selected model, use non-modeling approach to estimate those components

Decision tree process illustrated in Figure 2-1:

Step 1. Initial Assessment:
   A. Why do you need a total water budget?
   B. At what timescale and period do you need the water budget?
   C. What components of the total water budget are significant or applicable to your area?

Step 2. Do you need a model to develop missing components of the water budget?
   A. If no, then use the non-modeling approach.
   B. If yes, then go to Step 3.

Step 3. Is there an integrated model that covers your area? Or could you develop an integrated model that covers your area?
   A. If no, then use non-modeling approach.
   B. If yes, then go to Step 4.

Step 4. Is the model calibrated and accepted by stakeholders?
    A. If yes, go to Step 5.
    B. If no, then do you have resources and time to calibrate and gain stakeholder acceptance?
        a. If no, then use non-modeling approach
        b. If yes, go to Step 5.

Step 5. Was the model developed specifically for your area?
    A. If yes, then go to Step 6.
    B. If no, then does the model represent your area adequately to develop a water budget?
        a. If yes, then go to Step 6.
        b. If no, then can you adequately refine the model representation for your areas?
            1. If yes, then go to Step 6.
            2. If no, then use non-modeling approach

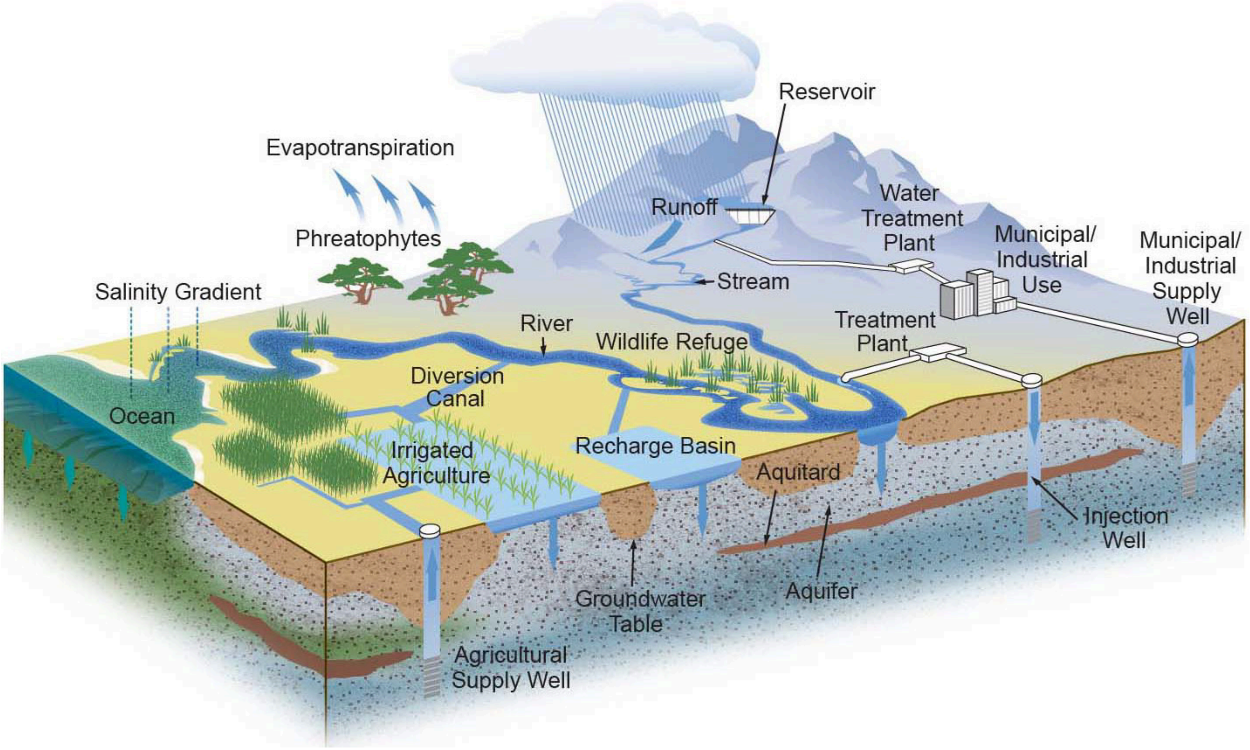
Step 6. Use modeling approach (If all required water budget components are not available in the selected model, use non-modeling approach to estimate those components)

Generally, a non-modeling approach will allow quick calculation of water budgets with available data and simpler methods. If a water agency is not using a model, the methods described in this handbook will help the agency to estimate water budgets. In contrast, an integrated model will be necessary to assess complex groundwater flow patterns, the timing of groundwater recharge, groundwater-streamflow interaction, and long-term future water budget projections. Even when a model is used for water budget development, priority should be given to using measured data when available; model results should not be used as a surrogate for measured data.

2.4 HYDROGEOLOGIC CONCEPTUAL MODEL

Development of a hydrogeologic conceptual model (HCM) is the first step in developing any water budget. An HCM does not include specific quantities of water inflows into or outflows from a basin, but rather provides a general understanding of the physical setting, characteristics, and processes that govern groundwater occurrence and flow within the basin. The purpose of developing an HCM is to simplify the complex natural system and organize relevant field data and information so that the hydrogeologic system can be analyzed (Anderson and Woessner 1992). The HCM forms the basis for mathematical (analytical or numerical) model development and sets the stage for quantifying the water budget components. DWR's Best Management Practices for the Sustainable Management of Groundwater: Hydrogeologic Conceptual Model document provides guidance on how to develop an HCM. A schematic representation of the HCM from the document is reproduced in Figure 2-2.

Figure 2-2 A Schematic Representation of Hydrogeologic Conceptual Model



2.5 BASIN UNDERSTANDING

Once an HCM has been developed and the basin boundary/water budget zone has been delineated, the next step in water budget development is to gain basin understanding. Developing a water budget requires both data and professional judgment based on a sound understanding of the groundwater basin and watershed. Basin understanding is necessary to support assumptions that may be required to complete the water budget and to provide quality control for the results of the analysis.

Data provide the fundamental building blocks for developing water budgets. The steps described in the following subsections will help identify the data available in the basin that is needed to guide basin understanding.

2.5.1 Collect Data

To develop an understanding of the groundwater basin and watershed, a wide variety of available data should be compiled and reviewed. There are several publicly available databases in California that provide useful data to support improved basin understanding. A list of the related data sources is provided in Section 9, "Data Resources Directory."

Selected data elements that describe the groundwater basin or watershed and their potential influence on the water budget are:

- **Topography** — Topography influences the runoff and eventually the recharge of applied water and precipitation, rim inflows, and groundwater interaction with streams.
- **Climate** — Climatic conditions affect both spatial and temporal distribution of recharge of precipitation.
- **Hydrology** — Hydrologic parameters, such as stream stage, affect the stream-aquifer interactions.
- **Land and water use** — Land use conditions of agricultural, urban, and managed wetlands areas affect the amounts of evapotranspiration and applied water (irrigation) requirements, which in turn, affect the recharge of applied water and precipitation. Water use is often a consequence of land use in a given area.
- **Infrastructure** — Project facilities (e.g., lakes, conveyance facilities, diversion structures) constructed over time impact evaporation, recharge, and stream-aquifer interactions.
- **Surface water diversions/deliveries** — Land use activities, availability of conveyance facilities, and hydrologic conditions dictate the quantities of surface water diversions/deliveries.
- **Soil** — Soil parameters such as texture, porosity, field capacity, and hydraulic conductivity can affect the spatial and temporal distribution of recharge of applied water and precipitation.
- **Geologic setting** — Three-dimensional distribution and geometry of geologic deposits form aquifers and aquitards that store groundwater.

- **Aquifer characteristics** — The distribution of aquifer hydraulic conductivity represents the groundwater flow direction and impacts the subsurface flows. Aquifer storage parameters such as specific yield impact the change in groundwater storage.
- **Groundwater elevation data** — Variations in groundwater elevations represent the changes in groundwater storage and are an indication of balance between aquifer inflows and outflows. These data can also help quantify inter-basin flows.
- **Groundwater extraction data** — Land use activities and availability of surface water impact the quantity of groundwater extraction. Droughts and associated reductions in surface water availability result in increased groundwater extraction while a wet hydrology and abundance of surface water result in decreased groundwater extraction.

2.5.2 Review Past Studies

Past studies may contain data and analyses that can support the development of new or revised water budgets. Previous estimates of water budget components may exist for the area of interest and surrounding groundwater basins and watershed of interest. Additional sources of information for development of water budgets with respect to data and methods may include the following, many of which are described in Section 9, "Data Resources Directory."

- DWR studies/reports.
    - California's Groundwater (Bulletin 118).
    - California Water Plan (Bulletin 160).
- DWR region offices.
- Local agencies, including water districts, cities, and counties.
- Groundwater/hydrologic model reports.
    - DWR's California Central Valley Groundwater Surface Water Simulation (C2VSim) model.
    - U. S. Geological Survey (USGS) Central Valley Hydrologic Model (CVHM).
    - DWR's Sacramento Valley Simulation (SVSim) model.
    - Regional and local models.

- USGS scientific investigation reports and circulars.
- Universities and academic organizations.
- Non-governmental organizations.

2.5.3 Complete Data Availability Checklist

Developing a summary of available data can assist in identifying major data gaps and readiness to develop a water budget. A sample data availability checklist, shown in Figure 2-3, displays the water budget components for the land, surface water, and groundwater systems, along with the minimum data needed to calculate each of the components. If the required data for a specific water budget component are not available, then either additional data will need to be collected or the application of a rough approximation technique or an empirical method needs to be used to calculate the water budget component. The missing water budget component may also be back-calculated after all other components of the water budget have been calculated.

Figure 2-3 Example of a Water Budget Components Checklist with Minimum Data Elements

Water Budget Component	Aquifer Characteristics	Groundwater Level	Groundwater Pumping	Precipitation	Land Use	SW Diversion/Delivery	Stream/Canal Flow	Stream/Canal Characteristics	Managed Aquifer Recharge	Soil Characteristics	ET/ Crop Coefficients/ Pan Evap.	Irrigation Practices and Efficiency	Population	Per Capita Water Use	Lake Elevation
Land System															
Precipitation				✓											
Evapotranspiration					✓					✓	✓				
Applied Water				✓	✓					✓	✓	✓	✓	✓	
Surface Water Delivery					✓	✓				✓	✓	✓			
Groundwater Extraction			✓		✓						✓	✓			
Applied Water Reuse and Recycled Water					✓						✓	✓	✓	✓	
Recycled Water Export							✓	✓							
Runoff				✓	✓					✓					
Return Flow					✓					✓	✓	✓			
Change in Land System Storage				✓	✓	✓				✓	✓	✓			
Surface Water System															
Stream Inflow and Outflow							✓								
Surface Water Diversion						✓									
Stream Evaporation							✓	✓			✓				
Conveyance Evaporation							✓	✓							
Conveyance Seepage							✓	✓							
Imported Water and Surface Water Export						✓									
Stream-Lake Interaction		✓				✓	✓	✓							
Lake Evaporation											✓				✓
Change in Surface Water Storage							✓								✓
Groundwater System															
Recharge of Applied Water and Precipitation			✓	✓	✓	✓				✓		✓			
Subsurface Inflow and Outflow	✓	✓													
Stream-Groundwater Interaction		✓				✓	✓	✓							
Lake-Groundwater Interaction		✓				✓	✓	✓							
Managed Aquifer Recharge									✓						
Stored Water Extraction			✓						✓						
Groundwater Export			✓												
Stored Water Export			✓												
Change in Groundwater Storage	✓	✓													

2.5.4 Identify Data Gaps

During the development of a water budget, data gaps will become apparent. Data gaps may appear as limited data, poor-quality data, or inconsistent data. These data gaps should be clearly identified and prioritized to provide direction for developing water budgets in the future by focusing on:

- Components that are most significant for the water budget zone.
- Components that have the highest level of uncertainty and are important to quantify.

Additional data collection is not necessary where sufficient data exist to quantify a water budget component or where the contribution of the component to inflow or outflow is relatively minor.

2.6 WATER YEAR TYPES

Hydrologic conditions represented by water year types can affect the water budget of an area. Dry hydrologic conditions will typically result in less surface water availability, potentially increasing the amount of groundwater extractions and overall lowering of groundwater levels. Wet hydrologic conditions generally do the reverse, resulting in recovery of groundwater levels. The water year types for the Sacramento and San Joaquin valleys are determined by the Sacramento Valley Water Year Index and the San Joaquin Valley Water Year Index. These two indices classify water year types into five categories: wet, above normal, below normal, dry, and critically dry conditions. For an area without an existing water year index, water year types can be developed and classified based on annual precipitation as a percentage of the previous 30-year average precipitation for the area. Additionally, like the Sacramento Valley and San Joaquin Valley indices, water year type determination could also consider antecedent and projected runoff conditions for the classification of a water year.

2.7 WATER BUDGET ANALYSIS PERIOD AND TIME STEPS

During the data collection process for water budget development, focus should be on collecting and analyzing data for different water year types and applicable time scales to improve the understanding of water budgets under a range of hydrologic conditions. Because annual water budgets do not account for seasonal variability within a year, a monthly time scale analysis may be needed to fully capture the interdependencies among water budget components.

To support a more robust analysis, data for multiple consecutive years should be collected. Working with more available recent years' data may also facilitate stakeholder acceptance of the analysis. To examine more extreme hydrologic conditions that may not be reflected in historical records, additional analysis using data from non-consecutive years may be conducted. Water budget analysis may be conducted for various time periods, described below, to meet different planning, operational, and regulatory needs:

- **Single Year — Selected Hydrologic Condition:** A water budget may be developed for a single year that is representative of desired hydrological and operational conditions, such as analysis of increased groundwater pumping in a dry year.
- **Three Year — Selected Hydrologic Conditions:** A water budget may be developed for three non-consecutive years representing extreme hydrologic conditions. This option could be used to evaluate how changes in surface water deliveries affect groundwater storage.
- **Long-Term — 20 to 50 Years of Variable Hydrologic Conditions:** A water budget may be developed for several decades that represents the long-term hydrological condition of the basin and includes one or more cycles of average, wet, and dry years. Selecting a relatively long period for water budget analysis is more likely to include a wide range of hydrological conditions and system responses. This option requires a significant amount of data and is used to evaluate the effects of historical pumping and land use and assessment of alternative management actions. If a model is developed and used, a longer calibration period is beneficial because the model is calibrated based on historical changes in groundwater levels, which are driven by historical changes in land use, groundwater extraction, recharge and climate. As a result, a well-calibrated model will result when at least several decades of historical records are used. Furthermore, when creating a water budget in an area subject to conditions of chronic overdraft, using a 20- to 50-year historical water budget may be necessary to capture a time period before overdraft was occurring. Identifying those key, non-overdraft time periods and the corresponding water budgets is important for the identification of future water management objectives and actions.

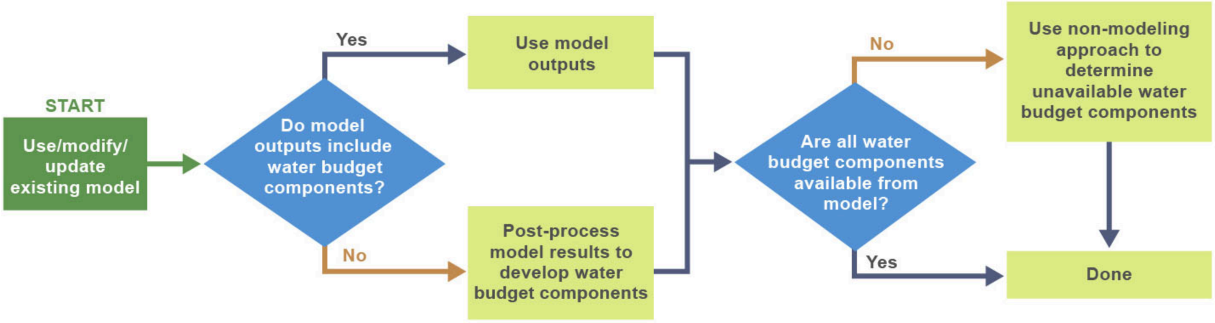
If the water budget analysis is conducted using data from multiple years, an average water budget condition can be estimated by averaging across all the years used for analysis. It is a good practice to maintain and present the information for the individual years including the associated monthly data and analysis, as they provide information on the annual and seasonal variability of water budget under different hydrologic conditions.

2.8 MODELING APPROACH

The modeling approach for developing a water budget involves using an existing integrated model. The process flowchart in Figure 2-4 shows the steps required to obtain the water budget information using the modeling approach. If the model does not provide all water budget components in the water budget zone, then the non-modeling approach can be used to estimate components that are not available from the model.

When using a model for developing a water budget, it should be ensured that the model is well-calibrated and documented. The most important indicator of a well-calibrated model is how closely the model reproduces measured streamflows, groundwater levels, and fluxes. For a model to be considered reliable for use, the model needs to reproduce historical conditions through the adjustment of model parameters within the bounds of hydrogeologic measurements and reasonable assumptions. A well-calibrated model that is accepted by stakeholders may still have uncertainty in its calculated water budget components. This is especially true for water budget components with no measured data available for use in model calibration, which is often the case with stream-aquifer interaction. Uncertainties associated with water budget estimates using the non-modeling approach are usually larger. Even with acknowledgement of uncertainties in water budget estimates with models, one overriding advantage of using a model is its ability to provide estimates of water budget components that cannot be measured. Another advantage of the modeling approach is to better understand and quantify what the uncertainty is in the various water budget components. Understanding the uncertainty allows water managers to make better decisions.

Figure 2-4 **Flowchart for Extracting Water Budget Components from Existing Models**



*The model should be a calibrated model that is accepted by stakeholders and has proper documentation.

Flowchart process illustrated in Figure 2-4:

Step 1. Use/Modify/Update Existing Model.
Step 2. Do model outputs include water budget components?
  A. If yes, then use model outputs, then go to Step 3.
  B. If no then post-process model results to develop water budget components, then go to Step 3.
Step 3. Are all water budget components available from model?
  A. If no, then use non-modeling approach to determine unavailable water budget components.
  B. If yes, then you are done.

Note: The model should be a calibrated model that is accepted by stakeholders and has proper documentation.

Water resources planning and management in California commonly incorporate hydrologic modeling approaches that fall under three broad categories.

- Integrated models.
- Subsystem models.
- Other models.

2.8.1 Integrated Models

Integrated models are fully coupled, numerical groundwater and surface water models that simulate the processes of the terrestrial hydrologic cycle from the land system to the surface water system to the groundwater system. As a result, these models can compute most or all of the water budget components depending on model features and extent of the model application in the water budget zone. But, proper construction of these models requires knowledge of physical processes and numerical modeling, extensive data collection, hydrologic analysis, quality control, calibration, basin understanding, and stakeholder involvement. A successful application also requires familiarity with such models, including underlying codes and assumptions; simply obtaining the model code, populating the model with data, and running the model is not sufficient.

The most commonly used integrated numerical groundwater and surface water models in California are the Integrated Water Flow Model (IWFM) developed by DWR and various MODFLOW versions including the MODFLOW One Water Hydrologic Flow Model (MODFLOW-OWHM) developed by the USGS. Summary descriptions of IWFM and MODFLOW-OWHM are furnished below. Both models are open-source software and available freely from the developers.

2.8.1.1 Integrated Water Flow Model

The IWFM is a water resources planning and management model that simulates the entire hydrologic system including the land surface, surface water, and groundwater systems. IWFM simulates stream flow, soil moisture accounting in the root zone, flow in the unsaturated zone (also known as vadose zone), groundwater flow, and stream-aquifer interactions. A distinctive feature of IWFM is the land use-based approach for calculating water demand, which is also incorporated in other models such as MODFLOW-OWHM. Agricultural and urban water demands can be pre-specified or calculated internally based on different land use types. It also simulates water reuse, tile drains, and lakes or open water areas. Consistent with other similar models, it includes features for simulation of subsurface flow computations across basin boundaries.

IWFM is designed such that during model development, “subregions” may be defined to facilitate the development and assignment of input data. Model elements are grouped into subregions that may represent different types of boundaries and scales depending on the scale of the model application. In addition, there is the ability to specify element groups for assignment of input data. Different datasets can use different element groups for assigning data to the model elements. By default, IWFM outputs water budgets by user defined subregions. In addition to reporting water budgets at the subregional scale, it includes a "Z-Budget" post-processor to generate water budgets for a user defined water budget zone. This feature allows extracting, reporting, and analyzing water budgets for the selected water budget zones.

A list of total water budget components that can be extracted from the different types of water budget outputs of the current version of IWFM (2015.0.706) is provided in Table 2-1. A component-by-component description of how to obtain the various water budget components for the total water budget from model outputs is provided in Section 7, "Case Study: Integrated Water Flow Model." DWR is enhancing IWFM to make all water budget components available as model outputs.

Table 2-1 Availability of Water Budget Components in IWFM Outputs of Version 2015.0.706

Water Budget Component	Availability
Land System	
Precipitation	Available
Evapotranspiration	Available
Applied Water	Available
Surface Water Delivery	Available
Groundwater Extraction	Available
Applied Water Reuse and Recycled Water	Only Reuse is Available
Recycled Water Export	Not Available
Runoff	Available
Return Flow	Available
Change in Land System Storage	Available
Surface Water System	
Stream Inflow and Outflow	Available
Surface Water Diversion	Available
Stream Evaporation	Not Available
Conveyance Evaporation	Available (see Note A)
Conveyance Seepage	Available (see Note B)
Imported Water and Surface Water Export	Available
Stream-Lake Interaction	Available
Lake Evaporation	Available
Change in Surface Water Storage	Available
Groundwater System	
Recharge of Applied Water and Precipitation	Available
Subsurface Inflow and Outflow	Available
Stream-Groundwater Interaction	Available
Lake-Groundwater Interaction	Available
Managed Aquifer Recharge	Available (see Note C)
Stored Water Extraction	Available (see Note D)
Groundwater Export	Not Available (see Note E)
Stored Water Export	Not Available (see Note E)

Water Budget Component	Availability
Water Release Caused by Land Subsidence	Available
Change in Groundwater Storage	Available

Table 2-1 Notes:
Note A: Available in diversion detail output. Volume is by diversion and cannot be split into user specified zones.
Note B: Available in diversion detail output. Volume is by diversion and cannot be split into user specified zones.
Note C: Grouped into recharge term in groundwater budget. Recharge also includes recoverable losses from diversions.
Note D: Grouped into total pumping. No easy way to extract aside from looking at input data.
Note E: User can specify where pumping is used but the model only reports total pumping by zone, not where it is applied. One could potentially determine it by comparing the groundwater budget and land and water use budget only if a zone only imports or exports groundwater, but not both.

The California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) is an existing application of IWFM that covers the Central Valley of California. DWR developed, maintains, and periodically updates this model. The model has been used for several large-scale Central Valley studies. It is an integrated numerical groundwater and surface water model that simulates the movement of water through the linked land, surface water, and groundwater systems of the Central Valley. It includes monthly historical stream inflows, surface water diversions, precipitation, land use, and crop acreage data. It simulates historical responses of the Central Valley’s groundwater and surface water systems to historical stresses and can also be used to simulate responses of projected future stresses including the effects of climate change. Results from the model can be used as a source of information and starting point for basins within the Central Valley that currently do not have local models. To use C2VSim for a basin water budget, the first step is to identify whether the model grid covers the area of interest. If the basin coincides with a subregion, results for the area can be extracted as described in Section 7, “Case Study: Integrated Water Flow Model.” If the basin overlaps one or more subregions or is contained within a subregion, a zone will need to be defined for the basin to extract the associated “Z-Budget.” Additional information on C2VSim are furnished in Section 9, “Data Resources Directory.”

2.8.1.2 MODFLOW: One-Water Hydrologic Flow Model

MODFLOW is the USGS's three-dimensional finite difference groundwater model, and it is used for simulating and forecasting groundwater conditions and groundwater-surface water interactions. Originally developed and released solely for groundwater flow simulation in 1984, it now includes additional capabilities to simulate coupled groundwater-surface water systems, solute transport, variable-density flow, and aquifer system compaction and land subsidence. MODFLOW-OWHM is an integrated hydrologic model implementation based on MODFLOW, which also includes the farm process allowing for the simulation of the land system including irrigated agriculture. Since its initial release in 2014, MODFLOW-OWHM was one of three recommended models by the World Bank Water Resource Software Review (Borden et al., 2016) for groundwater-surface water conjunctive use simulation. The model allows for the use of different packages to produce different components of the complete hydrologic budget. Each module outputs its own results, and the output features that link multiple modules will vary based on the components being simulated.

A list of total water budget components that can be extracted from the different types of water budget outputs of the current version of the model (v2.05/31/2018) is provided in Table 2-2. A component-by-component description of how to obtain the various water budget components for the total water budget from model outputs is provided in Section 8, “Case Study: One Water Hydrologic Flow Model.” Depending on the model configuration, users may need to specify additional output files to obtain targeted information for water budget components. User specified budget data are available by package (e.g., Multi-Node Well, General Head Boundary), by water balance subregion (i.e., farm or area of interest), by water balance subregion and land-use type, or for each model cell.

Table 2-2 Availability of Water Budget Components in MODFLOW-OWHM Outputs of Version 1.0.12

Water Budget Component	Availability
Land System	
Precipitation	Available
Evapotranspiration	Available
Applied Water	Available
Surface Water Delivery	Available
Groundwater Extraction	Available
Applied Water Reuse and Recycled Water	Available
Recycled Water Export	Available
Runoff	Available (see Note A)
Return Flow	Available (see Note A)
Change in Land System Storage	Available (see Note B)
Surface Water System	
Stream Inflow and Outflow	Available
Surface Water Diversion	Available
Stream Evaporation	Available
Conveyance Evaporation	Available
Conveyance Seepage	Available
Imported Water and Surface Water Export	Available
Stream-Lake Interaction	Available
Lake Evaporation	Available
Change in Surface Water Storage	Available (see Note C)
Groundwater System	
Recharge of Applied Water and Precipitation	Available
Subsurface Inflow and Outflow	Available
Stream-Groundwater Interaction	Available
Lake-Groundwater Interaction	Available
Managed Aquifer Recharge	Available (see Note D)
Stored Water Extraction	Available (see Note E)
Groundwater Export	Available (see Note F)
Stored Water Export	Available (see Note F)

Water Budget Component	Availability
Water Release Caused by Land Subsidence	Available
Change in Groundwater Storage	Available

Table 2-2 Notes:
Note A: Runoff and return flow are grouped together. Runoff can be output by model cell if desired.
Note B: Change in land system storage is only available if the unsaturated zone flow package is used.
Note C: Dynamic reservoir operations mimics operator agreements to meet downstream demands subject to delivery gains and losses, required fish flow rates, and flood protection.
Note D: Managed aquifer recharge can be simulated but output may be grouped with other recharge.
Note E: Stored water extraction can be grouped into total pumping, or separated by well.
Note F: Pumping can be assigned and used elsewhere. Exported data are written to well budget files.

The Central Valley Hydrologic Model (CVHM) is an application of MODFLOW-OWHM that covers the Central Valley of California. USGS developed CVHM, an integrated surface water-groundwater flow model, that simulates monthly groundwater and surface water flows, irrigated agriculture, and other key hydrologic processes over the Central Valley. The model simulates groundwater and surface water flows and land subsidence in response to stresses from water use and climate variability in the Central Valley. Like C2VSim, CVHM can also be used to simulate responses to projected future stresses including the effects of climate change. Results from the model can be used as a source of information and starting point for basins within the Central Valley that currently do not have local models. To use it for a basin water budget, the first step is to identify whether the model grid covers the area of interest. If the basin coincides with a subregion, results for the area can be extracted as described in Section 8, "Case Study: One Water Hydrologic Flow Model." If the basin overlaps one or more subregions or is contained within a subregion, a zone will need to be defined for the basin to extract the associated "zone budget." Additional information on CVHM are furnished in Section 9, "Data Resources Directory."

2.8.2 Subsystem Models

Hydrologic subsystem models are numerical models that simulate the hydrologic processes of only one subsystem of the hydrologic cycle. DWR's Integrated Water Flow Model Demand Calculator (IDC) only simulates the land surface processes to calculate agricultural and urban demands as well as root zone water storage changes. USGS's MODFLOW basic version (MODFLOW 2000, MODFLOW 2005, or MODFLOW6) simulates the groundwater system of the hydrologic cycle; many of the existing applications of groundwater models in California are based on MODFLOW basic version or other similar models. USGS's Basin Characterization Model is a grid-based land system model that calculates the water balance for any time step or spatial scale by using climate inputs, precipitation, and minimum and maximum air temperature. Hydrologic subsystem models such as these can only provide estimates of water budget components included in the represented subsystems. An integrated numerical groundwater and surface water model such as IWFM or MODFLOW-OWHM includes the required subsystem models to enable the simulation of the entire hydrologic cycle.

2.8.3 Other Models

When integrated or subsystem models are not needed, or unavailable, simpler models can be developed to capture various levels of detail and complexity of the hydrologic cycle using empirical and analytical methods. These models can be used to estimate several water budget components with different levels of accuracy depending on the methods of estimation and availability of suitable data. Typically, these are developed using spreadsheets and use a monthly or annual accounting for tracking different components of demand (e.g., agricultural, urban, and managed wetlands demand), supply (e.g., surface water diversions and groundwater pumping), inflows (e.g., stream inflows, subsurface boundary inflows, imported water), and outflows (e.g., stream outflows, subsurface boundary outflows, exports). Spreadsheets can also support water budget development using the non-modeling approach, as described in the next subsection, by providing a consistent structure to track individual component estimation as illustrated in Section 6, "Case Study: Non-Modeling Approach."

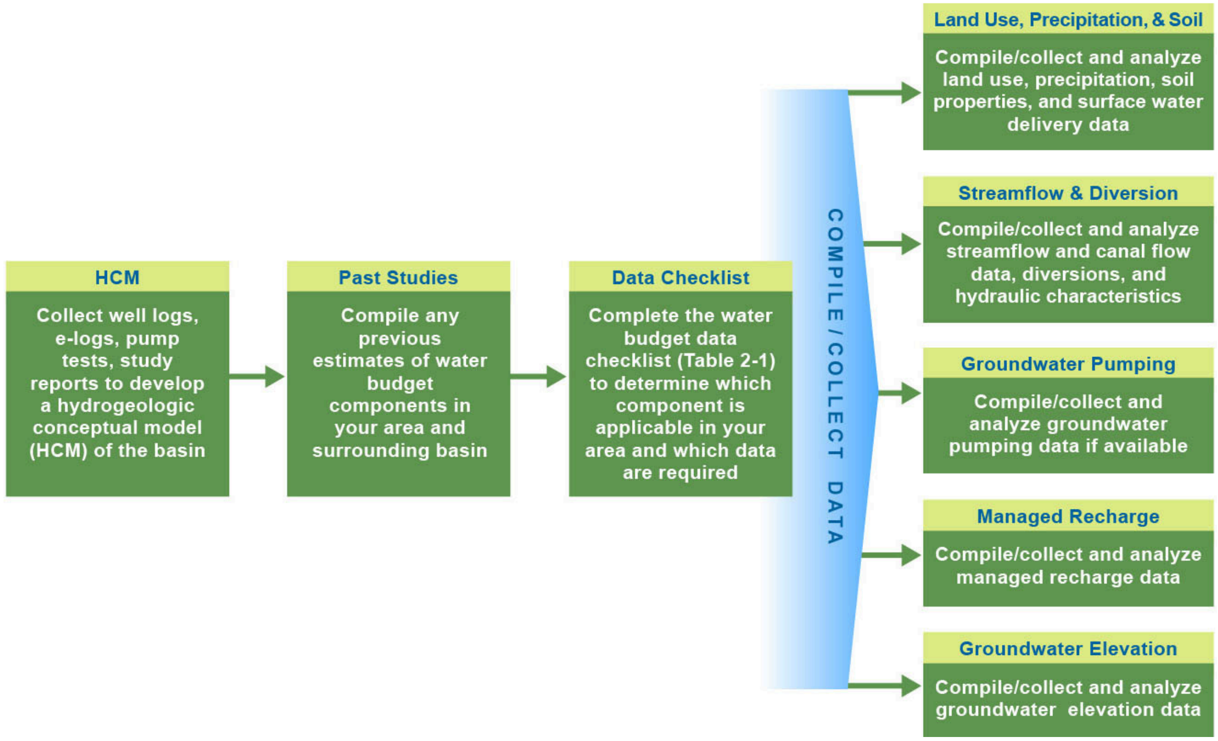
2.9 NON-MODELING APPROACH

The non-modeling approach is used when an integrated numerical groundwater and surface water model is not available to develop water budget components for the water budget zone or when an existing model only provides information for a partial set of water budget components. The non-modeling approach may also be the preferred option when basin problems are relatively simple and can be answered on the basis of historical monitoring data supplemented by additional field data.

2.9.1 General Data Collection for the Non-Modeling Approach

The process flowchart in Figure 2-5 shows the steps required to compile data and information in preparation for developing a water budget using the non-modeling approach. Data compilation for the modeling approach requires a similar set of steps.

Figure 2-5 Flowchart for Compiling Data for the Non-Modeling Approach



Flowchart process illustrated in Figure 2-5:

Step 1. HCM: Collect well logs, e-logs, pump tests, study reports to develop a hydrogeologic conceptual model (HCM) of the basin.

Step 2. Past Studies: Compile any previous estimates of water budget components in your area and surrounding basin.

Step 3. Data Checklist: Complete the water budget data checklist (Figure 2-3) to determine which component is applicable in your area and which data are required.

Step 4. Compile/Collect Data.

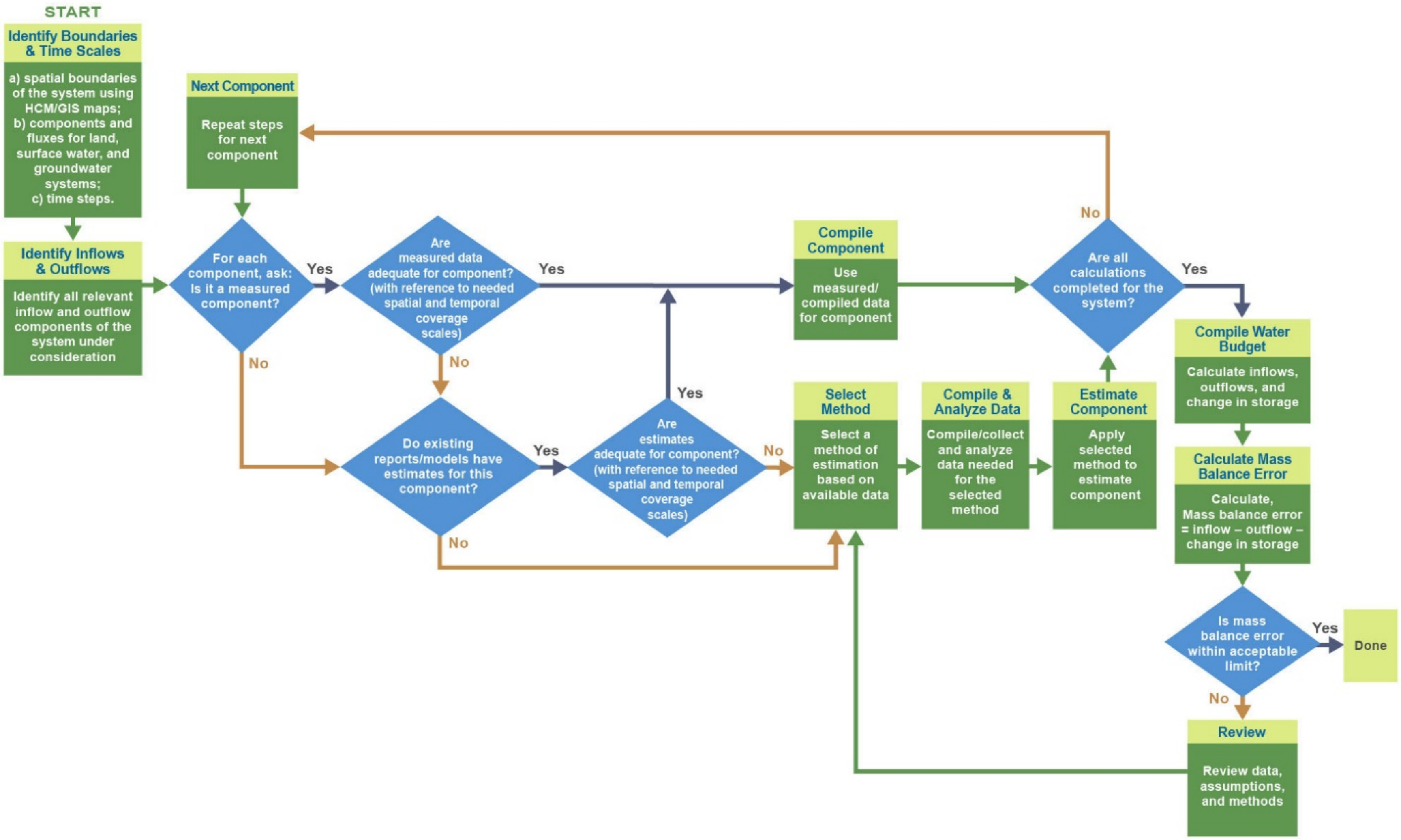
A. Land Use, Precipitation, and Soil: Compile/collect and analyze land use, precipitation, soil properties, and surface water delivery data.
B. Streamflow and Diversion: Compile/collect and analyze streamflow and canal flow data, diversions, and hydraulic characteristics.
C. Groundwater Pumping: Compile/collect and analyze groundwater pumping data if available.
D. Managed Recharge: Compile/collect and analyze managed recharge data.
E. Groundwater Elevation: Compile/collect and analyze groundwater elevation data

2.9.2 Developing Water Budgets Using the Non-Modeling Approach

After relevant data and information are collected, compiled, and analyzed, a systematic and stepwise process should be followed to develop a total water budget using the non-modeling approach by applying data and methods to one component at a time, as illustrated in Figure 2-6. The methods for estimating individual water budget inflow and outflow components using data, without the use of an integrated numerical model, are described in detail with examples in Section 3, "Land System;" Section 4, "Surface Water System;" and Section 5, "Groundwater System."

Water budget accounting template to facilitate and standardize water budget development process is provided in Section 1, "Introduction." A component-by-component example of developing a total water budget using the non-modeling approach and the standardized template is furnished in Section 6, "Case Study: Non-Modeling Approach."

Figure 2-6 Non-Modeling Approach: Stepwise Process for Developing a Total Water Budget



Flowchart process illustrated in Figure 2-6:

Step 1. Identify Boundaries and Time Scales.
  A. Spatial boundaries of the system using HCM/GIS maps.
  B. Components and fluxes for the land, surface water, and groundwater systems.
  C. Time steps.

Step 2. Identify Inflows and Outflows: Identify all relevant inflow and outflow components of the system under consideration.

Step 3. For each component, ask: is it a measured component?
  A. If yes, then are the measured data adequate for component (with reference to needed spatial and temporal coverage scales)?
    a. If yes, then use measured/compiled data for component and skip to Step 9.
    b. If no, then go to Step 4.
  B. If no, then go to Step 4.

Step 4. Do existing reports/models have estimates for this component?
  A. If yes, then go to Step 5.
  B. If not, then go to Step 6.

Step 5. Are estimates adequate for the component (with reference to needed spatial and temporal coverage scales)?
  A. If yes, then use measured/compiled data for component and skip to Step 9.
  B. If no, then go to Step 6.

Step 6. Select Method: Select method of estimation based on available data.

Step 7. Compile and Analyze Data: Compile/collect and analyze data needed for the selected method.

Step 8. Estimate Component: Apply selected method to estimate component.

Step 9. Are all calculations completed for the system?
  A. If no, then repeat Steps 3 through 8 for next component.
  B. If yes, then go to Step 10.

Step 10. Compile Water Budget: Calculate inflows, outflows, and change in storage.

Step 11. Calculate Mass Balance Error: Calculate, mass balance error equals inflow minus outflow minus change in storage.

Step 12. Is the mass balance error within acceptable limit?

A. If yes, then you are done.
B. If no, then review data, assumptions, and methods and return to Step 6.

2.10 AGGREGATION OF WATER BUDGETS

For a basin where multiple agencies are preparing water budgets or have management responsibilities, there is a need to understand how groundwater and surface water fluxes occur across adjacent water budget zones. These fluxes affect individual water budgets as well as the overall basin water budget. When a water budget for a basin needs to be developed from multiple water budget zones, the integration of water budgets from those zones to the basin level is an important consideration. Care should be taken during aggregation to ensure proper accounting (crediting and debiting, as shown in the Water Budget Accounting Template) of individual water budget components across water budget zones to avoid double counting. For example, an outflow from one zone and the corresponding inflow to a neighboring zone may both become an internal flow within the larger water budget zone. Cross-boundary flows calculated for adjacent water budget zones should be equal or close, so that error in the aggregated water budget for a basin is small. A similar case where flows across boundaries should be coordinated occurs in the Central Valley where groundwater basin boundaries can be based on jurisdictional boundaries.

If a water budget is developed for each water budget zone, coordination among the adjacent water agencies in the basin will be easier if consistent vocabulary, spatial and time scales, and methods are used for their respective water budget development. This type of coordination among water agencies will help ensure that water budgets are comparable across water budget zones in the basin and can be spatially and temporally aggregated to the basin scale.

2.11 UNCERTAINTY IN WATER BUDGET ESTIMATES

All water-budget calculations contain some level of uncertainty. Uncertainty originates from the variability in hydrology, geology, climate, and land use; errors associated with measurements, data, and tools; and data gaps. Uncertainty also arises from temporal variability in storage and fluxes largely tied to diurnal, seasonal, and long-term trends in weather and climate. All these uncertainties in a water budget can be further compounded by misalignment between boundaries of a water budget zone with hydrologic boundaries, as is often the case with jurisdictional boundaries of local governments and agencies.

The goal of uncertainty analysis is to properly characterize the range of variation in a water budget resulting from uncertainty in data and estimation methods used. The general emphasis should be to identify uncertainty in data used to estimate the water budget components, evaluate uncertainty introduced by estimation methods, and assess and quantify the overall influence of the data and estimation methods on the total water budget.

For historical water budgets, uncertainty in land use, associated groundwater pumping estimates, and recharge of precipitation and applied water typically have the largest effect on overall water budget uncertainty. When developing future water budgets to help formulate projects and evaluate management actions, uncertainty in future land use, population projections, and climate change will typically have the largest effect on overall water budget uncertainty.

Uncertainty analysis helps identify significant components with large uncertainty bands. Through targeted data collection, these components can be estimated with a higher level of confidence. Once uncertainties in significant components have been addressed, similar efforts could be undertaken to reduce uncertainties associated with other water budget components. Over time, this incremental approach will lead to improved and more robust water budget estimates.

Discussion of detailed methods for assessing uncertainty in water budget estimation is beyond the scope of this Water Budget Handbook. Uncertainty is discussed here because it is an essential step for the practitioners to consider as the assessment of uncertainty will help to quantify, understand, and improve their water budget estimates over time.

2.12 DOCUMENTATION OF WATER BUDGET

Appropriate and sufficient documentation of the water budget is essential for stakeholders, neighboring jurisdictions, and regulators to understand the basis of the developed water budget. The documentation also serves as a knowledge base for a water agency, as well as facilitating staff development and succession planning.

Without good documentation, the developed water budgets could be open to misinterpretation of water budget assumptions, process, and development. Good documentation provides latitude and incentives to understand and improve water budgets over time, focusing on the important unknowns one at a time. The following could be used as high-level guidance on how to document water budget development and uncertainty.

1. **Geographic Setting:** Provide description of the hydrogeologic conceptual model and maps of water budget zone and management area boundaries highlighting key features associated with water budget components, such as land use; streams, creeks, and other surface water bodies; surface water and groundwater flow directions; and inflows and outflows to the water budget zone.
2. **Data Sources and Gaps:** Provide full description of data sources and gaps**.** Consider what data are necessary for a water budget and how frequently data are needed. Take care to include any relevant data, while ensuring that evidently unreliable data are not used for developing water budgets.
3. **Spatial and Time Scales:** Ensure that time and space scales of measurement and estimation methods match the needs of the water budget to address the relevant water management issues. Consider what spatial scale to use and how different scales will be consistent with each other in relation to the systems and water budget zones being analyzed.
4. **Current Conditions:** Provide information describing the current conditions of the water budget zone including population, land use, and climate.
5. **Future Scenario:** If the water budget includes future estimates, document how climate change, land use change, and population projection are addressed.
6. **Methods and Assumptions:** Provide a full description of the methods used for estimating water budget components, including key assumptions used in the analysis. As far as practicable, use technically appropriate and defensible methods.
   A. Non-Modeling Approach: Document the rationale for the choice of methods while giving preference to well-established methods

described in the Water Budget Handbook. Consider cross-validating water budget estimates by using different methods and documenting the results. Whenever possible, validate estimates with local knowledge or experience gathered from basins with similar hydrogeologic conditions. In cases where adjustments are made to balance the inflows and outflows, document the rationale for the adjustments as well as the water budget component(s) with high uncertainty.

B. Modeling Approach: In cases where newly developed numerical model applications are used for water budgets, provide a complete modeling report with documentation on the hydrogeologic conceptual model, source code, data sources, assumptions, model construction, calibration, and any relevant review of the model platform. In cases where an existing numerical model is used, provide reference to published model report(s) and any additional supporting documents for assessment of the study area by the model. In cases where multiple existing models cover the study area, select the model that best characterizes water budget components for the area. Document the model’s definitions of water budget components as well as the methods used to extract water budget results from the model. Where applicable, include excerpts of model input/output files in the documentation.

7. **Water Budget Validation:** Discuss the final water budget, determine how reasonable or reliable it is, and why. The goal is to attain a consistent and defensible water budget over time.

A. Non-Modeling Approach: The computed water budget can be deemed sufficiently reliable to support water resources planning provided all of the following conditions are met:

   a. Best available geologic and hydrologic data are used.
   b. Methods used are well documented and defensible.
   c. Validated with local water budget experts and stakeholders.

B. Modeling Approach: The computed water budget can be deemed sufficiently reliable to support water resources planning provided all of the following conditions are met:

   a. An integrated numerical groundwater and surface water model was developed using best available geologic and hydrologic data.
   b. The model was calibrated by carefully adjusting model inputs without going outside the bounds of parameters and fluxes indicated by data and hydrogeologic reasoning.
   c. The model can reasonably reproduce gauged streamflows.
   d. The model can reasonably reproduce measured groundwater levels.

8. **Data Gaps and Monitoring Needs:** Based on assessment of the water budget, identify data gaps and recommend future data collection and analysis efforts to improve the water budget.

9. **Human Resources:** Document the resources used to develop the water budget. Developing a detailed water budget requires a substantial commitment of funding and human resources.

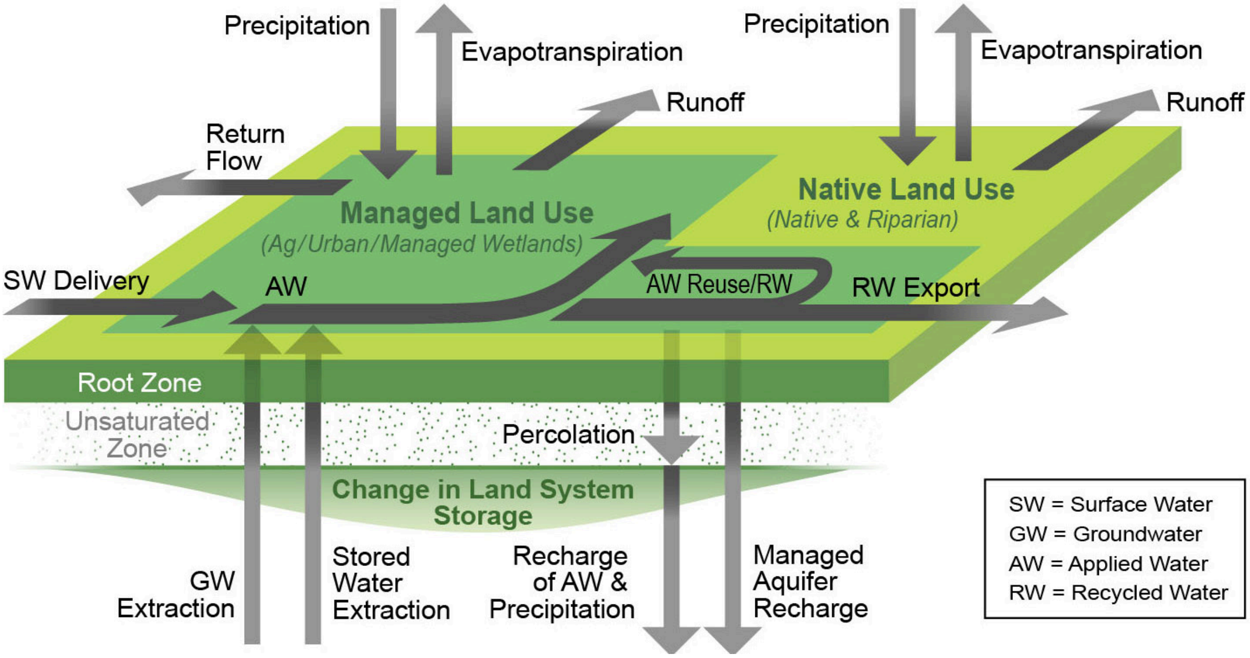
3. LAND SYSTEM

3.1 INTRODUCTION

The total water budget captures the entire hydrologic cycle of water flow, and the land system is an integral part of it. The components of land system water budget are shown in Figure 3-1, which is a subset of Figure 1-1. The color coding of Figure 1-1 was not carried over to Figure 3-1 to avoid confusion as the designation of inflows and outflows are different in a single system compared to the total water budget. The definition of the land system and land system water budget is presented in Section 1.3.1. The definitions of the associated components are provided in Table 1-1.

The purpose of this section is to describe how to develop reasonable estimates for these water budget components without a model. To set context, a general description of land system water budget is provided for agricultural, urban, managed wetlands, and native lands. This description is followed by individual sections on each component of the land system water budget as shown in Figure 3-1.

Figure 3-1 Inflow and Outflow Components of Land System Water Budget



Multiple methods are provided for estimating these components. The handbook user should evaluate if a method described in this section or in textbooks or reference manuals is the most appropriate to use for the study area. The methods described here can also be used in case an available model only provides information for a partial set of land system water budget components. In case a model is available that provides information for all components of the land system, the user should refer to Section 2.8, "Modeling Approach."

Descriptions of inflow and outflow components in the land system along with methods for estimating each component are furnished below. Because of the interdependencies between the systems, several of the components of the land system are described in other sections: managed aquifer recharge, recharge of applied water and precipitation, and stored water extraction are described in Section 5, "Groundwater System."

3.2 LAND SYSTEM: WATER BUDGET AND CHANGE IN STORAGE

The components shown in Figure 3-1 are primarily outcomes of land use practices in the land system, which include the broad categories of native, riparian, and managed land uses. Managed land uses are further subdivided into "water use sectors" representing specific water management practices and conditions. Water use sectors categorize water demands based on the general land uses to which the water is applied including residential, commercial, industrial, agricultural, managed wetlands, and managed recharge. These land uses create a demand for water to be met from precipitation, stream corridors, surface water, groundwater, applied water reuse, recycled water, or any combination thereof. The water budget can be influenced by plant uptake of shallow groundwater, the effects of fog in coastal areas, and other local factors. The water budget for the land system is comprised of inflow, outflow, and change in land system storage and can be expressed as:

$$\text{Inflows} - \text{Outflows} = \text{Change in Land System Storage}$$

The interrelationships among inflow, outflow, demand, and supply are discussed in the following sub-sections for agriculture, urban, managed wetlands, and native lands along with a formulation of how to calculate change in land system storage for corresponding land use category.

3.2.1 Land System Water Budget for Agricultural Lands

For agricultural lands, precipitation and applied water constitute the water supply that is provided to meet the evapotranspiration (ET) requirements of crops. In general, the combination of precipitation and applied water is greater than the crop ET requirements for agricultural lands to account for distribution inefficiencies and crop management goals. ET of applied water (ETAW) is the amount of irrigation water needed to meet total crop ET in excess of effective precipitation. Effective precipitation is the amount of precipitation stored in the root zone that is available for crop ET. Irrigation efficiency, as used in this document, represents the effectiveness of water application on agricultural lands over an entire growing season and is the ratio of the ETAW to the total applied water. In literature, this term has multiple definitions or may be identified as application efficiency, seasonal application efficiency, consumed fraction, etc., and thus it is important to understand the context of how irrigation efficiency values are presented. However, in some cases, irrigation efficiency may also include applied water for salt management (leaching). In these cases, irrigation efficiency is calculated as the ratio of ETAW plus applied water for salt management to the total applied water.

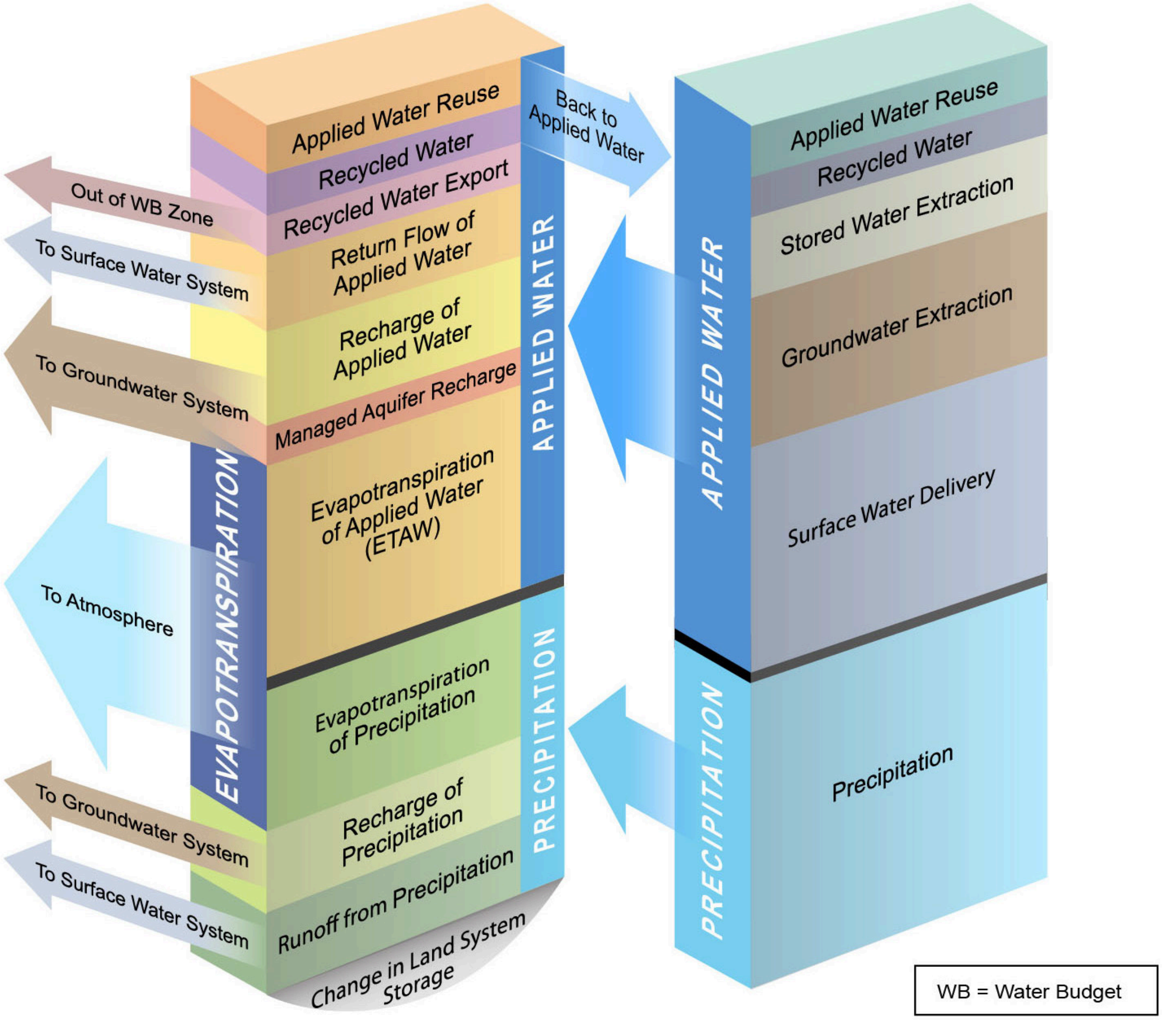
As shown in Figure 3-2, the **water supply** components for agricultural land are precipitation, surface water delivery, groundwater extraction, stored water extraction, recycled water, and applied water reuse. Applied water includes all water supply components except precipitation, which is a natural supply of water on agricultural land. In limited cases, shallow groundwater, not shown in Figure 3-2, may be a source for meeting some or all ET requirements for an area where it can be estimated.

Precipitation on agricultural land is accounted for in four ways: (1) as ET of precipitation to meet part (or all) of the crop water requirements (this amount is also known as effective precipitation or consumptive use of precipitation); (2) as recharge into the groundwater system (passing through the unsaturated zone, including the root zone); (3) as runoff into the surface water system; and (4) as change in land system storage.

Applied water on agricultural land is accounted for in seven ways:
(1) as ETAW to meet the crop water requirements not met by precipitation;
(2) as managed aquifer recharge and recharge of applied water into the groundwater system (passing through the unsaturated zone, including the

root zone); (3) as return flow of applied water into the surface water system; (4) as recycled water export into another water budget zone; (5) as recycled water that is routed back to applied water for application within the water budget zone; (6) as applied water reuse that is routed back to applied water for re-application within the water budget zone; and (7) as change in land system storage.

Figure 3-2 Land System Water Budget for Agricultural Lands



The land system water budget for agricultural lands can be expressed by the following equations:

$$\text{Inflows} = \text{Precipitation} + \text{Surface Water Delivery} + \text{Groundwater Extraction} + \text{Stored Water Extraction}$$

$$\text{Outflows} = \text{ET of Precipitation} + \text{Recharge of Precipitation} + \text{Runoff from Precipitation} + \text{ETAW} + \text{Managed Aquifer Recharge} + \text{Recharge of Applied Water} + \text{Return Flow of Applied Water} + \text{Recycled Water Export}$$

$$\text{Change in Land System Storage for Agricultural Lands} = \text{Inflows} - \text{Outflows}$$

Applied water reuse and recycled water shown in Figure 3-2 are not considered inflows or outflows for developing a water budget because both are internal flows within a water budget zone resulting in the reduction in the amount of surface water delivery, groundwater extraction, and stored water extraction needed to meet the applied water requirement for agricultural lands within a water budget zone.

3.2.2 Land System Water Budget for Urban Areas

For urban areas, applied water consists of indoor and outdoor water uses including distribution system water losses. Indoor water use most commonly consists of residential, commercial, and industrial water use; this water is most often non-consumptively used and generally becomes return flow to the surface water system (e.g., wastewater discharges) or recharge to the groundwater system (e.g., wastewater percolation ponds or septic tanks). A part of the indoor water use may become recycled water to meet demands inside or outside the water budget zone. The recycled water delivered to irrigate landscape reduces the amount of surface water delivery, groundwater extraction, and stored water extraction within a water budget zone. Recycled water used outside the water budget zone is called recycled water export (Table 1-1).

Urban outdoor water use is for landscape irrigation, and the water budget analysis for urban outdoor use is the same as that for agricultural lands described in Section 3.2.1. The water demand for urban landscape irrigation that is not met by precipitation is met by groundwater extraction, surface water delivery, and recycled water delivery.

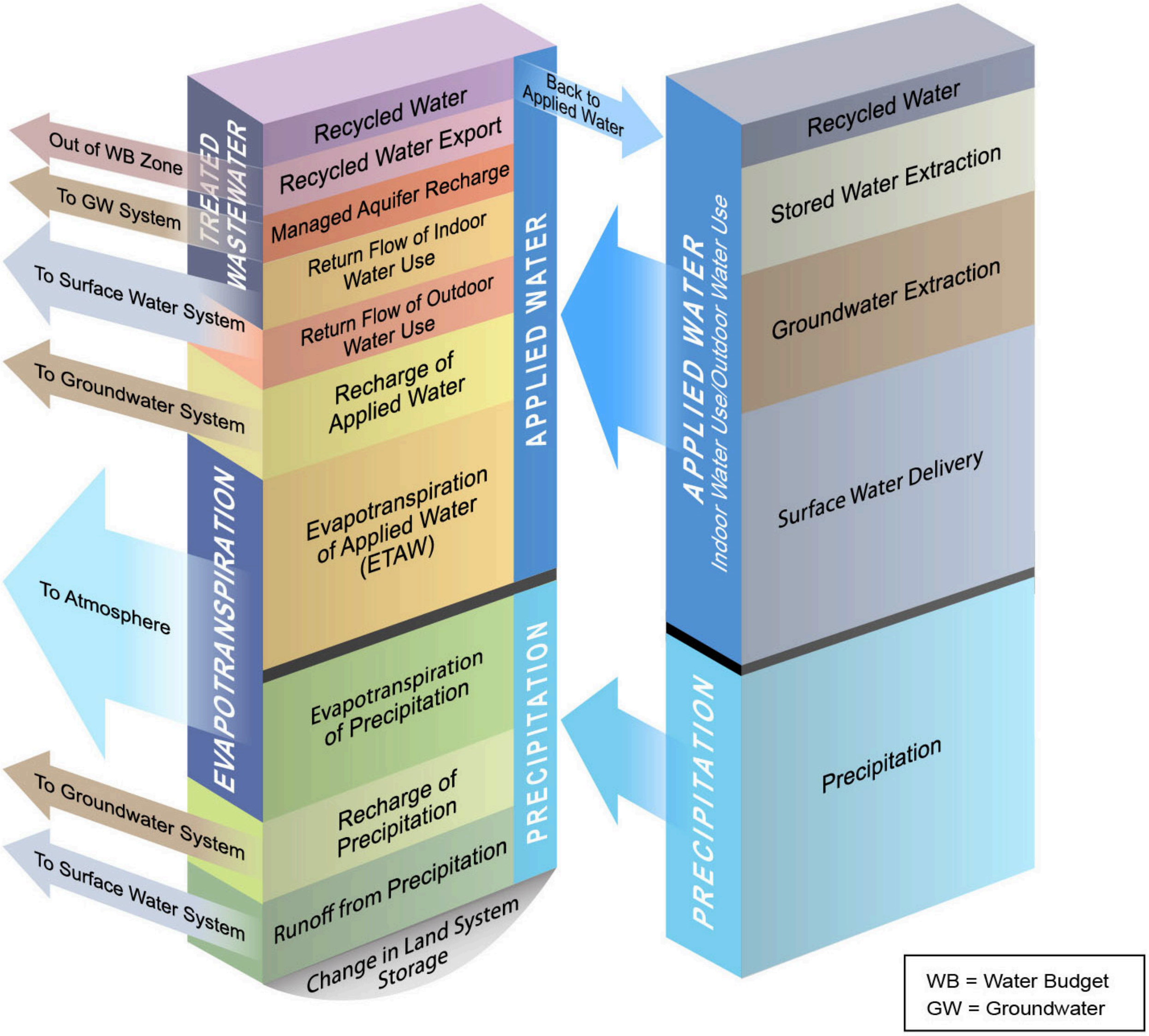
Urban applied water, as described in Section 3.5.2, is defined as the “volume of water delivered from any source to the intake of a municipal, industrial, or large landscape water system.” After intake delivery and treatment, water then enters the distribution system for delivery to its end user. Most distribution systems incur losses that include seepage, illegal connections, and other unaccounted for water, all of which may be difficult to differentiate. Seepage loss from distribution systems is typical, and its magnitude is a function of the age, materials, and condition of the system. Understanding this seepage loss, which is not part of conveyance seepage as defined in Section 4.6, is important for estimating how much recharge of applied water occurs from urban areas. For some distribution systems, seepage loss could be quantified and may be identified separately as "distribution system water loss" instead of being included in indoor and outdoor water use. For other systems, distribution system water losses may be difficult to quantify but estimates may help to quantify recharge of applied water while lumping losses with indoor and outdoor water uses.

As shown in Figure 3-3, the **water supply** components for urban area are precipitation, surface water delivery, groundwater extraction, stored water extraction, and recycled water. Applied water includes all water supply components except precipitation, which is a natural supply of water in urban areas.

Precipitation in urban areas is accounted for in three primary ways: (1) as ET of precipitation to meet part (or all) of the landscape irrigation requirements (this amount is also known as effective precipitation or consumptive use of precipitation); (2) as recharge into the groundwater system (passing through the unsaturated zone, including the root zone); and (3) as runoff into the surface water system. Runoff from precipitation could be intercepted and collected as stormwater, which could become a source of supply for managed aquifer recharge.

Applied water in urban areas is accounted for in four primary ways: (1) as ETAW to meet the landscape water requirements not met by precipitation; (2) as recharge of applied water into the groundwater system (passing through the unsaturated zone, including the root zone); (3) as return flow of outdoor water use into the surface water system; and (4) as treated wastewater generated from indoor water use. **Treated wastewater** in urban areas is accounted for in four primary ways: (1) as return flow of indoor water use into the surface water system, (2) as managed aquifer recharge into the groundwater system, (3) as recycled water export to areas outside the water budget zone, and (4) as recycled water that is routed back to applied water for re-application within the water budget zone.

Figure 3-3 Land System Water Budget for Urban Areas



The land system water budget for urban areas can be expressed by the following equations:

$$\textbf{Inflows} = \text{Precipitation} + \text{Surface Water Delivery} + \text{Groundwater Extraction} + \text{Stored Water Extraction}$$

$$\textbf{Outflows} = \text{ET of Precipitation} + \text{Recharge of Precipitation} + \text{Runoff from Precipitation} + \text{ETAW (Landscape)} + \text{Recharge of Applied Water} + \text{Return Flow of Outdoor Water Use} + \text{Return Flow of Indoor Water Use} + \text{Managed Aquifer Recharge} + \text{Recycled Water Export}$$

$$\textbf{Change in Land System Storage for Urban Areas} = \text{Inflows} - \text{Outflows}$$

Recycled water shown in Figure 3-3 is not considered an inflow or an outflow for developing a water budget because it is an internal flow within a water budget zone resulting in the reduction in the amount of surface water delivery, groundwater extraction, and stored water extraction needed to meet the applied water requirement for urban areas within a water budget zone.

3.2.3 Land System Water Budget for Managed Wetlands

For managed wetlands, precipitation and applied water constitute the water supply that would meet the wetland water requirements for vegetation, habitat, and ponding. Applied water includes groundwater extraction, surface water delivery, applied water reuse, and recycled water.

Precipitation on managed wetlands is accounted for in three ways from the land surface: (1) as evaporation from ponded areas (i.e., open water surface); (2) as ET of precipitation to meet part (or all) of the habitat water requirements (this amount is also known as effective precipitation or consumptive use of precipitation); and (3) as recharge into the groundwater system (passing through the unsaturated zone, including the root zone).

Applied water on managed wetlands is accounted for in four ways from the land surface: (1) as ET of applied water to meet the habitat water requirements not met by precipitation; (2) as recharge into groundwater system (passing through the unsaturated zone, including the root zone); (3) as return flow to surface water system; and (4) as managed aquifer recharge. Managed aquifer recharge is not a common practice on managed wetlands as the sites are typically selected with soil conditions that reduce recharge from occurring; however, some multi-benefit projects may include managed aquifer recharge as part of their managed wetlands design.

The land system water budget for managed wetlands can be expressed by the following equations:

$$\textbf{Inflows} = \text{Precipitation} + \text{Surface Water Delivery} + \text{Groundwater Extraction}$$

$$\textbf{Outflows} = \text{Evaporation of Precipitation} + \text{ET of Precipitation} + \text{Recharge of Precipitation} + \text{ETAW} + \text{Return Flow of Applied Water} + \text{Recharge of Applied Water} + \text{Managed Aquifer Recharge}$$

$$\textbf{Change in Land System Storage for Managed Wetlands} = \text{Inflows} - \text{Outflows}$$

Applied water reuse and recycled water are not considered inflows or outflows for developing a water budget because both are internal flows within a water budget zone, which reduces the amount of surface water delivery and groundwater extraction needed to meet the applied water requirement for managed wetlands within the water budget zone.

3.2.4 Land System Water Budget for Native Lands

Native lands, which includes both native and riparian vegetation, rely only on precipitation, stream corridors, and shallow groundwater, or combinations thereof to meet water demand. Generally, precipitation is the only water supply to meet the water demands for the growth and sustenance of native vegetation on native lands; however, in cases where shallow groundwater exists, part of the water demand may be met by uptake of shallow groundwater by plants. Similarly, the water demand associated with riparian (or phreatophytic) vegetation is met by precipitation, surface water from stream corridors, shallow groundwater, or any combination thereof. The total inflow or water supply for native lands should include precipitation as well as any contributions from adjoining stream corridors and shallow groundwater to meet the ET requirements.

Precipitation on native lands is accounted for in four primary ways: (1) as ET of precipitation to meet water requirements for native and riparian vegetation (this amount is also known as effective precipitation or consumptive use of precipitation); (2) as recharge into the groundwater system (passing through the unsaturated zone, including the root zone); (3) as runoff into the surface water system; and (4) as change in land system storage.

The land system water budget for native lands can be expressed by the following equations:

$$\textbf{Inflows} = \text{Precipitation} + [\text{Plant Uptake of Shallow Groundwater} + \text{Plant Uptake of Streamflow from Stream Corridors}]$$ [1]

$$\textbf{Outflows} = \text{ET of Precipitation} + \text{Recharge of Precipitation} + \text{Runoff of Precipitation} + [\text{ET of Shallow Groundwater} + \text{ET of Streamflow from Stream Corridors}]$$ [2]

$$\textbf{Change in Land System Storage for Native Lands} = \text{Inflows} - \text{Outflows}$$

3.2.5 Change in Land System Storage

As mentioned above, the change in land system storage consists of change in storage of ponded areas (not lakes) on the land surface as well as the change in storage of the unsaturated zone, which includes the root zone.

From the equations in Sections 3.2.1 to 3.2.4, the total change in land system storage for the water budget zone of interest can be expressed as:

$$\textbf{Change in Land System Storage} = \text{Change in Land System Storage for Agricultural Lands} + \text{Change in Land System Storage for Urban Areas} + \text{Change in Land System Storage for Managed Wetlands} + \text{Change in Land System Storage for Native Lands}$$

3.3 PRECIPITATION

Definition: Volume of water vapor that falls to the earth (land and surface water systems) as rain, snow, hail, or is formed on the earth as dew, and frost.

Context: Precipitation (P) is an inflow to the land system and hence a source of water supply in the context of the overall water budget calculation.

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[1] Plant uptake of shallow groundwater and streamflow from stream corridors is typically equal to the ET of shallow groundwater and ET of streamflow from stream corridors. These terms are typically small and are not shown on the total water budget schematic.

[2] Although ET of shallow groundwater and ET of streamflow from stream corridors represent the volume of water needed for vegetation growth in excess of precipitation, these terms are typically small and are not shown on the total water budget schematic.

In general, portions of precipitation contribute to (1) ET (consumptive use) by agricultural crops, urban landscape, managed wetlands, and native and riparian vegetation; (2) runoff as overland flow on the land system and outflow to the surface water system; (3) evaporation from the soil, or (4) recharge to the groundwater system.

Precipitation is also an inflow to the surface water system, such as lakes. Precipitation over lakes could be calculated using the same methods described in this section.

Precipitation is measured by using gauges, which record the depth (in inches or millimeters) of precipitation falling over a time interval (e.g., 15 minutes, 1 hour, 1 day) at the gauge location. These point measurements are used to estimate the average areal volume of precipitation during a time interval over the land surface within a water budget zone.

Related Water Budget Components: Evapotranspiration, Runoff, Recharge of Applied Water and Precipitation

How to Determine Precipitation Inflow:

- Method 1 — Use published reports and numerical models.
- Method 2 — Use online databases.

Method 1 — Use Published Reports and Numerical Models

Collect and review published reports and existing numerical models for the area of interest. Data obtained from published reports and numerical models is typically derived from the online databases described in Method 2 but may have undergone additional processing/formatting to facilitate ease of use. These reports and models can be good sources of estimates of historical precipitation volume over an area. If reliable and defensible estimates of precipitation volume (monthly or annual) falling in the water budget zone are available, then use those estimates for developing water budget. If precipitation data from an existing numerical model are used, then the following should be validated:

- The numerical model is calibrated and accepted by stakeholders.
- There is documentation of both the source data and the basis of estimate used in the numerical model.

- Any geographic scaling factor that is used to convert model estimates to correspond to the water budget zone is defensible and is representative of the precipitation regime used in the model for the area.

Sources include:

- Central Valley Spatial Database (part of the Central Valley Hydrologic Model [CVHM] project).
- Cal-SIMETAW Unit Values: Monthly per acre precipitation (source: PRISM — See below) by DAUCO for 2000–2015.
- USGS Basin Characterization Model.
- Previous reports.
- Input files of numerical models, e.g., C2VSim, CalSim 3.

Method 2 — Use Online Databases

Published reports and numerical models may not be adequate for developing reliable and defensible estimates of precipitation for the water budget zone. In such a case, historical or current precipitation data (hourly, daily, monthly, etc.) from existing databases can be used to develop estimates of precipitation for the water budget zone. This method will generally require spatial analysis using a geographic information system (GIS) to aggregate data and calculate volumes of precipitation.

Common sources of precipitation data available at different spatial and temporal scales in California are listed below.

- National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center.
- California Data Exchange Center (CDEC).
- California Irrigation Management Information System (CIMIS).
- PRISM Historical Dataset (1895–1980).
- PRISM Recent Dataset (1981–Current).
- California Water Plan Water Portfolio.
- Local agency data, including flood control districts and water management agencies.

Additional information on data sources for precipitation is provided in Section 9, "Data Resources Directory."

Options for determining volumes of precipitation include:

- Option 1 — spatial analysis using PRISM data.
- Option 2 — spatial averaging techniques.

Option 1 — Spatial Analysis Using PRISM Data

Gridded precipitation data may be available from a variety of sources. One of the most widely available gridded precipitation data sources is the Parameter-elevation Relationships on Independent Slopes Model (PRISM). The PRISM monthly or daily data can be used to estimate precipitation volumes for the water budget zone. This option requires the use of spatial analysis tools (e.g., GIS) to analyze the PRISM data and compute volumes of precipitation based on geographic extent of the water budget zone.

"PRISM calculates a climate—elevation regression for each digital elevation model (DEM) grid cell, and stations entering the regression are assigned weights based primarily on the physiographic similarity of the station to the grid cell. Factors considered are location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of the terrain. Station data were spatially quality controlled, and short-period-of-record averages adjusted to better reflect the 1971—2000 period." (Source: Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States)

For the California Central Valley, DWR and USGS have developed two numerical models, the California Central Valley Simulation (C2VSim) Model and the Central Valley Hydrologic Model (CVHM), respectively. In both models, PRISM data are used to develop monthly estimates of precipitation volume over model elements, which range in size from 0.6 to 1.5 square miles. The estimated monthly precipitation volumes are available for the periods of 1921 through 2015 in C2VSim and 1962 through 2003 in CVHM. Data from these numerical models can be used and the values by model elements can be aggregated to develop estimates for precipitation in the water budget zone. In addition, the pre-processing for the USGS's Basin Characterization Model includes precipitation from PRISM that have been downscaled to 270-meter spatial resolution and are available from 1900 through 2017.

Option 2 — Spatial Averaging Techniques

Precipitation into the water budget zone can be estimated using gauged data within or at the periphery of the water budget zone and geographic information about the area. Gauges typically measure precipitation as depth. After obtaining precipitation timeseries data for the gauges of interest, various established methods can be used to estimate total precipitation volume. The methods include arithmetic mean method (precipitation gauges are weighted equally) and Thiessen Polygon (precipitation gauges are weighted by area). Additional information regarding using spatial averaging techniques to estimate precipitation can be found from the National Weather Service's Precipitation Measurements webpage.

Depending on the need and availability of resources and expertise, an agency may consider using other methods such as kriging or co-kriging to develop their own gridded precipitation.

3.4 EVAPOTRANSPIRATION

Definition: Volume of water entering the atmosphere through the combined process of evaporation from soil and plant surfaces and transpiration from plants.

Context: Evapotranspiration (ET) is an outflow component from the land system within the water budget zone to the atmosphere. It includes the following:

- Volume of water transpired by the plants (crops, native and riparian vegetation, landscape grasses, etc.) for growth.
- Volume of water evaporated from marshlands and managed wetlands.
- Volume of water evaporated from the bare soil surface.
- Volume of water evaporated from the plant leaves during and after a precipitation event.

For agricultural lands, ET is often equal to the crop water requirement because it is generally assumed that agricultural land is well watered and the amount of ET from precipitation supply and applied water is equal to what the crop needs to grow. However, this assumption does not always represent crop water management and actual ET within a water budget zone. Deficit irrigation may be used for various reasons such as crop management goals or managing limited supplies; where this occurs, reduced crop ET may occur.

Native vegetation typically uses only precipitation, and the amount of ET will be limited to the amount of water that infiltrates into the soil and is stored as available soil moisture. In cases where shallow groundwater is available to the plants, native vegetation may also draw from this source to meet its water requirements.

Riparian vegetation may use precipitation, surface water from stream corridors, shallow groundwater, or any combination thereof to meet its water requirements.

Related Water Budget Components: Surface Water Delivery, Groundwater Extraction, Applied Water Reuse, Recycled Water, Precipitation, Recharge of Applied Water and Precipitation, Return Flow, Runoff

How to Determine ET

ET is not a measured water budget component and hence no measured data is available for this component. It is a complex land phenomenon that varies from crop to crop (or vegetation type) and depends on a suite of hydrologic, meteorological, climatic, and agricultural factors. Several approaches are available to make these estimates. One general approach uses remote sensing-based image processing models (e.g., METRIC, SEBAL, Satellite Irrigation Management Support [SIMS]) that can provide ET estimates from field observation data and satellite data by performing a complete energy balance of each surface. Another approach uses reference ET rates, crop or vegetation coefficients, and land uses to estimate ET. This later approach is not limited to available satellite data when reconstructing water budget further back in time. DWR has published two land use based stand-alone models, DWR’s Integrated Water Flow Model Demand Calculator (IDC) and Cal-SIMETAW, that use this approach to develop estimates for ET in a water budget zone. The purpose of this handbook is not to provide detailed information on how to use METRIC, SEBAL, IDC, or Cal-SIMETAW but to provide a general introduction about these methods while also describing simpler methods. These methods can be used to estimate ET volume with consideration for crop type and crop acreage.

Remote sensing techniques can help to quantify actual ET (e.g., Metric). Local knowledge and University of California Cooperative Extension (UCCE) farmer advisors can provide input as to how much deficit irrigation may be occurring, such as reduced or altered irrigation cycles. A crop water use model (e.g., Cal-SIMETAW, IDC) is another method to evaluate deficit irrigation and its effects on ET and soil moisture storage. The reduction in applied water may not result in a corresponding reduction in ET because of stored soil moisture. Deficit irrigation may be represented in crop water use models by adjusting crop coefficients, harvest dates, or applying a reduction factor to ET.

To develop ET estimates for a water budget zone, use one or more of the following methods:

- Method 1 — Obtain estimates from available reports.
- Method 2 — Obtain estimates from models.
- Method 3 — Use crop coefficient approach.
- Method 4 — Use water-duty based approach.

Method 1 — Obtain Estimates from Available Reports

Step 1 - Collect and Review Reports: Collect and review available relevant technical reports, such as agricultural water management plans, urban water management plans, groundwater management plans, integrated regional water management plans, water supply master plans, etc. that cover the water budget zone of interest. These reports may have direct estimates of monthly or annual ET at different spatial scales or may have model-generated estimates, which can also be obtained directly from the inputs and outputs of models described in Method 2.

Sources include:

- Agricultural water management plans.
- U.S. Bureau of Reclamation (Reclamation) water conservation plans.
- Irrigation Training and Research Center (ITRC) California evapotranspiration data.

- ITRC report tables.
- ITRC metric (including native vegetation).

Step 2 - Scale the Available Information: After obtaining the relevant data from existing reports, an appropriate method should be used to scale the reported numbers for a given area to the water budget zone of interest. Direct area proportioning should not be used without due consideration for the proportion of agricultural land use in the respective areas.

Method 2 — Obtain Estimates from Models

The discussion below is divided into remote sensing-based image-processing models, numerical hydrologic models, and spreadsheet models. It should be noted that a user can also obtain model generated estimates from technical reports described in Method 1.

Remote sensing-based image-processing models: Remote sensing-based model estimation of ET at field scales are available for more recent years in different parts of California. These studies are conducted by federal, State, and local agencies and university research centers. If available, ET estimates from these models can be used for the water budget zone of interest.

Two of the most common remote sensing-based image-processing models in California are:

- Mapping evapotranspiration at high resolution with Internalized Calibration (METRIC): It uses a satellite-based energy balance approach for computing and mapping ET at the field scale and with high-resolution (30 meter) for water-stressed vegetation and evaporation from wet soil. As an example of available information, the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo (Cal Poly) uses a modified METRIC procedure to compute ET_a using LandSAT Thematic Mapper data and published the resulting data. This ITRC-METRIC process is based on surface energy balance and includes corrections for aerodynamic resistance. The method depends upon both accurate and frequent LandSAT satellite thermal images and understanding of the cropping systems within a region. The METRIC programs have gradually evolved from research in the U.S. and other countries with the objective of being able to directly estimate ET_a over large areas with limited data availability (such as crop type, irrigation method, irrigation practices, etc.). For additional information, see Section 9, "Data Resources Directory."

- Surface Energy Balance Algorithms for Land (SEBAL): It is an image-processing model that comprises 25 computational steps to calculate actual and potential ET rates (respectively, ET_a and ET_p) as well as other energy exchanges between the land and atmosphere. SEBAL has been extensively validated in the US and worldwide over more than 15 years and has been found to consistently provide estimates of ET_a that agree within 5 percent to 20 percent of reliable ground-based estimates on a seasonal or annual basis.

Other remote sensing-based models include:

- The USGS's operational Simplified Surface Energy Balance (SSEBop) approach estimates ET by combining "ET fractions generated from remotely sensed Moderate Resolution Imaging Spectroradiometer (MODIS) thermal imagery, acquired every 8 days, with reference ET using a thermal index approach." For more information on SSEBop, see Section 9, "Data Resources Directory."
- The Satellite Irrigation Management Support (SIMS) system is a "National Aeronautics and Space Administration (NASA) supported effort to apply publicly available data from earth observing satellites to map crop cover, crop coefficients and crop evapotranspiration, with the longer-term goal of developing information products and tools to provide decision-support for water managers and agricultural producers. The project is using the Terrestrial Observation and Prediction System (TOPS), a NASA modeling framework developed to monitor and forecast environmental conditions." For additional information on SIMS, see Section 9, "Data Resource Directory."

Existing numerical hydrologic models: There are two existing numerical hydrologic models from DWR that have estimates for crop ET for different historical periods at various geographic scales as described below:

- The California Simulation of Evapotranspiration of Applied Water (Cal-SIMETAW*)* model is a tool developed by DWR and the University of California at Davis to perform daily soil water balance and determine crop ET, ET of applied water, and applied water in support of water resources planning in California, including the California Water Plan. Cal-SIMETAW provides daily, monthly, and annual estimates of crop ET for the period 2001 to 2015. The geographic scale of input and output is detailed analysis units (DAUs) by county (DAUCO) areas for the entire state of California. There are 278 DAUs covering California, excluding islands. The Cal-SIMETAW results can be obtained by DAUCO in spreadsheet format from DWR (Section 9, "Data Resources Directory"). Once the DAUCO data are obtained, the water budget zone of interest can be related to DAUCO with use of spatial scaling, if appropriate, to develop initial estimates of ET for the water budget zone. This model is not publicly available; but model outputs can be obtained from DWR. For additional information on Cal-SIMETAW, see Section 9, "Data Resources Directory."

- The California Central Valley Simulation (C2VSim) model is an application of IWFM, and it provides monthly and annual estimates of various water budget components described in this handbook. Estimates of crop ET for the period 1922 to 2015 for all the groundwater basins in the Central Valley of California can be obtained. The C2VSim input data file can be modified to construct a model zone that corresponds approximately to the water budget zone of interest, and ET and other water budget outputs can be derived at the scale of the water budget zone. For additional information on C2VSim, refer to Section 9, "Data Resources Directory."

Spreadsheet model: DWR's California Water Plan team has a spreadsheet model, called the Water Portfolio, that provides an accounting of water budget components by DAUCO using collected data and various analysis tools. This accounting occurs annually, and data are available for the period 2002 to 2015. The Water Portfolio incorporates data and analysis resulting in estimates of ET, ET of applied water, and applied water by crop type by DAUCO. For more information, see Section 9, "Data Resources Directory."

Use of models: ET estimates from these models should be carefully reviewed to determine if the results reflect current or historical crop water management. Input parameters can be modified, and results updated to reflect local crop and native vegetation conditions, including irrigation methods, planting and harvest dates, etc. Crop production and on-farm water management are continually changing with technology, and farmers are implementing advanced irrigation technologies that may not be fully represented in these models.

Method 3 — Use Crop Coefficient Approach

In this method, the volume of crop (or vegetation) ET is obtained by multiplying the crop acreage with the crop ET rate (ET_c).

$$Crop\ ET\ (acre - ft) = CropArea\ (acres) \times\ ET_C\ (ft)$$

Where, ET_c is defined as

$$ET_C = K_C\ \times\ ET_o$$

K_c is the crop coefficient that depends on the type of crop and growth stage of the crop, and ET_o is reference crop ET that represents the ET from a reference surface closely resembling an extensive surface of green, well-watered grass of uniform height (0.12 meter), which is actively growing and completely shading the land surface.

Native vegetation ET can be determined through a process like that used for crops by using a reference ET (ET_o) and applying vegetation coefficients to determine potential vegetation ET. Because precipitation is the only source of supply for native vegetation, it becomes the limiting factor in determining the actual ET for any native vegetation type (actual ET is always less than potential ET). A soil moisture balance is needed to evaluate how much precipitation is effective (the amount stored in the rootzone and available for crop ET) by determining how much precipitation infiltrates the soil versus runoff, how much precipitation is stored in the soil versus recharge to groundwater, and then how much of the effective precipitation that can contribute to vegetation ET. For native vegetation, ET will equal effective precipitation if no other sources of water in the root zone are available (i.e., shallow groundwater).

The following steps can be taken to estimate ET using Method 3:

Step 1: Collect Crop Acreage Data: Collect crop acreage and land use data in the water budget zone of interest. Crop data are available from local and state agencies. The most common sources of land use data are DWR’s agricultural land and water use estimates, DWR’s land use surveys, and county agricultural commissioner reports of crop acreage.

Step 2: Obtain ET_c Value (or K_c and ET_o values, if ET_c values are not available): Multiple ways by which ET_c and ET_o values can be obtained are described below.

- DWR Cal-SIMETAW Unit Values: The Cal-SIMETAW dataset contains monthly unit values (per acre) of crop evapotranspiration (ETc), applied water, and six other parameters for the period 2000—2015. Individual monthly unit values are reported for 20 crops and 4 non-agricultural land use types in each DAUCO in California. The unit values data are published together with Cal-SIMETAW input (Land Use Crop Information [LUCI]) files which include crop coefficients (Kc) and crop growing periods. For more information, see Section 9, “Data Resources Directory.”
- Statewide ITRC Report: The Irrigation Training and Research Center’s (ITRC’s) report titled *California Crop and Soil Evapotranspiration* contains crop and soil ET information for each of DWR’s 13 ET zones. The crop and soil ET information are listed for three types of precipitation years (typical, wet, and dry) on a 12-month basis. It also includes instructions on how to adjust ET values for different irrigation systems and different growing seasons. ET_c for different crops in California can be found in Tables 40 through 43 of the ITRC report for different zones and for typical years, wet years, and dry years.
- The California Irrigation Management Information System (CIMIS): The system has more than 150 weather stations throughout the state that provide calculated estimates of daily and hourly ET_o, data. For instructions on how to access CIMIS, see Section 9, “Data Resources Directory.”
    - In addition, CIMIS provides an ET_o zones map that allows users to view the reference evapotranspiration zones for California. This map divides the state into 18 zones based on long-term monthly average ET_o values calculated using historical data from CIMIS weather stations. Many areas of California are not sufficiently covered by the network of randomly placed CIMIS stations. Recognizing these spatial data gaps, CIMIS in cooperation with UC Davis developed a daily ET_o map known as

Spatial CIMIS that provides daily ET_o at 2-kilometer grids for the entire State. The ET_o maps are generated using complex sets of models where the input parameters are combinations of data from satellites and ground measurements.

  - Crop coefficients, K_c, vary by crop and the growth stage of the crop. Numerically, it is simply the ratio of ET_c to ET_o and ranges from 0.1 to 1.3. Although crop coefficients vary from day to day, depending on many factors, they are mainly a function of crop growth and development. The rate of crop growth and development will change from year to year, but the crop coefficient corresponding to a specific growth and development stage is fixed from year to year. Values of K_c for annual crops are well under 1.0 in the early growth stages but, at least in dry climates, tend to increase up to 1.10 to 1.20 for many crops when they are fully shading the ground. This means that the ET rate of most crops exceeds the ET_o rate by 10 to 20 percent during periods of full cover. The range of crop coefficients varies from very small (approximately 0.15 for early season row crops) to very large (approximately 1.3 for walnuts in mid-season).
- Theoretical Equations for ET:
  - The Hargreaves-Samani Equation for ET provides a method for estimating potential ET when climate data are limited for planning studies. This method relies on minimum and maximum temperatures and location (i.e., latitude) to predict ET. The Hargreaves-Samani equation is used in Cal-SIMETAW.
  - The Penman-Monteith equation estimates ET using mean temperature, wind speed, relative humidity and solar radiation. It is used in the calculation of ET for CIMIS. The Priestley-Taylor equation is an alternative to the Penman—Monteith equation. It is not dependent on relative humidity and wind speed observations and only requires solar radiation.

Sources of information for ET and crop coefficients include:

- Cal-SIMETAW Unit Values.
- CIMIS Station Reports.
- CIMIS Reference Evapotranspiration Zones (Map).
- CWP Water Portfolio.
- ITRC Metric (including native vegetation).

- FAO 56 Chapter 6 Single Crop Coefficients (Kc).

Example: Grape field in Monterey County, California.

To estimate ET for the vineyard in the month of July, a grape grower uses the ET_c formula. ET_o for July in Monterey (Zone 3) is found from the CIMIS Reference ET Zones map to be 0.18 inch per day or 5.58 inches per month. The mid-season K_C is found to be 0.7 from Table 12 of FAO 56. Therefore:

$$ET_C = K_C \times ET_O = 0.7 \times 5.58 = 3.91\ inches$$

The grower estimates that a total of 3.91 inches of water will be required as ET from the vineyard in the month of July. If the total acreage of the vineyard field is 1,200 acres, then the total amount of ET from the vineyard field would be calculated as:

$$Crop\ ET\ (acre\_ft) = CropArea\ (acres) \times\ ET_C\ (ft)$$

$$Crop\ ET\ = 1200\ acres \times 3.91\ inches \times 1ft/(12\ inches) = 391\ acre\ ft$$

Method 4 — Use Water Duty Based Approach

Water duty for a crop is the amount of applied water (i.e., irrigation) water per unit area that is reasonable to apply for crop growth, including ET, evaporation, and seepage from ditches and canals, percolation below the soil zone, and the water flowing into streams as surface runoff. The water-duty based approach provides direct estimates of evapotranspiration of applied water (ETAW) instead of providing estimates of crop ET.

The following steps can be used for Method 4.

Step 1: Collect Water Duty Information: Collect unit water duty rates by crop from farmers and water purveyors. These rates are not measured data but are based on a rough approximation developed by farmers from experience for any specific crop in an area and might be available in historical reports. It is typically expressed as depth (feet or inches) or as volume per unit of area (e.g., acre-feet per acre).

For example, the unit water duty is 4.1 acre-feet per acre for alfalfa in the Buttonwillow area of Kern County, where the soil generally is heavy and the common practice is to irrigate heavily during the early months when surface water is available.

Step 2: Collect Crop Acreage Data: Collect crop acreage and land use data for the water budget zone of interest. Crop data are available from local and state agencies with the most common sources of land use data listed below.

- Agricultural commissioner reports.
- Department of Pesticide Regulation.
- Water purveyor accounting.
- DWR land use surveys.

Step 3: Collect Irrigation Efficiency Information: Obtain approximations of irrigation efficiencies from local knowledge or other sources.

Step 4: Estimate ETAW: Use the following equation to estimate ETAW from crop water duty and irrigation efficiency:

$$\text{ETAW} = \text{Crop Water Duty} \times \text{Crop Acreage} \times \text{Irrigation Efficiency}$$

Applied water can include water for cultural practices (e.g. pre-irrigation, frost protection, crop cooling, rice flood-up and ponding. etc.) and leaching fractions. Irrigation efficiency information can be obtained from farmers and agricultural extension offices in the area. Additional sources include:

- DWR agricultural and land use estimates.
- Cal-SIMETAW unit values.
- FAO 56.
- ITRC.
- Local studies.
- University of California Cooperative Extension farm advisors.
- DWR irrigation method surveys.

- DWR Water Portfolio.
- ITRC surveys.

3.5 APPLIED WATER

Applied water represents the water deliveries to the farm (agricultural) or managed wetland head gate or the intake of a municipal, industrial, or large landscape water system. Measured water delivery data should be collected where available; in the absence of such data, this section provides methods for estimating applied water applied based on information such as (1) crop acreage, ET, and irrigation efficiencies; (2) per-capita water use and population; or (3) ponding depths for managed wetlands. These and other methods account for the amount of applied water needed to meet the water demand after accounting for the effective precipitation. In addition, the amount of applied water may also reflect intentional recharge as part of irrigation practices or may be a dedicated use for a managed aquifer recharge project. Local knowledge can improve these estimates by confirming and updating existing land use data, identifying sources of supply to fields (surface water, groundwater, mixed sources, applied water reuse, or recycled water), and identifying irrigation types and management practices (e.g., pre-irrigation, ponding, managed aquifer recharge). Developing, refining, and querying such information through GIS will improve land use acreage estimates and characteristics to estimate volumes of ET, applied water, and water supply.

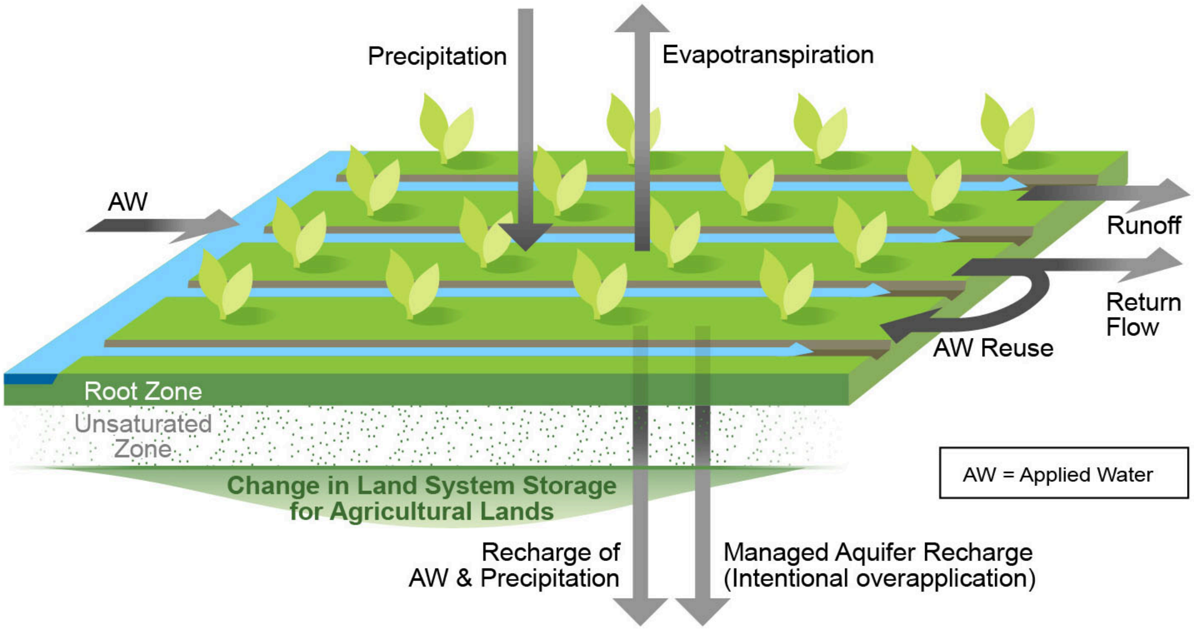
3.5.1 Agricultural Applied Water

Definition: Volume of water applied on agricultural land from all sources of water to meet on-farm crop irrigation requirements.

Context: The total amount of water that is needed for crop growth and management is applied water (AW) for agriculture; it includes irrigation to satisfy crop ET, cultural practices, leaching fractions, frost protection, pre-irrigation, etc. Agricultural applied water is almost always greater than the crop ET requirements to account for distribution inefficiencies and crop management goals.

As shown in Figure 3-4, the components of agricultural water use are applied water, precipitation, applied water reuse, ET, runoff, return flow, recharge of applied water and precipitation, managed aquifer recharge, and change in land system storage for agricultural lands. Applied water is met by a mix of water sources, such as surface water, groundwater, applied water reuse, recycled water, or any combination thereof. As a result, agricultural applied water is equal to agricultural water supply under ideal conditions when there is no shortage of water supply.

Figure 3-4 Components of Agricultural Water Use



Agricultural applied water is a function of the water management goals and the method used to irrigate a crop, such as sprinkler, drip, buried drip, border strip, furrow, check, etc. or a combination thereof. Water management may include overapplication of irrigation water when it is available to recharge groundwater. In other cases, on-farm tailwater may be reused within the same field that it was applied, thus reducing water deliveries. Any estimate of applied water should not include conveyance to the farm headgate.

Most often, applied water is not measured, and it is a common practice to estimate this volume based on crop ET, effective precipitation, and irrigation efficiency as follows:

$$\text{Agricultural Applied Water} = (\text{Crop ET} - \text{Effective Precipitation}) / \text{Irrigation Efficiency}$$

or

$$\text{Agricultural Applied Water} = \text{ETAW} / \text{Irrigation Efficiency}$$

Adjustments for Irrigation Efficiency: As shown above, irrigation efficiencies are used to calculate applied water from ETAW. Informational sources will cite typical irrigation efficiency ranges for a variety of irrigation methods and practices. The actual irrigation efficiencies in the water budget zone of interest may be higher or lower for any given irrigation method (e.g., drip, sprinkler, furrow, etc.). When adjusting irrigation efficiencies to reflect actual conditions, it is important to understand how irrigation efficiencies affect the return flow, recharge, and applied water reuse components when accounting the amount and destination of applied water in excess of ETAW. For example, a farmer uses border strip irrigation for a pasture. According to the U.S. Bureau of Reclamation's AgriMet Program, irrigation efficiencies, also known as seasonal application efficiencies, for border strip irrigation range from 55 percent to 90 percent. The farmer is using a 10-day rotation which may result in over application to fully meet ET between irrigations. The resulting irrigation efficiency may be 55 percent in contrast to a system on a 7-day rotation that would have a 65 percent irrigation efficiency. Each crop should be evaluated to best determine representative irrigation efficiency.

Adjustments for On-farm Managed Aquifer Recharge (Over-application): A common practice in some areas is to over-apply surplus surface water for recharging groundwater, which is referred to as managed aquifer recharge in this handbook. If the amount is known or can be approximated, it may be appropriate to add a depth of recharge to the applied water; otherwise, the irrigation efficiency could be lowered to better reflect this situation. As an example, local knowledge may indicate that 0.5 foot per acre was applied for groundwater recharge during a specific period. If a crop's unit applied water value was 4.5 acre-feet per acre for the entire growing season, then it would be adjusted as follows:

$$\text{Applied Water} = \text{Crop Applied Water} + \text{Recharge Applied Water} = 4.5 + 0.5 = 5.0 \text{ Acre-Feet per Acre (af/a)}$$

The volume of recharge purposefully occurring through the over-application applied water should be included in the volume of managed aquifer recharge, not in recharge of applied water and precipitation.

Adjustments for Shallow Groundwater Uptake: The need for irrigation applied water may be decreased by capillary rise from shallow groundwater to meet the crop evapotranspiration demand. It is difficult to estimate the contribution from shallow groundwater because it is sensitive to the depth to water table, and there are no simple methods to quantify it. If local knowledge exists regarding the location and potential magnitude of the shallow groundwater uptake, it can be accounted for as a source of supply. Although evapotranspiration from shallow groundwater uptake may reduce groundwater pumping from the aquifer, the net outflow from the groundwater system will remain the same. The only difference is that evapotranspiration of shallow groundwater is not part of total applied water, and hence there is no return flow associated with that amount.

Related Water Budget Components: Surface Water Delivery, Groundwater Extraction, Applied Water Reuse, Precipitation, Evapotranspiration, Recharge of Applied Water and Precipitation, Return Flow

How to Determine Agricultural Applied Water:

- Method 1 — Obtain available water delivery data.
- Method 2 — Use available technical reports and existing numerical models.
- Method 3 — Estimate applied water volumes.

Method 1 — Obtain Available Water Delivery Data

Water delivery data typically represent on-farm applied water and, when correlated with crop type and acreage served, these data can support estimates of unit applied water by crop for other areas without measured data within the water budget zone. Furthermore, where possible, the sources of the delivered water in terms of surface water, groundwater, and applied water reuse should be identified.

Available water delivery, crop type, and crop acreage data (daily, monthly, etc.) for all years of interest should be obtained from local water purveyors.

If all on-farm applied water is measured (and applied water reuse is measured), then all delivery data by crop type and acreage can be summed to determine the volume of applied water. Where tailwater reuse occurs but is not measured, local knowledge can be used to determine or approximate the amount of tailwater being used and that amount can be added to the water delivery to approximate on-farm applied water.

Sources of information include:

- Local agency water delivery records (water deliveries, crop type, and crop acreage).
- On-farm water use data.

Method 2 — Use Available Technical Reports and Existing Numerical Models:

Compile and evaluate applied water data available in technical reports, models, databases, etc. (daily, monthly, etc.) for all years of interest. Review all information to ensure representation throughout the water budget zone. Use local knowledge about irrigation practices to confirm or modify data to represent local conditions. Sources of information include:

- Cal-SIMETAW unit values: monthly applied water per acre by DAUCO for 2000 through 2015.
- Existing reports and studies.
- Existing models such as CVHM, C2VSIM or local models.
- Agricultural water management plans.
- Existing California Water Plan unit applied water by crop.
- UC Cooperative Extension farm advisors.

Method 3 — Estimate Applied Water Volumes

Estimating agricultural applied water can be approached in two ways; the method chosen for calculation of evapotranspiration in Section 3.4 will likely dictate the method used here.

1. Water-duty based approach.
2. Crop ET approach.

Water Duty Based Approach: In this approach, agricultural applied water is approximated based on water duty rates (also known as unit applied water) developed by local water purveyors and extrapolated to represent applied water for crops within the water budget zone. Local knowledge can be used to adjust water duty rates based on current water management practices (some areas may apply more or less than others).

Applied water can be approximated by using water duty rates by crop (see Method 4 of Section 3.4) and extrapolating the rates to all areas of interest. Determine acreage by crop type, apply the representative water duty rate by crop, and then sum the results as follows:

$$\text{Applied Water} = \sum (\text{Acreage by Crop Type} \times \text{Water Duty Rate by Crop})$$

If crop acreage by water source (surface water, groundwater, applied water reuse) can be determined, then:

$$\text{Applied Water by Water Source} = \sum (\text{Acreage by Crop by Water Source} \times \text{Water Duty Rate by Crop by Water Source})$$

It is important to note that water duty rates, or applied water, may differ among water sources for the same crop. The differences can be attributed to different irrigation methods and water management practices that are used for each water source type.

Crop ET Approach: In this approach, the estimation of agricultural applied water is obtained by using the equation described earlier. Crop ET requirements can be calculated by using methods described in Section 3.4. Effective precipitation can be estimated using methods described in Section 3.3. Identifying irrigation methods by field and by crop can contribute to better estimates of irrigation efficiencies when calculating agricultural applied water.

Applied water can be calculated using crop ETAW and irrigation efficiency (IE), like methods used for California Water Plan Water Portfolios. ETAW by crop type can be estimated using a soil moisture balance (e.g., Cal-SIMETAW, IDC) or an approximate method. Irrigation efficiencies and any additional amounts applied for cultural practices (CP) such as rice and rice straw decomposition flood-up, frost protection, or leaching requirements are added to the applied water calculation.

Applied water (AW) estimates should start by using acreage, ETAW, and irrigation practice information by crop and then sum all estimates to determine the total applied water for the water budget zone.

$$\text{Applied Water} = \sum (\text{Acreage} \times \text{unit Applied Water}) \text{ by crop}$$

or

$$\text{AW} = \sum (\text{Acreage} \times (\text{unit ETAW} / \text{IE} + \text{CP})) \text{ by crop}$$

In the equation above, irrigation efficiency (IE) is adjusted for over irrigation; cultural practices (CP) include volumes of flood-up, pre-irrigation, frost protection, and leaching; and ETAW is determined from:

- A soil moisture balance using crop ET data (see Section 3.4), soils, rooting depths, available soil moisture holding capacities, managed allowable depletion, deficit irrigation, and other factors that influence crop water use.
- Estimates of unit ETAW and applied water from existing data and models or developed using models, such as Cal-SIMETAW, IDC, and C2VSIM (see Section 3.4).
- An approximate method for determining ETAW using crop ET less effective precipitation (EP) as follows: ETAW = (ET minus EP) by crop.
- Adjusting ETAW for deficit irrigation.

Calculating applied water from land use data can facilitate initial estimates of water supplies. Using or creating water source information by field or geographic area can help initial estimates of how much surface water delivery [SW_{del}], groundwater [GW], and applied water reuse [R_u] is being applied. In many areas, there is no mapping of water source by field (surface water, groundwater, or a combination thereof [mixed water]); however, local water users may know the sources of supply and duration of its use (full or partial irrigation). That knowledge can be leveraged to make initial estimates of surface water delivery and groundwater extraction. Where a mix of the two sources occurs, an initial distribution of those source can be made, such as 50-50, 30-70, or 80-20 representing the proportion of surface water to groundwater. These estimates become input to the surface water delivery, groundwater extraction, and applied water reuse components. Land use data in GIS format (such as the 2014 LandIQ data or DWR land use surveys) can facilitate these initial estimates by identifying the crop, then identifying the water source for each crop, and then aggregating the data for the water budget zone.

The following steps can be used for Method 3, Approach 2.

Step 1: Calculate Crop ET Requirements — Using crop data and reference ET information (ET_o), calculate monthly crop ET requirements (see Section 3.4) for all months of the growing season. Adjust crop ET based on deficit irrigation practices within the water budget zone.

Step 2: Calculate Precipitation Volume for the Agricultural Area — Obtain measured precipitation data, and using methods described in Section 3.4, calculate monthly precipitation volume over the agricultural area during the growing season.

Step 3: Calculate Runoff Volume — Using any of the methods described in Section 3.10, calculate monthly runoff volume over the agricultural area.

Step 4: Calculate ET of Precipitation — Subtract runoff volume from the precipitation volume for agricultural lands and compare that with the crop ET requirements for each month of the growing season and take the minimum of two values as the consumptive use of precipitation, also known as effective precipitation (EP), for the corresponding month.

Step 5: Calculate ET of Applied Water — Subtract consumptive use of precipitation from the crop ET requirements to determine consumptive use of applied water, also known as ETAW.

Step 6: Estimate Applied Water Using Irrigation Efficiency — Agricultural applied water estimates depend on the understanding irrigation practices and irrigation efficiency. Applied Water is calculated as:

$$\text{Applied Water} = \text{ETAW} \,/\, \text{IE} + \text{CP} \text{ or } \text{Applied Water} = (\text{ET} - \text{EP}) \,/\, \text{IE} + \text{CP}$$

If crop acreage by water source type (i.e., groundwater, applied water reuse, and surface water) is known or can be estimated, then applied water can be used to make initial estimates of water supplies using the following steps:

Step 7: Calculate Volume of Groundwater Extraction — Multiply crop acreage and unit applied water for groundwater to determine the volume of groundwater extraction.

Step 8: Calculate Volume of Applied Water Reuse — Multiply crop acreage, unit applied water, and the reuse component of irrigation efficiency to determine the volume of applied water reuse.

Step 9: Calculate Volume of Surface Water Delivery — Multiply crop acreage and unit applied water for surface water to determine the volume of surface water, and then subtract the volume of applied water reuse.

The following example demonstrates how this process is used in the California Water Plan. A DAU in northeastern California consists of a mix of water purveyors and individual agricultural water users located in the upper Pit River system. Surface water comprises a majority of the water uses with diversions and ditch systems as the primary means of providing irrigation water to mostly pasture and alfalfa crops, and water diversion data are generally not available. This example uses DWR’s land use survey with water sources mapping that identifies land using surface water, groundwater, and mixed water sources. A spatial query aggregates the data by crop and by water source. The mixed source lands are split 50 percent / 50 percent to surface water and groundwater, respectively. The acreage by crop and unit applied water values are used for the calculation. Because groundwater is directly applied to fields through gated pipe, center pivots, or wheel line systems, the irrigation efficiency is higher than surface water.

First, the land use spatial data are queried through GIS and the mixed source split is applied to determine crop acreage by surface water and groundwater as shown in Table 3-1.

Table 3-1 **Example of Spatial Land Use and Water Source Data Analysis**

Crop	Full or Partial Irrigation	Data query SW use only	Data query GW use only	Data query mixed SW/GW use	Mixed source split SW/GW	Total SW use	Total GW use
Alfalfa	Full	3.6	5.2	1.2	50 / 50	4.2	5.8
Alfalfa	Partial	0.0	0.2	0.0	50 / 50	0.0	0.2
Grain	Full	1.9	0.4	0.5	50 / 50	2.0	0.5
Meadow Pasture	Full	8.2	1.5	0.8	50 / 50	8.6	1.9
Meadow Pasture	Partial	2.9	1.5	0.0	50 / 50	2.9	1.5
Pasture	Full	20.4	1.1	0.8	50 / 50	20.8	1.5
Pasture	Partial	0.6	0.0	0.0	50 / 50	0.6	0.0
Rice	Full	2.2	0.3	0.2	50 / 50	2.3	0.4
Total		**39.8**	**10.2**	**3.2**		**41.4**	**11.8**

Table Notes: GW = groundwater, SW = surface water
Units are in thousand acre-feet

Next, irrigation efficiency values are used with unit ETAW and land use acreage by water source type to calculate Applied Water for surface water deliveries and groundwater extraction as shown in the equations below and summarized in Table 3-2 and Table 3-3.

$$\text{Applied Water (AW)} = \text{AW}_{\text{SW}} + \text{AW}_{\text{GW}}$$

$$\text{AW}_{\text{SW}} = \sum \left(\text{Acreage} \times \left(\text{unit ETAW} \,/\, \text{IE} + \text{CP}\right)\right) \text{ by crop for surface water sources}$$

$$\text{AW}_{\text{GW}} = \sum \left(\text{Acreage} \times \left(\text{unit ETAW} \,/\, \text{IE} + \text{CP}\right)\right) \text{ by crop for groundwater sources}$$

CP is 0.6 feet for flood-up practices associated with rice and zero for all other crops.

Table 3-2 **Example Calculation of Applied Surface Water**

Crop	Thousands of Acres	ETAW (af/a)	Irrigation Efficiency	Cultural Practices (af/a)	Applied Water (taf)
Alfalfa	4.2	2.1	72%	0	12.2
Grain	2.0	1.1	74%	0	3.0
Meadow Pasture	8.6	2.1	68%	0	26.66
Meadow Pasture — Partially Irrigated (April–June)	2.9	0.3	68%	0	1.3
Pasture	20.8	2.2	65%	0	70.4
Pasture — Partially Irrigated (April–June)	0.6	1.0	70%	0	0.8
Rice	2.3	2.6	63%	0.6	10.9
Total Applied Surface Water (AW_{SW}) = 125.2					

Table Notes: af/a = acre-feet per acre, taf = thousand acre-feet

Table 3-3 **Example Calculation of Applied Groundwater**

Crop	Area (thousands of acres)	ETAW (af/a)	Irrigation Efficiency	Cultural Practices (af/a)	Applied Water (taf)
Alfalfa	5.8	2.1	76%	0	16.0
Alfalfa — Partially Irrigated (April–June)	0.2	1.0	76%	0	0.3
Grain	0.5	1.1	77%	0	0.7
Meadow Pasture	1.9	2.1	70%	0	5.7
Meadow Pasture — Partially Irrigated (April–June)	1.5	0.3	70%	0	0.6
Pasture	1.5	2.2	66%	0	5.0
Rice	0.4	2.6	63%	0.6	1.9
Total Groundwater Applied Water (AW_{GW}) = 30.2					

Table Notes: af/a = acre-feet per acre, ETAW = evapotranspiration of applied water, taf = thousand acre-feet

A majority of the water applied for crop irrigation is either consumed by ET or retained by the crop. The remainder of that water can be attributed to mostly non-consumptive uses of irrigation water (applied water less ETAW), such as infiltration through the root zone and unsaturated zone to recharge the groundwater or surface runoff (e.g., tailwater). That surface runoff may contribute to applied water reuse, return flow to the surface water system, or a combination of both. The amount of recharge, applied water reuse, and return flow is a function of the irrigation method, water management, cultural practices, and soils. These non-consumptive uses can be estimated from the loss portion of irrigation efficiency (i.e., 100 percent — irrigation efficiency) and cultural practices not meeting ET. Tables 3-4 and 3-5 provide the typical components of irrigation efficiency to estimate the disposition of the non-consumptive uses for applied water, namely recharge of applied water and return flow from irrigation systems.

Table 3-4 Potential Magnitude of Irrigation Losses for Furrow Irrigation (Percent)

Type of Irrigation System	Distribution System	Air Evap.	Soil Evap.	Canopy Evap.	Recharge	Surface Runoff	Overall Efficiency
Every row	1-5	<1.0	1-5	0.0	10-20	10-35	40-75
With surge valve	1-5	<1.0	1-5	0.0	5-15	5-15	60-85
With reuse	1-5	1-2	1-5	0.0	10-20	0	55-90
Siphon tube	5-10	1-2	1-5	0.0	15-25	15-25	40-75
Alternate row	1-5	< 0.5	1-3	0,0	5-15	10-20	60-85

Source: Plant and Soil Sciences eLibrary

Table 3-5 Potential Magnitude of Irrigation Losses for Sprinkler Irrigation (Percent)

Type of Irrigation System	Distribution System	Air Evap.	Soil Evap.	Canopy Evap.	Recharge	Surface Runoff	Overall Efficiency
Hand-moved	<1.0	3-5	1-5	10-15	5-10	0-5	60-80
Solid set	<1.0	3-5	1-5	10-15	0-10	0-5	60-85
Traveler	<1.0	1-3	1-5	1-5	0-5	5-10	55-75
High pressure impact	<0.5	1-3	0-1	1-5	0-5	0-5	70-80

Type of Irrigation System	Distribution System	Air Evap.	Soil Evap.	Canopy Evap.	Recharge	Surface Runoff	Overall Efficiency
Low pressure impact	<0.5	1-3	0-1	1-3	0-5	0-10	75-85
Low pressure spray	<0.5	1-3	0-1	1-3	0-5	0-20	70-90
Low pressure bubble	<0.5	0.0	0-0.5	0.0	0-5	20-40	60-95
Drip irrigation	<0.5	0.0	0.0	0.0	5-30	0.0	70-95

Source: Plant and Soil Sciences eLibrary

The following steps can be used to estimate of the amount of recharge, return flow, and applied water reuse based on proportioning the losses associated with irrigation efficiency:

Step 10: Calculate Volume of Irrigation Recharge — Multiply crop acreage, unit applied water, and recharge component of irrigation efficiency to determine the volume of irrigation recharge.

Step 11: Calculate Volume of Irrigation Return Flow — Multiply crop acreage, unit applied water, and return flow component of irrigation efficiency to determine the volume of irrigation return flow.

Example: Corn is irrigated on 1,000 acres of land with moderately permeable soils using surface water, furrows, and siphon tubes. The irrigation results in an ETAW of 2.2 af/a. Using Table 3-4 as a guide, furrow irrigation using siphon tubes is estimated to have a 70 percent irrigation efficiency, and the remaining irrigation loss are estimated to be 15 percent for moderate recharge, 3 percent for soil/air evaporation, and 12 percent for surface runoff. Local information indicates that about half of the surface runoff is either reused on-farm or diverted by others, translating to about 6 percent for applied water reuse. The following calculations show estimates of AW, applied water reuse (R_u), return flow (R_f), recharge of applied water (D_i) and precipitation, and ETAW using information in Table 3-4:

- Soil and canopy evaporation are estimated to be 0 percent.

- 50 percent of the tailwater is reused downstream and the other 50 percent becomes surface runoff.
- Surface runoff fraction estimate is 12 percent from Table 3-4.
- R_{uf} = reuse fraction of AW; in = 50 percent of surface runoff fraction
- R_{ff} = return flow fraction of AW = 50 percent of surface runoff fraction
- D_{if} = Recharge fraction of AW = estimate is 15 percent from Table 3-4.
- Using given information from above, calculate irrigation efficiency and applied water, applied water reuse, return flow, and recharge volumes:

$$\mathrm{IE} = 100\% - \mathrm{R_{uf}}(\%) - \mathrm{R_{ff}}(\%) - \mathrm{D_{if}}(\%) =$$
$$100\% - (0.5 \times 12\%) - (0.5 \times 12\%) - 15\% = 73\%$$

$$\mathrm{ETAW} = 2.2 \times 1000 = 2200\ \mathrm{AF}$$

$$\text{Applied Water} = \mathrm{ETAW} / \mathrm{IE} = 2.2 \times 1000 / 0.73 = 3{,}014\ \mathrm{AF}$$

$$\mathrm{R_u} = \text{Applied Water} \times \mathrm{R_{uf}} = 3{,}014 \times (0.12 \times 0.5) = 181\ \mathrm{AF}$$

$$\mathrm{R_f} = \text{Applied Water} \times \mathrm{R_{ff}} = 3{,}014 \times (0.12 \times 0.5) = 181\ \mathrm{AF}$$

$$\mathrm{D_i} = \text{Applied Water} \times \mathrm{D_{if}} = 3{,}014 \times 0.15 = 452\ \mathrm{AF}$$

These estimates can be used for estimating applied water reuse, return flow, and recharge. It is important to note that these should be used as initial estimates and computing the total water budget may require multiple iterations to develop a representative water budget, especially where one or more water budget components can be refined with available measured data.

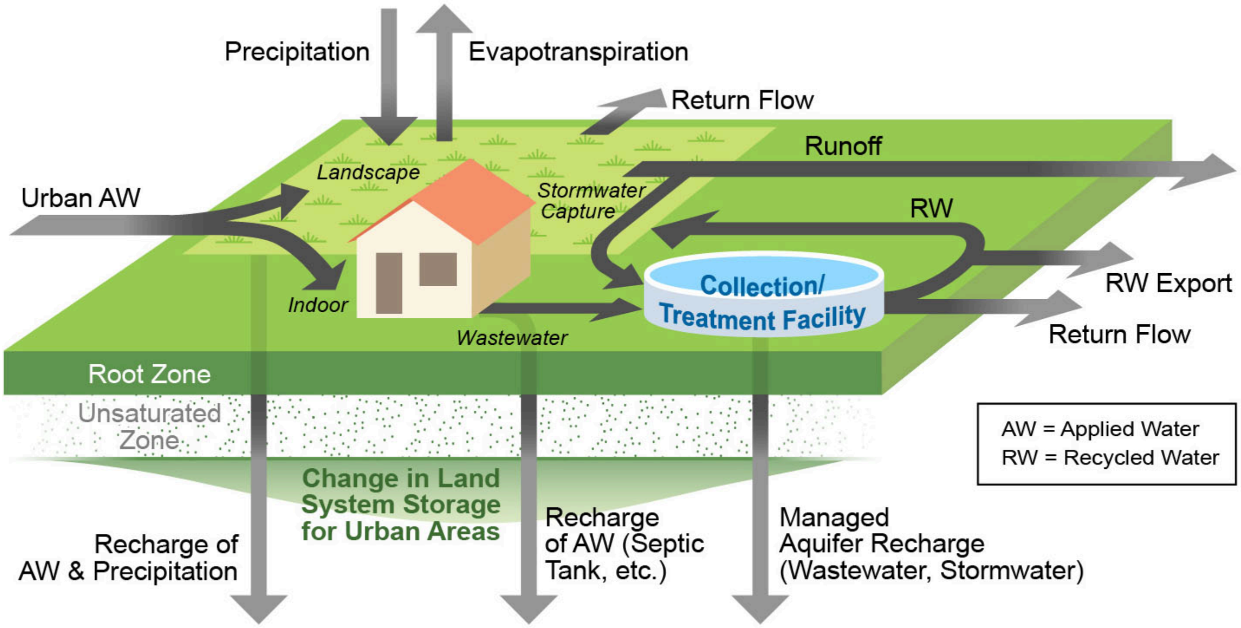
3.5.2 Urban Applied Water

Definition: Volume of water delivered from any source to the intake of a municipal, industrial, or large landscape water system. This would equal the volume of surface water delivery, groundwater water extraction, applied water reuse, and recycled water.

Context: Urban applied water consists of a broad category of water uses that include municipal, self-supplied rural, industrial, energy production, and large landscape uses. Urban water use represents water measured at the intake to an urban water supplier (i.e., water production) and does not include conveyance losses (evaporation and seepage) to the intake; however, it will include distribution system water losses (seepage, illegal connections, unaccounted for water) that occurs between the intake and the end user (Section 3.2.2). Available data should be known by the local purveyors and water users with larger municipalities having measured supplies and currently reporting their supplies and metered deliveries to the State Water Resources Control Board (State Water Board). This information was previously collected by DWR (Public Water Supply Statistics data). Self-supplied rural represents individual supplies serving individual or small groups of residences, commercial, industrial, etc., most of which are served by groundwater. Calculations of applied water may include supplies offset by reuse or recycled water.

As shown in Figure 3-5, the components of urban water use are applied water (landscape and indoor uses), precipitation, applied water reuse, recycled water, ET, recycled water export, runoff, return flow, recharge of applied water and precipitation (including septic tank recharge, distribution system water loss seepage), managed aquifer recharge, and change in land system storage for urban areas. Urban applied water is further subdivided into indoor and outdoor water uses. Indoor water use most commonly consists of interior residential, commercial, and industrial water use; this water is most often non-consumptively used and generally becomes return flow to the surface water system (e.g., wastewater discharges) or recharge to the groundwater system (e.g., waste water percolation ponds or septic tanks). A part of the indoor water use may become recycled water to meet demands inside or outside the water budget zone. The recycled water delivered to irrigate landscape reduces the amount of groundwater extraction and surface water delivery to urban areas within a water budget zone. Recycled water used outside the water budget zone is called recycled water export (Figure 1-1). Urban outdoor water use is largely for landscape irrigation, which is consists of landscape ET, return flow, or recharge of applied water.

Figure 3-5 **Components of Urban Water Use**



Related Water Budget Components: Surface Water Delivery, Groundwater Extraction, Recycled Water, Precipitation, Evapotranspiration, Recharge of Applied Water and Precipitation, Return Flow

How to Determine Urban Applied water:

- Method 1 — Obtain available urban water production data.
- Method 2 — Use available technical reports and existing numerical models.
- Method 3 — Estimate unavailable urban demand data using population and per-capita water use.

Method 1 — Obtain Available Urban Water Production Data

Obtain available urban water production data (daily, monthly, etc.) for all years of interest. Water production data represents the volume of surface water, groundwater extraction, imported water, and ocean desalination that is treated for distribution and delivery. Imported water may come from another water purveyor or wholesale water entity and may consist of both surface water and groundwater. Applied water reuse and recycled water may be treated and distributed for landscape use, recharge, other uses and included in the water purveyor data. It may be useful to collect data outside the water budget zone when there is a lack of data within the zone to represent urban water use conditions. Monthly data should be collected to support the calculation of indoor use based on lowest month production. Sources of information include:

- State Water Board’s Electronic Annual Report (Public Water Systems).
- State Water Board’s Monthly Urban Water Production Reporting.
- DWR Public Water Supply Statistics Data — Historical.
- Local agency water delivery records.
- Urban water management plans.
- Other.

It is important to thoroughly review all production data for accuracy. Often, the measured data from local purveyors or municipalities will not cover the entire population but can be helpful in making estimates for non-represented populations by computing per-capita water use and factoring it for non-represented populated areas.

Method 2 — Use Available Technical Reports and Existing Numerical Models

Compile and evaluate urban water production or applied water data that are available in technical reports, numerical models, and databases (daily, monthly, etc.) for all years of interest. It may be useful to collect data outside the water budget zone when there is a lack of data to represent urban water use conditions in the water budget zone. Sources of information include:

- Existing reports and studies.
- Existing models such as CVHM, C2VSIM, and local models.
- Urban water management plans.
- California Water Plan Water Portfolio data.
- DWR’s A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California.

All technical report data and numerical model input data and results should be carefully reviewed for adequacy and appropriateness of assumptions.

Method 3 — Use Population and Per-Capita Water Use

This method estimates urban applied water using population and per-capita water use. Collecting population data and service area coverage information from urban water purveyors in a spatial format (e.g., GIS) is needed for this analysis. U.S. Census track data provides decadal population data in spatial format for querying and can be used with service areas to determine population being served by urban water purveyors and those not being served. The California Department of Finance provides annual projections of population to help interpolate between decadal census data. These annual population projections are helpful in all situations but essential for rapidly expanding urban areas. Alternatively, some water purveyors estimate their annual population served based of an assumed number of persons per connection where the number of connections is known.

Per-capita water use estimates are based on production data from an existing urban area and divided by the population served when such data are available. For unmeasured municipal and self-supplied areas such as rural, industrial, and large landscapes (parks, gold courses, etc.), applied water estimates are calculated using population being served and estimates of representative per capita water use from similar areas.

Per-capita water use estimates by DAUCO are available through the California Water Plan Water Portfolios (information on Water Portfolios is available in Section 9.9), or for specific areas, these can be determined using public water supply statistics data compiled by the State Water Board or DWR. These statistics will include total water production, water production by source (surface water or groundwater) and may contain water delivery data by customer class types (residential, multi-family, industrial, large landscape, etc.). Data from Methods 1 and 2 can also inform these calculations.

Some landscape irrigation may not be included in per-capita water use estimates, such as golf courses or park with a self-produced supply. If measured water use is not available, then estimate the landscape irrigation using spatial land use data through GIS and coupling it with ET rates (see Section 3.4 - Evapotranspiration) and estimated irrigation efficiencies to determine applied water (see Section 3.5.1 for method to estimate applied water)

Urban water production, or applied water, can be estimated as:

$$\text{Applied Water} = \sum (\text{Population} \times \text{Per Capita Water Use}) \text{ by service area} + \sum \text{Industrial Use} + \sum \text{Landscape Irrigation}$$

Where:

- Population is estimated from city, water purveyor, or rural estimates of population or U.S. Census and California Department of Finance data.
- Per capita water use is estimated from municipal water use records (water deliveries divided by population served) and represents a “community per-capita” that reflects a certain mix of residential, commercial, landscape, industrial, and other use. These per-capita estimates can be extrapolated to unmeasured communities or rural areas with similar characteristics. Per capita water use is often represented as gallons per capita per day (GPCD). Lower rates of GPCD may reflect areas with low landscape irrigation (outdoor water use), such as coastal areas, whereas higher rates of GPCD may reflect more landscape irrigation (e.g., Central Valley) or seasonal tourism (e.g., Lake Tahoe).
- Industrial water use is estimated from data collected, correlating representative water use information from water use surveys or approximations. Sources of information can be industrial users, surveys of industrial users where gallons per employee or gallons per square foot may represent specific types of uses.
- Landscape irrigation includes golf courses and parks where the irrigated area and unit applied water values can estimate supply.

The following example shows the process for estimating urban applied water using California Water Plan information for Modoc County DAU 130 (Goose Lake — Alturas).

Example: This example consists of a mix of water purveyors and individual, unorganized agricultural and urban/rural water users located in the upper Pit River system around Alturas. Urban uses include the City of Alturas, rural development, and golf course irrigation. The urban and rural populations use groundwater. Water use estimates focus on the measured data for the city of Alturas and an estimate of rural population. Local knowledge indicates that the rural population often has larger landscaped areas than residents in Alturas. Reviewing data adjacent to the region, the large landscape areas are best represented by the community of Cedarville, which is thus selected as the representative per-capita water use for the rural areas.

Urban water use is calculated as the summation of areas with similar per-capita water uses:

$$\text{Applied Water} = \sum(\text{Population} \times \text{Per Capita Water Use}) \text{ by Service Area}$$

Where:

- Population of Alturas = 2,827 (Sources: Department of Finance, California Water Plan, and checked with population served by the water purveyor).
- Per Capita Water Use of Alturas = 0.251 acre-feet per capita annually.
- Rural Population = 3,637.
- Rural Per Capita Water Use (represented by Cedarville) = 0.328 acre-feet per capita annually.

$$\text{Applied Water} = \sum(2{,}827 \times 0.251 + 3{,}637 \times 0.328) = 1{,}903 \text{ AF (Urban/Rural Use of Groundwater)}$$

The estimate of applied water for the self-supplied golf course is based on land use and local information (data not reported). Golf course water use can be estimated by area irrigated, ETAW, and irrigation efficiency as follows:

$$\text{Applied Water} = \text{Landscape Area} \times \text{unit AW} = \text{Landscape Area} \times \text{unit ETAW} / \text{IE}$$

Where:

- Landscape Area = 49.6 acres (Source: DWR land use survey).
- Unit ETAW = 27.87 inches/acre.
- Irrigation Efficiency = 75 percent.

$$\text{Applied Water} = 49.6 \times (27.87 / 12) / 0.75 =$$
$$154 \text{ AF (Urban/Rural Use of Surface water)}$$

Thus:

$$\text{Total Urban Applied Water} = 1{,}903 \text{ AF} + 154 \text{ AF} = 2{,}057 \text{ AF}$$

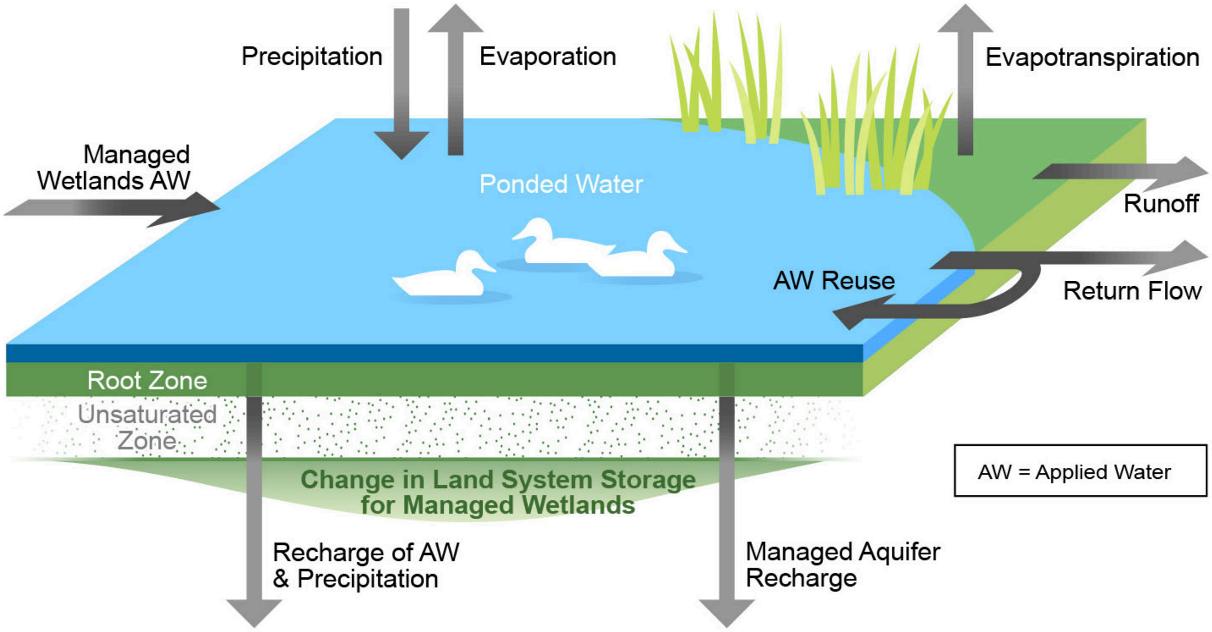
3.5.3 Managed Wetlands Applied Water

Definition: Volume of water delivered from any source as either direct or incidental flows to a marsh or wetland for wildlife areas. This would equal the volume of surface water delivery, groundwater water extraction, and reuse.

Context: Managed wetlands applied water is the total amount of water applied for habitat management, including irrigation to satisfy ET, ponded water evaporation, ponded water habitat flood-up, and habitat management practices (e.g., circulation rates, irrigation for forage production, etc.). Tailwater systems (reuse) may result in water deliveries less than actual applied water volumes as reuse is re-application of tailwater from water already applied. Applied water does not include conveyance to the headgate of the managed wetlands. When applied water is not measured, a common practice is to estimate the amount based on habitat evaporation and ET and volumes of habitat management practices. Available applied water or water delivery data can be used to estimate unmeasured applied water conditions.

As shown in Figure 3-6, the components of managed wetlands water use are applied water, precipitation, applied water reuse, ET, runoff, return flow, recharge of applied water and precipitation, managed aquifer recharge, and change in land system storage for managed wetlands.

Figure 3-6 Components of Managed Wetlands Water Use



Related Water Budget Components: Surface Water Delivery, Groundwater Extraction, Applied Water Reuse, Recycled Water, Precipitation, Evapotranspiration, Evaporation, Recharge of Applied Water and Precipitation, Return Flow

How to Determine Managed Wetlands Applied Water:

- Method 1 — Obtain available water delivery data.
- Method 2 — Collect available technical reports and existing numerical models for applied water data.
- Method 3 — Estimate applied water volumes.

Method 1 — Obtain Available Water Delivery Data

Obtain available water delivery data (daily, monthly, etc.) for all years of interest. Water delivery data can represent managed wetlands applied water if no reuse of tailwater occurs. If tailwater reuse occurs, determine or approximate the amount of tailwater being used. Adding water delivery and reuse can approximate managed wetlands applied water. Sources of information include:

- USFWS and CDFW refuge water management plans.
- Reclamation's Central Valley Project refuge water delivery data.

- Local agency water delivery records.
- California Water Plan Water Portfolio managed wetlands water use data.

Method 2 — Collect Available Technical Reports and Existing Numerical Models for Applied Water Data

Compile and evaluate applied water data available in technical reports, numerical models, and databases (daily, monthly, etc.) for all years of interest. Sources of information include:

- Existing reports and studies.
- Existing models such as CVHM, C2VSIM, and local models.
- Cal-SIMETAW Unit Values: Per acre AW for riparian vegetation and shallow water surface bodies by DAUCO for 2000—2015.
- California Water Plan Water Portfolio data.

Method 3 — Estimate Applied Water Volumes

Managed wetlands consist of federal or State wildlife refuges, private wetlands, and duck clubs that create habitat suitable for waterfowl and other wetland dependent species using managed wetlands water supplies. Federal and State refuges often have management plans providing valuable information on habitat types, water management objectives, and operations. Habitat objectives could include flood-up and drawdown dates (management periods), irrigation management, ponding depths, circulation rates, etc., all which support estimates of habitat applied water. It is important to note that the same habitat type may have different flood-up and drawdown dates within a given refuges, thus calculating applied water by habitat type by management period may be necessary. Examples of habitat include seasonal and permanent wetlands, open water, grasslands, forage (e.g., water grass), etc. It is best to estimate applied water for each habitat type because of the large differences in water requirement for different habitat types, and then sum the results. The typical unit applied water calculation involves depths of ETAW, flood-up, circulation, seepage, and forage irrigation and does not include irrigation efficiency because entire habitat is flooded to target depths. The resulting calculation from this approach is as follows:

$$\text{Managed Wetlands AW} = \sum(\text{Habitat Acreage} \times (\text{Unit ETAW} + \text{CP})) \text{ by habitat type and management period}$$

Where:

- Unit ETAW = ET of applied water per acre by habitat type and management. These values are generated from crop/habitat spreadsheets, models, or soil moisture balance.
- CP = Cultural Practices = (Flood-up Depth + Circulation Water + Seepage + Forage Irrigation) per acre.
    - Flood-up depth includes saturating soil pore space and depth of ponding.
    - Circulation is the continuous flow rate needed for waterfowl disease management. It is represented as a depth per acre.
    - Seepage is the amount of water percolating from the field that needs replacement to maintain the required water depth for the habitat. It is represented as a depth per acre.
    - Forage irrigation is the water applied to grow seed producing vegetation for waterfowl and commonly consists of one or two applications of water about 3 inches in depth for each irrigation.

Sources of information include:

- Individual refuges operated by USFWS or CDFW.
- Private wetlands or duck clubs (Ducks Unlimited, The Nature Conservancy, California Waterfowl Association, etc.)
- DWR Land Use Surveys (permanent managed wetlands, seasonal managed wetlands).
- California Water Plan Water Portfolio estimates by DAUCO for refuge, private wetland, or duck club, which include land use by habitat type, ETAW by habitat type, management practices by habitat, and estimates of water use.

Example: Modoc County DAU 130 (Goose Lake, Alturas) — This example represents the estimate of water use and resulting surface water diversion for the Modoc National Wildlife Refuge. Refuge habitat consists of open water (Dorris Reservoir), permanent ponds, wet meadows, and seasonal marsh. Water management is specific to habitat type and is calculated as:

$$\text{Managed Wetlands AW} = \sum(\text{Habitat Acreage} \times (\text{unit ETAW} + \text{CP})) \text{ by habitat type and management period}$$

First, the Modoc County land use spatial data are queried and the refuge management plan is consulted to determine the managed wetlands acreage by habitat type. Next, unit ETAW and cultural (habitat) practices are collected from available information for use in the above equation and the results are shown in Table 3-6.

Table 3-6 Example Calculation of Applied Water by Water Source

Habitat	Area (thousands of acres)	ETAW (af/a)	Cultural Practice (af/a)	Applied Water (taf)
Open Water	0.5	2.6	0.0	1.30
Permanent Ponds	0.4	2.8	0.3	1.24
Wet Meadows	0.7	1.2	0.5	1.19
Seasonal Marsh	0.3	0.5	1.4	0.57
Grain	0.2	1.3	0.8	0.42
Total Applied Surface Water for Managed Wetlands = 4.72				

Table Notes: af/a = acre-feet per acre, ETAW = evapotranspiration of applied water, taf = thousand acre-feet

3.6 SURFACE WATER DELIVERY

Definition: Volume of surface water delivered to a water budget zone. This does not equal the volume of surface water diversion and imported water because the latter also include conveyance seepage and evaporation during transport of the water.

Context: Surface water deliveries (SW_{del}) are typically measured at the farm, managed wetlands, or managed aquifer recharge project headgate or the intake to an urban water supplier and do not include conveyance losses (evaporation and seepage); however, conveyance or distribution losses occurring on-farm or within an urban water supplier's distribution system would be included. Available data should be known by the local water purveyors and users. Where delivery data are not readily available (including historical), volumes of applied water can be used to estimate the delivery volumes based on lands fully or partially using surface water. Tailwater systems recapturing drainage may result in water deliveries less than applied water volumes.

Adjustments for Deficit Irrigation: See Section 3.4, "Evapotranspiration," for more information on adjustments for deficit irrigation.

Adjustments for Irrigation Efficiency: See Section 3.5.1, "Agricultural Applied Water," for more information on adjustments for irrigation efficiency.

Adjustments for On-farm Managed Aquifer Recharge (Over-application): See Section 3.5.1, "Agricultural Applied Water," for more information on adjustment for on-farm recharge (over-application).

Inclusion of Managed Aquifer Recharge: See Section 5.6, "Managed Aquifer Recharge," — for more information on quantifying managed aquifer recharge. Surface water deliveries should include supplies for managed aquifer recharge projects.

Related Water Budget Components: Surface Water Imports, Surface Water Diversions, Groundwater Extraction, Applied Water Reuse, Recycled Water, Conveyance Evaporation, Conveyance Seepage

How to Determine Surface Water Deliveries:

- Method 1 — Obtain available surface water delivery data.
- Method 2 — Use published reports and numerical models.
- Method 3 — Estimate unavailable surface water delivery data.

Method 1 — Obtain Available Surface Water Delivery Data

Obtain surface water delivery data (daily, monthly, etc.). Sources of information include:

- Local agency records, including flood control districts or entities managing stormwater.
- For additional sources, see Section 9, "Data Resources Directory."

Method 2 — Use Published Reports and Numerical Models

Collect and review published reports and existing numerical models for the area of interest; these are good sources of estimates for historical surface water delivery data over an area. If reliable and defensible estimates of surface water delivery volumes (monthly or annual) are available for the water budget zone, those estimates can be used for developing water budgets. If surface water deliveries from an existing numerical model are used, then the following should be validated:

- The numerical model is calibrated and accepted by stakeholders.
- There is documentation of both the source data and the basis of estimate used in the numerical model.
- Any geographic scaling factor used to convert model estimates to correspond to the water budget zone is defensible and representative for the area.

Method 3 — Estimate Unavailable Surface Water Delivery Data

Surface water deliveries can be estimated for agricultural, urban, and managed wetlands systems using volumes of applied water, like the approach used in the California Water Plan Water Portfolio. Section 3.5, "Applied Water," describes methods to estimate the amount of applied water met by surface water, groundwater, and applied water reuse. Details for estimating agricultural, urban, and managed wetlands applied water are provided, respectively, in Sections 3.5.1, 3.5.2., and 3.5.3.

Calculating applied water from land use data can facilitate initial estimates of water supplies. Using or creating water source information by field or geographic area can help initial estimates of how much surface water delivery [SW_{del}], groundwater [GW], and applied water reuse [R_u] is being applied. In many areas, there is no mapping of water source by field (surface water, groundwater, or a combination thereof [mixed water]); however, local water users may know the sources of supply and duration of its use (full or partial irrigation). That knowledge can be leveraged to make initial estimates of surface water delivery and groundwater extraction. Where a mix of the two sources occurs, an initial distribution of those source can be made, such as 50-50, 30-70, or 80-20 representing the proportion of surface water to groundwater. These estimates become input to the surface water delivery, groundwater extraction, and applied water reuse components. Land use data in GIS format (such as the 2014 LandIQ data or DWR Land Use Surveys) can facilitate these initial estimates by identifying the crop, then identifying the water source for each crop, and then aggregating the data for the water budget zone.

For agricultural and managed wetlands uses where water sources are identified, surface water deliveries can be simply estimated from Agricultural Applied Water (Section 3.5.1) and Managed Wetlands Applied Water (Section 3.5.3) as:

$$SW_{del} = \text{Applied Water from Surface Water} = AW_{SW}$$

If applied water by water source is unknown, then estimates should be made for groundwater extraction (GW_{ext}) and applied water reuse (R_U), which may be an iterative process. Applied water reuse can be simplified as a percentage of applied water based on local knowledge of irrigation practices and tailwater conditions for the area of interest. Surface water delivery can then be estimated as:

$$SW_{del} = AW - GW_{ext} - R_U$$

where applied water reuse (R_U) can be estimated as a fraction of applied water (R_{uf}), then

$$SW_{del} = AW \times (1 - R_{uf}) - GW_{ext}$$

Estimating applied water reuse can become more complex when agricultural, urban, or managed wetlands return flows become sources of supply for another use within the water budget zone. This quantity is not a new supply but more than likely an applied water reuse (double counting of supply should be carefully avoided). Thus, all reuses should be considered.

If the amount of applied water met by surface water has been calculated, then:

$$SW_{del} = AW_{SW} - R_U$$

Where the amount of applied water reuse (R_U) is unknown but can be estimated as a fraction of applied water reuse (R_{uf}), then:

$$SW_{del} = AW_{SW} \times (1 - R_{uf})$$

For urban water supplies, recycled water (R_W) for landscape irrigation can reduce the amount of surface water treated for distribution, also known as water production or applied water. It is important to know if recycled water is accounted for in urban water deliveries to customers or if the recycled water becomes a separate use. For example, a wastewater treatment plant provides recycled water for landscape irrigation along a highway, and this irrigation is not accounted for by the urban purveyor because it is directly supplied by the wastewater treatment plant. The recycled water would not reduce the urban supply but rather is used to meet additional applied water in the form of landscape irrigation (Section 3.5.2, "Urban Applied Water"). Surface water deliveries can in this case be estimated as:

$$SW_{del} = AW_{SW} - R_W$$

$$AW = SW_{del} + GW_{ext} + R_W$$

If an estimate of GW_{ext} is available, then:

$$SW_{del} = AW - R_W - GW_{ext}$$

If how much applied water is surface water has been calculated, then:

$$SW_{del} = AW_{SW} - R_W$$

Example: This example consists of a mix of water purveyors and individual, agricultural and urban/rural water users located in the upper Pit River system. Surface water comprises a majority of the water uses with diversions and ditch systems as the primary means of providing irrigation water to mostly pasture and alfalfa crops, and deliveries are mostly unmeasured. Other uses include golf course irrigation and refuge management. For the urban and rural populations, the applied water estimate is used for surface water deliveries. This example represents estimating surface water delivery to a golf course served by surface water, which is based on land use and local information (data not reported). Applied water is estimated to be 0.2 thousand acre-feet (taf). It is assumed that no applied water reuse occurs, and the calculation of surface water delivery is:

$$SW_{del} = AW_{SW} - R_U$$

Where applied water reuse (R_U) can be estimated using the fraction of applied water reuse (R_{uf}), then:

$$SW_{del} = AW_{SW} \times (1 - R_{uf})$$

Where AW (Surface Water) = 0.2 taf and R_{uf} = 0, then:

$$SW_{del} = 0.2 \times (1 - 0) = 0.2 \text{ taf (Urban Surface Water Deliveries)}$$

For agricultural uses, the volumes of applied water can be used to estimate these deliveries based on land and water use estimates in the California Water Plan and is based on the identification of lands using surface water, groundwater, and a mix of both. For the mixed source, the distribution is estimated at 50 percent surface water and 50 percent groundwater so that these lands and use can be categorized as surface water and groundwater only. The example in Section 3.5.1 presents this calculation. In dry years, this distribution can change. Water management for this area includes significant applied water reuse of previously diverted or applied water resulting from soil conditions that facilitate more runoff than deep percolation. Applied water from surface water is estimated to be 125.2 taf. The estimate of reuse is 22 percent. The calculation of surface water delivery is:

$$SW_{del} = AW_{SW} \times (1 - R_{uf})$$

Where AW_{SW} = 125.2 taf and R_{uf} = 0.22, then:

$$SW_{del} = 125.2 \times (1 - 0.22) = 97.7 \text{ taf (Agricultural Surface Water Deliveries)}$$

For managed wetlands, the applied water estimate is also used to determine the associated surface water delivery for managed wetlands, specifically Modoc National Wildlife Refuge. The refuge habitat consists of open water (Dorris Reservoir), permanent ponds, wet meadows, and seasonal marsh. There is little or no tailwater re-capture within the system. The calculation of surface water delivery is:

$$SW_{del} = AW_{SW} \times (1 - R_{uf})$$

Where AW_{SW} = 4.6 taf and R_{uf} = 0, then:

$$SW_{del} = 4.6 \times (1 - 0) = 4.6 \text{ taf (Managed Wetlands Surface Water Deliveries)}$$

3.7 GROUNDWATER EXTRACTION

Definition: Volume of groundwater pumped (extracted) from the underlying aquifer(s) for use within the water budget zone. It does not include groundwater export, stored water extraction, and stored water export.

Context: Groundwater extraction (GW_{ext}) for municipal uses is often measured; in contrast, GW_{ext} for agricultural and managed wetlands groundwater has often not been measured. In the absence of measured data, groundwater extraction can be approximated using volumes of applied water estimated using methods in Section 3.5 and local knowledge of surface water availability. This requires the need to identify lands fully or partially using groundwater. This can be difficult where groundwater and surface water uses occur on the same field; however, local knowledge could assist in approximating reasonable estimates. Irrigation with groundwater often makes use of drip and sprinkler technology, resulting in higher irrigation efficiencies and lower applied water use than surface water. An alternative method for estimating groundwater extraction is to subtract surface water deliveries and applied water reuse from total applied water.

Adjustments for Deficit Irrigation: See Section 3.4, "Evapotranspiration," for more information on adjustments for deficit irrigation.

Adjustments for Irrigation Efficiency: See Section 3.5.1, "Agricultural Applied Water" or more information on adjustments for irrigation efficiency.

Adjustments for On-farm Groundwater Recharge (Over-application): See Section 3.5.1, "Agricultural Applied Water" for more information on adjustment for on-farm recharge (over-application).

Related Water Budget Components: Surface Water Deliveries, Groundwater Export, Stored Water Extraction, Applied Water Reuse, Recycled Water, Applied Water

How to Estimate Groundwater Extraction:

- Method 1 — Obtain measured groundwater extraction data.
- Method 2 — Use published reports and numerical models.
- Method 3 — Estimate groundwater extraction volumes.

Method 1 — Obtain Measured Groundwater Extraction Data

Obtain groundwater extraction data (daily, monthly, etc.). Sources of information include:

- Available pumping data from local agencies (municipal, industrial, large landscape, agriculture).
- DWR or State Water Board Urban Water Supply Statistics data.

Method 2 — Use Published Reports and Numerical Models

Collect and review published reports and existing numerical models for the area of interest; these are good sources of estimates for historical groundwater extraction data over an area. If reliable and defensible estimates of groundwater extraction volumes (monthly or annual) are available for the water budget zone, then those estimates can be used. Sources of data for groundwater extraction volumes include:

- Existing reports and studies.
- Existing groundwater models such as CVHM, C2VSim and local models.
- Existing crop applied water based on land use, crop unit applied water volumes and groundwater extraction data.
- California Water Plan Update data.

If groundwater extraction data are used from an existing numerical model, then the following should be validated.

- The numerical model is calibrated and accepted by stakeholders.
- There is documentation of both the source data and the basis of estimate used in the numerical model.
- Any geographic scaling factor used to convert model estimates to correspond to the water budget zone is defensible and representative for the area.

Method 3 — Estimate Groundwater Extraction Volumes

Groundwater extraction can be estimated for urban, agricultural, and managed wetland systems using techniques like the ones used in the California Water Plan. Section 3.5.1, “Agricultural Applied Water” and Section 3.5.3, “Managed Wetlands Applied Water,” respectively, provide guidance on how to estimate the amount of applied water uses for agricultural and managed wetlands met by surface water, groundwater, and applied water reuse using spatial land use data, identifying which lands are served by what source of water, and aggregating uses by crop acreage and water source type.

Calculating applied water from land use data can facilitate initial estimates of water supplies. Using or creating water source information by field or geographic area can help initial estimates of how much surface water delivery [SW_{del}], groundwater [GW], and applied water reuse [R_u] is being applied. In many areas, there is no mapping of water source by field (surface water, groundwater, or a combination thereof [mixed water]); however, local water users may know the sources of supply and duration of its use (full or partial irrigation). That knowledge can be leveraged to make initial estimates of surface water delivery and groundwater extraction. Where a mix of the two sources occurs, an initial distribution of those source can be made, such as 50-50, 30-70, or 80-20 representing the proportion of surface water to groundwater. These estimates become input to the surface water delivery, groundwater extraction, and applied water reuse components. Land use data in GIS format (such as the 2014 LandIQ data or DWR Land Use Surveys) can facilitate these initial estimates by identifying the crop, then identifying the water source for each crop, and then aggregating the data for the water budget zone.

For agricultural and managed wetlands uses where water sources are identified, groundwater extraction can be simply estimated as:

$$GW_{ext} = \text{Applied Water from Groundwater} = AW_{GW}$$

If applied water by source is unknown, then estimates should be made first for surface water deliveries (SW_{del}) and applied water reuse (R_u); this is often an iterative process. Applied water reuse can be estimated as a percentage of applied water based on local knowledge of irrigation practices and tailwater conditions for the area of interest. Groundwater extraction can then be estimated as:

$$GW_{ext} = AW - SW_{del} - R_U$$

Where applied water reuse is estimated using the fraction of applied water reuse (R_{uf}), then:

$$GW_{ext} = AW \times (1 - R_{uf}) - SW_{del}$$

For urban water supplies, the use of recycled water for landscape irrigation can reduce the amount of groundwater treated for distribution, also known as water production. It is important to know if the recycled water is accounted for in urban water deliveries to customers or if the recycled water becomes a separate use. For example, a wastewater treatment plant supplies recycled water for landscape irrigation along a highway, and this irrigation is not accounted for by the urban purveyor because it is directly supplied by the wastewater treatment plant. This recycled water would not reduce the urban supply but rather create additional applied water in the form of landscape irrigation (Section 3.5.2, "Urban Applied Water"). Groundwater extraction can be estimated as:

$$GW_{ext} = AW - SW_{del} - R_{w}$$

Where the groundwater portion of urban applied water has been calculated, then:

$$GW_{ext} = AW_{GW} - R_{W}$$

Example: This example consists of a mix of water purveyors and individual, unorganized agricultural and urban/rural water users located in the upper Pit River system. Groundwater extraction occurs generally for individual, unorganized agricultural groundwater pumpers and urban/rural water users.

For urban and rural populations, an applied water estimate is used for calculating groundwater extraction. This example represents the City of Alturas and self-supplied rural residential water uses, all using groundwater (Section 3.5.2, "Urban Applied Water"). Applied water is estimated to be 1.9 taf. There is no applied water reuse, thus the calculation of groundwater extraction is:

$$GW_{ext} = AW_{GW} \times (1 - R_{uf})$$

Where AW_{GW} = 1.9 taf and R_{uf} = 0, then:

$$GW_{ext} = 1.9 \text{ taf} \times (1 - 0) = 1.9 \text{ taf (Urban Groundwater Extraction)}$$

For agricultural uses, volumes of applied water are used to estimate groundwater extraction based on the land and water use estimates in the California Water Plan, which are based on the identification of lands using surface water, groundwater, and a mix of both. For mixed sources, the distribution may be estimated at 50 percent surface water and 50 percent groundwater so that these lands and use can be categorized as surface water and groundwater only. The example in Section 3.5.1 presents this calculation. In dry years, this distribution can change. Water management for this area includes direct irrigation of groundwater (no conveyance) with mostly sprinkler and border strip irrigation. Applied water from groundwater is estimated to be 30.2 taf. The estimate of applied water reuse is 5 percent. The calculation of groundwater extraction is:

$$GW_{ext} = AW_{GW} \times (1 - R_{uf})$$

Where AW_{GW} = 30.2 taf and R_{uf} = 0.05, then:

$$GW_{ext} = 30.2 \text{ taf} \times (1 - 0.05) = 28.7 \text{ taf (Agricultural Groundwater Extraction)}$$

3.8 APPLIED WATER REUSE AND RECYCLED WATER

Definition of Applied Water Reuse: Volume of applied water contributing (1) lateral flow below the land that is influenced by impermeable layers and re-emerges as return flow for reuse in the land system, (2) tailwater available for reuse in the land system, or (3) a combination of both.

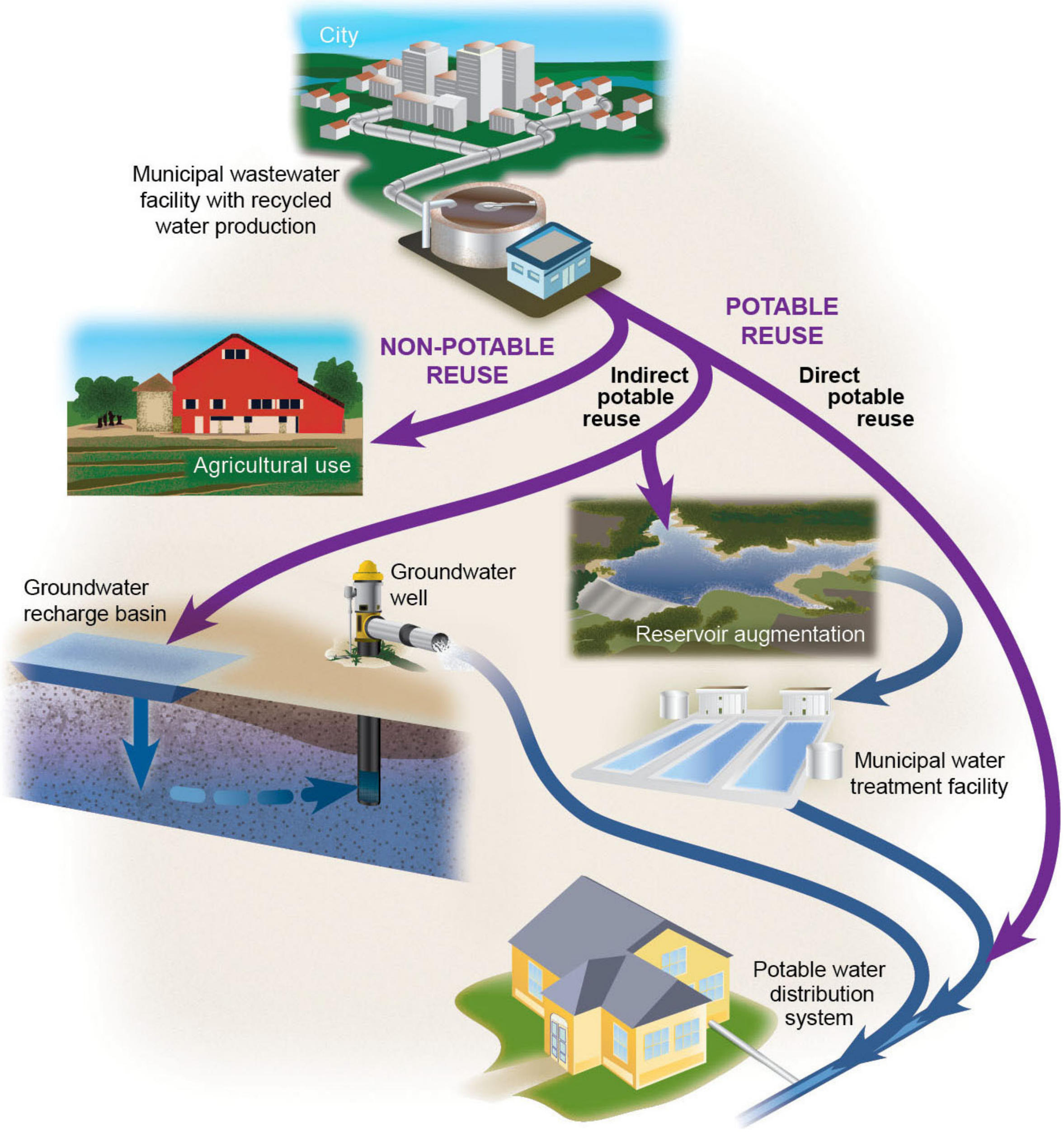
Definition of Recycled Water: Volume of water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur within the water budget zone. It includes wastewater that is treated, stored, distributed, and reused or recirculated for beneficial uses.

Context: Applied water reuse (R_u) and recycled water (R_w) cover the spectrum of water reuse terminology within the land system. The term "applied water reuse" focuses on agricultural and managed wetlands discharges where treatment is not generally needed. On the other hand, "recycled water" requires processing of wastewater to remove contaminants and sanitize prior to reuse, which is often associated with urban and industrial uses. Both terms, not considered new supply to the system, address how applied water is met. In a water budget, applied water is a combination of surface water, groundwater, applied water reuse, and recycled water.

Applied water reuse can be an essential component of the water budget where tailwater and subsurface drainage recovery lead to re-application of previously applied water, thus making additional use of existing supply; however, reuse is most often not measured, difficult to quantify, and requires careful assessment of local conditions. The amount of reuse occurring in each area varies widely based on such factors as cultural practices, irrigation management and methods, and field conditions (soil, geology, and land slope). Cultural practices for rice operations can include flood-up and drawdown for planting, weed and salinity management, thermal control, and harvest, all of which contribute to tailwater conditions. Similarly, managed wetlands operations can contribute to tailwater conditions through flood-up and drawdown of permanent and seasonable wetlands to manage waterfowl habitat along with providing circulation rates to manage waterfowl diseases. Irrigation methods and field conditions, such as border strip irrigation and flooding from head ditches on moderate slopes, may contribute to tailwater conditions. Field conditions, such as relatively impermeable clay and hardpan layers, may contribute to perched water table conditions above the unsaturated zone, thus restricting or limiting vertical flow (Section 5.2, "Recharge of Applied Water and Precipitation") and causing subsurface lateral flow to the land system for applied water reuse. Local knowledge of these practices and conditions can help to refine estimates of applied water reuse and can include the identification of lands and estimated portions of on-farm irrigation that can be attributed to applied water reuse.

Recycled water includes both potable and non-potable uses as shown in Figure 3-7. Non-potable applied water reuse can include agricultural and managed wetlands uses, as well as landscape use and energy production (e.g., geothermal). Potable reuse includes both direct and indirect reuse. Direct potable reuse requires the appropriate level of treatment suitable for re-distributing through the potable water distribution system. Indirect potable reuse includes reservoir augmentation and managed aquifer recharge (basins or injection), all of which can later be diverted or extracted for additional treatment and distribution as potable water. Because of the need to meet regulatory standards, the use of recycled water is generally documented.

Figure 3-7 Potable and Non-Potable Uses of Recycled Water



Adapted from California Water Plan Update 2013

Related Water Budget Components: Surface Water Delivery, Groundwater Extraction, Applied Water, Evapotranspiration, Recharge of Applied Water and Precipitation, Return Flow, Recycled Water Export, Managed Aquifer Recharge

How to Determine Applied Water Reuse and Recycled Water:

- Method 1 — Obtain available applied water reuse and recycled water data.
- Method 2 — Use published reports and numerical models.
- Method 3 — Estimate applied water reuse and recycled water volumes.

Method 1 — Obtain Available Applied Water Reuse and Recycled Water Data

Obtain applied water reuse and recycled water data (daily, monthly, etc.). The most authoritative source for historical recycled water data is the State Water Board’s Urban Water Supply Statistics data. Other sources may include:

- Urban water management plans.
- Agricultural water management plans.
- Recycled water data from local/municipal water suppliers.
- Wastewater data and disposition of that water.
- California Water Plan Update data.
- Recycled water data from industrial users.
- Existing water right information from the State Water Board (identify who can divert and their source of water — might be tailwater).

Method 2 — Use Published Reports and Numerical Models

Collect and review published reports and existing numerical models for the area of interest; these can be sources for estimates for applied water reuse or measured recycled water data over an area. If reliable and defensible estimates of applied water reuse or recycled water volumes (monthly or annual) are available for the water budget zone, these estimates can be used for developing water budgets. If applied water reuse data from an existing numerical model are used, then the following should be validated:

- The numerical model is calibrated and accepted by stakeholders.
- There is documentation of both the source data and the basis of estimates used in the numerical model.

- Any geographic scaling factor used to convert model estimates to correspond to the water budget zone is defensible and representative for the area.

Method 3 — Estimate Applied Water Reuse and Recycled Water Volumes

Recycled water and applied water reuse can be estimated for urban, agricultural, and managed wetlands systems using methods like those used in the California Water Plan. Recycled water data are generally measured and reflect internal reuse within the urban sector; however, unmeasured recycled water may include treated wastewater recycling, disposal through irrigation of landscape or other vegetation, or treated water percolated as managed aquifer recharge (including injection wells for seawater intrusion control). Recycled water data can be obtained from municipal water suppliers and wastewater treatment plants, but where it is unavailable, it can be estimated based on the volumes of applied water as:

$$\text{Recycled Water} = \text{Urban Applied Water} - \text{Surface Water Delivery} - \text{Groundwater Extraction}$$

Applied water reuse can occur within and between sectors of use. As an example, tailwater or return flow from agricultural lands may be re-diverted within the water budget zone for managed wetlands use and vice-versa. Similarly, urban wastewater discharge can be diverted for agricultural or managed wetlands uses. These discharges and subsequent diversions can be identified through local knowledge and estimated based on applied water use to estimate the volume of applied water reuse. However, both reuse and groundwater extraction could be closure terms in the calculation of applied water (as applied water is made up of surface water delivery, groundwater extraction, and applied water reuse), thus introducing additional uncertainty in the estimates.

Section 3.5.1, “Agricultural Applied Water,” provides guidance on how to estimate the amount of agricultural applied water met by surface water, groundwater, and applied water reuse using spatial land use data, identifying which lands are served by what source of water for irrigation, and aggregating use by crop acreage and water source type. If agricultural applied water by water source is unknown, then estimates should be made for surface water and groundwater, which can be an iterative process.

Applied water reuse can also be estimated as a percentage of applied water or using a fraction of applied water reuse (R_{uf}), that is based on local knowledge of irrigation practices and tailwater conditions. Applied water reuse (R_u) can then be estimated as:

$$R_u = AW \times R_{uf}$$

Another option is to proportion applied water using irrigation efficiency and percentages of applied water reuse, return flows, and recharge of applied water as fractions of non-consumptive use of applied water. This option, which is described in Method 3, Approach 2 in Section 3.5.1, "Agricultural Applied Water," is a quick approach to addressing the non-consumptive uses based on local knowledge of irrigation practices, soils, geology, and drainage. Using Tables 3-4 and 3-5 as guides, irrigation efficiency (IE) as well as fractions applied water reuse (R_{uf}), return flow (R_{ff}), and recharge of applied water (D_{if}) can help to identify the disposition of applied water as follows:

$$IE + R_{uf} + R_{ff} + D_{if} = 1.0$$

The recharge fraction of applied water can also be determined as:

$$D_{if} = D_i / AW$$

Where D_i = recharge of applied water

The return flow fraction of applied water can also be determined as:

$$R_{ff} = R_f / AW$$

Where R_f = return flow of irrigation

Estimation of these components can be an iterative process and will require verification of the results in a total water budget.

Estimating applied water reuse can become more complex when agricultural, urban, or managed wetland return flows become sources of supply for another use within the area of interest. The resulting volume of water available is not considered a new supply (supply should not be double counted), but rather becomes reuse. Reuse under such situations should be calculated with due diligence to ensure that there is no double counting.

3.9 RECYCLED WATER EXPORT

Definition: Volume of recycled water diverted from the land system within a water budget zone for use outside the zone.

Context: Recycled water includes both potable and non-potable uses as described in Section 3.8. The amount of recycled water export from a water budget zone is often measured and documented as part of a water recycling program. Also, recycled water export can include managed aquifer recharge projects outside the water budget zone.

Related Water Budget Components: Applied Water Reuse, Recycled Water

How to Determine Return Flow:

- Method 1 — Obtain available recycled water export data.
- Method 2 — Use published reports and numerical models.
- Method 3 — Estimate recycled water export volumes.

Method 1 — Obtain Available Recycled Water Export Data

Obtain recycled water export flow data (daily, monthly, etc.). Sources of information include:

- Urban water management plans.
- Wastewater data and discharge location.
- California Water Plan Update data.
- Existing reports and studies.
- Existing groundwater models such as CVHM, C2VSim or local models.

Method 2 — Use Published Reports and Numerical Models

Collect and review published reports and existing numerical models for the area of interest; these can be sources of estimates for recycled water exports for a water budget zone. If reliable and defensible estimates of recycled water export volumes (monthly or annual) are available for the water budget zone, those estimates can be used for developing water budget. If recycled water export flow data are used from an existing numerical model, then the following should be validated:

- The numerical model is calibrated and accepted by stakeholders.
- There is documentation of both the source data and the basis of estimate used in the numerical model.
- Any geographic scaling factor used to convert model estimates to correspond to the water budget zone is defensible and representative for the area.

Method 3 — Estimate Recycled Water Export Volumes

Recycled water data are generally measured and reflect internal reuse within the urban sector; however, unmeasured recycled water may include treated wastewater recycling, disposal through irrigation of landscape or other vegetation, or treated water percolated as recharge. The amount of recycled water exported can be estimated based on the area and uses outside the water budget. The applied water methods outlined in Section 3.5 can be used for this estimation.

3.10 RUNOFF

Definition: Runoff is the volume of water flowing into the surface water system within a water budget zone from precipitation over the land surface.

Context: Runoff (R) is a major component of the water budget. When the infiltration capacity of the soil is less than the precipitation rate, the portion of the precipitation that is in excess of infiltration becomes surface runoff and contributes to streams and large bodies of water such as lakes. The occurrence of surface runoff also depends on factors as soil type, vegetation, and the presence of shallow, relatively impermeable, soil horizons. In urban areas, runoff is high because impermeable surfaces like rooftops, paved roads, and parking lots abound. Runoff from urban areas is sometimes captured in stormwater collection facilities and can be used for managed aquifer recharge or urban outdoor use. In these cases, runoff should be reduced by the volume of stormwater capture.

Related Water Budget Components: Precipitation, Evapotranspiration, Recharge of Applied Water and Precipitation

How to Determine Runoff:

- Method 1 — Obtain data from previous reports and numerical models.
- Method 2 — Calculate direct runoff using the Runoff Curve Number method.
- Method 3 — Use the Precipitation-Runoff Modeling System (PRMS).
- Method 4 — Apply other approaches.

Method 1 — Obtain Data from Previous Reports and Numerical Models

Runoff is an important part of the water cycle and an important factor in urban water management. USGS provides historical annual runoff estimate for California, which is the quantity of water that is discharged as runoff from the state in one year. Other historical publications, records, and numerical models may include estimates of runoff in the water budget zone of interest. Sources of information include:

- USGS Publications Warehouse.
- USGS Water Resources.
- USGS Runoff Estimates for California.

Method 2 — Calculate Direct Runoff Using the Runoff Curve Number Method

For drainage basins where no runoff has been measured, the Runoff Curve Number method can be used to estimate the depth of direct runoff from the rainfall depth. Direct runoff of precipitation from small watersheds can be estimated with the Natural Resources Conservation Service (NRCS) Runoff Curve Number method (NRCS was previously known as the Soil Conservation Service):

$$Q_r = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (if\ P \geq 0.2S)$$

Where:

- Q_r is direct unit runoff in inches.
- P is precipitation (depth in inches).
- S is the potential maximum retention (inches).

This equation allows the runoff depth to be estimated from rainfall depth, given the value of the potential maximum retention, S. The potential maximum retention, S, is determined using the following equation:

$$S = \frac{1000}{CN} - 10$$

Where CN is the curve number.

To obtain total runoff volume (R), the direct runoff (Q_r) calculated above may be multiplied by the watershed area:

$$\mathrm{R} = \mathrm{Q_r} \times \text{Watershed Area}$$

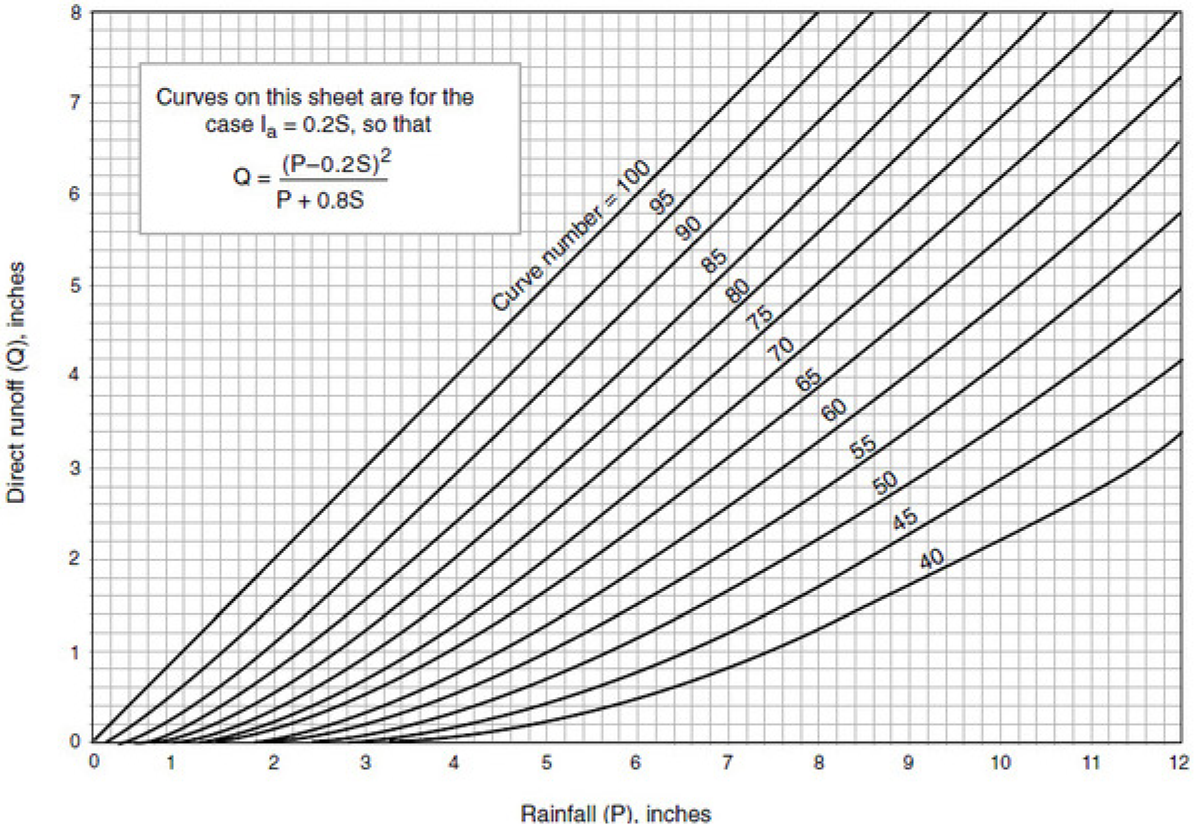
In cases where the precipitation is less than 0.2S, no runoff is assumed to occur and initial abstractions absorb all the water, and thus Q_r is zero.CN has a range from 30 to 100, with lower numbers indicating more permeable soil with a lower runoff potential. CN is a function of land use, land treatment, land cover, hydrological condition, hydrologic soil group, and antecedent soil moisture condition in the watershed. Soils are classified into hydrologic soil groups A, B, C, or D according to the following criteria: Group A (high infiltration rates), group B (moderate infiltration rates), group C (slow infiltration rates), and group D (very slow infiltration rates).

The value of CN can be found for different cultivation practices, hydrological conditions, and soil groups from various publications. Sources of information include:

- Runoff curve numbers presentation.
- Runoff curve numbers publication.
- TR-55 method.

Figure 3-8 shows the graphical solution of runoff equation, indicating a volume of runoff depth Q_r as a function of rainfall depth P for selected values of curve numbers. For paved areas, for example, S will be zero, CN will be 100 and all rainfall will become runoff. For highly permeable, flat-laying soil, S will go to infinity, CN will be zero and there will be no runoff. In most watersheds, the reality will be somewhere in between.

Figure 3-8 **Runoff Depth for Curve Numbers and Rainfall Amounts**



Example: A watershed has a soil with slow infiltration rates (i.e., group C). The land use is row crops on contoured and terraced land in a good condition. The 24-hour, 10-year precipitation is estimated as 8 inches (from NOAA database). From the CN tables (see any of the provided references), the CN is 78, and therefore, the potential maximum retention is calculated as:

$$S = \frac{1000}{78} - 10 = 2.82$$

Since the precipitation (8 inches) is greater than 0.2 × 2.82, or 0.564, the SCS method can be used to obtain an estimated depth of runoff as follows:

$$Q_r = \frac{(8 - 0.2 \times 2.82)^2}{8 + 0.8 \times 2.82} = 5.4\,inches$$

The same results would be obtained if the above figure is used instead.

Total runoff (R) would then be calculated as:

$$R = Q_r \times \text{Watershed Area}$$

Method 3 — Use the Precipitation-Runoff Modeling System (PRMS)

Runoff from un-gauged watersheds contribute to a water budget zone and quantifying the volume and timing of runoff may require a more detailed approach than the Runoff Curve Number method. One detailed approach to use is the USGS's Precipitation-Runoff Modeling System (PRMS), which simulates basin hydrology. Model documentation states that: "PRMS is a modular-design, deterministic, distributed-parameter modeling system developed to evaluate the impacts of various combinations of precipitation, climate, and land use on streamflow, sediment yields, and general basin hydrology. Basin response to normal and extreme rainfall and snowmelt can be simulated to evaluate changes in water-balance relationships, flow regimes, flood peaks and volumes, soil-water relationships, sediment yields, and ground-water recharge. Parameter-optimization and sensitivity analysis capabilities are provided to fit selected model parameters and evaluate their individual and joint effects on model output. The modular design provides a flexible framework for continued model-system enhancement and hydrologic-modeling research and development."

The approach used in PRMS states that "a watershed is divided into subunits based on such basin characteristics as slope, aspect, elevation, vegetation type, soil type, land use, and precipitation distribution. Two levels of partitioning are available. The first divides the basin into hydrologic response units (HRU) based on the basin characteristics. Water and energy balances are computed daily for each HRU. The sum of the responses of all HRU's, weighted on a unit-area basis, produces the daily system response and streamflow for a basin. A second level of partitioning is available for storm hydrograph simulation. The watershed is conceptualized as a series of interconnected flow planes and channel segments. Surface runoff is routed over the flow planes into the channel segments; channel flow is routed through the watershed channel system. An HRU can be considered the equivalent of a flow plane or it can be delineated into a number of flow planes."

Method 4 — Apply Other Approaches

When the previous methods cannot be utilized, average annual runoff can be roughly estimated using maps of the average historical runoff. This type of approach is relatively coarse and may not be appropriate at local spatial scales. The following are three examples of such approaches:

Example 1: The Public Policy Institute of California (PPIC) published a map of relative runoff as a percentage of annual runoff. The map uses data from PRISM, CIMIS, and the U.C. Davis Soil Resource Laboratory. The description states that "the map shows the distribution of runoff — the amount of local precipitation that flows into streams and recharges groundwater. Relative runoff is represented as a percentage of annual runoff after adjusting average monthly precipitation (PRISM 1970—2000) by losses to soil storage capacity (U.C. Davis Soil Resource Laboratory, Beaudette, and O'Geen) and average monthly reference ET (CIMIS 2000—2005, Hart)." Source: PPIC California's Variable Climate.

Example 2: USGS's Basin Characterization Model calculates a monthly water balance using potential ET as calculated from solar radiation with topographic shading and cloudiness, snow as it accumulates and melts; and excess water as it moves through the soil profile, which are used to calculate actual ET and climatic water deficit—the difference between potential and actual ET. Depending on soil properties and the permeability of underlying bedrock, surface water can be classified for each cell as either recharge or runoff. Post-processing calculations are made to estimate baseflow, streamflow, and potential recharge to the groundwater system for watersheds. Source: USGS California Basin Characterization Model.

Example 3: This method directly estimates storm water runoff. The Los Angeles Regional Water Quality Control Board (RWQCB) has developed requirements for the Standard Urban Stormwater Mitigation Plan (SUSMP) requiring specific development categories to manage storm water runoff. The RWQCB proposes using a site-specific rainfall, based on a spatially distributed statistical rainfall distribution, and requires using the 85th percentile 24-hour rainfall event. The volume (V_M) of stormwater runoff to be mitigated from the new development is calculated using:

$$V_M = I \times (0.9A_I + A_P C_U + A_U C_U) \times 2722.5$$

Where A_I, A_P, and A_U are the impervious percentage of developed area, the pervious percentage of developed area, and the contributing developed upstream area, which is assumed zero here ($i.e., A_U = 0$); I is the rainfall intensity; and C_U is the undeveloped runoff coefficient for each of the seven zones. For example. assuming 5 percent of area is impervious for each zone, A_I and A_P can be calculated as 0.05 and 0.95, respectively.

More information is available at:

- Los Angeles County Low Impact Development Standards Manual.
- Analysis of 85th Percentile 24-hour Rainfall Depth Analysis Within the County of Los Angeles.

3.11 RETURN FLOW

Definition: Volume of applied water that is not consumptively used and flows to the surface water system. It includes treated wastewater discharges to the surface water system.

Context: Two primary components of return flow (R_f) are urban wastewater discharge and irrigation runoff to a surface water body. Urban wastewater discharge relates to non-consumptively used indoor water uses but also includes water for industrial processing, etc. Irrigation of landscape, crops, and managed wetlands can result in tailwater (surface runoff) - some recaptured for applied water reuse and the other part becoming return flow to streams.

Related Water Budget Components: Surface Water Delivery, Groundwater Extraction, Applied Water Reuse, Recycled Water, Applied Water, Evapotranspiration, Recharge of Applied Water and Precipitation

How to Determine Return Flow:

- Method 1 — Obtain available return flow data.
- Method 2 — Use published reports and numerical models.
- Method 3 — Estimate return flow volumes.

Method 1 — Obtain Available Return Flow Data

Obtain return flow data (daily, monthly, etc.). Sources of information include:

- Urban water management plans.
- Wastewater data and discharge location.
- National Pollution Discharge Elimination System permits.

- California Water Plan Update data.
- Existing reports and studies.
- Existing groundwater models such as CVHM, C2VSim or local models.

Method 2 — Use Published Reports and Numerical Models

Collect and review published reports and existing numerical models for the area of interest; these can be sources of estimates for return flows over an area. If return flow data are used from an existing numerical model, then the following should be validated:

- The numerical model is calibrated and accepted by stakeholders.
- There is documentation of both the source data and the basis of estimate used in the numerical model.
- Any geographic scaling factor used to convert model estimates to correspond to the water budget zone is defensible and representative for the area.

Method 3 — Estimate Return Flow Volumes

The two primary components of return flow are irrigation runoff and urban indoor use; each has a different approach for estimation.

Irrigation: Return flow from urban landscape, agriculture, and managed wetlands irrigation is highly dependent on irrigation methods, practices, water management, and soils, which commonly result in one or more of the following:

- Transpiration by crops and vegetation (ET).
- Evaporation.
- Recharge.
- Runoff.

Estimating return flow is an iterative process using either a simplified water balance of applied water (inflow versus outflow) or apportioning irrigation efficiencies. The simplified water balance for applied water is:

$$AW = SW + GW + R_U = ETAW + R_f + Di$$

$$R_f = SW + GW + R_U - ETAW - Di$$

Where:

- AW = Applied Water.
- R_U = Applied Water Reuse.
- ETAW = Evapotranspiration of Applied Water.
- R_f = Return Flow.
- Di = Recharge.

If no estimate of recharge is available, then it can be estimated by proportioning the non-consumptive portion of irrigation efficiency as outlined in the Crop ET Approach in Method 3 of Section 3.5.1 for use in the equation below

$$\mathrm{Di} = \mathrm{AW} \times \mathrm{D_{if}}$$

Where D_{if} is estimated from Table 3-4 and Table 3-5.

When estimates of recharge as well as other components of simplified water balance equation are not available, then both return flow and recharge can be estimated using information from Table 3-4 and Table 3-5 and Section 3.5.1 for input to the following equations:

$$\text{Return Flow} = \mathrm{R_f} = \mathrm{AW} \times \mathrm{R_{ff}}$$

$$\text{Recharge} = \mathrm{Di} = \mathrm{AW} \times \mathrm{D_{if}}$$

Where:

- $R_{ff} = 1.0 - IE - R_{uf} - D_{if}$, as derived from $IE + R_{uf} + R_{ff} + D_{if} = 1.0$.
- D_{if} = Recharge Fraction of Applied Water (from Tables 3-4 and 3-5).
- R_{uf} = Reuse Fraction of Applied Water (from Tables 3-4 and 3-5).

Above approach is an iterative procedure of estimating these components and verifying the results in the total water budget.

Urban Indoor Use: This is an inclusive category accounting for domestic, industrial, commercial, and other water uses that are non-consumptive and not associated with landscape irrigation (commonly referred to outdoor use). Two different methods can be used to estimate urban indoor use:

- Option 1 - Use wastewater treatment plant (WWTP) data.
- Option 2 — Use lowest month urban water production.

Option 1 consists of using WWTP data to quantify indoor use. This method assumes that most indoor water use is non-consumptively used and will return as wastewater. WWTP data are commonly reported and should be collected for the water budget zone of interest. National Pollution Discharge Elimination Program discharge permits can help identify location of wastewater treatment and discharge. Measured WWTP data are very useful but may also have several limitations, such as: (1) city with combined sewer systems conveying both stormwater and sewage, and (2) precipitation infiltration into sewer systems during the rainy season, especially in areas with significant precipitation and aging systems. Where a combined sewer system or significant precipitation infiltration occurs, wastewater treatment may be approximated by using the lowest month urban water production for the same population served. Adjustments may be needed to remove the effects of precipitation infiltration in the calculation of urban indoor use.

Collecting WWTP within and adjacent to the water budget zone of interest can support estimates of indoor water use or return flow. The service area and the resulting population served should be determined to support the calculation of indoor per-capita water use that can then be applied to areas without such information. Self-supplied use is often covered by septic systems, which contribute to recharge of applied water and precipitation and not wastewater discharge or return flow. Keeping these treatment processes separate is essential.

The specific calculation steps include:

1. Collect monthly or annual WWTP discharge data.
2. Check data for precipitation accretion. Is it an issue? Adjust as needed.
3. Determine population served by WWTP (data report by WWTP or GIS query of population data).
4. Compute per-capita indoor water uses for all measured data as:

$$\text{Per-Capita Urban Indoor Water Use} = \text{WWTP discharge volume (annual/monthly) / population served}$$

5. Determine what areas are best represented by the calculated per-capita urban indoor use.
6. Determine what areas are served by WWTP (return flows) and what areas are served by septic systems (recharge of applied water).
7. Calculate return flow from wastewater as:

$$\text{Return Flow from Wastewater} = \sum(\text{Population} \times \text{Per-capita Urban Indoor Water Use})$$

In Option 2, a simplified method is used to quantify indoor water use by utilizing the lowest month water production by an urban water purveyor. Lowest month water production most often occurs during the winter months, typically January or February in the Central Valley, where precipitation and colder temperatures reduces or eliminates the need for landscape irrigation. Exceptions to this general approach may occur in drought years, in warmer inland areas of southern California, or when urban water use is heavily influences by commercial and industrial users or tourists. This option assumes that indoor water use remains relatively constant throughout the year; however, in some areas, seasonal use may need to be factored in such as recreational areas, food processing, etc. Careful review of the records and local knowledge are needed to support these calculations.

The specific calculation steps include:

1. Collect monthly urban water production data and determine lowest month water production.
2. Identify and apply any seasonal adjustments.
3. Determine population served by water production from water purveyor or GIS query of population data.
4. Compute per-capita indoor water uses for all measured data as:

$$\text{Per-Capita Indoor Water Use} = \text{Lowest Month Water Production} \times 12 \text{ Months} / \text{Population Served}$$

5. Determine what areas are best represented by the estimated per-capita indoor water use.
6. Determine what areas have wastewater discharges (return flow), what portion of treated wastewater is recharged (managed aquifer recharge), and what areas are served by septic systems (recharge of applied water).
7. Calculate return flow from wastewater as:

$$\text{Return Flow from Wastewater} = \sum(\text{Population} \times \text{Per-capita Urban Indoor Water Use})$$

3.12 CHANGE IN LAND SYSTEM STORAGE

Definition: Net change in the volume of water stored within the land system, which includes ponded water on the land surface (not including streams, lakes, and conveyance facilities) and soil moisture within the unsaturated zone, which includes the root zone.

Context: The land system storage as presented in this handbook represents the change in volume of water storage that occurs in three forms: (1) as ponded water storage on the land surface (not including streams, lakes, and conveyance facilities); (2) as soil moisture storage in the root zone; and (3) unsaturated zone storage (Figure 3-1). Water storage on the land surface can include managed land use practices such as flood-up and drawdown for rice ponding, rice-straw decomposition, managed wetlands habitat, etc. where storage may occur over one or more monthly time steps of the water budget (e.g., daily, monthly). It also includes precipitation detention on the land surface, which cannot readily be estimated. Similarly, a soil moisture balance of the root zone can tract fluxes in soil moisture storage because of precipitation, irrigation, evaporation, transpiration, and percolation. However, storage change in the unsaturated zone is often difficult to quantify or estimate because there are no commonly used measurements that can indicate the status of percolation and interflow entering and leaving the unsaturated zone. To quantify these changes, a monthly time step analysis of change in land system storage may reveal the effects associated with precipitation and irrigation. A simple mass balance to determine the change in land system storage would be expressed as:

$$\text{Change in Land System Storage} = \text{Inflow to the Land System} - \text{Outflow from the Land System}$$

Assessing mass balance error for the land system is unrealistic given the lack of measured parameters. Surface ponding can be estimated through measured water depths, area, and duration. However, both soil moisture storage and unsaturated zone storage do not have direct measurements. Changes in soil moisture storage are generally determined through a soil moisture balance as computed balance of inflow less outflow, which will then have no mass balance error. Similarly, a numerical model is needed to estimate change in unsaturated zone storage because there are no commonly used measurements to indicate the status and amount of percolation and interflow entering and leaving the unsaturated zone. Without a numerical model, a simple mass balance would be used to estimate change in unsaturated zone storage as follows:

$$\text{Change in Unsaturated Zone Storage} = \text{Inflow to the Land System} - \text{Outflow from the Land System} - \text{Change in Ponded Water} - \text{Change in Root Zone Storage}$$

Related Water Budget Components: Surface Water Delivery, Groundwater Extraction, Applied Water Reuse, Recycled Water, Precipitation, Applied Water, Evapotranspiration, Recharge of Applied Water and Precipitation, Return Flow, Runoff

How to Estimate Change in Land System Storage:

One or more the methods may be needed to estimate change in land system storage and its three sub-components — (1) change in ponded storage, (2) change in soil moisture storage, and (3) change in unsaturated storage.

- Method 1 — Use published reports and numerical models.
- Method 2 — Estimate using inflow and outflow balance.
- Method 3 — Estimate change in ponded water storage using water use calculations.
- Method 4 — Estimate change in soil moisture storage using water use models.

- Method 5 — Estimate change in unsaturated zone storage as a water balance.
- Method 6 — Estimate change in unsaturated zone storage using numerical models.

Method 1 — Use Published Reports and Numerical Models

Collect and review published reports and existing numerical models for the area of interest. These can be good sources of estimates for root zone soil moisture storage and ponded water for agriculture and managed wetlands. Numerical models such as Cal-SIMETAW and C2VSIM use a soil moisture balance to determine root zone storage in support of estimating ET. Furthermore, numerical models such as C2VSIM and CalSim 3 have agricultural and managed wetlands ponding functions where model input specifies the depth, timing, and duration of the respective ponding practices and ponding volumes can be determined from model output. If reliable and defensible estimates of soil moisture storage and ponded storage volumes (monthly or annual) within the water budget zone are available, then use those estimates.

Sources include:

- Previous reports.
- Result files of numerical models, e.g., Cal-SIMETAW, C2VSim, and CVHM.

Method 2 — Estimate Using Inflow and Outflow Balance

The change in land system storage can be estimated through a simple calculation using the inflow and outflow components of the land system. The calculation is expressed as:

$$\text{Change in Land System Storage} = \text{Inflow to the Land System} - \text{Outflow from the Land System}$$

Where:

$$\text{Inflow to the Land System} = \text{Precipitation} + \text{Surface Water Delivery} + \text{Groundwater Extraction}$$

$$\text{Outflow from the Land System} = \text{ET} + \text{Runoff} + \text{Return Flow} + \text{Recharge of Applied Water and Precipitation}$$

Method 3 — Estimate Change in Ponded Water Storage Using Water Use Calculations

Ponded water storage for agricultural and managed wetlands is part of applied water. The calculations of applied water may be based on ETAW and irrigation efficiency or specifically represented as a target depth of ponding in a numerical model such as C2VSIM or CalSim 3. Where ETAW and irrigation efficiency are used, agricultural water ponding depths by month should be estimated based on local knowledge of flood-up and drawdown pattern for rice cultivation and rice straw decomposition.

Method 4 — Estimate Change in Soil Moisture Storage Using Water Use Models

Change in soil moisture storage can be determined using numerical models where a soil moisture budget is calculated. Numerical models supporting the calculation of ET and ETAW contain such an accounting, and Section 3.4 describes several such models. The analysis should have a daily or monthly soil moisture storage for the root zone.

Method 5 — Estimate Change in Unsaturated Zone Storage as a Water Balance

Estimating the change in unsaturated zone storage is often a difficult task that requires the use of a numerical model and the estimation of unsaturated zone properties. If conducting such an analysis is not feasible, then a simple water balance can be used to make the initial estimates of change in unsaturated zone storage. For example, if ponded water storage analysis and root zone soil moisture storage balances have been computed, then the unsaturated zone storage can be computed as:

$$\text{Change in Unsaturated Zone Storage} = \text{Change in Land System Storage} - \text{Change in Root Zone Soil Moisture Storage} - \text{Change in Ponded Water Storage}$$

Method 6 —Estimate Change in Unsaturated Zone Storage Using Numerical Models

Unsaturated zone numerical models can be used to estimate the change in unsaturated zone storage for a specified time step. It is beyond the scope of this handbook to list a particular model and the dataset needed for such a model. The UC Davis’ Division of Agriculture and Natural Resources maintains a website containing useful links to unsaturated (Vadose) zone modeling software and soil surveys, databases, and software to estimate unsaturated zone properties.

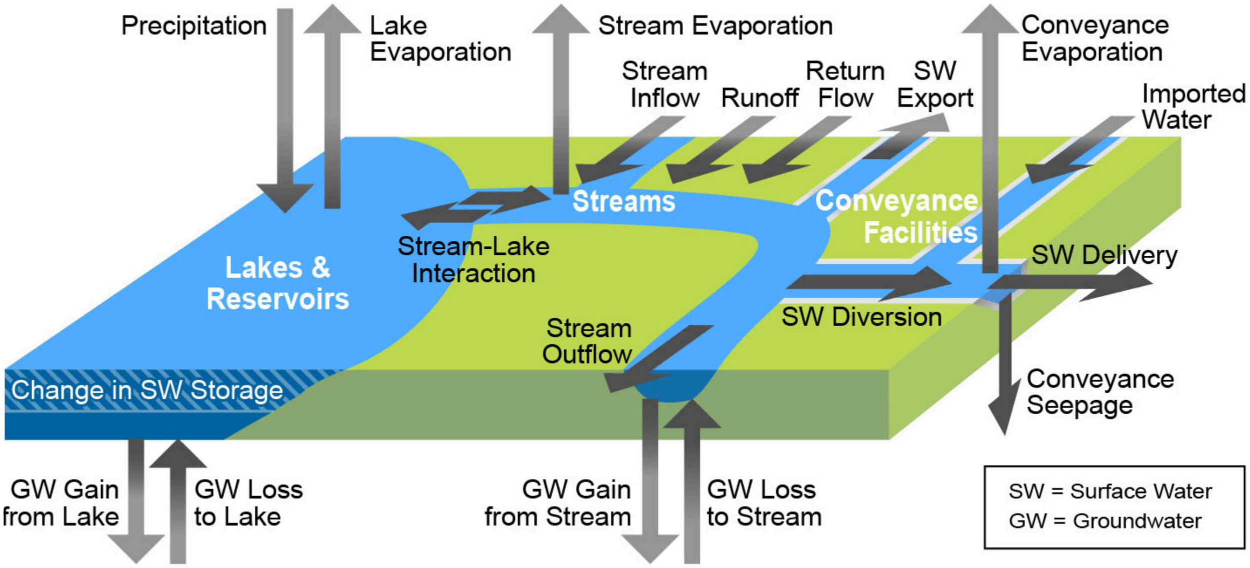
4. SURFACE WATER SYSTEM

4.1 INTRODUCTION

The total water budget captures the entire hydrologic cycle of water flow, and the surface water system is an integral part of it. The components of surface water system water budget are shown in Figure 4-1, which is a subset of Figure 1-1. The color coding of Figure 1-1 was not carried over to Figure 4-1 to avoid confusion as the designation of inflows and outflows are different in a single system compared to the total water budget. The definition of the surface water system and surface water system water budget is presented in Section 1.3. The definitions of the associated components are provided in Table 1-1.

The purpose of this section is to describe how to develop reasonable estimates for these water budget components without a model. The methods described in this section can also be used when an available model only provides information for a partial set of surface water system water budget components. When a model is available that provides information for all components of the surface water system, the user should refer to Section 2.8, "Modeling Approach." Many of the methods described in this section involve a mass balance approach, which should be used with caution. While a mass balance approach is appropriate for estimating an individual component, there are inherent dependencies of one component with other components of the mass balance equation. Therefore, it would be inappropriate to use the mass balance approach for more than one term in the mass balance equation. The mass balance approach in the surface water system is also not suitable at the daily time scale because of potential changes in stream storage that may need to be considered. For longer time scales, the change in stream storage can be assumed to be negligible and therefore ignored in the mass balance.

Figure 4-1 **Components of Surface Water System and Its Interaction with Other Systems**



Descriptions of inflow and outflow components in the surface water system along with methods for estimating each component are furnished below. Because of the interdependencies between the systems, several of the components of the surface water system are described in other sections: precipitation (on lakes), runoff, and return flow are described in Section 3, “Land System;” stream-aquifer interaction is described in Section 5, “Groundwater System.”

4.2 STREAM INFLOW AND OUTFLOW

Definition: Stream inflow is the volume of water entering through streams at the periphery of a water budget zone. Stream outflow is the converse of the stream inflow and represents the volume of water leaving through streams at the periphery of a water budget zone.

Context: A water budget zone having surface water supplies may include a network of streams entering and leaving the water budget zone at one or more points along its periphery. Water may be diverted from these streams for agricultural, urban, and managed wetlands uses within or outside the water budget zone. The difference between stream inflows and outflows is a key indicator of the net gain or loss in the surface water system within the water budget zone.

Stream inflows and outflows from individual streams can be measured or estimated in one of three ways: (1) measured by a stream gauge at the periphery of the water budget zone where streams enter or leave the water budget zone, (2) estimated by adjusting data from upstream or downstream streamflow gauges, and 3) calculated using computational methods such as the drainage area ration method or a rainfall-runoff model for the upstream watershed.

Related Water Budget Components: Precipitation, Runoff, Return Flow, Surface Water Diversions, Groundwater loss to Stream, Groundwater gain from Stream, Stream-Lake Interaction

How to Determine Stream Inflow or Outflow:

First, identify all streams entering and leaving the water budget zone. Next, identify gauge locations within or adjacent to the water budget zone where streamflow data are recorded. Federal, State, and local agencies maintain streamflow gauges in the United States, and a search in their databases can furnish information on gauge locations, period of record, and time intervals of available data.

For each stream and river that enters or leaves the water budget zone, develop streamflow data for all years of interest using one of the following methods:

- Method 1 — Obtain available streamflow data.
- Method 2 — Estimate from available streamflow data.
- Method 3 — Estimate streamflow using drainage area ratio method.
- Method 4 — Estimate streamflow using rainfall-runoff model.

Method 1 — Obtain Available Streamflow Data

Streamflow and stages at many stations along streams are regularly monitored by the USGS. In addition, DWR publishes streamflow and stage data for various locations in the state through California Data Exchange Center and Water Data Library websites. There are other State and local agencies that maintain and publish streamflow records as well. These data are available for different time periods and at different temporal scales (15 minute, hourly, daily, and monthly). Data from multiple sources may need to be obtained for developing the water budget for the surface water system. The steps for obtaining streamflow data include the following:

1. Identify the streams entering and leaving the water budget zone.
2. Obtain streamflow data from existing federal, State, and local agencies.

Streamflow data for streams can also be obtained from published reports, in addition to those from online databases.

If there is a numerical hydrologic model covering the water budget zone, measured or estimated streamflow data may be available from the model input/output files. If streamflow data from an existing numerical model are used, then the following should be validated:

- There is documentation of both the source data and the basis of estimated flow.
- The numerical model is calibrated and accepted by stakeholders.

Key sources of streamflow data in California are:

- USGS Surface-Water Data for California.
- USGS publications: Water-Resources Investigations Reports, Scientific Investigations Reports.
- DWR California Data Exchange Center (CDEC).
- DWR Water Data Library.
- Local agency records, including flood control districts or entities managing storm water.
- State Water Board’s Irrigated Lands Regulatory Program.
- Previous hydrologic and hydraulic investigation reports.
- Input/output files of numerical models (e.g., rainfall-runoff model).
- California Nevada River Forecast Center.

Method 2 — Estimate from Available Streamflow Data

Use this method if data are available from a streamflow gauge or other source that is located upstream (or downstream) of the location where the stream enters (or leaves) the water budget zone. The process of adjusting streamflow data for the boundary location involves the following steps:

1. Identify a nearby location where streamflow data are available.
2. Obtain measured streamflow flow (at location, G).
3. Calculate net gain/loss in the stream reach between the measured flow location (G) and point of interest location (L) using the equation below. Each of the above components can be estimated using the methods described in Section 3, "Land System," and Section 4, "Surface Water System."

$$\text{Net Streamflow Gain (+) or Loss (-) in the Stream Reach between Location G and L} = (\text{Runoff} + \text{Return Flow} + \text{Loss to Stream from Groundwater} + \text{Loss from Lake to Stream} + \text{Outflow to Stream} + \text{Precipitation [on Stream]}) - (\text{Surface Water Diversions} + \text{Gain from Stream to Groundwater} + \text{Evaporation from Stream})$$

4. Calculate the adjusted streamflow at the location of interest using a mass balance approach as follows:

$$\text{Adjusted streamflow (at location L)} = \text{Measured flow (at location G)} + \text{Net Streamflow Gain/Loss in the Stream Reach between Location G and L}$$

Method 3 — Estimate Streamflow Using Drainage Area Ratio Method

When stream inflows enter the water budget zone from unimpaired watersheds, the drainage-area ratio method can be used to estimate streamflows. The method assumes that streamflows at a location of interest can be approximated from gauged streamflow data at a nearby location by using the ratio of drainage areas as shown by the equation below.

$$Y_{ij} = \left(\frac{A_y}{A_x}\right) \times X_{ij}$$

Where:

- Y_{ij} is the estimated streamflow (cubic feet per second) for month i and year j at the location of interest.
- A_y is the drainage area (square miles) of the location of interest.

- A_x is the drainage area (square miles) of the streamflow gaging station where measured data is available.
- X_{ij} is the measured streamflow (cubic feet per second) for month i and year j for the streamflow gaging station.

Drainage areas can be estimated using watershed boundary datasets from the USDA Natural Resources Conservation Service. Corresponding gauged streamflows can be obtained from USGS or DWR gauges.

Method 4 — Estimate Streamflow Using a Rainfall-Runoff Model

Stream inflow from an unimpaired watershed can be estimated using a rainfall-runoff model. There are numerous rainfall-runoff models including:

- USGS's Precipitation-Runoff Modeling System (PRMS).
- Water Resource Associates' HYSIM.
- Vieux & Associates' Vflo.
- USGS's DR3M.
- University of Washington's Variable Infiltration Capacity Model (VIC).

The Precipitation-Runoff Modeling System (PRMS) developed by USGS is a commonly used rainfall-runoff model. It evaluates the impacts of various combinations of precipitation, climate, and land use on streamflow and other basin hydrology using a modular-design, deterministic, distributed-parameter modeling system. Data requirements and potential sources of data for this model are provided in Table 4-1.

Table 4-1 **Data Requirements and Sources for PRMS**

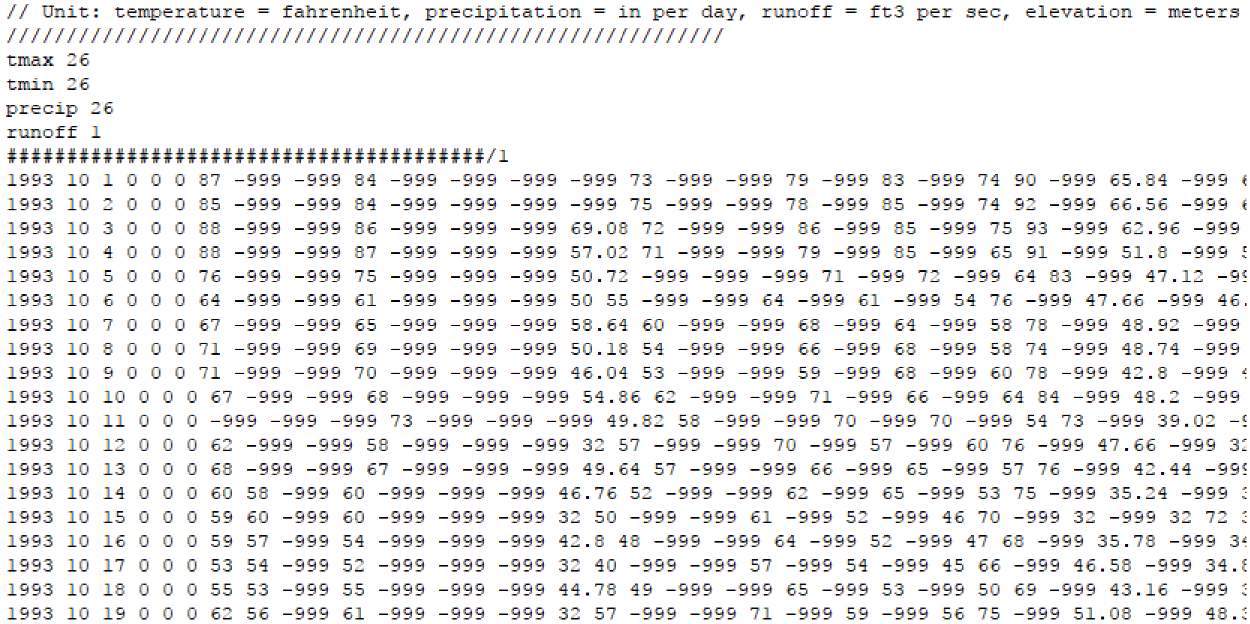
Data Requirements	Potential Sources of Data
• Daily precipitation • Daily maximum and minimum air temperature (or substitute daily pan evaporation in areas without snow melt) • Daily short-wave solar radiation (for snowmelt computation)	• California Data Exchange Center (CDEC) • California Irrigation Management Information System (CIMIS)
Descriptive data of topography, soils, and vegetation	• USDA Soil Survey Geographic Database (SSURGO) • USDA State Soil Geographic Dataset (STATSGO)

The process for estimating streamflow from PRMS involves the following steps:

1. **Download Model:** The most recent version of PRMS is available from the USGS website.
2. **Input Control File parameters:** The Control File contains all of the control parameters that PRMS uses during the simulation, including those related to model input, output, initial conditions, and active modules.
3. **Input Time-series Data into the Data File:** Daily precipitation and maximum and minimum air temperatures are required; solar radiation, pan evaporation, measured streamflow, humidity, wind speed, and snowpack-water equivalent may also be included.

The example, shown in Figure 4-2, was processed using TextPad. Each row has an associated column with data of interest (26 columns with maximum temperature data, 26 columns with minimum temperature data, 26 columns with precipitation data, and 1 column with runoff data). The first six rows of the time series data are the year, month, day, hour, minute, and second, respectively.

Figure 4-2 **Example of a PRMS Input**

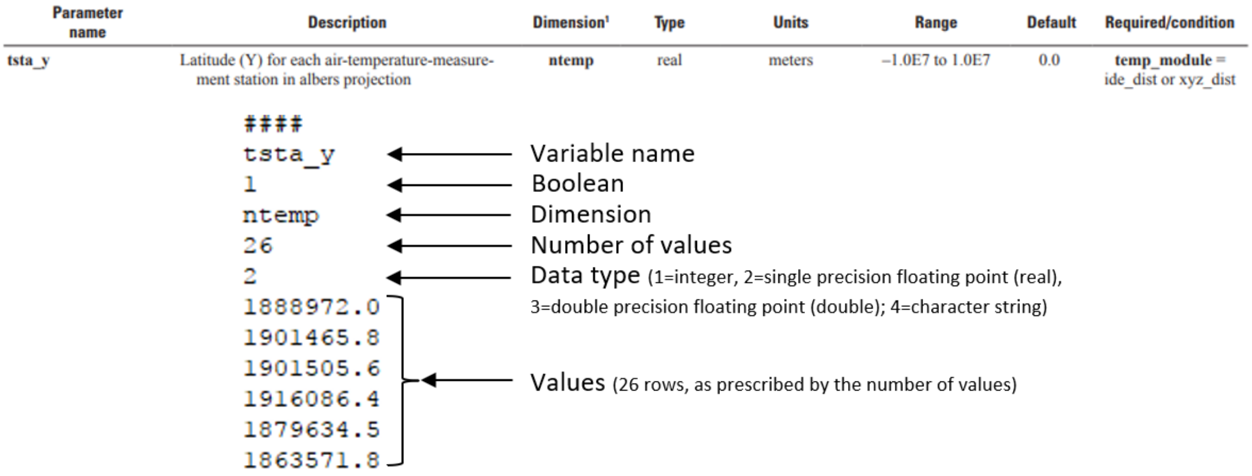


```
// Unit: temperature = fahrenheit, precipitation = in per day, runoff = ft3 per sec, elevation = meters
////////////////////////////////////////////////////////////
tmax 26
tmin 26
precip 26
runoff 1
########################################/1
1993 10 1 0 0 0 87 -999 -999 84 -999 -999 -999 -999 73 -999 -999 79 -999 83 -999 74 90 -999 65.84 -999
1993 10 2 0 0 0 85 -999 -999 84 -999 -999 -999 -999 75 -999 -999 78 -999 85 -999 74 92 -999 66.56 -999
1993 10 3 0 0 0 88 -999 -999 86 -999 -999 -999 69.08 72 -999 -999 86 -999 85 -999 75 93 -999 62.96 -999
1993 10 4 0 0 0 88 -999 -999 87 -999 -999 -999 57.02 71 -999 -999 79 -999 85 -999 65 91 -999 51.8 -999
1993 10 5 0 0 0 76 -999 -999 75 -999 -999 -999 50.72 -999 -999 -999 71 -999 72 -999 64 83 -999 47.12 -9
1993 10 6 0 0 0 64 -999 -999 61 -999 -999 -999 50 55 -999 -999 64 -999 61 -999 54 76 -999 47.66 -999 46.
1993 10 7 0 0 0 67 -999 -999 65 -999 -999 -999 58.64 60 -999 -999 68 -999 64 -999 58 78 -999 48.92 -999
1993 10 8 0 0 0 71 -999 -999 69 -999 -999 -999 50.18 54 -999 -999 66 -999 68 -999 58 74 -999 48.74 -999
1993 10 9 0 0 0 71 -999 -999 70 -999 -999 -999 46.04 53 -999 -999 59 -999 68 -999 60 78 -999 42.8 -999
1993 10 10 0 0 0 67 -999 -999 68 -999 -999 -999 54.86 62 -999 -999 71 -999 66 -999 64 84 -999 48.2 -999
1993 10 11 0 0 0 -999 -999 -999 73 -999 -999 -999 49.82 58 -999 -999 70 -999 70 -999 54 73 -999 39.02 -
1993 10 12 0 0 0 62 -999 -999 58 -999 -999 -999 32 57 -999 -999 70 -999 57 -999 60 76 -999 47.66 -999 3
1993 10 13 0 0 0 68 -999 -999 67 -999 -999 -999 49.64 57 -999 -999 66 -999 65 -999 57 76 -999 42.44 -99
1993 10 14 0 0 0 60 58 -999 60 -999 -999 -999 46.76 52 -999 -999 62 -999 65 -999 53 75 -999 35.24 -999
1993 10 15 0 0 0 59 60 -999 60 -999 -999 -999 32 50 -999 -999 61 -999 52 -999 46 70 -999 32 -999 32 72
1993 10 16 0 0 0 59 57 -999 54 -999 -999 -999 42.8 48 -999 -999 64 -999 52 -999 47 68 -999 35.78 -999 3
1993 10 17 0 0 0 53 54 -999 52 -999 -999 -999 32 40 -999 -999 57 -999 54 -999 45 66 -999 46.58 -999 34.
1993 10 18 0 0 0 55 53 -999 55 -999 -999 -999 44.78 49 -999 -999 65 -999 53 -999 50 69 -999 43.16 -999
1993 10 19 0 0 0 62 56 -999 61 -999 -999 -999 32 57 -999 -999 71 -999 59 -999 56 75 -999 51.08 -999 48.
```

4. **Input the Parameter File:** Use values of the parameters specified for each of the 39 modules. Each module either defines a set of parameter/variables or simulates a process. For example, the "basin" module defines watershed-wide parameters and variables. The "soilzone" module computes inflows and outflows from the soil zone from various sources.

   For example, one parameter of air temperature and precipitation distribution is latitude of air-temperature measurement stations ("tsta_y"). The data are added into the .param file shown in Figure 4-3.

Figure 4-3 **Example of a PRMS Parameter File (.param)**



Parameter name	Description	Dimension[1]	Type	Units	Range	Default	Required/condition
tsta_y	Latitude (Y) for each air-temperature-measurement station in albers projection	ntemp	real	meters	–1.0E7 to 1.0E7	0.0	temp_module = ide_dist or xyz_dist

```
####
tsta_y
1
ntemp
26
2
1888972.0
1901465.8
1901505.6
1916086.4
1879634.5
1863571.8
```

5. **Analyze the Model's Output:** The Water-Budget File includes a listing of measured and simulated flow, as well as other fluxes in the watershed.

4.3 SURFACE WATER DIVERSION

Definition: Volume of water taken from the surface water system within a water budget zone for use within the zone.

Context: Water is diverted from streams and conveyance facilities and delivered to the place of use through canals and pipes. Sources could include stream flow and storage releases with different types of diversions including appropriative and riparian water rights, contracts, and adjudications. Diversions are generally measured by federal or State agencies and local purveyors or water users, but specific distributions and allocations are the responsibilities of the local water purveyors or distributors to maintain.

In the context of the water budget for a water budget zone, surface water diversion only includes that portion of diverted surface water which originates from a stream or conveyance facilities inside the water budget zone and also is used inside the water budget zone. The portion of diverted water that originates outside of the water budget zone but is used inside the water budget zone is treated separately as Imported Water; the portion of diverted water that originates inside the water budget zone but is used outside of the water budget zone is also treated separately as Surface Water Export (see Section 4.7). Sometimes water can be rediverted from irrigation ditches for reuse in an agricultural field; this volume of water is not included in surface water diversion as defined above; rather, it is separately accounted for as Applied Water Reuse (see Section 3.8).

Where diversion data are not readily available, estimates can be made using the volume of applied water and the knowledge of i) whether lands fully or partially use surface water and ii) estimates of conveyance evaporation and seepage.

Related Water Budget Components: Applied Water, Conveyance Evaporation, Conveyance Seepage, Imported Water, Surface Water Export

How to Determine Surface Water Diversions:

First identify all land use areas that are served by surface water, and then identify the source of water (i.e., stream diversion) for each land use area. For each stream diversion, estimate the volume of surface water using one or both of the following methods:

- Method 1 — Obtain surface water diversion measurements or existing estimates.
- Method 2 — Estimate unavailable surface water diversions data.

Method 1 — Obtain Surface Water Diversion Measurements or Existing Estimates

Surface water diversion data are available from online databases maintained by federal, State, and local agencies. These data are available for different time periods and at different temporal scales (15 minute, hourly, daily, and monthly). Data from multiple sources may be needed to develop a complete set of diversion data.

The process for obtaining available surface water diversion data involves the following steps:

1. Identify the surface water diversion locations in the water budget zone.
2. Obtain surface water diversion data from existing federal, State, local agency data sources.

In addition to the online databases, there are also published reports (such as a water master reports) where surface water diversion data can be obtained.

If there is a numerical hydrologic model covering the water budget zone, measured or estimated surface water diversion data may be available in the model input/output files. If diversion data from an existing numerical model are used, then the following should be validated:

- There is documentation of both the source data and the basis of estimating the diversion, if any.
- The numerical model is calibrated and accepted by stakeholders.

Key sources of surface water diversion data in California include:

- Local agency records, including flood control districts or entities managing stormwater.
- State Water Project - Bulletin 132.
- Reclamation's Central Valley Operations (including Central Valley Project).
- Surface Water Diversions and Delivery Reports from Other Local and Regional Water Projects.
- State Water Board's water rights information: eWRIMS.
- USGS Surface-Water Data for California.
- CALSIM 3 Model.
- C2VSim and CVHM input files for surface water diversions in the Central Valley.

Method 2 — Estimate Unavailable Surface Water Diversion Data

Where data are not readily available from existing sources, surface water diversions may be estimated from applied water and conveyance losses if groundwater extraction volume is known or can be estimated. Conveyance losses typically represent the additional amount of water needed to convey the water from the point of diversion to the farm or managed wetlands headgate or to the municipal (urban) water intake.

The process for estimating unavailable surface water diversion data involves the following steps:

1. Calculate agricultural applied water (Section 3.5.1).
2. Calculate urban applied water (Section 3.5.2).

3. Calculate managed wetlands applied water (Section 3.5.3).
4. Determine conveyance losses (evaporation and seepage) per Sections 4.5 and 4.6 or approximate it as the fraction of the surface water diversion volume, which is referred to as the conveyance loss fraction (CLF), as follows:

   $$\text{CLF} = \text{CEF} + \text{CSF}$$

   Where CEF is the fraction of surface water diversions attributed to conveyance evaporation, and CSF is the fraction of surface water diversions attributed to conveyance seepage. The California Water Plan estimates of conveyance loss are available by DAUCO (Section 9.9).

   Example: Conveyance evaporation is estimated as 1 percent of the surface water diversion, and conveyance seepage is estimated as 5 percent of the surface water diversion. As a result, CLF is 6 percent.

5. Estimate operational spills, if applicable. Some conveyance facilities may include operational spills that leave the system. Request information from facility operators or local water districts. In cases where data are not available, estimate the operational spill as a fraction of applied water. Whether measured or estimated, include the operation spill in Return Flow.
6. Estimate surface water diversion (SW_{div}), if groundwater extraction volume (GWext) is known or can be estimated, as:

   $$SW_{div} = AW_{div} / (1 - \text{CLF}) + \text{Operational Spill}$$

Where:

- AW_{div} is the portion of the applied water met by surface water diversions and can be estimated as:

$$AW_{div} = \text{Agricultural Applied Water} + \text{Urban Applied Water} + \text{Managed Wetlands Applied Water} - AW_{I} - AW_{GW}$$

7. Perform a “reality check” with existing information, if available. If local knowledge exists about surface water diversions, compare

the estimate from Step 6 with existing information. Assess and reconcile discrepancies, as applicable.

4.4 STREAM EVAPORATION

Definition: Volume of water evaporated into the atmosphere from streams.

Context: As water flows through streams, some water is lost to evaporation (E_S). Stream evaporation is considered a net loss from the water budget zone to the atmosphere and cannot be recovered. It is not measured directly. Evaporation rates can be computed as a function of solar radiation, atmospheric pressure, vapor pressure profile above the stream, temperature, wind, and water quality. Computational methods for open-water evaporation include aerodynamic mass transfer, energy balance Bowen ratio, Priestley-Taylor available energy, various energy-mass transfer methods based on Penman, etc. (Maidment 1993)

Methods to compute evaporation from shallow water bodies differ from methods for deep water bodies. For this handbook, streams are assumed to be “shallow water bodies” if they are less than about 4 meters (13 feet) deep. Deeper water bodies having high turbidity can also be assumed to behave like “shallow water bodies” (Hill, R.W. et al, 2011 after Allen and Robison, 2007). Methods for estimating evaporation from “deep water bodies” are furnished in Section 4.9, “Lake Evaporation.”

Related Water Budget Components: Surface Water Delivery, Surface Water Diversion, Conveyance Evaporation, Lake Evaporation, Imported Water, Stream-Aquifer Interaction

How to Determine Stream Evaporation:

- Method 1 — Obtain stream evaporation data from existing sources.
- Method 2 — Estimate stream evaporation by using a mass balance.
- Method 3 — Estimate stream evaporation from shallow water bodies using ET rates.
- Method 4 — Estimate stream evaporation using Mass Transfer equations.

Method 1 — Obtain Stream Evaporation Data from Existing Sources

Measurements, estimates, and records from local agencies may be the best source of knowledge of the evaporative losses occurring in the streams within a water budget zone based on the estimates of evaporative losses in their canal systems. Stream evaporation data may also be available from online databases maintained by federal, State, and local agencies. These data are available for different time periods and at different temporal scales (15 minute, hourly, daily, and monthly).

The process for obtaining available stream evaporation data involves the following steps:

1. Identify the streams in the water budget zone.
2. Obtain information from local agencies on evaporative losses from open channels that can be used to develop preliminary estimates of evaporative losses from streams based on length, width, and flow rates within the stream.
3. Obtain stream evaporation data from existing federal, State, and local agency data sources.

In addition to online databases, there are also published reports (such as a water master reports) where stream evaporation data may be found.

If there is a numerical hydrologic model covering the water budget zone, estimated stream evaporation information may be available in the model input/output files. Stream evaporation in a model is likely incorporated as a factor rather than an independently calculated volume. If stream evaporation data from an existing numerical model are used, then the following should be validated:

- There is documentation of both the source data and the basis of estimating the stream evaporation, if any.
- The numerical model is calibrated and accepted by stakeholders.

Method 2 — Estimate Stream Evaporation by Using a Mass Balance

Perform a mass balance on the stream using available flows at the desired time step over the period of interest. Similar to the mass balance approach used for determining stream outflows, evaporation can be estimated if all other components in the surface water system are known. If any of the other components are unknown, the mass balance approach will not work; then use Method 3.

The process for estimating stream evaporation by using a mass balance involves the following steps:

1. Obtain stream inflows and outflows, surface water diversions, and runoff and return flows, stream-aquifer interactions, and stream-lake interactions.
2. Apply the following mass balance calculation to determine stream evaporation for the period of interest at the desired time increment (e.g., monthly):

$$\textbf{Evaporation from Stream} = \text{Stream Inflow} - \text{Stream Outflow} + (\text{Runoff} + \text{Return Flow} + \text{Loss to Stream from Groundwater} + \text{Loss from Lake to Stream} + \text{Tributary Inflow to Stream} + \text{Precipitation [on Stream]}) - (\text{Surface Water Diversions} + \text{Gain from Stream to Groundwater})$$

3. Perform “reality check” against existing information, if available. If local knowledge exists about total evaporative losses in a stream, compare the estimate above to existing information. Assess and reconcile discrepancies, as applicable.

Method 3 — Estimate Stream Evaporation from Shallow Water Bodies Using ET Rates

Open water evaporation for shallow water bodies can be estimated by multiplying water surface area by a unit ET rate for “shallow, open water.” The unit evapotranspiration rates can be compiled using the following options:

- Option 1 — Obtain DWR estimates of statewide regional unit ET rates.
- Option 2 — Compute from reference ET using either CIMIS station data or Spatial CIMIS and a representative crop coefficient for shallow, open water.
- Option 3 — Obtain ET data from alternative sources.

The process for estimating stream evaporation by using unit evapotranspiration rate involves the following steps:

1. Obtain or calculate monthly unit evapotranspiration for “shallow open water” ($ET_{c,\text{ shallow, open water}}$) from DWR.
   A. Option 1 - Locate the DAUCO most representative of the water budget zone (DAUCO boundary map). If the water budget zone overlies more than one DAUCO, it may make sense to perform a weighting of unit ET rates based on the proportion of the water budget zone in each DAUCO. Download monthly unit ET rates for “shallow, open water” for the DAUCO of interest. These unit ET rates are output from the Cal-SIMETAW model and computed according to the process outlined for Option 2. Monthly unit ET rates have been averaged for each DAUCO, the smallest area that DWR uses for planning purposes.
   B. Option 2 - Obtain reference ET (ET_o) from CIMIS or Spatial CIMIS. CIMIS allows obtaining ET data at two spatial resolutions, either i) individual CIMIS stations or ii) gridded data. Methods for obtaining these data are provided in Section 9, “Data Resources Directory.” Compute shallow, open water ET as follows:

$$ET_{c,\text{shallow,open water}} = K_{c,\text{shallow,open water}} \times ETo$$

   Where $K_{c,\text{shallow,open water}}$ is the crop coefficient for shallow, open water, and $K_{c,\text{shallow,open water}} = 1.1$

2. Compute the surface area of stream (A_s) as shown below. The stream width will vary with the amount of flowing water in the stream channel; therefore, use a width that represents average flow conditions if more detailed information is not available.

$$A_s = \text{Stream Length} \times \text{Average Stream Width}$$

3. Compute Stream Evaporation (E_c) as:

$$E_c = A_s \times ET_{c,\text{ shallow, open water}}$$

Method 4 — Estimate Stream Evaporation Using Mass Transfer Equations

The evaporation rate of streams can be estimated by using mass transfer equations. The evaporation rate is proportional to the vapor pressure deficit and wind speed, according to the following equation:

$$E = \psi(e_s^* - e_a)$$

Where:

- E=evaporation rate (mm/hr)
- e_s^*=saturation vapor pressure (kPa)
- e_a=vapor pressure of the above air (kPa)
- ψ=wind function (mm/day/kPa)

Calculate stream evaporation as follows based on methodology from Chapter 3 of FAO 56:

1. Identify the stream location and investigate the availability of nearby reports. Two common resources include CIMIS and CDEC.
2. Calculate the **saturation vapor pressure (e_s^*)** from the maximum and minimum temperature.

$$e_s^* = \frac{1}{2}(e^o(T_{max}) + e^o(T_{min}))$$

$$e^o = 0.6108 \exp\left(\frac{17.27T}{T + 237.3}\right)$$

Where T is the temperature in Celsius and the saturated vapor pressure (e_s^*) is in kPa. The temperature can be obtained directly from vailable reports.

3. Determine the **actual vapor pressure (e_a).** The vapor pressure can be:

A. Obtained directly from available CIMIS station reports (“Vap Pres (mBars)”).

B. Calculated from the dew point temperature (T_{dew}).

$$e_a = e^o(T_{dew})$$

C. Calculated from relative humidity (RH) and maximum and minimum temperature. Relative humidity can be obtained from CIMIS, CDEC, and weather data sources.

$$e_a = \frac{1}{2}(e^o(T_{min}) \cdot \frac{RH_{max}}{100} + e^o(T_{max}) \cdot \frac{RH_{min}}{100})$$

4. Determine the wind function (ψ) from the wind speed and river width. The wind speed can be obtained directly from the CIMIS, CDEC, and weather data sources. The wind function has not been calibrated for all streams, but the list of known wind functions (mm / (day kPa)) are tabulated in Table 4-2 and should match the river of interest based on (i) stream width and (ii) description of water body as closely as possible.

Table 4-2 Stream Width and Wind Function Relationships

Stream Width (m)	Wind Function (mm / (day kPa))	Description of Water Body	Location	Source
0.2 to 5129	$\psi = \frac{2.33 + 1.65u_{2m}}{L^{0.1}}$	Evaporation, pans, streams, lakes	Various	McJannet et al. (2012)
0.8 to 11.3	$\psi = 0.12 + 1.43u_{2m}$	Streams in moorland, grassland and woodland	Exe Basin, UK	Webb and Zhang (1997)
4.3	$\psi = 3.2 + 0.8u_{2m}$	Concrete channel	Browns Ferry Nuclear Plant, AL, USA	Fulford and Sturm (1984)
3.7	$\psi = 3.02 + 1.13u_{4m}$	Aqueduct	San Diego Aqueduct, CA, USA	Jobson (1980)
80	$\psi_{day} = 3.09 + 0.84u_{2m}$ $\psi_{night} = 1.13 + 1.78u_{2m}$	Stream in forested catchment	Little Southwest Miramichi River, NB, Canada	Maheu *et al.* (2014)
8	$\psi = 2.64 + 2.92u_{2m}$	Stream in forested catchment	Catamaran Brook, NB, Canada	Maheu *et al.* (2014)
9	$\psi = 3.46 + 2.04u_{0.5m}$	Stream in open meadows	John Day River, OR, USA	Benner (1999)
1.5	$\psi = 1.02u_{1.5m}$	Stream in harvested forest catchment	Griffith Creek, BC, Canada	Guenther *et al.* (2012)

Table Notes: m = meters, mm = millimeters, kPa = kilopascals
Mass transfer equations for streams and lakes of various sizes and environments u_{2m} is the wind speed measured at a 2-meter height (meter per second) and L is the channel average width (meter).

5. Calculate the evaporation rate (*E*) from calculated values from previous steps.

$$E = \psi(e_s^* - e_a)$$

4.5 CONVEYANCE EVAPORATION

Definition: Volume of water evaporated into the atmosphere from conveyance facilities, other than streams, during water delivery.

Context: As water flows through open channels, some water is lost to conveyance evaporation (E_c) and to conveyance seepage (D_c). Together, evaporation and seepage account for total conveyance losses in canals. For the purposes of water budget estimation in a water budget zone, evaporation of surface water from the stream system to the atmosphere is separately accounted for as stream evaporation (see Section 4.4). *Conveyance evaporation* represents a net loss from the water budget zone to the atmosphere that cannot be recovered.

In a water budget, it is important to separate evaporation losses from conveyance losses because evaporation is a net loss from the water budget zone to the atmosphere and cannot be recovered while seepage, although a loss from conveyance facilities, it can be a net gain to the groundwater system or surface water system. Depending on the method selected, evaporation may be estimated first and then used to calculate or estimate seepage through a mass balance, or vice versa.

Evaporation is not measured directly. Evaporation rates can be computed as a function of solar radiation, atmospheric pressure, vapor pressure profile above conveyance facilities, temperature, wind, and water quality. Computational methods for open-water evaporation include aerodynamic mass transfer, energy balance Bowen ratio, Priestley-Taylor available energy, various energy-mass transfer methods based on Penman, etc. (Maidment, 1993).

Methods to compute evaporation from shallow water bodies differ from methods for deep water bodies. For this handbook, canals are assumed to be “shallow water bodies” if they are less than about 4 meters (13 feet) deep. Deeper water bodies having high turbidity can also be assumed to behave like “shallow water bodies” (Hill, R.W. et al, 2011 after Allen and Robison, 2007). Methods for estimating evaporation from “deep water bodies” are furnished in Section 4.9, “Lake Evaporation.” Local knowledge is useful to verify estimates of conveyance losses.

Related Water Budget Components: Surface Water Delivery, Surface Water Diversion, Conveyance Seepage, Imported Water, Lake Evaporation

How to Determine Conveyance Evaporation:

- Method 1 — Obtain conveyance evaporation data from existing sources.
- Method 2 — Estimate conveyance evaporation by using a mass balance, if seepage has been estimated and conveyance flows are available.
- Method 3 — Estimate conveyance evaporation from shallow water bodies using ET rates.

Method 1 — Obtain Conveyance Evaporation Data from Existing Sources

Conveyance evaporation data may be available from online databases maintained by federal, State, and local agencies. These data are available for different time periods and at different temporal scales (15 minute, hourly, daily, and monthly). Data from multiple sources may be needed to develop a complete set of evaporation data.

The process for obtaining available conveyance evaporation data involves the following steps:

1. Identify the conveyance infrastructure in the water budget zone.
2. Obtain conveyance evaporation data from existing federal, State, and local agency data sources.

In addition to the online databases, there are also published reports (such as a water master reports) where conveyance evaporation data can be obtained.

If there is a numerical hydrologic model covering the water budget zone, estimated conveyance evaporation information may be available in the model input/output files. If conveyance evaporation data from an existing numerical model are used, then the following should be validated:

- There is documentation of both the source data and the basis of estimating the conveyance evaporation, if any.
- The numerical model is calibrated and accepted by stakeholders.

Key sources of conveyance evaporation data in California include:

- California Water Plan.
- Local reports.
- C2VSim and CVHM input files for surface water deliveries in the Central Valley.

Method 2 — Estimate Conveyance Evaporation by Using a Mass Balance

Perform a mass balance on the conveyance facilities using available conveyance flow and seepage data at the desired time step over the period of interest. If an estimate for conveyance seepage is not available, the mass balance approach will not work; then use Method 3.

The process for estimating conveyance evaporation by using a mass balance involves the following steps:

1. Obtain surface water delivery, surface water diversion, and imported water estimates for the conveyance facility. Methods for estimating these components are included in Section 3.6, "Surface Water Delivery;" Section 4.3, "Surface Water Diversion;" and Section 4.7, "Imported Water and Surface Water Export."
2. Estimate conveyance seepage based on methods described in Section 4.6, "Conveyance Seepage."
3. Estimate Operational Spills, if applicable. Request information from conveyance facility owners or operators, and local water

districts for operational spills data. If no data are available, then estimate the operational spill as a fraction of applied water. Whether measured or estimated, include the operation spill in return flow.

4. Apply the following mass balance calculation to determine conveyance evaporation (E_c) for the period of interest at the desired time increment (e.g., monthly):

$$E_c = \sum \text{Surface Water Diversions (Inflow)} + \sum \text{Imported Water (Inflow)} - \sum \text{Surface Water Deliveries (Outflow)} - \sum \text{Conveyance Seepage (Outflow)} - \text{Operational Spills (Outflow)}$$

5. Perform "reality check" against existing information, if available. If local knowledge exists about total conveyance losses in the conveyance facility, compare the estimate from Step 4 above to existing information. Assess and reconcile discrepancies, as applicable.

Alternative Rough Approximation Technique (for small, unlined ditches only): If the conveyance network consists of a small, unlined ditch network with minimal data, a rough approximation technique used for the California Water Plan is to assume conveyance evaporation as one percent of the total inflows:

$$E_c = \left(\sum \text{Surface Water Diversions} + \sum \text{Imported Water}\right) \times \text{CEF}$$

Where CEF is the Conveyance Evaporation Factor. It can be approximated as 1 percent of supply or another fraction based on local knowledge.

Method 3 — Estimate Conveyance Evaporation from Shallow Water Bodies Using ET Rates

Open water evaporation for shallow water bodies can be estimated by multiplying water surface area by a unit ET rate for "shallow, open water." The unit ET rates can be compiled using the following options:

- Option 1 — Obtain DWR estimates of statewide regional unit ET rates.

- Option 2 — Compute from reference ET using either CIMIS station data or Spatial CIMIS and a representative crop coefficient for shallow, open water.
- Option 3 — Obtain ET data from alternative sources.

The process for estimating conveyance evaporation by using unit evapotranspiration rate involves the following steps:

1. Obtain or calculate monthly unit evapotranspiration for "shallow open water" ($ET_{c,\text{ shallow, open water}}$), from DWR.
   A. Option 1 — Locate the DAUCO most representative of the water budget zone (DAUCO boundary map). If the water budget zone overlies more than one DAUCO, it may make sense to perform a weighting of unit ET rates based on the proportion of the water budget zone in each DAUCO. Download monthly unit ET rates for for "shallow, open water" for the DAUCO of interest. These unit ET rates are output from the Cal-SIMETAW model and computed according to the process outlined for Option 2. Monthly unit ET rates have been averaged for each DAUCO, the smallest area that DWR uses for planning purposes.

   B. Option 2 — Obtain reference ET (ET_o) from CIMIS or Spatial CIMIS. CIMIS allows obtaining ET data at two spatial resolutions, either (i) individual CIMIS stations or (ii) gridded data. Methods for obtaining these data are provided in Section 9, "Data Resources Directory." Compute shallow, open water ET as follows:

$$ET_{c,\text{shallow,open water}} = K_{c,\text{shallow,open water}} \times ETo$$

   Where $K_{c,\text{shallow,open water}}$ is the crop coefficient for shallow, open water, and $K_{c,\text{shallow,open water}} = 1.1$

2. Compute the surface area of canal (A_c) as shown below. The canal width will vary with the amount of flowing water in the conveyance channel; therefore, use a width that represents average flow conditions if more detailed information is not available.

$$A_c = \text{Canal Length} \times \text{Average Canal Width}$$

3. Compute Conveyance Evaporation (E_c) as:

$$E_c = A_c \times ET_{c,\,\text{shallow, open water}}$$

4.6 CONVEYANCE SEEPAGE

Definition: Volume of water recharged to the groundwater system from the conveyance facilities, other than streams, during water delivery.

Context: As water flows through open channels (streams and canals), some water is lost to conveyance evaporation (E_c) and to conveyance seepage (D_c). Together, evaporation and seepage account for total conveyance losses from open channels. For the purposes of water budget estimation in a water budget zone, percolation of surface water from the stream system to the groundwater system is separately accounted for as stream-groundwater interaction (see Section 5.4).

In a water budget, it is important to separate evaporation losses from conveyance losses because evaporation is a net loss from the water budget zone to the atmosphere and cannot be recovered while seepage, although a loss from the conveyance facility, is a net gain to the groundwater system. Depending on the method selected, evaporation may be estimated first and then used to calculate or estimate seepage through a mass balance, or vice versa.

Conveyance seepage is the predominant portion of conveyance losses in open channels. Seepage is water that percolates into the subsurface through the bed and walls of open water channels, and thus represents a loss from the surface water system and a gain for the groundwater system. Conveyance seepage does not necessarily always make it past the unsaturated zone and reach the aquifer. Instead, it could remain in the soil and serve to meet vegetation demand. However, this volume is addressed via groundwater uptake and for accounting purposes can be counted towards the aquifer storage. Although not directly measured, seepage can be (1) obtained from published sources of information (Method 1),
(2) calculated using either a mass balance approach (Method 2), or
(3) estimated using seepage rates based on the hydraulic conductivity of the conveyance facility (Method 3).

Conveyance seepage can be expressed as a rate (percent of flow per mile). Larger conveyance facilities, in general, lose less water as a percent of flow per mile than smaller ones.

Related Water Budget Components: Surface Water Delivery, Surface Water Diversion, Conveyance Evaporation, Imported Water

How to Determine Conveyance Seepage:

- Method 1 — Obtain conveyance seepage data from existing sources.
- Method 2 — Estimate conveyance seepage by using a mass balance.
- Method 3 — Estimate conveyance seepage based on canal characteristics.

Method 1 — Obtain Conveyance Seepage Data from Existing Sources

Conveyance seepage estimates may be available from online databases maintained by federal, State, and local agencies. These data are available for different time periods and at different temporal scales (15 minute, hourly, daily, and monthly). Data from multiple sources may be needed to develop a complete set of conveyance seepage data.

The process for obtaining available conveyance seepage data involves the following steps:

1. Identify the conveyance infrastructure in the water budget zone.
2. Obtain conveyance seepage data from existing federal, State, and local agency public data sources.

In addition to the online databases, there may be published reports (such as a water master reports) where conveyance seepage data can be obtained.

If there is a numerical hydrologic model covering the water budget zone, estimated conveyance seepage information may be available in the model input/output files. If conveyance seepage data from an existing numerical model are used, then the following should be validated:

- There is documentation of both the source data and the basis of estimating the conveyance seepage, if any.
- The numerical model is calibrated and accepted by stakeholders.

Key sources of conveyance seepage data in California include:

- California Water Plan.
- Local reports.
- C2VSim and CVHM input files for surface water deliveries in the Central Valley.

Method 2 — Estimate Conveyance Seepage Using a Mass Balance

Perform a mass balance on the conveyance facilities using conveyance flow and evaporation at the desired time step over the period of interest. If an estimate for conveyance evaporation is not available, the mass balance approach will not work; then use Method 3.

The process for estimating conveyance seepage using a mass balance involves the following steps:

1. Obtain surface water delivery, surface water diversion, and imported water estimates for the conveyance facility. Methods for estimating these components are included in Section 3.6, "Surface Water Delivery;" Section 4.3, "Surface Water Diversion;" and Section 4.7, "Imported Water and Surface Water Export."
2. Estimate conveyance evaporation based on methods described in Section 4.5, "Conveyance Evaporation."
3. Estimate operational spills, if applicable. Some conveyance facilities may include operational spills that leave the system. Request information from facility owners or operators and local water districts. If no data are available data, estimate the operational spill as a fraction of applied water. Whether measured or estimated, include the operation spill in return flow.
4. Apply the following mass balance calculation to determine conveyance seepage (D_c) for the period of interest at the desired time increment (e.g., monthly):

$$D_c = \sum \text{Surface Water Diversions (Inflow)} + \sum \text{Imported Water (Inflow)} - \sum \text{Surface Water Deliveries (Outflow)} - \sum \text{Conveyance Evaporation (Outflow)} - \text{Operational Spills (Outflow)}$$

5. Perform "reality check" against existing information, if available. If local knowledge exists about total conveyance losses in the

conveyance facility, compare the estimate from Step 4 to existing information. Assess and reconcile discrepancies, as applicable.

Method 3 — Estimate Conveyance Seepage based on Canal Characteristics

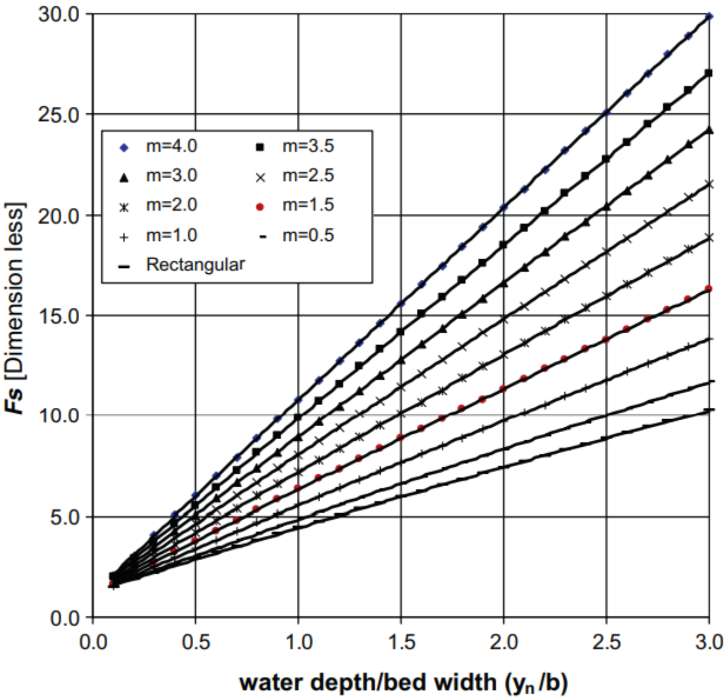
Conveyance seepage can be estimated based on the lining of canals, soil characteristics, wetted perimeter, length of canal, and hydraulic conductivity of canal bed. The process for estimating conveyance seepage rate based on conveyance facility characteristics involves the following steps:

1. Explore the availability of aquifer parameter data from local models, if available, or regional groundwater models such as C2VSim or CVHM. Estimate hydraulic conductivity using information on soil and aquifer properties as well as well construction data or aquifer test data.
2. Compute wetted perimeter of the canals. The wetted perimeter is the portion of the canal cross section that is “wet,” and thus, varies with the amount of flowing water in the channel. Use a wetted perimeter that represents average flow conditions if more detailed information is not available.
3. Measure the length of the conveyance facility.
4. Compute Conveyance Seepage (D_c) using the following equation:

$$D_c = \text{Canal Length} \times \text{Canal Normal Flow Depth} \times \text{Hydraulic Conductivity} \times \text{Seepage Factor}$$

The seepage factor is a dimensionless parameter that is a function of the channel geometry. Figure 4-4 shows the variation in seepage factor F_S, with the ratio of water depth/bed width for different side slope m.

Figure 4-4 **Seepage Factor vs Channel Geometry**



Source: Figure taken from the article "Design and analysis of a canal section for minimum water loss," in the December 2011 issue of the Alexandria Engineering Journal

4.7 IMPORTED WATER AND SURFACE WATER EXPORT

Definition: Imported water is the "volume of water brought from outside the water budget zone for use within the water budget zone, such as State Water Project (SWP) water, Central Valley Project (CVP) water, water produced from desalination of ocean water, and water produced from desalination of deep groundwater from below the base of freshwater." Conversely, surface water exports refer to the "volume of water diverted from the surface water system within a water budget zone for use outside the zone."

Context: Imported water (I_W) can include one or more sources of water being diverted from stream or conveyance facilities (including groundwater) originating outside of the water budget zone and are generally measured and known by the local agencies. Water deliveries from SWP and CVP are considered imported water into a water budget zone. If water is simply purchased and the specific source is unknown, the agency from which the water is purchased should have these records. General deliveries to a region or water budget zone may be reported by federal or State agencies, but specific distributions and allocations are the responsibilities of local agencies or distributors to maintain. Direct measures or estimates of those distributions should be available or could be calculated. Imported water includes water transfers, both surface water and groundwater, originating outside of the water budget zone.

Surface water export (SW_x) in the Water Budget Handbook is a concept tied to the delineation of a water budget zone. If an amount of water is diverted from a stream inside a defined water budget zone but delivered/used outside the zone, then that amount of water is considered a surface water export from the source water budget zone and a surface water import (after conveyance losses are accounted for) into the destination water budget zone. Exported water could include project allocations (e.g., SWP or CVP) or surface water transfers. A surface water export is usually measured at the point of diversion unless it is a riparian diversion from a stream that is at the boundary of two water budget zones. There may be surface water exports from one area to another which are managed through permits and legal agreements amongst counties and water agencies; in such cases, the amount is almost always measured and reported by the involved water agencies.

Related Water Budget Components: Applied Water, Applied Water Reuse, Return Flow, Surface Water Delivery, Surface Water Diversion, Stream Inflow, Conveyance Evaporation, Conveyance Seepage

How to Determine Imported Water and Surface Water Exports:

- Method 1 — Obtain available imported water and surface water export data.
- Method 2 — Estimate unavailable imported water and surface water export data.

Method 1 — Obtain Available Imported Water and Surface Water Export Data

Imported water and surface water export data are available from existing public databases maintained by federal, State, and local agencies. These data are available for different time periods and at different temporal scales

(15 minute, hourly, daily, and monthly). Data from multiple sources may be needed to develop a complete set of data.

The process for obtaining imported water and surface water export data involves two steps:

1. Identify imported water and surface water export locations in the water budget zone.
2. Obtain imported water and surface water export data from existing federal, State, and local agency data sources.

In addition to databases, there are published reports where imported water and surface water export data for local agencies can be obtained.

If there is a numerical hydrologic model covering the water budget zone, measured or estimated imported water and surface water export data may be available in the model input/output files. If data from an existing numerical model are used, then the following should be validated:

- There is documentation for both the source data and the basis of the estimated imported water and surface water export data or estimates, if any.
- The numerical model is calibrated and accepted by stakeholders.

Key sources of imported water and surface water export data in California are:

- State Water Project — Bulletin 132.
- Central Valley Project.
- Regional transfers (Truckee River Operating Agreement, etc.).
- Water transfers (DWR, Reclamation, local agencies).
- Surface water diversions and delivery reports from local and regional water projects.
- CALSIM 2 Model.
- State Water Board’s water rights information (eWRIMS).
- DWR CDEC.
- USGS Surface-Water Data for the Nation.
- Reports containing information on water transfers between entities.

- C2VSim and CVHM input files for surface water diversions in the Central Valley.
- Local area hydrologic model input files.
- Diversion and delivery databases maintained by local and regional agencies.

Method 2 — Estimate Unavailable Imported Water and Surface Water Export Data

In cases where no data are readily available from existing sources, imported water and surface water export data can be estimated based on applied water estimates for agricultural, urban, and managed wetlands using the methods described in Section 3.5, "Applied Water." Imported water meets demands within the water budget zone, while surface water exports meet demand outside the water budget zone.

The process for estimating unavailable imported water data involves the following steps:

1. Calculate applied water for agriculture, urban, and managed wetlands (Section 3.5, "Applied Water") for the area within the water budget zone that is served by imported water from outside the zone. If an area is served both by local surface water and groundwater in addition to imported water, the local supplies, that are known or can be estimated reasonably, should be subtracted from the applied water to calculate the demand met by imported water.
2. Determine conveyance losses (evaporation and seepage) based on methods described in Section 4.5, "Conveyance Evaporation;" and Section 4.6, "Conveyance Seepage," or approximate the total conveyance loss as a fraction of the surface water diversion, referred to as the conveyance loss fraction (CLF), as follows:

$$\mathrm{CLF} = \mathrm{CEF} + \mathrm{CSF}$$

Where CEF is the fraction of surface water diversions attributed to conveyance evaporation, and CSF is the fraction of surface water diversions attributed to conveyance seepage. The California Water Plan is a potential source of conveyance loss estimates by DAUCO.

Example: Conveyance evaporation is estimated as 1 percent of the surface water diversion, and conveyance seepage is estimated as 5 percent of the surface water diversion. Thus, CLF is 6 percent.

3. Estimate operational spills, if applicable. Some conveyance facilities may include operational spills that leave the system. Request information from facility operators or local water districts. In cases where data are not available, estimate the operational spill as a fraction of water demand. Whether measured or estimated, include the operational spill in return flow.
4. Estimate imported water (I_W) as follows based on use within the water budget zone:

$$I_W = AW_I / (1 - \text{CLF}) + \text{Operational Spill}$$

Where AW_I is the portion of the applied water met by imported water and can be estimated as:

$$AW_I = \text{Agricultural Applied Water} + \text{Urban Applied Water} + \text{Managed Wetlands Applied Water} - AW_{div} - AW_{GW}$$

5. Perform a “reality check” with existing information, if available. If local knowledge exists about imported water, compare the estimates from Steps 4 and 5, respectively, to existing information. Assess and reconcile discrepancies, as applicable.

The process for estimating unavailable surface water export data involves the following steps:

1. Calculate applied water for agriculture, urban, and managed wetlands (Section 3.5, “Applied Water”) at the place of use outside the water budget zone. If an area is served both by local surface water and groundwater in addition to surface water export, the local supplies, that are known or can be estimated reasonably, should be subtracted from the applied water to calculate the demand met by surface water export.
2. Follow the same steps 2 through 5 used for estimating imported water but apply these steps for estimating surface water export to meet demand outside the water budget zone.

4.8 STREAM-LAKE INTERACTION

Definition: Both the inflow and outflow components of the stream-lake interaction are covered in this section. The stream-lake interaction is defined as the "volume of water exchanged between rivers/streams and lakes/reservoirs." In this handbook, the term lake is all inclusive, representing both natural lakes and man-made reservoirs operated for water storage and supply and including both onstream and offstream storage. The terminology for the stream-lake interaction covers both lake inflow from streams ($Q_{L(in)}$) and lake outflow to streams ($Q_{L(out)}$).

Context: A water budget zone with surface water supplies may include lakes that receive inflow from streams. The stream inflows into the lake may then be withdrawn for agricultural, urban, or managed wetlands water uses within or outside the water budget zone. Lake outflow, or releases, to streams are usually measured and included in reservoir operational records. In many cases, lake operators will measure precipitation, estimate lake evaporation and seepage, and then determine lake inflow using a mass balance approach.

Related Water Budget Components: Precipitation, Applied Water, Runoff, Return Flow, Surface Water Diversion, Lake Evaporation, Stream Inflow, Stream Outflow

How to Determine Stream-Lake Interaction Data: First, identify the lakes/reservoirs within the water budget zone that receive water from streams within the water budget zone. For each lake, estimate stream inflow and outflow using one of the following methods:

- Method 1 — Obtain available lake inflow and outflow data.
- Method 2 — Use mass balance to estimate lake inflows and outflows.
- Method 3 — Estimate lake inflows and outflows using reservoir operations rule curve or model.
- Method 4 — Estimate lake outflows using a mass curve.

Method 1 — Obtain Available Lake Inflow and Outflow Data

Lake inflow from streams and outflow to streams are commonly available from online databases, published reports, numerical models, or lake operators. Operators of lake facilities often measure outflow and water elevations (levels) and estimate lake evaporation and seepage to determine inflow through a mass balance approach. After the lakes that receive water from streams in the water budget zone are identified, the most feasible method to obtain inflow and outflow data is to use existing public data from federal, State, and local agencies. Many lakes are regularly monitored by or report data to the USGS. In addition, DWR publishes lake inflows and outflows on CDEC for California. There are other federal, State, and local agencies who maintain and publish lake inflow and outflow records. These data are available for different time periods and at different temporal scales (15 minute, hourly, daily, and monthly). Data from multiple sources may be needed to develop a complete data set. In addition to the online databases, there are published reports where lake inflow and outflow data can be obtained.

If there is a numerical hydrologic model covering the water budget zone, measured or estimated lake inflow and outflow data may be available in the model input/output files. If data from an existing numerical model are used, then the following should be validated:

- There is documentation of both the source data and the basis of the included lake inflow and outflow data, if any.
- The numerical model is calibrated and accepted by stakeholders.

Key sources of lake inflow and outflow data in California are:

- USGS Surface-Water for the Nation.
- DWR CDEC: Current River Conditions.
- Local agency records, including flood control districts or entities managing reservoirs.
- Previous reports.
- Input/output files of numerical models.
- USGS Water-Resources Investigations Reports.
- USGS Scientific Investigations Reports.
- California Nevada River Forecast Center.

Method 2 — Use Mass Balance to Estimate Lake Inflows and Outflows

To estimate lake inflow, perform a mass balance at the desired time step over the period of interest. Typically, water budget components are computed at a monthly time step. Depending on the application, some water budgets may require finer temporal resolution in order to capture the availability of water. Data needed include:

- Surface water outflow from the lake.
- Change in lake storage (from elevation-area-capacity curves).
- Precipitation.
- Lake evaporation.
- Gain to groundwater from the lake.
- Loss from groundwater to the lake.

Methods to estimate surface water outflow, lake evaporation, gain to groundwater from lake, and loss from groundwater to lake are included in Section 4, "Surface Water System;" and Section 5, "Groundwater System." Lake storage and elevation records can be found using the same sources as described under Method 1 of this section.

The mass balance approach needs key information as presented in the equation below to determine either lake inflow ($Q_{L(in)}$) or lake outflow ($Q_{L(out)}$). This equation requires (1) either inflow or outflow to be measured or estimated, (2) measured or estimated reservoir elevation data, and (3) an elevation-area-capacity curve for input to the following equation:

$$\text{Change in Lake Storage} = \text{Stream Inflow to Lake } (Q_{L(in)}) - \text{Stream Outflow from Lake } (Q_{L(out)}) + \text{Precipitation} - \text{Lake Evaporation} - [\text{Gain } (+) \text{ to Groundwater from Lake or Loss } (\text{-}) \text{ from Groundwater to Lake}]$$

Use the following equation to estimate lake inflow:

$$\text{Stream Inflow to Lake } (Q_{L(in)}) = \text{Stream Outflow from Lake } (Q_{L(out)}) + \text{Change in Lake Storage} - \text{Precipitation} + \text{Lake Evaporation} + [\text{Gain } (+) \text{ to Groundwater from Lake or Loss } (\text{-}) \text{ from Groundwater to Lake}]$$

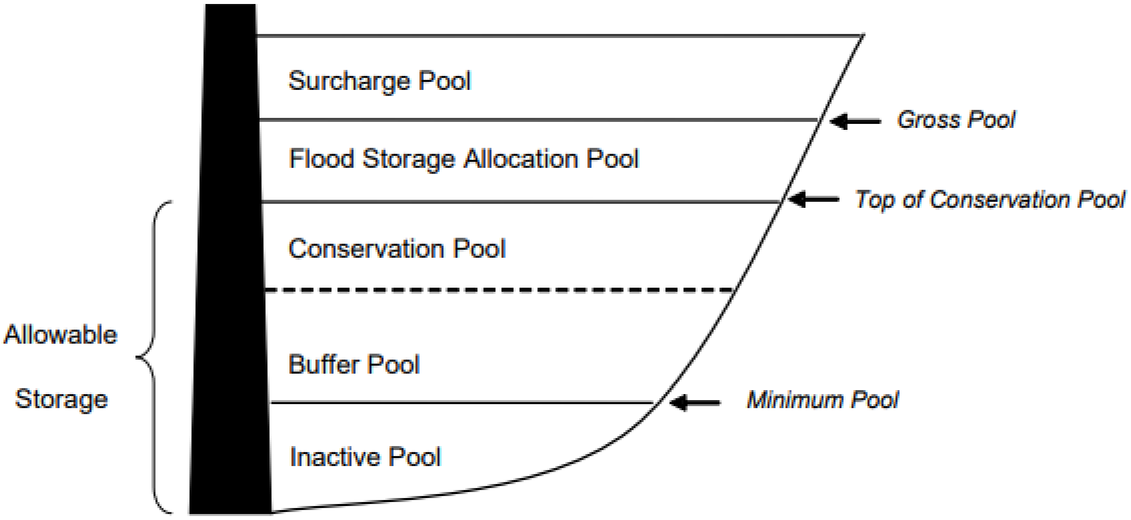
Use the following equation to estimate lake outflow:

$$\text{Stream Outflow from Lake } (Q_{L(out)}) = \text{Stream Inflow to Lake } (Q_{L(in)}) - \text{Change in Lake Storage} + \text{Precipitation} - \text{Lake Evaporation} - [\text{Gain } (+) \text{ to Groundwater from Lake or Loss } (-) \text{ from Groundwater to Lake}]$$

Method 3 — Estimate Lake Inflows and Outflows Using a Reservoir Operation Rule Curve or Model

In cases where lake releases are not monitored and reported, it may be possible to estimate the reservoir operations using a rule curve. Rule curves for reservoirs govern the release of water to balance the demands of flood control, water supply, recreation, and other purposes as shown in Figure 4-5. Most reservoirs have a reservoir operation rule curve that can be used to forecast reservoir outflows, given knowledge of reservoir water surface elevations.

Figure 4-5 Rule Curve for Reservoir Releases



Adapted from Hickey et al., 2003
Inactive Pool – Storage in this pool may be zero or a minimum pool.
Buffer Pool – This is part of the conservation pool; when the water level drops into the buffer pool, only essential demands will be met.
Conservation Pool – Space is reserved for various water demands on the reservoir (e.g., agricultural, municipal).
Flood Storage Allocation Pool – Water is stored in this pool when it cannot be safely passed downstream within objective flow targets.
Surcharge Pool – Water in this pool is above the emergency spillway; outflows are determined by the spillway capacity or Emergency Spillway Release Diagram.

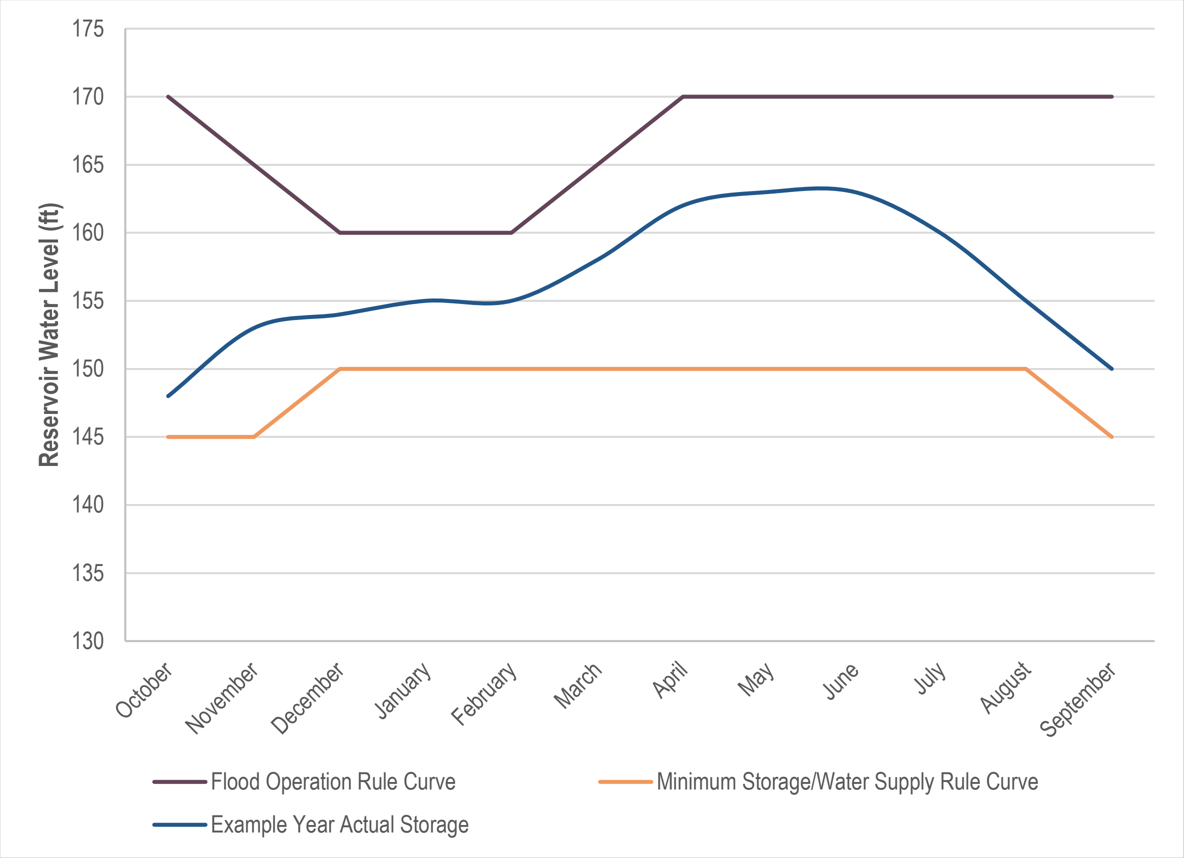
One example of a simple rule curve is shown in the Table 4-3. Often the rule curves are much more complex, may include parameters related to the water index, demand, etc., and are processed in a model.

Table 4-3 Rule Curve

Storage	Outflow
If reservoir storage is above top of conservation pool	Then reservoir outflow varies between objective flow targets and total storage minus conservation storage
If reservoir storage is between top of conservation pool and top of inactive pool	Then reservoir outflow varies between zero cfs, and minimum flow requirement
If reservoir storage is below top of inactive pool	Then reservoir outflow is zero cfs

The example rule curve shown in Figure 4-6 illustrates the maximum and minimum storage in the reservoir, based on flood control and water supply requirements. If the storage is at or above the flood control rule curve level, then the outflow will be greater than or equal to the inflow. If the storage is at or below the water supply rule curve, then there will be no outflow. The reservoir is operated to adjust outflows to maintain levels between the rule curves.

Figure 4-6 Example of Reservoir Rule Curve



The process for estimating reservoir storage and outflow involves the following steps:

1. Obtain reservoir rule curve, often available from water agencies and reservoir operators.
2. Obtain reservoir elevation or storage, generally available from the California Data Exchange Center or reservoir operators.
3. Use rule curve to calculate outflows, as shown in Table 4-3.

Method 4 — Estimate Lake Outflows Using a Mass Curve

A mass curve is a plot of cumulative inflow into a reservoir overtime. Although it is usually used to determine reservoir capacity, outflows from a reservoir can be calculated from reservoir storage and demand.

The process for estimating reservoir outflows based on a mass curve involves the following steps:

1. Determine the time series inflow into the reservoir and plot the cumulative inflow over the time period of interest (volume versus time, solid line displayed in Figure 4-7).
2. Determine the reservoir storage capacity (volume). This is typically available from the reservoir operator or is published online.
3. Calculate the average demand from the reservoir (volume per time), often available from irrigation districts, ditch companies, or water rights data. This is typically related to the surface water diversion data for areas where the stream is controlled through reservoir releases. Diversions from the streams will govern the volume of releases from the reservoirs.
4. Using the cumulative inflow plot, superimpose the average demand rate at all points such that the cumulative inflow rate is equal to the demand rate (dashed line displayed in Figure 4-7).
5. Calculate the outflow depending on the relative inflow, as outlined in Table 4-4.

Figure 4-7 Example of Reservoir Inflows Over Time

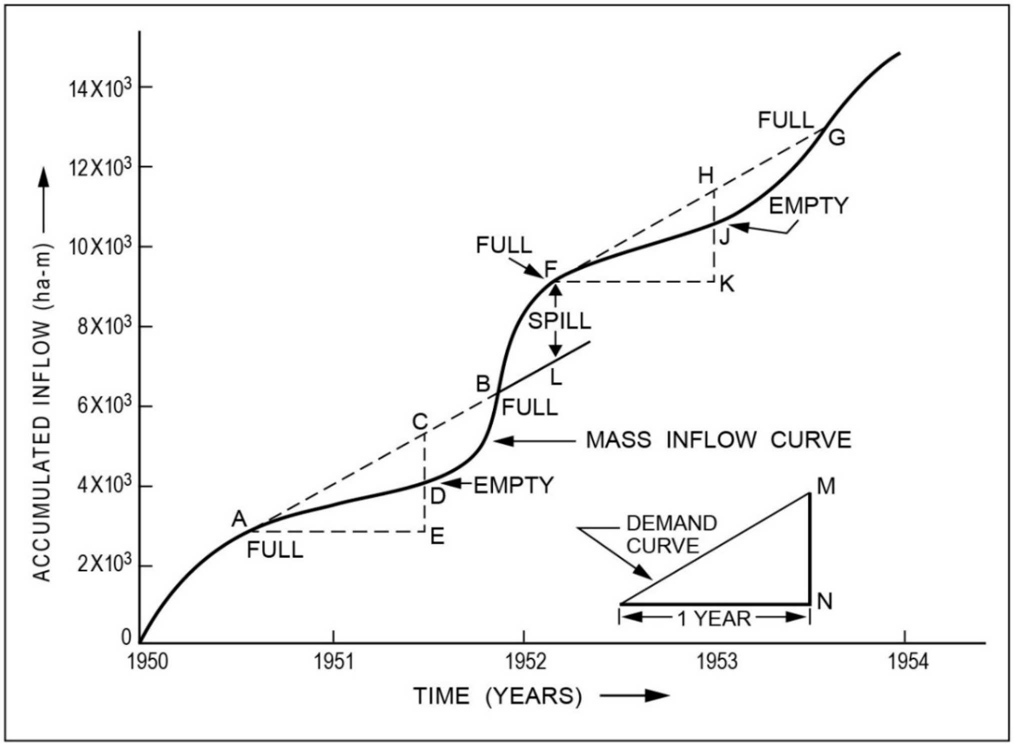


Table 4-4 Reservoir Inflow and Outflow Relationship

Inflow	Outflow
Cumulative inflow is greater than demand curve	Outflow = Inflow
Demand curve is greater than cumulative inflow	Outflow = Average demand
Demand curve minus cumulative inflow is greater than storage capacity	No outflow

4.9 LAKE EVAPORATION

Definition: Volume of evaporation from lakes and reservoirs.

Context: Lake evaporation (E_L) is the process by which water changes from a liquid to a gas or vapor. It is a function of solar radiation, atmospheric pressure, vapor pressure profile above the water body, temperature, wind, and the quality of water. Evaporation from open water surface is directly proportional to the exposed area. If the exposed area is not large, the evaporation is typically a relatively small component of the overall water budget within a water budget zone.

Related Water Budget Components: Precipitation, Applied Water, Runoff, Return Flow, Surface Water Diversion, Lake Evaporation, Stream Inflow, Stream Outflow, Stream-Lake Interaction

How to Determine Lake Evaporation: First, identify the lakes within the water budget zone and determine the approximate exposed water surface area. Use existing maps to generate this information or obtain elevation-area-capacity curves and water elevation data to better approximate the surface area. Then estimate the evaporation for each lake using one of the following methods:

- Method 1 — Obtain measured/reported data for evaporation rates inside the water budget zone.
- Method 2 — Use pan evaporation method to estimate lake evaporation.
- Method 3 — Use aerodynamic method (mass transfer) to calculate lake evaporation.

Method 1 — Obtain Measured/Reported Data for Evaporation Rates Inside the Water Budget Zone

Obtain historical or current evaporation rate data (daily, monthly, etc.) from existing reports or data sources. Evaporation is of great importance in regions such as California, and thus some agencies closely measure and monitor the spatial variation of evaporation in the state. For example, NOAA's Climate Prediction Center (CPC) provides real time estimates of daily and monthly evaporation from multiple sources. Also, NOAA's National Climatic Data Center (NCDC) is responsible for providing public access to the

Nation's treasure of climate and historical weather data including daily pan evaporation and wind speed for many stations within the U.S.

DWR's Bulletin 73-79, "Evaporation from Water Surfaces in California," summarizes all readily available data on pan evaporation measurements in California. It includes data from Bulletin 54-A, "Evaporation from Water Surfaces in California (1948)," and Bulletin 73-1, "Evaporation from Water Surfaces in California (1973)." This bulletin not only provides an array of monthly total evaporation data from 478 stations, dating back to the 1880s, but also includes information about the environment and type of measuring station, which are of significant value to users for interpreting the data. This bulletin is of practical and economic importance to water agencies and others who need evaporation data, as evaporation data are basic to reservoir operations and irrigation scheduling. For more information on this bulletin, see Section 9, "Data Resources Directory."

Sources of information include:

- Previous reports and models.
- NOAA: U.S Evaporation Data.
- NOAA: U.S. Soil Moisture Monitoring, Evaporation.
- NOAA: National Climate Data Center, Climatological Data Publications.
- DWR Agricultural Land and Water Use Estimates.
- DWR's Bulletin 73-79.

Method 2 — Use Pan Evaporation Method to Estimate Lake Evaporation

If there are no evaporation estimates, but pan evaporation data are available, the following formula can be used to estimate evaporation loss from a water body such as a lake:

$$E_L = K_p \times E_{pan} \times A_s$$

Where:

- E_L = Lake evaporation.
- K_p = Pan coefficient, a correction factor to the actual evaporation rate, with a range from 0.64 to 0.81 and an average of 0.70 for the United

States. This coefficient is specific for each water body and varies with the geometry of the lake, water depth, lake surface conditions (turbidity, presence of vegetation), and local weather conditions. Local or regional calibration or verification of the pan coefficient used is highly recommended, and caution is needed to account for poor pan siting and handling.

- E_{pan} = Measured pan evaporation rate.
- A_s = Surface area of the lake.

Example: DAU 130 (Goose Lake, Alturas) — This example presents how to estimate lake evaporation for Goose Lake using pan evaporation data. The surface area of the lake, as determined using an aerial map, is 94,000 acres. A Class A evaporation pan is located next to the lake, and daily recording of water depths are 15.20 inches and 15.17 inches on day 1 and day 2, respectively. The pan coefficient (K_{pan}) for this lake is 0.7. With no precipitation over that time period, E_{pan} after 24 hours is 0.03 inch. The total estimated evaporation from the lake over 24 hours is:

$$E_L = 0.7 \times \left(\frac{0.03}{12}\right) \times 94{,}000 = 164.5 \text{ acre-feet}$$

Method 3 — Use the Aerodynamic Method (Mass Transfer) to Calculate Lake Evaporation

The aerodynamic method is widely used to calculate evaporation from lakes. The basic equations were tested and developed on Lake Hefner in Oklahoma in the 1950s. The aerodynamic method (mass transfer) is expressed as:

$$E_L = M(e_s - e_z) \times u_z$$

Where:

- E_L = Lake evaporation in mm / t.
- M = Mass transfer coefficient in mm s / (t kPa m).
- e_s = Saturation vapor pressure at the surface water temperature (kPa).
- e_z = Saturation vapor pressure of the air at level z (kPa).
- u_z = Wind speed at level z (m/s).

In practice, researchers employ the bulk aerodynamic equation:

$$E_L = \frac{1000 k_t C_E \rho_a (q_s - q_z) u_z}{\rho_w}$$

Where:

- E_L = Lake evaporation in mm / t.
- k_t = Conversion for time (k_t = 86400 for E_L in mm/d and K_t = 3600 for E_L in mm/h).
- C_E = Bulk evaporation coefficient for level z (dimensionless).
- ρ_a = density of the air kg/m^3.
- ρ_w = density of the water kg/m^3.
- q_s = Saturation specific humidity at the temperature of water surface.
- q_z =Specific humidity of the air at temperature at level z.
- u_z = Wind speed at level z (m/s).

DWR has funded a study conducted by the Desert Research Institute and Reclamation using the aerodynamic method at Folsom Reservoir. The results are included on the Reclamation Final Report ST-2012-7662-1 published in March 2016. A floating weather station (buoy) was placed on the lake which included sensors for measuring air temperature, relative humidity, wind speed, net radiation and water surface temperature.

The satellite-based model METRIC uses the aerodynamic method to estimate lake evaporation using the thermal band of Landsat data (see Section 9, "Data Resources Directory").

4.10 CHANGE IN SURFACE WATER STORAGE

Definition: Net change in the volume of water stored within the surface water system, which includes lakes and reservoirs, streams, and conveyance facilities.

Context: The term "lake" for the purposes of this handbook include natural lakes and man-made reservoirs. Storage in a lake fluctuates throughout the year with changing inflows and outflows. In the water budget schematic, lake inflows include precipitation and inflows from streams and groundwater aquifers. Lake outflows include evaporation and outflows to streams and groundwater aquifers. Lake levels are commonly reported as either stage or elevation. “Stage” refers to the depth of water in the lake at the location of the measurement, and lake surface elevation is the elevation (typically relative to mean sea level) of the water surface. Changes in the volume of water within streams may be important components in daily or monthly water budgets but are typically negligible in annual water budgets. For simplicity, the change in surface water storage focuses primarily on lakes.

Change in lake storage can be estimated from a simple mass balance of measured or estimated inflows and outflows or be computed directly from lake level measurements in combination with an elevation-storage curve. A simple mass balance would calculate change in lake storage as:

$$\text{Change in Lake Storage} = \text{Inflow to Lake} - \text{Outflow from Lake}$$

When actual change in lake storage is estimated from measured parameters, the resulting estimate should be used to evaluate the mass balance error, which reflects how well the inflow, outflow, and change in storage components can be estimated. Large mass balance errors may indicate the need to re-evaluate the inflow and outflow components along with methods to estimate change in lake storage directly. The mass balance error is calculated as:

$$\text{Mass Balance Error (Lake)} = \text{Inflow to Lake} - \text{Outflow from Lake} - \text{Change in Lake Storage (measured)}$$

A mass balance error for the entire surface water system is often difficult to determine where the amount of water stored in stream channels and conveyance facilities is significant. If stream and conveyance storage are directly estimated from parameters such as channel shape and water levels, then the mass balance error could be estimated as:

$$\text{Mass Balance Error (Surface Water System)} = \text{Inflow to Surface Water System} - \text{Outflow from Surface Water System} - \text{Change in Lake Storage} - \text{Change in Stream/Conveyance Storage}$$

The mass balance error for the entire surface water system indicates how well the inflow, outflow, and change in storage components are estimated. Large mass balance errors may indicate the need to re-evaluate the inflow and outflow components along with methods to estimate change in lake and stream/conveyance storage directly.

Related Water Budget Components: Precipitation, Lake Evaporation, Stream-Lake Interaction, Lake-Groundwater Interaction (Groundwater Loss to Lake, Groundwater Gain from Lake)

How to Determine Change in Lake Storage:

- Method 1 — Obtain available technical reports and studies.
- Method 2 — Use measured lake level data.
- Method 3 — Estimate using a mass balance approach.
- Method 4 — Use information from available spreadsheets and numerical models.

Method 1 — Obtain Available Technical Reports and Studies

Lake storage is commonly available from online databases, published reports, numerical models, or lake operators. Operators of lake facilities often measure outflow and water elevations (levels) and estimate lake evaporation and seepage to determine inflow through a mass balance approach. Many lakes are regularly monitored by or report data to the USGS. In addition, DWR publishes lake operations on CDEC for California. There are other federal, State, and local agencies who maintain and publish lake storage. These data are available for different time periods and at different temporal scales (15 minute, hourly, daily, and monthly). Data from multiple sources may be needed to develop a complete data set. In addition to the online databases, there are published reports where lake storage data can be obtained.

If there is a numerical hydrologic model covering the water budget zone, measured or estimated lake inflow and outflow data may be available in the model input/output files. If data from an existing numerical model are used, then the following should be validated:

- There is documentation of both the source data and the basis of the included lake inflow and outflow data, if any.
- The numerical model is calibrated and accepted by stakeholders.

Key sources of lake inflow and outflow data in California are:

- USGS Surface-Water Data for the Nation.
- DWR CDEC: Current River Conditions.
- Local agency records, including flood control districts or entities managing reservoirs.
- Previous reports.
- Input/output files of numerical models.
- USGS Water-Resources Investigations Reports.
- USGS Scientific Investigations Report.
- California Nevada River Forecast Center.

Method 2 — Use Measured Lake Level Data

Using measured lake level data to estimate change in lake storage is a matter of obtaining lake level data and the reservoir “area-capacity-curve,” which plots lake levels (or elevations) and corresponding surface area measurements and storage volumes. Change in storage over time can be estimated as follows:

$$\text{Change in Lake Storage} = \text{Storage (timestep 2)} - \text{Storage (timestep 1)}$$

Where storage is determined from area-capacity curve for the lake level at each selected timestep.

The lead agency responsible for operation of a lake or reservoir is the best source for data. Some sources of lake data include:

- DWR CDEC.
- USGS National Water Information System.
- Reclamation Water Operations.
- USACE Sacramento District’s Water Control Data System.
- Local agencies.

Method 3 — Estimate Using a Mass Balance Approach

In the mass balance approach, inflows (from streams and aquifer, and precipitation) and outflows (to streams and aquifer, and evaporation) need to be estimated. The difference between inflows and outflows for the lake is the change in lake storage, expressed as:

$$\text{Change in Lake Storage} = \text{Inflows to Lake} - \text{Outflows from Lake}$$

Where:

$$\text{Inflows to Lake} = \text{Inflows from Streams} + \text{Groundwater Losses to Lake} + \text{Precipitation} + \text{Imported Water Delivery to Lake}$$

$$\text{Outflows from Lake} = \text{Outflows to Streams (Lake Releases or Spills)} + \text{Groundwater Gains from Lake} + \text{Lake Evaporation} + \text{Diversions/Withdrawal from Lake}$$

Inflow from streams are typically measured and Section 4.2, “Stream Inflow and Outflow,” describes methods for obtaining or estimating stream inflow data. If there are no measured inflow data, the runoff from the upstream watershed can be estimated using methods described in of Section 3.10, “Runoff.” Section 5.5, “Lake-Groundwater Interaction,” describes methods for estimating groundwater gains from and losses to lake. Section 3.3, “Precipitation,” describes methods to obtain precipitation data. Imported water delivery to a lake is always measured and so are lake releases (outflow to streams) and diversions/withdrawals from the lake.

Method 4 — Use Information from Available Spreadsheets and Numerical Models

Numerical hydrologic models developed for various basins in California may have change in lake storage estimates. These models, whether spreadsheet or numerical models, may be convenient sources for estimates of change in lake storage for the water budget zone of interest. Sources of information include:

- DWR CDEC.
- DWR CALSIM 2 and CALSIM 3.
- USGS California Water Science Center: Central Valley Hydrologic Model.
- C2VSim.
- Local models by local agencies.

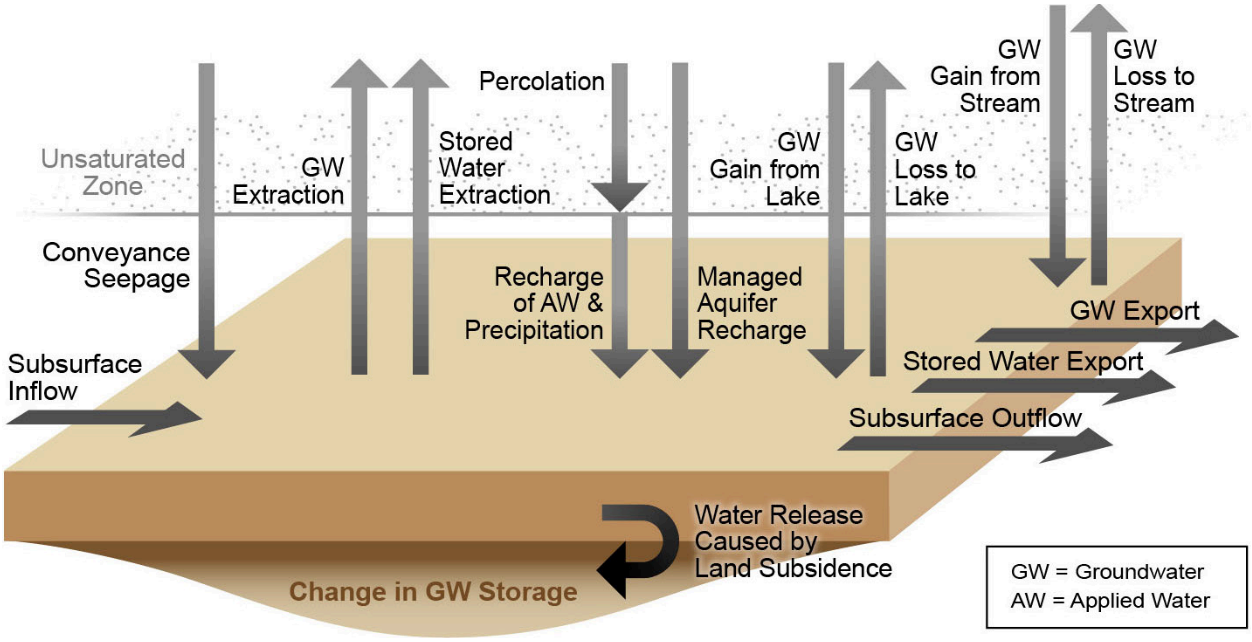
5. GROUNDWATER SYSTEM

5.1 INTRODUCTION

The total water budget captures the entire hydrologic cycle of water flow, and the groundwater system is an integral part of it. The components of groundwater system water budget are shown in Figure 5-1, which is a subset of Figure 1-1. The color coding of Figure 1-1 was not carried over to Figure 5-1 to avoid confusion as the designation of inflows and outflows are different in a single system compared to the total water budget. The definition of the groundwater system and groundwater system water budget is presented in Section 1.3. The definitions of the associated components are provided in Table 1-1.

The purpose of this section is to describe how to develop reasonable estimates for these inflow and outflow components if there is no existing model to estimate these components for the water budget zone of interest. The methods described in this section can also be used in case an available model only provides information for a partial set of groundwater system water budget components. If a model is available that provides information for all components of the groundwater system, the user should refer to Section 2.8, "Modeling Approach."

Figure 5-1 **Components of Groundwater System and Its Interaction with Other Systems**



Descriptions of inflow and outflow components in the groundwater system along with methods to estimate each component are provided in the following subsections. The outflow from shallow groundwater through capillary rise to meet part of the crop ET demand is not shown in Figure 5-1 nor is described in this section. There are no simple methods to estimate the contribution from shallow groundwater because it is highly sensitive to the depth to water table. If local knowledge exists pertaining to the quantification of the shallow groundwater uptake, it can be accounted for in the water budget for groundwater systems. But caution should be taken in this regard because although the ET from shallow groundwater will result in a reduction in groundwater pumping from the aquifer, the net outflow from the groundwater system will only see a small change. The only difference is that ET of shallow groundwater is not part of total applied water, and hence, there is no return flow associated with that amount. Similarly, recharge of urban indoor use through septic tank and percolation ponds of wastewater treatment plants is not shown in Figure 5-1 nor is it described in this section. It is addressed in Section 3.11, "Return Flow."

Some of the components of the groundwater system that are shown in Figure 5-1 are discussed in Sections 3 and 4. Groundwater extraction for agriculture and urban applied water is described in Section 3.7, "Groundwater Extraction." Conveyance seepage is discussed in Section 4.6, "Conveyance Seepage."

5.2 RECHARGE OF APPLIED WATER AND PRECIPITATION

Definition: Volume of applied water and precipitation that travels vertically through the soil/unsaturated zones and reaches the saturated zone of the aquifer (groundwater system).

Context: Recharge (D) of applied water and precipitation refers to the amount of water entering the saturated zone of the groundwater system from the land system, originating either as applied water or precipitation on the land surface. This inflow component is commonly referred to as "deep percolation" in literature. However, in a literal sense of physical processes, deep percolation is the volume of water that travels downward through the unsaturated zone to reach the groundwater table. Hence, use of term deep percolation to indicate recharge of applied water and precipitation may create confusion regarding whether other sources of recharge to the groundwater system are included or not, such as managed aquifer recharge, conveyance seepage, groundwater gain from lake, and groundwater gain from stream. To avoid a confusion, these inflow components are identified as separate and individual components in the water budget schematic (Figure 1-1), and in Figure 5-1.

Combined recharge of applied water (D_i) and precipitation (D_p) is a significant inflow component to the groundwater system. It occurs because of the infiltration of applied water and precipitation that exceeds the water holding capacity of the rootzone and thus moves downward through the unsaturated zone to the saturated zone. On the other hand, rice growing areas and managed wetlands typically have clay soils and restrictive zones that reduce or restrict the downward movement of water where hardpan conditions or depositional features cause portions of the percolating water to move laterally downslope and re-emerge in canals and streams without percolating into the groundwater system. This shallow lateral subsurface flow is also called interflow and may become “applied water reuse” to meet demands in downgradient agricultural lands or become “return flow” to the surface water system (Figure 1-1). In other areas, tile drains capture and remove infiltrated applied water to manage shallow groundwater tables resulting from restrictive layers in the soil stratum. Any flow collected in the tile drain system is also included as part of either “applied water reuse” to augment supply or “return flow” to the surface water system. Recharge from indoor water use can take place through leach drains in rural areas or through percolation ponds of regional treatment facilities in urban areas.

Related Water Budget Components: Precipitation, Applied Water, Managed Aquifer Recharge, Conveyance Seepage, Groundwater Gain from Lake, Groundwater Gain from Stream

How to Estimate Recharge of Applied Water and Precipitation: The processes to estimate the precipitation and applied water components of recharge differ and are presented separately in the next two subsections to simplify the calculation process.

5.2.1 Recharge of Precipitation

The process to estimate the precipitation component of recharge is presented in this subsection.

How to Estimate Recharge of Precipitation:

Recharge of precipitation is not a measured quantity; it is typically estimated as a closure term of a mass balance equation.

- Method 1 — Obtain estimates from existing reports and models.
- Method 2 — Estimate using rainfall-runoff method.
- Method 3 — Estimate using a constant percentage.

Method 1 — Obtain Estimates from Existing Reports and Models

Obtain estimates of recharge of precipitation (monthly, annual) from existing study reports and integrated hydrologic models for the water budget zone of interest. Sources of information include:

- Existing reports and studies.
- Existing hydrologic and groundwater models such as CVHM, C2VSim, or local models.

Method 2 — Estimate Using Rainfall-Runoff Method

Recharge of precipitation can be estimated by solving the mass balance equation for rainfall-runoff and consumptive use of precipitation:

$$P = R + EP + D_p$$

Where:

- P = Precipitation.
- R = Runoff.
- EP = Consumptive Use of Precipitation.
- D_p = Recharge of Precipitation.

Precipitation is measured data and available from numerous sources (see Section 3.3, "Precipitation"). Runoff is usually quantified by using a rainfall-runoff model, an example of which is Runoff Curve Number method developed by the Natural Resources Conservation Service (NRCS). The Runoff Curve Number method is discussed in Section 3.10, "Runoff."

The consumptive use of precipitation, also known as effective precipitation (EP), is that portion of the precipitation that is not runoff but is stored in the root zone and contributes to meeting the ET requirements during the growing season. It can be approximated as follows:

$$\mathrm{EP} = \mathrm{Minimum}\ [(\mathrm{P} - \mathrm{R}), \mathrm{ET}]$$

Where

- ET = Evapotranspiration.

The methods for calculating crop ET requirements are discussed in Section 3.4, "Evapotranspiration." Typically, during the growing season, almost all of precipitation that is not runoff is consumptively used because crop ET requirements on a monthly basis are almost always higher than the precipitation during the months of March through September, which is the growing season for most agricultural crops in California. As a result, during the growing season, recharge of precipitation is nearly zero unless there is considerable rainfall in a month. On the other hand, during the non-growing season, there are no crop ET requirements; as a result, precipitation that is not runoff will mostly become recharge of precipitation, after contributing to soil moisture storage. In case of native vegetation areas, the native vegetation has often developed root systems such that almost all the precipitation is consumed by ET. As a result, the recharge of precipitation for native vegetation is very low.

Method 3 — Estimate Using A Constant Percentage

A simpler method with lower accuracy for quantifying recharge of precipitation is to assume that a fixed percentage of precipitation is recharged to the groundwater system. This fixed percentage could be based on previous studies or existing models for areas that are similar to the water budget zone of interest. The percentage may vary from basin to basin and is dependent on land use conditions, hydrology, and soil type. The percentage of precipitation that is recharged into groundwater varies from 5 percent to 20 percent in the Central Valley of California (Brush et al., 2013).

5.2.2 Recharge of Applied Water

The process to estimate the applied water component of recharge is presented in this subsection.

How to Estimate Recharge of Applied Water:

Recharge of applied water is not a measured quantity. It can be estimated by the following methods:

- Method 1 — Obtain estimates from existing reports and models.
- Method 2 — Estimate using agricultural applied water.
- Method 3 — Estimate using urban applied water.

Method 1 — Obtain Estimates from Existing Reports and Models

Obtain estimates of recharge of applied water (monthly, annual) from existing study reports and/or hydrologic models for the water budget zone of interest. Sources of information include:

- Existing reports and studies.
- Existing hydrologic and groundwater models such as CVHM, C2VSim, or local models.
- California Water Plan Water Portfolios.

Method 2 — Estimate Using Agricultural Applied Water

Recharge of applied water can be estimated by solving the mass balance equation for applied water (irrigation). Irrigation water is applied to meet the crop ET requirements that are not met by precipitation. Any applied water in excess of ET requirements becomes non-consumptive use that either percolates below the root zone or becomes runoff. The percolated water takes three different paths:

1. A portion of the percolated water moves laterally to drainage systems and becomes applied water reuse on irrigated lands within the water budget zone.
2. A portion of the percolated water moves laterally to a canal, drainage ditch, or a stream and becomes return flow that will flow out of the water budget zone.
3. The remainder becomes recharge of applied water.

Using the mass balance equation and calculating its component from methods presented in other sections, the recharge of applied water can be calculated as

$$\mathrm{Di} = \mathrm{AW} - (\mathrm{ET} - \mathrm{EP}) - \mathrm{R_U} - \mathrm{R_f}$$

Where:

- Di = Recharge of Applied Water.
- ET = Crop Evapotranspiration.
- EP = Consumptive Use of Precipitation.
- R_U = Applied Water Reuse.
- R_f = Return Flow.

Another option is to proportion applied water using irrigation efficiency and percentages of applied water reuse, return flow, and recharge as fractions of the non-consumptive use of applied water. This option, which is described in Method 3, Approach 2 in Section 3.5.1, "Agricultural Applied Water," is a quick approach to addressing the non-consumptive uses based on local knowledge of irrigation practices, soils, geology, and drainage within the water budget zone of interest. Using Tables 3-4 and 3-5 as a guide, irrigation efficiency (IE) as well as fractions of applied water reuse (R_{uf}), fractions of return flow (R_{ff}), and fractions of recharge of applied water (D_{if}) can identify the disposition of applied water to determine recharge. Volume of recharge of applied water (Di) can be estimated from the following equation:

$$\mathrm{Di} = \mathrm{AW} \times \mathrm{D_{if}}$$

Where:

$$\mathrm{D_{if}} = 1.0 - \mathrm{IE} - \mathrm{R_{uf}} - \mathrm{R_{ff}}\text{, as derived from } \mathrm{IE} + \mathrm{R_{uf}} + \mathrm{R_{ff}} + \mathrm{D_{if}} = 1.0$$

$$\mathrm{R_{uf}} = \mathrm{R_u} / \mathrm{AW}\text{, where } \mathrm{R_u} = \text{Applied Water Reuse}$$

$$\mathrm{R_{ff}} = \mathrm{R_f} / \mathrm{AW}\text{, where } \mathrm{R_f} = \text{Return flow}$$

Proportioning the disposition of applied water can be an iterative estimation process that should be verified in the total water budget.

Method 3 — Estimate Using Urban Applied Water

Recharge of urban applied water can include contributions from septic tanks, wastewater treatment percolation, landscape irrigation, distribution system water loss seepage, etc. Using a mass balance equation and calculating its component from methods presented in Sections 3.2.2, 3.5.2, 3.8, 3.9, and 3.11, the recharge of applied water can be calculated as

$$\text{Recharge of Applied Water} = \text{Urban Applied Water} - (\text{Landscape Evapotranspiration} - \text{Consumptive Use of Precipitation}) - \text{Applied Water Reuse} - \text{Return Flow} - \text{Recycled Water} - \text{Recycled Water Export}$$

5.3 SUBSURFACE INFLOW AND OUTFLOW

Definition: Subsurface Inflow is the "volume of water entering as groundwater into a water budget zone through its subsurface boundaries", and Subsurface Outflow is the "volume of water leaving as groundwater from a water budget zone through its subsurface boundaries."

Context: The subsurface inflow and outflow (Q_b) in the water budget framework are concepts tied to the delineation of a boundary, such as groundwater subbasin, water budget zone, or irrigation district. Groundwater flows from areas of high hydraulic head (high water-level elevation) to areas of low hydraulic head (low water-level elevation). Because hydraulic heads vary laterally and vertically in a groundwater system, groundwater movement will generally have a horizontal as well as a vertical component.

Subsurface flows through saturated zones can move significant amounts of water in or out of the water budget zone. The quantity of subsurface inflow and outflow depends on the groundwater elevations and the hydraulic conductivity of the aquifer material along the boundary of the water budget zone. In coastal groundwater basins, seawater intrusion occurs when groundwater elevations in the aquifer are lower than the sea level elevation.

Subsurface flows are never directly measured. They are calculated from measured groundwater level data or by using numerical models. Subsurface flows are computed across the boundary of a water budget zone and can be tied to one of the three types of boundary conditions:

1. Subsurface flow under no flow boundary conditions: When the aquifer is surrounded by impermeable bedrock along a boundary of the water budget zone, there will be little to no subsurface inflow or outflow along the corresponding boundary of the water budget zone. Any flow from impermeable bedrock is likely

negligible and can be ignored for the purposes of water budget calculations. Examples of no flow boundary conditions are relatively impermeable rock at mountain fronts, along the upland ridges of groundwater divides, or along the crests of the groundwater mounds under topographic highs.

2. Subsurface flow under fixed head boundary conditions: When a large stream or lake defines one or more boundaries of a water budget zone, the elevation in the stream or lake is considered constant for all practical purposes. The subsurface inflow (or outflow) is computed by using the hydraulic gradient between the boundary stream (or lake) and the groundwater aquifer.
3. *Subsurface flow under general head boundary condition:* When boundaries of the water budget zone are not natural boundaries (e.g., impermeable rock or stream) but rather political or jurisdictional boundaries dividing a continuous aquifer, this becomes the most complex case of determining subsurface inflow and outflow. Adjoining water budget zones may have to divide a continuous aquifer for their respective water budget calculations; in such cases, the subsurface flows are computed based on groundwater elevation differences across the boundary of the water budget zone. General head boundary condition should be used with due diligence; because of complexity, it is prone to misapplication and errors.

Related Water Budget Components: Change in Groundwater Storage

How to compile subsurface flow inflow and outflow:

- Method 1 — Obtain available technical reports and studies.
- Method 2 — Obtain available spreadsheets and numerical models.
- Method 3 — Calculate estimates of subsurface flow using Darcy’s law.

Method 1 — Obtain Available Technical Reports and Studies

USGS and other agencies publish historical investigation reports on hydrogeology of many regions in the U.S. Such reports may provide a quantitative description of subsurface flow conditions along the boundary of groundwater basins and subbasins in California. Key sources of information include:

- Local agency records, including flood control districts or entities managing water resources.
- USGS Water-Resources Investigations Reports.
- USGS Scientific Investigations Report.

Method 2 — Obtain Available Spreadsheets and Numerical Models

Various numerical hydrologic models developed for various regions of California may contain information regarding estimated subsurface flows across boundaries. These models, whether a spreadsheet or numerical model, may be useful in determining subsurface inflows and outflows to and from the water budget zone of interest. Spreadsheet models are more often used in local studies where a numerical model does not exist. The availability of spreadsheet models varies locally. Sources of information include:

- Local agency studies and reports.
- USGS Groundwater Data.
- USGS California Water Science Center — Groundwater Modeling.
- USGS California Water Science Center — Central Valley Hydrologic Model.
- C2VSim.

Method 3 — Calculate Estimates of Subsurface Flow Using Darcy's Law

Subsurface flows between two water budget zones depend on the groundwater level gradient between boundary of the two zones. Darcy's law and groundwater elevation gradient data across the boundary can quantify the subsurface inflows (and outflows) from adjacent groundwater basins using the following equation and referencing Figure 5-2 that illustrates the hydrogeologic cross section:

$$Q_b = K \times A_b \times i$$

$$Q_b = K \times b \times w \times i$$

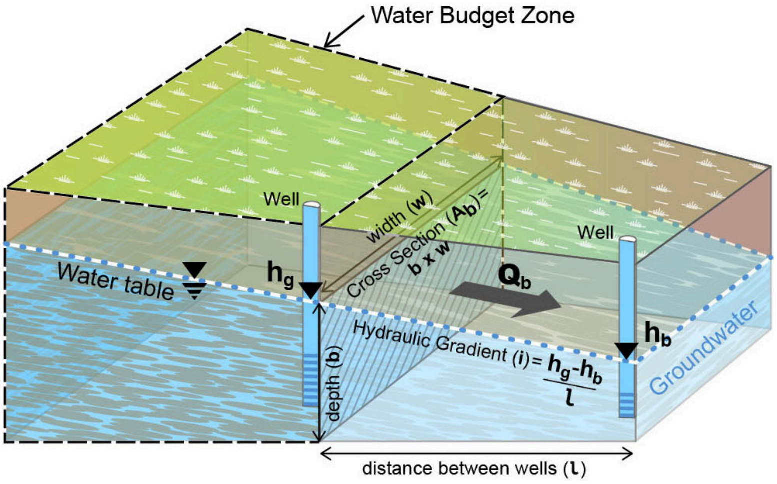
$$Q_b = T \times w \times i$$

Where:

- Q_b = Subsurface flow across the boundary.
- K = Hydraulic conductivity of the aquifer at the boundary.
- A_b = Cross-sectional area subject to boundary flow.
- i = Hydraulic gradient through the cross section = $(h_g - h_b) / l$.
- h_g = Known groundwater elevation inside the boundary of water budget zone.
- h_b = Known groundwater elevation outside the boundary of water budget zone.
- b = Depth of cross section.
- w = Width of cross section.
- l = Distance between two points with known head, h_g and h_b.
- T = Transmissivity of the aquifer at the boundary = $K \times b$.

If h_b is greater than h_g, then Q_b will be subsurface inflow into the water budget zone; if h_b is lower than h_g, then Q_b will be subsurface outflow from the water budget zone.

Figure 5-2 An Illustrative Hydrogeologic Cross Section for Calculating Subsurface Flow



The process for calculating subsurface inflow and outflow consists of the following steps:

1. Collect groundwater level data from available sources that spatially represent the boundaries of the water budget zone. The

groundwater level data can be averaged for the temporal scale of interest. It is important to select wells that represent the flow direction as horizontal or vertical and not a combination of both. Well construction information can be used to verify the groundwater levels are from similar perforations. Sources include:

   A. Local agencies, including counties, cities, water purveyors.
   B. DWR Water Data Library.
   C. DWR CASGEM.
   D. DWR Groundwater Level Monitoring.
   E. USGS Groundwater Data for the Nation.
   F. USGS CVHM Digital Data Sets.
   G. CV2Sim.

2. Estimate aquifer thickness at the boundaries of the water budget zone using available well construction data and geologic information. The depths of impermeable clay layers or bedrock, for example, can be used to establish the base for the aquifer.
3. Divide the boundary interface into smaller sections for a more accurate analysis if groundwater elevation data are available to define its variability along the boundary. The boundary should run parallel to the contours, otherwise flow cannot be calculated.
4. Calculate the cross-sectional areas using the length and depth of the sections.
5. Estimate aquifer hydraulic conductivity at the boundaries of the water budget zone using information on soil and aquifer properties along with well construction data or aquifer test data. Use regional groundwater models such as C2VSim and CVHM or available local groundwater models as a source to obtain applicable information.
6. Estimate aquifer hydraulic gradient (the term $(h_g-h_b) / l$) using hydrogeology reports or groundwater contour maps that are available for the water budget zone. Groundwater elevation contour maps provide a means by which groundwater movement can be assessed. These maps can be developed from water-level measurements from multiple wells. Contour maps of the

groundwater elevations are constructed to determine the horizontal direction of flow. The vertical component of flow can be determined by comparing groundwater elevations in nearby wells completed at different depths in the same aquifer or in different aquifers. The horizontal direction of ground-water flow is generally perpendicular to the contour lines, and water flows down the slope of the contours in a manner analogous to the flow of water down the slope of the land surface. DWR publishes seasonal contour maps for California. The contours are available as part of the SGMA data viewer.

7. Calculate subsurface inflow by applying the Darcy's law for each boundary section. Sum up subsurface inflows (or outflows) of all sections to obtain total subsurface inflow (or outflow) along the boundary of the water budget zone.

Example: Referring to the illustrative hydrogeologic cross-section shown in Figure 5-2, subsurface outflow beneath the right boundary of a water budget zone can be estimated directly from the Darcy's law. Transmissivity of the hydrogeologic section was estimated to be 1,500 ft^2/d from two pumping tests, and the approximate width of the unconsolidated sediments was 4,000 feet. Hydraulic gradient through the cross-section was about 0.004 ft/ft, and the estimated subsurface outflow for that cross-section is estimated as:

$$Q_b = T \times w \times i$$

$$Q_b = 1{,}500 \times 4{,}000 \times 0.004 = 24{,}000\,\frac{ft^3}{day} = 201 \text{ acre-ft/yr}$$

5.4 STREAM-GROUNDWATER INTERACTION

Definition: Groundwater gain from streams is defined as the volume of water entering the groundwater system (gain) from rivers and streams. Conversely, groundwater loss to streams is defined as the volume of water entering rivers and streams from the groundwater system. Both the gain and loss components of the stream-groundwater interaction, $Q_{GW(gain/loss)}$, are covered in this section.

Context: Streams play an important role in the total water budget. During periods when groundwater elevations are lower than the stream stage, the stream may contribute water to the groundwater system and during periods when groundwater elevations are higher than the stream stage, the stream will drain water away from the groundwater system. The rate of water exchange between stream and the aquifer is a function of the hydraulic gradient and the streambed permeability, a relatively uncertain parameter. If the stream is overlain on a low permeability layer such as peat, it may be hydraulically disconnected from the aquifer even though groundwater levels may be high.

If the stream stage is lower than the surrounding groundwater levels, the groundwater system will lose water to the stream proportional to the hydraulic gradient between the stream stage and the surrounding groundwater levels.

If the stream stage is higher than the surrounding groundwater levels, the groundwater system will gain water from the stream. Two situations may arise:

1. When the surrounding groundwater levels are higher than the bottom elevation of streambed sediments, the groundwater gain from stream is proportional to difference between stream stage and the surrounding groundwater elevation.
2. When the surrounding groundwater levels are lower than the bottom elevation of streambed sediments, the groundwater gain is proportional to difference between stream stage and bottom elevation of streambed sediments. In this second situation, the stream is not hydraulically connected to the groundwater system, and the net groundwater gain from stream is independent of the surrounding groundwater levels as the stream and aquifer are not directly in contact. It should be noted that the exact condition when a stream is disconnected from the groundwater system is still a research topic. Streams can be losing or gaining at different locations depending on the corresponding hydraulic gradient between the stream and the surrounding groundwater levels at those locations. In addition, streams can be losing or gaining at different times of the same year or different years over a time period. The definition of disconnected stream provided in this paragraph is a widely accepted method and used by many integrated numerical groundwater and surface water models,

such as MODFLOW-OWHM, USGS's FEMFLOW3D, and the Integrated Groundwater Surface water Model (IGSM); the IWFM model also includes a user option to use this definition.

Related Water Budget Components: Change in Groundwater Storage

How to determine groundwater gain from streams and losses to streams:

- Method 1 — Use available studies and numerical models.
- Method 2 — Use a mass balance approach.
- Method 3 — Calculate using Darcy's law.
- Method 4 — Calculate using flow net analysis.
- Method 5 — Use constant seepage percentage method for a losing stream.
- Method 6 — Baseflow separation techniques.

Method 1 — Use Available Studies and Numerical Models

Agencies such as USGS or DWR may have done historical studies to delineate a water budget or hydrogeologic conditions for the water budget zone of interest. Also, regional integrated, numerical models such as CVHM, C2VSim, SVSim, etc., could be reliable sources of stream gain or loss information. Sources of information include:

- USGS Water Budgets for Major Streams in the Central Valley (1985).
- Groundwater Availability of the Central Valley Aquifer (2009).
- USGS CVHM Database.
- C2VSim.

Method 2 — Use A Mass Balance Approach

Use the mass balance approach to calculate groundwater gains (or losses) for each stream reach using the following steps:

1. **Delineate Stream Reaches:** Divide the streams in the water budget zone into several smaller reaches. Use stream characteristics and available data as criteria for delineation of stream reaches.

2. **Identify Locations of Inflow and Outflow Components for Each Stream Reach:** Identify upstream and downstream gauges, tributary inflow, diversion points, runoff inflow, and return flow locations (Figure 5-3).
3. **Estimate Stream Inflows:** Estimate stream inflows at the upstream gauge and from tributary streams. Upstream inflow stream data may be obtained from local agencies and water purveyors, or estimated using methods describes in Section 4.2, "Stream Inflow and Outflow." The Runoff Curve Number Method described in Section 3.10, "Runoff," can be used to estimate direct runoff quantities from ungauged watersheds of tributaries of the stream reach outside of the water budget zone.
4. **Estimate Diversions:** Estimate all diversions and inflows for each stream reach. Diversion data may be obtained from local agencies and water purveyors as specified in Section 4.3, "Surface Water Diversion."
5. **Estimate Runoff and Return Flows:** Use methods in Section 3.10, "Runoff;" and Section 3.11, "Return Flow;" to estimate runoff and return flow, respectively, into each stream reach within the water budget zone.
6. **Estimate Stream Evaporation:** Use methods in Section 4.4, "Stream Evaporation," to estimate stream evaporation from each stream reach.
7. **Calculate Groundwater Inflow from Each Stream Reach:** Use the following mass balance equation to calculate groundwater gain (or loss) from each stream reach. To quantify the total stream-groundwater interaction, sum groundwater gains (inflow) or losses (outflow) for all stream reaches within the water budget zone.

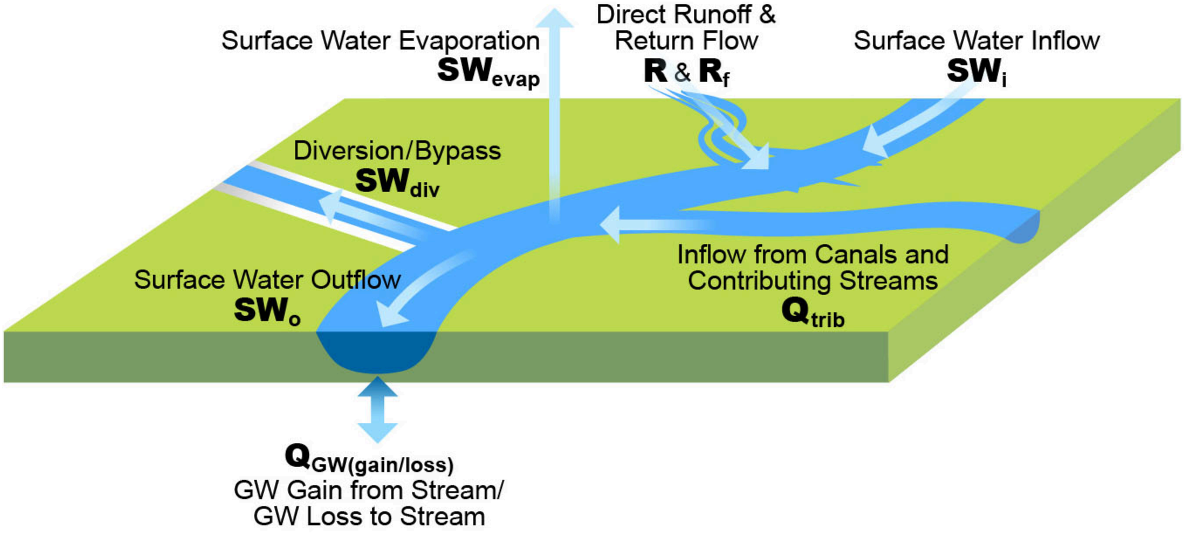
$$Q_{GW(gain/loss)} = (SW_i + Q_{trib} + R + R_f - SW_{div} - SW_{evap}) - SW_o$$

Where:

- $Q_{GW(gain/loss)}$ = Groundwater gain (or loss) from streams.
- SW_i = Streamflow at the upstream gauge.
- Q_{trib} = Inflow from contributing or tributary streams.

- R = Direct runoff from precipitation to a stream reach.
- R_f = Return flow from applied water (agriculture, urban, managed wetlands, operational spills).
- SW_{div} = Surface water diversion.
- SW_{evap} = Stream evaporation.
- SW_o = Streamflow at the downstream gauge.

Figure 5-3 Flow Components in a Stream Reach



$$Q_{GW(gain/loss)} = (SW_i + Q_{trib} + R + R_f - SW_{div} - SW_{evap}) - SW_o$$

A positive value indicates "Groundwater Gain from Stream"; a negative value indicates "Groundwater Loss to Stream".

Method 3 — Estimate Using Darcy's Law

Darcy's law can be used to estimate the net groundwater gain (or loss) for streams. Darcy's law uses soil properties and vertical gradients to calculate the flow of fluid through a porous medium. Depending on the groundwater elevations in the surrounding aquifer, the stream can be gaining, or losing, or percolating. A percolating stream is a type of losing stream where the surrounding groundwater elevations are lower than the bottom elevation of the streambed materials.

Groundwater Loss to Stream: When the surrounding groundwater elevations are higher than the water stage in a stream, the stream acts as a discharge zone for the local groundwater system. Using Darcy's law, the net groundwater loss ($Q_{GW(loss)}$) through the bottom and wetted perimeter of the stream can be calculated as:

If $H_{aquifer} > H_{stream} > H_{streambed\ bottom}$ then,

$$Q_{GW(loss)} = (K_s \times A_{wps}) \frac{(H_{aquifer} - H_{stream})}{B_{stream}}$$

Where:

- H_{stream}, $H_{aquifer}$ and $H_{streambed\ bottom}$ are the water stage in the stream, groundwater level in the surrounding aquifer, and the bottom elevation of the streambed sediments, respectively.
- B_{stream} is the average thickness of the streambed.
- K_s is the hydraulic conductivity of the streambed material.
- A_{wps} is the effective area of flow exchange, which is the product of the stream segment's length and wetted perimeter.
- The difference between $H_{aquifer}$ and H_{stream} is the vertical gradient used to determine the flow in Darcy's law for a connected stream.

Groundwater Gain from Stream: When the surrounding groundwater elevation are lower than the water stage in the stream but above the bottom elevation of streambed sediments, the stream is hydraulically connected to the groundwater system and acts as a source of groundwater recharge. Using Darcy's law, the net groundwater gain through the bottom and wetted perimeter of the stream can be calculated as:

If $H_{stream} > H_{aquifer} > H_{streambed\ bottom}$ then

$$Q_{GW(gain)} = (K_s \times A_{wps})(H_{stream} - H_{aquifer}) / B_{stream}$$

Groundwater Gain through Percolation from a Stream: When the surrounding groundwater levels are lower than the bottom elevation of streambed sediments, then the stream is not hydraulically connected to the groundwater system. In these cases, the vertical gradient used in Darcy's law is the difference between H_{stream} and $H_{streambed\ bottom}$. The net groundwater gain through the bottom of the stream is independent of groundwater level and can be calculated as:

If $H_{stream} > H_{streambed\ bottom} > H_{aquifer}$ then,

$$Q_{GW(gain)} = (K_s \times A_{wps})(H_{stream} - H_{streambed\ bottom})/B_{stream}$$

Compiling Relevant Data for the Use of Darcy's Law: Information on streambed conductivity, K_s, can be obtained from available reports and studies. The stream stage information can be obtained from USGS, CDEC, and DWR Water Data Library (see Section 9, "Data Resources Directory," for specific sources). The streambed bottom (or channel invert) elevation can be obtained from bathymetric surveys. If bathymetric surveys are not available, USGS quad maps and digital elevation models or existing numerical models can also be used as a source of information. One caution in using USGS quad maps for estimating streambed bottom elevation: Using the streambed bottom elevation from USGS quad maps may not be adequate to capture the hydraulic radius. In many cases, the methods and resolution of the data yield a value representative of the water surface elevation and not necessarily the channel bottom. Monitoring wells or contour maps can be used to determine the groundwater levels in the surrounding aquifer.

Method 4 — Calculate Using Flow Net Analysis

The flow net analysis is a graphical method for solving groundwater flow using the Darcy's law as presented by Cedergren (1997) and USGS (2008). The method involves drawing equipotential lines (lines of equal hydraulic head) based on hydraulic head in the wells and flow lines (also called streamlines) based on stage in the surface-water body. The flow lines are drawn perpendicular to both the no-flow boundaries and to the equipotential lines, which assume the porous medium is homogeneous and isotropic. The number of flow lines to be drawn should result in rectilinear shapes that approximate squares. The areas between the flow lines are called streamtubes, and the intervals between equipotential lines are termed "head drops." After constructing the flow net, Darcy's law is used to approximate flow to or from the surface-water body:

$$Q = M \times K \times b \times H/n$$

Where:

- Q = Flow through a vertical plane that extends beneath the shoreline of a surface water body.

- *M* = Number of streamtubes across a flow net.
- *K* = Horizontal hydraulic conductivity of the aquifer at the boundary.
- *b* = Effective thickness of the aquifer.
- *H* = Total head drop across the area of interest.
- *n* = Number of equipotential head drops over the area of interest.

Method 5 — Use Constant Seepage Percentage Method for a Losing Stream

A simpler method with lower accuracy for quantifying the gains to the groundwater system from a stream is to assume that a fixed percentage of total streamflow volume flows to the groundwater system as seepage over the length of the stream (or a stream reach). The same assumption can be made for canals to estimate the conveyance facility seepage to the groundwater system in a water budget zone.

Method 6 — Baseflow Separation Techniques

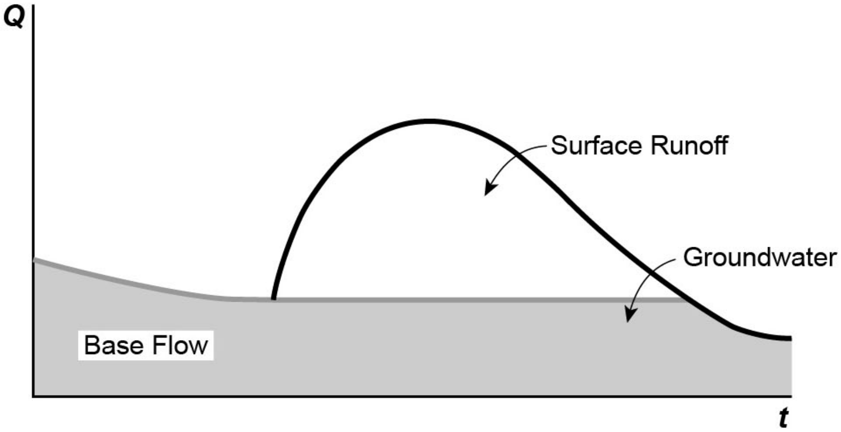
Streamflow is fed by both surface runoff and subsurface flow from aquifers. The streamflow resulting from groundwater outflow is called baseflow. Similar to the mass balance approach discussed earlier, a separate but related approach is to use stream gaging stations immediately upstream and downstream of a water budget zone and perform a hydrograph analysis to determine the baseflow from the hydrograph. This allows the computation of groundwater contributions, even during stormwater events.

There are numerous methods for baseflow separation. The USGS maintains the HYSEP: Hydrograph Separation Program software to calculate baseflow using streamflow timeseries data.

Purdue University maintains a similar program, the WHAT: Web-based Hydrograph Analysis Tool, that utilizes USGS daily streamflow data to do a similar hydrograph analysis.

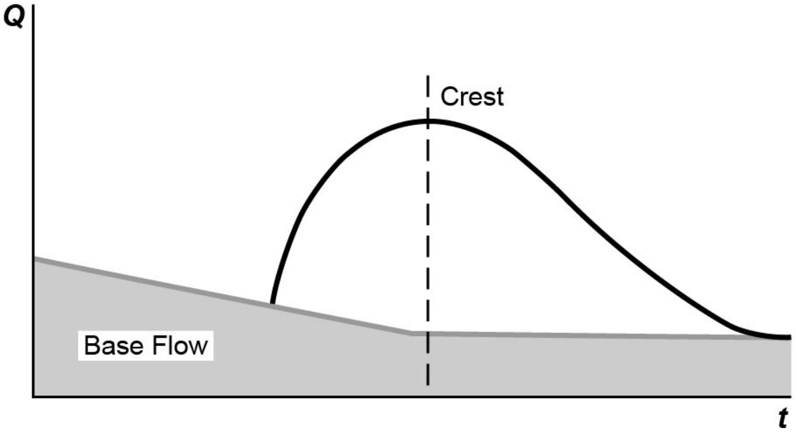
Empirical methods for baseflow separation can also be used to separate out the portion of streamflow originating from groundwater. In the straightline method, shown in Figure 5-4, a horizontal line is drawn from the start of the rising limb to the falling limb. All of the flow under the horizontal line is considered baseflow.

Figure 5-4 **Applying the Straightline Method**



In the fixed base method, shown in Figure 5-5, the baseflow existing before the storm is projected graphically down to a point directly under the peak of the hydrograph. Then a straight line is used to connect the projection to the falling limb. The duration of the recession limb is determined by inspection.

Figure 5-5 **Applying the Fixed Base Method**



Both the straightline method and the fixed base method are based on streamflow hydrographs developed from measured streamflow data. The smaller the time unit, the more accurate the analysis will be.

5.5 LAKE-GROUNDWATER INTERACTION

Definition: Groundwater gain from lakes is defined as the volume of water entering the groundwater system from lakes and reservoirs. Similarly, groundwater loss to lakes is defined as the volume of water entering lakes and reservoirs from the groundwater system. Both the gain and loss components of the lake-groundwater interaction ($Q_{L(gain/loss)}$) are covered in this section.

Context: The interaction of lakes, natural wetlands, and ponds with groundwater can be calculated as a simplified one-dimensional Darcian flow, but in reality, it is spatially and temporally variable. In this section, lakes, reservoirs, ponds, wetlands, and other surface water bodies are referred to as lakes. Lakes interact with groundwater in three basic ways: (1) some receive groundwater inflow throughout their entire bed (discharge lakes); (2) some have seepage loss to groundwater throughout their entire bed (recharge lakes); but perhaps most commonly (3) lakes receive groundwater inflow through part of their bed and have seepage loss to groundwater through other parts (flow-through lakes).

If the average water levels in the lake are lower than the surrounding groundwater levels, the groundwater system loses water to the lake in proportion to the hydraulic gradient. Such conditions may result from excessive surface water export or diversion from the lake, from high lake evaporation rates in warm or windy weather conditions, or normal reservoir management during periods of below average precipitation.

If the average water levels in the lake are higher than the surrounding groundwater levels, the groundwater system gains water from the lake. Two situations may arise:

1. When the surrounding groundwater levels are higher than the bottom elevation of lakebed sediments, the groundwater gain from lake is proportional to difference between water level in the lake and the surrounding groundwater level.
2. When the surrounding groundwater levels are lower than the bottom elevation of lakebed sediments, the groundwater gain is proportional to difference between water level in the lake and bottom elevation of lakebed sediments. Under this situation, the net gain is independent of the surrounding groundwater levels as the lake and aquifer are not directly connected.

Although the interaction of aquifers with lakes is very similar to that with streams, there are a few key differences. The water level of natural lakes, that is, those not controlled by dams, generally does not change as rapidly as the water level of streams; therefore, bank storage is of lesser importance in lakes than it is in streams. Evaporation generally has a greater effect on lake levels than on stream levels because the surface area of lakes is generally larger and less shaded than many reaches of streams and because lake water is not replenished as readily as a reach of a stream. Lakes can be present in many different parts of the landscape and can have complex groundwater flow systems associated with them. This is especially true for lakes in glacial and dune terrain. Furthermore, lake sediments commonly have greater volumes of organic deposits than streams. These poorly permeable organic deposits can affect the distribution of seepage and biogeochemical exchanges of water and solutes more in lakes than in streams.

Related Water Budget Components: Precipitation, Lake Evaporation, Stream-Lake Interaction, Change in Surface Water Storage

How to determine lake-groundwater interaction:

- Method 1 — Obtain from available hydrogeologic reports and numerical models.
- Method 2 — Estimate using Darcy’s law.
- Method 3 — Calculate using flow net analysis.
- Method 4 — Calculate using a mass balance.

Method 1 - Obtain from Available Hydrogeologic Reports and Numerical Models

Collect previous reports and models that include the water budget zone of interest.

- Technical reports/studies published by federal, State, and local agencies.
- Spreadsheet and numerical models published by federal, State, and local agencies that include the water budget zone of interest (lakes are usually presented as a river or reservoir boundary or as a specified or constant head boundary in numerical models).

Method 2 - Estimate Using Darcy’s Law

Darcy’s law is used to calculate the net groundwater gain from lakes or groundwater loss to lakes. Depending on the groundwater levels in the surrounding aquifer, lake conditions can be gaining, losing, or percolating. A percolating lake is a type of losing lake where the surrounding groundwater elevations are lower than the bottom elevation of the lakebed materials.

Groundwater Loss to Lake: When the surrounding groundwater elevations are higher than the water stage in a lake, the lake acts as a discharge zone for the local groundwater system. Using Darcy's law, the net groundwater loss ($Q_{L(loss)}$) through the lake bottom and wetted perimeter of the lake can be calculated as:

If $H_{aquifer} > H_{lake} > H_{lakebed\ bottom}$, then,

$$Q_{L(loss)} = (K_h \times A_{wpl} + K_v \times A_l)\frac{(H_{aquifer} - H_{lake})}{L}$$

Where:

- H_{lake} = Water level in the lake.
- $H_{aquifer}$ = Groundwater elevation in the surrounding aquifer.
- $H_{lakebed\ bottom}$ = Bottom elevation of the lakebed sediments.
- L = Distance between points where H_{lake} and $H_{aquifer}$ are measured.
- K_h = Horizontal conductivity of the surrounding aquifer.
- K_v = Vertical hydraulic conductivity of the surrounding aquifer.
- A_l = Surface area of the lake.
- A_{wpl} = Wetted perimeter of lake multiplied by the average saturated thickness of aquifer around the lake.

Despite the high level of uncertainty associated with this simple equation, it is widely used.

Groundwater Gain from Lake: When the surrounding groundwater elevations are lower than the water stage in the lake but above the bottom elevation of lakebed sediments, the lake is hydraulically connected to the groundwater system and acts as a recharge source. Using Darcy's law, the net groundwater gain ($Q_{L(gain)}$) through the lake bottom and wetted perimeter of the lake can be calculated as:

If $H_{lake} > H_{aquifer} > H_{lakebed\ bottom}$, then,

$$Q_{L(gain)} = (K_h \times A_{wpl} + K_v \times A_l)\frac{(H_{lake} - H_{aquifer})}{L}$$

Groundwater Gain through Percolation from a Lake: When the surrounding groundwater elevations are lower than the bottom elevation of lakebed sediments, then the lake is not hydraulically connected to the groundwater system. The net groundwater gain ($Q_{L(gain)}$) through the bottom of the lake is independent of groundwater level and can be calculated as:

If $H_{lake} > H_{lakebed\ bottom} > H_{aquifer}$ then,

$$Q_{L(gain)} = (K_v \times A_l)\frac{(H_{lake} - H_{lakebed\ bottom})}{B_{lake}}$$

Where:

- B_{lake} = Average thickness of the lakebed sediments.

Estimating the Hydraulic Gradient: If there are any hydrogeology reports or groundwater contour maps available for the water budget zone, the hydraulic gradient, the term $(H_{lake} - H_{aquifer}) / L$, can be estimated from contour maps. Groundwater elevation contour maps of aquifers provide a means by which groundwater movement can be assessed. These maps can be constructed from water-level measurements obtained from multiple wells. Alternatively, maps can be based on water levels generated by groundwater flow models. In general, groundwater moves downgradient, from areas of higher elevation to areas of lower elevation.

Example: Lake-groundwater interaction — A wet mine is developed from extracting sand and gravel, thus creating an approximately 1-acre lake (400 feet by 120 feet). There is no precipitation and the lake stage and groundwater levels in the sandy-gravely aquifer are expected to be the same. But, surface water diversions of about 3,250 ft^3/day from the lake and evaporation from the lake induce a water level difference between the lake and surrounding groundwater table. A hydraulic conductivity of 100 ft/day is estimated from aquifer testing in the medium-coarse sand aquifer. The average slope of the water table from the wells toward the lake is 0.0008 ft/ft, computed by dividing the difference between water levels in a nearby monitoring well and the lake by the distance of the monitoring well from the lake. The estimated rate of gradual water loss from the aquifer to the lake is calculated as:

$$Q_{L(loss)} = 100 \times (400 \times 120) \times (0.0008) = 3{,}840 \frac{ft^3}{d}$$

The extra 590 ft^3/day is likely the result of lake evaporation.

Method 3 — Calculate Using Flow Net Analysis

The flow net analysis is a graphical method for solving groundwater flow using the Darcy's law as presented by Cedergren (1997) and USGS (2008). The method involves drawing equipotential lines (lines of equal hydraulic head) based on hydraulic head in the wells and flow lines (also called streamlines) based on stage in the surface-water body. The flow lines are drawn perpendicular to both the no-flow boundaries and to the equipotential lines, which assume the porous medium is homogeneous and isotropic. The number of flow lines to be drawn should result in rectilinear shapes that approximate squares. The areas between the flow lines are called streamtubes, and the intervals between equipotential lines are termed "head drops." After constructing the flow net, the Darcy's law is used to approximate flow to or from the surface-water body:

$$Q = M \times K \times b \times H/n$$

Where:

- Q = Flow through a vertical plane that extends beneath the shoreline of a surface water body.
- M = Number of streamtubes across a flow net.
- K = Horizonal hydraulic conductivity of the aquifer at the boundary.
- b = Effective thickness of the aquifer.
- H = Total head drop across the area of interest.
- n = Number of equipotential head drops over the area of interest.

Method 4 — Calculate Using a Mass Balance

In the mass balance approach (see also Section 4.8 "Stream-Lake Interaction"), streamflow and change in total lake storage must be measured or obtained from available sources. This method is appropriate for managed reservoirs or lakes having gauged inflow or outflow data but is not feasible for lakes where inflow and outflow data cannot be obtained. Calculate a mass balance of the lake as follows:

$$\text{Groundwater Gain from / Loss to Lake} = \text{Inflow to Lake from streams} - \text{Outflow from Lake to streams} - \text{Lake Evaporation} + \text{Precipitation} - \text{Change in Lake Storage}$$

A positive value indicates groundwater gain from lake; a negative value indicates groundwater loss to lake.

Inflow to lake from streams and outflow from lake to streams can be obtained from streamflow gauge measurements. These inflow and outflow terms are zero for standalone lakes with no connected streams. Precipitation can be estimated from local precipitation gauges; lake evaporation can be calculated using procedures outlined in Section 4.9, "Lake Evaporation;" and change in lake storage can be computed from water level data and elevation-storage capacity curves.

Example: Goose Lake — The groundwater discharge to Goose Lake is estimated based on surface water runoff and potential evaporation estimates derived from historical reports. The water budget data for Goose Lake are summarized in Table 7 on Page 36 of "Geohydrology and numerical Model analysis of "Groundwater Flow in the Goose Lake Basin, Oregon and California." It is reproduced as Figure 5-6.

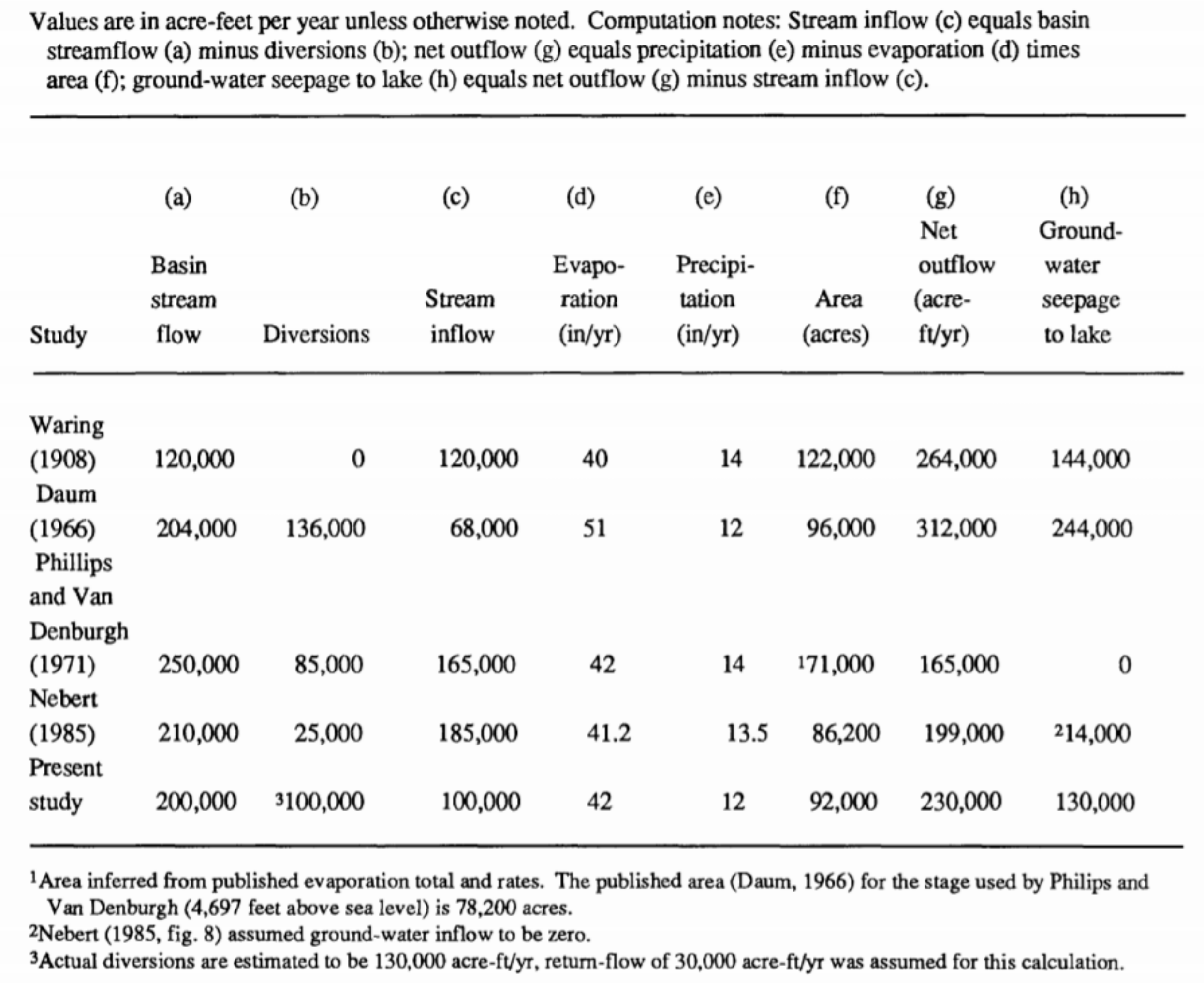
Mean annual surface water inflow to the lake totals 200,000 acre-feet per year (af/y), irrigation diversions total 130,000 af/y, and return flows total 30,000 af/y. The result is a net outflow from the lake of 100,000 af/y. In this study, the potential rate of evaporation from the lake surface was assumed to be 42 inches per year, which is in close agreement with those used by others. Precipitation on the lake surface is approximately 12 inches per year. Goose Lake covers 92,000 acres at a water surface elevation of 4,700 feet above sea level (Daum 1966); at this elevation, Goose Lake loses 322,000 af/y to evaporation and gains 92,000 af/y from precipitation. Using the mass balance approach, the groundwater loss to Goose Lake can be calculated based on the following compiled data:

- Inflow to the lake = 200,000 af/y.

- Diversions = 130,000 af/y.
- Return flow = 30,000 af/y.
- Outflow from the lake = 130,000 minus 30,000 = 100,000 af/y.
- Assumed change in lake storage = 0.

$$\text{Groundwater Loss to Lake} = 200{,}000 - 100{,}000 - 322{,}000 + 92{,}000 - 0$$
$$= -130{,}000 \text{ af/y (negative number indicating groundwater loss to lake)}$$

Figure 5-6 Summary of Water Budget Estimates for Various Goose Lake Studies



Values are in acre-feet per year unless otherwise noted. Computation notes: Stream inflow (c) equals basin streamflow (a) minus diversions (b); net outflow (g) equals precipitation (e) minus evaporation (d) times area (f); ground-water seepage to lake (h) equals net outflow (g) minus stream inflow (c).

Study	(a) Basin stream flow	(b) Diversions	(c) Stream inflow	(d) Evapo-ration (in/yr)	(e) Precipi-tation (in/yr)	(f) Area (acres)	(g) Net outflow (acre-ft/yr)	(h) Ground-water seepage to lake
Waring (1908)	120,000	0	120,000	40	14	122,000	264,000	144,000
Daum (1966)	204,000	136,000	68,000	51	12	96,000	312,000	244,000
Phillips and Van Denburgh (1971)	250,000	85,000	165,000	42	14	[1]71,000	165,000	0
Nebert (1985)	210,000	25,000	185,000	41.2	13.5	86,200	199,000	[2]14,000
Present study	200,000	[3]100,000	100,000	42	12	92,000	230,000	130,000

[1] Area inferred from published evaporation total and rates. The published area (Daum, 1966) for the stage used by Philips and Van Denburgh (4,697 feet above sea level) is 78,200 acres.

[2] Nebert (1985, fig. 8) assumed ground-water inflow to be zero.

[3] Actual diversions are estimated to be 130,000 acre-ft/yr, return-flow of 30,000 acre-ft/yr was assumed for this calculation.

Source: Geohydrology and Numerical Model Analysis of Groundwater Flow in the Goose Lake Basin, Oregon and California

5.6 MANAGED AQUIFER RECHARGE

Definition: Volume of water intentionally added to the groundwater system as part of defined recharge and water banking programs through spreading basins, injection wells, and other means.

Context: Managed aquifer recharge may be a component of a water banking program or local practices to recharge water to the aquifer and then extract that recharged water for later use. Water recharged as part of a water banking program is not considered part of native groundwater and is tracked separately as stored water for accounting purposes; all other water recharged is considered part of native groundwater. Stored water may be extracted for overlying users within the water budget zone (see Section 5.7, "Stored Water Extraction") and/or exported to contracting agencies outside of the water budget zone (see Section 5.9, "Stored Water Export"). Managed aquifer recharge can include flood water, stormwater, and treated wastewater recharge as well as seawater intrusion control for urban areas (see Section 3.5.2, "Urban Applied Water"). Additionally, on-farm managed aquifer recharge may be less formal as surplus surface water is over-applied to agricultural fields for the purpose of creating recharge (see Section 3.5.1, "Agricultural Applied Water"), and the amount of surface water recharge may need to be estimated from surface water deliveries and crop ET.

Related Water Budget Components: Evapotranspiration, Applied Water, Surface Water Deliveries, Groundwater Extraction, Stored Water Extraction, Groundwater Export, Stored Water Export

How to Determine Managed Aquifer Recharge:

- Method 1 — Obtain measured managed aquifer recharge data.
- Method 2 — Estimate managed aquifer recharge of on-farm application.
- Method 3 — Estimate managed aquifer recharge for treated wastewater.

Method 1 — Obtain Measured Managed Aquifer Recharge Data

Managed aquifer recharge is often a measured quantity and is known by the local agencies and water banks. Obtain managed aquifer recharge data (daily, monthly, etc.) from the following sources:

- Records for local agency stormwater recharge, treated wastewater recharge, and seawater intrusion control.
- Annual water bank and spreading basin program operation reports.
- Reports containing information on water transfers between entities.
- Numerical model input files.

Method 2 — Estimate Managed Aquifer Recharge of On-Farm Application

Use the methods outlined in Section 3.5.1, "Agricultural Applied Water," to estimate on-farm application of managed aquifer recharge.

Method 3 — Estimate Managed Aquifer Recharge for Treated Wastewater

Where treated wastewater recharge is unmeasured, use the methods outlined in Section 3.8, "Applied Water Reuse and Recycled Water" to estimate the recharge volume for treated waste water.

5.7 STORED WATER EXTRACTION

Definition: Volume of groundwater pumped (extracted) from the underlying aquifer(s) through a defined recharge and extraction program for use within the water budget zone. For example, a water bank with dedicated extraction wells can provide data for stored water extraction. It does not include stored water export, groundwater extraction, and groundwater export. Groundwater extraction and stored water extraction will be combined if stored water extraction amounts are unknown or are not separately measured; in such a case, the total volume of combined extractions will be reported as groundwater extraction.

Context: Stored water extraction is part of a managed water banking program to recharge water to the aquifer (see Section 5.6, "Managed Aquifer Recharge") and extract that recharged water for overlying users within the water budget zone. Stored water extracted for contracting agencies outside of the water budget zone is discussed in Section 5.9, "Stored Water Export." These are managed programs that require an accounting of recharge and withdrawals. Stored water extraction data are always measured and are available from bank operators.

Related Water Budget Components: Groundwater Extraction, Groundwater Export, Stored Water Export, Managed Aquifer Recharge

How to Determine Stored Water Extraction: Obtain measured stored water extraction data for all years of interest from water bank operators. Obtain stored water extraction data (daily, monthly, etc.) from the following sources:

- Annual water bank operation reports.
- Reports containing information on water transfers between entities.
- Numerical model input files.
- Measured groundwater pumping from wells in the well field supplying water to areas inside the water budget zone.

5.8 GROUNDWATER EXPORT

Definition: Volume of groundwater pumped (extracted) from the underlying aquifer for use outside the water budget zone. It does not include groundwater extraction, stored water extraction, and stored water export.

Context: Groundwater export (GW_x) in the total water budget schematic is a concept tied to the delineation of a water budget zone. If an amount of native groundwater is pumped from the underlying aquifer inside a defined water budget zone but is delivered/used outside the zone, then that amount of water is considered a groundwater export from the source water budget zone and as imported water (after conveyance losses are accounted for) into the destination water budget zone. The groundwater exports from one agency jurisdiction to another agency are always measured except when pumped groundwater from the same agency jurisdiction is used in a different water budget zone from where it is pumped.

An important distinction to make is that groundwater exports will be transported via conveyance facilities. In order to avoid double counting of water leaving the region, exported water from different sources needs to be accounted for separately. Surface water exports refers to surface water leaving the region that originates as surface water whereas groundwater exports refer to water leaving the region that originates as groundwater.

Related Water Budget Components: Applied Water, Surface Water Export, Groundwater Extraction, Stored Water Extraction, Conveyance Evaporation, Conveyance Seepage

How to Determine Groundwater Export: If extraction wells, excluding those used for water banking, are identified for the water budget zone of interest, find out which of those wells deliver water outside of the water budget zone along with the proportion of the total pumped water that is delivered outside. Two methods of compiling groundwater export data are described below:

- Method 1 — Obtain measured groundwater export data.
- Method 2 — Estimate groundwater exports using the estimates of applied water.

Method 1 — Obtain Measured Groundwater Export Data

Groundwater exports are often measured and known by local agencies. Obtain groundwater export data (daily, monthly, etc.) from the following sources:

- Reports containing information on water transfers between entities, excluding water banking operations.
- Numerical model input files.
- Measured groundwater pumping from wells within the well field supplying water to areas outside the water budget zone, excluding water banking operations.

Method 2 — Estimate Groundwater Export Using the Estimates of Applied Water

Groundwater exports from a water budget zone can be estimated by calculating the amount of applied groundwater at the place of use and adding the conveyance losses for transporting the groundwater to its place of use. Volumes of on-farm total applied water can be determined by estimating crop types, acreage, and irrigation practices at the place of use and using the estimates of applied water as calculated in Section 3.5.1, "Agricultural Applied Water." Applied groundwater is calculated by subtracting the surface water deliveries and applied water reuse from the total applied water needed.

5.9 STORED WATER EXPORT

Definition: Volume of groundwater pumped (extracted) from the underlying aquifer(s) through a defined recharge and extraction program for use outside the water budget zone. For example, a water bank with dedicated extraction wells can provide data for stored water export. It does not include stored water extraction, groundwater extraction, and groundwater export. Groundwater export and stored water export will be combined if stored water export amounts are unknown or are not separately measured. In such a case, the total volume of combined exports will be reported as groundwater export.

Context: The Central Valley of California is home to numerous water banking operations; these operations play a critical role during the dry years by providing a reliable supply of water to the banking partners, which may or may not be in the water budget zone. The stored water is pumped in dry years and could be used within the water budget zone for overlying use or transported outside the water budget zone. Stored water extraction for overlying use within the water budget zone only accounts for the amount of water that is used on the overlying land; whereas, stored water export accounts for pumped water from water banks that is used outside of the water budget zone. Stored water export data are always measured and are available from water bank operators.

Related Water Budget Components: Groundwater Extraction, Stored Water Extraction, Groundwater Export, Managed Aquifer Recharge

How to Determine Stored Water Export: Obtain measured stored water export data for all years of interest from water bank operators. Obtain stored water export data (daily, monthly, etc.) from the following sources:

- Annual water bank operation reports.
- Reports containing information on water transfers between entities.
- Numerical model input files.

- Measured or metered groundwater pumping from wells in the well field supplying water to areas outside the water budget zone.

5.10 CHANGE IN GROUNDWATER STORAGE

Definition: Net change in the volume of groundwater stored within the underlying aquifer of the water budget zone.

Context: Groundwater is the water that is present underground in the pore spaces of soil and sand and in the fractures of rock. It moves slowly through geologic formations of soil, sand, and rocks called aquifers. Aquifers are recharged through percolation of precipitation, applied water, and managed aquifer recharge; seepage from canals, lakes, and streams; and subsurface inflows. Aquifers are discharged through groundwater extraction, accretion to lakes and streams, and subsurface outflows. The difference of recharge (inflows) and discharge (outflows) in the aquifer is the change in groundwater storage. It can be calculated using a simple mass balance approach as follows:

$$\text{Change in Groundwater Storage} = \text{Inflow to Aquifer} - \text{Outflow from Aquifer}$$

In addition to an analysis of inflow and outflow, change in groundwater storage can be estimated by using direct measurements, such as measuring groundwater levels, or using indirect measurements, such as remote sensing, both coupled with modeling tools to estimate the change in the volume of groundwater storage. When actual change in groundwater storage can be estimated from measured parameters, the resulting estimate can be used to evaluate the mass balance error, which reflects how well the inflow, outflow, and change in storage components can be estimated. Large mass balance errors may indicate the need to re-evaluate the inflow and outflow components along with methods to directly estimate change in groundwater storage directly. The mass balance error is expressed as:

$$\begin{gathered}\text{Mass Balance Error} = \text{Inflow to Aquifer} - \text{Outflow from Aquifer} \\ - \text{Change in Groundwater Storage (measured)}\end{gathered}$$

Groundwater storage is also affected by one-time only water release caused by land subsidence (see Section 5.11).

Change in groundwater storage is not the same as groundwater overdraft. Bulletin 118 defines overdraft as: "…the condition of a groundwater basin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years during which water supply conditions approximate average conditions." The differences include:

- Change in storage is an annual construct whereas overdraft is calculated over a period of representative years.
- Change in storage accounts for all inflow and outflow components whereas overdraft only includes groundwater pumping and recharge (from precipitation, applied water, seepage, managed aquifer recharge, etc.).
- Change in storage can be an accretion or depletion of the system whereas overdraft always indicates a depletion in the system.

Related Water Budget Components: Groundwater Extraction, Stored Water Extraction, Groundwater Export, Recharge of Applied Water and Precipitation, Managed Aquifer Recharge, Conveyance Seepage, Subsurface Inflow, Subsurface Outflow, Stream-Groundwater Interaction, Lake-Groundwater Interaction

How to Determine Change in Groundwater Storage:

- Method 1 — Obtain available technical reports and studies.
- Method 2 — Obtain available spreadsheets and numerical models.
- Method 3 — Estimate using measured groundwater level data and aquifer parameters.
- Method 4 — Estimate using a mass balance approach.

Method 1 — Obtain Available Technical Reports and Studies

USGS and other agencies publish historical investigation reports on hydrogeology of many regions in the U.S. Such reports may provide a quantitative description of change in groundwater storage for groundwater basins and subbasins in California. Key sources of information include:

- Local agency records, including flood control districts, or water resource management agencies.
- USGS Water-Resources Investigations Reports.
- USGS Scientific Investigations Report.

Method 2 — Obtain Available Spreadsheets and Numerical Models

Various numerical hydrologic models developed for basins in California may have change in groundwater storage estimates. These models, whether a spreadsheet or numerical model, may be useful in determining change in groundwater storage for the water budget zone of interest. Sources of information include:

- USGS Water Resources.
- USGS California Water Science Center — Groundwater Modeling.
- USGS California Water Science Center: Central Valley Hydrologic Model.
- C2VSim.

Method 3 — Estimate Using Measured Groundwater Level Data and Aquifer Parameters

Groundwater level data, in conjunction with estimated aquifer storage parameters, can be used to estimate change in groundwater storage for the water budget zone. Groundwater levels are measured, compiled, and reported by USGS, DWR, local agencies, and water banking projects. Obtain groundwater level data (daily, monthly, etc.) from the following sources:

- California Statewide Groundwater Elevation Monitoring (CASGEM) Program.
- DWR Water Data Library: Groundwater Level Data.
- USGS Groundwater Levels for California.
- Local monitoring records.

The change in groundwater storage is calculated as the product of (1) the difference in groundwater elevation between two monitoring periods, (2) the area overlying the water budget zone, and (3) the average specific yield in an unconfined aquifer or storativity in a confined aquifer.

$$\text{Change in Groundwater Storage} = (\text{GWE}_{t0} - \text{GWE}_{t1}) \times \text{Overlying Area} \times \text{Specific Yield}$$

Where:

- GWE_{t0} = Average groundwater elevation in the overlying area at monitoring period 1.
- GWE_{t1} = Average groundwater elevation in the overlying area at monitoring period 2.

The average groundwater elevation in an overlying area can be developed from point groundwater elevation measurements at wells at a given period of time using GIS interpolation function. Interpolating the point groundwater elevations in GIS allows for spatial weighting and removes some of the uncertainty associated with using point measurements over a larger area. Caution should be taken when developing the average groundwater elevations from a monitoring network. Depending on the network of wells, areas with less data will likely result in higher uncertainty in groundwater elevation estimates.

Specific yield represents the water-yielding capacity of a material and is defined as the ratio of the volume of water that will drain by gravity from a saturated rock or soil compared to the total volume of rock or soil. Specific yield values can be determined in the field or laboratory using direct or indirect methods. Direct methods divide the measured volume of water that drains from a volume of saturated material by the measured volume of the saturated material. Based on aquifer material texture analysis, a range of specific yield values from 0.07 to 0.17 are reported in C2VSim for aquifers in the Central Valley. For confined aquifers, storativity describes the volume of water released from, or taken into, storage per unit surface area per unit change in hydraulic head in the confined aquifer. The typical storativity of a confined aquifer, which varies with specific storage and aquifer thickness, ranges from 5×10^{-5} to 5×10^{-3} (Todd 1980).

Specific yield estimates can be obtained from the following sources:

- Well completion reports or driller logs.
- Local studies.
- USGS California Water Science Center: Central Valley Hydrologic Model.
- C2VSim.

For a detailed explanation of calculating change in groundwater storage using groundwater level data, see "Appendix E: California's Groundwater Update 2013 Technical Memorandum: Calculating Annual Change in Groundwater in Storage by Using Groundwater-Level Data."

Method 4 — Estimate Using A Mass Balance Approach

In the mass balance approach, inflows and outflows need to be determined for the aquifer within the water budget zone of interest. The difference between inflows and outflows in the aquifer is the change in groundwater storage, expressed as:

$$\text{Change in Groundwater Storage} = \text{Inflow to Aquifer} - \text{Outflow from Aquifer}$$

Inflows to the aquifer consist of recharge of applied water and precipitation, conveyance seepage, subsurface inflows, gains from lakes and streams, and managed aquifer recharge. Outflows from the aquifer consist of groundwater pumping and exports, subsurface outflows, losses to lakes and streams, and stored water extraction. The inflow and outflow components can be determined from data identified and methods described for each component in this handbook.

5.11 WATER RELEASE CAUSED BY LAND SUBSIDENCE

Definition: Volume of water released to an aquifer on a one-time basis as a result of land subsidence, which is caused by the inelastic consolidation of porous fine-grained material.

Context: USGS defined land subsidence as "a gradual settling or sudden sinking of the Earth's surface owing to subsurface movement of earth materials… Three distinct processes account for most of the water-related subsidence — compaction of aquifer systems, drainage and subsequent oxidation of organic soils, and dissolution and collapse of susceptible rocks." Land subsidence occurs in California's Central Valley because of long periods of over-pumping from aquifers. When land subsidence occurs from inelastic consolidation of porous fine-grained material, a volume of water is released on a one-time only basis from the pore spaces, and the corresponding aquifer storage space is permanently lost because of compaction (Riley 1969). The porous material cannot be "inflated" back to their original volume by simply replacing the water that was released as a result of land subsidence.

Related Water Budget Components: Change in Groundwater Storage, Groundwater Extraction

How to Determine Water Release Caused by Land Subsidence:

- Method 1 — Obtain available technical reports and modeling studies.
- Method 2 — Estimate using model results and groundwater level data.

Method 1 — Obtain Available Technical Reports and Modeling Studies

The estimates for water release caused by land subsidence is not widely available because it cannot be directly estimated or measured without a numerical model. USGS has published historical hydrogeologic investigations and modeling reports that could be a good source of available information. Key sources of information for the Central Valley of California include:

- USGS California Water Science Center: Central Valley Hydrologic Model.
- C2VSim.
- DWR Water Data Library Ground Surface Displacement — Land Subsidence Monitoring.
- USGS Water Data for the Nation.

Method 2 — Estimate Using Model Results and Groundwater Level Data

Water release caused by land subsidence could be estimated if a numerical model is available for a groundwater basin where there is evidence of land subsidence and where extensive groundwater level measurements are available. One can calculate the change in storage using the groundwater level measurements and compare that with the model computed change of storage. The difference between the two numbers may be the result of many factors such as modeling errors or because of unaccounted water released from demonstrated land subsidence. As a result, a portion of this difference can be attributed to water release caused by land subsidence, subject to the 10 to 30 percent limits of total groundwater pumping.

6. CASE STUDY: NON-MODELING APPROACH

6.1 INTRODUCTION

There can be situations when a model may not be needed, may not be available, or may not be appropriate for developing a water budget. A case study is presented in this section to illustrate how to generate estimates of water budget components using the non-modeling approach. The case study is an application of the process described in Section 2.9, "Non-Modeling Approach," and of methods described in Section 3, "Land System;" Section 4, "Surface Water System;" and Section 5, "Groundwater System." The case study relies on measured data as well as estimates developed using the non-modeling approach. To facilitate application of the non-modeling approach, a spreadsheet tool was developed.

The methodology and results of the case study are presented in the following subsections. A summary of the contents of the figures and tables used in the case study is provided in Table 6-1.

Table 6-1 Summary of Case Study Figures and Tables

Table/Figure	Description
Figure 6-1	Map showing the water districts within the water budget zone.
Figure 6-2	Map showing the groundwater sustainability agencies (GSA) within the water budget zone.
Figure 6-3	Map showing land use within the water budget zone, which is used to determine evapotranspiration and applied water.
Figure 6-4	Map showing surface water features within the water budget zone, which is used for identifying and analyzing conveyance facility seepage and evaporation.
Figure 6-5	Map showing groundwater elevation contours, which are used to estimate the subsurface flows in the basin resulting from groundwater gradients.
Figure 6-6 — results Table 6-2 — documentation	Results of the land system budget analysis and the associated documentation of the data sources, assumptions, methods, and references to sections in the Water Budget Handbook.
Figure 6-7 — results Table 6-3 — documentation	Results of the surface water system budget analysis and the associated documentation of the data sources, assumptions, methods, and references to sections in the Water Budget Handbook.
Figure 6-8 — results Table 6-4 — documentation	Results of the groundwater system budget analysis and the associated documentation of the data sources, assumptions, methods, and references to sections in the Water Budget Handbook.

Table/Figure	Description
Figure 6-9	Schematic showing the inflows and outflows from the water budget zone
Figure 6-10	The total water budget, which combines the results of Figure 6-7, Figure 6-8, and Figure 6-9.
Table 6-5	Components that were found to be challenging to estimate or obtain during the development of the water budget presented in the case study.

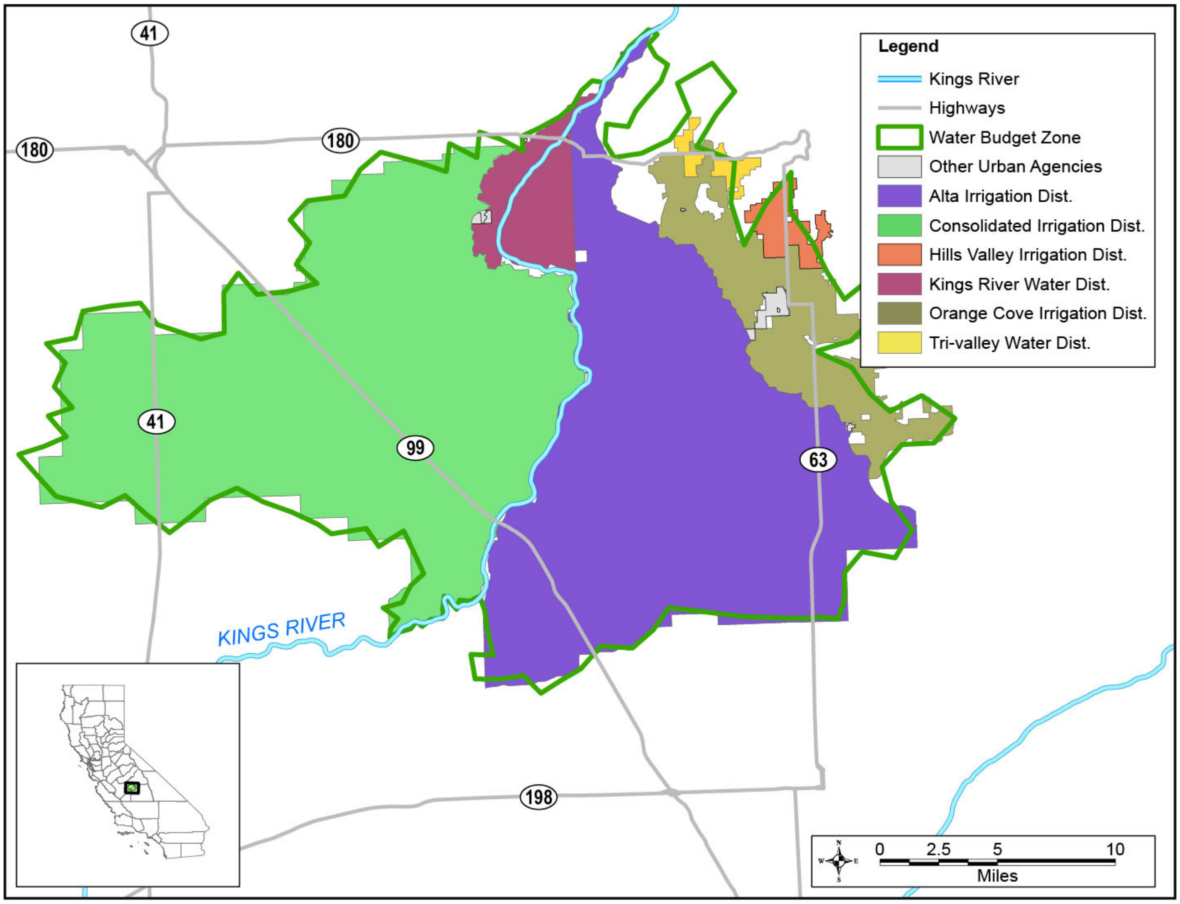
6.2 STUDY AREA

A portion of the southern Central Valley was chosen as the water budget zone of interest for the case study because of the access to processed data from reports, data sources, and prior integrated hydrologic model applications in the area. The water budget zone selected for the case study is the same as the C2VSim Subregion 17 and is also covered by the Kings Basin Integrated Groundwater and Surface Water Model.

The water budget zone selected for the case study is shown in Figure 6-1. It contains the following agricultural and urban water agencies:

- Alta Irrigation District (AID).
- Consolidated Irrigation District (CID).
- Kings River Water District (KRWD).
- Orange Cove Irrigation District.
- Hills Valley Irrigation District.
- Tri-Valley Water District.
- Several urban agencies.

Figure 6-1 **Water Districts within the Water Budget Zone**



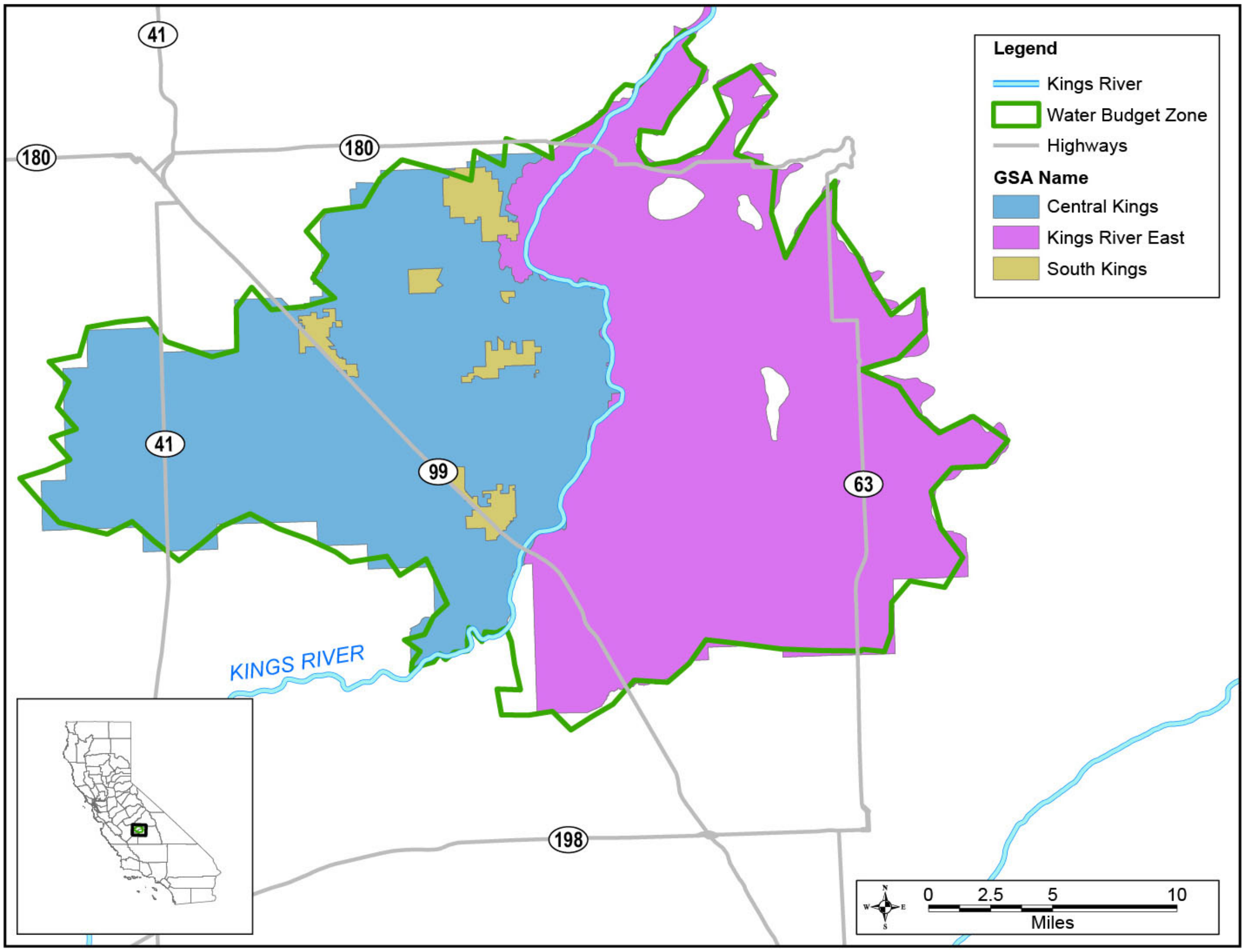
Data sources: CalAtlas, Caltrans, DWR, USGS

The water budget zone is within the Tulare Lake Hydrologic Region and covers part of the San Joaquin Valley — Kings Subbasin (Bulletin 118 No. 5-22.08). The Kings River flows from north to south through the water budget zone, bisecting it into eastern and western halves. The boundaries of the water budget zone are as follows:

- Eastern boundary: The Sierra Nevada foothills.
- Western boundary: The western boundary of the CID.
- Northern boundary: The southern boundary of the Fresno Irrigation District (FID).
- Southern boundary: The southern boundaries of AID and CID.

As shown in Figure 6-2 there are three GSAs in the water budget zone. The Central Kings GSA and South Kings GSA have jurisdiction over areas west of the Kings River while the Kings River East GSA has jurisdiction over areas east of the river.

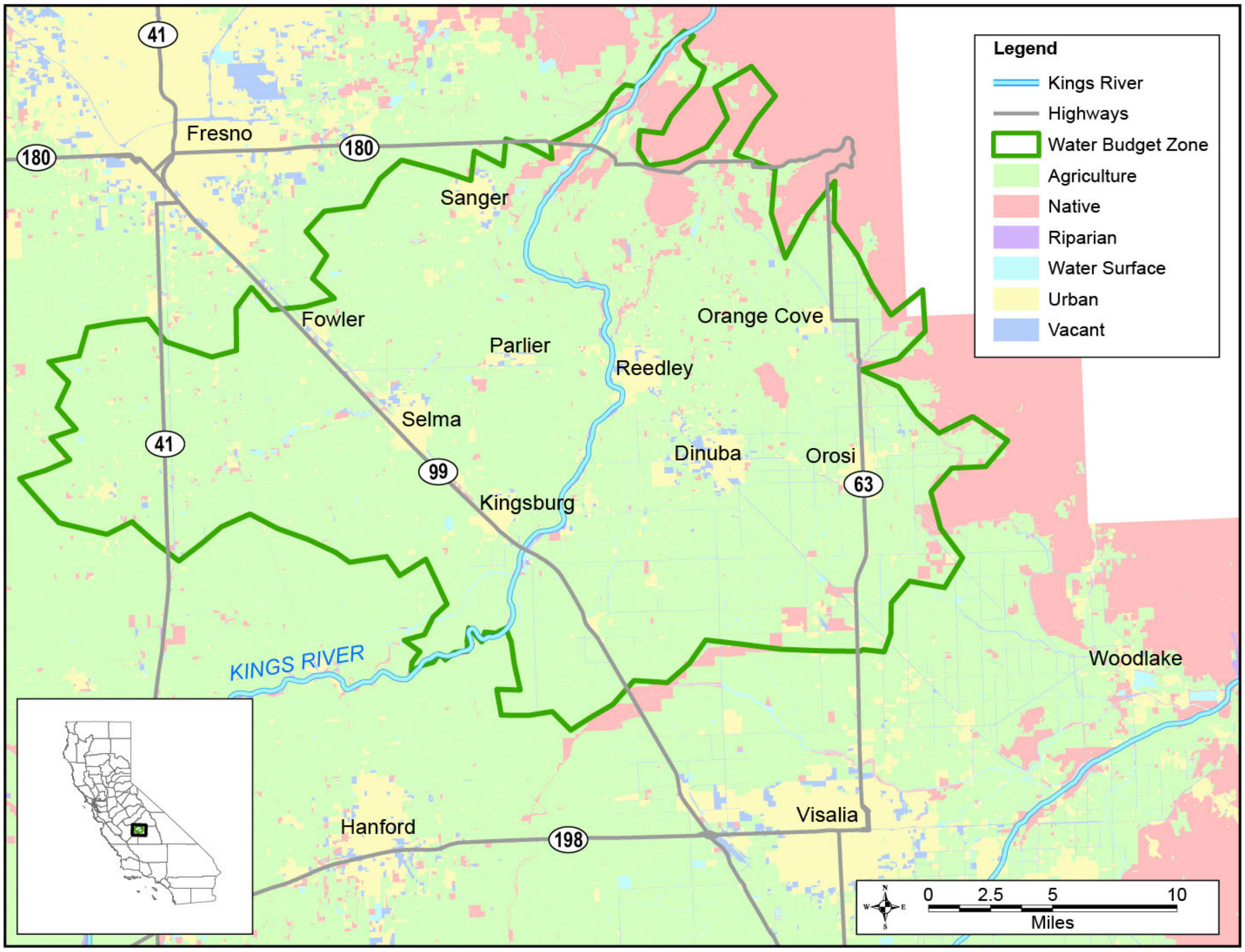
Figure 6-2 Groundwater Sustainability Agencies within the Water Budget Zone



Data sources: CalAtlas, Caltrans, DWR, USGS

Agriculture is the primary land use in the water budget zone. Irrigation water supply is a combination of surface water and groundwater while municipal supply is exclusively groundwater. Figure 6-3 shows the distribution of land use in the water budget zone.

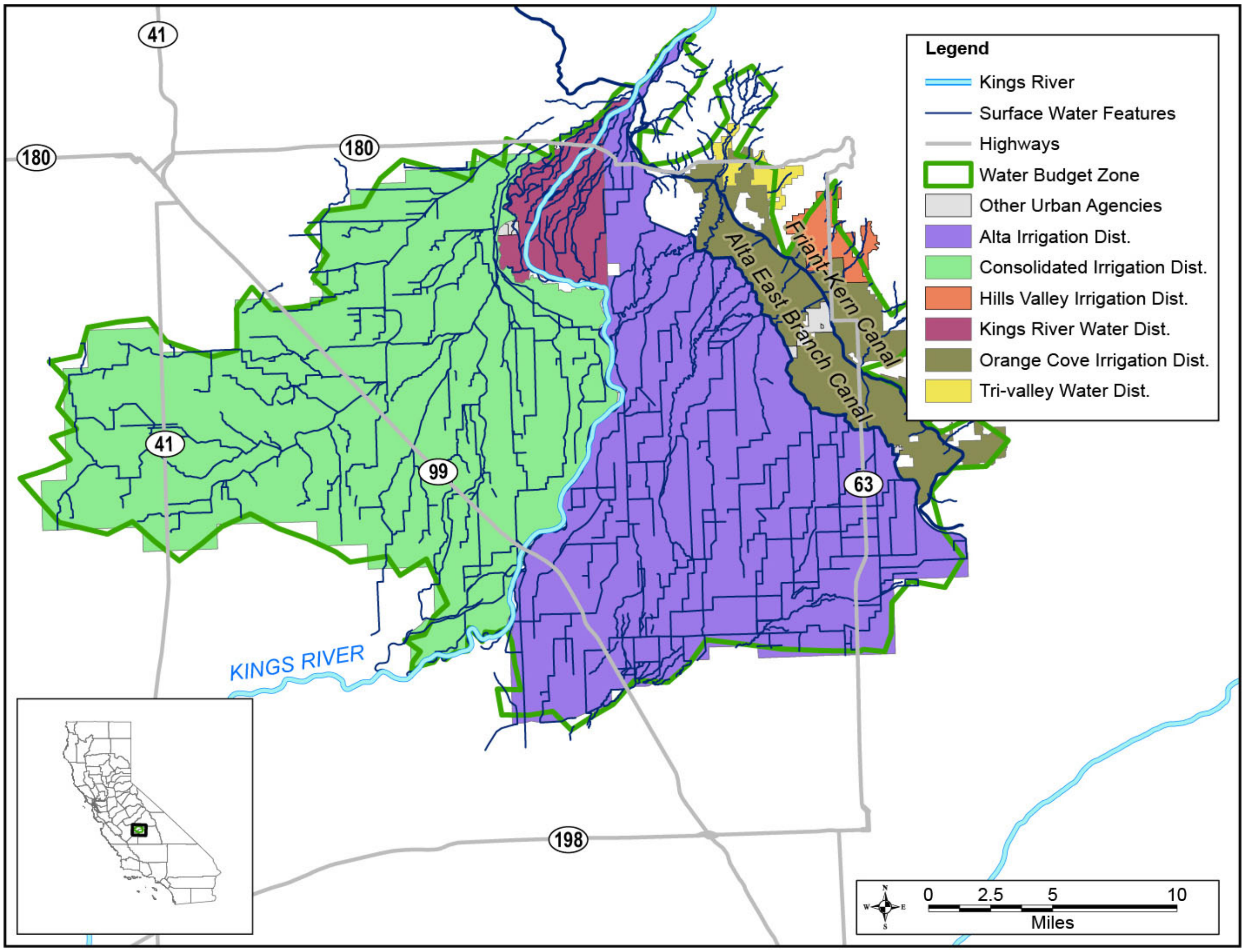
Figure 6-3 Land Use in the Water Budget Zone



Data sources: CalAtlas, Caltrans, DWR, USGS

Surface water is distributed through a network of streams and irrigation canals as shown in Figure 6-4. Diversions from the Kings River supplies irrigation water via a network of canals. The Kings River Water Association is the water master for the Kings River and represents 28 members that divert water and have water rights to Kings River flows.

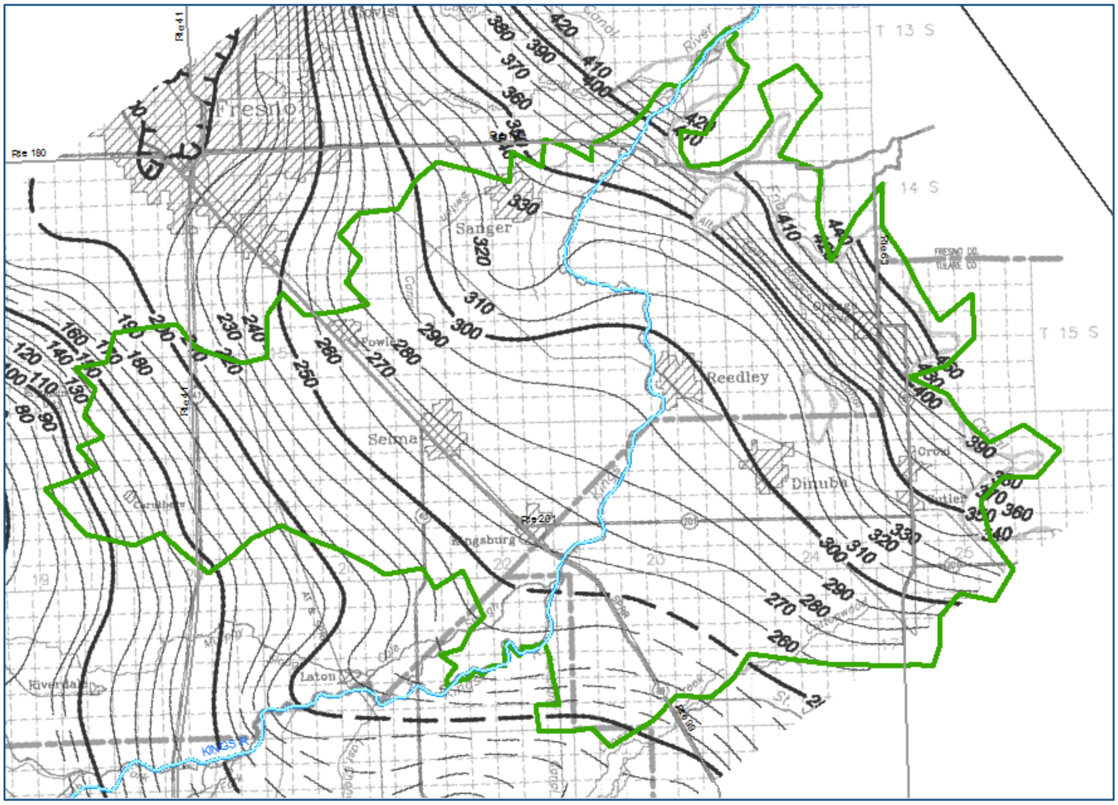
Figure 6-4 Surface Water System within the Water Budget Zone



Data sources: CalAtlas, Caltrans, DWR, USGS

The groundwater system of the water budget zone consists of unconsolidated continental deposits of Tertiary and Quaternary periods overlain by a younger series of deposits of the Quaternary period that can be divided into older alluvium, lacustrine and marsh deposits, younger alluvium, and flood-basin deposits. The general movement of groundwater is from the northeast to the southwest direction as depicted by the contour map shown in Figure 6-5.

Figure 6-5 Groundwater Level Contour Map within the Water Budget Zone



6.3 INVENTORY OF AVAILABLE INFORMATION

A data search was conducted to determine what relevant water budget data and information were available for the case study area. This data collection process is in accordance with the steps described in Section 2.9.1, "General Data Collection for Non-Modeling Approach." Each water budget component was estimated using one or more methods presented in Section 3, "Land System;" Section 4, "Surface Water System;" and Section 5, "Groundwater System." The availability of data is often the determining factor in deciding which method to use.

Listed below are the data sources used to compute the various water budget components.

Land System

- Evapotranspiration.
    - Crop evapotranspiration (ETc): DWR Agricultural Land and Water Use Estimates.
    - Crop efficiencies (CF): DWR Agricultural Land and Water Use Estimates.
    - Crop areas: DWR Land Use Surveys and DWR Agricultural Land and Water Use Estimates.
    - Reference ET (ETo): California Irrigation Management Information System zone map.
- Precipitation.
    - Monthly precipitation data: California Irrigation Management Information System.
- Groundwater Extraction.
    - Groundwater pumping data: Kings River Conservation District
- Runoff.
    - Soil type for curve number: Natural Resources Conservation Service.

Surface Water System

- Surface Water Inflow and Outflow.

    - Streamflow: Kings River Water Association.
- Surface Water Diversions.
    - Streamflow diversions: Kings River Water Association.

Groundwater System

- Subsurface Inflow and Outflow.
    - Groundwater level contours: SGMA Data Viewer.
    - Groundwater hydraulic conductivity: USGS Report "Ground Water in The Fresno Area, California."
    - Historical groundwater elevations: CASGEM Report of Groundwater Elevation Data.
- Change in Groundwater Storage
    - Groundwater level contours: SGMA Data Viewer.
    - Groundwater hydraulic conductivity: USGS Report "Ground Water in The Fresno Area, California."
    - Historical groundwater elevations: CASGEM Report of Groundwater Elevation Data.

6.4 APPLICATION OF NON-MODELING APPROACH

The results of the monthly water budget computations for Water Year 2003 using the non-modeling approach, including specific data source, assumptions, and method for calculating each component, are presented in Figures 6-6 through 6-8 with documentation provided in Tables 6-2 through 6-4, for the land system, surface water system, and groundwater system, respectively. The results of the case study are also available in accessible Excel format on the Water Budget Handbook webpage. The water budget components shown in these figures correspond to the components shown in Figure 1-1.

Figure 6-6 Land System Water Budget for Water Year 2003 (in acre-feet)

		Component*	Credit (+) /Debit(-)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1	**INFLOWS**	*Precipitation*														
2		Precip Ag	+	0	40,905	37,530	7,983	35,699	20,852	51,922	17,101	0	382	462	0	212,835
3		Precip Native	+	0	6,642	6,093	1,296	5,796	3,386	8,430	2,777	0	62	75	0	34,557
4		Precip Urban	+	0	5,184	4,756	1,012	4,524	2,643	6,580	2,167	0	48	59	0	26,972
5		SW Delivery Ag (Diversion minus losses)	+	4,652	568	243	64	137	2,032	4,661	45,517	138,496	125,280	26,666	6,210	354,527
6		*Groundwater Extraction*														
7		GW Extraction Ag	+	49,747	0	0	0	0	18,407	39,251	109,588	85,416	122,440	181,477	146,613	752,940
8		GW Extraction Urban	+	3,867	2,386	2,033	1,990	1,661	2,455	2,610	4,043	7,886	5,848	10,554	4,912	50,245
9		Applied Water		58,265	2,953	2,276	2,054	1,798	22,895	46,522	159,149	231,798	253,569	218,697	157,735	1,157,712
10		Appliied Water Ag		54,399	568	243	64	137	20,440	43,912	155,106	223,912	247,721	208,143	152,823	1,107,467
11		Applied Water Urban		3,867	2,386	2,033	1,990	1,661	2,455	2,610	4,043	7,886	5,848	10,554	4,912	50,245
12		*Total Inflow*		*58,265*	*55,684*	*50,655*	*12,345*	*47,818*	*49,775*	*113,453*	*181,194*	*231,798*	*254,061*	*219,292*	*157,735*	*1,432,076*
13	**OUTFLOWS**	*Evapotranspiration*														
14		ET Ag	-	45,237	14,537	6,825	6,587	9,850	34,073	79,127	141,784	183,897	203,345	171,042	125,770	1,022,075
15		ET Native	-	0	5,434	1,799	1,296	4,722	3,386	8,430	2,777	0	62	75	0	27,981
16		ET Urban	-	3,867	1,901	702	702	1,843	4,110	5,807	6,210	7,886	5,896	8,425	4,912	52,262
17		*Runoff*														
18		Runoff Ag	-	0	6,355	4,947	0	4,241	362	11,761	37	0	0	0	0	27,704
19		Runoff Native	-	0	0	0	0	0	0	0	0	0	0	0	0	0
20		Runoff Urban	-	0	2,772	2,436	0	2,258	952	3,383	0	0	0	0	0	11,801
21		*Recharge of Applied Water*														
22		Recharge of Ag Applied Water	-	1,632	17	7	2	4	613	1,317	4,653	6,717	7,432	6,244	4,585	33,224
23		Recharge of Urban Applied Water	-	116	72	61	60	50	74	78	121	237	175	317	147	1,507
24		*Recharge of Precipitation*														
25		Recharge of Precipitation on Ag	-	0	1,227	1,126	239	1,071	626	1,558	513	0	11	14	0	6,385
26		Recharge of Preciptation on Native	-	0	199	183	39	174	102	253	83	0	2	2	0	1,037
27		Recharge of Precipitation on Urban	-	0	156	143	30	136	79	197	65	0	1	2	0	809
28		*Total Outflow*		*50,852*	*32,669*	*18,230*	*8,956*	*24,350*	*44,376*	*111,912*	*156,244*	*198,738*	*216,925*	*186,121*	*135,414*	*1,184,786*
29	**STORAGE CHANGE**	Change in Land System Storage		-	-	-	-	-	-	-	-	-	-	-	-	-
30		**Land System Mass Balance Error**		**7,414**	**23,015**	**32,425**	**3,389**	**23,468**	**5,399**	**1,542**	**24,949**	**33,060**	**37,136**	**33,172**	**22,321**	**247,289**

*Note: Stored Water Extraction, Applied Water Reuse/Recycled Water, Return Flow, Recycled Water Export, Managed Aquifer Recharge, and Change in Land System Storage are not included as there was no data available for those components and estimated to be insignificant in the area.

Table 6-2 Documentation: Land System

Row(s) of Figure 6-6	Water Budget Component	Data Sources, Assumptions, and Estimation Methods	Handbook Section Reference
2–4	Precipitation	Precipitation data for the study area came from California Irrigation Management Information System Stations #39 and #142. Thiessen polygons were used to distribute monthly station data over the agricultural, urban, and native areas. Each area was computed separately. The Thiessen method was adequate for distributing precipitation over the water budget zone because the variation over the zone was not significant.	3.3
5	SW Delivery Ag (Agricultural Surface Water Delivery)	Agricultural surface water deliveries were based on measured diversion data that was adjusted for conveyance seepage and evaporative losses (Table 6-3). Monthly surface water diversion data for all agencies using Kings River water is from the Kings River Water Association.	3.6
-	SW Delivery Urban (Urban Surface Water Delivery)	The study area does not have any surface water deliveries for urban use.	3.6
7	GW Extraction Ag (Agricultural Pumping)	Agricultural pumping was calculated based on the assumption that groundwater was used when there were insufficient surface water deliveries to meet applied water. Agricultural pumping was calculated as agricultural water requirement (described in applied water calculation below) minus effective precipitation and agricultural surface water deliveries.	3.7
8	GW Extraction Urban (Urban Pumping)	Monthly urban pumping data in the water budget zone were available from local agencies (cities and water agencies). Data was obtained from the Kings River Conservation District.	3.7

Row(s) of Figure 6-6	Water Budget Component	Data Sources, Assumptions, and Estimation Methods	Handbook Section Reference
10	Applied Water Ag. (Agricultural Applied Water)	Agricultural applied water was used to estimate agricultural pumping. The crop coefficient method was used to calculate crop evapotranspiration (ET_c). Irrigation efficiency data were used to estimate applied water for each major crop type in the water budget zone. Crop parameters were based on DWR's Agricultural Land and Water Use Estimates. Agricultural applied water for each crop is ET_c minus effective precipitation, divided by irrigation efficiency and multiplied by crop area. Example data included maximum monthly ET_c of approximately 10 inches for almonds and irrigation efficiencies ranging from 78 percent for grain to 90 percent for tomatoes. The estimated monthly applied water for each crop was added to obtain the total annual agricultural applied water in Row 10.	3.5.1
11	Applied Water Urban (Urban Applied Water)	Urban applied water in the study area is met exclusively by groundwater pumping. As a result, urban applied water is equal to urban pumping.	3.5.2
12	Total Inflow	Equal to the sum of rows 2–5 and 7–8.	
14–16	Evapotranspiration for Agricultural, Native, and Urban Areas	The crop coefficient approach was used to estimate evapotranspiration. It is assumed that evapotranspiration for each crop is equal to crop ET_c multiplied by crop area. ET is capped by precipitation over native and urban areas. Data were obtained from Agricultural Land and Water Use Estimates, DWR Land Use Surveys, and the Cal Poly Irrigation Training and Research Center: California Evapotranspiration Data.	3.4

Row(s) of Figure 6-6	Water Budget Component	Data Sources, Assumptions, and Estimation Methods	Handbook Section Reference
18–20	Runoff for Agricultural, Native, and Urban Areas	Runoff was calculated using the curve number method. Soil data in the water budget zone were obtained from Natural Resources Conservation Service Soil Surveys. Soil type B is dominant in the water budget zone. Curve numbers of 75, 48, and 85 are representative of agricultural, native, and urban areas in the water budget zone, respectively.	3.10
22–23 and 25–27	Recharge for Agricultural, Native, and Urban Areas	Monthly recharge of applied water and precipitation was calculated as a constant percentage of the volume of applied water and precipitation. In the water budget zone, it was assumed that 3 percent of applied water and precipitation percolated into the groundwater system.	5.2
28	Total Outflow	Equal to sum of rows 14–16, 18–20, 22–23, and 25–27.	
30	Land System Mass Balance Error	Equal to total inflow minus total outflow minus change in land system storage.	

Figure 6-7 Surface Water System Water Budget for Water Year 2003 (in acre-feet)

		Component*	Credit (+) /Debit(-)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1	INFLOWS	*Stream Inflow*														
2		Kings River Inflow	+	9,130	6,329	5,617	6,853	5,254	24,865	42,118	127,581	391,930	402,768	194,924	86,498	1,303,868
3		Mill Creek Inflow	+	0	95	791	734	996	1,882	1,952	1,863	157	0	0	0	8,470
4		Hughes Creek Inflow	+	0	14	93	93	125	234	240	226	16	0	0	0	1,041
5		Friant Kern to Kings Inflow	+	341	0	0	0	195	0	1,873	4,615	23,071	19,806	9,367	0	59,268
6		Runoff	+	0	9,126	7,384	0	6,500	1,314	15,144	37	0	0	0	0	39,505
7		Return Flow	+	1,165	59	46	41	36	458	930	3,183	4,636	5,071	4,374	3,155	23,154
8		*Total Inflow*		*10,637*	*15,624*	*13,931*	*7,721*	*13,106*	*28,754*	*62,257*	*137,505*	*419,809*	*427,645*	*208,665*	*89,653*	*1,435,306*
9	OUTFLOWS	*Stream Outflow*														
10		Kings River Outflow	-	4,615	8,178	6,879	5,822	4,756	18,495	11,435	26,117	161,377	180,069	96,548	22,259	546,550
11		*Surface Water Diversions*														
12		AID Diversions		0	0	0	0	0	0	0	26,568	44,235	46,062	20,737	0	137,602
13		CID Diversions		0	0	0	0	0	0	0	14,914	91,134	75,236	0	0	181,284
14		KRWD Diversions		5,044	698	337	208	329	2,374	5,927	6,998	8,450	9,223	8,513	7,863	55,964
15		Conveyance Evaporation	-	237	115	59	79	125	217	325	435	497	514	454	344	3,401
16		Conveyance Seepage	-	155	16	35	65	67	125	941	2,528	4,826	4,727	2,130	1,309	16,923
17		SW Delivery (Diversion minus losses)	-	4,652	568	243	64	137	2,032	4,661	45,517	138,496	125,280	26,666	6,210	354,527
18		*Surface Water Exports*														
19		Gould Canal Export	-	303	0	0	1,363	415	831	5,839	13,262	18,343	20,281	18,332	14,789	93,758
20		FID Canal Export	-	2,426	81	1,414	1,664	2,594	3,025	35,298	64,660	79,148	85,550	58,894	42,780	377,534
21		Stream Loss to Groundwater	-	37	65	55	47	38	148	91	209	1,291	1,441	772	178	4,372
22		*Total Outflow*		*12,425*	*9,022*	*8,685*	*9,104*	*8,132*	*24,873*	*58,590*	*152,728*	*403,978*	*417,862*	*203,796*	*87,869*	*1,397,064*
23	STORAGE CHANGE	Change in Surface Water System Storage		-	-	-	-	-	-	-	-	-	-	-	-	-
24		**Surface Water System Mass Balance Error**		**-1,788**	**6,601**	**5,246**	**-1,382**	**4,974**	**3,881**	**3,666**	**-15,223**	**15,831**	**9,783**	**4,869**	**1,784**	**38,242**

*Note: Precipitation on Lakes, Stream Gain from GW, Lake Gain from GW, Imported Water, Lake loss to GW, Lake Evaporation, Stream Evaporation, and Change in Surface Water System Storage are not included as there was no data available for those components and estimated to be insignificant in the area.

Table 6-3 Documentation: Surface Water System

Row(s) of Figure 6-7	Water Budget Component	Data Sources, Assumptions, and Estimation Methods	Handbook Section Reference
2–5	Stream Inflow	Stream inflows to the water budget zone are measured and available from the Kings River Water Association. Inflows are reported for the Kings River, Mill Creek, Hughes Creek, and deliveries from the Friant-Kern Canal to the Kings River.	4.2
-	Groundwater Loss to Streams	In the water budget zone, the groundwater system is predominantly gaining water from streams and does not lose any water to streams.	5.4
6	Runoff	Runoff is an outflow from the land system to the surface water system. It is the sum of runoff from the agricultural, native, and urban areas. Runoff was calculated using the curve number method. Soil data in the water budget zone were obtained from Natural Resources Conservation Service soil surveys. Soil type B is dominant in the water budget zone. Curve numbers of 75, 48, and 85 are representative of agricultural, native, and urban areas in the water budget zone, respectively.	3.10
7	Return Flow	Return flow is an inflow to the surface water system and was calculated as a fixed percentage of applied water. It was assumed as 2 percent of the agricultural surface water deliveries, agricultural pumping, and urban pumping.	3.11
8	Total Inflow	Equal to sum of rows 2–7.	
10	Stream Outflow	The primary stream outflows from the water budget zone are from the Kings River. Surface water outflow from the Kings River is based on Kings River streamflow data measured at Peoples Weir, which is available from the Kings River Water Association.	4.2

Row(s) of Figure 6-7	Water Budget Component	Data Sources, Assumptions, and Estimation Methods	Handbook Section Reference
12–14	Surface Water Diversion	Surface water diversions to Alta Irrigation District, Consolidated Irrigation District, and Kings River Water District are based on measured data at weirs on the Kings River. Monthly diversion data are available from KRWA.	4.3
15	Conveyance Evaporation	Conveyance evaporation losses were calculated using the equation “1.1 × ET_o × River Surface Area”, where ET_o is from the California Irrigation Management Irrigation System Reference Evapotranspiration zone map.	4.5
16	Conveyance Seepage	Conveyance seepage was estimated as a constant percentage of diversions and exports. It was assumed that 2 percent of diversions and exports became seepage to the groundwater system. This percentage is based on a rough approximation technique when no other information is available.	4.6
17	Surface Water Delivery	Calculated as the surface water diversions minus conveyance evaporation and conveyance seepage.	3.6
19–20	Surface Water Export	Surface water exports were based on measured data obtained from the KRWA for: (1) Fresno Irrigation District from Could Canal, and (2) Fresno Irrigation District Canal.	4.7
21	Stream Loss to Groundwater (Groundwater Gain from Streams)	Surface water loss to groundwater (groundwater gain from streams) was estimated to be 0.8 percent of surface water outflows, which was based on an average ratio from the Kings Basin Integrated Groundwater and Surface water Model.	5.4
22	Total Outflow	Equal to the sum of rows 10, 15–17, and 19–21.	
23	Stream System Mass Balance Error	Equal to total inflow minus total outflow minus change in stream system storage.	

Figure 6-8 Groundwater System Water Budget for Water Year 2003 (in acre-feet)

		Component*	Credit (+) /Debit(-)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1	INFLOWS	Recharge of Applied Water	+	1,748	89	68	62	54	687	1,396	4,774	6,954	7,607	6,561	4,732	34,731
2		Recharge of Precipitation	+	0	1,582	1,451	309	1,381	806	2,008	661	0	15	18	0	8,231
3		Groundwater Gain from Stream	+	37	65	55	47	38	148	91	209	1,291	1,441	772	178	4,372
4		Conveyance Seepage	+	155	16	35	65	67	125	941	2,528	4,826	4,727	2,130	1,309	16,923
5		Subsurface Inflow	+	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	13,416
6		*Total Inflow*		*3,058*	*2,870*	*2,728*	*1,600*	*2,657*	*2,884*	*5,554*	*9,291*	*14,189*	*14,907*	*10,599*	*7,337*	*77,674*
7	OUTFLOWS	*Groundwater Extraction*														
8		GW Extraction Ag	-	49,747	0	0	0	0	18,407	39,251	109,588	85,416	122,440	181,477	146,613	752,940
9		GW Extraction Urban	-	3,867	2,386	2,033	1,990	1,661	2,455	2,610	4,043	7,886	5,848	10,554	4,912	50,245
10		Subsurface Outflow	-	24,750	24,750	24,750	24,750	24,750	24,750	24,750	24,750	24,750	24,750	24,750	24,750	296,994
11		*Total Outflow*		78,363	27,135	26,783	26,739	26,411	45,612	66,610	138,381	118,052	153,038	216,780	176,274	1,100,179
12	STORAGE CHANGE	Change in Groundwater Storage (computed)		-65,335	-2,907	-2,478	-2,425	-2,024	-25,424	-51,013	-138,474	-113,700	-156,335	-234,013	-184,651	-978,779
13		**Groundwater System Mass Balance Error**		**-9,970**	**-21,358**	**-21,577**	**-22,715**	**-21,729**	**-17,305**	**-10,043**	**9,384**	**9,838**	**18,205**	**27,831**	**15,714**	**-43,727**

*Note: Managed Aquifer Recharge, GW gain from Lake, Water Release Caused by Land Subsidence, Stored Water Extraction, GW Loss to Stream, GW loss to Lake, GW Export, and Stored Water Export are not included as there was no data available for those components and estimated to be insignificant in the area.

Table 6-4 Documentation: Groundwater System

Row(s) of Figure 6-8	Water Budget Component	Data Sources, Assumptions, and Estimation Methods	Handbook Section Reference
1	Recharge of Applied Water	Recharge of applied water into the groundwater system is equal to the sum of the land system recharge of applied water (agricultural and urban areas). For the case study, a rough approximation technique was used to estimate recharge as 3 percent of applied water.	5.2.2
2	Recharge of Precipitation	Recharge of applied water and precipitation into the groundwater system is equal to the sum of the land system recharge of precipitation. For the case study, a rough approximation technique was used to estimate recharge as 3 percent precipitation.	5.2.1
3	Groundwater Gain from Stream	Groundwater gain from the surface water system was estimated to be 0.8 percent of surface water outflows, which is based on an average ratio from the Kings Basin Integrated Groundwater and Surface water Model.	5.4
4	Conveyance Seepage	Conveyance seepage was estimated as a constant percentage of diversions and exports. For the case study, a rough approximation technique of 2 percent of diversions and exports was used to estimate seepage to the groundwater system.	4.6
5	Subsurface Inflow	Subsurface inflows from adjacent aquifer areas were calculated using groundwater contours and Darcy’s law. Groundwater contours maps were obtained from DWR monitoring data (see Figure 6-5). Based on the contour maps, it was assumed that inflow only occurred at the eastern boundary of the study area. Hydraulic conductivity was assumed to be 40 feet per day, which was based on a 10–70 feet per day range reported in a 1984 study in the Fresno area. Flow along the eastern boundary is assumed to occur over a thickness of 50 feet and a length of 120,000 feet.	5.3

Row(s) of Figure 6-8	Water Budget Component	Data Sources, Assumptions, and Estimation Methods	Handbook Section Reference
6	Total Inflow	Equal to sum of rows 1–5.	
8	GW Extraction Ag (Agricultural Pumping)	Agricultural pumping was calculated based on the assumption that groundwater was used when there were insufficient surface water deliveries to meet applied water. Agricultural pumping was calculated as agricultural applied water minus agricultural surface water deliveries.	3.7
9	GW Extraction Urban (Urban Pumping)	Monthly urban pumping data were available from local agencies (cities and water agencies) in the water budget zone. Data was obtained from the Kings River Conservation District.	3.7
10	Subsurface Outflow	Subsurface outflows to downgradient aquifers were calculated using groundwater contours and Darcy’s law. Groundwater contours maps were obtained from DWR monitoring data. Based on the contour maps, it was assumed that outflows only occur at the western boundary of the water budget zone. Hydraulic conductivity was assumed to be 40 feet per day, which was based on a 10–70 feet per day range reported in a 1984 study in the Fresno area. Flow along the western boundary is assumed to occur over a depth of 1,000 feet and a length of 185,000 feet.	5.3
11	Total Outflow	Equal to sum of rows 8–10	
12	Change in Groundwater Storage (computed)	Change in groundwater storage is computed using groundwater contours and points selected from DWR monitoring data and California Statewide Groundwater Elevation Monitoring wells. The change in storage is calculated for the period of fall 2002 through spring 2003. A porosity of 0.15 was assumed.	5.10
13	Groundwater Budget Mass Balance Error	Equal to total inflow minus total outflow minus change in groundwater storage.	

The water budgets of the land system, surface water system, and groundwater systems, as presented in Figure 6-6, Figure 6-7, and Figure 6-8, are aggregated to develop the total water budget as shown in Figure 6-9 and presented in Figure 6-10. The total water budget includes only the inflows and outflows into the water budget zone, not the flows between systems or flows within systems shown in Figure 1-1. The inflows and outflows of Figure 6-10 are visually presented in Figure 6-9, which is a modified version of Figure 1-1 without the flows between systems and flows within systems.

Figure 6-9 **Total Water Budget (Only Inflows to and Outflows from Water Budget Zone)**

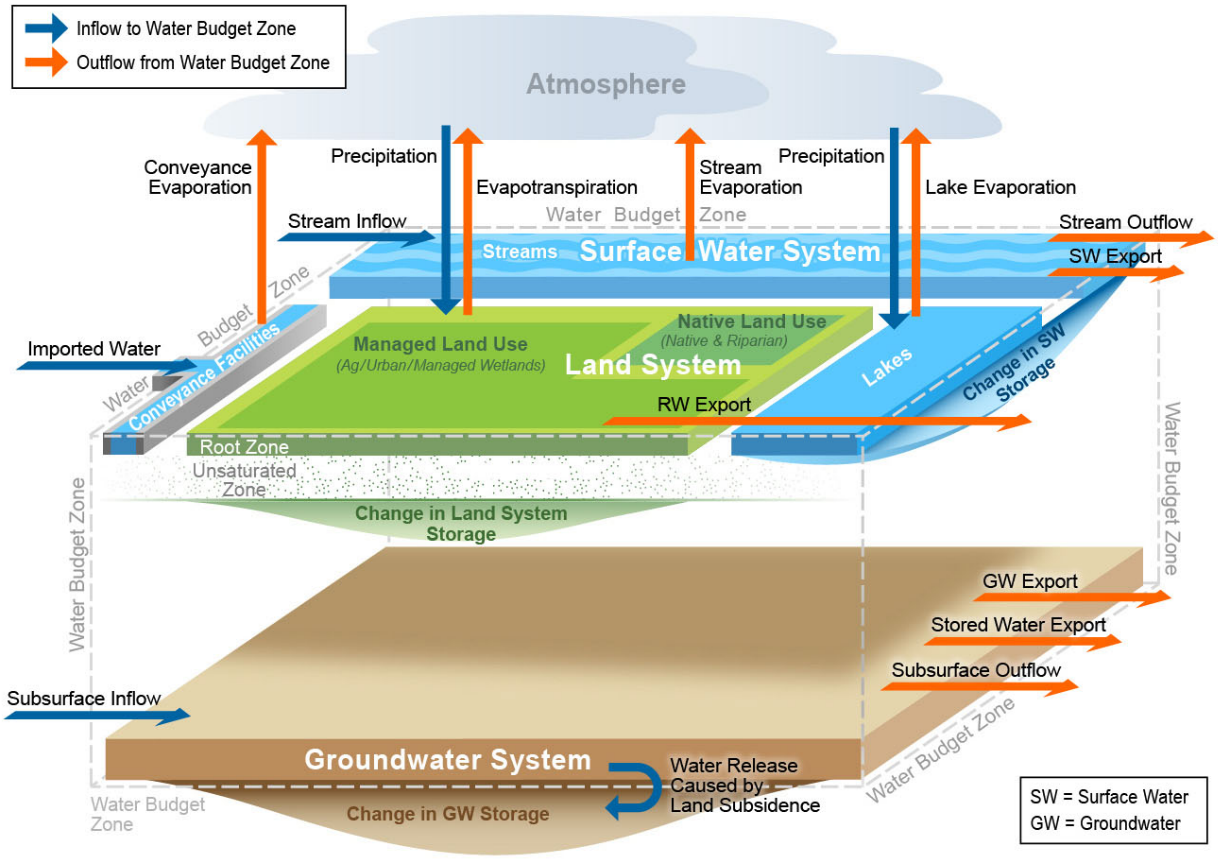


Figure 6-10 Total Water Budget for Water Year 2003 (in acre-feet)

Component		Credit (+)/Debit(-)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
INFLOWS	Precipitation on Land System	+	0	52,731	48,379	10,291	46,020	26,880	66,932	22,045	0	492	595	0	274,364
	Precipitation on Lakes	+	na	na	na	na	na	na	na	na	na	na	na	na	na
	Stream Inflow	+	9,471	6,438	6,502	7,680	6,570	26,982	46,182	134,285	415,173	422,574	204,291	86,498	1,372,646
	Imported Water	+	na	na	na	na	na	na	na	na	na	na	na	na	na
	Subsurface Inflow	+	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	13,416
	Water Release Caused by Land Subsidence	+	na	na	na	na	na	na	na	na	na	na	na	na	na
	Total Inflow		10,589	60,287	55,999	19,089	53,708	54,980	114,232	157,447	416,291	424,183	206,004	87,616	1,660,427
OUTFLOWS	Evapotranspiration from Land System	-	49,104	21,873	9,326	8,586	16,415	41,569	93,364	150,771	191,784	209,303	179,542	130,682	1,102,319
	Stream Evaporation	-	na	na	na	na	na	na	na	na	na	na	na	na	na
	Lake Evaporation	-	na	na	na	na	na	na	na	na	na	na	na	na	na
	Conveyance Evaporation	-	237	115	59	79	125	217	325	435	497	514	454	344	3,401
	Stream Outflow	-	4,615	8,178	6,879	5,822	4,756	18,495	11,435	26,117	161,377	180,069	96,548	22,259	546,550
	Subsurface Outflow	-	24,750	24,750	24,750	24,750	24,750	24,750	24,750	24,750	24,750	24,750	24,750	24,750	296,994
	Surface Water Export	-	2,729	81	1,414	3,027	3,009	3,856	41,137	77,922	97,491	105,831	77,226	57,569	471,292
	Groundwater Export	-	na	na	na	na	na	na	na	na	na	na	na	na	na
	Stored Water Export	-	na	na	na	na	na	na	na	na	na	na	na	na	na
	Recycled Water Export	-	na	na	na	na	na	na	na	na	na	na	na	na	na
	Total Outflow		*81,434*	*54,996*	*42,428*	*42,263*	*49,055*	*88,886*	*171,010*	*279,994*	*475,898*	*520,466*	*378,520*	*235,604*	*2,420,555*
STORAGE CHANGE	Change in Total Storage		-65,335	-2,907	-2,478	-2,425	-2,024	-25,424	-51,013	-138,474	-113,700	-156,335	-234,013	-184,651	-978,779
Total System Mass Balance Error			**-5,510**	**8,199**	**16,049**	**-20,749**	**6,677**	**-8,483**	**-5,766**	**15,927**	**54,093**	**60,052**	**61,498**	**36,664**	**218,650**

6.5 INSIGHTS FROM THE CASE STUDY

Developing a water budget for the case study area using the non-modeling approach was straightforward but required application of professional judgment. The water budget calculation tables presented in this section are based on the water budget accounting template presented in Figures 1-2 through 1-5 and can be adapted to meet the needs of other water budget zones of interest.

The most time-consuming aspect of the non-modeling approach was data collection. In instances where data are not measured or readily available, rough approximation techniques were used to develop initial estimates. These initial estimates can be adjusted and refined later as better data are compiled or become available. These estimates should be validated with local knowledge and information to ensure that the estimates are defensible.

In the process of balancing the overall water budget, each of the water budget systems was evaluated and an attempt was made to balance the inflows and outflows in each of the systems. When the systems are not balanced, it is an indication that there are water budget components that need to be further adjusted and refined, specifically components that are gross estimations based on minimal information. In this case study, the components listed in Table 6-5, were found to be challenging to estimate because of lack of additional corroborating information.

Table 6-5 Challenging Components to Estimate and/or Obtain Data

Water Budget Component	Handbook Section
Return Flow	3.11
Recharge of Applied Water and Precipitation	5.2
Conveyance Seepage	4.6
Subsurface Inflow and Outflow	5.3
Stream-Groundwater Interaction	5.4

It should be noted that no efforts were made to adjust the above components in this case study, because the purpose of the case study is to demonstrate the application of the non-modeling approach, using a standardized water accounting template.

7. CASE STUDY: INTEGRATED WATER FLOW MODEL

7.1 INTEGRATED WATER FLOW MODEL INTRODUCTION

The Integrated Water Flow Model (IWFM) is DWR's water resources management and planning model. It calculates groundwater flows, soil moisture movement in the topsoil, stream flows, land surface flows, and flow exchange between the groundwater, streams, and land surface as generated by precipitation, agricultural irrigation, and urban (i.e., municipal, industrial) water use. IWFM also calculates agricultural water demands based on crop types, crop acreage, soil types, irrigation methods and rainfall rates, as well as the urban water demands based on population and per-capita water use rates. Agricultural and urban water demands can be pre-specified or calculated internally based on different land use types. Water reuse, as well as tile drains and lakes or open water areas, is also modeled. IWFM is a powerful tool that can help water managers to understand the historical evolution of the surface and subsurface water flows within their basin and to plan the use of groundwater and surface water for meeting future agricultural and urban water demands.

IWFM-2015 (Version 2015) is the latest release of the model's code and builds upon prior updates. It takes a more modular approach relative to past IWFM models and allows more options for the simulation of each water budget component. IWFM-2015 serves as a container for various versions of code to simulate hydrologic components, including different versions of the root zone simulation, stream component, and lake component simulation modules. While the IWFM framework allows the user to customize packages and methodology used to simulate the hydrologic system, the outputs are generally consistent between simulation options, making postprocessing easier to standardize. Modules and simulation options are designed such that minimal changes to the input file formats are required. All modules are designed as part of IWFM and integrate seamlessly into the greater model framework.

7.2 EXTRACTING WATER BUDGET COMPONENTS FROM IWFM

This case study section provides information on how to extract water budget components from IWFM inputs and outputs. This section does not follow the standard case study format of a study area inclusive of data collection, model input file development, model runs, and results analysis. Rather, it assumes that an IWFM model is already developed for an area and provides examples of how to extract different water budget components from model results using a sample model developed using IWFM-2015. As a reminder, many applications of IWFM exist in California, however, the outputs discussed for this sample model are from IWFM-2015 and may differ from earlier versions. This sample model is used to present the most comprehensive example of extracting model inputs and outputs to illustrate development of the total water budget.

By default, the IWFM model generates water budgets at the model subregion scale. Model subregions are defined during model development. Subregions may represent different jurisdictional areas such as water districts, cities, or counties; regions with different water management strategies or sources of water; or hydrologically separated areas. An IWFM application can also be configured to generate water budget outputs for a user-defined "water budget zone" that is delineated as a collection of elements in the model, which can then produce water budget outputs for the specified water budget zone. IWFM outputs are consistent with the water budget framework as illustrated in Figure 1-1 and described in Sections 3 through 5.

Before running IWFM, output files are specified for subregional or zone budget areas. There are three files where the user can specify model outputs:

- Root zone component main: User specifies output files for the land and water use budget and the root zone moisture budget.
- Stream parameters main: User specifies output files for the stream budget and diversion detail report. Stream budgets are specified for predefined stream reaches or nodes, not subregions or user defined zones.
- Groundwater component main: User specifies output for the groundwater budget.

7.2.1 IWFM Tools Add-In for Excel

The model outputs can be exported for easier processing using the IWFM tools Add-in for Excel plugin, which will be referred to as the IWFM Excel tool. The plugin can be downloaded from the IWFM and IDC Support Tools webpage. The tool allows the user to import model generated results into MS Excel and will automatically convert the units of the results and aggregate them to the desired time interval.

After installing the plugin, open Excel and navigate to the “IWFM Tools” tab. Under the “Data Import” heading, click on either “Import Budget” or “Import Z-Budget” depending on the desired type of outputs. Then, navigate to the desired model output file and specify units, timeseries, and timescale. A separate water budget table will be generated for every subregion or user-defined water budget zone, depending on budget type. All water budget output tables in the following sections were generated using the IWFM Tools Add-in for Excel plugin. Excel tables generated using the tool provide water budget timeseries in user specified spatial and temporal units.

Water budget components contained in various IWFM budget tables are listed in Table 7-1. The components are organized by the three systems outlined in the total water budget: land system, surface water system, and groundwater system, as illustrated in Figure 1-1 and described in Sections 3 through 5.

Components of the water budget can be extracted from IWFM through six primary outputs:

- Land and water use budget: The total agricultural and urban areas, as well as the agricultural potential consumptive use of applied water and the water supply requirements are reported in the output, followed by the components that the land and water use budget is comprised of. The land and water use budget corresponds closely to the land system described in this document and is available by the default model subregion or user defined zones based on a selection of model elements. IWFM also allows for the generation of crop specific budgets, where the generated budget tables are separated out by crop.
- Groundwater budget: The groundwater budget reports the inflows and outflows as well as the beginning and ending groundwater storages. In addition to the inflows and outflows from the groundwater system, the groundwater budget also reports the percolation of water from the root zone to the unsaturated zone to compare to the deep percolation into the groundwater and cumulative subsidence for informational purposes. The groundwater budget is available by model subregion or user defined zone. The groundwater budget output corresponds closely with the groundwater system.
- Root zone moisture budget: The root zone moisture budget provides information on processes that are used to compute soil moisture in the

root zone. Agricultural areas represent lands where crops are grown; urban areas represent both indoor and outdoor urban water uses; and native and riparian lands represent the undeveloped area in the subregion. For each area type (agricultural, urban, and native and riparian vegetation), precipitation and irrigation (except for native and riparian vegetation areas) along with direct runoff and return flows are listed. Similar to the land and water use budget, the root zone moisture budget is available for model subregions, user defined zones, and separated out by individual crops.

- Lake budget: Lakes are modeled to determine their interaction with the groundwater and stream systems. The lake budget provides the lake water balance, lake storage, and lake surface elevation at the end of each time interval. Lakes are reported by lake system and are not split by elements. However, the interaction with individual model elements can be obtained from the groundwater budget.
- Stream budget: The stream reach budget tables provide information on the flows in and out of the reaches as well as the impacts of other processes on stream flows such as small stream watershed flows, tile drainage, surface runoff, return flows, diversions and bypass flows. The mass balance check for the reach is listed in the "Discrepancy" column. The "Diversion Shortage" column reports the difference between simulated diversions and the user specified diversion requirements. This term does not affect the mass balance in the reach but is listed as an informational term. Version 5.0 of the Stream Component in IWFM can simulate flows using kinematic wave routing and includes a change in storage, which is reported in the stream budget. The stream budget is available by steam reach as well as individual stream node. The stream node budget is useful if the user requires reporting at a scale inconsistent with the model stream reach.
- Diversion detail report: This data file reports surface water deliveries and diversions, as well as the difference between the required and actual deliveries and diversions for each diversion simulated in the model. Each diversion is associated with a required diversion amount, along with recoverable and non-recoverable losses and a required delivery amount. The diversion detail report lists the actual diversions and deliveries as well as the shortages. The "Actual Delivery" and "Delivery Shortage" columns also list the delivery destinations. The

destination can be a subregion, an element, a group of elements, or a delivery made to outside the model domain.

- Unsaturated zone budget: The unsaturated zone budget reports the inflows and outflows, as well as the beginning and ending moisture storage in the unsaturated zone. The beginning and ending storage, along with the storage terms in the root zone moisture budget, account for the change in storage in the land system. The inflow to the unsaturated zone is the percolation leaving the root zone above, and the outflow is the recharge to the underlying aquifer system. The unsaturated zone budget is available by subregion or user defined zones.

Table 7-1 IWFM Components for Establishing Total Water Budget

Water Budget Component	**IWFM Budgets**
Land System	
Precipitation	Root Zone Moisture Budget
Evapotranspiration	Root Zone Moisture Budget
Surface Water Delivery	Land and Water Use Budget
Groundwater Extraction	Land and Water Use Budget, Groundwater Budget
Applied Water Reuse	Root Zone Moisture Budget
Recycled Water	Not Available
Recycled Water Export	Not Available
Runoff	Root Zone Moisture Budget
Return Flow	Root Zone Moisture Budget
Change in Land System Storage	Root Zone Moisture Budget
Surface Water System	
Surface Water Inflow and Outflow	Stream Budget
Surface Water Diversion	Stream Budget
Stream Evaporation	Not Available
Conveyance Evaporation	Diversion Detail Report
Conveyance Seepage	Diversion Detail Report
Imported Water	Diversion Detail Report
Surface Water Exports	Diversion Detail Report
Stream-Lake Interaction	Lake Budget, Stream Budget
Lake Evaporation	Lake Budget
Change in Surface Water Storage	Lake Budget
Groundwater System	

Water Budget Component	**IWFM Budgets**
Recharge of Applied Water	Groundwater Budget
Recharge of Precipitation	Groundwater Budget
Subsurface Inflow and Outflow	Groundwater Budget
Stream-Groundwater Interaction	Groundwater Budget, Stream Budget
Lake-Groundwater Interaction	Groundwater Budget, Lake Budget
Managed Aquifer Recharge	Groundwater Budget
Stored Water Extraction	Land and Water Use Budget, Groundwater Budget
Groundwater Export	Land and Water Use Budget, Groundwater Budget
Stored Water Export	Land and Water Use Budget, Groundwater Budget
Water Release Caused by Land Subsidence	Groundwater Budget
Change in Groundwater Storage	Groundwater Budget

7.2.2 IWFM Model Units

IWFM budget output results are presented as timeseries. The IWFM Excel tool allows the user to assign conversion factors to obtain the results in Excel in the desired units. IWFM simulates in timesteps ranging between one minute and one year. The model outputs are presented with actual dates of simulation, and the IWFM Excel tool can aggregate results to larger timescales if needed. The IWFM Excel tool reads the model files and recognizes dates, and the user does not need to go into the input files to find this. Length units are provided in individual model files, and units are generally in feet and can be converted to other units in the IWFM Excel tool.

The examples presented in this section are based on results exported using the IWFM Excel tool that also converts outputs to units of acre feet and a monthly timestep.

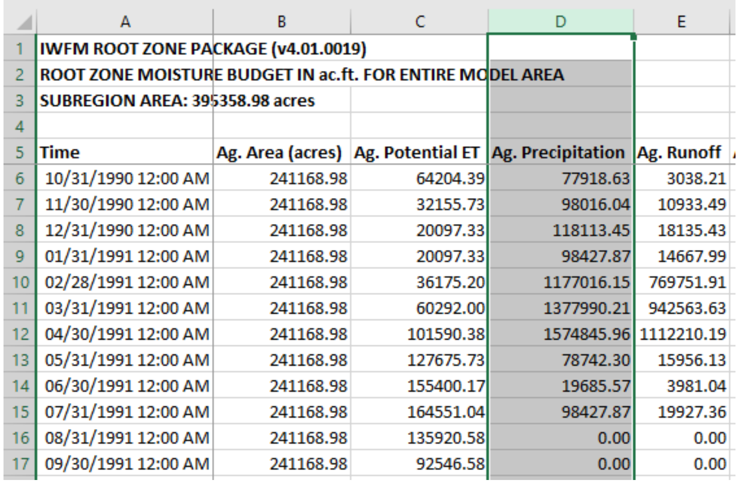
Descriptions in the following sections focus on deriving water budget components from an existing, calibrated IWFM application. Refer to Section 9, “Data Resources Directory”, for reference documentation that discusses how IWFM computes components and what input data are required.

7.3 LAND SYSTEM

7.3.1 Precipitation

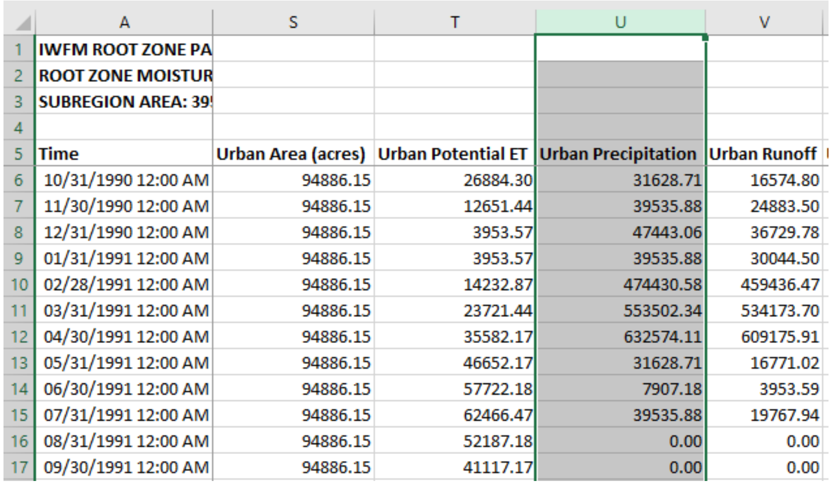
Precipitation, as defined in Section 1.3, refers to the "volume of water vapor that falls to the earth (land and surface water systems) as rain, snow, hail, or is formed on the earth as dew, and frost." IWFM accounts for total volume of precipitation in the Root Zone Moisture Budget output. For the subregions or water budget zone of interest, find the precipitation data in the "Ag. Precipitation", "Urban Precipitation", and "Native and Riparian Veg. Precipitation" columns (Figure 7-1 through Figure 7-3). For each time step, sum the three columns to obtain the total volume of precipitation for the water budget zone.

Figure 7-1 **Root Zone Moisture Budget: Ag. Precipitation**



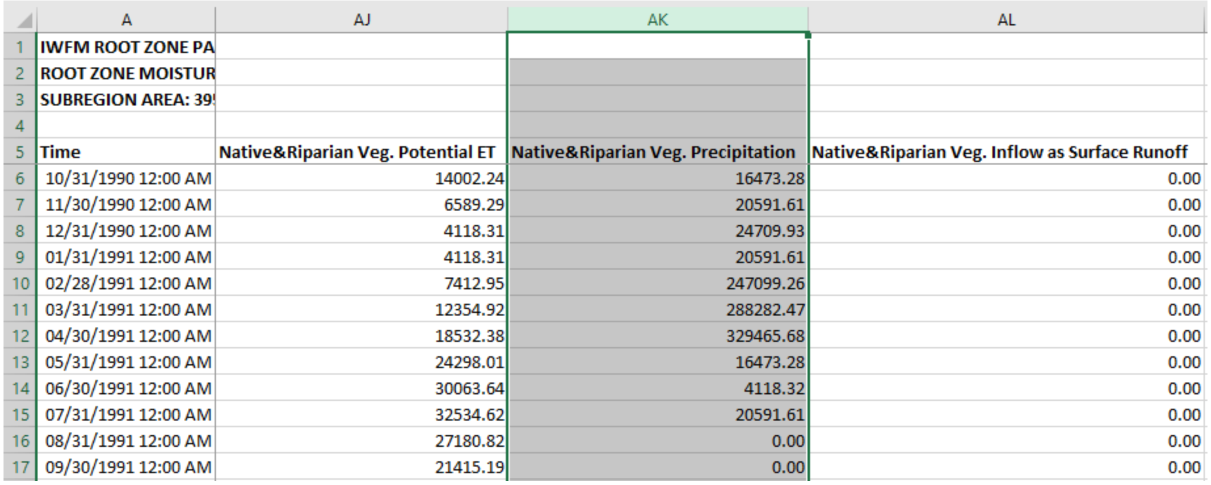
	A	B	C	D	E
1	IWFM ROOT ZONE PACKAGE (v4.01.0019)				
2	ROOT ZONE MOISTURE BUDGET IN ac.ft. FOR ENTIRE MODEL AREA				
3	SUBREGION AREA: 395358.98 acres				
4					
5	Time	Ag. Area (acres)	Ag. Potential ET	Ag. Precipitation	Ag. Runoff
6	10/31/1990 12:00 AM	241168.98	64204.39	77918.63	3038.21
7	11/30/1990 12:00 AM	241168.98	32155.73	98016.04	10933.49
8	12/31/1990 12:00 AM	241168.98	20097.33	118113.45	18135.43
9	01/31/1991 12:00 AM	241168.98	20097.33	98427.87	14667.99
10	02/28/1991 12:00 AM	241168.98	36175.20	1177016.15	769751.91
11	03/31/1991 12:00 AM	241168.98	60292.00	1377990.21	942563.63
12	04/30/1991 12:00 AM	241168.98	101590.38	1574845.96	1112210.19
13	05/31/1991 12:00 AM	241168.98	127675.73	78742.30	15956.13
14	06/30/1991 12:00 AM	241168.98	155400.17	19685.57	3981.04
15	07/31/1991 12:00 AM	241168.98	164551.04	98427.87	19927.36
16	08/31/1991 12:00 AM	241168.98	135920.58	0.00	0.00
17	09/30/1991 12:00 AM	241168.98	92546.58	0.00	0.00

Figure 7-2 **Root Zone Moisture Budget: Urban Precipitation**



	A	S	T	U	V
1	IWFM ROOT ZONE PA				
2	ROOT ZONE MOISTUR				
3	SUBREGION AREA: 39				
4					
5	Time	Urban Area (acres)	Urban Potential ET	Urban Precipitation	Urban Runoff
6	10/31/1990 12:00 AM	94886.15	26884.30	31628.71	16574.80
7	11/30/1990 12:00 AM	94886.15	12651.44	39535.88	24883.50
8	12/31/1990 12:00 AM	94886.15	3953.57	47443.06	36729.78
9	01/31/1991 12:00 AM	94886.15	3953.57	39535.88	30044.50
10	02/28/1991 12:00 AM	94886.15	14232.87	474430.58	459436.47
11	03/31/1991 12:00 AM	94886.15	23721.44	553502.34	534173.70
12	04/30/1991 12:00 AM	94886.15	35582.17	632574.11	609175.91
13	05/31/1991 12:00 AM	94886.15	46652.17	31628.71	16771.02
14	06/30/1991 12:00 AM	94886.15	57722.18	7907.18	3953.59
15	07/31/1991 12:00 AM	94886.15	62466.47	39535.88	19767.94
16	08/31/1991 12:00 AM	94886.15	52187.18	0.00	0.00
17	09/30/1991 12:00 AM	94886.15	41117.17	0.00	0.00

Figure 7-3 Root Zone Moisture Budget: Native and Riparian Vegetation Precipitation

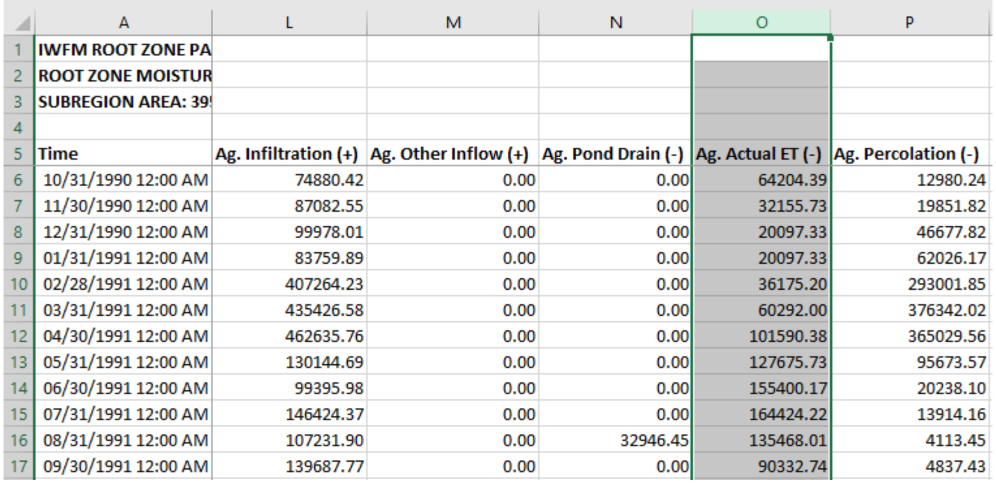


	A	AJ	AK	AL
1	IWFM ROOT ZONE PA			
2	ROOT ZONE MOISTUR			
3	SUBREGION AREA: 39			
4				
5	Time	Native&Riparian Veg. Potential ET	Native&Riparian Veg. Precipitation	Native&Riparian Veg. Inflow as Surface Runoff
6	10/31/1990 12:00 AM	14002.24	16473.28	0.00
7	11/30/1990 12:00 AM	6589.29	20591.61	0.00
8	12/31/1990 12:00 AM	4118.31	24709.93	0.00
9	01/31/1991 12:00 AM	4118.31	20591.61	0.00
10	02/28/1991 12:00 AM	7412.95	247099.26	0.00
11	03/31/1991 12:00 AM	12354.92	288282.47	0.00
12	04/30/1991 12:00 AM	18532.38	329465.68	0.00
13	05/31/1991 12:00 AM	24298.01	16473.28	0.00
14	06/30/1991 12:00 AM	30063.64	4118.32	0.00
15	07/31/1991 12:00 AM	32534.62	20591.61	0.00
16	08/31/1991 12:00 AM	27180.82	0.00	0.00
17	09/30/1991 12:00 AM	21415.19	0.00	0.00

7.3.2 Evapotranspiration

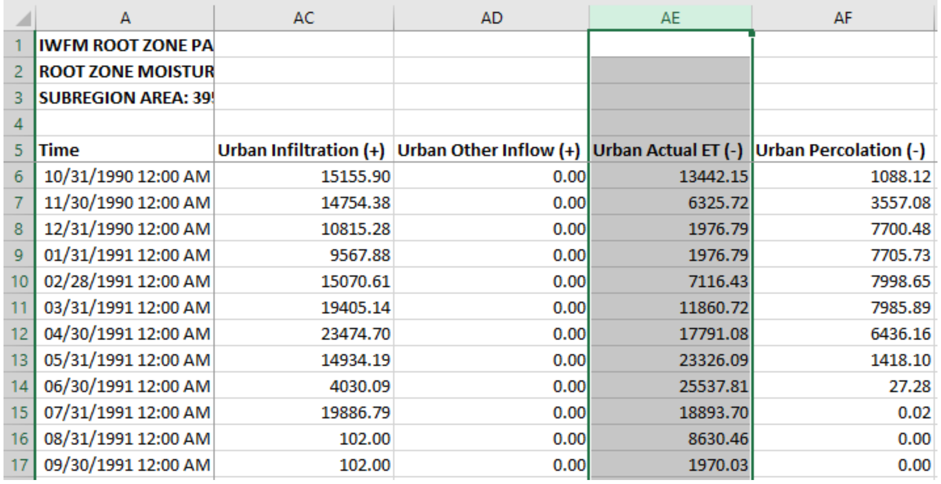
Evapotranspiration (ET), as defined in Section 1.3, is the “volume of water entering the atmosphere through the combined process of evaporation from soil and plant surfaces and transpiration from plants.” IWFM accounts for the volumes of ET in the Root Zone Moisture Budget output. For the subregions or water budget zone of interest, find the ET data under the “Ag. Actual ET”, “Urban Actual ET”, and “Native and Riparian Veg. Actual ET” columns (Figures 7-4 through 7-6). For every timestep, sum all three columns to obtain total ET for the water budget zone.

Figure 7-4 Root Zone Moisture Budget: Agricultural Actual ET



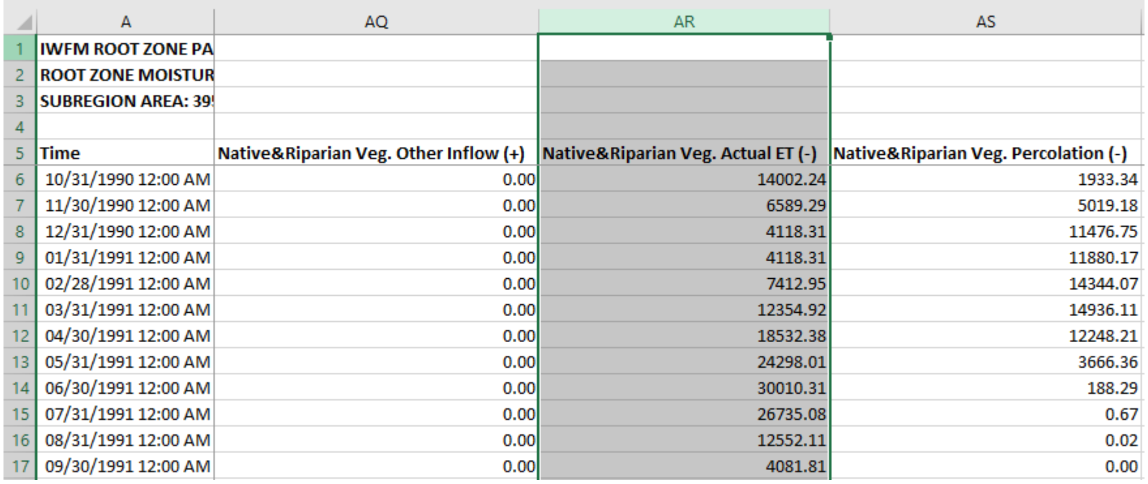
	A	L	M	N	O	P
1	IWFM ROOT ZONE PA					
2	ROOT ZONE MOISTUR					
3	SUBREGION AREA: 39					
4						
5	Time	Ag. Infiltration (+)	Ag. Other Inflow (+)	Ag. Pond Drain (-)	Ag. Actual ET (-)	Ag. Percolation (-)
6	10/31/1990 12:00 AM	74880.42	0.00	0.00	64204.39	12980.24
7	11/30/1990 12:00 AM	87082.55	0.00	0.00	32155.73	19851.82
8	12/31/1990 12:00 AM	99978.01	0.00	0.00	20097.33	46677.82
9	01/31/1991 12:00 AM	83759.89	0.00	0.00	20097.33	62026.17
10	02/28/1991 12:00 AM	407264.23	0.00	0.00	36175.20	293001.85
11	03/31/1991 12:00 AM	435426.58	0.00	0.00	60292.00	376342.02
12	04/30/1991 12:00 AM	462635.76	0.00	0.00	101590.38	365029.56
13	05/31/1991 12:00 AM	130144.69	0.00	0.00	127675.73	95673.57
14	06/30/1991 12:00 AM	99395.98	0.00	0.00	155400.17	20238.10
15	07/31/1991 12:00 AM	146424.37	0.00	0.00	164424.22	13914.16
16	08/31/1991 12:00 AM	107231.90	0.00	32946.45	135468.01	4113.45
17	09/30/1991 12:00 AM	139687.77	0.00	0.00	90332.74	4837.43

Figure 7-5 Root Zone Moisture Budget: Urban Actual ET



	A	AC	AD	AE	AF
1	IWFM ROOT ZONE PA				
2	ROOT ZONE MOISTUR				
3	SUBREGION AREA: 39				
4					
5	Time	Urban Infiltration (+)	Urban Other Inflow (+)	Urban Actual ET (-)	Urban Percolation (-)
6	10/31/1990 12:00 AM	15155.90	0.00	13442.15	1088.12
7	11/30/1990 12:00 AM	14754.38	0.00	6325.72	3557.08
8	12/31/1990 12:00 AM	10815.28	0.00	1976.79	7700.48
9	01/31/1991 12:00 AM	9567.88	0.00	1976.79	7705.73
10	02/28/1991 12:00 AM	15070.61	0.00	7116.43	7998.65
11	03/31/1991 12:00 AM	19405.14	0.00	11860.72	7985.89
12	04/30/1991 12:00 AM	23474.70	0.00	17791.08	6436.16
13	05/31/1991 12:00 AM	14934.19	0.00	23326.09	1418.10
14	06/30/1991 12:00 AM	4030.09	0.00	25537.81	27.28
15	07/31/1991 12:00 AM	19886.79	0.00	18893.70	0.02
16	08/31/1991 12:00 AM	102.00	0.00	8630.46	0.00
17	09/30/1991 12:00 AM	102.00	0.00	1970.03	0.00

Figure 7-6 Root Zone Moisture Budget: Native and Riparian Vegetation Actual ET

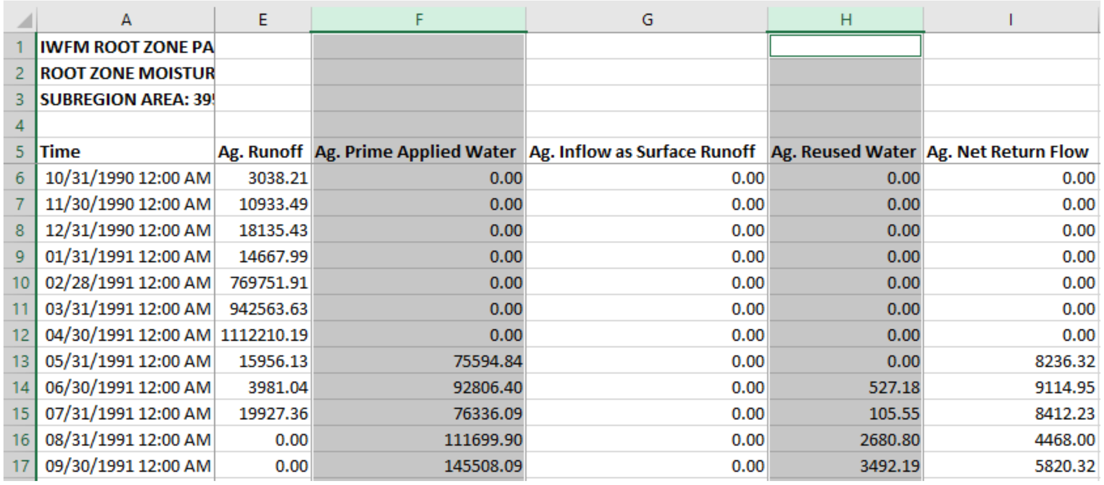


	A	AQ	AR	AS
1	IWFM ROOT ZONE PA			
2	ROOT ZONE MOISTUR			
3	SUBREGION AREA: 39			
4				
5	Time	Native&Riparian Veg. Other Inflow (+)	Native&Riparian Veg. Actual ET (-)	Native&Riparian Veg. Percolation (-)
6	10/31/1990 12:00 AM	0.00	14002.24	1933.34
7	11/30/1990 12:00 AM	0.00	6589.29	5019.18
8	12/31/1990 12:00 AM	0.00	4118.31	11476.75
9	01/31/1991 12:00 AM	0.00	4118.31	11880.17
10	02/28/1991 12:00 AM	0.00	7412.95	14344.07
11	03/31/1991 12:00 AM	0.00	12354.92	14936.11
12	04/30/1991 12:00 AM	0.00	18532.38	12248.21
13	05/31/1991 12:00 AM	0.00	24298.01	3666.36
14	06/30/1991 12:00 AM	0.00	30010.31	188.29
15	07/31/1991 12:00 AM	0.00	26735.08	0.67
16	08/31/1991 12:00 AM	0.00	12552.11	0.02
17	09/30/1991 12:00 AM	0.00	4081.81	0.00

7.3.3 Applied Water

Applied water, as defined in Section 1.3, refers to the “volume of water delivered to the intake of a city water system, a factory, a farm headgate, or managed wetlands; it includes all sources of supply (surface water, groundwater, applied water reuse, and recycled water).” IWFM accounts for the total volume of applied water in the Root Zone Moisture Budget output file. Applied water is split into “Prime applied water”, which refers to the volume of applied water without the reuse component, and “Reused Water”, which is the reused component. Agricultural applied water is found under the “Ag. Prime Applied Water” and “Ag Reused Water” columns (Figure 7-7). For each timestep, sum the two values to obtain the total volume of agricultural applied water.

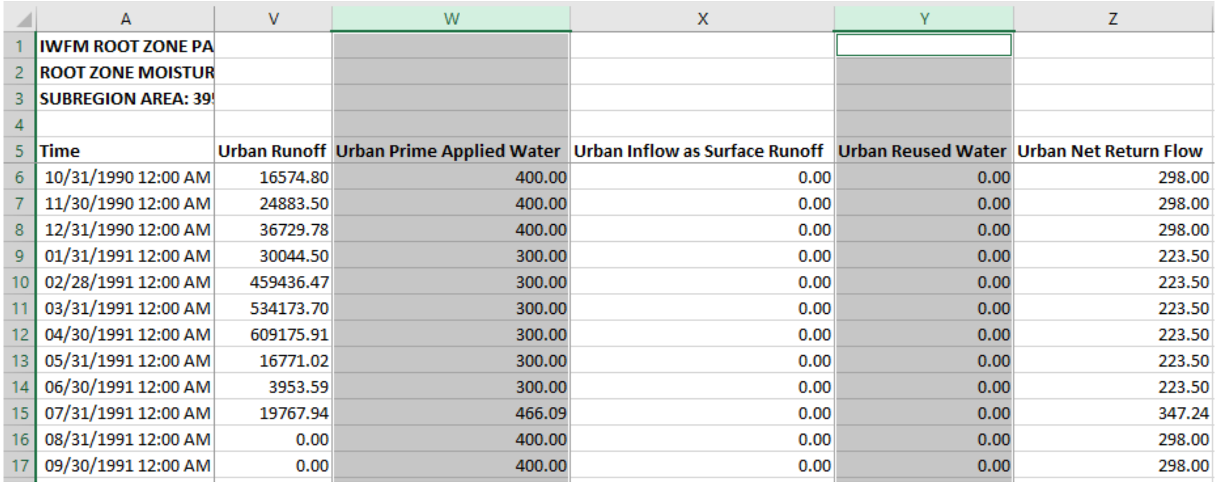
Figure 7-7 **Root Zone Moisture Budget: Agricultural Prime Applied Water and Agricultural Reused Water**



	A	E	F	G	H	I
1	IWFM ROOT ZONE PA					
2	ROOT ZONE MOISTUR					
3	SUBREGION AREA: 39					
4						
5	Time	Ag. Runoff	Ag. Prime Applied Water	Ag. Inflow as Surface Runoff	Ag. Reused Water	Ag. Net Return Flow
6	10/31/1990 12:00 AM	3038.21	0.00	0.00	0.00	0.00
7	11/30/1990 12:00 AM	10933.49	0.00	0.00	0.00	0.00
8	12/31/1990 12:00 AM	18135.43	0.00	0.00	0.00	0.00
9	01/31/1991 12:00 AM	14667.99	0.00	0.00	0.00	0.00
10	02/28/1991 12:00 AM	769751.91	0.00	0.00	0.00	0.00
11	03/31/1991 12:00 AM	942563.63	0.00	0.00	0.00	0.00
12	04/30/1991 12:00 AM	1112210.19	0.00	0.00	0.00	0.00
13	05/31/1991 12:00 AM	15956.13	75594.84	0.00	0.00	8236.32
14	06/30/1991 12:00 AM	3981.04	92806.40	0.00	527.18	9114.95
15	07/31/1991 12:00 AM	19927.36	76336.09	0.00	105.55	8412.23
16	08/31/1991 12:00 AM	0.00	111699.90	0.00	2680.80	4468.00
17	09/30/1991 12:00 AM	0.00	145508.09	0.00	3492.19	5820.32

Urban applied water is found under the "Urban Prime Applied Water" and "Urban Reused Water" columns (Figure 7-8). For each timestep, sum the two values to obtain the total volume of urban applied water.

Figure 7-8 **Root Zone Moisture Budget: Urban Prime Applied Water and Urban Reused Water**



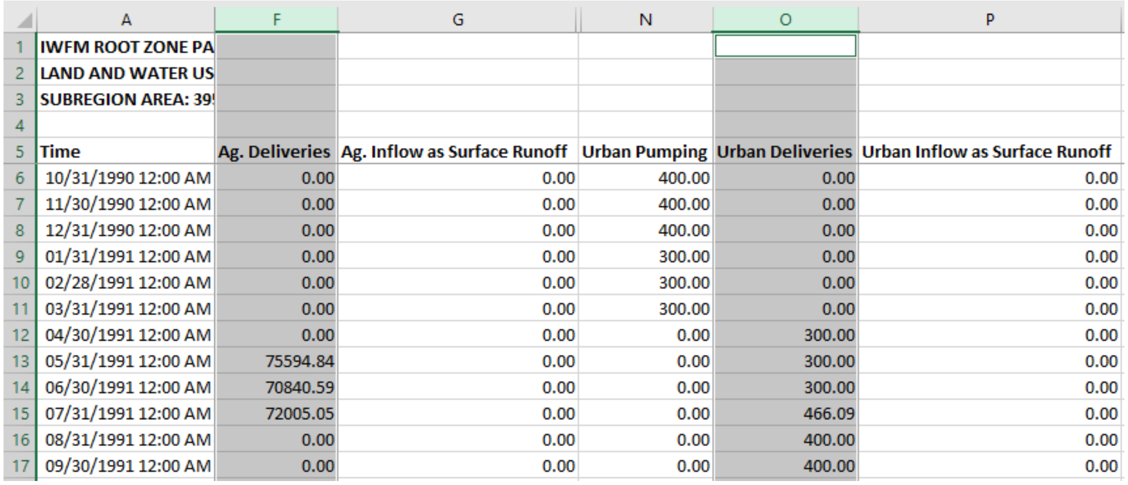
	A	V	W	X	Y	Z
1	IWFM ROOT ZONE PA					
2	ROOT ZONE MOISTUR					
3	SUBREGION AREA: 39					
4						
5	Time	Urban Runoff	Urban Prime Applied Water	Urban Inflow as Surface Runoff	Urban Reused Water	Urban Net Return Flow
6	10/31/1990 12:00 AM	16574.80	400.00	0.00	0.00	298.00
7	11/30/1990 12:00 AM	24883.50	400.00	0.00	0.00	298.00
8	12/31/1990 12:00 AM	36729.78	400.00	0.00	0.00	298.00
9	01/31/1991 12:00 AM	30044.50	300.00	0.00	0.00	223.50
10	02/28/1991 12:00 AM	459436.47	300.00	0.00	0.00	223.50
11	03/31/1991 12:00 AM	534173.70	300.00	0.00	0.00	223.50
12	04/30/1991 12:00 AM	609175.91	300.00	0.00	0.00	223.50
13	05/31/1991 12:00 AM	16771.02	300.00	0.00	0.00	223.50
14	06/30/1991 12:00 AM	3953.59	300.00	0.00	0.00	223.50
15	07/31/1991 12:00 AM	19767.94	466.09	0.00	0.00	347.24
16	08/31/1991 12:00 AM	0.00	400.00	0.00	0.00	298.00
17	09/30/1991 12:00 AM	0.00	400.00	0.00	0.00	298.00

The total volume of applied water is the sum of agricultural applied water and urban applied water.

7.3.4 Surface Water Delivery

Surface water delivery, as defined in Section 1.3, refers to the "volume of surface water delivered to a water budget zone. This does not equal the volume of surface water diversion and imported water because the latter also include conveyance seepage and evaporation during transport of the water." IWFM splits surface water into diversions, which are taken out of a simulated stream, and imports, which come from outside the model area or from a stream that is not explicitly simulated. The total volume of surface water that is delivered to a zone, after conveyance losses, is reported as "Deliveries." IWFM accounts for the total volume of deliveries in the Land and Water Use Budget output. For the subregions or water budget zone of interest, the volumes of water deliveries are reported in the "Ag. Deliveries" and "Urban Deliveries" columns (Figure 7-9). For each timestep, sum both columns to obtain total surface water delivery to a water budget zone.

Figure 7-9 Land and Water Use Budget: Agricultural and Urban Deliveries



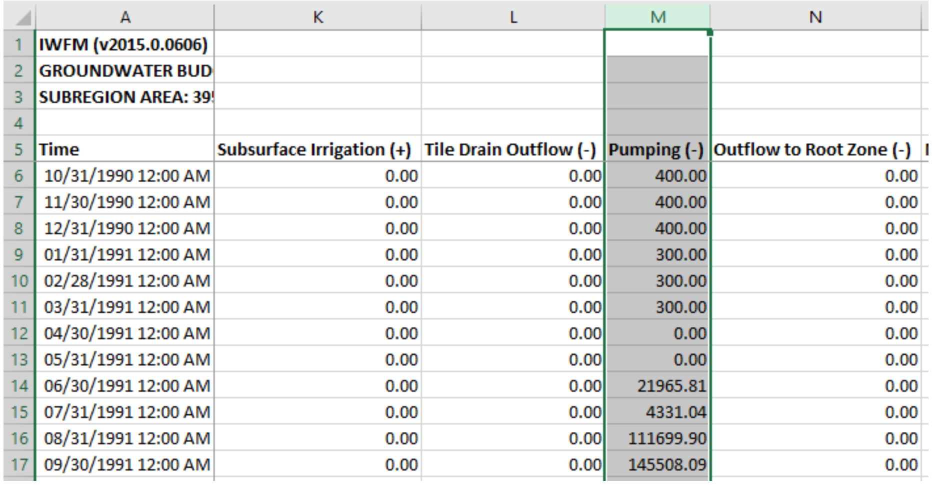
	A	F	G	N	O	P
1	IWFM ROOT ZONE PA					
2	LAND AND WATER US					
3	SUBREGION AREA: 39					
4						
5	Time	Ag. Deliveries	Ag. Inflow as Surface Runoff	Urban Pumping	Urban Deliveries	Urban Inflow as Surface Runoff
6	10/31/1990 12:00 AM	0.00	0.00	400.00	0.00	0.00
7	11/30/1990 12:00 AM	0.00	0.00	400.00	0.00	0.00
8	12/31/1990 12:00 AM	0.00	0.00	400.00	0.00	0.00
9	01/31/1991 12:00 AM	0.00	0.00	300.00	0.00	0.00
10	02/28/1991 12:00 AM	0.00	0.00	300.00	0.00	0.00
11	03/31/1991 12:00 AM	0.00	0.00	300.00	0.00	0.00
12	04/30/1991 12:00 AM	0.00	0.00	0.00	300.00	0.00
13	05/31/1991 12:00 AM	75594.84	0.00	0.00	300.00	0.00
14	06/30/1991 12:00 AM	70840.59	0.00	0.00	300.00	0.00
15	07/31/1991 12:00 AM	72005.05	0.00	0.00	466.09	0.00
16	08/31/1991 12:00 AM	0.00	0.00	0.00	400.00	0.00
17	09/30/1991 12:00 AM	0.00	0.00	0.00	400.00	0.00

7.3.5 Groundwater Extraction

Groundwater extraction, as defined in Section 1.3, refers to the "volume of groundwater pumped (extracted) from the underlying aquifer(s) for use within the water budget zone. It does not include groundwater export, stored water extraction, and stored water export." IWFM accounts for the total volume of pumping in the Groundwater Budget output. For the subregions or water budget zone of interest, the pumping volume is reported in the "Pumping" column (Figure 7-10).

If stored water extraction is simulated (as described in Section 5.7, "Stored Water Extraction"), that volume will need to be subtracted to compute groundwater extraction as defined in this handbook. Typically, groundwater extraction is used for overlying use and not for export. If groundwater is pumped for use elsewhere, then that volume will also need to be accounted for and subtracted from the total groundwater pumping reported in the Groundwater Budget output file. IWFM currently does not include separate reporting of groundwater exports. Typically, volumes of groundwater pumped for stored water extraction and groundwater export are measured and readily available through reports or model input data.

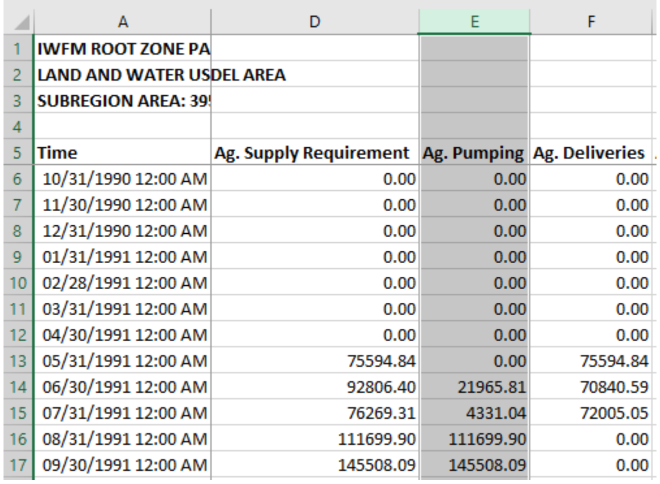
Figure 7-10 Groundwater Budget: Pumping



	A	K	L	M	N
1	IWFM (v2015.0.0606)				
2	GROUNDWATER BUD				
3	SUBREGION AREA: 39				
4					
5	Time	Subsurface Irrigation (+)	Tile Drain Outflow (-)	Pumping (-)	Outflow to Root Zone (-)
6	10/31/1990 12:00 AM	0.00	0.00	400.00	0.00
7	11/30/1990 12:00 AM	0.00	0.00	400.00	0.00
8	12/31/1990 12:00 AM	0.00	0.00	400.00	0.00
9	01/31/1991 12:00 AM	0.00	0.00	300.00	0.00
10	02/28/1991 12:00 AM	0.00	0.00	300.00	0.00
11	03/31/1991 12:00 AM	0.00	0.00	300.00	0.00
12	04/30/1991 12:00 AM	0.00	0.00	0.00	0.00
13	05/31/1991 12:00 AM	0.00	0.00	0.00	0.00
14	06/30/1991 12:00 AM	0.00	0.00	21965.81	0.00
15	07/31/1991 12:00 AM	0.00	0.00	4331.04	0.00
16	08/31/1991 12:00 AM	0.00	0.00	111699.90	0.00
17	09/30/1991 12:00 AM	0.00	0.00	145508.09	0.00

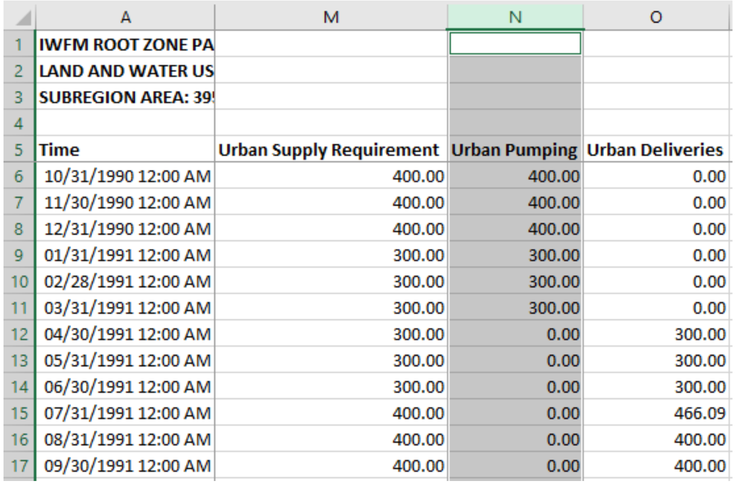
IWFM's Land and Water Use Budget also reports pumping for overland use by use type. In the Land and Water Use Budget, pumping volumes for each timestep can be found under the "Ag. Pumping" and "Urban Pumping" columns (Figures 7-11 and 7-12). This is useful if the user wants to separate the pumping volumes by use type rather than lumping them into a single total value.

Figure 7-11 Land and Water Use Budget: Agricultural Pumping



	A	D	E	F
1	IWFM ROOT ZONE PA			
2	LAND AND WATER US	DEL AREA		
3	SUBREGION AREA: 39			
4				
5	Time	Ag. Supply Requirement	Ag. Pumping	Ag. Deliveries
6	10/31/1990 12:00 AM	0.00	0.00	0.00
7	11/30/1990 12:00 AM	0.00	0.00	0.00
8	12/31/1990 12:00 AM	0.00	0.00	0.00
9	01/31/1991 12:00 AM	0.00	0.00	0.00
10	02/28/1991 12:00 AM	0.00	0.00	0.00
11	03/31/1991 12:00 AM	0.00	0.00	0.00
12	04/30/1991 12:00 AM	0.00	0.00	0.00
13	05/31/1991 12:00 AM	75594.84	0.00	75594.84
14	06/30/1991 12:00 AM	92806.40	21965.81	70840.59
15	07/31/1991 12:00 AM	76269.31	4331.04	72005.05
16	08/31/1991 12:00 AM	111699.90	111699.90	0.00
17	09/30/1991 12:00 AM	145508.09	145508.09	0.00

Figure 7-12 Land and Water Use Budget: Urban Pumping

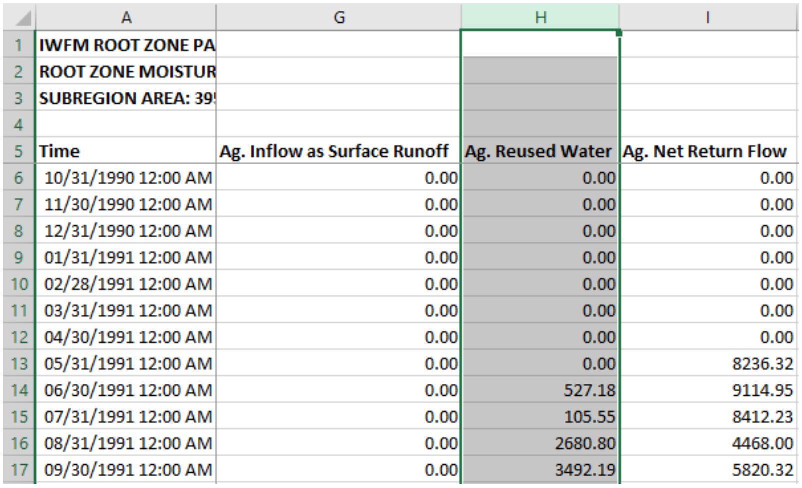


	A	M	N	O
1	IWFM ROOT ZONE PA			
2	LAND AND WATER US			
3	SUBREGION AREA: 39			
4				
5	Time	Urban Supply Requirement	Urban Pumping	Urban Deliveries
6	10/31/1990 12:00 AM	400.00	400.00	0.00
7	11/30/1990 12:00 AM	400.00	400.00	0.00
8	12/31/1990 12:00 AM	400.00	400.00	0.00
9	01/31/1991 12:00 AM	300.00	300.00	0.00
10	02/28/1991 12:00 AM	300.00	300.00	0.00
11	03/31/1991 12:00 AM	300.00	300.00	0.00
12	04/30/1991 12:00 AM	300.00	0.00	300.00
13	05/31/1991 12:00 AM	300.00	0.00	300.00
14	06/30/1991 12:00 AM	300.00	0.00	300.00
15	07/31/1991 12:00 AM	400.00	0.00	466.09
16	08/31/1991 12:00 AM	400.00	0.00	400.00
17	09/30/1991 12:00 AM	400.00	0.00	400.00

7.3.6 Applied Water Reuse

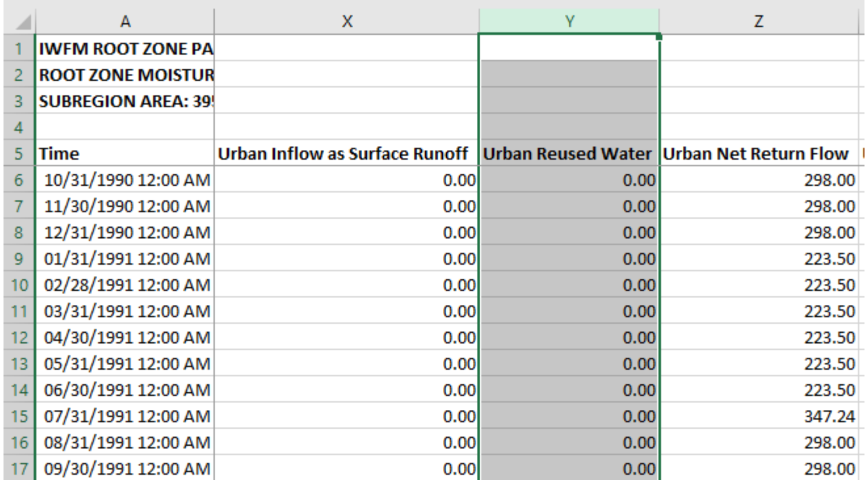
Applied water reuse, as defined in Section 1.3, refers to the "volume of applied water contributing to 1) lateral flow below the land surface that is influenced by impermeable layers and re-emerges as return flow for reuse in the land system, 2) tailwater available for reuse in the land system, or 3) a combination of both." The key distinction between Applied Water Reuse and return flow is that Reuse must be reapplied to meet some form of demand. IWFM accounts for the total volume of reuse in the Root Zone Moisture Budget output. The total volume of reuse is reported in the "Ag. Reused Water" and the "Urban Reused Water" columns (Figures 7-13 and 7-14). Reuse in the "Urban Reused Water" column may include recycled water not specifically identified as such because recycled water is not explicitly simulated in IWFM.

Figure 7-13 **Root Zone Moisture Budget: Agricultural Reused Water**



	A	G	H	I
1	IWFM ROOT ZONE PA			
2	ROOT ZONE MOISTUR			
3	SUBREGION AREA: 39			
4				
5	Time	Ag. Inflow as Surface Runoff	Ag. Reused Water	Ag. Net Return Flow
6	10/31/1990 12:00 AM	0.00	0.00	0.00
7	11/30/1990 12:00 AM	0.00	0.00	0.00
8	12/31/1990 12:00 AM	0.00	0.00	0.00
9	01/31/1991 12:00 AM	0.00	0.00	0.00
10	02/28/1991 12:00 AM	0.00	0.00	0.00
11	03/31/1991 12:00 AM	0.00	0.00	0.00
12	04/30/1991 12:00 AM	0.00	0.00	0.00
13	05/31/1991 12:00 AM	0.00	0.00	8236.32
14	06/30/1991 12:00 AM	0.00	527.18	9114.95
15	07/31/1991 12:00 AM	0.00	105.55	8412.23
16	08/31/1991 12:00 AM	0.00	2680.80	4468.00
17	09/30/1991 12:00 AM	0.00	3492.19	5820.32

Figure 7-14 **Root Zone Moisture Budget: Urban Reused Water**

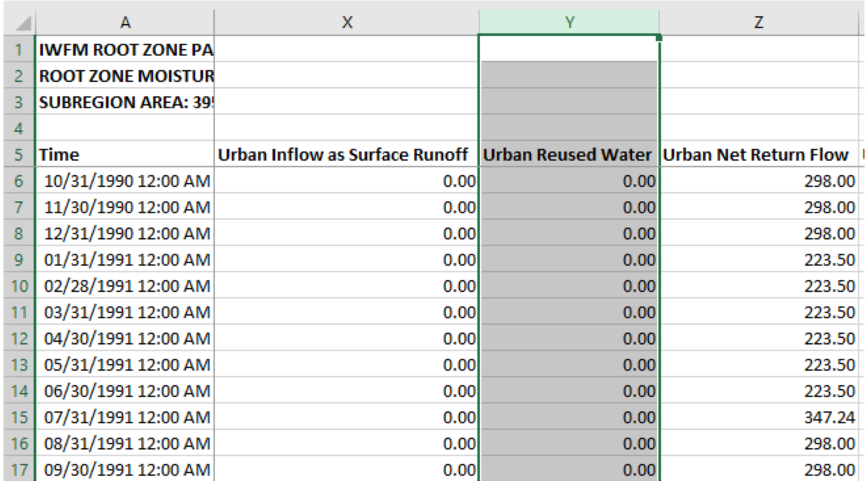


	A	X	Y	Z
1	IWFM ROOT ZONE PA			
2	ROOT ZONE MOISTUR			
3	SUBREGION AREA: 39			
4				
5	Time	Urban Inflow as Surface Runoff	Urban Reused Water	Urban Net Return Flow
6	10/31/1990 12:00 AM	0.00	0.00	298.00
7	11/30/1990 12:00 AM	0.00	0.00	298.00
8	12/31/1990 12:00 AM	0.00	0.00	298.00
9	01/31/1991 12:00 AM	0.00	0.00	223.50
10	02/28/1991 12:00 AM	0.00	0.00	223.50
11	03/31/1991 12:00 AM	0.00	0.00	223.50
12	04/30/1991 12:00 AM	0.00	0.00	223.50
13	05/31/1991 12:00 AM	0.00	0.00	223.50
14	06/30/1991 12:00 AM	0.00	0.00	223.50
15	07/31/1991 12:00 AM	0.00	0.00	347.24
16	08/31/1991 12:00 AM	0.00	0.00	298.00
17	09/30/1991 12:00 AM	0.00	0.00	298.00

7.3.7 Recycled Water

Recycled water, as defined in Section 1.3, refers to the "volume of water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur within the water budget zone. It includes wastewater that is treated, stored, distributed, and reused or recirculated for beneficial uses." Recycled water is not explicitly simulated in IWFM; but, the Root Zone Moisture Budget results file reports for the volume of reuse in the "Urban Reused Water" column (Figure 7-15). Reuse in the "Urban Reused Water" column may include recycled water not specifically identified as such. Consult the model documentation to determine whether recycled water is accounted for and can be derived from the reuse component.

Figure 7-15 **Root Zone Moisture Budget: Urban Reused Water**



	A	X	Y	Z
1	IWFM ROOT ZONE PA			
2	ROOT ZONE MOISTUR			
3	SUBREGION AREA: 39			
4				
5	Time	Urban Inflow as Surface Runoff	Urban Reused Water	Urban Net Return Flow
6	10/31/1990 12:00 AM	0.00	0.00	298.00
7	11/30/1990 12:00 AM	0.00	0.00	298.00
8	12/31/1990 12:00 AM	0.00	0.00	298.00
9	01/31/1991 12:00 AM	0.00	0.00	223.50
10	02/28/1991 12:00 AM	0.00	0.00	223.50
11	03/31/1991 12:00 AM	0.00	0.00	223.50
12	04/30/1991 12:00 AM	0.00	0.00	223.50
13	05/31/1991 12:00 AM	0.00	0.00	223.50
14	06/30/1991 12:00 AM	0.00	0.00	223.50
15	07/31/1991 12:00 AM	0.00	0.00	347.24
16	08/31/1991 12:00 AM	0.00	0.00	298.00
17	09/30/1991 12:00 AM	0.00	0.00	298.00

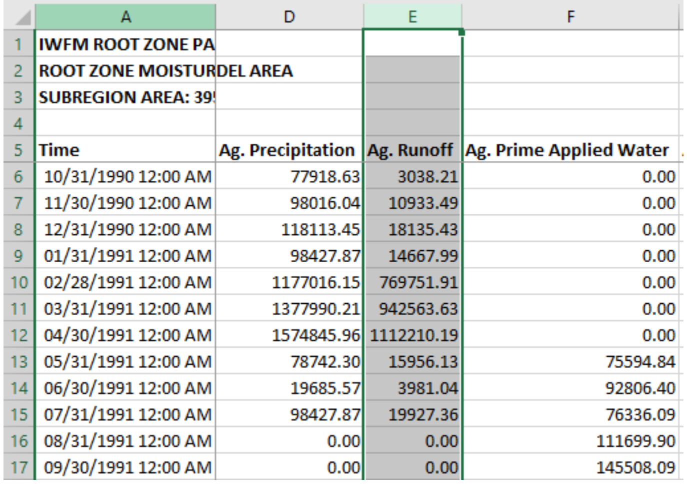
7.3.8 Recycled Water Export

Recycled water export, as defined in Section 1.3, refers to the "volume of recycled water diverted from the land system within a water budget zone for use outside the zone." IWFM currently does not simulate or report recycled water export.

7.3.9 Runoff

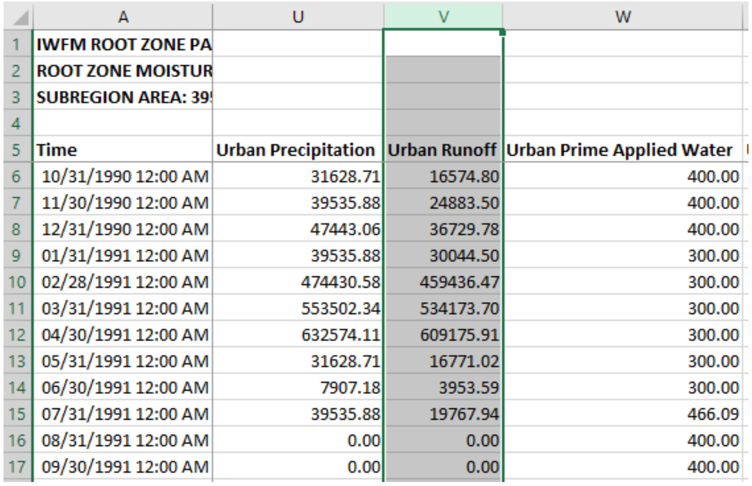
Runoff, as defined in Section 1.3, refers to the "volume of water flowing into the surface water system within a water budget zone from precipitation over the land surface." IWFM accounts for the volume of runoff in the Root Zone Moisture Budget output file. For the subregion or water budget zone of interest, the volume of runoff is reported in the "Ag. Runoff", "Urban Runoff", and "Native and Riparian Vegetation Runoff" columns (Figures 7-16 through 7-18). For each timestep, sum all three columns to obtain total runoff.

Figure 7-16 Root Zone Moisture Budget: Agricultural Runoff



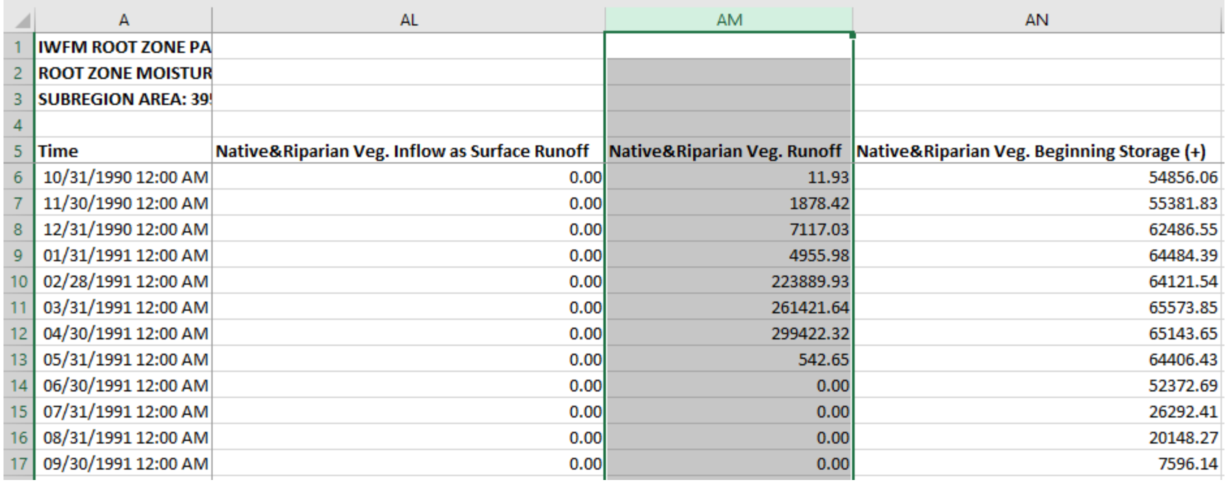
	A	D	E	F
1	IWFM ROOT ZONE PA			
2	ROOT ZONE MOISTUR	DEL AREA		
3	SUBREGION AREA: 39			
4				
5	Time	Ag. Precipitation	Ag. Runoff	Ag. Prime Applied Water
6	10/31/1990 12:00 AM	77918.63	3038.21	0.00
7	11/30/1990 12:00 AM	98016.04	10933.49	0.00
8	12/31/1990 12:00 AM	118113.45	18135.43	0.00
9	01/31/1991 12:00 AM	98427.87	14667.99	0.00
10	02/28/1991 12:00 AM	1177016.15	769751.91	0.00
11	03/31/1991 12:00 AM	1377990.21	942563.63	0.00
12	04/30/1991 12:00 AM	1574845.96	1112210.19	0.00
13	05/31/1991 12:00 AM	78742.30	15956.13	75594.84
14	06/30/1991 12:00 AM	19685.57	3981.04	92806.40
15	07/31/1991 12:00 AM	98427.87	19927.36	76336.09
16	08/31/1991 12:00 AM	0.00	0.00	111699.90
17	09/30/1991 12:00 AM	0.00	0.00	145508.09

Figure 7-17 Root Zone Moisture Budget: Urban Runoff



	A	U	V	W
1	IWFM ROOT ZONE PA			
2	ROOT ZONE MOISTUR			
3	SUBREGION AREA: 39			
4				
5	Time	Urban Precipitation	Urban Runoff	Urban Prime Applied Water
6	10/31/1990 12:00 AM	31628.71	16574.80	400.00
7	11/30/1990 12:00 AM	39535.88	24883.50	400.00
8	12/31/1990 12:00 AM	47443.06	36729.78	400.00
9	01/31/1991 12:00 AM	39535.88	30044.50	300.00
10	02/28/1991 12:00 AM	474430.58	459436.47	300.00
11	03/31/1991 12:00 AM	553502.34	534173.70	300.00
12	04/30/1991 12:00 AM	632574.11	609175.91	300.00
13	05/31/1991 12:00 AM	31628.71	16771.02	300.00
14	06/30/1991 12:00 AM	7907.18	3953.59	300.00
15	07/31/1991 12:00 AM	39535.88	19767.94	466.09
16	08/31/1991 12:00 AM	0.00	0.00	400.00
17	09/30/1991 12:00 AM	0.00	0.00	400.00

Figure 7-18 Root Zone Moisture Budget: Native and Riparian Vegetation Runoff

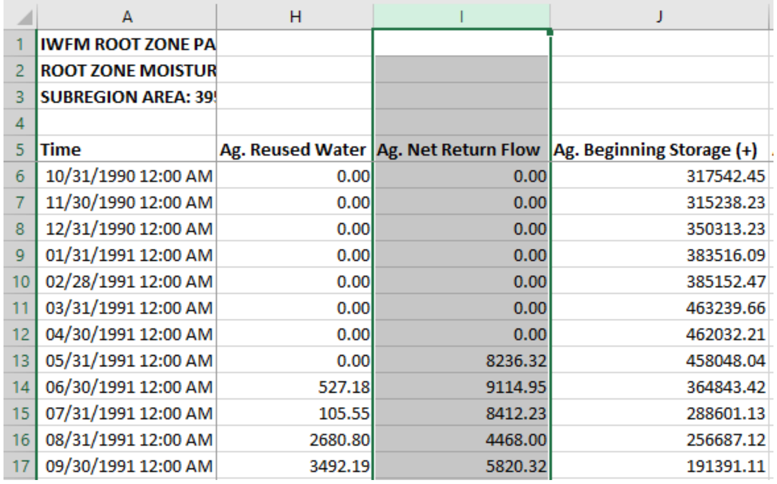


	A	AL	AM	AN
1	IWFM ROOT ZONE PA			
2	ROOT ZONE MOISTUR			
3	SUBREGION AREA: 39			
4				
5	Time	Native&Riparian Veg. Inflow as Surface Runoff	Native&Riparian Veg. Runoff	Native&Riparian Veg. Beginning Storage (+)
6	10/31/1990 12:00 AM	0.00	11.93	54856.06
7	11/30/1990 12:00 AM	0.00	1878.42	55381.83
8	12/31/1990 12:00 AM	0.00	7117.03	62486.55
9	01/31/1991 12:00 AM	0.00	4955.98	64484.39
10	02/28/1991 12:00 AM	0.00	223889.93	64121.54
11	03/31/1991 12:00 AM	0.00	261421.64	65573.85
12	04/30/1991 12:00 AM	0.00	299422.32	65143.65
13	05/31/1991 12:00 AM	0.00	542.65	64406.43
14	06/30/1991 12:00 AM	0.00	0.00	52372.69
15	07/31/1991 12:00 AM	0.00	0.00	26292.41
16	08/31/1991 12:00 AM	0.00	0.00	20148.27
17	09/30/1991 12:00 AM	0.00	0.00	7596.14

7.3.10 Return Flow

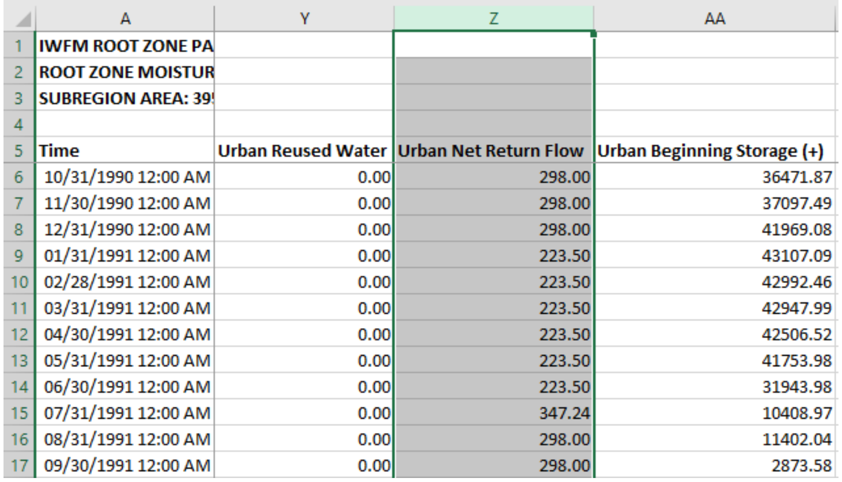
Return flow, as defined in Section 1.3, refers to the "volume of applied water that is not consumptively used and flows to the surface water system. It includes treated wastewater discharges to the surface water system." IWFM accounts for the volume of return flow in the Root Zone Moisture Budget output file. For the subregion or zone corresponding to the water budget zone of interest, the volume of return flow is reported in the "Ag. Net Return Flow" and "Urban Net Return Flow" columns (Figures 7-19 and 7-20). For each timestep, sum both columns to obtain total volume of return flow in the water budget zone.

Figure 7-19 Root Zone Moisture Budget: Agricultural Net Return Flow



	A	H	I	J
1	IWFM ROOT ZONE PA			
2	ROOT ZONE MOISTUR			
3	SUBREGION AREA: 39			
4				
5	Time	Ag. Reused Water	Ag. Net Return Flow	Ag. Beginning Storage (+)
6	10/31/1990 12:00 AM	0.00	0.00	317542.45
7	11/30/1990 12:00 AM	0.00	0.00	315238.23
8	12/31/1990 12:00 AM	0.00	0.00	350313.23
9	01/31/1991 12:00 AM	0.00	0.00	383516.09
10	02/28/1991 12:00 AM	0.00	0.00	385152.47
11	03/31/1991 12:00 AM	0.00	0.00	463239.66
12	04/30/1991 12:00 AM	0.00	0.00	462032.21
13	05/31/1991 12:00 AM	0.00	8236.32	458048.04
14	06/30/1991 12:00 AM	527.18	9114.95	364843.42
15	07/31/1991 12:00 AM	105.55	8412.23	288601.13
16	08/31/1991 12:00 AM	2680.80	4468.00	256687.12
17	09/30/1991 12:00 AM	3492.19	5820.32	191391.11

Figure 7-20 **Root Zone Moisture Budget: Urban Net Return Flow**

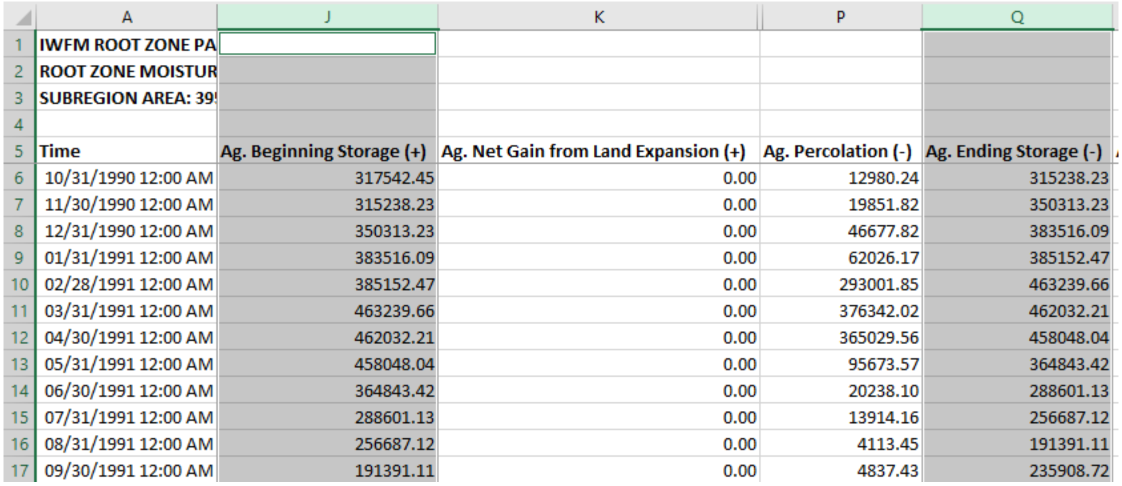


	A	Y	Z	AA
1	IWFM ROOT ZONE PA			
2	ROOT ZONE MOISTUR			
3	SUBREGION AREA: 39			
4				
5	Time	Urban Reused Water	Urban Net Return Flow	Urban Beginning Storage (+)
6	10/31/1990 12:00 AM	0.00	298.00	36471.87
7	11/30/1990 12:00 AM	0.00	298.00	37097.49
8	12/31/1990 12:00 AM	0.00	298.00	41969.08
9	01/31/1991 12:00 AM	0.00	223.50	43107.09
10	02/28/1991 12:00 AM	0.00	223.50	42992.46
11	03/31/1991 12:00 AM	0.00	223.50	42947.99
12	04/30/1991 12:00 AM	0.00	223.50	42506.52
13	05/31/1991 12:00 AM	0.00	223.50	41753.98
14	06/30/1991 12:00 AM	0.00	223.50	31943.98
15	07/31/1991 12:00 AM	0.00	347.24	10408.97
16	08/31/1991 12:00 AM	0.00	298.00	11402.04
17	09/30/1991 12:00 AM	0.00	298.00	2873.58

7.3.11 Change in Land System Storage

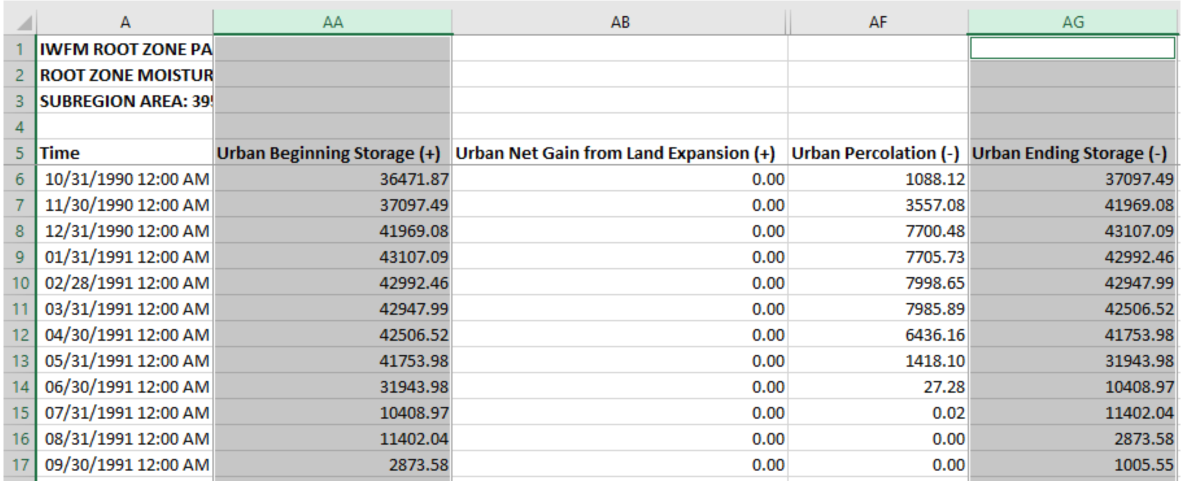
Change in land system storage, as defined in Section 1.3, refers to the "net change in the volume of water stored within the land system, which includes ponded water on the land surface (not including streams, lakes, and conveyance facilities) and soil moisture within the unsaturated zone, which includes the root zone." IWFM accounts for the root zone and unsaturated zone portions of the change in land system storage through the root zone and unsaturated zone packages. Change in storage in the ponded land areas is not explicitly reported in IWFM. Change in ponded land area refers to water applied to fields for ponding that has yet to evaporate, transpire through a crop or habitat, become return flow or recharge, or any combination thereof. While IWFM simulates the practice of ponded crops, it does not report the volume of water remaining on the surface at each timestep. The change in root zone storage is reported in the Root Zone Moisture Budget output file. Agricultural, urban, and native and riparian lands are reported separately in the Root Zone Moisture Budget. For the subregion or water budget zone of interest, change in root zone storage for each timestep can be calculated by subtracting the "Ending Storage" from the "Beginning Storage" columns (Figures 7-21 through 7-23). The change in storage in the unsaturated zone beneath the root zone is reported in the Unsaturated Zone Budget output file. Similarly, for the subregion or water budget zone of interest, the change in storage in the unsaturated zone for each timestep can be calculated by subtracting the "Ending Storage" from the "Beginning Storage" columns (Figure 7-24). The total change in storage in the land system for each timestep is the sum of root zone change in storage and the unsaturated zone change in storage.

Figure 7-21 Root Zone Moisture Budget: Agricultural Beginning and Ending Storage



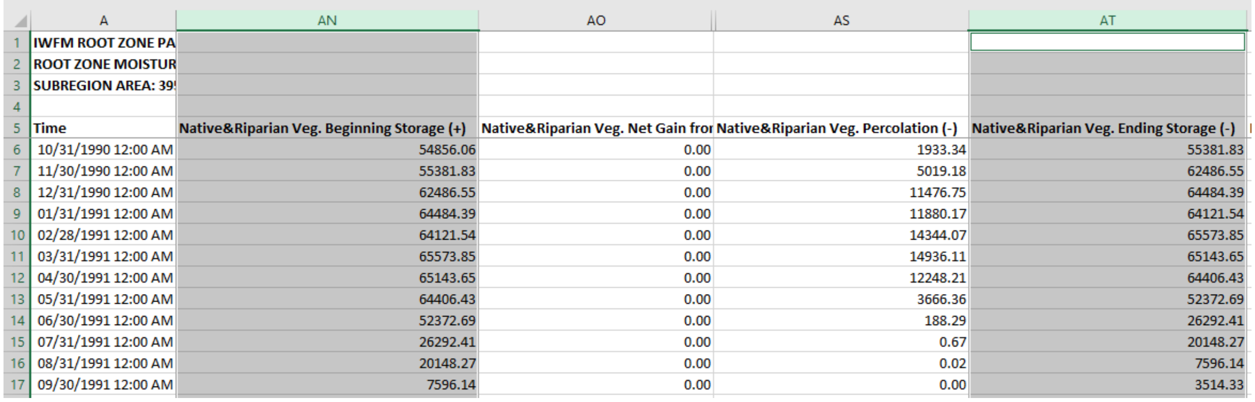
	A	J	K	P	Q
1	IWFM ROOT ZONE PA				
2	ROOT ZONE MOISTUR				
3	SUBREGION AREA: 39				
4					
5	Time	Ag. Beginning Storage (+)	Ag. Net Gain from Land Expansion (+)	Ag. Percolation (-)	Ag. Ending Storage (-)
6	10/31/1990 12:00 AM	317542.45	0.00	12980.24	315238.23
7	11/30/1990 12:00 AM	315238.23	0.00	19851.82	350313.23
8	12/31/1990 12:00 AM	350313.23	0.00	46677.82	383516.09
9	01/31/1991 12:00 AM	383516.09	0.00	62026.17	385152.47
10	02/28/1991 12:00 AM	385152.47	0.00	293001.85	463239.66
11	03/31/1991 12:00 AM	463239.66	0.00	376342.02	462032.21
12	04/30/1991 12:00 AM	462032.21	0.00	365029.56	458048.04
13	05/31/1991 12:00 AM	458048.04	0.00	95673.57	364843.42
14	06/30/1991 12:00 AM	364843.42	0.00	20238.10	288601.13
15	07/31/1991 12:00 AM	288601.13	0.00	13914.16	256687.12
16	08/31/1991 12:00 AM	256687.12	0.00	4113.45	191391.11
17	09/30/1991 12:00 AM	191391.11	0.00	4837.43	235908.72

Figure 7-22 Root Zone Moisture Budget: Urban Beginning and Ending Storage



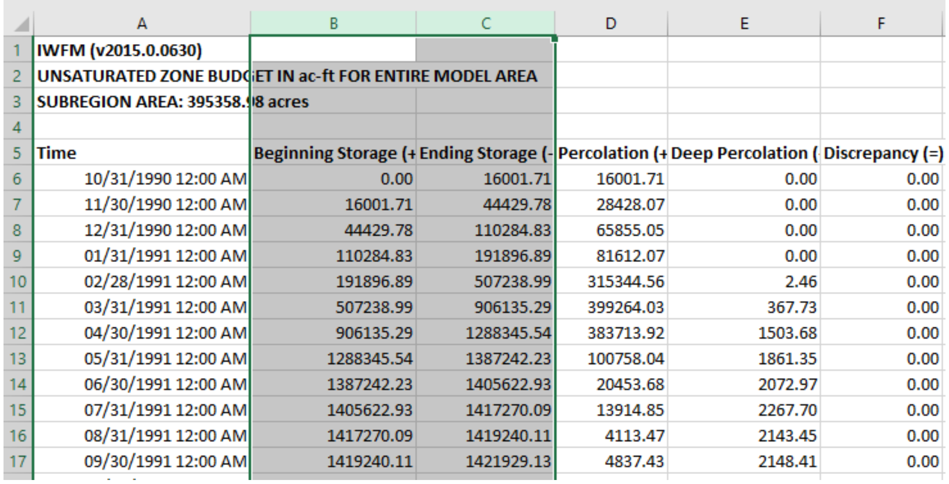
	A	AA	AB	AF	AG
1	IWFM ROOT ZONE PA				
2	ROOT ZONE MOISTUR				
3	SUBREGION AREA: 39				
4					
5	Time	Urban Beginning Storage (+)	Urban Net Gain from Land Expansion (+)	Urban Percolation (-)	Urban Ending Storage (-)
6	10/31/1990 12:00 AM	36471.87	0.00	1088.12	37097.49
7	11/30/1990 12:00 AM	37097.49	0.00	3557.08	41969.08
8	12/31/1990 12:00 AM	41969.08	0.00	7700.48	43107.09
9	01/31/1991 12:00 AM	43107.09	0.00	7705.73	42992.46
10	02/28/1991 12:00 AM	42992.46	0.00	7998.65	42947.99
11	03/31/1991 12:00 AM	42947.99	0.00	7985.89	42506.52
12	04/30/1991 12:00 AM	42506.52	0.00	6436.16	41753.98
13	05/31/1991 12:00 AM	41753.98	0.00	1418.10	31943.98
14	06/30/1991 12:00 AM	31943.98	0.00	27.28	10408.97
15	07/31/1991 12:00 AM	10408.97	0.00	0.02	11402.04
16	08/31/1991 12:00 AM	11402.04	0.00	0.00	2873.58
17	09/30/1991 12:00 AM	2873.58	0.00	0.00	1005.55

Figure 7-23 Root Zone Moisture Budget: Native and Riparian Vegetation Beginning and Ending Storage



	A	AN	AO	AS	AT
1	IWFM ROOT ZONE PA				
2	ROOT ZONE MOISTUR				
3	SUBREGION AREA: 39				
4					
5	Time	Native&Riparian Veg. Beginning Storage (+)	Native&Riparian Veg. Net Gain fro	Native&Riparian Veg. Percolation (-)	Native&Riparian Veg. Ending Storage (-)
6	10/31/1990 12:00 AM	54856.06	0.00	1933.34	55381.83
7	11/30/1990 12:00 AM	55381.83	0.00	5019.18	62486.55
8	12/31/1990 12:00 AM	62486.55	0.00	11476.75	64484.39
9	01/31/1991 12:00 AM	64484.39	0.00	11880.17	64121.54
10	02/28/1991 12:00 AM	64121.54	0.00	14344.07	65573.85
11	03/31/1991 12:00 AM	65573.85	0.00	14936.11	65143.65
12	04/30/1991 12:00 AM	65143.65	0.00	12248.21	64406.43
13	05/31/1991 12:00 AM	64406.43	0.00	3666.36	52372.69
14	06/30/1991 12:00 AM	52372.69	0.00	188.29	26292.41
15	07/31/1991 12:00 AM	26292.41	0.00	0.67	20148.27
16	08/31/1991 12:00 AM	20148.27	0.00	0.02	7596.14
17	09/30/1991 12:00 AM	7596.14	0.00	0.00	3514.33

Figure 7-24 Unsaturated Zone Budget: Beginning and Ending Storage



	A	B	C	D	E	F
1	IWFM (v2015.0.0630)					
2	UNSATURATED ZONE BUDGET IN ac-ft FOR ENTIRE MODEL AREA					
3	SUBREGION AREA: 395358.98 acres					
4						
5	Time	Beginning Storage (+	Ending Storage (-	Percolation (+	Deep Percolation (	Discrepancy (=)
6	10/31/1990 12:00 AM	0.00	16001.71	16001.71	0.00	0.00
7	11/30/1990 12:00 AM	16001.71	44429.78	28428.07	0.00	0.00
8	12/31/1990 12:00 AM	44429.78	110284.83	65855.05	0.00	0.00
9	01/31/1991 12:00 AM	110284.83	191896.89	81612.07	0.00	0.00
10	02/28/1991 12:00 AM	191896.89	507238.99	315344.56	2.46	0.00
11	03/31/1991 12:00 AM	507238.99	906135.29	399264.03	367.73	0.00
12	04/30/1991 12:00 AM	906135.29	1288345.54	383713.92	1503.68	0.00
13	05/31/1991 12:00 AM	1288345.54	1387242.23	100758.04	1861.35	0.00
14	06/30/1991 12:00 AM	1387242.23	1405622.93	20453.68	2072.97	0.00
15	07/31/1991 12:00 AM	1405622.93	1417270.09	13914.85	2267.70	0.00
16	08/31/1991 12:00 AM	1417270.09	1419240.11	4113.47	2143.45	0.00
17	09/30/1991 12:00 AM	1419240.11	1421929.13	4837.43	2148.41	0.00

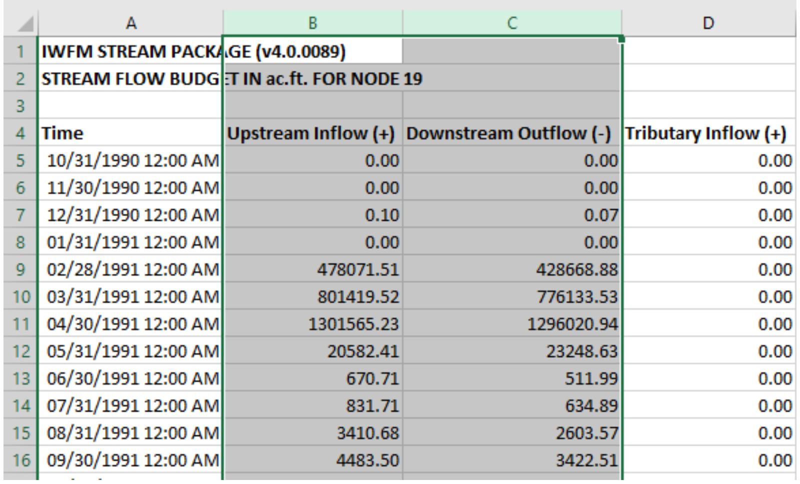
7.4 SURFACE WATER SYSTEM

7.4.1 Stream Inflow and Outflow

Stream inflow, as defined in Section 1.3, refers to the “volume of water entering through streams at the periphery of a water budget zone.” Stream outflow refers to the “volume of water leaving through streams at the periphery of a water budget zone.” IWFM does not report stream budgets by subregion or by user-defined water budget zone; however, the stream budget is available by both reach and stream node. Stream inflows and outflows are reported at both scales. The Stream Node Budget output reports the volume of surface water inflow in the “Upstream Inflow” column and the volume of surface water outflow in the “Downstream Outflow” column for each node. The first step is to identify the stream nodes at the periphery of the water budget zone using the model documentation and maps of the model layout. Next, of the stream nodes at the periphery, identify which nodes flow into the water budget zone (Upstream Inflow) and which nodes flow out (Downstream Outflow). Finally, using the Stream Node Budget, select the appropriate "Upstream Inflow" and "Downstream Outflow" values at each node (Figure 7-25), and then sum the results by "Upstream Inflow" and "Downstream Outflow" to determine the total volume of surface water inflow and surface water outflow.

Additionally, streamflow hydrographs can be developed for every stream node. Hydrographs of stream nodes at the periphery of a water budget zone can be used to develop the timeseries data of surface water inflows and outflows.

Figure 7-25 Stream Budget: Upstream Inflow and Downstream Outflow



	A	B	C	D
1	IWFM STREAM PACKAGE (v4.0.0089)			
2	STREAM FLOW BUDGET IN ac.ft. FOR NODE 19			
3				
4	Time	Upstream Inflow (+)	Downstream Outflow (-)	Tributary Inflow (+)
5	10/31/1990 12:00 AM	0.00	0.00	0.00
6	11/30/1990 12:00 AM	0.00	0.00	0.00
7	12/31/1990 12:00 AM	0.10	0.07	0.00
8	01/31/1991 12:00 AM	0.00	0.00	0.00
9	02/28/1991 12:00 AM	478071.51	428668.88	0.00
10	03/31/1991 12:00 AM	801419.52	776133.53	0.00
11	04/30/1991 12:00 AM	1301565.23	1296020.94	0.00
12	05/31/1991 12:00 AM	20582.41	23248.63	0.00
13	06/30/1991 12:00 AM	670.71	511.99	0.00
14	07/31/1991 12:00 AM	831.71	634.89	0.00
15	08/31/1991 12:00 AM	3410.68	2603.57	0.00
16	09/30/1991 12:00 AM	4483.50	3422.51	0.00

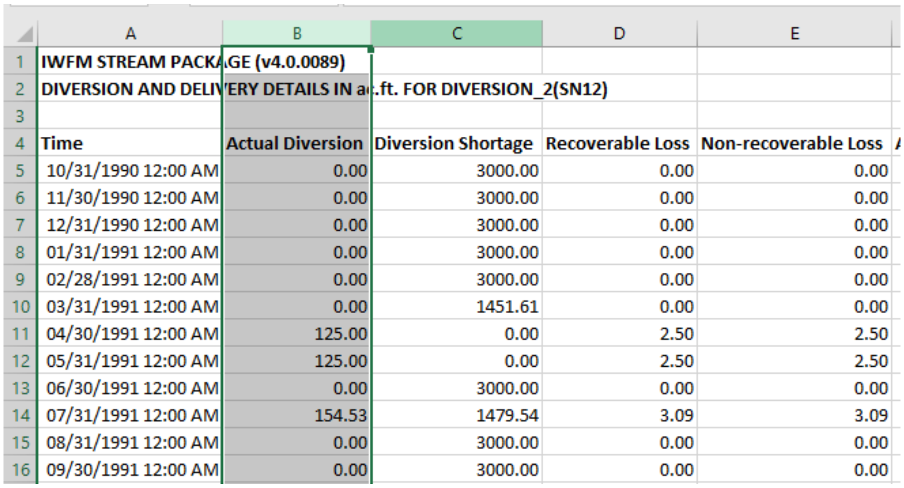
7.4.2 Surface Water Diversion

Surface water diversion, as defined in Section 1.3, refers to the "volume of water taken from the surface water system within a water budget zone for use within the zone." In IWFM diversions from a stream are delivered to user-specified areas for urban or agricultural use; however, the model does not output diversion volumes by subregion or user-defined water budget zone.

The Diversion Detail Report output file reports a balance for each diversion specified in the model. The user must check the model input files to find the elements where each diversion is delivered to; furthermore, water deliveries are dynamically distributed across delivery areas based on the demand within the group of elements. Because of this, manually trying to determine diversions is difficult and inherently inaccurate. IWFM does not currently report surface water diversions by subregion and user-defined water budget zone. This feature may become available in the future.

If the boundaries of the delivery areas are not in conflict with the water budget zone, then the Diversion Detail Report can be used to determine the surface water diversions out of a water budget zone. Identify the diversions falling within the water budget zone of interest. The “Actual Diversion” column reports the volume of water diverted from the stream (Figure 7-26). For each timestep, the “Actual Diversion” volume from each diversion leaving the water budget zone should be summed to obtain the total surface water diversion volume.

Figure 7-26 Diversion Detail: Actual Diversion



	A	B	C	D	E
1	**IWFM STREAM PACKAGE (v4.0.0089)**				
2	**DIVERSION AND DELIVERY DETAILS IN ac.ft. FOR DIVERSION_2(SN12)**				
3					
4	**Time**	**Actual Diversion**	**Diversion Shortage**	**Recoverable Loss**	**Non-recoverable Loss**
5	10/31/1990 12:00 AM	0.00	3000.00	0.00	0.00
6	11/30/1990 12:00 AM	0.00	3000.00	0.00	0.00
7	12/31/1990 12:00 AM	0.00	3000.00	0.00	0.00
8	01/31/1991 12:00 AM	0.00	3000.00	0.00	0.00
9	02/28/1991 12:00 AM	0.00	3000.00	0.00	0.00
10	03/31/1991 12:00 AM	0.00	1451.61	0.00	0.00
11	04/30/1991 12:00 AM	125.00	0.00	2.50	2.50
12	05/31/1991 12:00 AM	125.00	0.00	2.50	2.50
13	06/30/1991 12:00 AM	0.00	3000.00	0.00	0.00
14	07/31/1991 12:00 AM	154.53	1479.54	3.09	3.09
15	08/31/1991 12:00 AM	0.00	3000.00	0.00	0.00
16	09/30/1991 12:00 AM	0.00	3000.00	0.00	0.00

7.4.3 Stream Evaporation

Stream evaporation, as defined in Section 1.3, refers to the “volume of water evaporated into the atmosphere from streams.” IWFM currently does not simulate or report stream evaporation.

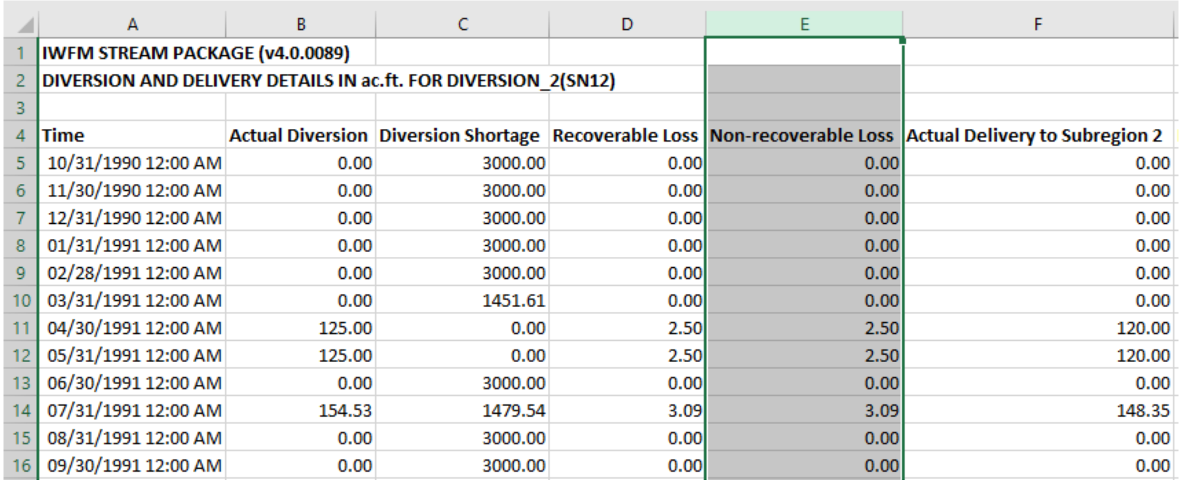
7.4.4 Conveyance Evaporation

Conveyance evaporation, as defined in Section 1.3, refers to the “volume of water evaporated into the atmosphere from conveyance facilities, other than streams, during water delivery.” Diversions in IWFM are assigned fractions for recoverable (seepage) and non-recoverable (evaporation) losses in the

Diversion Specification input file, which refers to the fraction of each diversion that enters the groundwater system as seepage or the atmosphere as evaporation. The volume of each diversion that becomes evaporation to the atmosphere can be obtained from the Diversion Detail *r*eport file under the “Non-Recoverable Loss” column (Figure 7-27). Identify which diversions occur in the water budget zone of interest and sum the “Non-recoverable Loss” column for each relevant diversion.

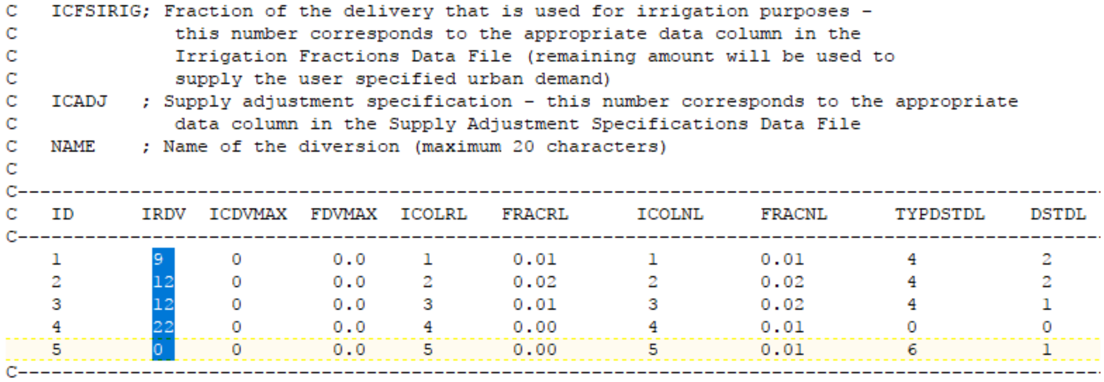
The model documentation may contain details regarding the location of diversions; if not, the user can find the diversion locations from the Diversion Specification file (Figure 7-28). The second column in the Diversion Specification file refers to the stream node where water is diverted from. Using a map of model stream nodes from the model documentation, the user can identify the diversions that occur in the water budget zone of interest and calculate the corresponding conveyance evaporation. If a diversion is not simulated in the model, then there will be no estimate of its conveyance evaporation.

Figure 7-27 **Diversion Detail: Non-Recoverable Loss**



	A	B	C	D	E	F
1	**IWFM STREAM PACKAGE (v4.0.0089)**					
2	**DIVERSION AND DELIVERY DETAILS IN ac.ft. FOR DIVERSION_2(SN12)**					
3						
4	**Time**	**Actual Diversion**	**Diversion Shortage**	**Recoverable Loss**	**Non-recoverable Loss**	**Actual Delivery to Subregion 2**
5	10/31/1990 12:00 AM	0.00	3000.00	0.00	0.00	0.00
6	11/30/1990 12:00 AM	0.00	3000.00	0.00	0.00	0.00
7	12/31/1990 12:00 AM	0.00	3000.00	0.00	0.00	0.00
8	01/31/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
9	02/28/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
10	03/31/1991 12:00 AM	0.00	1451.61	0.00	0.00	0.00
11	04/30/1991 12:00 AM	125.00	0.00	2.50	2.50	120.00
12	05/31/1991 12:00 AM	125.00	0.00	2.50	2.50	120.00
13	06/30/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
14	07/31/1991 12:00 AM	154.53	1479.54	3.09	3.09	148.35
15	08/31/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
16	09/30/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00

Figure 7-28 **IWFM Diversion Specification Input**

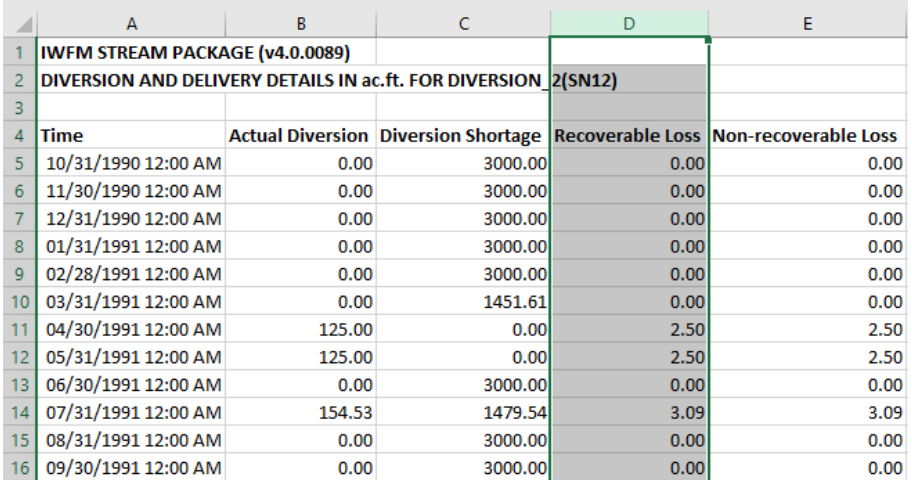


```
C   ICFSIRIG; Fraction of the delivery that is used for irrigation purposes -
C              this number corresponds to the appropriate data column in the
C              Irrigation Fractions Data File (remaining amount will be used to
C              supply the user specified urban demand)
C   ICADJ    ; Supply adjustment specification - this number corresponds to the appropriate
C              data column in the Supply Adjustment Specifications Data File
C   NAME     ; Name of the diversion (maximum 20 characters)
C
C-----------------------------------------------------------------------------------------------
C   ID      IRDV  ICDVMAX  FDVMAX  ICOLRL   FRACRL      ICOLNL     FRACNL      TYPDSTDL     DSTDL
C-----------------------------------------------------------------------------------------------
    1       9       0       0.0     1       0.01        1          0.01        4            2
    2       12      0       0.0     2       0.02        2          0.02        4            2
    3       12      0       0.0     3       0.01        3          0.02        4            1
    4       22      0       0.0     4       0.00        4          0.01        0            0
    5       0       0       0.0     5       0.00        5          0.01        6            1
C-----------------------------------------------------------------------------------------------
```

7.4.5 Conveyance Seepage

Conveyance seepage, as defined in Section 1.3, refers to the "volume of water recharged to the groundwater system from the conveyance facilities, other than streams, during water delivery." Diversions in IWFM are assigned fractions for recoverable (seepage) and non-recoverable (evaporation) losses in the Diversion Specification file, which refers to the fraction of each diversion that enters the groundwater system as seepage or the atmosphere as evaporation. The volume of each diversion that becomes seepage to the groundwater system can be obtained in the Diversion Detail report file under the "Recoverable Loss" column (Figure 7-29). Identify which diversions occur in the water budget zone of interest and sum the "Recoverable Loss" column for each relevant diversion.

Figure 7-29 **Diversion Detail: Recoverable Loss**



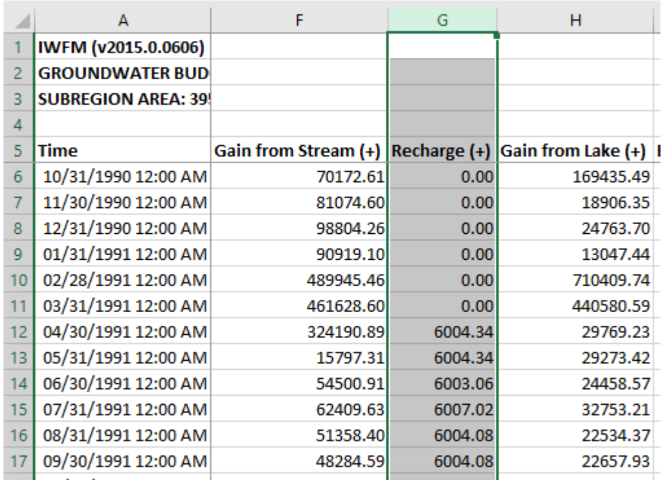
	A	B	C	D	E
1	IWFM STREAM PACKAGE (v4.0.0089)				
2	DIVERSION AND DELIVERY DETAILS IN ac.ft. FOR DIVERSION_2(SN12)				
3					
4	Time	Actual Diversion	Diversion Shortage	Recoverable Loss	Non-recoverable Loss
5	10/31/1990 12:00 AM	0.00	3000.00	0.00	0.00
6	11/30/1990 12:00 AM	0.00	3000.00	0.00	0.00
7	12/31/1990 12:00 AM	0.00	3000.00	0.00	0.00
8	01/31/1991 12:00 AM	0.00	3000.00	0.00	0.00
9	02/28/1991 12:00 AM	0.00	3000.00	0.00	0.00
10	03/31/1991 12:00 AM	0.00	1451.61	0.00	0.00
11	04/30/1991 12:00 AM	125.00	0.00	2.50	2.50
12	05/31/1991 12:00 AM	125.00	0.00	2.50	2.50
13	06/30/1991 12:00 AM	0.00	3000.00	0.00	0.00
14	07/31/1991 12:00 AM	154.53	1479.54	3.09	3.09
15	08/31/1991 12:00 AM	0.00	3000.00	0.00	0.00
16	09/30/1991 12:00 AM	0.00	3000.00	0.00	0.00

The model documentation may contain details regarding the location of diversions; if not, the user can find the diversion locations from the

Diversion Specification file (Figure 7-28). The second column in the Diversion Specification file refers to the stream node where water is diverted from. Using a map of model stream nodes, the user can identify the diversions that occur in the water budget zone of interest and calculate the corresponding conveyance seepage. If a diversion is not simulated in the model, then there will be no estimate of its conveyance seepage.

Conveyance seepage can also be determined from the "Recharge" column in the Groundwater Budget output file (Figure 7-30). The output contains information by subregion or user-defined water budget zone, which may be more convenient for developing the total water budget. The only caveat is that the "Recharge" column also contains the volume of managed aquifer recharge (i.e., water banking operations), if simulated. In this scenario, the user must subtract the volume of managed aquifer recharge (Section 7.5.5) from the "recharge" volume specified in the Groundwater Budget output file. If a diversion is not simulated in the model, then there will be no estimate of its conveyance seepage.

Figure 7-30 Groundwater Budget: Recharge



	A	F	G	H
1	IWFM (v2015.0.0606)			
2	GROUNDWATER BUD			
3	SUBREGION AREA: 39			
4				
5	Time	Gain from Stream (+)	Recharge (+)	Gain from Lake (+)
6	10/31/1990 12:00 AM	70172.61	0.00	169435.49
7	11/30/1990 12:00 AM	81074.60	0.00	18906.35
8	12/31/1990 12:00 AM	98804.26	0.00	24763.70
9	01/31/1991 12:00 AM	90919.10	0.00	13047.44
10	02/28/1991 12:00 AM	489945.46	0.00	710409.74
11	03/31/1991 12:00 AM	461628.60	0.00	440580.59
12	04/30/1991 12:00 AM	324190.89	6004.34	29769.23
13	05/31/1991 12:00 AM	15797.31	6004.34	29273.42
14	06/30/1991 12:00 AM	54500.91	6003.06	24458.57
15	07/31/1991 12:00 AM	62409.63	6007.02	32753.21
16	08/31/1991 12:00 AM	51358.40	6004.08	22534.37
17	09/30/1991 12:00 AM	48284.59	6004.08	22657.93

7.4.6 Imported Water

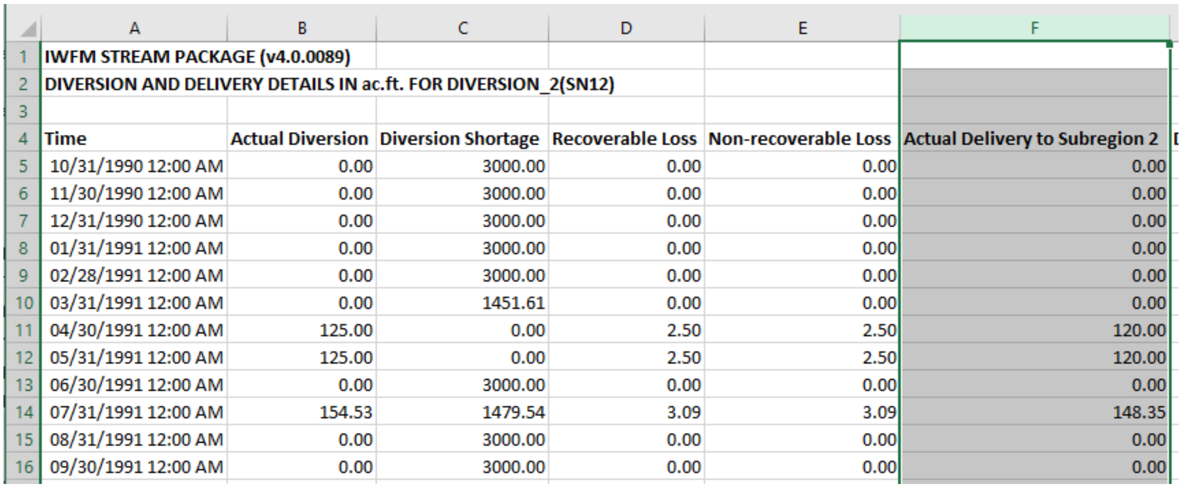
Imported water, as defined in Section 1.3, refers to the "volume of water brought from outside the water budget zone for use within the water budget zone, such as State Water Project water, Central Valley Project water, water produced from desalination of ocean water, and water produced from desalination of deep groundwater from below the base of freshwater." The total volume of imported water is not explicitly reported in IWFM; rather, the model outputs total surface water used in a region, regardless of where the surface water originated.

The Diversion Detail output file reports a balance for each diversion specified in the model. The user must check the model input files to find the elements where each diversion is delivered to; furthermore, water deliveries are dynamically distributed across delivery areas based on the demand within the group of elements. Because of this, manually trying to determine how much of the diversions is imported water is difficult and inherently inaccurate.

IWFM currently does not report surface water diversions by subregion or user-defined water budget zone. This feature may be available in the future.

In cases where a diversion originates from outside the water budget zone and is delivered entirely to within the water budget zone, the total volume of imported water can be obtained from the Diversion Detail output. For the relevant water budget zones, the volumes of imported water will be reported in the “Actual Delivery” column (Figure 7-31). The user will need to consult the model input files to determine stream node at which a diversion is taken and the group of elements to which the diversion is delivered. The example below has a column header of “Actual Delivery to Subregion 2”. Delivery areas can also be specified as element groups, in which case the “to subregion” heading will be absent.

Figure 7-31 **Diversion Detail: Actual Delivery**



	A	B	C	D	E	F
1	IWFM STREAM PACKAGE (v4.0.0089)					
2	DIVERSION AND DELIVERY DETAILS IN ac.ft. FOR DIVERSION_2(SN12)					
3						
4	Time	Actual Diversion	Diversion Shortage	Recoverable Loss	Non-recoverable Loss	Actual Delivery to Subregion 2
5	10/31/1990 12:00 AM	0.00	3000.00	0.00	0.00	0.00
6	11/30/1990 12:00 AM	0.00	3000.00	0.00	0.00	0.00
7	12/31/1990 12:00 AM	0.00	3000.00	0.00	0.00	0.00
8	01/31/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
9	02/28/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
10	03/31/1991 12:00 AM	0.00	1451.61	0.00	0.00	0.00
11	04/30/1991 12:00 AM	125.00	0.00	2.50	2.50	120.00
12	05/31/1991 12:00 AM	125.00	0.00	2.50	2.50	120.00
13	06/30/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
14	07/31/1991 12:00 AM	154.53	1479.54	3.09	3.09	148.35
15	08/31/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
16	09/30/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00

7.4.7 Surface Water Exports

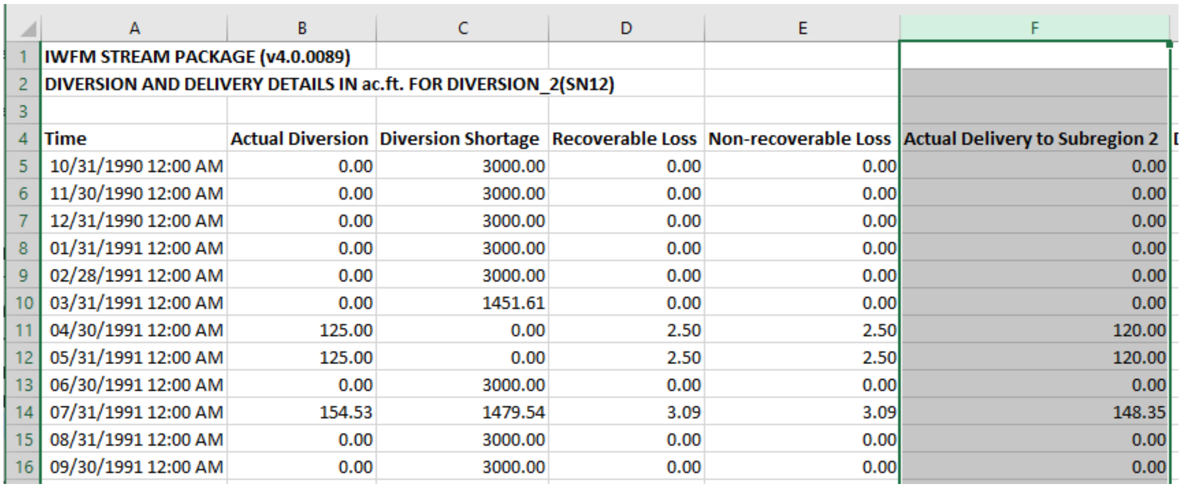
Surface water exports, as defined in Section 1.3, refer to “the volume of water diverted from the surface water system within a water budget zone for use outside the zone.” IWFM does not explicitly specify which diversions are exported out of a subregion or user-defined water budget zone in the output files.

The Diversion Detail output file reports a balance for each diversion specified in the model. The user must check the model input files to find the elements where each diversion is delivered to; furthermore, deliveries are dynamically distributed across delivery areas based the demand within the group of elements. Because of this, manually trying to determine how much of any given diversion ends up as an export out of the water budget zone is difficult and inherently inaccurate.

IWFM currently does not report surface water diversions by subregion or user-defined water budget zone. This feature may be available in the future.

Similar to the Imported Water component, if a diversion originates within a water budget zone and is delivered to an element group entirely outside the water budget zone, the total volume of surface water exports can be found in the Diversion Detail output file. For the relevant diversions, find the volume of exported water in the “Actual Delivery to Subregion” column (Figure 7-32).

Figure 7-32 Diversion Detail: Actual Delivery

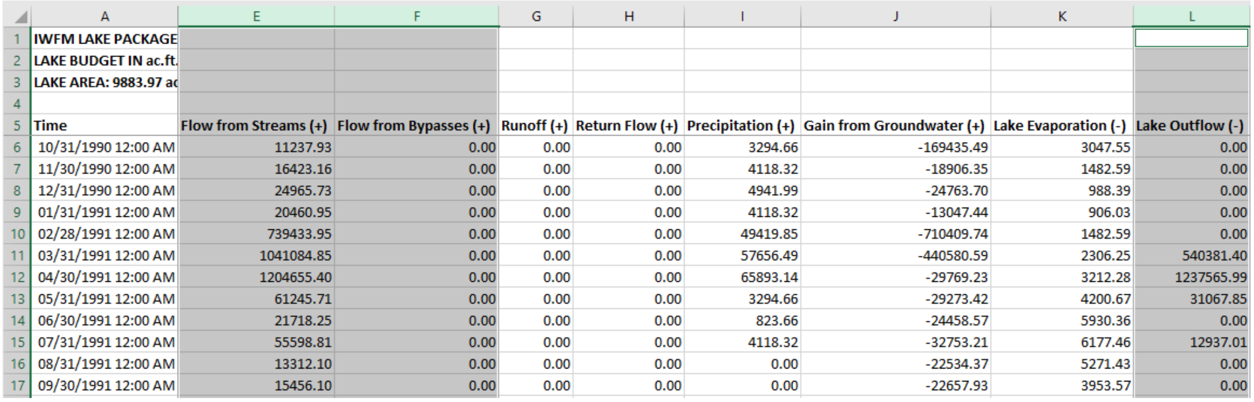


	A	B	C	D	E	F
1	IWFM STREAM PACKAGE (v4.0.0089)					
2	DIVERSION AND DELIVERY DETAILS IN ac.ft. FOR DIVERSION_2(SN12)					
3						
4	Time	Actual Diversion	Diversion Shortage	Recoverable Loss	Non-recoverable Loss	Actual Delivery to Subregion 2
5	10/31/1990 12:00 AM	0.00	3000.00	0.00	0.00	0.00
6	11/30/1990 12:00 AM	0.00	3000.00	0.00	0.00	0.00
7	12/31/1990 12:00 AM	0.00	3000.00	0.00	0.00	0.00
8	01/31/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
9	02/28/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
10	03/31/1991 12:00 AM	0.00	1451.61	0.00	0.00	0.00
11	04/30/1991 12:00 AM	125.00	0.00	2.50	2.50	120.00
12	05/31/1991 12:00 AM	125.00	0.00	2.50	2.50	120.00
13	06/30/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
14	07/31/1991 12:00 AM	154.53	1479.54	3.09	3.09	148.35
15	08/31/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00
16	09/30/1991 12:00 AM	0.00	3000.00	0.00	0.00	0.00

7.4.8 Stream-Lake Interaction

Stream-lake interaction, as defined in Section 1.3, refers to the "volume of water exchanged between streams and lakes", covering both the inflow and outflow component of this interaction. Lakes are reported independently from other surface water features. For the lakes within the water budget zone, the stream-lake interaction can be determined from the Lake Budget output file by summing the "Flow from Streams" and "Flow from Bypasses" columns (Figure 7-33). Lake outflow can flow into a stream node, into a downstream lake directly, or out of the model area. If lake outflow flows into a stream node, "Lake Outflow" column should also be included in this summation. A positive value means a net gain to the lake from streamflow, while a negative value means a net loss from the lake to streamflow.

Figure 7-33 Lake Budget: Flow from Streams, Bypasses, and Lake Outflow

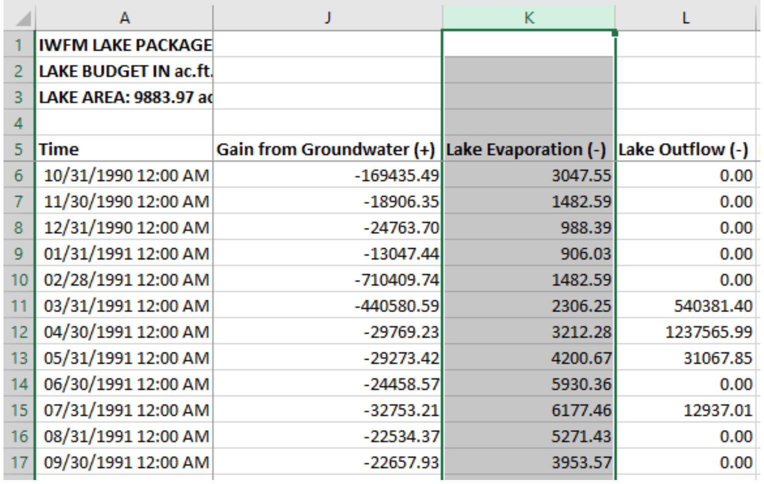


	A	E	F	G	H	I	J	K	L
1	IWFM LAKE PACKAGE								
2	LAKE BUDGET IN ac.ft.								
3	LAKE AREA: 9883.97 ac								
4									
5	Time	Flow from Streams (+)	Flow from Bypasses (+)	Runoff (+)	Return Flow (+)	Precipitation (+)	Gain from Groundwater (+)	Lake Evaporation (-)	Lake Outflow (-)
6	10/31/1990 12:00 AM	11237.93	0.00	0.00	0.00	3294.66	-169435.49	3047.55	0.00
7	11/30/1990 12:00 AM	16423.16	0.00	0.00	0.00	4118.32	-18906.35	1482.59	0.00
8	12/31/1990 12:00 AM	24965.73	0.00	0.00	0.00	4941.99	-24763.70	988.39	0.00
9	01/31/1991 12:00 AM	20460.95	0.00	0.00	0.00	4118.32	-13047.44	906.03	0.00
10	02/28/1991 12:00 AM	739433.95	0.00	0.00	0.00	49419.85	-710409.74	1482.59	0.00
11	03/31/1991 12:00 AM	1041084.85	0.00	0.00	0.00	57656.49	-440580.59	2306.25	540381.40
12	04/30/1991 12:00 AM	1204655.40	0.00	0.00	0.00	65893.14	-29769.23	3212.28	1237565.99
13	05/31/1991 12:00 AM	61245.71	0.00	0.00	0.00	3294.66	-29273.42	4200.67	31067.85
14	06/30/1991 12:00 AM	21718.25	0.00	0.00	0.00	823.66	-24458.57	5930.36	0.00
15	07/31/1991 12:00 AM	55598.81	0.00	0.00	0.00	4118.32	-32753.21	6177.46	12937.01
16	08/31/1991 12:00 AM	13312.10	0.00	0.00	0.00	0.00	-22534.37	5271.43	0.00
17	09/30/1991 12:00 AM	15456.10	0.00	0.00	0.00	0.00	-22657.93	3953.57	0.00

7.4.9 Lake Evaporation

Lake evaporation, as defined in Section 1.3, refers to the "volume of evaporation from lakes and reservoirs." Identify lakes within the water budget zone of interest. IWFM reports the volume of lake evaporation in the Lake Budget output. For the relevant lakes within the water budget zone, the total volume of lake evaporation is reported under the "Lake Evaporation" column (Figure 7-34). If there are multiple lakes within the water budget zone, sum the volumes from each lake to obtain the total volume of lake evaporation.

Figure 7-34 **Lake Budget: Lake Evaporation**

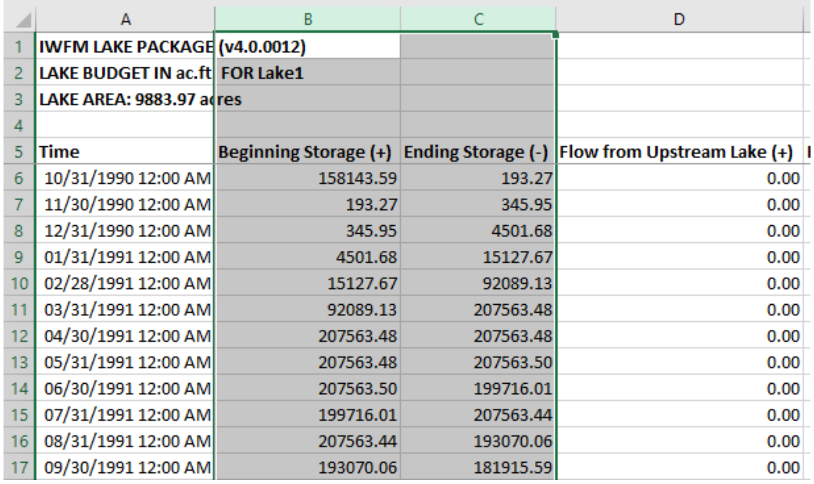


	A	J	K	L
1	IWFM LAKE PACKAGE			
2	LAKE BUDGET IN ac.ft.			
3	LAKE AREA: 9883.97 ac			
4				
5	Time	Gain from Groundwater (+)	Lake Evaporation (-)	Lake Outflow (-)
6	10/31/1990 12:00 AM	-169435.49	3047.55	0.00
7	11/30/1990 12:00 AM	-18906.35	1482.59	0.00
8	12/31/1990 12:00 AM	-24763.70	988.39	0.00
9	01/31/1991 12:00 AM	-13047.44	906.03	0.00
10	02/28/1991 12:00 AM	-710409.74	1482.59	0.00
11	03/31/1991 12:00 AM	-440580.59	2306.25	540381.40
12	04/30/1991 12:00 AM	-29769.23	3212.28	1237565.99
13	05/31/1991 12:00 AM	-29273.42	4200.67	31067.85
14	06/30/1991 12:00 AM	-24458.57	5930.36	0.00
15	07/31/1991 12:00 AM	-32753.21	6177.46	12937.01
16	08/31/1991 12:00 AM	-22534.37	5271.43	0.00
17	09/30/1991 12:00 AM	-22657.93	3953.57	0.00

7.4.10 Change in Surface Water Storage

Change in surface water storage, as defined in Section 1.3, refers to the "net change in the volume of water stored within the surface water system, which includes lakes and reservoirs, streams, and conveyance facilities.". It is assumed that while changes in water volume contained in streams and conveyance facilities may be important components in the daily or monthly water budgets, they are typically negligible in annual water budgets. Therefore, the majority of the change in surface water storage will occur in lakes. IWFM accounts for the change in lake storage in the Lake Budget output file. For the lakes within the water budget zone of interest, the Lake Budget in IWFM accounts for the change in surface water storage in the "Beginning Storage" and "Ending Storage" columns of the lake budget output (Figure 7-35). The change in storage for a particular time step is the difference between the beginning storage and the ending storage.

Figure 7-35 Lake Budget: Beginning and Ending Storage



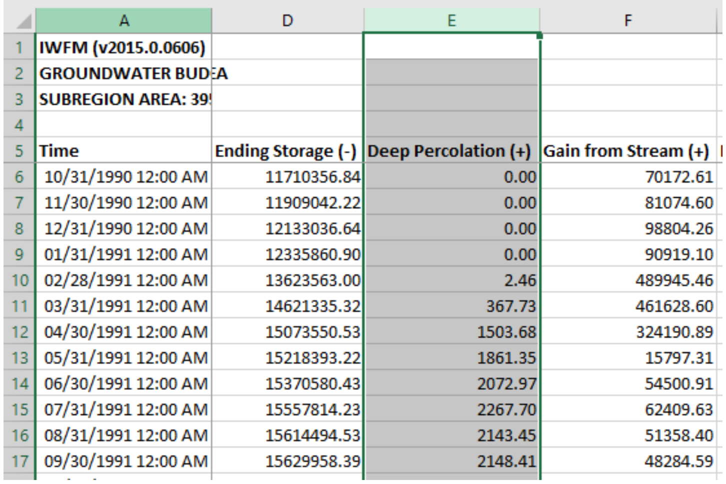
	A	B	C	D
1	IWFM LAKE PACKAGE (v4.0.0012)			
2	LAKE BUDGET IN ac.ft FOR Lake1			
3	LAKE AREA: 9883.97 acres			
4				
5	Time	Beginning Storage (+)	Ending Storage (-)	Flow from Upstream Lake (+)
6	10/31/1990 12:00 AM	158143.59	193.27	0.00
7	11/30/1990 12:00 AM	193.27	345.95	0.00
8	12/31/1990 12:00 AM	345.95	4501.68	0.00
9	01/31/1991 12:00 AM	4501.68	15127.67	0.00
10	02/28/1991 12:00 AM	15127.67	92089.13	0.00
11	03/31/1991 12:00 AM	92089.13	207563.48	0.00
12	04/30/1991 12:00 AM	207563.48	207563.48	0.00
13	05/31/1991 12:00 AM	207563.48	207563.50	0.00
14	06/30/1991 12:00 AM	207563.50	199716.01	0.00
15	07/31/1991 12:00 AM	199716.01	207563.44	0.00
16	08/31/1991 12:00 AM	207563.44	193070.06	0.00
17	09/30/1991 12:00 AM	193070.06	181915.59	0.00

7.5 GROUNDWATER SYSTEM

7.5.1 Recharge of Applied Water and Precipitation

Recharge of applied water and precipitation, as defined in Section 1.3, refers to the "volume of applied water and precipitation that travels vertically through the soil/unsaturated zones and reaches the saturated zone of the aquifer (groundwater system)." IWFM accounts for the volume of recharge in the Groundwater Budget output file. For the subregions or water budget zone of interest, find the volume of recharge in the "Deep Percolation" column (Figure 7-36). IWFM does not currently report recharge by source.

Figure 7-36 Groundwater Budget: Deep Percolation

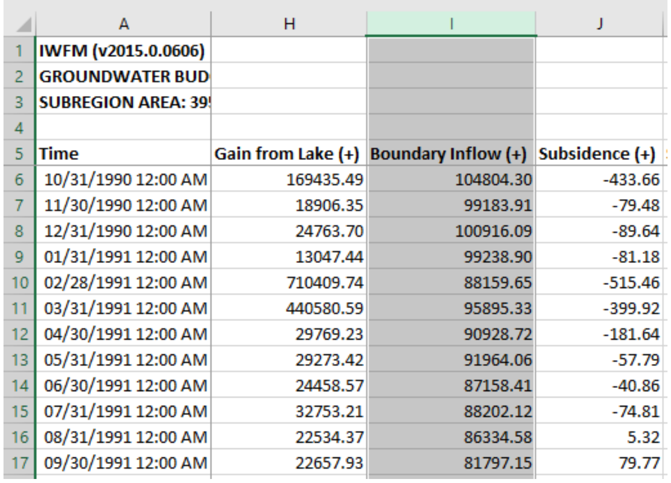


	A	D	E	F
1	IWFM (v2015.0.0606)			
2	GROUNDWATER BUD			
3	SUBREGION AREA: 39			
4				
5	Time	Ending Storage (-)	Deep Percolation (+)	Gain from Stream (+)
6	10/31/1990 12:00 AM	11710356.84	0.00	70172.61
7	11/30/1990 12:00 AM	11909042.22	0.00	81074.60
8	12/31/1990 12:00 AM	12133036.64	0.00	98804.26
9	01/31/1991 12:00 AM	12335860.90	0.00	90919.10
10	02/28/1991 12:00 AM	13623563.00	2.46	489945.46
11	03/31/1991 12:00 AM	14621335.32	367.73	461628.60
12	04/30/1991 12:00 AM	15073550.53	1503.68	324190.89
13	05/31/1991 12:00 AM	15218393.22	1861.35	15797.31
14	06/30/1991 12:00 AM	15370580.43	2072.97	54500.91
15	07/31/1991 12:00 AM	15557814.23	2267.70	62409.63
16	08/31/1991 12:00 AM	15614494.53	2143.45	51358.40
17	09/30/1991 12:00 AM	15629958.39	2148.41	48284.59

7.5.2 Subsurface Inflow and Outflow

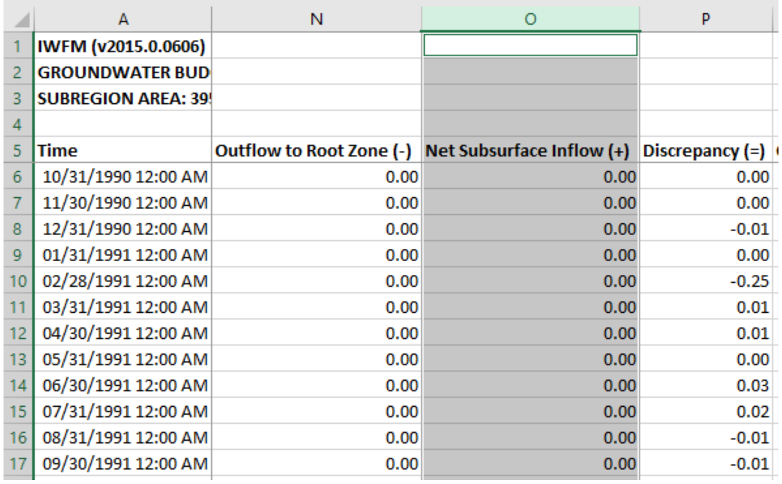
Subsurface inflow, as defined in Section 1.3, refers to the "volume of water entering as groundwater into a water budget zone through its subsurface boundaries." Subsurface outflow refers to the "volume of water leaving as groundwater from a water budget zone through its subsurface boundaries." IWFM accounts for subsurface flows in the Groundwater Budget output file. The Groundwater Budget output file accounts for the total volume of subsurface flow in the "Boundary Inflow" and "Net Subsurface Inflow" columns. The "Boundary Inflow" refers to the subsurface inflow resulting from the boundary conditions. It includes subsurface inflow from small watersheds as well as net inflows/outflows resulting from specified head or specified flow boundary conditions. "Net Subsurface Inflow" refers to the flow from the subregion or user-defined water budget zone to neighboring subregions or zones. For the subregions or water budget zone of interest, subsurface flows can be obtained by summing the "Boundary Inflow" and "Net Subsurface Inflow" columns (Figures 7-37 and 7-38). Positive values indicate groundwater entering the water budget zone while negative values indicate groundwater leaving the water budget zone.

Figure 7-37 Groundwater Budget: Boundary Inflow



	A	H	I	J
1	**IWFM (v2015.0.0606)**			
2	**GROUNDWATER BUD**			
3	**SUBREGION AREA: 39**			
4				
5	**Time**	**Gain from Lake (+)**	**Boundary Inflow (+)**	**Subsidence (+)**
6	10/31/1990 12:00 AM	169435.49	104804.30	-433.66
7	11/30/1990 12:00 AM	18906.35	99183.91	-79.48
8	12/31/1990 12:00 AM	24763.70	100916.09	-89.64
9	01/31/1991 12:00 AM	13047.44	99238.90	-81.18
10	02/28/1991 12:00 AM	710409.74	88159.65	-515.46
11	03/31/1991 12:00 AM	440580.59	95895.33	-399.92
12	04/30/1991 12:00 AM	29769.23	90928.72	-181.64
13	05/31/1991 12:00 AM	29273.42	91964.06	-57.79
14	06/30/1991 12:00 AM	24458.57	87158.41	-40.86
15	07/31/1991 12:00 AM	32753.21	88202.12	-74.81
16	08/31/1991 12:00 AM	22534.37	86334.58	5.32
17	09/30/1991 12:00 AM	22657.93	81797.15	79.77

Figure 7-38 Groundwater Budget: Net Subsurface Inflow

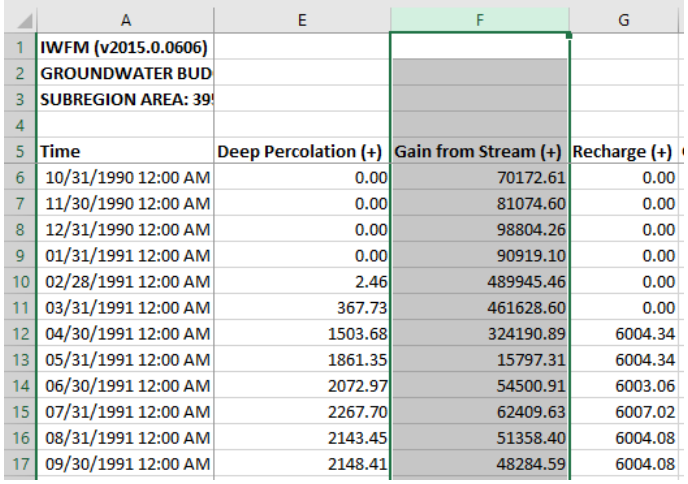


	A	N	O	P
1	IWFM (v2015.0.0606)			
2	GROUNDWATER BUD			
3	SUBREGION AREA: 39			
4				
5	Time	Outflow to Root Zone (-)	Net Subsurface Inflow (+)	Discrepancy (=)
6	10/31/1990 12:00 AM	0.00	0.00	0.00
7	11/30/1990 12:00 AM	0.00	0.00	0.00
8	12/31/1990 12:00 AM	0.00	0.00	-0.01
9	01/31/1991 12:00 AM	0.00	0.00	0.00
10	02/28/1991 12:00 AM	0.00	0.00	-0.25
11	03/31/1991 12:00 AM	0.00	0.00	0.01
12	04/30/1991 12:00 AM	0.00	0.00	0.01
13	05/31/1991 12:00 AM	0.00	0.00	0.00
14	06/30/1991 12:00 AM	0.00	0.00	0.03
15	07/31/1991 12:00 AM	0.00	0.00	0.02
16	08/31/1991 12:00 AM	0.00	0.00	-0.01
17	09/30/1991 12:00 AM	0.00	0.00	-0.01

7.5.3 Stream-Groundwater Interaction

Groundwater gain from stream, as defined in Section 1.3, refers to the "volume of water entering the groundwater system from rivers and streams." Groundwater loss to stream refers to the "volume of water entering rivers and streams from the groundwater system." IWFM accounts for stream-aquifer interactions in the Groundwater Budget output file. For the subregions or water budget zone of interest, find the volume of stream-aquifer interaction in the "Gain from Stream" column of the groundwater budget (Figure 7-39). Positive values represent flow from the stream into the groundwater system while negative values represent flow from the groundwater system into the stream.

Figure 7-39 Groundwater Budget: Gain from Stream

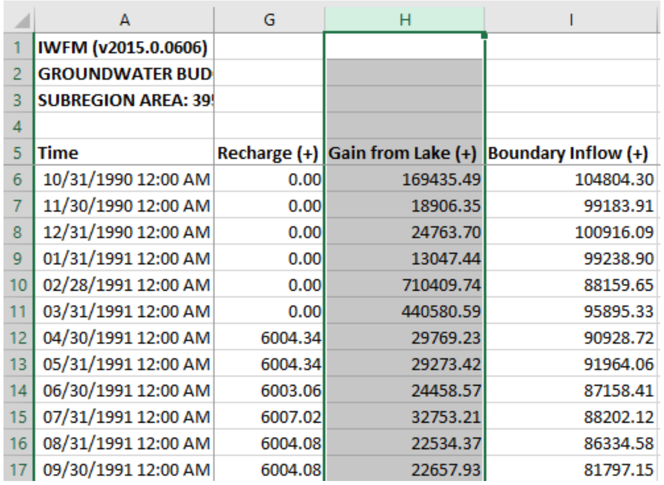


	A	E	F	G
1	IWFM (v2015.0.0606)			
2	GROUNDWATER BUD			
3	SUBREGION AREA: 39			
4				
5	Time	Deep Percolation (+)	Gain from Stream (+)	Recharge (+)
6	10/31/1990 12:00 AM	0.00	70172.61	0.00
7	11/30/1990 12:00 AM	0.00	81074.60	0.00
8	12/31/1990 12:00 AM	0.00	98804.26	0.00
9	01/31/1991 12:00 AM	0.00	90919.10	0.00
10	02/28/1991 12:00 AM	2.46	489945.46	0.00
11	03/31/1991 12:00 AM	367.73	461628.60	0.00
12	04/30/1991 12:00 AM	1503.68	324190.89	6004.34
13	05/31/1991 12:00 AM	1861.35	15797.31	6004.34
14	06/30/1991 12:00 AM	2072.97	54500.91	6003.06
15	07/31/1991 12:00 AM	2267.70	62409.63	6007.02
16	08/31/1991 12:00 AM	2143.45	51358.40	6004.08
17	09/30/1991 12:00 AM	2148.41	48284.59	6004.08

7.5.4 Lake-Groundwater Interaction

Groundwater gain from lake, as defined in Section 1.3, refers to the "volume of water entering the groundwater system from lakes and reservoirs." Groundwater loss to lake refers to the "volume of water entering the lakes and reservoirs from the groundwater system." IWFM accounts for lake-groundwater interactions in the Groundwater Budget output file. For the subregions or water budget zone of interest, find the volume of lake-groundwater interaction in the "Gain from Lake" column (Figure 7-40). Positive values represent flow from the lake into the groundwater system while negative values represent flow from the groundwater system into the lake.

Figure 7-40 **Groundwater Budget: Gain from Lake**



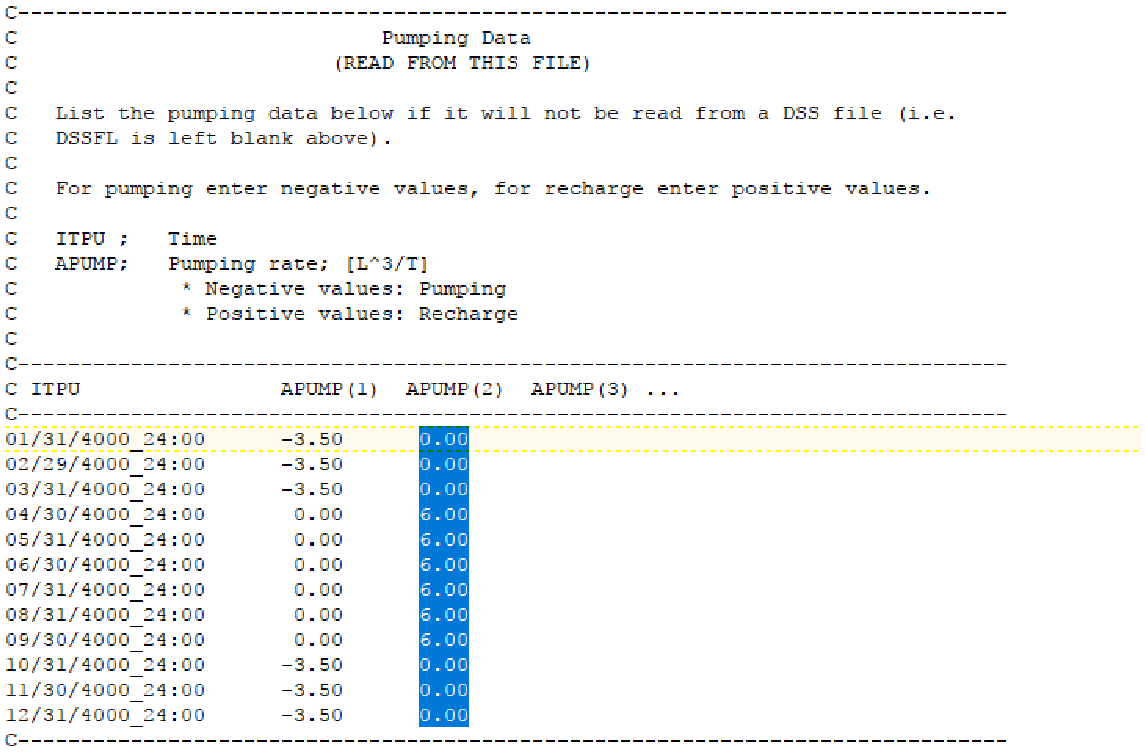
	A	G	H	I
1	IWFM (v2015.0.0606)			
2	GROUNDWATER BUD			
3	SUBREGION AREA: 39			
4				
5	Time	Recharge (+)	Gain from Lake (+)	Boundary Inflow (+)
6	10/31/1990 12:00 AM	0.00	169435.49	104804.30
7	11/30/1990 12:00 AM	0.00	18906.35	99183.91
8	12/31/1990 12:00 AM	0.00	24763.70	100916.09
9	01/31/1991 12:00 AM	0.00	13047.44	99238.90
10	02/28/1991 12:00 AM	0.00	710409.74	88159.65
11	03/31/1991 12:00 AM	0.00	440580.59	95895.33
12	04/30/1991 12:00 AM	6004.34	29769.23	90928.72
13	05/31/1991 12:00 AM	6004.34	29273.42	91964.06
14	06/30/1991 12:00 AM	6003.06	24458.57	87158.41
15	07/31/1991 12:00 AM	6007.02	32753.21	88202.12
16	08/31/1991 12:00 AM	6004.08	22534.37	86334.58
17	09/30/1991 12:00 AM	6004.08	22657.93	81797.15

7.5.5 Managed Aquifer Recharge

Managed aquifer recharge, as defined in Section 1.3, refers to the "volume of water intentionally added to the groundwater system as part of defined recharge and water banking programs through spreading basins, injection wells, and other means." IWFM does not have an explicit category for the simulation of managed aquifer recharge. It can be simulated through injection wells or through diversion seepage, but the Groundwater Budget output file does not distinguish between the two because it is reported as a combined volume for both in the "Recharge" column. Because direct managed recharge is not internally calculated by IWFM, managed aquifer recharge will need to be added as model input.

Refer to Section 9, "Data Resources Directory," for IWFM reference documentation that discusses how IWFM computes this component and what input data are required. Review model documentation to determine how managed aquifer recharge is simulated. If it is simulated as injection wells, use model documentation to identify the timeseries of injection data that are entered into the pumping data file. Identify which timeseries are associated with the recharge, and then find the appropriate column(s) in the pumping data file (Figure 7-41).

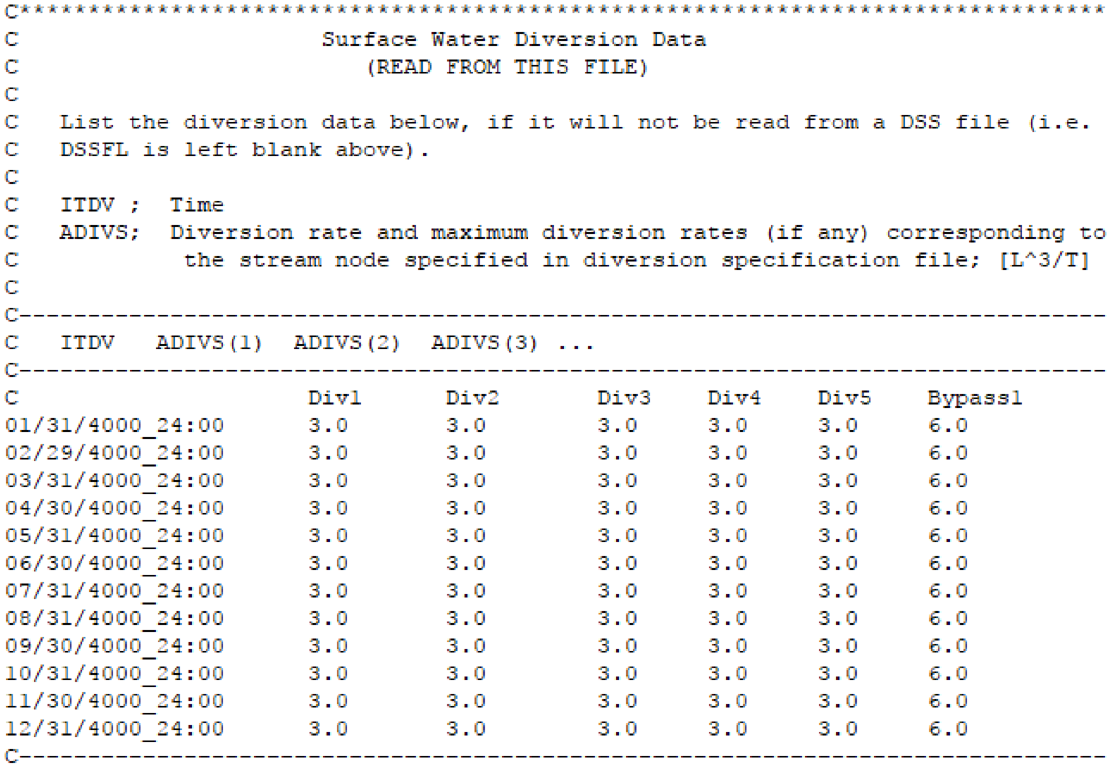
Figure 7-41 IWFM Pumping Data File



```
C-------------------------------------------------------------------------------
C                             Pumping Data
C                         (READ FROM THIS FILE)
C
C   List the pumping data below if it will not be read from a DSS file (i.e.
C   DSSFL is left blank above).
C
C   For pumping enter negative values, for recharge enter positive values.
C
C   ITPU ;    Time
C   APUMP;    Pumping rate; [L^3/T]
C              * Negative values: Pumping
C              * Positive values: Recharge
C
C-------------------------------------------------------------------------------
C ITPU                 APUMP(1)  APUMP(2)  APUMP(3) ...
C-------------------------------------------------------------------------------
01/31/4000_24:00       -3.50       0.00
02/29/4000_24:00       -3.50       0.00
03/31/4000_24:00       -3.50       0.00
04/30/4000_24:00        0.00       6.00
05/31/4000_24:00        0.00       6.00
06/30/4000_24:00        0.00       6.00
07/31/4000_24:00        0.00       6.00
08/31/4000_24:00        0.00       6.00
09/30/4000_24:00        0.00       6.00
10/31/4000_24:00       -3.50       0.00
11/30/4000_24:00       -3.50       0.00
12/31/4000_24:00       -3.50       0.00
C-------------------------------------------------------------------------------
```

Alternatively, if managed aquifer recharge is simulated through the application of diversion seepage, use model documentation to identify which diversions are associated with the specified recharge. The appropriate timeseries is available in the Surface Water Diversion Data input file (Figure 7-42).

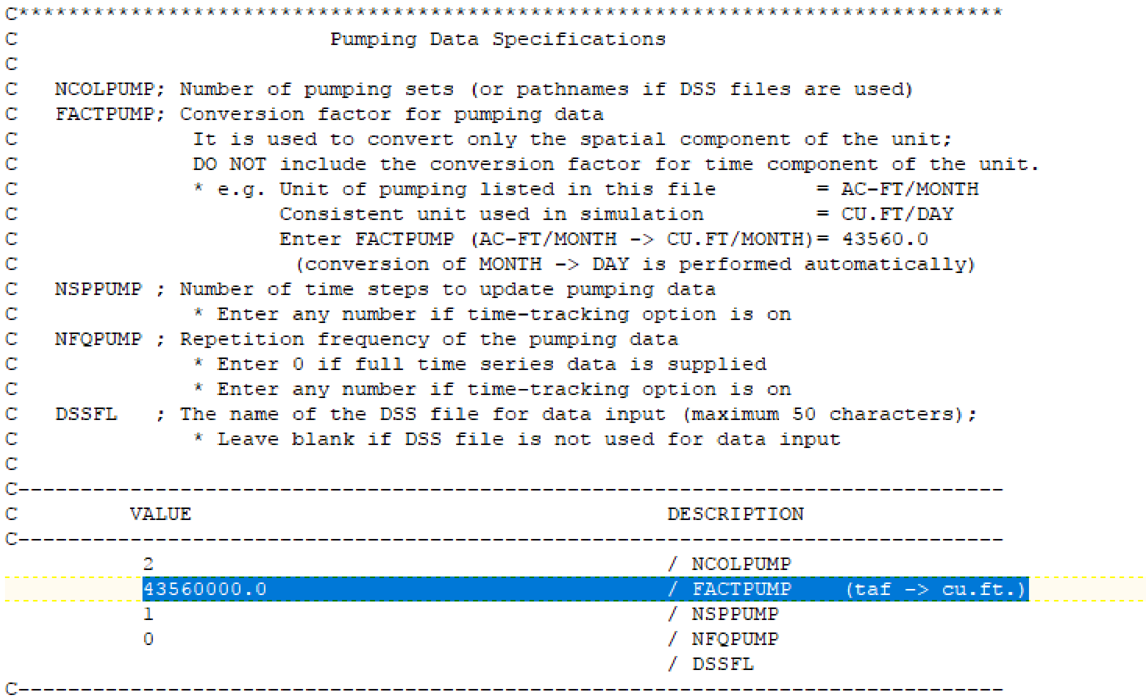
Figure 7-42 **IWFM Surface Water Diversion Data File**



```
C*******************************************************************************
C                      Surface Water Diversion Data
C                         (READ FROM THIS FILE)
C
C   List the diversion data below, if it will not be read from a DSS file (i.e.
C   DSSFL is left blank above).
C
C   ITDV ;  Time
C   ADIVS;  Diversion rate and maximum diversion rates (if any) corresponding to
C            the stream node specified in diversion specification file; [L^3/T]
C
C-------------------------------------------------------------------------------
C   ITDV   ADIVS(1)  ADIVS(2)  ADIVS(3) ...
C-------------------------------------------------------------------------------
C                     Div1      Div2       Div3    Div4    Div5    Bypass1
01/31/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
02/29/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
03/31/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
04/30/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
05/31/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
06/30/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
07/31/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
08/31/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
09/30/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
10/31/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
11/30/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
12/31/4000_24:00      3.0       3.0        3.0     3.0     3.0     6.0
C-------------------------------------------------------------------------------
```

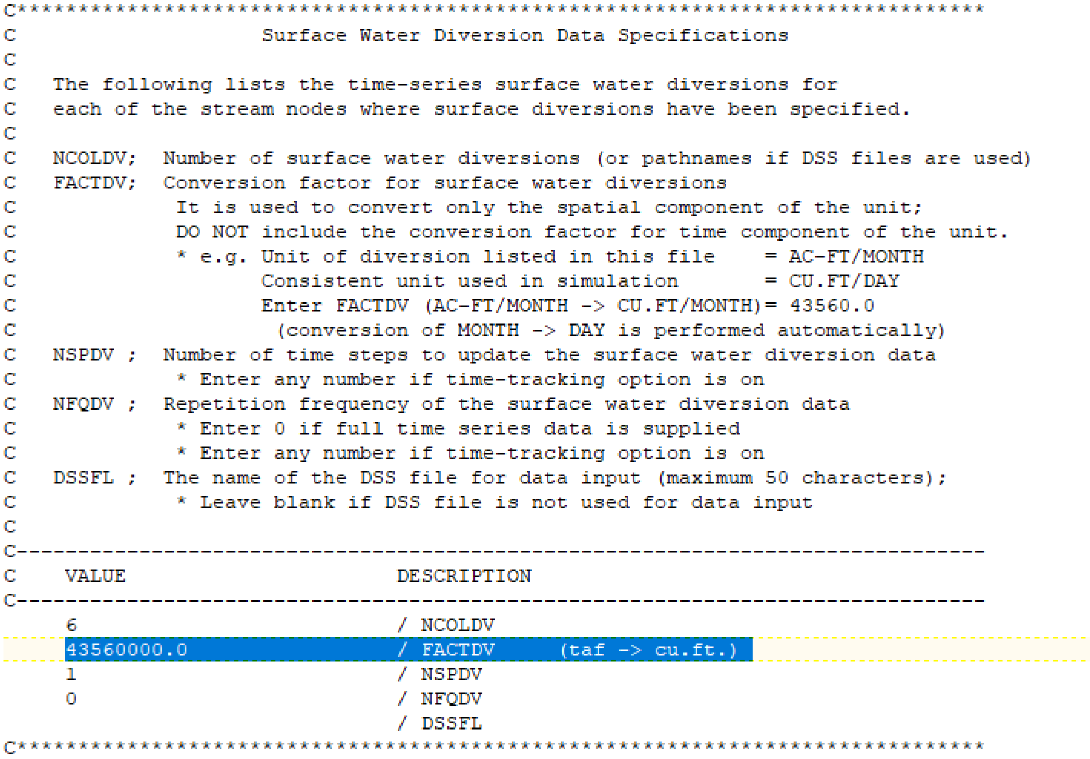
For both the above cases, because data are extracted directly from the model input file, modifications to units may be required. The heading of each model input file will specify the factors used to convert units used for input data to the units used by the model (Figures 7-43 and 7-44).

Figure 7-43 **IWFM Pumping Data Specification Units**



```
C*******************************************************************************
C                          Pumping Data Specifications
C
C   NCOLPUMP; Number of pumping sets (or pathnames if DSS files are used)
C   FACTPUMP; Conversion factor for pumping data
C              It is used to convert only the spatial component of the unit;
C              DO NOT include the conversion factor for time component of the unit.
C              * e.g. Unit of pumping listed in this file        = AC-FT/MONTH
C                     Consistent unit used in simulation         = CU.FT/DAY
C                     Enter FACTPUMP (AC-FT/MONTH -> CU.FT/MONTH)= 43560.0
C                      (conversion of MONTH -> DAY is performed automatically)
C   NSPPUMP ; Number of time steps to update pumping data
C              * Enter any number if time-tracking option is on
C   NFQPUMP ; Repetition frequency of the pumping data
C              * Enter 0 if full time series data is supplied
C              * Enter any number if time-tracking option is on
C   DSSFL   ; The name of the DSS file for data input (maximum 50 characters);
C              * Leave blank if DSS file is not used for data input
C
C-------------------------------------------------------------------------------
C         VALUE                                    DESCRIPTION
C-------------------------------------------------------------------------------
           2                                      / NCOLPUMP
           43560000.0                             / FACTPUMP     (taf -> cu.ft.)
           1                                      / NSPPUMP
           0                                      / NFQPUMP
                                                  / DSSFL
C-------------------------------------------------------------------------------
```

Figure 7-44 **IWFM Surface Water Diversion Data Specification Units**

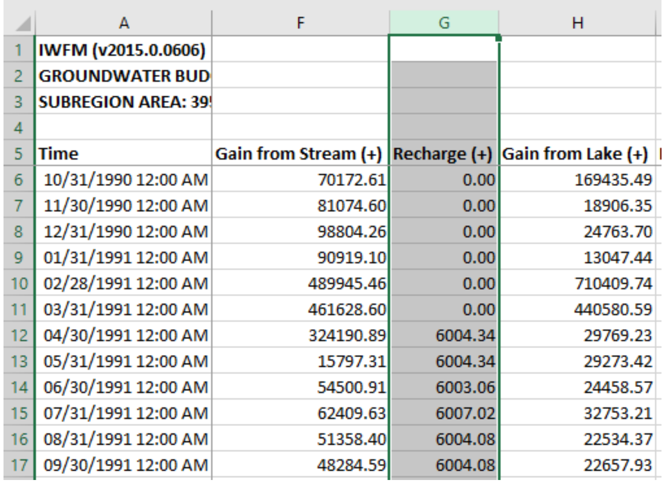


```
C*******************************************************************************
C                     Surface Water Diversion Data Specifications
C
C   The following lists the time-series surface water diversions for
C   each of the stream nodes where surface diversions have been specified.
C
C   NCOLDV;  Number of surface water diversions (or pathnames if DSS files are used)
C   FACTDV;  Conversion factor for surface water diversions
C             It is used to convert only the spatial component of the unit;
C             DO NOT include the conversion factor for time component of the unit.
C             * e.g. Unit of diversion listed in this file     = AC-FT/MONTH
C                    Consistent unit used in simulation        = CU.FT/DAY
C                    Enter FACTDV (AC-FT/MONTH -> CU.FT/MONTH)= 43560.0
C                     (conversion of MONTH -> DAY is performed automatically)
C   NSPDV ;  Number of time steps to update the surface water diversion data
C             * Enter any number if time-tracking option is on
C   NFQDV ;  Repetition frequency of the surface water diversion data
C             * Enter 0 if full time series data is supplied
C             * Enter any number if time-tracking option is on
C   DSSFL ;  The name of the DSS file for data input (maximum 50 characters);
C             * Leave blank if DSS file is not used for data input
C
C-------------------------------------------------------------------------------
C    VALUE                          DESCRIPTION
C-------------------------------------------------------------------------------
     6                              / NCOLDV
     43560000.0                     / FACTDV      (taf -> cu.ft.)
     1                              / NSPDV
     0                              / NFQDV
                                    / DSSFL
C*******************************************************************************
```

Often there will be a comment in the data file specifying the exact unit conversion that is used. In the example above, the input data are specified as thousand acre-feet and then multiplied by the factor 43.56 million for conversion to the model units of cubic feet.

In cases where there is no conveyance seepage and all recharge can be attributed to managed aquifer recharge, IWFM accounts for the recharge volume in the Groundwater Budget output file. For the subregions or water budget zone of interest, the volume of managed aquifer recharge is reported in the "Recharge" column (Figure 7-45).

Figure 7-45 **Groundwater Budget: Recharge**

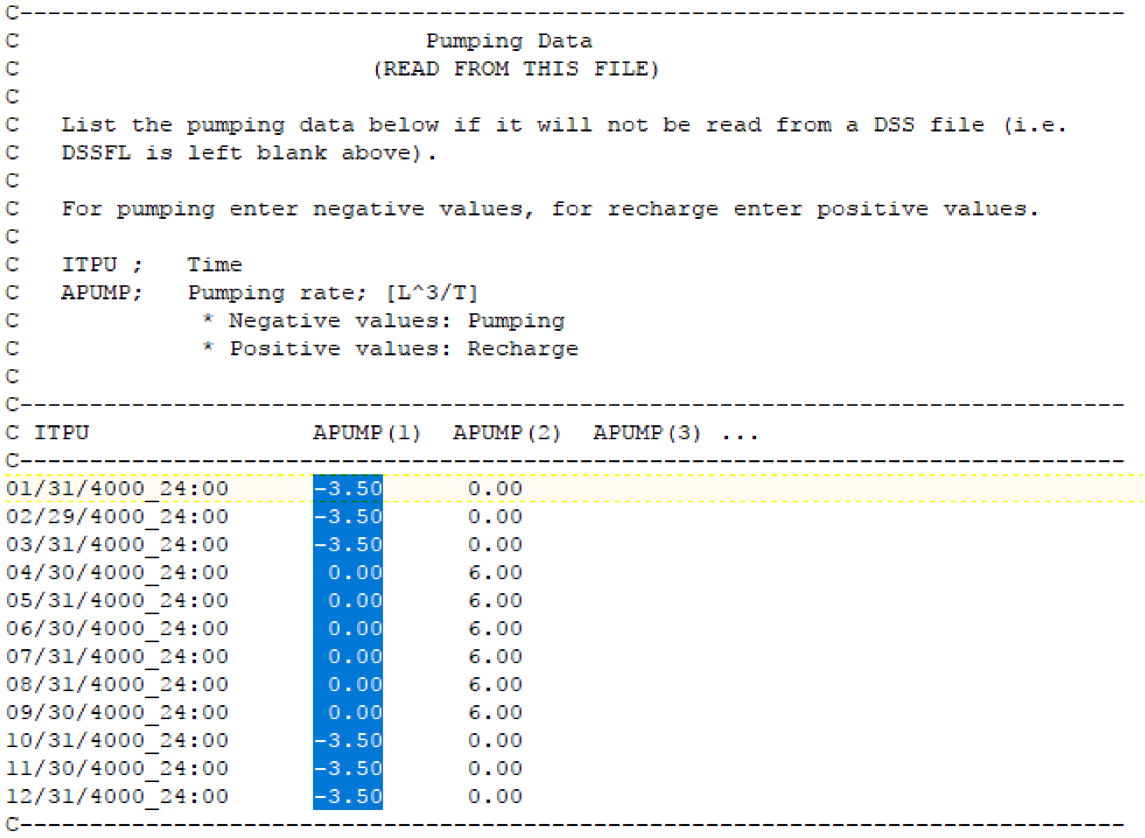


	A	F	G	H
1	IWFM (v2015.0.0606)			
2	GROUNDWATER BUD			
3	SUBREGION AREA: 39			
4				
5	Time	Gain from Stream (+)	Recharge (+)	Gain from Lake (+)
6	10/31/1990 12:00 AM	70172.61	0.00	169435.49
7	11/30/1990 12:00 AM	81074.60	0.00	18906.35
8	12/31/1990 12:00 AM	98804.26	0.00	24763.70
9	01/31/1991 12:00 AM	90919.10	0.00	13047.44
10	02/28/1991 12:00 AM	489945.46	0.00	710409.74
11	03/31/1991 12:00 AM	461628.60	0.00	440580.59
12	04/30/1991 12:00 AM	324190.89	6004.34	29769.23
13	05/31/1991 12:00 AM	15797.31	6004.34	29273.42
14	06/30/1991 12:00 AM	54500.91	6003.06	24458.57
15	07/31/1991 12:00 AM	62409.63	6007.02	32753.21
16	08/31/1991 12:00 AM	51358.40	6004.08	22534.37
17	09/30/1991 12:00 AM	48284.59	6004.08	22657.93

7.5.6 Stored Water Extraction

Stored water extraction, as defined in Section 1.3, refers to the "volume of groundwater pumped (extracted) from the underlying aquifer(s) through a defined recharge and extraction program for use within the water budget zone. For example, a water bank with dedicated extraction wells can provide data for stored water extraction. It does not include stored water export, groundwater extraction, and groundwater export. Groundwater extraction and stored water extraction will be combined if stored water extraction amounts are unknown or are not separately measured. In such a case, the total volume of combined extractions will be reported as groundwater extraction." IWFM does not include a separate simulation component for stored water extraction. If water banking operations are simulated, the pumping will be grouped with other groundwater extraction in the "Pumping" column in the Groundwater Budget output file. Because stored water extraction will typically be an input parameter rather than something internally calculated within the model, timeseries data for stored water extraction will need to be included as input data. These data can be extracted from the timeseries data in the Pumping Data input file (Figure 7-46). Use model documentation to identify which time series are associated with stored water extraction.

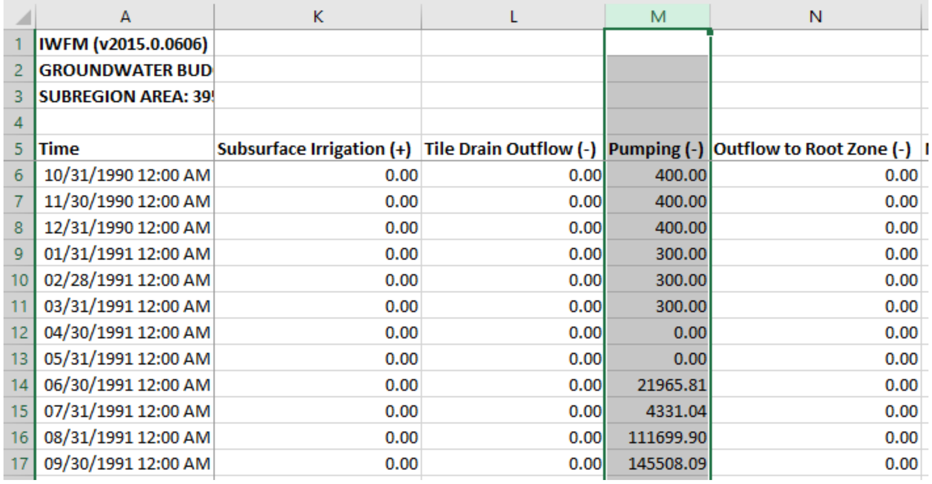
Figure 7-46 **IWFM Pumping Data File**



```
C-------------------------------------------------------------------------------
C                              Pumping Data
C                          (READ FROM THIS FILE)
C
C   List the pumping data below if it will not be read from a DSS file (i.e.
C   DSSFL is left blank above).
C
C   For pumping enter negative values, for recharge enter positive values.
C
C   ITPU ;    Time
C   APUMP;    Pumping rate; [L^3/T]
C              * Negative values: Pumping
C              * Positive values: Recharge
C
C-------------------------------------------------------------------------------
C ITPU                  APUMP(1)  APUMP(2)  APUMP(3) ...
C-------------------------------------------------------------------------------
01/31/4000_24:00        -3.50       0.00
02/29/4000_24:00        -3.50       0.00
03/31/4000_24:00        -3.50       0.00
04/30/4000_24:00         0.00       6.00
05/31/4000_24:00         0.00       6.00
06/30/4000_24:00         0.00       6.00
07/31/4000_24:00         0.00       6.00
08/31/4000_24:00         0.00       6.00
09/30/4000_24:00         0.00       6.00
10/31/4000_24:00        -3.50       0.00
11/30/4000_24:00        -3.50       0.00
12/31/4000_24:00        -3.50       0.00
C-------------------------------------------------------------------------------
```

In cases where the only pumping in a water budget zone is attributed to the Stored Water Extraction, IWFM reports the pumping volume in the Groundwater Budget. The total volume of stored water extraction is reported in the “Pumping” column (Figure 7-47).

Figure 7-47 Groundwater Budget: Pumping



	A	K	L	M	N
1	IWFM (v2015.0.0606)				
2	GROUNDWATER BUD				
3	SUBREGION AREA: 39				
4					
5	Time	Subsurface Irrigation (+)	Tile Drain Outflow (-)	Pumping (-)	Outflow to Root Zone (-)
6	10/31/1990 12:00 AM	0.00	0.00	400.00	0.00
7	11/30/1990 12:00 AM	0.00	0.00	400.00	0.00
8	12/31/1990 12:00 AM	0.00	0.00	400.00	0.00
9	01/31/1991 12:00 AM	0.00	0.00	300.00	0.00
10	02/28/1991 12:00 AM	0.00	0.00	300.00	0.00
11	03/31/1991 12:00 AM	0.00	0.00	300.00	0.00
12	04/30/1991 12:00 AM	0.00	0.00	0.00	0.00
13	05/31/1991 12:00 AM	0.00	0.00	0.00	0.00
14	06/30/1991 12:00 AM	0.00	0.00	21965.81	0.00
15	07/31/1991 12:00 AM	0.00	0.00	4331.04	0.00
16	08/31/1991 12:00 AM	0.00	0.00	111699.90	0.00
17	09/30/1991 12:00 AM	0.00	0.00	145508.09	0.00

7.5.7 Groundwater Export

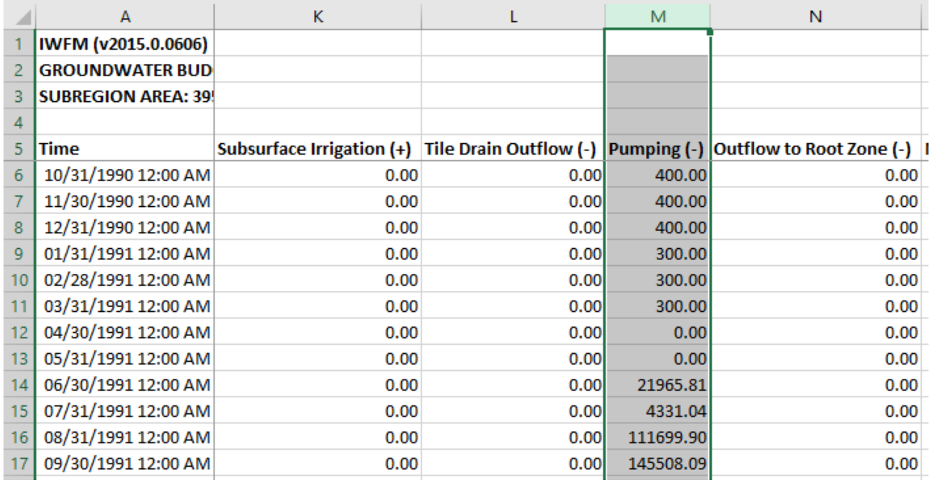
Groundwater export, as defined in Section 1.3, refers to the “volume of groundwater pumped (extracted) from the underlying aquifer for use outside the water budget zone. It does not include groundwater extraction, stored water extraction, and stored water export.” IWFM simulates groundwater exports but does not explicitly specify the amount and destination of that export out of a subregion or user-defined water budget zone in the output files.

Groundwater exports can be obtained from an IWMF model using a combination of the Groundwater Budget and Land and Water Use Budget outputs. “Pumping” in the groundwater budget reports all pumping that happens within a zone or subregion, regardless of the end use. The Land and Water Use budget reports “Ag. Pumping” and “Urban Pumping”, which refer to the volumes of groundwater in the water budget zone that are used to meet agricultural and urban demands.

For the subregions or water budget zone of interest, find the total pumping in the water budget zone from the “Pumping” column in the Groundwater Budget output file (Figure 7-48). From the Land and Water Use Budget output file, find the volume of groundwater used for overlying use through the “Ag. Pumping” and “Urban Pumping” columns (Figures 7-49 and 7-50). The total volume of groundwater export is the difference between the total pumping and pumping for overlying use.

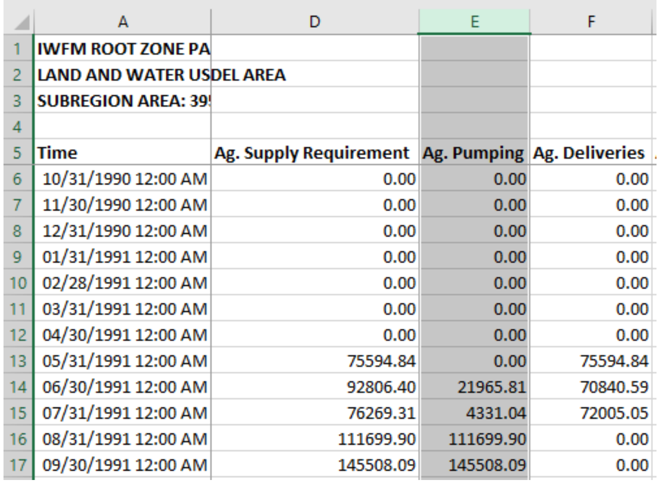
If stored water export also exists in the water budget zone, this volume will need to be subtracted from the previously calculated value.

Figure 7-48 Groundwater Budget: Pumping



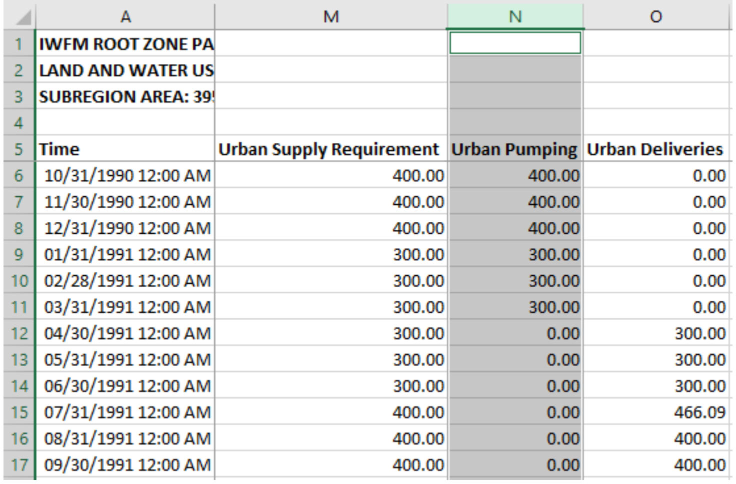
	A	K	L	M	N
1	IWFM (v2015.0.0606)				
2	GROUNDWATER BUD				
3	SUBREGION AREA: 39				
4					
5	Time	Subsurface Irrigation (+)	Tile Drain Outflow (-)	Pumping (-)	Outflow to Root Zone (-)
6	10/31/1990 12:00 AM	0.00	0.00	400.00	0.00
7	11/30/1990 12:00 AM	0.00	0.00	400.00	0.00
8	12/31/1990 12:00 AM	0.00	0.00	400.00	0.00
9	01/31/1991 12:00 AM	0.00	0.00	300.00	0.00
10	02/28/1991 12:00 AM	0.00	0.00	300.00	0.00
11	03/31/1991 12:00 AM	0.00	0.00	300.00	0.00
12	04/30/1991 12:00 AM	0.00	0.00	0.00	0.00
13	05/31/1991 12:00 AM	0.00	0.00	0.00	0.00
14	06/30/1991 12:00 AM	0.00	0.00	21965.81	0.00
15	07/31/1991 12:00 AM	0.00	0.00	4331.04	0.00
16	08/31/1991 12:00 AM	0.00	0.00	111699.90	0.00
17	09/30/1991 12:00 AM	0.00	0.00	145508.09	0.00

Figure 7-49 Land and Water Use Budget: Agricultural Pumping



	A	D	E	F
1	IWFM ROOT ZONE PA			
2	LAND AND WATER USDEL AREA			
3	SUBREGION AREA: 39			
4				
5	Time	Ag. Supply Requirement	Ag. Pumping	Ag. Deliveries
6	10/31/1990 12:00 AM	0.00	0.00	0.00
7	11/30/1990 12:00 AM	0.00	0.00	0.00
8	12/31/1990 12:00 AM	0.00	0.00	0.00
9	01/31/1991 12:00 AM	0.00	0.00	0.00
10	02/28/1991 12:00 AM	0.00	0.00	0.00
11	03/31/1991 12:00 AM	0.00	0.00	0.00
12	04/30/1991 12:00 AM	0.00	0.00	0.00
13	05/31/1991 12:00 AM	75594.84	0.00	75594.84
14	06/30/1991 12:00 AM	92806.40	21965.81	70840.59
15	07/31/1991 12:00 AM	76269.31	4331.04	72005.05
16	08/31/1991 12:00 AM	111699.90	111699.90	0.00
17	09/30/1991 12:00 AM	145508.09	145508.09	0.00

Figure 7-50 **Land and Water Use Budget: Urban Pumping**

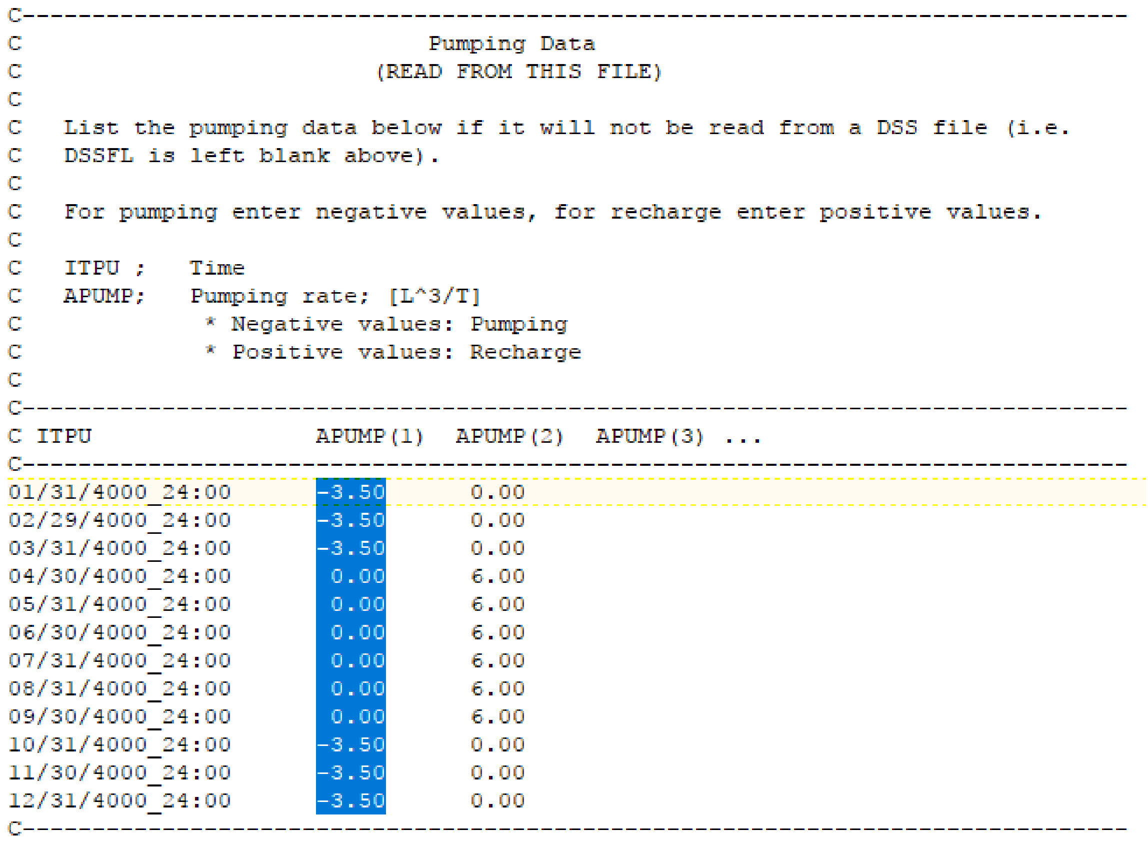


	A	M	N	O
1	IWFM ROOT ZONE PA			
2	LAND AND WATER US			
3	SUBREGION AREA: 39			
4				
5	Time	Urban Supply Requirement	Urban Pumping	Urban Deliveries
6	10/31/1990 12:00 AM	400.00	400.00	0.00
7	11/30/1990 12:00 AM	400.00	400.00	0.00
8	12/31/1990 12:00 AM	400.00	400.00	0.00
9	01/31/1991 12:00 AM	300.00	300.00	0.00
10	02/28/1991 12:00 AM	300.00	300.00	0.00
11	03/31/1991 12:00 AM	300.00	300.00	0.00
12	04/30/1991 12:00 AM	300.00	0.00	300.00
13	05/31/1991 12:00 AM	300.00	0.00	300.00
14	06/30/1991 12:00 AM	300.00	0.00	300.00
15	07/31/1991 12:00 AM	400.00	0.00	466.09
16	08/31/1991 12:00 AM	400.00	0.00	400.00
17	09/30/1991 12:00 AM	400.00	0.00	400.00

7.5.8 Stored Water Export

Stored water export, as defined in Section 1.3, refers to the "volume of groundwater pumped (extracted) from the underlying aquifer(s) through a defined recharge and extraction program for use outside the water budget zone. For example, a water bank with dedicated extraction wells can provide data for stored water export. It does not include stored water extraction, groundwater extraction, and groundwater export. Groundwater export and stored water export will be combined if stored water export amounts are unknown or are not separately measured. In such a case, the total volume of combined exports will be reported as groundwater export." IWFM does not include a separate simulation component for stored water export. It can be obtained using a similar process as stored water extraction. If water banking operations are simulated, the pumping will be grouped with other groundwater extraction in the "Pumping" column in the Groundwater Budget output file. Similar to stored water extraction, stored water export will typically be an input parameter rather than something internally calculated within the model. Timeseries data for stored water export will need to be included as input data. For wells used for stored water export, data can be extracted from the timeseries data in the Pumping Data input file (Figure 7-51). Use model documentation to identify which time series are associated with stored water export.

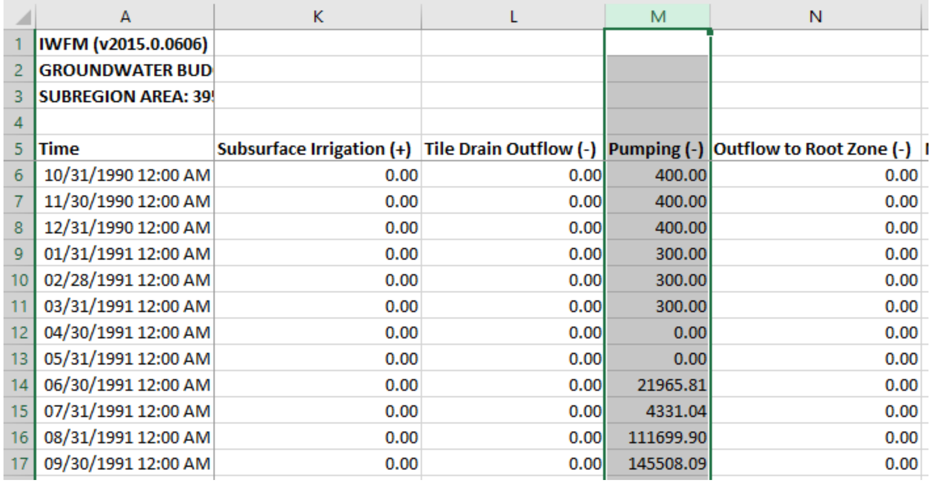
Figure 7-51 IWFM Pumping Data File



```
C-------------------------------------------------------------------------------
C                             Pumping Data
C                         (READ FROM THIS FILE)
C
C   List the pumping data below if it will not be read from a DSS file (i.e.
C   DSSFL is left blank above).
C
C   For pumping enter negative values, for recharge enter positive values.
C
C   ITPU ;    Time
C   APUMP;    Pumping rate; [L^3/T]
C              * Negative values: Pumping
C              * Positive values: Recharge
C
C-------------------------------------------------------------------------------
C ITPU                     APUMP(1)  APUMP(2)  APUMP(3) ...
C-------------------------------------------------------------------------------
01/31/4000_24:00           -3.50       0.00
02/29/4000_24:00           -3.50       0.00
03/31/4000_24:00           -3.50       0.00
04/30/4000_24:00            0.00       6.00
05/31/4000_24:00            0.00       6.00
06/30/4000_24:00            0.00       6.00
07/31/4000_24:00            0.00       6.00
08/31/4000_24:00            0.00       6.00
09/30/4000_24:00            0.00       6.00
10/31/4000_24:00           -3.50       0.00
11/30/4000_24:00           -3.50       0.00
12/31/4000_24:00           -3.50       0.00
C-------------------------------------------------------------------------------
```

In cases where the only pumping in a water budget zone is attributed to the Stored Water Export, IWFM reports the pumping volume in the Groundwater Budget. The total volume of stored water extraction is reported in the "Pumping" column (Figure 7-52).

Figure 7-52 Groundwater Budget: Pumping

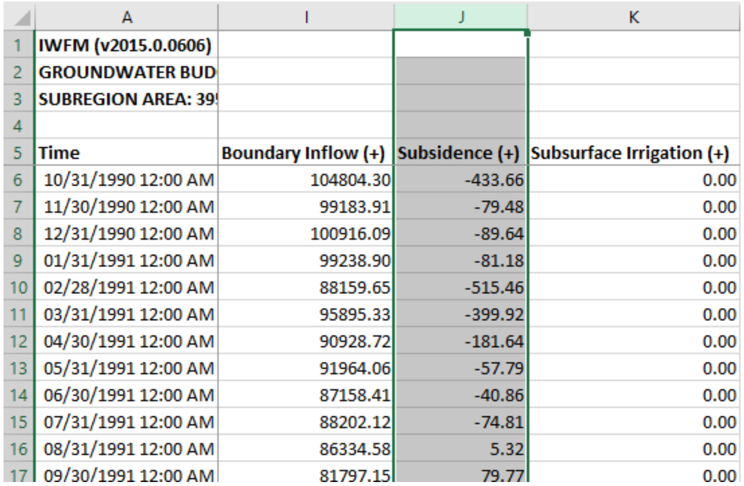


	A	K	L	M	N
1	IWFM (v2015.0.0606)				
2	GROUNDWATER BUD				
3	SUBREGION AREA: 39				
4					
5	Time	Subsurface Irrigation (+)	Tile Drain Outflow (-)	Pumping (-)	Outflow to Root Zone (-)
6	10/31/1990 12:00 AM	0.00	0.00	400.00	0.00
7	11/30/1990 12:00 AM	0.00	0.00	400.00	0.00
8	12/31/1990 12:00 AM	0.00	0.00	400.00	0.00
9	01/31/1991 12:00 AM	0.00	0.00	300.00	0.00
10	02/28/1991 12:00 AM	0.00	0.00	300.00	0.00
11	03/31/1991 12:00 AM	0.00	0.00	300.00	0.00
12	04/30/1991 12:00 AM	0.00	0.00	0.00	0.00
13	05/31/1991 12:00 AM	0.00	0.00	0.00	0.00
14	06/30/1991 12:00 AM	0.00	0.00	21965.81	0.00
15	07/31/1991 12:00 AM	0.00	0.00	4331.04	0.00
16	08/31/1991 12:00 AM	0.00	0.00	111699.90	0.00
17	09/30/1991 12:00 AM	0.00	0.00	145508.09	0.00

7.5.9 Water Release Caused by Land Subsidence

Water release caused by land subsidence, as defined in Section 1.3 is the "volume of water released to an aquifer on a one-time basis as a result of land subsidence, which is caused by the inelastic consolidation of porous fine-grained material." IWFM accounts for the water release resulting from both elastic and inelastic fluctuations in interbed thicknesses in the Groundwater Budget output (Figure 7-53). The value reported in the "Subsidence" column of the groundwater budget output is the net water released (+) or taken up (-); currently there is no way to separate out the volume of water released to an aquifer on a one-time basis as a result of land subsidence.

Figure 7-53 Groundwater Budget: Subsidence

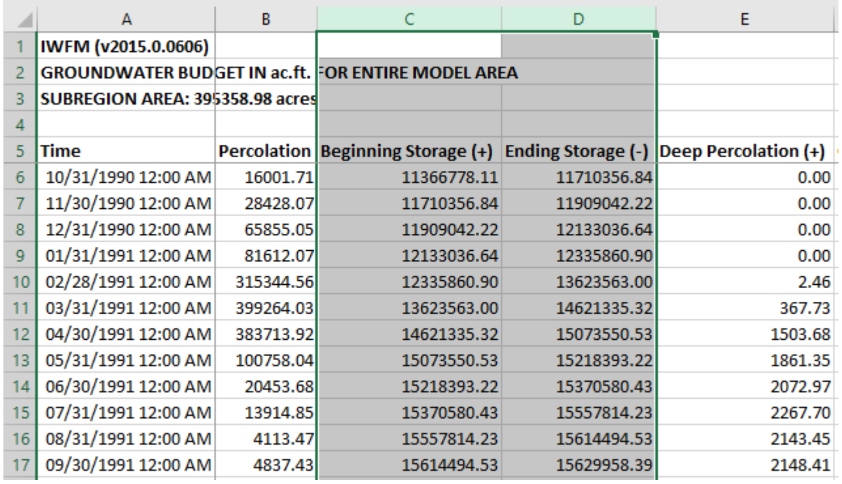


	A	I	J	K
1	IWFM (v2015.0.0606)			
2	GROUNDWATER BUD			
3	SUBREGION AREA: 39			
4				
5	Time	Boundary Inflow (+)	Subsidence (+)	Subsurface Irrigation (+)
6	10/31/1990 12:00 AM	104804.30	-433.66	0.00
7	11/30/1990 12:00 AM	99183.91	-79.48	0.00
8	12/31/1990 12:00 AM	100916.09	-89.64	0.00
9	01/31/1991 12:00 AM	99238.90	-81.18	0.00
10	02/28/1991 12:00 AM	88159.65	-515.46	0.00
11	03/31/1991 12:00 AM	95895.33	-399.92	0.00
12	04/30/1991 12:00 AM	90928.72	-181.64	0.00
13	05/31/1991 12:00 AM	91964.06	-57.79	0.00
14	06/30/1991 12:00 AM	87158.41	-40.86	0.00
15	07/31/1991 12:00 AM	88202.12	-74.81	0.00
16	08/31/1991 12:00 AM	86334.58	5.32	0.00
17	09/30/1991 12:00 AM	81797.15	79.77	0.00

7.5.10 Change in Groundwater Storage

Change in groundwater storage, as defined in Section 1.3 is the "net change in the volume of groundwater stored within the underlying aquifer of the water budget zone." IWFM accounts for the change in groundwater storage in the Groundwater Budget output. For the subregions or water budget zone of interest, the Groundwater Budget accounts for the change in groundwater storage in the "Beginning Storage" and "Ending Storage" columns of the groundwater budget output (Figure 7-54). The change in storage for a particular time stop is the difference between the beginning storage and the ending storage.

Figure 7-54 **Groundwater Budget: Groundwater Storage**



	A	B	C	D	E
1	IWFM (v2015.0.0606)				
2	GROUNDWATER BUDGET IN ac.ft. FOR ENTIRE MODEL AREA				
3	SUBREGION AREA: 395358.98 acres				
4					
5	Time	Percolation	Beginning Storage (+)	Ending Storage (-)	Deep Percolation (+)
6	10/31/1990 12:00 AM	16001.71	11366778.11	11710356.84	0.00
7	11/30/1990 12:00 AM	28428.07	11710356.84	11909042.22	0.00
8	12/31/1990 12:00 AM	65855.05	11909042.22	12133036.64	0.00
9	01/31/1991 12:00 AM	81612.07	12133036.64	12335860.90	0.00
10	02/28/1991 12:00 AM	315344.56	12335860.90	13623563.00	2.46
11	03/31/1991 12:00 AM	399264.03	13623563.00	14621335.32	367.73
12	04/30/1991 12:00 AM	383713.92	14621335.32	15073550.53	1503.68
13	05/31/1991 12:00 AM	100758.04	15073550.53	15218393.22	1861.35
14	06/30/1991 12:00 AM	20453.68	15218393.22	15370580.43	2072.97
15	07/31/1991 12:00 AM	13914.85	15370580.43	15557814.23	2267.70
16	08/31/1991 12:00 AM	4113.47	15557814.23	15614494.53	2143.45
17	09/30/1991 12:00 AM	4837.43	15614494.53	15629958.39	2148.41

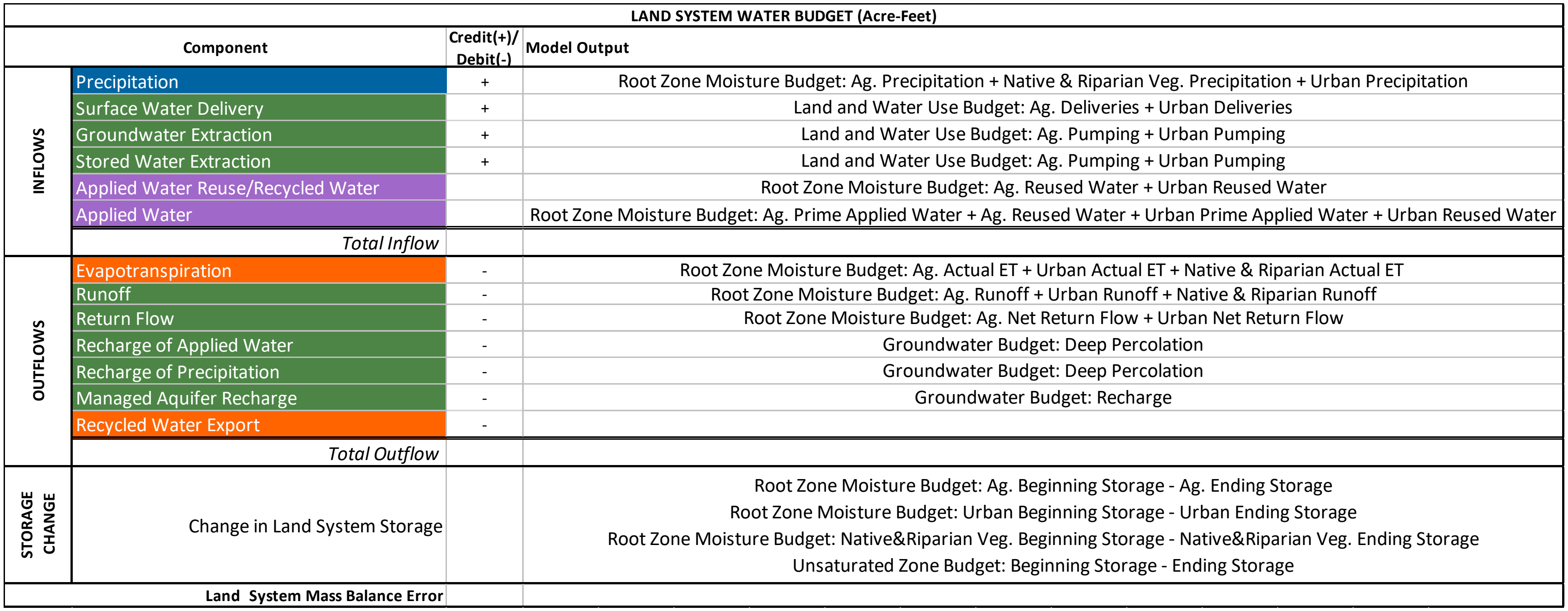
7.6 TOTAL WATER BUDGET FROM IWFM

After individual water budget components are extracted from an IWFM application, the total water budget can be compiled for the water budget zone. The total water budget is an accounting of all water entering or leaving the water budget zone, as well as components flowing between systems within the water budget zone. Water budget tables for the land system, surface water system, groundwater system, and total water budget are presented in Figures 7-55 through 7-58. The tables demonstrate the interconnectivity between the three systems and highlight the inflows and outflows from the water budget zone. The tables are also available in accessible Excel format on the Water Budget Handbook webpage.

Color Key:

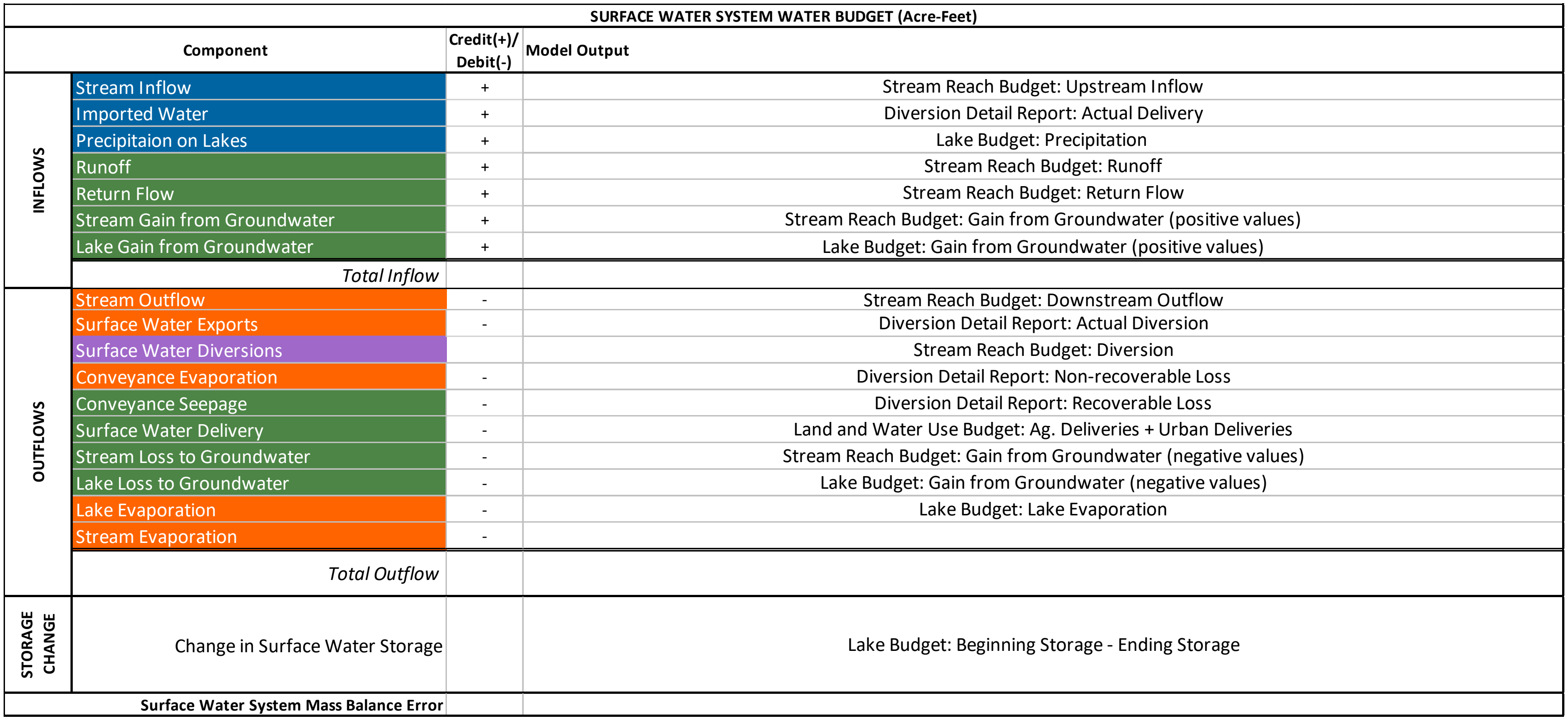
Blue	Inflow to Water Budget Zone
Orange	Outflow from Water Budget Zone
Green	Flow between Systems
Purple	Flow within Systems

Figure 7-55 Land System Water Budget Components and IWFM Water Budget Elements



LAND SYSTEM WATER BUDGET (Acre-Feet)			
	Component	**Credit(+)/ Debit(-)**	**Model Output**
INFLOWS	Precipitation	+	Root Zone Moisture Budget: Ag. Precipitation + Native & Riparian Veg. Precipitation + Urban Precipitation
	Surface Water Delivery	+	Land and Water Use Budget: Ag. Deliveries + Urban Deliveries
	Groundwater Extraction	+	Land and Water Use Budget: Ag. Pumping + Urban Pumping
	Stored Water Extraction	+	Land and Water Use Budget: Ag. Pumping + Urban Pumping
	Applied Water Reuse/Recycled Water		Root Zone Moisture Budget: Ag. Reused Water + Urban Reused Water
	Applied Water		Root Zone Moisture Budget: Ag. Prime Applied Water + Ag. Reused Water + Urban Prime Applied Water + Urban Reused Water
	Total Inflow		
OUTFLOWS	Evapotranspiration	-	Root Zone Moisture Budget: Ag. Actual ET + Urban Actual ET + Native & Riparian Actual ET
	Runoff	-	Root Zone Moisture Budget: Ag. Runoff + Urban Runoff + Native & Riparian Runoff
	Return Flow	-	Root Zone Moisture Budget: Ag. Net Return Flow + Urban Net Return Flow
	Recharge of Applied Water	-	Groundwater Budget: Deep Percolation
	Recharge of Precipitation	-	Groundwater Budget: Deep Percolation
	Managed Aquifer Recharge	-	Groundwater Budget: Recharge
	Recycled Water Export	-	
	Total Outflow		
STORAGE CHANGE	Change in Land System Storage		Root Zone Moisture Budget: Ag. Beginning Storage - Ag. Ending Storage Root Zone Moisture Budget: Urban Beginning Storage - Urban Ending Storage Root Zone Moisture Budget: Native&Riparian Veg. Beginning Storage - Native&Riparian Veg. Ending Storage Unsaturated Zone Budget: Beginning Storage - Ending Storage
	Land System Mass Balance Error		

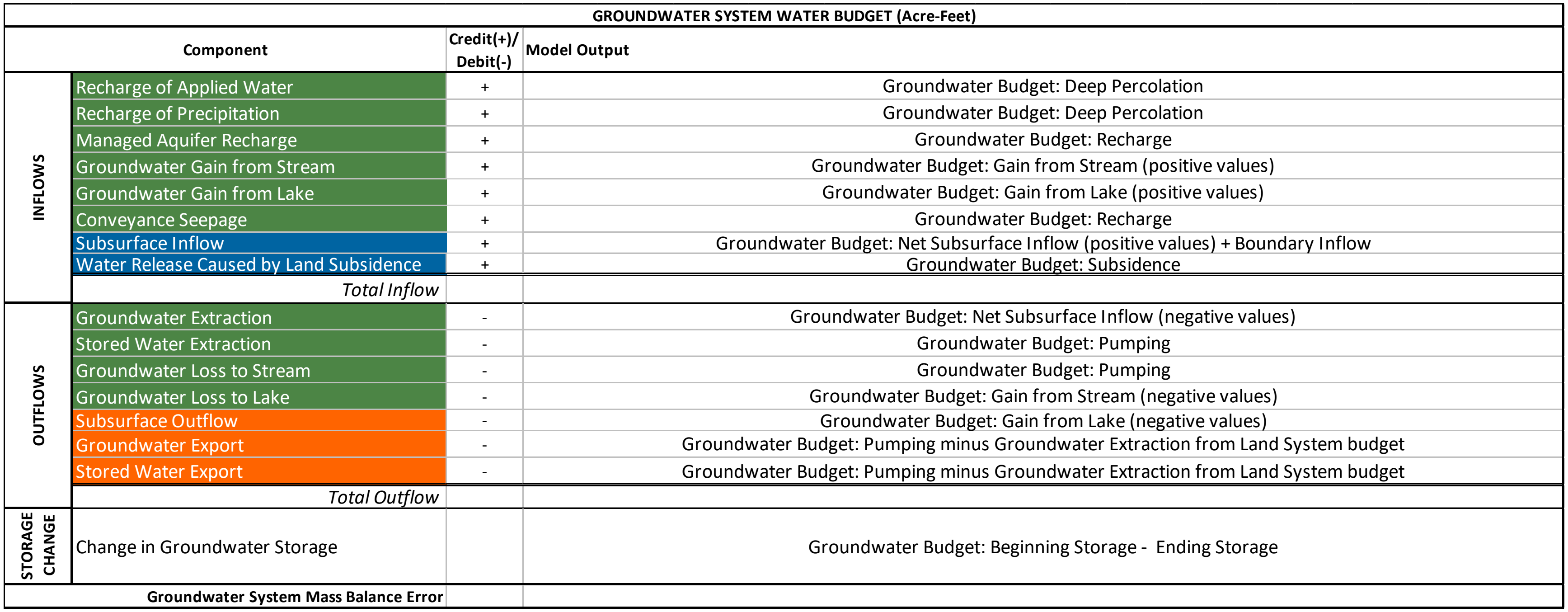
Figure 7-56 Surface Water System Budget Components and IWFM Water Budget Elements



SURFACE WATER SYSTEM WATER BUDGET (Acre-Feet)

	Component	Credit(+)/ Debit(-)	Model Output
INFLOWS	Stream Inflow	+	Stream Reach Budget: Upstream Inflow
	Imported Water	+	Diversion Detail Report: Actual Delivery
	Precipitaion on Lakes	+	Lake Budget: Precipitation
	Runoff	+	Stream Reach Budget: Runoff
	Return Flow	+	Stream Reach Budget: Return Flow
	Stream Gain from Groundwater	+	Stream Reach Budget: Gain from Groundwater (positive values)
	Lake Gain from Groundwater	+	Lake Budget: Gain from Groundwater (positive values)
	Total Inflow		
OUTFLOWS	Stream Outflow	-	Stream Reach Budget: Downstream Outflow
	Surface Water Exports	-	Diversion Detail Report: Actual Diversion
	Surface Water Diversions		Stream Reach Budget: Diversion
	Conveyance Evaporation	-	Diversion Detail Report: Non-recoverable Loss
	Conveyance Seepage	-	Diversion Detail Report: Recoverable Loss
	Surface Water Delivery	-	Land and Water Use Budget: Ag. Deliveries + Urban Deliveries
	Stream Loss to Groundwater	-	Stream Reach Budget: Gain from Groundwater (negative values)
	Lake Loss to Groundwater	-	Lake Budget: Gain from Groundwater (negative values)
	Lake Evaporation	-	Lake Budget: Lake Evaporation
	Stream Evaporation	-	
	Total Outflow		
STORAGE CHANGE	Change in Surface Water Storage		Lake Budget: Beginning Storage - Ending Storage
	Surface Water System Mass Balance Error		

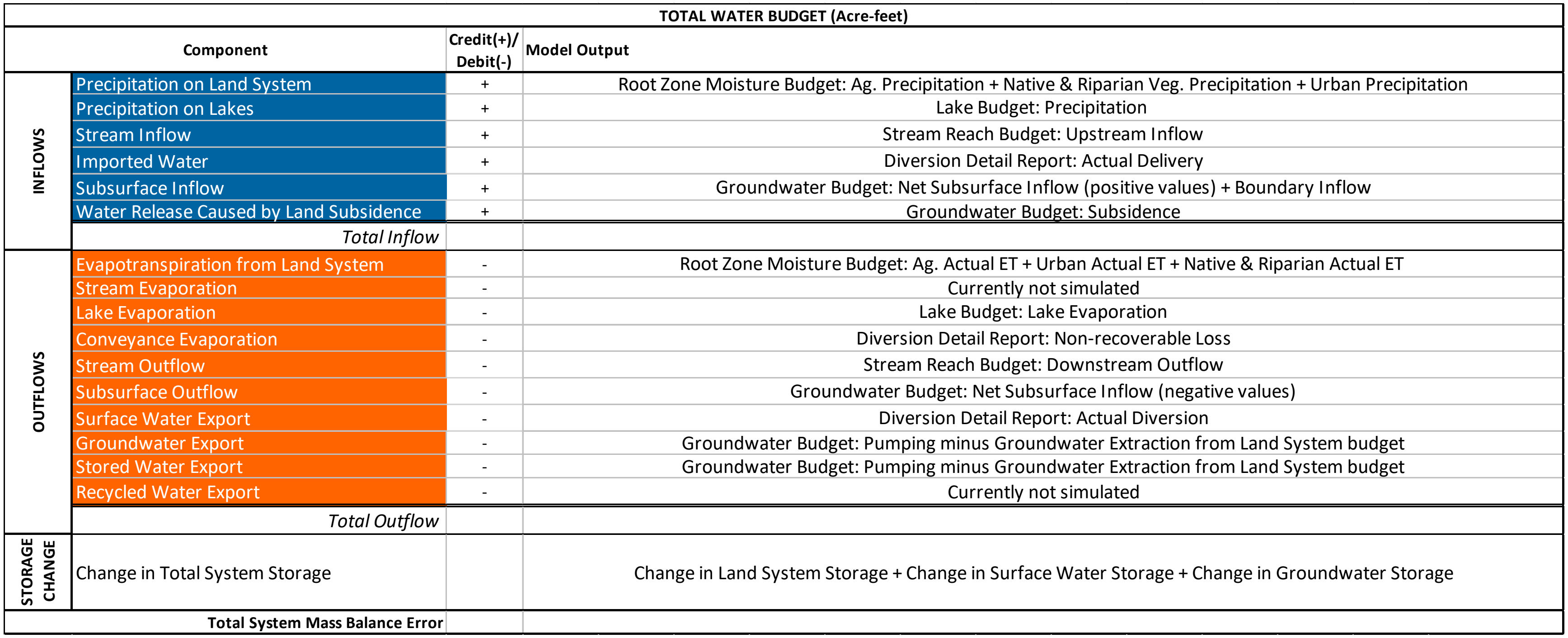
Figure 7-57 **Groundwater System Budget Components and IWFM Water Budget Elements**



GROUNDWATER SYSTEM WATER BUDGET (Acre-Feet)

	Component	Credit(+)/ Debit(-)	Model Output
INFLOWS	Recharge of Applied Water	+	Groundwater Budget: Deep Percolation
	Recharge of Precipitation	+	Groundwater Budget: Deep Percolation
	Managed Aquifer Recharge	+	Groundwater Budget: Recharge
	Groundwater Gain from Stream	+	Groundwater Budget: Gain from Stream (positive values)
	Groundwater Gain from Lake	+	Groundwater Budget: Gain from Lake (positive values)
	Conveyance Seepage	+	Groundwater Budget: Recharge
	Subsurface Inflow	+	Groundwater Budget: Net Subsurface Inflow (positive values) + Boundary Inflow
	Water Release Caused by Land Subsidence	+	Groundwater Budget: Subsidence
	Total Inflow		
OUTFLOWS	Groundwater Extraction	-	Groundwater Budget: Net Subsurface Inflow (negative values)
	Stored Water Extraction	-	Groundwater Budget: Pumping
	Groundwater Loss to Stream	-	Groundwater Budget: Pumping
	Groundwater Loss to Lake	-	Groundwater Budget: Gain from Stream (negative values)
	Subsurface Outflow	-	Groundwater Budget: Gain from Lake (negative values)
	Groundwater Export	-	Groundwater Budget: Pumping minus Groundwater Extraction from Land System budget
	Stored Water Export	-	Groundwater Budget: Pumping minus Groundwater Extraction from Land System budget
	Total Outflow		
STORAGE CHANGE	Change in Groundwater Storage		Groundwater Budget: Beginning Storage - Ending Storage
	Groundwater System Mass Balance Error		

Figure 7-58 Total Water Budget Components and IWFM Water Budget Elements



TOTAL WATER BUDGET (Acre-feet)

	Component	Credit(+)/ Debit(-)	Model Output
INFLOWS	Precipitation on Land System	+	Root Zone Moisture Budget: Ag. Precipitation + Native & Riparian Veg. Precipitation + Urban Precipitation
	Precipitation on Lakes	+	Lake Budget: Precipitation
	Stream Inflow	+	Stream Reach Budget: Upstream Inflow
	Imported Water	+	Diversion Detail Report: Actual Delivery
	Subsurface Inflow	+	Groundwater Budget: Net Subsurface Inflow (positive values) + Boundary Inflow
	Water Release Caused by Land Subsidence	+	Groundwater Budget: Subsidence
	Total Inflow		
OUTFLOWS	Evapotranspiration from Land System	-	Root Zone Moisture Budget: Ag. Actual ET + Urban Actual ET + Native & Riparian Actual ET
	Stream Evaporation	-	Currently not simulated
	Lake Evaporation	-	Lake Budget: Lake Evaporation
	Conveyance Evaporation	-	Diversion Detail Report: Non-recoverable Loss
	Stream Outflow	-	Stream Reach Budget: Downstream Outflow
	Subsurface Outflow	-	Groundwater Budget: Net Subsurface Inflow (negative values)
	Surface Water Export	-	Diversion Detail Report: Actual Diversion
	Groundwater Export	-	Groundwater Budget: Pumping minus Groundwater Extraction from Land System budget
	Stored Water Export	-	Groundwater Budget: Pumping minus Groundwater Extraction from Land System budget
	Recycled Water Export	-	Currently not simulated
	Total Outflow		
STORAGE CHANGE	Change in Total System Storage		Change in Land System Storage + Change in Surface Water Storage + Change in Groundwater Storage
	Total System Mass Balance Error		

8. CASE STUDY: ONE-WATER HYDROLOGIC FLOW MODEL (MODFLOW-OWHM)

8.1 MODFLOW-OWHM INTRODUCTION

MODFLOW is the USGS's three-dimensional finite difference groundwater model. It is used for simulating and forecasting groundwater, surface water, flow in the unsaturated zone, groundwater/surface-water interactions and other components of the hydrologic system. Originally developed and released solely for groundwater-flow simulation in 1984, it now includes additional capabilities to simulate coupled groundwater/surface-water systems, solute transport, variable-density flow, and aquifer-system compaction and land subsidence.

The One-Water Hydrologic Flow Model (MODFLOW-OWHM) is an integrated hydrologic model implementation based on MODFLOW). MODFLOW-OWHM combines all the MODFLOW-2005 versions into one software. All versions of MODFLOW-OWHM are compatible with any MODFLOW-2005 based model or MODFLOW-NWT (Newton-Raphson formulation), with some special considerations for the Farm Process. MODFLOW-OWHM supports features such as the Farm Process (FMP), Subsidence package, Local Grid Refinement, Reservoir Operations, Surface-water Routing Process, Seawater Intrusion, and Riparian ET.

Note: USGS is currently developing MODFLOW-OWHM version 2, an update to MODFLOW-OWHM with significant improvements to model run times, enhanced input and output options, and includes a substantial update to the Farm Process. Because of substantial modifications in FMP input files for MODFLOW-OWHM version 2, MODFLOW-OWHM version 2 FMP input files are not backward compatible. To use the advanced features of MODFLOW-OWHM version 2 with the Farm Process, an updated FMP input file must be created. New keyword-based input and file structure help simplify the FMP input file conversion process.

Features of MODFLOW-OWHM version 2 are described using callout boxes in subsequent sections, where applicable, based on input from USGS.

The modular structure of MODFLOW-OWHM allows for the use of different packages to support a variety of model configurations for different applications. Hydrologic budget component outputs are separated by packages and will vary based on the specific model configuration. Users may have to aggregate information from selected packages to determine the water budget framework components as conceptualized and described in Section 1.3 of this handbook. But, most of the desired information is contained within a few files. There are global budgets, zone budgets, and cell-by-cell budgets for all packages. In the Farm Process, additional budgets are available by water budget zones (i.e., water balance subregion [WBS]) and land-use. In addition, each package can output its own results, and individual package output formats can vary. For models with the Farm Process, agricultural, riparian and native vegetation, and urban water demands can be pre-specified or calculated internally based on different land-use types. Drainage network water reuse and diversions, recycled water, tile drains, lakes or open water areas, and reservoirs can also be modeled.

Throughout Section 8, there is some specific terminology that is used to describe surface water networks in MODFLOW. Similar to other hydrologic models, a surface water drainage network can be defined which may include canals, streams, etc. In MODFLOW, the network is discretized into stream segments that have consistent catchments or properties (e.g. stream bed conductivity, morphology). Each model cell within a stream segment is classified as a stream reach. Diversions can be specified from any stream segment. If the Farm Process is used, (1) diversions can be routed to a WBS to meet land-use water demands, and (2) return flows from WBS can be routed to a specific segment or split among all nearby streams.

8.2 EXTRACTING WATER BUDGET COMPONENTS FROM MODFLOW-OWHM

This case study section provides information on how to extract water budget components from MODFLOW-OWHM inputs and outputs. This section does not follow the standard case study format of a study area inclusive of data collection, model input file development, model runs, and results analysis. Rather, it assumes that a MODFLOW-OWHM application is already developed for an area and provides examples of how to extract different water budget components from model results. In this section, several MODFLOW-OWHM applications are used to present the most comprehensive example of extracting model inputs and outputs to illustrate development of the water budget.

MODFLOW-OWHM produces five primary types of outputs that are useful for developing the total water budget:

- Zone Budget*:* The ZONEBUDGET function in MODFLOW allows reporting groundwater budgets for user-defined areas. MODFLOW saves a cell-by-cell groundwater budget that accounts for every component of the groundwater budget at the model cell scale and can be aggregated to user desired scales. The user can specify exactly which model cells are assigned to a zone to output groundwater budget results for that zone. Many of the terms relevant for developing a water budget are found in the ZONEBUDGET results. Instructions for setting up zone budgets are available on the USGS ZONEBUDGET webpage.
- Farm Budget*:* MODFLOW-OWHM outputs a Farm Budget, which accounts for all inflows and outflows out of predefined land surface areas otherwise known as a WBS. In this document this file is referred to as "DetailedFarmBudget.out" but can vary depending on the user specified file name in the farm process input file. Land uses are defined for each WBS, and water demands are satisfied using sources of water available to each WBS. The terms in the Farm Budget match closely with the land system water budget depicted in this handbook. The Detailed Farm budget does not explicitly report demands but rather the actual inflows and outflows of a the WBS.
    - **Note:** If an existing WBS matches the desired areas of interest for development of water budgets, the land system water budget can be developed using the Detailed Farm Budget output file. WBS are initially defined during model preparation; however, the extent of the WBS can be updated to examine different areas. If the number of regions is kept the same and the same sources of water remain connected to each WBS, updating the areas associated with WBS can be modified by updating one file. If a more complex redistribution of a WBS and its associated water supplies are desired, more model data sets will have to be updated. It is also important to note that values in the columns of Detailed Farm Budget are provided as rates by timestep. To obtain a volume for the desired budget, multiply the rate for that budget item by the length of that timestep and sum up the values. This yields a volumetric value in model units (e.g., cubic feet [ft^3] or cubic meters [m^3]). This approach allows for

consistent and accurate computation of volumes across potentially variable time step lengths resulting from variation in stress period lengths (e.g., variation in the number of days in a timestep or stress period).

- Stream Budget*:* MODFLOW-OWHM simulates streams using the Streamflow-Routing (SFR) Package, which outputs stream water budgets for each stream model cell defined as a stream. A cell defined as a stream in MODFLOW is called “stream reach”. The user can compile the stream water budgets for relevant streams reaches to develop a complete stream budget for their water budget zone.
- Lake Budget*:* Unlike the previous three budgets, the Lake Budget is not a default output of MODFLOW. If the Lake Package is used to simulate lakes in MODFLOW, the water balance for the lake will be output in the Lake budget. The Lake Budget accounts for atmospheric, surface water, and subsurface fluxes into and out of each lake. A separate output is provided for each lake simulated in the model.
- Reservoir Budget*:* Similar to the Lake Budget, the Reservoir Budget is not a default output of MODFLOW. If the Surface Water Operations Package is used to simulate reservoirs in MODFLOW-OWHM, the water balance for the reservoir will be output in the Reservoir Budget. The Reservoir Budget accounts for atmospheric, surface water, and releases from the reservoir. Output is provided for each reservoir simulated in the model.

Water budget components contained in various MODFLOW-OWHM budget tables are listed in Table 8-1. The components are organized by the three systems outlined in the total water budget: land system, surface water system, and groundwater system, as illustrated in Figure 1-1 and described in Sections 3 through 5.

Table 8-1 MODFLOW-OWHM Components for Establishing Total Water Budget

Water Budget Framework Component	MODFLOW-OWHM Budgets and Files
Land System	
Precipitation	Farm Budget
Evapotranspiration	Farm Budget
Applied Water	Farm Budget
Surface Water Delivery	Farm Budget
Groundwater Extraction	Farm Budget
Applied Water Reuse	See Note A
Recycled Water	See Note A
Recycled Water Export	Not Available
Runoff	Farm Budget, See Note B
Return Flow	Farm Budget, See Note B
Change in Land System Storage	Not Available
Surface Water System	
Stream Water Inflow and Outflow	Stream Budget
Surface Water Diversion	Stream Budget
Stream Evaporation	Stream Budget
Conveyance Evaporation	Stream Budget
Conveyance Seepage	Stream Budget
Imported Water	Farm Budget, Zone Budget, See Note A
Surface Water Exports	Stream Budget
Stream-Lake Interaction	Stream Budget, Lake Budget
Lake Evaporation	Stream Budget, Lake Budget
Change in Surface Water Storage	Lake Budget, Reservoir Budget File
Groundwater System	
Recharge of Applied Water	Farm Budget, Zone Budget
Recharge of Precipitation	Farm Budget, Zone Budget
Subsurface Inflow and Outflow	Zone Budget
Stream-Groundwater Interaction	Zone Budget, Stream Budget
Lake-Groundwater Interaction	Lake Budget
Managed Aquifer Recharge	Farm Budget, Zone Budget
Stored Water Extraction	Zone Budget, Well Input File
Groundwater Export	Zone Budget, Well Input File
Stored Water Export	Zone Budget, Well Input File
Water Release Caused by Land Subsidence	Zone Budget
Change in Groundwater Storage	Zone Budget

Table 8-1 Notes:
Note A: Reused water, recycled water, and imported water are specified as non-routed deliveries for model input. Although these terms are aggregated in the Farm Budget file, detailed budgets are available by water balance subregion (WBS), WBS and specified land-use, and cell. Each non-routed delivery can be assigned to a specific WBS and

specified with an order of use to meet demands and with a routing of excess delivered water to injection wells or to a stream network.
Note B: Runoff and return flow are aggregated and routed to streams after land-use water demands have been satisfied.

Note: In MODFLOW-OWHM, two additional farm process budgets can be written to a user specified file and provide Farm Budget data (1) by WBS and land-use (e.g., LandUse.Out) and (2) by WBS, Land-Use, and model cell (e.g., LandUseDetailed.out).

In MODFLOW-OWHM version 2, the user can specify package specific budgets to the cell-by-cell flow file that can be aggregated by zone or WBS. Supported packages include the General Head Boundary (GHB) Package, and the Multi-Node Well (MNW) Package. These optional budget groups are defined by a user-specified keyword at the top of the package input file, then the relevant items of locations associated with the desired budget group are tagged throughout the input file. The flows from these specific items are summed in a separate budget item for the package. Here we provide two examples of this optional feature. The first is defining GHB cells associated with a coastal boundary to assess sea water intrusion in layer 1 of the model.

MODFLOW-OWHM Model Units: MODFLOW-OWHM budget output results are presented as time series. To properly process the time series data into meaningful results, the user must understand the differences between the different “time” terms used in the model. There are three types of “time” in MODFLOW-OWHM:

1. Simulation Time: It is the duration of the transient simulation. It starts with a beginning date, it lasts for the length of simulation, and it ends with an end date.
2. Stress Period: MODFLOW-OWHM discretizes the duration of a transient simulation into several time periods at which the boundary conditions are assumed to change (e.g. pumping rates) and output data are printed (recorded). Stress periods are specified in model units and stress period lengths can be specified as daily, weekly, monthly, or yearly.

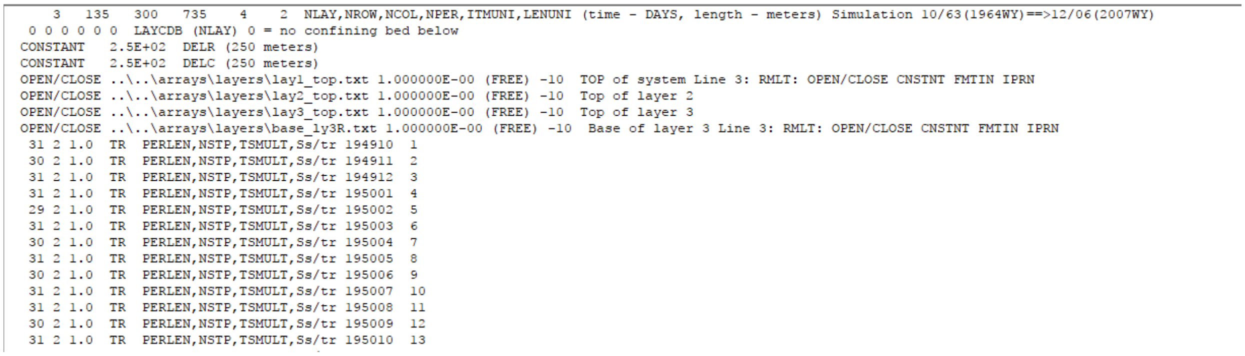
Time Step: Each stress period is further divided into time steps. Time steps are internal simulation periods upon which the calculations are performed. For example, if the model stress periods are monthly (meaning pumping and climate change each month), a stress period can be defined as 28-31 days. If two time-steps are selected for each stress period, the time step length will be 14-15.5 days each. Every budget except the Farm Budget outputs volumetric data for each stress period. Farm process output files provide rates for every timestep. To convert the rate in the Farm Budget to a volume, multiply the rate by the time step length. The beginning date, duration (length), and corresponding end date of each time period in MODFLOW-OWHM are specified with a file extension of ".dis", representing the discretization file. The first line in the discretization file contains the number of layers, rows, columns, stress periods, time unit, and length unit. MODFLOW-OWHM does not use text to specify units; rather, it specifies flags to indicate time units and length units, as shown in Table 8-2.

Table 8-2 MODFLOW-OWHM Time and Length Unit Flags

Time Unit Flag	Time Unit	Length Flag	Length Unit
0	Undefined	0	Undefined
1	Seconds	1	Feet
2	Minutes	2	Meters
3	Hours	3	Centimeters
4	Days		
5	Years		

Further down in the discretization file, a line is included for each stress period in the model as shown in the Figure 8-1 example. The first value in these lines refers to the length of the stress period in the units specified in Table 8-2. The example has a time flag of 4 (days) and length unit of 2 (meters). In the stress period section of the data file, each stress period contains 28-31 days, indicating that the model stress period is in months. The second value on each line of the stress period input defines the number of timesteps. In this example, the number of timesteps is 2, meaning the groundwater and surface water calculations will be performed two times. The example also contains some text indicating the units, but this is not a requirement of the input file and is not always present.

Figure 8-1 **Example MODFLOW-OWHM Discretization File Format**



```
    3   135   300   735    4    2  NLAY,NROW,NCOL,NPER,ITMUNI,LENUNI (time - DAYS, length - meters) Simulation 10/63(1964WY)==>12/06(2007WY)
 0 0 0 0 0 0  LAYCDB (NLAY) 0 = no confining bed below
CONSTANT   2.5E+02  DELR (250 meters)
CONSTANT   2.5E+02  DELC (250 meters)
OPEN/CLOSE ..\..\arrays\layers\lay1_top.txt 1.000000E-00 (FREE) -10  TOP of system Line 3: RMLT: OPEN/CLOSE CNSTNT FMTIN IPRN
OPEN/CLOSE ..\..\arrays\layers\lay2_top.txt 1.000000E-00 (FREE) -10  Top of layer 2
OPEN/CLOSE ..\..\arrays\layers\lay3_top.txt 1.000000E-00 (FREE) -10  Top of layer 3
OPEN/CLOSE ..\..\arrays\layers\base_ly3R.txt 1.000000E-00 (FREE) -10  Base of layer 3 Line 3: RMLT: OPEN/CLOSE CNSTNT FMTIN IPRN
 31 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 194910  1
 30 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 194911  2
 31 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 194912  3
 31 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 195001  4
 29 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 195002  5
 31 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 195003  6
 30 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 195004  7
 31 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 195005  8
 30 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 195006  9
 31 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 195007  10
 31 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 195008  11
 30 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 195009  12
 31 2 1.0  TR  PERLEN,NSTP,TSMULT,Ss/tr 195010  13
```

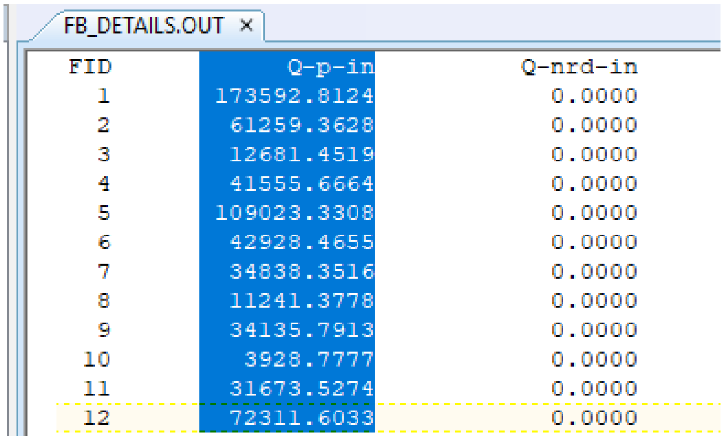
The following sections describe where to locate water budget components in the MODFLOW-OWHM results files. Different versions of MODFLOW may have different outputs or methods of simulating various water budget components. There are numerous graphical user interfaces (GUI) for MODFLOW, all of which contain different ways of extracting and processing water budget information. Rather than discuss the different GUIs available for MODFLOW, the following sections focus on extracting the relevant data from the model output files available, regardless of which GUI is used. The components are organized by the systems outlined in the total water budget — land system, surface water system, and groundwater system. Volumes in the output files will typically be provided in the default model units specified in the discretization file. The values obtained in cubic feet (ft^3) or cubic meters (m^3) can be converted to AF by multiplying by 2.2957×10^{-5} or 8.10714×10^{-4}, respectively.

8.3 LAND SYSTEM

8.3.1 Precipitation

Precipitation, as defined in Section 1.3, refers to the "volume of water vapor that falls to the earth (land and surface water systems) as rain, snow, hail, or is formed on the earth as dew, and frost." The Farm Budget in MODFLOW-OWHM accounts for the volume of precipitation in the DetailedFarmBudget.out file. For the farms corresponding to the water budget zone, find the precipitation data in the "Q-p-in" (Rate of precipitation inflow to a water-balance subregion) column. To obtain a volume for the desired budget component for each model timestep, multiply the rate by the time-step length (e.g., the "Days" column if model units are days). This yields a volumetric value in model units (e.g., cubic feet or cubic meters).

Figure 8-2 **Farm Budget: Precipitation**

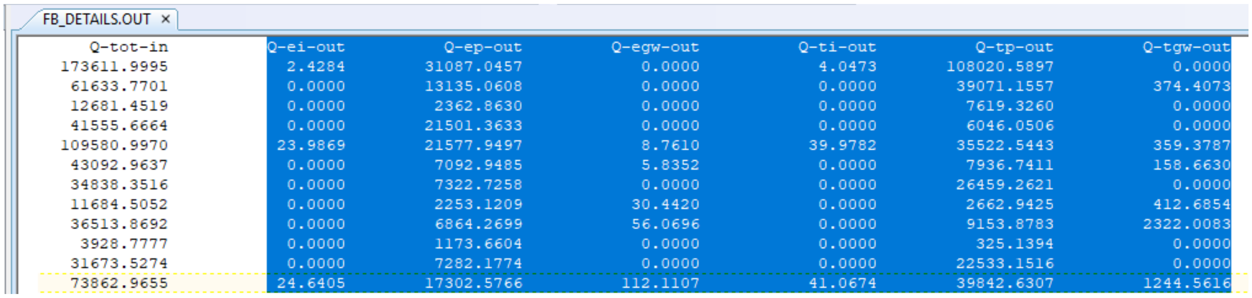


```
FID       Q-p-in        Q-nrd-in
  1  173592.8124          0.0000
  2   61259.3628          0.0000
  3   12681.4519          0.0000
  4   41555.6664          0.0000
  5  109023.3308          0.0000
  6   42928.4655          0.0000
  7   34838.3516          0.0000
  8   11241.3778          0.0000
  9   34135.7913          0.0000
 10    3928.7777          0.0000
 11   31673.5274          0.0000
 12   72311.6033          0.0000
```

8.3.2 Evapotranspiration

Evapotranspiration (ET), as defined in Section 1.3, is the "volume of water entering the atmosphere through the combined process of evaporation from soil and plant surfaces and transpiration from plants." The Farm Budget in MODFLOW-OWHM accounts for volumes of ET in the DetailedFarmBudget.out file. For the farms corresponding to the water budget zone of interest, ET rates can be found under the "Q-ei-out" (rate of evaporation from irrigation out of the farm), "Q-ep-out" (rate of evaporation from precipitation out of the farm), "Q-egw-out" (rate of evaporation from groundwater out of the farm), "Q-ti-out" (rate of transpiration from irrigation out of the farm), "Q-tp-out" (rate of transpiration from precipitation out of the farm), and "Q-tgw-out" (rate of transpiration from groundwater out of the farm) columns (Figure 8-3). For each time step, the total ET is the sum of the values in the previously mentioned columns for each farm of interest multiplied by the time-step length (e.g. the "Days" column if model units are days). This yields a volumetric value in model units (e.g., cubic feet or cubic meters).

Figure 8-3 **Farm Budget: Evapotranspiration**

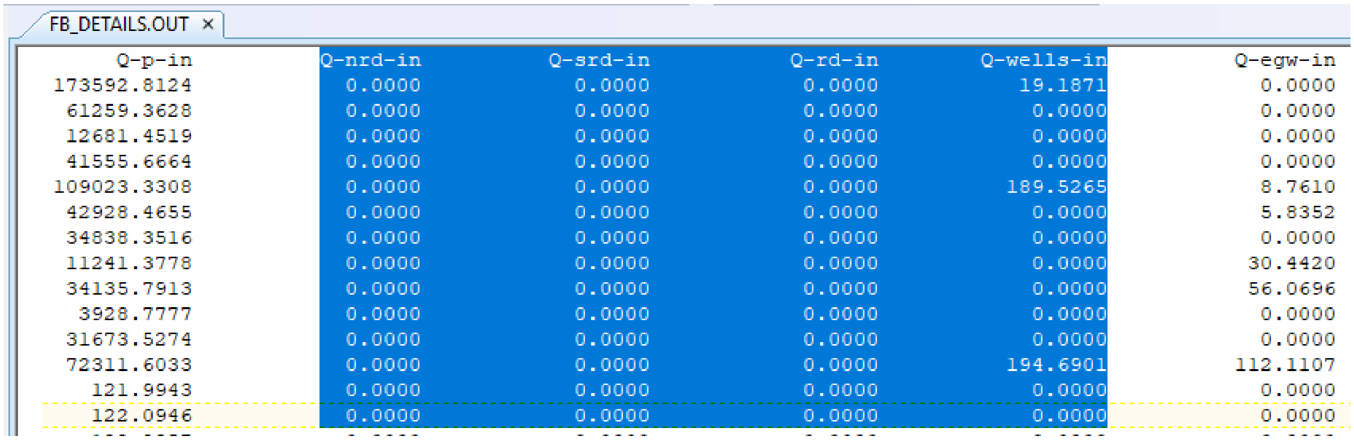


```
  Q-tot-in        Q-ei-out       Q-ep-out      Q-egw-out       Q-ti-out        Q-tp-out    Q-tgw-out
173611.9995         2.4284     31087.0457         0.0000         4.0473     108020.5897       0.0000
 61633.7701         0.0000     13135.0608         0.0000         0.0000      39071.1557     374.4073
 12681.4519         0.0000      2362.8630         0.0000         0.0000       7619.3260       0.0000
 41555.6664         0.0000     21501.3633         0.0000         0.0000       6046.0506       0.0000
109580.9970        23.9869     21577.9497         8.7610        39.9782      35522.5443     359.3787
 43092.9637         0.0000      7092.9485         5.8352         0.0000       7936.7411     158.6630
 34838.3516         0.0000      7322.7258         0.0000         0.0000      26459.2621       0.0000
 11684.5052         0.0000      2253.1209        30.4420         0.0000       2662.9425     412.6854
 36513.8692         0.0000      6864.2699        56.0696         0.0000       9153.8783    2322.0083
  3928.7777         0.0000      1173.6604         0.0000         0.0000        325.1394       0.0000
 31673.5274         0.0000      7282.1774         0.0000         0.0000      22533.1516       0.0000
 73862.9655        24.6405     17302.5766       112.1107        41.0674      39842.6307    1244.5616
```

8.3.3 Applied Water

Applied water, as defined in Section 1.3, refers to the "volume of water delivered to the intake of a city water system, a factory, a farm headgate, managed wetlands, or managed aquifer recharge; it includes all sources of supply (surface water, groundwater, applied water reuse, and recycled water)." MODFLOW-OWHM accounts for the total volume of water being applied to the land surface in the DetailedFarmBudget.out file. Water is not divided into use sectors within a WBS. Water deliveries in MODFLOW-OWHM are classified as non-routed, semi-routed, and fully-routed. Non-routed deliveries (NRD) refer to water that originates from outside the model whereas semi-routed and fully-routed deliveries originate from streams within the model domain. For the WBS corresponding to the water budget zone, find the columns "Q-nrd-in" (rate of NRD into a water-balance subregion), "Q-srd-in" (rate of semi-routed deliveries into a water-balance subregion), "Q-rd-in" (rate of routed deliveries into a water-balance subregion), "Q-wells-in" (rate of groundwater pumping deliveries into a water balance subregion), and 'Q-ext-in" (rate of external deliveries into a water balance subregion). To obtain a volume for applied water for each model timestep, multiply the rate by the time-step length (e.g. the "Days" column if model units are days). This yields a volumetric value in model units (e.g., ft^3 or m^3). The total applied water to all farms in the water budget zone is the sum of these five values. Units for surface water delivery are typically ft^3 or m^3 and should be verified (refer to Section 8.2).

Figure 8-4 Farm Budget: Applied Water



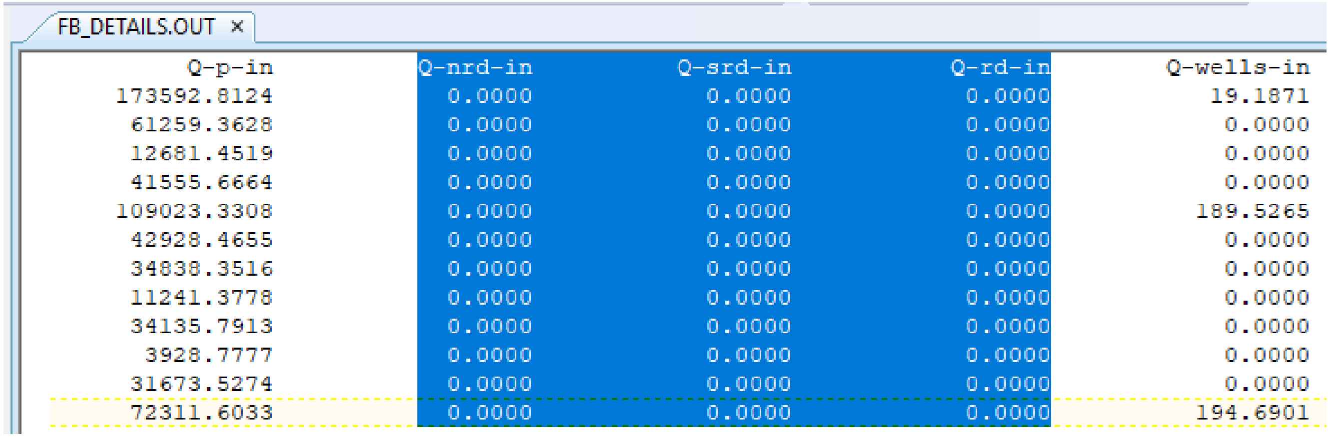
```
        Q-p-in          Q-nrd-in         Q-srd-in          Q-rd-in       Q-wells-in          Q-egw-in
   173592.8124            0.0000           0.0000           0.0000          19.1871            0.0000
    61259.3628            0.0000           0.0000           0.0000           0.0000            0.0000
    12681.4519            0.0000           0.0000           0.0000           0.0000            0.0000
    41555.6664            0.0000           0.0000           0.0000           0.0000            0.0000
   109023.3308            0.0000           0.0000           0.0000         189.5265            8.7610
    42928.4655            0.0000           0.0000           0.0000           0.0000            5.8352
    34838.3516            0.0000           0.0000           0.0000           0.0000            0.0000
    11241.3778            0.0000           0.0000           0.0000           0.0000           30.4420
    34135.7913            0.0000           0.0000           0.0000           0.0000           56.0696
     3928.7777            0.0000           0.0000           0.0000           0.0000            0.0000
    31673.5274            0.0000           0.0000           0.0000           0.0000            0.0000
    72311.6033            0.0000           0.0000           0.0000         194.6901          112.1107
      121.9943            0.0000           0.0000           0.0000           0.0000            0.0000
      122.0946            0.0000           0.0000           0.0000           0.0000            0.0000
```

8.3.4 Surface Water Delivery

Surface water delivery, as defined in Section 1.3, refers to the "volume of surface water delivered to a water budget zone. This does not equal the volume of surface water diversion and imported water because the latter also include conveyance seepage and evaporation during transport of the water." MODFLOW-OWHM divides surface water delivery into three groups: non-routed, semi-routed, and fully routed surface water inflows to the water budget zone.

The Farm Budget in MODFLOW-OWHM accounts for the volume of surface water delivery in the DetailedFarmBudget.out file. For the farms corresponding to the water budget zone, find the surface water delivery data in the "Q-nrd-in" (rate of NRD inflow into a water-balance subregion), "Q-srd-in" (rate of semi-routed delivery inflow into a water-balance subregion), and "Q-rd-in" (rate of fully routed delivery inflow into a water-balance subregion) columns (Figure 8-5). To obtain a volume for surface water deliveries for each model timestep, multiply the rate by the time-step length (e.g. the "Days" column if model units are days). This yields a volumetric value in model units (e.g., ft^3 or m^3). The total surface water deliveries to all farms in the water budget zone is the sum of these three values. Units for surface water delivery are typically ft^3 or m^3 and should be verified (refer to Section 8.2).

Figure 8-5 Farm Budget: Surface Water Deliveries

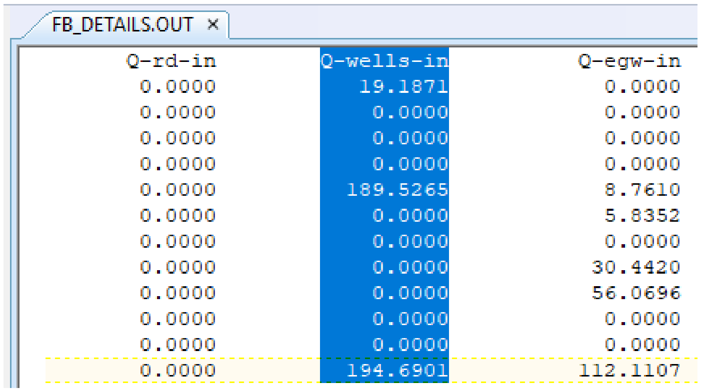


```
            Q-p-in        Q-nrd-in         Q-srd-in          Q-rd-in       Q-wells-in
       173592.8124          0.0000           0.0000           0.0000          19.1871
        61259.3628          0.0000           0.0000           0.0000           0.0000
        12681.4519          0.0000           0.0000           0.0000           0.0000
        41555.6664          0.0000           0.0000           0.0000           0.0000
       109023.3308          0.0000           0.0000           0.0000         189.5265
        42928.4655          0.0000           0.0000           0.0000           0.0000
        34838.3516          0.0000           0.0000           0.0000           0.0000
        11241.3778          0.0000           0.0000           0.0000           0.0000
        34135.7913          0.0000           0.0000           0.0000           0.0000
         3928.7777          0.0000           0.0000           0.0000           0.0000
        31673.5274          0.0000           0.0000           0.0000           0.0000
        72311.6033          0.0000           0.0000           0.0000         194.6901
```

8.3.5 Groundwater Extraction

Groundwater extraction, as defined in Section 1.3, refers to the "volume of groundwater pumped (extracted) from the underlying aquifer(s) for use within the water budget zone. It does not include groundwater export, stored water extraction, and stored water export.” The Farm Budget in MODFLOW-OWHM accounts for the volume of groundwater extraction in the DetailedFarmBudget.out file. For the farms corresponding to the water budget zone of interest, find the groundwater extraction data in the “Q-wells-in” (rate of groundwater well pumping deliveries) column (Figure 8-6). To obtain a volume for groundwater extraction for each model timestep, multiply the rate by the time-step length (e.g., the “Days” column if model units are days). This yields a volumetric value in model units (e.g., cubic feet or cubic meters).

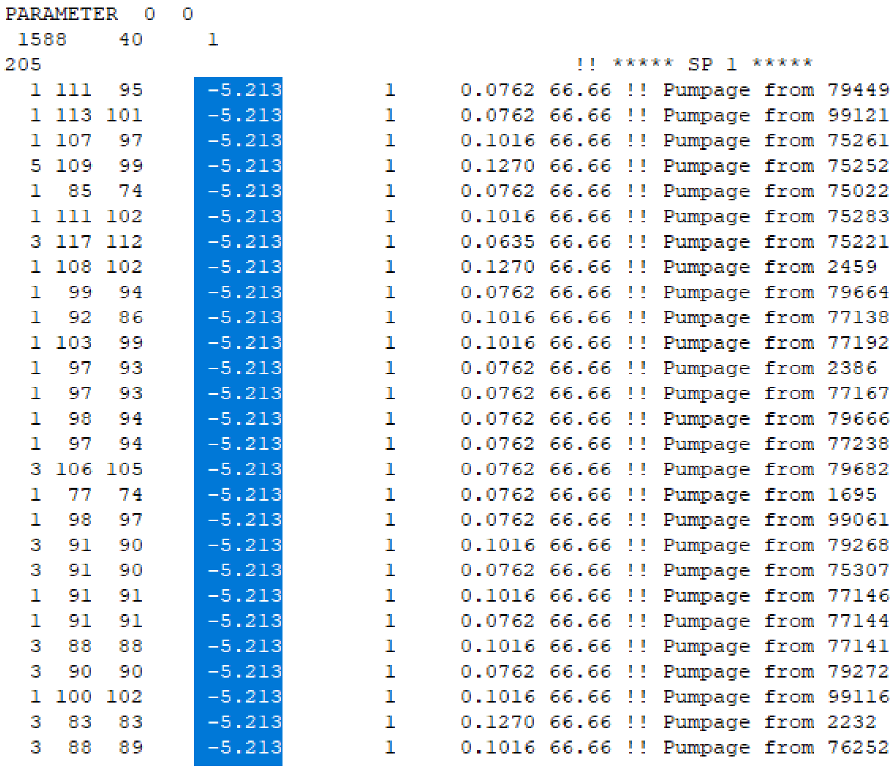
Figure 8-6 Farm Budget: Groundwater Extraction



```
         Q-rd-in      Q-wells-in         Q-egw-in
          0.0000         19.1871           0.0000
          0.0000          0.0000           0.0000
          0.0000          0.0000           0.0000
          0.0000          0.0000           0.0000
          0.0000        189.5265           8.7610
          0.0000          0.0000           5.8352
          0.0000          0.0000           0.0000
          0.0000          0.0000          30.4420
          0.0000          0.0000          56.0696
          0.0000          0.0000           0.0000
          0.0000          0.0000           0.0000
          0.0000        194.6901         112.1107
```

If stored water extraction, as described in Section 5.7, “Stored Water Extraction,” is simulated, that volume will need to be subtracted to compute groundwater extraction as defined in this handbook. Typically, groundwater extraction is used for overlying use and not for export. If groundwater is pumped for use elsewhere, then that volume will also need to be accounted for and subtracted from the total groundwater pumping reported in the Zone Budget results file. Typically, volumes of groundwater pumped for water bank extraction are measured and readily available through reports or model input data. Using the maps or information in the model documentation or any associated hydrogeologic report, find which wells in the model that corresponds to the wells in the water budget zone. If specific wells correspond to stored water extraction, the volumes can be obtained from the Well input file (Figure 8-7) and subtracted from the total pumping.

Figure 8-7 MODFLOW-OWHM WEL File



```
PARAMETER  0  0
 1588    40     1
205                                          !! ***** SP 1 *****
  1 111  95     -5.213        1     0.0762 66.66 !! Pumpage from 79449
  1 113 101     -5.213        1     0.0762 66.66 !! Pumpage from 99121
  1 107  97     -5.213        1     0.1016 66.66 !! Pumpage from 75261
  5 109  99     -5.213        1     0.1270 66.66 !! Pumpage from 75252
  1  85  74     -5.213        1     0.0762 66.66 !! Pumpage from 75022
  1 111 102     -5.213        1     0.1016 66.66 !! Pumpage from 75283
  3 117 112     -5.213        1     0.0635 66.66 !! Pumpage from 75221
  1 108 102     -5.213        1     0.1270 66.66 !! Pumpage from 2459
  1  99  94     -5.213        1     0.0762 66.66 !! Pumpage from 79664
  1  92  86     -5.213        1     0.1016 66.66 !! Pumpage from 77138
  1 103  99     -5.213        1     0.1016 66.66 !! Pumpage from 77192
  1  97  93     -5.213        1     0.0762 66.66 !! Pumpage from 2386
  1  97  93     -5.213        1     0.0762 66.66 !! Pumpage from 77167
  1  98  94     -5.213        1     0.0762 66.66 !! Pumpage from 79666
  1  97  94     -5.213        1     0.0762 66.66 !! Pumpage from 77238
  3 106 105     -5.213        1     0.0762 66.66 !! Pumpage from 79682
  1  77  74     -5.213        1     0.0762 66.66 !! Pumpage from 1695
  1  98  97     -5.213        1     0.0762 66.66 !! Pumpage from 99061
  3  91  90     -5.213        1     0.1016 66.66 !! Pumpage from 79268
  3  91  90     -5.213        1     0.0762 66.66 !! Pumpage from 75307
  1  91  91     -5.213        1     0.1016 66.66 !! Pumpage from 77146
  1  91  91     -5.213        1     0.0762 66.66 !! Pumpage from 77144
  3  88  88     -5.213        1     0.1016 66.66 !! Pumpage from 77141
  3  90  90     -5.213        1     0.0762 66.66 !! Pumpage from 79272
  1 100 102     -5.213        1     0.1016 66.66 !! Pumpage from 99116
  3  83  83     -5.213        1     0.1270 66.66 !! Pumpage from 2232
  3  88  89     -5.213        1     0.1016 66.66 !! Pumpage from 76252
```

8.3.6 Applied Water Reuse

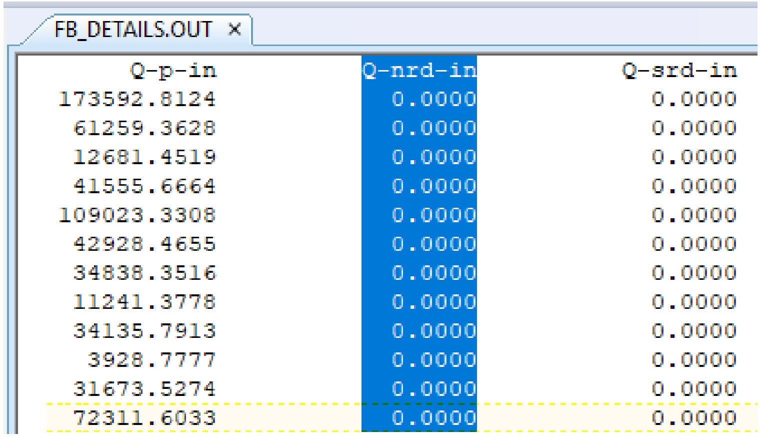
Applied water reuse, as defined in Section 1.3, refers to the "volume of applied water contributing to (1) lateral flow below the land surface that is influenced by impermeable layers and re-emerges as return flow for reuse in the land system, (2) tailwater available for reuse in the land system, or (3) a combination of both." For the lateral flow component of applied water reuse in MODFLOW-OWHM, lateral inflows to streams are not directly accounted for. Flows from groundwater to the streams occur through the streambed with regional groundwater flow and are accounted for in the Stream Budget, but output values aggregate all inflows from groundwater to each stream reach. For the second definition, tailwater is aggregated with precipitation runoff and routed to streams after land-use demands have been satisfied. Also, MODFLOW-OWHM combines runoff and return flow into a single term for reporting purposes. Runoff data are provided in the *DetailedFarmBudget.out* file. These data may be used to obtain estimates of reuse. The model documentation or associated reports may provide information on reuse processes in the water budget zone.

8.3.7 Recycled Water

Recycled water, as defined in Section 1.3, refers to the "volume of water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur within the water budget zone. It includes wastewater that is treated, stored, distributed, and reused or recirculated for beneficial uses." MODFLOW-OWHM can account for recycled water as a NRD. Information about volumes of recycled water can be obtained from the farm process NRD input files. The way recycled water is accounted for using NRD will vary from model to model. The user will need to consult the model documentation to determine how a particular model is handling recycled water. Details for determining how NRDs work in a model are described below.

If the only NRD to a farm can be attributed to recycled water, then the volume can be obtained from the DetailedFarmBudget.out file. NRDs are reported in the "Q-nrd-in" (rate of NRD inflow to a water-balance subregion column (Figure 8-8). To obtain a volume for recycled water for each model timestep, multiply the rate by the time-step length (e.g., the "Days" column if model units are days). This yields a volumetric value in model units (e.g., cubic feet or cubic meters).

Figure 8-8 **Farm Budget: Non-routed Deliveries**



```
     Q-p-in              Q-nrd-in             Q-srd-in
173592.8124                0.0000               0.0000
 61259.3628                0.0000               0.0000
 12681.4519                0.0000               0.0000
 41555.6664                0.0000               0.0000
109023.3308                0.0000               0.0000
 42928.4655                0.0000               0.0000
 34838.3516                0.0000               0.0000
 11241.3778                0.0000               0.0000
 34135.7913                0.0000               0.0000
  3928.7777                0.0000               0.0000
 31673.5274                0.0000               0.0000
 72311.6033                0.0000               0.0000
```

Note: If more than one NRD is provided for a WBS, the rank of the NRD determines the order from which land-use water demands will be satisfied from available NRD sources. The NRD input file can be used to determine: volumes (NRD_Vol) of water provided from different sources such as reuse, wastewater, pipelines, or other off-grid sources; rank of these NRD sources for satisfying demand (Rank); and a flag to indicate where the excess goes (0-excess is not dispensed, 1-stream network, 2-wells) Here the NRD distribution is provided for one stress period for WBS 1. Using the volume of NRD from the farm budget file, the available volumes and ranks can be used to determine the value of many hydrologic budget components simulated using NRDs. Note that the second NRD source available to WBS 1 would not be used until at least 1,000 cubic units of water we already delivered to the WBS.

```
1   1000   1   0   10,000.0   2   0   # WBS_ID   NRD1_Vol   Rank   Excess   NRD2_Vol   Rank   Excess
```

Using this information along with the budget information, one can determine which NRD is associated with the recycled water use for a given WBS. This information can be used with the budget file to determine the amount of recycled water used. The modeling documentation or associated reports may provide information on recycled water applications in the water budget zone.

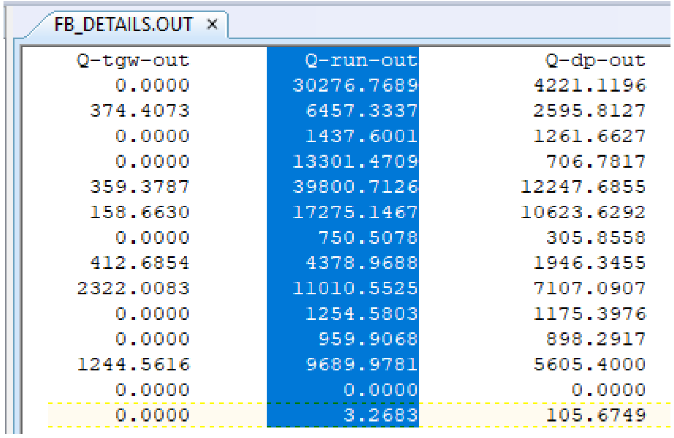
8.3.8 Recycled Water Export

Recycled water export, as defined in Section 1.3, refers to the “volume of recycled water diverted from the land system within a water budget zone for use outside the zone.” MODFLOW-OWHM currently does not simulate or report recycled water export.

8.3.9 Runoff

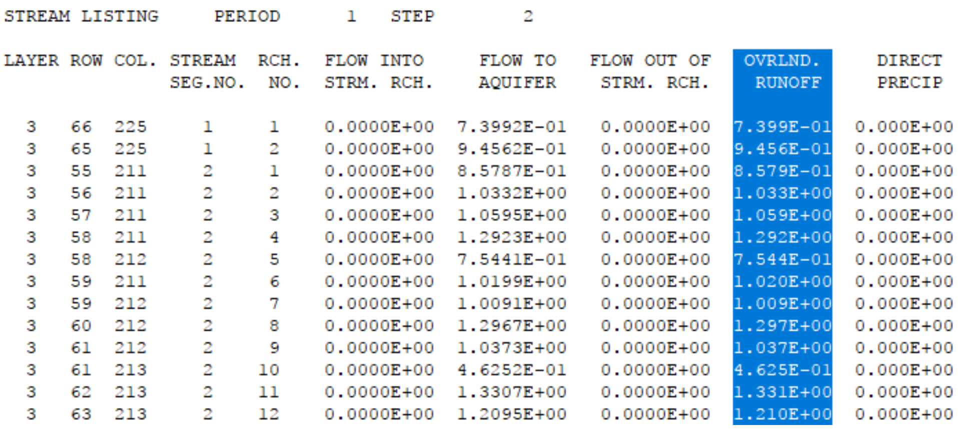
Runoff, as defined in Section .3, refers to the “volume of water flowing into the surface water system within a water budget zone from precipitation over the land surface.” MODFLOW-OWHM combines runoff and return flow into a single term for reporting purposes. The Farm Budget in MODFLOW-OWHM accounts for the volume of total runoff in the DetailedFarmBudget.out file. For the WBS corresponding to the water budget zone, find the data in the column “Q-run-out” (rate of total runoff outflow to a water-balance subregion) and multiply each value by the time step length to get a volume (Figure 8-9). Alternatively, runoff for each stream reach at each time step is available in the “OVRLND. RUNOFF” column in the Stream Budget (Figure 8-10). Units for runoff in the Stream Budget are typically cubic feet or cubic meters and should be verified (refer to Section 8.2).

Figure 8-9 Farm Budget: Runoff



```
        Q-tgw-out            Q-run-out            Q-dp-out
           0.0000           30276.7689           4221.1196
         374.4073            6457.3337           2595.8127
           0.0000            1437.6001           1261.6627
           0.0000           13301.4709            706.7817
         359.3787           39800.7126          12247.6855
         158.6630           17275.1467          10623.6292
           0.0000             750.5078            305.8558
         412.6854            4378.9688           1946.3455
        2322.0083           11010.5525           7107.0907
           0.0000            1254.5803           1175.3976
           0.0000             959.9068            898.2917
        1244.5616            9689.9781           5605.4000
           0.0000               0.0000              0.0000
           0.0000               3.2683            105.6749
```

Figure 8-10 Stream Budget: Runoff



```
 STREAM LISTING      PERIOD      1   STEP        2

 LAYER ROW COL. STREAM  RCH.  FLOW INTO    FLOW TO    FLOW OUT OF  OVRLND.    DIRECT
                SEG.NO.  NO.  STRM. RCH.   AQUIFER    STRM. RCH.   RUNOFF     PRECIP

   3    66  225     1     1   0.0000E+00  7.3992E-01  0.0000E+00 7.399E-01  0.000E+00
   3    65  225     1     2   0.0000E+00  9.4562E-01  0.0000E+00 9.456E-01  0.000E+00
   3    55  211     2     1   0.0000E+00  8.5787E-01  0.0000E+00 8.579E-01  0.000E+00
   3    56  211     2     2   0.0000E+00  1.0332E+00  0.0000E+00 1.033E+00  0.000E+00
   3    57  211     2     3   0.0000E+00  1.0595E+00  0.0000E+00 1.059E+00  0.000E+00
   3    58  211     2     4   0.0000E+00  1.2923E+00  0.0000E+00 1.292E+00  0.000E+00
   3    58  212     2     5   0.0000E+00  7.5441E-01  0.0000E+00 7.544E-01  0.000E+00
   3    59  211     2     6   0.0000E+00  1.0199E+00  0.0000E+00 1.020E+00  0.000E+00
   3    59  212     2     7   0.0000E+00  1.0091E+00  0.0000E+00 1.009E+00  0.000E+00
   3    60  212     2     8   0.0000E+00  1.2967E+00  0.0000E+00 1.297E+00  0.000E+00
   3    61  212     2     9   0.0000E+00  1.0373E+00  0.0000E+00 1.037E+00  0.000E+00
   3    61  213     2    10   0.0000E+00  4.6252E-01  0.0000E+00 4.625E-01  0.000E+00
   3    62  213     2    11   0.0000E+00  1.3307E+00  0.0000E+00 1.331E+00  0.000E+00
   3    63  213     2    12   0.0000E+00  1.2095E+00  0.0000E+00 1.210E+00  0.000E+00
```

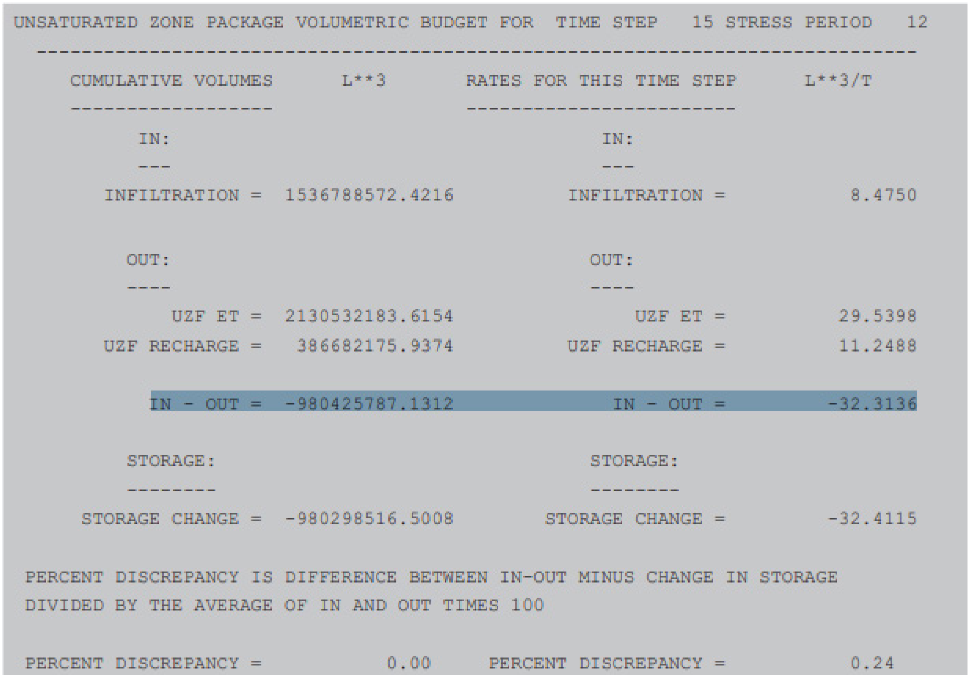
8.3.10 Return Flow

Return flow, as defined in Section 1.3, refers to the "volume of applied water that is not consumptively used and flows to the surface water system. It includes treated wastewater discharges to the surface water system." In MODFLOW-OWHM, return flow is grouped with precipitation runoff. Therefore, the runoff output budget terms described in the previous section can be used to estimate the return flow component. Model documentation or associated hydrogeologic reports may provide additional information on return flows in the water budget zone of interest.

8.3.11 Change in Land System Storage

Change in land system storage, as defined in Section 1.3, refers to the "net change in the volume of water stored within the land system, which includes ponded water on the land surface (not including streams, lakes, and conveyance facilities) and soil moisture within the unsaturated zone, which includes the root zone.” The change in storage in ponded areas is not explicitly reported in MODFLOW. MODFLOW accounts for the subsurface portions of the change in land system storage through the optional Unsaturated-Zone Flow (UZF1) Package. MODFLOW applications without the UZF1 Package have no accounting of the change in unsaturated zone storage. For models with the UZF1 Package, the change in land system storage is reported in the Unsaturated Zone Budget. For every timestep, the change in unsaturated zone storage is computed by the model and reported under “IN — OUT” (Figure 8-11). Units for change in storage are typically cubic feet or cubic meters and should be verified (refer to Section 8.2). Not every MODFLOW application utilizes the UZF1 Package to simulate the unsaturated zone. For models that do not include the UZF1 Package, the land surface processes interact directly with the aquifer and change in land system storage is not calculated.

Figure 8-11 **Unsaturated Zone Budget**



```
UNSATURATED ZONE PACKAGE VOLUMETRIC BUDGET FOR  TIME STEP   15 STRESS PERIOD   12
  ------------------------------------------------------------------------------
     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                    IN:
           ---                                    ---
        INFILTRATION =  1536788572.4216          INFILTRATION =           8.4750

          OUT:                                   OUT:
          ----                                   ----
              UZF ET =  2130532183.6154                UZF ET =          29.5398
        UZF RECHARGE =   386682175.9374          UZF RECHARGE =          11.2488

            IN - OUT =  -980425787.1312              IN - OUT =         -32.3136

          STORAGE:                               STORAGE:
          --------                               --------
      STORAGE CHANGE =  -980298516.5008        STORAGE CHANGE =         -32.4115

 PERCENT DISCREPANCY IS DIFFERENCE BETWEEN IN-OUT MINUS CHANGE IN STORAGE
 DIVIDED BY THE AVERAGE OF IN AND OUT TIMES 100

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.24
```

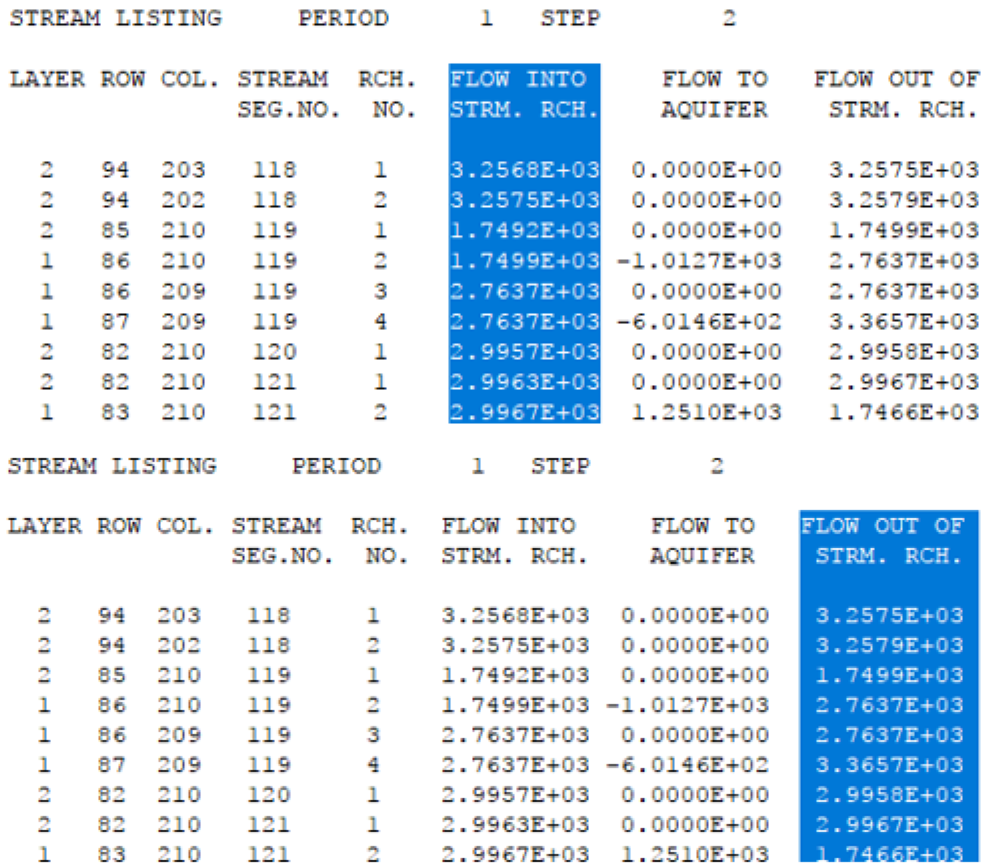
8.4 SURFACE WATER SYSTEM

8.4.1 Stream Inflow and Outflow

Stream inflow, as defined in Section 1.3, refers to the “volume of water entering through streams at the periphery of a water budget zone.” Stream outflow refers to the "volume of water leaving through streams at the periphery of a water budget zone."

Streamflow is calculated for each stream reach separately. The Stream Budget in MODFLOW-OWHM accounts for the volume of stream inflow and outflow for each stream reach and at each time step in the "FLOW INTO STRM. RCH." (Flow into Stream Reach) and "FLOW OUT OF STRM. RCH." (Flow Out of Stream Reach) columns (Figure 8-12). Identify which model stream reaches correspond to the streams entering and leaving the water budget zone of interest. For each time step, sum the "FLOW INTO STRM. RCH." columns for reaches entering the water budget zone to obtain stream inflow. Similarly, sum the "FLOW OUT OF STRM. RCH." columns for reaches exiting the water budget zone to obtain stream outflow.

Figure 8-12 **Stream Budget: Surface Water Inflows and Outflows**



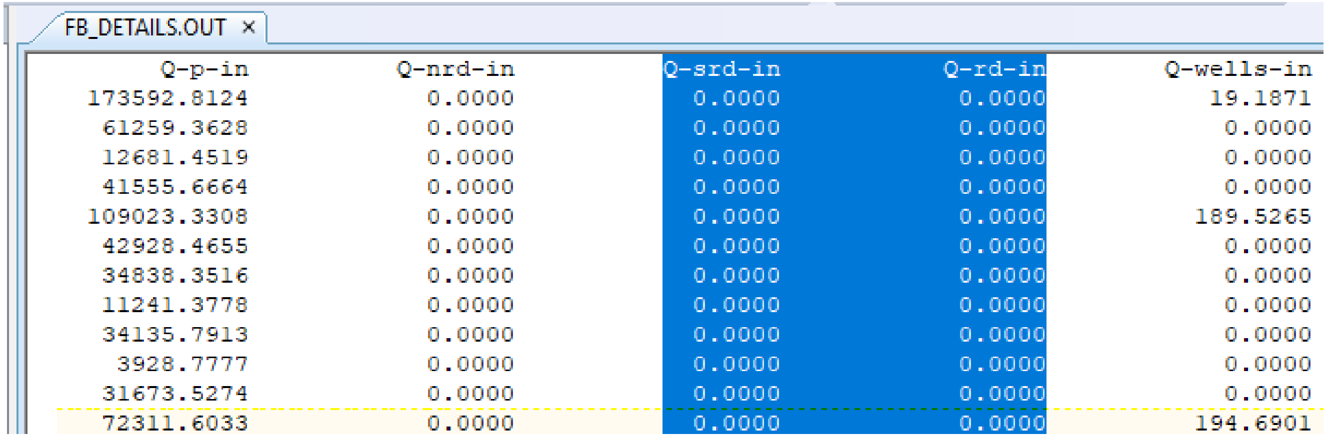
```
 STREAM LISTING      PERIOD      1    STEP         2

 LAYER ROW COL. STREAM  RCH. FLOW INTO     FLOW TO   FLOW OUT OF
                SEG.NO.  NO. STRM. RCH.    AQUIFER    STRM. RCH.

   2    94  203   118      1 3.2568E+03  0.0000E+00   3.2575E+03
   2    94  202   118      2 3.2575E+03  0.0000E+00   3.2579E+03
   2    85  210   119      1 1.7492E+03  0.0000E+00   1.7499E+03
   1    86  210   119      2 1.7499E+03 -1.0127E+03   2.7637E+03
   1    86  209   119      3 2.7637E+03  0.0000E+00   2.7637E+03
   1    87  209   119      4 2.7637E+03 -6.0146E+02   3.3657E+03
   2    82  210   120      1 2.9957E+03  0.0000E+00   2.9958E+03
   2    82  210   121      1 2.9963E+03  0.0000E+00   2.9967E+03
   1    83  210   121      2 2.9967E+03  1.2510E+03   1.7466E+03
```

```
 STREAM LISTING      PERIOD      1    STEP         2

 LAYER ROW COL. STREAM  RCH. FLOW INTO     FLOW TO   FLOW OUT OF
                SEG.NO.  NO. STRM. RCH.    AQUIFER    STRM. RCH.

   2    94  203   118      1 3.2568E+03  0.0000E+00   3.2575E+03
   2    94  202   118      2 3.2575E+03  0.0000E+00   3.2579E+03
   2    85  210   119      1 1.7492E+03  0.0000E+00   1.7499E+03
   1    86  210   119      2 1.7499E+03 -1.0127E+03   2.7637E+03
   1    86  209   119      3 2.7637E+03  0.0000E+00   2.7637E+03
   1    87  209   119      4 2.7637E+03 -6.0146E+02   3.3657E+03
   2    82  210   120      1 2.9957E+03  0.0000E+00   2.9958E+03
   2    82  210   121      1 2.9963E+03  0.0000E+00   2.9967E+03
   1    83  210   121      2 2.9967E+03  1.2510E+03   1.7466E+03
```

8.4.2 Surface Water Diversion

Surface water diversion, as defined in Section 1.3, refers to the "volume of water taken from the surface water system within a water budget zone for use within the zone.” In MODFLOW-OWHM, semi-routed deliveries or fully-routed deliveries refer to deliveries that originate from streams within the model domain. The Farm Budget in MODFLOW-OWHM accounts for the volume of surface water delivery data in the DetailedFarmBudget.out file. For the farms inside the water budget zone, find the surface water diversion data in the “Q-srd-in” (rate of semi-routed delivery inflow to a water-balance subregion) and “Q-rd-in” (rate of fully routed delivery inflow into a water-balance subregion) columns (Figure 8-13). Total surface water delivery is the sum of each value in these two columns multiplied by their associated time step length.

Figure 8-13 **Farm Budget: Semi-routed and Routed Deliveries**

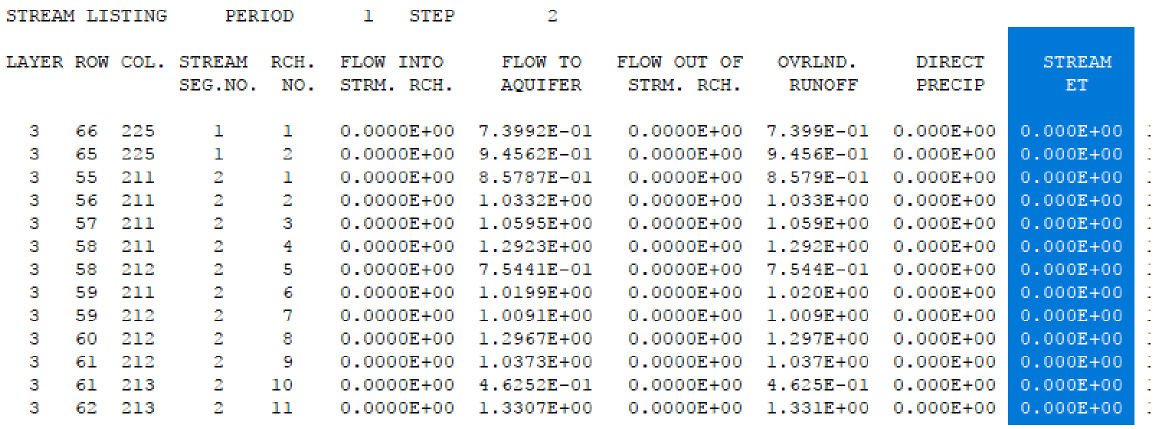


```
       Q-p-in         Q-nrd-in        Q-srd-in          Q-rd-in       Q-wells-in
  173592.8124           0.0000          0.0000           0.0000          19.1871
   61259.3628           0.0000          0.0000           0.0000           0.0000
   12681.4519           0.0000          0.0000           0.0000           0.0000
   41555.6664           0.0000          0.0000           0.0000           0.0000
  109023.3308           0.0000          0.0000           0.0000         189.5265
   42928.4655           0.0000          0.0000           0.0000           0.0000
   34838.3516           0.0000          0.0000           0.0000           0.0000
   11241.3778           0.0000          0.0000           0.0000           0.0000
   34135.7913           0.0000          0.0000           0.0000           0.0000
    3928.7777           0.0000          0.0000           0.0000           0.0000
   31673.5274           0.0000          0.0000           0.0000           0.0000
   72311.6033           0.0000          0.0000           0.0000         194.6901
```

8.4.3 Stream Evaporation

Stream evaporation, as defined in Section 1.3, refers to the “volume of water evaporated into the atmosphere from streams.” The Stream Reach Budget in MODFLOW-OWHM accounts for the volume of stream evaporation in the “Stream ET” column (Figure 8-14). For each time-step, sum the “Stream ET” for all relevant stream reaches. Units for conveyance evaporation are typically ft^3 or m^3 and should be verified (refer to Section 8.2).

Figure 8-14 **Stream Budget: Stream ET**



```
 STREAM LISTING      PERIOD      1    STEP        2

 LAYER ROW COL. STREAM  RCH.  FLOW INTO      FLOW TO   FLOW OUT OF   OVRLND.     DIRECT     STREAM
                SEG.NO.  NO.  STRM. RCH.     AQUIFER   STRM. RCH.     RUNOFF     PRECIP       ET

   3   66  225     1      1   0.0000E+00  7.3992E-01   0.0000E+00  7.399E-01  0.000E+00  0.000E+00
   3   65  225     1      2   0.0000E+00  9.4562E-01   0.0000E+00  9.456E-01  0.000E+00  0.000E+00
   3   55  211     2      1   0.0000E+00  8.5787E-01   0.0000E+00  8.579E-01  0.000E+00  0.000E+00
   3   56  211     2      2   0.0000E+00  1.0332E+00   0.0000E+00  1.033E+00  0.000E+00  0.000E+00
   3   57  211     2      3   0.0000E+00  1.0595E+00   0.0000E+00  1.059E+00  0.000E+00  0.000E+00
   3   58  211     2      4   0.0000E+00  1.2923E+00   0.0000E+00  1.292E+00  0.000E+00  0.000E+00
   3   58  212     2      5   0.0000E+00  7.5441E-01   0.0000E+00  7.544E-01  0.000E+00  0.000E+00
   3   59  211     2      6   0.0000E+00  1.0199E+00   0.0000E+00  1.020E+00  0.000E+00  0.000E+00
   3   59  212     2      7   0.0000E+00  1.0091E+00   0.0000E+00  1.009E+00  0.000E+00  0.000E+00
   3   60  212     2      8   0.0000E+00  1.2967E+00   0.0000E+00  1.297E+00  0.000E+00  0.000E+00
   3   61  212     2      9   0.0000E+00  1.0373E+00   0.0000E+00  1.037E+00  0.000E+00  0.000E+00
   3   61  213     2     10   0.0000E+00  4.6252E-01   0.0000E+00  4.625E-01  0.000E+00  0.000E+00
   3   62  213     2     11   0.0000E+00  1.3307E+00   0.0000E+00  1.331E+00  0.000E+00  0.000E+00
```

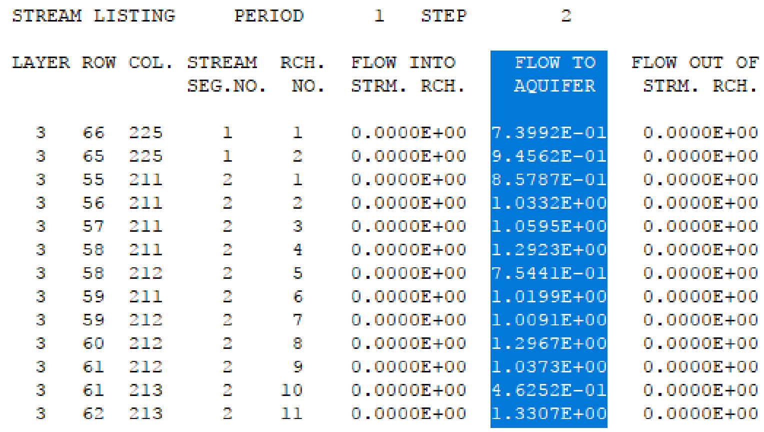
8.4.4 Conveyance Evaporation

Conveyance evaporation, as defined in Section 1.3, refers to the "volume of water evaporated into the atmosphere from conveyance facilities, other than streams, during water delivery." For canals simulated as streams in the model, the *Stream Reach Budget* in MODFLOW-OWHM accounts for the volume of stream and conveyance evaporation in the "Stream ET" column (Figure 8-14). For each time-step, sum the "Stream ET" for all relevant stream reaches. Units for conveyance evaporation are typically cubic feet or cubic meters and should be verified (refer to Section 8.2). The user will need to differentiate between streams and canals in the model to separate stream evaporation from conveyance evaporation.

8.4.5 Conveyance Seepage

Conveyance seepage, as defined in Section 1.3, refers to the "volume of water recharged to the groundwater system from the conveyance facilities, other than streams, during water delivery." For canals simulated as streams in the model, the Stream Budget in MODFLOW-OWHM accounts for the volume of stream and conveyance seepage for each reach in the "Flow to Aquifer" column (Figure 8-15). A positive value means flow from the stream reach to the groundwater system, while a negative value means the stream reach is gaining water from the groundwater system. For each time-step, sum the "Flow to Aquifer" for all relevant stream segments and reaches. Units for conveyance seepage are typically cubic feet and cubic meters and should be verified (refer to Section 8.2).

Figure 8-15 **Stream Budget: Flow to Aquifer**

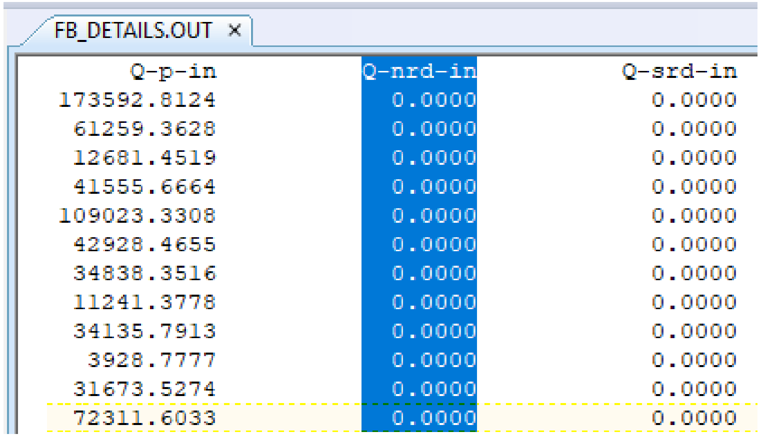


```
 STREAM LISTING      PERIOD      1    STEP        2

 LAYER ROW  COL. STREAM  RCH.  FLOW INTO   FLOW TO    FLOW OUT OF
                 SEG.NO.  NO.  STRM. RCH.  AQUIFER     STRM. RCH.

   3   66  225      1      1   0.0000E+00 7.3992E-01  0.0000E+00
   3   65  225      1      2   0.0000E+00 9.4562E-01  0.0000E+00
   3   55  211      2      1   0.0000E+00 8.5787E-01  0.0000E+00
   3   56  211      2      2   0.0000E+00 1.0332E+00  0.0000E+00
   3   57  211      2      3   0.0000E+00 1.0595E+00  0.0000E+00
   3   58  211      2      4   0.0000E+00 1.2923E+00  0.0000E+00
   3   58  212      2      5   0.0000E+00 7.5441E-01  0.0000E+00
   3   59  211      2      6   0.0000E+00 1.0199E+00  0.0000E+00
   3   59  212      2      7   0.0000E+00 1.0091E+00  0.0000E+00
   3   60  212      2      8   0.0000E+00 1.2967E+00  0.0000E+00
   3   61  212      2      9   0.0000E+00 1.0373E+00  0.0000E+00
   3   61  213      2     10   0.0000E+00 4.6252E-01  0.0000E+00
   3   62  213      2     11   0.0000E+00 1.3307E+00  0.0000E+00
```

8.4.6 Imported Water

Imported water, as defined in Section 1.3, refers to the "volume of water brought from outside the water budget zone for use within the water budget zone, such as State Water Project water, Central Valley Project water, water produced from desalination of ocean water, and water produced from desalination of deep groundwater from below the base of freshwater." The Farm Budget in MODFLOW-OWHM accounts for the volume of all imported water in the DetailedFarmBudget.out file. For the farms corresponding to the water budget zone, find the imported water data in the "Q-nrd-in" (rate of NRD inflow to a water-balance subregion) column (Figure 8-16). Multiply the rate for each timestep by the timestep length to obtain a volume. The total imported water is the sum of these NRD values. Units for imported water are typically cubic feet or cubic meters and should be verified (refer to Section 8.2).

Figure 8-16 **Farm Budget: Non-Routed Deliveries**

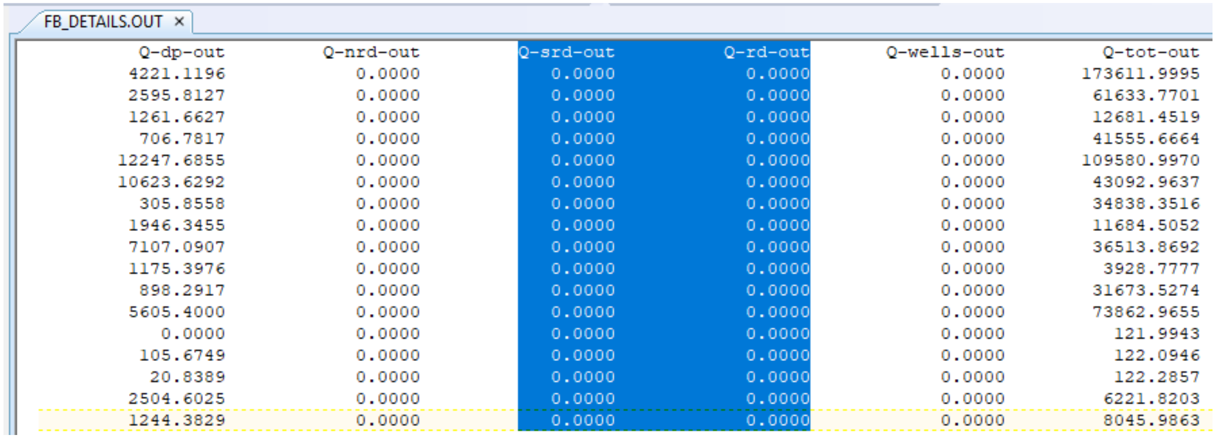


```
        Q-p-in          Q-nrd-in           Q-srd-in
   173592.8124            0.0000             0.0000
    61259.3628            0.0000             0.0000
    12681.4519            0.0000             0.0000
    41555.6664            0.0000             0.0000
   109023.3308            0.0000             0.0000
    42928.4655            0.0000             0.0000
    34838.3516            0.0000             0.0000
    11241.3778            0.0000             0.0000
    34135.7913            0.0000             0.0000
     3928.7777            0.0000             0.0000
    31673.5274            0.0000             0.0000
    72311.6033            0.0000             0.0000
```

8.4.7 Surface Water Exports

Surface water exports, as defined in Section 1.3, refer to "the volume of water diverted from the surface water system within a water budget zone for use outside the zone." Water deliveries in MODFLOW-OWHM are classified as non-routed, semi-routed, and fully-routed. NRDs refer to water that originates from outside the model whereas semi-routed and fully-routed deliveries originate from streams within the model domain. The Farm Budget in MODFLOW-OWHM accounts for the volume of all surface water deliveries in the DetailedFarmBudget.out file. For the farms corresponding to the water budget zone, find the surface water export data in the "Q-srd-out" (rate of semi-routed delivery outflow from a water-balance subregion) and "Q-rd-out" (rate of fully routed delivery out of a water-balance subregion) columns (Figure 8-17). Total surface water exports volumes are the sum of each value in these two columns multiplied by the associated time step length. Units for surface water exports are typically in cubic feet or cubic meters but should be verified (refer to Section 8.2).

Figure 8-17 Farm Budget: Exported Water

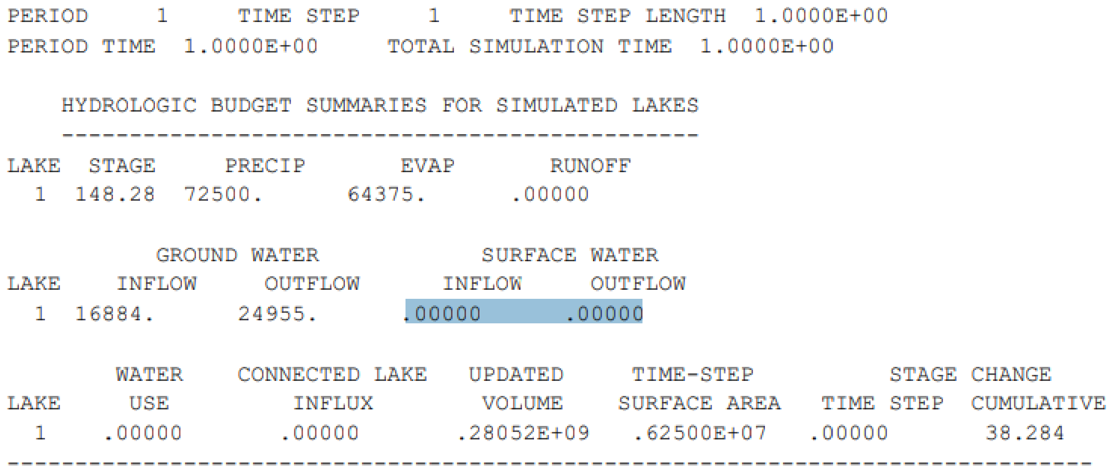


```
        Q-dp-out          Q-nrd-out          Q-srd-out           Q-rd-out        Q-wells-out          Q-tot-out
       4221.1196             0.0000             0.0000             0.0000             0.0000        173611.9995
       2595.8127             0.0000             0.0000             0.0000             0.0000         61633.7701
       1261.6627             0.0000             0.0000             0.0000             0.0000         12681.4519
        706.7817             0.0000             0.0000             0.0000             0.0000         41555.6664
      12247.6855             0.0000             0.0000             0.0000             0.0000        109580.9970
      10623.6292             0.0000             0.0000             0.0000             0.0000         43092.9637
        305.8558             0.0000             0.0000             0.0000             0.0000         34838.3516
       1946.3455             0.0000             0.0000             0.0000             0.0000         11684.5052
       7107.0907             0.0000             0.0000             0.0000             0.0000         36513.8692
       1175.3976             0.0000             0.0000             0.0000             0.0000          3928.7777
        898.2917             0.0000             0.0000             0.0000             0.0000         31673.5274
       5605.4000             0.0000             0.0000             0.0000             0.0000         73862.9655
          0.0000             0.0000             0.0000             0.0000             0.0000           121.9943
        105.6749             0.0000             0.0000             0.0000             0.0000           122.0946
         20.8389             0.0000             0.0000             0.0000             0.0000           122.2857
       2504.6025             0.0000             0.0000             0.0000             0.0000          6221.8203
       1244.3829             0.0000             0.0000             0.0000             0.0000          8045.9863
```

8.4.8 Stream-Lake Interaction

Stream-lake interaction, as defined in Section 1.3, refers to the "volume of water exchanged between streams and lakes", covering both the inflow and outflow component of this interaction. The Lake Package in MODFLOW accounts for the volume of stream-lake interaction (inflow and outflow) in the "Surface Water Inflow" and "Surface Water Outflow" columns (Figure 8-18). Sum the inflow and outflow for all lakes in the water budget zone. Units for inflows and outflows are typically cubic feet or cubic meters but should be verified (see Section 8.2).

Figure 8-18 **Lake Budget: Stream Lake Interaction**



```
PERIOD     1     TIME STEP     1     TIME STEP LENGTH  1.0000E+00
PERIOD TIME  1.0000E+00     TOTAL SIMULATION TIME  1.0000E+00

    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------

LAKE   STAGE     PRECIP       EVAP        RUNOFF
  1  148.28  72500.      64375.      .00000

           GROUND WATER             SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  16884.      24955.       .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP          STAGE CHANGE
LAKE     USE         INFLUX         VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       .00000       .28052E+09   .62500E+07   .00000        38.284
--------------------------------------------------------------------------------
```

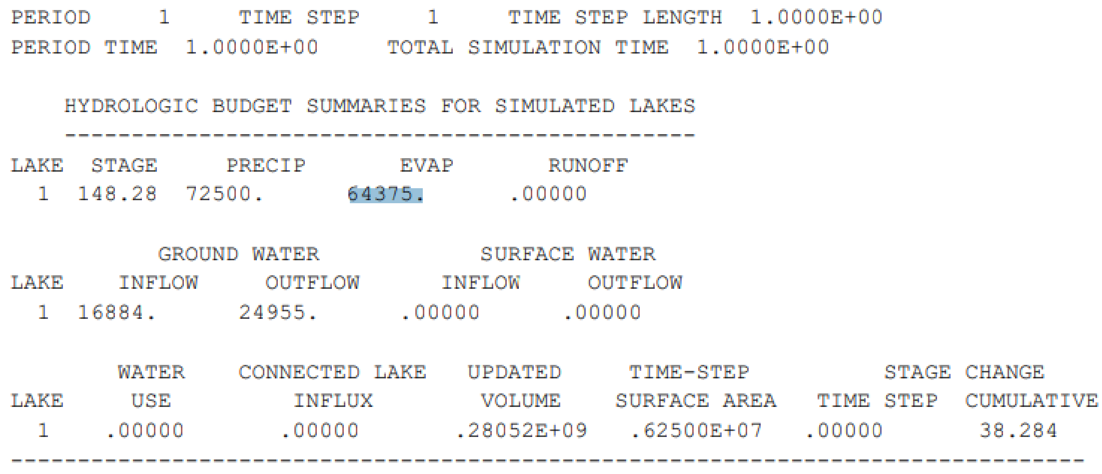
Note: Reservoirs can be simulated in MODFLOW-OWHM version 2. The seepage to groundwater from the reservoir is not directly simulated but reservoir stage, storage, release, and spill to the stream network along with inflow, precipitation, evaporation, and transfers into the reservoir are provided in the Reservoir Budget. Similar to the Farm Budget, volumes are obtained by multiplying each value in the column of interest by its time step length and then summing them to obtain a total volume in units of cubic feet or cubic meters. The only exception to this is the reservoir storage term, which is already a volume and does not need to be multiplied.

8.4.9 Lake Evaporation

Lake evaporation, as defined in Section 1.3, refers to the "volume of evaporation from lakes and reservoirs." The Lake (LAK) Package in MODFLOW-OWHM simulates lakes and allows the head in the lakes to rise and fall. Implementation of a lake water budget requires a set of input parameters including the rate of lake evaporation. Lake evaporation is thus input data in MODFLOW-OHWM, and EVAPLK contains the rate of evaporation per unit area from the surface of a lake. Lake evaporation data may be exported from Lake Budget if the Lake Package is used; otherwise, lake evaporation will need to be calculated and implemented outside of MODFLOW-OWHM and cannot be obtained from the model files.

The Lake Budget in MODFLOW-OWHM contains a water balance for the lake system for each timestep. The volume of lake evaporation is in the EVAP column (Figure 8-19). Sum the EVAP column for all lakes in the water budget zone. Units for lake evaporation are typically cubic feet or cubic meters but should be verified (refer to Section 8.2).

Figure 8-19 **Lake Budget: Lake Evaporation**



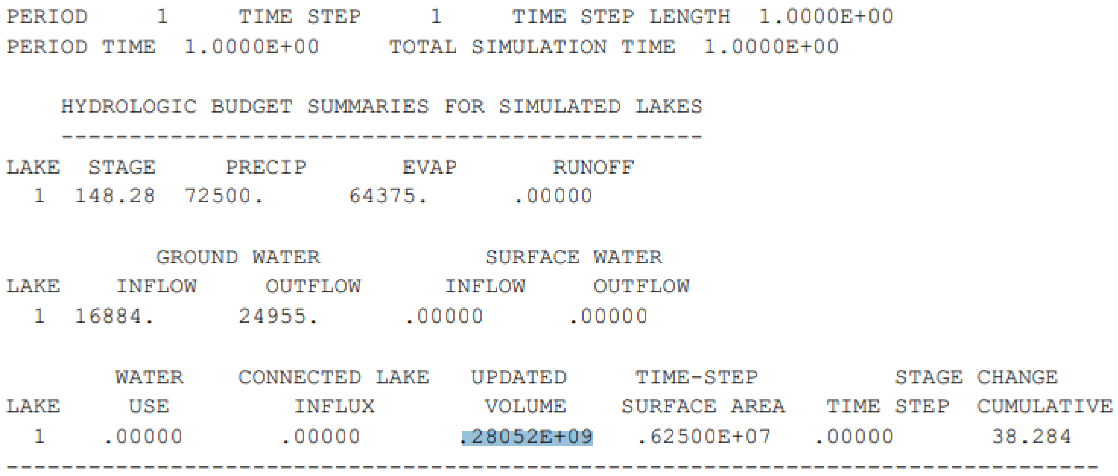
```
PERIOD     1     TIME STEP     1     TIME STEP LENGTH  1.0000E+00
PERIOD TIME  1.0000E+00     TOTAL SIMULATION TIME  1.0000E+00

    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------
LAKE  STAGE     PRECIP       EVAP        RUNOFF
  1  148.28  72500.      64375.      .00000

       GROUND WATER            SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  16884.      24955.      .00000      .00000

        WATER    CONNECTED LAKE  UPDATED     TIME-STEP          STAGE CHANGE
LAKE     USE         INFLUX       VOLUME    SURFACE AREA  TIME STEP  CUMULATIVE
  1    .00000       .00000      .28052E+09   .62500E+07   .00000       38.284
--------------------------------------------------------------------------------
```

Note: If reservoirs are simulated using the Surface Water Operations Package available in MODFLOW-OWHM version 2, then reservoir evaporation can be computed by multiplying each value in the EVAP column in the Reservoir Budget file by its time step length and then summing them to obtain a total volume.

8.4.10 Change in Surface Water Storage

Change in surface water storage, as defined in Section 1.3, refers to the "net change in the volume of water stored within the surface water system, which includes lakes and reservoirs, streams, and conveyance facilities.". It is assumed that while changes in water volume contained in streams may be important components in the daily or monthly water budgets, they are typically negligible in annual water budgets. Therefore, the majority of the change in surface water storage will occur in lakes. MODFLOW-OWHM accounts for the change in lake storage in the Lake Budget output file. For the lakes within the water budget zone of interest, the Lake Budget accounts for the change in surface water storage in the Updated Volume column. The difference between the Updated Volume terms between two timesteps is the change in surface water storage.

Figure 8-20 Lake Budget: Change in Storage



```
PERIOD     1     TIME STEP     1     TIME STEP LENGTH  1.0000E+00
PERIOD TIME  1.0000E+00     TOTAL SIMULATION TIME  1.0000E+00

    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------
LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1  148.28  72500.      64375.      .00000

           GROUND WATER            SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  16884.      24955.      .00000      .00000

        WATER    CONNECTED LAKE   UPDATED     TIME-STEP          STAGE CHANGE
LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       .00000       .28052E+09   .62500E+07   .00000       38.284
--------------------------------------------------------------------------------
```

8.5 GROUNDWATER SYSTEM

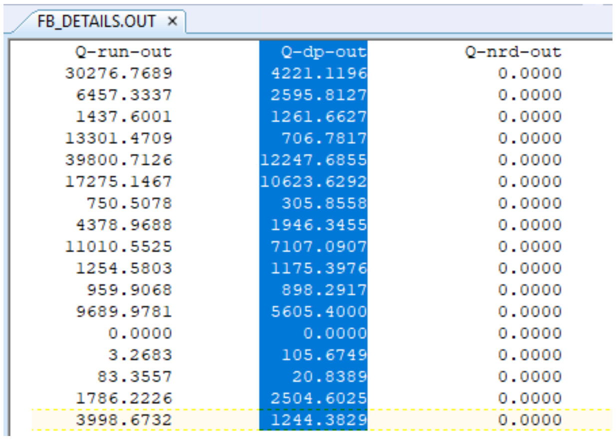
8.5.1 Recharge of Applied Water and Precipitation

Recharge of applied water and precipitation, as defined in Section 1.3, refers to the "volume of applied water and precipitation that travels vertically through the soil/unsaturated zones and reaches the saturated zone of the aquifer (groundwater system)." In MODFLOW-OWHM, recharge of applied water and precipitation is defined as recharge, which is the areal infiltration of precipitation and applied water for irrigation.

Two values are written for inflows to the subsurface for each cell and water-budget subregion: (1) the amount of water that enters the soil zone (deep percolation) and may become recharge, and (2) the amount of Farm Net Recharge that is the deep percolation minus ET. The Farm Net Recharge is the term most useful for developing groundwater budgets.

The deep percolation for each WBS is provided in the Q-dp-out (rate of deep percolation out of the farm) column of the DetailedFarmBudget.out file (Figure 8-21). Multiply the rate for each timestep by the timestep length to obtain a volume. Units for recharge of applied water and precipitation are typically cubic feet or cubic meters but should be verified (refer to Section 8.2). MODFLOW-OWHM does not currently separate recharge by source.

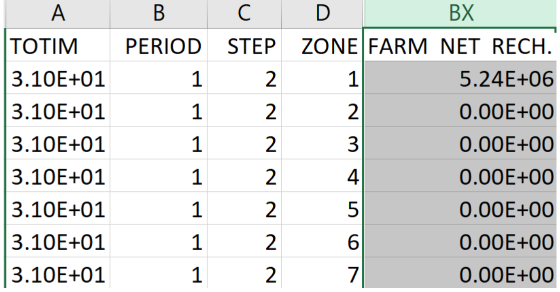
Figure 8-21 Farm Budget: Deep Percolation



```
      Q-run-out          Q-dp-out          Q-nrd-out
     30276.7689         4221.1196             0.0000
      6457.3337         2595.8127             0.0000
      1437.6001         1261.6627             0.0000
     13301.4709          706.7817             0.0000
     39800.7126        12247.6855             0.0000
     17275.1467        10623.6292             0.0000
       750.5078          305.8558             0.0000
      4378.9688         1946.3455             0.0000
     11010.5525         7107.0907             0.0000
      1254.5803         1175.3976             0.0000
       959.9068          898.2917             0.0000
      9689.9781         5605.4000             0.0000
         0.0000            0.0000             0.0000
         3.2683          105.6749             0.0000
        83.3557           20.8389             0.0000
      1786.2226         2504.6025             0.0000
      3998.6732         1244.3829             0.0000
```

The total recharge is the Farm Net Recharge (FARM NET RECH.) column in the Zone Budget (Figure 8-22). The Zone Budget in MODFLOW-OWHM accounts for the volume of recharge of applied water and precipitation. The Zone Budget lists inflows and outflows from the perspective of the groundwater system. Use the data in the first occurrence of the FARM NET RECH column, which accounts for Farm Net Recharge entering the aquifer. MODFLOW-OWHM outputs ET from groundwater as Farm Net Recharge leaving the aquifer, which is in the second occurrence of FARM NET RECH columns. The column order may be different in model files; for example, there will not be a column for recharge in the Zone Budget if a recharge package is not used in the model. Units for recharge of applied water and precipitation are typically cubic feet or cubic meters but should be verified (refer to Section 8.2).

Figure 8-22 Zone Budget: Farm Net Recharge



A	B	C	D	BX
TOTIM	PERIOD	STEP	ZONE	FARM NET RECH.
3.10E+01	1	2	1	5.24E+06
3.10E+01	1	2	2	0.00E+00
3.10E+01	1	2	3	0.00E+00
3.10E+01	1	2	4	0.00E+00
3.10E+01	1	2	5	0.00E+00
3.10E+01	1	2	6	0.00E+00
3.10E+01	1	2	7	0.00E+00

It is uncommon for a MODFLOW-OWHM application to use the Recharge Package because recharge is computed for the whole model domain using the farm process. But, if additional recharge is specified using the Recharge

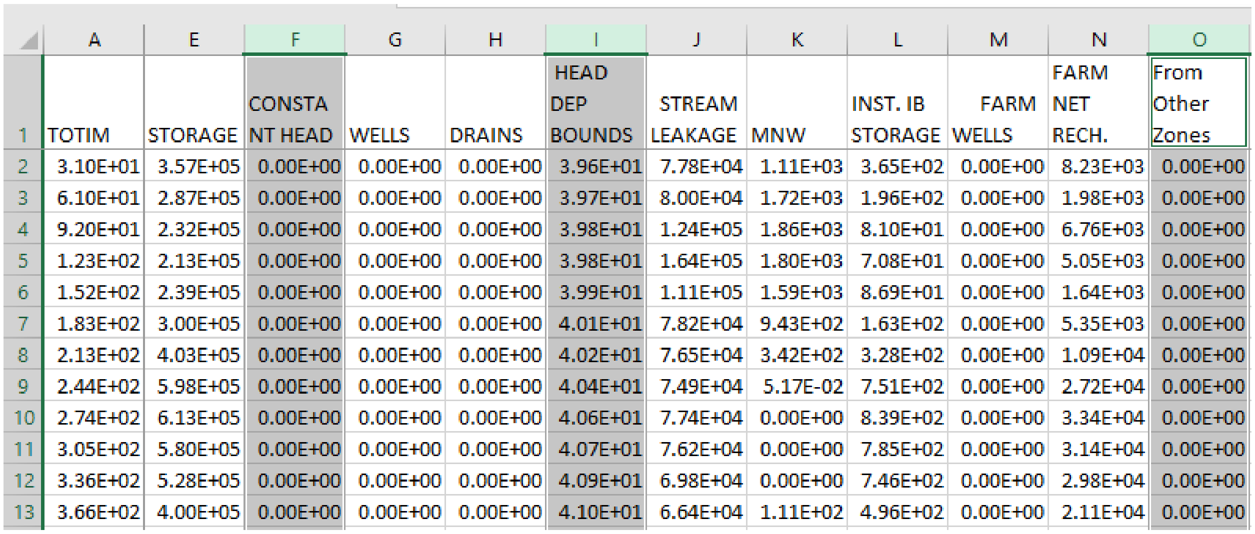
Package, the Zone Budget in MODFLOW-OWHM accounts for the volume of that recharge in the RECH column.

8.5.2 Subsurface Inflow and Outflow

Subsurface inflow, as defined in Section 1.3, refers to the "volume of water entering as groundwater into a water budget zone through its subsurface boundaries." Subsurface outflow refers to the "volume of water leaving as groundwater from a water budget zone through its subsurface boundaries." In MODFLOW-OWHM, subsurface flows from each zone are the summation of flows across the boundaries.

The Zone Budget in MODFLOW-OWHM includes the volume of boundary flow for calculating subsurface inflows and outflows. For the water budget zone of interest, find the subsurface inflow data in the following two columns within the first block of columns: CONSTANT HEAD and HEAD DEP BOUNDS; total inflow is the sum of these two columns. If there are multiple zones in the Zone Budget results, then an additional column corresponding to flow between zones will appear in the output file in the first block of columns. Add the values from From Other Zones column in the subsurface inflow summation to get the total subsurface inflow (Figure 8-23).

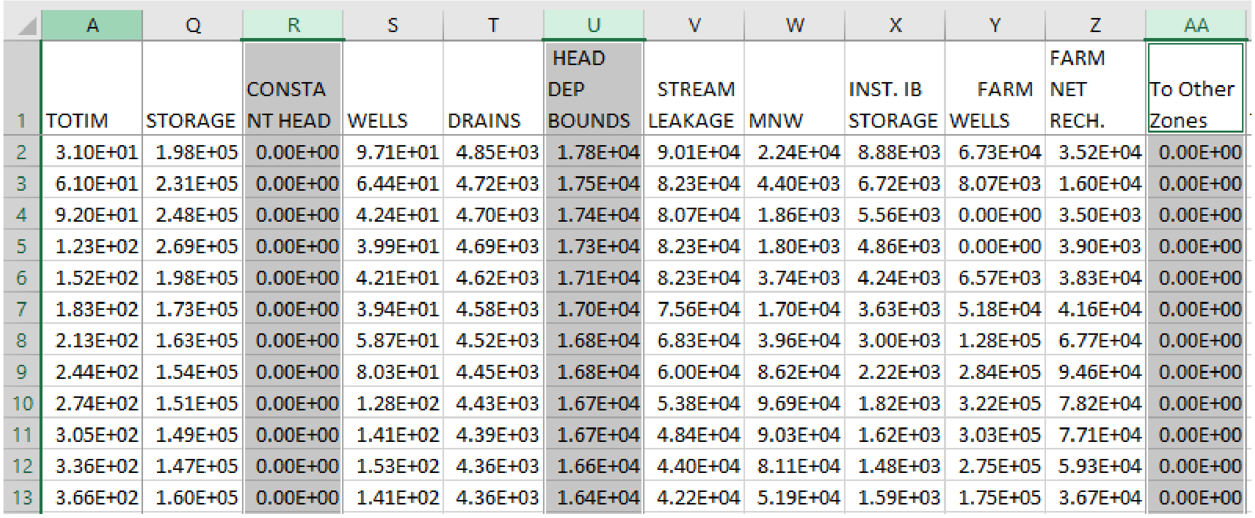
Figure 8-23 **Zone Budget: Subsurface Inflows**



	A	E	F	G	H	I	J	K	L	M	N	O
1	TOTIM	STORAGE	CONSTA NT HEAD	WELLS	DRAINS	HEAD DEP BOUNDS	STREAM LEAKAGE	MNW	INST. IB STORAGE	FARM WELLS	FARM NET RECH.	From Other Zones
2	3.10E+01	3.57E+05	0.00E+00	0.00E+00	0.00E+00	3.96E+01	7.78E+04	1.11E+03	3.65E+02	0.00E+00	8.23E+03	0.00E+00
3	6.10E+01	2.87E+05	0.00E+00	0.00E+00	0.00E+00	3.97E+01	8.00E+04	1.72E+03	1.96E+02	0.00E+00	1.98E+03	0.00E+00
4	9.20E+01	2.32E+05	0.00E+00	0.00E+00	0.00E+00	3.98E+01	1.24E+05	1.86E+03	8.10E+01	0.00E+00	6.76E+03	0.00E+00
5	1.23E+02	2.13E+05	0.00E+00	0.00E+00	0.00E+00	3.98E+01	1.64E+05	1.80E+03	7.08E+01	0.00E+00	5.05E+03	0.00E+00
6	1.52E+02	2.39E+05	0.00E+00	0.00E+00	0.00E+00	3.99E+01	1.11E+05	1.59E+03	8.69E+01	0.00E+00	1.64E+03	0.00E+00
7	1.83E+02	3.00E+05	0.00E+00	0.00E+00	0.00E+00	4.01E+01	7.82E+04	9.43E+02	1.63E+02	0.00E+00	5.35E+03	0.00E+00
8	2.13E+02	4.03E+05	0.00E+00	0.00E+00	0.00E+00	4.02E+01	7.65E+04	3.42E+02	3.28E+02	0.00E+00	1.09E+04	0.00E+00
9	2.44E+02	5.98E+05	0.00E+00	0.00E+00	0.00E+00	4.04E+01	7.49E+04	5.17E-02	7.51E+02	0.00E+00	2.72E+04	0.00E+00
10	2.74E+02	6.13E+05	0.00E+00	0.00E+00	0.00E+00	4.06E+01	7.74E+04	0.00E+00	8.39E+02	0.00E+00	3.34E+04	0.00E+00
11	3.05E+02	5.80E+05	0.00E+00	0.00E+00	0.00E+00	4.07E+01	7.62E+04	0.00E+00	7.85E+02	0.00E+00	3.14E+04	0.00E+00
12	3.36E+02	5.28E+05	0.00E+00	0.00E+00	0.00E+00	4.09E+01	6.98E+04	0.00E+00	7.46E+02	0.00E+00	2.98E+04	0.00E+00
13	3.66E+02	4.00E+05	0.00E+00	0.00E+00	0.00E+00	4.10E+01	6.64E+04	1.11E+02	4.96E+02	0.00E+00	2.11E+04	0.00E+00

Next, find the subsurface outflow data in the following two columns within the second block of columns: CONSTANT HEAD and HEAD DEP BOUNDS; total outflow is the sum of these two columns. If there are multiple zones in the Zone Budget results, then an additional column corresponding to flow between zones will appear in the output file in the second block of columns. Add the values from To Other Zones column in the subsurface outflow summation to get the total subsurface outflow (Figure 8-24).

Figure 8-24 Zone Budget: Subsurface Outflows



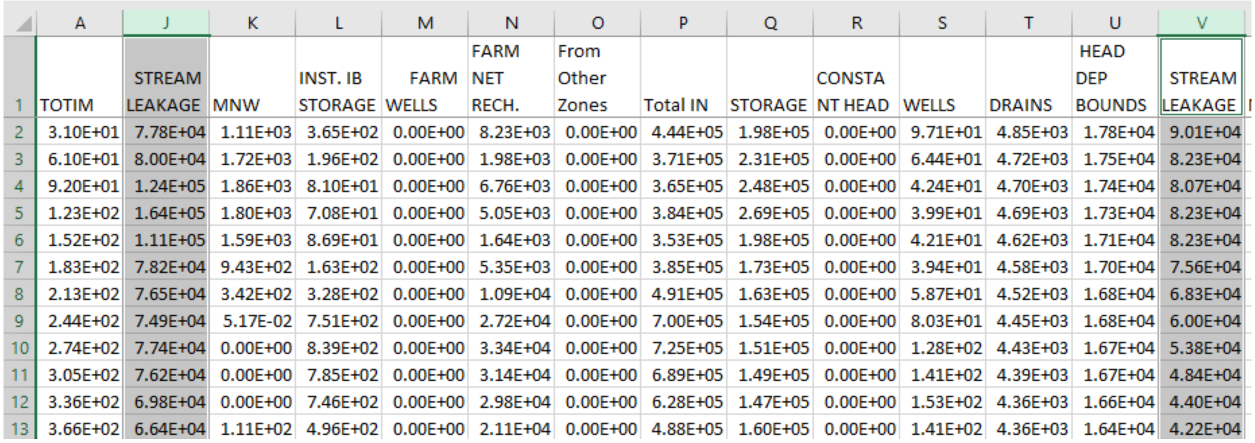
	A	Q	R	S	T	U	V	W	X	Y	Z	AA
1	TOTIM	STORAGE	CONSTANT HEAD	WELLS	DRAINS	HEAD DEP BOUNDS	STREAM LEAKAGE	MNW	INST. IB STORAGE	FARM WELLS	FARM NET RECH.	To Other Zones
2	3.10E+01	1.98E+05	0.00E+00	9.71E+01	4.85E+03	1.78E+04	9.01E+04	2.24E+04	8.88E+03	6.73E+04	3.52E+04	0.00E+00
3	6.10E+01	2.31E+05	0.00E+00	6.44E+01	4.72E+03	1.75E+04	8.23E+04	4.40E+03	6.72E+03	8.07E+03	1.60E+04	0.00E+00
4	9.20E+01	2.48E+05	0.00E+00	4.24E+01	4.70E+03	1.74E+04	8.07E+04	1.86E+03	5.56E+03	0.00E+00	3.50E+03	0.00E+00
5	1.23E+02	2.69E+05	0.00E+00	3.99E+01	4.69E+03	1.73E+04	8.23E+04	1.80E+03	4.86E+03	0.00E+00	3.90E+03	0.00E+00
6	1.52E+02	1.98E+05	0.00E+00	4.21E+01	4.62E+03	1.71E+04	8.23E+04	3.74E+03	4.24E+03	6.57E+03	3.83E+04	0.00E+00
7	1.83E+02	1.73E+05	0.00E+00	3.94E+01	4.58E+03	1.70E+04	7.56E+04	1.70E+04	3.63E+03	5.18E+04	4.16E+04	0.00E+00
8	2.13E+02	1.63E+05	0.00E+00	5.87E+01	4.52E+03	1.68E+04	6.83E+04	3.96E+04	3.00E+03	1.28E+05	6.77E+04	0.00E+00
9	2.44E+02	1.54E+05	0.00E+00	8.03E+01	4.45E+03	1.68E+04	6.00E+04	8.62E+04	2.22E+03	2.84E+05	9.46E+04	0.00E+00
10	2.74E+02	1.51E+05	0.00E+00	1.28E+02	4.43E+03	1.67E+04	5.38E+04	9.69E+04	1.82E+03	3.22E+05	7.82E+04	0.00E+00
11	3.05E+02	1.49E+05	0.00E+00	1.41E+02	4.39E+03	1.67E+04	4.84E+04	9.03E+04	1.62E+03	3.03E+05	7.71E+04	0.00E+00
12	3.36E+02	1.47E+05	0.00E+00	1.53E+02	4.36E+03	1.66E+04	4.40E+04	8.11E+04	1.48E+03	2.75E+05	5.93E+04	0.00E+00
13	3.66E+02	1.60E+05	0.00E+00	1.41E+02	4.36E+03	1.64E+04	4.22E+04	5.19E+04	1.59E+03	1.75E+05	3.67E+04	0.00E+00

Note: If MODFLOW-OWHM version 2 is used, individual budget group names can be defined for groups of cells associated with boundaries of interest. In this case, the flows for that subset of cells are aggregated for analysis. For example, if the custom budget was assigned to the GHB, the GHB associated with sea level for layer 1 (GHB_SEA_L1) can be obtained from column G in the Zone Budget output. This can be useful for distinguishing boundary conditions meant to represent different physical features.

8.5.3 Stream-Groundwater Interaction

Groundwater gain from stream, as defined in Section 1.3, refers to the "volume of water entering the groundwater system from rivers and streams." Groundwater loss to stream refers to the "volume of water entering rivers and streams from the groundwater system." The Zone Budget in MODFLOW-OWHM accounts for gain from and loss to stream in the "stream leakage" column. For the zones corresponding to the water budget zone of interest, find the gain from stream data in the first occurrence of the STREAM LEAKAGE column. Next, find the loss to stream data under the second occurrence of the STREAM LEAKAGE column. Units for the stream-groundwater interaction are typically cubic feet or cubic meters but should be verified (refer to Section 8.2). The stream-aquifer interaction is also reported in the Stream Budget, but it is generally easier to obtain the values for a water budget zone through the Zone Budget rather than manually aggregating the relevant stream reaches.

Figure 8-25 **Zone Budget: Stream-Groundwater Interaction**



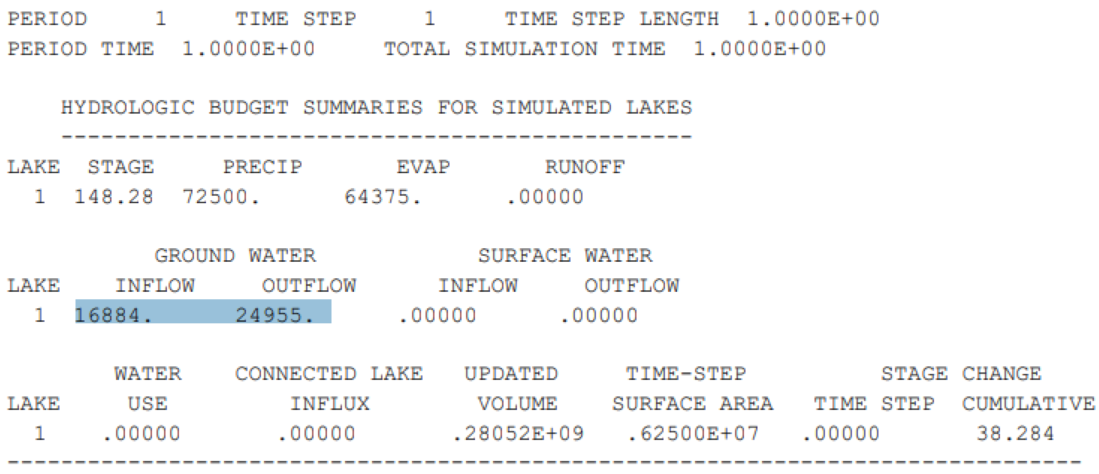
	A	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	TOTIM	STREAM LEAKAGE	MNW	INST. IB STORAGE	FARM WELLS	FARM NET RECH.	From Other Zones	Total IN	STORAGE	CONSTANT HEAD	WELLS	DRAINS	HEAD DEP BOUNDS	STREAM LEAKAGE
2	3.10E+01	7.78E+04	1.11E+03	3.65E+02	0.00E+00	8.23E+03	0.00E+00	4.44E+05	1.98E+05	0.00E+00	9.71E+01	4.85E+03	1.78E+04	9.01E+04
3	6.10E+01	8.00E+04	1.72E+03	1.96E+02	0.00E+00	1.98E+03	0.00E+00	3.71E+05	2.31E+05	0.00E+00	6.44E+01	4.72E+03	1.75E+04	8.23E+04
4	9.20E+01	1.24E+05	1.86E+03	8.10E+01	0.00E+00	6.76E+03	0.00E+00	3.65E+05	2.48E+05	0.00E+00	4.24E+01	4.70E+03	1.74E+04	8.07E+04
5	1.23E+02	1.64E+05	1.80E+03	7.08E+01	0.00E+00	5.05E+03	0.00E+00	3.84E+05	2.69E+05	0.00E+00	3.99E+01	4.69E+03	1.73E+04	8.23E+04
6	1.52E+02	1.11E+05	1.59E+03	8.69E+01	0.00E+00	1.64E+03	0.00E+00	3.53E+05	1.98E+05	0.00E+00	4.21E+01	4.62E+03	1.71E+04	8.23E+04
7	1.83E+02	7.82E+04	9.43E+02	1.63E+02	0.00E+00	5.35E+03	0.00E+00	3.85E+05	1.73E+05	0.00E+00	3.94E+01	4.58E+03	1.70E+04	7.56E+04
8	2.13E+02	7.65E+04	3.42E+02	3.28E+02	0.00E+00	1.09E+04	0.00E+00	4.91E+05	1.63E+05	0.00E+00	5.87E+01	4.52E+03	1.68E+04	6.83E+04
9	2.44E+02	7.49E+04	5.17E-02	7.51E+02	0.00E+00	2.72E+04	0.00E+00	7.00E+05	1.54E+05	0.00E+00	8.03E+01	4.45E+03	1.68E+04	6.00E+04
10	2.74E+02	7.74E+04	0.00E+00	8.39E+02	0.00E+00	3.34E+04	0.00E+00	7.25E+05	1.51E+05	0.00E+00	1.28E+02	4.43E+03	1.67E+04	5.38E+04
11	3.05E+02	7.62E+04	0.00E+00	7.85E+02	0.00E+00	3.14E+04	0.00E+00	6.89E+05	1.49E+05	0.00E+00	1.41E+02	4.39E+03	1.67E+04	4.84E+04
12	3.36E+02	6.98E+04	0.00E+00	7.46E+02	0.00E+00	2.98E+04	0.00E+00	6.28E+05	1.47E+05	0.00E+00	1.53E+02	4.36E+03	1.66E+04	4.40E+04
13	3.66E+02	6.64E+04	1.11E+02	4.96E+02	0.00E+00	2.11E+04	0.00E+00	4.88E+05	1.60E+05	0.00E+00	1.41E+02	4.36E+03	1.64E+04	4.22E+04

8.5.4 Lake-Groundwater Interaction

Groundwater gain from lake, as defined in Section 1.3, refers to the "volume of water entering the groundwater system from lakes and reservoirs." Groundwater loss to lake refers to the "volume of water entering the lakes and reservoirs from the groundwater system." If the lakes are simulated by the model, identify which lakes in the model corresponds to the lakes in the water budget zone of interest. If reservoirs are simulated using the Surface Water Operations (SWO) Package, then the seepage to groundwater from the reservoir is not simulated.

The Lake Budget in MODFLOW-OWHM contains a water balance for the lake system for each timestep. The lake-aquifer interaction results are in the "Inflow" and "Outflow" columns under the "Groundwater" heading (Figure 8-26). These numbers are from the lake perspective, so inflow refers to flow from the groundwater system into the lake and outflow refers to flow from the lake into the groundwater system. Units for the lake-groundwater interaction are typically cubic feet or cubic meters but should be verified (refer to Section 8.2).

Figure 8-26 Lake Budget: Lake-Groundwater Interaction



```
PERIOD     1     TIME STEP     1     TIME STEP LENGTH  1.0000E+00
PERIOD TIME  1.0000E+00     TOTAL SIMULATION TIME  1.0000E+00

    HYDROLOGIC BUDGET SUMMARIES FOR SIMULATED LAKES
    -----------------------------------------------

LAKE  STAGE     PRECIP       EVAP       RUNOFF
  1  148.28  72500.      64375.      .00000

           GROUND WATER            SURFACE WATER
LAKE    INFLOW     OUTFLOW      INFLOW     OUTFLOW
  1  16884.      24955.     .00000      .00000

        WATER    CONNECTED LAKE   UPDATED      TIME-STEP          STAGE CHANGE
LAKE     USE         INFLUX        VOLUME    SURFACE AREA   TIME STEP  CUMULATIVE
  1    .00000       .00000       .28052E+09   .62500E+07   .00000       38.284
--------------------------------------------------------------------------------
```

Alternatively, the lake aquifer interaction is reported in the Zone Budget under the heading “Lake”.

8.5.5 Managed Aquifer Recharge

Managed aquifer recharge, as defined in Section 1.3, refers to the “volume of water intentionally added to the groundwater system as part of defined recharge and water banking programs through spreading basins, injection wells, and other means.” Using the maps in the model documentation or associated hydrogeologic reports, find information on zones with similar recharge values (recharge zones), and determine which recharge zones in the model correspond to the water budget zone of interest. If managed aquifer recharge data have not been incorporated into the model, data such as the rate and areal extent of recharge may be obtained and added to the model using the Recharge Package in MODFLOW-OWHM.

In MODFLOW-OWHM, direct recharge is specified using the Recharge Package. The Zone Budget in MODFLOW-OWHM accounts for the volume of direct recharge in the RECH column. It lists inflows and outflows from the perspective of the groundwater system. The columns order may be different in the model files; for example, there will not be a column for a specific feature in the Zone Budget file if that feature is not used in the model. Units for the direct managed recharge are typically cubic feet or cubic meters but should be verified (refer to Section 8.2).

Note: In MODFLOW-OWHM version 2, a direct recharge option was developed where an array of recharge rates by stress period can be specified. If this option is used, the direct recharge component (Q-drch-out) of total recharge (i.e., Farm Net Recharge) is provided in the *DetailedFarmBudget.out* file. For each time step, the total direct recharge is the sum of the values in the previously mentioned columns for each WBS of interest multiplied by the time-step length. This yields a volume in model units of ft^3 or m^3.

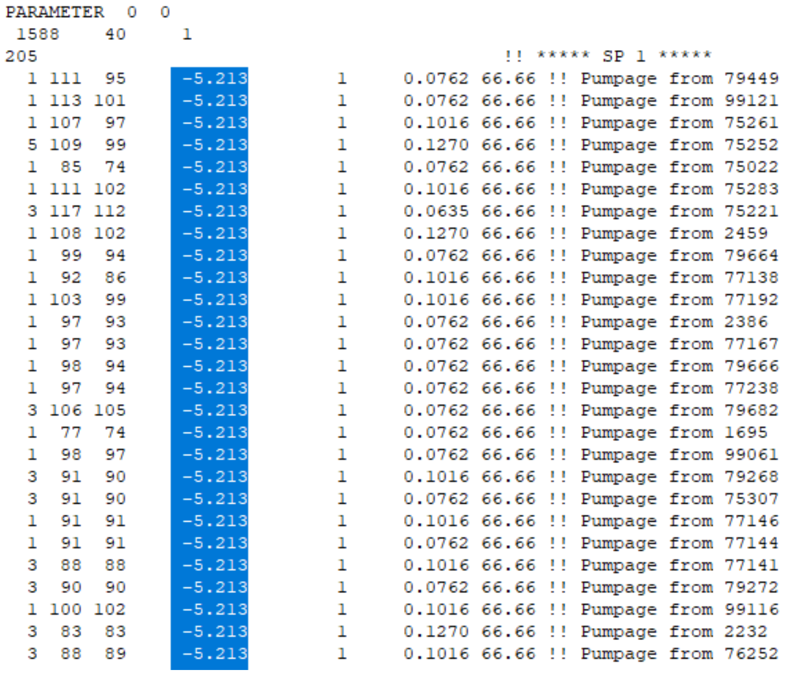
8.5.6 Stored Water Extraction

Stored water extraction, as defined in Section 1.3, refers to the "volume of groundwater pumped (extracted) from the underlying aquifer(s) through a defined recharge and extraction program for use within the water budget zone. For example, a water bank with dedicated extraction wells can provide data for stored water extraction. It does not include stored water export, groundwater extraction, and groundwater export. Groundwater extraction and stored water extraction will be combined if stored water extraction amounts are unknown or are not separately measured. In such a case, the total volume of combined extractions will be reported as groundwater extraction." If water banking operations do not exist in the water budget zone of interest, then this term can be ignored.

There are two ways that stored water extraction can be specified in MODFLOW-OWHM, either as (1) a specified pumping rate from a well, represented by the Well (WEL) or Multi Node Well (MNW) packages or, (2) a demand driven calculated pumping rate based on land-use water demands.

In cases where the stored water extraction is an input parameter, the pumping volume can be obtained from the input file that is identified with a file extension of ".wel or .MNW" (Figure 8-27). This file contains a timeseries of pumping volumes by timestep by well. Identify the relevant wells in the water budget zone and sum the pumping volumes to compute the stored water extraction.

Figure 8-27 **MODFLOW-OWHM WEL File**



```
PARAMETER  0  0
 1588    40     1
205                                                !! ***** SP 1 *****
   1 111  95     -5.213        1      0.0762 66.66 !! Pumpage from 79449
   1 113 101     -5.213        1      0.0762 66.66 !! Pumpage from 99121
   1 107  97     -5.213        1      0.1016 66.66 !! Pumpage from 75261
   5 109  99     -5.213        1      0.1270 66.66 !! Pumpage from 75252
   1  85  74     -5.213        1      0.0762 66.66 !! Pumpage from 75022
   1 111 102     -5.213        1      0.1016 66.66 !! Pumpage from 75283
   3 117 112     -5.213        1      0.0635 66.66 !! Pumpage from 75221
   1 108 102     -5.213        1      0.1270 66.66 !! Pumpage from 2459
   1  99  94     -5.213        1      0.0762 66.66 !! Pumpage from 79664
   1  92  86     -5.213        1      0.1016 66.66 !! Pumpage from 77138
   1 103  99     -5.213        1      0.1016 66.66 !! Pumpage from 77192
   1  97  93     -5.213        1      0.0762 66.66 !! Pumpage from 2386
   1  97  93     -5.213        1      0.0762 66.66 !! Pumpage from 77167
   1  98  94     -5.213        1      0.0762 66.66 !! Pumpage from 79666
   1  97  94     -5.213        1      0.0762 66.66 !! Pumpage from 77238
   3 106 105     -5.213        1      0.0762 66.66 !! Pumpage from 79682
   1  77  74     -5.213        1      0.0762 66.66 !! Pumpage from 1695
   1  98  97     -5.213        1      0.0762 66.66 !! Pumpage from 99061
   3  91  90     -5.213        1      0.1016 66.66 !! Pumpage from 79268
   3  91  90     -5.213        1      0.0762 66.66 !! Pumpage from 75307
   1  91  91     -5.213        1      0.1016 66.66 !! Pumpage from 77146
   1  91  91     -5.213        1      0.0762 66.66 !! Pumpage from 77144
   3  88  88     -5.213        1      0.1016 66.66 !! Pumpage from 77141
   3  90  90     -5.213        1      0.0762 66.66 !! Pumpage from 79272
   1 100 102     -5.213        1      0.1016 66.66 !! Pumpage from 99116
   3  83  83     -5.213        1      0.1270 66.66 !! Pumpage from 2232
   3  88  89     -5.213        1      0.1016 66.66 !! Pumpage from 76252
```

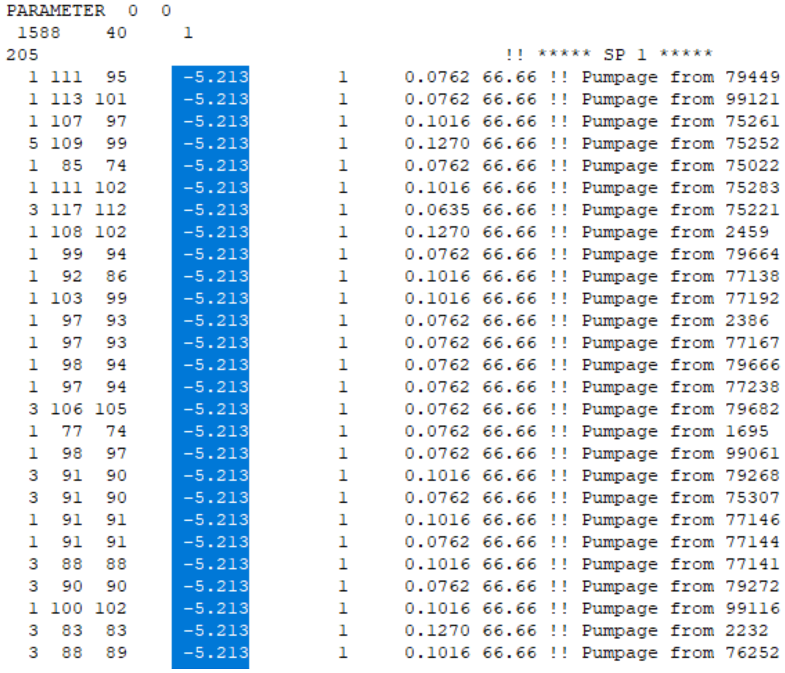
Note: To set up a demand driven option where land use water demands can be used to compute withdrawals, define the well(s) or non-routed deliveries in the farm process input that will be used for supply in the associated WBS. This can be specified using a specific well in the farm process or using an option to provide a well as a source for a non-routed delivery.

Budgets for the stored water extraction can be summed from the Well Package input or specified as a specific budget item for output to the Zone Budget in MODFLOW-OWHM version 2 as indicated in Section 8.2. If the demand driven options for computing stored water extraction are used, then the computed pumping rates for the wells associated with the stored water operation can be summed in the standard Farm Well output file whose name is specified in the farm process input.

8.5.7 Groundwater Export

Groundwater export, as defined in Section 1.3, refers to the "volume of groundwater pumped (extracted) from the underlying aquifer for use outside the water budget zone. It does not include groundwater extraction, stored water extraction, and stored water export." In MODFLOW-OWHM, groundwater export can be simulated by assigning pumping but no water application in the Well (WEL) or Multi-node Well (NMW) packages. If groundwater export data are not incorporated into the model, data such as the extraction rate and location of wells may be obtained and added to the model using the Well Package. Because groundwater exports are typically measured and reported, inclusion in the model means explicitly adding these values as input data. Well pumping rates can be found in the Well Package input files labeled with a file extension of ".wel" or ".MNW". Find these files, identify the wells used for groundwater exports, and sum the volumes for the appropriate timesteps. Well extractions are reported as negative numbers in the Well Package files. Units for groundwater export are typically cubic feet or cubic meters but should be verified.

Figure 8-28 **MODFLOW-OWHM WEL File**



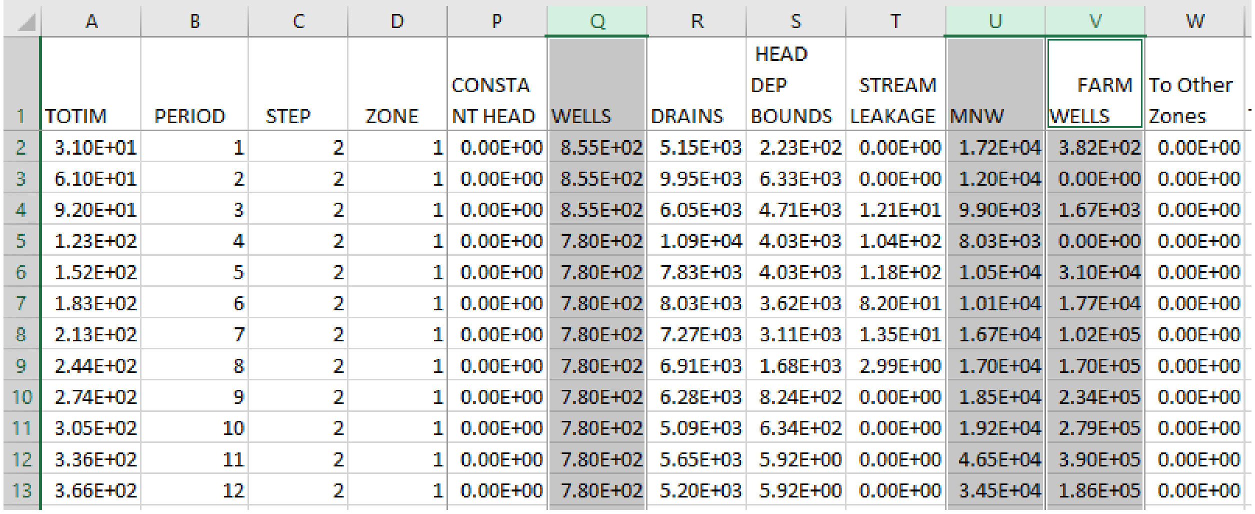
```
PARAMETER  0  0
 1588    40     1
205                                          !! ***** SP 1 *****
  1 111  95     -5.213        1     0.0762 66.66 !! Pumpage from 79449
  1 113 101     -5.213        1     0.0762 66.66 !! Pumpage from 99121
  1 107  97     -5.213        1     0.1016 66.66 !! Pumpage from 75261
  5 109  99     -5.213        1     0.1270 66.66 !! Pumpage from 75252
  1  85  74     -5.213        1     0.0762 66.66 !! Pumpage from 75022
  1 111 102     -5.213        1     0.1016 66.66 !! Pumpage from 75283
  3 117 112     -5.213        1     0.0635 66.66 !! Pumpage from 75221
  1 108 102     -5.213        1     0.1270 66.66 !! Pumpage from 2459
  1  99  94     -5.213        1     0.0762 66.66 !! Pumpage from 79664
  1  92  86     -5.213        1     0.1016 66.66 !! Pumpage from 77138
  1 103  99     -5.213        1     0.1016 66.66 !! Pumpage from 77192
  1  97  93     -5.213        1     0.0762 66.66 !! Pumpage from 2386
  1  97  93     -5.213        1     0.0762 66.66 !! Pumpage from 77167
  1  98  94     -5.213        1     0.0762 66.66 !! Pumpage from 79666
  1  97  94     -5.213        1     0.0762 66.66 !! Pumpage from 77238
  3 106 105     -5.213        1     0.0762 66.66 !! Pumpage from 79682
  1  77  74     -5.213        1     0.0762 66.66 !! Pumpage from 1695
  1  98  97     -5.213        1     0.0762 66.66 !! Pumpage from 99061
  3  91  90     -5.213        1     0.1016 66.66 !! Pumpage from 79268
  3  91  90     -5.213        1     0.0762 66.66 !! Pumpage from 75307
  1  91  91     -5.213        1     0.1016 66.66 !! Pumpage from 77146
  1  91  91     -5.213        1     0.0762 66.66 !! Pumpage from 77144
  3  88  88     -5.213        1     0.1016 66.66 !! Pumpage from 77141
  3  90  90     -5.213        1     0.0762 66.66 !! Pumpage from 79272
  1 100 102     -5.213        1     0.1016 66.66 !! Pumpage from 99116
  3  83  83     -5.213        1     0.1270 66.66 !! Pumpage from 2232
  3  88  89     -5.213        1     0.1016 66.66 !! Pumpage from 76252
```

Alternatively, groundwater exports can be obtained from a MODFLOW application using a combination of the Zone Budget and Farm Budget outputs. The pumping terms in the Zone Budget include all pumping that happens in the zone regardless of end use. The Farm Budget reports the pumping that is used to meet demands within the zone.

For the areas corresponding to the water budget zone of interest, first find the total pumping in the water budget zone by summing up the various "Well" columns in the Zone Budget (Figure 8-29). From the Farm Budget, find the volume of groundwater for overlying use through the Q-well-in column (Figure 8-30). The total volume of the groundwater export is the difference between total pumping and pumping for overlying use.

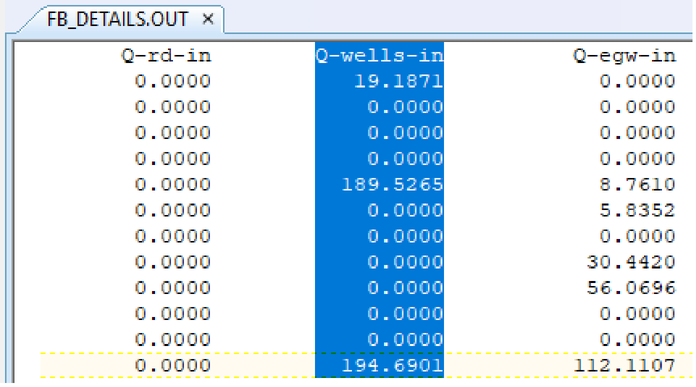
If stored water export also exists in the water budget zone, this volume will need to be subtracted from the previously calculated value.

Figure 8-29 **Zone Budget: Groundwater Extraction**



	A	B	C	D	P	Q	R	S	T	U	V	W
1	TOTIM	PERIOD	STEP	ZONE	CONSTANT HEAD	WELLS	DRAINS	HEAD DEP BOUNDS	STREAM LEAKAGE	MNW	FARM WELLS	To Other Zones
2	3.10E+01	1	2	1	0.00E+00	8.55E+02	5.15E+03	2.23E+02	0.00E+00	1.72E+04	3.82E+02	0.00E+00
3	6.10E+01	2	2	1	0.00E+00	8.55E+02	9.95E+03	6.33E+03	0.00E+00	1.20E+04	0.00E+00	0.00E+00
4	9.20E+01	3	2	1	0.00E+00	8.55E+02	6.05E+03	4.71E+03	1.21E+01	9.90E+03	1.67E+03	0.00E+00
5	1.23E+02	4	2	1	0.00E+00	7.80E+02	1.09E+04	4.03E+03	1.04E+02	8.03E+03	0.00E+00	0.00E+00
6	1.52E+02	5	2	1	0.00E+00	7.80E+02	7.83E+03	4.03E+03	1.18E+02	1.05E+04	3.10E+04	0.00E+00
7	1.83E+02	6	2	1	0.00E+00	7.80E+02	8.03E+03	3.62E+03	8.20E+01	1.01E+04	1.77E+04	0.00E+00
8	2.13E+02	7	2	1	0.00E+00	7.80E+02	7.27E+03	3.11E+03	1.35E+01	1.67E+04	1.02E+05	0.00E+00
9	2.44E+02	8	2	1	0.00E+00	7.80E+02	6.91E+03	1.68E+03	2.99E+00	1.70E+04	1.70E+05	0.00E+00
10	2.74E+02	9	2	1	0.00E+00	7.80E+02	6.28E+03	8.24E+02	0.00E+00	1.85E+04	2.34E+05	0.00E+00
11	3.05E+02	10	2	1	0.00E+00	7.80E+02	5.09E+03	6.34E+02	0.00E+00	1.92E+04	2.79E+05	0.00E+00
12	3.36E+02	11	2	1	0.00E+00	7.80E+02	5.65E+03	5.92E+00	0.00E+00	4.65E+04	3.90E+05	0.00E+00
13	3.66E+02	12	2	1	0.00E+00	7.80E+02	5.20E+03	5.92E+00	0.00E+00	3.45E+04	1.86E+05	0.00E+00

Figure 8-30 **Farm Budget: Groundwater Extraction**



```
          Q-rd-in       Q-wells-in           Q-egw-in
           0.0000          19.1871             0.0000
           0.0000           0.0000             0.0000
           0.0000           0.0000             0.0000
           0.0000           0.0000             0.0000
           0.0000           0.0000             0.0000
           0.0000         189.5265             8.7610
           0.0000           0.0000             5.8352
           0.0000           0.0000             0.0000
           0.0000           0.0000            30.4420
           0.0000           0.0000            56.0696
           0.0000           0.0000             0.0000
           0.0000           0.0000             0.0000
           0.0000         194.6901           112.1107
```

Note: If MODFLOW-OWHM version 2 is used, a specific budget item for these wells can be specified (refer to Section 8.2).

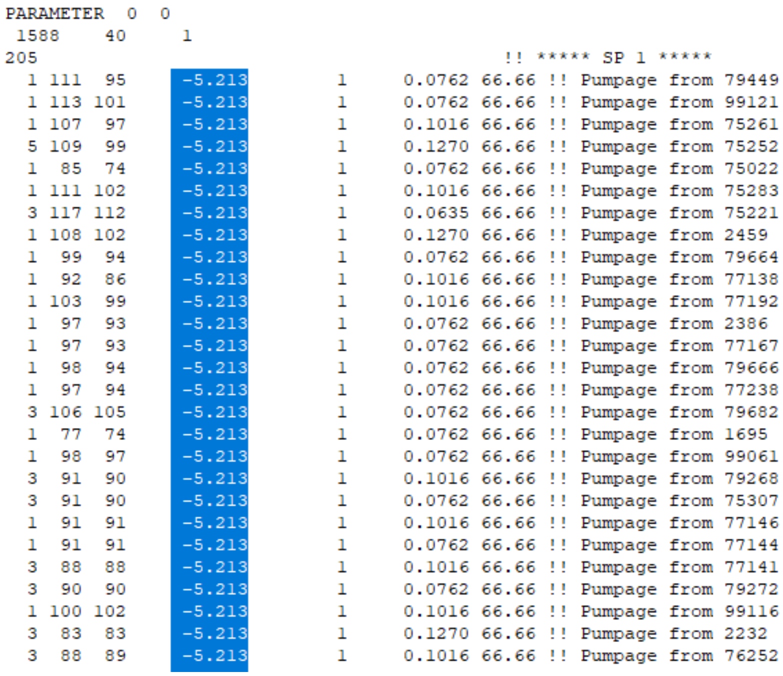
8.5.8 Stored Water Export

Stored water export, as defined in Section 1.3, refers to the "volume of groundwater pumped (extracted) from the underlying aquifer(s) through a defined recharge and extraction program for use outside the water budget zone. For example, a water bank with dedicated extraction wells can provide data for stored water export. It does not include stored water extraction, groundwater extraction, and groundwater export. Groundwater export and stored water export will be combined if stored water export amounts are unknown or are not separately measured. In such a case, the total volume of combined exports will be reported as groundwater export." If water banking operations do not exist in the water budget zone of interest, then this term can be ignored.

There are two ways that stored water exports can be specified in MODFLOW-OWHM, either as (1) a specified pumping rate from a well, represented by the Well (WEL) or Multi Node Well (MNW) packages or, (2) a demand driven calculated pumping rate based on land-use water demands.

In cases where the stored water extraction is an input parameter, the pumping volume can be obtained from the input file that is identified with a file extension of ".wel or .MNW" (Figure 8-31). This file contains a timeseries of pumping volumes by timestep by well. Identify the relevant wells used for stored water export in the water budget zone and sum up the pumping volumes to compute the stored water export.

Figure 8-31 **MODFLOW-OWHM WEL File**



```
PARAMETER  0  0
 1588   40     1
205                                               !! ***** SP 1 *****
   1 111  95     -5.213         1      0.0762 66.66 !! Pumpage from 79449
   1 113 101     -5.213         1      0.0762 66.66 !! Pumpage from 99121
   1 107  97     -5.213         1      0.1016 66.66 !! Pumpage from 75261
   5 109  99     -5.213         1      0.1270 66.66 !! Pumpage from 75252
   1  85  74     -5.213         1      0.0762 66.66 !! Pumpage from 75022
   1 111 102     -5.213         1      0.1016 66.66 !! Pumpage from 75283
   3 117 112     -5.213         1      0.0635 66.66 !! Pumpage from 75221
   1 108 102     -5.213         1      0.1270 66.66 !! Pumpage from 2459
   1  99  94     -5.213         1      0.0762 66.66 !! Pumpage from 79664
   1  92  86     -5.213         1      0.1016 66.66 !! Pumpage from 77138
   1 103  99     -5.213         1      0.1016 66.66 !! Pumpage from 77192
   1  97  93     -5.213         1      0.0762 66.66 !! Pumpage from 2386
   1  97  93     -5.213         1      0.0762 66.66 !! Pumpage from 77167
   1  98  94     -5.213         1      0.0762 66.66 !! Pumpage from 79666
   1  97  94     -5.213         1      0.0762 66.66 !! Pumpage from 77238
   3 106 105     -5.213         1      0.0762 66.66 !! Pumpage from 79682
   1  77  74     -5.213         1      0.0762 66.66 !! Pumpage from 1695
   1  98  97     -5.213         1      0.0762 66.66 !! Pumpage from 99061
   3  91  90     -5.213         1      0.1016 66.66 !! Pumpage from 79268
   3  91  90     -5.213         1      0.0762 66.66 !! Pumpage from 75307
   1  91  91     -5.213         1      0.1016 66.66 !! Pumpage from 77146
   1  91  91     -5.213         1      0.0762 66.66 !! Pumpage from 77144
   3  88  88     -5.213         1      0.1016 66.66 !! Pumpage from 77141
   3  90  90     -5.213         1      0.0762 66.66 !! Pumpage from 79272
   1 100 102     -5.213         1      0.1016 66.66 !! Pumpage from 99116
   3  83  83     -5.213         1      0.1270 66.66 !! Pumpage from 2232
   3  88  89     -5.213         1      0.1016 66.66 !! Pumpage from 76252
```

8.5.9 Water Release Caused by Land Subsidence

Water release caused by land subsidence, as defined in Section 1.3 is the "volume of water released to an aquifer on a one-time basis as a result of land subsidence, which is caused by the inelastic consolidation of porous fine-grained material." MODFLOW-OWHM simulates the groundwater flow from interbeds using the Subsidence (SUB) package. Values for the groundwater flow to and from clay interbeds are provided in the Zone Budget (Figure 8-32).

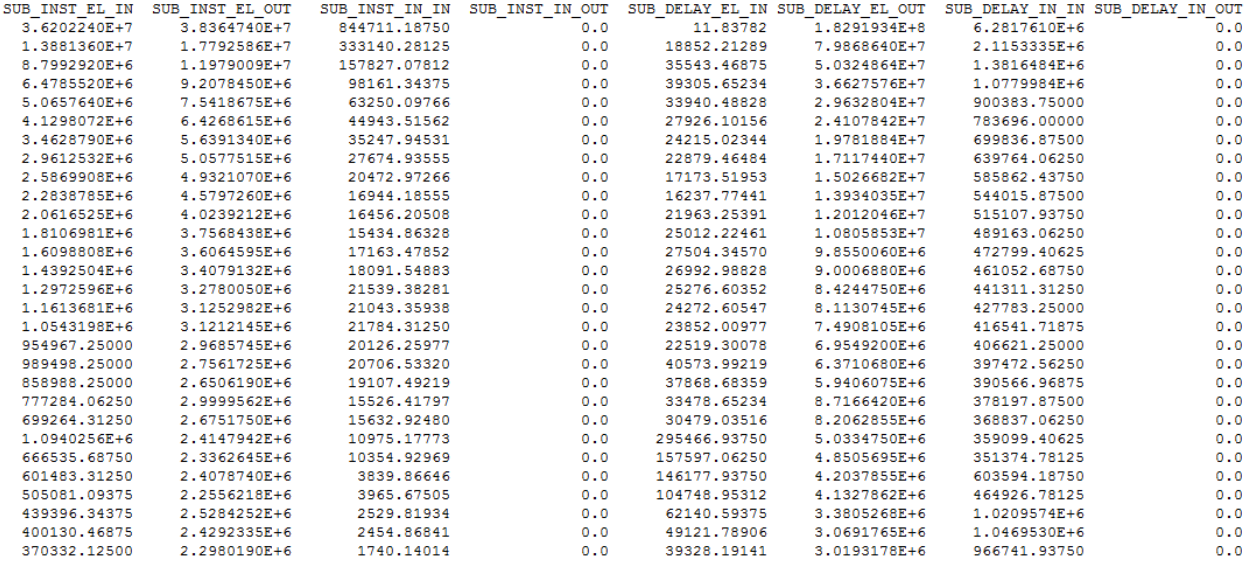
Eight values for the groundwater flow to and from clay interbeds are provided in the cell-by-cell groundwater budget as shown in Table 8-3. Water release caused by land subsidence refers to the SUB_INST_IN_IN and SUB_DELAY_IN_IN terms.

Table 8-3 MODFLOW-OWHM Data Columns Related to Subsidence

Column Heading	Column Description
SUB_INST_EL_IN	Instantaneous elastic flow to the groundwater system from interbeds
SUB_INST_EL_OUT	Instantaneous elastic flow from the groundwater system to interbeds
SUB_INST_IN_IN	Instantaneous inelastic flow to the groundwater system from interbeds
SUB_INST_IN_OUT	Instantaneous inelastic flow from the groundwater system to interbeds
SUB_DELAY_EL_IN	Delayed elastic flow to the groundwater system from interbeds
SUB_DELAY_EL_OUT	Delayed elastic flow from the groundwater system to interbeds
SUB_DELAY_IN_IN	Delayed inelastic flow to the groundwater system from interbeds
SUB_DELAY_IN_OUT	Delayed inelastic flow from the groundwater system to interbeds

Note on SUB_INST_IN_OUT and SUB_DELAY_IN_OUT: These terms are included to be consistent with the MODFLOW-OWHM budget format, but they are always zero because inelastic flow from interbeds is irreversible, so inelastic flow back to the interbeds is not possible.

Figure 8-32 Zone Budget: Subsidence

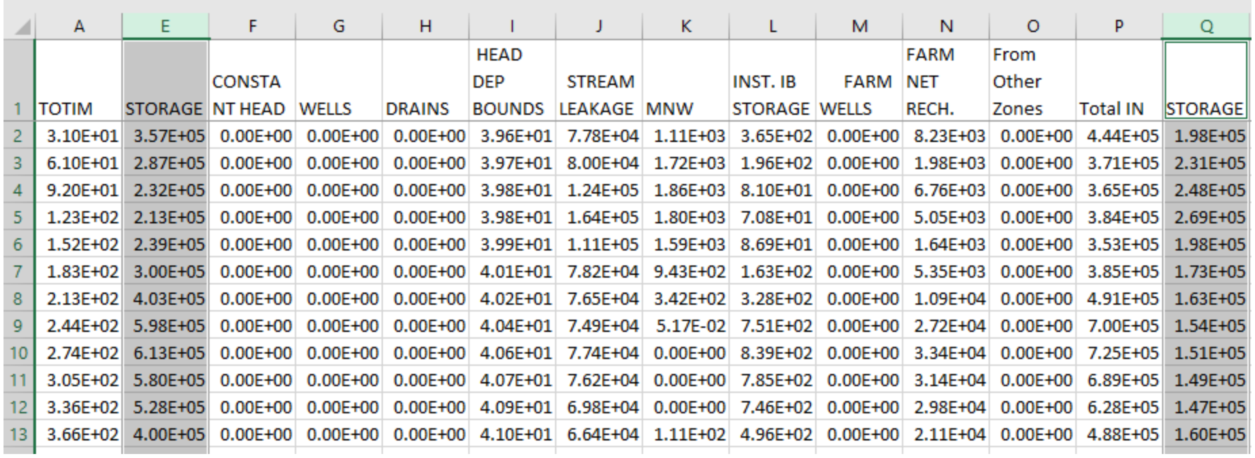


```
SUB_INST_EL_IN  SUB_INST_EL_OUT   SUB_INST_IN_IN  SUB_INST_IN_OUT  SUB_DELAY_EL_IN SUB_DELAY_EL_OUT  SUB_DELAY_IN_IN SUB_DELAY_IN_OUT
  3.6202240E+7     3.8364740E+7     844711.18750              0.0         11.83782     1.8291934E+8     6.2817610E+6              0.0
  1.3881360E+7     1.7792586E+7     333140.28125              0.0      18852.21289     7.9868640E+7     2.1153335E+6              0.0
  8.7992920E+6     1.1979009E+7     157827.07812              0.0      35543.46875     5.0324864E+7     1.3816484E+6              0.0
  6.4785520E+6     9.2078450E+6      98161.34375              0.0      39305.65234     3.6627576E+7     1.0779984E+6              0.0
  5.0657640E+6     7.5418675E+6      63250.09766              0.0      33940.48828     2.9632804E+7     900383.75000              0.0
  4.1298072E+6     6.4268615E+6      44943.51562              0.0      27926.10156     2.4107842E+7     783696.00000              0.0
  3.4628790E+6     5.6391340E+6      35247.94531              0.0      24215.02344     1.9781884E+7     699836.87500              0.0
  2.9612532E+6     5.0577515E+6      27674.93555              0.0      22879.46484     1.7117440E+7     639764.06250              0.0
  2.5869908E+6     4.9321070E+6      20472.97266              0.0      17173.51953     1.5026682E+7     585862.43750              0.0
  2.2838785E+6     4.5797260E+6      16944.18555              0.0      16237.77441     1.3934035E+7     544015.87500              0.0
  2.0616525E+6     4.0239212E+6      16456.20508              0.0      21963.25391     1.2012046E+7     515107.93750              0.0
  1.8106981E+6     3.7568438E+6      15434.86328              0.0      25012.22461     1.0805853E+7     489163.06250              0.0
  1.6098808E+6     3.6064595E+6      17163.47852              0.0      27504.34570     9.8550060E+6     472799.40625              0.0
  1.4392504E+6     3.4079132E+6      18091.54883              0.0      26992.98828     9.0006880E+6     461052.68750              0.0
  1.2972596E+6     3.2780050E+6      21539.38281              0.0      25276.60352     8.4244750E+6     441311.31250              0.0
  1.1613681E+6     3.1252982E+6      21043.35938              0.0      24272.60547     8.1130745E+6     427783.25000              0.0
  1.0543198E+6     3.1212145E+6      21784.31250              0.0      23852.00977     7.4908105E+6     416541.71875              0.0
  954967.25000     2.9685745E+6      20126.25977              0.0      22519.30078     6.9549200E+6     406621.25000              0.0
  989498.25000     2.7561725E+6      20706.53320              0.0      40573.99219     6.3710680E+6     397472.56250              0.0
  858988.25000     2.6506190E+6      19107.49219              0.0      37868.68359     5.9406075E+6     390566.96875              0.0
  777284.06250     2.9999562E+6      15526.41797              0.0      33478.65234     8.7166420E+6     378197.87500              0.0
  699264.31250     2.6751750E+6      15632.92480              0.0      30479.03516     8.2062855E+6     368837.06250              0.0
  1.0940256E+6     2.4147942E+6      10975.17773              0.0     295466.93750     5.0334750E+6     359099.40625              0.0
  666535.68750     2.3362645E+6      10354.92969              0.0     157597.06250     4.8505695E+6     351374.78125              0.0
  601483.31250     2.4078740E+6       3839.86646              0.0     146177.93750     4.2037855E+6     603594.18750              0.0
  505081.09375     2.2556218E+6       3965.67505              0.0     104748.95312     4.1327862E+6     464926.78125              0.0
  439396.34375     2.5284252E+6       2529.81934              0.0      62140.59375     3.3805268E+6     1.0209574E+6              0.0
  400130.46875     2.4292335E+6       2454.86841              0.0      49121.78906     3.0691765E+6     1.0469530E+6              0.0
  370332.12500     2.2980190E+6       1740.14014              0.0      39328.19141     3.0193178E+6     966741.93750              0.0
```

8.5.10 Change in Groundwater Storage

Change in groundwater storage, as defined in Section 1.3 is the "net change in the volume of groundwater stored within the underlying aquifer of the water budget zone." MODFLOW-OWHM accounts for the change in groundwater storage in the Zone Budget output. The Zone Budget reports storage as an inflow and outflow. For zones corresponding to the water budget zone of interest, find the storage data in the "Storage" columns (Figure 8-33). The total change in groundwater storage for any particular timestep is the difference between storage inflow and storage outflow.

Figure 8-33 Zone Budget: Storage



	A	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	TOTIM	STORAGE	CONSTA NT HEAD	WELLS	DRAINS	HEAD DEP BOUNDS	STREAM LEAKAGE	MNW	INST. IB STORAGE	FARM WELLS	FARM NET RECH.	From Other Zones	Total IN	STORAGE
2	3.10E+01	3.57E+05	0.00E+00	0.00E+00	0.00E+00	3.96E+01	7.78E+04	1.11E+03	3.65E+02	0.00E+00	8.23E+03	0.00E+00	4.44E+05	1.98E+05
3	6.10E+01	2.87E+05	0.00E+00	0.00E+00	0.00E+00	3.97E+01	8.00E+04	1.72E+03	1.96E+02	0.00E+00	1.98E+03	0.00E+00	3.71E+05	2.31E+05
4	9.20E+01	2.32E+05	0.00E+00	0.00E+00	0.00E+00	3.98E+01	1.24E+05	1.86E+03	8.10E+01	0.00E+00	6.76E+03	0.00E+00	3.65E+05	2.48E+05
5	1.23E+02	2.13E+05	0.00E+00	0.00E+00	0.00E+00	3.98E+01	1.64E+05	1.80E+03	7.08E+01	0.00E+00	5.05E+03	0.00E+00	3.84E+05	2.69E+05
6	1.52E+02	2.39E+05	0.00E+00	0.00E+00	0.00E+00	3.99E+01	1.11E+05	1.59E+03	8.69E+01	0.00E+00	1.64E+03	0.00E+00	3.53E+05	1.98E+05
7	1.83E+02	3.00E+05	0.00E+00	0.00E+00	0.00E+00	4.01E+01	7.82E+04	9.43E+02	1.63E+02	0.00E+00	5.35E+03	0.00E+00	3.85E+05	1.73E+05
8	2.13E+02	4.03E+05	0.00E+00	0.00E+00	0.00E+00	4.02E+01	7.65E+04	3.42E+02	3.28E+02	0.00E+00	1.09E+04	0.00E+00	4.91E+05	1.63E+05
9	2.44E+02	5.98E+05	0.00E+00	0.00E+00	0.00E+00	4.04E+01	7.49E+04	5.17E-02	7.51E+02	0.00E+00	2.72E+04	0.00E+00	7.00E+05	1.54E+05
10	2.74E+02	6.13E+05	0.00E+00	0.00E+00	0.00E+00	4.06E+01	7.74E+04	0.00E+00	8.39E+02	0.00E+00	3.34E+04	0.00E+00	7.25E+05	1.51E+05
11	3.05E+02	5.80E+05	0.00E+00	0.00E+00	0.00E+00	4.07E+01	7.62E+04	0.00E+00	7.85E+02	0.00E+00	3.14E+04	0.00E+00	6.89E+05	1.49E+05
12	3.36E+02	5.28E+05	0.00E+00	0.00E+00	0.00E+00	4.09E+01	6.98E+04	0.00E+00	7.46E+02	0.00E+00	2.98E+04	0.00E+00	6.28E+05	1.47E+05
13	3.66E+02	4.00E+05	0.00E+00	0.00E+00	0.00E+00	4.10E+01	6.64E+04	1.11E+02	4.96E+02	0.00E+00	2.11E+04	0.00E+00	4.88E+05	1.60E+05

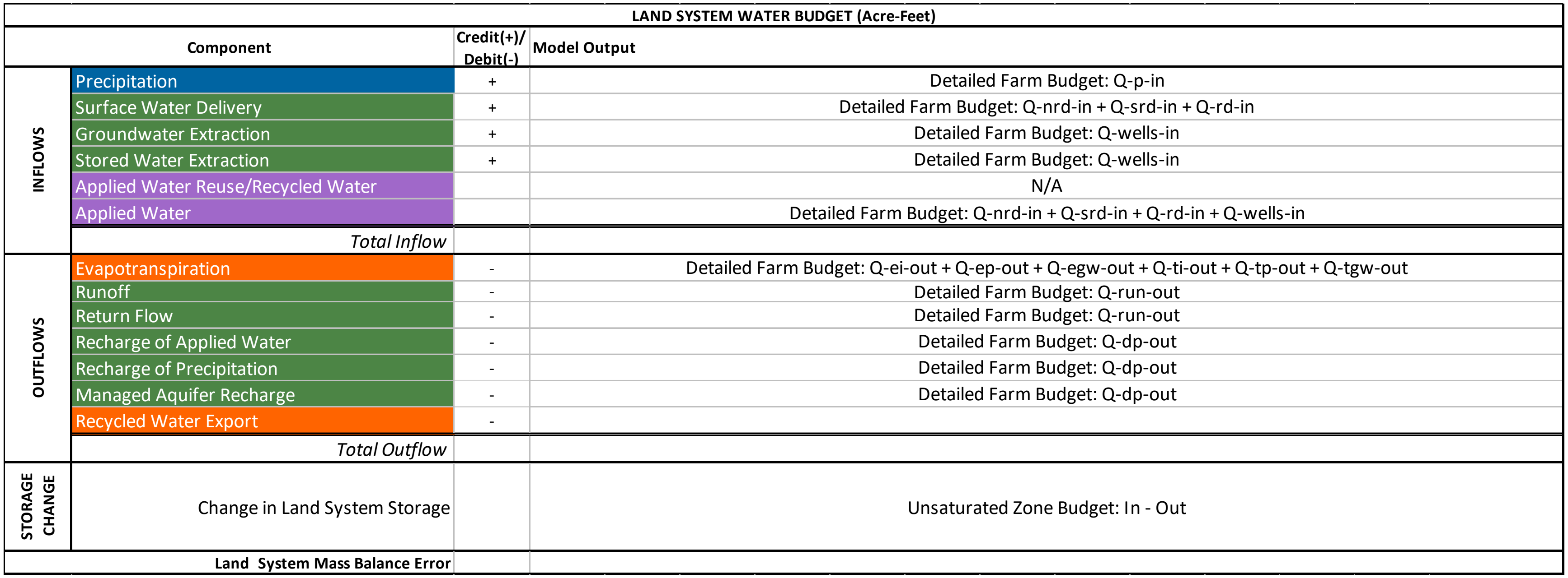
8.6 TOTAL WATER BUDGET FROM MODFLOW-OWHM

After individual water budget components are extracted from a MODFLOW-OWHM application, the total water budget can be compiled for the water budget zone. The total water budget is an accounting of all water entering or leaving the water budget zone, as well as components flowing between systems within the water budget zone. Water budget tables for the land system, surface water system, groundwater system, and total water budget are presented in Figure 8-34 through Figure 8-37. The tables demonstrate the interconnectivity between the three systems and highlight the inflows and outflows from the water budget zone. The tables are also available in accessible Excel format on the Water Budget Handbook webpage.

Color Key:

Blue	Inflow to Water Budget Zone
Orange	Outflow from Water Budget Zone
Green	Flow between Systems
Purple	Flow within Systems

Figure 8-34 Land System Water Budget Components and MODFLOW-OWHM Water Budget Elements



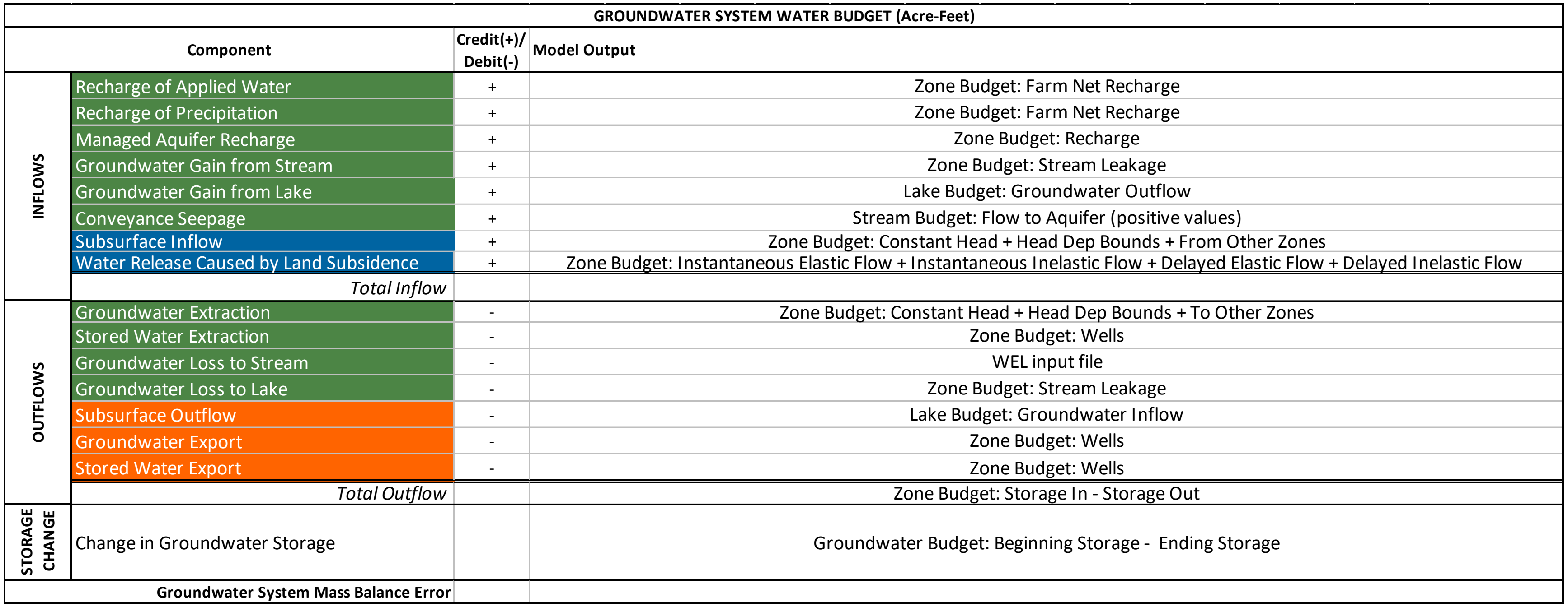
LAND SYSTEM WATER BUDGET (Acre-Feet)

	Component	**Credit(+)/ Debit(-)**	**Model Output**
INFLOWS	Precipitation	+	Detailed Farm Budget: Q-p-in
	Surface Water Delivery	+	Detailed Farm Budget: Q-nrd-in + Q-srd-in + Q-rd-in
	Groundwater Extraction	+	Detailed Farm Budget: Q-wells-in
	Stored Water Extraction	+	Detailed Farm Budget: Q-wells-in
	Applied Water Reuse/Recycled Water		N/A
	Applied Water		Detailed Farm Budget: Q-nrd-in + Q-srd-in + Q-rd-in + Q-wells-in
	Total Inflow		
OUTFLOWS	Evapotranspiration	-	Detailed Farm Budget: Q-ei-out + Q-ep-out + Q-egw-out + Q-ti-out + Q-tp-out + Q-tgw-out
	Runoff	-	Detailed Farm Budget: Q-run-out
	Return Flow	-	Detailed Farm Budget: Q-run-out
	Recharge of Applied Water	-	Detailed Farm Budget: Q-dp-out
	Recharge of Precipitation	-	Detailed Farm Budget: Q-dp-out
	Managed Aquifer Recharge	-	Detailed Farm Budget: Q-dp-out
	Recycled Water Export	-	
	Total Outflow		
STORAGE CHANGE	Change in Land System Storage		Unsaturated Zone Budget: In - Out
Land System Mass Balance Error			

Figure 8-35 Surface Water System Budget Components and MODFLOW-OWHM Water Budget Elements

SURFACE WATER SYSTEM WATER BUDGET (Acre-Feet)			
Component		Credit(+)/ Debit(-)	Model Output
INFLOWS	Stream Inflow	+	Stream Budget: Flow into Strm. Rch.
	Imported Water	+	Detailed Farm Budget: Q-nrd-in
	Precipitaion on Lakes	+	Lake Budget: Precip
	Runoff	+	Stream Budget: Ovrlnd Runoff
	Return Flow	+	Stream Budget: Ovrlnd Runoff
	Stream Gain from Groundwater	+	Zone Budget: Stream Leakage
	Lake Gain from Groundwater	+	Lake Budget: Groundwater Inflow
	Total Inflow		
OUTFLOWS	Stream Outflow	-	Stream Budget: Flow Out of Strm. Rch.
	Surface Water Exports	-	Detailed Farm Budget: Q-srd-out+ Q-rd-out
	Surface Water Diversions		Detailed Farm Budget: Q-srd-in + Q-rd-in
	Conveyance Evaporation	-	Stream Budget: Stream ET
	Conveyance Seepage	-	Stream Budget: Flow to Aquifer (positive values)
	Surface Water Delivery	-	Detailed Farm Budget: Q-srd-in + Q-rd-in + Q-nrd-in
	Stream Loss to Groundwater	-	Zone Budget: Stream Leakage
	Lake Loss to Groundwater	-	Lake Budget: Groundwater Outflow
	Lake Evaporation	-	Lake Budget: Evap
	Stream Evaporation	-	Steram Budget: Stream ET
	Total Outflow		
STORAGE CHANGE	Change in Surface Water Storage		Lake Budget: Updated Volume minus Volume from previous timestep
Surface Water System Mass Balance Error			

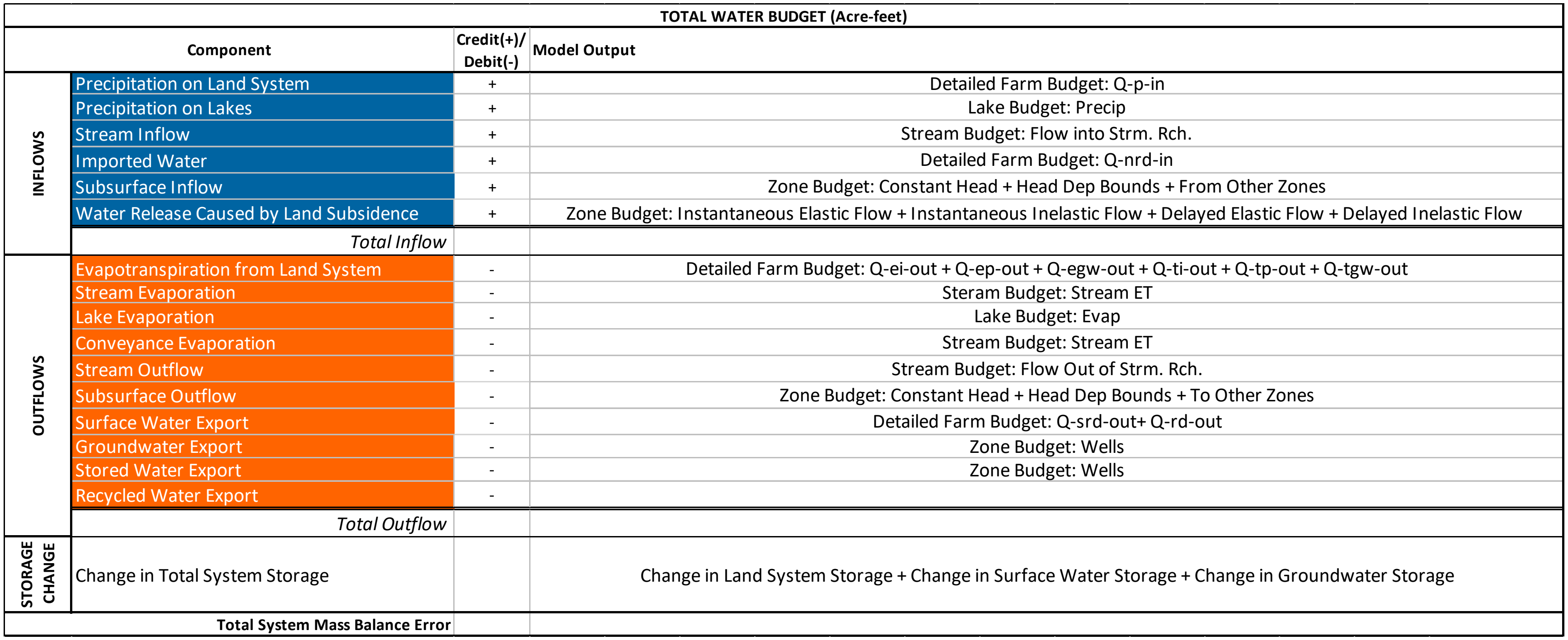
Figure 8-36 Groundwater System Budget Components and MODFLOW-OWHM Water Budget Elements



GROUNDWATER SYSTEM WATER BUDGET (Acre-Feet)

	Component	**Credit(+)/ Debit(-)**	**Model Output**
INFLOWS	Recharge of Applied Water	+	Zone Budget: Farm Net Recharge
	Recharge of Precipitation	+	Zone Budget: Farm Net Recharge
	Managed Aquifer Recharge	+	Zone Budget: Recharge
	Groundwater Gain from Stream	+	Zone Budget: Stream Leakage
	Groundwater Gain from Lake	+	Lake Budget: Groundwater Outflow
	Conveyance Seepage	+	Stream Budget: Flow to Aquifer (positive values)
	Subsurface Inflow	+	Zone Budget: Constant Head + Head Dep Bounds + From Other Zones
	Water Release Caused by Land Subsidence	+	Zone Budget: Instantaneous Elastic Flow + Instantaneous Inelastic Flow + Delayed Elastic Flow + Delayed Inelastic Flow
	Total Inflow		
OUTFLOWS	Groundwater Extraction	-	Zone Budget: Constant Head + Head Dep Bounds + To Other Zones
	Stored Water Extraction	-	Zone Budget: Wells
	Groundwater Loss to Stream	-	WEL input file
	Groundwater Loss to Lake	-	Zone Budget: Stream Leakage
	Subsurface Outflow	-	Lake Budget: Groundwater Inflow
	Groundwater Export	-	Zone Budget: Wells
	Stored Water Export	-	Zone Budget: Wells
	Total Outflow		Zone Budget: Storage In - Storage Out
STORAGE CHANGE	Change in Groundwater Storage		Groundwater Budget: Beginning Storage - Ending Storage
	Groundwater System Mass Balance Error		

Figure 8-37 Total Water Budget Components and MODFLOW-OWHM Water Budget Elements



TOTAL WATER BUDGET (Acre-feet)

	Component	Credit(+)/ Debit(-)	Model Output
INFLOWS	Precipitation on Land System	+	Detailed Farm Budget: Q-p-in
	Precipitation on Lakes	+	Lake Budget: Precip
	Stream Inflow	+	Stream Budget: Flow into Strm. Rch.
	Imported Water	+	Detailed Farm Budget: Q-nrd-in
	Subsurface Inflow	+	Zone Budget: Constant Head + Head Dep Bounds + From Other Zones
	Water Release Caused by Land Subsidence	+	Zone Budget: Instantaneous Elastic Flow + Instantaneous Inelastic Flow + Delayed Elastic Flow + Delayed Inelastic Flow
	Total Inflow		
OUTFLOWS	Evapotranspiration from Land System	-	Detailed Farm Budget: Q-ei-out + Q-ep-out + Q-egw-out + Q-ti-out + Q-tp-out + Q-tgw-out
	Stream Evaporation	-	Steram Budget: Stream ET
	Lake Evaporation	-	Lake Budget: Evap
	Conveyance Evaporation	-	Stream Budget: Stream ET
	Stream Outflow	-	Stream Budget: Flow Out of Strm. Rch.
	Subsurface Outflow	-	Zone Budget: Constant Head + Head Dep Bounds + To Other Zones
	Surface Water Export	-	Detailed Farm Budget: Q-srd-out+ Q-rd-out
	Groundwater Export	-	Zone Budget: Wells
	Stored Water Export	-	Zone Budget: Wells
	Recycled Water Export	-	
	Total Outflow		
STORAGE CHANGE	Change in Total System Storage		Change in Land System Storage + Change in Surface Water Storage + Change in Groundwater Storage
	Total System Mass Balance Error		

9. DATA RESOURCES DIRECTORY

9.1 Introduction

This data resources directory provides a starting point for water budget practitioners to review and evaluate many of the data sources referenced in Sections 3, 4, and 5 for applicability to their own water budgets. This list is not exhaustive, and some resources may be duplicative, covering the same information but in different formats or time scales. While an attempt has been made to curate these resources, and verify links and metadata, users of this inventory do so at their own risk and are responsible for independently verifying any information presented here.

Data resources are organized alphabetically. To help users navigate through the Data Resources Directory, Figure 9-1 lists individual water budget components and directs users to appropriate data resources where information helpful to estimating those components can be found.

For each identified resource, a summary metadata sheet has been prepared containing the following information:

- Developer/author/owner.
- Source for water budget components.
- Available information.
- Brief description.
- Data link (or contact).
- Metadata link.
- Period of record.
- Coverage.
- Temporal resolution.
- Spatial resolution.
- Format.
- Software requirements.
- Tips to access/download.

The metadata sheets contain either direct quotes or paraphrased information from the sources referenced in the sheet. The information provided in the metadata sheets is for convenience of use and should be confirmed by visiting the data links for the source.

Suggested improvements to the characterization or content of the resource sheets are invited and will be included through the errata process. This section was last updated on July 1, 2019. As a print-ready document, many links will quickly become outdated; if the information has moved since the above date, the links provided may not function properly. An updated errata sheet will be provided on the Water Budget Handbook webpage when updated links are made available. If you find a broken link and the corrected link is not available in the errata sheet, please email Paul Shipman with information on the broken link, and if possible, provide an updated link.

Disclaimer

The authors of the Water Budget Handbook make no guarantees as to the accuracy, appropriateness, completeness, or availability of the data at the URLs specified in this section.

Figure 9-1 Key to Sources and Related Water Budget Components

Handbook Chapter Reference	Resources
	Title of Resource
9.2	Agricultural Water Management Plans
9.3	ALEXI: Atmosphere-Land Exchange Inverse Model
9.4	BCM: Basin Charactization Model
9.5	California Department of Finance
9.6	California Department of Transportation's Highway Design Manual
9.7	California Nevada River Forecast Center
9.8	California Pesticide Information Portal
9.9	California Water Plan - Water Portfolios
9.10	CALSIM 2
9.11	CALSIM 3
9.12	Cal-SIMETAW
9.13	CASGEM: California Statewide Groundwater Elevation Monitoring
9.14	CDEC: California Data Exchange Center
9.15	CHRS: Center for Hydrometeorology & Remote Sensing Data Portal
9.16	CIMIS: California Irrigation Management Information System
9.17	CIMIS (Spatial): California Irrigation Management Information System
9.18	County Agricultural Commissioner Crop Reports
9.19	CVHM: Central Valley Hydrologic Model
9.20	C2VSIM Coarse Grid Model
9.21	C2VSIM Fine Grid Model
9.22	DWR - Agricultural Land and Water Use Estimates
9.23	DWR Bulletin 73: Evaporation from Water Surfaces in California (1979)
9.24	DWR Bulletin 113: Crop Water Use
9.25	DWR Bulletin 118: Groundwater Report
9.26	DWR Bulletin 132: Management of the California State Water Project
9.27	DWR Demographic Data
9.28	DWR Irrigation Methods Survey
9.29	DWR Land Use Survey Data
9.30	DWR Land Use Viewer
9.31	DWR SGMA Data Viewer
9.32	DWR Water Data Library: Surface Water and Groundwater Data

Water Budget Components

Precipitation	Evapotranspiration	Applied Water	Surface Water Delivery	Groundwater Extraction	Applied Water Reuse	Recycled Water Use	Recycled Water Export	Runoff	Return Flow	Stream Inflow and Outflow	Stream Evaporation	Surface Water Diversion	Conveyance Evaporation	Conveyance Seepage	Imported Water	Surface Water Export	Stream-Lake Interaction	Lake Evaporation	Change in Surface Water Storage	Recharge of Applied Water and Precip.	Subsurface Inflow and Outflow	Stream-Groundwater Interaction	Lake-Groundwater Interaction	Managed Aquifer Recharge	Stored Water Extraction	Groundwater Export	Stored Water Export	Change in Groundwater Storage	Water Release Caused by Land Sub.
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Handbook Chapter Reference	Resources Title of Resource
9.33	GRACE: Gravity Recovery and Climate Experiment
9.34	IDC: IWFM Demand Calculator
9.35	ITRC Evapotranspiration Data
9.36	ITRC METRIC
9.37	IWFM: Integrated Water Flow Model
9.38	METRIC-EEFLUX
9.39	MOD16: MODIS Global Evapotranspiration Project
9.40	MODFLOW-OWHM: One Water Hydrologic Flow Model
9.41	NLCD: National Land Cover Database
9.42	NLDAS-2: North American Land Data Assimilation System
9.43	NOAA National Centers For Environmental Information - Climate Data Online
9.44	NOAA National Centers for Environmental Information - Climatological Data Pubs.
9.45	NWS Climate Prediction Center Evaporation
9.46	PRISM Gridded Precipitation Data
9.47	SSEBop: Operational Simplified Surface Energy Balance
9.48	SWRCB Water Conservation Portal
9.49	SWRCB Water Rights Information (eWRIMS)
9.50	TOPS-SIMS: Satellite Irrigation Management Support
9.51	United States Census
9.52	Urban Water Management Plans
9.53	USBR Central Valley Operations (including Central Valley Project)
9.54	USDA County Ag Commissioner's Data Listing
9.55	USDA CropScape
9.56	USDA Natural Resources Conservation Service Geospatial Web Soil Survey
9.57	USGS Publications
9.58	USGS Surface-Water Data for California
9.59	Validated Water Loss Reporting
9.60	VegScape: Vegetation Condition Explorer
9.61	Water Recycling Survey (2015)
9.62	WUCOLS: Water Use Classification of Landscape Species

Water Budget Components

Precipitation	Evapotranspiration	Applied Water	Surface Water Delivery	Groundwater Extraction	Applied Water Reuse	Recycled Water Use	Recycled Water Export	Runoff	Return Flow	Stream Inflow and Outflow	Stream Evaporation	Surface Water Diversion	Conveyance Evaporation	Conveyance Seepage	Imported Water	Surface Water Export	Stream-Lake Interaction	Lake Evaporation	Change in Surface Water Storage	Recharge of Applied Water and Precip.	Subsurface Inflow and Outflow	Stream-Groundwater Interaction	Lake-Groundwater Interaction	Managed Aquifer Recharge	Stored Water Extraction	Groundwater Export	Stored Water Export	Change in Groundwater Storage	Water Release Caused by Land Sub.
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9.2 Agricultural Water Management Plans

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Evapotranspiration, Applied Water, Applied Water Reuse, Recycled Water, Recycled Water Exports, Recharge of Applied Water and Precipitation
Available Information:	Water supply information, irrigation efficiency, evapotranspiration, agricultural land use by crop type, irrigation methods
Brief Description:	The Water Conservation Act of 2009 (SB X7-7) requires agricultural water suppliers serving more than 25,000 irrigated acres (excluding recycled water deliveries) to adopt and submit to DWR an agricultural water management plan (AWMP). These plans had to include specific content, including reporting on the implementation status of specific efficient water management practices (EWMPs) that were required under SB X7-7. In 2015, under the Drought Emergency Executive Order B-29-15, agricultural water suppliers serving 10,000 to 25,000 irrigated acres were also required to prepare and submit an AWMP to DWR. Additionally, all agricultural water suppliers had to include more information in their AWMPs than required by SB X7-7.
Data Link:	Water Use Efficiency Data: https://wuedata.water.ca.gov/
Metadata Link:	Agricultural Water Use Efficiency: https://water.ca.gov/Programs/Water-Use-And-Efficiency/Agricultural-Water-Use-Efficiency
Period of Record:	Varies depending on the agricultural water management plan. At minimum, includes 5 years of record.
Coverage:	Statewide coverage by agricultural water suppliers.
Temporal Resolution:	Varies, typically monthly or annual data.
Spatial Resolution:	By agricultural water supplier.
Format:	XLS and PDF
Software Requirements:	Recommended: Excel or similar spreadsheet software.
Tips to Access/Download:	Individual AWMPs are available for download through the “View 2015 AWMPs” link. Relevant data can be found within the individual PDFs.

9.3 Atmosphere-Land Exchange Inverse Model

Developer/Author/Owner:	NOAA Office of Satellite and Product Operations
Source for Water Budget Components:	Evapotranspiration
Available Information:	Actual ET
Brief Description:	GOES Evapotranspiration and Drought (GET-D) products are derived from the Atmosphere-Land Exchange Inversion model (ALEXI). ALEXI computes principle surface energy fluxes, including Evapotranspiration (ET), which is a critical boundary condition for weather and hydrologic modeling, and a quantity required for regional water resource management. ALEXI ET estimates have been rigorously evaluated in comparison with ground-based data and perform well over a range in climatic and vegetation conditions. The GET-D system is designed to generate ET and drought maps operationally. ALEXI ET is retrieved over clear-sky pixels daily and ALEXI drought product is generated over 1- to 6-month compositing periods each day.
Data Link (or Contact):	Servir Global Evaporative Stress Index: http://catalogue.servirglobal.net/Product?product_id=198 GOES Image Viewer: https://www.star.nesdis.noaa.gov/GOES/index.php
Metadata Link:	Hydrology and Earth System Sciences: https://www.hydrol-earth-syst-sci.net/15/223/2011/hess-15-223-2011.pdf
Period of Record:	1 month is available online.
Coverage:	Contiguous United States.
Temporal Resolution:	Daily, with 2-, 4-, 8-, and 12-week composites.
Spatial Resolution:	Not available
Format:	Low-quality image (PNG) is available online.
Software Requirements:	Unknown
Tips to Access/Download:	This product is not being archived, although it may be archived in the future by the National Centers for Environmental Information (NCEI). For additional information please contact the NCEI satellite division at ncei.sat.info@noaa.gov. For any questions regarding what Comprehensive Large Array-data Stewardship System (CLASS) has in the archive, please contact class.help@noaa.gov.

9.4 Basin Characterization Model

Developer/Author/Owner: U. S. Geological Survey (USGS)

Source for Water Budget Components: Precipitation, Evapotranspiration, Runoff, Recharge of Applied Water and Precipitation, Stream-Groundwater Interaction

Available Information: View model documentation for complete listing of all related data.

Brief Description: The Basin Characterization Model (BCM) can translate fine-scale maps of climate trends and projections into the hydrologic consequences, to permit evaluation of the impacts to water availability at regional, watershed, and landscape scales, as caused by changes in temperature and precipitation. The BCM was developed at a 270-m spatial resolution, using monthly data, and has been supported by numerous federal, State, and local agencies, and international organizations. The BCM uses historical climate data from 1896 through 2010, and an ensemble of 18 future climate projections that were used to develop hydrologic output such as snowpack, recharge, runoff, and climatic water deficit. To produce this dataset, digital maps of soils and geology for the California hydrologic region were integrated with monthly maps of climate and hydrology, to generate average water year and 30-year water year maps for the historical record (1951–1980 and 1981–2010) and future projections (2010–2039, 2040–2069, and 2070–2099).

Data Link: USGS California Basin Characterization Model: https://ca.water.usgs.gov/projects/reg_hydro/basin-characterization-model.html

Metadata Link: Same as Data Link.

Period of Record: Historical record (1981–2010) and projections (2010–2099).

Coverage: Statewide coverage

Temporal Resolution: Monthly and annual input data, output statistics calculated on 30-year periods.

Spatial Resolution: 270-m grid cells

Format: ASCII grid file (.asc)

Software Requirements: GIS

9.5 California Department of Finance

Developer/Author/Owner:	California Department of Finance
Source for Water Budget Components:	Applied Water
Available Information:	Population
Brief Description:	The California Department of Finance provides population estimates for historical years and future projections of population in five-year increments through 2060. Population estimates and projections are available at the city and county level.
Data Link:	California Department of Finance Demographics: http://www.dof.ca.gov/Forecasting/Demographics/
Metadata Link:	California Department of Finance Projections: http://www.dof.ca.gov/Forecasting/Demographics/projections/ Click on “Methodology”
Period of Record:	Historical estimates (1940–2017) and projections (2010–2060)
Coverage:	Statewide
Temporal Resolution:	Not available
Spatial Resolution:	City, county, or state
Format:	XLS
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	Click on “Estimates” under “Data” to see historical and current year population estimates. Click on “Projections” under “Data” to see historical and current year population estimates.

9.6 California Department of Transportation’s Highway Design Manual

Developer/Author/Owner:	California Department of Transportation (Caltrans)
Source for Water Budget Components:	Stream Inflow, Stream Outflow, Runoff
Available Information:	Runoff coefficient
Brief Description:	This manual was prepared for Caltrans by the Division of Design for use on the California State highway system. Tables 819.2A and 819.2B provide runoff coefficients for different land use types.
Data Link:	Caltrans Highway Design Manual: https://dot.ca.gov/programs/design/manual-highway-design-manual-hdm
Metadata Link:	Not available
Period of Record:	Last Updated December 14, 2018
Coverage:	Not available
Temporal Resolution:	Not available
Spatial Resolution:	Not available
Format:	PDF
Software Requirements:	Acrobat Reader
Tips to Access/Download:	Refer to Tables 819.2A and 819.2B in the “Hydrology” chapter of PDF linked above.

9.7 California Nevada River Forecast Center

Developer/Author/Owner:	National Oceanic and Atmospheric Administration (NOAA) and National Weather Service (NWS)
Source for Water Budget Components:	Stream Inflow, Stream Outflow, Precipitation
Available Information:	Stream Flow, Precipitation
Brief Description:	Contains current flow data for river and reservoir gauge throughout California
Data Link (or Contact):	NOAA California Nevada River Forecast Center: http://www.cnrfc.noaa.gov/
Metadata Link:	NOAA River/Reservoir Data: http://www.cnrfc.noaa.gov/river_data.php
Period of Record:	Observed precipitation available monthly starting October 1996, other data available four hours previous.
Coverage:	Statewide
Temporal Resolution:	Monthly or hourly depending on dataset.
Spatial Resolution:	Gauge location
Format:	Web viewer
Software Requirements:	None
Tips to Access/Download:	Find the appropriate gauge location on the map interface and click on it to bring up flow data.

9.8 California Pesticide Information Portal

Developer/Author/Owner:	California Department of Pesticide Regulation
Source for Water Budget Components:	Applied Water, Evapotranspiration
Available Information:	Pesticide application dates, crop type that pesticide was applied to, acreage of land treated
Brief Description:	The California Pesticide Information Portal (CalPIP) provides access to a collection of pesticide use information. At the heart of CalPIP is a data warehouse that serves up pesticide data produced, maintained, and used by a variety of programs within DPR. CalPIP can be used to determine and refine estimation of crop planting periods as well as spatial coverage of different crop types by examining the distribution of pesticide applications.
Data Link:	CalPIP Application Home: https://calpip.cdpr.ca.gov/main.cfm
Metadata Link:	CalPIP Help/User Guide: https://calpip.cdpr.ca.gov/infodocs.cfm?page=helpdoc1
Period of Record:	1990–2016
Coverage:	Statewide
Temporal Resolution:	Daily
Spatial Resolution:	Meridian/township/range/section (including ranch maps).
Format:	Text file
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	You can query for pesticide use statistics categorized by the use date (year), application location (county, meridian/township/range/section, zip code), site or crop treated, pesticide product name, and chemical name (active ingredient). These categories appear on the left side of the screen. Under each major category, there are subcategories of data to narrow the search to the information of specific interest. Once selections are complete, click on the “Format Output” option and click the “Submit Query” button. Tips for navigating the resource are available at Navigating CalPIP for First Time Users: https://calpip.cdpr.ca.gov/infodocs.cfm?page=navigate

9.9 California Water Plan — Water Portfolios

Developer/Author/Owner:	California Department of Water Resources
Source for Water Budget Components:	Evapotranspiration, Applied Water, Precipitation, Surface Water Delivery, Groundwater Extraction, Applied Water Reuse, Recycled Water, Recycled Water Export, Return Flow, Stream Inflow, Stream Outflow, Surface Water Diversion, Conveyance Evaporation, Conveyance Seepage, Imported Water, Surface Water Export, Lake Evaporation, Recharge of Applied Water and Precipitation, Managed Aquifer Recharge, Stored Water Extraction, Groundwater Export, Change in Groundwater Storage
Available Information:	The spreadsheet “*DataParam”* contains a complete listing of all related data for the Water Portfolios. A partial list of available categories of information includes Agricultural Water Use, Urban Water Use, Precipitation Volume, Surface Water Supply, Recycled Water, Groundwater Supply, and Environmental Flow Requirements.
Brief Description:	Water use and water supply estimates developed by the California Water Plan for years 2002–2015
Data Link:	Water Portfolios: https://water.ca.gov/Programs/California-Water-Plan/Water-Portfolios
Metadata Link:	Same as Data Link
Period of Record:	2002–2015
Coverage:	Statewide
Temporal Resolution:	Annual
Spatial Resolution:	Planning Area, Hydrologic Region, Statewide. DAUCO data are available upon request.
Format:	XLS
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	Click on the link for the Water Supply and Balance Data Interface (Zip).

9.10 CALSIM 2

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Surface Water Diversion, Imported Water, Surface Water Export, Stream Inflow, Stream Outflow
Available Information:	Surface water diversion, SWP/CVP deliveries, reservoir outflows, rim inflow, stream flow
Brief Description:	The CalSim 2 model was developed using the Water Resource Integrated Modeling System (WRIMS), which is a generalized water resources modeling system for evaluating operational alternatives of large, complex river basins. CalSim 2 is the model used by DWR to simulate California State Water Project (SWP)/Central Valley Project (CVP) operations. CalSim2 simulates the hydrology of the Central Valley, including the water resources infrastructure of the Sacramento and San Joaquin river systems, as well as the water operations of the CVP, SWP, and the Sacramento-San Joaquin Delta. CalSim 2 operates on a monthly time step for Water Years 1922 through 2003.
Data Link:	CalSim2: https://water.ca.gov/Library/Modeling-and-Analysis/Central-Valley-models-and-tools/CalSim-2
Metadata Link:	Same as Data Link
Period of Record:	Current and future levels of development using hydrology from October 1922 through September 2003.
Coverage:	CVP-SWP Water System
Temporal Resolution:	Monthly
Spatial Resolution:	Model node location
Format:	HEC-DSS
Software Requirements:	HEC-DSS data can be accessed using the free software HEC-DSSVue: http://www.hec.usace.army.mil/software/hec-dssvue/
Tips to Access/Download:	Recommend using Delivery Capability Report and Studies 2017: https://water.ca.gov/Library/Modeling-and-Analysis/Central-Valley-models-and-tools/CalSim-2/DCR2017 Download and unzip the CalSim 2 study. Input files are in the Common/DSS folder; output files are in the CONV/DSS folder.

9.11 CALSIM 3

Developer/Author/Owner:	California Department of Water Resources
Source for Water Budget Components:	Evapotranspiration, Applied Water, Precipitation, Surface Water Delivery, Groundwater Extraction, Applied Water Reuse, Recycled Water, Recycled Water Export, Return Flow, Runoff, Stream Inflow, Stream Outflow, Surface Water Diversion, Conveyance Evaporation, Conveyance Seepage, Imported Water, Surface Water Export, Recharge of Applied Water and Precipitation, Managed Aquifer Recharge, Stored Water Extraction, Groundwater Export
Available Information:	The “CalSim 3 Draft Report” contains a complete listing of the input and output data.
Brief Description:	CalSim 3 is the next generation of the CalSim 2 model. Major improvements and enhancements in CalSim 3 include finer model spatial resolution, better water supply and demand estimation, improved groundwater representation and simulation, enhanced model validation, extended model spatial and temporal domain, advanced model engine (WRIMS 2.0), thorough model documentation, and model supporting tools.
Data Link:	CalSim3: https://water.ca.gov/Library/Modeling-and-Analysis/Central-Valley-models-and-tools/CalSim-3
Metadata Link:	Same as Data Link
Period of Record:	Current and future levels of development using hydrology from October 1922 through September 2015.
Coverage:	CVP-SWP Water System
Temporal Resolution:	Monthly
Spatial Resolution:	Model node location
Format:	HEC-DSS
Software Requirements:	HEC-DSS data can be accessed using the free software HEC-DSSVue: http://www.hec.usace.army.mil/software/hec-dssvue/
Tips to Access/Download:	Download and unzip the CalSim 3. Input files are in the Common/DSS folder; output files are in the CONV/DSS folder.

9.12 Cal-SIMETAW Unit Values

Developer/Author/Owner:	California Department of Water Resources (DWR) and University of California, Davis
Source for Water Budget Components:	Evapotranspiration, Stream Evaporation, Conveyance Evaporation, Applied Water, Precipitation
Available Information:	ETo, ETc, ETaw, applied water, precipitation, effective precipitation, Kc, irrigation periods, irrigation efficiency
Brief Description:	The Cal-SIMETAW model was developed to compute soil water balance to estimate crop evapotranspiration (ETc), evapotranspiration of applied water (ETaw), and applied water (AW) for California water resources planning. Computations are made at a 4km resolution; output is compiled by DAUCO. Model inputs include PRISM climate data, U.S. National Climate Data Center climate stations, Spatial CIMIS, and SSURGO. This *Cal-SIMETAW Unit Values* dataset contains cumulative monthly unit values (per acre) of ETc, AW, and six other parameters for the period 2000–2015. Unit values from the overlying DAUCO can be multiplied by land use acreages to compute total ETc or AW for a given study area. Along with ET estimates, DWR has published the model assumptions for each DAUCO (LUCI files), including growth periods and Kc values for each crop.
Data Link:	Cal-SIMETAW Unit Values https://data.cnra.ca.gov/dataset/cal-simetaw-unit-values For additional data and/or a daily resolution, contact: Morteza.Orang@water.ca.gov
Metadata Link:	Same as Data Link
Period of Record:	2000–2015; earlier years dating to 1922 may be available upon request (see contact above)
Coverage:	Statewide
Temporal Resolution:	Monthly
Spatial Resolution:	Detailed Analysis Unit by County (DAUCO)
Format:	CSV
Software Requirements:	Recommended: Text editor and Excel or similar spreadsheet software Optional: GIS

Tips to Access/Download:

Download “Cal-SIMETAW Unit Et Values” CSV file for unit (per acre) ETc, AW, and ETo values. Because of the large number of records in this CSV file, a text editor is necessary to split the file prior to opening in Excel (maximum rows: 1,048,576).

Download “Cal-SIMETAW’s Land Use and Crop Information (LUCI) input file for each DAUCO, zipped by DWR Region Office” (Region Office boundaries can be viewed on the Water Management Planning Tool: https://gis.water.ca.gov/app/boundaries/) for Kc and growth dates.

Download the Readme file for more information including a key to the output and input file headers.

9.13 California Statewide Groundwater Elevation Monitoring

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Subsurface Inflow, Subsurface Outflow, Change in GW Storage
Available Information:	Groundwater levels
Brief Description:	In accordance with the Water Code, DWR developed the California Statewide Groundwater Elevation Monitoring (CASGEM) program. The intent of the CASGEM program is to establish a permanent, locally-managed program of regular and systematic monitoring in all of California's alluvial groundwater basins. The CASGEM program will rely and build on the many, established local long-term groundwater monitoring and management programs. DWR's role is to coordinate the CASGEM program, to work cooperatively with local entities, and to maintain the collected elevation data in a readily and widely available public database. DWR will also continue its current network of groundwater monitoring as funding allows.
Data Link:	Groundwater Monitoring (CASGEM): https://water.ca.gov/Programs/Groundwater-Management/Groundwater-Elevation-Monitoring--CASGEM
Metadata Link:	Same as Data Link
Period of Record:	1901 to present, varies by well.
Coverage:	Statewide
Temporal Resolution:	Intermittent readings, or daily (varies by well).
Spatial Resolution:	Well location
Format:	CSV, XLS
Software Requirements:	Excel or similar spreadsheet software is recommended.
Tips to Access/Download:	The CASGEM online portal (https://www.casgem.water.ca.gov/OSS/) requires login for full access (free). Data can be downloaded at user defined spatial and temporal scales from the “Reports” tab of the website.

9.14 California Data Exchange Center

Developer/Author/Owner:	California Department of Water Resources
Source for Water Budget Components:	Stream Inflow, Stream Outflow, Stream-Lake Interaction, Precipitation, Change in Surface Water Storage
Available Information:	Reservoir operations, reservoir summary reports, precipitation, snow water content, river stage and discharge
Brief Description:	The California Data Exchange Center (CDEC) provides a centralized database to store, process, and exchange real-time hydrologic information gathered by various cooperators throughout the state. The data collected by CDEC enable forecasters to prepare flood forecasts and water supply forecasts; reservoir and hydroelectric operators to schedule reservoir releases; and water suppliers to anticipate water availability. The two main entities that collect and manage data related to flood forecasting and response for California are CDEC and the NWS California-Nevada River Forecast Center (CNRFC). Collection efforts by the CNRFC are centered on data necessary to fulfill its mission of flood forecasting. CDEC's original data collection efforts revolved around supporting the State-Federal Flood Operations Center, but since have grown into managing hydrometeorological data statewide for a variety of resource management uses.
Data Link:	California Data Exchange Center http://cdec.water.ca.gov/
Metadata Link:	California Data Exchange Center General Information http://cdec.water.ca.gov/general.html
Period of Record:	Variable
Coverage:	Statewide
Temporal Resolution:	Hourly, daily, or monthly
Spatial Resolution:	Gauge location
Format:	Text file, CSV
Software Requirements:	Recommended using text reader such as TextPad or Microsoft Excel.
Tips to Access/Download:	To download individual timeseries, under Query Tools click Historical Data: CSV Format. From there, the user can search and download data by station, sensor type, and date range.

9.15 Center for Hydrometeorology and Remote Sensing Data Portal

Developer/Author/Owner:	Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California (UC), Irvine
Source for Water Budget Components:	Precipitation
Available Information:	Precipitation
Brief Description:	CHRS Data Portal is an archive for global satellite precipitation data and information produced by the PERSIANN, PERSIANN-CCS, and PERSIANN-CDR systems developed by CHRS and directed by Dr. Soroosh Sorooshian at UC Irvine. The portal allows users to visualize and download spatiotemporal statistics of global regular-interval satellite precipitation from the PERSIANN, PERSIANN-CCS, and PERSIANN-CDR systems.
Data Link and Contacts:	CHRS Data Portal: http://chrsdata.eng.uci.edu/
	Dr. Soroosh Sorooshian (soroosh@uci.edu) or Dr. Phu Nguyen (ndphu@uci.edu)
Metadata Link:	Same as Data Link.
Period of Record:	PERSIANN: March 2000 –Present
	PERSIANN-CCS: January 2003–Present
	PERSIANN-CDR: January 1983–April 2017
Coverage:	Global
Temporal Resolution:	PERSIANN: 1-, 3-, and 6-hourly, daily, monthly, yearly
	PERSIANN-CCS: 1-, 3-, and 6-hourly, daily, monthly, yearly
	PERSIANN-CDR: daily, monthly, yearly
Spatial Resolution:	PERSIANN: 0.25° × 0.25°
	PERSIANN-CCS: 0.04° × 0.04°
	PERSIANN-CDR: 0.25° × 0.25°
Format:	ArcGrid, TIF, NETCDF
Software Requirements:	GIS
Tips to Access/Download:	A tutorial is available on the data portal home page.

9.16 California Irrigation Management Information System

Developer/Author/Owner: California Department of Water Resources (DWR)

Source for Water Budget Components: Evapotranspiration, Conveyance Evaporation, Lake Evaporation, Stream Evaporation, Precipitation

Available Information: Precipitation, reference evapotranspiration, other weather data

Brief Description: The California Irrigation Management Information System (CIMIS) includes more than 145 weather stations used to assist irrigators in managing their water resources more efficiently. CIMIS station data include measured parameters such as solar radiation, air temperature, soil temperature, relative humidity, wind speed, and wind direction; and derived parameters such as vapor pressure, dew point temperature, and reference evapotranspiration (ETo).

Data Links: CIMIS: http://www.cimis.water.ca.gov/

Evapotranspiration Zone Maps: https://cimis.water.ca.gov/App_Themes/images/etozonemap.jpg

Bulk data download: ftp://ftpcimis.water.ca.gov/pub2/

Metadata Link: CIMIS Stations: http://www.cimis.water.ca.gov/Stations.aspx

Period of Record: Varies with station; earliest station date is 5-30-1982

Coverage: Statewide (agricultural areas)

Temporal Resolution: Hourly, daily, monthly

Spatial Resolution: Variable (151 active stations; 102 inactive)

Format: HTML (website) and CSV (bulk)

Software Requirements: Recommended: Excel or similar software, GIS.

Tips to Access/Download: Full Access requires a login (Free).

1. Use Station Location Map tab to find stations in area of interest.
2. Use Station List to discover period of record for specific stations.
3. Go to “Data” tab and select “Run Report” for those stations at desired time step. Output will be an html file. From Internet Explorer, right click and select “Export to Microsoft Excel” and use the tool to import the data one table at a time.
4. The ftp site includes a station list with coordinates that can be imported into GIS.

9.17 CIMIS (Spatial): California Irrigation Management Information System

Developer/Author/Owner:	California Department of Water Resources (DWR) and University of California, Davis
Source for Water Budget Components:	Evapotranspiration, Conveyance Evaporation, Lake Evaporation, Stream Evaporation
Available Information:	Reference evapotranspiration, Precipitation, other weather data
Brief Description:	Many areas of California are not sufficiently covered by the network of CIMIS stations. Recognizing these spatial data gaps, CIMIS, in cooperation with the UC Davis, developed a daily ETo (reference evapotranspiration) map known as Spatial CIMIS. The ETo maps are generated using complex sets of models. The input parameters to these models are combinations of data from satellites and ground measurements. Spatial CIMIS data consists of ETo and solar radiation only. Daily reference evapotranspiration (ETo) at a 2-km spatial resolution are calculated statewide using the American Society of Civil Engineers version of the Penman-Monteith equation (ASCE-PM). Daily solar radiation is generated from the visible band of the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite (GOES) using the Heliosat-II model.
Data Link:	CIMIS Spatial Data: https://cimis.water.ca.gov/SpatialData.aspx
Metadata Link:	Same as Data Link
Period of Record:	2003–present
Coverage:	Statewide
Temporal Resolution:	Daily, monthly
Spatial Resolution:	2-kilometer
Format:	XML, CSV, PDF
Software Requirements:	Recommended: Excel or similar spreadsheet software; Acrobat Reader
Tips to Access/Download:	Create a (free) login to access spatial CIMIS data. After that, ET estimates can be obtained for anywhere in the state using Spatial CIMIS. Navigate to the Spatial Report Tab to obtain ETo and solar radiation data for user specified points.

9.18 County Agricultural Commissioner Crop Reports

Developer/Author/Owner:	California Agricultural Commissioners
Source for Water Budget Components:	Applied Water, Evapotranspiration
Available Information:	Agricultural land use by crop type
Brief Description:	California Department of Food and Agriculture provides links to the various county annual crop reports. Crop reports can also be accessed directly from the agricultural commissioners in each county. As required by the California Food and Agriculture Code, the county agricultural commissioner compiles and records information in the annual crop and livestock report regarding the gross production and value of the county's commodities.
Data Link:	County Crop Reports: https://www.cdfa.ca.gov/exec/county/CountyCropReports.html
Metadata Link:	None
Period of Record:	Varies by county.
Coverage:	Statewide: agricultural lands only.
Temporal Resolution:	Annual
Spatial Resolution:	County: agricultural lands only.
Format:	PDF
Software Requirements:	Acrobat Reader
Tips to Access/Download:	Select county of interest to be redirected to a webpage listing annual crop reports. Relevant data is found within tables in the PDF crop reports.

9.19 CVHM: Central Valley Hydrologic Model

Developer/Author/Owner:	United States Geological Survey
Source for Water Budget Components:	The Central Valley Hydrologic Model (CVHM) contains information relevant to almost all water budget components. For more detailed information about which components CVHM addresses, please see Figure 9-1
Available Information:	View model documentation for complete listing of all related data.
Brief Description:	CVHM is a MODFLOW-FMP (Farm Process) application developed by the USGS to simulate the historical hydrology of California's Central Valley. CVHM simultaneously accounts for changing water supply and demand across the landscape and simulates surface water and groundwater flow across the Central Valley. Hydraulic properties were assigned to the CVHM grid based on a lithologic texture analysis of available driller's logs (Faunt, Belitz, and Hanson 2009). It is built upon knowledge from USGS and other federal, State, and local studies.
Data Link:	Central Valley Hydrologic Model (CVHM): https://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html
Metadata Link:	Same as Data Link.
Period of Record:	October 1961–September 2003
Coverage:	California Central Valley
Temporal Resolution:	Monthly
Spatial Resolution:	1 square mile
Format:	Text files
Software Requirements:	Recommended using text reader such as TextPad, Excel, MODFLOW GUI
Tips to Access/Download:	From the right side of the CVHM webpage, under "Data," download the "Central Valley Hydrologic Model Database" and the "Numerical Model Data files" (Input and Output). After downloading and unzipping the model, refer to the modeling section of this document for more detailed instructions on extracting data from MODFLOW models.

9.20 C2VSIM Coarse Grid Model

Developer/Author/Owner:	California Department of Water Resources
Source for Water Budget Components:	The California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) contains information relevant to almost all water budget components. For more detailed information about relevant components, see Figure 9-1
Available Information:	View model documentation for complete listing of all related data.
Brief Description:	C2VSim is an integrated numerical model that simulates water movement through the linked land surface, groundwater and surface water flow systems in California's Central Valley using the Integrated Water Flow Model (IWFM) modeling platform. C2VSim contains monthly historical stream inflows, surface water diversions, precipitation, and land use (including crop acreage) from October 1921 through September 2009. C2VSim dynamically calculates crop applied water, allocates contributions from precipitation, soil moisture, and surface water diversions, and calculates the groundwater extractions required to meet the remaining demand. The model simulates the historical response of the Central Valley's groundwater and surface water flow system to historical stresses and can also be used to simulate the response to projected future stresses.
Data Link:	C2VSim: https://www.water.ca.gov/Library/Modeling-and-Analysis/Central-Valley-models-and-tools/C2VSim
Metadata Link:	Same as Data Link.
Period of Record:	October 1921–September 2009
Coverage:	California Central Valley
Temporal Resolution:	Monthly
Spatial Resolution:	14 square mile average (range from 2.1 to 33 square miles)
Format:	Text file, Spreadsheet
Software Requirements:	Recommend using text reader such as TextPad or Microsoft Excel to view input/output files.
Tips to Access/Download:	After downloading and unzipping the model, refer to the modeling section of this document for detailed instructions on extracting data from IWFM models.

9.21 C2VSIM Fine Grid Model

Developer/Author/Owner:	California Department of Water Resources
Source for Water Budget Components:	The California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) contains information relevant to almost all water budget components. For more detailed information about relevant components, see Figure 9-1.
Available Information:	View model documentation for listing of related data.
Brief Description:	The beta version of the C2VSim fine grid model (C2VSimFG Beta) simulates water movement through the linked land surface, groundwater, and surface water flow systems using the Integrated Water Flow Model Version 2015. C2VSimFG Beta contains monthly historical stream inflows, surface water diversions, precipitation, evapotranspiration, and land use acreages. C2VSimFG Beta dynamically calculates crop applied water, allocates contributions from precipitation, soil moisture and surface water diversions, and calculates the groundwater extraction required to meet the remaining demand. It simulates the historical response of the Central Valley's groundwater and surface water flow system to historical stresses and can also be used to simulate the response to projected stresses.
Data Link (or Contact):	C2VSim FG Beta Model: https://data.cnra.ca.gov/dataset/c2vsimfg-beta-model
Metadata Link:	The model is currently in development. Details are available in this factsheet: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/ Groundwater-Management/Data-and-Tools/Files/ FAQ-and-Fact-Sheets/C2VSim-FG-Fact-Sheet.pdf
Period of Record:	Simulation period is October 1973–September 2015.
Coverage:	California Central Valley
Temporal Resolution:	Monthly
Spatial Resolution:	Ranges from 0.006 to 2.8 square miles.
Format:	Text file, Spreadsheet
Software Requirements:	Recommended using text reader such as TextPad or Microsoft Excel
Tips to Access/Download:	After downloading and unzipping the model, refer to the modeling section of this document for more instructions on extracting data from IWFM models.

9.22 DWR Agricultural Land and Water Use Estimates

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Evapotranspiration, Applied Water, Precipitation, Lake Evaporation, Stream Evaporation, Conveyance Evaporation
Available Information:	Irrigated crop acreages, crop evapotranspiration (ETc), evapotranspiration of applied water (ETAW), effective precipitation (EP), and applied water (AW), evaporation pan data (Ep), irrigation efficiency (referred to as consumed fraction [CF])
Brief Description:	DWR estimates irrigated crop acreages, crop evapotranspiration (ETc), evapotranspiration of applied water (ETAW), effective precipitation (EP), and applied water (AW) for 20 crop categories each year using the California Agricultural Water Used Model (Ag Model). Inputs to the Ag Model include evaporation pan data (Ep), planting and harvest dates, crop development over time (crop coefficients), soil characteristics, rooting depths, and precipitation. Applied water (AW) estimates reflect irrigation efficiencies as well as the water required for cultural practices such as the ponding of water in rice fields or the leaching of accumulated salts from the soil.
Data Link:	Agricultural Land and Water Use Estimates: https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates
Metadata Link:	Same as Data Link.
Period of Record:	1998–2010
Coverage:	Statewide
Temporal Resolution:	Annual
Spatial Resolution:	Detailed analysis unit by county (DAUCO)
Format:	XLS
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	To download, expand the menu under Statewide, County, Hydrologic Region (HR), or Detailed Analysis Unit (DAU), click on a year and select "Save As." (County, HR, or DAU boundaries can on the Water Management Planning Tool: https://gis.water.ca.gov/app/boundaries/)

9.23 DWR Bulletin 73: Evaporation from Water Surfaces in California (1979)

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Lake Evaporation, Stream Evaporation, Conveyance Evaporation
Available Information:	Pan Evaporation
Brief Description:	Bulletin 73-79 summarizes all readily available data on evaporation pan measurements in California up to 1979. It reports monthly total evaporation data from 478 stations, dating back to the 1880s.
Data Links:	Bulletin 73-69 Evaporation from Water Surfaces in California: http://wdl.water.ca.gov/waterdatalibrary/docs/historic/Bulletins/Bulletin_73/Bulletin_73__1979.pdf
Metadata Links:	Same as Data Links.
Period of Record:	Varies by station: 1913–1979
Coverage:	Statewide (individual stations)
Temporal Resolution:	Monthly
Spatial Resolution:	Individual stations
Format:	Scanned PDF
Software Requirements:	Acrobat Reader

9.24 DWR Bulletin 113: Crop Water Use

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Evapotranspiration
Available Information:	ETc, ETAW, crop coefficients
Brief Description:	Bulletin 113-4: Crop Water Use in California (April 1986) is the fourth in a series of DWR publications that provides the basis for estimating per-acre ET of water and the quantities of water applied by irrigation. The data presented was collected from 1973 through 1983. Bulletin 113-3: Vegetative Water Use in California, 1974 (April 1975) is the third in a series of DWR publications on the rate of water use by crops. The report is based on field studies conducted from 1954 to 1972 and expands the previously published data. It summarizes growing season ET and ETAW water for principal crops.
Data Links:	Bulletin 113-4 Crop Water Use in California: http://wdl.water.ca.gov/waterdatalibrary/docs/historic/Bulletins/Bulletin_113/Bulletin_113-4__1986.pdf Bulletin 113-3 Vegetative Water Use in California: http://wdl.water.ca.gov/waterdatalibrary/docs/historic/Bulletins/Bulletin_113/Bulletin_113-3__1975.pdf
Metadata Link:	Same as Data Links.
Period of Record:	1973–1983, 1954–1972
Coverage:	Statewide agricultural areas
Temporal Resolution:	Seasonal, annual
Spatial Resolution:	Not available (per acre unit values by crop type).
Format:	PDF
Software Requirements:	Acrobat Reader

9.25 DWR Bulletin 118: California's Groundwater

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Subsurface Inflow, Subsurface Outflow, Change in Groundwater Storage
Available Information:	Aquifer Parameters
Brief Description:	Bulletin 118 is California's official statewide compendium on the occurrence and nature of groundwater. Bulletin 118 defines the boundaries and describes the hydrologic characteristics of California's groundwater basins. Bulletin 118 also provides information on groundwater management and recommendations for the future. With the passage of SGMA in 2014, Bulletin 118 now serves an additional role by providing groundwater sustainability agencies with three critical pieces of information regarding groundwater basins: critical conditions of overdraft, basin boundaries, and basin priority.
Data Link:	Bulletin 118: https://water.ca.gov/Programs/Groundwater-Management/Bulletin-118
Metadata Link:	Same as Data Link.
Period of Record:	N/A
Coverage:	Statewide, groundwater basin
Temporal Resolution:	Not available
Spatial Resolution:	Hydrologic Region
Format:	PDF
Software Requirements:	Acrobat Reader
Tips to Access/Download:	From the data link, access is available to statewide reports, regional reports, basin descriptions, and bulletin updates.

9.26 DWR Bulletin 132: Management of the California State Water Project

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Surface Water Delivery, Surface Water Diversion, Conveyance Evaporation, Conveyance Seepage, Imported Water, Surface Water Export
Available Information:	State Water Project (SWP) surface water diversions and deliveries, SWP water transfers
Brief Description:	Bulletin 132 is an annual series of reports describing SWP status, operations and water deliveries. Each report updates project costs and financing, water supply planning, power operations and significant events that affect SWP management. Hydrologic information for the water year, capital construction information for the fiscal year, and water delivery, operations, maintenance and other activities for the calendar year are included as well. The complete report series, beginning in 1963, is available in PDF format.
Data Link:	Bulletin 132: https://water.ca.gov/Programs/State-Water-Project/Management/Bulletin-132
Metadata Link:	Same as Data Link.
Period of Record:	1963–2016
Coverage:	SWP systems
Temporal Resolution:	Monthly, annual
Spatial Resolution:	By SWP contractor
Format:	PDF
Software Requirements:	Acrobat Reader
Tips to Access/Download:	Each version of Bulletin 132 contains deliveries to each SWP contractor for one calendar year. In recent years, delivery water transfer data can be found in Chapter 9. Historical versions of B-132 can be accessed at http://wdl.water.ca.gov/waterdatalibrary/docs/historic/bulletins.cfm.

9.27 DWR Demographic Data

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Applied Water
Available Information:	Population
Brief Description:	DWR develops annual demography data for California Water Plan Updates based on U.S. Census, American Community Survey and California Department of Finance (DOF) data. The population data are computed at the various resolutions for use by DWR in planning studies for hydrologic regions, planning areas, and detailed analysis units (DAUs) — a DAU is the smallest study area. Each county consists of multiple DAUs. The DAUs are often split by two or more counties. DWR updates regional population data every year using GIS to allocate census year block level population into DAU population estimates for each of California’s 58 counties. For years that fall between census years, DWR uses DOF's county and city total numbers.
Data Link and Contact:	Economic Modeling and Analysis Tools: https://www.water.ca.gov/Library/Modeling-and-Analysis/Statewide-models-and-tools/Economic-Modeling-and-Analysis-Tools Contact: Salma.Kibrya@water.ca.gov
Metadata Link:	Embedded with data
Period of Record:	2000–one year behind the current year
Coverage:	Statewide
Temporal Resolution:	Annual
Spatial Resolution:	DAU
Format:	XLS
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	Census data aggregated by DWR region office: County, HR, planning area, and DWR region office boundaries. Spreadsheet data by DWR region offices are available for download from the data link. The GIS boundaries can be viewed with the Water Management Planning Tool (https://gis.water.ca.gov/app/boundaries/).

9.28 DWR Irrigation Methods Survey

Developer/Author/Owner: California Department of Water Resources (DWR)

Source for Water Budget Components: Applied Water, Recharge of Applied Water and Precipitation, Return Flow, Applied Water Reuse

Available Information: Irrigation method by crop type

Brief Description: Approximately every 10 years, a one-page irrigation survey form is mailed to California growers to update records on irrigation system methods. A statewide survey of current irrigation methods was conducted during 2011 to determine which irrigation methods were used in California during 2010. The 1991, 2001, and 2010 studies were conducted by mailing questionnaires to growers who were randomly selected. A list of approximately 58,000 growers in California from the California Department of Food and Agriculture was used to determine the mailing list. All rice-only, non-irrigation, and livestock-only growers were excluded from the list. Growers were asked to state the main county in which they farmed and the acreages they had planted during 2001 and 2010 to each of 20 possible crop categories, by irrigation method, within that county.

Data Link: Statewide Irrigation Systems Methods Surveys: https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Statewide-Irrigation-Systems-Methods-Surveys

Metadata Link: Same as Data Link

Period of Record: 1991, 2001, and 2010

Coverage: Statewide

Temporal Resolution: Not available

Spatial Resolution: Statewide, Hydrologic Region

Format: XLS

Software Requirements: Recommended: Excel or similar spreadsheet software

Tips to Access/Download: Request the survey from DWR’s Land and Water Use Program.

9.29 DWR Land Use Survey Data

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Evapotranspiration, Applied Water, Surface Water Delivery, Groundwater Extraction, Applied Water Reuse, Recycled Water
Available Information:	Agricultural land use by crop type. Urban land use, managed wetlands land use by habitat type, and native vegetation land use (i.e., undeveloped land) - acreage tracked varies by survey. Water source identified for fields in select surveys.
Brief Description:	Since 1950 DWR has conducted more than 250 land use surveys of all or parts of California's 58 counties. Early land use surveys were recorded on paper maps of U.S. Geological Survey 7.5' quadrangles. In 1986, DWR began to develop georeferenced digital maps of land use survey data. The main emphasis of DWR's land use surveys is the mapping of agricultural land. More than 70 different crops or crop categories are included in the surveys. Irrigation methods and water sources have also been mapped in some surveys. Urban and native vegetation (undeveloped) areas are mapped but not in the detail of agricultural land. DWR staff visit and visually identify land uses on more than 95 percent of the developed agricultural areas within each survey area.
Data Link:	Land Use Surveys: https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Land-Use-Surveys
Metadata Link:	Same as Data Link.
Period of Record:	1976–2015 (website); contact DWR for 1950–1976 data
Coverage:	Approximately two counties are surveyed each year.
Temporal Resolution:	Summer. Approximately two to four counties are surveyed each year, some counties have been surveyed only once since 1950, others multiple times.
Spatial Resolution:	County
Format:	Shapefile (1976–2015)
Software Requirements:	GIS
Tips to Access/Download:	Click on the survey of interest and select "Save" to download the data to your computer.

9.30 DWR Land Use Viewer

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Evapotranspiration, Applied Water
Available Information:	Agricultural land use by crop type. Urban and native vegetation land use tracked by category, managed wetlands land use by habitat type
Brief Description:	The Land Use Viewer allows groundwater sustainability agencies (GSAs) and the public to easily access both statewide (2014 crop data) and county land use datasets (same datasets as provided above in the DWR Land Use Survey data) that have been collected over the last 30 years. The viewer also includes a variety of tools that allow users to download and analyze land use data. The viewer provides consistent, centralized land use data to improve coordination across the state and help GSAs meet the requirements of SGMA and regulations for groundwater sustainability plans.
Data Link:	Land Use Viewer: https://gis.water.ca.gov/app/CADWRLandUseViewer/
Metadata Link:	See “About this application” on the Data Link.
Period of Record:	1976–2015
Coverage:	Agricultural lands primarily; statewide for 2014, variable (by county) for other years.
Temporal Resolution:	Summer snapshot
Spatial Resolution:	Field-scale (>2 acres)
Format:	Geodatabase, Shapefile
Software Requirements:	GIS
Tips to Access/Download:	Turn on County Land Use Download Layer in the Layer List Select a County of interest by clicking on map (it will be highlighted). A popup will appear. Click the gray arrow to expand the box to show all available past land use datasets for download. Note: Only individual crop types from historic land use surveys can be viewed in the Land Use Viewer. Entire historic land use data sets cannot be viewed.

9.31 DWR Sustainable Groundwater Management Act Data Viewer

Developer/Author/Owner: California Department of Water Resources (DWR)

Source for Water Budget Components: Evapotranspiration, Applied Water, Precipitation, Groundwater Extraction, Surface Water Diversion, Stream Inflow, Stream Outflow, Groundwater Gain from Stream, Groundwater Loss to Stream, Change in Groundwater Storage

Available Information: Groundwater level measurements, land subsidence data, CDEC surface water information, agricultural land use by crop type, climate change information including precipitation, diversions, and streamflow change factors, soil and geologic maps

Brief Description: The purpose of the SGMA Data Viewer is to compile and display regional and statewide groundwater information so groundwater sustainability agencies and related stakeholders can efficiently access this information during groundwater sustainability plan development and implementation.

Data Link: SGMA Data Viewer: https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#gwlevels

Metadata Link: SGMA Data Viewer factsheet: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Data-and-Tools/Files/FAQ-and-Fact-Sheets/SGMA-Data-Viewer-Fact-Sheet.pdf

Period of Record: Varies by dataset

Coverage: Statewide as applicable for the individual dataset

Temporal Resolution: Varies by dataset

Spatial Resolution: Varies by dataset

Format: XLS, Shapefile

Software Requirements: Recommended: Excel or similar spreadsheet software, GIS

Tips to Access/Download: Click on the information button (looks like an “i" inside a circle) to be directed to more information on the layers. If a download option is available for those layers, there should be a link to download them from the California Natural Resources Agency Open Data platform (https://data.cnra.ca.gov/).

9.32 DWR Water Data Library: Surface Water and Groundwater Data

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Stream Inflow, Stream Outflow, Surface Water Diversion, Subsurface Inflow, Subsurface Outflow, Change in Groundwater Storage
Available Information:	Streamflow, groundwater levels, water quality
Brief Description:	The Water Data Library contains hydrologic data for surface water flow and water levels (more than 250 stations), groundwater level data and some groundwater quality data for more than 35,000 California wells, water quality data, historical DWR reports, and data collected by DWR region offices and dozens of federal and local cooperators.
Data Link:	Water Data Library: http://wdl.water.ca.gov/waterdatalibrary/
Metadata Link:	Not available
Period of Record:	1901 to present
Coverage:	Statewide
Temporal Resolution:	Intermittent readings, daily time step
Spatial Resolution:	Surface water station, well location, water quality sampling location
Format:	CSV
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	A bulk data download of all groundwater levels (compressed file) is available from the California Natural Resources Agency Open Data platform (https://data.cnra.ca.gov/).

9.33 GRACE: Gravity Recovery and Climate Experiment

Developer/Author/Owner: National Aeronautics and Space Administration — Earth System Science Pathfinder Program

Source for Water Budget Components: Change in Groundwater Storage

Available Information: Measurement of changes in mass redistribution in the Earth system

Brief Description: Launched in March 2002, the GRACE mission is to accurately map variations in Earth's gravity field. GRACE consists of two identical satellites that fly approximately 220 kilometers (137 miles) apart in a polar orbit of 500 kilometers (310 miles) above Earth. The Earth's gravity field is mapped by making accurate measurements of the distance between the two satellites, using GPS and a microwave ranging system. The results from this mission are yielding crucial information about the distribution and flow of mass within Earth and its surroundings.

The gravity variations studied by GRACE include: changes caused by surface and deep currents in the ocean, runoff and ground water storage on land masses, exchanges between ice sheets or glaciers and the ocean, and variations of mass within Earth. Another goal of the mission is to create a better profile of Earth's atmosphere.

Data Link: GRACE:
https://grace.jpl.nasa.gov/

Metadata Link: Same as Data Link.

Period of Record: 2002–present

Coverage: Worldwide

Temporal Resolution: Monthly

Spatial Resolution: 1-degree global grids

Format: NetCDF, GEOTIFF

Software Requirements: GIS

9.34 IDC: IWFM Demand Calculator

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Evapotranspiration, Applied Water, Applied Water Reuse, Runoff, Return Flow, Recharge of Applied Water and Precipitation
Available Information:	Calculation methods for estimating evapotranspiration, applied water, applied water reuse, return flow, runoff, and recharge of applied water and precipitation are based on relevant input files including land use acreage and precipitation.
Brief Description:	The Integrated Water Flow Model Demand Calculator (IDC) is the stand-alone executable version of the root zone component of the Integrated Water Flow Model (IWFM). It calculates agricultural, urban, managed wetlands, and native vegetation water uses at a river-basin scale under user-specified climatic, soil and land-use characteristics. It also routes precipitation and irrigation water through the root zone and simulates land-surface and root zone flow processes. It can be linked to finite-element as well as finite-difference type integrated hydrologic models. IDC uses a computational grid to represent spatial distribution of land use, climatic, soil and farm management properties.
Data Link:	IDC: https://water.ca.gov/Library/Modeling-and-Analysis/Modeling-Platforms/Integrated-Water-Flow-Model-Demand-Calculator
Metadata Link:	IWFM Demand Calculator User’s Manual: http://baydeltaoffice.water.ca.gov/modeling/hydrology/IDC/IDCv4_0_226/downloadables/IDCv4.0_Documentation.pdf
Period of Record:	Varies depending on application
Coverage:	Varies depending on application
Temporal Resolution:	Hourly, daily, or monthly
Spatial Resolution:	Varies depending on application
Format:	Text file
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	IDC is a modeling platform, not a specific application. The data in a specific modeling application will vary depending on assumptions and scale of the model. The user manual, available from the Data Link, will provide information regarding the data contained in various model files.

9.35 Irrigation Training and Research Center Evapotranspiration Data

Developer/Author/Owner:	Irrigation Training and Research Center, Cal Poly, San Luis Obispo
Source for Water Budget Components:	Evapotranspiration
Available Information:	Crop Evapotranspiration (ETc)
Brief Description:	The Irrigation Training and Research Center (ITRC) provides estimates of crop and soil unit (per acre) evapotranspiration values for 1997–1999 for specific irrigation methods and precipitation amount in different zones within California. ITRC offers ET data for two purposes: water balance, and irrigation scheduling and design. The monthly ET data for different land cover (23 crop types) are provided for 13 of the 18 ETo zones.
Data Link:	California Evapotranspiration Data: http://www.itrc.org/etdata/index.html
Metadata Link:	California Crop and Soil Evapotranspiration: http://www.itrc.org/reports/pdf/californiacrop.pdf
Period of Record:	1997–1999
Coverage:	13 of 18 ETo Zones (see map via Data Link above)
Temporal Resolution:	Monthly
Spatial Resolution:	ETo Zone (see map via Data Link above)
Format:	PDF or Spreadsheet
Software Requirements:	Excel or similar software; Acrobat Reader
Tips to Access/Download:	1. Data type: Water Balance includes adjustments for bare spots and reduced vigor, and therefore estimates lower ETc values compared to Irrigation Scheduling and Design. 2. Irrigation method: A crop with a higher irrigation frequency or a soil surface with higher wetting percentage should have a higher multiplier. 3. Precipitation year (1997 typical year, 1998 wet year, 1999 dry year): The terms typical, wet, and dry are relative, and should be based on the actual amount of the precipitation during the year. 4. ET_0 Zone (see map via Data Link above). Output contains monthly precipitation, reference evapotranspiration (ET_0), and crop evapotranspiration (ET_c) for different crops, in inches per acre.

9.36 ITRC METRIC

Developer/Author/Owner:	Irrigation Training and Research Center, Cal Poly, San Luis Obispo
Source for Water Budget Components:	Evapotranspiration
Available Information:	Evapotranspiration
Brief Description:	Irrigation Training and Research Center (ITRC) uses a modified Mapping of Evapotranspiration with Internal Calibration (METRIC) procedure to compute actual evapotranspiration using LandSAT Thematic Mapper data. The original METRIC procedure was developed by Dr. Richard Allen (University of Idaho). ITRC has made many modifications to the original procedures including using a grass reference evapotranspiration instead of alfalfa, a semi-automated calibration procedure, spatially interpolated ETo, modifications to the aerodynamic resistance and albedo computations for certain crops.
Data Link:	ITRC-Metric: http://www.itrc.org/projects/metric.htm
Metadata Link:	Same as Data Link.
Period of Record:	Varies depending on application
Coverage:	Varies depending on application
Temporal Resolution:	Varies depending on application
Spatial Resolution:	30 x 30 meter
Format:	PDF
Software Requirements:	Acrobat Reader
Tips to Access/Download:	ITRC METRIC is a methodology for mapping ET, not a data source. The data derived from the methodology will vary depending on application.

9.37 IWFM: Integrated Water Flow Model

Developer/Author/Owner:	California Department of Water Resources
Source for Water Budget Components:	IWFM can be used to generate almost all the water budget components. For information about components addressed by IWFM, see Figure 9-1.
Available Information:	Calculation methods for estimating almost all water budget components based on relevant input files. Refer to the modeling section of this document for information on what IWFM models provide.
Brief Description:	IWFM is a computer program used for water resources management and planning within a basin. It calculates groundwater flows, soil moisture movement in the topsoil, stream flows, land surface flows, and flow exchange between groundwater, streams, and land surface as generated by precipitation, agricultural irrigation, and municipal and industrial water use. IWFM also calculates agricultural applied water based on crop types, crop acreages, soil types, irrigation methods and rainfall rates, as well as the municipal and industrial applied water based on population and per-capita water use rates. IWFM can help water managers understand the historical evolution of the surface and subsurface water flows within their basin and plan the use of groundwater and surface water to meet future applied water needs.
Data Link:	Integrated Water Flow Model: https://water.ca.gov/Library/Modeling-and-Analysis/Modeling-Platforms/Integrated-Water-Flow-Model
Metadata Link:	Same as Data Link.
Period of Record:	Varies depending on application
Coverage:	Varies depending on application
Temporal Resolution:	Hourly, daily, or monthly
Spatial Resolution:	Varies depending on application
Format:	Text file
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	IWFM is a modeling platform, not a specific application. The data included in a specific modeling application will vary depending on assumptions and scale of the model. The user manual, available from the Data Link, will provide information regarding the data contained in various model files.

9.38 METRIC-EEFLUX

Developer/Author/Owner:	University of Nebraska-Lincoln, University of Idaho, and Desert Research Institute with funding support by Google
Source for Water Budget Components:	Evapotranspiration
Available Information:	Evapotranspiration
Brief Description:	Earth Engine Evapotranspiration Flux (EEFlux) is a version of METRIC that operates on the Google Earth engine system. The Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC) model, uses satellite-based image processing to calculate actual ET (ETa). Landsat satellite images are used to calculate actual ET as a residual of the surface energy balance. EEFlux uses North American Land Data Assimilation System and GridMET gridded weather data to calibrate the surface energy balance in the U.S. The model also uses STATSGO soils data, National Land Cover Database land use data, PRISM precipitation data, and U.S. Geological Survey Digital Elevation Models.
Data Link:	EEFlux: http://eeflux-level1.appspot.com/
Metadata Link:	Operational remote Sensing of ET and Challenges: http://www.intechopen.com/books/evapotranspiration-remote-sensing-and-modeling/operational-remote-sensing-of-et-and-challenges Google Earth Engine — EEFlux: https://landsat.usgs.gov/sites/default/files/documents/Allen_UNL_DRI_UI_EEFlux_update_LST_meeting_July_8_2015c.pdf Satellite-Based Energy Balance for METRIC Model: http://ascelibrary.org/doi/10.1061/%28ASCE%290733-9437%282007%29133%3A4%28380%29 Satellite-Based Energy Balance for METRIC Applications: http://ascelibrary.org/doi/abs/10.1061/%28ASCE%290733-9437%282007%29133%3A4%28395%29 A scientific description of SEBAL procedure: http://www.waterwatch.nl/fileadmin/bestanden/Tools/A_scientific_description_of_SEBAL_procedure.pdf
Period of Record:	1984–present
Coverage:	Global

Temporal Resolution:	Point in time based on eight-day Landsat imagery
Spatial Resolution:	30-meter
Format:	TIFF
Software Requirements:	GIS (EEFlux uses Google Earth Engine to produce ET in a raster format)
Tips to Access/Download:	Time consuming to download, process, and aggregate data. Highly technical. Only one scene and date can be downloaded at a time. Aggregating into monthly ET: “If total (integrated) ET over a time period, such as one month or one growing period or one year is desired, then one will need to process multiple images and then conduct a time-integration using a spline or similar model as described in Allen et al., (2007) (ASCE J. Irrig. Drain. Engrg.) and Kilic in Intech. This is done by using the spline function to interpolate between the instantaneous ETrF images over the time period of interest, producing an ETrF estimate for every day during that period from the spline, and multiplying that ETrF value by the reference ET (tall reference) for every day during that period. The daily ET values are then summed over the period of interest, for example, over one month. Prior to the splining, mitigation for clouds may be required (see FAQ 5).” Addressing cloud cover: “[Clouds can be mitigated] by interpolating between 'adjoining' image dates that have valid ETrF values for the pixel of interest. During the interpolation, some adjustment for background evaporation caused by rainfall events may be needed to produce a more 'seamless' patching of ETrF data, as described in Kjaersgaard et al., 2011 (Hydrological Processes). If adjustment for background evaporation is not needed, then the spline or linear interpolation can be run, where it is forced to pass through the cloud and cloud shadow 'holes' and to the next available image.”

9.39 MOD16: MODIS Global Evapotranspiration Project

Developer/Author/Owner:	National Aeronautics and Space Administration
Source for Water Budget Components:	Evapotranspiration
Available Information:	Evapotranspiration
Brief Description:	The MOD16 evapotranspiration (ET) datasets are estimated using Mu et al.'s improved ET algorithm (2011) over previous Mu et al.'s paper (2007a). The ET algorithm is based on the Penman-Monteith equation (Monteith 1965). Surface resistance is an effective resistance to evaporation from land surface and transpiration from the plant canopy. Terrestrial ET includes evaporation from wet and moist soil, from rain water intercepted by the canopy before it reaches the ground, and the transpiration through stomata on plant leaves and stems.
Data Link:	MODIS: http://files.ntsg.umt.edu/data/NTSG_Products/MOD16
Metadata Link:	MODIS Project Summary: http://www.ntsg.umt.edu/project/modis/mod16.php
Period of Record:	2000–2014
Coverage:	Global — vegetated areas only
Temporal Resolution:	Eight day, monthly, and annual
Spatial Resolution:	1 kilometer; 500 meter is available for 8-day interval
Format:	HDF-EOS (http://hdfeos.org/software/library.php), an extension of HDF4
Software Requirements:	GIS
Tips to Access/Download:	Special fill values are assigned to excluded land use types, e.g. water bodies, barren land, snow and ice, wetlands, urban, and other "non-vegetated' areas. (listed in user guide available from the metadata link).

9.40 MODFLOW-OWHM: One Water Hydrologic Flow Model

Developer/Author/Owner: U.S. Geological Survey (USGS)

Source for Water Budget Components: The One-Water Hydrologic Flow Model (MF-OWHM) can be used to generate almost all the water budget components. For more information about the components MF-OWHM addresses, see Figure 9-1.

Available Information: Calculation methods for estimating almost all water budget components based on relevant input files. Refer to the modeling section of this document for more information on what can be obtained from MODFLOW-OWHM models.

Brief Description: MF-OWHM is a MODFLOW-based integrated hydrologic flow model. MF-OWHM allows the simulation, analysis, and management of nearly all components of human and natural water movement and its use in a physically-based supply-and-demand framework. The supply-constrained and demand-driven framework combined with the linkages between packages and processes provides relations of water use and movement and helps to prevent mass loss to an open system, thus facilitating the accounting for “all of the water everywhere and all of the time."

Data Link: One Water Hydrologic Flow Model: https://ca.water.usgs.gov/modeling-software/one-water-hydrologic-model.html

Metadata Link: USGS Techniques and Methods: https://pubs.usgs.gov/tm/06/a51/

Period of Record: Varies depending on application.

Coverage: Varies depending on application.

Temporal Resolution: Hourly, daily, or monthly

Spatial Resolution: Varies depending on application.

Format: Text file

Software Requirements: Recommended: Excel or similar spreadsheet software

Tips to Access/Download: MF-OWHM is a modeling platform, not a specific application. The data included in a specific modeling application will vary depending on assumptions and scale of the model. The user manual, available from the Data Link, will provide information regarding the data contained in various model files.

9.41 National Land Cover Database

Developer/Author/Owner:	Multi-Resolution Land Characteristics (MRLC) Consortium
Source for Water Budget Components:	Evapotranspiration, Applied Water
Available Information:	Continuous land use coverage by aggregated land use categories
Brief Description:	As with two previous National Land Cover Database (NLCD) land cover products, NLCD 2011 keeps the same 16-class land cover classification scheme that has been applied consistently across the United States at a spatial resolution of 30 meters. NLCD 2011 is based primarily on a decision-tree classification of circa 2011 Landsat satellite data.
Data Link:	National Land Cover Database: https://www.mrlc.gov/data?f%5B0%5D=category%3Aland%20cover U.S. Geological Survey National Map: https://viewer.nationalmap.gov/basic/
Metadata Link:	Same as Data Link.
Period of Record:	1992, 2001, 2006, and 2011
Coverage:	Contiguous United States
Temporal Resolution:	Every 5–8 years
Spatial Resolution:	30-meter
Format:	ERDAS (version Imagine 9.3) IMG file
Software Requirements:	GIS
Tips to Access/Download:	

9.42 NLDAS-2: North American Land Data Assimilation System

Developer/Author/Owner:	National Aeronautics and Space Administration
Source for Water Budget Components:	Evapotranspiration
Available Information:	Precipitation, Evaporation, and Evapotranspiration. Evaporation components: Total ET, Transpiration, Canopy water evaporation, Sublimation (evaporation from snow), direct evaporation from bare soil
Brief Description:	The goal of the North American Land Data Assimilation System (NLDAS) is to construct quality-controlled, and spatially and temporally consistent, land-surface model (LSM) datasets from the best available observations and model output to support modeling activities. Specifically, this system is intended to reduce the errors in the stores of soil moisture and energy which are often present in numerical weather prediction models, and which degrade the accuracy of forecasts. NLDAS is currently running in near real-time on a 1/8th-degree grid over central North America; retrospective NLDAS datasets and simulations extend back to January 1979. NLDAS constructs a forcing dataset from gauge-based observed precipitation data (temporally disaggregated using Stage II radar data), bias-correcting shortwave radiation, and surface meteorology re-analyses to drive several different LSMs to produce model outputs of surface fluxes, soil moisture, and snow cover. Phase 2 of NLDAS is referred to as NLDAS-2 and covers the period of January 2, 1979 to the present.
Data Link:	NLDAS Project Goals: http://ldas.gsfc.nasa.gov/nldas
Metadata Link:	Metadata is included with downloaded data. Documentation is in this ReadMe file (https://hydro1.gesdisc.eosdis.nasa.gov/data/NLDAS/README.NLDAS2.pdf) including a brief description of three land use models: Mosaic, Noah, and VIC.
Period of Record:	January 2, 1979 to present
Coverage:	North America
Temporal Resolution:	3-hour, monthly
Spatial Resolution:	1/8th degree (Note: 0.125 degrees ~ 8.6 miles ~ 13.9kilometers)

Format: HDF, NetCDF, ASCII, and KMZ

Software Requirements: GIS

Tips to Access/Download: Mosaic dataset: https://disc.sci.gsfc.nasa.gov/datasets/NLDAS_MOS0125_M_V002/summary

Five variables: Total ET, transpiration, canopy water evaporation, sublimation (evaporation from snow), and direct evaporation from bare soil.

Noah: https://disc.sci.gsfc.nasa.gov/datasets/NLDAS_NOAH0125_M_V002/summary

In addition to five variables listed above (for Mosaic), Noah also outputs potential ET.

VIC: https://disc.sci.gsfc.nasa.gov/datasets/NLDAS_VIC0125_M_V002/summary

Same five outputs as Mosaic (see above).

9.43 NOAA National Centers for Environmental Information — Climate Data Online

Developer/Author/Owner:	National Oceanic and Atmospheric Administration — Cooperative Observe Program (COOP) Weather Stations
Source for Water Budget Components:	Evapotranspiration, Precipitation, Runoff, Recharge of Applied Water and Precipitation, Lake Evaporation, Stream Evaporation, Conveyance Evaporation,
Available Information:	Precipitation, temperature, pan evaporation, soil temperature
Brief Description:	COOP stations data are collected from a variety of sources including National Weather Service reporting stations, volunteer cooperative observers, Federal Aviation Administration (FAA), and utility companies.
Data Link:	NOAA Climate Data: https://www.ncdc.noaa.gov/cdo-web/
Metadata Link:	Hourly Precipitation Data Documentation: https://www1.ncdc.noaa.gov/pub/data/cdo/documentation/PRECIP_HLY_documentation.pdf 15 Minute Precipitation Data Documentation: https://www1.ncdc.noaa.gov/pub/data/cdo/documentation/PRECIP_15_documentation.pdf
Period of Record:	Varies with station
Coverage:	United States (208 stations in California)
Temporal Resolution:	15 minute, hourly
Spatial Resolution:	Station
Format:	DAT, CSV
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	Period of record in the map interface is incorrect. The Mapping Tool (https://gis.ncdc.noaa.gov/maps/ncei/) is a superior interface to the Search Tool mapping interface included in the Data Link. The most recent seven days of select station data (http://www.cpc.ncep.noaa.gov/products/GIS/GIS_DATA/JAWF/) are also available.

9.44 NOAA National Centers for Environmental Information — Climatological Data Publications

Developer/Author/Owner: National Oceanic and Atmospheric Administration — National Centers for Environmental Information

Source for Water Budget Components: Evapotranspiration, Precipitation, Recharge of Applied Water and Precipitation, Lake Evaporation, Stream Evaporation, Conveyance Evaporation

Available Information: Precipitation, temperature, pan evaporation, soil temperature, snowfall, and snow on ground

Brief Description: The climate data publications are a compilation of observations from weather sites supervised by NOAA/National Weather Service and received at the National Centers for Environmental Information (NCEI). Monthly editions contain station daily maximum and minimum temperatures and precipitation. Some stations provide daily snowfall, snow depth, evaporation, and soil temperature data. Each issue also contains monthly summaries for heating and cooling degree days. The July issue also contains monthly heating degree days and snow data for the preceding July through June. The annual issue contains monthly and annual averages of temperature, precipitation, temperature extremes, freeze data, soil temperatures, evaporation, and a recap of monthly cooling degree days.

Data Link: NOAA Climatological Data Publications: https://www.ncdc.noaa.gov/IPS/cd/cd.html

Metadata Link: Same as Data Link

Period of Record: 1891–6 months prior present day

Coverage: Individual stations across the United States

Temporal Resolution: Hourly, daily, monthly, annual

Spatial Resolution: Various stations throughout California

Format: CSV, PDF

Software Requirements: Recommended: Excel or similar spreadsheet software

Tips to Access/Download: Select the Data Access tab, and choose from Land-Based Station, Satellite, Radar, etc. options.

For Land Based Stations data, select Datasets and Products to find Local Climatological Data (LCD) or Cooperative Observer Network (COOP), then query the dataset using maps or entering state, years of interest, etc.

9.45 NWS Climate Prediction Center Evaporation

Developer/Author/Owner:	National Weather Service (NWS) Climate Prediction Center
Source for Water Budget Components:	Evapotranspiration, Lake Evaporation, Stream Evaporation, Conveyance Evaporation
Available Information:	Evaporation, Potential Evaporation
Brief Description:	A series of maps showing current month and most recent 12 month's average evaporation and anomalies; previous 12 month's percentiles; evaporation climatology and 1- and 2-week outlooks. This evaporation is computed from a soil moisture balance model that uses precipitation and temperature as inputs.
Data Link:	National Weather Service image viewer: http://www.cpc.ncep.noaa.gov/soilmst/e.shtml National Weather Service text file: ftp://ftp.cpc.ncep.noaa.gov/wd51yf/us
Metadata Link:	Same as Data Link
Period of Record:	1931–2012
Coverage:	Contiguous United States
Temporal Resolution:	Daily, monthly
Spatial Resolution:	Seven California Climate Divisions: https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php
Format:	Text file
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	Select "e.1931_2012.friendly" (e stands for evaporation) from the text file link above. Years are in first column with months of evaporation listed from left to right. Data are listed by climate division (https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php). Climate Divisions 1 through 7 are in California.

9.46 PRISM Gridded Precipitation Data

Developer/Author/Owner:	PRISM Climate Group, Oregon State University
Source for Water Budget Components:	Precipitation
Available Information:	Precipitation
Brief Description:	Parameter elevation Regression on Independent Slopes Model (PRISM) Gridded Precipitation is the result of sophisticated climatological modeling of a large network of historic and active weather stations and radar data. The PRISM model accounts for complex climatological factors including orography, rain shadows, temperature inversions, slope aspect, coastal proximity, and others. PRISM climate data are widely used for modeling and analysis at multiple scales.
Data Link:	PRISM Climate Group: http://www.prism.oregonstate.edu/
Metadata Link:	Included in data download package.
Period of Record:	1895–Present
Coverage:	Statewide
Temporal Resolution:	Daily and monthly for 1981–present; monthly for 1895–1980
Spatial Resolution:	4-kilometer grid (free), 800-meter grid (for purchase)
Format:	GIS file formats: BIL, ASC
Software Requirements:	GIS
Tips to Access/Download:	For Monthly Precipitation Data for years 1981–present, navigate to “Recent Years.” Choose climate variable “Precipitation” and Temporal period “Monthly”. For years 1895–1980, navigate to “Historical Past”. Bulk downloads (http://prism.oregonstate.edu/documents/PRISM_downloads_FTP.pdf) are also available.

9.47 SSEBop: Operational Simplified Surface Energy Balance

Developer/Author/Owner: U.S. Geological Survey

Source for Water Budget Components: Evapotranspiration

Available Information: Evapotranspiration

Brief Description: Actual ET (ETa) is produced using the operational Simplified Surface Energy Balance (SSEBop) model (Senay and others 2013) for the period 2000–2015. The SSEBop setup is based on the Simplified Surface Energy Balance (SSEB) approach (Senay and others 2007, 2011) with unique parameterization for operational applications. It combines ET fractions generated from remotely sensed MODIS thermal imagery, acquired every eight days, with reference ET using a thermal index approach. The unique feature of the SSEBop parameterization is that it uses pre-defined, seasonally dynamic, boundary conditions that are unique to each pixel for the hot/dry and cold/wet reference points.

Data Link: U.S. SSEBop Evapotranspiration: https://earlywarning.usgs.gov/useta

Metadata Link: Actual Evapotranspiration Modeling Using the Operational Simplified Surface Energy Balance (SSEBop) Approach: https://pubs.usgs.gov/sir/2013/5126/

SSEBop ET Products: https://earlywarning.usgs.gov/docs/SSEBopETreadme.pdf

Period of Record: 2000–2015

Coverage: Contiguous US

Temporal Resolution: 2000–2015

Spatial Resolution: 1 kilometer

Format: NetCDF, PDF, PNG. TIF maps also available.

Software Requirements: GIS, Acrobat Reader

Tips to Access/Download: Data available from NCSS for Grids: https://cida.usgs.gov/thredds/ncss/ssebopeta/monthly/dataset.html

Help page on using the NetCDF file type: https://www.esrl.noaa.gov/psd/data/gridded/help.html#netcdf

9.48 State Water Resources Control Board's Water Conservation Portal

Developer/Author/Owner:	California State Water Resources Control Board
Source for Water Budget Components:	Applied Water, Groundwater Extraction, Surface Water Delivery, Applied Water Reuse, Recycled Water
Available Information:	Urban water use, water supply information
Brief Description:	The State Water Resources Control Board has been collecting water production information from urban water suppliers since the July 2014 board action to adopt an emergency water conservation regulation. In November 2017, the emergency water conservation regulation expired, and monthly reporting is now voluntary.
Data Link:	Water Conservation and Production Reports: https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation_reporting.shtml California Open Data Portal: https://data.ca.gov/dataset/drinking-water-public-water-system-operations-monthly-water-production-and-conservation
Metadata Link:	Same as Data Link
Period of Record:	July 2014 to present
Coverage:	Statewide
Temporal Resolution:	Monthly
Spatial Resolution:	Urban water supplier
Format:	XLS, CSV, JSON, RDF
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	Click on the most recent release of the “Urban Water Supplier Report Dataset" for water production, conservation, and monthly water use in gallons per capita day (gpcd).

9.49 State Water Resources Control Board's Water Rights Information (eWRIMS)

Developer/Author/Owner:	California State Water Resources Control Board
Source for Water Budget Components:	Surface Water Diversion, Imported Water, Surface Water Export
Available Information:	Surface water diversions, downstream water rights
Brief Description:	The Electronic Water Rights Information Management System (eWRIMS) is a computer database developed by the State Water Resources Control Board to track information on water rights in California. eWRIMS contains information on statements of water diversion and use that have been filed by water diverters. There is also registrations, certificates, and water right permits and licenses that have been issued by the State Water Resources Control Board and its predecessors.
Data Link:	eWRIMS: https://www.waterboards.ca.gov/waterrights/water_issues/programs/ewrims/index.html
Metadata Link:	Same as Data Link.
Period of Record:	1914 to present
Coverage:	Statewide
Temporal Resolution:	Varies
Spatial Resolution:	By water right
Format:	Web-based report, XLS
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	Open the eWRIMS Database System and use the Water Rights Record Search and Water Rights Web Mapping Application to find water rights in a water budget zone. Water rights information can be accessed in Web-based report or Excel format.

9.50 TOPS-SIMS: Satellite Irrigation Management Support

Developer/Author/Owner:	National Atmospheric and Space Administration — Ames Research Center, California Department of Water Resources, California State University (Monterey Bay and Fresno), and U.S. Department of Agriculture — Agricultural Research Service
Source for Water Budget Components:	Evapotranspiration
Available Information:	ETcb (basal crop ET), Kcb (basal crop coefficient)
Brief Description:	Different than other remote sensing ET models, Satellite Irrigation Management Support (SIMS) is based on vegetation indices, rather than the energy balance (e.g., METRIC-EEFLUX, MOD16, etc.). SIMS captures vegetation growth (amount of green biomass) but cannot capture changes in crop temperature caused by stress because, unlike the energy balance methods, SIMS does not use thermal information. SIMS also doesn't account for evaporation from wet bare soil. The advantage of SIMS is that it can use more satellites which results in more frequent observations, at higher resolution.
Data Link and Contact:	SIMS: https://ecocast.arc.nasa.gov/simsi/about/ Thee datasets should be considered provisional. They are distributed for research, demonstration, and evaluation purposes only. Please send questions and comments to forrest.s.melton@nasa.gov.
Metadata Link:	Same as Data Link.
Period of Record:	2010–present
Coverage:	Statewide
Temporal Resolution:	Daily
Spatial Resolution:	30-meter grid
Format:	CSV
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	To download the seasonal ETcb for a point of interest, type in the address or latitude and longitude for a field of interest. Adjust the map so that the field boundaries can be clearly seen. Click on the center of the field, a location which is representative of the overall field condition. Click on the 'Download as CSV' link to save the file. Delete data prior to and after the planting/harvest date and sum the remaining entries.

9.51 United States Census

Developer/Author/Owner: U.S. Census Bureau

Source for Water Budget Components: Applied Water

Available Information: Population

Brief Description: The U.S. Census Bureau provides population estimates for historical years and future projections of population through 2060. Population estimates and projections are available at the city and county level.

Data Link: Population and Housing Unit Estimates (Historical): https://www.census.gov/programs-surveys/popest.html

Population Projections: https://www.census.gov/programs-surveys/popproj.html

Metadata Link: Population and Housing Unit Estimates (Technical Documentation): https://www.census.gov/programs-surveys/popest/technical-documentation.html

Population Projections (Technical Documentation): https://www.census.gov/programs-surveys/popproj/technical-documentation.html

Period of Record: Historical estimates from 1970–2016; future projections from 2010–2060.

Coverage: Statewide

Temporal Resolution: Not Applicable

Spatial Resolution: City, county, state

Format: Web-based report, CSV

Software Requirements: Recommended: Excel or similar spreadsheet software

Tips to Access/Download: On the left side of the website, navigate to Data and click on Datasets. From there, access is available to various data for different years and spatial resolutions.

9.52 Urban Water Management Plans

Developer/Author/Owner: California Department of Water Resources (DWR)

Source for Water Budget Components: Applied Water, Surface Water Delivery, Groundwater Extraction, Applied Water Reuse, Recycled Water, Recycled Water Export

Available Information: Urban water use, population, water supply information

Brief Description: Urban water management plans (UWMPs) are prepared by urban water suppliers every five years. These plans support the suppliers' long-term resource planning to ensure that adequate water supplies are available to meet existing and future water needs. Every urban water supplier that either provides more than 3,000 acre-feet of water annually or serves more than 3,000 urban connections is required to submit an UWMP.

Urban water includes the following uses:

- Drinking
- Toilets and showers
- Landscaping
- Car washing
- Businesses
- Industrial processes

Data Link: Water Use Efficiency Data: https://wuedata.water.ca.gov/

Metadata Link: Urban Water Management Plans: https://water.ca.gov/Programs/Water-Use-And-Efficiency/Urban-Water-Use-Efficiency/Urban-Water-Management-Plans

Period of Record: Historical data from 2006–2010, with projected data through 2035

Coverage: Statewide

Temporal Resolution: Annual

Spatial Resolution: By urban water supplier

Format: XLS, PDF

Software Requirements: Recommended: Excel or similar spreadsheet software; Acrobat Reader

Tips to Access/Download: PDF reports of individual UWMPs can be downloaded from the "View 2010 UWMPs" and "2010 and 2005 UWBPs" links. Tables from the 2015 UWMPs (aggregated for all submitted UWMPs) can be downloaded from the "2015 UWMP Data" link.

9.53 U.S. Bureau of Reclamation Central Valley Operations (including Central Valley Project)

Developer/Author/Owner: U.S. Bureau of Reclamation (Reclamation)

Source for Water Budget Components: Surface Water Delivery, Surface Water Diversion, Conveyance Evaporation, Conveyance Seepage, Imported Water, Surface Water Export, Change in Surface Water Storage

Available Information: Central Valley Project (CVP) - surface water diversions, water transfers

Brief Description: Website contains operational reports for CVP operations.

Data Link: Reclamation’s Central Valley Operations Office: https://www.usbr.gov/mp/cvo/index.html

Metadata Link: Not available

Period of Record: 1985–present

Coverage: Central Valley Project system

Temporal Resolution: Monthly, annual

Spatial Resolution: By contractor

Format: PDF

Software Requirements: Acrobat Reader

Tips to Access/Download: For CVP delivery data, click on “Water Deliveries.” This goes to a page with monthly delivery tables for the current year. Click on the links at the bottom for delivery data from previous years.

9.54 USDA County Ag Commissioner’s Data Listing

Developer/Author/Owner: U.S. Department of Agriculture (USDA) — National Agricultural Statistics Service, California Field Office (Part of the Pacific Regional Field Office)

Source for Water Budget Components: Applied Water, Evapotranspiration

Available Information: Agricultural land use by crop type.

Brief Description: This summary, which is published annually, is based on the annual crop reports compiled by the California County Agricultural Commissioners. These reports provide the most detailed annual data available on agricultural production by county. As of crop year 2011, the summary and data reports are combined into one publication.

Data Link: USDA’s National Agricultural Statistics Service: https://www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/index.php

Metadata Link: California County Agricultural Commissioner’s Annual Crop Report Manual: https://www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/CCAC_Annual_Crop_Report_Manual_r2012.pdf

Period of Record: 1980–2015

Coverage: Statewide — agricultural lands only.

Temporal Resolution: Annual

Spatial Resolution: County — agricultural lands only.

Format: PDF, XLS, CSV

Software Requirements: Recommended: Excel or similar spreadsheet software; Acrobat Reader

Tips to Access/Download: Open as a CSV file to be able to sort by county and crop type. While these spreadsheets provide a good starting place, users should independently verify that values in these summary sheets against the original crop reports.

Note: Many county agricultural reports are corrected the year after submission, which are based on investigation of this database. Those corrections are not always reflected in the USDA’s composite products.

9.55 U.S. Department of Agriculture CropScape

Developer/Author/Owner:	U. S. Department of Agriculture — National Agricultural Statistics Service (NASS)
Source for Water Budget Components:	Applied Water, Evapotranspiration
Available Information:	Crop acreage
Brief Description:	The U. S. Department of Agriculture has produced a remotely sensed crop data layer (CropScape) that is publicly available for California for 2007 through 2016. These data are a gridded dataset with 30-meter by 30-meter pixels each with a single crop identified. CropScape can generally differentiate classifications of land coverage (permanent crops vs. annual crops vs. urban). But, it has difficulty accurately distinguishing between native grassland and irrigated pasture, as well as between different types of orchards. Additionally, the individual land use identified is often not consistent between years.
Data Link:	CropScape: https://nassgeodata.gmu.edu/CropScape/
Metadata Link:	CropScape and Cropland Data Layer: https://www.nass.usda.gov/Research_and_Science/Cropland/metadata/meta.php
Period of Record:	2007–2016
Coverage:	Contiguous United States
Temporal Resolution:	Annual
Spatial Resolution:	30 meter
Format:	Grid (TIF), CSV
Software Requirements:	Recommended: Excel or similar spreadsheet software; GIS
Tips to Access/Download:	A boundary shapefile may be imported into the interface using the “Import Area of Interest” button. Once an area of interest is defined, data can be exported as a CSV file (“Export Table as a CSV file”) or as a TIF (“Export the selected crops for mapping”). Bulk download: To download data for California, do not define an area of interest. Instead, select the rightmost button “download data for area of interest,” and it will ask whether to download all data for the selected year by state as a compressed (tar.gz) file.

9.56 U.S. Department of Agriculture Natural Resources Conservation Service Geospatial Web Soil Survey

Developer/Author/Owner:	U. S. Department of Agriculture — Natural Resources Conservation Service (NRCS)
Source for Water Budget Components:	Applied Water, Recharge of Applied Water and Precipitation, Return flow
Available Information:	Soil properties (including depth of soils), hydraulic soil type, hydraulic conductivity
Brief Description:	Web Soil Survey (WSS) provides soil data and information produced by the National Cooperative Soil Survey. NRCS has soil maps and data available online for more than 95 percent of the nation's counties; it anticipates having 100 percent in the future. The site is updated and maintained online as a single authoritative source of soil survey information.
Data Link:	Web Soil Survey: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
Metadata Link:	Soils: https://www.nrcs.usda.gov/wps/portal/nrcs/main/ca/soils/
Period of Record:	Current
Coverage:	Statewide
Temporal Resolution:	Not available
Spatial Resolution:	User defined area of interest
Format:	Web viewer
Software Requirements:	None
Tips to Access/Download:	• Click the "Start WSS" button at the top of the page. • Use the Area of Interest tab to define an area of interest. • Click the Soil Map tab to view or print a soil map, and detailed descriptions of the soils in your area of interest. • Click the Soil Data Explorer tab to access soil data for an area and determine the suitability of the soils for a particular use. • Use the Shopping Cart tab to get a custom printable report.

9.57 U.S. Geological Survey Publications

Developer/Author/Owner:	U. S. Geological Survey (USGS)
Source for Water Budget Components:	Surface Water Diversions, Stream Inflow, Stream Outflow, Stream-Lake Interaction, Subsurface Inflow, Subsurface Outflow, Runoff, Return Flow, Groundwater Gain from Stream, Groundwater Loss to Stream
Available Information:	Stream flows, surface water flow conditions, subsurface flow conditions
Brief Description:	Many USGS reports on water resources are available online. Most publications located at this site and other USGS sites can be located by subject, author, date, USGS series or publication series number by using the reports and thematic maps.
Data Link (or Contact):	Water-Resources Investigation Reports: https://pubs.usgs.gov/wri/ Scientific Investigations Reports: https://pubs.usgs.gov/sir/ USGS Water Resources Mission Area Publications: https://www.usgs.gov/mission-areas/water-resources/publications USGS Publications Warehouse: https://pubs.er.usgs.gov/
Metadata Link:	Not applicable.
Period of Record:	Varies depending on publication.
Coverage:	Varies depending on publication.
Temporal Resolution:	Varies depending on publication.
Spatial Resolution:	Varies depending on publication.
Format:	PDF
Software Requirements:	Acrobat Reader

9.58 U.S. Geological Survey Surface-Water Data for California

Developer/Author/Owner:	U. S. Geological Survey (USGS)
Source for Water Budget Components:	Stream Inflow, Stream Outflow, Surface Water Diversion, Stream-Lake Interaction, Imported Water, Surface Water Export, Runoff, Return Flow, Change in Surface Water Storage
Available Information:	Surface water flow, surface water diversion, lake storage
Brief Description:	The USGS's National Water Information System (NWIS) is a comprehensive and distributed application that supports the acquisition, processing, and long-term storage of water data. "Water Data for the Nation" serves as the publicly available portal to a geographically seamless set of much of the water data maintained within NWIS. Nationally, USGS surface-water data includes more than 850,000 station years of time-series data that describe stream water levels, streamflow (discharge), lake levels, surface-water quality, and precipitation. The data are collected by automatic recorders and manual field measurements at installations across the nation. The data relayed through the Geostationary Operational Environmental Satellite (GOES) system are processed automatically in near real time, and in many cases, current data are online within minutes. Once a complete day of readings are received from a site, daily summary data are generated and made available online. USGS finalizes data at individual sites on a continuous basis as environmental conditions and hydrologic characteristics permit.
Data Link:	USGS Surface-Water Data for California: https://waterdata.usgs.gov/ca/nwis/sw
Metadata Link:	Same as Data Link.
Period of Record:	January 1, 1838–present
Coverage:	Statewide
Temporal Resolution:	15-minute, daily, monthly, or annual
Spatial Resolution:	Gauge location
Format:	Graph, table, or tab-separated
Software Requirements:	Recommended: Excel or similar spreadsheet software
Tips to Access/Download:	Select "Daily Data" and search for appropriate gauge locations

9.59 Validated Water Loss Reporting

Developer/Author/Owner:	California Department of Water Resources (DWR)
Source for Water Budget Components:	Conveyance Seepage, Recharge of Applied Water and Precipitation
Available Information:	Water loss estimations
Brief Description:	Water loss audits evaluate real water losses (leaks) and apparent water losses (e.g., data errors, water theft) occurring in a potable water distribution system. Water loss audit submissions are reviewed by validators. The reviews followed the validation methodology detailed in Water Research Foundation Project 4639: Level 1 Water Audit Validation. Level 1 water audit validation aims to: 1. Identify and, where possible, correct inaccuracies in water audit data and application of methodology. 2. Evaluate and communicate the uncertainty inherent in water audit data.
Data Link:	Water Use Efficiency Data: https://wuedata.water.ca.gov/
Metadata Link:	Validated Water Loss Reporting: https://water.ca.gov/Programs/Water-Use-And-Efficiency/Urban-Water-Use-Efficiency/Validated-Water-Loss-Reporting
Period of Record:	2016–present
Coverage:	Statewide coverage by water district
Temporal Resolution:	Annual
Spatial Resolution:	By water district
Format:	XLS and PDF
Software Requirements:	Recommended: Excel or similar spreadsheet software; Acrobat Reader
Tips to Access/Download:	Water loss spreadsheets for each water supplier can be downloaded from the data link from the “View Water Audit Reports” link. Water loss information may also be reported within urban water management plans.

9.60 VegScape: Vegetation Condition Explorer

Developer/Author/Owner:	U. S. Department of Agriculture — National Agricultural Statistics Service (NASS)
Source for Water Budget Components:	Evapotranspiration, Applied Water
Available Information:	Vegetation indices including NDVI and VCI
Brief Description:	The vegetation condition refers to the density of vegetation, which changes through a plant's growth cycles. Vegetation indices available: • Normalized difference vegetation index (NDVI) products — Current Vegetation Condition Explorer can provide daily, weekly, and biweekly NDVI products from 2000 to 2013. • Vegetation Condition Index (VCI) products — represents the weather condition or the vegetation condition. Currently, Vegetation Condition Explorer can provide weekly and biweekly VCI products from 2000 to 2013. The annual crop condition can be plotted from downloaded data or using the interface.
Data Link:	VegScape Vegetation Condition Explorer: https://nassgeodata.gmu.edu/VegScape/
Metadata Link:	VegScape User Guide: https://nassgeodata.gmu.edu/VegScape/help/help.html
Period of Record:	2000–2013
Coverage:	Contiguous United States
Temporal Resolution:	Daily (NDVI only), weekly, biweekly
Spatial Resolution:	30 meter
Format:	Grid (TIF)
Software Requirements:	GIS
Tips to Access/Download:	Use map interface to select area of interest and download data for period of interest. The shapefile of the boundary of an area of interest may be imported into the interface using the "Import Area of Interest" button. Once an area of interest is defined, data can be downloaded as a TIF ("Export the selected crops for mapping").

9.61 Water Recycling Survey (2015)

Developer/Author/Owner: California State Water Resources Control Board (Water Board) in collaboration with the California Department of Water Resources (DWR)

Source for Water Budget Components: Recycled Water, Recycled Water Exports

Available Information: Total RW used by location and beneficial reuse types

Brief Description: The 2015 data set contains data from a Water Board survey of wastewater agencies and the 2015 urban water management plans. The merging and validation of the data were conducted jointly by both agencies. Only treated municipal wastewater, originating in whole or in part from a domestic source and directly used for beneficial reuse, was included. The data set includes direct agricultural application and has been checked to remove duplication from overlapping reporting by producers, wholesale distributors, and users. In-plant process water use within a wastewater treatment plant was considered part of treatment plant operations and was not included as recycled water. Discharges required by the treatment plant permit to maintain habitat or instream flows or to complete treatment were considered a permit requirement and not recycled water. Groundwater recharge was only included in the data set if the project is permitted by a regional water quality control board. This data set is considered the most accurate and inclusive for recycled water use in California.

Data Link: Municipal Wastewater Recycling Survey: https://www.waterboards.ca.gov/water_issues/programs/grants_loans/water_recycling/munirec.shtml

Metadata Link: Same as Data Link.

Period of Record: Main survey of 2015; other surveys in 1970, 1977, 1987, 2001, and 2009.

Coverage: Statewide coverage

Temporal Resolution: Data for specific years

Spatial Resolution: By general region and location (jurisdiction) of use

Format: PDF

Software Requirements: Acrobat Reader

Tips to Access/Download: Table 3 details, “Beneficial Reuse for Agencies Submitting Water Recycling Data for 2015.”

9.62 Water Use Classification of Landscape Species: Water Use Classification of Landscape Species

Developer/Author/Owner:	University of California Cooperative Extension, California Department of Water Resources
Source for Water Budget Components:	Evapotranspiration, Applied Water
Available Information:	Method to estimate Kc for landscape
Brief Description:	Water Use Classification of Landscape Species (WUCOLS) IV provides evaluations of the irrigation water needs for more than 3,500 taxa (taxonomic plant groups) used in California landscapes. It is based on the observations and extensive field experience of 36 landscape horticulturists and provides guidance in the selection and care of landscape plants relative to their water needs.
Data Link:	Water Use Classification of Landscape Species: http://ucanr.edu/sites/WUCOLS/
Metadata Link:	Same as Data Link.
Period of Record:	Varies depending on application.
Coverage:	Varies depending on application.
Temporal Resolution:	Varies depending on application.
Spatial Resolution:	Varies depending on application.
Format:	PDF
Software Requirements:	Acrobat Reader
Tips to Access/Download:	From the homepage, plants can be searched by region using the “Plant Search Database” link. The entire plant list can be downloaded from the “Download WUCOLS IV Plant List” link.

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