AUGUST 2021

CHAPTER 2: PLAN AREA
AND BASIN SETTING

SISKIYOU COUNTY FLOOD CONTROL & WATER CONSERVATION DISTRICT

Shasta Valley Groundwater Sustainability Plan

PUBLIC DRAFT REPORT

SISKIYOU COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT
GROUNDWATER SUSTAINABILITY AGENCY
SHASTA VALLEY GROUNDWATER SUSTAINABILITY PLAN

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2.1 Description of the Plan Area

2.1.1 Summary of Jurisdictional Areas and Other Features

Jurisdictional Areas and Land Use

The population of the Basin was estimated at 13,070 during the 2010 Census (DWR SGMA Basin Prioritization Dashboard), including the populations of the incorporated cities of Yreka (7,765), Weed (2,967), and Montague (1,443). The Valley also is home to the census-designated places (CDP) of Grenada (367), Carrick (131), Gazelle (70), and Edgewood (43). Communities in the Valley categorized as either disadvantaged or severely disadvantaged include: Gazelle, Grenada, Montague, Weed, and Yreka. Communities with an annual median household income (MHI) of less than 80% of the average annual MHI in California are classified as Disadvantaged Communities (DACs), while communities with annual MHIs of less than 60% of California's average annual MHI are considered Severely Disadvantaged Communities (SDACs). Based on the 2012-2016 DAC Mapping Tool, the statewide average annual MHI is $63,783 and Gazelle, Grenada, Weed, and Yreka all qualify as SDACs with annual MHIs of $31,389, $29,773, $29,427, and $30,202, respectively (DWR 2019a). Montague has an annual MHI of $41,923, which qualifies it as a DAC. Carrick and Edgewood are not listed in the government database as either a DAC or SDAC as no MHI data is provided for either CDP (DWR 2019a).

The majority of the land within the Valley is under private ownership with the remaining area managed by the California Department of Fish and Wildlife (CDFW), United States Bureau of Land Management (BLM), and the United States Forest Service (USFS). Much of the Watershed surrounding the Basin is a mixture of private (mostly timber) and USFS land. Two large conservation properties (CDFW's Shasta Valley and Big Springs Ranch Wildlife Areas) cover a the northern and central portions of the Basin (Figure 2). The dominant land use in the Valley is agriculture with pasture, alfalfa, and grain and hay comprising the primary crops (Figure 3). The original Bulletin 118 Shasta Valley Groundwater Basin (DWR 2004) consisted of 52,589 acres and was classified as medium priority. The Agency successfully applied to DWR to modify the Basin boundary during their 2018 Basin Boundary Modification Process. The modified Basin was finalized by DWR in February of 2019. The modified Basin increased to 217,980 total acres. The updated boundary accounts for much more of the groundwater pumping in the Valley allowing for more holistic management moving forward. This modification substantially increased the area designated under SGMA, and also expanded the extent of the Basin to include various complex geological and hydrological areas of the Watershed which requires significantly more resources to fully develop an understanding of the various hydrological connections in the Valley. Gaining such understanding will require filling numerous data gaps. Portions of the Basin lack sufficient well monitoring sites within its network grid and some regions are completely lacking monitoring wells. Some locations,

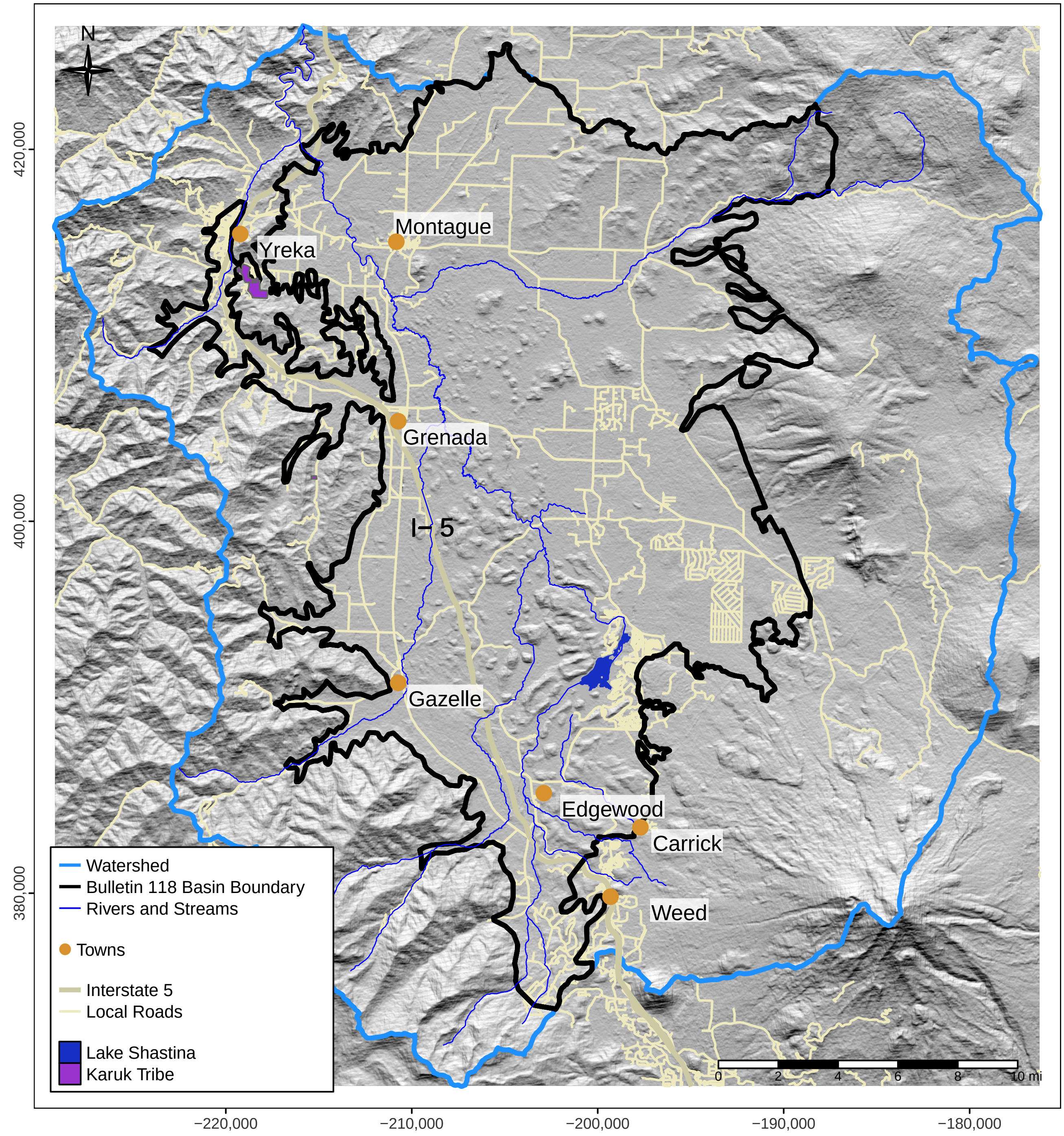


Figure 1: Shasta Valley Bulletin 118 Basin Boundary (black) and watershed boundary (light blue).

where sparse datasets show declining groundwater level trends, need improved groundwater monitoring and management activities. Surface water-groundwater interaction is a key sustainability criterion to evaluate within the Basin's GSP. Therefore, continuously measured water levels are necessary to build on the biannual measurements collected under DWR's California Statewide Groundwater Elevation Monitoring (CASGEM) Program.

Groundwater and surface water are hydraulically connected in the Basin. Beginning in 1992, the SWRCB, in conjunction with the North Coast Regional Water Control Board (NCRWQCB, or more simply, the Regional Water Board), identified water quality objectives within the Shasta River. The Shasta River is in exceedance of the Total Maximum Daily Load (TMDL) for temperature and dissolved oxygen. The Shasta River TMDL is explored in greater detail in Section 2.1.2. Under the California Water Action Plan, the Shasta River was named one of five priority stream reaches that the California State Water Resources Control Board (SWRCB; State Board), in coordination with CDFW, will "seek to enhance flows to support and improve critical habitat for anadromous fish" (State of California 2014).

In September 2018, SWRCB released their "Draft Shasta River Watershed Characterization and Model Study Plan" which outlines a proposed groundwater-surface water modeling plan on the Shasta River. Creation of such a model will be an integral part of this Basin's GSP development process to enable the decision-makers to run different scenarios, create the Basin's water budget, and determine projects that will assist the Valley in attaining groundwater sustainability and improving in-stream flows for anadromous fishery needs in the Shasta River. The County of Siskiyou (County), Valley stakeholders, and SWRCB staff have been collaborating on combining aspects of both modeling projects including collaborating on data collection. The County and SWRCB entered into a Memorandum of Understanding (MOU) on October 18, 2019 to coordinate future collaborations. Data gaps should be filled for modeling inputs to enable tracking water movement through the Basin and establishing a water budget. Therefore, strategic continuous groundwater observations and measurements will provide valuable information for model development and installation of soil moisture sensors is crucial in the Valley's efficient water use. Additionally, water users are encouraged to pursue projects that aid in the NCRWQCB TMDL requirements including minimizing tailwater from entering the Shasta River and associated tributaries by working with the Regional Board to develop land management plans.

Groundwater is not adjudicated within the Basin. No other GSA is present within the Basin. An Alternative Plan (to a GSP) was not prepared for the Basin.

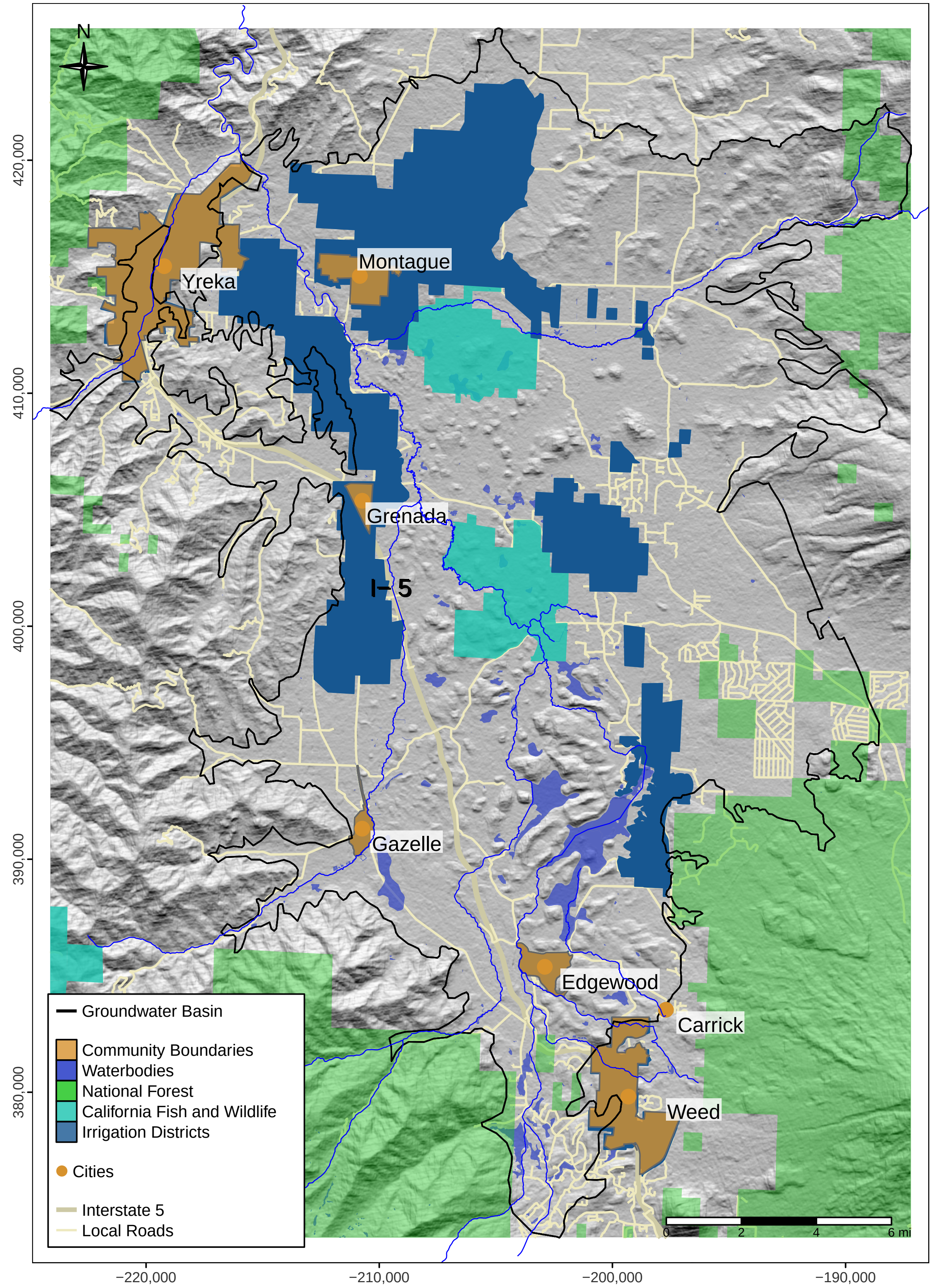


Figure 2: Irrigation districts and administrative areas within Shasta Valley Groundwater Basin

Current Land Use

Acreages associated with various land uses surveyed by the County in 2010 and updated based on stakeholder comments are presented in Table 1 (DWR 2010). Land use within the Basin are discussed in further in Section 2.1.3.

Table 1: Acreage and percent of total Basin area covered by all identified land uses in the updated 2010 County of Siskiyou land use survey. Updates provided by stakeholder comments.

Land Use Description	Area (Acres)	Percent (%)
Alfalfa	7990.16	1.6
Barren	9.03	0
Commerical	1556.44	0.3
Farmsteads	954.73	0.2
Fruit	36.03	0
Grain and Hay	10755.66	2.1
Idle	2286.93	0.4
Native	420905.43	82.8
Native Water	4555.87	0.9
Pasture	41734.78	8.2
Riparian	1954.93	0.4
Semi-Ag	5.89	0
Truck, Nursery, and Berry	180.18	0
Unknown	226.88	0
Urban	15346.09	3
Total	508499.02	100

Well Records

Public data regarding wells is limited in the Basin. Using data from the DWR Online System for Well Completion Reports (OSWCR; DWR, n.d.b), it is possible to visualize the approximate distribution (i.e., well density) of domestic, agricultural production, and public drinking water wells in the Basin, aggregated to each Public Land Survey System (PLSS) section (Figure 4). Because OSWCR represents an index of Well Completion Report records dating back many decades, this dataset may include abandoned wells, destroyed wells, or wells with quality control issues such as inaccurate, missing or duplicate records, but is nevertheless a valuable resource for planning efforts.

The primary uses of the wells reviewed were:

- Domestic Wells: 3,264
- Agricultural Production Wells: 388
- Public/Municipal Wells: 35

Currently only CASGEM wells (Section 2.1.2) and future monitoring networks are included as observation wells (https://water.ca.gov/Programs/Groundwater-Management/Groundwater-Elevation-Monitoring--CASGEM).

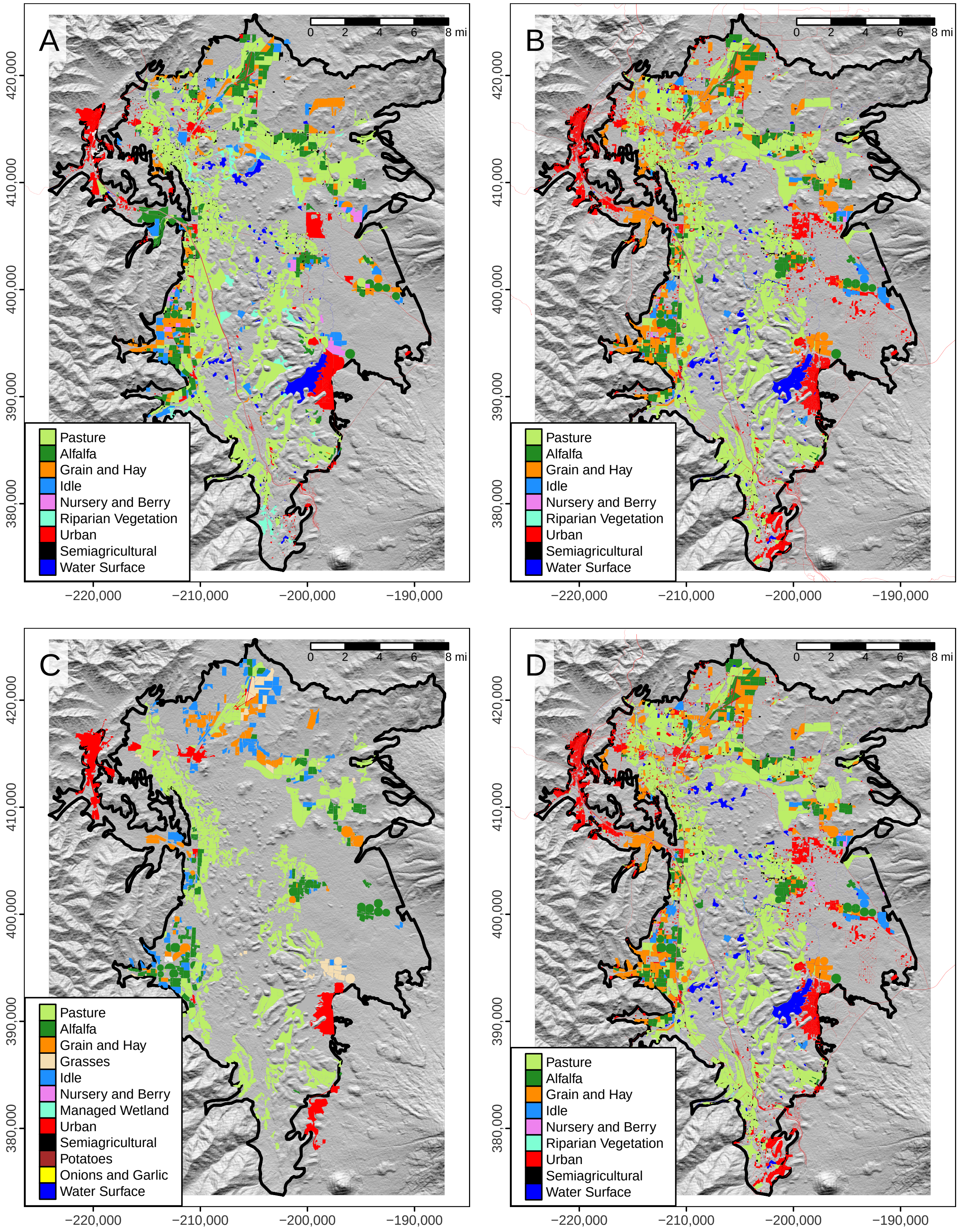


Figure 3: Land uses within the Shasta Valley Groundwater Basin boundary taken from the 2000 DWR Siskiyou Land Use Survey (Panel A), the 2010 DWR Siskiyou Land Use Survey (Panel B), the 2014 DWR LandIQ Land Use Survey (Panel C), and the stakeholder updated 2010 DWR Siskiyou Land Use Survey (Panel D).

Note: ***This section will be updated as model and monitoring network development progresses.***

The density of groundwater wells is highest in the south and northwest sections of the Basin, especially near the cities of Montague, Grenada, Weed and Yreka, following the heavy land use areas, as shown in Figure 4.

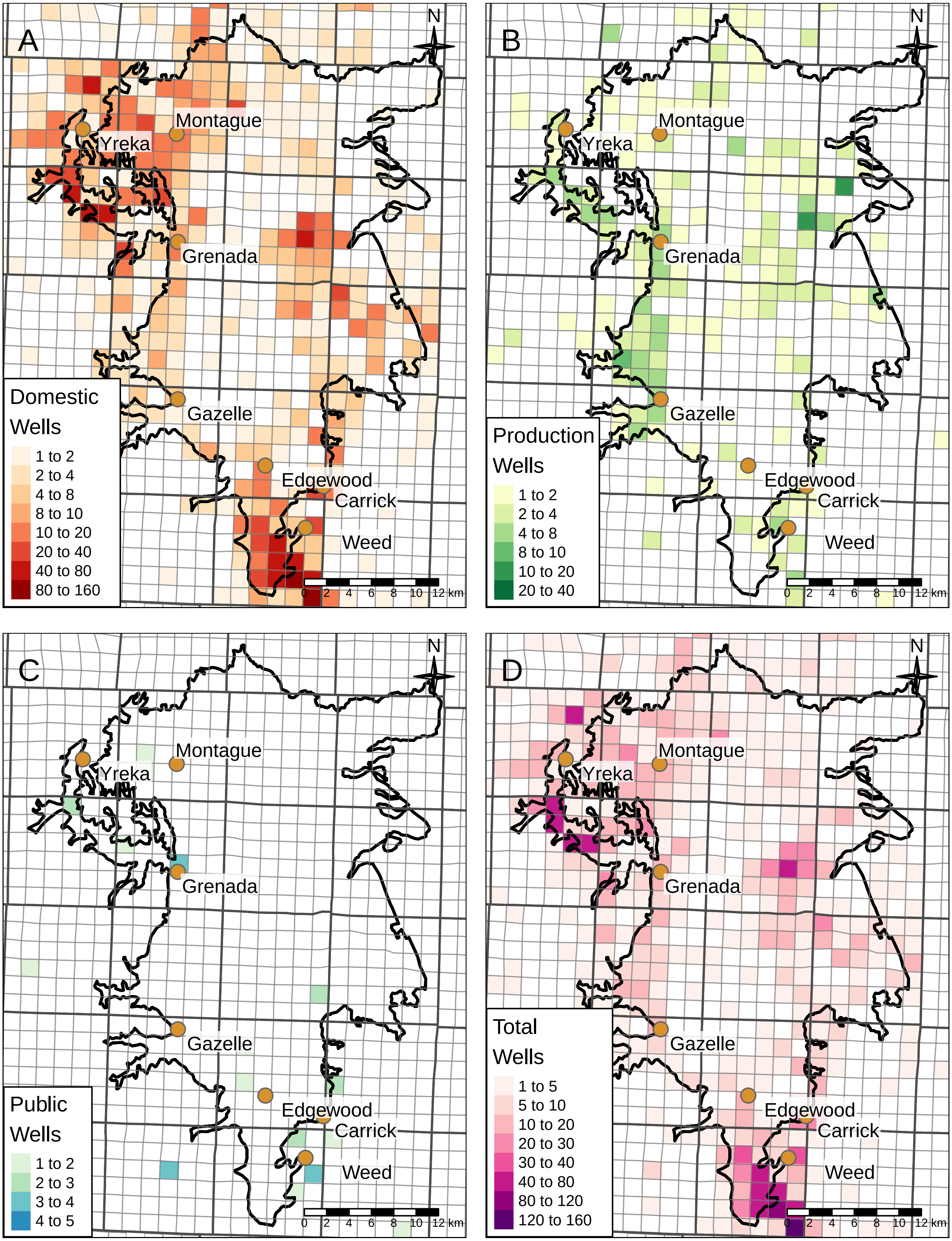


Figure 4: Well density maps indicating number of domestic (panel A), agricultural (panel B), and public (panel C) Well Completion Reports present in each Public Land Survey System (PLSS) section, based on data from the DWR Online System for Well Completion Reports (OSWCR). Panel D shows the sum of panels A-C.

2.1.2 Water Resources Monitoring and Management Programs

There is historical and ongoing work in the Basin and Watershed related to monitoring and management of surface water and groundwater resources. The following section describes each monitoring and/or management program, and outlines the current understanding of a) how those programs will be incorporated into GSP implementation and b) how they may limit operational flexibility in GSP implementation.

Overview of Monitoring and Management Programs

Statewide Monitoring and Management Programs:

- California Department of Water Resources (DWR):
    - California Statewide Groundwater Elevation Monitoring Groundwater Information Center Interactive Mapping Application (CASGEM GICIMA)
- California Department of Fish and Wildlife (CDFW)
    - Big Springs Ranch
    - Shasta Valley Wildlife Area
- California Department of Pesticide Regulation (CDPR)
- California State Water Resources Control Board (SWRCB; State Board):
    - Division of Drinking Water (DDW)
    - Division of Water Rights
    - Groundwater Ambient Monitoring and Assessment Program (GAMA)
- Endangered Species Conservation Laws
    - Federal Endangered Species Act (ESA)
    - California Endangered Species Act (CESA)
- University NAVSTAR Consortium (UNAVCO)
- United States Bureau of Reclamation (USBR)
- United States Geological Survey (USGS)

Regional Monitoring and Management Programs:

- California North Coast Regional Water Quality Control Board (NCRWQCB; Regional Board)
    - Water Quality Control Plan for the North Coast Region (Basin Plan)
    - Total Maximum Daily Loads (TMDLs)
- Klamath Basin Monitoring Program (KBMP)
- Klamath National Forest (USFS)
- Shasta National Forest (USFS)

Local Monitoring and Management Agencies:

- Karuk Tribe Department of Natural Resources (KTDNR)
- Irrigation Districts and Associations
  - Big Springs Irrigation District (BSID)
  - Grenada Irrigation District (GID)
  - Montague Water Conservation District (MWCD)
  - Shasta River Water Association (SRWA)
- Shasta Valley Resource Conservation District (SVRCD)
- Siskiyou County Flood Control and Water Conservation District (SCFCWCD)
- The Nature Conservancy (TNC)
- Scott Valley and Shasta Valley Watermaster District (SSWD)

2.1.2.1 California Department of Water Resources (DWR)

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

As of October 2019, records from the CASGEM well network in the Basin spatially cover much of the Basin with 37 wells of varying temporal coverage spanning the 1950's to present (27 stations were active in 2018/2019, 24 are currently active in 2019, and 10 are no longer active). The majority of these wells within the Basin boundary are designated as "Voluntary" status (DWR 2019b). "Voluntary" status indicates that the well owner has contributed water level measurements to the CASGEM database but the well is not enrolled in the CASGEM monitoring program. Well monitoring under the CASGEM Program is ongoing. CASGEM water level data are used in the GSP to characterize historical Basin conditions and water resources (see Section 2.2.2). No limitations to operational flexibility in GSP implementation are expected in the Basin due to implementation of the CASGEM Program.

In addition to the CASGEM Program, DWR operates two stream gages within the Basin. The stations are located at the Parks Creek diversion near Edgewood (Station ID: MPD; records from 2005 to present) and the Shasta River at the Grenada pumping plant (Station ID: SPU; records from 2013 to present). These and other stream gages are critical for calibration of integrated hydrologic models as well as developing conceptual knowledge models of the hydrologic system in the Valley.

2.1.2.2 California Department of Fish and Wildlife (CDFW)

Big Springs Ranch Wildlife Area (BSRWA)

The Big Springs Ranch area contains the largest groundwater springs (by water flow rate) in the Valley. The Big Springs Complex (including Big and Little Springs) is a very critical water source to the Shasta River, often contributing more water flux than flows in the Shasta River upstream of the confluence of Big Springs Creek with the Shasta River. The Big Springs Complex is one of the most important groundwater-dependent ecosystems (GDEs) in the Valley due to its critical aquatic habitat for anadromous fish. CDFW recently acquired the Big Springs Ranch from The Nature Conservancy (TNC) in mid-year 2019. BSRWA was purchased for the protection and preservation of water rights and for anadromous fish habitat. The location of BSRWA and its access to nutrient-rich cold spring water provides critical habitat for Fall Chinook and the endangered and threatened Coho salmon, making protection and restoration of the ranch's waterways essential for these populations. TNC and its partners restored 10 miles of river, planted 6,000 native riparian trees, invested in over 60 scientific research projects and implemented new practices developed to improve salmon habitat by decreasing water temperatures and increasing stream flows, all while running an active cattle ranch. The numerous scientific studies focusing on the surface water and groundwater features of this property were conducted by University of California, Davis (Center for Watershed Sciences, UC Davis), the SVRCD, and numerous environmental consultants. Many of those affiliated with a number of those projects are currently either directly or indirectly involved with the development of this GSP. Future operations will be run by the CDFW Fisheries Branch rather than the CDFW Wildlife Area Lands Department. All monitoring and management operations past, present, and future in BSRWA will be incorporated in the development of this GSP.

Shasta Valley Wildlife Area (SVWA)

The Shasta Valley Wildlife Area was designated as a wildlife area by the Fish and Game Commission in 1991. It contains approximately 4,700 acres of Great Basin juniper woodland, riparian forest, seasonal wetlands, and crop lands, with Mt. Shasta as a backdrop. Sandhill cranes, waterfowl, raptors, and shorebirds are commonly seen at Shasta Valley Wildlife Area. Deer, porcupines, and coyotes are among the mammals that can be seen. There are three deep water reservoirs and numerous seasonal wetlands on the wildlife area. There are three domestic wells and no irrigation wells that CDFW operates on this property. CDFW does not utilize groundwater for managing habit in SVWA, only surface water management via a diversion from the Little Shasta River. Operations of surface water management at SVWA will be incorporated in the development of this GSP.

2.1.2.3 California Department of Pesticide Regulation (CDPR)

The CDPR maintains a current well inventory database containing data from wells sampled for pesticides by a variety of agencies, including the California Department of Public Health (prior to CDPR reporting being taken over by SWRCB), CDPR, DWR, USGS, and SWRCB DDW. These agencies monitor a variety of wells, including monitoring, domestic, large and small water systems, irrigation, and community wells for 35 different pesticides and report measurements to the CDPR. Exact locations are not known, but based on an estimation of coordinates using county, township, range, and section data, there are 33 wells monitored within the Basin with groundwater quality measurements for pesticides, such as atrazine, aldrin, and simazine.

2.1.2.4 California State Water Resources Control Board (SWRCB)

The California State Water Resources Control Board manages several programs that are active in the Basin and are described below.

Division of Drinking Water (DDW)

The State Water Resources Control Board's Division of Drinking Water, (formerly the Department of Health Services) monitors public water system wells per the requirements of Title 22 of the California Code of Regulations relative to levels of organic and inorganic compounds such as metals, microbial compounds and radiological analytes. Data are available for active and inactive drinking water sources, for water systems that serve the public, and wells defined as serving 15 or more connections, or more than 25 people per day. In the Basin, Division of Drinking Water wells were monitored for Title 22 requirements, including pH, alkalinity, bicarbonate, calcium, magnesium, potassium, sulfate, barium, copper, iron, zinc, and nitrate.

Division of Water Rights

The State Water Resources Control Board's Division of Water Rights have jurisdiction over diversions of water not covered by the Scott Valley and Shasta Valley Watermaster District (SSWD).

Groundwater Ambient Monitoring and Assessment Program (GAMA)

Established in 2000, the Groundwater Ambient Monitoring and Assessment (GAMA) Program monitors groundwater quality throughout the state of California. The GAMA Program will create a comprehensive groundwater monitoring program throughout California and increase public availability and access to groundwater quality and contamination information. The GAMA Program receives data from a variety of monitoring entities including DWR, USGS, and the State Water Resources Control Board. GeoTracker, operated by the State Board, is a subset program of the GAMA program. GeoTracker GAMA does not regularly monitor for general groundwater quality constituents. GeoTracker contains records for sites that require cleanup, such as leaking underground storage tank sites, Department of Defense sites, and cleanup program sites. GeoTracker also contains records for various unregulated projects as well as permitted facilities including: Irrigated Lands Regulatory Program, oil and gas production, operating permitted underground storage tanks, and land disposal sites. GeoTracker receives records and data from State Board programs and other monitoring agencies.

2.1.2.5 Endangered Species Conservation Laws

Federal Endangered Species Act (ESA)

The Endangered Species Act of 1973 (ESA) outlines a structure for protecting and recovering imperiled species and their habitats. Under the ESA, species are classified as “endangered”, referring to species in danger of extinction throughout a significant portion of its range, or “threatened”, referring to species likely to become endangered in the foreseeable future. The ESA is administered by two federal agencies, the Interior Department’s U.S. Fish and Wildlife Service (FWS), primarily responsible for terrestrial and freshwater species, and the Commerce Department’s National Marine Fisheries Service (NMFS) which primarily handles marine wildlife and anadromous fish. In Shasta River Valley, coho salmon are listed as threatened under the ESA, as part of the Southern Oregon and Northern California coasts (SONCC) evolutionary significant unit (ESU).

California Endangered Species Act (CESA)

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

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

2.1.2.6 University NAVSTAR Consortium (UNAVCO)

In the Watershed, subsidence monitoring is partially performed using continuous global positioning system (GPS) stations monitored by UNAVCO’s Plate Boundary Observatory (PBO) program. The UNAVCO PBO network consists of a network of about 1,100 continuous global positioning system (CGPS) and meteorology stations in the western United States to measure deformation resulting from the constant motion of the Pacific and North American tectonic plates in the western United States. Information from this monitoring can support the monitoring of land subsidence resulting from the extraction of groundwater.

There are four CGPS stations (P657, P658, P661, and P663) within the Watershed but not within the Basin (all are on the north slope of Mt. Shasta) with records spanning 2007 to the present. There is one borehole strainmeter operated by UNAVCO within the Basin near Gazelle (B039) with data records from 2007 to present. However, this instrument does not record vertical displacement and is not capable of characterizing land subsidence.

2.1.2.7 United States Bureau of Reclamation (USBR)

USBR is granting funds to the Agency to install 10 co-located, continuous groundwater level and soil moisture sensors that will be incorporated into the Basin's GSP development and implementation.

2.1.2.8 United States Geological Survey (USGS)

USGS operates two stream gages within the Watershed (one within the Basin boundary). The stations are located on the Shasta River near Montague (DWR Station ID: SRM [USGS Station ID: 11517000]; records from 1999 to present) and on the Shasta River near Yreka (Station ID: SRY [USGS Station ID: 11517500]; records from 2000 to present).

Although neither of these stream gages provide a comprehensive picture of surface water flows in the Basin, they provide some information about the inflow and outflow of surface water through the Basin.

2.1.2.9 California North Coast Regional Water Control Board (Regional Board)

The Water Quality Control Plan for the North Coast Region encompasses groundwater within the Valley and is regulated via the North Coast Regional Water Quality Control Board (NCRWQCB) Basin Plan (NCRWQCB 2018):

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

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

- Municipal and Domestic Supply (MUN)
- Agricultural Supply (AGR)
- Industrial Service Supply (IND)
- Native American Culture (CUL).

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

Section 3.4 and Table 3-1 of the Basin Plan outlines the water quality objectives for all groundwaters in the North Coast Region and those specific to the Shasta Valley Hydrologic Area (NCRWQCB 2018). The Basin Plan refers to the California Code of Regulations for Domestic Water Quality and Monitoring Regulations (Title 22) for nearly all numeric limits [NCRWQCB (2018); Title 22]. The Basin Plan water quality objectives and numerical limits are used in Section 2.2.2 of the GSP regarding water quality characterization and issues of concern. They will also guide Section 3 of the GSP regarding groundwater sustainability criteria related to degraded water quality. No limitations to operational flexibility in GSP implementation are expected in the Basin due to implementation of the Basin Plan.

Total Maximum Daily Loads (TMDLs)

Total Maximum Daily Loads (TMDLs) regulating temperature and dissolved oxygen in the Watershed were first promulgated in 2006 (NCRWQCB 2006). The Shasta River TMDLs for dissolved oxygen and temperature were established in accordance with Section 303(d) of the Clean Water Act. The USEPA added the Shasta River to the impaired water list in 1992 due to low dissolved oxygen. The listing was modified in 1994 to include elevated temperature. In 2006 the North Coast Regional Water Quality Control Board (NCRWQCB) incorporated these TMDLs into the *Water Quality Control Plan for the North Coast Region* (Basin Plan) (NCRWQCB (California North Coast Regional Water Quality Control Board) 2006). The plan has undergone multiple updates with the current iteration released in 2018 (NCRWQCB (California North Coast Regional Water Quality Control Board) 2018).

Since 2006 the NCRWQCB has waived the requirement for Dischargers (entities or individuals which may discharge waste to the Shasta River, or which are responsible for controlling such discharge), if they were not already covered by an existing permit, to file a Report of Waste Discharge (ROWD) and obtain Waste Discharge Requirement permits (WDRs) (NCRWQCB (California North Coast Regional Water Quality Control Board) 2018).

2.1.2.10 United States Forest Service (USFS)

Klamath National Forest

The United States Forest Service (USFS) manages the Klamath National Forest which is managed under the Klamath National Forest Land and Resource Management Plan (Klamath NF, 2010). The Management Plan includes monitoring of aquatic ecosystems, of which water quality monitoring is included. Water temperature and stream flow in Klamath River tributaries is monitored to establish watershed condition and stream health, and to assess the contribution of tributaries in maintaining water quality in the Klamath River. Water quality data are compared to the standards and criteria of the Clean Water Act to determine if water quality and the health of aquatic systems are being maintained. Water quality monitoring reports are posted to the Klamath National Forest website, and include the following: bacteria, storm monitoring, stream sediment, stream shade, stream temperature, and Best Management Practices. Monitoring of groundwater is not conducted under the Management Plan.

The Klamath National Forest does not manage groundwater wells that report data to CDPH or SWRCB (SWRCB, 2019a; SWRCB, 2019b). Due to the minimal amount of land overlying the

Basin that is managed by the Klamath National Forest, it is unlikely the Forest Service will be a major partner for GSP implementation; however, this may change in the future as monitoring requirements and programs evolve.

Shasta National Forest

USFS manages the Shasta-Trinity National Forest which is managed under the Shasta-Trinity National Forest Land and Resource Management Plan (Shasta-Trinity NF, 1995). The Management Plan includes a Monitoring Action Plan that uses monitoring of the following metrics to evaluate BMPs as well as the effectiveness of BMPs for the protection of water quality: water quality parameter monitoring in affected streams, paired watershed studies, monitoring of beneficial uses, site-specific soil erosion monitoring, and slope stability site monitoring. The Shasta-Trinity National Forest also conducts watershed scale analysis to meet the requirements of the Aquatic Conservation Strategy adopted for the President's Plan, Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl; Standards and Guidelines for Management of Habitat for Late-Successional and Old-Growth Related Species (USDA, 1994). Groundwater monitoring is not conducted as part of the Management Plan or the watershed analysis. Watershed Analysis/Assessment Reports, and Monitoring and Evaluation Reports are posted to the Shasta-Trinity National Forest website.

The Shasta-Trinity National Forest does not manage groundwater wells that report data to CDPH or SWRCB (SWRCB, 2019a; SWRCB, 2019b). Due to the minimal amount of land overlying the Basin that is managed by the Shasta-Trinity National Forest, it is unlikely the Forest Service will be a major partner for GSP implementation; however, this may change in the future as monitoring requirements and programs evolve.

2.1.2.11 Karuk Tribe Department of Natural Resources (KTDNR)

The Karuk DNR operate a field monitoring program in the Valley and posts information to the interactive web portal waterquality.karuk.us. We look forward to working with the Karuk Tribe to share information about monitoring programs.

2.1.2.12 Irrigation Districts

The irrigation season in Basin generally extends from March 1 or April 1 to October 1. During this time there are four large users of surface water and groundwater:

- Big Springs Irrigation District
- Grenada Irrigation District
- Montague Water Conservation District
- Shasta Water Association

Taken together these four districts maintain water diversions totaling 227 cfs, subject to flow availability, during the irrigation season (Shasta Valley Resource Conservation District 2013). The four major irrigation districts are shown below (Figure 5).

Big Springs Irrigation District (BSID)

Big Springs Irrigation District (BSID) has rights to 30 cfs from Big Springs. BSID no longer relies on surface water rights to meet district demands (Deas 2006) instead relying on groundwater resources. Big Springs Irrigation District system has an upper and lower ditch. The upper ditch tailwater fortifies the lower ditch flows. BSID consists of approximately 1,800 irrigable acres. Operations of surface water management at BSID will be incorporated in the development of this GSP.

Grenada Irrigation District

The Grenada Irrigation District (GID) was formed in 1916 and currently services approximately 1,600 acres of irrigable land, however, GID does not irrigate the entire acreage every year. For example, during the 2018 irrigation season only 445 acres were irrigated. The GID maintains five miles of open ditch canals, continuous improvements are being made to line the canals with concrete (Personal Communication, 2019). Operations of surface water management at GID will be incorporated in the development of this GSP.

Montague Water Conservation District

The Montague Water Conservation District (MWCD) was formed in 1925 and provides both agricultural and municipal customers. MWCD services the town of Montague and provides water to approximately 14,000 irrigable acres. The water rights of approximately 70 cfs are met through releases of Dwinnell Reservoir and transported through over 60 miles of canals in the area (Center for Watershed Sciences and Watercourse Engineering Inc. 2013). MWCD has flow meters below the reservoir and on Parks Creek diversion. MWCD augments supply with groundwater pumping during dry years. Operations of surface water management at MWCD will be incorporated in the development of this GSP.

Shasta River Water Association

The Shasta River Water Association (SRWA) services an area located in the north end of the Valley west of Montague. Current water rights include 42 cfs during the irrigation season (SVRCD and Trush 2013). Operations of surface water management at SRWA will be incorporated in the development of this GSP.

2.1.2.13 Shasta Valley Resource Conservation District (SVRCD)

The Shasta Valley Resource Conservation District (SVRCD) is a special district serving central Siskiyou County, California. The SVRCD service area includes the Klamath watershed and all its minor tributaries from the California State line near Keno to below Happy Camp, the entire portion of the Applegate River in California, the lower end of the Scott River, the entire Shasta River drainage basin, and the Siskiyou County portions of the Sacramento River watershed, McCloud watershed and Fall River watersheds.

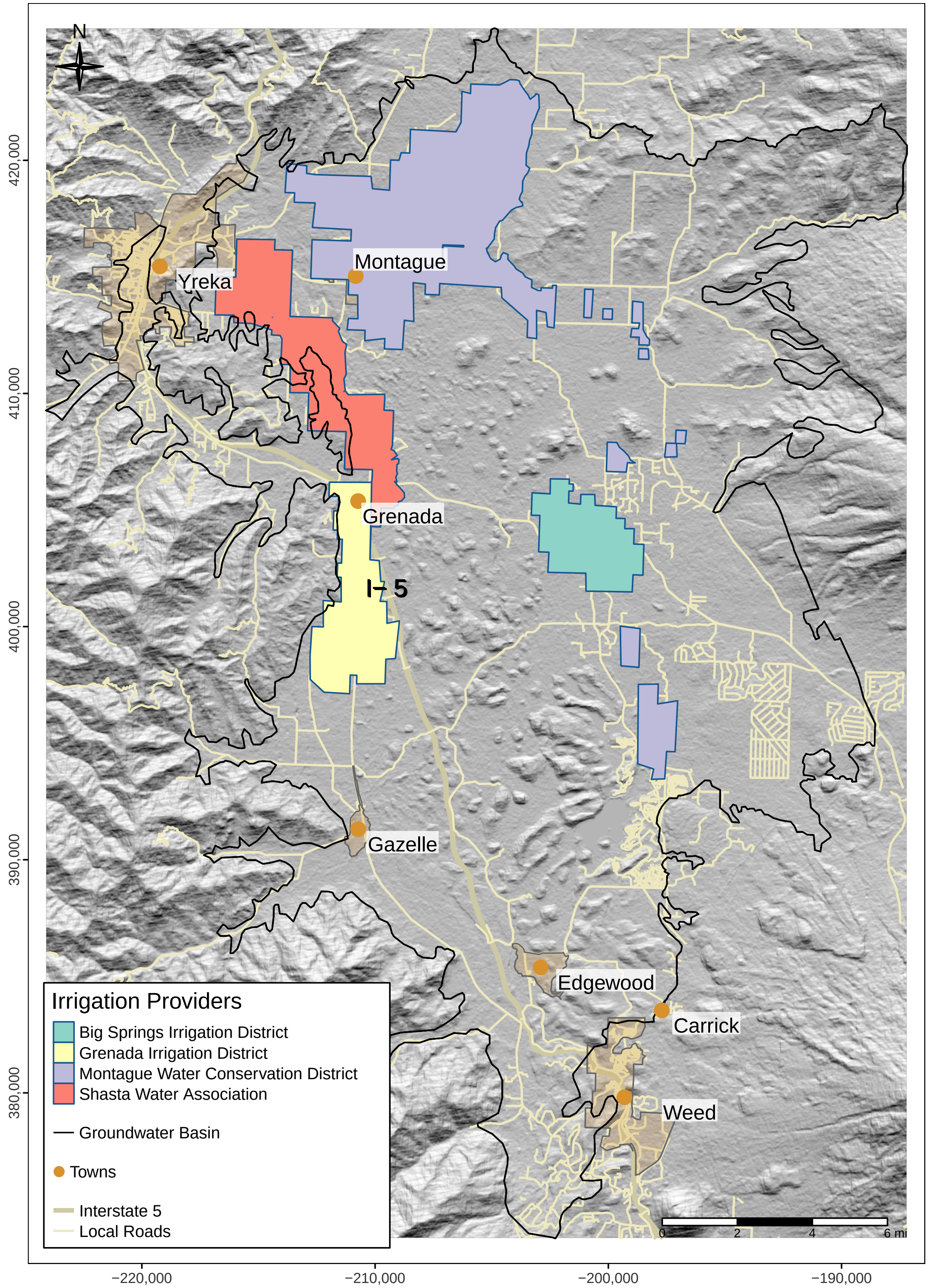


Figure 5: Irrigation Districts of Shasta Valley Groundwater Basin

The SVRCD conducts a variety of surface water and groundwater monitoring efforts through the Watershed for public and private land owners needing assistance with environmental monitoring efforts. The SVRCD is currently installing a DWR-funded monitoring network in the Basin (11 out of a total of 12 continuous monitoring groundwater level stations have been installed). All well owners (public and private) have access to their specific groundwater level data through a secure, private web portal.

The SVRCD performs monitoring for some landowners in the upper Shasta River below Dwinnell Reservoir (Lake Shastina) as part of a Safe Harbor Agreement with local landowners. The data are supplied to the landowner for reporting purposes related to annual use reports.

The SVRCD operates one stream gage within the Watershed (outside of Basin) that is located on Yreka Creek at Anderson Grade Road (Station ID: YCK; records from 2014 to present).

2.1.2.14 County of Siskiyou Flood Control and Water Conservation District (SCFCWCD)

The SCFCWCD is currently installing a DWR- and USBR-funded monitoring network in the Basin for use with GSP development and implementation. USBR funding has provided 10 co-located groundwater level and soil moisture monitoring stations, two of which are already installed. Soil moisture sensors are expected to help well owners to improve irrigation efficiency. All well owners (public and private) have access to their specific groundwater level data through a secure, private web portal, as well as real-time soil moisture data from their irrigated land. DWR and the SCFCWCD are working towards the installation of new groundwater monitoring wells within the Basin.

2.1.2.15 The Nature Conservancy (TNC)

Big Springs Ranch (CDFW)

TNC formerly owned and managed the Shasta Big Spring Ranch property until mid-2019 when CDFW agreed to purchase the land from TNC. TNC conducted a variety of surface water and groundwater monitoring activities on the property in conjunction with UC Davis researchers (see CDFW section for further information on Big Springs Ranch).

Stream gage

TNC operates one stream gage within the Basin. The station is located on the Little Shasta River near Montague (Station ID: LSR; records from 2010 to present), which was previously operated by DWR.

Instream Flows

TNC has been conducting additional monitoring of surface flows related to salmonid migration and rearing as part of its instream flows program.

2.1.2.16 Scott Valley and Shasta Valley Watermaster District (Watermaster)

Surface water diversion rights for the Shasta River and tributaries were set forth in adjudication decrees which span from 1932 to the present. The diversions are located within the Shasta River Watermaster Service Area (Service Area) and controlled by the Scott Valley and Shasta Valley Watermaster (Watermaster). The Service Area was created in 1932 to administer water rights within the Valley. Multiple amendments to the Service Area have occurred, the largest occurring in 1962 for the creation of the Montague Water District (Decree 3647, 1962) and the exclusion of Cold Creek (Superior Court of Siskiyou County, 2018). Currently the Watermaster oversees and manages (primarily through water diversions) approximately 460 cfs of water rights during the irrigation season and 89 cfs of water rights during the winter season. The Watermaster is evaluating the potential to administer surface flow diversions related to adjudicated and riparian uses within the Watershed, providing data to the landowners for reporting purposes beyond that of the SSWD.

Surface water diversion rights for the Shasta River and tributaries were set forth in the Shasta River Decree, No. 7035 and adjudicated in 1932. One supplemental decree was filed with the Siskiyou County Superior Court in 2014. Since February 1, 2012 the service area has been managed by the SSWD per the Petition for Substitution of Watermaster filed with the Siskiyou County Superior Court by Hon. Laura Masunaga, Judge on December 23, 2011. Between February 1, 2012 and June 30, 2018 the appointed Deputy Watermaster was a third party consultant, GEI Consulting, Inc. Beginning July 1, 2018 the Deputy Watermaster appointment was made to SSWD employees at which time the collection of preliminary diversion data commenced for the purpose of supporting the annual Statement of Use required under Water Code Section 5101. Any data used for reporting prior to July 1, 2018 cannot be verified by the SSWD and is assumed to duplicate other Statements of Use or Supplemental Statements submitted by riparian, permitted, and licensed right holders.

In 1933 the Orders Creating Shasta River Water Master District (aka. Watermaster Service Area) was filed with the Siskiyou County Superior Court. The responsible party for providing Watermaster Service at that time was the State of California, Department of Water Resources. Multiple amendments were made over time to reduce or modify the service area.

Currently the Watermaster regulates 365 cfs of water rights during the irrigation season (of which 40 cfs is allocated to the Grenada Irrigation District) and 58 cfs of water rights during the winter, of which 42 cfs is allocated to the Shasta River Water Association. The Watermaster also regulates Montague Water Conservation District's storage rights held in Dwinnell Reservoir of 49,000 acre feet annually.

The amounts indicated above are seldom available for diversion during the irrigation season and, based on the Prior Appropriation Doctrine that determines the adjudicated water users priority system of “first in time, first in right”, the lower priority water right holders are typically curtailed early in the irrigation season to meet the needs of higher priority users, as well as to meet instream bypass requirements.

The SSWD has implemented a Voluntary Monitoring Program (VMP) for diversions that require measurement data beyond the scope of work for Court-Ordered Service. The VMP is available to riparian users and diverters having permits or licenses issued by the State Water Resources Control Board, Division of Water Rights and subject to SB88 monitoring requirements.

SSWD is a regulatory entity that routinely and frequently measures surface diversion volumes from all adjudicated diversions from an entire stream system within service areas to determine current availability of the established priority system, as set forth in the various decrees.

Information can be found on the SSWD website at sswatermaster.org, visit the Services page, click on links to court-ordered watermaster service and the Voluntary Monitoring Program.

Big Springs Irrigation District had 30 cfs of adjudicated surface water rights but now relies on groundwater to avoid early season curtailment by the Watermaster.

In progress: *A map of diversion locations and a table of diversions during wet, average, and dry years.*

2.1.3 Land Use Elements or Topic Categories of Applicable General Plans

2.1.3.1 General Plans

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

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

The Open Space Element of the General Plan includes, in its definition of open space, watershed and groundwater recharge land (County of Siskiyou 1972). The importance of protecting these lands is recognized for maintaining water quality and quantity. Mechanisms to preserve these spaces include maintaining or creating scenic easement agreements, preserves, open space agreements, and designation of lands for recreational or open space purposes. A policy for open space requirements is included with minimum thresholds of 15% of proposed developments as open space. Protection of open space for habitat, water quality and water quantity align with the objectives of the GSP.

Siskiyou County Zoning Plan

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

2.1.3.2 City Plans

Yreka General Plan

The City of Yreka General Plan (YGP; Yreka (2003)) was developed to guide community decisions related to land use and development. The 2003 version of the YGP incorporates a long-term view of planning decisions, extending to the year 2022 and includes the required elements of land use, open space, noise, safety, circulation, housing and conservation. Surface water impacts from the City of Yreka include the release of treated water into percolation ponds near Yreka Creek. The City of Yreka operates under the authority of NCRWQCB Water Quality Control Plan. The City of Yreka Zoning Plan is the controlling land use document within the portion of the Basin that is within the Yreka city limits.

City of Weed General Plan

The City of Weed has a General Plan (WGP; Weed (2017)) represents the adopted goals and policies of the City of Weed. The WGP provides the framework for development decisions leading up to the year 2040, and includes the elements of land use, circulation, housing, conservation, open space, safety, and noise. The Conservation Element of the WGP discusses natural resources within the City of Weed and aims to minimize negative impacts of development on the natural environment while allowing the City to grow. The Conservation Element addresses federal and state standards of environmental regulation.

The City has adequate water supplies but must continue to explore opportunities for future water supply as this resource may be a limiting factor for growth. As stated in the WGP, the City is using close to the full capacity of its water supply with approximately 2.46 million gallons of water available per day. Water savings from conservation efforts are needed to meet the per capita water consumption goals established in Senate Bill X7-7; additionally, the City does not have an Urban Water Management Plan, which would address current and future water supply. With respect to wastewater, an increase in population would require an expansion of the Weed Wastewater System that serves the northern half of the City, and the Shastina Wastewater System that serves the southern half.

2.1.3.3 Williamson Act

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

2.1.4 Additional GSP Elements

2.1.4.1 Policies governing wellhead protection, well construction, destruction, abandonment and well permitting

In the Shasta Valley Basin, wellhead protection and well construction, destruction, and abandonment are conducted according to relevant state guidelines. Well standards are codified in Title 5, Chapter 8 of the Siskiyou County Code. These well standards define minimum requirements, including those for monitoring wells, well construction, deconstruction, and repair, with the objective of preventing groundwater pollution or contamination (County of Siskiyou 2020b). Processes and requirements for well permitting, inspections, and reporting are included in this chapter. The CSEHD is the local enforcement agency with the authority to issue well permits in the County. Well permit applications require information from the applicant and an authorized well contractor, along with a fee.

2.1.4.2 Groundwater Extraction and Illegal Cannabis

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

A current and recently expanding (5 to 7 years) land use practice not accounted for in either the historical or future water budget analysis is groundwater extraction for the cultivation of illegal cannabis. Siskiyou County has adopted multiple ordinances relating to the regulation of cannabis. Chapter 15 of Title 10 of the Siskiyou County Code prohibits all commercial cannabis activities, and Chapter 14 limits personal cannabis cultivation to the indoor growth of a maximum of 12 plants on premises with a legal water source and an occupied, legally established residence connected to an approved sewer or septic system. Personal cultivators are also prohibited from engaging in unlawful or unpermitted surface drawing of water and/or permitting illegal discharges of water from the premises. Despite these ordinances, illegal cannabis cultivators continue to operate within the basin. In the Shasta basin, the illegal cannabis grows of the most substantial concern are primarily found in what is known as the Pluto's Cave Basalt flow (or commonly recognized as the Big Springs/Shasta Vista area), which is the region where two critical springs are located, Big Springs and Little Springs, along with other smaller, but important spring complexes. Illegal cannabis growers rely on groundwater from production and residential well owners within the basin and utilize water trucks to haul groundwater off the parcel from which it is extracted for use at other locations. The proliferation and increase of illegal cannabis cultivation taking place in the basin is a significant community concern, however, obtaining an accurate estimate of overall consumptive groundwater use for this illegal activity has been a challenge for the GSA due to it occurring on private and secluded parcels and the increasing use of covered greenhouses for illegal cannabis cultivation. The Advisory Committee discussed modeled scenarios using the Siskiyou County Sheriff Department's estimate of 2 million illicit cannabis plants and a consumptive use of 4-10 gallons of water per plant per day, to consider the potential impacts to groundwater resources from this activity under current and future conditions. In addition to community concern about estimated consumptive use of groundwater in the basin for illegal cannabis cultivation, there is also concern about water quality impacts from the potential use of illegal and harmful chemicals at illegal grow sites, which may leach into the groundwater (see Chapter 2, Water Quality), and the non-permitted human waste discharge methods that have been found to occur at some of these sites. Data on baseline water quality conditions at illegal cannabis cultivation sites within the basin or at nearby wells has not been collected, however, the GSA intends to include available wells within close proximity to these sites in its future monitoring network for the purpose of measuring water quality.

The GSA considers groundwater used for illegal cannabis cultivation to be a “waste and unreasonable use of water”, but acknowledges that there is not substantial enough data to include groundwater the use estimates from illegal cannabis production in the overall and future water budgets. The GSA will coordinate with local enforcement agencies regarding providing collected hydrologic information and will also use the emphasis on collecting data during the first 5 years of plan implementation to better understand the impacts of groundwater use for illegal cannabis on overall basin-wide use estimates and the relation to nearby groundwater aquifers.

2.1.4.3 Groundwater export

Groundwater export is regulated in the County under Title 3, Chapter 13 of the Siskiyou County Code. Since 1998, Chapter 13 has regulated the extraction of groundwater from Bulletin 118 basins underlying the County for use outside of the basin from which it was extracted. Exceptions include 1) groundwater extractions by a district purveyor of water for agricultural, domestic, or municipal use where the district is located partially within the County and partially in another county, so long as extracted quantities are comparable to historical values; and 2) extractions to boost heads for portions of these same water purveyor facilities, consistent with historical practices of the district. Groundwater extractions for use outside the County that do not fall within the exceptions are required to obtain a permit for groundwater extraction. Permit application processes, timelines, and specifications are described in this ordinance.. In May of 2021, Title 3, Chapter 13, was amended to add Article 3.5, which regulates, through ministerial permitting, the extraction of groundwater for use off the parcel from which it was extracted. This provision requires extracted groundwater be for uses and activities allowed by the underlying zoning designation of the parcel(s) receiving the water and does not apply to the extraction of water for the purposes of supplying irrigation districts, emergency services, well replenishment for permitted wells, a “public water system,” a “community water system,” a “noncommunity water system,” or “small community water system” as defined by the Health and Safety Code, serving residents of the County of Siskiyou.

2.1.4.4 Policies for Dealing with Contaminated Groundwater

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

2.1.4.5 Replenishment of Groundwater Extractions and Conjunctive Use

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

2.1.4.6 Coordination with Land Use Planning Agencies

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

2.1.4.7 Relationships with State and Federal Regulatory Agencies

The GSA has relationships with multiple state and federal agencies, as described in the Section 2.1.2 Monitoring and Management Programs. The GSA will continue to coordinate and collaborate with these agencies throughout GSP development and implementation.

2.2 Basin Setting

2.2.1 Hydrogeologic Conceptual Model

2.2.1.1. Physical Geography

The Shasta River drainage basin (i.e. the Watershed) is located in central Siskiyou County in north-central California and is bounded by Mount Shasta to the south, the Klamath Mountains to the west, and the Cascade Range to the east. Within the Watershed, the Shasta River Valley (hereafter, the Valley) trends northward and is drained by the Shasta River, a tributary to the Klamath River. The Valley covers approximately 800 square miles (sq mi) (about 2,000 square kilometers (sq km)) and consists of a north dipping and topographically rough valley floor surrounded by mountain terrain (Figure 6). The topography of the Valley ranges in elevation from just over 2,000 feet (ft) (~610 meters [m]) above mean sea level (amsl) near the confluence with the Klamath River (the hydrologic terminus for the Watershed) to over 14,100 ft (~4,300 m) amsl near the volcanic peak of Mount Shasta. The valley floor transitions sharply to the mountains bordering the valley, all of which are either part of the Klamath or Cascade Mountain Ranges. The Klamath Mountains on the west side of the Valley are less steep and reach lower elevations (4,000 to 9,000 ft, or about 1,200 to 2,700 m, amsl than the Cascades that border the east side of the Valley (6,000 to 8,000 ft, or about 1,800 to 2,500 m, amsl, not including the topography roughly associated with Mount Shasta). The south side of the Valley is headed by the geologically active stratovolcano Mount Shasta which is part of the Cascade Range (most voluminous of the active Cascade volcanoes), but sits west of the Cascade Range axis which runs predominantly northwest to southeast. Most of the topography associated with Mount Shasta is above 5,000 ft (~1,500 m) amsl and, as its relief extends west to the Klamath Mountains, it acts as a closure feature to the head of the Watershed. The closure topography to the north is largely a lower-relief saddle region bridging the Cascade and Klamath range extents east to west.

The Shasta Valley Groundwater Basin (i.e. the Basin) contains the majority of water-bearing geologic formations, or aquifers, within the Valley and are the most-utilized sources 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 or 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. The complexity and variety of geologic formations in the Watershed are extreme enough that any attempt to model or even conceptualize the system at a high degree of characterization would result in an over-simplification of the natural system. However, the effort of this GSP seeks to produce models that are fit-for-purpose by design and represent the latest approach to characterize the hydrogeologic nature this watershed.

Vegetation on the mountains to the east, south, and west of the Valley mainly consists of evergreen tree species (National Land Cover Database), with lower flank elevations containing shrub and scrub vegetation. The remaining lower-lying areas in the Valley core are vegetated by shrub and scrub, grasslands, wetland, pasture, small forested pockets, and cultivated crops (mainly alfalfa). The Shasta River and its tributaries within the Valley provide key spawning and rearing habitat for native anadromous fish species, including *Oncorhynchus tschawytscha* (Chinook salmon) and the threatened *Oncorhynchus kisutch* (Coho salmon) (NCRWQCB 2005).

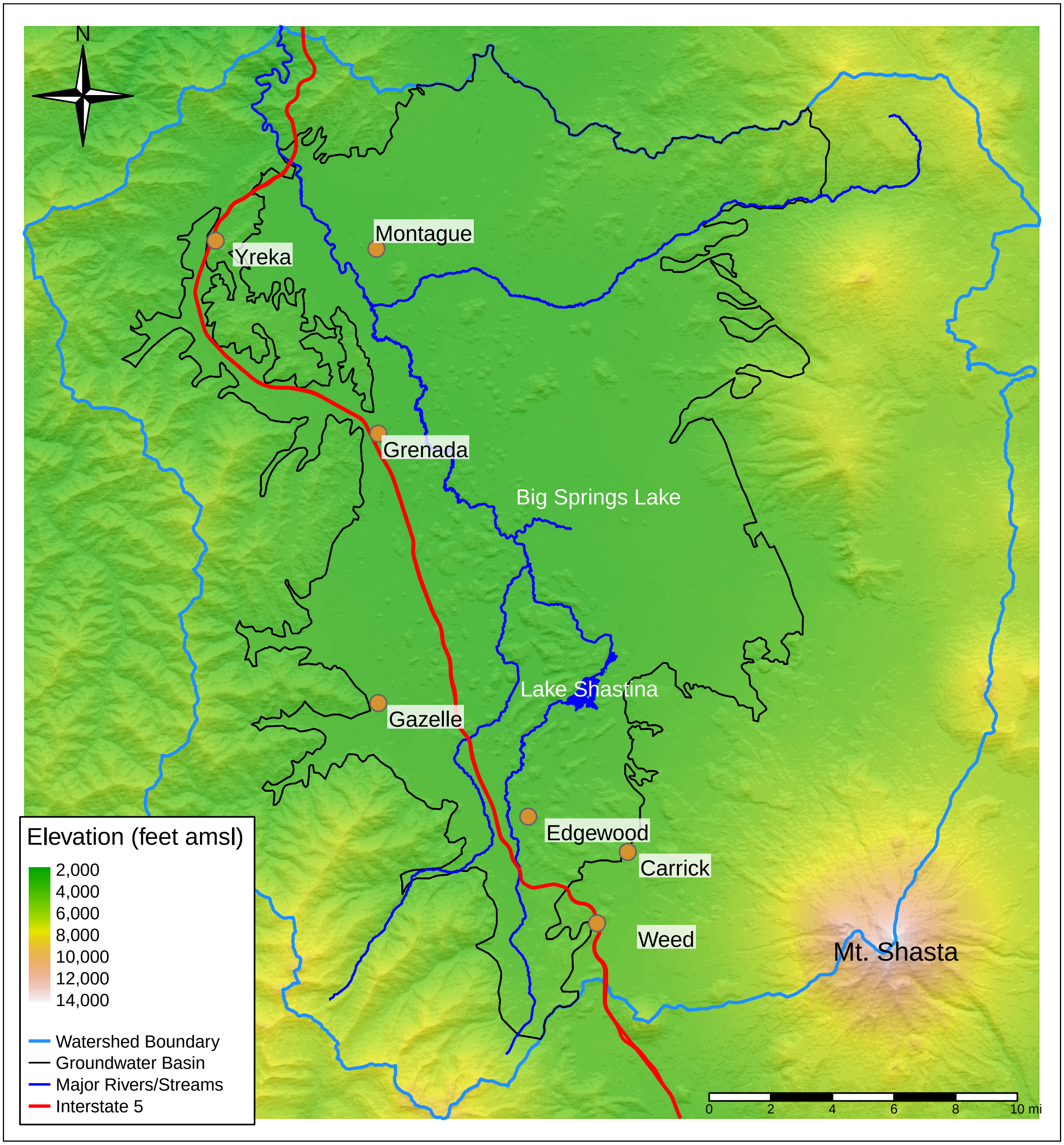
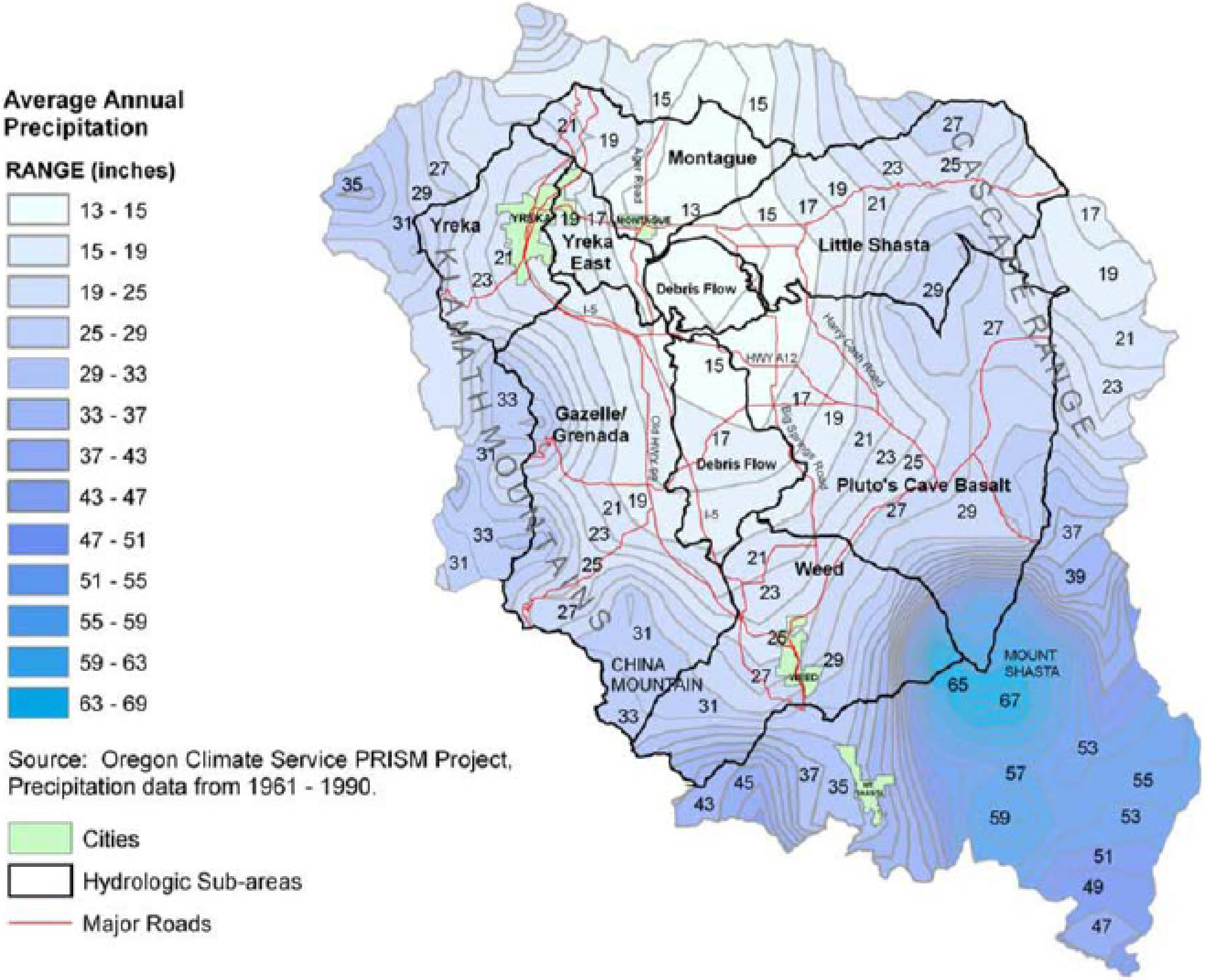


Figure 6: Topography of the Shasta River Valley Groundwater Basin and surrounding watershed.

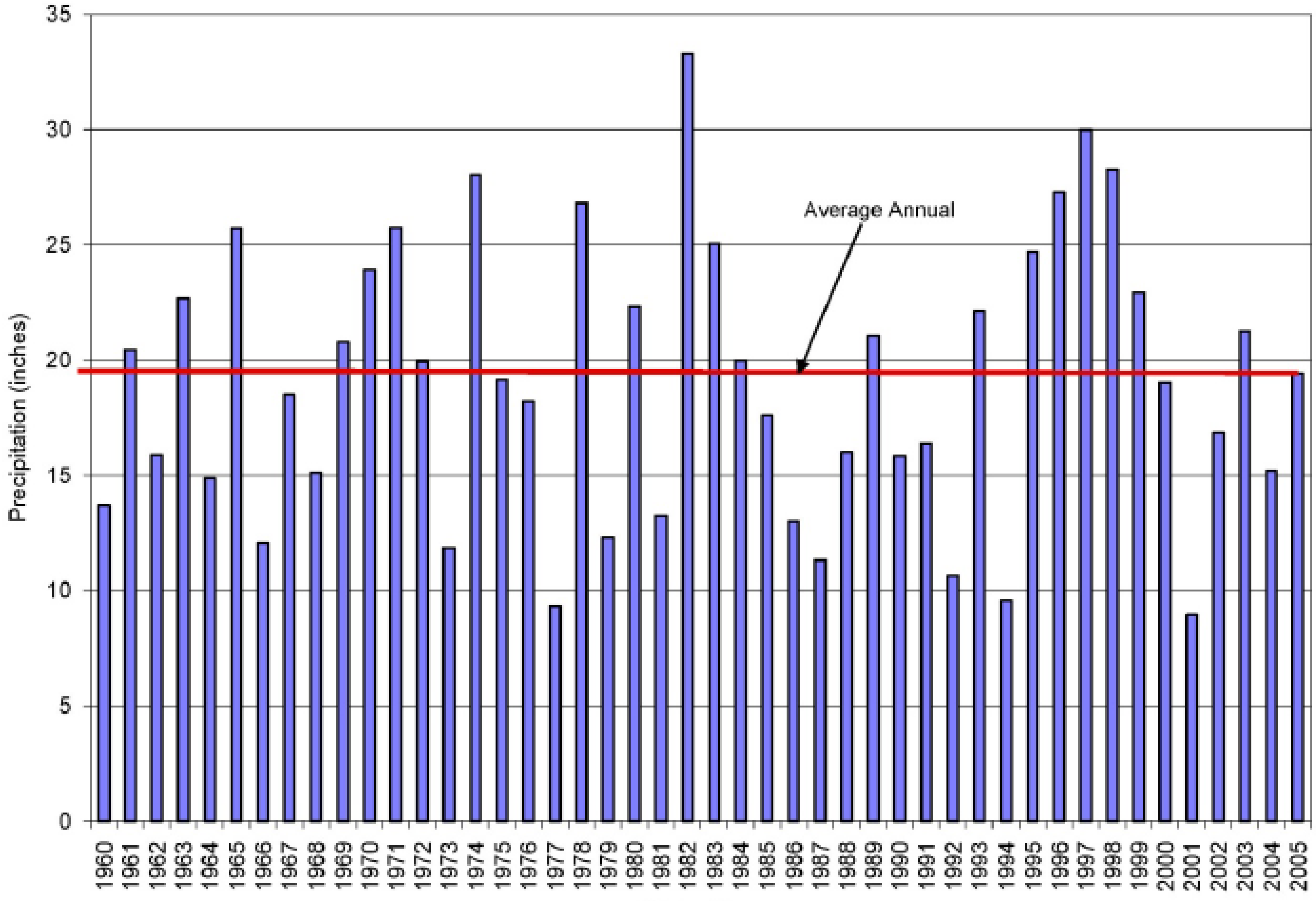
2.2.1.2 Climate

The Valley generally has a mixture of warm-summer Mediterranean and high desert environment climates with distinctive seasons of cooler, wetter winters and warm, dry summers. The orographic effect of the mountains to the west and south sides of the Valley creates a rain shadow in eastern areas of the Valley. The higher elevation areas to the west and south of the Valley historically receive greater annual precipitation (30–70 inches [in], or about 76–177 centimeters [cm]) in comparison to annual precipitation on the east side of the Valley (12–15 in) [see temporal isohyetal (precipitation contour) placeholder figure; PRISM ref?]. Annual mean precipitation ranges from a low of about 13 to 15 in (33–38 cm) at lower elevations to a high of about 67 in (170 cm) at Mount Shasta; see the summary statistics table for the (out of Watershed but close to the southern border) Mount Shasta rainfall gauge (station ID: 045983; SWRCB 2018). In the City of Yreka, annual precipitation averages range from 19 to 21 in (48–53 cm); see the attached plot of 1960–2005 Yreka annual precipitation (CDWR 2011) and the summary statistics table for the Yreka rainfall gauge (station ID: 049866; SWRCB 2018). Annual precipitation ranges from 25 to 29 in (64–74 cm) at higher elevations of the Klamath Mountains to the west, and up to 33 in (84 cm) near China Mountain. To the east, higher elevations of the Cascade Range receive from 19 to 27 in (48–69 cm) of precipitation annually. The rainy season, which generally begins in October and lasts through April, accounts for about 80 percent of total annual rainfall.



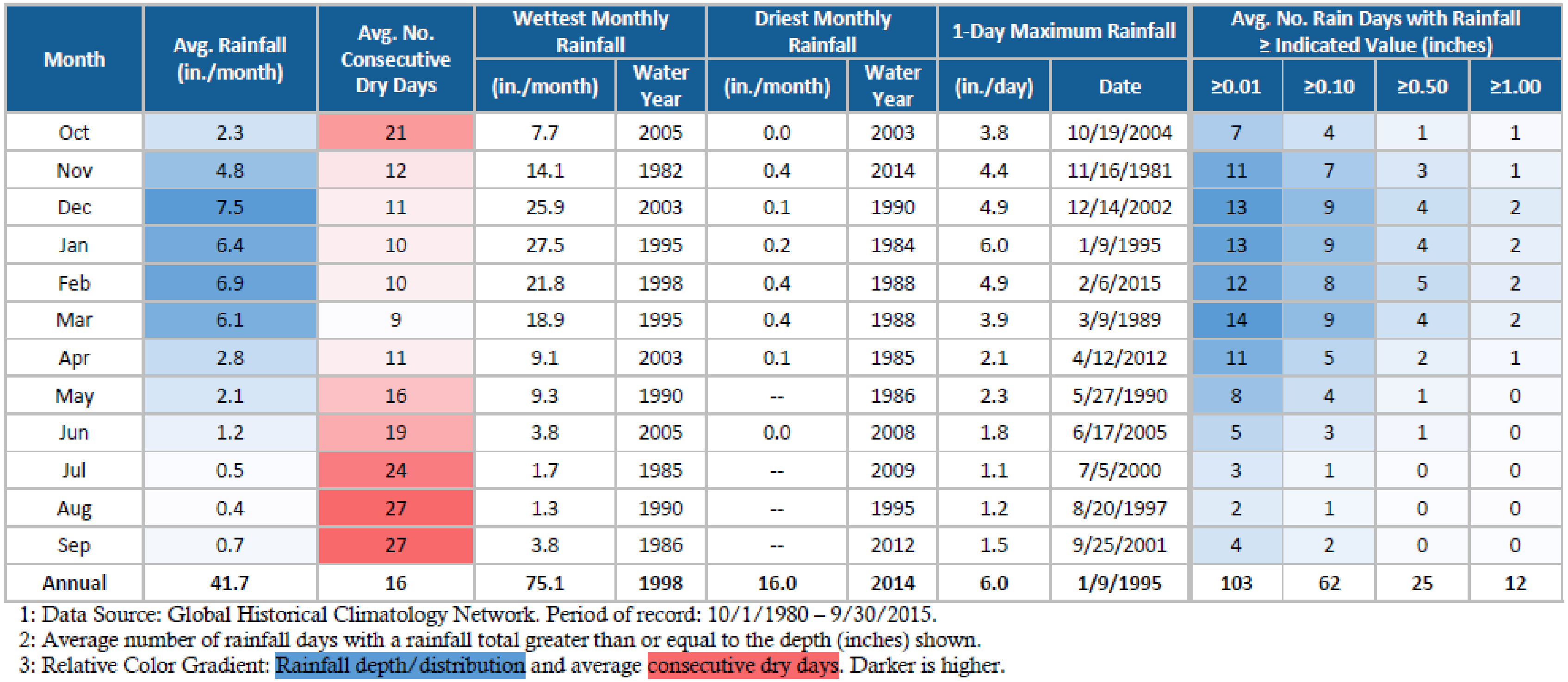
Source: Oregon Climate Service PRISM Project, Precipitation data from 1961 - 1990.

Figure 7: Central Siskiyou County area isohyetal (precipitation) contour map covering the greater Shasta River drainage basin area. Reprinted from CDWR (2011).



Source: Climatedata 2005

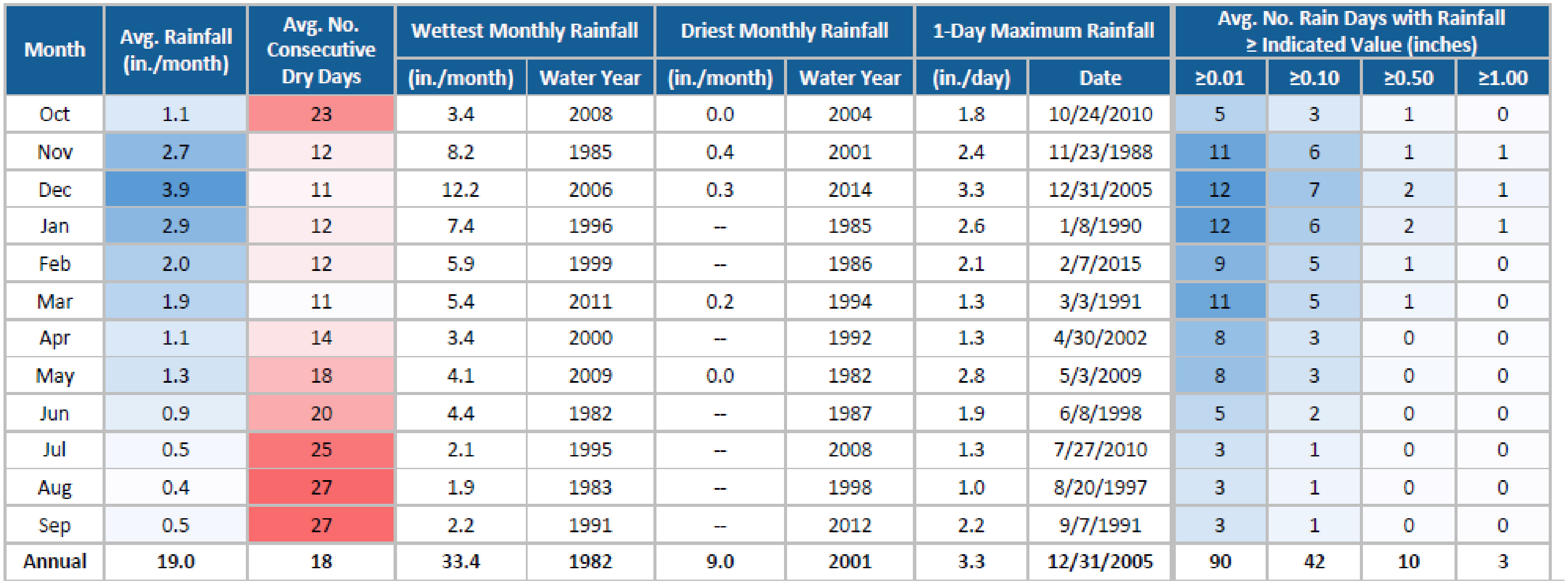
Figure 8: Yreka annual precipitation from 1983 - 2020, according to CDEC data. The long term mean (18 in) shown as a red dotted line, and the 10 year rolling mean is the blue trendline *[Update figure for late July 2021 draft]*.



Month	Avg. Rainfall (in./month)	Avg. No. Consecutive Dry Days	Wettest Monthly Rainfall		Driest Monthly Rainfall		1-Day Maximum Rainfall		Avg. No. Rain Days with Rainfall ≥ Indicated Value (inches)			
			(in./month)	Water Year	(in./month)	Water Year	(in./day)	Date	≥0.01	≥0.10	≥0.50	≥1.00
Oct	2.3	21	7.7	2005	0.0	2003	3.8	10/19/2004	7	4	1	1
Nov	4.8	12	14.1	1982	0.4	2014	4.4	11/16/1981	11	7	3	1
Dec	7.5	11	25.9	2003	0.1	1990	4.9	12/14/2002	13	9	4	2
Jan	6.4	10	27.5	1995	0.2	1984	6.0	1/9/1995	13	9	4	2
Feb	6.9	10	21.8	1998	0.4	1988	4.9	2/6/2015	12	8	5	2
Mar	6.1	9	18.9	1995	0.4	1988	3.9	3/9/1989	14	9	4	2
Apr	2.8	11	9.1	2003	0.1	1985	2.1	4/12/2012	11	5	2	1
May	2.1	16	9.3	1990	--	1986	2.3	5/27/1990	8	4	1	0
Jun	1.2	19	3.8	2005	0.0	2008	1.8	6/17/2005	5	3	1	0
Jul	0.5	24	1.7	1985	--	2009	1.1	7/5/2000	3	1	0	0
Aug	0.4	27	1.3	1990	--	1995	1.2	8/20/1997	2	1	0	0
Sep	0.7	27	3.8	1986	--	2012	1.5	9/25/2001	4	2	0	0
Annual	**41.7**	**16**	**75.1**	**1998**	**16.0**	**2014**	**6.0**	**1/9/1995**	**103**	**62**	**25**	**12**

1: Data Source: Global Historical Climatology Network. Period of record: 10/1/1980 – 9/30/2015.
2: Average number of rainfall days with a rainfall total greater than or equal to the depth (inches) shown.
3: Relative Color Gradient: Rainfall depth/distribution and average consecutive dry days. Darker is higher.

Figure 9: Mount Shasta rainfall gauge (045983) summary statistics. Note that the station is out of the Watershed but is close to the southern border. Reprinted from SWRCB (2018).



Month	Avg. Rainfall (in./month)	Avg. No. Consecutive Dry Days	Wettest Monthly Rainfall		Driest Monthly Rainfall		1-Day Maximum Rainfall		Avg. No. Rain Days with Rainfall ≥ Indicated Value (inches)			
			(in./month)	Water Year	(in./month)	Water Year	(in./day)	Date	≥0.01	≥0.10	≥0.50	≥1.00
Oct	1.1	23	3.4	2008	0.0	2004	1.8	10/24/2010	5	3	1	0
Nov	2.7	12	8.2	1985	0.4	2001	2.4	11/23/1988	11	6	1	1
Dec	3.9	11	12.2	2006	0.3	2014	3.3	12/31/2005	12	7	2	1
Jan	2.9	12	7.4	1996	--	1985	2.6	1/8/1990	12	6	2	1
Feb	2.0	12	5.9	1999	--	1986	2.1	2/7/2015	9	5	1	0
Mar	1.9	11	5.4	2011	0.2	1994	1.3	3/3/1991	11	5	1	0
Apr	1.1	14	3.4	2000	--	1992	1.3	4/30/2002	8	3	0	0
May	1.3	18	4.1	2009	0.0	1982	2.8	5/3/2009	8	3	0	0
Jun	0.9	20	4.4	1982	--	1987	1.9	6/8/1998	5	2	0	0
Jul	0.5	25	2.1	1995	--	2008	1.3	7/27/2010	3	1	0	0
Aug	0.4	27	1.9	1983	--	1998	1.0	8/20/1997	3	1	0	0
Sep	0.5	27	2.2	1991	--	2012	2.2	9/7/1991	3	1	0	0
Annual	**19.0**	**18**	**33.4**	**1982**	**9.0**	**2001**	**3.3**	**12/31/2005**	**90**	**42**	**10**	**3**

1: Data Source: Global Historical Climatology Network. Period of record: 10/1/1980 – 9/30/2015.
2: Average number of rainfall days with a rainfall total greater than or equal to the depth (inches) shown.
3: Relative Color Gradient: Rainfall depth/distribution and average consecutive dry days. Darker is higher.

Figure 10: Yreka rainfall gauge (049866) summary statistics. Reprinted from SWRCB (2018).

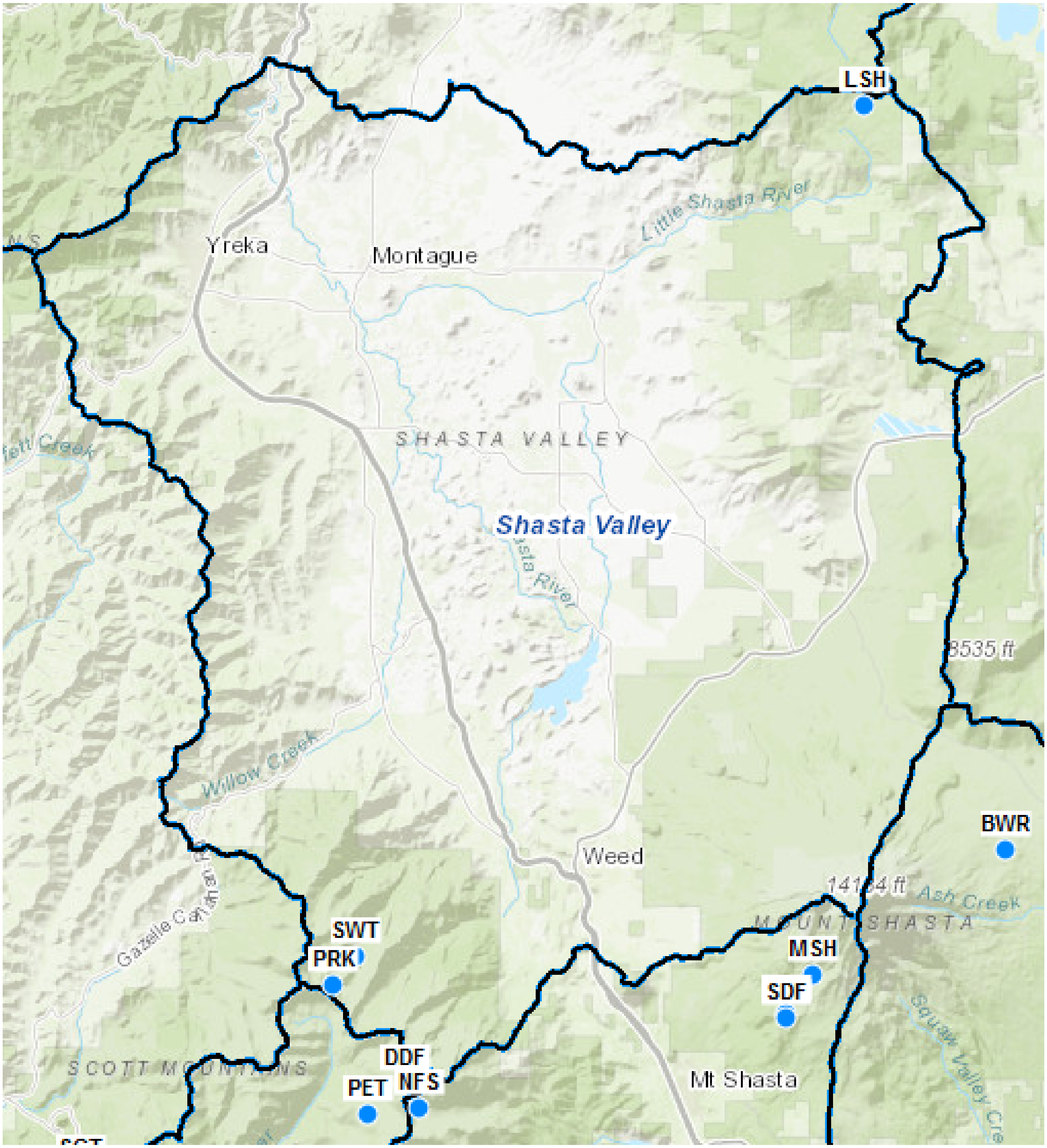


Figure 11: California Data Exchange Center snow stations for the Shasta River drainage basin (Watershed). Adapted from https://cdec.water.ca.gov/cdecstations.

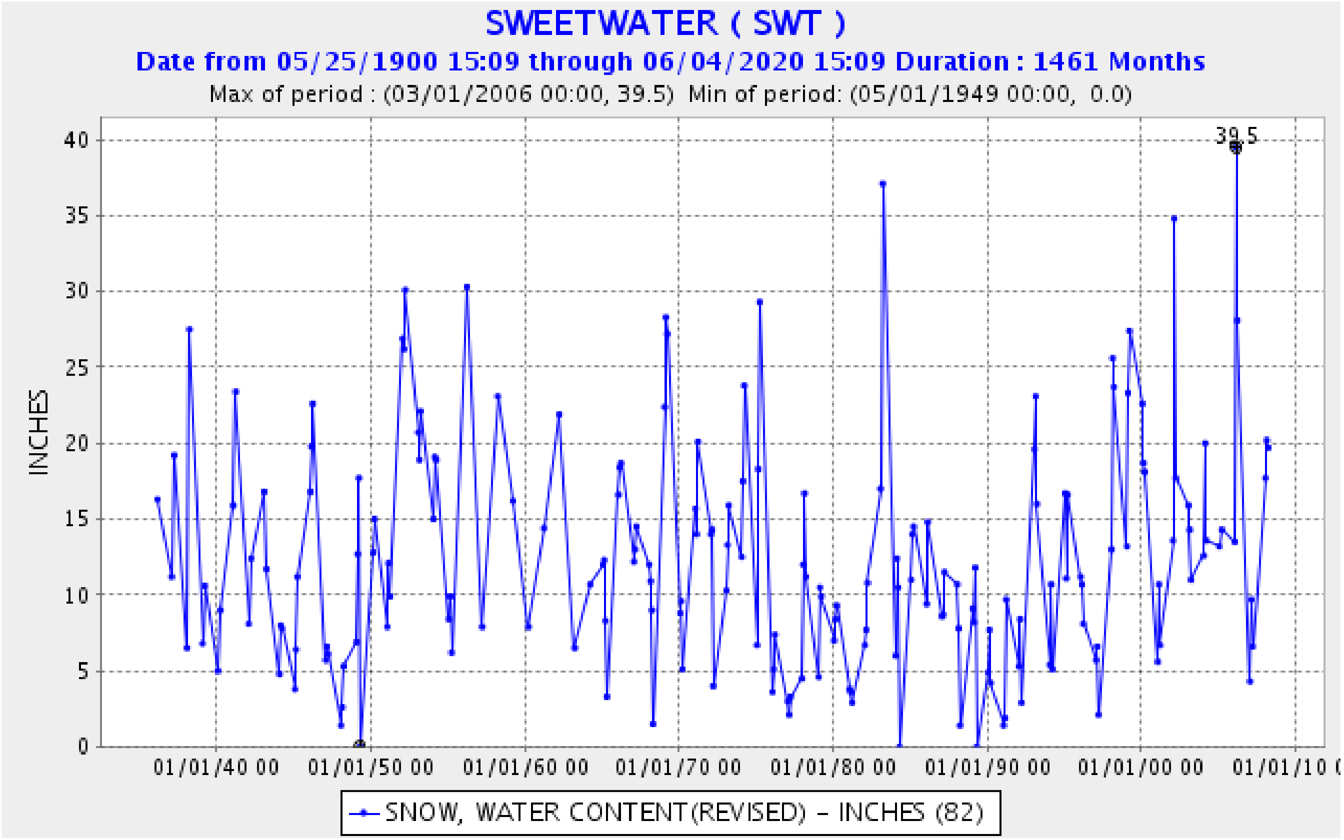


Figure 12: Snow water content record for Sweetwater station (SWT) from xxxx to xxx *[Figures will be updated in late July draft]*. Adapted from https://cdec.water.ca.gov/cdecstations.

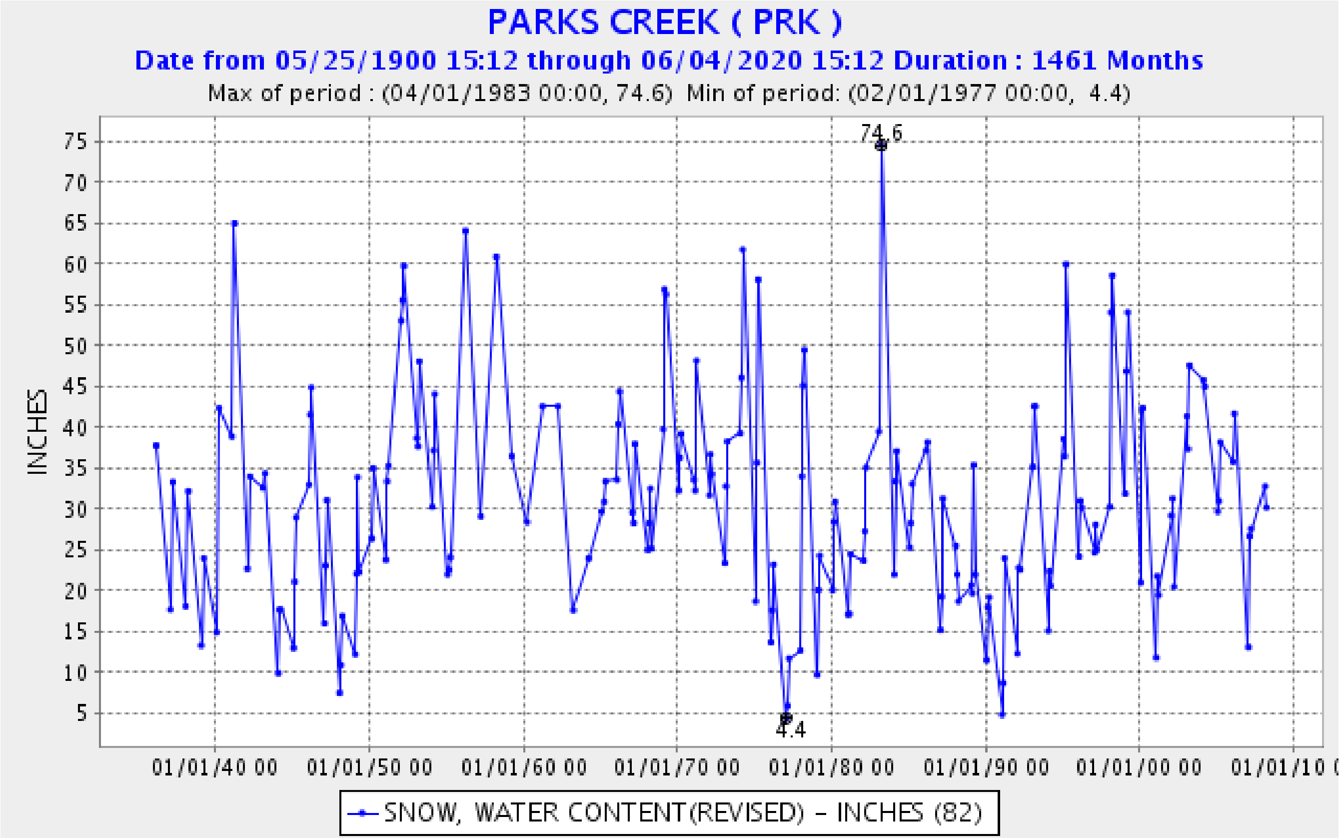


Figure 13: Snow water content record for Parks Creek station (PRK). Adapted from https://cdec.water.ca.gov/cdecstations.

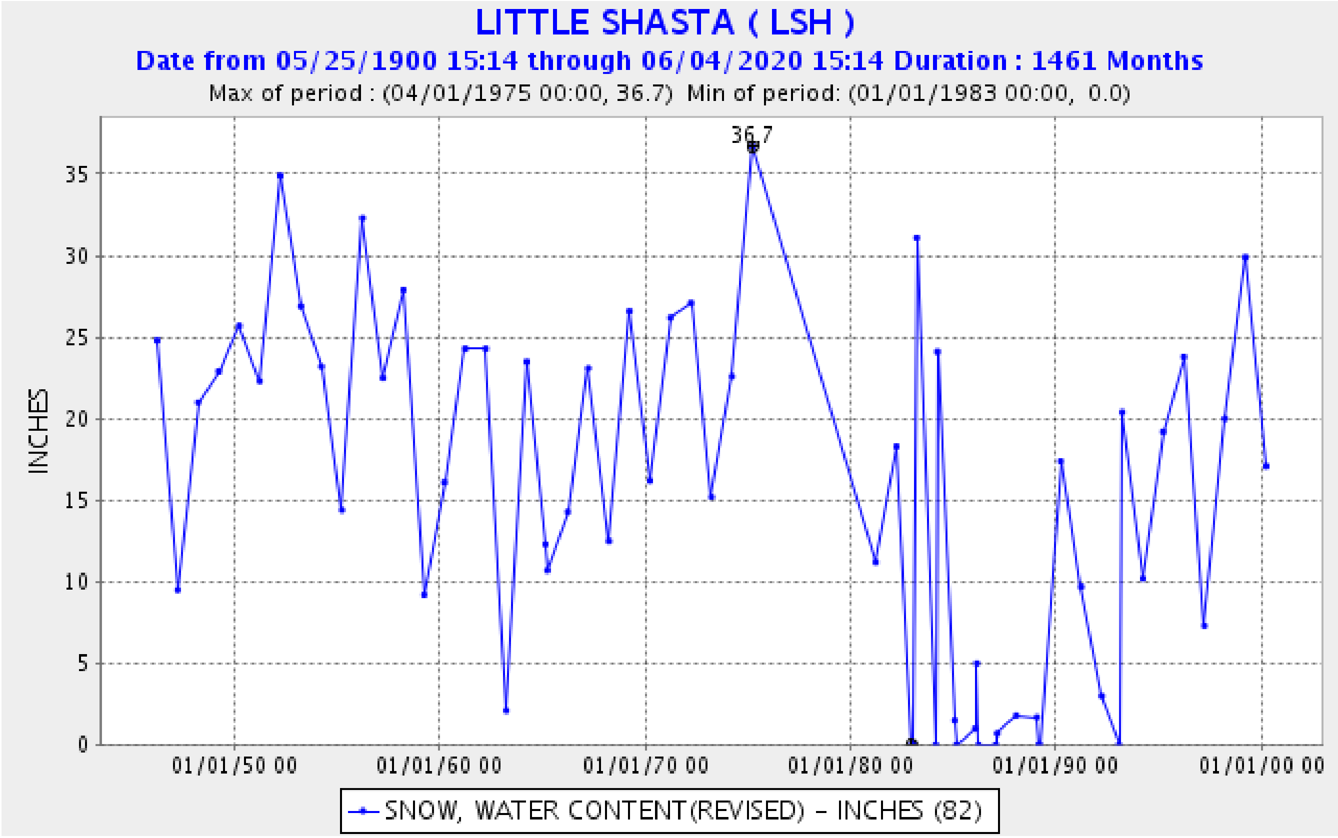


Figure 14: Snow water content record for Little Shasta station (LSH). Adapted from https://cdec.water.ca.gov/cdecstations.

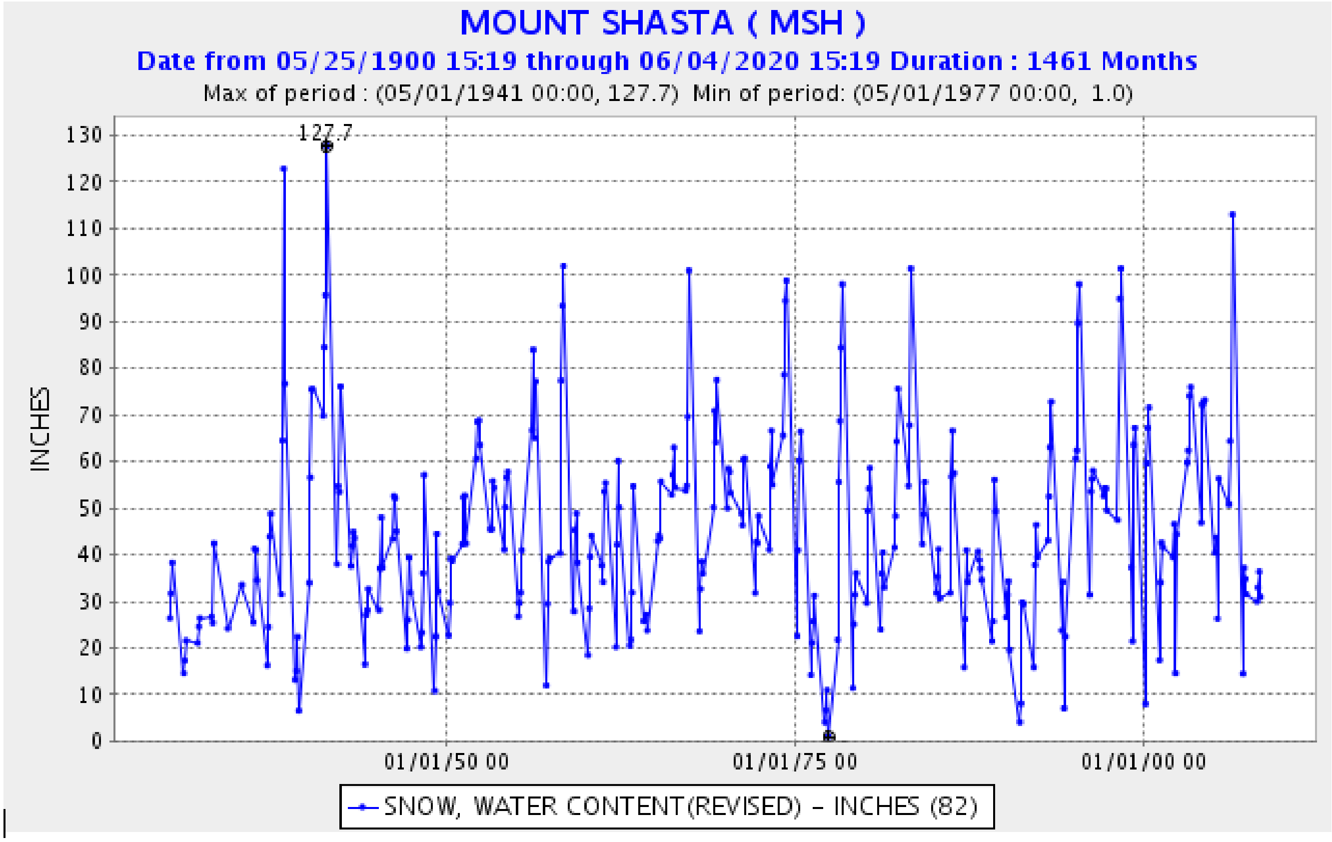


Figure 15: Snow water content for Mount Shasta station (MSH). Adapted from https://cdec.water.ca.gov/cdecstations.

Table 2: Station details and record length for NOAA weather stations Shasta River drainage basin.

Station ID	Station Name	Elevation (ft amsl)	Start Date	End Date	Record Length (years)	No. Missing Days
US1CASK0002	YREKA 4.5 S, CA US	2937	2008-10-07	2014-11-02	6.1	25
US1CASK0003	WEED 5.4 N, CA US	3064	1998-06-17	2020-04-17	21.8	152
US1CASK0005	YREKA 0.9 WNW, CA US	2692	2008-12-01	2020-04-18	11.4	59
US1CASK0007	MONTAGUE 1.6 ESE, CA US	2556	2010-12-01	2018-11-28	8.0	40
US1CASK0020	GRENADA 0.8 SW, CA US	2650	2018-02-23	2020-04-18	2.1	1
USC00043564	GRASS LAKE HIGHWAY MNTC, CA US	5092	1960-09-01	1967-11-30	7.2	26
USC00049498	WEED FIRE DEPARTMENT, CA US	3514	1943-05-01	1957-02-28	13.8	78
USC00049499	WEED FIRE DEPARTMENT, CA US	3589	1957-04-18	1989-07-31	32.3	35
USC00049866	YREKA, CA US	2709	1893-02-01	2020-04-18	127.2	1690
USR0000CBZE	BRAZIE RANCH CALIFORNIA, CA US	3000	1990-06-28	2020-04-18	29.8	10634
USR0000CWEE	WEED AIRPORT CALIFORNIA, CA US	2930	1990-05-02	2020-04-18	30.0	10799
USW00024214	MONTAGUE YREKA MUNICIPAL AIRPORT, CA US	2519	1948-01-01	1949-12-31	2.0	0
USW00024259	MONTAGUE SISKIYOU AIRPORT, CA US	2651	1948-07-01	2020-04-17	71.8	146

2.2.1.3 Geology

Plate tectonic, volcanic, and erosional (particularly fluvial- and landslide-related erosion) processes have formed and reformed the geomorphology of Watershed area and its different aquifer systems. The geologic and hydrologic characteristics of the Watershed are highly variable and are delineated by the boundaries of the regional geomorphic provinces. The Valley's western boundary, the Klamath Mountain terrane, is the result of subduction of the Pacific Plate beneath the North American Plate. The ocean sediments deposited on the Pacific Plate have been unloaded onto the North American Plate and have undergone episodes of burial, faulting, and folding yielding the rich assortment of many kinds of metamorphic rocks of igneous, sedimentary, and even prior metamorphic origins. The subduction of tectonic plates overlying the Pacific Ocean has also driven multiple events of more recent uplift, giving rise to more faults, fissures, and even eruptions of volcanic materials. Much of the Valley floor is covered with volcanic deposits originating from these eruptive episodes, along with more recent alluvial deposits resulting from the erosion of uplifted mountain ranges. These surficial deposits are underlain by marine deposits of the Hornbrook Formation, which were deposited in a shallow sea after the end of the addition of the Klamath Mountains terrane but before the Cascadian volcanic episode had begun. The volcanic rocks of the Cascade Range form the eastern and northeastern boundaries of the Valley. The collective deposits from these geologic events constitute most of the Valley's usable groundwater aquifers and, in particular, the geologically recent Pluto's Cave basalt and shallow, surficial alluvial fill deposits.

2.2.1.3.1 Geologic Units

A detailed description of the geology of the Watershed is provided below and overview maps of the previously most-recent surface geology (CDWR 2011; SVRCD 2017) and the current modeled surface geology can be viewed in the figures below (Figures 16 to 18). A more detailed description of geology is provided below and can be viewed in Figure (18).

A more detailed description of geology is provided below and whose units are referenced in Figure (18).

Klamath Mountains Province (Map unit: Basement group)

The Klamath Mountains Physiographic Province comprises rocks ranging in age from the early Paleozoic to late Mesozoic eras (Mack 1960). The Klamath Mountains trend north-south and consist of four east-dipping belts that are mainly separated by thrust faults (Fuis et al. 1987). Within the Watershed, the Klamath Mountains are composed of marine mafic and ultramafic volcanic rocks (such as basalt produced from underwater volcanism), marine sediments, and their metamorphic equivalents (Ward and Eaves 2008). Occurrence of the marine rock-bearing portion of the Klamath Mountains and its metamorphosed equivalents range from Yreka in the north to China Mountain in the south. Parent material of the marine deposits range in size from sand to silt and has undergone extensive metamorphism. Heat and pressure recrystallized individual quartz grains, cementing materials within the marine sandstone deposits forming primarily quartzite. Resulting quartzite deposits are highly resistant to weathering and provide poor conditions for the formation of soil. The first metamorphic product of clay-rich sedimentary rocks is slate with continued metamorphism leading to the formation of phyllite and eventually mica schist, which have slightly thicker sediment horizons than quartzite-dominant areas. Mafic and ultramafic materials of the Klamath Mountains represent parent materials basalt, gabbro, and peridotite that have largely undergone metamorphism forming abundant serpentinite in many locations. These areas also contain little sediment cover, but usually a little more than the quartzite-dominated areas. In the Shasta Valley Watershed geologic model, the various Klamath Mountain Province geologic units observed in the Watershed are lumped as a Basement group. A description of each of these units can be found in the Basement group description Table 3. The Basement group is found in all cross sections produced from the model except for one (*Cross Section H-H'*). While the Basement group is almost entirely positioned on the western side of the Watershed, the Yellow Butte fault zone activity has uplifted a portion (known as a horst) of the Basement group material (seen in *Cross Sections A-A' and E-E'*).

Table 3: Basement Group Unit Descriptions.

Unit ID	General Lithology	Age	Description
Mzd	Basement (group) - Plutonic Dioritic rocks	Jurassic	Mostly diorite, but locally includes gabbro and quartz diorite; also some granite
MzPz s	Basement (group) - Stuart Fork Formation	Mesozoic-Paleozoic	Micaceous quartzite and phyllite (representing bedded chert, shale, and sandstone) and actinolitic schist and phyllonite (representing metavolcanic rocks); contains blueschist-facies metamorphic minerals
MzPz ms	Basement (group) - metasedimentary rocks	Mesozoic-Paleozoic	Includes slate, feldspathic metagraywacke, metachert, quartzite, and chert-argillite breccia
MzPz mv	Basement (group) - metavolcanic rocks	Mesozoic-Paleozoic	Intermediate-composition to felsic, pillowed to massive, predominantly aphyric flows, tuff, and minor intrusive rocks
DSg	Basement (group) - Gazelle Formation	Devonian-Silurian	Shale, mudstone, siltstone, sandstone, limestone, bedded chert, and siliceous mudstone; poorly to well bedded
Smc	Basement (group) - Moffett Creek Formation	Silurian-Ordovician	Tan-weathering shale and mudstone, calcareous siltstone, sandstone, and minor bedded chert, siliceous mudstone, and limestone; mostly massive and disrupted; generally unfossiliferous, but chert contains Ordovician or Silurian radiolarians; common in fault contact with adjacent units, but locally is depositionally overlain by the Gazelle Formation
SOd	Basement (group) - Duzel Formation	Silurian and/or Ordovician	Phyllitic calcareous siltstone and calcareous sandstone
Pza	Basement (group) - Abrams Mica Schist	Devonian(?)-Ordovician(?)	Predominantly metasedimentary rocks, including quartz-mica schist, calc shist, micaceous marble, and minor intercalated amphibolite schist
Oam	Basement (group) - Antelope Mountian Quartzite	Silurian and/or Ordovician	Well-bedded quartz sandstone; locally thin and rhythmically bedded; includes chert beds and lenses adjacent to Duzel Formation
Op	Basement (group) - Trinity peridotite	Ordovician	Dominantly serpentinized tectonitic peridotite and minor dunite; ophiolite sequence

Hornbrook Formation (Map unit: Kh)

Exposed to the north and east of Montague, the Cretaceous-aged Hornbrook Formation was deposited at the end of the tectonic period that created the Klamath Mountains but ended before the volcanic activity that created the Cascade Range. It sporadically outcrops for roughly 50 mi (~80 km) from the Medford Valley in southwestern Oregon to the Valley (Nilsen 1993). Many of the exposures within the Valley lie to the north and east of Montague in the Little Shasta River drainage basin. Rocks comprising the Hornbrook Formation consist of interlayered beds of shallow marine sandstone and deep marine mudstone as well as siltstone, shale, conglomerate, and fossils (Nilsen 1993). The marine rocks of the Hornbrook Formation underlie much of the geologically younger alluvium and volcanic deposits on the Valley floor east of the Klamath Mountain province. This is observed in all of the geologic cross sections of the Shasta Valley Watershed geologic model.

Cascade Range Province (Map units: Pv, Qv, Qvs, & Tv)

The Cascade Range in the Valley consists of two main volcanic rock types: the Western and High Cascade volcanic rock series. The Western Cascade volcanic series were deposited during a period from about the Eocene to the Oligocene, but possibly even into the Miocene (Mack 1960). These are the older volcanic rocks of the east side of the Valley and have been overlain by younger volcanic deposits of the High Cascades, which are Pleistocene to Holocene in age. Over long periods of geologic time after deposition, the Western Cascade units were faulted and tilted to the northeast before being buried by the High Cascade volcanic deposits (Fuis et al. 1987). Pluto's Cave basalt, which is a highly permeable volcanic deposit found in the Valley (Buck 2013), is a subunit of the High Cascade lava flows (Wagner and Saucedo 1987). Volcanic rock in the Valley is mainly differentiated by the debris avalanche in the central part of the Valley and Pluto's Cave basalt on the eastern side (CDWR 2006). The volcanic rocks range in thickness from as little as 20 ft in the northern part of the Valley to over 400 ft in the southern Valley (CDWR 2006). The most prominent feature of the Cascade Range Province in the Valley is Mount Shasta, a large stratovolcano reaching over 14,000 ft (~4,200 m) amsl that largely forms the southern terminus of the Cascade Range in the Valley. Mount Shasta is composed of at least four main volcanic cones formed in the last 250,000 years with the most recent eruptive activity taking place only 200 years ago (Blodgett 1985).

Western Cascades Volcanic Rock Series (Map unit: Tv)

Rocks of the Western Cascades volcanic series form a major portion of the Cascade Mountains and are an assemblage of differing volcanic rock and sediment types of Eocene to Oligocene (possibly Miocene) age including not only lava flows but also dense beds of hardened tuff, airborne pyroclastics, massive volcanic mudflow deposits, and highly variable breccias (CDWR 2011). The Western Cascades are a significant component of the hillslopes of the northeastern portion of the basin. Rocks of this series underlie some of the western portions of the Valley and most of the eastern portion and constitutes the main bedrock material along the eastern margins (Mack 1960). The age of Western Cascade volcanic deposits has provided sufficient time for extensive weathering, fracturing, and subsequent infilling prior to and during the deposition of the High Cascades volcanic rock series. The Western Cascade volcanic deposits are present, to varying levels of abundance, in every geologic cross section.

High Cascades Volcanic Rock Series (Map units: Pv, Qv, & Qvs)

The High Cascades volcanic rock series are Pliocene- to Holocene-aged volcanic rocks that overlie the older rocks of the Western Cascades at the eastern margin of the Valley as well as to the south as the volcanic activity of Mount Shasta is slightly west of the rest of the Cascade Range in the Valley. The High Cascade volcanic rocks consist of highly fractured lava rock deposits and ash deposits originating from a number of geologically young volcanic peaks (e.g., Miller Mountain, Goosenest Mountain, Willow Creek Mountain, Ball Mountain, Deer Mountain, The Whaleback, and Mount Shasta). The volcanic rocks of this series mainly consist of andesite or basalt and compose the uplands, volcanoes, and cones forming the southern and eastern portions of the Watershed (Mack 1960, Hotz 1977, Wagner and Saucedo 1987). The High Cascade volcanic deposits include more recent effuse basaltic flows (e.g., Pluto's Cave basalt) that cover much of the eastern side of the Valley and the expansive, fine-grained pyroclastic (andesitic and volcaniclastic) sediment deposits. These pyroclastic deposits result from a Late-Pleistocene debris avalanche originating from the northwest flank of a previous version of Mount Shasta (i.e. Ancestral Mount Shasta), creating the unique morphological assortment of conical hillocks, ridges, and depressions that are ubiquitous across the central portion of the Valley floor (Crandell et al. 1984, Crandell 1989).

Pleistocene Debris Avalanche (Map units: Qvs)

A catastrophic, volcanic debris avalanche deposited materials across approximately 260 sq mi (~680 sq km) of the Valley floor, covering an area from just northeast of the peak of modern Mount Shasta to the Shasta River Canyon north of Yreka. The debris flow formed the dominant geology and topography of the central portion of the Valley, which consists of hundreds of hummocks, ridges, hills, and flat surfaces. Ancestral Mount Shasta was the origin of the debris avalanche which occurred during the Pleistocene epoch roughly 300,000 to 380,000 years ago (Crandell 1989). The debris avalanche incorporated existing deposits of alluvium, lahars, and pyroclastic flows as it progressed northward scouring the preexisting landscape. The deposits are made up of two primary components: a block facies and a matrix facies. As the name implies, the block facies consists of blocks of volcanic rock that, in many areas, have retained some internal structure from their original deposition. The hummocks, ridges and hills in the region typify the block facies from the debris flow comprising individual andesite blocks (ranging in size from tens to hundreds of feet in maximum dimension) and intact stratigraphic sequences of volcaniclastic materials transported in the same relative positions as the original deposition (Crandell et al. 1984, Crandell 1989). The matrix facies is made up of a fine, sandy ash-rich material with a mudflow, lahar-like character in which the blocks are embedded. Similar in nature to a mudflow, the matrix facies contain an unstratified and poorly sorted mixture of pebbles, cobbles, boulders, and consolidated silty sand (Crandell 1989).

The deposit from the volcanic debris avalanche ranges in thickness from about 650 to 1,000 ft (200-300 m; see *Cross Sections E-E', H-H', and North-South*) on the lower slopes of Mount Shasta to about 20 ft along the Shasta River near Montague (CDWR 2011). Crandell (1989) notes that the size fraction (relative percentages of differently sized materials such as sand and rock) and types of material within the avalanche deposits changes from south to north. Near Mount Shasta in the south, nearly 100 percent of the deposits consist of volcanic material. In the north near Montague, only about 25 percent of the deposits are volcanic. As the avalanche moved north during its deposition, it scoured the ground surface and incorporated pre-existing rocks into the flows matrix. Embedded within the deposit are clasts of Klamath metamorphic rocks, sandstones of the Hornbrook Formation, and lacustrine clays. The wide range of rock types comprising the debris avalanche deposits attest to the varied nature of the pre-existing landscape. Because of its chaotic mode of deposition, there is no coherent internal structure to the deposits and as a result, well yields from avalanche deposits are highly variable.

Pluto's Cave Basalt (Map unit: Qv (subset))

Pluto's Cave basalt is a particular portion of interest in the High Cascade volcanic rock series and whose deposition dates to either the Pleistocene epoch somewhere in the range of 190,000 to 160,000 years ago or possibly the Holocene, which would be less than 10,000 years ago (Mack 1960; CDWR 2011). This basalt flow covers more than 50 sq mi (~130 sq km) of the eastern portion of the Valley (Williams, 1949) and overlies the older Western Cascade volcanic series rocks. The formation is a composite of several dark, porous basalt flows (CDWR 2004). Individual flow units are considered to be approximately 10 to 30 ft (3-9 m) thick, while the thickness of the entire basalt flow ranges from about 400 (or more) ft (120+ m) near the flanks of Mount Shasta to 50 ft (15 m) or less at its northern edge near the Little Shasta River (Williams 1949). Mack (1960) reports that Pluto's Cave Basalt appeared to have developed from fissures close to the northeastern base of Mount Shasta. According to CDWR (2011), Deer Mountain and Whaleback Mountain are the source of Pluto's Cave basalt flows. The formation is a composite of several flows each composed of black, vesicular olivine-rich augite basalt (CDWR 2004). Pluto's Cave basalt can primarily be seen in the cross-sectional intersection of the *Cross Sections A-A' and H-H'* from the Shasta Valley Watershed geologic model.

Quaternary Alluvium (Map units: Q & Qg)

Alluvial deposits, including the stream and terrace deposits originating mainly from fluvial processes associated with Parks Creek, Willow Creek, Julien Creek, Yreka Creek, Whitney Creek, the Little Shasta River, and the Shasta River, as well as the alluvial fan deposits of the Klamath Mountains, comprise the remainder of the surficial deposits within the Valley. Stream deposits are generally confined to active stream channels, and terrace deposits follow these channels. Alluvial fans are found along the western and northern perimeters of the Valley and form the sedimentary aprons at the base of the mountains. These coarse fan deposits transition into finer floodplain deposits on the Valley floor. Significant accumulations of alluvium are present along the Highway A12 corridor south of Big Springs, in the Gazelle-Grenada area and the Little Shasta Valley. Alluvial deposits range from coarse grained sand in higher-gradient locations to silt and clay in low-gradient locations. In addition to the most recent alluvium (Q), glacial alluvium (Qg) from the most recent glacial moraine advance of glaciers originating from the slopes of Mount Shasta are present at the base of Mount Shasta. The unconsolidated glacial deposits (both fluvioglacial and morainal) range from clay- to boulder-sized materials and are poorly sorted. The glacial alluvium (Qg) is mainly present in *Cross Sections E-E' and H-H'*. The most recent alluvium (Q) is mainly present in *Cross Sections A-A', E-E', West-East, and North-South*.

Geologic Basin Structures, Surface Processes, and Geomorphology

Much of the geological complexity resulting from the long and dynamic geologic history of the Watershed has resulted in the formation of hydrologically controlling structures (subsurface and surface) across the Watershed. These controlling structures have led to the formation of the Valley's numerous springs and streams. Additionally, the geologic legacy of the Watershed has had a direct impact on where precipitation occurs as mostly rain or snow for much of the year.

Surface Processes and Channel Geomorphology

Tributaries draining the western and southwestern Basin flow off the eastern slopes of the Klamath Mountains and are underlain by the Paleozoic Eastern Klamath Belt terrane (Hotz 1977, Wagner and Saucedo 1987). Tributaries in the southeastern and eastern Basin drain the western slope of the Cascade Range, which are underlain by the Cenozoic Western Cascade and High Cascade Volcanic subprovinces (Hotz 1977, Wagner and Saucedo 1987). The Shasta River flows through the Valley before entering Shasta River Canyon, eventually joining the Klamath River. The Valley is primarily underlain by various volcanic and volcaniclastic units of the High Cascades subprovince and deposits of Quaternary alluvium in the Montague vicinity. The canyon reach of the Shasta River is incised into the Western Paleozoic and Triassic (Mesozoic) Belt terrane of the Klamath province (Hotz 1977, Wagner and Saucedo 1987).

The Shasta River exhibits distinct longitudinal variability in channel morphology primarily controlled by the underlying geologic regime. Stream channels in headwater areas of the Eastern Klamath Belt terrane are steep and cobble dominated. Upon crossing the lithologic contact with the High Cascade subprovince, the drainage network transitions to predominantly gravel-bedded channels with moderate gradient. Meandering single-thread channel morphology in these reaches is interspersed with short multi-thread channel morphology containing active lateral, mid-channel, and point bars (Nichols 2008). The presence of active gravel bars and trapezoidal channel cross-sectional morphology indicate a hydrologic regime dominated by precipitation (via both rain and snow) driven runoff (Nichols et al. 2010). Analysis of aerial photos and historical maps indicate channel morphology in these reaches has changed little since 1923 (Nichols 2008). Channel gradient steadily decreases downstream of Dwinnell Dam as Shasta River flows across the Late-Pleistocene debris avalanche described above (Crandell et al. 1984, Crandell 1989). These reaches have gravel- and sand-bedded, single-thread and meandering channel morphology without exposed point bars. Following closure of Dwinnell Dam in 1928, Shasta River between Dwinnell Dam (river mi 40.6/river km 65.3) and the confluence of Big Springs Creek (river mi 33.5/river km 53.9) transitioned from a gravel-bedded meandering stream with exposed point bars to its present-day form without exposed point bars (Nichols 2008). Downstream of the Big Springs Creek confluence, Shasta River takes on a more rectangular channel morphology with greater width-to-depth ratio that has changed little since 1923. A lack of change reflects less dynamic fluvial processes and a muted hydrologic response dominated by stable year-round baseflows controlled by groundwater inputs (Nichols 2008, Nichols et al. 2010). The Shasta River meanders at a near-constant low gradient throughout the central and northern portions of the Valley before steeply descending through the bedrock canyon near Yreka to the Klamath River.

The Eastern Klamath Belt is the eastern-most terrane in the Klamath Mountains geomorphic province, which is interpreted as a structural sequence of east dipping thrust sheets, decreasing in age from east to west, formed by accretion of oceanic and island-arc assemblages (Irwin 1981, Saleeby et al. 1982). Paleozoic rocks of the Eastern Klamath Belt terrane in the Watershed consist of partially-serpentinized peridotite, gabbro, diorite, and marine meta-sedimentary units including sandstone, shale, phyllite, chert, conglomerate, and limestone (Mack 1960, Hotz 1977, Wagner and Saucedo 1987). These lithologic units compose the east face of the Scott Mountains and are dissected by a dendritic drainage pattern of Shasta River tributaries including Dale Creek, Eddy Creek, Parks Creek, Willow Creek, Julien Creek, and Yreka Creek. These stream channels flow roughly perpendicular to the northerly strike of the Eastern Klamath Belt. Hillslope mass wasting and valley bottom fluvial erosion are the dominant geomorphic processes in these tributary basins. Runoff response time is short during rainfall and snowmelt events in these areas of the Klamath Mountain terraces due to steep topography, high relief, shallow and well-drained soils, and less permeable bedrock (McNab and Avers 1994).

Geologic Structure Controlling Hydrology

The Watershed contains a mélange of various, unique, geologic situational components that either directly or indirectly control the hydrologic setting of the Watershed. The surface geology found in the China Mountain area of the Klamath Mountain Range, for example, initiates the headwaters of the Shasta River, Parks Creek, and the South Fork of Willow Creek due to the relatively impermeable surface materials (e.g., serpentinite) and steeper slopes that comprise these mountains. The concentrated overland flow routing depends on the surface restricting water infiltration into the subsurface and channelizing to form the headwaters of these important creeks and rivers (CDWR 2011). However, while the majority of the igneous and metamorphic rock initially is almost entirely impermeable, the subsequent tectonic processes produced secondary porosity through jointing and faulting of the rocks, allowing some limited and highly localized water storage and transmission. This high level of variability in the relative spacing, size, and degree of interconnection of these secondary openings adds to the overall complexity in characterizing the hydrology of the Watershed as the western mountain region cannot truly be considered completely impermeable or as a distinct aquifer material.

On the east side of the Valley there is a thin region of block faulting, the Yellow Butte Fault Zone, which is where a vertical sliver of geologic units (i.e. a horst block) bounded by faults on either side have effectively moved the entire section out of alignment with the same geologic units on each side of the parallel faults (see *Figure: Shasta Valley Watershed geologic model overview and cross section map*). This is the only geologically recent faulting residing within the Basin boundary. This region of block faulting may be a factor in impeding groundwater flow recharged on the east side of the Valley that would likely flow into the Pluto’s Cave basalt aquifer area of the Basin; however, it is unclear at this time whether this feature acts as a barrier to groundwater or not. The block faulting along the Yellow Butte Fault Zone has produced exposures of the Late Cretaceous marine-deposited Hornbrook Formation and the Mesozoic rocks (primarily monzonite) of Yellow Butte and can been seen in a few of the geologic cross sections (seen in *Cross Sections A-A’ and E-E’*) of the Watershed. From previous efforts to characterize this feature (Mack 1960; Holliday 1983) and recent geologic modeling undertaken for this Plan (Appendix A-D) shows that a few thousand feet of displacement (~2,000-4,000 ft; 600-1,200 m) has likely taken place as the aforementioned rocks within the fault block underlie much of the Valley as deep-lying basement rock.

The variability of groundwater chemistry across the Watershed is likely heavily dependent on the varying rock types where groundwater is stored, as well as flows through; generally, the longer groundwater is stored in an aquifer material, the more its chemistry mirrors the host rock or sediment chemistry. Faults in the Watershed, not only the Yellow Butte Fault Zone but also the ancient faults of the Klamath Mountains, might also contribute in part to the variability in groundwater chemistry by acting as conduits for increased groundwater flow, allowing for water chemistry contributions from greater distance than in-place mixing. This fault mechanism, or even the high variability in surface geologic units that may differ wildly in hydrologic properties, might explain water chemistry observed in specific wells appearing different from other wells located nearby.

Hydrogeologic Units of Shasta River Valley Watershed and Groundwater Basin

The Watershed's long and complex geologic history has resulted in a very heterogeneous hydrogeologic setting, which is illustrated by the juxtaposition of a variety of water-bearing geologic units across the Watershed. The Basin is a geologic mix of alluvial valley deposits, fractured metamorphic with thin sediment veneers, volcanic rock and sediment debris flows, and lava flow deposits of varying geologic ages. Much of the surficial deposits that form the primary aquifers of the Basin are relatively young (less than 400,000 years old). These deposits include the volcanic debris avalanche (most likely deposited a little less than 400,000 years ago), lava flows of the High Cascades, such as Pluto's Cave basalt (some of which are possibly less than 10,000 years old), and various alluvial deposits, many of which date to less than 10,000 years in age. While not primary aquifers, the remaining geologic units do bear some amounts of water; however, they do not store or transmit enough water to define as usable primary aquifers, but still have localized use for domestic and small stock water applications. While grouping the water-bearing units of the Basin might be somewhat of an arbitrary exercise, this GSP's approach is to describe all the water-bearing units in the Watershed relevant to the Basin, but designate the primary aquifers based on public usage statistics, hydrogeologic properties, and water storage and conveyance ability. The hydrogeologic aquifer units as described in detail in the following text and *table* below are (1) Klamath Mountains Province; (2) Hornbrook Formation; (3) Cascade Range Province, divided into the (3.1) Western Cascades and (3.2) High Cascades, which is further divided into the (3.2.1) Debris Avalanche Deposits and the (3.2.2) Pluto's Cave basalt[1]; and (4) Quaternary Alluvium[1].

Klamath Mountains Province (Map unit: Basement (group))

The Paleozoic-aged Klamath Mountain Province composes the western boundary of the Watershed. The province consists of marine sediments and intrusive rocks that experienced varying degrees of structural deformation and metamorphism during major tectonic episodes in the early Paleozoic through the late Cenozoic, resulting in the Klamath Mountains of today. Extensive mineral recrystallization resulting from the process of metamorphism has reduced the primary porosity in these units to confining conditions. Structural deformation from tectonic activity after the metamorphic rock formed resulted in secondary porosity through the formation of fractures, joints, faults, and shear zones. These units are not an important groundwater source due to limited holding capacity and conveyance (CDWR 2011). However, many wells are still constructed in the Paleozoic rocks of the Klamath Mountains, where well yields range from one (1) to 12 gallons per minute (gpm) (~0.06-0.75 liters per second [lps]). In this Plan's approach, all Klamath geologic units are grouped as one metamorphic formational group as an (effectively) impermeable formation comprising both the western boundary and underlying bedrock for much of the model area.

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[1] Primary aquifers of Shasta Valley Groundwater Basin

Hornbrook Formation (Map unit: Kh)

The Hornbrook Formation underlies most of the surface deposits throughout the Valley. The Hornbrook Formation is a thick sequence of Cretaceous-aged marine sedimentary rocks, with total thickness up to several thousand feet (Mack 1960). The increased amount of consolidation and cementation of the formation results in minimal quantities of groundwater storage and low well yields. It is typically only sufficient for domestic and stock uses only. The order of magnitude of typical well yields for wells completed in the Hornbrook Formation is roughly one (1) to 10 gpm (~0.06-0.63 lps) but this not a robust statistic (CDWR 2011). It is also likely that much of the formation may also act as a largely impermeable bed for the surficial aquifer system in the Valley. This can be seen in all of the geologic cross sections as the Hornbrook Formation effectively operates as the hydrostratigraphic basement deposit for much of the Valley aquifer units.

Cascade Range Province (Map units: Pv, Qv, Qvs, & Tv)

A significant body of work has explored the Cascade Range hydrogeology, mainly focused in Oregon (James and Manga 2000; Jefferson et al. 2006; Nathenson et al. 2003; Saar and Manga 1999; Tague et al. 2007; Tague and Grant 2004). The Cascade Range is characterized by varying types of volcanic deposits. Volcanic deposits can be highly porous and fractured and potentially store and transmit large volumes of groundwater. However, these deposits can also be quite impermeable, or transmit large volumes of water but store relatively little water volume and vice versa. Numerous groundwater springs are present in these young, permeable volcanic units and contribute significant flow to Shasta River and tributary creeks. Abundant and high discharge groundwater springs demonstrate a well-developed subsurface drainage network that exists in the southern and central extents of the Valley (Mack 1960; Jeffres et al. 2008; Nichols 2008; Nichols et al. 2010). This section characterizes the Western and High Cascades as two distinct hydrogeologic aquifer systems within the Watershed.

The Western Cascades are Eocene to Oligocene (possibly as late as Miocene) in age and tend to have lower permeability than the geologically younger (Pleistocene to Holocene in age) basalt flows of the High Cascades characterized by spring-fed rivers and aquifer systems with high transmissivities and large portions of precipitation recharging groundwater systems (Jefferson et al. 2006; Mack 1960). The Western Cascades tend to have shallow subsurface flow paths along steep gradients with high horizontal conductivities, while the High Cascades environment reflects a deeper groundwater system (Tague and Grant 2004). Basin geology and geomorphology play a dominant role on flow patterns related to peak timing and magnitude of stream flow (Tague et al. 2007). The timing and shape of stream flow hydrographs and summer monthly stream flow volumes are related to the percentage of High Cascade geology in the contributing area (Tague and Grant 2004). Jefferson and others (2006) published findings that indicate recharge areas in the Cascades can extend beyond modern topographic boundaries. Well logs from the Cascades Range area in Oregon show that wells drilled in Quaternary lavas recorded static water levels higher than the elevation where water was first encountered during drilling suggests the High Cascades aquifer system behaves as a confined aquifer, at least in some areas (Jefferson et al. 2006).

The younger High Cascade volcanics, which overlay the Western Cascade volcanics, are highly vesicular and fractured rocks that can store and transmit large volumes of groundwater. Many springs discharge from the contact between the Western and High Cascade subprovinces due to the discontinuity in permeability (CDWR 2011). The High Cascades volcanics include the

Holocene-age Pluto's Cave basalt aquifer, a highly vesicular and fractured unit that critically influences groundwater storage and recharge in the Valley, contributing large volumes of water to wells and springs (CDWR 2011). Wells in the Pluto's Cave basalt yield up to 4,000 gpm (~250 lps), with an average of 1,300 gpm (~80 lps; Mack 1960; PGS 2001; CDWR 2011). The unit is composed of multiple individual flows providing permeable contact surfaces, and lava tubes (including Pluto's Cave) that facilitate groundwater flow. Recharge to the aquifer occurs from direct precipitation on the ground surface, streamflows that become subsurface upon reaching the unit (e.g., Whitney Creek), irrigation ditch loss, percolation from applied irrigation water (mainly through flood irrigation), and groundwater flow from snowmelt in the Cascade peaks to the south and east (Mack 1960, CDWR 2011).

Western Cascades Volcanic Rock Series (Map unit: Tv)

The diverse Western Cascade volcanics can be highly fractured and weathered, although they tend to have reduced porosity and permeability due to secondary infilling of fine-grained sediments. These units have shallow subsurface flow paths yielding springs and seeps on basin hillslopes – an indication of impermeable horizons that impede vertical groundwater flow through the aquifer (CDWR 2011). Potentially due to the lower permeability of the underlying older Western Cascade rocks, many springs and seeps appear at the contact between the Western Cascade and High Cascade volcanic series, reflecting a contact where more permeable rock abuts much less permeable rock (i.e. Western Cascade series). Considerable portions of the Western Cascades are deeply fractured and weathered, containing a great deal of secondary infilling of clays and fine silt and sands. Springs and seeps observed along steep slopes indicate the locations of impermeable horizons that restrict vertical movement of groundwater. Well yields are likely between five (5) and 400 gpm (~0.3-25 lps) based on limited data analyses (Mack 1960; CDWR 2011).

High Cascades Volcanic Rock Series (Map units: Pv, Qv, & Qvs)

High Cascade volcanics overlie older materials of the Western Cascade volcanics and are predominantly composed of highly fractured andesitic and basaltic lava flows. These highly permeable materials likely originated from peaks along the eastern edge of the Valley, including: Goosenest Mountain, Deer Mountain, Whaleback Mountain, and Mount Shasta (CDWR 2004). The highly permeable effuse basalt flows of the High Cascade subprovince allow rainfall and snowmelt to quickly infiltrate the porous groundwater aquifer, resulting in a poorly-developed, surficial drainage pattern (Mack 1960; Tague and Grant 2004). The High Cascade volcanics act as an important groundwater reservoir and source of springs in the Valley (Mack 1960). Geophysical estimates of aquifer depths range from hundreds to possibly thousands of feet deep (hundreds of meters; Fuis et al. 1987; Stanley et al. 1990).

The interface between individual lava flows, fractures, and lava tubes provides preferential flowpaths capable of transmitting large quantities of water (CDWR 2004). For example, some of the geologic units provide substantial quantities of water to wells with yields averaging 1,300 gpm (~80 lps) and as high as 4,000 gpm (~250 lps) (CDWR 2004). The interface between the highly fractured and permeable basalt flow and the low permeability debris flow deposits give rise to numerous springs (CDWR 2011). As a result of the heterogeneous nature of fracture flow in the aquifer and systems of both local and regional flows, spring water can travel up to 16 mi (25 km) before it surfaces. Analysis of naturally occurring isotopes from springs range from 9.9 to 50+ years in age (Nichols, 2015). These ages and distances indicate that the water in the volcanic aquifer is connected in both small- and large-scale flow paths. Because of the heterogeneity produced by faults, fractures, and lava tubes, localized pumping may have varying influences on the regional system.

Pleistocene Debris Avalanche (Map unit: Qvs)

During the Pleistocene epoch, a catastrophic debris avalanche, originating at the stratovolcano that formed Ancestral Mount Shasta, caused a debris flow to fill a portion of the Valley (Crandell et al. 1984; Crandell 1989). The avalanche deposits consist primarily of matrix facies embedded with occasional volcanic rocks, boulders, and blocks scattered throughout the region. The deposits are estimated to range from 150 to 200 ft (~46-61 m) thick. The block facies are made up of masses of volcanic rock; some of the internal structure in the facies was derived from the development of the stratovolcano that formed Ancestral Mount Shasta, a taller, antecedent version of Mount Shasta. During the debris avalanche event(s), the block facies were transported and deposited along the avalanche flow path. The blocks came to rest on the Valley floor and now overlie the Paleozoic rocks of the Klamath Mountains, the Late Cretaceous marine deposits of the Hornbrook Formation, and the alluvial deposits of local streams that existed at the time of the debris avalanche. The matrix facies, which acted as a mudflow during deposition, flowed beyond the initial avalanche toe and is now part of the alluvium found within many other areas of the Valley. Within the debris flow area, the matrix deposits form the sediments in which the blocks are embedded. The matrix facies likely underlie Pluto's Cave basalt deposits to the east as the debris avalanche occurred before the eruption of the Pluto's Cave basalt and acted as western boundary to the basalt flows.

Highly variable rock types within the volcanic debris avalanche, and the chaotic modes of transport and deposition during the event have resulted in a lack of coherent internal structure. Consequently, well yields from within the debris avalanche deposits are highly variable (CDWR 2011). Although groundwater yields are variable, the avalanche deposit exerts control on regulating and redirecting groundwater flow through the valley and to the Shasta River. Both the matrix facies and the block facies are water-bearing units and can more or less supply water for domestic purposes. Compared to the matrix facies, the debris blocks may be more permeable and transmit groundwater from the more permeable Pluto's Cave basalt deposits to the east. The blocks may also serve to transmit groundwater from deeper, semi-to-fully-confining aquifers below. Although few wells have been constructed in the debris flow, available data show that well yields can range from 6 to 40 gpm (~0.4-2.5 lps) for domestic wells and from 100 to 1,200 gpm (~6.3-76 lps) for irrigation wells. Although both the block and matrix facies are considered water-bearing units, the block facies may be more permeable and transmit groundwater from both deep, confined aquifers, as well as the younger, more permeable basalt flows (CDWR 2011).

The greatest significance of the volcanic debris avalanche is the role it plays in regulating and redirecting the natural flow of groundwater to the Shasta River. The avalanche deposits acted as a barrier to the subsequent lava flows and deposition of the Pluto's Cave basalt. The less permeable avalanche deposits act as a barrier to groundwater flow through the more permeable Pluto's Cave basalt, resulting in multiple voluminous groundwater springs (including the Big Springs Complex) along the contact between the two formations (Mack 1960, CDWR 2011).

Pluto’s Cave Basalt (Map unit: Qv (subset))

The southeastern portion of the Valley is covered by High Cascade basalt flows (known as Pluto’s Cave Basalt, referencing a notable eponymous lava tube cave within the unit) of Pleistocene (likely 160,000 to 190,000 years ago) or possibly Holocene age (PGS 2001, GRD 1997). Pluto’s Cave Basalt is one of the primary aquifer units within the Basin as well as the entire Watershed. The entire subarea’s shallow subsurface is characterized by many successive series of overlapping lava flow units ranging in thickness from about 10 to 30 ft (~3-9 m; Williams 1949). The total thickness of the Pluto’s Cave Basalt flow ranges from more than 500 ft (>150 m) in the south (i.e. the head of the lava flow) to 50 ft (~15 m) or less in the north (i.e. toe of the lava flow). During these past lava flow events, clinkery surfaces (quickly hardened volcanic rock) formed at the contact between successive lava flows, producing “cinders” (drillers commonly use this term, which is more or less correct). These clinkery surfaces, together with cooling lava tube and fracture structures, act as functional conduits for water and can transmit large volumes of groundwater through these interconnected hollows. Geologic cross sections A-A’ and H-H’ provide the best vertical sections of the Pluto’s Cave basalt aquifer unit as modeled in the Shasta Valley Watershed geologic model (Appendix 2-A). According to CDWR (2011), most wells within this subarea yield between 10 and 100 gpm (0.6 to 6 lps), although several wells reportedly yield over 1,000 gpm (~63 lps).

Recharge to Pluto’s Cave basalt occurs from precipitation, percolation from irrigation and leaky water conveyance ditch losses, and groundwater underflow associated with meltwater from snowfall on the Cascade Range. Mount Shasta, Deer Mountain, and Whaleback Mountain are all likely source areas of groundwater (i.e. recharge) found in Pluto’s Cave basalt. A number of freshwater springs generally arise from the contact between Pluto’s Cave basalt and the debris avalanche deposits, as well as, at least locally, from the contact with the less conductive Western Cascade volcanic series. These contact zone springs include Big Springs, Hole in the Ground Spring, and a multitude of other named and unnamed springs. These springs are the principal source of cold freshwater for the Shasta River. Past investigations suggest that spring water discharged in the area is slightly thermal, meaning that groundwater sampled was at a slightly higher temperature which indicates higher recharge elevation, likely above 8,000 ft (>2,500 m) amsl. Past studies also suggest that this recharged groundwater likely interacts with marine sedimentary rock deposits at depth (likely in the Hornbrook Formation), due to the detection of elevated levels of chloride, nitrate, phosphate, and sulfate (McClain 2008; Nathenson et al. 2003). Mack (1960) showed that groundwater quality samples from Pluto’s Cave basalt contain the highest average concentration of silica (63 parts per million [ppm], or 1 mg/L) of waters in the Valley, which may partly be due to the pyroclastic debris and glacial outwash deposits that groundwater would recharge through up gradient on the north slopes of Mount Shasta. In contrast, groundwater sampled in the andesitic volcanic rocks of the debris avalanche material has on average a lower silica content (45 ppm).

Quaternary Alluvium (Map units: Q & Qg)

The Shasta Valley Groundwater Basin previously consisted of only the Quaternary-aged unconsolidated alluvium located along the western and northern portions of the Valley, not including the glacial deposits at the base of Mount Shasta (Bulletin 118 - CDWR 2016). In 2019, CDWR updated this basin boundary at the Agency’s petition to additionally include the glacial deposits (Qg), debris avalanche deposits (Qvs), Pluto’s Cave basalt (Qv subset), and portions of the Western Cascade volcanics (Tv) from the western portions of the Cascade Range adjacent to the previous Basin boundary (*see geology overview maps*). The previous alluvial aquifer unit (Q) includes stream and terrace deposits of Parks Creek, Willow Creek, Julien Creek, Yreka Creek, Shasta River, Little Shasta River, and Oregon Slu, as well as alluvial fan deposits forming the sedimentary apron at the base of the Klamath Mountains (CDWR 2011).

According to Mack (1960) and CDWR (2011), alluvial deposits of the Julien Creek and Willow Creek drainages vary in thickness. To the north in the Julien Creek drainage, the maximum thickness of the alluvial deposits is an estimated 300 ft (~90 m); this alluvium consists primarily of Julien Creek channel and alluvial fan deposits. In the south, channel deposits are estimated at 50 ft (~15 m) thick in the Willow Creek drainage. Well yields in matrix deposits generally range from 20 to 220 gpm (1.3-14 lps), while one well reportedly has a yield of 1,500 gpm (95 lps). In Julien Creek, drainage well yields range from 33 to 166 gpm (2-10.4 lps); in Willow Creek drainage, well yields are slightly less productive ranging from 20 to 100 gpm (1.3-6.3 lps). Most agricultural production in the valley occurs in areas containing alluvial deposits because they provide the soil structure and water holding capacity necessary for plant growth with well yields generally fluctuating from four (4) to 60 gpm (1.3-6.3 lps). The younger and older alluviums of recent and Pleistocene age yield water sufficient for domestic and stock uses. Along the west side of the Valley the younger alluvium produces adequate water for irrigation and supplies the City of Yreka with abundant water for municipal uses.

The Holocene alluvium found in the Basin is primarily silt and clay interbedded with sand and gravel with depths up to 150 ft (46 m) in some locations, and well yields measured at 150 to 1,000 gpm (9.5-63 lps; Mack 1960). North of Montague, the Basin is underlain by older Pleistocene alluvium up to 100 ft thick (~30 m) containing gravels derived from the Klamath Mountains. This portion of the Valley contains an iron-cemented hardpan just below the ground surface. Additionally, calcium derived from mafic volcanic rocks in the Little Shasta Valley has cemented the subsoil into hardpan, while the alluvial western valley margin extending south past Gazelle contains no hardpan (Mack 1960). The alluvial aquifer is generally much less productive than the underlying volcanic aquifer. Most large wells in the Valley, including those in locations with Quaternary alluvium, produce groundwater from the underlying volcanic aquifer. The alluvial aquifer (Q) is mainly present in *Cross Sections A-A', E-E', West-East, and North-South*.

Deposits from the debris avalanche redirected flow paths of the Shasta River, Parks Creek, and Willow Creek within the alluvial system of the Gazelle/Grenada hydrologic region of the aquifer. Shasta River and Parks Creek have migrated back across the avalanche deposits; however, Willow Creek now flows in a northerly direction, adjacent to the topographically higher block facies portion of the debris avalanche deposit. Consequently, Willow Creek channel deposits, which have developed over the last 300,000 years, may convey unconfined groundwater north to the Willow Creek confluence with the Shasta River.

During the Pleistocene epoch, glaciers that descended the northwest slopes of Mount Shasta spread into the Valley to an altitude of about 2,800 ft (~850 m). The record of this glaciation is preserved in the southern part of the valley in the form of morainal hills and ridges, remarkably similar in appearance to the erosional remnants of the volcanic rocks of the western Cascades and in bouldery outwash deposits that extend from the shores of Dwinnel Reservoir (Lake Shastina) southward to Weed. Glaciers still remain on Mount Shasta and continue to supply fluvioglacial debris to the Valley to the present day. Fluvioglacial materials derived from the remaining glaciers (Whitney, Bolam, and Hotlum Glaciers) are still being deposited on the lower northwest flank of Mount Shasta as broad fans which are spreading over the edges of the Pluto's Cave basalt. The glacial aquifer unit (Qg) is mainly present in *Cross Sections E-E' and H-H'*. The morainal and fluvioglacial deposits generally yield sufficient water for domestic and stock uses. Several irrigation wells tapping glacial materials east of Edgewood yield 600 to 1,500 gpm (38-95 lps).

Table 4: Hydrostratigraphic Model Unit Descriptions.

Unit ID	General Lithology	Age	Description	Aquifer Properties
Q	Alluvium	Holocene-Pleistocene	Alluvium, lake, playa, and terrace deposits; unconsolidated and semi-consolidated	Typically shallow deposits (generally <200 ft thick; <61 m) concentrated on western and northern parts of the Valley along fluvial corridors; highly utilized aquifer in the Valley; well yields range from 10's to 100's of gal/min (0.6-6.3+ liters/sec)
Qg	Glacial deposits	Holocene-Pleistocene	Glacial till and moraines	Heterogeneous glacial aquifer material; shallow deposits are limited spatially across the Valley floor, mostly at the base of Mt. Shasta; few wells completed in this unit; moderate yields of typically 10-100+ gal/min (0.6-6.3+ liters/sec), some east of Edgewood yield 600-1,500 gal/min (38-95 liters/sec)
Qv	Pleistocene Volcanic rocks	Holocene(?)-Pleistocene	Basaltic and andesitic flows and pyroclastic rocks of Cascade Range	Highly heterogeneous volcanic aquifer material; significant recharge material in the Valley; Pluto' Cave basalt subunit is the most important aquifer material in the Valley; thickness increases toward Mt. Shasta (50-500+ ft; 15-150+ m); yields can be low but can easily top 1,000+ gal/min (63+ liters/sec) in permeable zones (usually in lava tubes)

Table 4: Hydrostratigraphic Model Unit Descriptions. *(continued)*

Unit ID	General Lithology	Age	Description	Aquifer Properties
Qvs	Volcanic rocks of Shasta Valley	Pleistocene	Catastrophic volcanic-debris avalanche incorporated existing deposits of andestic volcanic rock, alluvium, lahars, and pyroclastic flows	Highly heterogeneous volcanic/sedimentary debris flow aquifer material; both matrix and block facies are water-bearing units; blocks may be more permeable and transmit groundwater across or under surface deposits; few wells have been completed in this unit; well yields range 6-40 gal/min (0.4-2.5 liters/sec) for domestic wells and 100-1,200 gal/min (6.3-76 liters/sec) for irrigation wells
Pv	Pliocene Volcanic rocks	Pliocene	Basaltic and andesitic flows, breccia, and tuff of Cascade Range	Heterogeneous volcanic aquifer material; surface outcrops are uncommon on Valley floor; generally the least important High Cacade aquifer material in the Valley; few wells completed in this formation leading to a lack of information on yields
Tv	Western Cascade Volcanics	Miocene(?)-Eocene	Andesitic and basaltic flows, breccia, tuff, minor rhyolitic tuff, and intercalated sedimentary units of Cascade Range	Heterogeneous volcanic aquifer material; generally the least important aquifer material in the Valley; yielding lower supplies for domestic and stock purposes
Kh	Hornbrook Formation	Cretaceous	Shallow- and deep-water marine and nonmarine shale, sandstone, and conglomerate	Functions as a partial hydrogeologic basement for younger basin deposits in some portions of the Valley; Some wells in these units, typically in jointed/faulted rock or in more sandy rock subunits, yielding minimal water supply for domestic and stock uses
Basement	Basement (group)	Mesozoic-Paleozoic	Various Paleozoic metamorphic (metasedimentary and metavolcanic) units and Mesozoic igneous (granite/diorite) units	Hydrogeologic basement for basin deposits; Very few wells in these units, typically in jointed/faulted rock, yielding minimal water supply for domestic and stock uses

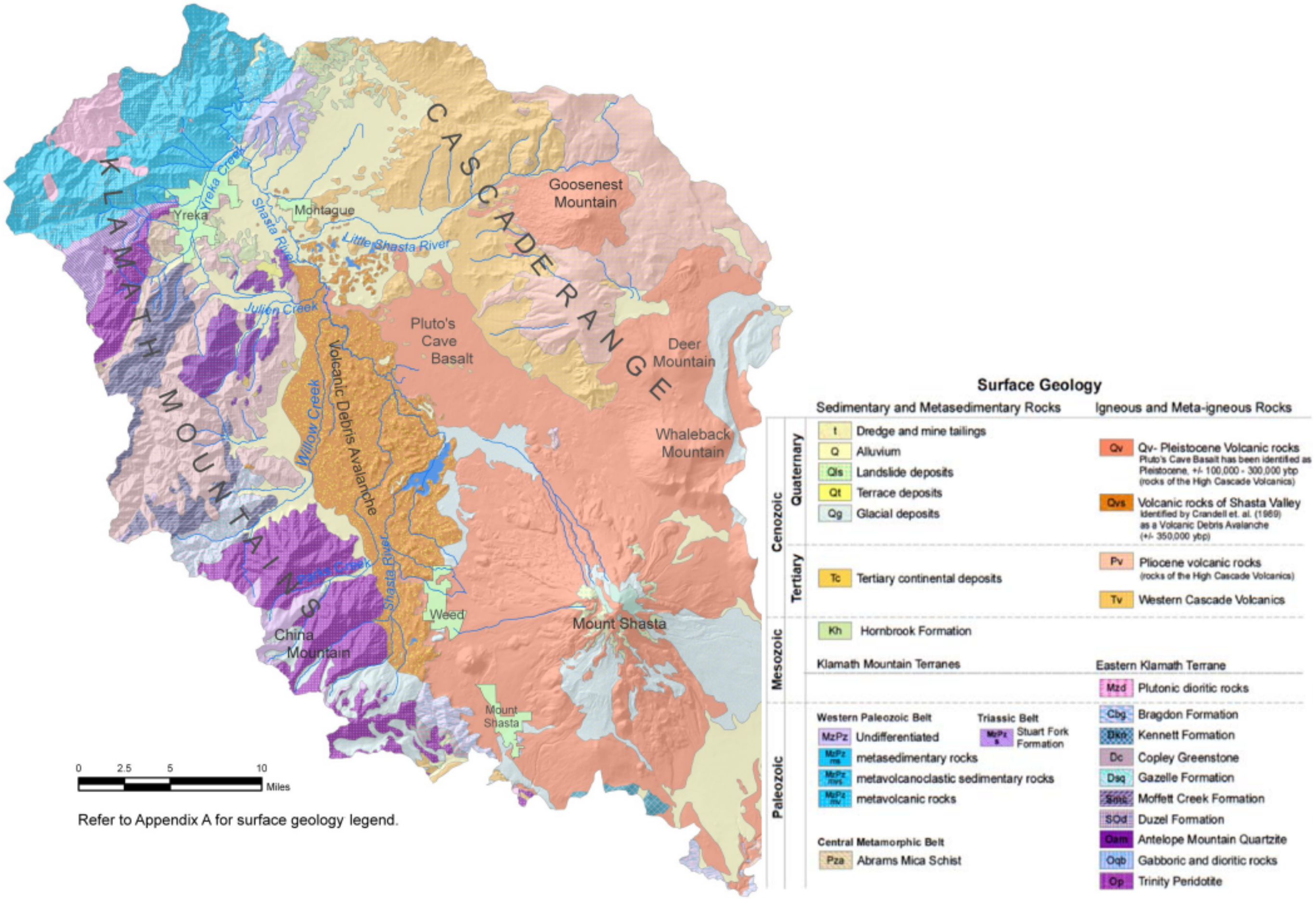


Figure 16: Shasta River Valley Watershed and extended Mount Shasta area - previous surface geologic map (reprinted and adapted from CDWR 2011).

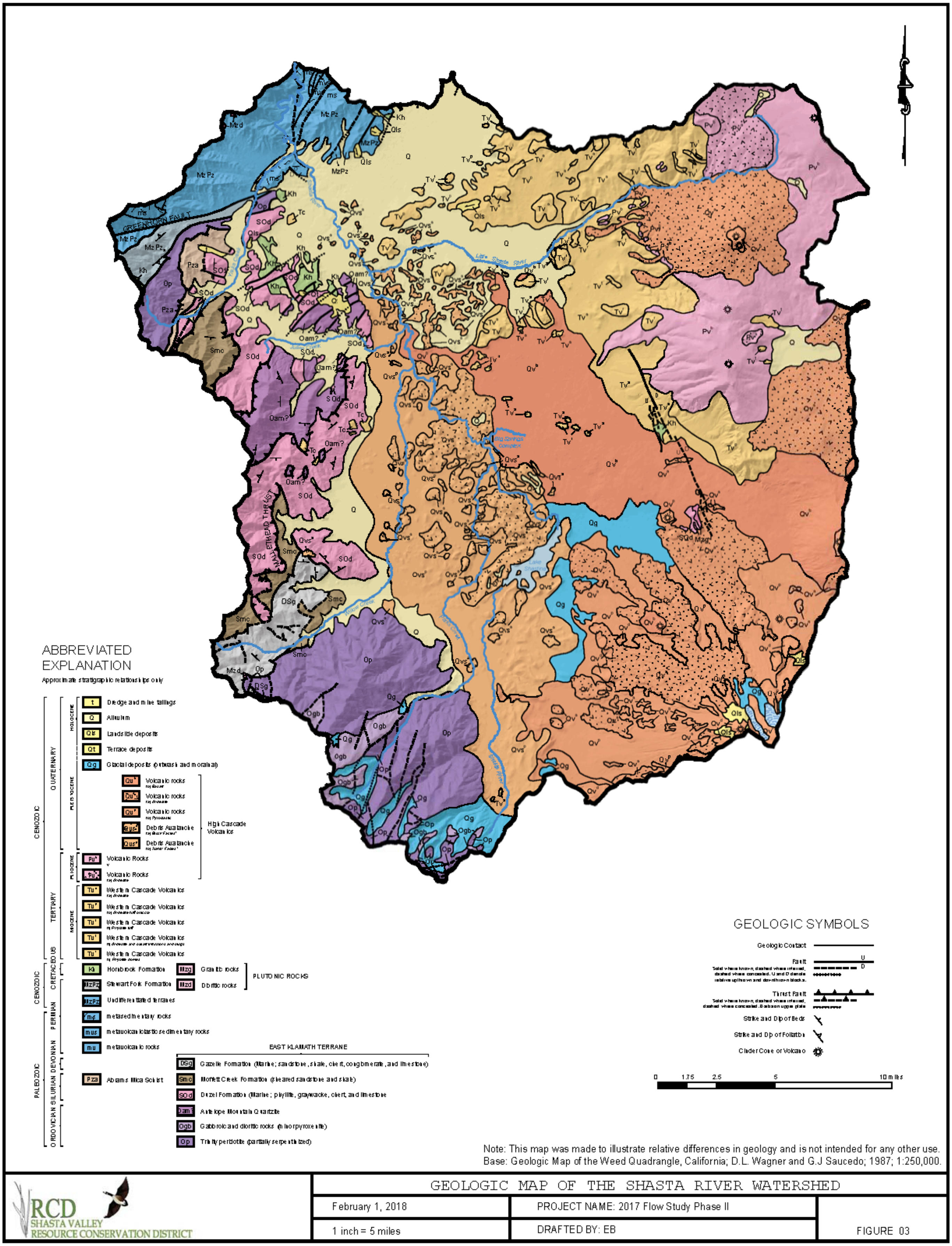


Figure 17: Shasta River Valley Watershed - previous surface geologic map (reprinted from SVRCD 2018).

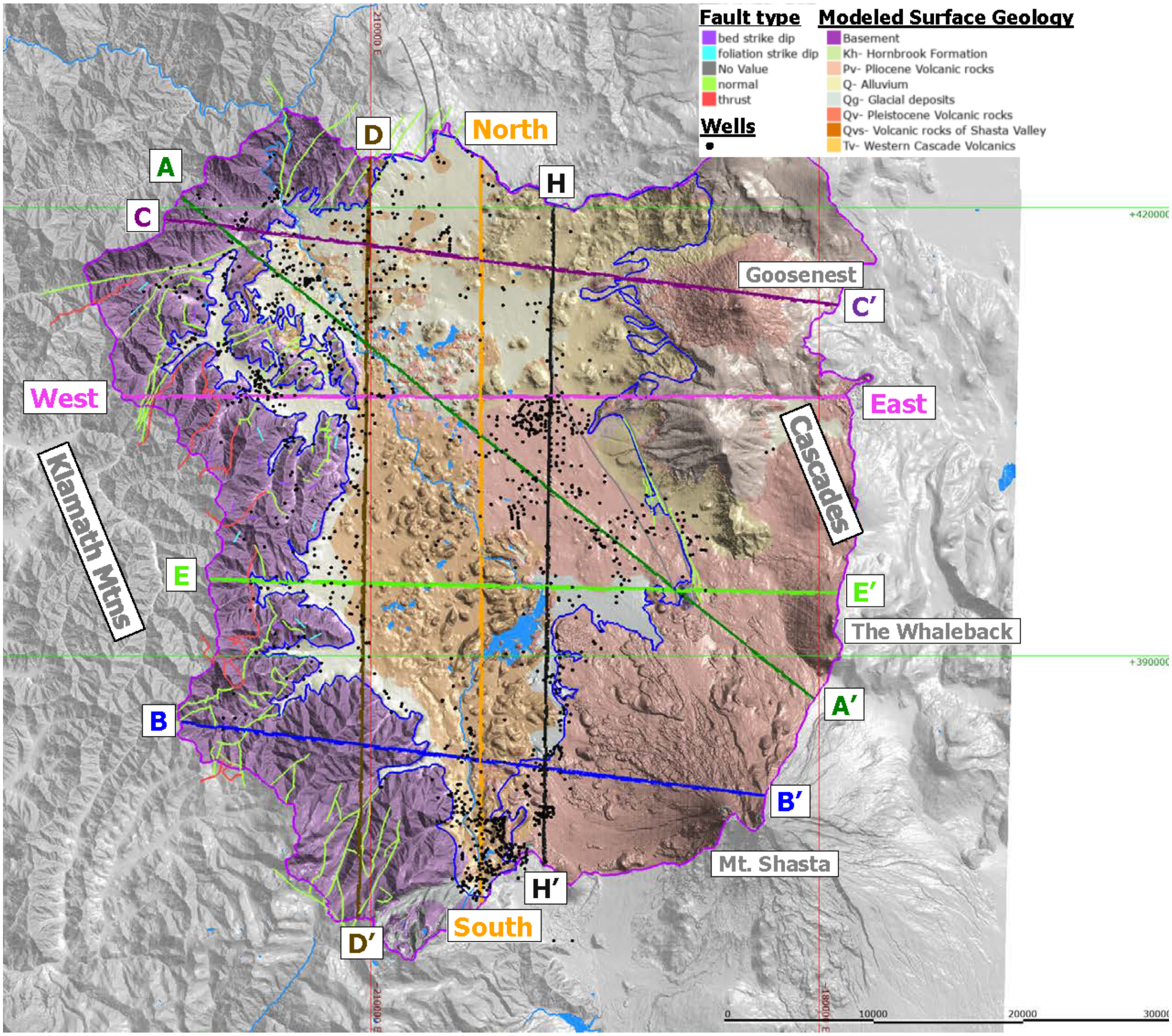


Figure 18: Shasta Valley Watershed geologic model overview and cross section map. Wells pictured in the map are the approximate locations noted in the Well Completion Reports used to construct the geologic model. The surface geology utilized in the geologic model is based on CDWR (2011) and SVRCD (2018).

Vertical cross sections

Vertical cross sections of the Watershed originate from the Shasta Valley Watershed geologic model (Appendix 2-A) are shown below and will be referred to in the following ***Geologic Units*** section (*cross section line locations are shown in Figure (18)*).^[Cross section naming conventions followed the names of previous cross sections published (primarily Mack [1960] and DWR [2011]) covering the same vertical cross sectional plane (i.e. along the same line at the ground surface); however, they are not necessarily identical in area and extent. Additionally, cross sections names identical in name and not in location to previously published cross sections of the area were avoided to prevent confusion and aide in comparison to published literature of the area (i.e. *Cross Sections*

F-F' and G-G').

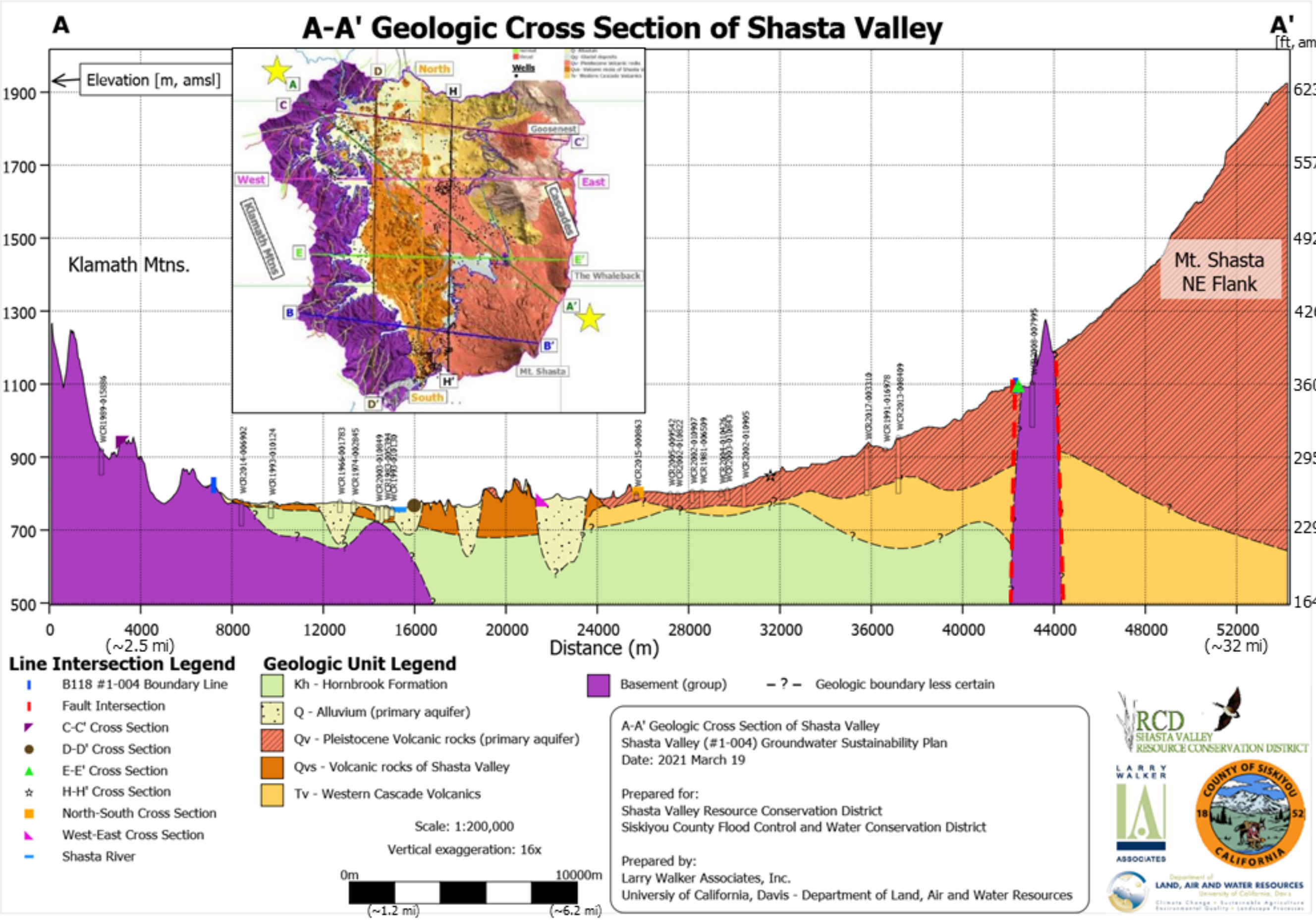


Figure 19: Geologic cross section A-A' from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

2.2.1.4 Soils

The Natural Resources Conservation Service's (NRCS) State Soil Geographic and Soil Survey Geographic Database (STATSGO/SSURGO) is a soils database that has four main hydrologic soil groups that characterize surface water runoff potential. Group A generally has the lowest runoff potential with the highest infiltration rates and Group D has the highest runoff potential and the lowest infiltration rates. Groups B and C are intermediates between Groups A and D. Soil characteristics of each hydrologic soil group are described in Table (XXX). Group A contains very well-drained sand, loamy sand, or sandy loam. Group B contains silt, silt loam, or loam. Group C contains sandy clay loams that are moderately to poorly drained with low infiltration rates. Group D contains poorly-drained clays, sandy and silty clays, clay loam, and silty clay loam, silt loams, and loams. Figures 28 shows the spatial distribution of the STATSGO/SSURGO data for the Watershed's hydrologic soil groups. There is no dominant soil group in the Watershed with Groups A, C, and D comprising almost the entirety of the Watershed's surficial soils. Each of these groups occupy roughly one quarter to one third of the total area of the Watershed. Group B is not widely observed in the Watershed like the other groups.

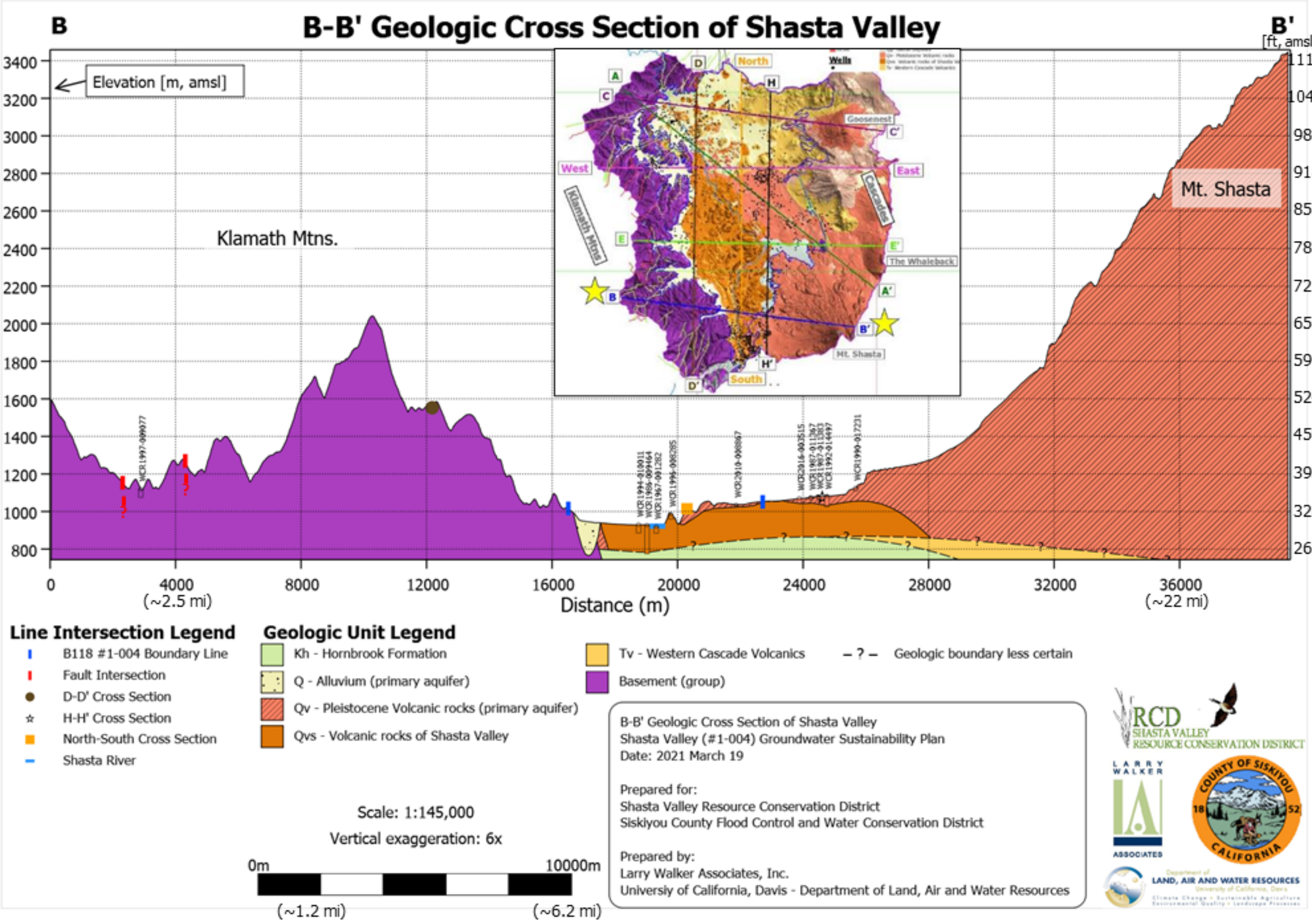


Figure 20: Geologic cross section B-B’ from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

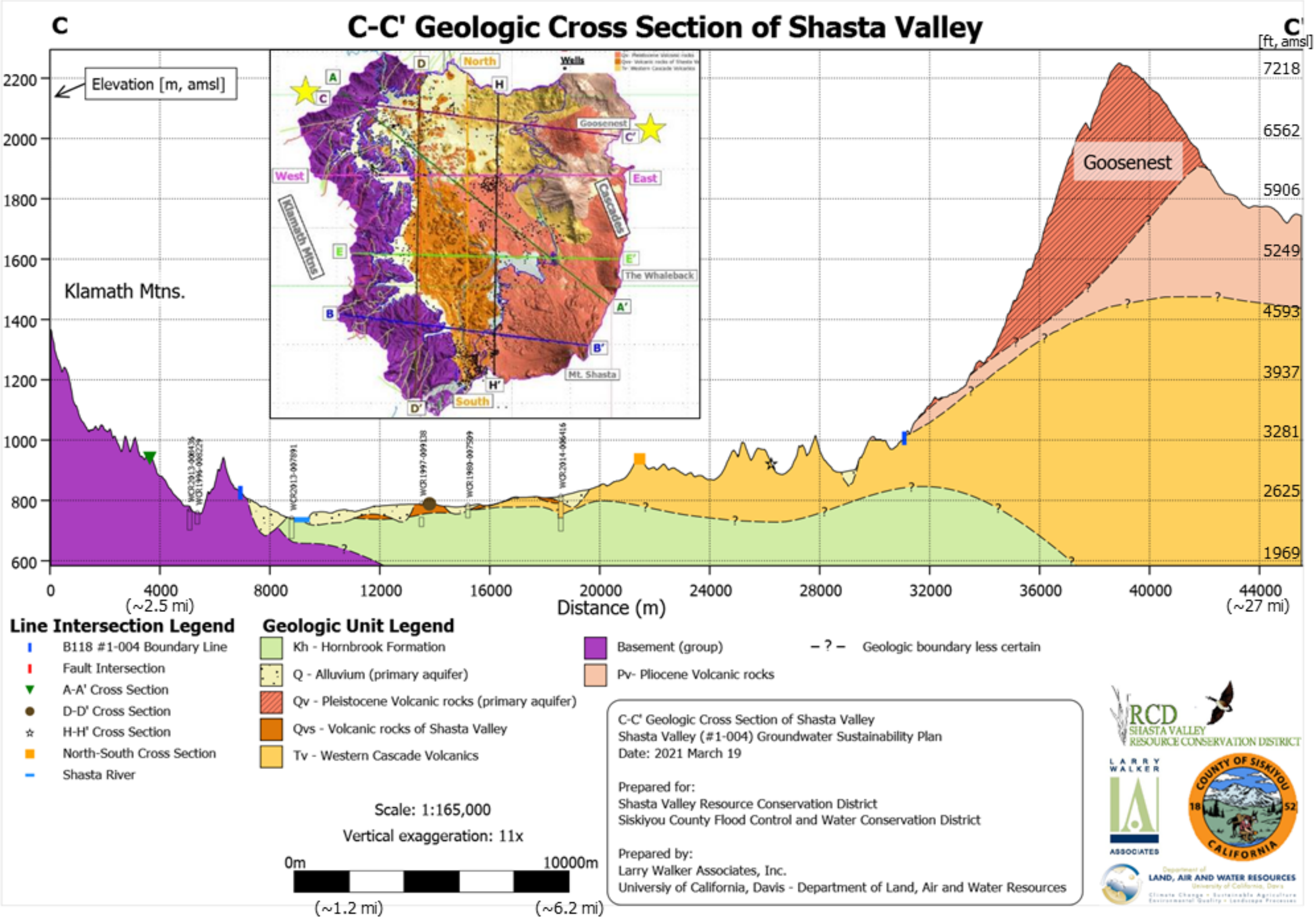


Figure 21: Geologic cross section C-C' from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

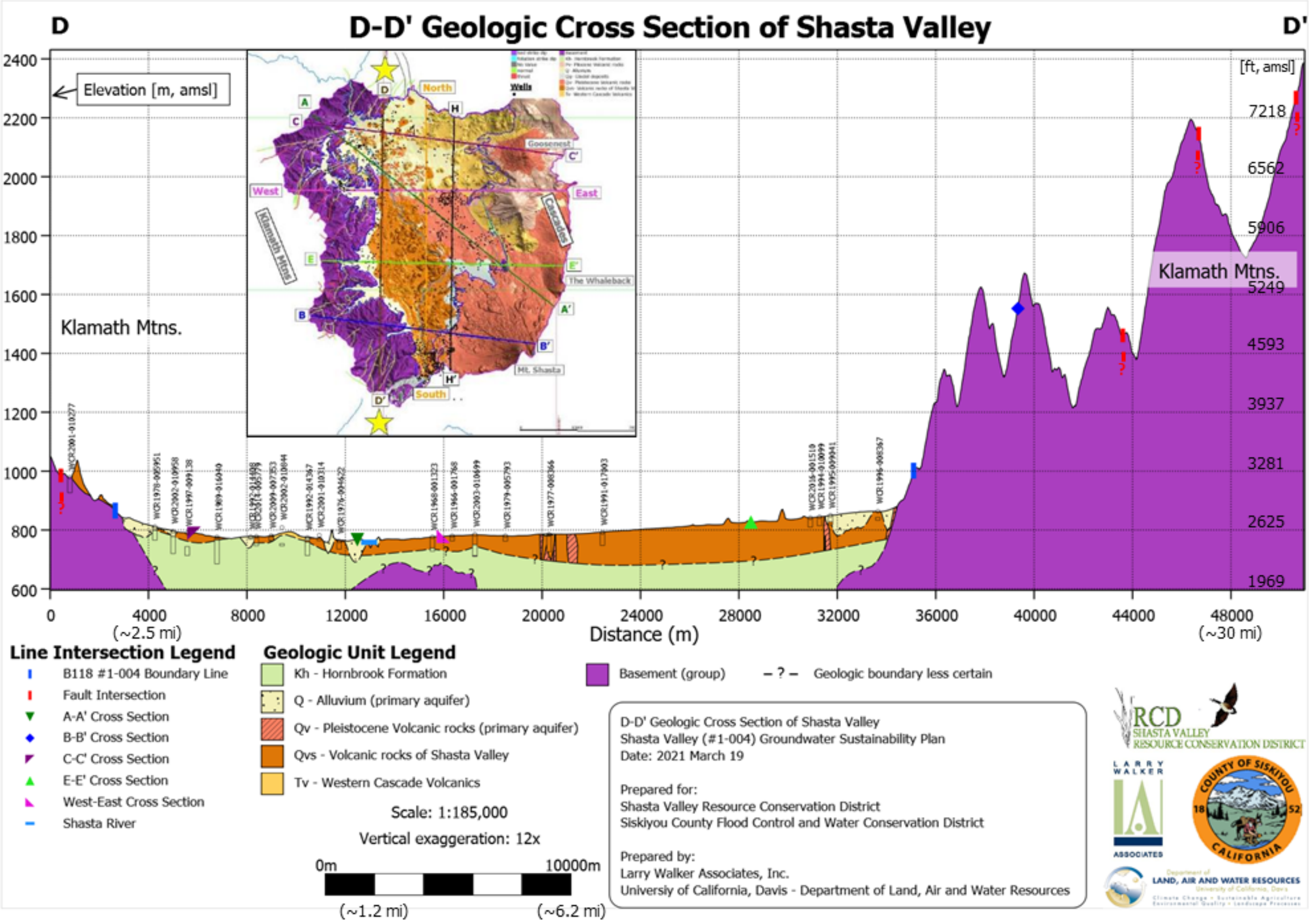


Figure 22: Geologic cross section D-D’ from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

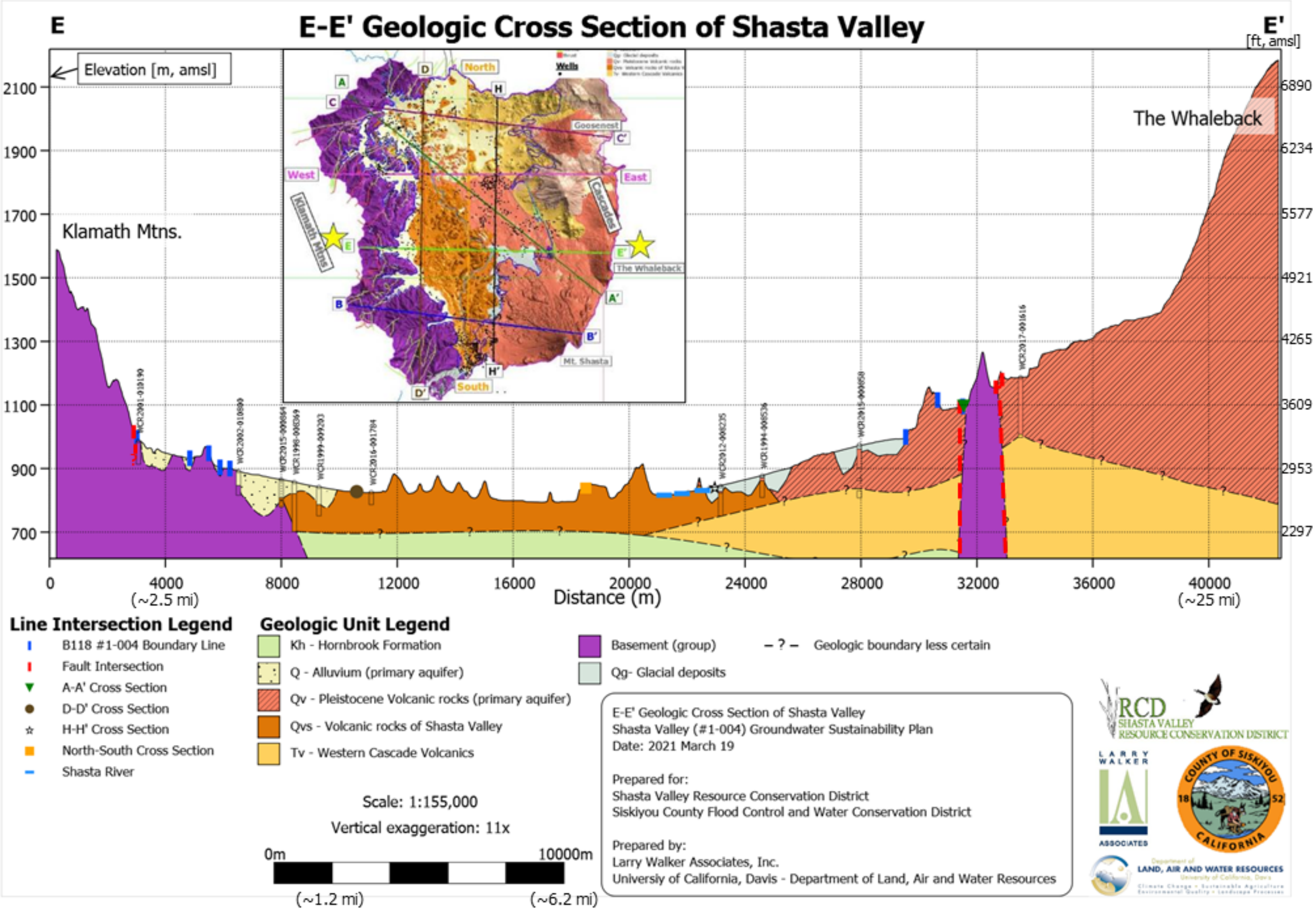


Figure 23: Geologic cross section E-E’ from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

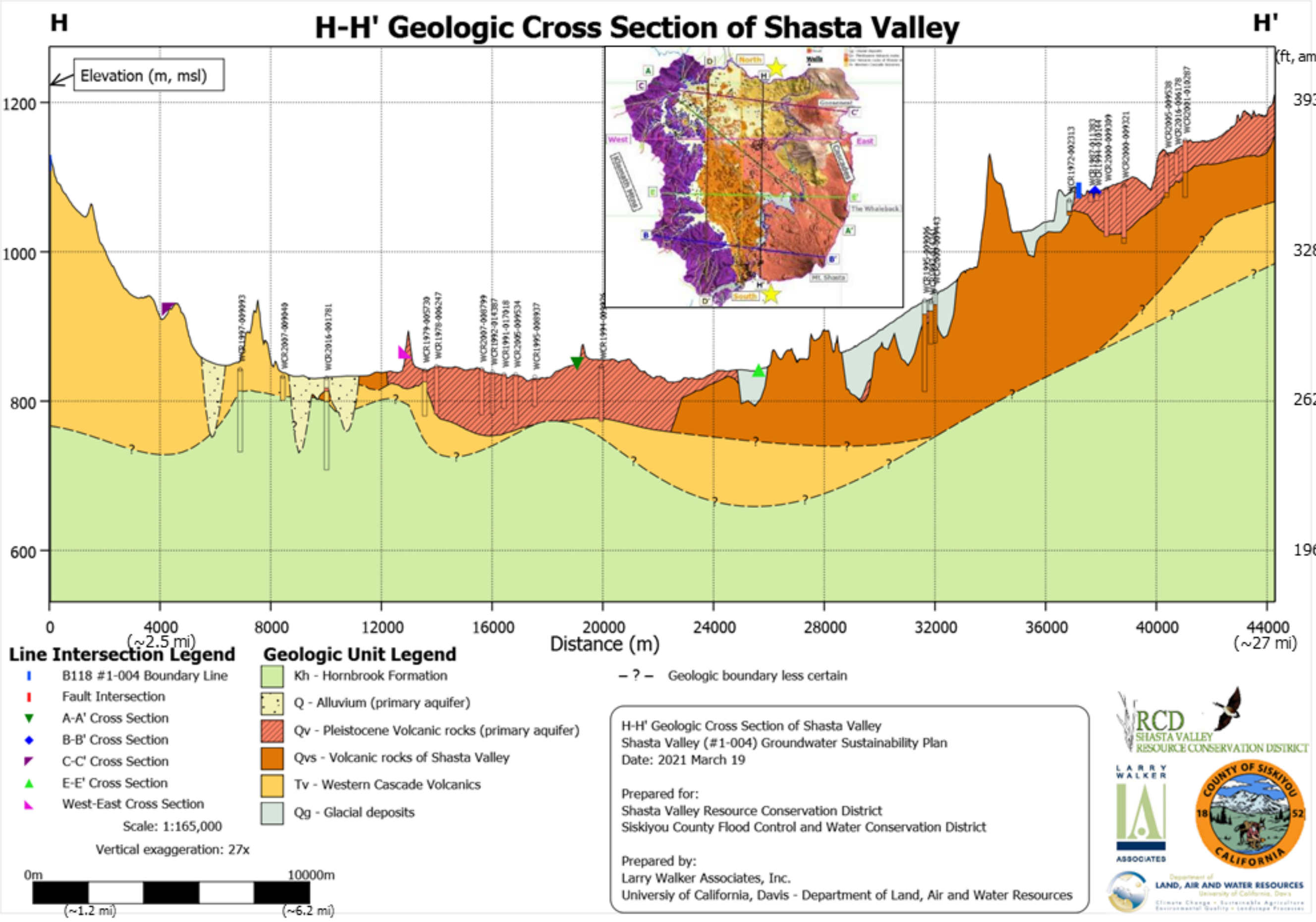


Figure 24: Geologic cross section H-H’ from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

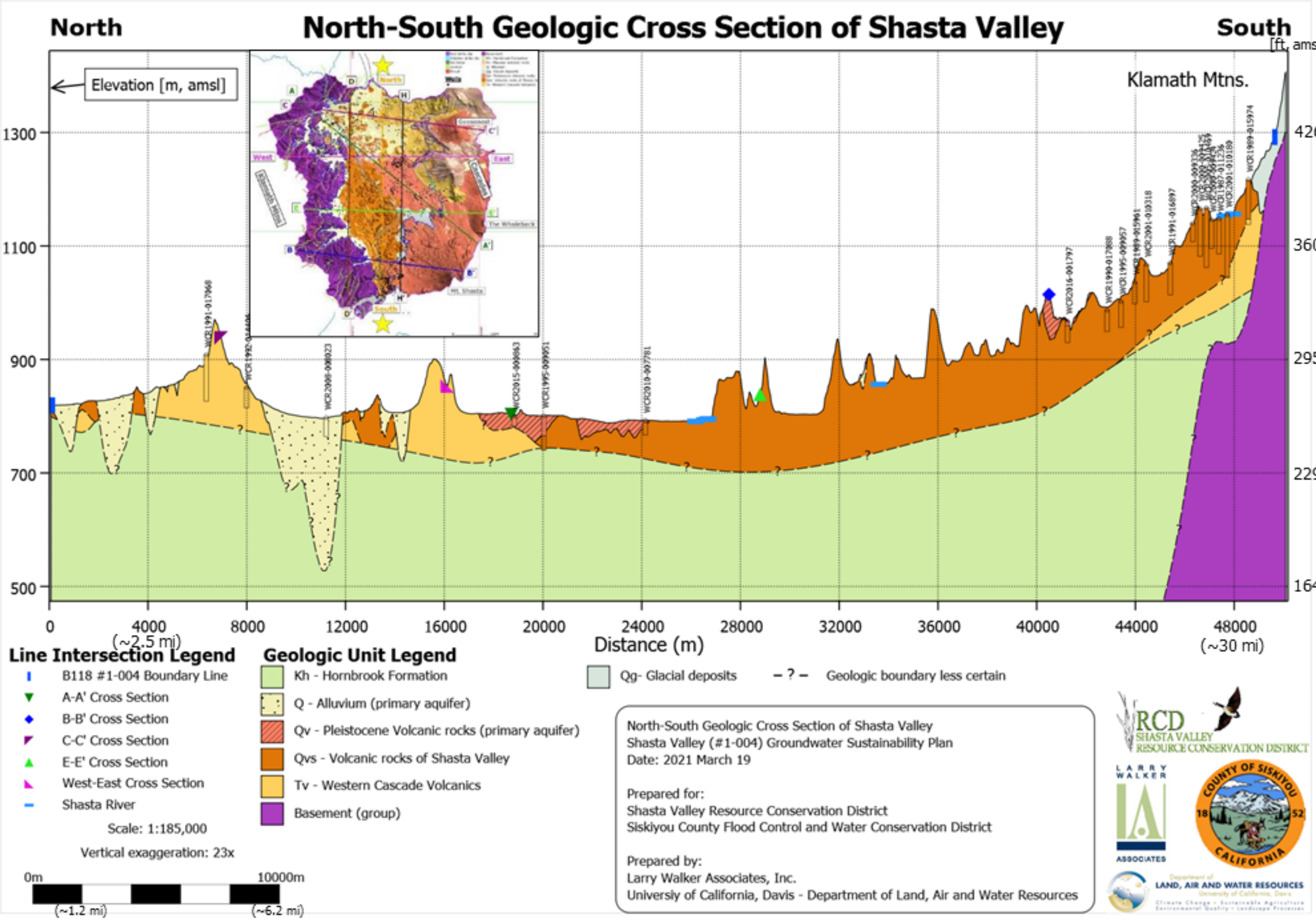


Figure 25: Geologic cross section North-South from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

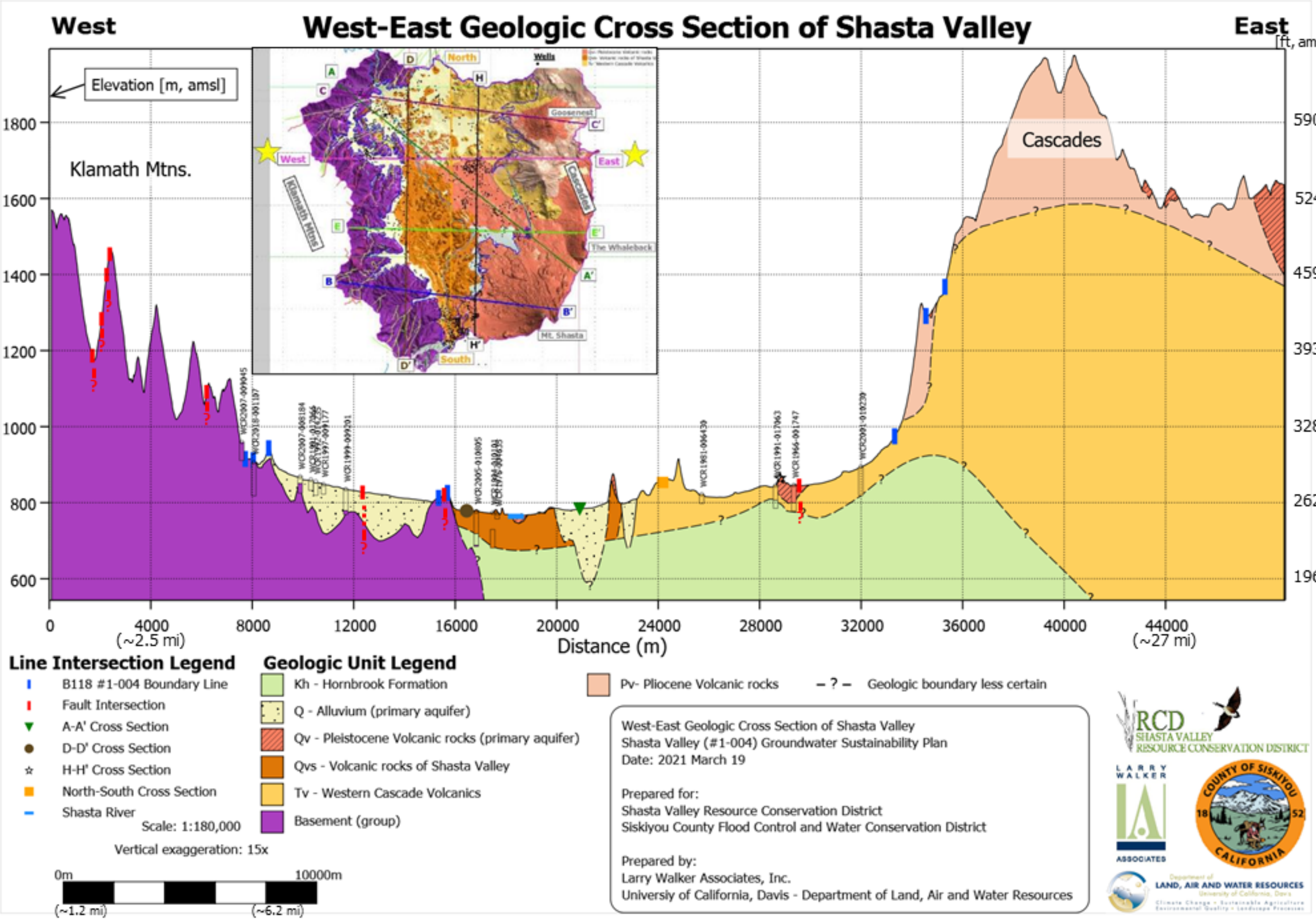


Figure 26: Geologic cross section West-East from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

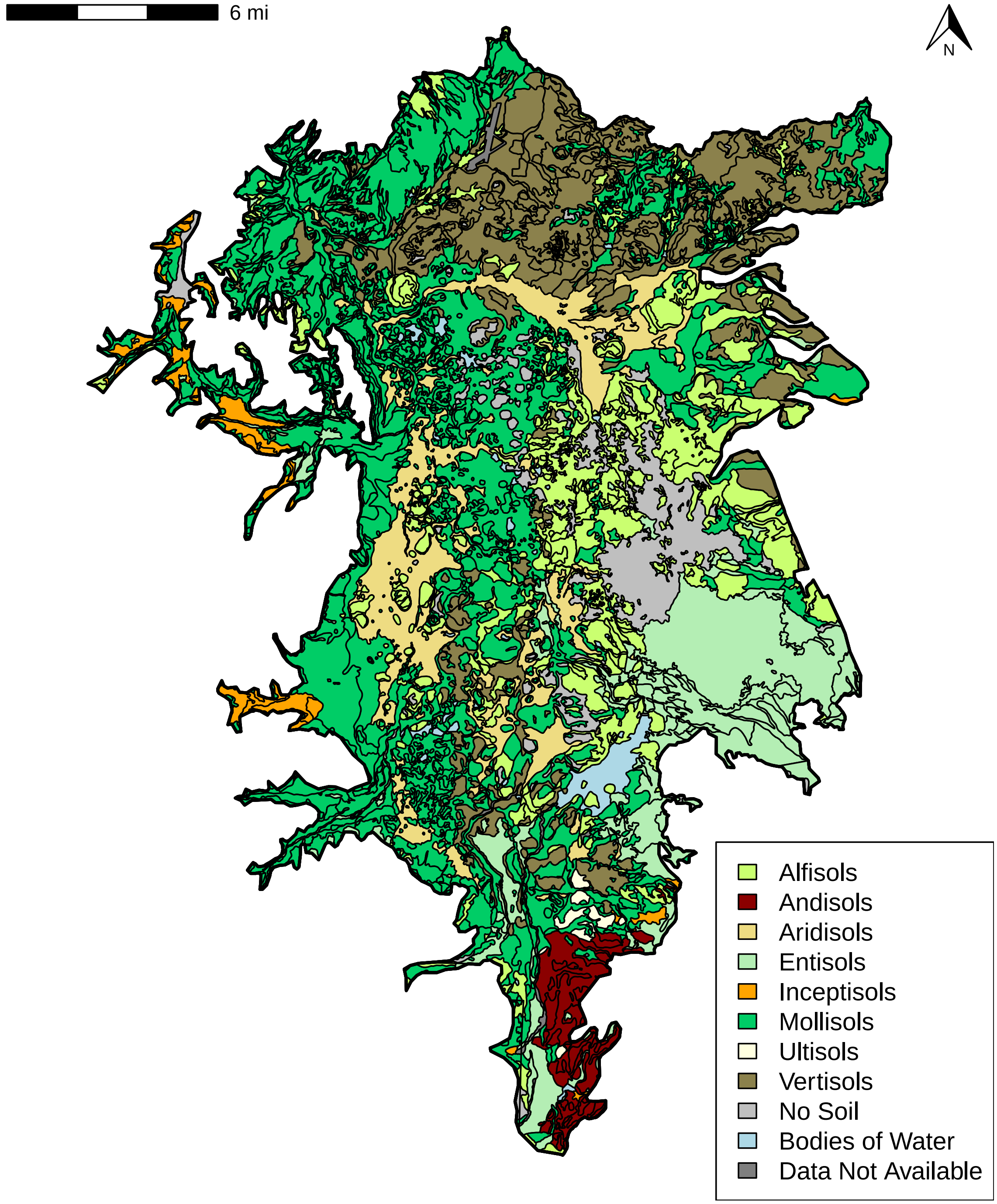


Figure 27: Soil classifications in the Shasta Valley Groundwater Basin

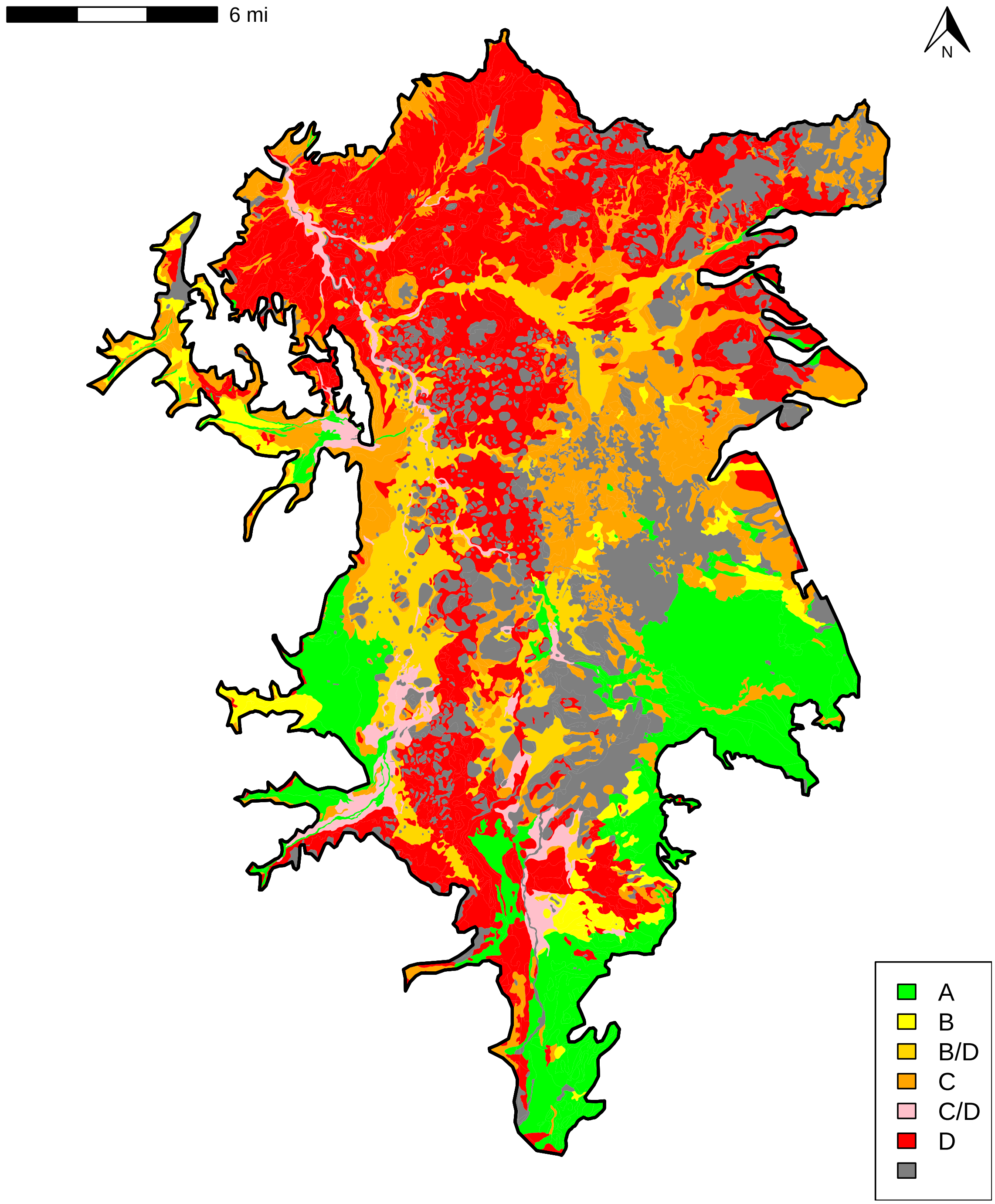


Figure 28: Hydrologic soil groups in the Shasta Valley Groundwater Basin area, where Group A are soils with a high infiltration rate and low runoff potential to Group D with very slow infiltration and high runoff potential. Soils have two Groups if a portion is artificially drained and the rest undrained.

2.2.1.4.1 Soil Recharge Suitability

The Soil Agricultural Banking Index (SAGBI) identifies the potential for groundwater recharge on areas of land based on five factors: deep percolation, root zone residence time, topography, chemical limitations, and the condition of soil surfaces (O'Geen et al. 2015). The deep percolation factor is derived from the soil horizon with the lowest saturated hydraulic conductivity. Saturated hydraulic conductivity is a measure of soil permeability when soil is saturated. The root zone residence time factor estimates the likelihood of maintaining good drainage within the root zone shortly after water is applied. This rating is based on the harmonic mean of the saturated hydraulic conductivity of all horizons in the soil profile, soil drainage class and shrink-swell properties. The chemical limitations factor is quantified using the electrical conductivity of the soil, which is a measure of soil salinity. Level topography is better suited for holding water on the landscape, thereby allowing for infiltration across large areas, reducing ponding and minimizing erosion by runoff. Ranges in slope percent are used to categorize soils into five slope classes: optimal, good, moderate, challenging, and extremely challenging. Depending on the water quality and depth, standing water can lead to the destruction of aggregates, the formation of physical soil crusts, and compaction, all of which limit infiltration. Two soil properties are used to diagnose surface condition: sodium adsorption ratio is used to identify soils prone to crusting, and the soil erosion factor is used to estimate the potential soil susceptibility to erosion, disaggregation, and physical crust formation.

The unmodified SAGBI does not account for modifications by deep tillage. The modified index is theoretical and assumes that all soils with restrictive surficial layers have been modified by deep tillage. The SAGBI ratings for the soil series in the Watershed area is shown in Figures 29 to 30 and can also be viewed on a web application developed by the California Soil Resource Lab at University of California Davis and the University of California Agriculture and Natural Resources (O'Geen et al. 2015). The unmodified SAGBI ratings for the Valley largely show that most areas are listed as "Very Poor" or do not have data coverage. Particularly, the index ratings are absent for much of the eastern portion of the Valley along Pluto's Cave basalt, a recharge area for the Watershed, and in some central portions of the Valley in the debris avalanche area. However, the missing eastern area is covered by the STATSGO/SSURGO Database discussed above, which lists much of this missing area as Group A that generally has the lowest runoff potential with the highest infiltration rates. There is a significant area of "Excellent" ratings in the Gazelle area in the Bonnet soil. Additionally, there is an area assigned "Excellent" and "Good" ratings following the Whitney Creek drainage area north from Mount Shasta (this is the drainage path for Whitney Glacier) in the Delaney soil. The modified SAGBI ratings for the Valley show a very different picture than the unmodified index. The modified index ratings increase much of the "Very Poor" areas by a number of levels, and in some cases, to "Excellent" and "Good" in the central, eastern, and northern areas of the Valley. Although these SAGBI ratings can provide an indication of suitability for recharge projects, groundwater transit times may need to be investigated for prior to implementation of groundwater recharge projects.

Pertinent to the Valley, alfalfa was not considered in the root zone residence time factor. The authors of the SAGBI state that "…alfalfa may be an ideal crop for groundwater banking because it requires little or no nitrogen fertilizer, reducing the risk that groundwater recharge would transport nitrates into aquifers. Alfalfa is sensitive to flooding and saturated conditions; thus, the timing of flooding should coincide with older fields (typically 4 to 5 years old) slated for replanting. Because the financial risk associated with crop damage is lower in alfalfa than in tree and vine crops, the financial incentive needed to drive grower participation in groundwater banking programs likely would be lower as well." (Article Published online April 01, 2015 in *California Agriculture*

69(2):75-84 https://doi.org/10.3733/ca.v069n02p75. Other limitations to consider when evaluating the SAGBI are a lack of consideration of proximity to surface water sources. This is especially important to groundwater-dependent agriculture operations not connected to surface water supply conveyances, and the particular characteristics of the unsaturated zone and the depth to groundwater.

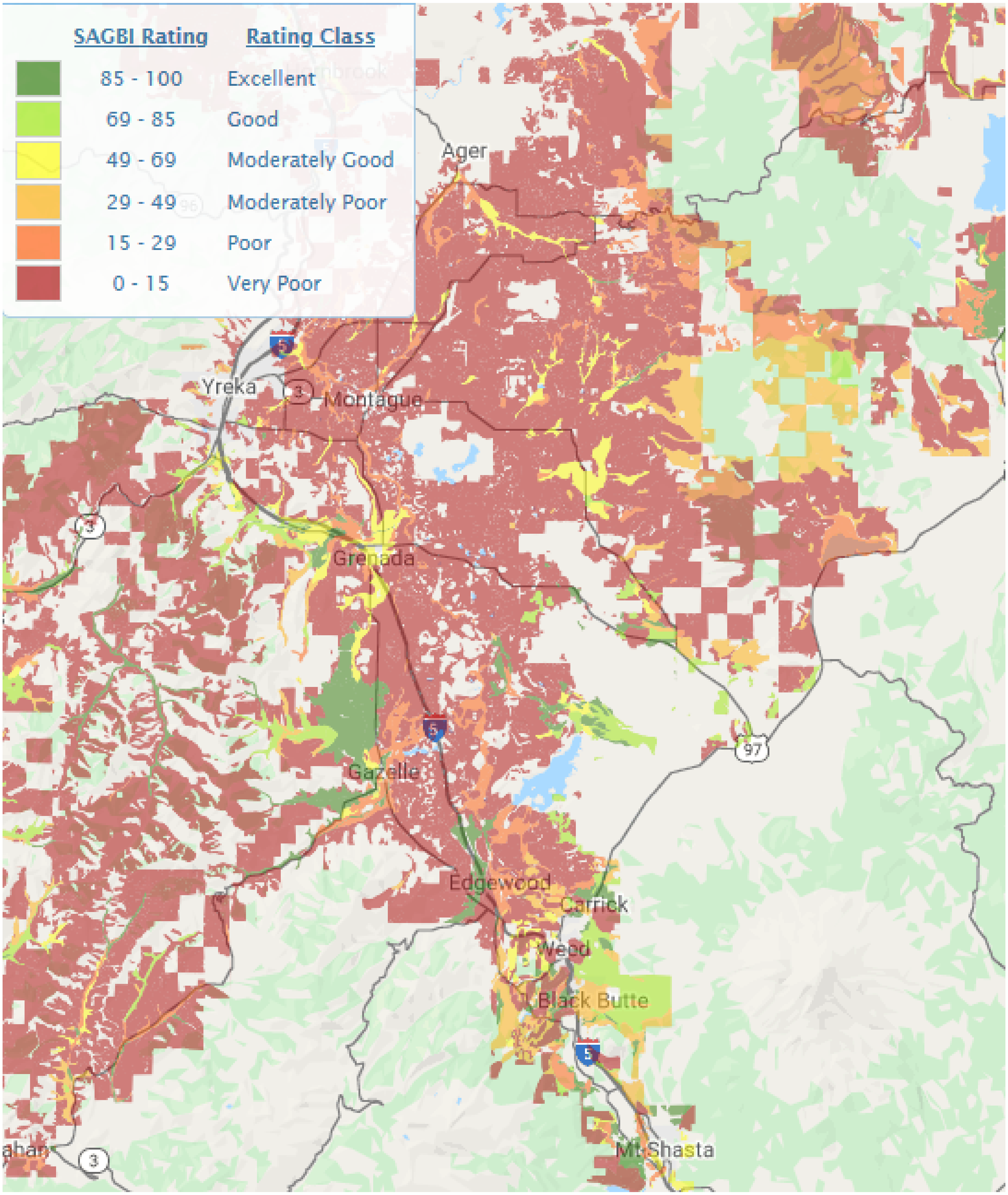


Figure 29: Unmodified Soil Agricultural Banking Index (SAGBI) of the greater the Shasta Valley Groundwater Basin area. Unmodified overlay shows SAGBI suitability groups when not accounting for modifications by deep tillage. Adapted from https://casoilresource.lawr.ucdavis.edu/sagbi/.

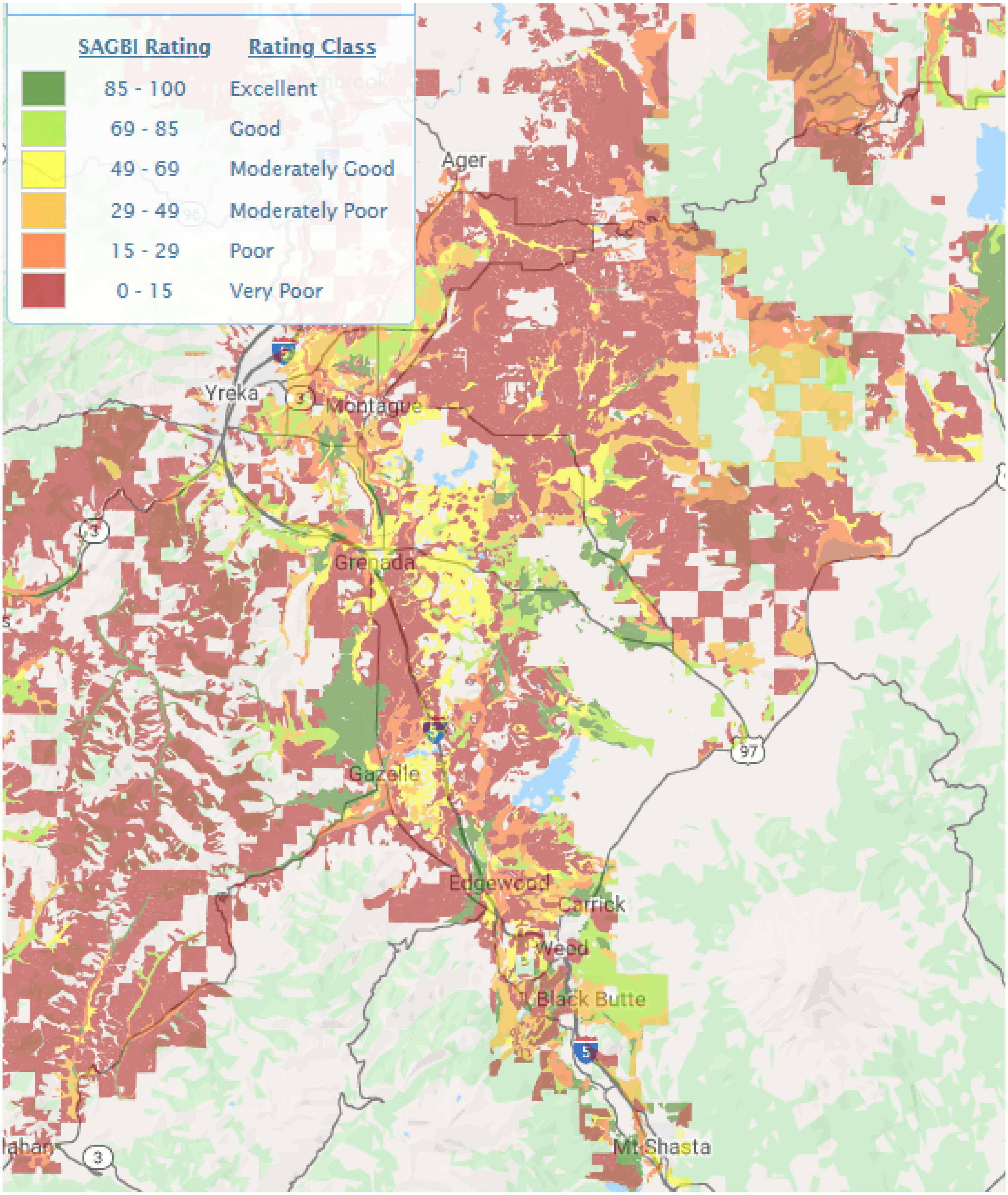


Figure 30: Modified Soil Agricultural Banking Index (SAGBI) of the greater Shasta Valley Groundwater Basin area. Modified overlay is theoretical; it shows SAGBI suitability groups when assuming that all soils with restrictive layers have been modified by deep tillage. Adapted from https://casoilresource.lawr.ucdavis.edu/sagbi/.

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. 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 (UCD 2010?).

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 Lake Shastina (Dwinnell Reservoir). 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 (i.e., upstream of Dwinnell Dam) originates on the eastern slope of the Mt. 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). **Feedback needed:** *How much seepage is estimated to occur under the lake? What were the specific improvements made in 1965?*

Flows in the lower Shasta River (i.e., 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). Instream flows downstream of Big Springs Creek confluence quickly rebound to spring-fed baseflow conditions following irrigation season (Nichols et al. 2010).

Dwinnell Dam (constructed in 1928) 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). The largest storage and delivery systems in the Shasta Basin are maintained by water service agencies or private water users which operate in accordance with the Watermaster service requirements (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 (April 1-September 30), 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 instream 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 gauges (stations SRM and SRY) are present in the Watershed with observed data spanning water years 1958 to 1978, and 2002 to 2016. Five additional gauging stations are maintained by DWR and are associated with sporadic data collection in two to three-year periods. Gauge locations in the Watershed are shown in Figure (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)." Table (?; Table: Summary of streamflow data quantity and quality in the Shasta Valley Groundwater Basin) 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 gauges 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 will be further 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.

Instream 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 instream flow needs in the Watershed (McBain & Trush 2013, CDFW 2017). The Instream 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: Historic stream flows at notable gauges along the Shasta River and Parks Creek). 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.

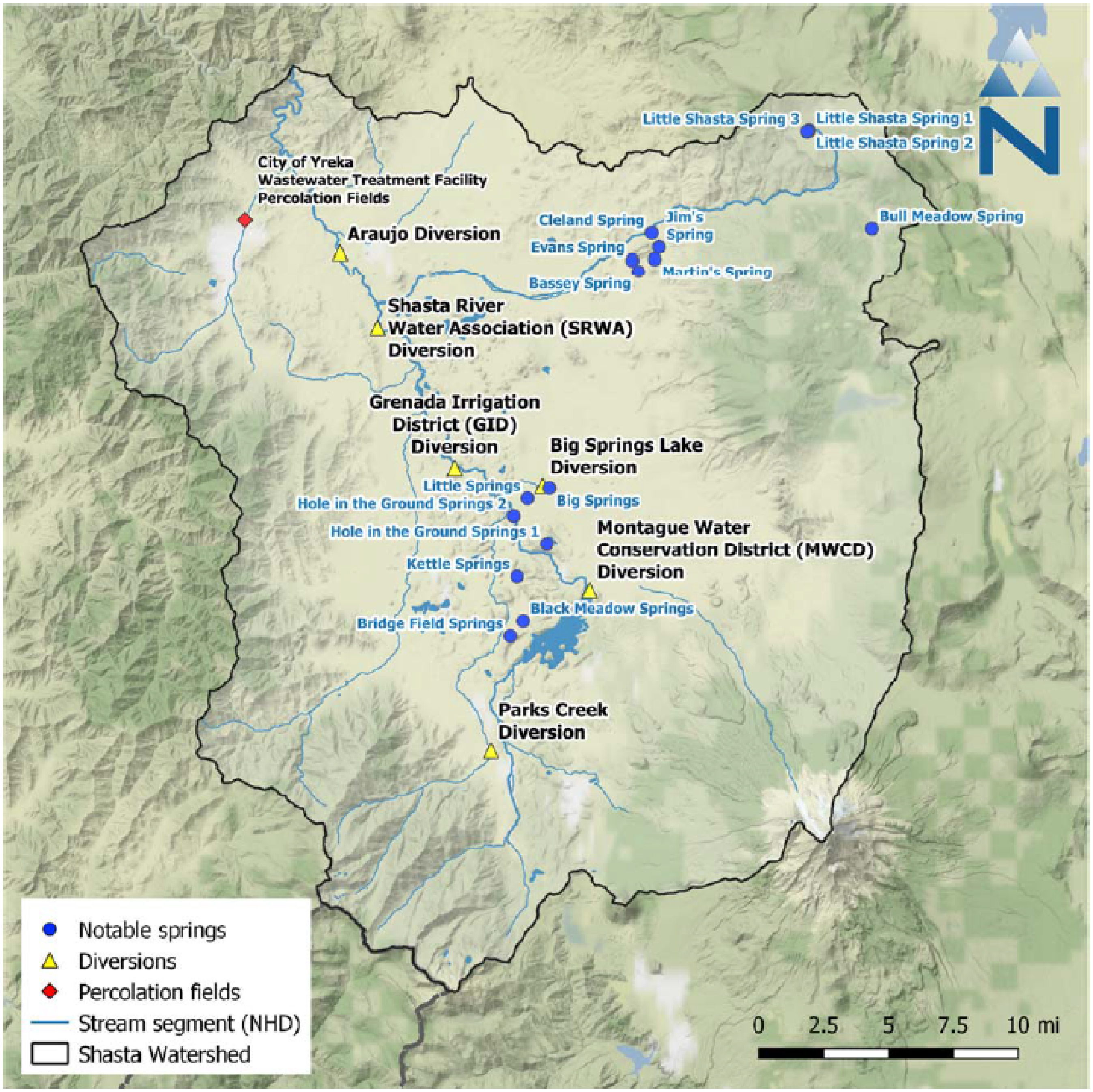


Figure 31: Notable hydrologic features of the Shasta River drainage basin. Reprinted from SWRCB (2018).

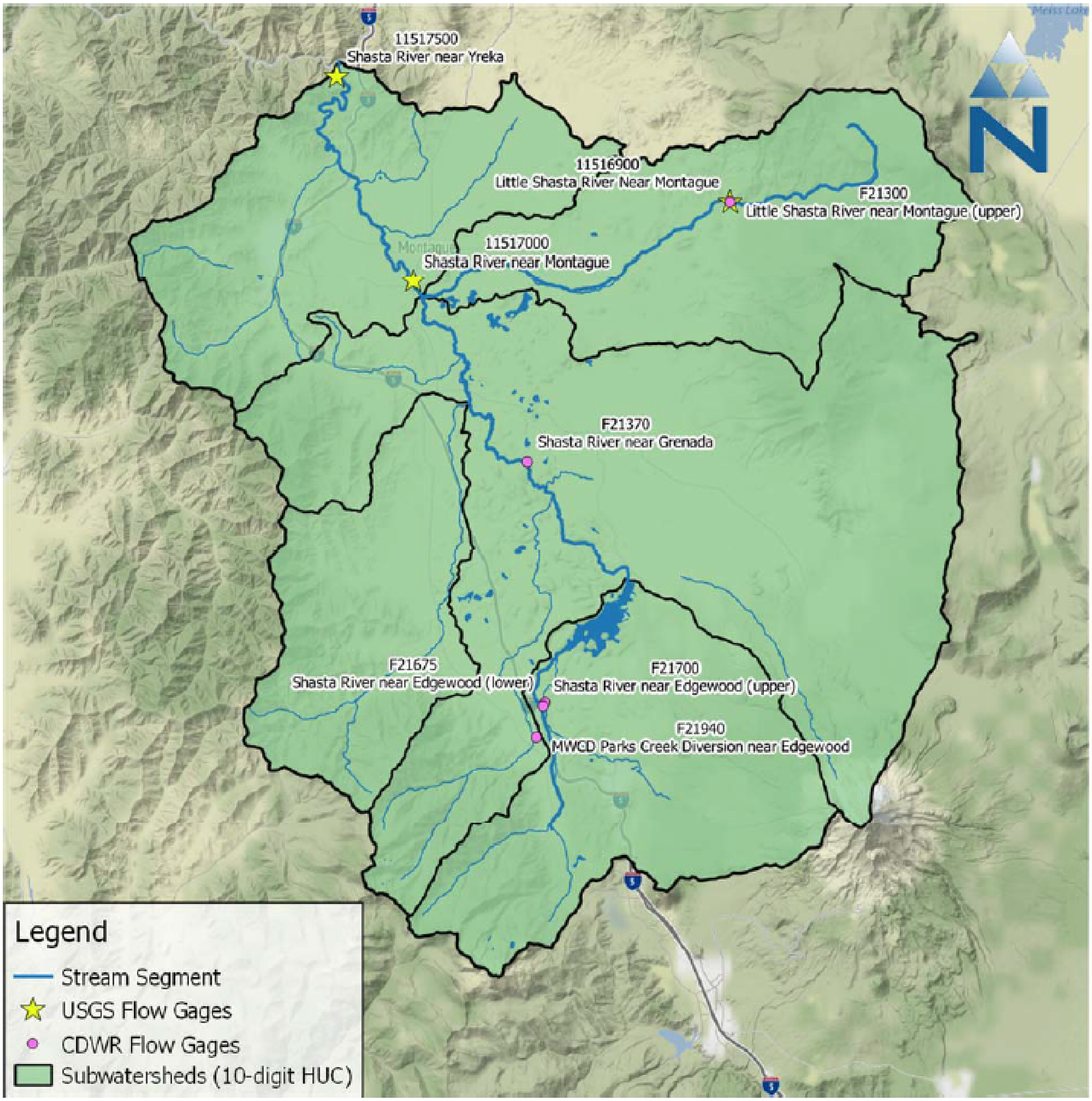


Figure 32: Flow gages in the Shasta River drainage basin. Reprinted from SWRCB (2018).

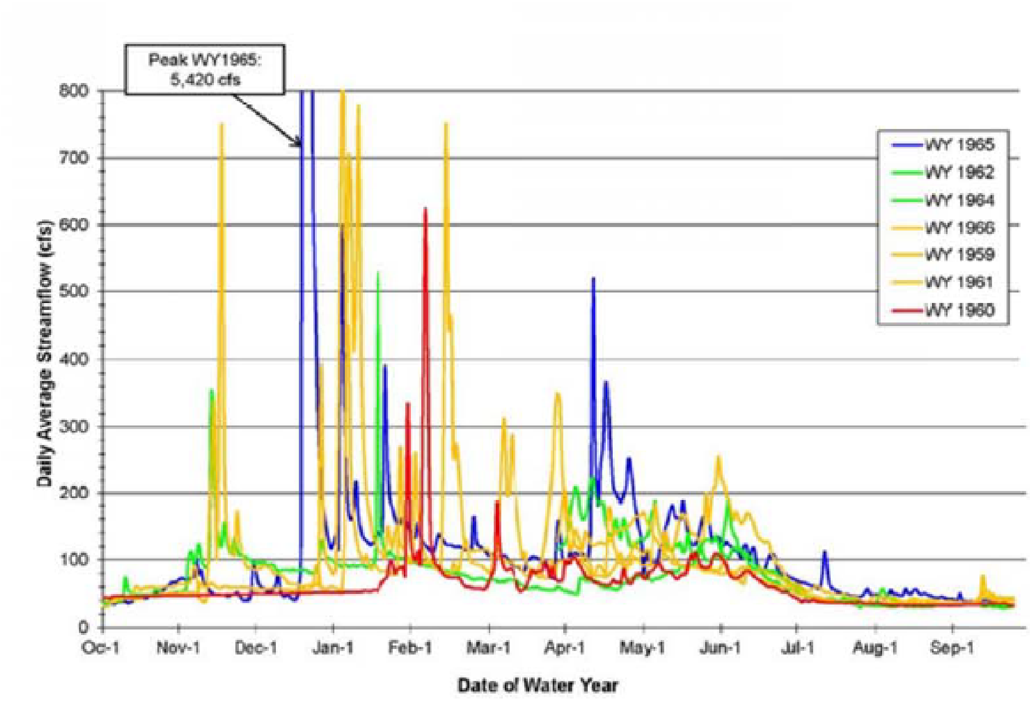


Figure 6. Estimated unimpaired annual hydrographs, for the Shasta River immediately downstre of the Parks Creek confluence in Reach No.3.

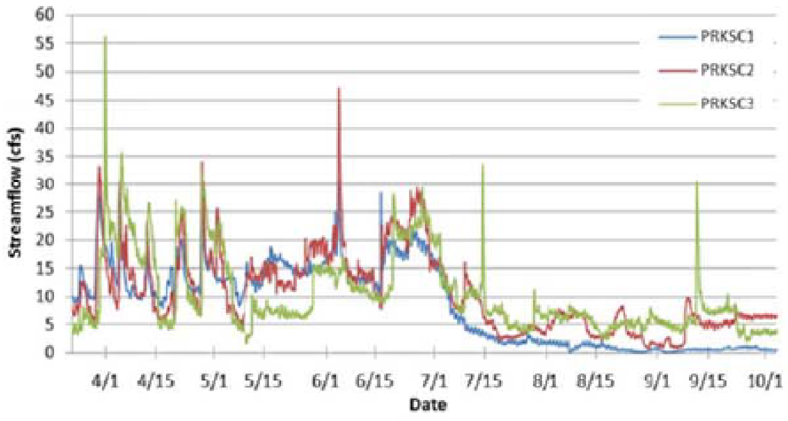


Figure 9. Observed streamflows for April 1 – October 1 2010, in Parks Creek.

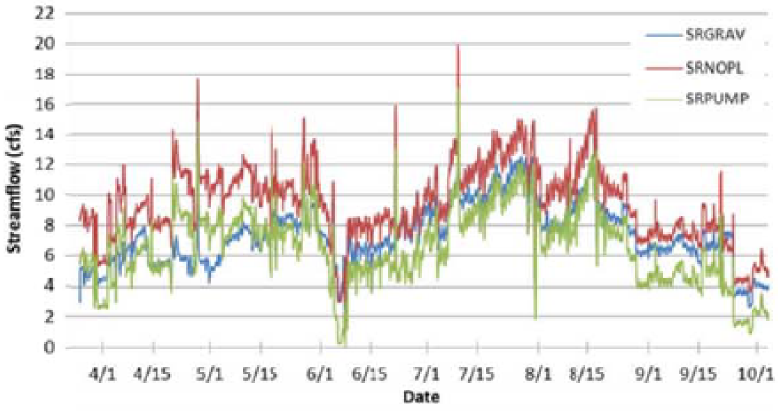
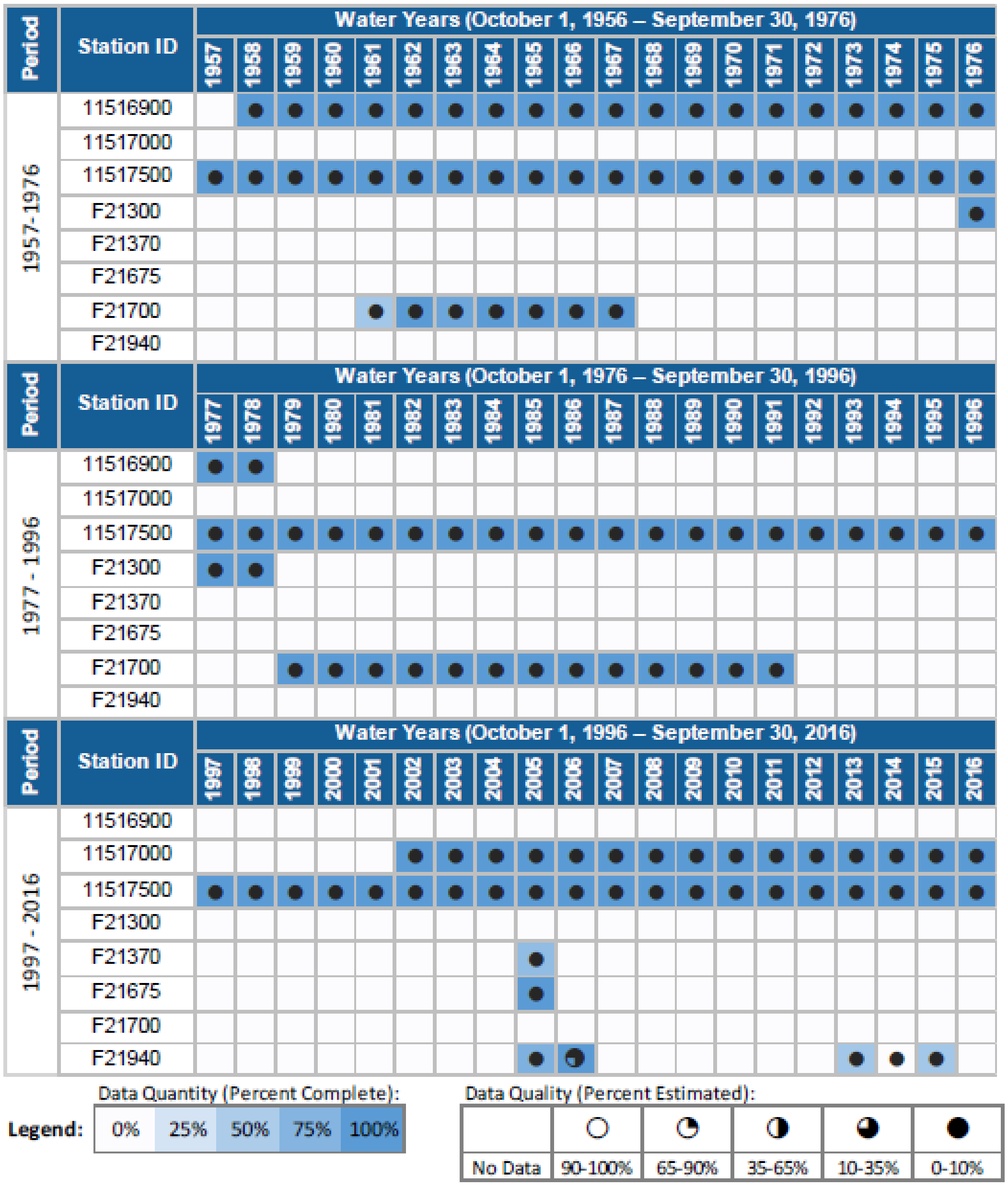


Figure 12. Observed streamflows for April 1 – October 1 2010, in the Shasta River above Parks Creek.

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 drainage basin. 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 Mt. 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 Mt. 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 at least 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. Groundwater level data are shown as surface contours in Figure 35 to Figure 38 (shown as Spring and Fall measurements for the years 2010, 2015, and 2020), as well as select hydrographs in Figure 40. 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.

The groundwater levels in the central to west-central portions of the Basin are largely shallow (<20-40 ft below ground surface). These areas are dominantly alluvial or debris avalanche (consists 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 northwest area of Gazelle has a deeper groundwater table likely due to shallower alluvium and increased usage of groundwater for irrigation purposes. The groundwater level in this area follows more closely to drought conditions than to seasonal variations. The eastern section of the Basin is dominated by volcanic aquifers whose groundwater levels are deeper (generally >60 ft 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 various deep volcanic aquifers present across much of the Basin. 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 and for instream flows for fish.

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 integrated hydrologic model results described in detail in Section 2.3.

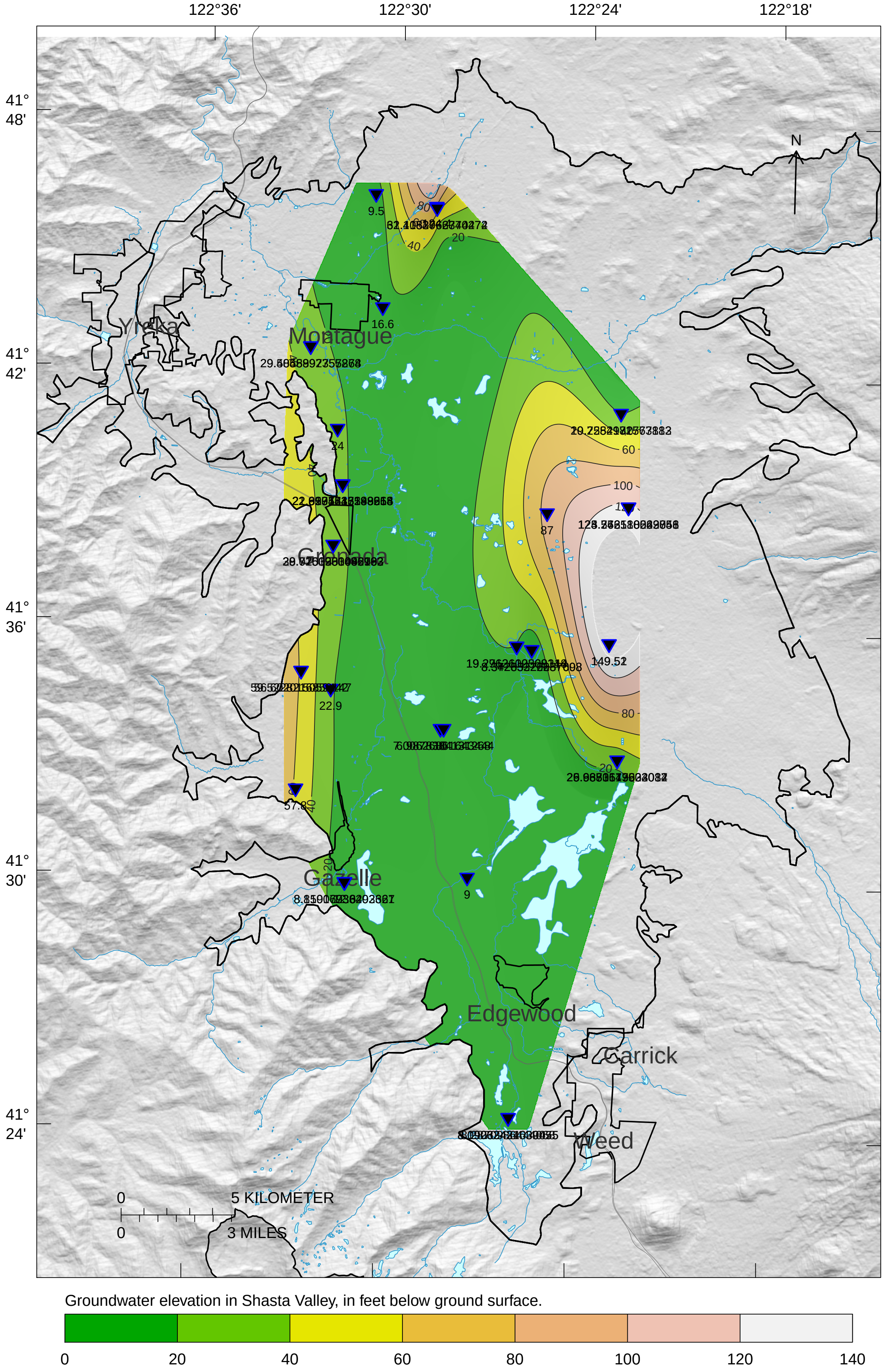


Figure 35: Shasta Valley Groundwater Elevations, Spring 2020

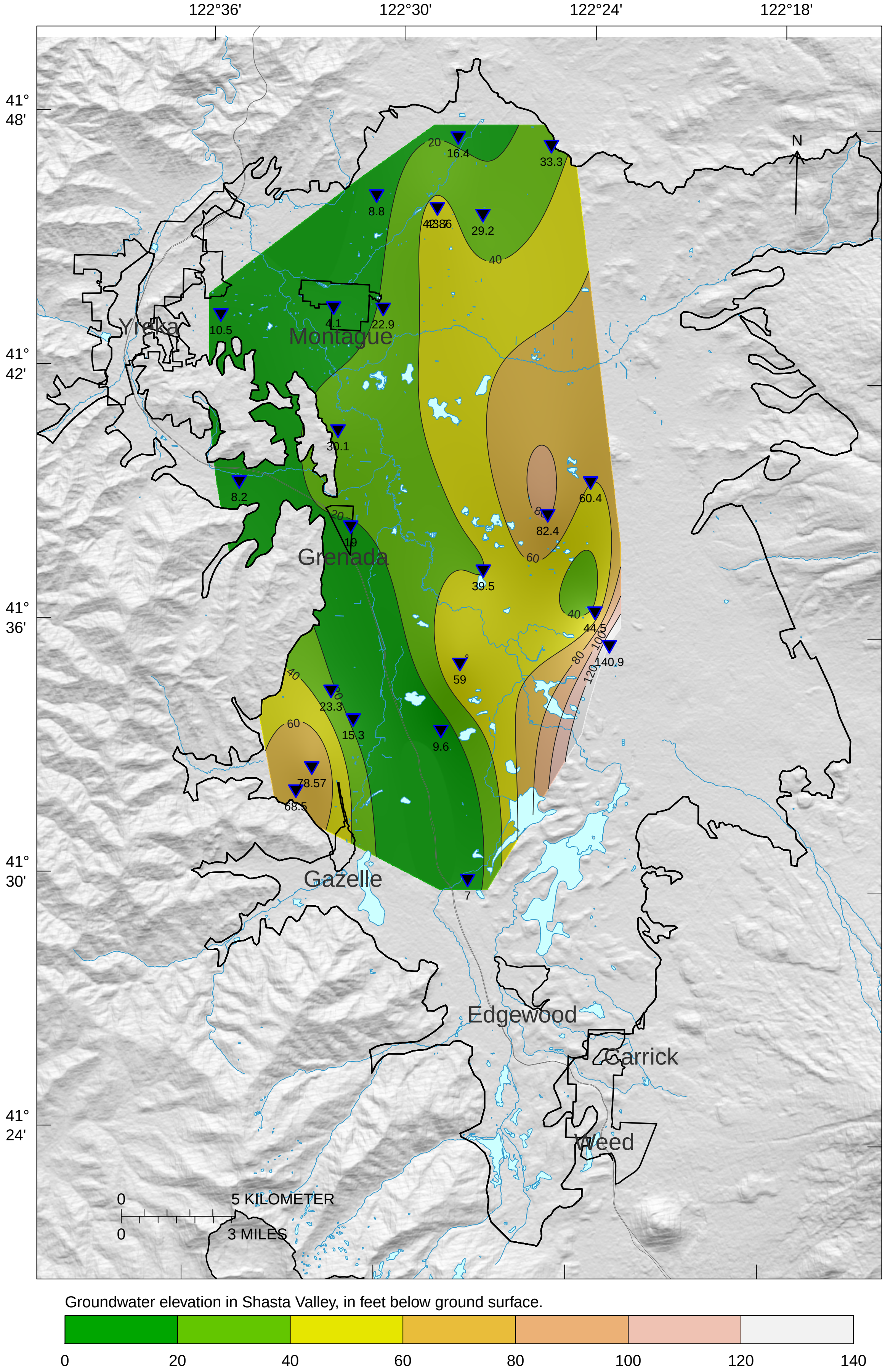


Figure 36: Shasta Valley Groundwater Elevations, Spring 2015

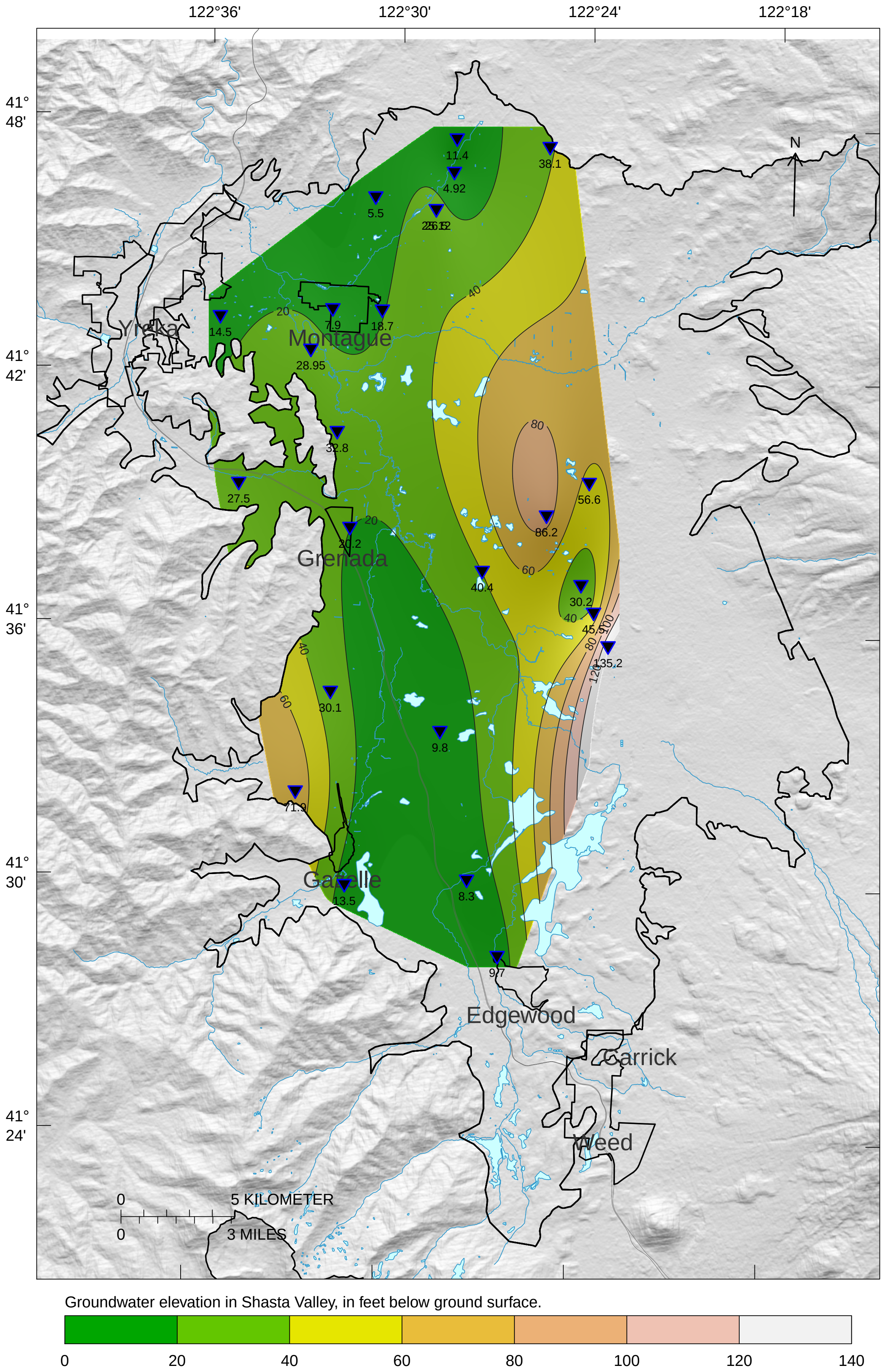


Figure 37: Shasta Valley Groundwater Elevations, Fall 2015

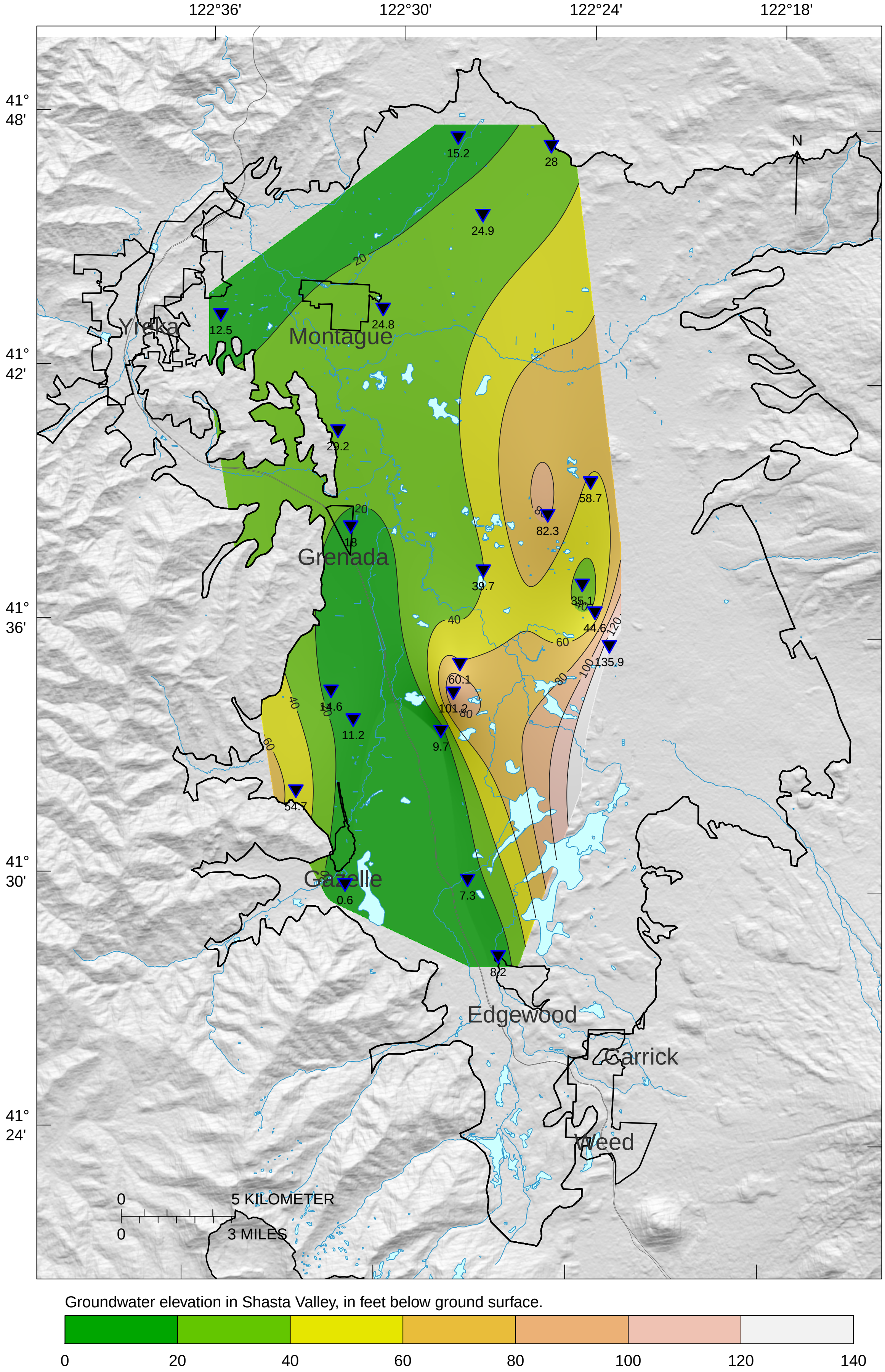


Figure 38: Shasta Valley Groundwater Elevations, Spring 2010

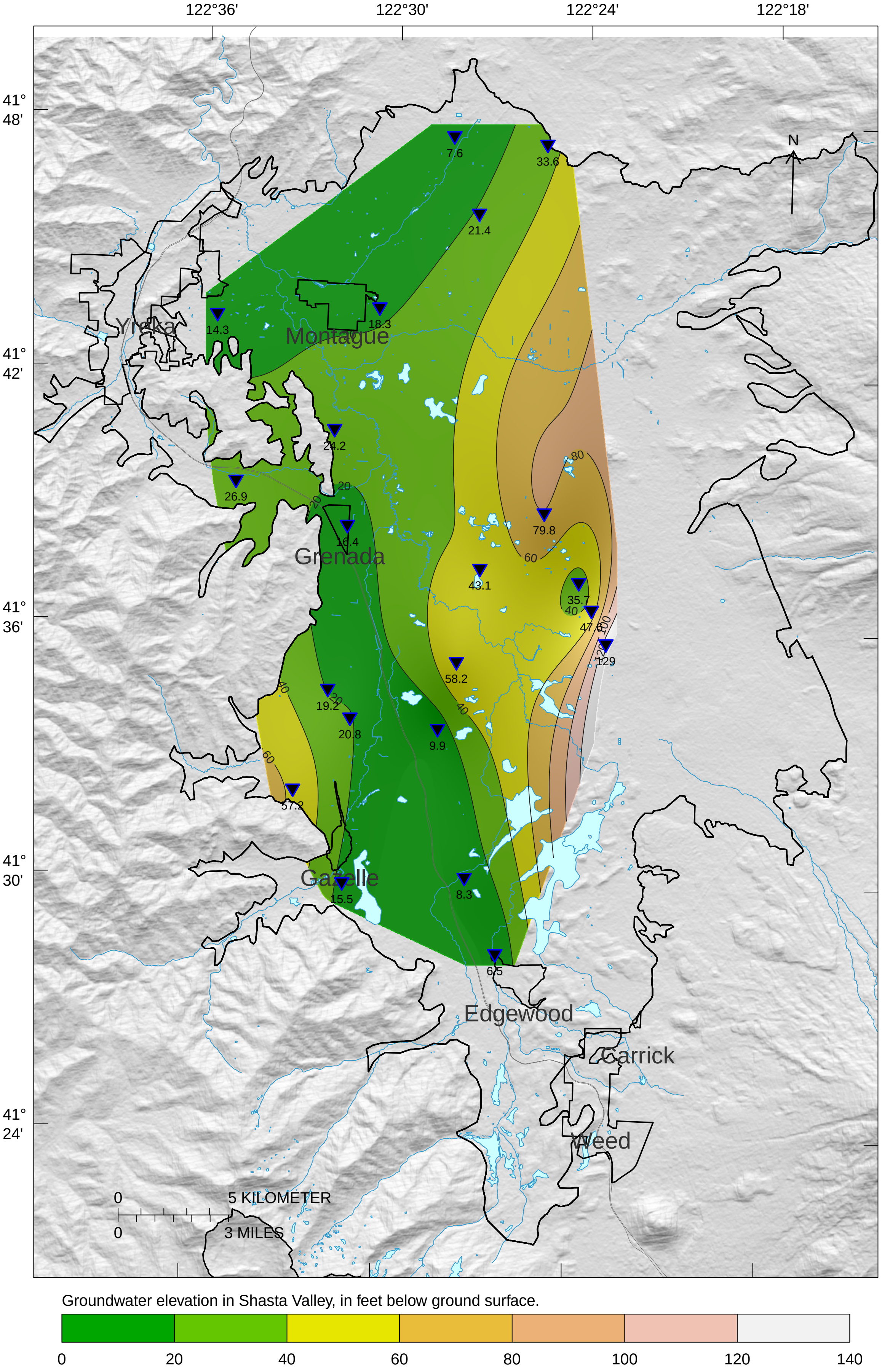


Figure 39: Shasta Valley Groundwater Elevations, Fall 2010

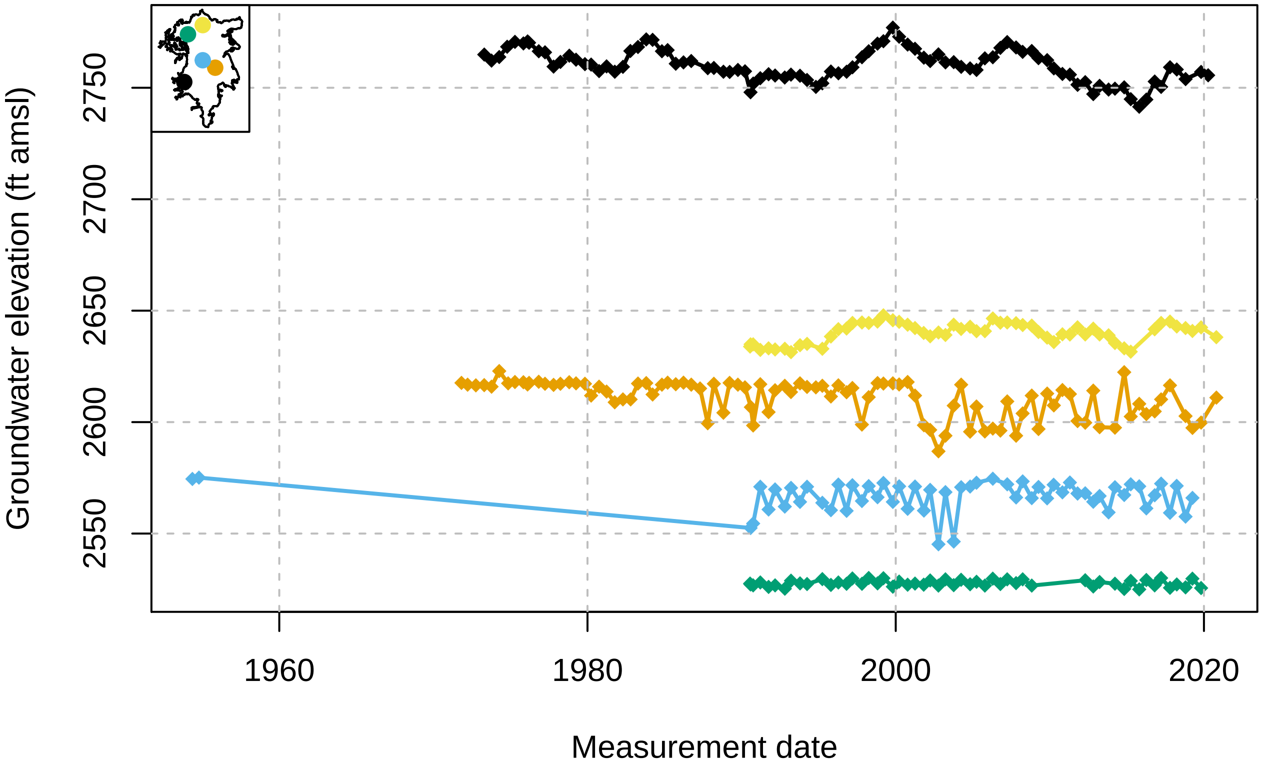


Figure 40: Groundwater elevation measurements over time in five wells, one located in each hydrogeologic zone.

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 2in- (5 cm) or 4 in- (10 cm) diameter PVC pipes and screened at or near the water table. They may have multiple completion depths (multi-level monitoring), but depths typically do not exceed 200 ft (60 m) below the water table.

Data Sources for Characterizing Groundwater Quality

The assessment of groundwater quality for the Basin was prepared using available information obtained from the California Groundwater Ambient Monitoring and Assessment (GAMA) Program database, which includes water quality information collected by the California Department of Water Resources (DWR); State Water Resources Control Board (SWRCB), Division of Drinking Water (DDW); Lawrence Livermore National Laboratory (LLNL) special studies; and the United States Geological Survey (USGS). 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 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. Time-series 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^o 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 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 41.

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 RWQCB 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 RWQCB 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.

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 42). 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 42), they are all either located on basement rock or are too far from the basin to be relevant for subsidence monitoring.

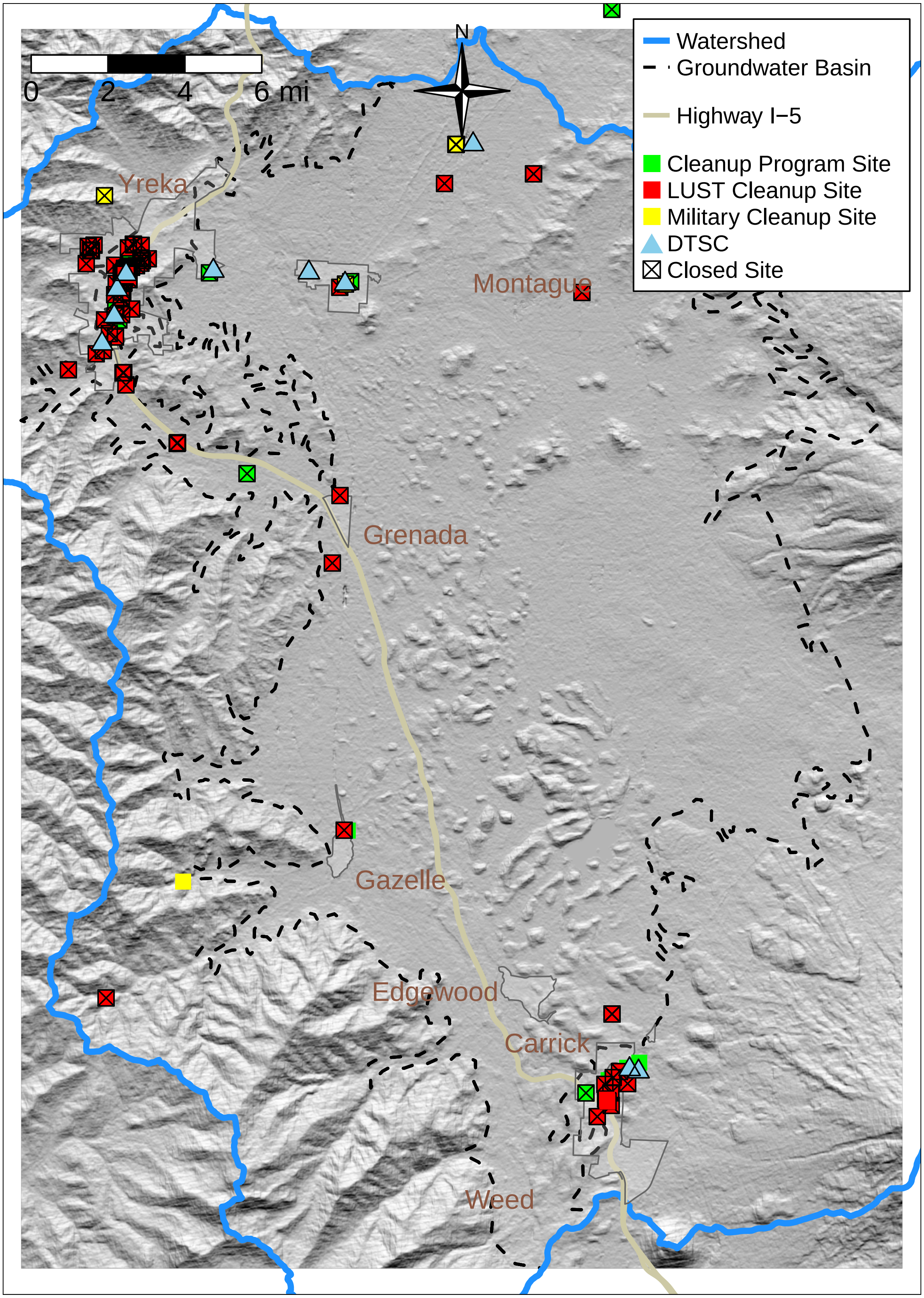


Figure 41: Contaminated Sites

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 42 using raster data from the TRE Altamira report [DWR2019c]. 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 42]). 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.

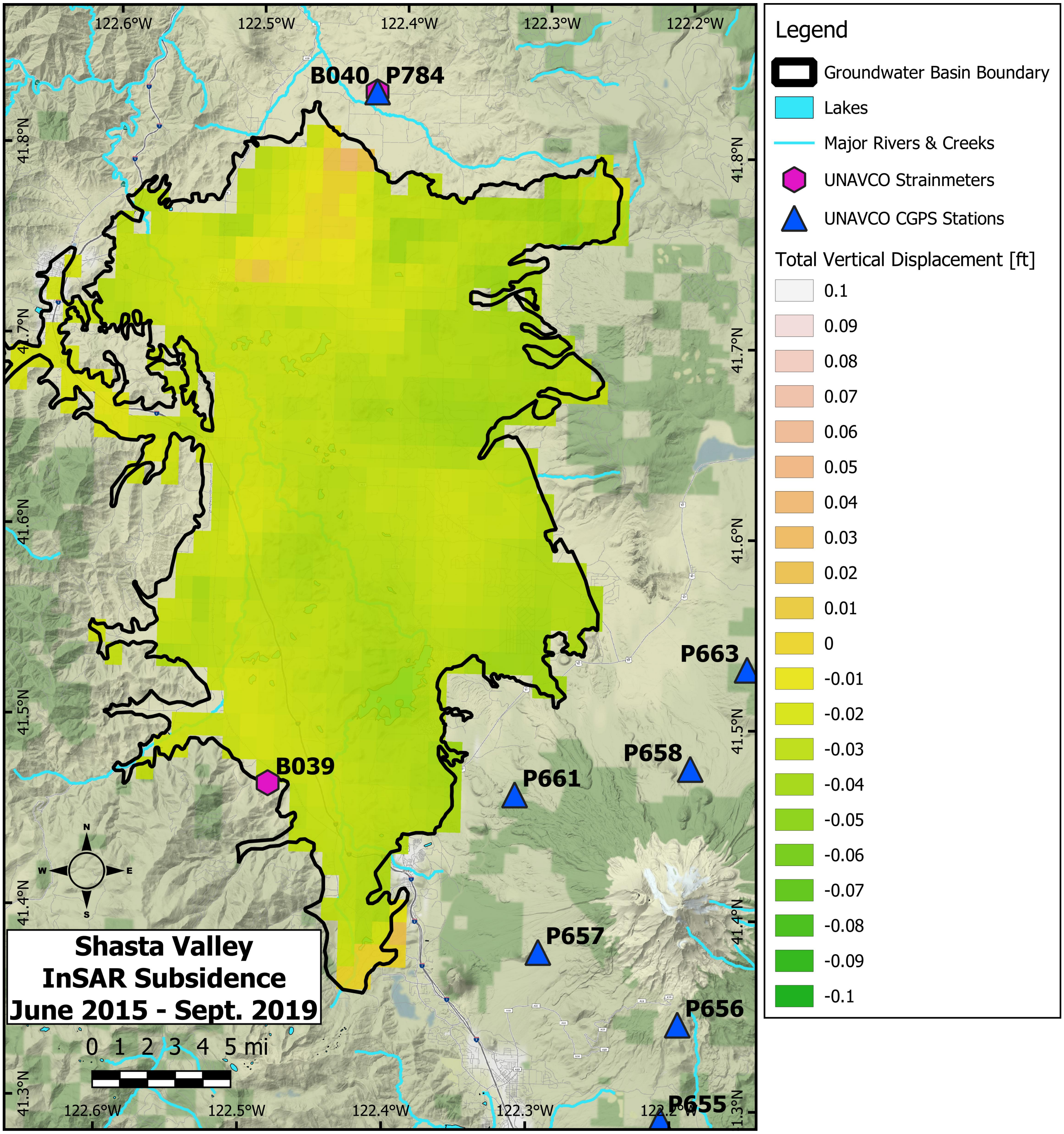


Figure 42: InSAR Total Subsidence (in feet) between 6.2015 and 9.2019

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 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 Mt. Shasta and other Cascade volcanic mountains (Figure 43). 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 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).

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

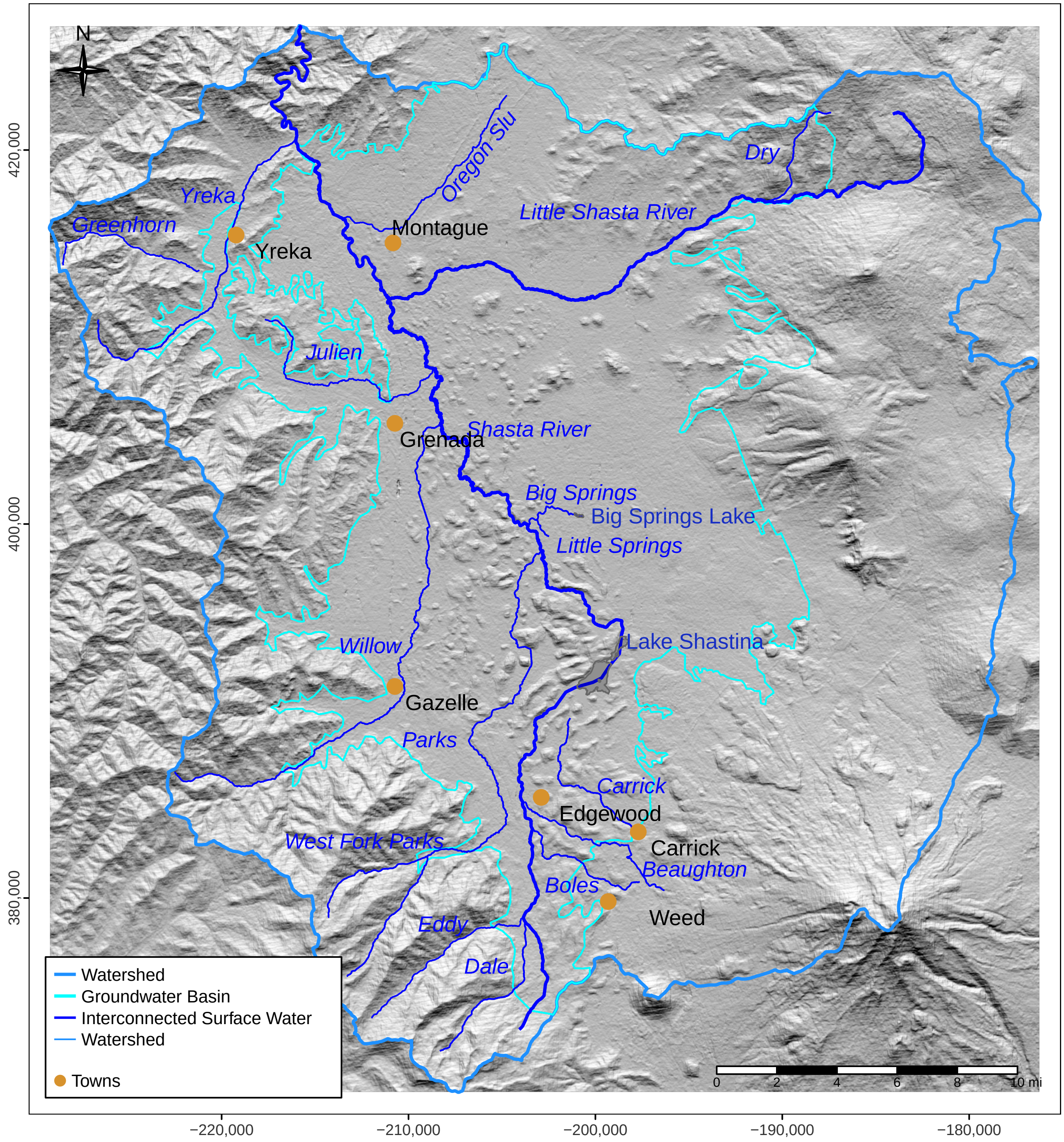


Figure 43: Major interconnected surface waters in the Shasta Valley groundwater basin includes the Shasta River tributaries and Lake Shastina and Big Springs Lake.

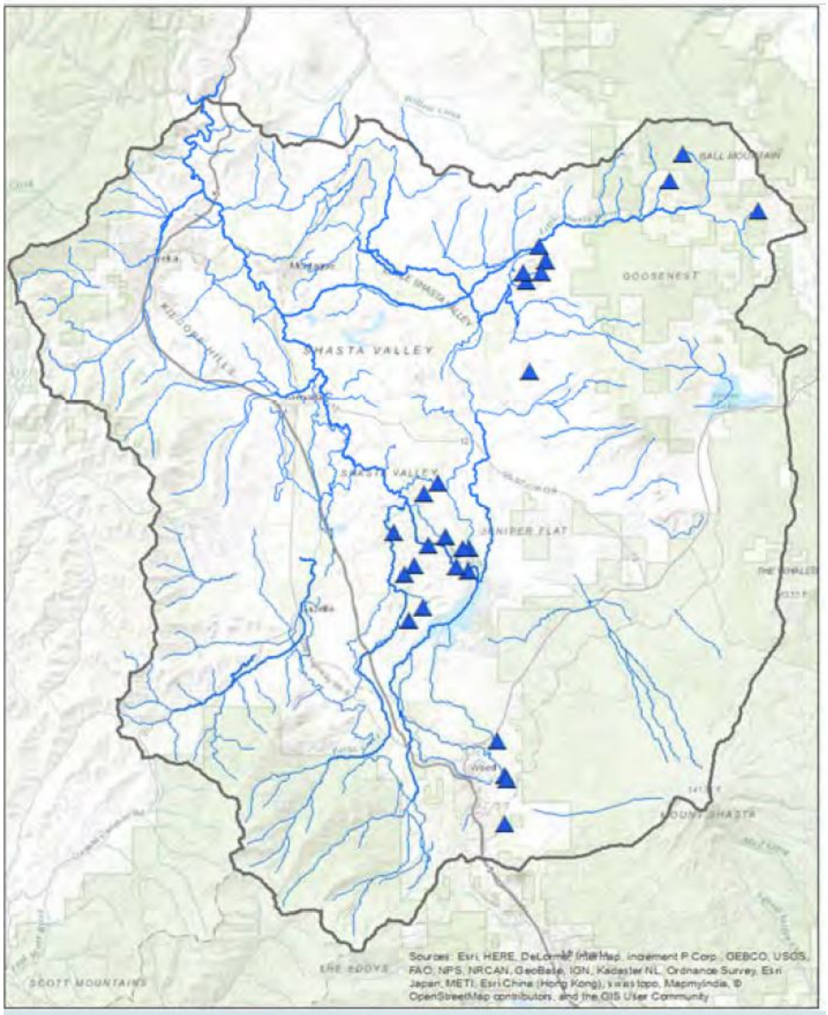
mainstem Shasta River is alternately gaining and losing depending on the season, on the location, and on the year type. In other words, river water weaves in and out of the aquifer on its journey north to south along the valley floor. When considered as a whole, the mainstem of the Shasta River is a 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.

Springs

Springs feed surface waters on the east side of the watershed due to the volcanic geology (Figure 44). The Plutos 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 Plutos 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 43). 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 44: Major springs in Shasta Valley (Shasta Watershed).

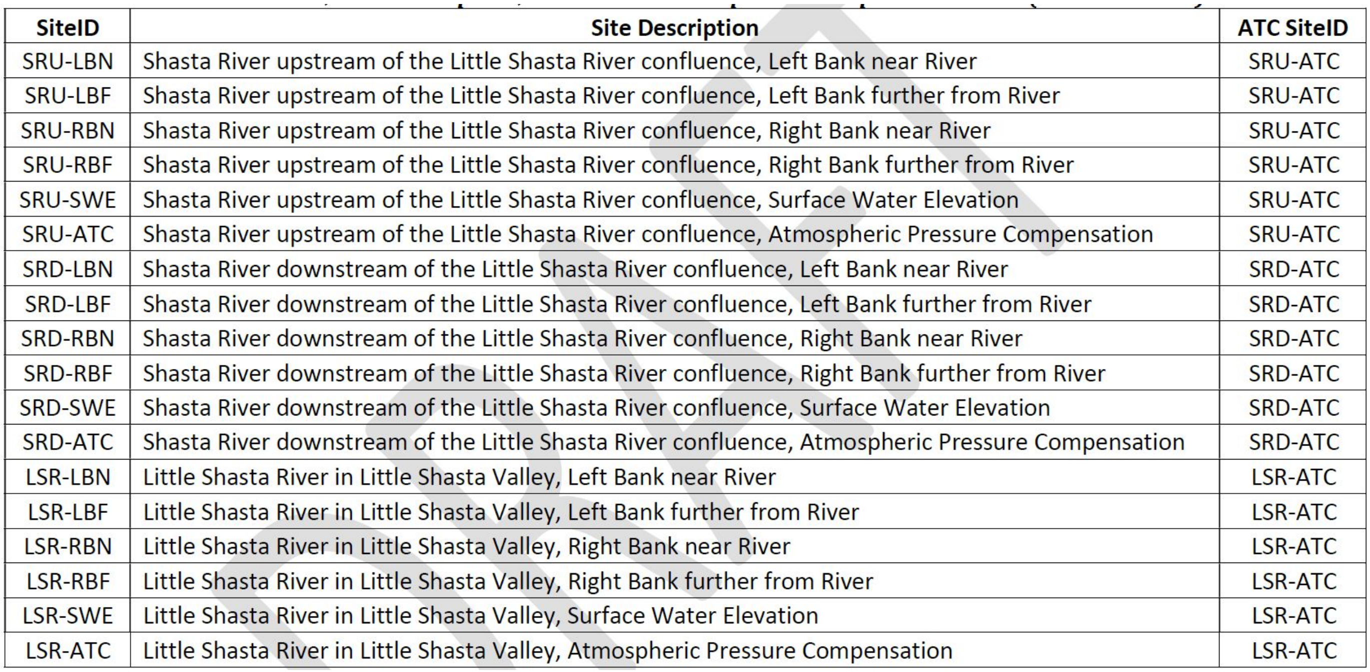
Transect Study

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 46). 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 45).



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 45: The SiteID, site name, and location of each site (David's Engineering 2020).

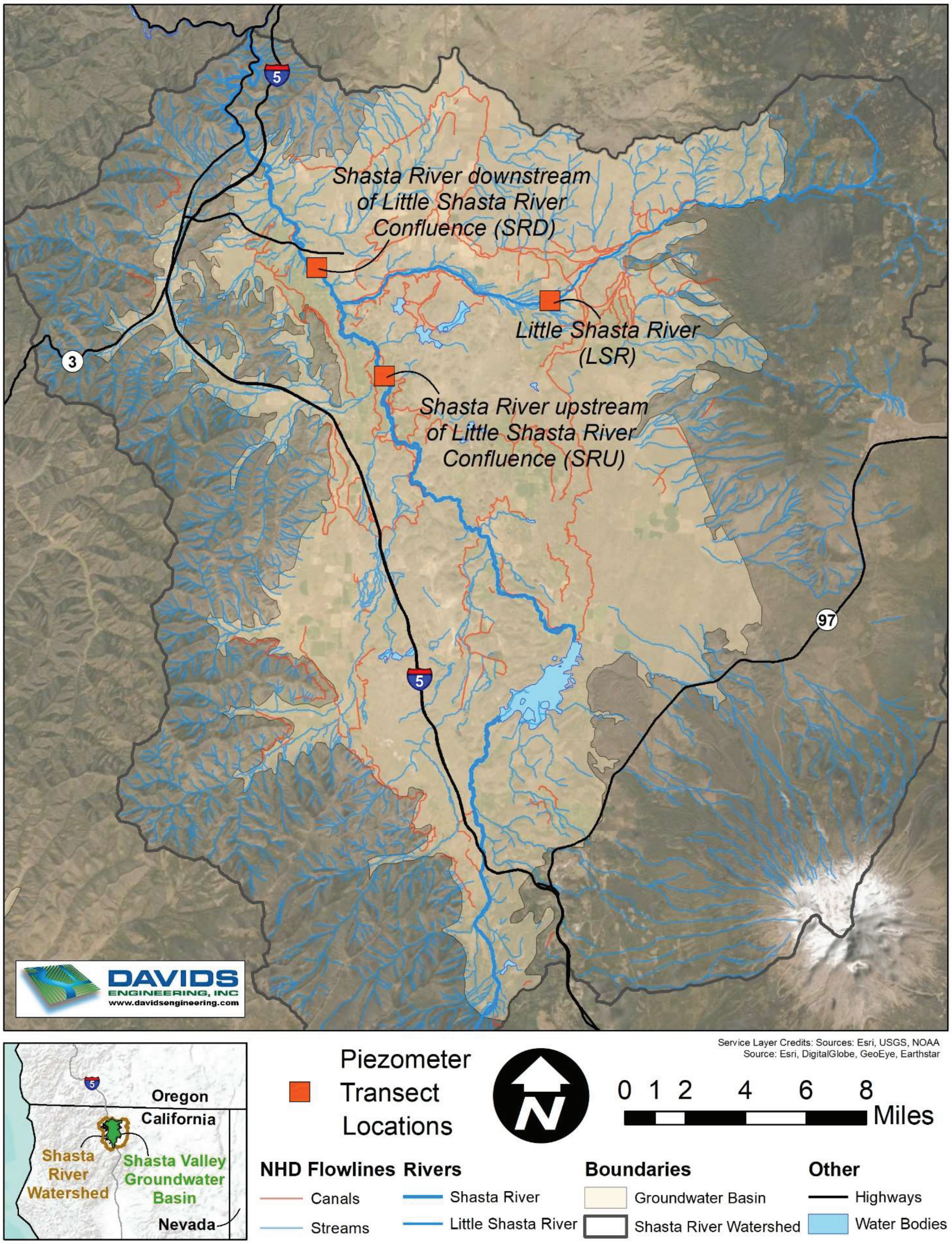


Figure 46: Approximate Location of Piezometer Transects within the Shasta Valley (David's Engineering 2020).

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 47) (David's Engineering 2020).

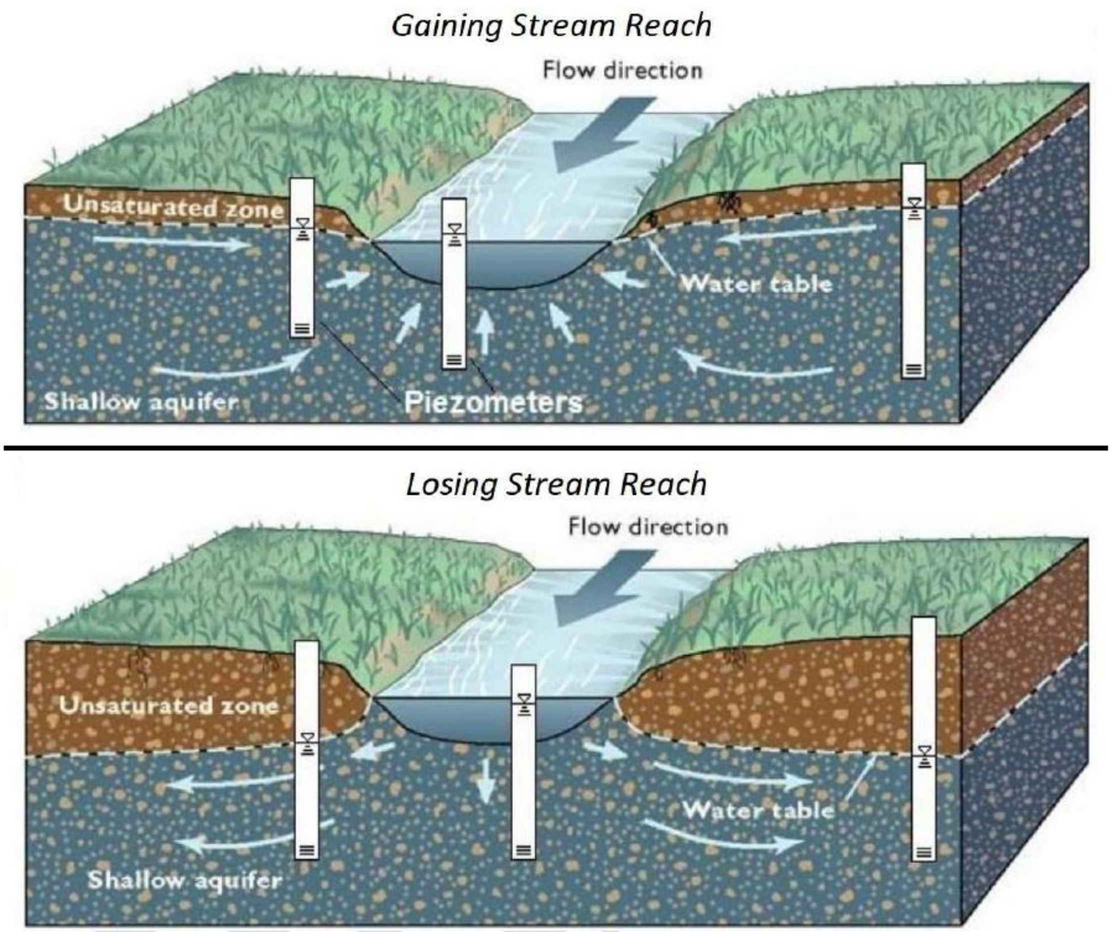


Figure 2. Conceptual Diagram of Piezometers in Gaining and Losing Stream Reaches (Modified from Winter et al., 1999).

Figure 47: Conceptual Diagram of Piezometers in Gaining and Losing Stream Reaches (Modified from Winter et al., 1999) (David's 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 (David's Engineering 2020).

With the exception of the RBN piezometer in late July and early August, all piezometers showed higher water surface elevations during the study period (Figure 49). 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 (David's Engineering 2020).

Shasta River Downstream of Little Shasta River Confluence (SRD)

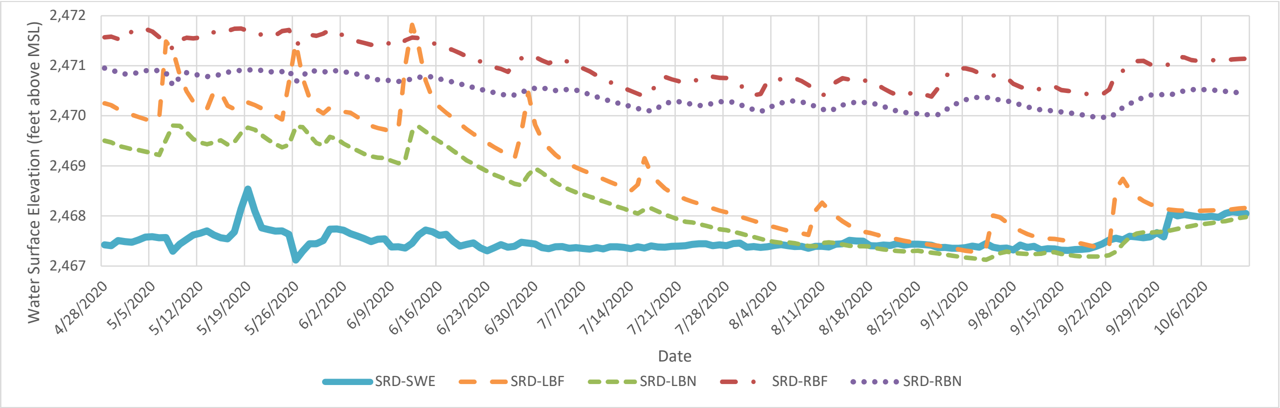
The river stage remained steady during the study period, excluding fluctuations in May. There was also an increase in stage in late September and early October, potentially coinciding with the end of the irrigation season and cessation of upstream diversions. Groundwater elevations in the piezometers 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 (David's 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 48). 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 (David's Engineering 2020).

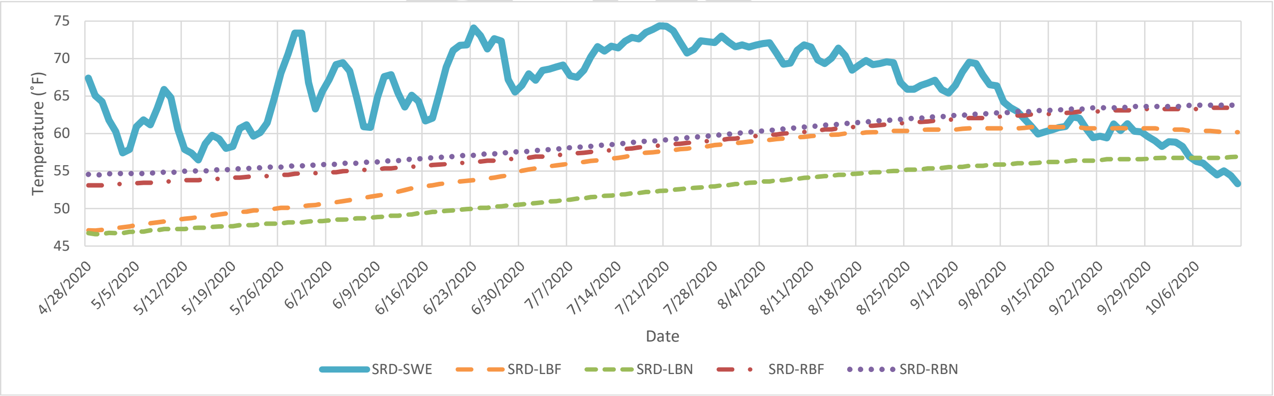
Little Shasta River in Little Shasta Valley (LSR)

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 (David's 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 50). These results indicate that the Little Shasta River was losing in the transect location over the study period (David's Engineering 2020).



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

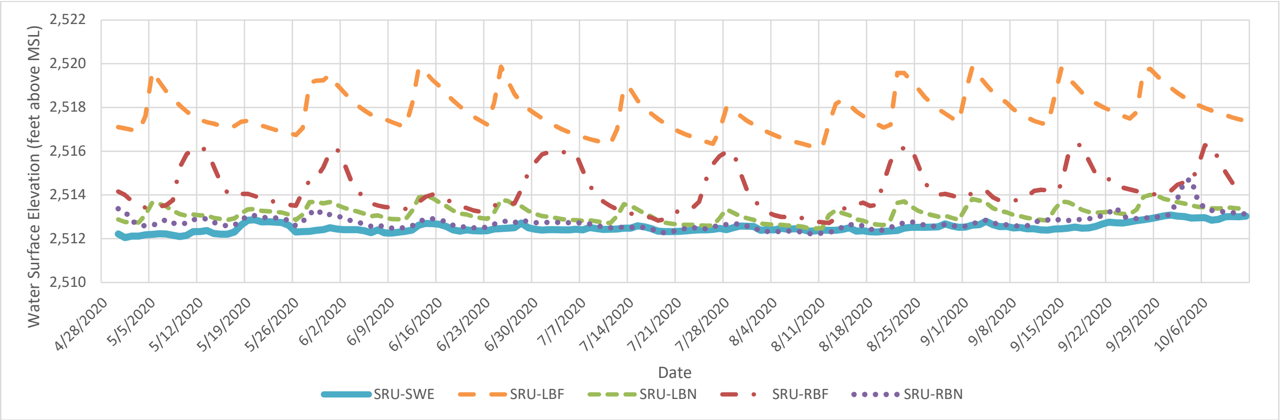


Daily Average Temperatures at Shasta River Downstream of Little Shasta River Confluence (SRD) Transect.

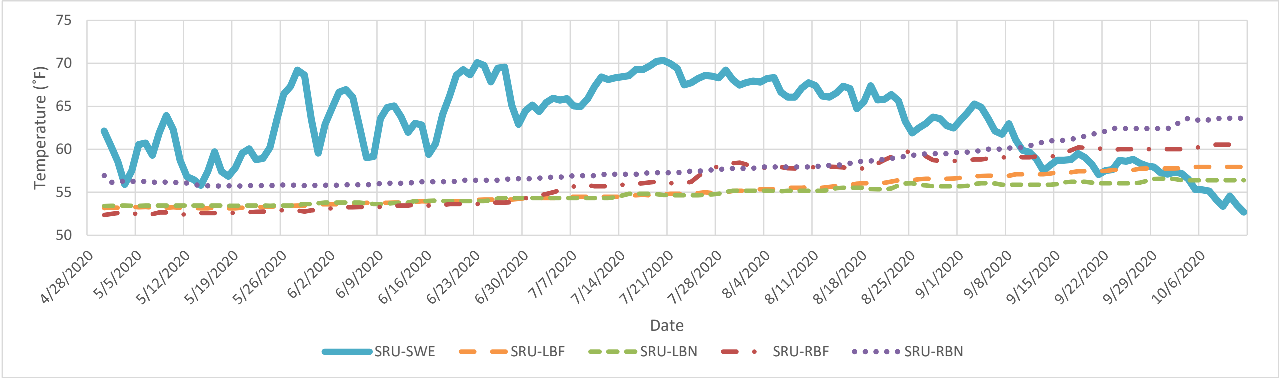
Davids Engineering

Shallow Piezometer
Transect Study

Figure 48: Study data from the Downstream Shasta River transect (David's Engineering 2020).



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

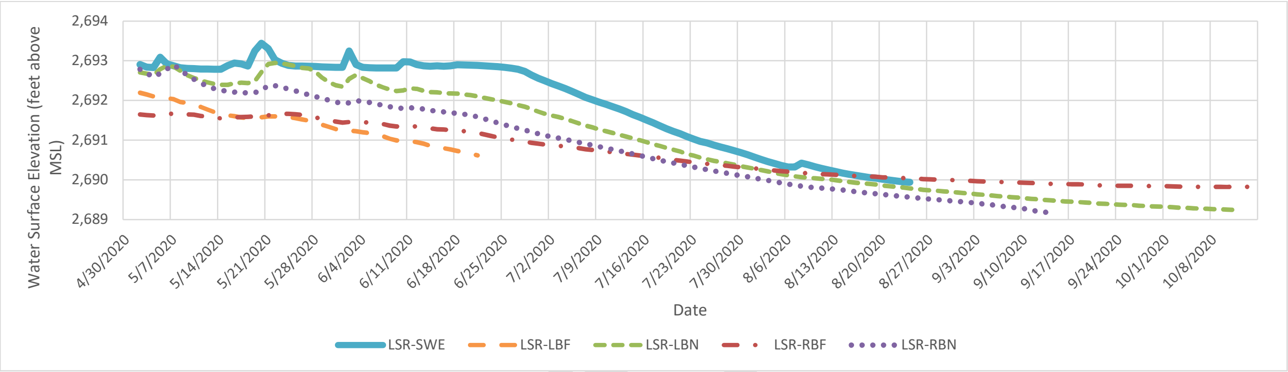


Daily Average Temperatures at Shasta River Upstream of Little Shasta River Confluence (SRU) Transect.

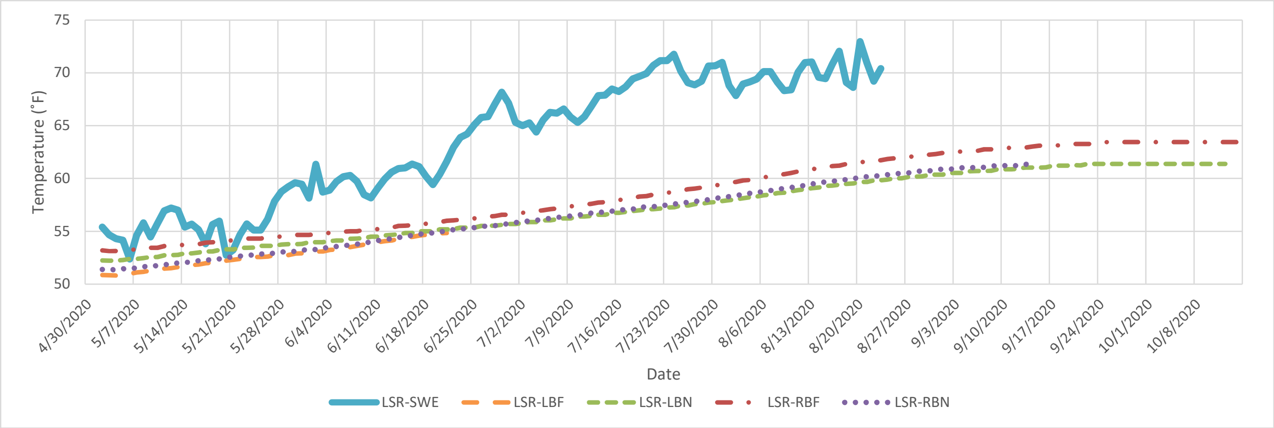
Davids Engineering

Shallow Piezometer
Transect Study

Figure 49: Study data from the Upstream Shasta River transect (David’s 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 50: Study data from the Little Shasta River in Little Shasta Valley transect (David's Engineering 2020).

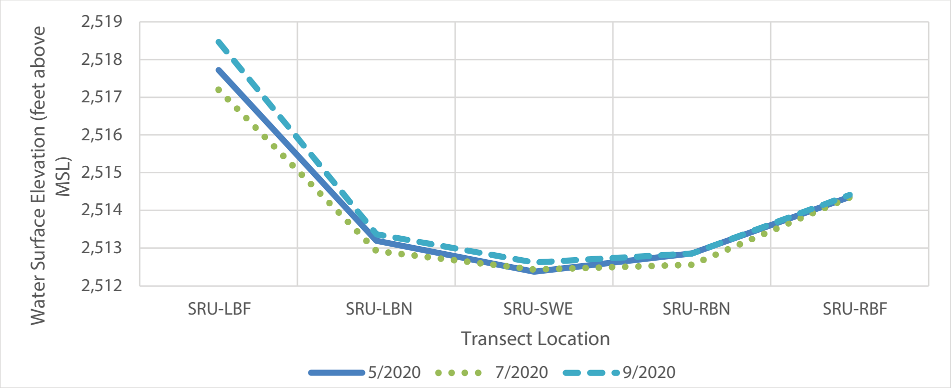
Average Monthly Water Elevations During May, July, and September 2020

Each transect had differing trends in water surface elevation (Figure 51). 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 (David's Engineering 2020).

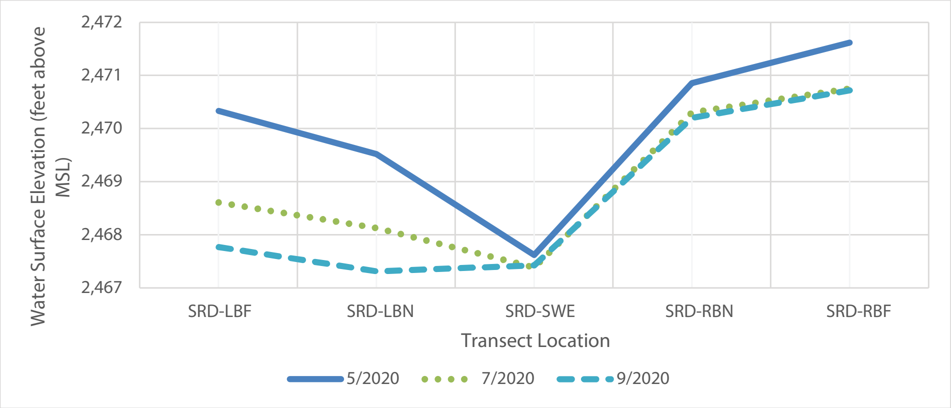
Summary

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.

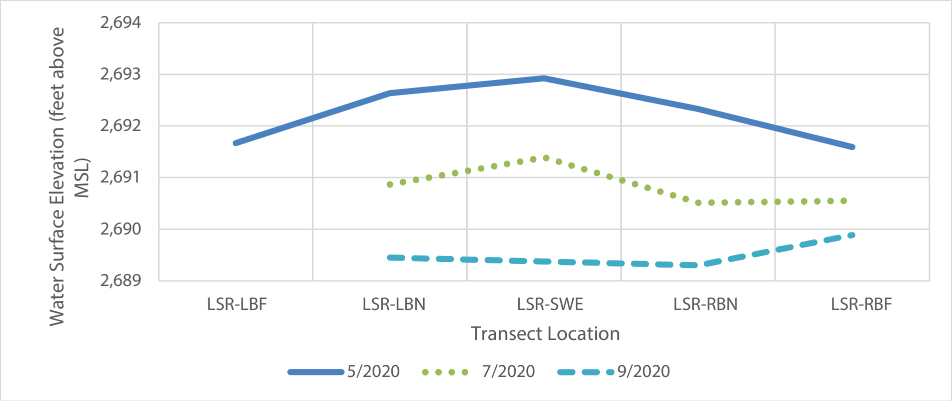
Temperature differences varied between the transects, but overall showed the same general trends. The shallow groundwater was lower in temperature at the start of the study in May 2020 (e.g. negative values), and the differences increased into the summer as surface water temperatures increased more rapidly 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 (David's 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 51: 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 (David's 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 52).

[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 irrigation diversions or 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.

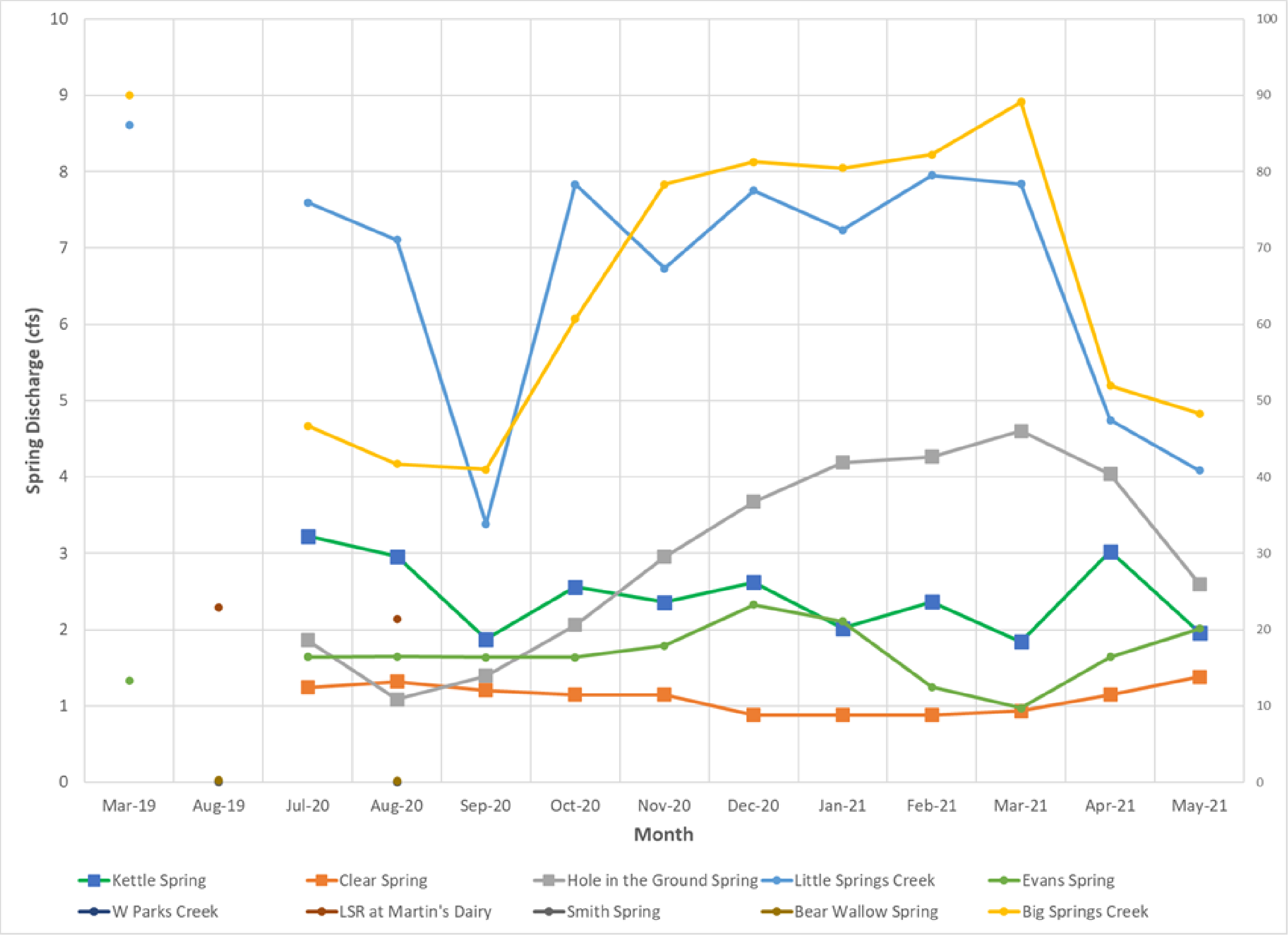


Figure 52: Monthly spring discharge measurement results. Please note that only Big Springs Creek discharge corresponds to the secondary vertical axis values. Please also note that the horizontal axis is not at regular intervals (Shasta Valley Resource Conservation District 2021).

2.2.2.7 Identification of Groundwater-Dependent Ecosystems

Section 354.16(g) of the GSP Regulations 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 Groundwater Sustainability Plan describes and considers the impacts to GDEs.

To adequately consider potential effects of the regional aquifer system's operations 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 53):

- 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.

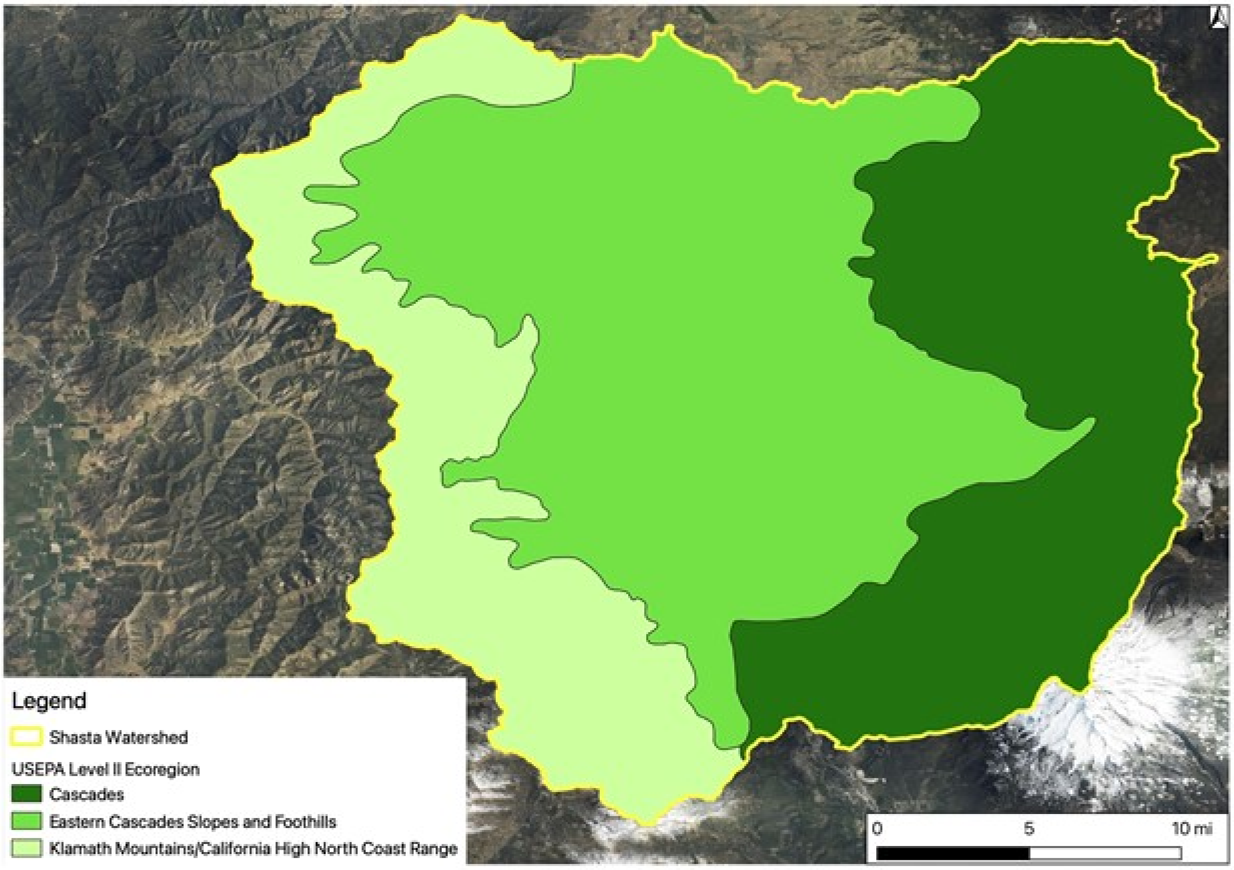


Figure 53: Ecoregions in Shasta Watershed

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.

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
Riparian vegetation	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 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 instream flows addressed in the interconnected surface water (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 54 and Figure 55, respectively.

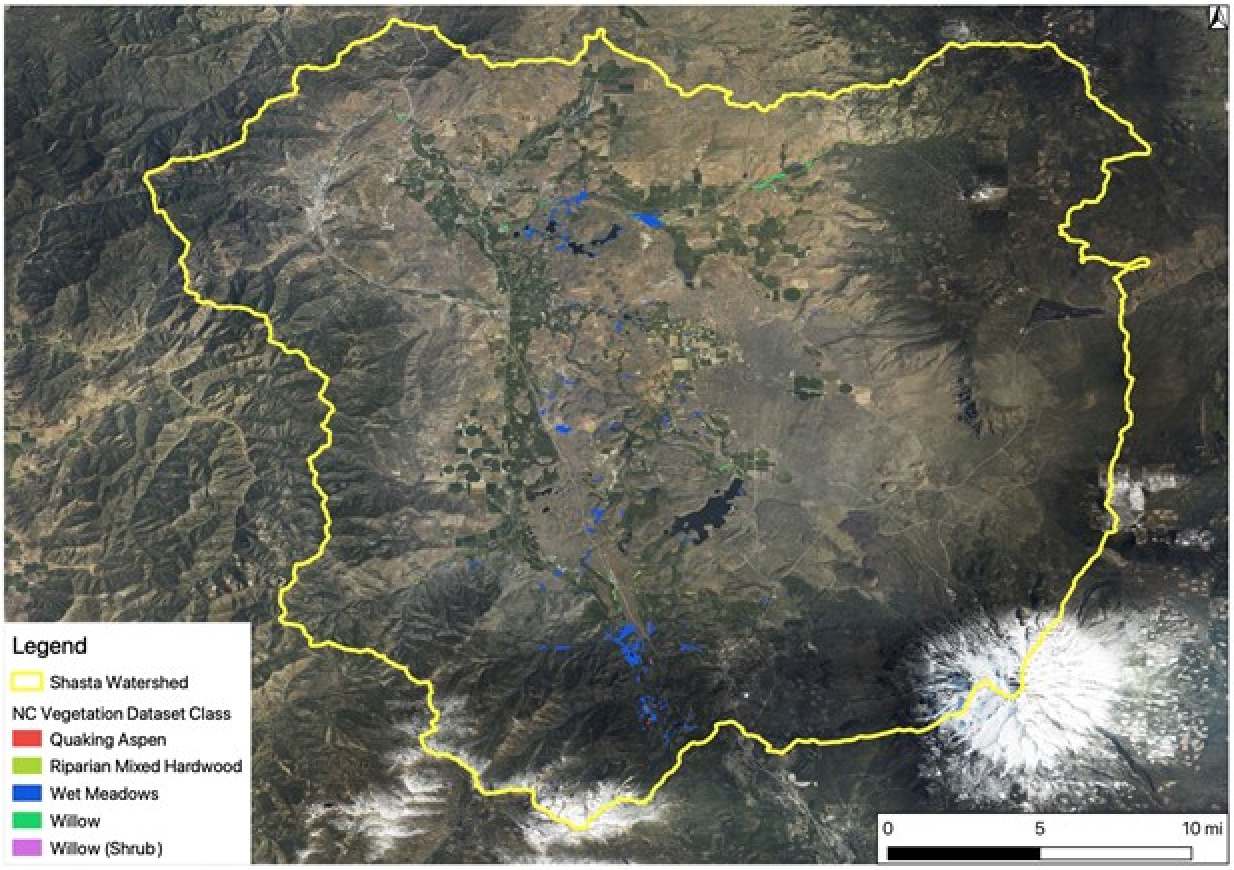


Figure 54: Classes Within NCCAG Vegetation Dataset for the Shasta Watershed.

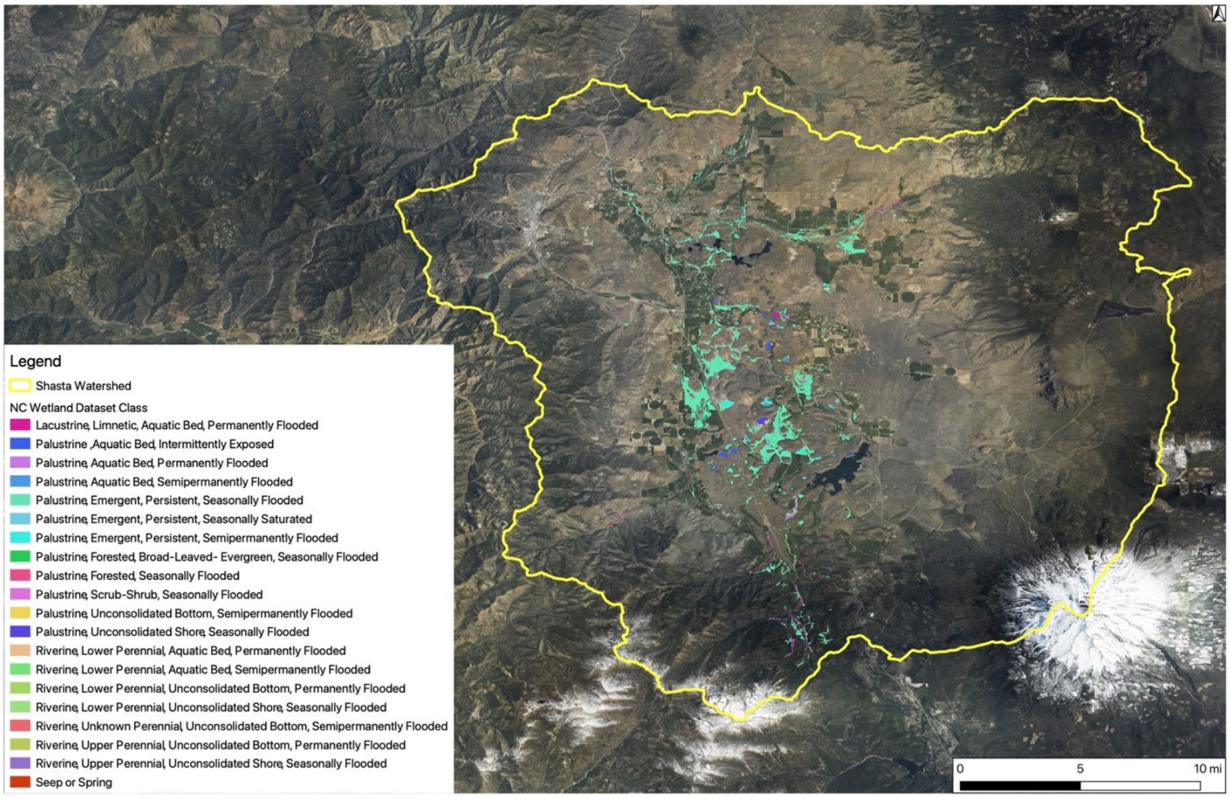


Figure 55: Classes Within NCCAG Wetland Dataset for the Shasta Watershed.

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 instream 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 56 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 57.

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:

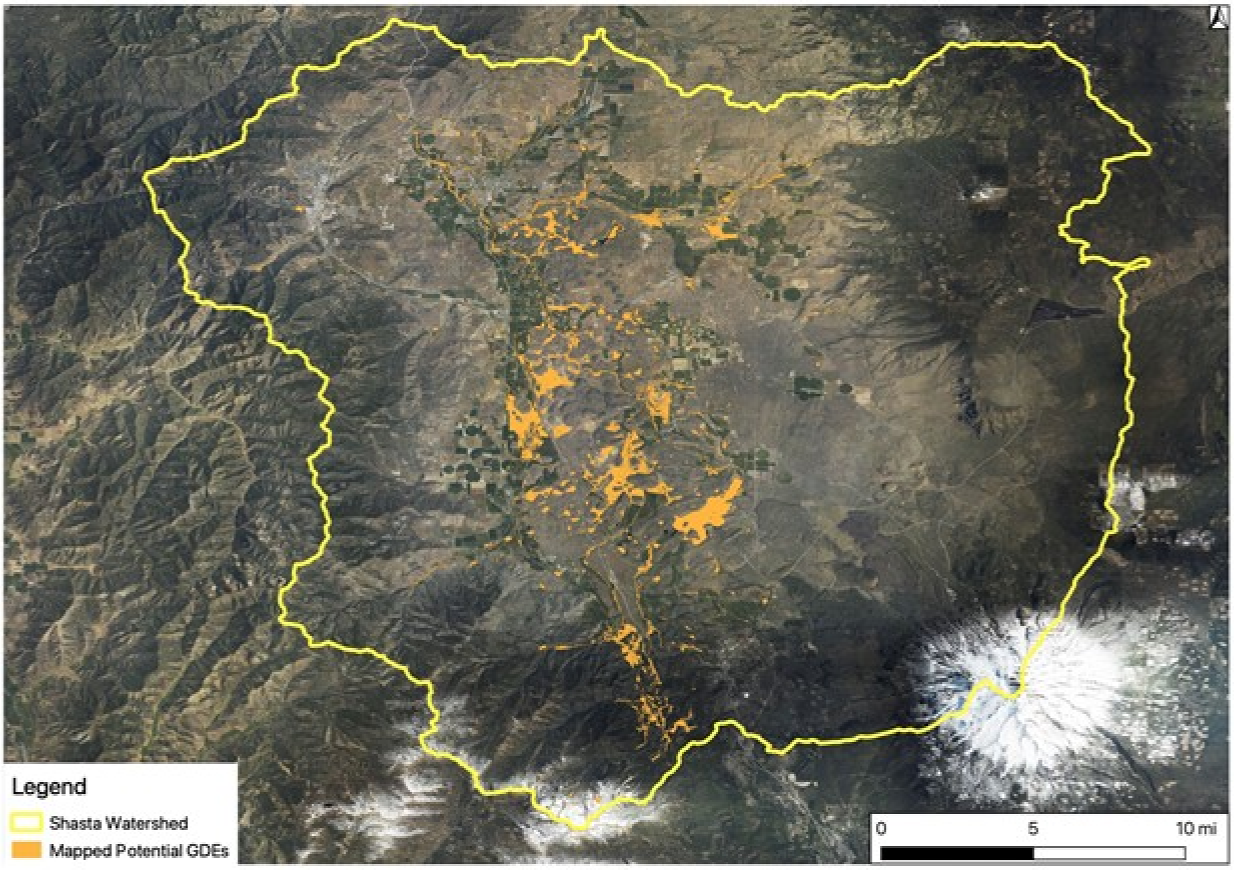


Figure 56: Mapped Potential GDEs for the Shasta Watershed.

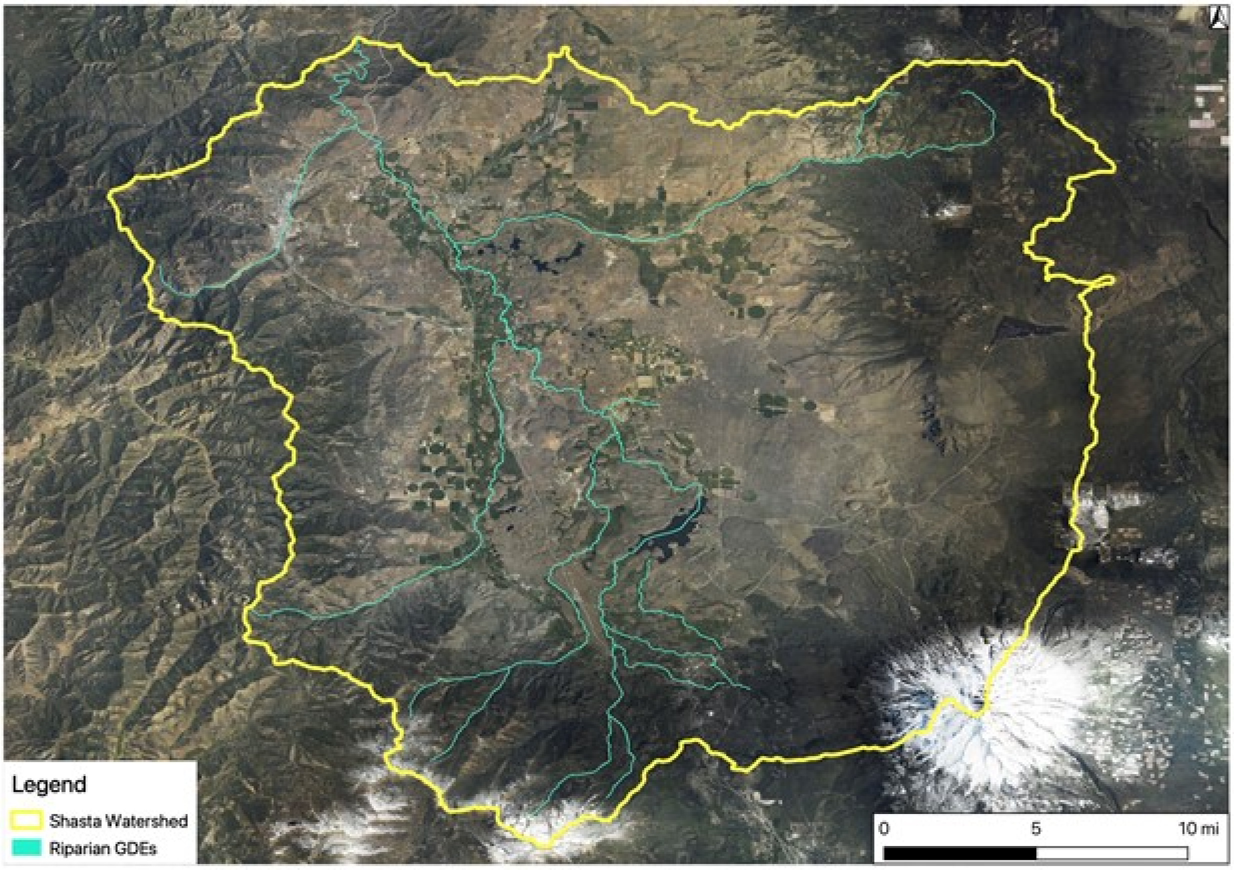


Figure 57: Assumed Riparian GDEs in the Shasta Watershed

- 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

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
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
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 California Statewide Groundwater Elevation Monitoring (CASGEM) Program using the well-establish kriging method.

An example representation of depth to groundwater for the Shasta basin is presented in Figure 58. Representations of depth to groundwater for each of the 16 representation of three-year rolling depth to groundwater are presented in Appendix 2-G.

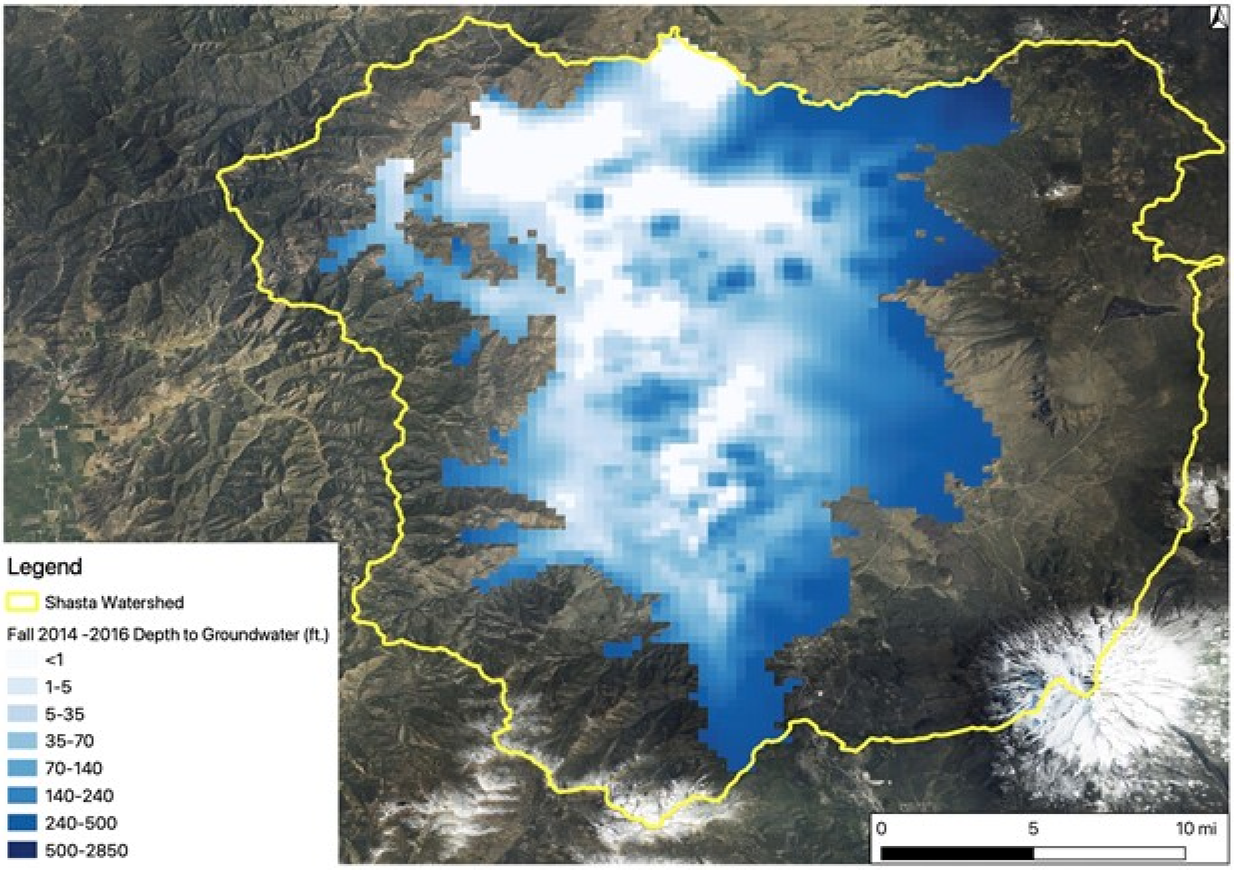


Figure 58: Depth to Groundwater for the Three-Year Rolling Period Between Fall 2014 and Fall 2016.

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 58 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:

- Assumed GDE;
- Assumed not a GDE.

Areas where the grid-based analysis showed that the mapped potential vegetative GDE was likely connected to groundwater were categorized as “assumed GDE.” Similarly, areas that were shown to be disconnected from groundwater were considered a “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 59.

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

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

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.

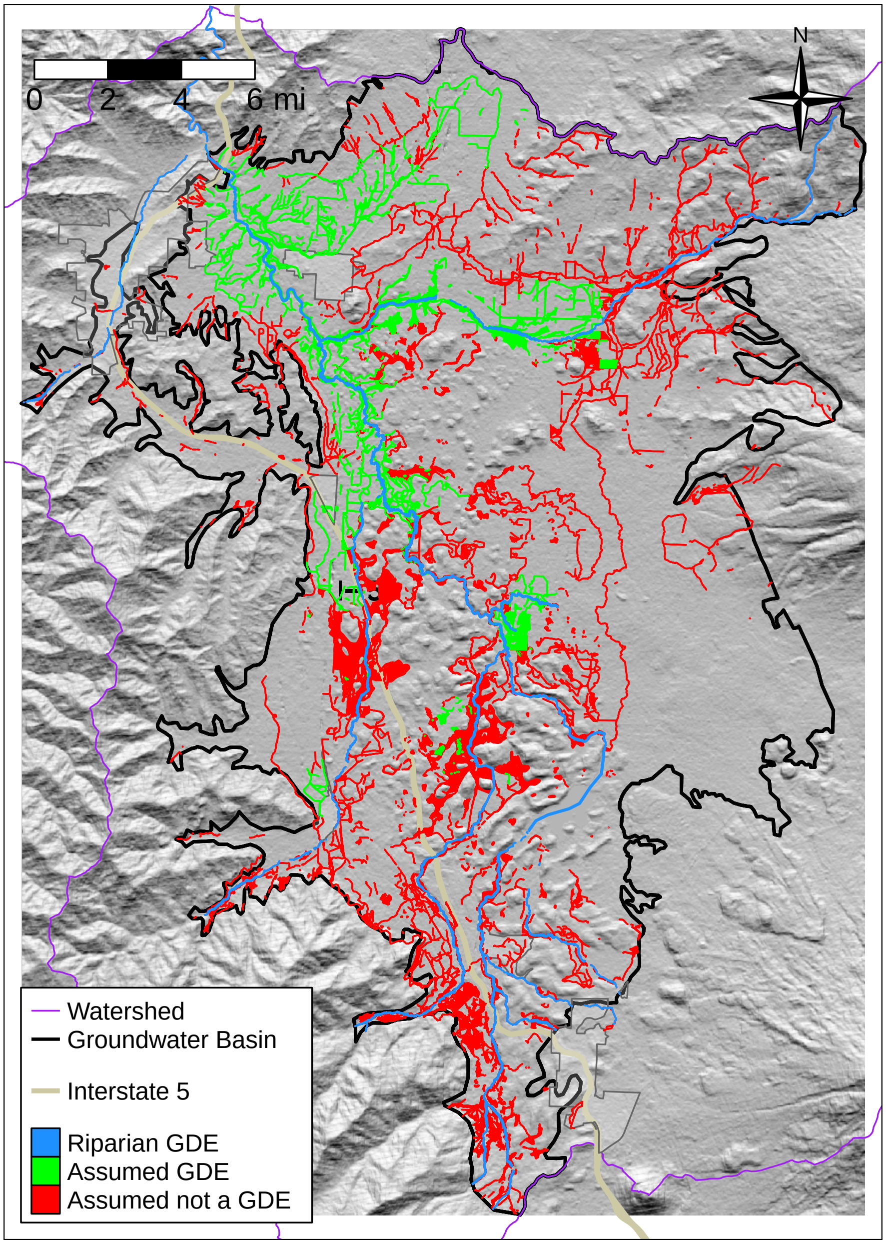


Figure 59: Categorized Riparian and Vegetative GDEs Within the Shasta Watershed.

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 the model development Appendix 2-E.

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 60 and Figure 61 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 provides critical rationale that is later used in this GSP for the design of the monitoring networks, the design of the sustainable management criteria, and the development of projects and management actions (Chapters 3 and 4).

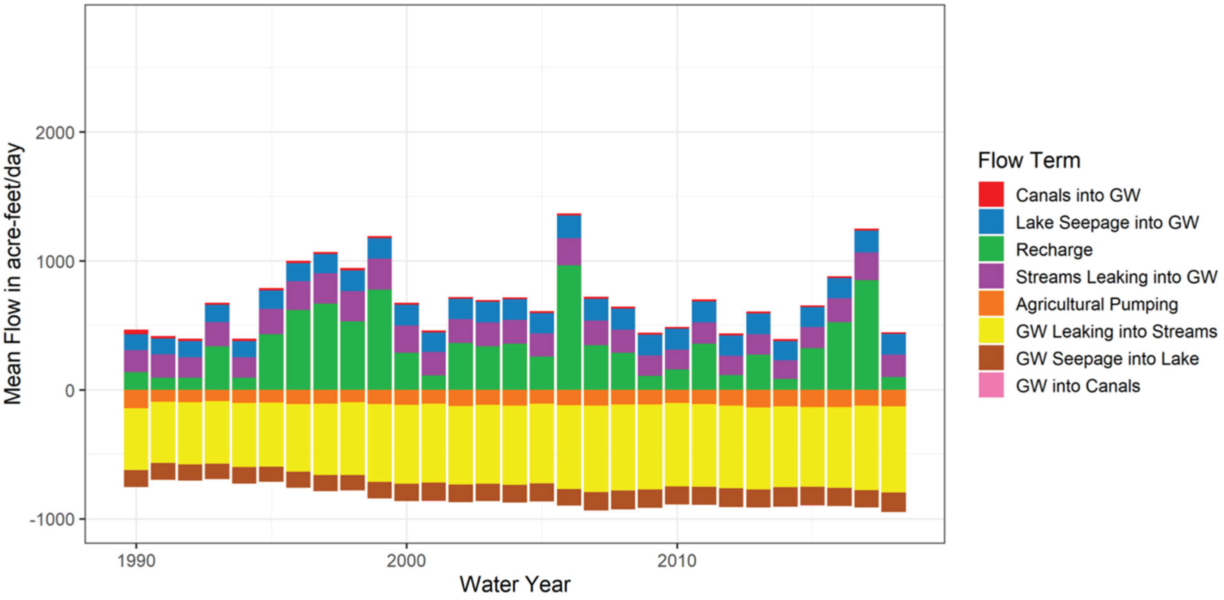


Figure 60: Annual water budgets for all flow terms for the Shasta Basin Bulletin 118 boundary.

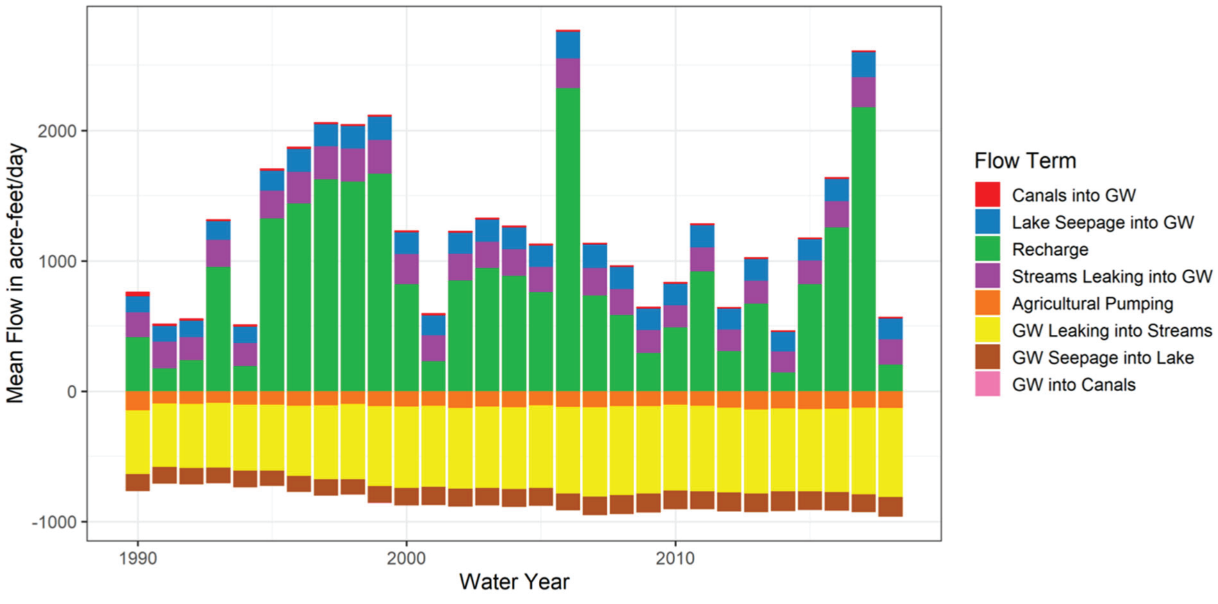


Figure 61: Annual water budgets for all flow terms for the Shasta Watershed.

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 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 integrated model of the Shasta Valley watershed 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[2]). 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.

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

- The land/soil subsystem and the surface subsystem of the entire watershed is simulated using the USGS PRMS software[3](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[4](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[5](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 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 60 (Shasta Basin) and Figure 61 (Shasta watershed):

- Contributions to groundwater include
  - Canal seepage (from SW)
  - Lake seepage (from SW)
  - Recharge (from L)

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

[4] {Harbaugh, A.W., 2005, MODFLOW-2005, The U.S. Geological Survey modular ground-water model—the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16, various p.}

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

  - 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 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 Basin boundary and the Shasta Watershed in Table 15 and Table 16, 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 17 and Table 18, respectively.

Table 13: Summary of Average Annual Flows from Surface Water to the Groundwater subsystem within the Basin boundary.

Flow Term	Unit	Average	Minimum	Maximum	Standard Deviation
Canal Seepage	TAF/year	5	5	10	1
Lake Seepage	TAF/year	57	45	65	5
Stream Leakage	TAF/year	67	53	87	10

Table 14: Summary of Average Annual Flows from Surface Water to the Groundwater subsystem within the watershed boundary.

Flow Term	Unit	Average	Minimum	Maximum	Standard Deviation
Canal Seepage	TAF/year	5	5	10	1
Lake Seepage	TAF/year	59	45	74	7
Stream Leakage	TAF/year	74	59	11	10

Table 15: Summary of Average Annual Flows from the Groundwater subsystem to Surface Water within the within the Basin boundary.

Flow Term	Unit	Average	Minimum	Maximum	Standard Deviation
Seepage to Canals	TAF/year	0.1	0.2	0.07	0.04
Seepage to Lakes	TAF/year	50.0	43.0	58.00	4.00
Leakage to Streams	TAF/year	219.0	173.0	244.00	22.00

Table 16: Summary of Average Annual Flows from the Groundwater subsystem to Surface Water within the within the Basin boundary.

Flow Term	Unit	Average	Minimum	Maximum	Standard Deviation
Seepage to Canals	TAF/year	0.1	0.2	0.07	0.04
Seepage to Lakes	TAF/year	50.0	43.0	58.00	4.00
Leakage to Streams	TAF/year	223.0	177.0	249.00	23.00

Table 17: Summary of Average Annual Flows between the Land/soil subsystem and Groundwater within the Bulletin 118 boundary.

Flow Term	Unit	Average	Minimum	Maximum	Standard Deviation
Recharge to Aquifer	TAF/year	126	31	352	90
Agricultural Pumping	TAF/year	43	32	61	6

Table 18: Summary of Average Annual Flows between the Land/soil subsystem and Groundwater within the Watershed boundary.

Flow Term	Unit	Average	Minimum	Maximum	Standard Deviation
Recharge to Aquifer	TAF/year	312	43	849	224
Agricultural Pumping	TAF/year	69	33	61	6

2.2.3.3 Summary of Historical Water Budget

Stream and lake seepage account for 96% of the contributions from the Surface Water to the Groundwater subsystem within the Basin (124 TAF/year) as well as the broader Shasta River watershed (133 TAF/year). Canal seepage accounts for only 4% of the flux to the Groundwater subsystem (5.5 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 81% and 82% of flows to surface water from the Groundwater subsystem for the Basin boundary and Shasta watershed (219 and 223 TAF/year), respectively. Groundwater seepage into lakes accounts for 18% of fluxes between these two subsystems for both the Basin and watershed area (50 TAF/year for both areas) with canal seepage accounting for a near negligible contribution at 0.04% (0.1 TAF/year for both areas) of the total volume (Table 15 and Table 16).

Agricultural pumping to the Land/soil subsystem in the Basin (43 TAF/year) is about one-third of the total land/soil subsystem recharge within the Basin (126 TAF/year). But total watershed pumping (slightly over 43 TAF/year, i.e., almost all within the Basin) amounts to only 14% of the total recharge across the watershed Land/soil subsystem (312 TAF/year) (Table 17 and Table 18). 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.

The L and SW recharge to the GW subsystem are of similar magnitude within the Basin (129 TAF/year and 126 TAF/year). The GW outflow to the SW subsystem (269 TAF/year) is five times larger than pumping to the L subsystem (43 TAF/year). The difference between L and SW inflows to GW (255 TAF/year) and total outflows to L and SW (312 TAF/year) are due to net groundwater inflow of 56 TAF/year via the subsurface from outside the Basin into the Basin groundwater system.

At the watershed scale, L inflows to GW (312 TAF/year) are more than twice as large as SW inflows to GW (138 TAF/year) due to highly permeable infiltration conditions across the volcanic soils of the watershed. GW discharge to L (69 TAF/year groundwater pumping) is 15% of the total GW inflow from L and SW across the watershed (450 TAF/year). The difference between total GW inflows from L and SW (450 TAF/year) and GW outflows to L and SW (342 TAF/year) is due to an average of 108 TAF/year subsurface outflow toward the Klamath River, downstream from the Basin and watershed. For the Basin, net subsurface inflow of 57 TAF/year therefore corresponds to an actual subsurface inflow of 165 TAF/year (57 TAF/year + 108 TAF/year), predominantly from its southern boundary toward Mount Shasta, and Basin subsurface outflow of 108 TAF/year toward the Klamath River in the north.

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

The Shasta Valley Groundwater Basin (i.e. 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 fill the aquifer system between October and April (Figure 23). Groundwater pumping further enhances 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 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 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_{ref}), 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 ETref 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 62 and Figure 63). All scenarios predict higher future ET than the Baseline (Figure 64 and Figure 65).

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 66. An overview of projected streamflow conditions at the Shasta River near the Yreka gage under the baseline and projected scenarios is presented in Figure 67. 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 EW (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.

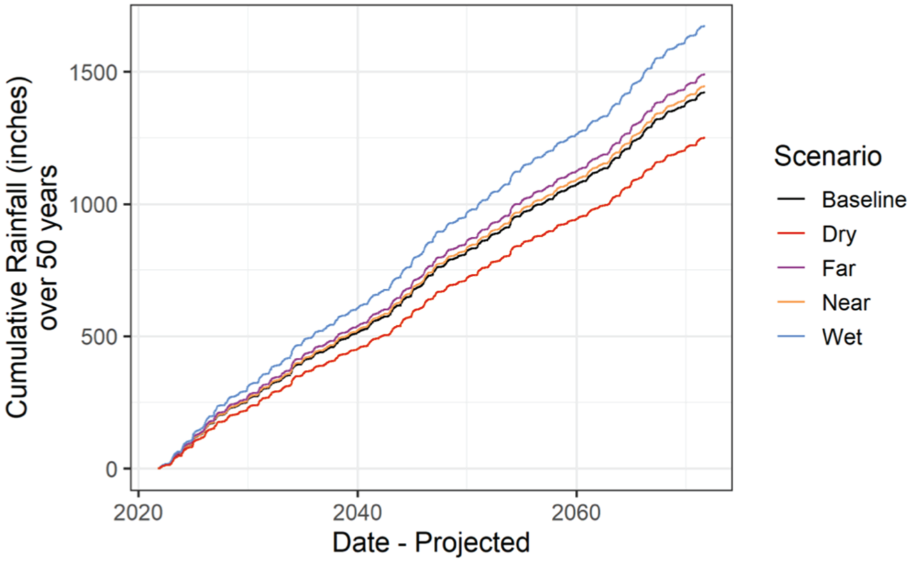

Figure 62: Cumulative precipitation for the future projected climate conditions, with baseline and four DWR climate scenarios including the 2070 DEW (Dry), 2070 (Far), 2030 (Near), and 2070 WMW (Wet) projections.

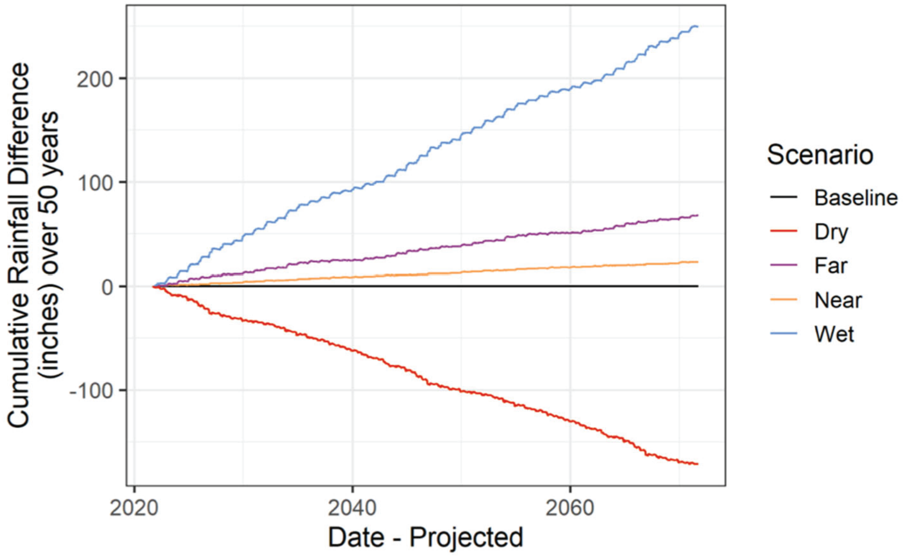

Figure 63: Projected change in cumulative precipitation for the future climate conditions, with baseline and four DWR climate scenarios including the 2070 DEW (Dry), 2070 (Far), 2030 (Near), and 2070 WMW (Wet) projections.

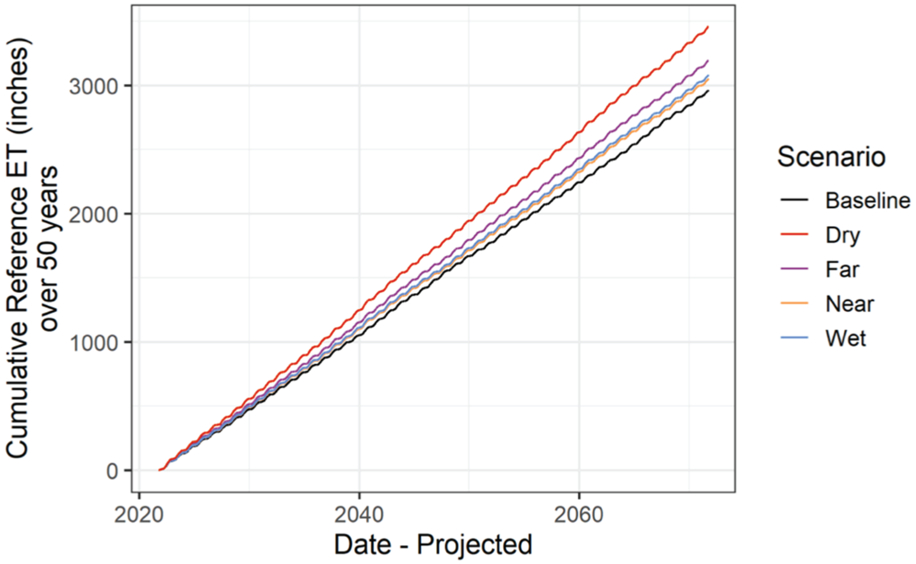

Figure 64: Cumulative precipitation for the future projected climate conditions, with baseline and four DWR climate scenarios including the 2070 DEW (Dry), 2070 (Far), 2030 (Near), and 2070 WMW (Wet) projections.

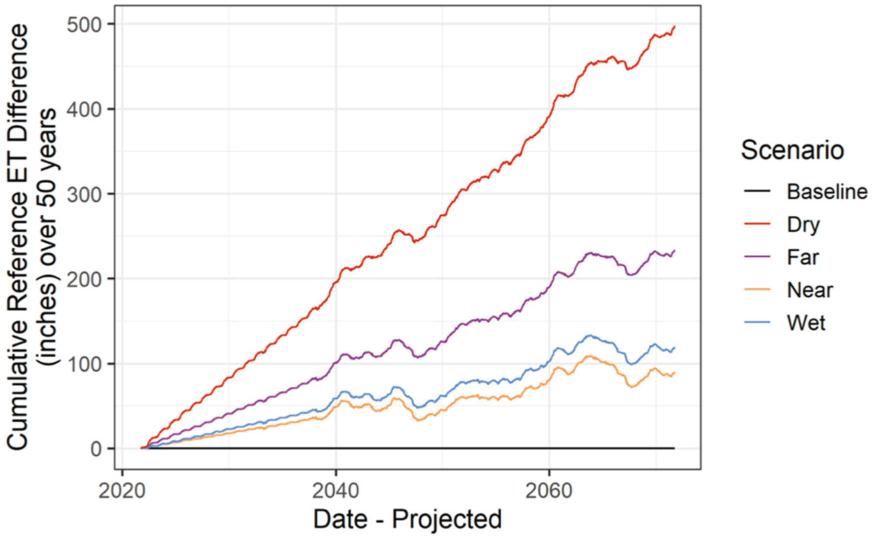

Figure 65: Projected change in cumulative reference evapotranspiration (ET) for the future climate conditions, with baseline and four DWR climate scenarios including the 2070 DEW (Dry), 2070 (Far), 2030 (Near), and 2070 WMW (Wet) projectionsProjected change in cumulative reference evapotranspiration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

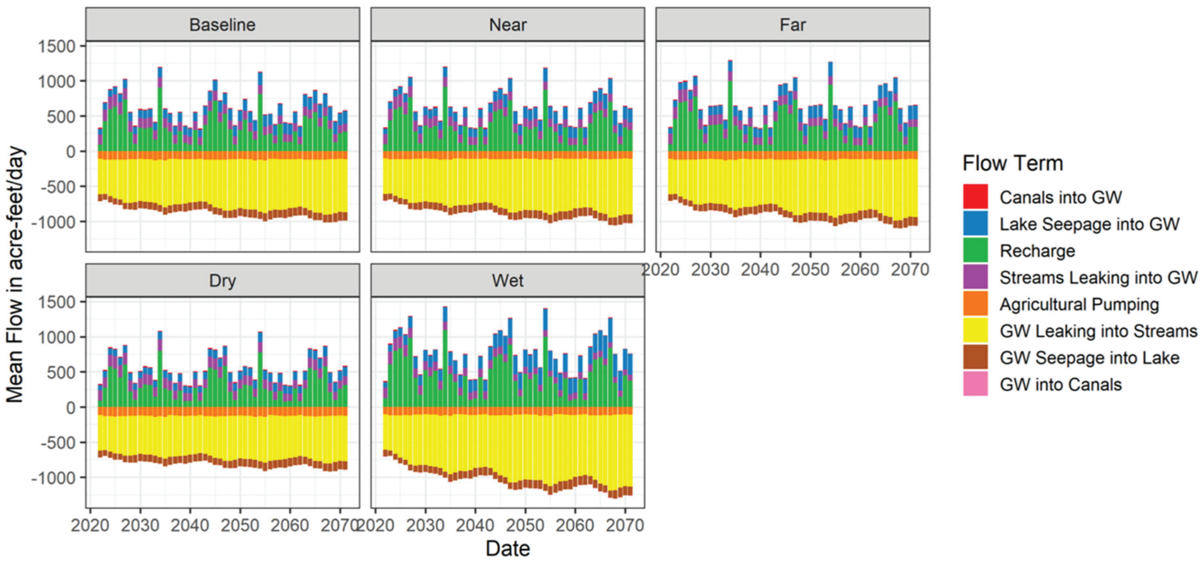

Figure 66: Annual budget summaries for the baseline and four projected climate change scenarios.

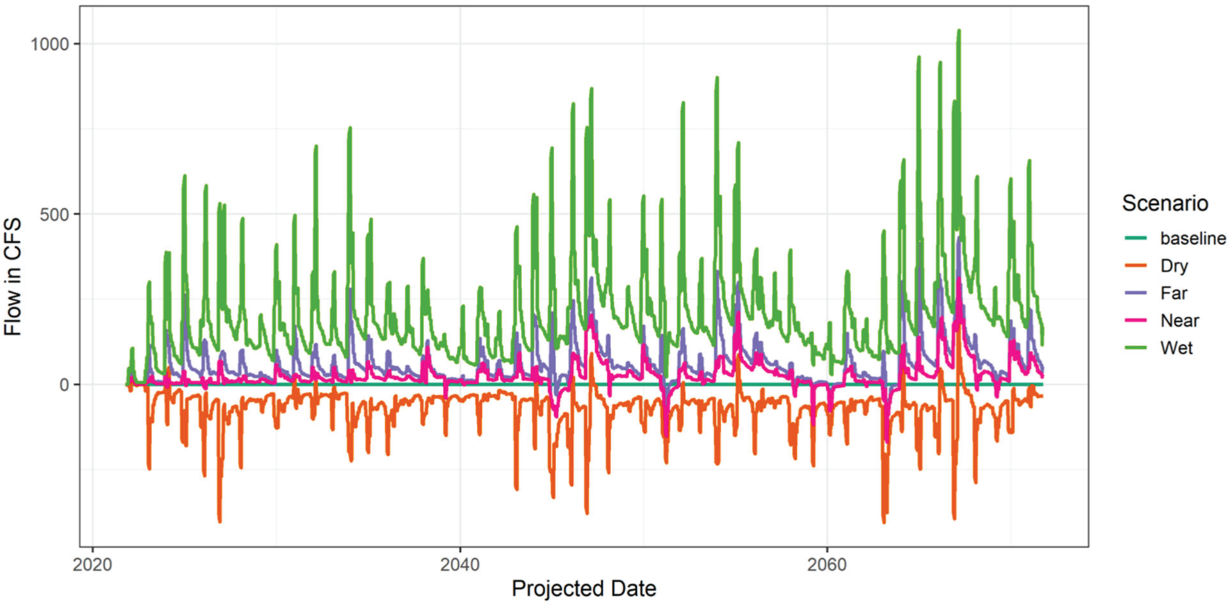

Figure 67: Projected flow at the Shasta River near Yreka gage, in difference (cfs) from Baseline, for four future projected climate change scenarios.

2.2.5 Sustainable Yield

To understand the sustainable yield of the basin, the following findings are important:

- The Basin is not in overdraft. While groundwater levels declined during the 2012-2015 drought, levels quickly rebounded back. Groundwater pumping has not caused significant and unreasonable conditions in the Basin during the last 20 years.
- The sustainable yield "means the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result." (California Water Code Section 10721).
- The sustainable yield is not a number that is constant over time, as future conditions may decrease or increase the amount of groundwater that can be withdrawn without causing undesirable results.

For the Shasta Valley, the sustainable yield is based on historical data and equal to 42 - 45 thousand acre-feet per year minus any future reduction in groundwater pumping resulting from the implementation of project and management actions (see Chapter 4) to meet the milestones and, after 2042, the minimum threshold and measurable objectives for the interconnected surface water indicator and for the water level indicator. Since these reductions in groundwater pumping will vary over time and will be a function of the PMAs that will be implemented, the sustainable yield will vary over time as new PMAs are added. Similarly, some future PMAs (not currently identified in chapter 4) may include schemes that may target a quantifiable, perhaps seasonal increase in groundwater pumping (recharge specifically for groundwater pumping, surface water leases to offset groundwater pumping), which then leads to a commensurate increase in the sustainable yield when such PMAs are implemented.

Why is the sustainable yield not a constant number?

The Sustainable Groundwater Management Act explicitly makes the sustainable yield a function of long-term conditions and of the conditions causing undesirable results. The sustainable yield in Shasta Valley is not equal to the historic 1991 – 2018 average groundwater pumping, although those conditions have not resulted in overdraft. Future groundwater pumping may need to be reduced. However, the amount of pumping reductions needed will vary by the type of project and management actions and the spatial extent of implementation. Winter recharge does not require reductions in groundwater pumping for implementation. In-lieu recharge results in some reduction in groundwater pumping. Similarly, irrigation efficiency improvements result in a reduction in groundwater pumping, but also in a reduction in recharge. To the degree that irrigation efficiency improvements reduce evaporation, they result in a reduction of net groundwater use (net groundwater use is the difference between pumping and recharge). Upland management, habitat improvements, and small reservoirs do not require reductions in pumping. For every implementation of a PMA resulting in the reduction in groundwater pumping, including some conservation easements, there is a commensurate downward adjustment in sustainable yield. The exact amount of that adjustment varies over time and will depend on the future portfolio of PMAs implemented (see chapters 3 and 4). Without the automatic adjustment of the sustainable yield to future agreed-upon reductions in groundwater pumping, other water users in the Basin may claim that the reduction in groundwater pumping, e.g., for in lieu recharge, makes groundwater available for pumping elsewhere or at other times, up to the (constant) limit of the sustainable yield. This must be avoided to successfully manage the basin.

2.2.6 Management Areas

The 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 Ecoystem 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.

———. 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.” 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/.

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.”

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.

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.”