California Department of Water Resources
Best Management Practices for the Sustainable Management of Groundwater

DRAFT
Water Budget
Best Management Practice

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Water Budget Best Management Practice

1. Objective

The objective of this Best Management Practice (BMP) is to provide technical assistance to Groundwater Sustainability Agencies (GSAs) and other stakeholders on the preparation of a water budget in accordance with requirements of the Groundwater Sustainability Plan (GSP) Emergency Regulations (Regulations) and the long-term groundwater sustainability goal of the Sustainable Groundwater Management Act (SGMA). The information provided in this BMP also identifies available resources to support development, implementation, and reporting of water budget information for the basin.

This BMP includes the following sections:

1. Objective. The objective and brief description of the contents of this BMP.
2. Use and Limitations. A brief description of the use and limitation of this BMP.
3. Water Budget Fundamentals. A description of fundamental water budget concepts
4. Relationship of Water Budgets to other BMPS. A description of how the water budget BMP relates to other BMPs and how water budgets information may be used to support development of other GSP requirements.
5. Technical Assistance. A description of technical assistance to support the development a water budget, potential sources of information, and relevant datasets that can be used to further define each component.
6. Key Definitions. Definitions relevant for this BMP as provided in the GSP Regulations, Basin Boundary Regulations, the SGMA, and DWR Bulletin 118.
7. Related Materials. References and other materials that provide supporting information related to the development of water budget estimates.

2. Use and Limitations

This BMP is only intended to provide technical assistance to GSAs and other stakeholders. GSAs and other stakeholders have the option of using this BMP; the content provided in this BMP does not create any new requirements or obligations for the GSA or other stakeholders.

This BMP does not serve as a substitute for the GSP Regulations and the SGMA. Those submitting a GSP are strongly encouraged to read the GSP Regulations and the SGMA. In addition, using this BMP to develop a GSP does not equate to an approval by the Department.

3. WATER BUDGET FUNDAMENTALS

Earth's water is moved, stored, and exchanged between the atmosphere, land surface, and the subsurface according to the hydrologic cycle (**Figure 1**). The hydrological cycle begins with evaporation from the ocean. As the evaporated water rises, the water vapor cools, condenses, and ultimately returns to the Earth's surface as precipitation (rain or snow). As the precipitation falls on the land surface, some water may infiltrate into the ground to become groundwater, some water may runoff and contribute to streamflow, some will evaporate, and some may be used by plants and transpired back into the atmosphere to continue the hydrologic cycle (Healy, R.W., et.al., 2007).

The water budget takes into account the storage and movement of water between the three components of the hydrologic cycle, the atmosphere, the land surface, and the subsurface. A water budget is a foundational tool used to compile or estimated water inflows (supplies) and outflows (demands) into an accounting of the total groundwater and surface water entering and leaving a basin, and to calculate the difference between inflows and outflows as a change in the amount of water stored.

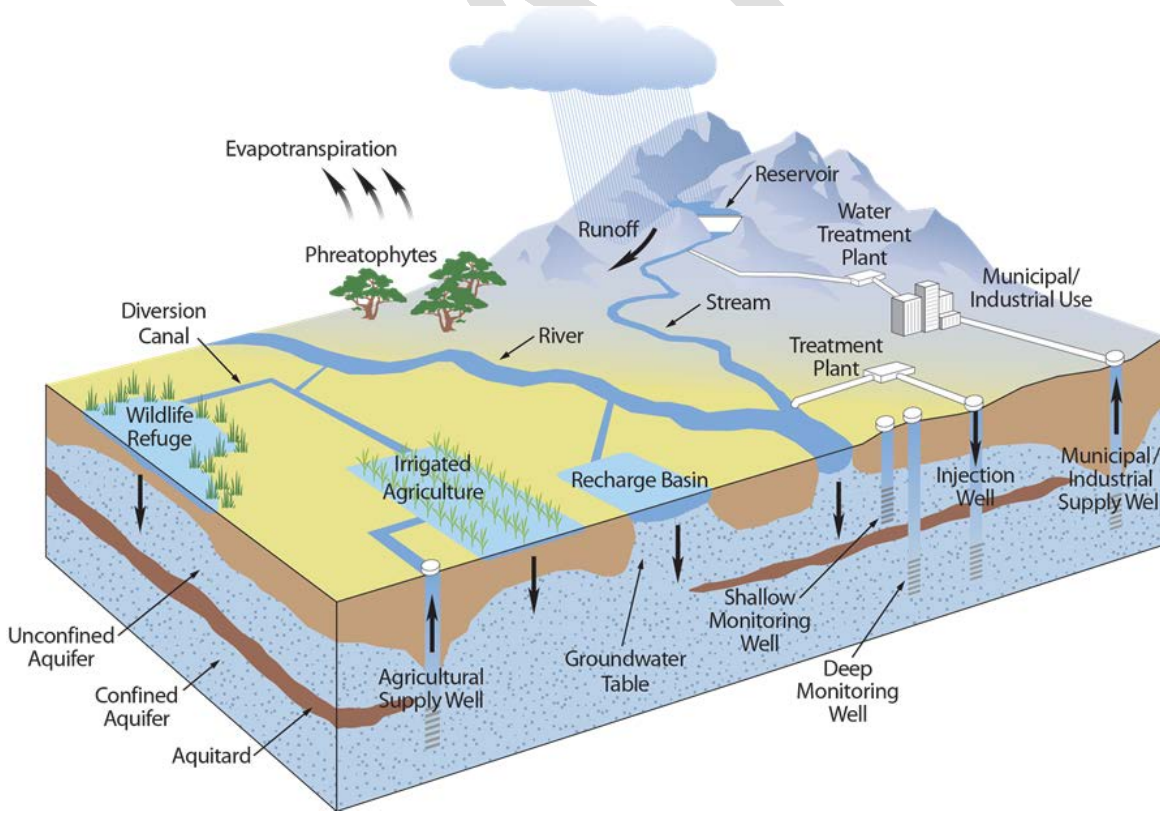


Figure 1 –The Hydrologic Cycle (updated figure in development)

In the world of resource management, it's often said you can't manage what you don't measure. Similar to a checking account, water budget deposits (inflows) and withdrawals (outflows) are tracked and compared over a given time period to help identify if the ending account balance is positive (increase in amount of water stored) or negative (decrease in the amount of water stored). During periods when inflows exceed outflows, the change in volume stored is positive. Conversely, during periods when inflows are less than outflows, the change in aquifer storage is negative. Surpluses from previous budget periods can act as a buffer towards isolated annual water budget deficits, but a series of ongoing negative balances can result in conditions of long-term overdraft.

In some basins, precipitation may be the largest contributor to groundwater recharge. In other basins, leading sources of recharge may stem from infiltration of irrigation water, conveyance systems, septic systems, and various surface water systems (streams, lakes, reservoirs, etc.). In areas where the groundwater levels are above the surface water systems and the direction of groundwater flow is towards the surface water system, the surface water system will receive water from the groundwater system.

In principle, a water budget is a simple concept that measures, evaluates, and takes into consideration water inflow and outflow from all parts of the atmosphere, land surface and subsurface components of a basin. In reality, it can be difficult to accurately measure and account for all components of the water budget for a given area. Some water budget components may be estimated independent of the water budget, while others may be calculated based on the fundamental principle that the difference between basin inflows and outflows are balanced by the change in water in storage. This principle is quantified according to the following water budget equation.

$$\text{Inflows (a, b, c)} - \text{Outflows (a, b, c)} = \text{Change in Storage}$$

Equation 1 – Water Budget Equation

Because groundwater basin inflows and outflows are balance by a change in amount of water in storage, the above equation may be rearranged to calculate, or back into, an unknown component of the water budget equation. For example, if one wishes to determine unknown Outflow component "a", and all other components of the water budget for the groundwater system have been determined, outflow(a) can be calculated by rearranging the above water balance as follows:

$$\text{Outflow (a)} = \text{Inflow (a, b, c)} - \text{Outflow (b, c)} - \text{Change in Storage}$$

To illustrate this example, consider an annual groundwater budget where total inflow from components (a, b, and c) equal 100 units of water, and total outflow from all components other than "a" equals 40 units of water, and the annual change in storage identified through groundwater level measurements is approximately equal to +10 units of water. An estimate of outflow(a) during this period may be calculated from the above water budget equation as follows:

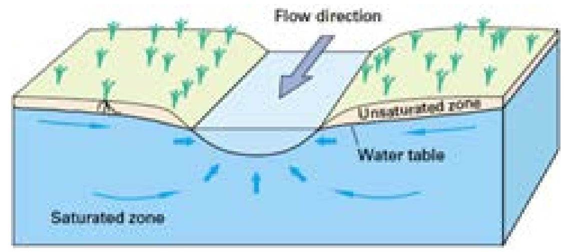
Outflow (a) = Inflow (a, b, c) – Outflow (b, c) – Change in Storage
50 units = 100 units – 40 units – 10 units

Identifying which water budget components are most appropriate to estimate through balancing of the water budget equation will depend on the local ability to independently measure or estimate the remaining water budget components and on the relative importance, versus *uncertainty*, associated with each component in the overall water budget. A higher level of water budget uncertainty often translates to a higher risk that the proposed projects and management actions being evaluated, based on future water budget projections, may not achieve the intended outcome within the intended timeframe.

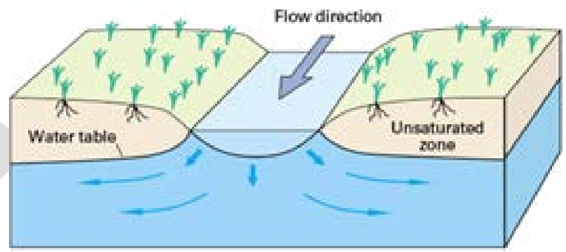
An important water budget component that needs to be considered when implementing sustainable water resource management is the interaction between groundwater and surface water systems. Groundwater flow naturally moves down-gradient, from areas of groundwater recharge to areas of groundwater discharge. In areas where groundwater levels have dropped below the surface water system, the direction of groundwater flow will be from the surface water system and to the groundwater system. Streams which receive water from the groundwater system are called "gaining" streams and those that lose water to the groundwater system are called "losing" streams (see associated text box). The gaining or losing character of streamflow may be consistent throughout a stream system or it may be highly variable based on stream reach location and the seasonal versus annual changes in local climatic conditions and the water inflow (recharge) or outflow (groundwater extraction) for the basin.

Unless additional inflows or supplies are developed, ongoing increases in groundwater extraction will eventually result in a complete disconnection between the surface water and groundwater systems. Once surface water and groundwater systems become disconnected, all further extraction from the groundwater system will be largely balanced through a decline of groundwater in storage and/or a reduction of subsurface outflow from the basin.

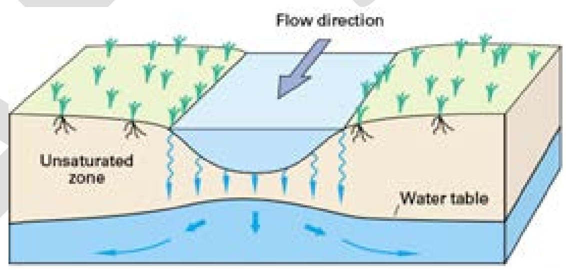
Another important water budget consideration is stream depletion due to groundwater pumping. In basins with *interconnected surface water* systems, if inflows (recharge) to the basin remain fixed while the amount of groundwater extraction increases, the increased volume of groundwater extraction won't necessarily express itself as a one-to-one decline in the volume of aquifer storage. Instead, the amount of groundwater extraction will be offset through the direct or indirect depletion of surface water systems. Shallow production wells in close proximity to surface water systems commonly capture flow directly from the surface water system through induced recharge. Stream depletion associated with pumping wells further removed from surface water systems is more commonly the result of the indirect capture of groundwater flow that would otherwise have discharged to the surface water system sometime in the future. In both situations, streamflow depletion will continue until a new equilibrium between the outflow associated with groundwater extraction and the inflow from surface water depletion is established. The time lag to reach this new equilibrium is directly related to the location and construction of production wells, the thickness and hydrologic conductivity of the aquifer system, and the capacity and timing of the groundwater extraction wells. In many basins, stream depletion due to groundwater extraction will continue for decades prior to reaching a new equilibrium (Barlow, P.M., and Leake, S.A., 2012).



Gaining Stream



Losing Stream



Losing Stream that is Disconnected from the Water Table

(*Source: Winter, T.C., et.al., 1998*)

In order to accurately identify and evaluate the various inflow and outflow components of the water budget, it is important to adequately characterize the interaction between surface water and groundwater systems through sufficient monitoring of groundwater levels and streamflow conditions. The Monitoring Networks and Monitoring Protocol BMPs have additional information regarding GSP monitoring requirements.

Due to the complexities of characterizing stream depletion due to groundwater extraction, integrated groundwater - surface water models are commonly used to assist with water budget accounting and forecasting. Additional information regarding consideration of models under the GSP Regulations is provided in the Modeling BMP and in Section 5 of this BMP (*Technical Assistance*).

Common Water Budget Uses

Water budget accounting may be very general or very detailed, depending on the hydrologic complexities of the basin, the scale and intent of water budget accounting, and the importance of understanding the individual water budget components to support water resource decision making. Some of the general and GSP Regulation-specific water budget uses and applications are provided below.

General Water Budget Uses:

- Develop an accounting and spatial distribution of inflows and outflows to a watershed, groundwater basin, or management area.
- Identify the primary beneficial uses and users of water and determine which water budget components are most critical to the area.
- Improve communication between the local land use planners and water resource managers.
- Estimate water budget components that are not easily measured or well understood.
- Evaluate how the surface and groundwater systems respond to the seasonal and long-term changes to supplies, demands, and climatic conditions.
- Identify the timing and volume of inflows and outflows that will result in a balanced water budget condition for a management area.
- Develop a water supply assessment of future conditions to better understand the effects of proposed land and water use changes to the local and regional water budget.
- Inform additional monitoring needs.
- Identify the interaction between surface water and groundwater systems.

GSP-Related Water Budget Uses:

The SGMA requires local agencies to develop and implement GSPs that achieve *sustainable groundwater management* by implementing projects and management actions intended to ensure that the basin is operated within its *sustainable yield* by avoiding *undesirable results*. A key component in support of this effort is an accounting and assessment of the current, historical, and projected water budgets for the basin. The following provides a partial list of GSP-related water budget applications and uses:

- Develop an accounting and spatial distribution of inflows and outflows to the basin by *water source type* and *water use sector,* to identify the main beneficial uses and users and determine which water budget components are most critical to achieving sustainable groundwater management.
- Assess how annual changes in historical inflows, outflows, and change in basin storage vary by *water year type* (hydrology) and water supply reliability.
- Develop an understanding of how historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability to operate the basin within sustainable yield.
- Improve coordination and communication between the GSA and water supply or management agencies, local land use approval agencies, and interested parties who may be subject to sustainable groundwater management fees.
- Facilitate coordination of water budget data and methodologies between agencies preparing a GSP within the basin (intra-basin) or between basins (inter-basin).
- Identify data gaps and *uncertainty* associated with key water budget components and develop an understanding of how these gaps and uncertainty may affect implementation of proposed projects and water management actions.
- Evaluate how the surface and groundwater systems respond to the annual historical changes in the water budget inflows and outflows.
- Determine the rate and volume of surface water depletion caused by groundwater use that has adverse impacts on the beneficial uses of the surface water and may lead to undesirable results.
- Identify which water budget situations commonly result in *overdraft conditions*.
- Estimate the sustainable yield for the basin
- Forecast projected inflows and outflows to the basin over the *planning and implementation horizon*.
- Evaluate the effect of proposed projects and management actions on future water budget projections.
- Evaluate future scenarios of water demand uncertainty associated with projected changes in local land use planning, population growth, and climate.
- Inform monitoring requirements.
- Inform development and quantification of sustainable management criteria, such as the *sustainability goal*, undesirable results, *minimum thresholds*, and *measureable objectives*.
- Help identify potential projects and management actions to achieve the sustainability goal for the basin within twenty years of GSP implementation.

Water Budgets in Reference to the GSP Regulations

As previously mentioned, water budgets are a foundational tool used to account for the various inflows, outflows, and change in storage over a given area and time period. With respect to the GSP Regulations, developing a water budget that accurately identifies and tracks changing inflows and outflows to the basin will be a critically important tool to support decision making regarding the implementation of sustainable management actions and projects.

The simplicity or complexity of water budgets will vary by groundwater basin according to the local complexities of the basin hydrology, physical setting, spatial distribution of supplies and demands, historical water management practices and the presence or absence of undesirable result. Ongoing parallel efforts to monitor and verify water budget components will help improve accuracy; however, some level of uncertainty is inherent in each water budget. An important objective of water budget accounting under the GSP Regulations is to develop an understanding of what level of water budget uncertainty and detail is sufficient for making effective basin management decisions.

The GSP water budget requirements are not intended to be a direct measure of groundwater basin sustainability; rather, the intent is to quantify the water budget in sufficient detail so as to build local understanding of how historical changes to supply, demand, hydrology, population, land use, and climatic conditions have affected the six *sustainability indicators* in the basin and ultimately utilize this information to predict how these same variables may affect or guide future management actions. Building a coordinated understanding of the interrelationship between changing water budget components and aquifer response will allow local water resource managers to effectively identify future management actions and projects most likely to achieve and maintain the sustainability goal for the basin.

Another important aspect of documenting water budget information in the GSP is to ensure DWR is provided with sufficient information to demonstrate the GSP conforms to all the SGMA and GSP Regulation requirements and, when implemented, is likely to achieve the sustainability goal in the basin within 20 years of the GSP implementation.

4. Relationship of the Water Budget to Other BMPs

Quantifying the current, historical, and projected water budget for the basin is just one of several interrelated GSP elements the GSAs will use to help understand the basin setting, evaluate groundwater conditions, determine undesirable results, develop sustainability criteria, establish appropriate monitoring networks, and ultimately identify future projects and management actions that are likely to achieve and maintain the sustainability goal for the basin. **Figure** 2 illustrates the relationship of the water budget BMP to the other BMPs, and to the overall steps towards achieving sustainability under SGMA and the GSP Regulations.

Figure 2 identifies the water budget BMP as part of the Basin Setting portion of the GSP Regulations (§354.12). However, the water budget BMP also directly supports, or is supported, by several other BMPs such as, stakeholder outreach, development of the Hydrogeologic Conceptual Model (HCM), modeling, monitoring networks, monitoring protocols, and establishing sustainable management criteria. Basin monitoring feeds into the understanding of the HCM and groundwater conditions, which helps support the understanding and quantification of the water budget and model development, and ultimately supports evaluation of sustainability indicators, undesirable results, and basin management decisions to achieve the sustainability goal for the basin.

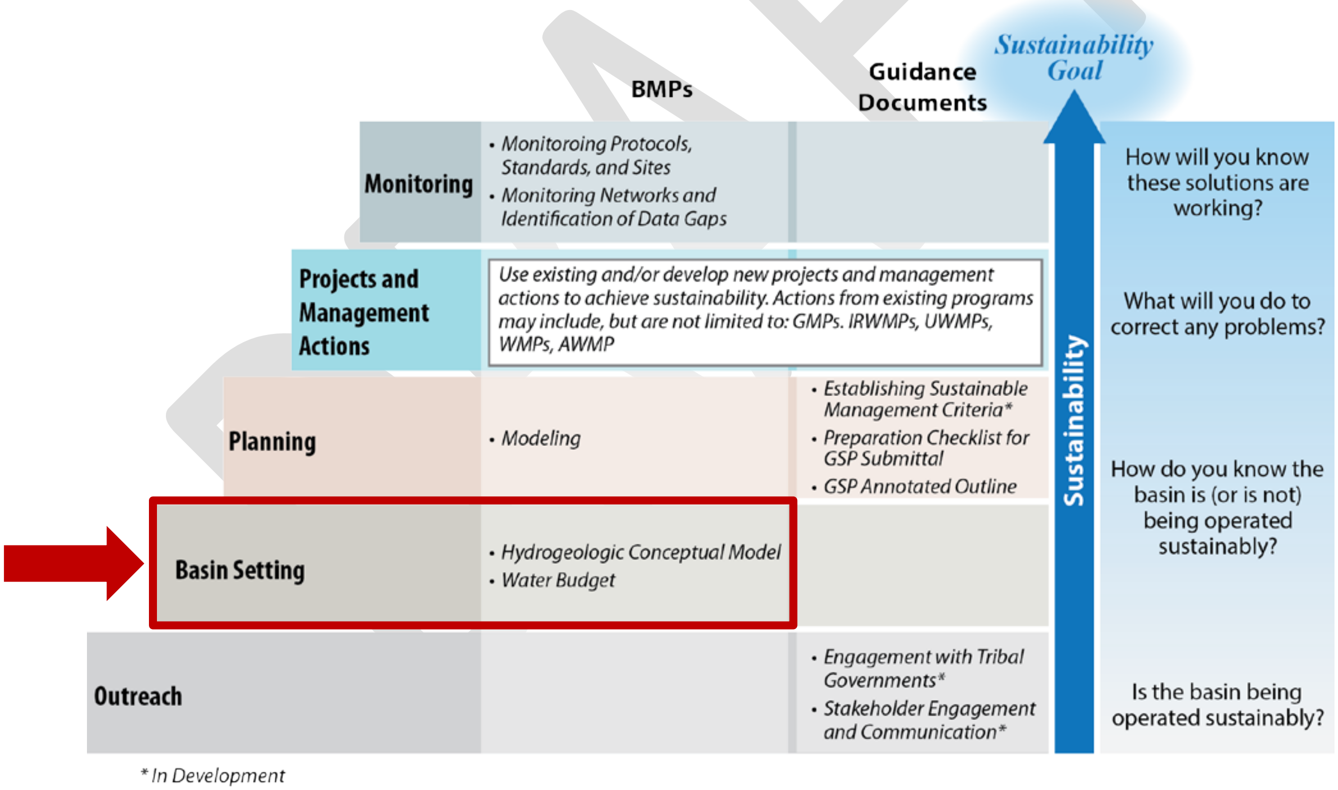


Figure 2 - Steps to Sustainability under SGMA

5. TECHNICAL ASSISTANCE

Implementing sustainable groundwater management under SGMA and the GSP regulations requires development of a water budget that can accurately identify and account for basin inflows, outflows, and change in storage over changing temporal and spatial conditions of supply, demand, and climate. This section provides technical assistance and guidance to support the development of a water budget under SGMA and the GSP Regulations, including potential sources of information, reporting formats, and relevant datasets that can be used to further quantify and estimate the various water budget components.

GENERAL WATER BUDGET REQUIREMENTS:

The following section highlights and provides guidance and technical assistance on the general requirements for all GSP-developed water budgets.

Professional Certification:

> ***Subarticle 2. Basin Setting***
> ***§354.12: Introduction to Basin Setting***
> *Information provided pursuant to this Subarticle shall be prepared by or under the direction of a professional geologist or professional engineer.*

Water budget requirements are provided in Subarticle 2, under the Basin Setting portion of the GSP Regulations. Introduction to the basin setting stipulates that GSP water budget information, and all information provided under Subarticle 2 of the GSP Regulations, is to be prepared by, or under the direction of, a professional geologist or professional engineer. The qualifications and requirements for professional engineers and geologists are governed by the Professional Engineers Act (Business and Professions Code §6700) and the Geologist and Geophysicist Act (Business and Professions Code §8700). Information regarding the professional codes and licensing lookup are provided below.

- **Professional Engineers Act:** http://www.bpelsg.ca.gov/laws/pe_act.pdf
- **Professional Geologist and Geophysicist Act:** http://www.bpelsg.ca.gov/laws/gg_act.pdf
- **Professional License Lookup:** http://www.bpelsg.ca.gov/consumers/lic_lookup.shtml

Water Budget Data, Information, and Modeling Requirements:

> ***§354.18(e):*** *Each Plan shall rely on the best available information and best available science to quantify the water budget for the basin in order to provide an understanding of historical and projected hydrology, water demand, water supply, land use, population, climate change, sea level rise, groundwater and surface water interaction, and subsurface groundwater flow. If a numerical groundwater and surface water model is not used to quantify and evaluate the projected water budget conditions and the potential impacts to beneficial uses and users of groundwater, the Plan shall identify and describe an equally effective method, tool, or analytical model to evaluate projected water budget conditions.*

Water Budget Data Requirements: GSP Regulations stipulate the need to use the best available information and the *best available science* to quantify the water budget for the basin. Best available information is common terminology that is not defined under SGMA or the GSP Regulations. Best available science refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision that is consistent with scientific and engineering professional standards of practice.

It is understood that initial steps to compile and quantify water budget components may be constrained by GSP timelines and limited funding, and may consequently need to rely on the best available information that is obtainable at the time the GSP is developed. Information describing potential sources of data to support the quantification of water budget components is provided later in this BMP under *Water Budget Data Resources*. This section also includes a listing of data to be provided by the Department as part of DWR's technical assistance in support of GSAs developing GSP water budget components.

As GSAs compile and assess the various water budget components for the basin, it is also understood and expected each GSA will work to identify, prioritized, and fill data gaps as an ongoing effort to further refine water budget data and information based on the best available science.

Successful achievement of the sustainability goal for the basin will ultimately depend on the GSAs ability to manage the basin within the identified uncertainty of water budget information to meet the locally defined objectives and thresholds of the outcome-based sustainable management criteria identified in §354.22. However, the initial approval of the GSP by the Department will require GSAs to gather and present a level and quality of water budget information that will demonstrate the GSP will likely achieve the sustainability goal for the basin under the substantial compliance requirements in Section §355.2 of the GSP Regulations.

Use of Models to Determine Water Budgets: GSP Regulations do not require the use of a model to quantify and evaluate the projected water budget conditions and the potential impacts to beneficial uses and users of groundwater. However, if a model is not used, the GSA is required to describe in the GSP an equally effective method, tool, or analytical model to evaluate projected water budget conditions.

Groundwater basins characterized by balanced water budget conditions, an absence of undesirable results, and limited proposed changes to future groundwater demands may be able to identify and describe equally effective methods or tools to quantify and forecast future water budget conditions in sufficient detail to develop sustainable management criteria and meet the overall GSP requirement of substantial compliance.

In most basins subject to SGMA, historical supplies and demands have already adversely impacted one or more sustainability indicators, resulting in undesirable results and a need for a more active approach to sustainable management to mitigate or curtail potential escalation of undesirable results in the future. In addition, basins with *interconnected surface water* systems or complex spatial and temporal variations in water budget components, will find quantification and forecasting of streamflow depletion and other water budget components extremely difficult without the use of a numerical groundwater and surface water model. Modeling results may also be an effective tool for outreach and communication, and can prove instrumental in analyzing and quantifying some of the more difficult to measure water budget components.

Additional information regarding the requirements, application, and availability of models and modeling data is provided in the Modeling BMP.

Defining Basin Area and Water Budget Systems

> ***§354.18(a):*** *Each Plan shall include a water budget for the basin that provides an accounting and assessment of the total annual volume of groundwater and surface water entering and leaving the basin, including historical, current and projected water budget conditions, and the change in the volume of water stored. Water budget information shall be reported in tabular and graphical form.*

Basin Area: Prior to developing a water budget for the basin, GSAs must first identify the physical boundaries and three dimensional area of the basin as described under the HCM (§354.14) portion of the GSP Regulations. The HCM is based on technical studies and qualified maps that characterize the physical basin area and the interaction of the surface water and groundwater systems in the basin. It requires evaluation of the regional geology, structural setting, water quality, principal aquifers, and principal aquitards in the basin. Additional information regarding development of the HCM may be found in the HCM BMP.

The lateral boundaries of the basin are determined by the Department and conform to those boundaries provided in Bulletin 118. The vertical basin boundary, or definable bottom of the basin, is determined by the GSA and may be delineated by either, 1) a structural barrier to groundwater flow as determined by local geology, or 2) the base of fresh water as determined by ground water quality information. Basin boundaries may be periodically modified through SGMA under §10722.

Surface Water Systems: The surface water system is represented by water on the land surface within the lateral boundaries of the basin. Surface water systems include lakes, streams, canals, springs, and conveyance systems. Near-surface processes such as infiltration from surface water systems or outflow due to evapotranspiration from the root zone are often included for convenience as part of the surface water accounting. **Figure** 3 illustrates the conceptual basin boundaries, including the surface water and groundwater systems.

Groundwater System: The groundwater system is represented by that portion of the basin from the ground surface to the definable bottom of the basin and extending to the lateral boundary of the basin. The groundwater system will be characterized by one or more *principal aquifers* and represents the physical basin area used to quantify the annual change in volume of groundwater stored, as required in the water budget. The same three-dimensional basin area should also be used for GSAs to optionally identify the volume of groundwater in storage or the groundwater storage capacity, as necessary, to assist in the determination of sustainable yield.

Required components of the water budget include inflows and outflows across the basin boundary, and inflows and outflows to and from the surface water system and the groundwater system. Some inflows and outflows do not cross the basin boundary, but instead represent exchanges between these systems (**Figure** 3). In **Figure** 3, the solid black line represents the water budget accounting volume encompassing the surface and groundwater systems, while the dashed line represents the interface between the surface water system and the groundwater system. Solid arrows represent inflows to and outflows from the basin, while dashed arrows represent exchanges between the surface water and groundwater systems within the basin.

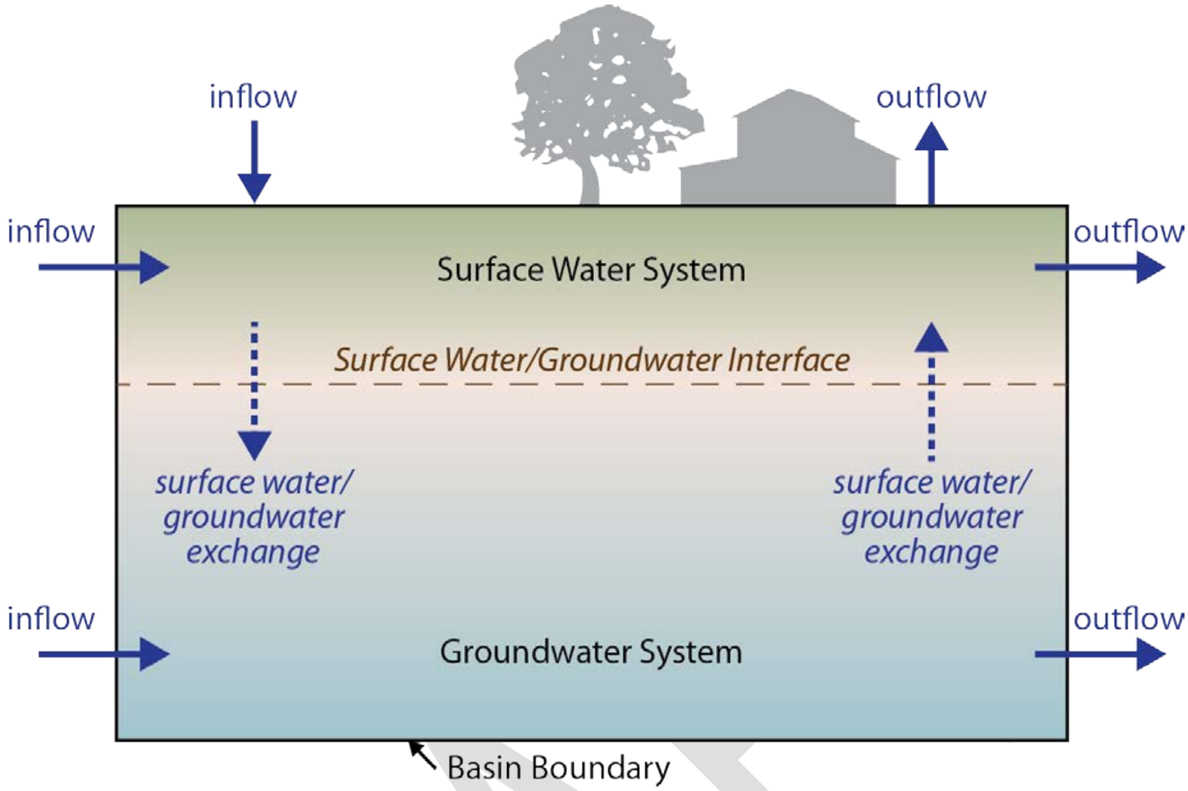


Figure 3 - Conceptual Basin Boundary, Surface Water and Groundwater Systems, and Inflows and Outflows

Management Areas: Although the GSP Regulations only require quantification of water budget components for the basin, each GSA may choose to further subdivide and report the water budget by one or more management areas to help facilitate GSP implementation, and to help demonstrate GSP substantial compliance to the Department under §355.2 of the GSP Regulations. Management areas are defined and further characterized in Sections §351 and §354.20 of the GSP Regulations. If management areas are developed, additional information and graphics will be needed to define the name, location, and distribution of management areas within the basin. Graphical representation of the physical setting and characteristics of the basin will be largely provided under HCM requirements in §354.14 of the Regulations.

Coordination of Water Budget Data: When one or more GSPs are being develop for the same basin by one or more GSAs, Section §10727(b)(3) of the SGMA requires a coordination agreement between all GSAs developing a GSP within the basin. In addition, Section §10727.6 of the SGMA requires that each GSP developed by the coordinating agencies utilize the same data and methodologies for the following water budget related components:

- Groundwater extraction data
- Surface water supply
- Total water use
- Change in groundwater storage
- Water budget
- Sustainable Yield

When presenting water budget information for basins with one or more GSPs, all the GSPs for the basin need to identify and describe the existing coordination agreements for the basin, the point of contact of each agreement, how the individual coordinating agencies have taken steps to ensure that each GSP for the basin is utilizing the same data and methodologies for the above water budget components, and how the GSP is fulfilling the coordination requirements identified under Section §357.4 of the GSP Regulations.

In addition, for many basins within the Central Valley, Salinas Valley and elsewhere, not all the lateral basin boundaries serve as a barrier to groundwater or surface water flow. In situations where a basin is adjacent or contiguous to one or more additional basins, or when a stream or river serve as the lateral boundary between two basins, it is highly recommended that water budget accounting in adjacent basins develop "interbasin" agreements to facilitate exchange of water budget information, as described in Section §357.2 of the GSP Regulations.

Accurate accounting and water budget forecasting of surface water and groundwater flows across the basin boundaries, application of best available data and the best available science, and the GSP Regulation requirement that GSP implementation will not adversely affect an adjacent basin's ability to implement its GSP or impede the ability to achieve its sustainability goal, will in most cases also require coordination and sharing of water budget data and assumptions between contiguous basins. In these interbasin situations, it is highly recommend that water budget accounting should describe how individual coordinating agencies have taken steps to ensure that each GSP for the basin is utilizing similar data and compatible methodologies for the water budget components identified under interbasin coordination in Section §357.4 of the GSP Regulations.

Accounting and Quantification of Water Budget Components:

> *§354.18(b): The water budget shall quantify the following, either through direct measurements or estimates based on data:*
>
> *(1) Total surface water entering and leaving a basin by water source type.*
>
> *(2) Inflow to the groundwater system by water source type, including subsurface groundwater inflow and infiltration of precipitation, applied water, and surface water systems, such as lakes, streams, rivers, canals, springs and conveyance systems.*
>
> *(3) Outflows from the groundwater system by water use sector, including evapotranspiration, groundwater extraction, groundwater discharge to surface water sources, and subsurface groundwater outflow.*
>
> *(4) The change in the annual volume of groundwater in storage between seasonal high conditions.*
>
> *(5) If overdraft conditions occur, as defined in Bulletin 118, the water budget shall include a quantification of overdraft over a period of years during which water year and water supply conditions approximate average conditions.*
>
> *(6) The water year type associated with the annual supply, demand, and change in groundwater stored.*
>
> *(7) An estimate of sustainable yield for the basin*

Accounting of the water budget components includes an annual quantification of inflows and outflows across the basin boundaries, inflows and outflows to and from the surface water and groundwater systems, and the associated change in groundwater in storage. Surface water entering and leaving the basin and inflow to the groundwater system must be accounted for by *water source type*. Outflows from the groundwater system must be accounted for by *water use sector*. Accounting of the annual change in surface water and groundwater in storage is also required under the GSP Regulations.

The GSP water budget components are conceptually illustrated in Figure 4. Figure 4 expands upon Figure 3 by depicting the individual water budget components identified by the GSP Regulation. In the same manner as Figure 3, the solid black line represents the basin boundary, while the dashed line represents the interface between the surface water system and the groundwater system. Solid arrows represent inflows to and outflows from the basin, while dashed arrows represent exchanges between the surface water and groundwater systems within the basin.

Quantification of the basin inflows, outflows, and change in storage is to be generated through direct measurements or estimates based on data. As previously discussed, quantification of the water budget must also be based on best available information and best available science. Methods to quantify water budget components may vary depending on basin-specific conditions, best available information, and the consideration of uncertainties associated with each method. It is anticipated that the quantification methods may change over time as monitoring networks are improved and data gaps are filled.

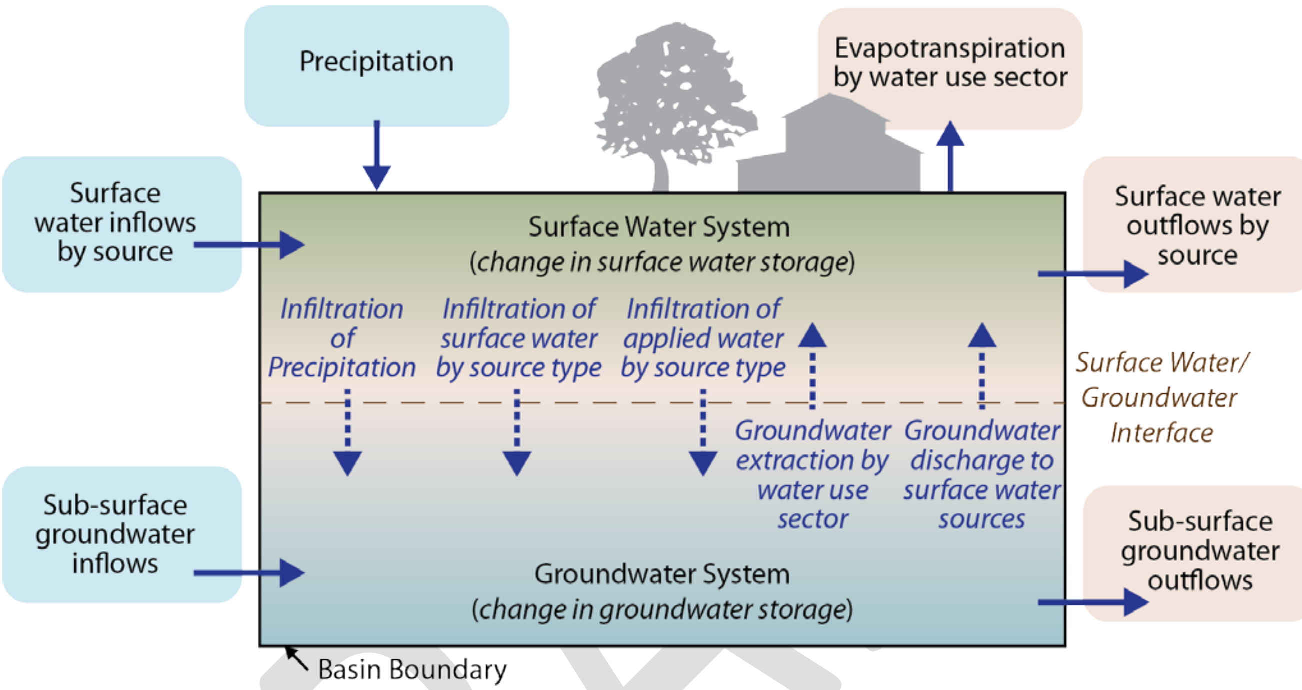


Figure 4 – Required Water Budget Components

Additional discussion regarding consideration of direct and indirect approaches to quantify water budget components is provided below under *Identifying and Selecting Methodologies to Estimate Water Budget Components*. Information describing potential data sources to support quantification of change in storage is provided later in this section under *Water Budget Data Resources*, including data to be provided by DWR specifically for the purpose of supporting GSP water budget development.

A breakdown of the specific water budget components requirements listed in Section §354.18(b) of the GSP Regulations is provided below.

(1) Total surface water entering and leaving the basin by water source type.

Surface water entering (inflow) and leaving (outflow) the basin is required to be annually quantified for the basin as a total annual volume in acre-feet per year (af/yr) according to the surface water body (name) and the water sources type. Water source type represents the source from which water is derived to meet the applied beneficial uses. Surface water sources should be identified as one of the following:

- Central Valley Project,
- State Water Project,
- Colorado River Project,
- Local supplies, and
- Local imported supplies.

Much of the surface water flowing into the basin is diverted and applied to meet the beneficial uses within the basin. It is recommended that total annual volume of applied surface water (af/yr) also be quantified according to the appropriate water use sector and the total applied water area (acres). For urban water suppliers, the diverted and applied surface water use should include the total annual volume of use for all urban areas within the basin and the average daily gallons of per capita use (gpcd) for the basin. A breakdown of the applied surface water accounting by basin and by water use sector is provided as follows:

- Urban: total annual volume (af/yr) and the average daily per capita use (gpcd).
- Industrial: total annual volume (af/yr) and total applied water area (acres)
- Agricultural: total annual volume (af/yr) and applied water area (acres)
- Managed Wetlands: total annual volume (af/yr) and applied water area (acres)
- Managed Recharge: total annual volume (af/yr) and applied water area (acres)
- Native Vegetation: total annual volume (af/yr) and applied water area (acres)
- Other (as needed): total annual volume (af/yr) and applied water area (acres)

Applied surface water supply may be further subdivided by *management area* as needed to facilitate water budget accounting and to help demonstrate GSP substantial compliance under Section §355.2 of the GSP Regulations.

Surface Water Available for Groundwater Recharge or In-Lieu Use: In addition to the above GSP Regulation requirement to include an accounting of the total surface water entering and leaving the basin, Section §10727.2(d)(5) of SGMA requires the GSP include a description of the surface water supply used, or available for use, for groundwater recharge or in-lieu use.

As part of the Department's technical assistance under SGMA, the Department is currently estimating, based on available information, the volume of water available for replenishment of the groundwater in the State. The statewide evaluation of water available for replenishment is being conducted on a regional basis. The regional estimates of water available for replenishment provided by the Department will not fulfill the SGMA requirement to identify the surface water supply used, or available for use, for groundwater recharge or in-lieu use at the basin level. However, the

Department's documentation of the process, methods, and sources of data for evaluating surface water supply availability should provide valuable assistance to GSAs who are also estimating surface water supply available for recharge information at the basin level. The Department's report on Water Available for Replenishment is currently under development. A draft release is scheduled for the end of December, 2016.

(2) Inflow to the groundwater system by water source type, including subsurface groundwater inflow and infiltration of precipitation, applied water, and surface water systems, such as lakes, streams, rivers, canals, springs and conveyance systems.

Inflows to the groundwater system are to be annually quantified for the basin as the total annual volume (af/yr) according to the water source type and water use sector.

An accounting of inflows to the groundwater systems should include, but may not be limited to, the following:

- Subsurface Groundwater Inflow (af/yr)
- Infiltration of precipitation (af/yr)
- Infiltration of applied water (af/yr)
- Infiltration from surface water systems (af/yr).

Infiltration of oil field-produced water should be identified as a separate source of imported source of water, if applicable (see text box discussion of oil field-produced water considerations).

For areas having Urban Water Management Plans (UWMP) or Agricultural Water Management Plans (AWMP), the GSP water budget assessment of urban and agricultural areas should be consistent with the water

Oil & Gas Field-Produced Water

Significant quantities of water are produced as a by-product of oil and gas extraction in some basins. Where applicable, it is important to characterize this water in terms of aquifer depletion, beneficial use, quality, and reliability.

- Aquifer Depletion. Oil and gas-bearing formations are often at a depth below the groundwater flow system. Is the quantity of produced water accounted for in the hydrogeologic conceptual model? Will depletion of this water cause Undesirable Results such as subsidence?
- Beneficial Use. Describe the uses for the produced water. Is the produced water being supplied as a beneficial use such as irrigation or recharge, or is it being evaporated? If so, it should be included as a water supply type in the water budget accounting.
- Quality. Describe the quality of the produced water, existing use permits, and any treatment processes employed. Describe the use or discharge relative to RWQCB Basin Plan Objectives.
- Reliability. Availability of produced water will fluctuate with oil and gas production. Oil fields have limited production durations which may be incompatible with long-term groundwater sustainability. Oil field-produced water will generally not be an acceptable supply for establishing sustainability, but may be a component of an initial basin recovery effort. The reliability of produced water should be characterized in the GSP if it is being use as a source of supply.

budget reporting in the most recent UWMPs and AWMPs, unless more recent information is available.

(3) ***Outflows from the groundwater system by water use sector, including evapotranspiration, groundwater extraction, groundwater discharge to surface water sources, and subsurface groundwater outflow***.

An annual accounting of groundwater outflow from the basin is to be quantified as the total volume (ac-ft) by water source type and water use sector. Sources of groundwater outflow should include, but may not be limited to, the following:

- Evapotranspiration: (af/yr)
- Groundwater discharge to surface water sources (af/yr)
- Subsurface groundwater outflow (af/yr)
- Groundwater extraction by water use sector:
    - Urban: (af/yr) and (gpcd)
    - Industrial: (af/yr)
    - Agricultural: (af/yr)
    - Managed Wetlands: (af/yr)
    - Managed Recharge: (af/yr)
    - Infiltration from the following: (af/yr)
    - Native vegetation: (af/yr)
    - Other (as needed): Note: if oil and gas production wells are producing or applying water within the basin, as defined in the HCM, an accounting of the produced water is to be included as a source of applied water.

Outflows from the groundwater system may be further subdivided by management area as needed to facilitate water budget accounting and to help demonstrate GSP substantial compliance under Section §355.2 of the GSP Regulations.

(4) The change in the annual volume of groundwater in storage between seasonal high conditions.

In addition to the inflow and outflow components of the water budget, the annual change in the volume of groundwater in storage (af/yr) is required to be provided in tabular and graphical form according to water year type and according to the associated total annual volume of groundwater extraction for the basin. In addition, the GSP should provide some level of discussion regarding the relationship and variation between annual change of groundwater in storage versus annual changes in surface water supply reliability, water year type, water use sector, sustainable yield and overdraft conditions (if present or are potentially present, i.e., negative change in annual groundwater storage is occurring, but overdraft conditions are still unconfirmed).

The change in groundwater in storage is to be determined as the total change in storage between *seasonal high* conditions, which typically occurs in the spring. It is recommended that the change in storage estimates be based on observed changes in groundwater levels within the basin. However, change in groundwater storage may also be calculated as the difference between annual inflows and outflows according to the water budget equation in Section 3, where all inflows and outflows can be reliably measured or estimated.

Similar to other water budget components, the method to quantify change in storage will likely vary depending on basin-specific conditions and available information, and include consideration of uncertainties associated with each method.

Assessment of change in storage under future water budget projections will likely require the use and application of a groundwater flow model. If a model is used to estimate future changes in groundwater storage, the modeling requirements and principles identified in the Model BMP should be followed.

Changes in surface water storage (reservoirs, lakes, and ponds) will also be an important water budget component in some basins. For these basins, change in storage should be identified as change in groundwater in storage and change in surface water storage.

The annual change in groundwater storage may also be further subdivided according to *management areas, as* needed, to help facilitate water budget accounting and to help demonstrate GSP substantial compliance under Section §355.2 of the GSP Regulations.

(5) ***If overdraft conditions occur, as defined in Bulletin 118, the water budget shall include a quantification of overdraft over a period of years during which water year and water supply conditions approximate average conditions****.*

The GSP water budget must include an assessment of groundwater overdraft conditions. Determination of overdraft conditions requires the evaluation of current and historical water budget conditions. As described in DWR Bulletin 118, overdraft occurs when groundwater extraction exceeds groundwater recharge over a period of years, resulting in a decrease in groundwater storage.

Overdraft conditions are to be assessed by calculating change in groundwater storage over a period of years during which water year and water supply conditions approximate average conditions. Assessment of overdraft conditions should include an evaluation of changes in groundwater storage by water year type. For basins without an existing water year index, water year types will be developed, classified, and provided by DWR based on annual precipitation as a percentage of the previous 30-year average precipitation for the basin. Water year classifications will be divided into five categories ranging from wet, above normal, below normal, dry, to critically dry conditions.

Single-year reduction in groundwater storage during critical, dry or below normal water years may not represent overdraft conditions. Reductions in groundwater storage in above normal or wet years or over a period of average water year conditions may indicate overdraft conditions. All annual change in groundwater storage estimates from water budget accounting should be included and discussed in the GSP.

If overdraft conditions are identified, the GSP shall describe projects or management actions, including a quantification of demand reduction or other methods, for the mitigation of overdraft, as required under Section §354.44(b)(2) of the GSP Regulations.

When evaluating if the GSP is likely to achieve the sustainability goal for the basin, the Department will consider whether the GSP includes a reasonable assessment of overdraft conditions and a reasonable means to mitigate overdraft as required under Section §354.4(b)(6) of the GSP Regulations.

(6) The water year type associated with the annual supply, demand, and change in groundwater stored.

In order for local resource managers to develop an understanding of the relationship between changing hydrologic conditions and the associated aquifer response to changing water supply, demand, and storage, the GSP water budget accounting must be reported according to water year type. Even though the GSP Regulations only require annual water budget accounting and reporting, in order for local water resource managers to adequately understand the timing and distribution of water supply and demand and to implement effective water management actions, it is highly recommended that local water budget accounting be conducted on a monthly or more frequent basis. As mentioned in the overdraft discussion, water year types will be developed, classified, and provided by DWR for those basins not having an existing water year index. GSP reporting of supply, demand, and change in groundwater stored according to water year type will help facilitate assessment of overdraft conditions and estimates of sustainable yield for the basin.

(7) An estimate of sustainable yield for the basin

Estimating sustainable yield includes evaluating current, historical, and projected water budget conditions. Sustainable yield is defined in the SGMA legislation and refers to the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result. Water budget accounting information should directly support an estimate of sustainable yield. However, by definition, additional information will be needed to clarify how locally developed criteria to define undesirable results supports the estimate of sustainable yield for the basin. Additional information should include an explanation of the relationship or linkage between the water budget information and the sustainability indicators, undesirable results, measureable objectives, and minimum thresholds will be required to support the GSP estimate of sustainable yield.

TABULAR AND GRAPHICAL REPRESENTATION OF THE WATER BUDGET COMPONENTS:

The above water budget information is to be developed in tabular and graphical form. Tabular and graphical presentation of the data may take many forms depending on the sources of water inflow and outflow to the basin and the water use sectors within the basin.

A sample water budget tabulation is illustrated in Table 1. Table 1 includes a listing of required water budget components in to support a complete accounting of groundwater basin inflows and outflows, additional water budget components not explicitly listed in the Regulations may be required for some basins. For example, in basins where treated produced water generated from oil and gas operations is used as a source of supply, the annual volume of the produced water being applied for beneficial use should be quantified and described according to water supply type and water use sector. Although produced water being injected beneath the defined basin bottom does not need to be included in the water budget accounting, a description of the location and annual injection volumes should be described and quantified in the basin setting.

Additional tables depicting a breakdown of water budget accounting by water use sector and water source type will also likely be need in order to better understand the individual supplies and demands for the basin, and the percent of total supply that is met by each water source type. Supplementary example tables are being developed and will be provided as part of the Departments technical assistance.

Multiple graphical depictions of the various water budget components will be needed to fully illustrate the water budget accounting. The graphics should include charts and maps to show the trends and spatial distribution of the various water budget components. A general graphic summarizing the inflows, outflows and change in storage by water year type will be needed to provide an understanding of the overall water balance for the basin by water year type. In addition, more detailed maps and figures that separately depict basin inflows and outflows by water source type, water use sector, and water year will be needed to better understand the relationship and overall importance of the various water sources and water use sectors.

Water Year:
Water Year Type:

INFLOWS		OUTFLOWS	
Inflow Source	Volume (af/yr)	Outflow Sink	Volume (af/yr)
Surface Water Inflow\1		Surface Water Outflow\1	
Precipitation		Evapotranspiration\4	
Subsurface Groundwater Inflow		Subsurface Groundwater Outflow	
Total Basin Inflow		Total Basin Outflow	
Subsurface Groundwater Inflow		Subsurface Groundwater Outflow	
Infiltration of Precipitation		Groundwater Extraction\1	
Infiltration from Surface Water Systems\2		Discharge to surface water systems\2	
Infiltration of Applied Water\3			
Total Groundwater Inflow		Total Groundwater Outflow	

Change in Surface Storage Volume	
Change in Groundwater Volume	

\1 by water source type
\2 lakes, streams, canals, springs, conveyance systems
\3 includes applied surface water, groundwater, recycled water, and reused water
\4 by water use sector

Table 1 - Simple Water Budget Tabulation Example

A sample paired bar graphic illustrating balanced water budgets for both the basin and the groundwater system including the required water budget components is presented as Figure 5. Each pair of bars shows inflows on the left and outflows on the right. In this illustration, more water comes into the basin than flows out during the water year, with the difference stored as carry-over surface storage. Similarly, groundwater outflows exceed groundwater inflows, resulting in an annual reduction in groundwater storage.

Additional graphical examples depicting water supplies and water use by water year type are provided in the Department's *California Water Plan Update 2013* (*Volume 1, Chapter 3, pages 3-33 - 3-40)*, and the *California Groundwater Update 2013 (Chapter 2, pages*

17-22). Online links to these reports are provided in Section 7, under *Guidance and General References.* Supplementary example graphics are being developed and will be provided as part of the Departments technical assistance.

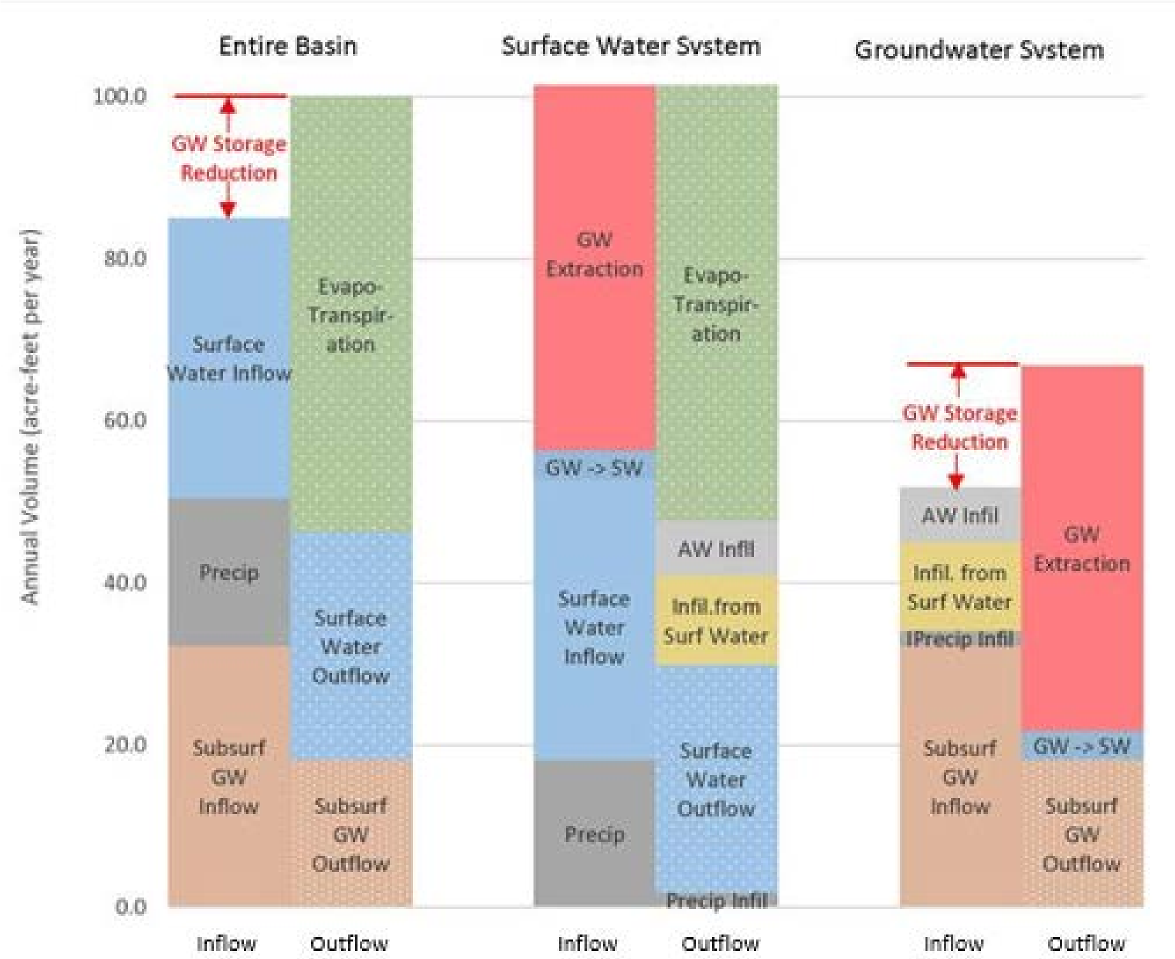


Figure 5 – Paired Bar Water Budgets Illustrating Balanced Water Budget

DEFINING WATER BUDGET TIME FRAMES:

§354.18(c): Each Plan shall quantify the current, historical, and projected water budget for the basin…

The GSP Regulations require quantification of a water budget for current, historical, and projected basin conditions. A description of the current, historical, and projected water budget requirements are provided below.

Current Water Budget Assessment §354.18(c)(1)

The GSP is required to provide an accounting of current water budget conditions to inform local resource managers and help the Department understand the existing supply, demand and change in storage under the most recent population, land use, and hydrologic conditions. The current water budget is required to quantify all seven of the general water budget requirements listed in §354.18(b).

Historical Water Budget Assessment §354.18(c)(2)

The historical water budget accounting is required to evaluate how past water supply availability or reliability has previously affected aquifer conditions and the ability of the local resource managers to operate the basin within sustainable yield. The historical assessment is specifically required to include the following:

- Utilize the most recent ten years of surface water supply information to quantify the availability or reliability of historical surface water supply deliveries. The reliability of historical surface water deliveries is to be calculated based on the planned versus actual annual surface water deliveries, by surface water source, and water year type.
- Quantify and assess the most recent ten years of historical water budget information by water year type. The ten years of historical water budget information is to be used to help estimate the projected future water budgets and future aquifer response to the sustainable groundwater management projects and actions being proposed over the GSP planning and implementation horizon. The intent of the historical water budget evaluation is also to provide the necessary data and information to calibrate the tools or methods used to project future water budget conditions. Depending on the historical variability of supplies, demands, and land use; the level of historical groundwater monitoring in the basin; and the type of tool being used to estimate future projects and associated aquifer response; additional historical water budget information may be needed for adequate calibration.
- Utilizing the most recent ten years of water supply reliability and water budget information, the GSP is required to describe how the historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability of the local agency to operate the basin within sustainable yield. To assist in the evaluation, it is recommended that the assessment of safe yield be evaluated by water year type, as previously described in *An estimate of sustainable yield for the basin.*

Projected Water Budget Assessment §354.18(c)(3)

The projected water budget accounting is used to quantify the estimated future baseline conditions of supply, demand, and aquifer response to GSP implementation. The projected water budget assessment in the GSP is also required to evaluate and identify the level of uncertainty in the projected water budget estimate, and to include historical water budget information to estimate future baseline conditions concerning hydrology, water demand and surface water supply reliability over the 50-year planning and implementation horizon. Methods used to estimate the project water budget include the following three requirements:

- Utilize 50 years of historical precipitation, evapotranspiration, and stream flow information as the future baseline hydrology conditions, while taking into consideration uncertainties associated with the estimated climate change and sea level rise projections.
- Utilize the most recent land use, evapotranspiration, and crop coefficient information as the baseline condition for estimating future water demands, while taking into account future water demand uncertainty associated with projected changes in local land use planning, population growth, and climate.
- Utilize the most recent water supply information as the baseline condition for estimating future surface water supply, while applying the historical surface water supply reliability identified in 354.18(c)(2) and taking into consideration the projected changes in local land use planning, population growth, and climate.

Time frames required for the evaluation of current, historical, and projected water budget conditions are illustrated graphically in Figure 6. The illustration also includes a description of data to be supplied by DWR. Additional discussion of data and data sources is discussed in greater detail in subsequent sections of this BMP (*Water Budget Data Resources)*.

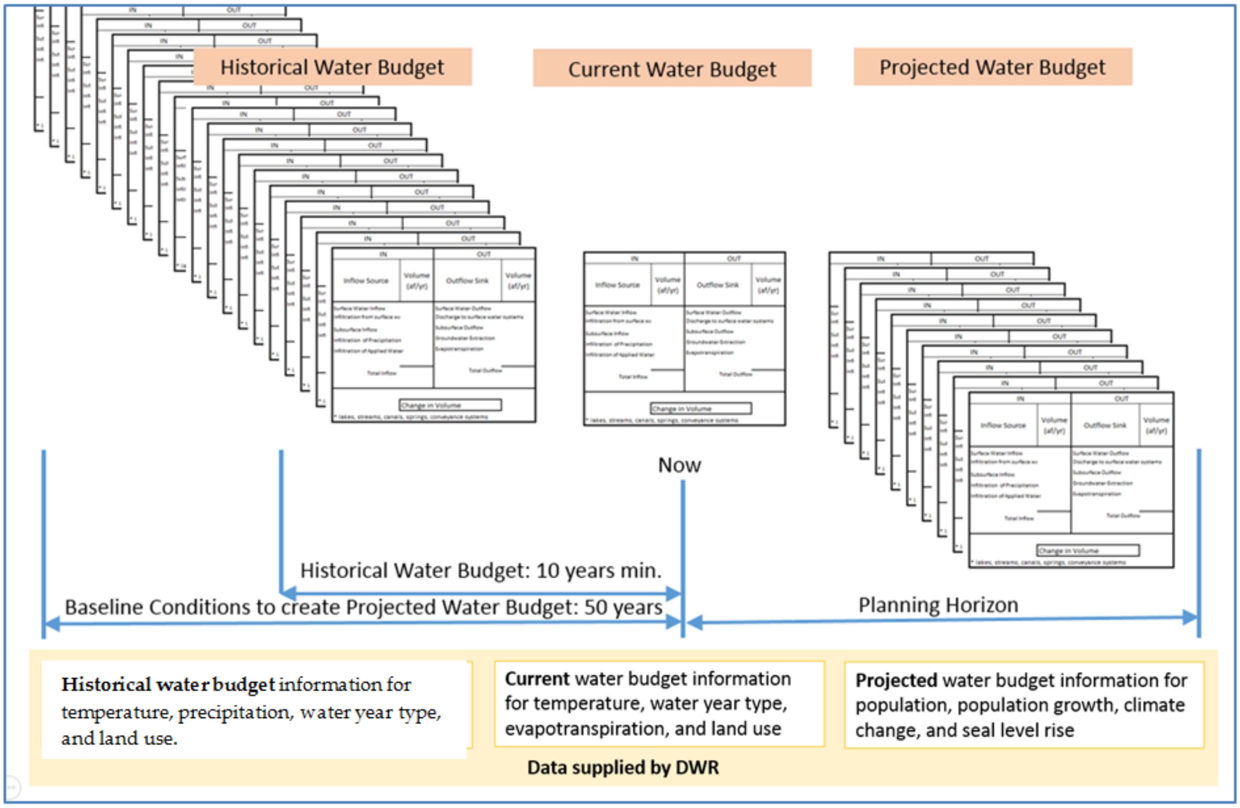


Figure 6 - GSP Water Budget Time Frames

Although the GSP Regulations only require annual quantification of the current, historical, and projected water budget information, it is anticipated that many GSAs will want to perform water budget accounting on a monthly or even a daily basis, especially if a groundwater model is used to compile and assess future water budget and aquifer conditions. In these situations, model results can be aggregated to annual values to support the GSP and subsequent annual reporting. Water budget accounting for shorter than annual time periods provides information necessary to support sustainable management of the basin through more timely evaluation of the water supply and demands by water use sector, of the potential undesirable results, and of the associated need for potential projects and management actions.

IDENTIFYING AND SELECTING METHODOLOGIES TO ESTIMATE WATER BUDGET COMPONENTS

As discussed above, individual components of the water budget may be estimated independently or based on estimates of other water budget components using the water budget equation. A comprehensive review of methodologies for each water budget component is beyond the scope of this BMP; however the reader is encouraged to review water budget data resources described under *Water Budget Data Resources* and related materials referenced in Section 7. Selection of a methodology for a particular water budget component should consider the following:

- How historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability to operate the basin within sustainable yield.
- Past and current approaches to quantifying water budget components in the basin.
- Alternative approaches representing the best available information and the best available science.
- Data available to support application of the methodology.
- The methodology used for other GSPs within the basins or adjacent basins.
- The magnitude of the water budget component relative to other components in the basin.
- Accuracy and uncertainty associated with the methodology and supporting data

Some water budget components lend themselves to direct monitoring and measurement more than others. For example, physical processes at the ground surface, such as surface water diversion, groundwater extraction, and precipitation can be directly measured with a high degree of accuracy, certainty, and reliability using various meters, dataloggers, and other readily available monitoring devices. In addition, these approaches to monitoring support utilization of the best available science, reflect industry standards, and result in defensible data that meets the uncodified finding of SGMA to collect data necessary to resolve disputes regarding sustainable yield, beneficial uses, and water rights (SGMA Uncodified Findings (b)(3)).

In contrast, other processes such as infiltration and subsurface *groundwater flows* across basin boundaries cannot be measured directly and must be estimated using other approaches.

The methodologies, assumptions and data sources used to quantify water budget components are to be documented in the GSP. Much of the information needed to quantify a component of the water budget may be available in existing planning documents and on-line data sources (see *Water Budget Data Resources* below).

As described in the *Coordination of Water Budget Data* section in this BMP, for situations where basin boundaries are adjacent or contiguous to one or more additional basins, or when a stream or river serve as the lateral boundary between two basins, it is highly recommended that water budget accounting in adjacent basins develop "interbasin" agreements to facilitate exchange of water budget information, as described in Section §357.2 of the GSP Regulations..

EVALUATING ACCURACY AND UNCERTAINTY OF WATER BUDGET COMPONENTS

Careful consideration should be given to documenting the accuracy and uncertainty of the data being used and in selecting which components are estimated independently versus estimated based on the principle of mass balance, as described above. In all cases, any components estimated based on the water budget equation (Equation 1) should be examined closely for reasonableness. For example, if past experience suggests that a typical value for infiltration of precipitation is around 5 to 10 percent of the total inflow for a given basin, but solution of the water budget equation for infiltration of precipitation results in an estimate of 50 percent of total inflow from infiltration of precipitation, additional examination of the other water budget components is warranted.

Evaluation of accuracy and uncertainty associated with individual water budget components is important because it improves understanding of the sensitivity and range of uncertainty of the various water budget components, which subsequently helps support and inform development of GSP sustainable management criteria (§354.22) and projects and management actions (§354.44) that are being implemented and proposed to achieve sustainability.

WATER BUDGET DATA RESOURCES

Data resources to assist in development a water budget will vary according to past water management studies and water resource investigations conducted in the region. However, several sources of potentially useful information have been identified and are described below. These sources include data to be provided by DWR as part of technical assistance to support GSP development and sustainable water management, as well as other available sources of information.

Data Provided by DWR (§354.18(d) and (f))

Data to be provided by DWR to develop the water budget identified in the Regulations includes the following (§354.18(d) and (f)):

- **Historical Information:** Monthly minimum, maximum, and mean temperature and precipitation; water year type for areas outside the Central Valley; and Central Valley land use information.
- **Current Information:** Monthly minimum, maximum, and mean temperature; water year type; evapotranspiration, and statewide land use information

- **Projected Information:** Population, population growth, climate change, and sea level rise.
- **Modeling Support**: The California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM) and Integrated Water Flow Model (IWFM)

Agencies developing a water budget may choose to use other data of comparable quality, as allowed by Regulation §354.18(d). As mentioned previously, if a numerical groundwater and surface water model is not used to quantify and evaluate the projected water budget conditions, an equally effective method, tool, or analytical model must be identified and described in the plan (§354.18(e)). A water budget completed outside of a model may be useful as part of model calibration to confirm the reasonableness of water budget produced by the model.

Climate Change and Sea Level Rise. GSP Regulations require future water budget estimates to take into consideration changing climate and sea level rise when evaluating water supply, demand, and reliability for the basin over the planning and implementation horizon. Due to the spatial and temporal complexities associated with evaluating the basin response to changing climate, land use, and proposed projects, it is anticipated that most GSAs will utilize a hydrologic model to evaluate the various potential future basin conditions. In an effort to support consistent GSP analysis of future sustainability conditions, DWR will provide GSAs with the methods and data to be used in their analysis of future conditions. One of these datasets will include a range of future supply variability resulting from changing climate effects on temperature, precipitation, runoff, and sea level rise. The methods and analysis used to evaluate the future climate effects on water supply availability will be consistent with the data and methods used in the Proposition 1 Water Storage Investment Program Grant Application Process. The data and methods will be provided online by DWR in a separate document, and will not assume implementation of the Delta Fix Program.

Additional Data and Resources

Several other data sources exist in addition to those data specifically identified in the Regulation to be provided by DWR. Some of these include data available from DWR not specifically listed in the Regulation. A summary of data available to support water budget development is provided in Table 2. The table is not intended to provide an exhaustive list of data and sources to support water budget development, but rather to provide a reference to data that may be helpful. Specific data selected to support water budget development will depend on methodologies selected to estimate water budget components.

Table 2 – Potential Data Sources to Support Water Budget Development

Data Type	Data Sources	Notes
Air Temperature	DWR, PRISM, CIMIS, NOAA, USBR	Historical and current conditions available from DWR, PRISM, CIMIS, and NOAA. Projected future conditions available from DWR and USBR.
Precipitation	DWR, PRISM, CIMIS, NOAA, NASA, USBR	Historical and current conditions available from DWR, PRISM, CIMIS, NOAA, and NASA. Projected future conditions available from DWR and USBR.
Water Year Type	DWR	
Land Use	DWR, USDA, County General Plans, Local Agencies	Historical and current conditions available from DWR, USDA CDL, county general plans, and local agencies (including county agricultural commissioners).
Evapotranspiration	DWR, CIMIS, CalSIMETAW, UCCE	Historical and current conditions include reference evapotranspiration, total evapotranspiration, and amount of evapotranspiration derived from applied irrigation water. Could include traditional approaches and/or satellite remote sensing approaches.
Population	DWR, State Dept. of Finance, U.S. Census Bureau, UWMPs	Historical and current conditions from Dept. of Finance, U.S. Census, and UWMPs. Projected future conditions from DWR and UWMPs.
Climate Change	DWR, USBR	May include projected temperature, precipitation, evapotranspiration, streamflows, projected project supplies, etc.
Sea Level Rise	DWR	
Applied Water	AWMPs, UWMPs, UCCE, DWR	Historical and current applied irrigation water demands reported in AWMPs, UCCE publications, and DWR reports. Historical, current, and projected urban demands described in UWMPs.
Groundwater Level	DWR, USGS, Local Agencies	DWR sources include GIC and WDL.
Aquifer Thickness and Layering	DWR, USGS, Local/Regional Studies	DWR and USGS sources include C2VSIM and CVHM models and other studies. Local and regional studies and models may also be available.
Aquifer Hydraulic Conductivity	DWR, USGS, Local/Regional Studies	DWR and USGS sources include C2VSIM and CVHM models and other studies. Local and regional studies and models may also be available.
Digital Elevation Model	USGS	Utilized to estimate surface water runoff from precipitation.
Streamflow	DWR, USGS, Local Agencies	DWR sources include CDEC and WDL.
Surface Water Diversions	Local Agencies, SWRCB eWRIMS, DWR, USBR	

Data Type	Data Sources	Notes
Municipal/Industrial Groundwater Pumping	UWMPs	
Agricultural Groundwater Pumping	AWMPs, DWR, USGS	
Specific Yield	DWR, USGS, Local/Regional Studies	DWR and USGS sources include C2VSIM and CVHM models and other studies. Local and regional studies and models may also be available.
Surface Soil Properties	NRCS	
Per-Capita Water Use	UWMPs, DWR, USGS	

Tabled Acronyms:

AWMP – Agricultural Water Management Plan
C2VSIM – California Central Valley Groundwater-Surface Water Simulation Model
CalSIMETAW – California Simulation of Evapotranspiration of Applied Water Model
CDEC – California Data Exchange Center
CIMIS – California Irrigation Management Information System
CVHM – Central Valley Hydrologic Model
DWR – Department of Water Resources
eWRIMS – Electronic Water Rights Information Management System
GIC – Groundwater Information Center
NASA – National Aeronautics and Space Administration
NOAA – National Oceanic and Atmospheric Administration
NRCS – Natural Resources Conservation Service
PRISM –Parameter-elevation Relationships on Independent Slopes Model
SWRCB – State Water Resources Control Board
UCCE – University of California Cooperative Extension
USBR – United States Bureau of Reclamation
USDA – United States Department of Agriculture
USGS – United States Geological Survey
UWMP – Urban Water Management Plan
WDL – Water Data Library

Additional Data Sources:

Additional sources of available information include data from state and federal agencies, research institutions, local water resource management entities, and other local data collection and sharing activities. A partial list of data sources associated with existing water resource management programs are provided below:

- Urban Water Management Plans (UWMPs) [http://www.water.ca.gov/urbanwatermanagement/]
- Agricultural Water Management Plans (AWMPs), [http://www.water.ca.gov/wateruseefficiency/agricultural/agmgmt.cfm]

- Groundwater Management Plans (GWMPs), [http://water.ca.gov/groundwater/groundwater_management/GWM_Plans_inCA.cfm]
- Integrated Regional Water Management Plans (IRWMPs), [http://water.ca.gov/irwm/stratplan/]
- Groundwater Ambient Monitoring and Assessment Program (GAMA), [http://www.swrcb.ca.gov/gama/]
- Irrigated Lands Regulatory Program (ILRP) http://www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/

A comprehensive list of all available sources of water budget data from state and federal agencies, research institutions, and local water management entities is beyond the scope of this BMP. Some additional sources of water budget-related information from select state and federal agencies are provided below.

Department of Water Resources:

- Groundwater Information Center (GIC): http://water.ca.gov/groundwater/gwinfo/index.cfm
- California Statewide Groundwater Elevation Monitoring Program (CASGEM): http://water.ca.gov/groundwater/casgem/
- Water Data Library (WDL) http://www.water.ca.gov/waterdatalibrary/
- California Data Exchange Center (CDEC) http://cdec.water.ca.gov/
- California Irrigation Management Information System (CIMIS) http://wwwcimis.water.ca.gov/cimis/welcome.jsp
- Land Use Surveys: http://www.water.ca.gov/landwateruse/lusrvymain.cfm
- Groundwater –Surface Water Simulation Model: The following DWR Bay-Delta site list information for the C2VSim Central Valley Groundwater-Surface water simulation model. This same website contains additional links to DWR water budget tools such as:
    - Integrated Water Flow Model (IWFM)
    - Irrigation Demand Calculator (IDC)
    - CalLite: Central Valley Water Management Screening Model
    - Water Resource Integraded Modeling System (WRIMS) model engine (formally named CALSIM)
    - Delta Simulation Model II (DSM2)

  http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm
- Bulletin 118: http://water.ca.gov/groundwater/bulletin118/index.cfm

- California Groundwater Update 2013:
- http://www.water.ca.gov/waterplan/topics/groundwater/index.cfm
- California Water Plan Update 2013: http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm
- Additional DWR Data Topics: http://water.ca.gov/nav/index.cfm?id=106

State Water Resources Control Board:

- Electronic Water Rights Information Management System (eWRIMS) http://www.swrcb.ca.gov/waterrights/water_issues/programs/ewrims/
- GeoTracker: https://geotracker.waterboards.ca.gov/

United States Geological Survey:

- Central Valley Hydrologic Model (CVHM): http://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html
- Water Data Discovery: http://water.usgs.gov/data/
- Surface Water Information: http://water.usgs.gov/osw/
- Groundwater Information Pages: http://water.usgs.gov/ogw/

Additional USGS Water budget Related Materials by Topic

Developing a Water Budget:

This USGS Circular is a general reference for developing a water budget; it includes the key components of the water budget, exchanges of water between these components, and case studies of water-budget development and the use of water budgets in managing hydrologic systems. http://pubs.usgs.gov/circ/2007/1308/

Recharge Estimation:

Modeling, field-based, and other methods have been used to estimate recharge. Those included here are examples of methods potentially applicable to relatively large areas. A comprehensive overview of recharge estimation methods is available in this book: https://pubs.er.usgs.gov/publication/70156906.

This USGS report is a compilation of methods and case studies for recharge estimation in the arid and semiarid southwestern U.S., including eastern and southeastern California: http://pubs.usgs.gov/pp/pp1703/index.html

Modeling of Recharge:

The Basin Characterization Model (BCM) was developed by the USGS for use in estimating natural recharge, and has been applied to all of California and other regions in the western US and internationally. This regional water-balance model differs from rainfall-runoff models because it incorporates estimates of shallow bedrock permeability to spatially distribute in-place natural recharge across the landscape. Content on the website below describes the model and associated methods, and provides links to output datasets available for historical and future projections of climate, and to associated publications of applications. The BCM is currently undergoing revisions to further improve the accuracy of recharge estimates for California; these revisions will be completed in mid-2017.
http://ca.water.usgs.gov/projects/reg_hydro/projects/dataset.html

The Farm Process: is a tool developed by the USGS to improve the estimation of recharge (and pumping) associated with irrigated agriculture. It is available in various versions of MODFLOW; the most recent version is in MODFLOW-OWHM.

- Primary documentation, Version 1: http://pubs.usgs.gov/tm/2006/tm6A17/
- Documentation of Version 2: http://pubs.usgs.gov/tm/tm6a32/
- Version 3 is in MODFLOW-OWHM: http://water.usgs.gov/ogw/modflow-owhm/

GSFLOW: Is a coupled ground-water and surface-water flow model developed by the USGS and based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005). Features of both PRMS and MODFLOW aid in recharge estimation. http://pubs.usgs.gov/tm/tm6d1/

SWB: Is a modified Thornthwaite-Mather soil-water-balance code developed by the USGS for estimating groundwater recharge. http://pubs.usgs.gov/tm/tm6-a31/

INFIL: Is a grid-based, distributed-parameter watershed model developed by the USGS, for estimating net infiltration below the root zone. The link below provides documentation of the model, the associated software, and examples of applications.
http://water.usgs.gov/nrp/gwsoftware/Infil/Infil.html

Case Studies for Recharge Estimation using Modeling:

MODFLOW: Natural recharge estimates, and uncertainty analysis of recharge estimates, using a regional-scale model of groundwater flow and land subsidence, Antelope Valley, California. https://pubs.er.usgs.gov/publication/70155814

INFIL: Estimating spatially and temporally varying recharge and runoff from precipitation and urban irrigation in the Los Angeles Basin, California http://dx.doi.org/10.3133/sir20165068

Geophysical Methods for Estimating Recharge:

This USGS report describes many geophysical methods for investigating groundwater recharge; it includes case studies and a list of references for further information. http://pubs.usgs.gov/pp/pp1703/app2/pp1703_appendix2.pdf

Surface-Water/Groundwater Interactions:

- This USGS Circular is a general reference for groundwater and surface water, and their interdependence: http://pubs.usgs.gov/circ/circ1139/
- This USGS Circular describes the process of streamflow depletion by wells, and ways of understanding and managing the effects of groundwater pumping on streamflow: http://pubs.usgs.gov/circ/1376/
- This USGS document outlines *Field Techniques for Estimating Water Fluxes Between Surface Water and Ground Water*: http://pubs.usgs.gov/tm/04d02/
- This USGS document identifies methodologies for *Using Diurnal Temperature Signals to Infer Vertical Groundwater-Surface Water Exchange*: http://onlinelibrary.wiley.com/doi/10.1111/gwat.12459/abstract

Baseflow Analysis:

- General link to USGS software associated with baseflow analysis http://water.usgs.gov/software/lists/groundwater#flow-based

- U.S. Geological Survey Groundwater Toolbox, A Graphical and Mapping Interface for Analysis of Hydrologic Data (Version 1.0)—User Guide for Estimation of Base Flow, Runoff, and Groundwater Recharge From Streamflow Data: http://pubs.usgs.gov/tm/03/b10/ and http://water.usgs.gov/ogw/gwtoolbox/

Streamflow Trend Evaluation:

User Guide to Exploration and Graphics for RivEr Trends (EGRET) and dataRetrieval: R Packages for Hydrologic Data: http://pubs.usgs.gov/tm/04/a10/

Water Use:

Guidelines for preparation of State water-use estimates for 2005: http://pubs.usgs.gov/tm/2007/tm4e1/

Climate-related Analysis:

HydroClimATe: Hydrologic and Climatic Analysis Toolkit: http://pubs.usgs.gov/tm/tm4a9/

BCM Time Series Graph Tool: Enabling analyses of climate and hydrology variables, including recharge and runoff, for all HUC-8 watersheds in California for historical and future climates:http://climate.calcommons.org/article/about-bcm-time-series-graph-tool

Climate Smart Watershed Analyst: Enabling analyses of climate and hydrology variables, for time series and seasonality for planning watersheds in the San Francisco Bay Area for historical and future climates: http://geo.pointblue.org/watershed-analyst/

6. KEY DEFINITIONS

The key definitions related to Water Budget development outlined in applicable SGMA code and regulations are provided below for reference.

SGMA DEFINITIONS (CALIFORNIA WATER CODE 10721):

(b) "Basin" means a groundwater basin or subbasin identified and defined in Bulletin 118 or as modified pursuant to Water Code § 10722.

(c) "Bulletin 118" means the department's report entitled "California's Groundwater: Bulletin 118" updated in 2003, as it may be subsequently updated or revised in accordance with § 12924.

(r) "Planning and implementation horizon" means a 50-year time period over which a groundwater sustainability agency determines that plans and measures will be implemented in a basin to ensure that the basin is operated within its sustainable yield.

(t) "Recharge area" means the area that supplies water to an aquifer in a groundwater basin.

(v) "Sustainable groundwater management" means the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results.

(w) "Sustainable yield" means the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result.

(x) "Undesirable result" means one or more of the following effects caused by groundwater conditions occurring throughout the basin:

> (1) Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.
>
> (2) Significant and unreasonable reduction of groundwater storage.
>
> (3) Significant and unreasonable seawater intrusion.
>
> (4) Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.

(5) Significant and unreasonable land subsidence that substantially interferes with surface land uses.

(6) Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

(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.

(aa) "Water year" means the period from October 1 through the following September 30, inclusive

GROUNDWATER BASIN BOUNDARIES REGULATIONS (CALIFORNIA CODE OF REGULATIONS 341):

(f) "Aquifer" refers to a three-dimensional body of porous and permeable sediment or sedimentary rock that contains sufficient saturated material to yield significant quantities of groundwater to wells and springs, as further defined or characterized in Bulletin 118.

(q) "Hydrogeologic conceptual model" means a description of the geologic and hydrologic framework governing the occurrence of groundwater and its flow through and across the boundaries of a basin and the general groundwater conditions in a basin or subbasin.

GROUNDWATER SUSTAINABILITY PLAN REGULATIONS (CALIFORNIA CODE OF REGULATIONS 351):

(b) "Agricultural water management plan" refers to a plan adopted pursuant to the Agricultural Water Management Planning Act as described in Part 2.8 of Division 6 of the Water Code, commencing with Section 10800 et seq.

(d) "Annual report" refers to the report required by Water Code Section 10728.

(e) "Baseline" or "baseline conditions" refer to historic information used to project future conditions for hydrology, water demand, and availability of surface water and to evaluate potential sustainable management practices of a basin.

(g) "Basin setting" refers to the information about the physical setting, characteristics, and current conditions of the basin as described by the Agency in the hydrogeologic conceptual model, the groundwater conditions, and the water budget, pursuant to Subarticle 2 of Article 5.

(h) "Best available science" refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, that is consistent with scientific and engineering professional standards of practice.

(l) “Data gap” refers to a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of Plan implementation, and could limit the ability to assess whether a basin is being sustainably managed.

(n) “Groundwater flow” refers to the volume and direction of groundwater movement into, out of, or throughout a basin.

(a) “Interconnected surface water” refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted.

(c) “Interim milestone” refers to a target value representing measurable groundwater conditions, in increments of five years, set by an Agency as part of a Plan.

(d) “Management area” refers to an area within a basin for which the Plan may identify different minimum thresholds, measurable objectives, monitoring, or projects and management actions based on differences in water use sector, water source type, geology, aquifer characteristics, or other factors.

(e) “Measurable objectives” refer to specific, quantifiable goals for the maintenance or improvement of specified groundwater conditions that have been included in an adopted Plan to achieve the sustainability goal for the basin.

(f) “Minimum threshold” refers to a numeric value for each sustainability indicator used to define undesirable results.

(aa) “Principal aquifers” refer to aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems.

(ad) “Seasonal high” refers to the highest annual static groundwater elevation that is typically measured in the Spring and associated with stable aquifer conditions following a period of lowest annual groundwater demand.

(ae) “Seasonal low” refers to the lowest annual static groundwater elevation that is typically measured in the Summer or Fall, and associated with a period of stable aquifer conditions following a period of highest annual groundwater demand.

(af) “Seawater intrusion” refers to the advancement of seawater into a groundwater supply that results in degradation of water quality in the basin, and includes seawater from any source.

(ah) “Sustainability indicator” refers to any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results, as described in Water Code Section 10721(x).

(ai) “Uncertainty” refers to a lack of understanding of the basin setting that significantly affects an Agency’s ability to develop sustainable management criteria and appropriate projects and management actions in a Plan, or to evaluate the efficacy of Plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed.

(aj) "Urban water management plan" refers to a plan adopted pursuant to the Urban Water Management Planning Act as described in Part 2.6 of Division 6 of the Water Code, commencing with Section 10610 et seq.

(ak) "Water source type" represents the source from which water is derived to meet the applied beneficial uses, including groundwater, recycled water, reused water, and surface water sources identified as Central Valley Project, the State Water Project, the Colorado River Project, local supplies, and local imported supplies.

(al) "Water use sector" refers to categories of water demand based on the general land uses to which the water is applied, including urban, industrial, agricultural, managed wetlands, managed recharge, and native vegetation.

(am) "Water year" refers to the period from October 1 through the following September 30, inclusive, as defined in the Act.

(an) "Water year type" refers to the classification provided by the Department to assess the amount of annual precipitation in a basin.

BULLETIN 118 DEFINITIONS

"Groundwater overdraft" refers to 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.

"Groundwater in storage" refers to the quantity of water in the zone of saturation.

"Groundwater Storage Capacity" refers to the volume of void space that can be occupied by water in a given volume of a formation, aquifer, or groundwater basin.

"Safe yield" refers to the maximum quantity of water that can be continuously withdrawn from a groundwater basin without adverse effect

"Saturated zone" refers to the zone in which all interconnected openings are filled with water, usually underlying the unsaturated zone.

7. RELATED MATERIALS

This section provides a list of related materials including associated SGMA BMPs, general references, and selected case studies and examples pertinent to the development of water budgets. For the items identified, available links to access the materials are also provided.

GUIDANCE AND GENERAL REFERENCES:

- Barlow, P.M., and Leake, S.A., 2012, Streamflow depletion by wells—Understanding and managing the effects of groundwater pumping on streamflow: U.S. Geological Survey, Circular 1376. [http://pubs.usgs.gov/circ/1376/]

- Healy, R.W., Winter, T.C., LaBough, J.W., and Franke, L.O., 2007, Water Budgets: Foundations for Effective Water-Resources and Environmental Management. U.S. Geological Survey, Circular 1308. [http://pubs.usgs.gov/circ/2007/1308/]

- Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998, Ground Water and Surface Water, A Single Resource. U.S. Geological Survey, Circular 1139. [http://pubs.usgs.gov/circ/circ1139/#pdf]

- California Water Plan Update 2013. Department of Water Resources, 2013.[http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm]

- California's Groundwater Update 2013, Department of Water Resources, 2013.[http://www.water.ca.gov/waterplan/topics/groundwater/index.cfm]

SELECTED CASE STUDIES AND EXAMPLES:

- Development and Calibration of the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG. DWR Technical Memorandum. California Department of Water Resources (DWR) Bay-Delta Office. 2013. [http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/download/C2VSim_Model_Report_Final.pdf]

- Groundwater Availability of the Central Valley, California. Professional Paper 1766. USGS. 2009. [http://pubs.usgs.gov/pp/1766/PP_1766.pdf]

- Scott Valley Integrated Hydrologic Model: Data Collection, Analysis, and Water Budget. Final Report. University of California – Davis, Department of Land, Air, and Water Resources. 2013. [http://groundwater.ucdavis.edu/files/165395.pdf]

- Selected Approaches to Estimate Water-Budget Components of the High Plains, 1940 through 1949 and 2000 through 2009. Scientific Investigations Report 2011–5183. USGS. 2011. [http://pubs.usgs.gov/sir/2011/5183/pdf/sir2011-5183.pdf]
- Simulated Effects of Ground-Water Withdrawals and Artificial Recharge on Discharge to Streams, Springs, and Riparian Vegetation in the Sierra Vista Subwatershed of the Upper San Pedro Basin, Southeastern Arizona. Scientific Investigations Report 2009-5207. USGS. April, 2014. [http://pubs.usgs.gov/sir/2008/5207/sir2008-5207.pdf]
- Evaluation of Simulations to Understand Effects of Groundwater Development and Artificial Recharge on Surface Water and Riparian Vegetation, Sierra Vista Subwatershed, Upper San Pedro Basin Arizona. Open-File Report 2012-1206. USGS. 2012. [https://pubs.usgs.gov/of/2012/1206/of2012-1206.pdf\