Appendix 2-D Butte Valley Integrated Hydrologic Model (BVIHM) Documentation (2024 Revision)

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Appendix 2-D - Butte Valley Integrated Hydrologic Model (BVIHM) Documentation

1 Introduction and Background

This document is Appendix 2-D, supplemental to Chapter 2 of the Butte Valley Groundwater Sustainability Plan (GSP). The purpose of this appendix is to provide additional documentation on the Butte Valley Integrated Hydrologic Model (BVIHM), which was used to estimate water budget components and predict potential future water use and hydrologic conditions, as required under the

Sustainable Groundwater Management Act (Cal. Water Code, Division 6, Part 2.74). Specifically, objectives of this appendix are to:

1. Document the numerical model development
2. Document the calibration of the model
3. Publish the full tables and figures of annual water budget values, a subset of which have been included in Chapter 2 of the GSP.

The developed ~~Butte Valley Integrated Hydrologic Model (~~BVIHM~~)~~ ~~was developed to~~ calculates historical and projected water budgets~~,~~. It~~o~~ improves understanding of ~~long term~~long-term trends in groundwater levels, and ~~to assess~~ evaluates the impact of climate change, ~~and of~~ projects, and management actions on groundwater conditions. The model extends over the southwestern area of the Upper Klamath Basin defined by Gannett et al., stretching from California into Oregon (Gannett et al. 2007) (Gannett, Wagner, and Lite 2012). The BVIHM ~~model~~ area is bounded by the Klamath River to the north, and the Upper Klamath Basin boundary to the west and south. The eastern boundary of the ~~model~~ area extends a few miles to the east of the ~~actual~~ Butte Valley watershed (see Butte Valley GSP Chapter 2.2.3 for further details on the ~~model~~ area extent). The ~~model~~ area includes not only the entire Butte Valley groundwater basin ~~(“Basin”)~~, but also the entire Butte Valley watershed. The ~~model~~ area extent beyond the Butte Valley watershed honors the continuity of the volcanic groundwater system surrounding the ~~B~~basin with the larger Upper Klamath Basin, Oregon and California~~-~~. Besides the ~~B~~basin, BVIHM includes two other Bulletin 118 groundwater basins (DWR 2016): Red Rock Valley (1-018) and Bray Town Area (1-017). The eastern boundary of the BVIHM partially falls within the southwestern most areas of the Lower Klamath groundwater basin (1-002.02)

The BVIHM is an integrated hydrologic model explicitly coupling models of the land/soil subsystem and of the groundwater subsystem. For BVIHM, the surface water subsystem is ignored due to the lack of ~~larger~~ dominant river systems within the ~~model~~ area. Smaller creeks in the mountains surrounding the b~~B~~asin collect local runoff and baseflow. However, all creek runoff is recharged into the groundwater system upgradient of or near the upgradient boundary of the Basin. Within the ~~B~~basin, Meiss Lake is a prominent surface water feature, but its interaction with groundwater is handled through the land/soil subsystem modeling.

The BVIHM land/soil subsystem is divided into A) agricultural and developed lands, and B) the natural landscape. The agricultural and developed land/soil subsystem was simulated with the Davids Engineering Crop Root Zone Water Model (CRZWM) (Davids Engineering 2013), while the natural land/soil subsystem was simulated with the USGS PRMS model (Risley 2019). The land/soil subsystem models are driven by precipitation, evapotranspiration, and crop water de~~-~~mand. They generate spatially and temporally distributed groundwater pumping (CRZWM) and recharge (CRZWM, PRMS) used in the groundwater simulation ~~of the groundwater subsystem~~. CRZWM and PRMS simulate the land/soil subsystem over the ~~entire model~~ BVIHM area.

The BVIHM groundwater subsystem is simulated ~~with~~ by the USGS MODFLOW-2005 software (Har~~-~~baugh 2005). The groundwater model encompasses the alluvial aquifer system within the Basin, the volcanic aquifer system within the ~~B~~basin, ~~and also~~and the surrounding volcanic aquifer system over the remainder of the model area, which is fully connected to the Basin groundwater system. Toward presenting all geological units and adjusting magnitudes of stresses within environment (i.e., aquifer) system temporally and spatially, the BVIHM is under further refinement and calibration.

2 Model Software Summary

2.1 Precipitation Runoff Modeling Software (PRMS)

BVIHM uses ~~T~~the USGS PRMS model for the Upper Klamath Watershed (Risley 2019)~~ was applied to the BVIHM~~. The recent updated Upper Klamath PRMS model~~ is recently updated,~~ includes calibrated surface water ~~subsystem~~ and land/soil subsystems ~~model~~ based on publicly available and well documented software. The model was not only well suited to couple to the groundwater subsystem model, but its inputs could also be adjusted to account for the DWR projected climate scenarios. The main inputs for PRMS are climate data as is ~~(~~daily precipitation and temperature~~)~~ from 32 climate stations across the Upper Klamath ~~B~~basin. Of these, 4 climate stations are located within 20 miles of the BVIHM ~~model~~ area boundary, but none are located within the ~~model~~ area. PRMS utilizes the USGS “Draper” tool to extrapolate climate station data across the simulation domain (Risley 2019).

While the Upper Klamath PRMS model includes surface water features and is calibrated to measured stream flows at several gaging stations of the Klamath River ~~B~~basin, none of the simulated surface water features are within the BVIHM ~~model~~ area. Results from the PRMS model define the spatially and temporally distributed recharge across the natural landscape in the BVIHM model area, resulting from rainfall and excess soil moisture, after accounting for evapotranspiration. The temporal discretization in PRMS is daily, the spatial ~~discretization~~ is by hydrologic response units, discretized into raster pixels with a side length of 888 ft (270 m; also see Butte Valley GSP Chapter 2.2.3).

2.2 Crop Root Zone Water Model (CRZWM)

Davids Engineering developed a Crop Root Zone Water Model (CRZWM) (Appendix 2-E ET and Applied Water Estimates) that calculates the root zone water budget based on the water budget components in Figure 1. PRMS accounts for the root zone water balance parameters using soil type-specific information and crop information for years 2000, 2010, and 2014. Similar to~~Like~~ PRMS, the CRZWM uses precipitation and reference evapotranspiration as the driving model inputs. In CRZWM, spatially interpolated rainfall data from Oregon State’s PRISM tool[1] are employed. CRZWM also uses remotely sensed crop data (NDVI estimates using Landsat imagery) to complement crop and irrigation type information when computing crop evapotranspiration (Davids Engineering 2013). Importantly, CRZWM (unlike PRMS) estimates the water demand (*applied water*) needed to produce the crops imaged by the satellite, given the amount of precipitation, evapotranspiration, crop type, and irrigation system. All irrigation (*applied water*) in the ~~B~~basin is from groundwater pumping. Hence, *applied water* defines the spatially and temporally distributed amount of groundwater pumping. The model’s simulation of “*deep percolation*” is assumed to become groundwater recharge.

CRZWM covers all agricultural and developed lands in the ~~model~~ area including those within and adjacent to the ~~B~~basin, including smaller agricultural areas in Red Rock Valley and near the Braytown area. The temporal discretization in CRZWM is daily, the spatial discretization is by individual field polygons (also see Butte Valley GSP Chapter 2.2.3). Daily water budget components were aggregated to monthly values for the BVIHM.

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[1] PRISM website: http://prism.oregonstate.edu/

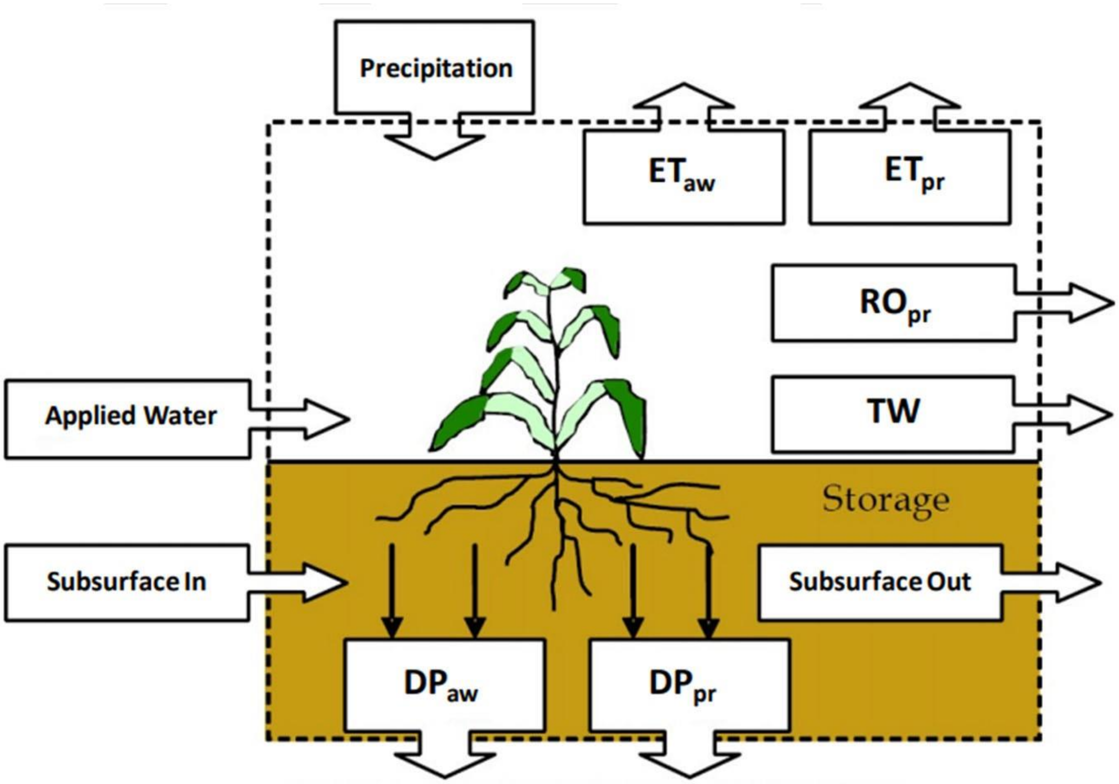

Figure 1: Conceptualization of Fluxes of Water Into and Out of the Crop Root Zone

2.3 MODFLOW

MODFLOW software uses~~is~~ a finite difference method to ~~groundwater model that to~~ simulate~~s~~ groundwater ~~(GW)~~ flow numerical model via ~~given~~ user-provided inputs of initial conditions, aquifer hydraulic parameters, and ~~of~~ boundary conditions. ~~-~~MOD~~-~~FLOW simulates the spatially and temporally variable dynamics of groundwater fluxes and ground~~-~~water elevations. The data~~information~~ is used to characterize a water budget for the basin and ~~to assess~~ evaluate changes in future water levels due to climate changes, projects, and water resources managements~~ actions~~.

3 Model Construction

~~The d~~Development of the two land/soil subsystem models in BVIHM is documented extensively in the above-~~-~~mentioned references. The following sections explain ~~Here, we focus on~~ the development of the groundwater flow numerical ~~subsystem~~ model~~,~~ by using MODFLOW-2005.

3.1 Model Domain

The BVIHM domain encompasses the entire Butte Valley w~~W~~atershed which includes the Butte Valley alluvial aquifer that nearly covers the same area as the Bulletin 118 ~~Groundwater B~~basin in Figure 2. The watershed that encompasses the alluvial aquifer has a volcanic subsurface. Details of the model domain boundary are described in the Butte Valley GSP Chapter 2.2.3.

3.2 Model Discretization and Boundary Conditions

3.2.1 Spatial Discretization

The MODFLOW model has a grid cell size of 270 m x 270 m corresponding to and spatially coinciding with individual grid cells of the PRMS grid. The same grid was also used for the development of a three-dimensional geological model.

3.2.2 Temporal Discretization

The BVIHM has monthly stress periods with two time steps per month and runs for water years (WY) 1990 to 2018~~,~~ (i.e., from October 1, 1989 to September 30, 2018). Monthly stress periods are appropriate for the BVIHM ~~as there is no~~ without surface water routing component.~~ and~~ ~~a~~All modeling objectives of interest focus on the groundwater budget at the monthly and annual timescale at which groundwater is typically managed. The BVIHM climate projection model runs were completed from WY1990-~~WY~~2070 ~~using~~ via the same ~~discretization~~domain area.

3.2.3 Boundary Conditions

The BVIHM utilizes three types of groundwater boundary conditions: 1. “Specified Head” boundary conditions are used to represent the northern boundary along the Klamath River. The specified head corresponds to the average river surface elevation. 2. “Specified Flux” boundaries with flux specified as zero (“No Flow boundary”) encompass the western and southern boundary and are also specified for the bottom of the simulation domain, and 3. “Head-dependent Flux” boundary conditions are used to represent permeable conditions along the eastern boundary with subsurface outflow to the Lower Klamath Lake ~~B~~basin and other areas east of the model area. The surface of the groundwater simulation domain has a spatially and temporally varying “Specified Flux” boundary condition equal to the recharge defined by CRZWM and PRMS. Groundwater pumping (an internal “Specified Flux” boundary condition) is defined by CRZWM, also a spatially and temporally varying condition.

3.3 Model Layering and Zonation

The MODFLOW model has 8 layers to represent the hydrogeologic model with the alluvial aquifer represented in layers one to three and ends in layer 4. The Quaternary volcanic aquifer represents the majority of the active model domain surrounding the alluvial aquifer. A relatively small portion of the model area, abutting~~ to~~ the Klamath River consists of low permeability tertiary volcanics. An outcrop of Quaternary Basalt is found south of and adjacent to the alluvial aquifer. It is present in the first two layers of the model. However, this geologic system was parameterized identical to the larger Quaternary Volcanics aquifer, as only very limited water level observation data exist in the Basalt. A separate calibration of Basalt hydraulic conductivity was therefore not possible. Hence, the current version of BVIHM relies on three hydrogeologic zones, each characterized by its own hydraulic conductivity, specific yield, and specific storage coefficient: tertiary volcanics (low permeability), Quaternary volcanics (intermediate permeability), and alluvium (high permeability).

Table 1: Model Layers and Hydrogeologic Units

Model Layers	Hydrogeologic Unit
1-4	Butte Valley Alluvium
1-2	Quaternary Basalt
1-8	Quaternary Volcanics
1-8	Tertiary Volcanics

3.4 MODFLOW Packages Used to Calculate Groundwater Flows

Table 2: MODFLOW ~~Pachages~~packages used to Calculate Groundwater Flows in the Basin

MODFLOW Package	Application
LPF	Geologic model
GHB	Subsurface outflow to Lower Klamath Lake Basin
CHD	Subsurface outflow to Klamath River
RCH	Recharge from irrigation and rainfall
WEL	Groundwater pumping for irrigation needs
OC	Output control for each stress period
PCGN	Numerical solver

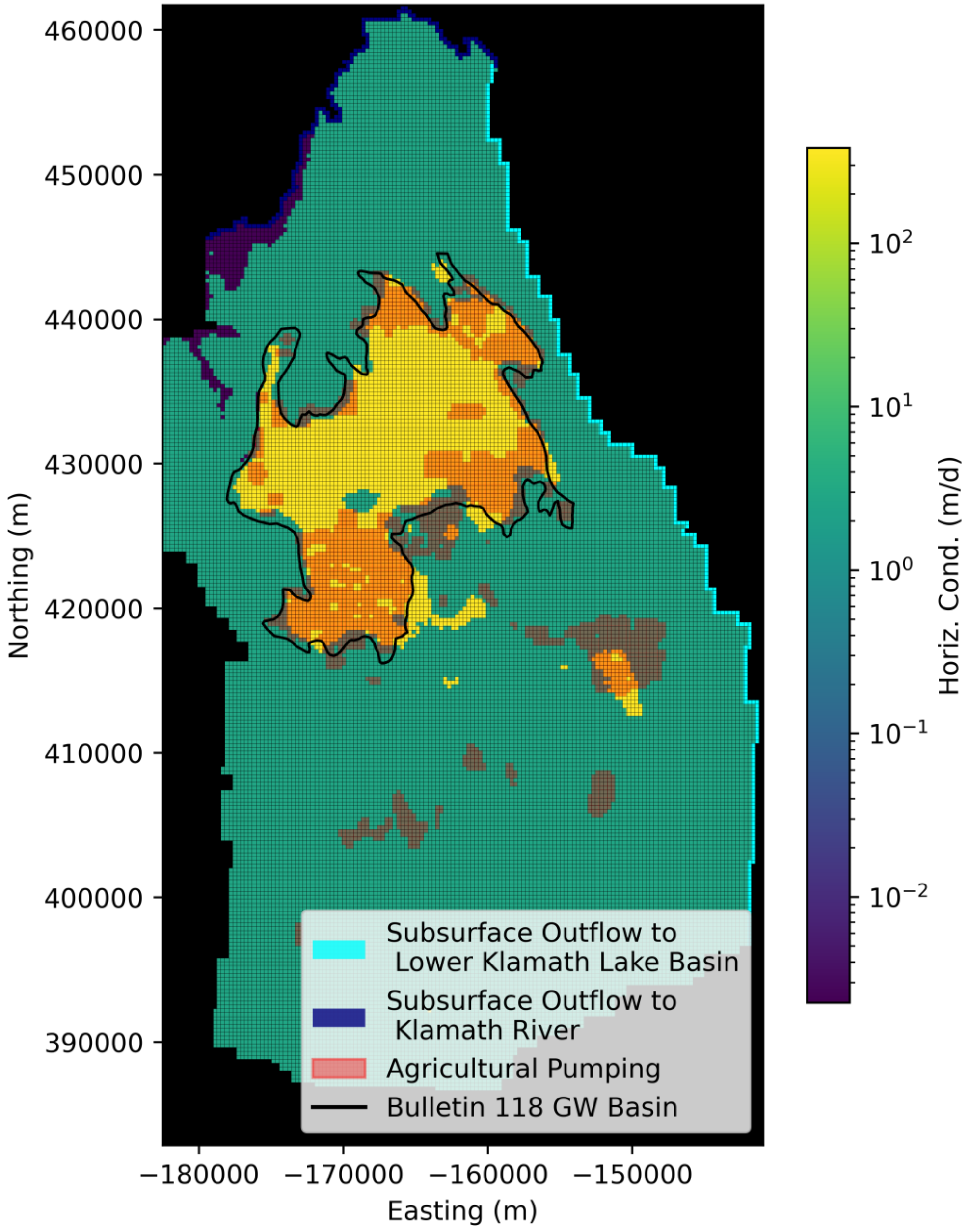

Figure 2: Active model domain with ~~hydrostratigraphy~~hydro stratigraphy identified by horizontal hydraulic conductivity; Tertiary Volcanics are in purple, Quaternary Volcanics are in green and the Alluvium is in yellow.

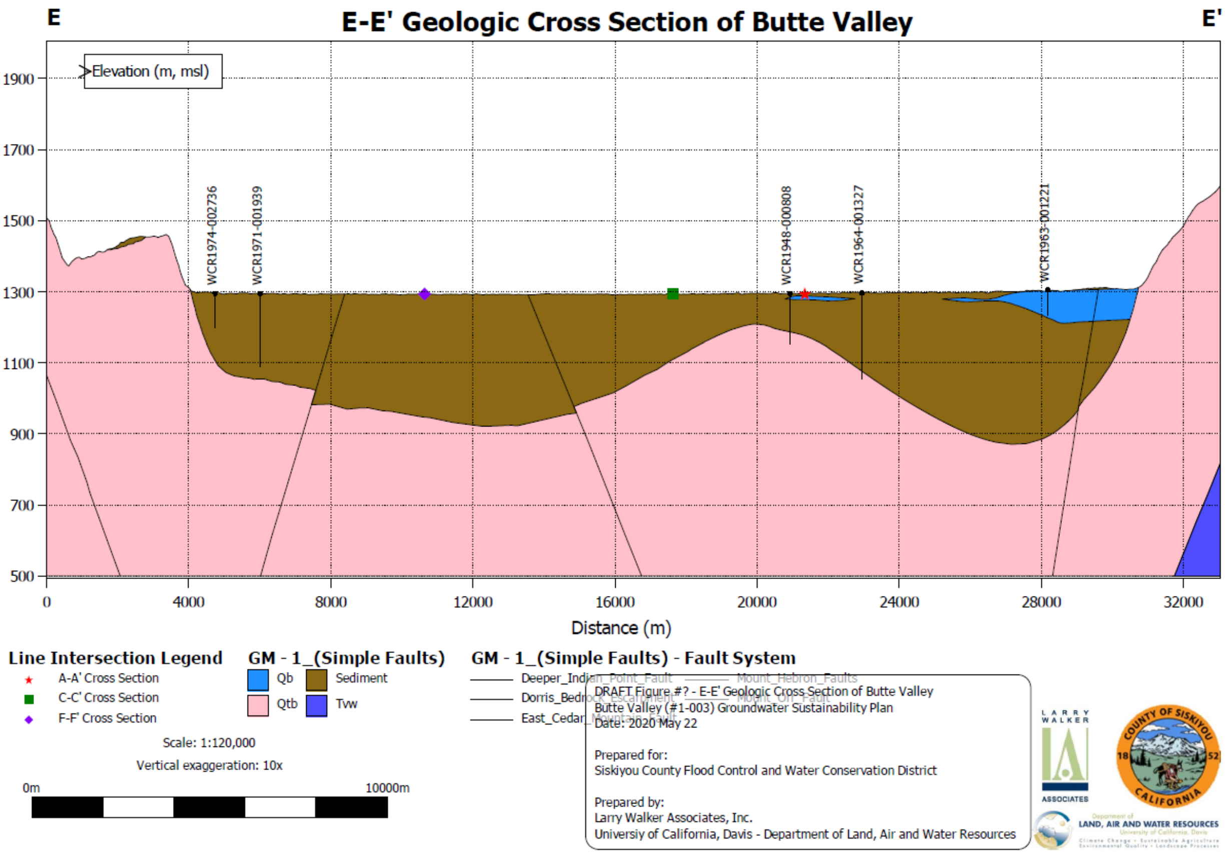

Figure 3: Cross Section E-E’ crosses Butte Valley from the south to the north

4 Model Inputs ~~Data~~

A geologic model was developed to represent the alluvium, Quaternary volcanic, Quaternary basalt and Tertiary volcanic hydrogeologic units based on the digitization and analysis of hundreds of DWR well logs. The Klamath River specified head boundary was created using NHD Streamlines and an upscaled USGS ~~10-meter~~10-meter DEM. The Lower Klamath Lake Basin head dependent boundary was created using the head output and model discretization from the upper Klamath Basin regional groundwater model (Gannett, Wagner, and Lite 2012).

4.1 Land Use

The urban areas in Butte Valley are relatively small and dispersed throughout the agriculturally developed region. The latter represents ~~the majority of~~most of the Butte Valley groundwater basin land use. Most of the upper watershed surrounding the Basin is represented by natural lands that are non-irrigated. Three land use maps are available from the California Department of Water Resources for the Basin: 2000, 2010, and 2014.

4.2 Atmospheric Data and Watershed Data

Atmospheric data is not directly used in the MODFLOW model but rather applied to the PRMS and CRZWM models whose output are then passed to the MODFLOW model as recharge. Details are well documented in the documentation of PRMS (Risley 2019) and CRZWM (Appendix 2-E ET and Applied Water Estimates). Briefly, for precipitation, the CRZWM model uses PRISM data[2] from Oregon State University to distribute climate station data to individual locations. The PRMS model for the Upper Klamath Basin utilizes a methodology ("Draper") equivalent to PRISM to distribute climate station data to individual hydrologic response units by mathematical extrapolation. For evapotranspiration, the CRZWM model uses bi-weekly NDVI values derived from Landsat imagery and the California Irrigation Management Information System (CIMIS) reference evapotranspiration (ET_o) data[3] to calculate actual evapotranspiration. Air temperature data from a NOAA weather station was used to calculate ET_o using the Hargreaves and Samani method (1985) when CIMIS ET_o was not available for a given period. PRMS utilizes the Jensen-Haise method to estimate potential evapotranspiration and adjusts to match documented mean monthly evapotranspiration in the Upper Klamath Basin.

Other watershed input data used by PRMS and CRZWM include soil type, vegetation type, slope, and others Davids Engineering (2013).

4.3 Hydrofacies Hydraulic Properties (Aquifer Properties)

The expected range of hydraulic properties (i.e., specific storage, *Ss*, specific yield, S_Y, horizontal hydraulic conductivity, *HK*, and vertical hydraulic conductivity, *VK*) for the four hydrogeologic units were obtained from a literature survey of aquifer hydraulic properties found elsewhere for

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[2] PRISM website: http://prism.oregonstate.edu/

[3] Spatial CIMIS is a gridded ETo product available from DWR. Long-term average gridded ETo was estimated based on ETo grids for the years 2004 to 2018.

these diverse aquifer types (Kuang et al. 2020). These hydraulic properties were set as the initial conditions of the MODFLOW model before undergoing model calibration. The sensitivity analysis found that the model had little sensitivity to the Quaternary Basalt formation because of the lack of observations in the unit, thus it was set to match the properties of the Quaternary Volcanics.

4.4 Pumping Well Data

Groundwater pumping data assigned to specific pumping well location and depth are not currently detailed to a degree sufficient for groundwater modeling. Instead, groundwater pumping for each individual MODFLOW grid cell was assigned based on the *Applied Water* calculated in CRZWM. Based on review of DWR well logs it was found that the typical agricultural well depth was 150-450 ft below ground surface. Grid cell specific pumping was distributed evenly across layers 2-4, which correspond approximately to these well depths.

4.5 Crop types, crop coefficients, and irrigation efficiencies

Alfalfa, grain and hay, strawberries and pasture are the primary irrigated crops in Butte Valley. As crop coefficient data was calculated using LandSat NDVI data there are not three values for each crop, but rather a gradual change from dormancy to the growing season and after harvest. Plots of the crop coefficient data over time area available in Section 4.4 of Appendix-2E on CRZWM.

4.6 Data Gaps in Model Input Data

As stated in Section 4.4, there is no pumping well data available in the basin which is remedied by estimating groundwater pumping based on the expected applied water for irrigated lands. As the GSP process moves forward, metering agricultural and public supply wells (i.e., all wells except de minimis users) would improve the estimates of current and future groundwater pumping, benefiting the understanding of storage dynamics in the basin. Additionally, the currently available DWR well record completion reports have limited data on total well depth and screened interval which are essential to accurately allocating groundwater pumping to the correct vertical aquifer sections being pumped. Drawdown in the relatively unconfined Alluvial Aquifer will be different from that in the confined Quaternary Volcanics Aquifer. A field campaign using a well borehole camera would be able to measure the screened interval(s) of all active agricultural and public supply wells in the basin if funding is available. Future iterations of the BVIHM will include the Meiss Lake water budget (it was unavailable for inclusion at the time of model development) in the groundwater flow model as it is an artificial wetland that is operated by pumping groundwater to the surface where some water is recharged to the aquifer, and some is lost to evapotranspiration. Currently Meiss

Table 3: Expected ranges of hydraulic properties

	Ss min (m^{-1})	Ss max (m^{-1})	K min (m/s)	K max (m/s)	Ss mean (m^{-1})	K mean (m/s)
Sand	10^{-7}	0.00241	1.13×10^{-5}	0.00255	2.88×10^{-5}	1.21×10^{-4}
Fractured igneous and metamorphic rocks	1.28×10^{-8}	3.63×10^{-5}	7.52×10^{-9}	10^{-5}	8.58×10^{-7}	7.93×10^{-8}
Basalt	1.3×10^{-7}	4.7×10^{-6}	0.003	0.019	4.3×10^{-7}	0.00755

Lake is represented as natural lands where the net recharge is calculated from PRMS accounting for precipitation and evapotranspiration and other soil water budget terms. Future iterations of the Meiss Lake region in the BVIHM will account for the applied water demand that exists to maintain saturation of the wetlands.

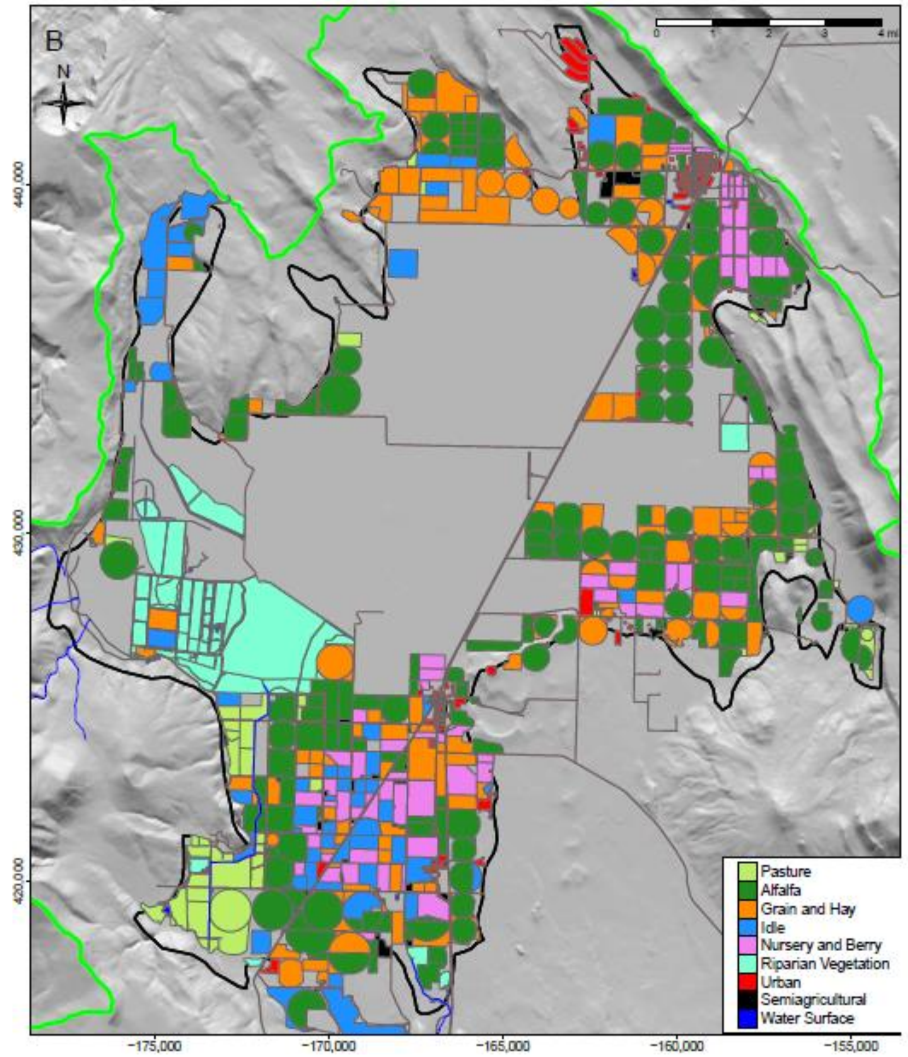


Figure 4: Land use within the Butte Valley groundwater basin (black outline) in the summer of 20104. Grey areas are natural vegetation or outside the Basin boundaries.

5 Calibration Target Data and Objective Functions

The sensitivity analysis and calibration software UCODE2014 was applied to the BVIHM under both steady state and transient groundwater flow conditions. UCODE2014 uses the sum of square weighted residuals as the objective function for determining the ~~models~~model’s ability to match observations.

5.1 Groundwater Outflow Calibration Targets

Previous groundwater modelling work by Gannett et al. quantified the expected subsurface seepage to the ~~Klamath River~~Klamath River, which was applied as a low weighted flow observation, with a coefficient of variation of 40% (Gannett, Wagner, and Lite 2012). This observation was largely controlled by the hydraulic conductivity of the (low permeable) Tertiary volcanics that groundwater flow must pass through to reach the Klamath River specified head boundary. The Tertiary volcanics provide a critical barrier that keeps groundwater from flowing into the topographically much lower Klamath River, which is as much as 1000 ft lower than Butte Valley. This outflow target provides a tool to determine appropriate hydraulic conductivity values for this important geologic formation.

5.2 Groundwater Elevation Calibration Targets

The state database of periodic groundwater level measurements was filtered and cleaned for the Butte Valley area and modeled ~~time period~~period to create a database of groundwater observations that were corrected with respect to the model top elevations. In addition to the periodic groundwater level measurements, LWA has collected continuous groundwater level data in stakeholder wells from 2015-present that were included as well ~~on a monthly basis~~monthly in Figure 5. The groundwater level observations were weighted using a variance of 1.0025. ~~Additionally~~Additionally, the locations and ground sur~~—~~face locations of creeks and springs throughout the upper watershed of Butte Valley were included as head observations in the ~~spring time~~springtime, but with a coefficient of variation of 10%.

5.3 Data Gaps in Calibration Data

Currently observation well data are limited to the extent of the Alluvial Aquifer with a few wells located on the boundary with the Quaternary Volcanic Aquifer. ~~The majority of~~Many of these observation wells do not have total well depth or screened interval data ~~available~~available, so it is uncertain whether they are screened in the Alluvial or Quaternary Volcanic aquifer or both. A field campaign using a well borehole camera to measure this missing data would be able to better determine which aquifer the wells are screened in and improve the calibration of specific yield and specific storage that are dependent on well drawdown data. The construction of new monitoring wells in the Quaternary Volcanics and Basalt Aquifers would provide data on the long term and seasonal trends in wa~~–~~ter levels which would enable the Basalt Aquifer to be calibrated separately from the Quaternary Volcanics aquifer. This would improve understanding of storage coefficients and drawdown in the Basalt Aquifer to improve the estimate of the sustainable yield.

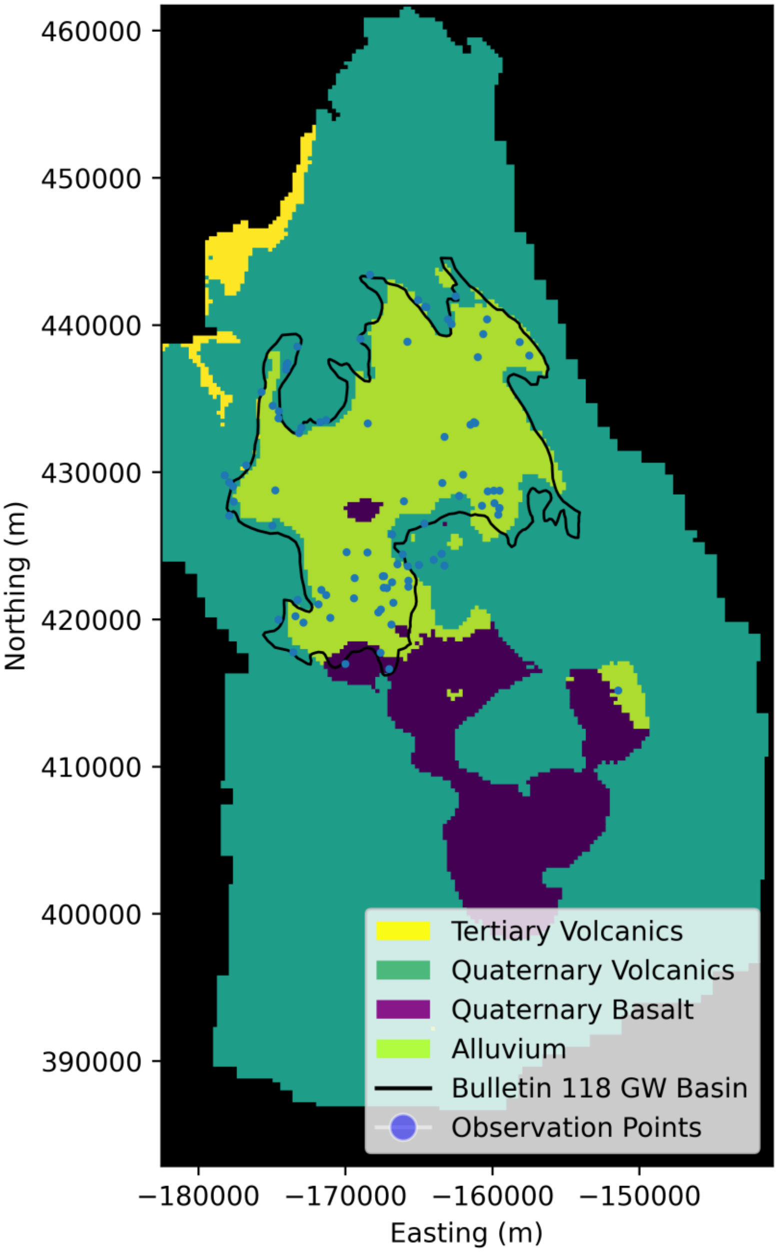


Figure 5: Location of observation wells, creeks and springs for groundwater model calibration

6 Calibration Methodology Summary

The BVIHM steady state model was developed using spatially distributed average recharge and pumping for the first ten years of the model run ~~period,from~~period, from WY1990-2000. The steady-state model was calibrated using the averaged observations for the same period. Steady state calibration was performed on the three horizontal hydraulic conductivity parameters for the previously identified hydrogeologic units. Due to North-South faulting the horizontal hydraulic conductivity in the north- south direction was assumed to be twice as large as the conductivity in the east-west direction, and the vertical hydraulic conductivity was assumed to be 1/30 of the horizontal conductivity, which is approximately the logarithmic average between a vertical anisotropy ratio 1/10 and 1/100.

The BVIHM transient model which ran from WY1990-2018 was calibrated against the groundwater elevation and outflow targets described previously. The hydraulic conductivity and storativity were calibrated for the same three hydrogeologic units.

7 Model Calibration Results

7.1 Sensitivity Analyses

Through Sensitivity Analysis the Composite Scaled Sensitivity (CSS) was used to determine that the groundwater pumping and ~~recharge~~recharging have a very large influence on the simulated groundwater heads as expected. Testing of different initial hydraulic parameters demonstrated that the hydraulic parameters of the alluvium and Quaternary volcanics tended to have the largest CSS. The storage coefficients of the Quaternary Volcanics had a slightly larger CSS after calibration than the storage coefficients of the alluvium, this makes sense as the volcanic aquifer surrounds the alluvium and enforces the heads at the boundary of the alluvium. And as the alluvium has a much larger hydraulic conductivity there is a very mild hydraulic gradient, further increasing the impact of the groundwater heads of the volcanic aquifer on the observations in the alluvium.

Under initial hydraulic parameters the Quaternary and Tertiary volcanics had a large correlation as expected because the Quaternary volcanics limit outflow to the Tertiary volcanics, however, as model calibration further decreased the hydraulic conductivity of the Tertiary volcanics to limit outflow to the Klamath River, given observed groundwater gains in the Klamath River. This leads to dissipation of a significant correlation with the Quaternary volcanics.

7.2 Groundwater Head Calibration Results (MODFLOW)

The hydrographs below present the observed groundwater hydrographs versus the simulated heads (after calibration) for all wells with more than 20 measurements in Figure 7. The map below shows the location of each observation well in the model domain using the MODFLOW node as the naming convention for observations. The map of observations demonstrates that the majority of wells with observations are spatially located at locations overlying the alluvial aquifer, except for few wells near the margin of the alluvial aquifer. For the latter it is ~~unknown,~~unknown whether the well screen would be intersecting with the alluvial units, the volcanic units, or both. The information was not available from well driller reports Figure 8.

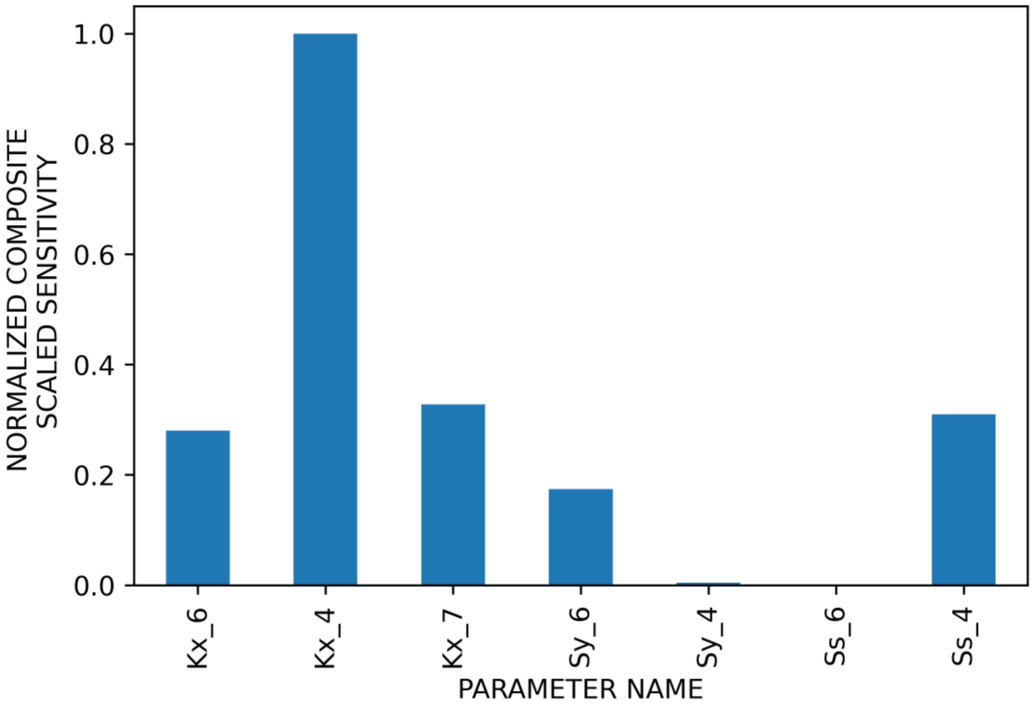


Figure 6: Normalized Composite Scaled Sensitivity of the final parameters used in model calibration.

The hydrographs, on average, show a relatively good fit of the simulated data to the observed data: some wells are matched closely, some well water levels are consistently under-estimated, and some water level hydrographs are consistently over-estimated. In general, both the observed seasonal and the observed ~~longterm~~long-term water level dynamics (~~longterm~~long-term decline and rise of water levels) are well captured by the simulated data; ~~the~~The seasonal groundwater pumping amplitudes were very closely matched by some wells and over- or under-estimated by others. Differences between simulated and observed seasonal hydrograph amplitudes may be due to the wells not being screened in aquifer unit that was modeled based on the geologic model~~n~~ and well depth. Currently, there is no information on screened interval for many of the wells for which water level data are available (Section 5.3).

7.2.1 Hydraulic Properties by Layer/Zone (MODFLOW)

As stated in section ~~section~~ 6, the steady state calibration was done for the hydraulic conductivity of the alluvium, Tertiary volcanics and Quaternary volcanics. The hydraulic conductivity for the Quaternary basalt was set equal to that of the Quaternary volcanics. The initial values for the calibration were based on a combination of the expected ranges in hydraulic parameters and previous test models that manually matched groundwater levels in the census-designated area of MacDoel and the city of Dorris. Water levels at the northern and eastern boundary of the model are defined with fixed and with general head boundary conditions. Hence, the hydraulic conductivity of the Quaternary volcanics strongly controls water levels in the region near Dorris, at the boundary between the alluvium and the Quaternary volcanics. The very small hydraulic gradient between MacDoel area and the Dorris area is largely determined by the (high) hydraulic conductivity of the alluvium. The steady state calibration with UCODE2014 showed a significant decrease in the sum of squared weighted residuals (SOSWR) due to calibration of the hydraulic conductivities. Calibrating the hydraulic conductivity in the Quaternary volcanics determines the simulated groundwater levels in the area near Dorris and the entire eastern boundary of the alluvium due to groundwater outflow from the alluvium into the eastern and northern Quaternary volcanics and further through those to the constant and general head boundaries along the eastern and northern model area boundary.

Because of the shallow gradient across the alluvium, the K value for the Quaternary volcanics has a strong influence on water levels across all wells in the alluvial Basin. A single, uniform K value for the Quaternary volcanics could be calibrated to set simulated heads to be in the correct range of observed values. The calibration of the hydraulic conductivity of the alluvium focused on the hydraulic gradient across the (alluvial) Basin itself, where most of the observation wells are. The calibration of the K value for the alluvium sought to best match observed regional groundwater level gradients within the Basin. The calibration of the hydraulic conductivity of the alluvium also adjusted for the observed larger cones of depression from pumping by wells. However, localized cones of depression and water levels in pumping wells were not matched due to the coarser spatial resolution of the model (270 m x 270 m).

Transient calibration was first implemented to calibrate the hydraulic conductivity and storativity (STORAGE COEFFICIENT option in MODFLOW-2005) for all four hydrogeologic units individually. The initial SOSWR is larger for the transient calibration than after the steady state calibration because 20 more years of observation data is now included, and it is no longer averaged. Calibration and sensitivity analysis found that the hydraulic conductivity and storativity of the Quaternary basalt and the storativity of the Tertiary volcanics do not have a large impact on model results. It is more difficult to calibrate the storage coefficients of the aquifers because the well observations available often do not have data on their screened interval. The simulated screen location was therefore highly uncertain.

The transient calibration included the hydraulic conductivity previously calibrated and storage coefficients for the Quaternary volcanics and alluvium; ~~t~~The Tertiary volcanics were not calibrated for storage coefficients because there are no groundwater level observations in or near that aquifer to represent the seasonal and interannual head fluctuations. Contrary to initial expectation, the calibration suggested that the alluvium should have a much smaller storage coefficient due to the large seasonal head fluctuations seen in the observations. This result suggests that the alluvial aquifer may be more heterogeneous with potential for partially confining layers. Also, wells that are potentially screened in the volcanic aquifer below the alluvium within which they are simulated.

7.2.2 Boundary Condition Calibration (MODFLOW)

The boundary conditions were not directly calibrated as the outflow to both the Klamath River and the Lower Klamath Lake Basin were controlled by the hydraulic conductivities of the Tertiary vol-

Table 4: Steady state calibration results

Iteration	Alluvium Kx (m/d)	Quaternary Volcanics Kx (m/d)	Tertiary Volcanics Kx (m/d)	Sum of Squared Weighted Residuals
0	316	1.7	0.024	7.61 × 104
9	575	3.1	0.0295	1.04 × 104

Table 5: First Transient Model Calibration Results

Iteration	**Alluvium Kx (m/d)**	**Quaternary Volcanics Kx (m/d)**	**Quaternary Basalt Kx (m/d)**	**Tertiary Volcanics Kx (m/d)**	**Alluvium S Observations**	**Quaternary Volcanics S**	**Quaternary Basalt S**	**Tertiary Volcanics S**	**Sum of Squared Weighted Residuals**	**Total**
0	600	2	2	0.5	0.15	0.15	0.15	0.15	9.7×10^{5}	1636
9	316.1	1.712	0.033	0.0241	0.05	0.4	0.05	0.39	3.1201×10^{4}	1636

Table 6: Final Transient Model Calibration Results

Iteration	Alluvium Kx (m/d)	Quaternary Volcanics Kx (m/d)	Tertiary Volcanics Kx (m/d)	Alluvium S	Volcanics S	Alluvium S_s (m^{-1})	Volcanics S_s (m^{-1})	Sum of Squared Weighted Residuals	Total
0	364	2.8	0.008	0.12	0.002	5×10^{-8}	7×10^{-5}	7.1393×10^{4}	1940
9	383.4	2.755	0.00225	0.1138	0.001	1.8×10^{-8}	9.69×10^{-5}	5.4049×10^{4}	1940

canics and Quaternary volcanics respectively. The general head boundary condition was indirectly calibrated by using the Quaternary volcanics K value for computing the general head conductance term.

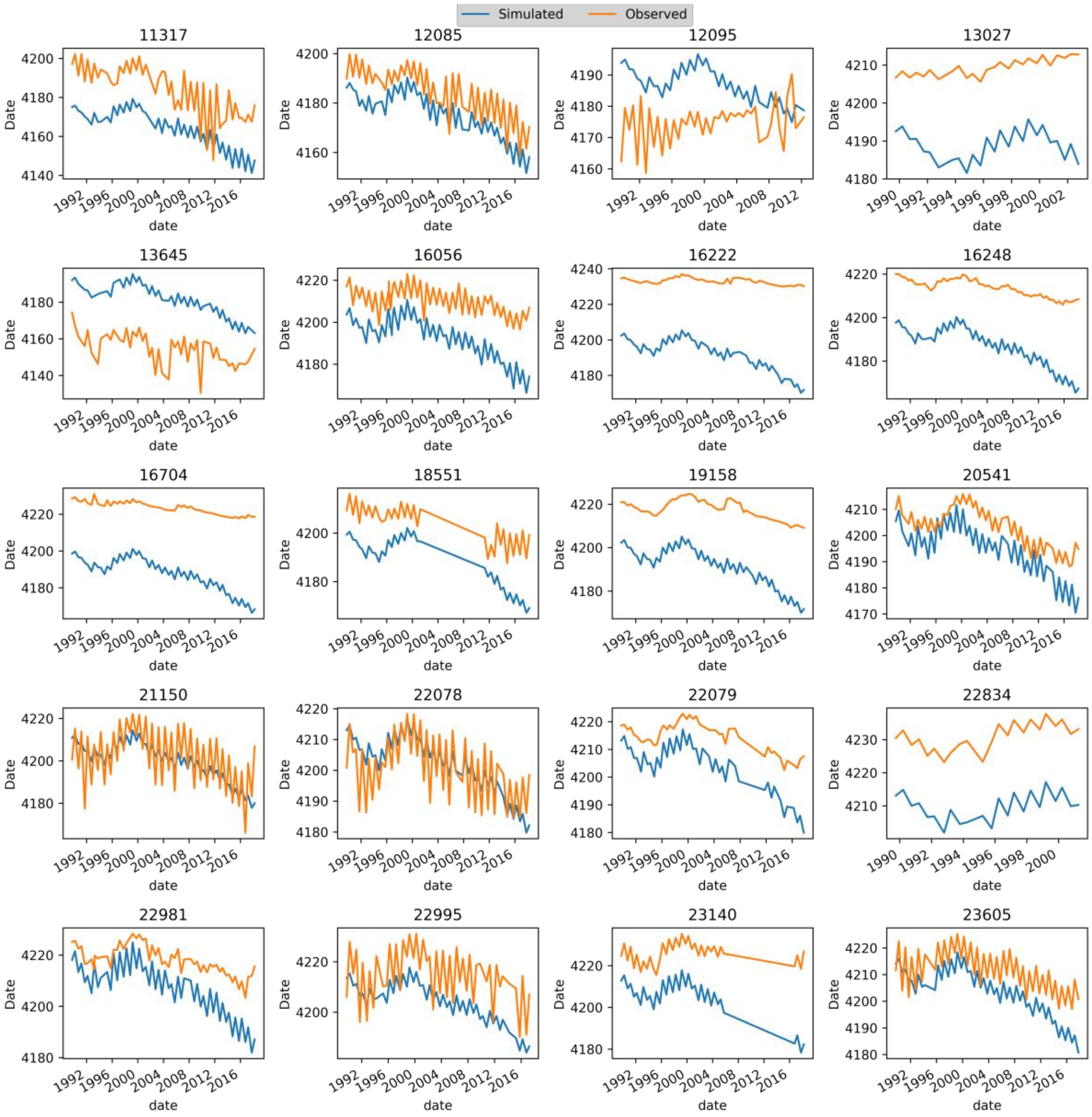


Figure 7: Simulated and observed heads for wells with more than 20 measurements where observed data is in orange and simulated data is in blue

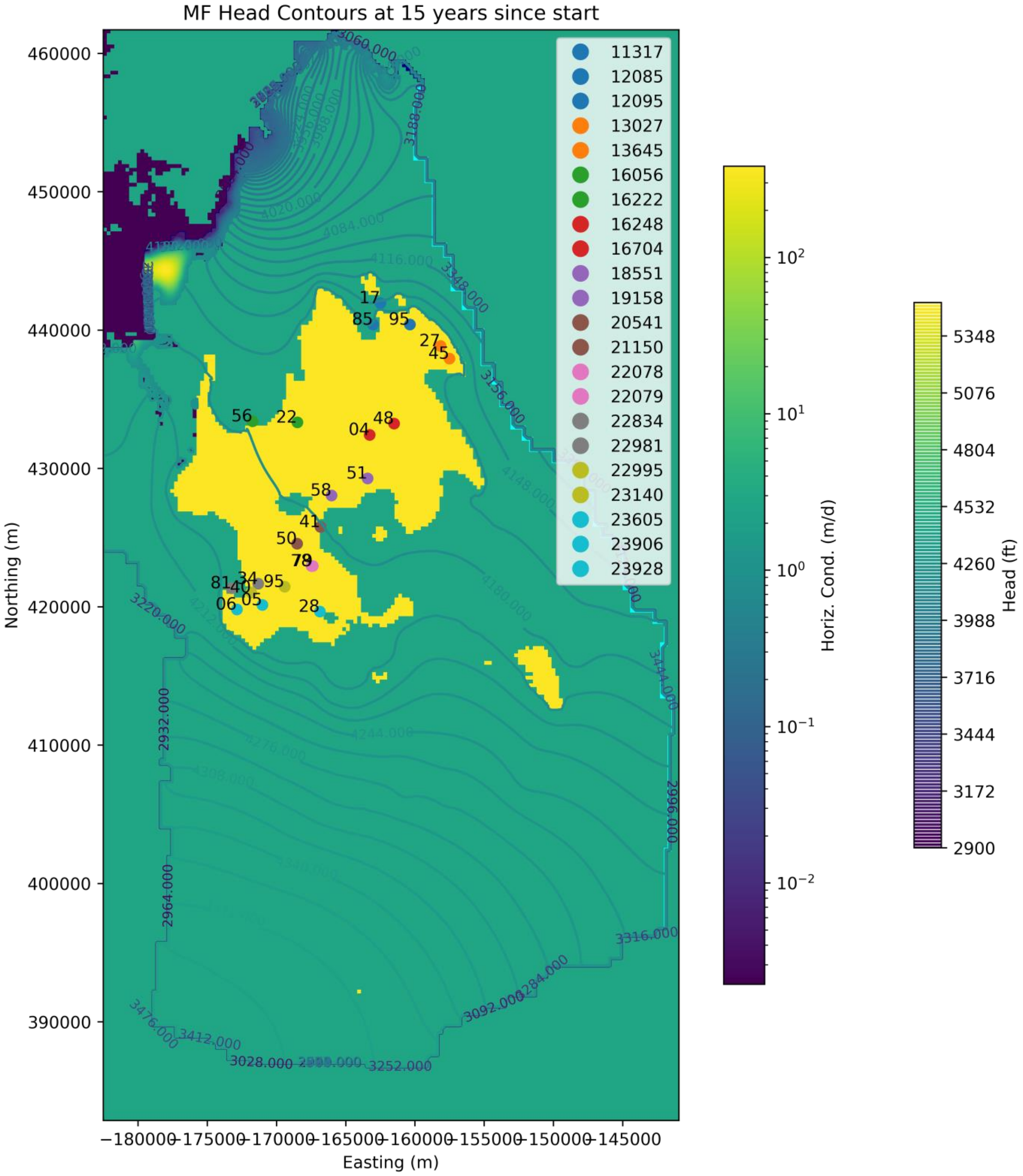


Figure 8: Map of observation wells with more than 20 measurements

8 Results for Calibrated Model

8.1 Groundwater Hydrographs

The simulated groundwater hydrographs obtained from the calibrated model for locations where observations are available demonstrate strong seasonal fluctuations due to summer time ground- water pumping and winter recharge as well as a long term dynamics of lowered groundwater levels due to drought, offset by periods of very wet water years with increased recharge into the aquifer; it is important to point out that the modeled years 2016, 2017 and 2018 did not have output from the PRMS model so we reused PRMS data from other years which resulted in 2017 having a much lower recharge than likely occurred in reality. It is possible that an updated future PRMS model that includes actual data for 2016-2018 would lead to groundwater hydrographs showing similar effects to observed groundwater storage changes in water years 1997-2000 Figure 9.

The observation wells and `springs/creeks` with more than 20 data points are plotted in Figure 8; the point labels are denoted by the model grid node they are located in. The simulated groundwater hydrographs at these same observation wells are plotted below in Figure 9 to demonstrate the seasonal and ~~long term~~long-term trends of the groundwater elevations in the basin.

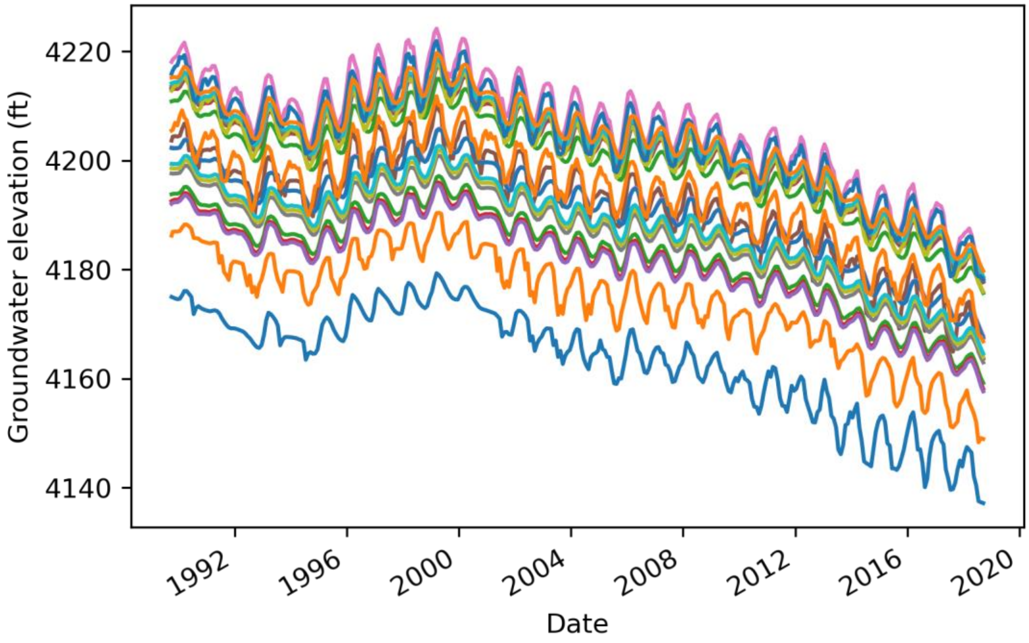


Figure 9: Simulated groundwater hydrographs for wells with more than 20 measurements

The simulated groundwater hydrographs for the same locations of the observation wells demon~~-~~strate strong seasonal fluctuations due to ~~summer time~~summertime groundwater pumping and winter recharge as well as a ~~long term~~long-term trend of lowered groundwater levels which are offset by periods of very wet water years recharge the aquifer; it is important to point out that the modeled years 2016, 2017 and 2018 did not have output from the PRMS model so we reused PRMS data from other years which resulted in 2017 having a much lower recharge than it did. Most likely with actual PRMS data for 2016-2018 the groundwater hydrograph would show a similar recharge of groundwater storage as in water years 1997-2000 Figure 9.

8.2 Model Area Groundwater Budget

The annual groundwater budget for the model area includes the entire Butte Valley watershed and additional areas to the west, north, and east of the watershed. The model area is bounded to the west and south by groundwater divides along the boundary of the larger Upper Klamath basin, to the north by the Klamath River (an outflow boundary) and to the east by an arbitrary groundwater outflow boundary within the High Cascade volcanics (“Quaternary volcanics” zone), represented as a general head boundary. The black ~~line~~ (“~~dStorage~~Incremental Storage Change”) and dark red (“Cumulative Storage Change”) lines represent~~s~~ the annual (but not cumulative) and cumulative changes in groundwater storage respectively. It represents the difference in total inflows (positive bar length) and total outflows (negative bar length).

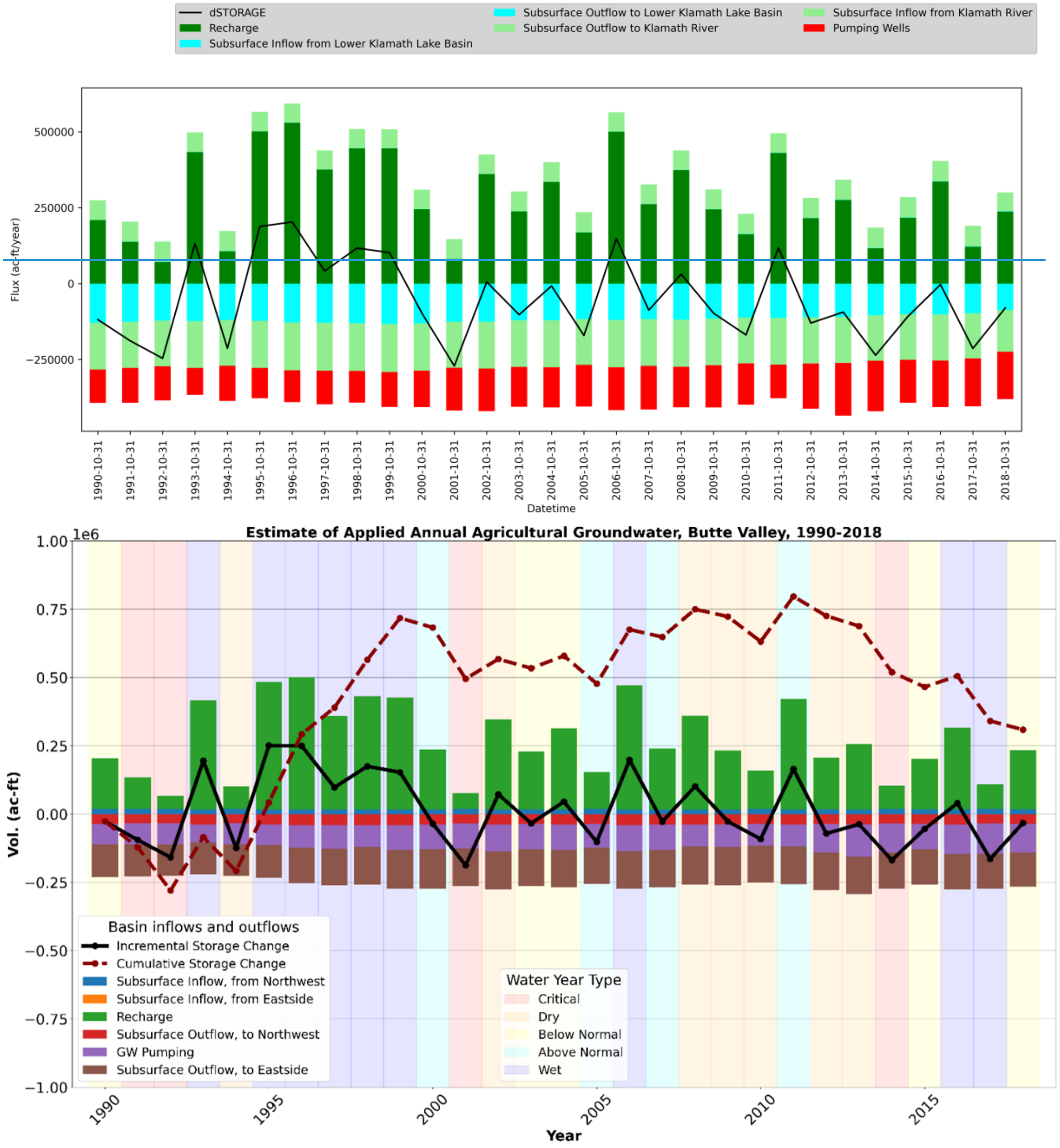
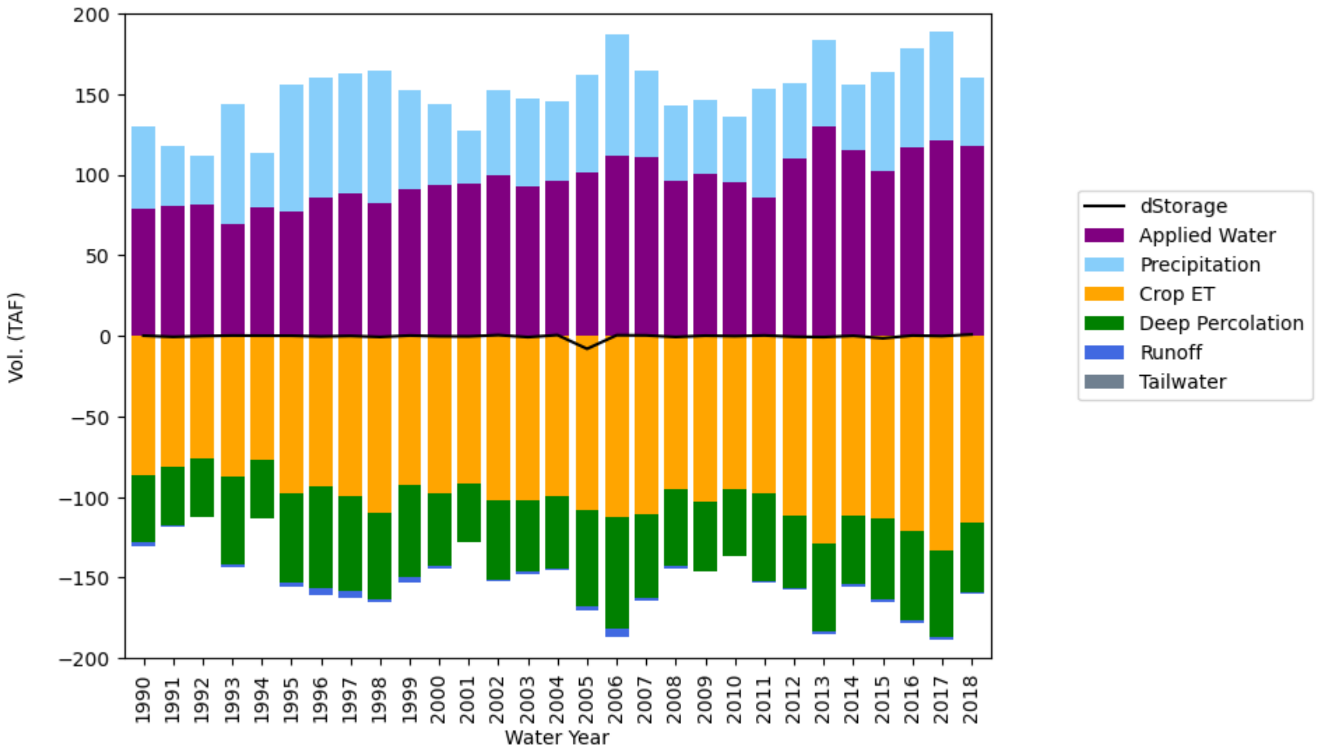


Figure 10: Annual Model Area Groundwater Budget

The model area groundwater budget shows high interannual variability ~~for the amount of~~for net inflow to the model ~~area as a whole, because~~area, because that inflow is entirely a function of the amount of rainfall ~~in a given year~~each year. On the other hand, the net outflow from the basin is nearly constant throughout the simulation period with only long-term changes, as outflow is limited to groundwater discharge out of the model area and groundwater pumping in Figure 10. The groundwater pumping is rela~~-~~tively constant because the dominant growing season is summer, which is mostly dry regardless of overall precipitation amounts. Most agricultural land is regularly irrigated. In dry years, irriga~~-~~tion slightly increases due to earlier start of the irrigation season and winter crops not receiving sufficient spring rainfall. Additionally, the combined net outflow from the groundwater subsystem remains near constant because increased groundwater pumping generally leads to a decline in subsurface outflow towards the Lower Klamath Lake Basin and Klamath River. Additional ground~~-~~water pumping captures more of the ~~the~~ natural recharge from the upper watershed flowing into the Basin as subflow. Further discussion of this and other water budgets is provided in Chapter 2.2.3 of the Butte Valley Groundwater Sustainability Plan. The following provide bar charts and tables of the two Basin water budgets: the agricultural Land/Soil subsystem, simulated by CRZWM, and the groundwater subsystem.

8.3 ~~Basin Agricultural~~ Irrigated ~~(CRZWM)~~ Land/Soil Subsystem Water Budget (CRZWM)



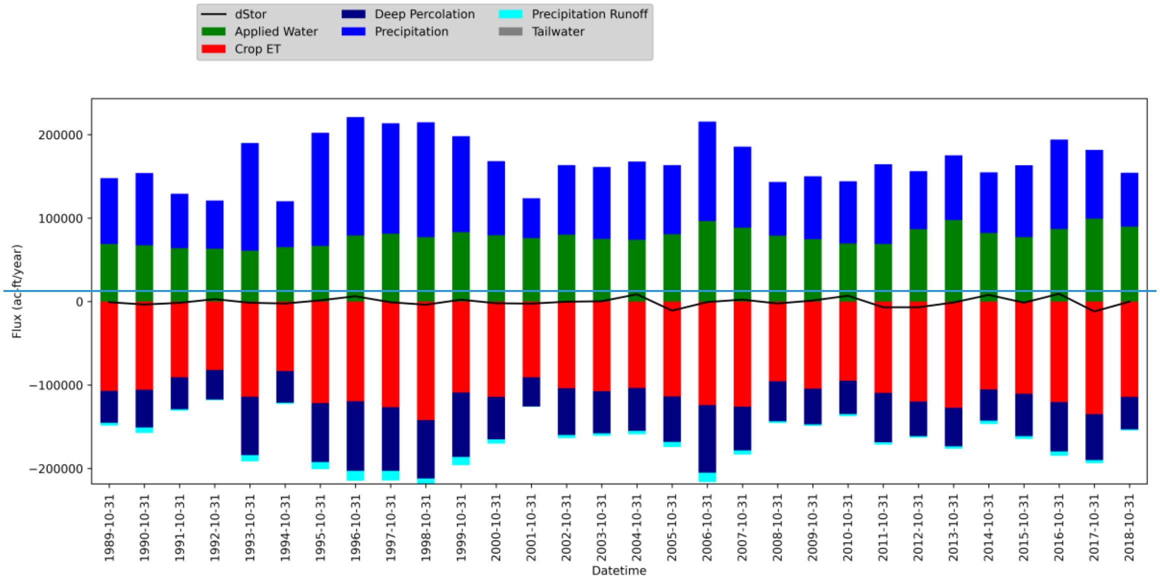


Figure 11: Annual~~ Basin~~ Land/Soil Subsystem Water Budget (CRZWM)~~Root Zone Budget Limited to Irrigated Lands~~within model area

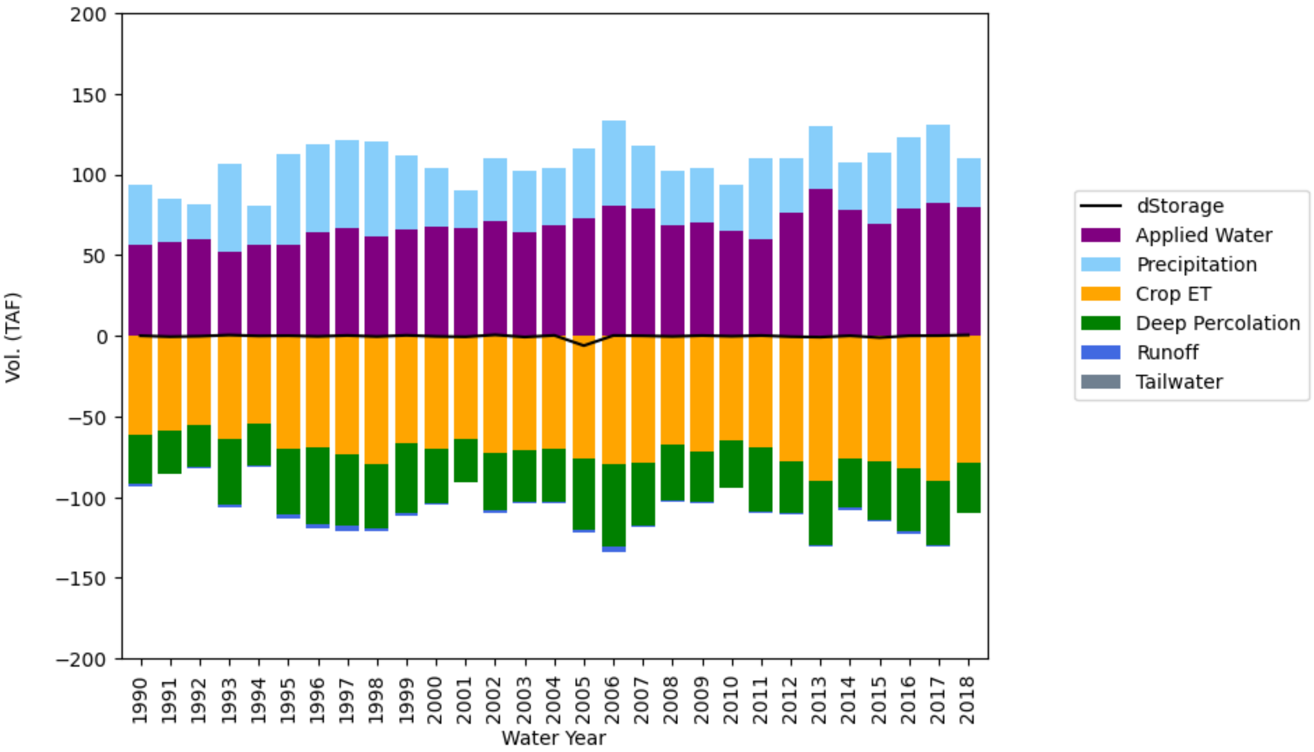


Figure 12: Annual Land/Soil Subsystem Water Budget (CRZWM) within Bulletin 118 groundwater basin

The irrigated land/soil subsystem~~agricultural~~ water budget is similar to the model area budget because it also has large interannual fluctuations in precipitation and additionally it has large interannual fluctuations of evapotranspiration (Figure 11 and Figure 12). The irrigated land~~agricultural~~ water budgets are~~is~~ useful because ~~it~~they demonstrate~~s~~ the interannual variability in deep percolation due to changes in rainfall and evapotranspiration.

8.4 Bulletin 118 Groundwater Budget

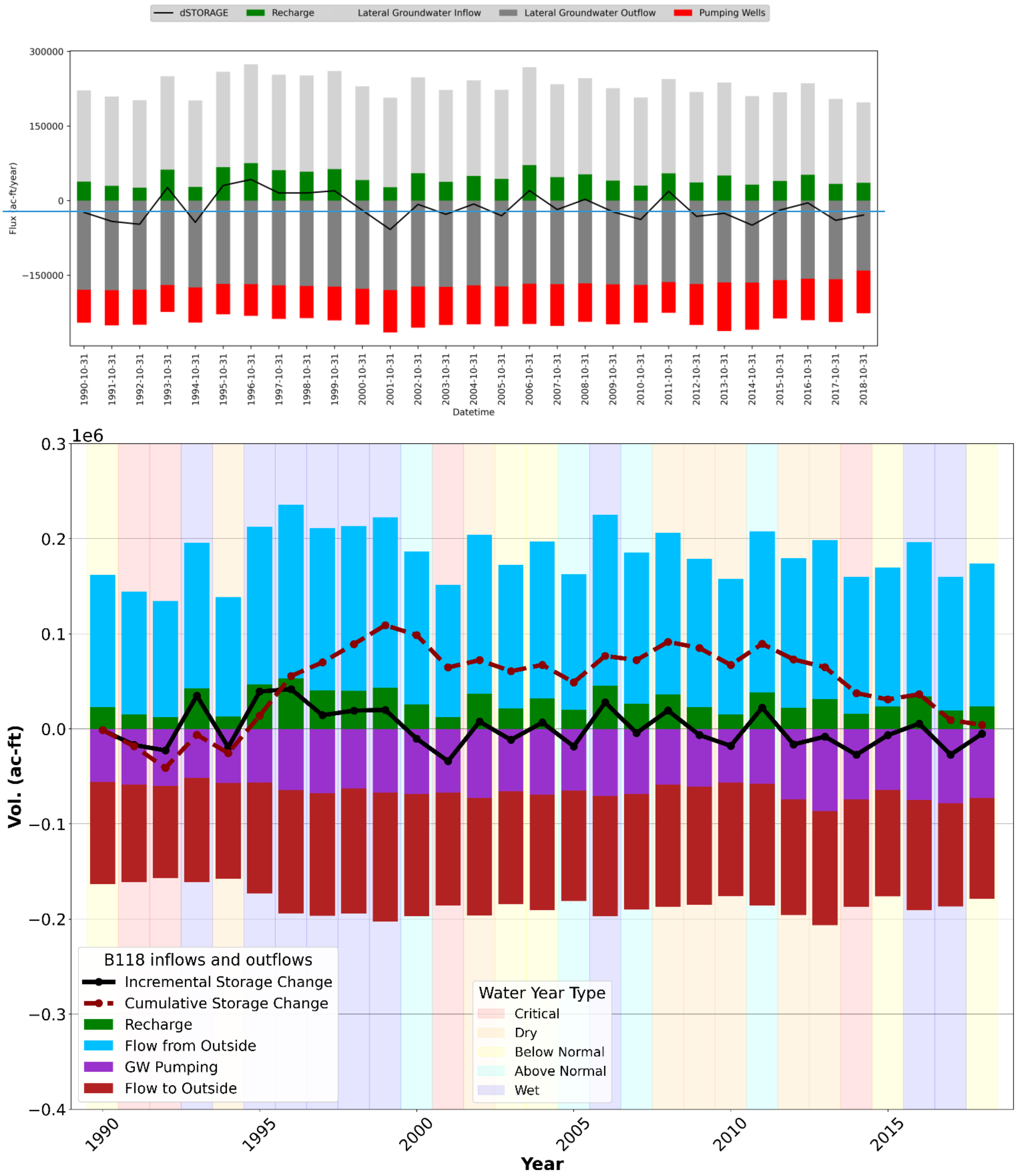
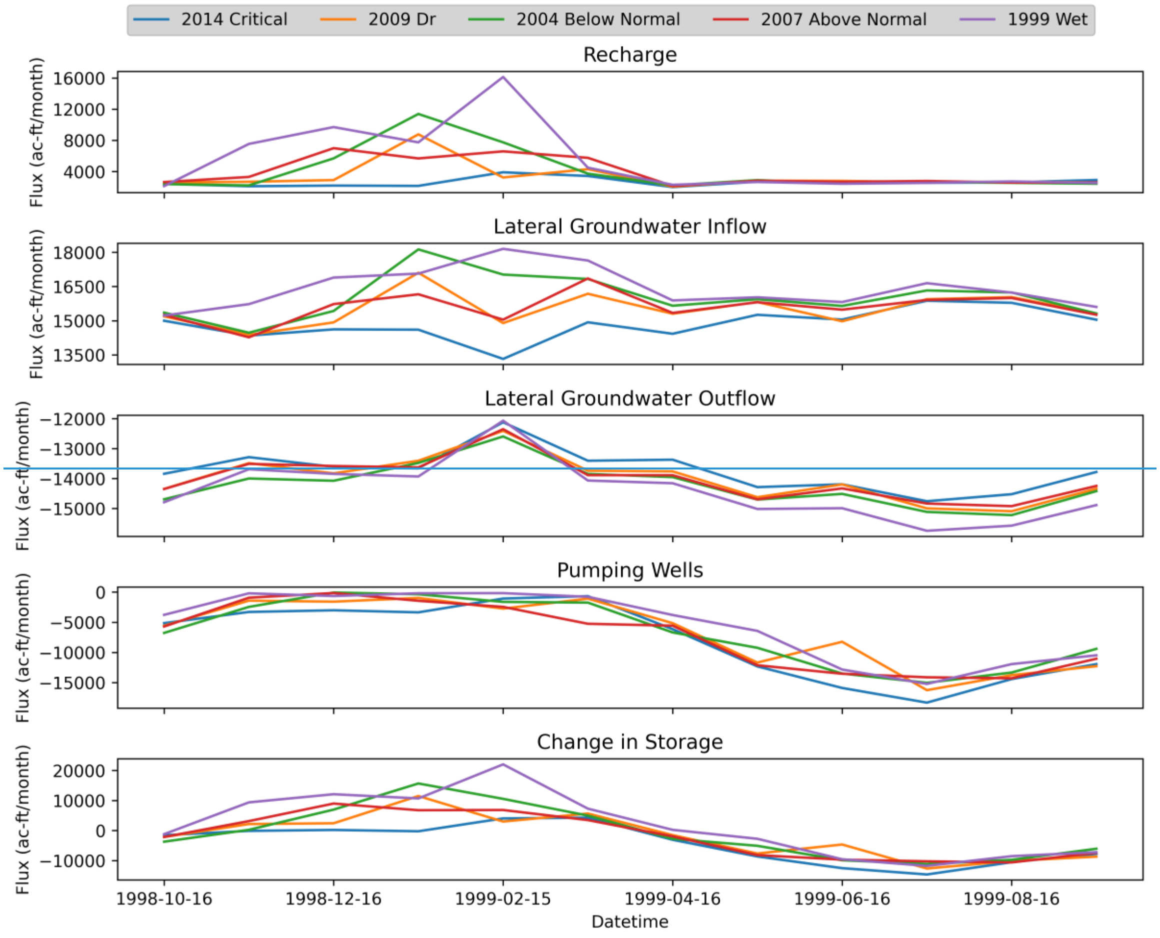


Figure 1~~3~~2: Annual Bulletin 118 Basin Aquifer Water Budget

The Bulletin 118 groundwater budget demonstrates a decrease in interannual variability as the high natural recharge in the watershed slowly travels through the Quaternary Volcanics aquifer provid~~-~~ing subsurface inflow, designated as Lateral Groundwater Inflow Figure 13~~12~~. ~~Again~~Again, the groundwater pumping is relatively constant between years as most crops are grown in the summer and require ~~a relatively~~relatively constant irrigation each year. As a result of this the interannual change in storage for the Bulletin 118 groundwater basin is much less pronounced than the change in storage for the watershed groundwater basin.

8.5 Bulletin 118 Groundwater Budget for Select Water Year Types



Monthly values of selected water budget components for the Bullet-118 Butte Valley, CA

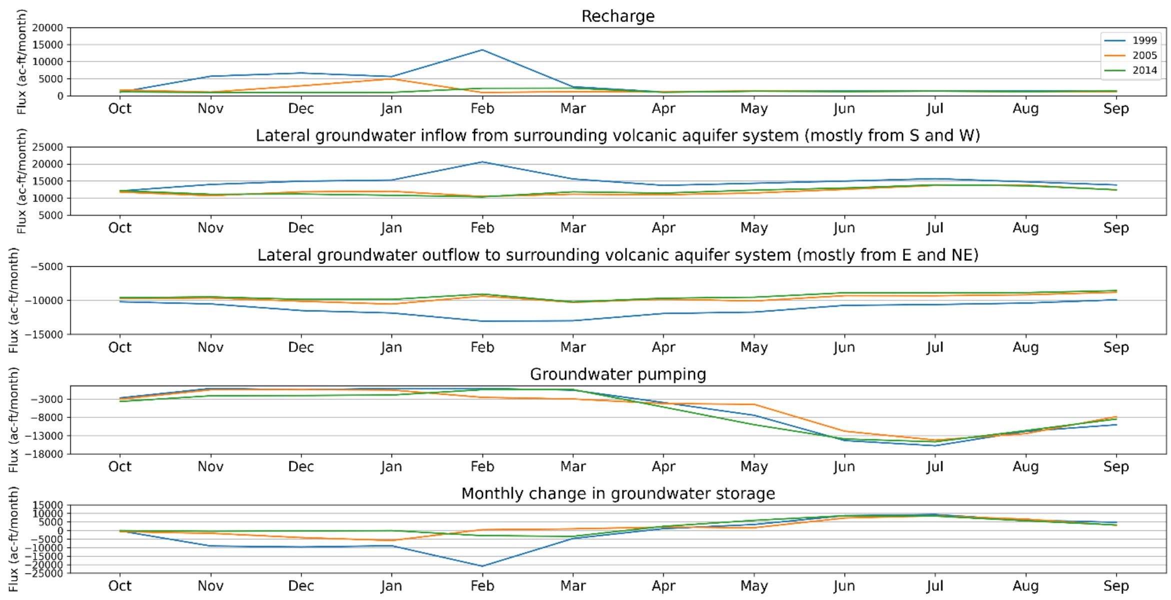


Figure 14~~3~~: Monthly Bulletin 118 Basin Aquifer Water Budget for selected water year types (i.e. 2014~~Dry~~, 2005~~Average~~, - and 1999 as Dry, Average, and Wet years respectively)

Selected water years were plotted to represent the 5 categories of water years developed by DWR to aid in GSP development (DWR 2021). The major difference between selected water year types is a large peak in recharge in the wet year that is entirely missing in critically dry years and a corresponding relationship in lateral groundwater inflow (driven by recharge in the upgradient watershed area, outside the Basin). Lateral groundwater outflow increases over several months after the recharge and inflow peaks, coinciding with the pumping season. The lateral groundwater out- flow and groundwater pumping remain relatively similar between years. Thus, there is an increase in groundwater storage due to the increase in groundwater recharge and inflow during the wet year Figure 14~~13~~.

8.6 Tables of Annual Sum Water Budgets

Table 7: Table of Annual Model Area Aquifer Water Budget in TAF

WY~~D~~	From Recharge	From GHB	To GHB	To Constant Head	From Constant Head	To Wells
1990	185.03	0.00	-119.24	-35.34	18.22	-75.43
1991	115.48	0.00	-117.50	-34.04	18.79	-77.36
1992	48.47	0.00	-114.30	-33.05	19.31	-78.65
1993	399.65	0.00	-117.17	-37.72	17.18	-66.47
1994	83.70	0.00	-116.15	-33.88	18.83	-76.77
1995	467.93	0.00	-120.35	-38.61	16.84	-74.62
1996	485.76	0.00	-128.99	-40.40	16.27	-82.90
1997	342.15	0.00	-134.30	-39.91	16.40	-86.92
1998	415.86	0.00	-137.57	-39.66	16.52	-80.11
1999	409.77	0.00	-142.69	-40.94	15.96	-88.95
2000	219.51	0.00	-142.97	-37.76	17.37	-91.38
2001	57.51	0.00	-138.18	-34.48	18.66	-90.82
2002	330.51	0.00	-138.27	-38.40	16.97	-98.75
2003	211.93	0.00	-135.90	-36.64	17.70	-90.75
2004	296.58	0.00	-136.46	-38.14	17.15	-93.74
2005	135.24	0.00	-133.76	-34.74	18.52	-87.21
2006	454.35	0.00	-137.23	-40.49	16.14	-94.36
2007	223.00	0.00	-137.27	-37.60	17.30	-92.77
2008	343.66	0.00	-140.33	-39.06	16.82	-79.48
2009	215.59	0.00	-139.76	-37.04	17.56	-83.28
2010	141.75	0.00	-136.84	-35.48	18.21	-78.99
2011	405.45	0.00	-139.04	-39.09	16.69	-78.92
2012	190.00	0.00	-138.61	-36.71	17.76	-103.55
2013	238.43	0.00	-137.72	-36.84	17.58	-118.76
2014	85.62	0.00	-132.75	-34.69	18.53	-105.19
2015	184.76	0.00	-129.58	-35.64	18.12	-92.30
2016	299.52	0.00	-130.45	-37.61	17.34	-108.48
2017	90.05	0.00	-127.13	-34.51	18.59	-111.39
2018	215.44	0.00	-124.03	-35.87	18.00	-105.84

~~**Table 7:** Table of Annual Model Area Aquifer Water Budget~~

~~Date~~	~~From Recharge~~	~~From GHB~~	~~To GHB~~	~~To Constant Head~~	~~From Constant Head~~	~~To Wells~~
~~1989~~	~~32.58~~	~~0.06~~	~~-22.22~~	~~-26.29~~	~~10.92~~	~~-14.25~~
~~1990~~	~~209.17~~	~~0.45~~	~~-129.18~~	~~-153.96~~	~~64.78~~	~~-109.72~~
~~1991~~	~~137.57~~	~~0.62~~	~~-125.49~~	~~-152.05~~	~~65.70~~	~~-114.76~~
~~1992~~	~~70.88~~	~~0.84~~	~~-121.49~~	~~-150.69~~	~~66.77~~	~~-112.34~~
~~1993~~	~~433.00~~	~~0.75~~	~~-123.44~~	~~-154.16~~	~~64.50~~	~~-88.51~~
~~1994~~	~~106.18~~	~~0.81~~	~~-119.75~~	~~-150.94~~	~~66.27~~	~~-115.70~~
~~1995~~	~~500.94~~	~~0.72~~	~~-122.39~~	~~-155.08~~	~~64.17~~	~~-100.18~~
~~1996~~	~~529.43~~	~~0.48~~	~~-127.70~~	~~-157.66~~	~~63.30~~	~~-104.94~~
~~1997~~	~~375.49~~	~~0.34~~	~~-129.36~~	~~-157.42~~	~~63.03~~	~~-110.56~~
~~1998~~	~~445.53~~	~~0.33~~	~~-130.39~~	~~-157.21~~	~~63.13~~	~~-104.42~~
~~1999~~	~~445.49~~	~~0.26~~	~~-133.00~~	~~-158.56~~	~~62.38~~	~~-114.56~~
~~2000~~	~~244.94~~	~~0.31~~	~~-130.90~~	~~-155.97~~	~~64.13~~	~~-119.85~~
~~2001~~	~~80.38~~	~~0.50~~	~~-125.46~~	~~-151.88~~	~~65.75~~	~~-140.52~~
~~2002~~	~~360.39~~	~~0.55~~	~~-125.02~~	~~-154.90~~	~~64.18~~	~~-139.92~~
~~2003~~	~~237.63~~	~~0.64~~	~~-121.02~~	~~-153.39~~	~~65.05~~	~~-131.39~~
~~2004~~	~~334.56~~	~~0.66~~	~~-120.71~~	~~-154.81~~	~~64.69~~	~~-132.26~~
~~2005~~	~~168.43~~	~~0.81~~	~~-116.55~~	~~-151.15~~	~~66.21~~	~~-137.38~~
~~2006~~	~~500.17~~	~~0.70~~	~~-119.57~~	~~-156.18~~	~~63.62~~	~~-140.88~~
~~2007~~	~~261.39~~	~~0.68~~	~~-117.11~~	~~-154.01~~	~~64.81~~	~~-143.33~~
~~2008~~	~~373.78~~	~~0.64~~	~~-118.74~~	~~-155.29~~	~~64.43~~	~~-133.64~~
~~2009~~	~~244.32~~	~~0.72~~	~~-115.59~~	~~-153.20~~	~~65.19~~	~~-138.98~~
~~2010~~	~~162.65~~	~~0.94~~	~~-111.55~~	~~-151.19~~	~~66.16~~	~~-136.05~~
~~2011~~	~~429.81~~	~~0.91~~	~~-112.75~~	~~-154.11~~	~~64.66~~	~~-110.69~~
~~2012~~	~~215.36~~	~~0.99~~	~~-110.67~~	~~-152.41~~	~~65.99~~	~~-149.14~~
~~2013~~	~~275.40~~	~~1.00~~	~~-109.50~~	~~-151.98~~	~~65.79~~	~~-173.25~~
~~2014~~	~~116.32~~	~~1.27~~	~~-104.22~~	~~-149.58~~	~~67.04~~	~~-166.70~~
~~2015~~	~~216.52~~	~~1.48~~	~~-100.99~~	~~-150.05~~	~~66.83~~	~~-141.39~~
~~2016~~	~~335.95~~	~~1.43~~	~~-101.43~~	~~-151.97~~	~~66.20~~	~~-153.43~~
~~2017~~	~~121.15~~	~~1.62~~	~~-97.59~~	~~-148.73~~	~~67.54~~	~~-157.62~~
~~2018~~	~~237.10~~	~~1.62~~	~~-87.23~~	~~-137.00~~	~~61.31~~	~~-156.02~~

Table 8: Annual Land/Soil Subsystem Water Budget (CRZWM) within model area in TAF~~Basin Root Zone Budget Limited to Irrigated Lands~~

WY	Applied Water	Crop ET	Deep Percolation	Precipitation	Precipitation Runoff	Tailwater	dStorage
1990	78.95	-86.54	-41.49	37.71	-2.22	0	0.19
1991	80.89	-80.84	-36.84	26.71	-0.54	0	-0.56
1992	81.60	-75.91	-36.08	21.63	-0.23	0	-0.04
1993	69.19	-87.19	-54.28	54.75	-2.43	0	0.27
1994	79.67	-76.86	-36.16	24.34	-0.45	0	0.19
1995	77.40	-97.39	-55.62	56.45	-2.83	0	0.16
1996	85.72	-93.60	-62.91	54.65	-3.91	0	-0.32
1997	88.50	-99.38	-59.25	54.32	-3.92	0	0.04
1998	82.84	-109.73	-53.61	58.66	-2.24	0	-0.63
1999	90.99	-92.20	-57.56	45.85	-2.87	0	0.27
2000	93.38	-97.85	-44.70	36.87	-1.87	0	-0.19
2001	94.59	-91.51	-36.24	23.41	-0.20	0	-0.27
2002	99.89	-102.31	-48.65	39.07	-1.40	0	0.54
2003	92.59	-102.37	-44.17	38.62	-1.30	0	-0.74
2004	96.34	-99.11	-44.88	35.64	-1.39	0	0.56
2005	101.84	-108.16	-59.50	43.41	-2.45	0	-8.00
2006	111.93	-112.40	-69.65	53.56	-4.53	0	0.46
2007	110.90	-110.36	-52.53	39.35	-1.33	0	0.34
2008	96.32	-95.28	-47.53	34.15	-1.18	0	-0.63
2009	100.71	-102.72	-43.09	33.64	-0.55	0	0.19
2010	95.50	-95.28	-41.00	29.20	-0.29	0	-0.12
2011	85.66	-98.04	-53.82	49.87	-1.61	0	0.32
2012	110.37	-111.87	-44.36	33.80	-0.74	0	-0.49
2013	129.94	-128.48	-54.86	38.99	-1.46	0	-0.71
2014	115.41	-111.10	-43.20	29.36	-1.28	0	0.10
2015	102.47	-113.21	-50.53	44.31	-1.78	0	-1.45
2016	117.34	-120.99	-55.24	43.80	-1.94	0	0.27
2017	121.07	-132.82	-54.13	48.58	-1.97	0	-0.07
2018	118.12	-115.54	-43.60	30.50	-0.58	0	0.91

~~Date~~	~~Applied Water~~	~~Crop ET~~	~~Deep Percolation~~	~~Precipitation~~	~~Precipitation Runoff~~	~~Tailwater~~	~~dStorage~~
~~1989~~	~~68.89~~	~~-107.06~~	~~-38.28~~	~~79.02~~	~~-3.35~~	~~0~~	~~-0.80~~
~~1990~~	~~67.37~~	~~-105.69~~	~~-45.22~~	~~86.56~~	~~-6.53~~	~~0~~	~~-3.54~~
~~1991~~	~~63.93~~	~~-90.80~~	~~-38.15~~	~~65.33~~	~~-1.83~~	~~0~~	~~-1.55~~
~~1992~~	~~63.25~~	~~-81.97~~	~~-35.39~~	~~57.88~~	~~-0.88~~	~~0~~	~~2.86~~
~~1993~~	~~60.90~~	~~-114.10~~	~~-69.82~~	~~129.18~~	~~-7.59~~	~~0~~	~~-1.47~~
~~1994~~	~~65.24~~	~~-83.26~~	~~-37.97~~	~~55.00~~	~~-1.36~~	~~0~~	~~-2.38~~
~~1995~~	~~66.67~~	~~-121.62~~	~~-70.65~~	~~135.52~~	~~-8.48~~	~~0~~	~~1.41~~
~~1996~~	~~79.19~~	~~-119.46~~	~~-83.31~~	~~142.00~~	~~-12.03~~	~~0~~	~~6.36~~
~~1997~~	~~81.32~~	~~-126.63~~	~~-76.27~~	~~132.30~~	~~-11.57~~	~~0~~	~~-0.89~~
~~1998~~	~~77.25~~	~~-142.01~~	~~-69.92~~	~~137.49~~	~~-6.55~~	~~0~~	~~-3.78~~
~~1999~~	~~83.12~~	~~-108.89~~	~~-77.35~~	~~115.10~~	~~-9.75~~	~~0~~	~~2.20~~
~~2000~~	~~79.44~~	~~-114.10~~	~~-51.04~~	~~88.86~~	~~-5.15~~	~~0~~	~~-2.03~~
~~2001~~	~~76.11~~	~~-90.77~~	~~-35.02~~	~~47.59~~	~~-0.36~~	~~0~~	~~-2.48~~
~~2002~~	~~80.18~~	~~-103.89~~	~~-55.95~~	~~83.33~~	~~-3.83~~	~~0~~	~~-0.19~~
~~2003~~	~~75.11~~	~~-107.32~~	~~-50.47~~	~~86.16~~	~~-3.11~~	~~0~~	~~0.34~~
~~2004~~	~~73.93~~	~~-103.55~~	~~-51.43~~	~~93.79~~	~~-3.98~~	~~0~~	~~8.73~~
~~2005~~	~~80.66~~	~~-113.68~~	~~-54.53~~	~~82.79~~	~~-6.09~~	~~0~~	~~-10.86~~
~~2006~~	~~96.37~~	~~-124.02~~	~~-80.98~~	~~119.38~~	~~-11.33~~	~~0~~	~~-0.61~~
~~2007~~	~~88.54~~	~~-125.89~~	~~-52.51~~	~~97.07~~	~~-4.87~~	~~0~~	~~2.29~~
~~2008~~	~~78.91~~	~~-95.44~~	~~-47.95~~	~~64.45~~	~~-2.28~~	~~0~~	~~-2.33~~
~~2009~~	~~74.75~~	~~-104.28~~	~~-42.94~~	~~75.42~~	~~-1.71~~	~~0~~	~~1.21~~
~~2010~~	~~69.66~~	~~-94.75~~	~~-40.02~~	~~74.57~~	~~-2.44~~	~~0~~	~~6.98~~
~~2011~~	~~69.07~~	~~-109.48~~	~~-59.05~~	~~95.47~~	~~-2.81~~	~~0~~	~~-6.84~~
~~2012~~	~~86.67~~	~~-119.78~~	~~-41.49~~	~~69.62~~	~~-1.82~~	~~0~~	~~-6.82~~
~~2013~~	~~97.69~~	~~-127.34~~	~~-46.13~~	~~77.54~~	~~-2.87~~	~~0~~	~~-1.15~~
~~2014~~	~~82.15~~	~~-105.33~~	~~-37.37~~	~~72.69~~	~~-4.09~~	~~0~~	~~8.01~~
~~2015~~	~~77.27~~	~~-110.39~~	~~-50.87~~	~~86.03~~	~~-3.37~~	~~0~~	~~-1.36~~
~~2016~~	~~86.84~~	~~-120.49~~	~~-59.01~~	~~107.31~~	~~-5.36~~	~~0~~	~~9.26~~
~~2017~~	~~99.28~~	~~-134.95~~	~~-55.05~~	~~82.49~~	~~-3.64~~	~~0~~	~~-11.90~~
~~2018~~	~~89.82~~	~~-114.13~~	~~-38.95~~	~~64.55~~	~~-1.37~~	~~0~~	~~-0.11~~
~~2019~~	~~2.34~~	~~-7.58~~	~~-6.25~~	~~17.84~~	~~-0.68~~	~~0~~	~~5.66~~

Table 9: Table of Annual Bulletin 118 Basin Aquifer Water Budget in TAF

~~Date~~WY	From Recharge	From ~~Groundwater~~Aquifer Storage	To ~~Groundwater~~Aquifer Storage	To Wells
1990	23.07~~38.22~~	24.78~~183.61~~	-26.15~~-179.33~~	-55.99~~-66.04~~
1991	14.98~~29.84~~	10.00~~179.39~~	-26.95~~-180.19~~	-58.56~~-70.77~~
1992	12.47~~26.12~~	5.77~~175.90~~	-28.49~~-179.14~~	-60.08~~-70.39~~
1993	42.79~~62.15~~	62.64~~187.91~~	-27.81~~-169.75~~	-51.85~~-54.11~~
1994	13.12~~27.46~~	6.13~~174.10~~	-25.40~~-174.61~~	-56.84~~-70.52~~
1995	47.01~~67.23~~	71.56~~191.84~~	-32.29~~-167.58~~	-56.68~~-61.01~~
1996	53.15~~75.35~~	81.14~~198.88~~	-39.40~~-167.87~~	-64.64~~-63.87~~
1997	40.39~~61.07~~	54.61~~192.06~~	-40.23~~-170.31~~	-67.98~~-67.43~~
1998	40.07~~58.16~~	55.75~~193.49~~	-36.56~~-171.72~~	-62.55~~-64.50~~
1999	42.98~~63.43~~	59.86~~197.22~~	-39.95~~-173.02~~	-67.22~~-67.84~~
2000	25.76~~41.40~~	28.54~~188.44~~	-38.91~~-177.36~~	-68.70~~-71.93~~
2001	12.41~~26.91~~	3.49~~180.02~~	-37.51~~-179.92~~	-67.06~~-85.05~~
2002	37.09~~55.09~~	47.21~~192.94~~	-39.60~~-172.71~~	-72.90~~-82.86~~
2003	21.29~~37.83~~	23.24~~184.73~~	-34.83~~-173.49~~	-65.69~~-76.54~~

2004	31.95~~49.62~~	43.07~~192.20~~	-36.45~~-170.26~~	-69.24~~-78.35~~
2005	20.21~~43.63~~	15.42~~179.27~~	-33.84~~-172.63~~	-64.81~~-80.04~~
2006	45.41~~71.36~~	65.70~~196.80~~	-37.87~~-167.06~~	-70.37~~-80.91~~
2007	26.39~~47.13~~	30.15~~186.77~~	-34.53~~-168.04~~	-68.75~~-83.84~~
2008	36.22~~52.84~~	52.06~~193.42~~	-32.81~~-166.35~~	-58.66~~-77.24~~
2009	22.85~~40.15~~	26.17~~186.02~~	-32.64~~-168.30~~	-60.78~~-80.38~~
2010	14.83~~30.15~~	11.04~~177.25~~	-28.91~~-169.57~~	-56.34~~-75.78~~
2011	38.45~~54.82~~	55.54~~189.56~~	-33.29~~-163.90~~	-57.69~~-61.60~~
2012	22.45~~36.61~~	21.68~~181.89~~	-38.11~~-167.80~~	-74.46~~-82.27~~
2013	31.41~~50.38~~	34.58~~187.00~~	-42.75~~-164.46~~	-86.34~~-97.67~~
2014	15.83~~32.04~~	11.31~~178.12~~	-38.58~~-164.64~~	-74.33~~-94.91~~
2015	23.29~~39.59~~	27.75~~178.32~~	-34.43~~-159.80~~	-63.97~~-77.16~~
2016	33.94~~52.03~~	45.44~~183.95~~	-39.92~~-157.09~~	-74.99~~-83.39~~
2017	19.07~~33.59~~	15.38~~170.90~~	-42.55~~-158.04~~	-78.07~~-86.07~~
2018	23.66~~35.81~~	29.83~~161.70~~	-35.00~~-140.60~~	-73.01~~-85.93~~

Table 10: Table of Annual Land/Soil Subsystem Water Budget (CRZWM) within Bulletin 118 groundwater basin in TAF

WY	Applied Water	Crop ET	Deep Percolation	Precipitation	Precipitation Runoff	Tailwater	dStorage
1990	56.06	-61.46	-30.49	37.71	-1.71	0	0.11
1991	58.48	-58.41	-26.83	26.71	-0.41	0	-0.48
1992	59.92	-55.20	-26.36	21.63	-0.16	0	-0.18
1993	52.04	-64.22	-40.21	54.75	-1.82	0	0.53
1994	56.70	-54.45	-26.27	24.34	-0.33	0	-0.02
1995	56.53	-70.12	-40.71	56.45	-2.00	0	0.14
1996	64.39	-69.19	-47.18	54.65	-2.97	0	-0.31
1997	66.70	-73.50	-44.34	54.32	-2.89	0	0.28
1998	61.89	-79.66	-39.55	58.66	-1.72	0	-0.39
1999	66.24	-66.24	-43.20	45.85	-2.29	0	0.35
2000	67.63	-70.16	-33.22	36.87	-1.41	0	-0.31
2001	66.91	-64.26	-26.47	23.41	-0.13	0	-0.55
2002	71.01	-72.39	-35.89	39.07	-1.15	0	0.64
2003	64.13	-70.58	-31.93	38.62	-0.93	0	-0.71
2004	68.44	-70.27	-32.53	35.64	-0.93	0	0.33
2005	72.61	-76.16	-43.92	43.41	-1.95	0	-6.02
2006	80.28	-79.24	-50.99	53.56	-3.34	0	0.25
2007	79.00	-78.87	-38.31	39.35	-1.09	0	0.07
2008	68.30	-67.29	-34.53	34.15	-0.96	0	-0.34
2009	70.17	-72.06	-31.04	33.64	-0.47	0	0.23
2010	64.72	-64.89	-28.99	29.20	-0.24	0	-0.21
2011	60.29	-69.37	-39.20	49.87	-1.33	0	0.24
2012	76.07	-77.51	-32.20	33.80	-0.62	0	-0.47
2013	90.79	-89.96	-39.51	38.99	-1.05	0	-0.76
2014	78.45	-76.12	-30.55	29.36	-1.03	0	0.10
2015	69.72	-77.88	-35.85	44.31	-1.33	0	-1.04
2016	78.92	-81.90	-39.32	43.80	-1.41	0	0.08
2017	82.57	-90.19	-39.23	48.58	-1.54	0	0.17
2018	80.04	-78.36	-31.16	30.50	-0.45	0	0.56

9 Climate Projection Scenarios

Under their SGMA climate change guidance, DWR provided a dataset of climate change factors which each GSA can use to convert local historical weather data into 4 different climate change scenarios (DWR 2018). Change factors are geographically and temporally explicit. Geographically, a grid of 1/16-degree resolution cells covers the extent of California; for each of these cells, one change factors applies to each month, 1911-2011. The plots of precipitation and evapotranspiration demonstrate the impact of the change factors on the inputs to the BVIHM both directly and to the PRMS model that calculates recharge as an input to the MODFLOW model (see the Butte Valley Groundwater Sustainability Plan Chapter 2.2.4 for further explanation of the future climate scenario construction).

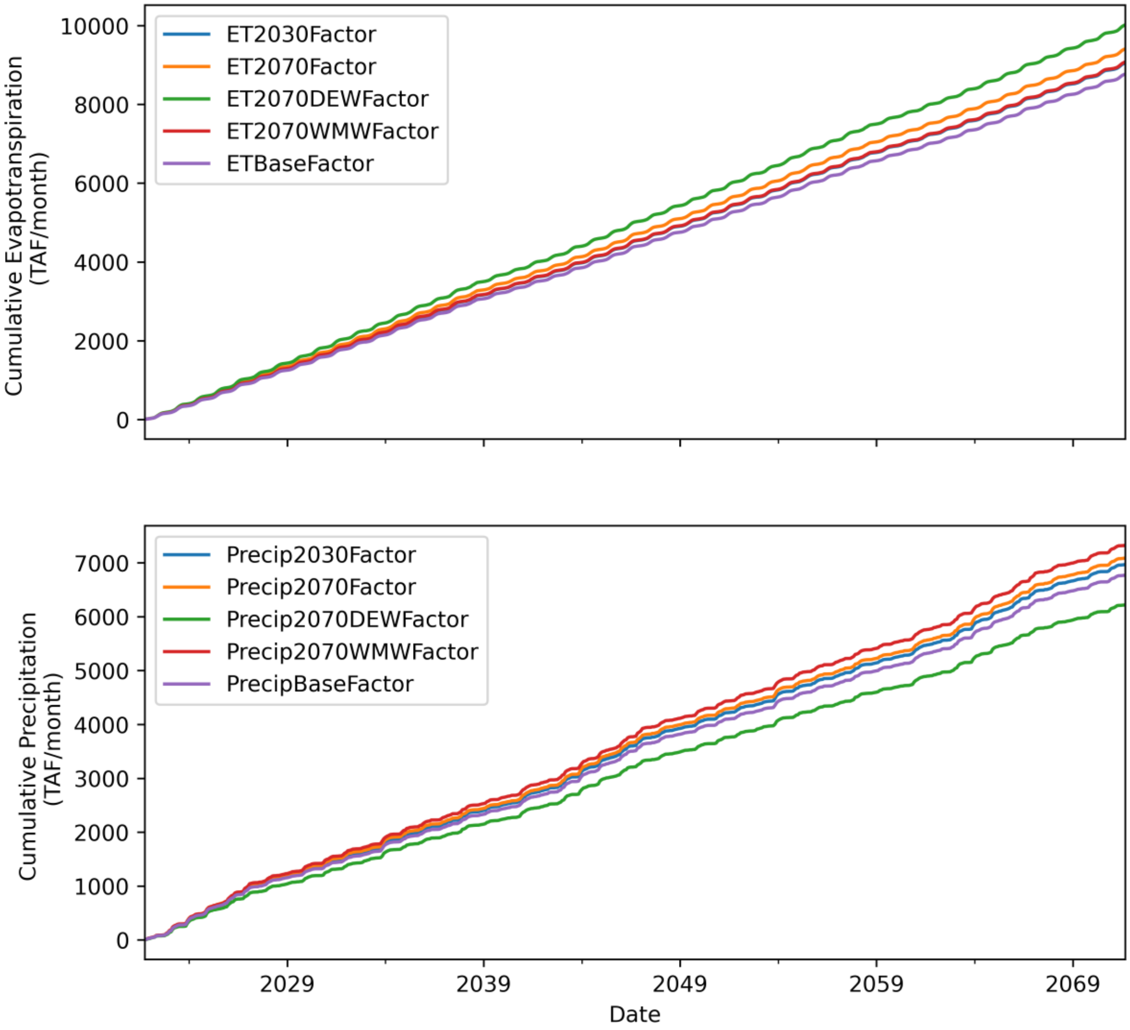


Figure 15~~14~~: Future Climate Projections of Precipitation and Actual Evapotranspiration for the Butte Valley Watershed

The 2030 (Near) and 2070 central tendency (Far) scenarios predict similar rainfall conditions to the Base case, while the 2070 DEW (Dry) and 2070 WMW (Wet) scenarios show less and more cumulative rain, respectively. Conversely, all scenarios predict higher future ET than the Base case.

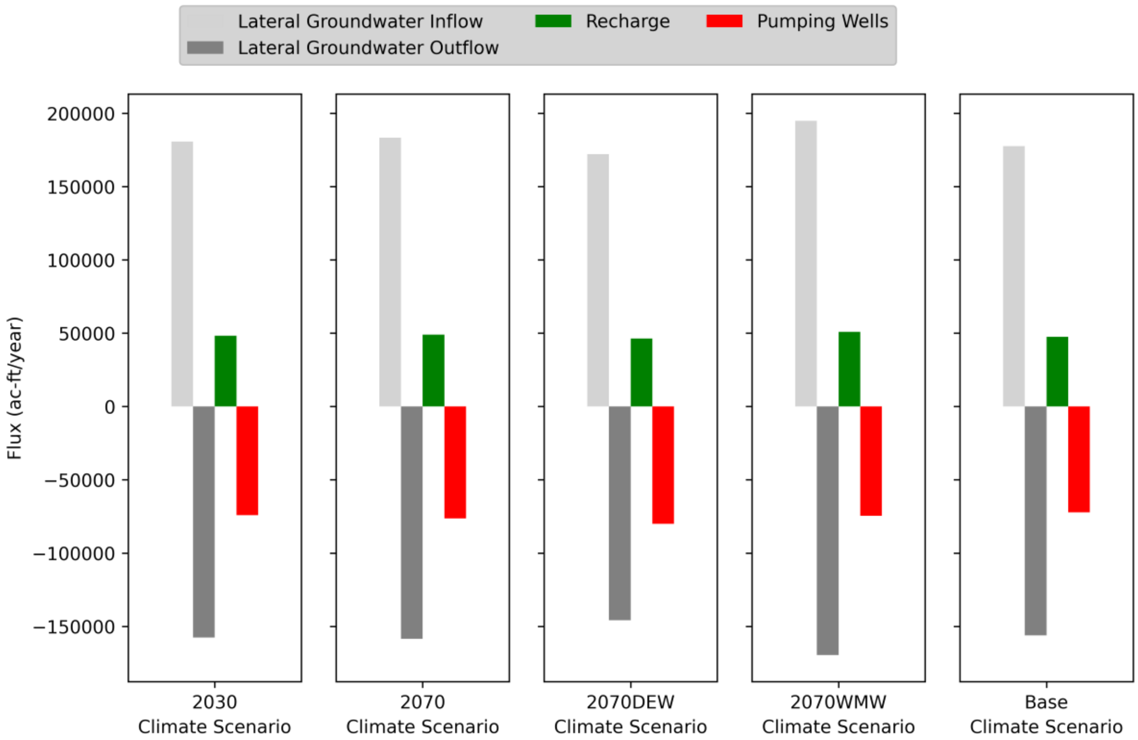


Figure 16~~15~~: Average Bulletin 118 Basin Water Budget 1990-2070

These climate change scenarios directly impact the monthly groundwater recharge, precipitation dependent, and groundwater pumping, evapotranspiration dependent. All of the climate change scenarios expect the 2070 DEW predict an increase in both ~~precipitation and~~precipitation and ~~evapotranspi~~evapotranspiration- ration for Butte Valley that lead to an overall increase in groundwater storage over the 50 year future modeled climate scenarios. The 2070 DEW climate scenario depicted losses in groundwa~~—~~ter storage in Butte Valley for the recent future until groundwater levels were lowered such that the subsurface outflow to the Lower Klamath Lake Basin was reduced, stabilizing water levels in the Basin itself.

9.1 Future Climate Individual Annual Water Budget Plots

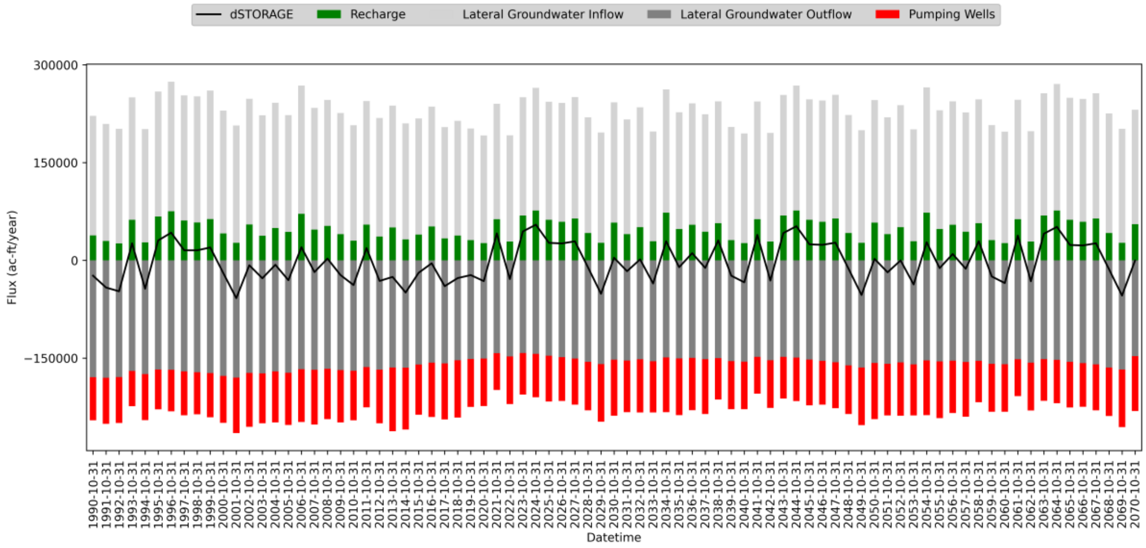


Figure 17~~16~~: Bulletin 118 Basin Water Budgets from 1990-2070 for 2030 Climate Scenario

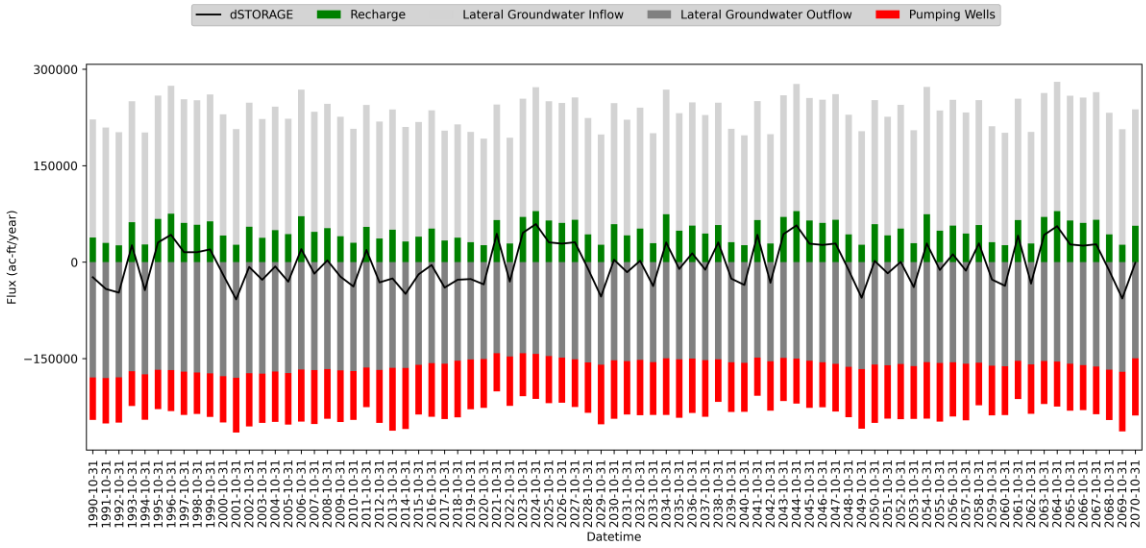


Figure 18~~17~~: Bulletin 118 Basin Water Budgets from 1990-2070 for 2070 Climate Scenario

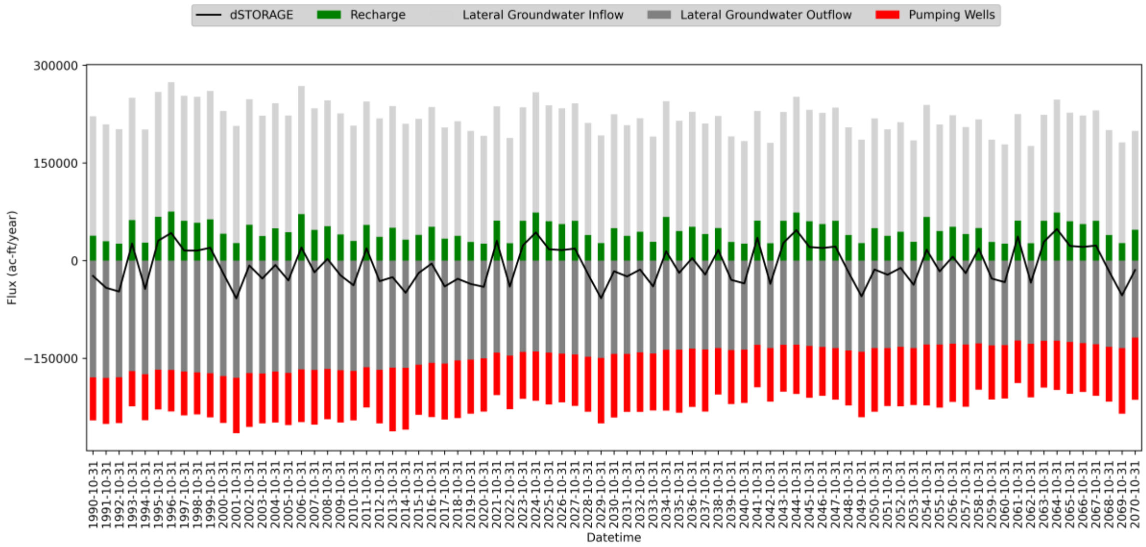


Figure 19~~18~~: Bulletin 118 Basin Water Budgets from 1990-2070 for 2070DEW Climate Scenario

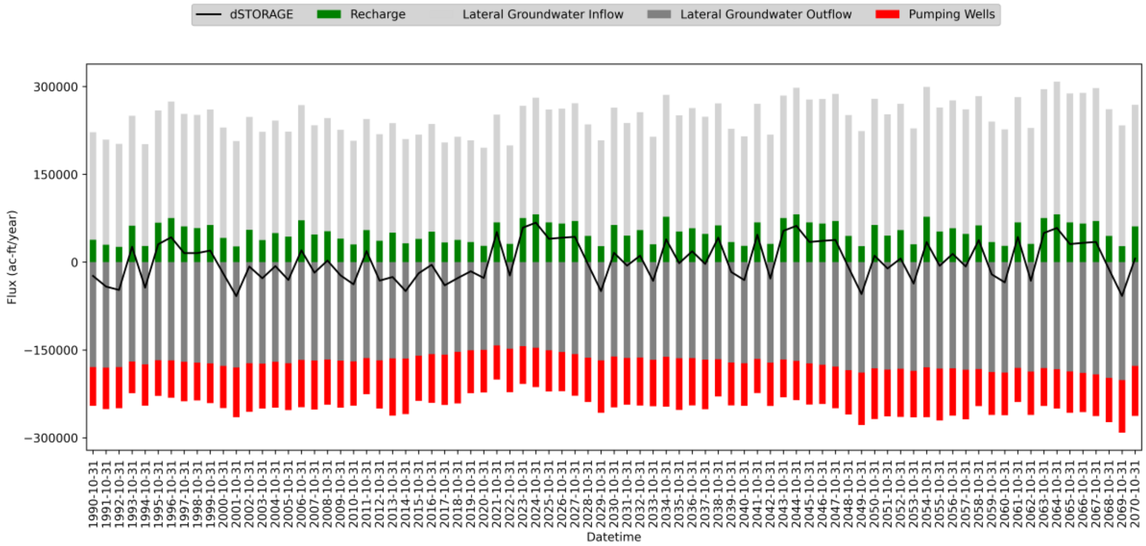


Figure 20~~19~~: Bulletin 118 Basin Water Budgets from 1990-2070 for 2070WMW Climate Scenario

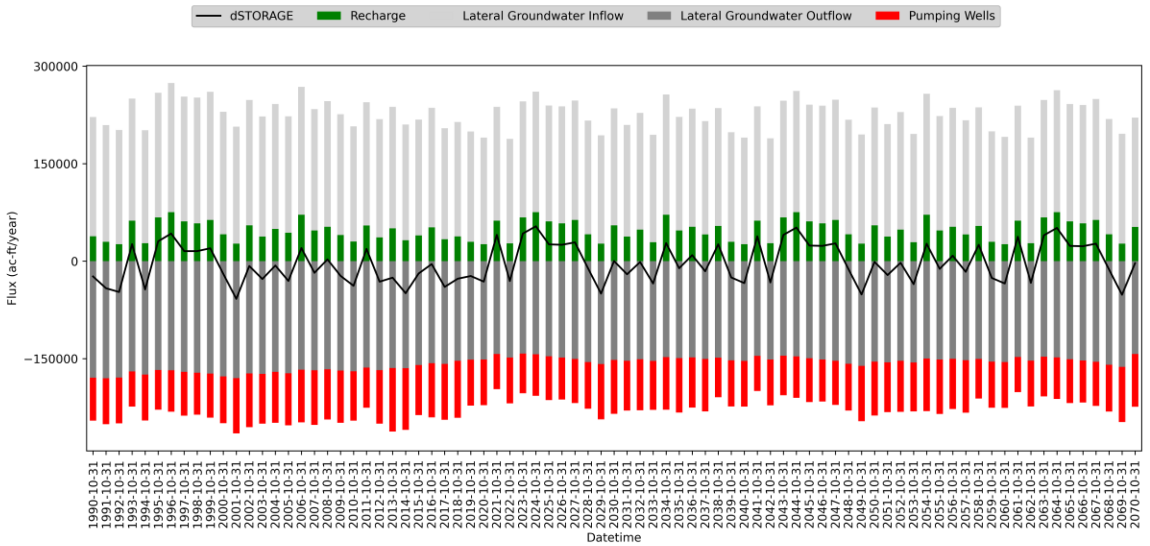


Figure 21~~20~~: Bulletin 118 Basin Water Budgets from 1990-2070 for base Climate Scenario

9.2 Tables of Future Climate Individual Annual Water Budget Data

Table 11~~10~~: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2030 Climate Scenario in TAF

Year	From Recharge	From ~~Groundwater~~Aquifer Storage	To ~~Groundwater~~Aquifer Storage	To Wells
2019	31.11	171.28	-151.30	-73.69
2020	26.39	165.32	-150.71	-72.83
2021	63.19	177.22	-142.49	-56.51
2022	28.94	163.00	-147.44	-73.12
2023	68.78	181.60	-142.10	-63.93
2024	76.34	188.44	-143.45	-66.56
2025	62.19	181.27	-146.39	-70.21
2026	59.16	182.53	-148.56	-67.14
2027	64.19	186.41	-150.74	-70.66
2028	41.96	177.56	-155.65	-74.60
2029	26.91	169.26	-159.14	-88.37
2030	57.86	184.67	-152.36	-86.16
2031	40.28	176.07	-153.81	-79.18
2032	50.88	184.08	-151.73	-81.76
2033	29.37	168.45	-154.96	-78.37
2034	73.08	189.33	-148.98	-84.07
2035	48.15	179.04	-150.58	-87.09
2036	54.56	186.50	-149.60	-80.38
2037	43.86	180.28	-151.66	-84.13
2038	57.06	187.05	-150.09	-63.42
2039	31.11	173.69	-154.66	-73.69
2040	26.39	168.26	-155.51	-72.83
2041	63.19	180.53	-148.09	-56.51
2042	28.95	166.53	-153.40	-73.12

Table 11~~10~~: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2030 Climate Scenario in TAF*(continued)*

Year	From Recharge	From ~~Groundwater~~Aquifer Storage	To ~~Groundwater~~Aquifer Storage	To Wells
2043	68.78	185.07	-148.01	-63.93
2044	76.34	191.92	-149.30	-66.56
2045	62.19	184.83	-152.22	-70.21
2046	59.16	186.08	-154.27	-67.14
2047	64.19	189.92	-156.30	-70.66
2048	41.96	181.09	-161.14	-74.60
2049	26.91	172.75	-164.48	-88.37
2050	57.86	188.03	-157.48	-86.16
2051	40.28	179.42	-158.83	-79.18
2052	50.88	187.34	-156.60	-81.76
2053	29.37	171.70	-159.72	-78.37
2054	73.08	192.43	-153.53	-84.07
2055	48.15	182.11	-155.05	-87.09
2056	54.56	189.48	-153.92	-80.38
2057	43.86	183.25	-155.91	-84.13
2058	57.06	189.94	-154.21	-63.42
2059	31.11	176.56	-158.72	-73.69
2060	26.39	171.07	-159.47	-72.83
2061	63.19	183.19	-151.86	-56.51
2062	28.95	169.21	-157.14	-73.12
2063	68.78	187.61	-151.57	-63.93
2064	76.34	194.39	-152.77	-66.56
2065	62.19	187.30	-155.64	-70.21
2066	59.16	188.51	-157.63	-67.14
2067	64.19	192.28	-159.56	-70.66
2068	41.96	183.44	-164.36	-74.60
2069	26.91	175.06	-167.63	-88.37
2070	55.52	175.57	-146.96	-84.39

Table 12~~11~~: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070 Climate Scenario in TAF

Year	From Recharge	From ~~Groundwater~~Aquifer Storage	To ~~Groundwater~~Aquifer Storage	To Wells
2019	30.88	171.52	-151.46	-77.30
2020	26.21	165.79	-150.67	-75.97
2021	65.39	179.62	-141.57	-59.41
2022	29.06	164.27	-146.79	-76.81
2023	70.23	183.92	-141.67	-66.97
2024	79.19	192.71	-142.86	-69.85
2025	64.71	185.38	-146.14	-73.23
2026	61.07	186.32	-148.55	-70.13
2027	65.86	190.26	-151.18	-74.10
2028	43.06	181.02	-155.94	-78.39

Table 12~~11~~: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070 Climate Scenario in TAF *(continued)*

Year	From Recharge	From ~~Groundwater~~Aquifer Storage	To ~~Groundwater~~Aquifer Storage	To Wells
2029	26.91	171.68	-159.59	-92.63
2030	58.92	188.34	-152.73	-90.88
2031	41.50	179.84	-153.93	-83.08
2032	52.08	188.02	-152.09	-85.99
2033	29.41	171.10	-155.64	-82.15
2034	74.47	193.73	-149.65	-87.96
2035	48.77	182.79	-151.17	-91.03
2036	56.73	191.53	-150.12	-84.47
2037	44.42	184.21	-152.43	-88.03
2038	57.58	190.39	-151.10	-66.28
2039	30.88	176.51	-155.83	-77.30
2040	26.21	171.02	-156.76	-75.97
2041	65.39	185.00	-148.54	-59.41
2042	29.07	169.79	-154.21	-76.81
2043	70.23	189.22	-149.01	-66.97
2044	79.19	197.92	-150.15	-69.85
2045	64.71	190.61	-153.43	-73.23
2046	61.07	191.49	-155.74	-70.13
2047	65.86	195.31	-158.20	-74.10
2048	43.06	186.07	-162.91	-78.39
2049	26.91	176.64	-166.41	-92.63
2050	58.92	193.09	-159.28	-90.88
2051	41.50	184.54	-160.38	-83.08
2052	52.08	192.60	-158.36	-85.99
2053	29.41	175.63	-161.80	-82.15
2054	74.47	198.02	-155.55	-87.96
2055	48.77	187.05	-156.98	-91.03
2056	56.73	195.64	-155.74	-84.47
2057	44.42	188.30	-157.97	-88.03
2058	57.58	194.36	-156.49	-66.28
2059	30.88	180.45	-161.15	-77.30
2060	26.21	174.86	-161.96	-75.97
2061	65.39	188.63	-153.49	-59.41
2062	29.07	173.44	-159.14	-76.81
2063	70.23	192.67	-153.71	-66.97
2064	79.19	201.27	-154.72	-69.85
2065	64.71	193.95	-157.95	-73.23
2066	61.07	194.77	-160.17	-70.13
2067	65.86	198.50	-162.51	-74.10
2068	43.06	189.25	-167.18	-78.39
2069	26.91	179.76	-170.60	-92.63
2070	56.58	181.00	-149.53	-89.12

Table 13~~12~~: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070DEW Climate Scenario in TAF

Year	From Recharge	From ~~Groundwater~~Aquifer Storage	To ~~Groundwater~~Aquifer Storage	To Wells
2019	28.71	170.54	-152.07	-83.05
2020	26.11	165.45	-150.00	-81.85
2021	61.48	175.61	-141.28	-65.30
2022	26.73	161.60	-145.85	-82.32
2023	61.13	174.28	-140.29	-71.88
2024	73.86	184.75	-139.60	-75.67
2025	60.44	178.12	-141.39	-79.70
2026	56.16	177.76	-142.76	-74.98
2027	61.15	180.54	-144.11	-79.12
2028	39.25	172.22	-147.74	-84.30
2029	26.91	165.43	-149.39	-100.68
2030	49.82	174.94	-143.33	-97.79
2031	38.10	169.85	-143.20	-89.07
2032	44.46	174.16	-140.90	-91.49
2033	28.80	161.68	-142.73	-87.39
2034	67.11	177.77	-136.90	-93.56
2035	45.55	169.24	-136.77	-96.83
2036	52.06	176.57	-135.14	-89.59
2037	40.85	169.75	-136.45	-95.54
2038	50.07	172.08	-134.44	-71.22
2039	28.71	162.12	-137.34	-83.05
2040	26.11	157.50	-136.80	-81.85
2041	61.48	168.26	-129.37	-65.30
2042	26.73	154.19	-134.31	-82.32
2043	61.13	167.22	-129.42	-71.88
2044	73.86	177.88	-129.14	-75.67
2045	60.44	171.20	-131.07	-79.70
2046	56.16	170.94	-132.71	-74.98
2047	61.15	173.89	-134.36	-79.12
2048	39.25	165.55	-138.11	-84.30
2049	26.91	158.92	-140.04	-100.68
2050	49.82	168.67	-134.32	-97.79
2051	38.10	163.67	-134.38	-89.07
2052	44.46	168.13	-132.32	-91.49
2053	28.80	155.77	-134.37	-87.39
2054	67.11	172.12	-128.89	-93.56
2055	45.55	163.63	-128.87	-96.83
2056	52.06	171.20	-127.56	-89.59
2057	40.85	164.37	-128.93	-95.54
2058	50.07	166.84	-127.13	-71.22
2059	28.71	156.96	-130.19	-83.05
2060	26.11	152.51	-129.87	-81.85
2061	61.48	163.58	-122.80	-65.30
2062	26.73	149.45	-127.74	-82.32
2063	61.13	162.72	-123.14	-71.88

Table 13~~12~~: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070DEW Climate Scenario in TAF *(continued)*

Year	From Recharge	From ~~Groundwater~~Aquifer Storage	To ~~Groundwater~~Aquifer Storage	To Wells
2064	73.86	173.53	-123.06	-75.67
2065	60.44	166.82	-125.02	-79.70
2066	56.16	166.62	-126.76	-74.98
2067	61.15	169.66	-128.55	-79.12
2068	39.25	161.32	-132.33	-84.30
2069	26.91	154.81	-134.43	-100.68
2070	47.48	151.81	-118.21	-95.51

Table 14~~13~~: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070WMW Climate Scenario in TAF

Year	From Recharge	From ~~Groundwater~~Aquifer Storage	To Aquifer Storage~~Groundwater~~	To Wells
2019	34.23	173.92	-150.53	-73.26
2020	27.86	167.72	-149.81	-72.79
2021	67.92	184.07	-142.26	-58.24
2022	31.15	168.14	-148.02	-74.08
2023	75.28	191.73	-143.55	-64.63
2024	81.67	199.16	-146.28	-67.10
2025	67.93	192.93	-150.51	-70.50
2026	65.95	196.33	-153.48	-67.05
2027	70.22	201.22	-157.14	-71.08
2028	44.79	190.56	-163.31	-75.68
2029	27.35	180.65	-167.86	-89.57
2030	63.37	200.62	-161.31	-86.76
2031	45.14	192.53	-163.76	-79.85
2032	54.83	201.24	-162.86	-82.23
2033	30.49	183.75	-166.83	-79.33
2034	77.57	208.21	-161.65	-85.21
2035	52.28	198.51	-164.12	-88.47
2036	57.96	205.28	-163.92	-80.81
2037	48.05	200.21	-166.67	-84.69
2038	62.67	208.59	-165.95	-63.52
2039	34.23	193.57	-171.42	-73.26
2040	27.86	186.94	-172.62	-72.79
2041	67.92	202.51	-165.39	-58.24
2042	31.15	186.64	-171.69	-74.08
2043	75.28	209.19	-166.39	-64.63
2044	81.67	216.17	-168.75	-67.10
2045	67.93	209.81	-172.81	-70.50
2046	65.95	212.87	-175.38	-67.05
2047	70.22	217.30	-178.49	-71.08
2048	44.79	206.61	-184.55	-75.68

Table 14~~13~~: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070WMW Climate Scenario in TAF *(continued)*

Year	From Recharge	From ~~Groundwater~~Aquifer Storage	To ~~Groundwater~~Aquifer Storage	To Wells
2049	27.35	196.43	-188.72	-89.57
2050	63.37	215.69	-181.35	-86.76
2051	45.14	207.38	-183.47	-79.85
2052	54.83	215.68	-182.08	-82.23
2053	30.49	198.01	-185.75	-79.33
2054	77.57	221.78	-179.77	-85.21
2055	52.28	211.88	-181.94	-88.47
2056	57.96	218.31	-181.31	-80.81
2057	48.05	213.01	-183.73	-84.69
2058	62.67	221.00	-182.52	-63.52
2059	34.23	205.88	-187.80	-73.26
2060	27.86	199.02	-188.69	-72.79
2061	67.92	214.00	-180.77	-58.24
2062	31.15	198.08	-186.93	-74.08
2063	75.28	220.06	-180.98	-64.63
2064	81.67	226.73	-182.95	-67.10
2065	67.93	220.23	-186.78	-70.50
2066	65.95	223.08	-189.05	-67.05
2067	70.22	227.23	-191.81	-71.08
2068	44.79	216.49	-197.75	-75.68
2069	27.35	206.13	-201.65	-89.57
2070	61.03	207.72	-177.35	-85.29

Table 15~~14~~: Table of Annual Bulletin 118 Basin Aquifer Water Budget for base Climate Scenario in TAF

Year	From Recharge	From ~~Groundwater~~Aquifer Storage	To ~~Groundwater~~Aquifer Storage	To Wells
2019	29.77	169.64	-151.50	-70.77
2020	26.12	164.03	-151.27	-70.39
2021	62.15	175.33	-142.93	-54.11
2022	27.44	160.71	-148.25	-70.52
2023	67.23	178.57	-142.31	-61.01
2024	75.35	185.59	-143.41	-63.87
2025	61.07	178.44	-146.30	-67.43
2026	58.16	179.89	-148.41	-64.50
2027	63.43	183.76	-150.44	-67.84
2028	41.40	174.90	-155.22	-71.93
2029	26.91	166.65	-158.47	-85.05
2030	55.09	179.94	-152.08	-82.86
2031	37.83	171.78	-153.31	-76.54
2032	48.60	179.52	-150.86	-78.65
2033	29.19	165.24	-153.55	-75.30
2034	71.43	184.93	-147.70	-80.91

Table 15~~14~~: Table of Annual Bulletin 118 Basin Aquifer Water Budget for base Climate Scenario in TAF*(continued)*

Year	From Recharge	From ~~Groundwater~~Aquifer Storage	To ~~Groundwater~~Aquifer Storage	To Wells
2035	47.13	174.91	-149.16	-83.84
2036	52.84	181.83	-148.21	-77.24
2037	41.04	174.49	-150.51	-80.64
2038	54.28	181.18	-148.60	-60.91
2039	29.77	168.64	-152.75	-70.77
2040	26.12	163.97	-153.46	-70.39
2041	62.15	175.88	-145.77	-54.11
2042	27.46	161.58	-151.31	-70.52
2043	67.23	179.55	-145.40	-61.01
2044	75.35	186.68	-146.48	-63.87
2045	61.07	179.65	-149.35	-67.43
2046	58.16	181.16	-151.38	-64.50
2047	63.43	185.05	-153.31	-67.84
2048	41.40	176.24	-158.02	-71.93
2049	26.91	168.00	-161.17	-85.05
2050	55.09	181.26	-154.65	-82.86
2051	37.83	173.12	-155.82	-76.54
2052	48.60	180.84	-153.27	-78.65
2053	29.19	166.58	-155.90	-75.30
2054	71.43	186.21	-149.93	-80.91
2055	47.13	176.20	-151.34	-83.84
2056	52.84	183.08	-150.30	-77.24
2057	41.04	175.75	-152.56	-80.64
2058	54.28	182.41	-150.58	-60.91
2059	29.77	169.88	-154.69	-70.77
2060	26.12	165.19	-155.34	-70.39
2061	62.15	177.04	-147.55	-54.11
2062	27.46	162.75	-153.08	-70.52
2063	67.23	180.66	-147.08	-61.01
2064	75.35	187.76	-148.10	-63.87
2065	61.07	180.74	-150.95	-67.43
2066	58.16	182.23	-152.94	-64.50
2067	63.43	186.09	-154.83	-67.84
2068	41.40	177.28	-159.53	-71.93
2069	26.91	169.03	-162.64	-85.05
2070	52.75	168.09	-142.89	-81.04

9.3 Estimation of Sustainable Yield via BVIHM

Via use of the uncalibrated BVIHM, the modeled long-term average annual pumping stresses do not indicate any undesirable result. Following the two previous analyses as are the closed and open basins, and sensitivity analyses of the model presented long-term dynamically stable groundwater storage and water level conditions. Modeled stresses for the conditions included the past 23-year climate conditions and a yearly average pumping rate of 65 TAF (Figure 22).

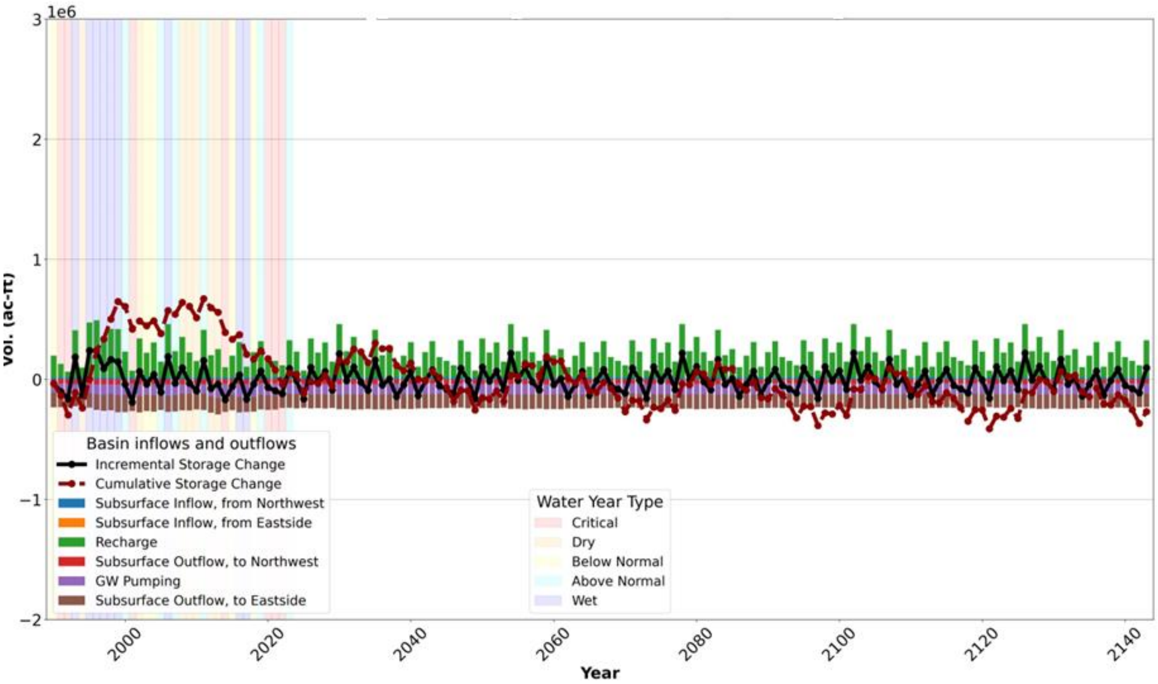


Figure 22. Sustainable Yield estimates via simulation of 2000-2023 climate-change stresses for five times after 2023

10 Model Archiving

The original steady state MODFLOW models for Butte Valley were developed in Groundwater Vistas to perform manual sensitivity analysis on hydraulic conductivity, average groundwater pumping, and recharge. Parameters and key outcomes for these varying steady state trial models are captured in a spreadsheet to understand their general impact on simulated groundwater levels.

Results are available upon request.

Later versions of the steady state and transient models were developed with the USGS developed python package *flopy* which allows a user to write scripts to import data, clean and adjust it, and to write model input files (Bakker et al. 2016). Additional python scripts were developed to run the model and model calibration and to post-process model results using the Jupyter Notebooks python development environment Kluyver et al. (2016). One set of python scripts was continuously developed to create the historical BVIHM which had input files written to different directories to create model archives or to note different model set ups such as when more observation data was included. A different set of python scripts were used to alter the historical BVIHM for the ~~50 year~~50-year climate projections, each of these models were written to their own model directory.

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