DECEMBER 2021

CHAPTER 2: PLAN AREA AND BASIN SETTING

SISKIYOU COUNTY FLOOD CONTROL & WATER CONSERVATION DISTRICT

Shasta Valley Groundwater Sustainability Plan

FINAL DRAFT REPORT

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

BOARD

Brandon Criss, County of Siskiyou
Ed Valenzuela, County of Siskiyou
Michael Kobseff, County of Siskiyou
Nancy Ogren, County of Siskiyou
Ray A. Haupt, County of Siskiyou

STAFF

Matt Parker, Natural Resources Specialist, County of Siskiyou

TECHNICAL TEAM

Laura Foglia, LWA
Thomas Harter, UC Davis

Andrew Calderwood, UC Davis
Brad Gooch, UC Davis
Cab Esposito, LWA
Katrina Arredondo, LWA
Kelsey McNeil, LWA
Claire Kouba, UC Davis
Bill Rice, UC Davis

ADVISORY COMMITTEE

John Tannaci, Chair, Residential
Blair Hart, Private Pumper
Gregg Werner, Environmental/Conservation
Justin Holmes, Edson Foulke Ditch Company
Pete Scala, Private Pumper
Grant Johnson, Tribal Representative
Tristan Allen, Montague Water Conservation District
Steve Mains, Grenada Irrigation District
Robert Moser, Municipal/City
Lisa Faris, Big Springs Irrigation District
Justin Sandahl, Shasta River Water Users Association

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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 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). Communities in the Valley categorized as either disadvantaged or severely disadvantaged include: Gazelle, Grenada, Montague, Weed, and Yreka (\autoref{fig:dac_boundaries). 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 DAC and SDAC communities depend on groundwater as a source of drinking water.

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 forest) and USFS land. Two large conservation properties (CDFW's Shasta Valley and Big Springs Ranch Wildlife Areas) cover the northern and central portions of the Basin (Figure 3). The dominant land use in the Valley is agriculture with pasture, alfalfa, and grain and hay comprising the primary crops (Figure 4). The original Bulletin 118 Shasta Valley Groundwater Basin (DWR 2004) consisted of 52,589 acres and was classified as medium priority. The Agency successfully modified the Basin through DWR's 2018 Basin Boundary Modification Process. The modified Basin was finalized by DWR in February of 2019 and increased to 217,980 total acres. The updated boundary accounts for much more of the groundwater pumping in the Valley allowing for more comprehensive 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 requiring 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 and some regions completely lack monitoring wells. The absence of a comprehensive well monitoring network is a critical data gap in the analysis of groundwater level trends. Surface water-groundwater interaction is a key sustainability criterion to evaluate within the Basin's GSP. Therefore, continuously measured surface water and groundwater levels are necessary to build on the biannual measurements collected under DWR's California Statewide Groundwater Elevation Monitoring (CASGEM) Program when analyzing groundwater-surface water interaction.

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 out of compliance 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, the SWRCB released their "Draft Shasta River Watershed Characterization and Model Study Plan" which outlines a proposed groundwater-surface water modeling plan for the Shasta River, distinct from the current integrated model developed for the GSP. The development of such a model will be an integral part of this Basin's GSP implementation 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 the 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.

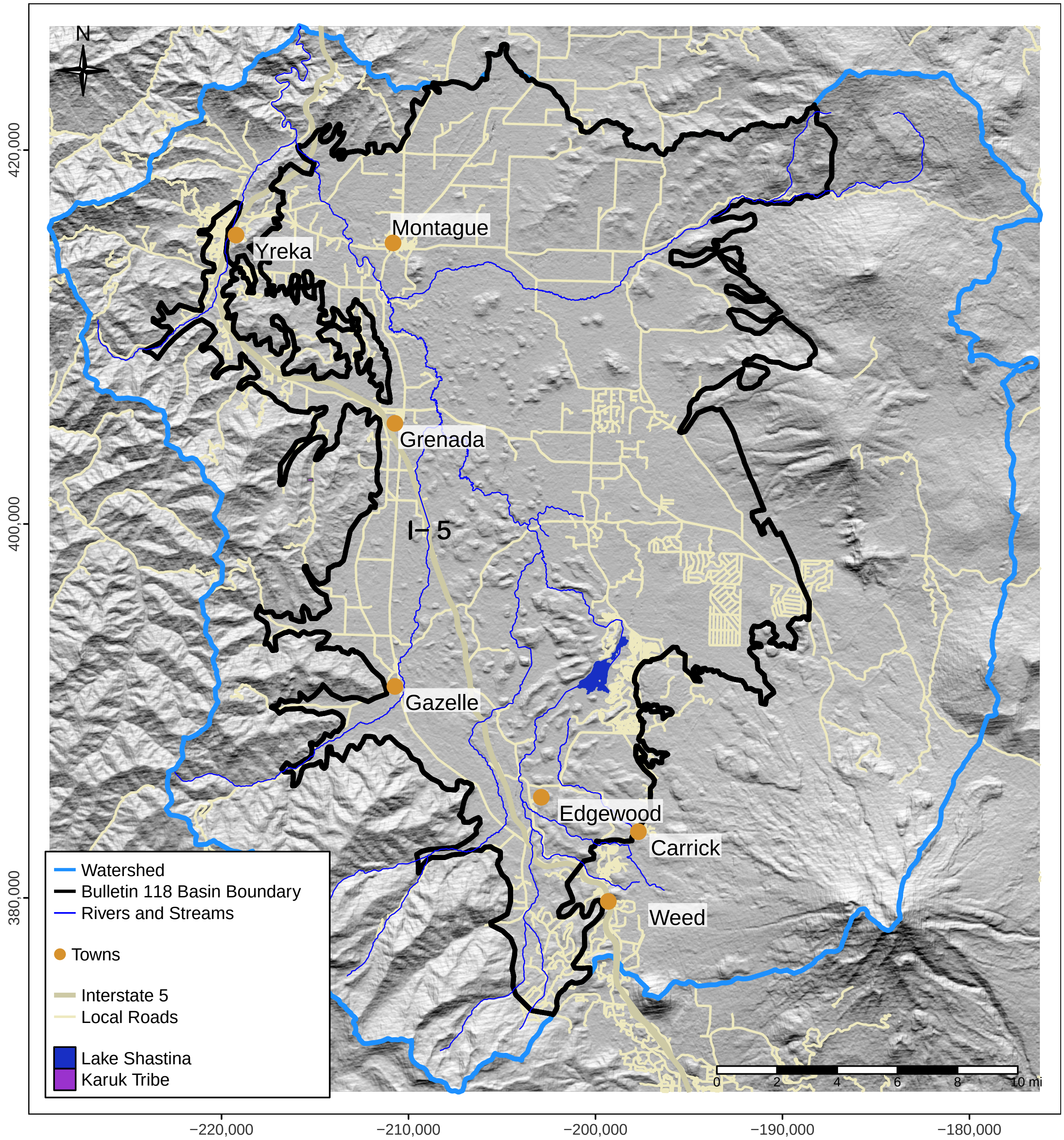

Figure 1: Shasta Valley Bulletin 118 Basin Boundary (black) and watershed boundary (light blue).

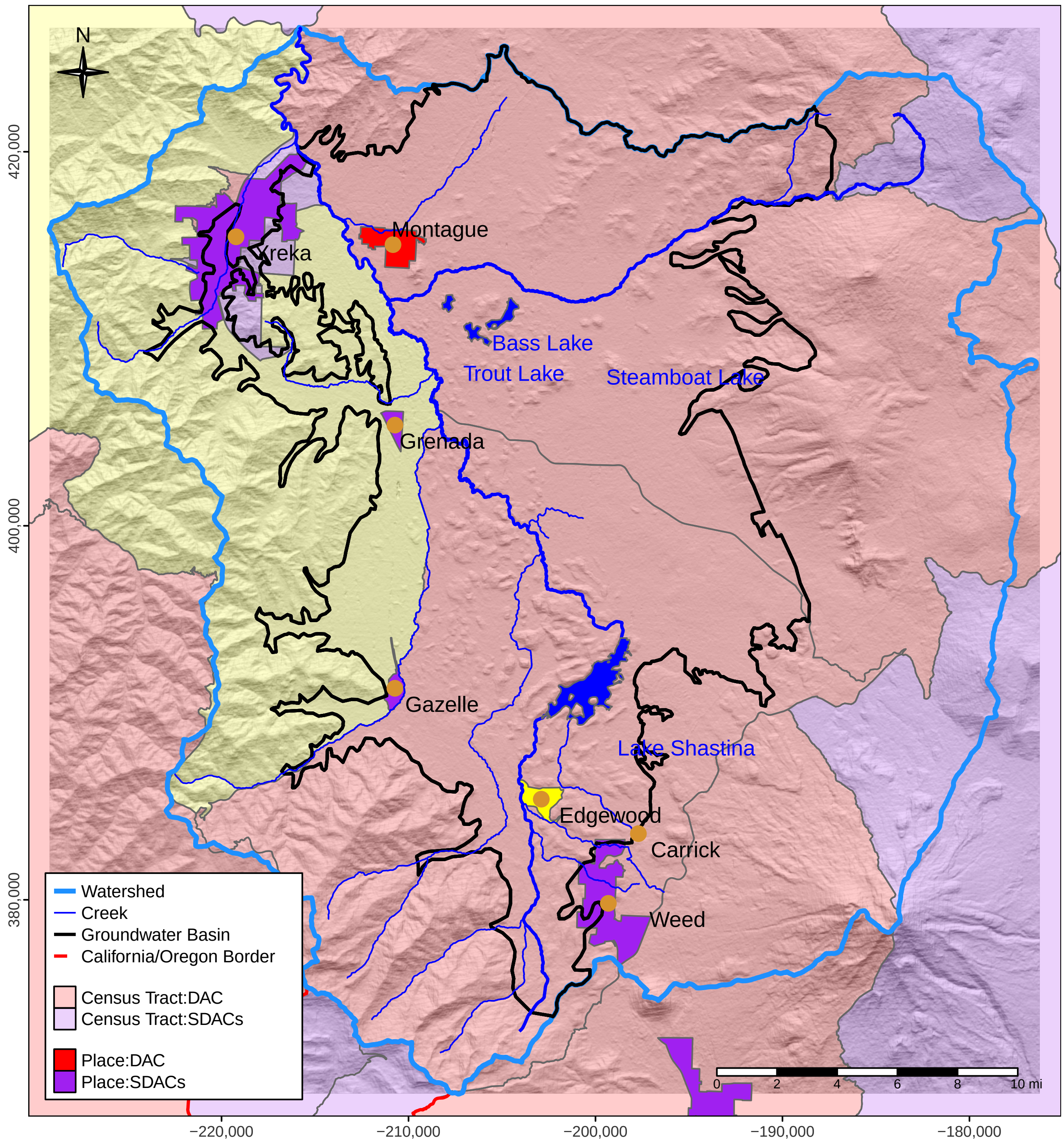

Figure 2: Based on the 2016 U.S. Census, place and track boundaries of Disadvantaged Communities and Severely Disadvantaged Communities in Shasta Valley (Department of Water Resources DAC Mapping Tool).

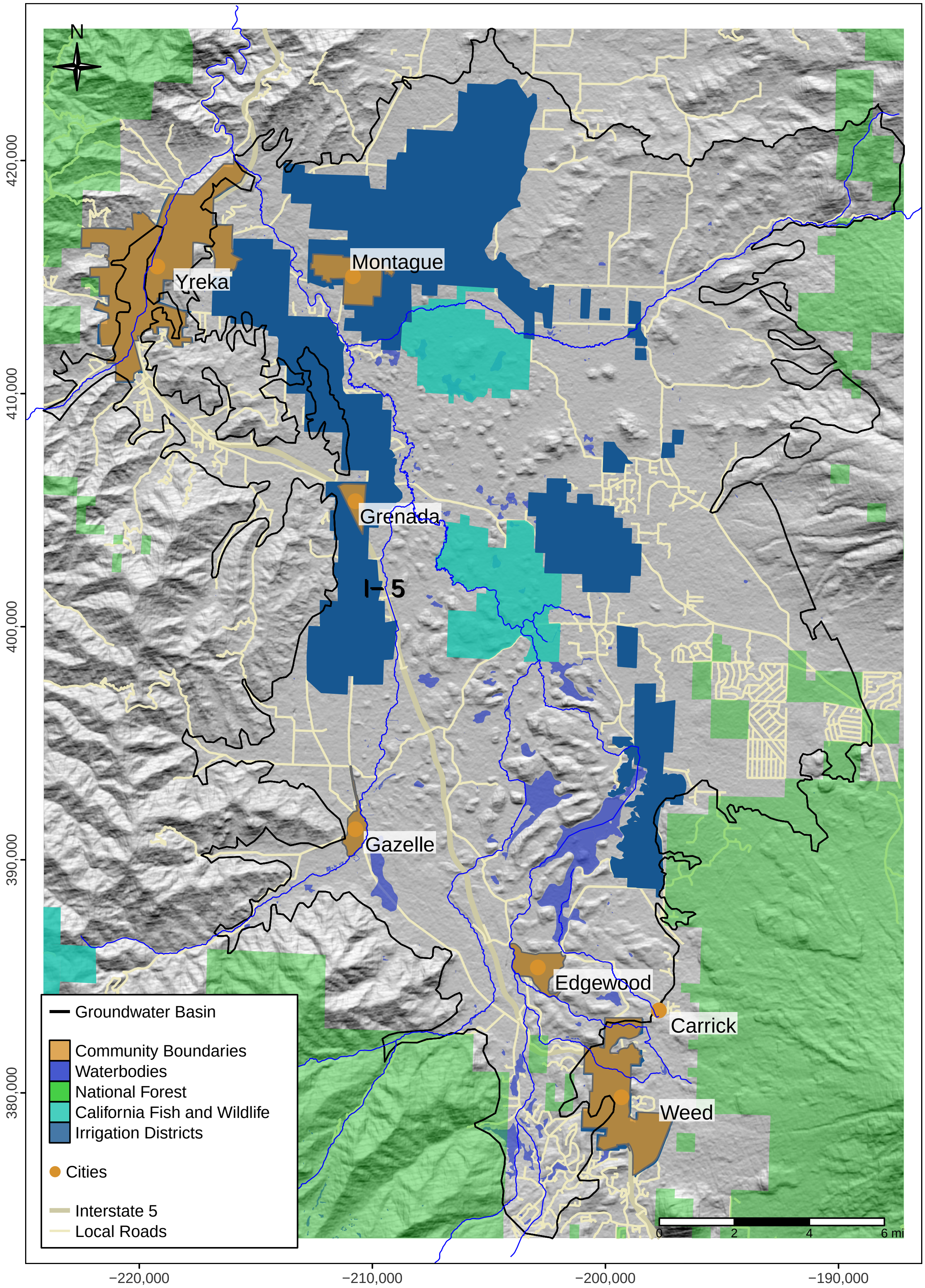

Figure 3: Irrigation districts and administrative areas within Shasta Valley Groundwater Basin

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

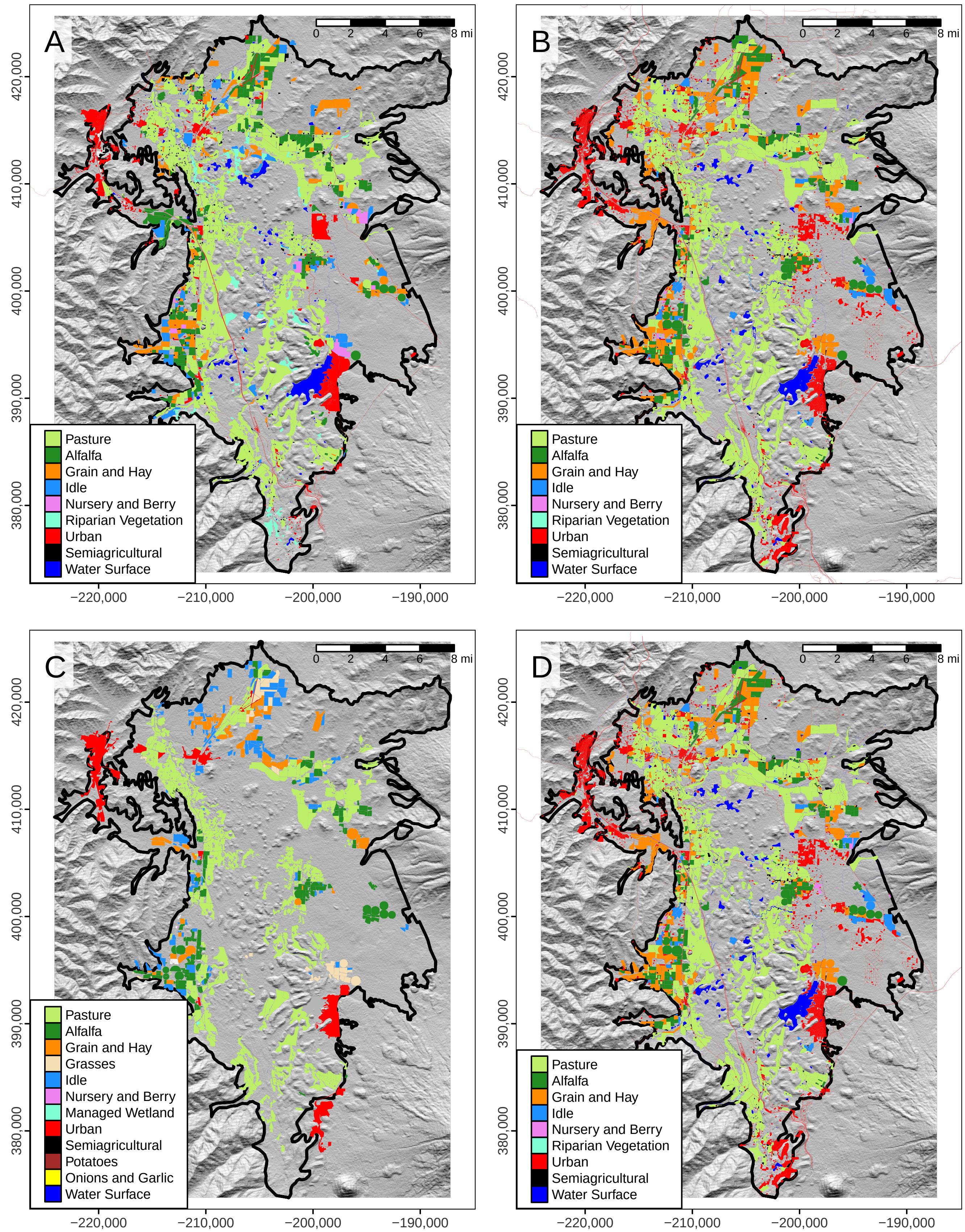

Figure 4: Land uses within the Shasta Valley Groundwater Basin boundary taken from the 2000 DWR Siskiyou Land Use Survey (Panel A), the 2010 DWR Siskiyou Land Use Survey (Panel B), the 2014 DWR LandIQ Land Use Survey (Panel C), and the stakeholder updated 2010 DWR Siskiyou Land Use Survey (Panel D).

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 5). 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[1].

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 urban land use areas, as shown in Figure 5.

[1] {https://water.ca.gov/Programs/Groundwater-Management/Groundwater-Elevation-Monitoring--CASGEM}

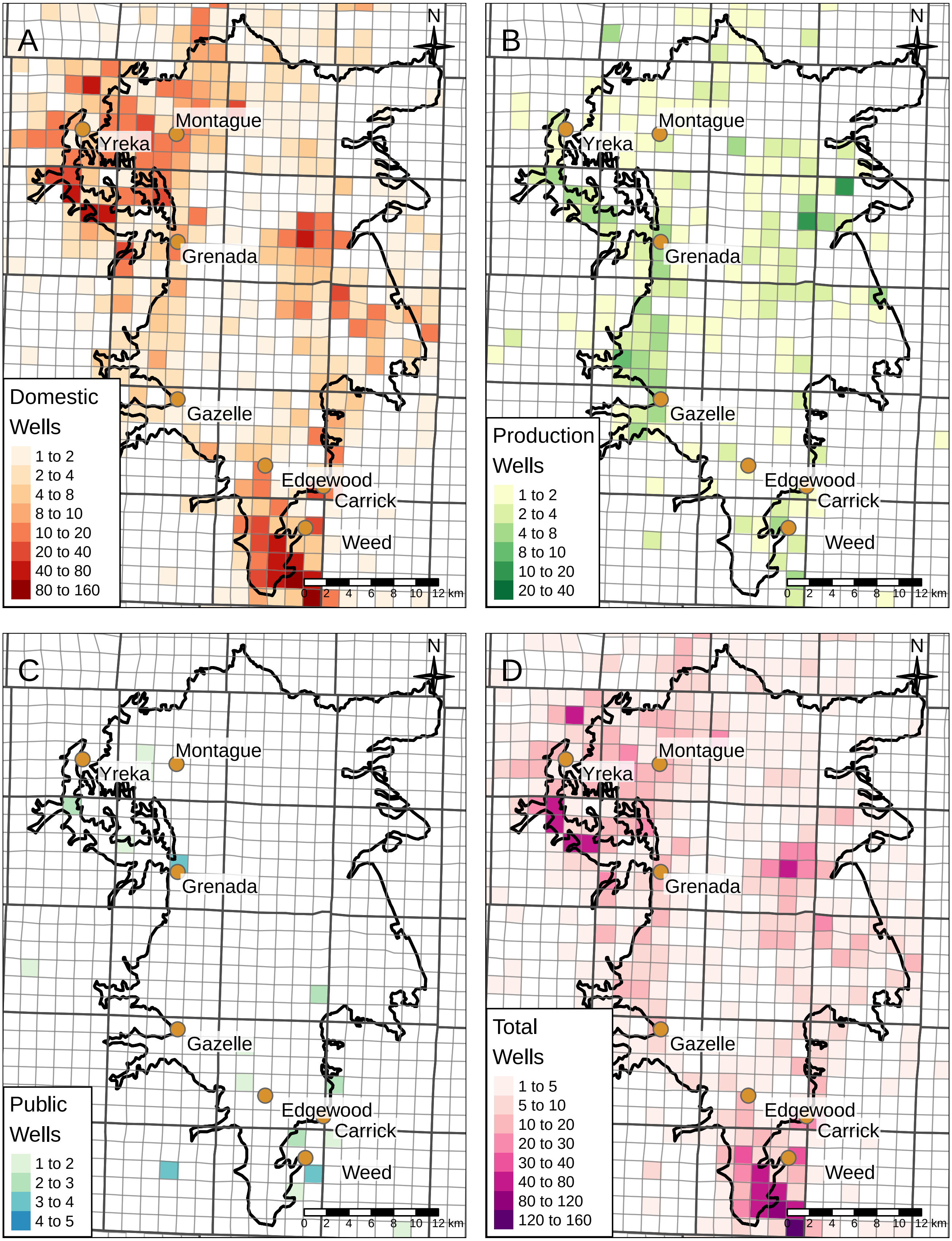

Figure 5: Well density maps indicating number of domestic (panel A), agricultural (panel B), and public (panel C) Well Completion Reports present in each Public Land Survey System (PLSS) section, based on data from the DWR Online System for Well Completion Reports (OSWCR). Panel D shows the sum of panels A-C.

2.1.2 Water Resources Monitoring and Management Programs

An array of historical and ongoing efforts have been carried out in the Basin and Watershed related to the management of surface 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)
- Public Trust Doctrine
- 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 (divert groundwater)
  - Big Springs Irrigation District (BSID)
  - Montague Water Conservation District (MWCD)
- Irrigation Districts and Associations (adjudicated surface water)
  - Grenada Irrigation District (GID)
  - 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.[2] Additionally, the full dataset can be retrieved from the California Natural Resources Agency (CNRA) Open Data website.[3]

As of October 2019, records from the CASGEM well network in the Basin 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 of monitoring groundwater levels in GSP implementation are expected in the Basin due to implementation of the CASGEM Program as continuous monitoring stations can be jointly biannually measured.

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]{https://water.ca.gov/Programs/Groundwater-Management/Groundwater-Elevation-Monitoring--CASGEM}
[3]{https://data.cnra.ca.gov/}

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 critical water source to the Shasta River, often contributing more water than flows derived from the Shasta River upstream of the confluence with Big Springs Creek. The Big Springs Complex supplies approximately 95 percent of summer baseflow in the lower Shasta River via Big Springs Creek (Nichols, 2010). 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 the middle of 2019. The BSRWA was purchased for the protection and preservation of water rights and 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 Shasta Valley Resource Conservation District (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 carried out 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. According to CDFW, 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[4]. 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

[4] {https://wildlife.ca.gov/Lands/Places-to-Visit/Shasta-Valley-WA}

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 (SWRCB) manages several programs that are active in the Basin and are described below. In addition to managing a water rights permitting licensing program, the SWRCB Division of Water Rights, is also responsible for conducting statutory and court reference adjudications. The SWRCB receives statements of water use and diversion from surface water users in accordance with SB 88 (California State Senate 2015).

The SWRCB may also issue curtailment orders under drought emergency conditions, similar to what occurred between 2014 and 2017. On August 30, 2021, the SWRCB issued a drought emergency order for the Scott and Shasta River watersheds that authorized the Division of Water Rights to issue ccurtailment orders for a range of users including groundwater pumpers. On September 10, 2021, curtailment notices were sent to all surface water diverters, to all pumpers within the adjudicated zone (see below), and to all overlying groundwater pumpers outside the adjudicated zone in Scott Valley. Certain domestic, public, and stockwater use rights were exempt.

Division of Drinking Water (DDW)

The SWRCB's Division of Drinking Water, (formerly under 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 SWRCB'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 created 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 SWRCB, 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: the Irrigated Lands Regulatory Program (ILRP), oil and gas production, operating permitted underground storage tanks, and land disposal sites. GeoTracker receives records and data from SWRCB 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 conserving threatened or endangered 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 Department of the Interior's U.S. Fish and Wildlife Service (FWS), primarily responsible for terrestrial and freshwater species, and the Department of Commerce'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 federal ESA, the 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 for "candidate species" exists under CESA that includes species or subspecies that have been formally noticed as under review. 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 Public Trust Doctrine

The public trust doctrine is a legal doctrine under which the State is a Trustee to protect resources including waters, tidelands, and wildlife resources of the state, which are held in a trust for all people. In 2010, the Environmental Law Foundation (ELF), Pacific Coast Federation of Fisherman's Associates, and the Institute for Fisheries Resources filed against the SWRCB and the County of Siskiyou over permitting of wells near Scott River, alleging that these wells decreased flows in Scott River, diminishing suitability for recreational uses of Scott River and harming fish populations. The petitioners argued that the public trust doctrine applies to groundwater that is hydrologically connected to navigable surface water and sought an injunction to stop the County from issuing permits for groundwater wells until it complied with the public trust doctrine. The ruling by the trial court affirmed that the County had a duty to consider the public trust doctrine prior to issuing well permits and that the doctrine "protects navigable waters from harm caused by extraction of groundwater, where the groundwater is so connected to the navigable water that its extraction adversely affects public trust uses." After an appeal, the Third Appellate District published an opinion in 2018 on the *Environmental Law Foundation v. State Water Resources Control Board ("ELF")* which noted that the County has a public trust duty, when issuing well permits, to consider if groundwater extractions impact public trust uses and that SGMA does not supersede, fulfill, or replace the County's public trust duties.

2.1.2.7 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 Mount 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.

2.1.2.8 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.

2.1.2.9 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.

2.1.2.10 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 as TMDL components generally align with the water quality standards.

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 waters list in 1992 due to low dissolved oxygen. The listing was modified in 1994 to include elevated temperature. In 2006 the 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 pollutants 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).

2.1.2.11 United States Forest Service (USFS)

Klamath National Forest

The United States Forest Service (USFS) manages the Klamath National Forest in a manner consistent with the Klamath National Forest Land and 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 are monitored to establish watershed condition and stream health, and to assess the role 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[5], and include sediment and water temperature monitoring coordinated with the Regional Water Board. 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 the SWRCB (SWRCB, 2019a; SWRCB, 2019b). Due to the minimal about of Klamath National Forest land in the Basin that is managed by the USFS, 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

[5]{https://www.fs.usda.gov/detail/klamath/landmanagement/resourcemanagement/?cid=stelprdb5312713}

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 the SWRCB (SWRCB, 2019a; SWRCB, 2019b). Due to the minimal amount of Shasta-Trinity National Forest land in the Basin that is managed by the USFS, 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.

2.1.2.12 Karuk Tribe Department of Natural Resources (KTDNR)

The Karuk Tribe DNR operates a field monitoring program in the Valley and posts information to the interactive web portal[6]. The GSA will work with the Karuk Tribe to share information about monitoring programs.

2.1.2.13 Irrigation Districts and Associations

The irrigation season in the 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 (BSID)
- Montague Water Conservation District (MWCD)
- Grenada Irrigation District (GID)
- Shasta Water Association (SRWA)

The first two districts (BSID and MWCD) divert groundwater while the last two districts (GID and SRWA) are adjudicated surface water users outside of SGMA jurisdiction. BSID does not divert surface water. 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 areas served by the four major irrigation districts are shown below (Figure 6).

Big Springs Irrigation District (BSID)

Big Springs Irrigation District (BSID) does not divert surface water and no longer has water rights to Big Springs Lake (of the original CFS water right, 25 cfs was abandoned in 1987 and the remaining 5 cfs was abandoned in 1996). BSID no longer relies on surface water rights to meet district demands (Deas 2006) instead relying on groundwater resources. Big Springs Irrigation District uses a water delivery system with 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 are incorporated in the GSP in regards to sources of surface water recharge to groundwater.

[6] {waterquality.karuk.us}

Montague Water Conservation District

The Montague Water Conservation District (MWCD) was formed in 1925 and serves 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 from Dwinnell Reservoir (Lake Shastina) that are 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 and augments supply with groundwater pumping during dry years. Operations of surface water management at MWCD are incorporated in the GSP in regards to sources of surface water recharge to groundwater.

Grenada Irrigation District

The Grenada Irrigation District (GID) was formed in 1916 and currently serves 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 (GID Personal Communication, 2019). The GID has adjudicated surface water rights via the Shasta River Decree that are not subject to SGMA. Operations of surface water management at GID are incorporated into the Shasta Watershed Groundwater Model (SWGM).

Shasta River Water Association

The Shasta River Water Association (SRWA) serves 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). SRWA has adjudicated surface water rights via the Shasta River Decree that are not subject to SGMA. Operations of surface water management at GID are incorporated into the Shasta Watershed Groundwater Model (SWGM).

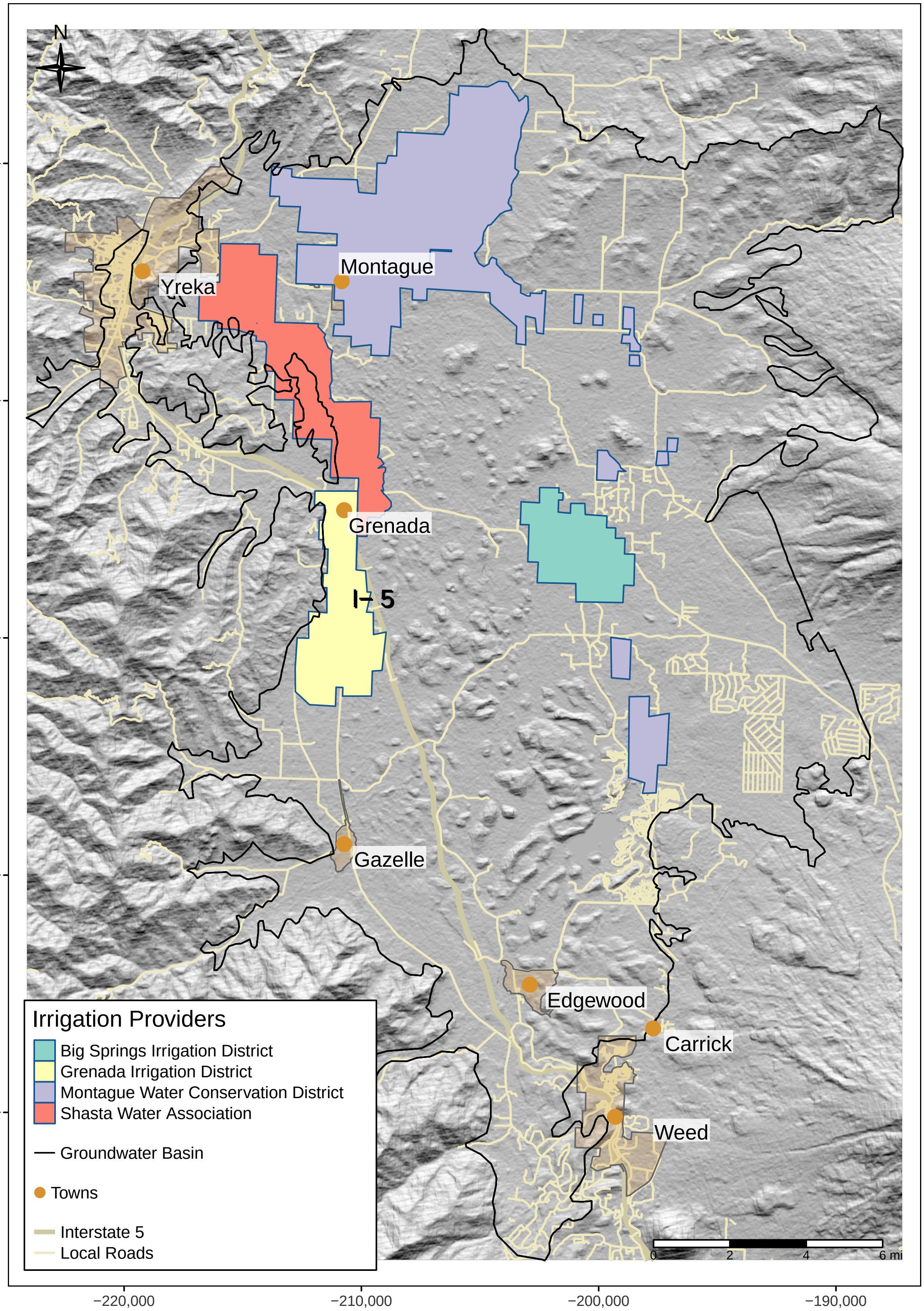

Figure 6: Irrigation Districts of Shasta Valley Groundwater Basin

2.1.2.14 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.

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).

2.1.2.15 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 during GSP 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.

2.1.2.16 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. 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.

In-stream Flows

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

2.1.2.17 Scott Valley and Shasta Valley Watermaster District (Watermaster)

Surface water diversion rights for the Shasta River and tributaries were set forth in the Shasta River Decree, No. 7035 and adjudicated in 1932. The diversions are located within the Shasta River Watermaster Service Area (Service Area) and controlled by the Scott Valley and Shasta Valley Watermaster (Watermaster). In 1933 the Orders Creating Shasta River Water Master District (aka. Watermaster Service Area) was filed with the Siskiyou County Superior Court. Multiple amendments to the Service Area have been adopted, 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). 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 an SSWD was appointed as the Deputy Watermaster 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.

Currently the Watermaster regulates 365 cfs of water rights (primarily through water diversions) during the irrigation season, of which 40 cfs is allocated to the Grenada Irrigation District, and the Watermaster regulates 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 of 49,000 acre feet annually which are held in Dwinnell Reservoir (Lake Shastina).

The flow rates 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 in-stream bypass requirements. 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.

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.

The 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[7], 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.

[7] {sswatermaster.org}

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)) that 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 County of Siskiyou Environmental Health Department (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 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 application of fertilizers and pesticides in a manner inconsistent with best practices that may adversely affect surface and groundwater water quality (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 historical and future water budgets. The GSA will coordinate with local enforcement agencies to collect information relevant to the water balance within the Basin and will place an emphasis on collecting data to fill relevant gaps in understanding during the 5 years of plan implementation.

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. 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 .to be used in a manner consistent with what is allowed under the 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 "non-community 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 the Basin. 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 (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 7). 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, the 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 ranges' extents east to west.

The Shasta Valley Groundwater Basin (earlier defined as 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 2020). 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). The Valley's hydrogeology, including its shallow grade, unique mineral deposits/chemical composition, and continual inputs of glacial-fed spring water, make the Shasta River prime salmon habitat that historically boasted a significant majority percentage of salmon returning to spawn in the Klamath River system. Such hydrological conditions are supported by winter snowpack, but as winter snowpack is diminishing under current and projected warming the hydrological conditions are changing.

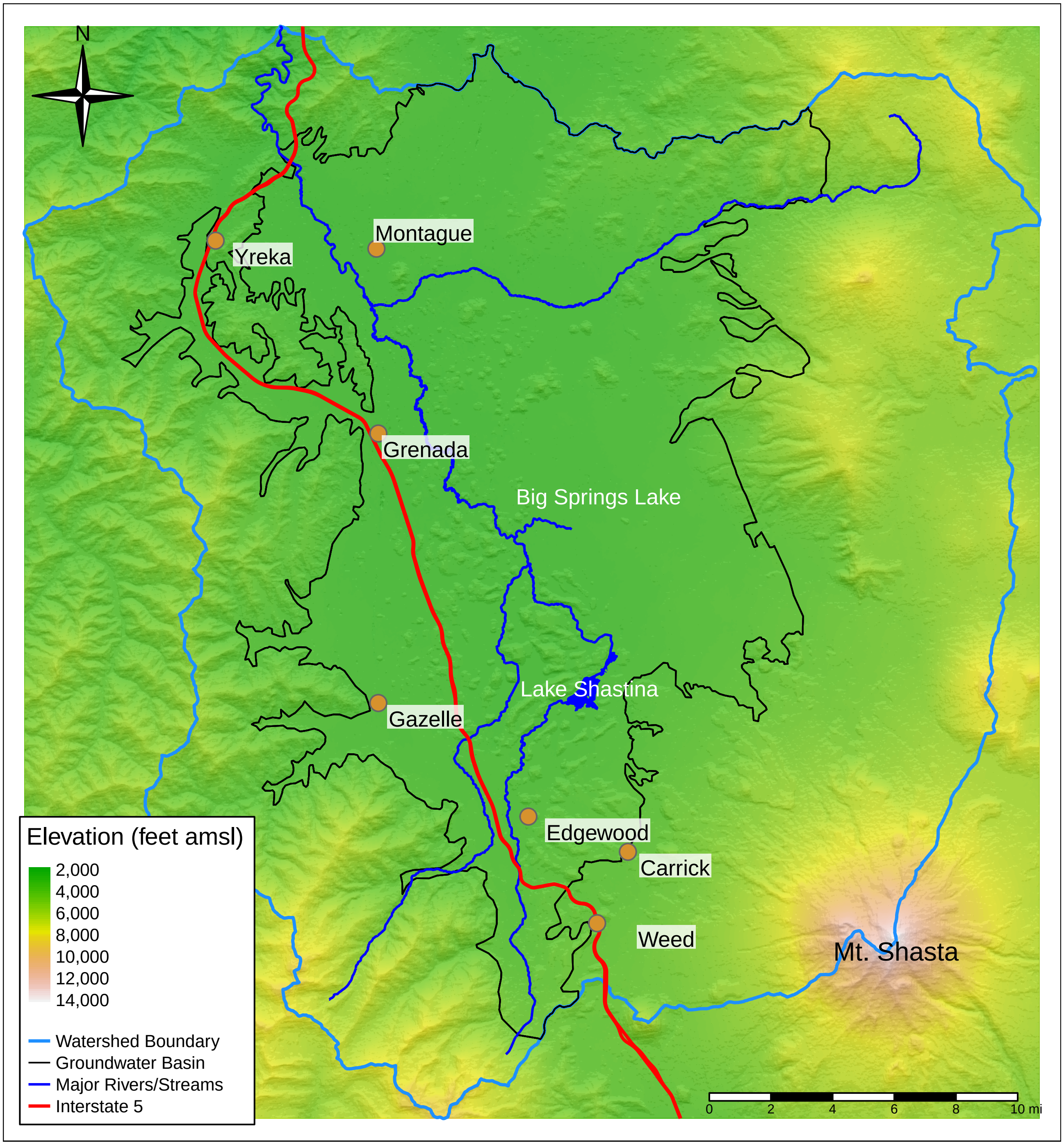

Figure 7: Topography of the Shasta River Valley Groundwater Basin and surrounding watershed.

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) (Figure 8). 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 the Watershed but close to the southern border) Mount Shasta rainfall gauge (station ID: 045983; SWRCB 2018) (Figure 10). Annual precipitation for the City of Yreka is presented in Figure 9, annual precipitation averages range from 19 to 21 inches (48–53 cm) and the summary statistics for the Yreka rainfall gauge are in Figure 11 (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.

At elevations below 4,000 ft (~1,200 m) amsl, precipitation mostly occurs as rainfall, as is the case on the valley floor. Precipitation accumulates as snow in the surrounding mountains, with a rain-snow transition zone from 4,000 to 5,000 ft (~1,200–1,500 m) amsl. Accumulation of snowfall in the surrounding mountains results in runoff during spring snowmelt.

There are four snow depth measurement stations in the Watershed shown in Figure 12. Average snow depth at snow measurement stations near the western boundary of the Watershed has gradually decreased over time, though at three stations near the southern boundary of the Watershed the snow depth has remained relatively stable.

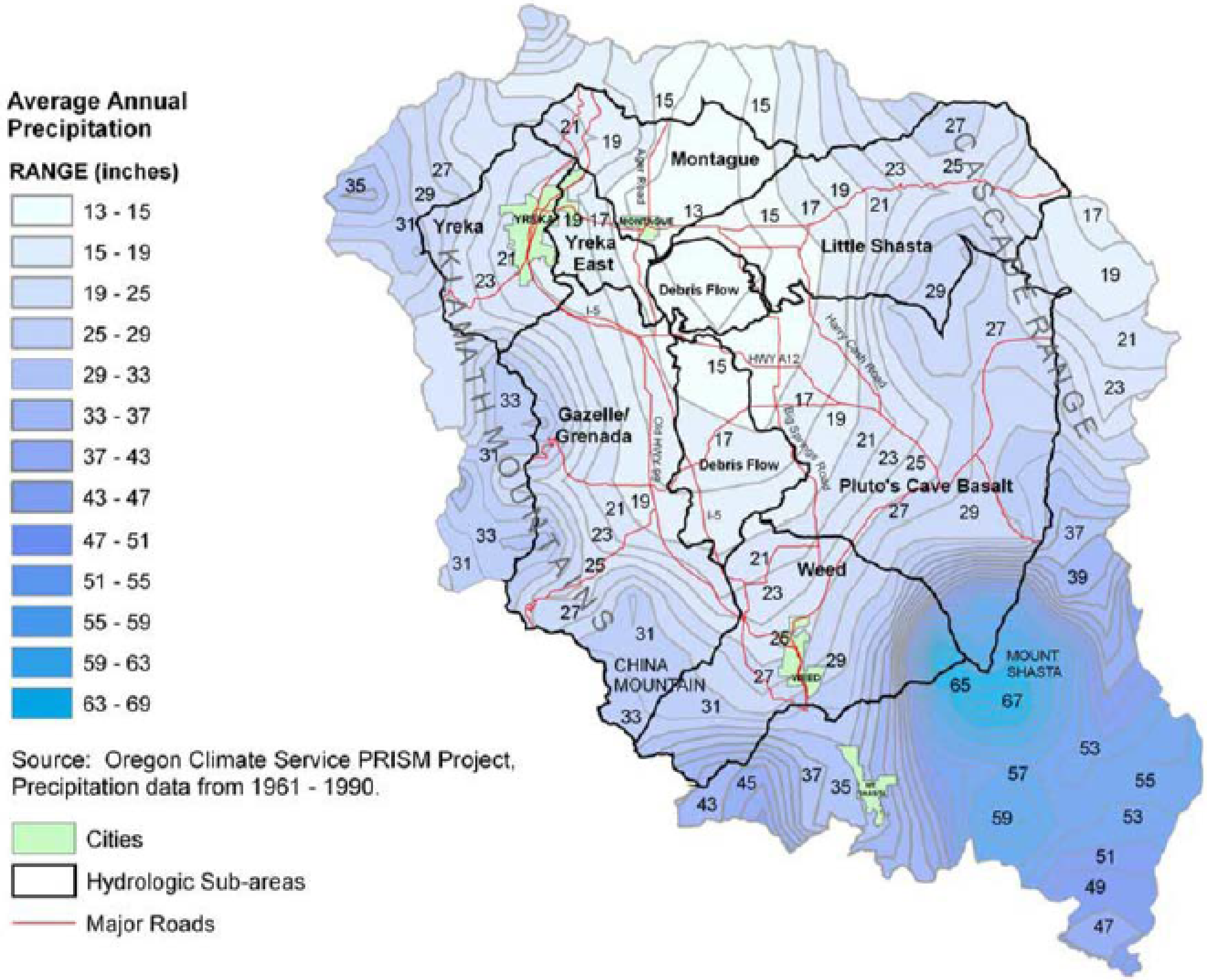

Figure 8: Central Siskiyou County area isohyetal (precipitation) contour map covering the greater Shasta River drainage basin area. Reprinted from CDWR (2011).

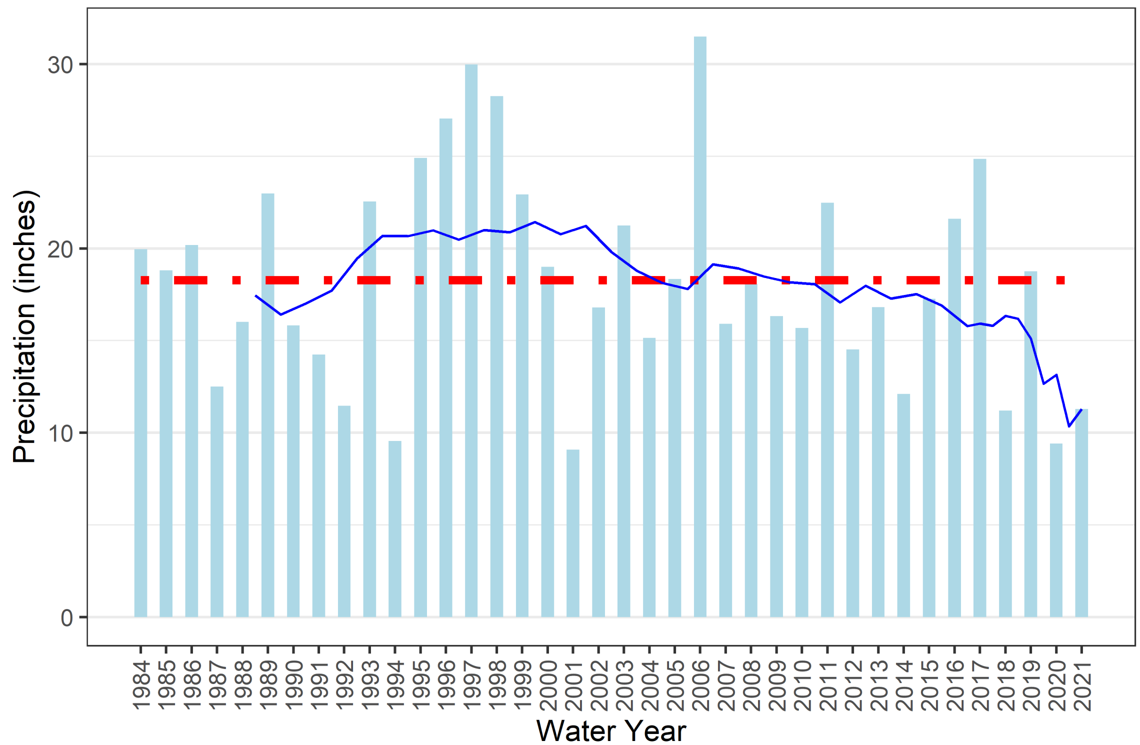

Figure 9: Yreka annual precipitation from 1983 - 2021, according to CDEC data. The long term mean (18 in) shown as a red dashed line, and the 10 year rolling mean is the blue trendline.

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 10: 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 11: Yreka rainfall gauge (049866) summary statistics. Reprinted from SWRCB (2018).

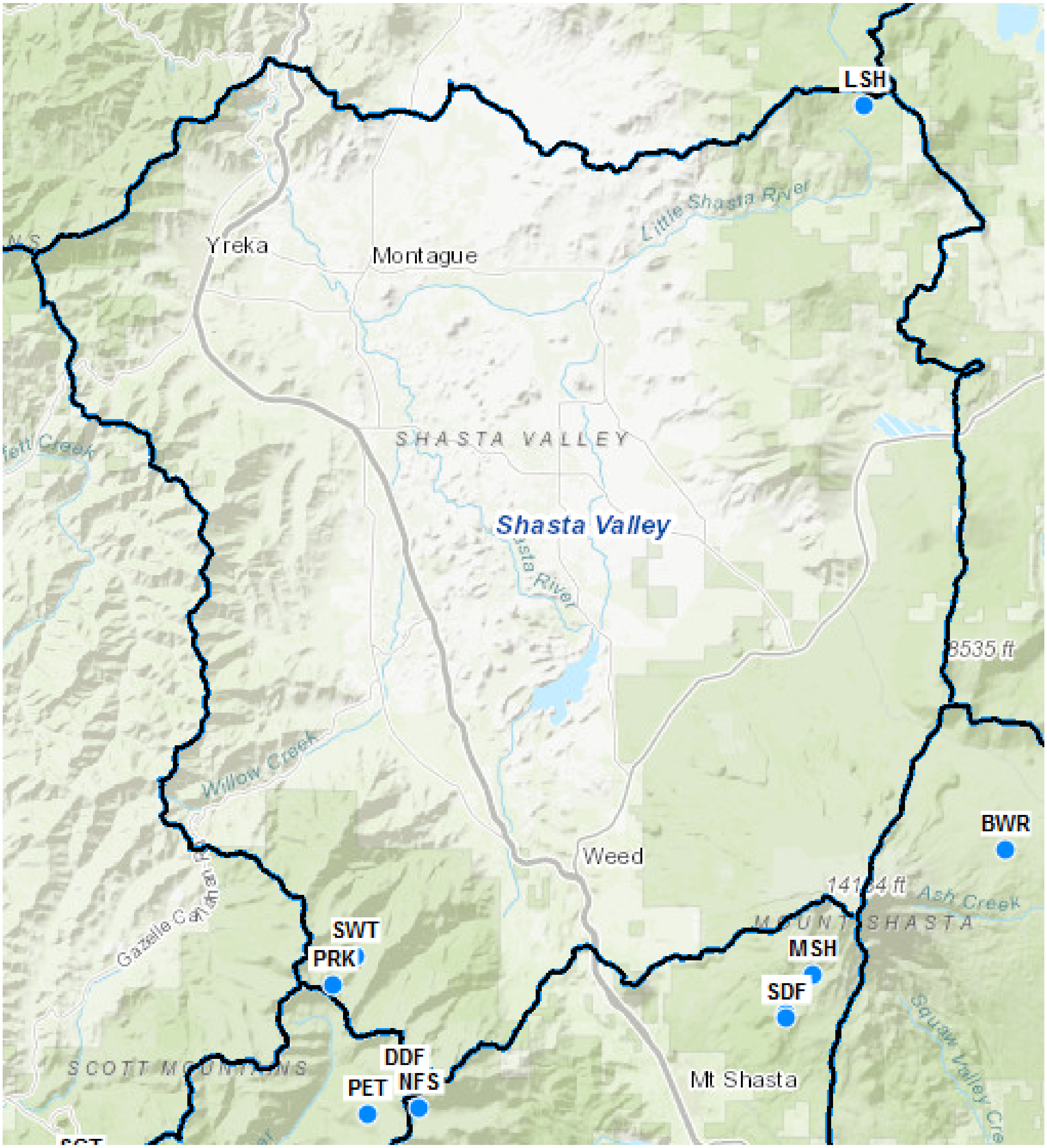

Figure 12: California Data Exchange Center snow stations for the Shasta River drainage basin (Watershed). Adapted from https://cdec.water.ca.gov/cdecstations.

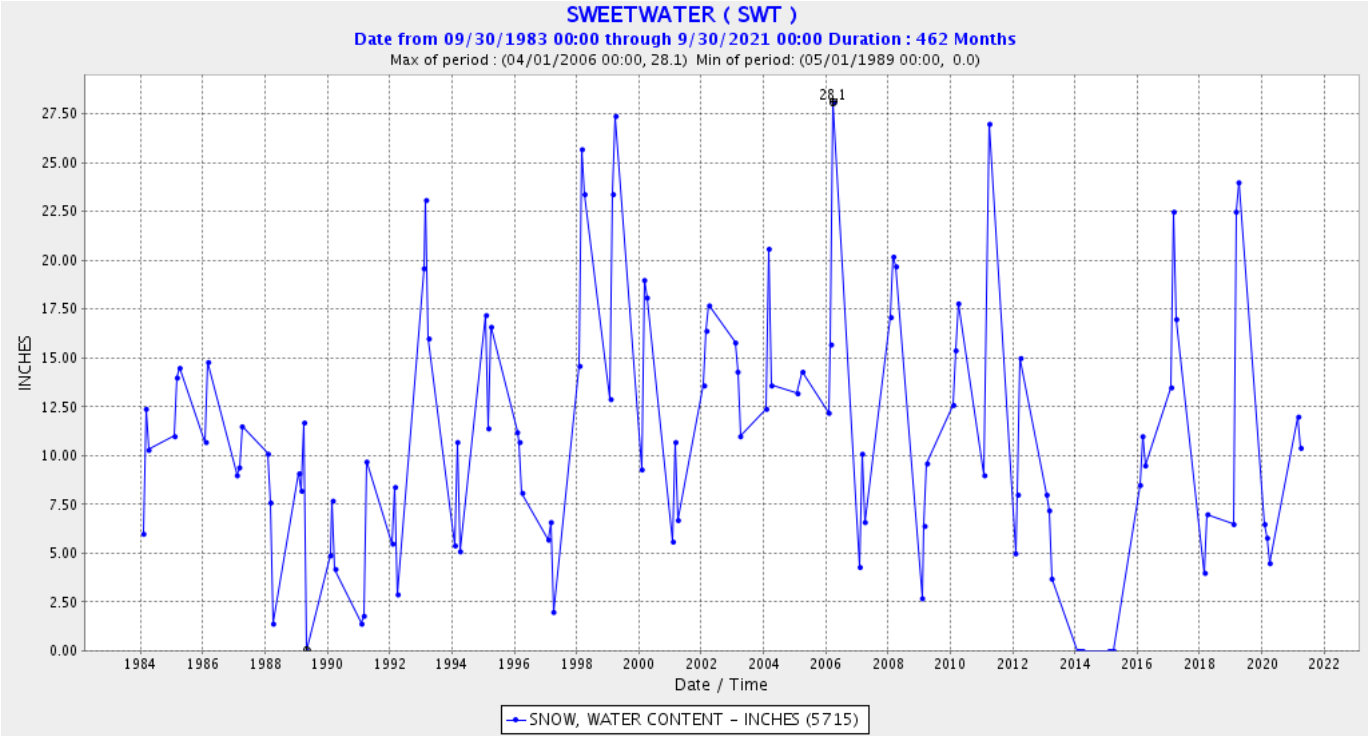

Figure 13: Snow water content record for Sweetwater station (SWT) from WY 1984 to WY 2021. Adapted from https://cdec.water.ca.gov/cdecstations.

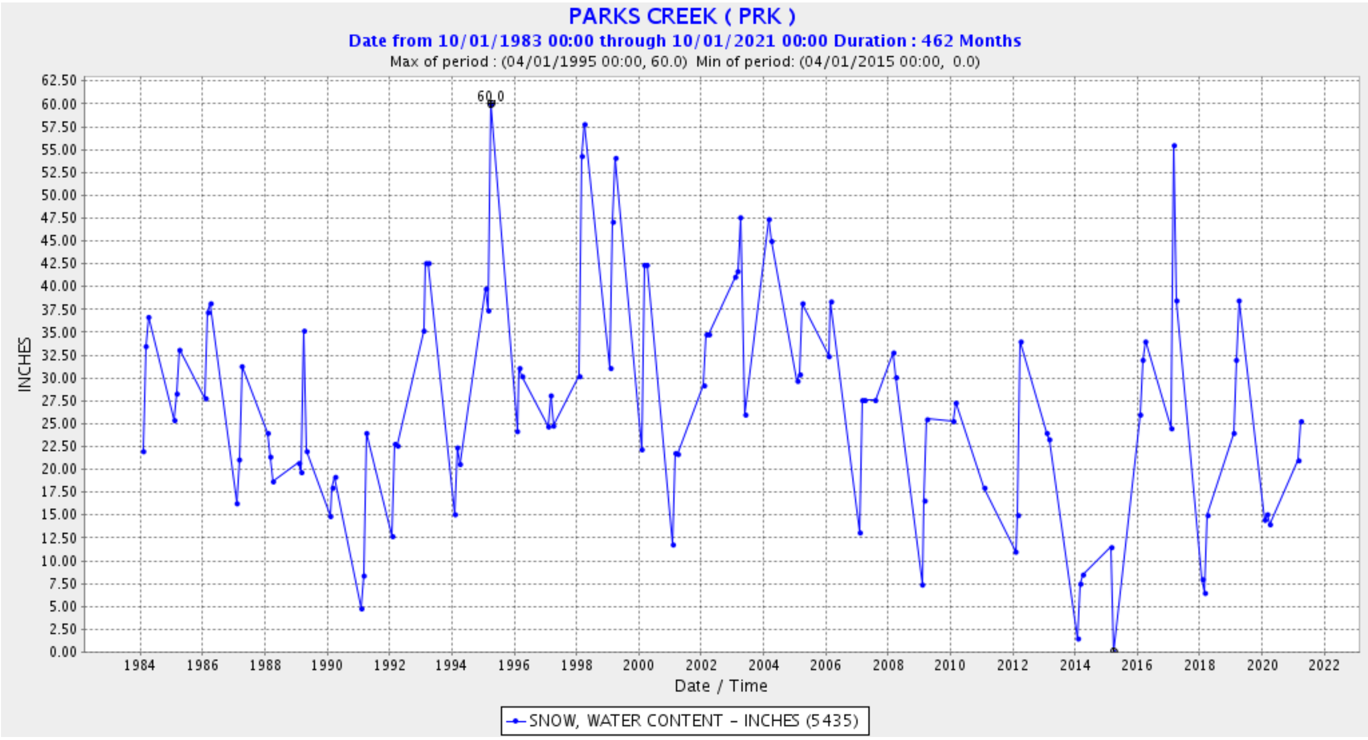

Figure 14: Snow water content record for Parks Creek station (PRK). Adapted from https://cdec.water.ca.gov/cdecstations.

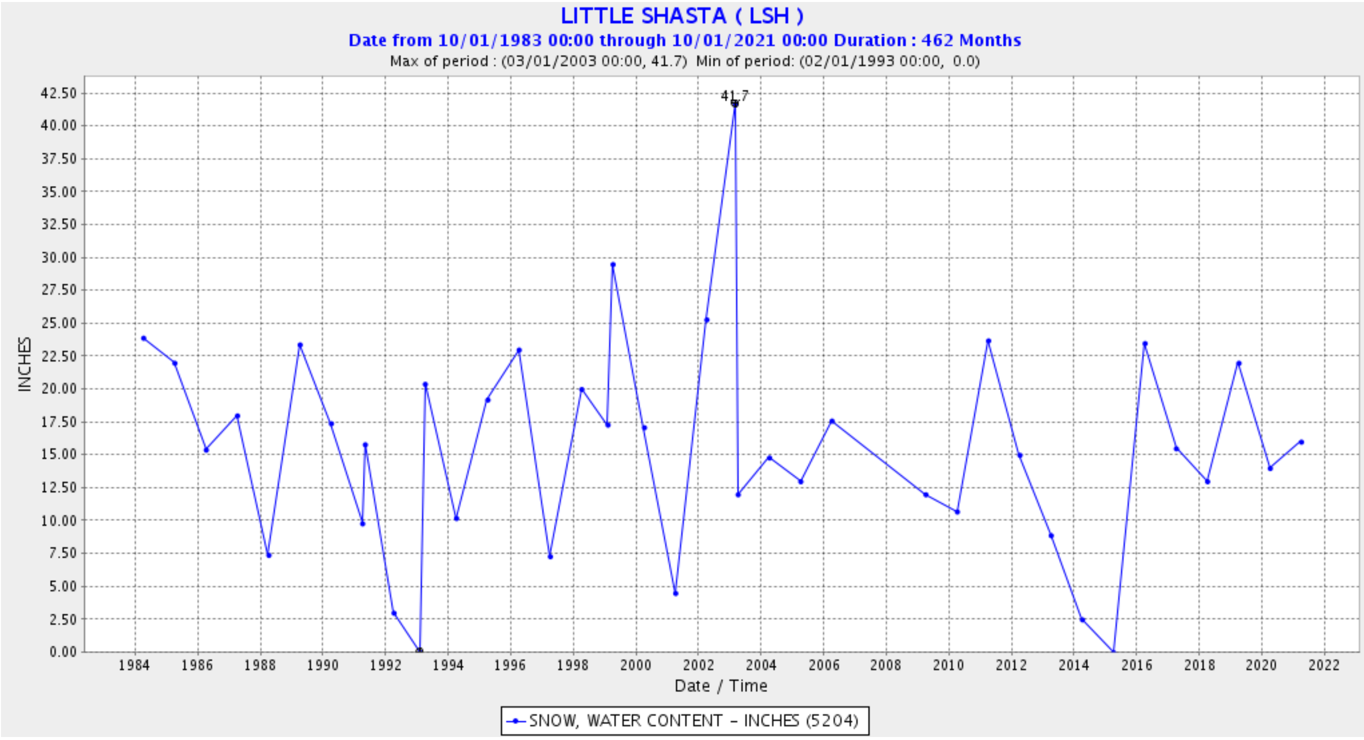

Figure 15: Snow water content record for Little Shasta station (LSH). Adapted from https://cdec.water.ca.gov/cdecstations.

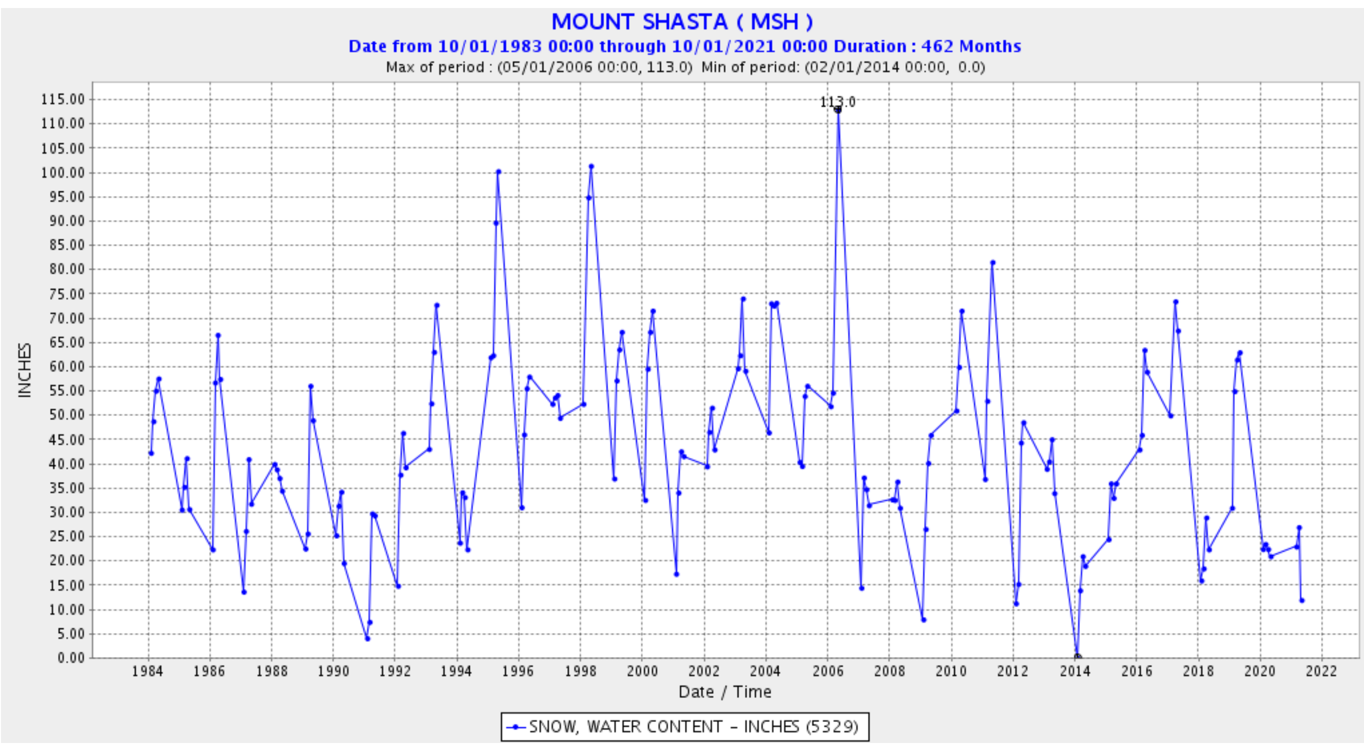

Figure 16: Snow water content for Mount Shasta station (MSH). Adapted from https://cdec.water.ca.gov/cdecstations.

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	2021-06-27	23.0	158
US1CASK0005	YREKA 0.9 WNW, CA US	2692	2008-12-01	2021-06-27	12.6	65
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	2021-06-27	3.3	2
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	2021-06-27	128.4	1691
USR0000CBZE	BRAZIE RANCH CALIFORNIA, CA US	3000	1990-06-28	2021-06-27	31.0	11069
USR0000CWEE	WEED AIRPORT CALIFORNIA, CA US	2930	1990-05-02	2021-06-27	31.2	11234
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	2021-06-26	73.0	148

2.2.1.3 Geology

Plate tectonic, volcanic, and erosional (particularly fluvial- and landslide-related erosion) processes have formed and reformed the geomorphology of the 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 17 to 19). A more detailed description of geology is provided below and can be viewed in Figure 19.

A more detailed description of geology is provided below and whose units are referenced in Figure 19.

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 in Table 3. The Basement group is found in all cross sections produced from the model except for *Cross Section H-H'* (Figure 25). 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'* (Figures 20 and 24).

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* (Figures 24, 25 and 26)) 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 (Figures 20 and 25).

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'* (Figures 24 and ref{fig:xsec_hhp}). The most recent alluvium (Q) is mainly present in *Cross Sections A-A', E-E', West-East, and North-South* (Figures 20, 24, 27 and 26).

Geologic Basin Structures, Surface Processes, and Geomorphology

The dynamic geologic history of the Watershed resulted in many vastly different geologic formations and structures which control the surface and subsurface flow and storage of water in varying ways (such as the nearly impermeable volcanic rock, highly conductive lava tubes and moderately conductive alluvium all exist in the Watershed). Some of these geologic formations and structures led to the formation of the Valley's numerous springs and streams; this occurs when water encounters an impermeable formation or structure where it then seeks a path of least resistance. The varying geologic formations coincide with varying elevations in the Watershed which impacts where precipitation occurs as mostly rain or snow for much of the year year with formations like alluvium tending to exist in lower elevations where rainfall is dominant.

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 and eventually joins 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 the 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 the closure of Dwinnell Dam in 1928, the 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, the 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. 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 (Figure 19). 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 of the Watershed seen in *Cross Sections A-A' and E-E'* (Figures 20 and 24). 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[8].

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]). For the purposes of this GSP, all Klamath geologic units

[8] Primary aquifers of Shasta Valley Groundwater Basin

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.

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) (Figures 20 and 25). 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 snow-fall 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 (Figure 19). 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* (Figures 20 24, 27 and 26).

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'* (Figures 24 and 25). 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

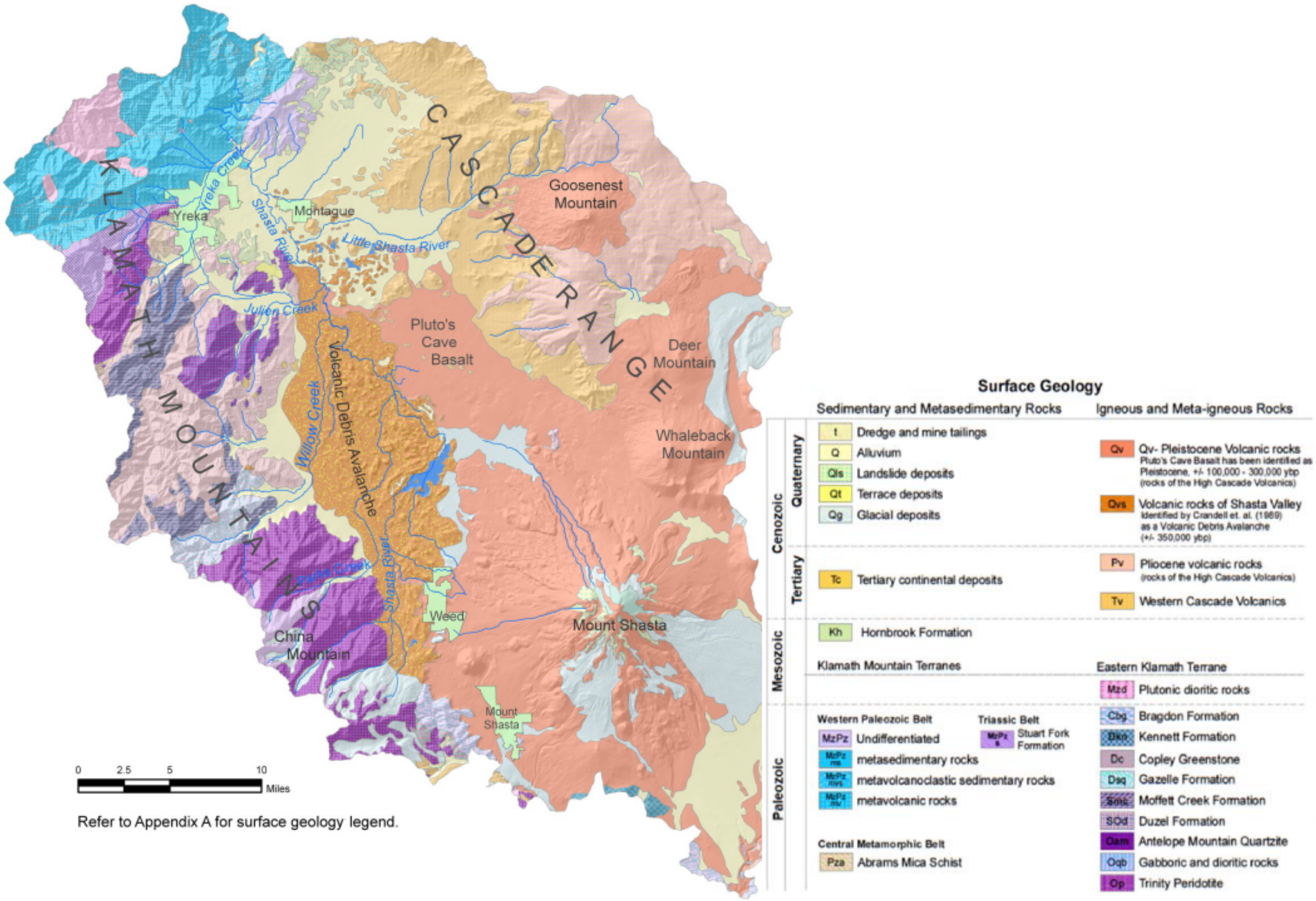

Figure 17: Shasta River Valley Watershed and extended Mount Shasta area - previous surface geologic map (reprinted and adapted from CDWR 2011).

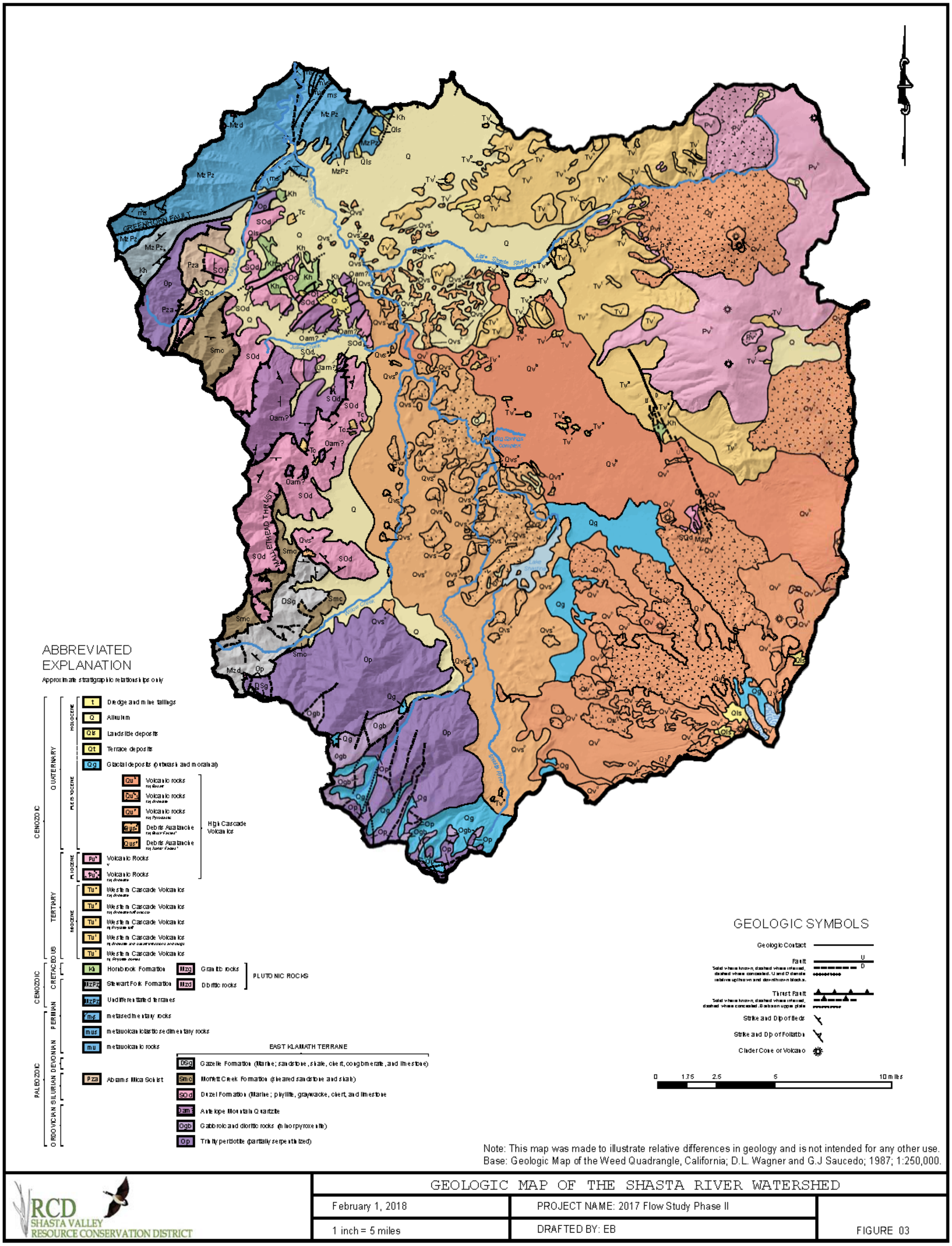

Figure 18: Shasta River Valley Watershed - previous surface geologic map (reprinted from SVRCD 2018).

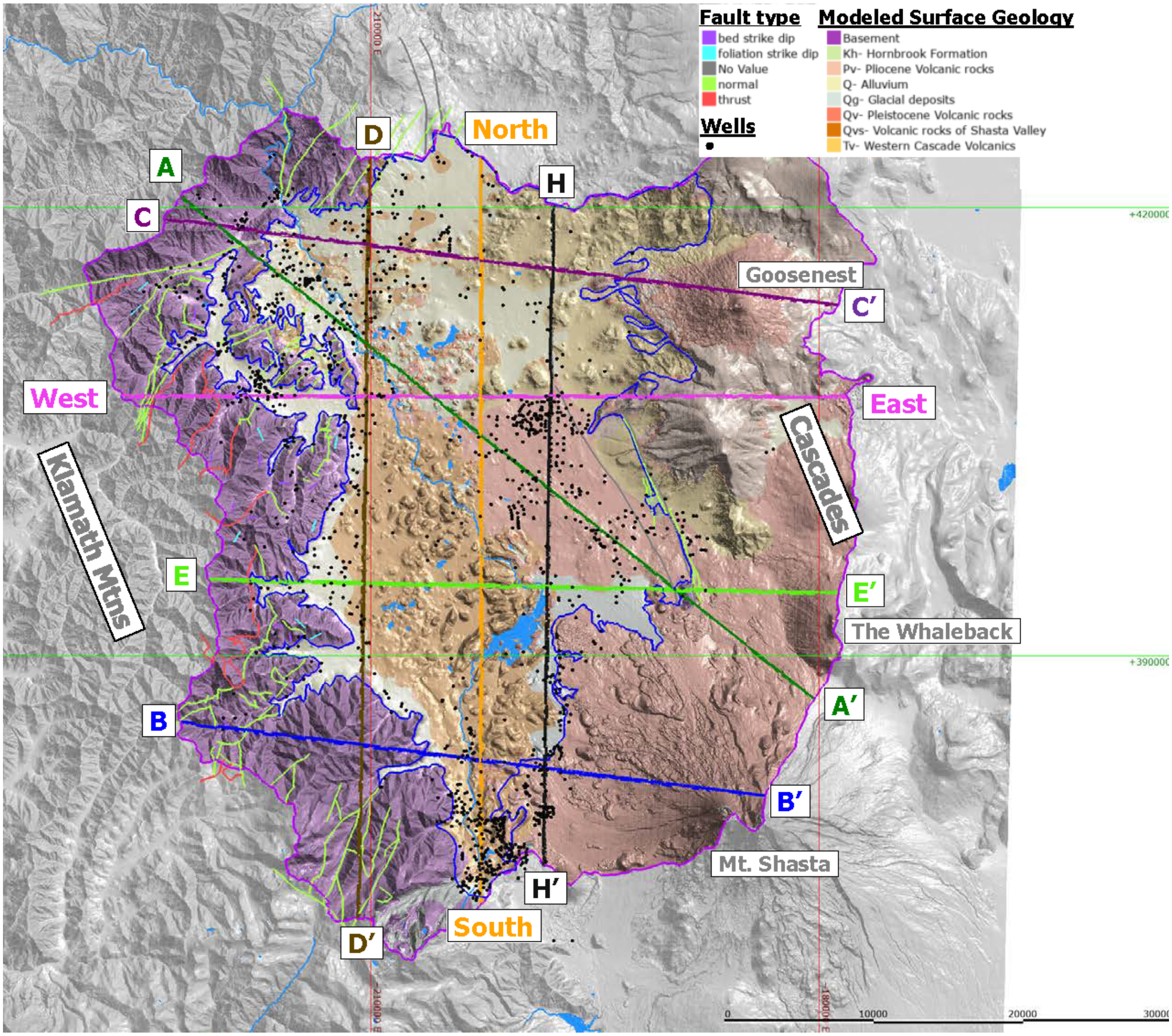

Figure 19: Shasta Valley Watershed geologic model overview and cross section map. Wells pictured in the map are the approximate locations noted in the Well Completion Reports used to construct the geologic model. The surface geology utilized in the geologic model is based on CDWR (2011) and SVRCD (2018).

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 (19)*). Cross section naming convention 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 section 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' are not used).

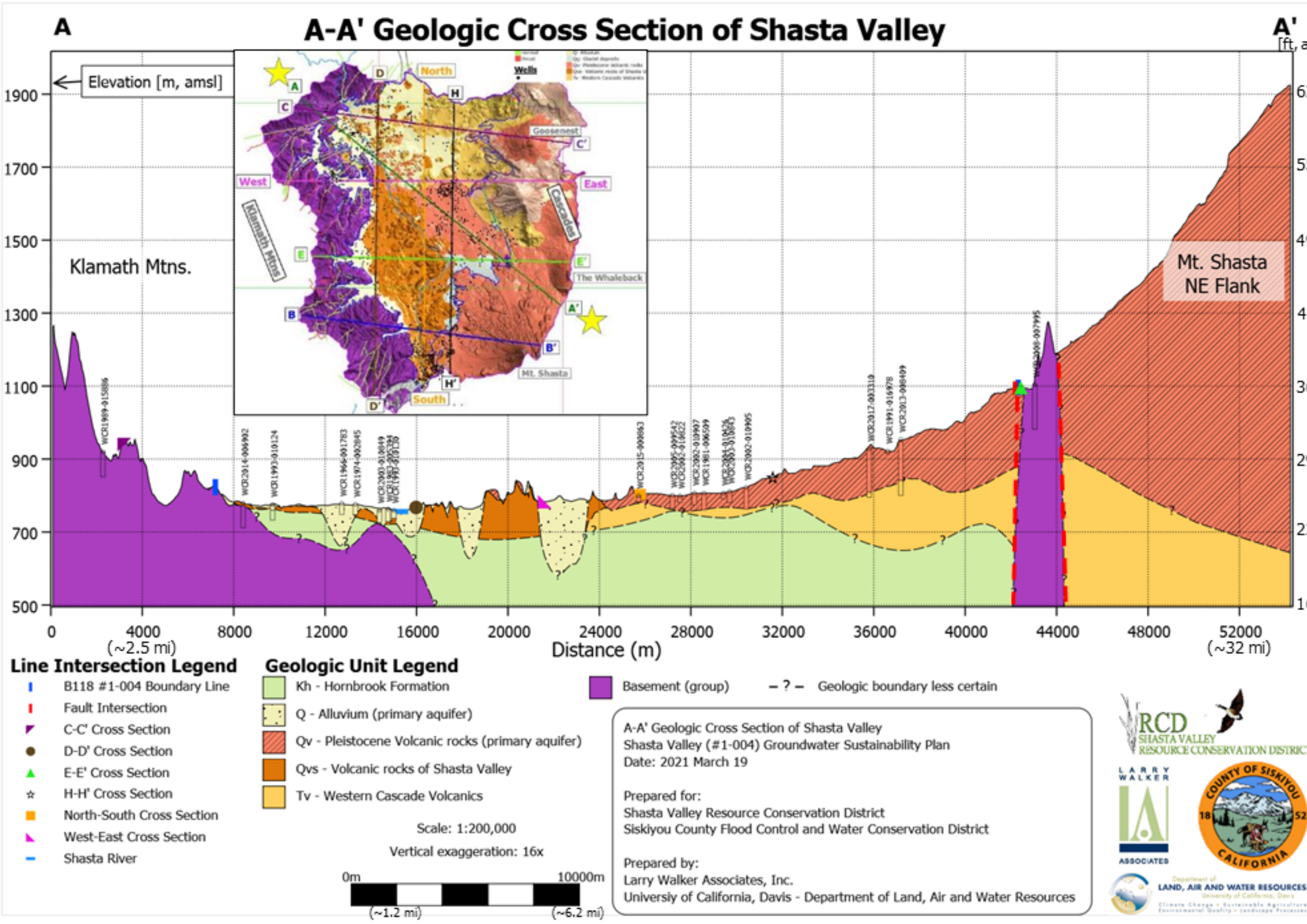

Figure 20: Geologic cross section A-A' from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

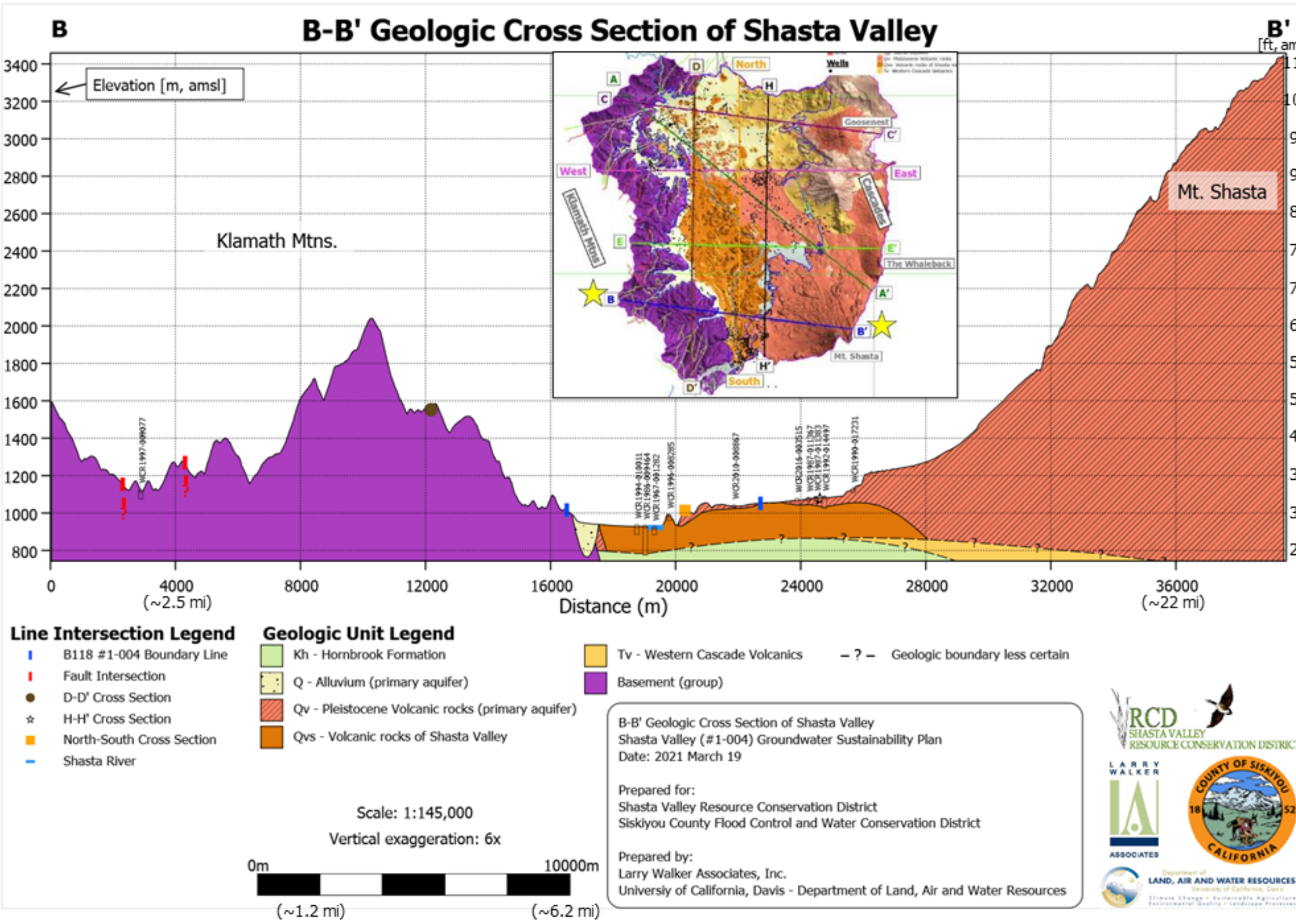

Figure 21: Geologic cross section B-B' from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

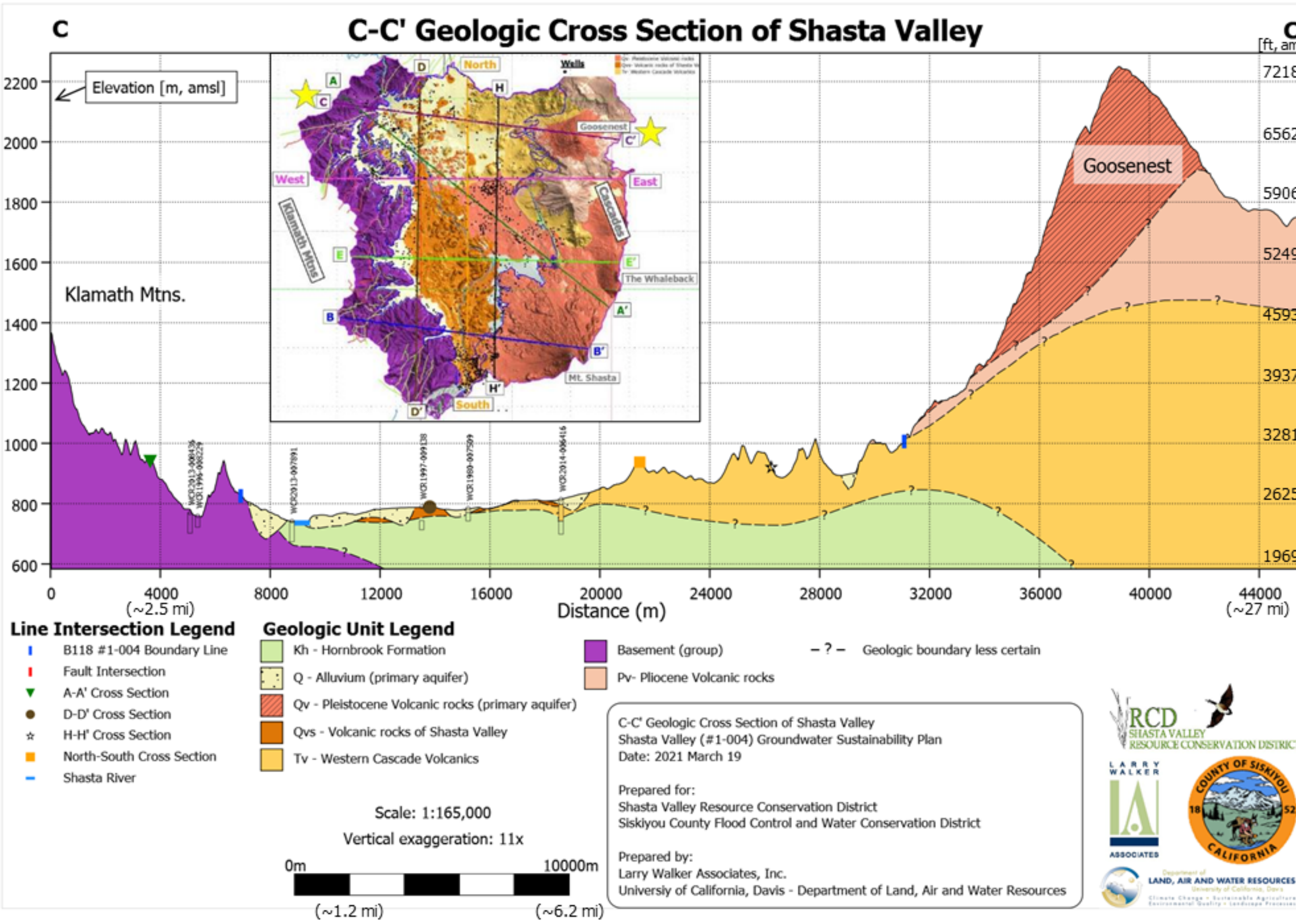

Figure 22: Geologic cross section C-C' from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

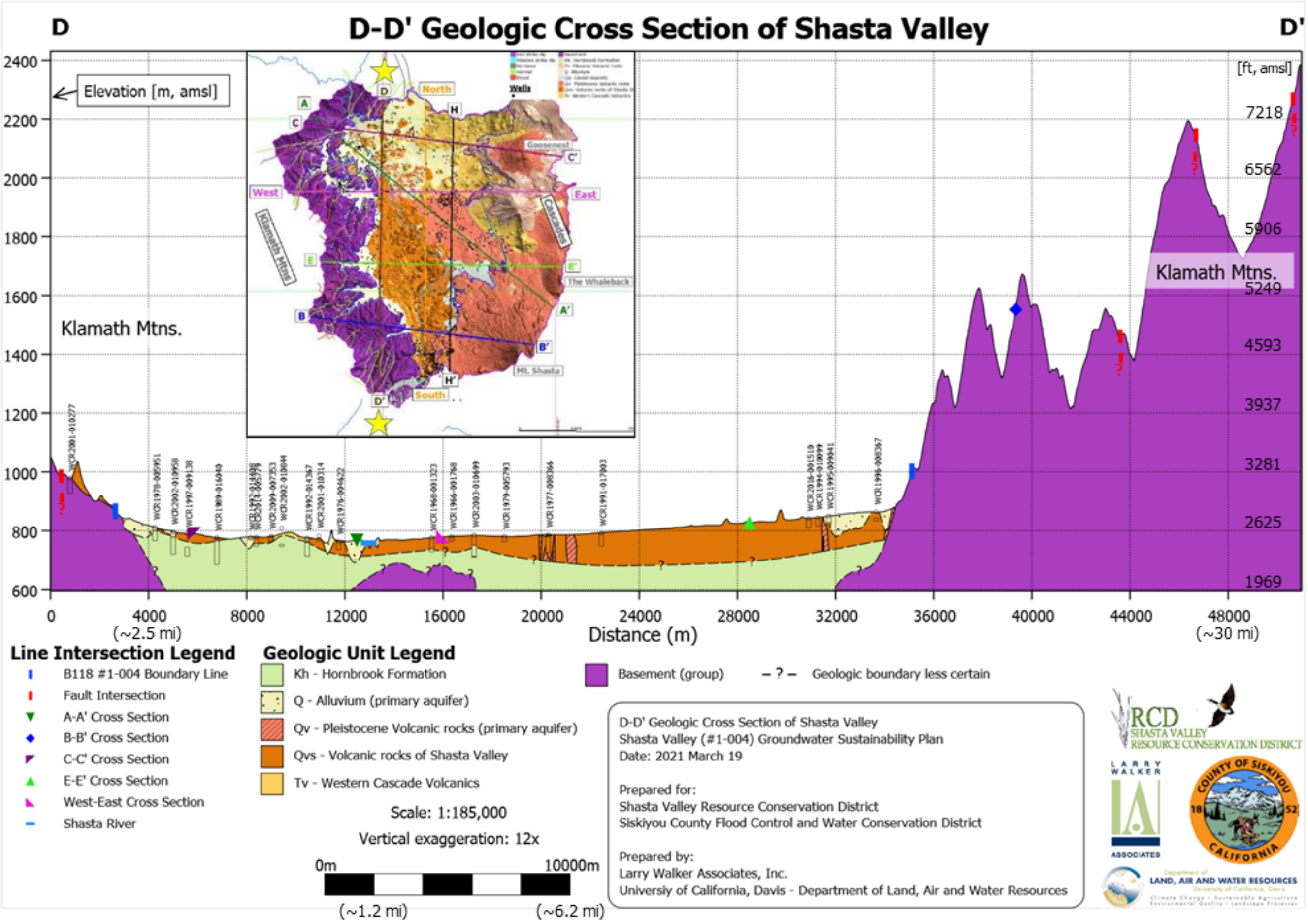

Figure 23: Geologic cross section D-D' from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

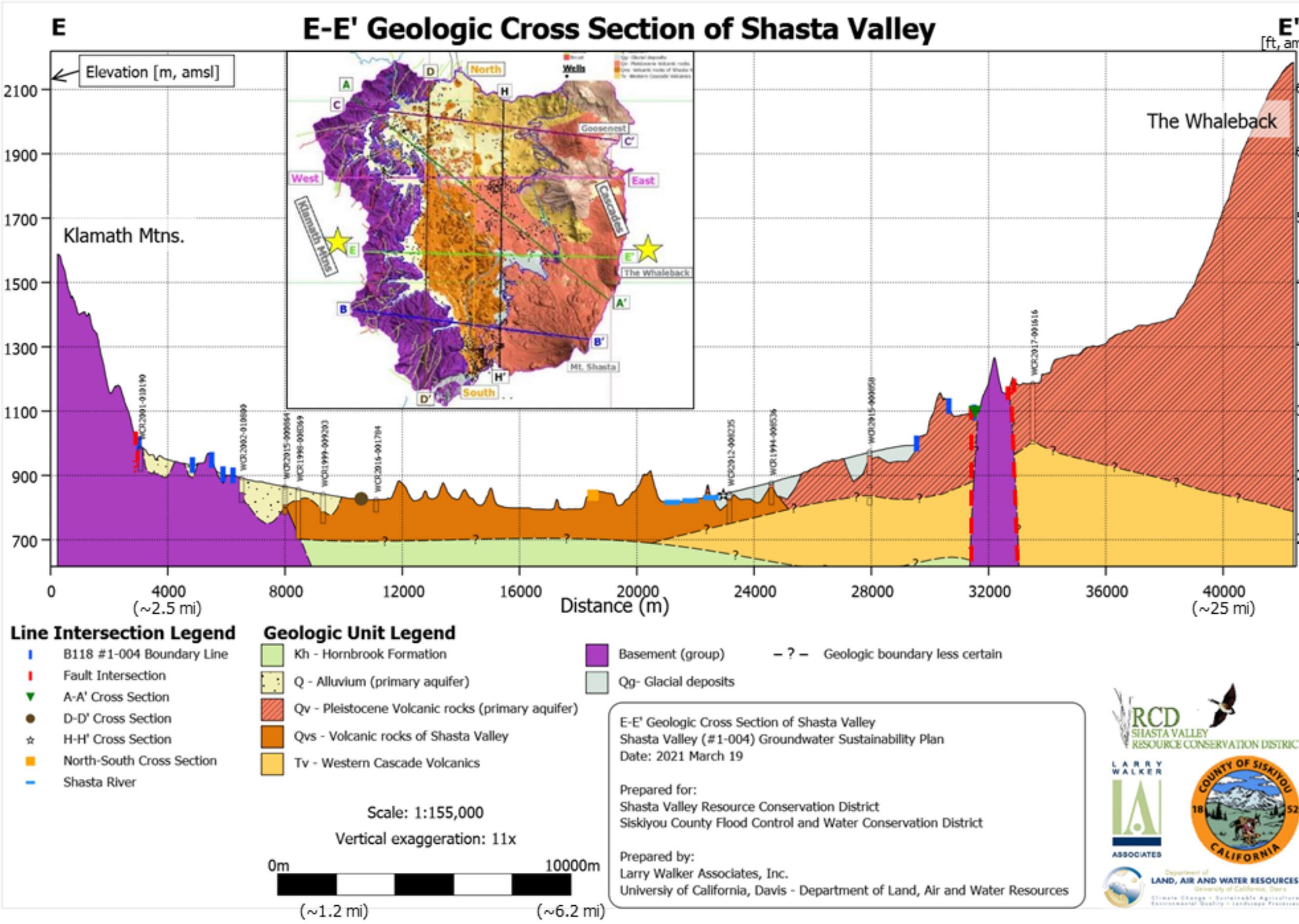

Figure 24: Geologic cross section E-E' from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

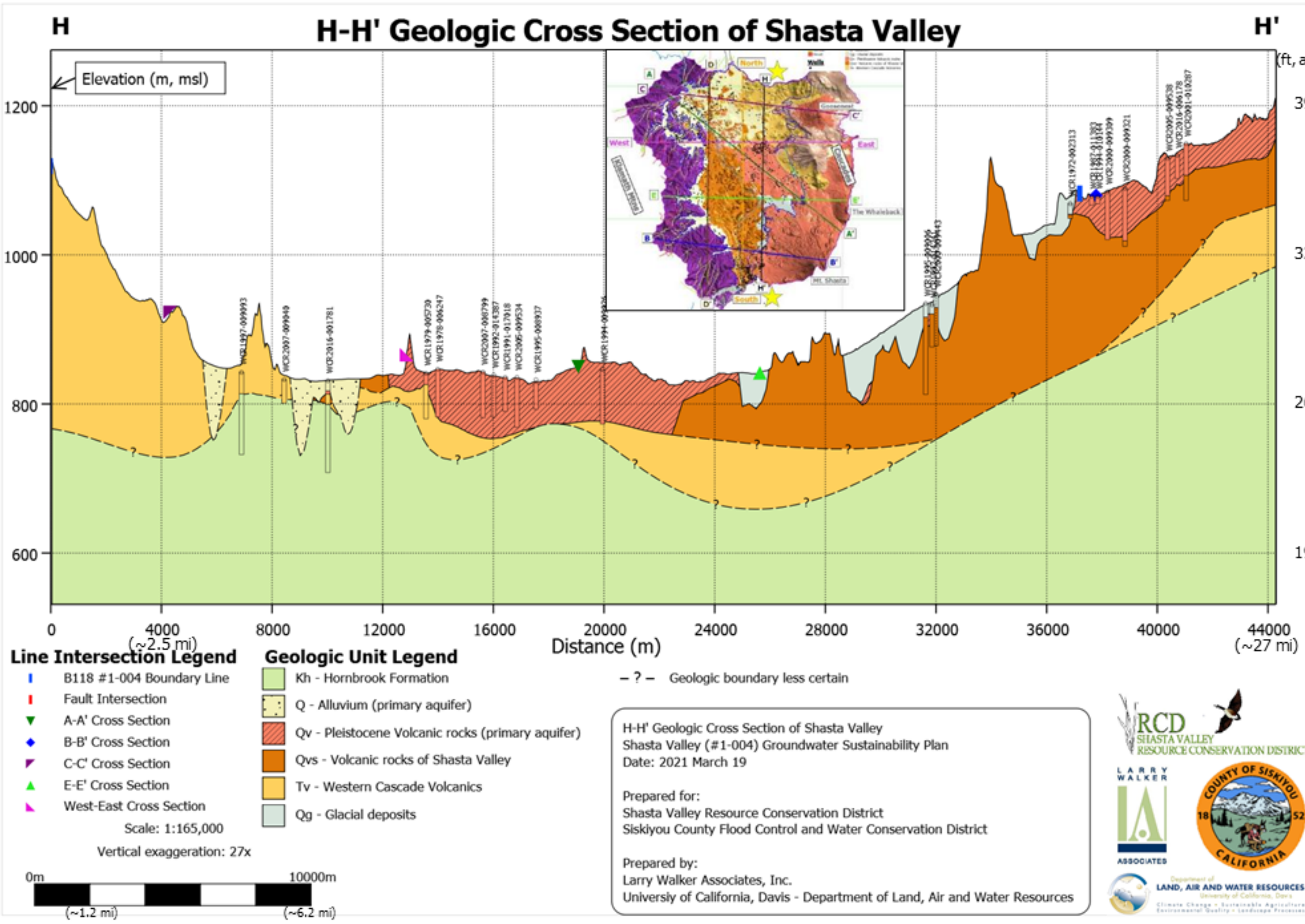

Figure 25: Geologic cross section H-H' from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

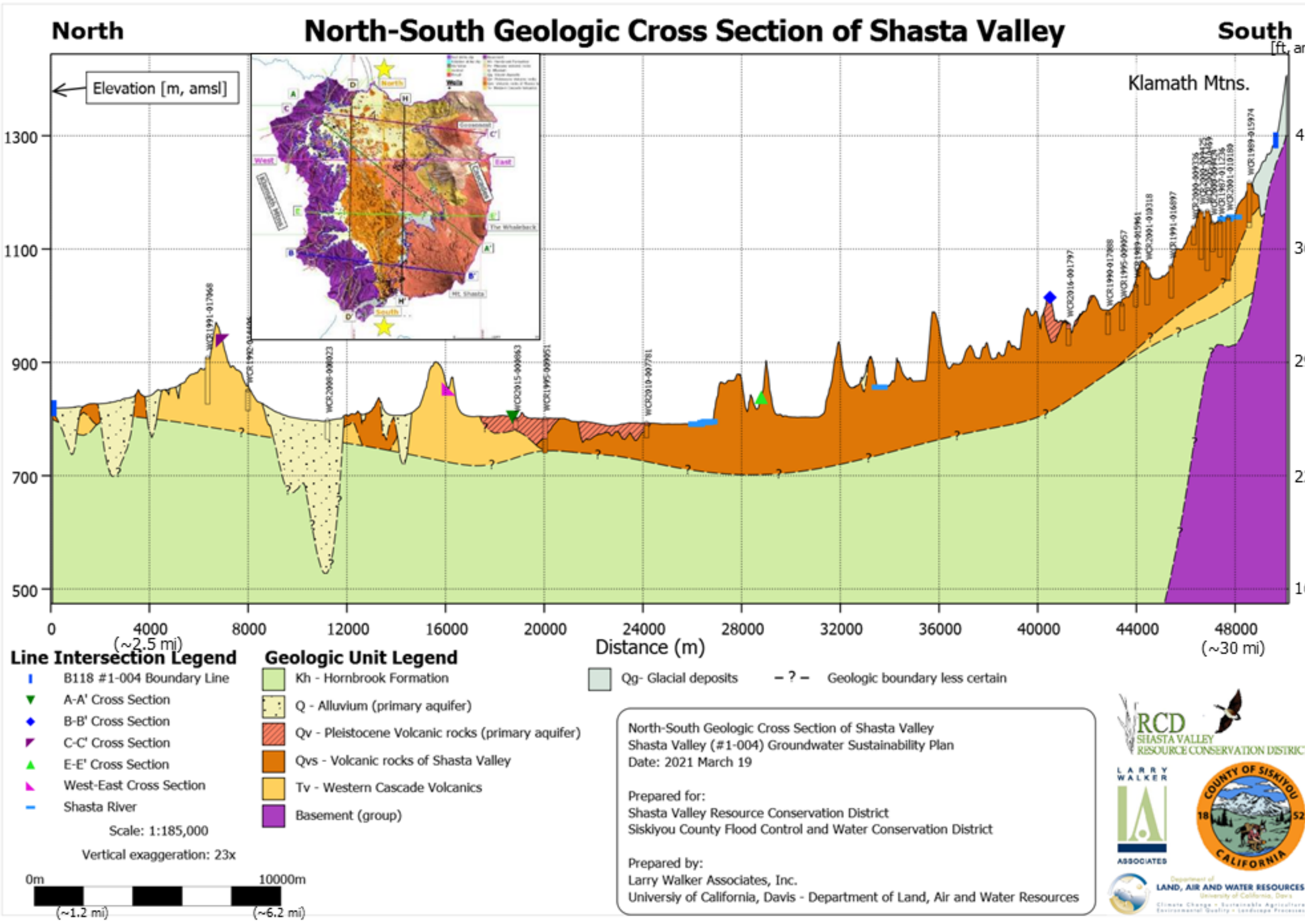

Figure 26: Geologic cross section North-South from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

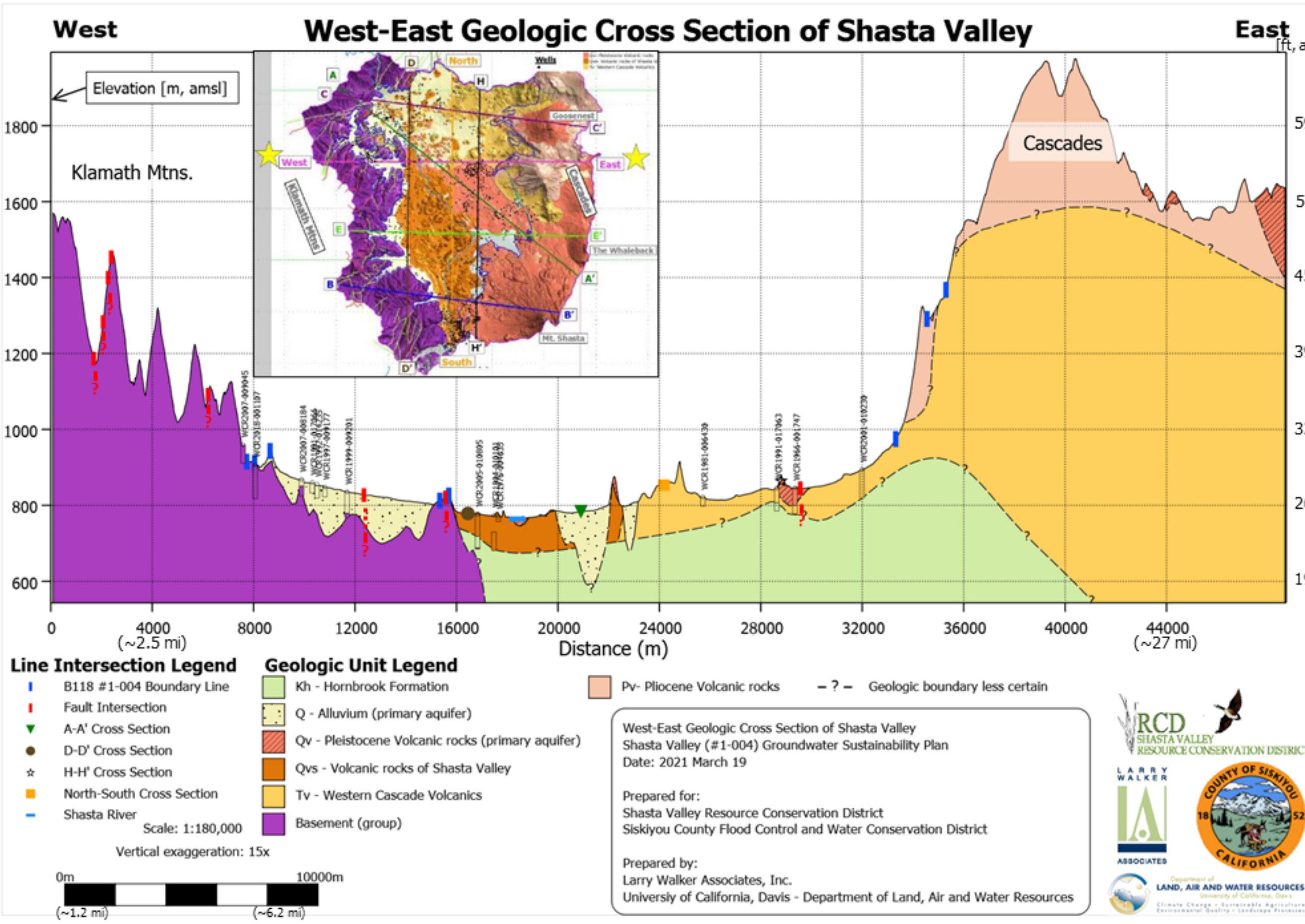

Figure 27: Geologic cross section West-East from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

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. 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.

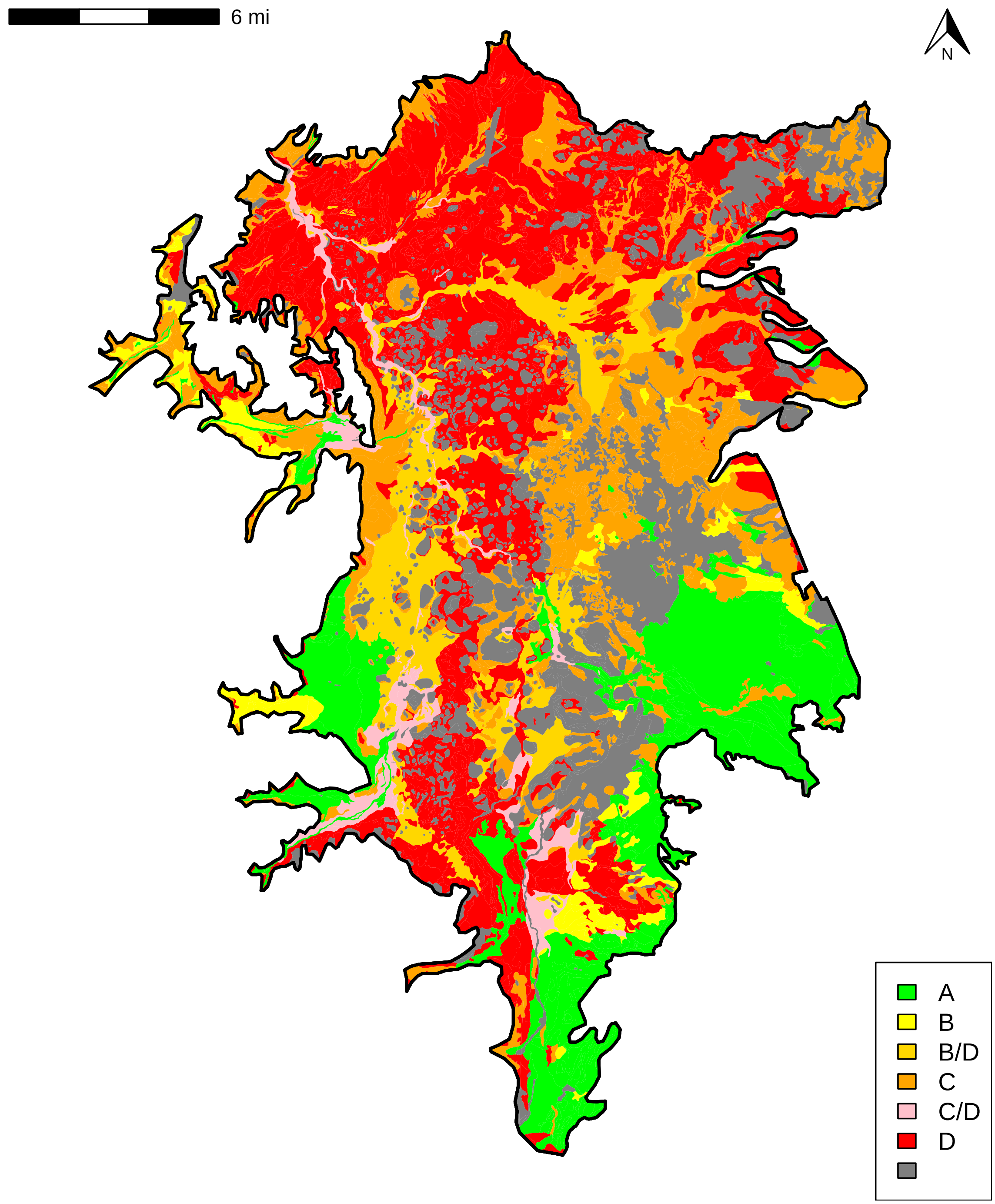

Figure 28: Hydrologic soil groups in the Shasta Valley Groundwater Basin area, where Group A are soils with a high infiltration rate and low runoff potential to Group D with very slow infiltration and high runoff potential. Soils have two Groups if a portion is artificially drained and the rest undrained.

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." (O'Geen et al. 2015). 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.

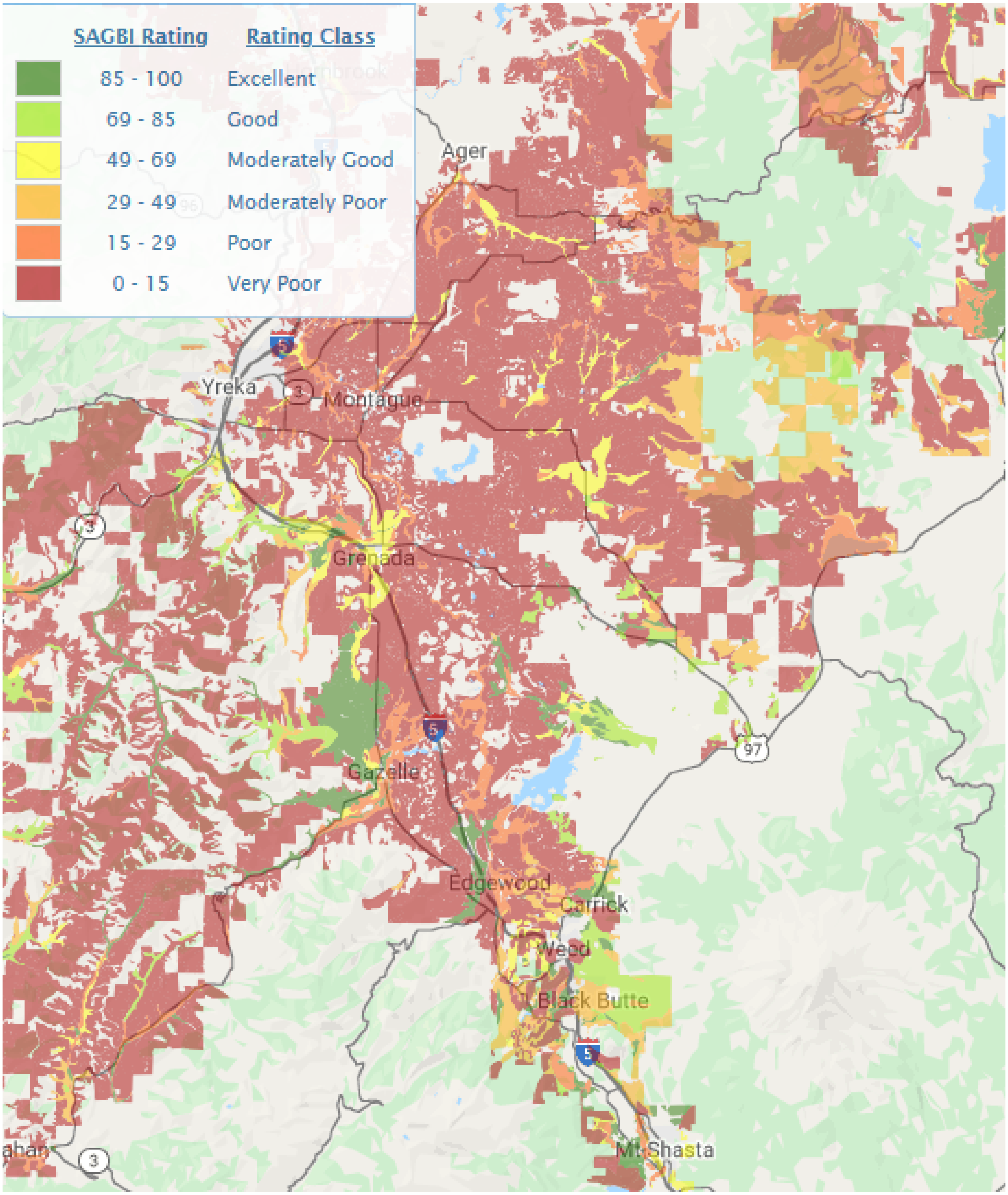

Figure 29: Unmodified Soil Agricultural Banking Index (SAGBI) of the greater the Shasta Valley Groundwater Basin area. Unmodified overlay shows SAGBI suitability groups when not accounting for modifications by deep tillage. Adapted from https://casoilresource.lawr.ucdavis.edu/sagbi/.

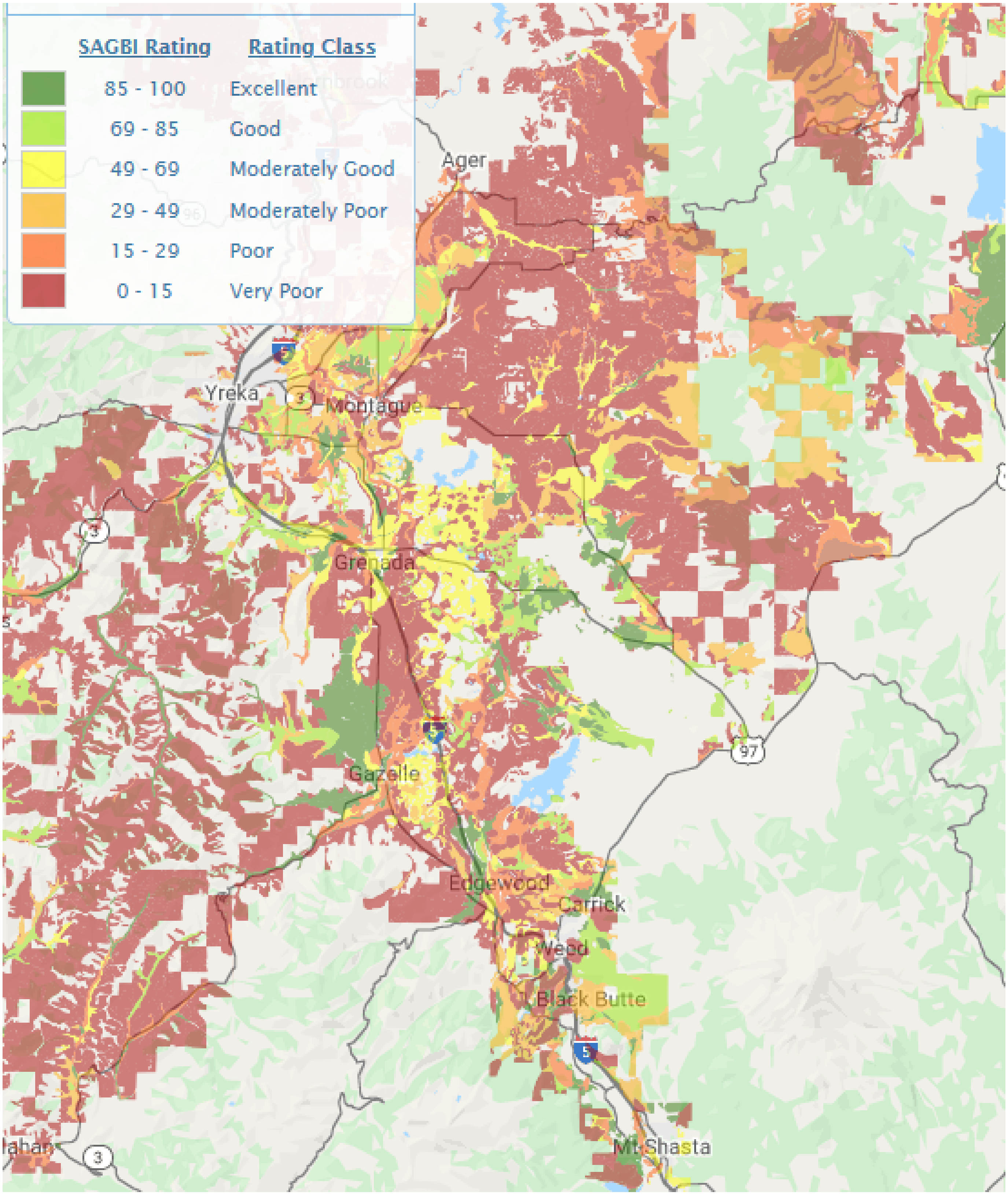

Figure 30: Modified Soil Agricultural Banking Index (SAGBI) of the greater Shasta Valley Groundwater Basin area. Modified overlay is theoretical; it shows SAGBI suitability groups when assuming that all soils with restrictive layers have been modified by deep tillage. Adapted from https://casoilresource.lawr.ucdavis.edu/sagbi/.