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Technical Memorandum

To: Interested Parties

From: Davids Engineering

Date: May 2021

Subject: **Water Budget Development for Butte Valley Wildlife Area**

Summary

An estimated water budget was developed for Butte Valley Wildlife Area (BVWA) using a water budget tool developed to estimate applied water demands based on estimated acres for seasonal wetlands, upland vegetation, and cropland based on water management regimes. BVWA is located in northwestern Siskiyou County west of Macdoel and lies west of Meiss Lake, a shallow natural water body.

The water budget results indicate that water sources in a typical year include applied water (2.2 taf[1] or 3 inches annually[2]) and precipitation (11.4 taf or 15 inches annually). Primary outflows include evapotranspiration (12.5 taf or 16 inches annually) and percolation (1.1 taf or 1.5 inches annually). Other outflows estimated include surface runoff of precipitation (0.1 taf or 0.1 inches annually) and return flows from applied water (0.1 taf or 0.1 inches annually). These small runoff amounts are reused within BVWA. Only during extreme flooding do outflows from the BVWA occur, during which water is pumped out of the wildlife area to either the Klamath River or the National Grasslands. The WWBT simulates management for individual cells, rather than routing of flows between cells; under normal conditions these small runoff amounts will be reused within BVWA.

Background and Overview

This technical memorandum describes water budgets developed for wetlands at Butte Valley Wildlife Area (BVWA) as part of an effort for Audubon to prepare water budget information that is consistent with and adequate to satisfy requirements for water budgets developed for Groundwater Sustainability Plans (GSPs) under the Sustainable Groundwater Management Act of 2014 (SGMA) while also supporting other wetlands water management activities. In addition to supporting SGMA implementation, these water budgets and the water budget tool described below could support future decision-making by wetlands managers related to the optimization of available water supplies to maximize habitat value.

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[1] Thousand acre-feet.

[2] These estimates, generated by the model represent relatively full water supply conditions and may vary in dry years during which refuge water supply is reduced.

The water budgets were generated using a Microsoft Excel-based Wetlands Water Budget Tool (WWBT) developed as part of this effort (Davids Engineering 2020) to quantify primary inflows to and outflows from managed wetlands based on publicly available information and information received through consultation with BVWA representatives. This tool could also be used in the future to evaluate additional wetlands management scenarios that may be contemplated by wetlands managers.

BVWA Land and Water Management

Managed wetlands at BVWA include approximately 4,300 acres of seasonal wetlands, of which approximately sixteen percent receive applied water for winter flooding. Water management practices, in general, may be summarized as follows:

- Approximately 300 wetlands acres receive applied groundwater in stages in August and September. An additional 300 acres receive applied groundwater during October, and an additional 100 acres receive applied water during the first half of November. Runoff of precipitation from upslope areas through three creeks that flow into BVWA may also provide a source of supply at times in the fall to supplement applied groundwater supplies and help flood wetland areas.
- After mid-November, the wetland ponds then rely on available precipitation to maintain habitat. Flow through the three creeks in the winter and spring are redirected from the wetlands to flow directly into Meiss Lake.
- To the extent supplies are adequate, wetlands ponds are maintained through the spring and drawdown occurs in May and June.
- The wetlands remain dry during the summer until water is applied again in the fall.
- In addition to wetlands receiving applied water, approximately 3,600 acres of additional wetlands habitat exists within BVWA. These lands are managed to capture upslope precipitation runoff, direct precipitation, and water pumped from Meiss Lake[3] on the wetlands cells when available. Historically, in very wet years, a substantial percentage of these acres may have been flooded. However, due to a variety of factors including decreasing creek flows into BVWA and budget constraints, in more recent years, none of this acreage has received water, even during wet years.
- Approximately 600 acres of additional land can be planted and irrigated for grain production. However, due to limited funding, labor, and water supply, the planted and irrigated acreage is typically around 300 acres. These lands are irrigated in July and August. The remaining 300 acres of crop land are typically idle.
- Finally, the BVWA includes approximately 4,400 acres of upland vegetation.

This summary of water management practices was originally developed using the 1996 Management Plan for the BVWA and was refined and revised through coordination and discussion with the BVWA Manager to incorporate recent management practices.

[3] Meiss Lake overtopping and flooding private lands to the east is a concern in Butte Valley. When the lake is nearly full during wet periods, water is pumped from Meiss Lake to these adjacent wetland cells or overland to the Klamath River or National Grasslands.

Water Budget Methodology

Structure

Water budgets were developed using methodologies consistent with existing water budgets from the California Department of Water Resources (DWR) for managed wetlands. These DWR water budgets support the California Water Plan, the CalSim water resources planning model, and the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim). A general schematic depicting the water budget structure is shown in Figure 1.

For a given wetlands complex, estimates of water budget components including inflows, outflows, and change in storage[4] are estimated over time on a monthly time step. Water budgets are estimated for the period 1991 to 2017 to evaluate differences in water requirements over a range of hydrologic conditions. Applied water requirements are estimated through closure of the water budget based on the principle of conservation of mass, as shown in Equation 1, where AW = applied water, ET = evapotranspiration, SR = surface runoff, RF = return flow, Perc = percolation, Precip = precipitation, and dS = change in storage.

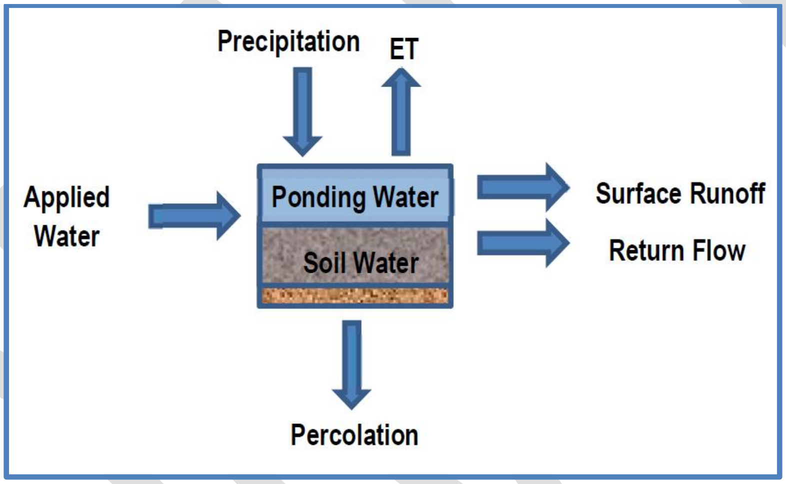

Figure 1. Wetlands Water Budget Structure (DWR 2017).

$$AW = ET + SR + RF + Perc - Precip - dS \qquad [1]$$

The methodology used to estimate individual water budget components is described in the following section. Some component methodologies vary based on the operational mode of a given wetland, which varies over time based on habitat and water management objectives. The following modes are considered:

- Floodup – Period during which ponds are filled, typically during late summer/fall;
- Maintenance – Period during which ponds are maintained, and water is applied as needed to maintain desired water levels, typically during fall/winter;
- Hold – Period during which pond drainage is prevented, but additional water is not applied, typically during fall/winter;
- Drawdown – Period during which ponds are drained, typically during late spring;

[4] Change in storage refers to the change in pond storage and stored moisture in the top few feet of the soil.

- Irrigation – Period during which water is applied for irrigation to produce feed (e.g. smartweed, watergrass, timothy, etc.) for migratory waterfowl and shorebirds, typically during late spring/summer;
- Cropped – Period following irrigation when an actively growing crop is present but additional irrigation water is not applied, typically during summer; and
- No Action – Period during which water is not present, typically during summer.

For a given wetlands complex, the timing of water management operations is estimated for unique habitat types, and estimated water budgets for each habitat type are aggregated to develop the water budget for the complex as a whole to estimate total AW. Once total AW requirements are estimated, groundwater demand can be estimated as the difference between the total AW and available surface water supplies.

Components

Evapotranspiration (ET)

ET over time for each habitat type is estimated based on the well accepted reference evapotranspiration (ET_o) – crop coefficient methodology (ASCE, 2016). ET_o is available from DWR through the Spatial CIMIS system (https://cimis.water.ca.gov/SpatialData.aspx) and estimated habitat coefficients (Kh) relating ET_o to actual ET (Allen et al. 1998) according to Equation 2. For this effort, values of actual ET have been estimated based on Landsat satellite imagery and the METRIC energy balance model (Allen et al. 2007), and used to estimate Kh. The METRIC model was applied to the Sacramento National Wildlife Refuge (NWR) in 2017-2018. The actual ET and corresponding Kh resulting from the energy balance inherently accounts for stress during the operational modes when a full water supply is unavailable. Estimated monthly ETo, Kh, and actual ET are shown in Figure 2. As shown, actual ET tends to equal or exceed ETo between December and March when conditions are relatively wet due to precipitation and applied water and falls below ETo during the remainder of the year due to drier conditions as cells dry following spring drawdown. The Kh is typical for seasonal operational modes and can be used with ET_o from the BVWA to estimate actual ET for the BVWA area.

$$\text{Actual ET} = ET_o \times Kh \qquad [2]$$

Surface Runoff (SR)

SR represents runoff occurring due to precipitation[5]. SR is estimated as follows:

- Periods when individual wetlands cells are not ponded: Runoff is calculated using the Natural Resources Conservation Service (NRCS) curve number method, applied on a daily basis as described by Schroeder et al. (1994) and aggregated to monthly SR. Daily precipitation was estimated as described below.
- Periods when cells are ponded: When ponds are maintained at targeted levels by applying water (Maintenance mode) for individual cells, it is assumed that all precipitation runs off. When ponds are held, but water is not applied for individual cells, it is assumed that no precipitation runs off, unless the target water level is exceeded.

[5] Surface runoff is estimated in the WWBT at the cell level. The volume is estimated to leave the specific cell, but not necessarily the wildlife refuge as a whole. It may still be available for recapture and reuse within the wildlife refuge.

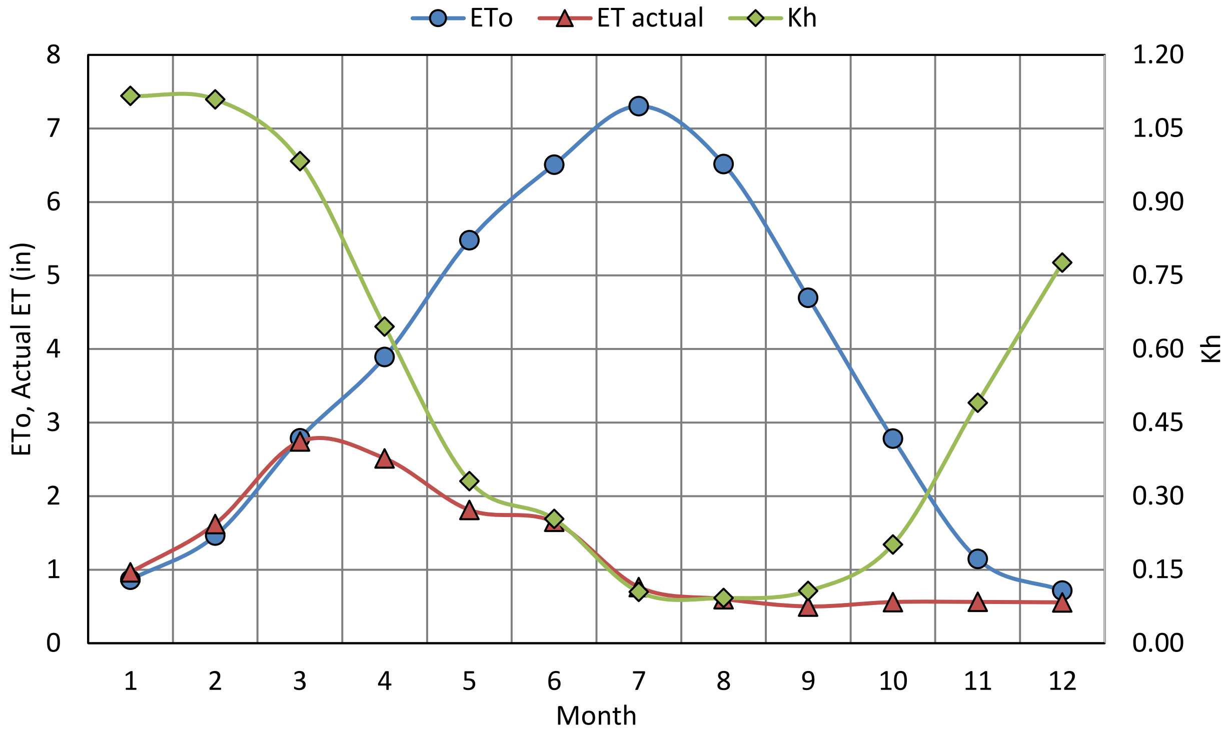

Figure 2. Reference ET (ET_o), Habitat Coefficients (Kh), and Actual ET for 2017-2018 for the Sacramento NWR.

Return Flow (RF)

RF represents runoff occurring due to applied surface water and/or groundwater[6]. RF is estimated as follows:

- Periods when cells are not ponded – For periods when summer irrigation occurs, RF is estimated based on a user-specified percentage of applied water running off of an irrigated cell and ultimately leaving the wetlands complex, if any.
- Periods when cells are ponded – For periods when cells are ponded, RF can occur through three modes:
  - Specified flow-through water from individual cells ultimately leaving wetlands complex,
  - Specified lateral seepage to natural waterways or manmade drains ultimately leaving wetlands complex, and
  - Pond drainage during periods of drawdown.

Percolation (Perc)

Perc represents the rate of percolation of water below the root zone entering the groundwater system and is estimated using the Campbell equation (Campbell 1974) based on estimated soil hydraulic parameters and soil moisture content. For periods when the soil moisture is above field capacity (e.g. ponded periods or periods within the first few days following irrigation), the percolation rate is

[6] Return flow is estimated in the WWBT at the cell level. The volume is estimated to leave the specific cell, but not necessarily the wildlife refuge as a whole. It may still be available for recapture and reuse within the wildlife refuge.

equivalent to the soil's saturated hydraulic conductivity. For periods when the soil moisture is below field capacity, the percolation rate is calculated based on unsaturated flow, as described by the Campbell equation. Soil parameters were estimated based on NRCS soil surveys and then calibrated as part of water budget development.

Precipitation (Precip)

Precipitation is estimated using interpolated local rainfall data from the Parameter Regression for Independent Slopes Model (PRISM) (http://www.prism.oregonstate.edu/) developed at Oregon State University for the centroid of the refuge boundary.

Change in Storage (dS)

During the non-ponded period, changes in storage are estimated based on a daily root zone water balance for each cell tracking AW, Precip, ET, SR, RF, and Perc as described by DWR (2017). During the ponded period, changes in storage are estimated based on daily changes in pond depth resulting from AW, Precip, ET, SR, RF, and Perc. Changes in pond depth are estimated based on estimated target pond depths and days required to flood each cell. Changes in storage over the course of a year are typically near zero, but vary somewhat from year to year.

Applied Water (AW)

As described previously, AW is estimated through closure of the water budget using Equation 1.

Results

Monthly Water Budget

Monthly water budget results for a relatively typical year (Water Year 2016[7]) are presented in Tables 1 and 2 and Figures 3 and 4, respectively. Table 1 and Figure 3 present estimated water budget components volumetrically in acre-feet per month, while Table 2 and Figure 4 express the water budget components as a depth in inches per month.

AW occurs in the late summer and fall between August and November, with the greatest applied water occurring in August and September. It then decreases into October and November as maintenance stops, and water is held through the winter. A positive change in storage (dS) occurs during months in late summer and fall in which water is applied and increases pond storage and soil moisture; positive dS also occurs in the winter months of December and January from precipitation. A negative change in storage in subsequent months reflects decreases in pond storage and reduction in stored soil moisture.

ET generally increases during the spring and decreases in summer due to relatively dry conditions. ET then increases again in fall as water is applied but subsequently decreases in winter due to decreases in evaporative demand (ETo).

SR is small due to precipitation being held to maintain pond storage. RF is also small, due to almost all applied water being consumed as ET or entering the groundwater system through percolation. SR is negligible in most months; it is highest in April when drawdown in the ponds occurs and precipitation collected in the ponds over the winter is drained. RF is negligible in most months, although minimal amounts occur during the months of water application. All of the estimated runoff (SR) or return flow

[7] A water year refers to the period from October to September. For example, the 2016 water year corresponds to the period from October 2015 to September 2016. The 2016 water year was selected as a recent year with near average precipitation based on the period 1991-2017.

(RF) is recaptured and reused before leaving the refuge under normal conditions; however, the WWBT is applied at the individual cell scale, rather than for the refuge as a whole.

Table 1. Water Year 2016 Monthly Water Budget (acre-feet).

Month	Area (ac)	Inflows		Outflows				dS (af)	Check
		Precip (af)	AW (af)	ET (af)	Perc (af)	SR (af)	RF (af)		
10	9,300	698	893	410	136	45	33	966	0
11	9,300	457	221	380	169	3	0	126	0
12	9,300	3,480	0	393	181	9	0	2,897	0
1	9,300	2,100	0	737	181	0	0	1,182	0
2	9,300	698	0	1,577	169	0	0	-1,048	0
3	9,300	1,860	0	2,416	179	0	0	-735	0
4	9,300	612	6	2,797	25	0	0	-2,204	0
5	9,300	558	4	1,352	0	27	0	-818	0
6	9,300	736	0	1,235	0	20	0	-518	0
7	9,300	124	100	608	0	0	20	-404	0
8	9,300	39	467	337	30	0	20	119	0
9	9,300	85	465	221	66	3	16	245	0
Total	**9,300**	**11,447**	**2,155**	**12,465**	**1,136**	**107**	**89**	**-194**	**0**

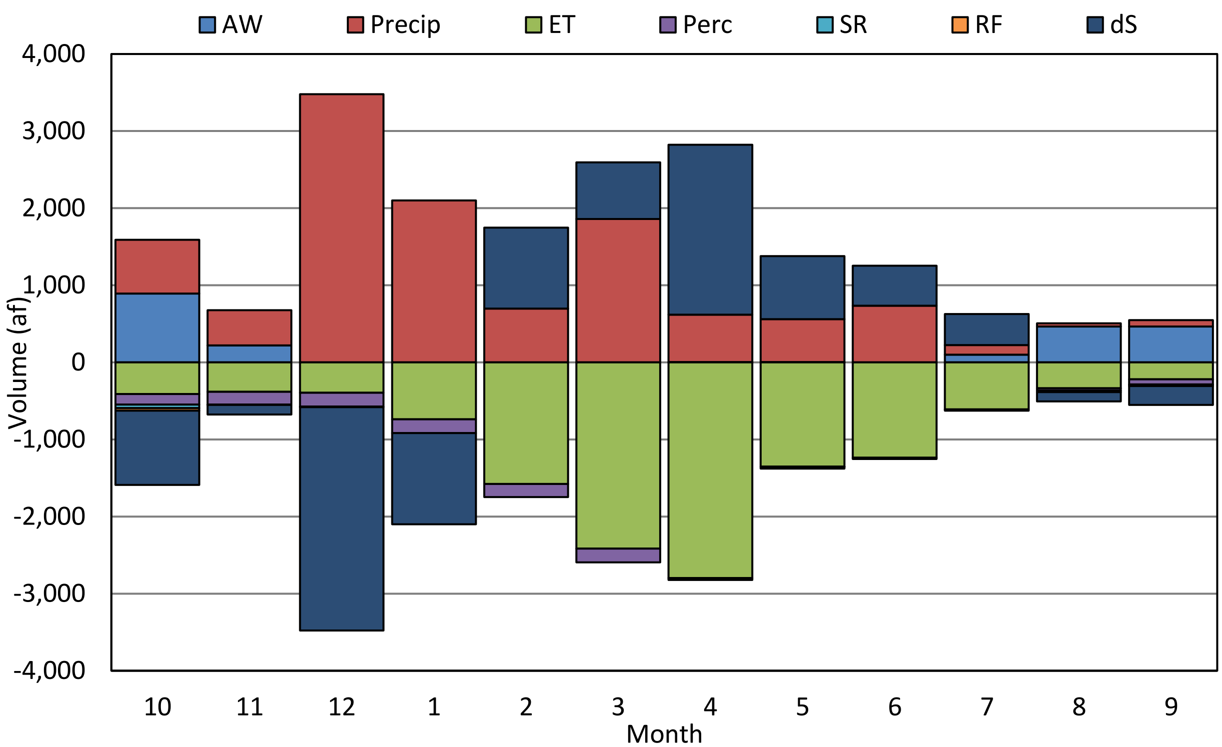

Figure 3. Water Year 2016 Monthly Water Budget (acre-feet).

Table 2. Water Year 2016 Monthly Water Budget (inches).

Month	Area (ac)	Inflows		Outflows				dS (in)	Check
		Precip (in)	AW (in)	ET (in)	Perc (in)	SR (in)	RF (in)		
10	9,300	0.9	1.2	0.5	0.2	0.1	0.0	1.2	0.0
11	9,300	0.6	0.3	0.5	0.2	0.0	0.0	0.2	0.0
12	9,300	4.5	0.0	0.5	0.2	0.0	0.0	3.7	0.0
1	9,300	2.7	0.0	1.0	0.2	0.0	0.0	1.5	0.0
2	9,300	0.9	0.0	2.0	0.2	0.0	0.0	-1.4	0.0
3	9,300	2.4	0.0	3.1	0.2	0.0	0.0	-0.9	0.0
4	9,300	0.8	0.0	3.6	0.0	0.0	0.0	-2.8	0.0
5	9,300	0.7	0.0	1.7	0.0	0.0	0.0	-1.1	0.0
6	9,300	1.0	0.0	1.6	0.0	0.0	0.0	-0.7	0.0
7	9,300	0.2	0.1	0.8	0.0	0.0	0.0	-0.5	0.0
8	9,300	0.1	0.6	0.4	0.0	0.0	0.0	0.2	0.0
9	9,300	0.1	0.6	0.3	0.1	0.0	0.0	0.3	0.0
Total	**9,300**	**14.8**	**2.8**	**16.1**	**1.5**	**0.1**	**0.1**	**-0.3**	**0.0**

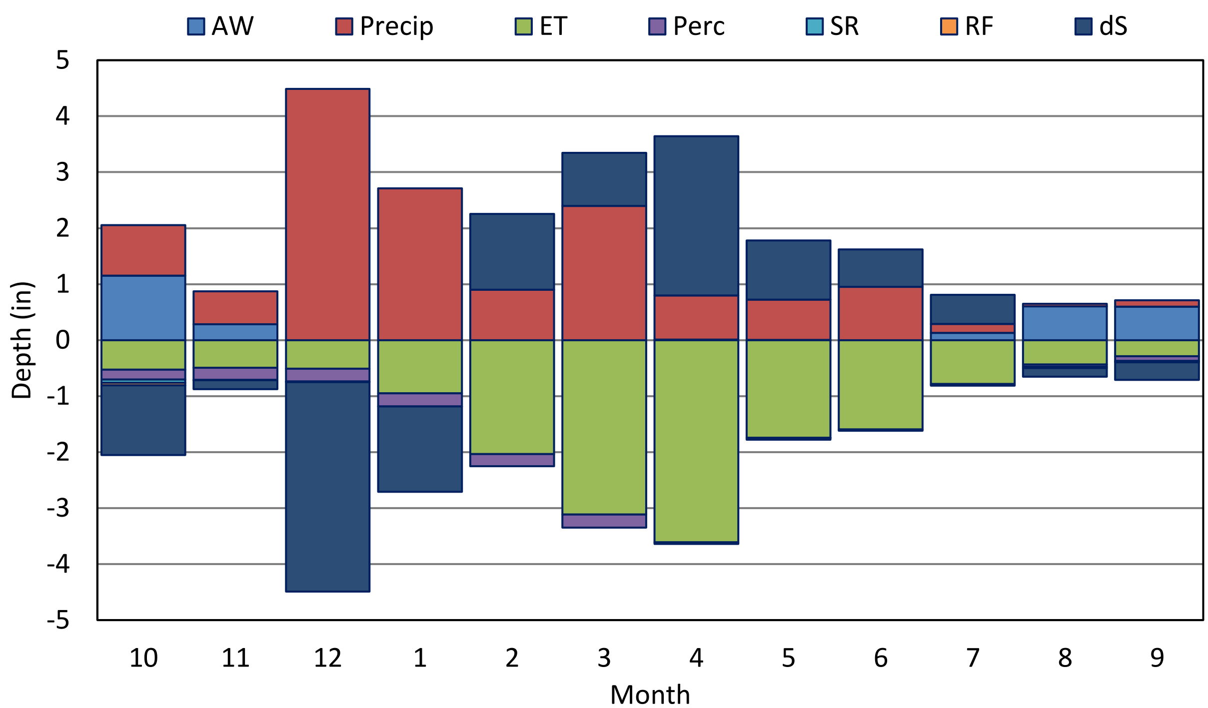

Figure 4. Water Year 2016 Monthly Water Budget (inches).

Annual Water Budget

Annual water budget results for water years 1991 to 2017 are presented in Table 3 and summarized by year type (wet, dry, and average) in Figure 5.

AW is relatively consistent across years and year types; precipitation varies across years and is obviously greatest in wet years and least in dry years. ET varies from year to year and is largely influenced by precipitation; the greater water availability in wet years results in higher ET values, as compared to dry years. Similarly, Perc and SR are also higher in wet years and lower in dry years, although the overall volumes and changes from year to year are not as great. RF is generally small and is relatively consistent across years and year types. Change in storage (dS) varies from year to year but averages near zero over the period of analysis.

Table 3. Annual Water Budget, 1991 – 2017 (acre-feet).

Water Year	Year Type	Inflows		Outflows				dS (af)	Check
		AW (af)	Precip (af)	ET (af)	Perc (af)	SR (af)	RF (af)		
1991	Dry	2,152	8,122	9,997	906	116	89	-834	0
1992	Dry	2,148	6,030	6,911	991	92	89	94	0
1993	Wet	2,083	15,523	15,606	1,233	191	89	486	0
1994	Dry	2,083	6,991	8,370	917	153	89	-455	0
1995	Wet	2,093	15,655	16,179	1,252	117	89	110	0
1996	Wet	2,102	16,399	16,399	1,574	216	89	223	0
1997	Wet	2,097	16,337	16,258	1,231	324	89	531	0
1998	Wet	2,039	17,081	17,776	1,266	251	89	-262	0
1999	Wet	2,091	13,880	14,659	1,459	255	89	-491	0
2000	Wet	2,148	10,680	11,610	1,054	90	89	-16	0
2001	Dry	2,120	6,239	7,173	880	92	89	124	0
2002	Dry	2,152	10,486	11,927	1,067	82	89	-528	0
2003	Wet	2,155	10,238	10,927	1,072	40	89	264	0
2004	Dry	2,136	8,959	9,911	1,063	74	89	-42	0
2005	Wet	2,097	11,393	12,136	980	255	89	30	0
2006	Wet	2,101	13,842	14,288	1,412	292	89	-138	0
2007	Dry	2,130	10,277	11,027	1,050	63	89	177	0
2008	Dry	2,120	8,672	9,812	1,014	172	89	-296	0
2009	Dry	2,153	8,982	9,830	992	110	89	115	0
2010	Dry	2,121	7,649	8,432	928	84	89	238	0
2011	Wet	2,100	12,788	13,655	1,138	174	89	-169	0
2012	Dry	2,112	8,796	9,929	935	69	89	-115	0
2013	Dry	2,142	9,455	9,148	971	165	89	1,224	0
2014	Dry	2,118	6,921	8,474	882	67	89	-473	0
2015	Dry	2,090	11,579	12,888	1,031	177	89	-516	0
2016	Dry	2,155	11,447	12,465	1,136	107	89	-194	0
2017	Wet	2,063	13,322	13,903	1,146	187	89	59	0
Minimum		2,039	6,030	6,911	880	40	89	-834	-
Maximum		2,155	17,081	17,776	1,574	324	89	1,224	-
Averages	Wet	2,097	13,928	14,450	1,235	199	89	52	0
	Dry	2,129	8,707	9,753	984	108	89	-99	0
	All	2,115	11,027	11,840	1,096	149	89	-32	0

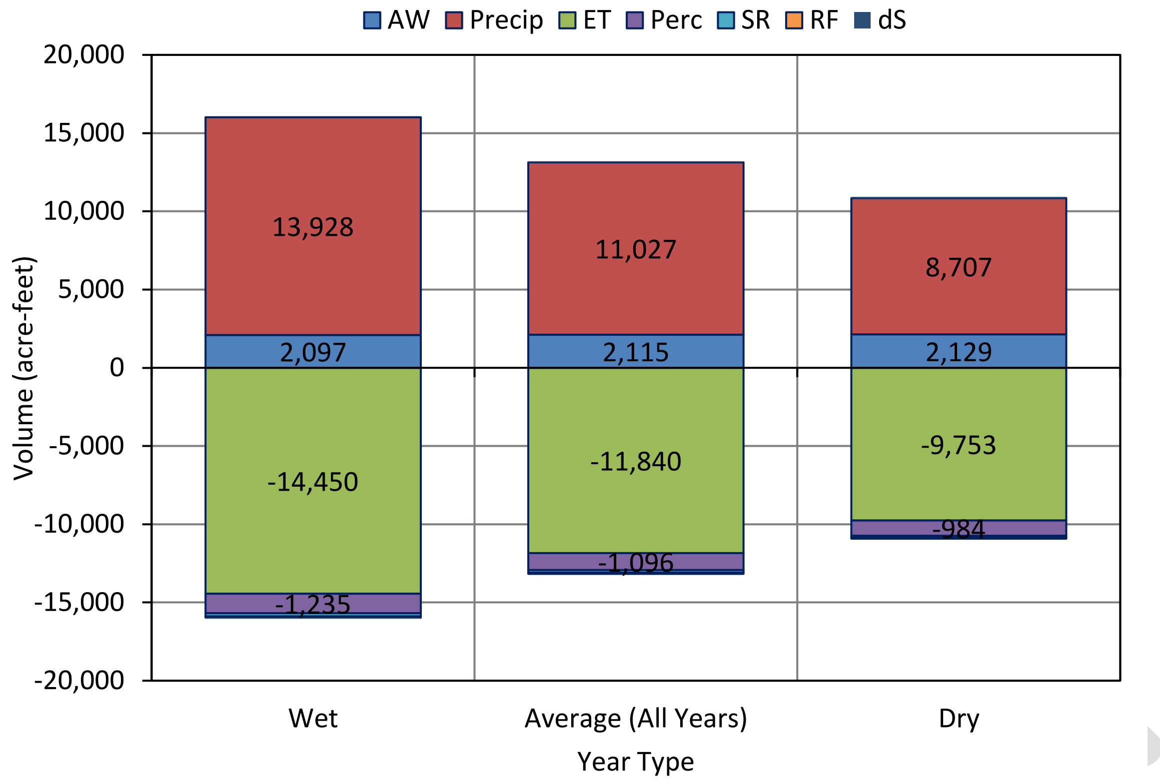

Figure 5. Annual Water Budget Results for Wet and Dry Years, and Overall Average, for 1991 – 2017 Period (acre-feet).

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