2.2.1.5 Hydrology

The Watershed covers approximately 800 sq mi (~2,070 sq km) ranging in elevation from just over 2,000 ft (610 m; near the confluence with the Klamath River) to over 14,000 ft (4,300 m; near the peak of Mount Shasta) amsl. The Watershed encompasses several smaller watersheds; the two most notable being the Little Shasta River and Parks Creek. Shasta Valley also includes the Grass Lake area, a high volcanic plateau to the north of Mount Shasta. This area has few streams, none of which are connected to the Klamath River and which all flow into dry sinks; none of these streams support anadromous fish species (NOAA 2012). The Watershed is bounded to the west by the Scott River watershed, to the south by the Sacramento River watershed, to the east by the Butte Creek watershed, and by the Klamath River to the north. The Shasta River is approximately 58 miles (93 km) long stretching from the peak of Mount Eddy at about 9,000 ft (2,750 m) amsl to the confluence with the Klamath River. The Little Shasta River drainage basin within the Watershed is bounded by Goosenest Mountain (8,260 ft; 2520 m amsl) to the south, Ball Mountain (7,792 ft; 2375 m amsl) to the east and Willow Creek Mountain (7,828 ft; 2386 m amsl) to the north. Little Shasta River is predominantly spring fed, sustained by a series of springs emerging from Quaternary and Tertiary High Cascade volcanic materials, discussed further in the following sections.

Mount Shasta, snow-covered year-round, is the most conspicuous feature of the landscape, visible from all parts of the Valley. Several glaciers stretch along its upper slopes which are the primary source of recharge to the Basin. On its north slope, Whitney, Bolam, and Hotlum Glaciers descend to altitudes of about 10,000 ft (3,048 m) amsl. On the south slope, the Koiiwakiton Glacier descends to an altitude of 12,000 ft (3,658 m) amsl, and the Clear Creek and Winton Glaciers to about 11,000 ft (3,353 m) amsl. Regional climate models generally predict the loss of Mount Shasta's glacier volume over the next 50 years and total loss of the glacier by the year 2100, likely resulting in reduced recharge in the Basin (Pelto 2008).

The Shasta River has a complicated seasonal and longitudinal flow regime due to intricate surface water and groundwater interactions, coupled with extensive agricultural diversion and return flows (Vignola and Deas 2005; Nichols et al. 2010). The Watershed includes a small number of small-scale diversion dams and diversions of the Shasta River or major tributaries, with the two main sources of water being the Shasta River and Parks Creek with storage in Dwinnell Reservoir (Lake Shastina). A number of the small-scale diversion dams have been or are in the process of being removed or modified for fish passage. Water rights dictating usage throughout the Shasta Basin are a combination of riparian and appropriative water rights adjudicated as a part of the 1932 Decree (CDWR 1932). Buck (2013) constructed a groundwater model for a portion of the Watershed and summarized major balance components for the period 2008–2011.

The upper Shasta River, upstream of Dwinnell Dam, originates on the eastern slope of the Mount Eddy and is characterized by a runoff-driven hydrograph derived from rainfall and snowmelt (Nichols et al. 2010). Inflows to Lake Shastina consist of the upper Shasta River, flows diverted from Parks Creek near Edgewood, and Carrick Creek originating from the northwest flank of Mount Shasta. In 1928, construction of Dwinnell Dam was completed, impounding Lake Shastina to primarily serve as a storage reservoir and diversion for agricultural irrigation water throughout the Valley. Lake Shastina is the largest single water source in the Watershed. Outflow from Lake Shastina to the lower Shasta River, regulated by Dwinnell Dam, has reduced mean annual discharge in the reaches immediately downstream of the reservoir by up to 90 percent (Jeffres et al. 2008; Nichols 2008; Nichols et al. 2010). Maximum reservoir storage capacity in Lake Shastina is rarely achieved because of the permeable underlying volcaniclastic rocks which allow impounded water to flow into the underlying aquifer (Vignola and Deas 2005). Mack (1960) reported that multiple springs along the base of the ridge forming the western embankment of Lake Shastina increased in flow following construction of the reservoir. Seepage losses from Lake Shastina have been estimated at 6,500 to 42,000 acre-feet (AF) (~8-52 million cubic meters (m^3)) annually, significant relative to the reservoir's 50,000 AF (~62 million m^3) storage capacity, representing a loss of 13 to 84 percent of storage capacity (Paulsen 1963, NCRWQCB 2006).

Flows in the lower Shasta River, downstream of Dwinnell Dam, are composed of minimal releases from Lake Shastina, tributary creeks (e.g., Parks Creek, Willow Creek, Little Shasta River), multiple discrete groundwater springs (e.g., Big Springs, Little Springs, Clear Springs, Kettle Springs, Bridge Field Springs), and additional diffuse groundwater springs. The lower Shasta River is characterized by a spring-dominated hydrograph primarily sourced from Big Springs Creek, supplied by multiple groundwater springs in the Big Springs Complex vicinity (Jeffres et al. 2008, Nichols 2008, Nichols et al. 2010). Spring-fed baseflows from Big Springs Creek outside the irrigation season (i.e., November to March) are five times those of the lower Shasta River upstream of the Big Springs Creek confluence (including Parks Creek) for the same time period (Jeffres et al. 2009). Approximately 95 percent of baseflows during irrigation season (i.e., April to October) in the lower Shasta River originate from the Big Springs Complex. During irrigation season, Big Springs Creek baseflows are approximately 35 percent lower, caused by temporally variable irrigation diversions and unquantified groundwater pumping (Jeffres et al. 2009). in-stream flows downstream of Big Springs Creek confluence quickly rebound to spring-fed baseflow conditions following irrigation season (Nichols et al. 2010).

Dwinnell Dam is the largest water storage structure in the Basin, with current capacity of 50,000 AF (~62 million m^3), upgraded from 36,000 AF (~44 million m^3) in 1955 (CDFW 1997). Water is delivered to users in Shasta Basin via canals, diversion facilities, pumps, and storage infrastructure (Willis et al. 2013). Major diversions and smaller dams or weirs are located below Dwinnell Dam, along with numerous diversions on tributaries (CDFW 1997; Lestelle 2012; NOAA Fisheries 2014; CDFW 2016). Several diversions and return channels exist largely for agricultural purposes that primarily operate during the irrigation season, including the Grenada Irrigation District Ditch, the Shasta River Water Association, and Oregon Slough (Jeffres et al. 2010) (Figure 31).

The City of Yreka obtains much of its water supply from Fall Creek (Figure 32), located outside the Watershed near Iron Gate Reservoir (Pace Engineering 2016). The City's treated wastewater, totaling 966 AF (1.2 million m^3) in 2015, is discharged to percolation fields near Yreka Creek (Pace Engineering 2016). Historical in-stream flow data were collected from the United States Geological Survey (USGS) and DWR Water Data Library and California Data Exchange Center (CDEC). Two (2) USGS streamflow gages (stations SRM and SRY) are present in the Watershed with observed discharge data spanning water years 1911-2021 and 1933-2021 respectively. Five additional gauging stations are maintained by DWR and are associated with sporadic data collection in two to three-year periods. Gage locations in the Watershed are shown in Figure 32.

Data were analyzed to assess quantity and quality of the observed record. Quantity was measured as percent of days with recorded flow data at each gauge, and quality was assessed as percent of days flagged by USGS as having been "edited or estimated by USGS personnel" (USGS 2018). Figure 34 provides a summary of USGS data quantity and quality in the Watershed; a continuous flow record of reliable data (in terms of quantity and quality) is present throughout the watershed from 1957 to present. In 2005 and 2009, The Nature Conservancy acquired property in the Watershed, and at this time the University of California at Davis Center for Watershed Science, the Nature Conservancy, and Watercourse Engineering began monitoring streamflow in Big Springs

Creek, the mainstem Shasta River, and Little Shasta River (Jeffres et al. 2008, 2009, 2010; Nichols et al. 2016, 2017; Null et al. 2010; Willis et al. 2012, 2013, 2017). Additional sources of flow data include gages placed on the Shasta River and Parks Creek in 2001 and 2002 (Watercourse Engineering 2006); estimates of unimpaired flows (Deas et al. 2004); a 2016 water balance study (SVRCD 2016); summaries of discrete flow measurements for springs in the Watershed including Little Springs Creek (Deas et al. 2015) and Big Springs Creek (Appendix G of NCRWQCB 2006); measurements of springs, creeks, and diversions on the Shasta Springs Ranch (Chesney et al. 2009, Davids Engineering 2011); and a compilation of data for sites in the Little Shasta River drainage basin (CDFW 2016). Streamflow data from all available sources was assessed during hydrologic model development to identify important critical conditions. Data quantity and quality impact both selection of data to be used for calibration and interpretation of model performance during associated time periods. More weight is given to locations and time periods with higher quality data. Data from several USGS stream gages were used in calibration with equal weighting as the data sets had similar quantity and quality of data. As the modeled time period is expanded to recent years more streamflow data will be included and further assessment of data quantity and quality will be done.

In-stream flows in the Watershed have been significantly affected by water resource management in the Basin. Seasonal low flow and drought conditions naturally occur in the watershed, but are becoming more common. Studies have been conducted to characterize hydrology and hydrologic habitat in the Watershed and to determine interim and minimum in-stream flow needs in the Watershed (McBain & Trush 2013, CDFW 2017). The in-stream Flow Needs study documented historical and current sampling above and below Parks Creek confluence, in the center of the Watershed (McBain & Trush 2013). Historical data of unimpaired mean monthly flow in the Upper Shasta River and Parks Creek estimate a maximum of approximately 208 cubic feet per second (cfs) (~6 cubic meters per second (m3/s)) and a minimum of 6 cfs (~0.2 m3/s) during spring and summer months. Baseflows in spring and summer 2010 recorded a maximum of 36 cfs (~1 m3/s) and a minimum of 5.6 cfs (0.16 m3/s; see Figure 33). According to these studies, considerable inter-annual streamflow variability exists along with uniformity and predictability of streamflow between June and late October, consistent with other streams in the region.

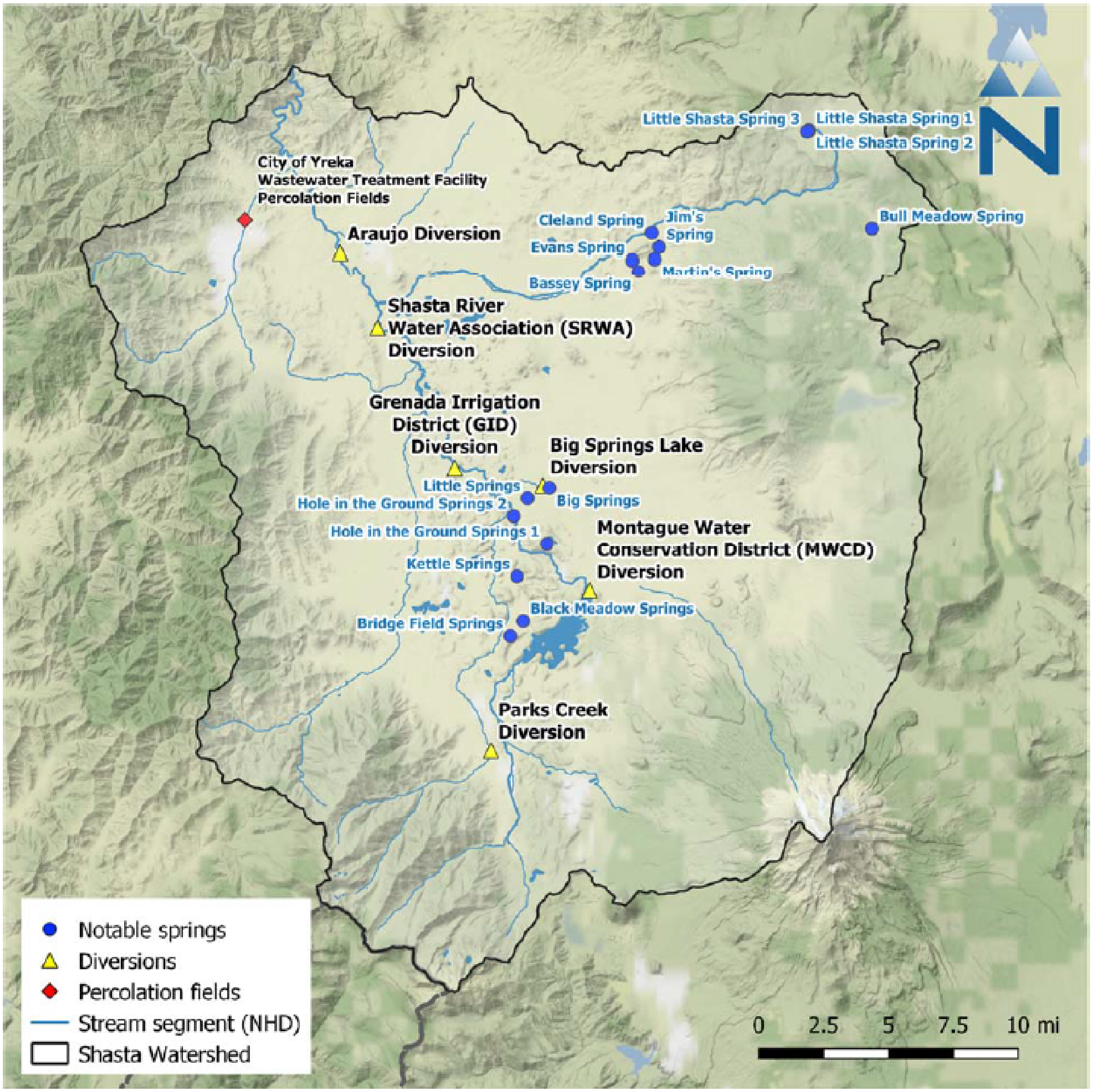


Figure 31: Notable hydrologic features of the Shasta River Watershed. Reprinted from SWRCB (2018).

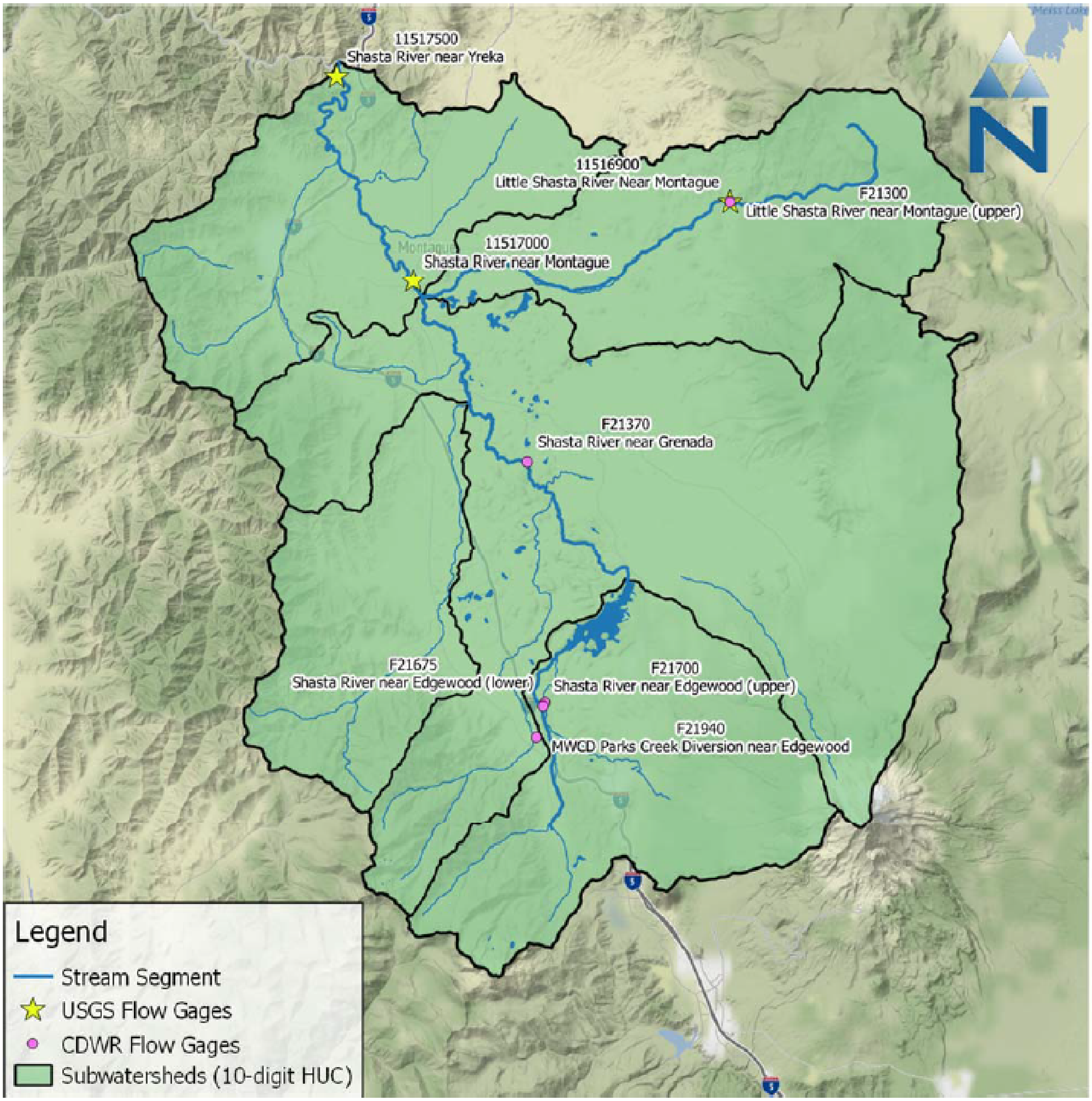


Figure 32: Flow gages in the Shasta River Watershed. Reprinted from SWRCB (2018).

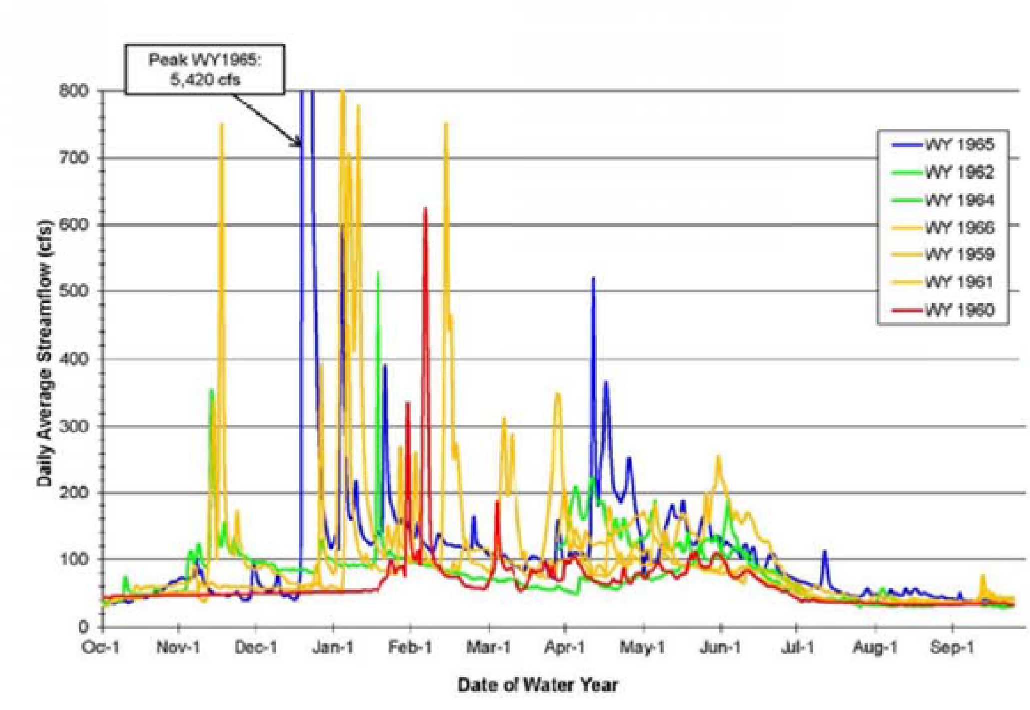


Figure 6. Estimated unimpaired annual hydrographs, for the Shasta River immediately downstrea of the Parks Creek confluence in Reach No.3.

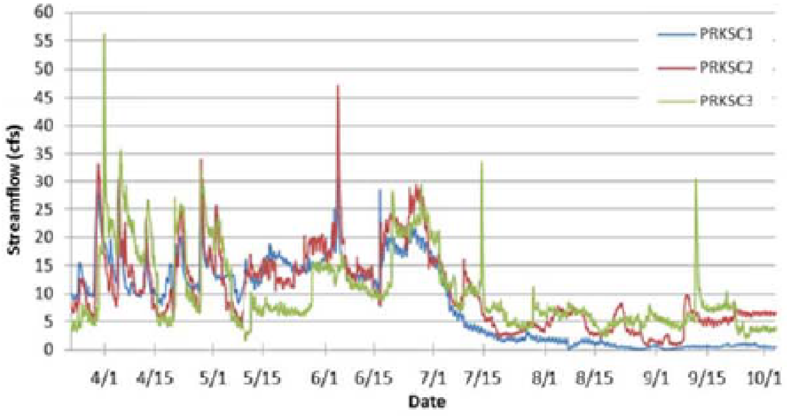


Figure 9. Observed streamflows for April 1 – October 1 2010, in Parks Creek.

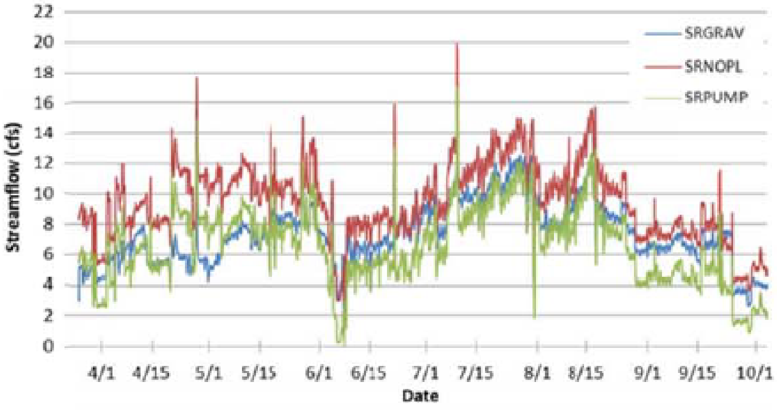
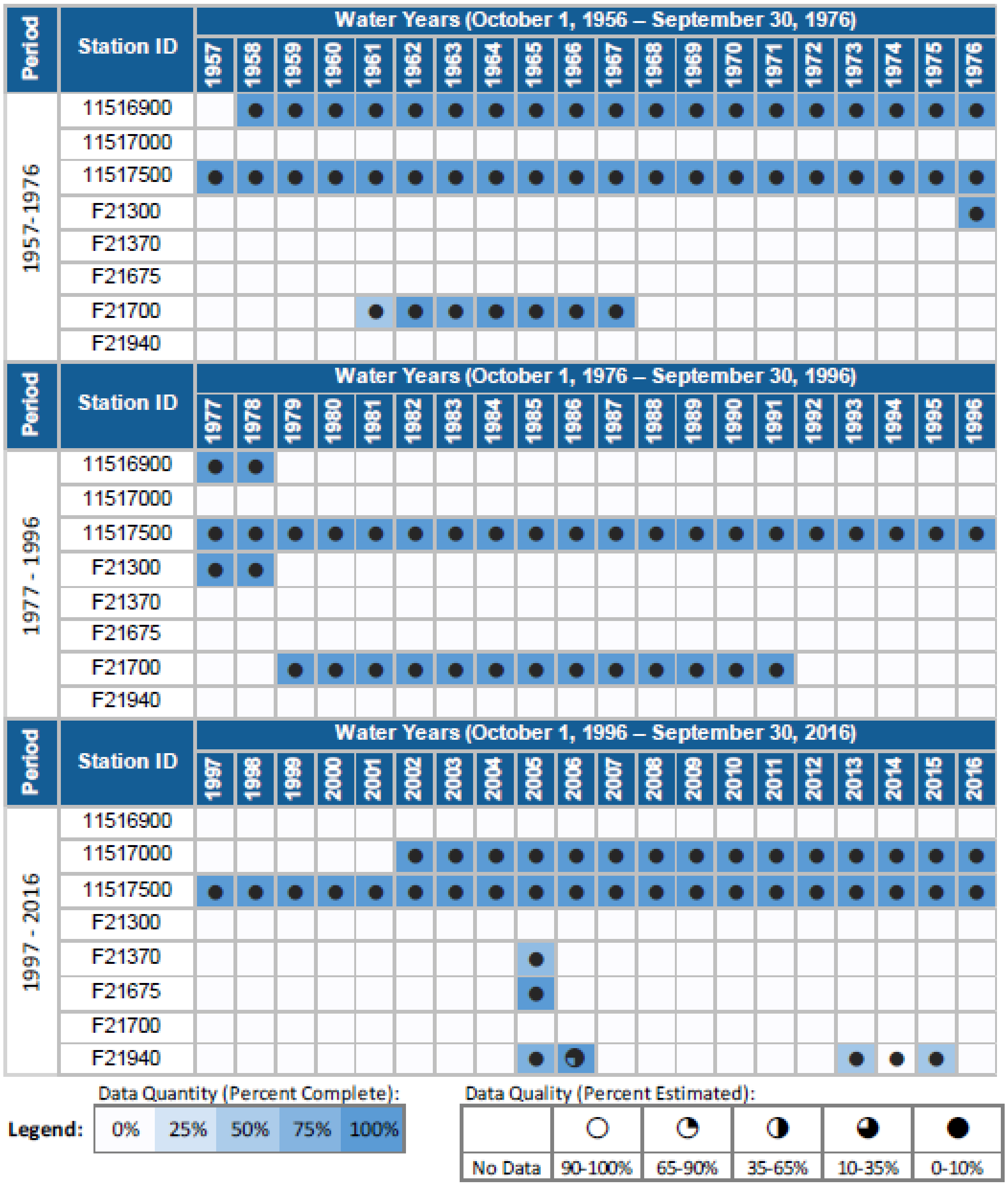


Figure 12. Observed streamflows for April 1 – October 1 2010, in the Shasta River above Parks Creek.

Figure 33: Historic stream flows at notable gages along the Shasta River and Parks Creek. Reprinted from SWRCB (2018); adapted from McBain and Trush (2013).



Period	Station ID	Water Years (October 1, 1956 – September 30, 1976)																			
		1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
1957-1976	11516900		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	11517000																				
	11517500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	F21300																				●
	F21370																				
	F21675																				
	F21700					●	●	●	●	●	●	●									
	F21940																				

Period	Station ID	Water Years (October 1, 1976 – September 30, 1996)																			
		1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
1977 - 1996	11516900	●	●																		
	11517000																				
	11517500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	F21300	●	●																		
	F21370																				
	F21675																				
	F21700			●	●	●	●	●	●	●	●	●	●	●	●	●					
	F21940																				

Period	Station ID	Water Years (October 1, 1996 – September 30, 2016)																			
		1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1997 - 2016	11516900																				
	11517000						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	11517500	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	F21300																				
	F21370									●											
	F21675									●											
	F21700																				
	F21940									●	◕							●	●	●	

Legend:

Data Quantity (Percent Complete):

0%	25%	50%	75%	100%

Data Quality (Percent Estimated):

	○	◔	◑	◕	●
No Data	90-100%	65-90%	35-65%	10-35%	0-10%

Figure 34: Summary of streamflow data quantity and quality in the Shasta River Watershed. Reprinted from SWRCB (2018).

2.2.1.6 Geophysical Studies

In September of 2020, a geophysical study was conducted in Shasta Valley to collect data to aide in understanding the geological and hydrological structures of key areas of the valley that were poorly represented in the hydrogeological conceptual model. The study utilized two electromagnetic survey tools: the towed-TEM (or tTEM) and WalkTEM devices. The tTEM and WalkTEM instruments are time-domain electromagnetic systems specifically designed for hydrogeophysical and environmental investigations. The tTEM system measures continuously while towed on the ground by an ATV or similar vehicle. The WalkTEM instrument is a pair of large electrical coil loops that are manually placed on the ground to record electromagnetic response of the subsurface. The WalkTEM system is essentially identical to the one used in the airborne electromagnetic (AEM) system currently flown in California by DWR that records continuously along pre-planned flight lines.

Additionally, the electromagnetic geophysical surveying work was instrumental in testing the potential data quality for future AEM survey flights to be conducted by DWR in late 2021 (data from the AEM flights will not be available until 2022). This is because the ground-based electromagnetic surveying equipment used in this study is both theoretically and operationally similar to that to be used with the future AEM flights.

The surveying took place in two key areas. One area is the Shasta Big Springs Ranch (Area 1) and the other is a large portion of the headwaters area for the Pluto's Cave basalt aquifer (Area 2). The significance of Area 1 is that it is a hydrogeologically complex area containing sensitive groundwater dependent ecosystems (or GDEs), particularly the Big and Little Springs Complex areas. These areas that contain many groundwater springs that supply the immediate areas with a constant flow of fresh spring water from the Pluto's Cave basalt aquifer which comes into direct contact with the less permeable debris avalanche deposits, resulting in groundwater flow to the surface rather than continuing flowing laterally through the subsurface. Area 2 is a very arid area of the valley that has little-to-no groundwater level measurements and is situated in the upgradient area of the Pluto's Cave basalt aquifer, opposite of Area 1. Due to the lack of groundwater level information in Area 2 and the dryness of the surface sediments in the area, despite ephemeral glacial streams periodically recharging the area, electromagnetic surveying was employed to study the geological structure of the area and prospect for potential indicators of groundwater level.

The results of the electromagnetic geophysical surveying can be found in Appendix 2-F. The most important resulting data product figures from the geophysical study are shown in the report in Figures 9-11, as well as the vertical tTEM sections of A-A' and F-F' containing the co-located, full-length WalkTEM results. The orange, red, and magenta colored electrical resistivity zones shown in the data collected in Area 1 largely represent the debris avalanche materials which are thought to be barriers to groundwater flow and surface recharge. The lateral yellow to green features under the debris avalanche materials are likely sedimentary deposits that were originally paleo-surfaces prior to the collapse of Ancestral Mount Shasta. Where these deposits are darker green to blue in color are likely saturated by groundwater. The darker blue zones nearest the surface streams are likely zones of active recharge and relate to interconnected surface water-groundwater systems. The tTEM system was towed around the edge of the dry Bass Lake to aide in future characterization efforts by the GSA and CDFW to potentially use this site as a managed aquifer recharge area. The survey results show that the outer rim of the lakebed appears to contain potentially decent structure for recharge efforts, such as managed aquifer recharge (MAR). This is shown by the bowl-shaped yellow to green resistivity values, which likely deepen toward the center of the dry lakebed. It is possible that fine-grained sediment deposits nearest the lakebed surface may impede future MAR efforts and are not shown in these surfaces as they would be thought to be thin and could easily be moved to improve MAR efficiency. The deep WalkTEM results from stations W02 along vertical section F-F' and W03 along vertical section A-A' show that there might be an effective base to the groundwater aquifer past ~350-400 feet below ground surface. This is shown as the very dark blue sections which are likely fine-grained sediments and sedimentary rocks that may act as basal confining units. This may be where the top of the Hornbrook Formation lies under the surface deposits.

In Area 2, it was hypothesized that if groundwater was within the depth of penetration of the tTEM system (<300 feet), electromagnetic signal returns would be possible. If deeper, it was thought that the thick, dry sediments would present an obstacle to obtaining results. As the tTEM results were not able to be used to estimate electrical resistivity confidently across this whole area, it is likely that the groundwater level in this area is greater than 400-500 feet below ground surface. The WalkTEM results at station W01 are additionally difficult to determine however it appears from the results that there begins to be conductive signal past 600 feet below ground surface, which may represent where the groundwater level is located. This is not surprising as this area at the northern base of Mount Shasta likely contains a thick sequence of sediment deposits from glacial outwash and volcanic lahars (mudflows) and lies at a higher elevation the northern toe of the Pluto's Cave basalt deposit.

This work was funded by Prop 68 funding granted to the GSA by DWR.

2.2.2 Current and Historical Groundwater Conditions

2.2.2.1 Groundwater Level Data

The historical groundwater elevation data available for the Basin is entirely based on DWR CASGEM records, with the majority going back to the early 1990's and some into the 1960's and 1970's. However, there are also some stations with only post-2010 data. Generally, the data show that groundwater levels are stable over the full period of record throughout the area historically monitored by the CASGEM program. Full rebound of groundwater levels occurs by the spring of each year. Groundwater level data are shown as surface contours in Figure 35 to Figure 38 for the spring and fall measurements from 2015 and 2010, as well as select hydrographs in Figure 39. Groundwater level contours were created using the interpolation method known as kriging that interpolates an elevation between two or more points using the variance between the measurements and distance to the point as a means of weighting the influence of a measurement on an interpolated point. All available groundwater level data are shown in Appendix 2-C, which include all available CASGEM data and recently collected continuous groundwater level monitoring data. CASGEM data is primarily collected bi-annually in the spring and fall. Continuously monitored wells provides better data for the true seasonal maximum and minimum groundwater levels, as well as their timing.

The groundwater levels in the central to west-central portions of the Basin are largely shallow, typically less than 20-40 ft (6-12 m) below ground surface. These areas are dominantly alluvial or debris avalanche (consisting of mainly alluvial materials in between large andesite blocks) deposits. The groundwater levels in these aquifer materials do not typically show large seasonal (or longer) variations. The area northwest of Gazelle has a deeper groundwater table likely due to shallower alluvium and increased usage of groundwater for irrigation purposes. The groundwater levels in this area are more likely to see changes due to water year type than to seasonal variations. The eastern section of the Basin is dominated by volcanic aquifers whose groundwater levels are deeper (generally >60 ft (18 m) below ground surface) than the more alluvial aquifers to the west. The groundwater levels in the volcanic aquifers have historically been relatively stable. However, recent increased pumping and drought conditions (post-2019) have resulted in increased lowering of groundwater levels, particularly in the Pluto's Cave basalt aquifer area. The small area of the Basin where Yreka is located is mainly reliant on surface water and groundwater levels have not been historically monitored there.

Groundwater recharge occurs as stream leakage, and from irrigation ditch leakage, as percolation through the soil zone (including under irrigated agricultural fields), and along the valley margin as mountain front recharge (MFR). Groundwater leaves the aquifers in the Basin through groundwater pumping for irrigation, discharge to streams, discharge to springs, and by direct evapotranspiration in areas where the water table is near the land surface. Additionally, groundwater leaves the Basin through deeper underflow in the Hornbrook Formation and the other various deep volcanic aquifers. The availability of water in critical periods, during the end of summer and beginning of fall, is a key concern in Shasta Valley for agricultural uses, domestic well users, and for in-stream flows and cold surface water temperatures (cold groundwater discharges for baseflow and springs discharging to the river) for fish.

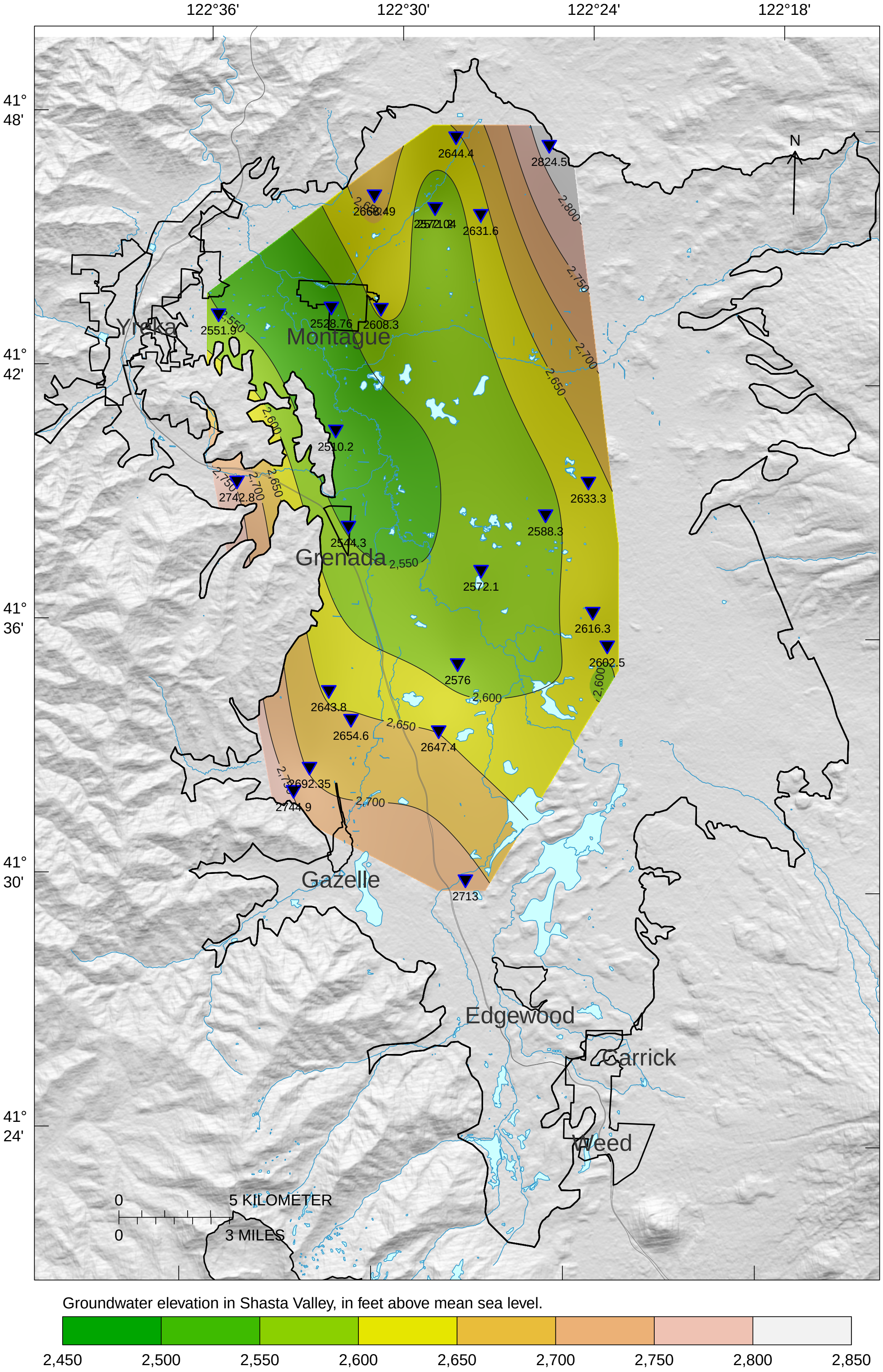


Figure 35: Interpolated representation of Shasta Valley Groundwater Elevations, Spring 2015

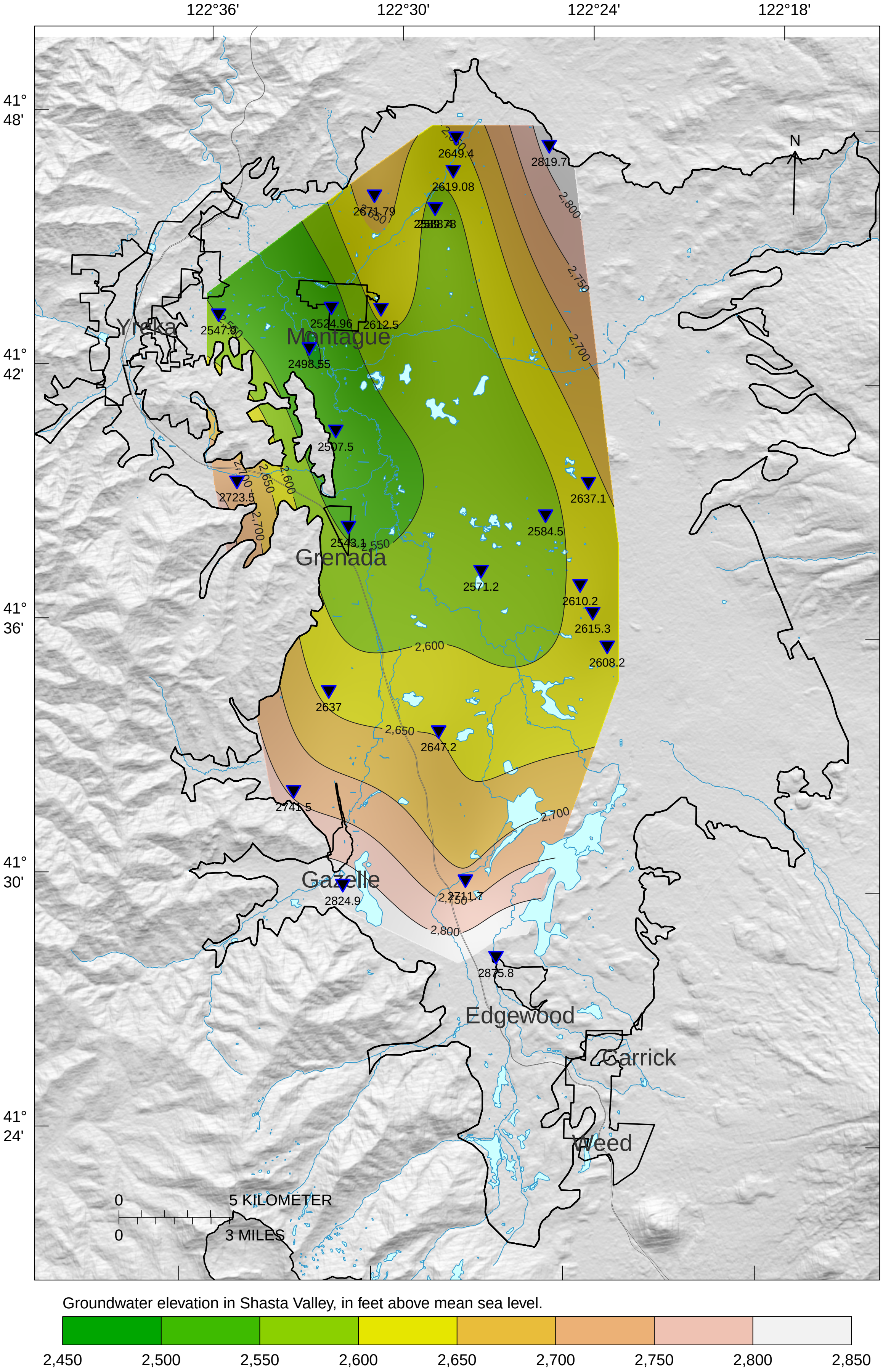


Figure 36: Interpolated representation of Shasta Valley Groundwater Elevations, Fall 2015

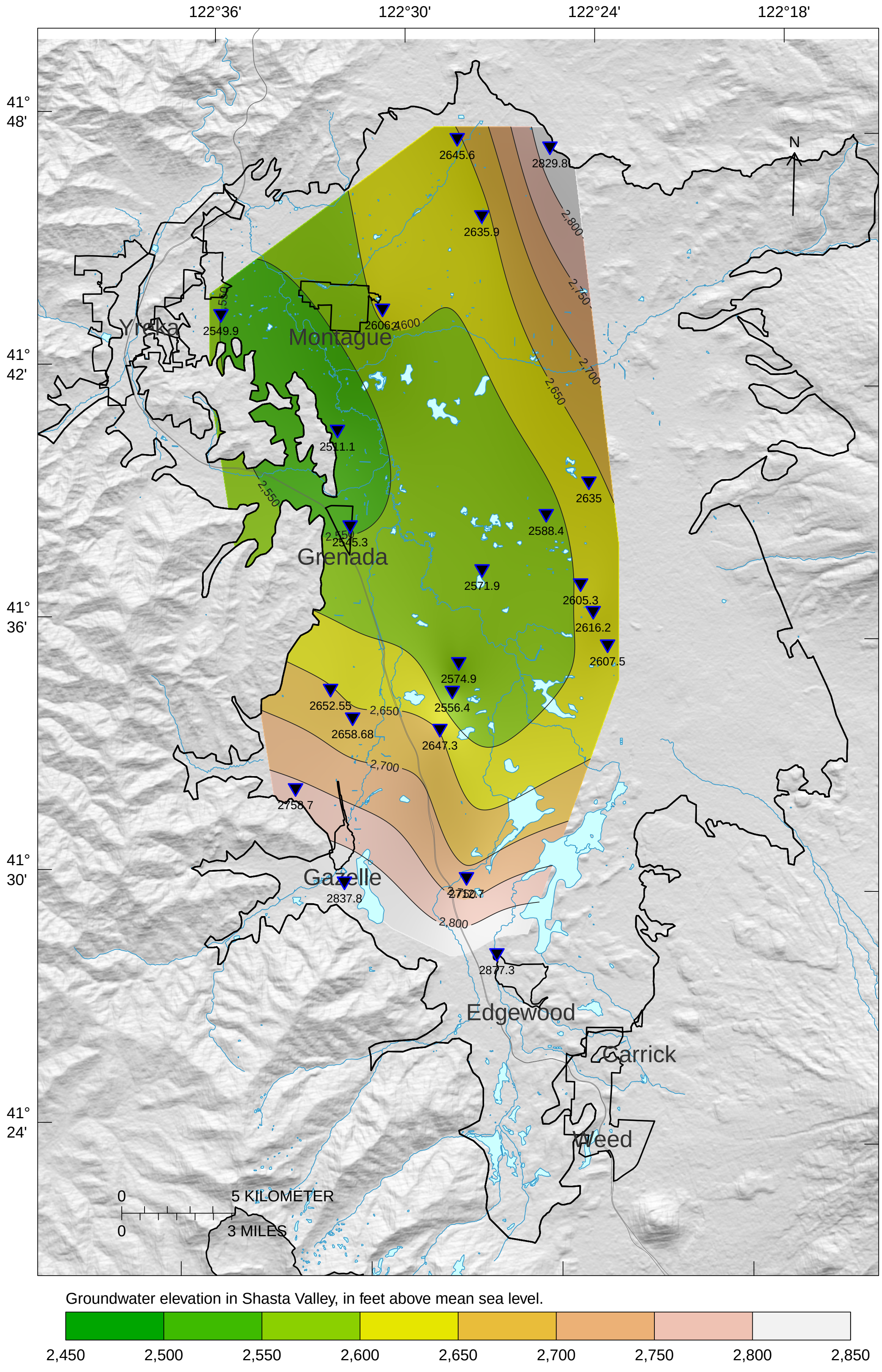


Figure 37: Interpolated representation of Shasta Valley Groundwater Elevations, Spring 2010

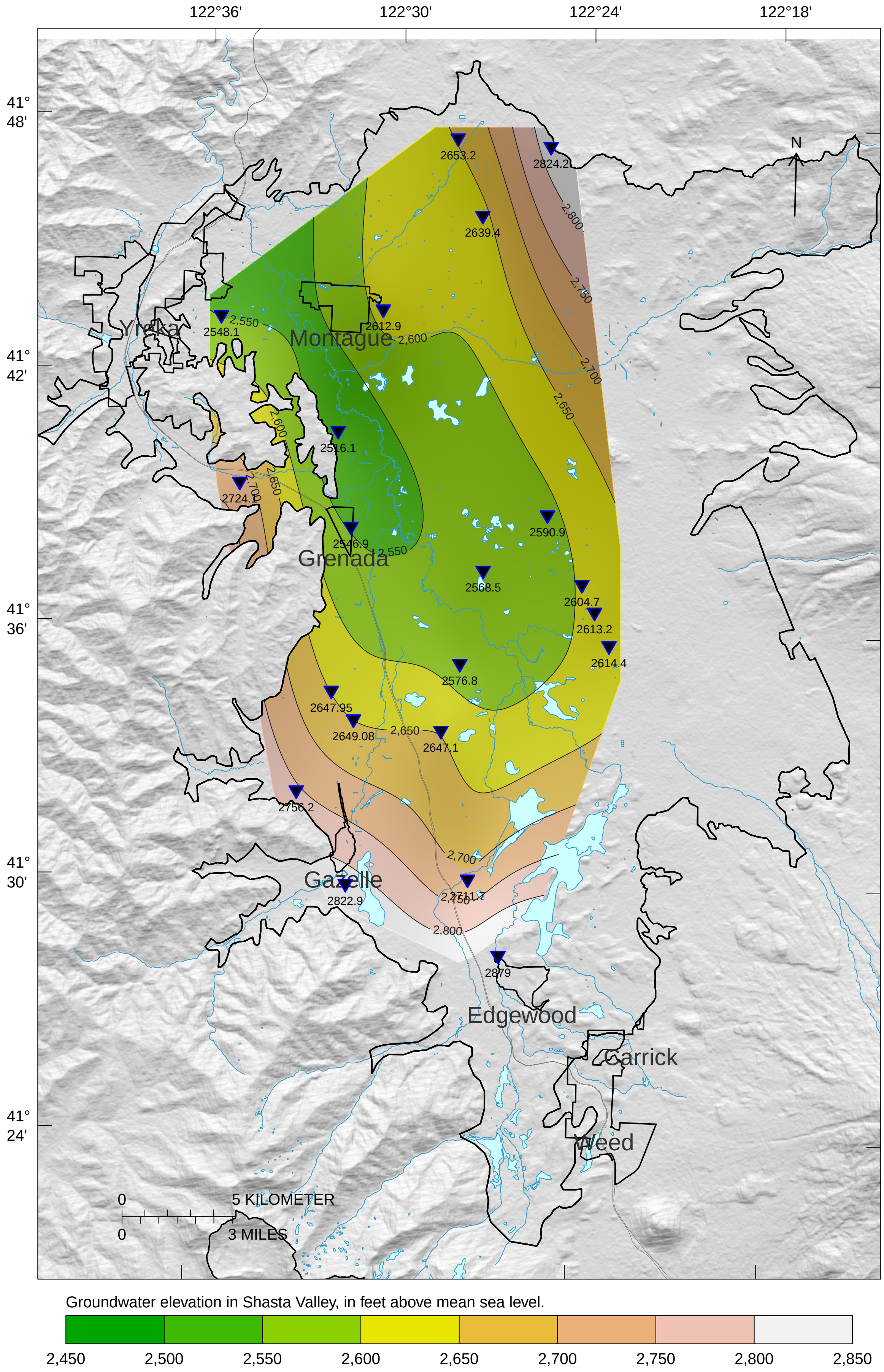


Figure 38: Interpolated representation of Shasta Valley Groundwater Elevations, Fall 2010

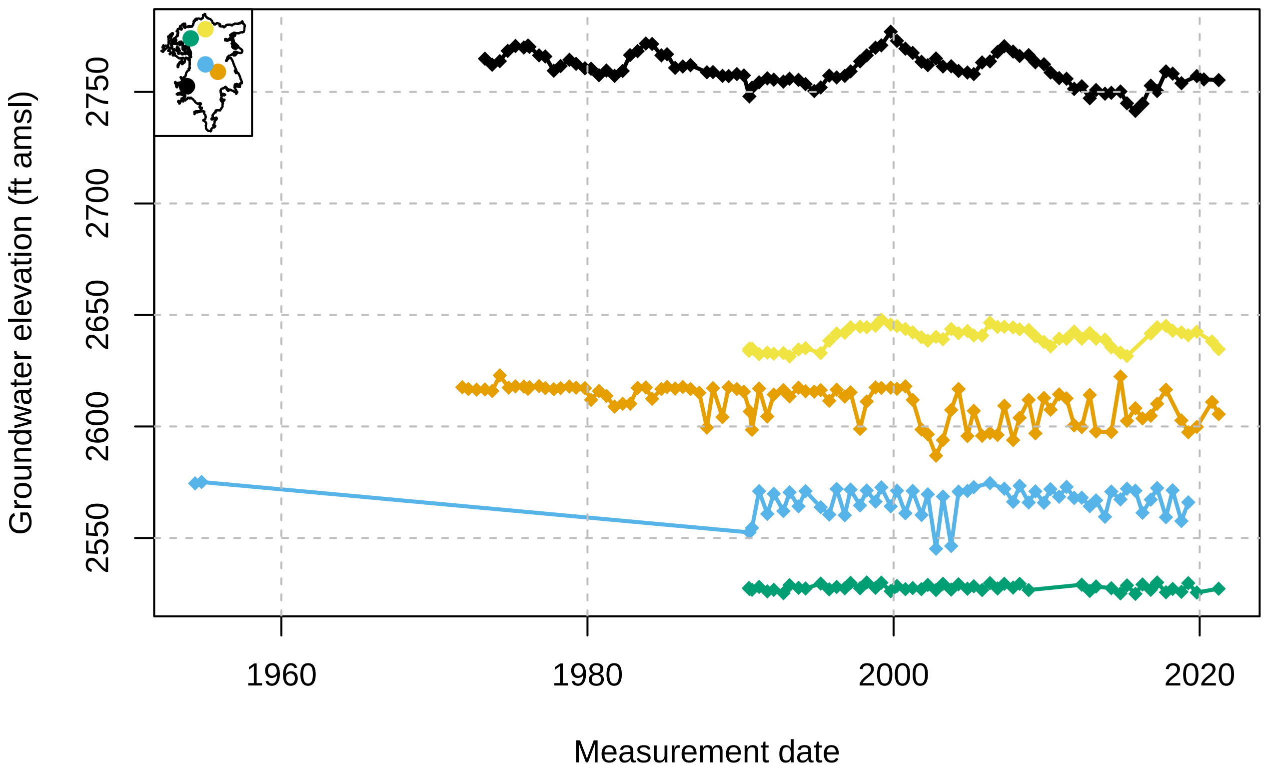


Figure 39: Groundwater elevation measurements over time in five wells, one located in each hydrogeologic zone.

2.2.2.2 Estimate of Groundwater Storage

Overall groundwater storage in Shasta Valley has not been previously estimated. Seymour Mack with the U.S. Geological Survey attempted to estimate this in 1960, however, the effort was left undone due to the complexity in estimating storage properties of the volcanic aquifers of the Basin (Mack 1960). The only current estimate of storage is based off of the Shasta Watershed Groundwater Model results described in detail in Section 2.2.3.

2.2.2.3 Groundwater Quality

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

Basin Groundwater Quality Overview

Water quality includes the physical, biological, chemical, and radiological quality of water. Physical water quality includes temperature. Examples of biological water quality constituents include E. coli bacteria, commonly used as an indicator species for fecal waste contamination. Radiological water quality parameters refer to the radioactivity of waters. 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 has a usually low level 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 content 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. Hardness refers to high amounts of calcium and magnesium 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, of contamination from anthropogenic point sources, or originates from diffuse (non-point) sources that are the result of human activity.

Previous work has characterized groundwater in the Basin as calcium magnesium bicarbonate type (DWR 2004). Within Shasta Valley, groundwater quality issues have historically been localized and attributed to natural sources. Elevated constituents have included: boron, calcium, chloride, conductivity, magnesium, iron, fluoride, nitrate, sodium, sulfate and hardness. Total dissolved solids in the Basin have historically been within the range of 131 mg/L to 1,240 mg/L with locally elevated levels (DWR 2004). Groundwater quality has been noted to be closely connected to local geology, in particular high magnesium has been attributed to serpentine and elevated calcium has been attributed to the presence of limestone (Mack 1960). Identified localized groundwater quality issues include Table Rock Springs with high sodium, chloride and boron, areas near Willow Creek and Julian Creek with elevated boron, dissolved solids and sodium, near Montague, Grenada and Big Springs and near Oregon Slough and Little Shasta River (DWR 2004; Gwynne 1993).

Groundwater in the Basin is generally of good quality and meets local needs for municipal, domestic, and agricultural uses. Ongoing monitoring programs show that some constituents, including arsenic, boron, iron, manganese, and benzene, in addition to pH and specific conductivity, 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.

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 – Water Quality Assessment.

2.2.2.3.2 Existing Water Quality Monitoring Networks

Water quality data of 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, but some are or 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 the California Department of Water Resources (DWR); State Water Resources Control Board (SWRCB), Division of Drinking Water (DDW); Lawrence Livermore National Laboratory (LLNL) special studies; and the United States Geological Survey (USGS). 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 1949. Figures in Appendix 2-B show the Basin boundary, as well as the locations and density of all wells with available water quality data. Within the Basin, a total of 266 wells were identified and used to characterize 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 are compared. Numeric thresholds are set by state and federal agencies to protect water users (environment, humans, industrial and agricultural users). The numeric standards selected for the current analysis represent all relevant state and federal drinking water standards and state water quality objectives for the constituents evaluated and are consistent with state and North Coast Regional Water Quality Control Board (Regional Water Board) assessment of beneficial use protection in groundwater. The standards are compared against groundwater quality data to determine if a constituent's concentration exists above or below the threshold and is currently impairing or may impair beneficial uses designated for groundwater at some point in the foreseeable future.

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

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

Constituents may have one or more applicable drinking water standard or WQO; for this GSP, a prioritization system was used to select the appropriate numeric threshold: The strictest value among the state and federal drinking water standards and state WQOs specified in the Basin Plan was used 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 identified 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 1949 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 during the past 30 years (1990-2020) (see Appendix 2-B). Finally, for each constituent, an effort was undertaken to examine changes in groundwater quality over time at a location. Constituent data collected in the past 30 years (1990-2020) were further limited to wells that have three 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: benzene, 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 5 provides the list of constituents of interest identified for the Basin and their associated regulatory threshold.

Table 5: Regulatory water quality thresholds for constituents of interest in the Shasta Valley Groundwater Basin

Constituent	Regulatory Basis	Water Quality Threshold
Arsenic (μg/L)	Title 22	10
Benzene (μg/L)	Title 22	1
Boron (mg/L)	Basin Plan 90% Upper Limit	1
Boron (mg/L)	Basin Plan 50% Upper Limit	0.3
Iron (μg/L)	Title 22	300
Manganese (μg/L)	Title 22	50
Nitrate (mg/L as N)	Title 22	10
pH	Basin Plan	7.0-8.5
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.

ARSENIC

Arsenic is a naturally occurring element in soils and rocks and has been used in wood preservatives and pesticides. Classified as a carcinogen by the USEPA, the International Agency for Research on Cancer (IARC) and the Department of Health and Human Services (DHHS), arsenic in water can be problematic for human health. Drinking water with levels of inorganic arsenic from 300 to 30,000 ppb can have effects including stomach irritation and decreased red and white blood cell production (ASTDR 2007a). Long-term exposure can lead to skin changes and may lead to skin cancer. The Title 22 1° MCL for arsenic is 10 micrograms per liter (μg/L).

Arsenic data, collected in the past 30 years (1990-2020) from municipal and monitoring wells, is distributed throughout the Basin, with numerous measurements along the western Basin boundary and more limited data in the northeast section of the Basin (Appendix 2-B). The majority of measurements are below half of the 1° MCL. Values above the 1° MCL are located near Grenada, Edgewood and Carrick. These findings are 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 the municipal wells near Edgewood as having “high” arsenic levels (greater than 10 ug/L) based on measurements between 1995 to 2014 (Dupuy et al., 2019). Based on the timeseries in Appendix 2-B, wells with arsenic levels below the 1° MCL have fairly stable concentrations over time. Wells with values that exceed the 1° MCL show more variation in measured arsenic levels, with no general identifiable trend.

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 (ASTDR 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 of red blood cells and potentially leading to anemia. Acute exposure can cause dizziness, rapid or irregular heartbeat, irritation to the stomach and vomiting and can be fatal at very high concentrations (ASTDR 2007b). The 1° MCL for benzene is 1 μg/L, as defined in Title 22.

Recent benzene data (1990-2020) is from municipal and monitoring wells and is concentrated along the western and southeastern Basin boundary with limited measurements in the northern and northeastern parts of the Basin (Appendix 2-B). The majority of the measurements are non-detected values and measurements that exceed the 1° MCL are located in the south of the Basin near Carrick and near Yreka. Benzene levels in wells with multiple monitoring events from 1990-2020 are generally stable or decreasing over time.

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 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 (ASTDR 2010). The Basin Plan specifies a 50% upper limit for boron of 0.3 mg/L and a 90% upper limit for Boron of 1.0 mg/L.

As shown in Appendix 2-B, boron measurements over the past 30 years (1990-2020) are distributed throughout the Basin. While the majority of measurements do not exceed the 50% or 90% upper limits, values that do exceed these limits are also distributed throughout the Basin. Timeseries of boron levels in wells with multiple monitoring events from the past 30 years show boron levels to be generally stable or decreasing over time.

IRON AND MANGANESE

Iron and manganese in groundwater are primarily from natural sources. As abundant metal elements in rocks and sediments, iron and manganese can be mobilized under favorable geochemical conditions. Iron and manganese occur in the dissolved phase under oxygen-limited conditions. Anthropogenic sources of iron and manganese can include waste from human activities including industrial effluent, mine waste, sewage, and landfills. As essential nutrients for human health, iron and manganese are only toxic at very high concentrations. Concerns with iron and manganese in groundwater are commonly related to the aesthetics of water and the potential to form deposits in pipes and equipment. The Title 22 SMCLs, for iron and manganese are 300 μg/L and 50 μg/L, respectively.

Iron measurements in the Basin, collected in the past 30 years (1990-2020) are distributed throughout the Basin (Appendix 2-B). The majority of the measurements are either not detected or below half of the 2° MCL; values that exceed the MCL are located along the southern boundary of the Basin and in wells throughout the central region of the Basin. Timeseries of wells with multiple iron measurements over the past 30 years (1990-2020) indicate that wells with iron levels consistently below the 2^o MCL are relatively stable over time while wells with values that exceed the 2^o MCL have more variation in measured concentrations and do not show a general Basin-wide increasing or decreasing trend.

Recent monitoring for manganese levels (from 1990-2020) is distributed throughout the Basin (Appendix 2-B). Measurements range from non-detected values to values above the 2^o MCL. Manganese levels are variable within the Basin, with multiple localized exceedances throughout the Basin. Timeseries constructed for wells with multiple monitoring events over this same time period show variability between and within wells, with stable, increasing and decreasing values over time.

pH

The pH of groundwater is determined by a number of factors including the composition of rocks and sediments through which water travels in addition to pollution caused by human activities. Variations in pH can affect the solubility and mobility of constituents. Acidic or basic conditions can be more conducive for certain chemical reactions to occur; arsenic is generally more likely to mobilize under a higher pH while iron and manganese are more likely to mobilize under more acidic conditions. High or low pH can have other detrimental effects on pipes and appliances including formation of deposits at a higher pH and corrosion at a lower pH, along with alterations in the taste of the water. The Basin Plan specifies a pH range of 7.0-8.5 as a water quality objective for groundwater in the Shasta Valley hydrologic area.

Measurements for pH, conducted over the past 30 years (1990-2020) are located primarily along the western and southwestern Basin boundaries, with several measurements in the central area near Grenada. Data are limited in the north and northeastern portions of the Basin. Most of the measured levels are outside of the pH range specified in the Basin Plan. Trends in pH values over time are not able to be evaluated with current data due to a lack of wells with multiple measurements over time.

SPECIFIC CONDUCTIVITY

Specific conductivity, also referred to as electrical conductivity, 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. The Basin Plan specifies a 50% upper limit (UL) of 500 micromhos per centimeter (µmhos/cm) and a 90% UL of 800 µmhos/cm for specific conductivity.

Specific conductivity measurements over the past 30 years (1990-2020) are located throughout the Basin but are mostly concentrated along the western and southeastern Basin boundaries, with limited data in the northeast part of the Basin (Appendix 2-B). Multiple values exceed the 50% and 90% ULs specified in the Basin Plan. Wells with specific conductivity measurements that exceed these limits are distributed throughout the Basin. In wells with multiple monitoring events over the past 30 years, wells with specific conductivity values consistently below the Basin Plan 50% UL are relatively stable over time while wells with specific conductivity measurements above the Basin Plan 90% UL have greater variability in measured values over time.

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 six months who are susceptible to methemoglobinemia, a condition that affects the ability of red blood cells to carry and distribute oxygen to the body. The 1° MCL for nitrate is 10 milligrams per liter (mg/L) as N.

Recent (1990-2020) nitrate data in the Basin are concentrated in the south and west, with more limited data in the eastern and central portions of the Basin. Wells with exceedances of the 1° MCL are located near Montague, Grenada, and Carrick (Appendix 2-B). Measurements range from non-detected values to above the 1° MCL. Nitrate concentrations in wells with multiple measurements between 1990 and 2020, can be increasing, decreasing or stable.

Contaminated Sites

Groundwater monitoring activities also take place in the Basin in response to known and potential sources of groundwater contamination including underground storage tanks. These sites are subject to oversight by regulatory entities, and any monitoring associated with these sites can provide opportunities to improve the regional understanding of groundwater quality.

To identify known plumes and contamination within the Basin, SWRCB GeoTracker was reviewed for active clean-up sites of all types. The GeoTracker database shows one open Leaking Underground Storage Tank (LUST) site and two open cleanup program sites with potential or actual groundwater contamination located within the Basin.

Underground storage tanks (UST) are containers and tanks, including piping, that are completely or significantly below ground and are used to store petroleum or other hazardous substances. Soil, groundwater and surface water near the site can all be affected by releases from USTs. 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 including methyl tertiary butyl ether (MTBE) and benzene, toluene, ethylbenzene and xylenes (BTEX), as well as lead scavengers including ethylene dibromide (EDB) and 1, 2-dichlororethane.

A brief overview of notable information 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 40.

The Davenport Property, located in Yreka, is the sole open LUST site in the Basin. The case at this site was opened in 2017, after an authorized release was reported following removal of a heating oil UST. Remediation efforts have included soil excavation and monitoring activities have included groundwater and soil vapor sampling. Though water quality objectives in groundwater have been reported to be below, or close to water quality objectives, a review summary report from February of 2019 concludes that the site does not meet all criterial for closure due to lack of definition of the benzene plume (SWRCB 2019).

Three open cleanup program sites fall within the Basin boundary, all located in Yreka. Two of the sites are associated with an oil and gas plant. All three cleanup sites have a cleanup status of open and inactive as of 2011. At this time, no cleanup actions have been completed at any of these sites.

There are six California Department of Toxic Substances Control (DTSC) sites within the Basin. Three of these sites have a cleanup status as no further action, meaning that a Phase I Environmental Assessment at the site has concluded no action is required. One site has been referred to the NCRWQCB as of 1989. The remaining two sites are classified as inactive, one with action required, as suggested by a preliminary investigation at the site; the other site requires evaluation.

In addition to contaminated sites located within the Basin boundary, several sites are in close proximity to the Basin boundary (all within 5 miles or 8 km). These include a LUST site, multiple cleanup program sites, a military cleanup site and DTSC sites, including a Federal Superfund Site. The J.H. Baxter Superfund site, located in northern Weed was previously used as a wood-treatment facility dating back to the late 1930s. Contaminants of concern include: polynuclear aromatic hydrocarbons (PAHs), pentachlorophenol (PCP), dioxin and metals including arsenic, chromium III, chromium VI, copper, lead and zinc in the soil, groundwater and surface water surrounding the site. Investigation into contamination at the site began in 1982 under the DTSC and NCRWQCB and the site was officially added to the EPA's National Priorities List in 1989. The cleanup status has been listed as "Certified Operation & Maintenance" since 2007, meaning that certified cleanup activities have been implemented but ongoing operation and maintenance is required.

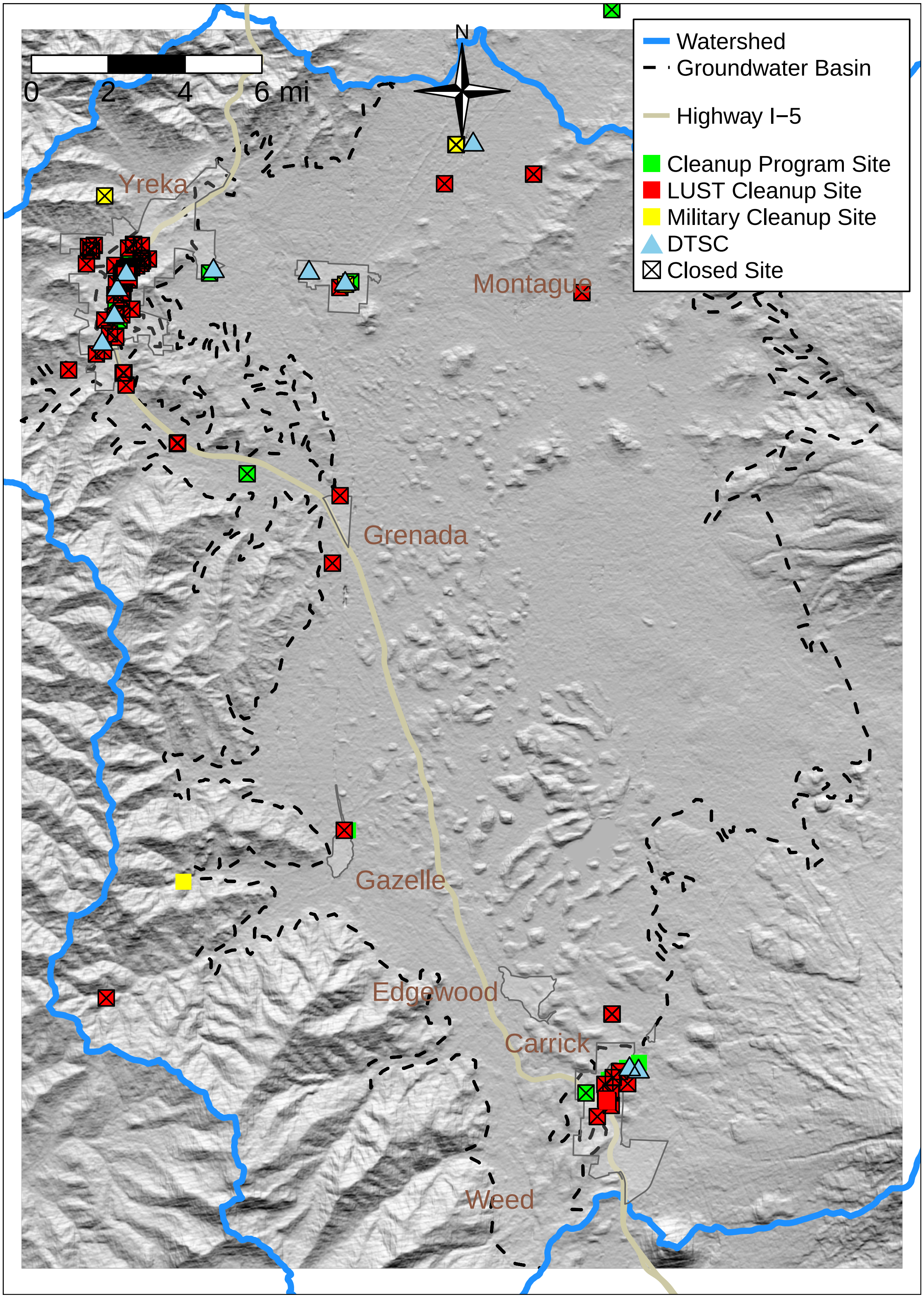


Figure 40: Contaminated Sites

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 evaluation of trends. From a review of all available information, none of the sites listed above have been determined to have an impact on the aquifer and the potential for groundwater pumping to induce contaminant plume movement towards water supply wells is negligible. Currently, there is not enough information to determine if the contaminants are sinking or rising with groundwater levels.

2.2.2.4 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. Land subsidence, particularly inelastic subsidence, is not known to be historically or currently significant in Shasta Valley. The lithology that may cause subsidence, particularly thick clay units that typically define the confining layers of aquifers found in the Central Valley of California, are not present in Shasta Valley. The geologically recent, shallow alluvial and volcanic rock aquifers of Shasta Valley are largely insusceptible to inelastic subsidence.

Data Sources

There are no known Basin-wide survey data available for estimating subsidence in Shasta Valley.

The single borehole strainmeter in the Basin (UNAVCO station #B039), while recording four horizontal displacement directions, does not record vertical displacement and, thus, is not able to accurately record evidence of inelastic subsidence (Figure 41). The strainmeter is also on the very edge of the Basin boundary on a foundation of andesite and serpentinite rock with minimal sediment overburden, also effectively invalidating this station as a monitoring location for groundwater basin subsidence monitoring. There is one other UNAVCO strainmeter station (B040) just north of the basin in the Willow Creek watershed but it also does not record vertical displacement, only horizontal.

There are no known CGPS stations located within the Basin boundary. While there are a number of CGPS stations adjacent to the Basin boundary (Figure 41), they are all either located on basement rock or are too far from the Basin to be relevant for subsidence monitoring.

DWR has made Interferometric Synthetic Aperture Radar (InSAR) satellite data available on their SGMA Data Viewer web map [SGMA Data Viewer] as well as downloadable raster datasets to estimate subsidence (DWR contracted TRE Altamira to make this data available). These are the only data used for estimating subsidence in this GSP as they are the only known subsidence-related data available for this basin.

The TRE Altamira InSAR dataset provides estimates of total vertical displacement from June 2015 to September 2019 and is shown in Figure 41 using raster data from the TRE Altamira report (DWR 2019b). It is important to note that the provided 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 (B. Brezing, personal communication, February 27, 2020):

1. The error between InSAR data and continuous GPS data is 0.052 ft (0.016 m) 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 ft (0.015 m) with 95% confidence level.

The addition of the both of these errors results in the combined error is 0.1 ft (0.03 m). 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 (0.03 m) is within the noise of the data and

is likely not indicative of groundwater-related subsidence in the Basin. DWR contracted Towill, Inc. to complete a data accuracy report. It found similar results to the error presented above. The full report is included in Appendix 2-D.

Data Analysis

Using the TRE Altamira InSAR Dataset provided by DWR, it is observed that the majority of the vertical displacement values in Shasta Valley are essentially near-zero, within the range of 0.1 ft (0.03 m; uplift) to -0.1 ft (-0.03 m; subsidence [see Figure 41]). 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 ft (1.1 m) of subsidence.

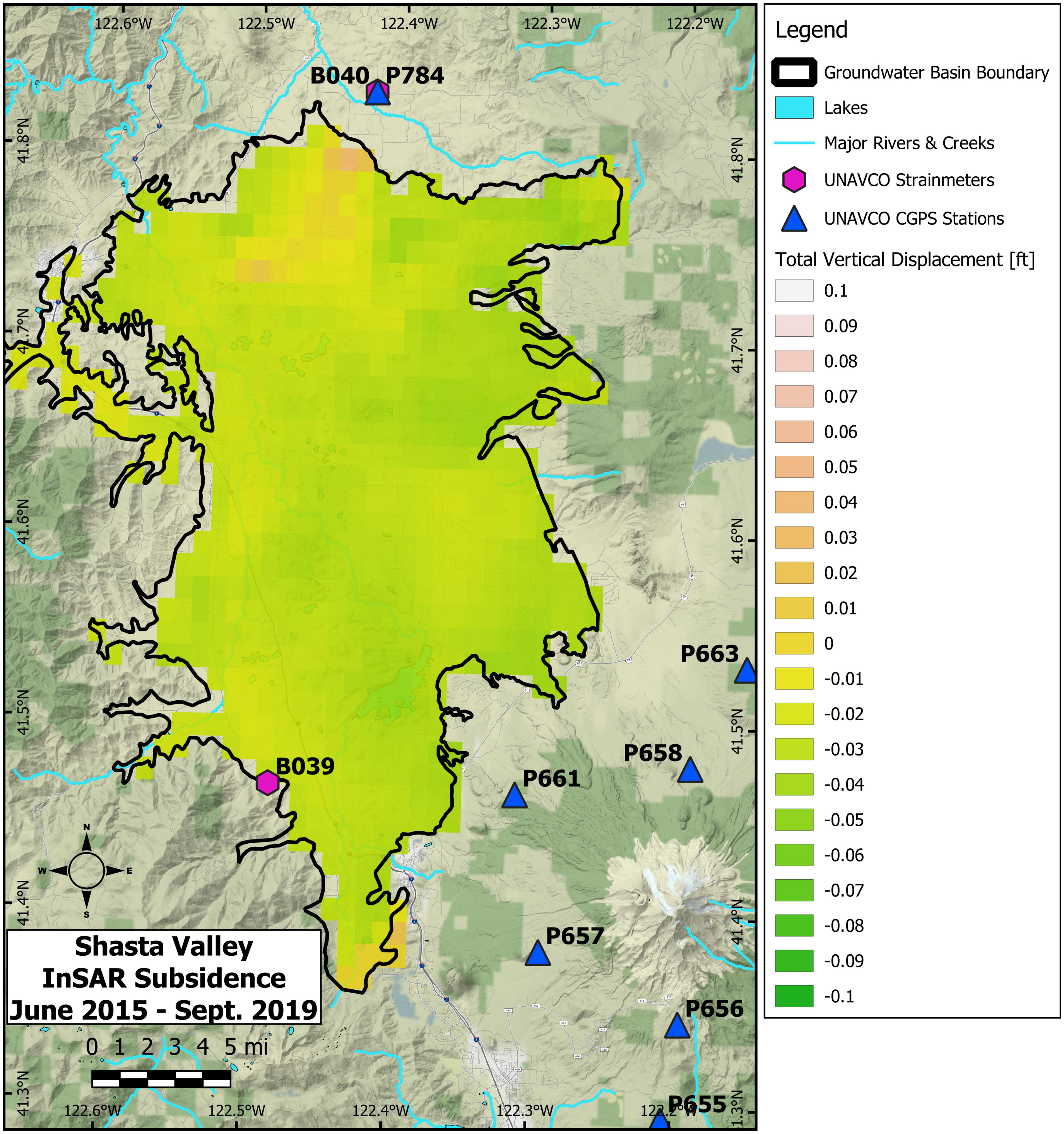


Figure 41: InSAR Total Subsidence (in feet) between 6.2015 and 9.2019

2.2.2.5 Seawater Intrusion

Due to the distance between the Shasta Valley Groundwater Basin and the Pacific Ocean, seawater intrusion is not evident nor of concern and therefore, is not a sustainability indicator applicable to the Basin.

2.2.2.6 Identification of Interconnected Surface Water Systems

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

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

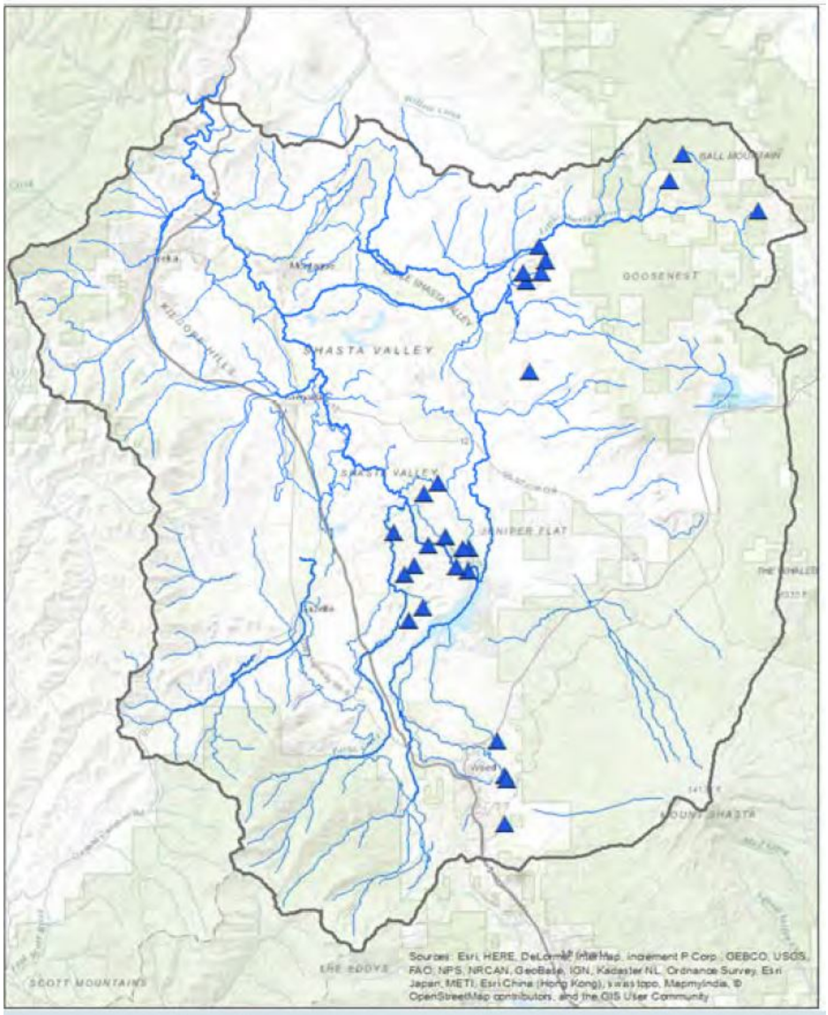
Interconnected surface water (ISW) is defined as surface water which is connected to groundwater through a continuous saturated zone. SGMA mandates an assessment of the location, timing, and magnitude of ISW depletions, and to demonstrate that projected ISW depletions will not lead to significant and undesirable results for beneficial uses and users of groundwater.

The Shasta Valley Groundwater Basin (Basin) is within the watershed of the Shasta River, a major tributary to the Klamath River that eventually flows to the Pacific Ocean. The Shasta River is fed by its tributaries and springs originating from Mount Shasta and other Cascade volcanic mountains. Its major tributaries are the Little Shasta River, Parks Creek, Big Springs Creek, and Yreka creek. Minor tributaries include Oregon Slough and Carrick, Julian, Willow, and Eddy Creeks. The upper quarter of the Shasta River is marked by Lake Shastina (Dwinnel Reservoir) and Dwinnell Dam on the north lake side. Prior to Lake Shastina the river has high slopes, while below the dam the river becomes slow and meandering (SVRCD 2018b).

Springs

Springs feed surface waters on the east side of the watershed due to the volcanic geology (Figure 42). The Pluto's Cave Basalt transmits the majority of Shasta River base flows, discharged as springs in the southeast, and is responsible for nearly all the unimpaired summer base flow of >100 cfs in the Shasta River (SVRCD 2018; SVRCD 2018b). This base flow sustains summer flows in the river despite low precipitation in the valley and is dependent on snowmelt from annual snowfall and glaciers in the surrounding mountains (SVRCD 2018b).

Springs fed by the Pluto's Cave Basalt include the Big Springs Complex (SVRCD 2018). The Big Springs Complex encompasses Big Springs Lake, Big Springs Creek, and Little Springs Creek (Figure 52). The extent of the springs complex is a data gap but contributions of Big Springs Creek to the Shasta River is estimated to be 60 cfs, and historically (pre-diversion) contributed 100 to 125 cfs (Deas 2006).



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 42: Major springs in Shasta Valley (Shasta Watershed).

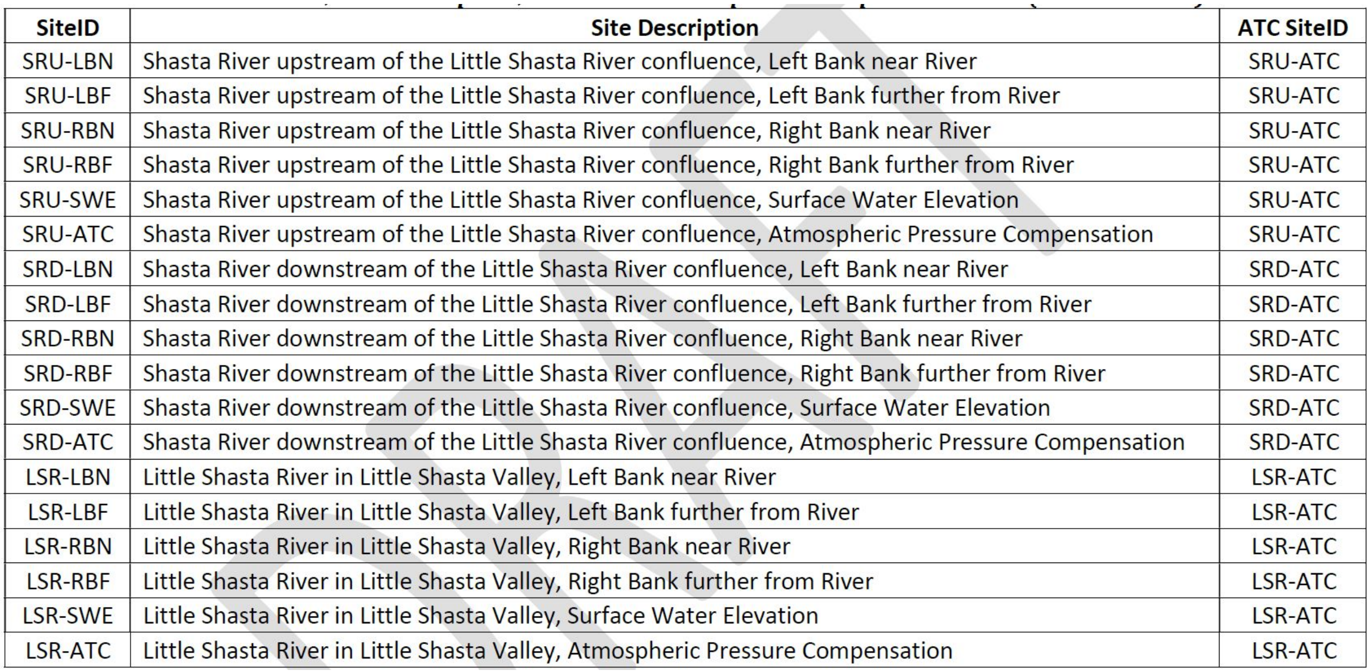
Transect Study

The GSA is working with SVRCD to conduct transect studies for the Little Shasta River and Shasta River to determine the direction of flow exchange. Historically, the Little Shasta River rarely has surface water during the irrigation season due to adjudicated water rights (SVRCD 2018). During that period, the Little Shasta River is known to disappear and reappear at locations upstream of the confluence with the Shasta River (SVRCD 2018). Preliminary results indicate that, between May to October 2020, the Little Shasta River was losing at its transect location in the Little Shasta Valley. Upstream and downstream of the Little Shasta River confluence, the Shasta River was gaining in both transect locations (David's Engineering 2020). For additional information, see Appendix 2-H. This study will continue as long as funding is available, with current funding allowing the study to last until December 2021. Expansion of the transect study to other locations in the Basin will depend on funding.

Shallow piezometers were installed in three transects across the Shasta Valley in late April 2020: two transects along different reaches of the Shasta River and one along the Little Shasta River. One of the transects on the Shasta River was upstream of the confluence with the Little Shasta River (SRU), and the other was downstream of the confluence with the Little Shasta River (SRD)

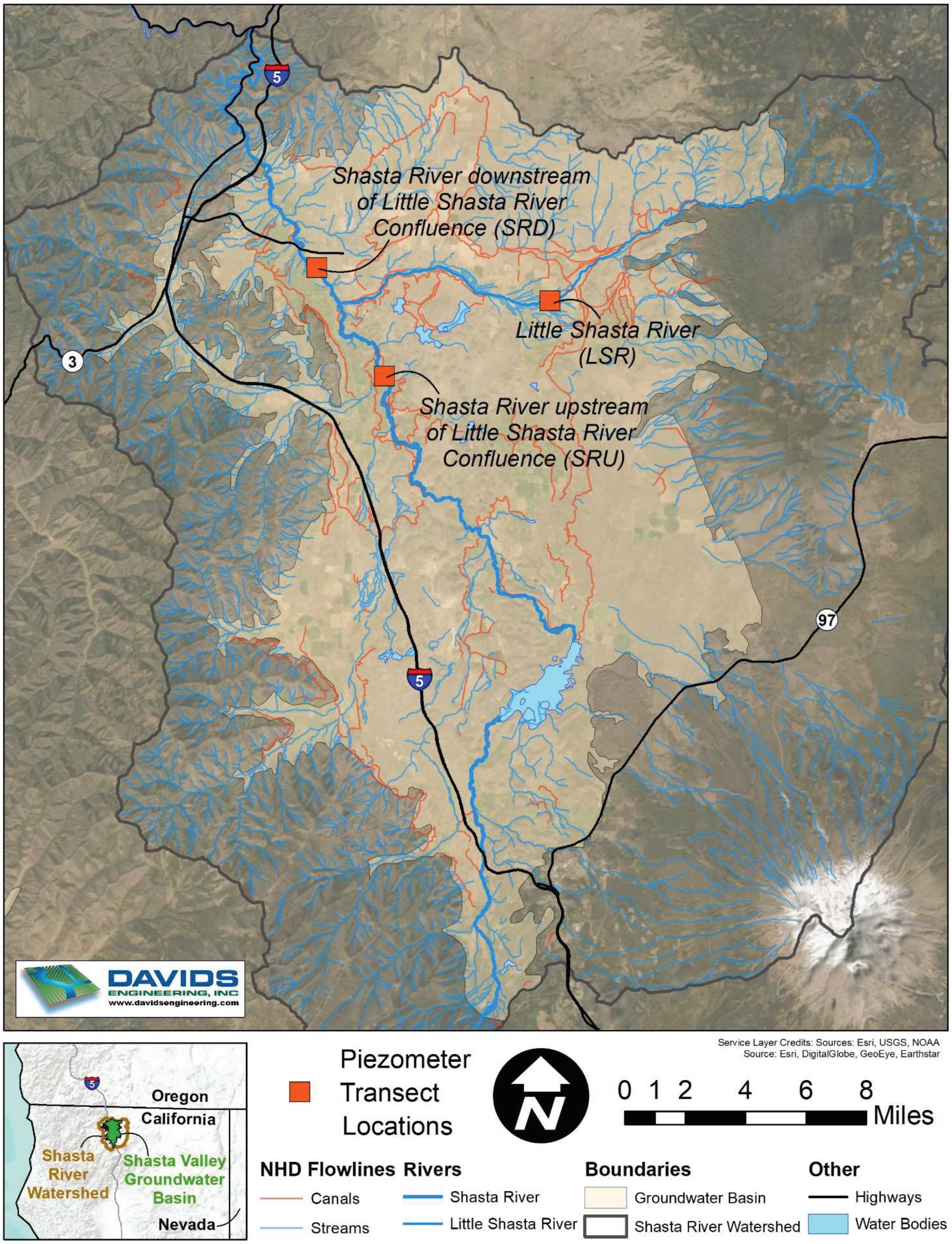
(Figure 44). The transect along the Little Shasta River (LSR) lay within the alluvial portion of the Little Shasta Valley. These piezometers, along with the rivers, were instrumented to continuously monitor water surface elevations and temperatures in and adjacent to surface water features.

Each transect includes six pressure transducers: one measuring atmospheric pressure, one installed in a temporary stilling well in the river to measure surface water levels, and four installed in piezometers (two on each bank of the river) to measure shallow groundwater levels. The individual location in each transect is marked as follows: LB Left bank, looking D/S; RB Right bank, looking D/S; N Near, Closer to stream/river; F Far, Further to stream/river; SWE Surface Water Elevation; ATC Atmospheric Compensation (Figure 43).



SiteID	Site Description	ATC SiteID
SRU-LBN	Shasta River upstream of the Little Shasta River confluence, Left Bank near River	SRU-ATC
SRU-LBF	Shasta River upstream of the Little Shasta River confluence, Left Bank further from River	SRU-ATC
SRU-RBN	Shasta River upstream of the Little Shasta River confluence, Right Bank near River	SRU-ATC
SRU-RBF	Shasta River upstream of the Little Shasta River confluence, Right Bank further from River	SRU-ATC
SRU-SWE	Shasta River upstream of the Little Shasta River confluence, Surface Water Elevation	SRU-ATC
SRU-ATC	Shasta River upstream of the Little Shasta River confluence, Atmospheric Pressure Compensation	SRU-ATC
SRD-LBN	Shasta River downstream of the Little Shasta River confluence, Left Bank near River	SRD-ATC
SRD-LBF	Shasta River downstream of the Little Shasta River confluence, Left Bank further from River	SRD-ATC
SRD-RBN	Shasta River downstream of the Little Shasta River confluence, Right Bank near River	SRD-ATC
SRD-RBF	Shasta River downstream of the Little Shasta River confluence, Right Bank further from River	SRD-ATC
SRD-SWE	Shasta River downstream of the Little Shasta River confluence, Surface Water Elevation	SRD-ATC
SRD-ATC	Shasta River downstream of the Little Shasta River confluence, Atmospheric Pressure Compensation	SRD-ATC
LSR-LBN	Little Shasta River in Little Shasta Valley, Left Bank near River	LSR-ATC
LSR-LBF	Little Shasta River in Little Shasta Valley, Left Bank further from River	LSR-ATC
LSR-RBN	Little Shasta River in Little Shasta Valley, Right Bank near River	LSR-ATC
LSR-RBF	Little Shasta River in Little Shasta Valley, Right Bank further from River	LSR-ATC
LSR-SWE	Little Shasta River in Little Shasta Valley, Surface Water Elevation	LSR-ATC
LSR-ATC	Little Shasta River in Little Shasta Valley, Atmospheric Pressure Compensation	LSR-ATC

Figure 43: The SiteID, site name, and location of each site (Davids Engineering 2020).



Service Layer Credits: Sources: Esri, USGS, NOAA
Source: Esri, DigitalGlobe, GeoEye, Earthstar

Figure 44: Approximate Location of Piezometer Transects within the Shasta Valley (Davids Engineering 2020).

Temperatures can be measured and monitored in the aquifer and stream to provide additional insight into stream-aquifer interactions. Surface water is exposed to four heat-transfer mechanisms, most notably radiative heat input from the sun and convective heat transfer as water flows downstream and mixes. In a losing reach, the temperature in the shallow aquifer adjacent to the stream will more closely mirror surface water temperatures in the stream as surface water flows from the stream into the adjacent groundwater system. Conversely, in a gaining reach, the temperature in the shallow aquifer adjacent to the stream will remain more constant, not following surface water temperature trends as closely, as groundwater flows from the aquifer into the stream (Figure 45) (Davids Engineering 2020).

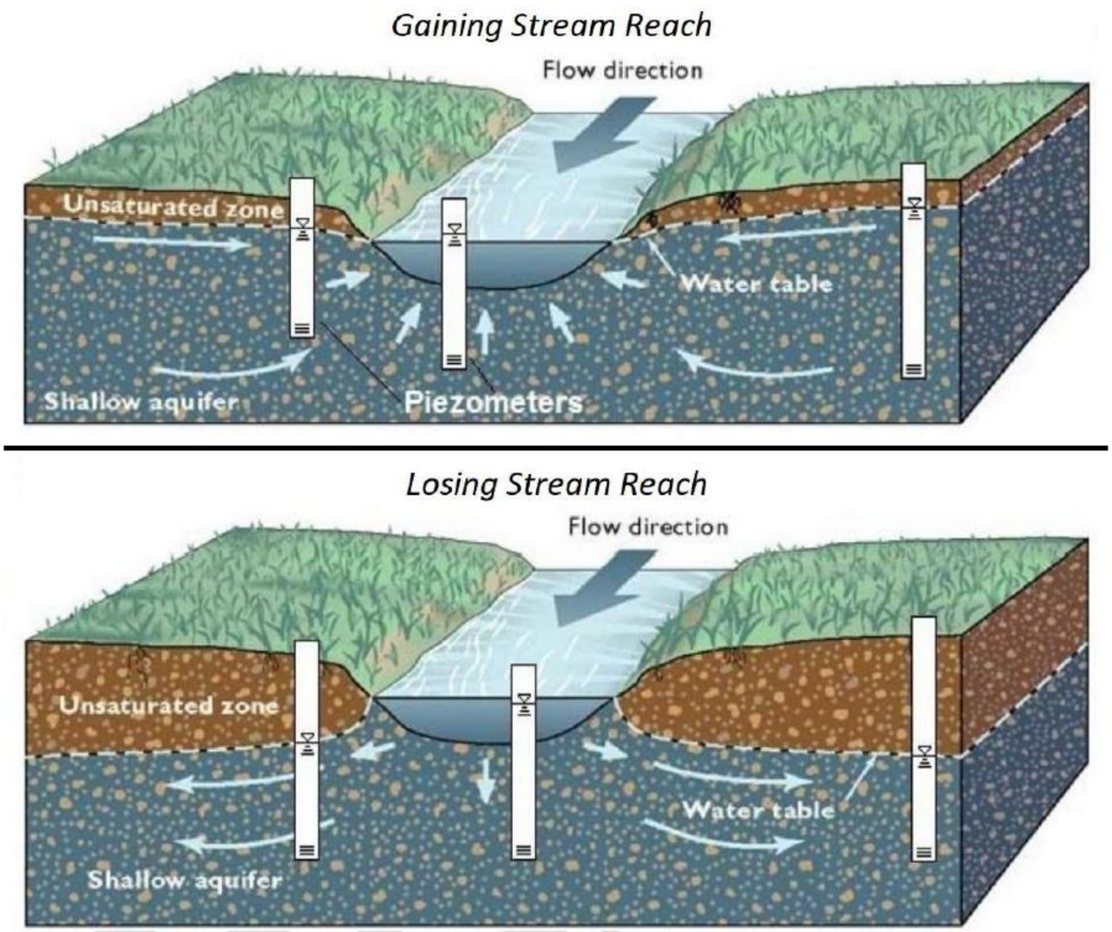


Figure 2. Conceptual Diagram of Piezometers in Gaining and Losing Stream Reaches (Modified from Winter et al., 1999).

Figure 45: Conceptual Diagram of Piezometers in Gaining and Losing Stream Reaches (Modified from Winter et al., 1999) (Davids Engineering 2020).

Shasta River Upstream of Little Shasta River Confluence (SRU)

The Shasta River had continuous flow past the transect location throughout the study period from May 2020 through October 2020. The river stage remained steady during this period, with fluctuations in stage of less than one foot. There was an increase in stage in late September and early October, potentially coinciding with the end of the irrigation season and cessation of upstream diversions. Groundwater elevations in the piezometers on both sides of the river tended to be higher than the surface water elevation in the river, with elevations increasing with distance from the river. The lands on either side of the river in this transect location were irrigated, and these periodic pulses of water observed in piezometers were likely reflective of irrigation events (Davids Engineering 2020).

With the exception of the SRU-RBN piezometer in late July and early August, all piezometers showed higher water surface elevations during the study period (Figure 47). Groundwater temperatures also tended to be lower than surface water temperatures for a majority of the study period, and did not show strong responses to surface water temperature fluctuations. These results indicate that the Shasta River was gaining in the transect location over the study period (Davids Engineering 2020).

Shasta River Downstream of Little Shasta River Confluence (SRD)

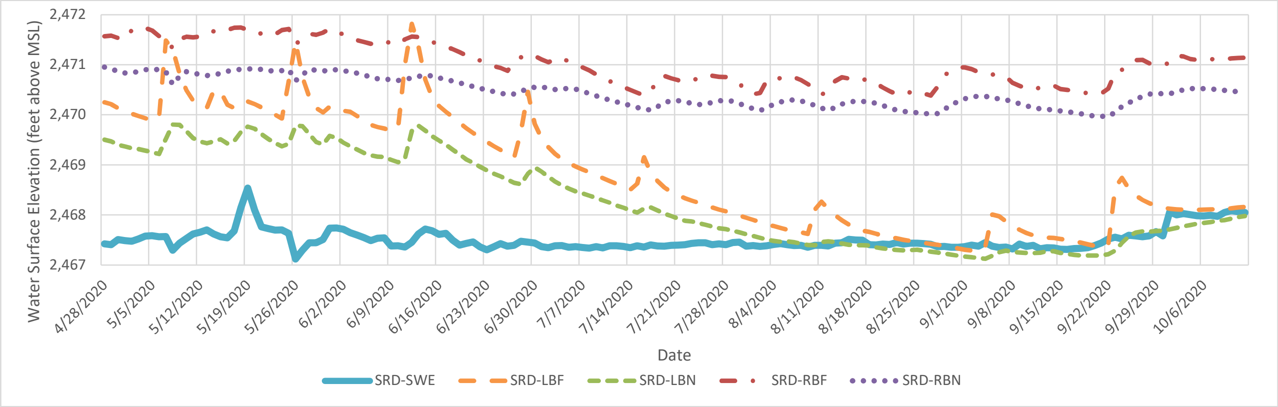
The river stage remained steady during the study period, excluding fluctuations in May. There was also an increase in stage in late September and early October, potentially coinciding with the end of the irrigation season and cessation of upstream diversions. Groundwater elevations in the piezometers on both sides of the river tended to be higher than the surface water elevation through most of the study period, with elevations increasing with distance from the river. The lands on either side of the river in this transect location were irrigated; increases in groundwater levels observed in piezometers were likely reflective of irrigation events (Davids Engineering 2020).

With the exception of the LBN piezometer from mid-August to mid-September, piezometers tended to show higher water surface elevations during the study period (Figure 46). Groundwater temperatures also tended to be lower than surface water temperatures for a majority of the study period, and did not show strong responses to surface water temperature fluctuations, although the LBF temperature appeared to be influenced by something distinct from the other sites. These results indicate that the Shasta River was generally gaining in the transect location over the study period, with some potential losses to the aquifer adjacent to the left bank in the late summer (Davids Engineering 2020).

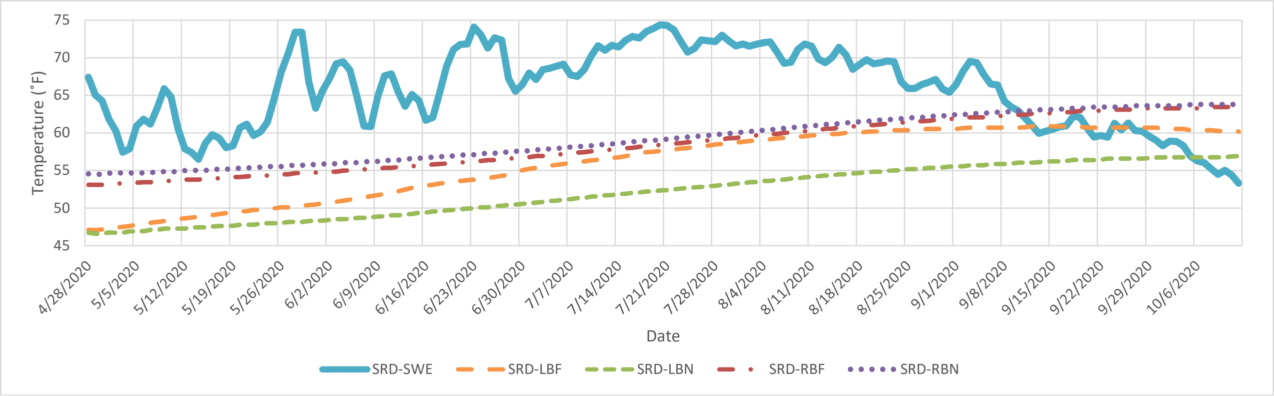
Little Shasta River in Little Shasta Valley (LSR)

The river stage at the transect remained relatively steady until late June - early July, where water levels declined until the river stretch completely dried out by August. Generally speaking, groundwater levels were declining during the study period. Due to underlying geological conditions (primarily the presence of large cobbles) the piezometer boreholes were not able to be drilled as deeply in this transect as the other two transects and groundwater levels in three of the four piezometers dropped below the level where they could be measured (Davids Engineering 2020).

Piezometers tended to have lower water surface elevations than the surface water site during the study period, and temperatures were typically within 10˚F between groundwater and surface water (Figure 48). These results indicate that the Little Shasta River was losing in the transect location over the study period (Davids Engineering 2020).



Daily Average Water Surface Elevations at Shasta River Downstream of Little Shasta River Confluence (SRD) Transect.

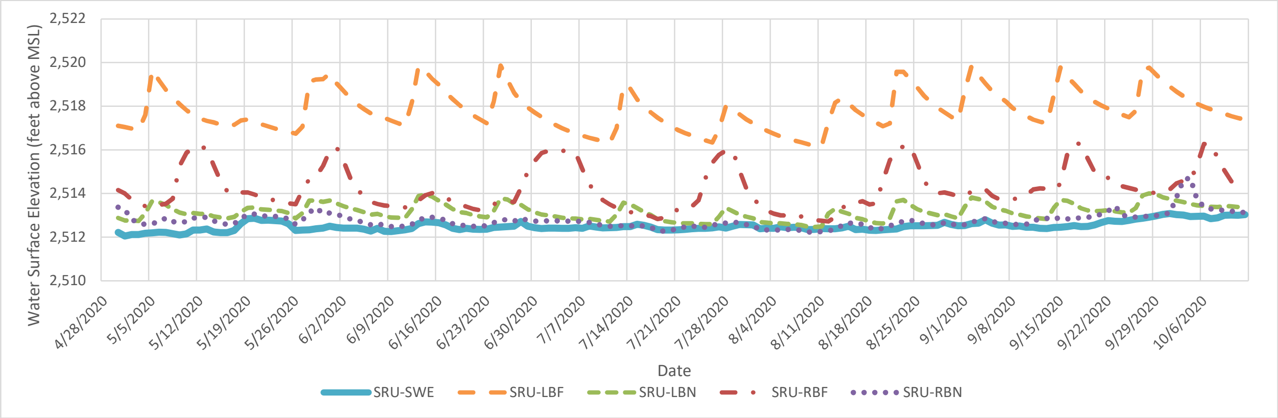


Daily Average Temperatures at Shasta River Downstream of Little Shasta River Confluence (SRD) Transect.

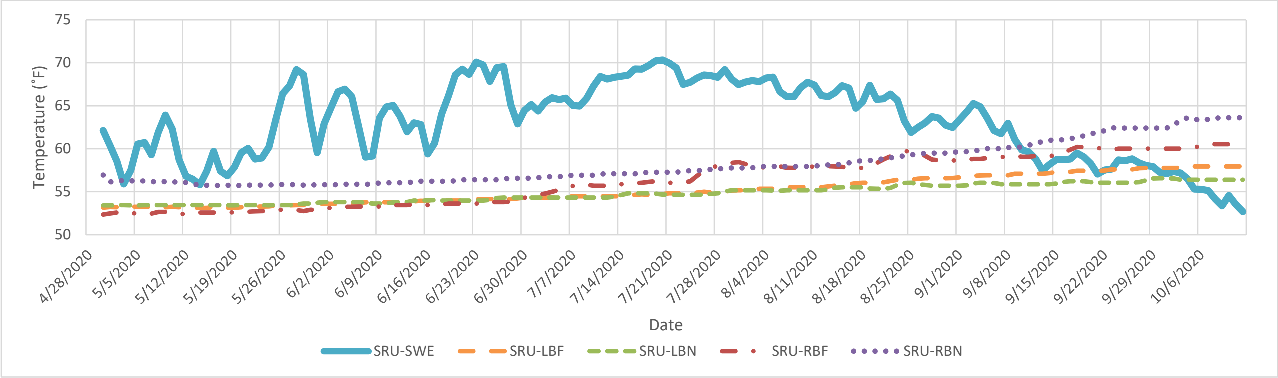
Davids Engineering

Shallow Piezometer
Transect Study

Figure 46: Study data from the Downstream Shasta River transect (Davids Engineering 2020).



Daily Average Water Surface Elevations at Shasta River Upstream of Little Shasta River Confluence (SRU) Transect.

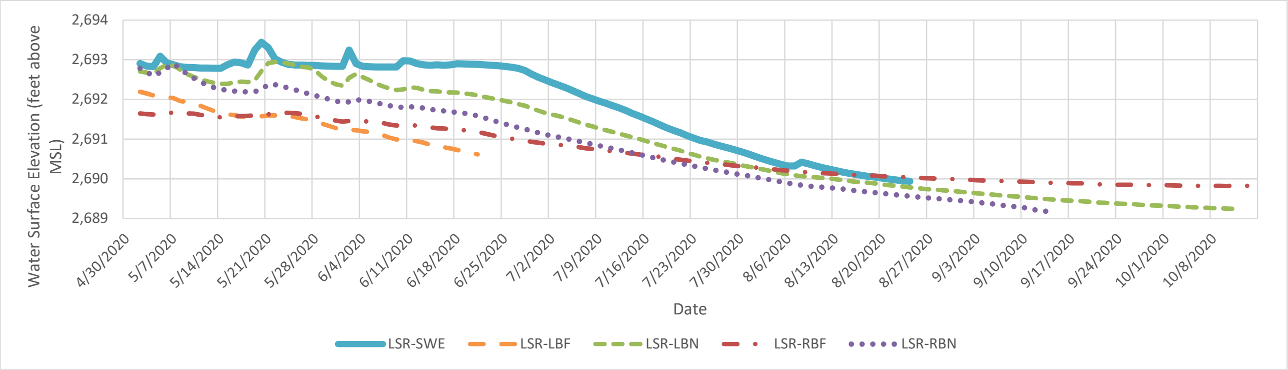


Daily Average Temperatures at Shasta River Upstream of Little Shasta River Confluence (SRU) Transect.

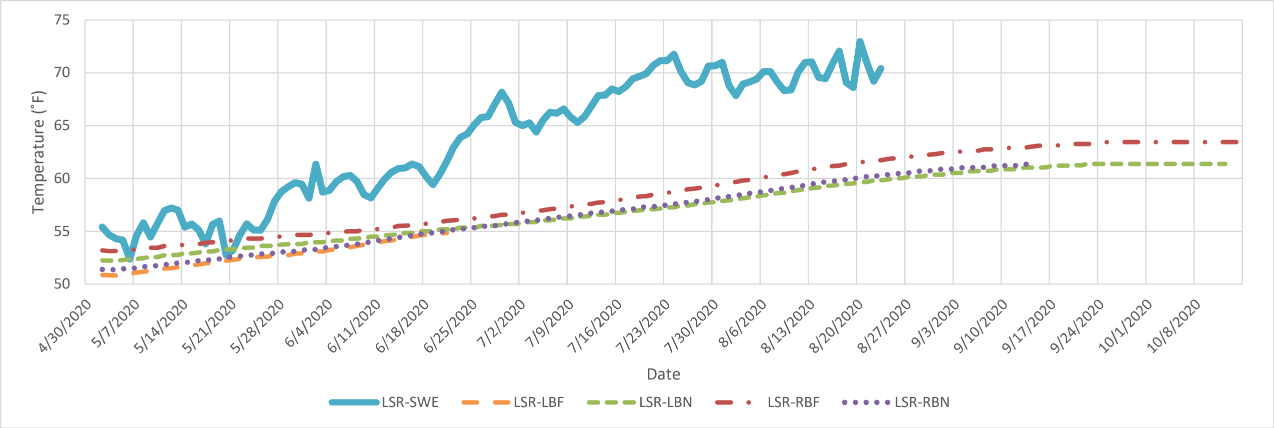
Davids Engineering

Shallow Piezometer
Transect Study

Figure 47: Study data from the Upstream Shasta River transect (Davids Engineering 2020).



Daily Average Water Surface Elevations at Little Shasta River (LSR) Transect.



Daily Average Temperatures at Little Shasta River (LSR) Transect.

Davids Engineering

Shallow Piezometer
Transect Study

Figure 48: Study data from the Little Shasta River in Little Shasta Valley transect (Davids Engineering 2020).

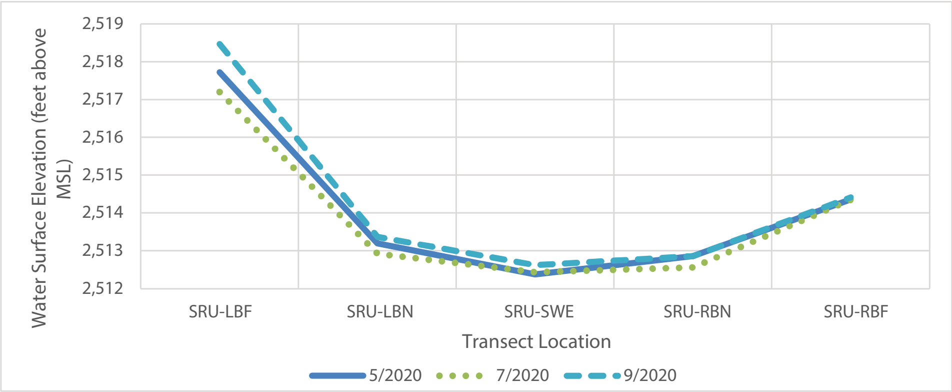
Average Monthly Water Elevations During May, July, and September 2020

Each transect had differing trends in water surface elevation (Figure 49). For the SRU transect, conditions remained relatively stable over the study period, and the hydraulic gradient towards the river from the left bank was substantially greater than from the right bank. For the SRD transect, decreasing water surface elevations were seen at all sites over the study period, but to varying degrees. The highest hydraulic gradient towards the river occurred from the right bank; water elevations in the RBN and RBF piezometers declined from May to July but remain steady from July to September. In contrast, along the left bank, the water surface elevations continually decreased from May through September. For the LSR transect, decreasing water surface elevations were seen at all sites over the study period. The smallest decrease was observed in the RBF piezometer in this transect (Davids Engineering 2020).

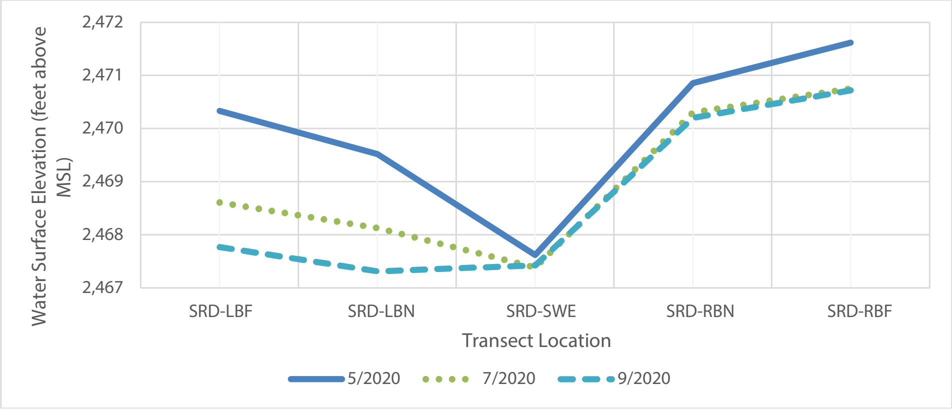
Summary

Both transects along the Shasta River (SRU and SRD) had higher shallower groundwater water surface elevations in the piezometers than surface water elevations throughout the study period. Overall, shallow groundwater levels relative to surface water showed relatively consistent trends during the study period. The shallow groundwater levels in the two transects along the Shasta River tended to be higher in elevation and have a hydraulic gradient towards the river, while in the Little Shasta River they tend to be lower in elevation and have a hydraulic gradient away from the river. While these trends were influenced by a variety of factors, one that may contribute to differences is the irrigation of lands on either side of the river, as the lands along the Shasta River in the vicinity of the transect were irrigated while lands along the Little Shasta River were unirrigated.

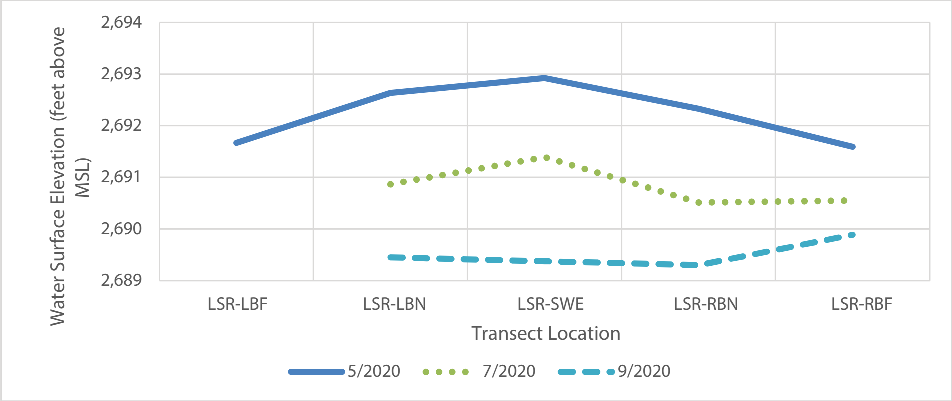
Temperature differences varied between the transects, but overall showed the same general trends. The shallow groundwater was lower in temperature at the start of the study in May 2020 (e.g. negative values), and the differences increased into the summer as surface water temperatures increased more rapidly than groundwater temperatures. However, in late summer and early fall, as groundwater temperatures continued to slowly rise and surface water temperatures began falling, the trend reversed. The differences decreased and then became positive, reflective of surface water temperatures decreasing below shallow groundwater temperatures. The temperature difference was the smallest for the LSR transect and greatest for the SRD transect. The temperature difference may have been greater at the SRD transect than the SRU transect because of surface warming in the Shasta River as it flowed downstream. The temperature difference comparison at all transects reflected the slower changes in shallow groundwater temperatures relative to surface water temperatures (Davids Engineering 2020).



Monthly Average Water Surface Elevations at Shasta River Upstream of Little Shasta River Confluence (SRU) Transect (Perspective Looking Downstream).



Monthly Average Water Surface Elevations at Shasta River Downstream of Little Shasta River Confluence (SRD) Transect (Perspective Looking Downstream).



Monthly Average Water Surface Elevations at Little Shasta River (LSR) Transect (Perspective Looking Downstream)

Figure 49: Cross-sectional view of water elevations at each piezometer transect, looking downstream. The horizontal axis is equally spaced and not representative of true distances between piezometers (Davids Engineering 2020).

Spring Discharge Monitoring Results

Discharge measurements are scheduled to be taken at a monthly interval at select springs in the Shasta Valley to evaluate seasonal variability and trends in spring discharge in different locations (Figure 50 and Figure 51).

[Data included below should be considered preliminary.]

Observations (Shasta Valley Resource Conservation District 2021):

- Big Springs Creek, Little Springs Creek and Hole in the Ground spring show relatively large changes in spring discharge.
- The fluctuations in Big Springs Creek align with the irrigation season, and are likely reflective of groundwater pumping (i.e. BSID groundwater pumps) resulting in decreased spring discharge during the spring and summer months.
- The trend in Hole in the Ground Springs generally follows the same pattern as Big Springs Creek in the data thus far, so it may be influenced by similar factors, although seems to have more delayed increases/decreases compared to Big Springs Creek.
- Little Springs Creek shows decreased flow in September 2020, which may be an anomaly. A construction project in the vicinity of the measurement location had recently been completed, and the channel may have been dewatered. It also shows decreased flow in April and May 2021, which may potentially be indicative of an upstream diversion between the spring source and the measurement location, or may be caused by another factor.
- Evans Spring, Kettle Spring, and Clear Spring appear to be more stable, not showing the same fluctuations in flow seen at the sites listed above. They also have lower flows.
- Kettle Spring Creek in the discharge measurement location has a soft channel bottom, making measurement of channel depth with a wading rod and placement of the velocity sensor at the correct depth in water column more difficult. Although the measurements can be considered representative, this adds uncertainty to these measurements that are not present at measurement sites with a firm channel bottom. Additionally, total discharge is calculated as sum of the transect measurement in Kettle Spring Creek and the measured diverted flows from Kettle Spring, which also adds uncertainty to the total flow.
- Both Evans Spring and Clear Spring show increasing flow in the past few months.

These conditions may change course during drought conditions.

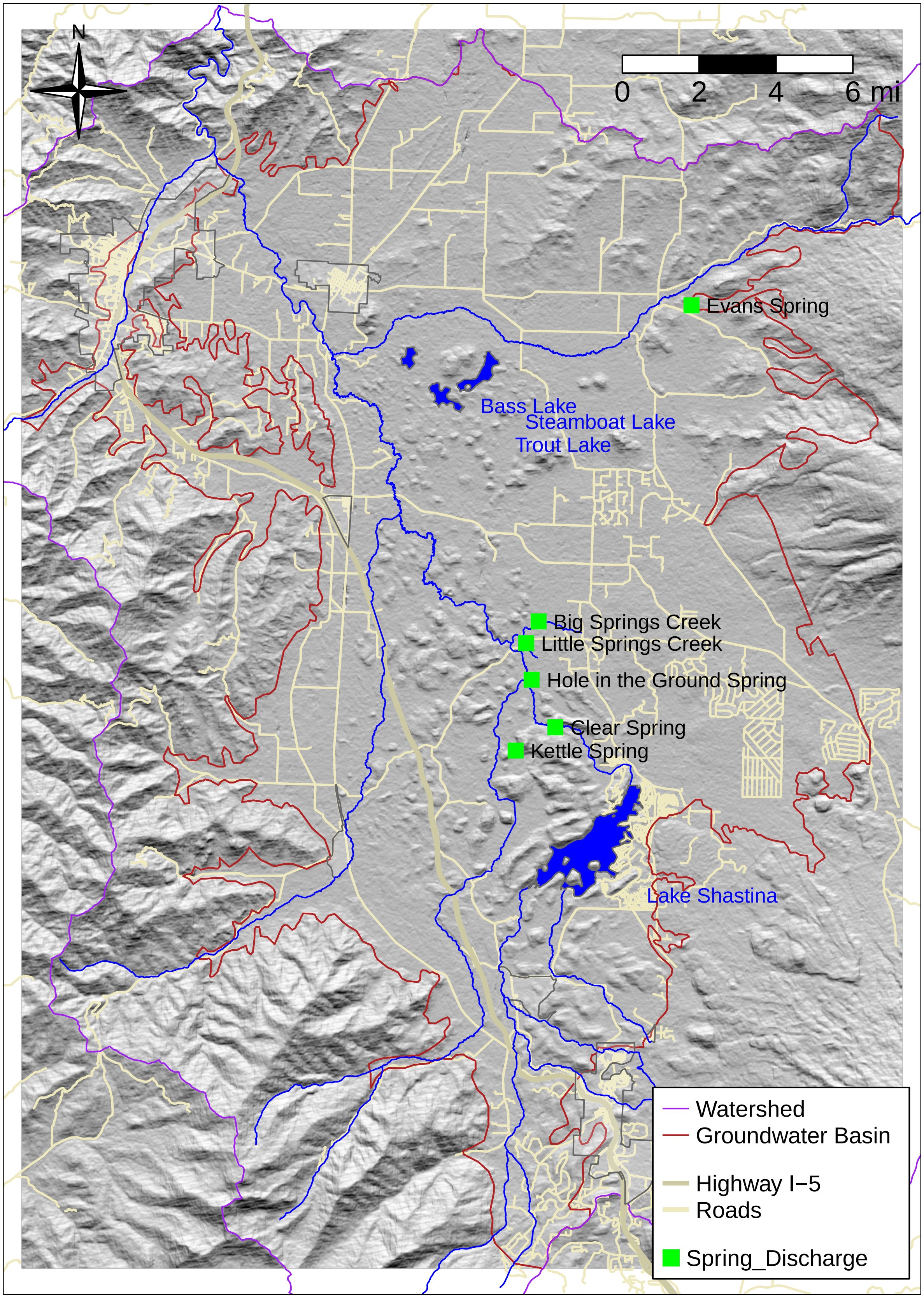


Figure 50: Monthly Spring Monitoring Networks.

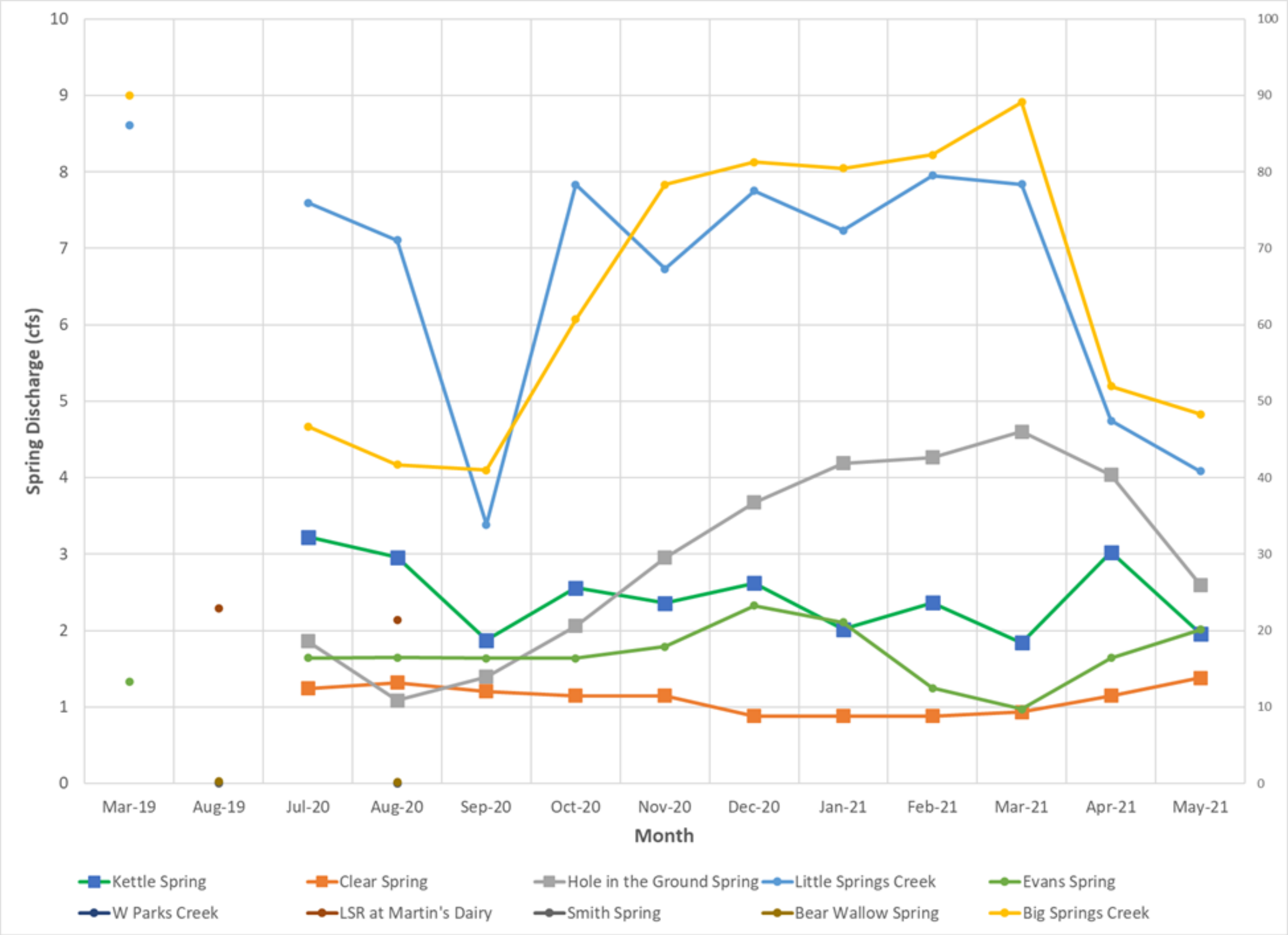


Figure 51: Monthly spring discharge measurement results. Please note that only Big Springs Creek discharge corresponds to the secondary vertical axis values. Please also note that the horizontal axis is not at regular intervals (Shasta Valley Resource Conservation District 2021).

Identified Interconnected Surface Waters

Assumed ISWs within the Basin, reflecting the current understanding of groundwater-surface water interactions are presented in a manner consistent with requirements outlined in SGMA in Figure 52. These ISWs are presented with representations of depth to groundwater for the spring and fall of 2015 in Figure 53 and Figure 54, respectively.

The link between surface and groundwater is based on historic reports (Mack, 1960) as well as continued summer baseflow within the Shasta River. Because the water table in many parts of Shasta Valley can be relatively shallow, the Shasta River surface water network contains many miles of stream channel that are connected to groundwater. The Shasta River and its major tributaries are all considered part of the interconnected surface water system in the Basin. Their large seasonal flow variations exhibit all five elements of the recently proposed functional flows framework for managing California rivers: fall flush flow, winter storm flow, winter baseflow, spring recess, and summer baseflow. The system is also subject to significant interannual variations in flow and largely affected by the complex springs system that is present throughout the valley as a result of the volcanic origin.

The magnitude and direction of flow exchanged between surface water and groundwater varies both in time and spatially (i.e., the geographic distribution of gaining and losing stream reaches is not constant). When this flux is net positive into the aquifer over the Basin, it is commonly referred to as stream leakage; when it is net positive into the stream it is referred to as groundwater discharge.

In most years, the net direction in the entire watershed of stream-aquifer flux is as groundwater discharge into the river, with the largest net groundwater replenishment from streams occurs in wet years. Seasonally, the magnitude of stream leakage from the streamflow system to the aquifer is greatest during late winter and early spring, while the net magnitude of groundwater discharge to the stream is greatest in late fall at the end of the dry season (least seasonal recharge). The mainstem Shasta River is alternately gaining and losing depending on the season, on the location, and on the year type. In other words, river water weaves in and out of the aquifer on its journey south to north along the valley floor. When considered as a whole, the mainstem of the Shasta River is a gaining reach. The upper sections of tributaries tend to be losing stream reaches but conditions depend on precipitation levels during any given water year and some of the tributaries tends to be dry in the summer months before connecting to the main stem of the Shasta River.

With respect to the functional flows of the Shasta River, depletion of surface water due to groundwater pumping affects the timing of the late spring recess, the amount of summer baseflow, and the onset of fall flush flow.

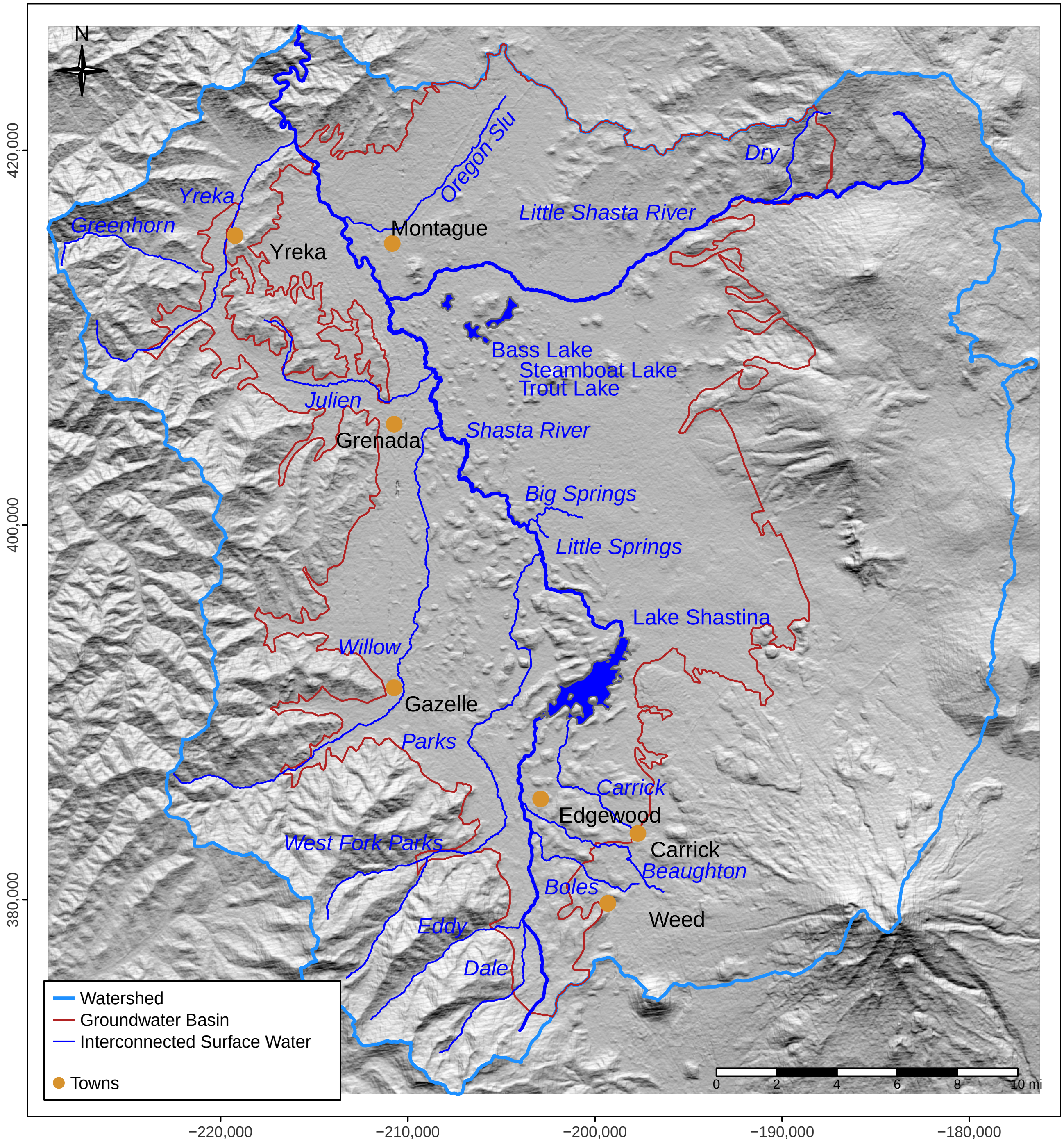


Figure 52: Major interconnected surface waters (ISW) in the Shasta Valley groundwater basin includes the Shasta River tributaries and Lake Shastina and Big Springs Lake. All surface water is considered a potential ISW.

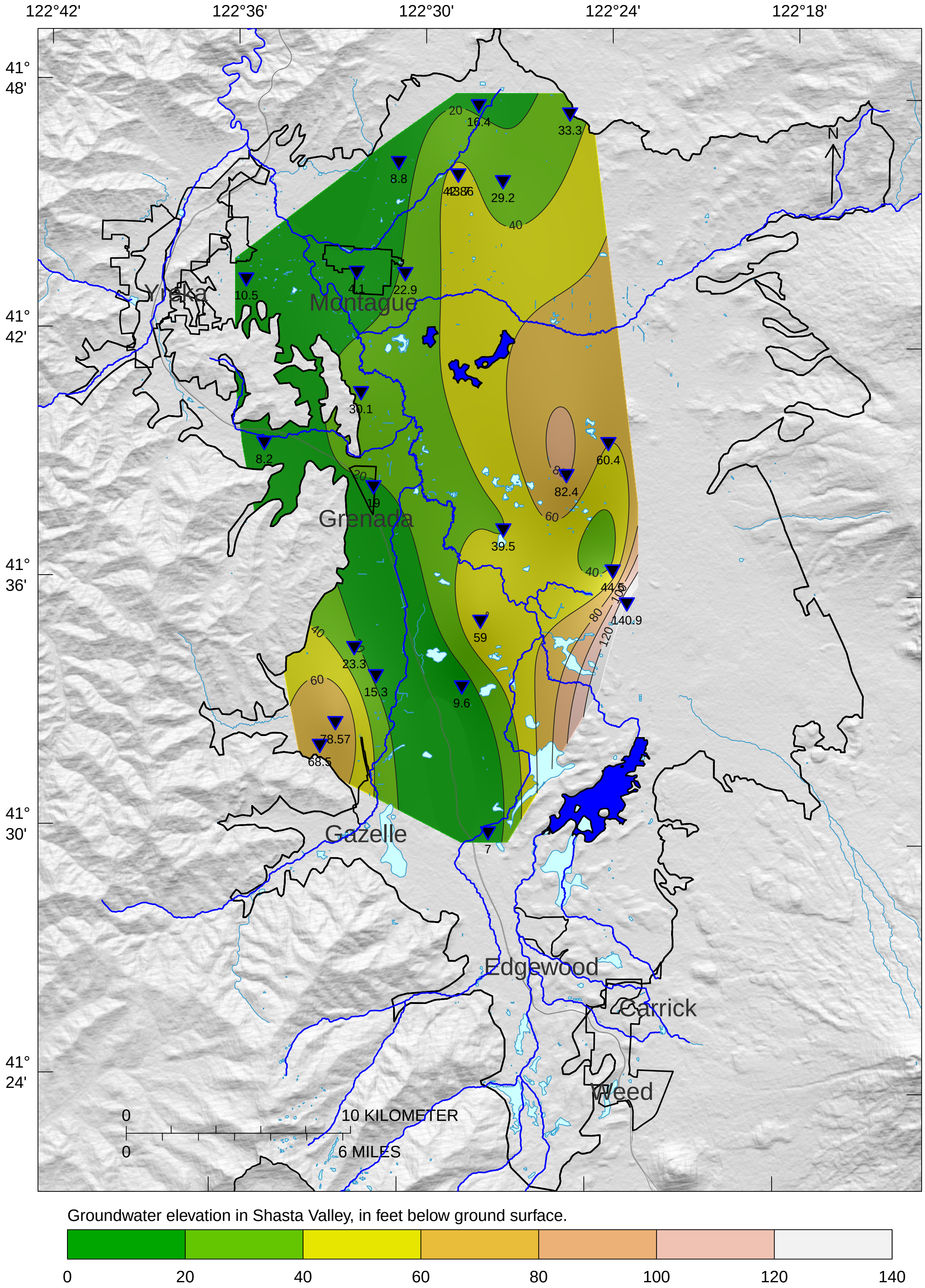


Figure 53: Major interconnected surface waters in Shasta Valley, with groundwater contours in terms of depth below ground surface in Sping 2015.

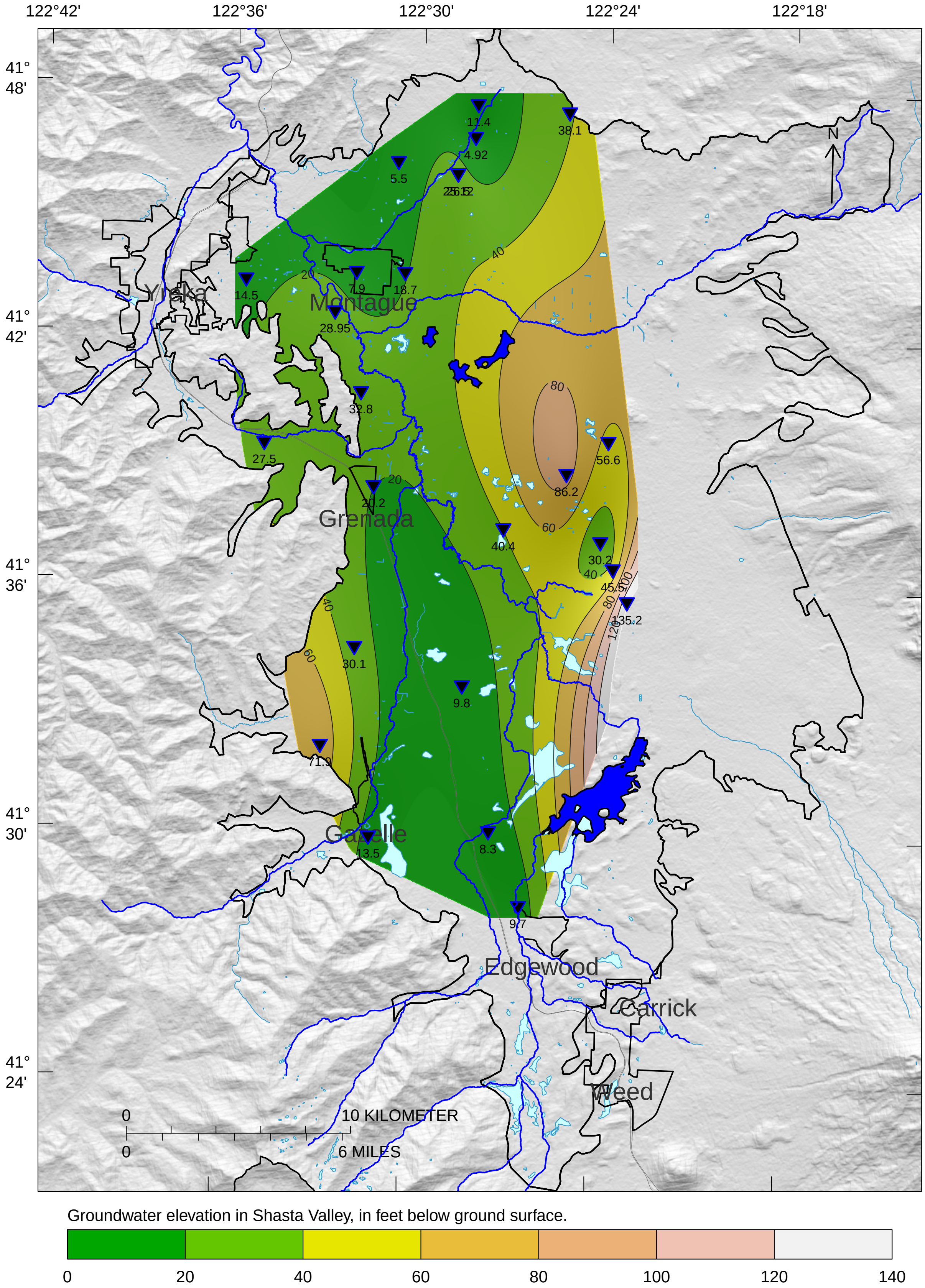


Figure 54: Major interconnected surface waters in Shasta Valley, with groundwater contours in terms of depth below ground surface in Fall 2015.

2.2.2.7 Identification of Groundwater-Dependent Ecosystems

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

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

Environmental Beneficial Water Uses and Users within the Basin

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

The Basin encompasses three USEPA Level III Ecoregions of California (Griffith et al., 2016) (Figure 55):

- Cascade (Ecoregion 4), which covers approximately 32% of the Shasta Watershed area, 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 accounts for 46% of the Watershed. 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.
- Klamath Mountain/California High North Cascade Range (Ecoregion 78), covers approximately 22% of the Watershed area. The mild Mediterranean climate of the ecoregion is characterized by hot, dry summers and wet winters. The region's mix of granitic, sedimentary, metamorphic, and extrusive rocks contrasts with the predominantly younger volcanic rocks of the Cascades Ecoregion 4 to the east. It includes ultramafic substrates, such as serpentinite and mafic lithologies that directly affect vegetation. The region's diverse flora, a mosaic of both northern Californian and Pacific Northwestern conifers and hardwoods, is rich in endemic and relic species.

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. An overview of jurisdictional areas and land uses can be found in Section 2.1.1.

Endangered, Threatened, or Species of Special Concern

The CDFW Biogeographic Information and Observation System (BIOS) Viewer was used to identify threatened and endangered species that may be present within the Shasta Watershed. A total of six species are listed as endangered at the federal level with 17 listed as endangered by the State of California. An additional nine species are listed as threatened at the federal level with ten receiving the same designation at the State level. An additional subset of species are listed as either being a candidate for endangered species status or rare at the federal level, proposed endangered at the State level, or species of special concern. Two species of special concern not present in the BIOS viewer summary were added to the list at the request of CDFW staff. These species were the Western pond turtle and the Pacific lamprey. A summary of endangered, threatened, or species of special concern for the Shasta watershed is presented in Table 6.

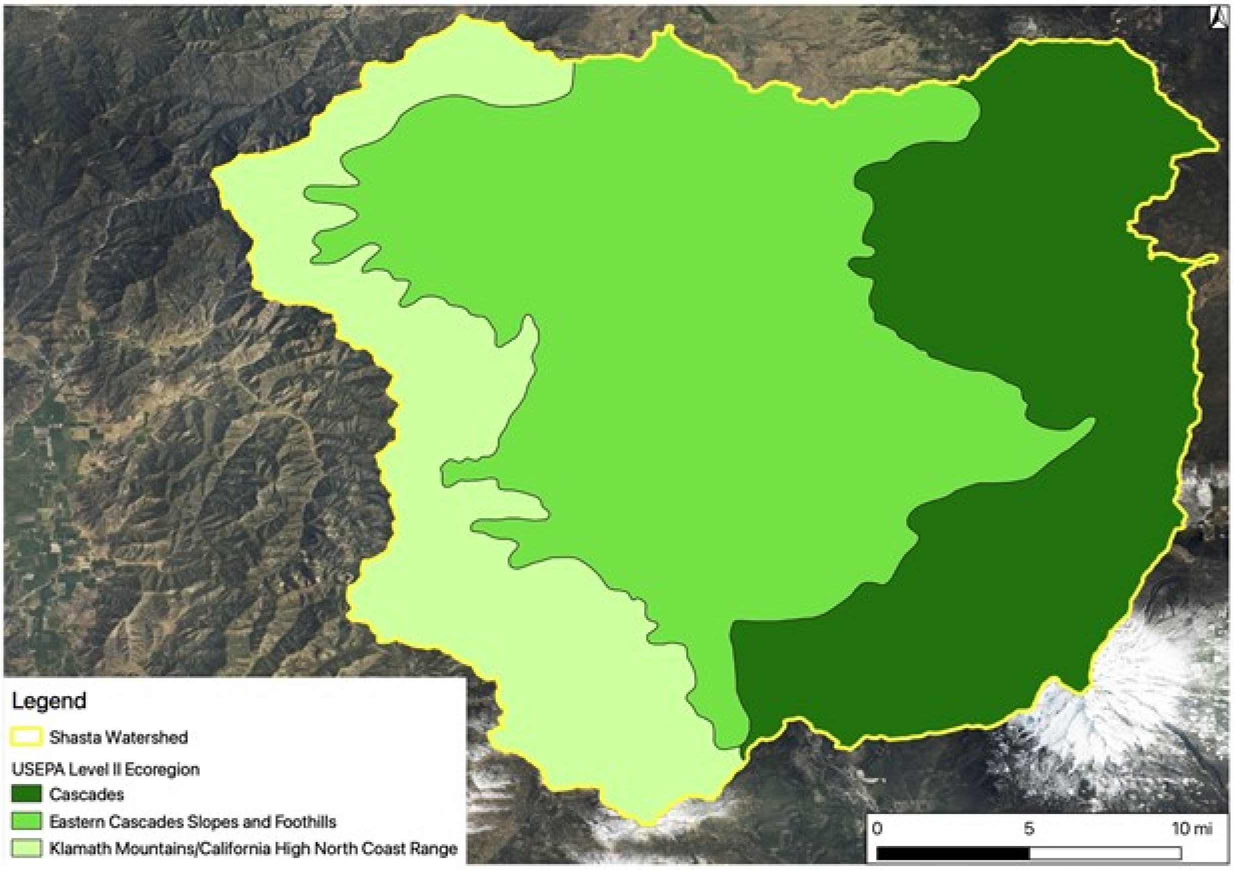


Figure 55: Ecoregions in Shasta Watershed

Table 6: Threatened and Endangered Species Within Siskiyou County Identified in the CDFW BIOS Viewer.

Species Common Name	Scientific Name	Group	State Status	Federal Status
Scott Bar salamander	Plethodon asupak	Animals - Amphibians	Threatened	None
Siskiyou Mountains salamander	Plethodon stormi	Animals - Amphibians	Threatened	None
Foothill yellow-legged frog	Rana boylii	Animals - Amphibians	Endangered	None
Cascades frog	Rana cascadae	Animals - Amphibians	Candidate Endangered	None
Oregon spotted frog	Rana pretiosa	Animals - Amphibians	None	Threatened
Western pond turtle	Actinemys marmorata	Animals - Amphibians	Species of Special Concern	Species of Concern
Swainson’s hawk	Buteo swainsoni	Animals - Birds	Threatened	None
Bald eagle	Haliaeetus leucocephalus	Animals - Birds	Endangered	Delisted
Western snowy plover	Charadrius nivosus nivosus	Animals - Birds	None	Threatened
Western yellow-billed cuckoo	Coccyzus americanus occidentalis	Animals - Birds	Endangered	Threatened
Greater sandhill crane	Antigone canadensis tabida	Animals - Birds	Threatened	None
Bank swallow	Riparia riparia	Animals - Birds	Threatened	None
Tricolored blackbird	Agelaius tricolor	Animals - Birds	Threatened	None
Great gray owl	Strix nebulosa	Animals - Birds	Endangered	None
Northern spotted owl	Strix occidentalis caurina	Animals - Birds	Threatened	Threatened
Willow flycatcher	Empidonax traillii	Animals - Birds	Endangered	None
Little willow flycatcher	Empidonax traillii brewsteri	Animals - Birds	Endangered	None
Green sturgeon	Acipenser medirostris	Animals - Fish	None	Threatened
Shortnose sucker	Chasmistes brevirostris	Animals - Fish	Endangered	Endangered
Lost River sucker	Deltistes luxatus	Animals - Fish	Endangered	Endangered
Coho salmon - southern Oregon / northern California ESU	Oncorhynchus kisutch pop. 2	Animals - Fish	Threatened	Threatened
Steelhead - northern California DPS	Oncorhynchus mykiss irideus pop. 16	Animals - Fish	None	Threatened
Summer-run steelhead trout	Oncorhynchus mykiss irideus pop. 36	Animals - Fish	Candidate Endangered	None
Chinook salmon - upper Klamath and Trinity Rivers ESU	Oncorhynchus tshawytscha pop. 30	Animals - Fish	Candidate Endangered	Candidate
Bull trout	Salvelinus confluentus	Animals - Fish	Endangered	Threatened
Pacific Lamprey	Entosphenus tridentatus	Animals - Fish	Species of Special Concern	Species of Concern

Table 6: Threatened and Endangered Species Within Siskiyou County Identified in the CDFW BIOS Viewer. *(continued)*

Species Common Name	Scientific Name	Group	State Status	Federal Status
Crotch bumble bee	Bombus crotchii	Animals - Insects	Candidate Endangered	None
Franklin’s bumble bee	Bombus franklini	Animals - Insects	Candidate Endangered	Proposed Endangered
Western bumble bee	Bombus occidentalis	Animals - Insects	Candidate Endangered	None
Suckley’s cuckoo bumble bee	Bombus suckleyi	Animals - Insects	Candidate Endangered	None
Gray wolf	Canis lupus	Animals - Mammals	Endangered	Endangered
Sierra Nevada red fox	Vulpes vulpes necator	Animals - Mammals	Threatened	Proposed Endangered
California wolverine	Gulo gulo	Animals - Mammals	Threatened	Proposed Threatened
Humboldt marten	Martes caurina humboldtensis	Animals - Mammals	Endangered	Proposed Threatened
Ashland thistle	Cirsium ciliolatum	Plants - Vascular	Endangered	None
McDonald’s rockcress	Arabis mcdonaldiana	Plants - Vascular	Endangered	Endangered
Siskiyou mariposa-lily	Calochortus persistens	Plants - Vascular	Rare	None
Gentner’s fritillary	Fritillaria gentneri	Plants - Vascular	None	Endangered
Boggs Lake hedge-hyssop	Gratiola heterosepala	Plants - Vascular	Endangered	None
Leafy reed grass	Calamagrostis foliosa	Plants - Vascular	Rare	None
Slender Orcutt grass	Orcuttia tenuis	Plants - Vascular	Endangered	Threatened
Yreka phlox	Phlox hirsuta	Plants - Vascular	Endangered	Endangered
Trinity buckwheat	Eriogonum alpinum	Plants - Vascular	Endangered	None
Scott Bar salamander	Plethodon asupak	Animals - Amphibians	Threatened	None

Table 7: GDE species prioritization for management. 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
Chinook salmon	Bank Swallow
Coho Salmon	Western Pond Turtle
Steelhead trout	Foothill Yellow-legged Frog
Pacific Lamprey	Greater Sandhill Crane
Unprotected species that depend on groundwater dependence ecosystem	Willow Flycatcher

CDFW's 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. BIOS also presents the extent of suitable habitat for a subset of the species presented in Table 6. Representation of the extent of habitat for species where such information is made available in the BIOS viewer are presented in Appendix 2-G.

Management Approach

Groundwater dependent species were prioritized for management, primarily focusing on anadromous fish species (Chinook Salmon, Coho Salmon, Steelhead Trout, and Pacific Lamprey) and GDEs located along the Shasta River, tributaries, and riparian corridors. 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, foothill yellow-legged frog, greater sandhill crane, willow flycatcher, and other bird species that use riverine habitats during their various life stages. 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 7, are considered throughout this GSP. Other species listed in Table 6 and Table 7 are protected by federal or state agencies. As needed, the GSA will partner with environmental agencies to protect non-threatened, threatened, and endangered species within the Basin.

GDE Analysis Approach

The GDE analysis for the Shasta Watershed was comprised of a two-part analysis first identifying riparian GDEs relying on in-stream flows addressed in the ISW analysis presented in Section 2.2.2.6 and then vegetative GDEs likely relying on groundwater in areas that are not in close proximity to surface water features or riparian corridors. The following sections discuss the process of mapping potential GDEs based on available resources and categorizing mapped potential GDEs into riparian GDE or vegetative GDE categories.

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. 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 56 and Figure 57, respectively.

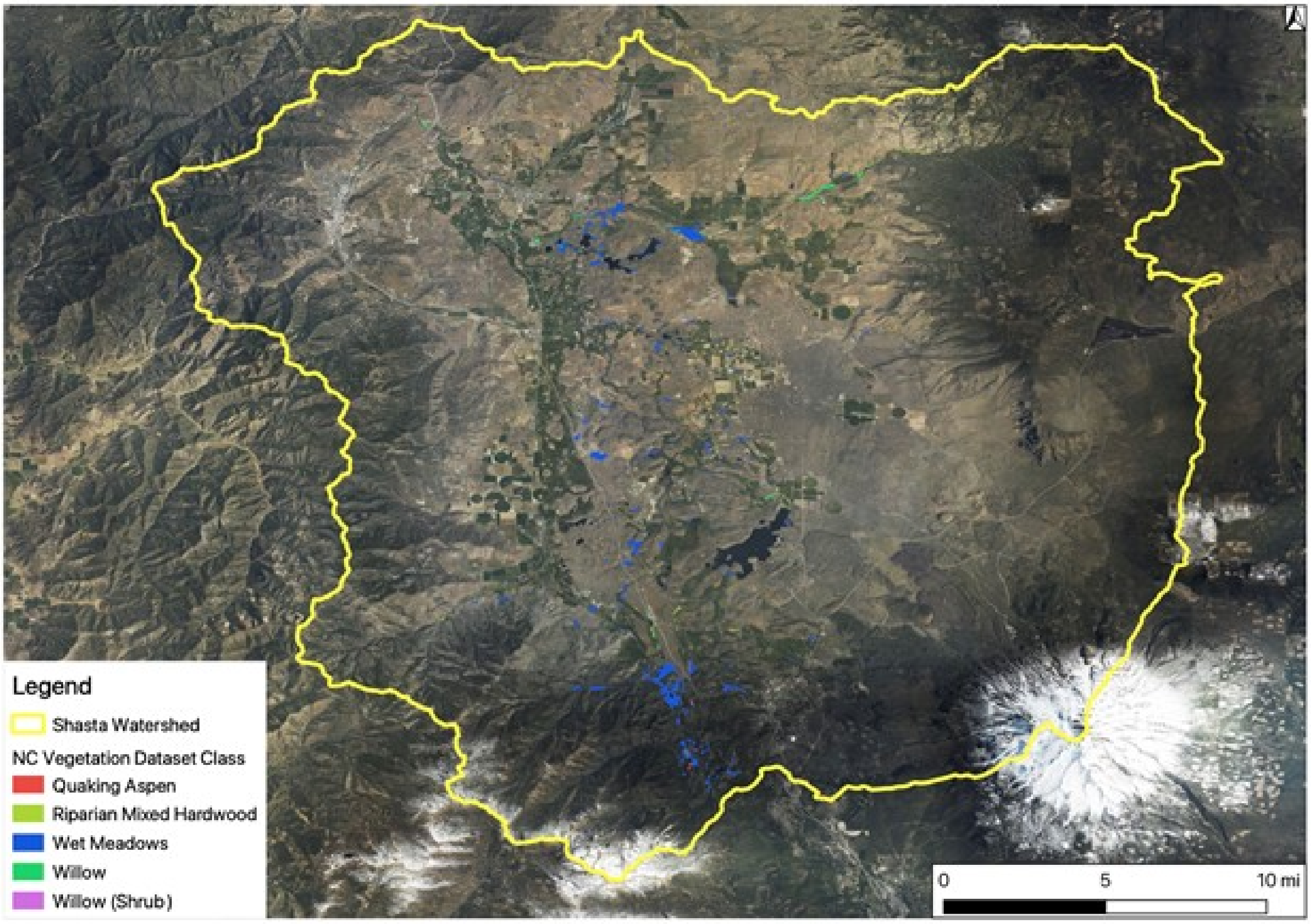


Figure 56: Classes Within NCCAG Vegetation Dataset for the Shasta Watershed.

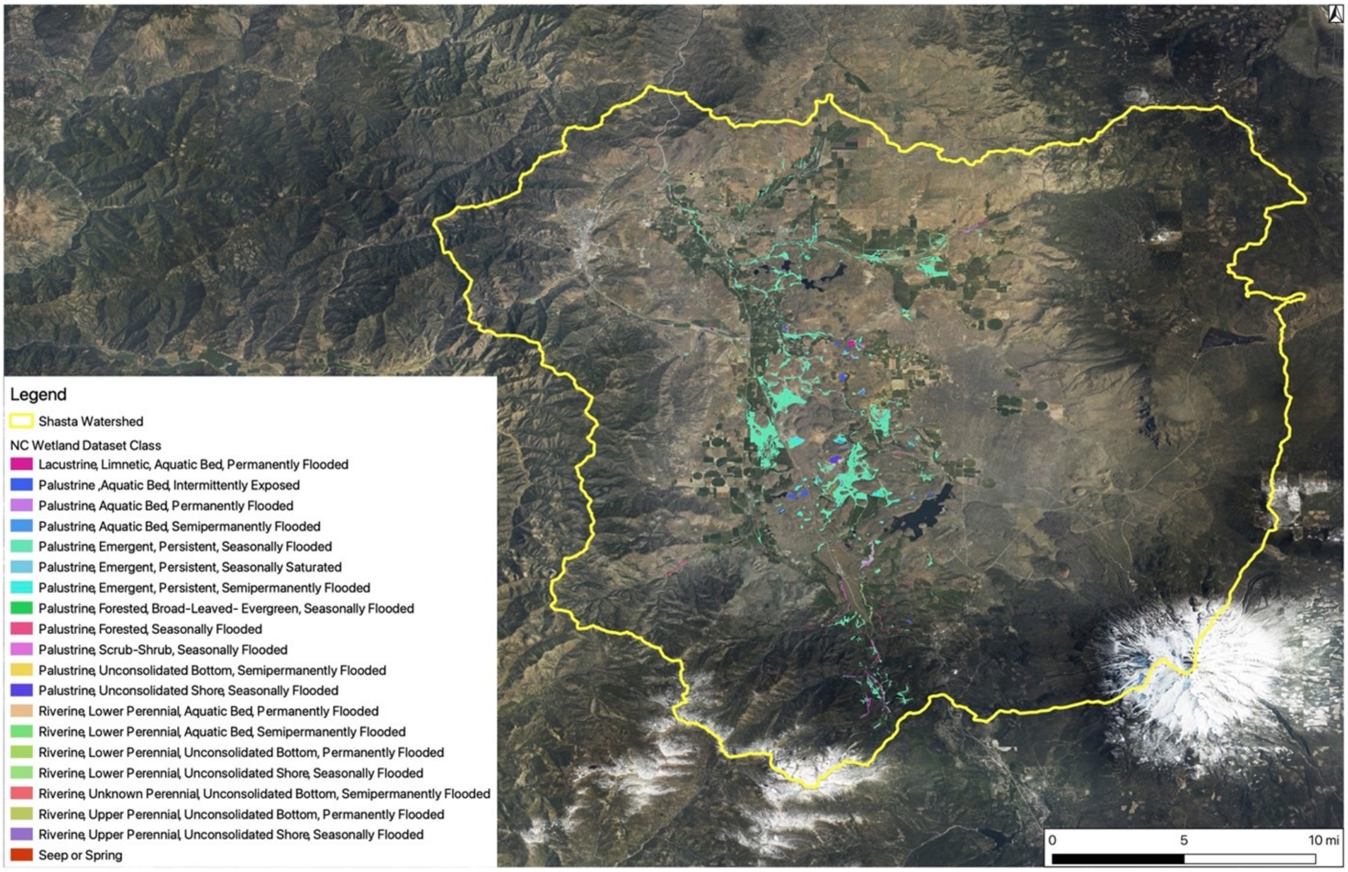


Figure 57: Classes Within NCCAG Wetland Dataset for the Shasta Watershed.

An initial review of NCCAG mapped potential wetland and vegetation 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, initially developed in 2010 by DWR and adapted based on stakeholder input in 2016, were incorporated into the analysis to more effectively represent mapped potential GDEs for the Shasta Basin. Siskiyou County LU/LC classes are presented in Appendix 2-G. Areas identified as agricultural areas, urban areas, and irrigated areas were removed from consideration as GDEs.

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. This combined or unioned NCCAG dataset was intersected with the adapted 2016 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 8 based on best professional judgment. Additional tables used in this process are presented in Appendix 2-G.

Table 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.

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 2016 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 2016 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. For 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.

Riparian GDE Identification and Classification

Mapped potential GDEs in close proximity to surface water features were assumed to be riparian GDEs and reliant on the presence of in-stream flows. Mapped river channels within the Shasta watershed were isolated and buffered to a distance of 100 ft on either side of the surface water feature centerline reflecting a conservative representation of the hyporheic zone supporting riparian vegetation. This representation of the assumed extent of riparian vegetation was overlaid or intersected with the mapped potential GDE presented in Figure 58 yielding potential mapped GDEs within the assumed riparian extent. The 1,700 acres assumed to represent riparian GDEs, accounting for 11.1% of mapped potential GDEs are presented in Figure 59.

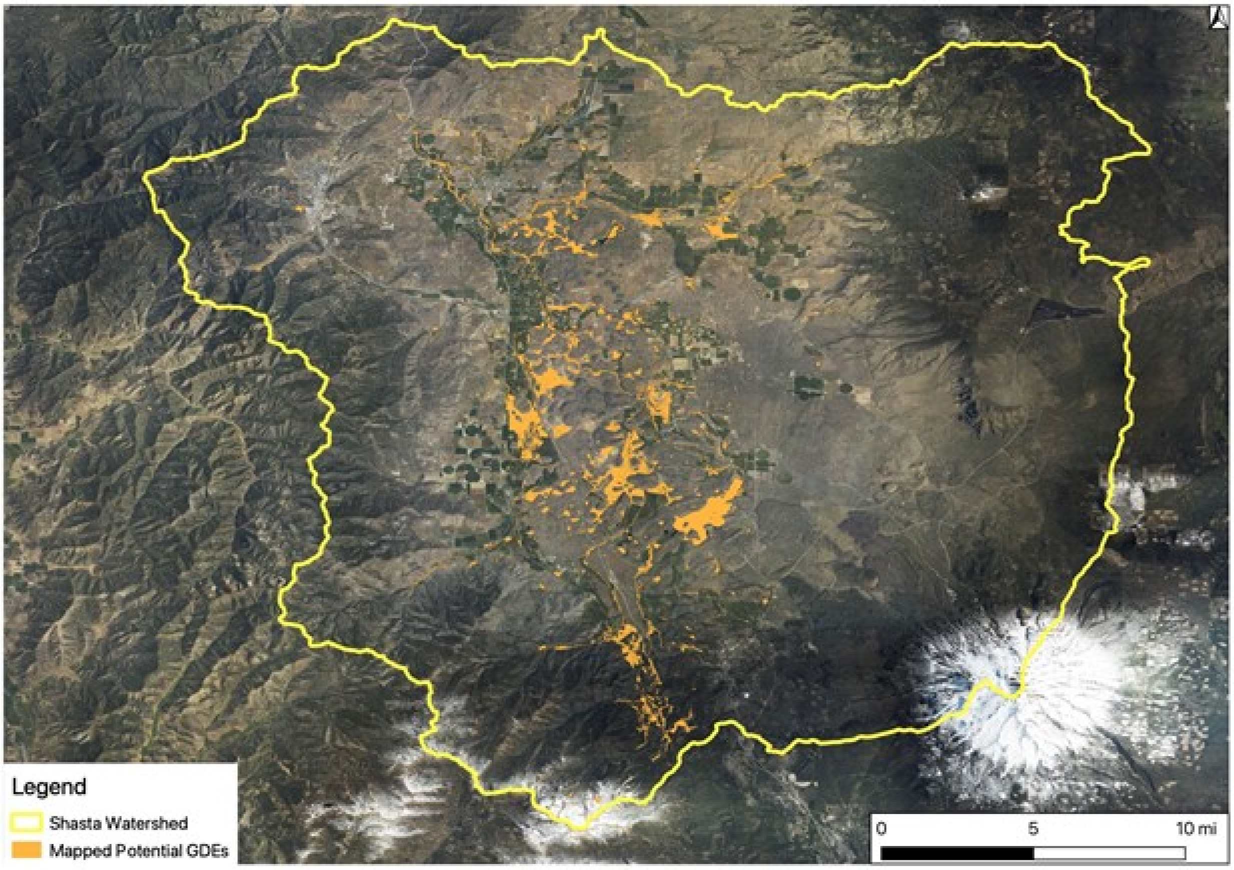


Figure 58: Mapped potential groundwater dependent ecosystems (GDEs) for the Shasta Watershed.

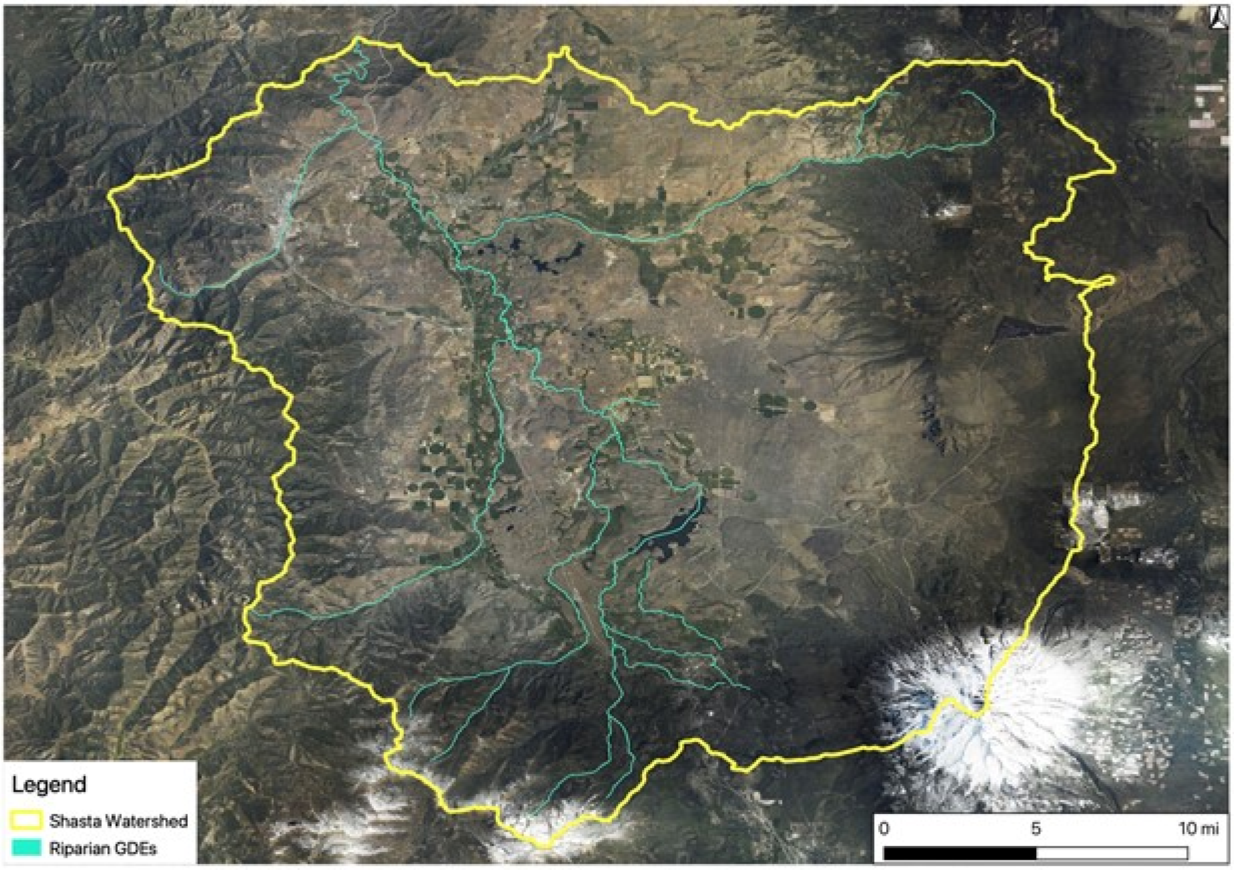


Figure 59: Assumed riparian groundwater dependent ecosystems (GDEs) in the Shasta Watershed

Vegetative GDE Identification and Classification

The following section discusses the process of identifying potential vegetative GDEs, effectively mapped potential GDEs that weren't classified as riparian 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 vegetative GDEs based on available resources;
- Assigning rooting depths based on predominant assumed vegetation type; and
- Establishing representations of depth to groundwater.

The following subsections discuss the process of assembling these three building blocks and the subsequent vegetative GDE categorization based on the relationship between them.

Assumed Rooting Zone Depths

Rooting zone depths were assigned to all combined or concatenated values for the NCCAG vegetation, NCCAG wetland, and 2016 Siskiyou County LU/LC 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 vegetation GDE dataset. Classifications from the NCCAG vegetation dataset were used to assign rooting zone depths based on a presumably higher level of mapping accuracy and more descriptive classes with values such as “wet meadow” or “willow shrub” present within the Shasta watershed. 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 2016 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 vegetative GDEs. Vegetation classifications were grouped into four broad categories based on best professional judgment. The relationship between mapped vegetation categories and assumed predominant or representative vegetation is presented in Table 9, Table 10, and Table 11 for the NCCAG vegetation, NCCAG wetland, and 2016 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 ft (Niswonger and Fogg 2008) indicating that this assumed depth of 13.1 ft is relatively conservative while additional resources suggest that rooting zone depths of 13.1 ft are consistent with mean values for deciduous broadleaf trees which would have deeper rooting depths than willows (Fang et al. 2017). A rooting depth of 9.51 ft was assumed for Quaking Aspen (Canadell et al. 1996).

Other vegetation classes such as those included in the NCCAG wetland dataset 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). The mean of mean literature values for grasses, forbs, sedges, and rushes was assumed be 4.8 ft with the maximum of mean literature values assumed to be 9.6 ft. 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 9: Assumed Rooting Zone Depth and Representative Vegetation for Classes Within the NCCAG Vegetation Dataset.

Vegetation Class	**Assumed Rooting Zone Depth (ft.)**	**Assumed Representative Vegetation**
Quaking Aspen	9.51	Quaking Aspen
Riparian Mixed Hardwood	13.10	Willow
Wet Meadows	4.80	Grasses, Forbs, Sedges, and Rushes Mean of Mean Rooting Depths
Willow	13.10	Willow
Willow (Shrub)	13.10	Willow

Table 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
Lacustrine, Limnetic, Aquatic Bed, Permanently Flooded	9.6	Grasses, Forbs, Sedges, and Rushes Max of Mean Rooting Depth
Palustrine, Aquatic Bed, Semipermanently Flooded	13.1	Willow
Palustrine, Aquatic Bed, Intermittently Exposed	13.1	Willows
Palustrine, Aquatic Bed, Permanently Flooded	13.1	Willows
Palustrine, Emergent, Persistent, Seasonally Saturated	4.8	Grasses, Forbs, Sedges, and Rushes Mean of Mean Rooting Depths
Palustrine, Emergent, Persistent, Seasonally Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean of Mean Rooting Depths
Palustrine, Emergent, Persistent, Semipermanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean of Mean Rooting Depths
Palustrine, Forested, Broad-Leaved- Evergreen, Seasonally Flooded	13.1	Willows
Palustrine, Forested, Seasonally Flooded	13.1	Willows
Palustrine, Scrub-Shrub, Seasonally Flooded	13.1	Willows
Palustrine, Unconsolidated Bottom, Semipermanently Flooded	13.1	Willows
Palustrine, Unconsolidated Shore, Seasonally Flooded	13.1	Willows
Riverine, Lower Perennial, Aquatic Bed, Semipermanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean of Mean Rooting Depths
Riverine, Lower Perennial, Aquatic Bed, Permanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean of Mean Rooting Depths
Riverine, Lower Perennial, Unconsolidated Bottom, Permanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean of Mean Rooting Depths
Riverine, Lower Perennial, Unconsolidated Shore, Seasonally Flooded	13.1	Willows

Table 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**
Riverine, Upper Perennial, Unconsolidated Bottom, Permanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean of Mean Rooting Depths
Riverine, Upper Perennial, Unconsolidated Shore, Seasonally Flooded	13.1	Willows
Riverine, Unknown Perennial, Unconsolidated Bottom, Semipermanently Flooded	4.8	Grasses, Forbs, Sedges, and Rushes Mean of Mean Rooting Depths
Seep or Spring	9.6	Grasses, Forbs, Sedges, and Rushes Max of Mean Rooting Depths

Table 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. Interpolation was carried out using ordinary kriging (Wackernagel 1995), and observed groundwater elevations were obtained from the Periodic Groundwater Level Database (CA-DWR 2021). Altogether, depth to groundwater conditions were developed for 16 three-year periods (e.g. spring 2012 through 2014 would involve spring representations for 2012, 2013, and 2014) between spring of 2011 and the fall of 2020, as sufficient groundwater level data is available during this timeframe. These periods represent water level data every 6 months from spring 2011 to fall 2020, with equal amounts of fall and spring periods. These depths to groundwater provide the best available representation of relatively modern depths to groundwater, pending estimates from the groundwater flow model in development. Mapped representations of depth to groundwater, the difference between surface elevations and groundwater elevation above mean sea level, were developed for 16 rolling three-year periods (e.g. spring 2012 through 2014 would involve spring representations for 2012, 2013, and 2014) between spring of 2011 and the fall of 2020. These grid or raster geospatial datasets were developed by interpolating between statistical representations of observed groundwater elevations for each three-year rolling period using data obtained from the CASGEM Program using the well-establish kriging method.

An example representation of depth to groundwater for the Shasta basin is presented in Figure 60. Representations of depth to groundwater for each of the 16 representation of three-year rolling depth to groundwater are presented in Appendix 2-G.

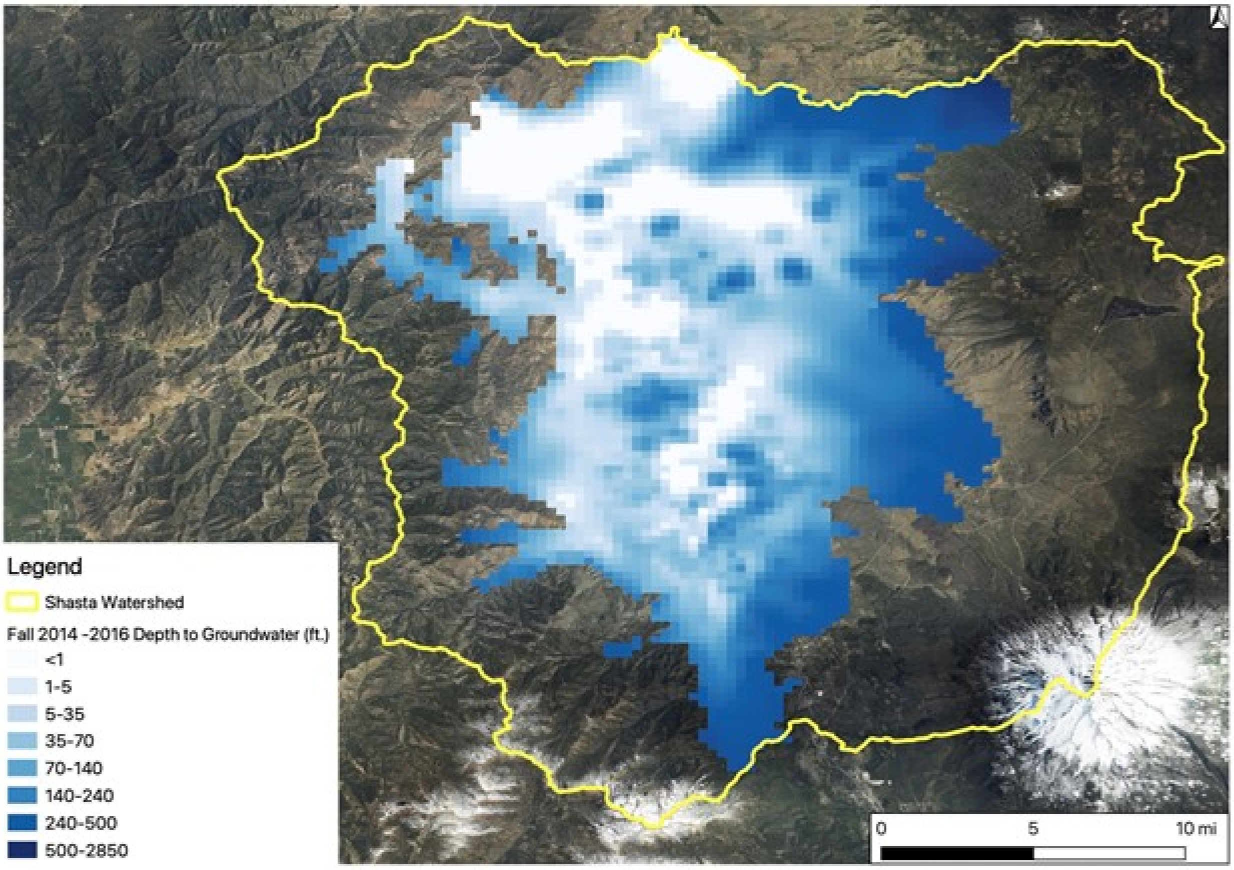


Figure 60: Depth to Groundwater for the Three-Year Rolling Period Between Fall 2014 and Fall 2016.

Relationship Between Rooting Zone Depths and Depth to Groundwater

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

Grid-Based Vegetative GDE Analysis

The grid-based analysis relied on the grid or raster-based representations of depth to groundwater similar to what is presented in Figure 60 in the previous subsection. 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 vegetative GDE area using the zonal statistics function in available many GIS programs. This zonal statistics function identifies what cells of the depth to groundwater grid or raster dataset fall within the bounds of each mapped potential vegetative GDE polygon and then computes an area-weighted average for that area. This zonal statistics analysis was carried out for each of the 16 three-year rolling average representations of depth to groundwater between spring 2011 and fall 2020 yielding 16 columns summarizing the average depth to groundwater for each mapped potential vegetative GDE area. The 16 periods used in the analysis represent water levels every 6 months from spring 2011 to fall 2020.

The second step involved simply subtracting the calculated depth to groundwater for each mapped potential vegetative 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 16 representations of depth to groundwater and was added as a new field for each representation of depth to groundwater.

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

Results of this grid-based analysis of mapped potential vegetative GDEs and their classification as connected or disconnected to groundwater for each of the 16 periods is presented in Appendix 2-G. Mapped potential vegetative GDEs were then further characterized based on the percentage of years when vegetation with their assumed rooting zone depth would reasonably have access to groundwater. Areas with assumed predominant vegetation types that would have access to groundwater for greater than 50% of all periods are categorized as “likely connected” to groundwater for this grid-based analysis. Areas with assumed vegetation that do not appear to have access to groundwater for greater than 50% of the period of record are assumed to be “likely disconnected” from groundwater. This is reasonable based on the quality of groundwater level data in Basin, where historical data is only available every 6 months, in the spring and fall. A potential GDE with vegetation connected to groundwater every spring will be labeled as “likely connected.” Disconnection from groundwater for greater than 50% of periods indicates a multi-year lack of groundwater in the rooting zone.

Mapped Potential Vegetative GDE Classification

A tabular summary of the grid-based GDE classifications for each mapped potential vegetative GDE area was developed. Potential mapped vegetative 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” (“Assumed GDE”). Similarly, areas that were shown to be disconnected from groundwater were considered a “Potentially not a GDE” (“Assumed not a GDE”). Riparian and vegetative GDEs analyses were integrated to produce a comprehensive representation of assumed GDEs for the Shasta watershed and are presented in Table 12 and Figure 61.

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

Table 12: Distribution of Mapped Potential GDEs into Vegetative and Riparian GDE Categories.

GDE Categorization	Grid Classification	Area (Acres)	% of Mapped Potential GDE Area
Riparian GDE	Likely connected to groundwater	1639	13.81%
Potential GDE	Likely connected to groundwater	2589	21.82%
Potentially not a GDE	Likely disconnected from groundwater	9008	75.92%

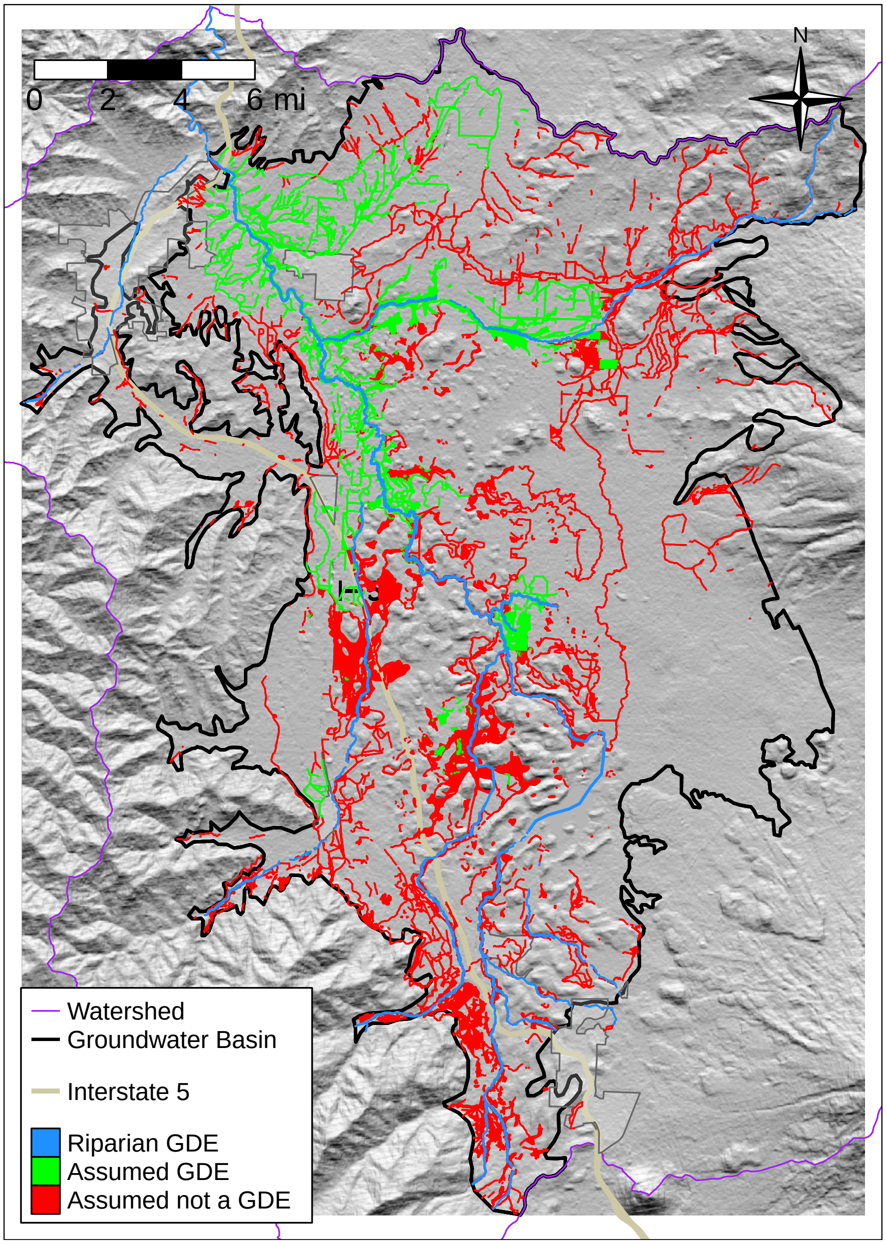


Figure 61: Categorized Riparian and Vegetative GDEs Within the Shasta Basin.

Assumptions and Uncertainty

The approach developed and carried out to identify and evaluate GDEs within the Shasta 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 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. Uncertainty and data gaps in the groundwater level data is discussed in Section 2.2.2.1.

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 a 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 Basin.

2.2.3 Historic Water Budget Information

This water budget section provides summary results for water years 1991-2018 period analyzed for developing the GSP baseline. It also describes future climate change projections. Details of the water budget with water year type analysis and month-by-month output is summarized in Appendix 2-E on model development. the water budgets are the best current representation of the Shasta Valley groundwater system and will be improved by the five year update with further model calibration with the ongoing collection of continuous groundwater elevation data.

The historical water budget for the Basin was estimated for the period October 1990 through September 2018, using the Shasta Watershed Groundwater Model (SWGM) presented and discussed in Section 2.2.3.1 Summary of Model Development. This 28-year model period includes water years ranging from very dry (e.g., 2001 and 2014) to very wet (e.g., 2006 and 2017). On an interannual scale, it includes a multi-year wet period in the late 1990s and a multi-year dry period in the late 2000s and mid-2010s.

Annual water budgets for the full model period are shown in Figure 62 and Figure 63 for the Shasta Basin Bulletin 118 boundary and Shasta Watershed, respectively. Annual summaries of these budgets are presented in Appendix 2-E. The following two sections provide an overview of the SWGM, which is used to determine the water budget for the three hydrologic subsystems of the Basin: the surface water subsystem, the land/soil subsystem, and the groundwater subsystem. The budget also includes the total water budget of the Basin. The second section provides a description of the water budget shown in the figures and tables below and explains the water budget dynamics in the context of the basin hydrogeology and hydrology described in previous sections. This sub-chapter presents critical rationale that is later used in this GSP for the design of monitoring networks, development of sustainable management criteria, and identification of projects or management actions (Chapters 3 and 4).

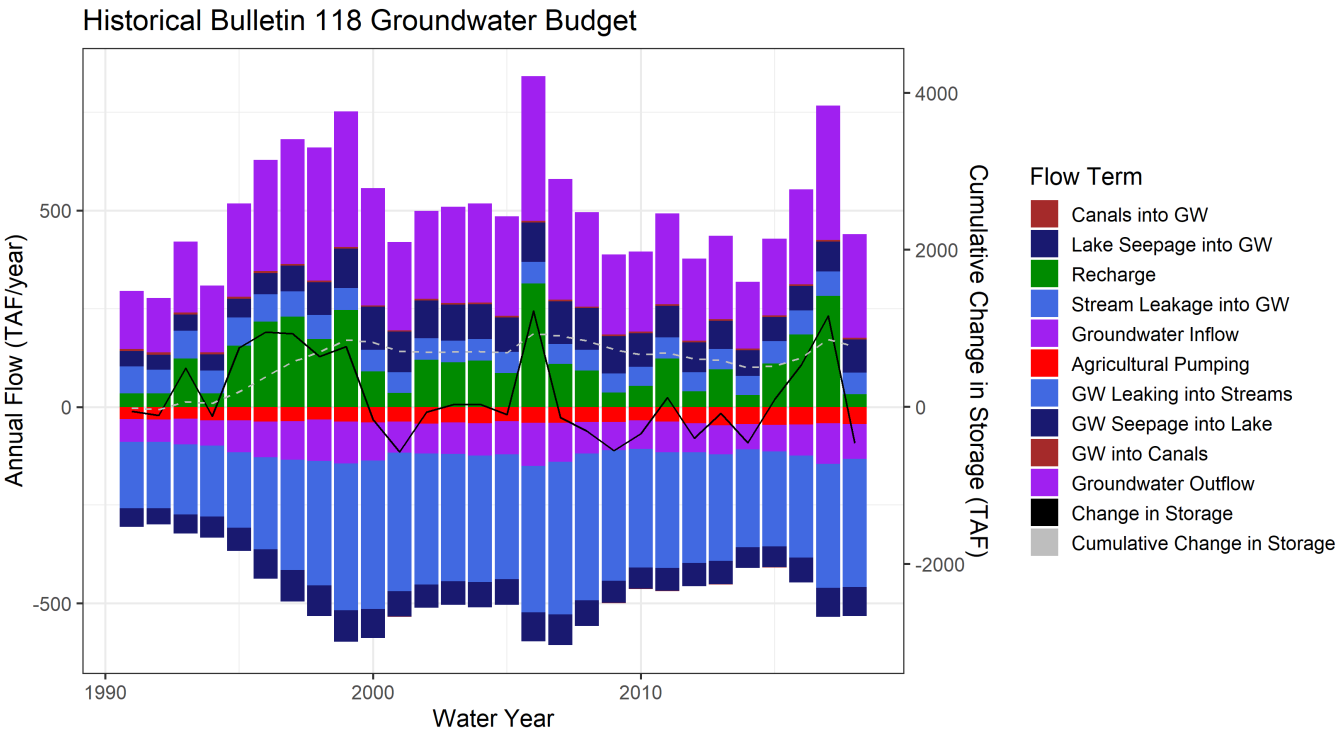


Figure 62: Annual water budgets for all flow terms for the Shasta Basin Bulletin 118 boundary.

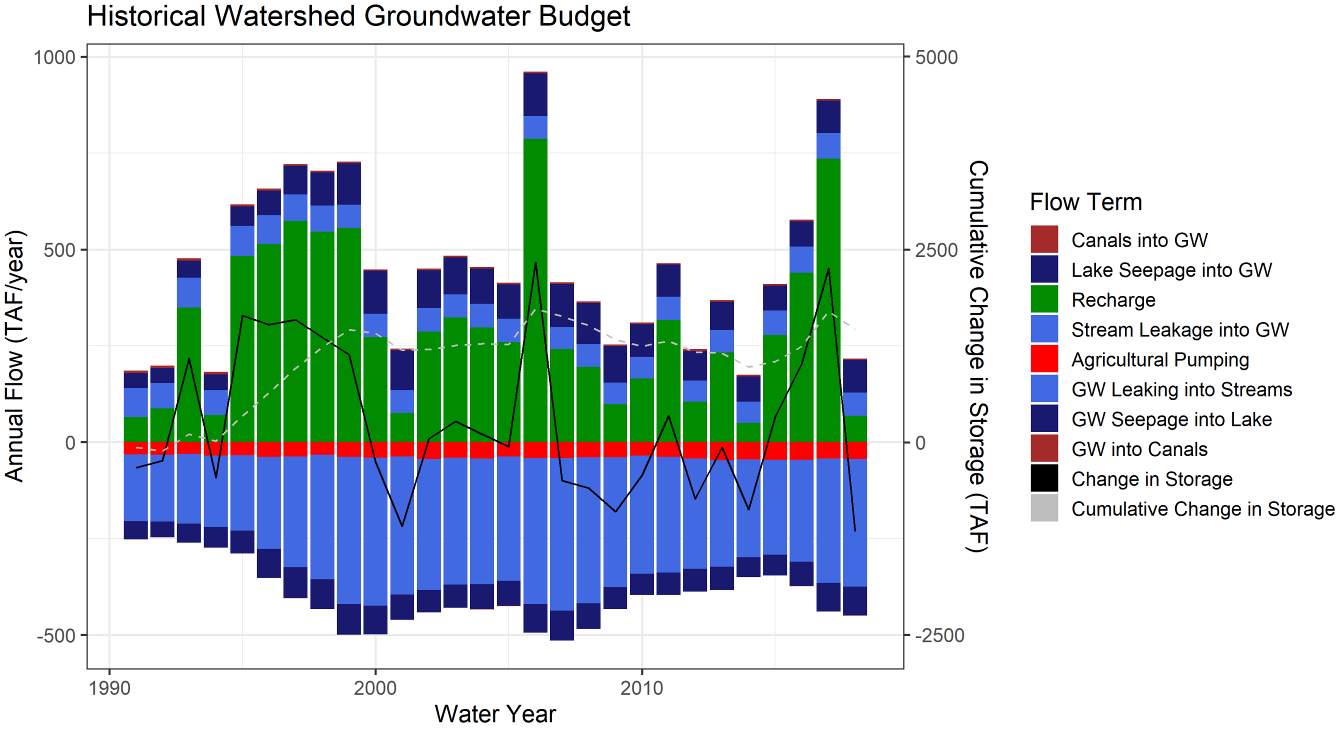


Figure 63: Annual water budgets for all flow terms for the Shasta Watershed.

2.2.3.1 Summary of Model Development

A three subsystem model was used to represent the hydrology of the Basin, the surrounding watershed, and the Basin-watershed hydrologic connections. The three sub-systems are as follows:

- Basin and watershed surface water system (SW)
- Basin and watershed land/soil system (land use and soil/vadose zone) (L)
- Basin and watershed groundwater (aquifer) (GW)

The Shasta Watershed Groundwater Model (SWGM) was used to estimate the stream and groundwater inflows from the upper watershed to the Basin, and the fluxes into, out of, and between the three sub-systems within the watershed and within the Basin. Full documentation on SWGM can be found in Appendix 2-E. .

In brief, the SWGM consists of three interlocking simulation modules: two land/soil subsystem modules, of which one is specifically designed for the agricultural and developed (urban) landscape and of which the other is designed to represent all other (natural) landscapes. Together they represent the land/soil subsystem (L) of the entire basin and of the entire watershed. The third simulation module is a groundwater-surface water model that represents both, the surface water (SW) and groundwater (GW) subsystems of the Basin and of the watershed:

- The land/soil subsystem of the irrigated landscape is simulated using a Crop Root Zone Water Model (CRZWM, Davids Engineering Report[9]). The output from this model include spatio-temporally distributed groundwater pumping (all applied water needs simulated by this module) and spatio-temporally distributed groundwater recharge. The spatial discretization is equal to individual land use polygons in the DWR land use surveys of 2000, 2010, and 2014. The temporal discretization is daily.
- The land/soil subsystem and the surface subsystem of the entire watershed is simulated using the USGS PRMS software (Markstrom et al. 2008). This simulation module generates spatio-temporally distributed groundwater recharge for the 1989-2018 simulation period. The spatial discretization is 888 ft (270 m). The temporal discretization is daily.
- The groundwater subsystem and the surface water subsystem are simulated with the USGS MODFLOW 2005 software (Harbaugh 2005). Pumping and recharge output from the land subsystem simulation is used as input for the 29-year groundwater subsystem simulation. Surface runoff from the PRMS simulation (L) is used as input to the surface water routing simulation within MODFLOW. The transient, three-dimensional groundwater-surface water simulation has a spatial discretization of 888 ft (270 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 second and third simulation modules are implicitly coupled through the USGS GSFLOW software (Markstrom et al. 2008). The CRZWM module is coupled explicitly: the 29-year agricultural and developed area pumping output from the CRZWM simulation is generated first, then provided as input to the groundwater simulation. The explicit coupling (rather than intrinsic, more integrated

---

[9] {David’s Engineering Report. Appendix 2-F.}

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 estimating groundwater pumping.

MODFLOW is a finite difference groundwater-surface water model that simulates spatial and temporal dynamics of groundwater (GW) and surface water (SW) conditions in the watershed's (including the Basin's) aquifer system and it's overlying stream system. The aquifer system consists of a mixture of alluvial and volcanic formations, with the latter consisting of aquifer features ranging from water-laden lava tubes to water-sediment-filled pockets within the cracks and crevices in the volcanic deposits. Unlike in many other alluvial groundwater basins of California, the volcanic portion of the Basins aquifer system continues beyond the Basin boundaries into the surrounding watershed to north, east, and south of the basin. Non-volcanic bedrock of low permeability borders the aquifer system and Basin on the westside. The MODFLOW model simulates the spatially and temporally variable dynamics of each of the flow terms presented in Figure 62 and Figure 63 for the Basin and the watershed, respectively:

- Contributions to groundwater include
    - Canal seepage (from SW)
    - Lake seepage (from SW)
    - Recharge (from L)
    - Stream leaking (from SW)
- Contributions from groundwater include:
    - Agricultural pumping (to L)
    - Leaking into streams (to SW)
    - Seepage into lakes (to SW)
    - Canal leakage (to SW)
    - Subsurface outflow toward areas to the north of the watershed

These groundwater module simulation results are driven in the model by the Basin's hydrogeologic properties and by the spatially and temporally variable dynamics of:

- Groundwater pumping and recharge provided by the Land/soil (L) simulation modules.
- Surface runoff, computed from daily, spatially distributed precipitation and temperature data by the land/soil (L) simulations. Surface runoff becomes input to the stream-lake-canal surface water subsystem (SW). The SW subsystem in turn interacts with the GW subsystem through recharge to and discharge from groundwater.
- Direct groundwater evapotranspiration in wetlands (determined by modeled land use ET demand as a model input). The spatial discretization of the land/soil subsystem in SWGM largely follows the digital land use maps published to date by the California Department of Water Resources as adapted by the GSP stakeholder group. The spatial discretization in MODFLOW (GW and SW subsystem) is 270 m horizontally. Vertical discretization of the aquifer follow the hydrogeological conceptual model and the geological model previously described (Appendix 2-E).

2.2.3.2 Description of Historical Water Budget Components

The section describes the full water budget of the watershed as well as the Basin including inflows to the watershed and Basin, outflows from the watershed and Basin, and the internal accounting of flow terms presented previously.

This section also describes fluxes between the three subsystems, L, SW, and GW. An increase in storage over a period of time occurs when fluxes into a subsystem exceed fluxes out of the subsystem over that period of time (similar to deposits exceeding the amount of withdrawals in a bank account: the account balance increases). 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).

Tabular summaries of flow term summary statistics are presented followed by a discussion. Comprehensive documentation of the water budget development process is presented in Appendix 2-E.

Flows from Surface Water to the Groundwater subsystem

An overview of flows from surface water to the groundwater subsystem for the historical modeled period is presented for the Bulletin 118 Basin boundary and the Shasta Watershed in Table 13 and Table 14, respectively.

Flows from the Groundwater Subsystem to Surface Water

An overview of flows from the groundwater subsystem to surface water for the historical modeled period is presented for the Bulletin 118 Basin boundary and the Shasta Watershed in Table 13 and Table 14, respectively.

Flows Between the Land/soil Subsystem and Groundwater

An overview of flows between the Land/soil subsystem and Groundwater for the historical modeled period is presented for the Bulletin 118 Basin boundary and the Shasta Watershed in Table 13 and Table 14, respectively.

Table 13: Summary of Average Annual Groundwater Budget Flows (TAF/year) within the Basin boundary.

Flow Term	Minimum	Mean	Maximum
Groundwater Inflow	138.4	244.5	368.4
Canals into GW	3.7	4.5	6.4
GW into Canals	0.1	0.2	0.3
Lake Seepage into GW	38.7	77.1	109.8
GW Seepage into Lake	41.0	63.4	80.1
Stream Leakage into GW	48.2	57.1	71.3
GW Leaking into Streams	169.1	290.4	389.1
Groundwater Outflow	56.3	81.7	110.2
Recharge	30.5	118.3	314.3
Agricultural Pumping	29.8	38.6	46.7

Table 14: Summary of Average Annual Groundwater Budget Flows (TAF/year) within the Watershed boundary.

Flow Term	Minimum	Mean	Maximum
Canals into GW	3.7	4.6	6.5
GW into Canals	0.1	0.2	0.3
Lake Seepage into GW	38.9	80.2	112.7
GW Seepage into Lake	41.0	63.4	80.1
Stream Leakage into GW	54.7	63.2	78.3
GW Leaking into Streams	172.7	295.6	395.5
Recharge	49.9	302.5	786.5
Agricultural Pumping	30.3	39.2	47.4

2.2.3.3 Summary of Historical Water Budget

Stream and lake seepage account for 96.7% of the contributions from the Surface Water to the Groundwater subsystem within the Basin (134.3 TAF/year) as well as the broader Shasta River watershed (143.3 TAF/year[10]). Canal seepage accounts for only 3.3% of the flux to the Groundwater subsystem (4.6 TAF/year) for both the Basin and Shasta Watershed (Table 13 and Table 14). Fluxes from the Groundwater subsystem to surface waters is driven predominantly by groundwater leaking into streams with 82.0% and 82.3% of flows to surface water from the Groundwater subsystem for the Basin boundary and Shasta watershed (290.4 and 295.6 TAF/year), respectively. Groundwater seepage into lakes accounts for 17.9% of fluxes between these two subsystems for both the Basin and watershed area (63.4 TAF/year for both areas) with canal seepage accounting for a near negligible contribution at 0.1% (0.2 TAF/year for both areas) of the total volume (Table 13 and Table 14).

Agricultural pumping to the Land/soil subsystem in the Basin (38.6 TAF/year) is about one-third of the total land/soil subsystem recharge within the Basin (118.3 TAF/year). But total watershed

---

[10] The Mean values from the Water Budget tables are used in the Section on Summary of Historical Water Budget

pumping (39.2 TAF/year, almost all within the Basin) amounts to only 13.0% of the total recharge across the watershed Land/soil subsystem (302.5 TAF/year) (Table 13 and Table 14). Groundwater pumping is limited to fields with groundwater as the source of irrigation water. The pumping amount varies as a function of soil type, crop, and irrigation type, which in turn determine soil moisture, irrigation efficiency, ET, among others. Groundwater pumping only occurs during the irrigation season, which is a function of the crop type and the dynamics of spring soil moisture depletion.

At the watershed scale, L inflows to GW (302.5 TAF/year) are more than twice as large as SW inflows to GW (147.9 TAF/year) due to highly permeable infiltration conditions across the volcanic soils of the watershed. The L and SW recharge to the GW subsystem are of similar magnitude within the Basin (118.3 TAF/year and 138.8 TAF/year). The GW outflow to the SW subsystem (353.9 TAF/year) is five times larger than pumping to the L subsystem (38.6 TAF/year). The difference between L and SW inflows to GW (257.2 TAF/year) and total outflows to L and SW (392.5 TAF/year) are met by a groundwater inflow of 244.5 TAF/year and groundwater outflow of 81.7 via the subsurface from outside the Basin.

2.2.3.4 Groundwater Dynamics in the Shasta Valley Aquifer System: Key Insights

The Shasta Valley Groundwater Basin (the Basin) contains the majority of water-bearing geologic formations, or aquifers, within the watershed and is the most-utilized source of groundwater to the population living in the area (California Department of Water Resources (DWR) Bulletin 118 forthcoming version 2020, will need reference when published). The Basin's aquifer system consists of a mixture of alluvial and volcanic formations, with the latter consisting of aquifer features ranging from water-laden lava tubes to water-sediment-filled pockets within the cracks and crevices in the volcanic deposits. Much of the complexity and unique juxtaposition of markedly differing aquifer formations result in a multitude of springs or diffuse wetlands where groundwater more easily discharges to the surface than into less-conductive aquifer materials and where head levels are close to or exceed the ground level. The discharge levels of the springs can vary over many orders of magnitude from one spring to the next and can also significantly vary seasonally at the same spring as well as year-to-year averages. The largest spring complexes, such as the Big Springs complex, contribute a significant quantity of water to the surface water features in the Valley. The aquifer system is very complex in its nature, including fractures and sediment pore space ranging over many length scales.

For most of the year, groundwater discharges into the main stem of the Shasta River, and into the lower sections of the tributaries, but also emerges in springs and drainages. During critical summer months, portion of the main stem of the Shasta river and of the tributaries become losing stream and discharge water into the groundwater system. Precipitation occurs predominantly in the winter months, from October through April. Irrigation with surface water and groundwater between April and September is used to grow perennial crops (alfalfa, in occasional rotation with grains, and pasture). Groundwater pumping affects baseflow conditions during the summer. Winter rains and winter/spring runoff recharge the aquifer system between October and April (Figure 23). Groundwater pumping further exacerbates the natural lowering of water levels during the dry season, leading to less baseflow and less groundwater outflow from the Basin's northern boundary. Seasonal variability of recharge is accentuated by year-to-year climate variability: Years with low precipitation lead to a smaller snowpack and lower runoff from the surrounding watershed, hence less recharge from the tributaries into the alluvial fans, less recharge across the landscape of the Basin, and therefore less winter groundwater storage increase in the aquifer system. This in turn leads to a reduced slope of the water table to the Shasta River at the beginning of the irrigation season when compared to wetter years, and lower winter and spring water levels, particularly near the margins of the Basin.

Water levels are highest near the valley margin and slope from all sides of the valley toward the interior of the Basin, near the lower portions of the Pluto Cave basalt and toward the main-stem Shasta River below Lake Shastina and from there toward the Basin's northern boundary. Higher recharge during the winter months increases the slope of the water table from the valley margins toward locations of groundwater discharge into springs and streams. The lack of recharge for most of the dry period lowers the slope of the water table slope over the summer months, decreasing discharge from groundwater into the stream system.

Seasonal variability of recharge is accentuated by year-to-year climate variability: Years with low precipitation lead to a smaller snowpack and lower runoff and groundwater inflow from the surrounding watershed, and therefore less winter groundwater storage increases in the aquifer system. This in turn leads to a reduced slope of the water table to the stream system in the lower part of Shasta Valley at the beginning of the irrigation season when compared to wetter years, and lower winter and spring water levels, particularly near the margins of the Basin.

Any significant long-term decrease or increase of precipitation totals over the watershed along with watershed scale changes to anthropogenic recharge will lead to commensurate lowering or raising, respectively in the average slope of the water table from the watershed and Basin margins toward the center of the Basin, leading to a dynamic adjustment of water levels, even under otherwise identical land use and land use management conditions. These climate-induced adjustments will be relatively small near the Shasta River, but larger near the valley margins. Such changes, however, are unlikely to lead to groundwater overdraft. However, they will affect baseflow conditions, the timing of the spring recess in Shasta River flows and the arrival of the first fall flush flows in the river system. Water level slopes may change nearly imperceptibly in sections of the aquifer system that are highly conductive (e.g., lava tubes), despite these changes in groundwater flow through that part of the aquifer system.

Similarly, any increase or reduction in groundwater pumping leads to an equal decrease or increase in groundwater discharge to both, the stream systems and the subsurface outflow to the north of the Basin. Any managed increase in recharge will also lead to an equal increase in groundwater discharge to both, the stream system within the Basin and subsurface outflow to the north of the Basin. The response of the groundwater discharge to the stream system will be delayed relative to the timing of the changes in pumping or recharge – by a few days if changes occur within a few tens or hundreds of feet of a stream, by weeks to months if they occur at larger distances from the stream. But when these changes occur permanently (even if only seasonally each year), the annual total change to groundwater discharge into the stream system will be approximately the same as the change in pumping (leading to less discharge) or in recharge (leading to more discharge).

This delay in timing may be taken advantage of with managed aquifer recharge or in-lieu recharge during periods of excess flows in the stream system, used for recharge or irrigation (in lieu of pumping), but creating additional discharge of groundwater to the stream during the critical low flow period in the summer and (early) fall.

2.2.4 Projected Water Budgets

The future projected water budget contains all of the same components as the historical water budget. To inform long-term hydrologic planning, the future projected water budget was developed using the following method:

1. Observed weather and streamflow parameters from water years 1991-2011 were used multiple times to make a 50-year "Basecase" climate record (see Appendix 2-E for details). The Basecase projection represents a hypothetical future period in which climate conditions are the same as conditions from 1991-2011.
2. The climate-influenced variables Precipitation (as rain), Reference Evapotranspiration (ET_o), 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. The SWGM was run for the 50-year period of water years 2022-2071 for the Basecase and all four climate change projected scenarios.

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

Method Details

The climate record for the projected 50-year period of water years 2022-2071 (October 2021-September 2071) was constructed from model inputs for the years 1991-2011. The minimum bound of 1991 was imposed by (ET_o) data, which is not available prior to historical model period; the maximum bound of 2011 was imposed by DWR change factors, which are only available through 2011 (Appendix 2-E).

Under their SGMA climate change guidance, DWR provided a dataset of "change factors" which each GSA can use to convert local historical weather data into 4 different climate change scenarios (DWR 2018). Change factors are geographically and temporally explicit. Geographically, a grid of 1/16-degree resolution cells covers the extent of California; for each of these cells, one change factors applies to each month, 1911-2011.

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

2.2.4.1 Summary of Projected Water Budgets

The 2030 (Near) and 2070 central tendency (Far) scenarios predict marginally more rainfall conditions to the Baseline. The 2070 DEW (Dry) shows less cumulative rainfall while the 2070 WMW

(Wet) scenarios shows more cumulative rain (Figure 64 and Figure 65). All scenarios predict higher future ET than the Baseline (Figure 66 and Figure 67).

Projected annual water budgets for the baseline and four DWR climate scenarios including the 2070 DEW (Dry), 2070 (Far), 2030 (Near), and 2070 WMW (Wet) are presented in Figure 68. An overview of projected streamflow conditions at the Shasta River near the Yreka gage under the baseline and projected scenarios is presented in Figure 70 and Figure 71. Summary statistics and a tabular summary of annual flow terms for the baseline and each projected scenario is presented in Appendix 2-E.

The 2030 (Near) and 2070 (Far) climate change scenarios show slightly higher streamflow and recharge throughout the Watershed. The 2070 WMW (Wet) scenario shows much higher recharge and river flows while the 2070 DEW (Dry) scenario shows diminished river flows and recharge.

2.2.4.2 Discussion of Future Water Budget

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 Shasta River, leading to a dynamic adjustment of water levels, even under otherwise identical land use and land use management conditions. Such changes, however, are unlikely to lead to groundwater overdraft. However, they will affect baseflow conditions, the timing of the spring recess in Shasta River flows and the arrival of the first fall flush flows in the river system.

Similarly, any increase or reduction in groundwater pumping leads to an equal decrease or increase in groundwater discharge to the stream systems. Any managed increase in recharge will also lead to an equal increase in groundwater discharge to the stream system within the Basin. The response of the groundwater discharge to the stream system will be delayed relative to the timing of the changes in pumping or recharge – by days when changes occur within a few tens or hundreds of feet of a stream, by weeks to months at larger distances. But when these changes occur permanently (even if only seasonally each year), the annual total change to groundwater discharge into the stream system will be approximately the same as the change in pumping (leading to less discharge) or in recharge (leading to more discharge).

This delay in timing can be taken advantage of with managed aquifer recharge or in-lieu recharge during periods of excess flows in the stream system, used for recharge or irrigation (in lieu of pumping), but creating additional discharge of groundwater to the stream during the critical low flow period in the summer and (early) fall.

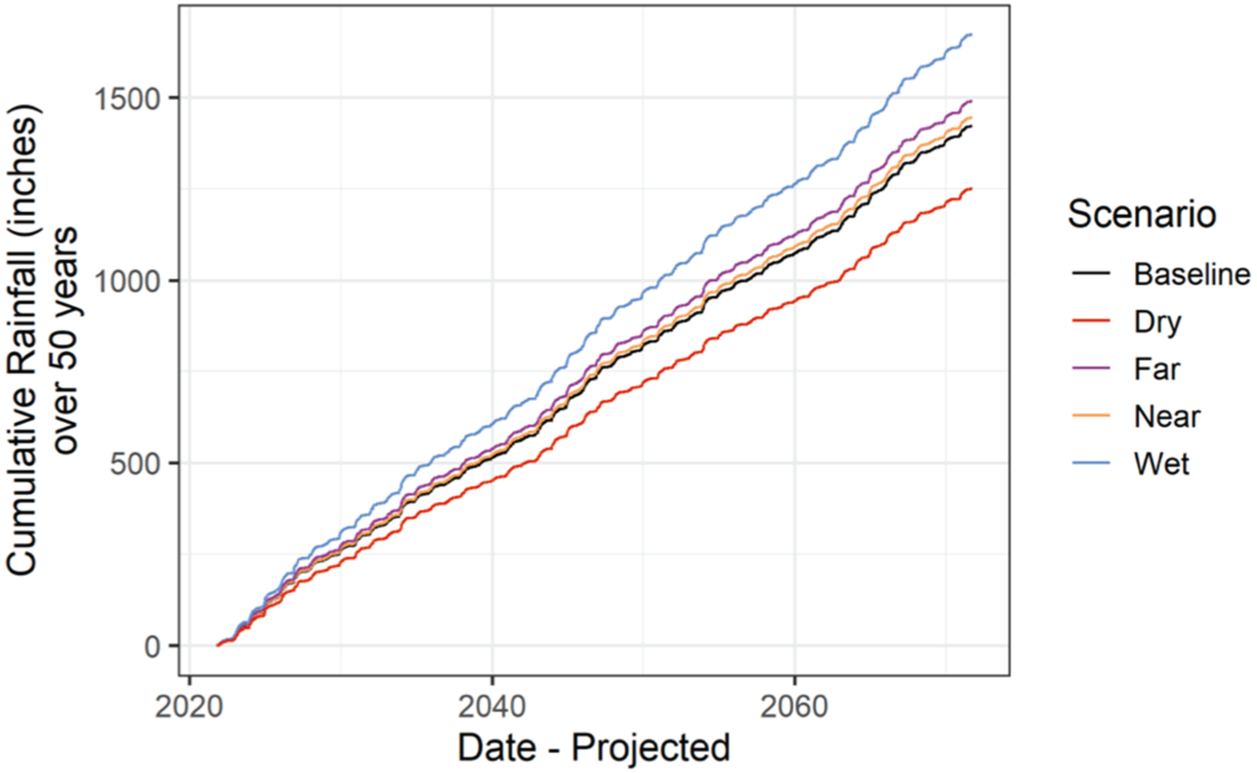


Figure 64: Cumulative precipitation for the future projected climate conditions, with baseline and four DWR climate scenarios including the 2070 DEW (Dry), 2070 (Far), 2030 (Near), and 2070 WMW (Wet) projections.

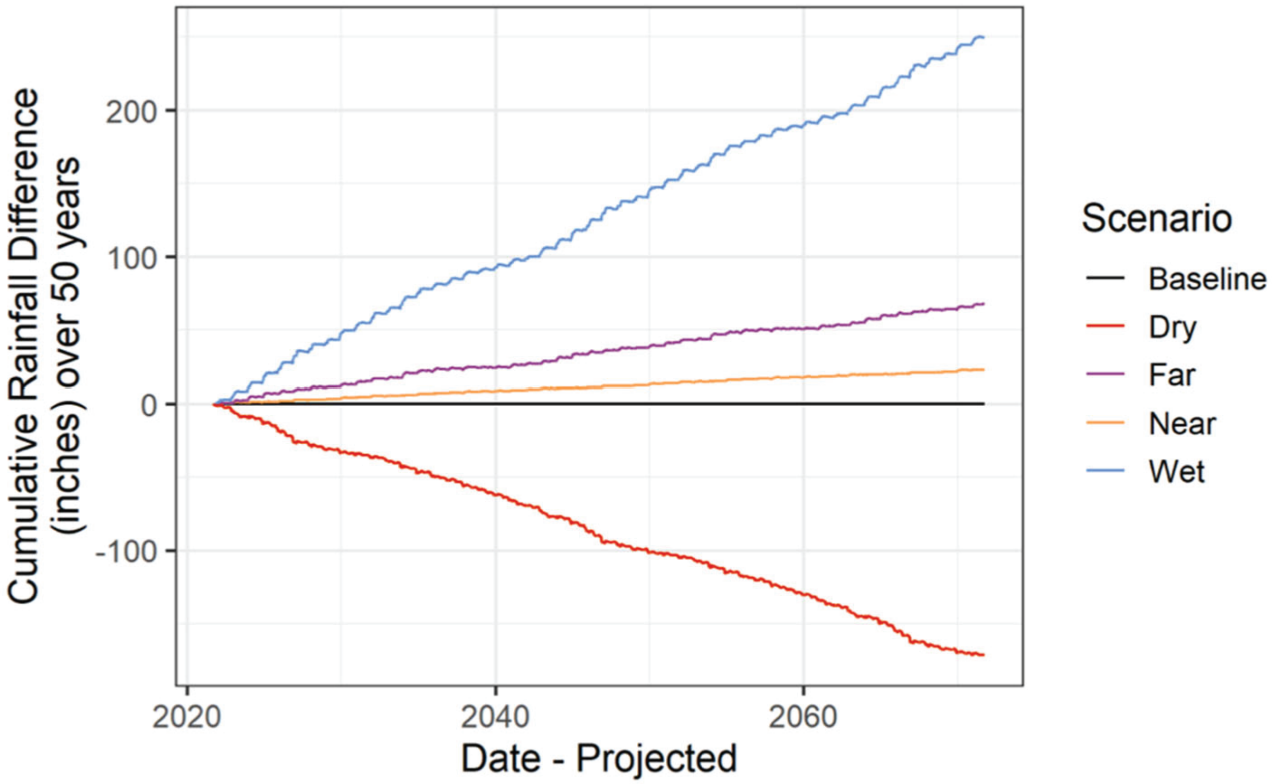


Figure 65: Projected change in cumulative precipitation for the future climate conditions, with baseline and four DWR climate scenarios including the 2070 DEW (Dry), 2070 (Far), 2030 (Near), and 2070 WMW (Wet) projections.

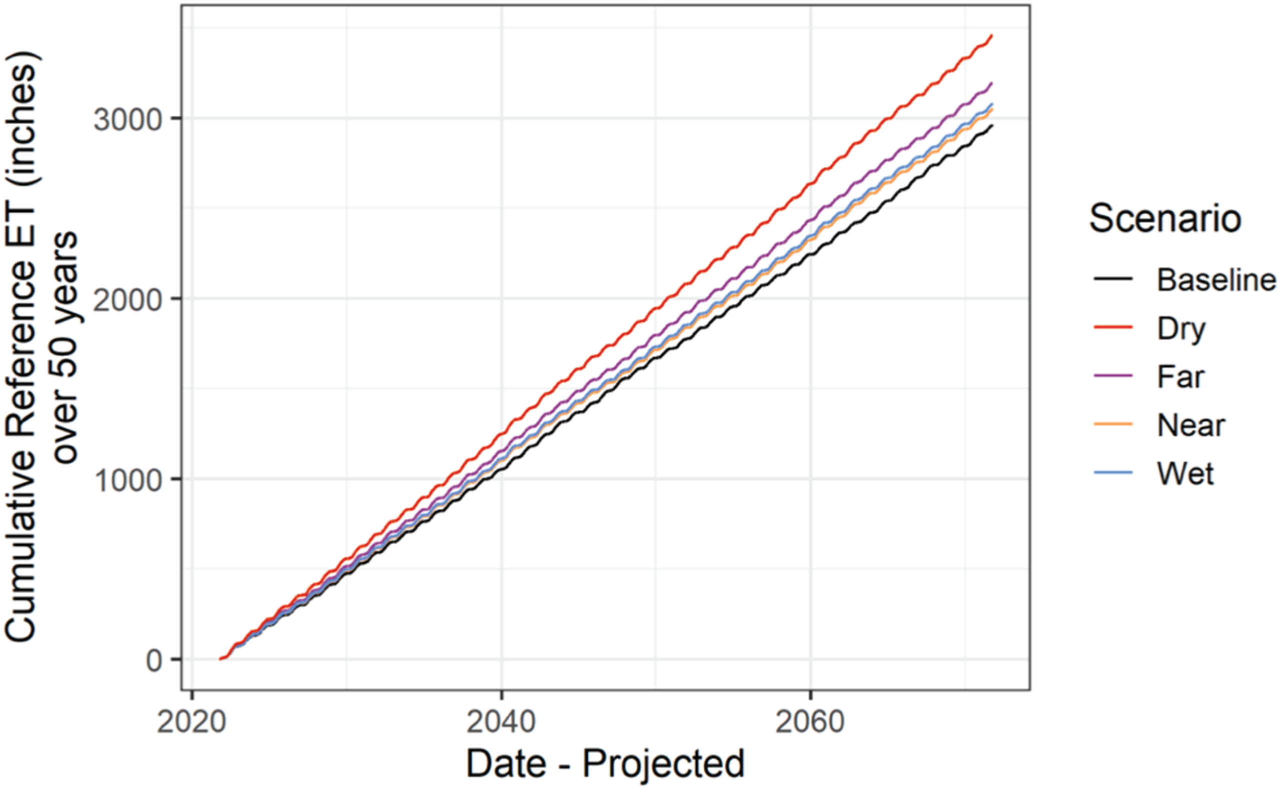


Figure 66: Cumulative reference evapotranspiration (ET_o) for the future projected climate conditions, with baseline and four DWR climate scenarios including the 2070 DEW (Dry), 2070 (Far), 2030 (Near), and 2070 WMW (Wet) projections.

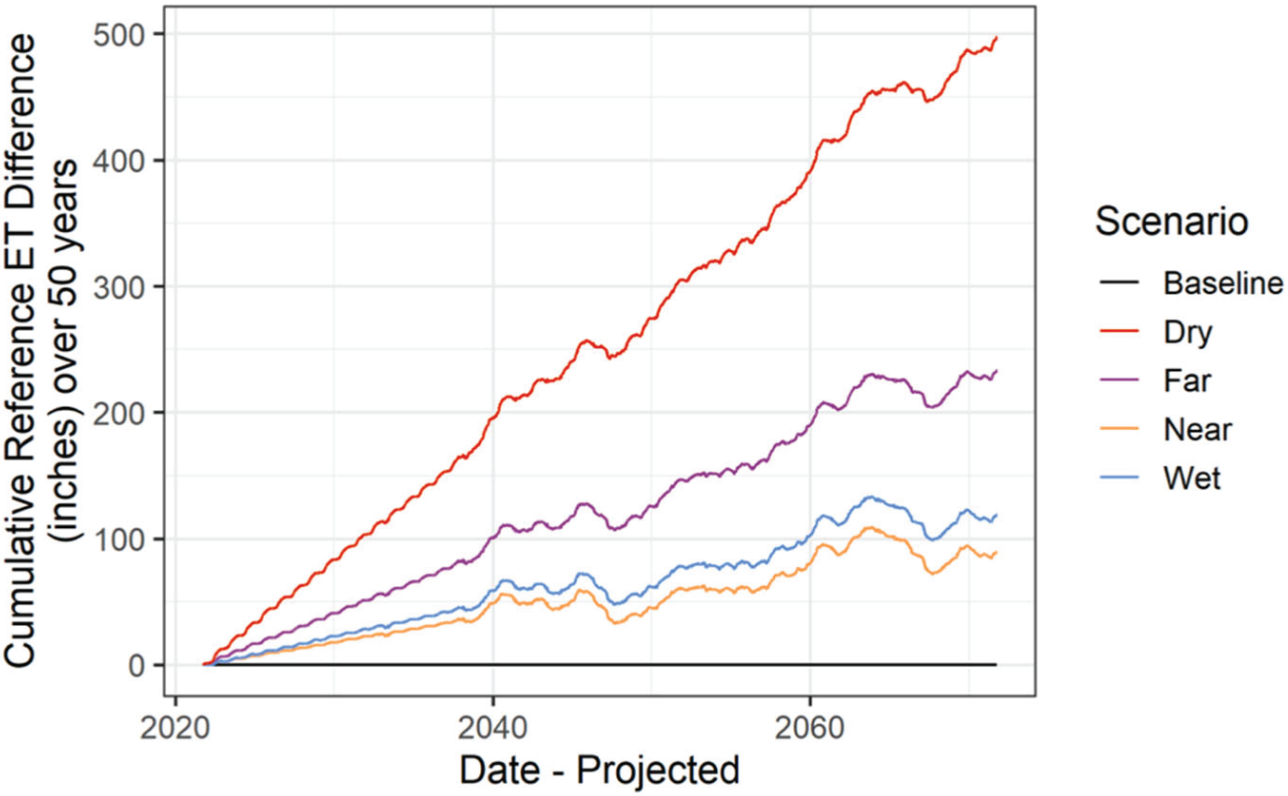
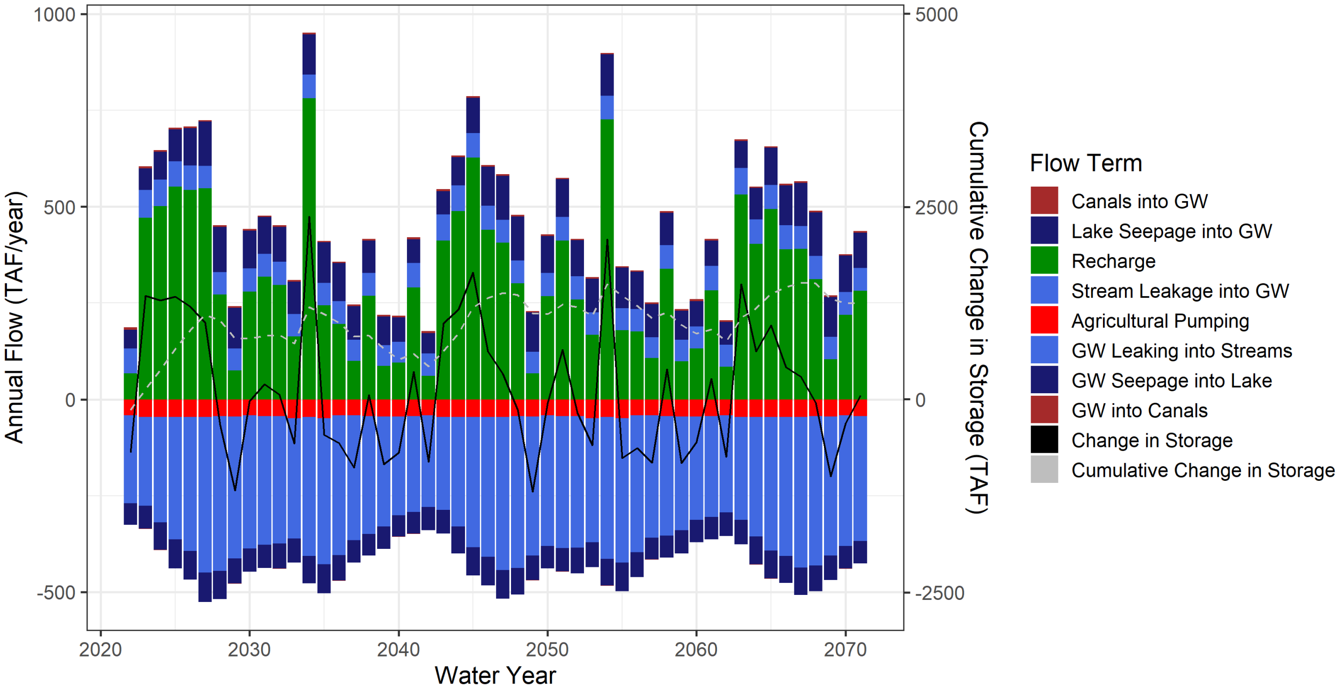
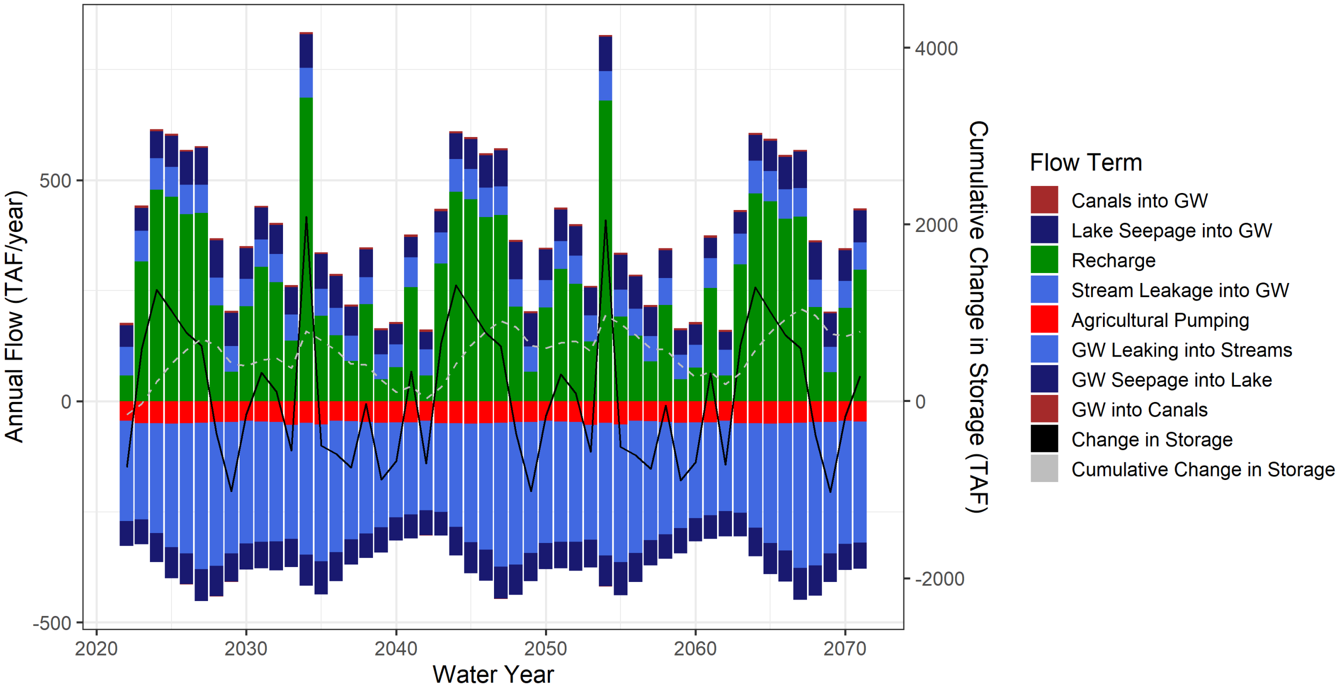
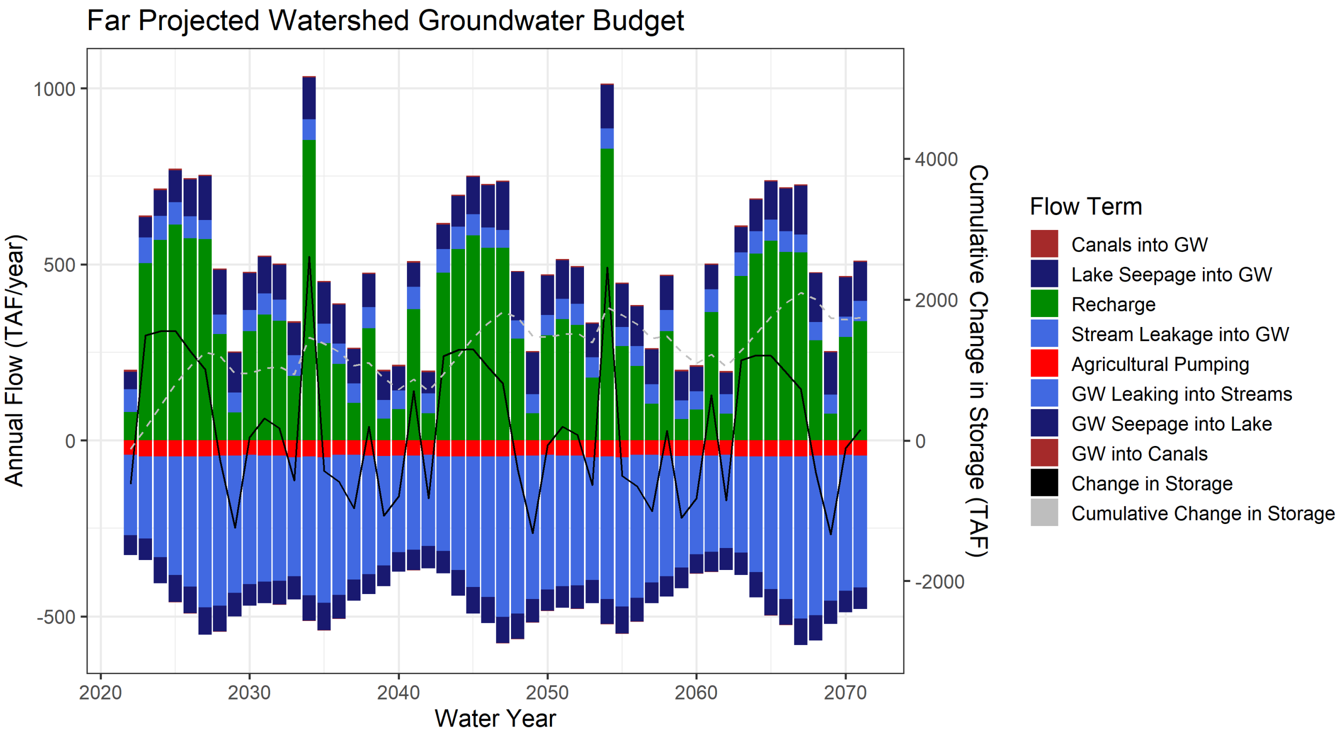
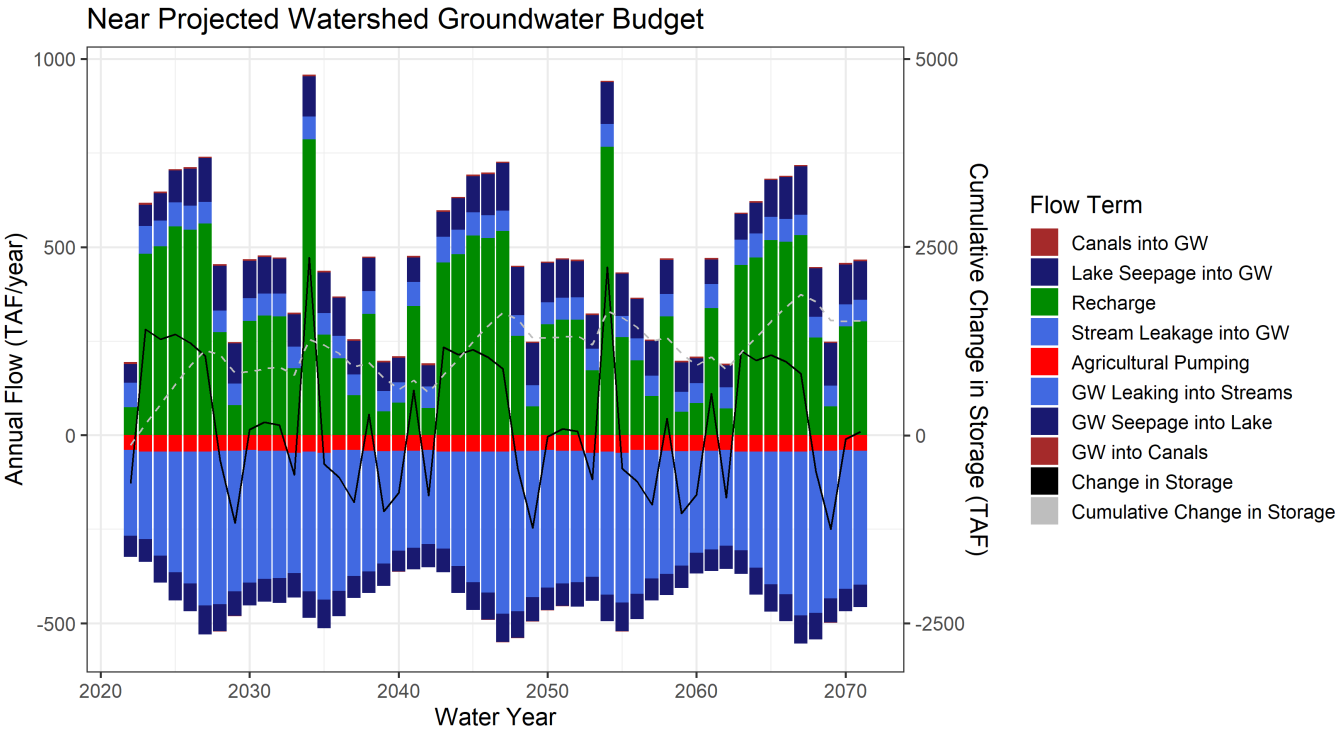


Figure 67: Projected change in cumulative reference evapotranspiration (ET_o) for the future climate conditions, with baseline and four DWR climate scenarios including the 2070 DEW (Dry), 2070 (Far), 2030 (Near), and 2070 WMW (Wet) projectionsProjected change in cumulative reference evapotranspiration (ET) for the future climate conditions, with baseline and four DWR climate scenarios including the 2070 DEW (Dry), 2070 (Far), 2030 (Near), and 2070 WMW (Wet) projections.


Baseline Projected Watershed Groundwater Budget


Dry Projected Watershed Groundwater Budget


Far Projected Watershed Groundwater Budget
Annual Flow (TAF/year)
1000
500
0
-500
Cumulative Change in Storage (TAF)
4000
2000
0
-2000
2020
2030
2040
2050
2060
2070
Water Year
Flow Term
Canals into GW
Lake Seepage into GW
Recharge
Stream Leakage into GW
Agricultural Pumping
GW Leaking into Streams
GW Seepage into Lake
GW into Canals
Change in Storage
Cumulative Change in Storage


Near Projected Watershed Groundwater Budget
Annual Flow (TAF/year)
1000
500
0
-500
Cumulative Change in Storage (TAF)
5000
2500
0
-2500
2020
2030
2040
2050
2060
2070
Water Year
Flow Term
Canals into GW
Lake Seepage into GW
Recharge
Stream Leakage into GW
Agricultural Pumping
GW Leaking into Streams
GW Seepage into Lake
GW into Canals
Change in Storage
Cumulative Change in Storage

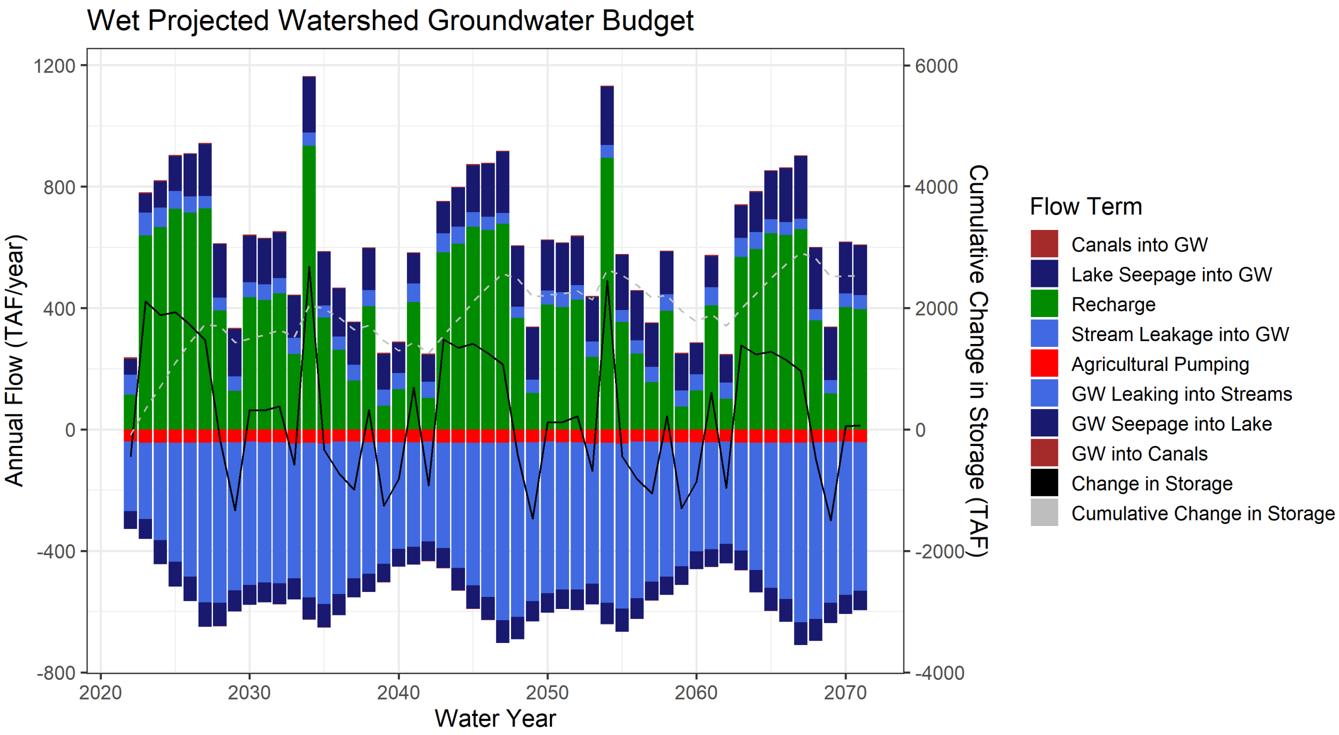


Figure 68: Annual budget summaries for the baseline and four projected climate change scenarios.

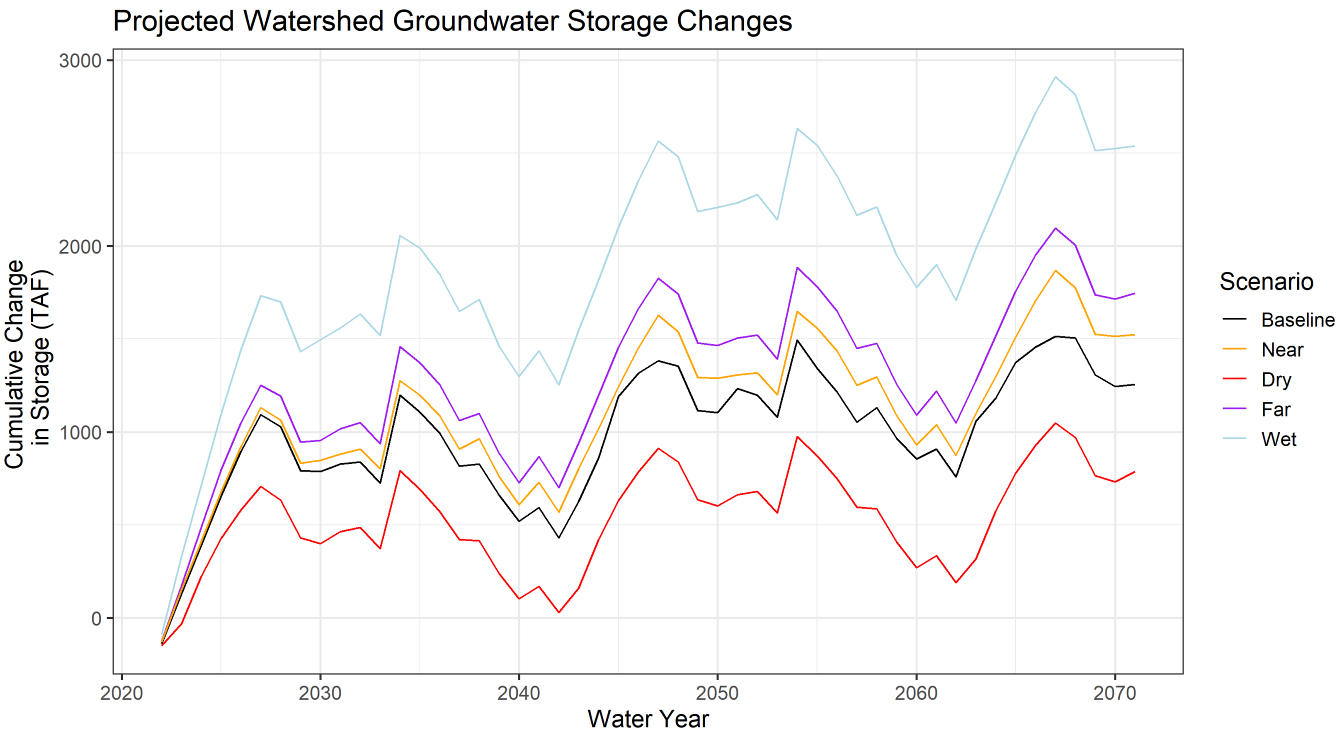


Figure 69: Cumulative groundwater storage change summaries for the baseline and four projected climate change scenarios.

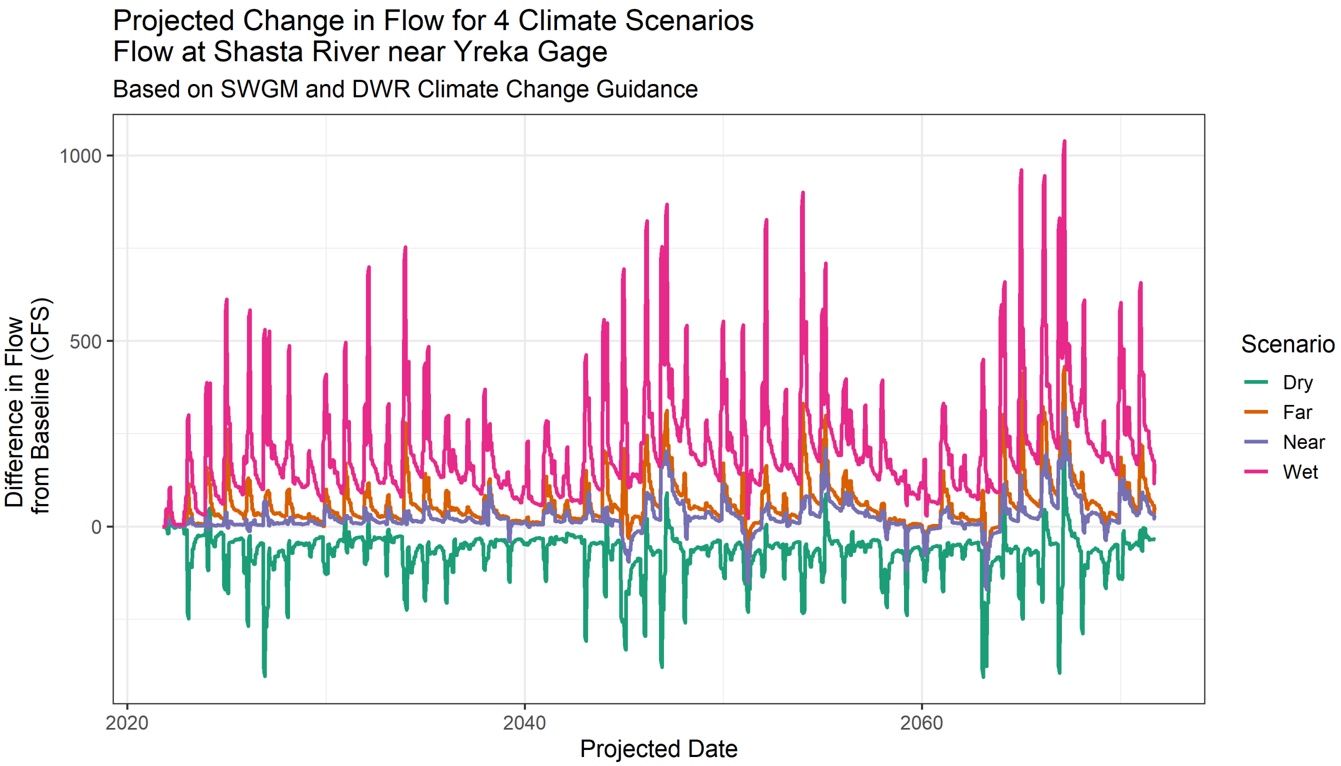


Figure 70: Projected flow at the Shasta River near Yreka gage, in difference (cfs) from Baseline, for four future projected climate change scenarios.

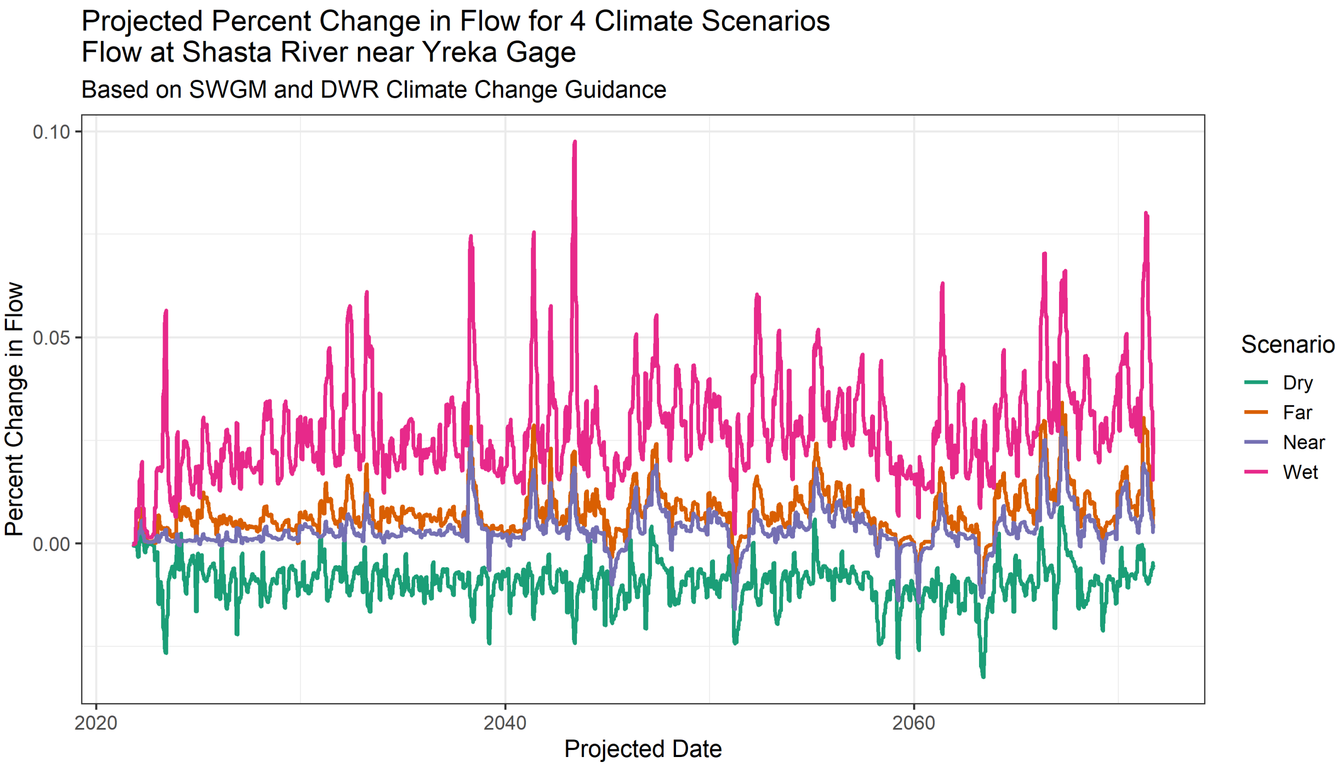


Figure 71: Projected flow at the Shasta River near Yreka gage, in percent change from Baseline, for four future projected climate change scenarios.

2.2.5 Sustainable Yield

Sustainable yield is defined in the California Water Code 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.” (California Water Code Section 10721).

In this plan, the sustainable yield is defined as the long-term average annual groundwater pumping rate, as defined by the water budget analysis, that does not cause an undesirable result. Chapter 2 defines the water budget analysis and chapter 3 defines undesirable results. The Basin is not currently in overdraft and has not incurred undesirable results with respect to the sustainability indicators for water level and groundwater storage. Since 2014, ongoing groundwater pumping has also not incurred new known undesirable results with respect to sustainability indicators for land subsidence, water quality, and GDEs. Water levels and groundwater storage have been in a long-term dynamic equilibrium between inflows to and outflows from the aquifer system. For interconnected surface water, data gaps exist that will be filled over the next five years to more clearly identify the undesirable results that must be avoided through groundwater management. Hence, for the Shasta Valley, **the sustainable yield is currently equal to the 28-year average annual groundwater pumping of 42 to 45 thousand TAF/year** as estimated with the Shasta Watershed Groundwater Model for the 1992-2018 period.

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

Whether and by how much future groundwater pumping may need to be reduced will be a function of the PMAs that are implemented and the spatial extent. For example, winter recharge to enhance summer stream flow does not require reductions in groundwater pumping for implementation. Similarly, 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. Hence, the sustainable yield will be continually adjusted from the 1991 – 2018 baseline average annual groundwater pumping of 42- to 45-thousand acre-feet using an assessment and simulation of implemented PMAs.

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

2.2.6 Management Areas

There are currently no management areas in the Shasta Valley GSP, but may be reconsidered and added in the 5-year GSP update in 2027.

List of Appendices

Appendix 2-A Geologic Modeling Methodology

Appendix 2-B Water Quality

Appendix 2-C Expanded Basin Setting

Appendix 2-D Subsidence

Appendix 2-E Numerical Model and Water Budget (In Progress)

Appendix 2-F Geophysics Investigation

Appendix 2-G Groundwater Dependent Ecosystem Assessment

Appendix 2-H Shallow Piezometer Transect Study

Appendix 2-I Shasta Valley Spring Monitoring (In Progress)

References (*Section is currently under development*)

California Department of Fish and Game. 1997. A Biological Needs Assessment for Anadromous Fish in the Shasta River Siskiyou County, California. Available: http://www.krisweb.com/biblio/klamath_cdfg_ncncr_1997_shastaneeds.pdf

Center for Watershed Sciences, and Watercourse Engineering Inc. 2013. "Water Resources Management Planning: Conceptual Framework and Case Study of the Shasta Basin."

CNRA. 2019. "DWR Periodic Groundwater Level Measurements Dataset." https://data.cnra.ca.gov/dataset/periodic-groundwater-level-measurements.

County of Siskiyou. 1972. "General Plan, Open Space Element." https://www.co.siskiyou.ca.us/sites/default/files/pln%7B/_%7Dgp%7B/_%7Dopenspaceelement.pdf.

County of Siskiyou. 1973. "The Conservation Element of the General Plan, Siskiyou County, California."

David's Engineering. 2020. "Technical Memorandum - DRAFT Monitoring Results of Shallow Piezometer Transect Study from May 2020 through October 2020 in the Shasta Valley, Siskiyou County, CA." Shasta Valley Groundwater Sustainability Plan – Appendix 2-H.

Deas, Mike. 2006. "Big Springs Creek and Spring Complex - Estimated Quantification."

DWR. 2004. "Basin Boundaries and Hydrology." Department of Water Resources.

DWR.. 2010. "2010 Land Use Survey."Department of Water Resources.

DWR.. 2019a. "DAC Mapping Tool." Department of Water Resources.https://gis.water.ca.gov/app/dacs/.

DWR.. 2019b. "Groundwater Monitoring (CASGEM) Website." Department of Water Resources. https://water.ca.gov/Programs/Groundwater-Management/Groundwater-Elevation-Monitoring--CASGEM.

DWR. 2020. California's Groundwater Update 2020. Department of Water Resources. https://data.cnra.ca.gov/dataset/3f87088d-a2f9-4a46-a979-1120069db2c6/resource/d2b45d3c-52c0-45ba-b92a-fb3c90c1d4be/download/calgw2020_full_report.pdf

DWR. n.d.a. "County of Siskiyou Zoning Ordinance." Department of Water Resources. https://library.municode.com/ca/siskiyou%7B/_%7Dcounty/codes/code%7B/_%7Dof%7B/_%7Dordinances?nodeId=TIT10PLZO.

DWR. n.d.b. "DWR Online System for Well Completion Reports (OSWCR)." Department of Water Resources. https://civicnet. resources.ca.gov/DWR%7B/_%7DWELLS/.

Mack, Seymour. 1960. "Geology and Groundwater Features of Shasta Valley, Siskiyou County California." Geological Survey Water-Supply Paper 1484.

National Oceanic and Atmospheric Administration. (2012). Authorization of Incidental Take and Implementation of Fruit Growers Supply Company's Multi-Species Habitat Conservation Plan: Environmental Impact Statement. https://books.google.com/books?id=fCE3AQAAMAAJ

NCRWQCB. 2018. "WATER QUALITY CONTROL PLAN FOR THE NORTH COAST REGION NORTH COAST REGIONAL WATER QUALITY CONTROL BOARD."

NCRWQCB (California North Coast Regional Water Quality Control Board). 2006. "Report for the Action Plan for the Shasta River Watershed Temperature and Dissolved Oxygen Total Maximum Daily Loads," 1123.

———. 2018. "Shasta River TMDL Conditional Waiver of Waste Discharge Requirements."

Nichols, A.L., C.A Jeffres, A.D. Willis, N.J. Corline, A.M. King, R.A. Lusardi, M.L. Deas, J.F. Mount, and P.B. Moyle. 2010. Longitudinal Baseline Assessment of Salmonid Habitat Characteristics of the Shasta River, March to September, 2008. Report prepared for: United States Bureau of Reclamation, Klamath Basin Area Office.

O'Geen, A. T., Matthew B. B. Saal, Helen Dahlke, David Doll, Rachel Elkins, Allan Fulton, Graham Fogg, et al. 2015. "Soil suitability index identifies potential areas for groundwater banking on agricultural lands." California Agriculture 69 (2): 75–84. https://doi.org/10.3733/ca.v069n02p75.

Shasta Valley Resource Conservation District. 2013. "STUDY PLAN TO ASSESS SHASTA RIVER SALMON AND STEELHEAD RECOVERY NEEDS."

Shasta Valley Resource Conservation District. 2017. "Lower Shasta River Water Balance: September 2016."

Shasta Valley Resource Conservation District. 2018. "Middle Shasta River Water Balance: September-October 2017."

Shasta Valley Resource Conservation District. 2018b. "Shasta River Watershed Stewardship Report."

State of California. 2014. "California Water Action Plan."

SVRCD, and McBain & Trush. 2013. "Study Plan to Assess Shasta River Salmon and Steelhead Recovery Needs." September. U.S. Fish; Wildlife Service.

Willis, A.D., Nichols, A.L., Jeffres, C.A., Deas, M.L., 2013. Water Resources Management Planning: Conceptual Framework and Case Study of the Shasta Basin. Report prepared for: National Fish and Wildlife Foundation.

Winter, T., Harvey, J., Franke, O., Alley, W. 1999. Ground Water and Surface Water: A Single Resource. United States Geological Survey (USGS) Survey Circular 1139.

Yreka, City of. 2003. "City of Yreka General Plan Update 2002 - 2022."

Center for Watershed Sciences, and Watercourse Engineering Inc. 2013. “Water Resources Management Planning: Conceptual Framework and Case Study of the Shasta Basin.”

County of Siskiyou. 1972. “General Plan, Open Space Element.” https://www.co.siskiyou.ca.us/sites/default/files/pln%7B/_%7Dgp%7B/_%7Dopenspaceelement.pdf.

———. 1973. “The Conservation Element of the General Plan, Siskiyou County, California.”

Deas, Mike. 2006. “Big Springs Creek and Spring Complex - Estimated Quantification.”

DWR. 2004. “Basin Boundaries and Hydrology.” DWR.

———. 2010. “2010 Land Use Survey.”

———. 2019a. “DAC Mapping Tool.” https://gis.water.ca.gov/app/dacs/.

———. 2019b. “Groundwater Monitoring (CASGEM) Website.” https://water.ca.gov/Programs/Groundwater-Management/Groundwater-Elevation-Monitoring--CASGEM.

———. n.d.a. “County of Siskiyou Zoning Ordinance.” https://library.municode.com/ca/siskiyou%7B/_%7Dcounty/codes/code%7B/_%7Dof%7B/_%7Dordinances?nodeId=TIT10PLZO.

———. n.d.b. “DWR Online System for Well Completion Reports (OSWCR).” https://civicnet.resources.ca.gov/DWR%7B/_%7DWELLS/.

Harbaugh, Arlen W. 2005. *MODFLOW-2005, the US Geological Survey Modular Ground-Water Model: The Ground-Water Flow Process*. US Department of the Interior, US Geological Survey Reston, VA.

Markstrom, Steven L, Richard G Niswonger, R Steven Regan, David E Prudic, and Paul M Barlow. 2008. “GSFLOW-Coupled Ground-Water and Surface-Water FLOW Model Based on the Integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005).” *US Geological Survey Techniques and Methods* 6: 240.

NCRWQCB. 2018. “WATER QUALITY CONTROL PLAN FOR THE NORTH COAST REGION NORTH COAST REGIONAL WATER QUALITY CONTROL BOARD.”

NCRWQCB (California North Coast Regional Water Quality Control Board). 2006. “Report for the Action Plan for the Shasta River Watershed Temperature and Dissolved Oxygen Total Maximum Daily Loads,” 1123.

———. 2018. “Shasta River TMDL Conditional Waiver of Waste Discharge Requirements.”

O’Geen, A. T., Matthew B. B. Saal, Helen Dahlke, David Doll, Rachel Elkins, Allan Fulton, Graham Fogg, et al. 2015. “Soil suitability index identifies potential areas for groundwater banking on agricultural lands.” *California Agriculture* 69 (2): 75–84. https://doi.org/10.3733/ca.v069n02p75.

Pelto, Mauri S. 2008. “Impact of Climate Change on North Cascade Alpine Glaciers, and Alpine Runoff.” *Northwest Science* 82 (1): 65–75.

Shasta Valley Resource Conservation District. 2013. “STUDY PLAN TO ASSESS SHASTA RIVER SALMON AND STEELHEAD RECOVERY NEEDS.”

State of California. 2014. “California Water Action Plan.”

SVRCD, and McBain & Trush. 2013. “Study Plan to Assess Shasta River Salmon and Steelhead Recovery Needs.” September. U.S. Fish; Wildlife Service.

Yreka, City of. 2003. “City of Yreka General Plan Update 2002 - 2022.”