Yolo Subbasin Groundwater Agency
2022 Groundwater Sustainability Plan

Yolo County, CA

Appendix F

Yolo Subbasin Water Budget Documentation

Contents

List of Figures

List of Tables

1. Yolo Subbasin Water Budget

1.1. Introduction

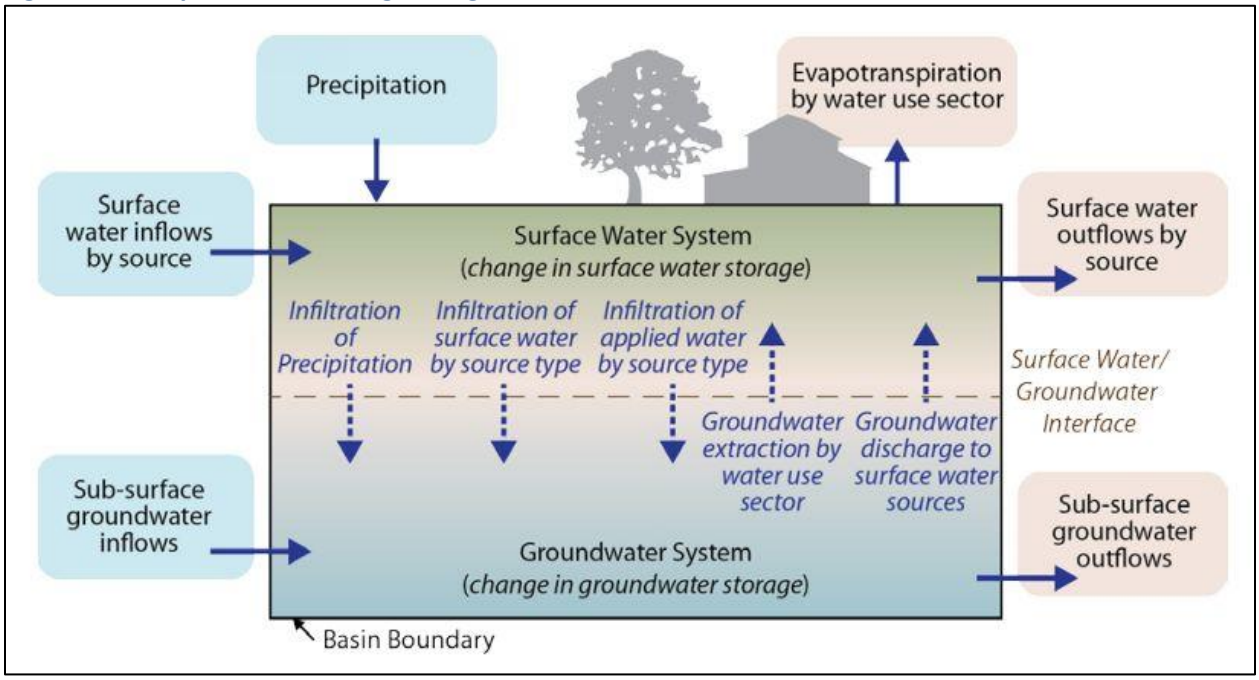
This chapter describes the water budget of the Yolo Subbasin (henceforth, "Basin" or "Yolo Subbasin"). Water budgets quantify all inflows and outflows of the area of interest (AOI) with surrounding boundaries, and within the AOI boundary at a spatial and temporal resolution that balances data and resource (human, financial, and time) availability with the overall goals of the water budget.

Figure 1 presents a simplified conceptual water budget schematic (California DWR, 2016), that includes typical inflows and outflows of the land surface and groundwater systems. Figure 1 can be thought of as a simplified slice of the land surface and underlying aquifer of the Basin. Land surface and groundwater budgets were calculated for the Yolo Subbasin.

Land surface water budgets quantify all the inflows and outflows to a specified area, from the bottom of the root zone, up to the land surface. As later sections show, land surface inflows in the Basin are dominated by precipitation, surface water supply, and groundwater supply to meet multiple water demands (primarily agricultural and municipal water needs). Applied water re-use and recycled water are relatively minor inflows, quantitatively. Land surface outflows in the Basin are dominated by evapotranspiration (of precipitation and applied water), deep percolation (i.e., groundwater recharge), and surface runoff. Managed aquifer recharge is a quantitatively small land surface outflow for the Basin as a whole. The difference between these inflows and outflows represents the net change in land surface storage.

Groundwater budgets show all the inflows and outflows to the aquifer from the bottom of the root zone, down through all aquifer layers. Much of the Basin is underlain by an aquifer with three layers, as described in the Basin Setting section. Groundwater inflows in the Basin are dominated by deep percolation from the overlying land surface, followed by smaller contributions as recharge from the unlined Yolo County Flood Control and Water Conservation District (YCFC) earthen canal system. Groundwater outflows are largely comprised of pumping (for irrigation and municipal uses). Lateral flows (exchanges with neighboring basins), and surface-groundwater (SW-GW) exchanges with surface water bodies like rivers and creeks are the other, smaller groundwater outflows from the Basin. The difference between groundwater inflows and outflows represents the net change in groundwater storage. ***In the Basin, groundwater storage changes are positive in wet years and negative in dry years, with no significant trend (decline or increase) over the past 50 years.***

Figure 1 Conceptual Water Budget Diagram



Historical, present and future land surface and groundwater budgets were estimated at catchment, management area, and basin scale (model disaggregation is described in Section 1.1.1). In this chapter we describe the land surface water budgets at county scale and groundwater budgets at basin scale, while explanations of the management area-scale groundwater budgets are provided in Appendix A.

Table 1. Useful Terms in this section.

Term	Description
Basin	In this Chapter, Basin refers to the Yolo Subbasin
Land surface water budget	Mass balance describing the inflows and outflows of the surface water system, typically from the root zone up to the land surface
Groundwater budget	Mass balance of the groundwater system describing the inflows and outflows of the aquifer(s) underlying the basin.
Lateral flows	Groundwater flows, typically driven by hydraulic head differences. At the Basin scale, this refers to lateral flows to/from all adjacent basins. At the management area scale this refers to lateral flows to/from adjacent management areas and/or adjacent basins.

Term	Description
SW-GW exchange	Exchange between surface water bodies and groundwater aquifers. Includes seepage (from surface water to groundwater) and groundwater flow into surface water bodies
Boundary flows	Flows at the edges of boundaries of basins and models. When referring to models, boundary conditions are set as appropriately as possible given the state of knowledge.
Management Area	The Yolo Subbasin has 6 management areas (Figure 4).
Entity	Organizations with a water management role, authority, or mandate to manage water. In the Yolo Subbasin Groundwater Agency (YSGA) model, there are 19 entities explicitly represented made up of irrigation districts, cities, community services districts, and reclamation districts.
White Area	Parts of the County that do not formally fall within the service area or jurisdiction of an Entity.
Catchment	A catchment is an area in the YSGA model for which the land surface water budget is calculated. There are 47 catchments in the YSGA model domain, and 37 catchments in the County (See Figure 2). Each catchment was drawn by considering topography, hydrogeology, and administrative/entity boundaries.
MODFLOW	Modular Three-Dimensional Finite-Difference Groundwater Flow Model
WEAP	Water Evaluation And Planning Model
IWFM	Integrated Water Flow Model
IGSM	Integrated Groundwater and Surface Water Model
YSGA Model	The coupled WEAP-MODFLOW model that has been developed for the YSGA and preparations of the Groundwater Sustainability Plan.

1.1.1. Model Overview

The Yolo Subbasin Groundwater Agency model (YSGA model) is a linked surface water-groundwater model developed using Water Evaluation And Planning (WEAP)[1] and MODFLOW[2]. WEAP (Yates et al., 2005a, 2005b) is an integrated surface water – groundwater modeling tool, which integrates rainfall-runoff hydrology, reservoir operation, water demands from cities and crops, and allocations of water to those demands from surface water and groundwater supplies. The WEAP model used in the YSGA model builds on several years of development of the Cache Creek system at the Yolo County scale (Mehta et al., 2018, 2011; Winter et al., 2017).

MODFLOW is a finite-difference groundwater modeling tool developed by the USGS (Harbaugh, 2005). In the YSGA model, MODFLOW simulates the groundwater budget of the Yolo Subbasin's three-layer aquifer. The MODFLOW model was built using the inputs, aquifer parameters, boundary conditions, and aquifer representation from a Yolo County IWFM model (Flores Arenas, 2016), which in turn was informed by an IGSM model of Yolo County (WRIME, 2006).

1.1.1.1.Temporal Scope

SGMA regulations point to three time periods regarding water budgets: a 10-year historical period, the 'current' year, and a projected period informed by a 50-year history. The current water year is defined in the GSP Regulations (§354.18(c)(1)) as the year with "the most recent population, land use, and hydrologic conditions". According to the GSP Regulations §354.18(c)(3)(A), "projected hydrology shall utilize 50 years of historical precipitation, evapotranspiration, and streamflow information as the baseline condition for estimating future hydrology". The Yolo Subbasin Water Budget model relies on a 48-year historical and future period, which is sufficient to project the 50-year period referenced by the Regulations.

1.1.1.1.1. Historical and Current Period

The YSGA model runs at a monthly time step. The historical to current period covers 48 years, from Water Year (WY) 1971 to WY 2018. Although GSP Regulations require a minimum 10-year period for historical water budgets, we leveraged and extended our earlier work that modeled a substantially longer period (WY 1971-WY 2005 (Mehta et al., 2013) and WY 1971-2008 (Mehta et al., 2018)).

These 48 years (WY 1971-WY 2018) cover a large spread of water year types, significant and contiguous drought periods (WY 1976-WY 1977, WY 1987-WY 1992, WY 2007-WY 2009, and WY 2012-WY 2016), and significant and contiguous wet periods of note (WY 1971-WY 1975, WY 1982-WY 1984, WY 1995-WY 2000, and WY 2005-WY 2006). The Water Year Index (Sacramento Valley) and the Water Year Types for the historical to current water year type are listed in Table 2. Water Year 2018 – the last year of the model simulation in the historical period – is treated as the current period. This is the most recent year for which almost all datasets are available. Climate and water rights data are updated to WY 2018 in the

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[1] See https://www.weap21.org/ for more information.

[2] See https://water.usgs.gov/ogw/modflow/ for more information.

YSGA model. Land use data, however, is only available to 2016 (the LandIQ dataset provided by DWR in the SGMA Data Viewer[3]). Hence 2016 Land use data is used and kept constant through WY 2018.

Table 2. Sacramento River Water Year Index and Water Year Types.

Water Year	Water Year Index	Water Year Type	Water Year	Water Year Index	Water Year Type
1971	10.37	W	1995	12.89	W
1972	7.29	BN	1996	10.26	W
1973	8.58	AN	1997	10.82	W
1974	12.99	W	1998	13.31	W
1975	9.35	W	1999	9.80	W
1976	5.29	C	2000	8.94	AN
1977	3.11	C	2001	5.76	D
1978	8.65	AN	2002	6.35	D
1979	6.67	BN	2003	8.21	AN
1980	9.04	AN	2004	7.51	BN
1981	6.21	D	2005	8.49	AN
1982	12.76	W	2006	13.2	W
1983	15.29	W	2007	6.19	D
1984	10.00	W	2008	5.16	C
1985	6.47	D	2009	5.78	D
1986	9.96	W	2010	7.08	BN
1987	5.86	D	2011	10.54	W
1988	4.65	C	2012	6.89	BN
1989	6.13	D	2013	5.83	D
1990	4.81	C	2014	4.07	C
1991	4.21	C	2015	4.00	C
1992	4.06	C	2016	6.71	BN
1993	8.54	AN	2017	14.14	W
1994	5.02	C	2018	7.14	BN

[3] See https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#waterbudget; Accessed 8.31.2018

1.1.1.1.2. Future period

Future projections use climate change projections provided by DWR on the SGMA Data Viewer[4], which are summarized here. Additional information is provided in later sections (Section 1.2) and in the Model Documentation Appendix. Climate projections in the YSGA model are based on climate change model simulations centered around the mid-2030's period and the mid-2070's period. In the YSGA model, each future projection uses the final state of the historical model simulation as the initial state of the future simulations. In other words, each climate projection in the model is investigating the outcome of that corresponding projection's climate occurring from WY 2019 on, for the next 48 years. For example, the future projection that uses the central tendency of the climate change models around the 2030's, investigates the outcome of that climate occurring from WY 2019 – WY 2067.

1.1.1.2.Spatial Scope

The spatial scope of the YSGA model is shown in Figure 2 and Table 3. An important feature to remember when reviewing the water budgets sections, is that the land surface water budget corresponds to the surface hydrology (Yolo County extent, overall), while the groundwater budget pertains to the alluvial aquifer of the Yolo Subbasin.

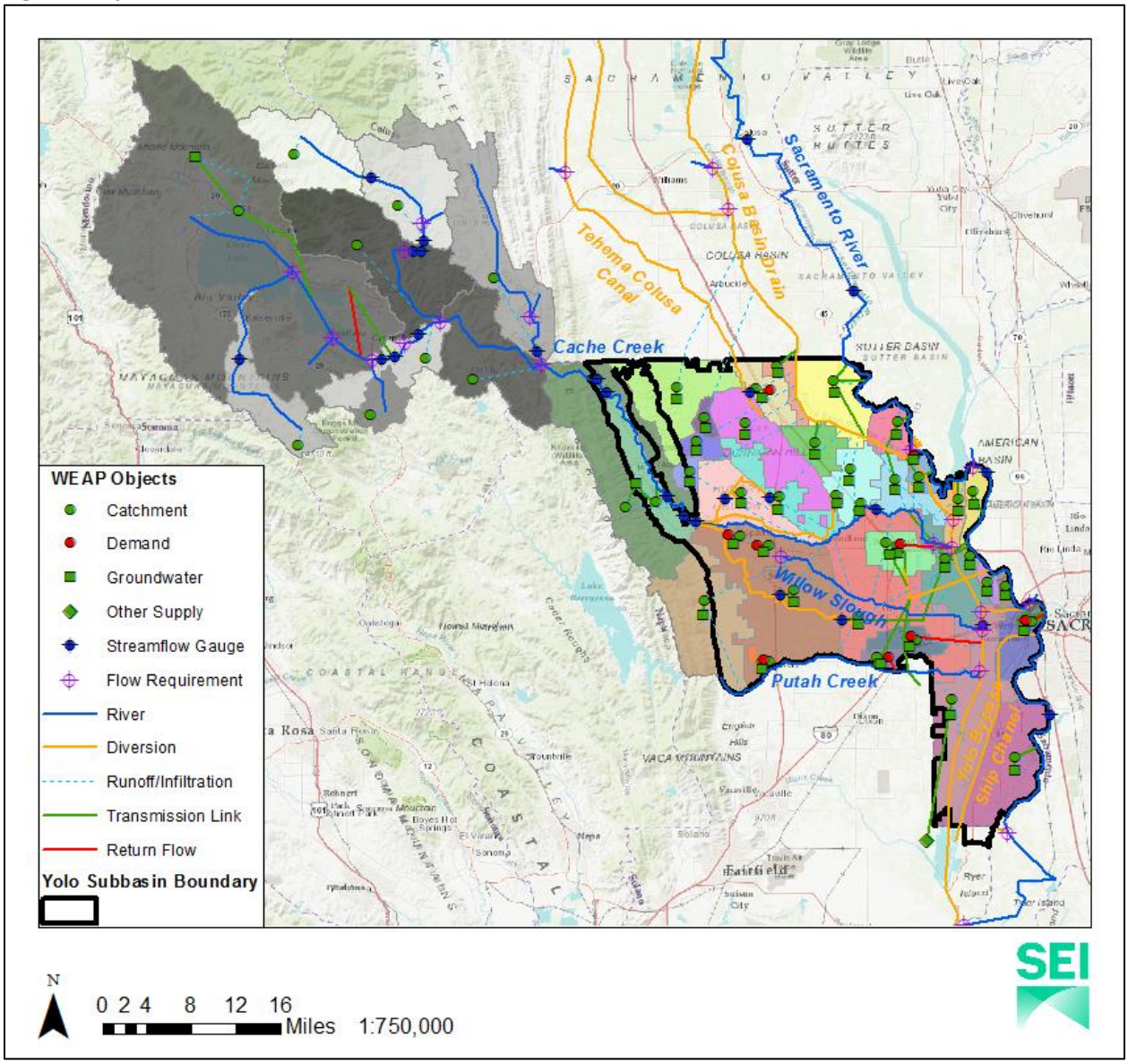
Figure 2 shows that the YSGA model explicitly includes not just the YSGA basin boundary, but also the portions of the Cache Creek watershed upstream of the Capay Valley (including Clear Lake and Indian Valley Reservoir). That is, the hydrology and operations of the entire Cache Creek watershed are simulated. Other important surface water inflows and boundaries are represented as input data, such as the flows of Tehama Colusa Canal and Colusa Basin Drain, and stream flows of the Sacramento River and Putah Creek. Surface water diversions and groundwater pumping were simulated at the scale of the catchments shown in Figure 3.

These boundaries mostly represent water district, urban, or hydrogeologic boundaries. Regions outside of water districts and urban areas are considered "white areas" that fall under County jurisdiction for purposes of SGMA.

Figure 3 shows a closer view of the Yolo Subbasin disaggregation into catchments in the YSGA model, with the MODFLOW computational grid overlaid. The MODFLOW grid covers only those parts of the Yolo Subbasin boundary in which the groundwater aquifer exists, as represented in the IWFM model that it is derived from. For purposes of calculating water budgets, the individual catchments have been grouped into Management Areas, as shown in Figure 4.

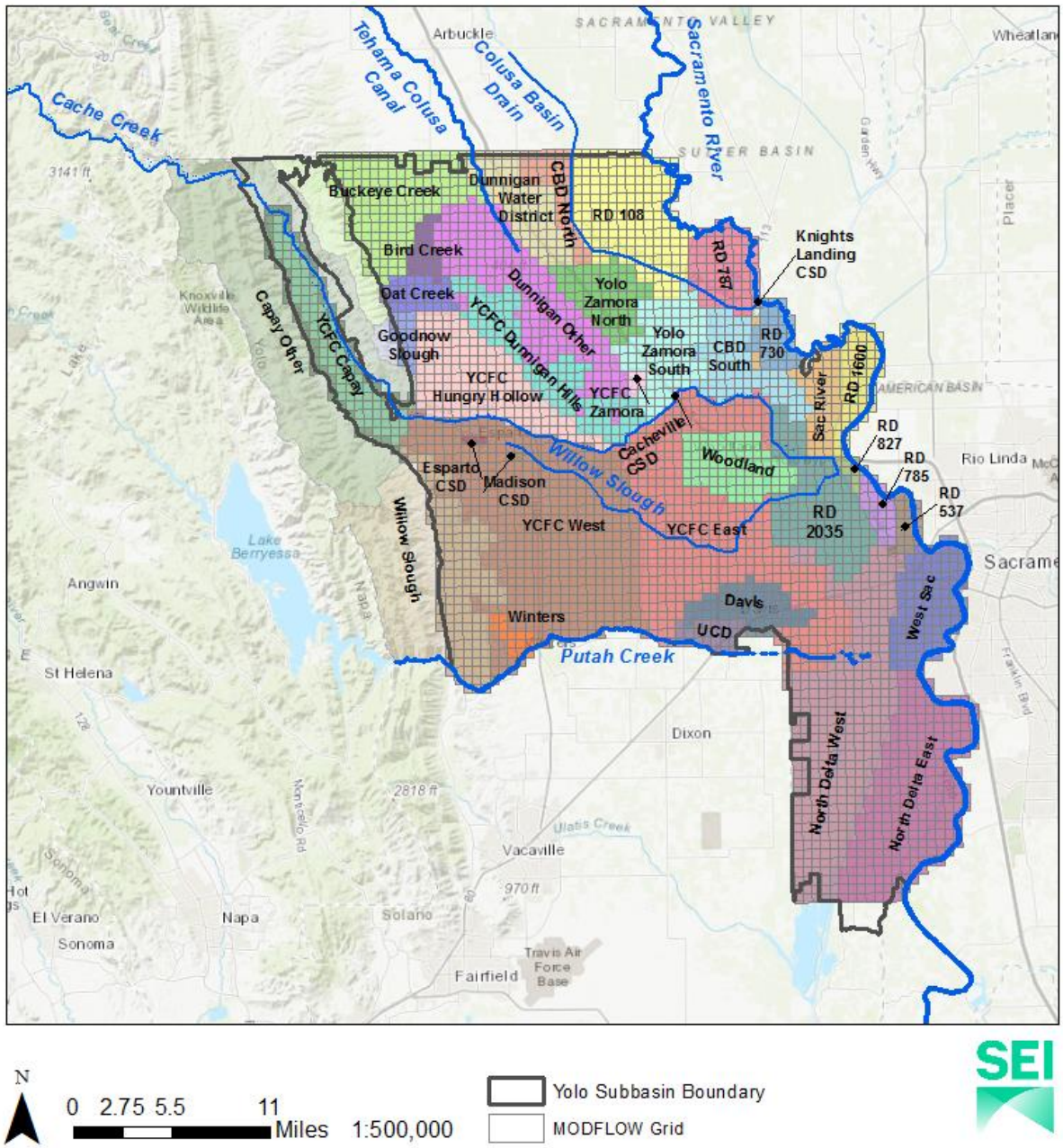
[4] See https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#waterbudget Accessed 8.31.2020

Figure 2. Spatial domain of the YSGA model.



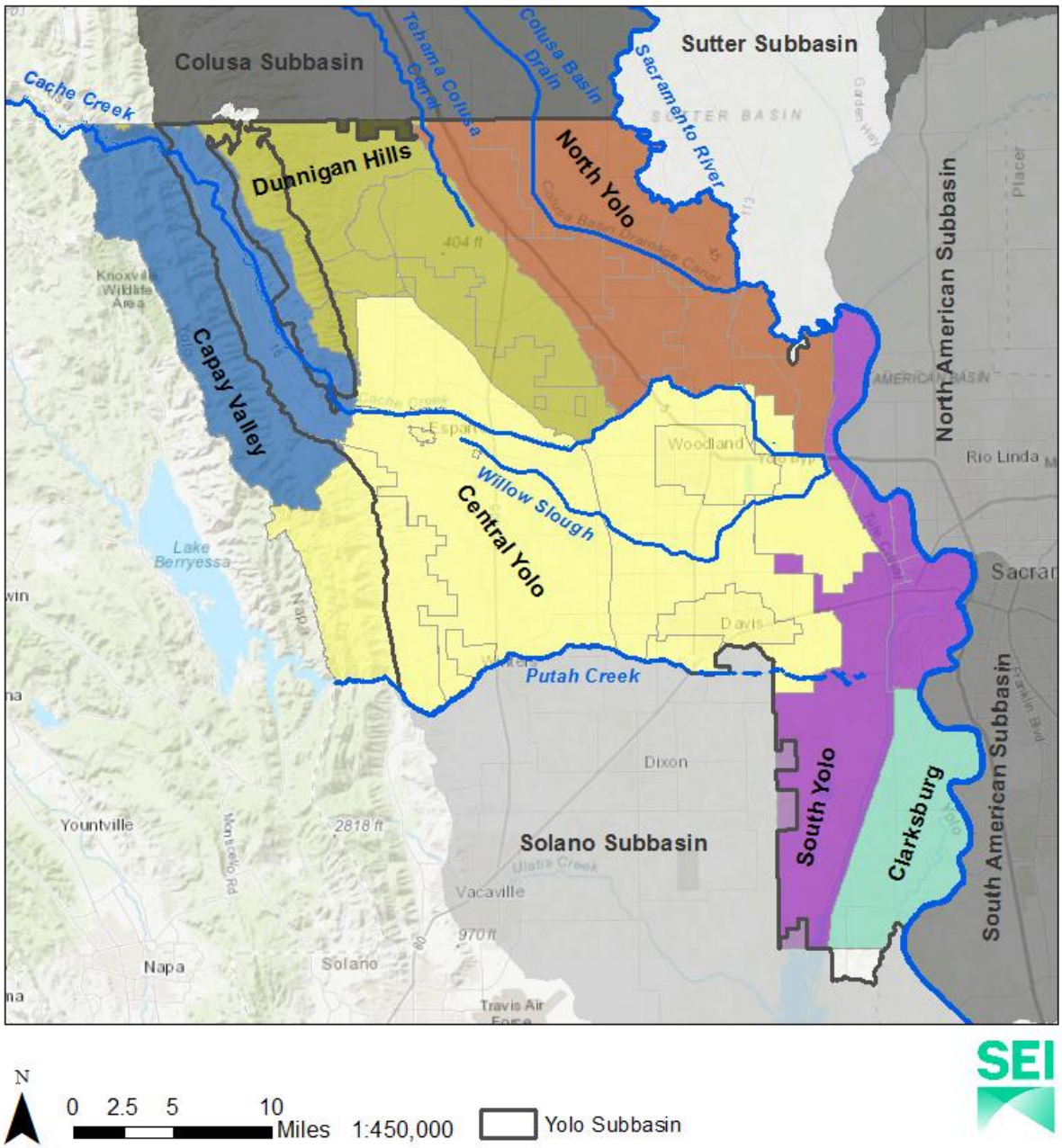
Catchments within Yolo County are shown as colored polygons, and catchments upstream of Capay Valley in the Cache Creek Watershed are shown in shades of grey. See the following figure for each catchment labeled by name.

Figure 3. Spatial domain of the MODFLOW groundwater model.



Black boundary represents the official Basin boundary. The MODFLOW grid, which represents the modeled alluvial aquifer, is shown in grey. Colored polygons are the model catchments. Model catchments, for which the land surface water budgets are computed, extend beyond the alluvial aquifer, as is most obvious in western Yolo County (hills in Capay, west of Winters, and west of Buckeye Creek).

Figure 4. Land Surface Budget Boundaries, Management Areas and Neighboring Subbasins.



The colored polygons show the model boundaries used to aggregate the land surface water budget into subregions for corresponding Management Areas. Entity boundaries are shown in light gray. The Yolo Subbasin is outlined in thick gray lines. Neighboring basins are shaded in grays. Major surface water bodies are labeled for reference. Official Management Area boundaries in this figure correspond to the intersection of the Yolo Basin boundary with the colored polygons.

The WEAP portion of the YSGA model, which covers the land surface system and hydrology, covers 1,197,657 acres. This includes all of Yolo County (639,089 acres in the WEAP portion of the model) and the Cache Creek system in Lake County (558,568 acres).

The MODFLOW portion of the YSGA model covers 559,840 acres (Table 3A). Due to the resolution and spatial extent of the MODFLOW model (as mentioned earlier, derived from the IWFM model), and the pre-existing WEAP model which covers the entire county, there are small differences between the official basin boundary (540,400 acres) and that in the YSGA model. Additionally, because catchment boundaries in the YSGA model are primarily determined by surface hydrology, there are small differences between the management area boundaries in the model and the official management area boundaries (shown in the Introduction and Basin Setting sections). Figure 5 below shows these differences, and Table 4 explains them. The total area of these differences is relatively small (19,440 acres, less than 3% of the Yolo Subbasin) and will not affect the model estimates substantively.

Table 3. Subdivisions of the YSGA model.

Modeled Area Name	Entity Name/White Areas Included	Area (ac)
Entire Modeled Area		1,197,657
Yolo County		639,089
Capay Valley Management Area*		85,515
Capay Other	White Area, Small towns in Capay Valley	67,097
YCFC Capay	YCFC, Yocha Dehe Wintun Nation, White Area, Small towns in Capay Valley	18,418
Central Yolo Management Area		242,680
Davis catch	Davis	8,688
Esparto CSD catch	Esparto CSD	446
Madison CSD catch	Madison CSD	68
RD 2035	RD 2035	20,375
UCD catch	UCD	3,701
Willow Slough	White Area	44,339
Winters catch	Winters	2,053
Woodland catch	Woodland	12,701
YCFC East	YCFC	55,340
YCFC Hungry Hollow	YCFC	23,872
YCFC West	YCFC	71,097
Clarksburg Management Area*		36,500
North Delta East	RD 150, RD 307, RD 765, Most of RD 999, Town of Clarksburg	36,500
Dunnigan Hills Management Area*		92,345
Bird Creek	White Area	3,467
Buckeye Creek	White Area	34,409
Dunnigan Other	White Area	28,916
Goodnow Slough	White Area	4,083
Oat Creek	White Area	4,742
YCFC Dunnigan Hills	YCFC	16,728
North Yolo Management Area*		103,770
Cacheville CSD catch	Cacheville CSD	98
CBD North	White Area	5,119
CBD South	White Area	12,177
Dunnigan Water District	Dunnigan Water District, Cal Am Water Dunnigan, Town of Dunnigan	11,597
Knights Landing CSD catch	Knights Landing CSD	162
RD 108	RD 108	25,075
RD 730	RD 730	4,829
RD 787	RD 787	10,286
Sac River	White Area	7,833
YCFC Zamora	YCFC	669
Yolo Zamora North	Town of Zamora, White Area	10,581
Yolo Zamora South	White Area	15,344
South Yolo Management Area*		78,279
North Delta West	Parts of 2068, White Area	49,635
RD 1600	RD 1600	7,056
RD 537	RD 537	2,455
RD 785	RD 785	3,226

Table 3. Subdivisions of the YSGA model.

Modeled Area Name	Entity Name/White Areas Included	Area (ac)
RD 827	RD 827	1,189
West Sac catch	West Sac, RD 900	14,718
Upper Cache Creek Watershed (in Lake County)		558,568
Bear Creek		66,247
Copsey Creek		20,384
Clear Lake		244,881
Kelsey Creek		26,165
Lower Indian Valley		66,445
Middle Indian Valley		36,751
Seigler Canyon		13,791
Upper Indian Valley		38,538
Upper Cache Creek		45,368
Yolo Subbasin (MODFLOW Model AREA)		559,840
Yolo Subbasin (Official)		540,400

- *Refers to boundaries as in Figure 4. Land Surface Budget Boundaries, Management Areas and Neighboring Subbasins*

Figure 5. Differences between model domain and YSGA/management area boundaries.

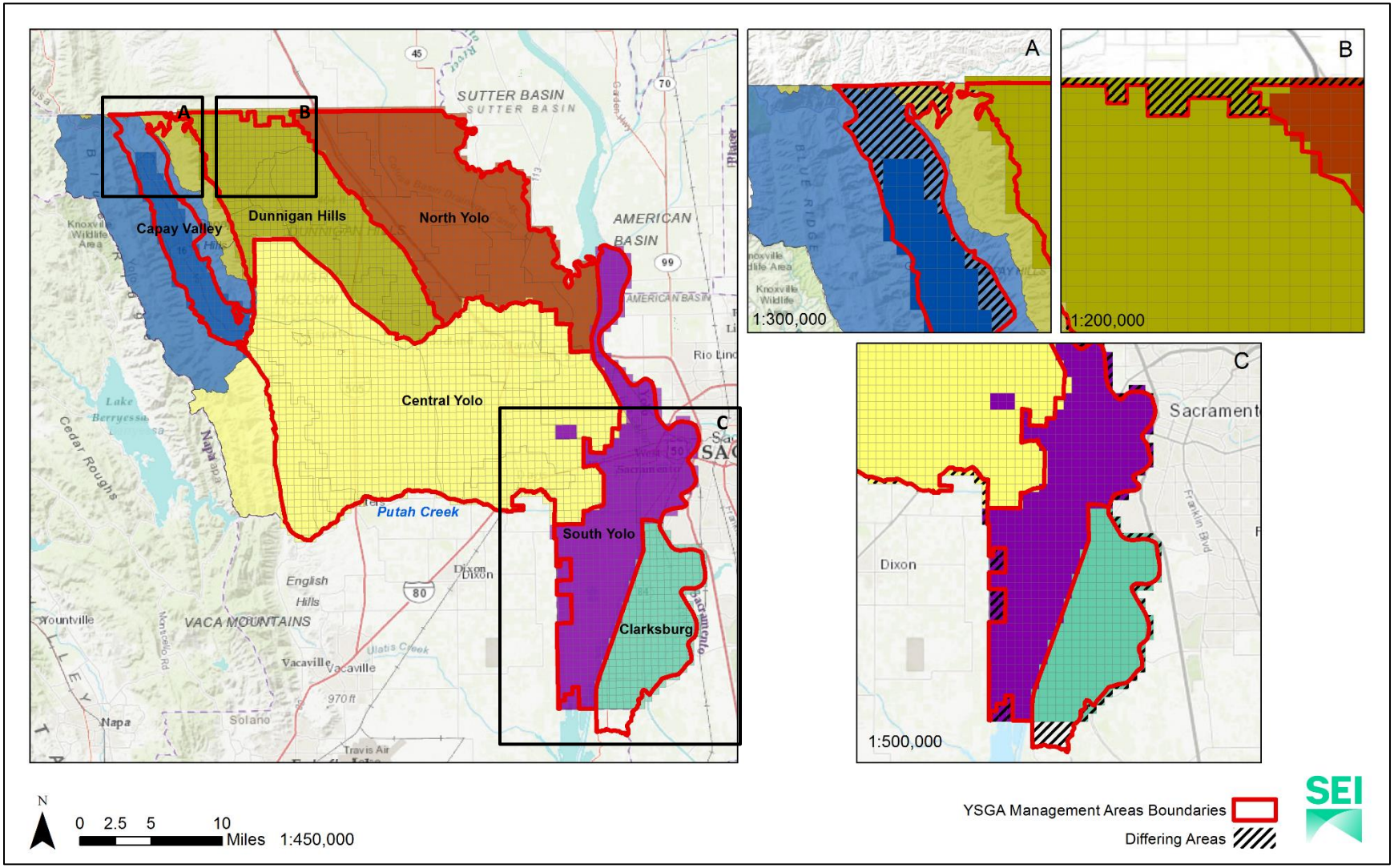


Table 4. Model domain difference from Yolo basin boundary.

Region	Description	Status
A	Uppermost, hilly portion of Capay bordering Buckeye Creek headwaters	This portion is included in the model's land surface budget, but the MODFLOW grid and associated information shows that the alluvial aquifer does not extend into the hills; hence it is not included in the MODFLOW model or groundwater budgets (also see Figure 2). Runoff from this area does influence the groundwater, however, and is included in the model land surface water budget.
B	Northern boundary of basin and county	This part is not included in the Yolo Subbasin boundary, but is included in the model.
C	Southern tip of Clarksburg Management Area (RD 999 territory)	Not included in the model domain but was included in the YSGA boundary at a late stage of model development. It is in Solano County, and the model does not cover any portion of Solano County.
C	Small cut outs in South Yolo Management Area	Included in the model because it is in Yolo County but not included in the Yolo Subbasin, because these entities (RD 2068 and RD 2093) are not part of YSGA.
C	Isolated plot to west	This portion is a 'white area' that does not fall into any entity, and was included into the South Yolo MA water budget.

1.1.2. Computational Aspects

This section summarizes the computational algorithms used in the YSGA model, with references to published literature for the detailed equations.

As mentioned in Section 1.1, the surface water budget (climate-driven hydrology and water allocation) is computed by WEAP's built-in routines, while the groundwater flow is computed by MODFLOW (Table 5).

Table 5. Computational aspects of model.

YSGA Model regions	Algorithm	Reference to algorithm details	Computation time step	Reporting time step
Watersheds in Lake county	Soil Moisture Model	(Yates, 1996; Yates et al., 2005a, 2005b)	Monthly	Monthly
Catchments within Yolo basin	MABIA	(Jabloun and Sahli, 2012)	Daily	Monthly
Valley floor	MODFLOW	(Harbaugh, 2005)	Sub-daily	Monthly

WEAP has several built-in soil moisture budget algorithms to choose from. WEAP uses a Linear Program solver to allocate water from one or more sources to one or more demands, at every time step, based on a user-defined assignment of supply preferences and demand priorities. The allocation is constrained by operational rules such as reservoir release rules, canal capacities, and diversion restrictions based on water rights. This allocation routine is the same irrespective of which soil moisture budget is chosen.

1.1.2.1.Soil Moisture Method (SMM)

In the YSGA model, the upstream Clear Lake catchments' water budget (almost in Lake County) is computed by WEAP's Soil Moisture Method (SMM) algorithm, at a monthly time step. This part of the model domain is largely unchanged from earlier modeling efforts using WEAP (Mehta et al., 2018, 2013). The SMM equations are described in Yates et al. (2005b) and online[5]. The root zone soil moisture balance is expressed as a one-dimensional differential equation that is solved at each time step.

1.1.2.2.MABIA Method

The MABIA Method is a daily simulation of transpiration, evaporation, irrigation requirements and scheduling, crop growth, and yields. It was derived from the MABIA suite of software tools, developed at the Institut National Agronomique de Tunisie by Dr. Ali Sahli and Mohamed Jabloun. The algorithms and equations for the combined MABIA-WEAP calculation procedure are described in (Jabloun and Sahli, 2012). The MABIA Method uses the standard and well-known 'dual' crop coefficient method, as described in the classic FAO-56 article (Allen et al. 2005) whereby the K_c value is divided into a 'basal' crop coefficient, K_{cb}, and a separate component, K_e, representing evaporation from the soil surface. The basal crop coefficient represents actual ET conditions when the soil surface is dry but sufficient root zone moisture is present to support full transpiration.

1.1.2.3.MODFLOW, and WEAP-MODFLOW linkage

MODFLOW is a three-dimensional finite-difference groundwater modeling platform created by the U.S. Geological Survey (USGS). When properly linked, data and results flow back and forth between WEAP and MODFLOW for each WEAP calculation timestep. The versions of MODFLOW that can be linked to WEAP are MODFLOW 2000, MODFLOW 2005 and MODFLOW-NWT[6]. In MODFLOW, the groundwater flow equation is solved using the finite-difference approximation.

The MODFLOW model grid for the YSGA model is shown in Figure 3. Active cells correspond to those areas with an underlying aquifer layer below the land surface. All model parameters were imported, as a

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[5] See https://www.weap21.org/WebHelp/Two-bucket_Method.htm#:~:text=The%20Soil%20Moisture%20Method%20calculates,water%20above%20ground%20to%20decrease. Accessed 8.31.2020.

[6] See https://water.usgs.gov/ogw/modflow/modflow or http://water.usgs.gov/nrp/gwsoftware/modflow2000/modflow2000.html or http://en.wikipedia.org/wiki/MODFLOW

starting point, from the IWFM model (Flores Arenas, 2016). Some parameters were adjusted during the calibration process, which is detailed in the Model Documentation Appendix.

1.1.3. Data Sources

This section summarizes the data sources used in the YSGA model for the historical period, and the main assumptions for both historical and future scenarios.

Table 6. Data sources.

Category	Variable	Historical		Future Projections	
		Sources	**Model use**	**Sources**	**Model use**
Climate	Precipitation	PRISM[1]	Input data	Historical, modified by Climate Change factors provided by DWR	Input data
	ETo	CIMIS[2]	Calibration	Historical, modified by Climate Change factors provided by DWR	Input data
	Minimum Temperature	PRISM[1]	Input data	NA	
	Maximum Temperature	PRISM[1]	Input data	NA	
	Wind speed	(Livneh et al., 2013); CIMIS[2]	Input data	NA	
	Humidity	PRISM[1]	Input data	NA	
Land Use	Agricultural land use	DWR Land Use Surveys3; Yolo County Annual Agriculture Commissioner Reports; DWR SGMA Portal (LandIQ dataset)	Input data	Agricultural landuse kept constant to Current Year	Input data
	Non-agricultural land uses	DWR Land Use Surveys[3];	Input data	Growth projections from urban master plans[6]	Input data
Irrigation	Schedule	Sacramento-San Joaquin basin Study[4] (Reclamation, 2015)	Input data	Same as historical	Input data
	Crop coefficients	Sacramento-San Joaquin basin Study[4] (Reclamation, 2015)	Input data; Calibration	Same as historical	Input data
	Irrigation efficiency	NA	Calibration	Same as historical	Input data
	Applied Water	DWR Applied Water Estimates[5], Groundwater management plans and personal communication[6]	Calibration	NA	Model output
	Water sources and supply	SWRCB eWRIMS water rights database[7],	Input Data	Same as historical	Input Data

Catego	Variable	Historical		Future Projections	
		Sources	Model use	Sources	Model use
		personal communication[6]			
Urban	Water demand, including population	Urban water plans and personal communication[6]; CA Department of Finance Population data[8]	Input data	Growth projections from urban master plans[6]	Input data
	Water sources and supply	Urban water plans and personal communication[6]; SWRCB eWRIMS water rights database[7]	Input data (water rights)	Urban water plans[6]	Input data (water rights)
Hydrology	Stream flows	USGS[9]; CDEC[10]	Calibration	NA	Model output
	Stream flows	USGS9; CDEC[10]	Input Data	Same as historical	Input data
	Initial groundwater conditions	WRID[11]; SGMA[12]; IWFM model (Flores Arenas, 2016)	Input data	Historical model end-of simulation set as future model run initial conditions	Input data
	Groundwater boundary conditions	IWFM model (Flores Arenas, 2016)	Input data, calibration	NA	Input data
	Groundwater elevations (time series)	WRID[11]; SGMA[12]; WDL [13];	Calibration, Model output	NA	Model output
	Reservoir operations (storage levels, outflows)	CDEC[10]; Conversations with and data supplied by YCFC[6]	Calibration, Model output	NA	Model output
	In-stream flow requirements	CDEC[10]; Conversations with and data supplied by YCFC[6]	Input data	Same as historical	Input data

1 http://www.prism.oregonstate.edu/explorer/ Accessed 5.19.2019

2 https://cimis.water.ca.gov/Default.aspx . Accessed 5.19.2019

3 https://gis.water.ca.gov/app/CADWRLandUseViewer/ Accessed 9.1.2020

4 https://www.usbr.gov/watersmart/bsp/docs/finalreport/sacramento-sj/Sacramento_SanJoaquin_TechnicalReport.pdf Accessed 9.1.2020

5 https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates Accessed 2.1.2019.

6 A complete list of entity-specific data sources and personal communication is provided in the Model Documentation Appendix, and in spreadsheet format to the YSGA

7 https://www.waterboards.ca.gov/waterrights/water_issues/programs/ewrims/

8 http://www.dof.ca.gov/Forecasting/Demographics/Estimates/

9 https://waterdata.usgs.gov/nwis/sw

10 https://cdec.water.ca.gov/

11 Yolo County Water Resources Information Database (https://wrid.facilitiesmap.com/Login.aspx)

12 SGMA Data Viewer https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#gwlevels
13 California Water Data Library https://wdl.water.ca.gov/GroundWaterLevel.aspx

1.2. Future Scenarios

GSP regulations require the evaluation of future water budgets, i.e. future scenarios. In this section the following is discussed:

(i) Projections of water demand
   a. Urban water demand projections were based on population and water use projections from urban water management plans.
   b. Irrigated landcover was kept constant at 2018 levels (which are based on 2016 datasets).

(ii) Climate change projections, in the form of perturbations (i.e. multipliers) applied to the historical climate.

1.2.1. Useful Terms in this section

Table 7. Useful Terms in this Section.

Term	Description
Scenario	A plausible, often simplified representation about the future. A single scenario is a combination of projections in different dimensions (e.g. population, land use, and climate) about the future.
Projection	A plausible, often simplified description of one future condition (e.g. population)
Climate change	A change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties (often by using statistical tests), and that persists for an extended period, typically decades or longer (California DWR, 2015)
Climate model	A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. (California DWR, 2015)
Climate projection	A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based on simulations by climate models. (California DWR, 2015)
Intergovernmental Panel on Climate Change (IPCC)	Scientific panel overseen by the United Nations, which investigates the global impacts of climate change. (California DWR, 2015)
AR5	IPPC 5th Climate Change Assessment Report published in 2014. (California DWR, 2015)

Table 7. Useful Terms in this Section.

Term	Description
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan

1.2.2. Climate projections

The California Department of Water Resources (DWR) provides datasets, tools, and guidance regarding climate change datasets that can be used by GSA's to develop future projections for GSP's. DWR provides processed climate change datasets related to climatology, hydrology, and water operations. Climate projections are in the form of change factors for precipitation and reference evapotranspiration, provided in gridded format for the state. These were downloaded from the DWR SGMA Data Viewer[7].

These data were originally developed for the California Water Commission's Water Storage Investment Program (WSIP).

Data represent projections for two future climate periods: 2030 and 2070.

- There are 4 scenarios; one for 2030 representing the central tendency from several downscaled climate models; and three for 2070 (central tendency, dry-extreme warming, and wetter with moderate warming)
- The process involved a "climate period analysis". Historical inter-annual variability (1915-2011) is preserved while the magnitude of events is perturbed based on projected temperature and precipitation changes from general circulation models.

Additional details about the methods involved are provided in DWR's Guidance Document on Climate Change datasets (California DWR, 2018). Details on the processing of the data are provided in the Model Documentation Appendix.

1.2.3. Future scenarios

Five future scenarios were incorporated into the YSGA model based on different climate projections. In each of these scenarios, (a) the land-use is the same: increasing urban water demand based on urban water management plan projections, and agricultural land-use is kept constant at current year levels; (b) water rights and supply conditions are kept the same as current year levels, and (c) Any change in irrigation demand is driven by the climate signal.

[7] https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#waterbudget , Accessed 8/27/2019

Table 8. Future scenarios.

Scenario name	Summary
Future_Baseline	Urban demand increasing; irrigated crops constant at 2016/2018 ; climate same as historical
Future_2030	Climate representing the central tendency from many downscaled climate models, centered around 2030
Future_2070	Climate representing the central tendency from many downscaled climate models, centered around 2070
Future_2070_DEW	Climate representing dry-extreme warming from many downscaled climate models, centered around 2030
Future_2070_WMW	Climate representing wetter-moderate warming from many downscaled climate models, centered around 2030

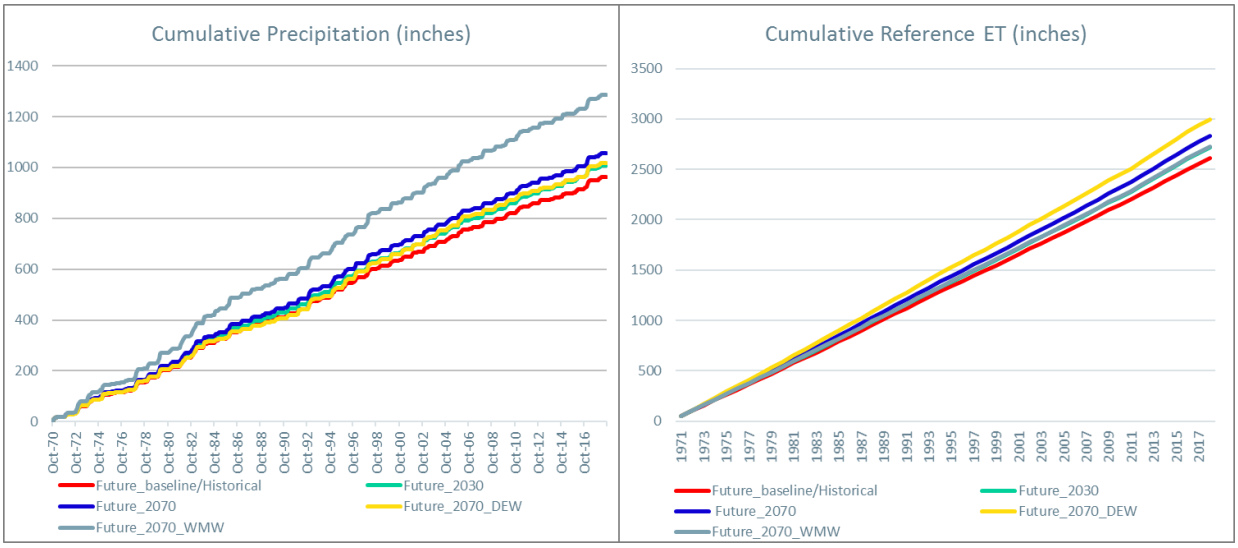
Table 9 below summarizes the differences in precipitation inputs over the City of Davis from these climate scenarios. Interestingly, the historical climate is dryer than any of the climate projections from the climate models. Within the 2070-centered projections, the wet-moderately warm projection is almost 20% wetter than the 2070 central tendency projection and the dry-extreme warming scenario is 3.5% drier.

Table 9. Total precipitation and reference ET over 48-year future simulations for the City of Davis.

Scenario	Future_Baseline (same as Historical)	Future_ 2030	Future_ 2070	Future_ 2070_DEW	Future_ 2070_WMW
Total Precipitation (inches)	962	1009	1055	1018	1285
Total reference ET (inches)	2609	2718	2833	2997	2728

Figure 6 shows the time series of cumulative precipitation and cumulative reference ET for historical and future climate projections, for the City of Davis. Note that the date timeline is figurative; it represents the actual timeline only for the historical (corresponding to “Future_Baseline”) climate; otherwise it represents a representative future period of the same number of years, i.e. 48 years.

Figure 6. Cumulative precipitation and Reference ET for the City of Davis.



1.3. Water Budgets

This section presents the land surface water budget, groundwater budget, and groundwater storage results for the historical (WY 1971 – WY 2018) and future scenarios. WY 2018 is considered as the "current year" in what follows, being the most recent year for which consistent datasets could be obtained or reasonably assumed (when not available).

Table 10. Useful terms in this section.

Term	Description
Deep percolation (DP)	Water that recharges the groundwater aquifer from all overlying catchments within the county. This includes water from precipitation and irrigation.
Drainage	In regions close to the Sacramento River where the water table can be close to the ground surface, surface channels provide a route for the discharge of groundwater into the surface water system. To mimic that process the MODFLOW DRN package was used to place a drainage boundary in Reclamation Districts 108, 1600, 730, 787, and North Delta East and North Delta West catchments.
Evapotranspiration (ET)	Evaporation from the land surface (soil and urban land cover) and transpiration from vegetation (agriculture and native vegetation) from all catchments within the county.
GW-SW Exchange	Exchange of groundwater to/from the Yolo basin and surface features (Cache Creek, the Colusa Basin Drain, Knights Landing Ridge Cut, Putah Creek, the Sacramento River, Ship Channel, Willow Slough, and the Yolo Bypass).
Lateral GW Flow: Outside Yolo subbasin	Groundwater flow between the Yolo Subbasin and the neighboring subbasins: Colusa, North American, Solano, South American, and Sutter subbasins.
Managed aquifer recharge: Woodland	Water recharged to the confined aquifer underlying the city of Woodland, through the Aquifer Storage and Recovery program.
Precipitation	Rain falling within the county.
Pumping: Irrigation	Groundwater supplied for agricultural irrigation in the county.
Pumping: Urban	Groundwater (from both the general aquifer and the Woodland confined aquifer) supplied to urban demands represented in the county
Surface Runoff (SRO)	Surface runoff from the land within the county to Cache Creek, the Colusa Basin Drain, Putah Creek, the Sacramento River, Willow Slough, and the Yolo Bypass,
SW supply: Irrigation	Water supplied for agricultural irrigation from the Colusa Basin Drain, Cache Creek via YCFC canals, the Delta, Putah Creek, Sacramento River and Tehama Colusa Canal, Willow Slough, and the Yolo Bypass.
SW supply: Urban	Water supplied from the Sacramento River (to West Sacramento and the Woodland Davis Clean Water Agency) and from Cache Creek (to the Yocha Dehe Wintun Nation Golf Course).
Tailwater re-use: Irrigation	Reuse of irrigation tailwater. Reclamation Districts and the North Delta East catchment can reuse 90% of tailwater for irrigation in the model, based on previous work describing reuse in RD108 (Davids Engineering, 2011).

Table 10. Useful terms in this section.

Term	Description
Treated WW Outflow	Return flows from the West Sacramento portion of the Sacramento wastewater treatment plant into the Sacramento River, from Davis and Woodland's wastewater treatment plants into the Yolo Bypass, and from Winters' wastewater treatment plant into Putah Creek.
Urban consumption	Water consumed within the urban demands represented in the county. Landscape irrigation is included within these demands.
YCFC canal recharge	Canal Recharge from the YCFC unlined canals.

1.3.1. Land Use

Landcover in the Yolo Subbasin is dominated by agriculture and native vegetation. Estimates of irrigated acreage have varied from 231,568 (in 2015, at the peak of a long-running drought) to 358,883 (in 1978) during the WY 1971-WY 2018 period (Source: DWR Land and Water Use Surveys

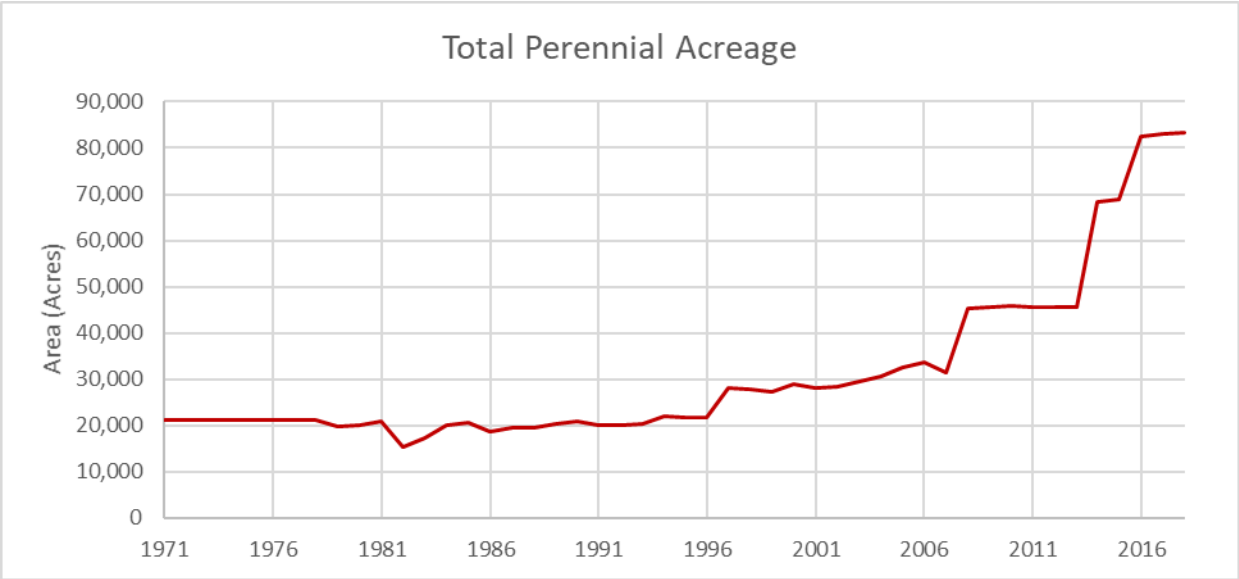
Figure 7 shows how perennial acreage has increased over the historical time period. Table 11 shows the acreage and proportion of the main categories of Basin-wide land use (as used in the YSGA model) for specific years where GIS data were available (1989, 1997, 2008, and 2016). Details on how a time series was constructed are in the Model Documentation Appendix. An important feature of land use change in the Yolo Subbasin is an increasing acreage of perennials, which have partly replaced field crops, and also brought previously uncultivated area into production in some regions.

Table 11. Land Use in the Yolo Subbasin.

	Land Use (ac)				Land Use (Percent)			
	1989	1997	2008	2016	1989	1997	2008	2016
Entire Basin	**639,089**	**639,089**	**639,089**	**639,089**				
Deciduous	17,550	18,406	30,717	59,434	3	3	5	9
Field Crops	96,679	108,427	36,475	41,446	15	17	6	6
Grain	80,354	57,993	52,369	27,200	13	9	8	4
Managed Wetlands	0	483	459	0	0	0	0	0
Native Vegetation	288,058	284,997	319,938	330,463	45	45	50	52
Pasture	42,612	44,822	63,801	33,129	7	7	10	5
Rice	22,652	24,754	35,056	38,847	4	4	5	6
Subtropical	118	135	1,331	3,670	0	0	0	1
Truck Crops	56,953	55,160	46,968	46,930	9	9	7	7
Urban	26,347	29,153	33,220	33,270	4	5	5	5
Vine	2,543	9,536	13,384	19,329	0	1	2	3
Water	5,222	5,222	5,372	5,372	1	1	1	1

Source: DWR Land and Water Use Surveys

Figure 7. Total acreage of perennial crops.



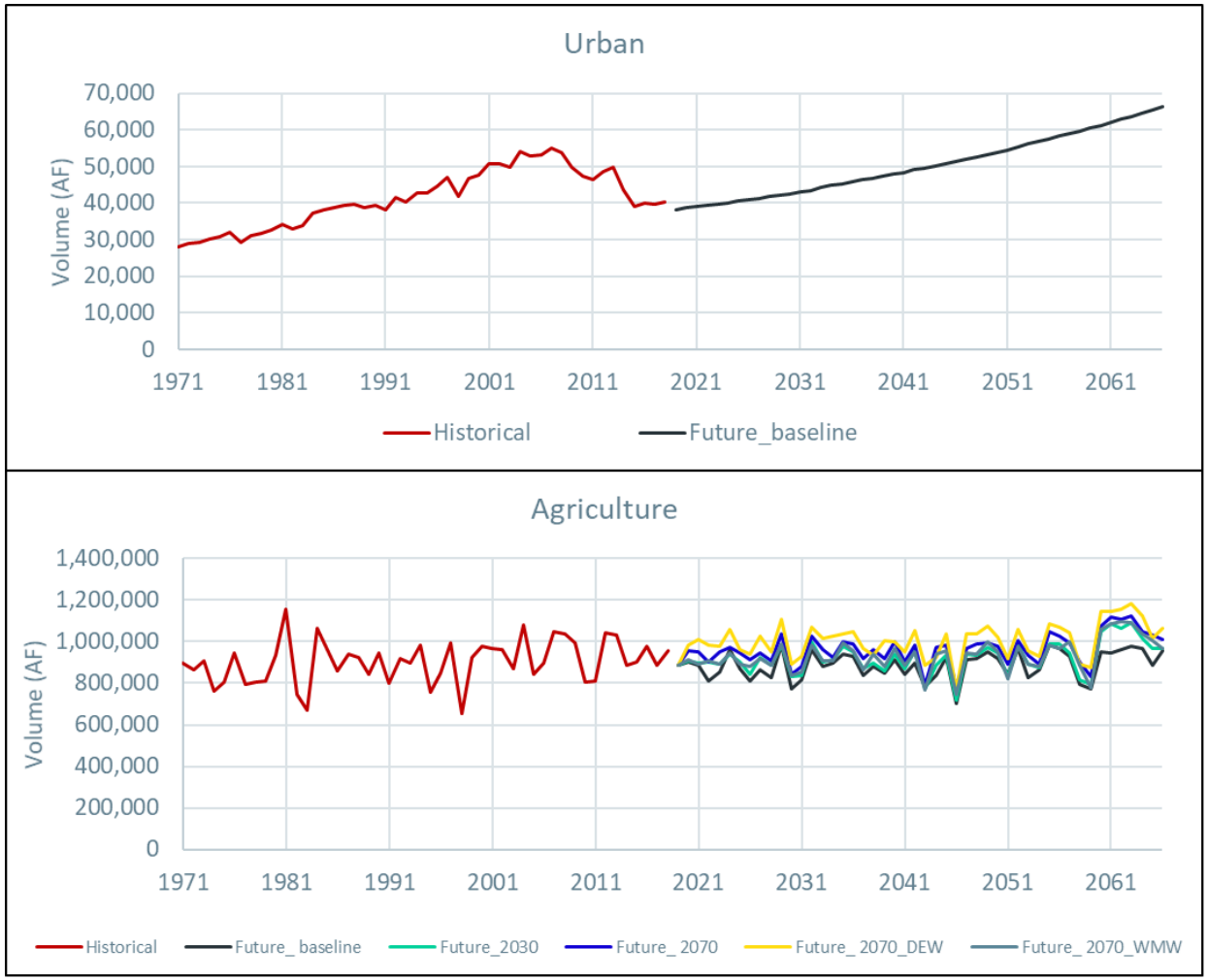
Source: DWR Land and Water Use Surveys; Yolo County Annual Crop Reports. Includes deciduous and subtropical orchards, and vineyards in Yolo County historically as represented in the model.

1.3.2. Water demand and supply

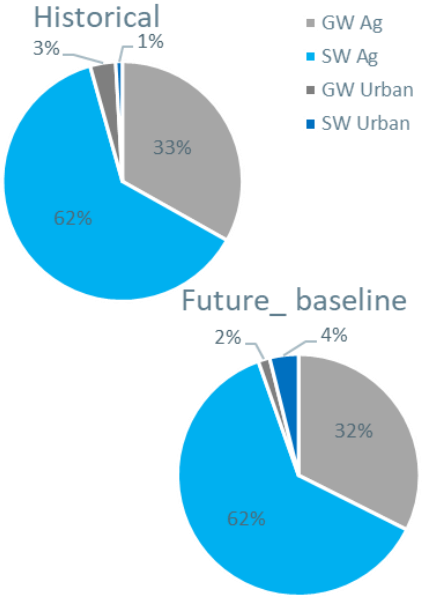
Before the Basin-wide water budgets are described in detail, this section summarizes the simulated total water demand and supply, for all scenarios. Total water demands for each scenario are presented below (Figure 8). Urban water demands, as informed by individual urban water management plans, rise steadily – but remain small relative to irrigation demand. Irrigation demand in the future scenarios, as shown in this figure, stay within the range of historical simulations, but their averages are successively higher than the Historical scenario in the following order: Future_baseline, Future_2030, Future_2070_WMW, Future_2070, and Future_2070_DEW.

The Future_baseline comparison against Historical is instructive: because the climate is the same between those two scenarios, it mainly shows the effect of current, increased perennial crop acreage in the Basin. The pie charts show that the supply sources are expected to be about the same, with surface water supply for irrigation on average at 66% of water supply, followed by groundwater for irrigation. The Woodland-Davis Clean Water Agency's water supply accounts for the increase in urban surface water supply in the Future_baseline scenario. Overall, the average annual water demand increases from 945 TAF in the historical scenario to a maximum of 1055 TAF in the extreme DEW scenario (Figure 8).

Figure 8. Water demands.



Average Annual Demand (Acre Feet)	
Urban	
Historical	41,102
Future[1]	50,270
Agriculture	
Historical	904,090
Future_baseline	888,139
Future_2030	922,000
Future_2070	961,712
Future_2070_DEW	1,005,341
Future_2070_WMW	931,403



[1] Urban demand is the same in all future scenarios

In comparison to the demands, a detailed assessment of the surface water supplies, and their reliability, can be made by characterizing the different types of surface water rights that exist in the Yolo subbasin.

1. The Yolo County Flood Control and Water Conservation District supplies surface water from Cache Creek to a large portion of the subbasin. Water under this right is supplied from Indian Valley reservoir and Clear Lake. The supply of water from year to year is constrained by hydrological conditions, and the in case of Clear Lake, by the Solano Decree.
2. Reclamation Districts along the Sacramento River and the City of West Sacramento have Settlement Contracts with the Central Valley Project. These contracts total 336,262 AF/year. These contracts are subject to restrictions in Shasta Critical Years.
3. The Dunnigan Water District has a water service contract with the Central Valley Project for 19,000 AF/year. This contract is subject to water availability in the Tehama Colusa Canal.
4. Analysis of the State Water Resources Control Board's eWRIMS water rights database show that there are a total of 667 water rights in Yolo County.
    a. Term 91 – an estimate of the water rights subject to Term 91, assuming appropriative rights with Acceptance Date after 1965 and not in the Putah or Cache watersheds, yields 17 water rights with a total face value of 89,608 AF/yr.
    b. Other, more senior appropriative rights, consist of 94 water rights with a total face value of 300,315 AF/year.
    c. Of the remaining rights, 263 are riparian or pre-1914 water rights. These rights are the least likely to be restricted.

In Table 12 surface water availability is presented in relation to the Sacramento Water Year Index. For the YCFCWCD diversions, the Cache Creek diversions into the District's canal system are shown. These diversions are limited by hydrological conditions and Solano Decree. Settlement contract allocations are a function of the critical water year type in which diversions are restricted by 25%. Water service contracts in the CVP are restricted based on water availability for north-of-Delta agricultural contractors. Additional restrictions to water rights containing Term 91 do occur most years. In very dry years, more senior water rights can also be restricted by SWRCB curtailments.

Table 12. Surface water availability as a function of water year type.

Water Year	Sacramento River Water Year Index	YCFC Cache Creek Diversions (AF)	Settlement Contract Allocations (AF)	Water Service Contract Allocations (AF)
2009	D	52,564	336,262	7,600
2010	BN	168,370	336,262	19,000
2011	W	171,314	336,262	19,000
2012	BN	199,161	336,262	19,000
2013	D	184,113	336,262	14,250
2014	C	5,655	252,196	0
2015	C	78,038	252,196	0
2016	BN	185,231	336,262	19,000
2017	W	155,897	336,262	19,000
2018	BN	155,458	336,262	19,000

1.3.3. Land Surface Water Budget

1.3.3.1.County-wide Historical and Current Year

The land surface water budget for the entire county is presented in this section, since all areas of Yolo County contribute to the overall water balance of the Yolo Subbasin (See Figure 4).

Results are presented in summary form first, as annual averages (Table 13). Inflows are dominated by precipitation and water supply deliveries. Outflows are dominated by ET, surface runoff (SRO), and deep percolation.

The key results for the historical average land surface water budget are as follows:

- Precipitation accounts for 1.15 million acre-feet (MAF), with total water supply accounting for the remaining 0.955 MAF of inflows.
- Surface water supply (0.6 MAF) makes up about 60% of the total water supply, with groundwater pumping making up the remaining 40%.
- Agricultural irrigation demand accounts for more than 90% of the total water demand of 1 MAF.

- Water supply sources to meet agricultural and urban demands are shown. Note that urban demand was, historically, met primarily by groundwater pumping.
- Total outflows are very close to total inflows, indicating an overall mass balance of inflows and outflows (i.e. without any trends on average in change in soil moisture).
- ET is the largest of the outflows, at 1.2 MAF, approximately 8% higher than precipitation.

Table 13 aggregates many fluxes into larger categories; these are summarized in Table 10. For example, urban surface water supply aggregates (sums) the surface water supply to all the urban demands in the model. Similarly, Surface Runoff and Deep Percolation sum all the surface runoff that occurs from all the catchments in the YSGA model in the County.

Annual surface water budgets are presented in Table 13 and Table 14. Note that climate, land use, and water supply conditions have varied over the 48-year historical period. As shown in Table 2, there have been several significant droughts, and wet periods. Also, surface water supply has increased at different times and for different parts of the Basin. For example, Indian Valley Reservoir came online in 1975; the Tehama Colusa Canal provided surface water to Dunnigan Water District starting in the mid-1980's; and the Woodland Davis Clean Water Agency started supplying Sacramento River water to Woodland, Davis, and UC Davis in 2016, which were entirely reliant on groundwater before then.

Some of the changes over time are apparent in the Current Year budget. In Table 14 and Figure 9, the surface water budget for the Current Year, WY 2018, is shown. WY 2018 was a below normal Water Year, with precipitation at approximately 66% of the historical average precipitation from WY 1971 – WY 2018. As a result, all fluxes in the Current Year – except urban-related fluxes – are lower than their historical average counterparts. In the urban sector, current year demands are comparable to historical averages; the main difference is that the supply source has shifted from groundwater to surface water being the dominant supply – as a result of the Davis-Woodland Clean Water Project that now supplies Sacramento River water for Davis, Woodland, and UC Davis for most of the year. Canal recharge also shows different behavior, being larger in 2018 than on average – canal recharge in the YCFC system is very dependent on total reservoir storage in Clear Lake and Indian Valley Reservoir, timing of precipitation in the winter and spring, and releases made through the canal system. Moreover, the historical period includes early years before Indian Valley Reservoir was constructed, and a few drought years when no water was legally allowed (by the Solano Decree) to be released for irrigation – these factors lower the historical average compared to the Current Year canal recharge.

1.3.3.2.County-wide Future Scenarios

Table 13 also includes the annual average land surface budget for the future scenarios. As noted earlier, **the cumulative and average precipitation for the County and Basin, is higher in all the climate projections, compared to that in the historical scenario.** For example, annual average precipitation for the County in Future_2070_WMW (the wet extreme climate projection) is 1,530 TAF compared to 1,147 TAF in the historical scenario. The increased precipitation explains some of the main results, as noted below.

1. **Overall land surface mass balance is maintained:** In each scenario, the total inflows and outflows at Basin and MA scale are maintained.
2. **Effect of increased perennial acreage: More ET, less DP**
   The Future_Baseline scenario has the same historical climate, but different demand (current irrigation demand and projected urban demand) compared to the Historical scenario. This scenario is dominated by a land-use effect as mentioned earlier. As expected, the increased acreage in perennial crops in this scenario leads to an increase in ET of almost 50 TAF on an annual average basis, over Historical ET. Deep Percolation decreases by 43 TAF. This is because of a shift in crops from those with lower irrigation efficiency to higher efficiency over time, as has been reported (Orang et al., 2008). Area-weighted average irrigation efficiency in the MABIA module was 62% for 1971-2018 and 70% for the future scenarios.
3. **Effect of climate change: More ET, more DP**
   The climate change scenarios (Future_2030, Future_2070, Future_2070_DEW, Future_2070_WMW), when compared to Future_Baseline, show the sensitivity of the system (and the model) to climate; the cropping pattern and urban demand is the same in these five scenarios. Table 13 shows that in all four climate change scenarios, ET is higher compared to Future_Baseline. This is a direct effect of increased warming, since all four scenarios are warmer than the historical climate used in the Future_Baseline scenario. The greatest increase in ET, is in the Dry and Extreme Warming scenario (Future_DEW), which has the most warming, followed by the Future_2070 scenario, which has the next highest warming. Meanwhile, Deep Percolation and runoff are affected more by precipitation differences: hence these fluxes are highest in the wettest scenario (Future_2070_WMW, which is the extreme wet with moderate warming scenario). Changes in the other budget components are small, although canal recharge and surface water supply for irrigation are slightly higher in the wetter scenarios.

1.3.3.3. Management Area budgets

Management Area budgets are presented in detail in Appendix A.

Table 13. County-wide average land surface water budgets.

All values are in Thousand Acre Feet

Historical Average Annual Land Surface Water Budget (TAF)														
	Outflows							Inflows						
	Evapotranspiration	Deep Percolation	Surface Runoff	Urban Consumption	YCFC Canal Recharge	Treated WW Outflow	Total Outflows	Precipitation	Pumping: Urban	Pumping: Irrigation	SW Supply: Urban	SW Supply: Irrigation	Tailwater Reuse: Irrigation	Total Inflows
Entire Basin														
Historical	-1,227	-353	-459	-18	-33	-13	-2,102	1,147	33	313	9	591	10	2,102
Future_Baseline	-1,274	-308	-437	-23	-37	-16	-2,095	1,147	16	304	34	584	10	2,095
Future_2030	-1,314	-321	-471	-23	-39	-16	-2,184	1,201	15	322	35	600	11	2,184
Future_2070	-1,345	-340	-519	-23	-40	-16	-2,282	1,259	15	343	36	619	11	2,282
Future_2070_DEW	-1,346	-323	-549	-23	-37	-16	-2,293	1,229	15	385	35	620	9	2,293
Future_2070_WMW	-1,326	-424	-692	-23	-43	-16	-2,523	1,530	14	311	37	620	11	2,524

Figure 9. Land surface water budget for Yolo County.

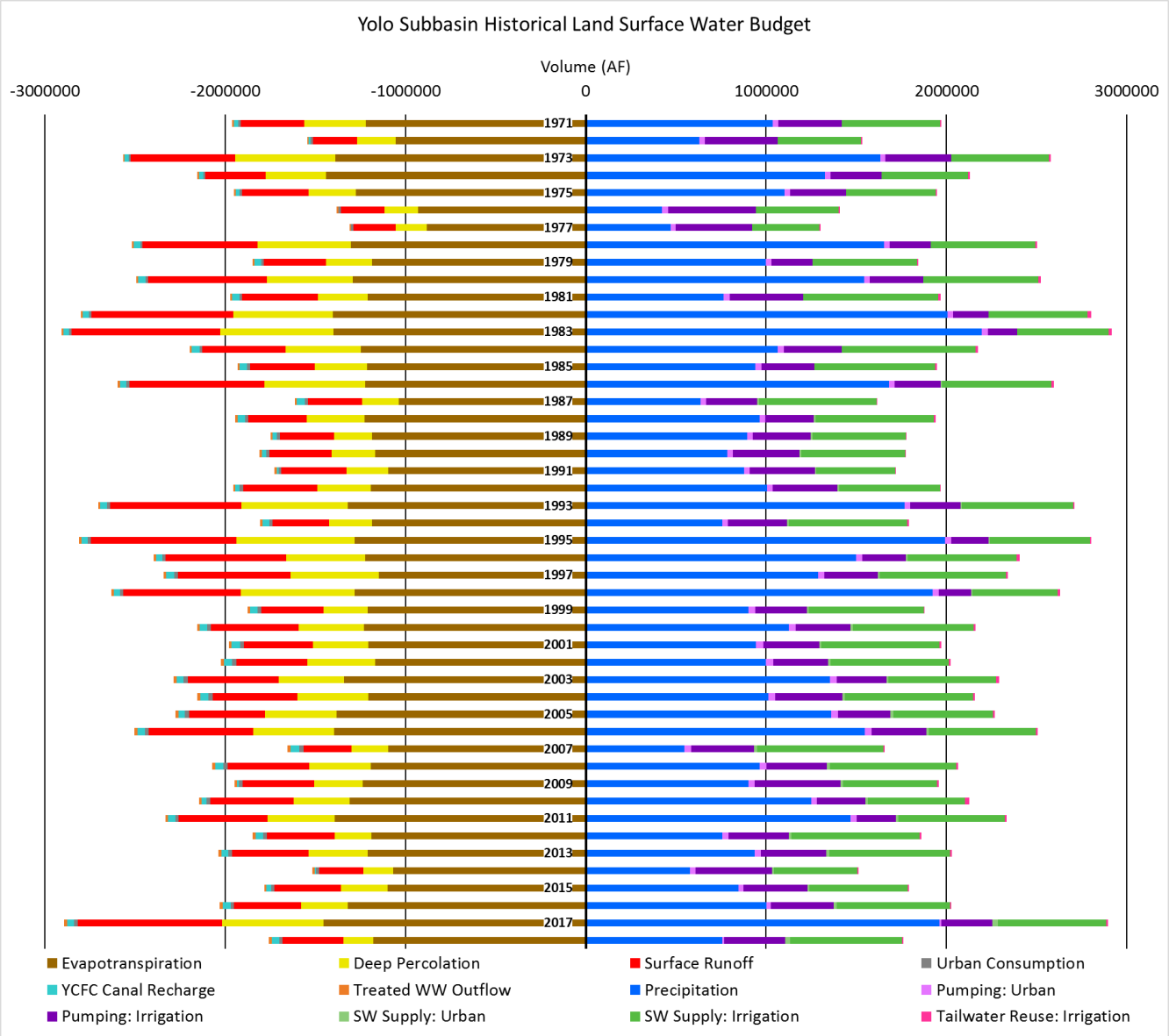


Table 14. Annual Land Surface Budget for the Yolo Subbasin.

All values are in Thousand Acre-feet

Yolo Subbasin Historical Land Surface Budget (TAF)														
	Outflows							Inflows						
WY	Evapotranspiration	Deep Percolation	Surface Runoff	Urban Consumption	YCFC Canal Recharge	Treated WW Outflow	Total Outflows	Precipitation	Pumping: Urban	Pumping: Irrigation	SW Supply: Urban	SW Supply: Irrigation	Tailwater Reuse: Irrigation	Total Inflows
Average	-1,227	-353	-459	-18	-33	-13	-2,102	1,147	33	313	9	591	10	2,102
1971	-1,221	-340	-354	-12	-26	-9	-1,960	1,038	28	355	0	543	9	1,972
1972	-1,056	-212	-247	-12	-9	-9	-1,545	630	29	405	0	462	8	1,534
1973	-1,389	-557	-577	-12	-23	-9	-2,567	1,633	29	365	0	541	10	2,578
1974	-1,440	-336	-333	-13	-23	-9	-2,154	1,327	30	282	0	482	7	2,128
1975	-1,275	-262	-370	-13	-23	-9	-1,952	1,103	31	308	0	500	5	1,946
1976	-932	-184	-242	-13	0	-10	-1,381	423	32	487	0	460	8	1,410
1977	-881	-174	-235	-12	0	-9	-1,311	470	29	423	0	375	6	1,302
1978	-1,301	-518	-638	-13	-37	-9	-2,517	1,655	31	227	0	579	11	2,504
1979	-1,184	-256	-346	-13	-37	-10	-1,847	998	32	228	0	580	6	1,844
1980	-1,293	-477	-656	-14	-43	-10	-2,493	1,543	33	296	0	636	14	2,523
1981	-1,211	-276	-418	-14	-43	-10	-1,973	763	34	409	0	749	13	1,968
1982	-1,404	-552	-786	-14	-34	-10	-2,799	2,005	33	195	0	549	20	2,802
1983	-1,400	-627	-825	-14	-32	-10	-2,908	2,197	34	163	0	506	16	2,916
1984	-1,249	-416	-461	-16	-44	-11	-2,198	1,063	37	320	0	743	11	2,173
1985	-1,214	-288	-361	-16	-41	-11	-1,931	938	38	292	0	670	11	1,949
1986	-1,224	-560	-747	-16	-37	-11	-2,596	1,682	31	254	8	608	12	2,595
1987	-1,036	-205	-301	-17	-43	-12	-1,614	636	32	284	8	655	3	1,617
1988	-1,229	-319	-325	-17	-42	-12	-1,943	964	31	270	8	655	11	1,940
1989	-1,186	-208	-302	-16	-24	-11	-1,748	895	31	322	8	519	5	1,779
1990	-1,167	-245	-344	-17	-25	-12	-1,809	785	31	370	8	575	7	1,776
1991	-1,095	-230	-363	-16	-10	-11	-1,726	879	30	361	8	438	2	1,718
1992	-1,193	-296	-412	-18	-24	-12	-1,956	1,004	32	360	10	558	5	1,968
1993	-1,319	-590	-728	-17	-37	-12	-2,704	1,767	33	277	8	619	7	2,710
1994	-1,184	-240	-313	-18	-37	-13	-1,805	756	34	328	9	655	9	1,790
1995	-1,282	-657	-806	-18	-34	-12	-2,809	1,993	34	206	9	554	9	2,804
1996	-1,222	-440	-667	-19	-35	-13	-2,397	1,499	35	241	10	606	17	2,407
1997	-1,148	-491	-623	-20	-46	-14	-2,343	1,287	37	296	10	699	10	2,339
1998	-1,282	-633	-652	-18	-34	-12	-2,631	1,923	33	180	9	473	12	2,630
1999	-1,208	-248	-345	-20	-41	-14	-1,876	902	36	286	10	640	5	1,879
2000	-1,229	-362	-488	-21	-41	-14	-2,155	1,125	37	307	11	671	11	2,163
2001	-1,205	-308	-383	-22	-47	-15	-1,980	944	39	311	12	656	9	1,971
2002	-1,168	-376	-395	-22	-47	-15	-2,023	1,000	39	306	12	657	9	2,022
2003	-1,339	-365	-503	-22	-40	-15	-2,285	1,355	38	273	12	598	15	2,291
2004	-1,207	-391	-470	-24	-47	-16	-2,155	1,011	39	371	15	710	10	2,156
2005	-1,382	-396	-422	-23	-36	-16	-2,275	1,360	38	291	14	553	10	2,268
2006	-1,395	-450	-578	-23	-41	-16	-2,503	1,545	38	304	15	592	11	2,506
2007	-1,095	-203	-267	-24	-48	-17	-1,654	545	39	348	16	702	8	1,658
2008	-1,192	-343	-451	-24	-44	-17	-2,071	965	38	334	16	702	10	2,065
2009	-1,238	-269	-396	-22	-9	-15	-1,949	902	36	476	14	520	10	1,958
2010	-1,311	-310	-462	-21	-27	-15	-2,145	1,249	34	267	13	539	24	2,126
2011	-1,394	-372	-491	-20	-40	-14	-2,331	1,467	33	219	13	590	11	2,333
2012	-1,191	-201	-378	-21	-41	-15	-1,847	757	35	334	14	709	13	1,862
2013	-1,211	-326	-424	-22	-39	-16	-2,038	935	35	365	15	669	13	2,031
2014	-1,069	-165	-245	-19	-7	-14	-1,518	578	31	422	12	463	7	1,513
2015	-1,099	-259	-370	-16	-28	-12	-1,784	846	29	356	10	544	6	1,791
2016	-1,320	-260	-373	-17	-44	-17	-2,031	1,002	24	349	16	629	8	2,028
2017	-1,456	-560	-803	-18	-41	-16	-2,894	1,959	11	286	29	602	8	2,895
2018	-1,178	-167	-337	-18	-42	-16	-1,757	755	11	338	30	619	9	1,762

1.3.4. Groundwater Budget

This section describes the groundwater inflows to, and outflows from the Yolo Subbasin aquifer as simulated by the YSGA model for the historical period (WY 1971-WY 2018, with WY 2018 representing the Current Year), as well as for the future scenarios.

Table 15. Useful terms in this section[8].

Term	Description
Managed aquifer recharge: (MAR) Woodland	Refers to the recharge estimated by the model from the Woodland Managed Aquifer Recharge project. For the historical scenario, these volumes are simply set to observed volume made available to the team.
Lateral GW Flow	Refers to groundwater flow entering (+) or leaving (-) the Yolo Subbasin.

1.3.4.1.Basin-wide Historical and Current Year

Table 16 includes the average annual groundwater fluxes. Current Year 2018 groundwater fluxes are included in the Basin-wide time series budget, in Table 17.

The key findings are:

- Inflows to the Yolo Subbasin are dominated by deep percolation, at 353 TAF averaged over the historical period (WY 1971 – WY 2018). Canal recharge from the YCFC canal system is about 10% of this, at 33 TAF per year.
- Pumping (urban and irrigation) is the largest groundwater outflow, estimated at an average of 346 TAF, with pumping for urban supply accounting for 9% of total pumping. Groundwater discharge in regions by the Sacramento River simulated as drains is less than 10% of total groundwater outflow on average (28 TAF per year).
- GW-SW exchange is on average positive at 14.8 TAF; considering Cache Creek, Putah Creek, Sacramento River, Willow Slough, and the Yolo Bypass, GW-SW exchange is a net positive to the groundwater balance. However, Table 17 and Figure 10 show that the direction and magnitude of GW-SW exchange varies with climate conditions. In successive wet years, the net direction of flow changes, i.e. groundwater tends to outflow to surface waters as the water table elevation increases.
- The net lateral exchange with neighboring basins is -28 TAF, that is, on average, the lateral flow is leaving the Yolo Subbasin. Approximately 12 TAF/yr on average leave the model domain flowing into Colusa County, however, much of that flow occurs from the portion of the model that is highly uncertain. Along the Sacramento River the annual average lateral exchange is 177 AF/yr out of the model domain. The lateral exchange with Solano County is an average of 15

[8] Terms described before are not repeated.

TAF/yr out of the model domain with most of that occurring along the boundary defined by Putah Creek. These flow change with climate conditions in direction and magnitude. In particular, in drought years such as 1976-1977 and 1991-1992, the aggregate lateral flow is into the Basin as the water table elevation decreases.

- Some fluxes are zero in some years. For example, City of Woodland's Aquifer Storage Recovery recharge wells became operational starting in 2017; and canal flows were zero in the deep drought of 1976-1977 and recent drought of 2014, when no water was available from Clear Lake for YCFC deliveries.
- The Current Year (WY 2018) Groundwater Budget (included in the annual water budget shown in Table 17 shows some distinct differences from the annual average, due to the same reasons as described for the Land Surface Water Budget. Namely, WY 2018 being a relatively dry year, deep percolation was lower while pumping was higher than the 48-year average, which resulted in outflows being higher than inflows. This is normally the case in dry years, as shown by the 48-year annual time series budget in Table 17 and Figure 10.

1.3.4.2.Basin-wide Groundwater Budget: Future Scenarios

Table 16 also includes the annual average groundwater budget for the future scenarios. The key messages are:

1. **Effect of increased perennial acreage and change in irrigation management: Less deep percolation, more outflow than inflow**
   The Future_Baseline scenario has the same historical climate but different demand (current year's irrigated acreage and projected urban demand) compared to the Historical scenario. This scenario is dominated by a land use effect caused by a shift to perennial crops and an increase in irrigation efficiency. As described in the earlier section on Land Surface Budgets, Deep Percolation decreases by 45 TAF, because of increased irrigation efficiency compared to the Historical scenario. Overall, the annual average deficit (outflows – inflows) increases slightly from 1 TAF in the historical period, to approximately 5 TAF. However, as the groundwater storage time series shows, the Basin continues to recover during wet periods (Section 1.3.5, Figure 14).
2. **Effect of climate change:**
   a. **More Deep Percolation**
      The climate change scenarios (Future_2030, Future_2070, Future_2070_DEW, Future_2070_WMW), when compared to Future_Baseline, show the sensitivity of the system (and the model) to climate changes only because the land use, irrigation management, and urban demand is the same in these five scenarios. Table 16 **shows that in all four climate change scenarios, Deep Percolation is higher compared to Future_Baseline.** This is a direct effect of wetter Future Scenarios (Table 9).
   b. **Falling storage in extreme dry scenario**
      When compared to the Future_Baseline scenario, the negative effect of climate change on groundwater storage is clearly demonstrated in only one of the four climate change

scenarios, the dry and extreme warming scenario (Future_2070_DEW), where the outflows, especially pumping, are substantially higher. Overall, the average annual outflows are approximately 14 TAF more than average annual inflows. Note that this is also the only scenario where the net direction of the 'varying flows' switches signs to become a net inflow and helps prevent even deeper deficits. Surface water streams contribute even more to the groundwater, and lateral outflows decrease in this scenario as water table elevations decrease.

c. **Balanced budgets in the central tendency scenarios**
In the central tendency climate scenarios (Future_2030 and Future_2070), the inflows and outflows are similar magnitudes. This is also seen in the groundwater storage time series presented later (Section 1.3.5) in Figure 14, which shows that groundwater storage recovers in wet periods, much like the historical scenario.

d. **Increasing storage in the extreme wet scenario**
The extreme wet scenario (Future_2070_WMW) leads to a surplus in the groundwater storage of 12 TAF on an annual average basis. This is despite the model estimating a net outflow of groundwater to surface water and a much higher lateral outflow to other basins. Deep percolation increases by more than 100 TAF over the Future_Baseline scenario. Again, the groundwater storage graph (Figure 14) shows this best.

Table 16. Basin-wide average groundwater budgets. *All values are in Thousand Acre Feet*

Historical Average Annual Groundwater Budget (TAF)												
	Outflows				Varying Flows				Inflows			
	Pumping: Urban	Pumping: Irrigation	Drainage	Total Outflows	GW-SW Exchange	Lateral GW Flow: Outside	Lateral GW Flow	Total Varying Flows	Deep Percolation	YCFC Canal Recharge	Managed aquifer	Total Inflows
Entire Basin												
Historical	-33	-313	-28	-374	15	-28	0.0	-13	353	33	0.04	386
Future_Baseline	-16	-304	-16	-336	25	-40	0.0	-15	308	37	1.37	346
Future_2030	-15	-322	-15	-352	23	-37	0.0	-15	321	39	1.43	361
Future_2070	-15	-343	-15	-373	22	-35	0.0	-13	340	40	1.31	381
Future_2070_DEW	-15	-385	-13	-413	46	-6	0.0	39	323	37	1.30	360
Future_2070_WMW	-14	-311	-24	-348	-29	-79	0.0	-108	424	43	1.40	468

Notes: In the historical scenario: GW-SW exchange is positive with Cache Cr (29 TAF), Putah Cr (13.9 TAF), Sacramento R (0.9 TAF) and negative with Yolo bypass (25.7 TAF), Knights Landing Ridge Cut (1.5 TAF) and Colusa Basin Drain (2 TAF). Other GW-SW exchanges are minor.

Figure 10. Groundwater budget for the Yolo Subbasin.

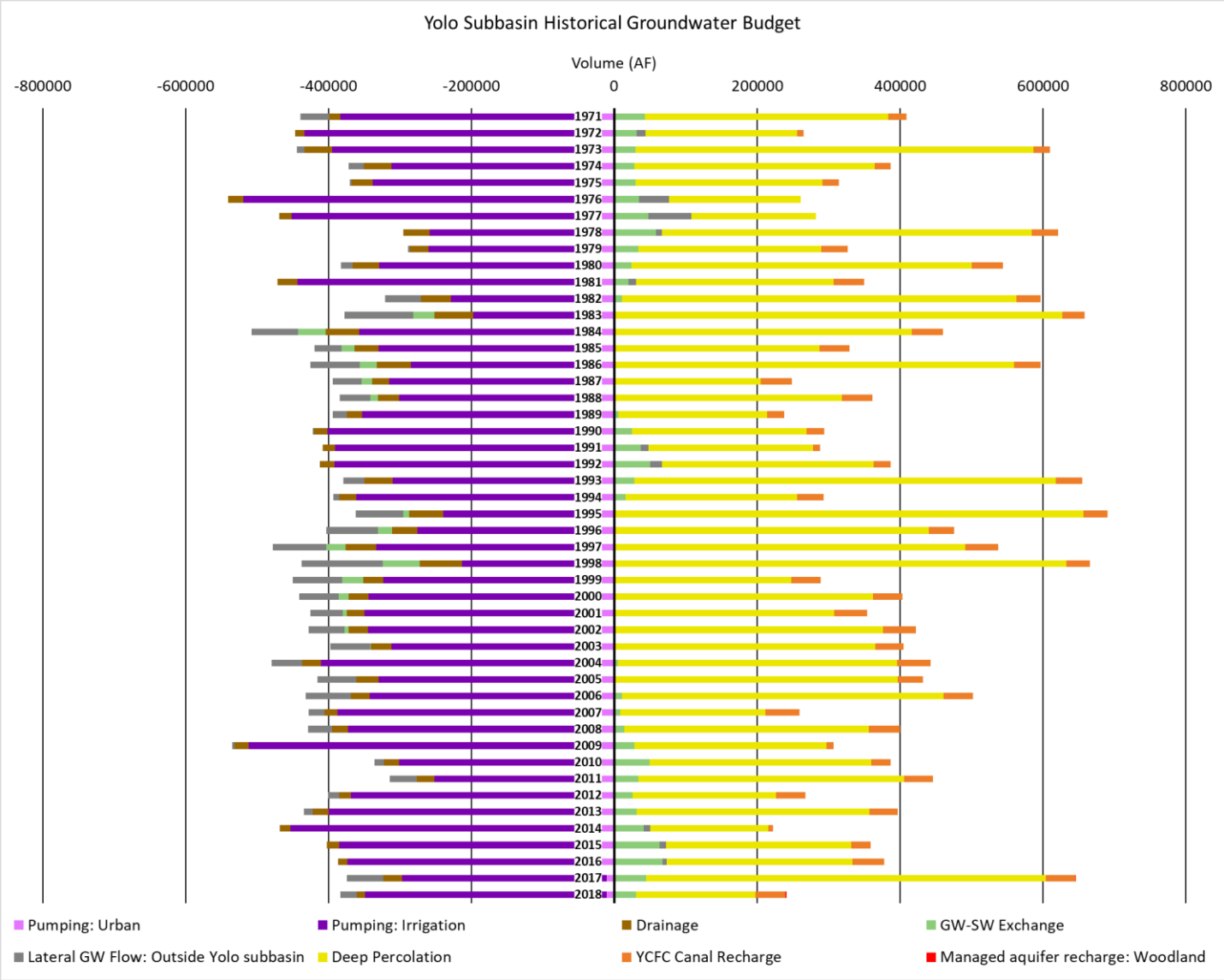


Table 17. Annual groundwater budget for the Yolo Subbasin. All values in Thousand Acre-feet.

Yolo Subbasin Historical Groundwater Budget (AF)											
	Outflows				Varying Flows			Inflows			
WY	Pumping: Urban	Pumping: Irrigation	Drainage	Total Outflows	GW-SW Exchange	Lateral GW Flow: Outside Yolo subbasin	Total Varying Flows	Deep Percolation	YCFC Canal Recharge	Managed aquifer recharge: Woodland	Total Inflows
Average	-33	-313	-28	-374	15	-28	-13	353	33	0	386
1971	-28	-355	-16	-399	43	-40	3	340	26	0	366
1972	-29	-405	-13	-447	32	12	44	212	9	0	222
1973	-29	-365	-39	-434	30	-10	19	557	23	0	580
1974	-30	-282	-38	-350	28	-22	7	336	23	0	359
1975	-31	-308	-30	-368	30	-2	28	262	23	0	285
1976	-32	-487	-21	-540	34	43	77	184	0	0	184
1977	-29	-423	-17	-469	48	60	108	174	0	0	174
1978	-31	-227	-36	-295	59	8	67	518	37	0	555
1979	-32	-228	-26	-286	34	-3	31	256	37	0	294
1980	-33	-296	-37	-366	24	-17	7	477	43	0	520
1981	-34	-409	-28	-471	20	11	31	276	43	0	319
1982	-33	-195	-42	-271	11	-50	-39	552	34	0	586
1983	-34	-163	-55	-252	-29	-96	-126	627	32	0	659
1984	-37	-320	-47	-404	-39	-65	-104	416	44	0	460
1985	-38	-292	-34	-363	-18	-38	-56	288	41	0	329
1986	-31	-254	-47	-332	-24	-69	-93	560	37	0	597
1987	-32	-284	-24	-339	-14	-40	-55	205	43	0	248
1988	-31	-270	-29	-330	-11	-43	-53	319	42	0	361
1989	-31	-322	-22	-375	6	-19	-13	208	24	0	232
1990	-31	-370	-19	-420	24	-1	23	245	25	0	270
1991	-30	-361	-17	-408	37	10	48	230	10	0	240
1992	-32	-360	-21	-412	51	16	67	296	24	0	321
1993	-33	-277	-40	-350	28	-29	-1	590	37	0	627
1994	-34	-328	-24	-385	16	-8	8	240	37	0	277
1995	-34	-206	-48	-287	-8	-67	-75	657	34	0	690
1996	-35	-241	-35	-310	-21	-72	-93	440	35	0	475
1997	-37	-296	-43	-376	-27	-75	-102	491	46	0	537
1998	-33	-180	-59	-272	-52	-114	-166	633	34	0	666
1999	-36	-286	-28	-351	-30	-69	-99	248	41	0	289
2000	-37	-307	-28	-372	-14	-55	-69	362	41	0	404
2001	-39	-311	-25	-374	-5	-45	-51	308	47	0	354
2002	-39	-306	-27	-372	-6	-50	-56	376	47	0	423
2003	-38	-273	-29	-341	-1	-56	-57	365	40	0	405
2004	-39	-371	-26	-437	5	-43	-38	391	47	0	438
2005	-38	-291	-31	-361	1	-55	-54	396	36	0	432
2006	-38	-304	-27	-369	11	-63	-52	450	41	0	491
2007	-39	-348	-18	-405	8	-22	-14	203	48	0	251
2008	-38	-334	-23	-395	14	-34	-20	343	44	0	387
2009	-36	-476	-19	-531	28	-3	24	269	9	0	279
2010	-34	-267	-22	-322	50	-13	37	310	27	0	337
2011	-33	-219	-24	-276	34	-38	-4	372	40	0	412
2012	-35	-334	-17	-385	26	-16	10	201	41	0	242
2013	-35	-365	-22	-422	31	-13	19	326	39	0	365
2014	-31	-422	-15	-468	41	9	51	165	7	0	172
2015	-29	-356	-18	-402	63	9	72	259	28	0	287
2016	-24	-349	-14	-387	68	6	73	260	44	0	304
2017	-11	-286	-27	-323	44	-51	-7	560	41	0	601
2018	-11	-338	-12	-360	31	-23	8	167	42	2	210

1.3.5. Groundwater Storage

Changes in groundwater storage over time are the aggregate (net) outcome of the individual inflows and outflows from the aquifer.

Available groundwater storage in Yolo County, in the depth interval of 20 to 420 feet, has been estimated at 14 million acre-ft (MAF) (Clendenen & Associates, 1976). The same report, which claims to be the first comprehensive Yolo County-wide groundwater investigation, estimates groundwater in storage in 1974 at 13 MAF, and estimated a decrease in storage of 0.5 MAF over the 30-year period from 1944-1974. The YSGA model (the MODFLOW part) estimates Basin-wide groundwater storage capacity at 13.7 MAF.

Modeled basin groundwater storage is presented as cumulative change from initial storage in September 1970, in Figure 11. The same is shown along with basin-averaged groundwater observations as standardized anomalies in Figure 12.

. The groundwater storage trace shows :

- Groundwater is lost from storage in dry years and recovers in wet years. Deep groundwater storage declines follow the deep droughts (WY 1976-WY 1977 ; WY 1987-WY 1992; WY 2007-2009; and WY 2012-WY 2016). Groundwater recovery follows in the intervening wet periods (WY 1971-WY 1975; WY 1982-1984; WY 1995-WY 2000; and WY 2005-WY 2006).

This feature of the Basin storage follows the pattern of groundwater-level observations basin-wide:

- So far, for the past nearly 50 years, there is no evidence of overdraft Basin-wide. Groundwater overdraft is defined by DWR[9], as a condition of pumping in excess of recharge, over a several-year period of average water supply conditions. In this GSP, we extend this definition, to (i) accommodate a longer time period of large hydroclimatic and water supply variability, and (ii) define overdraft as a continuously declining water table and modeled storage over this time period.
- At the end of the simulation in the historical period, modeled Basin groundwater storage is lower than the initial level by 86 TAF. To put this in context, this value is less than 6% of overall range in fluctuation (-553 TAF to +913TAF) modeled over the 48-year historical period (see Figure 11).
- Decadal changes in storage are summarized in Table 18, to further illustrate the fluctuation of groundwater storage in different wet and dry decades.

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[9] **groundwater overdraft —** "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." DWR, https://water.ca.gov/Water-Basics/Glossary (Accessed 9/15/2020)

- As described elsewhere, the dominant shift in land use in the basin has been from annual to perennial crops over this historical period. The groundwater storage trace implies that the climate signal has dominated over this historical period – at the scale of the Basin.
- The past decade was marked by extended drought, as well as an acceleration of perennial acreage. These factors drive increased extraction of groundwater. Despite these circumstances, a wetter 2017 appears to have helped the Basin storage to almost recover to initial levels.

Figure 11. Basin groundwater storage change from Oct 1971 – Sept 2018 (WY 1971 – WY 2018).

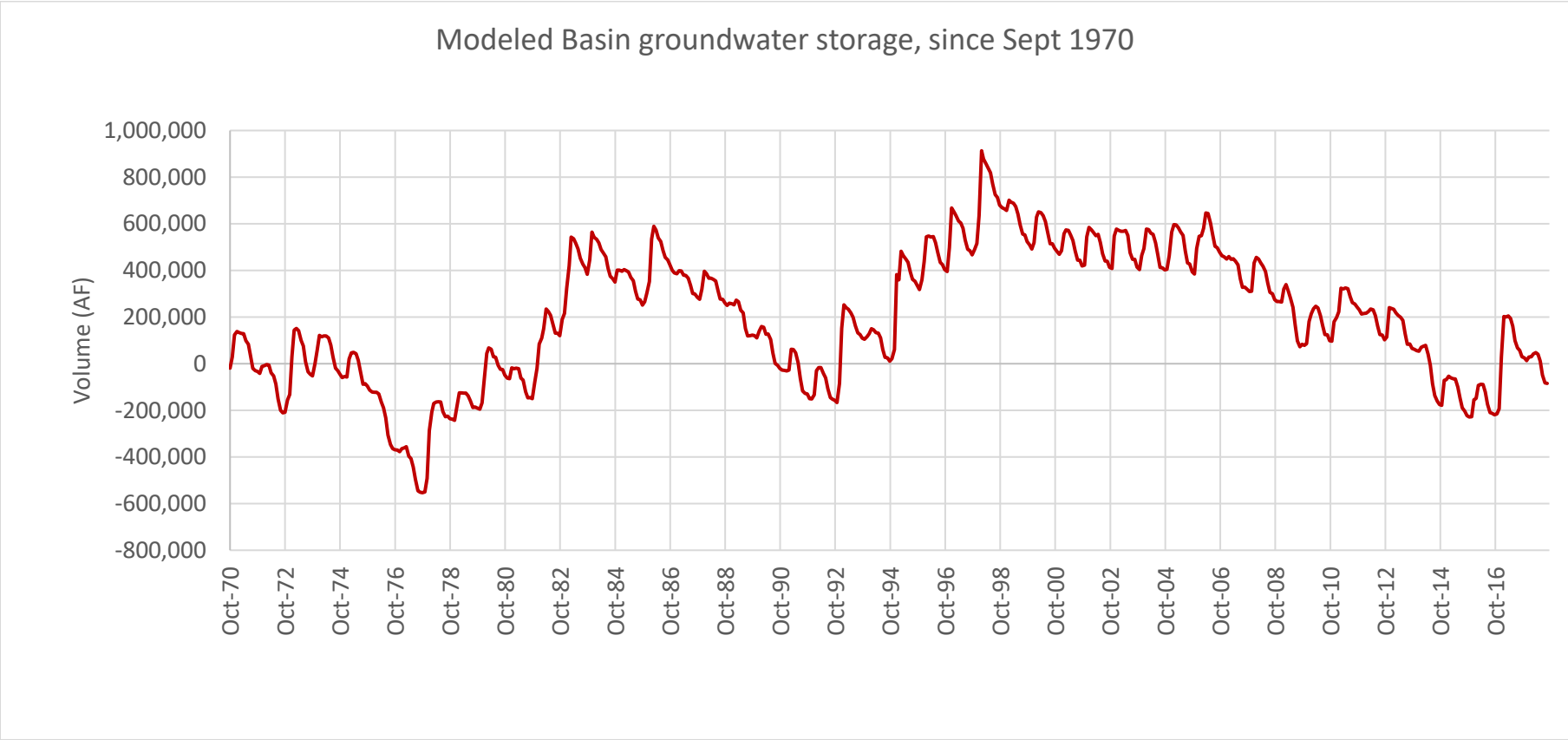
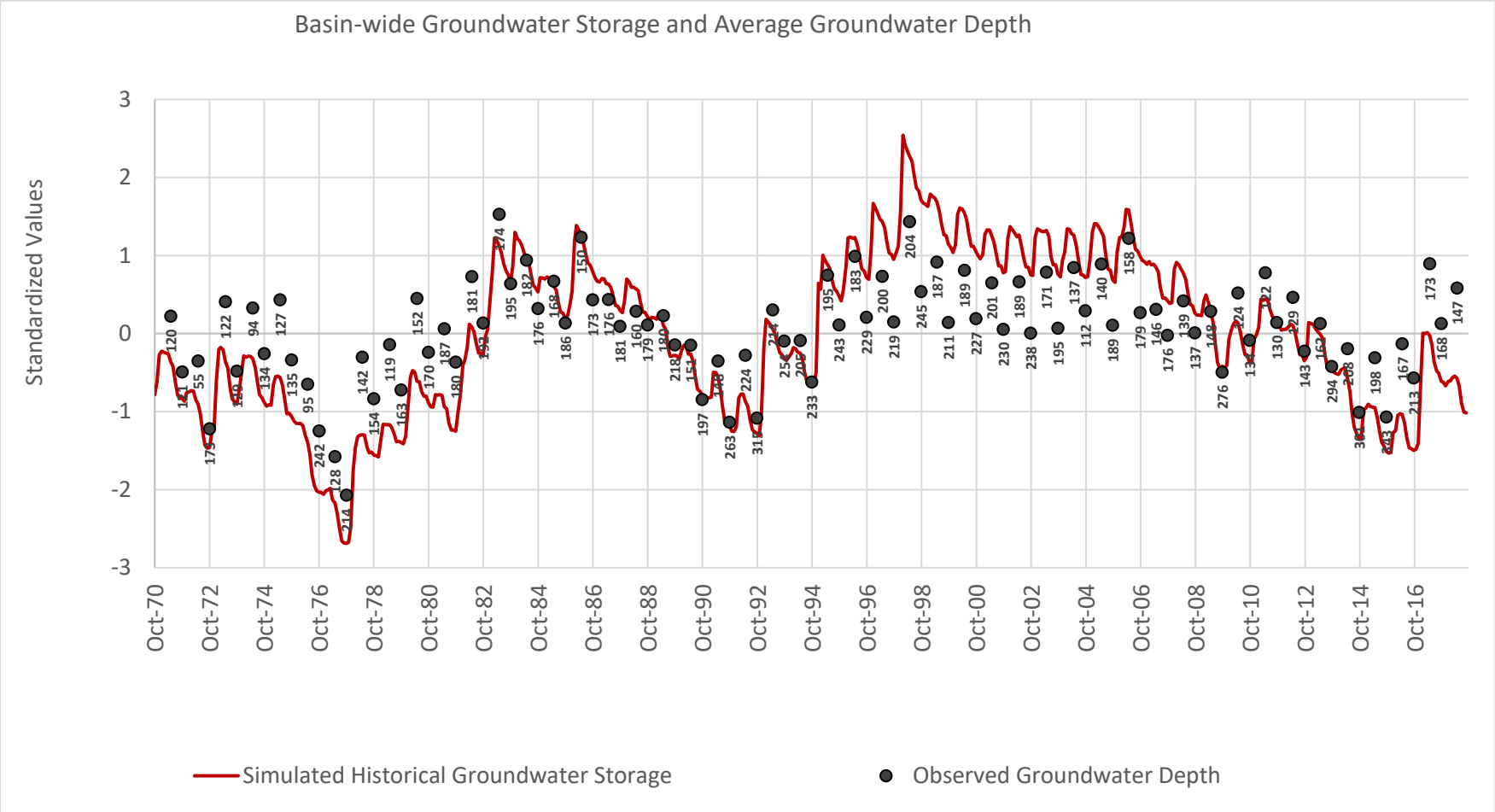


Figure 12. Standardized anomalies of groundwater storage and observed groundwater levels.



Note: data labels are the number of observations used to calculate the average.

Table 18. Decadal change in storage

Decade	Change in Storage (AF)
WY 1971-1980	-24,806
WY 1981-1990	17,992
WY 1991-2000	521,671
WY 2001-2010	-390,769
WY 2011-2018	-208,710

1.3.5.1. Management Areas: Groundwater Storage

In Section 1.3.5, the Basin-wide groundwater storage was discussed. In this section, modeled groundwater storage changes for Management Areas (MA) in the historical and current year period are discussed. Management Area maps and entities are in Figure 4.

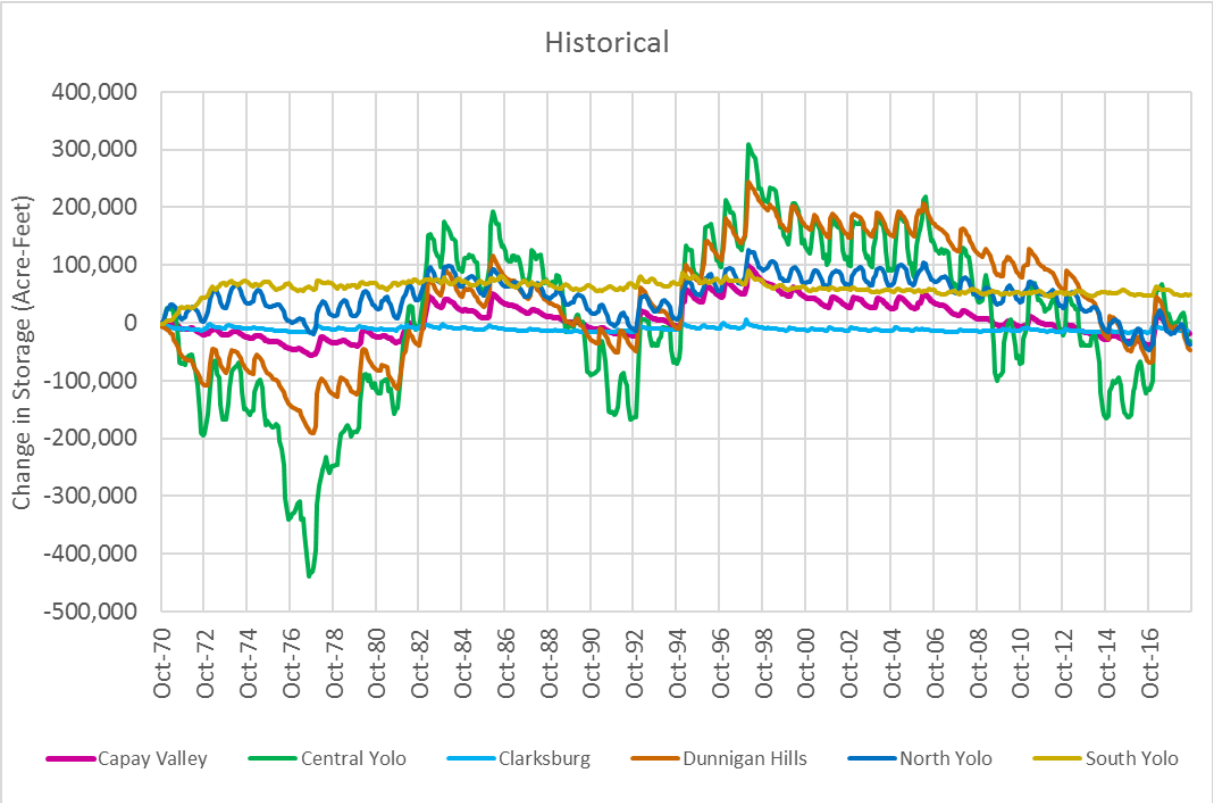
Groundwater storage in the historical scenario is presented first. Groundwater budgets and time series are presented in Appendix A.

Groundwater storage changes from the initial period (September 1970) are shown in Figure 13. Storage changes are shown on the same scale to visualize the relative volumes involved across Management Areas. For example, the MA's close to the Sacramento River, that also extract the least groundwater, show the least fluctuation in storage among all the MA's. This is followed by Capay Valley, and then by North Yolo and Dunnigan Hills MA's. The largest fluctuation is in the Central Yolo MA, which is the largest of the MA's in area, and is also an MA that uses a substantial amount of groundwater.

The description of the Basin-wide storage change applies to most of the MA's. Of note is the Dunnigan Hills MA, which may be showing a recent downward trend, due to increased perennial acreage in an area of the Basin that depends almost entirely on groundwater. This MA includes not just Dunnigan Hills, but also rangeland and new orchards in areas like Buckeye Creek, where no recent groundwater observations are available. New monitoring in this MA is recommended to fill this data and knowledge gap.

Note also that South Yolo MA shows an initial increase in storage in the first few years (the 1970's). The few groundwater observations from this MA appear to support this modeling result – although at the time of writing, the cause was unknown.

Figure 13. Groundwater Storage: Management Areas (WY 1971 – WY 2018).



1.3.6. Groundwater Storage: Future Scenarios

Figure 14 below shows the change in groundwater storage for each of the future scenarios, along with the groundwater storage change from the historical run (red line) for comparison.

Groundwater storage patterns among scenarios follow the precipitation and temperature trends among the scenarios, i.e.

- The most groundwater declines occur in the driest, warmest scenario – Future_70_DEW.
- Groundwater storage shows an overall increase compared to the historical simulation in the Future-70-WMW scenario.
- There is not much difference in groundwater storage between the central tendency scenarios (Future-30 and Future-70) and the Future-baseline.
- The historical and Future-baseline results provide useful insights. These simulations have the same climate input. Future-baseline shows the sensitivity to current cropping patterns and irrigation management, as described in the earlier section on groundwater budgets and fluxes.

Figure 14. Basin-wide groundwater storage for all scenarios.

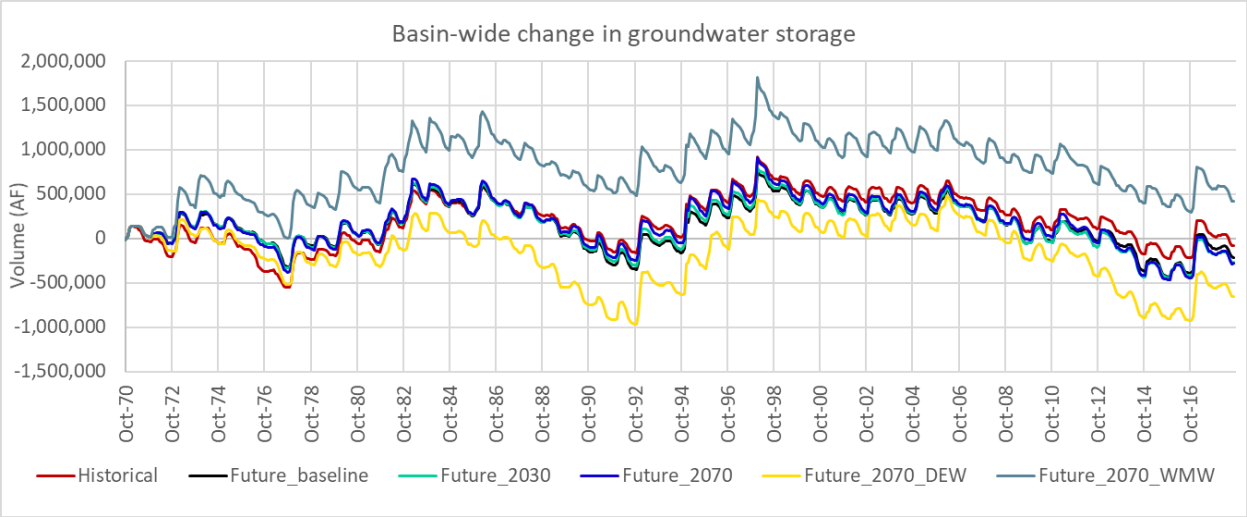


Table 19. Basin-wide storage change for all scenarios.

Scenario	Pumping (TAF) Avg (Range)	Groundwater storage change compared to corresponding start (TAF)
Historical	346 (197 – 519)	-85
Future Baseline	320 (204 – 517)	-213
Future 2030	337 (228 – 555)	-273
Future 2070	357 (252 – 572)	-279
Future DEW	401 (263 – 594)	-650
Future WMW	325 (226 – 444)	+418

Management area groundwater storage for future scenarios are included in Appendix A.

1.3.7. Evaluating water budget estimates

1.3.7.1. Uncertainty

All models are simplified abstractions of reality, and therefore water budgets will always exhibit uncertainty (Loucks and van Beek, 2017). Uncertainty in model outputs arise from uncertain or missing input data, model parameter uncertainty, differing model structures, natural variability (in climate, hydrology, geology, land use), and measurement errors (California DWR, 2020). For example, large uncertainties are likely to exist in model estimates of groundwater levels in Buckeye Creek simply

because of inadequate – or complete lack - of groundwater data. **These uncertainties directly affect model outputs.**

As described in more detail in Section 3.3 of the Model Documentation Appendix, the largest uncertainties in the Yolo Basin arise from:

Land use interpretation, and related irrigation management (variations in planting and harvest dates across space and time, for example) exhibit relatively large uncertainty. The Land use uncertainty affects all components of a water budget[10]. Details of crop acreage uncertainties rising from different data sources are in Section 2.1 of the Model Documentation Appendix.

Surface water supply in several areas of the Yolo Basin is not well known, as in some of the Reclamation Districts; and in the Willow Slough drainage, in the Clarksburg and Yolo bypass and Colusa Basin Drain region. Assumptions were made, which largely allowed surface water use to take precedence over groundwater pumping.

Groundwater levels and trends are uncertain in some areas like in north-west Yolo. Additionally, reference point elevations and screening depths from well logs are uncertain, and in many cases, missing. The latter made it challenging to ascertain which aquifer layer was being pumped; and the former directly impacted calibration statistics.

Geology and stratigraphy is uncertain in the Dunnigan Hills area (WRIME, 2006).

1.3.7.2. Discussion

For all the above reasons, any model, including the YSGA model, exhibits uncertainty. The same applies to other modeling efforts for Yolo County.

Additionally, different models are also not **strictly comparable** with each other because of differing spatial extents and resolution, time periods, boundary conditions, initial conditions, irrigation efficiencies, categorization of crops, assumptions involved in generating a time series of land use, calibration parameters and methods, and computational methods. In hydrology, **model equifinality – the fact that different parameters can give you equally good model calibration – remains a challenge.**

Keeping in mind the limitations of comparing different models, and of the major sources of uncertainty in the Yolo Basin, it may still be useful to compare certain important YSGA model outputs with a few studies.

Table 20 lists a summary of these differences for some modeling efforts in Yolo County, along with water budget estimates where available.

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[10] This is true of all Basins

In general, from Table 20:

- Total demand from these different efforts appear to be within 10% of each other.
- YSGA model estimates of pumping is higher than the 1970's estimate (Clendenen & Associates, 1976), and lower than the IGSM model (WRIME, 2006).
- YSGA model estimates of percolation are lower than that of the IGSM model (WRIME, 2006)

In particular, when comparing the YSGA model and the IGSM model (WRIME, 2006) for the same time frame 1971-2000:

- Total Demand and Irrigated Area

For the years 1971-2000, the average annual total demand in the IGSM model was 987 TAF while in the YSGA model it was 945 TAF. Closer inspection reveals that the IGSM model has larger annual average irrigated acreage of 360,882 acres while the YSGA model has an average of 308,839 acres. While there are many uncertainties in the processing of land use data, as described Section 2.1 of the Model Documentation Appendix, areas of pasture in northern Yolo were decided through interaction with YCFC to be largely unirrigated rangeland. This change explains some of the differences in irrigated areas.

- Average water applied

Both IGSM (WRIME, 2006, pp. 4–7) and YSGA average about 2.6 ac-ft/ac of irrigation water applied.

- Groundwater Pumping

In the IGSM model there is an average of 493 TAF/yr of groundwater pumping for the 1971-2000 time period. During the same period the YSGA model has an average pumping of 335 TAF/yr. Closer inspection reveals that more surface water is available for irrigation in the YSGA model, which results in less groundwater pumping. In the YSGA model there is an average of 574 TAF/yr of surface water used for irrigation while in the IGSM model there was 496 TAF/yr. Some of the largest differences in groundwater pumping occur in East-Yolo South (YCFC East) and CBD-South.

- Deep Percolation

The annual average deep percolation for 1971-2000 in the IGSM model is 484 TAF, while in the YSGA model it is 373 TAF. Some of this difference is likely due to the difference in irrigated acreage, however, most of the difference is probably due to differences in the soil moisture calculation algorithms.

Table 20. Summary of water budget estimates from earlier literature.

Source	Deep percolation (TAF)	Total Pumping (TAF)	Total demand (TAF)	Canal loss	Period	Spatial extent		Tools	
						Land surface budget	Groundwater budget	Land surface budget	Groundwater budget
YSGA Model **Aquifer area = 556,780 acres**	352	346	945	33	WY 1971-WY 2018	Yolo county, plus Cache Creek	Yolo Subbasin	WEAP MABIA Module	MODFLOW (finite difference)
Mehta et al, 2013	Not simulated at Basin scale	Not simulated at Basin scale	1035	NA	WY 1971-WY 2000	YCFC Boundary	YCFC Boundary	WEAP	WEAP's lumped model for groundwater
WRIME, 2006 **Aquifer Area = 566,044 acres**	484	493	987	22	WY 1971 - 2000	Yolo basin	Yolo Subbasin	IGSM	IGSM (finite element)
Borcalli and Associates, 2000	Not calculated	Not calculated	1035[11] 1976) 954 (1981) 1019 (1989)	NA	1976, 1981, 1989	Yolo County	NA	Spreadsheet estimates	NA
Clendenen & Associates, 1976	Not reported at Basin scale	305 (1963-1972)	835 (1970)	NA	1963-1972	Yolo County	Yolo Subbasin	Spreadsheet estimates	Partial

[11] *These estimates are for irrigation application only, based on DWR Landuse Surveys for the years listed in parenthesis (See Page 43 of the reference)*

1.3.7.3.Conclusion

An important observation from Table 19, is that the YSGA and IGSM models are consistent (in the 1971-2000 period) about pumping and deep percolation being fairly close to each other in magnitude. Additional information about model uncertainty is provided in the Model Documentation appendix.

1.4. Sustainable Yield

SGMA describes 'Sustainable Yield' as the amount of groundwater that can be withdrawn annually without causing undesirable results. Section 354.18(b)(7) of the GSP Regulations requires that an estimate of the basin's sustainable yield be provided in the GSP. This sustainable yield estimate can be helpful for estimating the projects and programs needed to achieve sustainability. Note that SGMA does not incorporate sustainable yield estimates directly into sustainable management criteria. "Basinwide pumping within the sustainable yield estimate is neither a measure of, nor proof of, sustainability. Sustainability under SGMA is only demonstrated by avoiding undesirable results for the six sustainability indicators" (California DWR, 2017).

The results presented above show that the Yolo Subbasin has historically been sustainable (for the 48 years between WY 1971-WY 2018). Groundwater observations and the YSGA model results during this period show that while groundwater is lost from storage in drought years, it is replenished in wet years. As a result, groundwater storage and observed elevations have almost recovered by end of WY 2018 to initial storage and elevations. These results show that the Yolo Subbasin has not been overdrafted. The conjunctive use of surface water and groundwater – especially due to surface water available from Indian Valley Reservoir and to some extent the Tehama Colusa Canal; improved irrigation practices toward low-volume irrigation methods (Orang et al., 2008); and improved urban water conservation practices in the past decade have all contributed to this state. This appears to be a marked improvement from groundwater conditions in the decades before 1971, when the Basin was estimated to be in a state of overdraft (Clendenen & Associates, 1976).

From the literature available for Yolo County, the closest definition to 'sustainable yield' is an estimate for perennial yield provided in the Yolo County groundwater investigation from 1976 (Clendenen & Associates, 1976; Scott and Scalmanini, 1975). These investigators defined 'perennial yield' as "the amount of water which can be pumped annually from that basin, with no net change in storage over a selected period of time". This definition is materially the same as the SGMA definition mentioned earlier. **Perennial yield for Yolo county, for the period 1963-1972, was calculated at 304.5 TAF.**

With the above in mind, this GSP proposes that:

(i) The average annual pumping over WY 1971 – WY 2018 as the sustainable yield for the Yolo Subbasin: **346 Thousand Acre Feet (TAF) per year**. The annual pumping estimated varies widely over the historical period, from 197-519 TAF/year. Note that

   a. The proposed sustainable yield of 346 TAF is based on a longer period of time, more data, and from a period of additional surface water availability than was available back

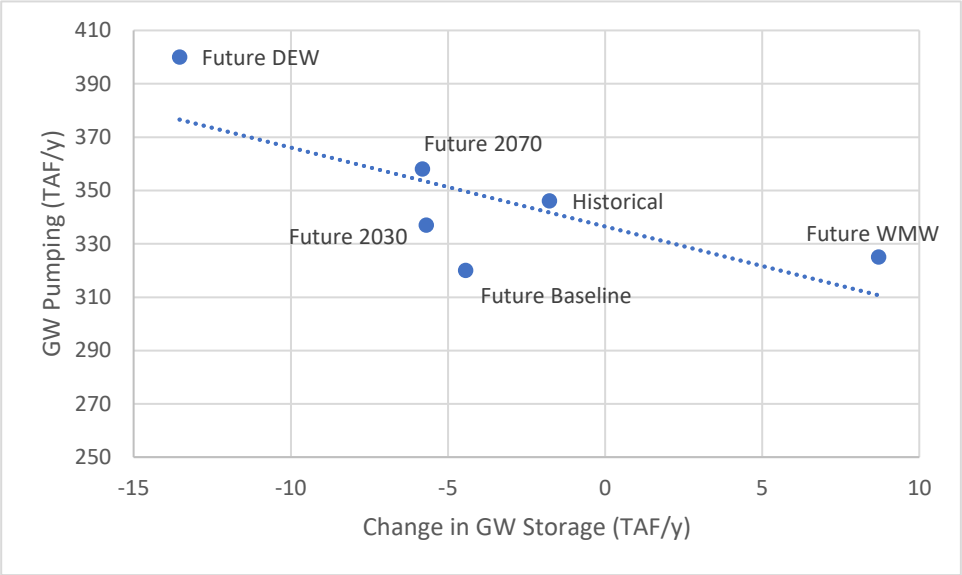
in the 1960's and early 1970's. Indeed, safe yield for Indian Valley reservoir is estimated at 50 TAF (Max Stevenson, pers. Comm 11/11/2020), which when added to the earlier perennial yield estimate from the 1970's, independently approximates the proposed 346 TAF value.

b. An analysis of model scenarios created for the GSP support this estimate. In Figure 15 the average annual groundwater pumping and change in groundwater storage are plotted. A regression line fit to the data has a y-intercept corresponding to zero change in groundwater storage of 336 TAF.

(ii) In the spirit of adaptive planning, the sustainable yield should be re-visited – and updated if needed – for each 5-year GSP update.

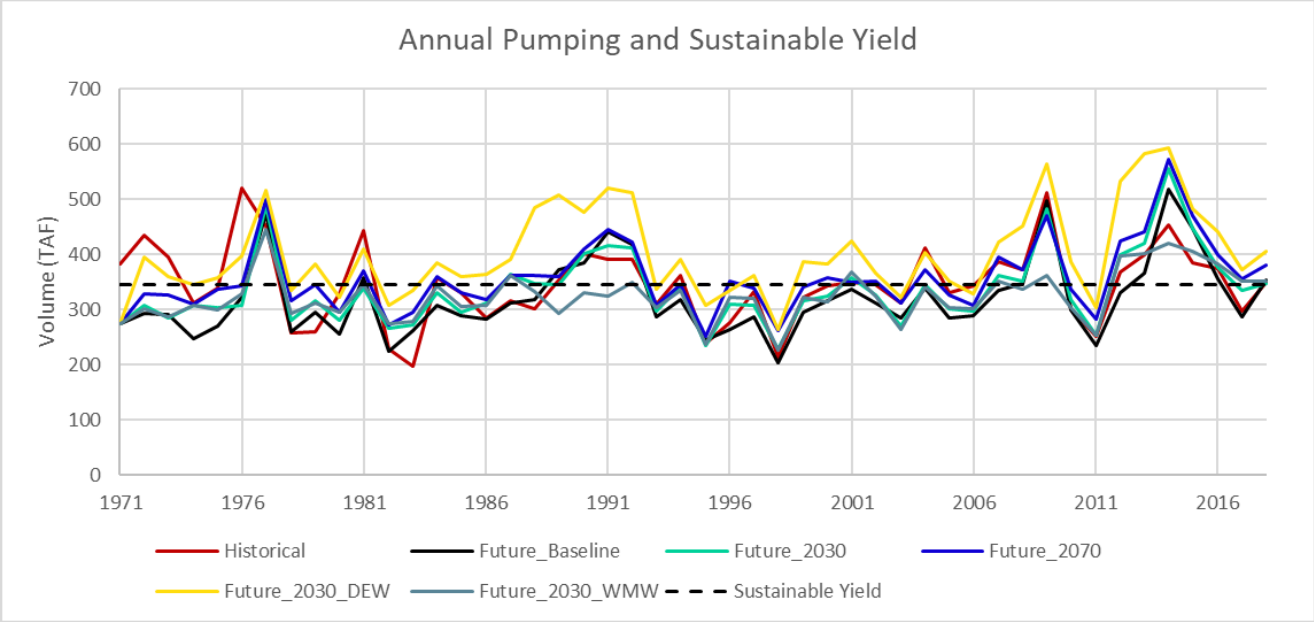
Based upon the analysis above, a sustainable yield of 346 TAF seems reasonable and justified.

Figure 15. Annual average groundwater pumping and change in storage for each model scenario.



For further comparison, Figure 16 below, shows the modeled pumping time series for the historical period, and for the future scenarios; the proposed Sustainable Yield of 346 TAF/year is shown as a horizontal reference line. Also, in Table 19, the average and range of annual pumping for each scenario is recorded. Figure 14 shows that Basin-wide groundwater storage, in all the investigated scenarios except for the DEW scenario, recovers to close to or above initial storage levels.

Figure 16. Annual pumping for all scenarios, compared to proposed sustainable yield.



The data in Figure 16 is aggregated in a different way in Table 21 below, showing the number and percent of years, for each scenario, when the proposed Sustainable Yield is exceeded. In all except the Dry Extreme scenario, the frequency is close to or smaller than in the Historical scenario.

Table 21. Modeled pumping versus sustainable yield.

Scenario	No. of years	%
Historical	25	52
Future_Baseline	14	29
Future_2030	17	35
Future_2070	26	54
Future_DEW	37	77
Future WMW	14	29

References

Allen, R.G., Pereira, L.S., Smith, M., Raes, D., Wright, J.L., 2005. FAO-56 Dual Crop Coefficient Method for Estimating Evaporation from Soil and Application Extensions. J. Irrig. Drain. Eng. 131, 2–13. https://doi.org/10.1061/(ASCE)0733-9437(2005)131:1(2)

California DWR, 2020. Handbook for Water Budget Development.

California DWR, 2018. Guidance for Climate Change Data Use During Groundwater Sustainability Plan Development, Sustainable Groundwater Management Program. California Department of Water Resources.

California DWR, 2017. Best Management Practices [WWW Document]. URL http://water.ca.gov/groundwater/sgm/bmps.cfm (accessed 3.1.17).

California DWR, 2015. Perspective and Guidance for Climate Change Analysis. California Department of Water Resources.

California DWR, 2004. Sacramento Valley Groundwater Basin: Capay Valley Subbasin (No. 118), California's Groundwater Bulletin. Department of Water Resources, Sacramento, California.

Clendenen & Associates, 1976. Yolo County Investigation of Groundwater Resources. Auburn, California.

Davids Engineering, 2011. Reclamation District 108 Water Balance Analysis.

Flores Arenas, C.I., 2016. New Approaches to Conjunctive Use and Groundwater Accounting. University of California, Davis, Davis, CA.

Harbaugh, A. w., 2005. MODFLOW-2005, The U.S. Geological Survey Modular Ground-Water Model—the Ground-Water Flow Process (No. 6-A16), USGS Techniques and Methods. USGS, Virginia.

Harwood, D.S., Helley, E., J., 1987. Late Cenozoic tectonics of the Sacramento Valley, California (No. 1359), USGS Professional Paper. US Geological Survey.

Jabloun, M., Sahli, A., 2012. WEAP-MABIA Tutorial. Institut National Agronomique de Tunisie.

Loucks, D.P., van Beek, E., 2017. System Sensitivity and Uncertainty Analysis, in: Loucks, D.P., van Beek, E. (Eds.), Water Resource Systems Planning and Management: An Introduction to Methods, Models, and Applications. Springer International Publishing, Cham, pp. 331–374. https://doi.org/10.1007/978-3-319-44234-1_8

Mehta, V.K., Haden, V.R., Joyce, B.A., Purkey, D.R., Jackson, L.E., 2013. Irrigation demand and supply, given projections of climate and land-use change, in Yolo County, California. Agric. Water Manag. 117, 70–82. https://doi.org/10.1016/j.agwat.2012.10.021

Mehta, V.K., Rheinheimer, D.E., Yates, D., Purkey, D.R., Viers, J.H., Young, C.A., Mount, J.F., 2011. Potential impacts on hydrology and hydropower production under climate warming of the Sierra Nevada. J. Water Clim. Change 29–43. https://doi.org/10.2166/wcc.2011.054

Mehta, V.K., Young, C.A., Bresney, S.R., Spivak, D.S., Winter, J.M., 2018. How can we support the development of robust Groundwater Sustainability Plans? Calif. Agric. 54–64. https://doi.org/10.3733/ca.2018a005

Orang, M.N., Matyac, J.S., Snyder, R.L., 2008. Survey of irrigation methods in California in 2001. J. Irrig. Drain. Eng. 134, 96.

RMC Water and Environment, 2016. Capay IGSM Update and Scenario Analysis: Final Report. Yocha Dehe Wintun Nation.

Scott, V.E., Scalmanini, J.C., 1975. Investigation of groundwater resources of Yolo County, California (No. 2006), Water Science and Engineeing paper. University of California, Davis, Davis.

Winter, J.M., Young, C.A., Mehta, V.K., Ruane, A.C., Azarderakhsh, M., Davitt, A., McDonald, K., Haden, V.R., Rosenzweig, C., 2017. Integrating water supply constraints into irrigated agricultural simulations of California. Environ. Model. Softw. 96, 335–346. https://doi.org/10.1016/j.envsoft.2017.06.048

WRIME, 2006. Yolo County Integrated Groundwater and Surface water Model: Model Development and Calibration. YCFCWCD, WRA and DWR.

Yates, D., 1996. WatBal: An integrated Water Balance Model for Climate Impact Assessment of River Basin Runoff. Water Resour. Dev. 12, 121:139.

Yates, D., Purkey, D., Sieber, J., Huber-Lee, A., Galbraith, H., 2005a. WEAP21 - A Demand-, priority-, and preference-driven water planning model: Part 2: Aiding freshwater ecosystem service evaluation. Water Int. 30, 501–512.

Yates, D., Sieber, J., Purkey, D., Huber-Lee, A., 2005b. WEAP21—A Demand-, Priority-, and Preference-Driven Water Planning Model. Water Int. 30, 487–500.

Appendix A: Subregional and Management Area Water Budgets

1.5. Capay

1.5.1. Description

The Capay watershed drains an area of 85,515 acres in the YSGA model, from the north-western boundaries of Yolo County to Capay Dam on Cache Creek (Figure 4). It includes the hills (named as the Capay Other catchment (67,097 acres) in the model) which overlays hard-rock terrain, and the valley floor (named as the YCFC Capay catchment in the model, 18,418 acres), overlaying the alluvial aquifer. This valley floor catchment corresponds closely to the official Capay Valley Management Area boundary.

The valley floor of Capay is represented in the DWR's 2003 Groundwater Bulletin 118 as the "Capay Valley Groundwater Subbasin, 5-21.68" (California DWR, 2004). Primary, fresh-water bearing deposits within the Capay Valley sub-basin include recent stream channel deposits and the Tehama Formation. This is underlain by older, saline Cretaceous Marine rocks. Recent stream channel deposits consist of unconsolidated silt, fine- to medium-grained sand, gravel and occasionally cobbles deposited in and adjacent to Cache Creek and its tributaries (California DWR, 2004). Overall freshwater-bearing sediments in Capay Valley are reportedly more than 1000 feet thick (Harwood and Helley, 1987; WRIME, 2006). In the YSGA model, groundwater storage capacity in this area is estimated as 953 TAF for 20 to 420 ft of depth.

Groundwater flow typically follows the topographical line of the Valley running southeast (RMC Water and Environment, 2016). Groundwater levels have been stable in Capay Valley, usually varying from 10 to 40 feet below ground surface. Even in dry years the water table varies from 10 to 40 ft below surface (California DWR, 2004). Most domestic and irrigation wells are screened within the top 60 feet of the surface. Shallow wells are particularly common close to Cache Creek. Additional domestic and irrigation wells extend from 60 feet to 160 feet, but these are less common. Generally only larger wells operated by Yocha Dehe Wintun Nation are screened from 160 feet to 460 feet, and no wells are screened below 460 feet (RMC Water and Environment, 2016).

Land use in Capay MA is dominated by native vegetation, oak woodland landscapes that are prone to wildfires. In the Valley portion, orchards, field crops, and truck crops are cultivated (Table 22).

Table 22. Land Use for Capay MA.

	Land Use (ac)				Land Use (Percent)			
	1989	1997	2008	2016	1989	1997	2008	2016
Capay Valley Management Area	**85,515**	**85,515**	**85,515**	**85,515**				
Deciduous	2,811	2,663	2,578	2,890	3	3	3	3
Field Crops	128	402	561	217	0	0	1	0
Grain	3,070	2,615	824	694	4	3	1	1
Managed Wetlands	0	0	0	0	0	0	0	0
Native Vegetation	77,478	78,028	79,021	79,187	91	91	92	93
Pasture	732	707	707	346	1	1	1	0
Rice	0	0	0	0	0	0	0	0
Subtropical	0	0	126	376	0	0	0	0
Truck Crops	735	422	508	596	1	0	1	1
Urban	58	176	635	635	0	0	1	1
Vine	3	2	55	74	0	0	0	0
Water	500	500	500	500	1	1	1	1

Source: DWR Land and Water Use Surveys

1.5.2. Data Sources and Assumption

In the YSGA model, Capay Valley floor (called YCFC Capay Catchment) irrigation demand is partly serviced by YCFC from Cache Creek. Demand not met by this surface water is met by groundwater pumping. The Capay Other catchment is largely composed of steep hills, dominated by natural oak and grassland vegetation. The region is dominated by native vegetation covering the hills. Deciduous orchards and grain crops dominate the irrigated land (Table 22). Several small towns, like Rumsey, Brooks, Guinda, and Capay, are assumed to pump groundwater through private wells. Information on water use for these, as well as the Cache Creek Casino and Yocha Dehe Wintun Nation, was available in the IGSM report from Capay (RMC Water and Environment, 2016). Non-agricultural water demand is small compared to agricultural demand in Capay Valley MA.

Data sources used to develop the representation of the Capay Valley MA are listed in the Model Documentation Section 3.4, Water Management Operation Inputs.

1.5.2.1.Assumptions for future scenarios.

- Urban water demands:
  - Population of all urban demands remains constant at 2004 levels, the last year for which data was available
- Agriculture water demands:
  - 2018 land use is held constant into the future
- Water supply:
  - Cache creek hydrology is modeled for each climate scenario.
  - The operating rules for releases from Clear Lake and Indian Valley Reservoir remain the same in the future simulations as in the last year in the historical simulation.

- Surface water available to the Yocha Dehe Golf Club and to agriculture in the YCFC Capay catchment are the same in the future simulations as in the last year of the historical simulation.
- There are no restrictions on groundwater pumping.

1.5.3. Water budgets

First, the table below describes what the inflows and outflows include for this region.

Table 23. Useful Terms in this section.

Term	Description
Deep percolation	Water that recharges the groundwater aquifer from the overlying catchments within the management area (these are listed in Table 3). This includes water from rain events, inefficiency of irrigation and seepage from septic systems. It is assumed most urban demands (Yocha Dehe Wintun Nation Casino, Tribal Housing and rural water use from private pumping) return all water that is not consumed to septic systems and therefore, deep percolation.
Evapotranspiration (ET)	Evaporation from the land surface (soil and urban land cover) and transpiration from vegetation (agriculture and native vegetation) from all catchments within this management area (listed in Table 3).
GW-SW Exchange	Exchange between Cache Creek and the underlying aquifer.
Lateral GW Flow	Subsurface groundwater flow between the Capay Valley management area and the Central Yolo Management area.
Precipitation	Rain falling within the boundary.
Pumping: Irrigation	Water sourced from groundwater supplied to agricultural irrigation in the catchments within this area (these are listed in Table 3)
Pumping: Urban	Water sourced from groundwater supplied to all non-agricultural demands in Capay Valley: Yocha Dehe Wintun Nation Casino, Golf course, Tribal Housing and rural water use from private pumping
Surface Runoff (SRO)	Surface runoff from the land within this management area to Cache Creek, due to precipitation or irrigation runoff.
SW supply: Irrigation	Water sourced from Cache Creek supplied to agricultural irrigation in the catchments within this management area (these are listed in Table 3)
SW supply: Urban	Water sourced from Cache Creek supplied to the Yocha Dehe Wintun Nation Golf Course.

Term	Description
Urban consumption	Water consumed within the urban demand in this management area (not returned to a septic system): Yocha Dehe Wintun Nation Casino, Golf course, Tribal Housing and rural water use from private pumping. This includes water used for landscape irrigation within these demands.

Table 24. Average Annual Land Surface Water Budget for Capay Subregion.

Historical Average Annual Land Surface Water Budget (TAF)											
	Outflows					Inflows					
	Evapotranspiration	Deep Percolation	Surface Runoff	Urban Consumption	Total Outflows	Precipitation	Pumping: Urban	Pumping: Irrigation	SW Supply: Urban	SW Supply: Irrigation	Total Inflows
Capay Valley											
Historical	-136	-24	-19	-0.2	-179	157	0.4	16	0.2	5	179
Future_Baseline	-136	-21	-18	-0.3	-176	157	0.5	14	0.2	4	176
Future_2030	-137	-23	-20	-0.3	-180	161	0.5	14	0.2	4	180
Future_2070	-139	-25	-26	-0.3	-191	170	0.5	15	0.2	5	191
Future_2070_DEW	-134	-24	-32	-0.3	-190	168	0.5	16	0.2	5	190
Future_2070_WMW	-138	-39	-47	-0.3	-224	205	0.5	14	0.2	4	224

Average annual land surface and groundwater budgets are presented in Table 24 and Table 25 respectively.

Key messages on the land surface water budget are similar to those provided for the County-wide results in the main body of this report.

- Overall outflows and inflows are in balance for all scenarios.
- There is not much substantive change in the budget in the future scenarios, with the exception of the wet scenario (Future_WMW) in which both surface runoff and deep percolation increase due to the additional precipitation.

Table 25. Average Annual Groundwater Budget for Capay Valley MA.

Historical Average Annual Groundwater Budget (TAF)								
	Outflows			Varying Flows			Inflows	
	Pumping: Urban	Pumping: Irrigation	Total Outflows	GW-SW Exchange	Lateral GW Flow	Total Varying Flows	Deep Percolation	Total Inflows
Capay Valley								
Historical	-0.4	-16	-16	-7	-1	-8	24	24
Future_Baseline	-0.5	-14	-14	-6	-1	-7	21	21
Future_2030	-0.5	-14	-15	-7	-1	-8	23	23
Future_2070	-0.5	-15	-15	-9	-1	-10	25	25
Future_2070_DEW	-0.5	-16	-16	-7	-1	-8	24	24
Future_2070_WMW	-0.5	-14	-15	-22	-1	-22	39	39

Figure 17. Capay Valley Groundwater Storage, all scenarios.

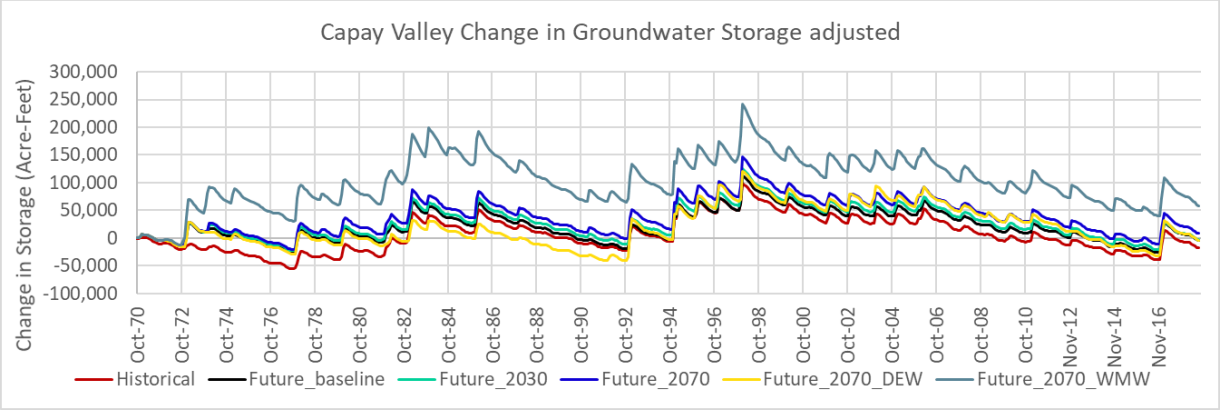


Table 25 and Figure 17 present the groundwater budget and storage change for all scenarios.

Key messages on the groundwater budget are:

- Historically, similar to the Basin-wide narrative, groundwater is depleted from storage in dry years, and recovers in wet years. The scale, or range, of these fluctuations is relatively small reflecting the stable groundwater levels that have been observed in the Capay Valley floor historically. At the end of the historical period of 48 years, groundwater storage is estimated to be 18 TAF below the start. The overall trace suggests that this MA has not been overdrafted in the past nearly five decades.

- Drought years like the 1976-1977 would not result in as severe a depletion as they did in the past, primarily because of increased surface water availability (e.g., Indian Valley Reservoir surface water).
- This MA has additional groundwater storage at the end of all future scenarios including in the extreme dry scenario (Future_DEW2070), reflecting the additional precipitation in these scenarios. This result is different from many of the other MA's and the basin-wide result. Partly, this is the result of the climate change factors being different not only for each climate projection, but also, (i) spatially among the MA's, and (ii) appear to have some trends over time. The Future_DW2070 scenario is wetter in the latter half of the simulation and shows some extremely wet months. Another reason is that the MA is dominated by native vegetation as the greatest proportion of land use, which tends to make the simulations more similar when compared to other MAs that are dominated by cropping.
- In the extreme wet scenario, GW-SW exchange increases to 22 TAF and groundwater storage increases to about 58 TAF above initial conditions, reflecting an elevated water table.

Overall, Capay Valley MA displays less vulnerability, both in the historical and future scenarios, when compared to the other MAs. The annual time series of the land surface and groundwater budgets are presented below in Figure 18 and Figure 19, respectively.

Figure 18. Capay Subregion Historical Land Surface Water Budget.

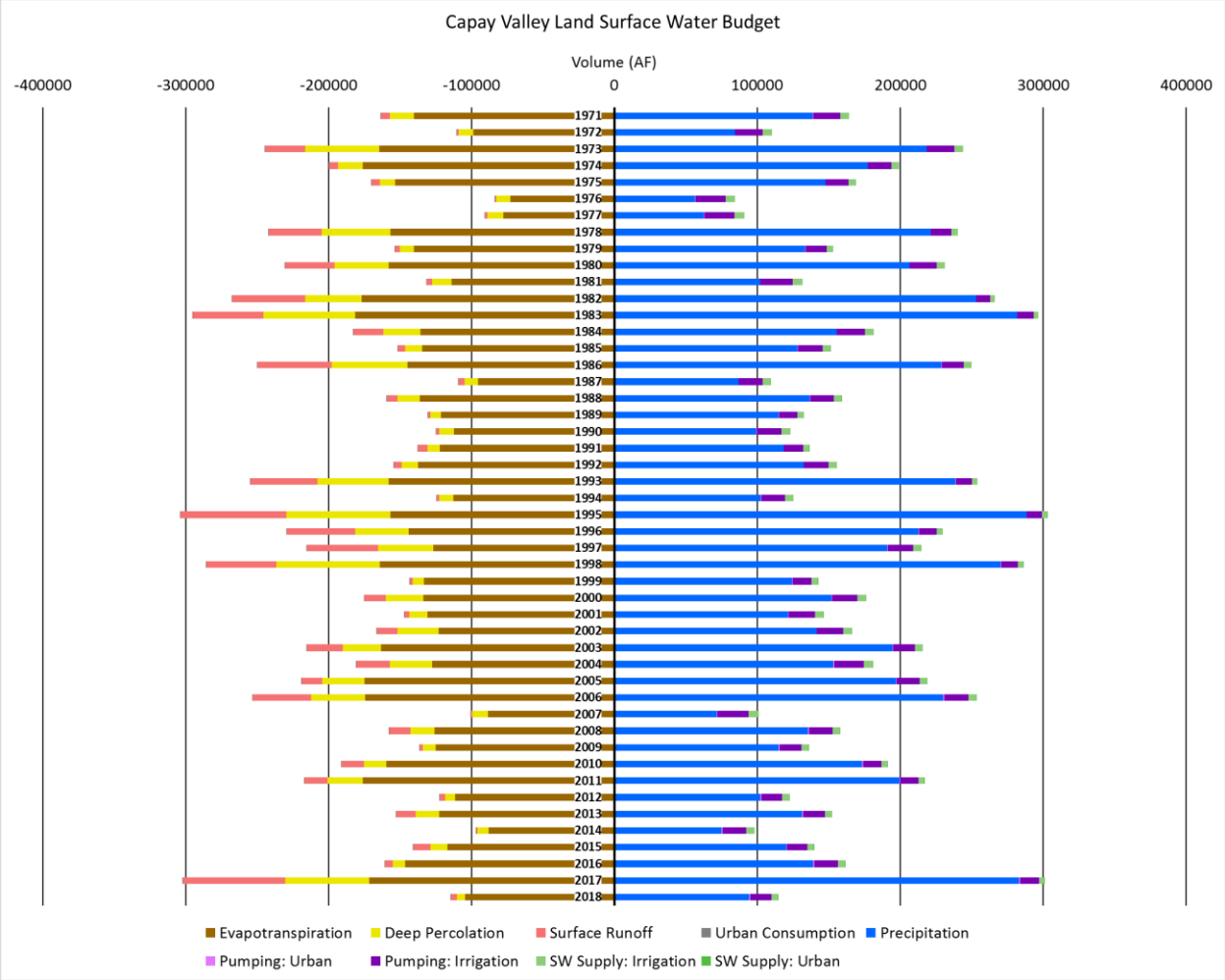
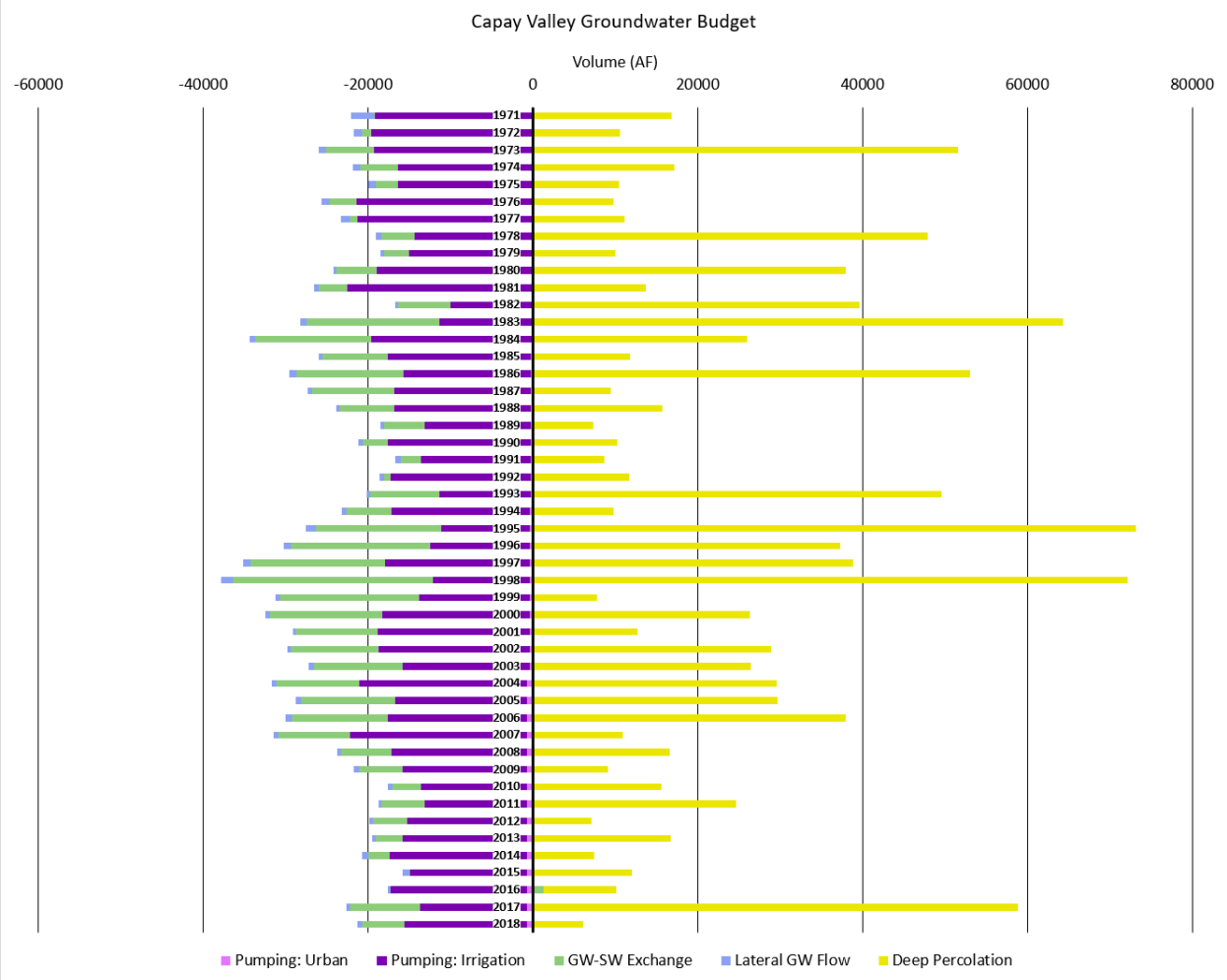


Figure 19. Capay Valley MA Historical Groundwater Budget.



1.6. Central Yolo Subregion

1.6.1. Description

The Central Yolo Subregion covers 242,860 acres and extends from the Capay Diversion Dam in the west to the YCFC District boundary in the east. It extends into Hungry Hollow to the north of Cache Creek, south to Putah Creek, and to the western boundary of the Yolo Subbasin west of Winters. This MA includes the municipal demands of the cities of Davis, Winters, and Woodland, along with UC Davis, the towns of Esparto and Madison, and the irrigation demands of RD 2035 and YCFC customers. Willow slough runs through the middle of this MA, and the YCFC's earthen, unlined canal system contributes significantly to annual groundwater recharge.

The YSGA model (the MODFLOW portion) estimates the storage capacity of this area to be 5.4 million acre-feet between 20 and 420 feet of depth. Note that the spatial boundary of this MA is different from earlier efforts (Clendenen & Associates, 1976; WRIME, 2006), making any comparison to them challenging.

Cultivated land dominates this subregion with a diverse array of crops including orchard crops, field crops, grain, pasture, rice, truck crops, and some vineyards. Orchard acreage has been increasing (Table 26).

Table 26. Land Use for Central Yolo Subregion.

	Land Use (ac)				Land Use (Percent)			
	1989	1997	2008	2016	1989	1997	2008	2016
Central Yolo Management Area	**242,680**	**242,680**	**242,680**	**242,680**				
Deciduous	8,210	8,574	13,867	30,533	3	4	6	13
Field Crops	34,817	44,405	17,795	17,901	14	18	7	7
Grain	46,679	32,201	26,922	14,461	19	13	11	6
Managed Wetlands	0	483	459	0	0	0	0	0
Native Vegetation	80,688	78,367	93,892	103,281	33	32	39	43
Pasture	18,164	23,513	32,714	14,677	7	10	13	6
Rice	9,794	11,077	13,052	17,100	4	5	5	7
Subtropical	118	86	494	655	0	0	0	0
Truck Crops	26,362	23,366	20,800	21,390	11	10	9	9
Urban	16,760	19,122	21,030	19,754	7	8	9	8
Vine	220	618	688	1,961	0	0	0	1
Water	867	867	967	967	0	0	0	0

Source: DWR Land and Water Use Surveys

1.6.2. Data Sources and Assumptions

Data sources used to develop the representation of the Central Yolo MA are listed in the Model Documentation Appendix, Section 2.1.5, Water Management Inputs.

1.6.2.1.Future scenarios Assumptions:

- Urban water demands:
  - For the City of Davis, the population grows from 70,000 (near 2019 level) at 0.7% (recent growth rate) and the water use rates are kept constant from the last historical levels, based on the 2015 Urban Water Management Plan.
  - For the City of Winters, the population grows at 1%. Recent population growth is closer to 2%, while in earlier years the population remained constant, so an average of 1% was used.
  - For the City of Woodland, population grows at 1.3%, based on the 2015 Urban Water Management Plan.
  - The population of Madison and Esparto CSDs were both kept constant from the last historical values.
  - UCD population grows at 1% while the aquaculture and landscape irrigation demands remain constant from the last historical values, based on the 2018 Long Range Development Plan.
  - Water demands for other small towns remain constant from the last historical values.
  - For all urban demands, per capita water use rates are kept constant from the last historical values.
- Agriculture water demands:
  - 2018 land use is held constant into the future.
- Water supply:
  - Since the climate and hydrology of the Cache Creek watershed is modeled, in future simulations flows in Cache Creek reflect the climate scenario.
  - Operating rules for releases at Clear Lake and Indian Valley Reservoir remain the same in the future simulations as the last year in the historical simulation.
  - YCFC operating rules remain the same in the future simulations as in the last year of the historical simulation.
  - Boundary conditions of all other streams entering the County remain the same as in the historical simulation.
  - There are no restrictions on groundwater pumping.
  - It is assumed the Woodland-Davis Clean Water Agency is able to use the entirety of both water rights (55 TAF in total) in the future scenarios, with limitations based on Shasta Critical Years, Project Water allocations and Term 91, when applicable.
  - Monthly distribution of the available water over the year is calculated from actual diversion data (2016-2018). The available water is divided among Woodland, Davis, and UC Davis as 60%, 34%, and 6%, based on the current operations of 18, 10.2, and 1.8 MGD, respectively.
  - The Woodland aquifer storage and recovery system in future scenarios has supply preferences set up in the following order: recycled water from the wastewater treatment plant (0.5 MGD) is first, then Aquifer Storage and Recovery (ASR) water, then the Woodland-Davis Clean Water Agency, and only after that is the confined aquifer (layer 2) used. Effectively, this represents Woodland's marked reduction in dependence historically on the unconfined aquifer. Woodland's stated goal of ASR injection is 10,000

AF per year. However, for the future simulations, the YSGA model currently uses the 2018 amount of water reported to be injected (500 million gallons per year, or 1,534 AF), with a monthly distribution also determined from 2018 data. Of this injected water, 1,368 AF is pumped from the ASR for City use (based on 2018 data).

1.6.3. Water budgets

Table 27. Useful terms in this section.

Term	Description
Deep percolation	Water that recharges the groundwater aquifer from the overlying catchments within the management area (these are listed in Table XX). This includes water from rain events, inefficiency of irrigation and seepage from septic systems (in the town of Capay and Monument Hills) and wastewater treatment ponds (these occur in Madison CSD, Esparto CSD, Winters and Davis)
Evapotranspiration (ET)	Evaporation from the land surface (soil and urban land cover) and transpiration from vegetation (agriculture and native vegetation) from all catchments within this management area (listed in Table XX) as well as evaporation from wastewater treatment ponds (these occur in Madison CSD, Esparto CSD, Winters and Davis)
GW-SW Exchange	Exchange between Cache Creek, Willow Slough, Putah Creek and the Yolo Bypass and the aquifer underlying the management area.
Lateral GW Flow	Subsurface groundwater flow between the Central Yolo management area and the neighboring management areas: Capay Valley, Dunnigan Hills, North Yolo and South Yolo.
Lateral GW Flow: Outside Yolo subbasin	Subsurface groundwater flow between the Central Yolo management area and the Solano subbasin.
Managed aquifer recharge: Woodland	Water recharged to the confined aquifer underlying the city of Woodland, through the Aquifer Storage and Recovery program.
Precipitation	Rain falling within the management area boundary.
Pumping: Irrigation	Water sourced from groundwater supplied to agricultural irrigation in the catchments within this management area (these are listed in Table 3)
Pumping: Urban	Water sourced from groundwater (both the general aquifer and the Woodland confined aquifer) supplied to the urban demands within this management area: City of Davis, City of Woodland, City of Winters, Esparto CSD, Madison CSD, UCD, and other small towns
Surface Runoff (SRO)	Surface runoff from the land within this management area to Cache Creek, Willow Slough, Putah Creek and the Yolo Bypass due to precipitation and irrigation runoff
SW supply: Irrigation	Water sourced from Cache Creek via YCFC canals, Putah Creek, Willow Slough, Sacramento River and the Yolo Bypass supplied to agricultural irrigation in the catchments within this management area (these are listed in Table 3).

Term	Description
SW supply: Urban	Water sourced from the Sacramento River supplied to the Woodland Davis Clean Water Agency.
Tailwater re-use: Irrigation	Reuse of irrigation tailwater. Reclamation Districts and the North Delta East catchment can reuse 90% of tailwater for irrigation in the model, based on previous work describing reuse in RD108 (Davids Engineering, 2011).
Treated WW Outflow	Return flows from wastewater treatment plants in the cities of Davis and Woodland to the Yolo Bypass and the city of Winters to Putah Creek.
Urban consumption	Water consumed within the urban demands in this management area (not returned to a septic system or wastewater treatment plant): City of Davis, City of Woodland, City of Winters, Esparto CSD, Madison CSD, UCD, Capay and Monument Hills. This includes water used for landscape irrigation within these demands.
YCFC canal recharge	Canal Recharge from the YCFC unlined canals.

Average annual land surface and groundwater budgets are presented in Table 28 and Table 29 respectively.

Key messages on the land surface water budget are similar to those provided for the Basin-wide results in the main body of this report.

- Overall outflows and inflows are in balance for all scenarios.
- The Future_Baseline scenario differs from Historical due to the land use effect of increased perennial acreage. The main effects of this are:
    - An increase in ET.
    - Surface water supply is higher in Projected_Baseline than Historical, because of more surface water availability such as through Indian Valley reservoir, and the recent Woodland Davis Clean Water project.
    - Decrease in Deep Percolation and Surface Runoff, due to an overall increase in irrigation efficiency.
- The four climate scenarios show that:
    - Deep Percolation follows the pattern of precipitation, with the highest Deep Percolation in the wettest scenario (Future_2070_WMW) and the least in the driest scenario (Future_2070_DEW).
    - Similarly, Surface water supply for irrigation is largest in the wettest scenario (Future_2070_WMW) and lowest in the extreme dry scenario (Future_2070_DEW).

Table 28. Average Annual Land Surface Water Budget: Central Yolo Subregion.

Historical Average Annual Land Surface Water Budget (TAF)														
	Outflows							Inflows						
	Evapotranspiration	Deep Percolation	Surface Runoff	Urban Consumption	YCFC Canal Recharge	Treated WW Outflow	Total Outflows	Precipitation	Pumping: Urban	Pumping: Irrigation	SW Supply: Urban	SW Supply: Irrigation	Tailwater Reuse: Irrigation	Total Inflows
Central Yolo														
Historical	-493	-169	-229	-12	-32	-8	-944	477	29	209	1	225	3	944
Future_Baseline	-514	-147	-215	-13	-36	-9	-933	477	14	187	17	235	3	933
Future_2030	-529	-151	-231	-13	-38	-9	-970	500	13	189	18	248	3	971
Future_2070	-541	-159	-255	-13	-39	-9	-1,016	526	13	200	19	255	3	1,016
Future_2070_DEW	-545	-153	-271	-13	-36	-9	-1,025	518	14	231	18	242	2	1,025
Future_2070_WMW	-532	-183	-334	-13	-41	-9	-1,112	635	12	177	20	265	3	1,112

Notes: Evapotranspiration is dominated by crop ET, evaporation from ponds is minor.

Table 29. Average annual groundwater budget for Central Yolo MA.

Historical Average Annual Groundwater Budget (TAF)											
	Outflows			Varying Flows				Inflows			
	Pumping: Urban	Pumping: Irrigation	Total Outflows	GW-SW Exchange	Lateral GW Flow: Outside Yolo subbasin	Lateral GW Flow	Total Varying Flows	Deep Percolation	YCFC Canal Recharge	Managed aquifer recharge: Woodland	Total Inflows
Central Yolo											
Historical	-28.6	-209	-238	40	-17	12	35	169	32	0	202
Future_Baseline	-14.1	-187	-201	43	-27	-1	15	147	36	1	185
Future_2030	-13.1	-189	-202	41	-28	-2	11	151	38	1	191
Future_2070	-12.8	-200	-213	42	-28	0	13	159	39	1	199
Future_2070_DEW	-13.5	-231	-245	59	-9	2	52	153	36	1	189
Future_2070_WMW	-11.8	-177	-189	9	-51	8	-34	183	41	1	226

Notes: GW-SW Exchange is positive in Cache Creek (30 TAF), Putah Creek (15 TAF), and negative with the Yolo Bypass (4.5 TAF); Lateral GW flow is positive (incoming) from South Yolo (10 TAF), Dunnigan Hills (8.9 TAF) and Capay Valley (0.7 TAF); and negative (outflow) to North Yolo (7 TAF). Lateral flow outside the basin is towards Solano subbasin (17 TAF).

Figure 20. Groundwater storage in Central Yolo, all scenarios.

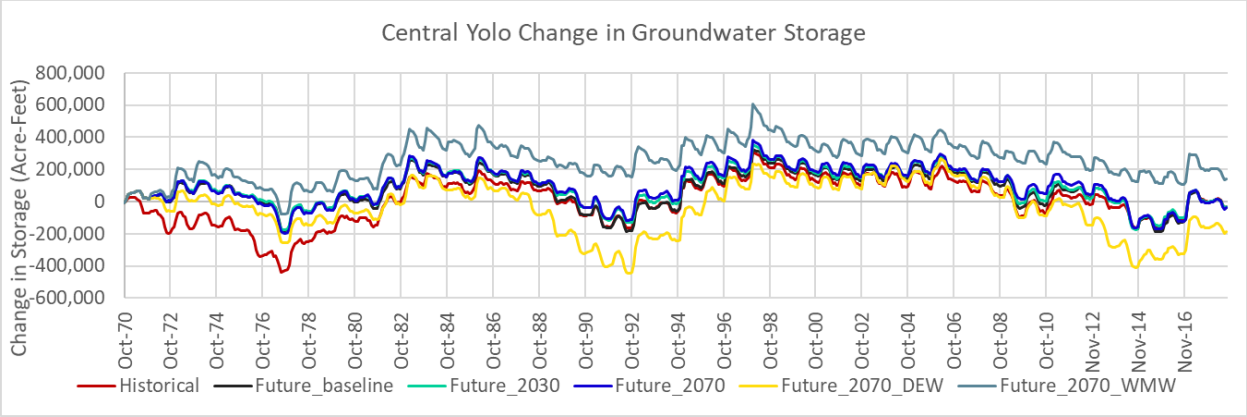


Table 29 and Figure 20 present the groundwater budget and storage change for all scenarios.

Key messages on the groundwater budget are:

- Historically, similar to the Basin-wide narrative, groundwater is depleted from storage in dry years, and recovers in wet years. At the end of the historical period of 48 years, groundwater storage is estimated to be 30 TAF below the start. The overall trace suggests that this MA has not been overdrafted in the past nearly five decades.
- Drought years like 1976-1977 would not result in as severe a depletion as they did in the past, primarily because of increased surface water availability (e.g., Indian Valley Reservoir surface water) and to some extent by overall increased irrigation efficiencies.
- Compared to the overall range of groundwater storage, there is not much difference between the Future_Baseline, and the Future_2030, Future_2070 scenarios.
- The greatest decrease in groundwater storage is in the extreme dry scenario (Future_DEW) when groundwater storage by the end of the 48-year simulation falls to almost 188 TAF below initial conditions.
- In contrast, in the extreme wet scenario, groundwater storage climbs to about 142 TAF above initial conditions.

Annual time series of the land surface and groundwater budgets for the Historical simulation are presented below in Figure 21 and Figure 22, respectively.

Figure 21. Annual Land Surface Water Budget for Central Yolo Subregion (WY 1971 – WY 2018).

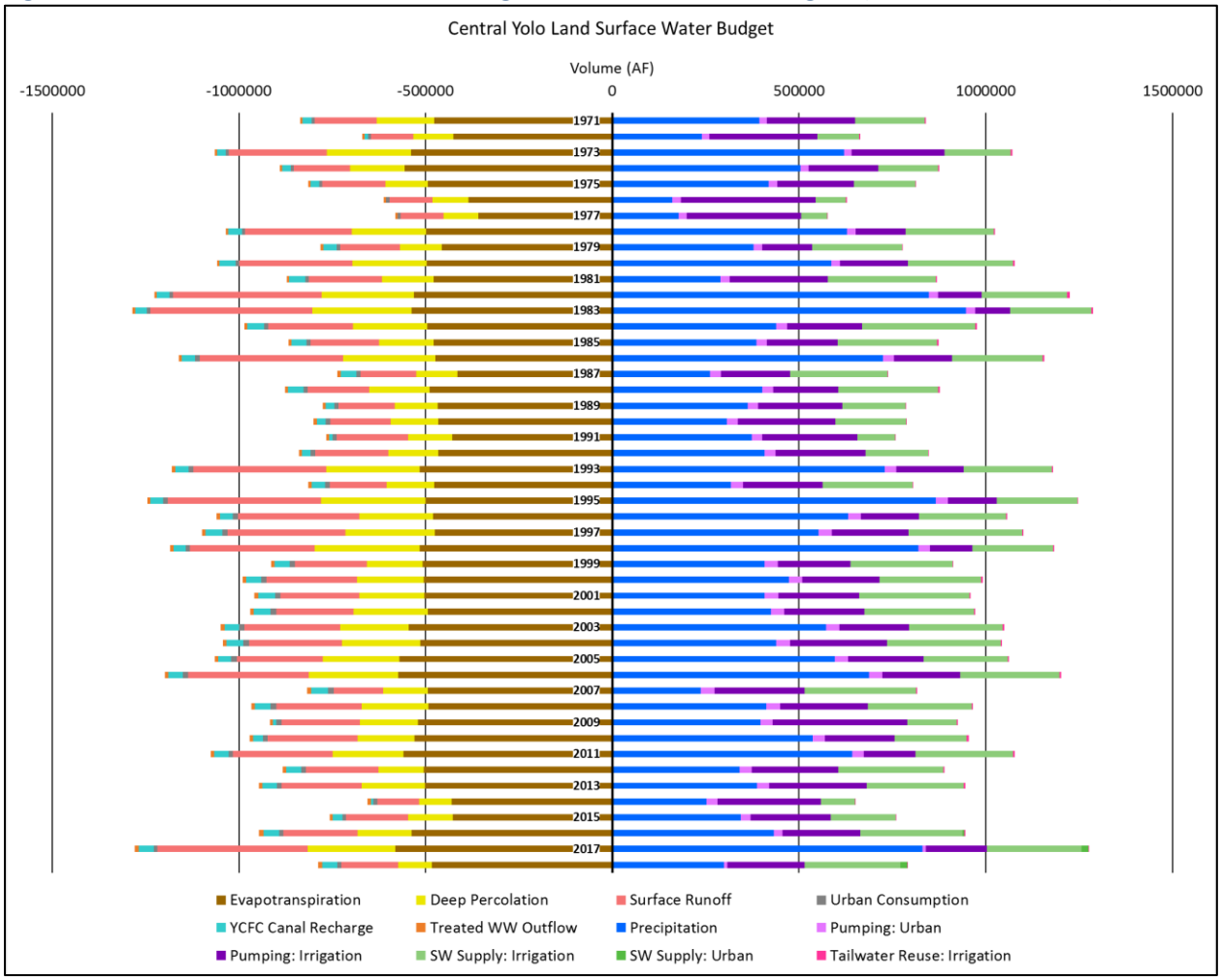
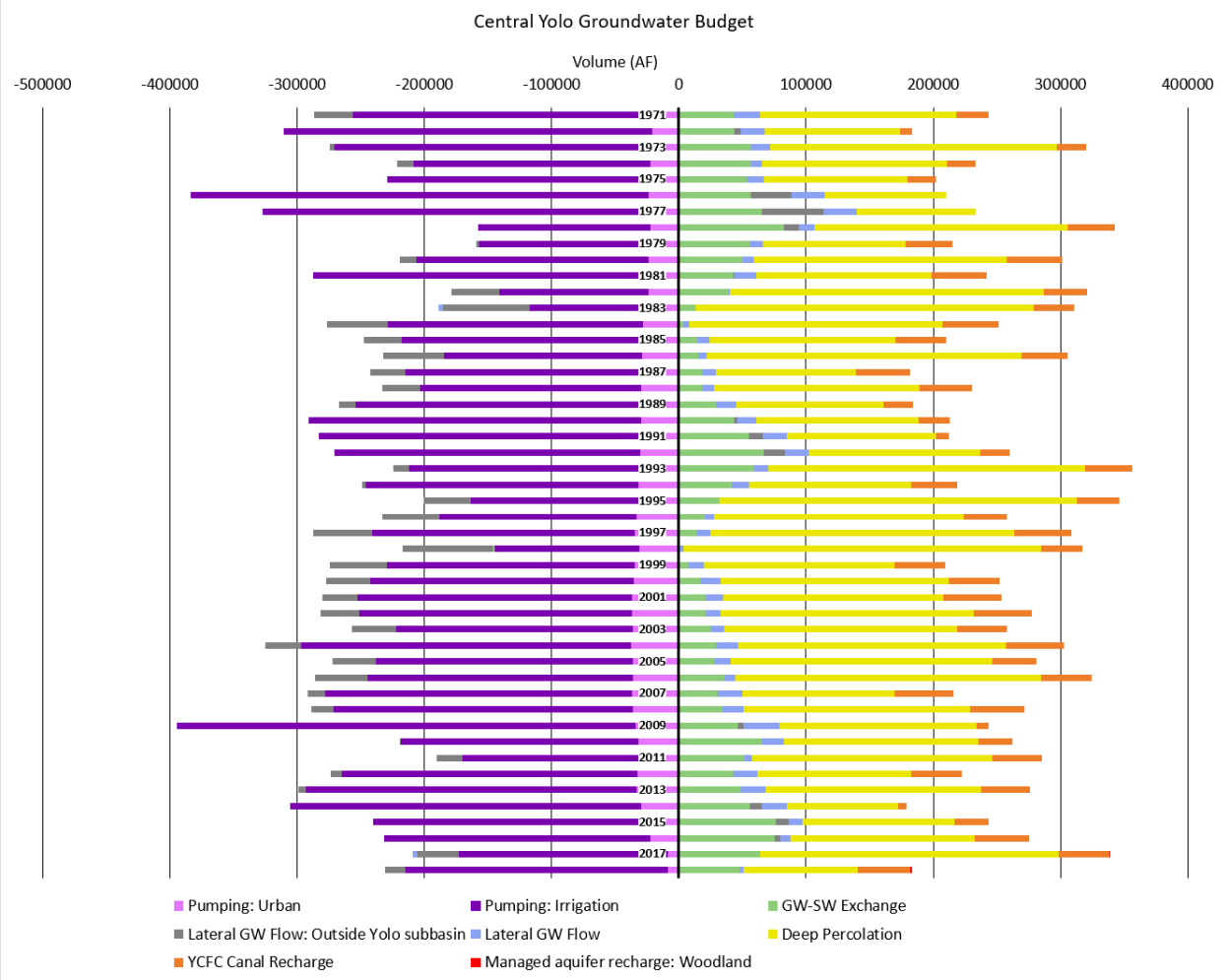


Figure 22. Annual Groundwater Budget for Central Yolo MA.



1.7. Clarksburg Management Area[12]

1.7.1. Description

Clarksburg Management Area covers 36,500 acres in the southeast corner of Yolo County, between the shipping channel to the west and the Sacramento River to the east (See Figure 4). It is almost entirely agricultural and includes the areas of several reclamation districts, namely RD 150, RD 307, RD 765, and most of RD 999.

This MA is within the floodplain of the Sacramento River, with generally poorly drained lands. Field and truck crops dominate; although in the past two decades, vineyard acreage has increased.

The YSGA model (the MODFLOW portion) estimates the storage capacity of this area to be 678 TAF.

Cultivation in this MA is marked by significant and increasing acreage in vineyards. Field crops, winter grain, pasture, and some acreage in truck crops are also present (Table 30).

Table 30. Land Use for Clarksburg MA.

	Land Use (ac)				Land Use (Percent)			
	1989	1997	2008	2016	1989	1997	2008	2016
Clarksburg Management Area	**36,500**	**36,500**	**36,500**	**36,500**				
Deciduous	464	646	646	488	1	2	2	1
Field Crops	12,923	13,316	3,646	4,334	35	36	10	12
Grain	5,280	3,591	5,016	3,633	14	10	14	10
Managed Wetlands	0	0	0	0	0	0	0	0
Native Vegetation	5,370	2,725	5,390	7,299	15	7	15	20
Pasture	4,096	6,991	9,914	6,094	11	19	27	17
Rice	0	0	0	0	0	0	0	0
Subtropical	0	0	0	1	0	0	0	0
Truck Crops	5,467	2,586	1,707	1,895	15	7	5	5
Urban	285	285	560	560	1	1	2	2
Vine	1,702	5,447	8,708	11,284	5	15	24	31
Water	913	913	913	913	3	3	3	3

1.7.2. Data sources and Assumptions

Data sources for the historical scenario are described in the Model Documentation Appendix.

1.7.2.1.Future scenarios Assumptions

- Urban water demands:
  - Water demands for the town of Clarksburg are kept constant from the last historical values.
- Agriculture water demands:
  - 2018 land use is held constant into the future.
- Water supply:

[12] Since the Clarksburg subregion boundary in the model is almost matches the official boundary, the description and budgets will refer simply to the Clarksburg MA.

- Boundary conditions of the Sacramento River flow into the County remains the same as in the Historical scenario.
- Surface water supply from the Sacramento River for irrigation is the same in the future simulations as in the last year of the historical simulation, unlimited.
- There are no restrictions on groundwater pumping.

1.7.3. Water Budgets

Table 31. Useful Terms in this section.

Term	Description
Deep percolation	Water that recharges the groundwater aquifer from the overlying catchments within the management area (these are listed in Table 3). This includes water from rain events, inefficiency of irrigation and seepage from septic systems. It is assumed the town of Clarksburg urban demand returns all water that is not consumed to septic systems, therefore, deep percolation.
Drainage	In regions close to the Sacramento River where the water table can be close to the ground surface, surface drains provide a route for the discharge of groundwater into the surface water system. To mimic that process the MODFLOW DRN package was used to place a drainage boundary in this management area in the model when the groundwater table reaches within 4 feet of the ground surface.
Evapotranspiration (ET)	Evaporation from the land surface (soil and urban land cover) and transpiration from vegetation (agriculture and native vegetation) from all catchments within this management area (listed in Table 3).
GW-SW Exchange	Exchange between the Sacramento River and Ship Channel and the aquifer underlying the management area.
Lateral GW Flow	Subsurface groundwater flow between the Clarksburg management area and the South Yolo management area.
Lateral GW Flow: Outside Yolo subbasin	Subsurface groundwater flow between the Clarksburg management area and the Solano and South American subbasins.
Precipitation	Rain falling within the management area boundary.
Pumping: Irrigation	Water sourced from groundwater supplied to agricultural irrigation in the catchments within this management area (these are listed in Table XX)
Pumping: Urban	Water sourced from groundwater supplied to the town of Clarksburg.
Surface Runoff (SRO)	Surface runoff from the land within this management area to the Sacramento River.
SW supply: Irrigation	Water sourced from the Sacramento River supplied to agricultural irrigation in the catchments within this management area (these are listed in Table 3).
Tailwater re-use: Irrigation	Reuse of irrigation tailwater. Reclamation Districts and the North Delta East catchment can reuse 90% of tailwater for irrigation in the model, based on previous work describing reuse in RD108 (Davids Engineering, 2011).
Urban consumption	Water consumed within the town of Clarksburg (not returned to a septic system). This includes water used for landscape irrigation within this demand.

The average annual land surface and groundwater budgets are presented for all scenarios in Table 32 and Table 33, respectively.

Key messages on the land surface water budget:

- Overall outflows and inflows are in balance for all scenarios.
- Future_Baseline vs Historical
  - The overall budget does not show much difference, except for somewhat reduced surface runoff and irrigation supply in the Future Baseline scenario. Both of these are related to the increase in perennial acreage in the form of vineyards, which replaced field and truck crops in this region.
- The four climate scenarios show that:
  - There is not that much variation between the Historical and Future_Baseline scenarios. Surface runoff and deep percolation do increase in the extreme scenario (Future_2070_WMW); and deep percolation is least in the extreme dry scenario (Future_DEW), as would be expected due to variation in precipitation.

Table 32. Average Annual Land Surface Water Budget for Clarksburg MA.

Historical Average Annual Land Surface Water Budget (TAF)										
	Outflows					Inflows				
	Evapotranspiration	Deep Percolation	Surface Runoff	Urban Consumption	Total Outflows	Precipitation	Pumping: Urban	SW Supply: Irrigation	Tailwater Reuse: Irrigation	Total Inflows
Clarksburg										
Historical	-81	-11	-43	-0.3	-135	60	1	74	1	135
Future_Baseline	-81	-11	-35	-0.3	-127	60	1	66	1	127
Future_2030	-84	-11	-38	-0.3	-134	63	1	70	1	134
Future_2070	-87	-11	-42	-0.3	-140	65	1	73	1	140
Future_2070_DEW	-88	-9	-43	-0.3	-140	63	1	76	1	140
Future_2070_WMW	-85	-14	-53	-0.3	-152	81	1	70	0	152

Notes: Surface runoff drains to the Sacramento River; ET is dominated by Crop ET (86%) followed by native vegetation (11%).

The key messages from the groundwater budget (Table 33) and the groundwater storage graphs (Figure 23) are:

- There is not much that substantially differentiates the scenarios from each other.

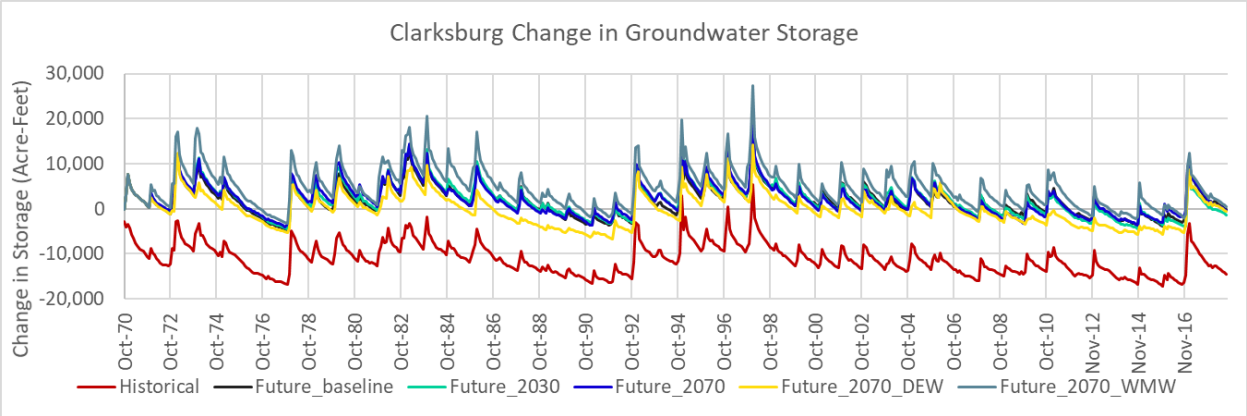
- Although there are few groundwater observations publicly available from this MA, there is general knowledge that water levels are shallow (or groundwater elevations are high) in this MA, and indeed in much of the larger Sacramento River flood plain.
- Given the scarcity of data, uncertainties in groundwater model parameters exist.
- Taken altogether, there is no evidence of overdraft in Clarksburg Management Area.

Table 33. Average annual groundwater budget: Clarksburg MA.

Historical Average Annual Groundwater Budget (TAF)									
	Outflows			Varying Flows				Inflows	
	Pumping: Urban	Drainage	Total Outflows	GW-SW Exchange	Lateral GW Flow: Outside Yolo subbasin	Lateral GW Flow	Total Varying Flows	Deep Percolation	Total Inflows
Clarksburg									
Historical	-0.6	-7	-8	-0.1	-10	6	-4	11	11
Future_Baseline	-0.6	-6	-6	0.0	-10	6	-4	11	11
Future_2030	-0.6	-6	-7	0.0	-10	6	-4	11	11
Future_2070	-0.6	-6	-7	0.0	-10	6	-4	11	11
Future_2070_DEW	-0.6	-5	-5	0.0	-9	5	-4	9	9
Future_2070_WMW	-0.6	-9	-9	-0.1	-11	6	-5	14	14

GW-SW exchange is near-zero because approximately the same amount that seeps in from the Sacramento River into this MA is drained/pumped out into the shipping channel; Lateral flow out of the Yolo Subbasin is to the South American Subbasin (-12.6TAF) and in from the Solano Subbasin (2.6TAF); and lateral inflow from is from South Yolo MA. Drainage represents the outflows from the catchment to the Sacramento River via the modeled drains.

Figure 23. Groundwater storage for Clarksburg MA, all scenarios.



Notes: Each scenario's groundwater storage change time series is relative to its own origin/initial condition. For all the future scenarios, the initial conditions are defined in the model from the end of the historical scenario.

The annual time series, for the historical scenario, of land surface and groundwater budgets are provided in Figure 24 and Figure 25, respectively.

Figure 24. Annual Land Surface Water Budget: Clarksburg MA.

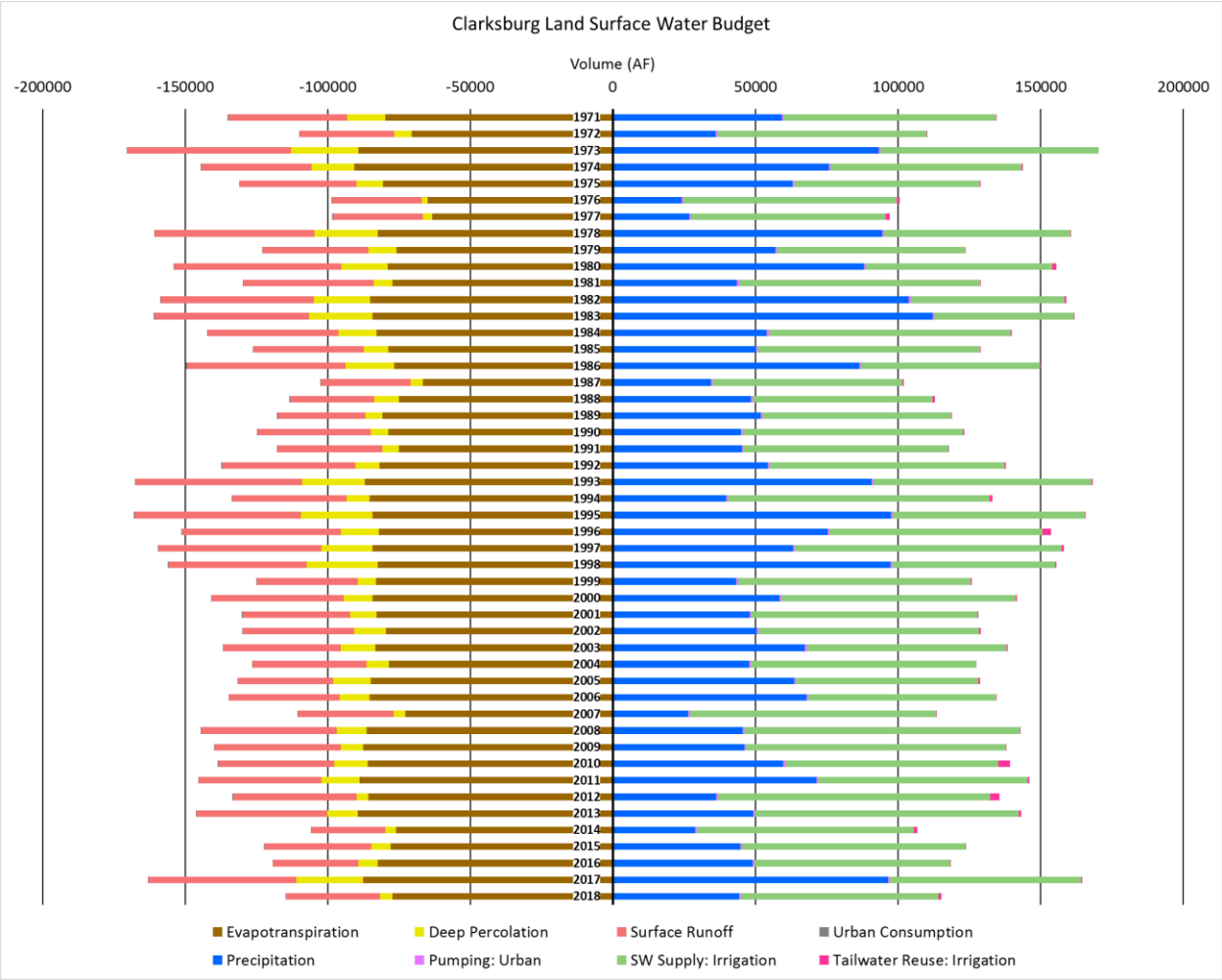
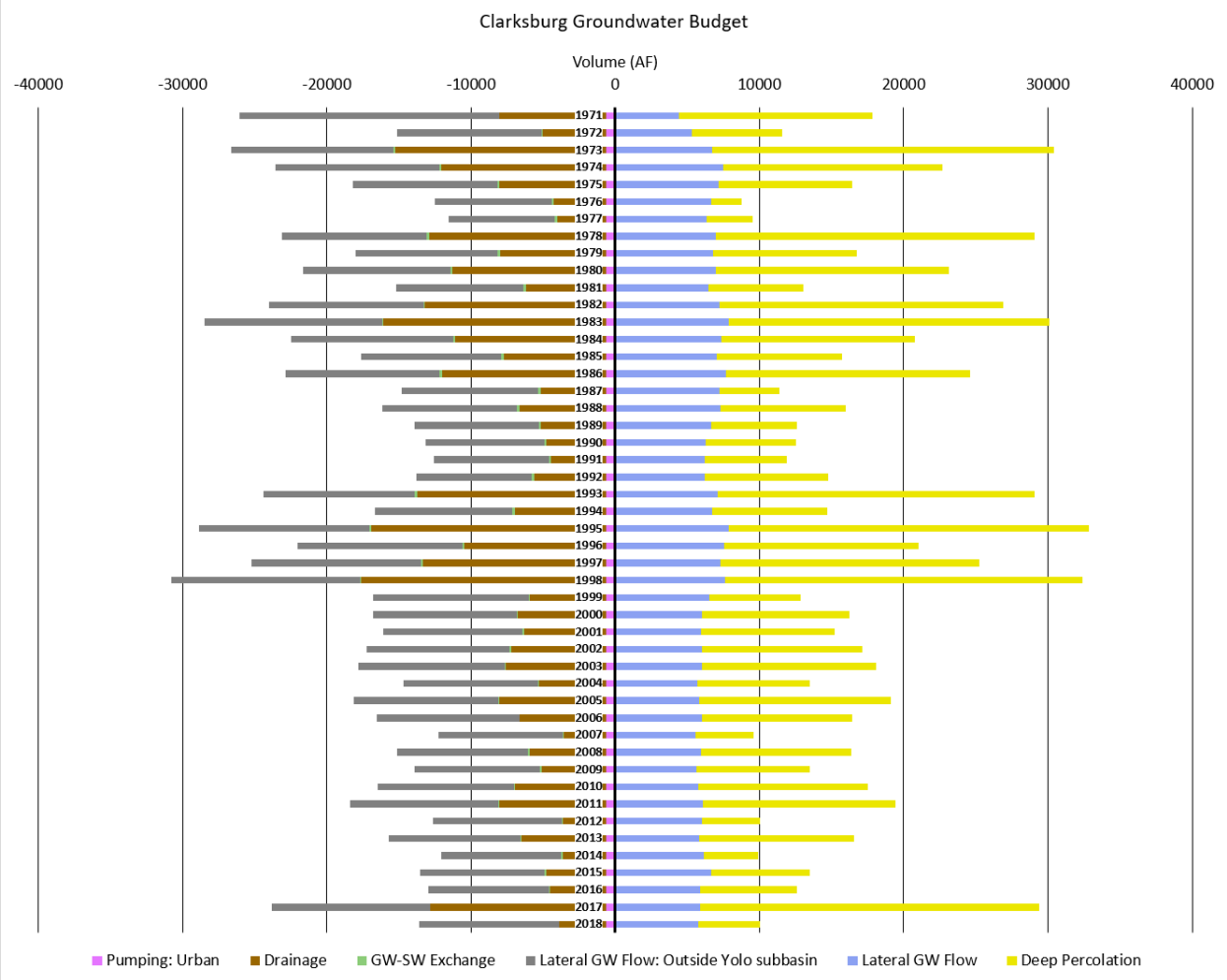


Figure 25. Historical Annual Groundwater Budget: Clarksburg MA.



1.8. Dunnigan Hills Subregion

1.8.1. Description

The Dunnigan Hills Subregion of the model cover 92,345 acres in the northern and western portion of the Yolo Subbasin. Its western boundary includes rangeland in the upper reaches of Bird Creek, Buckeye Creek, and Oat Creek. The northern boundary is the shared boundary with Colusa Subbasin, in the south it skirts around Hungry Hollow, and to the east extends across Dunnigan Hills. That portion of the Region underlain by the alluvial aquifer, constitutes the Dunnigan Hills official MA boundary (Figure 4 and Table 3).

Large areas of this region are not served by surface water. YCFC canals serve a small part, south of Dunnigan Hills (Figure 4 and Table 3).

This region has few monitoring wells. Especially in the northern rangelands in Buckeye and Bird Creeks, little groundwater development has happened, and little data is available. Similarly, there are no YSGA-monitoring wells in Dunnigan Hills proper; the few YSGA-monitoring wells are in the western foothills of Dunnigan Hills. However, groundwater development is active here, especially with rising acreage of orchards in the past decade. The Hills are a doubly plunging anticline; quaternary sediments have been uplifted and folded along the anticline axis, and the underlying Tehama formation is exposed through the Hills (WRIME, 2006) .

Groundwater storage capacity in this area is estimated as 2,775 TAF in the YSGA model; however, much less is known about the stratigraphy in this region of the model domain (WRIME, 2006).

Native vegetation and unirrigated rangeland make up most of this regions land use, mostly in the northern and north-western portions mentioned in the previous paragraphs. Of the cultivated acreage, orchards are significant, with acreage increasing over time (largely replacing annual field crops and also to some extent previously un-irrigated native vegetation) (Table 34).

Table 34. Land Use for Dunnigan Hills Region.

	Land Use (ac)				Land Use (Percent)			
	1989	1997	2008	2016	1989	1997	2008	2016
Dunnigan Hills Management Area	**92,345**	**92,345**	**92,345**	**92,345**				
Deciduous	1,705	1,570	3,602	6,575	2	2	4	7
Field Crops	1,116	1,117	1,121	492	1	1	1	1
Grain	6,629	3,521	2,219	1,634	7	4	2	2
Managed Wetlands	0	0	0	0	0	0	0	0
Native Vegetation	80,365	80,622	79,372	74,636	87	87	86	81
Pasture	771	830	744	77	1	1	1	0
Rice	0	0	0	20	0	0	0	0
Subtropical	0	49	711	2,472	0	0	1	3
Truck Crops	538	897	325	323	1	1	0	0
Urban	546	546	578	578	1	1	1	1
Vine	550	3,068	3,548	5,414	1	3	4	6
Water	125	125	125	125	0	0	0	0

Source: DWR Land and Water Use Surveys

1.8.2. Data sources and assumptions

Data sources for the historical scenario are described in the Model Documentation Appendix.

1.8.2.1.Future scenarios Assumptions

- Urban water demands:
  - There are no urban demands represented in this MA.
- Agriculture water demands:
  - 2018 land use is held constant into the future.
- Water supply:
  - Since the climate and hydrology of the Cache Creek watershed is modeled, in future simulations, flows in Cache Creek reflect the climate scenario.
  - Clear Lake and Indian Valley Reservoir operating rules remain the same in the future simulations as in the Historical.
  - YCFC operating rules remain the same in the future simulations as in the last year of the historical simulation.
  - Boundary conditions of all other surface water bodies flowing into the County remain the same as in the historical.
  - All other surface water rights remain the same in the future simulations as in the last year of the Historical simulation.
  - There are no restrictions on groundwater pumping.

1.8.3. Water budgets

Table 35. Useful terms in this section.

Term	Description
Deep percolation	Water that recharges the groundwater aquifer from the overlying catchments within the management area (these are listed in Table 3). This includes water from rain events and inefficiency of irrigation.
Evapotranspiration (ET)	Evaporation from the land surface (soil and urban land cover) and transpiration from vegetation (agriculture and native vegetation) from all catchments within this management area (listed in Table 3).
GW-SW Exchange	Exchange between Cache Creek and the aquifer underlying the management area.
Lateral GW Flow	Subsurface groundwater flow between the Dunnigan Hills management area and the neighboring management areas: Central Yolo and North Yolo.
Lateral GW Flow: Outside Yolo subbasin	Subsurface groundwater flow between the Dunnigan Hills management area and the Colusa subbasin
Precipitation	Rain falling within the boundary.
Pumping: Irrigation	Water sourced from groundwater supplied to agricultural irrigation in the catchments within this management area (these are listed in Table XX)

Term	Description
Surface Runoff (SRO)	Surface runoff from the land within this management area to Cache Creek and the Colusa Basin Drain.
SW supply: Irrigation	Water sourced from the Cache Creek via YCFC canals supplied to agricultural irrigation in the catchments within this management area (these are listed in Table 3).
SW supply: Urban	Not applicable as no urban demands are represented in this management area in the model.
Tailwater re-use: Irrigation	Not applicable as tailwater is not available for reuse to any catchments in this management area.
YCFC canal recharge	Canal Recharge from the YCFC unlined canals.

The average annual land surface and groundwater budgets are presented for all scenarios in Table 36 and Table 37, respectively.

Key messages on the land surface water budget:

- Overall outflows and inflows are in balance for all scenarios.
- Future_Baseline vs Historical
    - Irrigation and ET increase substantively in the Future Baseline scenario as a result of increased perennial orchard acreage in the Dunnigan Hills portion of this MA. This pattern seems important to consider since there is hardly any groundwater usage in other parts of the MA.
- The four climate scenarios show that:
    - There is not much variation between them and the Projected_Baseline scenarios, except in the extreme wet (Future_2070_WMW) scenario in which Deep Percolation and Surface Runoff do substantially increase.

Table 36. Average Annual Land Surface Water Budget: Dunnigan Hills Subregion.

Historical Average Annual Land Surface Water Budget (TAF)									
	Outflows					Inflows			
	Evapotranspiration	Deep Percolation	Surface Runoff	YCFC Canal Recharge	Total Outflows	Precipitation	Pumping: Irrigation	SW Supply: Irrigation	Total Inflows
Dunnigan Hills									
Historical	-114	-57	-7	-1	-179	154	18	7	179
Future_Baseline	-129	-58	-7	-1	-195	154	30	11	195
Future_2030	-133	-62	-7	-1	-204	161	31	12	204
Future_2070	-135	-69	-8	-1	-214	169	33	12	213
Future_2070_DEW	-132	-67	-9	-1	-209	163	35	11	209
Future_2070_WMW	-133	-102	-12	-1	-248	206	31	12	248

Notes: Surface runoff drains to Cache Creek (2.4 TAF AF) and the Colusa Basin Drain (4.8TAF); ET is dominated by native vegetation, however, crop ET grows from 17% to 34% of the total during the Historical simulation.

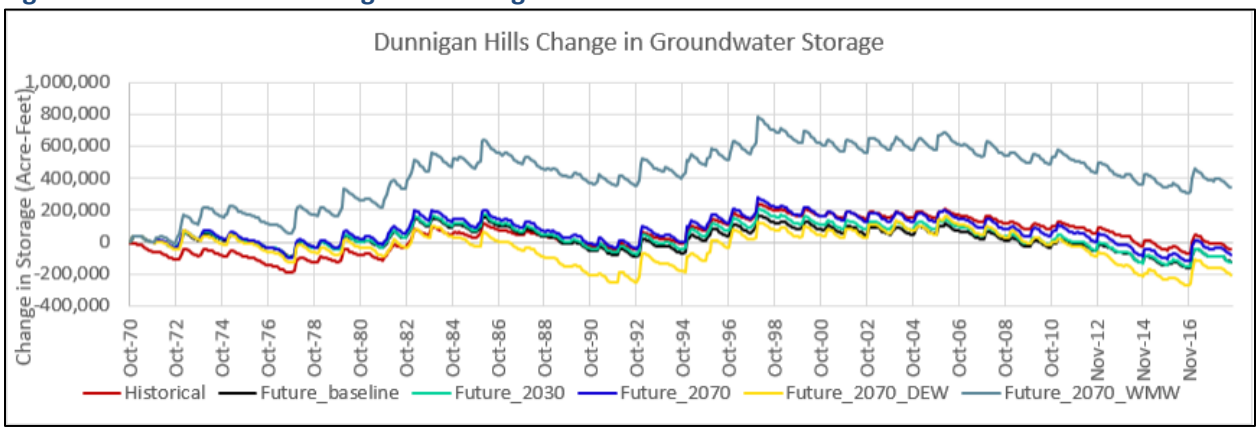
- The key messages from the groundwater budget (Table 37) and the groundwater storage graphs (Figure 26) are: Historically, similar to the Basin-wide narrative, groundwater is depleted from storage in dry years, and recovers in wet years. At the end of the historical period of 48 years, groundwater storage is estimated to be 48 TAF below the start. The overall trace suggests that this MA, as a whole, has not been overdrafted in the past nearly five decades, because it recovered in wet periods. However, within this MA:
    - The Dunnigan Hills portion of this MA shows some evidence of a gradual decline in water levels, based on the limited observations available here. More monitoring and possible projects may be required here.
    - Also, there are no known groundwater observations in the northern and northwestern rangelands of Buckeye Creek and Bird Creek. Hence, the model uncertainty is high here. New monitoring is recommended in this portion.
- Drought years like the 1976-1977 would not result in as severe a depletion as they did in the past, primarily because of increased surface water availability (e.g., Indian Valley Reservoir surface water) and to some extent by overall increased irrigation efficiencies.
- Compared to the overall range of groundwater storage, there is not much difference among the Future_Baseline, Future_2030, and Future_2070 scenarios.
- The greatest decrease in ground water storage is in the extreme dry scenario (Future_DEW) when groundwater storage by the end of the 48-year simulation falls to almost 204 TAF below initial conditions.
- In contrast, in the extreme wet scenario, groundwater storage climbs to about 342 TAF above initial conditions. This is the only scenario in which groundwater storage increases.

Table 37. Average Annual Groundwater Budgets: Dunnigan Hills MA.

Historical Average Annual Groundwater Budget (TAF)									
	Outflows		Varying Flows				Inflows		
	Pumping: Irrigation	Total Outflows	GW-SW Exchange	Lateral GW Flow: Outside Yolo subbasin	Lateral GW Flow	Total Varying Flows	Deep Percolation	YCFC Canal Recharge	Total Inflows
Dunnigan Hills									
Historical	-18	-18	-0.1	-9	-31	-41	57	1	58
Future_Baseline	-30	-30	0.0	-8	-24	-31	58	1	59
Future_2030	-31	-31	0.0	-8	-27	-35	62	1	63
Future_2070	-33	-33	0.1	-9	-31	-39	69	1	70
Future_2070_DEW	-35	-35	0.2	-8	-30	-37	67	1	68
Future_2070_WMW	-31	-31	-0.4	-19	-46	-66	102	1	103

Notes: GW-SW exchange with Cache Creek is minimal (<100 AF) in this MA; Lateral groundwater flow to outside of the Yolo Subbasin is to Colusa Subbasin. Lateral groundwater outflow is to Central Yolo MA (9TAF) and North Yolo MA (22.5 TAF).

Figure 26. Groundwater storage for Dunnigan Hills MA.



The annual time series, for the historical scenario, of land surface and groundwater budgets are provided in Figure 27 and Figure 28, respectively.

Figure 27. Annual Land Surface Water Budget: Dunnigan Hills.

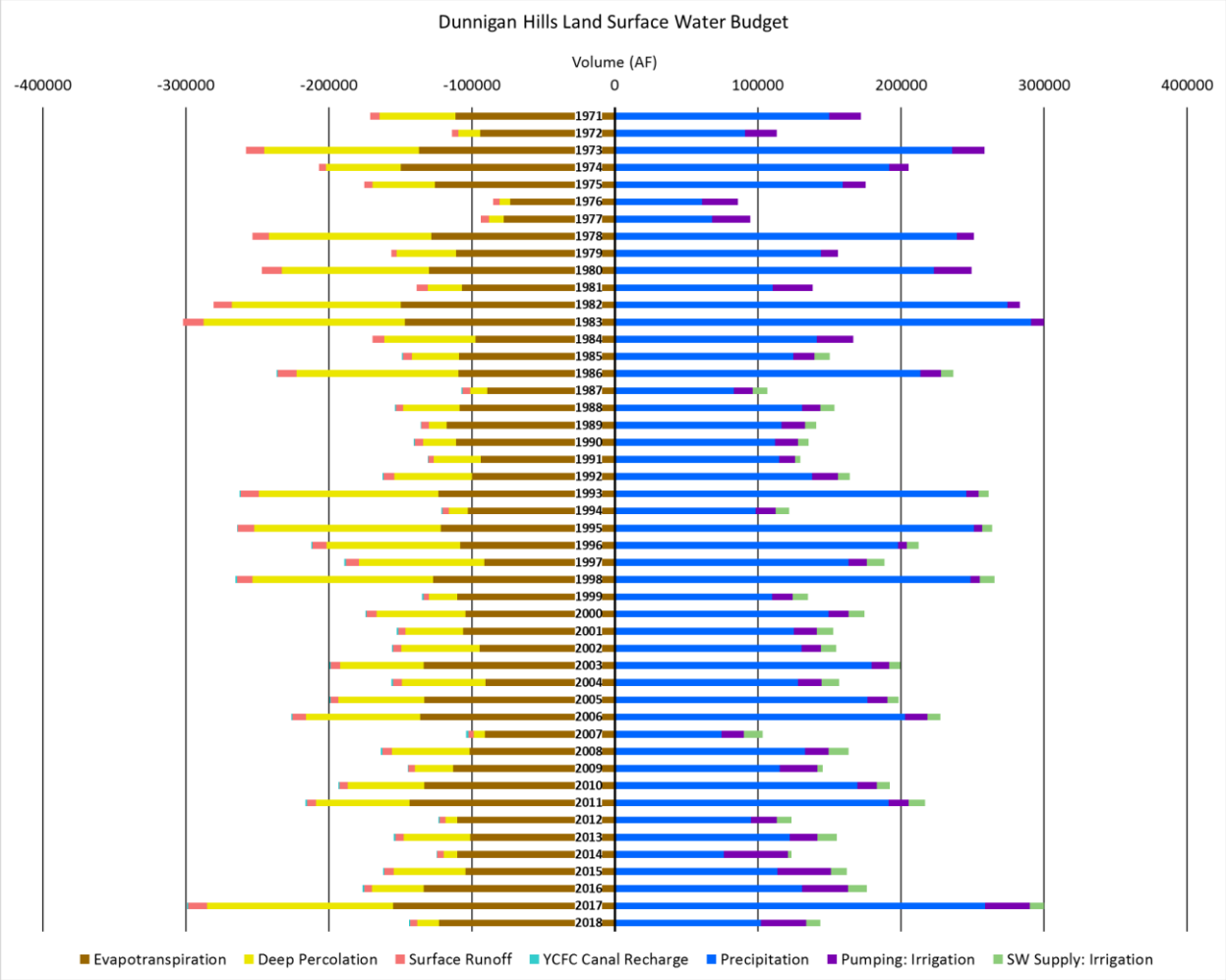
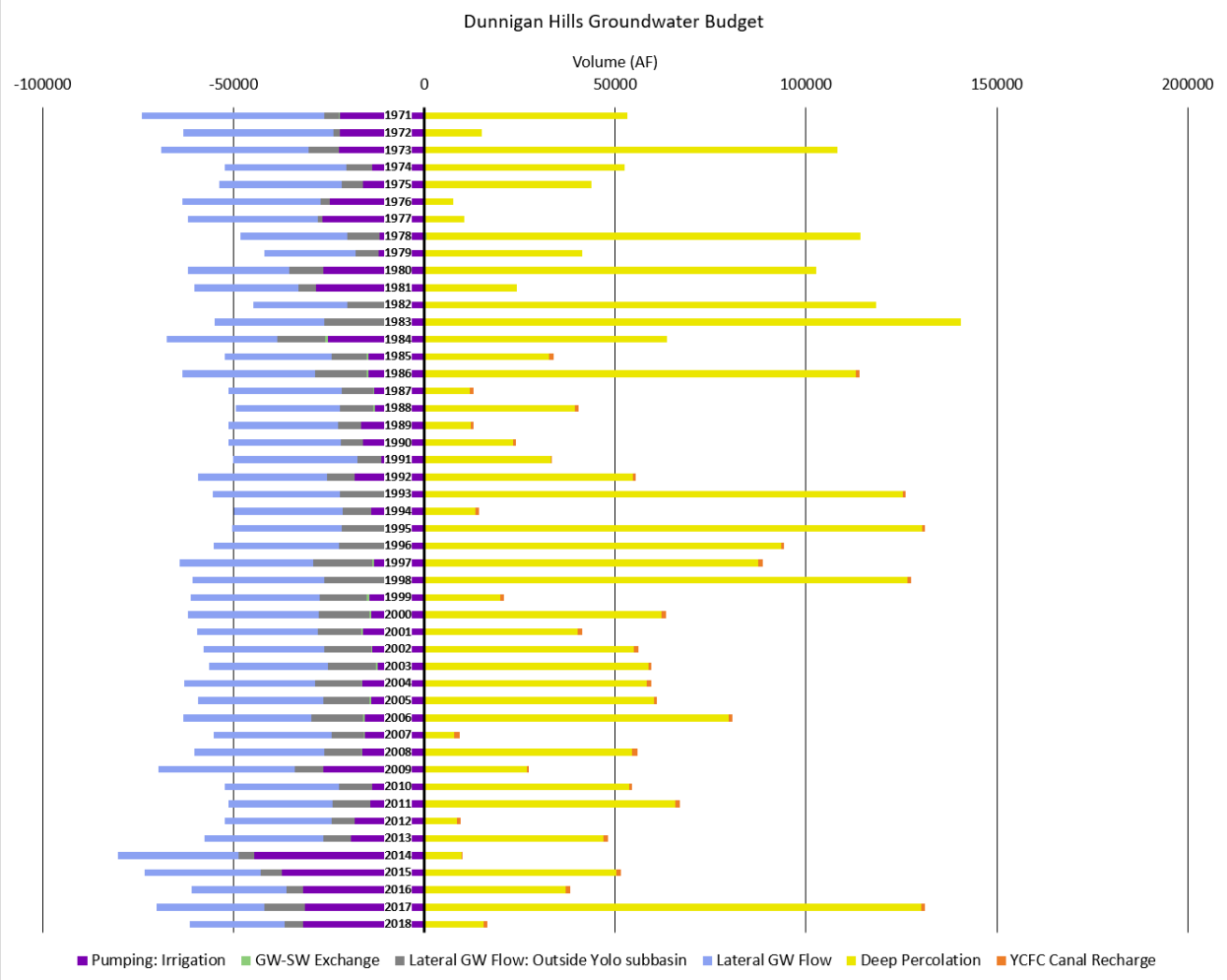


Figure 28. Annual Groundwater Budget: Dunnigan Hills MA.



1.9. North Yolo Management Area[13]

1.9.1. Description

The North Yolo MA is 103,770 acres and borders the Colusa subbasin to the north, the Sacramento River to the east, the edge of Dunnigan Hills MA to the west and the Central Yolo MA boundary to the south (Figure 4). This MA includes several entities, including Dunnigan Water District, Cacheville and Knights Landing CSD's, RD 108, RD 730, and RD 787 (See Table 3).

). This MA also include several white areas, particularly along the Colusa Basin Drain (called "CBD North" and "CBD South" in the model) and in the Yolo-Zamora area (called "Yolo Zamora North" and "Yolo Zamora South" in the model (See Table 3 and Figure 4).

Surface water is supplied to much of the area from the Sacramento River, Colusa Basin Drain, and Tehama Colusa Canal, with a small portion of land near Zamora being served by YCFC as well. Surface water availability varies widely in this MA, with abundant Sacramento River water available to the Reclamation Districts and no surface water supplies currently available to Yolo Zamora North and South.

Groundwater storage capacity of this area in the YSGA model is estimated as 1,611 TAF. Agricultural land use is diverse, with substantial rice cultivation along with truck crops and field crops (Table 38). Deciduous orchard acreage has been increasing considerably (Table 38).

Table 38. Land Use for North Yolo MA.

	Land Use (ac)				Land Use (Percent)			
	1989	1997	2008	2016	1989	1997	2008	2016
North Yolo Management Area	**103,770**	**103,770**	**103,770**	**103,770**				
Deciduous	2,124	2,265	7,597	15,622	2	2	7	15
Field Crops	23,254	27,016	10,336	14,500	22	26	10	14
Grain	14,647	13,045	11,700	5,799	14	13	11	6
Managed Wetlands	0	0	0	0	0	0	0	0
Native Vegetation	18,882	16,596	22,684	22,576	18	16	22	22
Pasture	9,970	4,564	8,565	5,686	10	4	8	5
Rice	12,711	13,452	18,550	18,295	12	13	18	18
Subtropical	0	0	0	106	0	0	0	0
Truck Crops	19,412	23,768	21,095	17,773	19	23	20	17
Urban	1,772	1,738	1,860	1,860	2	2	2	2
Vine	49	376	384	553	0	0	0	1
Water	950	950	1,000	1,000	1	1	1	1

Source: DWR Land and Water Use Surveys

[13] Since the subregion boundary in the model closely the official boundary, the description and budgets will refer simply to the MA.

1.9.2. Data sources and assumptions

Data sources for the historical scenario are in the Model Documentation Appendix.

1.9.2.1.Future scenarios Assumptions

In addition to the future scenario conditions and assumptions explained in Section 1.2, we made assumptions specific to this MA regarding the growth of demands, and the operations and availability of water supply, which were applied across all future scenarios.

- Urban water demands:
  - Water demands for Cacheville CSD, Knights Landing CSD, the town of Zamora and domestic wells within the Dunnigan Water District area remain constant from the most current year.
- Agriculture water demands:
  - 2018 land use is held constant into the future.
- Water supply:
  - Boundary conditions of all surface water bodies flowing into the County remain the same as in the historical simulation.
  - There are no restrictions on groundwater pumping.
  - It is assumed that Dunnigan Water District has their full water right available in the future scenarios (19 TAF), in all years except where water rights are reduced based on water allocations.
  - All other surface water rights remain the same in the future simulations as in the last year of the historical simulation with limitations based on Shasta Critical Years, Project Water allocations, and Term 91, where applicable.

1.9.3. Water Budgets

Table 39. Useful terms in this section.

Term	Description
Deep percolation	Water that recharges the groundwater aquifer from the overlying catchments within the management area (these are listed in Table 3). This includes water from rain events, inefficiency of irrigation and seepage from septic systems (Cacheville CSD, the town of Zamora and domestic wells within the Dunnigan Water District area) and wastewater treatment ponds (these occur in Knights Landing CSD).
Drainage	In regions close to the Sacramento River where the water table can be close to the ground surface, surface drains provide a route for the discharge of groundwater into the surface water system. To mimic that process the MODFLOW DRN package was used to place a drainage boundary in reclamation districts 108, 730 and 787 in the model when the groundwater table reaches within 4 feet of the ground surface.
Evapotranspiration (ET)	Evaporation from the land surface (soil and urban land cover) and transpiration from vegetation (agriculture and native vegetation) from all catchments within this management area (listed in Table 3) as well as evaporation from wastewater treatment ponds (these occur in Knights Landing CSD)
GW-SW Exchange	Exchange between Cache Creek, the Colusa Basin Drain, Sacramento River, Yolo Bypass, Knights Landing Ridge Cut and the aquifer underlying the management area.

Term	Description
Lateral GW Flow	Subsurface groundwater flow between the North Yolo management area and the neighboring management areas: Central Yolo, Dunnigan Hills and South Yolo.
Lateral GW Flow: Outside Yolo subbasin	Subsurface groundwater flow between the North Yolo management area and the Colusa and Sutter subbasins.
Precipitation	Rain falling within the boundary.
Pumping: Irrigation	Water sourced from groundwater supplied to agricultural irrigation in the catchments within this management area (these are listed in Table 3)
Pumping: Urban	Water sourced from groundwater supplied to the urban demands within this management area: Cacheville CSD, Knights Landing CSD, the town of Zamora and domestic wells within the Dunnigan Water District area.
Surface Runoff (SRO)	Surface runoff from the land within this management area to Cache Creek, the Colusa Basin Drain, Sacramento River and Yolo Bypass.
SW supply: Irrigation	Water sourced from the Colusa Basin Drain, Cache Creek via YCFC canals, Sacramento River an Tehema Colusa Canal supplied to agricultural irrigation in the catchments within this management area (these are listed in Table 3).
Tailwater re-use: Irrigation	Reuse of irrigation tailwater. Reclamation Districts and the North Delta East catchment can reuse 90% of tailwater for irrigation in the model, based on previous work describing reuse in RD108 (Davids Engineering, 2011).
Urban consumption	Water consumed within the urban demands in this management area (not returned to a septic system or wastewater treatment plant): Cacheville CSD, Knights Landing CSD, the town of Zamora and domestic wells within the Dunnigan Water District area. This includes water used for landscape irrigation within these demands.

The average annual land surface and groundwater budgets are presented for all scenarios in Table 40 and Table 41, respectively.

Key messages on the land surface water budget inlude:

- Overall outflows and inflows are in balance for all scenarios.
- Future_Baseline vs Historical
    - Irrigation and ET increase as a result of increased perennial orchard and rice acreage.
- The four climate scenarios show that:
    - In the extreme dry scenario (Future_2070_DEW), irrigation demand increases substantially, and ET is also highest.
    - In the extreme wet scenario (Future_2070_WMW) Surface Runoff and Deep Percolation are substantially increased.

Table 40. Average Annual Land Surface Water Budget: North Yolo MA.

Historical Average Annual Land Surface Water Budget (TAF)											
	Outflows					Inflows					
	Evapotranspiration	Deep Percolation	Surface Runoff	Urban Consumption	Total Outflows	Precipitation	Pumping: Urban	Pumping: Irrigation	SW Supply: Irrigation	Tailwater Reuse: Irrigation	Total Inflows
North Yolo											
Historical	-244	-46	-110	-0.3	-399	171	1	62	159	6	399
Future_Baseline	-270	-46	-116	-0.3	-433	171	1	73	181	7	433
Future_2030	-280	-48	-123	-0.3	-451	180	1	86	177	7	451
Future_2070	-289	-48	-132	-0.3	-470	188	1	94	180	7	470
Future_2070_DEW	-296	-45	-136	-0.3	-477	181	1	102	187	6	477
Future_2070_WMW	-283	-55	-165	-0.3	-504	231	1	87	177	8	504

Notes: SRO is to Sacramento River (28 TAF), Cache Creek (10 TAF), Colusa Basin Drain (66TAF), and Yolo Bypass (5.6TAF); SW supply is from the Sacramento River (111 TAF), Colusa Basin Drain (40 TAF), Tehama Colusa Canal (7.8 TAF), and YCFC (0.15T AF).

The key messages from the groundwater budget (Table 41) and the groundwater storage time series Figure 29) are:

- Historically, similar to the Basin-wide narrative, groundwater is depleted from storage in dry years, and recovers in wet years. At the end of the historical period of 48 years, groundwater storage is estimated to be 38 TAF below the start. The overall trace suggests that this MA, as a whole, has not been overdrafted in the past nearly five decades, because it recovered in wet periods. However, within this MA:
    - The Zamora portion of this MA shows some evidence of a gradual decline in water levels, based on the limited observations available here. More monitoring and possible projects may be required here.
- Increased Indian Valley Reservoir surface water is not as impactful here, at least not at the scale of the entire MA (since YCFC's canal system is not currently offering much coverage in the MA).
- The Future_2030, Future_2070 and the extreme dry scenario (Future_2070_DEW) are more impactful in this MA when compared to others, with groundwater storage showing signs of decline in these three respectively:
    - 111 TAF, 143 TAF, and 254 TAF below initial conditions
- Even in the extreme wet scenario, groundwater storage ends below initial conditions (5 TAF).

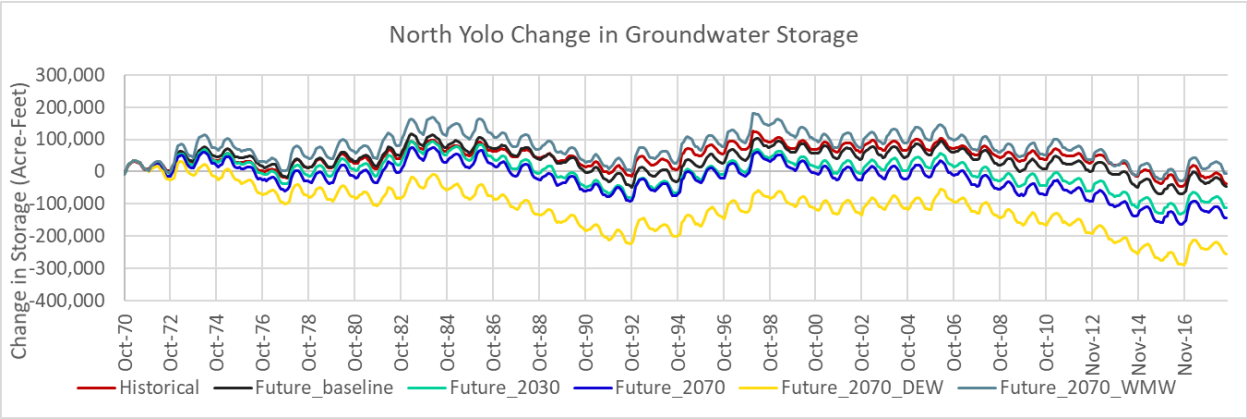
These results suggest that the North Yolo MA will need more attention; however only some parts of it, especially Zamora, may need management actions in the future.

Table 41. Average Annual Groundwater Budget: North Yolo MA.

Historical Average Annual Groundwater Budget (TAF)										
	Outflows				Varying Flows				Inflows	
	Pumping: Urban	Pumping: Irrigation	Drainage	Total Outflows	GW-SW Exchange	Lateral GW Flow: Outside Yolo subbasin	Lateral GW Flow	Total Varying Flows	Deep Percolation	Total Inflows
North Yolo										
Historical	-0.7	-62	-8	-71	-1	-4	29	25	46	46
Future_Baseline	-0.7	-73	-3	-77	-1	-1	31	29	46	46
Future_2030	-0.7	-86	-2	-89	0	5	35	39	48	48
Future_2070	-0.7	-94	-2	-96	0	7	38	45	48	48
Future_2070_DEW	-0.7	-102	-1	-103	3	13	38	53	45	45
Future_2070_WMW	-0.7	-87	-6	-94	-3	0	42	39	55	55

Notes: GW-SW exchange is the net of inflow from Sacramento River (0.7 TAF), Cache Creek (6.5 TAF), and outflow to Knights Landing Ridge Cut (1.5TAF) and Yolo Bypass (6.7 TAF). Lateral GW Flow is the net of inflow from Dunnigan Hills (22.5 TAF), Central Yolo (7.1 TAF), and outflows to South Yolo (0.5 TAF) MA's. Lateral Flow out of the Yolo Subbasin is to the Colusa Subbasin.

Figure 29. Groundwater Storage for North Yolo MA.



Annual time series of the budgets are provided in Figure 30 and Figure 31.

Figure 30. Annual Land Surface Water Budget for North Yolo MA.

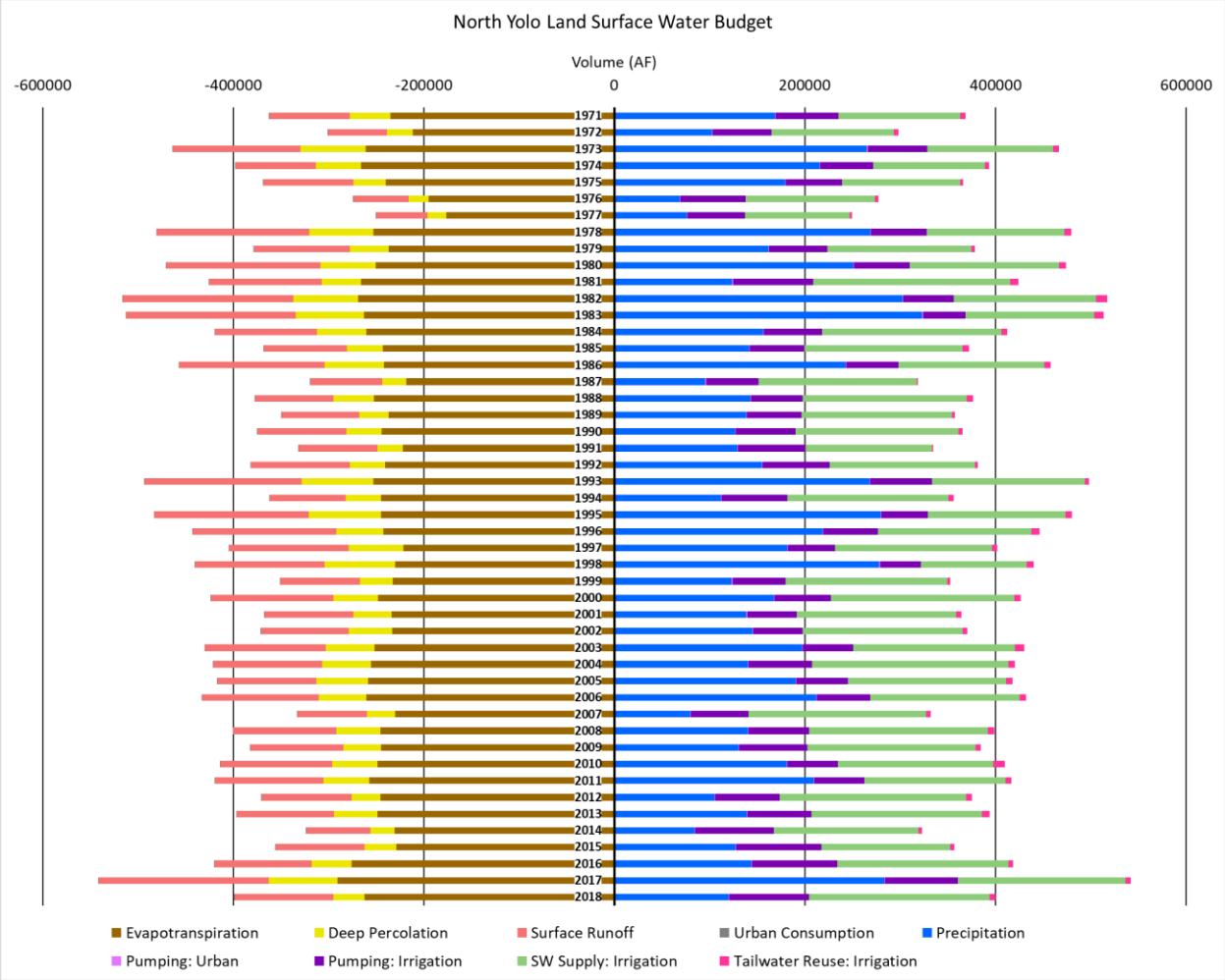
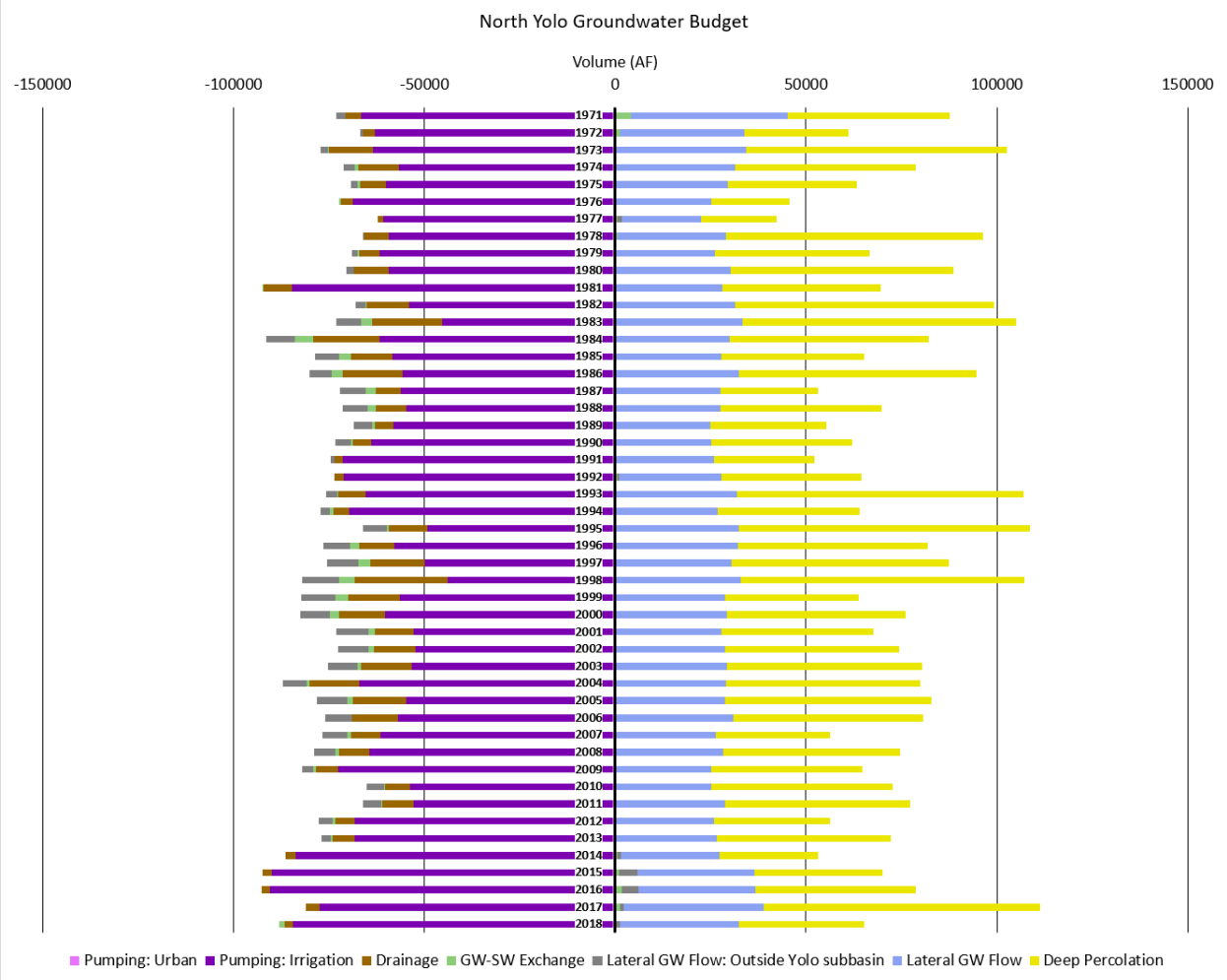


Figure 31. Annual Groundwater Budget for North Yolo MA.



1.10. South Yolo Management Area[14]

1.10.1. Description

The South Yolo MA covers 49,635 acres and lies east of the Central Yolo MA and west of the Sacramento River and the shipping channel. It borders the North Yolo MA in the north (Figure 4). It includes the Yolo Bypass, City of West Sacramento, and Reclamation District 1600, and Reclamation Districts 537, 785, and 827 (which have since been consolidated into RD 537), and part of RD 2068 (See Table 3).

The groundwater storage capacity of this MA is estimated in the YSGA model as 2,100 TAF.

Native vegetation covers about half of this MA, predominantly in the Yolo Bypass. Agriculture is diverse in this MA, with rice, pasture, truck crops, field crops, and orchards present (Table 42).

Table 42. Land Use for South Yolo MA.

	Land Use (ac)				Land Use (Percent)			
	1989	1997	2008	2016	1989	1997	2008	2016
South Yolo Management Area	**78,279**	**78,279**	**78,279**	**78,279**				
Deciduous	2,236	2,688	2,428	3,327	3	3	3	4
Field Crops	24,441	22,171	3,016	4,002	31	28	4	5
Grain	4,049	3,020	5,688	980	5	4	7	1
Managed Wetlands	0	0	0	0	0	0	0	0
Native Vegetation	25,275	28,659	39,579	43,484	32	37	51	56
Pasture	8,879	8,217	11,157	6,249	11	10	14	8
Rice	147	225	3,454	3,432	0	0	4	4
Subtropical	0	0	0	60	0	0	0	0
Truck Crops	4,439	4,121	2,533	4,952	6	5	3	6
Urban	6,926	7,286	8,557	9,883	9	9	11	13
Vine	19	25	0	43	0	0	0	0
Water	1,867	1,867	1,867	1,867	2	2	2	2

Source: DWR Land and Water Use Surveys

1.10.2. Data Sources and Assumptions

Data sources for the historical scenario are described in the Model Documentation Appendix.

1.10.2.1. Future scenarios Assumptions

- City of West Sacramento: For Future scenarios, using last available values for all parameters, except population, which starts at 2019 data value and grows at 2.72%, based on the 2015 UWMP's 20-year planning horizon (this is probably an overestimate if modeling for 50 years). Water use rates remain constant from 2018 values.

[14] Since the subregion boundary in the model closely the official boundary, the description and budgets will refer simply to the MA.

- Agriculture water demands:
    - 2018 land use is held constant into the future.
- Water supply:
    - Boundary conditions of all surface water bodies flowing into the County remain the same as in the historical simulation.
    - There are no restrictions on groundwater pumping.
    - All surface water rights remain the same in the future simulations as in the last year of the historical simulation, with limitations based on Shasta Critical Years, Project Water allocations, and Term 91, where applicable.

1.10.3. Water Budgets

Table 43. Useful terms in this section.

Term	Description
Deep percolation	Water that recharges the groundwater aquifer from the overlying catchments within the management area (these are listed in Table 3). This includes water from rain events and inefficiency of irrigation.
Drainage	In regions close to the Sacramento River where the water table can be close to the ground surface, surface drains provide a route for the discharge of groundwater into the surface water system. To mimic that process the MODFLOW DRN package was used to place a drainage boundary in reclamation district 1600 and North Delta West catchment in the model when the groundwater table reaches within 4 feet of the ground surface.
Evapotranspiration (ET)	Evaporation from the land surface (soil and urban land cover) and transpiration from vegetation (agriculture and native vegetation) from all catchments within this management area (listed in Table 3).
GW-SW Exchange	Exchange between Putah Creek, the Sacramento River, Ship Channel, Willow Slough, Yolo Bypass and the aquifer underlying the management area.
Lateral GW Flow	Subsurface groundwater flow between the South Yolo management area and the neighboring management areas: Central Yolo, North Yolo and Clarksburg.
Lateral GW Flow: Outside Yolo subbasin	Subsurface groundwater flow between the North Yolo management area and the nighborin subbasins: Sutter, North American, South American and Solano subbasins.
Precipitation	Rain falling within the boundary.
Pumping: Irrigation	Water sourced from groundwater supplied to agricultural irrigation in the catchments within this management area (these are listed in Table 3)
Pumping: Urban	Water sourced from groundwater supplied to West Sacramento, in the past.
Surface Runoff (SRO)	Surface runoff from the land within this management area to Putah Creek, the Sacramento River, Willow Slough and the Yolo Bypass.
SW supply: Irrigation	Water sourced from the Sacramento River and the Delta supplied to agricultural irrigation in the catchments within this management area (these are listed in Table 3).
SW supply: Urban	Water sourced from the Sacramento River supplied to West Sacramento.

Term	Description
Tailwater re-use: Irrigation	Reuse of irrigation tailwater. Reclamation Districts and the North Delta East catchment can reuse 90% of tailwater for irrigation in the model, based on previous work describing reuse in RD108 (Davids Engineering, 2011).
Treated WW Outflow	Return flows from the West Sacramento portion of the Sacramento wastewater treatment plant into the Sacramento River.
Urban consumption	Water consumed within West Sacramento. This includes water used for landscape irrigation within these demands.

The average annual land surface and groundwater budgets are presented for all scenarios in Table 44 and Table 45, respectively.

Key messages on the land surface water budget:

- Overall outflows and inflows are in balance for all scenarios.
- Future_Baseline vs Historical:
  - Irrigation and ET are less in the Future_Baseline, largely because of the replacement of agriculture with urban land use and a shift from irrigated agriculture to native vegetation.
  - Urban pumping in this MA is mostly for City West Sacramento, which switched from groundwater to surface water in the 1980's.
- The four climate scenarios show that:
  - There is not much difference compared to the Future_Baseline, except in the extreme wet scenario (Future_2070_WMW), in which there is much more surface runoff and more deep percolation.

Table 44. Annual Average Land Surface Water Budget: South Yolo MA.

Historical Average Annual Land Surface Water Budget (TAF)													
	Outflows						Inflows						
	Evapotranspiration	Deep Percolation	Surface Runoff	Urban Consumption	Treated WW Outflow	Total Outflows	Precipitation	Pumping: Urban	Pumping: Irrigation	SW Supply: Urban	SW Supply: Irrigation	Tailwater Reuse: Irrigation	Total Inflows
South Yolo													
Historical	-160	-45	-51	-5	-4	-266	128	2	8	8	120	0.2	266
Future_Baseline	-145	-25	-46	-9	-8	-232	128	0	1	17	87	0.2	232
Future_2030	-150	-26	-51	-9	-8	-244	135	0	1	17	91	0.3	244
Future_2070	-154	-27	-56	-9	-8	-253	140	0	1	17	95	0.3	253
Future_2070_DEW	-152	-26	-58	-9	-8	-252	135	0	1	17	99	0.3	252
Future_2070_WMW	-154	-30	-82	-9	-8	-283	173	0	1	17	91	0.2	283

Notes: SRO is to the Yolo Bypass (26.5 TAF), Willow Slough (0.3 TAF), Putah Creek (6.6 TAF), and Sacramento River (17.8 TAF). Surface water supply is from the Sacramento River.

The key messages from the groundwater budget (Table 45) and the groundwater storage time series Figure 32) are:

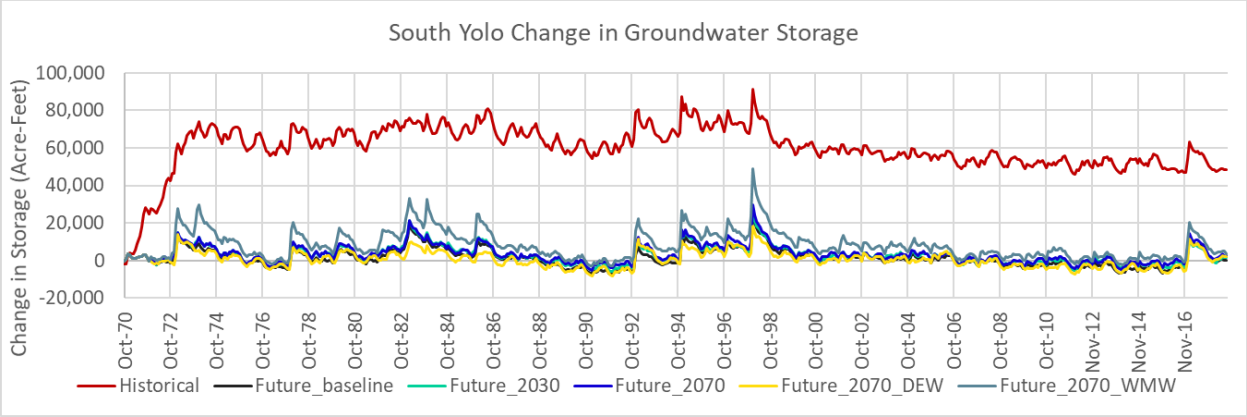
- Historically, there is very little variation in groundwater storage, except in the early years – the simulated increase in groundwater storage mimics an observed change in the observation wells, although the simulated change is more rapid than the observed. This MA has no signs of overdraft historically.
- Future_Baseline vs Historical:
    - The main difference is that urban supply for City of West Sacramento will continue to be entirely surface water.
- The four climate scenarios show little variation, except in the wet scenario (Future_2070_WMW), in which there is more deep percolation. These results suggest that South Yolo MA is not likely to face overdraft in the future scenarios investigated.

Table 45. Annual Average Groundwater Budget for South Yolo MA.

Historical Average Annual Groundwater Budget (TAF)										
	Outflows				Varying Flows				Inflows	
	Pumping: Urban	Pumping: Irrigation	Drainage	Total Outflows	GW-SW Exchange	Lateral GW Flow: Outside Yolo subbasin	Lateral GW Flow	Total Varying Flows	Deep Percolation	Total Inflows
South Yolo										
Historical	-2	-8	-13	-23	-17	12	-16	-21	45	45
Future_Baseline	0	-1	-7	-8	-10	5	-12	-17	25	25
Future_2030	0	-1	-7	-8	-11	4	-11	-17	26	26
Future_2070	0	-1	-8	-9	-11	4	-11	-18	27	27
Future_2070_DEW	0	-1	-7	-8	-10	7	-14	-17	26	26
Future_2070_WMW	0	-1	-9	-11	-13	2	-9	-20	30	30

Notes: GW-SW exchange is into this MA from Sacramento River (0.2 TAF), and out of the MA to the Yolo Bypass (14.6 TAF), Deep Water Ship Channel (1.6 TAF), and Putah Creek (0.6 TAF). Lateral GW flow comes in from North Yolo (0.5 TAF) and flows out to Clarksburg (-6 TAF) and Central Yolo (-10 TAF) MA's. Net annual flow from neighboring basins is inward at 12 TAF. These flows are as follows: Solano (-0.5 TAF), South American (1.9 TAF), and North American (10.1 TAF) Subbasins.

Figure 32. Groundwater Storage for South Yolo MA.



Annual time series of South Yolo MA's land surface and groundwater budgets are provided in Figure 33 and Figure 34.

Figure 33. Annual Land Surface Water Budgets: South Yolo MA.

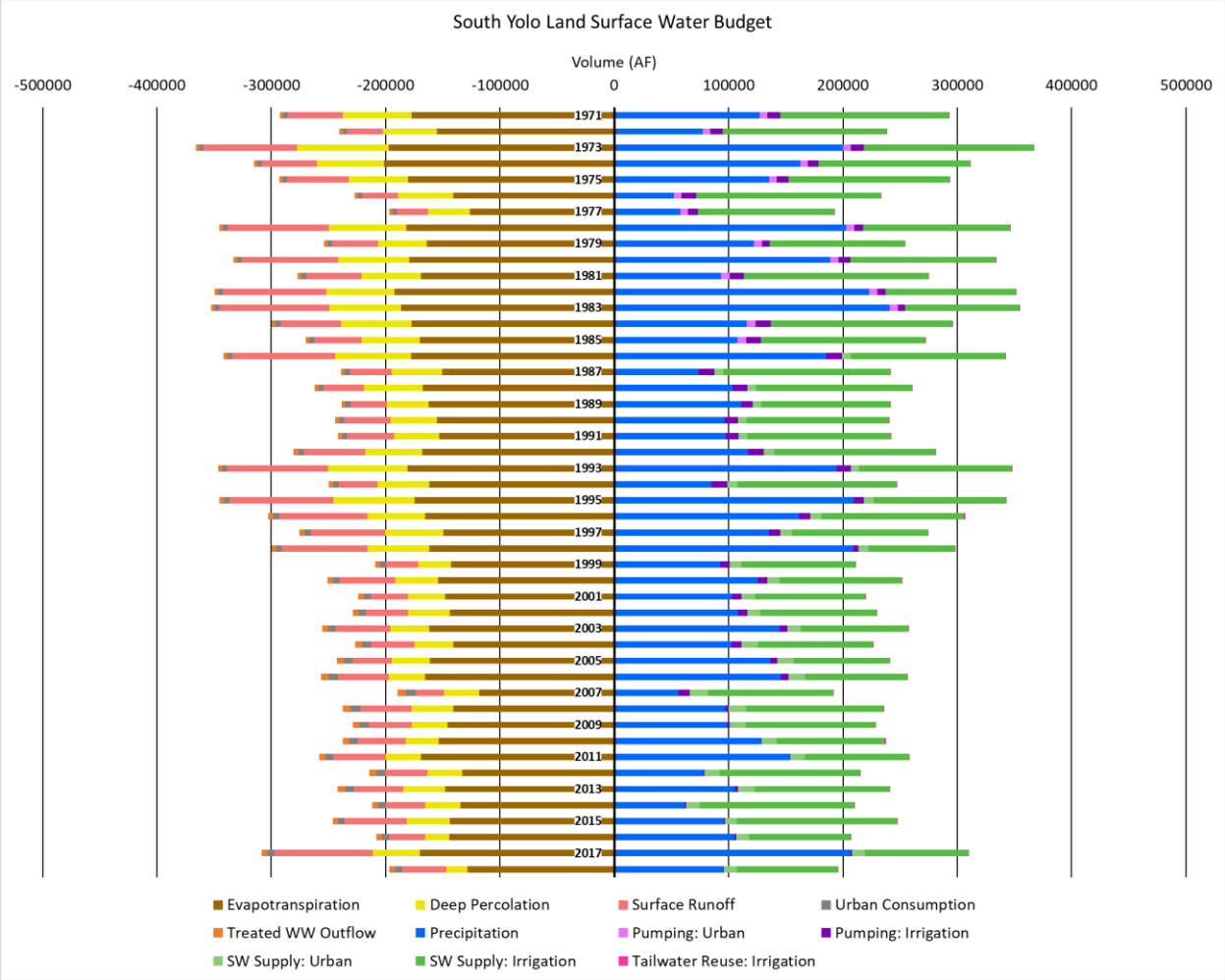


Figure 34. Annual Groundwater Budget: South Yolo MA.