only pre-1914 water right holder for Muskgrave, Harris, and Ike's Creek flow within the Basin.

In 1909, Prather Creek flowed directly into the southern end of Meiss Lake, and provided water and electrical power to a dairy (USDA 1909). In the 1940s, farming on the west side of Meiss Lake was accomplished by diverting Muskgrave, Harris, and Ikes Creeks out onto the fields in the winter months to build soil moisture (County of Siskiyou 1996). Today, all pre-1914 water rights to Prather Creek is split between Ralph's Prather Ranch (senior right) and CDFW. Creek flows are utilized by CDFW for wildlife, and enhancement and maintenance of 6,300 acres (25.5 sq km) of wetlands, including Meiss Lake (CIWQS - ID S004351). Water conservation efforts include drainage and reuse between land units for moist-soil management for waterfowl food plants (CIWQS - ID S004351). From 2005 to 2007, the combined total annual flow was 7,500, 18,000, and 11,500 AF (9.3E+06, 2.2E+07, and 1.4E+07 m^3), respectively (CIWQS - ID S004351).

2.2.2 Current and Historical Groundwater Conditions

Butte Valley is predominantly agricultural and development of groundwater as a major source of irrigation was critical for settlement in the Valley. Beginning in 1852, immigrant trains on the Yreka Trail reached Yreka in Shasta Valley by passing through Butte Valley (County of Siskiyou 1996). Nicknamed the "Desert," a lack of water prevented settlement in Butte Valley for many years (County of Siskiyou 1996). In the 1860s and 1880s, homesteads began to be established in Butte Valley (Novick 1996). In 1862, Butte Valley had some ranching activity and the west side of the Valley was harvested for natural grass hay (County of Siskiyou 1996). In 1876, field crops grown along Butte Creek included timothy, red top, oats for hay, wheat and barley (County of Siskiyou 1996). In 1903, alfalfa hay and grain were grown via dry-land farming on 11,000 acres (44.5 sq km) (County of Siskiyou 1996). Settlement in Butte Valley occurred in 1906 when William MacDoel bought 30,000 acres (121 sq km) of land, which he cut up into small farms and sold to experienced German-American Baptist farmers from Iowa and other Midwest states (USDA 1994; County of Siskiyou 1996). However, Butte Valley saw limited agricultural development due to a lack of major surface water and failure of various plans to develop groundwater and surface water irrigation systems (French 1915; County of Siskiyou 1996). Many of these initial farmers left Butte Valley discouraged, impoverished, or bankrupt (USDA 1994; County of Siskiyou 1996). In 1920, the United States Bureau of Reclamation (USBR) attempted to channel surface water from Antelope, Butte, and Bear Creeks to Macdoel, but the project failed (County of Siskiyou 1996). The Butte Valley Irrigation District (BVID) formed in 1921 and currently manages land west of the cities of Macdoel and Mount Hebron. BVID completed a project in 1923 to divert Shovel Creek to irrigate farmland but the creek went dry and most farmers lost their land and left Butte Valley (County of Siskiyou 1996). BVID drilled the first irrigation well in 1929 and has continued to drill groundwater wells as surface water resources have decreased (County of Siskiyou 1996). Since the successful development of deep groundwater wells in 1952, in BVID hundreds of acres of farmland were developed to grow alfalfa, grains, and potatoes (County of Siskiyou 1996). Private groundwater drilling for irrigation spread outside BVID as the technology became more easily accessible. From 1926 to 1994, more than 210 irrigation wells were constructed in Butte Valley (Novick 1996). Of the 38 irrigation wells constructed from 1980 to 1994, 20 were drilled in the High Cascade Volcanics water bearing formation and 18 in the Butte Valley Basalt and/or Lake Deposits water bearing formations (Novick 1996).

The development of groundwater resources encouraged agricultural expansion; where 1954 had 12,000 irrigated acres (48.6 sq km) (15% of Basin area), 1976 had 27,500 irrigated acres (111 sq km) (35%), and 2010 had about 37,000 irrigated acres (150 sq km) (46%) (County of Siskiyou 1996; DWR 2010). The agricultural expansion increased groundwater pumping demand for irrigation (County of Siskiyou 1996; Wood 1960). Within Butte Valley, from 1953 to 1979 to 1991, groundwater extraction increased from 22,200 to 62,000 to 81,000 AF (2.7E+07, 7.6E+07, 1.0E+08 m3), respectively (DOI 1980; DWR 1998). For comparison, the annual surface water supply in 1998 was about 20,000 AF (2.5E+07 m3) (DWR 1998). In 1998, the agricultural applied water demand was roughly 2.2 AF/acre per year (0.66 m/yr), of which 1.8 AF/acre (0.54 m/yr) stems from groundwater (DWR 1998). In 1998, DWR proposed that total irrigated acreage and water demand in Butte Valley had reached its maximum because nearly all arable land in the Valley was in production (DWR 1998).

2.2.2.1 Groundwater Elevation

Groundwater levels in Butte Valley show short-term seasonal fluctuations in response to summer pumping and winter recharge and long-term fluctuations in response to wet and dry precipitation cycles (DOI 1980). Historically, the volume of extracted groundwater depends on the availability of surface water, where wet years demand less groundwater compared to dry years (DWR 1998). At the 1980 and 1998 rates of groundwater extraction, groundwater levels and storage decline during years with below average rainfall, but recover during years with average or above average precipitation (DOI 1980; DWR 1998). Current spring groundwater levels have dropped from near ground surface at the beginning of the 20th century to approximately 30.5 meters (100 feet) below ground surface (bgs) in the north east edge of the valley near the town of Dorris and to 15 meters (50 feet) bgs at the town of Macdoel near the south edge of the valley (see below). The north west portion of the valley is still largely undeveloped with relatively shallow water levels between 3.5 and 12 meters (10 and 40 feet) bgs, possibly owing to the National Grassland and the BVWA which together account for roughly 40 percent of the land in Butte Valley.

A limited number of groundwater wells in Butte Valley have been mapped to their connecting water-bearing formation, which includes the three main formations, High Cascade Volcanics, Butte Valley Basalt, and Lake Deposits. Wells that tap into the High Cascade Volcanics are generally limited to the Valley edges, and Butte Valley Basalt wells are limited to the extent of the basalt flow in the south side of the Valley (Figure 1.20). Wells that tap into the Lake Deposits are situated within the Valley floor.

Elevation and Flow Direction

Historical Conditions (1880 - 1979)

Groundwater conditions in the early 1900s provide some observations of the groundwater supply before major settlement in the Valley (USDA 1909). In 1907 Butte Valley had a shallow water table with groundwater depths between 1-10 ft (0.3-3 m) bgs but was typically at 4-6 ft (1.2-1.8 m) depth (USDA 1909). Springs in Butte Valley were evidence of a confined potentiometric surface above ground surface and occurred in the town of Macdoel and on the hillside south of Meiss Lake (formerly Butte Lake) (USDA 1909; Wood 1960). Bubbling springs were active in the basalt outcrops near Macdoel. Springs near Macdoel had an average 200 parts per million (ppm) dissolved solids (USDA 1909). Butte Creek was observed to quickly sink underground soon after entering the Valley (named the Butte Creek Sink) but provided irrigation water for several hundred acres of alfalfa, timothy, clover, and grain crops. Following early settlement in 1880 alfalfa crops drew water directly from shallow groundwater (USDA 1909).

As late as the 1960s artesian wells existed near Meiss Lake, suggesting a potentiometric surface existed above ground level in that part of the Valley (Wood 1960). Springs existed along the western edge of Butte Valley (Wood 1960). In spring 1979 wells near Meiss Lake (46N/2W-9R1, 9R2, 9N, and 16N1) were observed to flow with potentiometric heads above ground level (DOI 1980). Meiss Lake received regular surface flows from Prather Creek and Muskgrave Creek, however Butte Creek had been sufficiently appropriated and diverted that flows terminated near the town of Macdoel (Wood 1960).

As of 1998 at least two springs still flowed on Holzhauser Ranch on the Butte Valley floor in Sam's Neck approximately 4.5 miles north of Meiss lake (DWR 1998). During a groundwater pumping test performed in 1998 at Meiss lake, spring discharge was observed to decrease in the Holzhauser Ranch South Spring from 4.1 gallons per minute (gpm) to 3.7 gpm, a 10% decrease (DWR 1998).

The best qualitative historical assessment of groundwater in Butte Valley is based on observations completed in May 1954 (Wood 1960) (Figure 1.20). Groundwater flow was eastward and northeastward across the valley into buried talus and volcanic rocks in the Mahogany Mountain ridge. Groundwater likely flowed through the ridge to supply groundwater flow to the neighboring groundwater basins. East of Dorris, groundwater gradients ranged from 30 to >70 feet per mile toward Mahogany Mountain ridge. The steep gradient may have been caused by barriers to flow due to faulting or a sudden increase in permeability. Groundwater discharged from the Valley may have moved through the fractured volcanic rocks in Mahogany Mountain ridge or along fault zones (Wood 1960).

In 1954, the groundwater gradient southwest of Mount Hebron was about 20 feet per mile northeastward (Figure 1.20). Between the towns of Mount Hebron and Macdoel the groundwater surface was nearly flat as the water moved through the highly permeable Butte Valley Basalt. Groundwater in the Lake Deposits water bearing formation northeast of Meiss Lake had a gradient from less than 2 to about 5 feet per mile, increasing to about 10 feet per mile near Cedar Point (Wood 1960). Local groundwater depressions from irrigation wells occurred in two areas, near Macdoel and west of Inlow Butte.

In 1954, in the west central part of the valley, the groundwater surface sloped gently away from Meiss Lake (Figure 1.20). The lake originally occupied a topographic depression west of its present location, where it was supplied in large part by groundwater seepage and its surface reflected the general level of the adjacent groundwater surface. An earthen dike constructed on higher ground east of the original lake bed bounds the west shore of the current lake, where water has been pumped from the original lake bed and allowed to spread over poorly productive land. The original lake bed is currently cultivated, but being an area of natural groundwater discharge, it must be kept drained to prevent waterlogging. Seepage loss from the present Meiss Lake is restricted by clayey lake deposits which underlie that part of the valley (Wood 1960).

Current Conditions (1979 - 2020)

Groundwater levels have a seasonal high in the spring and seasonal low in the fall. Groundwater recharge is dependent on the annual precipitation, which has been experiencing a decline in Butte Valley since the early 1980s, as shown in Figure 1.9. The average annual rainfall for the period 1942-1997 was 12.15 in (30.9 centimeters (cm)) (DWR 1998), while decreased precipitation in the past 20 years has brought the average annual rainfall for the period 1979-2020 down to 8.1 in (20.7 cm) per year as shown in Figure 1.9. Rainfall in both "wet" and "dry" years has decreased in the past 50 years.

In 1979, seasonal water-level fluctuations for wells in the High Cascade Volcanics ranged from no change to about 17 ft (5.2 m) and groundwater wells in other water-bearing units ranged from a few feet to about 25 ft (7.6 m) (DOI 1980). As shown in Figure 1.21, groundwater primarily flows toward Dorris, with low gradients in the middle of the valley and high gradients near Dorris. Groundwater levels and gradients are poorly constrained between Macdoel and Mount Hebron due to lack of data.

From the spring of 1979 to the spring of 2015, groundwater levels have dropped roughly 30 feet (Figure 1.21 and Figure 1.22). The 2014-2015 water year is the most recent year in Butte Valley with above average annual precipitation, at 9.96 inches Figure 1.9. In 2015, the groundwater gradient in the northeast part of the valley is poorly constrained due to the lack of groundwater data immediately southwest of Dorris. Groundwater gradients in the spring of 2015 are shallow near Macdoel and Mount Hebron due to the highly permeable Butte Valley basalt. Groundwater levels near Meiss Lake are poorly constrained due to lack of data. From the fall of 2014, the seasonal low, to the seasonal high in spring of 2015, groundwater levels vary between 0 to 20 ft, with the least change in the Butte Valley National Grasslands and greatest changes near Dorris, Macdoel and Mount Hebron. Water levels and changes over time are shown on Appendix 2-A.

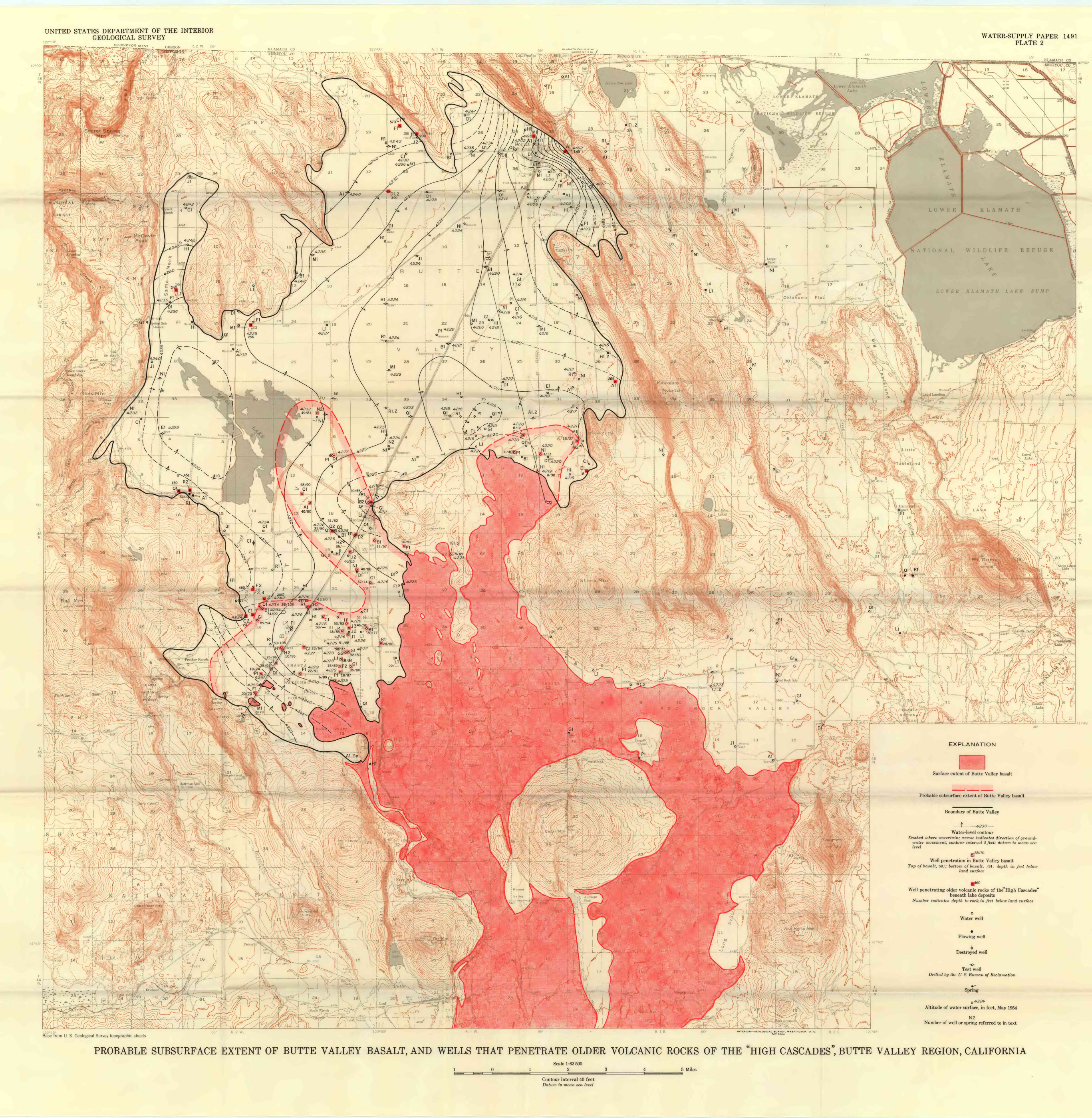
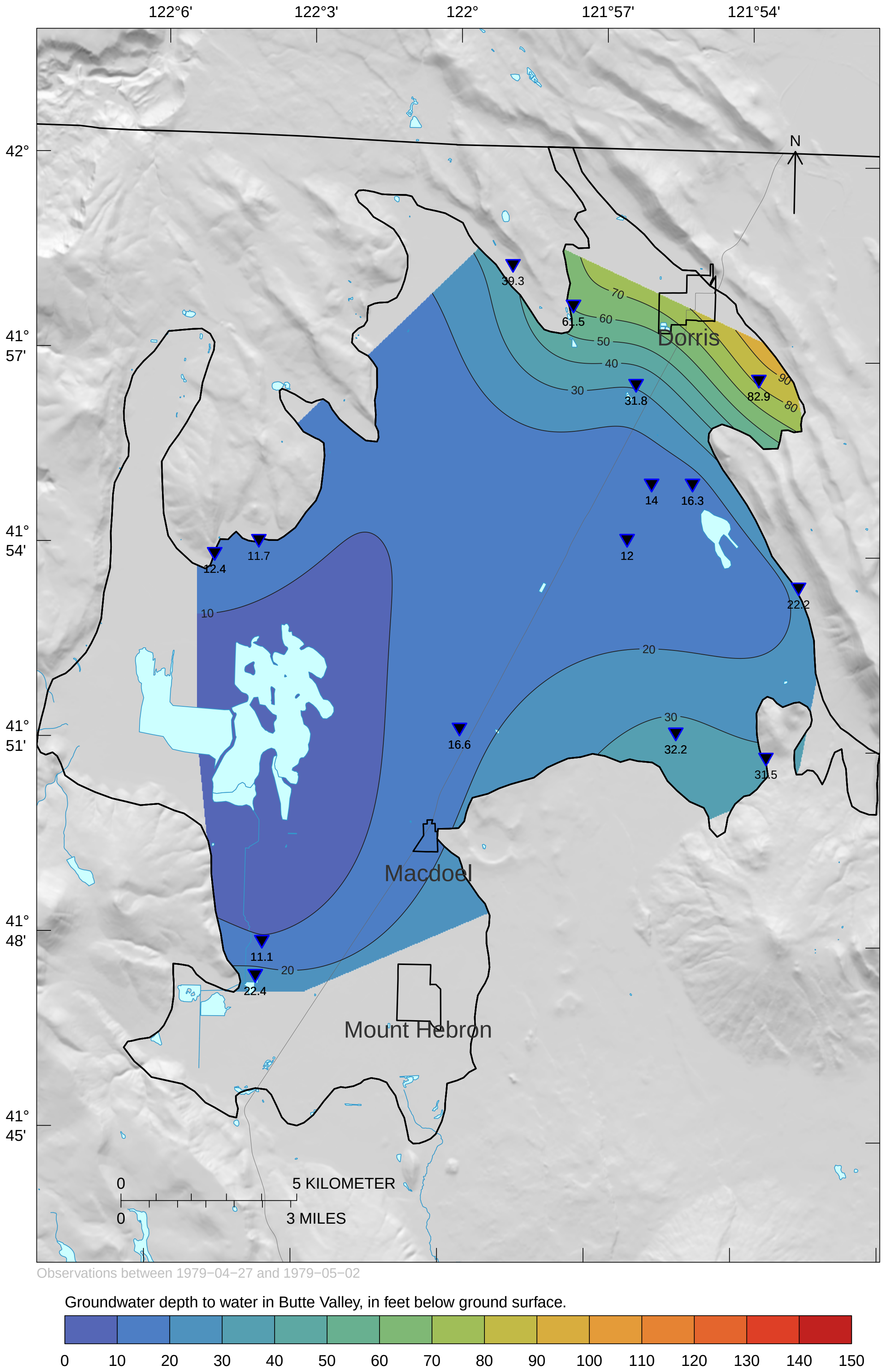


Figure 1.20: Groundwater elevations and flow based on observations during the first week of May 1954 (Wood 1960). The image is high quality so text can be distinguished when zoomed in.

Hydrographs

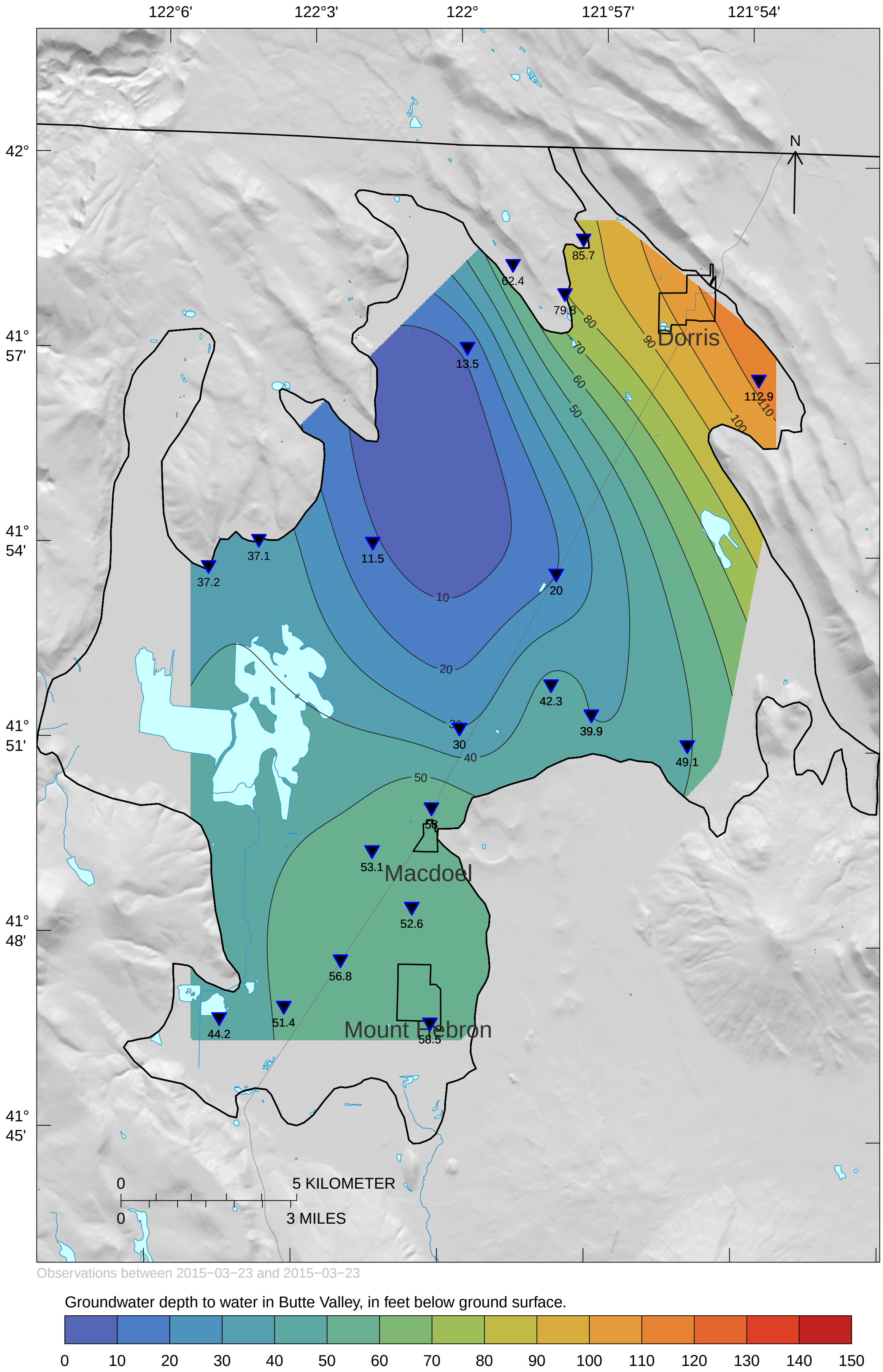
Groundwater levels have been declining in much of the basin since record keeping began in the 1950s. Pre-1915 records describe groundwater levels at 5-10 ft (1.5-3.0 m) below the ground surface (bgs) (French 1915). From 1976 to 77, BVID deepened irrigation wells to increase groundwater resources during a drought. In Spring 1979, the average depth to groundwater in the unconfined system was 25 ft (7.6 m) with a range of 6-48 ft (1.8-14.6 m) (DOI 1980). The average depth to groundwater in the confined system was 33 ft (10.1 m) with a range of 9-83 ft



Observations between 1979−04−27 and 1979−05−02

Groundwater depth to water in Butte Valley, in feet below ground surface.

Figure 1.21: Butte Valley Groundwater Elevations, Spring 1979



Observations between 2015−03−23 and 2015−03−23

Groundwater depth to water in Butte Valley, in feet below ground surface.

Figure 1.22: Butte Valley Groundwater Elevations, Spring 2015

(2.7-25.3 m) (DOI 1980). Groundwater elevations during the 1980-1981 drought were low enough that Butte Valley Irrigation District had 14 out of 28 wells either dry or surging (County of Siskiyou 1996). From 1983 to 1992, the water table dropped an average of 16 ft (4.9 m) (County of Siskiyou 1996). Groundwater levels at five different wells from different areas of Butte Valley are shown in Figure 1.23.

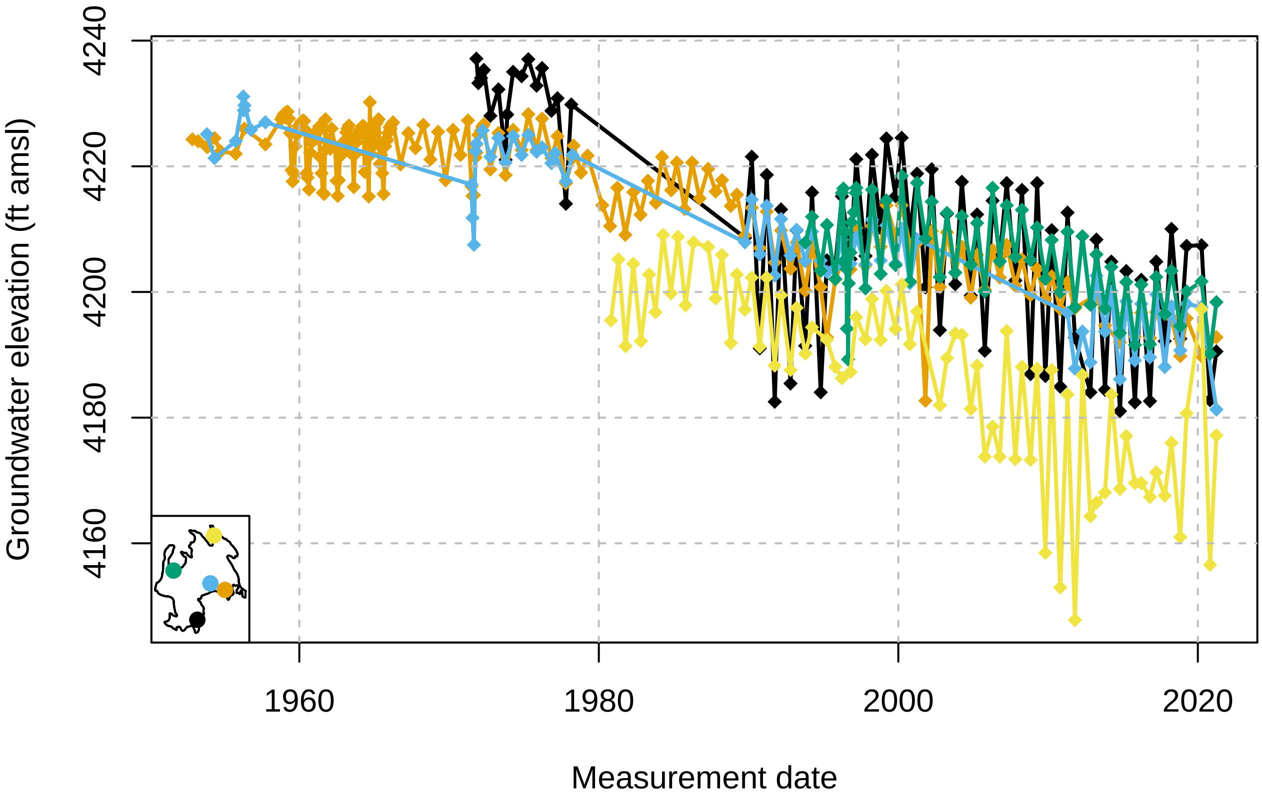


Figure 1.23: Groundwater elevation measurements over time in five wells, one located in each hydrogeologic zone.

2.2.2.2 Estimate of Groundwater Storage

Due to the complexity of the Basin and interbedded nature of alluvial, fluvial, and volcanic deposits within the major aquifer subunits, the California Department of Water Resources (DWR) could not provide an estimate of groundwater storage (Wood 1960; DWR 2004). Most wells in the Basin produce water from the underlying volcanic rock and some wells extract water from the overlying Lake Deposits. All units are hydrologically interconnected and DWR was unable to assign a reasonable specific yield to the volcanic units (Wood 1960; DWR 2004). The High Cascades Volcanic unit is the main unit for both recharge and storage in the Basin (Wood 1960). However, the depth and extent of the unit, which also extends well beyond the Basin boundaries, is not well defined.

A specific yield and storage capacity can be estimated for the unconfined units: Lake Deposits, pyroclastic rocks, and Butte Valley Basalt (DOI 1980). The weighted average specific yield for the unconfined units is calculated to be 9.5% and total groundwater storage capacity is 2,560,000 acre-feet. Specific yield and storativity has also been estimated using the Butte Valley Integrated Hydrologic Model (BVIHM), as described in Section 2.2.3.

2.2.2.3 Groundwater Quality

SGMA regulations require that the following be presented in the GSP, per §354.16 (d): Groundwater quality issues that may affect the supply and beneficial uses of groundwater including a description and map of the location of known groundwater contamination sites and plumes

Basin Overview

Water quality includes the physical, biological, chemical, and radiological quality of water. The physical property of water of most interest to water quality is temperature. An example of a biological water quality constituent is *E.coli* bacteria , commonly used as an indicator species for fecal waste contamination. Radiological water quality parameters measure the radioactivity of water. Chemical water quality refers to the concentration of thousands of natural and manufactured inorganic and organic chemicals. All groundwater naturally contains some microbial matter, chemicals, and usually has low levels of radioactivity. Inorganic chemicals that make up more than 90% of the "total dissolved solids" (TDS) in groundwater include calcium (Ca^{2+}), magnesium (Mg^{2+}) sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), bicarbonate (HCO_3^{-}), and sulfate (SO_4^{2-}) ions. Water with a TDS concentration of less than 1,000 mg/L is generally referred to as "freshwater." Brackish water has a TDS between 1,000 mg/L and 10,000 mg/L. In saline water, TDS exceeds 10,000 mg/L. Water hardness typically refers to the concentration of calcium and magnesium cations in water.

When one or multiple constituents become a concern for either ecosystem health, human consumption, industrial or commercial uses, or for agricultural uses, the water quality constituent of concern becomes a "pollutant" or "contaminant." Groundwater quality is influenced by many factors – polluted or not – including elevation, climate, soil types, hydrogeology, and human activities. Water quality constituents are therefore often categorized as "naturally occurring," "point source," or "non-point source" pollutants, depending on whether water quality is the result of natural processes, contamination from anthropogenic point sources, or originates from diffuse (non-point) sources that are the result of human activity.

Groundwater in the Basin has been characterized as mixed-cation to magnesium-bicarbonate water, and as sodium bicarbonate water near Dorris (DWR 1968, 2004). The dissolved-solids content of groundwater in the Basin is commonly less than 360 mg/l, though TDS concentrations have been measured in excess of 1,100 mg/L; locally high TDS values have been attributed to evaporites in localized playa deposits (DWR 1968, 2004). Within Butte Valley, groundwater quality issues have historically included locally high arsenic, iron, manganese, boron, TDS, sodium, calcium, ammonia, hydrogen sulfide, phosphorus, and electrical conductivity (DWR 2004). High TDS and sodium have also been noted in shallow wells with hydraulic continuity to Meiss Lake, where salts from natural inflow and irrigation-return flows are concentrated by evaporation (DWR 2004). The City of Dorris relies on a single groundwater well for water supply, drilled in 1971, which penetrates the volcanic water bearing formations below the lake deposits, reaching a depth of 1, 236 ft (377 m) (Bray & Associates 2015). Previous water supply wells penetrating lake deposits were found to have arsenic levels exceeding the 1962 drinking water standard of 0.05 parts per million (ppm; 1 ppm = 1 mg/L) (DWR 1968). A 1968 DWR investigation suggested the elevated arsenic levels were the result of industrial contamination, the effects of which continue to be an issue in shallow groundwater wells near Dorris (DWR 1968, 2004; Bray & Associates 2015).

Groundwater in the Basin is generally of good quality and has relatively consistent water quality characteristics which meet local needs for municipal, domestic, and agricultural uses. Ongoing monitoring programs show that some constituents, including benzene, 1,2 dibromoethane (EDB), arsenic, and boron exceed water quality standards in parts of the Basin. Exceedances may be caused by localized conditions and may not be reflective of regional water quality. In addition, there are potential risks of increasing salt and nutrient conditions from agricultural and municipal uses of water. Across the majority of the Basin, salt and nutrient concentrations are below levels of concern, with no upward trends. A few isolated areas have higher concentrations.

A report by the NCRWQCB in 2020 prioritized 62 groundwater basins in the North Coast Region with threats to groundwater quality due to excessive salts and nutrients, and categorized Butte Valley as “medium” priority (NCRWQCB 2020). If accepted by the Regional Board, the categorization will be adopted with Resolution No. R1-2021-0006. Based on the water quality analysis completed by the NCRWQCB, the percentage of wells in the Basin from 2010 to 2020 exceeding 5 mg/L nitrate was 21 - 30%, 10 mg/L nitrate was 10 - 20%, 250 mg/L TDS was 20-40%, and 500 mg/L TDS was <20%. The Basin was assigned a score, for “status and trends in the concentration of salts and nutrients in groundwater,” of 3 out of a range of 1 - 10. Categories in which the Basin had high scores included: hydrogeological basin factor including depth to groundwater and hydrogeologically vulnerable area, reliance on groundwater to supply the basin, and number and density of on-site wastewater treatment systems. The information used in the prioritization process included water quality data from the State Water Board GAMA database and dairy operators under the Waste Discharge Requirements for Dairies (NCRWQCB Order No. R1-2012-0002), the DWR SGMA Basin Prioritization Process and the seven evaluation factors listed in the Recycled Water Policy (NCRWQCB 2020).

A summary of information and methods used to assess current groundwater quality in the Basin, as well as key findings, are presented below. A detailed description of information, methods, and all findings of the assessment can be found in Appendix 2-B.

Existing Water Quality Monitoring Networks

Water quality data for at least one constituent – sometimes many - are available for some wells in the Basin but not most. Of those wells for which water quality data are available, most have only been tested once, some have been tested multiple times, and in few cases are tested on a regular basis (e.g. annual, monthly). The same well may have been tested for different purposes (e.g., research, regulatory, or to provide owner information), but most often, regulatory programs drive water quality testing.

For this GSP, all available water quality data, obtained from the numerous available sources, are first grouped by the well from where the measurements were taken. Wells are then grouped into monitoring well type categories. These include:

- *Public water supply wells*: A public water system well provides water for human consumption including domestic, industrial, or commercial uses to at least 15 service connections or serves an average of at least 25 people for at least 60 days a year. A public water system may be publicly or privately owned. These wells are tested at regular intervals for a variety of water quality constituents . Data are publicly available through online databases.
- *State small water supply wells*: Wells providing water for human consumption, serving 5 to 14 connections. These wells are tested at regular intervals – but less often than public water supply wells – for bacteriological indicators and salinity. Data are publicly available through the County of Siskiyou Environmental Health Division but may not be available through online databases.

- *Domestic wells*: For purposes of this GSP, this well type category includes wells serving water for human consumption in a single household or for up to 4 connections. These wells are not typically tested. When tested, test results are not typically reported in publicly available online databases, except when these data are used for individual studies or research projects.
- *Agricultural wells*: Wells that provide irrigation water, stock water, or other water for other agricultural uses, but are not typically used for human consumption. When tested, test results are not typically reported in publicly available online databases, except when these data are used for individual studies or research projects.
- *Contamination site monitoring wells*: Monitoring wells installed at regulated hazardous waste sites and other potential contamination sites (e.g., landfills) for the purpose of site characterization, site remediation, and regulatory compliance. These wells are typically completed with 2 in- (5 cm) or 4 in- (10 cm) diameter polyvinyl chloride (PVC) pipes and screened at or near the water table. They may have multiple completion depths (multi-level monitoring), but depths typically do not exceed 200 ft (60 m) below the water table. Water samples are collected at frequent intervals (monthly, quarterly, annually) and analyzed for a wide range of constituents related to the type of contamination associated with the hazardous waste site.
- *Research monitoring wells*: Monitoring wells installed primarily for research, studies, information collection, ambient water quality monitoring, or other purposes. These wells are typically completed with 2in- (5 cm) or 4 in- (10 cm) diameter PVC pipes and screened at or near the water table. They may have multiple completion depths (multi-level monitoring), but depths typically do not exceed 200 ft (60 m) below the water table.

Data Sources for Characterizing Groundwater Quality

The assessment of groundwater quality for the Basin was prepared using available information obtained from the California Groundwater Ambient Monitoring and Assessment (GAMA) Program Database, which includes water quality information collected by the California Department of Water Resources (DWR); State Water Resources Control Board (SWRCB), Division of Drinking Water (DDW); Lawrence Livermore National Laboratory (LLNL) special studies; and the United States Geological Survey (USGS). These data were augmented with data supplied by the California Department of Fish and Wildlife (CDFW). In addition to utilizing GeoTracker GAMA for basin-wide water quality assessment, GeoTracker was searched individually to identify data associated with groundwater contaminant plumes. Groundwater quality data, as reported in GeoTracker GAMA, have been collected in the Basin since 1952. Appendix 2-B figures show the Basin boundary, as well as the locations and density of all wells with available water quality data for the GSP constituents of interest collected in the past 30 years (1990-2020). Within the Basin, a total of 53 wells were identified and used to characterize existing water quality based on a data screening and evaluation process that identified constituents of interest important to sustainable groundwater management.

Classification of Water Quality

To determine what groundwater quality constituents in the Basin may be of current or near-future concern, a reference standard was defined to which groundwater quality data were compared. Numeric thresholds are set by state and federal agencies to protect water users (environment, humans, industrial and agricultural users). The numeric standards selected for the current analysis represent all relevant state and federal drinking water standards and state water quality objectives for the constituents evaluated and are consistent with state and North Coast Regional Water Quality Control Board (Regional Water Board) assessment of beneficial use protection in groundwater. The standards are compared against groundwater quality data to determine if a constituent's concentration exists above or below the threshold and is currently impairing or may impair beneficial uses designated for groundwater at some point in the foreseeable future.

Although groundwater is utilized for a variety of purposes, the use for human consumption requires that supplies meet strict water quality regulations. The federal Safe Drinking Water Act (SDWA) protects surface water and groundwater drinking water supplies. The SDWA requires the United States Environmental Protection Agency (USEPA) to develop enforceable water quality standards for public water systems. The regulatory standards are named maximum contaminant levels (MCLs) and they dictate the maximum concentration at which a specific constituent may be present in potable water sources. There are two categories of MCLs: Primary MCLs (1^o MCL), which are established based on human health effects from contaminants and are enforceable standards for public water supply wells and state small water supply wells; and Secondary MCLs (2^o MCL), which are unenforceable standards established for contaminants that may negatively affect the aesthetics of drinking water quality, such as taste, odor, or appearance.

The State of California has developed drinking water standards that, for some constituents, are stricter than those set at the federal level. The Basin is regulated under the North Coast Regional Water Quality Control Board (Regional Water Board) and relevant water quality objectives (WQOs) and beneficial uses are contained in the Water Quality Control Plan for the North Coast Region (Basin Plan). For waters designated as having a Municipal and Domestic Supply (MUN) beneficial use, the Basin Plan specifies that chemical constituents are not to exceed the Primary and Secondary MCLs established in Title 22 of the California Code of Regulations (CCR) (hereafter, Title 22). The MUN beneficial use applies to all groundwater in Butte Valley. The Basin Plan also includes numeric WQOs and associated calculation requirements in groundwater for select constituents in the Butte Valley aquifer.

Constituents may have one or more applicable drinking water standard or WQOs. For this GSP, a prioritization system was used to select the appropriate numeric threshold. This GSP used the strictest value among the state and federal drinking water standards and state WQOs specified in the Basin Plan for comparison against available groundwater data. Constituents that do not have an established drinking water standard or WQO were not assessed. The complete list of constituents, numeric thresholds, and associated regulatory sources used in the water quality assessment can be found in Appendix 2-B. Basin groundwater quality data obtained for each well selected for evaluation were compared to a relevant numeric threshold.

Maps were generated for each constituent of interest showing well locations and the number of measurements for a constituent collected at a well (see Appendix 2-B). Groundwater quality data were further categorized by magnitude of detection as a) not detected, b) detected below half of the relevant numeric threshold, c) detected below the relevant numeric threshold, and d) detected above the relevant numeric threshold.

To analyze groundwater quality that is representative of current conditions in the Basin, several additional filters were applied to the dataset. Though groundwater quality data are available dating back to 1952 for some constituents, the data evaluated were limited to those collected from 1990 to 2020. Restricting the time span to data collected in the past 30 years increases confidence in data quality and focuses the evaluation on information that is considered reflective of current groundwater quality conditions. A separate series of maps was generated for each constituent of interest showing well locations and the number of groundwater quality samples collected among the wells during the past 30 years (1990-2020) (see Appendix 2-B).

Finally, for each constituent, an effort was undertaken to examine changes in groundwater quality over time at a location. Constituent data collected in the past 30 years (1990-2020) were further limited to wells that have two or more water quality measurements. A final series of maps and timeseries plots showing data collected from 1990 to 2020 were generated for each constituent and well combination showing how data compare to relevant numeric thresholds. These maps and timeseries plots for each constituent of interest are provided in Appendix 2-B.

The approach described above was used to consider all constituents of interest and characterize groundwater quality in the Basin. Appendix 2-B contains additional detailed information on the methodology used to assess groundwater quality data in the Basin.

Basin Groundwater Quality

All groundwater quality constituents monitored in the Basin that have a numeric threshold were initially considered. The evaluation process described above showed the following parameters to be important to sustainable groundwater management in the Basin: 1,2 dibromoethane (EDB), arsenic, benzene, boron, nitrate, and specific conductivity. The following subsections present information on these water quality parameters in comparison to their relevant regulatory thresholds and how the constituent may potentially impact designated beneficial uses in different regions of the Basin. Table 1.5 contains the list of constituents of interest identified for the Basin and their associated regulatory threshold.

Table 1.5: Regulatory water quality thresholds for constituents of interest in the Butte Valley Groundwater Basin

Constituent	Regulatory Basis	Water Quality Threshold
1,2 Dibromoethane (µg/L)	Title 22	0.05
Arsenic (µg/L)	Title 22	10
Benzene (µg/L)	Title 22	1
Boron (mg/L)	Basin Plan 90% Upper Limit	0.2
Boron (mg/L)	Basin Plan 50% Upper Limit	0.1
Nitrate (mg/L as N)	Title 22	10
Specific Conductivity (µmhos/cm)	Basin Plan 90% Upper Limit	800
Specific Conductivity (µmhos/cm)	Basin Plan 50% Upper Limit	400

Additional maps and timeseries plots showing all evaluated groundwater quality constituents are presented in Appendix 2-B, including maps of select chemicals typically found associated with point-source contamination, including manufactured organic chemical compounds.

1,2 DIBROMOETHANE (EDB)

The main sources of 1,2 dibromoethane (also known as ethylene dibromide (EDB)) are anthropogenic, stemming from its use as a pesticide and historical use as a gasoline additive. Though most EDB in the environment is from anthropogenic sources, small quantities may be produced in the ocean from natural processes. EDB can enter groundwater through industrial or effluent discharges or through leaching from soils. Potential health effects from exposure to EDB in drinking water include damage to the stomach lining and ingestion of EDB in very high levels is toxic.

Recent data for EDB, collected from 1990 to 2020, is available in municipal and monitoring wells near Dorris, a well in Mount Hebron and a well near the southwest boundary of the Basin (Appendix 2-B). Exceedances of the 0.05 microgram per liter (μg/L) 1^{o} MCL for EDB are highly localized and are restricted to the monitoring wells in Dorris that are associated with known contaminated sites. As shown in Appendix 2-B, though there is some variation, concentrations are generally decreasing over time.

ARSENIC

Arsenic is a naturally occurring element in soils and rocks and has been used in wood preservatives and pesticides. Classified as a carcinogen by the USEPA, the International Agency for Research on Cancer (IARC) and the Department of Health and Human Services (DHHS), arsenic in water can be problematic for human health. Drinking water with levels of inorganic arsenic from 300 to 30,000 parts per billion (ppb; 1 ppb = 1 μg/L) can have effects including stomach irritation and decreased red and white blood cell production (CITE ASTDR). Long-term exposure can lead to skin changes and may lead to skin cancer. The Title 22 1^{o} MCL for arsenic is 10 μg/L.

Arsenic data in the Basin, between 1990 and 2020, are limited to municipal wells in Dorris, Macdoel and Mount Hebron, with several measurements near and along the eastern Basin boundary (Appendix 2-B). Monitoring results for one well in Dorris exceeded the 1^{o} MCL of 10 μg/L for arsenic. The three additional wells with arsenic data all have results below the 1^{o} MCL, as shown in Appendix 2-B. This is consistent with the results of a recent study that evaluated trends in groundwater quality for 38 constituents in public supply wells throughout California, the results of which also show one well near Dorris with “high” arsenic levels (greater than 10 μg/L) based on measurements between 1995 to 2014 (Jurgens et al. 2020). Based on available data, arsenic concentrations are generally observed to be stable or decreasing, as shown in Appendix 2-B.

BENZENE

Benzene in the environment generally originates from anthropogenic sources, though lesser amounts can be attributed to natural sources including forest fires (Tilley and Fry 2015). Benzene is primarily used in gasoline and in the chemical and pharmaceutical industries and is commonly associated with leaking underground storage tank (LUST) sites. Classified as a known human carcinogen by the USEPA and the Department of Health and Human Services, exposure to benzene has been linked to increased cases of leukemia in humans (Agency for Toxic Substances and Disease Registry (ATSDR) 2007). Long term exposure can affect the blood, causing loss of white blood cells and damage to the immune system or causing bone marrow damage, resulting in a decrease in the production of red blood cells and potentially leading to anemia. Acute exposure can cause dizziness, rapid or irregular heartbeat, irritation to the stomach and vomiting and can be fatal at very high concentrations (Agency for Toxic Substances and Disease Registry (ATSDR) 2007). The 1^{o} MCL for benzene is 1 milligram per liter (μg/L), as defined in Title 22.

Recent monitoring for benzene (from 1990 to 2020) includes background monitoring in municipal wells for Mount Hebron and Dorris and in monitoring wells associated with the known contaminated sites. Monitoring data collected in the municipal wells are all below the 1^{o} MCL. As shown in Appendix 2-B, measurements that exceed the 1^{o} MCL are all in the monitoring wells near Dorris, associated with known contaminated sites. Based on available data, these exceedances are highly localized and can be attributed to the contaminant plumes from the known contaminated sites, discussed in Section 2.2.3. Though there is some variability, benzene concentrations are generally seen to be decreasing over time, as illustrated in Appendix 2-B.

BORON

Boron in groundwater can come from both natural and anthropogenic sources. As a naturally occurring element in rocks and soil, boron can be released into groundwater through natural weathering processes. Boron can be released into the air, water or soil from anthropogenic sources including industrial wastes, sewage and fertilizers. If ingested at high levels, boron can affect the stomach, liver, kidney, intestines and brain (Agency for Toxic Substances and Disease Registry (ATSDR) 2010). The Basin Plan contains a 50 % upper limit (UL) for boron of 0.3 mg/L and a 90% UL of 1.0 mg/L.

Over the past 30 years (from 1990 to 2020), concentrations of boron in groundwater have been measured throughout the Basin. Numerous measurements exceed the 50% and 90% upper limits specified in the Basin Plan (Appendix 2-B). While recent monitoring data for boron is distributed throughout the Basin, wells with multiple measurements are mostly limited to areas near Macdoel and Mount Hebron, with an additional two wells at the western and eastern Basin boundaries. As shown in Appendix 2-B, concentrations of boron over time are seen to be relatively stable or decreasing.

SPECIFIC CONDUCTIVITY

Specific conductivity (electrical conductivity normalized to a temperature of 25°C), quantifies the ability of an electric current to pass through water and is an indirect measure of the dissolved ions in the water. Natural and anthropogenic sources contribute to variations in specific conductivity in groundwater. Increases of specific conductivity in groundwater can be due to dissolution of rock and organic material and uptake of water by plants, as well as anthropogenic activities including the application of fertilizers, discharges of wastewater and discharges from septic systems or industrial facilities. High specific conductivity can be problematic as it can have adverse effects on plant growth and drinking water quality.

Specific conductivity measurements, obtained from 1990 to 2020, are limited to areas near Dorris, Macdoel and Mount Hebron, with several additional locations near the Basin boundary (Appendix 2-B). While some measurements do exceed the Basin Plan 50% UL of 400 micromhos per centimeter (µmhos/cm), all measurements are below the Basin Plan 90% UL of 900 µmhos/cm. Available data are relatively stable over time, as seen in Appendix 2-B. Additional monitoring wells in different areas of the Basin are needed to evaluate spatial and temporal trends in specific conductivity.

NITRATE

Nitrate is one of the most common groundwater contaminants and is generally the water quality constituent of greatest concern. Natural concentrations of nitrate in groundwater are generally low. In agricultural areas, application of fertilizers or animal waste containing nitrogen can lead to elevated nitrate levels in groundwater. Other anthropogenic sources, including septic tanks, wastewater discharges, and agricultural wastewater ponds may also lead to elevated nitrate levels. Nitrate poses a human health risk, particularly for infants under the age of 6 months who are susceptible to methemoglobinemia, a condition that affects the ability of red blood cells to carry and distribute oxygen to the body. The 1° MCL for nitrate is 10 mg/L as N.

Recent nitrate data collected in the Basin (1990–2020) are concentrated near Dorris, Macdoel and Mount Hebron, with limited data throughout the rest of the Basin (Appendix 2-B). Exceedances are seen to primarily occur in the municipal wells near Macdoel and Mount Hebron; no measurements exceeded the 1 ^{o} MCL for nitrate in the northern section of the Basin. In wells with multiple monitoring events, nitrate concentrations can be seen to generally be decreasing or relatively stable, as illustrated in Appendix 2-B. However, additional monitoring data are needed for a complete determination of spatial and temporal trends in nitrate concentrations.

Contaminated Sites

Groundwater monitoring activities also take place in the Basin in response to known and potential sources of groundwater contamination, including underground storage tanks. These sites are subject to oversight by regulatory entities, and any monitoring associated with these sites can provide opportunities to improve the regional understanding of groundwater quality. To identify known plumes and contamination within the Basin, SWRCB GeoTracker was reviewed for active clean-up sites of all types. The GeoTracker database shows one open Leaking Underground Storage Tank (LUST) site and two open cleanup program sites with potential or actual groundwater contamination located within the Basin.

Underground storage tanks (UST) are containers and tanks, including piping, that are completely or significantly below ground and are used to store petroleum or other hazardous substances. Soil, groundwater and surface water near the site can all be affected by releases from USTs. A UST becomes a potential hazard when any portion of it leaks a hazardous substance at which point it is classified as LUST. The main constituents of concern due to contamination plumes in the Basin are tetrachloroethylene (PCE) and contaminants associated with releases of gasoline including fuel oxygenates such as methyl tertiary butyl ether (MTBE), benzene, toluene, ethylbenzene and xylenes (this collection of organic compounds is commonly referred to as “BTEX”). Other constituents of concern related to gasoline are lead scavenging compounds, including EDB and 1, 2-dichlororethane.

A brief overview of notable information related to contaminated sites in the Basin is provided below; however, an extensive summary for each of the contamination sites is not presented. The location of the contaminated sites are shown in Figure 1.24.

Dorris PCE Plume

The case (No. 1NSI23) for this cleanup site was opened in September 2013, after tetrachloroethylene (PCE) from an unidentified source was detected in LUST monitoring wells for the Shell site. This case is currently open and inactive (there are currently no regulatory oversight efforts by the Lead Agency).

Calzona Tankways

The case (No. 1NSI045) has been open for this cleanup site since 1988 with gasoline as the potential contaminant of concern. In 2011, the status of this case was changed to open and inactive.

Shell, Dorris

A former petroleum fueling facility, this LUST site is currently vacant. The case (No. 1TSI171) for this site was opened in 1999 following a reported unauthorized petroleum release after removal of seven underground storage tanks (USTs). The petroleum release is known to have affected the soil and shallow groundwater and 11 groundwater monitoring wells have been used to evaluate conditions at the site. Remediation activities have included pilot tests of bioventing and ozone sparging in 2007 and 2008, and full -scale ozone sparging from 2013 to 2019. The most recent review summary report from October 2019 notes that the site does not meet criteria for closure as groundwater quality objectives are not being meet and due to a lack of soil and soil vapor data.

While current data is useful to determine local groundwater conditions, additional monitoring is necessary to develop a basin-wide understanding of groundwater quality, and greater spatial and temporal coverage would improve the ability to evaluate trends. From a review of all available information, none of the sites listed above have been determined to have an impact on the aquifer, and the potential for groundwater pumping to induce contaminant plume movement towards water supply wells is negligible. Currently, there is not enough information to determine if the contaminants are sinking or rising with groundwater levels.

2.2.2.4 Seawater Intrusion Conditions

Due to the distance between Butte Valley and the Pacific Ocean, saltwater intrusion is not evident nor of concern and therefore, is not applicable to the Basin.

2.2.2.5 Land Subsidence Conditions

Land subsidence is the lowering of the ground surface elevation. This is often caused by pumping groundwater from within or below thick clay layers. Land subsidence can be elastic or inelastic, meaning that the lithologic structure of the aquifer can compress or expand elastically due to water volume changes in the pore space or is detrimentally collapsed when water is withdrawn (inelastic). Inelastic subsidence is generally irreversible. Elastic subsidence is generally of a smaller magnitude of change, and is reversible, allowing for the lowering and rising of the ground surface and can be cyclical with seasonal changes.

While lake sediments in the Valley floor have some inelastic subsidence risk as groundwater levels drop, land subsidence is not known to be historically or currently significant in the Butte Valley Groundwater Basin. While groundwater elevations have steadily declined in the past few decades, noticeable land subsidence has not been observed in the Valley. BVID has not seen any pipe breakages nor loss in conveyance capacity in recent memory, which suggests that no noticeable land subsidence has occurred in the BVID management area (Steve Lutz to Bill Rice on January 4th 2021, personal communication via phone). The City of Dorris has not observed any influence of land subsidence on city pipes (Pers. Comm., Carol Mckay, City of Dorris September 26, 2019).

Data Sources

Interferometric Synthetic Aperture Radar (InSAR) is a satellite-based remote sensing technique that measures vertical ground surface displacement changes at high degrees of measurement resolution and spatial detail. DWR has made InSAR satellite data available on their SGMA Data Viewer web map in two different forms: point data and a Geographic Information System (GIS) raster, which is point data interpolated into a continuous image or map (DWR 2019c). The point

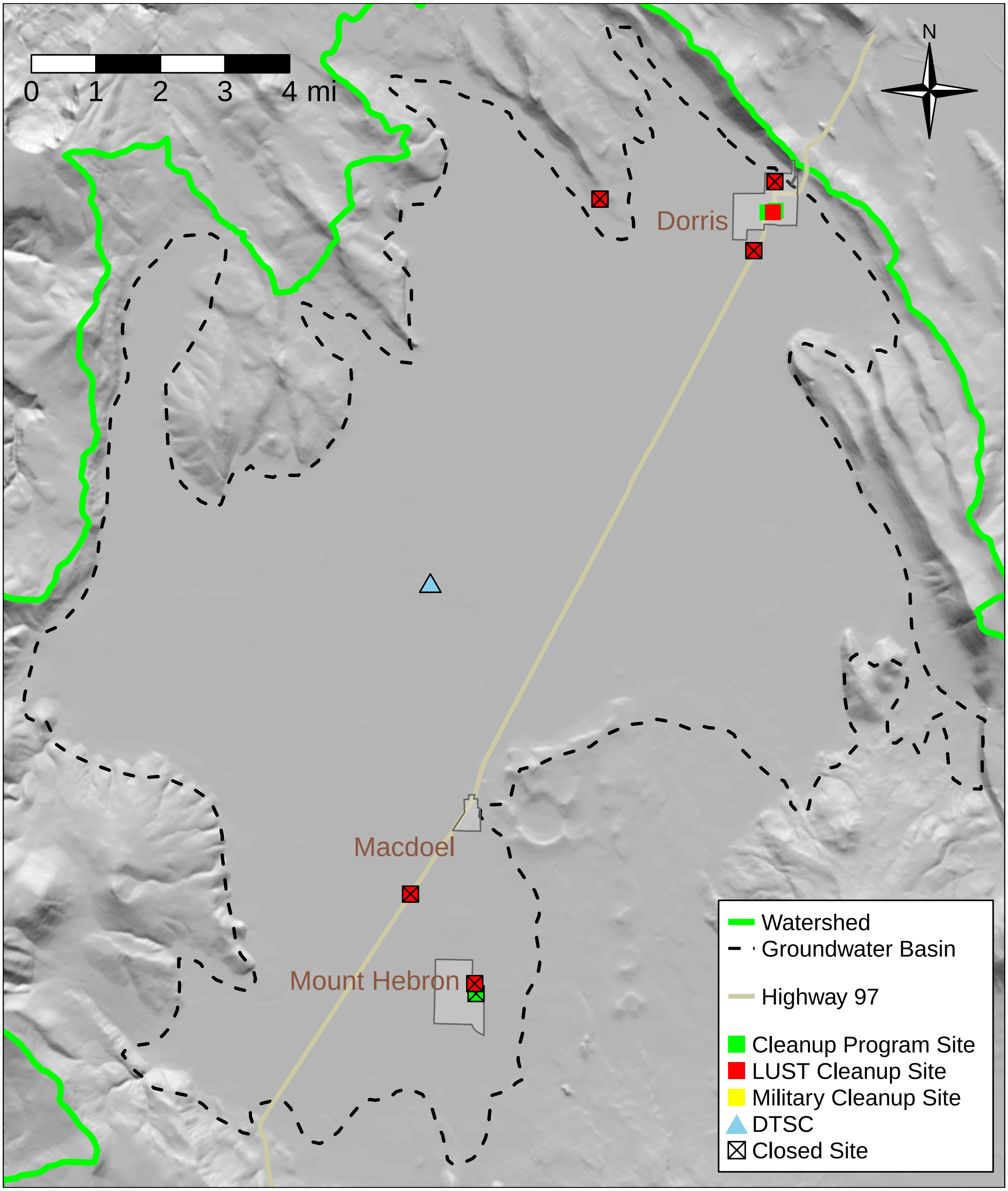


Figure 1.24: Contaminated Sites

data are the observed average vertical displacements within a 100 by 100 meter area. The raster datasets were processed by TRE ALTAMIRA under contract by DWR for all SGMA High- and Medium-Priority groundwater basins. These are the only data used for estimating subsidence in this GSP as they are the only known subsidence-related dataset available for this Basin. The DWR-funded TRE Altamira InSAR dataset provides estimates of total vertical displacement from June 2015 to September 2019 and is shown in Figure 1.19 using raster data from the TRE Altamira report (DWR 2019c). It is important to note that the provided DWR/TRE Altamira InSAR data reflect both elastic and inelastic subsidence and it can be difficult to isolate a signal solely for only the elastic subsidence amplitude. Visual inspection of monthly changes in ground elevations typically suggest that elastic subsidence is largely seasonal and can potentially be factored out of the signal, if necessary.

Data Quality

The TRE Altamira InSAR data provided by DWR are subject to compounded measurement and raster conversion errors. DWR has stated that for the total vertical displacement measurements, the errors are as follows (Brezing, personal communication):

1. The error between InSAR data and continuous GPS data is 16 mm (0.052 feet) with a 95% confidence level.
2. The measurement accuracy when converting from the raw InSAR data to the maps provided by DWR is 0.048 feet with 95% confidence level.

The addition of the both of these errors results in the combined error is 0.1 feet. While not a robust statistical analysis, it does provide a potential error estimate for the TRE Altamira InSAR maps provided by DWR. A land surface change of less than 0.1 ft is within the noise of the data and is likely not indicative of groundwater-related subsidence in the basin.

Data Analysis

The total subsidence raster used for this GSP uses the InSAR point data (DWR 2019c). The point data, which represent approximate areas of 328 x 328 ft (100 x 100 m) squares, are interpolated to a raster with a grid spacing of approximately 3,281 x 3,281 ft (1,000 x 1,000 m) squares. This is a lower resolution than the one available as the DWR/TRE Altamira raster on the online SGMA Data Viewer (DWR 2019c). This effectively smooths out the larger amplitude, small foot print signals. Groundwater extraction-related signals would typically be expected to be larger in scale that these small foot print signals. The subsidence anomaly observed in Butte Valley for the period June 2015 to September 2019 represents an approximately 1,600 x 1,600 ft signal. For comparison, this is not much larger than the area of one center-pivot irrigation plot.

Using the TRE Altamira InSAR Dataset provided by DWR, it is observed that the majority of the vertical displacement values in the Basin are mostly near-zero, especially given the range of 0.1 ft to -0.1 feet of estimated error for the data (see Figure 1.25). These values are largely within or less than the same order of magnitude of the combined data and raster conversion error, suggesting essentially noise or, at least non-groundwater related activity, in the data. Any actual signals at this level could be due to a number of possible activities, including land use change and/or agricultural operational activities at the field scale. For perspective, during this same period, sections of the San Joaquin Valley in California's Central Valley experienced up to ~3.5 feet of subsidence.

However, there is a localized hotspot near Dorris showing subsidence that may be of a magnitude above the potential instrument error of the InSAR instrumentation (DWR 2019c). Initial estimates of land subsidence between June 2015 to September 2019 are shown in Figure 1.19 using raster data from the DWR/TRE Altamira report (DWR 2019c).

Following detailed inspection of the DWR provided point subsidence data, satellite image review, and communication with the GSA Advisory Board, it seems likely that parcels APN 003-330-100 and 003-210-070 underwent sufficient grading and leveling during the period of record that may constitute a source of error in the apparent subsidence values shown in Figure 1.19. Subsidence throughout the Basin will require periodic reevaluation. At this time, subsidence in and around the highlighted parcels is slightly above potential instrument error that exists in the InSAR data and is either an artifact of significant grading or actual subsidence. The maximum observed subsidence shown in Figure 1.19 is approximately 0.15 ft (46 millimeters (mm)) between June 2015 to September 2019 in the area west of Dorris.

2.2.2.6 Identification of Interconnected Surface Water Systems

SGMA calls for the identification of interconnected surface waters (ISWs) in each GSP. ISWs are defined under SGMA as:

> *23 CCR § 351 (o): "Interconnected surface water" refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted.*

Several small streams and creeks flow discontinuously along the edges of Butte Valley, primarily on the southern and western flanks of the valley, but there are no recent public records for stream flow except estimates of diversions by water right holders. Historical monitoring of stream flow in Butte Creek at the National Water Information System (NWIS) gauge 11490500 is restricted to a period of record from 1952 to 1960. Records indicate historical peak flows during January to March in excess of 255 cubic feet per second (cfs) with summer time flows from July to September typically below 10 cfs. The lack of stream gage data for all creeks in the Basin is a major data gap that the GSA plans to address (see Appendix 3-A).

Surface water in the Valley is restricted to Meiss Lake and five creeks: Butte, Prather, Ikes, Harris, and Muskgrave (Figure 1.26). Only short stretches of Ikes, Harris, and Muskgrave Creeks lie within the Basin boundary before terminating at the Butte Valley Wildlife Area (BVWA) Perimeter Canal (Figure 1.7 and Figure 1.27). Section 2.2.1.9 provides an overview of these surface water bodies, many of which go dry in the summer and fall. Section 2.2.2.1 and Appendix 2-A show that historical groundwater level data is generally located far from surface waters. Water level elevations near potential ISWs has been identified as a data gap that the GSA plans to address (see Appendix 3-A).

Generally for all these surface waters, the nearest groundwater contours are deeper than 30 feet (see Appendix 2-A). The nearest wells to Ikes, Harris, and Muskgrave Creeks have groundwater levels typically deeper than 40 feet below ground surface (bgs). Wells to the north and south of Meiss Lake range from 25 to 50 ft bgs, with projected groundwater surfaces of Meiss Lake greater

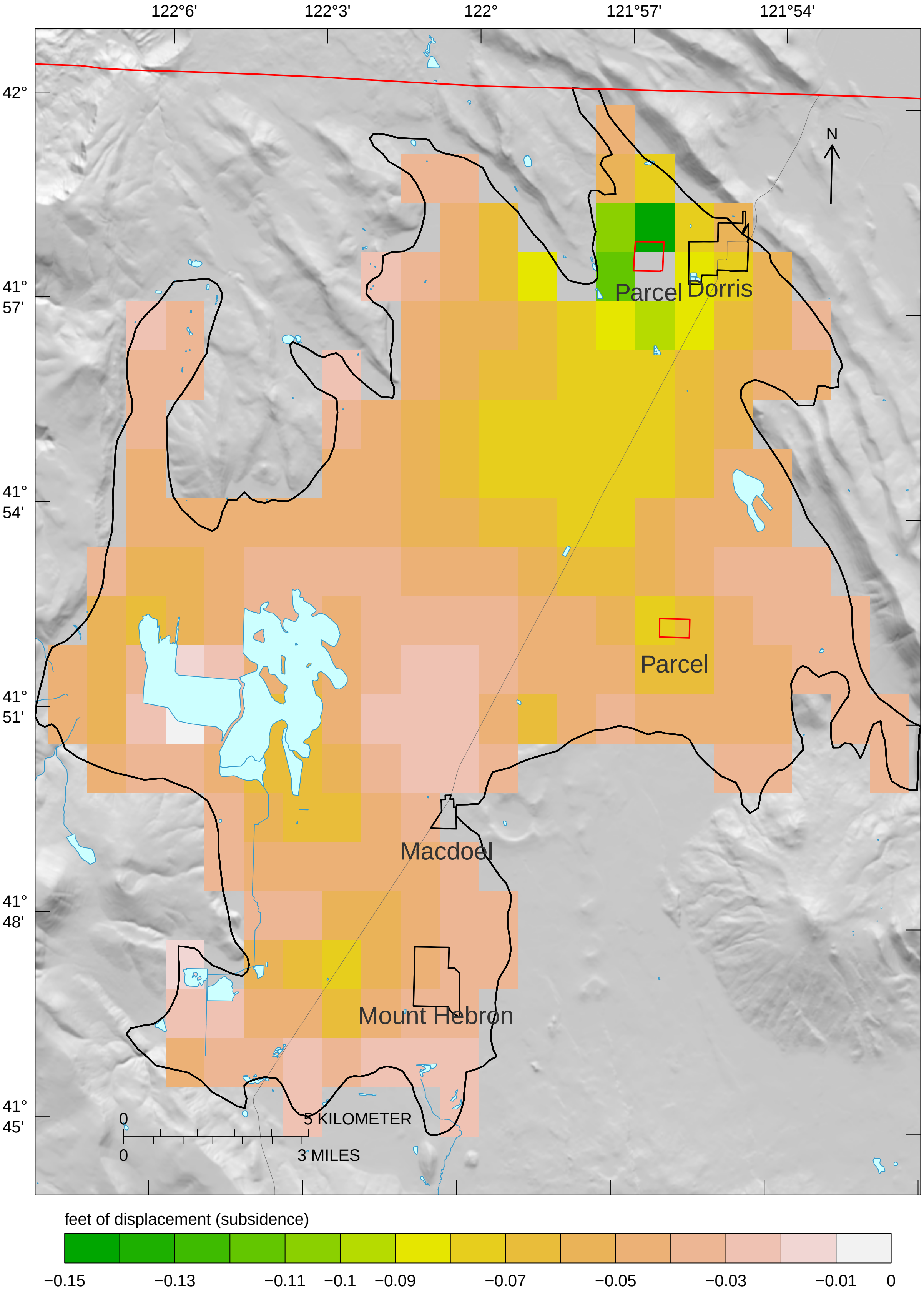


Figure 1.25: InSAR satellite measured total vertical subsidence (feet) between June 2015 and September 2019. Note that the processed InSAR instrument and GIS conversion error is roughly +/-0.1 feet.

than 30 feet. Groundwater level data at Prather Creek have groundwater levels greater than 30 feet. Due to the deep local groundwater levels, these surface waters are therefore tentatively assumed disconnected from the Basin groundwater aquifer. This assumption may be revised in the future as the GSA collects additional data and fills the discussed data gaps (see Appendix 3-A).

Butte Creek is a major surface water body in Butte Valley and terminates south of Mount Hebron, where all water is appropriated for irrigation. Large data gaps include the lack of historical flow within the Basin and no nearby groundwater level data. The nearest groundwater well to Butte Creek has groundwater levels ranging from 40 to 80 ft bgs (see Appendix 2-A). Studies of Butte Creek upstream of the Basin suggest that Butte Creek is a losing stream (USFS Kegg Meadow Restoration Reference). Until the above data gaps are addressed, Butte Creek is tentatively assumed disconnected from the Basin groundwater aquifer due to deep groundwater levels. Due to the importance of Butte Creek for irrigation and groundwater recharge within the Basin, the GSA is prioritizing addressing the stream gage and groundwater level data gaps (see Appendix 3-A). Future additional data will improve future analysis of Butte Creek as a potential ISW.

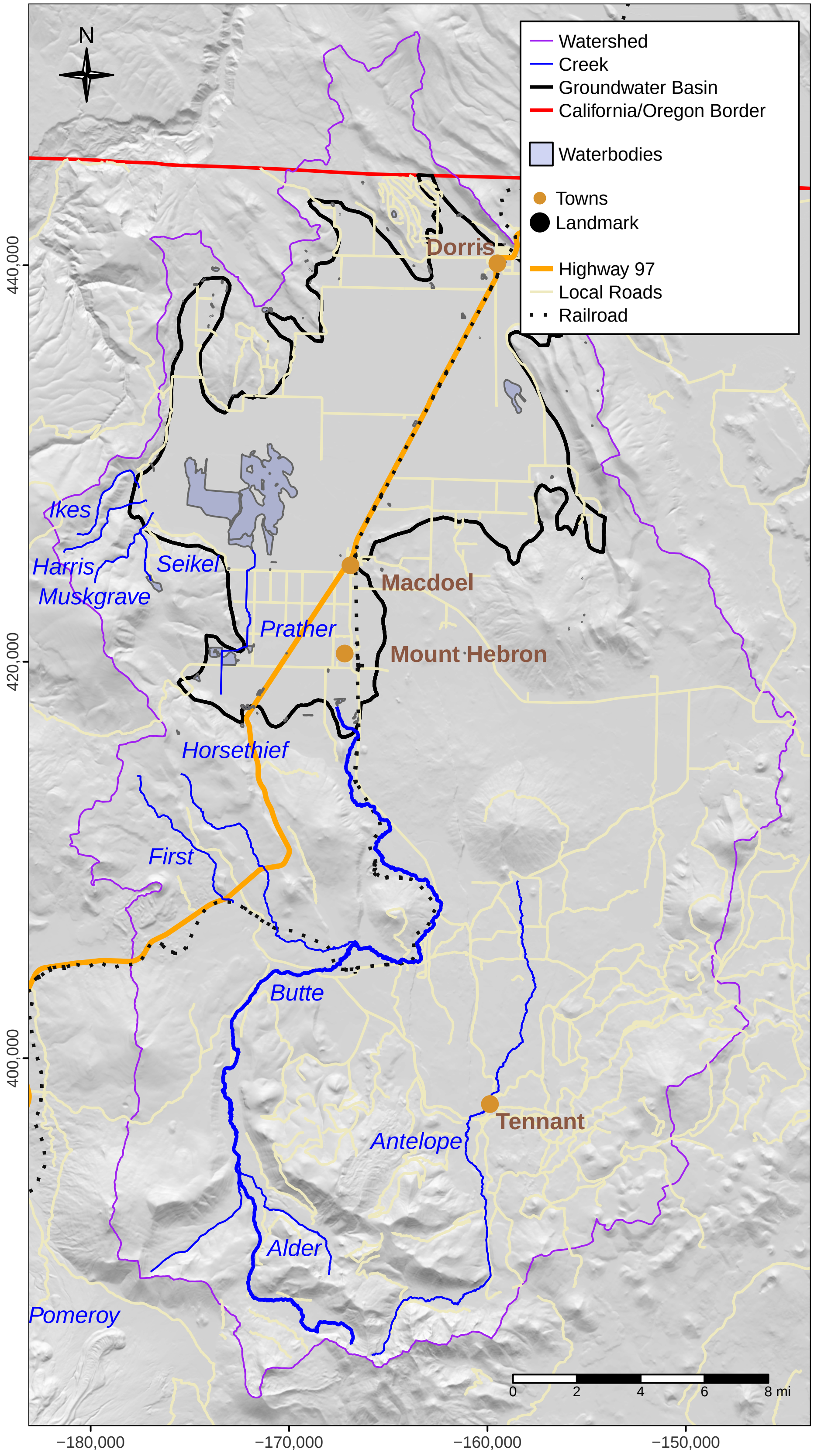


Figure 1.26: Surface Water in the Butte Valley Basin.

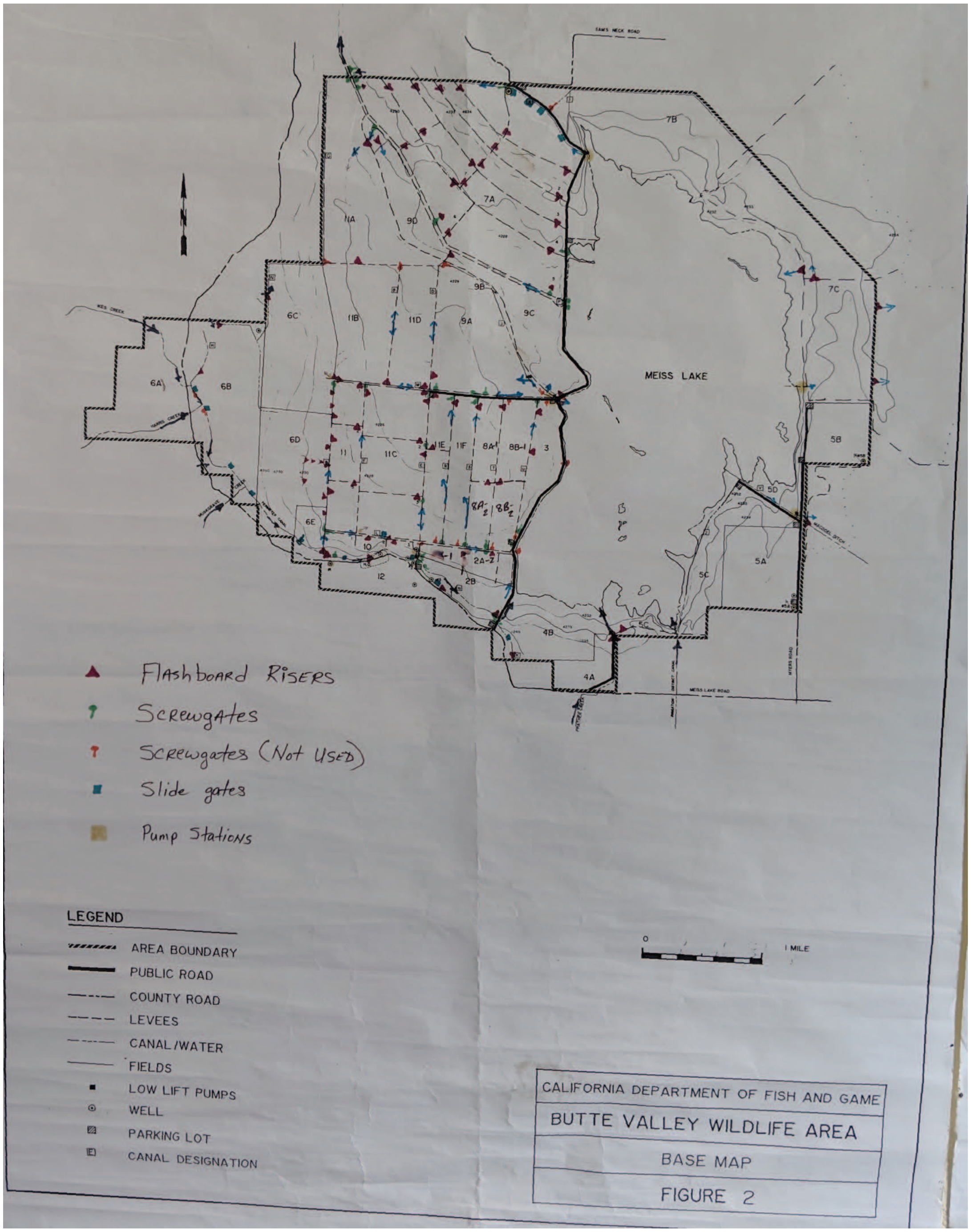


Figure 1.27: Photo of Butte Valley Wildlife Area (BVWA) map taken at the BVWA headquarters, showing that Ikes, Harris, and Muskgrave Creeks terminate at the BVWA Perimeter Canal. Prather Creek terminates in Meiss Lake.

2.2.2.7 Identification of Groundwater-Dependent Ecosystems

Section 354.16(g) of SGMA requires identification of groundwater dependent ecosystems (GDEs). Section 351(m) of these regulations refers to GDEs as *"ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface."* California Water Code 10727.4(l) further requires that a GSP describes and considers the impacts to GDEs.

In order to adequately consider potential effects of the potential effects of the management of regional groundwater resources on all beneficial uses and users of groundwater and interconnected surface water, including both human and natural beneficial uses, GDEs within the Basin area must be identified and potential effects of the Basin operations on GDEs must be determined. Such information is then used to establish Sustainable Management Criteria, improve the monitoring network, and define projects and management actions that help improve or maintain conditions for each GDE to achieve the sustainability goal in the basin, as discussed in Chapters 3, 4, and 5, respectively.

Major data gaps within the current analysis of groundwater-dependent ecosystems include unreliable or outdated habitat maps that require local knowledge and study and groundwater level data gaps near potential groundwater dependent ecosystems. The GSA presents a plan to address these data gaps in Chapter 4 and 5, and Appendix 3-A.

Environmental Beneficial Water Uses and Users within the Basin

To establish sustainable management criteria (SMCs) for the water level and for the depletion of interconnected surface water sustainability indicators, GSAs are required to prevent adverse impacts to beneficial users of groundwater and interconnected surface water, including environmental uses and users. Thus, identifying these uses and users is the first step to address undesirable results due to water level declines or surface water depletions from groundwater pumping.

The Basin encompasses two California ecoregions as identified by USEPA Level III Ecoregions of California (Griffith, 2016):

- Cascade (Ecoregion 4), which covers approximately 1.2% of the Basin area in the west and southwest. This ecoregion is characterized by broad, easterly trending valleys, a high plateau in the east, as well as both active and dormant volcanoes. Its moist, temperate climate supports an extensive and highly productive coniferous forest, while containing subalpine meadows at high elevations.
- Eastern Cascades Slopes and Foothills (Ecoregion 9), which covers the majority of the Basin. This region is in the rain shadow of the Cascade Range, with a more continental climate compared to ecoregions to the west, with greater temperature extremes, less precipitation, and frequent fires. Volcanic cones, plateaus, and buttes are common. Areas of cropland and pastureland in lake basins and larger river valleys provide habitat for migrating waterfowl, such as sandhill cranes, ducks, and geese.

Per 23 California Code of Regulations section 354.8(a)(3), CDFW recommends identifying Department-owned or Department-managed lands within the Basin, and carefully considering all environmental beneficial uses and users of water on Department lands to ensure fish and wildlife resources are being considered when developing the GSP. In the Basin, CDFW owns the Butte Valley Wildlife Area and manages Meiss Lake. Additionally, U.S. Forest Service and Bureau of Land Management own about 23.3% and 0.1% of the Basin area, respectively (Figure 1.2).

Freshwater Species within the Basin

The Nature Conservancy has provided a list of freshwater species located within each groundwater basin in California and the Butte Valley Wildlife Area (BVWA) tracks species that visit the wildlife area. Many bird species visit Butte Valley because Meiss Lake and BVWA are part of the Pacific Flyway for migrating birds. Based on the combined freshwater species lists, there are a total of thirty-seven species identified by the federal or state governments as endangered, threatened, species of special concern, or watch list within the Basin, including those under review or in the candidate or petition process. Of these species two are endangered species, four are designated as threatened, twenty-two are species of concern or special species, and nine are included on the watch list (Table 1.6) [2009 BVWA Plan Addendum; TNC (2021); CDFW (2021c); CDFW (2021b); CDFW (2021a)].

The predicted habitat for each of these species were evaluated using CDFW's Biogeographic Information and Observation System (BIOS) Viewer, with input from Butte Valley Wildlife Area. BIOS houses many biological and environmental datasets including the California Natural Diversity Database (CNDDB), which is an inventory of the status and locations of rare plants and animals in California. Local knowledge from BVWA indicates bald eagles are common year-round in BVWA, with dozens of eagles in the winter and successful nesting. American white pelicans and yellow headed blackbirds are abundant in the spring and summer and yellow-headed blackbirds nest in BVWA. Colonial-nesting waterbirds nest on the natural islands in Meiss Lake when water is present. No nesting occurs when the lake is dry. During wet cycles, nesting bird species include ring-billed gulls, California gulls (6,000 combined gull nests), Forster's terns (133 nests), double-crested cormorants (124 nests), Caspian terns (27 nests), and white pelicans (73 nests). The colony of white pelicans nesting is significant because, as of 2009, there were only 3 or 4 other colonies nesting in the state [2019 BVWA Plan Addendum; BVWA April 2021 GSP comments]. Additional birds such as ducks, pintail, goose and snow geese migrate through BVWA.

Brief descriptions about these species and their water demand are provided below:

- Bald Eagles live near waterbodies including estuaries, lakes, reservoirs, rivers, and occasionally by coastlines. They rely on a diet predominantly comprised of fish, but that also may include smaller birds including colonial waterbirds, waterfowl and small mammals. Populations have been threatened by hunting, loss of nesting habitat and poisoning from the pesticide DDT.
- The western pond turtle's preferred habitat is permanent ponds, lakes, streams or permanent pools along intermittent streams, associated with standing and slow-moving water. A potentially important limiting factor for the Western pond turtle is the relationship between water level and flow in off-channel water bodies, which can both be affected by groundwater pumping.

Because the basin is internally drained with no connection to the Klamath River or the sea, there are no anadromous fish populations.

Table 1.6: Freshwater Species in Butte Valley, as identified by Butte Valley Wildlife Area (2009 BVWA Plan Addendum), Nature Conservancy (TNC 2021) with species status verified by California Department of Fish and Wildlife (CDFW) statewide species lists (CDFW 2021 a,b,c).

Species	Group	Status	Notes
American White Pelican	Birds	Special Concern	Observed in Butte Valley Wildlife Area
An Amphipod	Crustaceans	Special	Nature Conservancy Butte Valley Basin List
Bald Eagle	Birds	Endangered (state only - under review)	Observed in Butte Valley Wildlife Area
Bank Swallow	Birds	Threatened	Nature Conservancy Butte Valley Basin List
Black Tern	Birds	Special Concern	Observed in Butte Valley Wildlife Area
Black-capped chickadee	Birds	Watch list	Observed in Butte Valley Wildlife Area
Burrowing Owl	Birds	Special Concern	Observed in Butte Valley Wildlife Area
California gull	Birds	Watch list	Observed in Butte Valley Wildlife Area
Canvasback	Birds	Special	Nature Conservancy Butte Valley Basin List
Columbia Yellowcress	Plants	Special	Observed in Butte Valley Wildlife Area
Cooper’s hawk	Birds	Watch list	Observed in Butte Valley Wildlife Area
Double-crested cormorant	Birds	Watch list	Observed in Butte Valley Wildlife Area
Golden eagle	Birds	Watch list	Observed in Butte Valley Wildlife Area
Greater sandhill crane	Birds	Threatened	Observed in Butte Valley Wildlife Area
Hot Springs Fimbry	Plants	Special	Nature Conservancy Butte Valley Basin List
Loggerhead shrike	Birds	Special Concern	Observed in Butte Valley Wildlife Area
Long-eared owl	Birds	Special Concern	Observed in Butte Valley Wildlife Area

Table 1.6: Freshwater Species in Butte Valley, as identified by Butte Valley Wildlife Area (2009 BVWA Plan Addendum), Nature Conservancy (TNC 2021) with species status verified by California Department of Fish and Wildlife (CDFW) statewide species lists (CDFW 2021 a,b,c). *(continued)*

Species	Group	Status	Notes
Newberry's Cinquefoil	Plants	Special	Nature Conservancy Butte Valley Basin List
Northern harrier	Birds	Special Concern	Observed in Butte Valley Wildlife Area
Northern spotted owl	Birds	Threatened	Observed in Butte Valley Wildlife Area
Oregon Spotted Frog	Herps	Special Concern	Observed in Butte Valley Wildlife Area
Osprey	Birds	Watch list	Observed in Butte Valley Wildlife Area
Pedate Checker-mallow	Plants	Endangered	Nature Conservancy Butte Valley Basin List
Prairie falcon	Birds	Watch list	Observed in Butte Valley Wildlife Area
Redhead	Birds	Special Concern	Nature Conservancy Butte Valley Basin List
Redhead duck	Birds	Special Concern	Observed in Butte Valley Wildlife Area
Sharp-shinned hawk	Birds	Watch list	Observed in Butte Valley Wildlife Area
Short-eared owl	Birds	Special Concern	Observed in Butte Valley Wildlife Area
Swainson's hawk	Birds	Threatened	Observed in Butte Valley Wildlife Area
Tricolored Blackbird	Birds	Special Concern	Nature Conservancy Butte Valley Basin List
Tule white-fronted goose	Birds	Special Concern	Observed in Butte Valley Wildlife Area
Vaux's swift	Birds	Special Concern	Observed in Butte Valley Wildlife Area
Wawona Riffle Beetle	Insects & other inverts	Special	Nature Conservancy Butte Valley Basin List
Western Pond Turtle	Herps	Special Concern	Observed in Butte Valley Wildlife Area
White-faced Ibis	Birds	Watch list	Observed in Butte Valley Wildlife Area

Table 1.6: Freshwater Species in Butte Valley, as identified by Butte Valley Wildlife Area (2009 BVWA Plan Addendum), Nature Conservancy (TNC 2021) with species status verified by California Department of Fish and Wildlife (CDFW) statewide species lists (CDFW 2021 a,b,c). *(continued)*

Species	Group	Status	Notes
Yellow warbler	Birds	Special Concern	Observed in Butte Valley Wildlife Area
Yellow-headed Blackbird	Birds	Special Concern	Observed in Butte Valley Wildlife Area

Management Approach

Groundwater dependent species prioritized for management primarily focus on riparian vegetation that is a groundwater-dependent ecosytem. Addressing the needs of these species is assumed to cover the needs of other special-status species such as the bank swallow, western pond turtle, and bald eagle that use riverine habitats during their life stage. Additionally, special status species that were not prioritized for management may exhibit flexible life-history strategies, are less susceptible to changing groundwater conditions, and/or have a different nature or lower degree of groundwater dependency. The species prioritized for management, shown in Table 1.7, are considered throughout this GSP. Other species listed in Table 1.6 and Table 1.7 are protected by federal or state agencies. As needed, the GSA will partner with those agencies to protect non-threatened, threatened, and endangered species within the Basin.

Table 1.7: GDE species prioritization for management, as identified by the Butte Valley Wildlife Area, Nature Conservancy, and CDFW (2009 BVWA Plan Addendum, TNC 2021, CDFW 2021 a,b,c). The GSA will work with relevant agencies to manage unprotected and protected species within the Basin.

Species Prioritized for Management	Species whose needs are covered through management for prioritized species
Unprotected species that depend on groundwater dependence ecosystems	American White Pelican
	An Amphipod
	Bald Eagle
	Bank Swallow
	Black Tern
	Black-capped chickadee
	Burrowing Owl
	California gull
	Canvasback
	Columbia Yellowcress
	Cooper’s hawk
	Double-crested cormorant
	Golden eagle
	Greater sandhill crane
	Hot Springs Fimbry
	Loggerhead shrike
	Long-eared owl
	Newberry’s Cinquefoil
	Northern harrier
	Northern spotted owl
	Oregon Spotted Frog
	Osprey
	Pedate Checker-mallow
	Prairie falcon

Table 1.7: GDE species prioritization for management, as identified by the Butte Valley Wildlife Area, Nature Conservancy, and CDFW (2009 BVWA Plan Addendum, TNC 2021, CDFW 2021 a,b,c). The GSA will work with relevant agencies to manage unprotected and protected species within the Basin. *(continued)*

Species Prioritized for Management	Species whose needs are covered through management for prioritized species
	Redhead
	Redhead duck Sharp-shinned hawk Short-eared owl Swainson's hawk Tricolored Blackbird
	Tule white-fronted goose Vaux's swift Wawona Riffle Beetle Western Pond Turtle White-faced Ibis
	Yellow warbler Yellow-headed Blackbird

Vegetative GDE Identification and Classification

The following section discusses the process of identifying potential GDEs and their classification based on the likelihood that they have access to groundwater. This analysis is carried out using three key building blocks:

- Mapping potential GDEs based on available resources;
- Assign rooting depths based on predominant assumed vegetation type;
- Establish representations of depth to groundwater;
- Identify potential areas where both, depth to groundwater, rooting depth, and presence of potential GDEs confirm likely groundwater-dependence.

The following subsections discuss the process of assembling these four building blocks.\

Mapped Potential GDEs

The primary resource used to establish the spatial extent of mapped GDEs is the Natural Communities Commonly Associated with Groundwater (NCCAG) dataset (https://gis.water.ca.gov/app/NCDatasetViewer/). The NCCAG dataset includes separate vegetation communities and wetland geospatial data layers for each of the groundwater basins identified in Bulletin 118. These layers identify potential locations of GDEs, which identify the phreatophytic vegetation, perennial streams, regularly flooded natural wetlands, and springs and seeps that may indicate the presence of/and or communities that and depend on groundwater, and therefore can be considered as indicators of GDEs. Representations of mapped potential GDEs from the NCCAG vegetation and wetlands datasets are presented in Figure 1.29 and Figure 1.28, respectively.

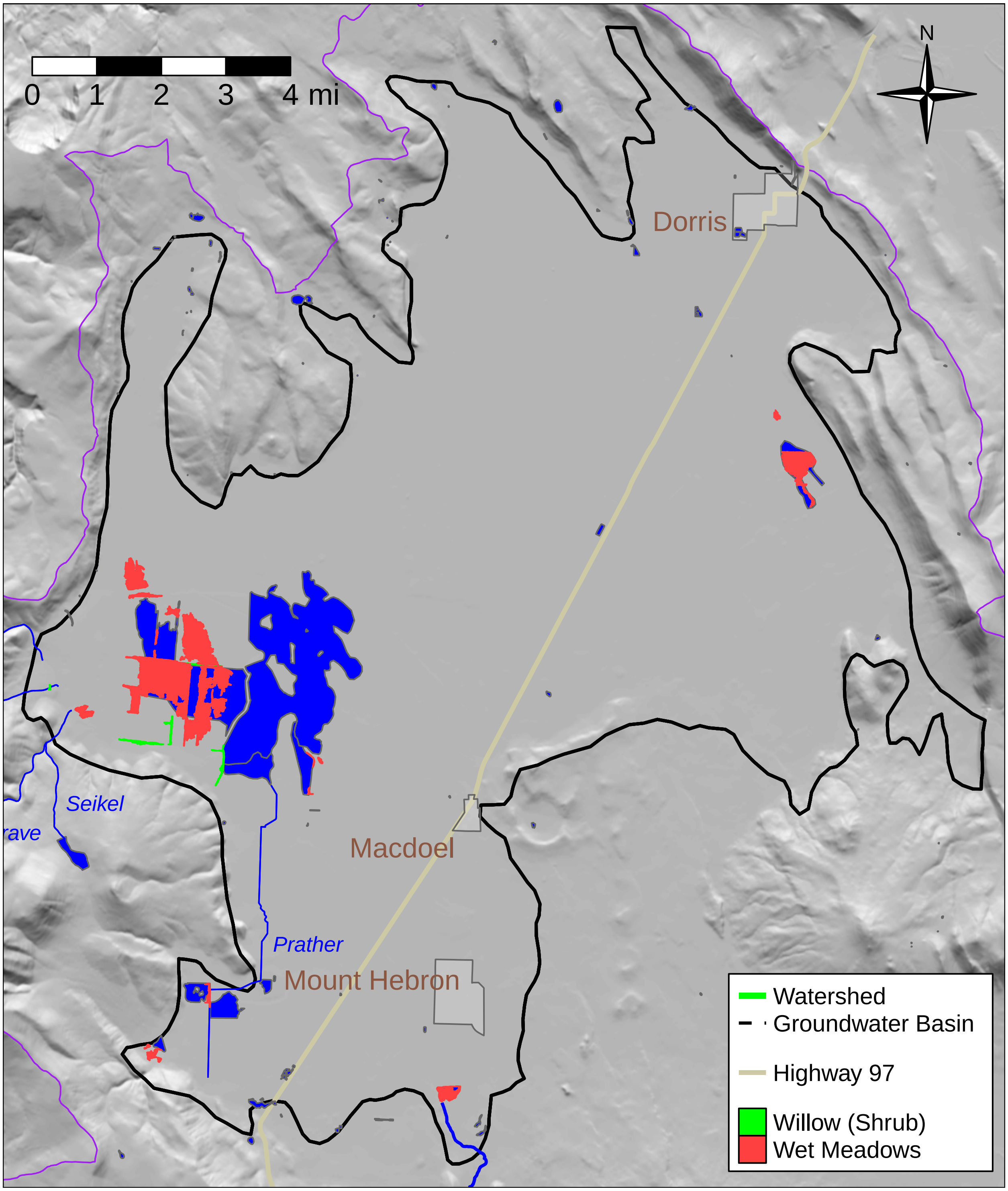


Figure 1.28: Vegetation types commonly associated with the sub-surface presence of groundwater (phreatophytes). Identified by the DWR Natural Communities Commonly Associated with Groundwater (NCCAG) dataset. The data included in the Natural Communities dataset do not represent DWRs determination of a GDE. However, the Natural Communities dataset can be used by GSAs as a starting point when approaching the task of identifying GDEs within a groundwater basin.

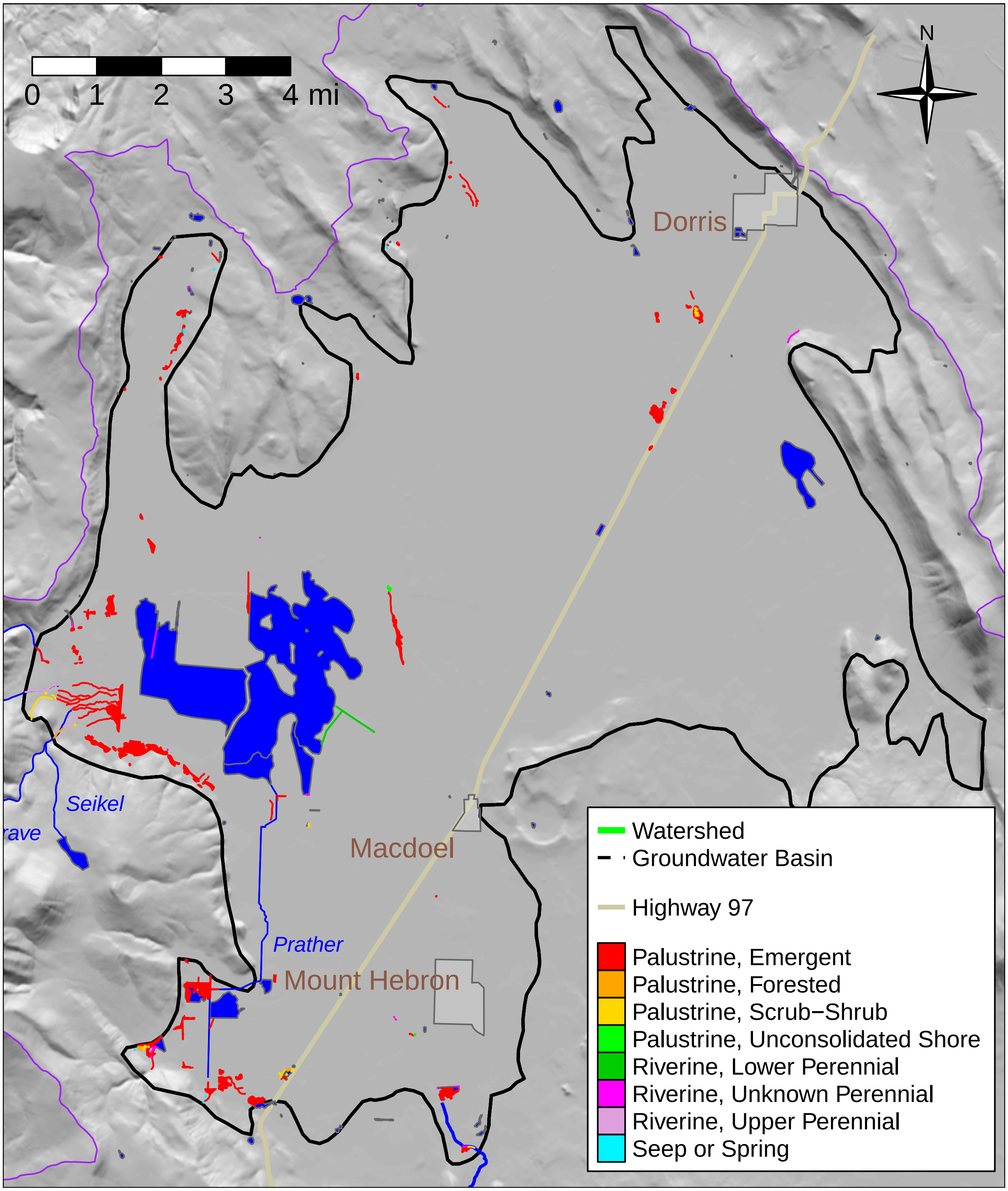


Figure 1.29: Wetland features commonly associated with the surface expression of groundwater under natural, unmodified conditions. Identified by the DWR Natural Communities Commonly Associated with Groundwater (NCCAG) dataset. The data included in the Natural Communities dataset do not represent DWRs determination of a GDE. However, the Natural Communities dataset can be used by GSAs as a starting point when approaching the task of identifying GDEs within a groundwater basin.

An initial review of NCCAG mapped potential GDEs for the Butte basin and a comparison to an initial review of NCCAG mapped potential GDEs for the Butte basin and a comparison to available land use mapping resources suggested that riparian communities were not effectively represented in some cases and mapped GDEs were identified in urban, agricultural, or managed vegetated areas. A subset of land uses from the 2010 Siskiyou County land use and land cover (LU/LC) dataset were incorporated into the analysis to more effectively represent mapped potential GDEs for the Butte Basin. Siskiyou County LU/LC classes are presented in Appendix 2-C.

The NCCAG vegetation and wetland layers were overlaid or unioned in a geographic information system (GIS) yielding a dataset where areas mapped as potential vegetation GDEs, wetland GDEs, or both vegetation and wetland GDEs are represented. A union is a geospatial process where the coverage and attributes of multiple layers in all area are combined into one spatial dataset. An intersection is a geospatial process where the coverage and attributes of multiple layers are combined into one spatial dataset only in areas where they share area or overlap. This combined or unioned NCCAG dataset was intersected with the adapted 2010 Siskiyou County LU/LC dataset yielding a combination of classifications for all three datasets for the area covered by either the NCCAG vegetation or wetland datasets. All observed combinations of combined fields were summarized in a master table and grouped into one of the five categories presented in Table 1.8 based on best professional judgment. Additional tables used in this process are presented in Appendix 2-C.

If, as an example, the NCCCAG Wetland dataset identified an area as class “PEM1C” corresponding to a “Palustrine, Emergent, Persistent, Seasonally Flooded” mapped potential wetland GDE and the 2010 Siskiyou County LU/LC dataset assigned the same area a “UR” representing “Urban Residential,” that area was assigned a “Remove Urban/Paved” classification and was subsequently removed. If, as a second example, neither the NCCAG Wetland or Vegetation datasets identified an area as a mapped GDE but the 2010 Siskiyou County LU/LC dataset assigned that area an “NW1” class representing “River or stream (natural fresh water channels),” it was included in the combined representation of mapped GDEs. Combined land use classes a “Retain Check” or “Check Remove Irrigated” classification were qualitatively evaluated using aerial imagery and included or removed based on best professional judgement.

Assumed Rooting Zone Depths

Rooting zone depths were assigned to all combined or concatenated values for the NCCAG vegetation, NCCAG wetland, and Siskiyou County land use and land cover dataset using a simple decision tree approach. An assumed dominant or representative vegetation was assumed for the best available dataset for each area or polygon within the mapped potential GDE dataset. Classifications from the NCCAG vegetation dataset were used to assign rooting zone depths based on a presumably higher level of mapping accuracy and more descriptive classes with values such as “wet meadow” or “willow shrub” present within the Butte basin. Classifications from the NCCAG wetland dataset were then used given their presumed lower level of accuracy and more general vegetative community classification with values such as “palustrine, emergent, persistent, seasonally flooded” and “riverine, upper perennial, unconsolidated bottom, permanently flooded.” All vegetation classification in areas mapped by either the NCCAG vegetation or wetland datasets were compared to mapped 2010 Siskiyou County LU/LC and a predominant or representative vegetation was assigned based on best professional judgment.

A review of available literature served as the foundation for assigning assumed rooting zone depths for each vegetative class present in the aggregated mapped representation of potential GDEs.

Vegetation classifications were grouped into three broad categories based on best professional judgment. The relationship between mapped vegetation categories and assumed predominant or representative vegetation is presented in Table 1.9, Table 1.10, and Table 1.11 for the NCCAG vegetation, NCCAG wetland, and 2010 Siskiyou County LU/LC datasets, respectively.

All classes directly referring to willows as well as those referring to scrub or forested areas were assumed to be effectively represented by an assumed 13.1 ft. rooting zone depths for willows. Relevant literature suggests a range for willow rooting depths of 2.62 ft. to 7.35 feet (Niswonger and Fogg 2008) indicating that this assumed depth of 13.1 is relatively conservative while additional resources suggest that rooting zone depths of 13.1 feet are consistent with mean values for deciduous broadleaf trees which would have deeper rooting depths than willows (Fang et al. 2017).

Other vegetation classes do not specifically identify predominant species and are therefore assumed to be emergent and limited to grasses, forbs, sedges, and rushes that are common in wetland communities. Rooting zone depths are assigned as the mean or maximum of mean values from aggregated measures presented in relevant literature (Schenk and Jackson 2002). Assumed rooting zone depths were generally conservative given the absence of the consistent and comprehensive coverage identifying predominant species for each community and reflected best professional judgment based on the broad classes of vegetation that could reasonably be present.

Table 1.8: Field Used to Create a Combined Representation of Mapped Potential GDE Coverage.

Action	Classification Description
Retain_Natural	Siskiyou/DWR mapping indicates natural vegetation present.
Retain_Check	Siskiyou/DWR mapping indicates natural vegetation may be present therefore retain or verify before removing
Remove_Ag	Siskiyou/DWR mapping indicates agricultural land is present which could warrant polygon removal.
Remove Urban_Paved	Siskiyou/DWR mapping indicates urban/paved land is present which could warrant polygon removal
Check_Remove_Irrigated	Siskiyou/DWR mapping indicates non-native irrigated land is present which could warrant polygon removal.

Table 1.9: Assumed Rooting Zone Depth and Representative Vegetation for Classes Within the NCCAG Vegetation Dataset.

Wetland Community Class	Assumed Rooting Zone Depth (ft.)	Assumed Representative Vegetation
Wet Meadow	4.8	Grasses, Forbs, Sedges, and Rushes Mean Rooting Depth
Willow (Shrub)	13.1	Willow

Table 1.10: Assumed Rooting Zone Depth and Representative Vegetation for Classes Within the NCCAG Wetland Dataset.

Wetland Community Class	Assumed Rooting Zone Depth (ft.)	Assumed Representative Vegetation
Palustrine, Emergent, Persistent, Seasonally Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean Rooting Depth
Palustrine, Scrub-Shrub, Seasonally Flooded	13.1	Willow
Riverine, Unknown Perennial, Unconsolidated Bottom, Semipermanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean Rooting Depth
Palustrine, Forested, Seasonally Flooded	13.1	Willow

Table 1.10: Assumed Rooting Zone Depth and Representative Vegetation for Classes Within the NCCAG Wetland Dataset. *(continued)*

Wetland Community Class	Assumed Rooting Zone Depth (ft.)	Assumed Representative Vegetation
Palustrine, Unconsolidated Shore, Seasonally Flooded	13.1	Willow
Riverine, Lower Perennial, Unconsolidated Bottom, Permanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean Rooting Depth
Riverine, Upper Perennial, Unconsolidated Bottom, Permanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean Rooting Depth
Palustrine, Emergent, Persistent, Semipermanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean Rooting Depth
Seep or Spring	9.6	Grasses, Forbs, Sedges, and Rushes Max Rooting Depth

Table 1.11: Assumed Rooting Zone Depth and Representative Vegetation for Classes Within the Siskiyou County Land Use and Land Cover Dataset.

Land Use/ Land Cover Class	Assumed Rooting Zone Depth (ft.)	Assumed Representative Vegetation
River or stream (natural fresh water channels)	13.1	Willow

Depth to Groundwater

Mapped representations of depth to groundwater were calculated consistent with the standard approach (e.g., TNC Best Practices for using the NC Dataset, 2019), as the difference between land surface elevation and interpolated groundwater elevation above mean sea level. Altogether, depth to groundwater conditions were developed for 23 periods between spring of 2008 and the fall of 2019. These periods represent water level data every 6 months from spring of 2008 to fall of 2019, with equal amounts of fall and spring periods. These grid or raster geospatial datasets were developed by interpolating between observed groundwater elevations obtained from the CASGEM Program and assumed elevations at surface water features using ordinary kriging (Wackernagel, 1995). Representations of depth to groundwater for each of the 23 periods are presented in Appendix 2-C.

Depth to Groundwater Assumptions and Data Gaps

The Butte Valley groundwater level network has good coverage over the center of the Basin, which gives good confidence on the GDE analysis. However, data gaps in the groundwater level network along the Basin edges yielding potential overestimation of depth to groundwater in those marginal areas of the Basin, particularly in Sam's Neck, the northern edge of the Valley, the western edge near Ikes, Harris, and Muskgrave Creeks, the western edge near Prather Creek, and south edge near Butte Creek. To complete a preliminary and conservative GDE analysis of these areas based on existing knowledge, the elevation of springs along the immediate edge of the valley sediments and mapped by the United States Geologic Survey were added as “water level” measurements for purposes of interpolating the water table within the Basin. Further rationale for this choice is provided in the next section. These additional “water level” data provide a more conservative, albeit only approximate estimate of depth to water table for the GDE analysis in areas near the Basin boundaries for this preliminary analysis. The preliminary analysis identifies areas with potential GDEs, but is not used to set specific sustainable management criteria until better data is available, e.g., from planned expansion of the groundwater level network. Instead, potential GDEs with high uncertainty due to lack of direct groundwater level data are identified as data gaps to be addressed during the implementation of the Plan.

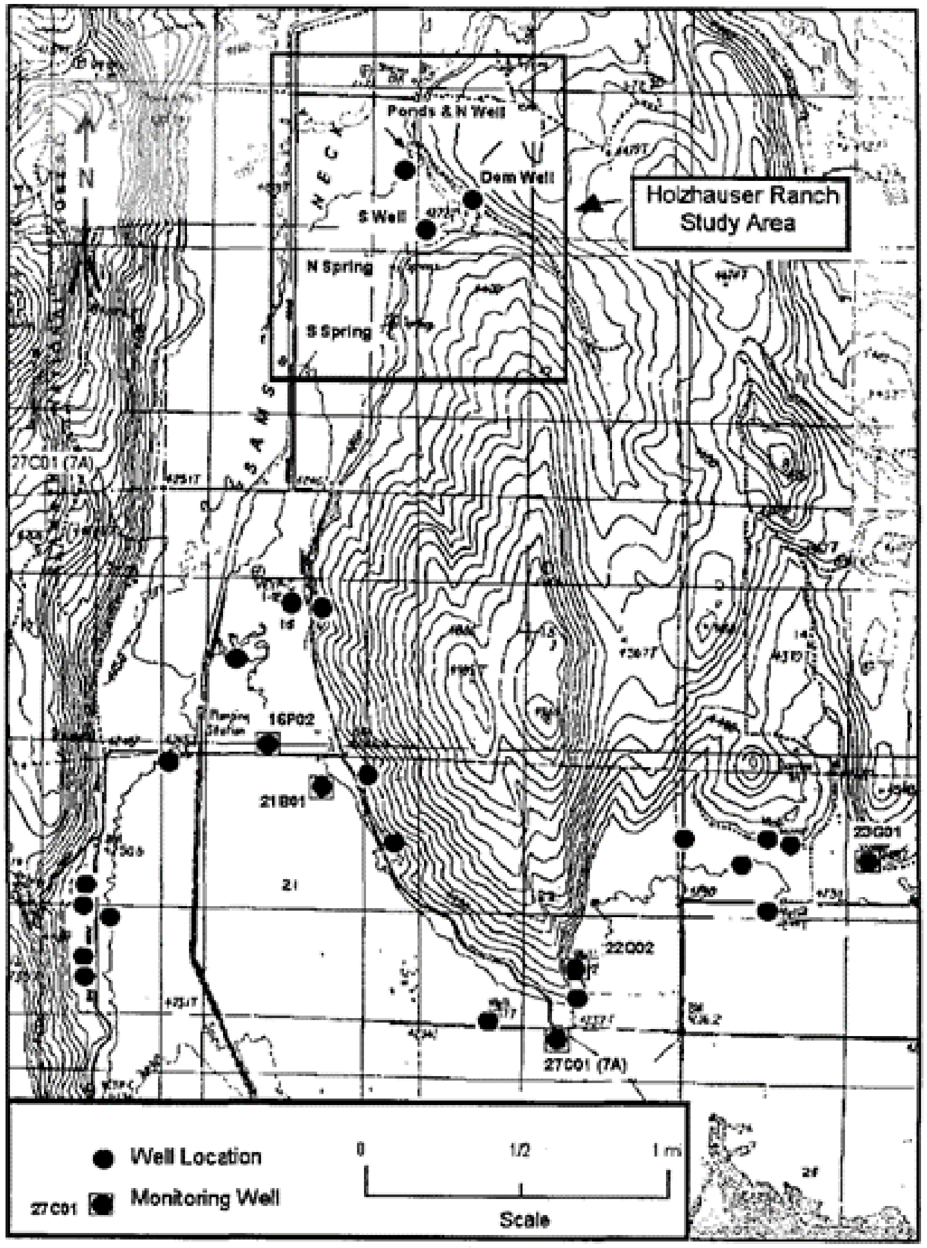


Figure 9. Holzhauser Ranch Location Map

Figure 1.30: Map from the 1998 DWR study. Well 7A is near the map bottom, above the legend. The studied springs are on the northeast side of Sam's Neck, within the boxed study area.

Spring to Groundwater Connection in Butte Valley

Spring interconnectivity is largely inferred by results from a 5.5-day pump test conducted by the California Department of Water Resources (DWR) in August 1997. During the pump test, two springs on Holzhauser Ranch in Sam's Neck were observed during pump operation on the California Department of Fish and Wildlife (CDFW) well 7A. This well is also referred to by the abbreviated DWR State Well Number (SWN) code 27C01. During pumping on this well, flow in two springs in Sam's Neck was observed to decline by 10 percent. This indicates that the wells and springs share hydraulic interconnectivity and likely are not separated by a major impermeable layer or represent a discontinuous perched water bearing formation. The location of the Holzhauser Ranch springs and CDFW Well 7A studied by DWR during the 1997 well interference study are shown on the figure below (DWR. 1998. “Butte Valley Wildlife Area Well Interference Investigation.” California Department of Water Resources, 1–96).

Relationship Between Rooting Zone Depths and Depth to Groundwater

This subsection discusses the method used to evaluate the relationship between assumed rooting zone depths and depth to groundwater for each mapped potential GDE area.

Grid-Based GDE Analysis

The grid-based analysis relied on the grid or raster-based representations of depth. This grid-based analysis was carried out using three general geospatial processing steps.

The first step involved computing an area-weighted statistical representation of depth to groundwater for each mapped potential GDE area using the zonal statistics function available in many GIS programs. This zonal statistics function identifies what cells of the depth to groundwater grid or raster dataset fall within the bounds of each mapped potential GDE polygon and then computes an area-weighted average for that area. This zonal statistics analysis was carried out for each of the 23 representations of depth to groundwater between spring 2008 and fall 2018 yielding 23 columns summarizing the average depth to groundwater for each mapped potential GDE area. The 23 periods used in the analysis represent water levels every 6 months from spring 2008 to fall 2018.

The second step involved simply subtracting the calculated depth to groundwater for each mapped potential GDE from the assumed rooting zone depth that was previously assigned based on assumed predominant vegetation. This field calculation was carried out in GIS for each of the 23 representation of depth to groundwater and was added as a new field for each calculation.

The third step of the grid-based geospatial processing effort involved identifying which mapped potential GDE areas can reasonably be assumed to have access to groundwater for each period. Mapped potential GDEs where the difference between assumed rooting zone depth and computed depth to groundwater is positive are assumed to be connected to groundwater for that season and year representation as the rooting zone depth is greater than the depth to groundwater. Conversely, mapped potential GDEs where the difference between assumed rooting zone depths and computed depth to groundwater is negative suggests that roots do not have access to groundwater. These areas are therefore assumed to be disconnected from groundwater for that season and year representation of conditions.

Results of this grid-based analysis of mapped potential vegetative GDEs and their classification as connected or disconnected to groundwater for each of the 23 periods is presented in Appendix 2-C. Mapped potential vegetative GDEs were then further characterized based on the percentage of years when vegetation with their assumed rooting zone depth would reasonably have access to groundwater. Areas with assumed predominant vegetation types that would have access to groundwater for greater than 50% of all periods are categorized as “likely connected” to groundwater for this grid-based analysis. Areas with assumed vegetation that do not appear to have access to groundwater for greater than 50% of the period of record are assumed to be “likely disconnected” from groundwater. This is reasonable based on the quality of groundwater level data in Basin, where historical data is only available every 6 months, in the spring and fall. A potential GDE with vegetation connected to groundwater every spring will be labeled as “likely connected.” Disconnection from groundwater for greater then 50% of periods indicates a multi-year lack of groundwater in the rooting zone.

Mapped Potential GDE Classification

A tabular summary of the grid-based GDE classifications for each mapped potential GDE area was developed. Potential mapped GDEs were grouped into two categories corresponding to areas assumed to be:

- Potential GDE;
- Potentially not a GDE.

Areas where the grid-based analysis showed that the mapped potential vegetative GDE was likely connected to groundwater were categorized as "potential GDE." Similarly, areas that were shown to be disconnected from groundwater were considered a "potentially not a GDE." The distribution of categorized GDEs for the Butte basin is presented in Figure 1.31 and Table 1.12.

The current map of likely connected GDEs are located in areas where direct groundwater levels are not available or has a short historical record. Consequently the current list of potential GDEs is considered tentative, a data gap, and dependent on collection of additional groundwater level data. All GDEs currently labeled as "potentially not a GDE" will be reviewed with future GDE analysis updates.

Table 1.12: Distribution of Mapped Potential GDEs into Vegetative and Riparian GDE Categories.

Grid Classification	GDE Categorization	Area (Acres)	% of Mapped Potential GDE Area
Assumed GDE	Likely connected to groundwater	131	10.30%
Assumed not a GDE	Likely disconnected from groundwater	1,134	88.98%

Assumptions and Uncertainty

The approach developed and carried out to identify and evaluate GDEs within the Butte Basin represents a conservative application of best available science through the formulation of reasonable assumptions. Representations of mapped potential GDEs were developed based on available geospatial datasets, though these resources cannot be assumed to be definitive. The vegetation classes present in the datasets and outlined in the Mapped Potential GDEs section above are broad and could reasonably represent an array of vegetation types requiring the development of conservative assumptions to guide the assignment of assumed rooting zone depths. Groundwater conditions were represented by the interpolation of observed conditions in the Basin's well network. These interpolated groundwater elevations may not reflect smaller scale variations in conditions both in space (less than 500 meters) and time (sub-seasonal). Because the groundwater elevations used herein represent regional, seasonal trends, they cannot capture the impact of perched aquifers on GDE health.

Notably, GDEs are not necessarily static and can vary in time and space depending on water year type and other environmental conditions. As such, this analysis is not intended to be a definitive cataloging of each class of GDE, but rather an initial survey of the maximum possible extent of above-ground, vegetated GDEs in the Shasta Basin. A physical determination of GDEs must show that roots are connected to groundwater, which would require an infeasible subsurface geophysical survey across the Butte Basin to inform the GSP.

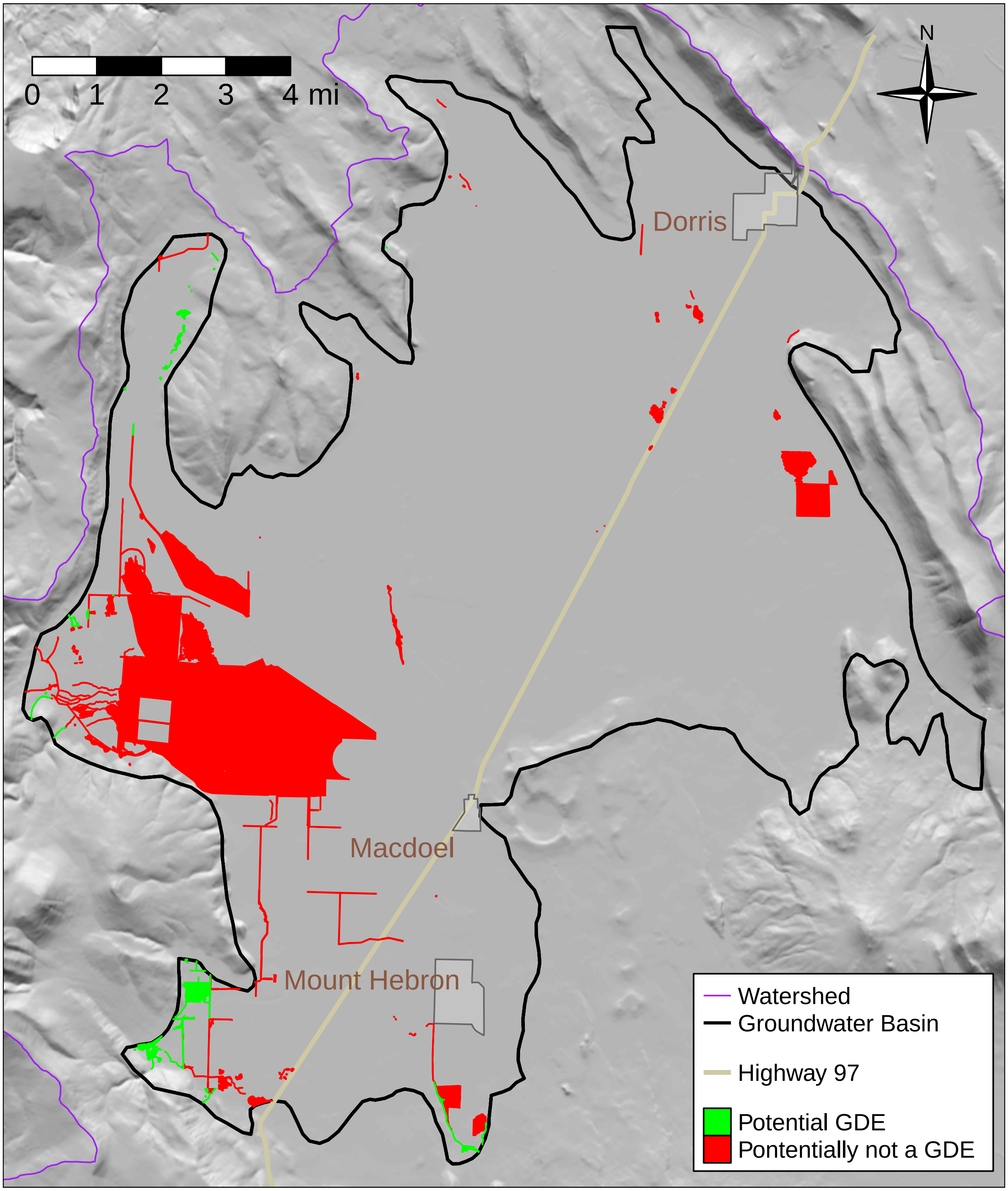


Figure 1.31: Categorized GDEs for the Butte Basin.

2.2.3 Water Budget Information

The historical water budget for the Basin was estimated for the period October 1989 through September 2018 (water years 1990 through 2018), using the recently developed Butte Valley Integrated Hydrologic Model (BVIHM), which extends over the entire Butte Valley watershed. This 29-year model period includes water year types ranging from very dry (e.g., 2001 and 2014) to very wet (e.g., 1999 and 2006). On an interannual scale, it includes a multi-year wet period in the late 1990s and a multi-year dry period in the late 2000s and mid-2010s.

Annual water budgets for the full model period are shown in Figure 1.32 and Figure 1.33 and monthly values of selected budget components are shown in Figure 1.34 for each of the four example water years. Table 1.13 and Table 1.14 show a summary of these budgets, and details are provided in Appendix 2-D. The following two sections provide an overview of the Butte Valley Integrated Hydrologic Model (BVIHM), which is used to determine the full water budget for the two relevant subsystems of the Basin: the land subsystem (including crops and soils) and the groundwater subsystem. The water budget also includes the total water budget of the Basin. Separately, water budgets for the entire watershed are presented for context, including the groundwater subsystem budget, the land subsystem budget, and the total water budget for the watershed (including the Basin contained within the watershed). The second section provides a description of the water budget shown in the Figures and Tables below and explains the water budget dynamics in the context of the basin hydrogeology and hydrology described in previous sections. This sub-chapter provides critical rationale for the design of the monitoring networks, the design of the sustainable management criteria, and the development of project and management actions (Chapters 3 and 4).

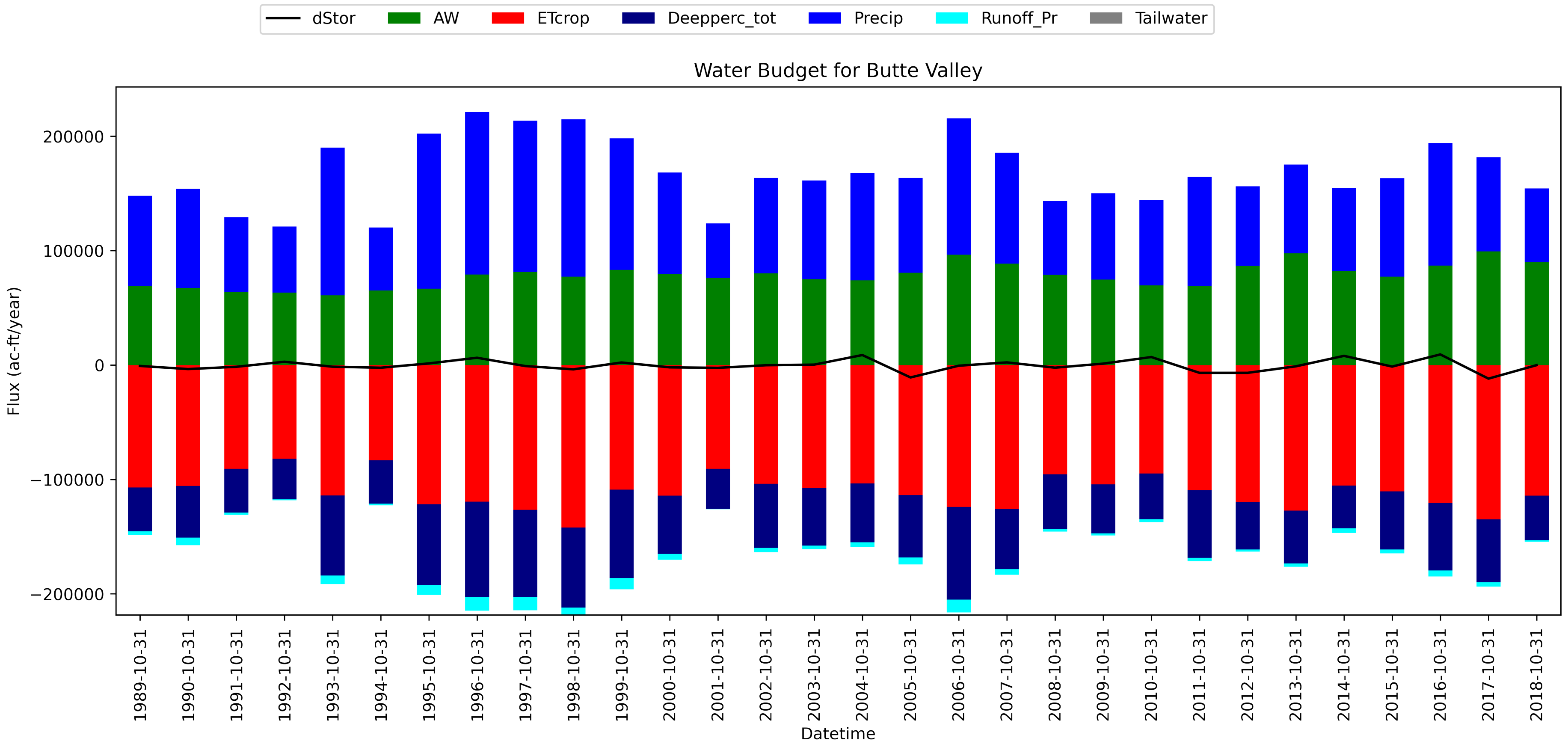


Figure 1.32: Annual water budgets for the land (land use, crop, soil) subsystem of the Basin. dStor: change in storage within the land subsystem (within the uppermost portion of the unsaturated zone, including the crop/vegetation root zone). AW: applied water. ETcrop: actual ET from crops, lawns, and natural vegetation. Deepperc tot: deep percolation from the upper portion of the unsaturated zone, assumed to be equal to groundwater recharge for the same year. Runoff Pr: surface runoff from precipitation. Tailwater: tailwater return flows, assumed to become groundwater recharge.

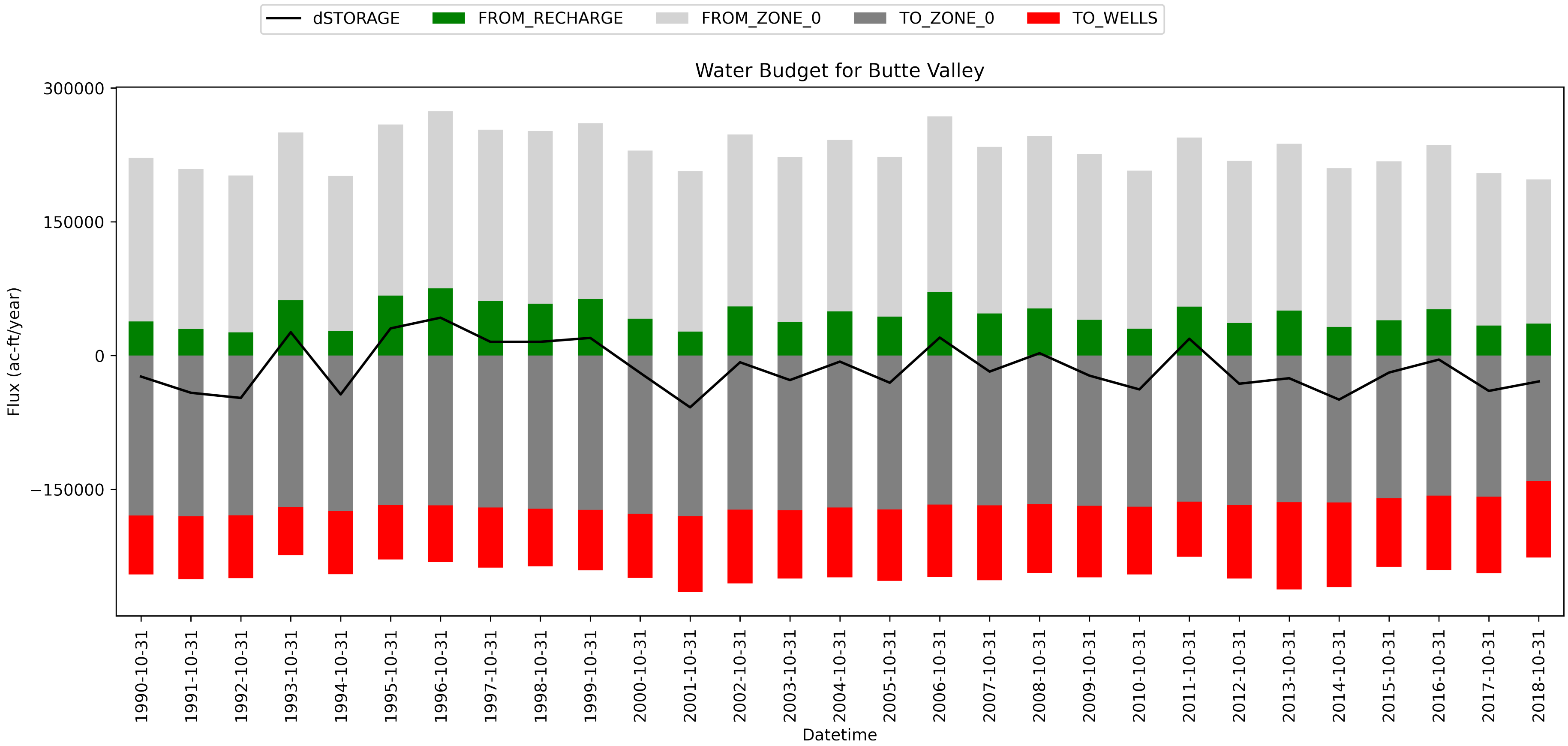


Figure 1.33: Annual water budgets for the groundwater sub-system of the Basin. dSTORAGE: change in groundwater storage. FROM RECHARGE: landscape recharge to groundwater (identical to the sum of Deepperc tot and Tailwater in the land subsystem budget). FROM ZONE 0: lateral groundwater flow into the Basin from the surrounding volcanic aquifer system. TO ZONE 0: lateral groundwater flow out of the Basin into the surrounding volcanic aquifer system. TO WELLS: groundwater pumping (identical to AW in the land subsystem budget)

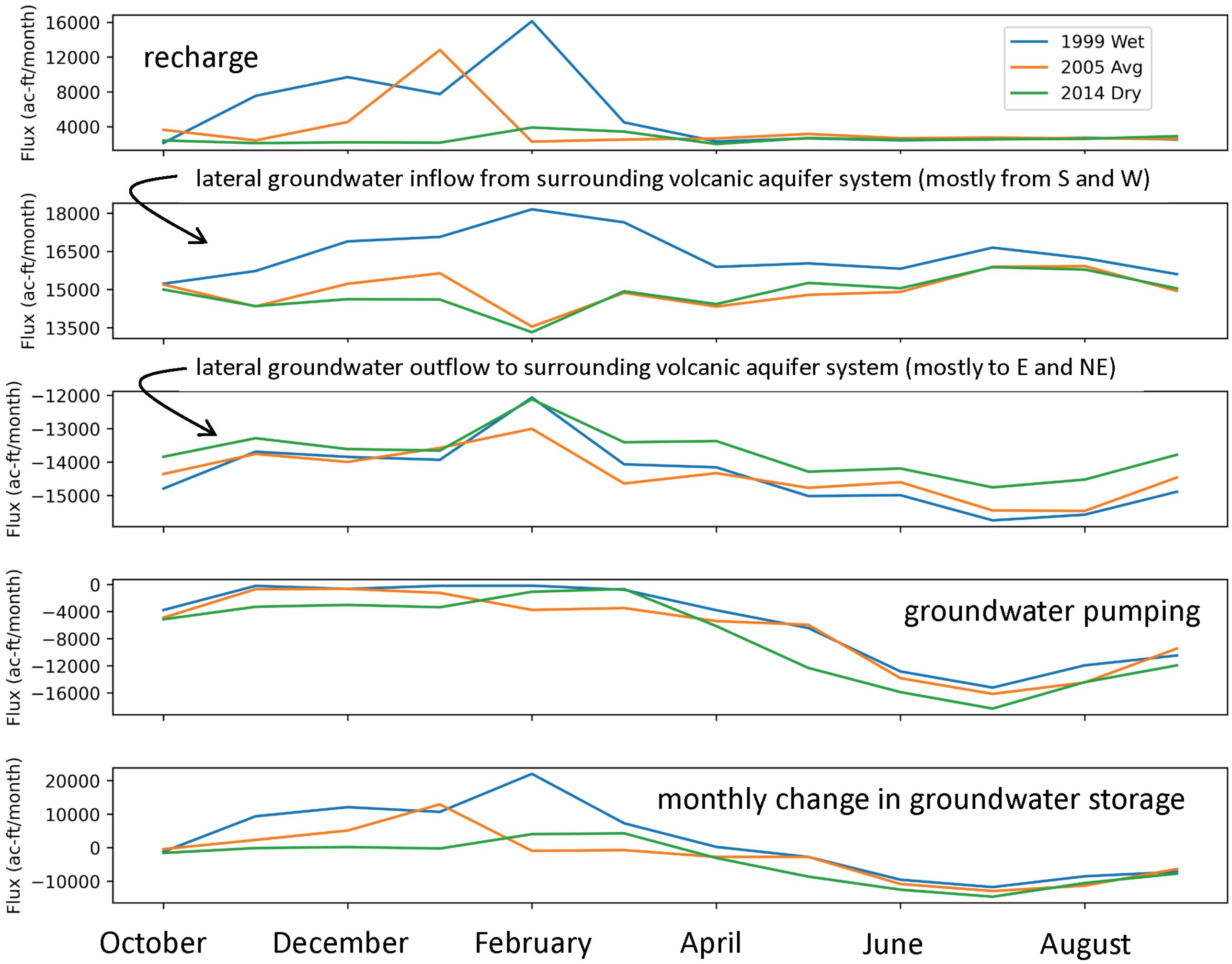


Figure 1.34: Monthly values of selected water budget components in the groundwater subsystem of the Basin in three example water years: 1999, 2005, and 2014.

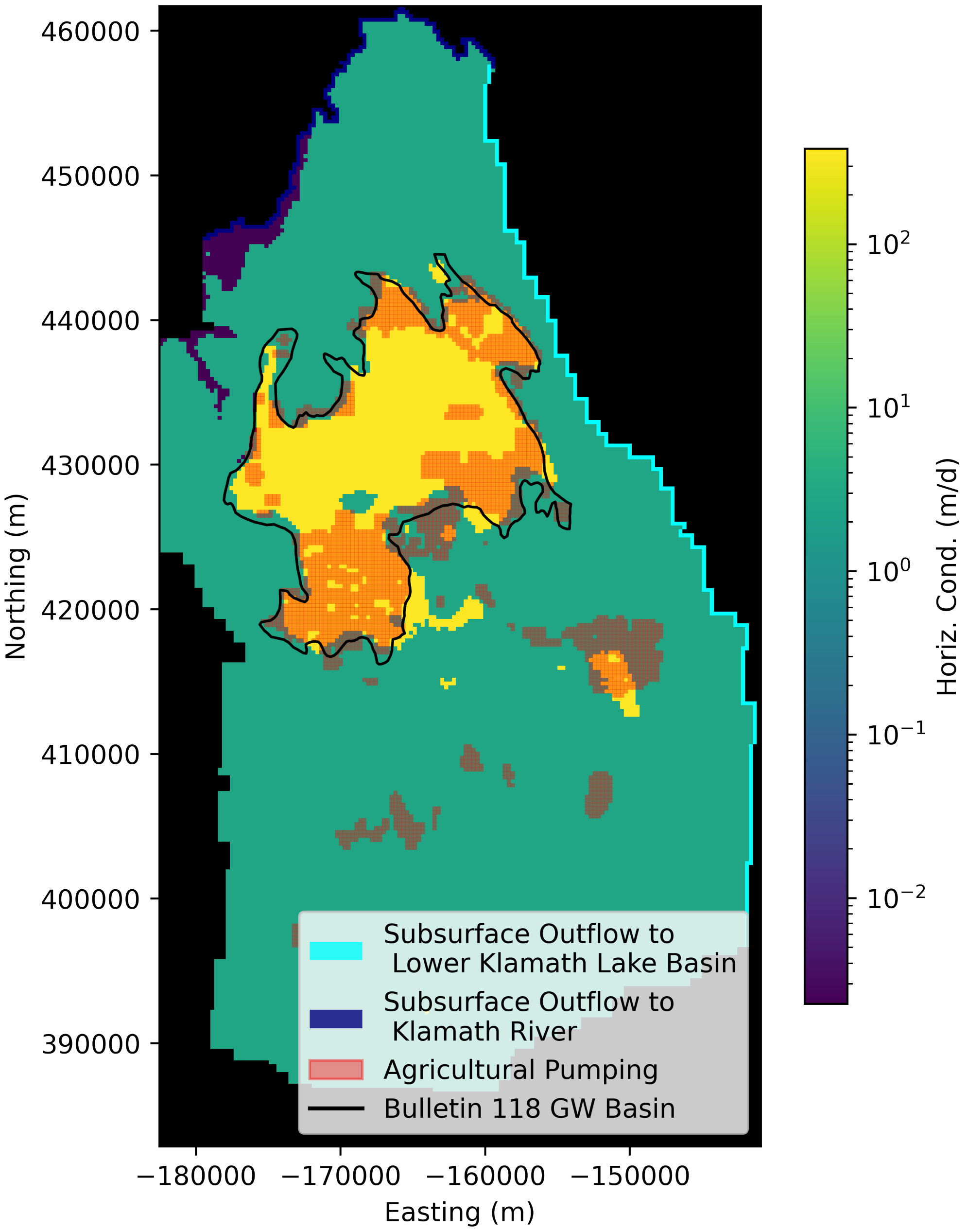


Figure 1.35: The hydrogeologic zones, model domain, and boundary conditions used in the BVIHM simulation of the surrounding watershed and Basin.

Table 1.13: Annual values (TAF) for water budget components simulated in the Land (L) or soil subsystem of Butte Valley. Positive values are water entering the soil volume: precipitation (Precip), surface water (SW), groundwater irrigation (GW); negative values are water leaving the soil volume: evapotranspiration (ET), recharge (Deepperc) to the aquifer. The overall change in soil water storage (dStor) can be negative or positive in different water years.

	AW	ETcrop	Deepperc	Precip	Runoff	dStor
Minimum	6111	-143650	-82731	22382	-11850	-7702
25th percentile	67952	-119228	-58548	67596	-6943	-1349

Table 1.13: Annual values (TAF) for water budget components simulated in the Land (L) or soil subsystem of Butte Valley. Positive values are water entering the soil volume: precipitation (Precip), surface water (SW), groundwater irrigation (GW); negative values are water leaving the soil volume: evapotranspiration (ET), recharge (Deepperc) to the aquifer. The overall change in soil water storage (dStor) can be negative or positive in different water years. *(continued)*

	AW	ETcrop	Deepperc	Precip	Runoff	dStor
Median	76273	-108203	-50521	86197	-3776	-185
75th percentile	84366	-101418	-39120	102892	-1836	1570
Maximum	98272	-13806	-9302	143243	-441	4595

Table 1.14: Annual values (TAF) for water budget com- ponents simulated in the Groundwater (GW) subsystem of the BVIHM. Positive values are water entering the aquifer: recharge from the soil zone, lateral subsurface inflow (FROM ZONE 0); negative values are water leaving the aquifer: lateral subsurface outflow (TO ZONE 0), groundwater pumping (WELLS). The overall change in water stored in the aquifer can be both negative and positive in different water years.

	RECHARGE	WELLS	FROM_ZONE_0	TO_ZONE_0	dSTORAGE
Minimum	7	-98	31	-180	-58
25th percentile	34	-83	179	-173	-31
Median	43	-77	185	-169	-19
75th percentile	55	-68	192	-165	12
Maximum	75	-9	199	-30	42

2.2.3.1 Summary of Model Development

The Butte Valley Integrated Hydrologic Model (BVIHM) was developed to support the development and implementation of the Butte Valley GSP. The simulation domain of BVIHM is a subset of the simulation domain for the USGS groundwater model of the Upper Klamath Basin (Gannett et al., 2012, USGS Scientific Investigations Report 2012-5062). The BVIHM approximately corresponds to the western half of the Upper Klamath groundwater model domain that is south of the Klamath River. In other words, it represents the southwestern portion of the 2012 USGS Upper Klamath groundwater model domain. As such the simulation domain is much larger than the Butte Valley GSA Basin (“Basin”) and somewhat larger, but fully inclusive of the Butte Valley watershed. The design of the simulation domain honors the fact that the Basin is a hydraulically well-connected sub-basin within the much larger regional volcanic aquifer system of the Upper Klamath Basin and Modoc Plateau (Gannett et al, Groundwater Hydrology of the Upper Klamath Basin, Oregon and California, USGS SIR 2007-5050).

More specifically, the BVIHM simulation domain’s northern boundary follows the Klamath River from Keno downstream past Rock Creek’s confluence with the Klamath River, near the California-Oregon border. From there the western simulation boundary includes most of the Shovel Creek watershed, then follows the western Butte Valley watershed boundary on its western and southern boundary. The southern boundary is also the southern boundary of the Upper Klamath Basin. The simulation domain follows the southern Upper Klamath Basin boundary (the northern boundary of the Sacramento River watershed) eastward to its intersection with Davis Road, immediately west of Little Glass Mountain. The eastern and northeastern boundary of the BVIHM domain does not follow any specific geographic features. From Davis Road, at the southeast corner of the simulation domain, the boundary runs due north to ephemeral source waters of Willow Creek near the northern boundary of Klamath National Forest, approximately follows northward along the westside of Willow Creek to near Souza Lake, then connects to a line from near Chip Butte along the eastern margin of the Mahogany Range to Little Tom Lake and to the northern model boundary with the Klamath River at Keno (Figure 1.35).

In BVIHM, the three hydrologic subsystems within the simulation domain (surface water, land/soil, and groundwater) are simplified into two subsystems that are explicitly modeled with BVIHM: the land/soil subsystem and the groundwater subsystem. This simplification was reasonable because:

- All water available to the Basin is via lateral groundwater inflow from the surrounding watershed and
- Because the Basin groundwater system is continuous with and hydraulically well-connected to the much larger, relatively permeable volcanic aquifer system underlying much of the simulation domain.

This two-subsystem simplification for purposes of developing model information for the GSP is also reasonable because of the high infiltration capacity of the volcanic soils of the surrounding watershed and the lack of surface water features throughout the watershed. The few creeks (described above) featured within the watershed typically recharge into the groundwater subsystem upgradient and outside of the Basin. The model did not attempt to capture in any detail surface water features near its eastern boundary (Souza Lake, Little Tom Lake).

Importantly, with this simplification, all applied water, including groundwater pumped for the Butte Valley Wildlife Area (BVWA), is considered to originate from groundwater. And all surface runoff is assumed to have recharged into the (volcanic) groundwater basin outside of the Basin itself. A known existing model shortcoming is the very simplified representation of the surface water operation described above for the BVWA. However, to the degree that runoff from the four creeks captured by BVWA is predominantly used by wetland ET, the small amount of recharge from the relatively impermeable soils within the BVWA is appropriately captured by the model.

The BVIHM is based on three separate software modules:

- The land/soil subsystem of the irrigated landscape is simulated using the data from Davids Engineering (Davids Engineering Report, Appendix 2-D). The output from this model include spatio-temporally distributed groundwater pumping (all applied water needs simulated by this module) and spatio-temporally distributed groundwater recharge. The spatial discretization is equal to individual land use polygons in the DWR land use surveys of 2000, 2010, and 2014. The temporal discretization is daily.
- The land/soil subsystem and the surface subsystem of the entire watershed is simulated using the USGS PRMS software. This simulation module generates spatio-temporally distributed groundwater recharge for the 1989-2018 simulation period. The spatial discretization is 888 ft (271 m). The temporal discretization is daily.
- The groundwater subsystem is simulated with the USGS MODFLOW 2005 software([1]Harbaugh 2005) using the pumping and recharge output from the land subsystem simulation as input

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[1] {Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW—Coupled groundwater and surface-water flow model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods 6-D1, 240 p.}

for the 29-year groundwater subsystem simulation. The transient, three-dimensional groundwater simulation has a spatial discretization of 888 ft (271 m), variable vertical discretization, a temporal discretization of daily time-steps with a monthly "stress period." The latter means that daily pumping and recharge are aggregated to monthly average values (and kept constant within a calendar month). This is consistent with common basin modeling practice

The three simulation modules are explicitly coupled: the 29-year output from the DE and PRMS simulations is generated first, then provided to the MODFLOW groundwater simulation. The explicit coupling (rather than intrinsic, more integrated coupling) is possible since historical groundwater levels throughout the Basin and over the entire simulation period are sufficiently deep that significant feedback to the land/soil subsystem are absent or negligible for purposes of this simulation:

- There is no groundwater interaction with the soil zone and
- Recharge is applied directly to the groundwater module, assuming that monthly recharge rates are that same month's deep percolation.

Full documentation on BVIHM can be found in Appendix 2-D.

Natural lands: Land/soil subsystem model summary

A deterministic, distributed-parameter, physical-process-based watershed model for the Upper Klamath Basin was recently developed by the US Geological Survey using the publically available software PRMS 5.0 (Risley 2019). This model includes the entire BVIHM simulation domain. The model is discretized into small sub-watershed units called hydrologic response units (HRUs). An HRU is defined as an area within the watershed defined by similar hydrologic, climatologic, vegetation, slope, and soil properties. Within the BVIHM simulation domain, this model distinguishes approximately 30 HRUs. For each HRU, the model simulates snow processes, plant interception of rainfall, infiltration, surface runoff, soil water storage, evapotranspiration, and groundwater recharge. It also simulates streamflow at the HRU outlet. The model uses daily time-step and uses daily precipitation and minimum and maximum daily air temperature as input, provided by the PRISM group at Oregon State University (Figure 1.36; (Markstrom et al. 2008)). The model is calibrated against streamflow data at several long-term gages operated within the Upper Klamath Basin. For BVIHM, the Upper Klamath Basin PRMS model represents the surface water and land/soil subsystem. Surface water simulated only included major streams downgradient from Butte Valley. Recharge computed by the land/soil module of PRMS was used as input to the MODFLOW-based groundwater module of BVIHM, described below.

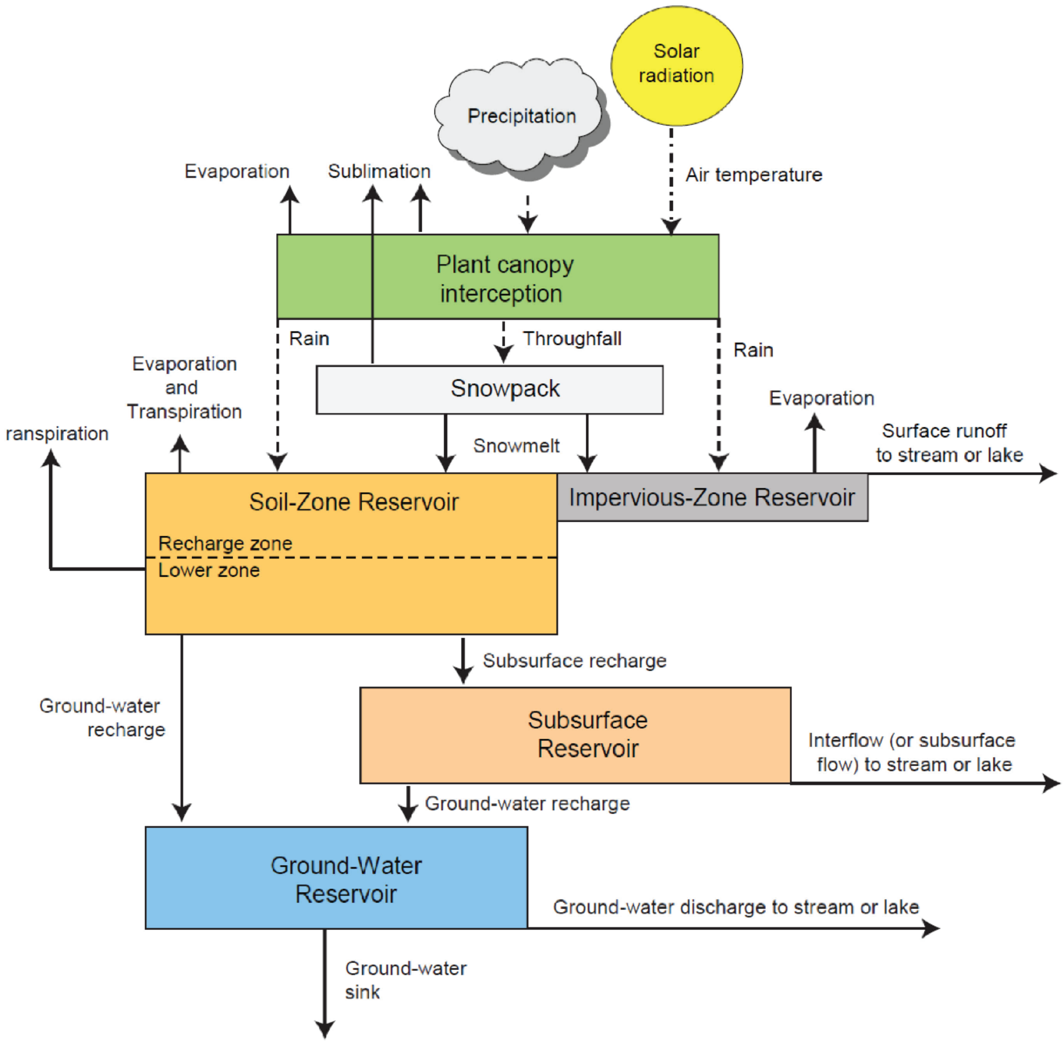

Figure 1.36: Schematic diagram of a watershed and its climate inputes (precipitation, air temperature, and solar radiation) simulated by PRMS (from Markstrom et al., 2008).

Irrigated agriculture, wetlands, and developed (urban) lands: Land/soil subsystem model summary

The PRMS model of the Upper Klamath Basin was considered adequate for estimating recharge in the BVIHM simulation domain, outside of irrigated or developed areas. Groundwater pumping and recharge from irrigated agriculture, wetlands, and developed (urban) lands was obtained using the crop root zone water model (CRZWM) developed by Davids Engineering (2020, see Appendix 2-D). CRZWM considers the water fluxes into and out of the root zone of crops, urban, and wetland vegetation: precipitation and applied water are inputs to this subsystem, ET (from applied water and from precipitation), surface runoff from precipitation and irrigation, and deep percolation (from applied water and from precipitation, here assumed to be equal to recharge) are outputs from the subsystem (Figure 1.37).

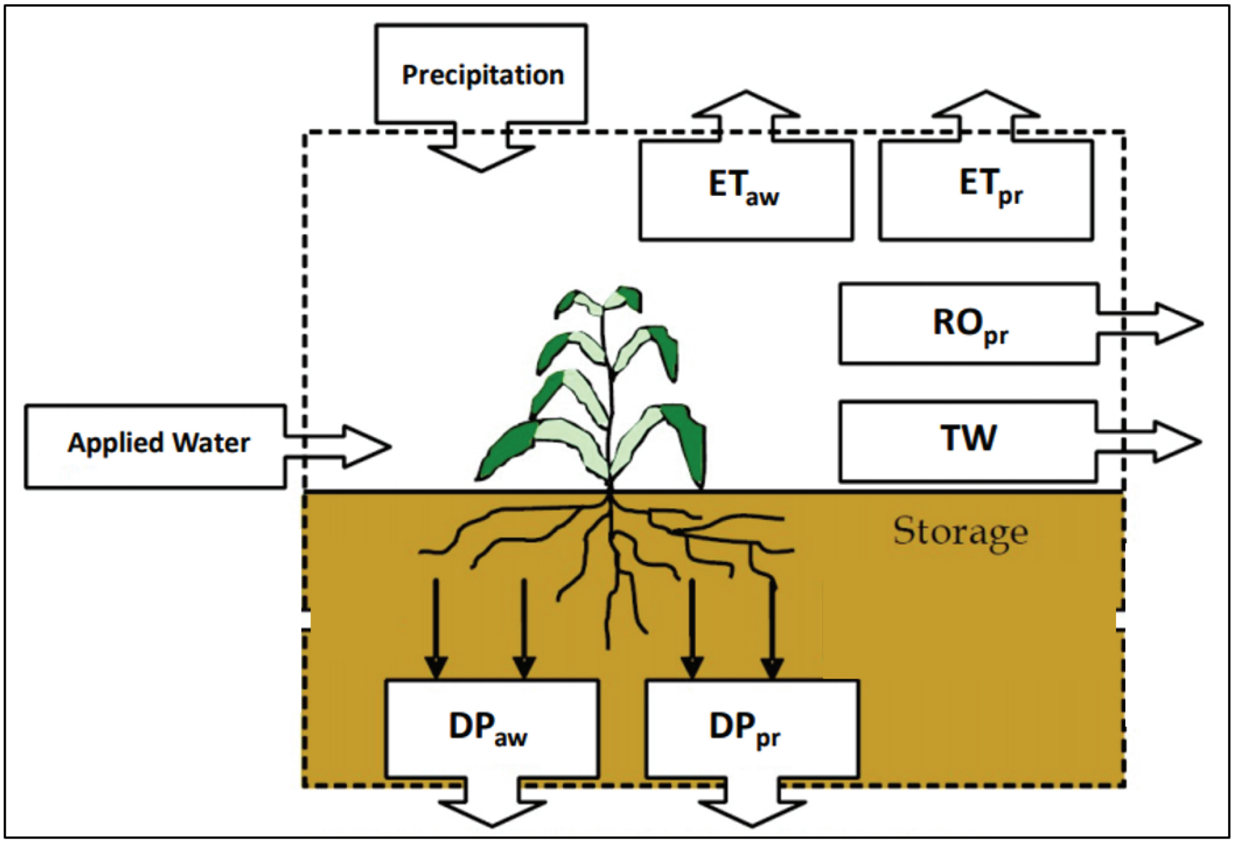

Figure 1.37: Conceptualization of fluxes of water into and out of the crop root zone (modified from Davids Engineering, 2020 in Appendix 2-D).

CRZWM uses information about crop and land use type, soil type, irrigation system, daily precipitation, and daily ET measured for the 29 year simulation period, to compute daily estimates of recharge and pumping. Crop types and irrigation information were obtained from DWR land use surveys available for 2000, 2010, and 2014. For simulation purposes, each year of the simulation period was assigned the land use survey year closest in time. Soils information was obtained from the National Soil Survey. Precipitation data was provided by the PRISM group at Oregon State University. Unique to CRZWM, the ET measurements are based on remote sensing data obtained throughout the 1989 – 2018 period. These data were combined with local climate information to estimate ET. The ET and precipitation information is used to compute applied water, runoff, and deep percolation (recharge) as a function of crop type, soils, and irrigation system.

Groundwater subsystem model summary

Overview

The groundwater module of BVIHM is a MODFLOW finite difference groundwater simulation model of the groundwater (GW) subsystem that also encompasses the entire BVIHM simulation domain. The purpose of the groundwater model is to simulate the temporal and spatial distribution of groundwater flow, groundwater potential, and water table location throughout and beyond the watershed's heterogeneous aquifer system. These simulation outcomes are driven in the model by the Basin's hydrogeologic properties and by the spatially and temporally variable dynamics of

- The spatially and temporally varying recharge (groundwater module input from the land/soil module, Figure 1.37)
- The spatially and temporally varying groundwater pumping extended watershed and subsurface outflows to the Klamath River and lower Klamath Lake basin (groundwater module input from the land/soil module)
- The subsurface inflows and outflows at the boundaries of the simulation domain (computed by the groundwater module of BVIHM).

Simulation domain boundary conditions

Insignificant amounts of groundwater are leaving or entering the simulation domain at the watershed boundaries of Butte Valley and the Upper Klamath Basin on the western and southern portion of the simulation domain. This boundary is considered a “no-flow” boundary. On the northern boundary, the Klamath River is considered a “constant head boundary,” defined by the elevation of the Klamath River. The Klamath River falls from about 4100 ft amsl at Keno, north of Butte Valley to about 3200 ft at the northwestern corner of the simulation domain, one-thousand feet below Butte Valley (the lowest surface elevation in the simulation domain). Gannett et al. (2012) provide streamflow gains for this mostly gaining section of the Klamath River, originating from groundwater inflows, including springs and associated creeks on either side of the Klamath River.

The southernmost part of the eastern boundary is thought to follow the general landscape gradient and approximately parallels groundwater flow lines hypothesized by Gannett et al. (2007). It is considered a “no-flow boundary” (i.e., flow occurs alongside this boundary). The central and northern portion of the eastern boundary is simulated as a “general head” boundary, allowing for unrestricted outflow (or inflow) toward the east and northeast. The outflow across this boundary is computed by the model using a user-defined estimate of the hydraulic conductivity and thickness of the volcanic aquifer system in the area to the east of the boundary, and by water level conditions well to the east of Butte Valley, described in the following paragraph.

The USGS groundwater model of the Upper Klamath Basin (Gannett et al., 2012) was investigated to find areas east of and closest to the eastern BVIHM simulation domain where water levels during its 1989-2004 simulation period remained relatively unchanged, either because groundwater levels were controlled by surface water features (groundwater discharge into streams or lakes) or otherwise remained unchanged. A line was thus defined and average 1989-2004 water levels in the Upper Klamath Basin groundwater model on this line were mapped. The northern end of this line begins at the Klamath River at the mouth of the Klamath Strait Drain, follows that Drain and West Canal south, wraps around the west- and southside of the Lower Klamath National Wildlife Refuge and follows the tunnel that connects the Refuge with the Tule Lake Basin. In the Tule Lake Basin, the line wraps around the west- and southside of Tule Lake, and from Tule Lake’s southeast corner follows a regional north-south groundwater convergence zone south toward the Upper Klamath Basin’s southern watershed boundary (Figure 1.38). For each general head boundary cell, the general head is that in the nearest cell of the defined head line, and the general head conductance parameter considers the distance to that cell and the effective hydraulic conductivity between these two cells (Figure 1.38).

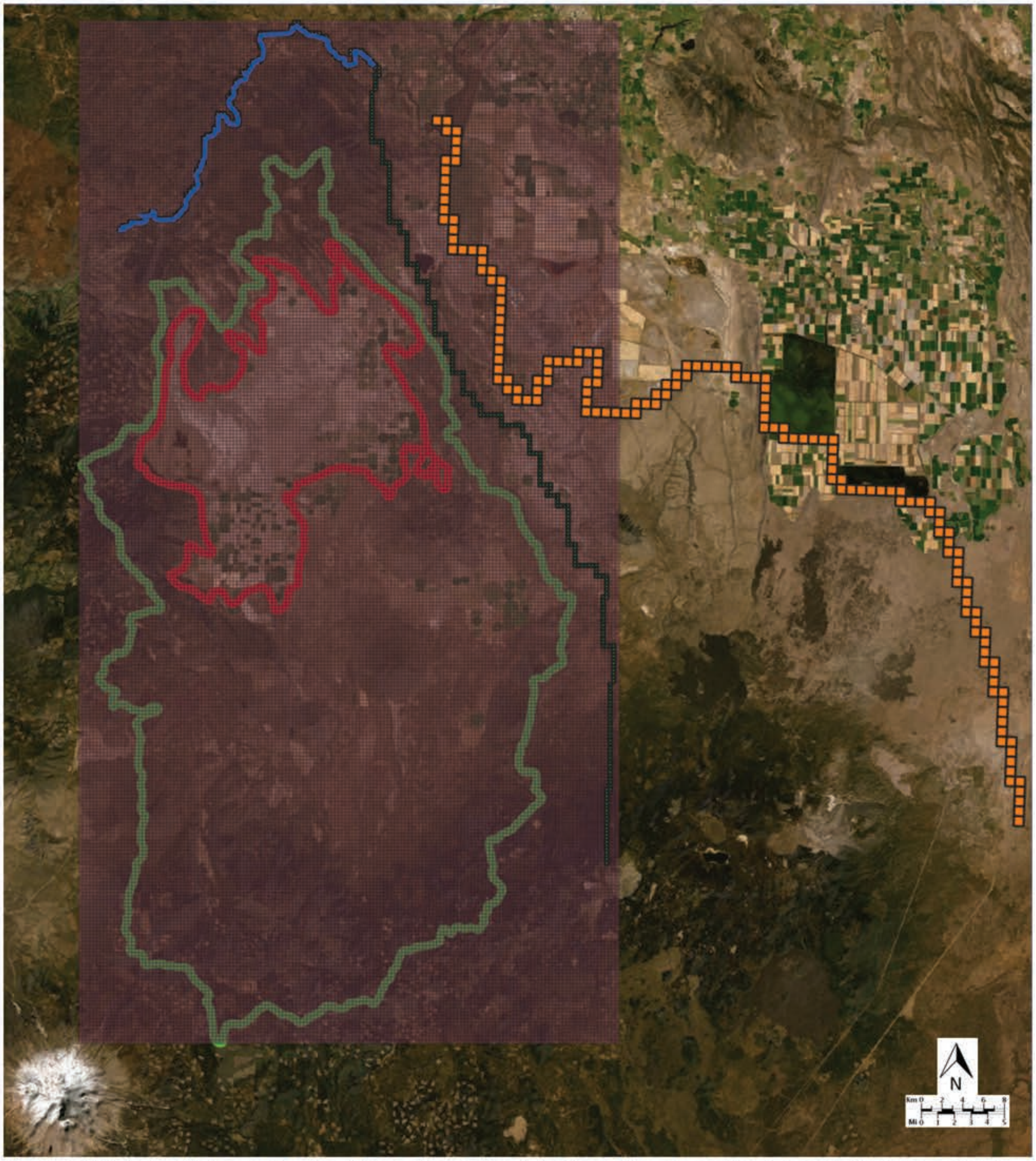

Figure 1.38: Butte Valley watershed (green boundary), Butte Valley groundwater basin (red boundary), the BVIHM “general head” boundary (dark green line to the northeast and east of the watershed), the Klamath River as a “prescribed head” boundary (dark blue line to the north of the watershed), and the line of defined heads used for the “general head” boundary (orange). Flow from the general head boundary is a function of the aquifer transmissivity between the dark green and the orange line, and of the head gradient between those two lines. The defined heads along the orange line are obtained from the USGS Upper Klamath Basin groundwater model.

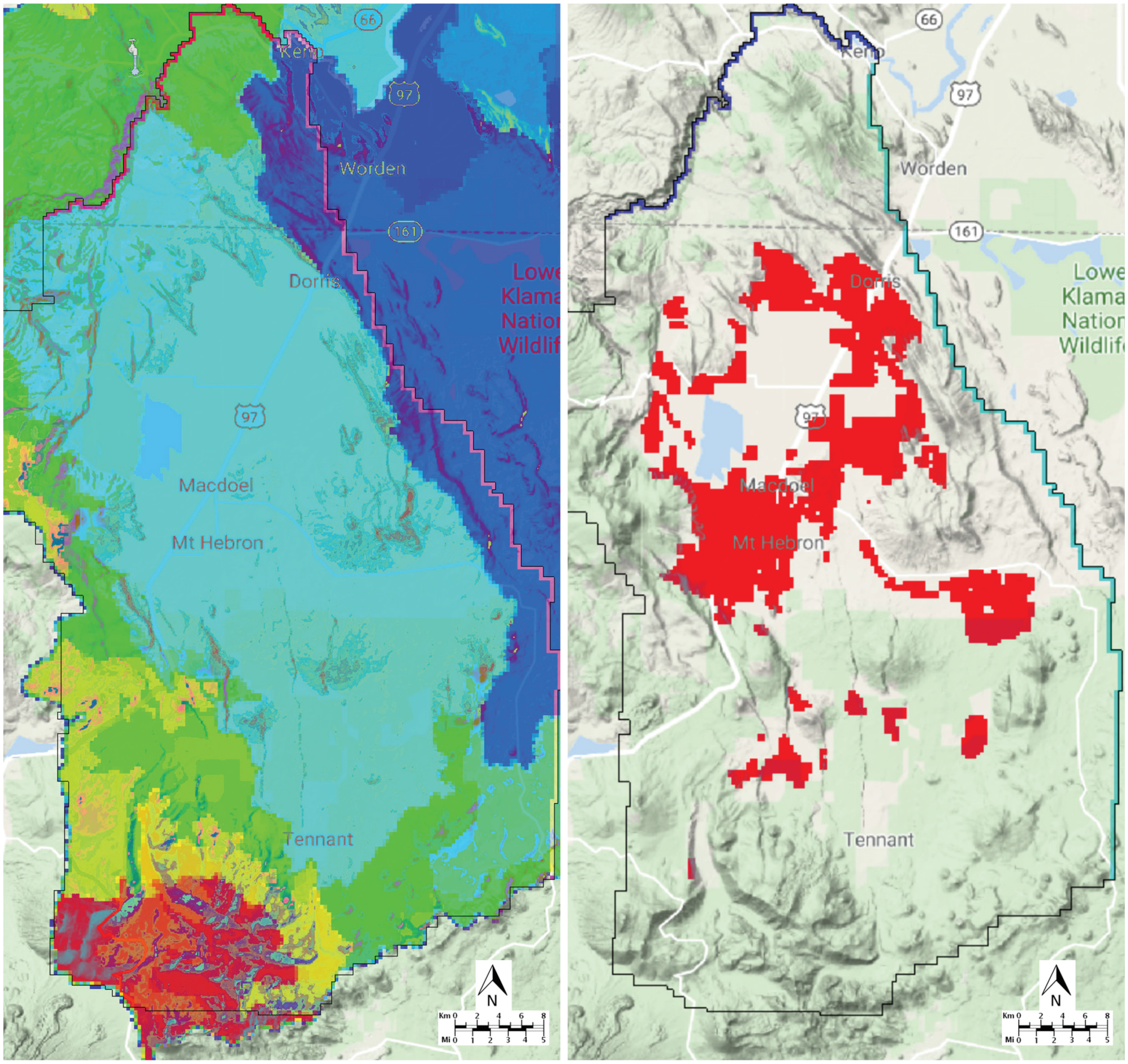

Figure 1.39: Spatial distribution of long-term average recharge (left, red: highest amounts of recharge, dark blue: lowest amounts of recharge) and location of areas with groundwater pumping (right). Black outline: BVIHM simulation domain boundary.

General groundwater flow dynamics and direction

For the BVIHM simulation domain, most of the precipitation occurs in the mountains to the south and west of Butte Valley, where it also recharges the volcanic aquifer system (Figure 1.39). Recharge may be preceded by surface runoff into a nearby creek that later disappears into the subsurface through recharge. Groundwater from that dominant recharge zone flows northward, northeastward, and eastward across Butte Valley and Redrock Valley, where significant amounts of the groundwater are pumped for irrigation and subsequently lost to ET (Figure 1.39). However, groundwater pumping is significantly less than estimated recharge. Hence, significant amounts of groundwater discharge laterally through the lakebed, alluvial, and volcanic aquifer system of the Butte Valley and the Upper Klamath Basin toward the Lower Klamath groundwater basin, toward an area east of the Butte Valley watershed south of the Lower Klamath groundwater basin, and possibly toward the Tule Lake groundwater basin, which is separated from Butte Valley groundwater basin by the larger volcanic aquifer system in this region (Gannett et al., 2007, 2012).

2.2.3.2 Description of Historical Water Budget Components

The section describes the full water budget of the Basin including inflows to the Basin, outflows from the Basin, and the fluxes from the land/soil subsystem, L, to the groundwater subsystem, GW (DWR 2020b).

Figure 1.32 and Figure 1.33 show the water budgets for the two subsystems. Fluxes between subsystems are shown twice: in the subsystem from where the flux originates as output (negative flux, analogous to an account withdrawal at a bank), and in the subsystem into which the flux occurs as input (positive flux, analogous to an account deposit at a bank).

This section also describes storage changes in the subsystems. An increase in storage over a period of time occurs when fluxes into a subsystem exceed fluxes out of the subsystem over that period of time (similar to deposits exceeding the amount of withdrawals in a bank account: the account balance increases). In Figure 1.32 and Figure 1.33, a storage increase is depicted as additional negative bar length needed to balance the negative bar length (fluxes out of the subsystem) with the positive bar length (fluxes into the subsystem). In other words, storage increase is depicted as if it were a negative flux. This is consistent with accounting principles in hydrologic modeling.

Similarly, a decrease in storage over a period of time occurs when fluxes into a subsystem are less than the fluxes out of the subsystem over that period of time (similar to withdrawals from a bank account exceeding the deposits into the bank account: the account balance decreases). In Figure 1.32 and Figure 1.33, a storage decrease is depicted as additional positive bar length needed to balance the positive bar length (fluxes into the subsystem) with the negative bar length (fluxes out of the subsystem). In other words, storage decrease is depicted as if it were a positive flux, consistent with hydrologic modeling practice.

Basin Inflows

There are two inflows in the historic water budget: precipitation on the valley floor (to L), and subsurface inflow or mountain front recharge from the surrounding quaternary volcanics underlying the upper watershed (to GW):

- *Precipitation (to L)*: Rainfall on the valley floor is a key input for the PRMS and CRZWM model which results in deep percolation. Groundwater recharge (from L to GW) occurs when root zone water storage exceeds its water holding capacity due to precipitation and/or irrigation amounts exceeding evapotranspiration needs.
- *Subsurface Inflow (to GW)*: The BVIHM domain includes the entire Butte Valley watershed. Recharge (across the landscape or in creeks) outside the Basin becomes groundwater flow, some of which flows into the Basin. BVIHM is used to compute monthly and annual subsurface inflows from the upper watershed across the Basin boundary, within the larger volcanic aquifer system of the region and into the unconsolidated deposits within the Basin.

Discussion

Precipitation is highly variable – more variable than any other Basin input/output flux. Precipitation amounts to the Basin range from less than 50 TAF to over 140 TAF. Median precipitation is 86 TAF. Precipitation has declined significantly over the last two decades relative not only to the simulated first decade, but also relative to the remainder of the second half of the 20th century. While precipitation is significant, subsurface inflows are more than twice as large, with a median of 185 TAF. Because of the large size of the upper watershed and its underlying volcanic aquifer system, it is not surprising that these inflows are much less variable than precipitation, varying within approximately 10% of the median. The median total water supply to the Basin is about 270 TAF annually.

Basin Outflows

The two outflows in the historic water budget component are evapotranspiration (from L) and subsurface outflow (from GW):

- *Evapotranspiration*: Evapotranspiration is the consumptive water use in the Basin, from crops and from natural vegetation (from L). Evapotranspiration loses water in the Basin to the atmosphere.
- *Subsurface Outflow*: Subsurface outflow from the Basin within the larger regional volcanic aquifer system is dominantly to the East and Northeast. Additionally there is some subsurface outflow to the North through less permeable tertiary volcanics. Volcanics of the Western Cascades to the Northwest are of very low permeability and prevent draining of the Basin toward the Klamath River near Rock Creek.

Discussion

Median consumptive use (evapotranspiration, ET) is 108 TAF. This flux is highly variable depending on water year type, despite the fact that irrigation can buffer significantly against drought conditions. However, significantly more land is fallowed in dry years and natural vegetation has significantly reduced evapotranspiration in dry years, when it can fall below 100 TAF. On the other hand, it can reach 143 TAF in wet years. Median ET is 25% higher than median precipitation. The discrepancy is even larger in dry years. But in wet years ET equals precipitation. This further demonstrates that ET is buffered against precipitation variability through soil water storage and irrigation.

Subsurface groundwater outflow from the basin, as its inflow, is relatively constant, varying by much less than 10% from its median 169 TAF annual outflow. Subsurface outflow represents slightly over 90% of subsurface inflows, and slightly over 60% of the total Basin outflow (with the remainder going to ET). Seasonally, outflow is consistently highest in the late winter months and lowest in the fall, corresponding to groundwater levels being highest in spring and lowest in the fall.

The fact that ET represents only 40% of the total Basin inflow demonstrates that the Basin is not in overdraft. However, precipitation, evapotranspiration, and – even more so - recharge estimates for the upper watershed have significant uncertainties, hence, groundwater inflow into the basin must also be regarded as highly uncertain. If recharge estimates were twice as large as actual recharge, and consequently the actual groundwater inflow into Butte Valley was only about half of simulated inflow, the total inflow (180 TAF) would still significantly exceed ET in the Basin.

Flows Between Land (Soil) Zone and Groundwater

All other fluxes depicted in the two subsystem water budgets of the Basin are flows between the land/soil subsystem and the groundwater system:

- *Recharge (from L to GW)*: Recharge from the land surface occurs primarily in winter months when there are larger amounts of precipitation and limited evapotranspiration. This results in excess water in the soil zone leading to deep percolation. Surface runoff and irrigation return flows are small and are also considered to become groundwater recharge, since the Basin has no surface drainage.
- *Groundwater Pumping for Applied Water (from GW to L)*: Groundwater pumping is the only applied water for irrigation in the Basin. Groundwater pumping is limited to the spring and summer, from April to September, when recharge is nearly negligible. We note that, as described above, the relatively small amounts of surface water irrigation are effectively simulated as (creek) recharge outside the Basin boundary and groundwater pumping within the Basin boundary.

Discussion

Surface runoff is a small fraction compared to deep percolation. Combined, they supply a median 54 TAF of recharge to groundwater. This is one-third of the total water applied to or precipitated onto the landscape (median of the sum of precipitation and applied water: 162 TAF). Median recharge to groundwater represents about 70% of the amount of groundwater pumping for irrigation. Were the basin considered isolated, and the large subsurface inflows ignored, the Basin would appear to be in overdraft. Instead, the difference between pumping and recharge is effectively supplied by the lateral inflow through the regional aquifer system. The 22 TAF by which pumping exceeds Basin recharge represents 12% of the total subsurface inflows from the upper watershed. Again, from a groundwater overdraft perspective, there is a significant hydrogeologic buffer, even if subsurface inflows were substantially overestimated by the PRMS model.

Annual groundwater pumping is quite variable, ranging from less than 60 TAF to nearly 100 TAF, with a median of 77 TAF. Pumping, while highly variable, has significantly increased during the 1989-2018 period, somewhat mirroring the declining trend in precipitation.

Change in Storage

Soil Zone Storage: As seen in the Soil Water Budget plots, there is minimal interannual change in the soil water storage, most likely due to the low storage capacity of the soil zone. Interannual storage changes can be gains as high has 4.5 TAF and losses as low as 7.7 TAF.

Aquifer Storage: Groundwater is the largest storage component in the Basin. Annual changes in groundwater storage range from as much as 42 TAF increase to as much as 58 TAF in decrease over a 12-month period. There is significant long-term trend indicating some groundwater depletion. Only few years had a net positive groundwater storage change: 1993, 1996-1999, 2006, and

2011. On September 30, 2018, total groundwater storage was 392 TAF lower than at the beginning of the simulation period (October 1, 1989). The change in storage is reflected in a steady decline in groundwater levels in many parts of the Basin, particularly in the eastern and northeastern part of the Basin. With lower water levels in the Basin, the simulations also show a decrease in groundwater outflow to areas east and northeast of the Basin due to a reduced gradients across the general head boundary.

2.2.3.3 Groundwater Dynamics in the Butte Valley Aquifer System: Key Insights

Butte Valley groundwater basin is an alluvial basin surrounded by a late tertiary and quaternary volcanic watershed that historically has had high rates of winter precipitation due to it's altitude, but little surface expression of flows and no surface storage reservoirs or canals connecting to any surface reservoirs. Most excess precipitation readily percolates into the subsurface, recharging a permeable volcanic aquifer system. Groundwater flows across the Basin toward groundwater sinks (discharge to surface water, pumping) in areas to the east and northeast of the Basin. Groundwater discharges into the Klamath River to the north through low permeability, tertiary volcanics into the lower Klamath Lake basin to the east through late tertiary and quaternary volcanics. Winter rains fill the aquifer system between October and April (Figure 1.34).

Groundwater pumping within the Basin leads to lower net outflow into areas to the east of the Basin, thus leading to a lower hydraulic gradient that connects the Basin to the areas east/northeast of the Basin, where groundwater discharges into surface water features or is pumped out. This creates a natural longer-term lowering of water levels superimposed on seasonal water level lowering during the dry season. Water levels are highest near the southern and western valley margin and slope toward the Klamath River and lower Klamath Lake basin.

Seasonal variability of recharge is accentuated by year-to-year climate variability: Years with low precipitation lead to lower recharge from the surrounding watershed, hence less subsurface inflow to the Alluvial Basin from the quaternary volcanics, but also less outflow to areas to the east. Again, this leads to lower groundwater levels in the Basin. Over the past thirty years, a decrease in precipitation and a commensurate increase in groundwater pumping have both led to less groundwater being discharged eastward, lessening the hydraulic gradient through the regional aquifer systems east of the Basin, thus lowering water levels within the Basin.

Any significant long-term decrease or increase of long-term precipitation totals over the watershed will lead to commensurate lowering or raising, respectively in the average slope of the water table from the valley margins toward the lower Klamath Lake Basin groundwater elevation, leading to a dynamic adjustment of water levels, even under otherwise identical land use and land use management conditions. Such changes, however, are unlikely to lead to groundwater overdraft as a lowering of groundwater elevations in the Basin will result in decreased subsurface outflow while a rise in groundwater elevations will result in increased subsurface outflows.

Similarly, any increase or reduction in groundwater pumping leads to a decrease or increase in groundwater storage until the change in groundwater elevation is sufficient that the subsurface outflow is increased or decreased reducing any further changes in storage.

2.2.4 Future Water Budget

The future projected water budget contains all of the same components as the historical water budget; for a description of those terms, see Section 2.2.3.

To inform long-term hydrologic planning, the future projected water budget was developed using the following method:

1. Observed weather and streamflow parameters from water years 1991-2011 were used multiple times to make a 50-year “Base case” climate record (see Table X in Appendix 2-D for details). The Base case projection represents a hypothetical future period in which climate conditions are the same as conditions from 1991-2011.
2. The climate-influenced variables Precipitation (as rain), Reference Evapotranspiration (ETref), and tributary stream inflow were altered to represent four climate change scenarios:

- (a) Near-future climate, representing conditions in the year 2030
- (b) Far-future climate, representing central tendency of projected conditions in the year 2070
- (c) Far-future climate, Wet with Moderate Warming (WMW), representing the wetter extreme of projected conditions in the year 2070
- (d) Far-future climate, Dry with Extreme Warming (DEW), representing the drier extreme of projected conditions in the year 2070

3. BVIHM was run for the 50-year period of water years 2022-2071 for the Base case and all four climate change projected scenarios.

For convenience, the scenarios described in points 2a-2d above will be referenced as the Near, Far, Wet and Dry future climate scenarios. Additional tables and figures for all five future climate scenarios are included in Appendix 2-D.

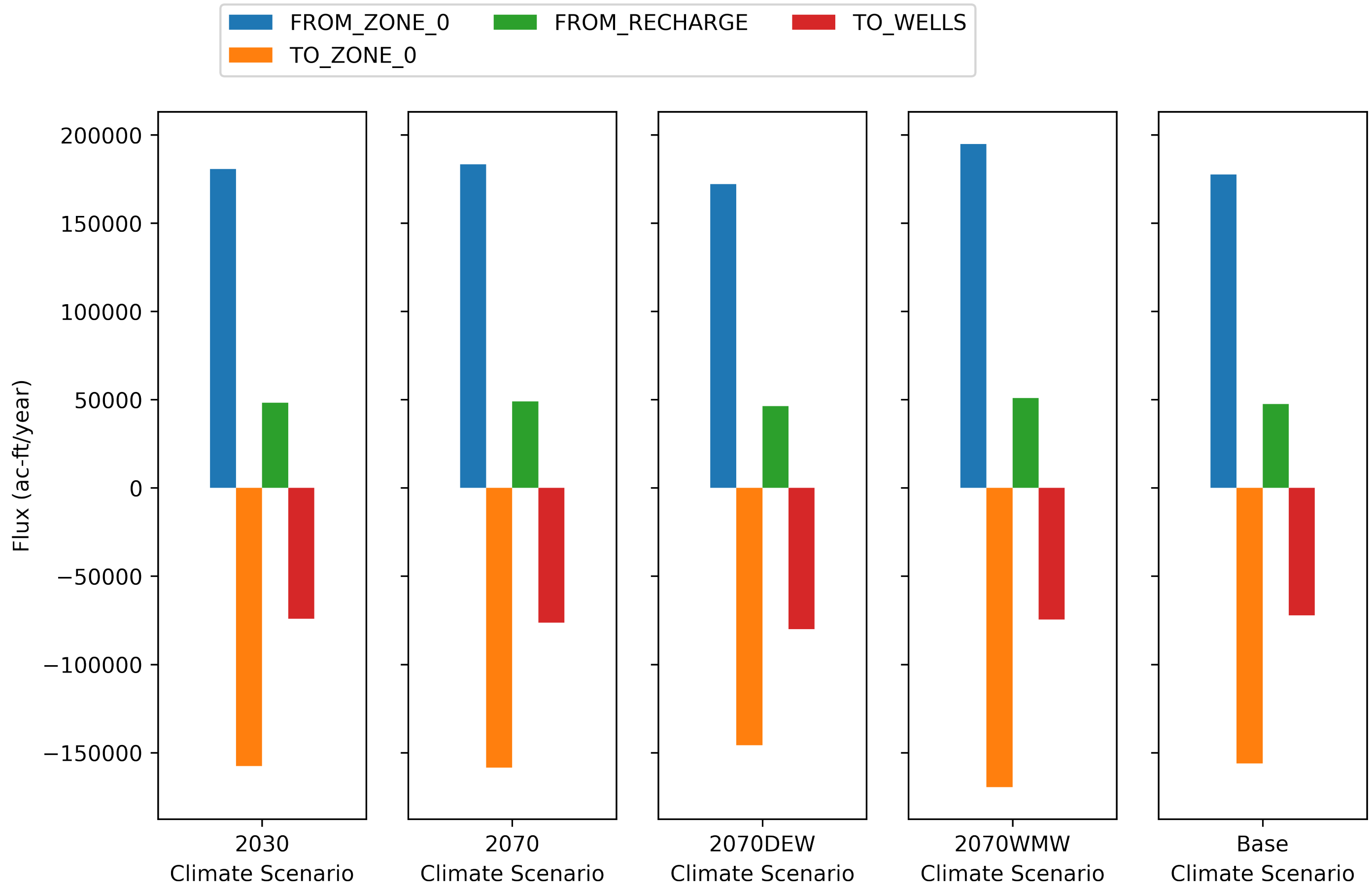

Figure 1.40: Water Budget components for different future climate scenarios.

Method Details

The climate record for the projected 50-year period of water years October 2021-September 2071 was constructed from model inputs for the years 1991-2011. The minimum bound of 1991 was imposed by ETref data, which is not available prior to the BVIHM historical period; the maximum bound of 2011 was imposed by DWR change factors, which are only available through (Table X in Appendix 2-D).

Under their SGMA climate change guidance, DWR provided a dataset of “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 change factor concept is intended to convert all past years to a single near or far future year; for example, imagine that in a hypothetical grid cell, the 2030 (Near) scenario change factor for ET ref in March 2001 was 5%. This would imply that, under the local results of the global climate change scenario used to inform this guidance, if March 2001 had occurred in the year 2030, there would be 5% more ET in that grid cell than historically observed.

Implications

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.

More groundwater is held in aquifer storage in the Wet scenario, and less in the Dry scenario. However, interannual variability is a greater driver of storage change than climate change scenarios (i.e., in future year 2045 the difference between the Wet and Dry scenarios was ~5 TAF, but the range in overall interannual variability in each scenario is greater than 40 TAF).

Conversely, the impact of future climate conditions on recharge in the upper watershed and subsurface flows is highly dependent on which scenario is selected. Near and Far scenarios show minimal differences from historical Base case flow conditions. The Dry scenario shows some periods of notably reduced flow, while the Wet scenario shows some years with much higher flow than historical Base case flow conditions.

Importantly, under all climate change scenarios, water table conditions remain stable over the long-term and are likely avoid minimum threshold exceedances. Future climate scenarios represent historic cropping patterns and therefore assume no expansion of irrigated lands beyond their historical footprint. Future scenarios therefore represent stable land use conditions. The lack of significant downward water level adjustment is a result of the fact that the surface water basin is closed, and because even the dry-hot year future scenario does not represent conditions that are more stressful than the most recent 10-year period.

2.2.5 Sustainable Yield

The sustainable yield “means the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result.” (California Water Code Section 10721).

In this plan, the sustainable yield is defined as the long-term average annual groundwater pumping rate, as defined by the water budget analysis, that does not cause an undesirable result. Chapter 2 defines the water budget analysis and chapter 3 defines undesirable results. The Basin is not in overdraft. It has not incurred undesirable results with respect to the sustainability indicators for water level and groundwater storage. Since 2014, ongoing groundwater pumping has also not incurred new known undesirable results with respect to sustainability indicators for land subsidence, water quality, and terrestrial GDEs. Water levels and groundwater storage have been in a long-term dynamic equilibrium between inflows to and outflows from the aquifer system. For interconnected surface water, data gaps exist that will be filled over the next five years to more clearly identify the undesirable results that must be avoided through groundwater management. Hence, for the Butte Valley, **the sustainable yield is currently equal to the most recent 10-year average annual groundwater pumping of 83-thousand acre-feet** as estimated with the Butte Valley Integrated Hydrologic Model for the 2009-2018 period.

The monitoring program and the actions to address data gaps through additional monitoring, data analysis, and modeling during the next 5-year period may reveal undesirable results that will require the implementation of PMAs. Chapter 4 defines projects and management actions (PMAs) that the GSA will implement as needed to avoid future undesirable results. Individual PMAs to address future undesirable results may include managed aquifer recharge, some reduction of pumping demand, both, or neither (see Chapter 4). Updated simulations, analyses, and technical-scientific assessments will guide the selection and design of PMAs to ensure effective and efficient responses that will avoid undesirable results.

Whether and by how much future groundwater pumping may need to be reduced will be a function of the PMAs that are implemented and their spatial extent. For example, irrigation efficiency improvements result in a reduction in groundwater pumping, but may also reduce recharge. For every implementation of a PMA that results in the reduction in groundwater pumping there is a commensurate downward adjustment in sustainable yield. This adjustment reflects the reduction in long-term average groundwater pumping achieved by a PMA, if any. Some managed aquifer recharge may allow for an increase in long-term average groundwater pumping without incurring undesirable results. The exact amount of that adjustment varies over time and will depend on the future portfolio of PMAs implemented.

Consequently, the sustainable yield will vary with the implementation of PMAs that allow the basin to meet the sustainable management criteria. The sustainable yield will be continually adjusted from the 2009-2018 baseline average annual groundwater pumping of 83-thousand acre-feet using an assessment and simulation of implemented PMAs.

The sustainable yield will be recomputed at least with every 5-year plan update, given the then-implemented PMAs that avoid the minimum thresholds and achieve the measurable objectives for all sustainability indicators. Future simulations and assessments will also consider measured changes in climate and update future climate predictions. Climate change may further impact the sustainable yield of the Basin.

List of Appendices

Appendix 2-A Expanded Basin Setting

Appendix 2-B Water Quality Assessment

Appendix 2-C Groundwater Dependent Ecosystem Assessment

Appendix 2-D Water Budget

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