Chapter 2 [June 2024 Draft Revision]

Plan Area and Basin Setting

2.1 Description of the Plan Area

2.1.1 Summary of Jurisdictional Areas and Other Features

The Butte Valley groundwater basin (Basin) is a 79,700 acre (125 square mile [sq mi]; 326 square kilometer [sq km]) subbasin within the upper Klamath Groundwater Basin that extends between California and Oregon (Wood 1960; Gannett, Wagner, and Lite Jr. 2012). The Butte Valley watershed (Watershed) is roughly three times larger than the Basin and contains two other Department of Water Resources (DWR) recognized groundwater basins. The Watershed is the drainage area that recharges surface water in the Basin, shown in Figure 2.1. The Watershed is located immediately northeast of Mount Shasta, whose flank can be seen in the bottom left corner of Figure 2.1.

The predominately agricultural Basin is in northern Siskiyou County, California, just south of the Oregon border (see Figure 2.1). Under the 2019 basin prioritization conducted by DWR, the Basin (DWR Basin 1-003) is designated as medium priority (DWR 2019d). The Basin sits on the western edge of the Modoc Plateau, a broad and rugged volcanic upland with land surface elevations generally between 4,500 to 5,000 feet (ft; 1371 to 1524 meters [m]) above mean sea level (amsl) (Gannett, Wagner, and Lite Jr. 2012). The Basin is located at an elevation of about 4,2~~00~~30 ft – 4,270 ft (129~~8~~0 m – 1300 m) amsl. The basin ~~and~~ is topographically closed and bounded by topographic highs in all directions: the Cascade Mountains in the north, south and west, the Mahogany Mountain ridge in the east and Sheep Mountain and Red Rock Valley in the southeast (DOI 1980; DWR 2004). The Basin contains Meiss Lake, the remnant of a prehistoric lake that once filled Butte Valley, and several streams that all flow into the Basin from the surrounding Watershed, as shown in Figure 2.1 (King 1994). Butte Creek is the largest stream flowing into Butte Valley.

2.1.1.1 Jurisdictional Areas and Land Use

The Siskiyou County Flood and Water Conservation District serves as the Groundwater Sustainability Agency (GSA) for the Basin. The Basin has three notable population centers: the City of Dorris (Population: 962), Macdoel (Population: 155), and Mount Hebron (Population: 81) (DWR 2016b). Due to their small populations, Macdoel and Mount Hebron are described as census-designated places by the United States (U.S.) Census Bureau. U.S. Highway 97 crosses the Basin from the southwest to northeast, passing through Dorris and Macdoel. The Union Pacific Railroad passes through Butte Valley from north to south, passing through all three cities. The railroad generally follows U.S. Highway 97 between Macdoel and Dorris and leaves the Valley north of Dorris via a train tunnel through the Mahogany Mountain ridge. South of Mount Hebron, the railroad generally follows the path of Butte Creek (Figure 2.1). The Basin and Watershed do not contain any tribal lands or tribal interests.

Disadvantaged Communities

There are three severely disadvantaged communities (SDACs) in the Basin that suffer from a combination of economic, health, and environmental burdens (Figure 2.3). By definition, disadvantaged communities (DACs) have a median household income (MHI) less than 80% of the statewide MHI while SDACs are below 60%. All three of the communities in the Basin are categorized as SDACs: Dorris has a MHI of $28,963, Macdoel has a MHI of $35,294, and Mount Hebron has a MHI of $28,170 (DWR 2016b). All SDAC communities rely on groundwater as their sole source of drinking water, using a combination of municipal water district, small water suppliers, and domestic wells.

Water Suppliers

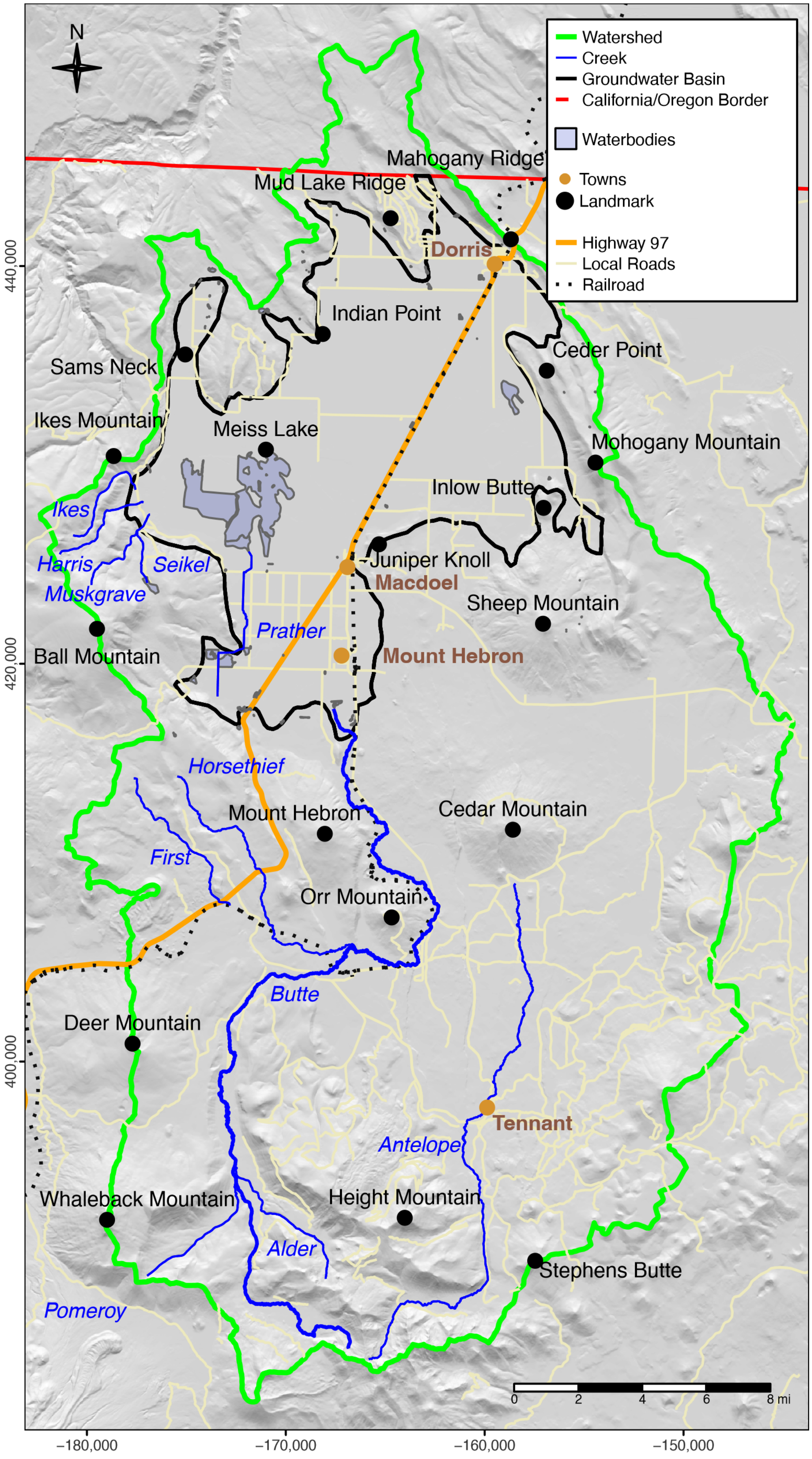
The Basin has no adjudicated areas and contains one irrigation district, one water district, and four small water suppliers (Figure 2.2). The Butte Valley Irrigation District (BVID) is a private water supplier that manages irrigation water for roughly 5,000 acres (20 square kilometers [sq mi]) of land northwest of Mount Hebron. It manages the largest groundwater distribution and management network in the Basin and distributes water throughout the service area through a network of pipes. Farms serviced by the irrigation district are allocated two acre-feet per acre per year (AFY; 0.6 meters per year [m/yr]). BVID supplies water from approximately 20 wells out of its 25 well network. The City of Dorris has a small municipal water district serving approximately 938 residents (McKay 2019). It has two wells in its supply network. However, one well is only used as an emergency supply (McKay 2019). Groundwater supplies 100% of the district water supply (McKay 2019).

In the region surrounding Macdoel and Mount Hebron, four small water suppliers report to the California Department of Public Health (CDPH) (SWRCB 2019a). Macdoel Waterworks operates in the middle of Macdoel and serves a population of 20 with two monitoring wells (SWRCB 2019a). Juniper Village Farm Labor Housing is located southeast of Macdoel and has one groundwater well serving a population of 200 (SWRCB 2019a; SWRCB 2019c). The Mt. Hebron Work Center is operated by the U.S. Forest Service (USFS) and operates in the middle of Mount Hebron with one groundwater well serving a population of 30 (SWRCB 2019a; SWRCB 2019c). The USFS Goosenest District Office operates west of Mount Hebron alongside U.S. Highway 97. It has one groundwater well serving a population of 30 (SWRCB 2019a; SWRCB 2019c).

Federal Managed Lands

Over 40% of the Basin is covered by federal and state managed lands, as shown in Figure 2.2. Federally managed land consists of the Klamath National Forest, including the Butte Valley National Grassland and small sections of the National Forest along the Basin border. The Butte Valley National Grassland is primarily north of U.S. Highway 97, covering 18,400 acres (74 sq km) or 23% of the total Basin surface area. Butte Valley Grassland became the nation’s 20th National Grassland in 1991 after strong support from the local Congressional delegation, California Cattlemen’s Association, California Department of Fish and Wildlife (CDFW; formerly California Department of Fish and Game), and the local public.

After serving as a military practice bombing range in the 1940s, the federal government and Natural Resources Conservation Service (formerly Soil Conservation Service) re-stabilized the soil by planting over 4,000 acres (16 sq km) of crested wheatgrass. They worked with local ranchers to set up grazing associations and developed local conservation practices, which continue to the present day. Today, the National Grassland is shrub-steppe, with sagebrush, rabbitbrush, bitterbrush, basin wildrye, intermediate wheatgrass, and other arid grasses and flowers with scattered western juniper trees. Grazing cattle reside within the National Grassland alongside local wildlife including mule deer, Roosevelt elk, pronghorn, coyote, marmot, weasel, porcupine and bobcat. Resident bird species include Swainson's Hawk, golden eagle, bald eagle, merlin, sandhill crane, great horned owls, short-eared owls, and long-eared owls, with winter visitors including red-tailed hawk, Ferruginous Hawk, rough-legged hawk, northern harrier, American Kestrel, and prairie falcon (USFS 2020).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Indian Point
Ceder Point
Sams Neck
Ikes Mountain
Meiss Lake
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Juniper Knoll
Macdoel
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Prather
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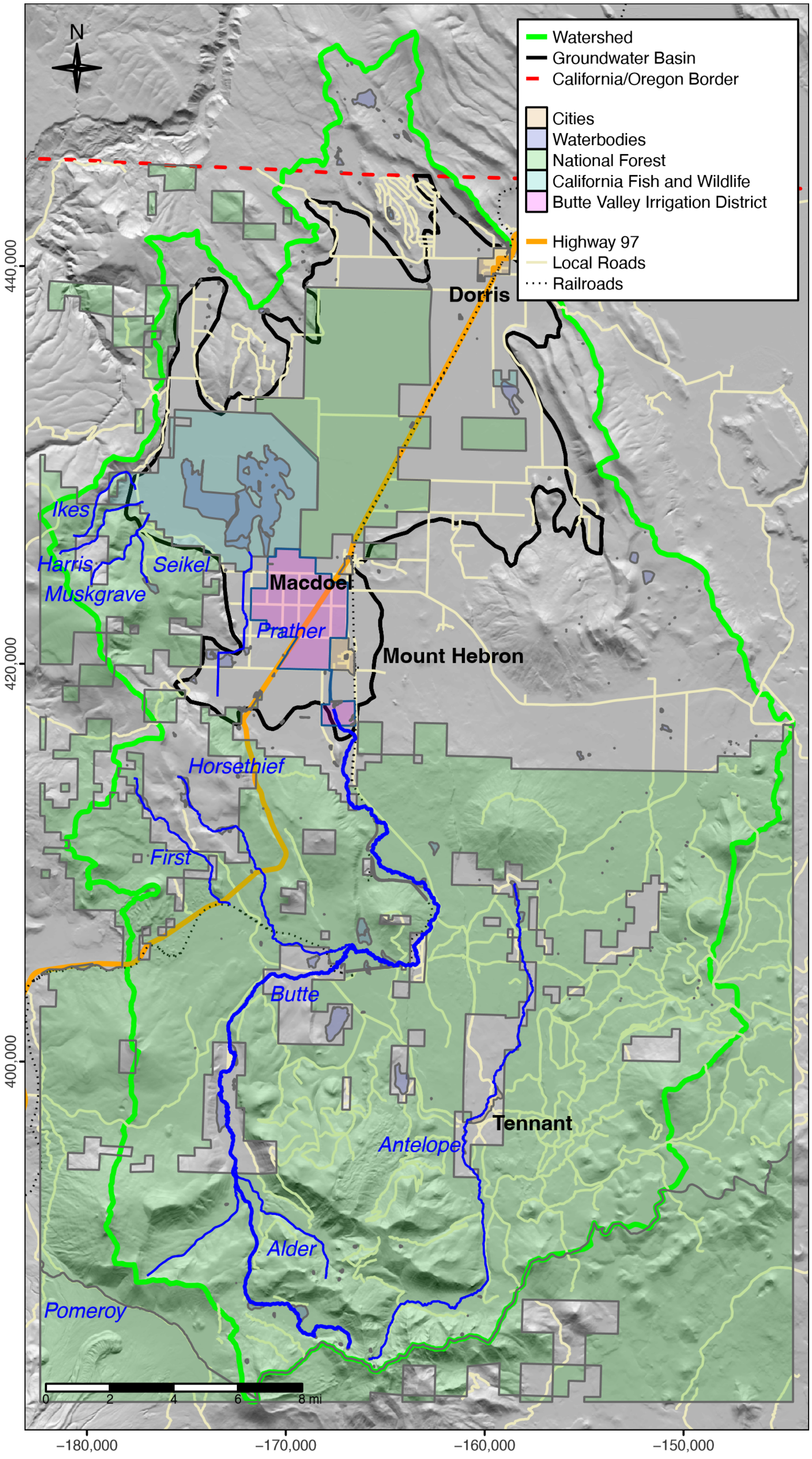
Figure 2.1: Butte Valley Watershed and Groundwater Basin Boundary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California/Oregon Border
Cities
Waterbodies
National Forest
California Fish and Wildlife
Butte Valley Irrigation District
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Local Roads
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Figure 2.2: Butte Valley Watershed Jurisdictional Authorities.

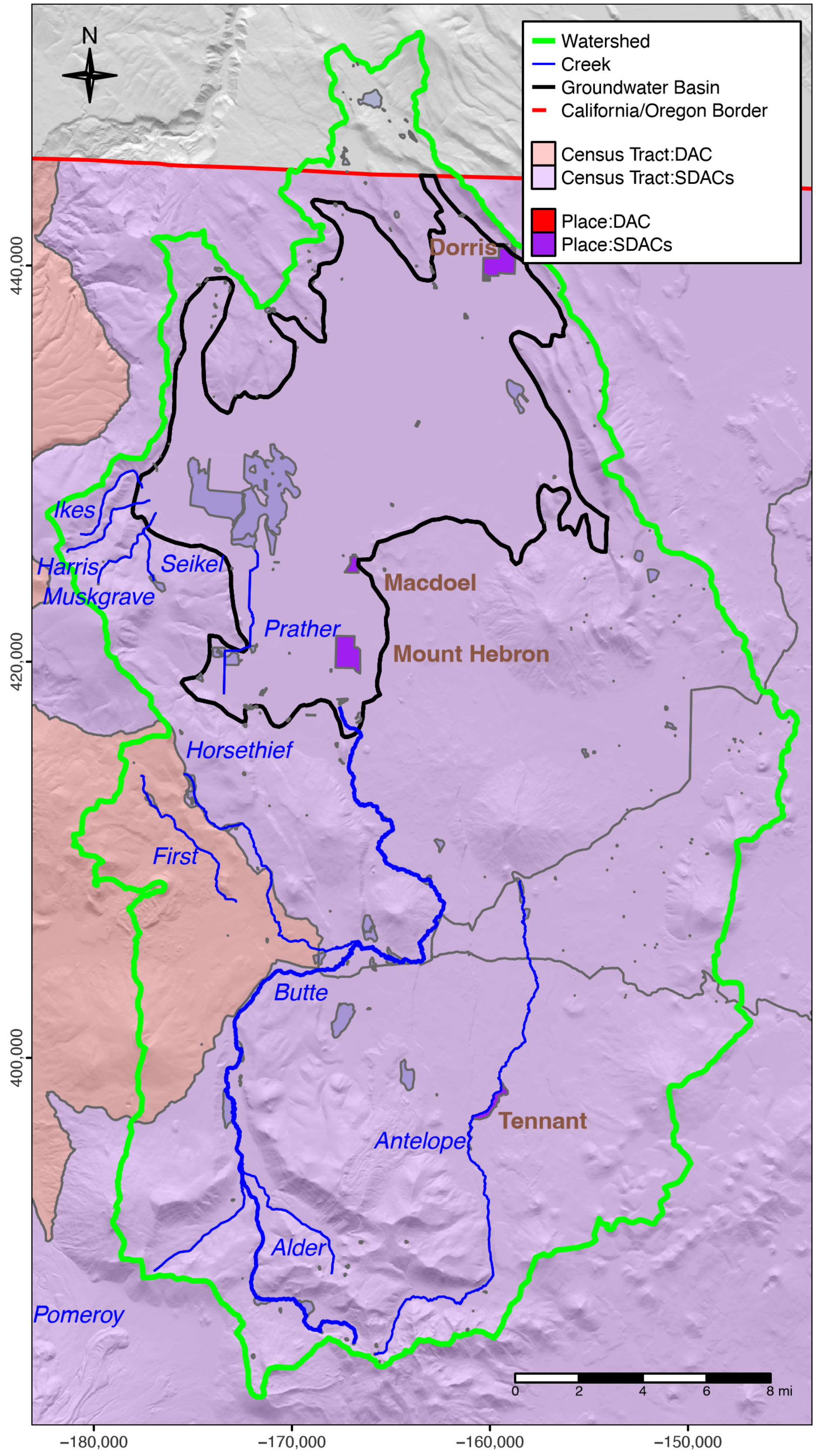


Figure 2.3: Based on the 2016 U.S. Census, place and tract boundaries of Disadvantaged Communities (DACs: $42,737 <= MHI < $56,982) and Severely Disadvantaged Communities (SDACs: MHI < $42,737) in the Butte Valley watershed, using data from the DWR DAC Mapping Tool (DWR 2016b).

During World War II the US Navy used 7,040 acres (28 sq km) of land to develop the Siskiyou Rocket and Bombing Range, an aerial gunnery range used in winter when other stations were inhibited by poor weather conditions. By May 1945, the U.S. Navy gained use of the area for airto-ground firing, high and low level bombing and strafing. Sub-Caliber Aerial Rockets were used at the site. The area covered parts of the Butte Valley National Grassland and Butte Valley Wildlife Area. The U.S. Department of Defense (DOD) has conducted site inspection and monitored the site for discarded military munitions and explosives, including unexploded ordinance. In 1984, a wildlife survey discovered a rocket that was removed by the DOD, though only inert practice rockets were used at the site. Qualitative site reconnaissance and soil sampling found that metal pollution does not exceed human health screening values. The Department of Toxic Substances Control is the oversight and cleanup agency for the site, but no further action is planned as of September 2013. The cleanup site floods in the winter and is populated with grazing cattle the rest of the year (DTSC 2020).

State Managed Lands

The state owns 13,500 (55 sq km) acres within the Basin, or 17% of the total Basin surface area, which includes the Butte Valley Wildlife Area (BVWA) and a small property at Mud Lake, as shown in Figure 2.2. The BVWA is approximately 13,400 acres (54 sq km) and contains wetlands, sage flats, farmlands, and the 4,000 acre (16 sq km) Meiss Lake. BVWA is 13,200 acres (53.4 sq km) with 4,400 acres (17.8 sq km) of intensively managed wetlands, 4,000 acres (16.2 sq km) of Meiss Lake, and 4,800 acres (19.4 sq km) of habitat (NCRWQCB 2008). It is bordered by the federal Klamath National Forest on the east and southwest. The Fish and Game Commission designated the site as a wildlife area in 1981 and it is currently managed by CDFW. Over 200 species of birds can be spotted in the Wildlife Area. Recreational activities include camping, hiking, wildlife viewing, and hunting. Hunting options include waterfowl, coots, moorhens, snipe, and doves. Four grain fields lie on the west and south side of the Wildlife Area. The small property at Mud Lake is owned but not managed by the state.

Land Use

Historical land use maps for Butte Valley are not available before 1996. Even without detailed historical land use surveys, there are enough historical records to form an image of changing land use over time. Irrigated land in Butte Valley has increased from approximately 12,000 acres (4,850 hectares) in 1952 to over 37,000 acres (15,000 hectares) in 2010 as shown in Figure 2.5 (County of Siskiyou 1996; DWR 2010). Early records for Butte Valley do not track irrigated land by water supply or crop type, but between 2000 and 2010 the fraction of land irrigated by groundwater also increased as shown in Figure 2.5 (DWR 2000, 2010).

Butte Valley's economy is dominated by agriculture. The 2010 County land use survey assessed 60.8% of the Basin area and identified the following land use percent coverage: agriculture (38.7%), idle land (5.3%), and urban (10.6%). As of 2010 the major crops in Butte Valley were alfalfa, hay, and nursery strawberry, which occupied approximately 18,400 acres, 8,000 acres, and 3,300 acres (7,450 hectares, 3,240 hectares, 1,300 hectares) respectively (DWR 2010). Butte Valley National Grassland is not included in the land use survey, but a number of local ranchers have permits to graze cattle (USFS 2020). Acreages associated with various land uses surveyed by DWR in 2010 are shown spatially in Figure 2.4, and numerically in Table 2.1 (DWR 2010).

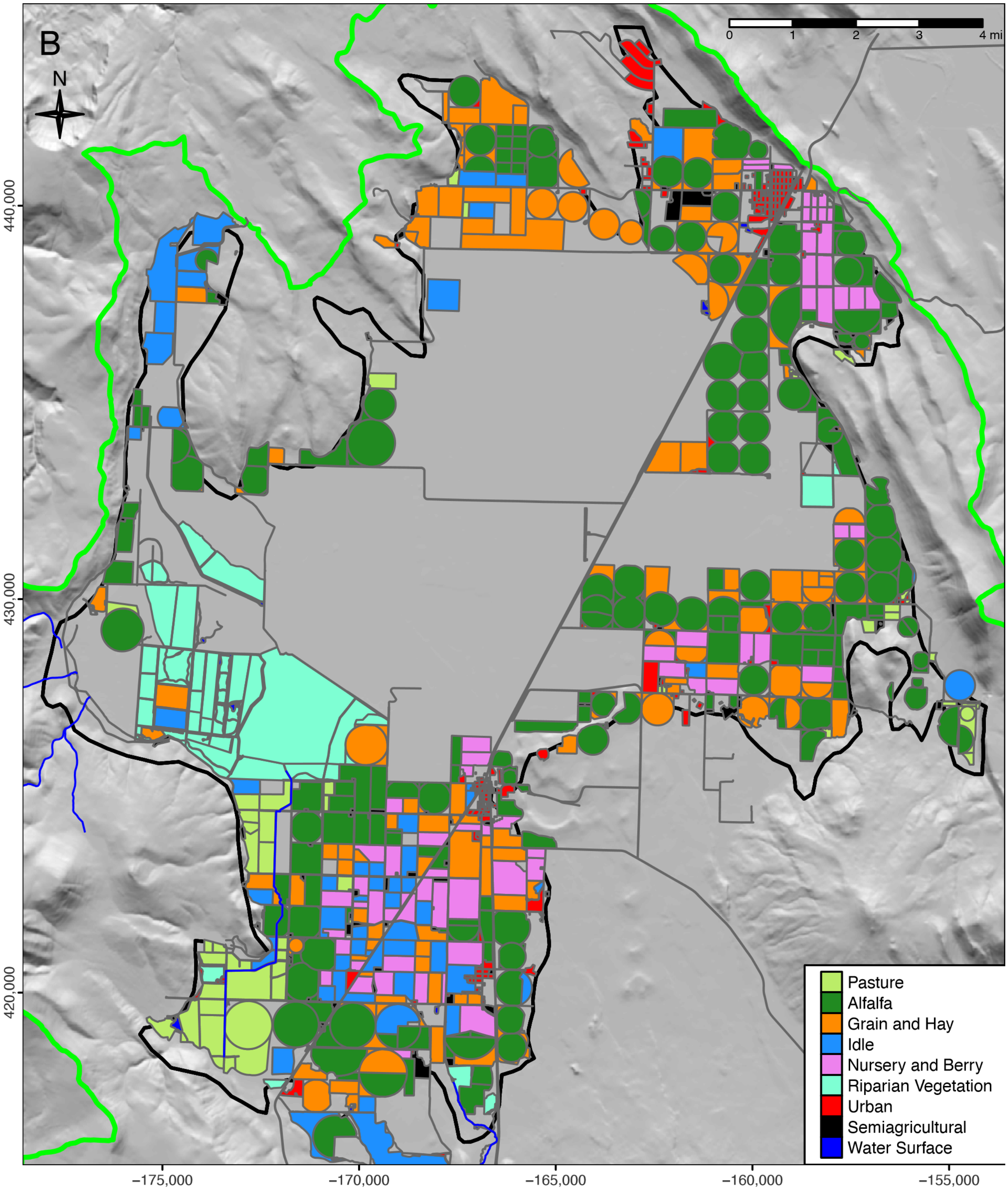
Nursery s~~S~~trawberry is a significant economic commodity in Butte Valley. Recent market prices are $50,000 per acre of nursery strawberries compared to $1,040 per acre of alfalfa (in 2016) and $822 per acre of hay (in 2016) (Smith 2016). Butte Valley nurseries produce~~s~~ approximately 500 million strawberry plants annually (Nelson 2021). Strawberries in California grow on approximately 39,000 acres (USDA 2020a) and approximately 3,000 of those acres are from nursery production in Butte Valley.

Table 2.1: Acreage and percent of total Basin area covered by all identified land uses in the 2010 DWR land use survey.

Land Use Description	Acres	Percent of Basin Area
Alfalfa pasture	16,081	20.2
Grain and Hay	8,110	10.2
Urban Vacant	7,242	9.1
Riparian Vegetation	4,543	5.7
Idle	4,192	5.3
Truck and Nursery and Berry Crops	3,633	4.6
Pasture	2,341	2.9
Urban Residential	819	1.0
Semiagricultural and Incidental to Agriculture	655	0.8
Water Surface	398	0.5
Urban Industrial	292	0.4
Urban Commercial	51	0.1
Barren and Wasteland	1	0.0
Urban Landscape	17	0.0

Butte Valley crops have several different growing cycles. Alfalfa is grown for four to six years before ripping soil and reseeding. In contrast, hay, idle/fallow, and strawberry rotate in three annual cycles with strawberries replanted in the same field every three years (Nelson et al. 2019). Each year that a field is part of the strawberry rotation it is either used for hay, idle, or strawberry. In 2010 approximately 9,900 acres (4,000 hectares) were part of that rotation. Strawberry is only grown from March to September and receives irrigation throughout (Nelson et al. 2019). A small amount of garlic, occupying less than 400 acres, is also grown from September to August with irrigation throughout the winter if precipitation is insufficient.

Strawberry is grown and harvested in Butte Valley for daughter plant production. Mother plants are started under protective coverings where they are grown for approximately twelve weeks under 22inch tall micro-tunnels of flat fabric slightly above crops (Nelson et al. 2019). After twelve weeks the micro-tunnels are removed and the plants are allowed to produce stolons, commonly called runners, which produce daughter plants (Nelson et al. 2019). Eventually the daughter plants produce roots and form independent cloned plants from the mother plant. The harvested product grown in Butte Valley are live plants for transplant. Daughter plants are then transplanted to other regions where they produce fruit. In mid to late September, the field is harvested for strawberry plants, which are later transported to other parts of the United States for eventual berry production (Nelson et al. 2019).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−160,000
−155,000
Pasture
Alfalfa
Grain and Hay
Idle
Nursery and Berry
Riparian Vegetation
Urban
Semiagricultural
Water Surface

Figure 2.4: Land uses within the Butte Valley Groundwater Basin boundary taken from the DWR 2010 Land Use Survey.

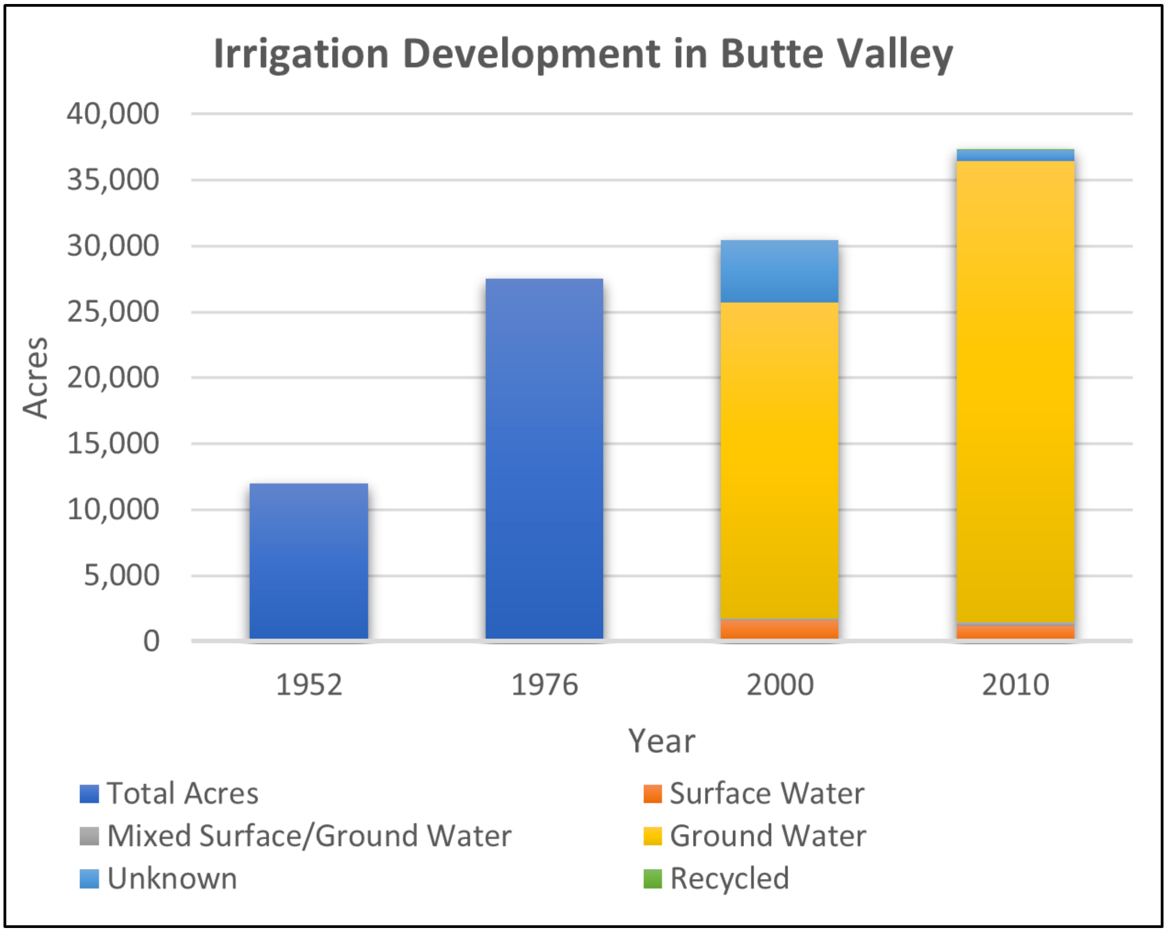


Figure 2.5: Change in Irrigated Acreage in Butte Valley, Siskiyou County, California (DWR 2000; DWR 2010; County of Siskiyou 1996). Sale price per ton and tons harvested per acre both vary per year.

2.1.1.2 Well Records

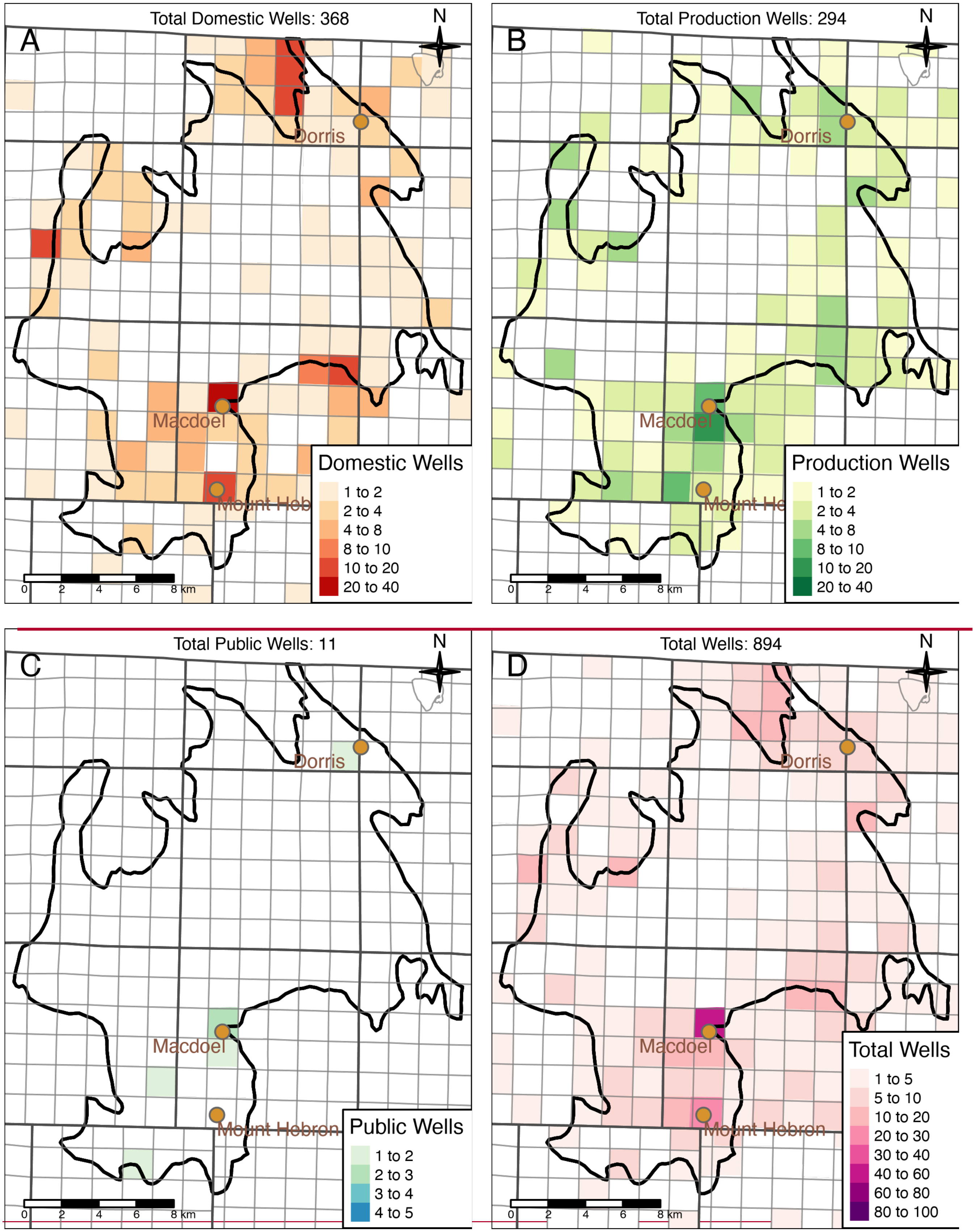
Public data regarding wells are limited in Butte Valley. Using data from the DWR Online System for Well Completion Reports (OSWCR; see DWR 2019a), it is possible to visualize the approximate distribution (i.e., well density) of domestic, agricultural ~~production~~, and public ~~drinking~~ water wells in the Basin, aggregated to each Public Land Survey System (PLSS) section (Figure 2.6). Because OSWCR represents an index of Well Completion Report records dating back many decades, this dataset may include abandoned or destroyed wells, or quality control issues such as inaccurate, missing, or duplicate records, but is nevertheless a valuable resource for planning efforts. BVID is the source of additional well records. For the revision of this GSP, location of well records were audited. Well records included in the original GSP were excluded if reported locations fell outside the Basin (if reported section locations were entirely outside the Basin).

The primary uses of the wells reviewed were:

- Domestic Wells: 163~~368~~
- Agricultural Production Wells: 148~~294~~
- Public/Municipal Wells: 6~~11~~

For 78 wells, no planned use was specified. Potentially, a large fraction of these wells serve domestic well water use. Other uses included industrial (2 wells), monitoring (22 wells), stock water (10 wells), and testing (14 wells). Of these ~~67~~443 wells, all were assessed to be in or near Butte Valley, and all wells were geolocated with the specificity necessary to include them in the Butte Valley geologic model. A database of these wells was created to facilitate model development.

The density of groundwater wells is highest in the south and east sections of the Basin, especially near the cities of Dorris, Macdoel, and Mount Hebron, following the extent of agricultural land use, as shown in Figure 2.6 and discussed further in Section 2.1.3.3. The density of wells per square mile is shown in Figure 2.6.


Total Domestic Wells: 368
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N
Dorris
Macdoel
Mount Hebron
Domestic Wells
1 to 2
2 to 4
4 to 8
8 to 10
10 to 20
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Total Production Wells: 294
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2 to 4
4 to 8
8 to 10
10 to 20
20 to 40
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30 to 40
40 to 60
60 to 80
80 to 100

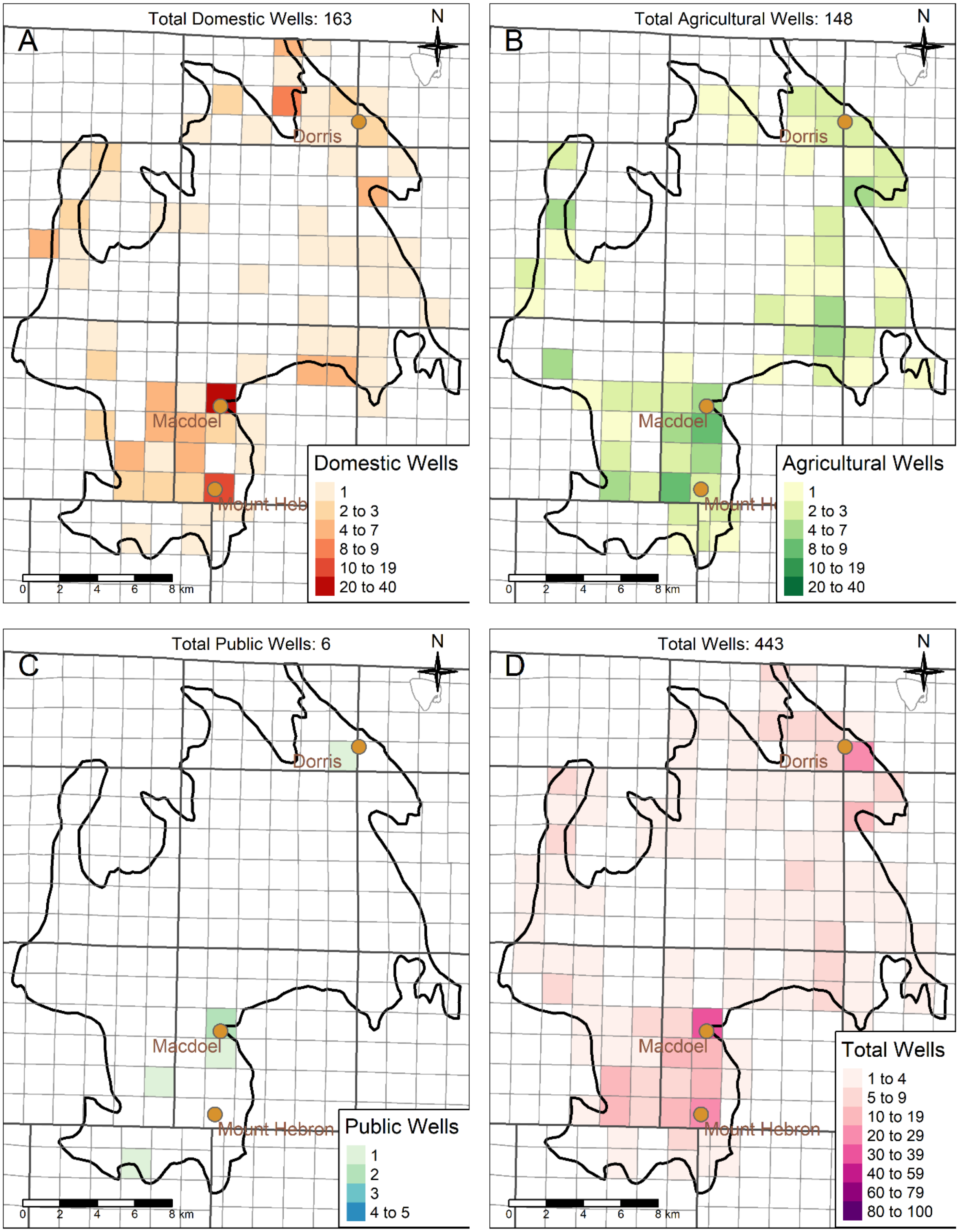


Figure 2.6: Choropleth maps indicating number of domestic (panel A), agricultural production (panel B), and public (panel C) Well Completion Reports present in each Public Land Survey

System (PLSS) section, based on data from the DWR Online System for Well Completion Reports (OSWCR). Panel D shows the sum of panels A-C. PLSS sections delineated on maps are nominally one square mile.

2.1.2 Water Resources Monitoring and Management Programs

There is historical and ongoing work in the Basin related to monitoring and the management of surface water and groundwater resources. The following section describes each monitoring and/or management program and outlines the current understanding of (a) how these programs will be incorporated into the groundwater sustainability plan (GSP) implementation and (b) how they may limit operational flexibility in GSP implementation. At this time Butte Valley does not have established conjunctive use programs for surface and groundwater allocation. The programs described include:

- Water Quality Control Plan for the North Coast Region (Basin Plan)
- California Statewide Groundwater Elevation Monitoring Program (CASGEM)
- Butte Valley Irrigation District (BVID)
- City of Dorris Municipal Water District
- United States National Forest Service (USFS)
- California Department to Fish and Wildlife (CDFW)
- United States Bureau of Reclamation (USBR)
- Butte Valley Sustainability Agency (GSA)
- Endangered Species Conservation Laws
    - Federal Endangered Species Act (ESA)
    - California Endangered Species Act (CESA)

2.1.2.1 Water Quality Control Plan for the North Coast Region

Groundwater within Butte Valley is regulated by the North Coast Regional Water Quality Control Board's (NCRWQCB) *Water Quality Control Plan for the North Coast Region* (Basin Plan; see NCRWQCB 2018). Groundwater is defined in the Basin Plan as:

> *Groundwater is defined as subsurface water in soils and geologic formations that are fully saturated all or part of the year. Groundwater is any subsurface body of water which is beneficially used or usable; and includes perched water if such water is used or usable or is hydraulically continuous with used or usable water.*

The Basin Plan includes water quality objectives for groundwater based on the assigned beneficial uses (NCRWQCB 2018). Table 2-1 in the Basin Plan designates all groundwaters with the following beneficial uses:

- Municipal and Domestic Supply (MUN)

- Agricultural Supply (AGR)
- Industrial Service Supply (IND) • Native American Culture (CUL).

Potential beneficial uses designated for groundwater include: Industrial Process Supply (PRO) and Aquaculture (AQUA; see NCRWQCB 2018). The MUN beneficial use designation is used to protect sources of human drinking water and has the most stringent water quality objectives. The MUN beneficial use applies to all groundwater in Butte Valley.

Section 3.4 and Table 3-1 of the Basin Plan outlines the water quality objectives for all groundwaters in the North Coast Region and those specific to the Butte Valley Hydrologic Area (NCRWQCB 2018). The Basin Plan refers to the California Code of Regulations for Domestic Water Quality and Monitoring Regulations (Title 22) for nearly all numeric limits (NCRWQCB 2018; State of California 2019). The Basin Plan water quality objectives and numerical limits are used in Section 2.2.2 of the GSP regarding water quality characterization and issues of concern. They also guide Chapter 3 of the GSP regarding groundwater sustainability criteria related to degraded water quality. The Basin Plan provides some limitations to operational flexibility in GSP implementation because the GSP must align with Basin Plan components such as water quality standards.

2.1.2.2 California Statewide Groundwater Elevation Monitoring Program

The California Statewide Groundwater Elevation Monitoring (CASGEM) Program collects and centralizes groundwater elevation data across the state, and makes them available to the public. The CASGEM Program was established in response to the passage of California State Senate Bill X7-6 in 2009. Currently, all CASGEM data are made available to the public through the interactive mapping tool on the CASGEM Public Portal website (DWR 2019b). Additionally, the full dataset can be retrieved from the California Natural Resources Agency (CNRA) Open Data website (CNRA 2019).

In Butte Valley, as of September 2019, there were 6 CASGEM wells and 40 wells designated as “voluntary” mapped within the Basin boundary, and an additional 18 voluntary wells immediately adjacent to the Basin (DWR 2019b). “Voluntary” status indicates that the well owner has contributed water level measurements to the CASGEM database, but the well is not enrolled in the CASGEM monitoring program.

Well monitoring under the CASGEM Program is ongoing. CASGEM water level data are used in the GSP to characterize historical Basin conditions and water resources (see Section 2.2.2) and will inform future management decisions. No limitations to operational flexibility in GSP implementation are expected in the Basin due to implementation of the CASGEM Program.

2.1.2.3 Butte Valley Irrigation District

Butte Valley Irrigation District (BVID) manages the largest groundwater distribution and management network in the Basin serving approximately 5,000 acres (20 sq km) of farmland.

BVID distributes water throughout the service area through a network of pipes. BVID only services agriculture customers and no domestic customers. Farms serviced by the irrigation district are allocated two acre-feet per acre per year (0.6 m/yr). BVID supplies water from approximately 20 wells within its 25 well network. BVID and BVWA have an agreement where both entities can divert water from Meiss Lake to farmland, however BVID has not exercised the agreement due to pumping costs and the poor quality of the lake water (Kit Novick 1996).

BVID surface water and groundwater operations are important to all aspects of the GSP, from historical water quality data to land use to groundwater recharge. BVID will be a key partner for GSP implementation. BVID operations and management will likely affect operational flexibility in GSP implementation in the Basin. The GSA will collaborate with BVID to balance flexibility of operations and management with GSP implementation in the Basin.

2.1.2.4 City of Dorris Municipal Water District

The City of Dorris has a small municipal water district serving approximately 938 residents (McKay 2019). Groundwater has supplied 100 percent of the district water supply since the town was founded in 1908. The municipal water supply is pumped from a single well, Well #6, which was drilled in 1971 to a depth of 1,236 ft (377 m). A back-up well, Well #4 (“Old Sandy”), is used for emergencies (Bray & Associates 2015; McKay 2019). “Old Sandy” was discontinued from use due to the production of an excessive amount of sand and elevated arsenic concentrations. Well #6 is metered and approximately 142 million gallons (gal) of water was pumped in 2014. Groundwater is treated with chlorine at the well site (Bray & Associates 2015).

The City of Dorris is designated as a severely disadvantaged community (SDAC) and has struggled to obtain funding to maintain its water distribution lines (Bray & Associates 2015; DWR 2016b). Many of the water distribution lines in Dorris are the original lines installed over 100 years ago, and some sections of pipe installed in 1912 are still in use (Bray & Associates 2015). The City is applying for grants and looking to increase assessment fees under Proposition 218 to fund extensive replacement of and upgrades to the City’s water distribution system (Bray & Associates 2015; McKay 2019). In the early 1980s, a federal grant funded the construction of a 750,000-gal (2,840 m^3) welded steel water reservoir, which remains in use today. Bray & Associates proposed a Capital Improvement Plan of several million dollars and recommend installation of water meters to encourage water conservation, a move that was estimated to reduce water consumption by 30% if implemented (Bray & Associates 2015). The City successfully received grants from the Department of Public Health Safe Drinking Water State Revolving Fund and State Revolving Fund to begin the Dorris Water Meter Installation Project in 2021. The project will install water meters, replace old pipelines, and locate missing services.

The Municipal Code of the City of Dorris includes a water conservation program (Title 13, Chapter 5). The City may order the appropriate stage of water conservation based on projected supply and customer demand. The three water stages with mandatory compliance applies restrictions to a variety of water-dependent activities such as landscape watering and car washing. The most severe water conservation stage applies water usage cuts for agricultural or commercial nurseries purposes and commercial, manufacturing, and processing processes.

City reports and data are used in the GSP to characterize historical Basin conditions and the City is expected to be a key partner for GSP implementation. City operations and management will likely affect operational flexibility in GSP implementation in the Basin. The GSA will collaborate with the City to balance flexibility of operations and management with GSP implementation in the Basin.

2.1.2.5 United States Forest Service

USFS manages the Klamath National Forest, of which the Butte Valley National Grassland is included. USFS manages the Mt. Hebron Work Center in the city of Mount Hebron and the Goosenest District Office, both of which have groundwater wells that report data to CDPH and SWRCB (SWRCB 2019a; SWRCB 2019c). The USFS also owns and manages Juanita Lake, with water rights to divert water from Seikel Creek (a tributary of Muskgrave Creek) to the lake. From April 30 to November 1, 0.56 cfs can be diverted directly from Seikel Creek and 340 acre-feet (AF) of water can be stored from November 1 to April 30 (Kit Novick 1996).

USFS will be a key partner for GSP implementation. USFS land covers roughly 23% of the Basin surface area and coordination with the GSA will be important for GSP implementation. Butte Valley National Grassland operations and management will likely affect operational flexibility in the Basin. The GSA will collaborate with the USFS to align operations with GSP implementation in the Basin.

2.1.2.6 California Department to Fish and Wildlife

The Butte Valley Wildlife Area (BVWA) is managed by the California Department Fish and Wildlife (CDFW). In 1979 the California Legislature adopted Senate Concurrent Resolution No. 28 (SCR28) to maintain existing wetlands and increase wetland acreage by 50 percent by the year 2000. Purchase of BVWA preserved its existing wetlands. CDFW is working on expanding BVWA wetlands by restoring former wetlands to functioning wetlands for wildlife habitat (Kit Novick 1996). The BVWA management area is shown in Figure 2.7. CDFW manages 13,400 acres (54 sq km) of land that includes Meiss Lake and its surrounding land (DWR 1998). CDFW directly owns 13,200 acres and cooperatively manages lands owned by the United States Bureau of Land Management (BLM) and USFS. In the northwest corner of BVWA, BLM owns 80 acres managed for wildlife (field 11A). Adjacent to the southwest BVWA boundary, USFS owns 150 acres managed for wildlife (Kit Novick 1996). Water resources in BVWA are used for irrigation and wetland maintenance (Kit Novick 1996). Wetland expansion and management of Meiss Lake floodwaters have improved wildlife habitat, increased groundwater recharge for agricultural wells, improved forage for livestock in the National Grasslands, and reduced Siskiyou County pumping costs for flood protection (K. Novick 2009).

BVWA is managed as waterfowl habitat for the Pacific Flyway and provides foraging, resting and sanctuary areas for migratory birds. Resident waterfowl such as the Canada Goose and several duck species use BVWA for nesting, brood-rearing and molting. Three threatened or endangered species, including the bald eagle (state endangered status under review), sandhill crane, and Swainson's hawk use BVWA for hunting, nesting and foraging (Kit Novick 1996; CDFW 2021c). Bald eagles are year round residents of BVWA with dozens of eagles during the winter.

Within BVWA is 4,000 acre (16 sq km) Meiss Lake, managed wetlands and crop lands, meadows, creeks, native grasslands, brush fields and pine-oak forests (Kit Novick 1996). The 8,400 acres of wetlands are maintained by 40 miles of dikes and levees, 31 miles of canals and channels, 325 nesting islands and over 150 water control structures (NCRWQCB 2008). Macdoel Ditch is a 0.8 mi long drainage canal leading from the east shore of Meiss Lake to the adjacent USFS Butte Valley National Grasslands that can transport lake water to the grasslands (Kit Novick 1996; County of Siskiyou 1996). BVWA also includes riparian corridors along Ikes, Harris, Muskgrave and Prather Creeks, tributaries to Meiss Lake. Cereal grain crops are grown for waterfowl food and include wheat, barley, oats, and rye (Kit Novick 1996). Perennial crops are grown to provide nesting cover for ground nesting birds and include wheatgrass, alfalfa and native meadow hay. During the summer and fall, parts of the BVWA are flooded to provide brood habitat and habitat for migratory waterfowl, respectively (DWR 1998).

Water used to flood the BVWA ponds is generally provided by surface water supplies but is augmented or replaced with groundwater during surface water deficient periods (DWR 1998). Surface water supplies are typically sufficient for wetland flooding in the spring but insufficient in the summer and fall. BVWA surface water comes from four creeks and one canal that flow toward Meiss Lake. From the west, spring-fed Ikes, Harris, and Muskgrave Creeks flow into the Perimeter Canal, which flows to Meiss Lake. From the south, spring-fed Prather Creek flows directly into Meiss Lake. Estimated creek inflows are 15,000 to 20,000 acre-feet annually but are low or nonexistent in the summer and fall. The Irrigated District Canal delivers excess irrigation water to Meiss Lake from wells and summer runoff, though flows are normally very low. Meiss Lake is a managed reservoir with a depth no greater than 6 feet. Lake depths greater than 6 feet cause flooding and subbage issues for adjacent private farmland. Lake water increases in alkalinity in the summer and fall and is not suitable to flood wetlands or irrigate crops when surface water supplies are low (Kit Novick 1996).

BVWA uses groundwater to meet its water demand when surface water supplies are insufficient, particularly in the summer and fall (Kit Novick 1996; DWR 1998). BVWA has five deep irrigation wells, though only four are currently used for production: Wells 1, 2, 3, and 5A. Wells 1, 2, and 3 tap into the High Cascade Volcanics water bearing formation. Groundwater from the three wells is used to irrigate food and nesting cover crops and maintain water levels in the BVWA wetlands for summer brood water for resident birds (500 to 600 acres of wetland) and fall migrating birds (increase to 1,000 to 1,200 acres of wetland). The four wells are operated intermittently from June to August and continuously from September to the end of October, though the pumps will run longer in drought years. In the southwest portion of BVWA, Wells 1, 2, and 3 are relatively shallow with depths of 90 to 284 feet. The wells once had artesian flows of 15 to 500 gpm. The artesian flows of Wells 1, 2, and 3, and several smaller domestic wells near BVWA headquarters stopped during the droughts of 1977, 1980 to 83, and from 1987 to Present. Wells 1, 2, and 3 have water yields of 2,588, 1,377, and 1,460 gpm, respectively. Well 7A is on the north side of BVWA with water yields of 2,500 gpm. Groundwater pumping from the four wells has no to minimal impact on offsite irrigation wells. Groundwater in the High Cascade water bearing formation near BVWA headquarters flows northerly then northeasterly (Kit Novick 1996).

Wells 5A is located southeast of Meiss Lake and taps into the Butte Valley Basalt water bearing formation. Groundwater from the well is only used to sprinkler-irrigate cereal grain crops in BVWA due to the seasonal depletion of the aquifer. It is 278 feet deep with water yields of 3,000. In the years 1981, 1991, 1992, and 1994, the well has gone dry near the end of the irrigation season when the Butte Valley Basalt water bearing formation was depleted (Kit Novick 1996).

In 1998 the BVWA total annual water demand was 13,200 AF. From the 1980s to 1998, the annual BVWA groundwater extraction amount has varied from 2,000 AF to 5,300 AF, with an average annual amount of approximately 3,000 AF. The average groundwater demand was expected to increase to 3,500 AF due to a proposed 500 AF increase in groundwater development. However the actual long-term average use (1987 to 2008) has actually decreased to 2,746 AF (K. Novick 2009). As of 1998, the BVWA applied groundwater demand was about 1.1 AF per acre (DWR 1998).

In 1998, DWR investigated DFG Well 7A (27C01M), located north of Meiss Lake, for an unacceptable level of interference with neighboring wells and springs. Well 7A taps into the highly transmissive High Cascade Volcanics water bearing formation and was confirmed to cause interference with adjacent wells but had minimal impact on nearby springs located on Holzhauser Ranch in Sam's Neck. Additionally, the 1998 DWR well interference study found that groundwater flow around Well 7A is noticeably influenced by nearby faults, which can act as both a flow barrier and a very transmissive conduit for flow (DWR 1998). CDFW altered use of Well 7A in a desire to be a good neighbor and minimize possible effects on the wells of private neighbors (K. Novick 2009). Actions included reduction of volume pumped from Well 7A from 2,800 gpm to 1,500 gpm and overall operation is coordinated with adjacent private landowners to minimize any impacts on their irrigation wells (K. Novick 2009).

CDFW will be a key partner for GSP implementation. CDFW land covers roughly 17% of the Basin surface area and coordination with the GSA will be important for GSP implementation. CDFW reports and data are used to characterize the Basin in Section 2.2 of the GSP. CDFW operations and management will likely affect operational flexibility in GSP implementation in the Basin. CDFW groundwater extraction may potentially impact neighboring wells and the resulting cone of depression may be asymmetrical due to local faults (DWR 1998). The GSA will collaborate with the CDFW to align operations with GSP implementation in the Basin.

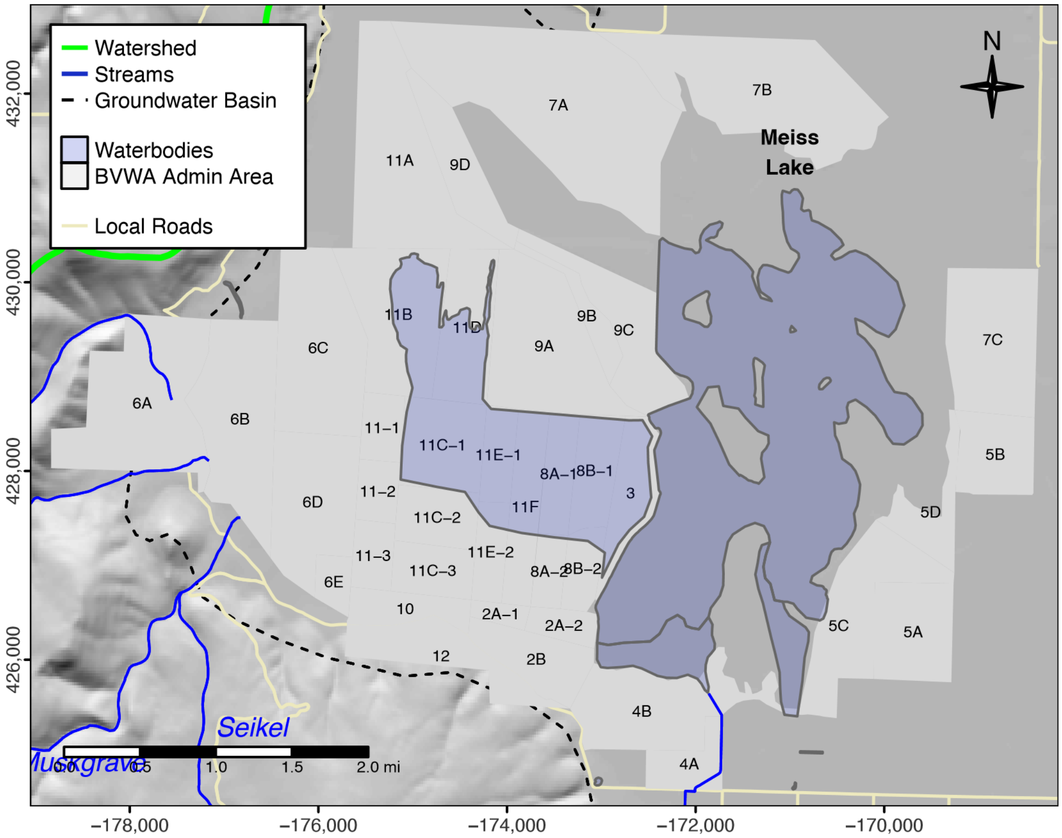


Figure 2.7: Map of the Butte Valley Wildlife Area adapted from the 1996 draft management plan for the wildlife area (Novick 1996).

2.1.2.7 United States Bureau of Reclamation

Through its WaterSMART program, the United States Bureau of Reclamation (USBR) is granting funds to the GSA to install 10 co-located, continuous groundwater level and soil moisture sensors that will be incorporated into the Basin's GSP development and implementation. The GSA will collaborate with the USBR to align operations with GSP implementation in the Basin.

2.1.2.8 Endangered Species Conservation Laws

Federal Endangered Species Act

The Federal Endangered Species Act (ESA) outlines a structure for protecting and recovering imperiled species and their habitats. Under the ESA, species are classified as "endangered," referring to species in danger of extinction throughout a significant portion of its range, or "threatened," referring to species likely to become endangered in the foreseeable future. The ESA is administered by two federal agencies, the Interior Department's U.S. Fish and Wildlife Service (FWS), primarily responsible for terrestrial and freshwater species, and the Commerce

Department's National Marine Fisheries Service (NMFS) which primarily handles marine wildlife and anadromous fish.

California Endangered Species Act

The California Endangered Species Act (CESA) was first enacted in 1970 with the purpose of conserving plant and animal species at risk of extinction. Similar to the ESA, CESA includes the designations "endangered" and "threatened," used to classify species. Definitions for these designations are similar to those under the ESA and apply to native species or subspecies of bird, mammal, fish, amphibian, reptile, or plant. An additional category "candidate species" exists under CESA that includes species or subspecies that have been formally noticed as under review for listing by CDFW. Additional detail on other species in Butte Valley listed under CESA can be found in Section 2.2.1.7 as part of the discussion on groundwater dependent ecosystems (GDEs).

Both the ESA and CESA are used in the GSP to guide the identification of key species for consideration as part of GDEs. Listed species will continue to be considered throughout GSP implementation, as part of any project and management actions (PMAs), and to help inform future management decisions. These endangered species conservation laws may limit operational flexibility in GSP implementation. The GSA will incorporate this legislation into its decision-making and may seek to coordinate with the relevant state and federal lead agencies, as necessary.

2.1.3 Land Use Elements or Topic Categories of Applicable General Plans

2.1.3.1 General Plans

The overarching framework for land use and development in the County of Siskiyou (County) is the Siskiyou County General Plan (General Plan). A community-specific General Plan was also developed in Butte Valley for the City of Dorris. Elements of the general plans outline goals for land use and development, and mechanisms for achieving those goals that include policies and zoning regulations. The GSP will be developed to conform with the general plans as much as possible.

County of Siskiyou General Plan

The County's General Plan (County of Siskiyou 2019b) serves as a guide for land use decisions within the County, ensuring alignment with community objectives and policies. While the General Plan does not prescribe land uses to parcels of land, it does identify areas that are not suitable for specific uses. The components of the General Plan with the most relevance to the GSP include the Conservation Element and Open Space Element. Many of the objectives and policies within the General Plan align with the aims of the GSP and significant changes to water supply assumptions within these plans are not anticipated.

The Conservation Element of the General Plan recognizes the importance of water resources in the County and outlines objectives for the conservation and protection of these resources to ensure continued protection of beneficial uses for people and wildlife. Methods for achieving these objectives include local legislation such as flood plain zoning and mandatory setbacks, subdivision regulations, grading ordinances, and publicly managed lands to ensure preservation of open spaces for recreational use. The importance of water resources is clearly noted in this element: “Groundwater resources, water quality, and flood control remain the most important land use determinants within the county” (County of Siskiyou 1973). Specific topics addressed include preventing pollution from industrial and agricultural waste, maintaining water supply and planning for future expansion, reclaiming and recycling wastewater, and protecting watershed and recharge lands from development. These objectives in the Conservation Element mirror the objectives of the GSP, namely ensuring a sustainable water supply, the protection and preservation of watershed and water recharge lands, and prevention of degradation of water quality.

The Open Space Element of the General Plan includes in its definition of open space any area of land that serves as open space, watershed and groundwater recharge land, among other uses. The importance of protecting these lands is recognized for maintaining water quality and quantity. Mechanisms to preserve these spaces include maintaining or creating scenic easement agreements, preserves, open space agreements, and the designation of lands for recreational or open space purposes. A policy for open space requirements is included with minimum thresholds of 15% of proposed developments as open space. Protection of open space for habitat, water quality, and water quantity align with the objectives of the GSP.

Siskiyou County Zoning Plan

The County of Siskiyou Zoning Plan (Zoning Plan) is codified in Title 10, Chapter 6 commencing with Article 37 (County of Siskiyou 2019a). The County of Siskiyou Zoning Ordinance outlines the permitted types of land use within each zoning district. Zoning categories include residential, commercial, industrial, agricultural, forestry, open space, and flood plains. Many of the purposes and policies of the Zoning Plan align with the objectives of the GSP. In particular, the “wise use, conservation, development and protection” of the County’s natural resources, protection of wildlife, and prevention of pollution support the objectives of the GSP. Mechanisms to achieve these goals include permitted and restricted uses for land parcels, and requirements and stipulations for land use and development.

2.1.3.2 Community Plans

Dorris General Plan

The City of Dorris General Plan (DGP) outlines objectives and programs to guide decision-making as it relates to land use and development to ensure the physical, economic, and social wellbeing of the community. The DGP is applicable through Year 2025 (updated in 2007) and incorporates all elements, as required by Section 65402 of the California Government Code: land use, circulation, housing, conservation, open space, noise, and safety (City of Dorris 2007).

2.1.3.3 Williamson Act Land

Contracts under the California Land Conservation Act of 1965, commonly known as the Williamson Act, are used to preserve open space and agricultural lands. Local governments and private landowners enter into voluntary agreements to restrict land for use in agriculture or as open space. Private landowners that enter into a Williamson Act contract benefit from lower property taxes. Lands that are eligible to be enrolled under these contracts must be a minimum of 100 acres and can be enrolled as either Prime or Non-Prime Williamson Act Farmland, based on the productivity specifications outlined in Government Code § 512021. In the County of Siskiyou, as of 2014, 96,993 acres (393 sq km) were enrolled as Prime Land and 324,300 acres (1,312 sq km) were enrolled as Non-Prime Land (DOC 2016).

2.1.3.4 Neighboring Groundwater Basins

The Butte Valley groundwater basin has several neighbors that could affect the ability of the GSA to achieve sustainable groundwater management: Tule Lake, Lower Klamath, Red Rock Valley, and Shasta Valley groundwater basins. DWR lists Tule Lake and Shasta Valley groundwater basins as medium priority basins, while the Lower Klamath and Red Rock Valley groundwater basins are low priority (DWR 2009).

2.1.4 Additional GSP Elements

2.1.4.1 Policies Governing Wellhead Protection and Well Construction, Destruction and Abandonment

In the Basin, wellhead protection and well construction, destruction and abandonment are conducted according to relevant state guidelines.

Well standards are codified in Title 5, Chapter 8 of the Siskiyou County Code. These well standards define minimum requirements, including those for monitoring wells, well construction, deconstruction, and repair, with the objective of preventing groundwater pollution or contamination (County of Siskiyou 2020). Processes and requirements for well permitting, inspections, and reporting are included under this chapter of the County Code of Ordinances.

The County of Siskiyou Environmental Health Division (CSEHD) is the local enforcing agency with the authority to issue well permits in the County. Well permit applications require information from the applicant and an authorized well contractor, along with a fee.

The County has worked on obtaining hydrological data/modeling to help inform individual well permitting decisions beginning with the Scott Valley; and public discussion and decision making related to the impacts of the public trust doctrine on groundwater management is on-going. The GSA will look for opportunities to coordinate with the County on providing collected hydrologic information that may assist the County.

2.1.4.2 Groundwater Extraction and Illegal Cannabis

On August 4, 2020, Ordinance 20-13 amended Chapter 13 of Title 3 of the County Siskiyou Code of Ordinances to add Article 7. Article 7 defines finds extracting and discharging use of groundwater for illegal cultivation of cannabis to be a public nuisance and a waste and/or unreasonable use of groundwater and prohibits extraction and discharge of groundwater underlying the County for this activity. Ordinance 20-13 was replaced by Ordinance 20-15 in the fall of 2020; however, the substantive provisions of the ordinance remain the same.

Groundwater extraction for the cultivation of illegal cannabis has expanded over the past five to seven years. This current land use practice is not accounted for in either the historical or future water budget analysis.

Siskiyou County has adopted multiple ordinances relating to the regulation of cannabis. Chapter 15 of Title 10 of the Siskiyou County Code prohibits all commercial cannabis activities, and Chapter 14 limits personal cannabis cultivation to the indoor growth of a maximum of 12 plants on premises with a legal water source and an occupied, legally established residence connected to an approved sewer or septic system. Personal cultivators are also prohibited from engaging in unlawful or unpermitted surface drawing of water and/or permitting illegal discharges of water from the premises. Despite these ordinances, illegal cannabis cultivators continue to operate within and near the Basin.

Illegal cannabis growers rely on groundwater from production and residential well owners and utilize water trucks to haul groundwater off the parcel from which it is extracted for use at other locations. The proliferation and increase of illegal cannabis cultivation taking place in the Basin is a significant community concern; however, obtaining an accurate estimate of overall consumptive groundwater use for this illegal activity has been a challenge for the GSA due to it occurring on private and secluded parcels and the increasing use of covered greenhouses for illegal cannabis cultivation. Future model scenarios may use an estimated number of cannabis plants from the Siskiyou County Sheriff Department and a consumptive use of four to ten gallons of water per plant per day to consider the potential impacts to groundwater resources from this activity under current and future conditions.

In addition to community concern about estimated consumptive use of groundwater in the Basin for illegal cannabis cultivation, there is also concern about water quality impacts from the potential use of illegal and harmful chemicals at illegal grow sites, which may leach into the groundwater (see Chapter 2, Water Quality), and the non-permitted human waste discharge methods that have been found to occur at some of these sites. Data on baseline water quality conditions at illegal cannabis cultivation sites within the Basin or at nearby wells have not been collected; however, the GSA intends to include available wells within close proximity to these sites in its future monitoring network for the purpose of measuring water quality.

The GSA considers groundwater used for illegal cannabis cultivation to be a “waste and unreasonable use of water,” but acknowledges that there is not substantial enough data to include groundwater the use estimates from illegal cannabis production in the overall and future water budgets. The GSA will coordinate with local enforcement agencies regarding providing collected hydrologic information and will also use the emphasis on collecting data during the first five years of plan implementation to better understand the impacts of groundwater use for illegal cannabis on overall Basin-wide use estimates and the relation to nearby groundwater aquifers.

2.1.4.3 Groundwater Export

Groundwater export is regulated in the County under Title 3, Chapter 13 of the Siskiyou County Code. Since 1998, Chapter 13 has regulated the extraction of groundwater from Bulletin 118 basins underlying the County for use outside of the basin from which it was extracted. Exceptions include 1) groundwater extractions by a district purveyor of water for agricultural, domestic, or municipal use where the district is located partially within the County and partially in another county, so long as extracted quantities are comparable to historical values; and 2) extractions to boost heads for portions of these same water purveyor facilities, consistent with historical practices of the district. Groundwater extractions for use outside the County that do not fall within the exceptions are required to obtain a permit for groundwater extraction. Permit application processes, timelines, and specifications are described in this ordinance.

In May of 2021, Title 3, Chapter 13, was amended to add Article 3.5, which regulates, through ministerial permitting, the extraction of groundwater for use off the parcel from which it was extracted. This provision requires extracted groundwater be for uses and activities allowed by the underlying zoning designation of the parcel(s) receiving the water and does not apply to the extraction of water for the purposes of supplying irrigation districts, emergency services, well replenishment for permitted wells, a “public water system,” a “community water system,” a “noncommunity water system,” or “small community water system” as defined by the Health and Safety Code, serving residents of the County of Siskiyou.

2.1.4.3 Policies for Dealing with Contaminated Groundwater

Migration of contaminated groundwater from point sources, such as leaking fuel tanks, is managed through coordination with NCRWQCB. Open and historic (“closed”) cleanup sites are discussed in Section 2.2.2.3, subsection “Contaminated Sites.” Non-point sources of contaminated groundwater, such as pesticides, are described in Section 2.2.2.3.

2.1.4.5 Replenishment of Groundwater Extractions and Conjunctive Use

There are no artificial groundwater replenishment or conjunctive use projects in Butte Valley. Proposed projects and management actions are described in Chapter 4.

2.1.4.6 Coordination with Land Use Planning Agencies

The GSA will manage land use plans and coordinate land use planning agencies to assess activities that potentially create risks to groundwater quality or quantity.

2.1.4.7 Relationships with State and Federal Regulatory Agencies

The GSA has relationships with multiple state and federal agencies, as described in the Section 2.1.2. These state and federal agencies include CDFW, NCRWQB, USFS, DWR, and USBR. The GSA will continue to coordinate and collaborate with these agencies throughout GSP development and implementation.

2.2 Basin Setting

2.2.1 Hydrogeologic Conceptual Model

Executive Summary

Butte Valley is a topographically closed internally drained basin at the boundary between the western Modoc Plateau and eastern Cascade Range geomorphic provinces, near the western and northwestern border of the Medicine Lake Highlands. Butte Valley experiences east-west directed extensional tectonics and north-trending normal faults expressed as block faulting (Bryant 1990). This chapter reviews the background of the hydrogeologic conceptual model. A hydrogeologic conceptual model (HCM; see DWR 2016a) fulfills the following:

1. *Provides an understanding of the general physical characteristics related to regional hydrology, land use, geology and geologic structure, water quality, principal aquifers, and principal aquitards of the Butte Valley groundwater basin (Basin) setting;*
2. *Provides the context to develop water budgets, mathematical (analytical or numerical) models, and monitoring networks; and,*
3. *Provides a tool for stakeholder outreach and communication.*

The following is a graphical and narrative description of the physical components of the Basin. The following elements are required by DWR (DWR 2016c):

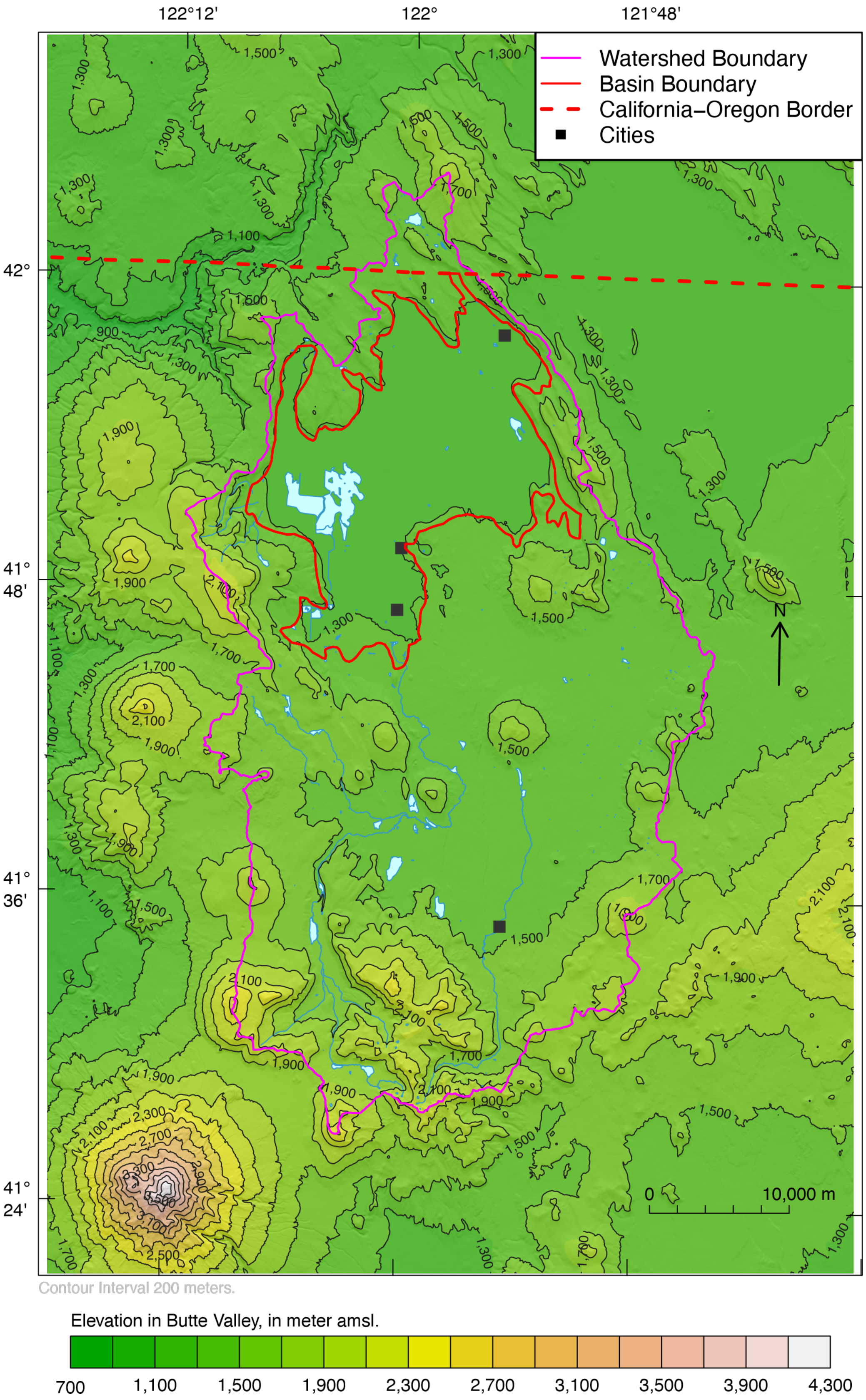
- Scaled cross-sections.
- Topographic information.
- Surficial geology.
- Soil characteristics.
- Delineation of existing recharge areas that substantially contribute to the replenishment of the Basin, potential recharge areas, and discharge areas.
- Surface water bodies.
- Source and point of delivery for local and imported water supplies.

2.2.1.1 Topography

Butte Valley is a structurally controlled closed drainage basin and the valley floor is a practically flat surface, with elevations ranging over an exceedingly narrow range from 4,226 to about 4,2~~3~~70~~6~~ ft (1,288 to 1,300~~291~~ m) amsl, shown in Figure 2.8 (Bryant 1990; County of Siskiyou

1996). Elevations near the basin margin may reach 4,400 ft (1340 m) amsl along the slopes of surrounding ranges. The Watershed is roughly three times larger than the Basin. As shown in Figure 2.13, the flat-floored structural depression is surrounded by youthful fault scarps and merges into fields of broken Quaternary basalts to the south (DOI 1980). The mountainous topography that bounds the Basin ranges from 5,000 to 8,000 ft (1,524 to 2,438 m) amsl (DWR 1968). The Basin is bounded in the north, south and west by the Cascade Mountains and on the southeast by Sheep Mountain and Red Rock Valley (Wood 1960; DWR 2004). Topography to the north is marked by block-faulted volcanic plateaus and several flat-floored grabens, including Sam's Neck and Pleasant Valley, that project beyond the Basin (DOI 1980; Bryant 1990). The eastern boundary has a prominent northwestward trending fault block (the Mahogany Mountain ridge or Mahogany Ridge), which isolates the Basin from the Lower Klamath Lake marshland in the northeast (DWR 2004). The Mahogany Ridge is 20 mi (32 km) long, 1 to 3 mi (1.6 to 4.8 km) wide and bordered by steep, slightly dissected, talus-covered fault scarps. The north end of the ridge is broken by several en-echelon faults while the south end is characterized by a gently southward sloping plateau (DOI 1980).

The Watershed is immediately northeast of Mount Shasta, seen in the bottom left corner of Figure 2.8. The northern Watershed border crosses the state border into Oregon, with the northernmost extent bounded between Chicken Hills and Hamaker Mountain. In Oregon, Grenada Butte and Randolph Flats are within the Watershed. In addition to Butte Valley, the Watershed includes Red Rock Valley (northeast of Cedar Mountain), Round Valley (between Cedar Mountain and Orr Mountain), the Bray Town Area (south of Orr Mountain), plus other unnamed valleys.



Contour Interval 200 meters.

Figure 2.8: Topography of the Butte Valley Groundwater Basin and surrounding Watershed. City names from north to south are: Dorris, Macdoel, Mount Hebron and Tennant.

2.2.1.2 Climate

Butte Valley has a semiarid climate characterized by warm, dry summers and cool, wet winters. The Cascade Range on the west side of the Basin casts a rain shadow across the Basin, where precipitation is highest on the west side of the valley and decreases eastward (Kit Novick 1996). Annual precipitation also increases northward (DWR 2004). In 1996, the mountains and foothills on the west side of the Butte Valley Wildlife Area received an average of 20 to 28 inches of rainfall a year, the crop lands on the west side of Meiss Lake received 15 to 22 inches, BVWA headquarters received 18 inches, and the east side of Meiss Lake received 10 to 12 inches. Snow can occur during any month of the year but normally falls between November and March (Kit Novick 1996). July through September are historically the driest months [DOI (1980); see Figure 2.9]. Longterm climate records are available from National Oceanic and Atmospheric Administration (NOAA) weather stations in the Butte Valley watershed; relevant stations are listed in Table 2.2.

The Basin has experienced decreasing precipitation during much of the period between 1970 to 2020. From the 1940s to 2020, the NOAA station in Mount Hebron has an average annual precipitation of 9.3 inches (Figure 2.9). Between 1942 and 1979, the 10-year trailing rolling average precipitation ranged from 9.5 to 12.4 in (24.1 to 31.5 cm; water years 1953 and 1971, respectively); since 1980, it has ranged between 5.7 and 10.8 in (14.5 to 27.4 cm; water years 2018 and 1980, respectively; see Figure 2.9). Much of the expansion in agricultural land in Butte Valley occurred before 1976, with irrigated land expanding to 11,130 hectares (27,500 acres), during a period when average rainfall was relatively stable and significantly greater.

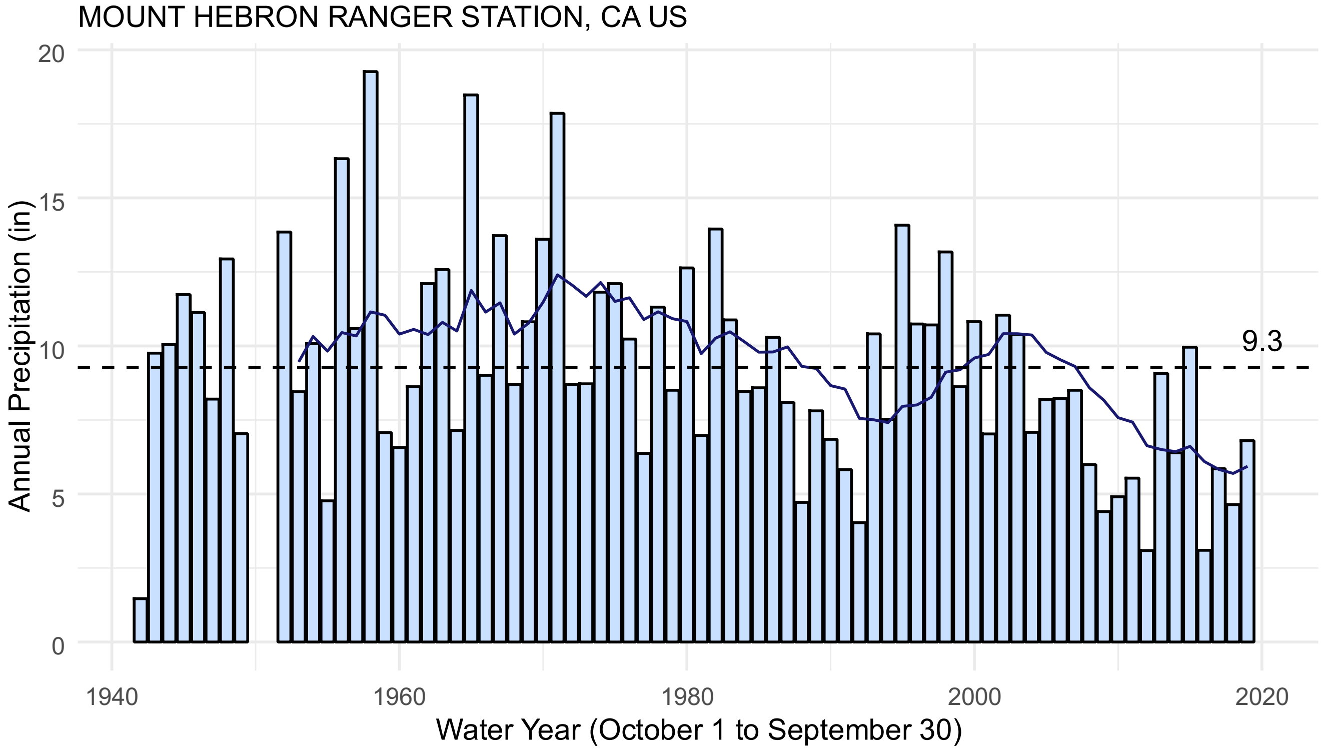
Mean daily low and high temperatures for January and July are -8 to 7°Celsius (C; 17 to 44°Farenheit [F]) and 5 to 29°C (41 to 84°F), respectively (Figure 2.10). Temperature extremes range from over 38°C (100°F) in the summer to below -18°C (0°F) in the winter (DOI 1980). Reference evapotranspiration (ET) ranges from 0.002 to 0.33 in/day (0.005 to 0.84 cm/day; Figure 2.10). Pan evaporation in Butte Valley is estimated to be 48 inches a year, with wind mainly responsible (Kit Novick 1996). Figure 2.11 illustrates the recent climate shift by comparing the average temperature in the past 15 years to historical records. In the past 15 years, the average maximum and minimum air temperature increased roughly 1° to 5°F (Figure 2.11).

Historically, killing frosts could occur at any time of the year and the growing season in Butte Valley was limited by the last and first killing frosts (<28°F). The growing season generally extended from May to October, but frequent killing frosts in May and June usually shortened the usable growing season. The average growing season was roughly 100 days but varied greatly. In 1952, only one day was frost-free. A short growing season and frost danger limited the type and amount of agricultural crops grown within Butte Valley (DOI 1980; Kit Novick 1996). Crops in BVWA were limited to hardy cereal grains and quickly maturing plants, which have marginal commercial value due to frost damage (Kit Novick 1996).

Over the past few decades, the frost danger in Butte Valley has decreased (Figure 2.12). The yearly average of days with temperatures less than 32 F has sharply declined since the 1980s. In recent years, strawberry crops have become increasingly important in Butte Valley.

Snow measurements in the Butte Valley watershed is a climate data gap. The nearest California Data Exchange Center (CDEC) weather stations are outside the watershed boundary. None of the NOAA weather stations in the Watershed are situated in the west or south mountains, which are important to surface and groundwater recharge.

A Annual water year precipitation with 10−year rolling and long−term means



B Monthly Precipitation Mean and Standard Deviation

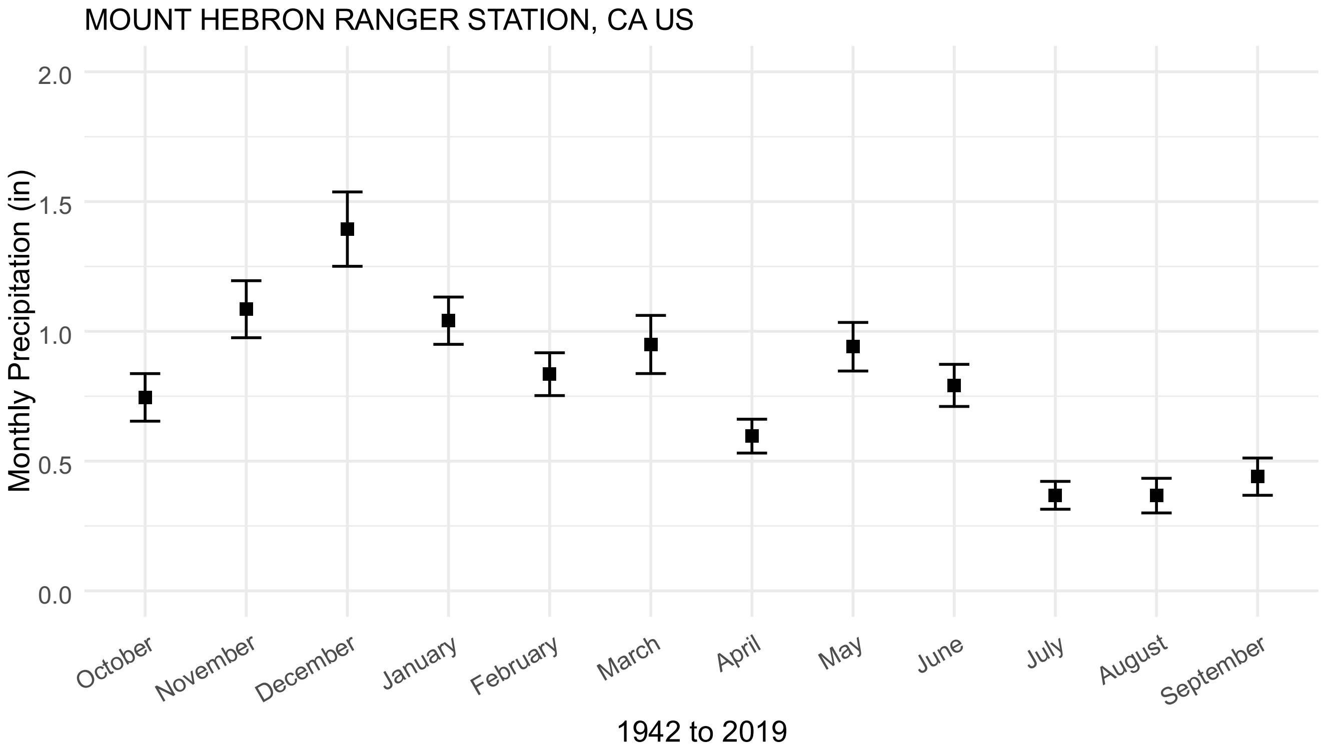
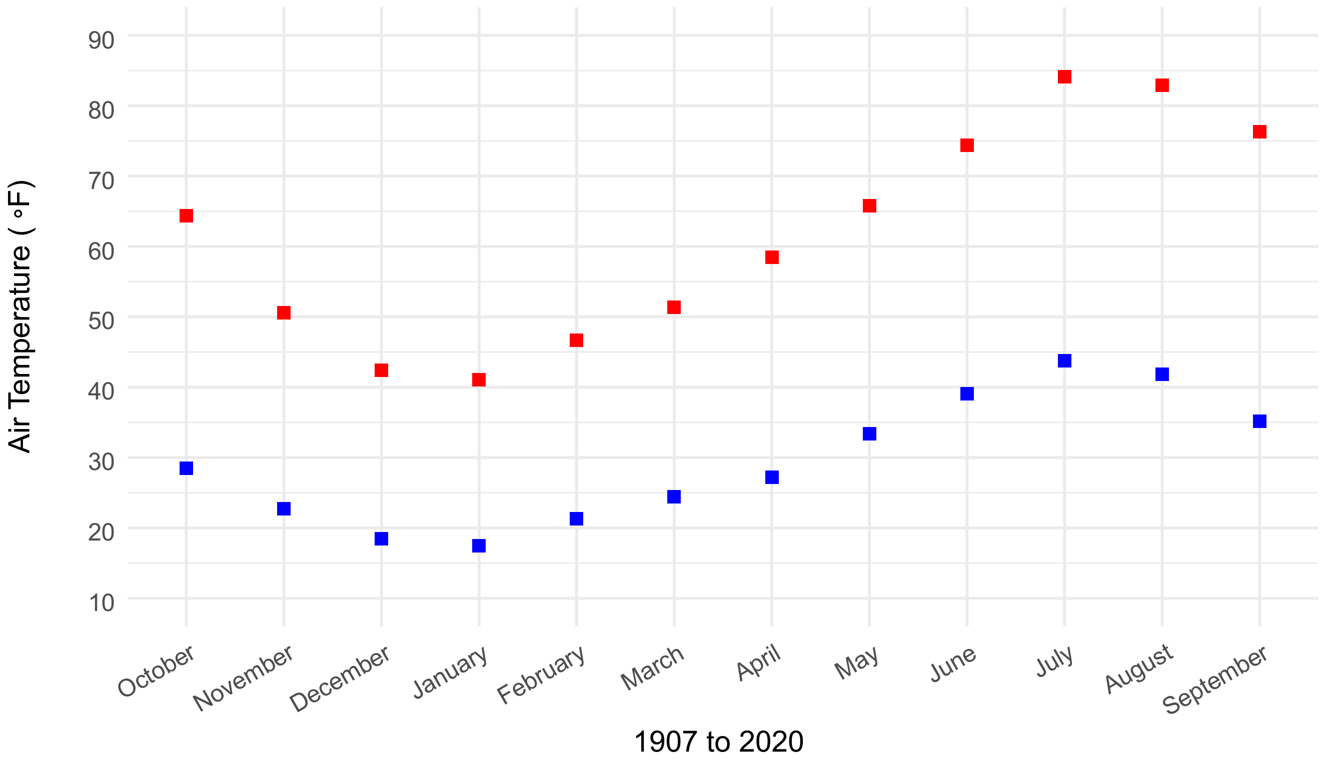


Figure 2.9: Annual (Panel A) and monthly precipitation (Panel B) over the 1942 to 2019 record as measured at the Mount Hebron Ranger weather station (USC00045941). In Panel A, the 10-year rolling average is shown as the average over the entire period of record. Each bar represents one water year, the total precipitation during the period between October 1 and September 30. Only the years 1950 and 1951 had significant data gaps and were removed.

Monthly average daily maximum and minimum temperatures

MOUNT HEBRON RANGER STATION, CA US


Air Temperature (∘F)
90
80
70
60
50
40
30
20
10
October
November
December
January
February
March
April
May
June
July
August
September
1907 to 2020

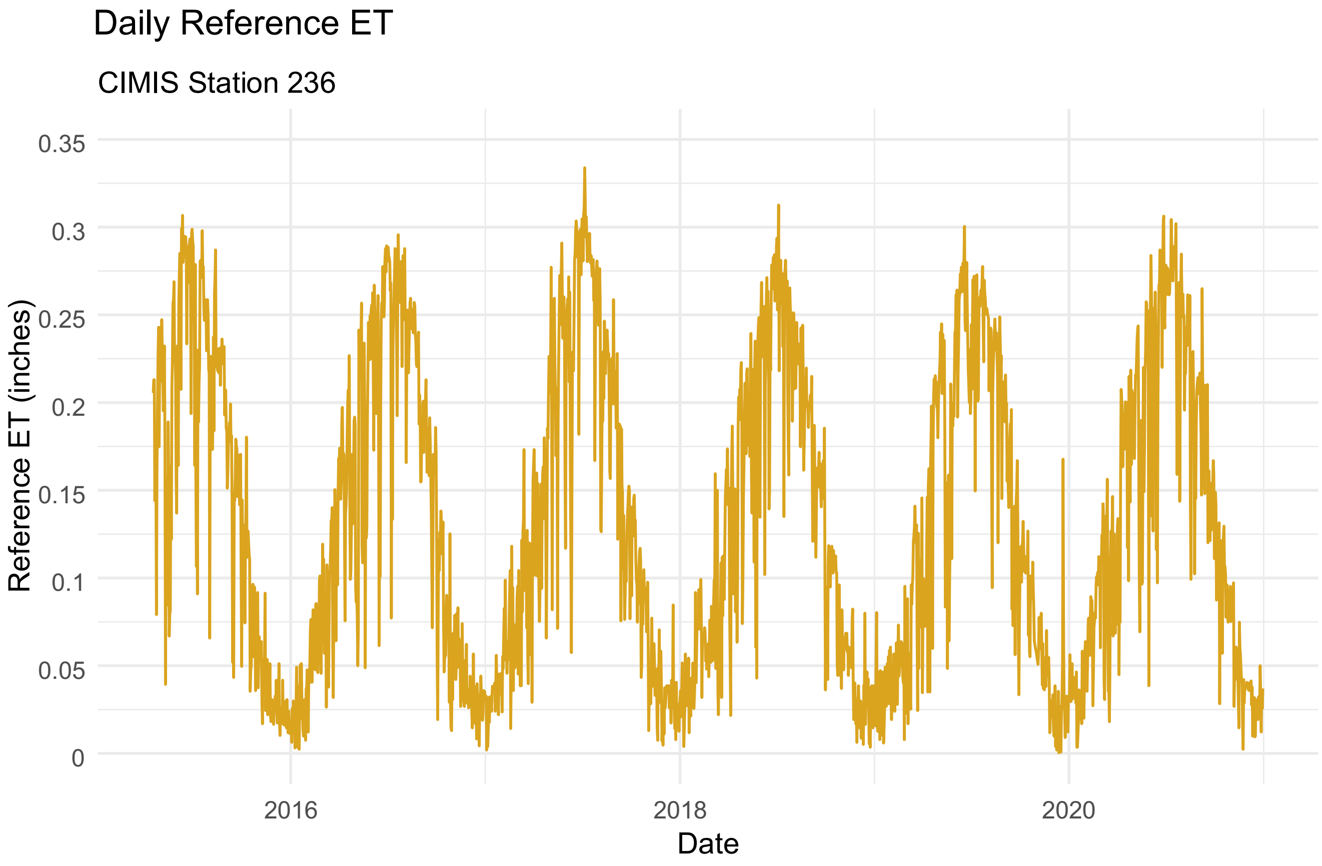
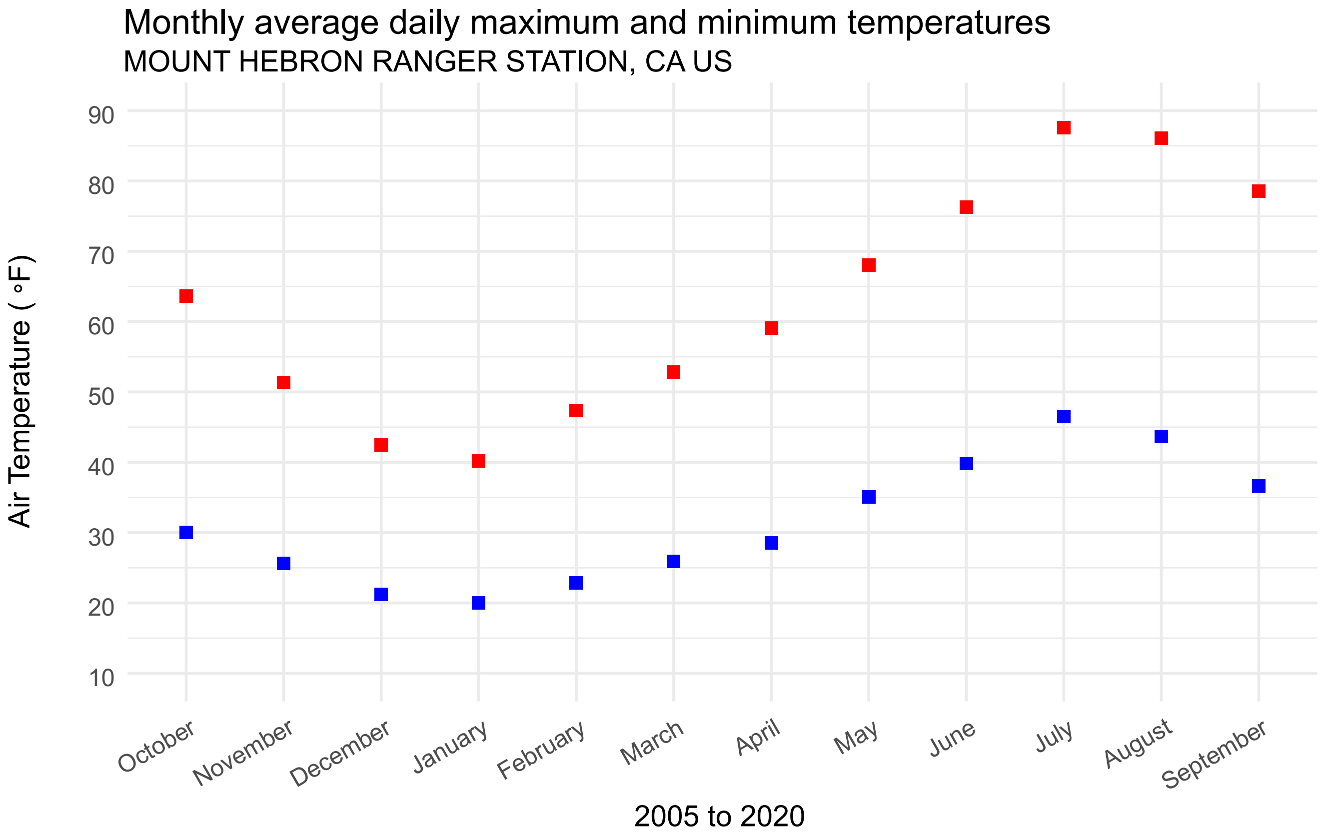

Daily Reference ET
CIMIS Station 236
Reference ET (inches)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2016
2018
2020
Date

Figure 2.10: Monthly averages of daily maximum and minimum air temperature (top panel) over the 1942 to 2020 record at the Mount Hebron Ranger Station (USC00045941), and reference evapotranspiration (ET) from 2015 to 2020 calculated at CIMIS Station 236 between Macdoel and Mount Hebron.



Monthly average daily maximum and minimum temperatures
MOUNT HEBRON RANGER STATION, CA US

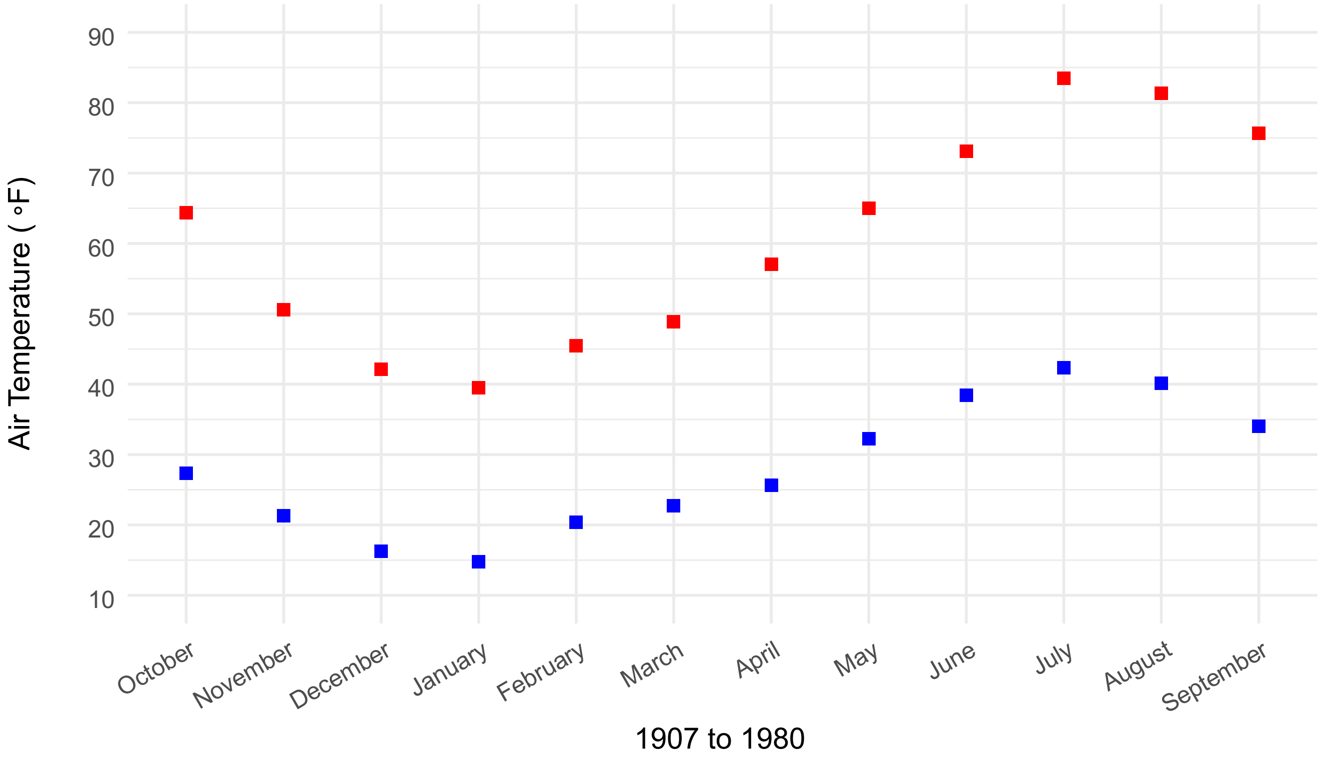


Figure 2.11: Monthly averages of daily maximum and minimum air temperature (top panel) over the 1942 to 1980 and 2005 to 2020 record at the Mount Hebron Ranger Station (USC00045941), which shows the recent warming of the Valley.

Annual Number of Days with Temperatures less than 32 F

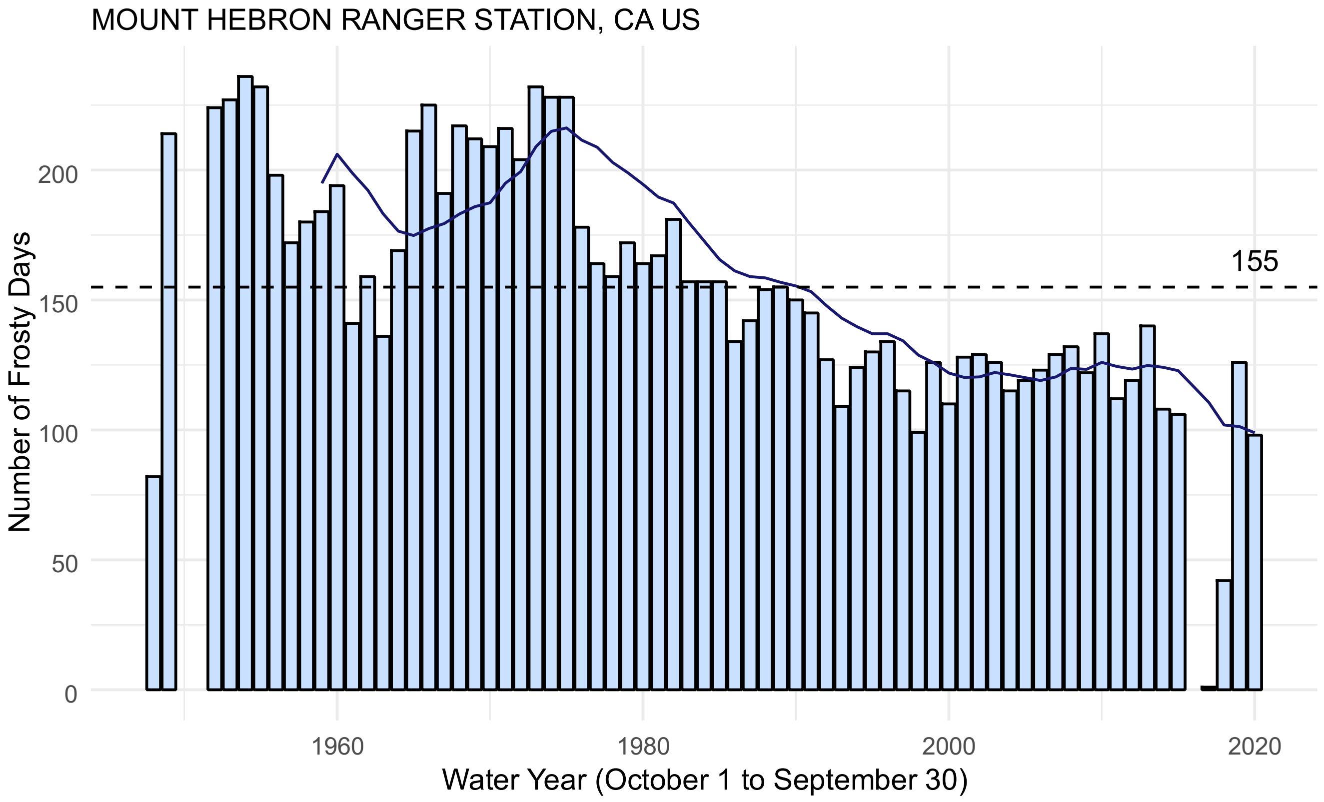


Figure 2.12: Total number of days with temperature minimums less than 32 F, representing frost potential. Totals are occasionally impacted by station equipment outtages.

Table 2.2: Station details and record length for NOAA weather stations in the Butte Valley watershed.

Station ID	Station Name	Elevation (ft amsl)	Start Date	End Date	Record Length (years)	No. Missing Days
US1CASK0010	DORRIS 0.2 SW, CA US	4249	1998-06-17	2021-06-27	23.0	1
USC00045940	MOUNT HEBRON 11 ESE, CA US	4383	1952-05-01	1960-12-31	8.7	7
USC00045941	MOUNT HEBRON RANGER STATION, CA US	4250	1907-01-01	2020-04-01	113.2	1956
USC00048860	TENNANT, CA US	4754	1952-05-01	1957-08-31	5.3	3
USR0000CJUA	JUANITA LAKE CALIFORNIA, CA US	5400	1988-12-30	2021-06-27	32.5	11102
USR0000CVAN	VAN BREMMER CALIFORNIA, CA US	4928	1993-06-01	2021-06-27	28.1	9921

2.2.1.3 Geologic History

The oldest rocks near Butte Valley were formed between the Eocene to Miocene (56 to 5.3 million years ago [Ma]) during the formation of the Western Cascades. The predominantly andesite volcanic rocks consist of interbedded basalts, dacites, rhyolite tuffs, and breccias. At the end of the Miocene (~5.3 Ma), the original Western Cascade landscape and parent cones were destroyed by uplift and erosion. During the same period, the regional uplift created the ancestral Cascade Range and a series of northwest-trending faults that cut through the Western Cascades. From the late Pliocene to the Pleistocene (3.6 to 0.012 Ma), volcanism reactivated in the region, forming a north-trending series of broad shield volcanoes along the crest of the ancestral Cascades. These volcanoes erupted the highly fluid basalts and andesites found in the High Cascade volcanic rocks in Butte Valley. The present Cascade Range was formed later in the Pleistocene (2.6 to 0.012 Ma) through the eruptions of andesites, dacites, and rhyolites. Sometime in the Pleistocene (2.6 to 0.012 Ma), faulting began to form the structural depression that would become Butte Valley (DOI 1980).

The Basin became a closed drainage basin as Butte Valley dropped and adjacent fault block mountains uplifted (County of Siskiyou 1996). At the same time Meiss Lake occupied Butte Valley, depositing the Lake Deposits on the valley floor (DOI 1980). During the Quaternary (2.6 Ma to Present), glaciation occurred in the high mountains that form the headwaters of Butte Creek, the largest creek in the Valley. Glaciation created glacial moraines and cirque valleys at the Butte Creek headwaters (King 1994). From the end of the Pleistocene to Present (0.012 Ma to Present), renewed volcanic activity erupted large amounts of fluid basalts from fissures in the High Cascades, including the Butte Valley Basalt (DOI 1980). This recent volcanic activity has shrunk the Butte Valley watershed by cutting off small drainages such as the Grass Lake area (King 1994). Today, the Cascade Range continues to be volcanically active. Butte Valley also remains seismically active (DOI 1980).

2.2.1.4 Geologic Units

The surface geology of Butte Valley and adjacent regions are primarily volcanic with lake deposits, alluvial fan deposits, and alluvium with some deposits of dune sand and talus (Wood 1960). A generalized geologic map of the Butte Valley watershed is shown in Figure 2.13 and described in Table 2.3 (Wood 1960; Jennings et al. 2013). Cross-sections A-A’ through C-C’ are shown in Figure 2.14, Figure 2.15, Figure 2.16. A 1,573 ft (479 m) deep test well drilled in 1978 by the U.S. Department of the Interior (DOI) in the south side of the Valley offers an example of Butte Valley stratigraphy (DOI 1980): from 0–47 ft (24–137 m) depth is alluvium deposits, from 47–78 ft (14–24 m) depth is Butte Valley Basalt, from 78–1,317 ft (24–401 m) is Lake Deposits (where 78–450 ft (24–137 m) is sands and gravels with thin clay interbeds, and 450–1,279 ft (137–390 m) is predominantly clay), and 1,279 to greater than 1,573 ft (390–479 m) is High Cascade Volcanics. Similar stratigraphy appears in Cross-section A-A’ between 400 to 12,000 m distance (Figure 2.14). In other parts of the valley, the Butte Valley Basalt disappears and the stratigraphy is limited to lake sediments and High Cascade Volcanics, shown in Figure 2.14, Figure 2.15, and Figure 2.16. The following outlines the geologic units from oldest to youngest, separating the volcanic and sedimentary deposits.

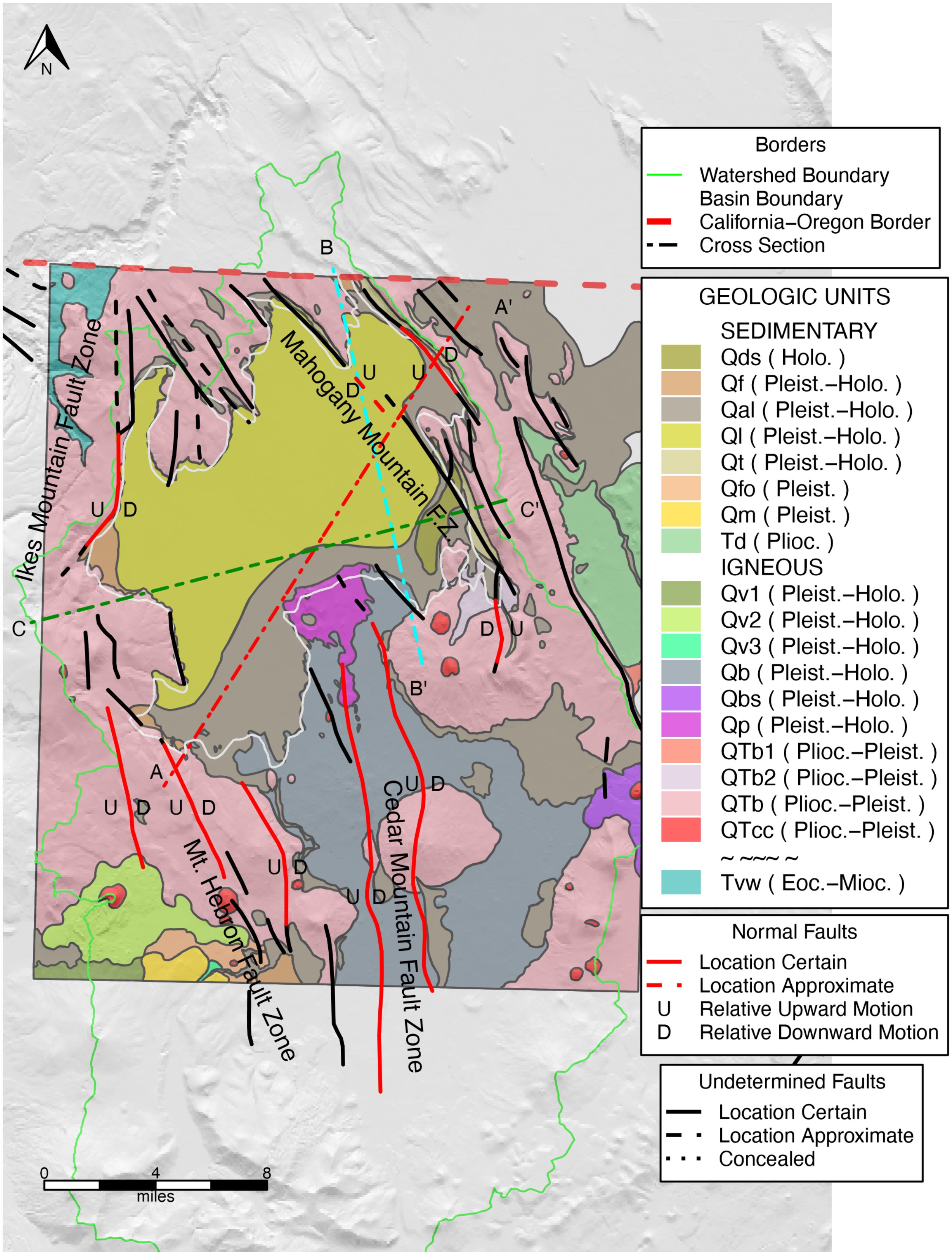

N
B
A'
C'
C
A
B'
U
D
Ikes Mountain Fault Zone
Mahogany Mountain F.Z.
Mt. Hebron Fault Zone
Cedar Mountain Fault Zone
0
4
8
miles
Borders
Watershed Boundary
Basin Boundary
California–Oregon Border
Cross Section
GEOLOGIC UNITS
SEDIMENTARY
Qds (Holo.)
Qf (Pleist.–Holo.)
Qal (Pleist.–Holo.)
Ql (Pleist.–Holo.)
Qt (Pleist.–Holo.)
Qfo (Pleist.)
Qm (Pleist.)
Td (Plioc.)
IGNEOUS
Qv1 (Pleist.–Holo.)
Qv2 (Pleist.–Holo.)
Qv3 (Pleist.–Holo.)
Qb (Pleist.–Holo.)
Qbs (Pleist.–Holo.)
Qp (Pleist.–Holo.)
QTb1 (Plioc.–Pleist.)
QTb2 (Plioc.–Pleist.)
QTb (Plioc.–Pleist.)
QTcc (Plioc.–Pleist.)
~ ~~~ ~
Tvw (Eoc.–Mioc.)
Normal Faults
Location Certain
Location Approximate
U Relative Upward Motion
D Relative Downward Motion
Undetermined Faults
Location Certain
Location Approximate
Concealed

Figure 2.13: Geology of the Butte Valley Groundwater Basin and surrounding watershed. Fault zones are plotted with their major faults (minor faults not plotted). Legend abbreviations include the time periods Holocene (H.), Pleistocene (Pleist.), Pliocene (Plioc.), Miocene (Mioc.) and, Eocene (Eoc.). Geology layer from Wood, 1960.

Table 2.3: Geology Map Unit Descriptions (Wood 1960).

Unit Name	General Lithology	Age	Description
Qds	Dune Sand	Holocene	Unconsolidated sand, in part actively drifting.
Qf	Alluvial-fan deposits	Pleistocene-Holocene	Unconsolidated deposits consisting of poorly sorted boulders, gravel, sand, and silt beneath alluvial fans. Also includes remnants of older alluvial-fan deposits. Generally poorly permeable but transmits water to underlying formations.
Qal	Alluvium	Pleistocene-Holocene	Includes sand, gravel, and clay in the eastern and southern parts of Butte Valley; poorly sorted alluvial deposits collected in relatively shallow basins or depressions; local playa deposits; and gravel and sand in major stream channels. Moderately permeable.
Ql	Lake deposits	Pleistocene-Holocene	Semiconsolidated clay, volcanic ash, diatomite, and sand with local stringers of gravelly sand. Locally interfingers with and is overlain by talus, alluvium, and alluvial-fan deposits. In general poorly permeable but moderately permeable along the east side of Butte Valley.
Qt	Talus	Pleistocene-Holocene	Wedge-shaped deposits of blocky debris at the base of steep fault scarps. Highly permeable. May contribute to groundwater recharge. May act as groundwater storage reservoir or drain.
Qfo	Fluvioglacial deposits	Pleistocene	Poorly sorted rounded to angular rock fragments, boulders, sand, clay, and silt.
Qm	Glacial moraines	Pleistocene	Unstratified bouldery deposits in a clayey matrix.
Td	Diatomite	Pliocene	Massive-appearing gray to white diatomite. Locally contains interbedded sand, cindery tuff-breccia, and volcanic ash.
Qv1	Younger volcanic rocks of the ”High Cascades”	Pleistocene-Holocene	Highly permeable and important as recharge media. Hypershene-rich andesitic flos of Deer Mountain.
Qv2	Younger volcanic rocks of the ”High Cascades”	Pleistocene-Holocene	Highly permeable and important as recharge media. Black vesicular olivine-augite basalt flows from Little Deer Mountain.
Qv3	Younger volcanic rocks of the ”High Cascades”	Pleistocene-Holocene	Highly permeable and important as recharge media. Black vesicular olivine basalt in Butte Creek Canyon.

Qb	Butte Valley basalt	Pleistocene-Holocene	Grey vesicular olivine basalt that is highly permeable.

Table 2.3: Geology Map Unit Descriptions (Wood 1960). *(continued)*

Unit Name	**General Lithology**	**Age**	**Description**
Qbs	Basaltic flows near Sharp Mountain	Pleistocene-Holocene	Dark-colored olivine basalt that is highly permeable.
Qp	Pyroclastic rocks	Pleistocene-Holocene	Well-consolidated massive to thin-bedded lapilli tuff, and tuff-breccia. It is moderately permeable.
QTb1	Basaltic lava flows	Pliocene-Pleistocene	Generally very permeable and important for groundwater recharge. Grey vesicular olivine basalt flows on Big and Little Tablelands and extensive basalt flows south of Klamath Lake.
QTb2	Basaltic lava flows	Pliocene-Pleistocene	Generally very permeable and important for groundwater recharge. Coarsely vesicular black aphantic basalt near Sheep Mountain.
QTb	Older volcanic rocks of the ”High Cascades”	Pliocene-Pleistocene	Pale-grey olivine basalt and basaltic andesite and discontinous layers of yellowish tuff and tuff-breccia. Very permeable and an important groundwater storage reservoir.
QTcc	Cinder-cone deposits	Pliocene-Pleistocene	Red, brown, and black scoria mounds and cinder cones composed chiefly of andesitic and basaltic ejecta of Pliocene age and younger. Very permeable and largely unsaturated.
~~	Erosional or non-depositional surface	Miocene-Pliocene	Major Unconformity
Tvw	Volcanic rocks of the ”Western Cascades”	Eocene-Miocene	Chiefly andesitic lava flows and lesser amounts of andesitic tuff-breccia and lapilli tuff.

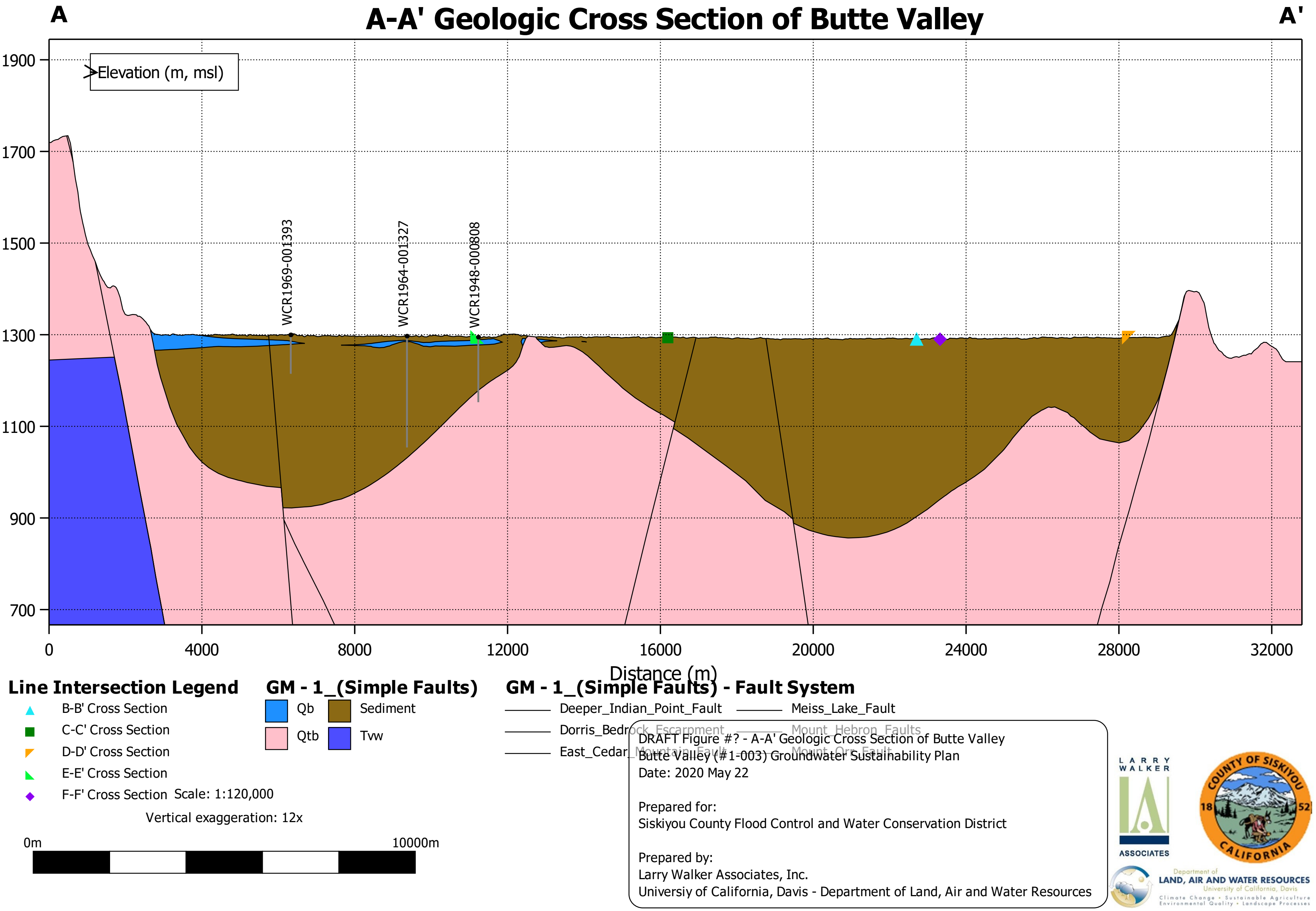
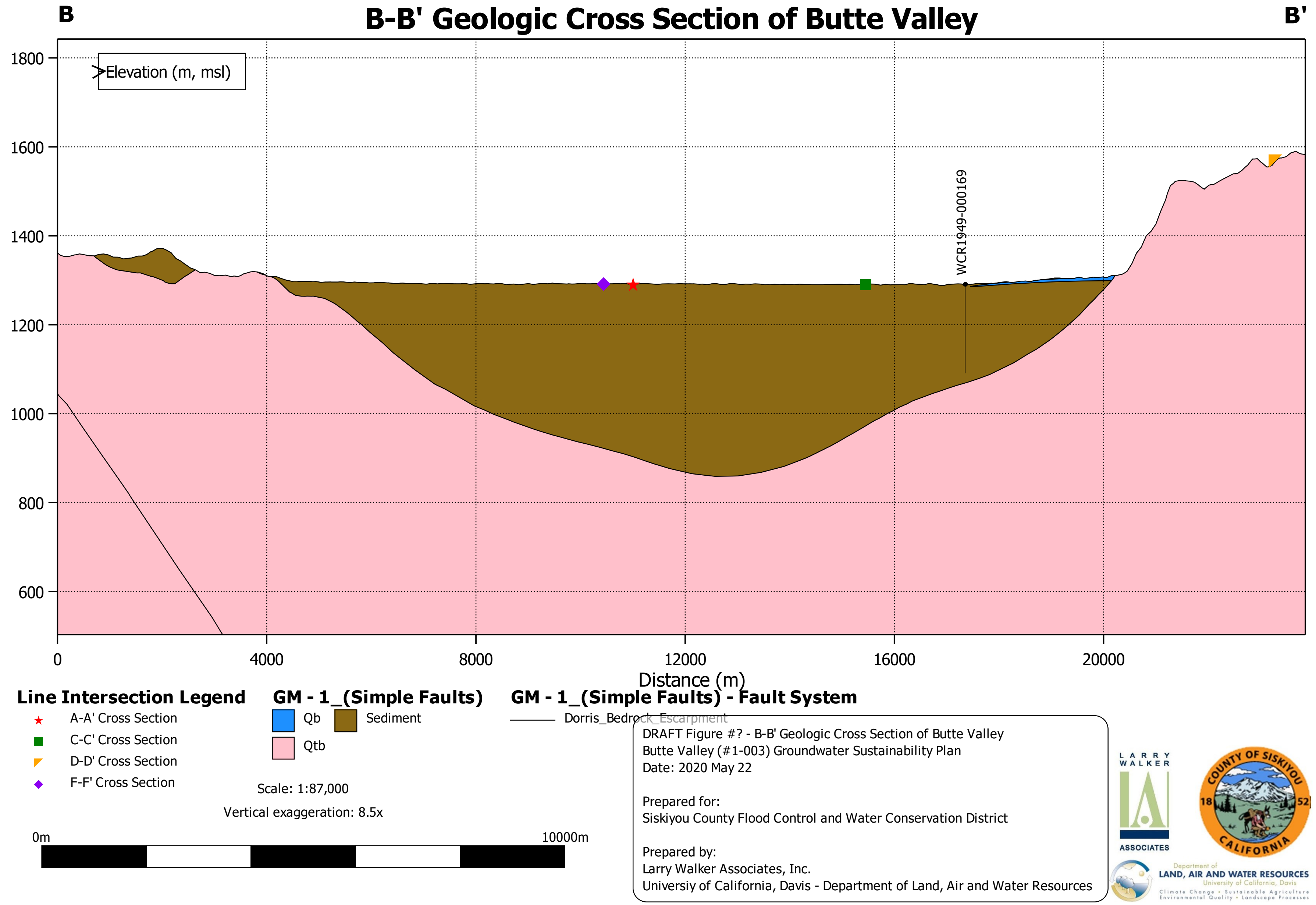


Figure 1.14: Cross Section A-A' crosses Butte Valley from the southwest to the northeast corner, shown in the geology map.



DRAFT Figure #? - B-B' Geologic Cross Section of Butte Valley
Butte Valley (#1-003) Groundwater Sustainability Plan
Date: 2020 May 22

Prepared for:
Siskiyou County Flood Control and Water Conservation District

Prepared by:
Larry Walker Associates, Inc.
Universiy of California, Davis - Department of Land, Air and Water Resources

Figure 1.15: Cross Section B-B’ crosses Butte Valley from north to south near Dorris, shown in the geology map.

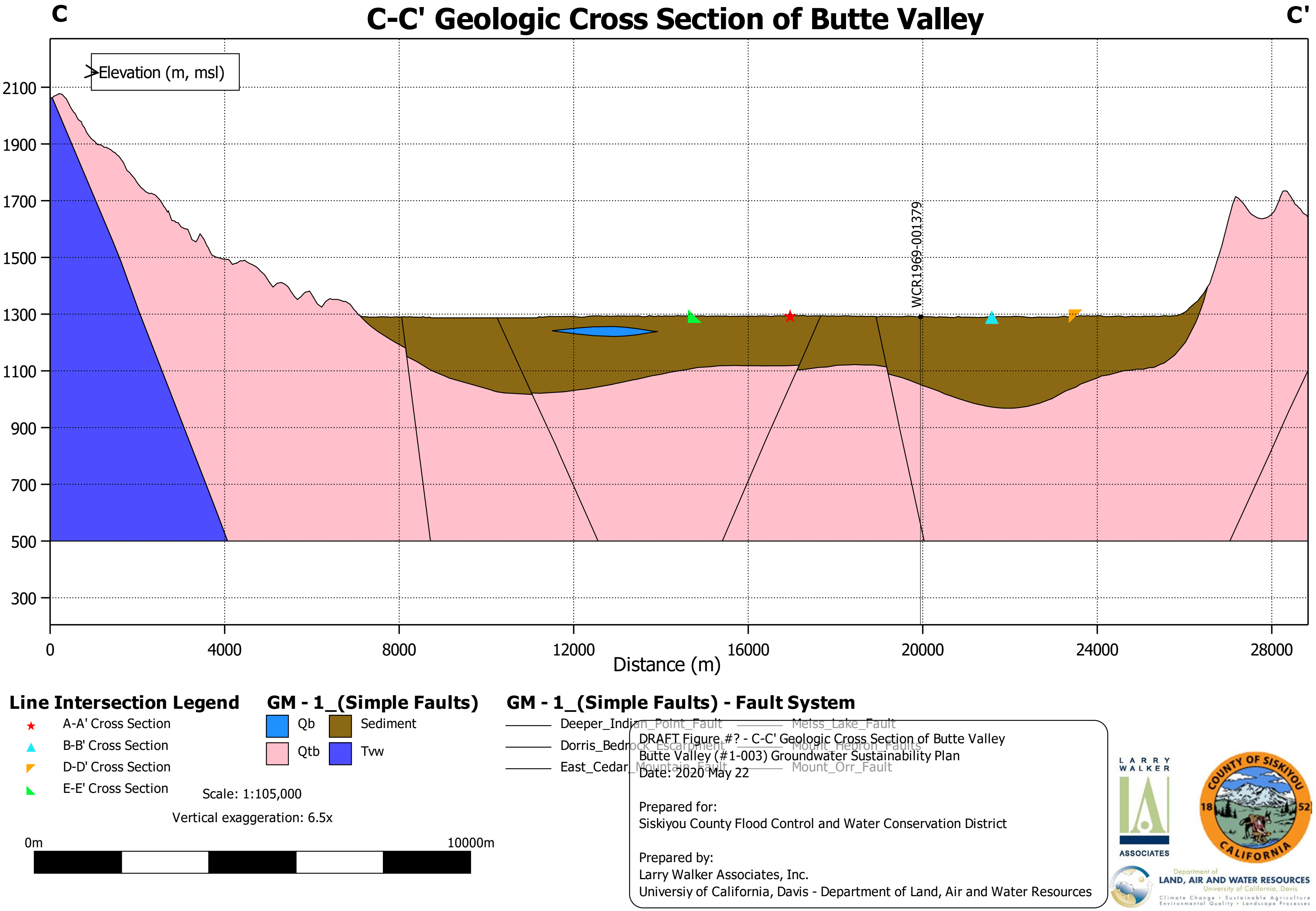


Figure 1.16: Cross Section C-C’ crosses Butte Valley from the west to east, shown in the geology map.

Western Cascades Subprovince

The upper Klamath Basin has been volcanically active for at least 35 million years with two subprovinces directly underlying Butte Valley: the Western Cascades subprovince and High Cascade subprovince (Gannett, Wagner, and Lite Jr. 2012). In Butte Valley, the oldest geologic unit with surface exposure is the volcanic rocks of the Western Cascades (Tv and Tvp in Figure 2.13). Western Cascades rocks are 20 to 33 million years old and can be up to 20,000 ft (6,096 m) thick with primarily early to middle Tertiary lava flows, andesitic mudflows, tuffaceous sedimentary rocks, and vent deposits (Gannett, Wagner, and Lite Jr. 2012). Near Butte Valley the unit is primarily andesite and andesitic tuff breccias (DOI 1980). In general, Western Cascade deposits have low permeability due to devitrified (changed to clays and other minerals) tuffaceous materials and weathered lava flows with abundant secondary minerals. Low permeability limits the flow of groundwater through the Western Cascade unit and acts as a barrier to regional groundwater flow. The unit dips to the east and defines the lower boundary of the regional groundwater flow where present (Gannett, Wagner, and Lite Jr. 2012). This formation has not been penetrated by Butte Valley wells (DOI 1980). The unknown depth to the Western Cascades Subprovince precludes its appearance in the cross-sections.

High Cascade Subprovince

The High Cascade subprovince unconformably overlies the Western Cascade unit, with ages from the late Miocene to late Pleistocene (5.3 to 0.012 Ma). Deposits within the upper Klamath Basin are constructional features such as volcanic vents and lava flows with relatively minor interbedded volcaniclastic and sedimentary deposits (Gannett, Wagner, and Lite Jr. 2012). High Cascade deposits in Butte Valley include Pliocene volcanic rocks and Pliocene cinder cone deposits (Wood 1960). Within the Valley, the depth to the High Cascade Volcanics confined water bearing formation varies from 47 to 1,317 feet bgs (Kit Novick 1996).

A 1977 seismic refraction survey attempted to find the depth and structural configuration of the High Cascade Volcanics water bearing formation. The survey may have detected the contact between the High Cascade Volcanics and underlying Western Cascade Volcanics or a transition to a more massive part of the High Cascades Series. The survey found that faulting through the High Cascades Volcanics has made the top of the unit very irregular and the depth to the unit can locally vary hundreds of feet between nearby wells. The surface of the High Cascade unit generally dips to the east, likely related to the fault system uplifting Mahogany Mountain (DOI 1980). Cross-sections A-A’ and C-C’ show that the top of the High Cascade Subprovince (Unit Qtb) is irregular and generally deepens toward the east (Figure 2.14 and Figure 2.16).

Butte Valley Basalt and Other Small Basalt Flows

All surface exposures of basaltic flows in Butte Valley and south of the Basin are important for groundwater recharge. Deposited in the late Pleistocene or Holocene, Butte Valley Basalt is a highly permeable uniform sheet of vesicular basalt that overlies and interfingers with lakebed deposits (DWR 2004). Surface exposures are in the southern part of the Basin and likely extend into the subsurface under the valley floor lake deposits through Macdoel and Meiss Lake, the southern valley floor and west of Inlow Butte (Wood 1960). The extent of the Butte Valley Basalt is shown in Figure B.2 in Appendix 2-A.

The depth of the Butte Valley Basalt varies from 0 to 110 feet bgs (Kit Novick 1996). The basalt ranges in thickness to 80 ft (24 m), averaging approximately 40 ft (12 m) (Figure 2.14 and Figure 2.15). The subsurface extent is estimated to be 27 sq mi (70 sq km). The fractured basalt is commonly rough, broken, cavernous, and scoriaceous at contacts between relatively thin flow units. The basalt is predominantly located in the southern and southeastern region of the Valley at depths of less than 150 ft (46 m) (DWR 2004). Other small basalt flows in Butte Valley include the very permeable Pleistocene lava flows near Sheep Mountain (Wood 1960).

Pyroclastic Rocks

Pyroclastic rocks in Butte Valley are typically well consolidated, massive to thin-bedded lapilli tuffs and cindery tuff breccias that are generally cross-bedded and include abundant fragments of basalt and scoria. The deposits underlie a region located east and southeast of Macdoel ranging up to 400 ft (122 m) in thickness near Juniper Knoll. These deposits rest upon lake deposits and are partially overlapped by Butte Valley basalt (Wood 1960; County of Siskiyou 1996).

Lake Deposits

During 1.8 million years of the Quaternary Period, times of decreased temperature and increased precipitation created lakes in many hydrologically-closed drainage basins in the Western United States, such as Lakes Bonneville and Lahontan in the Great Basin. The maximum size of the Quaternary paleolake in Butte Valley was 73 sq mi (189 sq km) with a maximum depth of 46 ft (14 m). This maximum extent created a shoreline terrace at 4,268 ft (1,301 m) amsl elevation around the valley rim. The 4,268 ft (1,301 m) amsl terrace is the best developed shoreline terrace in Butte Valley and is at its widest on the north and east valley rims, particularly near Picard Cemetery on Mud Lake Ridge and just east of Dorris. Compared to other Quaternary paleolakes, the Butte Valley 4,268 ft (1,301 m) amsl terrace is underdeveloped, suggesting that the paleolake maximum was short-lived. While at this maximum extent, the paleolake overflowed into Rock Creek, a tributary of the Klamath River, through Sam's Neck. This overflow may have been brief due to the lack of a distinct overflow channel connecting the Sam's Neck notch at 4,265 to 4,268 ft (1,300 to 1,301 m) amsl to the Rock Creek channel. However hard bedrock at the channel site may have resisted erosion of a deeply-cut overflow channel and therefore, lake overflow may have lasted over a longer period. Concurrently, Butte Creek may have deposited deltaic sediments at the 4,268 ft (1,301 m) amsl shoreline (King 1994).

The lack of well-developed shorelines at the Butte Valley rim suggests that the paleolake was mostly confined to the valley floor. However, shoreline terraces in Butte Valley have been highly disturbed by human activity, including disturbances from the construction of houses, buildings, and roads on top of existing terraces. Other weak paleolake shorelines occur at 4,262 ft (1299 m) and 4,255 ft (1297 m) amsl. An example of the 4,262 ft (1299 m) amsl terrace is located at the end of Indian Point, where it is 33 ft (10 m) wide and consists of coarse beach sand with scattered angular talus boulders. An example of the 4,255 ft (1297 m) amsl terrace is located on the west side of Cedar Point. Below 4,255 ft (1297 m) amsl is the shallow sloping valley floor, where any further paloelake shorelines may have been destroyed by agricultural activity or never formed due to a rapid reduction in lake size to modern levels (King 1994).

Based on core samples, where lake deposits can exceed 900 feet (300 meters) in thickness, Butte Valley has been the site of a lake for between one and three million years (Carter 1994; Mathias 2014) (Figure 2.14, Figure 2.15, and Figure 2.16). Based on sediment accumulation rates, shallow sediments appear to accumulate at a rate of 8.3 cm per thousand years to a depth of approximately 78 meters. Below 78 meters below ground surface, corresponding with approximately 930,000 years in age, sediment accumulation rates decrease to 0.9 cm per thousand years (Roberts et al. 1996). Quaternary pyroclastic deposits in older lake deposits show evidence of being laid down in lake water. At the end of the Pleistocene, the Butte Valley paleolake may have experienced rapid desiccation after the end of the last glacial cycle, reducing the lake size to the current Meiss Lake. Quaternary paleolakes in the Great Basin also have evidence of a rapid desiccation after the end of the last glacial cycle, about 10-12,000 years ago. A rapid desiccation reducing lake size could explain the gap in lake shorelines from 4,255 ft (1297 m) amsl elevation to 4,236 ft (1291 m) amsl (King 1994).

The rapid desiccation of the Butte Valley paleolake created an environment of playas and phytogenic dunes. Much of the original valley floor has been disturbed by human activity, particularly by the leveling of fields. A large remnant east of Meiss Lake has never been cultivated and highly resembles a playa surface. In the 1950s, the USGS mapped two small playas on the southeastern side of the Valley before the area was converted to agricultural fields. In some locations between Meiss Lake and Dorris, phytogenic dune ridges trend northwest/southeast in parallel with area faulting. These phytogenic dunes likely formed through increased scrub vegetation along fault fissures in the lakebed, where increased moisture can occur (King 1994).

Alluvial Fan Deposits

Isolated remnants of alluvial fan deposits are located on the west side of Butte Valley (DWR 2004). Alluvial fan deposits in Butte Valley are saturated, but poorly permeable with groundwater yields suitable for stock or domestic wells (DOI 1980).

In Butte Valley, these deposits were deposited during the Pleistocene to the Present and are composed of poorly-sorted volcanic rock debris, rounded cobbles of volcanic origin, gravel, sand, and clay from the Cascade Range (DOI 1980; DWR 2004). The deposits are coarse near the mountain fronts and grade into fine materials in the lower part of the fans. The fans interfinger with lake deposits at depth. The deposits have low permeability except where well-sorted gravel lenses are encountered and generally yield small quantities of water to wells. Thickness of the deposits range up to 350 ft (107 m) (DWR 2004).

Alluvium

In Butte Valley, alluvium deposits were deposited from the Pleistocene to Recent and are moderately permeable but generally above the water table. Within the Basin alluvium deposits include several different types (Wood 1960):

- Sand, gravel, and clay in the eastern and southern parts of Butte Valley.
- Poorly-sorted alluvial deposits in relatively shallow basins or depressions.
- Local playa deposits.
- Gravel and sand in major stream channels.

Alluvium in the northern Butte Valley was deposited by sheetfloods, slope wash, and other agents of erosion. Deposits on the eastern border are mainly fine to coarse-grained sand of volcanic origin, with perhaps lakeshore or beach deposits. They were deposited by sheetfloods, slope wash, rill wash, and other colluvial processes. Some alluvium has been redeposited as windblown or dune sand mantling parts of the steep fault scarps (Wood 1960).

In the south, sand and gravel alluvium deposits unconformably overlie the Butte Valley basalt and overlie and locally interfinger with the lake deposits (Wood 1960; DOI 1980). They are characterized by lenticular deposits of clay, silt and sand. The deposits are generally poorly permeable and can yield water for stock or domestic wells (DOI 1980). Along the valley margin, the alluvial deposits range from 0-60 ft (0-18 m) in thickness. Volcanic sand and gravel alluvium in the southwest of Butte Valley was likely deposited by Butte Creek flood waters and may represent a delta built by the creek during the high stages of the lake that formerly filled the Valley. Dune sand near Macdoel is wind reworked volcanic sand that is currently being leveled and cultivated (Wood 1960).

Playa deposits are common in the Butte Valley region, with clay, silt, and minor amounts of sand. They occur in the topographically lowest areas of small enclosed basins and merge laterally into alluvial slope deposits. They have low permeability and likely have highly saline water (Wood 1960).

Other alluvium deposits are poorly sorted and unconsolidated gravel, sand, and silt. They stem from the decomposition and erosion of volcanic material in adjacent mountainous areas and were deposited in basins and depressions by streams, sheetfloods, slope wash, and other erosional processes (Wood 1960).

Talus

Talus in Butte Valley are highly permeably wedge-shaped deposits of blocky debris at the base of steep fault scarps on the north and east sides of the Valley (Wood 1960). Talus deposits generally act as groundwater conduits and drains and may act as groundwater storage reservoirs where interfingered with saturated sediments. Water bearing properties are unknown and the few wells that penetrate talus deposits likely draw groundwater from both the talus sediments and other interconnected aquifer subunits (DOI 1980).

The deposits are unsorted, uncemented, angular blocks, boulders, and fragments of volcanic rocks of a few inches to greater than 6 ft (1.8 m). In some areas, the gaps between coarse materials have been filled by sand. In Butte Valley, large talus deposits primarily occur on the east margin, near the City of Dorris down to Sheep Mountain. In some areas the talus deposits are concealed underneath and likely interfinger alluvial and land-bed deposits. On westward-facing scarps, talus deposits are covered by windblown sand. The thickness and lateral extent of the talus deposits is not well defined, though two wells near Dorris encountered 143 and 360 ft (44 and 110 m) of talus (Wood 1960).

Dune Sand

A very young deposit generally above the water table, a large dune sand deposit sits on the eastern border of Butte Valley, west and north of Inlow Butte and south of Cedar Point (Wood 1960; King 1994). Dune sand deposits too small to plot on a geologic map exist elsewhere in Butte Valley. Dune sand covers High Cascade rock outcrops in westward-facing escarpments along the Butte Valley border (Wood 1960).

The deposit is unconsolidated, fine-to-coarse, massive, loosely compacted, crossbedded quartz sand that is in part actively drifting and up to 20 ft thick. The dune sand was reworked from lake and alluvial deposits which have migrated eastward and northward from old abandoned lake shorelines. Dunes have largely been stabilized by a sparse cover of vegetation, but some sections have dunes actively advancing upon older dunes, talus and High Cascades rock outcrops (Wood 1960). The majority of the extensive aeolian dune deposits south of Cedar Point were likely produced by wave action on the eastern shorelines of the Quaternary Butte Valley paleolake (King 1994).

2.2.1.5 Faults

Beginning in the Pleistocene (2.6 to 0.012 Ma), faulting began to form Butte Valley and remain active today (DOI 1980). Butte Valley is bordered on all sides by the Cedar Mountain fault system, a complex group of generally north- to north-northwest-striking normal faults along the boundary between the Cascade Ranges and the Modoc Plateau (Bryant 2000). Fault displacement is nearly vertical and ranges from a few feet to possibly more than several thousand feet along major faults (DOI 1980). The fault system has offset the latest Pleistocene and Holocene volcanic rocks, glacial, and alluvial deposits (Wood 1960; Bryant 1990, 2000). Historic surface fault rupture is associated with the local magnitude (ML; Richter magnitude) 4.6 Stephens Pass earthquake of August 1, 1978 (Bryant 2000). An earthquake in late June of 1966 shook the Dorris area and ruptured the clay lining of a waste effluent evaporative treatment pond about 0.5 mi (0.8 m) southwest of Dorris (DWR 1968; DOI 1980). The faults near Dorris exhibit evidence of continuing into the bedrock below the valley floor (DWR 1968).

Five sections of the Cedar Mountain fault system exist within Butte Valley: Cedar Mountain, Mahogany Mountain, Mount Hebron, Meiss Lake, and Ikes Mountain Faults. The Cedar Mountain Fault Zone begins at the northern border of the Basin through the middle to the southern border (see Figure 2.13). Within Butte Valley the fault zone is 6.8 mi (11 km) wide, with numerous short, northwest-trending faults in the Valley floor and through the Butte Valley Basalt. Offset features within the Valley indicate that the fault zone has been active during the Holocene (Bryant 2000). The northwest Basin border is characterized by the Ikes Mountain Fault, a north-trending normal fault. It was active in the late Quaternary with little evidence for more recent activity. The Meiss Lake Fault passes through the middle of Meiss Lake and is a north-trending fault with Holocene activity. Some geomorphic evidence suggests a component of right-lateral strike slip. The Valley border in the southwest is defined by the Mount Hebron Fault Zone, a 4.3 mi (7 km) wide series of north to northwest-trending normal faults. Geomorphic evidence limits fault activity to the Quaternary and late Quaternary. The Mahogany Mountain Fault Zone marks the northwest border of the Basin, a northwest-trending zone of normal faults with vertical displacement to the southwest. Geomorphic evidence suggests that the fault has been active in the Holocene (Bryant 1990, 2000).

A 1998 DWR Well Interference Investigation in the northwestern portion of the Basin indicates that local faults can act as both a flow barrier and very transmissive conduit for groundwater flow. The study's conclusions suggest that other faults in the area likely influence groundwater flow in a similar fashion. The aquifer performance test of the BVWA Well 7A shows structural continuities, including (DWR 1998):

- A strong north-south hydraulic continuity along a fault trace adjacent to two monitoring wells.
- Areas on either side of a fault adjacent to Well 7A are somewhat isolated from each other, with improved hydraulic continuity within a common fault-bounded area.
- There is a hydraulic connection in talus deposits along a fault trace.
- Well 7A has an asymmetrical cone of depression, attenuated on the east side of the fault trace.

Faults in the Basin support the formation of springs, where numerous Basin springs align with faults. Faults can impede groundwater flow and cause a buildup of groundwater, which can emerge at the surface in the form of a spring. Local agriculture in the Basin can be supported by springs, such as Holzhauser Ranch in Sam's Neck, where water from two springs are collected into ponds for irrigation (DWR 1998).

2.2.1.6 Water Bearing Formations

Water bearing formations within the Basin aquifer are described in the following discussion, where the principal water bearing formations are Lake Deposits, Butte Valley Basalt, and High Cascade Volcanics, and minor formations are Alluvial Fan Deposits and Pyroclastic Rocks (DWR 1998; DWR 2004). Unconfined formations include the Lake Deposits, Pyroclastic Rocks, and the Butte Valley Basalt (DOI 1980). Within the Basin the Lake Deposits cover the High Cascade Volcanics and Butte Valley Basalt, confining the two formations in most areas (DWR 1998). The Butte Valley Basalt can also be locally confined when overlain by fine-grained alluvium with low permeability (DOI 1980). Comparatively, the High Cascade Volcanics and Butte Valley Basalt have high yields and the Lake Deposits have relatively low yields (DWR 1998).

Groundwater flow and distribution in the Basin is controlled by localized faulting, aquifer material variability, and the interconnection of formation units, which can enhance, diminish, or block flow.

Faults and fractures can act as either groundwater conduits or barriers to flow (DWR 1998). Faults in Butte Valley may act as vertical paths of high permeability locally connecting the Lake Deposits and High Cascade Volcanics water bearing formations (DWR 1968). Faults can also offset formations and juxtapose more permeable formations against less permeable units (DWR 1998). There is limited vertical hydraulic continuity between the low, variably permeable Lake Deposits and high isotropic permeable High Cascade Volcanics due to the contrasting permeability (DWR 1968; DWR 1998). The High Cascade Volcanics water bearing formation is confined and separate from the Lake Deposits near Dorris (DWR 1968), and Meiss Lake (DWR 1998).

High Cascade Volcanics Water Bearing Formation

The High Cascade Volcanics water bearing formation is highly fractured, very permeable, highly transmissive, and an important regional groundwater source (DWR 1998; DWR 2004). The High Cascade Volcanics is divided into a series of "compartments" by fine-grained feeder dikes radiating out from parent cones and by a series of northwest-trending faults (Kit Novick 1996). Wells are routinely developed into this geologic unit and water yields range from 700 to 5,000 gallons per minute (gpm), but often produce over 3,000 gpm. Groundwater within the unit is usually confined by Lake Deposits and some irrigation wells have artesian flows (Kit Novick 1996; DWR 2004). Most wells in Butte Valley encounter the formation at depths between 240 to 600 ft, with some wells intercepting the formation at shallow depths of 47 ft or deep depths of 1,317 ft. Springs stemming from the High Cascade Volcanics supply the perennial flows for Prather, Muskgrave, Harris, and Ikes Creeks. By the 1990s, ~~T~~this water bearing formation had~~s~~ not experienced overdraft (Kit Novick 1996).

Beyond being a major element of the Basin's groundwater storage reservoir, the High Cascade Volcanics is also very important for groundwater recharge. It has a large areal extent beyond the Basin margin and acts as an intake media for groundwater recharge into the Basin (DWR 2004). It defines the Basin boundaries in the west, north, and east and underlies the lake bed deposits (Wood 1960; DWR 2004).

The High Cascade Volcanics consist of successive sheets of basalt, basaltic andesite, discontinuous layers of massive basaltic tuff and tuff breccia, and some isolated lapilli tuff, and cinder-cone deposits. The individual flow units range in thickness from 10- to 50-ft (3 to 15 m) and intermittently up to 100 ft (30 m) (DWR 2004). Individual well yields are highly dependent on the flow thickness and number of flow contacts intercepted, as well as vertical fracturing (DOI 1980; DWR 2004). Tuffaceous deposits are essentially non-water-bearing except for fracture zones and intercalated basaltic flows (DWR 2004).

Butte Valley Basalt Water Bearing Formation

Historically the Butte Valley Basalt has been the primary groundwater-producing water bearing formation in the southern part of the Basin (DWR 1998). The unit is also the most productive formation in the region, with water yields of 1,000 to 4,000 gpm and an average of 2,000 gpm (Kit Novick 1996). Highly productive wells from this formation are common in the Macdoel-Mount Hebron area and can generate up to 4,000 gpm (DWR 1998; DWR 2004). Specific capacities of

100 gpm per foot of drawdown are common and values up to 1,100 gpm per foot of drawdown have been documented (DWR 2004). A temporary seasonal overdraft occurs during the latter part of the irrigation season evidenced by well interference from overutilization (DWR 2004). This formation has been developed to its maximum productivity and in some years seasonal pumpage exceeds storage capacity (Kit Novick 1996; DWR 2004). Toward the end of the irrigation season, some shallow BVID and BVWA wells go dry but recover by the following season after groundwater recharge. The formation recharges annually with no year-over-year ~~long-term overdraft~~ decline in average to above average precipitation years (Kit Novick 1996).

The Butte Valley Basalt consists of a highly permeable, fractured, uniform sheet of vesicular basalt with an average thickness of 40 ft (12 m) and a range from 6 ft (1.8 m) to hundreds of feet thick (DOI 1980; DWR 1998; DWR 2004). A system of nearly vertical joints or shrinkage cracks through the unit facilitates the vertical migration of groundwater (DWR 1998). Internally, the formation consists of comparatively thin lava flows where contacts between flows are commonly rough, broken, cavernous, and scoriaceous (DWR 1998; DWR 2004). The combination of vertical and horizontal flow paths makes the Butte Valley Basalt a productive water bearing formation (DOI 1980). The basalt is predominantly located in the southern and southeastern region of the Basin at depths of less than 150 ft (46 m), overlies and interfingers with Lake Deposits, and has an estimated subsurface extent of 27 sq mi (70 sq km) (DWR 2004). The unit extends northward as far as the east side of Meiss Lake (Kit Novick 1996). The rough broken surface exposures provide areas of recharge (DWR 2004). Butte Creek is diverted to several locations to recharge the Butte Valley Basalt (Kit Novick 1996).

Lake Deposits Water Bearing Formation

The Lake Deposits is the most important water bearing formation on the east side of the Valley but yields less water than the Butte Valley Basalt and High Cascade Volcanics water bearing formations. The water bearing formation is locally both unconfined and confined. Lake Deposits can occur both above and below the Butte Valley Basalt but always above the High Cascade Volcanics. The formation depth ranges from 0 to 125 ft bgs. Water yields from the best wells range from 1,500 to 2,600 gpm (Kit Novick 1996).

Lake Deposits vary widely in their ability to transmit water, but are generally more permeable and coarser grained on the east and south sides of the Valley and more permeable along the Basin margin compared to mid-basin (DOI 1980; DWR 1998; DWR 2004). Mid-basin Lake Deposits generally represent fine-grained lake deposits while the valley margins generally contain coarser, sandier near-shore deposits from the paleolake that once filled Butte Valley. Along the Basin margins, Lake Deposits interlayer with volcanic rocks and can yield moderate to high groundwater yields (DWR 1998). Coarser Lake Deposits in the western and northwestern part of the basin generally yield sufficient water for stock wells, while the more sandy eastern valley margin can have yields up to 2,500 gpm (DWR 2004). At the southern Basin margin deposits are interfingered with the recharging Butte Valley Basalt and well yields can exceed 4,100 gpm (DWR 1998; DWR 2004). Lake Deposits are generally lenticular (DWR 1968).

The Lake Deposits consist of semi-consolidated deposits of relatively impermeable sand, silt, clay, ash, lenses of diatomaceous clay, and local stringers of gravelly sand (DWR 1998; DWR 2004). Unit thickness is variable from 350 to 1,300 ft (107 to 396 m), but generally thickens to the west and unconformably overlies the older volcanic rocks of the High Cascades (DOI 1980; DWR 2004). In the central Basin, a calcium carbonate cemented clay hardpan soil is usually present from six inches to several feet beneath most soils and is particularly close to the surface around Meiss Lake (County of Siskiyou 1996; DWR 2004). The hardpan impedes vertical groundwater recharge into the Lake Deposits water bearing formation (DWR 1998).

Sand deposits in the Lake Deposits exhibit a general grain size and thickness gradation from south to north, suggesting the presence of a major stream entering the paleolake from the south, with coarser material dropping out of suspension first in the south and the finer material being carried and deposited north and west. In the south, coarse-grained lake deposits are interfingered with and underlie the Butte Valley Basalt (DOI 1980).

West of U.S. Highway 97, Lake Deposits on the west and northwest valley sides are generally fine-grained silts and clays of very low permeability that commonly serve as confining layers (DOI 1980; DWR 2004). Though saturated with groundwater these fine-grained lake deposits yield only small quantities of water to stock wells (DOI 1980).

East of U.S. Highway 97, Lake Deposits are loose, fine to medium-grained bedded sands interbedded with clay (DWR 2004). East of U.S. Highway 97, northeast of Juniper Knoll and in the southern part of the Valley, lenses and beds of sands and gravels over 300 ft (91 m) thick are interbedded with and overlie finer-grained clays and silts. East of U.S Highway 97, northeast of Juniper Knoll and the east side of the Basin, the lake deposits are loose, fine to medium-grained, current-bedded sands interbedded with clay. To the north, the thickness and number of sand lenses generally diminish and the grain size decreases. Near Dorris are discontinuous lenses of fine to medium sand that yield water to mainly domestic or low-yielding irrigation wells (DOI 1980). In the eastern half of the Basin, specific capacities range from 9 to 62 gpm per foot of drawdown. Locally, and along the eastside Basin margin, specifically sandy lake deposits can interfinger with highly permeable deposits of beach sand and talus debris (DWR 2004).

South of Macdoel, the sand layers thicken and the grain size increases. The coarse-grained lake deposits in the south are moderately to highly permeable with loose sands and gravels that yield water freely but cause problems with well drilling and completion. Wells in these lake deposits often report “sanding up” problems and can have issues with caving (DOI 1980).

Alluvial Fan Deposits Water Bearing Formation

Isolated remnants of alluvial fan deposits are located on the west side of Butte Valley. These deposits are composed of poorly-sorted volcanic rock debris, cobbles, gravel, sand, and clay from the Cascade Range. The deposits are coarse near the mountain fronts and grade into fine materials in the lower part of the fans. The fans interfinger with Lake Deposits at depth. The deposits have low permeability except where well-sorted gravel lenses are encountered and generally yield small quantities of water to wells. Thickness of the deposits range up to 350 ft (107 m) (DWR 2004).

Pyroclastic Rocks Water Bearing Formation

The deposits underlie a region located east and southeast of Macdoel ranging up to 400 ft (122 m) in thickness near Juniper Knoll (Wood 1960; DWR 2004). Deposits are exposed on the surface over a large area east of Macdoel. The unit is moderately to highly permeable and will yield water freely to wells where it is saturated (DOI 1980). Most of the outcrop lies above the saturated zone, where it acts as an intake area for groundwater recharge (Wood 1960; DOI 1980). These rocks have largely been developed for stock wells (DWR 2004).

The Pyroclastic Rocks unit is characterized by well-consolidated, massive to thin-bedded lapilli tuffs and cindery tuff breccias that are generally cross-bedded and include abundant fragments of basalt and scoria (DWR 2004). Deposits were created via at least two widely separated eruptive events (DOI 1980). The deposit overlies the lake deposits. The Butte Valley Basalt was deposited between the two main pyroclastic events and locally overlaps and is interbedded with the pyroclastic deposit (DOI 1980; DWR 2004).

2.2.1.7 Groundwater Recharge

Natural recharge occurs primarily from the infiltration of precipitation, underflow from the Basin adjacent volcanic rocks (on the north, west, and south margins) and streamflow losses (DWR 2004). Surface exposures of Butte Valley Basalt, High Cascade Volcanics, and Pyroclastic Rocks within the watershed are sources of recharge from rain and snow (Kit Novick 1996; DWR 2004). The High Cascade Volcanics recharges via snow pack in the north, west, and south sides of the Watershed (Kit Novick 1996). Lake Deposits also contain sources of groundwater recharge where volcanic talus deposits occur along fault scarps that cut into deeper water bearing formations (DWR 1998). Groundwater recharge via streamflow losses are provided by Butte, Antelope, Prather, Ikes, Harris, and Muskgrave Creeks (Kit Novick 1996). In the southern part of the Basin, seepage losses from unlined canals along the western fringe and deep percolation from irrigation also contribute to recharge (DWR 2004). The wetlands and canals in BVWA also recharge the groundwater (Kit Novick 1996).

2.2.1.8 Soil Characteristics

Soils in Butte Valley have developed in the valleys, basins, foothills, and mountain slopes, with distinct characteristics in each location. The following discussion references map units, named for major soil components, in the U.S. Department of Agriculture (USDA) 1994 Soil Survey of Butte Valley-Tule Lake Area (USDA 1994). A map of soil orders in the watershed is shown in Figure 2.17. The general soil units discussed below are shown in Figure 2.18. The infiltration and runoff potential as defined in hydrologic soil groups is shown in Figure 2.19. In Butte Valley, areas of poor soil permeability have an accumulation of salt and alkali, and tend to occur in areas with a hardpan (1996 Siskiyou County). Soils in the center of the Basin and bench lands along the northern valley rim have a prominent heavy calcareous hardpan (DOI 1980). In adjacent cropland, fields are leached through deep canals to decrease salts and alkali, and the hardpan is ripped periodically to improve rooting depth and drainage (Kit Novick 1996).

Most soils in Butte Valley are derived from lacustrine deposits, from the paleolake that used to fill the Valley. The center of the Basin, from the lowest elevation at Meiss Lake to the eastern valley side, is slightly lower than the north and south valley areas. The center of the Basin has historically acted as an evaporation basin for the spring runoff (DOI 1980).

Valley Floor Soils

The Butte Valley floor contains several soil orders: Ultisols in the middle of the Valley, Mollisols at the Valley edges, and Inceptisols and Vertisols west of Meiss Lake. The valley floor is further divided into several general soil units, which are broad areas that have a distinctive pattern of soils, relief, and drainage. While each soil subunit is a unique natural landscape, the general soil units can be used for general land uses and broad interpretive purposes (USDA 1994).

The Inlow-Ocho soil unit is centered in the Butte Valley National Grasslands and extends southwest to Meiss Lake and crosses U.S. Highway 97 towards Inlow Butte. It is a silt to very fine sandy loam that forms on lake terraces. The unit formed from lacustrine sediment and alluvium derived from volcanic ash and extrusive igneous rock. It is moderately deep to shallow, moderately well drained to somewhat poorly drained, with slopes of 0-2%. Below the subsoil is a hardpan at about 18-33 in (0.46–0.84 m) below the surface. Below the hardpan is loamy sand. Minor components of this soil include well-drained loamy Modoc soils, with a subsoil of loam and sandy clay loam, and shallow, poorly-drained Ocho Variant soils, with a subsoil of clay. The soil unit is mainly used as rangeland. Hazards of the Inlow soils include soil blowing and sodicity, while the Ocho soils have issues with sodicity, a shallow effective rooting depth, surface crusting, and ponding. Soil hazards limit the production of forage and make seeding unfeasible. The moderate hazard of soil blowing requires onsite investigation prior to mechanical treatment. The sodicity hazard is deemed unfeasible to overcome (USDA 1994).

The agricultural land in Butte Valley is predominantly underlaid by Mollisols. Mollisols on the north half of Butte Valley are characterized by the Modoc-Rojo soil unit. The soil unit forms on lake terraces and was created in alluvium and lacustrine sediment derived from extrusive igneous rock and material weathered from tuff and volcanic ash. The loamy soil is moderately deep, with slopes from nearly level to moderately sloping (0-9% slope). The surface layer is loam to sandy loam and the subsoil is loam, sandy clay loam or sandy loam. A hardpan or duripan lies roughly 28-34 in (0.71-0.86 m) below the surface. Below the hardpan is sand, weathered tuff, and volcanic ash. The soil unit also has minor components of the well-drained Dehill, Dotta, Mudco, and Truax soils and the moderately well-drained Medord, Doel, and Rangee Variant soils. Dehill, Dotta, Medford, and Traux soils are deep soils at higher elevations with no duripan. Mudco and Rangee Variant soils have a duripan within 20 in (0.51 m) of the surface. Doel soils have a surface layer underlain by sand. The Mullisol Modoc-Rojo soil unit is used for cultivated crops, hay and pasture, and rangeland. Hazards include soil blowing, hardpan depth, low available water capacity, and frost potential. The depth to volcanic tuff in the Rojo soils discourages ripping. A temporary water table above the hardpan can be prevented with good irrigation management (USDA 1994).

Agricultural activity in the southern half of Butte Valley is predominantly underlain by the soil unit Poman-Fordney, whose subunits are classified as either an Ultisol or Mollisol. This unit also surrounds Dorris. The sandy soils lie on alluvial plains and terraces and were formed from volcanic tuff and other kinds of extrusive igneous rock. It is moderately deep to very deep and nearly level to strongly sloping (0-15% slope). The surface layer is loamy sand. The substratum of the very deep, excessively drained Fordney soils is loamy sand. The moderately deep and somewhat excessively drained Poman soils have a subsoil of loamy sand above a duripan at about 29 in (0.74 m) below the surface. Underlying the duripan is sand. Minor components of the soil unit are the well-drained Dehill soils, the moderately well-drained Doel soils and the somewhat poorly-drained Podus and Poe soils. Dehill soils are sandy loams at higher elevations. Podus soils have a duripan at 10-20 in

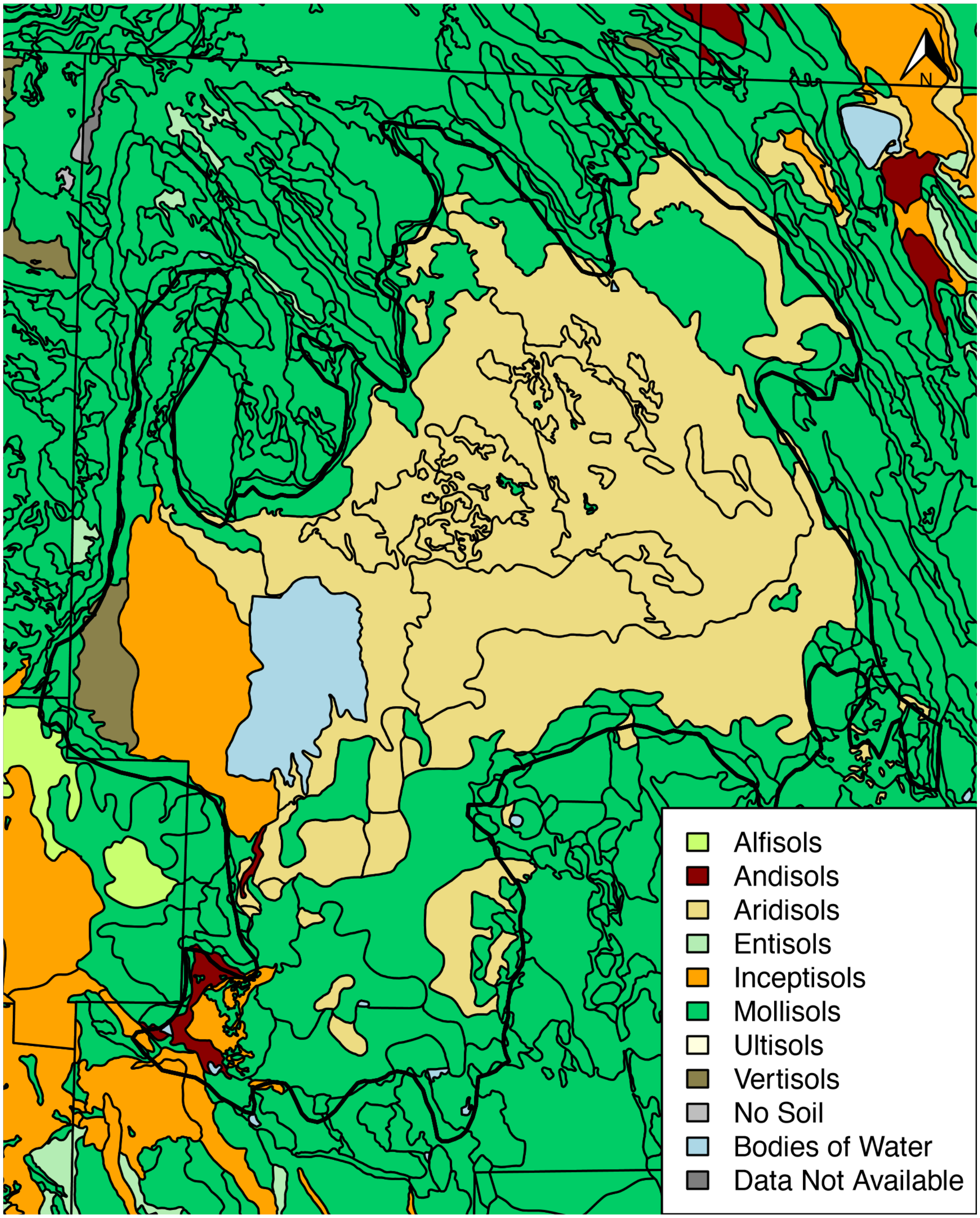


Figure 2.17: Soil classifications in Butte Valley

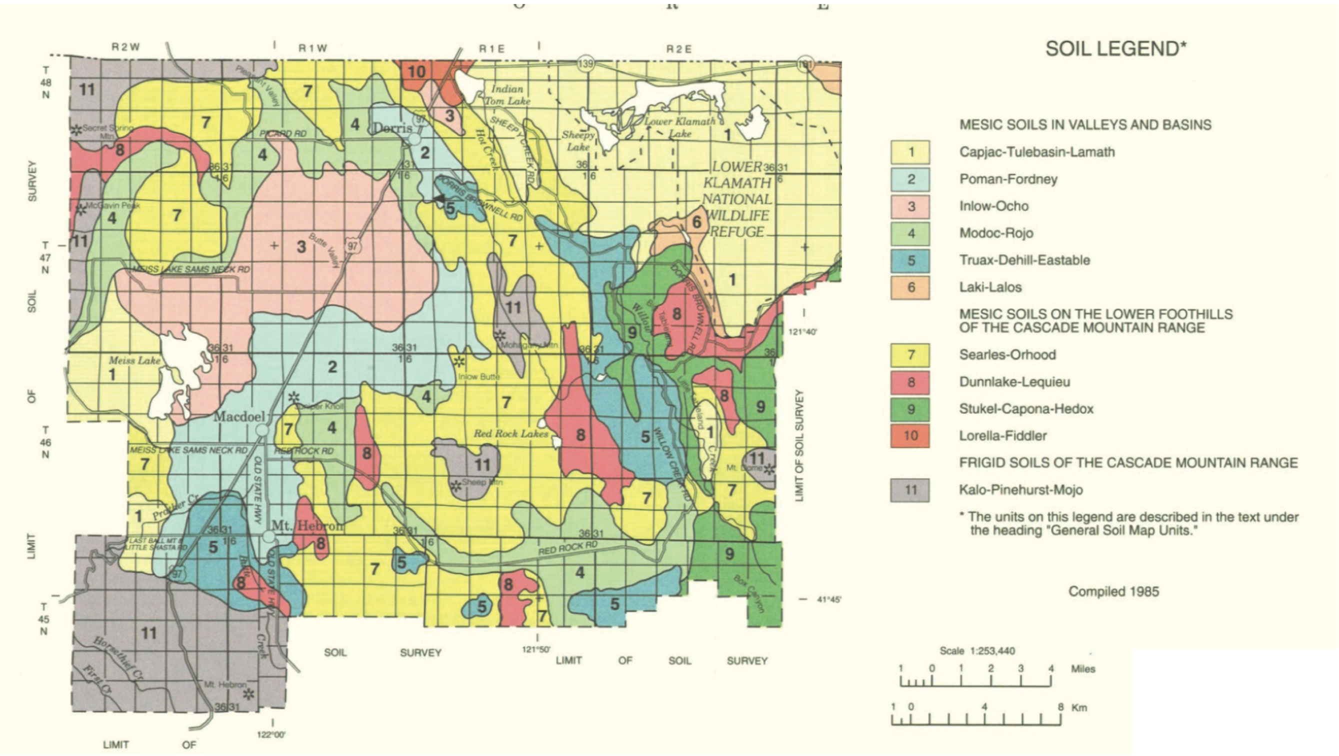


Figure 2.18: General Soil Map of Butte Valley from the 1994 USDA Soil Survey of the Butte ValleyTule Lake Area. Modified from the original 1994 USDA General Soil Map, included in Appendix 2-A.

(0.25-0.51 m) below the surface and have a high water table. Similarly, Poe soils, too, have a high water table, but with a duripan at 20-40 in (0.51-1.0 m) below the surface. The Poman-Fordney soil unit is used for cultivated crops, hay and pasture, rangeland, and home development. Issues include a rapid rate of water intake and low available water capacity. Hazards include soil blowing and a risk for frost (USDA 1994).

The Capjac-Tulebasin-Lamath soil unit has subunits that can be classified as an Inceptisol, Vertisol or Andisol. This loamy soil occurs in lake basins and forms from lacustrine sediment derived dominantly from diatomite, volcanic ash, and extrusive volcanic rock. The soil is very deep, nearly level (0 to 2% slope) and very poorly drained to poorly drained. The subunits in Butte Valley share further characteristics, where they are all very deep, artificially drained soil in lake basins, protected by dikes and levees, and have a water table controlled by pumping to deep lateral drains (USDA 1994).

The Vertisol subunit is a Pit silty clay, formed in poorly drained alluvium derived from extrusive igneous rock. Dikes and levees protect this soil from brief flooding from January through May (USDA 1994). The water table is maintained at a depth of 5-6 ft (1.5–1.8 m). It is a silty clay at 0-26 in depth, silty clay loam or clay loam at 26-31 in and silt loam at 26-31 in (0.66–0.79 m) (USDA 2020b). Permeability is low and available water capacity is high. The unit is used for cultivated crops such as wheat and barley, and rangeland. Soil issues include a high shrink-swell potential and a susceptibility to compaction (USDA 1994).

There are two pockets of Inceptisols on the eastern side of the Valley. The subunit west of Meiss Lake is a Teeters silt loam and the subunit south of Meiss Lake along Prather Creek is a Lamath silt loam. Both formed from poorly drained silty or lacustrine sediment derived from diatomite, volcanic

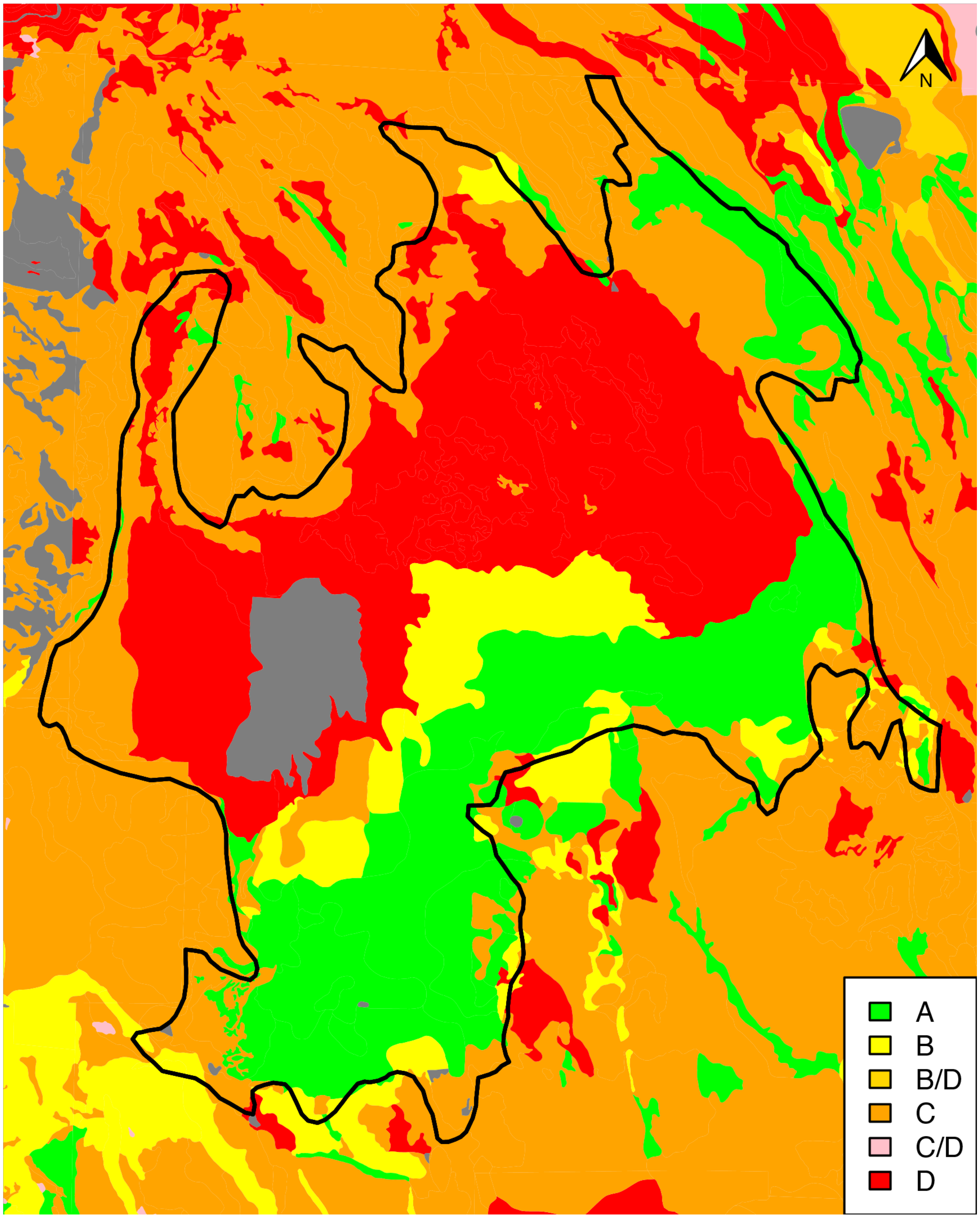


Figure 2.19: Hydrologic soil groups in Butte Valley, where Group A are soils with a high infiltration rate and low runoff potential to Group D with very slow infiltration rate and high runoff potential. Soils have two Groups if a portion is artificially drained and the rest undrained.

ash, and extrusive igneous rock. Dikes and levees protect the soil from brief flooding from March through May (USDA 1994). The water table is maintained at a depth of 1.5-4 ft (0.46-1.2 m). The soil is saline. The Teeters silt loam soil unit is silt loam, with some silt at 10-60 in (0.25-1.5 m) depth. The Lamath silt loam soil unit is silt loam at 0-21 in (0-0.53 m) depth, sand and loamy sand at 21-53 in (0.53-1.3 m) depth, and stratified sand to silt loam at 21-53 in (0.53–1.3 m) depth (USDA 2020b). The diatomite and volcanic ash origin of the soil creates a very high water capacity. Soil blowing is a moderate hazard when the surface layer is dry under high wind conditions. The soil is used for cultivated crops, hay and pasture and wildlife habitat (USDA 1994).

The Andisols are Capjac silt loam, formed in poorly drained lacustrine sediment derived from diatomite and volcanic ash. Dikes and levees protect this soil from rare flooding from October through May. The water table is maintained at a depth of 1.5-3.0 ft (0.46–0.91 m). The surface layer down to about 26 in (0.66 m) depth is silt loam and the substratum down to 60 in (1.5 m) or more is slightly saline silt loam. Permeability is moderate and frost is a hazard. The diatomite and volcanic ash origin of the soil creates a very high water capacity. Soil blowing is a moderate hazard when the surface layer is dry under high wind conditions. This soil is used for wildlife habitat, cultivated crops, and irrigated hay and pasture (USDA 1994).

Alluvial Fan Soils

From U.S. Highway 97 west of Mount Hebron to the southern valley rim below the highway and Mount Hebron is the Traux-Dehill-Eastable soil unit. It is a well drained, very deep, loamy soil that forms on alluvial fans, formed dominantly in alluvium derived from volcanic tuff and extrusive igneous rock. It is nearly level to strongly sloping, with slopes of 0-15%. Traux soils are predominantly sandy loam, with sandy clay loam subsoil. Dehill soils are fine sandy loam. Eastable soils are loams with a clay loam subsoil. Minor soil units are the well drained Dotta, Hedox, and Munnell soils and the moderately well-drained Leavers soil. The general sand unit is used for cultivated crops, irrigated hay and pasture, and rangeland. Soil hazards include soil blowing and frost (USDA 1994).

Soils of the Lower Foothills of the Cascade Mountain Range

The foothills bordering Butte Valley are dominated by the Mollisol Searles-Orhood soil unit. The well-drained soil forms on hills and mountains and formed in material weathered from extrusive igneous rock. The very stony or very cobbly loamy soil is moderately deep and shallow, and gently sloping to very steep (2-50% slope). The surface layer is a very stony or very cobbly loam. The upper part of the subsoil is very cobbly loam and the lower part is very cobbly clay loam and very cobbly loam. Extrusive ignous bedrock is about 16 or 28 in (0.41-0.71 m) deep. The soil unit has various minor components with variations on the main soils, such as a clayey subsoil, soils deeper than 60 in (1.5 m) deep or less than 10 in (0.25 m) deep. The soil unit also has instance of rock outcrops, with no soil cover, and areas of rubble, where 90% or more of the surface is covered by stones and boulders. The soil unit is used for rangeland and growth of western juniper. High surface slopes and general stoniness limits seeding, livestock access, and woodcutting (USDA 1994).

The Dunnlake-Lequieu soil unit occurs sparsely at the valley borders. The very stony loamy soils are shallow to very shallow, with slopes from 0-50%. The soil occurs on plateaus and mountain side slopes and formed from material weathered from extrusive igneous rock. Both Dunnlake and Lequieu soils have a very stony loam surface layer. Dunnlake soils have a clay loam upper subsoil and gravelly clay lower subsoil, with hard, extrusive igneous bedrock at about 16 in (0.41 m) depth. Lequieu soils have a 5 in (0.13 m) substratum of very cobbly loam and andesite bedrock at 8 in (0.20 m) depth. Due to the surface stoniness and depth to bedrock, the soil unit is used as rangeland (USDA 1994).

Soils of the Cascade Mountain Range

The edges of the Basin contain parts of the Kalo-Pinehurst-Mojo general unit. The stony to very stony loamy soil occurs on mountains and formed in material weathered from extrusive igneous rock. The soil is moderately deep to deep with slopes that are moderately sloping to steep (5-50% slope). The surface layer is very stony sandy loam, stony sandy loam or stony loam. The subsoil is very cobbly loam, very cobbly clay loam, gravelly loam, very stony loam, or clay loam. Extrusive igneous bedrock occurs between 27-55 in (0.69-1.4 m) depth. The soil unit is used as woodland, with some livestock grazing.

2.2.1.9 Surface Water Bodies

Surface water bodies in the Basin include Meiss Lake and spring-fed intermittent streams. Butte Creek is the largest stream in the Watershed. Spring-fed perennial streams include Ikes, Prather, Muskgrave, and Harris, which drain into Meiss Lake (DOI 1980). Seikel Creek is a tributary of Muskgrave Creek and its water is partially diverted to Juanita Lake by the USFS (Kit Novick 1996). Major surface water features are shown on Figure 2.1.

Historically, Mud Lake was a perennial lake residing southeast of Macdoel, with the aptly named Lakeview Cemetery on the east shore, but has recently become a small intermittent pond. Mud Lake was about 40 acres (0.16 sq km) in 1909, and was too alkaline for domestic or irrigation uses, but was used by cattle. A water body south of Cedar Point has historically been called Alkali or Soda Lake and occupied 600 to 700 acres (2.4 to 2.8 sq km) in 1909, but was deemed far too alkaline for domestic or irrigation use. The 1909 USDA Soil Survey observed a slight rise in the valley floor north of Macdoel towards Dorris, which separated Meiss Lake and Soda Lake (USDA 1909).

Outside the Basin, the Butte Valley Watershed includes three additional named streams and numerous small lakes and ponds. Antelope Creek was once a tributary of Butte Creek up until the eruption of the Butte Valley Basalt (King 1994). Spring-fed First and Horsethief Creeks are south of Ball Mountain. Intermittent surface water bodies in the high mountains of the southern watershed include: Duck Lake southwest of Haight Mountain, Surprise Lake on Ash Creek Butte;

Antelope Creek Lakes and Hemlock Lake near Rainbow Mountain; and Frog Lake on the valley floor northeast of Rainbow Mountain. Intermittent surface water bodies on the valley floor of the middle Watershed include: Antelope Sink north of Cedar Mountain; Orr Lake at the base of Orr Mountain; the unnamed pond west of Cedar Mountain formed by the Butte Creek spillway, Russell Lake in Red Rock Valley; and a large unnamed lake between Tennant and Butte Creek at 41.615389 north latitude, -122.008856 west longitude. Intermittent surface water bodies in the high elevations northwest of Mount Hebron include: Mud Lake where U.S. Highway 97 leaves the Butte Valley floor; and Pumpkinseed Lake northwest of Mount Hebron. Perennial surface water bodies include Mud Lake on Mud Lake Ridge, Juanita Lake near Ball Mountain, Red Rock Lakes east of Sheep Mountain, and Deyarmie Lake in Red Rock Valley.

Meiss Lake

Meiss Lake is a shallow, alkaline water body that lies on the west side of the Valley and is managed by CDFW in BVWA. BVWA and Meiss Lake are important for the Pacific Flyway and are a major migration and staging area for waterfowl, sandhill cranes, and other water birds (NCRWQCB 2008). Meiss Lake is a 4,000 acre (16.2 sq km) managed reservoir, with a maximum depth of six feet (Kit Novick 1996). Before the mid-1940s, Meiss Lake and adjacent wetlands covered about 10,000 acres (40.5 sq km) (NCRWQCB 2008). In 1909, the considerably deeper western half of Meiss Lake was 6 ft (1.8 m) deep, while the rest of the lake was only 2-3 ft (0.61-0.91 m) deep or less (USDA 1909). From the mid-1940s to 1981, Meiss Lake and adjacent wetlands were systematically diked, channeled, drained and converted to agricultural uses (NCRWQCB 2008). In the 1940s, a North-South dike was constructed to divide the lake in half and convert the western half into farmland. The eastern half of the lake was used as a reservoir to manage inflowing and outflowing water. In the winter, water from Muskgrave, Harris, and Ikes Creeks were diverted onto the fields to built soil moisture, then pumped into Meiss Lake in the spring for planting. As noted above, the lake bed on the eastern half is four feet higher than the former lake bed in the west. The farmland on the former lake bed has been periodically reflooded by Meiss Lake (Kit Novick 1996). By 1981, Meiss Lake its adjacent wetlands and tributaries had been substantially altered, lost or degraded from their pre-1940s state (NCRWQCB 2008). After BVWA was purchased by the State in 1981, the wetlands and tributaries are being managed and restored (Kit Novick 1996).

Meiss Lake is a closed basin and receives surface water from four spring-fed creeks and one canal. From the west flow Ikes, Harris, and Muskgrave Creeks and from the south flows Prather Creek. Estimated creek inflows are 15,000 to 20,000 acre-feet annually but are low or nonexistent in the summer and fall. The Irrigated District Canal delivers excess irrigation water to Meiss Lake from wells and summer runoff, though flows are normally very low. Seikel Creek, a tributary of Muskgrave Creek, is partially diverted by the USFS to Juanita Lake from April 30 to November 1. In the 1940s, dams were built at Juanita Lake to provide irrigation water to Meiss Ranch, the precursor of BVWA (Kit Novick 1996).

Historically, the size of Meiss Lake has varied. Commonly the lake nearly dries up by early fall (Kit Novick 1996). Meiss Lake typically goes completely dry every 15-20 years and was dry in 1955, 1965, 1981, 1987, 1988, 1990, 1991 and 1992 (County of Siskiyou 1996). Precipitation patterns have continued to fluctuate, with a wet period between 1993 to 1999 and dry cycle from 2000 to 2008 (2006 was very wet) [2009 BVWA Plan Addendum]. Meiss Lake went dry in 2000, 2001, 2002, 2003, 2004, 2005, 2007, and 2008 (K. Novick 2009). The hardpan and soil type at Meiss Lake create a large shallow impermeable basin subject to high evaporation rates (County of Siskiyou 1996). The pan evaporation rate for Butte Valley is estimated to be 48 in (1.2 m) per year, primarily driven by wind (Kit Novick 1996; County of Siskiyou 1996).

The water quality of Meiss Lake is heavily dependent on the season, where the quality is good during and shortly after the winter-spring runoff period then declines during the summer and fall as inflows cease and evaporation increases. During the summer and fall, electrical conductivity, pH, TDS, and alkalinity increase in value. For example, pH is roughly 7.4 in the spring and 10.1 in the fall. In general, the lake water has high turbidity due to the relatively shallow water (less than 6 ft) and is high in sodium bicarbonate. The high turbidity and alkalinity compared to the Klamath River restricts pumping of Meiss Lake water into the Klamath River after April 30. After July 1, BVWA does not use Meiss Lake water for crop irrigation or wetlands maintenance because alkalinity, pH, and electrical conductivity exceed safe levels for plant growth (Kit Novick 1996).

Evidenced by the hundreds of feet of lake sediment on the Butte Valley floor, paleolakes have occupied the Basin for at least hundreds of thousands of years. The flatness of the valley floor means small changes in Meiss Lake levels cause large changes in lateral lake size. Two Holocene (0.012 Ma to Present) shorelines can be distinguished via aerial photography interpretation of soil and vegetation and archaeological evidence. The prehistoric Meiss Lake at its maximum had its shoreline at the 4,236 ft (1,291 m) amsl elevation contour, covering an area of 11.6 sq mi (30 sq km) at a depth of 10 ft (3 m). The historic high level for Meiss Lake is 4,232 ft (1,290 m) amsl, which is marked by a change in vegetation. The current Meiss Lake shoreline is at 4229 ft (1,289 m) amsl. Above the prehistoric 4,236 ft (1,291 m) amsl shoreline, vegetation is marked by scrub vegetation similar to that growing on Quaternary lake deposits on the valley floor. Between the historic 4,232 ft (1,290 m) amsl shoreline and prehistoric 4,236 ft (1,291 m) amsl shoreline, the vegetation is marked by grasses and scattered scrub. Between the current lake shoreline and the historic 4,232 ft (1,290 m) amsl shoreline, the area is covered with grasses (King 1994).

Meiss Lake was likely below the 4,232 ft (1,290 m) amsl shoreline for most of the Holocene due to the well-defined soil profile between 4,232 ft (1290 m) and 4,239 ft (1292 m) amsl called the Pit Series, which suggests that the area has not been underwater for an extended time. Soils in the historically drained Meiss Lake bed are classified as the Teeters Series and are less developed then the Pit Series. Additionally, the Teeters Series soil is only 24 in (0.61 m) deep compared to the 40 in (1 m) deep Pit Series (King 1994).

Along the old Meiss Lake shorelines there is evidence of prehistoric human habitation. Prehistoric habitations on the eastern shore are dated from 6,640 to 565 years before present along both the 4,236 ft (1,291 m) and 4,232 ft (1,290 m) amsl shorelines. Additional prehistoric habitations along the west shore range from 9,000 to 1,400 years before present between 4229 ft (1,289 m) and 4,232 ft (1,290 m) amsl elevation. The variation of elevations of the prehistoric habitations suggest that the prehistoric Meiss Lake was not dry for long periods of time and had at least some water through most of the Holocene (King 1994).

In December 1964, Meiss Lake flooded to an area of 16 sq mi (10,500 acres; 42.5 sq km), which coincides with the 4,234 ft (1,291 m) amsl elevation contour including its former lake bed and adjacent farms (County of Siskiyou 1996). The County declared the Butte Valley flood a Major Disaster (USACE) and requested emergency relief from the federal government (County of Siskiyou 2017). In early 1965, the U.S. Army Corps of Engineers constructed the Sam's Neck Flood Control Facility, a drainage canal to pump excess floodwater to the Klamath River (NCRWQCB 2008; County of Siskiyou 2017). The drainage canal consists of an outlet from Meiss Lake that travels up Sam's Neck, where a pump lifts water 21 ft (6.4 m) from the valley floor to Rock Creek and ultimately to the Klamath River in Oregon (Kit Novick 1996; County of Siskiyou 2017). Rock Creek is outside the Butte Valley watershed and is a tributary of the Klamath River. By July 12, 1966, USACE was still pumping down Meiss Lake (County of Siskiyou 2017).

Management for the Sam's Neck Flood Control Facility has changed hands several times since its creation. The lift pumps require a contract for electricity and the facility requires maintenance. After completion of the project, USACE payed for one year's worth of power before turning over responsibility to the County. The County never expected to fund the project with taxpayer dollars and intended to hand over responsibility to the direct beneficiaries of the flood control project, originally BVID. BVID did not take over the project and the County authorized a local company to operate one of the lift pumps, with the condition that the company pay for all electric power bills and accept all liability. Months later the Pacific Power and Light Company requested that the County submit payment for a power bill associated with the pumps. After agreeing to pay the power bill, the County Board of Supervisors advised that the County would not be responsible for any further power bills from the pumping facilities thereafter. The Board of Supervisors also discussed that those benefiting from the flood control facility should pay for the power costs of the project or the power transformers should be removed. In the fall of 1967, the Board of Supervisors authorized the Meiss Ranch Company to operate the Flood Control Facility and soon after approved the arrangement between Meiss Ranch and Pacific Power and Light Company on a rolling year-to-year basis. From 1968 to mid-1985, the Flood Control Facility pumped excess floodwater from Meiss Lake at no cost to the County. Meiss Ranch may have made an agreement with BVID for operation of the pumps at the Ranch's expense (County of Siskiyou 2017).

Estimated yearly water volumes pumped from Meiss Lake are shown in Table 2.4. Sam's Neck Flood Control Facility usually only operated from January to April. Public opposition restricted operation of the facility after April due to the impact of the poor lake water quality (turbid and alkaline) on the Klamath River fishery (Kit Novick 1996).

In 1981, Meiss Ranch was purchased by the California Department of Fish and Game (currently CDFW), and the land was designated as the Butte Valley Wildlife Area (BVWA). The Department initially operated and paid for the Flood Control Facility pumps until 1985. The Department notified the County of releasing its operational and monetary responsibility for operating and maintaining the Sam's Neck Canal pumps. The Department outlined its long-term goal of utilizing all surplus water to create wetland habitat, which might eliminate the need for the Flood Control Facility. In 2017, the County submitted a request to the USACE that Sam's Neck Flood Control Facility be abandoned (County of Siskiyou 2017).

Table 2.4: Estimated Volume of Water Pumped From Meiss Lake to The Klamath River (BVWA 1996).

Year	Acre-Feet	Year	Acre-Feet
1968	638	1982	8,930
1969	585	1983	12,456
1970	10,064	1984	7,708
1971	12,545	1985	4,182
1972	14,582	1986	2,271
1973	89	1987	0
1974	9,674	1988	0
1975	4,164	1989	0
1976	142	1990	0
1977	89	1991	0
1978	4,571	1992	0
1979	213	1993	0
1980	4,363	1994	0
1981	0		

Butte Creek

Butte Creek is the largest stream in Butte Valley, with headwaters between the Whaleback and Haight Mountains at the southern end of the Watershed (Figure 2.8) (King 1994). Butte Creek historically flowed into Meiss Lake, but has been diverted for agricultural irrigation and spreading grounds for groundwater recharge (DOI 1980; Kit Novick 1996). Butte Creek has been sufficiently appropriated and diverted so that flows terminate near the town of Macdoel (Wood 1960). At normal flows, surplus water after irrigation is diverted into a lava crack or allowed to percolate into porous lava and alluvial deposits for groundwater recharge. Flood flows are diverted into Dry Lake / Cedar Lake to recharge the Butte Valley Basalt water bearing formation, and does not reach Meiss Lake (Kit Novick 1996; County of Siskiyou 1996).

In 1909, while supplying irrigation water for several hundred acres of alfalfa, timothy, clover, and grain crops, Butte Creek disappeared underground at the valley edge and flows to Meiss Lake via groundwater (USDA 1909). All surface evidence of the lower Butte Creek channel, from the Valley edge to Meiss Lake, has been destroyed by cultivation (King 1994).

Prather, Ikes, Harris, and Muskgrave Creeks

Prather, Ikes, Harris, and Muskgrave Creeks are spring-fed creeks that drain into Meiss Lake. Seikel Creek and Juanita Lake are tributary to Muskgrave Creek. Water from these creeks have excellent mineral quality, are soft with a calcium-magnesium bicarbonate character, and very low in chloride and sulfate (Kit Novick 1996). Springs from the High Cascade Volcanics water bearing formation provide perennial flows for four creeks, but flows vary seasonally (County of Siskiyou 1996). Historically, Harris and Ikes Creeks flowed all year but very low during the summer months.

In recent years, Harris, Ikes, and Muskgrave Creeks all dry up in the summer and fall. Upstream of BVWA, Prather Creek is diverted for agriculture and summer flows to Meiss Lake are very low to nonexistent. All four creeks are capable of intense flooding in a short period of time and all floodwater flows into and is managed by BVWA (Kit Novick 1996). CDFW is the 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 are 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. Water conservation efforts include drainage and reuse between land units for moist-soil management for waterfowl food plants. 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 (SWRCB 2020).

2.2.2 ~~Current and~~ Historical and Current Groundwater Conditions

2.2.2.1 General Groundwater Flow Conditions of Butte Valley – Overview

The major water-bearing formations within the Butte Valley groundwater Basin are Lake Deposits, Butte Valley Basalt, and High Cascade Volcanics. Other formations include Alluvial Fan Deposits and Pyroclastic Rocks (DWR 1998; DWR 2004, see Section 2.2.1.6 for further detail). The boundaries of the Basin mostly coincide with the margins of the topographically flat region formed by pleistocene occurrences of a larger Meiss Lake and associated occurrence of thick, unconsolidated ~~L~~lake ~~D~~deposits, bounded by the escarpments of volcanic uplands of the High Cascade volcanics along block fault lines on the eastern, northern, and western Basin boundary, and by recent (Quaternary) volcanic basalt flows on the southern boundary. Unlike most California alluvial/sedimentary basins, this Basin is not isolated from the groundwater flow system of the surrounding mountain ranges and uplands, which consist largely of variably permeable volcanic rocks of the High Cascade unit. Highly permeable horizontal contact zones between volcanic flows, vertical shrinkage cracks or joints, and sometimes ~~lava~~ horizontal flow channels created during cooling of magma are conducive to significant groundwater flow through these volcanic rocks. Hydrogeologically, the Basin is a subbasin of the larger groundwater flow system within the volcanic landscape of the Upper Klamath Basin and the adjacent Modoc Plateau (Wood 1960, Gannett et al., 2010, USGS SIR 2007-5050, Gannett et al., 2012, see Figures XX1 – XX3).

Near Butte Valley, ~~T~~the groundwater flow boundaries of the~~is~~ larger 8000 square-mile (5 million acres) Upper Klamath Basin (UKB) groundwater flow system roughly coincide with the watershed boundaries of Butte Valley to the south, which may coincide with a groundwater divide, and the much older, highly degraded volcanic rocks of the Western Cascades, which form a very low permeable boundary of the groundwater flow system against Shasta Valley and the Klamath River Canyon to the west of Butte Valley. To the north and east, the larger regional groundwater flow system extends beyond the Mahogany Mountain r~~R~~idge into the Lower Klamath Lake basin, the Tule Lake basin, and the watersheds of the Lost River and Upper Klamath River. Gannett et al., 2010, identified the eastern boundary of the larger UKB groundwater flow system as the older, low permeable volcanic rocks along the eastern watershed boundary of the UKB. The northern boundary was identified as a potentially permeable groundwater divide coinciding~~).~~ with the northern UKB watershed boundary. The southern boundary of the regional groundwater system is a permeable groundwater divide ~~at or~~ north of the UKB watershed boundary against the Pit River watershed. Prior to groundwater development the groundwater divide may have been as far north as Tule Lake, possibly draining Tule Lake toward the Pit River to the south (Gannett et al., 2010).

Groundwater flows from sources of recharge toward places of groundwater discharge. Across the UKB south of the Klamath and Lost Rivers (which includes the Basin),~~,~~ most recharge occurs at the higher elevations of the volcanic uplands north of Mount Shasta and Medicine Lake Volcano (south and southeast of the Basin) and west of the Basin. Upland recharge from precipitation has been estimated to be 20% of precipitation, on average, across the UKB (Gannett et al., 2010), but is highly variable. The highest fraction of recharge, relative to ~~from~~ precipitation, occurs at higher elevations where precipitation is also larger.

From those areas of recharge, groundwater flows north and east toward the topographic and water table low points of the southern UKB, discharging into the Klamath River/Lower Klamath Lake, Lost River, and Tule Lake sink (Wood 1960, Gannett et al, 2010) and also supporting ~~surrounding~~ wetlands around those surface water features. The elevations of these regional low drainage points of the UKB groundwater system are at 4082 ft amsl in the Lower Klamath National Wildlife Refuge (Lower Klamath Lake) and at 4037 ft amsl along the Lost River at the California-Oregon border. Groundwater levels in the Tule Lake Basin and on the adjacent Oregon side may be below 4000 ft amsl due to irrigation pumping in those regions, particularly since 2001. Prior to modern groundwater development, Meiss Lake, at 4230 ft in the southwest area of the Basin, and vegetation in surrounding wetlands may have been subregional groundwater discharge points, as indicated by nearby flowing wells (Wood, 1960).

Gannett et al. (2010) estimated average precipitation in the 8000 square-mile (5 million acre) UKB to be 10 MAF, of which 2 MAF become groundwater recharge. Groundwater discharge into streams of the UKB was estimated to be 1.8 MAF. Discharge to groundwater pumping across the entire UKB, under pre-2001 pumping conditions, was estimated to be 0.2 MAF. Surface outflows from the UKB, in the Klamath River, average 1.5 MAF.

Consumptive agricultural water use (ET) within the UKB was estimated to 0.68 MAF on the Oregon side and 0.07 MAF on the California side. Evapotranspiration from major wetlands was estimated to be 0.22 MAF for Tule Lake and Klamath Wildlife Refuge (not including open water) and 0.46 MAF for Oregon major wetlands (around Upper Klamath Lake, Klamath marsh). Most of these wetland's consumptive use is fed by surface water, which, in return, depends on groundwater discharge for a significant fraction of the total surface water flow.

The broader hydrologic context of the UKB provides the framework for understanding groundwater flow in the Basin (Butte Valley). Importantly, unlike m~~M~~ost other California basins that are topographically bounded by surrounding mountains, the Butte Valley Basin, due to its geologic position within the High Cascade volcanics, receives minimal measurable surface water inflows from its surrounding mountain ranges. Instead, precipitation over the volcanic uplands to the south and west of the Basin readily infiltrates into relatively permeable upland soils, recharging into the underlying High Cascades volcanic aquifer system. Runoff and baseflow feed a few streams to the south of the Basin. However, most streamflow recharges back into underlying highly permeable quaternary basalts before reaching the Basin's southern and western groundwater inflow boundary. Four creeks flowing into Meiss Lake are the main exception.

A potential estimate of "recharge" from subsurface inflow into the Basin is obtained by considering the reported runoff in Antelope Creek, draining an area of about 18.6 square miles, with an annual runoff of approximately 23,000 AF (or 1,200 AF per square mile drainage area). All of its flow recharges groundwater at Antelope Sink south of Cedar Mountain. Butte Creek, which has a drainage area of 178 square miles, has an estimated runoff of 13,000 AF per year before percolating into lava tubes just south of the Basin boundary (70 AF per square mile drainage area). Precipitation and vegetation in the Butte Creek and Antelope Creek drainage areas are comparable. Assuming that the difference in runoff per unit drainage area is due to larger groundwater recharge in the Butte Creek drainage area, total groundwater recharge within the Butte Creek drainage area is at least 178 sq,miles x 1200 AF/sq.mile drainage area or 214 TAF per year (including the 13 TAF/yr recharging at the southern Basin boundary). The total recharge of 237 TAF/yr is a lower bookend for groundwater recharge in these two drainage areas. Additional groundwater recharge likely occurs in both Butte Creek and Antelope Creek drainage areas, but never returns to runoff in either creek (DWR, 1973).

The drainage area of Meiss Lake features Prather, Ikes, Harris, and Muskgrave Creek is 29 square miles, had an estimated runoff of 15-20 TAF/yr in the 1970s, some of which recharges groundwater, some of which flows into Meiss Lake (DWR 1973). Again assuming that at least 1,200 AF/sq.mile is available for recharge or runoff, an additional 20 – 25 TAF/yr of recharge occur within the Meiss Lake drainage areas, at a minimum.

Precipitation over the Basin itself provides a small amount of direct recharge into the Basin groundwater system (also see Section 2.2.1.7). Irrigation return flows and the occasional flooding provide additional recharge within the Basin. Hence, most groundwater "recharge" to the Basin is groundwater inflow along its southern and western boundaries.

Groundwater outflow from the Basin includes groundwater pumping (for consumptive crop water use) and ~~as~~ subsurface outflow into the fractured volcanic rocks of the Mahogany Mountain ridge at the eastern and northeastern boundary of the basin. The subsurface outflow eventually discharges toward the outflow points of the larger regional groundwater flow system (Klamath and Lost River baseflow and into surrounding wetland GDEs). No gaining stream reaches exist within the Basin. The major surface water feature of the Basin, Meiss Lake, sits atop a low permeable clay layer and is fed by streams and groundwater pumping.

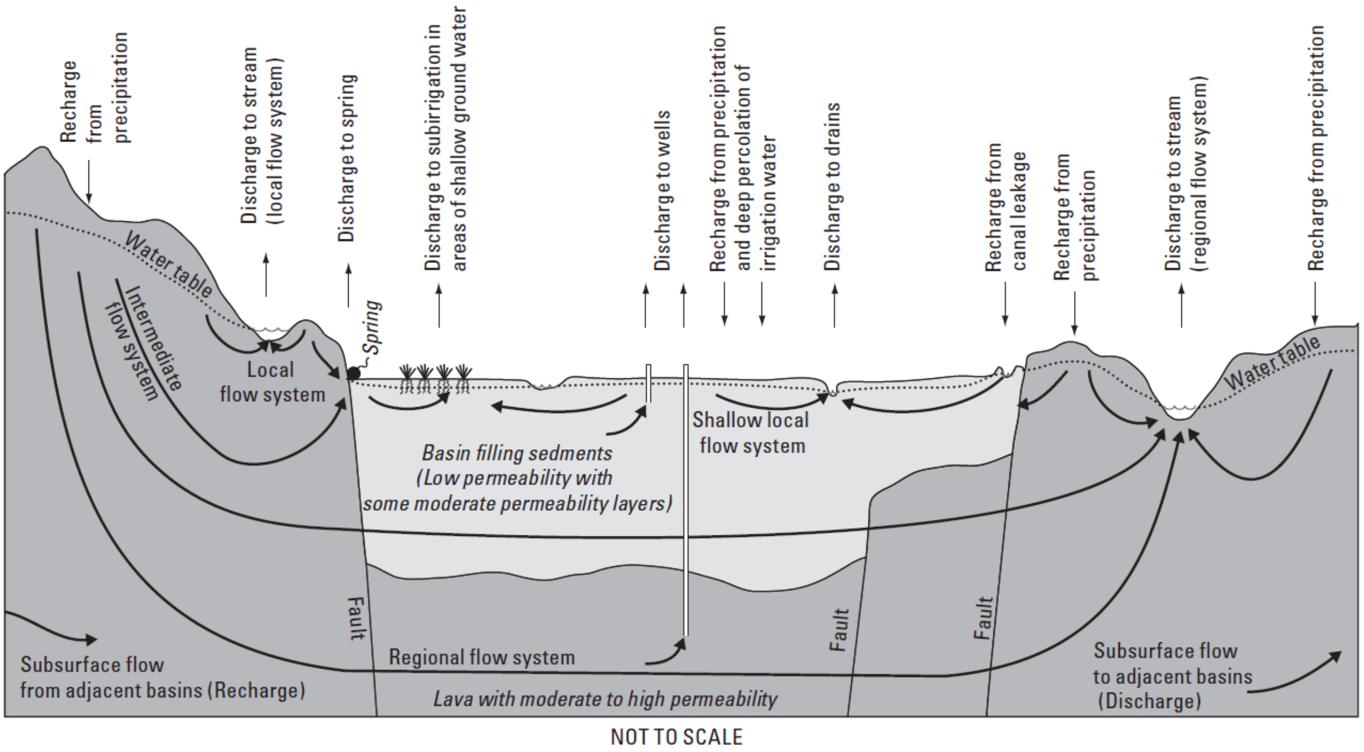


Figure XX1 (*from Gannett et al., 2010*): Schematic representation of sources of ground-water recharge, flow paths, and mechanisms of ground-water discharge in the upper Klamath Basin, Oregon and California.

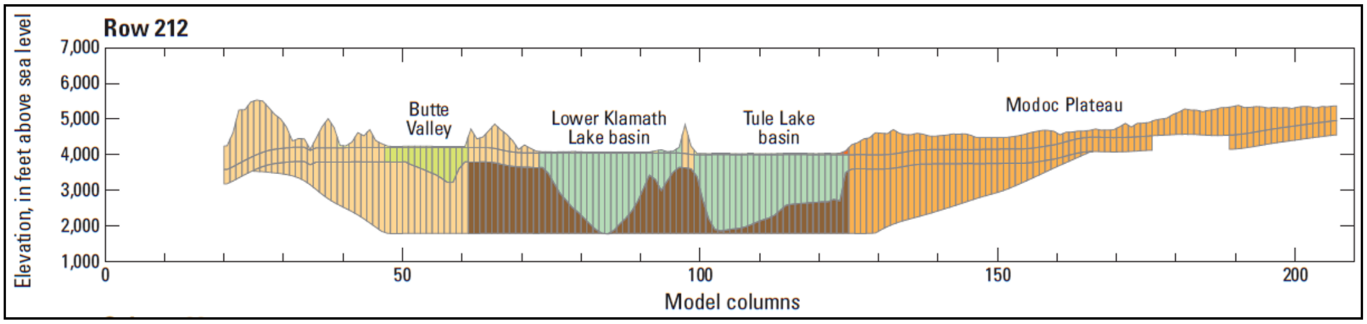


Figure XX2 (*from Gannett et al., 2012*): Simplified conceptual geologic west-east cross-section through the southern Upper Klamath Basin (UKB), as implemented in a USGS MODFLOW model of the UKB. The Butte Valley sedimentary groundwater basin is shown in light green, the sedimentary groundwater basins of the Lower Klamath Lake basin and Tule Lake basin are shown in dark green, mixed tertiary sedimentary and volcanic deposits in dark brown, and western and eastern tertiary volcanic deposits in beige and orange, respectively.

~~Butte Valley~~

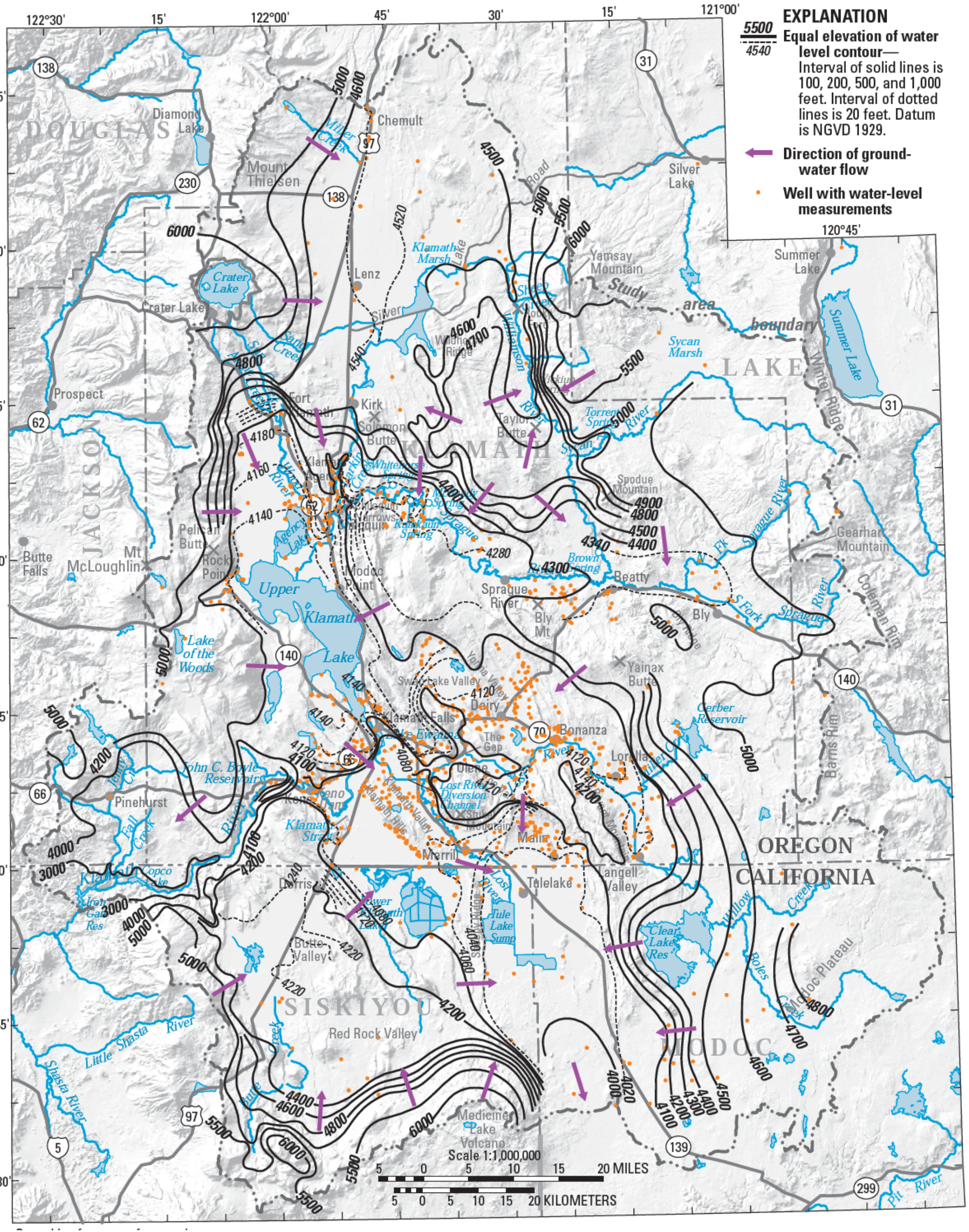


Figure XX3 (*from Gannet et al., 2010*): Generalized water-level contours and approximate directions of regional groundwater flow in the Upper Klamath Basin (UKB), Oregon and California. The Butte Valley groundwater basin ("Basin") is located in the southwest corner of the UKB. Major recharge areas are located in volcanic uplands to west, south,

and southeast of the Basin. Groundwater flows through the Basin to the east and northeast. Hydrogeologically, the Basin is a sub-basin of the larger volcanic-sedimentary UKB groundwater system.

2.2.2.2 Development of Groundwater Resources

Butte Valley is predominantly agricultural and development of groundwater as a major source of irrigation was critical for settlement in the Basin. Beginning in 1852, immigrant trains on the Yreka Trail reached Yreka in Shasta Valley by passing through Butte Valley. 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 (Kit Novick 1996). In 1862, Butte Valley had some ranching activity and the west side of the Valley was harvested for natural grass hay. In 1876, field crops grown along Butte Creek included timothy, red top, oats for hay, wheat and barley. 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. 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. BVID drilled the first irrigation well in 1929 and has continued to drill groundwater wells as surface water resources have decreased. 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. 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 (Kit 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), 1970 had 27,700 irrigated acres (DWR 1973), 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 AF (total irrigation: 29,100 AF on 10,400 acres, Wood, 1960) to 62,000 AF to 81,000 AF (on 45,000 acres, DWR 1998) (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). 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. 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~~3 Groundwater Elevation

Overview

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 100 feet (3~~0.5~~0 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 (15 m) bgs at the town of Macdoel near the south edge of the Basin (see below). The central and north~~-~~west portion of the Basin is still largely undeveloped with relatively shallow water levels between ~~3.5 and 12 meters (~~10 and 40 feet (3.5 and 12 meters) 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 Basin (Figure 2.20). Wells that tap into the Lake Deposits are situated within the Basin 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 Basin. In 1907 Butte Valley had a shallow water table with groundwater depths between 1 to 10 ft (0.3 to 3 m) bgs but was typically at 4 to 6 ft (1.2 to 1.8 m) depth (USDA 1909~~). ~~, French 1915).

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. Butte Creek was observed to quickly sink underground soon after entering Butte 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 Basin. 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. 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 (Figure 2.20). Groundwater flow was eastward and northeastward across the Basin 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 vertical permeability at the northeastern and eastern margin of the lake deposits, where groundwater flows into the High Cascade volcanics of the Mahogany Mountain ridge. Groundwater discharged northeastward and eastward from the Basin ~~may have~~ moved~~d~~ through the fractured volcanic rocks in the Mahogany Mountain ridge or along fault zones toward Lower Klamath Lake and areas to the east (Wood 1960).

In 1954, the groundwater gradient southwest of Mount Hebron was about 20 feet per mile northeastward (Figure 2.20). 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, at the margin of the Basin (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 2.20). 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 Basin (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 2.9. 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 2.9. 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 2.21, 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 2.21 and Figure 2.22). The 2014-2015 water year is the most recent year in Butte Valley with above average annual precipitation, at 9.96 inches Figure 2.9. 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.

Hydrographs

Groundwater levels were relatively stable throughout the Basin during the 1950s, 1960s, and 1970s, where long-term records are available (WSE418994N1219**643**W, WSE418994N1220**269**W, 418512N1219**183**W, WSE417944N1220**350**W, WSE 417920N1220**617**W~~417789N1220**759**W~~). Groundwater pumping and extended drought periods from the mid-1940s to 1950s, late 1980s to mid-1990s (DWR 1998), and frequently since 2001 (only 8 of 23 years above normal or wet, **Figure 2.9**) are major drivers of long-term variations in water levels.

Well “643” is located along Hwy 97, at the eastern edge of the Butte Valley National Grasslands. Water levels in the early 1950s were measured at 12 ft to 16 ft bgs (4222 ft amsl). Water levels rose to less than 10 ft bgs during most of the 1970s. Since 1990, water levels have steadily declined to 23’ bgs in 2023 (4214 ft amsl), slightly recovering in 2024.

Well “269” is located 3.3 miles to the west of well “643”, in the central-west portion of the National Grasslands. Water levels in the early 1950s were measured at 13 ft to 14 ft depth (4228 ft amsL), gradually rose to 1.6 ft bgs in 1975, declined to 10 ft bgs in 1995, rose to 4.5 ft bgs by 1999, and since gradually declined to 15 ft in 2024 (4226 ft amsl), exceeding historical low levels of the early 1950s since 2021.

Well “183” is located 3.8 miles due southeast of well “643”, in the eastern-central agricultural area of Butte Valley, east-northeast of Macdoel. Water levels in the early 1950s were at 22 ft bgs (4224 ft amsl) and rose to less than 20 ft bgs during the late 1950s. Spring water levels remained near 20 ft bgs through the mid-1970s (1975: 17.5 ft bgs), then declined into the early 1980s, and again during the late 1980s and early 1990s. Recovery of spring water levels reached 24 ft bgs in spring 1984, 32 ft bgs in spring 2000, and has gradually declined since then (spring 2021: 53 ft bgs, 4193 ft amsl).

Well “350” is located along Hwy 97, 2.8 miles southwest of the town of Macdoel. Spring water levels in the early 1950s were 31 ft bgs (4229 ft amsl) and rose to 23 ft bgs by the late 1950s and again in 1975. No records exist for the 1980, but spring water levels had declined to 50 ft bgs by 1993, recovering to 35 ft bgs in 2000. Since then, spring water levels have steadily declined, reaching 71 ft (~~4260~~4189 ft amsl) in spring 2024 (with an unusual albeit brief recovery during 2022 and 2023).

Well “~~759~~617” is located 1.5~~2.4~~ miles ~~south~~to the west of well “350”, at the western margin of the irrigated area. Spring water levels in the early 1950s were at 23 ft bgs (4236 ft amsl)~~.~~ and rose slightly to 20 ft bgs by the late 1950s. No measurements exist for the 1960s and 1970s, but spring water levels were at 20 ft bgs in the late 1970s, reached a high of 17.5 ft bgs in the mid-1980s. After declining in the early 1990s to 41 ft bgs (spring 1995), recovery in the late 1990s reached 21.5 ft in spring 1999. After 2000, spring water levels have been steadily declining, with a recovery to 30’ bgs in spring of 2015, reaching a low of 45 ft bgs in spring 2024.

Wells with more recent measurements (since the late 1970s) also show declines in water levels during early 1980s (recovery by mid-1980s), a more significant decline in water levels during drought of the late 1980s and early 1990s with recovery during the wet years of the late 1990s and a general decline since 2000 with sometimes brief recoveries around 2012 and in the late 2010s or around 2020.

Wells near the northern and northeastern margin of the basin have exhibited relatively stable conditions over the past ten years after significant declines post-2000:

WSE419451N1218967W, located near the northeastern boundary of the basin, 1.7 miles southeast of Dorris, had gradually declined from 89 ft bgs in spring of 2000 (4165 ft amsl) to 113 ft bgs (4141 ft amsl) in spring of 2015, but has since stabilized between 100 and 108 ft bgs.

WSE419803N1219570W, located 2.3 miles northeast of Dorris, declined from 62 ft bgs (4201 ft amsl) in spring 2000 to 96 ft bgs (4166 ft amsl) in spring 2013 and has since stayed above that level.

WSE419755N1219785W, 3.3 miles west of Dorris, declined from 42 ft bgs (4217 ft amsl) in spring 2000 to 65 ft bgs (4194 ft amsl) by spring 2017, dropped to 86 ft bgs in 2020 and recovered to 70 ft bgs (4189 ft amsl) since then.

~~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). The average depth to groundwater in the confined system was 33 ft (10.1 m) with a range of 9-83 ft (2.7-25.3 m) (DOI 1980). Groundwater elevations during the 1980-1981 drought were low enough that BVID had 14 out of 28 wells either dry or surging. 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 2.23.

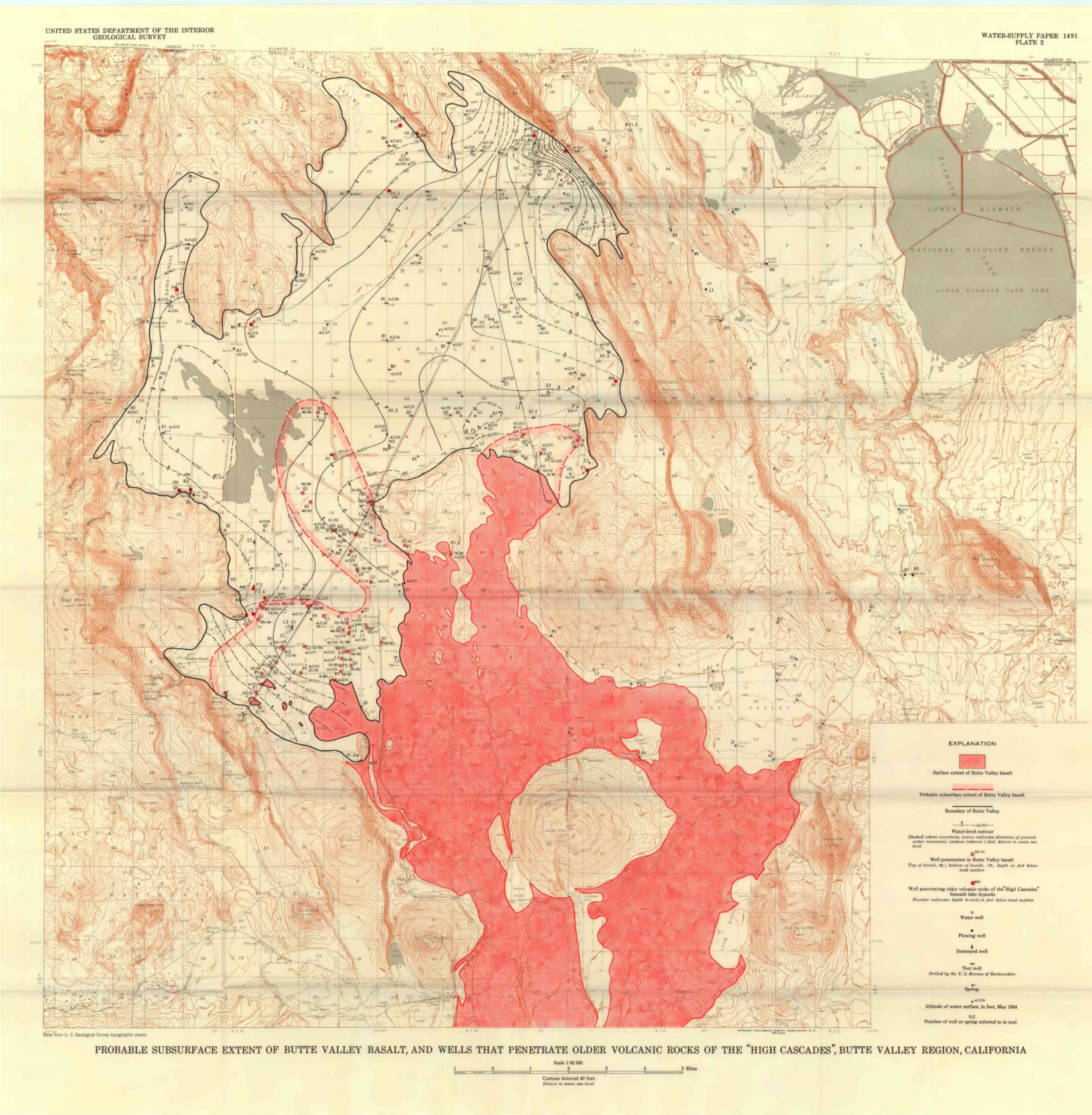
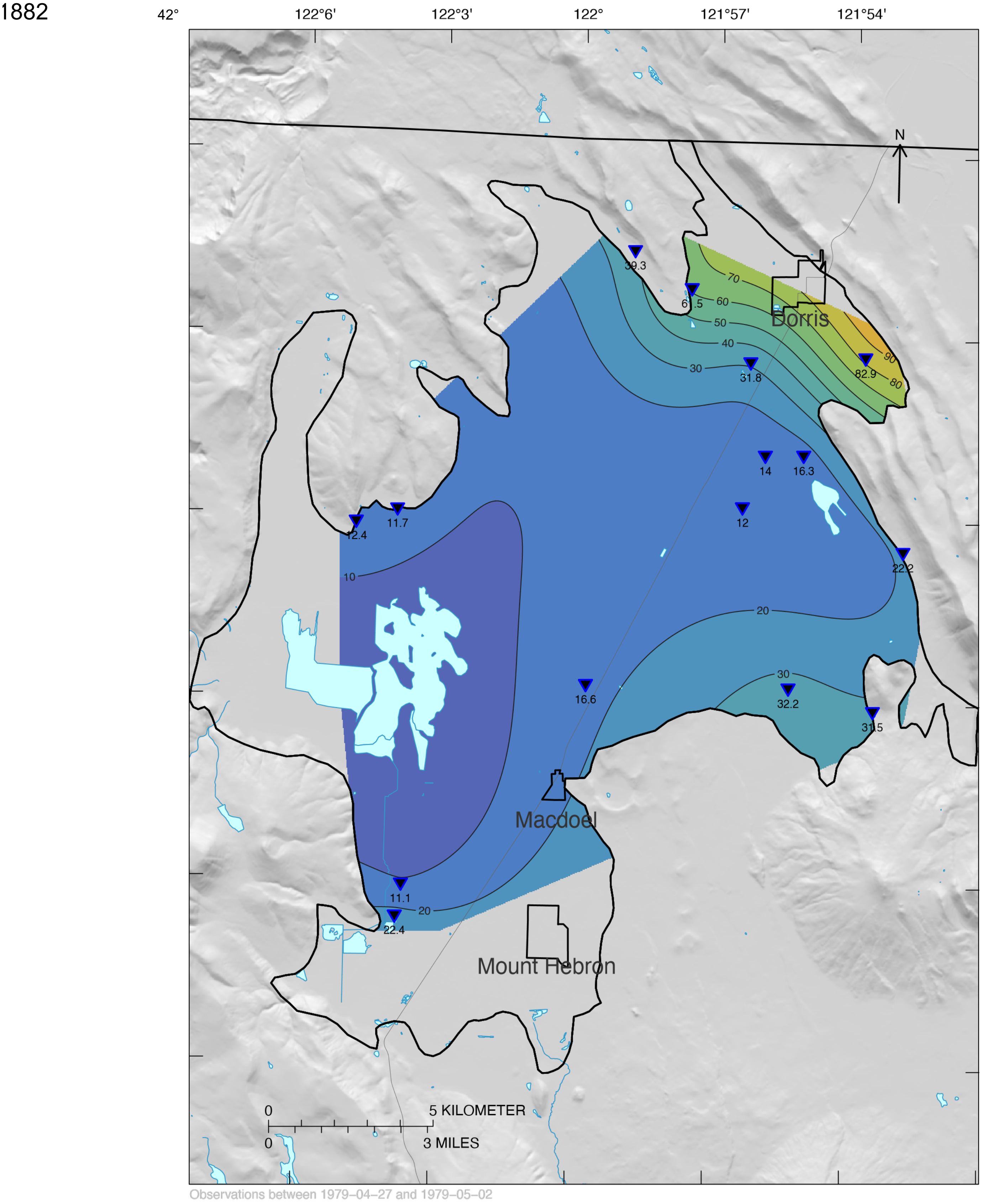


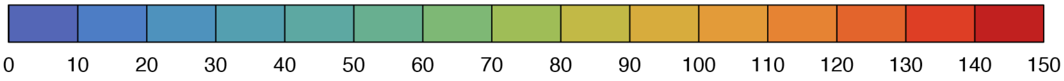
Figure 2.20: Groundwater elevations and flow based on observations during the first week of May 1954 (Wood 1960). The image is high quality so text can be distinguished when zoomed in.

1882



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

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



41° 57'

41° 54'

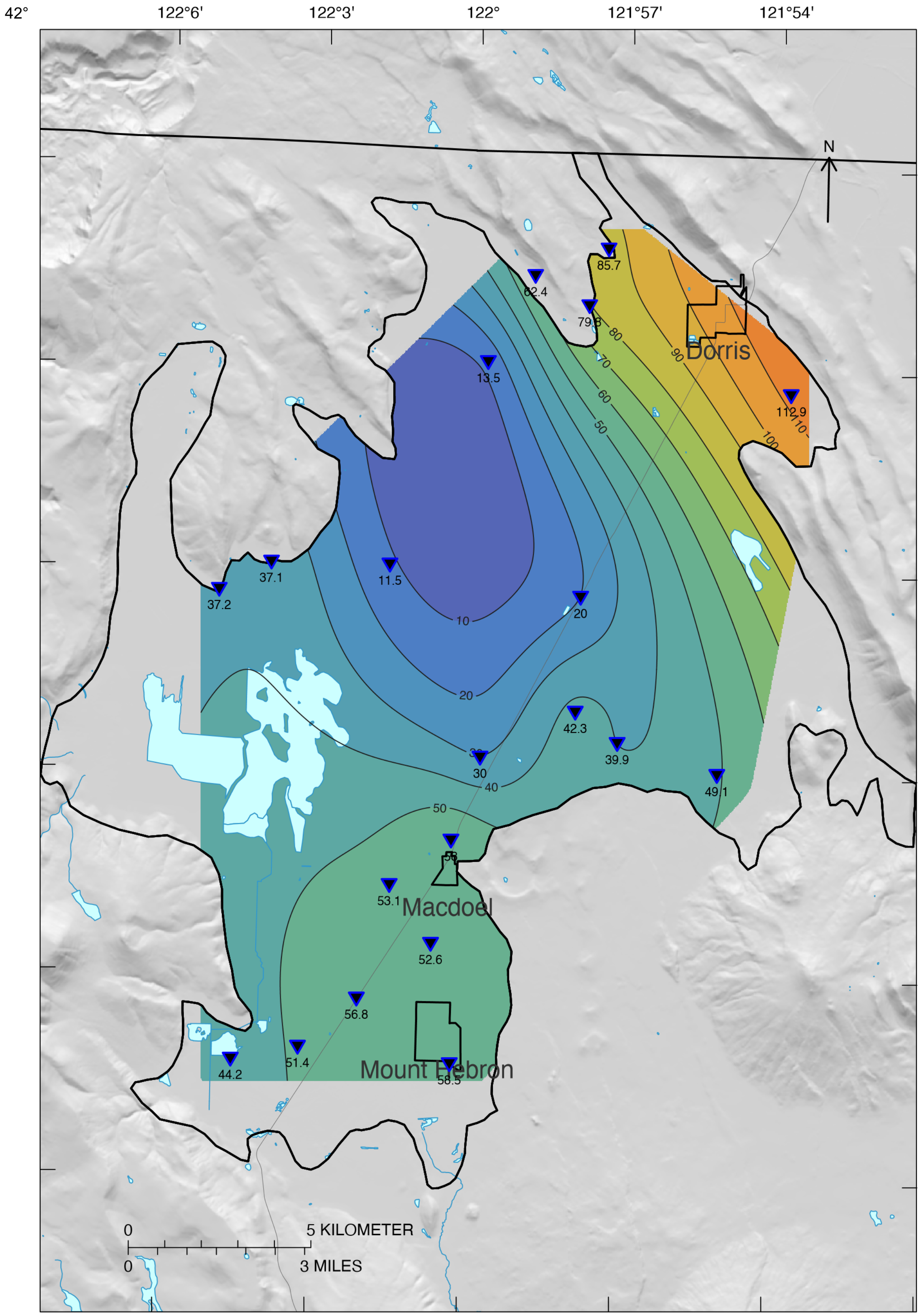
41° 51'

41° 48'

41° 45'

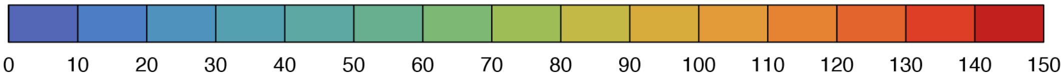
Figure 2.21: Butte Valley Groundwater Elevations, Spring 1979

1889



Observations between 2015–03–23 and 2015–03–23

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



41° 57'

41° 54'

41° 51'

41° 48'

41° 45'

Figure 2.22: Butte Valley Groundwater Elevations, Spring 2015

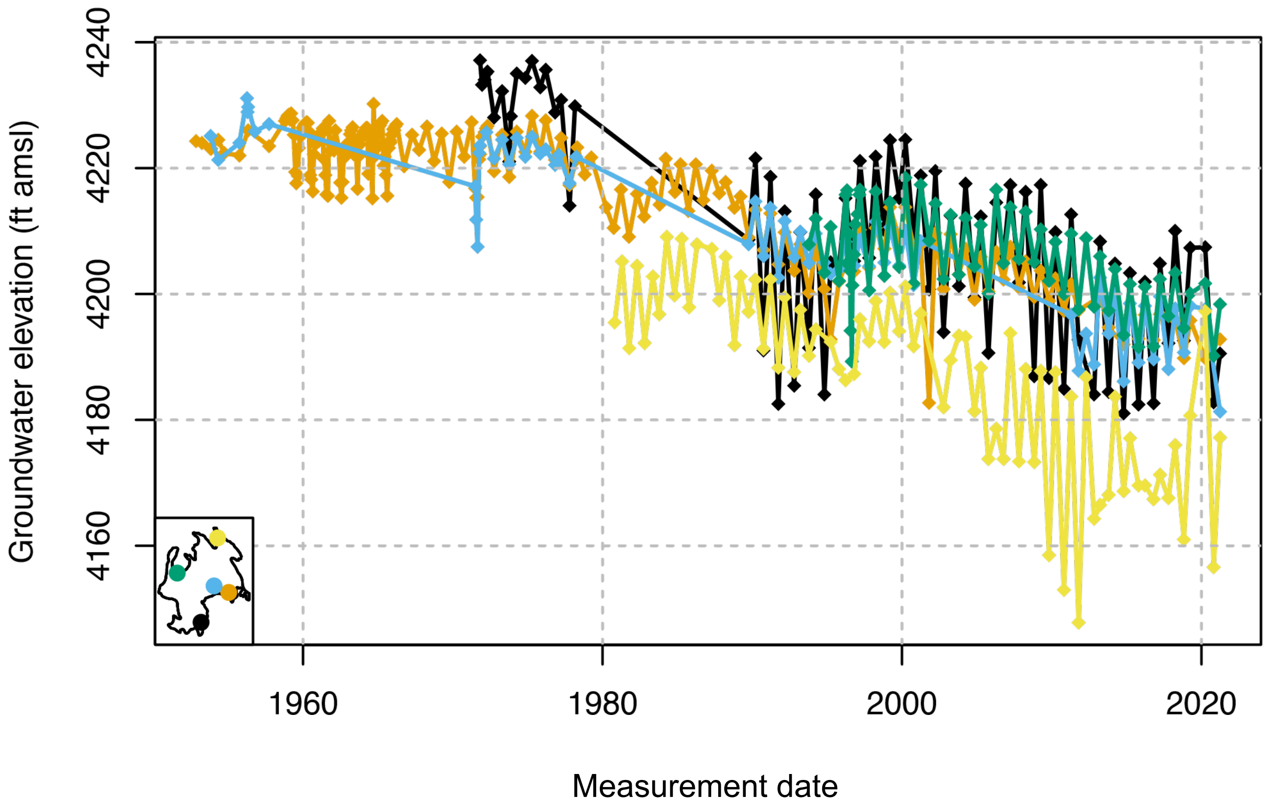


Figure 2.23: Groundwater elevation measurements over time in five wells, one located in each hydrogeologic zone.

2.2.2.4~~2~~ Estimate of Groundwater Storage and Groundwater Storage Changes

Due to the complexity of the Basin and interbedded nature of alluvial, fluvial, and volcanic deposits within the major aquifer subunits, DWR could not provide an estimate of groundwater storage. 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 in two well tests by California DWR measured 2% and 13%. Confined storage coefficients in those tests, for wells completed in the High Cascade Volcanics, measured

0.001 to 0.002 (DWR 1998). Specific yield and storativity has also been estimated using the Butte Valley Integrated Hydrologic Model (BVIHM), as described in Section 2.2.3.

Changes in groundwater storage are computed using the reported average Basin specific yield of 9.5% (see above), which is multiplied with the total volume of the aquifer within the Basin that is drained or filled over a specified period of time (DWR, 2013[1]). That volume is obtained as the difference in the water level surface across the basin between two specified years or seasons.

The GSA has employed **two different interpolation methods** to compute a water level surface for a specified year and season (fall or spring of a given water year) from the available water level elevations at monitored wells (including the RMPs):

1. Nonlinear, continuous interpolation using kriging. This method provides for a realistic, continuously distributed mapping of water table depth and water level elevations (e.g., Figures 2.21, 2.22), but is subject to selection of the interpolation method and its parameters.
2. extrapolation of the water level elevation at a measurement to the entire Thiessen polygon area associated with that measurement point, yielding a stepwise water level distribution for purposes of computing the aquifer volume filled or drained during a given time period (Figure 2.24). This is a simplified approach that makes a “naïve” (i.e., parameter-free) interpolation of water levels, yet provides a reasonable estimate of storage change across the basin, not dissimilar to any other interpolation method.

The GSA has also used **two different seasons** to compute year-over-year or long-term groundwater storage changes: spring and fall. Spring water levels are recommended by DWR (2013) for computation of storage changes due to absence of water level bias from large well pumping, as spring water levels are measured at the end of the non-pumping season, immediately prior to the year’s irrigation season. Year-over-year fall water level changes provide storage changes that coincide mostly with the duration of a water year.

For the GSA’s previous annual reporting (WY2021 and 2022) fall-to-fall change in groundwater elevations were used to calculate change in groundwater storage at the end of each water year, using the nonlinear interpolation method. However, water level data sampled in the fall are~~is~~ subject to potentially larger interannual changes due to groundwater pumping, different periods of short-term recovery from~~the~~ groundwater pumping, and other very localized effects that provide strongly biased results with either water level interpolation method. For groundwater storage change calculations, spring-to-spring change in groundwater levels will be preferable with water levels being regionally more representative and absent of local residual cones of depression. Using spring-to-spring changes in water level

This also aligns with recommended storage change estimation methods from DWR[1].

Here we use the Thiessen polygon (Voronoi polygon) method of water level extrapolation. A Thiessen polygon identifies the areal extent of the Basin that is closest to a given well. The area

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[1] Appendix E. California’s Groundwater Update 2013 Technical Memorandum: Calculating Annual Change in Groundwater in Storage by Using Groundwater-Level Data. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Bulletin-118/Files/Statewide-Reports/GWU2013_Apdx_E_Final.pdf

of each Thiessen polygon is multiplied by the change in water level at each well to calculate the change in the volume of saturated aquifer thickness. The change in saturated aquifer thickness was then multiplied by the average specific yield for the aquifer material in the Bulletin 118 Groundwater Basin (see equation below). A conceptual illustration of measured wells with their identified Thiessen polygons in Butte Valley groundwater basin is shown in Figure 2.24. Furthermore, a set of wells with consequential spring measurements throughout the recent years is used in the new Thiessen polygon approach to ensure that a more consistent set of measurements is used for the change in storage calculation, which should help avoid variability between years.

$$Annual\ \Delta Storage\ = \sum \Delta Storage\ (polygon)_i = \sum (Area_i \times S_y \times \Delta Head_i)$$

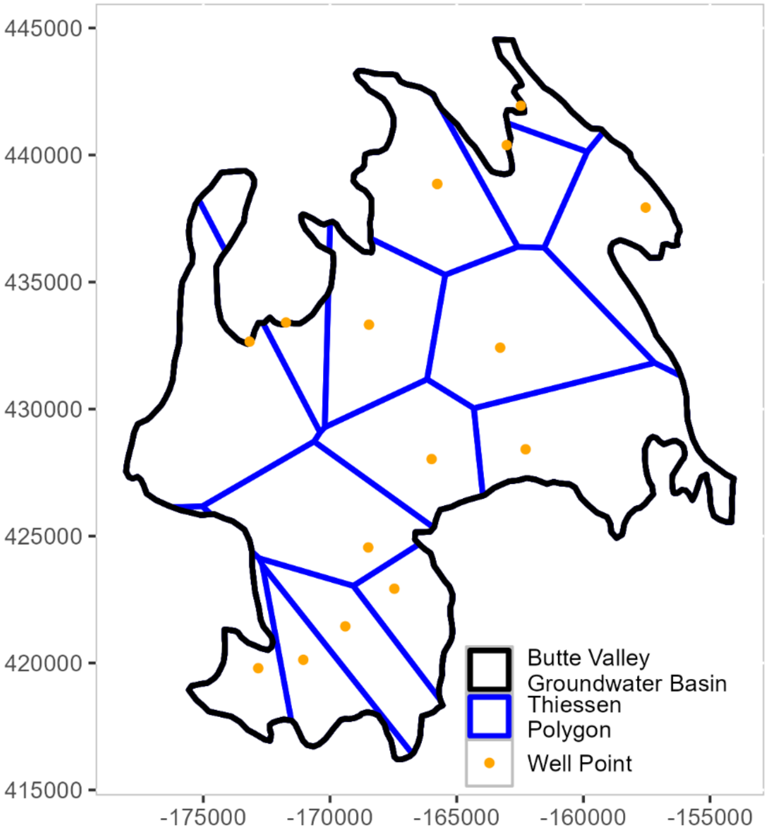

Figure 2.24: Concept of well points and their Thiessen polygons identified (cropped to Bulletin 118 boundary) in Butte Valley groundwater basin

Analysis of Groundwater Storage Changes in 2021, 2022, and 2023

WY	Calculated period	Approach	Change in Storage (TAF)	Note	Water level surface estimate by
2021	Fall-Fall	GWL based	-118	Unit Error; Number submitted in the WY2021 Annual Report	Nonlinear interpolation
2022~~1~~	Fall-Fall	GWL based	-28	Unit error corrected, as indicated in WY2022's submitted plot	Nonlinear interpolation
2023~~2~~	Fall-Fall	GWL based	-11	Number submitted in the WY2022 Annual Report	Nonlinear interpolation
2021	Spring-Spring	GWL based	-12	Unit error addressed; same set of well for WY2018-2024 computation	Nonlinear interpolation
2022	Spring-Spring	GWL based	-6	Unit error addressed; same set of well for WY2018-2024 computation	Nonlinear interpolation
2023	Spring-Spring	GWL based	2	Unit error addressed; same set of well for WY2018-2024 computation	Nonlinear interpolation
2021	Spring-Spring	GWL based	-18	Water level assumed identical across Thiessen polygon	Thiessen polygon
2022	Spring-Spring	GWL based	-12	Water level assumed identical across Thiessen polygon	Thiessen polygon
2023	Spring-Spring	GWL based	3	Water level assumed identical across Thiessen polygon	Thiessen polygon

Table XX1: Groundwater storage changes computed using Fall-to-Fall changes in water levels vs. Spring-to-Spring changes in water ~~levels, and~~levels and using nonlinear interpolation vs. stepwise extrapolation across Thiessen polygons.

In Butte Valley WY 2021 Annual Report[2], a total change in groundwater storage (fall to fall) of -118 TAF was reported. Through a review of historic annual report development, a unit conversion error was found in the WY2021 report, which resulted in a storage change 3.2808 times the true size based on the fall water level measurements used at the time and due to an outlier water level

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[2] 1-003 BUTTE VALLEY 2021 (OCT. 2020 - SEP. 2021) GSP Annual Report. https://sgma.water.ca.gov/portal/gspar/preview/102

measurement. The error was addressed in the WY2022 report, showing that the actual groundwater storage change to report for WY2021 (fall to fall) was -28 TAF, after also correcting for an outlying water level measurement.

Hence, the annual groundwater change, using nonlinear water level interpolation, yielded -28 TAF (F2021) and -11 TAF (F2022). For the same years, spring measurements and using nonlinear interpolation estimated storage changes at -12 and -6 TAF for Spring 2021 and 2022, respectively. Using the Thiessen polygon approach instead yielded -18, -12, and +3 TAF of groundwater storage change in 2021, 2022, and 2023, respectively. The results of the different~~two~~ approaches (fall-to-fall vs. spring-to-spring, nonlinear~~interpolated~~ interpolation of groundwater levels ~~and~~vs. Thiessen polygon extrapolation~~s~~) are in reasonable agreement ~~in the bulk part~~ but demonstrated differences in the predicted magnitude of storage change between years. Over the long-term, cumulative storage changes computed with either method are expected to converge.

Long-term Groundwater Storage Changes

Using water level hydrographs that provide spring water levels in the beginning and end year of various longer-term periods since 1990, groundwater storage changes were computed using the Thiessen polygon method over several different periods (Table XX2)~~,~~. The late 1990s were the last period with significant longer term positive groundwater storage changes. Since 2000 to current, corresponding to what is referred to as the Western U.S. mega-drought (Williams et al, 2020), average groundwater storage decline is estimated to be 6,280 acre-feet/yr. Over the 80,000 acre Basin with an average specific yield of 9.5%,~~,~~ this corresponds to an average annual water level decline of 0.8 ft/y in 2000-2024, i.e., consistent with observed hydrographs. The highest single-year decline has been observed in 2020-2021, when water levels declined by nearly 18,000 acre-feet in a single year.

The average storage decline since 1990 is 4,200 acft/yr, totalling 142,000 acft of storage loss.

Period (spring to spring)	**Period Length in Years**	**Number of Wells used for Thiessen Polygon Analysis**	**Groundwater Storage Change [acft / yr]**	**Period or Water-Year Type**
1990 - 2000	10	27	799	wetter than average
1990 - 2010	20	at least 12	-2,685	
1990 - 2014	24	20	-4,143	baseline period
1990 - 2024	34	at least 12	-4,198	entire period to date
2000 - 2014	14	21	-7,390	baseline mega-drought
2000 - 2024	24	17	-6,280	mega-drought
2010 - 2024	14	15	-6,359	
2014 - 2017	3	at least 12	-3,211	drought
2014 - 2024	10	at least 12	-4,725	past decade
2017 - 2024	7	12	-5,374	GSA period

2017 - 2018	1	12	4,773	2018 - Below Normal
2018 - 2019	1	12	2,416	2019 - Above Normal
2019 - 2020	1	12	-10,471	2020 - Critical
2020 - 2021	1	12	-17,622	2021 - Critical
2021 - 2022	1	12	-12,191	2022 - Critical
2022 - 2023	1	12	2,976	2023 - Above Normal
2023 - 2024	1	12	-7,502	2024 - Below Normal

Table XX2: Average annual groundwater storage changes, in acre-feet per year, spring to spring over the period indicated in the first column, based on the number of water level measurements indicated in the 3rd column during both, the start year and end year of the period and using the Thiessen polygon method.

~~*Causes of Long-term Groundwater Storage Changes*~~

~~In Butte Valley WY 2021 Annual Report[3], a total change in groundwater storage of -118 TAF was reported. Through a review of historic annual report development, a unit error was in the WY2021 report, which resulted in a storage change 3.2808 times the true size based on the fall water level measurements used at the time. This error was addressed in the WY2022 report.~~

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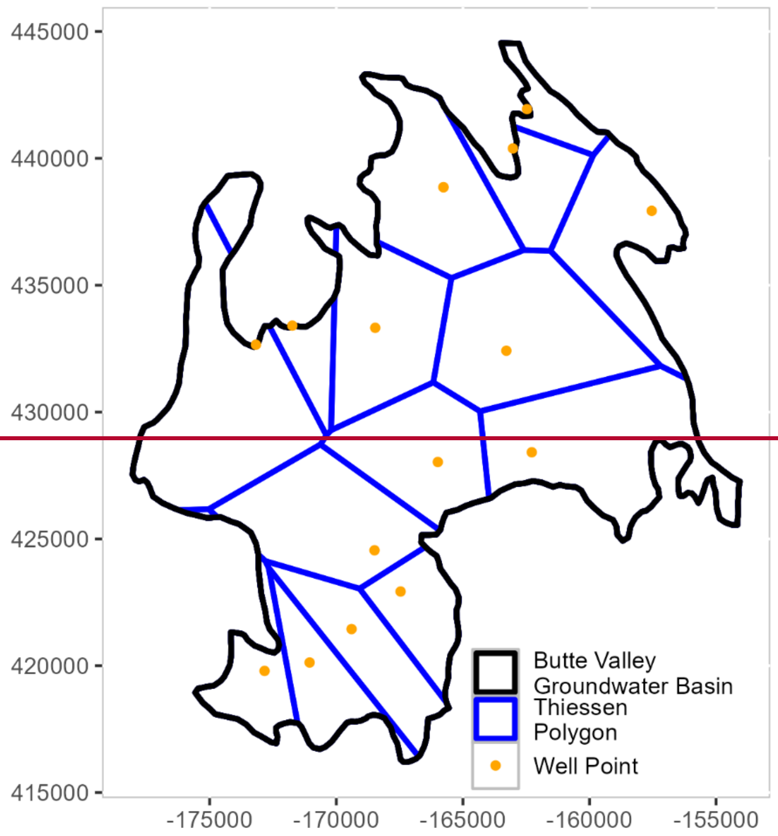
[3] ~~1-003 BUTTE VALLEY 2021 (OCT. 2020 - SEP. 2021) GSP Annual Report. https://sgma.water.ca.gov/portal/gspar/preview/102~~



~~Figure 2.24: Concept of well points and their Thiessen polygons identified (cropped to Bulletin 118 boundary) in Butte Valley groundwater basin~~

2.2.2.5~~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. 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 and Watt 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. R1-20120002), the DWR SGMA Basin Prioritization Process and the seven evaluation factors listed in the Recycled Water Policy (NCRWQCB and Watt 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 2 in- (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 DWR; SWRCB, Division of Drinking Water (DDW); Lawrence Livermore National Laboratory (LLNL) special studies; and USGS. These data were augmented with data supplied by 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 to 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 NCRWQCB assessments of beneficial use protection in groundwater. The standards are compared against groundwater quality data to determine if a constituent 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. Water quality in the Basin is regulated under the NCRWQCB Basin Plan, which lists relevant water quality objectives (WQOs) and beneficial uses. 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 Basin.

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 to 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 to 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 2.5 contains the list of constituents of interest identified for the Basin and their associated regulatory threshold.

Table 2.5: 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.

(Appendix 2-B). Exceedances of the 0.05 microgram per liter (μg/L) 1° MCL for EDB are highly 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 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

skin changes and may lead to skin cancer. The Title 22 1° MCL for arsenic is 10 μg/L.° 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 (ATSDR 2007a). Long-term exposure can lead to

Arsenic data in the Basin, between 1990 and 2020, are limited to municipal wells in Dorris,

μg/L for arsenic. The three additional wells with arsenic data all have results below the 1μ ° MCL,

as 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 MCL of 10

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 g/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 (ATSDR 2007b). 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 (ATSDR 2007b). The 1$_{o}$ MCL for benzene is 1 milligram per liter (μg/L), as defined in Title 22.$_{o}$ 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

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 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 (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 are 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^{o} MCL for nitrate is 10 mg/L as N.

Recent nitrate data collected in the Basin (1990 to 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 (SWRCB 2019b). 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 2.24.

Dorris PCE Plume

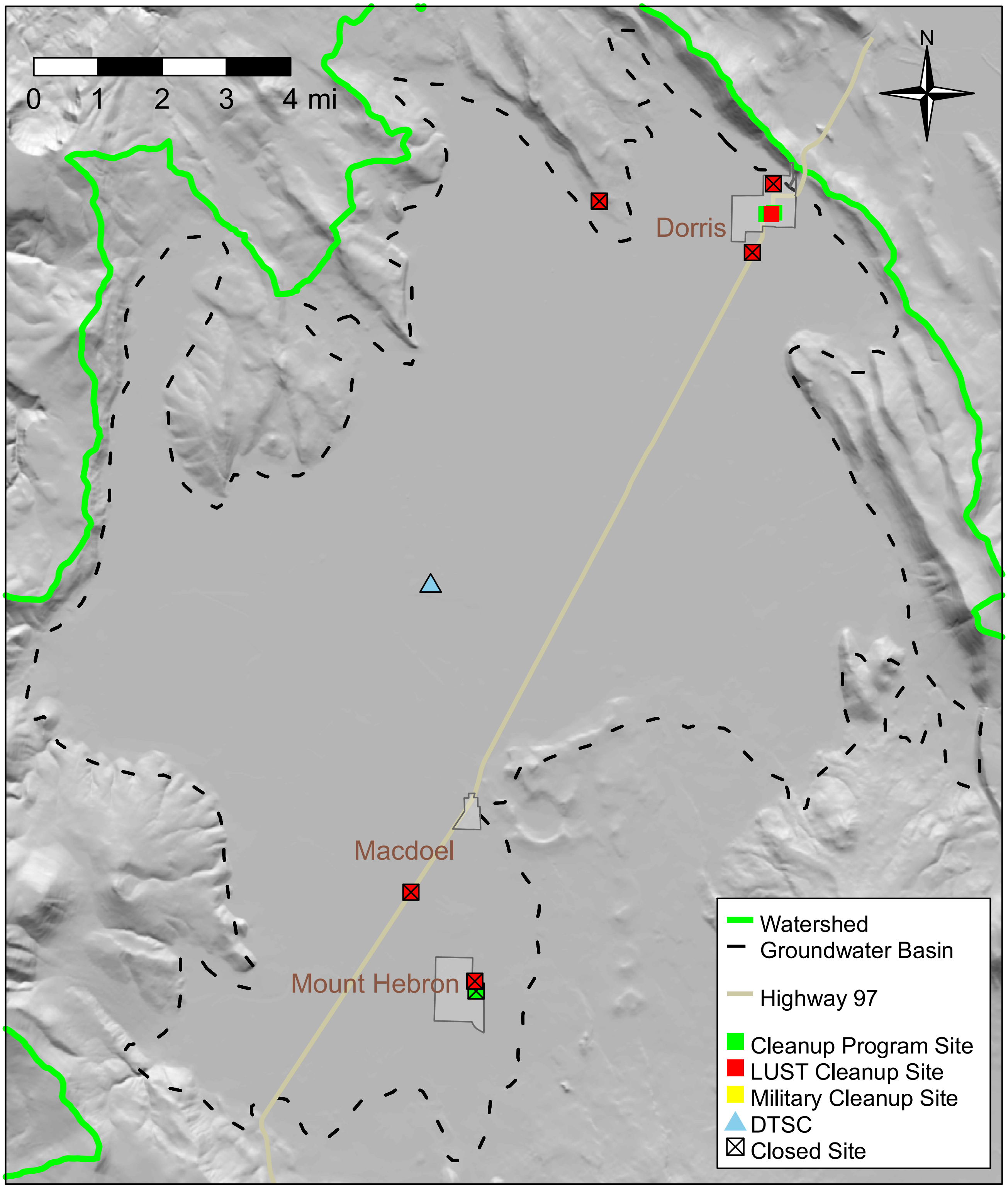
The case (No. 1NSI23) for this cleanup site was opened in September 2013, after tetrachloroethylene (PCE) from an unidentified source was detected in LUST monitoring wells for the Shell site. This case is currently open and inactive (there are currently no regulatory oversight efforts by the Lead Agency).

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.


0
1
2
3
4 mi
N
Dorris
Macdoel
Mount Hebron
Watershed
Groundwater Basin
Highway 97
🟩 Cleanup Program Site
🟥 LUST Cleanup Site
🟨 Military Cleanup Site
▲ DTSC
☒ Closed Site

2356

Figure 2.24: Contaminated Sites 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.

2.2.2.6~~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.

2.2.2.7~~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 Basin. While groundwater elevations have steadily declined in the past few decades, noticeable land subsidence has not been observed in the Basin. 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 (Lutz 2021). The City of Dorris has not observed any influence of land subsidence on city pipes (Mckay 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 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 2.25 using raster data from the TRE Altamira report (DWR 2019c). 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:

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 2.25). 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 2.25 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 2.25. 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 2.25 is approximately 0.15 ft (46 millimeters (mm)) between June 2015 to September 2019 in the area west of Dorris.

2.2.2.8~~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:

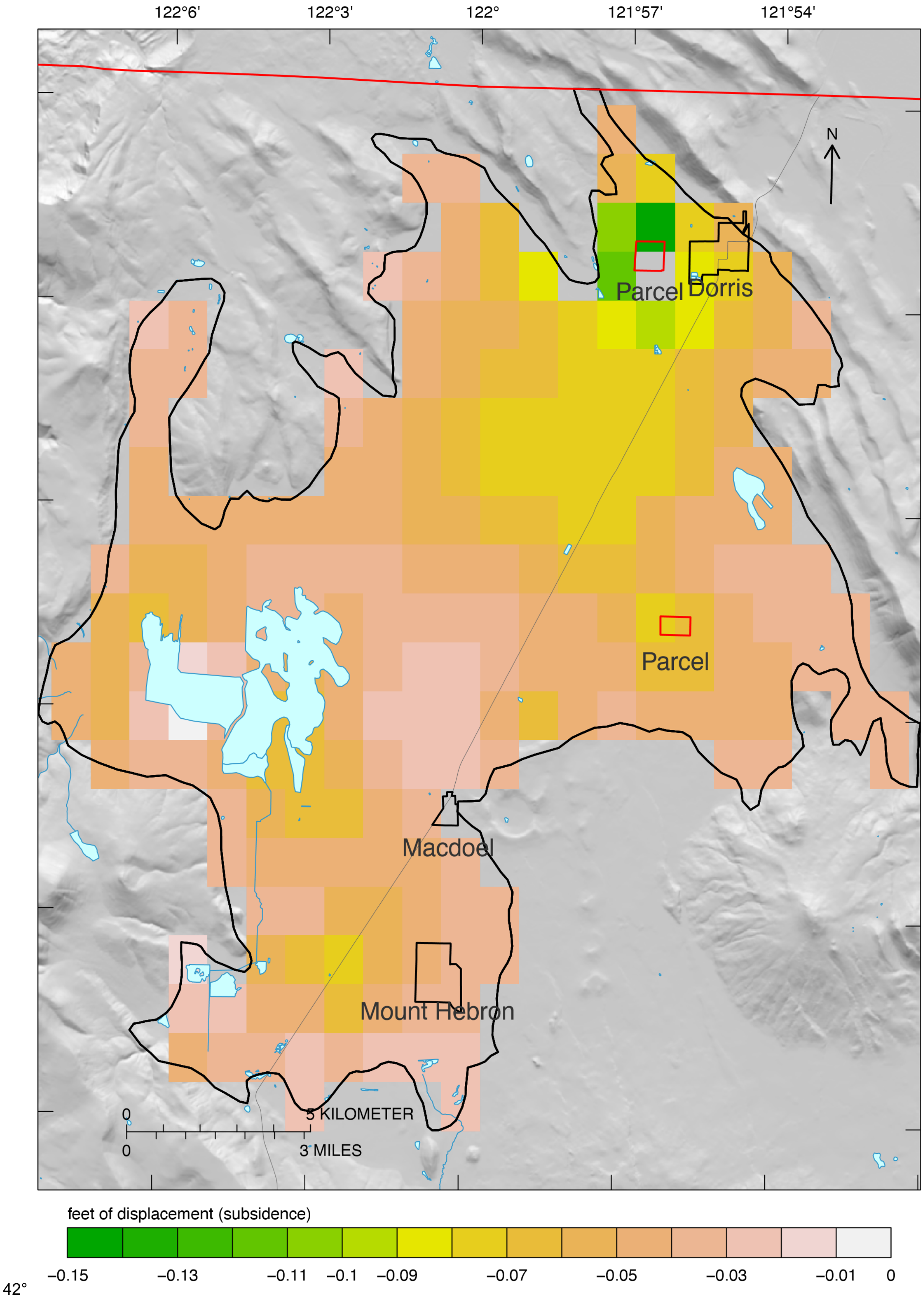
> *23 CCR § 351 (o): "Interconnected surface water" refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted.*

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 Basin is restricted to Meiss Lake and five creeks: Butte, Prather, Ikes, Harris, and Muskgrave (Figure 2.26). Only short stretches of Ikes, Harris, and Muskgrave Creeks lie within the Basin boundary before terminating at the BVWA Perimeter Canal (Figure 2.7 and Figure 2.27). 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 are 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 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 (Todd Sloat Biological


122°6'
122°3'
122°
121°57'
121°54'
N
Parcel
Dorris
Parcel
Macdoel
Mount Hebron
0
5 KILOMETER
0
3 MILES
feet of displacement (subsidence)
–0.15
–0.13
–0.11
–0.1
–0.09
–0.07
–0.05
–0.03
–0.01
0
42°

2482

41°
57'

41°
54'

41°
51'

41°
48'

41°
45'

Figure 2.25: 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.

Consulting 2012). 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.

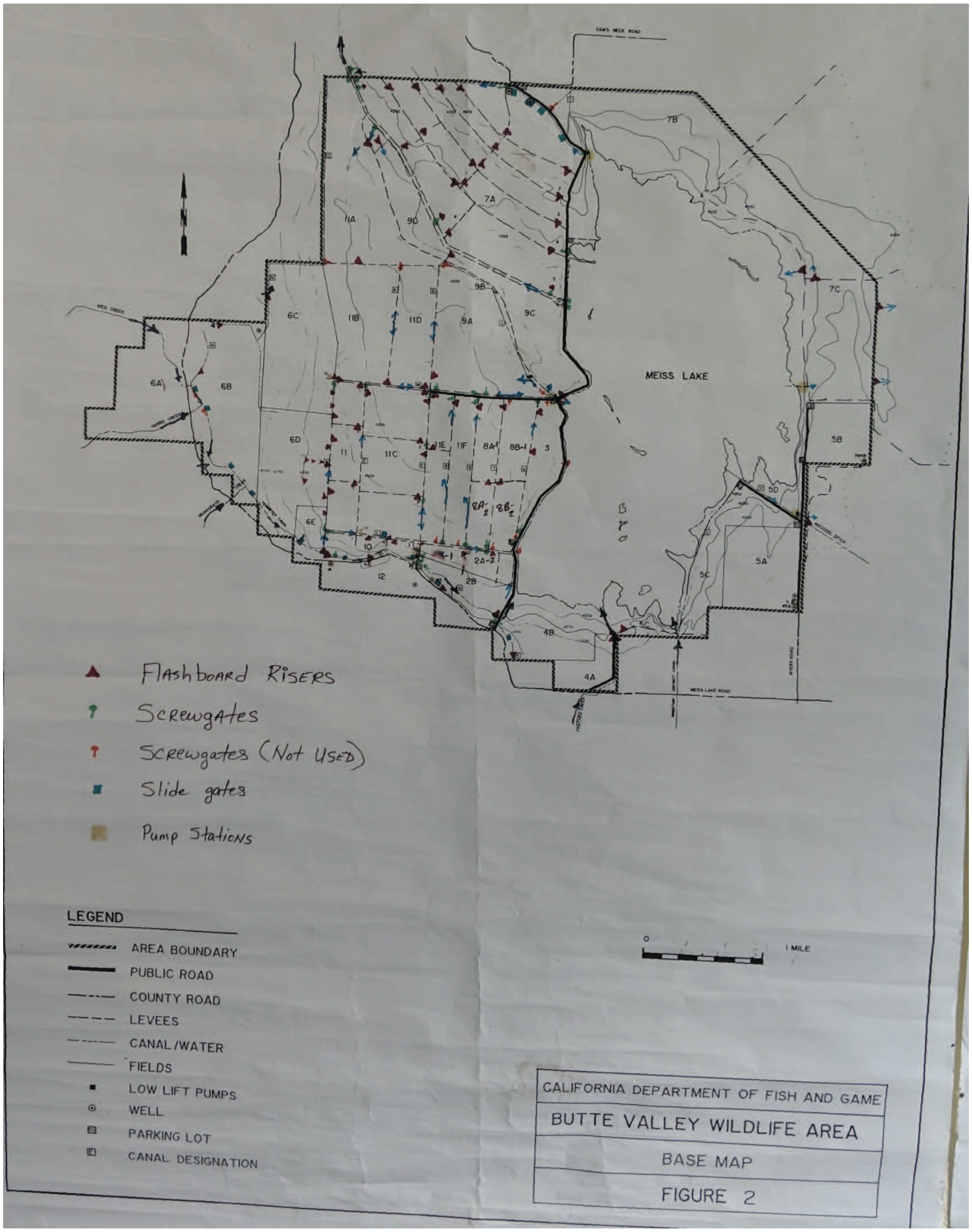
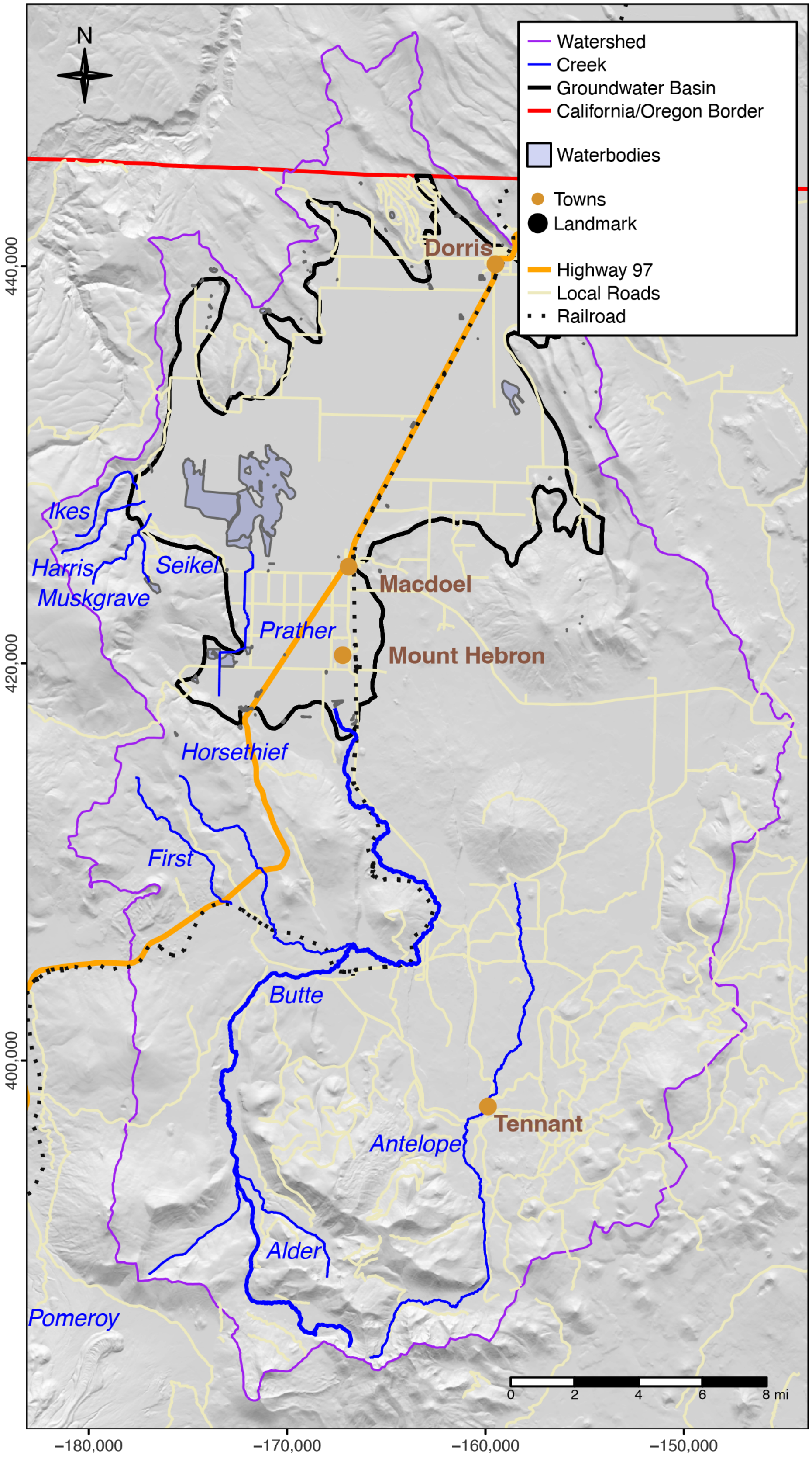


Figure 2.27: Photo of Butte Valley Wildlife Area (BVWA) map taken at the BVWA headquarters, showing that Ikes, Harris, and Muskgrave Creeks terminate at the BVWA Perimeter Canal. Prather Creek terminates in Meiss Lake.


N
Watershed
Creek
Groundwater Basin
California/Oregon Border
Waterbodies
Towns
Landmark
Highway 97
Local Roads
Railroad
Dorris
Macdoel
Mount Hebron
Tennant
Ikes
Harris
Muskgrave
Seikel
Prather
Horsethief
First
Butte
Antelope
Alder
Pomeroy
0
2
4
6
8 mi
440,000
420,000
400,000
−180,000
−170,000
−160,000
−150,000

2505

Figure 2.26: Surface Water in the Butte Valley Groundwater Basin.

2.2.2.9~~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 ISWs, 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 (SMC), improve the monitoring network, and define projects and management actions (PMAs) 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 GDEs include unreliable or outdated habitat maps that require local knowledge and study and groundwater level data gaps near potential GDEs. 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 ISW sustainability indicators, GSAs are required to prevent adverse impacts to beneficial users of groundwater and ISW, 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 et al. 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 BVWA and manages Meiss Lake. Additionally, USFS and BLM own about 23.3% and 0.1% of the Basin area, respectively (Figure 2.2).

Freshwater Species within the Basin

The Nature Conservancy (TNC) has provided a list of freshwater species located within each groundwater basin in California and the 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 2.6) (K. Novick 2009; TNC 2021; CDFW 2021c, 2021b, 2021a).

The predicted habitat for each of these species were evaluated using CDFW's Biogeographic Information and Observation System (BIOS) Viewer, with input from BVWA. 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. Colonialnesting 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), doublecrested 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 three or four other colonies nesting in the state (K. Novick 2009). 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.

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

Table 2.6: Freshwater Species in Butte Valley, as identified by BVWA (2009 BVWA Plan Addendum), The Nature Conservancy (TNC 2021) with species status verified by CDFW statewide species lists (CDFW 2021 a,b,c).

Loggerhead shrike	Birds	Special Concern	Observed in Butte Valley Wildlife Area
Long-eared owl	Birds	Special Concern	Observed in Butte Valley Wildlife Area

Table 2.6: Freshwater Species in Butte Valley, as identified by BVWA (2009 BVWA Plan Addendum), The Nature Conservancy (TNC 2021) with species status verified by CDFW statewide species lists (CDFW 2021 a,b,c).

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

Table 2.6: Freshwater Species in Butte Valley, as identified by BVWA (2009 BVWA Plan Addendum), The Nature Conservancy (TNC 2021) with species status verified by CDFW statewide species lists (CDFW 2021 a,b,c).

Western Pond Turtle	Herps	Special Concern	Observed in Butte Valley Wildlife Area
White-faced Ibis	Birds	Watch list	Observed in Butte Valley Wildlife Area

(continued)

Table 2.6: Freshwater Species in Butte Valley, as identified by BVWA (2009 BVWA Plan Addendum), The Nature Conservancy (TNC 2021) with species status verified by 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 GDE. 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 2.7, are considered throughout this GSP. Other species listed in Table 2.6 and Table 2.7 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 2.7: GDE species prioritization for management, as identified by BVWA, The 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

Table 2.6: Freshwater Species in Butte Valley, as identified by BVWA (2009 BVWA Plan Addendum), The Nature Conservancy (TNC 2021) with species status verified by CDFW statewide species lists (CDFW 2021 a,b,c).

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

Table 2.7: GDE species prioritization for management, as identified by BVWA, The 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

	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 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 (DWR 2021). 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 2.29 and Figure 2.28, respectively.

An initial review of NCCAG mapped potential GDEs for the Basin and a comparison to an initial review of NCCAG mapped potential GDEs for the 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 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 2.8 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

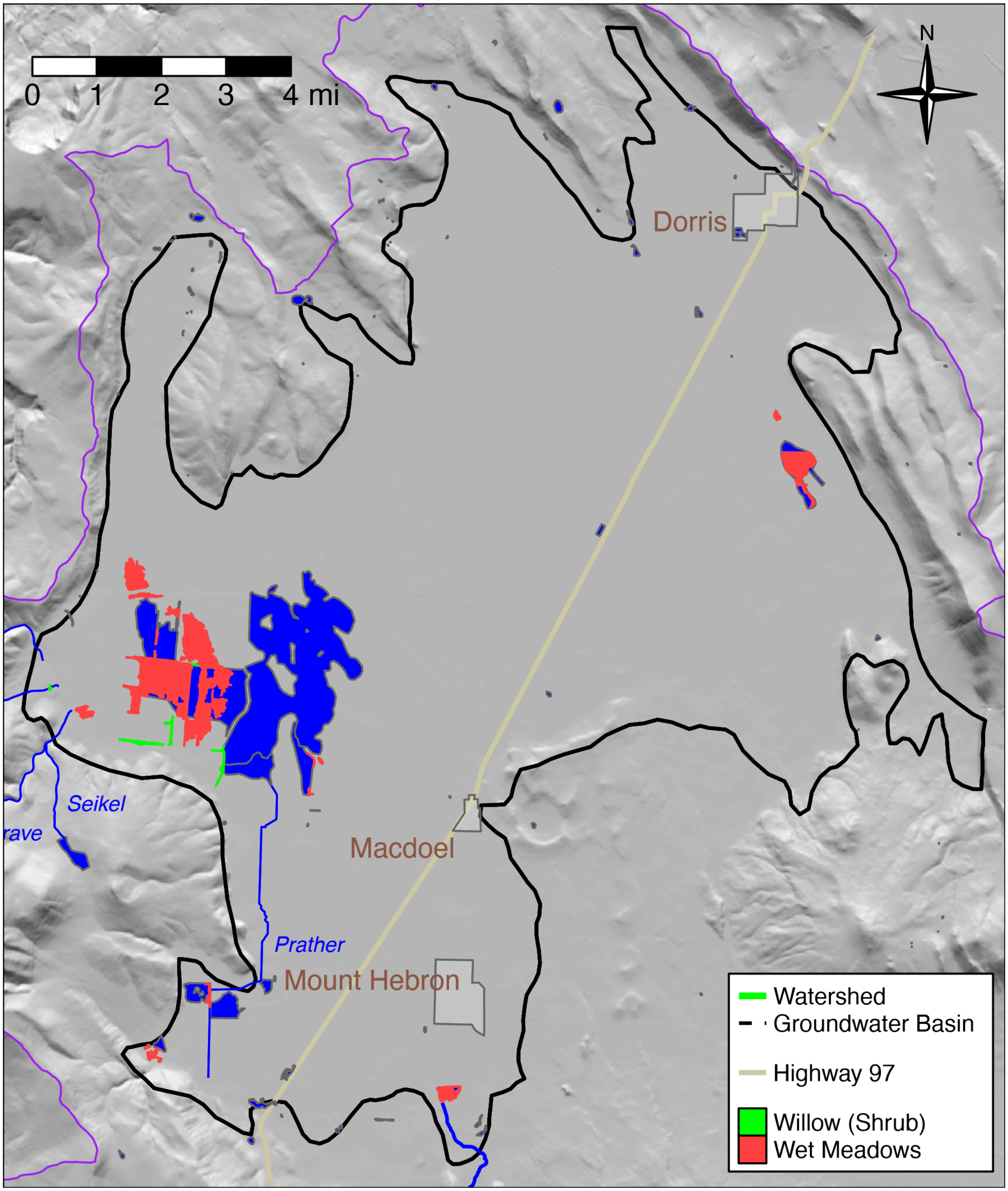


Figure 2.28: Vegetation types commonly associated with the sub-surface presence of groundwater (phreatophytes). Identified by the DWR Natural Communities Commonly Associated with Groundwater (NCCAG) dataset. The data included in the Natural Communities dataset do not represent DWRs determination of a 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.

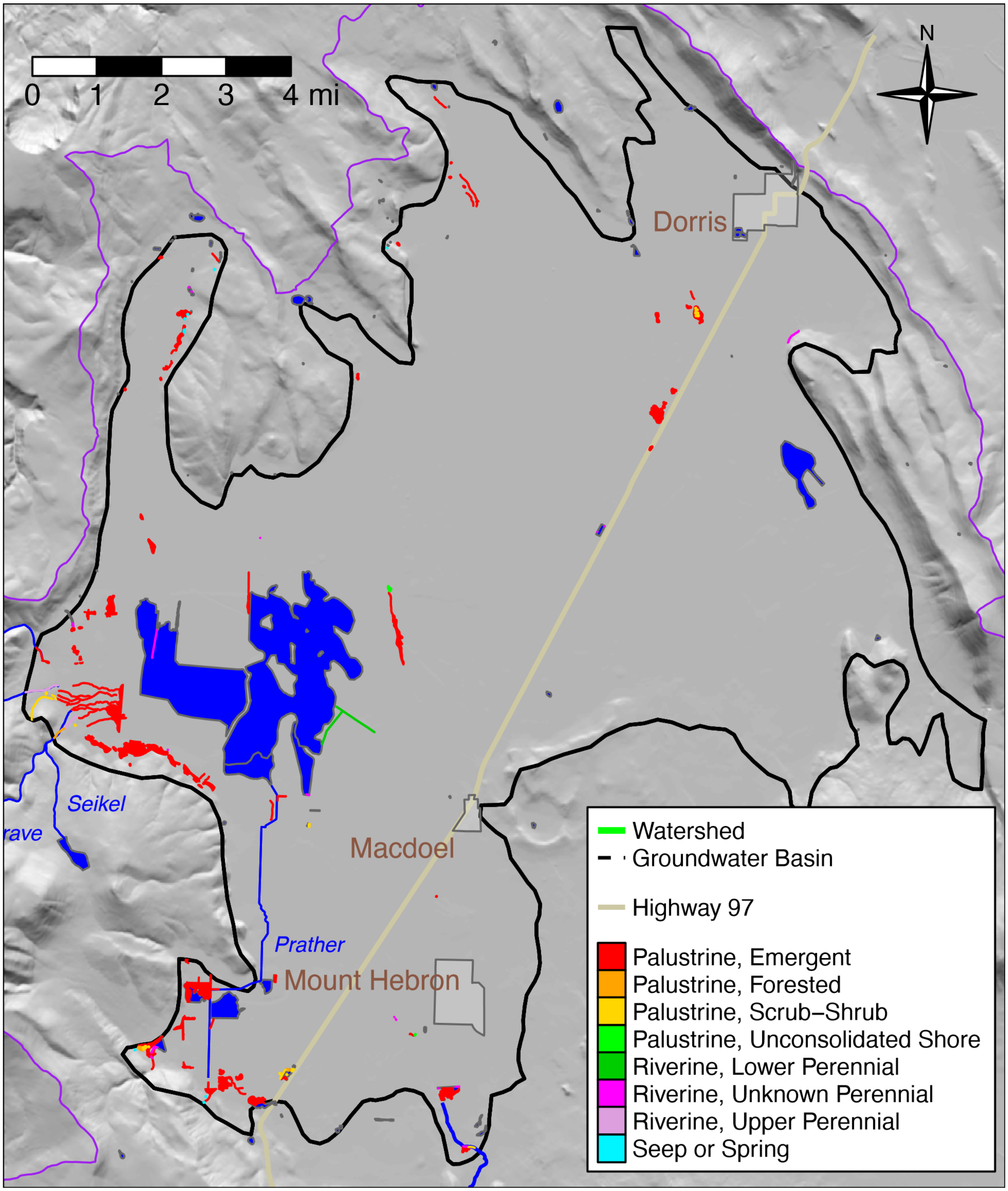


Figure 2.29: Wetland features commonly associated with the surface expression of groundwater under natural, unmodified conditions. Identified by the DWR Natural Communities Commonly Associated with Groundwater (NCCAG) dataset. The data included in the Natural Communities dataset do not represent DWRs 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.

a presumably higher level of mapping accuracy and more descriptive classes with values such as “wet meadow” or “willow shrub” present within the 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 2.9, Table 2.10, and Table 2.11 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 (Niswonger1and 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 (Fan 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 2.8: 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 2.9: 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 2.10: 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~~Semi permanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean Rooting Depth
Palustrine, Forested, Seasonally Flooded	13.1	Willow

Table 2.10: 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 2.11: 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 may cause overestimation of depth to groundwater, particularly in Sam's Neck, the northern edge of the Basin, 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 USGS 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 are 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.

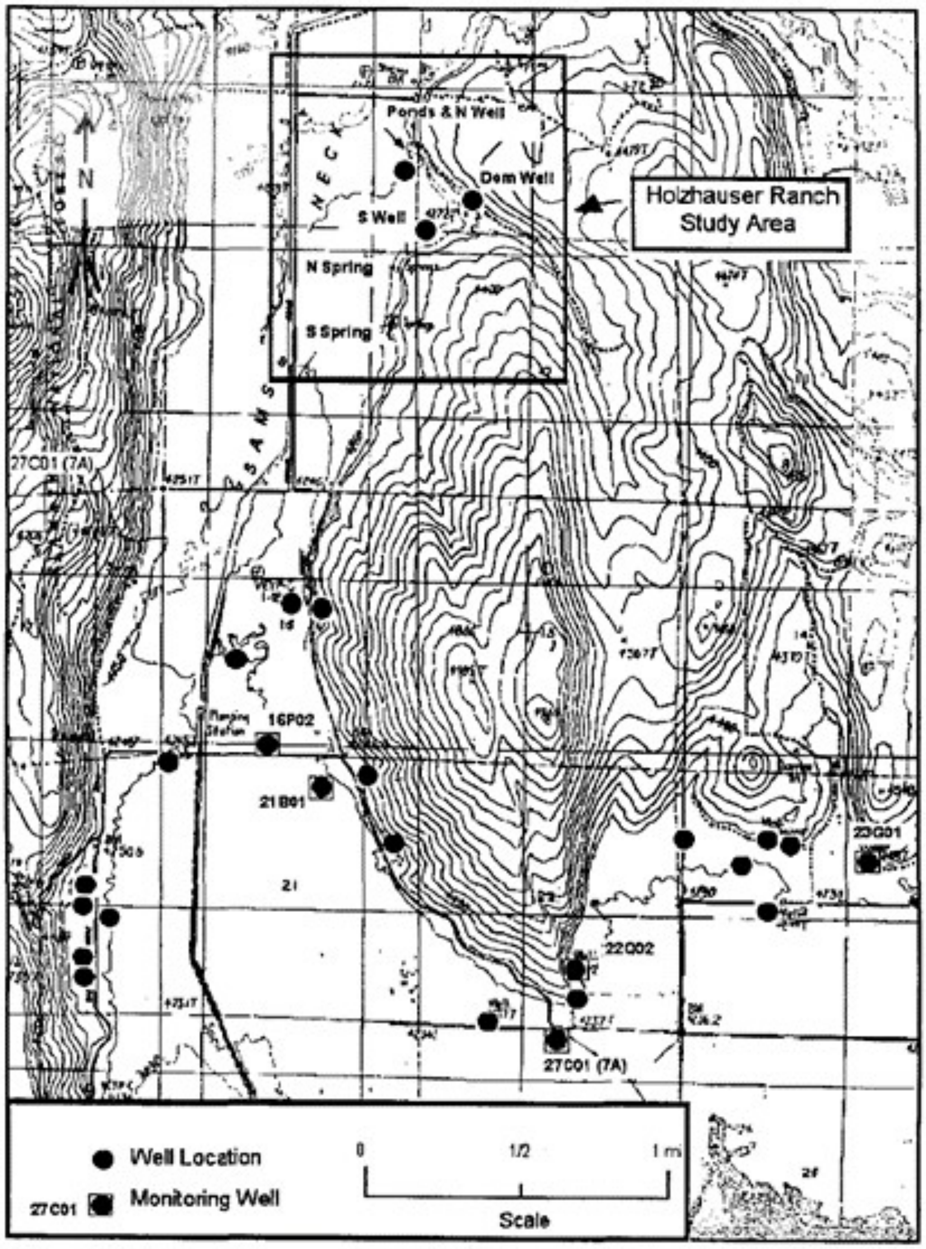


Figure 9. Holzhauser Ranch Location Map

Figure 2.30: 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 DWR in August 1997. During the pump test, two springs on Holzhauser Ranch in Sam's Neck were observed during pump operation on 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).

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 which 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 was positive were assumed to be connected to groundwater for that season and year representation as the rooting zone depth was greater than the depth to groundwater. Conversely, mapped potential GDEs where the difference between assumed rooting zone depths and computed depth to groundwater was negative suggested that roots did not have access to groundwater. These areas were 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 are only available every six 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.

Assumptions and Uncertainty

The approach developed and carried out to identify and evaluate GDEs within the 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.

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 Basin is presented in Figure 2.31 and Table 2.12.

The current map of likely connected GDEs are located in areas where direct groundwater levels are not available or areas with a short historical record. Consequently the current list of potential

GDEs is considered tentative and dependent on collection of additional groundwater level data. Since GDEs in the Basin are considered a data gap, all GDEs currently labeled as "potentially not a GDE" will be reviewed with future GDE analysis updates. Since the submittal of the GSP, work has been done to fill these data gaps. New rain, stream gage, and groundwater level monitoring added to fill data gaps in areas near potential GDEs, as shown in Figure 2.3.2,.

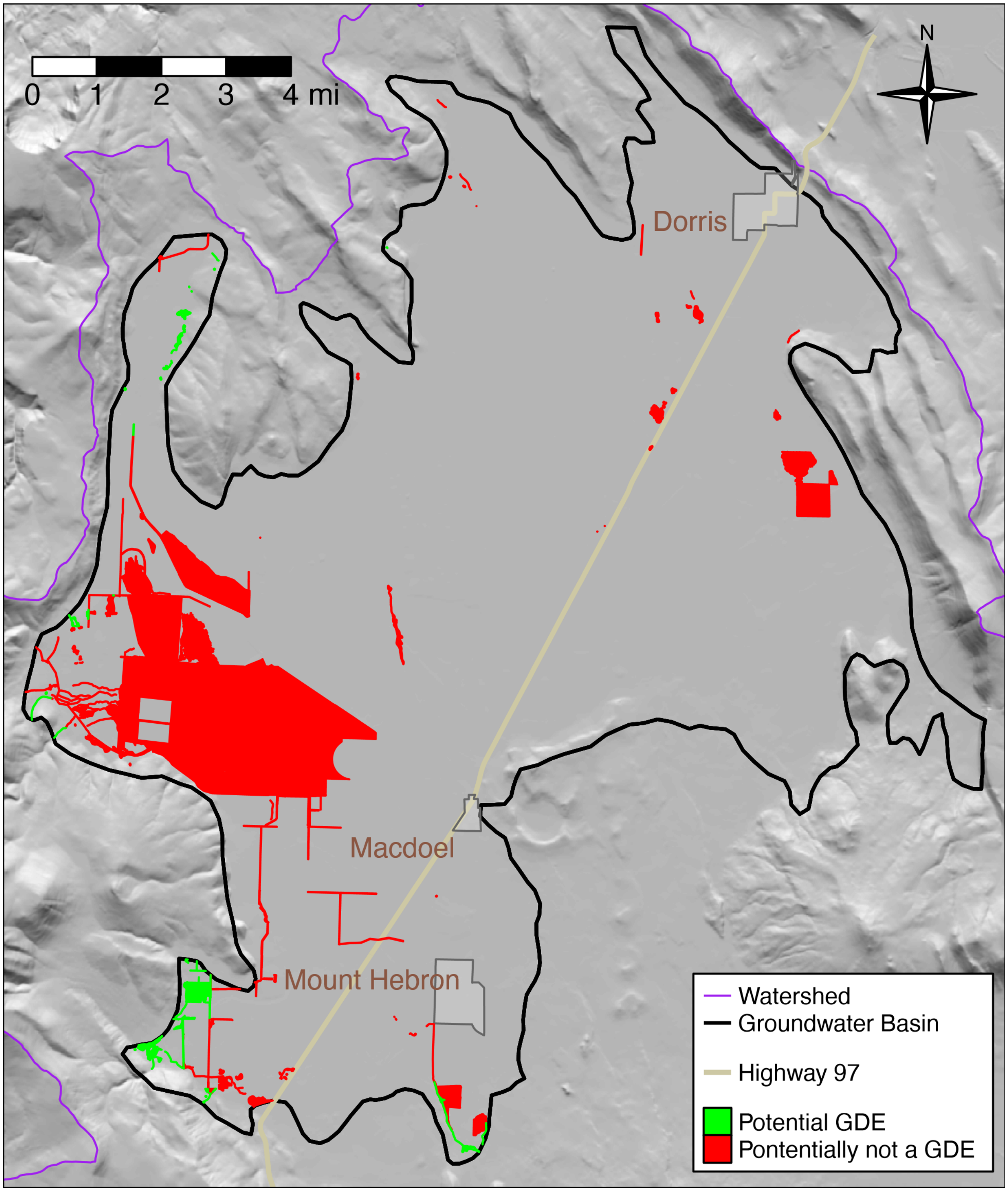


Figure 2.31: Categorized GDEs for the Basin.

Table 2.12: 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%

Progress on GDE Data Gap

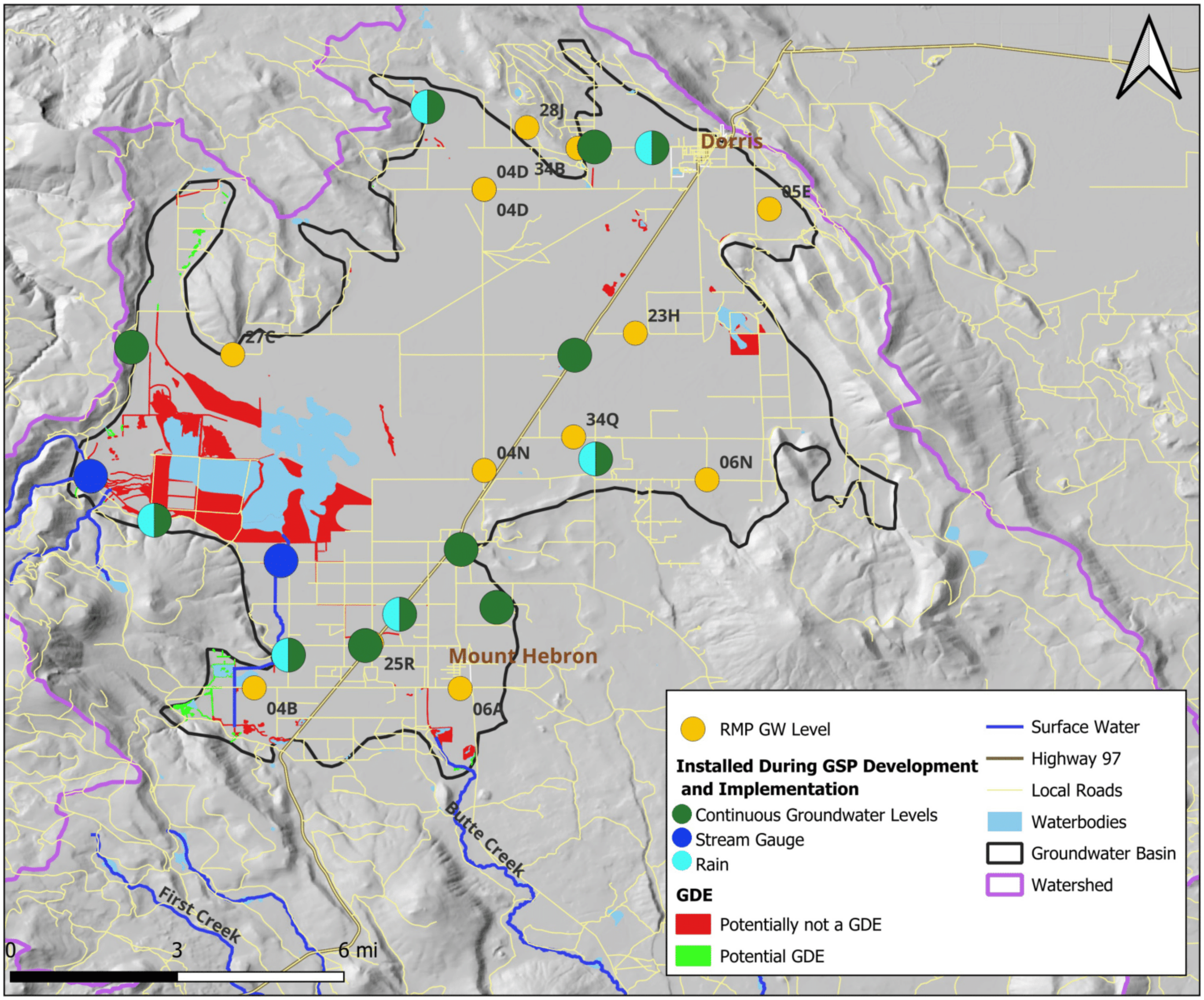
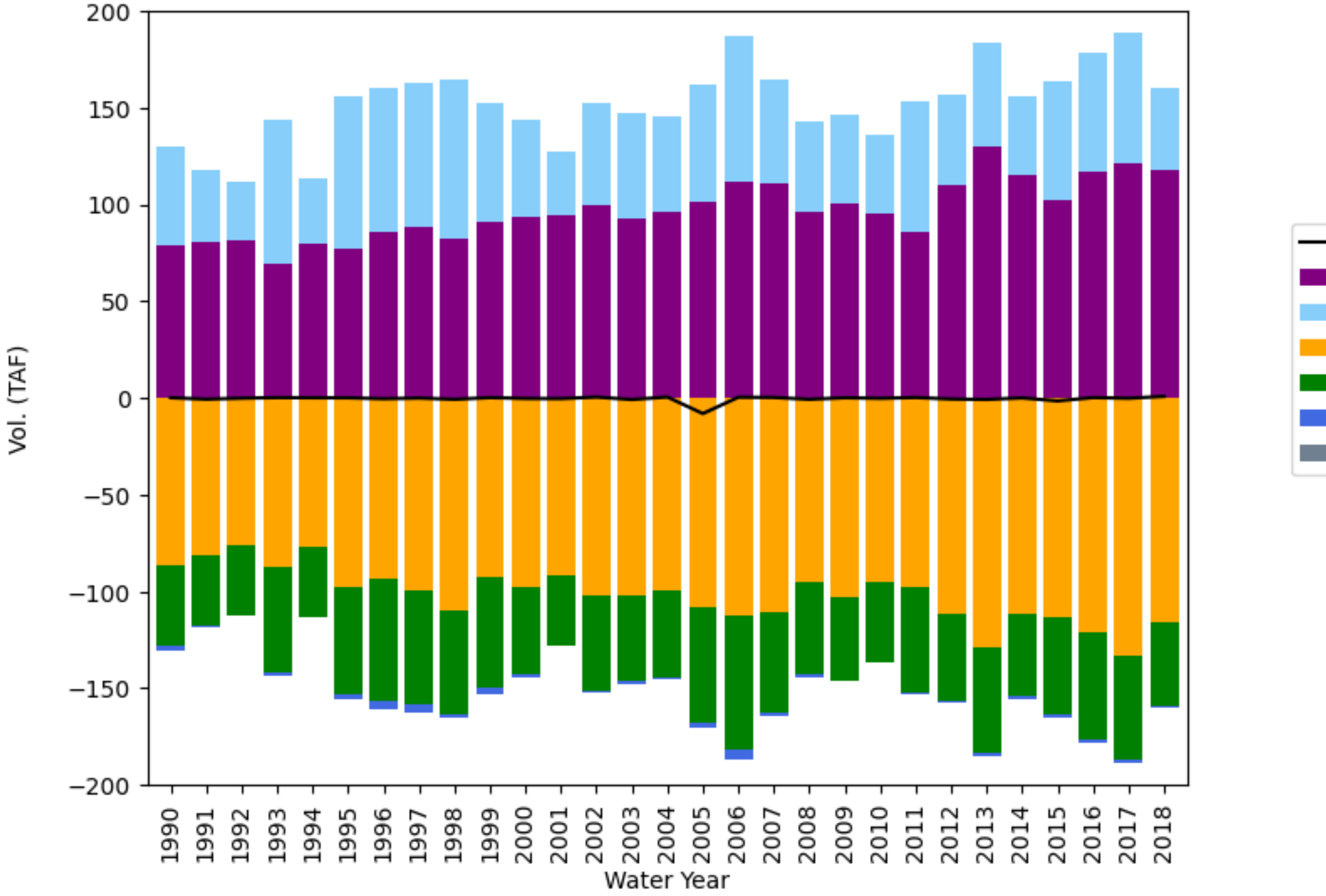


Figure 2.32: Categorized GDEs and Monitoring Stations Installed during GSP Development and Implementation for the Basin.

2.2.3 Water Budget Information

The historical water budget for the Butte Valley hydrologic watershed and the Bulletin-118 (B118) ~~B~~basin were~~as~~ estimated for the period October 1989 through September 2018 (i.e., water years 1990 through 2018). ~~using t~~The ~~recently ~~developed Butte Valley Integrated Hydrologic Model (BVIHM)~~, which~~ extends over the entire ~~Watershed~~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 BVIHM area and B118~~full~~ basin ~~model period ~~are shown in Figures 2.32~~ and Figure~~-~~ 2.33 ~~34 and monthly values of selected budget components are shown in Figure 2.~~34 ~~35 for each of the four example water years. Tables 2.13~~ and Table ~~-~~2.~~14 show a summary of these budgets, and details are provided in Appendix 2-D. The following two sections provide an overview of BVIHM, which is used to determine the full water budget for the two relevant subsystems of the B118 ~~B~~basin: the irrigated land subsystem (including crops and soils) and the groundwater subsystem. The water budget also includes the total water budget of the B118 ~~B~~basin. Separately, water budgets for the ~~entire ~~w~~W~~atershed are presented for context, including the groundwater subsystem budget, the irrigated land subsystem budget, and the total water budget for the watershed (including the B118 ~~B~~basin contained within the ~~Watershed~~watershed). The second section provides a description of the water budget shown in the ~~Figures ~~figures and t~~T~~ables below and explains the water budget dynamics in the context of the B118 ~~B~~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 (SMCs), and the development of project and management actions (PMAs) (Chapters 3 and 4).



Vol. (TAF)
200
150
100
50
0
−50
−100
−150
−200
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Water Year

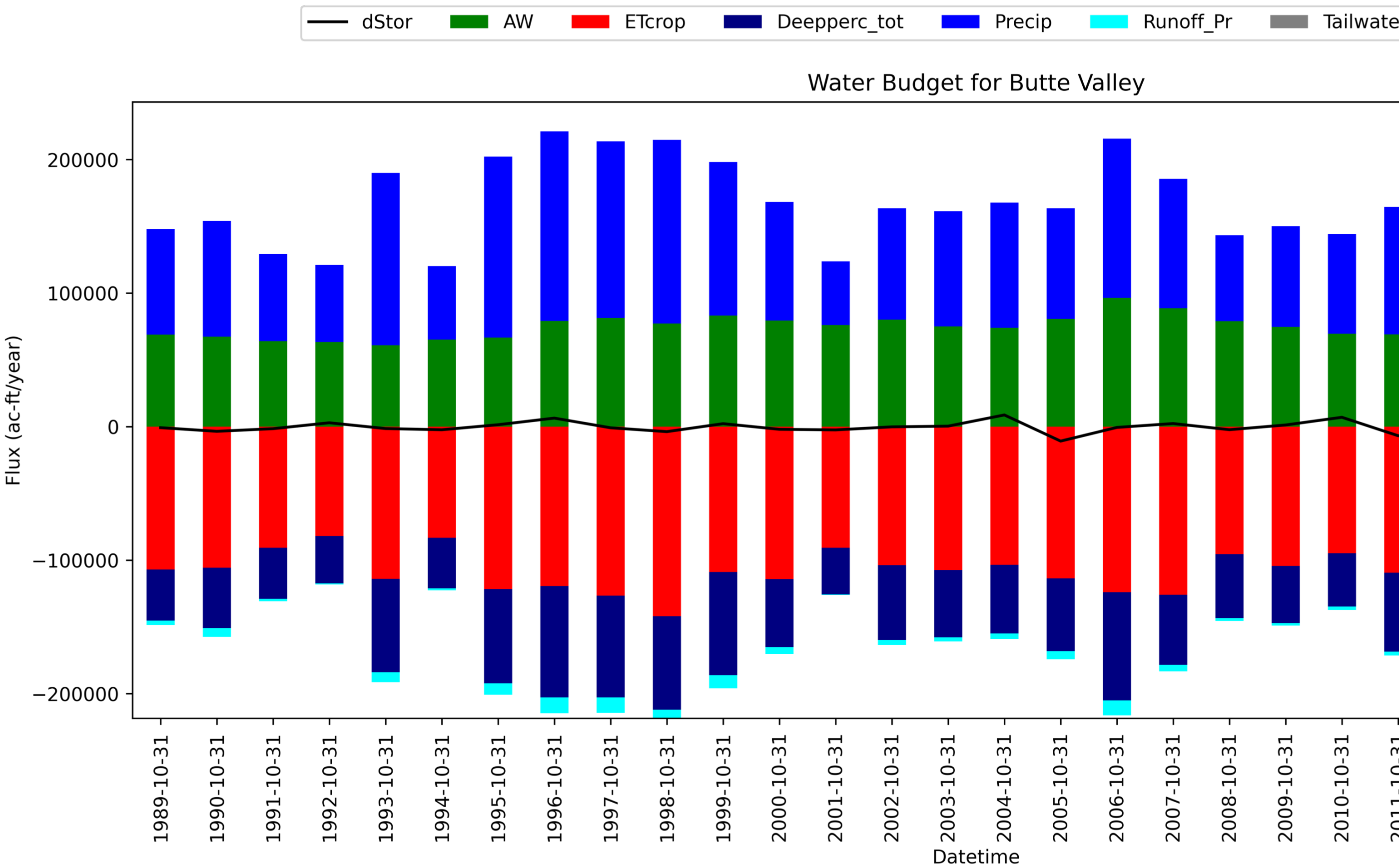


Figure 2.32: Annual water budgets for the irrigated land (land use, crop, soil) subsystem of the Butte Valley Integrated Hydrologic Model (BVIHM) area~~Basin~~. dStorage: change in storage within the land subsystem (within the uppermost portion of the unsaturated zone, including the crop/vegetation root zone). ~~AW: applied water.~~ Crop ET~~ETcrop~~: actual ET from crops, lawns, and natural vegetation. Deep~~perc_tot~~ percolation: 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.

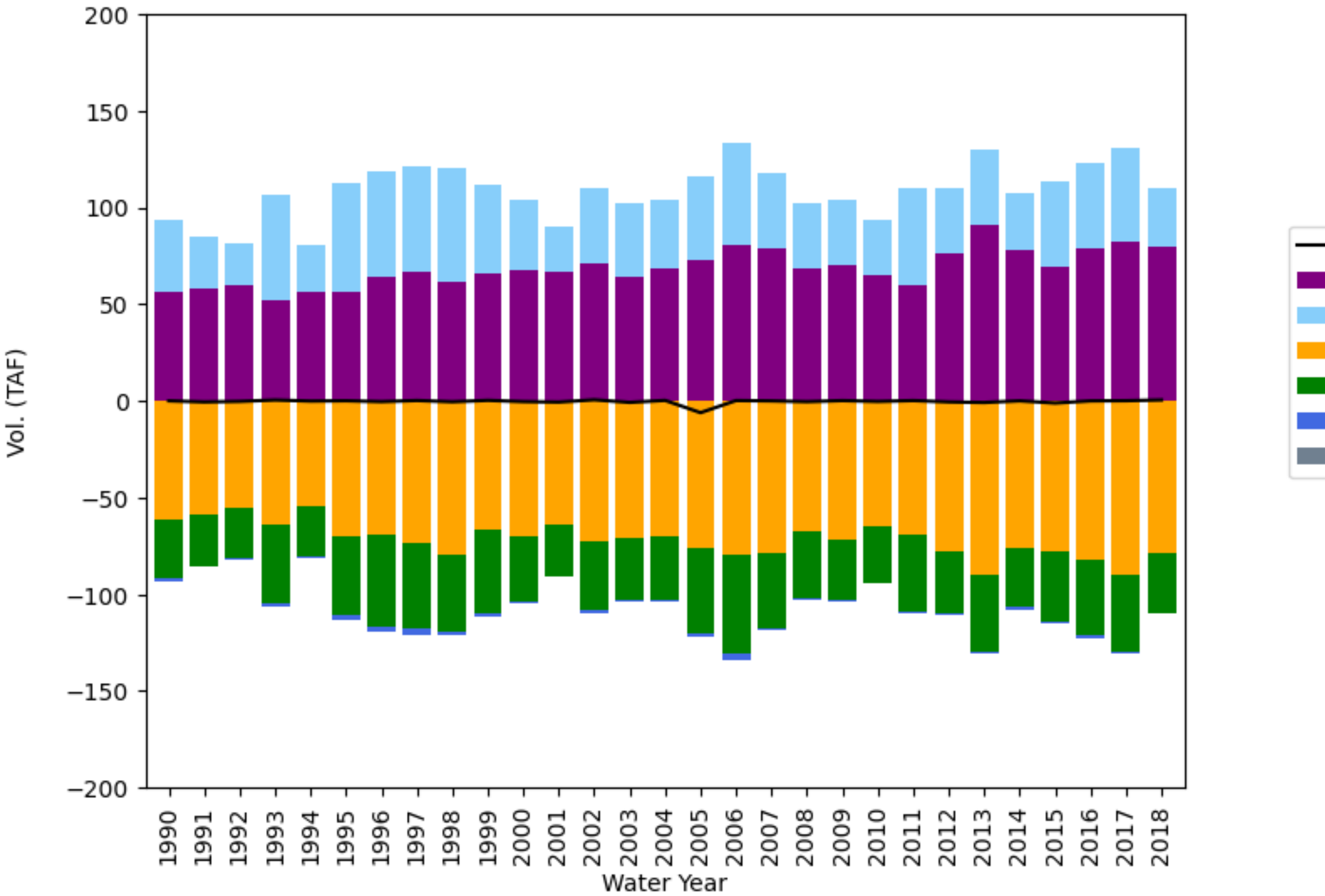
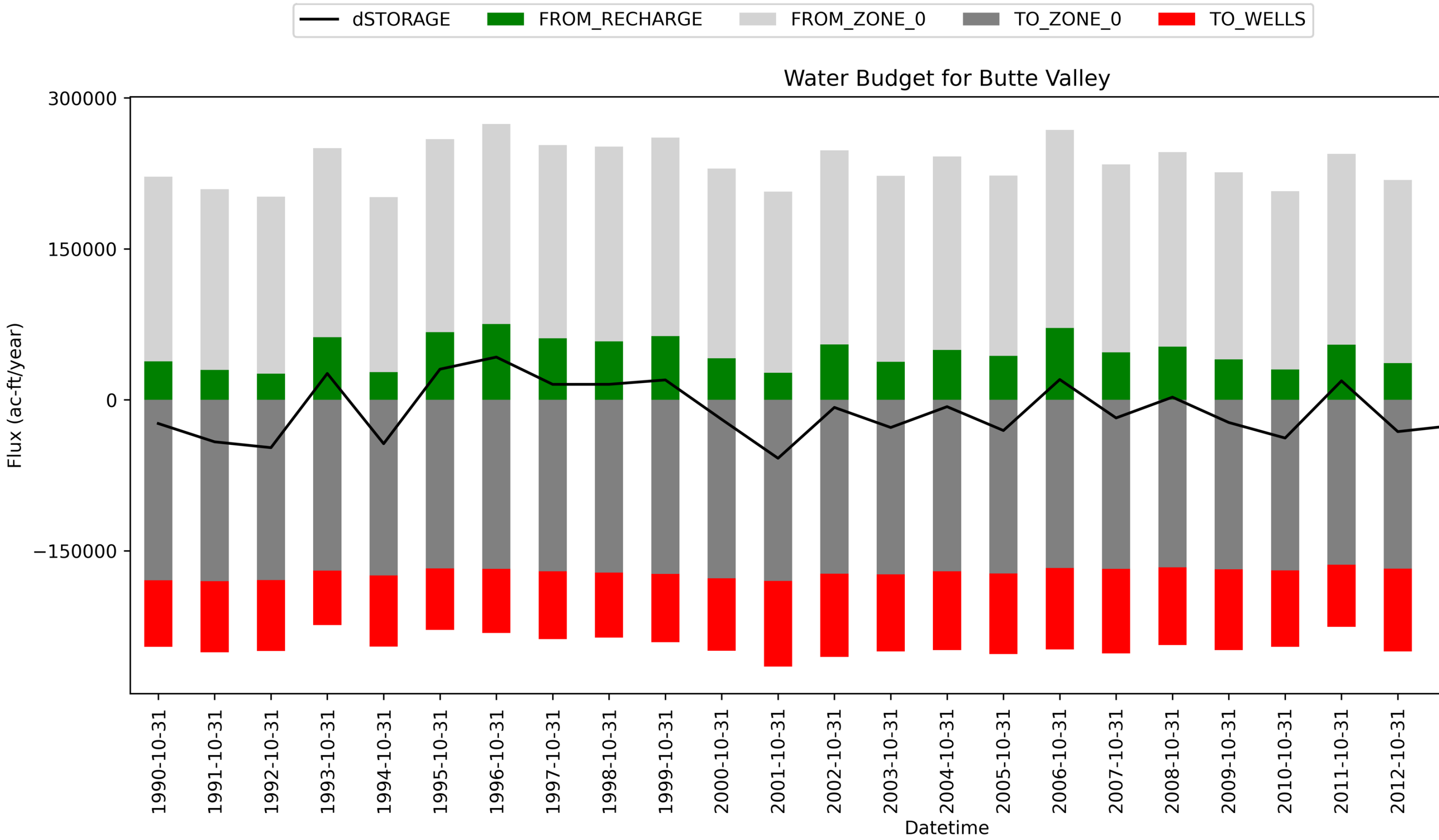


Figure 2.32: Annual water budgets for the irrigated land (land use, crop, soil) subsystem of the Bulletin-118 (B118) basin. dStorage: change in storage within the land subsystem (within the uppermost portion of the unsaturated zone, including the crop/vegetation root zone). Crop ET: actual ET from crops, lawns, and natural vegetation. Deep percolation: deep percolation from the upper portion of the unsaturated zone, assumed to be equal to groundwater recharge for the same year. Runoff: surface runoff from precipitation. Tailwater: tailwater return flows, assumed to become groundwater recharge.


dSTORAGE
FROM_RECHARGE
FROM_ZONE_0
TO_ZONE_0
TO_WELLS
Water Budget for Butte Valley
Flux (ac-ft/year)
300000
150000
0
−150000
1990-10-31
1991-10-31
1992-10-31
1993-10-31
1994-10-31
1995-10-31
1996-10-31
1997-10-31
1998-10-31
1999-10-31
2000-10-31
2001-10-31
2002-10-31
2003-10-31
2004-10-31
2005-10-31
2006-10-31
2007-10-31
2008-10-31
2009-10-31
2010-10-31
2011-10-31
2012-10-31
Datetime

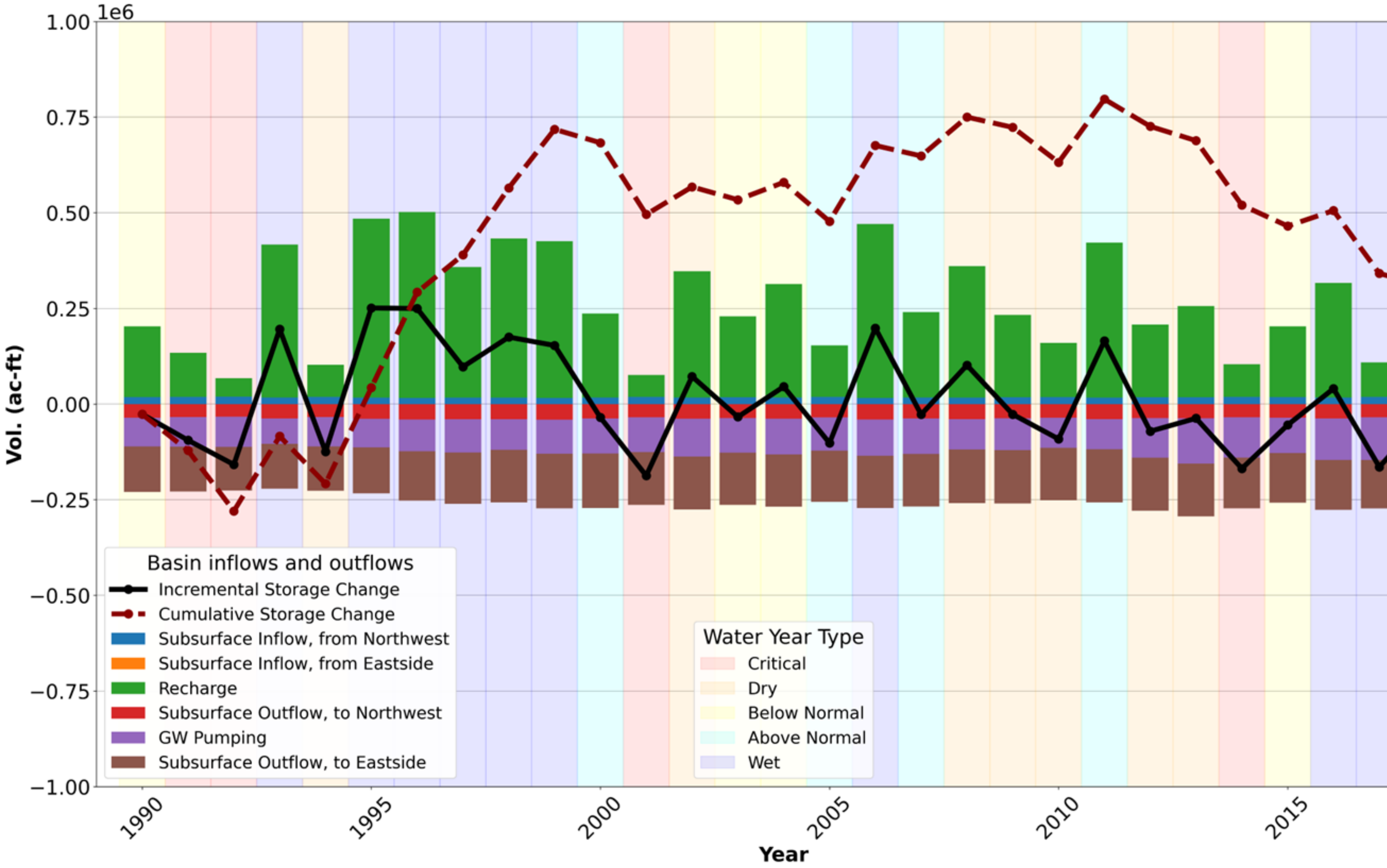


Figure 2.33: Annual water budgets for the Butte Valley Integrated Hydrologic Model (BVIHM) area. Incremental Storage Change: annual change in groundwater storage. Cumulative Storage Change: cumulative change in groundwater storage from the beginning time period. Subsurface Inflow from Northwest: lateral inflow to the BVIHM area from Northwest. Subsurface Inflow from Eastside: lateral inflow to the BVIHM area from Eastside. Recharge: landscape recharge to groundwater. Subsurface Outflow to Northwest: lateral groundwater outflows from the BVIHM area to Northwest. GW pumping: groundwater pumping (identical to AW in the land subsystem budget). Subsurface Outflow to Eastside: lateral groundwater outflows into Eastside.

~~Figure 2.33: 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)~~

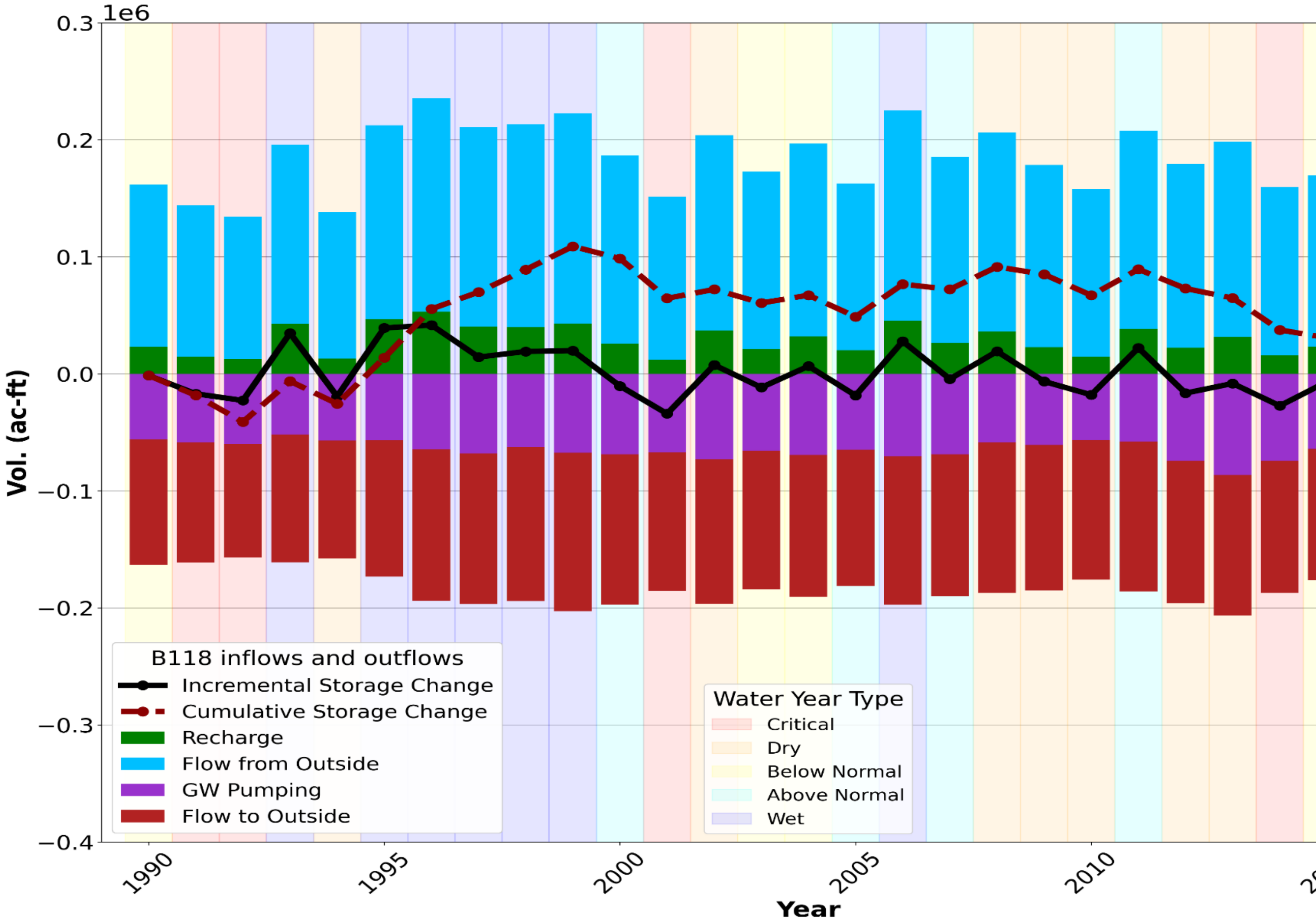
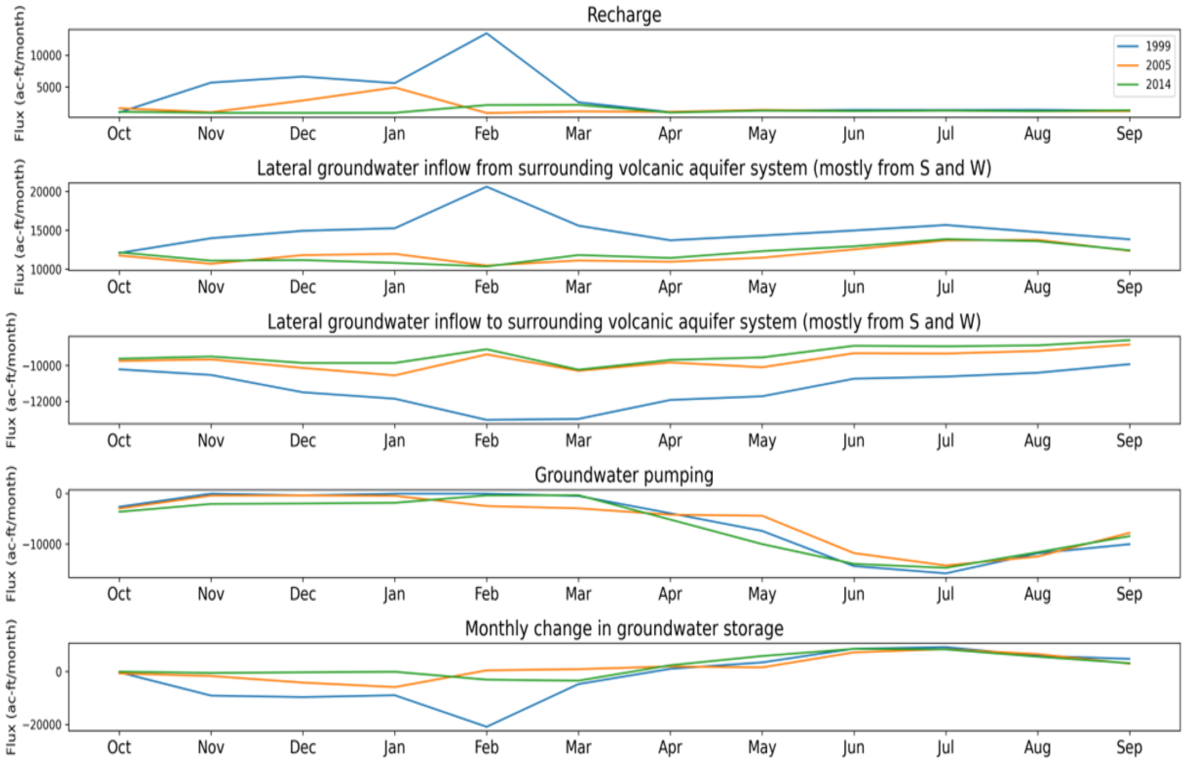


Figure 2.34: Annual water budgets for the Bulletin-118 (B118) basin. Incremental Storage Change: annual change in groundwater storage. RECHARGE: landscape recharge to groundwater (identical to the sum of Deepperc tot and Tailwater in the land subsystem budget). Flow from Outside: lateral groundwater flows into the Basin from the surrounding volcanic aquifer system. Flow to Outside: lateral groundwater flows out of the Basin into the surrounding volcanic aquifer system. GW pumping: groundwater pumping (identical to AW in the land subsystem budget).


Recharge
Flux (ac-ft/month)
10000
5000
1999
2005
2014
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Lateral groundwater inflow from surrounding volcanic aquifer system (mostly from S and W)
Flux (ac-ft/month)
20000
15000
10000
Lateral groundwater inflow to surrounding volcanic aquifer system (mostly from S and W)
Flux (ac-ft/month)
−10000
−12000
Groundwater pumping
Flux (ac-ft/month)
0
−10000
Monthly change in groundwater storage
Flux (ac-ft/month)
0
−20000

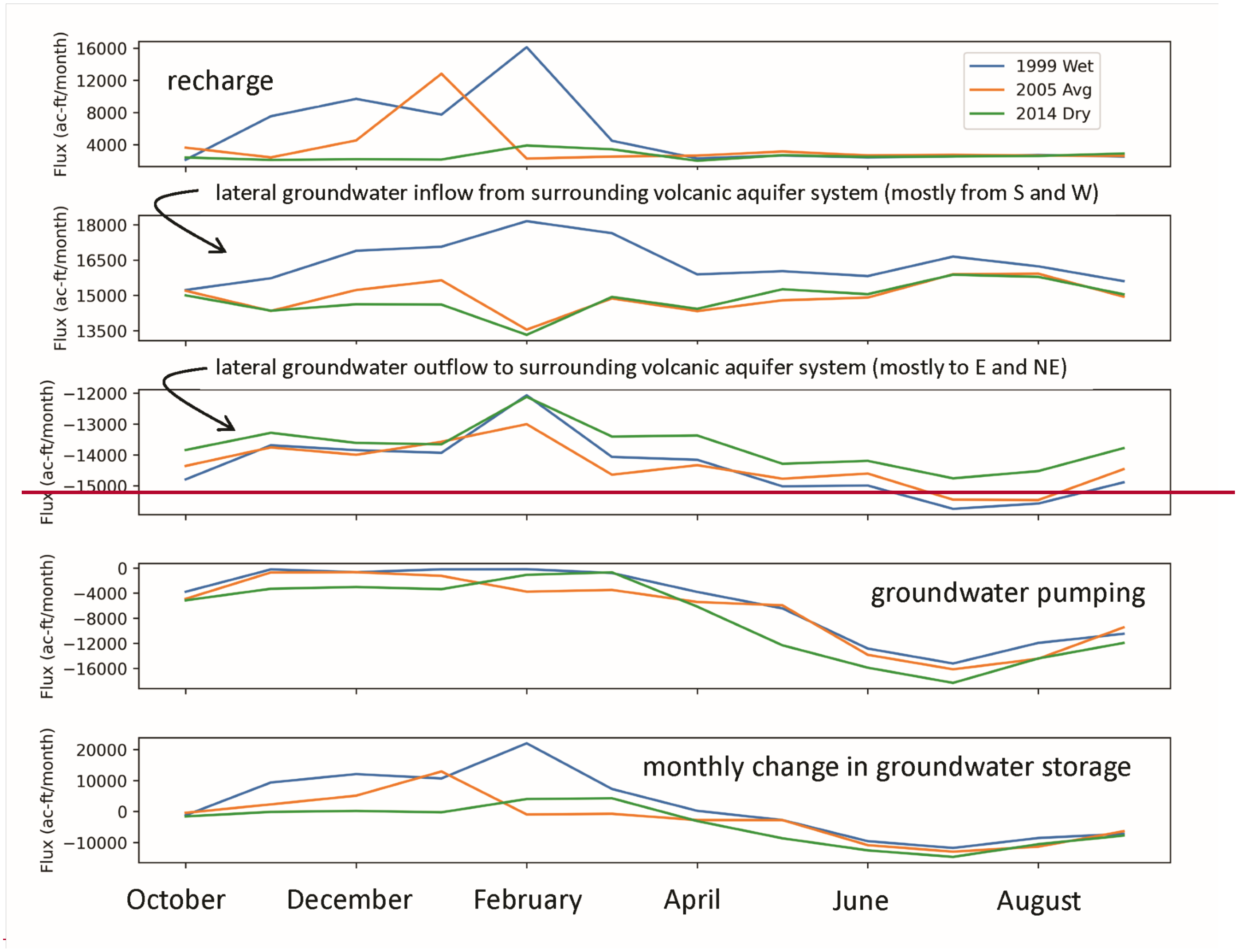


Figure 2.~~34~~35: Monthly values of selected water budget components in the groundwater subsystem of the Bulletin-118 (B118) ~~B~~basin in three example water years: 1999 (Wet year), 2005 (Avg. year), and 2014 (Dry year).

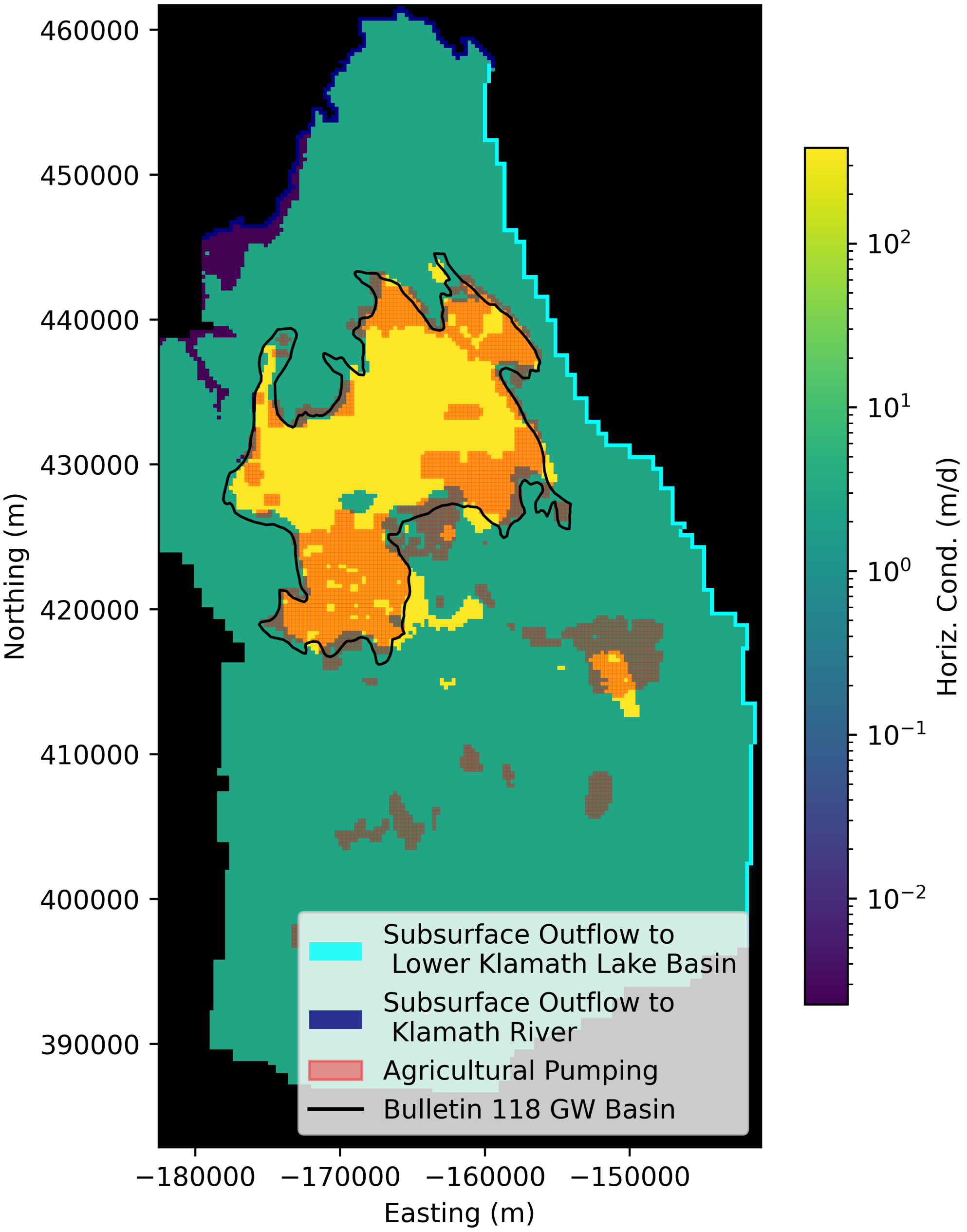


Figure 2.~~35~~36: The hydrogeologic zones, model domain, and boundary conditions used in the BVIHM simulation of the surrounding watershed and Basin.

Table 2.13: Annual values (TAF) for water budget components simulated in the irrigated l~~L~~and (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. Note: Tailwater values are zero throughout the estimated period (WY 1990-2018).

-	**BVIHM area**	**B118**	**BVIHM area**	**B118**	**BVIHM area**	**B118**	**BVIHM area**	**B118**	**BVIHM area**	**B118**	**BVIHM area**	**B118**
-	AW		ETcrop		Deepperc		Precip		Runoff		dStor	
Minimum	69.2	52.0	-132.8	-90.2	-69.6	-51.0	30.6	21.6	-4.5	-3.3	-8.0	-6.0
25th percentile	85.7	61.9	-111.1	-77.9	-54.9	-39.6	45.9	33.6	-2.2	-1.7	-0.5	-0.4
Median	95.5	67.6	-99.4	-70.6	-48.7	-35.8	53.7	39.0	-1.5	-1.1	0.0	0.1
75th percentile	110.4	76.1	-93.6	-66.2	-43.2	-31.0	67.8	48.6	-0.7	-0.6	0.3	0.2
Maximum	129.9	90.8	-75.9	-54.4	-36.1	-26.3	82.1	58.7	-0.2	-0.1	0.9	0.6

	~~AW~~	~~ETcrop~~	~~Deepperc~~	~~Precip~~	~~Runoff~~	~~dStor~~
~~Minimum~~	~~6111~~	~~-143650~~	~~-82731~~	~~22382~~	~~-11850~~	~~-7702~~
~~25th percentile~~	~~67952~~	~~-119228~~	~~-58548~~	~~67596~~	~~-6943~~	~~-1349~~
~~Median~~	~~76273~~	~~-108203~~	~~-50521~~	~~86197~~	~~-3776~~	~~-185~~
~~75th percentile~~	~~84366~~	~~-101418~~	~~-39120~~	~~102892~~	~~-1836~~	~~1570~~
~~Maximum~~	~~98272~~	~~-13806~~	~~-9302~~	~~143243~~	~~-441~~	~~4595~~

Table 2.14: Annual values (TAF) for water budget components simulated for ~~in the Groundwater (GW) subsystem of~~ the BVIHM area and B118 basin. Positive values are water entering the aquifer: recharge from the soil zone, lateral subsurface inflow (FROM OUTSIDE ~~ZONE 0~~) from outside of the B118 basin; negative values are water leaving the aquifer: lateral subsurface outflow (TO ~~ZONE 0~~OUTSIDE) to outside of the B118, groundwater pumping (WELLS). The overall change in water stored (dSTORAGE) in the aquifer can be both negative and positive in different water years.

	BVIHM area	**B118**	**B118**	**B118**	**BVIHM area**	**B118**	**BVIHM area**	**B118**
	RECHARGE		FROM OUTSIDE	TO OUTSIDE	WELLS		dSTORAGE	
Minimum	48.5	12.4	121.8	-135.5	-118.8	-86.3	-187.3	-34.0
25th percentile	141.7	20.2	143.2	-126.9	-94.4	-70.4	-91.4	-17.0
Median	219.5	25.8	157.1	-119.6	-88.9	-65.7	-27.3	-5.2
75th percentile	343.7	38.5	167	-112.4	-79.0	-58.7	101.6	19.2

Maximum	485.8	53.1	182.5	-97.0	-66.5	-51.9	251.2	41.7

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

2.2.3.1 Summary of Model Development

BVIHM was developed to support the development and implementation of this GSP. The simulation domain of BVIHM is a subset of the simulation domain for the USGS groundwater model of the Upper Klamath Basin (Gannett, Wagner, and Lite 2012). 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 Basin and somewhat larger, but fully inclusive of the 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. 2007).

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 2.~~35~~36).

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.
- 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 (Appendix 2-D). The output from this model include spatio-temporally distributed groundwater pumping (all applied water needs simulated by this module) and spatiotemporally 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 are simulated using the USGS PRMS software. This simulation module generates spatio-temporally distributed groundwater recharge for the 1989 to 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 (Harbaugh 2005; Markstrom et al. 2008) using the pumping and recharge output from the land subsystem simulation as input 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.
- 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 USGS 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 2.~~36~~37; see 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.

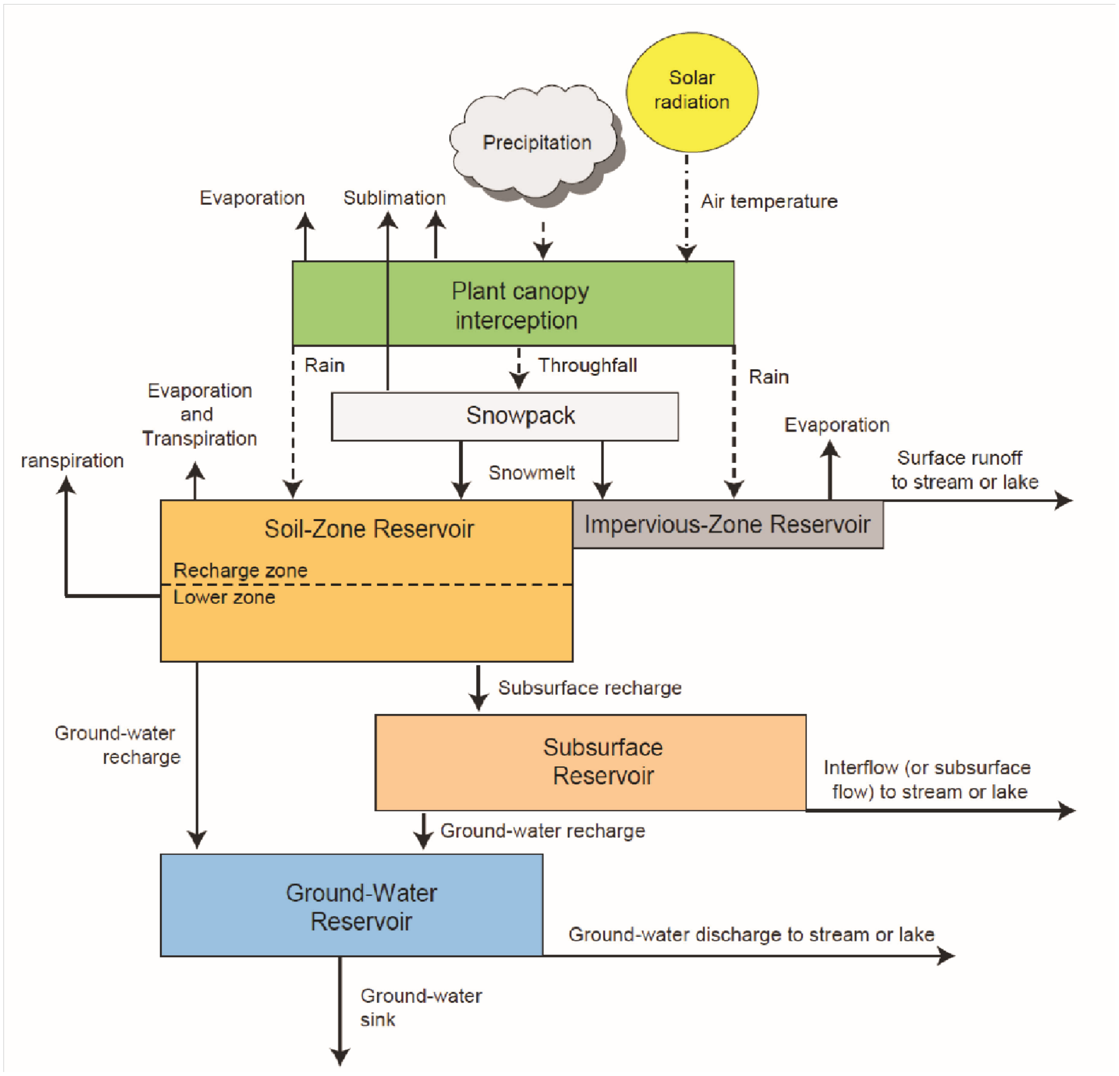


Figure 2.~~36~~37: Schematic diagram of a watershed and its climate inputes (precipitation, air temperature, and solar radiation) simulated by PRMS (from Markstrom et al., 2008).

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 2.~~37~~38).

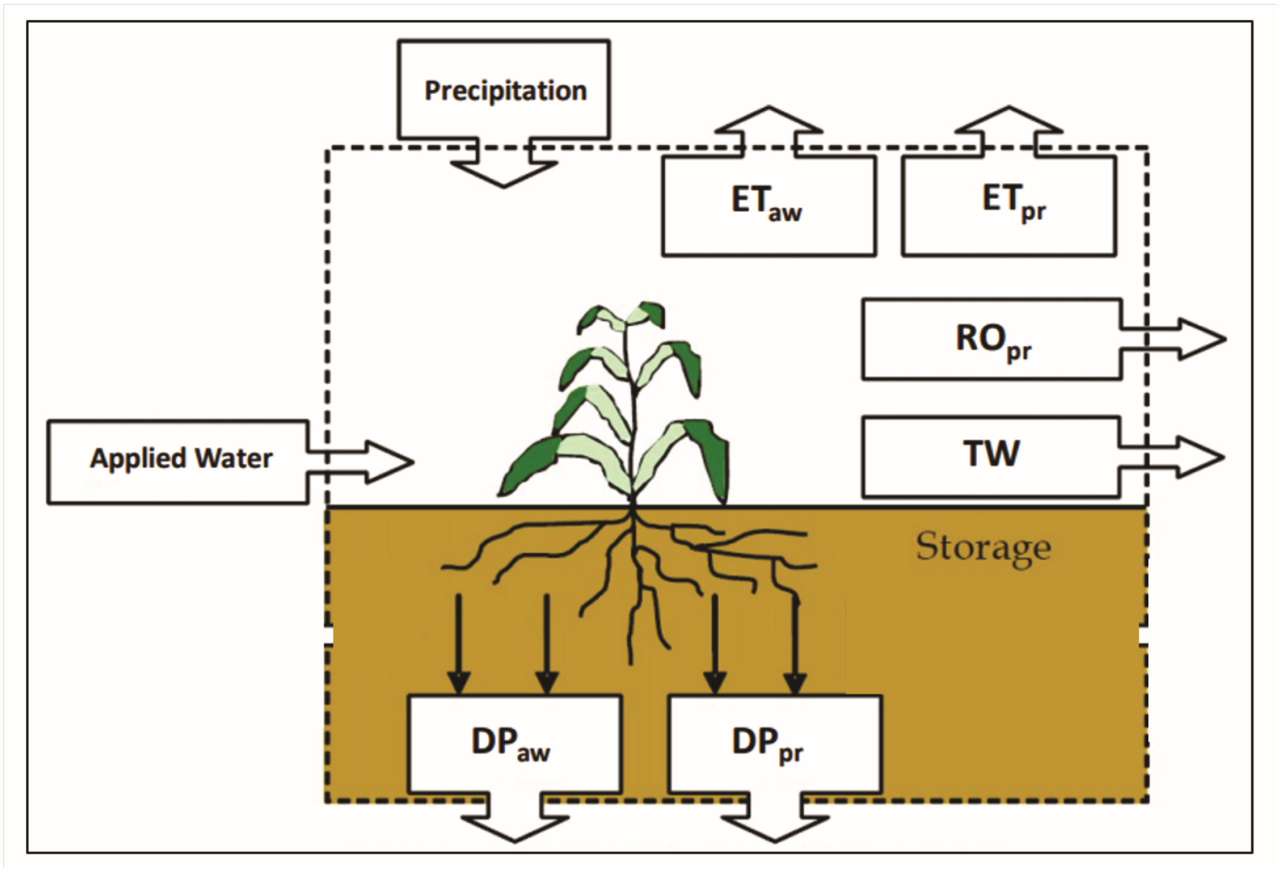


Figure 2.~~37~~38: Conceptualization of fluxes of water into and out of the crop root zone (modified from Davids Engineering, 2020 in Appendix 2-D).

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 to 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 2.~~37~~38).
- 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, Wagner, and Lite (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, Wagner, and Lite 2012) was investigated to find areas east of and closest to the eastern BVIHM simulation domain where water levels during its 1989 to 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 to 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 2.~~38~~39). 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 2.~~38~~39).

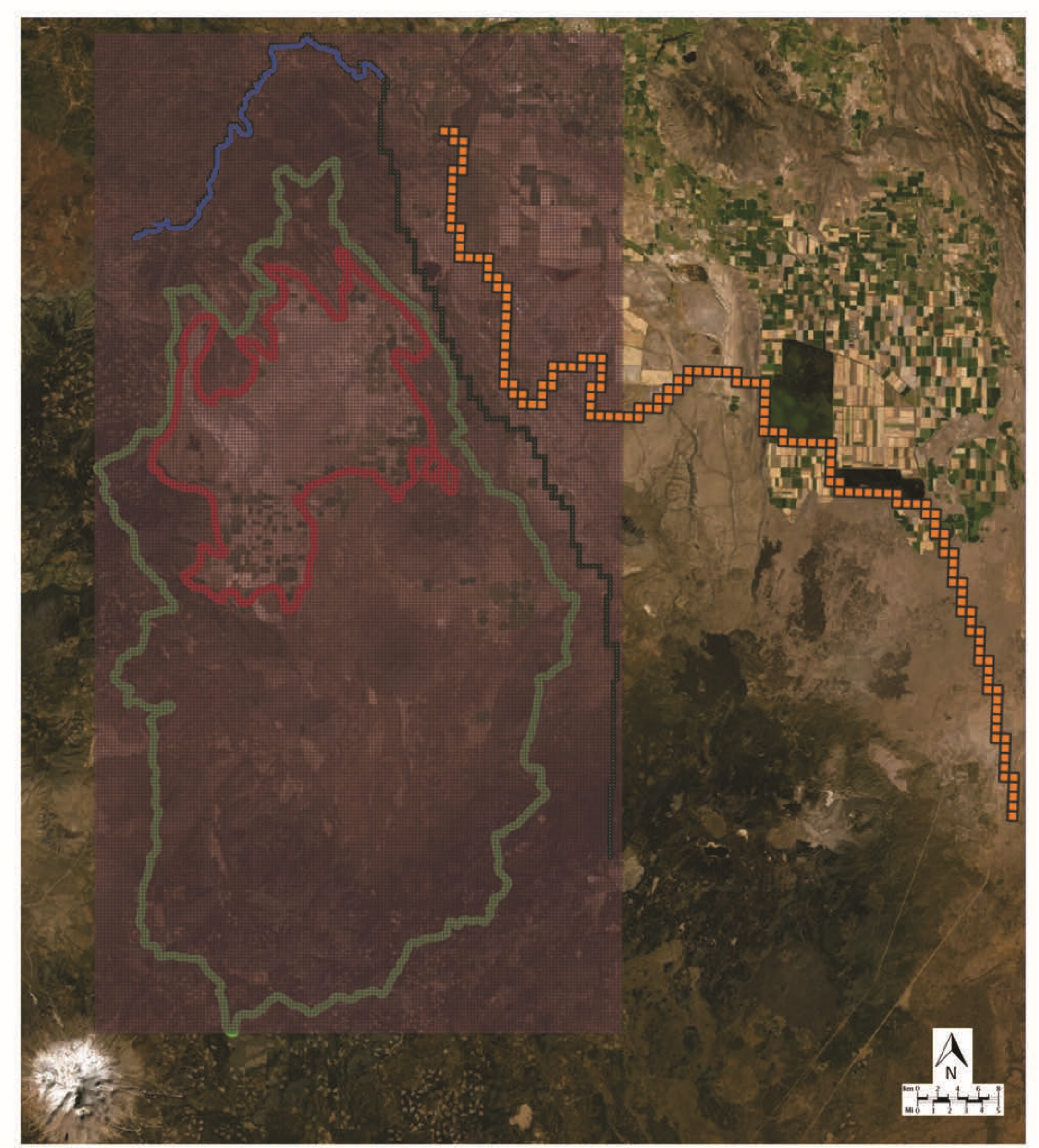
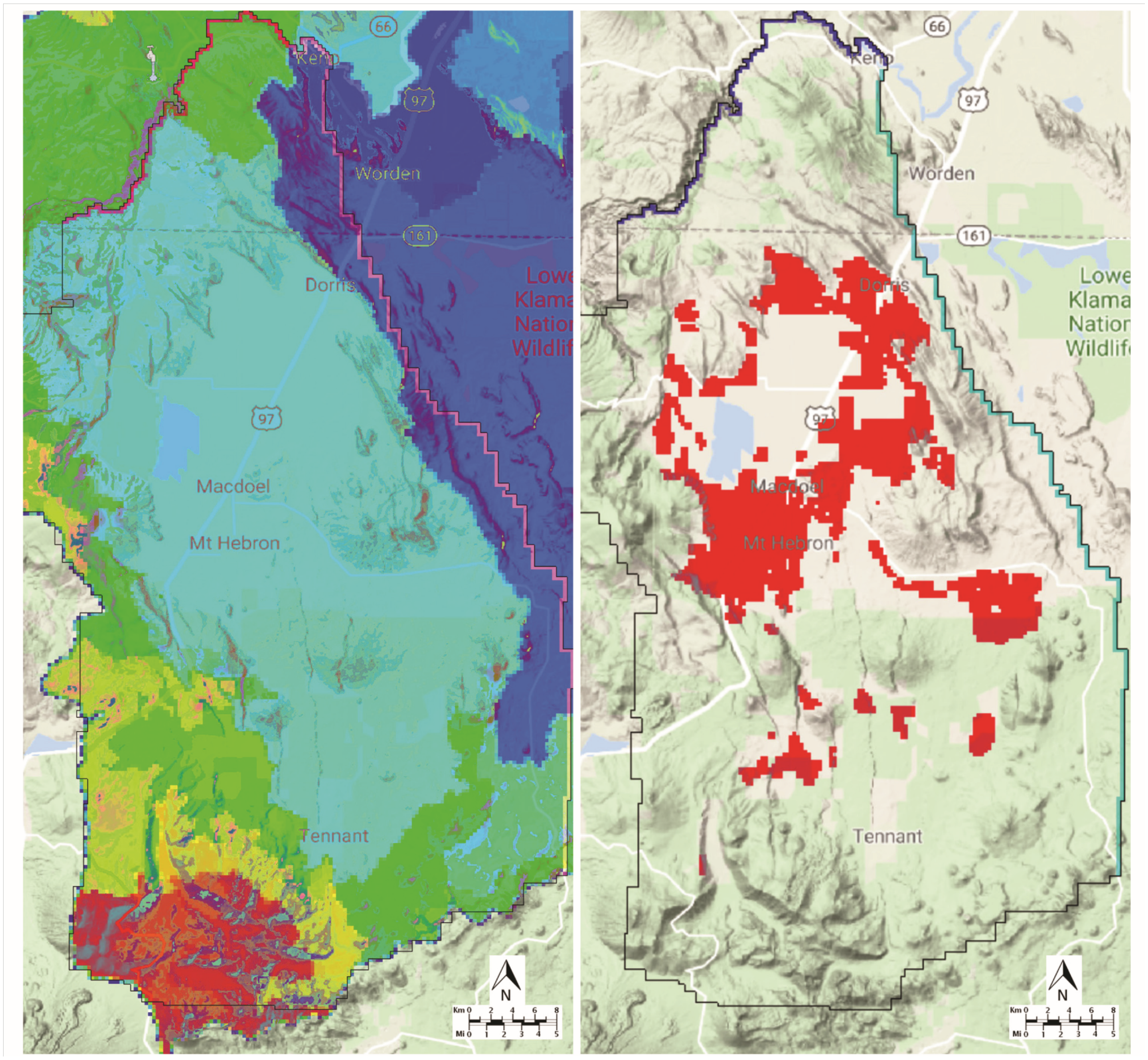


Figure 2.~~38~~39: Butte Valley watershed (green boundary), Butte Valley groundwater basin (red boundary), the BVIHM “general head” boundary (dark green line to the northeast and east of the watershed), the Klamath River as a “prescribed head” boundary (dark blue line to the north of the watershed), 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 2.3940~~Figure 2.41: 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 2.~~39~~40). 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 2.~~39~~40).

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; Gannett, Wagner, and Lite 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 irrigated land/soil subsystem, L, to the groundwater subsystem, GW.

Figure 2.32 and Figure 2.~~33~~ 34 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 where the account balance increases. In Figure 2.32 and Figure 2.~~33~~34, 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 2.32 and Figure 2.~~33~~34, 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 thousand acre-feet (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 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 (ET; 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 or 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 net groundwater use in the Basin ~~is not in overdraft~~does not exceed recharge, including subsurface inflows to the Basin. However, precipitation, evapotranspiration, and 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 overestimated actual~~were twice as large as actual~~ recharge by 100%, ~~and consequently~~ the actual groundwater inflow into Butte Valley would~~as~~ only be about half of simulated inflow. Even under that scenario,~~,~~ 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~~recharging is nearly negligible. 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 to 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 a significant long-term trend indicating some groundwater depletion. Only few years had a net positive groundwater storage change: 1993, 1996 to 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~~reduced gradients across the general head boundary.

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

The 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 its 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 2.~~34~~35).

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 a continuous 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:

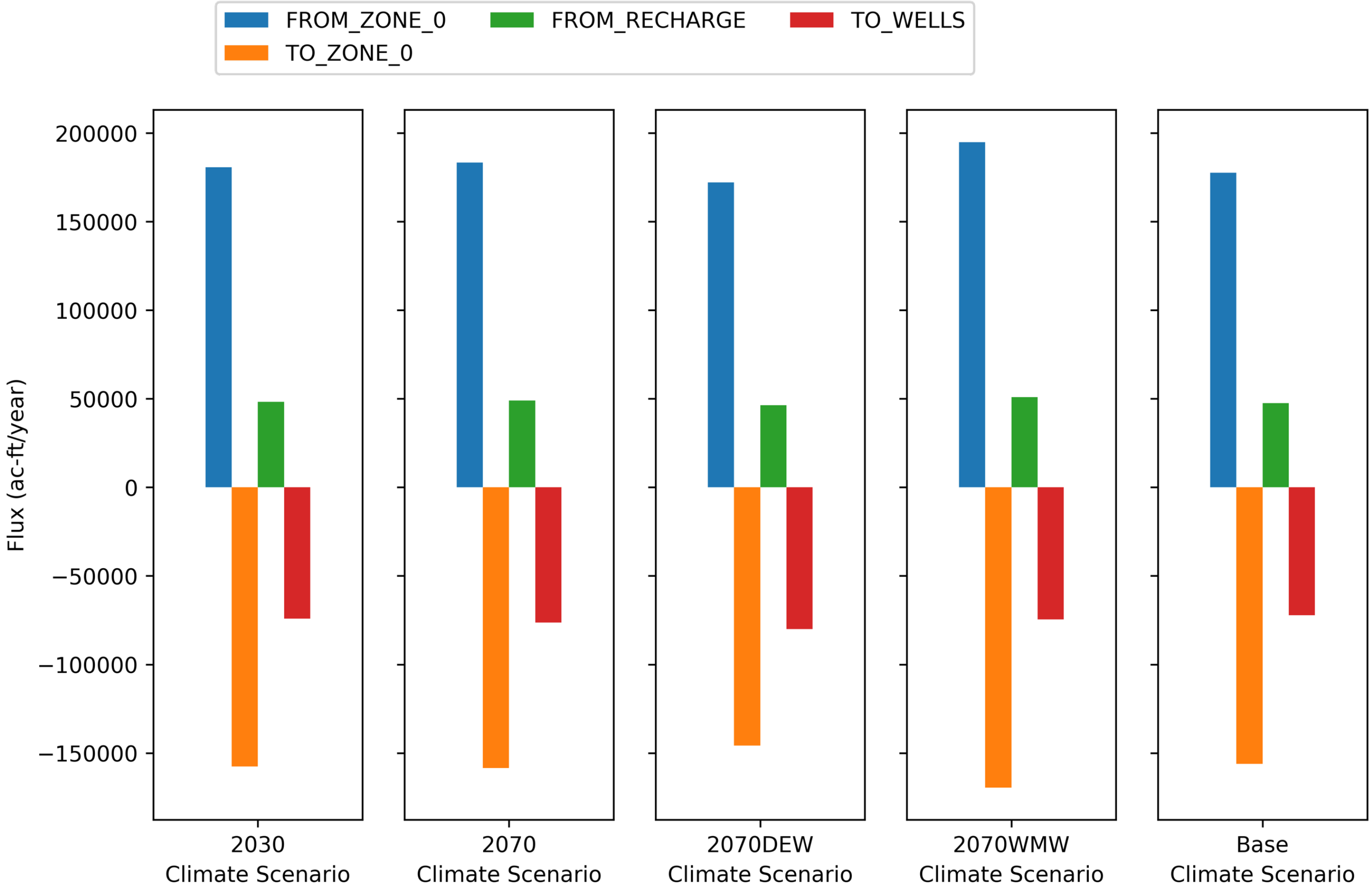
1. Observed weather and streamflow parameters from water years 1991 to 2011 were used multiple times to make a 50-year “Base case” climate record (see Appendix 2-D for details). The Base case projection represents a hypothetical future period in which climate conditions are the same as conditions from 1991 to 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 to 2071 for the Base case and all ~~four climate~~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 2.4041~~Figure 2.42: Water Budget components for different future climate scenarios.

Method Details

The climate record for the projected 50-year period of water years October 2021 to September 2071 was constructed from model inputs for the years 1991 to 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 (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 four 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 to 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 (MT) 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

2.2.5.1 Conceptual Basis for Estimating Sustainable Yield

Sustainable Yield in a Closed Groundwater Basin

In a closed groundwater basin, all inflow to and outflow from the groundwater basin come from and go back to the overlying landscape, streams, and lakes. On the inflow side, this includes recharge from losing streams, soil water percolation to the water table, and irrigation return flows under irrigated landscapes. On the outflow side of the groundwater budget, this includes discharge to wells, to gaining streams (baseflow) and to groundwater-dependent ecosystems (GDEs). Groundwater level and storage changes are directly related to the water mass balance of the landscape and surface water system overlying the basin: the annual storage change is equal to the difference between the sum of annual inflows from lakes, streams, and landscape recharge ("deposits") and the sum of annual outflow to wells, streams, and GDEs ("withdrawals"). If "deposits" exceed "withdrawals", groundwater storage increases (water levels rise). If "deposits" are less than "withdrawals", groundwater storage decreases (water levels fall).

SGMA defines sustainable yield as "*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.*" (CWC 10721(w)).

With respect to the water level and groundwater storage sustainable management indicators (SMCs), this means that water levels and groundwater storage must be in a long-term dynamic equilibrium. To the degree that recent long-term average historic "deposits" do not match "withdrawals" as defined above, the resulting average annual decline in groundwater storage must be addressed by either increasing the amount of "deposits" or by decreasing the amount of "withdrawals" or a combination of both, without causing additional undesirable outcomes with any of the sustainability indicators.

Hypothetically applied to the average annual groundwater storage changes that have been measured in the Butte Valley Basin, this principle would suggest that groundwater pumping must be reduced by 5 TAF/yr to 7 TAF/yr or external sources of water for MAR would have to be found in that amount (Table XX4, also see Section 2.2.2.4). For the period for which pumping has been estimated (1990 – 2023), average pumping was 67 TAF/yr and average measured groundwater storage decline was 4.2 TAF/yr. For the mega-drought period from 2000 to 2023, average pumping was 70 TAF/yr and the average measured groundwater storage decline was 6.3 TAF/yr. For more recent periods since 2010, average pumping is higher (73 – 76 TAF/yr), while groundwater storage changes remain at 4.7 – 6.4 TAF/yr).

Time Period	**Estimated Pumping (TAF/ Year)**	**Measured Groundwater Storage Change (TAF/year)**
Average 1990-2023	67	-4.2
Average 1990-2000	61	+0.8

Average 1990-2010	63	-2.7
Average 1990-2014	65	-4.1
Average 2000-2014	68	-7.4
Average 2010-2023	73	-6.4
Average 2014-2023	74	-4.7
Average 2017-2023	76	-5.4
Average 2000-2023	70	-6.3

Table XX4: Average groundwater pumping over several different time periods (Section 2.2.3.1) and the corresponding average measured groundwater storage change (Section 2.2.2.4). Groundwater pumping was estimated using the soil/landscape-subsystem model.

Sustainable Yield in an Open Groundwater Basin

In an open groundwater basin, significant subsurface inflows and/or outflows occur that must be accounted for in the water budget. The subsurface inflows add to the “deposits” in the water budget, while the subsurface outflows add to the “withdrawals” from the water budget. After accounting for these subsurface inflows and outflows, the sustainable yield of the groundwater basin, equivalent to a closed groundwater basin, is that which allows long-term dynamic equilibrium water levels and groundwater storage to remain sufficiently high to avoid undesirable results.

As described in Section 2.2.2.1., Butte Valley Basin is an open groundwater basin, that is, it is a sub-basin of the larger UKB groundwater system. The Basin has limited surface water inflows with creeks under losing conditions and likely disconnected from groundwater (Sections 2.2.1.9 and 2.2.2.9). Recharge from creeks and Meiss Lake are conservatively neglected for the water budget computation (Section 2.2.3).

~~U~~Under the developed groundwater conditions of the past 70 years, Butte Valley groundwater pumping for crop irrigation has been able to capture some of the naturally occurring subflow through the Basin, which enters on its southern and western boundary (subsurface inflow) and leaves through its eastern and northeastern boundary (subsurface outflow). The onset of groundwater pumping in the mid-20th century primarily affect~~ing~~ed the outflow through the Basin’s northern and northeastern boundary toward Lower Klamath Lake / Lost River (see Sections 2.2.2.1 and 2.2.2.2). T~~Potentially~~ the development of groundwater ~~has~~may also have captured ET from groundwater-dependent ecosystems (Wood, 1960).

Given the open nature of the Basin and the lack of large interaction with overlying surface water features or extensive GDEs, the largest “deposits” to and “withdrawals” from the Basin are subsurface inflow, recharge within the Basin (“deposits”), groundwater pumping within the Basin, and subsurface outflow (“withdrawals”). Neither subsurface inflow nor subsurface outflow can be measured or remotely observed and must be estimated using models. They are estimated to be the largest terms in the water budget (Section 2.2.3).

Subsurface inflow is primarily a function of the amount of recharge from precipitation upgradient of the Basin, in the volcanic uplands to the south and west (Section 2.2.3). In the Basin, groundwater pumping is significantly less than the long-term average amount of “deposits” (subsurface inflow and Basin recharge, Section 2.2.3) thus sustaining a large amount of subsurface outflow. The amount of ~~S~~subsurface outflow to the east and northeast is primarily driven by the difference between “deposits” (subsurface inflows and recharge within the Basin) and groundwater pumping. In other words, the subsurface outflow dynamically adjusts to the balance between “deposits” and groundwater pumping:

- Under long-term dynamically stable “deposits” –conditions, any change in groundwater pumping will cause a commensurate inverse change in subsurface outflow (more pumping leads to less outflow and less pumping leads to more outflow).
- Under long-term dynamically stable groundwater pumping conditions, any change in “deposits” will cause a commensurate change in subsurface outflow (less “deposits” will cause an equal decline in subsurface outflow).
- Subsurface outflow will dynamically adjust as long-term “deposits” may change (e.g., mega-drought) while groundwater pumping also changes (e.g., increased pumping due to drought conditions).

With respect to Butte Valley, the dynamic adjustment of the outflow to changes in either “deposits” or groundwater pumping or both is associated with two key insights that are relevant to sustainable yield and sustainable management of the basin:

1. It may take years to decades before subsurface outflow achieves it’s new equilibrium condition in response to changes in “deposits” or groundwater pumping. However, it’s dynamic reaction to such changes in “deposits” and groundwater pumping will be initiated as soon as such changes occur.
2. The amount of subsurface outflow controls the average elevation of the water table in the Basin above the downgradient regional (UKB) groundwater discharge points (see Textbox XX1)

Regarding the first key insight, the preliminary, uncalibrated version of BVIHM used for the water budget calculations indicates that the time for the Basin to reach new equilibrium conditions following a long-term change in either “deposits” or groundwater pumping for the Basin~~inin response~~ is on the order of several decades, but significant changes in water level and groundwater storage changes, beyond reactions to the specific water year type within the Basin may be observable within a five-year period, suggesting that it is reasonable to expect that PMAs will yield observable improvements in the water balance of the Basin within a five year period after initiation.

Regarding the second key insight, it follows that subsurface outflow must be increased to stop the chronic lowering of water levels and groundwater storage over the past 23 years. Absent significant sources of additional groundwater recharge (adding to the “deposits”), the Basin’s only option to achieve that is to decrease the amount of groundwater pumping. Were the Basin closed, the previous section already determined that a decline in groundwater pumping of 5 TAF/yr to 7.5 TAF/yr relative to recent groundwater pumping rates may achieve a balance. For the open basin, a sensitivity analysis was performed (see Textbox) to show at what level, relative to 1980’s assumed 62 TAF/yr groundwater pumping, future groundwater pumping would sustain groundwater levels at 2020 average water level conditions (assumed to be 30 ft lower than in 1980, corresponding to a 15% decline in subsurface outflow relative to 1980). Since the analysis is based on equilibrium conditions, this pumping level is an approximate estimate of sustainable yield. Table XX shows. Here are some examples of how to interpret the sensitivity analysis of that Table:

- If “deposits” in the future, R2020, will be the same as under 1980 conditions, and “deposits” amount to 180 TAF/yr (as estimated by BVIHM, Section 2.3), 2020 water level conditions would be afforded by a sustainable yield that is 129% of 1980 groundwater pumping (62 TAF) or 80 TAF/yr.
- If “deposits” in the future, R2020, will be 95% of 1980 conditions, and “deposits” in 1980 amounted to 180 TAF/yr, then a reasonable sustainable yield would be 114% of 1980 pumping or 71 TAF/yr.
- If “deposits” in the future, R2020, will be 90% of 1980 conditions, and “deposits” in 1980 amounted to 180 TAF/yr, then a reasonable sustainable yield would be 100% of 1980 pumping or 62 TAF/yr.
- If 1980 “deposits” were smaller than estimated by BVIHM, for example, 130 TAF/yr, then the three sustainable yield values above would be 116%, 106%, and 95% of 1980 pumping, 72, 66, and 59 TAF/yr, respectively.
- If 1980 “deposits” were higher than estimated by BVIHM, for example, 250 TAF/yr, then the three sustainable yield values above would be 145%, 125%, and 105% of 1980 pumping, 90, 78, and 65 TAF/yr, respectively.

2.2.5.2 Reported Estimates of Safe Yield

~~[~~DOI, 1980 reports that there is no long-term chronic decline in water levels in Butte Valley~~)~~ and that “the ultimate safe groundwater-supply (pumpage) is 102,00 acrefeet” (page 2 of DOI 1980). The source for 102 TAF/yr safe yield estimate was DWR, 1973, Bulletin 105-4, Supporting Studies Appendix, p.19. No other estimates of safe yield or sustainable yield have been reported for the Basin

Understanding why subsurface outflow from the Basin exerts critical control on the average water level elevation in the Basin

The Basin is a subbasin of the larger UKB groundwater system (Section 2.2.2.1). The groundwater discharge points of the Basin's subsurface outflow are the Lower Klamath Lake, Lost River, and Tule Lake, and possibly pumpers in those regions. The Basin is located upgradient of and approximately 200 ft higher than those groundwater discharge points. Average water level elevations in the Basin are primarily a function of subsurface outflow from the basin. Why is that?

Groundwater flow is governed by the basic principles of Darcy's Law, which states:

$$\text{groundwater flux} = \text{hydraulic conductivity} \times \text{hydraulic gradient}$$

The subsurface outflow from the Basin, in a simplified conceptual manner, can be understood as the groundwater flux from the eastern/northeastern boundary of the Basin to the groundwater discharge points further east. The hydraulic conductivity in the above equation therefore refers to the properties of the volcanic rocks separating the Basin from the groundwater discharge points to the east. And the hydraulic gradient is the average slope of the water table between the eastern/northeastern boundary of the Basin and the groundwater discharge points to the east.

The hydraulic conductivity of the region between the Basin and the groundwater discharge points is highly variable, unknown, but does not change in time. To understand why the Basin's average water level is controlled by the subsurface outflow, that is the groundwater flux through volcanics east of the Basin, we rearrange the above equation and obtain:

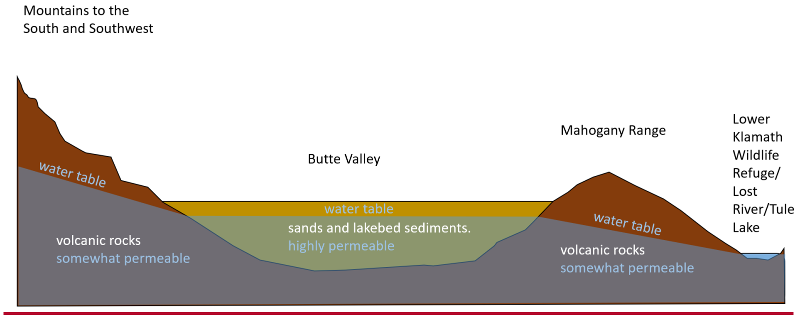
$$\text{hydraulic gradient} = \text{groundwater flux} / \text{hydraulic conductivity}$$

The equation now shows that the hydraulic gradient of the water level between the eastern/northeastern boundary of the Basin and the groundwater discharge points is directly proportional to the groundwater flux, that is, the subsurface outflow from the basin.

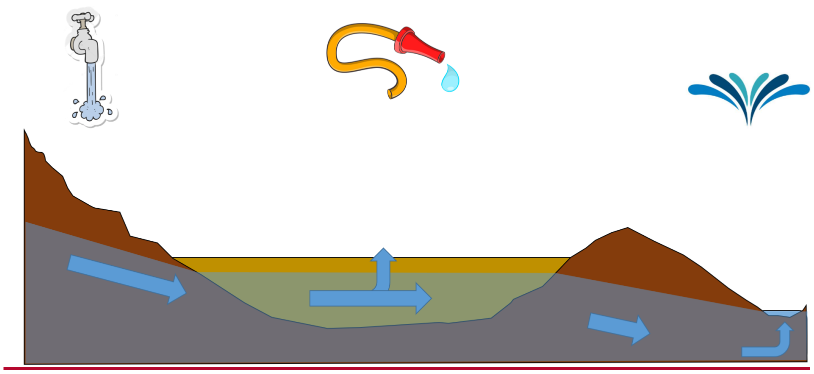
Since the elevation of the groundwater discharge points (Lower Klamath Wildlife Refuge, Lost River/Tule Lake) does not change, a change in the hydraulic gradient will, at equilibrium conditions, lead to a change in the water level elevation at the eastern/northeaster boundary of the Basin, which in turn controls the average water level elevation in the Basin.

3502

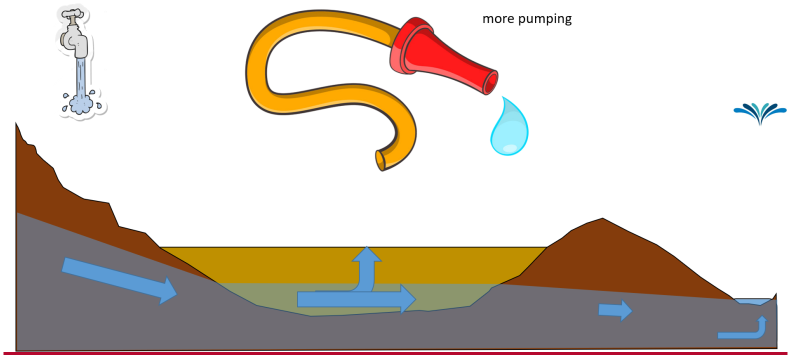
Simplified Conceptual South/Southwest to North/Northeast Cross-Section Butte Valley



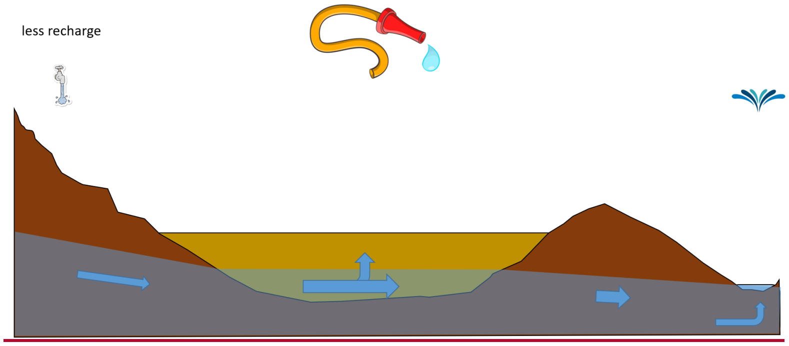
How Does Water Level Elevation Change in Such a System?



Same recharge, more pumping => less outflow from Butte Valley to "drain"



Less recharge, same amount of pumping => less outflow from Butte Valley to "drain"



Understanding why subsurface outflow from the Basin exerts critical control on the average water level elevation in the Basin [continued from the previous page]

To the degree that groundwater outflow from the Basin is reduced by groundwater pumping – or by a reduction in “deposits”, i.e., groundwater inflow from the volcanic uplands to the south and west of the Basin or Basin recharge – a proportionally smaller hydraulic gradient to the groundwater discharge points will develop at equilibrium conditions.

Practically speaking, and oversimplifying the exact outcome, a reduction of subsurface outflow by, for example, 30%, will lead to a reduction in the hydraulic gradient to the groundwater discharge points by 30%, and thus the elevation difference between water levels in the Basin and water levels at the groundwater discharge points will be reduced by 30%, once new groundwater flow equilibrium conditions are reached.

The time needed to reach equilibrium conditions is a function of the permeability and storage capacity of the groundwater system upgradient, within, and downgradient of the Basin, but is expected to be years to decades, given the size of the regional groundwater flow system that the Basin is part of. However, initial dynamic changes in water levels in response to changes in pumping, groundwater inflow, and recharge are readily observed on annual and seasonal time scales.

For groundwater management, the important corollary to understanding water level changes in the Basin as a response to changes in subsurface outflow toward downgradient groundwater discharge points is that those subsurface outflows must be maintained to establish stable water level conditions in the Basin. The subsurface outflow must be increased to counter long-term chronic declines in water levels, either by increased subsurface inflow, Basin recharge, or by decreased groundwater pumping.

Thus far, this conceptual outline above has assumed that the groundwater discharge points to the east remain constant in elevation. However, as pointed out by members of the Butte Valley GSA advisory committee, some or most of the groundwater discharge points maybe associated with pumping in the Tule Lake and Klamath Valley areas in both California and Oregon. Due to significantly increased pumping in those areas after the year 2000, median groundwater levels in those areas, between 2000 and 2014, have declined by 30 ft (Klamath Valley) and nearly 25 ft (Tule Lake). These areas are 15 to 25 miles east of the Basin boundary. It is hydrogeologically plausible that the observed decline in groundwater levels in the areas that likely are the groundwater discharge points for the Butte Valley Basin subsurface outflow have affected or will eventually affect water levels along the eastern/northeastern boundary of the Basin and, hence, impact average water levels in the Basin. However, the degree and time scale over which such impacts may occur are highly uncertain. A modeling study to assess such outcomes has not yet been initiated.

3505 ***Sensitivity Analysis: Relating observed water level changes in the Basin to increased pumping and decreased subsurface inflow.***

Applying Darcy's law as explained in the previous textbox, to the Basin, the following assumptions will be made:

- The average water level elevation in the Basin around 1980 was 4230 ft amsl
- The average water level elevation in the Basin around 2020 was 4200 ft amsl (30 ft lower)
- The average water level elevation at the groundwater discharge points is 4030 ft amsl

A 30 ft decline in water levels by 2020 is a 15% reduction of the difference in elevation between the Basin and the groundwater discharge points relative to 1980 conditions (4230 ft amsl minus 4030 ft amsl = 200 ft). It is therefore a 15% reduction in the hydraulic gradient and the subsurface outflow to the groundwater discharge points east of the Basin.

Using a simple mass balance approach for 1980 and 2020, we obtain the following relationships:

$$O1980 = R1980 – P1980$$

$$O2020 = R2020 – P2020$$

where:

O1980 and O2020 are the subsurface outflow in 1980 and 2020, respectively

R1980 and R2020 are the “deposits” (subsurface inflow and Basin recharge) in 1980 and 2020, respectively

P1980 and P2020 is the groundwater pumping in 1980 and 2020, respectively.

From the above, we know that O2020 = 0.85 x O1980 (15% lower in 2020 than in 1980).

If P2020 is expressed by a multiplier x (%) of P1980, the pumping in 1980 and, similarly, R2020 is expressed as a fraction y of R1980, the “deposits” in 1980, then, for given y, P1980, and R1980, the following two equations are used to also compute)1980 and the relative increase or decrease in pumping since 1980, x:

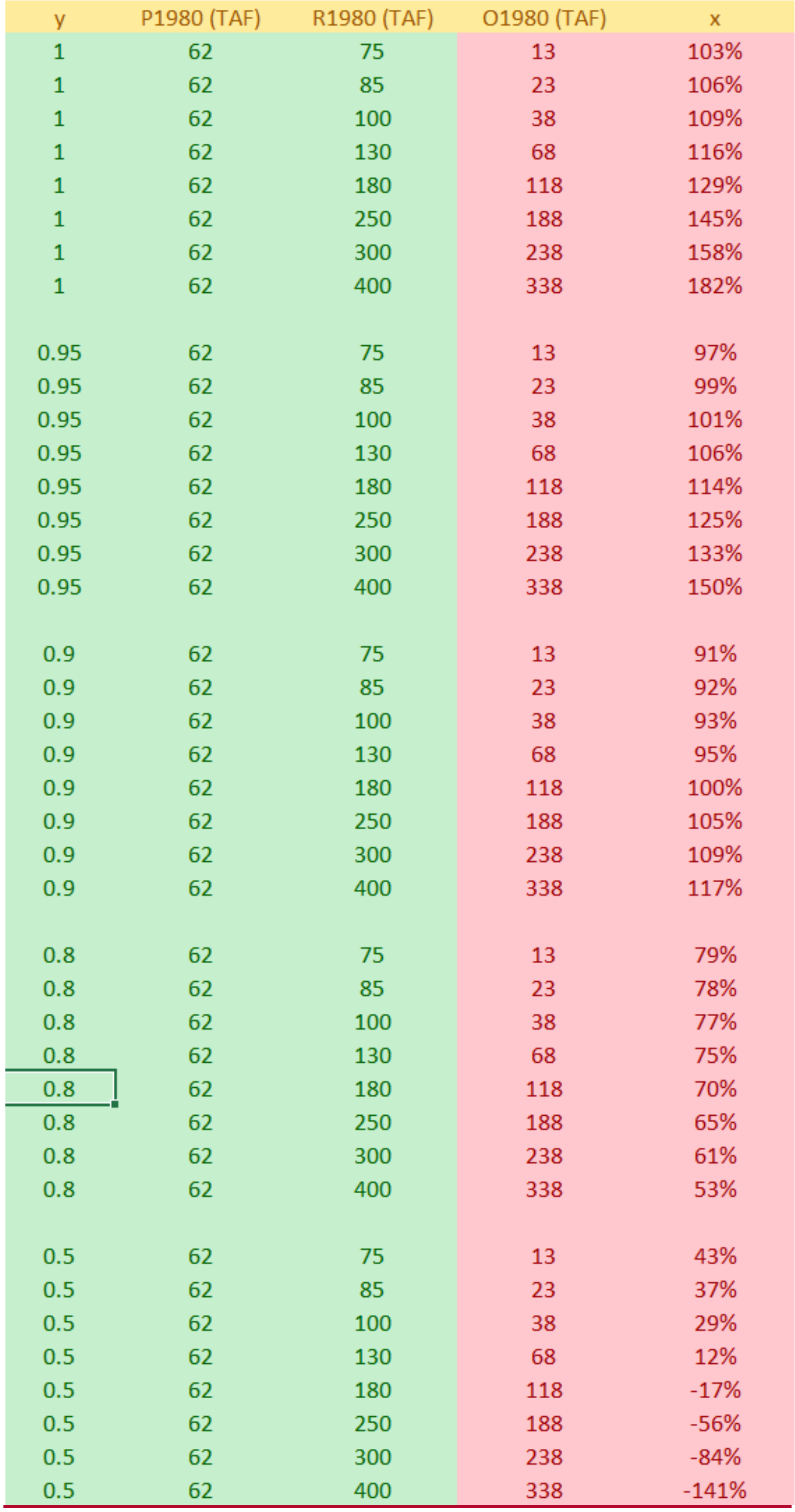
$$O1980 = R1980 - P1980$$

$$x = (y\ R1980 - z\ O1980) / P1980$$

A table for a range of plausible y, P1980, R1980, and commensurate O1980 was prepared to show how the observed 15% change in subsurface outflow between 1980 and 2020 may be explained by x, the change in groundwater pumping since 1980. For 1980, groundwater pumping was assumed to be 62 TAF (Section 2.2.2.2).

The analysis assumes equilibrium conditions in 1980 and in 2020. Hence, the fraction x provides a simple (and therefore approximate) estimate of the relative change in pumping to P1980 that provides long-term stable groundwater table and storage conditions at 2020 water level elevations, which are near the MO and well above the MT.

Sensitivity Analysis: Relating observed water level changes in the Basin to increased pumping and decreased subsurface inflow [continued]



y	P1980 (TAF)	R1980 (TAF)	O1980 (TAF)	x
1	62	75	13	103%
1	62	85	23	106%
1	62	100	38	109%
1	62	130	68	116%
1	62	180	118	129%
1	62	250	188	145%
1	62	300	238	158%
1	62	400	338	182%
0.95	62	75	13	97%
0.95	62	85	23	99%
0.95	62	100	38	101%
0.95	62	130	68	106%
0.95	62	180	118	114%
0.95	62	250	188	125%
0.95	62	300	238	133%
0.95	62	400	338	150%
0.9	62	75	13	91%
0.9	62	85	23	92%
0.9	62	100	38	93%
0.9	62	130	68	95%
0.9	62	180	118	100%
0.9	62	250	188	105%
0.9	62	300	238	109%
0.9	62	400	338	117%
0.8	62	75	13	79%
0.8	62	85	23	78%
0.8	62	100	38	77%
0.8	62	130	68	75%
0.8	62	180	118	70%
0.8	62	250	188	65%
0.8	62	300	238	61%
0.8	62	400	338	53%
0.5	62	75	13	43%
0.5	62	85	23	37%
0.5	62	100	38	29%
0.5	62	130	68	12%
0.5	62	180	118	-17%
0.5	62	250	188	-56%
0.5	62	300	238	-84%
0.5	62	400	338	-141%

Table XXX: Sensitivity analysis that shows the relationship between the observed decline in water levels over the past 40 years and possible increases in groundwater pumping (x).

~~3~~2.2.5.3~~43~~ Estimation of Sustainable Yield with BVIHM

Using the uncalibrated BVIHM, the sustainable yield is estimated as the long-term average annual groundwater pumping rate in the Basin that does not cause an undesirable result. Guided by the two previous analyses, one assuming that the Basin were a closed basin and the other accounting for the fact that the Basin is an open basin, a sensitivity analysis with BVIHM showed that, under climate conditions equal to the past 23 years, an average pumping rate of 65 TAF/yr leads to long-term dynamically stable groundwater storage and water level conditions (see Appendix 2D).

2.2.5.4 Setting the 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 (w)).

~~In this plan, ~~Chapter 2 defines the water budget analysis and Chapter 3 defines undesirable results. Based on the three analyses presented in this section, the analytical estimate of a sustainable yield assuming simple closed basin conditions, the analytical estimate of a sustainable yield assuming open basin conditions, and the analysis of a sustainable yield using a preliminary version of BVIHM suggest a **sustainable yield of 65 TAF/yr**.

After accounting for the fact that this includes groundwater pumping for BVWA (Meiss Lake riparian vegetation/wetlands), the sustainable yield likely is the **same or slightly smaller than 1980 levels of groundwater pumping in the Basin**. It represents a **10% to 15% reduction in groundwater pumping estimated for recent periods, since 2010**. The sustainable yield is equal to the average estimated groundwater pumping rate during the baseline period from 1990 to 2014. **It is a 10% reduction of average groundwater pumping over the past 23 year period during which chronic lowering of water levels has been observed**.

~~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 sustainable yield ~~future groundwater pumping ~~may need to be further adjusted~~reduced~~ will be a function of the PMAs that are implemented,~~ and~~ their spatial extent, and the resulting stabilization of water levels and groundwater storage. 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 to 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 five-year plan update, given the ~~thenimplemented~~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.