P2P Network Webinar Series

Handbook for Water Budget Development

September 2, 2020

Program Updates

- Welcome
  - Ashley Ward, Internet of Water
- Take note for today's webinar
  - We are recording!
  - Other administrative notes
- Peer-to-Peer (P2P) Network

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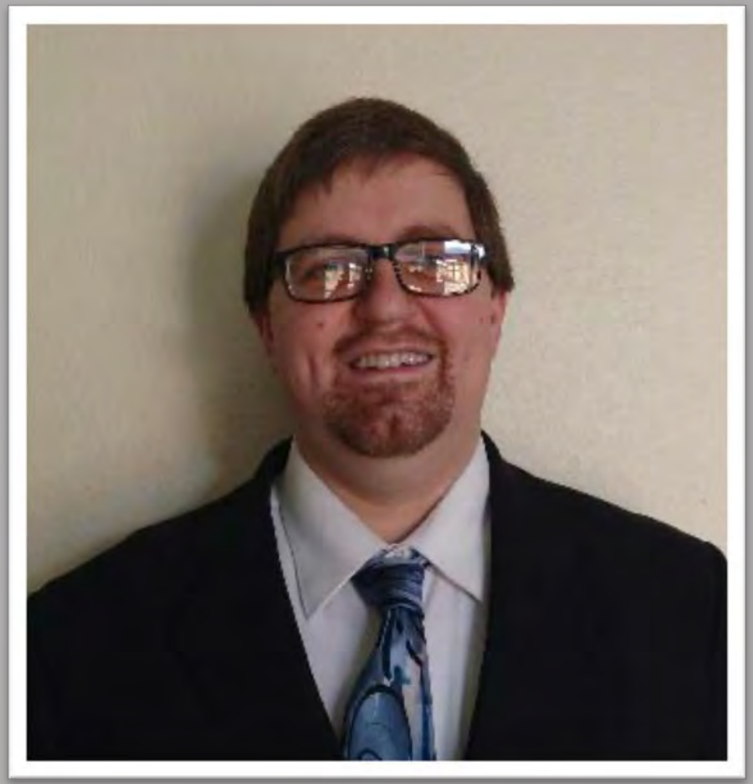
Todd Hillaire, P.E.



Paul Shipman, P.E.

CALIFORNIA DEPARTMENT OF WATER RESOURCES

Handbook for Water Budget Development: With or Without Models

Internet of Water, P2P-Network Webinar, September 2, 2020

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Presentation Purpose and Outline

Purpose: Improve how water is managed using water budgets as a water accounting tool.

Segment 1: Considerations for Development of a Water Budget

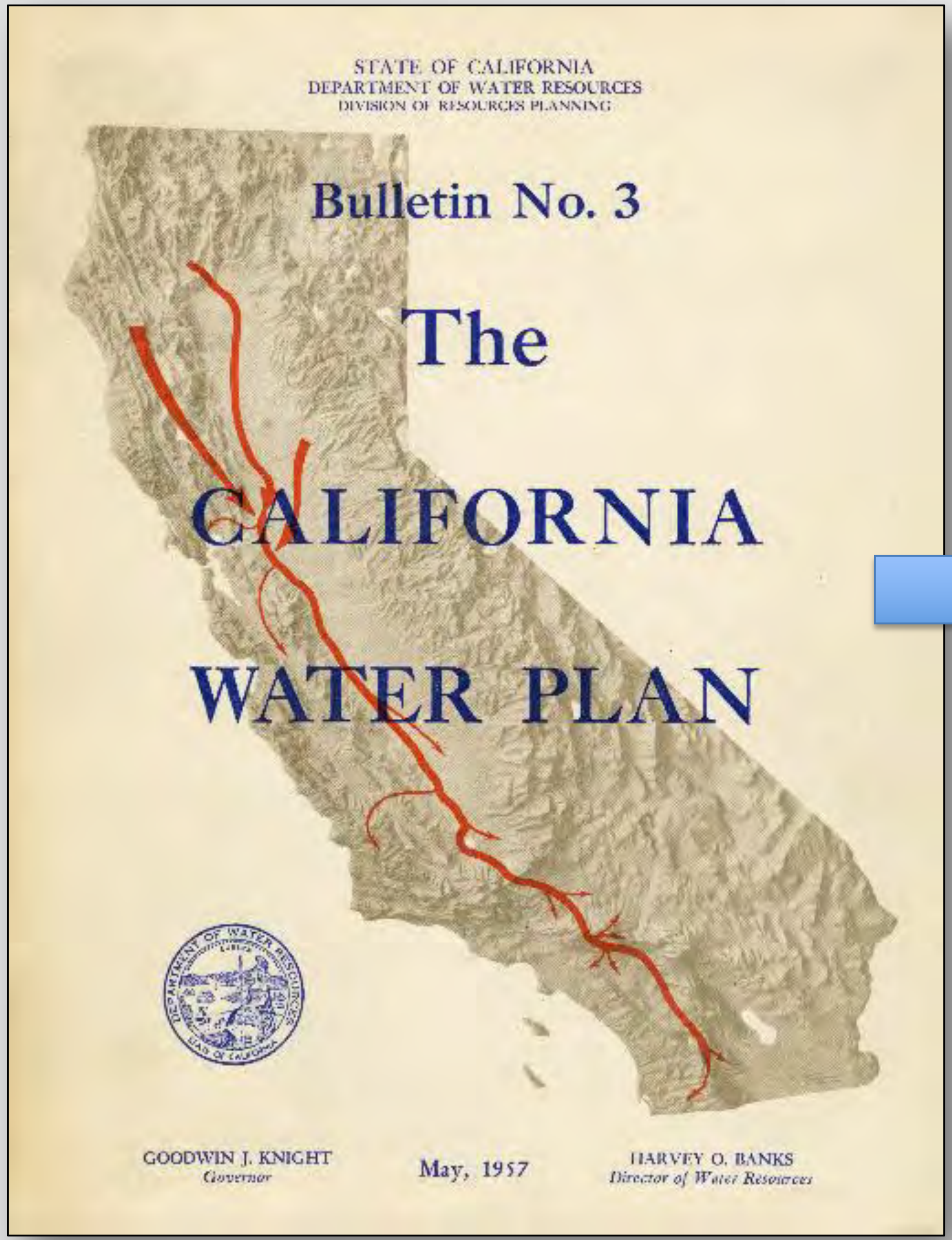
Segment 2: Methods for calculating water budget components

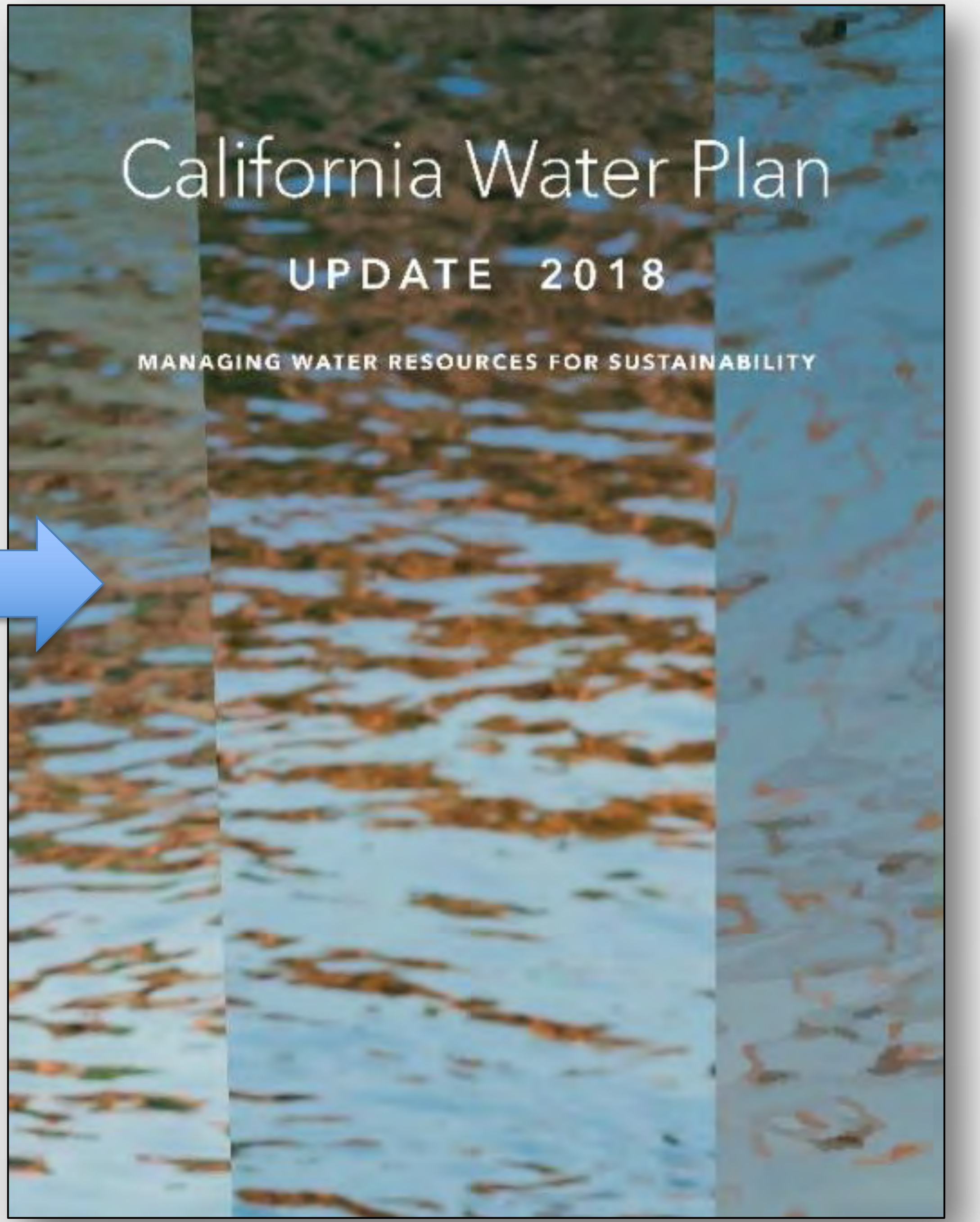
Segment 3: Applying the handbook to modeling and non-modeling approaches

Segment 4: Responses to common questions and links to additional resources

Segment 1: Considerations for Development of a Water Budget

California has a history of estimating water budgets to plan for the future of the state.





12 California Water Plans published to date

Table 1-1 California Water: How It Was Used and Where It Came From, 2011-2015

Statewide Applied Water Use - how water was used ... in millions of acre-feet

Water Year	2011	2012	2013	2014	2015
% Average Rainfall	134%	75%	77%	56%	77%
Precipitation in millions of acre feet (MAF)	*248.1*	*138.9*	*142.0*	*102.6*	*143.3*
Urban	**7.7**	**8.3**	**8.3**	**8.1**	**7.0**
Large Landscape	0.6	0.8	0.7	0.8	0.7
Commercial	1.1	1.1	1.2	1.1	1.0
Industrial	0.4	0.4	0.4	0.3	0.3
Energy Production	0.1	0.1	0.1	0.1	0.1
Residential - Interior	2.4	2.7	2.7	2.9	2.4
Residential - Exterior	2.3	2.4	2.5	2.4	1.9
Conveyance Applied Water	0.4	0.4	0.4	0.4	0.3
Groundwater Recharge Applied Water	0.5	0.5	0.2	0.1	0.2
Irrigated Agriculture	**31.7**	**35.0**	**35.7**	**35.0**	**32.4**
Applied Water-Crop Production	26.9	31.6	32.6	32.5	30.5
Conveyance Applied Water	3.4	3.0	2.9	2.3	1.8
Groundwater Recharge Applied Water	1.4	0.3	0.2	0.2	0.1
Environmental Water	**53.2**	**33.9**	**29.8**	**21.7**	**24.7**
Managed Wetlands	1.5	1.6	1.6	1.6	1.5
Minimum Req'd Delta Outflow	7.4	5.3	4.5	4.0	3.7
Instream Flow Requirements	7.9	6.8	6.6	5.6	5.3
Wild and Scenic Rivers	36.5	20.2	17.1	10.5	14.2
Total Uses	**92.7**	**77.2**	**73.7**	**64.7**	**64.1**

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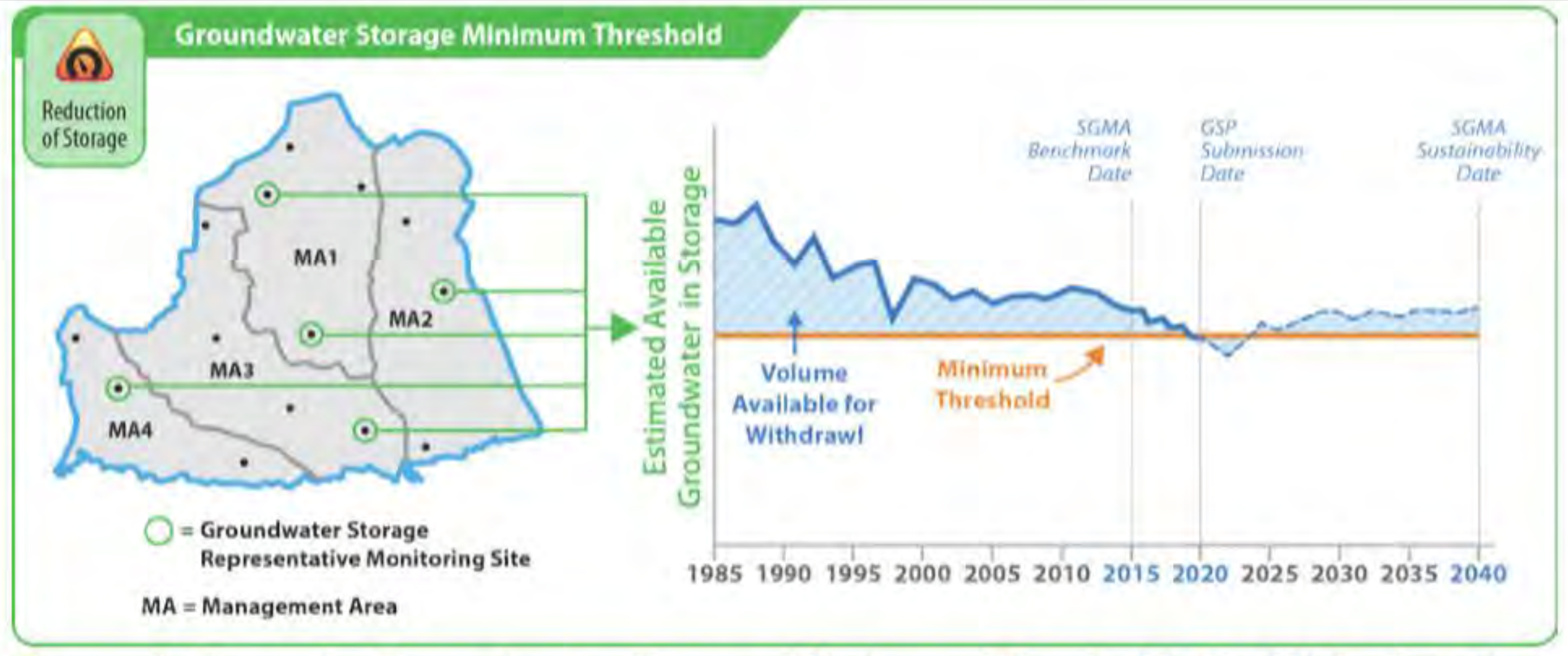
Recently, California passed a variety of legislation that relates to water budgeting.

2014 – Sustainable Groundwater Management Act
http://leginfo.legislature.ca.gov/faces/codes_displayexpandedbranch.xhtml?tocCode=WAT&division=6.&title=&part=2.74.&chapter=&article

2018 – Water Conservation Legislation: Assembly Bill 1668 and Senate Bill 606
https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB1668
https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB606

2014 – Sustainable Groundwater Management Act



Source: [Best Management Practices for Sustainable Groundwater Management: Sustainable Management Criteria]

California Water Code § 10721(y)
"Water budget" means an accounting of the total groundwater and surface water entering and leaving a basin including the changes in the amount of water stored.

http://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?sectionNum=10721.&lawCode=WAT

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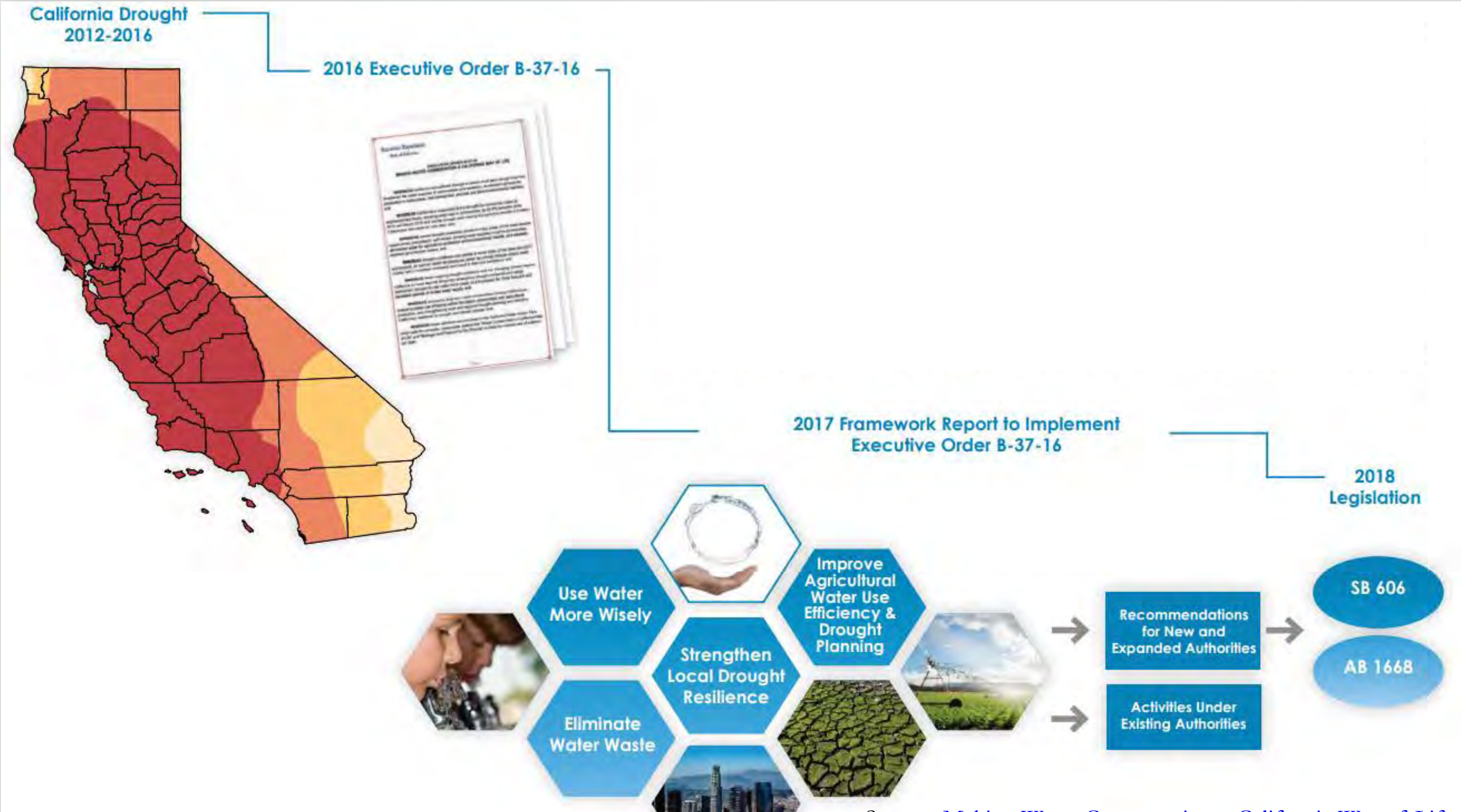
2018 – Water Conservation Legislation



Source: [Making Water Conservation a California Way of Life]

California Water Code §10826(c)
Include an annual water budget based on the quantification of all inflow and outflow components for the service area of the agricultural water supplier.

http://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?sectionNum=10826.&lawCode=WAT

However; water budgeting is not restricted to responding to legislation or geography.

Water availability is an important concern in the 21st century. Ensuring sustainable water supplies requires an understanding of the hydrologic cycle—how water moves through Earth's atmosphere, land surface, and subsurface. Water budgets are tools that water users and managers use to quantify the hydrologic cycle. A water budget is an accounting of the rates of water movement and the change in water storage in all or parts of the atmosphere, land surface, and subsurface. Although simple in concept, water budgets may be difficult to accurately determine.

-Robert M. Hirsch
Associate Director for Water
USGS Circular 1308-2007

Rather; water budgeting is what helps us to manage water more effectively.

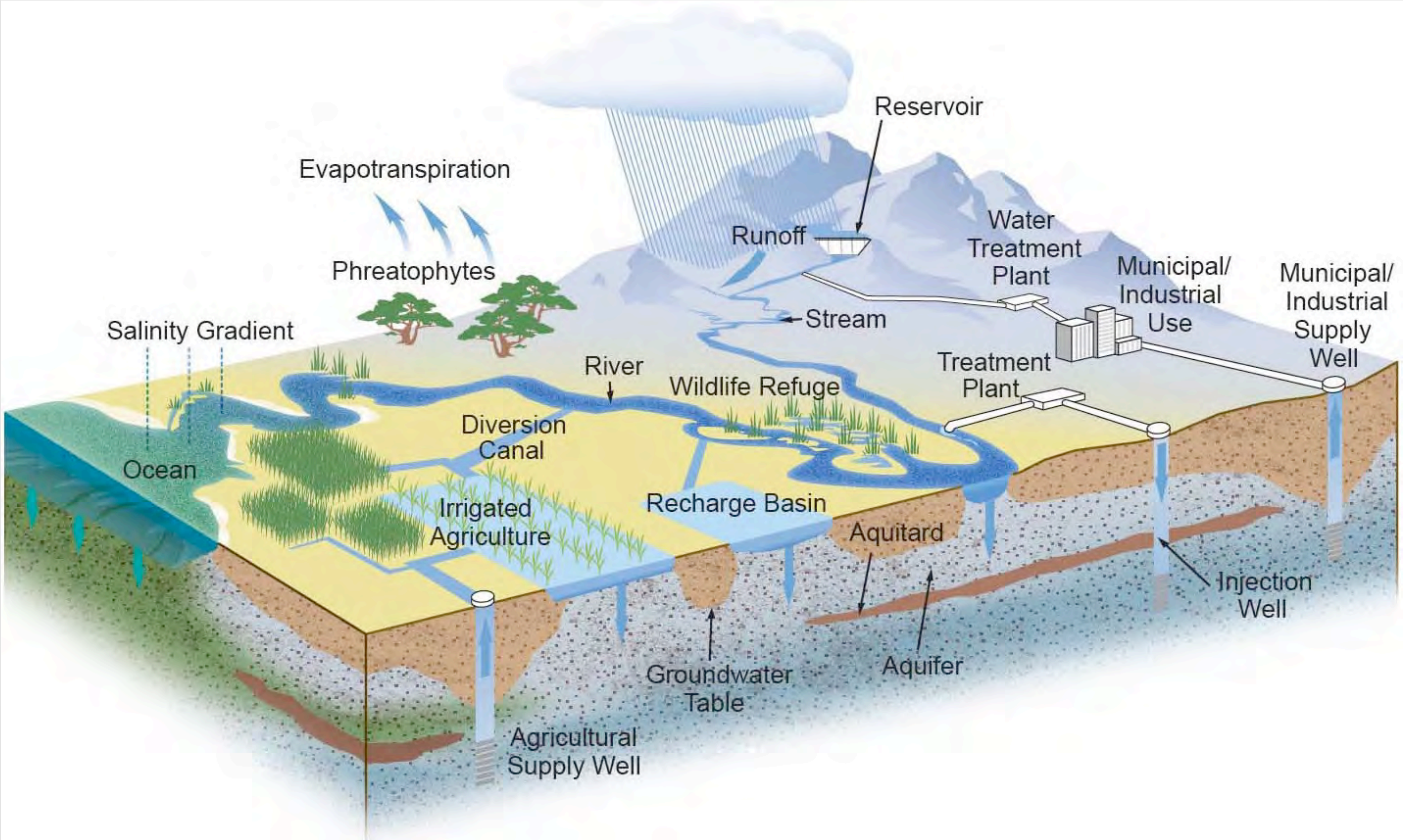
Thousands have lived without love,
not one without water.

— W. H. Auden
'First Things First' (1957)

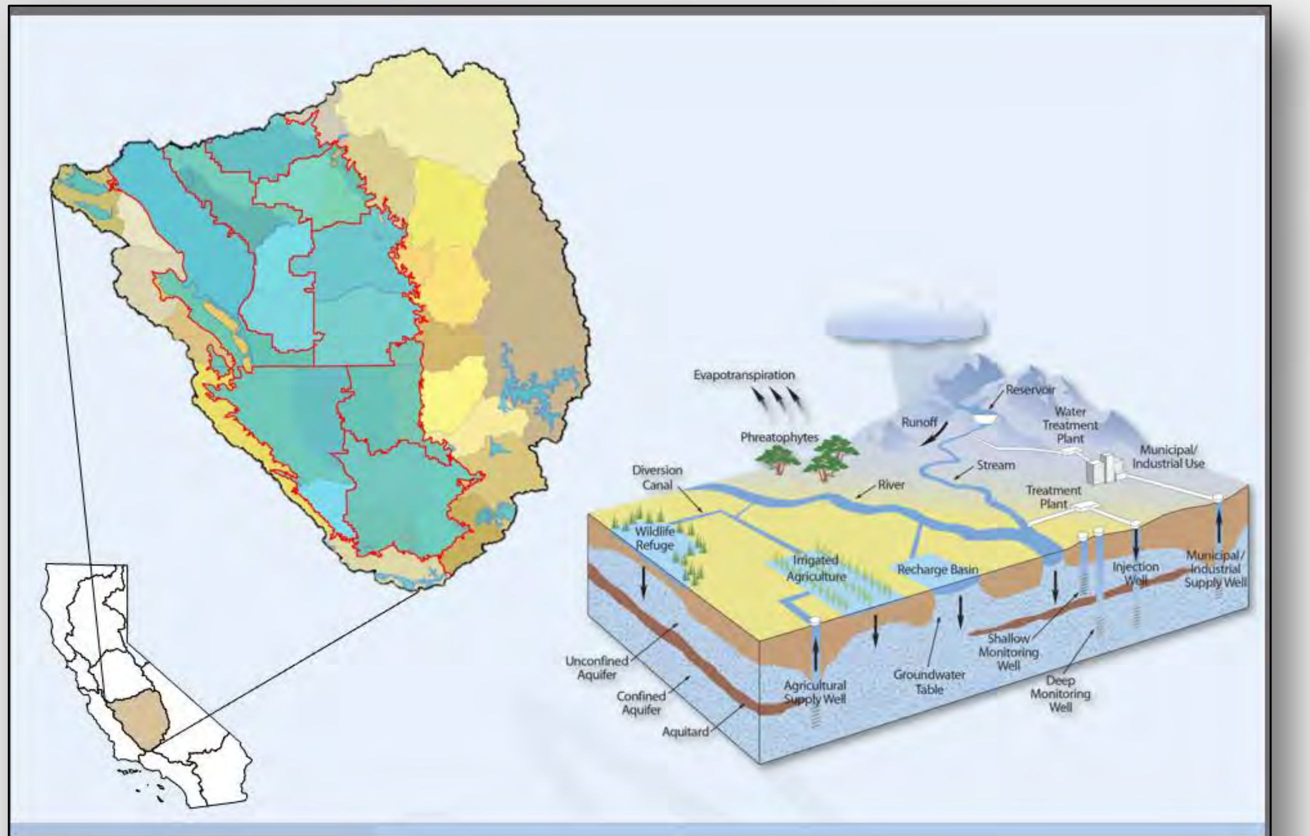
Water is the driving force of all nature

— Leonardo Da Vinci

A water budget is an essential element in water resources management.



The Water Budget Handbook is the outcome of two water budget pilot projects conducted by DWR.



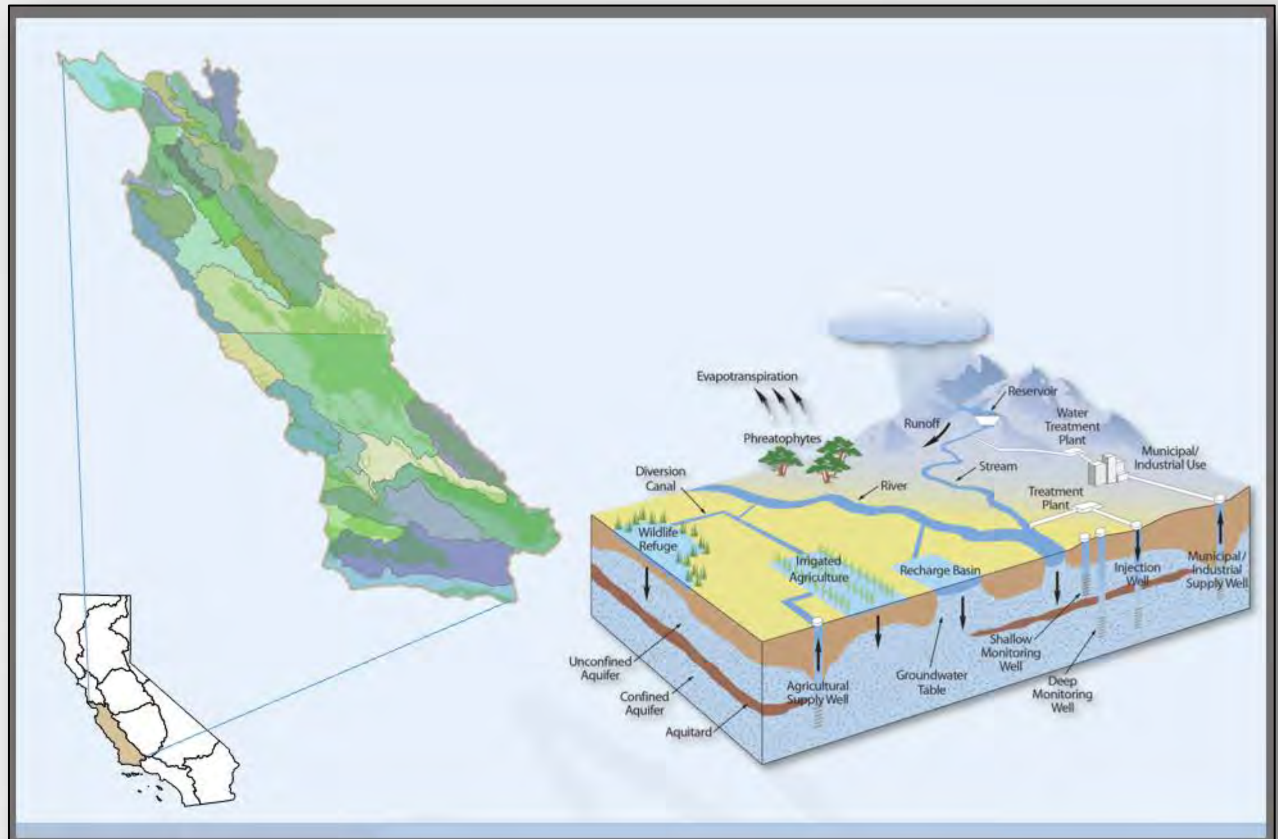
Water Budget Framework Project

Tulare Lake Hydrologic Region Pilot Study

Phase I Results and Recommendations

Final Technical Memorandum

February 2018



Water Budget Framework Project

Central Coast Hydrologic Region Pilot Study

Phase II Results and Recommendations

Preliminary Draft

January 2018

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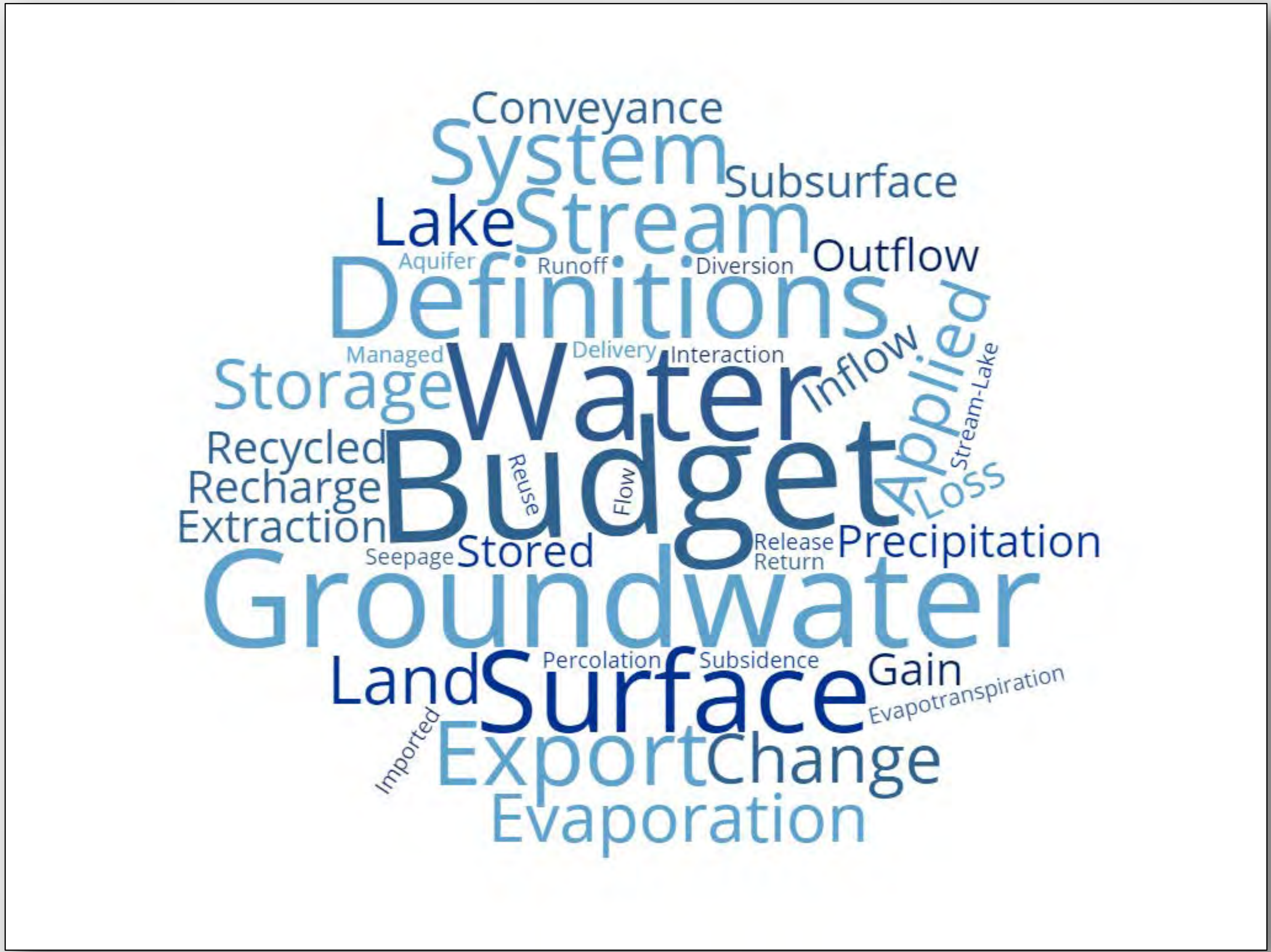
While conducting pilot projects, DWR identified several factors hindering water budget development.

INCONSISTENT DEFINITIONS



While conducting pilot projects, DWR identified several factors hindering water budget development.

NONSTANDARD WATER ACCOUNTING

	A	B	C	D	E
1	**REGION**	**Q1**			
2	North-East	$657			
3	North-West	$550			
4	**Total North**	**$1,207**	=SUM(B2:B3)		
5					
6	South-East	$295			
7	South-West	$443			
8	**Total South**	**$738**	=SUM(B6:B7)		
9					
10	**TOTAL**	**$3,890**	=SUBTOTAL(9,B2:B9)		
11					

Source: https://www.myexcelonline.com

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While conducting pilot projects, DWR identified several factors hindering water budget development.

POOR DOCUMENTATION

Source: https://twitter.com/mariofusco/status/781579431856967680

The Water Budget Handbook is a single-volume, technical reference for developing water budgets.

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Sections 1 and 2 focus on foundational concepts of water budget development.

Handbook for Water Budget Development

Contents

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Handbook for Water Budget Development

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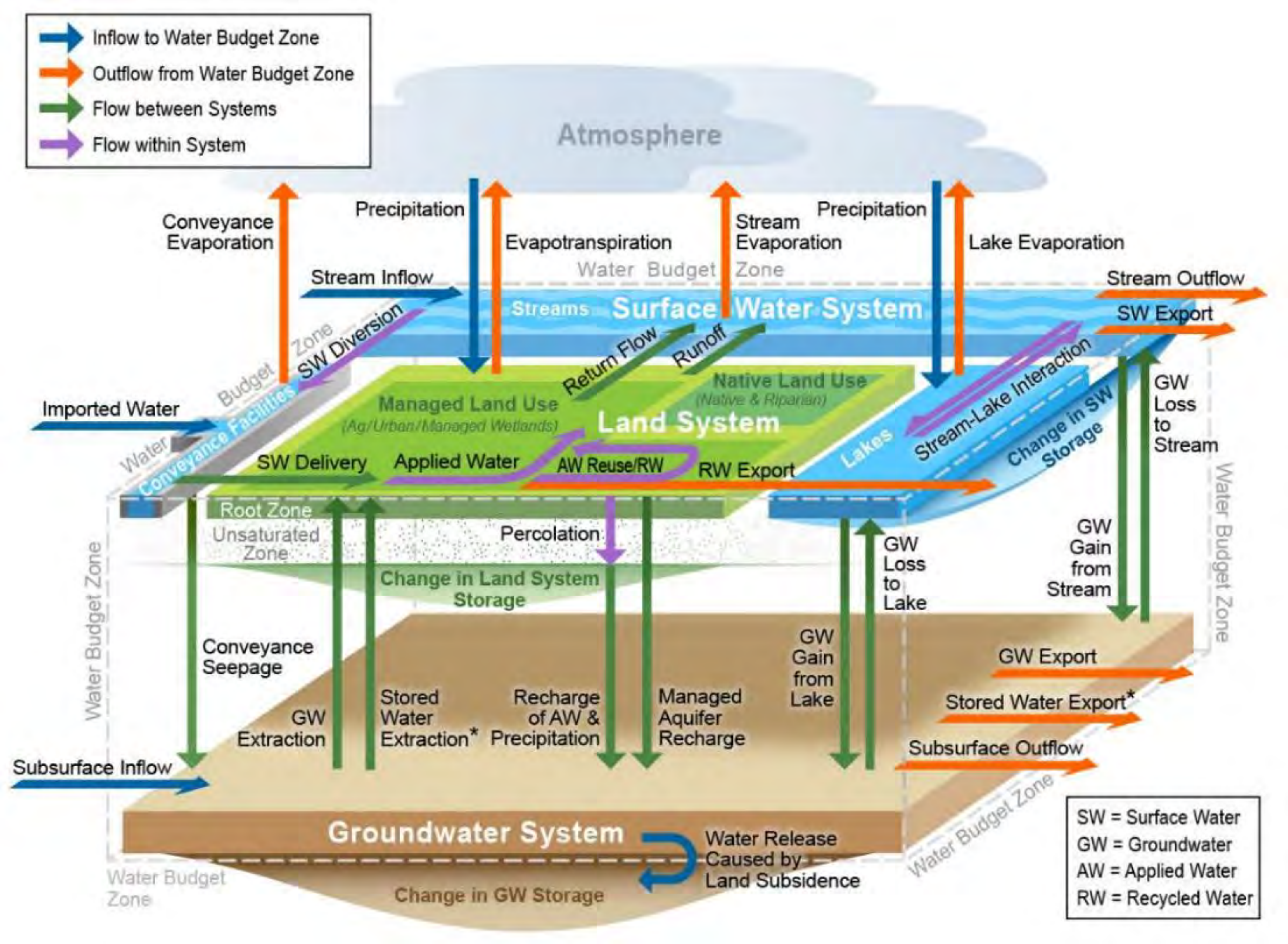
The total water budget is a comprehensive accounting of inflows and outflows.



Section 1 content

A common vocabulary for each component of water budget is included in the handbook. Section 1 content

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.
mported 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.

er Budget nponent habetical)	Definition
off	Volume of water flowing into the surface water system within a water budget zone from precipitation over the land surface.
ed Water ort*	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.
ed Water action*	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.
am poration	Volume of water evaporated into the atmosphere from streams.
am Inflow	Volume of water entering through streams at the periphery of a water budget zone.
am Outflow	Volume of water leaving through streams at the periphery of a water budget zone.
am-Lake raction	Volume of water exchanged between streams and lakes.
surface Inflow	Volume of water entering as groundwater into a water budget zone through its subsurface boundaries.
surface flow	Volume of water leaving as groundwater from a water budget zone through its subsurface boundaries.
face Water) 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.
face Water) Diversion	Volume of water taken from the surface water system within a water budget zone for use within the zone.

A common vocabulary for each component of water budget is included in the handbook. Section 1 content

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Change … System…	
Change … Water (… Storage	
Conveya… Evapora…	
Conveya… Seepage	
Evapotr…	… 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.
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Handbook for Water Budget Development

Water Budget Component (Alphabetical)	Definition
…off	Volume of water flowing into the surface water system within a water budget zone from precipitation over the land surface.
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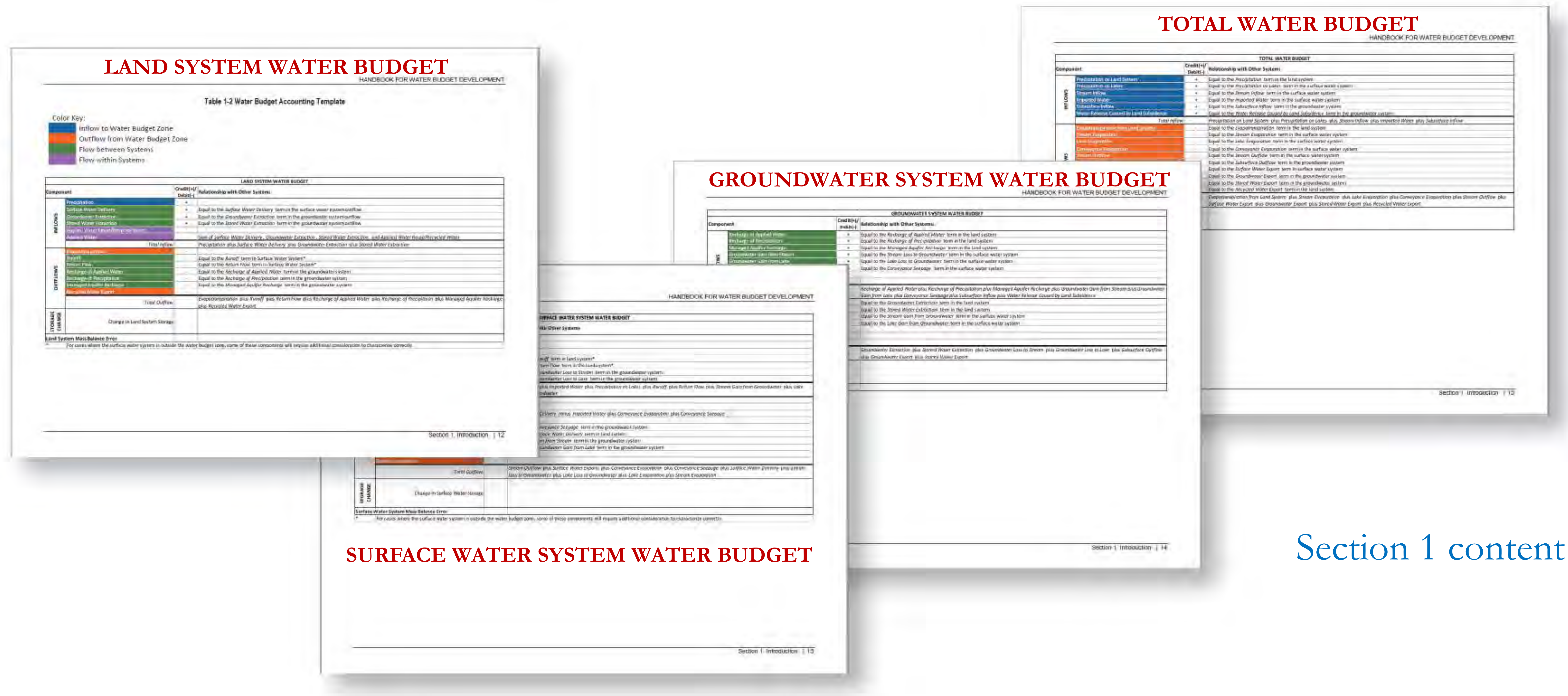
…face Water …) Diversion	Volume of water taken from the surface water system within a water budget zone for use within the zone.

A standardized accounting template will improve organization and communication of water budgets.



Section 1 content

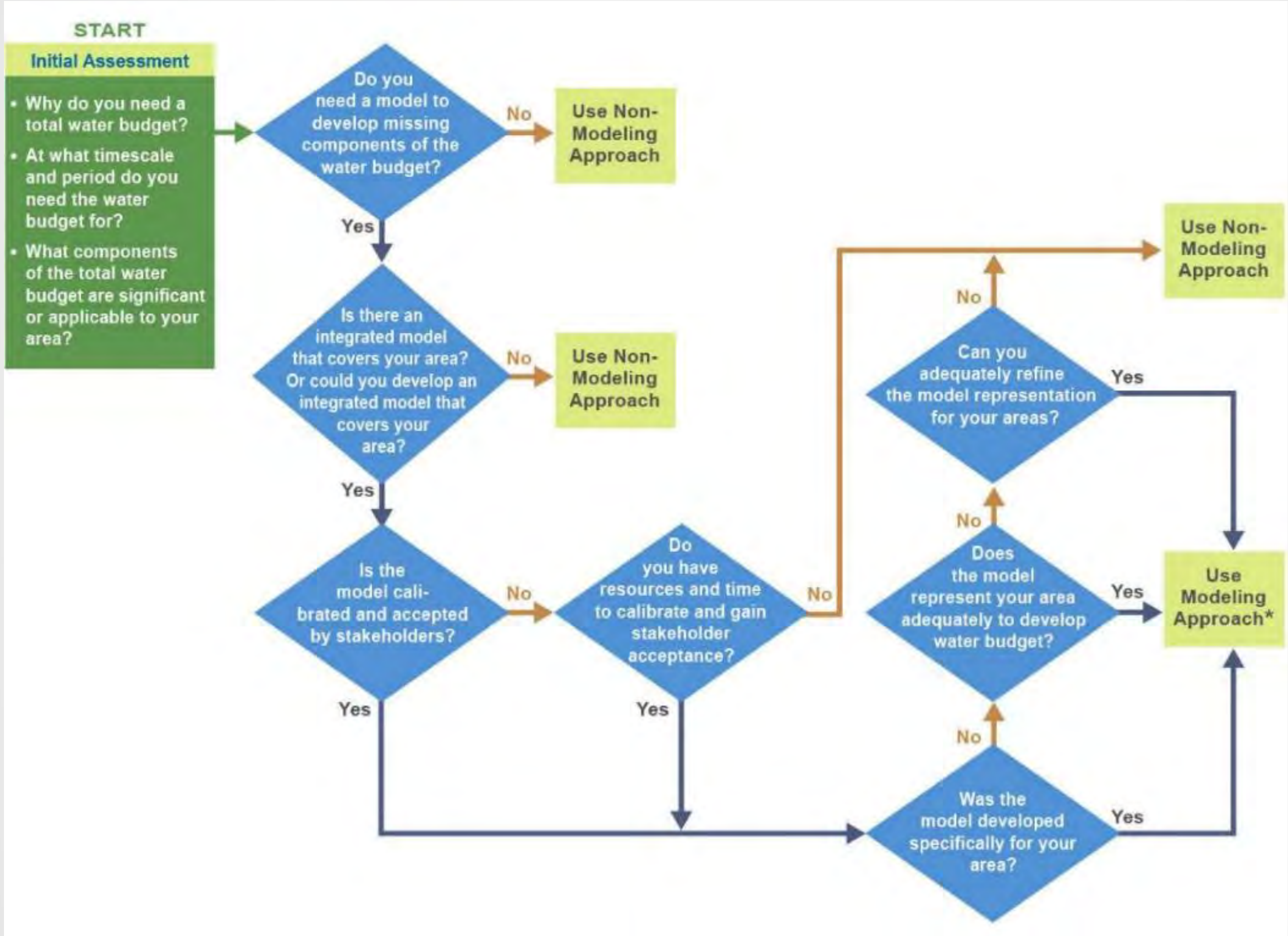
A water budget can be developed using a modeling approach and/or a non-modeling approach.

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.

Section 2 content

Several decision trees are available to guide approaches to water budget development.



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

Section 2 content

Detailed guidance on documentation of water budgets is available to improve communication.

Handbook for Water Budget Development

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

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Handbook for Water Budget Development

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:

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   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.

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Section 2 content

Segment 2: Methods for calculating water budget components

Sections 3, 4, and 5 of the handbook focus on the land, surface water, and groundwater systems.

Handbook for Water Budget Development

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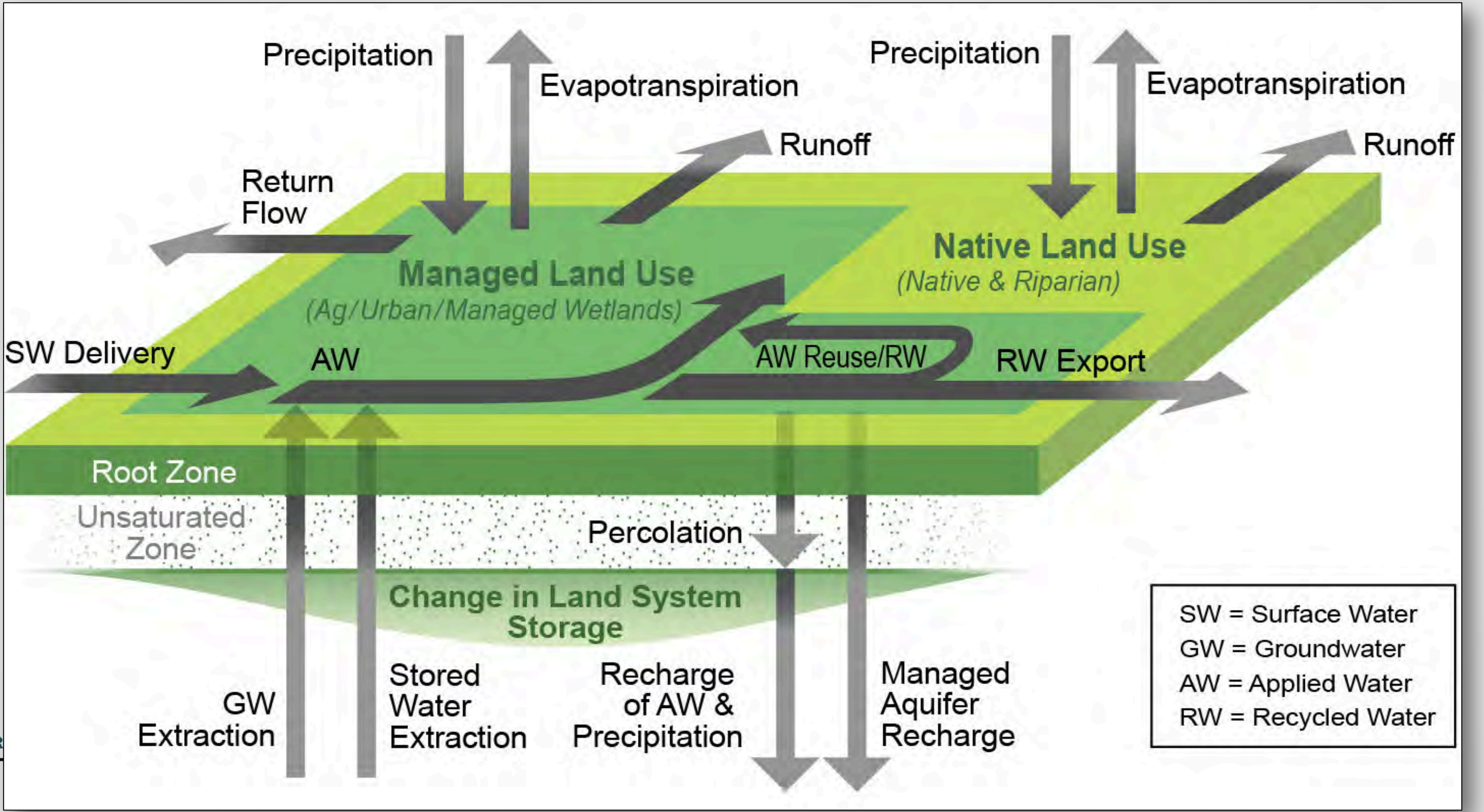
Section 3 focuses on methods for estimating each component of the land system.



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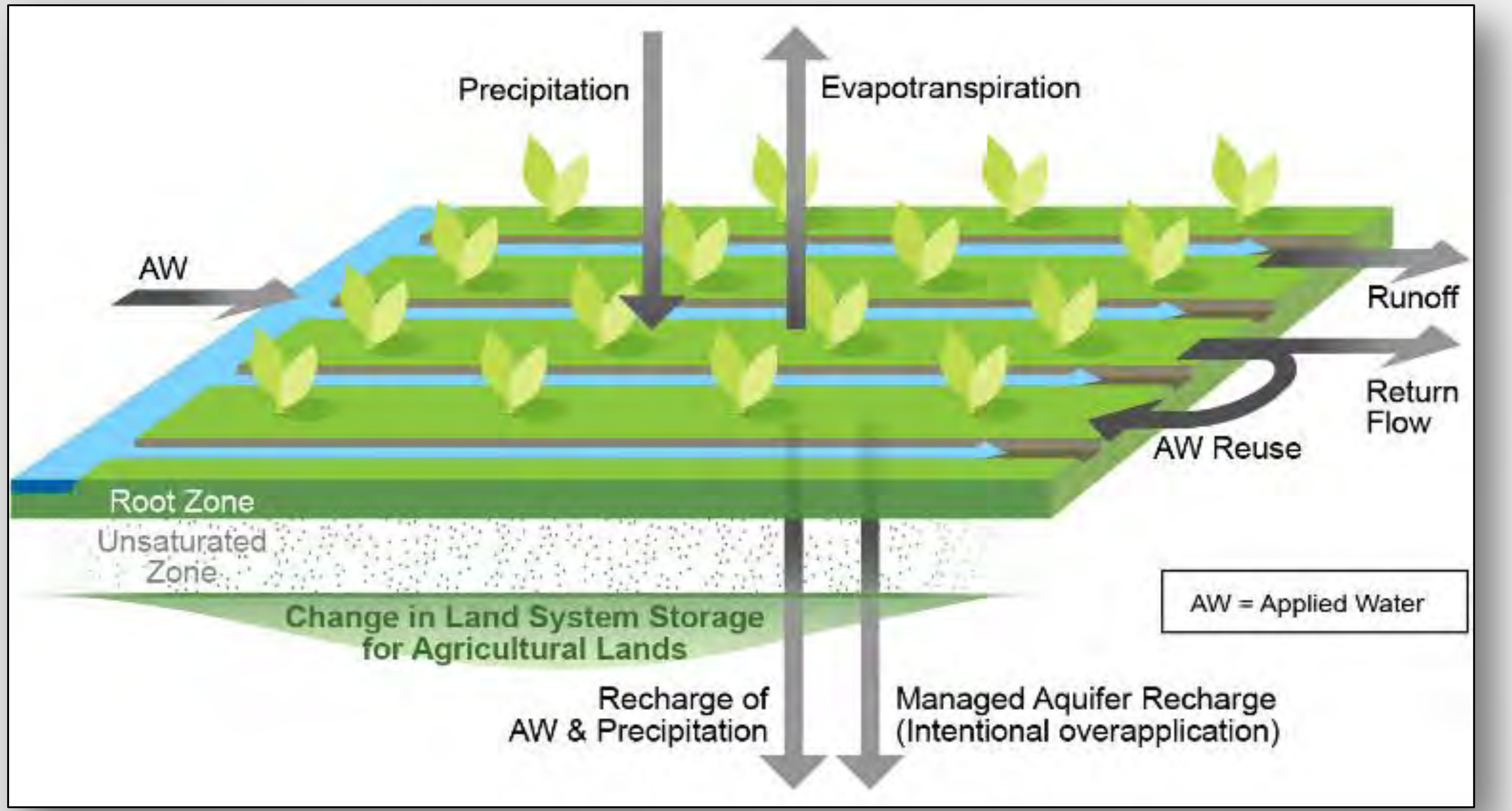
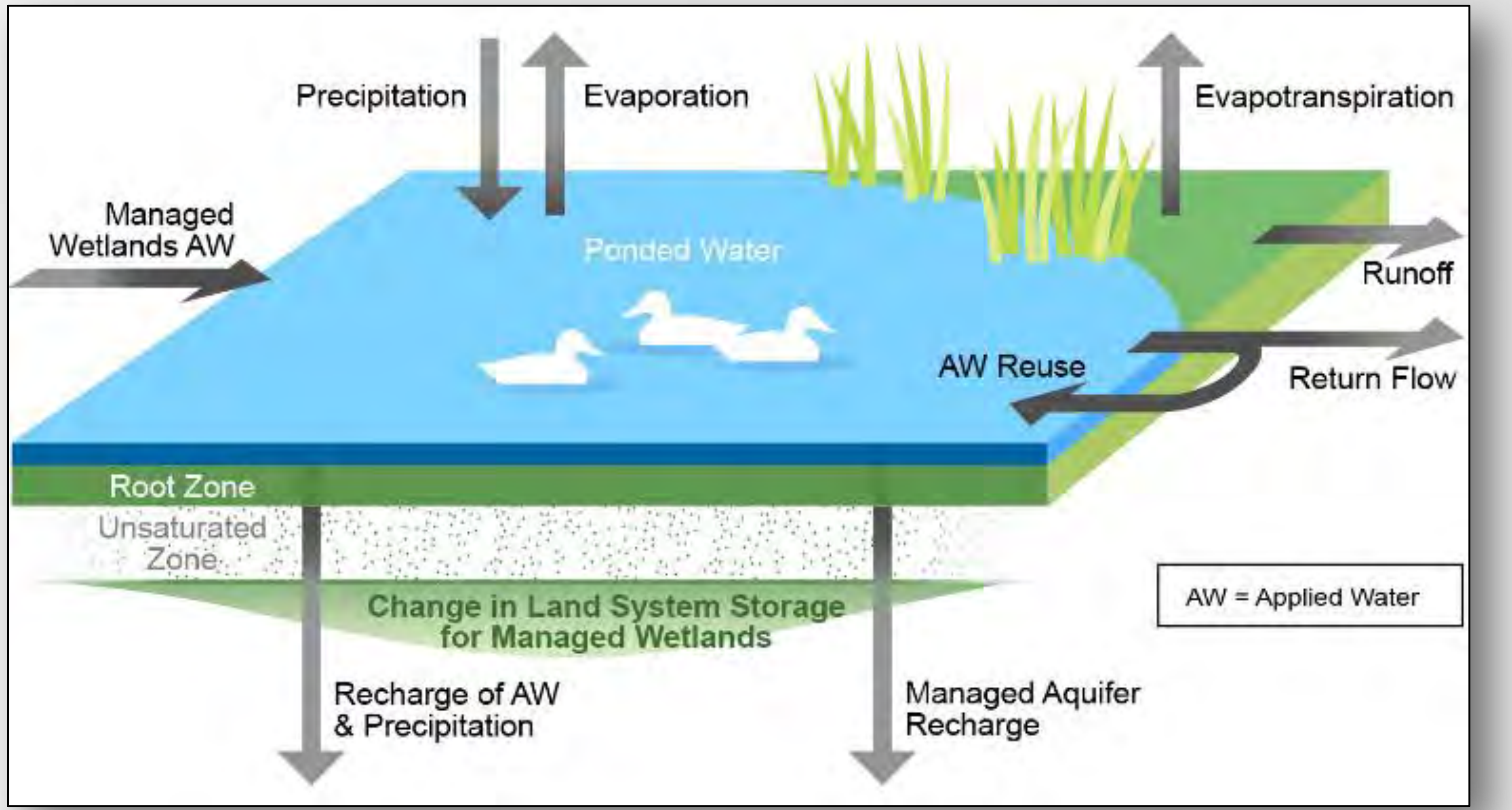
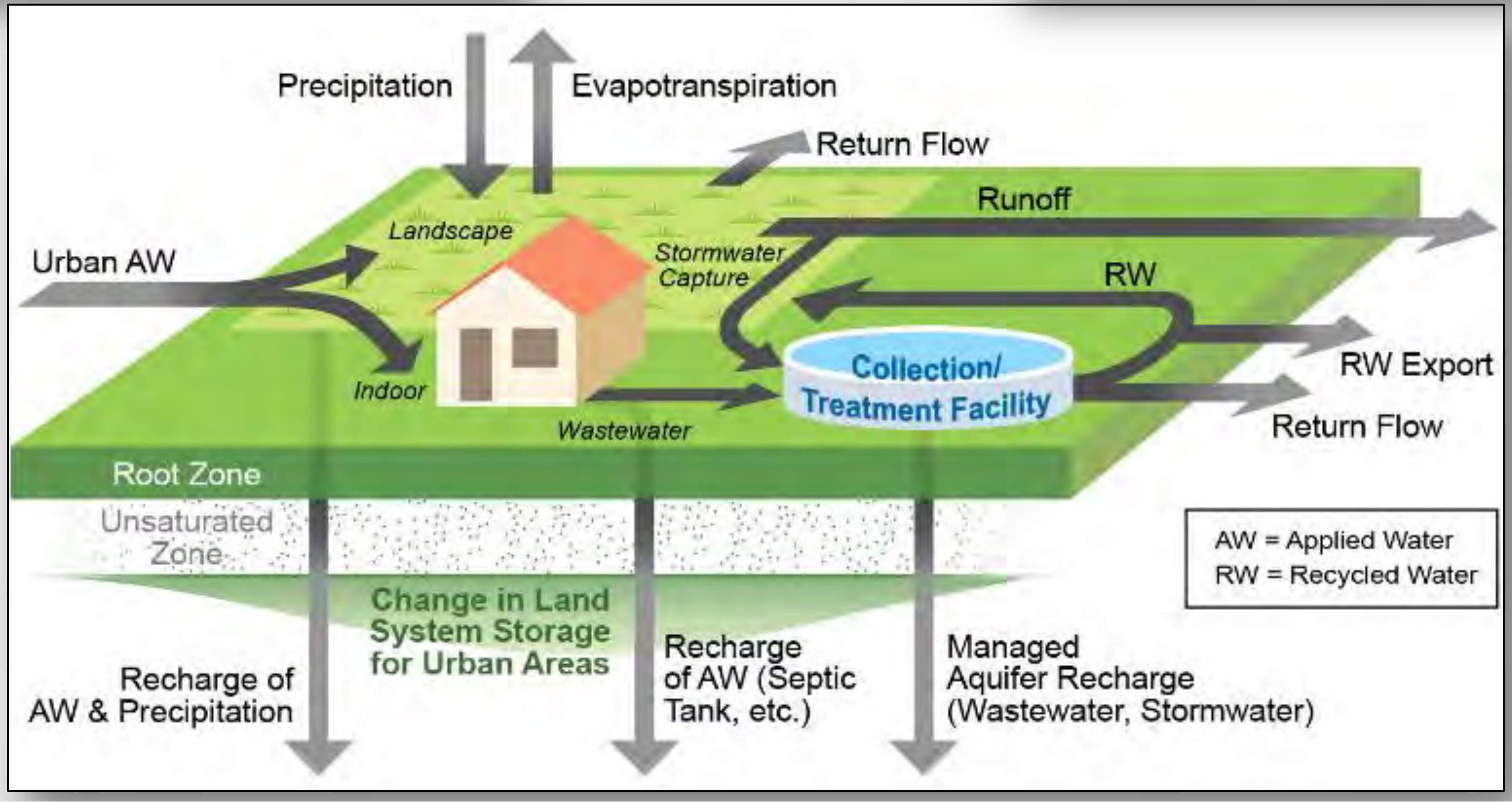
The land system includes many land use types with guidance to address components of each.



AGRICULTURAL LANDS



MANAGED WETLANDS

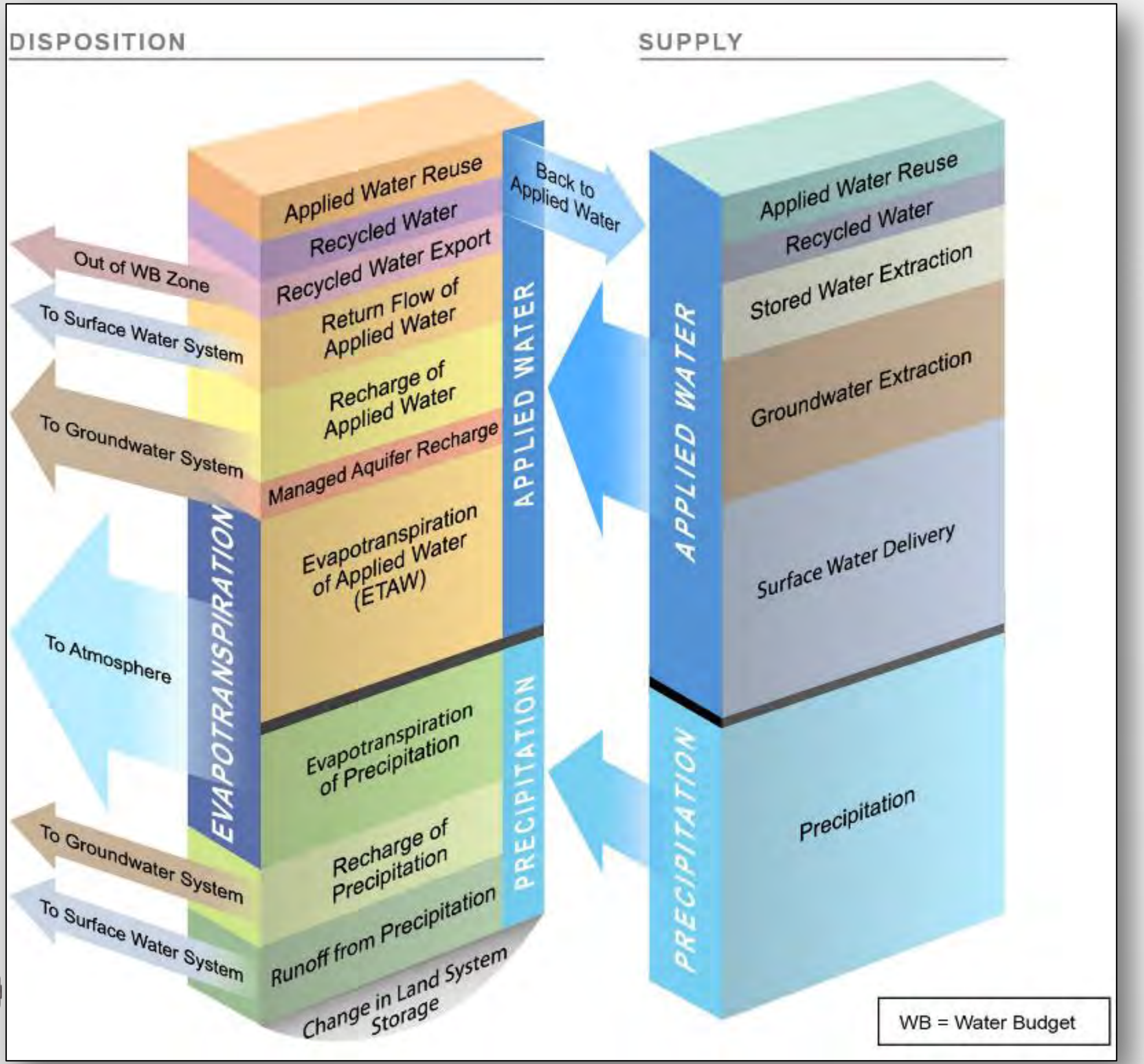


URBAN AREAS

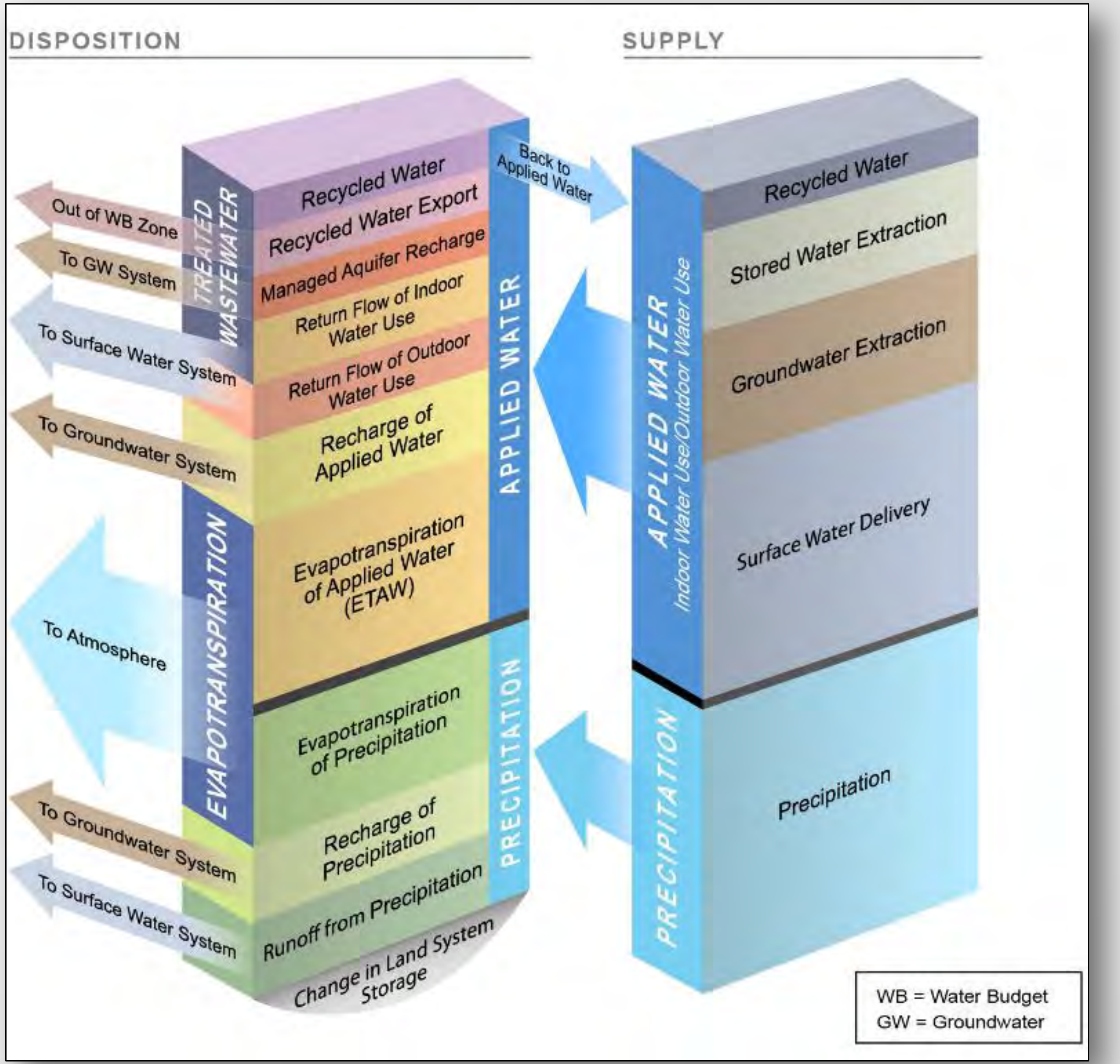
CALIFORNIA DEPARTMENT OF WATER RESOURCES

Applied water use is an important calculation, integral to the understanding of the land system water budget.

AGRICULTURAL LANDS



URBAN AREAS



Each component in the land system water budget includes multiple methods for estimation.

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.

are implementing advanced irrigation technologies that may
represented in these models.

Method 3 – Use Crop Coefficient Approach

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

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

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 an
of the crop, and ET_o is reference crop ET that represents the
reference surface closely resembling an extensive surface of
watered grass of uniform height (0.12 meter), which is active
completely shading the land surface.

Native vegetation ET can be determined through a process lik
crops by using a reference ET (ET_o) and applying vegetation
determine potential vegetation ET. Because precipitation is th
of supply for native vegetation, it becomes the limiting factor
the actual ET for any native vegetation type (actual ET is alwa
potential ET). A soil moisture balance is needed to evaluate h
precipitation is effective (the amount stored in the rootzone a
crop ET) by determining how much precipitation infiltrates th
runoff, how much precipitation is stored in the soil versus rec
groundwater, and then how much of the effective precipitatio
contribute to vegetation ET. For native vegetation, ET will equ
precipitation if no other sources of water in the root zone are
(i.e., shallow groundwater).

The following steps can be taken to estimate ET using Metho

Step 1: Collect Crop Acreage Data: Collect crop acreage a
data in the water budget zone of interest. Crop data are avail
and state agencies. The most common sources of land use da

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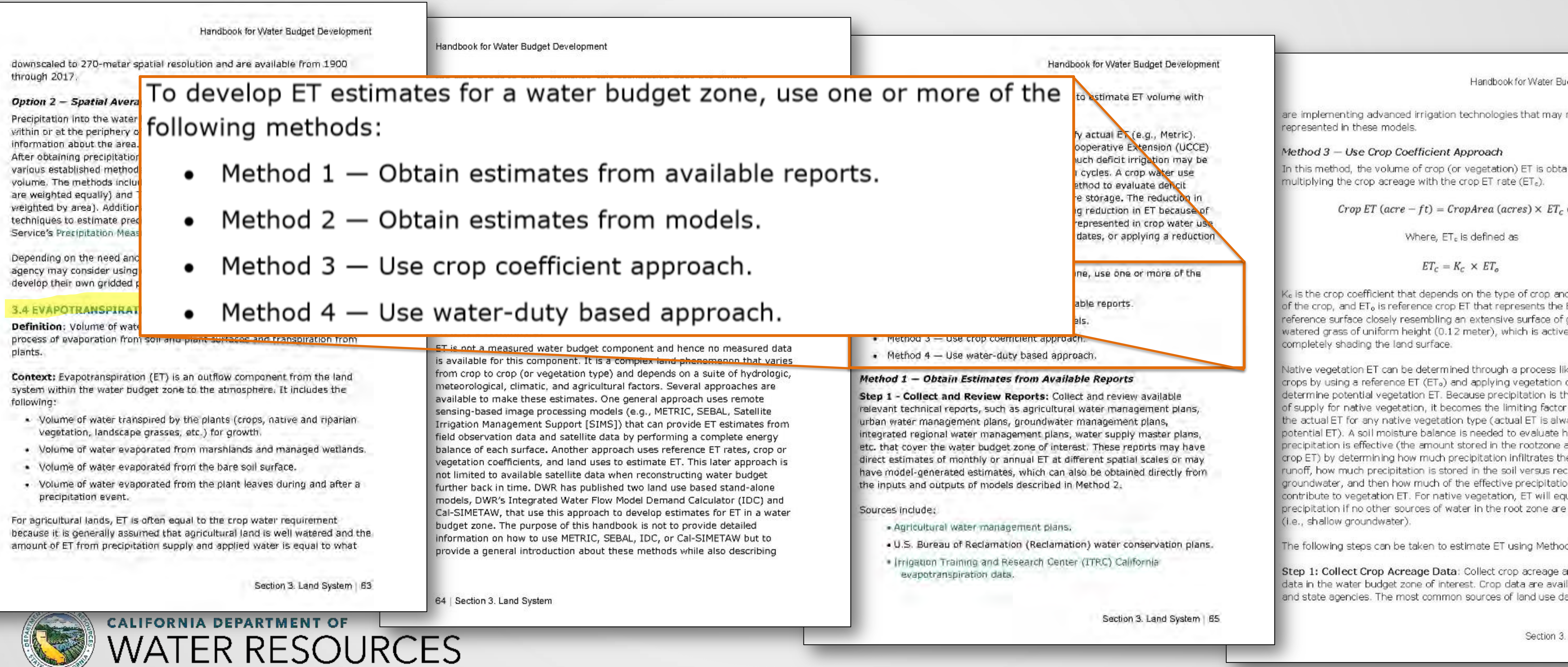
Each component in the land system water budget includes multiple methods for estimation.



Method 3 for calculating applied water provides a springboard to estimate other components.

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

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

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

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The handbook provides step-by-step instructions.

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:

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

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.

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

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

$$AW_{GW} = \sum (\text{Acreage} \times (\text{unit ETAW} / \text{IE} + \text{CP})) \text{ by crop for groundwater sources}$$

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

The steps include calculations and reference tables.

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.

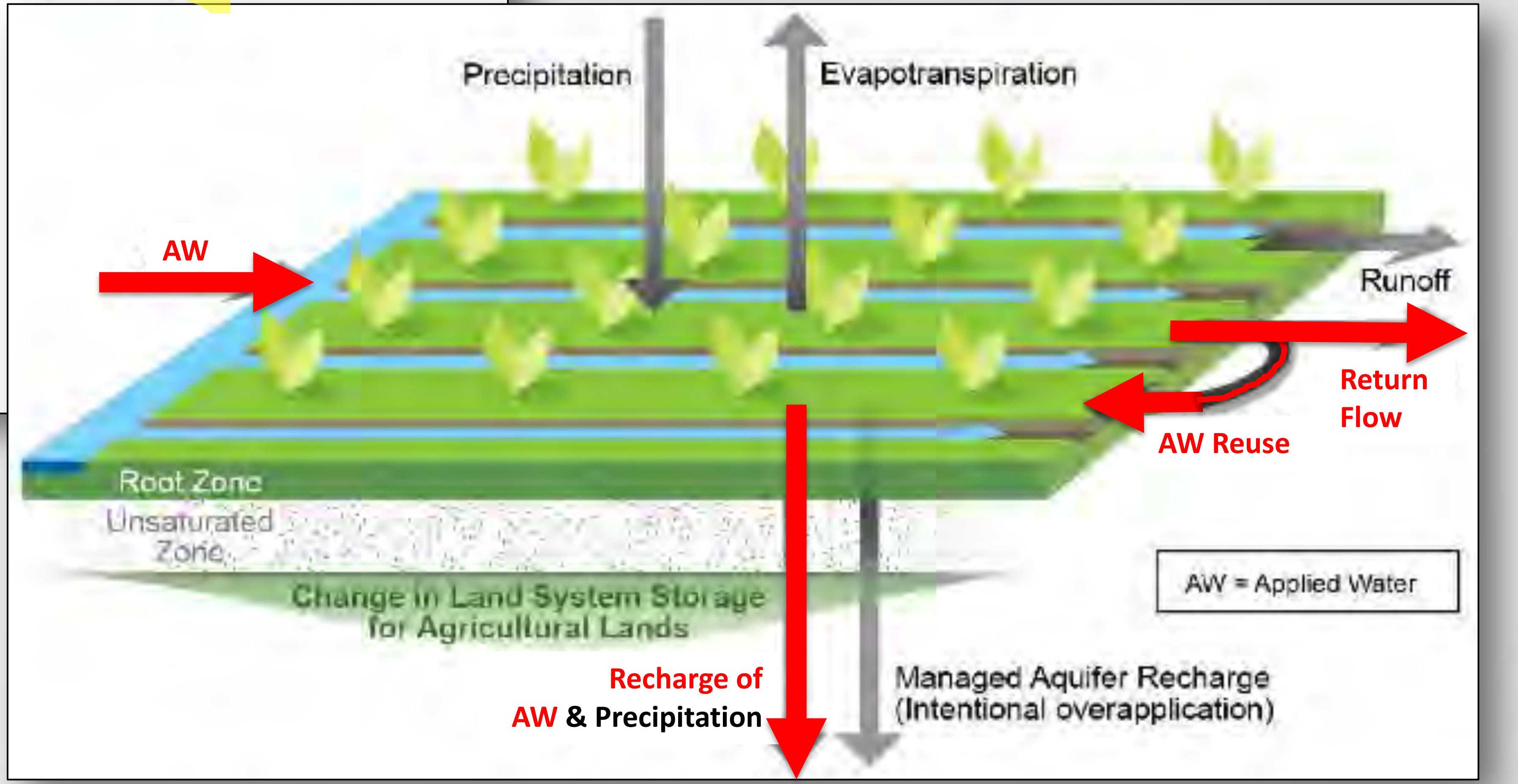
Example: Corn is irrigated on 1,000 acres of land with moderately permeable soils using surface water, furrows, and siphon tubes. The irrigation results in an ETAW of 2.2 af/a. Using Table 3-4 as a guide, furrow irrigation using siphon tubes is estimated to have a 70 percent irrigation efficiency, and 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.

The Handbook provides examples of component calculations.

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.



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Tables provide irrigation system information.

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

The Handbook provides example calculations.

- 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:

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

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

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

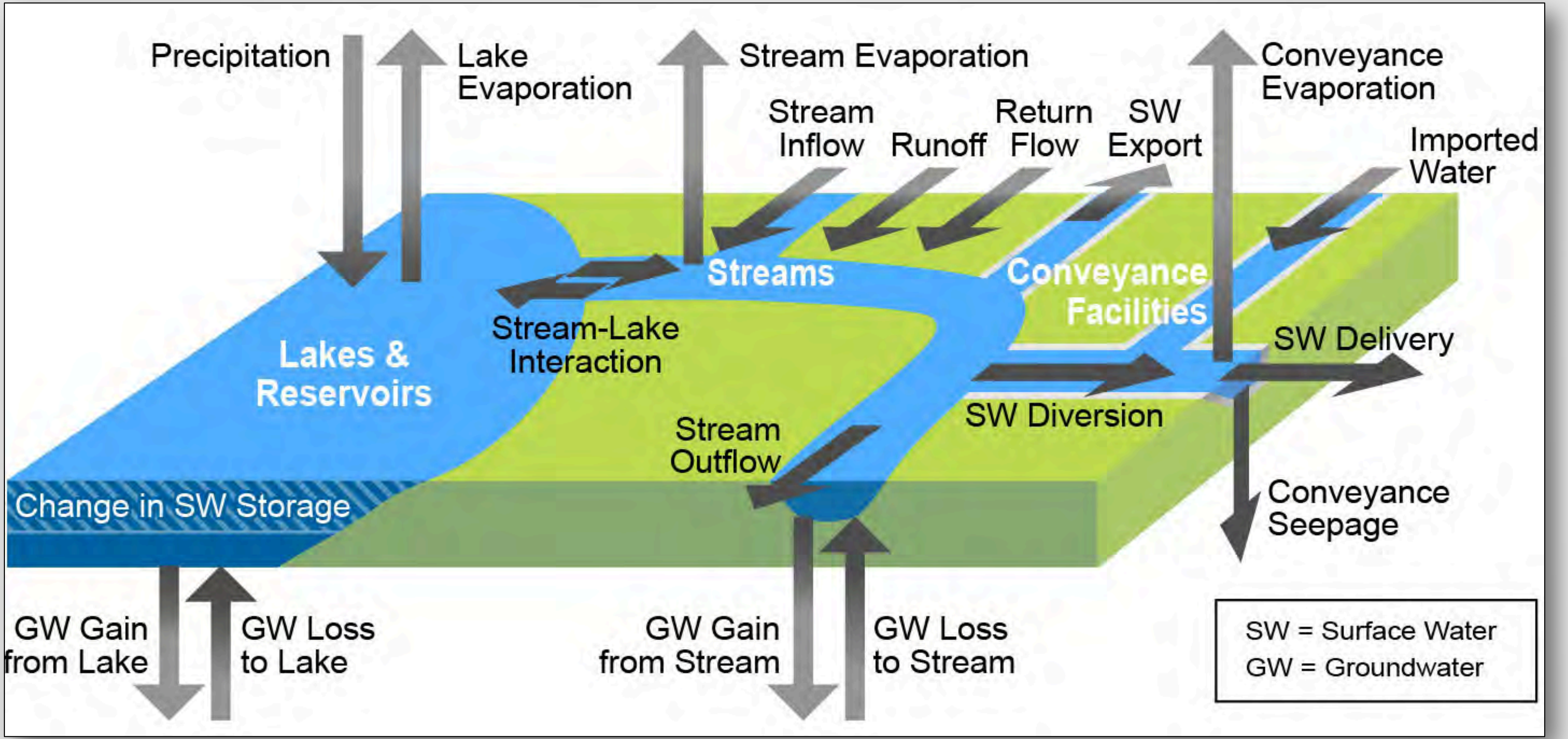
Applied Water Reuse → $$R_u = \text{Applied Water} \times R_{uf} = 3{,}014 \times (0.12 \times 0.5) = 181 \text{ AF}$$

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

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

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.

Section 4 focuses on methods for estimating each component of the surface water system.



Quantifying change in storage and mass balance error is important to fully understand each system.

$$E_L = \frac{1000 k_t C_E \rho_a (q_s - q_z) u_z}{\rho_w}$$

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/m³.
- ρ_w = density of the water kg/m³.
- 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:

Change in Lake Storage = Inflow to Lake – 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:

Mass Balance Error (Lake) = Inflow to Lake – Outflow from Lake – 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:

Mass Balance Error (Surface Water System) = Inflow to Surface Water System – Outflow from Surface Water System – Change in Lake Storage – 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

- USGS Surface-Water Data for th
- DWR CDEC: Current River Cond
- Local agency records, including managing reservoirs.
- Previous reports.
- Input/output files of numerical
- USGS Water-Resources Investig
- USGS Scientific Investigations R
- California Nevada River Forecas

Method 2 — Use Measured Lake L

Using measured lake level data to est matter of obtaining lake level data an which plots lake levels (or elevations) measurements and storage volumes. estimated as follows:

Change in Lake Storage = Storage

Where storage is determined from are each selected timestep.

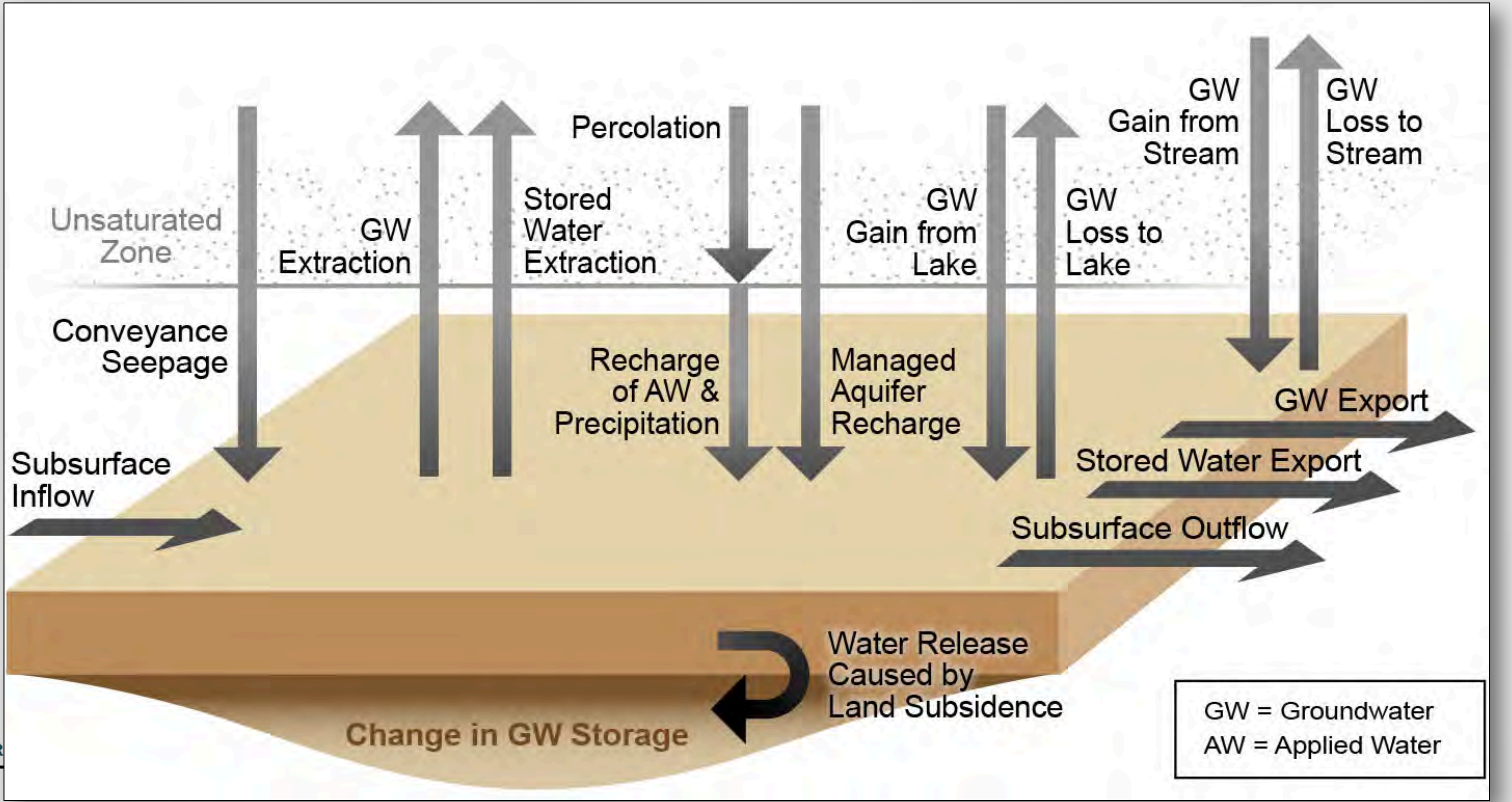
The lead agency responsible for opera source for data. Some sources of lake

- DWR CDEC.
- USGS National Water Informati
- Reclamation Water Operations.
- USACE Sacramento District's W
- Local agencies.

Method 3 — Estimate Using a Mas

In the mass balance approach, inflow precipitation) and outflows (to stream

Section 5 focuses on methods for estimating each component of the groundwater system.



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Recharge of applied water and precipitation is a critical inflow to the groundwater system.

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,

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

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

To support optional tracking of a managed aquifer recharge program, stored water is separated from GW.

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

"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.

Also included in the handbook are methods to estimate change in groundwater storage.

- 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:

$$\text{Mass Balance Error} = \text{Inflow to Aquifer} - \text{Outflow from Aquifer} - \text{Change in Groundwater Storage (measured)}$$

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.

$$\text{Change in Groundwater Storage} = (GWE_{t0} - GWE_{t1}) \times \text{Overlying Area} \times \text{Specific Yield}$$

Segment 3: Applying the handbook to modeling and non-modeling approaches

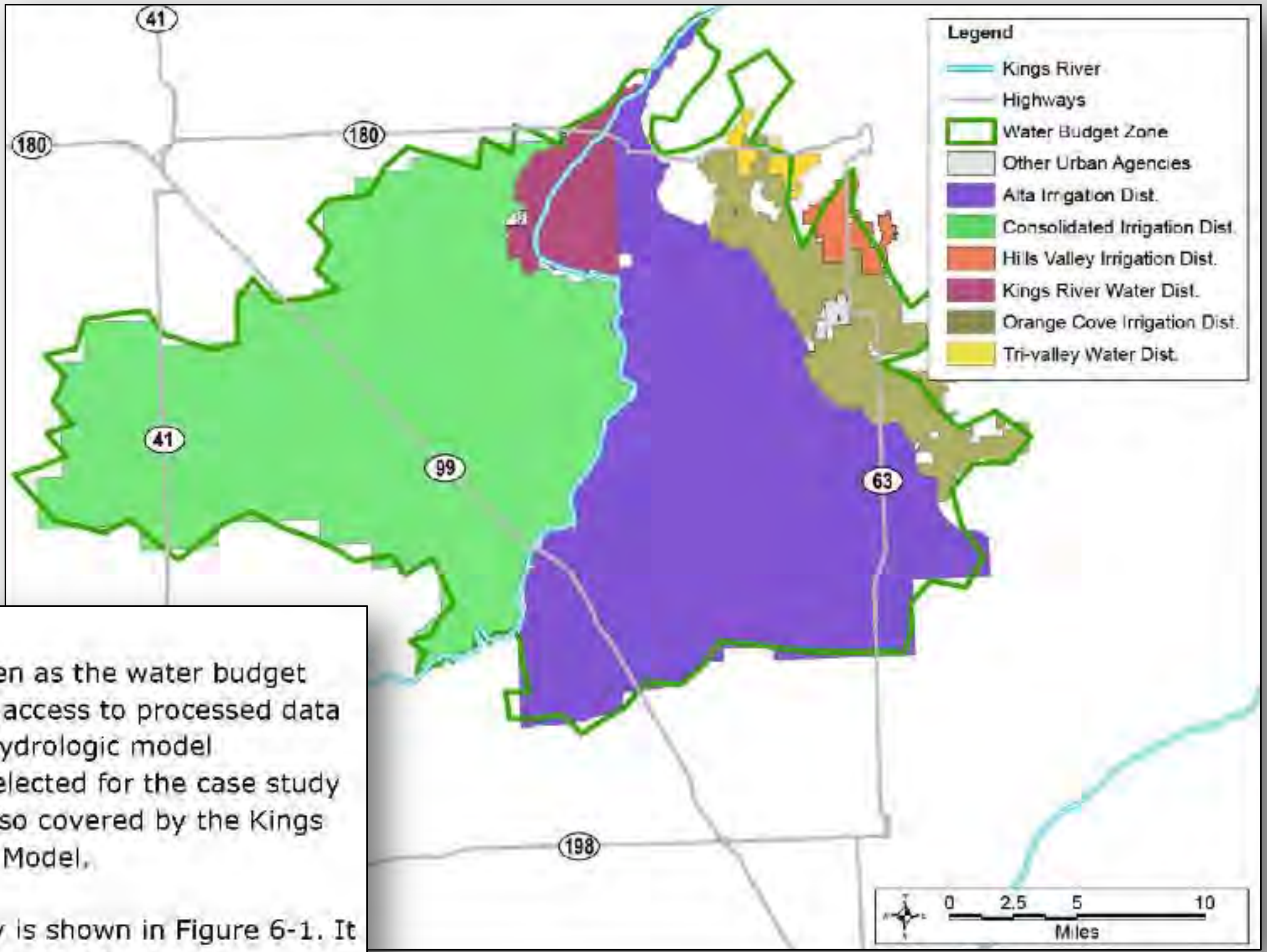
Sections 6, 7, and 8 provide case studies and how-to-guides to help users apply the handbook.

Handbook for Water Budget Development

Section 6 is a case study to apply the handbook using a non-modeling approach.

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.
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.

It contains a worked-out example of developing a water budget and documenting it.

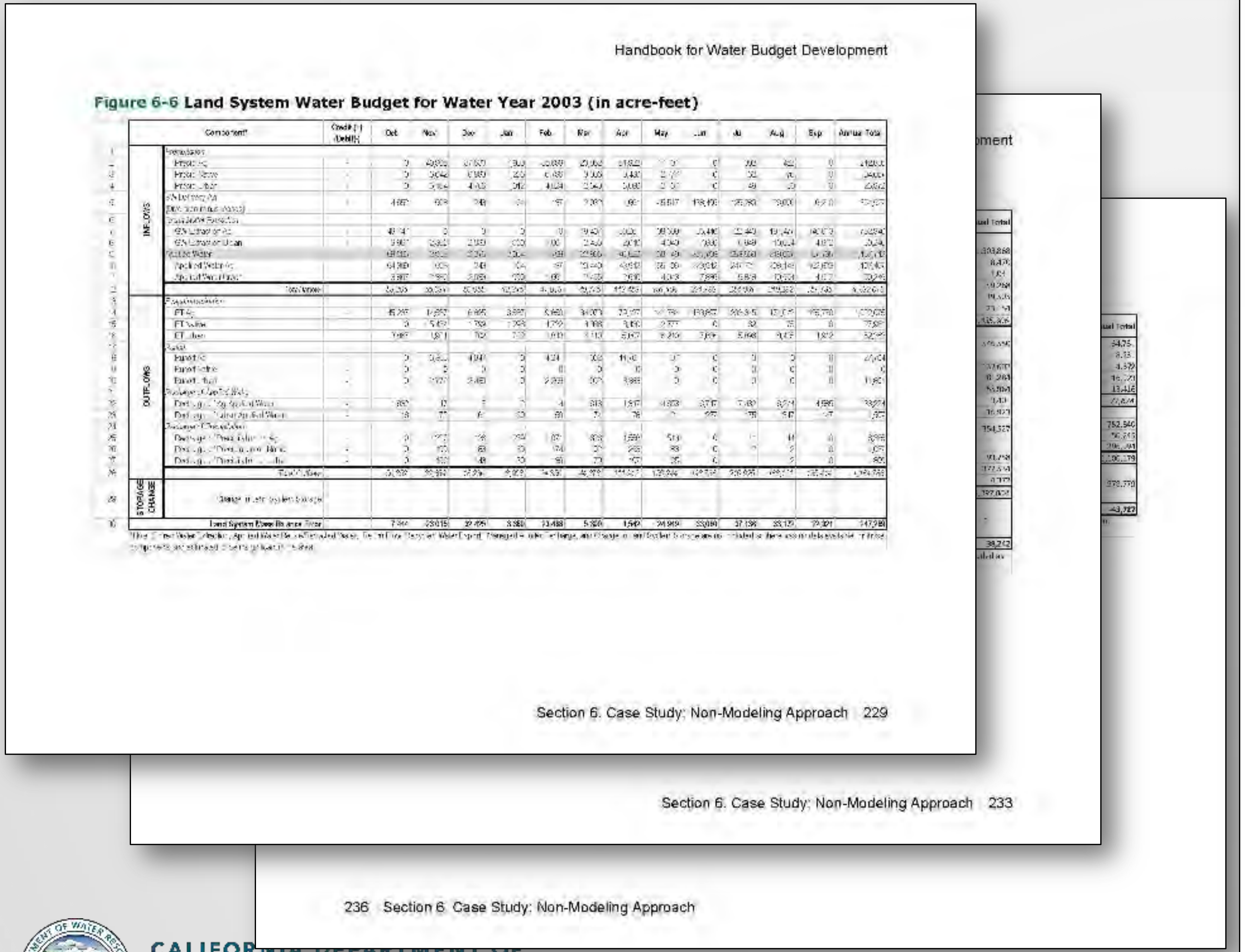


Table 6-2 Documentation: Land System

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

Section 7 explains how to develop a water budget from inputs/outputs of an Integrated Water Flow Model.

Handbook for Water Budget Development

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

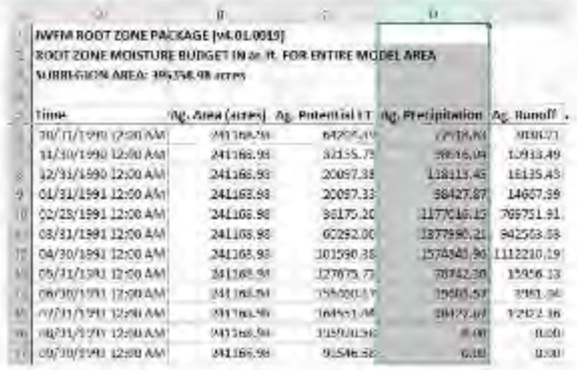
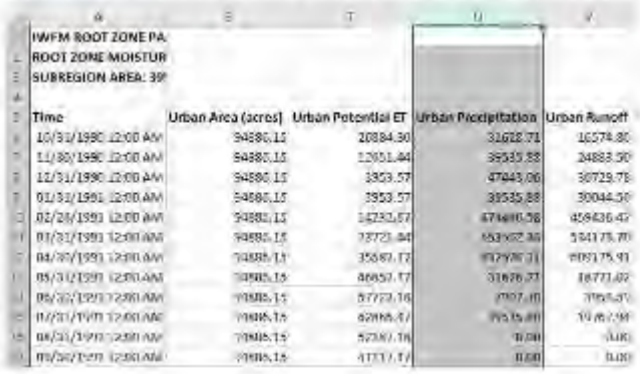


Figure 7-2 Root Zone Moisture Budget: Urban Precipitation



Handbook for Water Budget Development

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		

Section 8 explains how to develop a water budget from inputs/outputs of a MODFLOW-OWHM model.

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

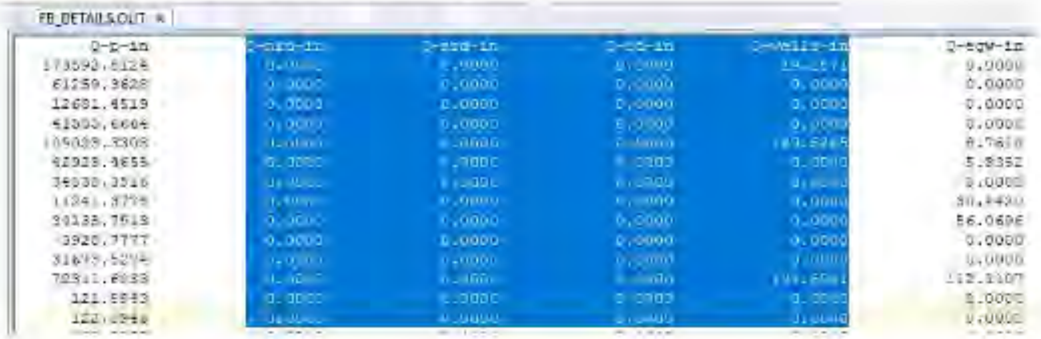


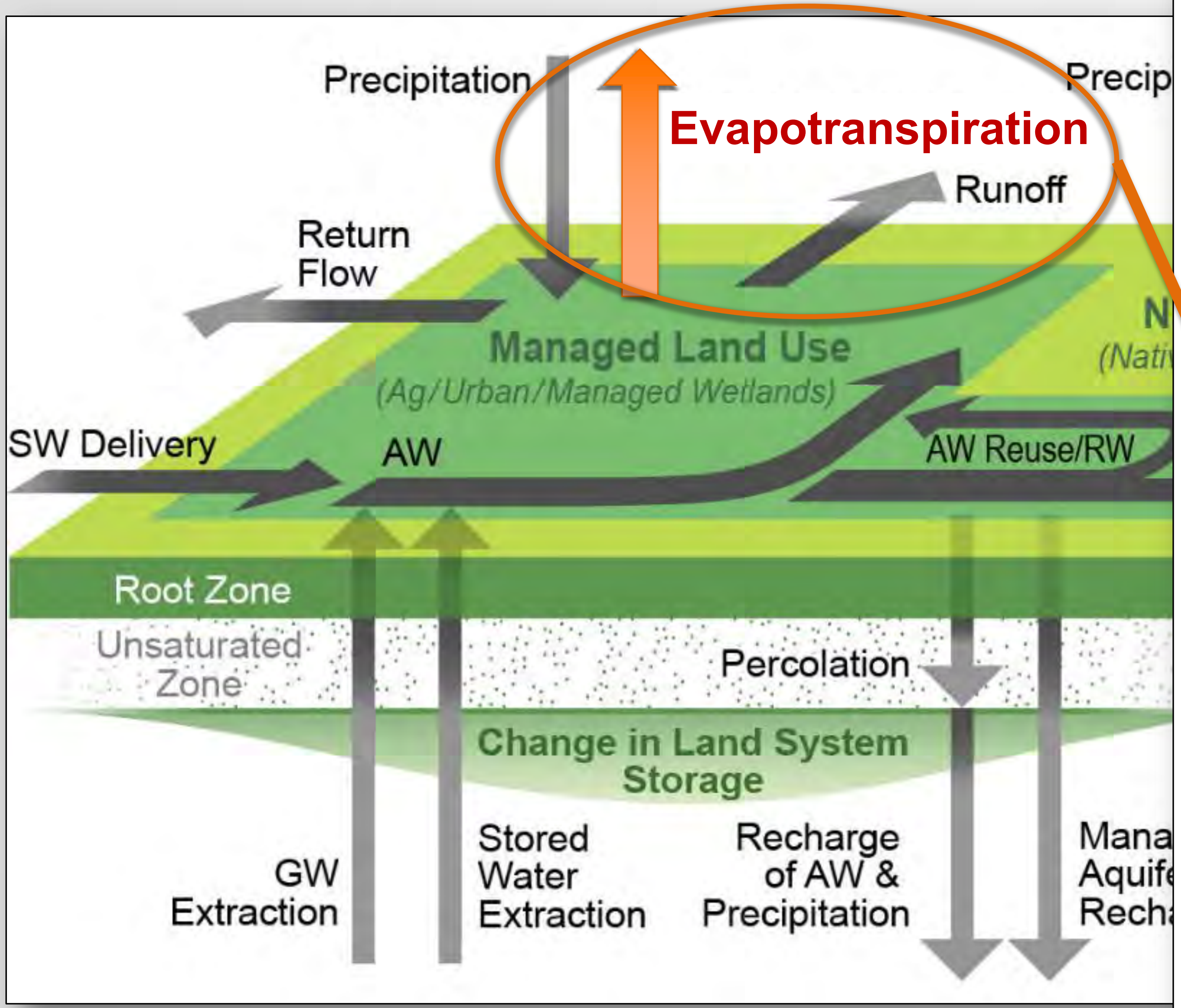
Figure 8-34 Land System Water Budget Components and MODFLOW-OWHM Water Budget Elements

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		

Section 9 is the Data Resources Directory, cataloging sources of data to help develop water budgets.

Figures

Let's say I want to estimate evapotranspiration. Section 3.4 has information but what if I want more sources?



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

mpler methods. These methods can be used to estimate ET volume with nsideration for crop type and crop acreage.

emote sensing techniques can help to quantify actual ET (e.g., Metric). ocal knowledge and University of California Cooperative Extension (UCCE) rmer advisors can provide input as to how much deficit irrigation may be ccurring, such as reduced or altered irrigation cycles. A crop water use odel (e.g., Cal-SIMETAW, IDC) is another method to evaluate deficit rigation and its effects on ET and soil moisture storage. The reduction in pplied water may not result in a corresponding reduction in ET because of tored soil moisture. Deficit irrigation may be represented in crop water use odels by adjusting crop coefficients, harvest dates, or applying a reduction ctor to ET.

o develop ET estimates for a water budget zone, use one or more of the llowing 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.

ethod 1 – Obtain Estimates from Available Re ports

tep 1 - Collect and Review Reports: Collect and review available elevant technical reports, such as agricultural wat management plans, rban water management plans, groundwater ma agement plans, tegrated regional water management plans, wa er supply master plans, c. that cover the water budget zone of interes These reports may have rect estimates of monthly or annual ET at dif rent spatial scales or may ave model-generated estimates, which can so be obtained directly from e inputs and outputs of models described i Method 2.

ources include:

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

The Data Resources Directory provides data sources organized by water budget components.

Figure 9-1 Key to Sources and Related Water Budget Components

Handbook Chapter Reference	Title of Resource	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.
9.2	Agricultural Water Management Plans		●	●			●	●	●													●									
9.3	ALEXI: Atmosphere-Land Exchange Inverse Model		●																												
9.4	BCM: Basin Characterization 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	●	●	●	●	●	●			●	●	●		●	●	●	●	●				●	●	●		●	●	●		●	●

Each resource page includes a one/two-page summary of information about the data source.

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.

9.9 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).

9.17 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.

Segment 4: Responses to common questions and links to additional resources

How can the handbook help me if I want to…

How can the handbook help me if I want to…

… avoid double counting when creating a water budget?

How can the handbook help me if I want to…

… avoid double counting when creating a water budget?

Section 1 contains a standardized accounting template and common vocabulary that will help ensure no component is counted more than once when compiling a water budget.

How can the handbook help me if I want to…

How can the handbook help me if I want to…

… decide whether or not to develop a model to estimate a water budget?

How can the handbook help me if I want to…

… decide whether or not to develop a model to estimate a water budget?

Section 2 contains discussion and flowcharts to help identify what methods would be most appropriate based on your purpose of developing a water budget.

How can the handbook help me if I want to…

How can the handbook help me if I want to…

… document the water budget work that I have done, but don't know what information I should record?

How can the handbook help me if I want to…

… document the water budget work that I have done, but don't know what information I should record?

Section 2.12 provides guidance on documenting a water budget to increase understanding and provide for knowledge transfer.

How can the handbook help me if I want to…

How can the handbook help me if I want to…

… estimate water budget components?

How can the handbook help me if I want to…

… estimate water budget components?

Sections 3, 4, and 5 provide multiple methods, sources of information, steps, and examples for estimating water budget components.

How can the handbook help me if I want to…

How can the handbook help me if I want to…

… find examples of applying the water budget standard accounting template in a physical setting?

How can the handbook help me if I want to…

… find examples of applying the water budget standard accounting template in a physical setting?

Section 6 has an example of developing and documenting a water budget using the standard accounting template for a region in California.

How can the handbook help me if I want to…

How can the handbook help me if I want to…

… use one of the two most commonly used integrated flow models in California to develop a water budget?

How can the handbook help me if I want to…

… use one of the two most commonly used integrated flow models in California to develop a water budget?

Sections 7 and 8 have detailed instructions and quick reference tables for how to develop a water budget based on IWFM or MODFLOW-OWHM.

How can the handbook help me if I want to…

How can the handbook help me if I want to…

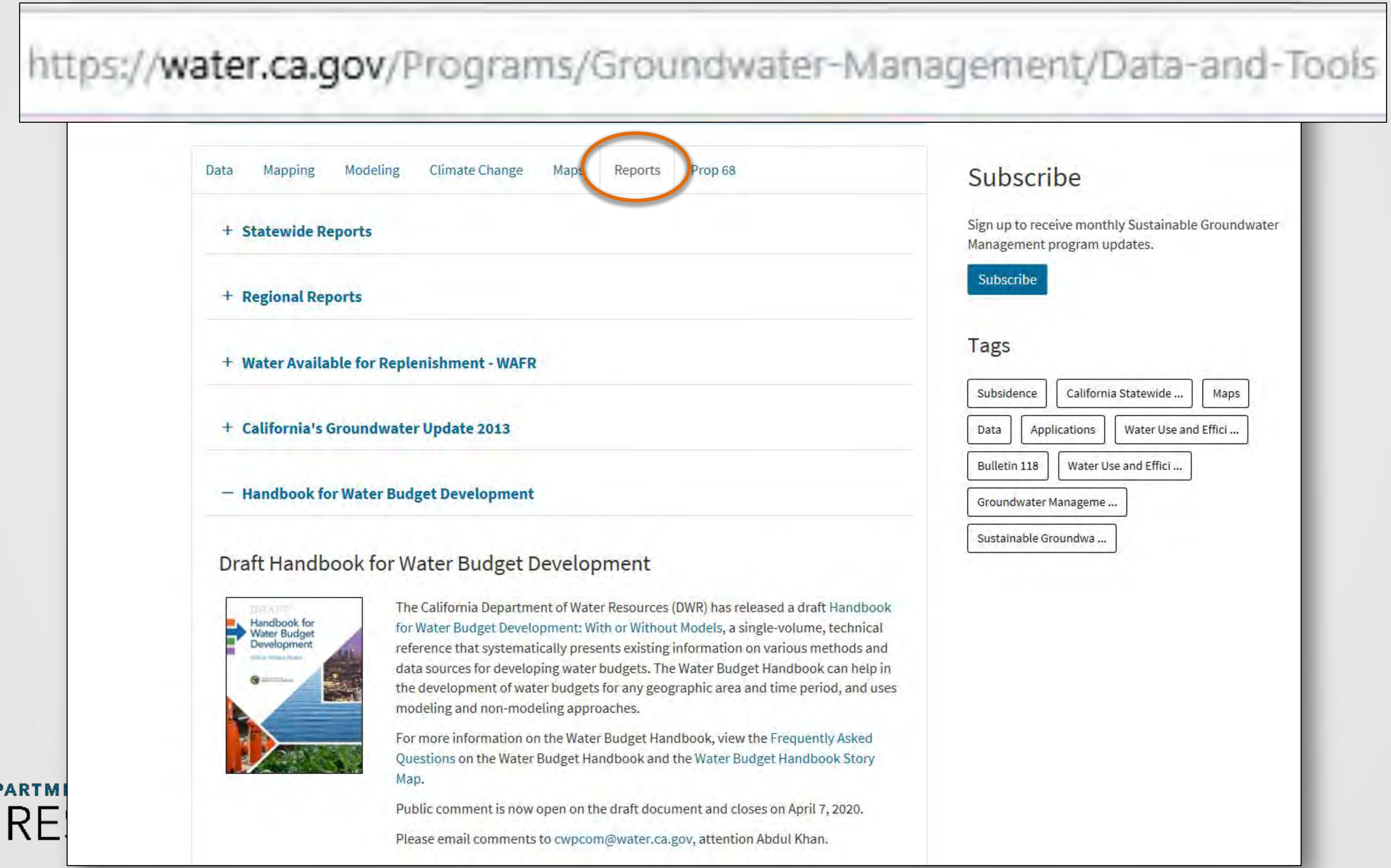
… develop a water budget but cannot find appropriate data sources for various methods?

How can the handbook help me if I want to…

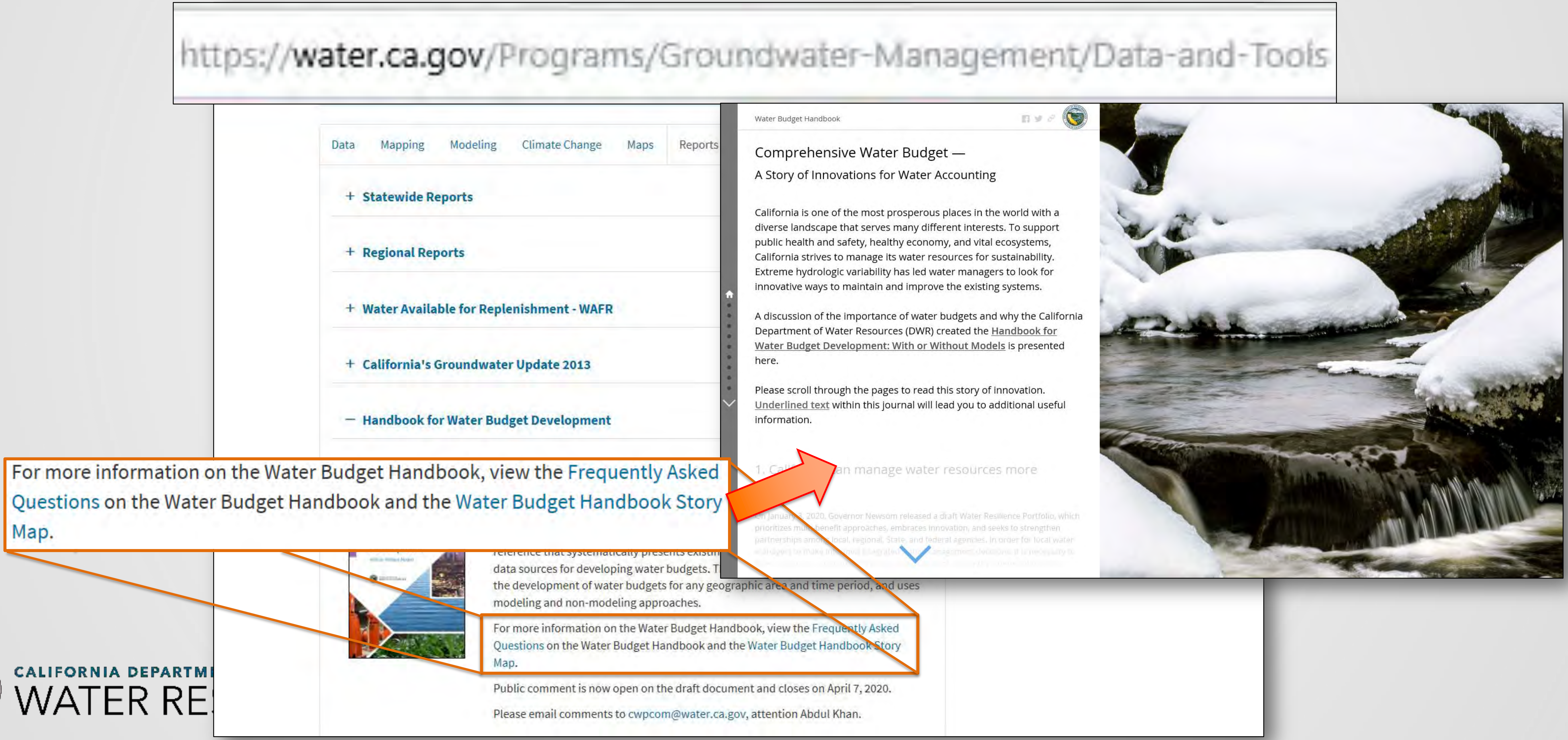
… develop a water budget but cannot find appropriate data sources for various methods?

Section 9 has a detailed list of resources and a cross-reference table to help you easily identify sources of data for water budget estimation.

The Handbook is available on DWR's Groundwater Management, Data and Tools page under "reports."



Also available from that page are some FAQs and the Water Budget Story Map, a story of innovation.



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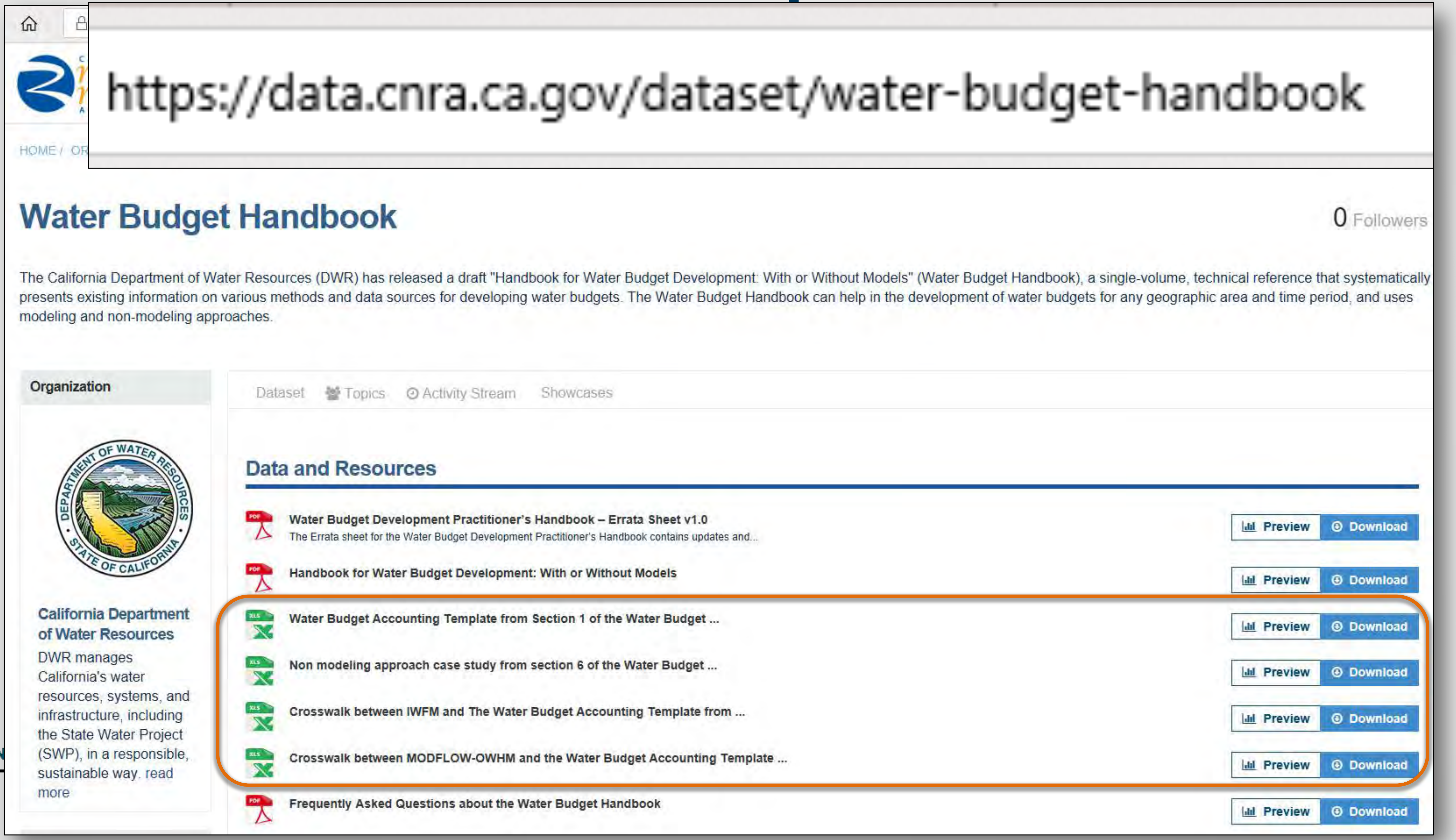
The templates and data from the Handbook are available from the CNRA Open Data Platform.

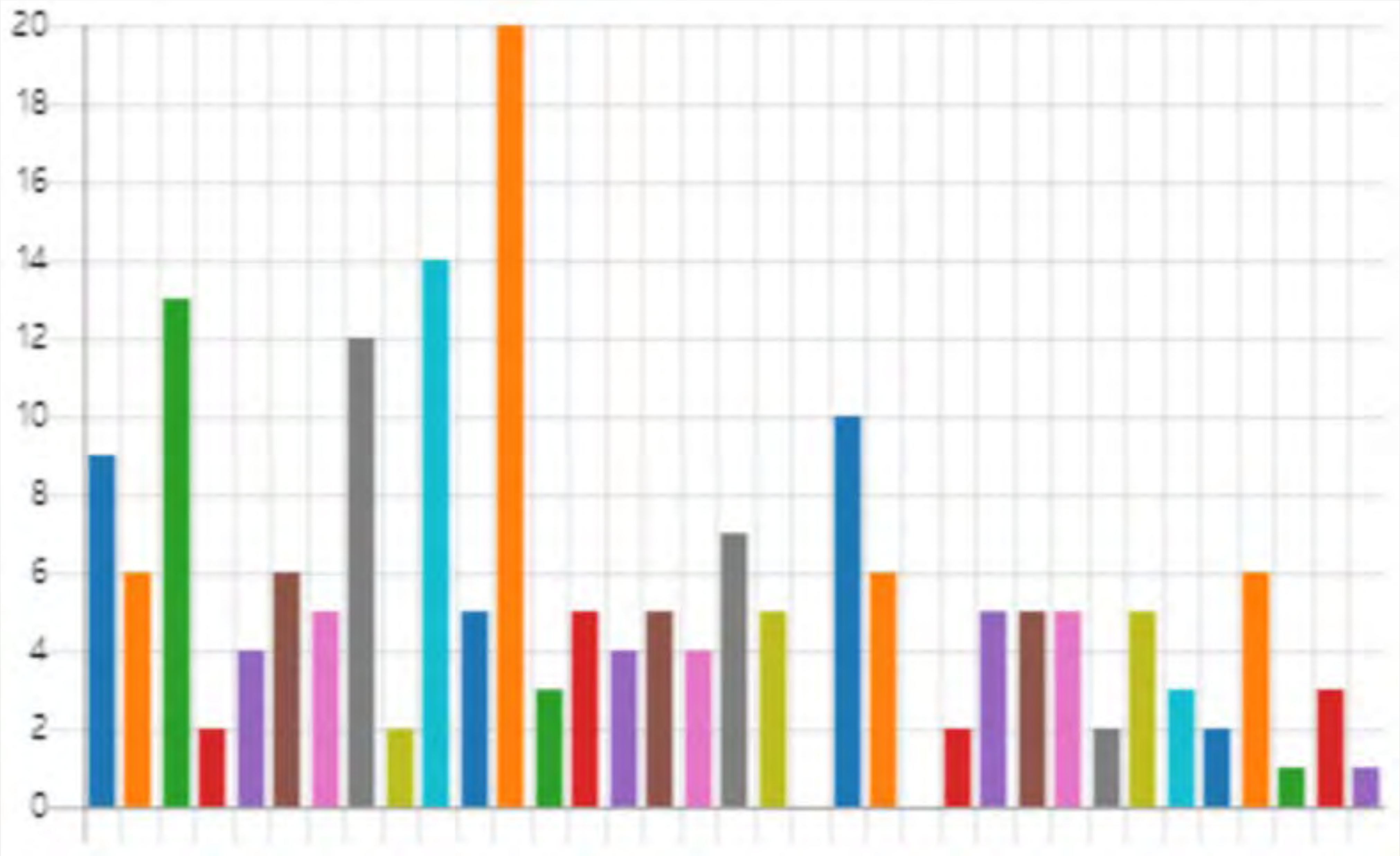


A recording of an Interactive Public webinar on Challenging Water Budget Topics is available.

- Link: https://www.youtube.com/watch?v=U1V4V-SG5jY

Top 4 Survey Responses

Groundwater-Stream Interacti...	20
Groundwater Extraction	14
Change in Groundwater Storage	13
Evapotranspiration	12



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Put the handbook to work to meet your needs and provide feedback to improve the product.

Comments can be submitted to Abdul Khan, by:

- Email: cwpcom@water.ca.gov
- Fax: 916-651-9289
- Postal mail: California Water Plan Update 2018

  Strategic Water Planning Branch
  Division of Planning
  California Department of Water Resources
  P.O. Box 942836, Sacramento, CA 94236-0001

Q & A

Please submit your *content-related questions* in the webinar's **Q&A box**. The moderator will read your question aloud.

Administrative questions can be placed in the **"Chat" box**.

Final Notes

IoW Contact Information:
internetofwater@duke.edu
https://internetofwater.org/

SAP2P Network:
Website: https://internetofwater.org/state-agency-p2p-network/
Webinars: https://internetofwater.org/webinars/

Join us for continued conversation at the IoW P2P Forum:

https://stateagencyforum.internetofwater.org

Poll: Please participate in a quick poll!

Follow-Up Information

- Links to the webinar recording and slides will be distributed once posted

Thank you for your participation!