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 without surface water routing component. 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 WY1990-2070 via the same 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 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 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 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

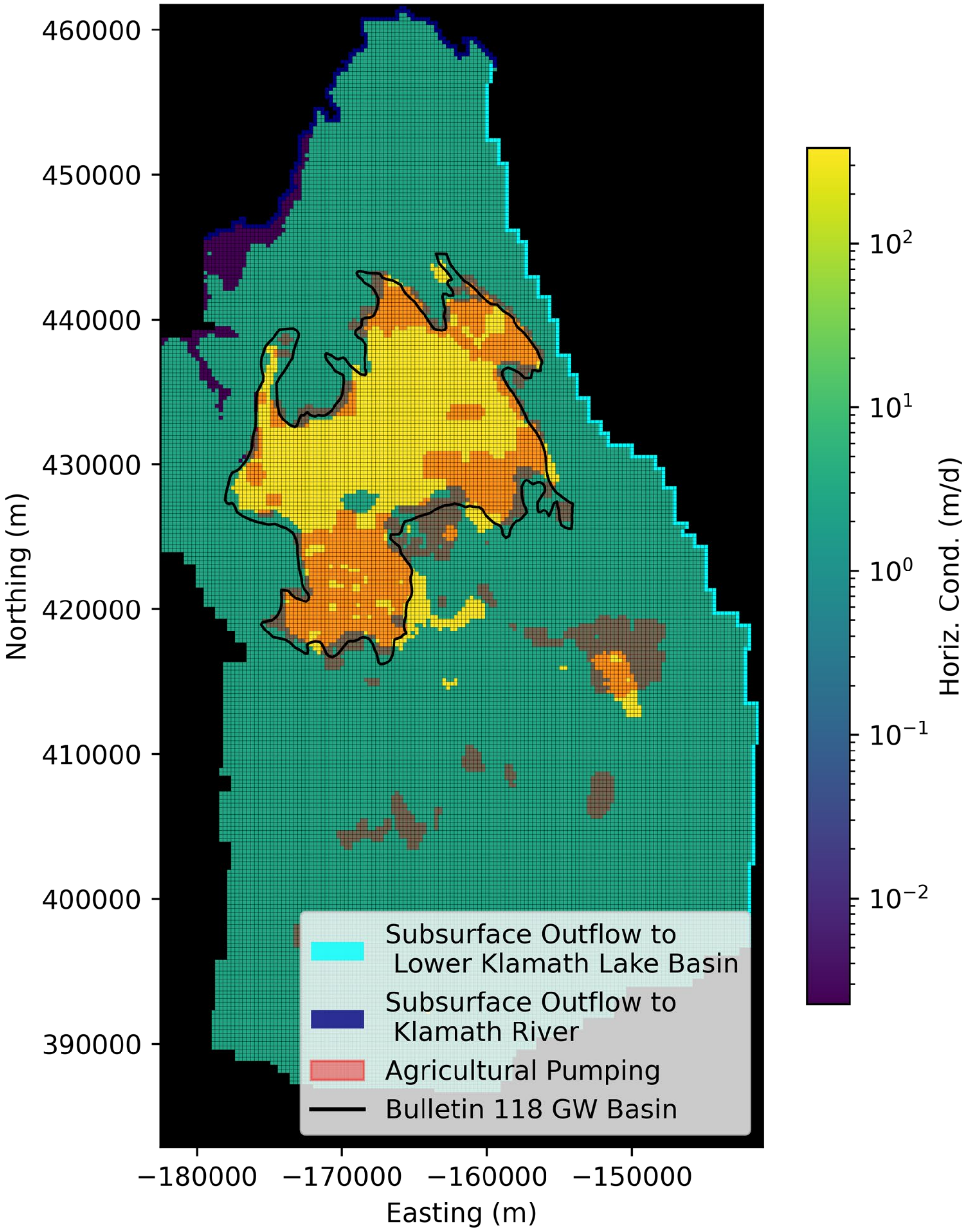

Figure 2: Active model domain with hydro stratigraphy identified by horizontal hydraulic conductivity; Tertiary Volcanics are in purple, Quaternary Volcanics are in green and the Alluvium is in yellow.

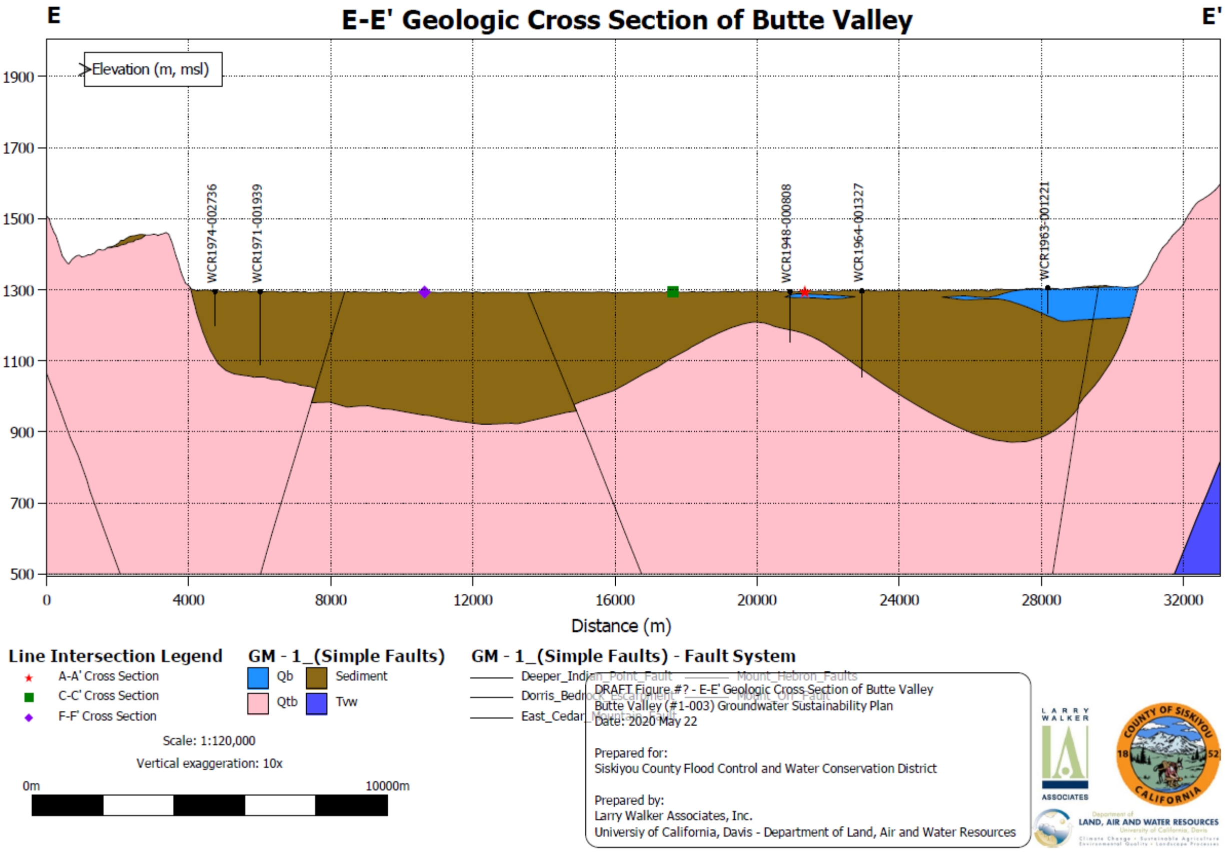

Figure 3: Cross Section E-E’ crosses Butte Valley from the south to the north

4 Model Inputs

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 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 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.

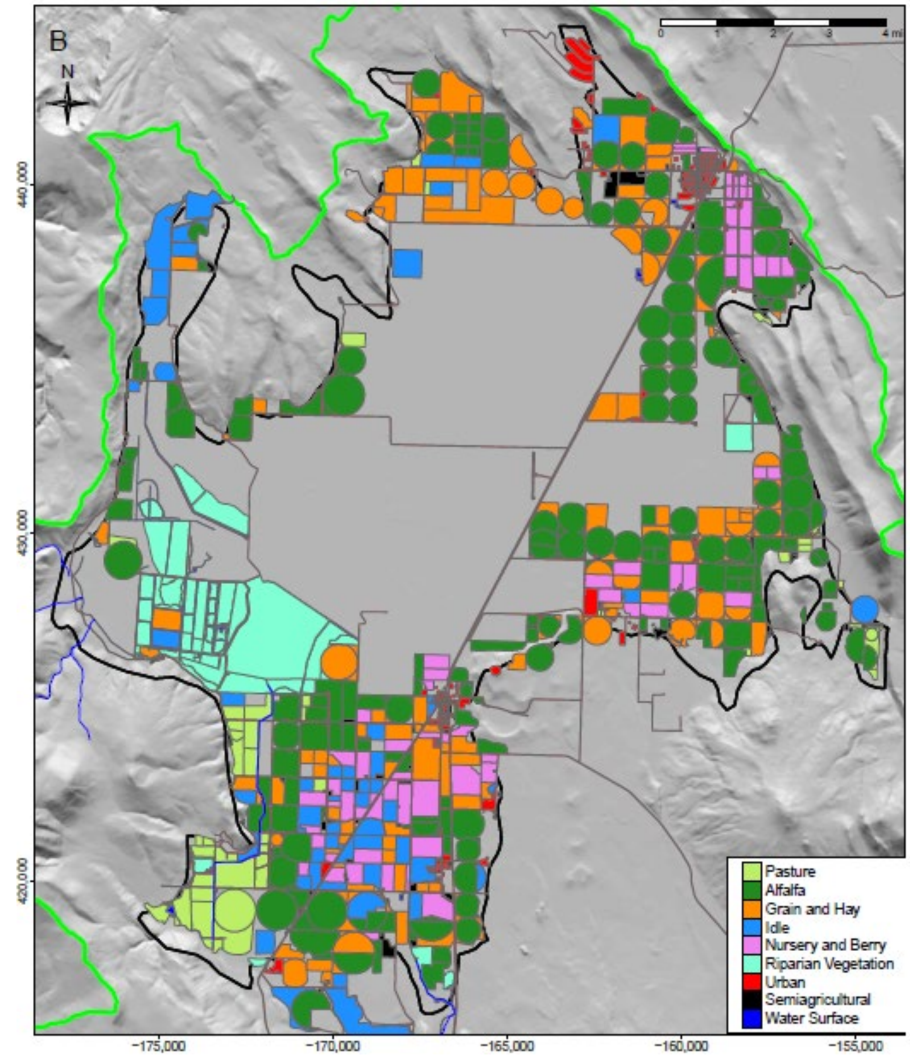

Figure 4: Land use within the Butte Valley groundwater basin (black outline) in the summer of 2010. Grey areas are natural vegetation or outside the Basin boundaries.

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 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, 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 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 monthly in Figure 5. The groundwater level observations were weighted using a variance of 1.0025. Additionally, the locations and ground surface locations of creeks and springs throughout the upper watershed of Butte Valley were included as head observations in the 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. Many of these observation wells do not have total well depth or screened interval data 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 water 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.

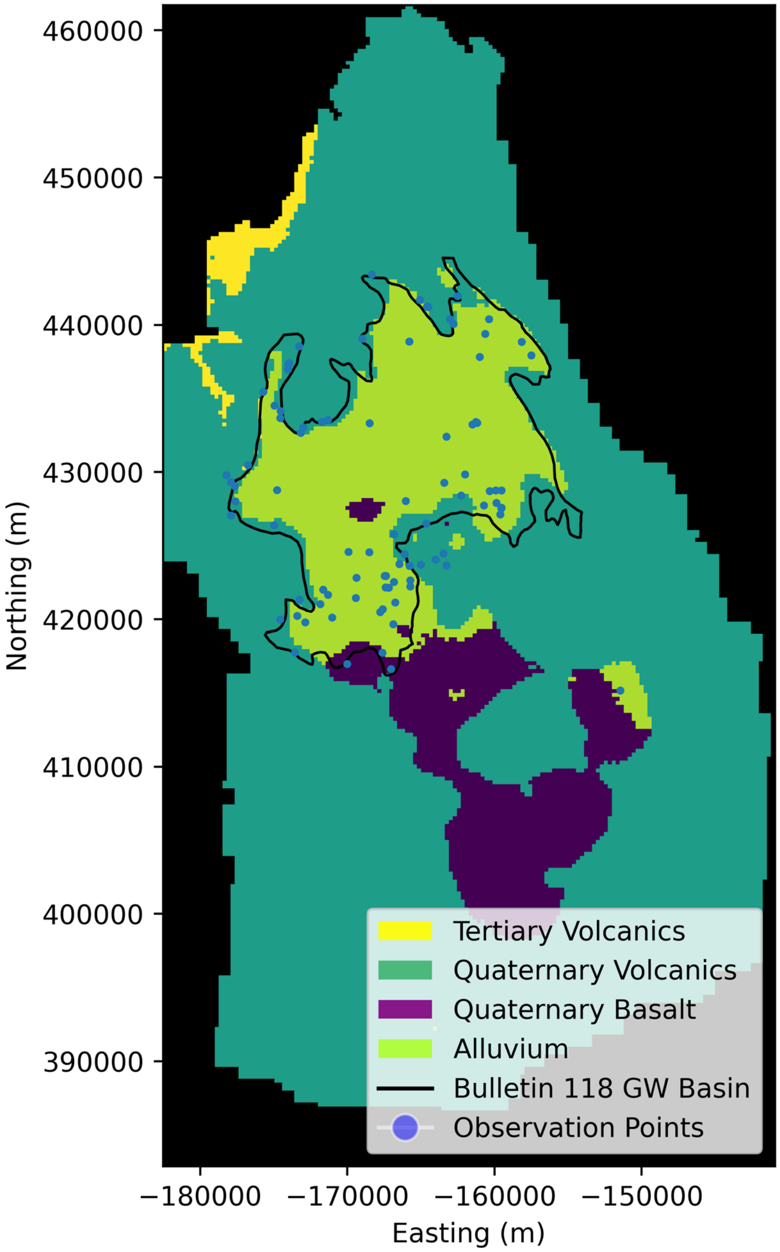

Figure 5: Location of observation wells, creeks and springs for groundwater model calibration

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 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 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 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.

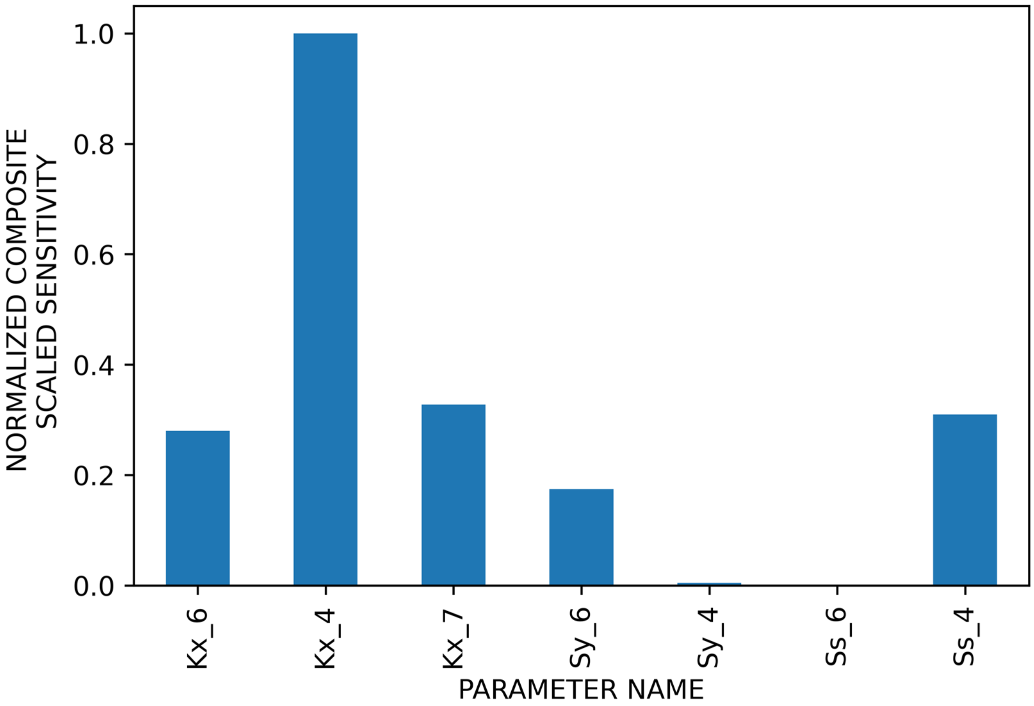

Figure 6: Normalized Composite Scaled Sensitivity of the final parameters used in model calibration.

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 long-term water level dynamics (long-term decline and rise of water levels) are well captured by the simulated data; 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 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 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; 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.

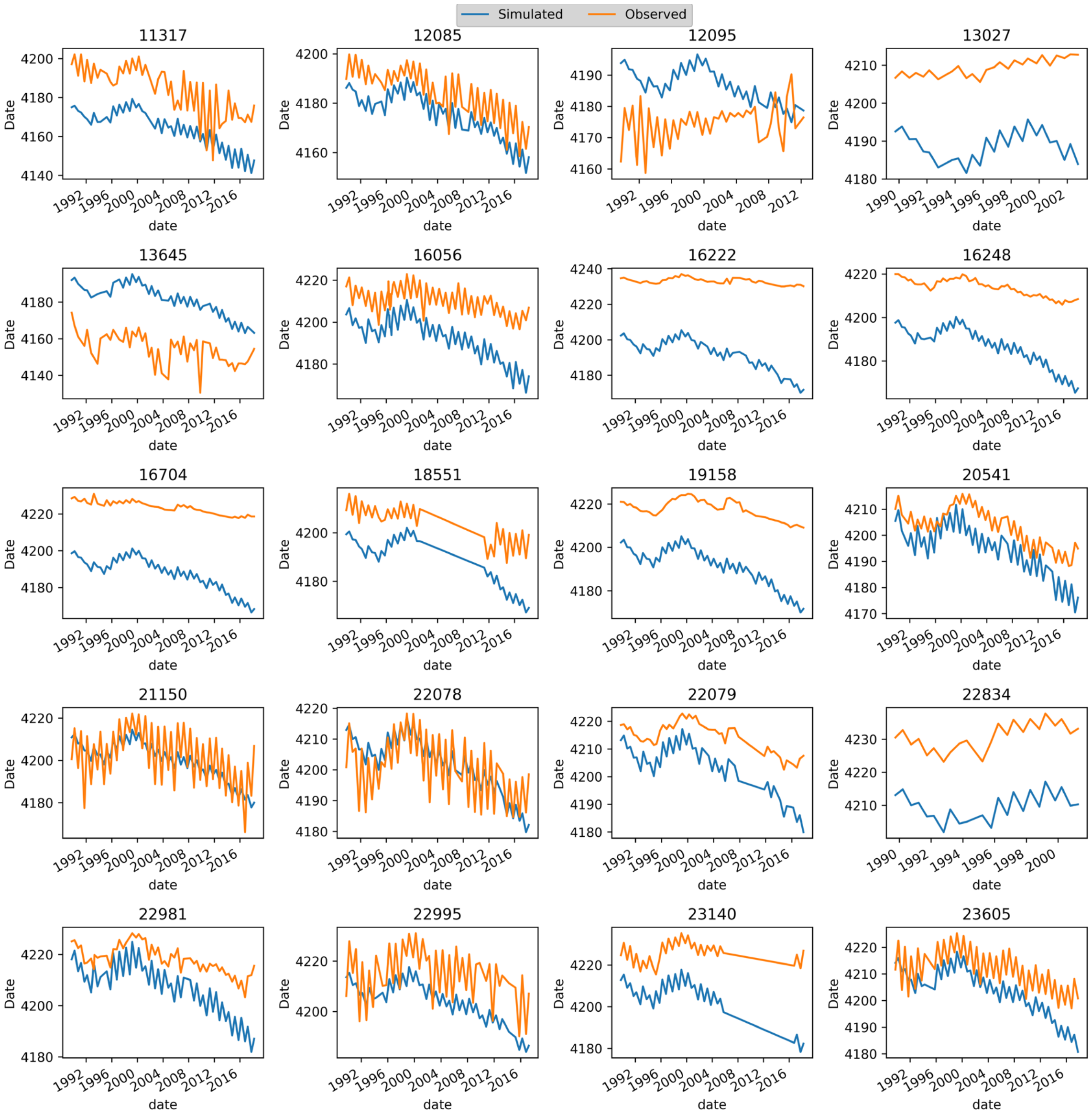

Figure 7: Simulated and observed heads for wells with more than 20 measurements where observed data is in orange and simulated data is in blue

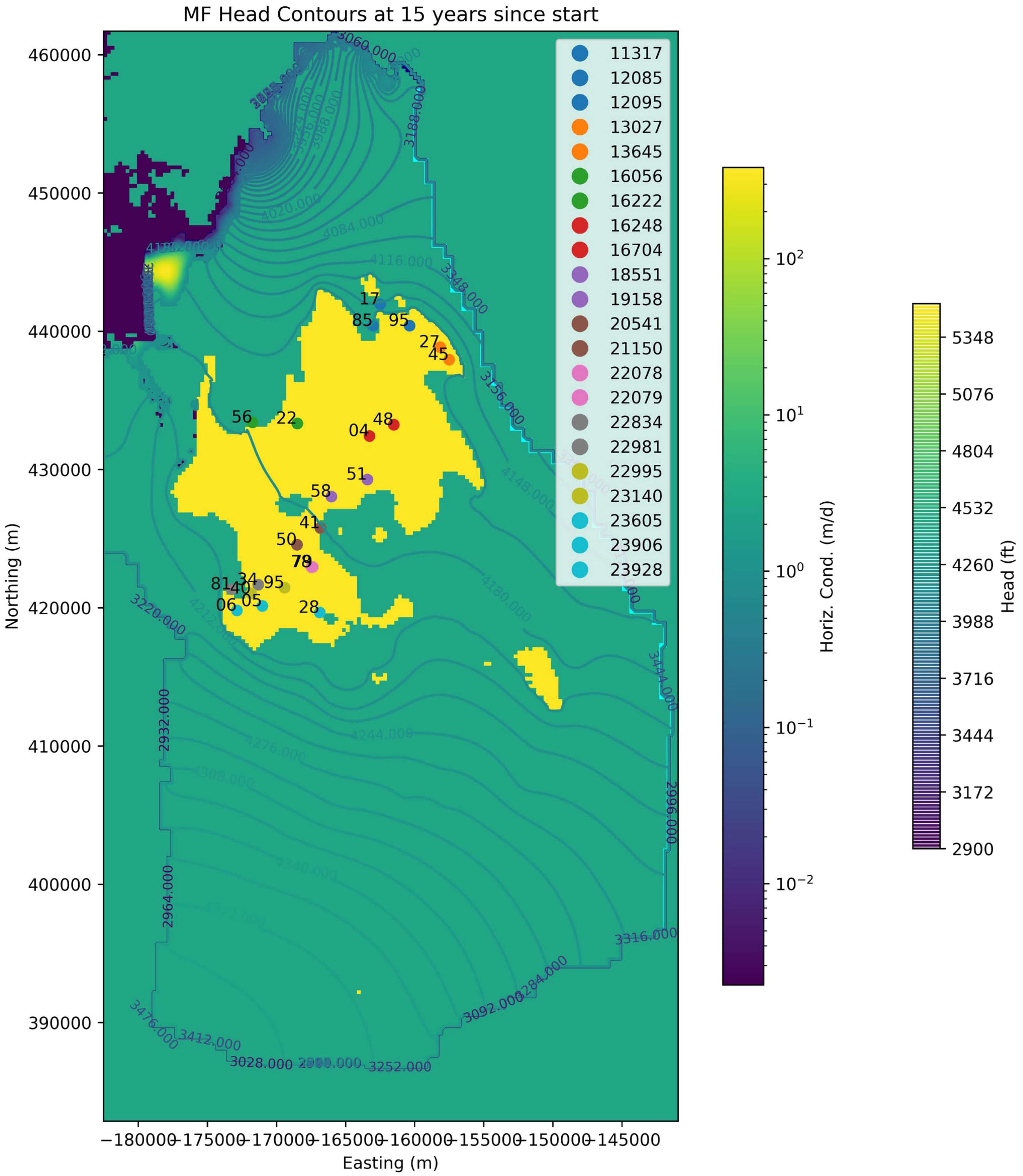

Figure 8: Map of observation wells with more than 20 measurements

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 trends of the groundwater elevations in the basin.

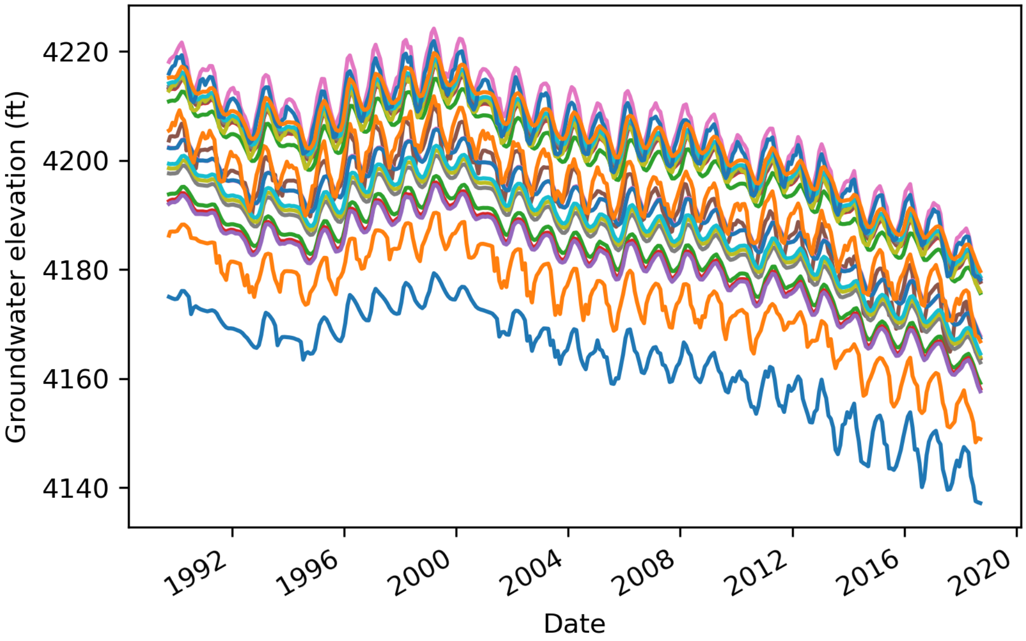

Figure 9: Simulated groundwater hydrographs for wells with more than 20 measurements

The simulated groundwater hydrographs for the same locations of the observation wells demonstrate strong seasonal fluctuations due to summertime groundwater pumping and winter recharge as well as a 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 ("Incremental Storage Change") and dark red ("Cumulative Storage Change") lines represent 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).

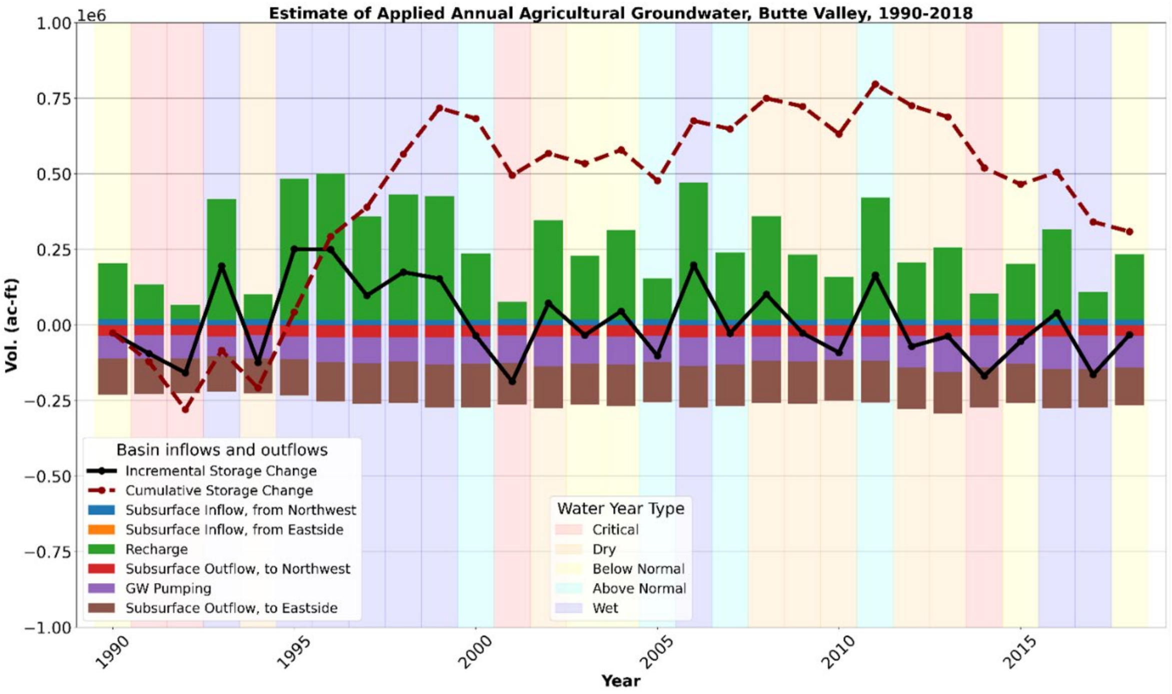

Figure 10: Annual Model Area Groundwater Budget

The model area groundwater budget shows high interannual variability for net inflow to the model area, because that inflow is entirely a function of the amount of rainfall 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 relatively 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, irrigation 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 groundwater pumping captures more of 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 Irrigated Land/Soil Subsystem Water Budget (CRZWM)

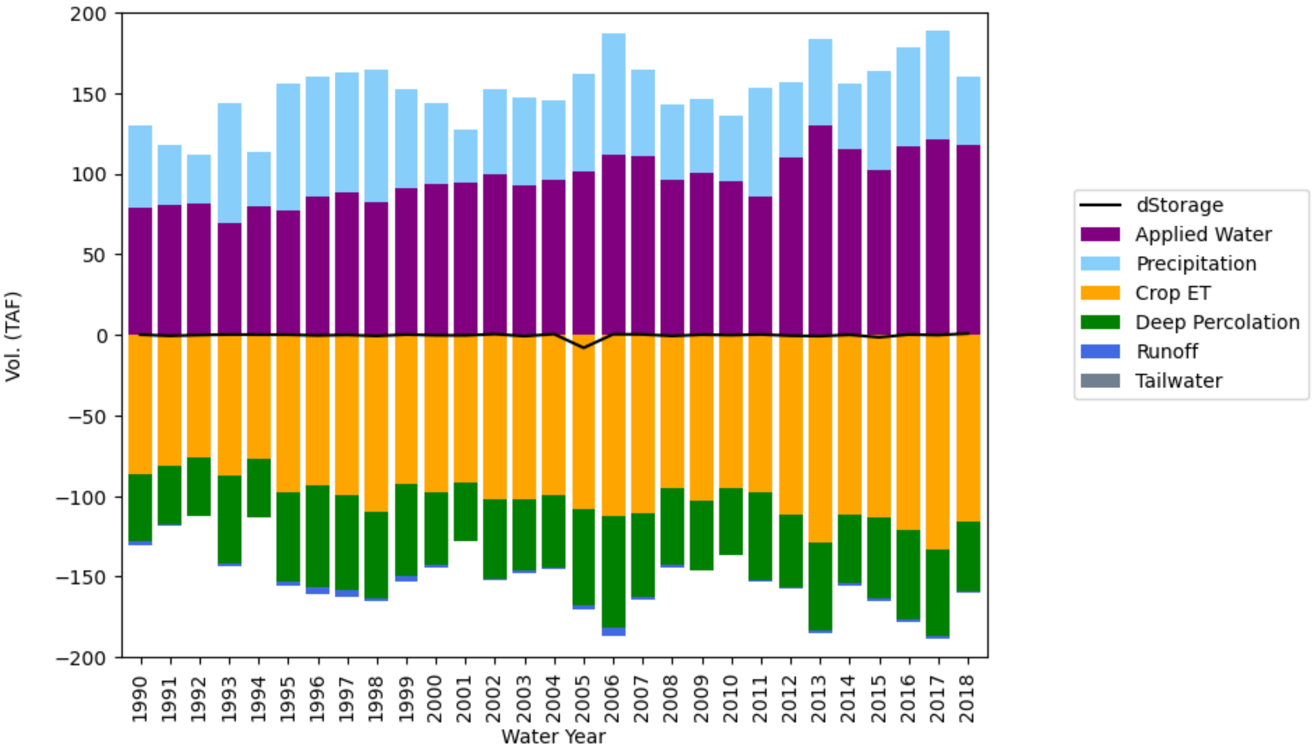

Figure 11: Annual Land/Soil Subsystem Water Budget (CRZWM)within model area

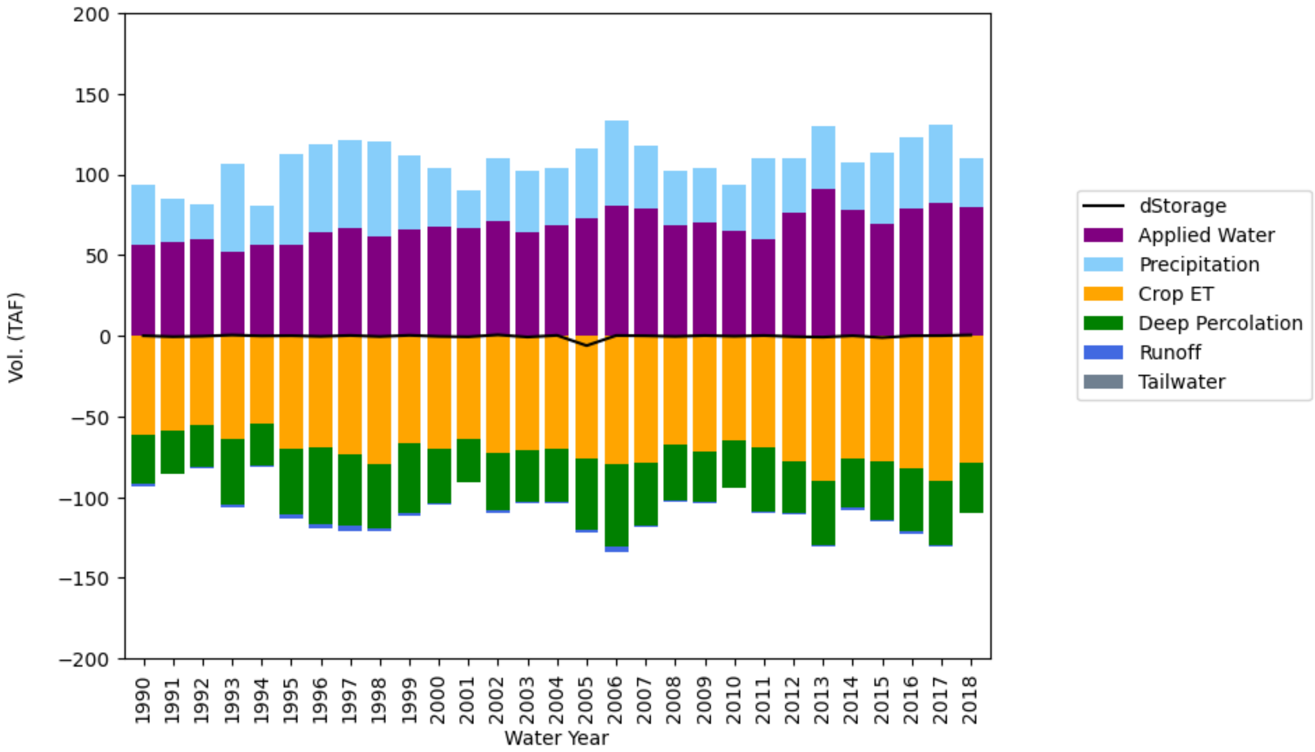

Figure 12: Annual Land/Soil Subsystem Water Budget (CRZWM) within Bulletin 118 groundwater basin

The irrigated land/soil subsystem 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 water budgets are useful because they demonstrate the interannual variability in deep percolation due to changes in rainfall and evapotranspiration.

8.4 Bulletin 118 Groundwater Budget

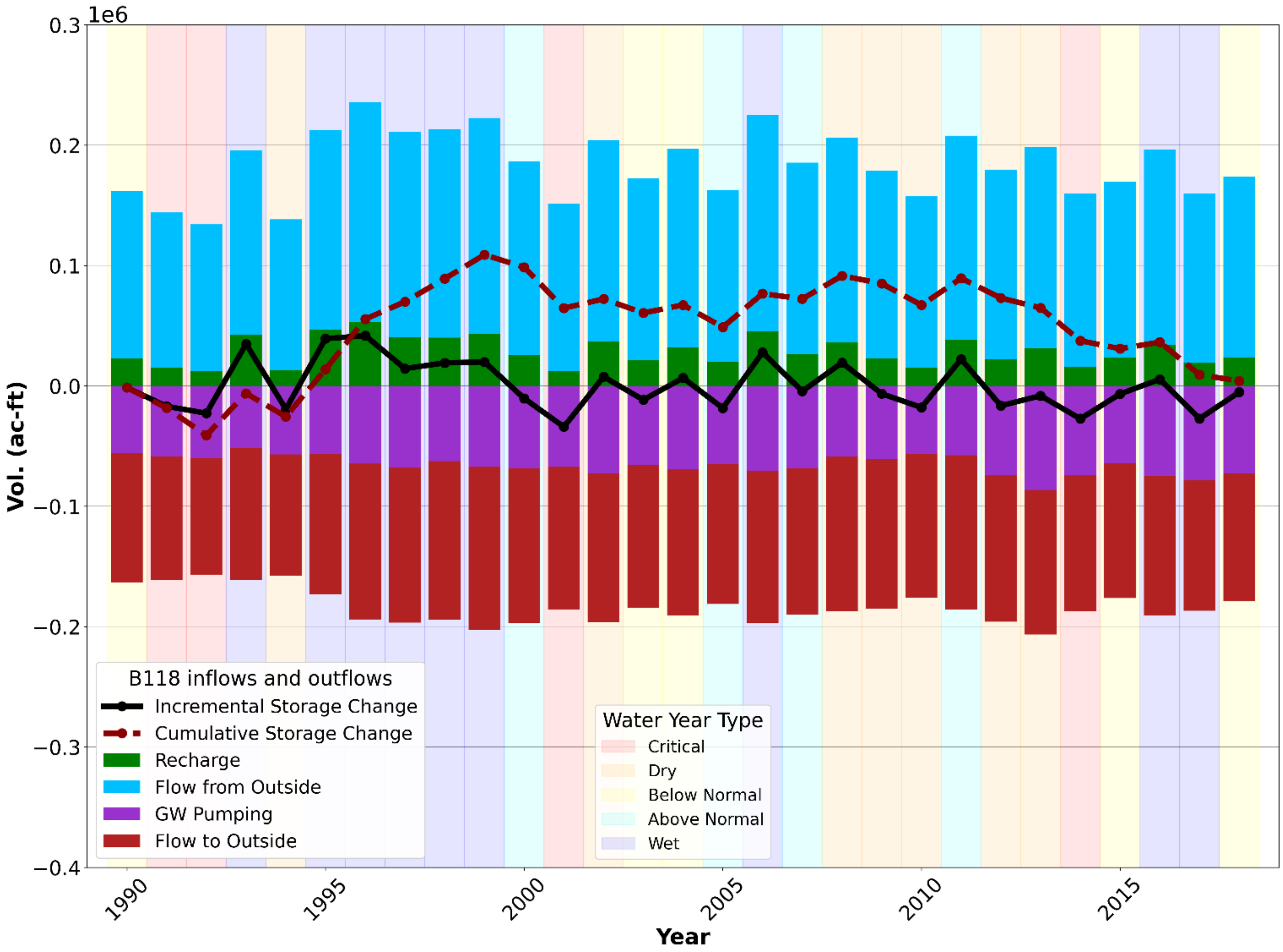

Figure 13: Annual Bulletin 118 Basin Aquifer Water Budget

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 providing subsurface inflow, designated as Lateral Groundwater Inflow Figure 13. Again, the groundwater pumping is relatively constant between years as most crops are grown in the summer and require 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

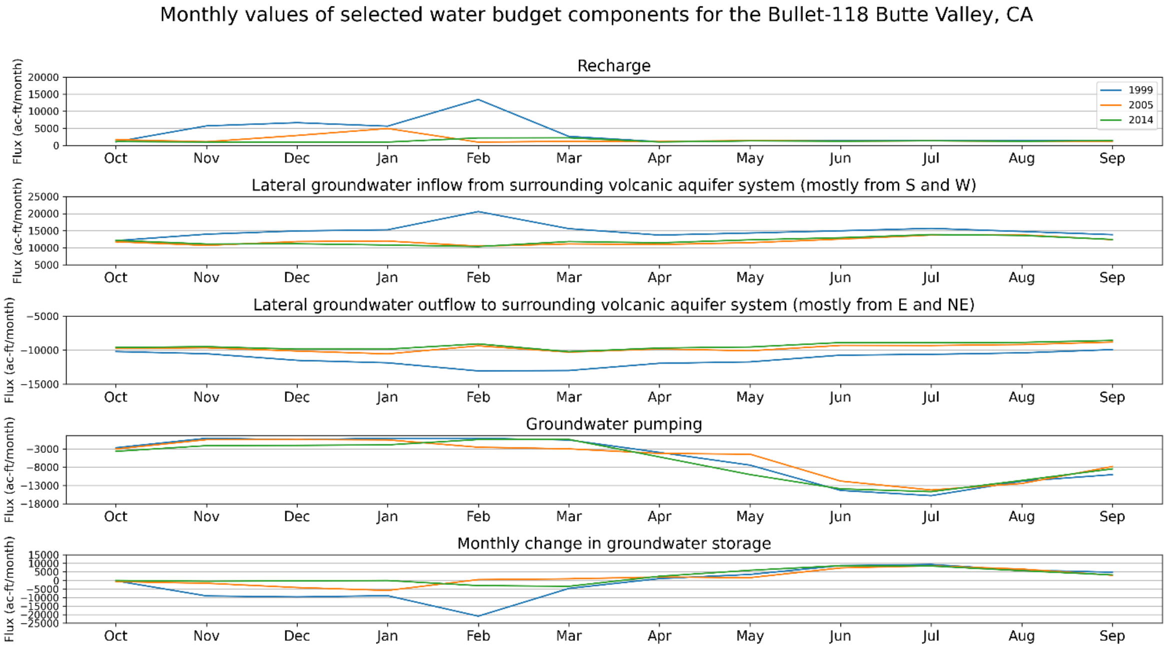

Figure 14: Monthly Bulletin 118 Basin Aquifer Water Budget for selected water year types (i.e. 2014, 2005, and 1999 as Dry, Average, and Wet years respectively)

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.

8.6 Tables of Annual Sum Water Budgets

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

WY	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 8: Annual Land/Soil Subsystem Water Budget (CRZWM) within model area in TAF

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

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

WY	From Recharge	From Aquifer Storage	To Aquifer Storage	To Wells
1990	23.07	24.78	-26.15	-55.99
1991	14.98	10.00	-26.95	-58.56
1992	12.47	5.77	-28.49	-60.08
1993	42.79	62.64	-27.81	-51.85
1994	13.12	6.13	-25.40	-56.84
1995	47.01	71.56	-32.29	-56.68
1996	53.15	81.14	-39.40	-64.64
1997	40.39	54.61	-40.23	-67.98
1998	40.07	55.75	-36.56	-62.55
1999	42.98	59.86	-39.95	-67.22
2000	25.76	28.54	-38.91	-68.70
2001	12.41	3.49	-37.51	-67.06
2002	37.09	47.21	-39.60	-72.90
2003	21.29	23.24	-34.83	-65.69
2004	31.95	43.07	-36.45	-69.24
2005	20.21	15.42	-33.84	-64.81
2006	45.41	65.70	-37.87	-70.37
2007	26.39	30.15	-34.53	-68.75
2008	36.22	52.06	-32.81	-58.66
2009	22.85	26.17	-32.64	-60.78
2010	14.83	11.04	-28.91	-56.34
2011	38.45	55.54	-33.29	-57.69
2012	22.45	21.68	-38.11	-74.46
2013	31.41	34.58	-42.75	-86.34
2014	15.83	11.31	-38.58	-74.33
2015	23.29	27.75	-34.43	-63.97
2016	33.94	45.44	-39.92	-74.99
2017	19.07	15.38	-42.55	-78.07
2018	23.66	29.83	-35.00	-73.01

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).

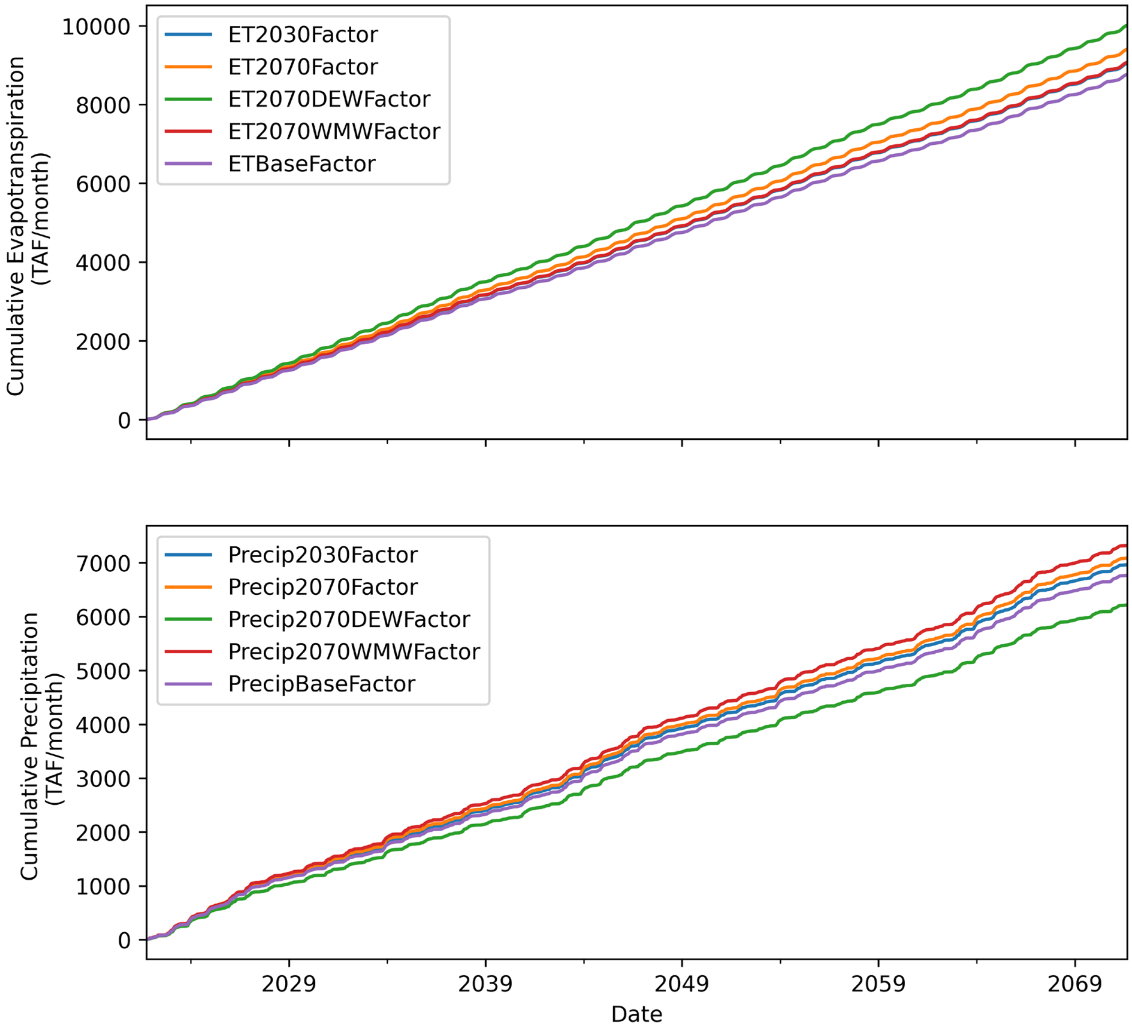

Figure 15: Future Climate Projections of Precipitation and Actual Evapotranspiration for the Butte Valley Watershed

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.

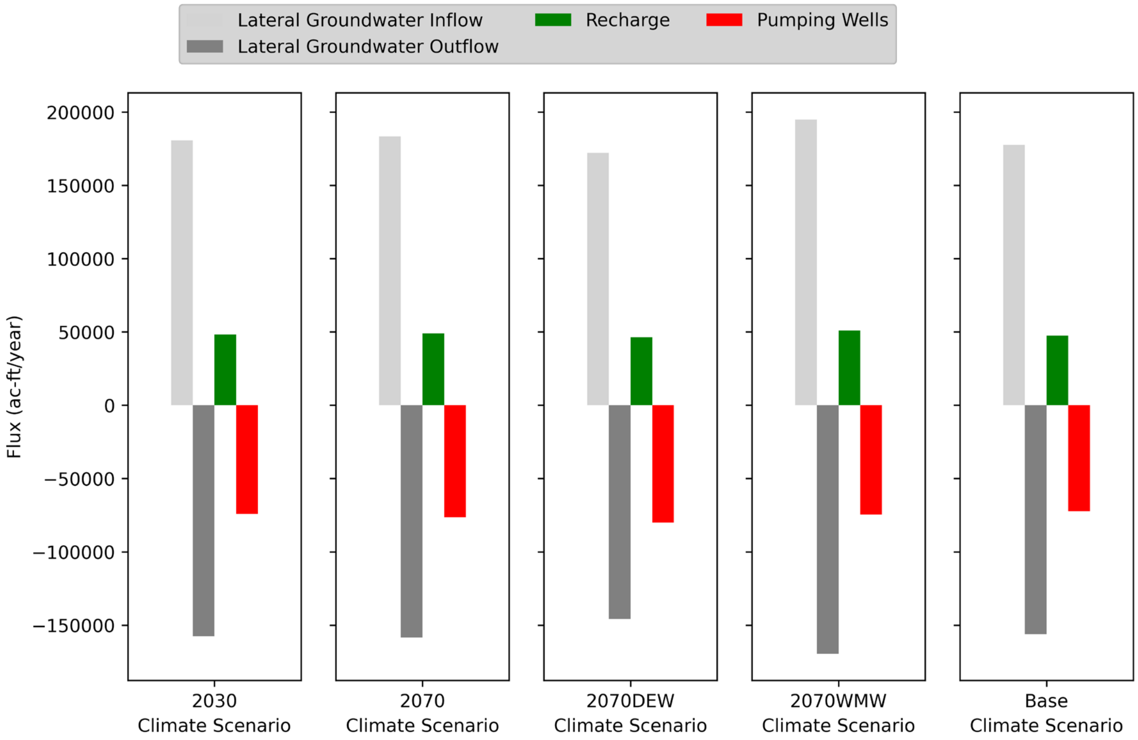

Figure 16: Average Bulletin 118 Basin Water Budget 1990-2070

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 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 groundwater 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

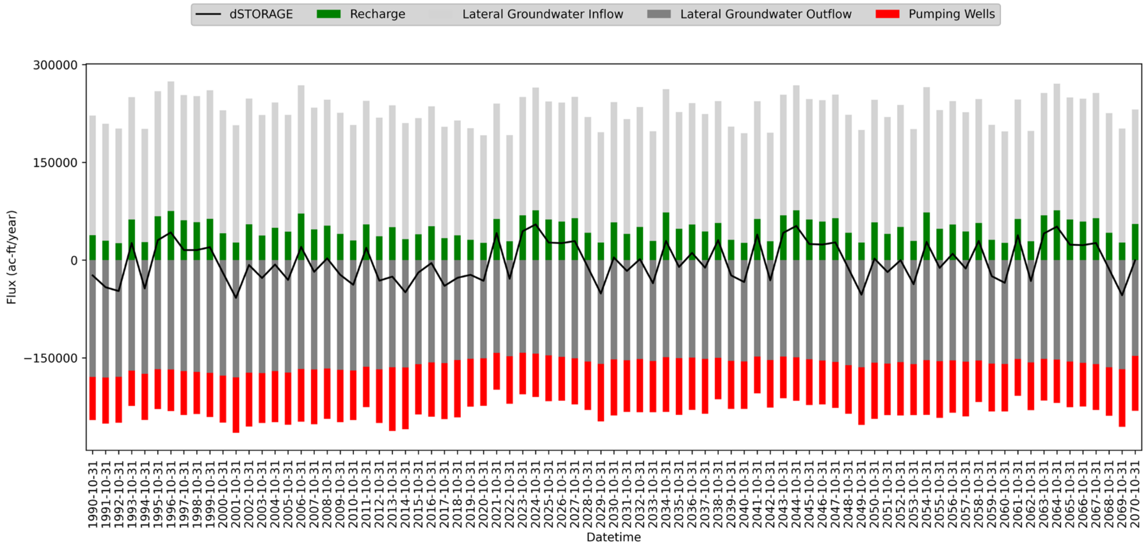

Figure 17: Bulletin 118 Basin Water Budgets from 1990-2070 for 2030 Climate Scenario

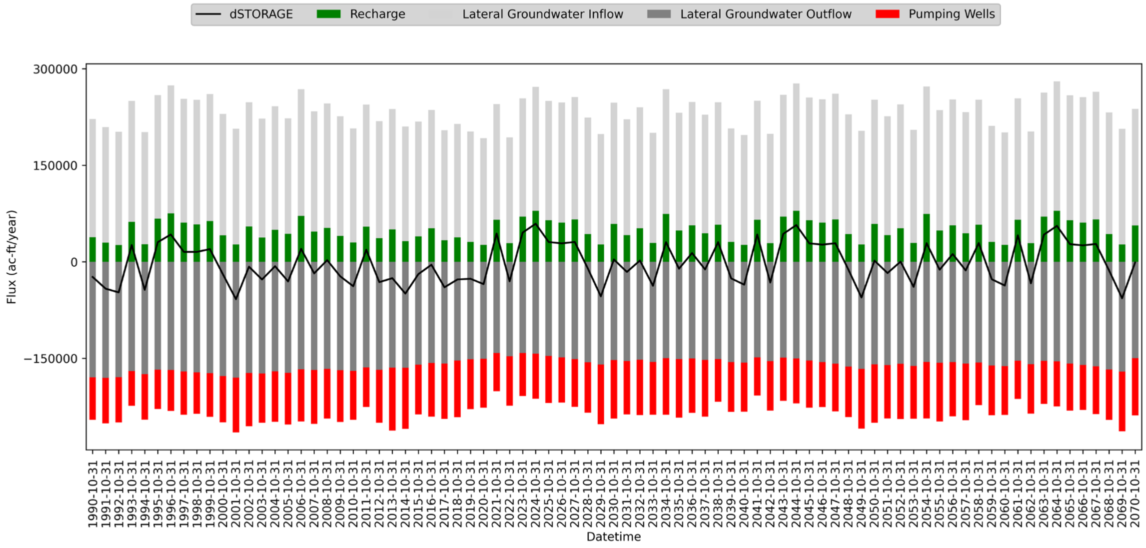

Figure 18: Bulletin 118 Basin Water Budgets from 1990-2070 for 2070 Climate Scenario

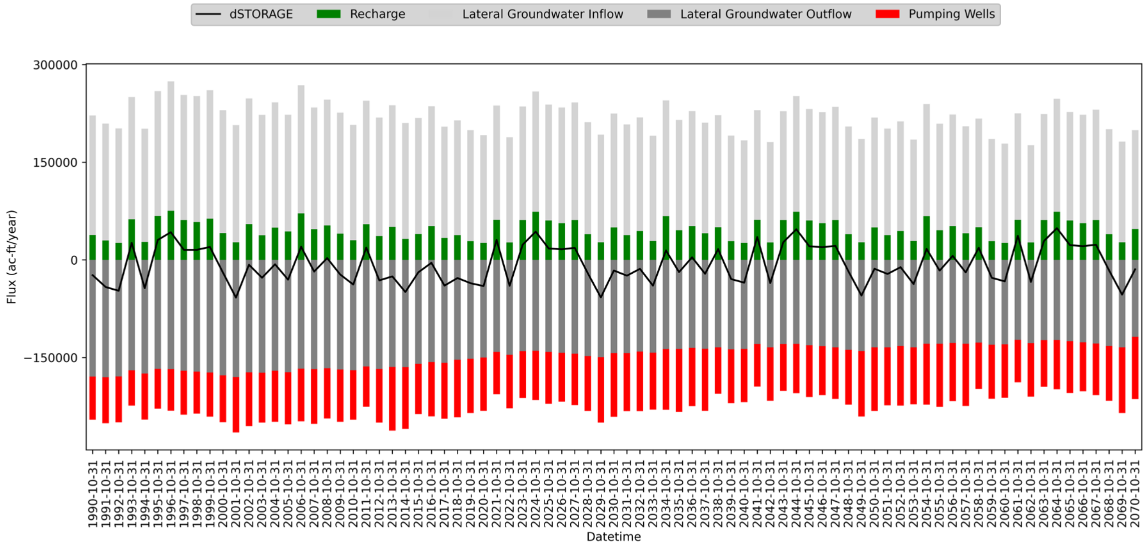

Figure 19: Bulletin 118 Basin Water Budgets from 1990-2070 for 2070DEW Climate Scenario

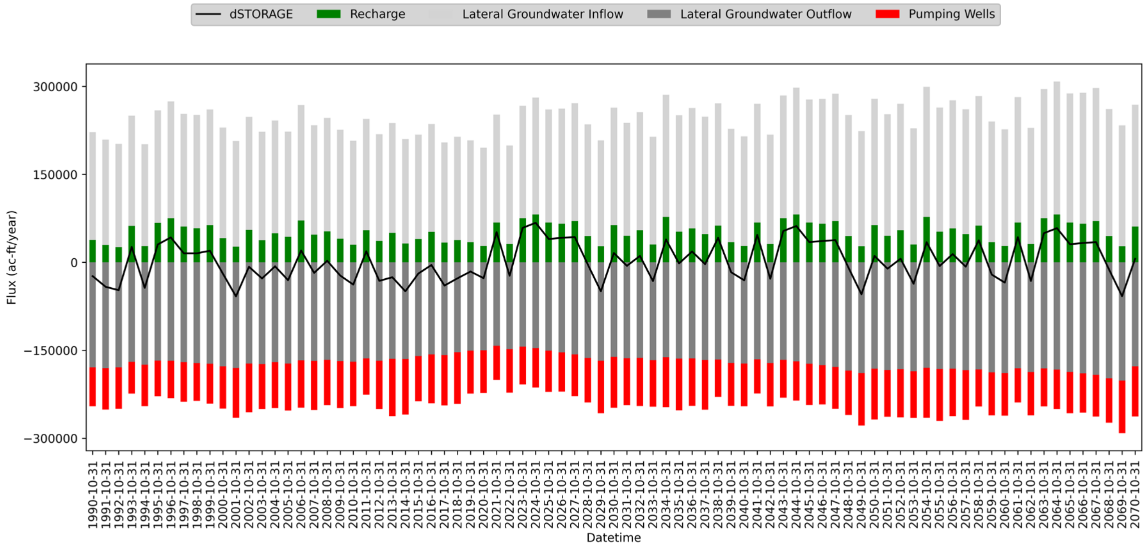

Figure 20: Bulletin 118 Basin Water Budgets from 1990-2070 for 2070WMW Climate Scenario

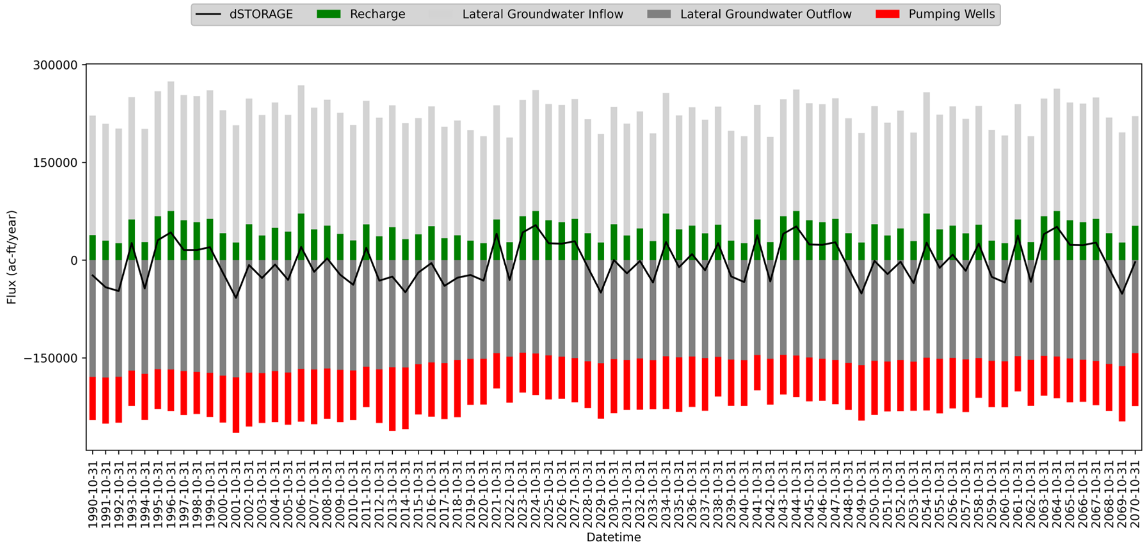

Figure 21: Bulletin 118 Basin Water Budgets from 1990-2070 for base Climate Scenario

9.2 Tables of Future Climate Individual Annual Water Budget Data

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

Year	From Recharge	From Aquifer Storage	To 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: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2030 Climate Scenario in TAF *(continued)*

Year	From Recharge	From Aquifer Storage	To 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: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070 Climate Scenario in TAF

Year	From Recharge	From Aquifer Storage	To 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: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070 Climate Scenario in TAF *(continued)*

Year	From Recharge	From Aquifer Storage	To 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: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070DEW Climate Scenario in TAF

Year	From Recharge	From Aquifer Storage	To 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: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070DEW Climate Scenario in TAF *(continued)*

Year	From Recharge	From Aquifer Storage	To 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: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070WMW Climate Scenario in TAF

Year	From Recharge	From Aquifer Storage	To Aquifer Storage	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: Table of Annual Bulletin 118 Basin Aquifer Water Budget for 2070WMW Climate Scenario in TAF *(continued)*

Year	From Recharge	From Aquifer Storage	To 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: Table of Annual Bulletin 118 Basin Aquifer Water Budget for base Climate Scenario in TAF

Year	From Recharge	From Aquifer Storage	To 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: Table of Annual Bulletin 118 Basin Aquifer Water Budget for base Climate Scenario in TAF *(continued)*

Year	From Recharge	From Aquifer Storage	To 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).

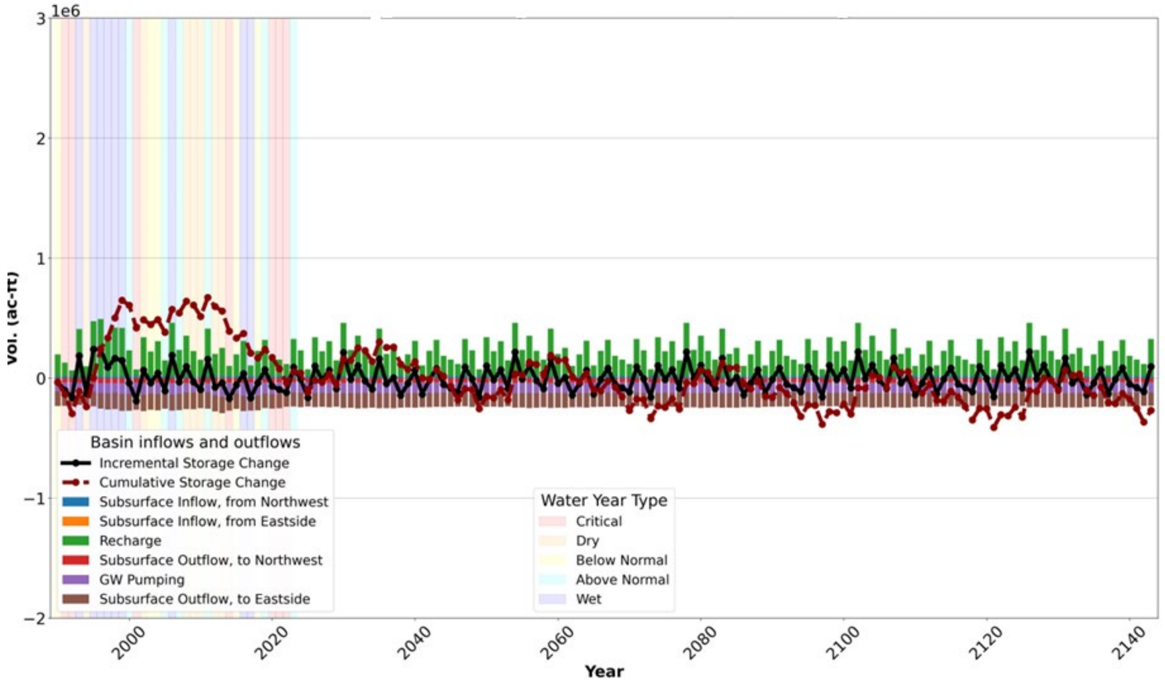

Figure 22. Sustainable Yield estimates via simulation of 2000-2023 climate-change stresses for five times after 2023

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 climate projections, each of these models were written to their own model directory.

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Technical Memorandum

To: Larry Walker Associates

From: Davids Engineering

Date: January 23, 2020

Subject: **Butte Valley Evapotranspiration and Applied Water Estimates**

1 Summary

The purpose of this effort is to develop time series estimates of agricultural water use for the Butte Valley Basin from January 1989 through December 2018. The approach builds upon estimates of actual evapotranspiration (ETa) developed using remotely sensed information from the Landsat satellite.

The consumptive use of water (i.e., evapotranspiration) is the primary destination of infiltrated precipitation and applied irrigation water within the Basin. Quantification of consumptive use was achieved by performing daily calculations of evapotranspiration (ET) for individual fields for the study period. ET was separated into its evaporation (E) and transpiration (T) components. Transpiration was quantified using a remote sensing approach where Landsat satellite images acquired from USGS were used to calculate the Normalized Difference Vegetation Index (NDVI), which was subsequently translated to a basal crop coefficient and combined with reference ET (ETo) to calculate transpiration over time.

A spatial coverage of field boundaries was developed for the study area, and individual field polygons were assigned cropping and irrigation method information over time based on available data. Field boundaries were delineated by combining polygon coverages in GIS format from the California Department of Water Resources (DWR).

ET was calculated based on a combination of remote sensing data and simulation of irrigation events in a daily root zone water balance model. Due to the remote sensing approach, ET estimates are relatively insensitive to crop or land use type and irrigation method so detailed, accurate assignment of crop types and irrigation methods to each field is not critical to developing relatively reliable estimates of ET. The amount of green vegetation present over time was estimated for each field polygon based on NDVI, which is calculated using a combination of red and near infrared reflectances as measured using multispectral satellite sensors onboard Landsat satellites. Following the preparation of NDVI imagery spanning the analysis period, all images were quality controlled to remove pixels affected by clouds.

Mean daily NDVI values for each field were converted to basal crop coefficients. Daily precipitation was estimated based on assembly and review of data from the PRISM Climate Group at Oregon State University[1]. Daily reference evapotranspiration (ET_o) was estimated based on information from the California Irrigation Management Information System (CIMIS) and from National Oceanic and

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

Atmospheric Administration (NOAA) weather stations. Root zone parameters that influence the amount of available soil moisture storage were estimated based on crops and soils present in the study area.

A summary for the analysis period of the annual ET of applied water (ET_{AW}), ET_c (synonymous with ET_a), applied water (AW), deep percolation of applied water (DP_{AW}) and deep percolation of precipitation (DP_{pr}) estimates based on the root zone water balance model is given in the Results section.

Application of remote sensing combined with daily remote sensing-based root zone water balance modeling (RS-RZ model) provides a reliable methodology in the absence of more detailed, ground-based information for estimation of surface interactions with the groundwater system including net groundwater depletion through estimation of ET of applied water and other fluxes.

2 Introduction

The purpose of this effort is to develop time series estimates of agricultural and native vegetation water use for the Butte Valley Basin from 1989 to 2018. Demand has been quantified at the field scale using a remote-sensing based daily root zone water balance model.

3 Methodology

3.1 *Daily Root Zone Simulation Model*

A conceptual diagram of the various surface layer fluxes of water into and out of the crop root zone is provided in Figure 3.1. The consumptive use of water (i.e., evapotranspiration or ET) is the primary destination of infiltrated precipitation and applied irrigation water within the study area. Quantification of consumptive use was achieved by performing daily calculations of ET for individual fields from January 1989 through December 2018. Evapotranspiration was separated into its evaporation (E) and transpiration (T) components. Additionally, each component was separated into the amount of E or T derived from precipitation or applied water.

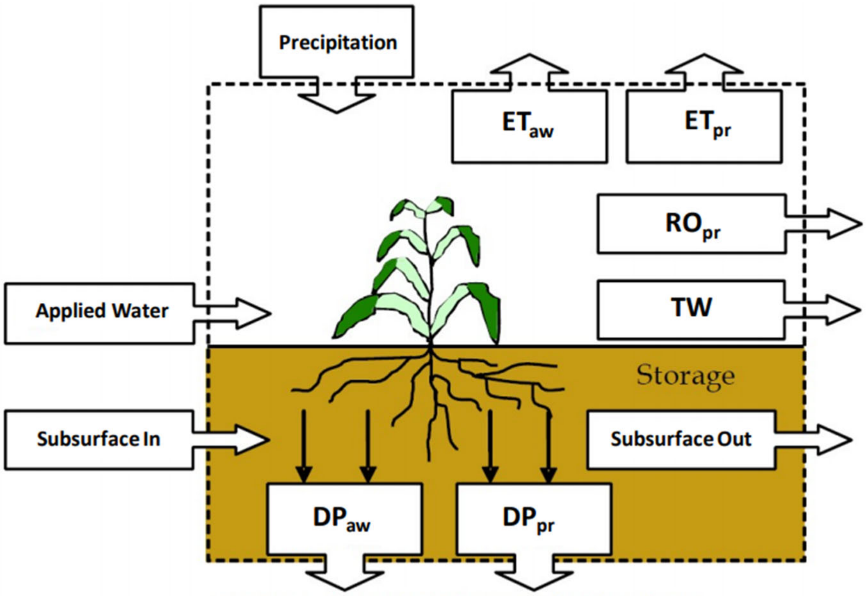

Figure 3.1. Conceptualization of Fluxes of Water Into and Out of the Crop Root Zone

Transpiration was quantified using a remote sensing approach whereby Landsat satellite images acquired from USGS were used to calculate the Normalized Difference Vegetation Index (NDVI), a measure of the amount of green vegetation present. NDVI values were calculated and interpolated for each field over time. NDVI values were then converted to transpiration coefficients that were used to calculate transpiration over time by multiplying daily NDVI by daily reference evapotranspiration (ET_o). Evaporation was quantified by performing a surface layer water balance for the soil based on the dual crop coefficient approach described in FAO Irrigation and Drainage Paper 56 (Allen et al. 1998). On a daily basis, evaporation was calculated based on the most recent wetting event (precipitation or irrigation) and the evaporative demand for the day (ET_o). This methodology is described in greater detail in Davids Engineering (2013).

3.2 Development of Field Boundaries

A spatial coverage of field boundaries was developed for the study area, and individual field polygons were assigned cropping and irrigation method information. For each polygon, daily water balance calculations were performed, and irrigation events were simulated to estimate the amount of water applied to meet crop irrigation demands. This section describes the development of the field polygon coverage and assignment of cropping and irrigation method attributes.

The Study Area includes areas within and immediately surrounding the Butte Valley and Red Rock Valley Basins, and areas along Butte Creek. This technical memorandum summarizes results for the Butte Valley groundwater basin.

Field boundaries in agricultural areas were delineated by combining polygon coverages from the California Department of Water Resources (DWR) in GIS format. Non-agricultural areas were filled using a grid of approximately 40-acre tracts based on the Public Land Survey System (PLSS).

3.3 Assignment of Cropping and Irrigation Method

As described previously, crop evapotranspiration (ET) was calculated based on a combination of remote sensing data, precipitation data, and simulation of irrigation events in a daily root zone water balance model. A result of the remote sensing approach is that crop transpiration was estimated with little influence from the assigned crop type for each field. Additionally, crop transpiration is the dominant component of ET, meaning that ET estimates are likewise largely independent of the assigned crop type.

Crop evapotranspiration is driven to some extent by the characteristics of the irrigation method and its management, including the area wetted during each irrigation event and the frequency of irrigation. Surface irrigation methods typically wet more of the soil surface than micro-irrigation methods; however, surface irrigated fields are typically irrigated less frequently than their micro-irrigated counterparts. As a result, evaporation rates can be similar among surface and micro-irrigated fields and estimates of evaporation are likewise somewhat independent of the assigned irrigation method. Parameters related to irrigation method were assigned based on the predominant irrigation method for each crop, as described by available DWR land and water use surveys.

A key result of the relative insensitivity of the crop ET estimates to crop type or irrigation method (due to the remote sensing approach), is that detailed, accurate assignment of crop types and irrigation methods to each field is not critical to developing reliable estimates of crop ET at the field scale and, more importantly, at coarser scales due to the cancellation of errors in individual field estimates as they are aggregated (Davids Engineering 2013).

Crop types were assigned to each field based on a combination of data from the 2000, 2010, and 2014 DWR land use surveys for Siskiyou County. In years without available survey data, crop type was assigned based on the nearest year in time for which crop data were available.

3.4 NDVI Analysis

The amount of green vegetation present over time was estimated for each field polygon based on the Normalized Difference Vegetation Index (NDVI), which is calculated using a combination of red and near infrared reflectances, as measured using multispectral satellite sensors onboard Landsat satellites. NDVI can vary from -1 to 1 and typically varies from approximately 0.15 to 0.2 for bare soil to 0.8 for green vegetation with full cover. Negative NDVI values typically represent water surfaces.

3.4.1 Image Selection

Landsat images are preferred due to their relatively high spatial resolution (30-meter pixels, approx. 0.2 acres in size). A total of 428 raw satellite images were selected and converted to NDVI spanning the study period (Table 3.1). Of the images selected, 217 were from the Landsat 5 satellite, 128 were from the Landsat 7 satellite (first available in 2001), and 83 were from the Landsat 8 satellite (first available in 2013). These images were used to process and download surface reflectance (SR) NDVI from the USGS Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA)[2].

The number of days between image dates ranged from 8 to 160, with an average of 25 days. Generally, there was at least one image selected for each month, with less images available during winter months when cloudy conditions are more likely to occur.

3.4.2 Extraction of NDVI Values by Field and Development of Time Series NDVI Results

Following the preparation of NDVI imagery spanning the analysis period, NDVI for water surfaces (such as lakes or some wetlands) was adjusted to a higher value to more accurately estimate ET. All images were then masked using the Quality Assessment Band (BQA) provided by ESPA to remove pixels affected by snow, clouds and cloud shadows. Then, mean NDVI was extracted from the imagery for each field for each image date. These NDVI values were interpolated across the full analysis period from January 1, 1989 to December 31, 2018 to provide a daily time series of mean NDVI values for each field.

3.4.3 Development of Relationship to Estimate Basal Crop Coefficient from NDVI

Basal crop coefficients (K_{cb}) describe the ratio of crop transpiration to reference evapotranspiration (ET_o) as estimated from a ground-based agronomic weather station. By combining K_{cb}, estimated from NDVI, with an evaporation coefficient (K_e), it is possible to calculate a combined crop coefficient ($K_c = K_{cb} + K_e$) over time[3]. By multiplying K_c by ET_o, crop evapotranspiration (ET_c) can be calculated. For this analysis, ET_o, K_{cb}, K_e, and ET_c (synonymous to actual ET, ET_a) were estimated for each field on a daily time step for the full analysis period.

Mean daily NDVI values for each field were converted to basal crop coefficients using a relationship following Er-Raki (2007) and as described in greater detail by Davids Engineering (2013)[4].

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[2] USGS ESPA website: https://espa.cr.usgs.gov/

[3] The estimation of Ke is based on a daily 2-stage evaporation model described in FAO Irrigation and Drainage Paper No. 56 (Allen et al. 1998).

[4] This relationship is developed based on comparison of the combined crop coefficient to NDVI for individual fields but represents only the transpiration component of ET. Thus, the relationship developed predicts the basal crop coefficient, Kcb.

Table 3.1. Landsat Image Selection by Month and Year for Study Period.

	Month												
Year	1	2	3	4	5	6	7	8	9	10	11	12	Total
1989	0	0	1	1	1	2	2	1	2	2	0	2	14
1990	1	1	1	2	1	2	0	1	1	2	0	0	12
1991	0	0	1	2	0	2	0	2	2	2	0	0	11
1992	0	0	1	1	2	1	2	2	2	2	2	1	16
1993	1	1	0	0	2	2	1	1	2	1	1	1	13
1994	2	1	1	2	1	1	2	2	2	1	1	0	16
1995	0	0	0	1	1	2	2	2	2	2	1	1	14
1996	1	1	1	2	2	1	2	2	1	2	1	0	16
1997	1	1	2	2	2	1	1	2	2	2	1	1	18
1998	0	1	2	2	0	2	2	1	2	2	0	2	16
1999	0	0	1	1	1	1	2	1	1	1	1	1	11
2000	0	0	1	0	2	2	1	2	1	1	0	1	11
2001	1	0	1	1	1	1	2	1	1	0	1	0	10
2002	1	1	0	1	1	2	1	1	1	1	1	0	11
2003	1	2	1	0	1	1	1	1	1	1	1	0	11
2004	0	1	1	1	1	1	2	1	1	0	1	1	11
2005	1	0	2	1	2	1	2	1	1	1	1	0	13
2006	0	1	0	1	2	1	2	1	1	1	1	0	11
2007	1	0	2	1	1	2	2	1	1	1	1	0	13
2008	0	0	1	1	1	2	2	2	0	1	1	0	11
2009	1	0	1	2	1	1	2	2	2	0	1	1	14
2010	0	1	1	2	1	1	2	1	2	0	1	0	12
2011	1	0	1	1	1	1	1	1	2	1	0	1	11
2012	1	1	0	1	2	0	1	2	2	0	1	1	12
2013	0	1	0	1	1	2	3	1	2	2	1	0	14
2014	1	0	0	1	1	2	2	1	1	2	0	0	11
2015	3	2	2	2	0	2	2	1	1	2	2	0	19
2016	4	1	4	2	3	2	2	3	3	1	3	2	30
2017	2	2	3	3	3	2	2	2	3	2	1	2	27
2018	1	2	0	1	2	2	2	2	2	2	2	1	19
Total	25	21	32	39	40	45	50	44	47	38	28	19	428

3.5 Precipitation

Daily precipitation was estimated based on assembly and review of data from the PRISM Climate Group at Oregon State University. Specifically, each field was assigned estimated daily precipitation from the 4km PRISM grid cell within which its centroid fell. The study area is represented by 99 individual grid cells.

Annual precipitation totals, averaged over the study area for water years 1990 to 2018, are shown in Figure 3.1. Water year precipitation over the study period varied from 7.9 inches in 2001 to 22.1 inches in 1998, with an annual average of 14.0 inches.

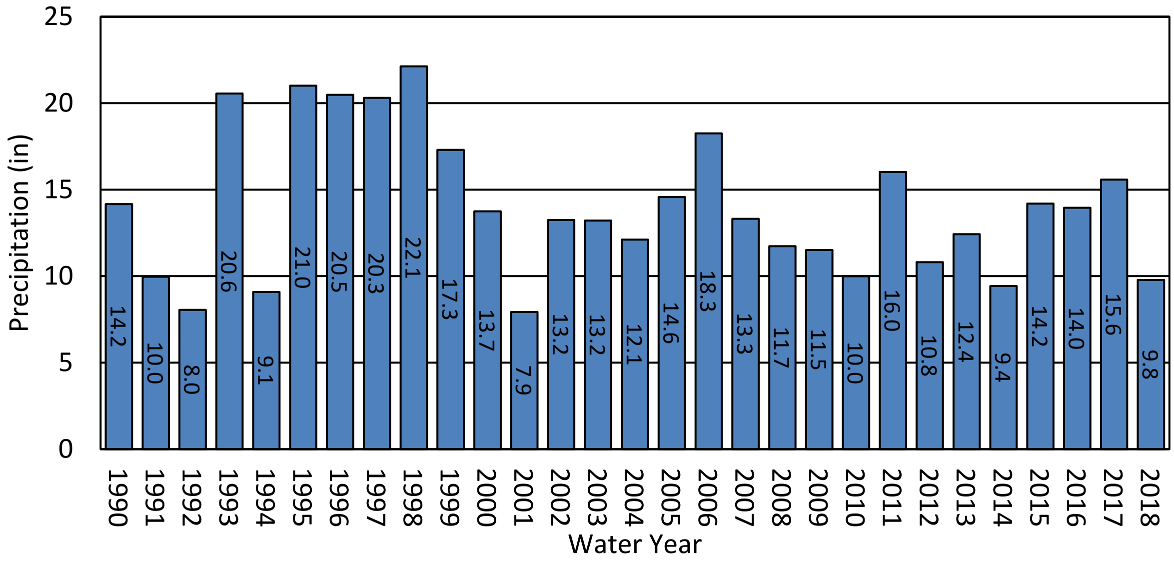

Figure 3.2. Annual Precipitation Totals

3.6 Reference Evapotranspiration

Daily reference evapotranspiration (ET_o) was estimated based on information from the MacDoel II CIMIS weather station (Station No. 236) and air temperature at the Juanita Lake NOAA[5] weather station. ET_o provides a means of estimating actual crop evapotranspiration over time for each field. Based on review of nearby weather stations with data available during the period of analysis, the MacDoel II station was selected based on it being located within the Butte Valley Basin, having relatively good fetch, and having available data during part of the analysis period. Since the MacDoel II station only had data available starting in 2015, estimated ET_o data based on temperature at the Juanita Lake station were used to fill in the remaining time period.

Individual parameters from the available CIMIS data including incoming solar radiation, air temperature, relative humidity, and wind speed were quality-controlled according to the procedures of Allen et al. (2005). The quality-controlled data were then used to calculate daily ET_o for the available period of record. Quality controlled NOAA temperature data were used to estimate daily ET_o using the method of Hargreaves and Samani (1985). The estimated Juanita Lake ET_o data were then correlated to the CIMIS data at MacDoel II during the period of overlap. This resulted in an adjustment factor that was applied to the Juanita Lake ET_o for the period during which MacDoel II data were not available.

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[5] https://www.ncdc.noaa.gov/cdo-web/search

ET_o zones were developed to account for the variability in elevation, slope, and aspect (and therefore ET) found in the study area based on long-term average spatialy distributed ETo from Spatial CIMIS[6]. One ET_o zone was created for each PRISM precipitation grid cell, resulting in the creation of 99 ET_o zones. ET values were multiplied by an adjustment factor for each zone to derive an ET time series for each land use and ET zone.

3.7 Root Zone Water Balance Parameters

Root zone parameters that influence the amount of available soil moisture storage were estimated based on crops and soils present in the study area. Crop parameters of interest include root depth, NRCS curve number[7], and management allowable depletion (MAD). Root depth was estimated by crop group based on published values. Curve numbers were estimated based on values published in the NRCS National Engineering Handbook, which provides estimates based on crop type and condition. MAD values by crop were estimated based on values published in FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998).

Soil hydraulic parameters of interest include field capacity (% by vol.), wilting point (% by vol.), saturated hydraulic conductivity (ft/day), total porosity (% by vol.), and the pore size distribution index (λ, dimensionless). These parameters were estimated by first determining the depth-weighted average soil texture (sand, silt, clay, etc.) based on available NRCS soil surveys. Next, the hydraulic parameters were estimated using hydraulic pedotransfer functions developed by Saxton and Rawls (2006). Then, hydraulic parameters were adjusted within reasonable physical ranges for each soil texture so that the modeled time required for water to drain by gravity from saturation to field capacity agreed with typically accepted agronomic values. Unsaturated hydraulic conductivity (e.g. deep percolation) within the root zone was modeled based on the equation developed by Campbell (1974) for unsaturated flow.

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

[7] The curve number runoff estimation method developed the Natural Resources Conservation Service (NRCS) was used to estimate runoff from precipitation in the model. For additional information, see NRCS NEH Chapter 2 (NRCS, 1993).

4 Results

4.1 Evapotranspiration

Estimated annual crop evapotranspiration volumes for agricultural fields in the Study Area are shown in Figure 4.1. Estimated volumes of ET derived from applied water (ETaw) and precipitation (ETpr) are shown in thousands of acre-feet (taf). Annual ETaw ranged from 28 taf to 61 taf, with an average of 41 taf. Annual ETpr ranged from 12 taf to 32 taf, with an average of 21 taf. Total crop ET ranged from 49 taf to 82 taf, with an average of 62 taf.

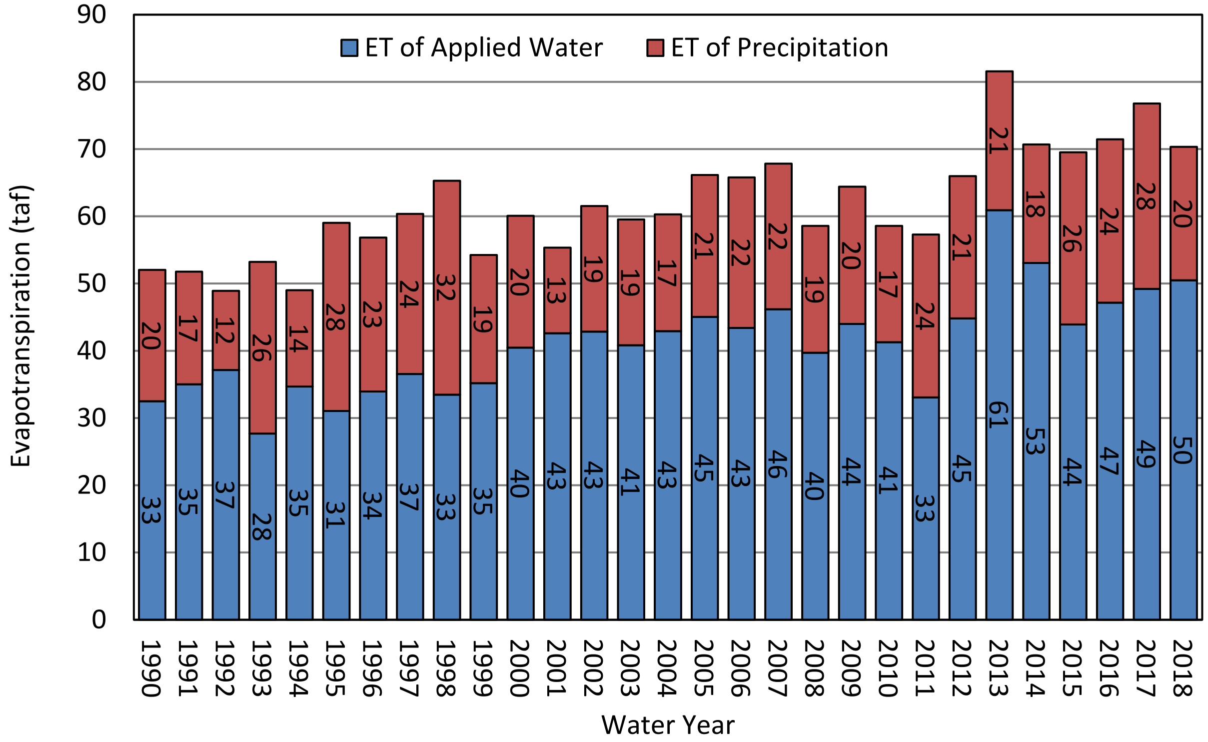

Figure 4.1. Crop ET by Water Year

4.2 Irrigation Demands

Annual estimated irrigation demands for fields in the Study Area are shown in Figure 4.2 in thousands of acre feet. Annual demands ranged from 42 taf to 82 taf, with an average of 59 taf.

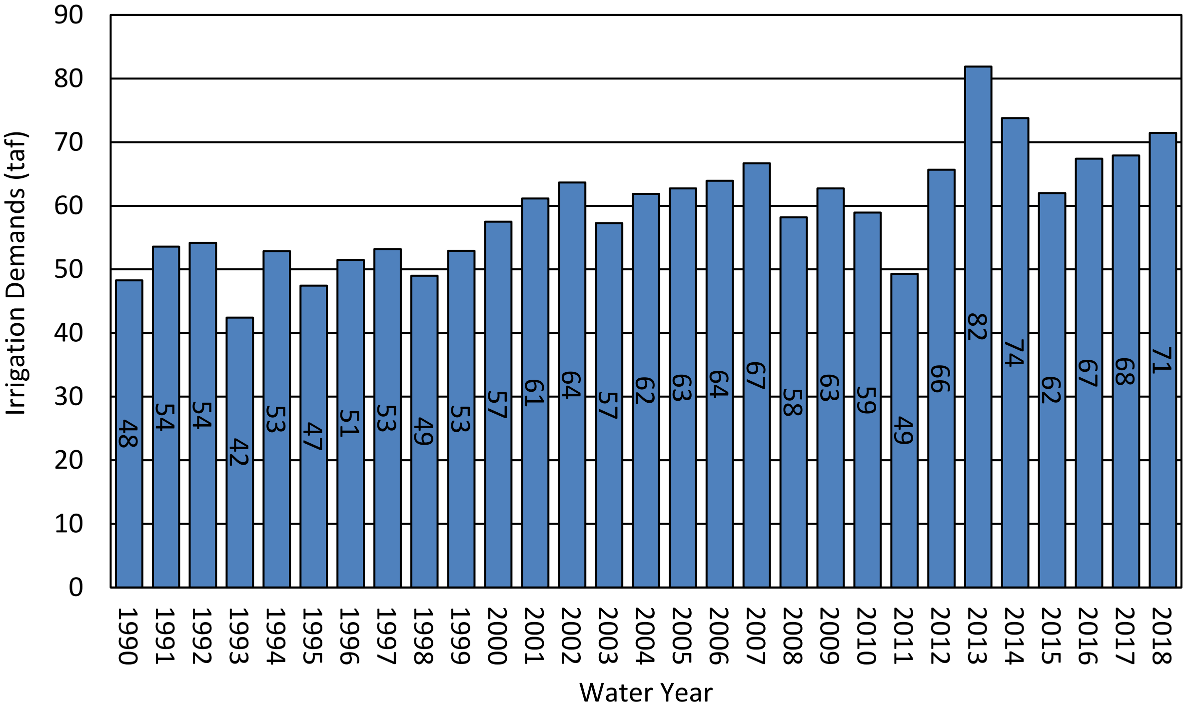

Figure 4.2. Study Area Irrigation Demands by Water Year

4.3 Deep Percolation

Estimated annual deep percolation volumes for fields in the Study Area are shown in Figure 4.3. Estimated volumes of deep percolation derived from applied water (DPaw) and precipitation (DPpr) are shown in thousands of acre-feet. Annual DPaw ranged from 15 taf to 23 taf, with an average of 18 taf. Annual DPpr ranged from 5 taf to 21 taf, with an average of 12 taf. Total deep percolation ranged from 23 taf to 42 taf, with an average of 30 taf.

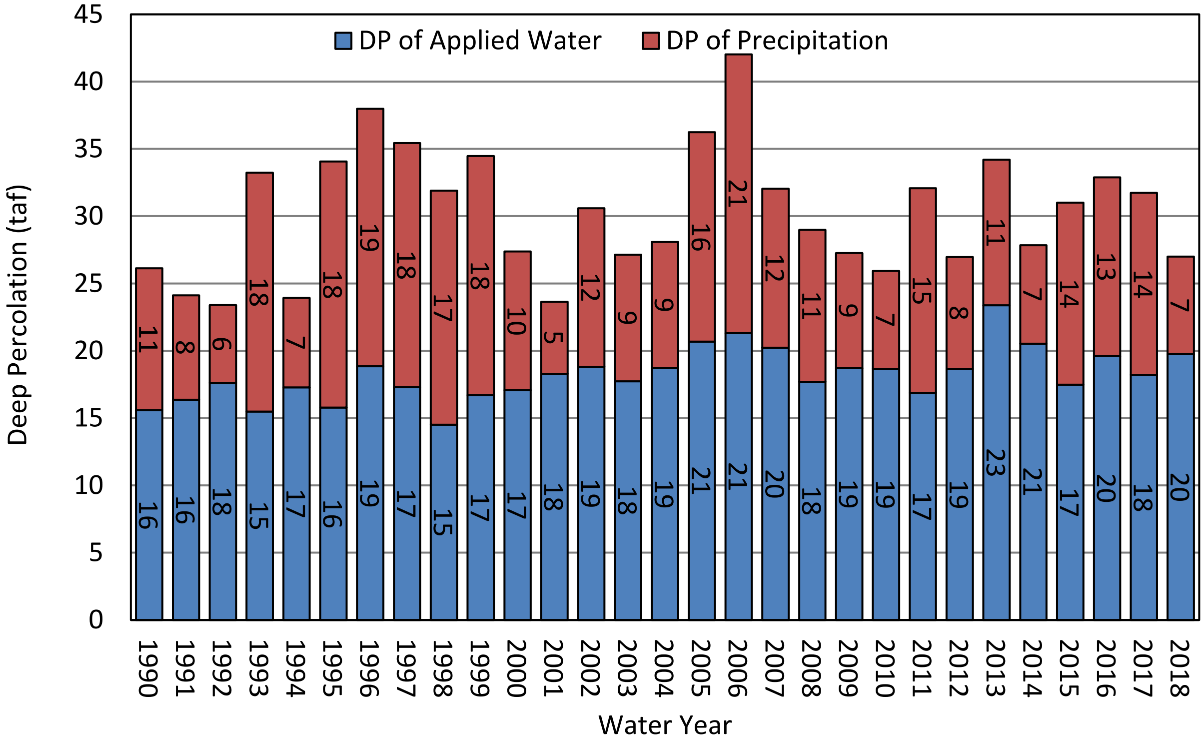

Figure 4.3. Study Area Deep Percolation by Water Year.

4.4 Evapotranspiration by Crop

Average monthly evapotranspiration by crop (ETc) is presented in Figures 4.4 through 4.9 for each year with available DWR land use survey data (2000, 2010, and 2014), along with averages for the three survey years. Additionally, monthly ETo values are shown along with monthly crop coefficients (Kc), calculated as ETc divided by ETo.

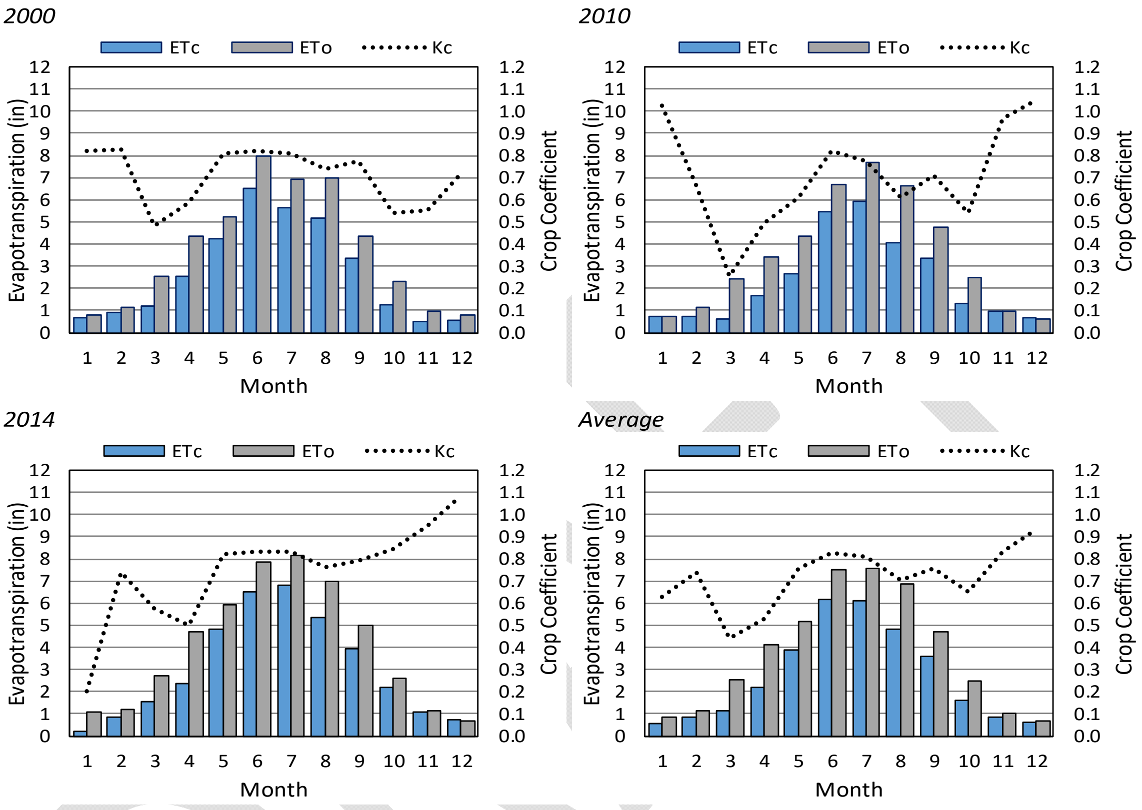

Figure 4.4. Alfalfa Monthly ETc, ETo, and Kc.

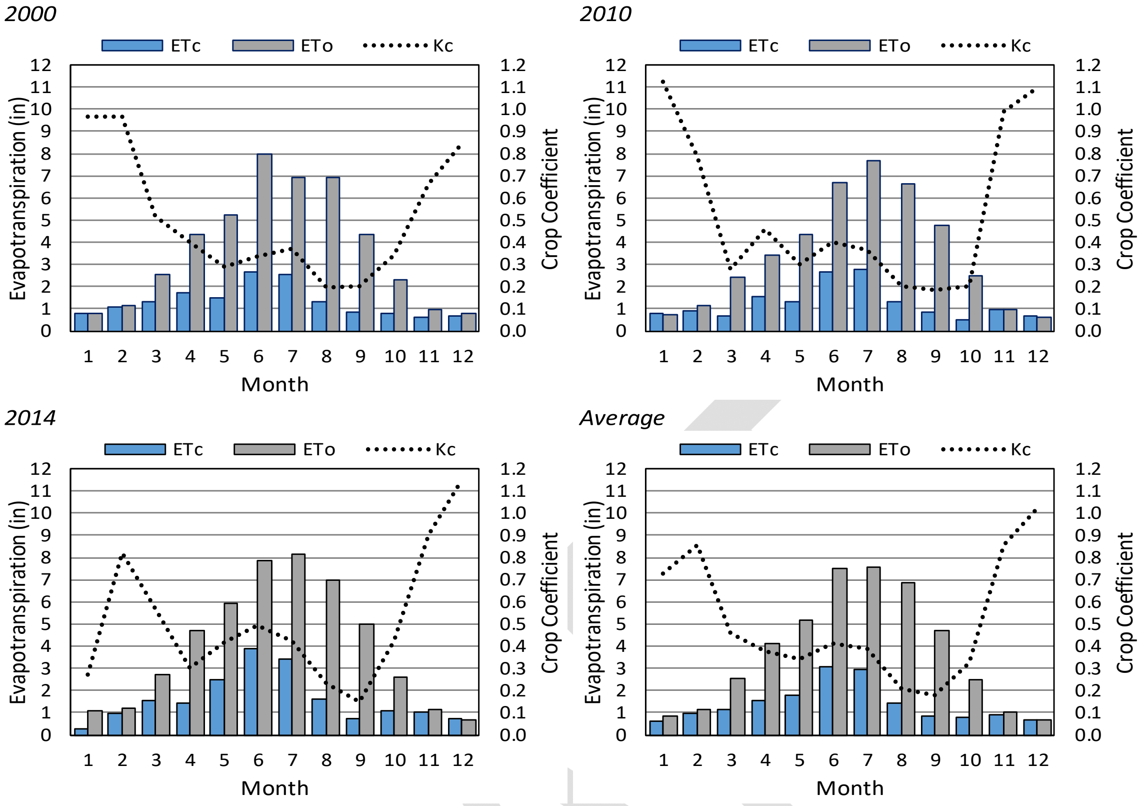

Figure 4.5. Grain and Hay Monthly ETc, ETo, and Kc.

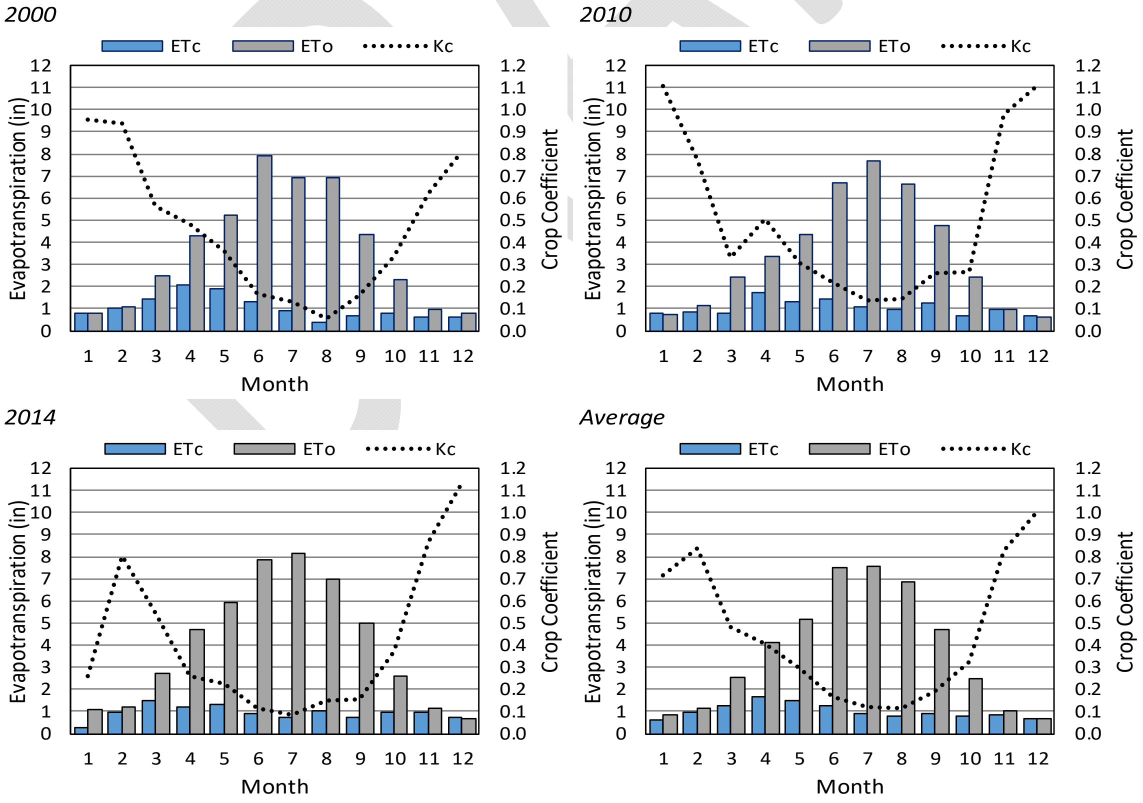

Figure 4.6. Idle Cropland Monthly ETc, ETo, and Kc.

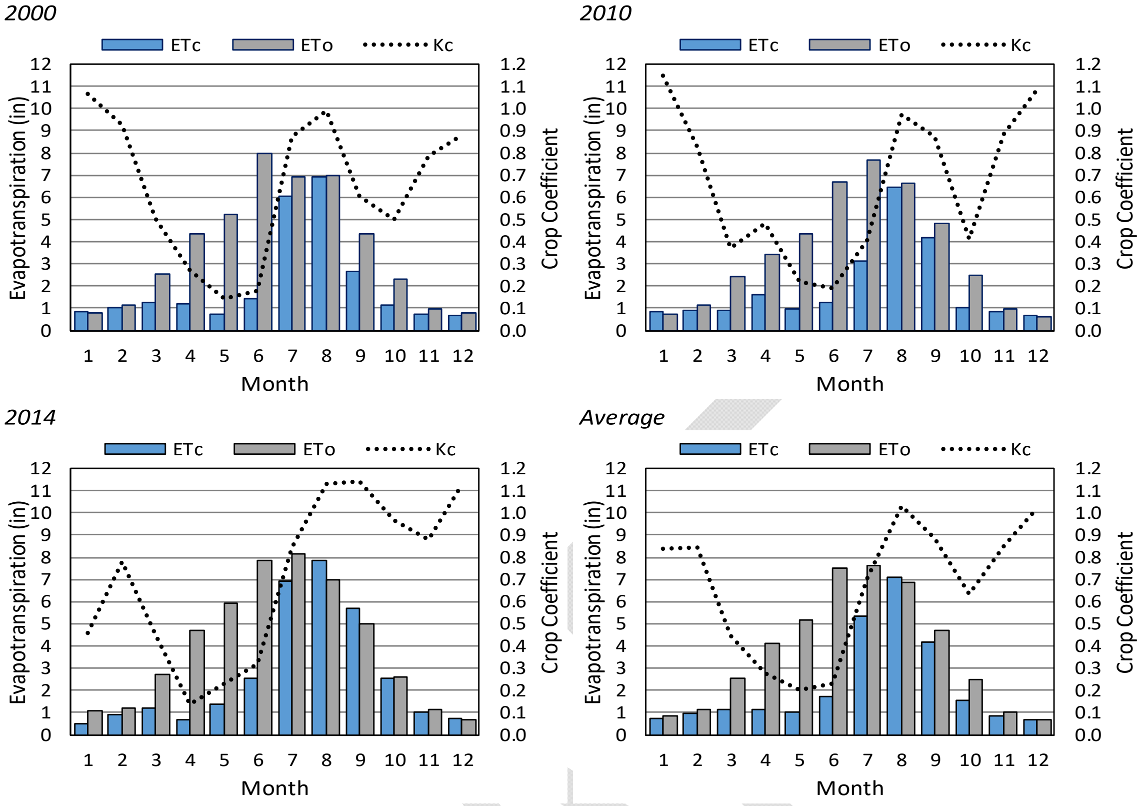

Figure 4.7. Miscellaneous Truck Crop Monthly ETc, ETo, and Kc.

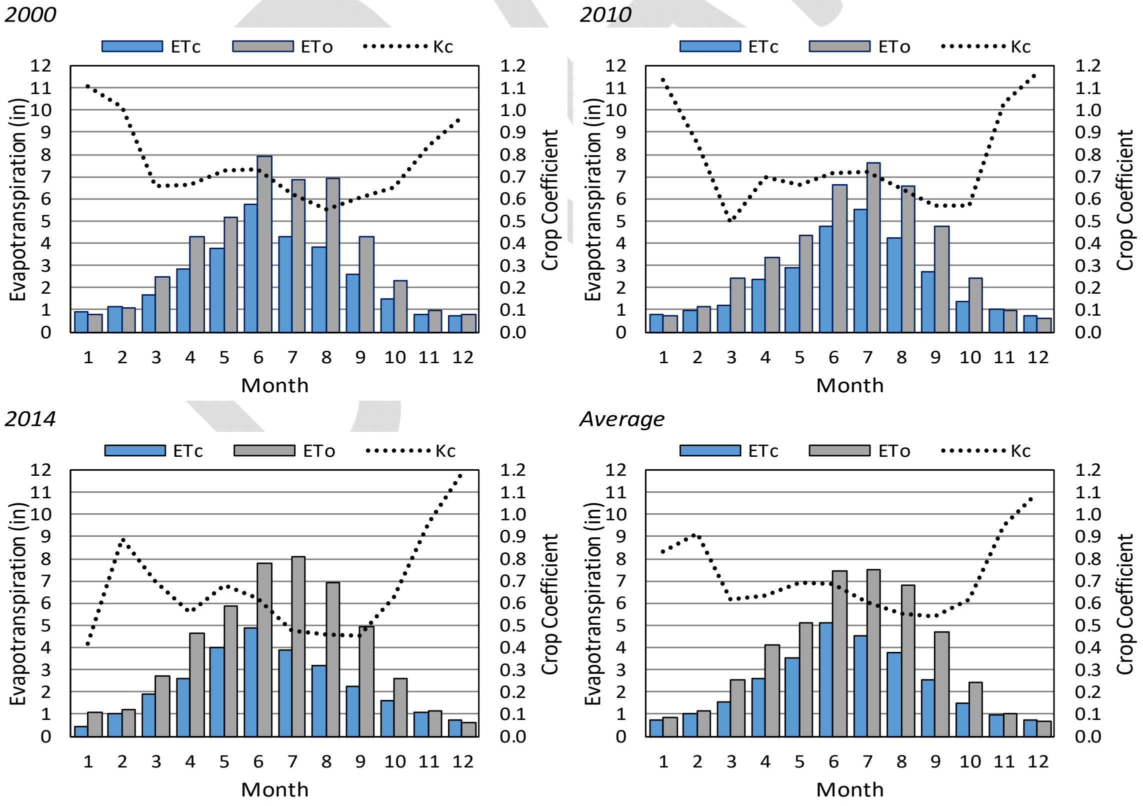

Figure 4.8. Pasture Monthly ETc, ETo, and Kc.

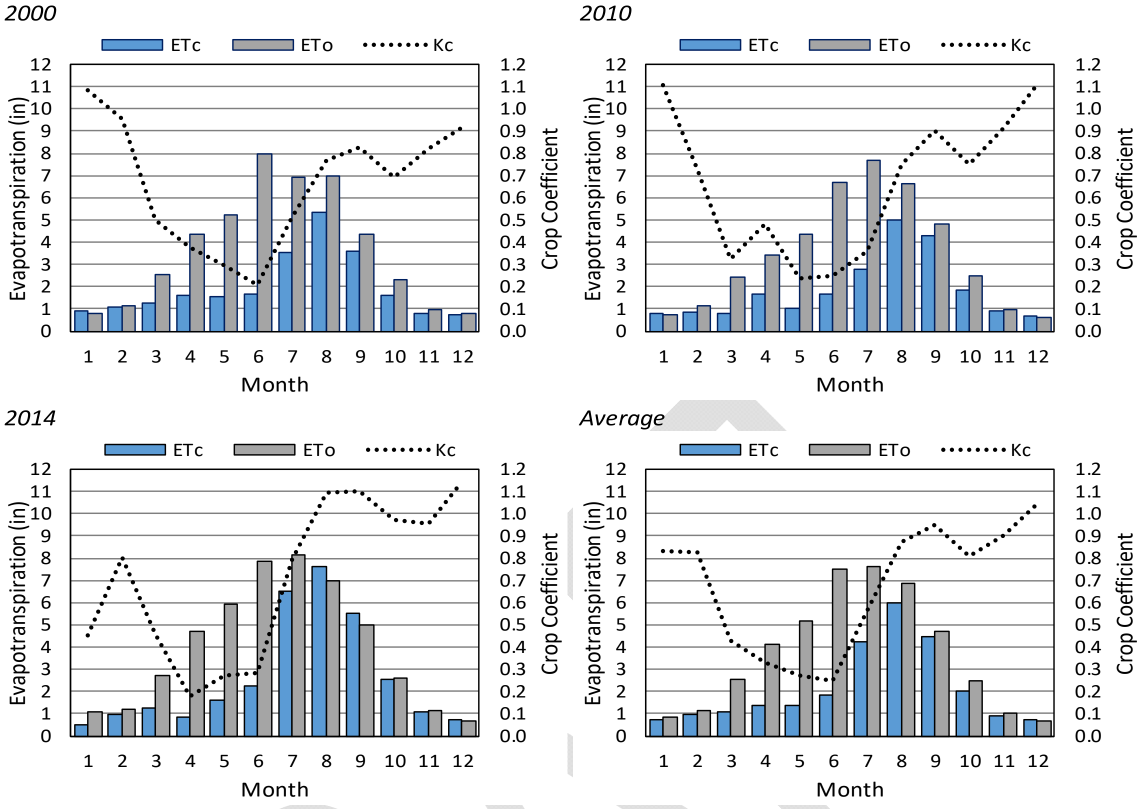

Figure 4.9. Strawberry Monthly ETc, ETo, and Kc.

5 References

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Technical Memorandum

To: Interested Parties

From: Davids Engineering

Date: May 2021

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

Summary

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

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

Background and Overview

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

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[1] Thousand acre-feet.

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

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

BVWA Land and Water Management

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

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

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

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

Water Budget Methodology

Structure

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

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

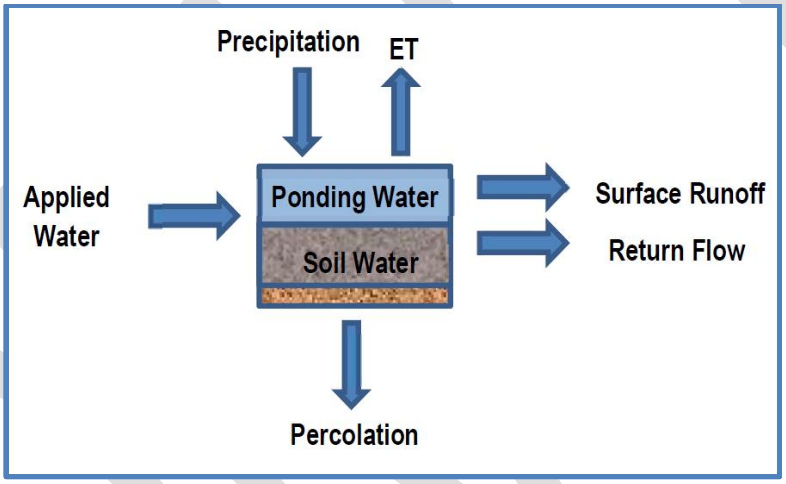

Figure 1. Wetlands Water Budget Structure (DWR 2017).

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

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

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

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

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

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

Components

Evapotranspiration (ET)

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

$$\text{Actual ET} = \text{ET}_o \text{ x Kh} \qquad [2]$$

Surface Runoff (SR)

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

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

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

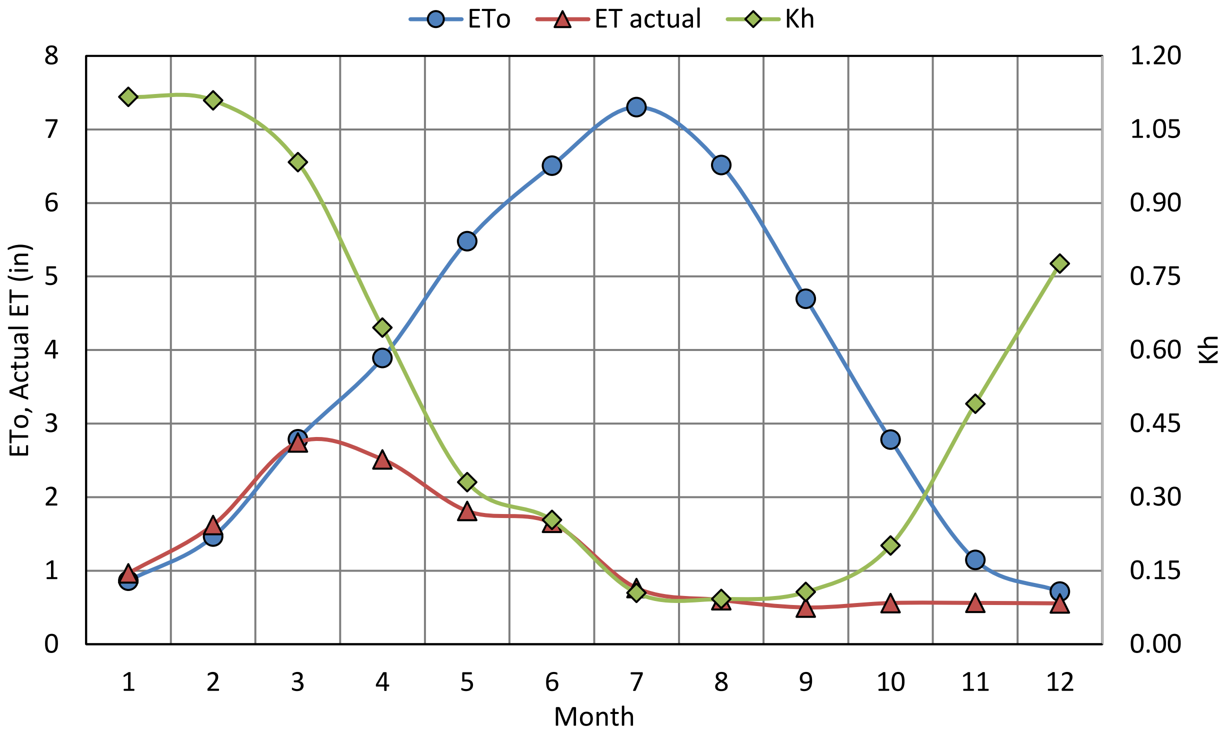

Figure 2. Reference ET (ET_o), Habitat Coefficients (Kh), and Actual ET for 2017-2018 for the Sacramento NWR.

Return Flow (RF)

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

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

Percolation (Perc)

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

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

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

Precipitation (Precip)

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

Change in Storage (dS)

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

Applied Water (AW)

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

Results

Monthly Water Budget

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

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

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

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

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

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

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

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

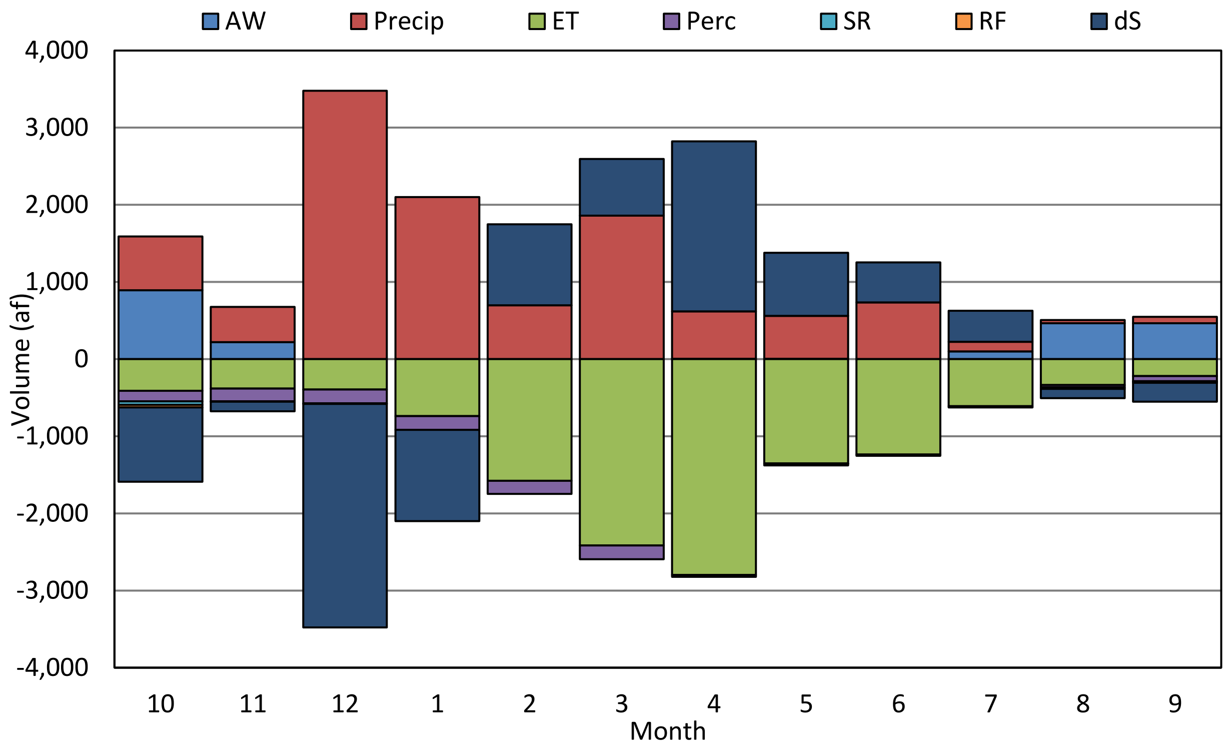

Figure 3. Water Year 2016 Monthly Water Budget (acre-feet).

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

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

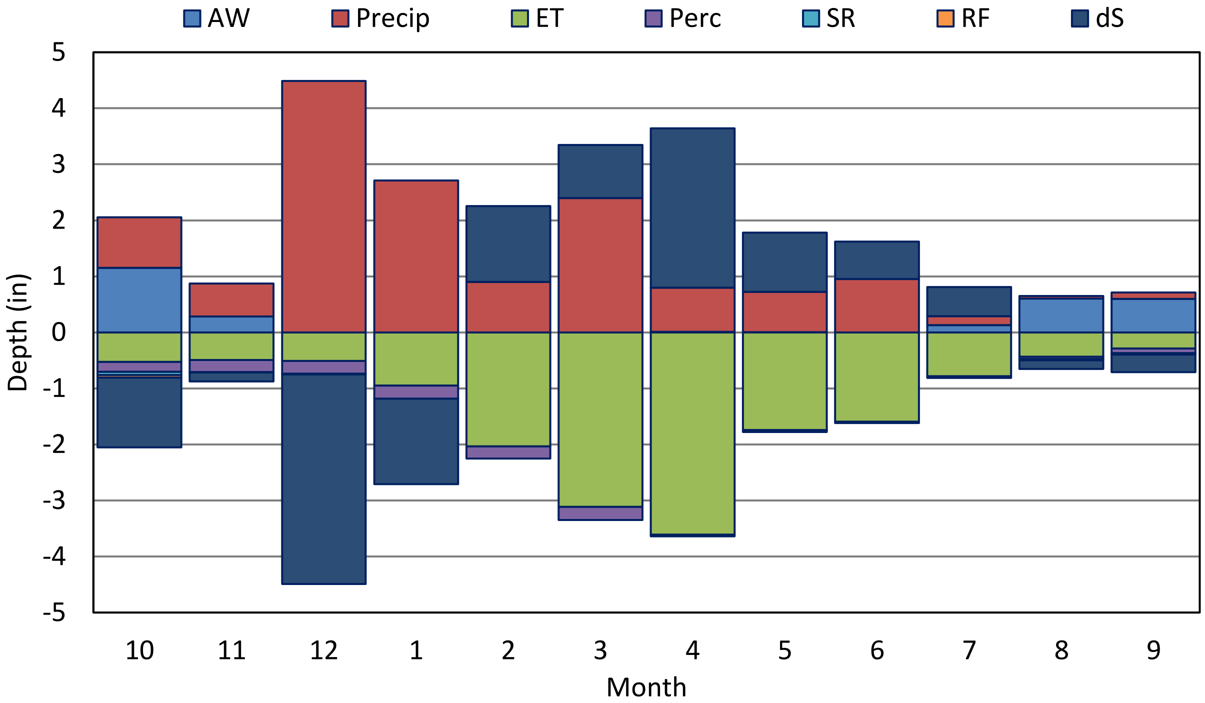

Figure 4. Water Year 2016 Monthly Water Budget (inches).

Annual Water Budget

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

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

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

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

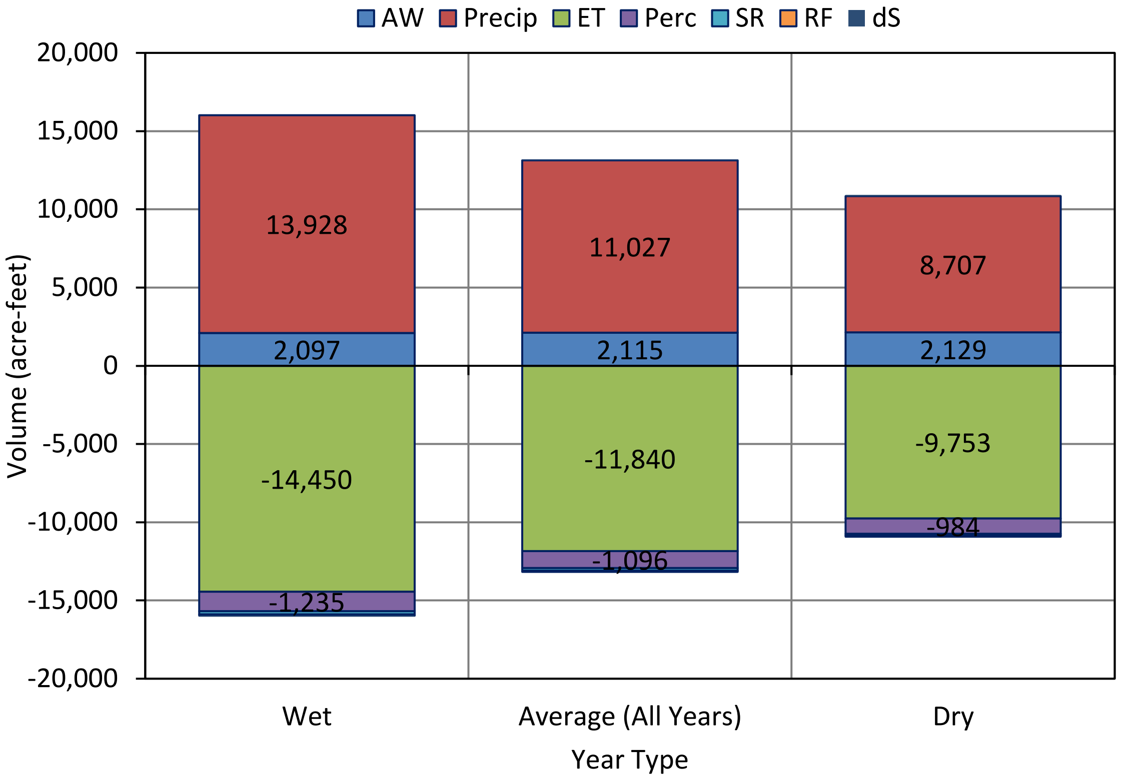

Figure 5. Annual Water Budget Results for Wet and Dry Years, and Overall Average, for 1991 – 2017 Period (acre-feet).

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Appendix 3-A. Data Gap Appendix

Introduction

Multiple datasets were utilized during development of this GSP to characterize current and historical Basin conditions. Monitoring networks were designed to support the evaluation of Basin conditions throughout GSP implementation, particularly with respect to the six sustainability indicators. The representative monitoring points (RMPs) in these monitoring networks are sites at which quantitative values for minimum or maximum thresholds, measurable objectives, and interim milestones are defined. New RMPs will be considered for the 5-years update based on the suggested expanded monitoring network. Data gaps that were identified throughout the GSP development process can be categorized into:

I. Data gaps in information used to characterize current and historical basin conditions.
II. Data gaps in monitoring networks developed to evaluate future Basin conditions which will be used in reporting and tracking Basin sustainability.
III. Additional data or information valuable for measuring progress towards the Basin's sustainability goal. This information has been identified as information that may be useful but has not been confirmed as a data gap.

These data gaps were identified based on spatial coverage of data, the period for which data are available, frequency of data collection, and representativeness of Basin conditions. An overview of data gaps in the first category is provided in Chapter 2, as part of the characterization of past and current Basin conditions, and the data gaps in the second and third categories are in Chapter 3 as part of descriptions of the monitoring networks. This appendix details the identification of data gaps and uncertainties in each of the categories and the associated strategies for addressing them. The process of data gap identification, and development of strategies to fill data gaps is illustrated in Figure 1 below, sourced from the Monitoring Networks and Identification of Data Gaps Best Management Practice (BMP), provided by DWR (2016).

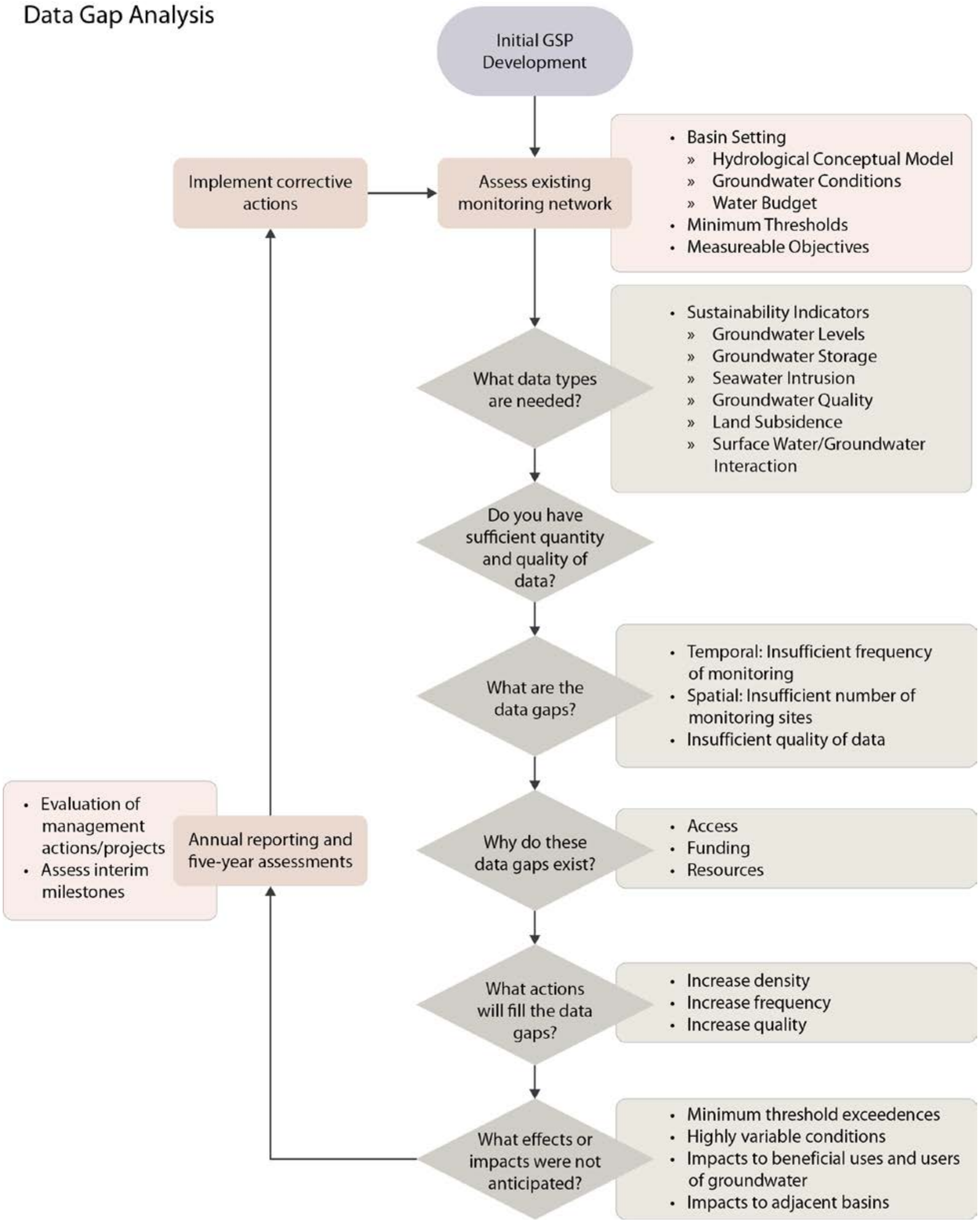

Figure 1: Data Gap Analysis Flowchart (DWR 2016).

I. Data Gaps in Existing Information Used for Basin Characterization

Definition of the hydrogeological conceptual model (HCM) is a key requirement for understanding the Basin setting and characterizing existing and historical Basin conditions. An accurate assessment of the physical setting and processes that control groundwater occurrence in the Basin is foundational to development of the sustainable management criteria and monitoring networks in Chapter 3 and identification of projects and management actions in Chapter 4.

Identification of data gaps and uncertainty within the HCM is a requirement per 23 CCR 354.14 (b)(5) and is important to choosing locations and types of additional monitoring that reduce these gaps and uncertainties.

Identification of Data Gaps

The HCM is detailed in Chapter 2 of this GSP. Data gaps and uncertainties were identified throughout development of the HCM and are briefly discussed in Chapter 2 under applicable subsections. A discussion of the components of the HCM for which key datasets were used, associated data gaps, and uncertainties is provided below.

Climate

Long-term records are available from National Oceanic and Atmospheric Administration (NOAA) weather stations in and around Butte Valley. A list of the applicable NOAA weather stations used in development of the climate component of the HCM can be found in Section 2.2.1.2. Data from these stations were used to evaluate historical and current precipitation and evaluate spatial and temporal (seasonal and long-term) trends in precipitation. Maximum and minimum air temperatures from 1942 to 2020 were obtained from the Mount Hebron Ranger weather station (USC00045941), and reference evapotranspiration (ET) from 2015 to 2020 is calculated at CIMIS Station 236, near Macdoel. Temperature and ET data was used to evaluate short and long-term trends in the Basin. Snow measurement data is not available in the Butte Valley watershed and is a data gap.

Current and historical climate data is readily available for the Butte Valley watershed (Watershed) and has insufficient spatial coverage, but adequate frequency of measurement and length of record to evaluate current and historical conditions and identify trends. Based on an initial assessment of the data, a rainfall gradient is suspected but not confirmed in the Watershed. The presence of a rainfall gradient is an uncertainty in this section of the HCM.

Geology

The primary sources of information used in development of the geology section of the HCM are the California Geologic Survey digitized geologic map (Charles W. Jennings, with modifications by Carlos Gutierrez, William Bryant and Wills 2010), and the foundational geologic report (Wood 1960).

Data gaps related to the total depth of alluvial deposits within the basin and the lateral extent of major buried features such as the Butte Valley Basalt were identified in development of this section of the HCM.

Soils

A 1985 soil survey of Butte Valley-Tule Lake Area (USDA 1994) was the primary source used for development of this component of the HCM. Additionally, soil properties as they relate to groundwater recharge were characterized through the Soil Agricultural Banking Index (SAGBI) ratings for the soil series in the Butte Valley area can be viewed on a web application (app), developed by the California Soil Resource Lab at the University of California at Davis and University of California Agriculture and Natural Resources (UC Davis Soil Resource Lab and University of California Agriculture and Natural Resources 2019).

No data gaps were identified in the development of this section.

Hydrology and Identification of Interconnected Surface Water Systems

The hydrology and natural flow regime in Butte Valley have previously been of limited study due to the limited number of surface water features. There are no stream gauges within the Butte Valley basin boundary. Historical surface water flows were recorded within the watershed along Butte Creek and Antelope Creek at USGS stations 11490500, 11489500, and 114900000, with no recent data. Reporting on Antelope Creek near Tenant from 1952 to 1979, on Antelope Creek nearer Macdoel from 1921 to 1922, and along Butte Creek during two periods, from 1921 to 1922 and from 1952 to 1960.

Data gaps were identified in historical and current information for this component of the HCM. Streamflow records contain significant data gaps any recent data since 1980. In addition, Ikes, Prather, Muskgrave, and Harris creeks also drain into Butte Valley but have no records. Data gaps were identified in the development of this section.

Identification of Groundwater Dependent Ecosystems

Data from the National Wetlands Inventory, The Nature Conservancy, and other sources (as detailed in Section 2.2.2.7) was used to identify groundwater dependent ecosystems (GDEs) in the Basin. While the results of the initial GDE inventory were evaluated by the Technical Advisory Committee, physical verification has not been completed. Uncertainty exists regarding habitat maps and presence of certain species in the Basin. Additionally, groundwater levels near the GDEs are poorly constrained and the groundwater level monitoring network must be expanded appropriately. There is therefore some uncertainty between riparian and non-riparian GDEs that were mapped and the existence and extent of these GDEs on the ground.

A GDE PMA addresses filling data gaps (see Chapter 4). Local habitat and potential GDEs must be groundtruthed using local knowledge, from ranchers to environmentalists. For example, local ranchers can review mapped GDE and habitat polygons on their property and mark the irrigation canals and natural stands of willow. The Butte Valley Wildlife Area (BVWA) manages its vegetation through irrigation (flooding) using both surface water and groundwater. Irrigation of natural vegetation and wetlands with groundwater does not establish these ecosystems as groundwater-dependent in the same way as natural, non-irrigated GDEs. The latter depend on specific water level depth, while the former depend on access of wells to groundwater. BVWA will work with the GSA to review mapped GDE and habitat polygons to provide feedback on which potential GDEs within their borders are irrigated versus natural habitat.

Current and Historical Groundwater Conditions

Groundwater Elevation Data

A total of 85 wells with groundwater elevation data are available in the Basin. Groundwater elevation data is sourced primarily from the California Statewide Groundwater Elevation Monitoring Program (CASGEM). Well data is available dating back to the 1950s and wells have reasonable spatial coverage of the Basin, measurement frequency and period of record. CASGEM wells are measured at a frequency of twice per year, however many wells have missed observations. These frequencies are reasonable to enable determination of seasonal, short-term, and long-term trends in most parts of the valley. A summary of the wells with groundwater elevation data, and additional available information is shown in Table 1. Some spatial and temporal data gaps are discussed in Chapter 3 and below.

Table 1: Wells with groundwater elevation data in the Butte Valley Basin. Recent is here used to refer to data from the past ten years.

Wells	Groundwater Basin
Wells with coordinates (including data from WCRs referenced to nearest PLSS section)	295
Wells with screen depth information	62
Wells with coordinates and recent1 water level data	74
Wells with pumping data	None

Estimate of Groundwater Storage

Partial groundwater storage data is available from the foundational geological report (Wood 1960) and overall specific yield and storativity were estimated using the Butte Valley Integrated Hydrologic Model (BVIHM). Data gaps include the depth and width of the High Cascades Volcanic unit (see Section 2.2.2.2).

Groundwater Extraction Data

No pumping monitoring program currently exists in the Basin and this data is not available for any of the wells with groundwater elevation data. This has been identified as a data gap.

Groundwater Quality

Groundwater quality data was obtained from several sources including the California Groundwater Ambient Monitoring and Assessment (GAMA) Program Database, the USEP Storage and Retrieval Data Warehouse (STORET), and GeoTracker GAMA. As detailed in Appendix 2-C, available water quality data were compared to regulatory standards and mapped. Constituents of concern were identified through visual analysis of recent data (within the past 30 years) of the generated maps and timeseries for each constituent (available in appendix 2-C). As seen on these maps, and noted in Section 2.2.2.3, there are multiple data gaps in the groundwater quality information used to develop the HCM. Spatially, groundwater quality data is frequently concentrated near Dorris and Mount Hebron and coverage in other areas of the Basin is missing for multiple constituents. Additionally, most of the groundwater quality data used in the assessment did not have a long record with consistent measurements, or measurements with a frequency that would be sufficient for determination of historical trends in groundwater quality. Further data gap discussion and the strategy for filling these data gaps is discussed under the groundwater quality monitoring network associated with Chapter 3, below.

Land Subsidence Conditions

Land subsidence data is entirely sourced from the TRE Altamira Interferometric Synthetic Aperture Radar (InSAR) dataset which provides estimates of vertical displacement from June 2015 to September 2019. No data gaps were noted in this section due to the lack of subsidence in the InSAR data and historical observations.

Water Budget

The water budget is dependent on monitoring data inputs. For data gaps in the water budget see previous sections on climate and hydrology (i.e., tributary) data gaps.

II. Data Gaps Monitoring Networks

Requirements

Multiple data gap requirements are relevant to the definition of monitoring networks for sustainability indicators. Per 23 CCR 354.38 (“Assessment and Improvement of Monitoring Network”):

(a) Each Agency shall review the monitoring network and include an evaluation in the Plan and each five-year assessment, including a determination of uncertainty and whether there are data gaps that could affect the ability of the Plan to achieve the sustainability goal for the basin.

(b) Each Agency shall identify data gaps wherever the basin does not contain a sufficient number of monitoring sites, does not monitor sites at a sufficient frequency, or utilizes monitoring sites that are unreliable, including those that do not satisfy minimum standards of the monitoring network adopted by the Agency

(c) If the monitoring network contains data gaps, the plan shall include a description of the following:

  i. The location and reason for data gaps in the monitoring network
  ii. Local issues and circumstances that prevent monitoring

(d) Each Agency shall describe steps that will be taken to fill the data gaps before the next five-year assessment, including the location and purpose of newly added or installed monitoring sites.

The following discussion summarizes the identified data gaps, description, and strategy to fill the identified data gaps.

Groundwater Level and Storage Monitoring Network

Data gaps in the groundwater level monitoring network are discussed in Section 3.3:

- Near surface water bodies (Meiss Lake and streams, particularly Butte Creek and Prather Creek)
- Potential groundwater dependent ecosystems
- Potential interconnected surface water
- Sam's Neck
- Butte Valley National Grassland
- Butte Valley Wildlife Area
- Wells within the Watershed in areas of interest, such as the Butte Creek diversion

The above spatial data gaps prevent completion of the groundwater dependent ecosystem (GDE) analysis, analysis of interconnected surface waters, and limits the analysis of Basin inflows and outflows for the Butte Valley Integrated Hydrogeologic Model (BVIHM). The GSA is seeking funding to install new monitoring wells.

Additionally, continuous groundwater level measurements would enable better monitoring of SMC compliance so PMAs can be initiated effectively in a timely manner. The GSA has begun the process of filling data gaps though voluntary continuous groundwater level metering (shown in Chapter 3 - Figure 1). Additional metering is needed.

Groundwater Quality Monitoring Network

Requirements

Requirements for the monitoring network for the degraded water quality sustainability indicator are outlined in 23 CCR 354.34 (c)(4):

Degraded Water Quality. Collect sufficient spatial and temporal data from each applicable principal aquifer to determine groundwater quality trends for water quality indicators, as determined by the Agency, to address known water quality issues.

Data Gaps

Data gaps in the groundwater quality monitoring network were identified due to inadequate spatial coverage, monitoring frequency, and/or lack of representativeness of Basin conditions and activities. The one site with existing and ongoing groundwater quality monitoring are public supply wells and is therefore concentrated near population, or seasonal population, centers near Dorris, leaving much of the Basin without representative monitoring data. The location of these data gaps is shown on the map of the existing groundwater quality monitoring locations (see Figure 2 in Chapter 3). The entire remaining basin has insufficient monitoring to interpret historical trends or are entirely outside the current monitoring network. These data gaps are due to the limited number of wells that conduct current and ongoing monitoring for the identified constituents of concern. The wells in the existing groundwater quality network also have a temporal data gap with a frequency of measurement annually or greater, corresponding to the public water supply system sampling frequency. A higher frequency of sampling, at minimum biannually, is necessary to enable determination of trends in groundwater quality on an intra-annual scale. No local issues or circumstances are expected to prevent monitoring. As discussed in Section 3.3.3, the groundwater quality monitoring network will be expanded with a minimum addition of five wells within the first five years of plan implementation to address this data gap. Candidate wells have been identified for inclusion in this expansion including wells in the monitoring network for groundwater levels.

Depletions of Interconnected Surface Water Monitoring Network

Requirements

The requirements for the depletion of interconnected surface water (ISW) monitoring network, as part of § 354.34. Monitoring Network, are detailed below:

(A) Flow conditions including surface water discharge, surface water head, and baseflow contribution.
(B) Identifying the approximate date and location where ephemeral or intermittent flowing streams and rivers cease to flow, if applicable.
(C) Temporal change in conditions due to variations in stream discharge and regional groundwater extraction.
(D) Other factors that may be necessary to identify adverse impacts on beneficial uses of the surface water.
(E) Changes in gradient between river and groundwater system.

Data Gaps

Due to the lack of sufficient data on potential ISWs in the Basin, sustainability management criteria (SMC) cannot be set until data gaps are addressed. Critical data gaps include sufficient coverage of the groundwater level monitoring network near potential ISWs and stream gages. One new stream flow station is under development on Butte Creek near the Butte Creek diversion the understanding of surface water flow into Butte Valley. Under sufficient funding conditions additional stream flow gauging stations will significantly reduce uncertainty caused by this data gap. The GSA will address these data gaps and revisit potential ISW SMCs in the 5-year GSP update.

III. Additional Data or Information Valuable for Measuring Progress Towards the Basin Sustainability Goal

Additional data has been identified that may be valuable to evaluations of progress towards the Basin’s sustainability goal. This is primarily additional monitoring information that may be useful to identify adverse impacts on biological uses of surface water, in addition to existing biological monitoring in the Basin.

These include evaluation of streamflow depletion impacts on juvenile salmonids and use of satellite imagery for monitoring riparian and non-riparian vegetation. The GSA may consult other entities or specialists, as feasible, to determine the value of this data.

IV. Data Gap Prioritization

The identified data gaps are prioritized for actions to be taken to resolve them. Data gaps are categorized into “high,” “medium,” and “low” prioritization statuses based on the value to understanding basin setting or in comparison to the defined SMCs to evaluate Basin sustainability. Filling data gaps can be achieved through increasing monitoring frequency, addition of monitoring sites to increase spatial distribution and density of the monitoring network or adding or developing new monitoring programs or tools. Summaries of the data gaps discussed in this appendix, associated prioritizations, and strategies to fill the data gap are shown in Table 2.

Table 2: Data gap prioritization

Priority	Data Gap Summary	Strategy to Fill Data Gap
High	Increase frequency of water quality sampling to develop a record of future seasonal and annual fluctuations in water quality	Develop and fund an annual sampling plan based on RMP groundwater elevation collection points
High	Expand the groundwater level network to cover current data gaps, particularly near surface waters (potential ISWs) and potential groundwater dependent ecosystems. The utmost priority is filling data gaps near Butte Creek and Butte Valley Wildlife Area (BVWA).	The GSA will seek local volunteers with historical groundwater level data and seek funding for installation of additional monitoring wells.
High	Expand groundwater sampling in RMP points to include continuous logging to improve the quality of observations during major pumping and recharge periods	Where possible, instrument RMP wells with continuous loggers and telemetry
Medium	Install surface water gauges on Butte, Ikes, Prather, Muskgrave, and Harris Creek to develop a record and surface water budget flowing into Butte valley	Establish stream gauges at strategic locations along creeks where existing infrastructure permits inexpensive observations, install data loggers and telemetry, and fund future work
Medium	Develop improved evapotranspiration estimates in Butte Valley to reduce uncertainty in the water budget	Install and maintain multi-season eddy covariance and energy balance towers on critical crops (alfalfa, hay, strawberry) and native vegetation in (sagebrush, willow).
Medium	Develop better estimates of snow water equivalent and weather station data from higher in the Butte watershed by building specialty stations	Develop weather stations in the western and south western watershed to collect snow water equivalent data and general atmospheric information

Table 2: Data gap prioritization *(continued)*

Priority	Data Gap Summary	Strategy to Fill Data Gap
Low	Improve the spatial coverage of irrigation management systems	Install an additional CIMIS station in Butte Valley

References

California Department of Water Resources (2016). BMP 2: Best Management Practices for the Sustainable Management of Groundwater Monitoring Networks and Identification of Data Gaps, December 2016. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/BMP-2-Monitoring-Networks-and-Identification-of-Data-Gaps_ay_19.pdf

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Appendix 3-B. Monitoring Protocols

Contents

Monitoring Protocols

This Appendix provides the monitoring protocols for the monitoring networks described in Chapter 3.

Groundwater Levels

Groundwater level data collection may be conducted remotely via telemetry equipment or with an in-person field crew. The following section provides the monitoring protocols for groundwater level data collection. Establishment of these protocols will ensure that data collected for groundwater levels are accurate, representative, reproducible, and contain all required information. All groundwater level data collection in support of this GSP is required to follow these established protocols for consistency throughout the Basin and over time. These monitoring protocols will be updated as necessary and will be re-evaluated every five years. The reference for the following text is the groundwater level monitoring protocols in the Santa Cruz Mid-County Sustainability Plan (MGA 2020), with modifications.

All groundwater elevation measurements are referenced to a consistent elevation datum, known as the Reference Point (RP), surveyed to the National Geodetic Vertical Datum of 1988 (NGVD 88). For monitoring wells, the RP consists of a mark on the top of the well casing while most production wells have the RP at the top of the well's concrete pedestal. State requirements for surveying the RP is a measurement within 0.1 ft (3 cm) horizontally and 0.01 ft (0.3 cm) vertically. Groundwater level measurements are taken to the nearest 0.01 ft (0.3 cm) relative to the RP.

Groundwater elevation is measured by subtracting the depth to water from the reference point:

GWE = RPE - DTW,

where:

- GWE = groundwater elevation
- RPE = reference point elevation
- DTW = depth to water

Sample Collection:

- Equipment must be operated and maintained in accordance with manufacturer's instructions.
- Water level measurements must use units of feet, tenths of feet, and hundredths of feet.
- Measurements must include a record of the date, well name/identifier, time (in 24-hour military format), RPE, DTW, and GWE.
- Comments must be included regarding factors which may influence the recorded measurement such as nearby production wells pumping, weather, flooding, or well condition (including oil and other foreign bodies floating on the water surface).

Manual Groundwater Level Measurement

Groundwater level data collected by an in-person field crew will follow the following general protocols:

- Prior to sample collection, all sampling equipment and the sampling port must be cleaned.
- Manual groundwater level measurements are made with electronic sounders or steel tape. Electronic sounders consist of a long, graduated wire equipped with a weighted electric sensor. When the sensor is lowered into water, a circuit is completed and an audible beep is produced, at which point the sampler will record the depth to water. Some production wells may have lubricating oil floating on the top of the water column, in which case electric sounders will be ineffective. In this circumstance, steel tape may be used. Steel tape instruments consist of simple graduated lines where the end of the line is chalked to indicate depth to water without interference from floating oil.
- All equipment is used following manufacturer specifications for procedure and maintenance.
- Measurements must be taken in wells that have not been subject to recent pumping. At least two hours of recovery must be allowed before a hand sounding is taken.
- For each well, multiple measurements are collected to ensure the well has reached equilibrium such that no significant changes in groundwater level are observed.
- Equipment is sanitized between well locations to prevent contamination and maintain the accuracy of concurrent groundwater quality sampling.

Data Logger Groundwater Level Measurement

Telemetry equipment and data loggers can be installed at individual wells to record continuous water level data, which is then remotely collected via satellite to a central database and accessed on the Water Level Portal in a web browser.

Installation and use of data loggers must abide by the following protocols:

- Prior to installation the sampler uses an electronic sounder or steel tape to measure and calculate the current groundwater level in order to properly install and calibrate the transducer. This is done following the protocols listed above.
- All data logger installations must follow manufacturer specifications for installation, calibration, data logging intervals, battery life, and anticipated life expectancy.
- Data loggers are set to record only measured groundwater level to conserve data capacity; groundwater elevation is calculated after data are downloaded.
- In any log or recorded datasheet, the well ID, transducer ID, transducer range, transducer accuracy, and cable serial number are recorded.
- The sampler notes whether the pressure transducer uses a vented or non-vented cable for barometric compensation. If non-vented units are used, data are properly corrected for natural barometric pressure changes.
- All data logger cables are secured to the well head with a well dock or another reliable method. This cable is marked at the elevation of the reference point to allow estimates of future cable slippage.
- Data logger data are periodically checked against hand-measured groundwater levels to monitor electronic drift, highlight cable movement, and ensure the data logger is operating correctly. This check occurs at least annually, typically during routine site visits.

For wells not connected to a supervisory control and data acquisition (SCADA) system, transducer data are downloaded as necessary to ensure no data are overwritten or lost. Data are entered into the data management system as soon as possible after download. After the transducer data are successfully downloaded and stored, the data are deleted or overwritten to ensure adequate data logger memory.

Groundwater Quality

Sample collection will follow the USGS National Field Manual for the Collection of Water Quality Data (Wilde 2008; USGS 2015) and Standard Methods for the Examination of Water and Wastewater (Rice, Bridgewater, and Association 2012), as applicable, in addition to the general sampling protocols listed below.

The following section provides a brief summary of monitoring protocols for sample collection and testing for groundwater quality. Establishment of these protocols will ensure that data collected for groundwater quality are accurate, representative, reproducible, and contain all required information. All sample collection and testing for water quality in support of this GSP are required to follow the established protocols for consistency throughout the Basin and over time. All testing of groundwater quality samples will be conducted by laboratories with certification under the California Environmental Laboratory Accreditation Program (ELAP). These monitoring protocols will be updated as necessary and will be re-evaluated every five years.

Wells used for sampling are required to have a distinct identifier, which must be located on the well housing or casing. This identifier will be included on the sample label to ensure traceability.

Event Preparation:

- Before the sampling event, coordination with any laboratory that will be used to test the samples is required. Coordination must include scheduling laboratory time for sample testing and reviewing the applicable sample holding times and preservation requirements that must be conducted before the sampling event.
- Sample labels must include the sample ID, well ID, sample date and time, personnel responsible for sample collection, any preservative, analyte, and analytical method. Sample containers may be labelled before or during the sampling event.

Sample Collection and Analysis:

- Collection of a raw sample must occur at, or close to, the wellhead for wells with dedicated pumps and may not be collected after any treatment, from tanks, or after the water has travelled through long pipes. Prior to sample collection, all sampling equipment and the sampling port must be cleaned. The sample equipment must also be cleaned between use at each new sample location or well.
- Sample collection in wells with low-flow or passive sampling equipment must follow protocols outlined in EPA's Low-flow (minimal drawdown) ground-water sampling procedures (Puls, Barcelona, and Agency 1996) and USGS Fact Sheet 088-00 (USGS 2000), respectively. Prior to sample collection in wells without low-flow or passive sampling equipment, at least three well casing volumes should be purged prior to sample collection to make sure ambient water is tested. The sample collector should use best professional judgement to ensure that the sample is representative of ambient groundwater. If a well goes dry, this should be noted, and the well should be allowed to return to at least 90% of the original level before a sample is collected.

- Sample collection should be completed under laminar flow conditions, which is defined as follows: the pump rate during sampling should produce a smooth, constant (laminar) flow rate, and should not produce turbulence during the filling of bottles.
- Samples must be collected in accordance with appropriate guidance and standards and should meet specifications for the specific constituent analyzed and associated data quality objectives.
- In addition to sample collection for the target analytes, field parameters, including temperature, pH and specific conductivity, must be collected at every site during well purging. Field parameters should stabilize before being recorded and before samples are collected. Field instruments must be calibrated daily and checked for drift throughout the day.
- Samples should be chilled and maintained at a temperature of 4 C degrees and maintained at this temperature during transport to the laboratory responsible for analysis.
- Chain of custody forms are required for all sample collection and must be delivered to the laboratory responsible for analysis of the samples to ensure that samples are tested within applicable holding limits.
- Laboratories must use reporting limits that are equivalent to, or less than, applicable data quality objectives.
- Quality control samples will be taken to confirm accuracy, replication, confidence, and robustness of the testing protocols procedures. Quality control samples will be collected during each monitoring event based on a schedule dependent on monitoring frequency. Quality control samples may include field blanks, field duplicates, lab duplicates or matrix spike/matrix spike duplicates. Field-generated quality control samples (field duplicates and field blanks) will be submitted “blind” to the laboratory, with an identifier different from the sampled sites. Issues with quality control samples that are flagged either by the laboratory or GSP QA/QC Officer will be used to correct any issues with the monitoring or lab testing protocol.

Subsidence

The subsidence monitoring network currently depends on data provided by DWR through the TRE ALTAMIRA InSAR Subsidence Dataset. The following describes the data collection and monitoring completed by DWR contractors to develop the dataset. The GSA will monitor all subsidence data annually. If any additional data become available, they will be evaluated and incorporated into the GSP implementation. If the annual subsidence rate is greater than minimum threshold, further study will be needed.

The statewide InSAR subsidence dataset was acquired by DWR to provide important SGMA relevant data to GSAs for GSP development and implementation. TRE ALTAMIRA processed InSAR data collected by the European Space Agency (ESA) Sentinel-1A satellite. Statewide data was collected between January 1, 2015 and September 19, 2019 and calibrated to data from 232 stations in the regional network of Continuous Global Positioning System (CGPS) stations. TRE ALTAMIRA compiled time series data of vertical displacement values for point locations on a grid with 100 m spacing, with values representing averages of vertical displacement measurements within the immediate 100 by 100 m square areas of each point. Gaps in the spatial coverage of the point data are areas with insufficient data quality. TRE ALTAMIRA also created two sets of GIS rasters: annual vertical displacement and total vertical displacement relative to the common start date of June 13, 2015, both in monthly time steps. An inverse distance weighted (IDW) method with a maximum search radius of 500 meter was used to interpolate the rasters from the point data.

Under contract with DWR, Towill Inc. conducted an independent study to ground truth and verify the accuracy of the InSAR dataset. In the study, variation in vertical displacement of California's ground surface over time, as measured from interferometric synthetic aperture radar (InSAR) satellites, was statistically compared to available ground-based continuous global positioning systems (CGPS) data. The study compared the InSAR-based vertical displacement point time series data to data from 160 CGPS stations that were not used for calibrating the InSAR data, as well as 21 CGPS stations that were used for calibrating InSAR data in Northern California. For the statewide dataset, the study provides statistical evidence that InSAR data accurately measured vertical displacement in California's ground surface to within 16 mm for the period January 1, 2015 through September 19, 2019. The statement of accuracy may vary for regional or localized area subsets (CDWR 2020).

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Appendix 3-C. Water Level Sustainable Management Criteria (2024 Revision)

Contents

Groundwater Level Sustainable Management Criteria

This Appendix provides further background information for Section Sustainable Management Criteria - Groundwater Elevation in Butte Valley GSP Chapter 3. The following provides additional figures and discussion to supplement the main text:

- The hydrographs used to set the minimum thresholds and measurable objectives.
- The process and figures of the well failure analysis.

Please note that drastic updates have been made to this appendix comparing to the 2022 version, where the groundwater level SMCs have been modified and reflected on the updated hydrographs, and the well failure analysis has been updated and reorganized for more in-depth and cohesive evaluations.

Hydrographs (2024 GSP Revision)

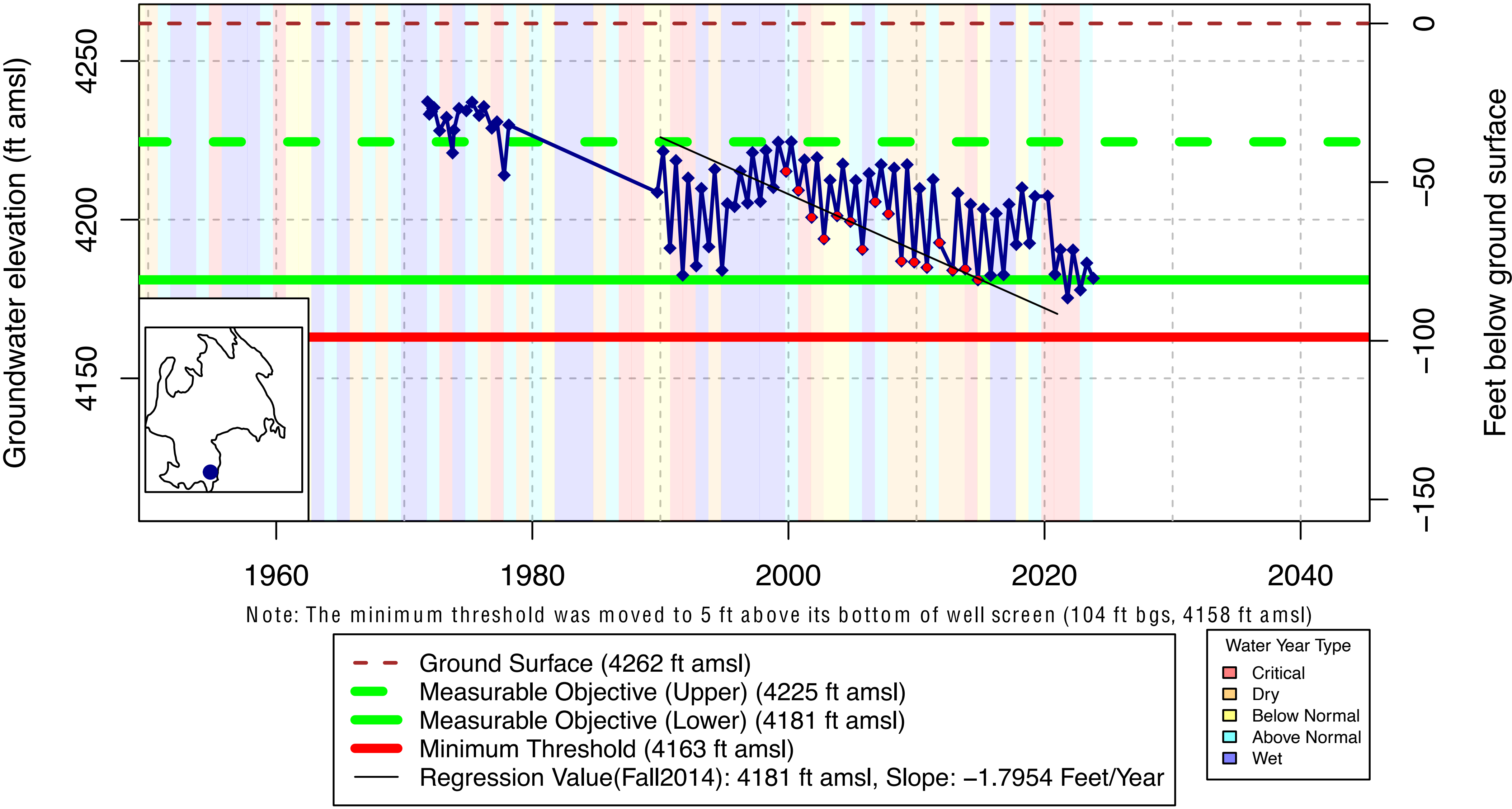
The hydrographs used to set the minimum thresholds and measurable objectives for each representative monitoring point are shown in the following figures. The groundwater level data used in the regression to calculate minimum thresholds have gone through a quality assurance and quality control (QAQC) process that removes data from the analysis for the following reasons:

- Oil or other foreign substances were floating at the groundwater surface inside the well and the data had high uncertainty as a result.
- The well was pumped recently.
- During the minimum threshold process and generation of a regression equation, a data point was deemed an outlier, which may result from the interference of drawdown from nearby wells.

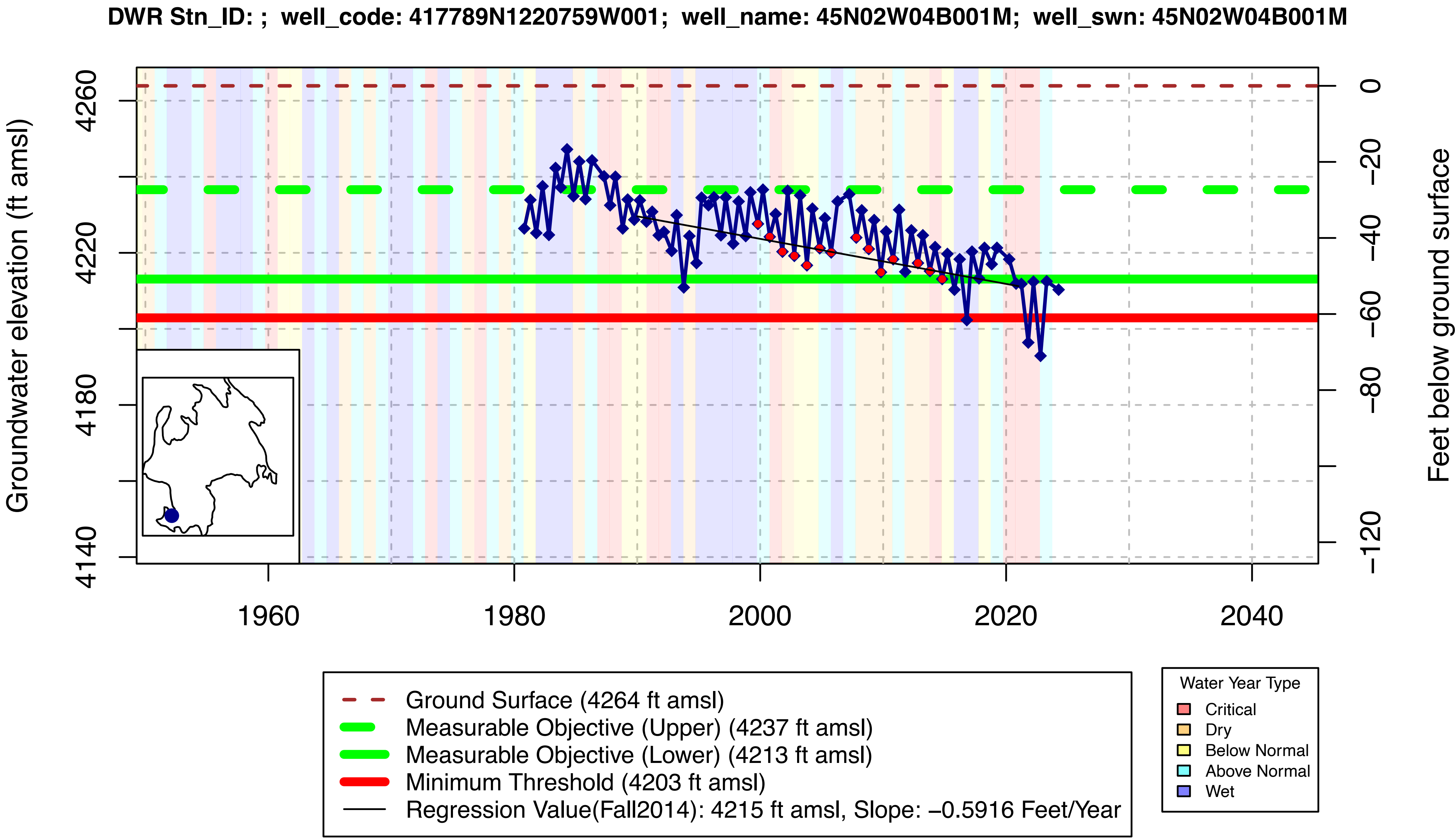
Table 1: Removed groundwater level (WL) data from the regression analysis. The water level is in units of feet above mean sea level (ft amsl).

Well Name	Date	Removed WL	Reason
419451N1218967W001	2000-10-10	4157.23	Oil or foreign substance in casing
417944N1220350W001	2012-10-29	4203.73	Oil or foreign substance in casing
418512N1219183W001	1999-10-26	4208.79	Oil or foreign substance in casing
419451N1218967W001	1999-10-26	4159.73	Oil or foreign substance in casing
418512N1219183W001	2013-10-21	4194.69	Oil or foreign substance in casing
417944N1220350W001	2011-10-18	4189.83	Pumped recently
419755N1219785W001	2014-10-20	4172.7	Oil or foreign substance in casing
419451N1218967W001	2002-10-11	4138.73	Oil or foreign substance in casing
418661N1219587W001	1999-10-26	4204.5	Oil or foreign substance in casing
417789N1220759W001	2011-10-18	4215.01	Oil or foreign substance in casing
418948N1220832W001	2013-10-21	4197.37	Oil or foreign substance in casing
418948N1220832W001	2011-10-18	4197.57	Oil or foreign substance in casing
418948N1220832W001	2009-10-27	4202.07	Oil or foreign substance in casing
418948N1220832W001	1999-10-27	4204.27	Oil or foreign substance in casing
419451N1218967W001	2005-10-10	4153.73	Oil or foreign substance in casing
418661N1219587W001	2013-10-21	4193.7	Oil or foreign substance in casing
418512N1219183W001	2014-10-20	4191.99	Oil or foreign substance in casing
419451N1218967W001	2003-10-20	4139.63	Oil or foreign substance in casing
418948N1220832W001	2007-10-25	4205.57	Oil or foreign substance in casing
418948N1220832W001	2010-10-25	4199.97	Oil or foreign substance in casing
418948N1220832W001	2008-10-30	4205.07	Oil or foreign substance in casing
418948N1220832W001	2006-10-12	4204.87	Oil or foreign substance in casing
418948N1220832W001	2000-10-10	4201.67	Pumping
418948N1220832W001	2012-10-29	4197.97	Oil or foreign substance in casing
418948N1220832W001	2005-10-10	4200.07	Oil or foreign substance in casing
419451N1218967W001	2006-10-12	4149.93	Oil or foreign substance in casing
418948N1220832W001	2002-10-11	4202.37	Oil or foreign substance in casing
418948N1220832W001	2003-10-20	4203.07	Oil or foreign substance in casing
419451N1218967W001	2004-11-02	4136.23	Oil or foreign substance in casing
418948N1220832W001	2004-11-03	4204.37	Oil or foreign substance in casing
418512N1219183W001	2001-10-23	4182.69	Outlier
417789N1220759W001	2006-10-12	4204.81	Outlier

DWR Stn_ID: ; well_code: 417786N1220041W001; well_name: 45N01W06A001M; well_swn: 45N01W06A001M



Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.



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Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

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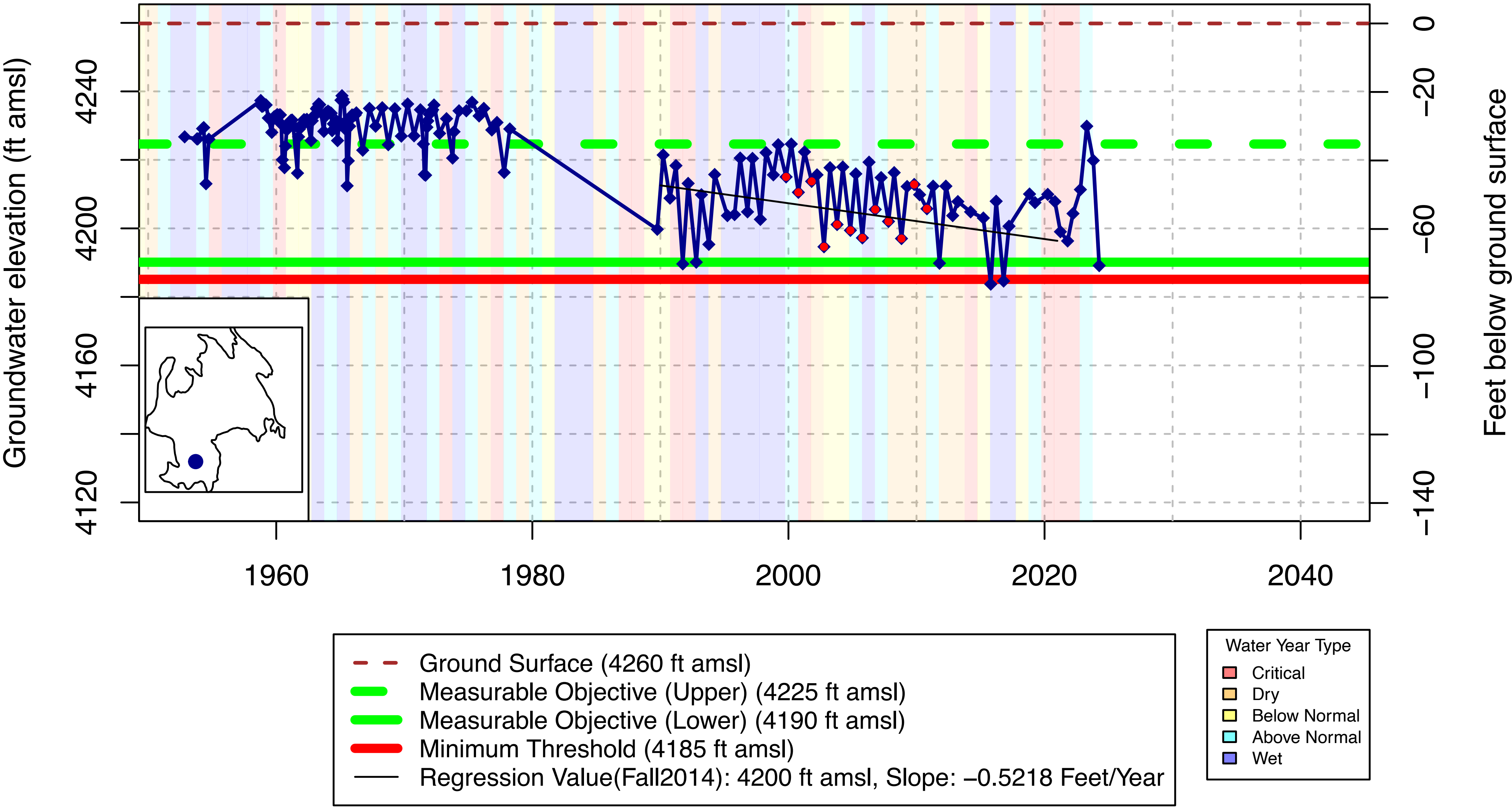

Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

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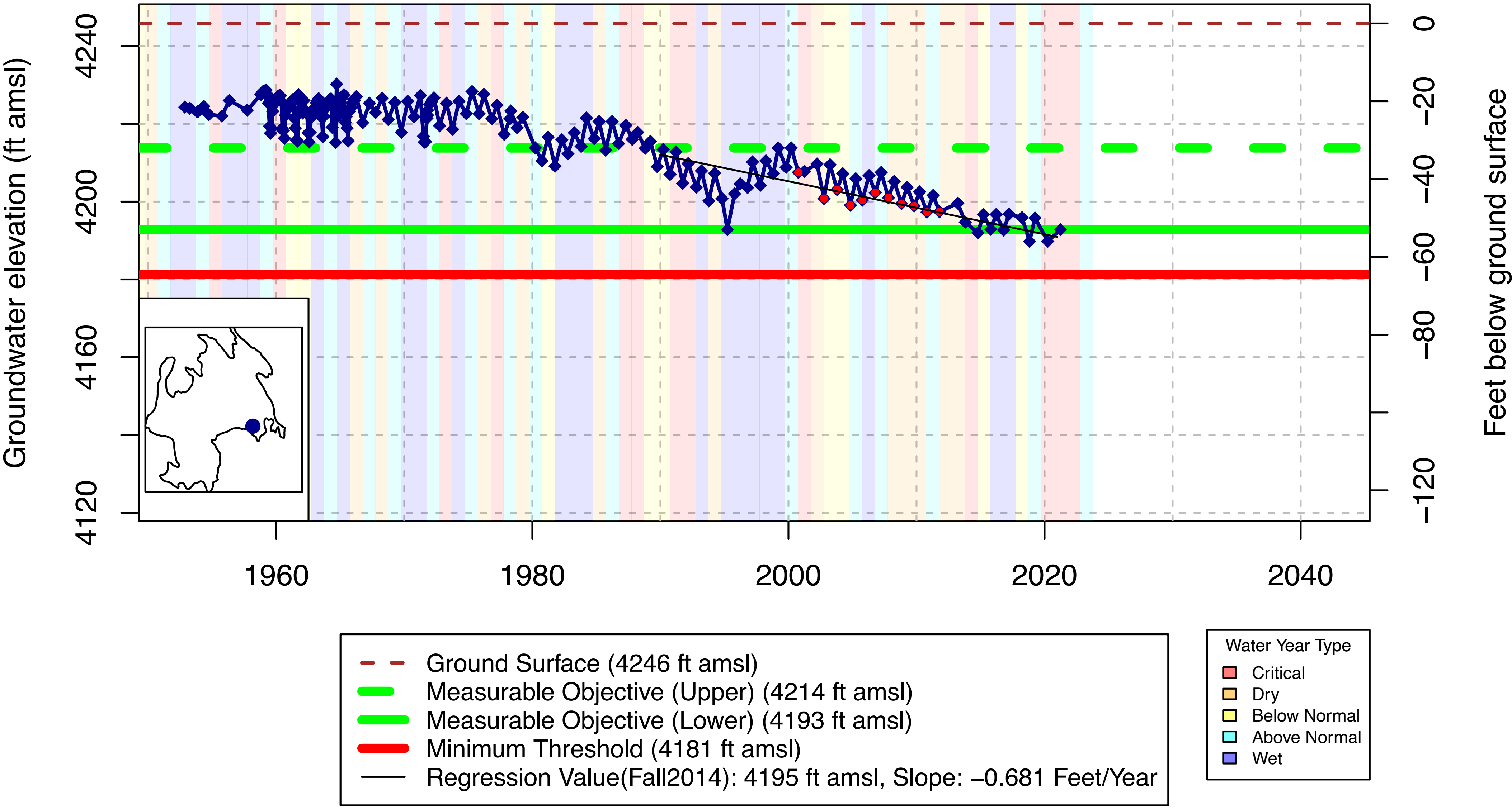

Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

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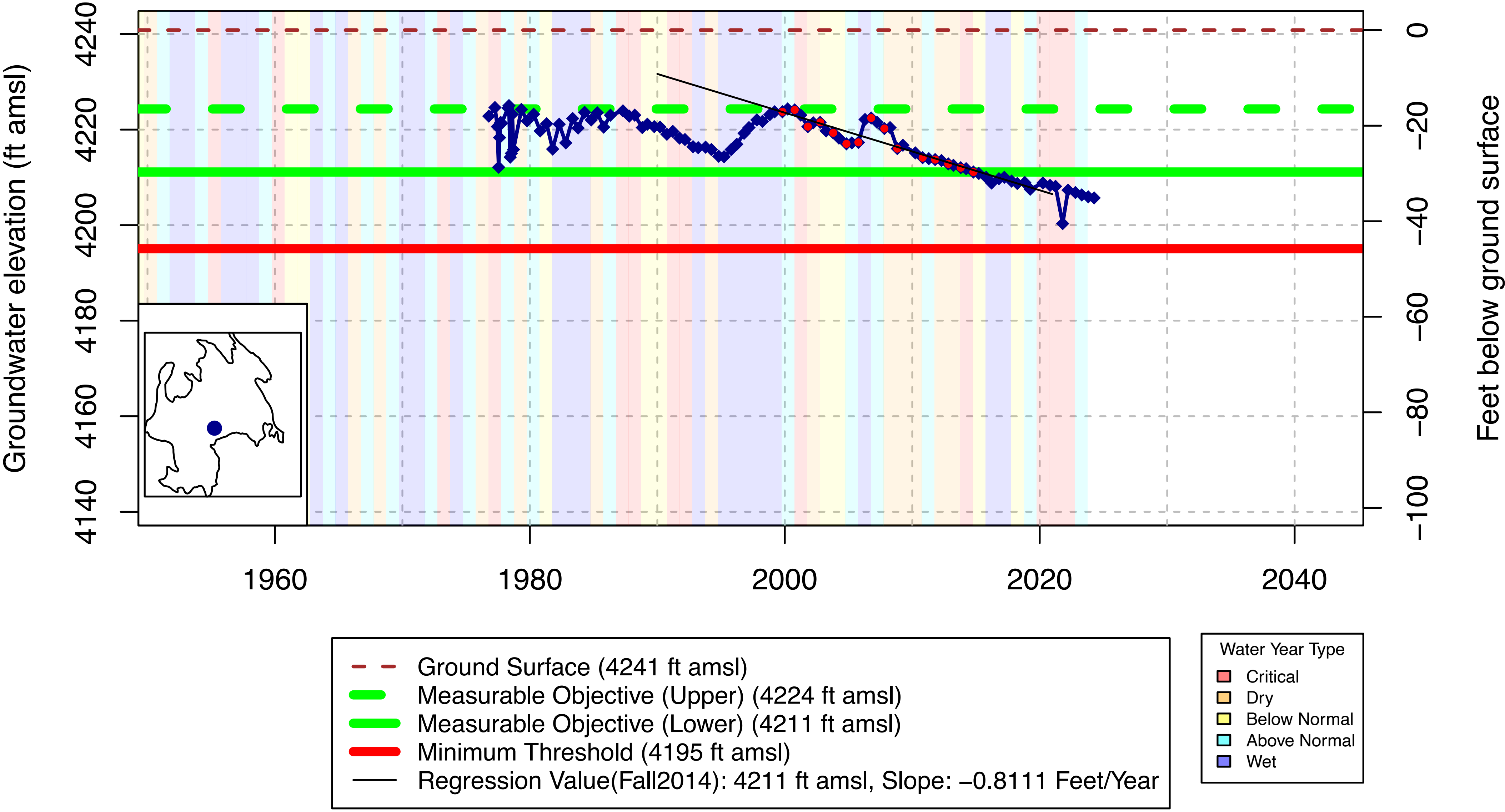

Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

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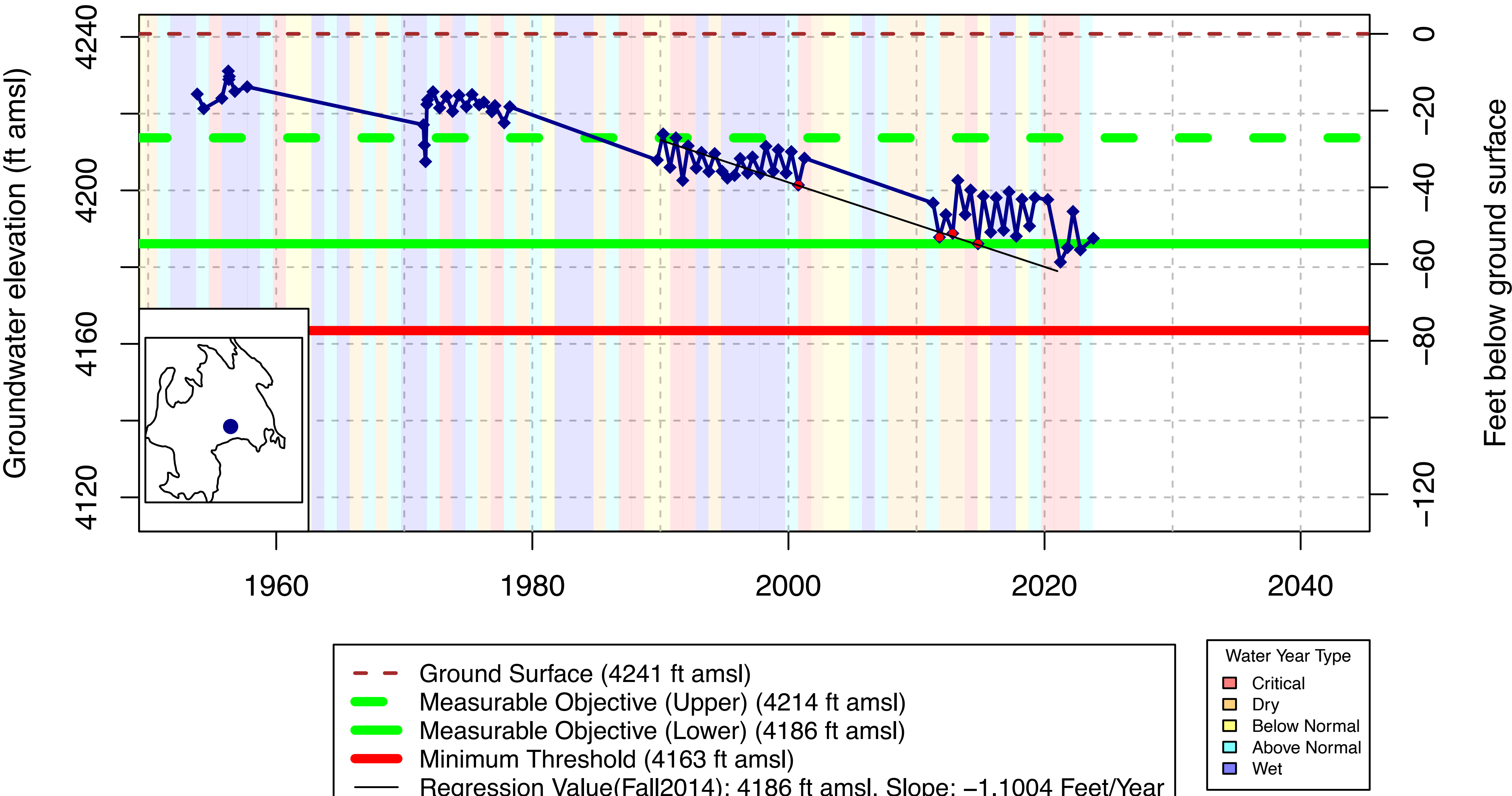

Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

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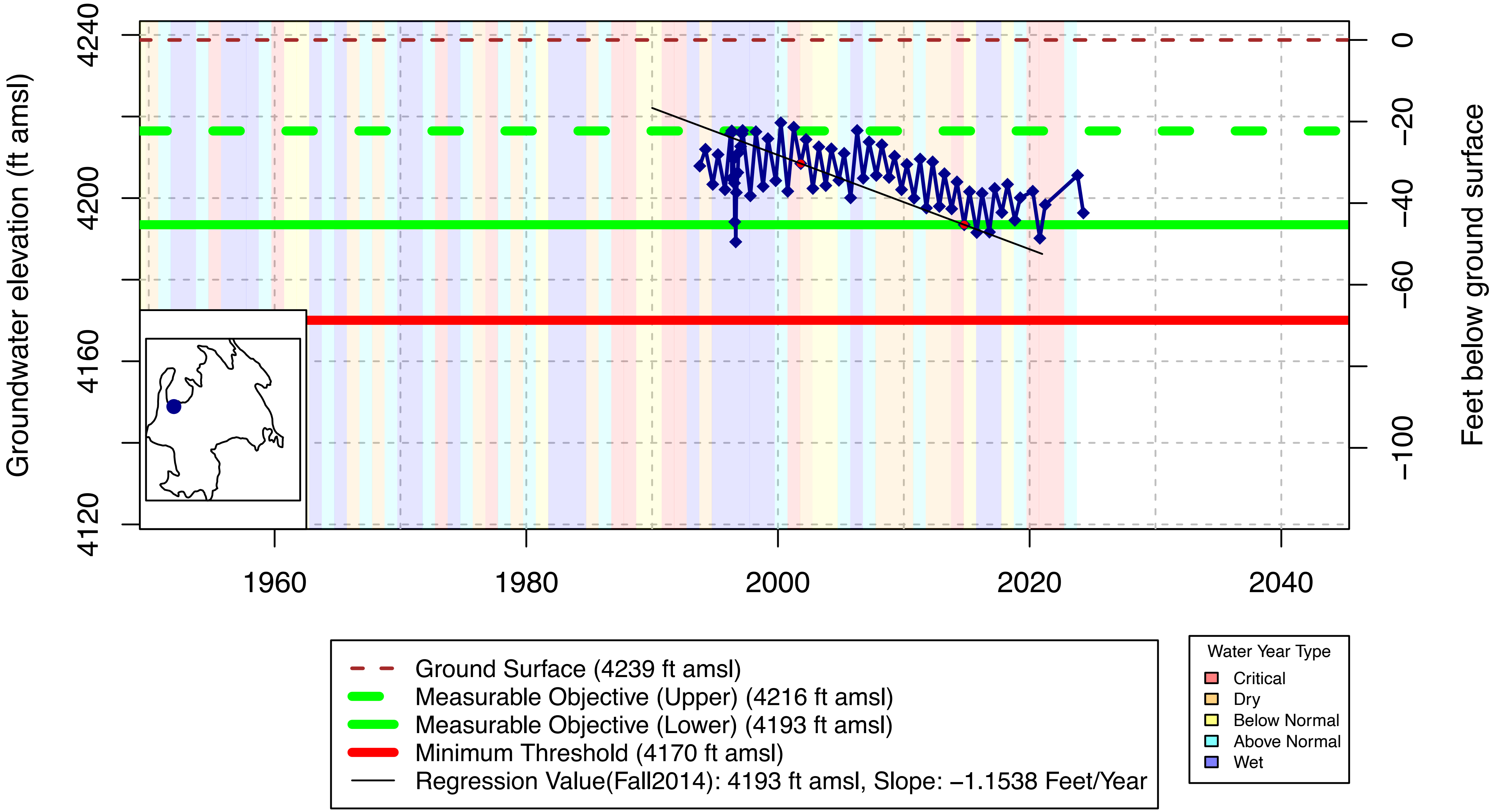
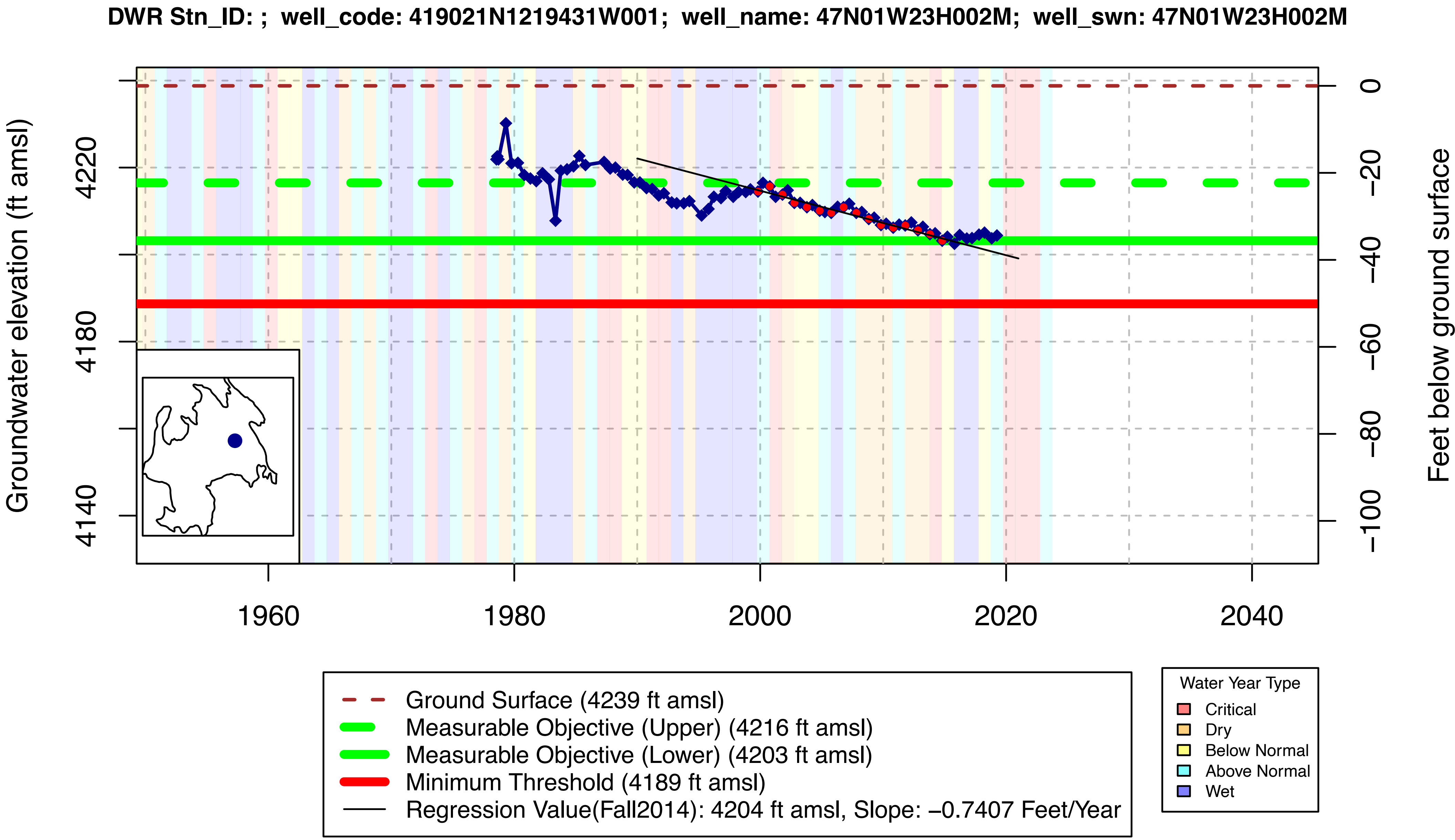


Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report. The results will be finalized once DWR updates the water year type dataset for these years.



Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

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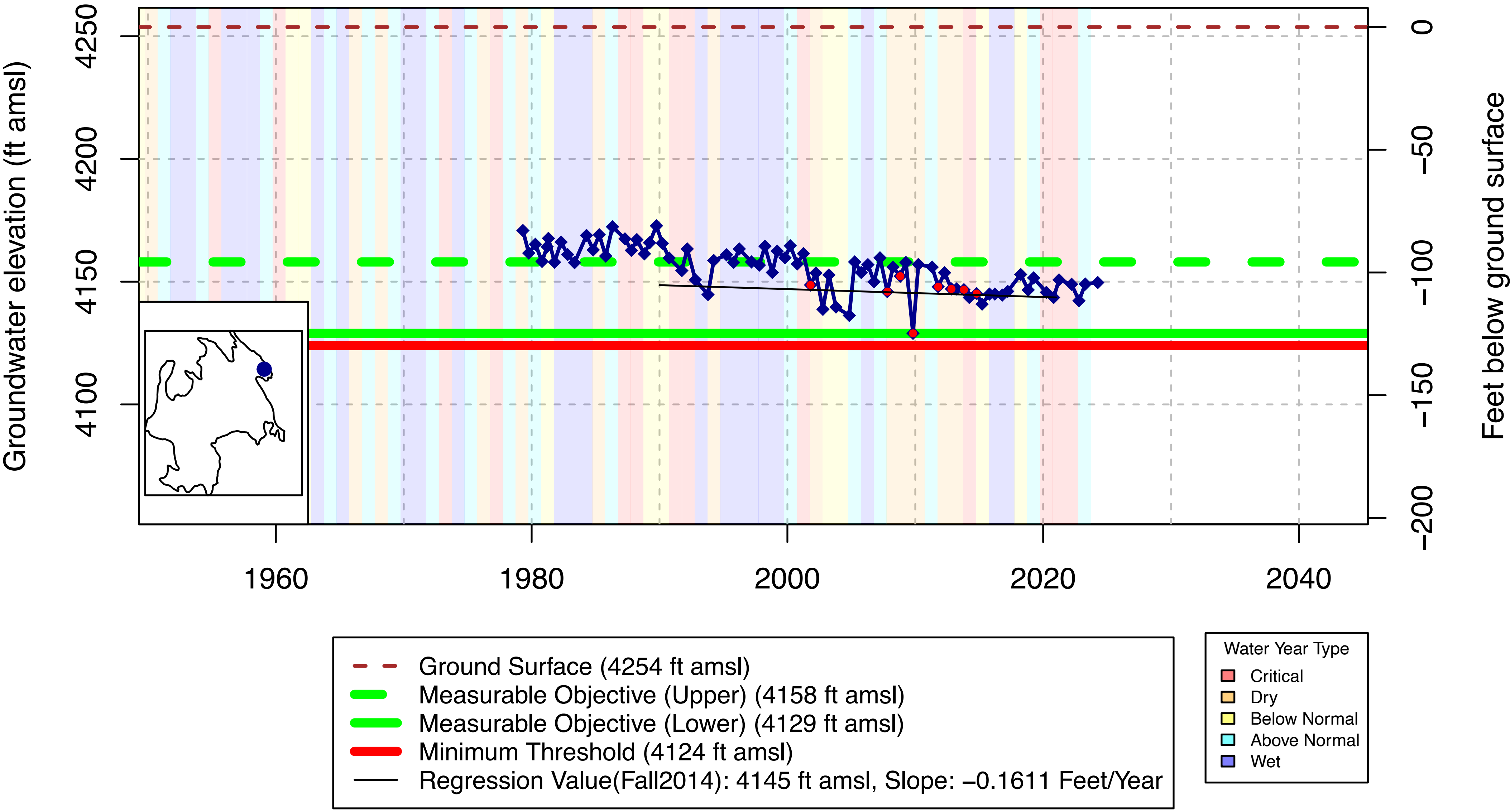

Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

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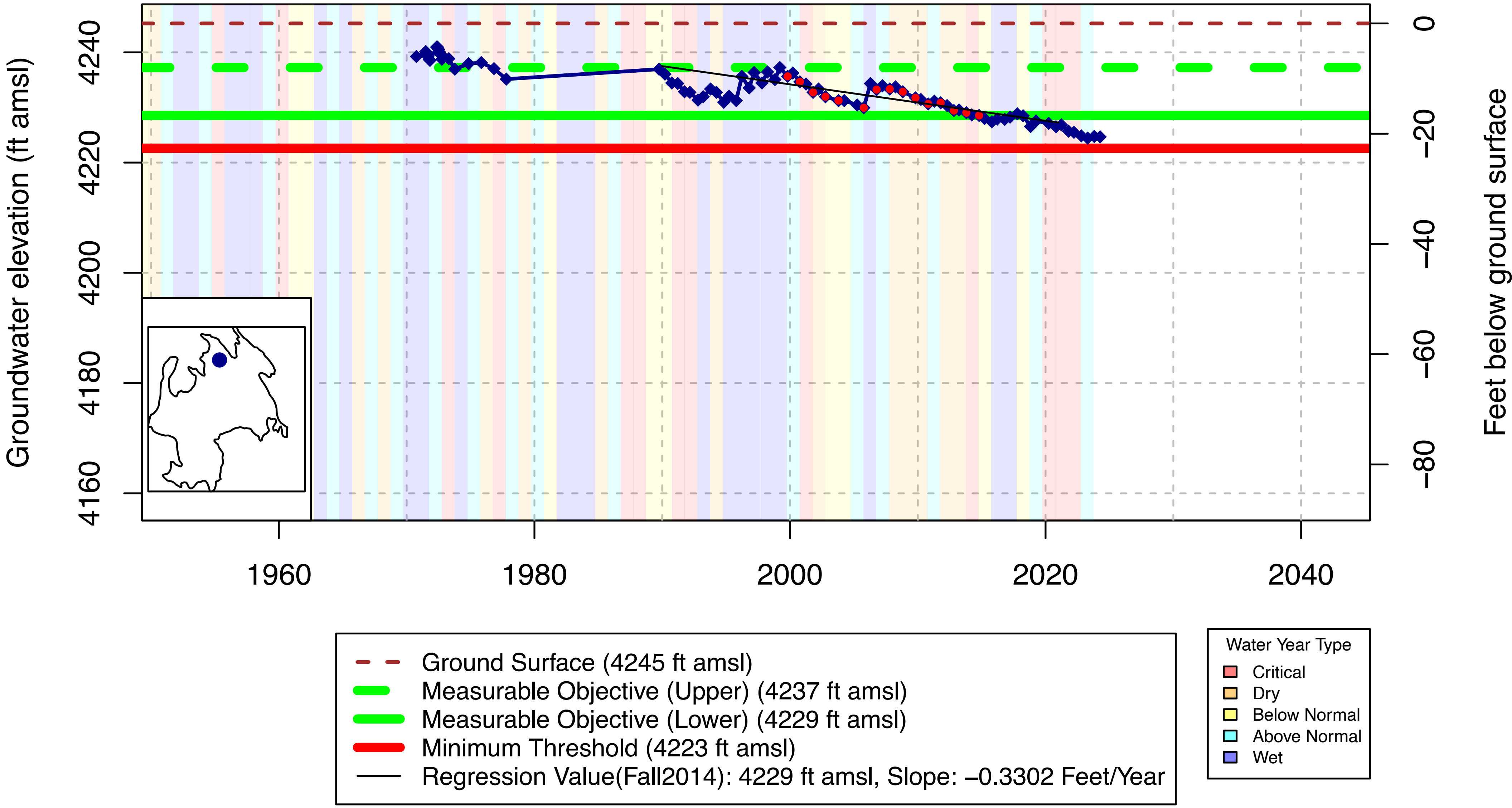

Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

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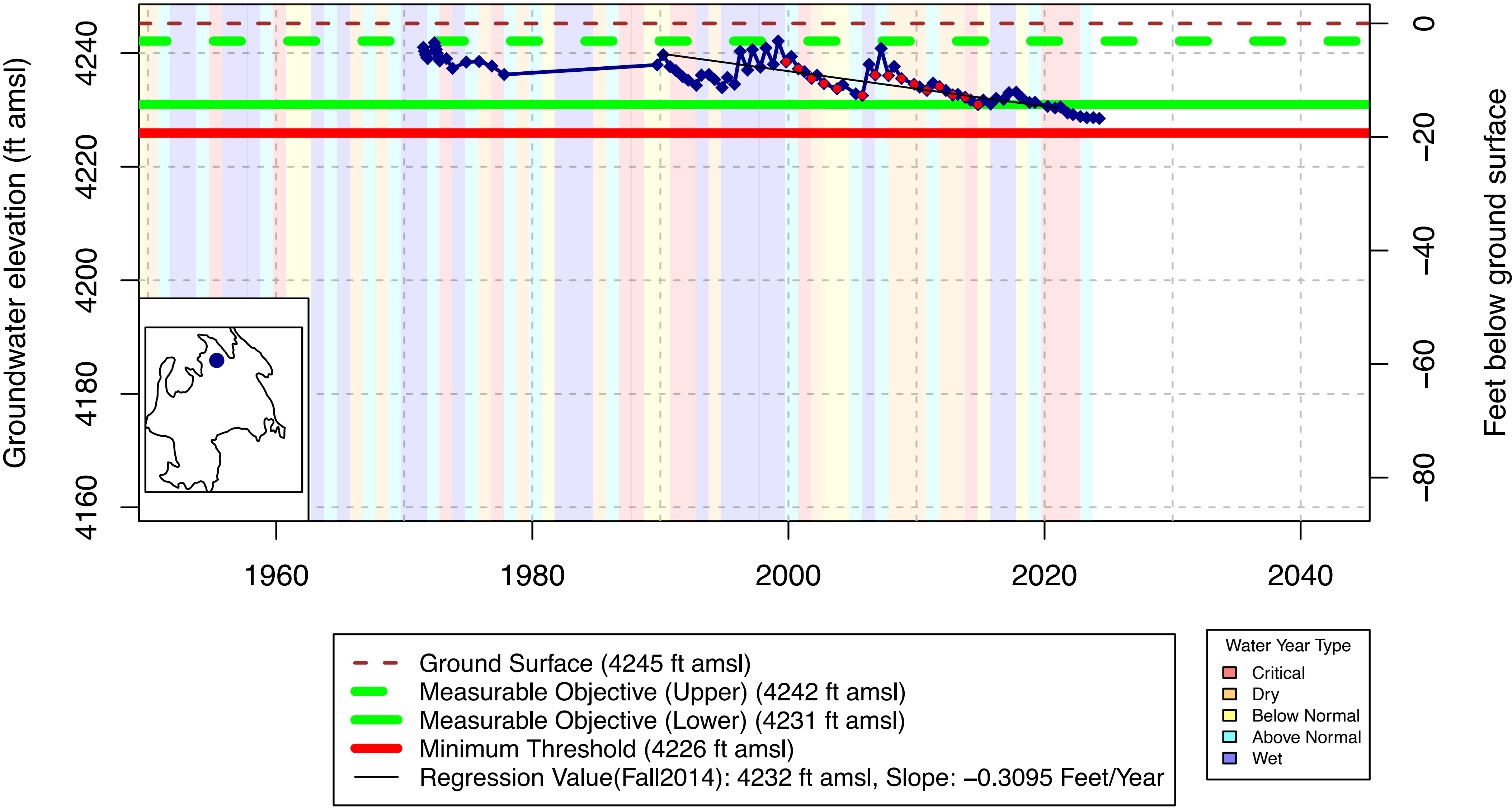

Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

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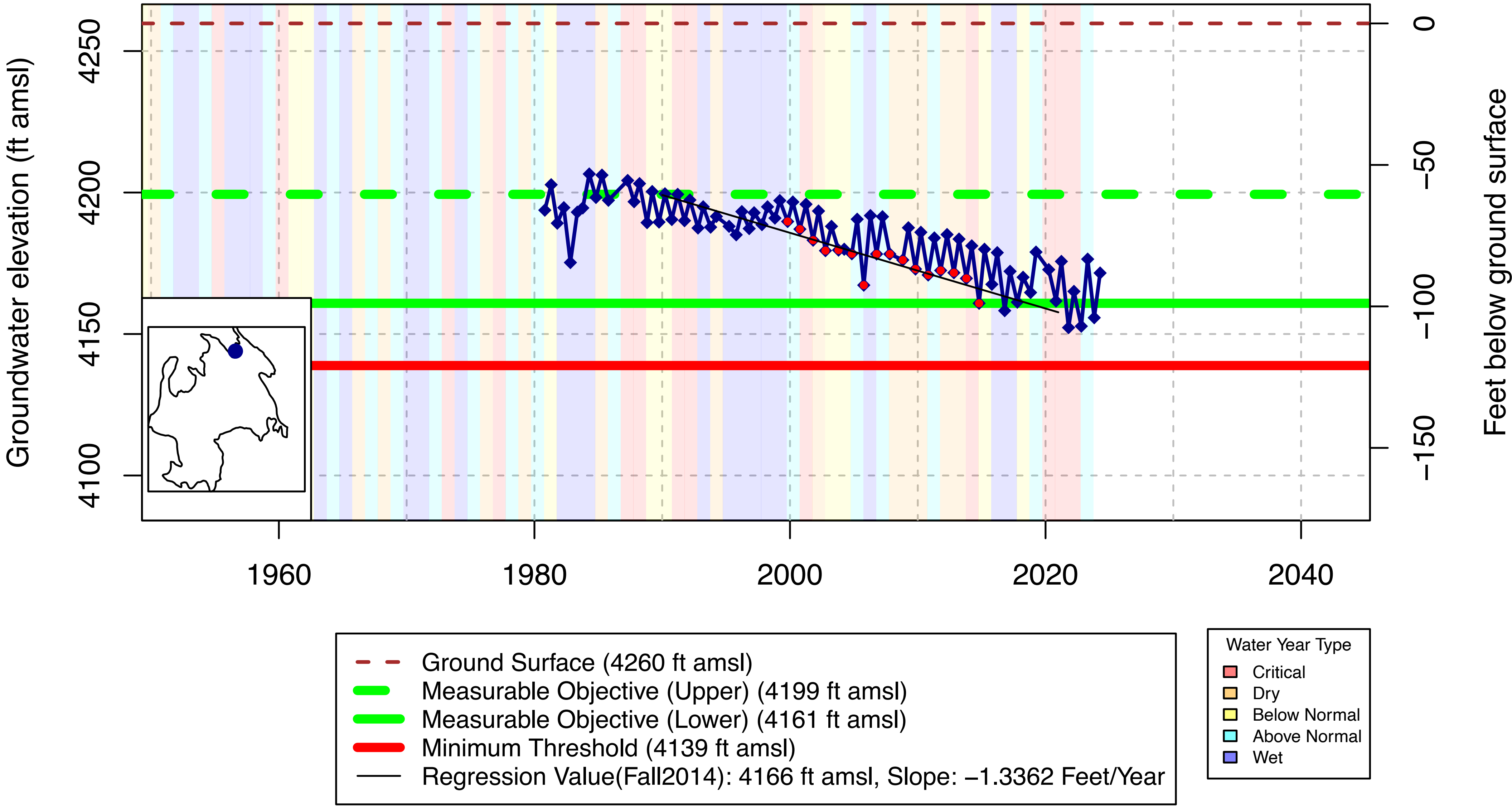

Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report. The results will be finalized once DWR updates the water year type dataset for these years.

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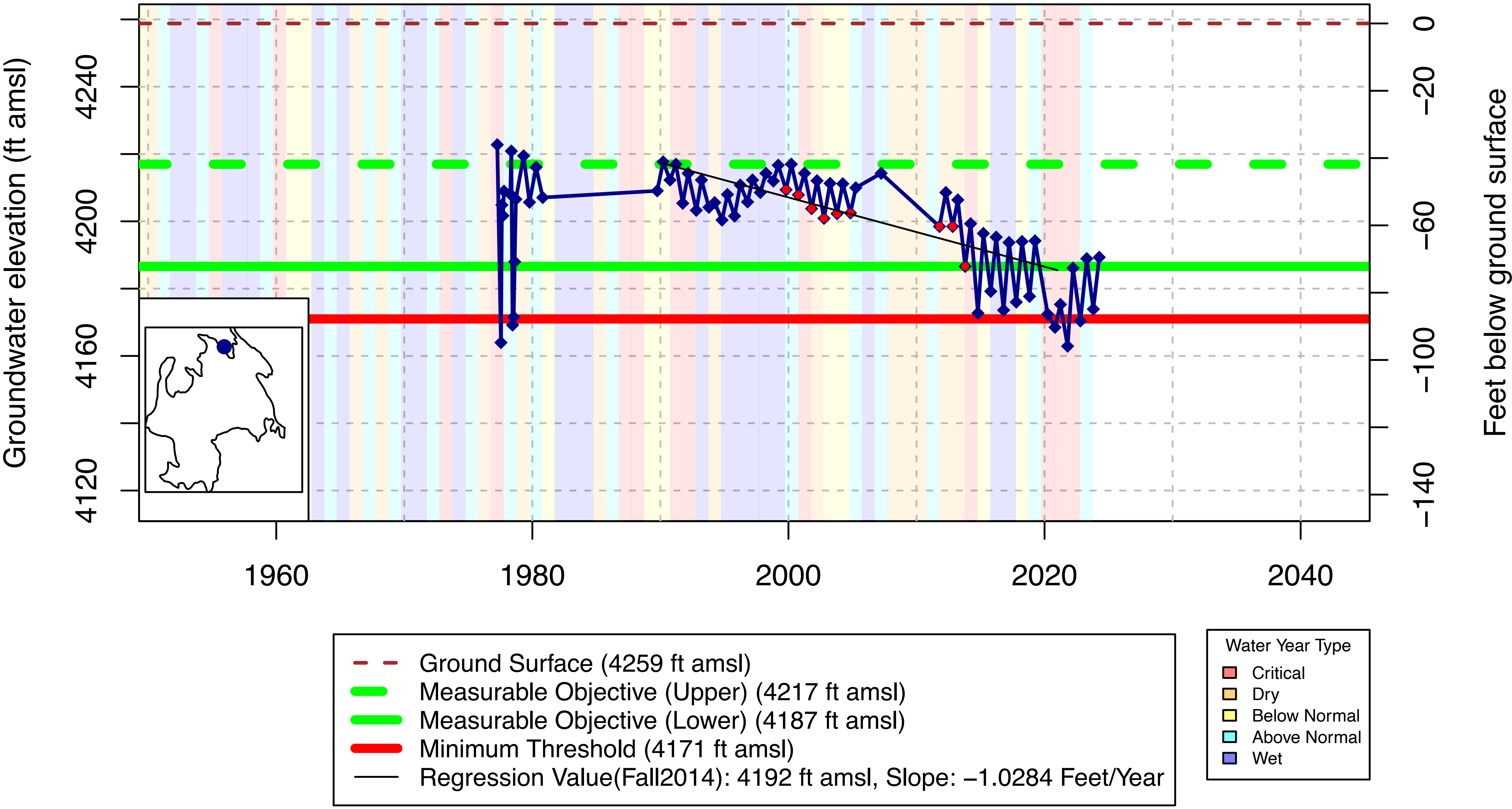


Water Year Types from WY 2019–2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

Well Failure Analysis (2024 GSP Revision)

Butte Valley Well Failure Discussion

Helen Zhou
Bill Rice
Dr. Thomas Harter
Larry Walker Associates & UC Davis

6/28/2024

Contents

Introduction

This analysis has been performed to determine the number of wells that may be dewatered due to declining groundwater levels. In the Butte Valley, groundwater elevations are highly seasonal. The highest risk of dewatering occurs in the late summer and early fall, when water levels are at their seasonal low.

Ideally, this assessment would involve a comparison of historic and current water levels against well construction details across all or a representative subset of wells in Butte Valley. However, key data limitations inhibit a comparison of well construction details with water levels where they have been measured in wells:

- Well depth, perforated intervals and water level observations have been collected by multiple organizations/agencies.
- The most common datum available for known wells (i.e., wells registered through DWR's Online System for Well Completion Reports, OSWCR) is well depth.
- Ground surface elevations are not commonly available with well construction information. Obtaining ground surface elevation from digital land surface elevation maps at the well location is hampered by the fact that the location of wells is reported by township, range, and section and the exact location within the reported one square-mile section is not readily available.
- Water level information, especially longer time series of such information, is available only for a small subset of monitoring wells, with location accuracy tied to the reported section location (+/- 0.7 miles).
- For most wells associated with water level measurements, the corresponding well construction information is not readily available, making a direct comparison of water level to depth to top of perforation (or to total well depth) impossible without significant further reconnaissance.

Consequently, rather than comparing groundwater elevations with the well depth to top of perforations, this analysis focuses on interpolated groundwater elevation data to assess the aggregated risk of wells not being able to pump water due to low water levels ("well outages"). The risk analysis necessarily utilizes information that is readily available and is therefore limited in its specificity. Future analysis may be able to provide a more refined risk assessment as better information becomes available.

Methods

2024 Updates to the 2022 GSP Well Failure Discussion

During the original development and this 2024 revision of the Butte Valley GSP, manual review of well logs from OSWCR for more accurate well locations have been performed by technical staff. In reviewing the original GSP, it was found that OSWCR data from within and outside the Bulletin 118 basin boundaries were used for the well record summary in Chapter 2. To augment the well failure analysis in the 2022 GSP, the following improvements and updates were incorporated in this revised well failure analysis:

- OSWCR well records used and computations in this analysis were audited.

- The analysis result of fall 2017 in the original well failure analysis was replaced by the analysis of fall 2023, which reflects the most recent fall conditions.
- Only OSWCR well records in PLSS sections that are fully or partially within the Bulletin 118 basin were included in this analysis. A total of 443 wells with the minimum required construction information were considered for the Basin well failure analysis.
- A review of recently submitted Well Completion Reports was conducted. A summary of wells constructed between 2019 and 2023 and the rationale for excluding the recently constructed wells for the well outage risk analysis is provided in the Results and Discussion section.
- In addition to considering a statistical measure that defines the fraction of well outages per average 10 ft water level decline in the Basin, a direct comparison of interpolated water level against the total well depth was performed. Results are consistent with this statistical measure and provide additional confidence in the estimated number of dry wells (well outages).
- Analysis was performed not only by comparing interpolated water level against the top of the perforation (available for only a small fraction of wells), but also by comparing interpolated water levels against the well depth (available for all of the 443 well records).
- The number of dry wells was determined at the minimum threshold (MT) across the basin, using both methods.

Butte Well Data Statistics

A total of 461 well logs from OSWCR were identified in the Butte Valley Bulletin 118 basin boundary from OSWCR. To determine the wells at risk of dewatering, a total of 443 wells have been identified with total well depth recorded. The remaining 18 records did not identify well depth or have any information about depth or length of screens. These 18 records are likely outdated and could not be used in the analysis.

The 443 wells considered in the analysis were classified by the dominant geologic formation identified at the bottom of the perforated interval during geologic model development. Formations are described in greater detail in the Basin Setting section of the GSP. Major formations and the number of wells identified are the Ql - Lake deposits, QTb - Older volcanic rocks of the “High Cascades”, Qal - Alluvium, and Qb - Butte Valley basalt, with 93, 36, 22, and 16, wells each respectively, summarized in Table 1. Formations with fewer than 10 wells or where the formation was unknown were grouped as “Other (including unknown formation)”.

Wells were also classified and mapped by their planned use (Figure 1 and Figure 2) Only six public wells are found within the basin; one in Dorris, three in Macdoel, and two in the southern part of the basin. Domestic wells are also scattered in the areas of the Basin outside the Butte Valley Wildlife Area and outside the National Grasslands, which occupy the central and southwestern portion of the Basin. The largest number of agricultural wells is found in the southern and eastern portions of the basin. Wells with missing planned use designation occur in and near Dorris, Macdoel, and Mt. Hebron and also are scattered in surrounding rural areas. Domestic wells constitute the largest group of wells (163 of 443), agricultural wells are the second numerous type of wells (148 of 443, in Table 2)

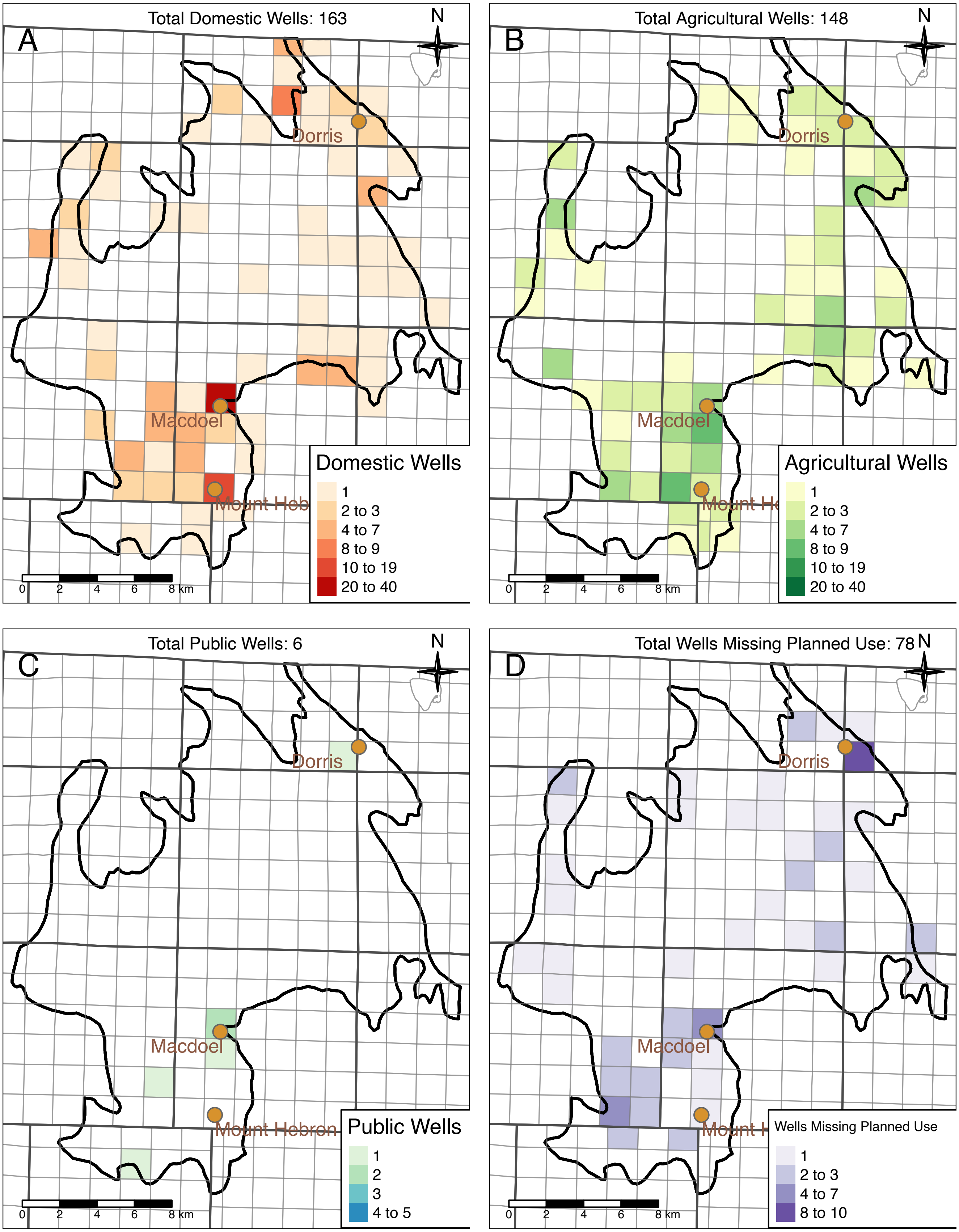


Figure 1: Butte Valley well choropleth maps by planned use from OSWCR.

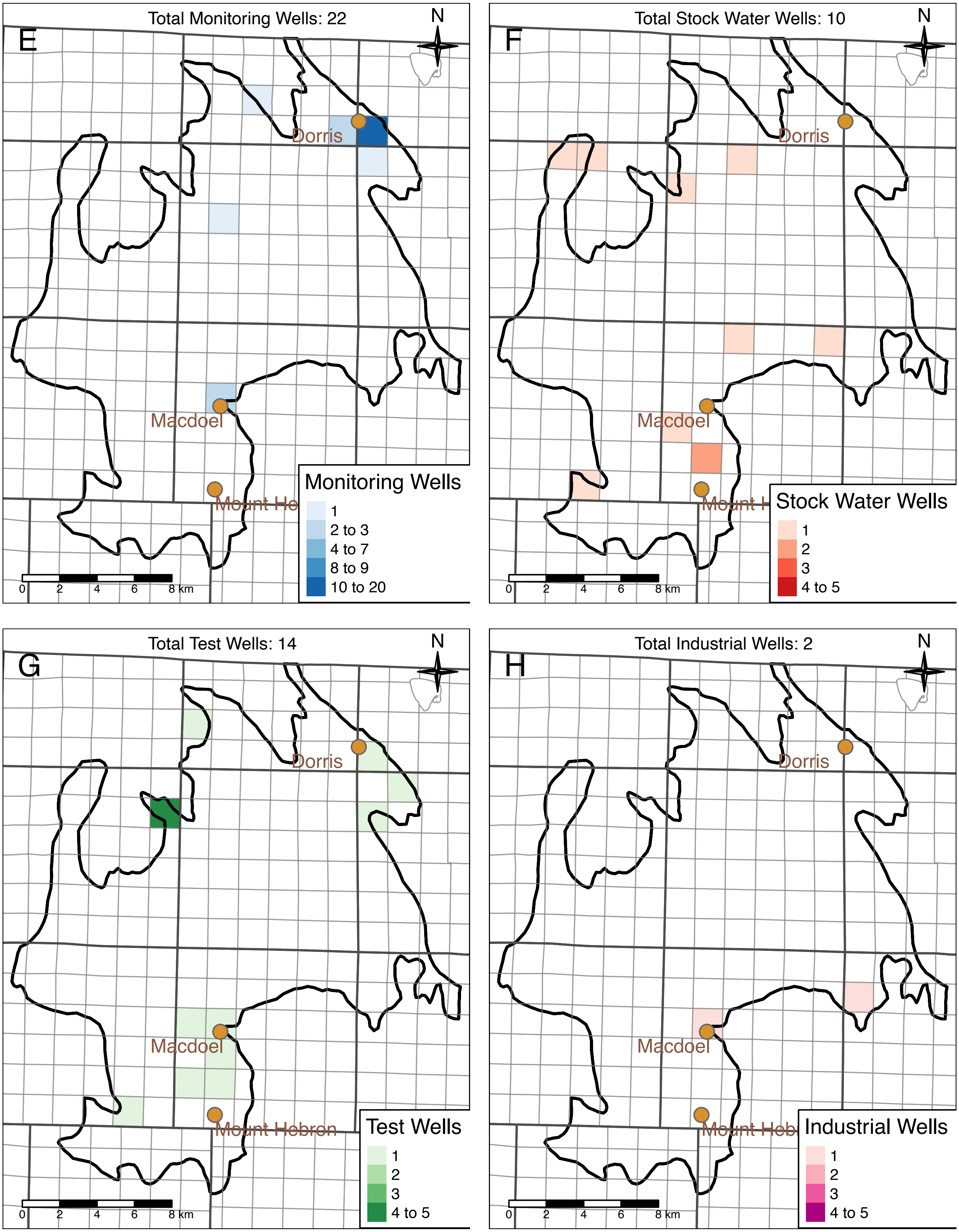


Figure 2: Butte Valley well choropleth maps by planned use from OSWCR (continued).

Table 1: Bottom Formation of Butte Valley Groundwater Basin Wells from OSWCR

Bottom Formation	No. of Wells
QTb - Older volcanic rocks of the ”High Cascades”	36
Ql - Lake deposits	93
Qb - Butte Valley basalt	16
Qal - Alluvium	22
Other (including unknown formation)	276

Table 2: Planned Use of Butte Valley Groundwater Basin Wells from OSWCR

Planned Use	No. of Wells
agriculture	148
domestic	163
industrial	2
missing	78
monitoring	22
public	6
stock	10
test well	14

Well Outage Risk Analysis

As noted previously, paired top of well perforation elevations and water level measurements were only available in a limited number of wells. For 24 wells, the California Statewide Groundwater Elevation Monitoring Program (CASGEM) provides records of water level, depth to top of screen (perforations) and well depth. For an additional 21 wells, water level and well depth is available in CASGEM (Table 3). The number of these records (45 of 443 wells) is not sufficiently spatially distributed or representative of well type, depth, and construction to be used alone in determining well failure risk. We therefore have utilized alternative methods for well failure analysis.

Due to the limited monitoring wells with water level data and human consumption wells with construction information available, a direct comparison of measured water levels to screened interval or well depth is not currently possible for the majority of Butte Valley consumption wells. Instead, two types of well failure analyses have been performed: a well failure analysis by direct comparison of estimated water level depth with well depth, and a more general trend analysis that considers the slope of the cumulative distribution of estimated wet water column depth. The rationales for and further details of these failure analyses are described in the following subsections.

Table 3: Available information for Butte Valley wells ('observations' refers to water level observations).

Depth, Obs., Perf. Available?	Well Info Source	No. of Wells
None (location only)	DWR TSS Well	1
None (location only)	LWA GWO	115
Total Depth Only	LWA GWO	8
Observations Only	Volunteer Monitoring	34
Observations Only	DWR TSS Well	3
Observations Only	DWR Well Completion	27
Observations Only	DWR	9
Observations Only	LWA GWO	2
Perforation Only	–	0
Observations and Depth	DWR	21
Observations and Depth	LWA GWO	9
Depth, Obs. and Perf.	DWR	24

Uncertainties in Estimating Risk of Well Failure

Absent direct observation of well construction records and water levels, water level elevation at the well location must be estimated from nearby water level observations, incurring an estimation error associated with the interpolation of water level elevations (or depth to water level) at monitored well sites to the hundreds of other well sites across the Basin.

The location of wells is recorded, in most cases, to the center of the PLSS section within which a well is located. While the land elevation at the center of a PLSS section is available from USGS digital elevation maps, and water level elevation or depth can be extrapolated to that exact location, there may be differences in the land elevation, water level elevation, or water level depth between the center of a PLSS section and the actual well location that cannot be accounted for in the spatial extrapolation.

To understand potential errors arising from lack of precise well location records, it is useful to consider the change in land elevation across a section and the change in water level depth across a single PLSS section, relative to the center of the PLSS section:

Much of the Butte Valley floor is essentially flat at elevations between 4226 ft amsl (west of Meiss Lake), 4236 ft amsl (Meiss Lake), 4240-4245 ft amsl (most of the central valley floor west, north, and northeast of MacDoel, south of Dorris), 4250 ft amsl (MacDoel), 4255 ft amsl, Dorris) and 4260 ft amsl (Mt. Hebron). The base of foothills is generally at 4270 ft amsl. For sections entirely contained within the Butte Valley floor, land elevation within a section commonly varies within +/- 5 ft from the section center. However, for sections overlapping with foothill or escarpment slopes, land elevations within a section may be tens or even hundreds of feet different from the section center.

Similar to land elevation, water levels across the floor of the Basin vary only gradually, especially in spring, prior to the pumping season, when local cones of depression have not yet developed. Analyses of water level interpolation across the Basin indicate that the depth to water level changes typically by less than 10 ft per mile (the length of a PLSS section), but can range up to about 20 ft in some years and locations (Figure 5 and Figure 6). In contrast, under foothill or escarpment terrain, depth to water may change as rapidly as land elevations (Figure 5 and Figure 6).

In light of these potential differences in land elevation and water level depth between interpolated data and actual water level, and between the center of a section and the unknown location of a well in that section, the uncertainty about measuring water level elevation above a reported depth to top of perforation, or above a depth to reported depth of well, is on the order of less than 5 ft to 20 ft for wells on the floor of the Basin. For wells in sections that include foothills or escarpments, comparison of estimated water level elevation with well construction information may be associated with errors far exceeding 10 ft.

Additional uncertainties arise from lack of pump placement records and lack of recorded physical limitations to pump placement within the existing well casing, which is a function of geology, well design, pumping rate and other construction details.

Water Level Interpolation

For both types of Well Outage Risk Analysis (direct comparison and trend analysis), three maps of water levels have been constructed: two from measured depth to groundwater, in the fall of 2015 (dry year) and in the fall of 2023 (most recent fall conditions), and one from the MTs at the Representative Monitoring Points (RMPs). The first two water level years have been used to estimate well outages in Butte Valley over the most recent 8 year period and to compare those to reported well outages in the DWR well outage database. The interpolation of MTs was used to predict the number of outages if the water levels reached the MTs at all RMPs simultaneously.

Fall season is considered to be the time period between September 15 - October 31, and the fall low is defined as the maximum depth to groundwater during that time interval. Fall lows are selected for the outage risk analysis to represent the typical low groundwater levels during a year. The interpolated water table depths are most accurate near the locations of the measured wells. The accuracy of estimates deteriorates with distance from a measured well.

Well Outage Risk Analysis by Direct Comparison

Measured water levels for the fall of years of interest and for MTs at the RMPs have been interpolated to the reported location of all wells in the Butte Valley groundwater basin for which construction information is available. This allows for a direct comparison of total well depth against the interpolated water levels, as follows:

```
[reported total depth of well] - [interpolated depth to groundwater at
reported location] = [wet depth to bottom of well]
```

For purposes of this first analysis, we have assumed that a **well outage** (dry well) occurs when the “wet depth to bottom of well” is less than 10 ft.

Considering that some wells may not be able to draw water when only 10 ft of water remain, a more conservative well outage risk criterion was used by comparing the depth to top of perforation and the interpolated water levels at each well, where construction information is available:

```
[reported depth to top of perforation] - [interpolated depth to groundwater
at reported location] = [wet depth to top of perforation]
```

In this conservative evaluation, we assume that a **well outage** occurs when the “interpolated depth to groundwater” is greater than the “depth to top of perforation”, that is, when the “wet depth to top of perforation” is negative, which also means the water table is below the top of perforation.

Note: By using the USGS reported elevation at the reported well location as the reference elevation for both terms on the left-hand-side, the wet depth to top of perforations can also be expressed as:

```
[interpolated water table elevation at reported location] - [reported elevation
of total depth/top of perforation] = [wet depth to total depth/top of perforation]
```

This first analysis may be expanded in the future, with a programmatic effort to better match water level data with well construction information and to obtain better well location information, particularly near the margins of the basin, which are also the areas with the most wells due to the lower flooding risk.

Well Outage Risk Analysis by Wet Depth Trend Analysis

Cumulative distributions have been created for the estimated wet water column depth obtained from the direct comparison method described above. The cumulative distribution values of the wet depth (either above the bottom of the well plus 10 ft, or above the top of the screen) show the fraction of wells that do not exceed the corresponding wet depth in a specific year (or at the MT). The cumulative distribution value at a wet depth of zero indicates the fraction of wells that is likely dry (subject to well outage), which is the same result obtained in the previous direct comparison analysis.

The cumulative distribution provides additional information that is useful considering that there is some uncertainty about the exact depth of the water level at the actual (but unknown) location of the well and about the pump placement requirement: The slope of the cumulative distribution in the shallower range of wet depth indicates the additional number of wells as a fraction of the total number of wells per feet of additional wet depth (or say, percent of total wells per feet of wet depth). The shallower range of wet depths has been quantified as the measures of wet depth between the 5th and 35th percentile of the cumulative distribution function. The slope determined within this range would be a reasonable metric, as the distribution within this range of wet depth has been found to be nearly linear. Additionally, this selection of percentile range not only ensures the shallowest set of wells are considered for well outage risk analysis, but also excludes wells with exceedingly negative wet depths, which may be due to: the well might have been dry for many years, abandoned, or, data errors might have occurred. Furthermore, the 5th to 35th percentile section of the cumulative distribution tends to also be the steepest section, which indicates it is also the range where the majority of wet depths occur (in other words, it has the most wells added to the cumulative distribution function for every 1, 2, 5, 10 ft etc increase in wet depth).

Knowing how many wells have an additional 1, 2, 5, 10 ft etc of wet depth provides a means for estimating the number wells that fall dry as a fraction of the total number of wells for each additional 1, 2, 5, 10 ft etc of water level decline, which is how the concept mentioned above was translated into estimating additional well outages through the linear slope between the 5th to 35 percentile of the cumulative distribution function.

In this analysis, the trend analysis results have been presented as the slope of the cumulative distribution, which is the fraction of total wells in percent per 10 ft increase in wet depth. This number represents an estimate of the percent of wells likely to fall dry per 10 ft of additional water level decline, on average, across the Basin.

Reported Well Outages

For this 2024 well analysis revision, a review of the DWR Dry Well Report database and the findings of 2023 Butte Valley Well Outage Survey have been conducted to further support and validate the findings from the well outage risk estimation for Butte Valley, and to identify potential missing well outages reported for the GSA.

Results and Discussion

Well Distribution and Construction Information in Butte Valley

The major planned use of wells of interest for beneficial uses and users of groundwater in Butte Valley are domestic, public, and agricultural water supply wells. In total, 317 out of 443 wells documented in OSWCR fall into these three categories (Figure 1, Figure 2 and Table 2). An analysis of the depth distribution among the 78 wells with "missing" planned use reveals significant similarity to that for domestic wells. For this analysis, the 78 wells are therefore assumed to be domestic wells. The summary of well depth and perforation statistics is presented in Table 4 for these wells. Table 4 shows that for all the OSWCR wells with total well depth available, a majority of them do not have perforation details.

The total completed depths of these wells below ground surface and their associated bottom formation are demonstrated in Figure 3. Of the known formations, domestic wells and "missing" planned use wells are mostly completed in quaternary lake deposits. Most domestic and "missing" planned use wells have depth in the range of 100 ft to 250 ft unless they are completed in the older volcanic rocks (at least 200 ft deep). Shallowest depths of all wells are over 30 ft and deepest wells can be more than 1400 ft.

Agricultural wells have a significantly broader depth distribution than domestic wells. Many newer agricultural wells are 300-500 feet deep while older wells have depths similar to domestic wells. The depth distribution of agricultural wells is similar across geologic formations except in the older volcanic rocks of the High Cascades (QTb) where agricultural wells are less common and are only found at significant depth, typically near the basin boundaries. In the QTb, the agricultural well depths range from about 30 ft to about 1800 ft (Table 4). Additional well construction information can be found in the Supplementary Information.

To understand how a chronic decline in water levels may affect human and natural beneficial uses, the following analysis was performed to evaluate the 247 domestic and public wells from OSWCR in Butte Valley groundwater basin (including "missing" planned use). Their spatial distribution by well formation is presented in Figure 4.

Well logs of newly constructed wells during 2019 and 2023 have been actively reviewed by technical staff for more accurate location information. The preliminary investigation of these wells' construction information indicates that a total of 17 wells were newly installed for domestic and public supply use (14 wells) and agricultural use (3 wells). The new domestic wells have total depths ranging from 80 to 400 ft below ground surface. For the purpose of this analysis, these newly constructed well are not included for the well outage risk analysis, given the need to provide a consistent set of wells for evaluations in 2015 and 2023, and at MT.

Table 4: Summary Statistics of Construction Information by Major Planned Well Use

Planned Use	Statistic	Total Completed Depth (ft bgs)	Top of Perforation (ft bgs)	Bottom of Perforation (ft bgs)	Perforated Length (ft)
agriculture	Min.	29	0	20	8
	1st Qu.	119	46	124	58
	Median	216	71	204	120
	Mean	332	148	317	169
	3rd Qu.	407	154	400	200
	Max.	1818	943	1626	995
	NA count	0	75	75	75
	Percent NA	0	51	51	51
domestic	Min.	32	0	23	4
	1st Qu.	90	38	90	20
	Median	125	62	128	40
	Mean	180	99	173	74
	3rd Qu.	202	128	181	79
	Max.	1450	541	1433	1342
	NA count	0	91	91	91
	Percent NA	0	56	56	56
missing	Min.	29	20	30	2
	1st Qu.	60	31	58	16
	Median	102	47	118	20
	Mean	158	89	131	42
	3rd Qu.	200	120	172	42
	Max.	805	321	341	170
	NA count	0	66	66	66
	Percent NA	0	85	85	85
public	Min.	77	58	78	9
	1st Qu.	111	85	105	20
	Median	143	92	132	20
	Mean	329	119	149	30
	3rd Qu.	241	99	159	40
	Max.	1236	261	270	60
	NA count	0	1	1	1
	Percent NA	0	17	17	17

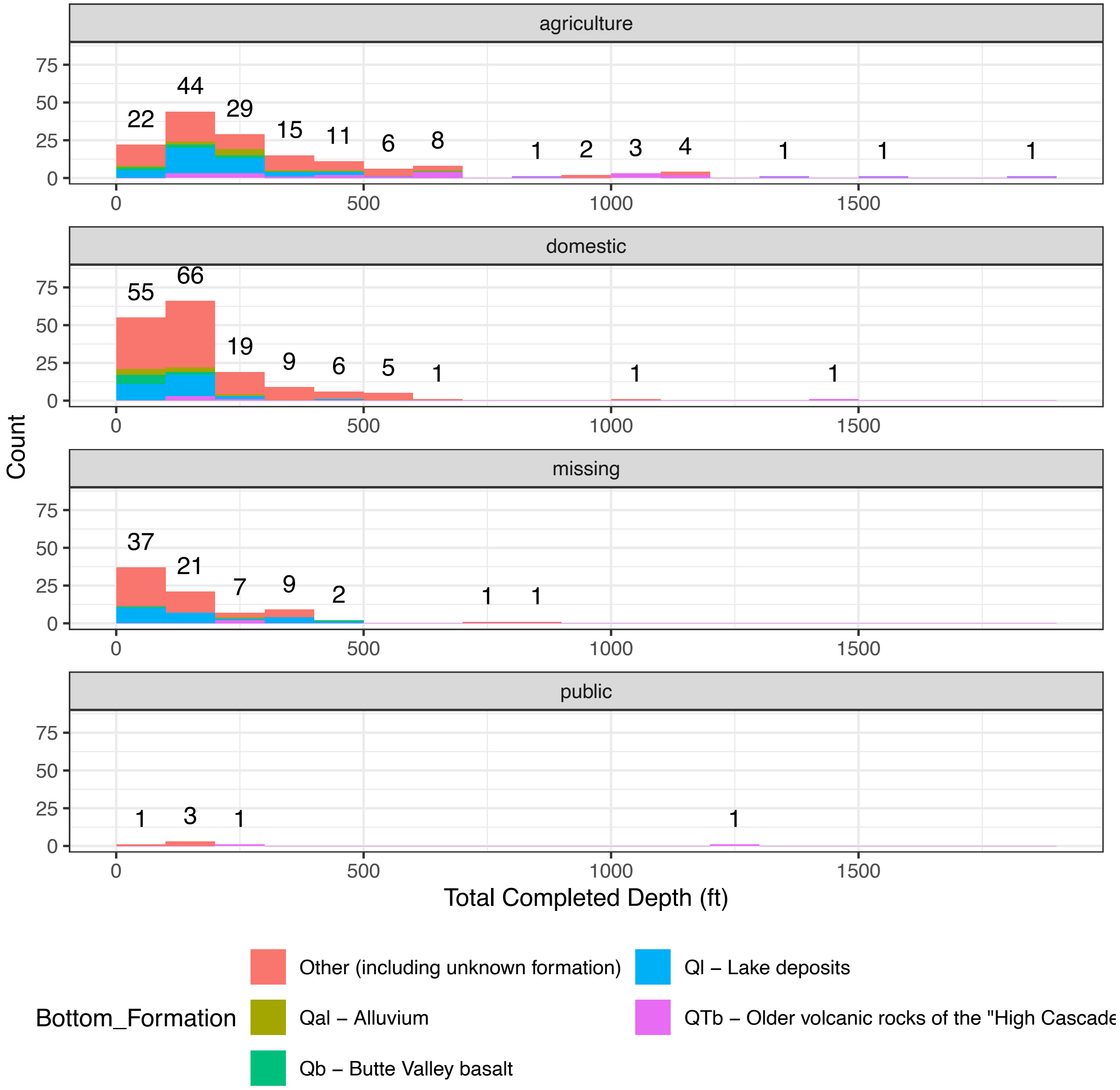


Figure 3: Histogram of Total Completed Depth of Domestic, public supply and agricultural Wells (including the 'missing' planned use wells that were assumed domestic wells in the analysis).

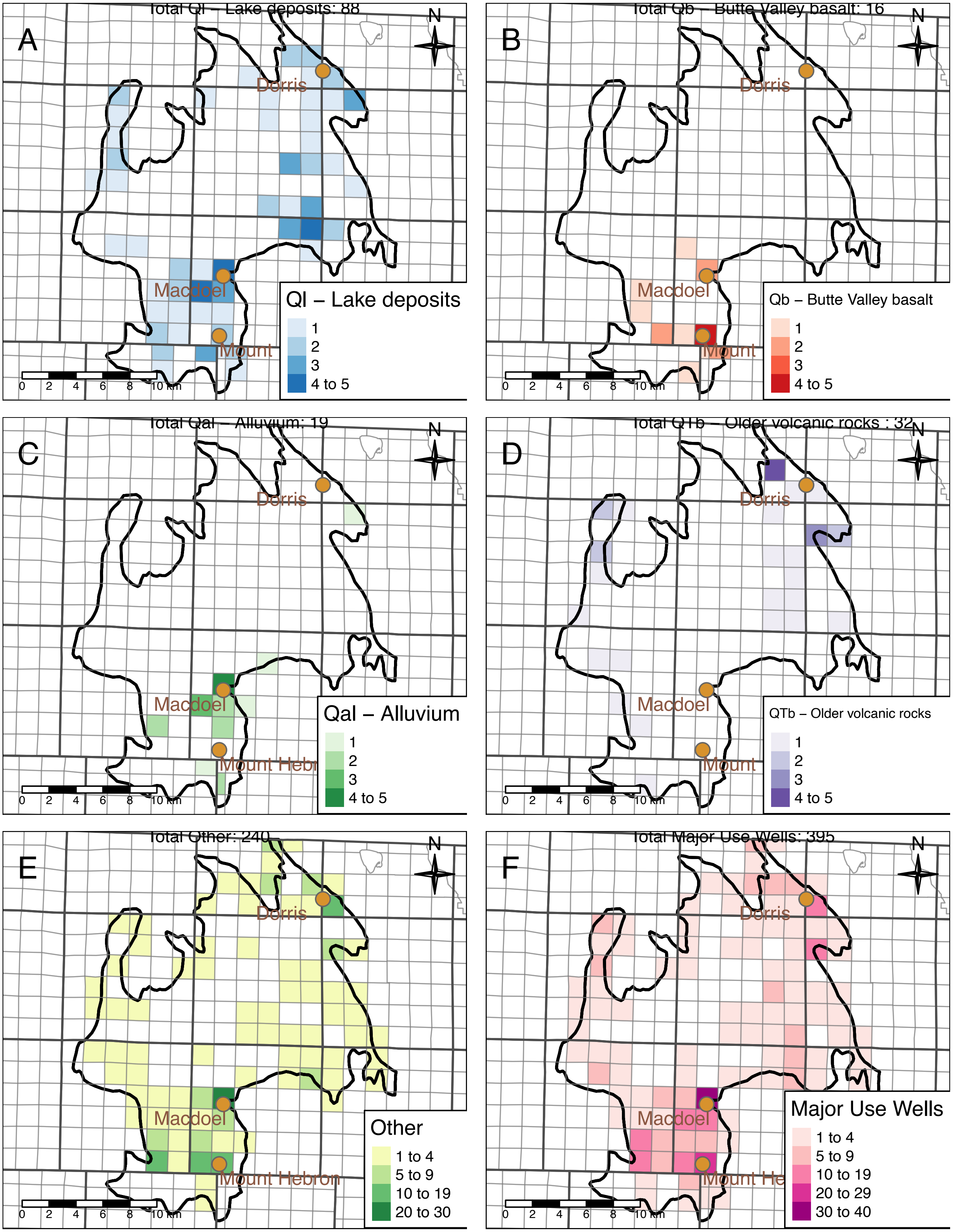


Figure 4: Butte Valley choropleth map of domestic, public supply and agricultural wells by bottom formations.

Well Outage Risk Analysis

Domestic Wells

Estimated Outages by Direct Comparison The interpolated groundwater elevation contours within the Butte Valley B118 boundary are constructed with the best available groundwater level measurements for fall 2015 and 2023, and are presented in Figure 5 and Figure 6, respectively. Histograms of the calculated wet depth to (a) top of perforation and to (b) bottom of well using the reported well information and the interpolated groundwater level at the reported location are presented for fall 2015 and 2023 in Figure 8 and Figure 9, respectively.

When using wet depth to 10 ft above bottom of wells as the criterion for well outage, Figure 8 (right panel) indicates that, in 2015, approximately 19 percent of wells, or 45 out of 241 domestic wells, are estimated to have been experiencing dry conditions (well outage). This may represent older wells that are inactive or abandoned, wells that have been inactive since 2015, and wells that have experienced temporary well failure.

The use of the wet depth to top of perforation as well outage criterion has been done on a much smaller subset of wells (84 out of 241). Nearly half of those wells (40 of 84), meets this alternative well outage criterion in 2015. It is unlikely that nearly half of the domestic wells reported in OSWCR were already dry in 2015. This indicates that the analysis using the wet depth to top of perforation as well outage criterion is limited by the data available for well perforation information in Butte Valley, and possibly many domestic wells may have pumps installed below reported top of perforations.

For the purposes of the well failure analysis, the estimated number of dry wells in 2015 provides a baseline to measure against the estimated additional well outages in a future year (i.e., 2023). The estimated additional well outages between 2015 and 2023 was determined by comparing the number of well outages due to the change of water levels between 2015 and 2023 across the basin.

Using the depth to 10 ft above bottom as the well outage criterion, 14 additional well outages occurred between 2015 and 2023, which is 6% of the total domestic wells analyzed (right panel of Figure 8 and Figure 9). Alternatively, using wet depth to top of perforation as the well outage criterion, an additional 4% of wells were estimated to be at risk for failure between 2015 to 2023 (left panel of Figure 8 and Figure 9). Hence, similar estimates of well failures are obtained from the use of both well outage criteria.

When applying the direct comparison to the water level contour representing MT conditions throughout the Basin (Figure 7), results for the depth to 10 ft above bottom criterion indicate that a water level decline from 2023 conditions (right panel of Figure 9) to MT conditions (right panel of Figure 10) would cause an estimated 14 additional well outages, for a total of 28, or 12% of domestic wells experiencing outage since 2015. The evaluation using wet depth to top of perforation criterion indicates an additional 3% wells at the risk of dewatering from 2023 to MT (6% of wells between 2015 conditions and MT conditions), again, a slightly lower number of well outages than estimated using the first well outage criterion, but essentially confirming the results (Figure 10).

The spatial distribution of the well outages estimated using the 10 ft to well bottom criterion is shown in Figure 11. Most of the 2015-2023 outages are near Dorris, Macdoel, and Mount Hebron, with scattered outages throughout rural areas. Additional outages, were water levels to decline to the MT, would occur mostly in the Mt. Hebron area with additional outages scattered across rural areas.

In summary, 45 domestic wells are estimated to be dry in 2015. From 2015 to 2023, an estimated 10 to 14 additional wells went dry (4-6% of the total domestic wells). From 2023, if levels dropped below MTs, an estimated 8 to 14 additional wells will go dry, bringing the total number of wells going dry, after 2015, at MT conditions, to an estimated 15 to 28 wells (6-12%).

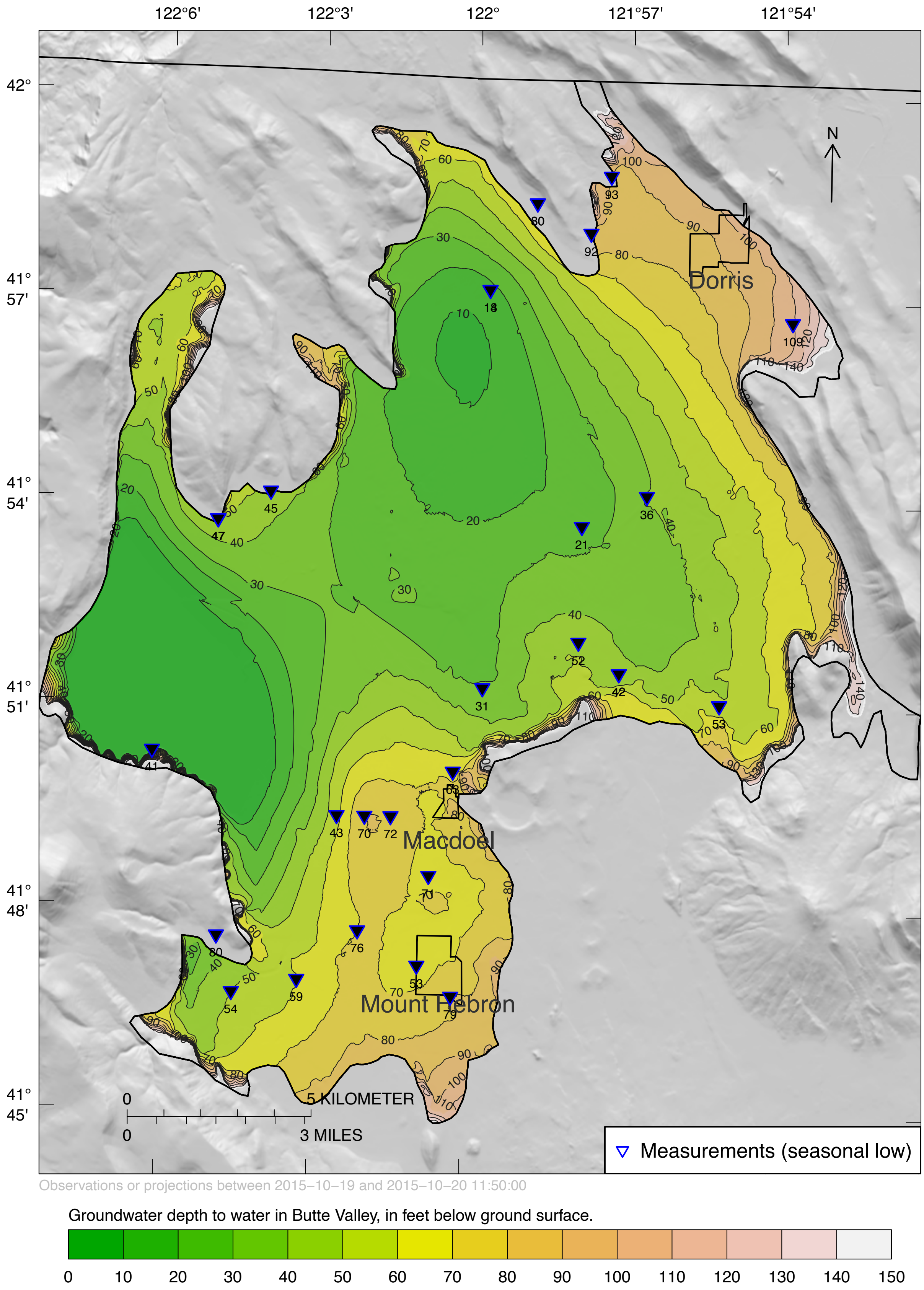


Figure 5: Butte Valley groundwater elevations reported as approximate depth to groundwater, fall low of 2015 and well failure estimates based on recent water level observations. Approximate basin-scale groundwater depths are shown.

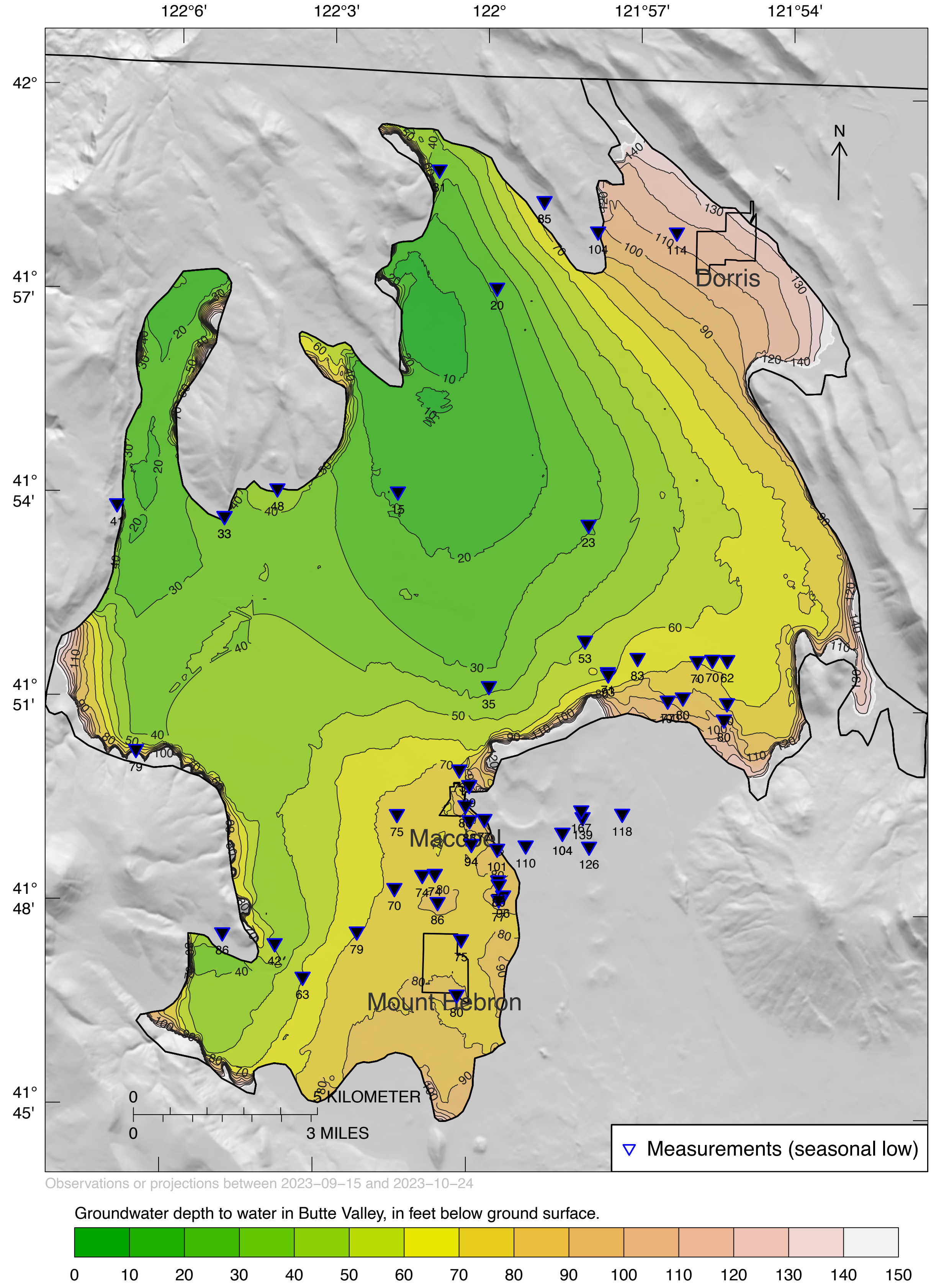
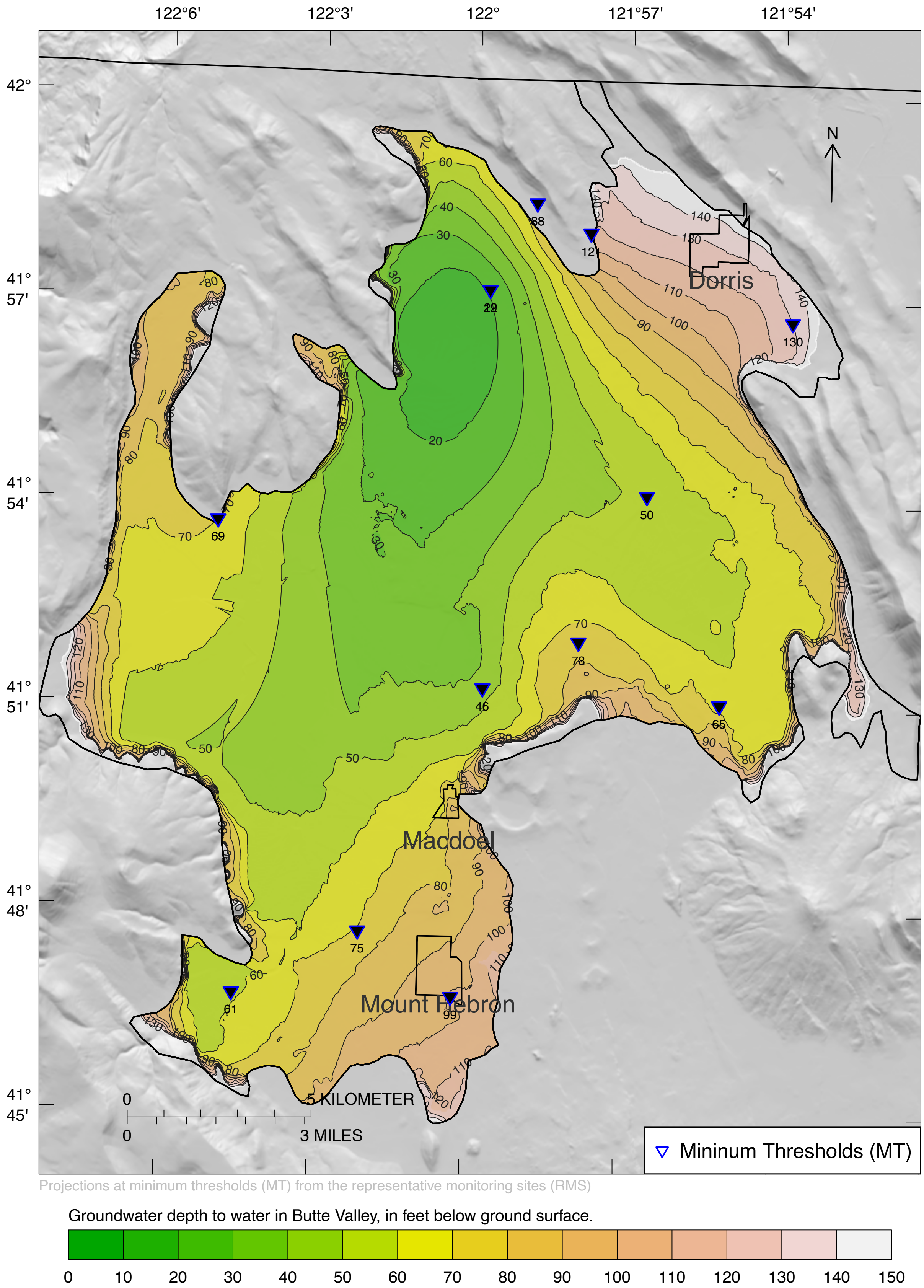


Figure 6: Butte Valley groundwater elevations reported as approximate depth to groundwater, fall low of 2023 and well failure estimates based on recent water level observations. Approximate basin-scale groundwater depths are shown.



Projections at minimum thresholds (MT) from the representative monitoring sites (RMS)

Figure 7: Contour of the predicted Butte Valley groundwater elevations if minimum thresholds were reached at representitive monitoring points. Approximate basin-scale groundwater depths are shown.

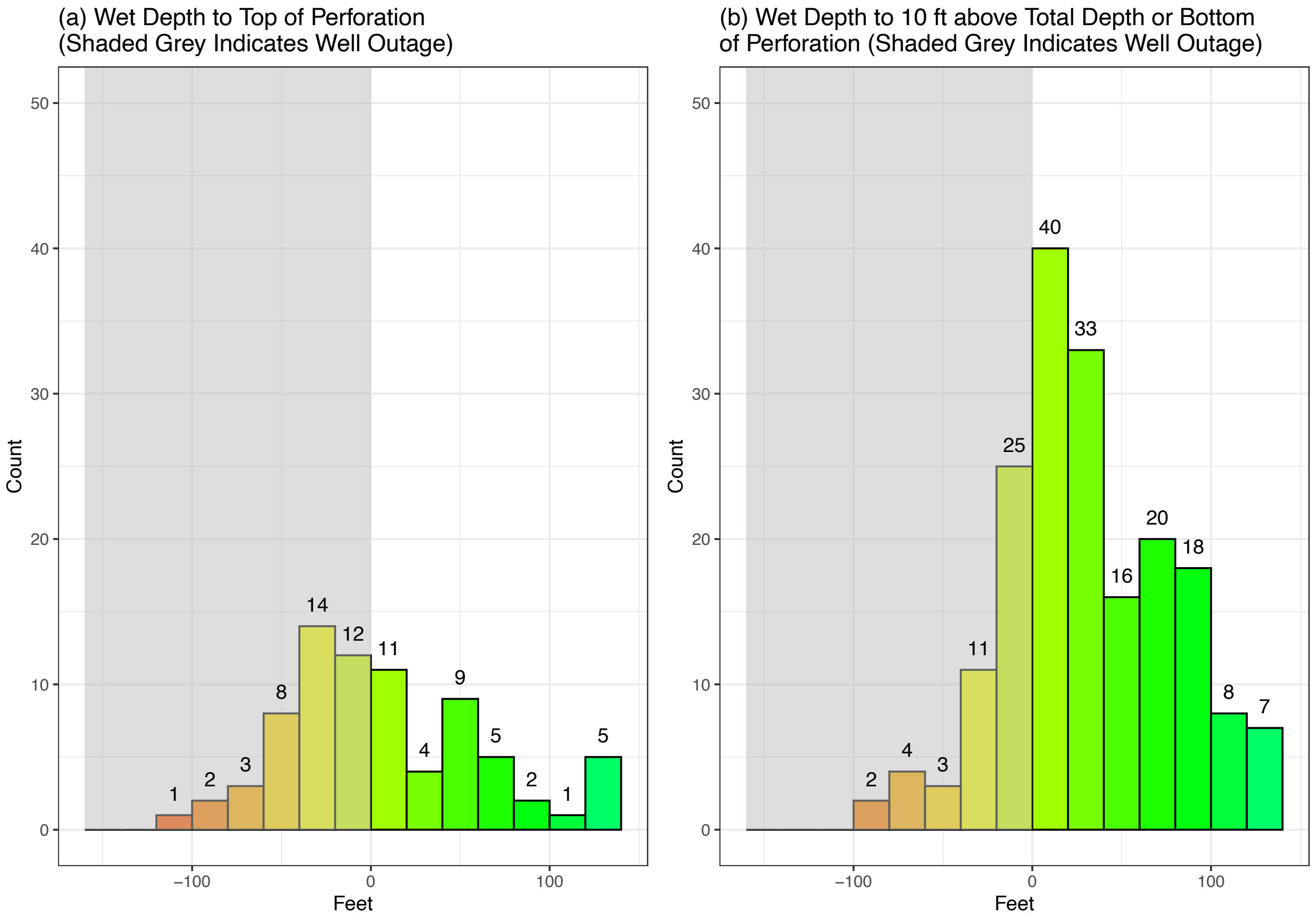


Figure 8: Histogram of wet depth to well perforations for domestic wells based on contoured groundwater elevations, fall 2015. Note: only the wet depths that are negative and less than 140 ft are shown for better illustration. A positive wet depth indicates the water level is above the bottom of well or its top of perforation, indicating the well is relatively deep and not at risk of an outage.

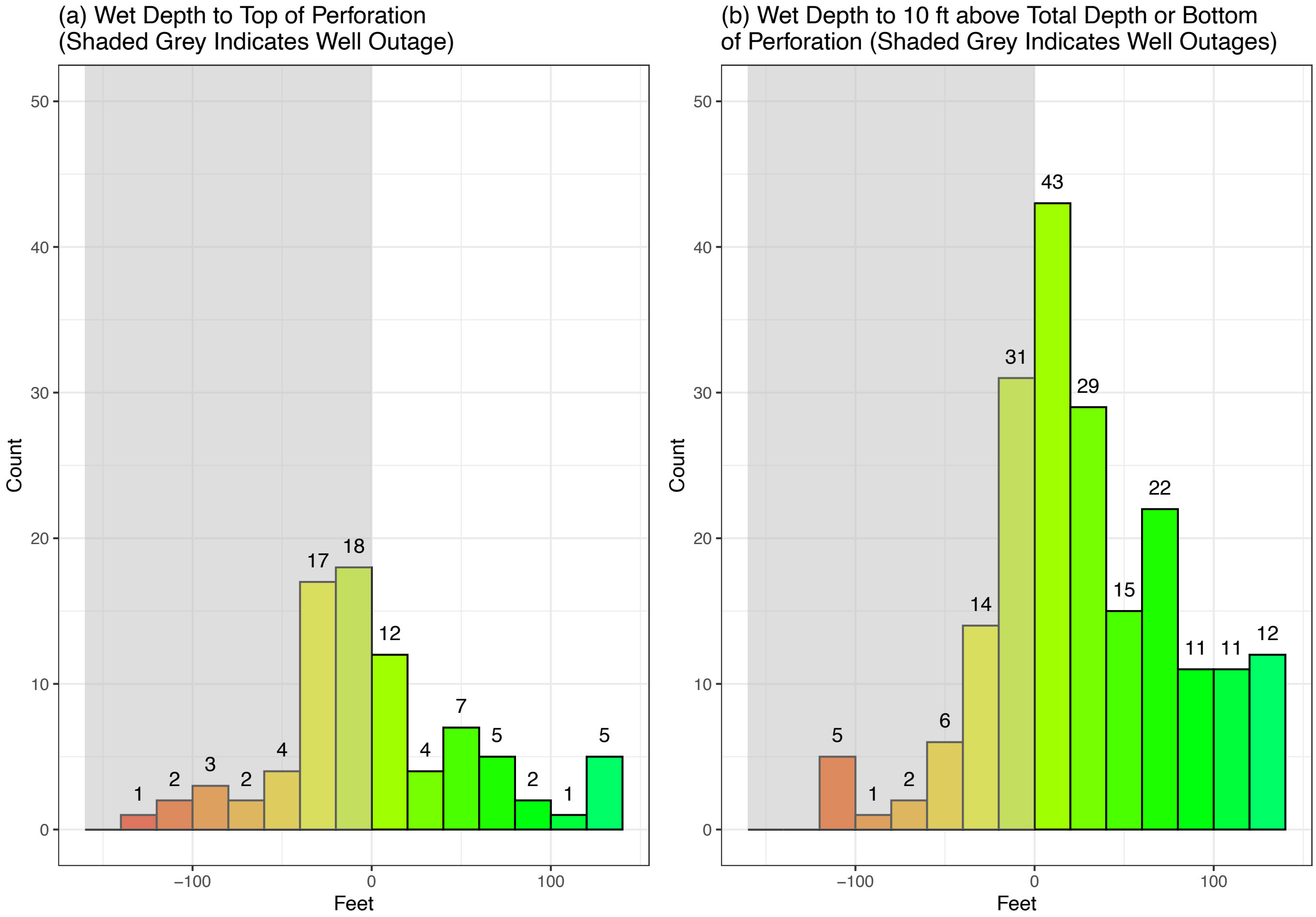


Figure 9: Histogram of wet depth to well perforations for domestic wells based on contoured groundwater elevations, fall 2023. Note: only the wet depths that are negative and less than 140 ft are shown for better illustration. A positive wet depth indicates the water level is above the bottom of well or its top of perforation, indicating the well is relatively deep and not at risk of an outage.

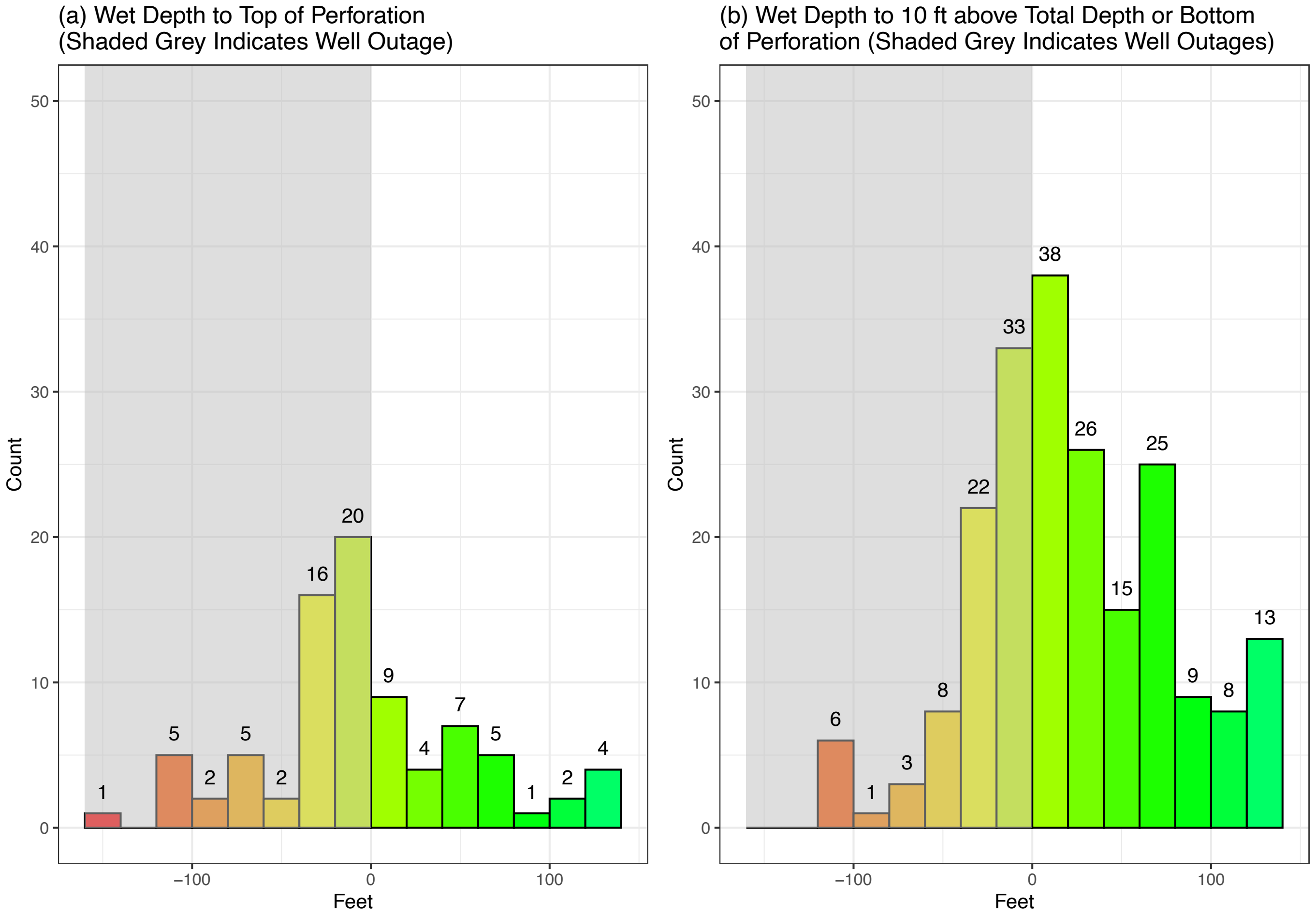


Figure 10: Histogram of wet depth to well perforations for domestic wells based on the predicted contoured groundwater elevations at minimum thresholds. Note: only the wet depths that are negative and less than 140 ft are shown for better illustration. A positive wet depth indicates the water level is above the bottom of well or its top of perforation, indicating the well is relatively deep and not at risk of an outage.

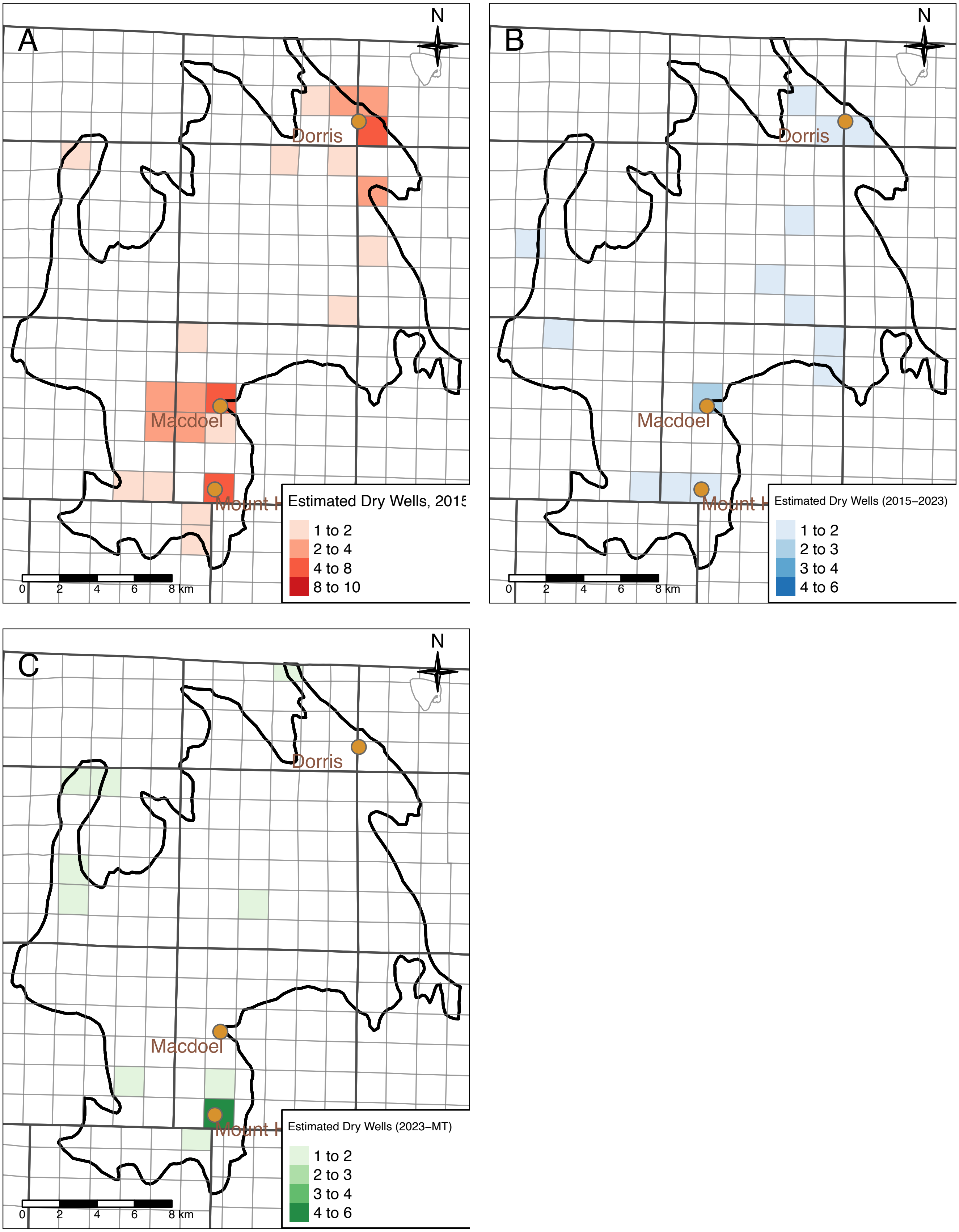


Figure 11: Butte Valley choropleth map of domestic wells indicating the number of estimated well outages in 2015 (panel A), additional well outages from 2015 to 2023 (panel B), and additional well outages from 2023 to MT Triggered across Basin (panel C).

Estimated Outages by Wet Depth Trend Analysis The cumulative distributions of the wet depth to top of perforation and the wet depth to 10 ft above bottom of well are shown in Figure 12 for fall 2015 conditions, fall 2023 conditions, and for MT conditions across the basin. The cumulative distributions of wet depth to top of perforations and wet depth to bottom of well have very similar shapes and show a consistent left shift across the entirety of the distribution. The latter is a result of the fact that water table depth in 2023 is deeper than 2015 across the entire basin. Similarly, MT conditions are deeper than 2023 across the entire basin.

All cumulative distribution functions are relatively flat at their left tail, indicating a few wells with widely spaced negative depths. Once the cumulative distribution functions reach approximately 5% to 10% of wells, the slope steepens to its maximum up to approximately 60% of wells, beyond which it slowly flattens out – fewer and fewer wells are deeper and deeper. The trend analysis takes advantage of the relatively consistent slope in the 5th to 35th percentile range of the cumulative distribution that is also intersecting with the zero wet depth threshold. Since it is the steepest part of the cumulative distribution function, it is also the most conservative estimate, i.e., it provides an upper limit for the estimate of well outages per 10 ft basin-wide decline in water levels.

Importantly, the absolute value of the wet depth of an individual well may have errors of less than +/- 5 ft to as much as +/- 20 ft. To the degree that the average of the error is near 0% (i.e., unbiased), this estimation error does not affect the shape or relative position (on the wet depth axis) of the cumulative distribution function of wet depths. Given the range over which the cumulative distribution function has a nearly consistent slope, the slope value is much less sensitive than the specific estimated wet depth at wells to well outage analysis. If we further assume that the minimum wet depth to either the bottom of the well or to the top of perforations is similar for most domestic wells, then this slope is a relatively robust estimator for the risk for well outages with additional water level decline below historically low values.

Importantly, this approach to estimating well outage risk does not require knowledge of specific well information about pumping bowl elevation relative to the screen location, or about a minimum wet water level depth needed to pump properly. It only assumes that some well outages occur if water levels fall below historic lows and, hence, the selected slope is representative of the one-third of wells at most risk to well outage.

The slope analysis across the two well outage indicators and the three water level conditions indicates that a 10 ft average decline in water levels results in 4% to 6.5% of domestic wells going dry across the Basin.

This slope estimate allows for an estimate of the number of well outages that occur due to a lowering of the water table from the minimum measurable objective (MO, which corresponds to the lowest observed water level between 1991 and 2014) and the MT. The basin-wide average difference between the minimum MO and the MT is 15 ft. The trend analysis suggests that 6% to 10% (per 15 ft, equivalent to the 4% to 6.5% per 10 ft in Figure 12) or (15 to 24) of domestic wells are at risk of well failure between MO conditions and MT conditions.

This result is consistent with the direct comparison method. The consistency of results is due to the similarity of the slope for 2015, 2023 and MT conditions from their cumulative distribution functions, which results in similarity of the intersects of these three regressions with zero wet depth. The trend method is considered slightly more robust due to fitting of the slope to a broader range of wells rather than just considering the difference in the cumulative distribution function specifically at a wet depth of zero.

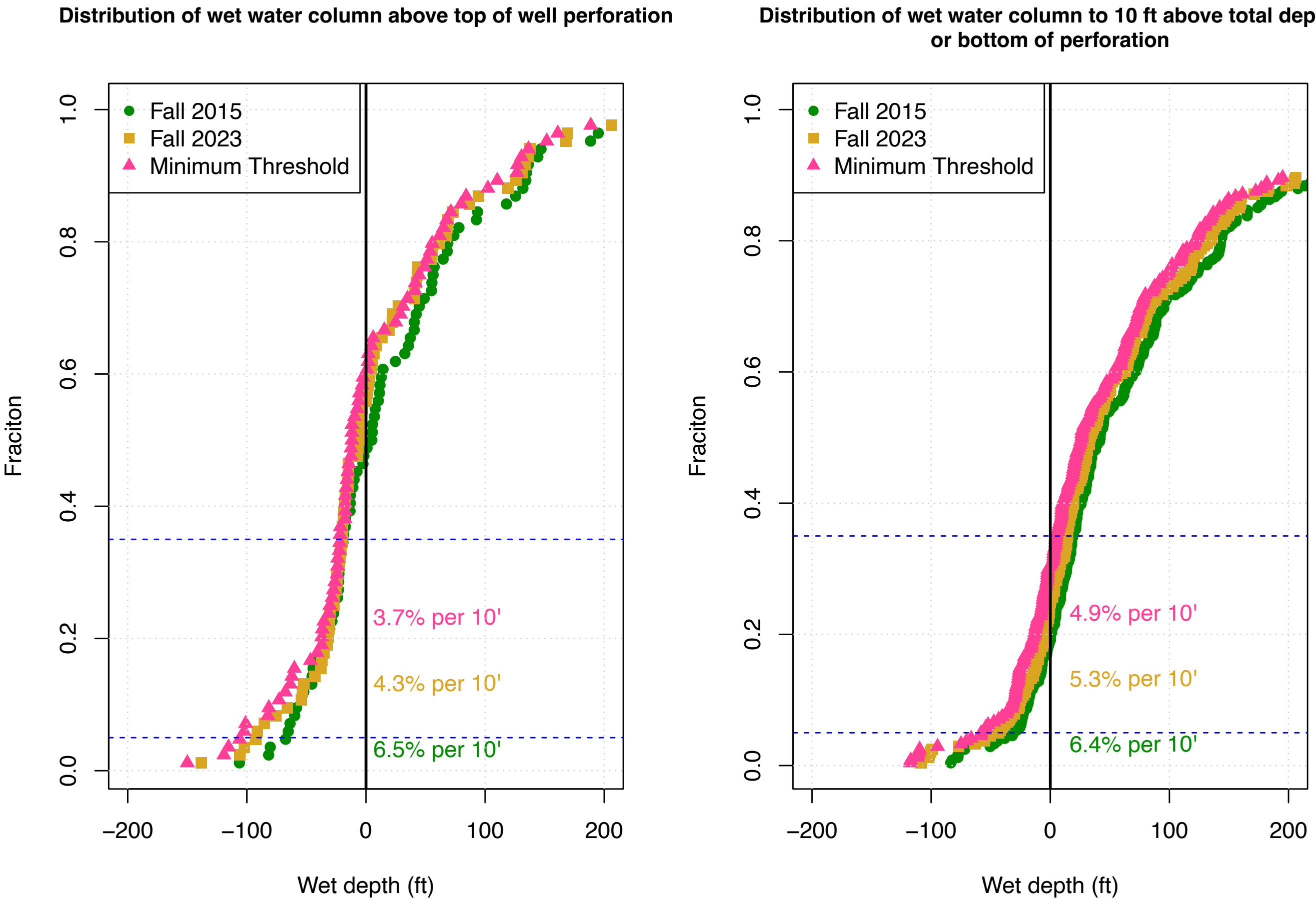


Figure 12: Cumulative distribution function of domestic well wet depth to top of perforations in all formations based on contoured groundwater elevations during Fall of 2015 and 2023, and prediction at mininum thresholds. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (blue dash line). Note: only the wet depths that negative and less than 200 ft are shown for better illustration. A positive wet depth indicates the water level is above the bottom of well or its top of perforation, indicating the well is relatively deep and not at risk of an outage.

Public Wells

An outage analysis has been performed for public wells with the same approach as domestic wells in the previous section. Through the “direct comparison” approach, the public well outage is 0 in 2015, and 0 additional well outages are identified from 2015 to 2023 and to MT. The analysis indicates that public wells in Butte Valley groundwater basin are less likely to experience outage from a chronic lowering groundwater level. The less likelihood of adverse impacts on public wells is because they were constructed with deeper depths compared to other types of wells (see Table 4).

Agricultural Wells

An outage analysis has been performed for agricultural wells with the same approach as domestic wells in the previous section. The percent outage identified through “trend analysis” for agricultural wells falls within the range identified for domestic wells. Through the “direct comparison” approach, the estimated number of agricultural well outages is 7 in 2015 (out of 148 agricultural wells, 5%). 3 additional well outages are estimated from 2015 to 2023. And 7 additional well outages are estimated from 2023 to MT. These results are illustrated in the choropleth maps in Figure 13.

Reported Well Outages

As of June 2024, the DWR Dry Well Report database contains four reports of wells that have gone dry with confirmed locations within the Butte Valley basin. Two of the reported dry wells are within the city of Mt. Hebron. In both wells, the issue was reportedly resolved by lowering the pump bowl. One of the reported dry wells is in the city of Macdoel, and the last dry well is northwest of Dorris. All four wells are domestic wells. The reports were filed with DWR in the summer of 2021 (1 report) and in the spring to fall of 2023 (3 reports).

The 2023 Butte Valley Well Outage Survey was conducted to identify domestic wells needing replacement or repair in Butte Valley. Twenty survey responses were received across the basin, with 10 reported wells needing repair or replacement, and 8 of the 10 wells being recommended for further actions (i.e., replacement, repair or follow up) based on field inspections after receiving the survey responses. Of the 8 dry or intermittent wells, 7 reported wells are around the Macdoel to Mt. Hebron region, and one is around the City of Dorris. The well outage survey and well repair and replacement are ongoing efforts. Details about the progress has been discussed in Chapter 4.

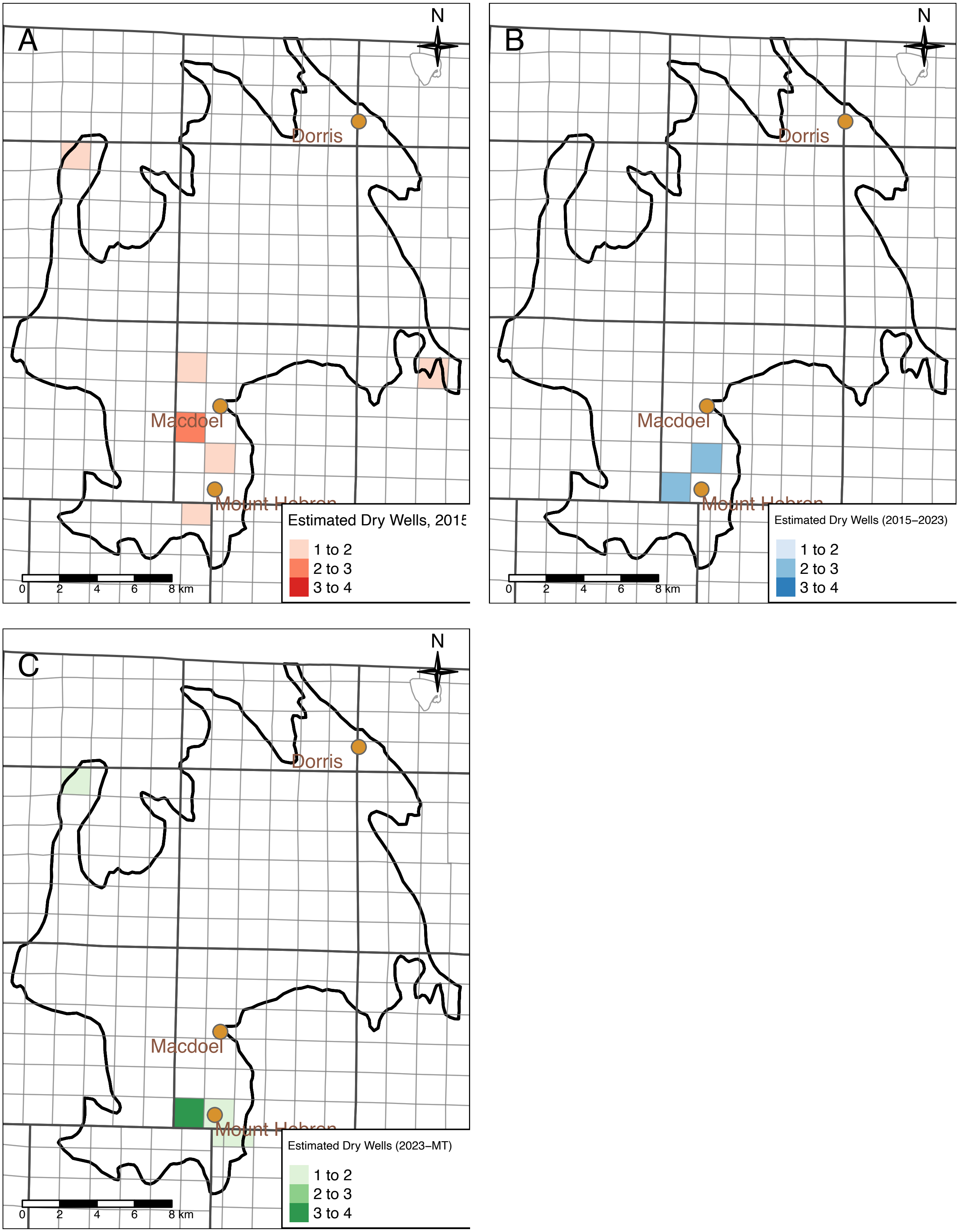


Figure 13: Butte Valley choropleth map of agricultural wells indicating the number of estimated well outages in 2015 (panel A), additional well outages from 2015 to 2023 (panel B), and additional well outages from 2023 to MT Triggered across Basin (panel C).

Conclusion

We identified three key findings with respect to well outages:

The majority of wells in the Butte Valley groundwater basin are unlikely to be affected by dewatering.

Uncertainty affects the quality of the outage analysis. The analysis has a level of uncertainty due to the lack of information, i.e., wells with both water level measurements and known well construction. Hence, we relied on interpolated water level data, which may be several feet or even tens of feet incorrect in some areas.

The number of wells affected by groundwater elevations at the Minimum Threshold can be mitigated. Well outage analyses by direct comparison and by wet depth trend analysis show relatively consistent results of additional well outages. If water levels across the basin fall to the minimum threshold as compared to 2015 conditions, the estimated outage percentages are 6 - 12% of additional wells through direct comparison and 6 - 10% of additional wells through trend analysis. This estimated range falls within the percent mitigatable wells margin set by the GSA (see section 3.4.1.1 Identification of Undesirable Results).

Further, a well replacement PMA (ongoing) and a well mitigation PMA (planning) will be implemented to address well outage issues that occur below the minimum threshold. Details of these two Tier II PMAs are described in Chapter 4.

Supplementary Information

A detailed characterization of construction information for the domestic, public and agricultural wells can be demonstrated through cumulative distribution plots. The distribution of depth to the top of the perforated interval follows a similar pattern as well depth: shallow-most top of screens are found in domestic wells, across all formations (see Figure 14). Figure 15 shows the distribution of total completed depths, and Figure 16 shows the resulting perforation lengths.

The few pumping test data that have been provided on Well Completion Reports submitted to the Department of Water Resources have shown that both domestic wells and public supply wells have low well yields, by design. As for comparison, agricultural wells tested are generally high production wells with 1000 to 5000 gpm (Figure 17). Agricultural wells have casing diameters of typically 12 to 18 inches, while domestic wells are mostly of smaller (2 to 8 inch) diameter with 10 inch diameter domestic wells in the Butte Valley Basalt (Qb), perhaps owing to miss-classification (Figure 18).

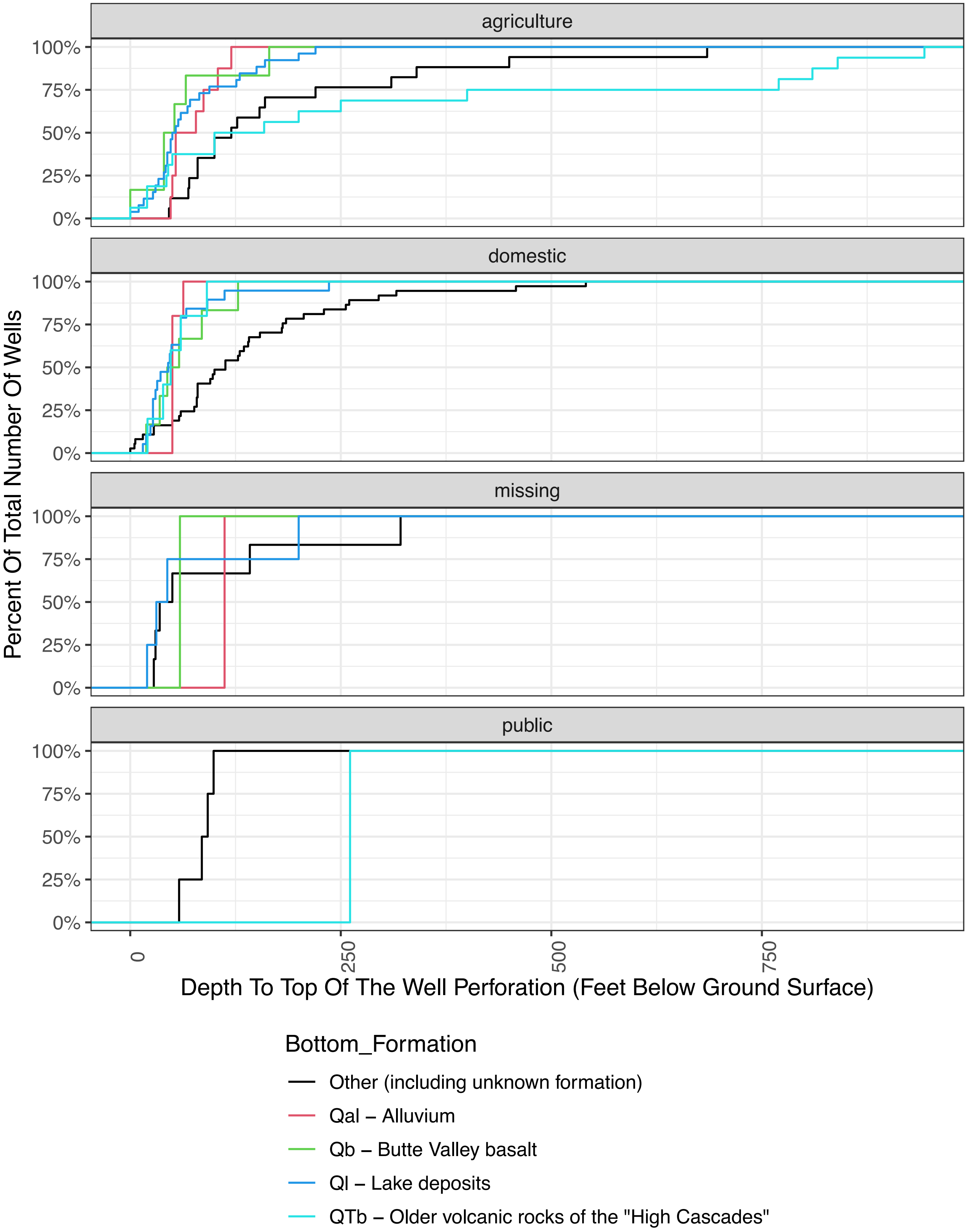


Figure 14: Butte Valley well perforation top. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

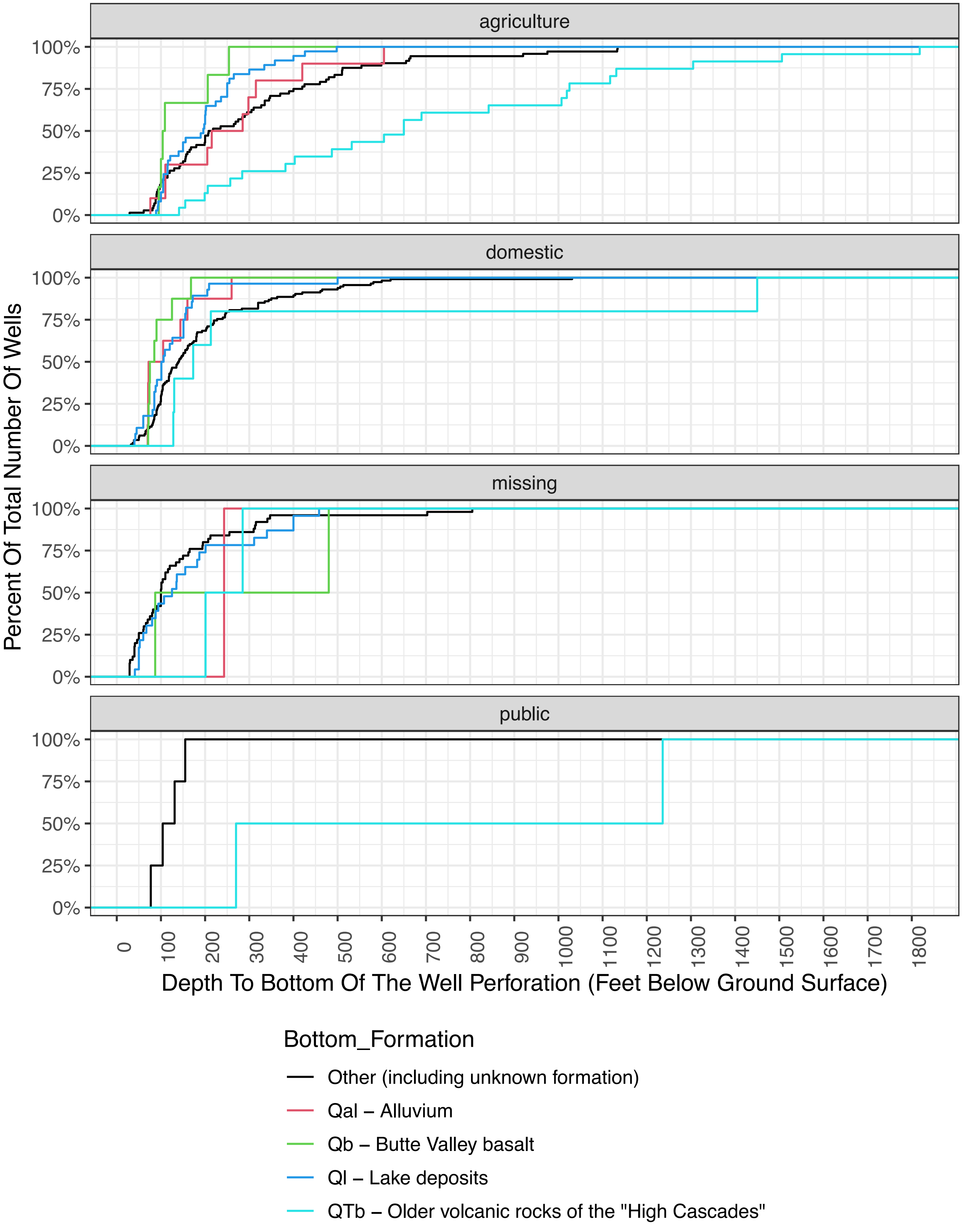


Figure 15: Butte Valley total completed depth for all wells in the valley, including those which have no data on perforated interval. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

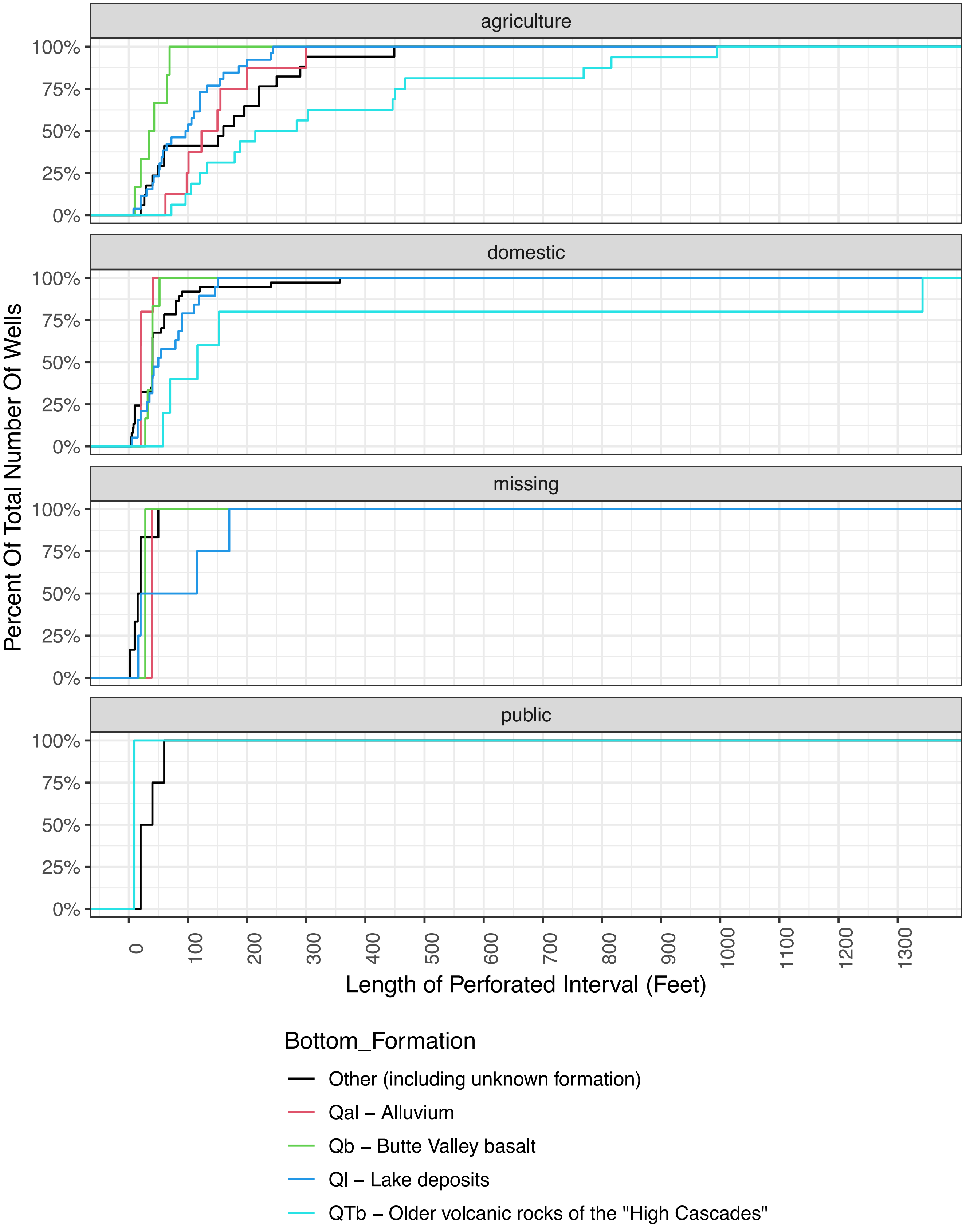


Figure 16: Butte Valley well perforation length. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

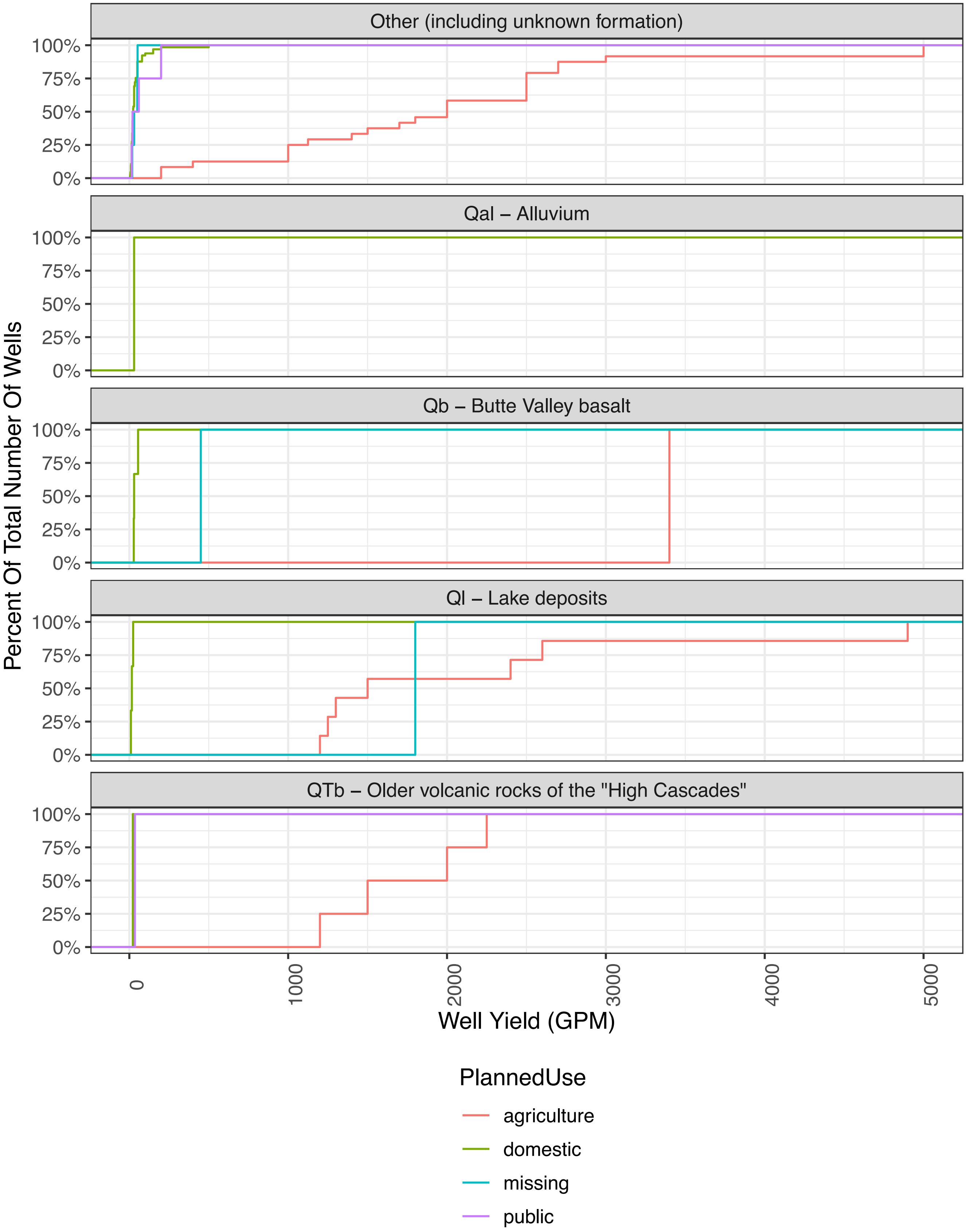


Figure 17: Butte Valley well yield by formation at the bottom of the well for major well types.

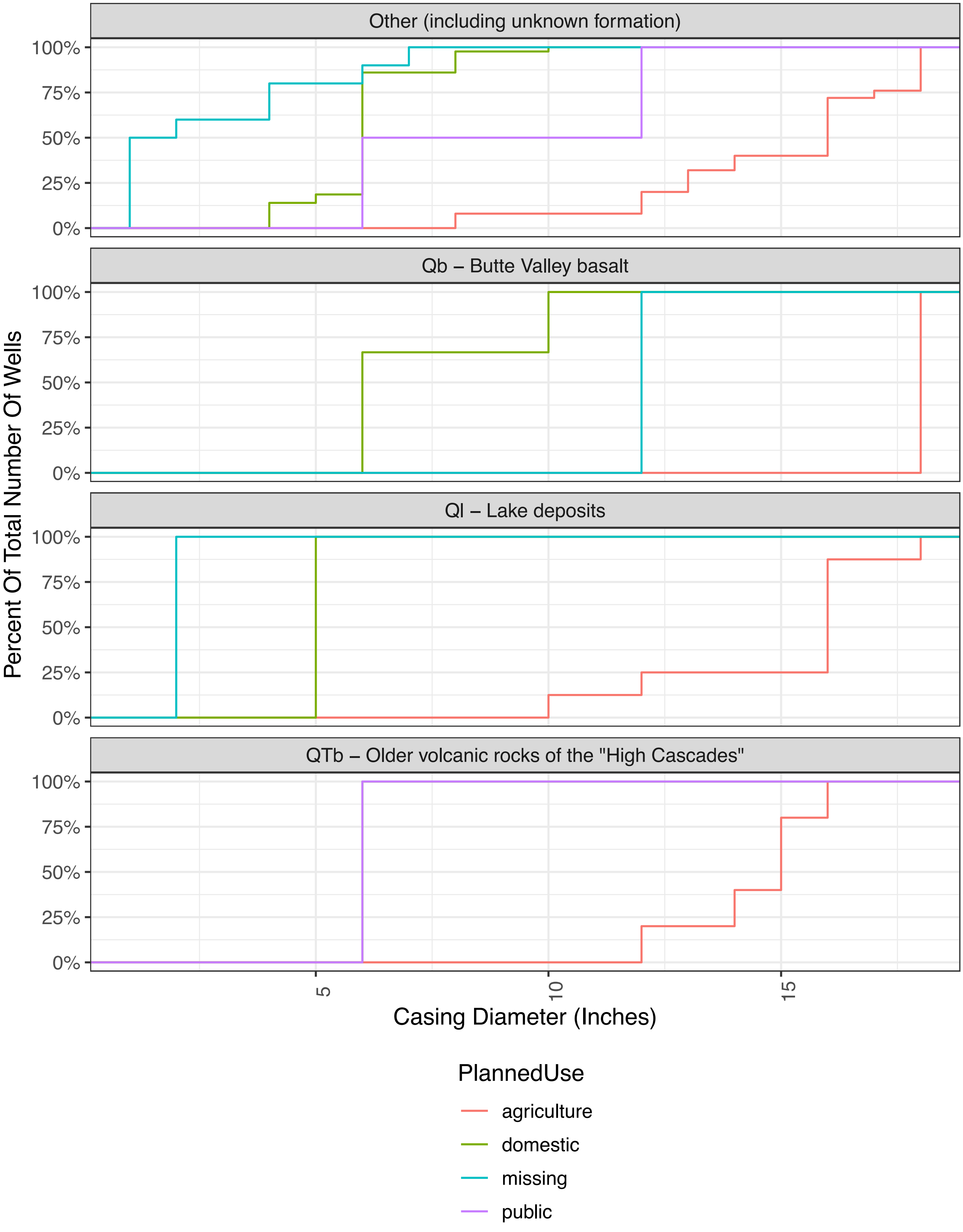


Figure 18: Butte Valley well casing diameter by formation at the bottom of the well for major well types.

Appendix 3-D Butte Valley GSP Deficiency List, Corrective Actions, and Response

Deficiency Number	Deficiency and Corrective Actions	Revision	Page Numbers of the Plan	Section Numbers	Figure Numbers	Table Numbers
1	**The GSP does not include a reasonable assessment of overdraft conditions and reasonable means to mitigate overdraft**					
1.a.	Reevaluate the assessment of overdraft conditions in the Basin. Specifically, the GSA should examine the assumptions that were used to develop the absence of historical and current overdraft and the projected overdraft estimates in the projected water budget considering the results vary greatly from the values reported in the recent annual report data. The assessment should include the latest information for the Basin to ensure the GSP includes the required projects and management actions to mitigate overdraft in the Basin.	**Chronic Lowering of Water Levels:** The GSA has re-evaluated hydrographs of wells throughout the basin and documented both, historic condition when water levels had been stable and identified recent conditions, since at least 2000, as chronic lowering of water levels.	103-110	2.2.2.2	2.2.1,2.2.2	N/A
1.a.		**Baseline and Recent Groundwater Storage Change Amount:** Four methods were employed and compared to estimate storage changes in the Basin: the GSA compared spring-to-spring storage changes and fall-to-fall storage changes using two different methods to interpolate/extrapolate water levels from measurement points: continuous interpolation and Thiessen polygon extrapolation. Results were consistent among each other. Errors in previous values of change in groundwater storage, reported in the annual reports, were corrected: For reporting purposes, the Thiessen polygon method is used to compute spring-to-spring groundwater storage changes in the Basin, past and present.	170-179	2.2.5	N/A	2.17
1.a.		**Sustainable Yield Re-examination:** Three analyses are provided to estimate the sustainable yield of the basin: two spreadsheet methods based on simplified conceptual models of the groundwater basin, as either closed or open basin, and a numerical model based analysis. Based on these analyses, the revised sustainable yield for the Basin is found to be 65 TAF/year. This also corresponds to the average groundwater extraction from 1990 to 2014 and is consistent with groundwater extraction numbers reported in the 1970s. **Achieving the sustainable yield of 65 TAF/year requires a 10-15% reduction in groundwater extraction** which will be achieved through the "Groundwater Demand Management" program in Chapter 4. Starting with the 2027-2032 implementation period, groundwater pumping in the Basin will be limited to the sustainable yield of the Basin. Monitoring and further analysis will be instrumental to consider future updates to the sustainable yield during the implementation period.	170-179	2.2.5	N/A	2.17
1.b.	Provide a reasonable means to mitigate the overdraft that is continuing to occur in the Basin. Specifically, the GSA should describe feasible proposed management actions that are commensurate with the level of understanding of groundwater conditions of the Basin and with sufficient details and consideration for Department staff to be able to clearly understand how the Plan's projects and management actions will mitigate overdraft in the Basin under different climate scenarios.	**Four new PMAs to address mitigation and need for reduced pumping:** The GSA added four projects and management actions to Chapter 4 to mitigate effects of declining groundwater levels in the Basin: a) City of Dorris Well Depending and Pipeline Replacement Project (already in progress), b) Well Inventory and Well Mitigation Program, c) Preliminary Groundwater Allocation Program and, d) Groundwater Demand Management. These PMAs are added to avoid groundwater level declines and ensure the Basin operates within its sustainable yield by the beginning of the 2027-2032 implementation period (Groundwater Demand Management Program and Groundwater Allocation Program) and immediately begins to address negative impacts to beneficial uses and users due to groundwater level declines (City of Dorris project, Well Mitigation Program).	234-238; 242-247	4.3	N/A	4.1
2	**The GSP does not establish sustainable management criteria for chronic lowering of groundwater levels in a manner substantially compliant with the GSP Regulations**					
2.a	Describe the specific, quantitative undesirable results they aim to avoid through implementing the Plan.	**Quantitative Description of the Undesirable Results:** The quantitative undesirable result occurs when fall water levels in more than 25% of wells exceed the MT in two or more consecutive years.	200-215	3.4.1	3.6, 3.7, 3.8, 3.9	3.4 ,3.5, 3.6
2.a	This must include a quantitative description of the negative effects to beneficial uses and users that would be experienced at undesirable result conditions. The GSA should fully disclose and describe and explain its rationale for determining the number of wells that may be dewatered and the level of impacts to groundwater dependent ecosystems that may occur without rising to significant and unreasonable levels constituting undesirable results. Lastly, the GSA should explain how well mitigation will be considered by the GSA during its management of the Basin in a project or management action as part of the GSP. Department staff also encourage the GSA to review the Department's April 2023 guidance document titled Considerations for Identifying and Addressing Drinking Water Well Impacts.	**Quantitative description of the negative effects to to beneficial uses and users:** **Well Users for domestic, public, agricultural, and wetland management water supplies**: An updated Well Failure Analysis (Appendix 3-C), was implemented and used to evlauate wells that may be dewatered under undesirable results. The quantitative undesirable result definition was modified to consider this updated evaluation. The GSA is committed to mitigate up to 20% of domestic wells (48 domestic wells) during the implementation period. Public supply wells and wetland management supply wells have been identified in the GSP. Well failures in these wells was identified as an undesirable result. Well mitigation s part of the "Well Inventory and Well Mitigation Program" in Chapter 4, which has been substantially updated. **Interconnected Surface Waters:** Butte Creek, Ikes Creek, Harris Creek, Muskrove Creek, Prather Creek, and Meiss Lake are now explicitily considered potentially interconnected surface waters (ISWs) and the extended data collection will help understanding which of those should be considered ISW. **ISWs and GDEs:** Understanding the impacts to ISWs and GDEs at 2015, current, or future conditions is subject to large data gaps. Monitoring of ISWs and GDEs has begun, and the planned work and timelines to further understand, evaluate, and protect ISWs and GDEs in the Basin have been updated.	200-215	3.4.1	3.6, 3.7, 3.8, 3.9	3.4 ,3.5, 3.6

2.b.	Revise minimum thresholds to be set at the level where the depletion of supply across the Basin may lead to undesirable results. Provide the criteria used to establish and justify minimum thresholds.	**Minimum Threshold (MT) revision:** Minimum thresholds were re-assessed based on the revised and more clearly defined qualitative and quantitative description of undesirable results. Minimum thresholds were set to avoid non-mitigatable undesirable results. The revised minimum thresholds are at least 15 ft above the originally proposed minimum thresholds.	200-215	3.4.1	3.6, 3.7, 3.8, 3.9	3.4 ,3.5, 3.6
2.b.	Consider and disclose how minimum thresholds may affect the interests of beneficial uses and users. Fully document the analysis and justifications performed to establish the criteria used to establish minimum thresholds. Clearly show each step of the analysis and provide supporting information used in the analysis.	**Analysis of Undesirable Results to set Sustainable Management Criteria:** The Well Failure Analysis was re-implemented, updated, extended and a revised, detailed documentation of methods and results was provided. Additional methods were introduced into the well failure analysis to expand on and validate the original results. Additional maps are provided including maps that document the location and type of wells at risk of well failure prior to 2015, in 2023, and if water levels consistently declined to the minimum thresholds across the Basin ("at MT"). The analysis found that as many as 14 domestic wells (6%) may have fallen dry between 2015 and 2023, which is somewhat higher but consistent with survey data and DWR well outage data. An additional 14 wells (6%) may fall dry "at MT". The estimated number of affected beneficial users of domestic wells, at the selected MTs, is therefore significantly less than the 20% of domestic wells that the GSA is committed to address throught it's well mitigation program. Post-2015, 10 agricultural wells would fall dry "at MT". None of the existing public supply wells or wetland management irrigation wells are at risk of failure if the Basin water levels all were to decline to "at MT". Impacts to ISWs and GDEs in 2015, current, or "at MT" is currently unknown, but will be addressed through monitoring that has already been initialized, additional studies scheduled for the current five-year implementation period, evaluation of mitigation measures where needed, and additional analyses. Discussion of these thresholds, and consideration for beneficial uses and users, is included in the revised discussion of the chronic lowering of groundwater levels sustainability indicator and the more clear connection of ISW sustainability indicator with the chronic groundwater level indicator in Chapter 3, and the updated Well Failure Analysis in Appendix 3-C. Section 3.4.1.5 has been updated to include more discussion on minimum thresholds and beneficial uses and users of groundwater. The number and location of wells that may be negatively affected when minimum thresholds are reached, as well as well infrastructure discussion, and maps of affected well locations by type can be found in Appendix 3-C.	200-215	3.4.1	3.6, 3.7, 3.8, 3.9	3.4 ,3.5, 3.6
2.c.	Provide an evaluation of how minimum thresholds may affect the interests of beneficial uses and users of groundwater or land uses and property interests. Identify the number and location of wells that may be negatively affected when minimum thresholds are reached. Compare well infrastructure for all well types in the Basin with minimum thresholds at nearby suitably representative monitoring sites. Document all assumptions and steps clearly so that it will be understood by readers of the GSP. Include maps of potentially affected well locations, identify the number of potentially affected wells by well type, and provide a supporting discussion of the effects. Also, provide an evaluation of how the proposed management may impact environmental users such as GDEs.		200-215	3.4.1	3.6, 3.7, 3.8, 3.9	3.4 ,3.5, 3.6

Appendix 5-A PMA Prioritization and Scoring System

Preliminary criteria, and an associated scoring system, were developed to assist in the evaluation and prioritization of the PMA options identified in Chapter 4. This prioritization system is intended to facilitate strategic implementation of PMAs based on factors including effectiveness, cost, and stakeholder support. The criteria and descriptions for each scoring category are shown in Table 1. A template, with the PMAs identified in Chapter 4 for near-term and for future implementation (Tiers II and III), is included as Table 2. Categories and scoring may be modified throughout GSP implementation to reflect the principal objectives for PMAs.

Table 1: PMA prioritization criteria and score descriptions.

		Score		
Category		**1**	**2**	**3**
Effectiveness	**Anticipated Benefit**	Some physical benefit anticipated	Medium level of benefit anticipated (relative to other PMAs identified).	High level of benefit anticipated (i.e., streamflow depletion reversal is expected to be significant).
	Frequency	One-time benefit expected	PMA expected to provide benefit on more than one occurrence.	Benefits expected to occur repeatedly.
	Duration	Only short-term benefits expected (1-2 years)	Benefits expected over 2-5 years.	Benefits expected to occur over the long term (>5 years)
Completeness		No planning or studies have been completed, required permitting and funding sources have not been identified.	Some planning or studies have been completed, required permitting and funding sources may be identified and/ or secured.	Plans or studies have been completed, permitting has been secured, project is funded.
Complexity		Requires little planning and design, labor or materials to implement	Requires some planning, design and/or some labor or materials to implement.	Requires significant planning, design and/or significant labor or material to implement
Cost		Low cost or funding has been secured.	Mid-range cost and/or potential funding sources identified.	High cost and / or funding sources have been identified.

Uncertainty		Unproven technology or mechanism, legal authority unclear or no legal authority, anticipated difficulty obtaining required permits for project implementation.	Proven technology may be unproven in Basin setting or conditions), and/ or modelled results show an expected benefit, legal authority exists, and permits are anticipated to be attainable.	Proven technology and/or modelled results show an expected benefit, clear legal authority and required permitting is attainable.
Acceptability		Low or no support from stakeholders.	Medium support or desirability from stakeholders.	Strong support from stakeholders.

Table 2: Butte Valley GSP PMA prioritization table template

Butte Valley GSP Proposed List of Projects and Management Actions																		
										Evaluation Criteria and Score								
			Relevant Sustainability Indicators Affected							**Effectiveness**								
Tier	**Project Name**	**Lead Agency**	**Groundwater Levels and Storage**	**Groundwater Quality**	**Land Subsidence**	**SW & GW Interconnection**	**Status**	**Timetable / Circumstances for Initiation**	**Physical Benefit (i.e., stream depletion reversal)**	**Anticipated Benefits**	**Frequency**	**Duration**	**Completeness**	**Complexity**	**Cost**	**Uncertainties**	**Acceptability/ Support**	**Total/ Ranking**
Tier II Projects (PMAs Planned for Near Term Implementation 2022-2027)																		
II	Well inventory and Mitigation Program	GSA	•				Active	2024 - 2025										

II	Preliminary Groundwater Allocation Program	GSA	•				Conceptual Phase	2024 - 2027										
II	Groundwater Demand Management	GSA	•				Active	2024 - 2026										
II	City of Dorris Well Deepening and Pipeline Replacement Project	GSA	•				Active	2021 - 2025										
II	Avoiding Increase of Total Net Groundwater Use Above Sustainable Yield	GSA, County of Siskiyou, local land use zoning agencies	•		•		Planning Phase	2023 - 2024										
II	Dorris Water Meter Installation Project	City of Dorris	•				Planning Phase	2021 - TBD										
II	Irrigation Efficiency Improvements	GSA	•				Planning Phase	TBD										
II	Public Outreach	GSA					Implementation	TBD										
II	Voluntary Managed Land Repurposing	GSA, TBD	•				Planning Phase	TBD										

Tier III Projects (PMAs with potential implementation in 2027-2042)																		
III	Alternative, Lower ET Crops	GSA, UCCE, TBD	•			•	Conceptual Phase	TBD										
III	Butte Creek Diversion Relocation	GSA/ USFS	•			•	Conceptual Phase	TBD										
III	Butte Valley National Grassland Groundwater Recharge Project	GSA/ USFS	•			•	Conceptual Phase	TBD										
III	Strategic Groundwater Pumping Restriction	GSA	•				Conceptual Phase	TBD										

Appendix 5-B Annual Reporting Template

This appendix presents an example template for annual reporting. Use of this appendix is intended as an example only and is not intended to be specific to the Basin. Modification will be required based on specifics outlined in the Basin’s Groundwater Sustainability Plan.

SMC Tracker: A web dashboard to support GSP annual reporting with centralized monitoring, modeling, and data access

Contents

Introduction

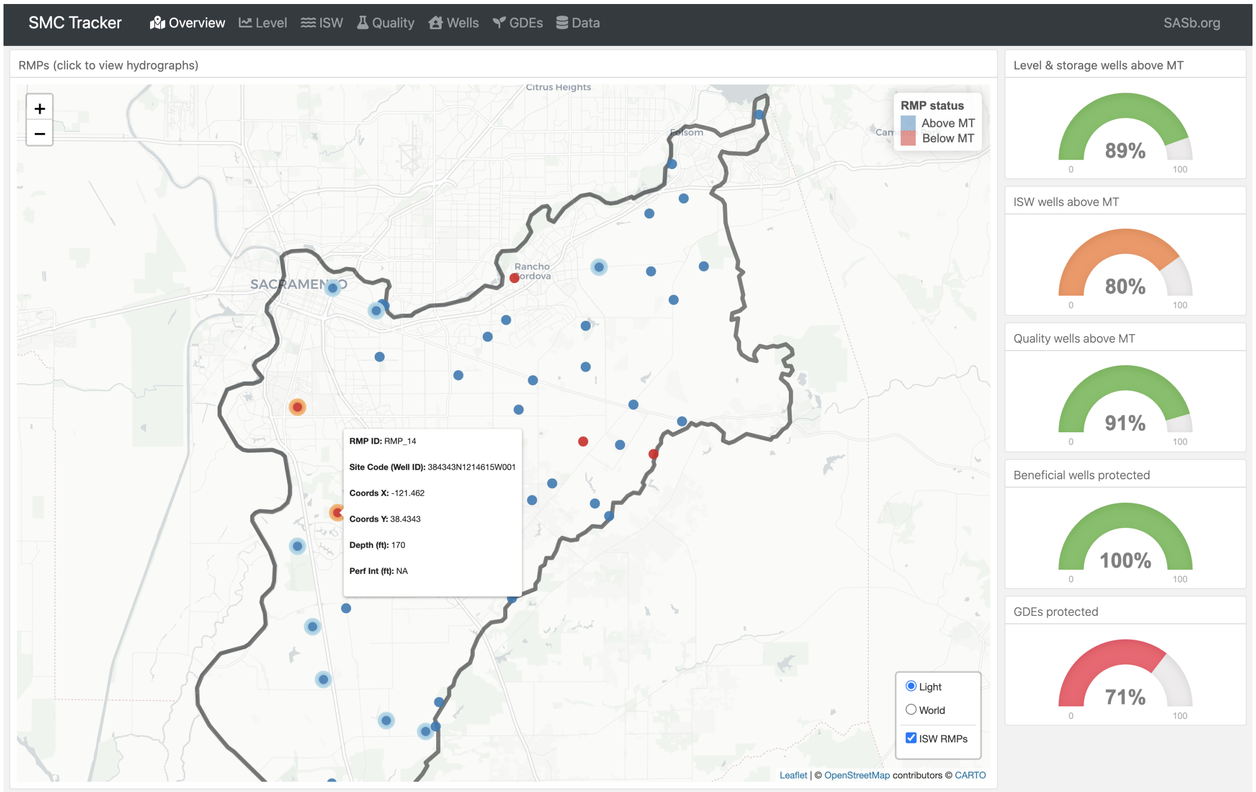
Annual reporting for SGMA requires monitoring at representative monitoring points (RMPs), analysis of potential impacts to beneficial users, evaluation of physical conditions in the basin to sustainable management criteria (SMC), and submission of data to the State. Data is collected different ways and at different sampling frequencies–often by multiple agencies and consulting firms–and the analysis, storage, reporting, and sharing of this information introduces friction into annual reporting, compliance assessment, and decision making. The need for streamlined annual reporting solutions is especially acute during severe drought where rapid access to information to guide critical decision making is paramount.

We propose a solution called **SMC Tracker**: a web-based data reporting and SMC tracking dashboard that integrates RMP monitoring data with assessments to beneficial users in automated interactive visualizations. This dashboard will summarize groundwater conditions in the basin, integrate data and models used in the annual report, and provide a central hub for tracking SMC in near-real time. Users will be able to visualize all RMPs at a glance, drill down into monitoring data collected at each RMP, and use summary panels to rapidly assess “basin vitals” that show if the basin has identified significant and unreasonable results for a given sustainability indicator and/or beneficial users of groundwater. And finally, users will be able to export data for analysis and in forms that directly comply with DWR submission criteria for a painless, drag-and-drop solution.

Overview page

The SMC Tracker main page provides an overview of basin sustainability at a glance. All RMPs for groundwater level and storage are shown. Users can:

- hover over points to view site metadata
- use the legend to quickly identify RMPs that are above or below their MT
- use the legend to toggle between groundwater level, storage, and ISW monitoring points
- toggle basemaps to view satellite imagery
- click points to expand interactive timeseries plots that allow the user to zoom, pan, and export plots. Plots show:
    - water year type
    - historical data through the present day
    - SMC (minimum thresholds, measurable objectives, and interim milestones)



RMP ID: RMP_14

Site Code (Well ID): 384343N1214615W001

Coords X: -121.462

Coords Y: 38.4343

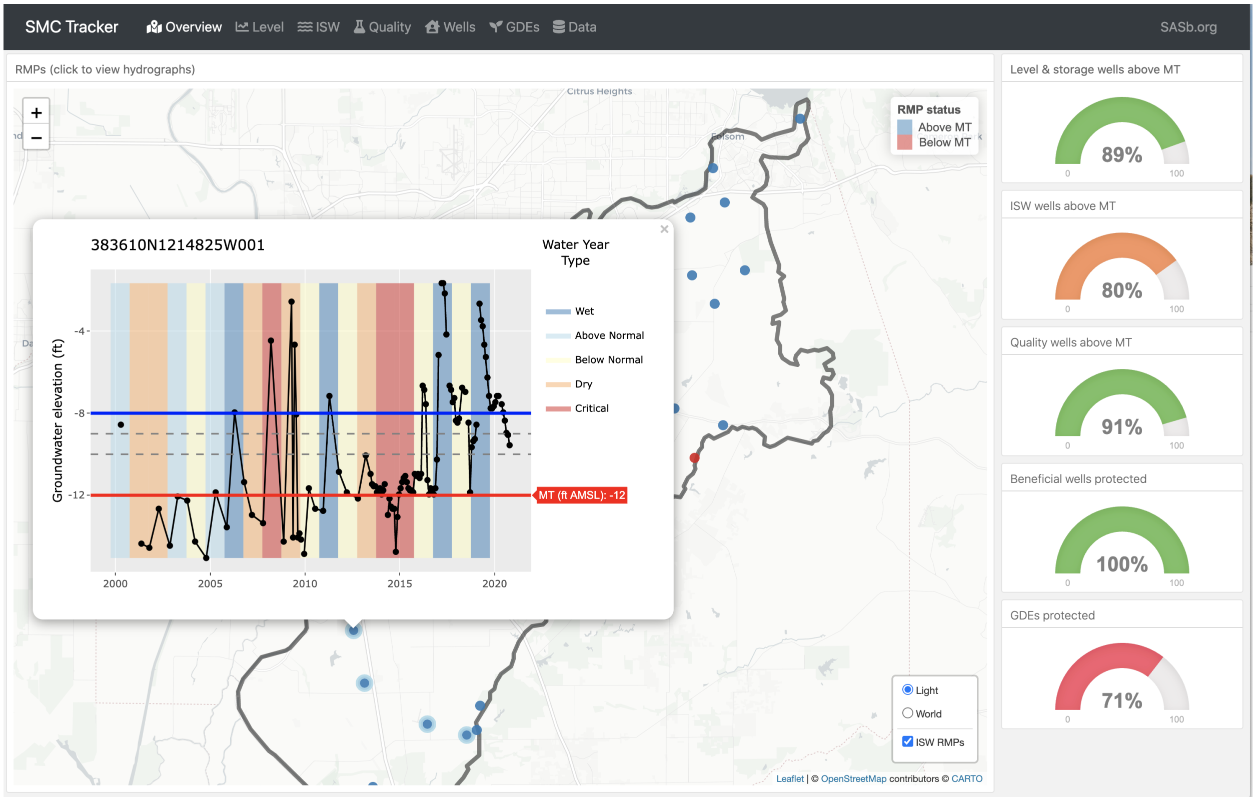
Depth (ft): 170

Perf Int (ft): NA

The lefthand sidebar shows “odometer” gauges which represent critical sustainability criteria, including:

- percentage of groundwater level and storage RMPs above the MT
- percentage of ISW RMPs above the MT
- percentage of water quality wells above the MT
- percentage of shallow wells protected at current groundwater levels
- percentage of GDEs protected

Colors of the gauges can be configured such that when the basin dips into “trigger” or “undesirable result” territory, the gauges show this.



Groundwater level page

The “Groundwater level” pageis one example of many other pages where users can drill down into aggreagted data for a particular sustainability indicator. Whereas in the “Overview” page, users interact with RMPs spatially and click on individual RMPs to view groundwater levels, on the “Groundwater level” page, all groundwater levels are shown in a single interactive visualization.

This page will be configured to automatically incorporate data as is it collected in a standard form by agencies and consultants. In the event that data is collected via telemetry, this page can be configured to auto-update at a regular time interval (e.g., daily) so that users can always view the most up-to-date data. Features include:

- a right hand legend that can be clicked to toggle individual points on and off or highlight one timeseries line
- interactive zoom and pan to inspect small details in the timeseries data
- two tabs that render the data in terms of water surface elevation (ft AMSL) and depth to groundwater (ft below land surface)
- groundwater level data on hover including the site ID, the date, and the groundwater level
- a button to export the current state of the plot to a .png file which can be included in a presentation or a report

Other pages

Just as the "Groundwater level" page allows the user to drill down into groundwater level data, users needs information on other Sustainability indicators that may include interconnected surface water (ISW), groundwater quality, land subsidence, and/or seawater intrusion. Moreover, key beneficial users may include shallow wells and GDEs, and the user may need information on impacts to these users suggested by the latest monitoring data and modeling. "Other" pages accomplish this, and are listed in the header from left to right. Here we include examples for ISW, groundwater quality, wells, and GDEs. Content on these pages will be developed to address basin-specific needs.

Data access

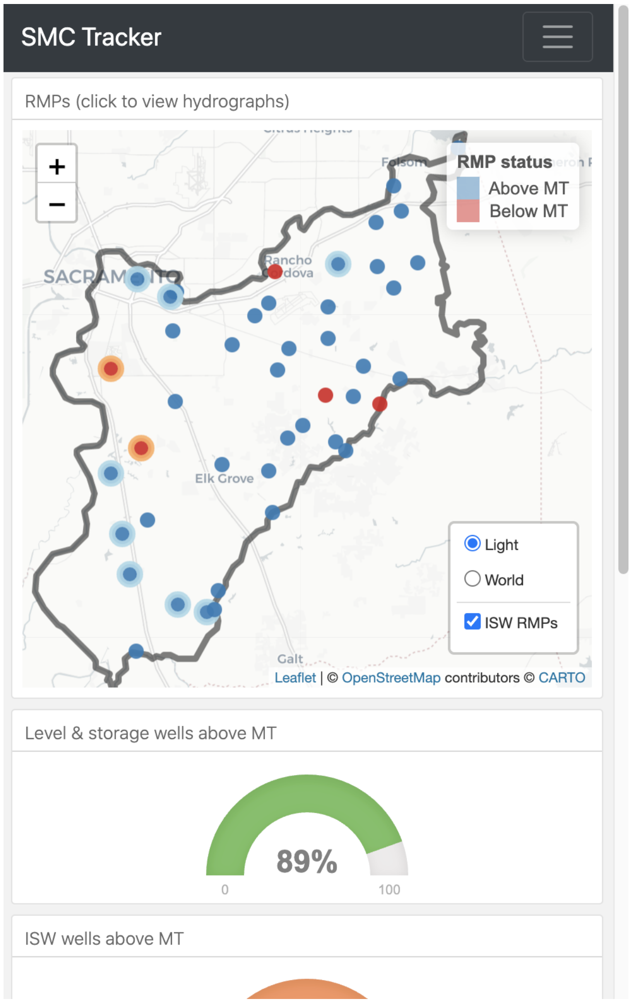
Agencies and consultants may require data from time to time, and as new data is made available, it must be centralized and distributed. SMC Tracker accomplishes this centralization and distribution on a "Data" page with links to the most up-to-date data. Also on this page are download links to data in DWR annual reporting templates for fast, painless, drag-and-drop solutions to annual reporting requirements.

Additional features

Dashboards are highly customizable and additional features may be added on an ad-hoc basis.

Mobile display

SMC Tracker is built with modern software optimized for mobile display. It looks great on smartphones and tablets.



Near-real time monitoring

Custom data extraction for any continuous monitoring sites can be integrated into SMC Tracker so that GSAs can track groundwater levels and other sustainability indicators in near-real-time (e.g., following a recharge project, or during a severe drought). Receiving automated information quickly and in a visual format can help focus priorities for working groups, and allow consultant teams access to standardized data as soon as it is available so data-driven management actions can be rapidly planned and executed.

Password protection and data privacy

Depending on GSA needs, dashboards can be made public or private. If dashboards are made private, they will sit behind password-protected walls for authorized users.

All data will be stored and protected on private servers configured by LWA.

Conclusion

Once developed, SMC defined in GSPs must be monitored for the identification of significant and unreasonable results. Monitoring at RMPs occurs throughout the year and is reported to DWR annually. Data collection, analysis, reporting, and sharing all present friction in the annual reporting and compliance process. These challenges are obviated by centralizing all monitoring data in one place to visualize near-real-time groundwater conditions in the basin and how they measure up to SMC. The SMC Tracker tool will aid agencies and consultants by providing access to monitoring data, SMC tables, and standardized excel data export sheets that can be dragged and dropped into DWR's online reporting system.

Appendix 5-C Financial Analysis for GSP Implementation

Siskiyou County Flood Control and Water Conservation District
Groundwater Sustainability Agency

Butte Valley, Scott Valley, and Shasta Valley Basins

Funding Options Technical Memorandum

July 2021

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Steve Mains, Grenada Irrigation District
Robert Moser, Municipal/City
Lisa Faris, Big Springs Irrigation District
Justin Sandahl, Shasta River Water Users Association

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INTRODUCTION AND EXECUTIVE SUMMARY

INTRODUCTION AND GOALS

The Siskiyou County Flood Control and Water Conservation District (District) was enacted in 1957 to provide for the control and conservation of flood and storm waters and the protection of watercourses, watersheds, public highways, life and property damage or destruction from such waters; to provide for the acquisition, retention, and reclaiming of drainage, storm, flood, and other waters; to save, conserve, and distribute such waters for beneficial use within the District boundaries, and to replenish and augment the supply of water in natural underground reservoirs. The boundaries of the District coincide with the County, and the Siskiyou County Board of Supervisors serve as the Board of Directors (Board) of the Flood and Water Conservation District; however, the District is a separate legal entity from the County, with independent rights and limited powers set forth in its originating act.

The Board passed a resolution on April 4th, 2017 to serve as the Groundwater Sustainability Agency (GSA or Agency) for the Butte Valley, Scott Valley, and Shasta Valley Basins (basins) as required by the Sustainable Groundwater Management (SGMA) Act of 2014.

In the Winter of 2018, the Agency engaged a consultant team led by Larry Walker Associates (LWA Team) to develop the Groundwater Sustainability Plan in compliance with the SGMA for the three basins.

A Groundwater Sustainability Plan (GSP) for each of the three basins includes goals and recommendations, as well as the associated costs required for its implementation. Accordingly, the purpose of this technical memorandum is to describe a path forward to fund the GSP's implementation. It should be noted that SGMA and its associated requirements and goals are quite new, and there is not a clear, well-tested path forward to fund GSP implementations. Rather, the funding efforts for GSP implementation in the three basins need to be carefully crafted for local conditions, preferences, and politics – as well as being flexible, creative, and reactive.

The GSA has been initially funded by existing general funds and grants. The general direction from the GSA Board of Directors in regard to funding the GSP implementation can be summarized as:

- GSA expenses should be well-controlled
- Funding strategy needs to be locally viable and right-sized
- Metering of wells is not desired

EXECUTIVE SUMMARY

Following is a brief summary of the findings and recommendations contained within this Technical Memo, including a summary of the GSP implementation costs, potential funding mechanisms, and recommendations for funding of the implementation.

REVENUE NEEDED FOR GROUNDWATER SUSTAINABILITY PLAN IMPLEMENTATION

The GSP makes numerous implementation recommendations, including annual operations and maintenance as well as capital projects. The associated costs for these tasks, including the low range and high range, are summarized in Tables 1, 2, and 3 below. The total estimated annual costs for all three basins combined ranges from $438,750 to $747,500.

TABLE 1 – SUMMARY OF TOTAL ESTIMATED ANNUAL COSTS FOR BUTTE VALLEY BASIN

Summary	**Annual Budget**	
	Low Range	**High Range**
Operations and Maintenance	$120,000	$210,000
Grant Writing	$15,000	$20,000
Capital Projects	TBD	TBD
Total	**$135,000**	**$230,000**

TABLE 2 – SUMMARY OF TOTAL ESTIMATED ANNUAL COSTS FOR SCOTT VALLEY BASIN

Summary	**Annual Budget**	
	Low Range	**High Range**
Operations and Maintenance	$120,000	$210,000
Grant Writing	$15,000	$20,000
Capital Projects	TBD	TBD
Total	**$135,000**	**$230,000**

TABLE 3 – SUMMARY OF TOTAL ESTIMATED ANNUAL COSTS FOR SHASTA VALLEY BASIN

Summary	**Annual Budget**	
	Low Range	**High Range**
Operations and Maintenance	$150,000	$262,500
Grant Writing	$18,750	$25,000
Capital Projects	TBD	TBD
Total	**$168,750**	**$287,500**

It is anticipated that capital projects will be primarily grant-funded. More detail is provided in Section II., below.

FUNDING APPROACHES AND OPTIONS FOR GSP IMPLEMENTATION

There are a variety of funding approaches, each with pros and cons, and most likely a portfolio of various approaches will prove optimal. The likely most optimal funding mechanisms are listed below:

Best Options

- Existing Revenue Sources
- Grants and Loans
- Regulatory Fees

If additional revenue is needed:

- Property Related Fees – non-Balloted (*allocated to well owners*)
- Special Taxes – Balloted (allocated to all property owners within the basins or County)

Less optimal

- Property Related Fees – Balloted
- Benefit Assessments

Each funding mechanism and approach has key attributes - each of which should be considered to select the optimal funding portfolio, including:

  - Flexibility of Methodology (per acre, per acre-feet pumped, per well, etc.)
  - Costs of Implementation
  - Revenue Potential
  - Political Viability / Community Acceptance
  - Legal Rigor
  - Administration

ALLOCATING IMPLEMENTATION COSTS TO WELL OWNERS VERSUS PROPERTY OWNERS

If funding beyond use of existing sources, grants and regulatory fees is needed, then one of the most important considerations for the GSP's is the allocation of the GSP implementation cost between the well owners and the larger group of all property owners within the three basins, or even County-wide. Conventional wisdom suggests that the costs of the implementation of groundwater mitigation policies should be directly borne by the immediate users of the groundwater – the well owners. However, there are clear benefits to all properties and residents within a well-managed groundwater basin that provides additional, lower cost water resources. It can be argued that a community-wide funding mechanism in which all properties and/or residents pay their fair share is a more optimal approach. Both types of approaches are discussed in Section II of this technical memo.

ROADMAP FORWARD AND RECOMMENDATIONS

A summary of this Technical Memo's major recommendations for implementation includes a step sequential roadmap as summarized below:

1. Conduct community outreach regarding the GSP and its implementation
2. Pursue use of existing revenue sources, grants, and regulatory fees to fund implementation

If additional revenue is needed:

3. Conduct a public opinion survey and focused community outreach
4. Implement a property related fee or special tax

The process of establishing long-term, sustainable, comprehensive funding for GSP implementation will likely take at least 18 months to complete. More detail is provided in Section III., below.

I. DETAILED REVENUE NEEDS

ANNUAL OPERATIONS AND MAINTENANCE COSTS

The GSP includes numerous recommendations for annual operations and maintenance in support of the long-term sustainability of the three basins. The costs of these recommendations have been developed and bracketed with a low range of $120,000 per year and a high range of $210,000 for Butte Valley and Scott Valley Basins, and a low range of $150,000 per year and a high range of $262,500 for Shasta Valley Basin. These figures are detailed in Tables 4, 5, and 6 below:

Table 4 – Detailed Summary of Estimated Maintenance and Operations Costs for Butte Valley Basin

Operations and Maintenance	Annual Budget	
	Low Range	High Range
General GSA Operations	$10,000	$25,000
Annual Reporting	$15,000	$25,000
Model Maintenance	$40,000	$80,000
Monitoring	$45,000	$60,000
Future Stakeholder Engagement	$10,000	$20,000
Mediation Fund	TBD	TBD
Total	**$120,000**	**$210,000**

Table 5 – Detailed Summary of Estimated Maintenance and Operations Costs for Scott Valley Basin

Operations and Maintenance	Annual Budget	
	Low Range	High Range
General GSA Operations	$10,000	$25,000
Annual Reporting	$15,000	$25,000
Model Maintenance	$40,000	$80,000
Monitoring	$45,000	$60,000
Future Stakeholder Engagement	$10,000	$20,000
Mediation Fund	TBD	TBD
Total	**$120,000**	**$210,000**

Table 6 – Detailed Summary of Estimated Maintenance and Operations Costs for Shasta Valley Basin

Operations and Maintenance

	Annual Budget	
	Low Range	**High Range**
General GSA Operations	$12,500	$31,250
Annual Reporting	$18,750	$31,250
Model Maintenance	$50,000	$100,000
Monitoring	$56,250	$75,000
Future Stakeholder Engagement	$12,500	$25,000
Mediation Fund	TBD	TBD
Total	**$150,000**	**$262,500**

Where:

General GSA Operations includes costs to operate the GSA including supporting and facilitating Board and committee meetings, disseminating information, satisfying existing grant administrative requirements, managing contracts for tasks listed below, maintaining the website, etc.

Annual Reporting: includes costs to draft and submit all required annual reports.

Model Maintenance: includes the annual installment costs to use the models every year to test scenarios of Projects and Management Actions and to recalibrate and update the model every 5 years.

Monitoring – Interconnected Surface Water: costs are different in Shasta and Scott Valley, and they do not apply to Butte Valley. In Shasta Valley, cost includes the periodic (likely semi-annual) inspection and maintenance at 3 transects sites already fully installed and equipped - approximately 6 visits per year. For both Shasta and Scott, cost of monitoring of the wells located near the river and already equipped with continuous data is already included in the Water Level Monitoring. Further data collections for SW/GW in both Shasta and Scott will be coordinated with other partners and included in the GSP as management action.

Monitoring - Water Level: includes the periodic (likely semi-annual) inspection of water level monitoring equipment at CASGEM and DWR well sites and 10-15 additional well sites with continuous monitoring – approximately 6 visits per year and, as needed, hardware replacement.

Monitoring - Water Quality: includes the periodic sampling of water quality – approximately 10-15 samples per year.

Mediation Fund: is a placeholder for funds in support of mediation. For example, a grant program could be established for local well-owners to access capital to address compliance issues.

Future Stakeholder Engagement: Costs for future stakeholder engagement have not been included in these budgets but may be incurred.

ANNUAL CAPITAL COSTS

The GSPs include numerous recommendations for capital improvements in support of the long-term sustainability of the Basins. Most likely, these capital improvements will be implemented if and only if significant grant funding is available. However, there are often associated costs with grants including grants writing and grants administration.

The costs of these recommendations have been developed and bracketed with a low range of $10,000 per year and a high range of $40,000, and are detailed in Tables 7, 8, and 9 below:

TABLE 7 – DETAILED SUMMARY OF ESTIMATED MAINTENANCE AND OPERATIONS COSTS FOR BUTTE VALLEY BASIN

Capital Projects	**Annual Budget**	
	Low Range	**High Range**
Grant Writing	$15,000	$20,000
Annual Grant Administration	TBD	TBD
Capital Projects Costs	TBD	TBD
Total	**$15,000**	**$20,000**

TABLE 8 – DETAILED SUMMARY OF ESTIMATED MAINTENANCE AND OPERATIONS COSTS FOR SCOTT VALLEY BASIN

Capital Projects	**Annual Budget**	
	Low Range	**High Range**
Grant Writing	$15,000	$20,000
Annual Grant Administration	TBD	TBD
Capital Projects Costs	TBD	TBD
Total	**$15,000**	**$20,000**

TABLE 9 – DETAILED SUMMARY OF ESTIMATED MAINTENANCE AND OPERATIONS COSTS FOR SHASTA VALLEY BASIN

Capital Projects

	Annual Budget Low Range	 High Range
Grant Writing	$18,750	$25,000
Annual Grant Administration	TBD	TBD
Capital Projects Costs	TBD	TBD
Total	**$18,750**	**$25,000**

Where:

Grant Writing: includes periodic grant writing primarily for capital projects.

Annual Grant Administration: includes costs satisfying annual grant administrative requirements including reporting and budget management.

TOTAL ANNUAL IMPLEMENTATION COSTS

The total costs of these recommendations have been developed and bracketed with a low range of $90,000 per year and a high range of $182,500, and are detailed in Tables 10, 11, and 12 below:

TABLE 10 – SUMMARY OF TOTAL ESTIMATED COSTS FOR BUTTE VALLEY BASIN

Summary

	Annual Budget Low Range	 High Range
Operations and Maintenance	$120,000	$210,000
Grant Writing	$15,000	$20,000
Capital Projects	TBD	TBD
Total	**$135,000**	**$230,000**

TABLE 11 – SUMMARY OF TOTAL ESTIMATED COSTS FOR SCOTT VALLEY BASIN

Summary

	Annual Budget Low Range	 High Range
Operations and Maintenance	$120,000	$210,000
Grant Writing	$15,000	$20,000
Capital Projects	TBD	TBD
Total	**$135,000**	**$230,000**

TABLE 12 – SUMMARY OF TOTAL ESTIMATED COSTS FOR SHASTA VALLEY BASIN

Summary

	Annual Budget	
	Low Range	**High Range**
Operations and Maintenance	$150,000	$262,500
Grant Writing	$18,750	$25,000
Capital Projects	TBD	TBD
Total	**$168,750**	**$287,500**

Shasta Valley Basin costs: Total estimated costs for the Shasta Valley Basin are generally estimated to be 25% higher than for Butte Valley and Scott Valley.

II. EVALUATION OF POTENTIAL FUNDING MECHANISMS

INTRODUCTION TO AVAILABLE POTENTIAL FUNDING MECHANISMS OPTIONS IN CALIFORNIA

Existing California law provides a relatively finite number of mechanisms for local public agencies to reliably generate revenue to provide services. In many cases, a portfolio approach of several of these mechanisms will be optimal. Also, it is crucial to work closely with legal counsel on the implementation of all funding mechanisms to ensure legal compliance. This section provides a discussion of the mechanisms best suited to provide funding for groundwater management services recommended in the Agency GSP, including, but not limited to, the following:

Best Options
- Existing Revenue Sources
- Grants and Loans
- Regulatory Fees

If Additional Revenue is Needed
- Property Related Fees – non-Balloted (*allocated to well owners*)
- Special Taxes – Balloted (allocated to all property owners within the basin)

Less Optimal
- Property Related Fees – Balloted
- Benefit Assessments

Existing Revenue Sources and Grants Are Likely the Preferred Approach

Of course, it is recommended that the Agency rigorously explore all opportunities to fund the recommended groundwater management services through existing revenue sources and grants, eliminating the need for an additional allocation for well owners or all basin property owners. However, there are likely not sufficient available existing revenue sources to support GSP implementation, especially over the long term. See the discussion "Grants and Loans" below.

Regulatory Fee Should Be Imposed

Regulatory fees are an excellent source of reimbursement of actual costs for inspections, plan checks, etc., and should be imposed.

However, If Additional Revenue is Needed

If additional revenue is need beyond the amount that can be generated by existing revenue sources, there are two primary approaches:

Revenue Generated from	Optimal Revenue Mechanism
Well Owners	Property Related Fee (non-balloted)
All Property Owners	Special Tax (balloting is required)

Additional Funding from Well Owners or Community Property Owners

One unique challenge, and opportunity, associated with implementation of a funding mechanism for groundwater sustainability management is the decision regarding how costs will be allocated between well owners and the overall community of property owners. Generally speaking, the development of the Sustainable Groundwater Management Act was based upon the assumption that the allocation of costs would be primarily, perhaps exclusively, assigned to well owners, with some consideration of *de minimis* ground water users. However, there are clear benefits to all properties and residents within a basin, or even the entire county, with well managed groundwater resources. It can be argued that a community-wide funding mechanism in which all properties and/or residents pay their fair share is a more optimal approach.

Local political forces, often concentrated with well owners, may dictate a preference for allocating the GSP implementation costs more broadly to all property owners within the basins or county, but it should be noted that California law requires that special taxes, which would be the mechanism required for an allocation on all basins or county property owners, requires a balloting. Balloted revenue mechanisms are arguably more legally rigorous, and legal challenges to voter-approved fees have rarely been successful. However, the balloting requirement significantly limits the total revenue that may be generated, as it is limited by the political "willingness to pay" of the local voters or property owners. Ballotings are also expensive and politically risky. For that reason, non-balloted approaches are typically preferable, and do not have the same apparent political limitation on the amount of revenue that can be generated, but political realities and influences are still significant.

As the Agency determines its funding strategy, it should take an in-depth look at many attributes, including flexibility of methodology (per acres, per water quantity, per well, per parcel, etc.), costs of implementation, revenue generation potential, political viability, legal rigor, administrative burden, etc., as described below.

EXISTING REVENUE SOURCES

If the Agency can fund the groundwater management services with existing revenue sources, that is certainly optimal. However, even if this is possible in the short term, it is likely not possible very far into the future.

GRANTS AND LOANS

Grant funding is highly desirable, as it eliminates/lessens the need to generate revenue directly from well owners and/or the broader community of property owners. Grant funding is typically available for capital projects but can be available for other programmatic activities, including maintenance and operations. It is worth noting that grants often come with other funding requirements such as matching funds or requirements for post-project maintenance. For these reasons, an underlying revenue stream is very important to have access to leverage these opportunities.

California has a limited number of State grants and programs which provide funding opportunities for groundwater sustainability. The primary grants in support of SGMA are described below (*from https://water.ca.gov/Work-With-Us/Grants-And-Loans/Sustainable-Groundwater*):

"The SGMA Grant Program is funded by Proposition 68 and Proposition 1. To date, the California Department of Water resources (DWR) has awarded $139.5 million in three rounds of planning grants for development of Groundwater Sustainability Plans (GSPs) and related projects. All Proposition 1 funds have been awarded, with about $103 million now remaining to be awarded using Proposition 68 funds. Additional information can be found below.

PROPOSITION 1, CHAPTER 10: GROUNDWATER SUSTAINABILITY

On November 4, 2014, California voters approved Proposition 1, which authorized $100 million be made available for competitive grants for projects that develop and implement groundwater plans and projects in accordance with groundwater planning requirements established under Division 6, commencing with §10000, Water Code §79775. DWR completed two grant solicitations for planning grants.

PROPOSITION 68, CHAPTER 11.6: REGIONAL SUSTAINABILITY FOR DROUGHT AND GROUNDWATER, AND WATER RECYCLING

On June 5, 2018, California voters approved Proposition 68, which amended the Water Code to add, among other articles, §80146, authorizing the Legislature to appropriate funds for competitive grants for proposals that:

- Develop and implement groundwater plans and projects in accordance with groundwater planning requirements.
- Address drought and groundwater investments to achieve regional sustainability for investments in groundwater recharge with surface water, stormwater, recycled water, and other conjunctive use projects, and projects to prevent or cleanup contamination of groundwater that serves as a source of drinking water."

The Agency should plan to submit an application for the next round of Proposition 68 funding.

FUTURE STATE GRANT OPPORTUNITIES

Since all of Proposition 1 funding has been awarded and the remaining portion of Proposition 68 funding (just over $100 million) will be awarded over the next several years, there will likely be a shortfall of grant funding for GSP implementation in the near future. Unfortunately, there are not any large statewide bond measures (with grant opportunities) on the political horizon, but the Agency should continue to track such efforts. Also, future bond measures will likely emphasize funding for multi-benefit projects and programs that cross traditional organizational structures, and the Agency should also consider coordinating with other affected local agencies to put forth larger and potentially more competitive grant applications.

Proposition 68

The final Proposition 68 Implementation Proposal contains $103 million in available funding. DWR has released Round 1 draft funding recommendations, allocating $26 million to high priority basins.[1] Of the remaining $77 million, $15 million will be reserved for Underrepresented Communities, leaving $62 million available for general awards in Round 2 Implementation.[2]

Round 2 Grant Solicitation will open in spring of 2022, with final awards disbursed in fall of that year. Awards will be allocated to medium and high priority basins that have adopted a GSP that has been deemed complete by DWR. Grant amounts must be between $2 million and $5 million, with a 25% locally matched cost share requirement. A cost share waiver is available for eligible projects proportionate to the degree that they serve Underrepresented Communities. Any local cost share cannot have contributed to other grant awarded projects. Project expenses must be incurred after January 31, 2022, the due date for medium and high priority basin GSPs. The state encourages applicants to work with the stakeholders and other non-member agencies in their basin that have potential activities and tasks that are complimentary to the overall project. Eligible projects are defined by Proposition 68 Chapter 11.6 and include sustainability measures such as groundwater recharge and contamination prevention.

OTHER TYPES OF GRANTS

The Agency should work to identify applicable Federal grants, if any, and compete, in coordination with other affected local agencies for funding. Also, the Agency should consider working with local elected officials to pursue provisions that direct approved funds to be spent on specific projects, often called earmarks.

Grants from non-profits, foundations, high-net-worth individuals, and other stakeholders should be considered, especially with an emphasis on environmental sustainability.

REQUIRED DOCUMENTS FOR GRANTS

- Grant applications meeting specific requirements.

FLEXIBILITY OF METHODOLOGY

Use of grant funding is well-specific in the specific grant.

REVENUE GENERATION POTENTIAL

Amount of grant funding is well-specific in the specific grant.

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[1] Proposition 68 SGM Grant Program's Implementation – Round 1 Draft Award List (ca.gov)

[2] https://www.grants.ca.gov/grants/sustainable-groundwater-management-sgm-grant-programs-proposition-68-implementation-round-2/

ADVANTAGES

- Does not require cost to be allocated to local well owners or property owners.
- Revenue generation can be sufficient to offset significant costs of certain key activities.
- Legally rigorous as long as grants are expended on eligible activities.

CHALLENGES

- Provides funding for a limited time period only – difficult for long term planning solution.
- Awarded through a highly competitive process.
- Often requires matching local funds, tends to be focused on capital expenses, and are often narrowly focused in terms of scope and services.

REGULATORY FEES

Public agencies throughout California often reimburse themselves for the costs of site inspections, permits, plan checks, plan reviews, and associated administrative and enforcement activities using regulatory fees. These fees are often approved and published as part of a "Master Fee Schedule," and are often collected as part of review for approval process. This approach can assist in significantly reducing the GSA's financial burden.

Proposition 26, approved by California voters in 2010, tightened the definition of regulatory fees. It defined a special tax to be *"any levy, charge, or exaction of any kind imposed by a local government"* with certain exceptions. Pursuant to law, all special taxes must be approved by a two-thirds vote of the electorate.

Regulatory fees are thus defined through the cited exceptions. The pertinent exception is, "a charge imposed for the reasonable regulatory costs to a local government for issuing licenses and permits, performing investigations, inspections, and audits, enforcing agricultural marketing orders, and the administrative enforcement and adjudication thereof." The other pertinent exception is, "assessments and property-related fees imposed in accordance with the provisions of Article XIIID."

The Proposition goes on to state that, "the local government bears the burden of proving by a preponderance of the evidence that a levy, charge, or other exaction is not a tax, that the amount is no more than necessary to cover the reasonable costs of the governmental activity, and that the manner in which those costs are allocated to a payor bear a fair or reasonable relationship to the payor's burdens on, or benefits received from, the governmental activity."

Proposition 26 provides the primary guidance for the funding of the Agency's plan review and inspection fees as regulatory fees. Moreover, Section 10730 of the California Water Code, (which corresponds well with Proposition 26 guidance) stipulates that these fees can be used "to fund the costs of a groundwater sustainability program, including, but not limited to, preparation, adoption, and amendment of a groundwater sustainability plan, and investigations, inspections, compliance assistance, enforcement, and program administration, including a prudent reserve." Hence, it seems that the intent of this section is that the development of the plan can be financed through regulatory fees (and this has been widely agreed upon) as well as some, but not all, GSP implementation activities. In any case, Water Code Section 10730 includes several unique requirements that should be carefully followed when implementing regulatory fees for GSP implementation.

REGULATORY FEE IMPLEMENTATION PROCESS

Regulatory fees are relatively easy and straightforward to implement. Neither a public noticing nor a balloting is required. Typically, a public agency will engage a specialized consultant to conduct a Fee Study. This Study will present findings to meet the procedural requirements of Proposition 26, which require analysis and support that:

1. The levy, charge, or other exaction is not a tax; and
2. The amount is not more than necessary to cover the reasonable cost of the governmental activity; and
3. The way those costs are allocated to a payor bears a fair or reasonable relationship to the payor's burden on, or benefits received from, the governmental activity.

Additionally, case law has provided further clarification of these substantive requirements, that:

1. The costs need not be "finely calibrated to the precise benefit each individual fee payor might derive."
2. The payor's burden or benefit from the program is not measured on an individual basis. Rather, it is measured collectively, considering all fee payors.
3. That the amount collected is no more than is necessary to cover the reasonable costs of the program is satisfied by estimating the approximate cost of the activity and demonstrating that this cost is equal to or greater than the fee revenue to be received. Reasonable costs associated with the creation of the regulatory program may be recovered by the regulatory fee.

REQUIRED DOCUMENTS FOR REGULATORY FEES

- A Fee Study, reviewed by legal counsel and adopted by the governing authority.

FLEXIBILITY OF METHODOLOGY

Legal requirements and industry practice limit these fees to recovery of costs associated with eligible activities (e.g., inspections, permits, etc.) The Agency is advised to work closely with legal counsel and review Proposition 26 and Water Code Section 10730 requirements.

REVENUE GENERATION POTENTIAL

Full recovery of costs associated with eligible activities (e.g., inspections, permits, etc.)

ADVANTAGES

- Quick and inexpensive to implement. No noticing nor balloting is required.

- Revenue generation is sufficient to offset significant costs of certain key activities.
- Legally rigorous as long as fees are for eligible activities.
- Efficient administration.

CHALLENGES

- Very limited revenue generation potential
- Potential for "push back" from affected well owners against fees.
- Potential legal scrutiny if fee covers non-eligible activities.
- Do not typically apply to infrastructure operations and capital costs.

IF ADDITIONAL REVENUE IS NEEDED

To be clear, this technical memorandum is recommending that (if the costs of GSP implementation necessitate it) the Agency consider either a Non-balloted Property Related Fee on Well Owner parcels or a Special Tax on all property owners in the basin, but likely not both, unless the financial need is very significant.

PROPERTY-RELATED FEE – (NON- BALLOTED) ON WELL OWNERS

Property-related fees were first described in 1996's Proposition 218, (which is manifested as Section 6 of Article XIII D of the California Constitution) and are commonly used today to fund water, sewer, solid waste and even storm drainage. They are most commonly referred to as a "water charge or a "sewer charge," etc., but are technically a property-related fee.

Proposition 218 imposes certain procedural requirements for imposing or increasing property related fees. There are two distinct steps: 1.) a mailed noticing of all affected property owners (well owners in this case) and 2.) a mailed balloting on all affected property owners requiring a 50% approval for adoption.

A REALLY IMPORTANT EXEMPTION ELIMINATES THE BALLOTING REQUIREMENT

Proposition 218 goes on to exempt fees for water, sewer and refuse collection from the second step – the balloting. Hence, a property-related fee imposed on well owners' properties would be exempt from the balloting requirement. This is very significant because it reduces costs and political risk and lessens willingness-to-pay limitations.

California Water Code Provides Additional Clarity in 10730.2
California Water Code, Division 6., Part 2.74., Chapter 8. Financial Authority [10730 - 10731] provides considerable direction and authority to local governments tasked with groundwater sustainability regarding property-related fees.

In particular, Section 10730.2 (c) in the water code states:

"Fees imposed pursuant to this section shall be adopted in accordance with subdivisions (a) and (b) of Section 6 of Article XIII D of the California Constitution."

Section 6 of Article XIII of the California Constitution describes the specific requirements of the implementation of a property related fee, and most importantly, refers to subdivision (a) as the noticing requirement, (b) as the limitations on fees and services, and subdivision (c) as the balloting requirement. Hence, by omission of (c) in Section 10730.2, balloting is not required for property related fees for groundwater sustainability.

PROPERTY RELATED FEE IMPLEMENTATION PROCESS

As described above, only the first step of the two-step process applies to property related fees in this context. That step is the noticed public hearing. Once the Agency has determined the fees they wish to impose, they must mail a written notice to each affected property owner at least 45 days prior to the public hearing. During that time, and up until the conclusion of the hearing, any affected property owner may file a written protest opposing the proposed fees. If the owners of a majority of the affected parcels file a written protest, the agency cannot impose the fee (known as a "majority protest"). If a majority protest is not formed, the agency may impose the fees.

Also, Section 10730.2 of the California Water Code includes several unique requirements that should be carefully followed when implementing property related fees for GSP implementation.

REQUIRED DOCUMENTS FOR A PROPERTY RELATED FEE

- Mailed Notices of Rate Proposal/Opportunity to Protest/Public Hearing.
- Fee Report and Presentation for Public Hearing.
- Report to Governing Board (assumes < 50% protest).
- Ordinance or Resolution Adopting Fees (assumes >50% support).

FLEXIBILITY OF METHODOLOGY

Long standing use of property related fees for water charges support relatively flexible use of this approach to fund a wide range of GSP implementation activities.

Section 10730.2 of the California Water Code lists potential uses as:
(1) Administration, operation, and maintenance, including a prudent reserve.
(2) Acquisition of lands or other property, facilities, and services.
(3) Supply, production, treatment, or distribution of water.
(4) Other activities necessary or convenient to implement the plan.

This section also specifies that "fees imposed pursuant to this section may include fixed fees and fees charged on a volumetric basis, including, but not limited to, fees that increase based on the quantity of groundwater produced annually, the year in which the production of groundwater commenced from a groundwater extraction facility, and impacts to the basin."

Other ideas to consider include:

- Parcel-based Administration Fee,
- Remediation Fee for over-pumping.

- Augmentation Fee on over users to pay to import water.

REVENUE GENERATION POTENTIAL

Two potential revenue methodologies are modelled below based upon the use of a property related fee. Tables 13, 14, and 15 model rates and revenue generated using a hypothetical "flat" annual rate for each type of well. Most notably, this approach relies on "estimated usage" based upon attributes such as land use, affected acreage, etc., and does not rely on use of metered extraction amount. (Number and types of wells is approximate):

TABLE 13 – MODEL OF ESTIMATED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON WELLS IN BUTTE VALLEY BASIN

Basin Wells

	Approx. Number	Low Range		High Range	
		Rate	Revenue	Rate	Revenue
Agricultural	34	$3,000.00	$102,000	$5,300.00	$180,200
Industrial	0	$3,000.00	$0	$5,300.00	$0
Municipal	7	$3,000.00	$21,000	$5,300.00	$37,100
Domestic	73	$125.00	$9,125	$150.00	$10,950
Other (Monitoring, injection, etc.)	24	$125.00	$3,000	$150.00	$3,600
Total	**138**		**$135,125**		**$231,850**
	Revenue Goals:		$135,000		$230,000

TABLE 14 –MODEL OF ESTIMATED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON WELLS IN SCOTT VALLEY BASIN

Basin Wells

	Approx. Number	Low Range		High Range	
		Rate	Revenue	Rate	Revenue
Agricultural	88	$1,100.00	$96,800	$2,000.00	$176,000
Industrial	0	$1,100.00	$0	$2,000.00	$0
Municipal	7	$1,100.00	$7,700	$2,000.00	$14,000
Domestic	336	$75.00	$25,200	$100.00	$33,600
Other (Monitoring, injection,etc.)	86	$75.00	$6,450	$100.00	$8,600
Total	**517**		**$136,150**		**$232,200**
	Revenue Goals:		$135,000		$230,000

TABLE 15 –MODEL OF ESTIMATED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON WELLS IN SHASTA VALLEY BASIN

Basin Wells

	Approx. Number	Low Range		High Range	
		Rate	**Revenue**	**Rate**	**Revenue**
Agricultural	139	$850.00	$118,150	$1,500.00	$208,500
Industrial	8	$850.00	$6,800	$1,500.00	$12,000
Municipal	10	$850.00	$8,500	$1,500.00	$15,000
Domestic	885	$30.00	$26,550	$50.00	$44,250
Other (Monitoring, injection, etc.)	206	$30.00	$6,180	$50.00	$10,300
Total	**1,248**		**$166,180**		**$290,050**
	Revenue Goals:		$168,750		$287,500

Also, a property related fee could be established based upon water drawn out of the basin (which would require of metered measuring of extraction amount), as modelled in Tables 16, 17 and 18, below:

TABLE 16 – MODEL OF METERED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON ACRE-FEET IN BUTTE VALLEY BASIN

Basin Wells

	Approx. Acre Feet	Low Range		High Range	
		Rate	**Revenue**	**Rate**	**Revenue**
All Wells	85,000	$1.60	$136,000	$2.75	$233,750
Total	**85,000**		**$136,000**		**$233,750**
	Revenue Goals:		$135,000		$230,000

TABLE 17 – MODEL OF METERED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON ACRE-FEET IN SCOTT VALLEY BASIN

Basin Wells

	Approx. Acre Feet	Low Range		High Range	
		Rate	Revenue	Rate	Revenue
All Wells	40,000	$3.25	$130,000	$5.75	$230,000
Total	**40,000**		**$130,000**		**$230,000**
	Revenue Goals:		$135,000		$230,000

TABLE 18 – MODEL OF METERED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON ACRE-FEET IN SHASTA VALLEY BASIN

Basin Wells

	Approx. Acre Feet	Low Range		High Range	
		Rate	Revenue	Rate	Revenue
All Wells	44,000	$3.75	$165,000	$6.50	$286,000
Total	**44,000**		**$165,000**		**$286,000**
	Revenue Goals:		$150,000		$262,500

It should be noted that while a “metered usage” rate fee will fluctuate each year with the amount of water drawn, and a fixed “estimated usage” rate fee would be relatively uniform each year. Costs are likely to be relatively uniform and do not fluctuate with amount of water drawn out of the basins.

ADVANTAGES

- Revenue generation is likely sufficient to fund all GSP implementation costs.
- Legally rigorous. Property related fees are the described in the Water Code for funding groundwater sustainability.
- Process is exempt from a balloting, and the likelihood of a 50% protest (out of +-1,900) well owners is unprecedented.
- Cost of implementation is relatively low and includes a fee study, a mailing and additional outreach.
- Efficient administration.

CHALLENGES

- Politically challenging. Many well owners within the basins have made it clear that they prefer the costs be allocated to all properties within the basin and/or county and not just the well owners. Well owners exert significant political influence within the basins. Although a balloting is not required, well owners may be able to stop the process legislatively or possibly could attain a 50% protest, which would force a balloting.

- Unfamiliar Process. One potential criticism of the property-related fee is that property owners are generally unfamiliar with the process, and opponents can exploit this. However, with the recent dramatic increase in voting by mail in California, this is less of a major issue. Nonetheless, political opponents can exploit this unfamiliarity and focus the public's attention on the Proposition 218 process, and away from the proposed groundwater sustainability goals and messaging.

SPECIAL TAX ON ALL PROPERTY OWNERS IN THE BASINS OR COUNTY-WIDE

Special taxes are decided by registered voters and almost always require a two-thirds majority for approval. Traditionally, special taxes have been decided at polling places, or more recently by mail, corresponding with general and special elections. Special taxes are well known to Californians but are not as common as property related fees for funding of water-related services and infrastructure activities.

As a reminder, this technical memorandum is recommending that (only if the costs of GSP implementation requires it) the Agency consider either a Non-balloted Property Related Fee on Well Owner parcels or a Special Tax (described below) on all property owners in the basin, but likely not both, unless the financial need is very significant.

PARCEL BASED TAXES

Many special taxes are conducted on a parcel basis with a uniform "flat" rate across all parcels, or varied rates based upon property attributes such as use and/or size. Parcel taxes based upon the assessed value of a property are not allowed. Parcel based taxes (as opposed to sales taxes, etc.) are the most viable type of special tax for funding water-related activities. As such, most discussion of special taxes in this report will focus on parcel taxes.

LIMITATIONS OF TAXING AUTHORITY – FLOOD CONTROL DISTRICT VERSUS COUNTY

State law requires that only a local government agency, with specific taxing authority, may propose and potentially impose a tax on its underlying parcels. (SGMA does not grant GSAs with specific taxing authority.) The Flood Control District, Siskiyou County and the potentially affected incorporated cities of (Etan, Dorris, Fort Jones, Montague, Yreka and Weed within the basins as well as Dunsmuir, Mount Shasta and Tule Lake if the effort was county-wide) do have taxing authority. Neither the Flood Control District, nor Siskiyou County can tax within the incorporated cities without specific permission.

The Flood Control District is likely the optimal agency to propose the tax, either county-wide or in specific basin areas. The Siskiyou County Flood Control District has the authority, granted by its establishing Act, to establish zones within its boundaries for the purpose of levying taxes. For the GSA to levy a special tax in specific basin areas these areas would need to be established as the zones of benefit for the purposes of the GSA and the implementation of the GSP. The governing board (Siskiyou County Board of Supervisors) is granted the authority to levy taxes upon the taxable property in the benefitting zones to carry out the purposes of its establishing Act, and "to pay the costs and expenses of maintaining, operating, extending and repairing any work or improvement of such zones for the ensuing fiscal year" (Cal Uncod. Water Deer, Act 1240 § 33). The Act stipulates that the Board shall have the power to control and order the expenditures of all tax revenue, with a limitation $0.05 per one hundred dollars of the assessed valuation of property within each zone, and that all taxes levied shall be apportioned in accordance with the established zones.

Other requirements and limitations are included in the Siskiyou County Flood Control District Act that may additionally hamper the District's ability to efficiently and effectively propose a well-designed tax. Modification of the Act, albeit requiring legislative State-level consideration and approval, should be considered.

COUNTY-WIDE VERSUS BASIN SPECIFIC SPECIAL TAX

Both a county-wide and basin area special tax should be considered. A county-wide tax would result in a lower and more voter-palatable proposed tax rate as the needed revenue would be spread over a large number of parcels. However, voters who do not reside within the basin areas may be significantly less likely to vote in favor of a prosed tax as they would be less likely to perceive a direct benefit. Also, special consideration would need to be made for the Tule Lake area which has a different GSA. See Table 26 for a county-wide model of the tax rates that would be need.

Because the tax rates are relatively low for all tax models (<<$15.00 per year) (Tables 23-26), the political advantage of a county-wide tax is muted.

SPECIAL TAX IMPLEMENTATION PROCESS

Public agencies typically work with special consultants familiar with the administrative and political aspects of proposing a special tax to a community. Special tax elections held at polling places are conducted on the statutorily designated dates (typically in November for the general election and either March or June for the primary).

If the Agency ultimately decides to pursue a special tax, it is highly recommended that a special all-mail election be considered. Special all-mail ballot elections are often less expensive and allow for more optimization of the election date, as well as having the advantage of presenting a single issue to the voters.

REQUIRED DOCUMENTS FOR A PARCEL BASED SPECIAL TAX

- Ordinance or Resolution stating: tax type, tax rates, collection method, election date and services provided
- Notice to the Registrar of Voters of measure submitted to voters
- Measure Text including:
    - Ballot question (75 words or less)
    - Full ballot text (300 words or less) including rate structure
    - Arguments in favor or against and independent analysis

- Tax Report

FLEXIBILITY OF METHODOLOGY

There is considerable flexibility in tax methodology. The Agency could propose a flat tax rate in which all parcels are charged the same or a "tiered approach" where, for example larger, and/or commercial parcels may be taxed more than vacant lots. If a tiered approach is considered, the Agency should consider using existing Community Facilities District ("CFD") law and practice which better defends the use of a tiered structure.

REVENUE GENERATION POTENTIAL

A detail breakdown of the parcel attributes including number of parcels, number of residential units (for multi-family parcels) and acres for agricultural parcels in the three basins is shown in Tables 19, 20, and 21 below:

TABLE 19 – PARCEL ATTRIBUTES WITHIN BUTTE VALLEY BASIN

	Parcels	Residential Units	Acres
Single Family	410	434	1,318
Multi: 2 - 4 units	68	136	117
Mobile Home	117	117	4,821
Commercial/Industrial	79	NA	114
Office	12	NA	6
Vacant	540	NA	2,198
Parking & Storage	11	0	16
Agricultural	442	NA	51,904
Timber & Pasture	119	NA	40,372
Not Assessable	55	NA	168
Totals	**1,853**	**687**	**101,035**

TABLE 20 – PARCEL ATTRIBUTES WITHIN SCOTT VALLEY BASIN

	Parcels	Residential Units	Acres
Single Family	1,375	1,401	10,684
Multi: 2 - 4 units	140	280	599
Mobile Home	191	191	3,926
Commercial/Industrial	150	NA	376
Office	16	NA	17
Vacant	659	NA	8,271
Institutional & Gov't	9	0	54
Multi: 5+ units	13	NA	80
Cemetaries	2	NA	34
Agricultural	972	NA	66,763
Timber & Pasture	77		13,981
Not Assessable	167		617
Totals	**3,527**	**1,872**	**90,803**

TABLE 21 – PARCEL ATTRIBUTES WITHIN SHASTA VALLEY BASIN

	Parcels	Residential Units	Acres
Single Family	4,671	4,868	19,828
Multi: 2 - 4 units	441	882	1,526
Condo	21	21	19
Mobile Home	465	465	8,921
Commercial/Industrial	384	NA	1,099
Office	89	NA	32
Vacant	5,303	0	27,291
Parking & Storage	11	NA	19
Multi: 5+ units	28	NA	10
Cemeteries	344	NA	2,405
Agricultural	1,238	NA	167,985
Timber & Pasture	136	NA	31,400
Unassessable	363	NA	1,822
Totals	**13,494**	**6,236**	**262,355**

Next, we have modelled hypothetical rates to generate the revenue goals in the three basins Tables 22, 23, and 24. Table 25 models Shasta Valley is the boundaries are enlarged to include all parcels with the Shasta Valley Watershed. Table 26 models a special tax for all of Siskiyou County (including the Tule Lake GSA area).

TABLE 22 – MODEL OF TAX RATE AND REVENUES FOR SPECIAL TAX IN BUTTE VALLEY BASIN

	Parcels	Residential Units	Acres	Low Range		High Range		Units
Single Family	410	434	1,318	$4.50	$1,953	$10.50	$4,557	*per residential unit*
Multi: 2 - 4 units	68	136	117	$4.50	$612	$10.50	$1,428	*per residential unit*
Mobile Home	117	117	4,821	$4.50	$527	$10.50	$1,229	*per residential unit*
Commercial/Industrial	79	NA	114	$4.50	$356	$10.50	$830	*per parcel*
Office	12	NA	6	$4.50	$54	$10.50	$126	*per parcel*
Vacant	540	NA	2,198	$4.50	$2,430	$10.50	$5,670	*per parcel*
Parking & Storage	11	0	16	$4.50	$0	$10.50	$116	*per parcel*
Agricultural	442	NA	51,904	$1.40	$72,666	$2.35	$121,975	*per acre*
Timber & Pasture	119	NA	40,372	$1.40	$56,521	$2.35	$94,875	*per acre*
Not Assessable	55	NA	168	$0.00	$0	$0.00	$0	*per parcel*
Totals	**1,853**	**687**	**101,035**		**$135,118**		**$230,805**	
				Revenue Goals:	**$135,000**		**$230,000**	

TABLE 23 – MODEL OF TAX RATE AND REVENUES FOR SPECIAL TAX IN SCOTT VALLEY BASIN

	Parcels	Residential Units	Acres	Low Range		High Range		Units
Single Family	1,375	1,401	10,684	$6.50	$9,107	$13.00	$18,213	*per residential unit*
Multi: 2 - 4 units	140	280	599	$6.50	$1,820	$13.00	$3,640	*per residential unit*
Mobile Home	191	191	3,926	$6.50	$1,242	$13.00	$2,483	*per residential unit*
Commercial/Industrial	150	NA	376	$6.50	$975	$13.00	$1,950	*per parcel*
Office	16	NA	17	$6.50	$104	$13.00	$208	*per parcel*
Vacant	659	NA	8,271	$6.50	$4,284	$13.00	$8,567	*per parcel*
Institutional & Gov't	9	0	54	$6.50	$0	$13.00	$117	*per parcel*
Multi: 5+ units	13	NA	80	$1.75	$140	$3.00	$240	*per acre*
Cemetaries	2	NA	34	$1.75	$59	$3.00	$101	*per acre*
Agricultural	972	NA	66,763	$1.75	$116,835	$3.00	$200,289	*per acre*
Timber & Pasture	77		13,981	$1.75	$24,466	$2.75	$38,447	*per acre*
Not Assessable	167		617	$0.00	$0	$0.00	$0	*per parcel*
Totals	**3,527**	**1,872**	**90,803**		**$134,565**		**$235,808**	
				Revenue Goals:	**$135,000**		**$230,000**	

TABLE 24 – MODEL OF TAX RATE AND REVENUES FOR SPECIAL TAX IN SHASTA VALLEY BASIN

	Parcels	Residential Units	Acres	Low Range		High Range		Units
Single Family	4,671	4,868	19,828	$3.00	$14,604	$7.00	$34,076	*per residential unit*
Multi: 2 - 4 units	441	882	1,526	$3.00	$2,646	$7.00	$6,174	*per residential unit*
Condo	21	21	19	$3.00	$63	$7.00	$147	*per residential unit*
Mobile Home	465	465	8,921	$3.00	$1,395	$7.00	$3,255	*per parcel*
Commercial/Industrial	384	NA	1,099	$3.00	$1,152	$7.00	$2,688	*per parcel*
Office	89	NA	32	$3.00	$267	$7.00	$623	*per parcel*
Vacant	5,303	0	27,291	$3.00	$0	$7.00	$37,121	*per parcel*
Parking & Storage	11	NA	19	$0.75	$14	$1.00	$19	*per acre*
Multi: 5+ units	28	NA	10	$0.75	$8	$1.00	$10	*per acre*
Cemeteries	344	NA	2,405	$0.75	$1,804	$1.00	$2,405	*per acre*
Agricultural	1,238	NA	167,985	$0.75	$125,989	$1.00	$167,985	*per acre*
Timber & Pasture	136	NA	31,400	$0.75	$23,550	$1.00	$31,400	*per acre*
Unassessable	363	NA	1,822	$0.00	$0	$0.00	$0	*per parcel*
Totals	**13,494**	**6,236**	**262,355**		**$171,491**		**$285,903**	
				Revenue Goals:	**$168,750**		**$287,500**	

Alternatively, a model of tax rate and revenues might be considered for the Shasta watershed as a whole, given the amount of interconnected surface water above the Basin. This model is shown in table 25 below:

TABLE 25 – MODEL OF TAX RATE AND REVENUES FOR SPECIAL TAX IN THE ENTIRE SHASTA VALLEY WATERSHED

	Parcels	Residential Units	Acres	Low Range		High Range		Units
Single Family	6,556	5,033	25,487	$2.50	$12,583	$4.50	$22,649	*per residential unit*
Multi: 2 - 4 units	552	882	552	$2.50	$2,205	$4.50	$3,969	*per residential unit*
Mobile Home	671	483	9,880	$2.50	$1,208	$4.50	$2,174	*per residential unit*
Commercial/Industrial	563	N/A	1,856	$2.50	$1,408	$4.50	$2,534	*per parcel*
Office	105	N/A	38	$2.50	$263	$4.50	$473	*per parcel*
Vacant	6,653	N/A	49,196	$2.50	$16,633	$4.50	$29,939	*per parcel*
Parking & Storage	11	N/A	19	$2.50	$28	$4.50	$50	*per parcel*
Agricultural	1,397	N/A	196,618	$0.50	$98,309	$0.85	$167,125	*per acre*
Timber & Pasture	266	N/A	76,341	$0.50	$38,170	$0.85	$64,890	*per acre*
Not Assessable	393	N/A	1,872	$0.00	$0	$0.00	$0	*per parcel*
Totals	**17,167**	**6,398**	**361,857**		**$170,804**		**$293,800**	
				Revenue Goals:	**$168,750**		**$287,500**	

Another consideration for a special tax is implementing a county-wide model. This would help to spread costs out among all landowners in the county, lessening the financial burden for well owners. This may be perceived as unfair to those who do not reside above the basins, but it can be asserted that the GSP implementation is beneficial to all county residents. A county-wide special tax is modelled below in Table 26:

TABLE 26 – MODEL OF TAX RATE AND REVENUES FOR SPECIAL TAX IN ENTIRE SISKIYOU COUNTY

	Parcels	Residential Units	Acres	Low Range		High Range		Units
Single Family	14,863	7,725	69,376	$2.75	$21,244	$5.25	$40,556	*per residential unit*
Multi: 2 - 4 units	2,185	1,323	5,993	$2.75	$3,638	$5.25	$6,946	*per residential unit*
Mobile Home	2,914	921	32,626	$2.75	$2,533	$5.25	$4,835	*per residential unit*
Commercial/Industrial	1,415	N/A	6,067	$2.75	$3,891	$5.25	$7,429	*per parcel*
Office	186	N/A	66	$2.75	$512	$5.25	$977	*per parcel*
Vacant	16,833	N/A	169,920	$2.75	$46,291	$5.25	$88,373	*per parcel*
Parking & Storage	46	N/A	135	$2.75	$127	$5.25	$242	*per parcel*
Agricultural	4,078	N/A	548,372	$0.30	$164,512	$0.50	$274,186	*per acre*
Timber & Pasture	2,078	N/A	660,295	$0.30	$198,088	$0.50	$330,147	*per acre*
Not Assessable	988	N/A	21,473	$0.00	$0	$0.00	$0	*per parcel*
Totals	**45,586**	**9,969**	**1,514,323**		**$440,835**		**$753,691**	
			Revenue Goals:		$438,750		$747,500	

ADVANTAGES

- Revenue generation is likely sufficient to fund all GSP implementation costs if voter approved.
- Legally rigorous. Special taxes, if approved by two-thirds of the registered voters within a community, are very reliable and very rarely legally challenged successfully. Special tax revenue has not been subject to state level "take-aways" like ERAF.
- Well known. Most property owners are aware and comfortable with (but not necessarily supportive of) the special taxes and the special tax process.
- Very low tax rates (<<$15.00) per year are often reasonably well-supported by voters
- Efficient administration

CHALLENGES

- Political support at required rate and revenue may be difficult. Generally speaking, the two-thirds majority threshold for approval is very politically challenging. Special taxes are subject to significant outside influence from media and opposition groups during voting and are more vulnerable to other measures and candidates that share the ballot. (However, a recent California Supreme Court decision called the “Upland Case” allows for voter initiatives to be approved with a more easily achievable 50% threshed. The Agency should evaluate the pros and cons of the effectiveness of an voter initiative.)

GENERAL OBLIGATION BONDS SUPPORTED BY A SPECIAL TAX

In California, special taxes can be linked directly to the sale of general obligation bonds to finance the construction of infrastructure. In 2004, the City of Los Angeles successfully passed "Measure O" which provided funding for a variety of capital improvements related to water quality. Arguably, voters are more likely to support general obligation bond special taxes than parcel-based taxes at equivalent rates.

However, since special taxes for general obligations bonds can only be used for the financing of capital improvements, this mechanism could only be used to fund the CIP portion of the needs – not the operating costs of the groundwater management infrastructure.

In other words, the passage of a G.O. Bond would not satisfy the Agency's overall groundwater management funding goals, because this source could not fund ongoing operations and maintenance. However, it is possible that community priorities and a revised funding strategy could dictate that pursuit of a G.O. bond measure is optimal to fund any significant groundwater management capital projects. Results of the public opinion survey should help guide this decision.

OTHER APPROACHES – LESS OPTIMAL

BALLOTED PROPERTY-RELATED FEE OR BENEFIT ASSESSMENTS ON ALL PROPERTY OWNERS IN THE BASIN

If the Agency decides to pursue a revenue mechanism applied to well owners, a non-balloted property related fee is optimal, and if the Agency decides to pursue a revenue mechanism applied to all property owners in the basin, a special tax is most likely the best choice. However, there are two other approaches described in Proposition 218 worthy of discussion, especially if voter support is marginal: 1.) a balloted property related fee or 2.) a benefit assessment. Both of these are more expensive to implement and administer and are considerably less legally rigorous (especially with no current precedent) than a special tax. Nonetheless, both require only a 50% approval for implementation. Further research and evaluation would need to be pursued.

OTHER CONSIDERATIONS

CONDUCT A SURVEY IF CONSIDERING A PROPERTY-RELATED FEE OR SPECIAL TAX

See a full discussion in the next section.

IMPLEMENT RIGOROUS COMMUNITY OUTREACH IF CONSIDERING A PROPERTY-RELATED FEE OR SPECIAL TAX

See a full discussion in the next section.

TIMING AND SCHEDULE

The selection of the balloting date is one of the most important factors affecting the success of any measure. Potential competition with other measures, income and property tax due dates, seasons, and holidays, etc. should all be evaluated when choosing a balloting date.

A COST ESCALATOR IS RECOMMENDED FOR BALLOTED MECHANISMS

Non-balloted funding mechanisms can be updated periodically using the noticed public hearing procedure described above. This is the typical method of keeping revenues aligned with costs through the years as in the case for retail water and sewer fees. Accordingly, the rates can be kept updated for inflationary forces and other cost increases on a five-year recurrence cycle.

However, for balloted mechanisms, any increase or change in rate structures requires a re-balloting unless the original balloting included a pre-determined formula for escalation – such as the Consumer Price Index (CPI). Infrastructure-intensive utilities are driven by many different forces than those that drive the CPI, including the need for capital investment programs, regulatory programs, and the economics of sustainability, conservation, and commodity constraints. Due, in part, to these other drivers, rates for utilities have not traditionally been tied to a straightforward CPI, but rather have been expressed as a specific rate amount for a given year based on actual projected costs. Nonetheless, costs do increase over time and a cost escalator is recommended to reimburse the Agency for this increase. The simplest to explain to property owners and to administer annually is a CPI, based upon a readily available index such as the U.S. Department of Labor, which would allow for annual rate increases without annual balloting. A CPI escalator is legally defensible with property related fees, regulatory fees, and special taxes.

However, a CPI approach may make it difficult to accommodate infrastructure-driven cost increases in coming years. An alternative approach would be to include a rate adjustment schedule that would include specific increases in future years that meet the UVBGAS's needs. (This approach, commonly used by water and sewer providers, often communicates to the property owner in table form with the proposed rate corresponding to each year for the next four or five years.)

At this point in the process, it is difficult to make a concise recommendation for the escalator mechanism. It would depend on the escalating costs and how they affect the proposed rates in the foreseeable future. It would also depend in part on the proposed rate structure itself, as some structures may be based on variables that intrinsically accommodate increasing groundwater management needs. Finally, it would depend on the political considerations that come with any ballot measure. Historically, the majority of survey data supports the fact that a CPI escalator introduces minimal decay in overall support.

A SUNSET PROVISION IS NOT RECOMMENDED, BUT SHOULD BE CONSIDERED

A "Sunset Provision" is a mechanism used to increase political support by setting an expiration date for a measure, and can be used with a property related fee, regulatory fee, or tax. Sunset provisions typically range from five years to as much as 20 years in some rare cases. However, the political advantage may be slight and does not outweigh the negative aspect of the increased costs and political risk of having to re-ballot at the termination of the sunset period.

One variation is the “sundown” clause. This is the name given to a tax or fee that would reduce after a specific date – leaving a portion of the tax or fee to continue indefinitely. This tactic is useful for programs that have a one-time capital need and then would reduce to fund only operations and maintenance beyond that. If the one-time capital need is debt financed, the “sundown” period would need to be at least as long as the debt repayment period.

A “DISCOUNT MECHANISM” SHOULD BE CONSIDERED, BUT MAY NOT BE COST-EFFECTIVE

Consistent with the efforts of obtaining higher quality groundwater, a discount or “rate reduction” program should be considered which rewards well owners implementing groundwater sustainability management measures on their properties with a lower fee, based on the reduced cost of providing groundwater service. Any such program would need to be coordinated with whatever rate structure the Agency decides on to ensure that it fits with the rationale and is compliant with Proposition 218.

The advantages of such a program include improved water quality, improved engagement by the community, as well as a rate more tailored to individual usage. Also, discount programs tend to be well received by the electorate, although most people do not participate. The downside of such a program is that the benefit may not justify the cost of administering this program, because the inspection of property-specific improvements is expensive and time consuming. Nonetheless, a couple of public agencies including the cities of Portland, Oregon, South Lake Tahoe, and Palo Alto have successfully implemented discount programs on their storm drainage fees. The community’s interest level for a discount mechanism will be evaluated as part of the mail survey opinion research.

III. RECOMMENDATIONS FOR IMPLEMENTATION OF FUNDING MECHANISMS

Following is a "Game Plan" outline of the recommended steps for implementation of funding for the GSA's GSP implementation. Most of the steps have been discussed above – a discussion of community public opinion surveying and community outreach is included below.

GAME PLAN

1. Conduct community outreach regarding the Plan and its implementation.
2. Pursue use of existing revenue sources to fund implementation.
3. Pursue Grants and Loan Opportunities to fund implementation.
4. Implement Regulatory Fees to offset eligible implementation costs.

If additional revenue is needed:

5. Conduct a survey and stakeholder outreach to better evaluate:
    a. Community priorities and associated messaging.
    b. Optimal rate.
    c. Preference of non-balloted property related fee versus special tax.
6. Use results of surveys, stakeholder input and other analyses to develop a community outreach plan.
7. Implement the community outreach.
8. Implement a property related fee or special tax balloting:
    a. Include a cost escalator schedule or mechanism.
    b. Include the use of rate zones or other distinguishing factors.
    c. Do not include a rate expiration date (also known as a "Sunset Clause").
    d. Include a Discount Program to encourage better groundwater management by well owners.

CONSIDER A PUBLIC OPINION SURVEY

The primary purpose of the public opinion survey is to produce an unbiased, statistically reliable evaluation of voters' and property owners' interest in supporting a local revenue measure. Should the Agency decide to move forward with a revenue measure (property-related fee or special tax), the survey data provides guidance as to how to structure the measure so that it is consistent with the community's priorities and expressed needs. Agencies typically engage specialized survey firms to conduct surveys.

Specifically, the survey should:

- Gauge current, baseline support for a local revenue measure associated with specific dollar amounts. (How much are well owners/property owners willing to pay?)
- Identify the types of services and projects that voters and property owners are most interested in funding.
- Identify the issues voters and property owners are most responsive to (e.g., preventing subsidence, maintaining water availability, reducing pumping costs, protecting water quality, etc.).

- Expose respondents to arguments in favor of—and against—the proposed revenue measure to gauge how information affects support for the measure.
- Identify whether local residents prefer the measure as a property related fee or a special tax.

As the nation struggles with the COVID-19 pandemic, it is more important than ever to measure a community's position on all of these elements. What community leaders thought they knew about public opinion may no longer be accurate in a post-COVID world. And while a survey can provide the Agency with valuable information, it will also be an opportunity to begin getting the groundwater "brand" out into the community – a valuable early step in this process.

COMMUNITY SUPPORT AND ENGAGEMENT

Clear, concise, and appropriate community outreach is one of the most important elements for successful implementation of a funding mechanism. The basic message components need to be simple, clear, and transparent, and need to be well supported with detailed and substantive information. Credibility is the most important factor in this outreach.

Agencies often, but not always, will engage specialized consultants to assist with community outreach in support of implementation of funding mechanisms. A community outreach plan should be developed and implemented. Three major steps are described blow.

Develop Communication Infrastructure

The GSA should carefully evaluate and develop potential communication infrastructure, ultimately coordinating with existing communication infrastructure, including stakeholder contacts, print media, website, social media, print publications, neighborhood groups, and newsletters, etc. Use of e-mail contacts (with HOA, neighborhood and stakeholder groups and leaders, and web-based platforms like nextdoor.com is encouraged). Develop a schedule of community stakeholder meetings, due dates for local group newsletters, etc.

In most cases, the most effective communication mechanisms for this type of infrastructure are small, local, and neighborhood-based, with personal communication or face-to-face (as appropriate in COVID-19 environment). This approach is not expensive, but it is a significant amount of work and is very effective when well-executed.

Develop Communication Messaging

The development of the messaging and supporting information is an iterative process with staff, consultant, and community members. (If a community survey is conducted, it can be extremely helpful in developing the most effective messaging.) Throughout this process, the Agency and consultant will analyze and refine messaging associated with groundwater sustainability management benefits. In this task, the Agency should develop draft communications of various types, including Frequently Asked Questions documents, social media content, mailers and brochures, PowerPoint presentations, and e-mails, scripts, and other adaptable messages.

Communications Rollout and Implementation
Once the outreach plan is well-vetted, reviewed, and refined, the Agency should coordinate the plan’s rollout and implementation.

Appendix 5-D Siskiyou County Agricultural Economics Analysis Considering Groundwater Regulation

University of California, Merced

Siskiyou County Agricultural Economics Analysis Considering Groundwater Regulation

Supplementary Information for the Groundwater Sustainability Plan

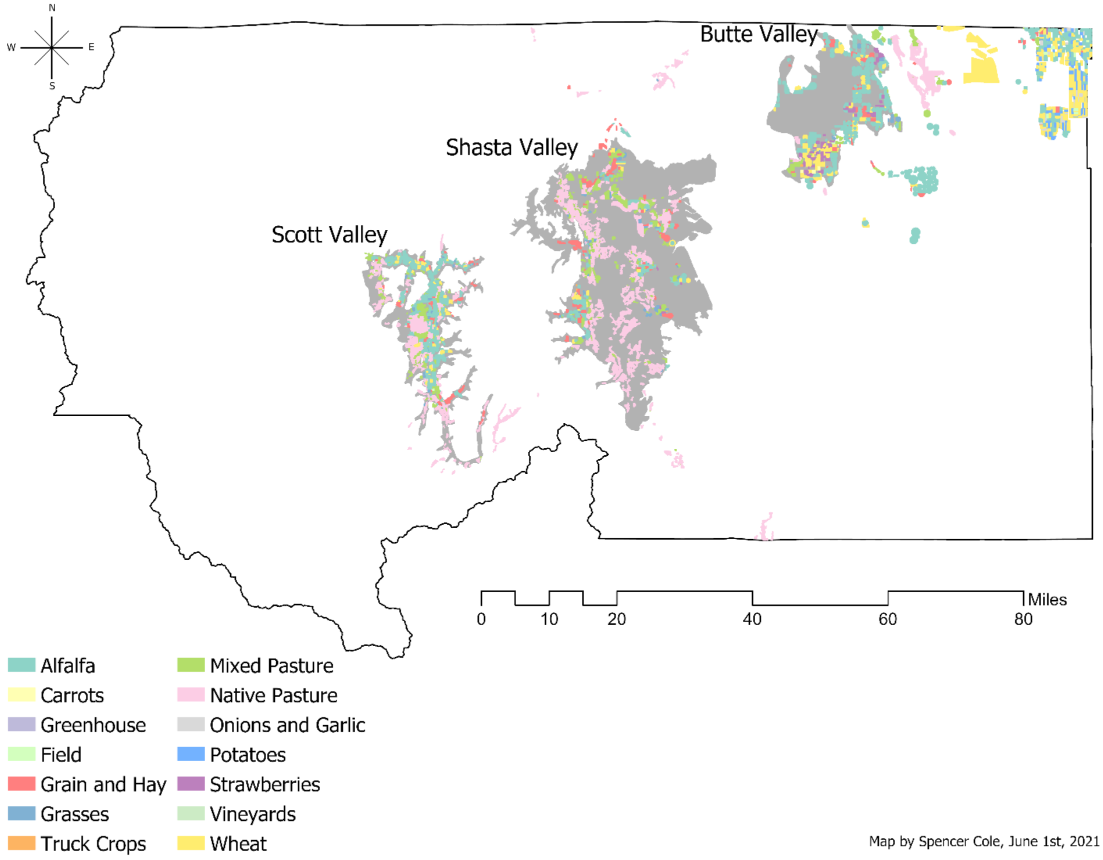
Spencer A. Cole & Josué MedellÍn-Azuara
9-2-2021

1. Introduction

1.1. Background

This economic analysis estimates potential impacts in gross revenues from changing cropping patterns in Siskiyou County's three agricultural valleys namely Butte Valley (Butte), Scott River Valley (Scott), and Shasta Valley (Shasta). This analysis provides insight on economic costs of benefits of land and water use decisions, while identifying areas that may benefit from intervention and stakeholder processes.

Below, we outline the structure and basis for an agricultural production and water use economic model whose purpose is to estimate impacts of land and water use policies on agricultural value in Siskiyou County. Model coverage includes most of the agriculture by irrigated area within the county, with the notable exception of the greater Tulelake area located in the northeast corner of the county (Figure 1) which contains some valuable commodities such potatoes. The Butte, Scott River, and Shasta Valleys were the most distinct agricultural regions within the county and showing significant differences in production factors such as access to groundwater and crop mix. The agricultural model is calibrated using 2018 as a baseline water year because it represents a relatively recent water year with most crop demands fulfilled in comparison to the drier 2014 and 2016 water years (Department of Water Resources, 2021), which are also available at the Department of Water Resources streamflow indices (Department of Water Resources, 2020).



Map by Spencer Cole, June 1st, 2021

Figure 1: Region delineations and crop coverage represented in the agricultural model. Parcels located outside grey valley boundaries are not included in the model. *Source: 2018 LandIQ land use survey (Department of Water Resources, 2021).*

1.2. Data sources

Information employed for defining the base case for production in the three valleys is summarized in Table 1. Land use calibration is based on 2018 data for land use and crop production economics where available. Recent cost information for crop commodities is prioritized when available and relevant to the production in Siskiyou County. Applied water requirements for crops are based on specific estimates at the valley scale for use in the integrated valley models. Whereas the model is calibrated using land use information from the LandIQ 2018 land use survey deployed through the California Land Use Viewer (Department of Water Resources, 2021), crop mix across the county and in individual valleys were cross-checked with parcel scale Department of Water Resources surveys for 2000 and 2010, the LandIQ 2016 survey, and the total agricultural footprint represented in the Siskiyou County Agricultural Commissioner's Report to ensure capture of key crops in the region.

Table 1: Summary of data sources for modeling of Siskiyou agricultural production.

Data type	Source	Spatial resolution	Temporal resolution
Valley boundaries	Department of Water Resources[1]	Polygon layer	N/A
Agricultural land use	LandIQ[2]	Parcel	Annual
Crop prices	Siskiyou County Agricultural Commissioner Reports[3]	County	Annual
Crop yields	Siskiyou County Agricultural Commissioner Reports[3]	County	Annual
Crop production costs	UC Davis Cost and Return Studies[4]	Regional	Varies
Applied water	Scott Valley Integrated Hydrologic Model[5], Butte Valley Integrated Hydrologic Model[1], Shasta Valley Integrated Hydrologic Model[6]	Valley	Annual

[1] Provided by Bill Rice.

[2] https://gis.water.ca.gov/app/CADWRLandUseViewer/.

[3] https://www.co.siskiyou.ca.us/agriculture/page/crop-report.

[4] https://coststudies.ucdavis.edu/en/.

[5] Provided by Claire Kouba.

[6] Provided by Cab Esposita.

1.3. Baseline conditions

Tables 2 to 4, below summarize the 2018 base conditions across each of the valleys in the model in terms of land and water use as well as crop revenues. Data is taken directly from the data sources described in section 1.2. above, apart from minor additions and adjustments when necessary to support the model function or to reflect farmer feedback during the workshop stakeholder meetings in June 2021. For example, in Butte Valley, 400 acres of onions and garlic were added to the model because the 2018 land use dataset did not identify any of these crops within the valley boundaries; farmers provided feedback noting that there was cultivation in areas within the valley. Currently, production cost information and crop water demand for nursery berries (raspberries and strawberries) is unavailable and is estimated based on the assumption that returns yield a 15% profit margin over total costs. Cost information available for carrot production is outdated and represents only fresh market cultivation, which does not represent the seed production in Siskiyou County; thus, costs for carrots are scaled to account for these differences. It is assumed that average profit margins for most crops range between zero and five percent of the crop gross revenues, thus some minor adjustments in selected crop prices were implemented in case negative profits from using the cost and return studies data were identified.

Table 2: Butte Valley base conditions. ***Source:*** **Author calculations using data listed in Table 1.**

Crop	Land (ac)	Applied water (AF/ac)	Price ($/ton)	Yield (ton/ac)	Labor cost ($/ac)	Supply cost ($/ac)	Land cost ($/ac)	Gross revenue ($ million)
Alfalfa	14,015	2.22	193	6.4	187	437	482	17.42 (10.6%)
Barley	1,460	1.51	286	2.3	122	285	204	0.97 (0.6%)
Carrots	313	2.09	56	66.7	976	2,278	248	1.16 (0.7%)
Onions and garlic	400	2.09	166	25.0	792	1,849	1,193	1.66 (1.0%)
Other hay	529	2.22	260	4.5	187	437	482	0.62 (0.4%)
Pasture	1,215	2.70	200	3.5	109	254	255	0.85 (0.5%)
Raspberries[†]	140	3.32	14	4,286	31,945	15,734	1,500	8.10 (4.9%)
Strawberries[†]	2,537	3.32	0.14	37,0000	28,495	14,035	1,500	131.39 (79.6%)
Wheat	4,502	1.51	203	3.2	122	285	204	2.90 (1.8%)
Total	**25,112**	**-**	**-**	**-**	**-**	**-**	**-**	**165.06 (100%)**

[†] Units in terms of plants rather than tons.

Table 3: Scott River Valley base conditions. ***Source:*** **Author calculations using data listed in Table 1.**

Crop	Land (ac)	Applied water (AF/ac)	Price ($/ton)	Yield (ton/ac)	Labor cost ($/ac)	Supply cost ($/ac)	Land cost ($/ac)	Gross revenue ($ million)
Alfalfa	12,267	1.97	193	6.4	187	437	482	15.25 (54.9%)
Barley	1,415	1.08	284	2.3	122	285	204	0.92 (3.3%)
Other hay	546	1.97	260	4.5	187	437	482	0.64 (2.3%)
Pasture	13,948	2.30	200	3.5	109	254	255	9.76 (35.1%)
Wheat	1,883	1.08	203	3.2	122	285	204	1.21 (4.4%)
Total	**30,060**	**-**	**-**	**-**	**-**	**-**	**-**	**27.79 (100%)**

Table 4: Shasta Valley base conditions. ***Source:*** **Author calculations using data listed in Table 1.**

Crop	Land (ac)	Applied water (AF/ac)	Price ($/ton)	Yield (ton/ac)	Labor cost ($/ac)	Supply cost ($/ac)	Land cost ($/ac)	Gross revenue ($ million)
Alfalfa	4,584	2.22	193	6.4	187	437	482	5.70 (14.7%)
Barley	3,780	1.51	286	2.3	122	285	204	2.49 (6.4%)
Other hay	1,660	2.22	260	4.5	187	437	482	1.95 (5.0%)
Pasture	30,642	2.70	200	3.5	109	254	255	21.45 (55.2%)
Strawberries[†]	125	3.32	0.14	370,000	28,495	14,035	1,500	6.49 (16.7%)
Wheat	1,273	1.51	203	3.2	122	285	204	0.83 (2.1%)
Total	**42,063**	**-**	**-**	**-**	**-**	**-**	**-**	**38.89 (100%)**

[†] Units in terms of plants rather than tons.

Table 5 summarizes overall land use, gross revenue, and water use summed across the three valleys. Following the modifications outlined above. The baseline dataset suggests the gross economic value within the three valleys totals $231.8 million, with $164.8 million, $27.6 million, and $38.4 million allocated to Butte, Scott River, and Shasta Valleys, respectively. Total agricultural land use in the study area is estimated to be about 97,000 acres, with 25,000 acres, 30,000 acres, and 42,000 acres in Butte, Scott River, and Shasta Valleys, respectively. Water use from irrigation is estimated at 220,000 acre-feet per year, of which 55,000 acre-feet, 61,000 acre-feet, and 104,000 acre-feet are used in Butte, Scott River, and Shasta Valleys, respectively on an annual basis. Agricultural value in Butte Valley is dominated by the small but extremely valuable berry plant transplant industry, which contributes $139.5 million of the region's $164.8 million gross revenue on only 11% of land (Siskiyou County Agricultural Commissioner, 2018). Both agricultural land and value in Scott River Valley consist of roughly 85% alfalfa and pasture in combination, with nearly equal area of each crop and small acres of other miscellaneous crops. About 75% of agricultural land and 50% of value in Shasta Valley is composed of pasture, with only about 125 acres of nursery strawberries making up a significant portion of remaining value.

Table 5: Baseline conditions across all three valleys. *Source:* Author calculations using data listed in Table 1.

Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Alfalfa	30,866 (31.7%)	65,511 (29.7%)	38.4 (16.6%)
Barley	6,655 (6.8%)	9,424 (4.3%)	4.4 (1.9%)
Carrots	313 (0.3%)	653 (0.3%)	1.2 (0.5%)
Onions and garlic	400 (0.4%)	834 (0.4%)	1.7 (0.7%)
Other hay	2,734 (2.8%)	5,942 (2.7%)	3.2 (1.4%)
Pasture	45,805 (47.1%)	118,017 (53.5%)	32.0 (13.8%)
Raspberries	139 (0.1%)	465 (0.2%)	8.1 (3.5%)
Strawberries	2,661 (2.7%)	8,837 (4.0%)	137.9 (59.5%)
Wheat	7,657 (7.9%)	10,735 (4.9%)	4.9 (2.1%)
Total	**97,236 (100%)**	**217,121 (100%)**	**231.8 (100%)**

2. Model calibration and assumptions

Calibration of the model is based on the concept of Positive Mathematical Programming (PMP; Howitt, 1995), a self-calibrating technique to economically represent agricultural production and water use based on profit maximization theory and capturing non-linearities in production. PMP modeling avoids overspecialization in land allocation decisions which is common in linear programming. Thus, highly profitable crops which are produced in limited amounts do not expand at the expense of low-value crops in a way that is inconsistent with observations. The PMP calibration method consists of three steps as described in Howitt et al. (2012): (1) constrained linear optimization to derive shadow values of crop land; (2) parametrization of a constant elasticity of substitution (CES) production function and non-linear cost function; and (3) specification of the model objective function and check for calibration quality. Once the model is fully calibrated, constraint and objective function modifications can be used to examine scenarios of interest. Each of the three regions in the model (Butte, Scott River, Shasta) are calibrated and run independently from one another with an annual decision period. The calibrated model employs the equations listed below which include a CES production function and a non-linear exponential cost function (Howitt et al. 2012).

Box 1: Specification of calibrated model.

$$max\ \{x_{i,land}\} \prod = \sum_i \left(p_i \tau_i \left(\sum_j \beta_{i,j}\, x_{i,j}^{\rho_i} \right)^{\frac{1}{\rho_i}} - \delta_i e^{\gamma_i x_{i,land}} - \sum_{labor,supplies,water} \alpha_{i,j} \omega_{i,j} x_{i,land} \right)$$

$s.t.$

$$\sum_i x_{i,land} \leq \sum_i \tilde{x}_{i,land}$$

$$\sum_i x_{i,land} \tilde{x}_{i,water} \leq \sum_i \tilde{x}_{i,land} \tilde{x}_{i,water}$$

$$\frac{x_{i,water}}{x_{i,land}} \leq 0.99\tilde{x}_{i,water}$$

$$\forall\ i\ \in \begin{bmatrix} alfalfa, barley, carrots, onions\ and\ garlic, other\ hay, pasture, raspebrries, \\ strawberries, wheat \end{bmatrix}$$

$$\forall\ j\ \in [land, labor, supplies, water]$$

The first equation is the profit maximization objective function, which is followed by the land and water availability constraint sets, and an irrigation stress constraint to avoid deficit irrigation of crops. Parameters in the three constraint sets above can be modified, including the limit of land and/or water available for crops and use of deficit irrigation as a potential adaptation to drought or water rationing policies.

2.4. Model assumptions

Interpretation of model function and output is contingent on several assumptions employed in the model framework. Agriculture is represented in the model as a “snapshot” of cropping patterns and economics observed across one or more years and pertains only to annual decision-making processes. In many cases, agriculture follows rotation cycles which are not captured explicitly in the model; land use data employed in model calibration is assumed to represent an pseudo-equilibrium state for rotating crops which is representative of a typical annual crop mix, with some portion of cropland in each cycle of their rotation. Farm-scale decisions for plantings oftentimes depend on multi-year investments and production conditions which are not captured in the annual structure of the model. As such, the model’s purpose is not to suggest planting decisions for individual parcels, but rather to present possible impacts on agriculture at the aggregate scale. To predict annual cropping patterns at the regional scale, the model assumes that some degree of water trading occurs within each region to retain more profitable crops when resource shortages are in place.

3. Scenarios Overview

The calibrated model was applied in seven scenarios which are designed to establish preliminary measure for the effects of land management policies on agricultural value across the three valleys. Table 6 below, summarizes the context and implementation of the scenarios in the model.

Table 6: Summary of model scenarios.

Scenario number / name	**Description**
Scenario 1a: 15% fallowing of pasture and alfalfa	All alfalfa and pasture are fallowed by 15%, with no ability to re-operationalize land and water use reductions with other crops.
Scenario 1b: 30% fallowing of pasture and alfalfa	All alfalfa and pasture are fallowed by 30%, with no ability to re-operationalize land and water use reductions with other crops.
Scenario 1c: 60% fallowing of pasture and alfalfa	All alfalfa and pasture are fallowed by 60%, with no ability to re-operationalize land and water use reductions with other crops.
Scenario 2: forego third alfalfa cutting	Simulate ceasing half of irrigation for alfalfa by July 1st, represented in the model as 33% deficit irrigation for alfalfa and a corresponding reduction

	in yield of 33%. Water use reductions from deficit irrigating alfalfa are retained.
Scenario 3: 15% fallowing (adaptive)	Total agricultural land undergoes 15% fallowing, and model given flexibility to optimize distribution of cutbacks across individual crops.
Scenario 4: 15% fallowing ("worst case")	Total agricultural land undergoes 15% fallowing, distributed evenly across all crops (area of all crop reduced by 15%).
Scenario 5: 15% water shortage (adaptive)	Total agricultural water use cutback by 15%, and model given flexibility to optimize distribution of cutbacks across individual crops.
Scenario 6: exploring economic tradeoffs between alfalfa and strawberries in Butte Valley	Comparison of marginal value and unit water use for alfalfa and berry plant transplant strawberries conducted to assess viability of converting between the two crops.
Scenario 7: exploring lower water use alternatives to alfalfa and pasture	Crop portfolio is assessed to locate water saving opportunities through crop conversion, with high retention or expansion of crop value.

4. Scenario Model Outcomes

4.1. Direct agricultural impacts (model results)

4.1.1. Scenario 1a: 15% fallowing of pasture and alfalfa

In this scenario, we simulate prescribed fallowing of pasture and alfalfa by 15% of baseline conditions within each region. Land and water previously devoted to these crops are treated as savings and thus are not allowed to be utilized in the model for the expansion of other crops. Under this land management policy, a total of 11,502 acres are fallowed (11.8%), of which 4,630 acres are alfalfa and 6,871 acres are pasture. Greatest cutbacks in land use occur in Shasta due to the exceptionally high baseline acreage of pasture, resulting in fallowing of 4,596 acres of pasture, nearly half of the total fallowed land. Slack water in lieu of irrigating the fallowed land total 27,530 acre-feet per year across the three valleys (12.5%). Gross revenue losses across all valleys together total $10.56 million (4.6%), concentrated in Scott ($3.75 million; 13.5%) and Shasta ($4.07 million; 10.5%). Economic losses in Butte – 1.7% as a percentage of baseline revenues – are weathered because of the high contribution of other crops such as nursery strawberries to overall agricultural value in the valley. Figure 2 and Table 7 below provide more detailed model outcomes of the cropping patterns, water use reductions, and value associated with this scenario.

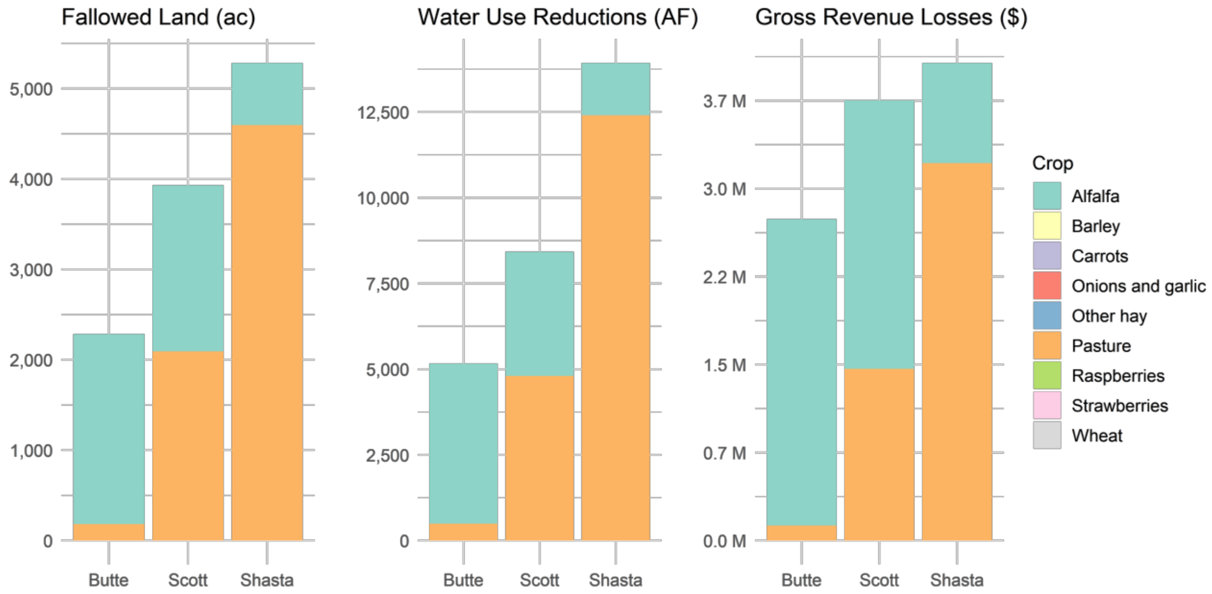


Figure 2: Results of land allocations, water use, and gross revenue differences from base for scenario 1a, 15% fallowing of pasture and alfalfa.

Table 7: Tabulated results of land allocations, water use, and gross revenues for scenario 1a, 15% fallowing of pasture and alfalfa.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	11,913	26,495	14.81
	Barley	1,460	2,199	0.96
	Carrots	313	654	1.16
	Onions and garlic	400	834	1.66
	Other hay	529	1,177	0.62
	Pasture	1,033	2,789	0.72
	Raspberries	140	465	8.10
	Strawberries	2,537	8,421	131.39
	Wheat	4,502	6,780	2.90
	Subtotal	**22,828 (-9.1%)**	**49,813 (-9.4%)**	**162.32 (-1.7%)**
Scott	Alfalfa	10,427	20,525	12.96
	Barley	1,415	1,532	0.92
	Other hay	546	1,076	0.64
	Pasture	11,856	27,229	8.30
	Wheat	1,883	2,039	1.21
	Subtotal	**26,128 (-13.1%)**	**52,400 (-13.9%)**	**24.04 (-13.5%)**
Shasta	Alfalfa	3,896	8,665	4.84
	Barley	3,780	5,693	2.49
	Other hay	1,660	3,691	1.95
	Pasture	26,046	70,298	18.23
	Strawberries	125	416	6.49
	Wheat	1,273	1,917	0.82
	Subtotal	**36,780 (-12.6%)**	**90,679 (-13.3%)**	**34.82 (-10.5%)**
Three valleys	**Total**	**85,735 (-11.8%)**	**192,892 (-12.5%)**	**221.18 (-4.6%)**

4.1.2. Scenario 1b: 30% fallowing of pasture and alfalfa

Scenario 1b is an upscaled version of scenario 1a, wherein the model prescribes a more severe fallowing of 30% of all pasture and alfalfa. As expected, the results follow the same trends as in scenario 1a but with more significant reductions in all categories. A total of 23,002 acres are fallowed (23.7%), of which 4,569 acres are in Butte, 7,865 acres are in Scott, and the remaining 10,568 acres are in Shasta. Cutbacks in land use represent about one-quarter of all land in Scott and Shasta as individual regions, and about one-fifth of total land in Butte. Water use reductions total 55,060 acre-feet across the three valleys (25.0%). Compared with scenario 1a gross revenue losses are doubled, valuing $21.13 million in total (9.1%) and distributed similarly to each valley (3.3%, 27.7%, and 20.9% loss for Butte, Scott, and Shasta, respectively). Figure 3 and Table 8 below provide more detailed predictions of the cropping patterns, water use reductions, and value associated with this scenario.

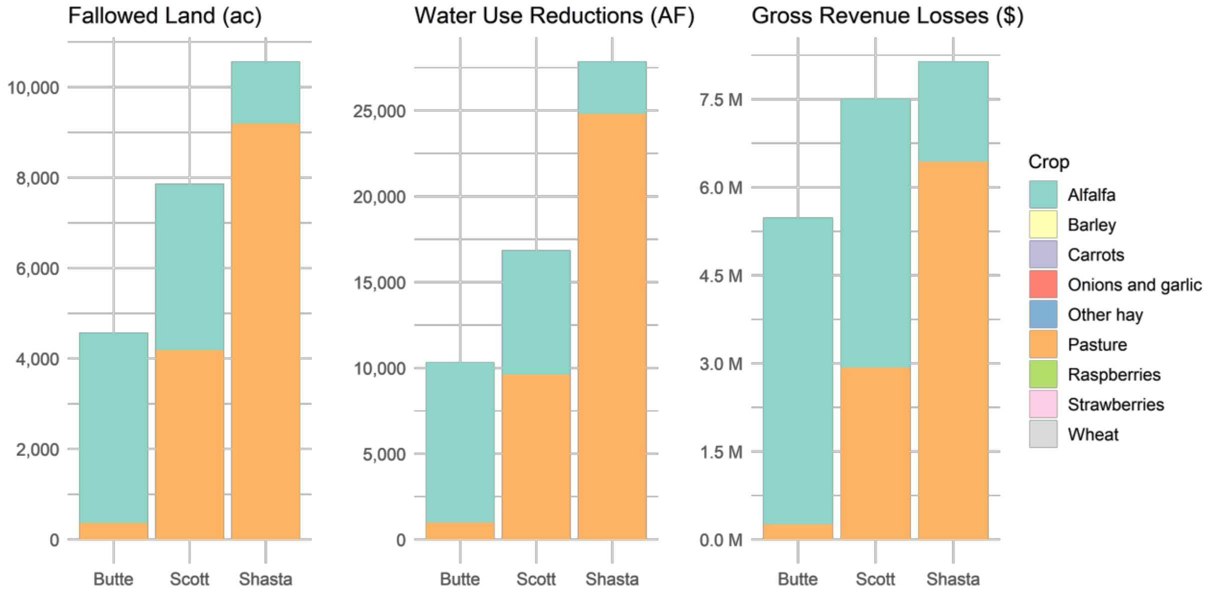


Figure 3: Results of land allocations, water use, and gross revenue differences from base for scenario 1b, 30% fallowing of pasture and alfalfa.

Table 8: Tabulated results of land allocations, water use, and gross revenues for scenario 1b, 30% fallowing of pasture and alfalfa.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	9,811	21,819	12.20
	Barley	1,460	2,199	0.96
	Carrots	313	654	1.16
	Onions and garlic	400	834	1.66
	Other hay	529	1,177	0.62
	Pasture	851	2,296	0.59
	Raspberries	140	465	8.10
	Strawberries	2,537	8,421	131.39
	Wheat	4,502	6,780	2.90
	Subtotal	**20,543 (-18.2%)**	**43,973 (-18.8%)**	**159.58 (-3.3%)**
Scott	Alfalfa	8,587	16,903	10.68
	Barley	1,415	1,532	0.92

	Other hay	546	1,076	0.64
	Pasture	9,764	22,424	6.83
	Wheat	1,883	2,039	1.21
	Subtotal	**22,196 (-26.2%)**	**43,973 (-27.7%)**	**20.29 (-27.7%)**
Shasta	Alfalfa	3,209	7,136	3.99
	Barley	3,780	5,693	2.49
	Other hay	1,660	3,691	1.95
	Pasture	21,449	57,892	15.01
	Strawberries	125	416	6.49
	Wheat	1,273	1,917	0.82
	Subtotal	**31,496 (-25.1%)**	**76,745 (-26.6%)**	**30.75 (-20.9%)**
Three valleys	**Total**	**74,234 (-23.7%)**	**165,363 (-25.0%)**	**210.63 (-9.1%)**

4.1.3. Scenario 1c: 60% fallowing of pasture and alfalfa

Scenario 1c further extends the fallowing cutbacks from the previous two scenarios and simulates a 60% fallowing of pasture and alfalfa. Total fallowing totals 46,003 acres (47.3%) with 9,139 acres, 15,729, and 21,136 acres occurring in Butte, Scott, and Shasta, respectively. Reductions in land represent over half of the agricultural acreage in Scott and Shasta but roughly one-third of Butte land use. Water use reductions in the three valleys total 110,117 acre-feet or about 50% of total estimated baseline irrigation demands. Gross revenue losses total $42.26 million (18.2%); Butte experiences the least value loss at $10.97 million (6.6%), followed by Scott at $15.01 million (54.0%), and lastly Shasta with $16.29 million (41.9%). Figure 4 and Table 9 below provide more detailed predictions of the cropping patterns changes, water use reductions, and value associated with this scenario.

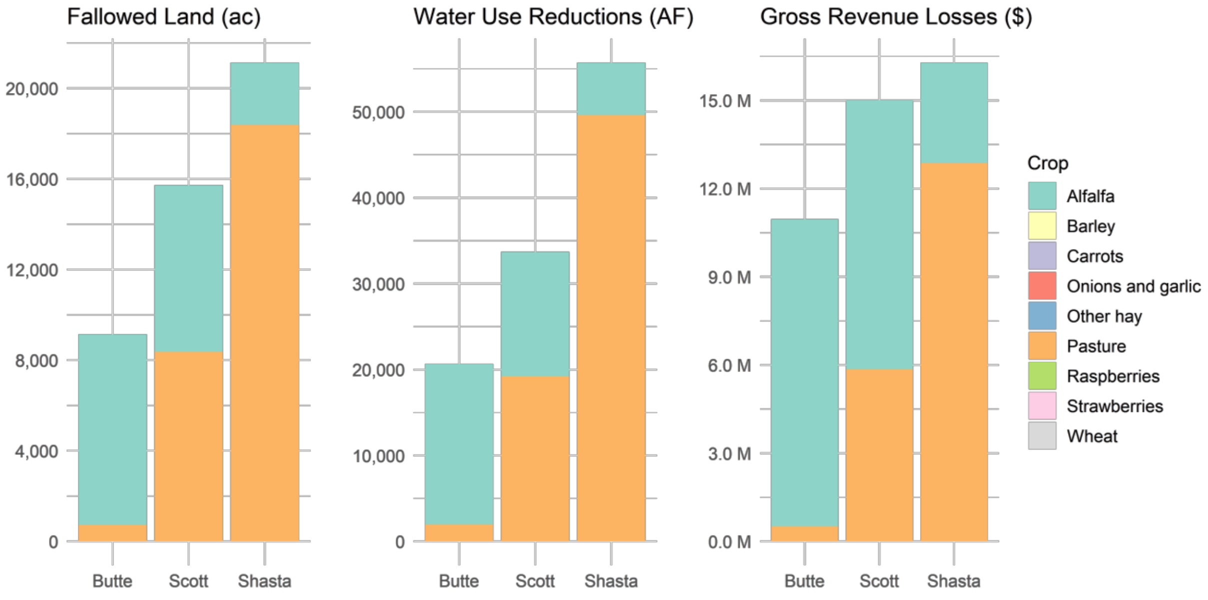


Figure 4: Results of land allocations, water use, and gross revenue differences from base for scenario 1c, 60% fallowing of pasture and alfalfa.

Table 9: Tabulated results of land allocations, water use, and gross revenues for scenario 1c, 60% fallowing of pasture and alfalfa.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	5,006	12,468	6.97
	Barley	1,460	2,199	0.96
	Carrots	313	654	1.16
	Onions and garlic	400	834	1.66
	Other hay	529	1,177	0.62
	Pasture	486	1,177	0.34
	Raspberries	140	465	8.10
	Strawberries	2,537	8,421	131.39
	Wheat	4,502	6,780	2.90
	Subtotal	**15,974 (-36.4%)**	**34,310 (-37.6%)**	**154.10 (-6.6%)**
Scott	Alfalfa	4,907	9,659	6.10
	Barley	1,415	1,532	0.92
	Other hay	546	1,076	0.64
	Pasture	5,579	12,814	3.91
	Wheat	1,883	2,039	1.21
	Subtotal	**14,331 (-52.3%)**	**27,118 (-55.4%)**	**12.78 (-54.0%)**
Shasta	Alfalfa	1,834	4,078	2.28
	Barley	3,780	5,693	2.49
	Other hay	1,660	3,691	1.95
	Pasture	12,257	33,081	8.58
	Strawberries	125	416	6.49
	Wheat	1,273	1,917	0.82
	Subtotal	**20,928 (-50.2%)**	**48,875 (-53.3%)**	**22.60 (-41.9%)**
Three valleys	**Total**	**51,233 (-47.3%)**	**110,304 (-50.0%)**	**189.49 (-18.2%)**

4.1.4. Scenario 2: forego third alfalfa cutting

Scenario 2 presents results of a less constrained case as compared with scenario 1. The model simulates deficit irrigation of alfalfa during the summer and consequentially a reduction in the number of cuttings harvested from the crop. Total annual irrigation for alfalfa is reduced by one-third (33%) to reflect these conditions, and crop yield is assumed to respond linearly to deficit irrigation. Changes in yield are accounted for in the profitability of alfalfa when land allocations are made by the model and are also applied to the final assessment of gross crop revenues. To reflect changes in harvesting and cultural costs, all costs are also scaled linearly with yield reductions. Reductions in water use connected to deficit irrigation are assumed to be retained in the model, meaning that the water cannot be reallocated to the expansion of other crops beyond what is otherwise used.

This scenario results in minor fallowing of alfalfa land (2.9% of baseline alfalfa) due to the steep decrease in marginal value making it less attractive to grow in comparison with other options, a factor that also lowers the returns of the allocated alfalfa land. Some compensation occurs to account for profitability shifts, leading to minor expansions of some select crops (Figure 5). Fallowing totals 117 acres across the three valleys (0.1%) after considering alfalfa losses and expansion in other crops. Water use reductions total 21,620 acre-feet (9.8%) of which most occur in Butte and Scott where alfalfa is plentiful. Total net gross revenue losses after accounting for combined cropping pattern shifts come to $12.8 million (5.5%), distributed as $5.7 million, $5.1 million, and $1.9 million in Butte, Scott, and Shasta, respectively. As compared with scenario 1a, both gross revenue losses and water use reductions are similar, but total changes in agricultural land use are much lower. Figure 5 and Table 10 below provide more detailed results of the cropping patterns, water use reductions, and value associated with this scenario.

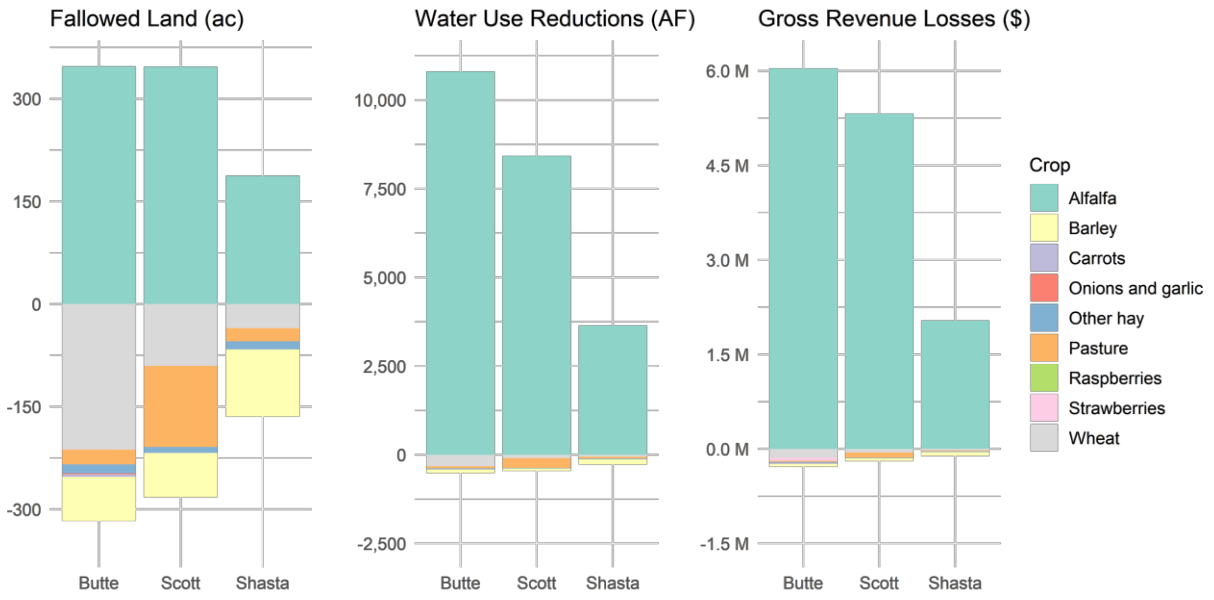


Figure 5: Results of land allocations, water use, and gross revenue differences from base for scenario 2, foregoing third cutting of alfalfa.

Table 10: Tabulated results of land allocations, water use, and gross revenues for scenario 2, foregoing third cutting of alfalfa.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	13,668	20,367	11.39
	Barley	1,525	2,296	1.00
	Carrots	317	662	1.17
	Onions and garlic	401	837	1.67
	Other hay	542	1,206	0.64
	Pasture	1,237	3,339	0.87
	Raspberries	140	465	8.10
	Strawberries	2,537	8,424	131.46
	Wheat	4,714	7,099	3.03
	Subtotal	**25,083** (-0.1%)	**44,695** (-18.7%)	**159.32** (-3.5%)
Scott	Alfalfa	11,921	15,721	9.93
	Barley	1,480	1,602	0.97
	Other hay	555	1,092	0.65
	Pasture	14,067	32,307	9.85
	Wheat	1,974	2,136	1.27
	Subtotal	**29,996** (-0.2%)	**52,859** (-13.1%)	**22.66** (-18.5%)
Shasta	Alfalfa	4,396	6,551	3.66
	Barley	3,879	5,841	2.55
	Other hay	1,671	3,717	1.96
	Pasture	30,661	82,754	21.46
	Strawberries	125	416	6.50

	Wheat	1,308	1,970	0.84
	Subtotal	**42,041** (-0.1%)	**101,250** (-3.2%)	**36.97** (-4.9%)
Three valleys	**Total**	**97,120** (-0.1%)	**198,803** (-9.8%)	**218.94** (-5.5%)

4.1.5. Scenario 3: 15% fallowing (adaptive)

Scenario 3 examines the expected impacts under a 15% land fallowing policy wherein cropping patterns can adapt to reduce the economic impacts. This scenario constrains the total land available to be allocated but does not prescribe fallowing in any given crop, meaning that the model is able to cut back in crops in such a way that minimizes farmer profit losses. Adaptive fallowing in this way assumes that there is some form of water trading which allows valuable crops to resist cutbacks because of some willingness to pay for scarce resources such as water.

Land fallowing totals 14,585 acres (15%) of which a large percentage (6,031 acres, 41.3%) consists of pasture reduction mostly in Shasta or Scott; remaining losses come in the form of alfalfa (4,101 acres, 28.1%), wheat (2,201 acres, 15.1%), barley (1,795 acres, 12.3%), and other crops (457 acres, 3.1%). Reductions in water use are slightly lower than land reductions by percentage, totaling 30,850 acre-feet (14.0%) across the three valleys. Gross revenue losses are in the order of $12.9 million (5.6%), distributed approximately equally across each of the valleys. Alfalfa receives the largest revenue loss of any crop ($5.1 million) followed by pasture ($4.2 million), and other minor crop losses representing the remaining economic impacts. Figure 6 and Table 11 below provide more detailed results of the cropping patterns, water use reductions, and value associated with this scenario.

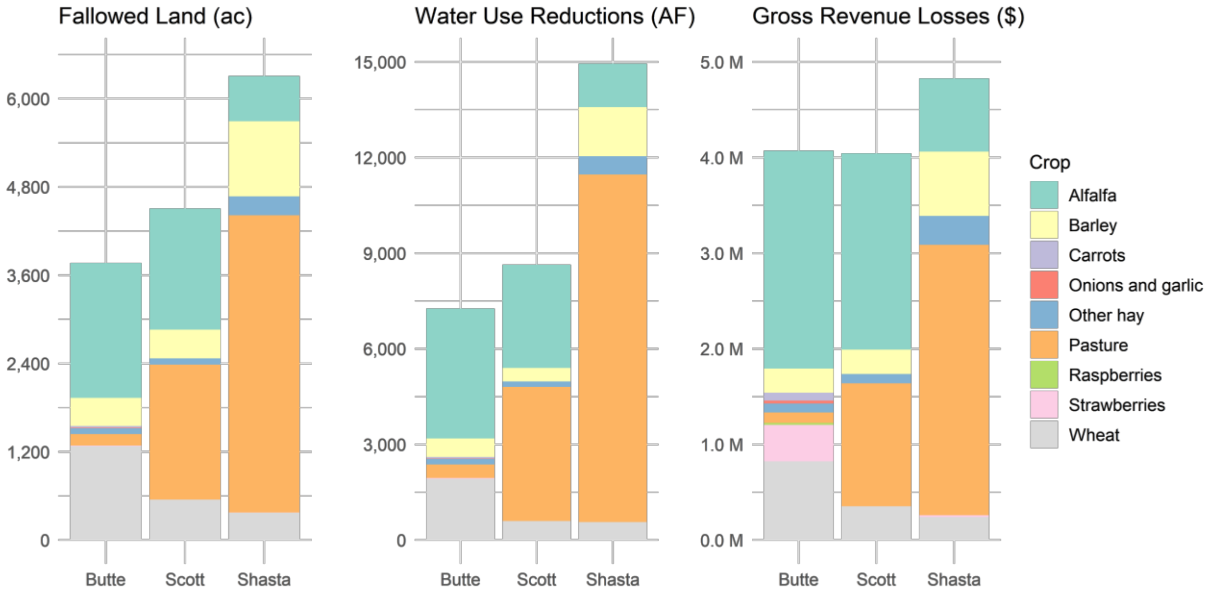


Figure 6: Results of land allocations, water use, and gross revenue differences from base for scenario 3, 15% fallowing of all cropland with adaptive management.

Table 11: Tabulated results of land allocations, water use, and gross revenues for scenario 3, 15% fallowing of all cropland with adaptive management.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	12,181	27,091	15.14

	Barley	1,078	1,623	0.71
	Carrots	291	607	1.08
	Onions and garlic	393	819	1.63
	Other hay	449	1,000	0.53
	Pasture	1,060	2,861	0.74
	Raspberries	140	463	8.08
	Strawberries	2,529	8,421	131.01
	Wheat	3,224	4,856	2.08
	Subtotal	**21,345** **(-15.0%)**	**47,717** **(-13.2%)**	**160.99** **(-2.5%)**
Scott	Alfalfa	10,617	20,899	13.20
	Barley	1,025	1,109	0.67
	Other hay	462	909	0.54
	Pasture	12,114	27,822	8.48
	Wheat	1,333	1,443	0.86
	Subtotal	**25,551** **(-15.0%)**	**52,182** **(-14.2%)**	**23.75** **(-14.5%)**
Shasta	Alfalfa	3,967	8,823	4.93
	Barley	2,758	4,154	1.81
	Other hay	1,403	3,120	1.64
	Pasture	26,601	71,796	18.62
	Strawberries	125	415	6.47
	Wheat	900	1,355	0.58
	Subtotal	**35,754** **(-15.0%)**	**89,663** **(-14.3%)**	**34.07** **(-12.4%)**
Three valleys	**Total**	**82,651** **(-15.0%)**	**189,562** **(-14.0%)**	**218.81** **(-5.6%)**

4.1.6. Scenario 4: 15% fallowing ("worst case")

Scenario 4 examines a similar land policy to that of scenario 3 (15% fallowing of all cropland) but restricts the model's ability to minimize losses. In this case all crop types are equally cut back by 15% without an implicit water trading potential. Removing the potential to shift cutbacks between crops leads to much more drastic economic losses compared to the previous scenario.

As a result of the restrictions imposed on the model, cutbacks across all categories (land, water use, and gross revenues) are all equal to the total fallowing percentage (15%) and do not change based on crop or region. Total fallow land remains at 14,585 acres as in scenario 3, distributed as 3,767 acres, 4,509 acres, and 6,310 acres lost in Butte, Scott, and Shasta, respectively. Water use reductions are slightly higher than the previous scenario, at 33,063 acre-feet. Agricultural revenue losses, however, are nearly three times higher than the adaptive scenario, totaling $34.8 million. Most revenue loss is attributed to reductions in strawberries and raspberries which value $21.9 million (62.9%) in combination; alfalfa and pasture make up most remaining value loss. Figure 7 and Table 12 below provide more detailed results of the cropping patterns, water use reductions, and value associated with this scenario.

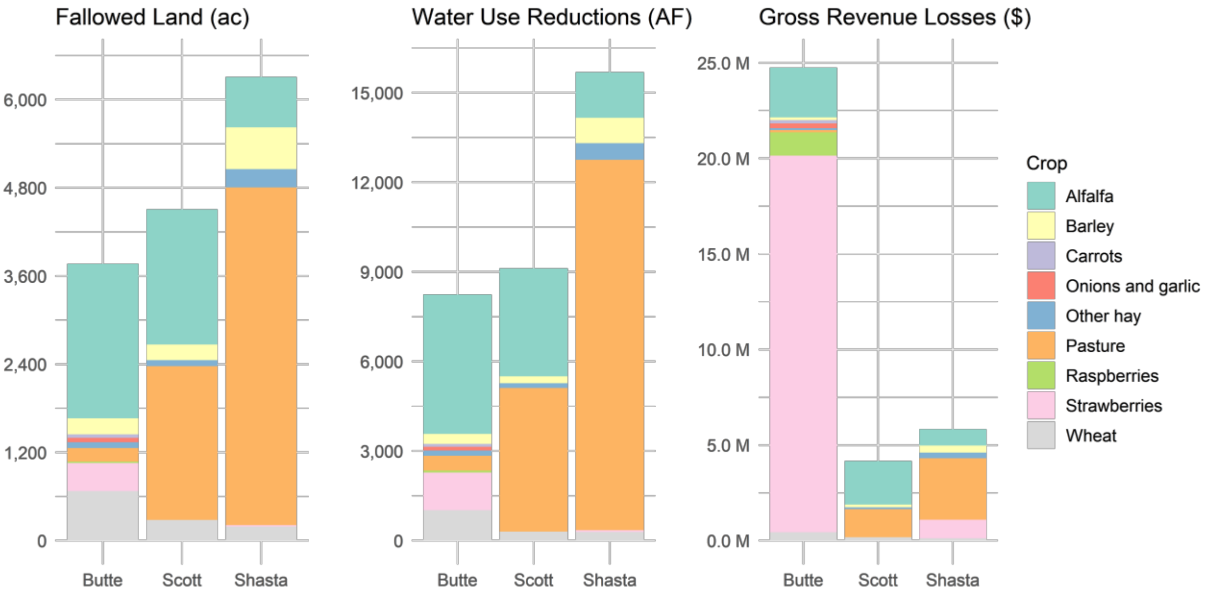


Figure 7: Results of land allocations, water use, and gross revenue differences from base for scenario 4, 15% fallowing of all cropland without adaptive management.

Table 12: Tabulated results of land allocations, water use, and gross revenues for scenario 4, 15% fallowing of all cropland without adaptive management.

Region	**Crop**	**Land (ac)**	**Water use (AF)**	**Gross revenue ($ million)**
Butte	Alfalfa	11,913	26,495	14.81
	Barley	1,241	1,869	0.82
	Carrots	266	556	0.99
	Onions and garlic	340	709	1.41
	Other hay	450	1,000	0.53
	Pasture	1,033	2,789	0.72
	Raspberries	119	395	6.88
	Strawberries	2,156	7,158	111.68
	Wheat	3,827	5,763	2.46
	Subtotal	**21,345 (-15.0%)**	**46,734 (-15.0%)**	**140.30 (-15.0%)**
Scott	Alfalfa	10,427	20,525	12.96
	Barley	1,203	1,302	0.79
	Other hay	464	914	0.54
	Pasture	11,856	27,229	8.30
	Wheat	1,601	1,733	1.03
	Subtotal	**25,551 (-15.0%)**	**51,703 (-15.0%)**	**23.62 (-15.0%)**
Shasta	Alfalfa	3,896	8,665	4.84
	Barley	3,213	4,839	2.11
	Other hay	1,411	3,137	1.65
	Pasture	26,046	70,298	18.23
	Strawberries	107	354	5.52
	Wheat	1,082	1,629	0.70
	Subtotal	**35,754 (-15.0%)**	**88,922 (-15.0%)**	**33.06 (-15.0%)**
Three valleys	**Total**	**82,651 (-15.0%)**	**187,358 (-15.0%)**	**196.99 (-15.0%)**

4.1.7. Scenario 5: 15% water shortage (adaptive)

Scenario 5 follows a similar concept and realization to that of scenario 3, however, restrictions are made more broadly to water as opposed to land availability. Under this scenario the model is again allowed flexibility in allocating land to crops and minimizing economic losses. Trends in overall resource use remain roughly the same as they were in the results of scenario 3 with minor differences in land allocation due to variability in unit water demand across crop types.

Fallowed land totals 13,848 acres across the three valleys and is composed primarily of alfalfa and pasture, with less severe cutbacks in barley and wheat owing to the lower unit water demands of these crops. In summary, total land fallowing is reduced compared with scenario 3, but targets towards higher water use crops. Water use reductions total of 32,760 acre-feet (15%). Changes in gross revenue losses are minimal compared with the land-limited scenario, and total $13.0 million. Both scenario 3 and 5 see much more evenly distributed economic impacts as compared to scenario 4, which experiences almost all effects in Butte Valley because of losses in berry plant transplant crops.

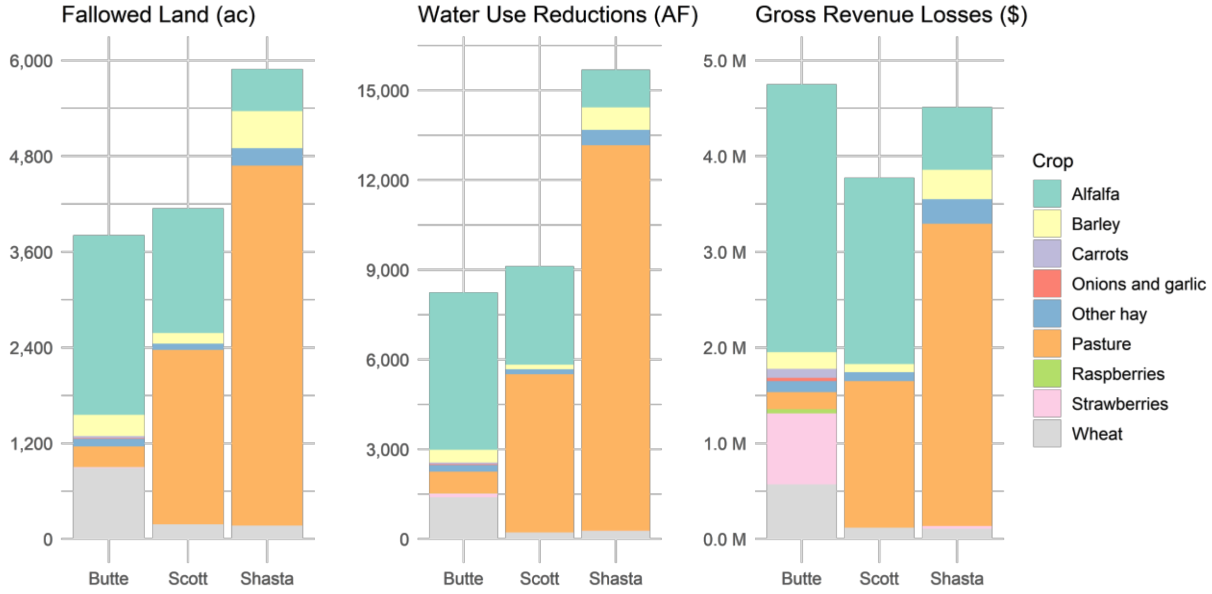


Figure 8: Results of land allocations, water use, and gross revenue differences from base for scenario 5, 15% total water shortage with adaptive management.

Table 13: Tabulated results of land allocations, water use, and gross revenues for scenario 5, 15% total water shortage with adaptive management.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	11,765	25,903	14.63
	Barley	1,193	1,779	0.78
	Carrots	288	595	1.07
	Onions and garlic	392	809	1.63
	Other hay	431	949	0.51
	Pasture	959	2,563	0.67
	Raspberries	139	458	8.06
	Strawberries	2,522	8,290	130.65
	Wheat	3,614	5,388	2.33

	Subtotal	**21,303** (-15.2%)	**46,734** (-15.0%)	**160.31** (-2.9%)
Scott	Alfalfa	10,702	20,854	13.31
	Barley	1,284	1,376	0.84
	Other hay	466	909	0.55
	Pasture	11,761	26,742	8.23
	Wheat	1,700	1,822	1.09
	Subtotal	**25,914** (-13.8%)	**51,703** (-15.0%)	**24.02** (-13.6%)
Shasta	Alfalfa	4,057	8,933	5.04
	Barley	3,316	4,943	2.18
	Other hay	1,441	3,172	1.69
	Pasture	26,129	69,817	18.29
	Strawberries	125	410	6.47
	Wheat	1,104	1,647	0.71
	Subtotal	**36,172** (-14.0%)	**88,922** (-15.0%)	**34.38** (-11.6%)
Three valleys	**Total**	**83,389** (-14.2%)	**187,358** (-15.0%)	**218.71** (-5.6%)

4.1.8. Scenario 6: exploring economic tradeoffs between alfalfa and strawberries in Butte Valley

Strawberry plants for transplant are a particularly unique specialty crop grown in Butte Valley due to their high value and importance in supporting downstream berry production on the Central Coast. As such, these crops pose an opportunity for generating great economic value with less land and water resource use – suggesting that conversion of other crops to strawberries may have benefits for managing water use while maintaining agricultural value. Given that alfalfa is the dominant crop by area in the valley (55.8%) and is relatively low value compared to nursery berries, this scenario explores tradeoffs in converting between these two crops.

In this analysis, the marginal revenue of an acre of transplant strawberry plants is estimated to be about $51,800 and the crop is estimated to operate with a 15% profit margin after costs are considered. Irrigation needs for strawberries are estimated at 3.32 AF/ac per year. Alfalfa is estimated to have a marginal revenue of $1,240/ac with a 5% profit margin and irrigation needs of 2.22 AF/ac per year in Butte Valley. Assuming constant returns to scale within both crop groups, about 42 acres of alfalfa produce the same gross revenue as 1 acre of nursery strawberries but use significantly more water in the aggregate.

Tables 14 and 15, below, outline possible options for retiring alfalfa in favor of transplant strawberries. The first strategy focuses on maintaining or expanding value while maximizing resource reductions (1:40 ratio of strawberries to alfalfa). The second strategy replaces alfalfa with strawberries at a higher rate (5:40 ratio of strawberries to alfalfa) in favor of economic expansion. These scenarios recognize the rotations exercised in growing transplant strawberry plants, which are understood to typically operate in 3-year rotations of strawberry-grain-fallow with roughly equivalent acreages of each at any given time. Based on this production model, for each acre of transplant strawberries planted, 1 acre of grain is planted, and 1 acre is set aside as fallow for the rotation with land, water use, and revenue impacts reflecting these conditions.

Table 14: Conservative strategy for converting alfalfa to strawberries (1:40 ratio of strawberries to alfalfa) focused on water use reductions.

Alfalfa fallowed (ac)	Strawberries planted (ac)	Grain planted (ac)	Fallow reserved (ac)	Land reductions (ac)	Water reductions (AF)	Revenue impact ($)
200	5	5	5	185	421	+13,570
400	10	10	10	222	505	+16,284
600	15	15	15	259	589	+18,998
800	20	20	20	296	673	+21,712
1000	25	25	25	333	757	+24,426

Table 15: Progressive strategy for converting alfalfa to strawberries (5:40 ratio of strawberries to alfalfa) focused on economic expansion.

Alfalfa fallowed (ac)	Strawberries planted (ac)	Grain planted (ac)	Fallow reserved (ac)	Land reductions (ac)	Water reductions (AF)	Revenue impact ($)
200	25	25	25	125	324	+1,062,443
400	50	50	50	150	389	+1,274,931
600	75	75	75	175	454	+1,487,420
800	100	100	100	200	519	+1,699,909
1000	125	125	125	225	583	+1,912,397

One consideration to make when examining conversion of alfalfa to higher value crops such as strawberries is the limit on strawberry expansion; consistent with PMP modeling which limits crop specialization, it is typically assumed that valuable crops that are observed to be grown in relatively low amounts are constrained by production conditions and upfront costs aside from profitability. For example, soils used in pasture are often less suitable to grow more sensitive crops such as vegetables because of nutrient deficiencies or soil composition. However, because transplant strawberries in Butte Valley are grown in nursery conditions, this may lend itself to better control of production conditions that might otherwise prevent expansion under natural cultivation practices. Expansion of nursery strawberry production is limited by several additional factors including labor availability and high upfront investment in technical knowledge and infrastructure. Many of the farmers currently involved in this sector have accumulated generational knowledge pertaining to management and business practice which are seen for other crops in the county but require fewer capital investments. These scenarios propose minor expansion of transplant berries by area in recognition of the challenges noted by farmers in this sector that currently prevent significant expansion from occurring.

4.1.9. Scenario 7: exploring lower water use alternatives to alfalfa and pasture

Among the crops cultivated in the three valleys examined for this study of Siskiyou County agriculture, pasture and alfalfa are the largest drivers of water demand, both at the aggregated and unit production scales. There is an interest in exploring the role that these crops play in the context of water use as well as economic value. This scenario examines potential for land use tradeoffs involving these crops with the goal of reducing water use while maintaining gross returns. It is worthwhile noticing alfalfa and pasture support downstream agricultural sectors such as the dairy and beef cattle industry, which may be impacted by higher feed crop costs resulting from a reduction in the local supply of irrigated pasture and alfalfa. Intermountain alfalfa is also known for its higher quality and is used as feed in more specialized animal operations beyond dairies and beef cattle.

Under baseline conditions, alfalfa covers roughly 32% of agricultural land across the three valleys while pasture makes up an additional 47% of crop cover. Alfalfa is mostly concentrated in Butte and Scott and pasture composes a majority of land use in Shasta. Unit water use for alfalfa is estimated at 2.22 acre-feet/acre in Butte and Shasta and 1.97 acre-feet/acre in Scott. Pasture is estimated to require 2.70 acre-feet/acre in Butte and Shasta and 2.30 acre-feet/acre in Scott. In the aggregate, these two crops contribute 83% of total water demand for the three valleys, of which 30% is attributed to alfalfa and 53% to irrigated pasture. Siskiyou does not have as stark of contrasts in unit water use between crops as other regions in California, where it is common to see grains with sub- 2 acre-feet/acre irrigation needs grown alongside alfalfa or almonds requiring over 4.5 acre-feet/acre in annual irrigation. However, there is still significant differences in unit demands which suggest opportunities for improving economic efficiency in applied water.

Table 16 below provides a baseline for comparison between water use and value for crops grown within each of the three valleys. This table serves to highlight opportunities for conversion between crop types in the interest of water management benefits. For example, wheat and barley offer some tradeoff from pasture and alfalfa for lowering total water demand at the expense of reduced agricultural revenue. Alfalfa demands roughly 1.5 times the irrigation of wheat or barley (per acre) but has nearly double the marginal value of these crops. In the Scott River Valley, where irrigation demands tend to be lower, each of these crops has comparable value per unit of applied water ($/acre-feet), however, in Butte and Shasta the economic return of water for grain crops is about 25% lower than that of alfalfa. Pasture, on the other hand, has both the highest unit water demands of any crop in the three valleys as well as the lowest value per unit of applied water. Marginal values for pasture are comparable to grain crops. Crops such as carrots and onions are suitable to be grown in Butte and have higher marginal value both per unit of land and water as compared with alfalfa or pasture. However, these crops are observed to be grown in only small amounts (approximately 400 acres at most), suggesting that other production factors may constrain their expansion despite higher value than alternatives. Likewise, transplant berries have higher water demands than alfalfa, carrots, or onions, but are vastly more valuable than other crops grown within the valley.

Table 16: Unit water use, marginal value, and economic efficiency of applied water for crops in Butte Valley.

Crop	Region	Unit water use (AF/ac)	Marginal value ($/ac)	Marginal value / unit water ($/AF)
Alfalfa	Butte/Shasta	2.22	1,243	559
Alfalfa	Scott	1.97	1,243	632
Barley	Butte/Shasta	1.51	658	437
Barley	Scott	1.08	653	603
Carrots	Butte	2.09	3,699	1,773
Onions and garlic	Butte	2.09	4,150	1,989
Other hay	Butte/Shasta	2.22	1,172	527
Other hay	Scott	1.97	1,172	596
Pasture	Butte/Shasta	2.70	700	259
Pasture	Scott	2.30	700	305
Raspberries	Butte	3.32	57,857	17,427
Strawberries	Butte/Shasta	3.32	51,800	15,602

Wheat	Butte	1.51	644	427
Wheat	Scott	1.08	644	595

4.2. Spillover effects of land and water use decisions

Table 17 lists spillover effects related to changes in the agricultural sector revenues within the County's economy based on the scenarios outlined above. We employed IMPLAN (https://www.implan.com/), an input-output model which allows estimation of broader impacts on employment, gross revenues and after sector-specific economic events, such as land fallowing or crop shifting. IMPLAN estimates direct, indirect, and induced effects. The direct effects correspond to the changes in revenues with respect to baseline (2018) conditions in crop farming. As various crops see reductions or changes in acreage, such changes indirectly affect production inputs including farm labor, agrochemicals, farm services and others. These are known as indirect effects. As agriculture and agriculture-related sectors face some impacts in gross revenues, households and government also face income impacts in what is known as an induced or second round effect. Altogether, direct, indirect, and induced impacts constitute the total or multiplier effect which is reported in this section for gross revenues (or output), value added (close to gross domestic product), and employment (full and part time jobs).

Scenario 1c shows the highest losses in all economic categories, resulting in $56 million in direct, indirect, and induced revenue losses, nearly $43 million in value added losses, and 393 fewer jobs in agriculture and all other sectors. Scenarios such as 3 or 4 are likely more realistic because they do not prescribe responses in specific crop categories, with scenario 3 assuming water trading allows retentions of higher value crops at the cost of deeper cutbacks in low value crops, and scenario 4 assuming all crops receive equal cutbacks. Management practices under water shortages would likely fall somewhere between these cases, representing slightly less aggressive water trading. Scenario 3 suggests total output losses of $17 million, $13 million in value added losses, and 120 fewer jobs. Meanwhile, scenario 4 falls closer to the extreme of scenario 1c with $46 million total revenue losses, $35 million in value added losses, and 323 fewer jobs. Other scenarios tend to fall within a similar range of economic impacts as those suggested by scenario 3.

Table 17: Combined direct and indirect regional economic impacts (IMPLAN results) for all scenarios.

Scenario	Region	Lost output ($ million)		Lost value added ($ million)		Lost jobs (#)	
		Direct	**Total**	**Direct**	**Total**	**Direct**	**Total**
Scenario 1a	Three valleys	10.57	14.05	5.82	10.68	71	98
	Butte	2.74	3.65	1.51	2.77	18	25
	Scott	3.75	4.99	2.07	3.79	25	35
	Shasta	4.07	5.42	2.24	4.12	27	38
Scenario 1b	Three valleys	21.13	28.11	11.65	21.36	142	197
	Butte	5.48	7.29	3.02	5.54	37	51
	Scott	7.50	9.98	4.14	7.59	51	70
	Shasta	8.14	10.83	4.49	8.23	55	76
Scenario 1c	Three valleys	42.26	56.21	23.30	42.72	285	393
	Butte	10.97	14.58	6.04	11.08	74	102
	Scott	15.01	19.96	8.27	15.17	101	140
	Shasta	16.29	21.66	8.98	16.46	110	151
Scenario 2	Three valleys	12.79	17.01	7.05	12.93	86	119
	Butte	5.74	7.63	3.16	5.80	39	53

	Scott	5.13	6.82	2.83	5.18	35	48
	Shasta	1.92	2.55	1.06	1.94	13	18
Scenario 3	Three valleys	12.94	17.21	7.13	13.08	87	120
	Butte	4.07	5.42	2.24	4.12	27	38
	Scott	4.04	5.38	2.23	4.09	27	38
	Shasta	4.83	6.42	2.66	4.88	33	45
Scenario 4	Three valleys	34.76	46.23	19.16	35.14	234	323
	Butte	24.76	32.93	13.65	25.03	167	230
	Scott	4.17	5.54	2.30	4.21	28	39
	Shasta	5.83	7.76	3.22	5.90	39	54
Scenario 5	Three valleys	13.04	17.34	7.19	13.18	88	121
	Butte	4.75	6.32	2.62	4.80	32	44
	Scott	3.77	5.02	2.08	3.82	25	35
	Shasta	4.51	6.00	2.49	4.56	30	42

Figure 9 summarizes the economic losses considering spillover effects in the regional economy for each scenario along with the average value lost per unit of water reductions. Scenario 1c, prescribing a large cutback (60%) in alfalfa and pasture cultivation, shows the greatest total economic output reduction at $56 million. Following closely in total output reduction is scenario 4 with $46 million, in which all crops receive an equal cutback of 15%. Scenarios 1a, 2, 3, and 5 are all found to have similar output impacts in the order of about $15-20 million. Average output losses per unit of reduced water is consistent across most scenarios at approximately $500/acre-foot. Scenario 2 has slightly higher value losses per unit of water because of the additional value lost from reduced alfalfa yield. Scenario 4 exhibits almost triple the average value lost per unit of water compared with other scenarios ($1,400/acre-foot) because of the higher marginal value of transplant berries.

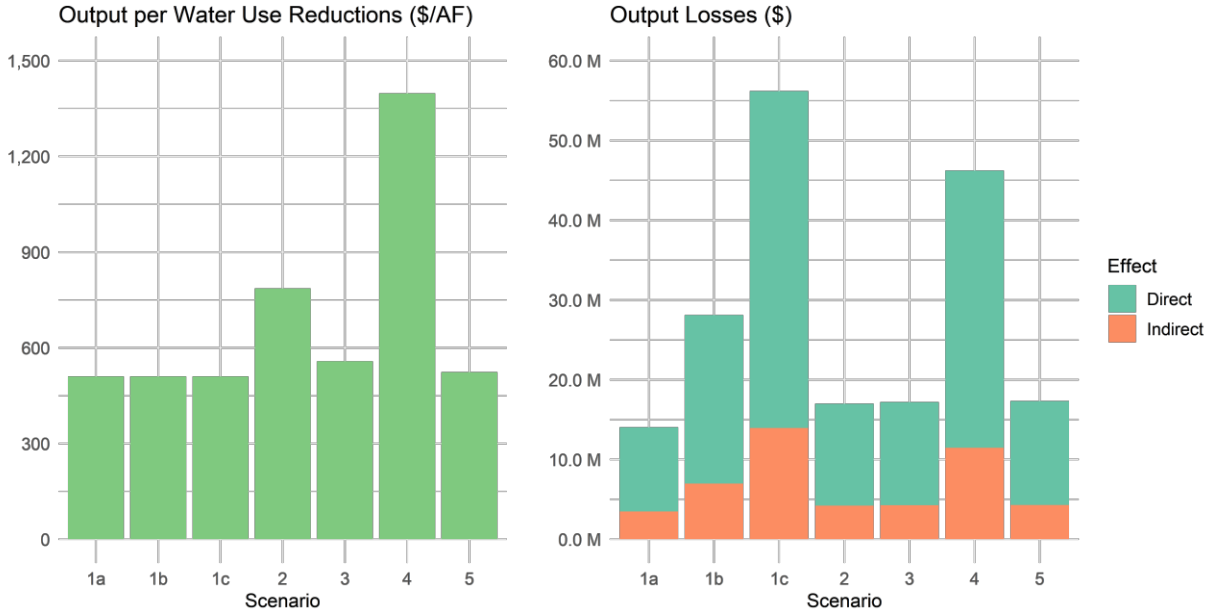


Figure 9: IMPLAN combined spillover effects and average value per unit of water reductions by scenario.

4.3. Economic value of instream flows in the Klamath Basin

Various studies and research reports exist for estimating value of water instream flows in the Klamath River Basin. Kruse and Scholz (2006) estimate a range of net costs for the removal of 4 dams in the Klamath Basin and benefits from temporary employment in the removal and non-use water value with many other costs and benefits unknown. The authors provide an estimate of $172 million in benefits from dam deconstructions, and increased tourism and visitors, and a cost of $2 million for the loss of jobs from the hydropower project. In addition, it is estimated a $104 million benefit from non-use value per year. Considering a flow mean annual flow of 13 million acre-feet in the Klamath River, the estimate in use value is in the order of $8 per acre-foot. This figure does not include the benefits of groundwater dependent ecosystems, fisheries, tourism, tribal, water supply increased reliability and other beneficial uses included in the $172 million above that do not have a direct association to the instream flow gains or change in patterns from dam removal. Yet the study demonstrates values exist for environmental flows and should be weighed against costs of water diversions.

4.4. Limitations of analysis

As with most models, the scenario results shown in this report merit recognition of some limitations. First, data availability on crop production represents average production conditions which rarely occur in specific commodities. Size distribution of farms influences activities and productivity and crop attributes that might also have an influence on crop prices and yields in specific market niches. This also influences the profits from farming. Nevertheless, a representation of the aggregate of production at the county level can still provide useful insights for planning and policy analysis. Second, a profit maximizing behavior and costless water exchanges within each of the valleys are assumed to occur. Thus, results may represent a reasonable lower bound for economic costs of water reductions. Lastly, crops in Siskiyou County have an influence that extends beyond the county boundaries as these are exported or serve as inputs to other sectors including animal operations and food processing. Estimates of these impacts is not estimated in this study yet for most of the scenarios modeled decreases in feed crops will result in higher costs to local ranchers in the dairies and beef cattle sectors which may intermittently or permanently reduce herd sizes to cope with higher production costs and maintain profitability. Animal operations represent roughly 20% of both crops and animal agricultural value in Siskiyou County, thus reductions in their total output due to higher costs should not be ignored. Something similar occurs for transplant berries, which provide inputs to other areas that grow specific commodities into end-products for wholesale or retail. Yet due to their value and profit margins, water shortage price increases from traded water or more expensive water could be absorbed easier than in other sectors. With these limitations in mind, this report may provide insights for discussion of paths forward in water management for Siskiyou County.

5. Conclusions

This report provides costs of agricultural land and water use decisions in selected cropping regions within Siskiyou County and contributes to an improved quantitative understanding of tradeoffs associated with such decisions. Some conclusions arise from this work.

1) Agriculture in Siskiyou County within the Butte, Scott River and Shasta Valleys in our baseline year accounts for 97,000 acres, using roughly 220,000 acre-feet of water per year and generating $231 million in direct gross revenues.

2) The agricultural crop mosaic in these three valleys differ substantially both in the selection of crops and access to water resources. Butte Valley holds the smallest agricultural footprint by area with about 25,000 acres but contributes the greatest value of the three regions owing to the production of berry plants for transplant. Scott River Valley contains about 30,000 acres of cropland consisting primarily of alfalfa and pasture. Shasta Valley has about 42,000 acres of cropland and is mostly pasture. Across the three valleys together, alfalfa and pasture account for 32% and 47%, respectively, of total cropland.
3) A range of scenarios for land and water management was analyzed. Scenarios 1a (15% fallowing alfalfa and pasture), 2 (forego third alfalfa cutting), 3 (15% fallowing, adaptive), and 5 (15% water shortage, adaptive) are expected to result in comparable revenues losses in the order of $10-13 million before considering spillover effects or $15-20 million in related sectors. Scenario 4 (15% fallowing, "worst case") results in the most extreme economic impact with an estimated $35 million in losses stemming in large part from transplant berry reductions. Scenarios 1b and 1c form an intermediate between other scenarios but concentrate impacts on alfalfa and pasture.
4) A 15% reduction in water across the board for all crops can potentially result in direct costs of $35 million for Butte, Scott River, and Shasta Valleys, and 234 jobs lost. When the multiplier effects are accounted for, sector output losses total $46 million and 323 jobs. The cost of applied water reductions in this scenario is about $1,400 per acre-foot when considering direct and indirect sectors.
5) Allowing trading within the valleys for up to 15% applied water reductions substantially decreases economic costs of water use reductions down to $13 million in sector output, and when spillover effects are accounted for such impacts can be as high as $17 million for sector output and 120 jobs. This highlights the potential gains from trading water across commodities to lower economic impacts.
6) Scenarios focusing on resource use reductions in alfalfa and pasture tend to concentrate economic impacts on Shasta Valley, followed by Scott River Valley and finally Butte Valley which generates much of its value from berries for transplant. However, when assessing alfalfa centric scenarios such as foregoing a third cutting (scenario 2), this trend reverses and Butte and Scott River Valleys experience much of the losses. Scenarios which prescribe general reductions in land or water use and allow for adaptive fallowing (scenarios 3 and 5) have nearly equal impacts across each of the regions. When water trading is prohibited and crops experience equal reductions (scenario 4), aggregate impacts become highly concentrated in Butte Valley owing to the exceptional value of berry plants for propagation.
7) Effects from crop production changes into downstream sectors such as dairies and beef cattle and the food processing industry can be sizeable for large enough reductions in crop production and depending on the downstream sector's response to local crop commodity shortages these estimates may merit further investigation.

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