State of California
The Natural Resources Agency
DEPARTMENT OF WATER RESOURCES

Shasta Valley, Siskiyou County Groundwater Data Needs Assessment

July 2011

Edmund G. Brown Jr. Governor State of California	**John Laird** Secretary Natural Resources Agency	**Mark W. Cowin** Director Department of Water Resources

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Executive Summary

This report presents the results of a data needs assessment to identify what additional data collection efforts are necessary to adequately characterize the groundwater resources of Shasta Valley. The general scope for this project is to compile available data related to groundwater resources, process the data for analysis, and assess what additional data are needed to help focus future investigations. To help in this assessment, the valley was divided into eight hydrologic sub-areas based on hydrology, surface geology, and land use. These divisions help to understand the different aquifer systems and their interaction.

Groundwater and surface water are both important sources of water supply in the valley. The 2001 land use survey conducted by the Department of Water Resources shows that about 23,511 acre-feet of groundwater and 151,494 acre-feet of surface water were used to irrigate 57,567 acres in Shasta Valley. Although groundwater is reported to make up only 13 percent of the annual irrigation supply, the survey does not reflect the level of contribution made by groundwater toward maintaining surface water resources. Effective management of both surface water and groundwater is essential to meet the needs of future development, agricultural production, and the ongoing water quality and flow requirements of the cold water fishery.

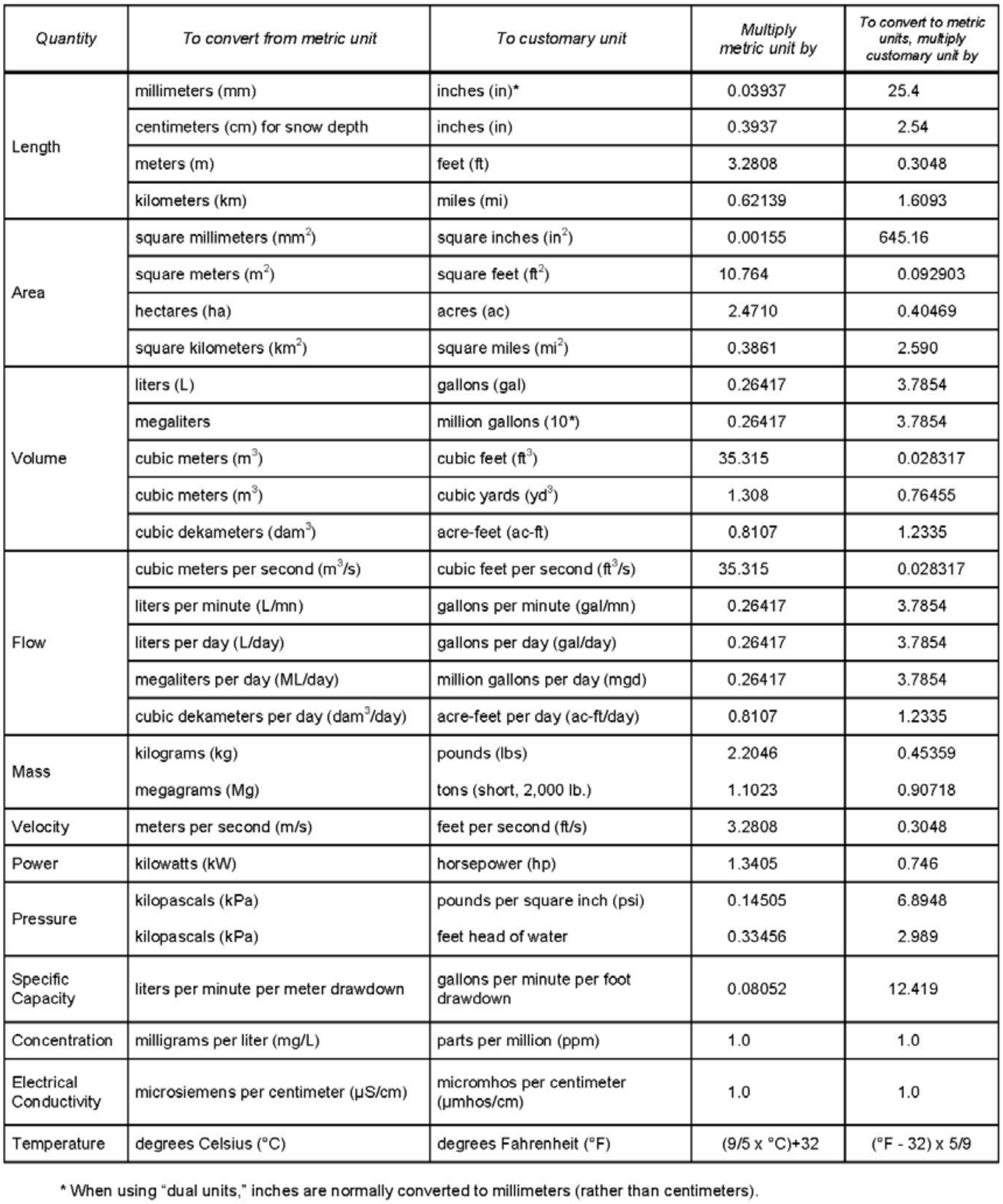
An important finding of this assessment concerns the role surface water plays with respect to groundwater. Irrigation with surface water has been a practice in the valley for more than 150 years. The application of surface water by flood irrigation methods is a source of groundwater recharge that contributes to domestic supplies and groundwater accretion to the river. Future urban and rural residential development may reduce this source of groundwater recharge if development requires the conversion of farm land to other uses. On-farm water conservation practices and efforts to reduce conveyance ditch losses will also reduce this source of recharge. These actions are not necessarily detrimental to groundwater resources; however, future planning efforts need to take the reduction of this source of recharge into account. Aquifers most susceptible to future development or changes in land use are the hydrologic sub-areas of Yreka, Yreka East, Montague, Little Shasta Valley, and Gazelle/Grenada.

Another finding of this assessment concerns the Pluto’s Cave basalt aquifer and its role in the cold water fishery. This aquifer system is the primary source of cold water inflow to the Shasta River below Dwinnell Dam during summer and fall months, a flow that is critically important to coho and other salmon. Groundwater extractions from this aquifer have historically affected groundwater discharge to the river. Future residential and agricultural development—and corresponding increases in groundwater usage—may further reduce this source of cold water supply to the river.

The greatest water challenge facing county planners and resource managers is the need to define the limits of available supplies and find the appropriate balance to meet present and future water demands. Each hydrologic sub-area in the valley has different resource requirements. To help define these requirements, it’s recommended that a groundwater budget be developed for each hydrologic sub-area defining the different sources of recharge, discharge, and changes in groundwater volumes. To support this effort, the following data collection efforts are recommended:

- Expanded groundwater level monitoring
- Aquifer performance testing
- Identification and quantification of the sources of recharge
- Stream characterization
- Water quality assessments

Metric Conversion Table



Quantity	*To convert from metric unit*	*To customary unit*	*Multiply metric unit by*	*To convert to metric units, multiply customary unit by*
Length	millimeters (mm)	inches (in)*	0.03937	25.4
	centimeters (cm) for snow depth	inches (in)	0.3937	2.54
	meters (m)	feet (ft)	3.2808	0.3048
	kilometers (km)	miles (mi)	0.62139	1.6093
Area	square millimeters (mm^2)	square inches (in^2)	0.00155	645.16
	square meters (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometers (km^2)	square miles (mi^2)	0.3861	2.590
Volume	liters (L)	gallons (gal)	0.26417	3.7854
	megaliters	million gallons (10*)	0.26417	3.7854
	cubic meters (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic meters (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekameters (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic meters per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	liters per minute (L/mn)	gallons per minute (gal/mn)	0.26417	3.7854
	liters per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megaliters per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekameters per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lbs)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb.)	1.1023	0.90718
Velocity	meters per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	liters per minute per meter drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per liter (mg/L)	parts per million (ppm)	1.0	1.0
Electrical Conductivity	microsiemens per centimeter (µS/cm)	micromhos per centimeter (µmhos/cm)	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(9/5 x °C)+32	(°F - 32) x 5/9

* When using "dual units," inches are normally converted to millimeters (rather than centimeters).

Acronyms and Abbreviations

APN	Assessor’s Parcel Number
BSID	Big Springs Irrigation District
CESA	California Endangered Species Act
CGS	California Geological Survey
DOQQ	Digital Ortho Quarter Quads
DWR	California Department of Water Resources
EPA	US Environmental Protection Agency
FESA	Federal Endangered Species Act
GID	Grenada Irrigation District
gpm	gallons per minute
mg/L	milligrams per liter
mya	million years ago
PRISM	Parameter-Elevation Regressions on Independent Slopes Model
RCD	Resource Conservation District
TDS	total dissolved solids
TDS	total dissolved solids
TMDL	total maximum daily load
USGS	US Geological Survey
WDL	DWR’s Water Data Library

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1 Introduction

Resource managers and planners in Shasta Valley face many challenges including the need to assess available water resources and arrive at an appropriate balance to meet the needs of urban development, agriculture, and the cold water fishery. Such an assessment can only be accomplished by understanding the hydrogeology of the region, the different aquifer systems, and the effects and impacts of current and future management practices. Recognizing this, the Shasta Valley Resource Conservation District (RCD) initiated discussions with California Department of Water Resources (DWR) in 2002 that led to the first steps of that process.

This report presents the results of data compilation efforts and identifies the data necessary to adequately characterize groundwater resources in Shasta Valley. This section summarizes the water resource issues for the valley and provides an overview of the assessment approach and methods.

1.1 Water Resource Issues

Probably the most immediate and pressing issues facing water users in Shasta Valley are water quality and quantity problems associated with the cold water fishery, as well as the potential for inadvertently taking coho salmon through agricultural diversions. There have been longstanding concerns about how the diversion of water from streams in Shasta Valley affects the fishery, but water management has focused primarily on the distribution of surface water resources for agriculture. Only since the early 1990s have fishery concerns been a focus of resource planning and management.

Among the resource problems facing planners is the need to identify and verify the water supplies necessary to meet the needs of ongoing urban and rural residential development and agricultural demands for groundwater.

1.1.1 Cold Water Fishery Issues

Historically, the Shasta River has been one of the most productive salmonid rivers in California. It has supported large runs of Chinook salmon, coho salmon, and steelhead. However, the river's productivity has declined over the past 75 years and is now the focus of major restoration efforts. The key feature that makes the river suitable for cold-water fish is the discharge of groundwater from natural springs to the river, which assures year-round flows and cold water temperatures. Continued salmonid use of the river is largely dependent on the groundwater resources of Shasta Valley.

In 1992, Shasta River was added to California's 303(d) List of Impaired Waters by the U.S. Environmental Protection Agency (EPA); it has remained on the list through subsequent listing cycles due to the organic enrichment, low dissolved oxygen, and elevated temperatures of its waters.

The coho salmon population within the watershed was listed as threatened under the Federal Endangered Species Act (FESA) and the California Endangered Species Act (CESA) in 1997 and 2004, respectively. To address the risk of inadvertent take of coho salmon resulting from irrigation and other agricultural activities, the RCD has applied for take protection through a Master Incidental Take Permit Application. The application lists the potential impacts to coho salmon that are covered under the permit and identifies the avoidance and minimization measures and mitigation actions that participants will perform. The measures and actions are based on the California Department of Fish and Game's *Recovery Strategy for California Coho*

Salmon (2003). In addition to describing actions that directly target stream temperature and dissolved oxygen issues, the document identifies several groundwater-related actions to help preserve or enhance in-stream flows, including the following:

- Initiate groundwater substitution during low-flow periods
- Evaluate groundwater recharge from unlined ditches
- Assess groundwater resources to update previous groundwater investigations
- Expand groundwater monitoring
- Provide data analysis to assess resource management options
- Evaluate the need for groundwater basin management planning

To address water quality issues, the North Coast Regional Water Quality Control Board issued the *Action Plan for the Shasta River Temperature and Dissolved Oxygen Total Maximum Daily Loads* (TMDL), which was approved by the EPA in January 2007. The plan identifies several actions to meet temperature, dissolved oxygen, and other water quality standards, and it focuses on existing restoration efforts, surface water management strategies, and discharges to surface water.

1.1.2 Urban Development Issues

Much of the municipal water supply in Shasta Valley is derived from surface water sources. The City of Yreka imports surface water from Fall Creek (off the Klamath River) and supplements the supply with groundwater from the underflow of Yreka Creek during periods of peak demand. The City of Montague diverts water from Little Shasta River in winter and Lake Shastina in summer for municipal and industrial use.

Other domestic needs are met by groundwater resources. The community of Lake Shastina relies on groundwater wells for domestic supply. The community of Grenada is supplied by a single groundwater well, and the City of Weed is supplied by spring flow from the flanks of Mount Shasta. Domestic water supplies for all users, with the exception of the cities of Yreka and Montague, depend on local groundwater resources. Resource planning and groundwater assessments are needed to identify sustainable levels of groundwater development to ensure future supply reliability.

1.2 Assessment Approach and Methods

This assessment entailed the compilation of data related to groundwater resources, the processing of compiled data as necessary for analysis, and the evaluation of the data to identify information gaps. The following presents a summary of the compilation efforts, processing methods, resources used, and general framework for the data needs assessment.

1.2.1 Data Compilation

Data compilation efforts included the review of previously published reports, unpublished data, and online data searches. The majority of the data resources used for this project were found in published reports from the U.S. Geological Survey (USGS) and the California Geologic Survey (CGS), as well as in unpublished data from DWR.

The primary data sources used for this project are summarized in the following sections. Also included is a list of other important references that provided additional background information on regional geology and water resources.

1.2.1.1 Published Data Resources

Published data sources used in this assessment are the following:

- Mack, S. 1960. *Geology and Groundwater Features of Shasta Valley, Siskiyou County California*. Water Supply Paper 1484. U.S. Geological Survey.
- Strand, R.G. 1963. Geologic Map of California, Weed Sheet. California Division of Mines and Geology.
- DWR. 1963. *Land and Water Use in Shasta-Scott Valleys Hydrographic Unit*. *Bulletin* No. 94-5.
- Wagner, D.L. and G.J. Saucedo. 1987. Geologic Map Series, Weed Quadrangle – Map No. 4A (Geology), Sheet 1 of 4. California Division of Mines and Geology.
- Nathenson M., et al. 2002. “Slightly Thermal Springs and Non-Thermal Springs at Mount Shasta, California: Chemistry and Recharge Elevations.” Journal of Volcanology and Geothermal Research, Volume 2545.
- DWR. Water Data Library [groundwater level data] (http://wdl.water.ca.gov).

1.2.1.2 Unpublished Data Resources

Unpublished data resources include groundwater chemistry, surface water chemistry, land use survey data, as well as well completion reports kept on file with DWR.

The water chemistry data collected by DWR included mineral concentrations from groundwater sampling conducted in 1991. The surface water chemistry data included analyses of mineral concentrations from a Shasta River sampling program that DWR conducted in 2001 and 2002. The land use data are from surveys in years 2000 and 2001.

DWR maintains a database of well completion reports that are submitted when groundwater wells are completed or destroyed. These data allowed DWR to evaluate the number of wells constructed, well uses, well depths, and periods of construction. The period of record extends back to1960 for well completion reports used in this assessment. The reports were used to identify groundwater development trends in the valley and to expand on previous subsurface geologic interpretation.

1.2.1.3 Other Important References

The following data resources were used to further define the geology and geomorphology of the region and to help characterize the different aquifer systems and their interaction. Data contained on maps or within the individual reports were not processed for GIS analysis.

- Williams, H. 1949. *Geology of the Macdoel Quadrangle, California.* Bulletin 151. U.S. Geological Survey.
- Irwin, W.P. 1972. *Terranes of the Western Paleozoic and Triassic Belt in the Southern Klamath Mountains, California.* Professional Paper 800-C. U.S. Geological Survey.
- Hotz, P.E. 1977. *Geology of the Yreka Quadrangle, Siskiyou County, California.* Bulletin 1436. U.S. Geologic Survey.
- Crandell, D.R. 1989. *Gigantic Debris Avalanche of Pleistocene Age From Ancestral Mount Shasta Volcano, California, and Debris Avalanche Hazard Zonation.* Bulletin 1861. U.S. Geological Survey.
- Irwin, W.P. 1994. Geologic Map of the Klamath Mountains, California and Oregon, Miscellaneous Investigation Map Series – Map I-2148 (Sheet 1 of 2) U.S. Geological Survey.
- Irwin, W.P. 2003. *Correlation of the Klamath Mountains and Sierra Nevada.* Open File Report 02-490. U.S. Geological Survey.

- Watershed Sciences, LLC. 2004. Aerial Surveys Using Thermal Infrared and Color Videography, Scott River and Shasta River Sub-Basins. Watershed Sciences.

1.2.2 Data Processing Methods

Data processing entailed the development and formatting of the data suitable for spatial analysis. Methods of data processing varied depending on whether data were in digital or hard copy format. Hard copy maps of surface geology and historical land and water use data were scanned and georeferenced. Linear features were digitized from rectified maps as appropriate. Point features were digitized from rectified maps or geocoded from information provided on well completion reports or other spatial data, including Digital Ortho Quarter Quads (DOQQ's), Assessor's Parcel Number (APN) maps, and road networks. Attribute data for geographic features were transcribed from the original data source. The unpublished data were processed through data transcription, statistical analysis, and geocoding of geographic features. A summary of data type, data sources, and processing methods is provided in Table 1.

Table 1. Summary of the data processed for this assessment

Subject area	Data resource	Organization(s) or sources	Processing	Product
Surface Geology	Strand (1963). Geologic Map of California – Weed Sheet	California Department of Conservation, Division of Mines and Geology	Scanned, georeferenced	Shapefile
Surface Geology	Wagner and Saucedo (1987.) Geologic Map of California – Weed Quadrangle – Map No. 4A (Geology)	California Department of Conservation, Division of Mines and Geology	Scanned, georeferenced	Shapefile
Well Lithology	Well Completion Reports	DWR	Well lithology transcribed from well completion reports and geocoded	Geologic cross sections
Geologic Faults	Wagner and Saucedo. (1987). Geologic Map of California – Weed Quadrangle – Map No. 4A (Geology)	California Department of Conservation, Division of Mines and Geology	Scanned, georeferenced, digitized	Shapefile
Geologic Faults	Mack (1960). Geology and Groundwater Features of Shasta Valley, Siskiyou County California, Plate 1	U.S. Department of the Interior, DWR	Scanned, georeferenced, digitized	Shapefile
Thermal Springs	Nathenson, et al. (2002). Slightly Thermal Springs and Non-thermal Springs at Mount Shasta, California: Chemistry and Recharge Elevations	Journal of Volcanology and Geothermal Research, Volume 2545	Geocoded	Shapefile
Springs	Mack (1960). Geology and Groundwater Features of Shasta Valley, Siskiyou County California, Plate 2	U.S. Department of the Interior, DWR	Scanned, georeferenced digitized	Shapefile
Springs	USGS quadrangle maps	U.S. Geological Survey	Digitized	Shapefile
Water Chemistry	Mack (1960). Geology and Groundwater Features of Shasta Valley, Siskiyou County California, Table 22	U.S. Department of the Interior, DWR	Digitized, data transcribed	Shapefile
Water Chemistry	Unpublished water quality data	DWR	Data reformatted	Shapefile
Well Data (data compilation)	Mack (1960). Geology and Groundwater Features of Shasta Valley, Siskiyou County California, Plate 1	U.S. Department of the Interior, DWR	Scanned, georeferenced, digitized	Shapefile
Well Data (data compilation)	Mack (1960). Geology and Groundwater Features of Shasta Valley, Siskiyou County California, Table 19	U.S. Department of the Interior, DWR	Data transcribed	Shapefile
Well Data (yield data)	Mack (1960). Geology and Groundwater Features of Shasta Valley, Siskiyou County California, Plate 1	U.S. Department of the Interior, DWR	Scanned, georeferenced, digitized	Shapefile
Well Data (yield data)	Mack (1960). Geology and Groundwater Features of Shasta Valley, Siskiyou County California, Tables 5, 6, 7,8	U.S. Department of the Interior, DWR	Data transcribed	Shapefile
Well Data (yield and depth data)	Unpublished well completion reports	DWR	Statistical analysis, geocoded	Shapefile
Watershed	Calw20a Shapefile	California Interagency Watershed Mapping Committee		Shapefile
Land Use	DWR (2001). Unpublished Land Use Data	DWR	None	Shapefile
Historic Land and Water Use	DWR (1963). Land and Water Use In Shasta-Scott Valleys Hydrographic Unit, Bulletin No. 94-5	DWR	Scanned, georeferenced	Rectified Scan

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2 Description of Study Area

This section summarizes the background data for groundwater resources in Shasta Valley. It includes summaries of climate, geology, hydrogeology, groundwater resources, and land use. Information specific to groundwater resources includes current monitoring efforts, levels of groundwater development in the valley, and groundwater chemistry as it relates to regional geology.

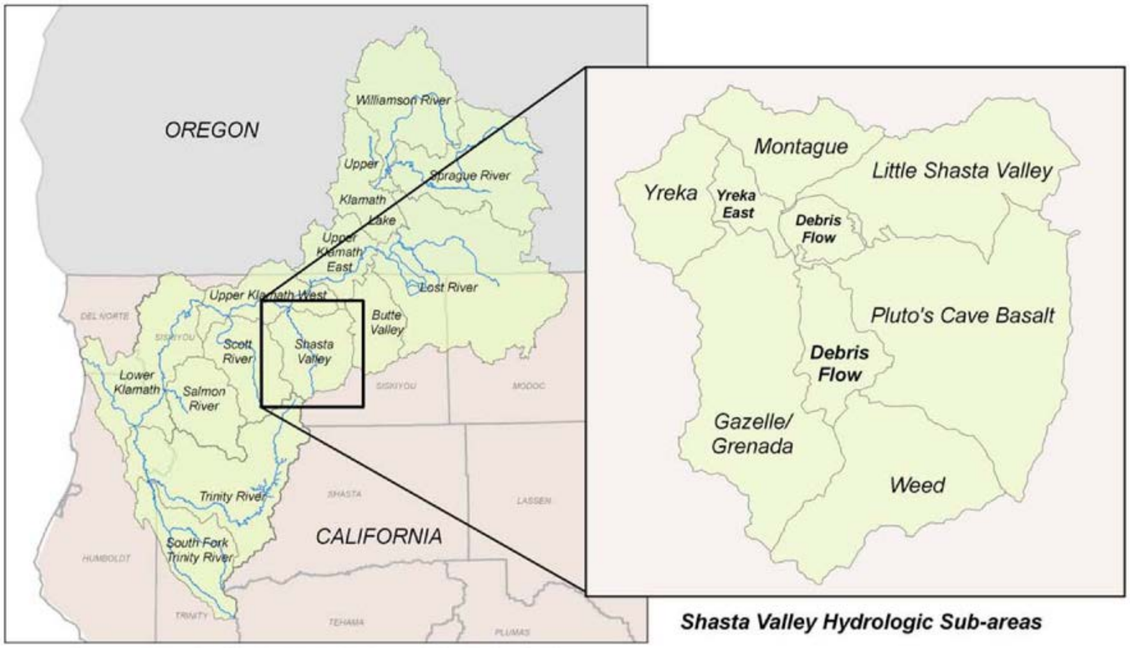
2.1 Project Location

Shasta Valley is located within central Siskiyou County and is a hydrologic area of the Klamath River hydrologic unit. A hydrologic area is part of a geographic classification which includes (from largest to smallest) hydrologic regions, hydrologic units, hydrologic areas, and hydrologic sub-areas.

For the purpose of this assessment, the Shasta Valley hydrologic area was subdivided into the hydrologic sub-areas shown in Figure 1 due to the complex hydrogeology of the region and to simplify data evaluation and needs assessment. The sub-area delineations are based on geology, hydrogeology, hydrology, groundwater chemistry, and sub-watershed boundaries. Land use survey data were also used to delineate the Gazelle/Grenada and Debris Flow hydrologic sub-areas.

For the most part, the sub-areas delineate different aquifer systems in the valley. These sub-areas form the basis of this assessment and are discussed further in the following subsections. The number of sub-areas and their boundaries will likely be modified in the future as more data become available.

Figure 1. Project location and Shasta Valley hydrologic sub-areas



Shasta Valley Hydrologic Sub-areas

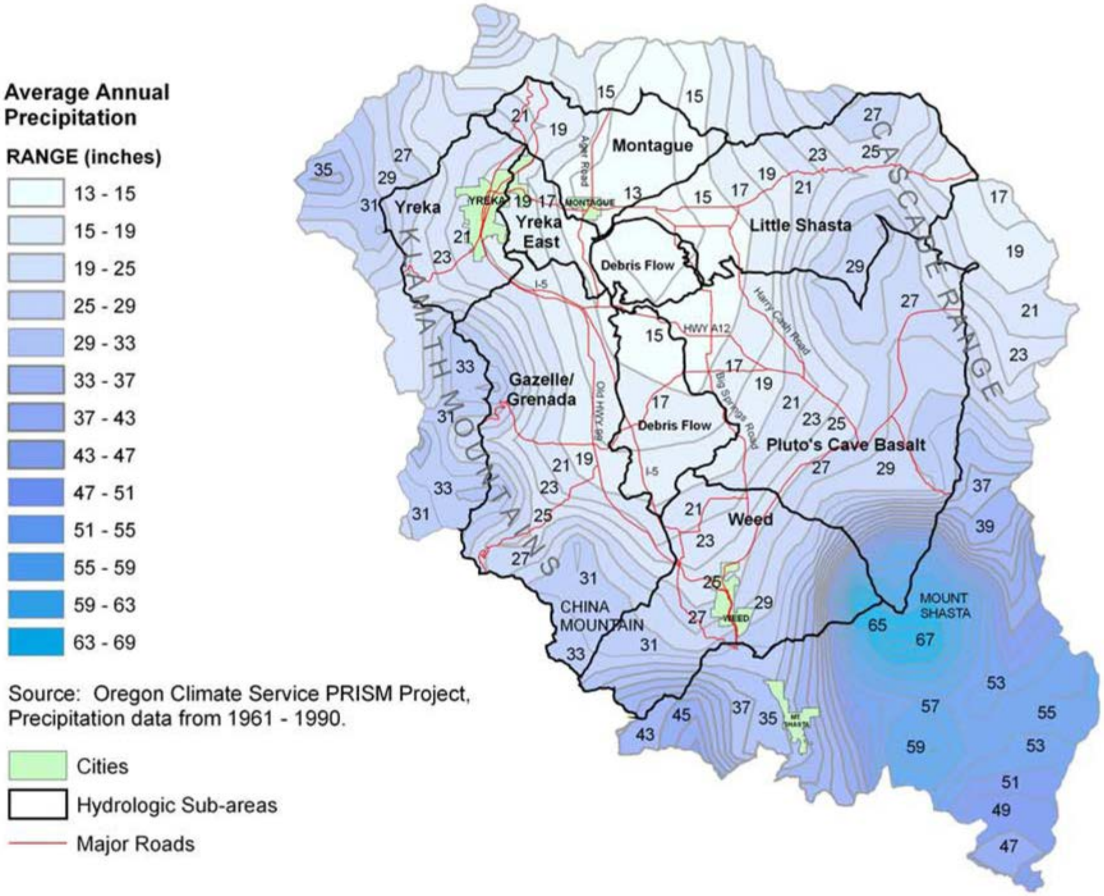
Klamath Basin Hydrologic Unit and Hydrologic Areas

2.2 Climate

Shasta Valley lies within the rain shadow of Mount Shasta and the Klamath Mountains. The valley is predominantly a high desert environment characterized by hot, dry summers and cool, wet winters. Annual mean precipitation ranges from a low of about 13 to 15 inches at lower elevations to a high of about 67 inches at Mount Shasta. In the City of Yreka, annual precipitation averages between 19 and 21 inches. Annual precipitation ranges from 25 to 29 inches at the higher elevations of the Klamath Mountains to the west and up to 43 inches near China Mountain. To the east, the higher elevations of the Cascade Range receive between 19 to 27 inches of precipitation annually.

Figure 2 provides an isohyetal map showing the mean annual rainfall pattern and hydrologic sub-areas for the valley. These data are generated from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) for 1961 through 1990 (PRISM Project).

Figure 2. Shasta Valley isohyetal map

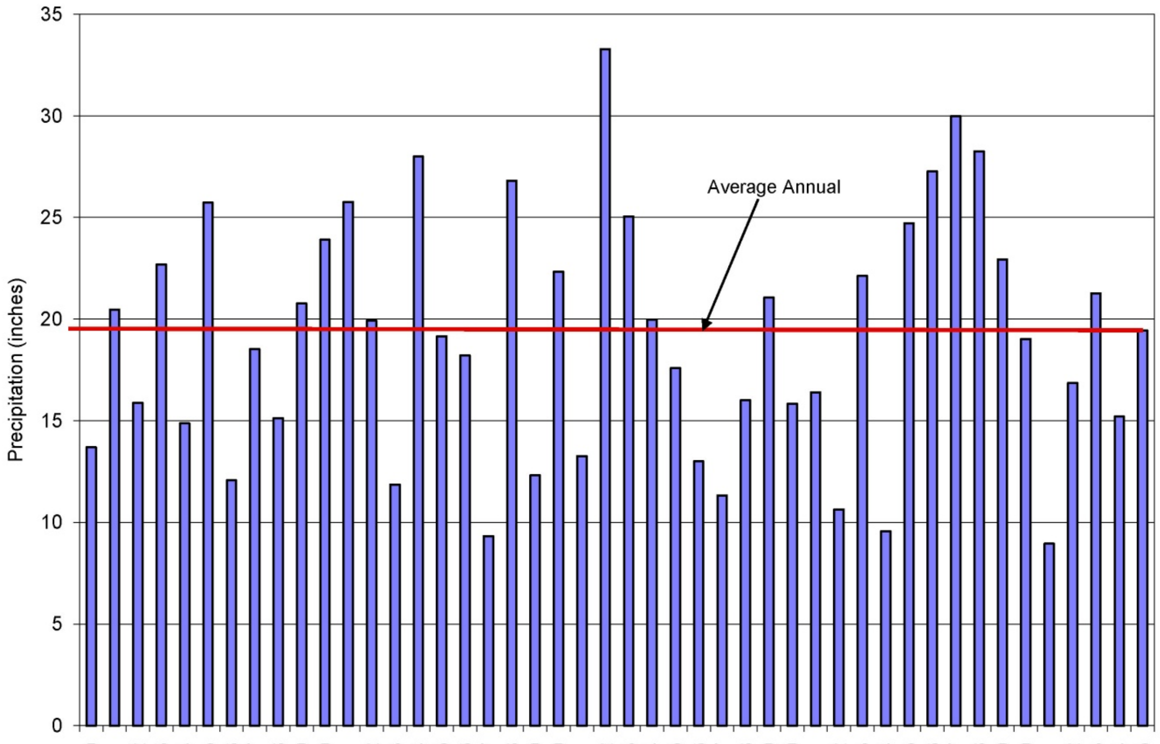


Source: Oregon Climate Service PRISM Project, Precipitation data from 1961 - 1990.

Figure 3 provides a summary of precipitation data for Yreka (Climatedata 2005). Precipitation amounts are provided by water year (the period extending from October of the previous year through September).

As illustrated in the histogram in Figure 3, the average water year precipitation is approximately 19 inches. Years with the least amount of rainfall were 1977, 1994, and 2001 with approximately 9 inches of precipitation.

Figure 3. Annual precipitation for Yreka, 1960–2005



Source: Climatedata 2005

2.3 Geology and Hydrogeology

This section provides an overview of the different geologic terrain types and geologic processes in the formation of Shasta Valley. Section 2.3.1 provides a summary of the valley's major geologic terrain types and surficial deposits, and Section 2.3.2 describes the geology and hydrogeology of each hydrologic sub-area.

2.3.1 Geology and Hydrogeology of Shasta Valley

The geomorphology of Shasta Valley is a study of plate tectonics, volcanic processes, and erosional processes that have formed and reformed the structure of the valley and its different aquifer systems. The Klamath Mountain terrane, which forms the valley's western boundary, is the result of subduction of the Pacific Plate beneath the North American Plate where ocean sediments have been "scraped off," folded, faulted, and metamorphosed. Plate subduction has also driven multiple events of uplift, giving rise to faults, fissures, and magma eruptions. Eruption events are evidenced by the volcanic rocks of the Cascade Range, which form the east and northeastern boundaries of the valley. The location of geologic terranes, geologic formations, and major streams are shown in Figure 4.

Most of Shasta Valley lies in the volcanic terrane of the Cascade Range. As such, the majority of the valley floor is covered with surficial volcanic deposits. These deposits constitute most of the valley's usable groundwater aquifers, which include the volcanic debris avalanche, Pluto's Cave basalt, and valley alluvium.

2.3.1.1 Klamath Mountains

The rocks that form the Klamath Mountains are primarily early Paleozoic to late Mesozoic in age (approximately 500 million to 65 million years ago [mya]). For this report, the Klamath Mountains are divided according to three primary rock types: the metamorphic marine rocks that make up most of the western upland region; the ultrabasic rocks of China Mountain; and the younger marine sediments of the Hornbrook Formation.

Most of the metamorphic marine rocks of the western upland region originated as marine sandstone, siltstone, and claystone that underwent regional metamorphism, which included intrusion by rocks of ultrabasic to granitic composition in major tectonic (mountain building) episodes. Metamorphic alteration of many of the sandstones included recrystallization of original granular textures into dense massive deposits of quartzite rocks. Marine claystone deposits were primarily altered to slates and phyllites. Subsequent tectonic processes created secondary porosity in the form of joints, faults, and shear zones in which water is stored and transmitted. The relative spacing, size, and degree of interconnection of the secondary openings vary throughout the western mountain region. Watersheds underlain by the metamorphic marine rocks give rise to Julien Creek and Yreka Creek.

The ultrabasic rocks of China Mountain originated as massive crystalline peridotites. Metamorphic processes have weakened the mineral and structural character of these rocks, which are highly sheared, faulted, and deeply weathered. The watersheds underlain by these rocks give rise to Shasta River, Parks Creek, and South Fork Willow Creek.

Exposed to the north and east of Montague, the younger marine rocks of the Hornbrook Formation were deposited around 65 mya after major tectonic activity had ended. The formation includes inter-layered beds of shale, sandstone, and conglomerate. These marine rocks underlie much of the younger alluvium and volcanic deposits on the valley floor.

Figure 4. Shasta Valley geology

Refer to Appendix A for surface geology legend.

2.3.1.2 Cascade Range

Rocks of the Cascade Mountains consist of two volcanic series: the Western Cascades and the High Cascades. Western Cascade volcanics are Tertiary in age and deposited during a period from about 50 mya to 5 mya. These older volcanic rocks have been overlain by younger volcanic deposits of the High Cascades, which are Pleistocene to Holocene in age (approximately 1.8 mya to present).

Rocks of the Western Cascades form a major portion of the Cascade Mountains and include an extensive assemblage of volcanic flows, dense tuffaceous beds, fragmental pyroclastics, and massive volcanic mudflows and breccias. Although portions of the Western Cascades is fractured and deeply weathered, these rocks also tend to have secondary infilling of clays and fines, which, to some degree, reduce void space and the ability to transmit water. Springs and seeps observed along steep slopes indicate the locations of impermeable horizons that restrict vertical movement of groundwater.

Rocks of the High Cascades overlie older rocks of the Western Cascades at the eastern margin of Shasta Valley. The High Cascade rocks consist of highly fractured andesitic or basaltic flows originating from Goosenest Mountain, Deer Mountain, Whaleback Mountain, and Mount Shasta. The deposits are highly vesicular and fractured and can transmit large volumes of groundwater. Several springs and seeps appear at the contact between the Western Cascade and High Cascade volcanic series, reflecting the lower permeability in the underlying older Western Cascade rocks. Deer Mountain and Whaleback Mountain are the source of Pluto’s Cave basalt flows, which form the primary aquifer in the valley.

2.3.1.3 Valley Deposits

Much of the surficial deposits that form the primary aquifers of the valley are relatively young (less than 400,000 years old). These deposits include the volcanic debris avalanche, lava flows of the High Cascades Pluto’s Cave basalt, and various alluvial deposits. Underlying these deposits throughout most of the valley is the Upper Cretaceous Hornbrook Formation (65 to 99 mya). The Hornbrook Formation is a sequence of marine sedimentary rocks ranging up to several thousand feet in thickness (Mack 1960). The high degree of consolidation and cementation of the formation results in minimal quantities of groundwater storage and low well yields. As a result, the younger valley deposits comprise the principal sources of groundwater in the valley. A detailed description of the valley deposits is provided below.

<u>Volcanic Debris Avalanche.</u> Rocks of the volcanic debris avalanche deposits were once part of a proto-Mount Shasta that existed during the Pliocene to early Pleistocene eras (approximately 5.3 to 1.8 mya). The avalanche deposits were transported into Shasta Valley as the result of a landslide event that is estimated to have occurred between 300,000 and 380,000 years ago during the Pleistocene. 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 matrix facies is made up of a fine, sandy ash-rich material with a mudflow, lahar-like character in which the blocks are embedded.

The deposit from the volcanic-debris avalanche ranges in thickness from at least 2,000 feet on the lower slopes of Mount Shasta to about 20 feet along the Shasta River near Montague. 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 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. As a result, well yields from avalanche deposits are highly variable.

Probably 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 resulted in a barrier to the subsequent flow and deposition of the Pluto’s Cave basalt. The juxtaposition of the less permeable avalanche deposits with the more permeable Pluto’s Cave basalt impedes the flow of groundwater from the basalt, giving rise to numerous springs (including Big Springs) along the line of contact between the formations.

The debris avalanche deposits may also affect the direction of groundwater flow within the alluvial system of the Gazelle/Grenada hydrologic sub-area. The flow paths of Shasta River, Parks Creek, and Willow Creek were redirected because of the avalanche. Shasta River and Parks Creek have worked their way back across the avalanche deposits; however, Willow Creek now flows in a northerly direction, adjacent to the topographically higher block facies portion of the 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.

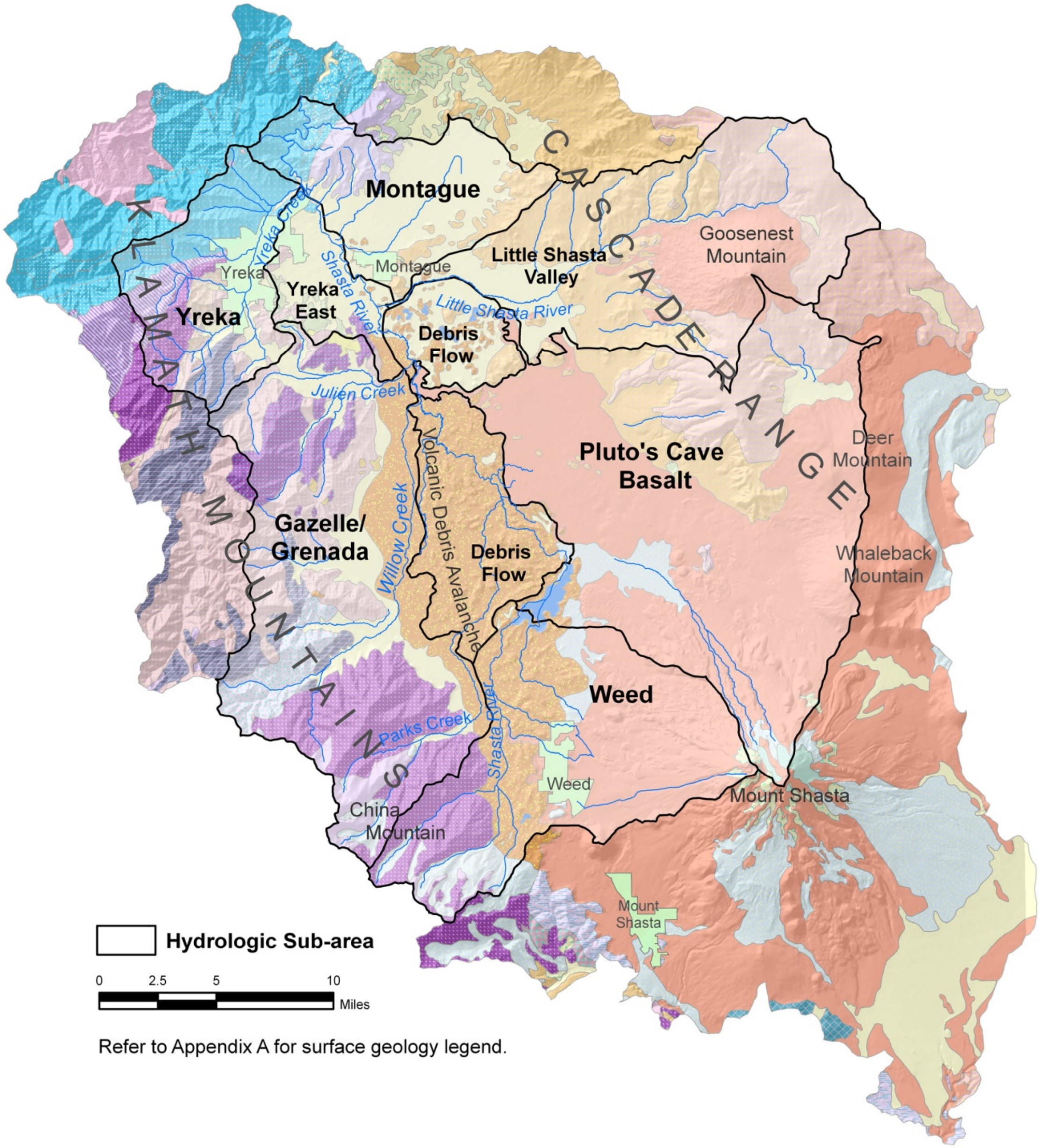
High Cascade Basalt Flows. Pleistocene High Cascade basalt flows cover the southeastern portion of the valley. The deposits, referred to as Pluto’s Cave basalt, are a highly vesicular and fractured basalt complex which formed about 160,000 to 190,000 years ago (PGS 2001, GRD 1997). Williams (1949) describes the formation as a series of overlapping flow units ranging in thickness from about 10 to 30 feet. During flow events, clinkery surfaces formed at the contact between successive flows, producing what drillers refer to as “cinders.” These surfaces, together with cooling fractures and lava tubes, serve as conduits for water and transmit large volumes of groundwater. The total thickness of the flow ranges from more than 500 feet in the south to 50 feet or less in the north. Recharge to the basalt occurs from precipitation, percolation of applied water used for irrigation, surface water conveyance ditch losses, and groundwater underflow associated with snowmelt from the Cascade Mountains and Mount Shasta.

Valley Alluvium. Other surficial deposits in the valley include unconsolidated Pleistocene to Holocene age alluvium (approximately 1.8 mya to present). These deposits include the stream and terrace deposits of Parks Creek, Willow Creek, Julien Creek, Yreka Creek, and Little Shasta River, as well as the alluvial fan deposits of the Klamath Mountains. 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.

2.3.2 Geology and Hydrogeology of Hydrologic Sub-areas

This section summarizes the geology and hydrogeology for each hydrologic sub-area. Throughout the summary, several references are made to geologic cross sections that have been developed along with the data needs assessment. These cross sections and an index to the surface geology are in Appendix A. Figure 5 illustrates the surface geology of the region and shows the boundaries for each hydrologic sub-area.

Figure 5. Surface geology of the Shasta Valley hydrologic sub-areas



Refer to Appendix A for surface geology legend.

2.3.2.1 Debris Flow Hydrologic Sub-area

The Debris Flow hydrologic sub-area encompasses the densest concentration of large surficial blocks that the volcanic debris avalanche deposited on the valley floor. As discussed in Section 2.3.1.3, the debris avalanche consists of a block facies and a matrix facies. The block facies is 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 an ancestral Mount Shasta. During the avalanche event, the blocks were transported and deposited along the avalanche flow path; they 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 area streams. The matrix facies, which acted as a mudflow during deposition, flowed beyond the hydrologic sub-area and is now part of the alluvium found within the Gazelle/Grenada, Montague, Yreka East, and Little Shasta Valley hydrologic sub-areas. The matrix facies likely underlies Pluto’s Cave basalt deposits to the east. Within the Debris Flow sub-area, the matrix deposits form the sediments in which the blocks are embedded.

Both the matrix facies and the block facies are water-bearing units. 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, confined aquifers.

Several of the Shasta Valley cross sections shown in Appendix A transect the avalanche deposits. These include cross sections G-G’, F-F’, E-E’, and D-D’. As shown in the cross sections, few wells have been drilled through the main body of the debris flow to bedrock. As a result, the thickness of the avalanche deposits is uncertain over most of its extent.

Although few wells have been constructed in the debris flow, available data show that well yields can range from 6 to 40 gallons per minute (gpm) for domestic wells and from 100 to 1,200 gpm for irrigation wells.

2.3.2.2 Gazelle/Grenada Hydrologic Sub-area

The Gazelle/Grenada hydrologic sub-area is on the west side of Shasta Valley, extending from the Parks Creek drainage in the south to just south of Juniper Creek in the north. The hummocky area of the volcanic debris avalanche forms the eastern boundary.

The surface geology of the sub-area consists of Paleozoic rocks of the Klamath Mountains, the western extents of the volcanic debris avalanche, and Quaternary alluvium deposits. Shasta Valley cross section D-D’ and portions of cross sections E-E’, F-F’, and G-G’ transect the sub-area (Appendix A). Cross section D-D’ shows that Paleozoic rocks of the Klamath Mountains forms bedrock in the region. Though not observed in cross section, older alluvium deposits likely underlie avalanche deposits that have subsequently been overlain by younger alluvium.

The thickness of the younger alluvium varies. To the north within the Julien Creek drainage, the maximum thickness is estimated to be 300 feet; this alluvium consists primarily of Julien Creek channel and alluvial fan deposits. Toward the south, channel deposits are estimated to be 50 feet in the Willow Creek drainage.

The avalanche deposits consist primarily of the matrix facies embedded with occasional volcanic rocks, boulders, and blocks scattered throughout the region. The deposits are estimated to range from 150 to 200 feet thick.

The primary water-bearing units within the sub-area are the matrix deposits of the debris avalanche and the alluvial deposits of the Julien Creek and Willow Creek drainages. Well yields within the matrix deposits range from 20 to 220 gpm; one well reportedly has a yield of 1,500 gpm. Well yields within the Julien Creek drainage range from 33 to 166 gpm. Within the Willow Creek drainage, well yields range from 20 to 100 gpm.

2.3.2.3 Little Shasta Valley Hydrologic Sub-area

The Little Shasta Valley hydrologic sub-area is in the northeast portion of Shasta Valley. The surface geology of the sub-area consists of Tertiary volcanic deposits of the Western Cascade Series, Pleistocene volcanic deposits of the High Cascades, and Quaternary alluvium deposits.

Few data are available for the subsurface geology of the sub-area; however, the matrix deposits of the volcanic debris avalanche likely comprise a significant portion of the valley’s alluvium. Available well driller reports indicate thick horizons of clays and volcanic “mixes” in both the Little Shasta Valley and Montague hydrologic sub-areas. The sub-area also has significant calcium-cemented hardpan in subsoil horizons, which is characteristic of matrix deposits.

The primary water-bearing units of the sub-area are the Quaternary alluvium and matrix deposits of the valley. Well yields range from 18 to 400 gpm.

2.3.2.4 Montague Hydrologic Sub-area

The Montague hydrologic sub-area is located at the far northern extent of Shasta Valley. The surface geology of the sub-area consists of the Paleozoic and Mesozoic rocks of the Klamath Mountains, Tertiary volcanic deposits of the Western Cascade Series, matrix deposits of the volcanic debris avalanche, and Quaternary alluvium deposits.

Cross sections B-B’ and C-C’ transect a portion of the hydrologic sub-area (Appendix A). As seen in both cross sections, Paleozoic rocks of the Klamath Mountains and the Late Cretaceous marine deposits of the Hornbrook Formation form the bedrock of the region. Tertiary volcanic rocks of the Western Cascade Series and Quaternary alluvium, in turn, overlie bedrock. Crandell (1989) notes that there are coarse alluvial fan deposits underlying matrix deposits near the northern extents of the sub-area, although they are not shown in any of the cross sections.

The matrix facies of the debris avalanche is the predominant water-bearing unit within the sub-area. As seen on cross sections B-B’ and C-C’, the thickness of the matrix deposits can range from a thin veneer at its northern extent to up to 150 feet towards the Shasta River. Several wells also derive water from the Hornbrook Formation.

Well yields within the sub-area generally range from 5 to 50 gpm. A few wells reportedly yield between 100 and 400 gpm. Yields for wells constructed predominantly in the Hornbrook Formation are generally low and sufficient for domestic and stock uses only.

2.3.2.5 Pluto’s Cave Basalt Hydrologic Sub-area

The Pluto’s Cave Basalt hydrologic sub-area occupies most of the southeastern half of Shasta Valley. Deposits of the volcanic debris avalanche form its western boundary. The surface geology of the sub-area consists of Tertiary volcanic rocks of the Western Cascade Series and of Pleistocene volcanic deposits of the High Cascade Series (Pluto’s Cave basalt).

Pluto’s Cave basalt is the primary water-bearing unit within the sub-area. The thickness of the unit varies throughout the region, ranging from an estimated 500 feet at its southern extent to 50 feet or less in the north. The basalt is highly vesicular and fractured, contains lava tubes, and transmits large volumes of groundwater.

Several springs arise from the contact between Pluto's Cave basalt and deposits of the debris avalanche, including Big Springs, Hole in the Ground Spring, and several unnamed springs. These springs are principal sources of cold water for the Shasta River. Most wells within the sub-area yield between 10 and 100 gpm, although several wells reportedly yield over 1,000 gpm.

2.3.2.6 Weed Hydrologic Sub-area

The Weed hydrologic sub-area is located at the southern extent of Shasta Valley. The surface geology of the sub-area consists of Paleozoic ultrabasic rocks from the Klamath Mountains; Quaternary-age volcanic deposits, glacial deposits, and alluvium; and deposits from the volcanic debris avalanche.

The primary water-bearing units within the sub-area include the Pleistocene volcanic deposits of Mount Shasta, debris avalanche deposits, and Quaternary alluvium. Well yields generally range from 5 to 60 gpm.

2.3.2.7 Yreka Hydrologic Sub-area

The Yreka hydrologic sub-area is located in the northwestern extent of Shasta Valley. The surface geology of the sub-area consists of Paleozoic marine deposits, metasedimentary rocks, ultrabasic intrusive rocks, and metavolcanic rocks, as well as Quaternary alluvium.

The primary water-bearing unit within the sub-area is Quaternary alluvium. Well yields within this sub-area generally range from 4 to 60 gpm. Many wells in the sub-area are also constructed in the Paleozoic rocks of the Klamath Mountains, where well yields range from 1 to 12 gpm.

2.3.2.8 Yreka East Hydrologic Sub-area

The Yreka East hydrologic sub-area is in the northwest part of Shasta Valley, directly east of the Yreka hydrologic sub-area. The surface geology of the sub-area consists of Paleozoic and Mesozoic marine rocks of the Klamath Mountains, matrix deposits of the volcanic debris avalanche, and Quaternary alluvium.

Cross section A-A' transects the northeastern portion of the sub-area (see Appendix A). As seen in cross section, Paleozoic rocks of the Klamath Mountains and Late Cretaceous marine deposits of the Hornbrook Formation form bedrock in the region. Also shown in cross section are the matrix deposits of the debris avalanche, which have a thickness ranging from 50 to 150 feet.

Matrix deposits are the primary water-bearing unit within the sub-area, where well yields typically range from 5 to 40 gpm. Wells that are constructed in the Hornbrook Formation yield between 1 and 12 gpm.

2.4 Groundwater Resource Data

Groundwater resource data that is collected and maintained by DWR include the following:

- Well completion reports
- Seasonal groundwater level monitoring
- Water chemistry

When discussing the degree of groundwater development in a region, reference is made to the number and type of groundwater wells that have been constructed. Since 1949, California Water Code § 17350 has required drillers to file a well completion report when a well has been completed or destroyed. The reports provide information about well depth, usage, geologic materials encountered during construction, and well yield. This information is entered into a database maintained by DWR.

Seasonal groundwater level monitoring is conducted by DWR in the spring and fall of each year. These data are uploaded and maintained in the DWR's Water Data Library (WDL). The WDL can be accessed on-line at http://www.water.ca.gov/waterdatalibrary.

DWR also monitors the groundwater chemistry on a multi-year cycle, which is also maintained in the WDL. Surface water chemistry is also collected but not on a statewide basis. Surface water chemistry has been collected in Shasta Valley and used in this assessment; however, a complete discussion of that data has not been provided in this report.

The following is a summary of groundwater development, groundwater monitoring, and groundwater water chemistry for Shasta Valley. The evaluation of groundwater level data is located in Section 3.

2.4.1 Groundwater Development by Hydrologic Sub-area

As discussed above, the following summary of groundwater development is based on the number of well completion reports submitted to DWR. It's important to note that not all of the current Shasta Valley wells have been recorded into the database due to the lack of reporting requirements prior to 1949 and the limitations associated with enforcing compliance with the existing Water Code. The number of wells without a completion report is unknown. As a result, the number of wells identified for each sub-area is likely less than what is actually in place.

Another limitation to the database is the accuracy of well locations. Although most well completion reports accurately locate wells to the nearest cadastral section (within about 1 square mile), some well completion reports are known to mislocate wells by several miles. Although the number and distribution of wells in the database are incomplete and known to contain errors, the data provide a good overview and general indicator of groundwater development trends.

2.4.1.1 Summary of Well Counts by Hydrologic Sub-area

The number of groundwater wells constructed within each hydrologic sub-area is summarized by well use in Table 2. Groundwater development in Shasta Valley has primarily been for domestic use, which accounts for approximately 82 percent of all groundwater wells. Irrigation wells, the next largest category, account for approximately 9 percent.

Table 2. Well types by hydrologic sub-area

Hydrologic sub-area	Number of groundwater wells by use[1]				
	Domestic	Irrigation	Municipal/public/ industrial	Other[2]	Total
Debris Flow	36	7	1	3	47
Gazelle/Grenada	329	91	10	41	471
Little Shasta Valley	31	18	0	13	62
Montague	212	16	2	21	251
Pluto's Cave Basalt	295	41	2	28	366
Weed	471	7	11	35	524
Yreka	294	14	3	15	327
Yreka East	169	3	2	6	180
Total	**1,837**	**197**	**31**	**162**	**2,228**

1 Through December 2003

2 Other use types include livestock wells, test wells, or unknown.

The number of domestic and irrigation wells constructed in the valley is also illustrated in Figure 6. Groundwater development for domestic use is greatest within the Weed hydrologic sub-area, followed by the Gazelle/Grenada, Pluto's Cave Basalt, and Yreka hydrologic sub-areas. Groundwater development for agriculture is greatest in the Gazelle/Grenada hydrologic sub-area, followed by the Pluto's Cave Basalt hydrologic sub-area.

This figure illustrates how vital groundwater resources are to meeting current and future urban and rural-residential development in the valley. As discussed later in this report, sustainable levels of groundwater development need to be determined to define limits of regional growth.

Figure 6. Groundwater development by hydrologic sub-area

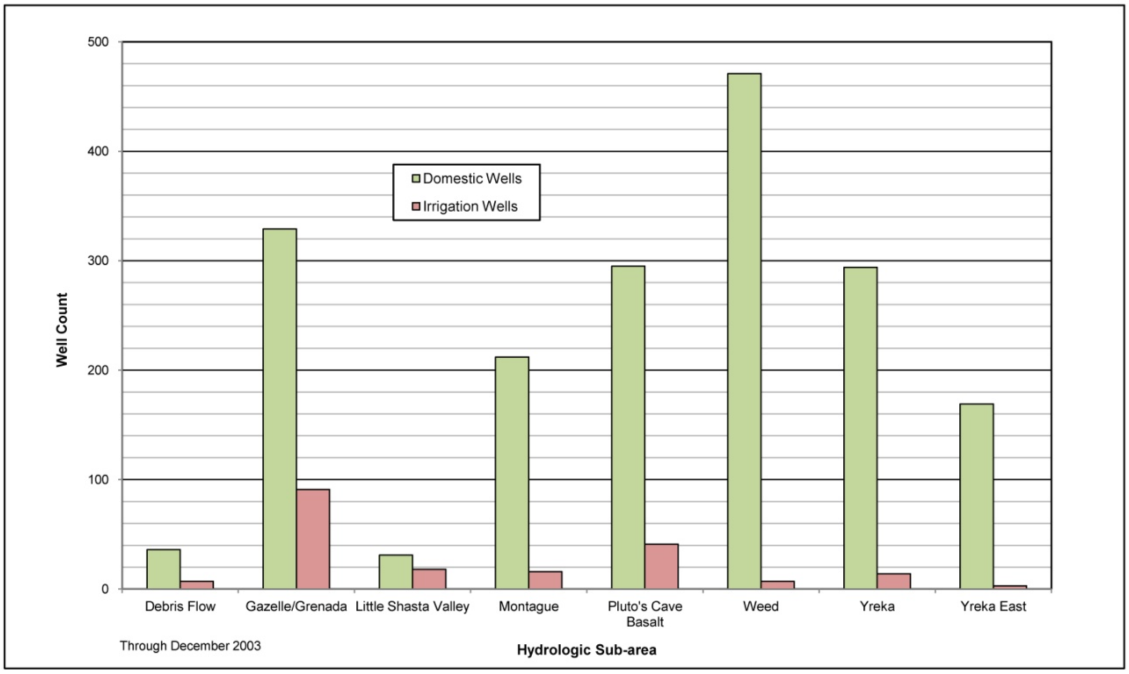
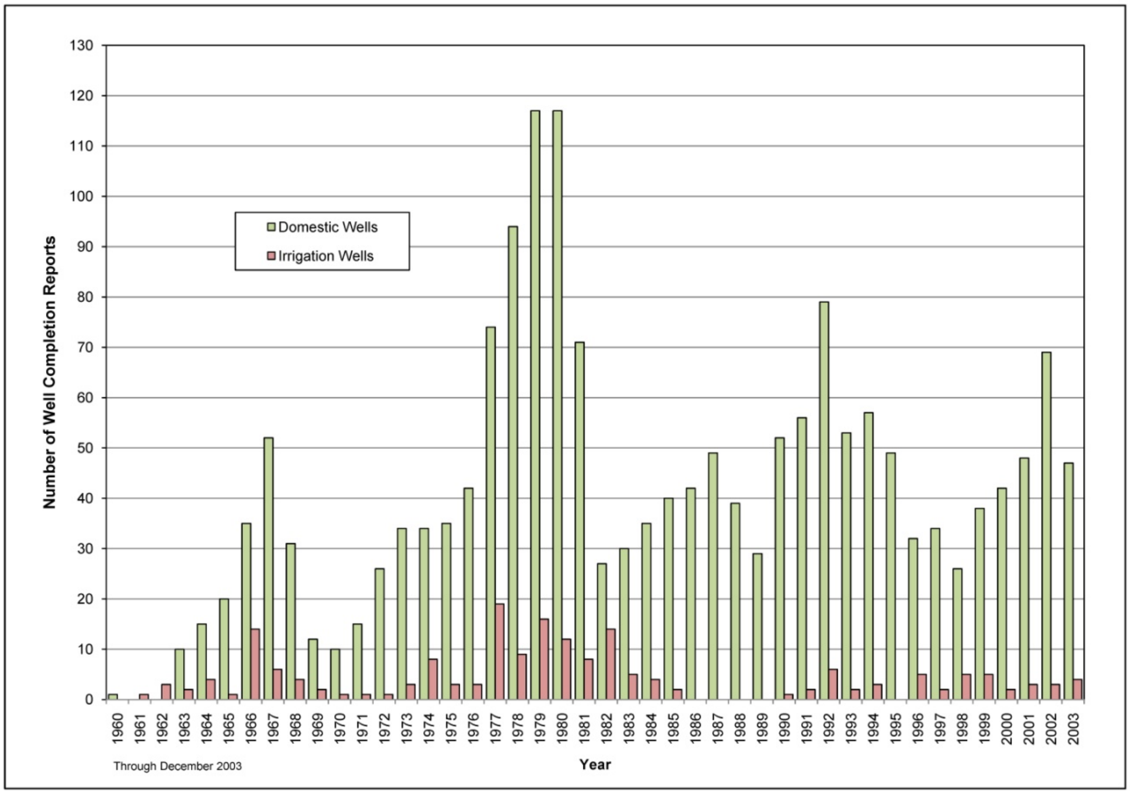


Figure 7. Annual well construction, 1960–2003



The number of wells constructed annually is illustrated in Figure 7. As the figure shows, the number of domestic wells constructed in the valley has been relatively steady since the early 1970s with peaks in well construction occurring from 1966 through 1968, 1977 through 1981, and 1990 through 1995. Well completion reports filed during these periods show that several wells were either deepened or reconstructed; however, the majority of the wells are new.

2.4.1.2 Summary of Well Depth Data by Hydrologic Sub-area

This section provides an overview of the range of well depths that are observed within each hydrologic sub-area. These data have limited use in assessing aquifers because the delineations for many sub-areas encompass several different geologic formations and rock types. The topography of a sub-area can also influence well depths because depth to water can be greater at higher elevations. Sub-areas with highly variable geology and topography can have wide ranges of well depths that may not be indicative of the variation in water production zones.

Table 3 provides a summary of well depth data and includes the minimum, maximum, average, and median well depth for domestic and irrigation wells. In most cases, median well depths are less than the average well depth calculated for a sub-area—the implication being that a few deep wells can skew results, resulting in deeper average depths.

Table 3. Well depth by hydrologic sub-area

Hydrologic sub-area	Well depth data (feet)				Total number of wells
	Average	Median	Minimum	Maximum	
Debris Flow					
Domestic	156	120	40	480	35
Irrigation	173	160	79	365	6
Gazelle/Grenada					
Domestic	163	140	30	783	328
Irrigation	192	165	40	810	91
Little Shasta Valley					
Domestic	157	121	39	435	31
Irrigation	182	200	60	300	18
Montague					
Domestic	149	120	32	630	212
Irrigation	218	238	100	340	16
Pluto’s Cave Basalt					
Domestic	217	179	32	700	294
Irrigation	176	170	59	425	41
Weed					
Domestic	154	139	32	500	470
Irrigation	165	145	62	372	7
Yreka					
Domestic	178	150	20	660	293
Irrigation	152	140	40	285	14
Yreka East					
Domestic	158	127	32	485	169
Irrigation	-	-	50	102	2

2.4.1.3 Summary of Well Yield Data by Hydrologic Sub-area

The range of potential well yield for each hydrologic sub-area is summarized in Table 4. Well yield, as reported by well drillers, is typically based on short-duration pump tests and should not be taken as an indicator of long-term sustainable yield.

It is important to note that well yields are not always reported on well completion reports. As a result, where there is a limited number of well completion reports with yield data and a wide range of reported well yields, the average well yield is typically greater than the median yield for each sub-area. This is particularly true for irrigation wells. As summarized in the following sections, the sub-areas with the highest well yields are Gazelle/Grenada and Pluto's Cave Basalt, which have maximum reported well yields of 1,500 and 1,400 gpm, respectively. Minimum well yields for most sub-areas (the exception being the Yreka sub-area) range from 1 to 6 gpm.

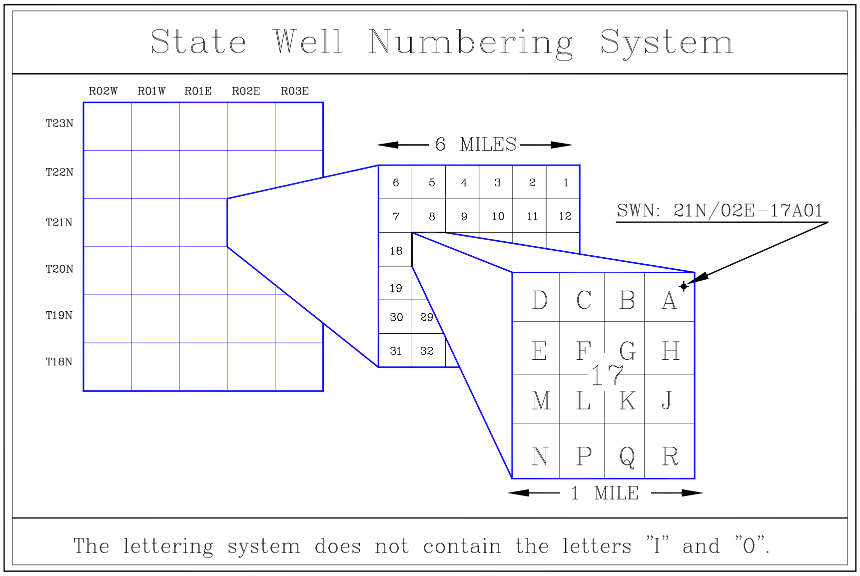
Table 4. Well yield by hydrologic sub-area

Hydrologic Sub-Area	Well yield data (gallons per minute)				Total number of wells
	Average	Median	Minimum	Maximum	
Debris Flow					
Domestic	39	23	6	150	10
Irrigation	517	250	100	1,200	3
Gazelle/Grenada					
Domestic	40	20	1	300	123
Irrigation	255	150	2	1,500	22
Little Shasta Valley					
Domestic	32	20	1	100	13
Irrigation	166	128	6	400	4
Montague					
Domestic	38	15	1	400	63
Irrigation	-	-	8	100	2
Pluto's Cave Basalt					
Domestic	52	22	5	300	132
Irrigation	342	100	1	1,400	10
Weed					
Domestic	32	20	2	405	259
Irrigation	-	-	5	150	2
Yreka					
Domestic	19	6	1	240	75
Irrigation	-	-	128	700	2
Yreka East					
Domestic	20	12	1	150	46
Irrigation	-	-	-	-	-

2.4.2 Groundwater Level Monitoring

This section summarizes current groundwater level monitoring efforts in the valley. Groundwater level monitoring is conducted by DWR each spring and fall. There are currently 26 active monitoring wells and 5 inactive wells. Each well is numbered using the State Well Numbering System which identifies the well by its location according to the township, range, section, and tract. Figure 8 shows how the State Well Numbering System works. Each well that is monitored has been field-verified and located geographically.

Figure 8. California State Well Numbering System



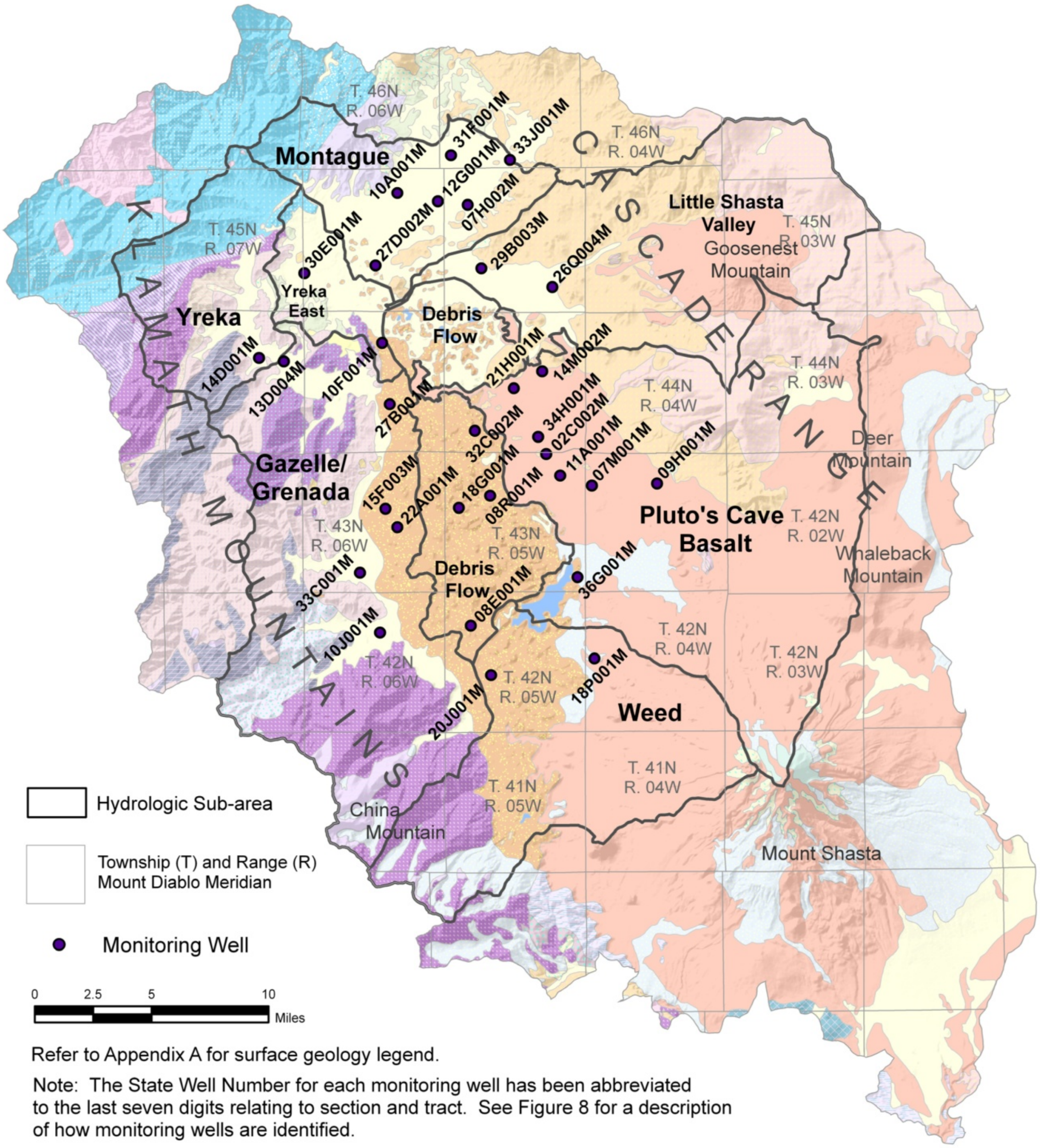
Historical data and groundwater level hydrographs are available online from DWR's Water Data Library (http://www.water.ca.gov/waterdatalibrary). DWR assigns a numerical code to all questionable groundwater level measurements to help in data analysis. As an example, a number code could indicate whether a groundwater measurement was taken when the well was being pumped or to identify whether nearby wells are pumping during the measurement. A key to explaining the various types of questionable measurement codes, used with the online hydrographs, is available at the Water Data Library website. For the hydrographs presented in this report, different symbols are used to indicate several of the more common types of questionable measurements, and a legend correlating the measurement symbol to the type of questionable measurement is presented within each hydrograph.

Table 5 lists the active and inactive monitoring wells and their characteristics, including well type, depth, period of record, and hydrologic sub-area where the well is located. Figure 9 illustrates the locations of monitoring wells with respect to surface geology and hydrologic sub-areas.

Table 5. Shasta Valley groundwater level monitoring wells

State well number	Well depth	Well use	Period of record	Hydrologic sub-area
42N04W18P001M	340	Domestic	1990 to Present	Weed
42N05W08E001M	Unknown	Domestic	1990 to Present	Debris Flow
42N05W20J001M	40	Domestic	1965 to Present	Weed
42N06W10J001M	110	Domestic	1959 to Present	Gazelle/Grenada
43N04W07M001M	395	Domestic	1990 to 2006	Pluto’s Cave Basalt
43N04W09H001M	410	Domestic	1990 to 2003	Pluto’s Cave Basalt
43N05W02C002M	102	Irrigation	1990 to Present	Pluto’s Cave Basalt
43N05W08R001M	Unknown	Domestic	1990 to 1998	Debris Flow
43N05W11A001M	167	Irrigation	1971 to Present	Pluto’s Cave Basalt
43N05W18G001M	329	Irrigation	1990 to Present	Debris Flow
43N05W36G001M	322	Public	1990 to Present	Pluto’s Cave Basalt
43N06W15F003M	100	Irrigation	1971 to Present	Gazelle/Grenada
43N06W22A001M	100	Irrigation	1966 to Present	Gazelle/Grenada
43N06W33C001M	317	Irrigation	1973 to Present	Gazelle/Grenada
44N05W14M002M	95	Domestic	1990 to Present	Pluto’s Cave Basalt
44N05W21H001M	335	Stock	1990 to Present	Pluto’s Cave Basalt
44N05W32C002M	79	Irrigation	1990 to Present	Debris Flow
44N05W34H001M	96	Irrigation	1966 to Present	Pluto’s Cave Basalt
44N06W10F001M	113	Domestic	1965 to Present	Yreka East
44N06W27B001M	110	Domestic	1975 to Present	Gazelle/Grenada
44N07W14D001M	168	Domestic	1990 to Present	Yreka
45N05W07H002M	80	Domestic	1990 to Present	Montague
45N05W29B003M	25	Domestic	1990 to 2002	Little Shasta Valley
45N05W26Q004M	34	Public	1990 to Present	Little Shasta Valley
45N06W10A001M	Unknown	Abandoned	1990 to Present	Montague
45N06W12G001M	150	Public	1990 to 2005	Montague
45N06W27D002M	45	Domestic	1990 to Present	Montague
45N06W30D004M	170	Irrigation	2000 to Present	Yreka East
45N06W30E001M	105	Domestic	1990 to Present	Yreka East
46N05W31F001M	75	Domestic	1990 to Present	Montague
46N05W33J001M	200	Domestic	1990 to Present	Montague

Figure 9. Groundwater level monitoring well locations



Refer to Appendix A for surface geology legend.

Note: The State Well Number for each monitoring well has been abbreviated to the last seven digits relating to section and tract. See Figure 8 for a description of how monitoring wells are identified.

2.4.3 Groundwater Chemistry by Hydrologic Sub-area

Water's natural chemistry is a product of several factors, including the regional geology, dissolution of rock minerals, biological activity, and atmospheric conditions. This section focuses on the primary mineral constituents found in groundwater and their relative concentrations. These constituents and their concentrations provide a chemical "signature" that helps to further define the hydrogeology of the valley.

The primary mineral constituents or ions found in water are largely derived from the dissolution of parent rock materials. These dissolved ions include calcium, magnesium, and sodium (positively charged ions or *cations*), and bicarbonate ions (negatively charged ions or *anions*). Dissolved bicarbonate is typically derived from carbonate rock but can also be derived from carbon dioxide sources. Other anions commonly found in groundwater include ions of chloride and sulfate. The primary source of chloride is connate brine, which was incorporated in sediments deposited in a sea environment or a closed drainage basin. Other potential sources of chloride include septic waste, animal waste, and fertilizer. Sulfate occurs in certain igneous rock minerals but is found extensively in evaporite deposits, which are deposits left from the evaporation of a body of water. Ions of potassium, carbonate, and nitrate are also commonly found in groundwater, but their concentrations are comparatively low. A list of the major ions is shown in Table 6.

Table 6. Major cations and anions found in groundwater

Cations	Anions
Calcium (Ca^{+2})	Bicarbonate (HCO_3^-)
Magnesium (Mg^{+2})	Sulfate (SO_4^{-2})
Sodium (Na^{+2})	Chloride (Cl^-)

The following summary provides an overview of the different chemical classifications of groundwater and the range of total dissolved solids (TDS) concentrations observed within each sub-area. The groundwater classification is a description of the primary ions (cations and anions) dissolved in the water. As an example, water that is classified as calcium bicarbonate has at least 50 percent calcium as the principal cation and at least 50 percent bicarbonate as the principal anion. When water is classified as magnesium-calcium sulfate, no single cation makes up more than 50 percent of the cations in solution. In this case, magnesium is the predominant cation and the combination of magnesium and calcium together make up more that 50 percent of the dissolved cations; sulfate is the predominant anion.

The TDS concentration is a measure of all of the ions dissolved in water and gives an indication about the quality of the water. High TDS concentrations in groundwater may be the result of increased groundwater contact time with rock minerals or increased mineral contact area from finer grained deposits. Generally, groundwater TDS concentrations above 500 milligrams per liter (mg/L) can be undesirable for irrigation under some applications.

The following evaluation of groundwater chemistry is based on groundwater sampling data from Mack (1960) and DWR. The water chemistry data from Mack (1960) was collected in May and October 1953 and was used in the development of USGS Water-Supply Paper 1484. The data collected by DWR are from groundwater sampling conducted in August 1991.

A review of groundwater chemistry data for Shasta Valley shows that each hydrologic sub-area has distinct groundwater chemistry. In several areas of the valley, the chemistry of the groundwater is fairly uniform, as observed in the Pluto's Cave Basalt sub-area. In other parts of the valley, groundwater chemistry is highly variable due to the varied rock types and possibly due to connate and evaporative source deposits. Applied irrigation water and other human activities may also affect groundwater chemistry. The following provides an overview of the chemical classification and TDS concentrations of groundwater found within each hydrologic sub-area.

Debris Flow Hydrologic Sub-area. Groundwater chemistry data for the Debris Flow hydrologic sub-area are limited. The groundwater is classified as magnesium-sodium-calcium bicarbonate based on three samples taken in August 1991 (DWR 2007). TDS concentrations range from 631 to 829 milligrams per liter (mg/L). The classification is similar to that found within the Quaternary and Tertiary volcanic rocks in the valley; however, mineral concentrations are higher within the debris deposits. The higher TDS concentrations are likely because the finer grained deposits of the matrix facies provide greater surface area for water contact and mineral absorption.

Gazelle/Grenada Hydrologic Sub-area. The chemical classification of groundwater within the Gazelle/Grenada hydrologic sub-area is based on samples from 26 wells. Twenty-two wells were sampled in May 1953 (four of the wells were sampled again in October 1953) (Mack 1960) and four wells were sampled by DWR in August 1991 (DWR 2007).

The chemistry data for the sub-area show up to three different groundwater classifications. Within the Julien Creek drainage, water is classified as calcium bicarbonate based on five water samples taken in May 1953 (Mack 1960) and two samples taken in August 1991 (DWR 2007). TDS concentrations range from 203 to 266 mg/L. Rock material in this region largely consists of Paleozoic marine rocks of the Klamath Mountains.

Within the region extending from Scarface Road to just north of Timmons Road, groundwater is classified as calcium-magnesium bicarbonate based on nine samples taken in May 1953 (Mack 1960) and two samples taken in August 1991 (DWR 2007). West of Old Highway 99, TDS concentrations range from 248 to 299 mg/L. East of Old Highway 99, TDS concentrations range from 327 to 347 mg/L. The increase in TDS concentrations is likely due to matrix deposits of the volcanic debris avalanche.

In the southern portion of the sub-area, the groundwater draining from the ultrabasic rocks of China Mountain is classified as magnesium bicarbonate based on four samples taken in May 1953 (Mack 1960). TDS concentrations range from 183 to 338 mg/L.

Applied surface water used for irrigation may also affect groundwater chemistry and TDS concentrations; however, available data are inadequate to gauge the effects. Surface water used for irrigation within the sub-area is diverted from Shasta River, Parks Creek, and Willow Creek and is applied to approximately 9,000 acres.

Little Shasta Valley Hydrologic Sub-area. The chemical classification of groundwater within the Little Shasta Valley hydrologic sub-area is based on samples from 11 wells. Nine wells were sampled in May 1953 (Mack 1960). Three of nine wells were sampled again in October 1953. Two additional wells were sampled by DWR in August 1991 (DWR 2007).

Groundwater chemistry data for the sub-area show at least two different chemical classifications. On the north side of the Little Shasta Valley, south of Ball Mountain Little Shasta Road, groundwater is classified as calcium-magnesium bicarbonate, based on five samples taken in May 1953 (Mack 1960) and one sample taken in August 1991 (DWR 2007). TDS concentrations range from 224 to 543 mg/L. The well with a TDS concentration of 543 mg/L is near the center of the valley, and has higher concentrations of chloride, sulfate, and nitrate compared to wells sampled along Ball Mountain-Little Shasta Road. The types of rocks that influence groundwater chemistry on the north side of the valley are Tertiary volcanics and matrix deposits of the volcanic debris avalanche.

On the south side of Little Shasta Valley, groundwater is classified as sodium-magnesium bicarbonate. Higher concentrations of chloride are also observed as compared to the north side of Little Shasta Valley. TDS concentrations range from 404 to 739 mg/L. Wells constructed in this area encounter matrix deposits and rocks of the Late Cretaceous Hornbrook Formation. The higher concentrations of chloride are likely the result of connate water within the marine-deposited Hornbrook Formation.

Surface water conveyed from Lake Shastina and from local diversions may also affect groundwater chemistry. Approximately 8,000 acres are irrigated with surface water within the sub-area. The three wells that were sampled in both May and October of 1953 showed slightly reduced TDS concentrations after the irrigation season. The applied surface water may be a factor in the reduced TDS concentrations.

Montague Hydrologic Sub-area. The chemical classification of groundwater within the Montague hydrologic sub-area is based on samples from 18 wells. Nine wells were sampled in May 1953, four of the wells were sampled again in October 1953 (Mack 1960), and nine wells were sampled by DWR in August 1991 (DWR 2007).

North and northwest of the City of Montague, groundwater is classified as magnesium-calcium bicarbonate with TDS concentrations ranging from 302 to 408 mg/L. This is based on five samples taken in May 1953 (Mack 1960) and two samples taken in August 1991 (DWR 2007).

Northeast of the city, groundwater has a mix of classifications. Each of the four wells sampled in spring 1953 have different percentages of the major cations, but all have bicarbonate as the dominant anion. Three of the samples have TDS values ranging from 263 to 483 mg/L. The fourth sample has a chemical classification of sodium bicarbonate with a TDS concentration of 614 mg/L.

The variability in groundwater chemistry within the sub-area is likely due to the different rock types and possibly due to faulting associated with the Klamath Mountains. Rock types in the region include Tertiary volcanic rocks on the east side of the sub-area and Paleozoic meta-sedimentary rocks and Mesozoic ultrabasic rocks and metavolcanic rocks on the west side. The Late Cretaceous marine-deposited Hornbrook Formation underlies much of the alluvial portion of the sub-area, which has been overlain by the matrix deposits of the volcanic debris avalanche.

With respect to the faulting associated with the Klamath Mountains (Wagner 1987), regional faulting may provide a conduit for higher TDS waters observed in two wells. Well number 45/5-6E1 (Mack 1960), located near the Siskiyou County Airport, has a chemical classification of sodium bicarbonate with a TDS concentration of 614 mg/L. Located north of the City of Montague, well number 45/6-22C1 (Mack 1960) has a chemical classification of magnesium-sodium-potassium-calcium bicarbonate with a TDS concentration of 981 mg/L.

Applied surface water may also play a role in groundwater chemistry with the dilution of dissolved solids. The Montague Water Conservation District provides irrigation water from Lake Shastina for approximately 7,200 acres. Although data are limited, three of the four wells that were sampled again in October 1953 show slightly reduced TDS concentrations in the fall compared to the spring measurement. Well number 45/6-22C1 shows a reduction in TDS concentration from 981 mg/L in the spring to 474 mg/L in the fall. The chemical classification for this well was also modified to magnesium-calcium bicarbonate from the spring classification of magnesium-sodium-potassium-calcium bicarbonate.

Pluto's Cave Basalt Hydrologic Sub-area. The chemical classification of groundwater for the Pluto's Cave Basalt hydrologic sub-area is based on groundwater samples taken from 20 wells. Eight samples were taken in May 1953 (Mack 1960), and 12 samples were taken in August 1991 (DWR 2007).

Groundwater is classified as magnesium-sodium-calcium bicarbonate with TDS values ranging from 136 to 457 mg/L. TDS concentrations are generally lower towards the eastern side of Pluto's Cave basalt deposits.

With one exception, the groundwater chemistry is fairly uniform throughout the sub-area. This becomes particularly evident when looking at the relative concentrations of chloride and sulfate ions. Chloride is observed in groundwater samples throughout the sub-area at bicarbonate/chloride ratios ranging from 6 to 14, averaging about 9. Sulfate is also observed in groundwater samples with bicarbonate/sulfate ratios ranging from 15 to 53, averaging about 27.

The uniformity of groundwater chemistry suggests that recharge is largely from the Quaternary and Tertiary volcanic rock sources of Mount Shasta, Whaleback Mountain, and Deer Mountain.

The primary exception to the uniformity of groundwater chemistry within the sub-area is well number 43N04W07M001. The chemical classification of groundwater from this well is magnesium-sodium bicarbonate with a TDS concentration of 1,240 mg/L. The well completion report shows that this well was drilled to a depth of 395 feet. Volcanic rock was encountered to a depth of about 360 feet, with the remaining 35 feet being gray-blue clay. The difference in chemistry for this well may be due to a region of saline groundwater associated with the clay underlying the volcanic deposits. The region of block faulting on the east side of the valley may also be a factor. Block faulting has produced exposures of the Late Cretaceous marine-deposited Hornbrook Formation (observed along the east side of the valley, north of Highway 97) and the Mesozoic metasedimentary rocks of Yellow Butte (located on the northern flank of Mount Shasta).

Weed Hydrologic Sub-area. The chemical classification of groundwater for the Weed hydrologic sub-area is based on groundwater samples taken from 12 wells. Six samples were taken in May 1953 (two wells were sampled again in October 1953) (Mack 1960) and six samples were taken in August 1991 (DWR 2007).

The groundwater chemistry varies from south to north within the sub-area. In the south (east of North Old Stage Road and south of Stewart Springs Road), groundwater is classified as magnesium bicarbonate based on four wells sampled in May 1953 (Mack 1960). TDS concentrations for these wells range from 183 to 338 mg/L. Groundwater within this area likely originates from the ultrabasic rocks of China Mountain to the west. Though rocks of the volcanic debris avalanche bound this area to the east and may underlie much of the area where the four samples were taken, groundwater from debris avalanche deposits does not appear to contribute significantly to the water chemistry.

Further north and near the town of Edgewood, groundwater is classified as magnesium-sodium bicarbonate, based on two wells sampled in May 1953 (Mack 1960) and two wells sampled in August 1991 (DWR 2007). TDS concentrations range from 201 to 405 mg/L. The classification is likely the result of groundwater originating from both China Mountain and deposits of the volcanic debris avalanche. The chemistry is not available for groundwater within the debris avalanche deposits of the sub-area; however, groundwater discharging from the debris flow gives rise to Boles, Beaughton, and Carrick creeks. The classification of surface water from Boles and Beaughton creeks is sodium-magnesium-calcium bicarbonate. The classification of surface water of Carrick Creek is magnesium-sodium-calcium bicarbonate.

East of the volcanic debris avalanche near the community of Carrick, groundwater is classified as magnesium-sodium bicarbonate with a TDS concentration of 743 mg/L (based on groundwater chemical analysis of samples taken from Carrick's municipal well in 2003). The high TDS concentration is likely due to glacial outwash deposits, where the finer grained deposits provide greater surface area for mineral absorption.

Surface water used for irrigation may also affect groundwater chemistry. Up to 3,500 acres in the sub-area are irrigated with surface water; however, the data available are insufficient to identify the impacts irrigation may have on groundwater.

Yreka Hydrologic Sub-area. Groundwater chemistry data are not available for the Yreka hydrologic sub-area; however, some assumptions can be made about its classification based on regional geology and surface water chemistry data for Yreka Creek.

Rock types within the sub-area are highly variable and include Mesozoic ultrabasic intrusive rocks (similar to the rocks of China Mountain); Mesozoic metavolcanic rocks (greenstone-chert); Paleozoic marine deposits and meta-sedimentary marine rocks (limestone and calcareous sandstone, shale, and siltstone); and Paleozoic mica schist deposits. These rock materials are sources of magnesium and calcium.

Surface water flow in Yreka Creek was sampled and analyzed in 2001 and 2002 as part of a program to establish total maximum daily loads (TMDL) by the California North Coast Regional Water Quality Control Board. Surface water was sampled at two locations: south of Oberlin Road and near the Yreka Creek confluence with the Shasta River. The classification of Yreka Creek water is magnesium bicarbonate at the sampling location near Oberlin Road (south of the City of Yreka). Above the confluence of Yreka Creek and Shasta River, the classification of Yreka Creek water is magnesium-calcium bicarbonate. The chemistry of Yreka Creek transitions from magnesium bicarbonate to magnesium-calcium bicarbonate with an increase in sodium over a distance of a little over 4 miles.

The chemistry of Yreka Creek surface water likely reflects the chemistry of local groundwater; however, other local inputs may also affect groundwater chemistry.

Yreka East Hydrologic Sub-area. The chemical classification of groundwater within the Yreka East hydrologic sub-area is based on groundwater samples from 19 wells. Ten samples were taken in May 1953 (two wells were sampled again in October 1953) (Mack 1960) and nine samples were taken in August 1991 (DWR 2007).

The classification of groundwater within the Yreka East sub-area can generally be described as magnesium-calcium-sodium bicarbonate; however, water chemistry varies throughout the region. Greater percentages of sulfate are observed on the west side of the sub-area; the chemical classification of one sample is magnesium-calcium sulfate. Another groundwater sample, taken near the Shasta River on the northeast side of the sub-area, has a chemical classification of sodium chloride. TDS concentrations also vary ranging from 218 to 846 mg/L, trending higher towards the north-eastern half of the sub-area.

The variability in groundwater chemistry is likely due to the different rock types. Northeast/southwest trending faults in the region may also contribute to some of the variability in water chemistry. Rock types in the region include Paleozoic meta-sedimentary, meta-igneous, and ultrabasic rocks, as well as rocks of the Late Cretaceous Hornbrook Formation. The Hornbrook Formation is exposed in the southwestern part of the sub-area and underlies much of the alluvium in the region. Alluvial deposits overlie most of the sub-area and largely consist of the matrix facies of the volcanic debris avalanche.

The sulfate observed in groundwater on the west side of the sub-area appears to come from rocks of the Hornbrook Formation. The higher TDS concentrations observed within the sub-area are likely due to matrix deposits of the volcanic debris avalanche. As seen in cross section A-A’ (Appendix A), matrix deposits of the debris avalanche range in thickness from 50 to 150 feet and are the primary source of groundwater in this area.

Although data are limited, applied surface water may be a factor for groundwater chemistry and TDS concentrations. Surface water is diverted from the Shasta River by the Shasta Water Users Association and used to irrigate approximately 4,400 acres within the sub-area. The two wells that were sampled again in the fall show a slight decrease in TDS concentrations compared to spring measurements.

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2.5 Land Use and Water Sources

DWR conducts periodic land and water use surveys throughout California. The land use surveys identify crop type, sources of irrigation water (for example, surface water, groundwater, mixed sources, etc.), and irrigation methods on a field-by-field basis. The following provides a summary of survey results for the year 2000 focusing on the amount of irrigated acreage, sources of water, and irrigation methods for each hydrologic sub-area. Estimates of the acre-feet of water applied by crop type by water use analysis are provided for the entire Shasta Valley.

2.5.1 Estimates of Irrigated Acreage and Sources of Irrigation Water by Hydrologic Sub-area

Table 7 provides estimates of the 2000 irrigated agricultural acreage by source of water for each hydrologic sub-area. Approximately 57,567 acres were irrigated in 2000. The dominant source of irrigation water was surface water, which was applied to approximately 45,859 acres or 80 percent of all irrigated acreage. An estimated 10,277 acres (18 percent) of agricultural land were irrigated with groundwater and the remaining acreage was irrigated with mixed sources of groundwater, surface water, or reclaimed water.

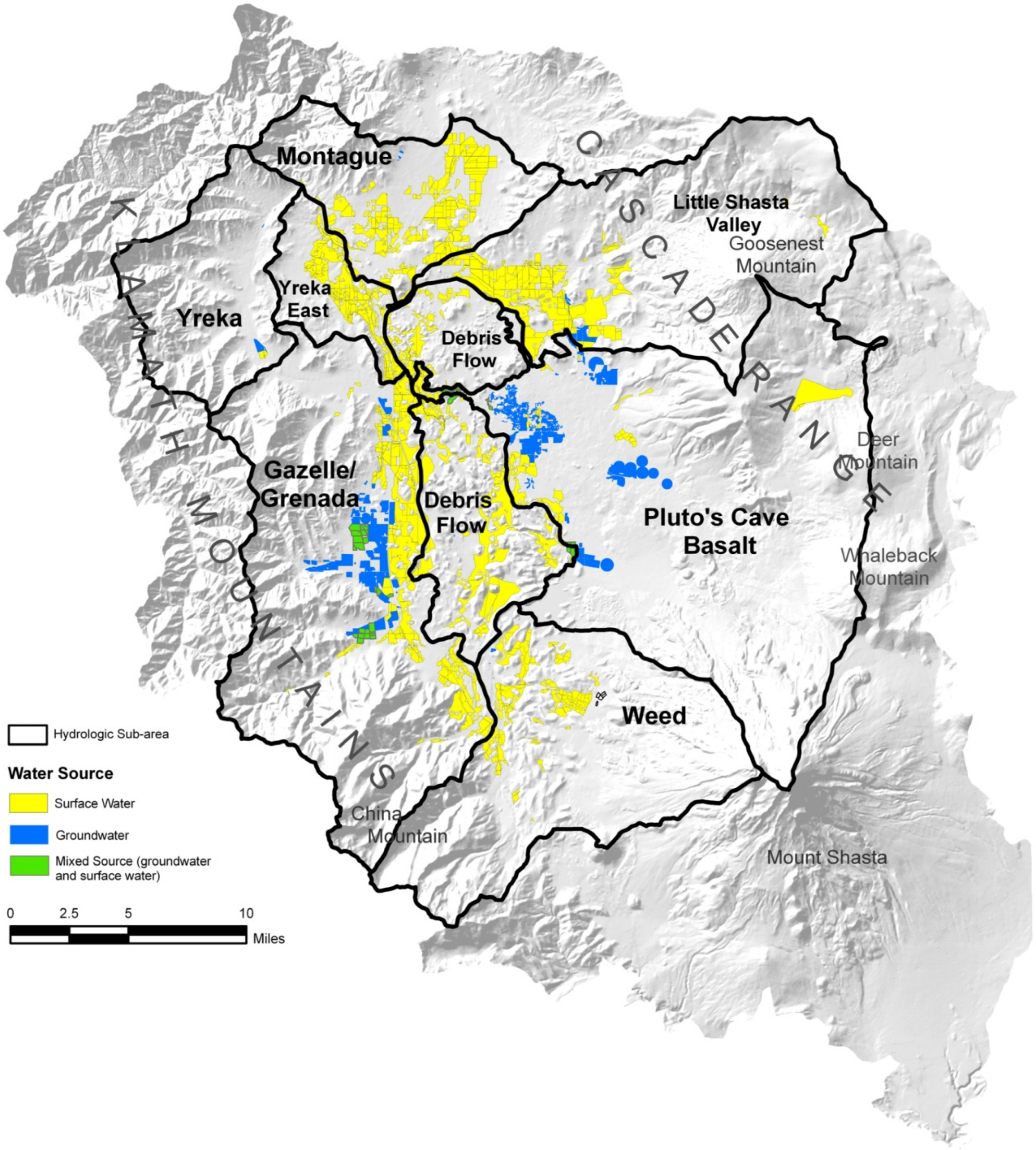
Table 7. Irrigation water source by hydrologic sub-area in 2000

Hydrologic sub-area	Irrigated acreage by water source (acres)				
	Surface water	Groundwater	Mixed sources*	Reclaimed water	Total
Debris Flow	8,516	138	177	-	8,831
Gazelle/Grenada	9,578	4,272	832	-	14,682
Little Shasta Valley	8,152	312	-	-	8,464
Montague	7,922	19	-	130	8,071
Pluto’s Cave Basalt	3,484	5,355	224	-	9,063
Weed	3,580	29	-	68	3,677
Yreka	87	99	-	-	186
Yreka East	4,540	53	-	-	4,593
Total	**45,859**	**10,277**	**1,233**	**203**	**57,567**

* Mixed sources represent a combination of surface water or groundwater.

Figure 10 shows the source of irrigation water and its distribution throughout Shasta Valley. As the figure illustrates, groundwater is the primary source of irrigation water within the Gazelle/Grenada sub-area east of Old Highway 99. The other hydrologic sub-area where groundwater is the primary source of irrigation water is the Pluto’s Cave Basalt sub-area, which includes Big Springs Irrigation District and private irrigators.

Figure 10. Sources of applied irrigation water



2.5.2 Irrigation Methods by Hydrologic Sub-area

The number of acres irrigated and irrigation methods is summarized by hydrologic sub-area in Table 8. In 2000, approximately 42,073 acres in the valley, or 73 percent of the total irrigated land, were flood irrigated. Sprinkler methods were utilized on 11,108 acres or 19 percent of the total irrigated land.

Table 8. Irrigation methods by hydrologic sub-area in 2000

Hydrologic sub-area	Irrigated acreage by irrigation method (acres)				
	Flood irrigation	Sprinkler methods	Border strip	Unknown Method	Total
Debris Flow	7,415	340	475	601	8,831
Gazelle/Grenada	8,043	4,181	987	1,471	14,682
Little Shasta Valley	5,451	1,697	1192	124	8,464
Montague	2,717	951	3698	705	8,071
Pluto’s Cave Basalt	4,358	3,293	202	1,210	9,063
Weed	3,219	326	53	79	3,677
Yreka	-	156	-	30	186
Yreka East	3,518	164	745	166	4,593
Total	**34,721**	**11,108**	**7352**	**4,386**	**57,567**

2.5.3 Applied Water by Crop Type for Shasta Valley

Estimates of the volume of applied water, by water source and crop type, are summarized in Table 9. These data are based on the California Agricultural Water Use Model developed by DWR and the U.S. Bureau of Reclamation (USBR) to estimate applied water requirements based on variables such as climate, crop type, soil type, and irrigation methods. The model takes cultural practices into account for the crop type and region; however, local circumstances, such as regulatory curtailment of surface water, are not included. The crop water use estimates are calculated by Detailed Analysis Units (DAU), which, in this case, covers all of the Shasta Valley watershed. Refinement of the data down to the hydrologic sub-area level was beyond the scope of this assessment.

Table 9 shows that approximately 151,494 acre-feet of all applied irrigation water, or 87 percent, comes from surface water sources. Groundwater accounts for approximately 23,511 acre-feet of irrigation water, or 13 percent.

Table 9. Applied water by crop type for Shasta Valley in 2000

Crop type	Applied water				
	Surface water		Groundwater		Total acre-feet
	Acre-feet	Acre-feet /acre	Acre-feet	Acre-feet /acre	
Alfalfa	13,719	3.2	9,567	3.0	23,286
Grain	2,054	1.8	3,097	1.7	5,151
Meadow pasture	115,666	3.6	4,308	3.4	119,974
Onions/garlic	0	-	1,171	3.0	1,171
Deciduous	0	-	36	2.6	36
Truck crops	76	2.2	1,219	2.0	1,295
Pasture	19,979	4.0	4,113	3.7	24,092
Total	**151,494**	**3.6**	**23,511**	**2.8**	**175,005**

3 Groundwater Data Evaluation

For a better understanding of Shasta Valley groundwater data, the different types of aquifers in the valley need to be clarified. An aquifer consists of a body of rock or sediment that is porous and permeable enough to store, transmit, and yield groundwater to wells or springs. “Alluvial” aquifers consist of clay, silt, sand, gravel or other unconsolidated materials which have been deposited by a stream or other body of moving water. Alluvial aquifers are considered groundwater basins.

Based on the description above, the portion of the valley that can be characterized as a groundwater “basin” is within the general region of Julien Creek. Available well logs for this area show alluvial deposits of gravel, sand, and clay to a depth of 186 feet. Other types of aquifers in the valley consist primarily of matrix facies deposits of the debris avalanche and the fractured hard-rock systems of the Klamath Mountains, the Cascade Range, and Pluto’s Cave basalt. The matrix facies deposits are located within the Gazelle/Grenada, Montague, Yreka East, and Little Shasta Valley hydrologic sub-areas and deliver a wide range of yields to wells and provide for groundwater storage. The hard-rock aquifer systems of the Klamath Mountains and the Cascade Range are low yielding aquifers with limited storage potential; however, the hard-rock aquifer system of Pluto’s Cave basalt is the most productive source of groundwater in the valley. Groundwater flows within the Pluto’s Cave basalt system can approach velocities similar to surface water, but there may be limited storage potential.

The following evaluation of groundwater data focuses on climate and land use and their relative impacts to groundwater levels. A review of Shasta River temperature data is also provided as it correlates to groundwater and surface water interaction.

3.1 Groundwater Level Trends

Generally speaking, groundwater levels fluctuate throughout the year due to a combination of factors including groundwater extraction, discharge to surface water streams, and recharge from natural and man-made sources. When evaluating annual changes in groundwater aquifers, a comparison is made of groundwater level measurements taken during similar times of the year (i.e., spring to spring). Typically, spring groundwater levels are used for aquifer assessments because spring conditions tend to be the most stable before the start of the irrigation season.

For most groundwater basins in California, spring groundwater levels are typically higher than fall levels due to the natural recharge provided by winter precipitation. The trend of higher spring groundwater levels is observed in parts of Shasta Valley; however, in several areas, fall groundwater levels are higher than spring levels. Identifying the cause of higher fall levels, or lack of seasonal fluctuations, is needed to understand the different sources of groundwater recharge in the valley.

Groundwater trends in Shasta Valley vary depending on the type of aquifer, overlying land use, and sources of recharge. In parts of the valley, groundwater levels show a response to groundwater extraction and extended periods of below average precipitation. The hydrographs that show these responses are for wells located predominantly on the west side of the valley and at margins of matrix deposits. These trends are discussed further in Section 3.1.1 Groundwater Level Trends and Climate.

Though several areas of the valley are susceptible to drought conditions as reflected in the downward trends of several groundwater level hydrographs, groundwater levels recover seasonally from year-to-year where surface water is applied for irrigation. Groundwater levels also recover due to naturally occurring recharge in the Pluto’s Cave basalt aquifer. The effects of applied surface water and natural recharge on groundwater levels are discussed in Section 3.1.2 Groundwater Level Trends and Land Use.

3.1.1 Groundwater Level Trends and Climate

Most aquifers respond to changes in climatic conditions. In general, groundwater levels decline during dry years because more water is discharged than recharged. During wet years, aquifers recover due to an increase in recharge relative to discharge. To illustrate the role that climate plays with respect to groundwater supplies for parts of Shasta Valley, Figures 11 and 12 show several hydrographs for wells where groundwater levels respond to changes in precipitation.

Shown in Figure 11, monitoring wells 43N06W33C001M (33C001) and 43N06W15F003M (15F003) are irrigation wells located in the Gazelle/Grenada hydrologic sub-area. The hydrograph for monitoring well 33C01 shows that spring groundwater levels have ranged from a low of 61 feet below ground surface during 1995, to a high of 36 feet below ground surface in 2000. A similar pattern is observed in the hydrograph for monitoring well 15F003; however, drought impacts are not as significant. This may be due in part to the surface water that’s applied for irrigation east of the well.

Monitoring well 44N07W14D001M (14D001) is a domestic well located near the southern boundary of the Yreka hydrologic sub-area. Static groundwater levels in this well have ranged from 77 feet below ground surface in spring 2000 to 104 feet below ground surface in spring 1996. Land use in this area is mixed residential and agriculture. East of this well are fields irrigated with surface water.

Monitoring well 45N05W07H002M (07H002M) is a domestic well located within the eastern margins of matrix deposits in the Montague hydrologic sub-area. Static groundwater levels in this well have ranged from 17 feet below ground surface in spring 1998 to 30.7 feet below ground surface in spring 1993. Land use in this area is primarily residential.

For the most part, each of the hydrographs discussed above show seasonal fluctuations where spring groundwater levels are higher than fall levels. It should be noted however that the hydrograph for monitoring well 33C001 has several years where fall levels are higher than the previous spring. This has generally occurred following a water year (October thru September) where precipitation was greater than average.

Although multiple factors play a role with respect to seasonal and long-term groundwater level fluctuations, downward trends due to climatic conditions are generally not observed in areas where surface water is applied for irrigation—a source of recharge. The role of land use relative to groundwater supplies is discussed further in Section 3.1.2.

Another source of recharge that supports groundwater levels within the Pluto’s Cave sub-area is recharge from Deer Mountain, Whaleback Mountain, and Mount Shasta. Shown in Figure 12, monitoring wells 44N05W34H001M (34H001) and 43N05W02C002M (02C002) are irrigation wells located within the Pluto’s Cave basalt aquifer system. Spring levels for monitoring well 34H001 average 29.8 feet with seasonal fluctuations of 0.3 to 14.2 feet. Spring levels for monitoring well 02C002 average 44.6 feet with seasonal fluctuations of 0.3 to 2.5 feet. It is important to note that seasonal fluctuations and recovery are slightly different for the two wells implying that the aquifer is not homogeneous.

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Figure 11. Climatic effects on groundwater levels in some areas of Shasta Valley

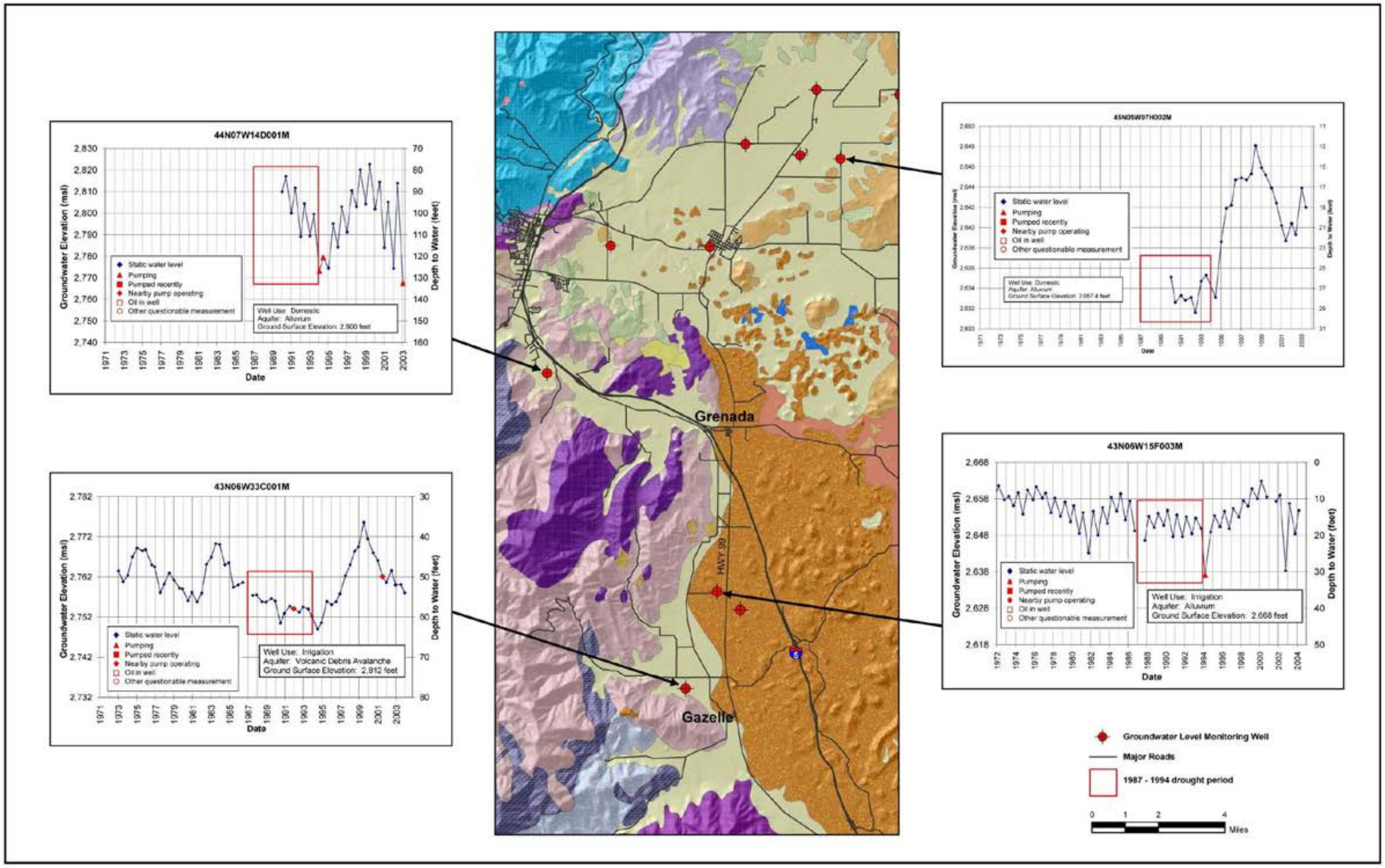


Figure 11 in large format (11x17)

Figure 12. Climatic effects on groundwater levels with High Cascade recharge

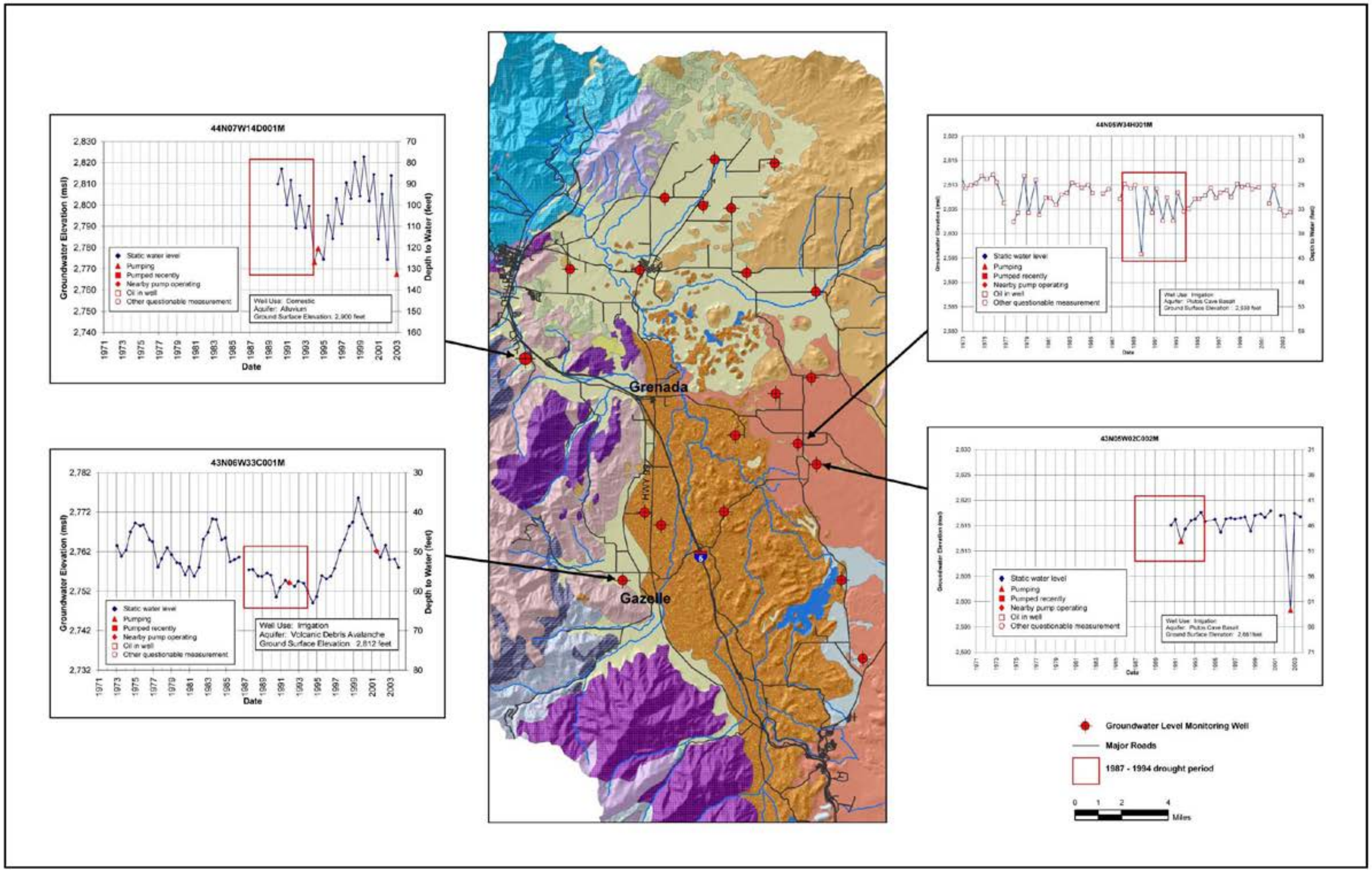


Figure 12 in large format (11x17)

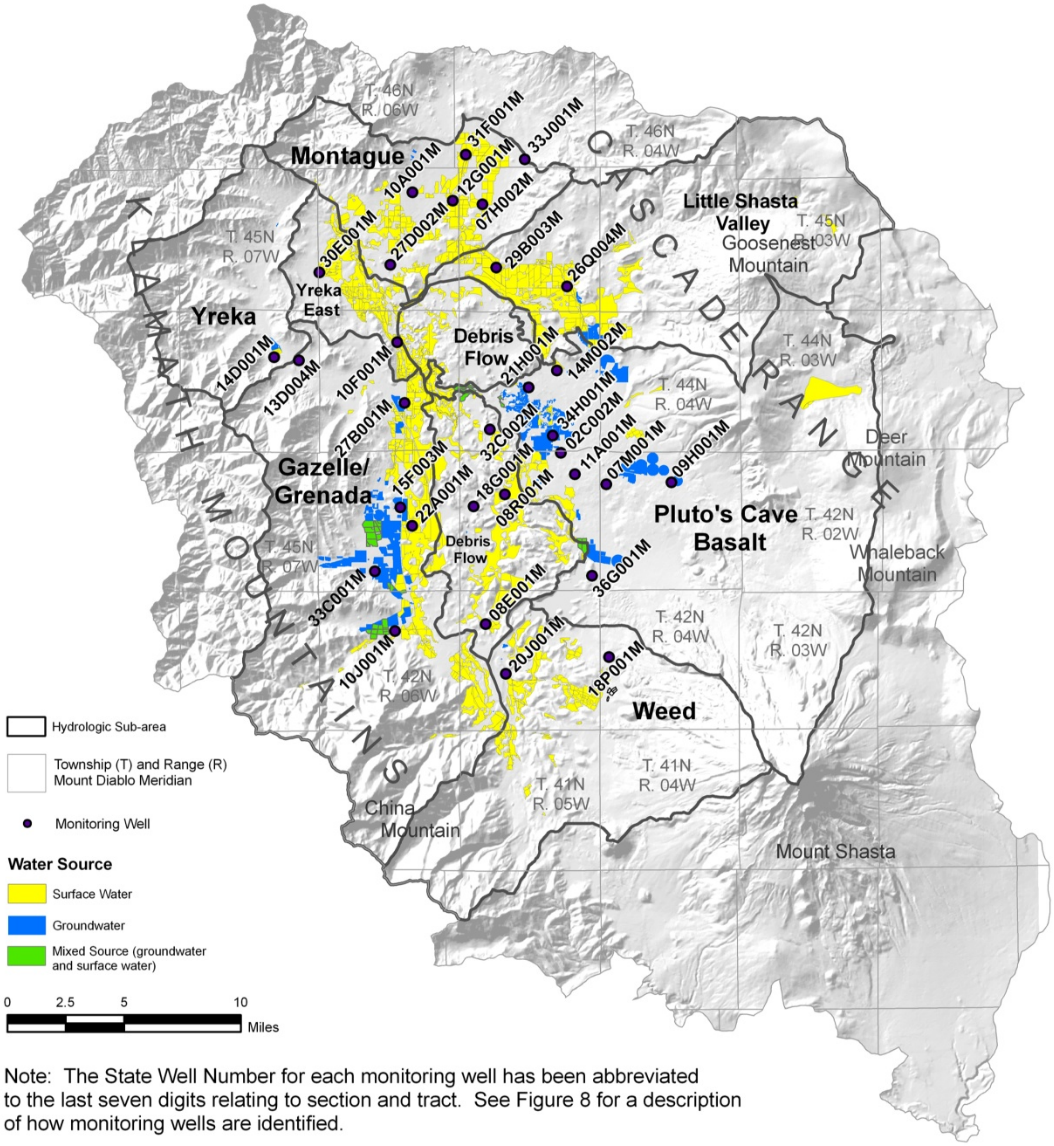
3.1.2 Seasonal Groundwater Level Trends and Land Use

Land use plays an important role in the availability of groundwater supplies. This is particularly evident in Shasta Valley where surface water is used for irrigation and is a source of groundwater recharge. When reviewing seasonal groundwater level data, one of the more uncommon findings is that fall levels are often higher than spring levels in certain parts of the valley. This runs counter to what is generally observed for many California groundwater basins where winter recharge is the primary source of recharge providing higher groundwater levels in the spring. Summer extraction and groundwater discharge typically result in the lower groundwater levels being recorded in summer or fall months.

Sources of recharge that contribute to higher fall levels are percolation of applied surface water for irrigation, surface water conveyance ditch losses, and recharge associated with melting snowpack.

Figure 13 shows the extent to which surface water is used for irrigation and the location of groundwater level monitoring wells. Table 10 provides a summary of seasonal groundwater level data showing the degree to which surface water serves as a source of recharge. Monitoring wells with higher fall season levels are shaded.

Figure 13. Irrigation water sources and groundwater level monitoring wells



Note: The State Well Number for each monitoring well has been abbreviated to the last seven digits relating to section and tract. See Figure 8 for a description of how monitoring wells are identified.

Table 10. Seasonal variation in groundwater levels by hydrologic sub-area

State Well Number	**Seasonal change in groundwater levels (feet)**			**Number of years where fall groundwater elevations were higher than spring elevations**	**Number of monitoring seasons**	**Well use**	**Applied water source in vicinity of nearby monitoring well (GW: Groundwater) (SW: Surface Water)**	**Hydrologic sub-area**
	Minimum	Maximum	Mean					
43N05W18G001M	0.4	18.2	5.8	4	14	Irrigation	GW	Debris Flow
44N05W32C0O2M	3.3	11.8	7.8	0	9	Irrigation	GW,SW	Debris Flow
42N05W08E001M	0.4	5	1.9	2	10	Domestic	SW	Debris Flow
43N06W33C001M	0.5	7.1	3.3	13	28	Irrigation	GW	Gazelle/Grenada
43N06W15F003M	1.5	20.7	5.5	0	29	Irrigation	GW	Gazelle/Grenada
44N06W27B001M	0.0	4.7	2.1	20	26	Domestic	GW,SW	Gazelle/Grenada
42N06W10J001M	1.1	19.7	8.4	0	37	Domestic	GW,SW	Gazelle/Grenada
43N06W22A001M	1.4	19.7	10.0	1	19	Irrigation	GW,SW	Gazelle/Grenada
45N05W26Q004M	0.6	3.9	2.4	0	13	Public	SW	Little Shasta Valley
45N05W29B003M	0.8	6.6	3.3	1	7	Domestic	SW	Little Shasta Valley
46N05W33J001M	0.4	6.4	3.5	1	11	Domestic	None	Montague
45N05W07H002M	0.2	5.5	2.1	8	10	Domestic	SW	Montague
45N06W27D002M	0.5	3.8	2.1	0	9	Domestic	SW	Montague
46N05W31F001M	0.4	7.5	2.5	4	12	Domestic	SW	Montague
45N06W10A001M	6.5	38.2	17.6	0	8	Abandoned	NA	Montague
43N05W02C002M	0.2	1.7	0.9	5	6	Irrigation	GW	Pluto’s Cave Basalt
43N04W09H001M	2.2	36.9	11.6	3	7	Domestic	GW	Pluto’s Cave Basalt
44N05W34H001M	0.3	14.2	3.1	17	26	Irrigation	SW	Pluto’s Cave Basalt
44N05W21H001M	0.7	17.8	5.8	7	10	Irrigation	SW	Pluto’s Cave Basalt
44N05W14M002M	0.1	3.4	1.5	11	12	Domestic	None	Pluto’s Cave Basalt
43N04W07M001M	0.2	9.7	2.1	7	10	Domestic	None	Pluto’s Cave Basalt
43N05W11A001M	0.0	17.1	4.7	11	28	Irrigation	None	Pluto’s Cave Basalt
43N05W08R001M	1.6	5.2	3.7	6	6	Domestic	SW	Pluto’s Cave Basalt
43N05W36G001M	Municipal well. Continuous operation.			-	-	Municipal	None	Pluto’s Cave Basalt
42N04W18P001M	0.2	3.5	1.5	3	8	Domestic	GW	Weed
42N05W20J001M	0.1	3.5	1.6	0	35	Domestic	SW	Weed
44N07W14D001M	7.5	30.7	18.3	1	10	Domestic	GW	Yreka
45N06W30E001M	2.0	13	5	36	12	Domestic	SW	Yreka East
44N06W10F001M	1.1	13	8.1	-	38	Domestic	SW	Yreka East
45N06W30D004M	Limited data.				-	Irrigation	GW	Yreka East

1. Through spring 2004.

Note: Shaded records are monitoring wells where higher fall season levels account for 50 percent or more of annual measurements.

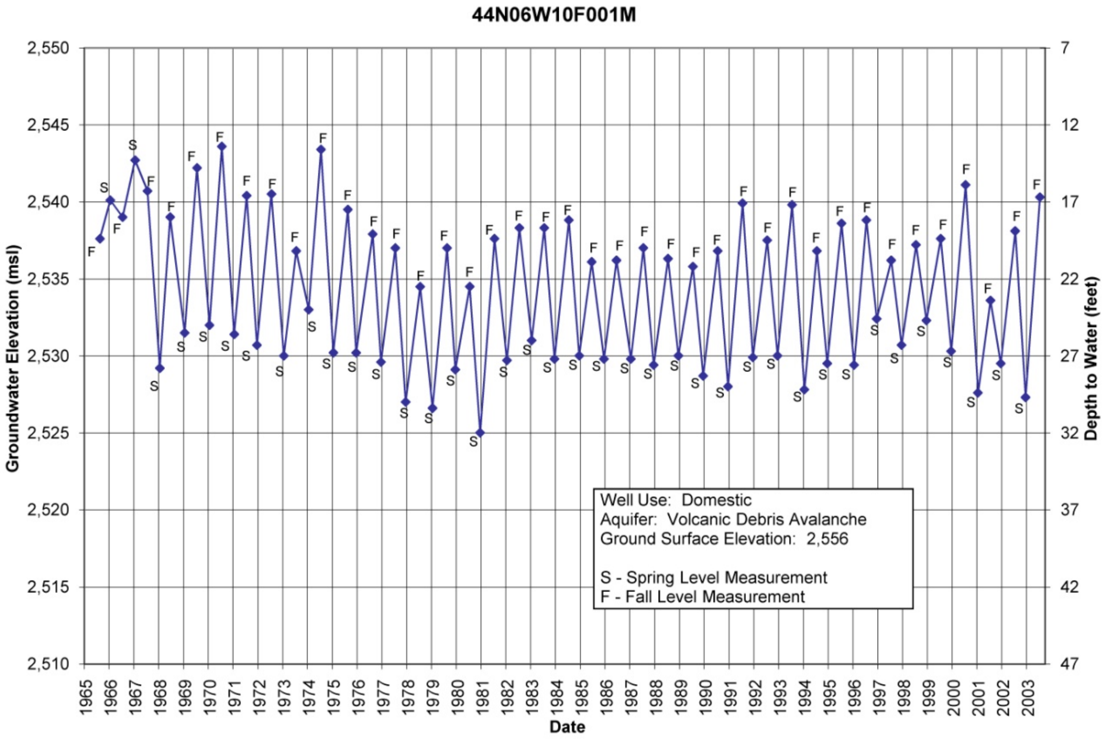
As shown in Table 10, all but one of the monitoring wells located within the Pluto’s Cave Basalt hydrologic sub-area show higher fall groundwater levels, although not for all years. Because locally derived groundwater is the dominant source of irrigation water within the sub-area, the higher fall groundwater levels are most likely due to recharge associated with snowmelt from Mount Shasta. Other sources of recharge include percolation of conveyance ditch losses from Montague Water Conservation District’s main canal and irrigation water supplied by Big Springs Irrigation District (BSID). Water supplied by BSID originates as groundwater from within the Pluto’s Cave aquifer, which is conveyed to the northern extent of the sub-area.

For other areas of Shasta Valley, percolation of water conveyance ditch losses and applied surface water may be important sources of groundwater recharge. This is best illustrated with the groundwater level hydrograph for monitoring well 44N06W10F001M shown in Figure 14. The well is located approximately 2.1 miles north of County Road A-12, west of Montague Grenada Road, and near a major irrigation canal. Construction data for the well are not available.

As Figure 14 illustrates, groundwater levels in the fall are consistently higher than spring levels. This trend is likely due to groundwater recharge from percolation of conveyance ditch losses and irrigation with surface water. The hydrograph also shows that this trend may not have been the norm prior to 1968. From 1965 (when measurements were first taken) to 1968, spring groundwater levels were higher than fall levels. Unfortunately, the period of record is limited, and it is impossible to determine if this was the trend prior to 1965.

If the prevailing trend prior to 1965 was for higher spring groundwater levels, the current fall-high spring-low trend is likely the result of changes in land use and reduced local groundwater demand. A review of historical land use data from DWR Bulletin 94-5 (1963) shows that land use in 1958 was similar to land use today, except that more fields north and south of Grenada were receiving full irrigation with surface water . Land use data for years close to 1968 are not available. The most recent land use surveys from 2000 and 2001 show a mixed usage of groundwater and surface water for irrigated lands east and southeast of Grenada.

Figure 14. Effects of conveyance ditch losses to groundwater recharge, 1965–2003



The effect of applied surface water on groundwater levels is also illustrated by several wells located in the Gazelle/Grenada hydrologic sub-area. Figure 15 shows several groundwater level hydrographs and the different sources of applied irrigation water. The region west of Old Highway 99 is largely irrigated with groundwater using sprinklers. East of Old Highway 99, the primary source of irrigation water is surface water applied through flood irrigation. Groundwater is also pumped east of Old Highway 99 when surface water supplies are inadequate.

As shown in Figure 15, groundwater level trends are different for areas located east and west of Old Highway 99. Hydrographs for monitoring wells 43N06W15F003M and 43N06W33C001M, which are located west of Highway 99 in an area of agricultural groundwater demand, show annual declines in groundwater levels for periods of below average precipitation. East of Highway 99, in an area where surface water is used for irrigation, the hydrograph for monitoring well 43N06W22A001M shows a consistent recovery in spring-to-spring groundwater levels during the same periods.

Though the emphasis here is on applied surface water as a source of groundwater recharge, the annual recovery of groundwater levels east of Highway 99 could also be due to other factors. Although recharge from surface water and limited groundwater pumping are important components, the regional geology may also play a role. Avalanche debris deposits may inhibit or reduce the flow of groundwater to the east increasing the amount of groundwater in storage. Snowmelt from Mount Shasta may also be a source of recharge, but the mechanics of recharge are unclear due to the complexity of the local geology.

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Figure 15. Hydrographs showing the effect of recharge to groundwater from irrigation

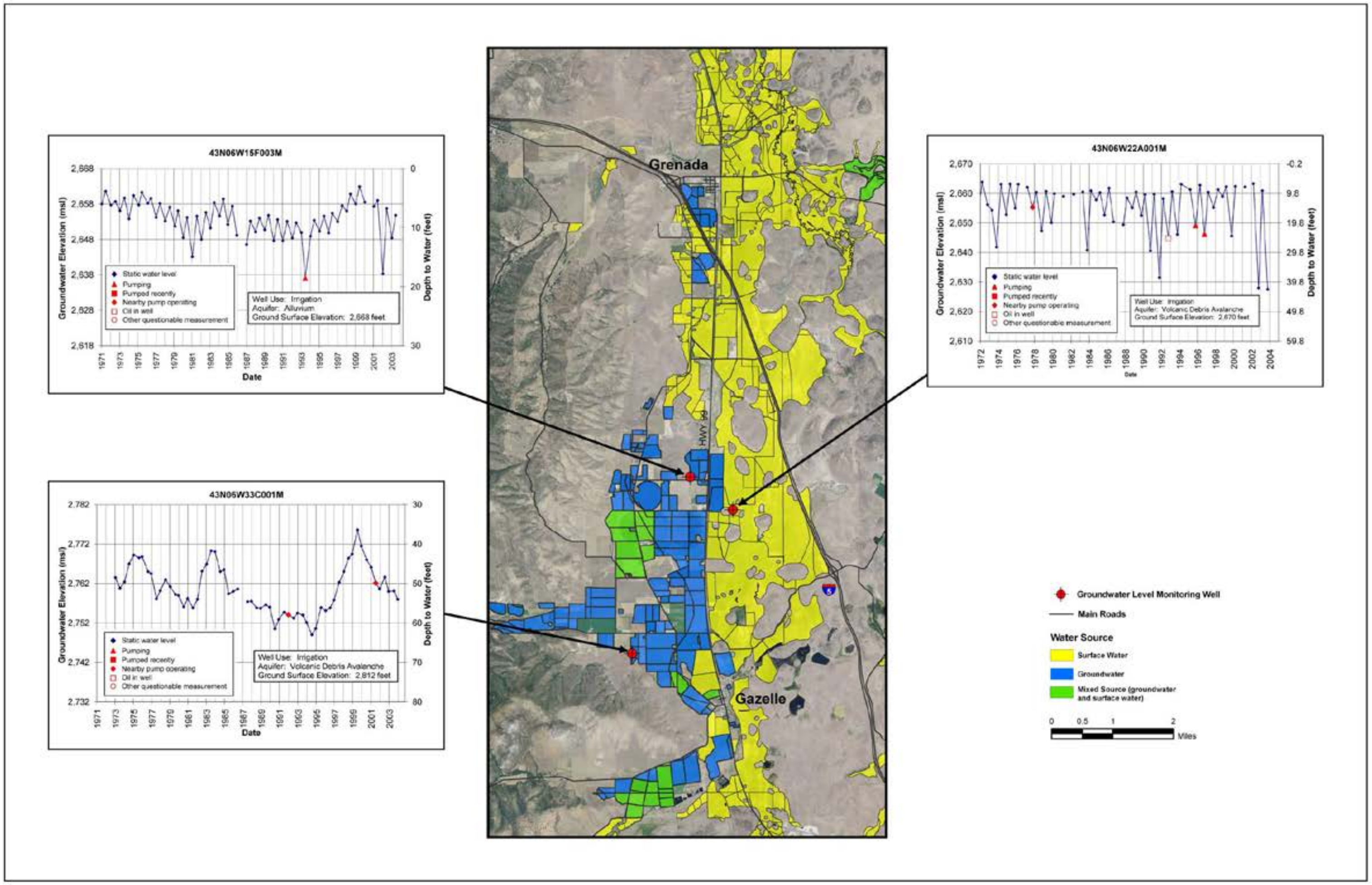

Figure 15 in large format (11x17)

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3.1.3 Implications of Seasonal Groundwater Level Trends

Available groundwater level data show that periods of low precipitation adversely affect groundwater supplies for matrix facies sediment aquifers. This is primarily seen along the west side of the valley and is also observed at margins of matrix facies deposits. An important source of groundwater recharge for these areas has been the application of surface water by flood irrigation methods. Efforts to reduce this source of recharge by improvements of on-farm irrigation methods or by irrigation with groundwater will reduce this source of recharge and negatively impact groundwater supplies.

Future urban and agricultural development, as well as conversion of farm land to other uses, will also have wide-ranging impacts on both surface water and groundwater resources. To evaluate future planning and development scenarios, a better understanding of the natural versus man-made contributions to groundwater recharge is needed. Sustainable levels of groundwater development need to be determined without applied surface water as a source of recharge. The sub-areas of the valley where groundwater is most susceptible to future development or changes in land use are Yreka, Yreka East, Montague, Little Shasta Valley, and Gazelle/Grenada.

Groundwater level data for the Pluto’s Cave aquifer show that groundwater levels generally recover from spring to spring. Though groundwater levels are stable, hydrographs for monitoring wells show that the aquifer is not a homogeneous system.

3.2 Groundwater/Surface Water Interaction

Effective management of water resources requires consideration of both surface water and groundwater. Groundwater and surface water bodies are physically connected, and changes in one affects the other. It is difficult to characterize this interaction without extensive monitoring; however, a recent aerial temperature survey of Shasta River provides important insights into groundwater/surface water interaction, local hydrogeology, and the potential impacts to the river from land use activity. The following summarizes the results of that survey.

3.2.1 Shasta River Temperature Trends

In July 2003, an airborne thermal infrared remote sensing survey was conducted of the Shasta River. The purpose of the survey was to characterize surface water temperatures in support of TMDL studies and modeling efforts of the California North Coast Regional Water Quality Control Board and the Department of Environmental Science and Policy at the University of California, Davis. The thermal graph that was generated from the survey is shown in Figure 16. The observed warming and cooling trends are the focus of this summary.

A variety of factors influence stream temperatures including physical river characteristics (width and depth), volume of water, shading, meteorological conditions, time of day, as well as groundwater discharge and land use activity. It was beyond the scope of this project to define the physical characteristics of the river, the meteorological conditions, and how they relate to river temperatures; however, the temperature trends observed in Figures 16 and 17 are well-defined, and river parameters likely play a limited role in generating these trends.

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Figure 16. Shasta River stream temperatures and water source data

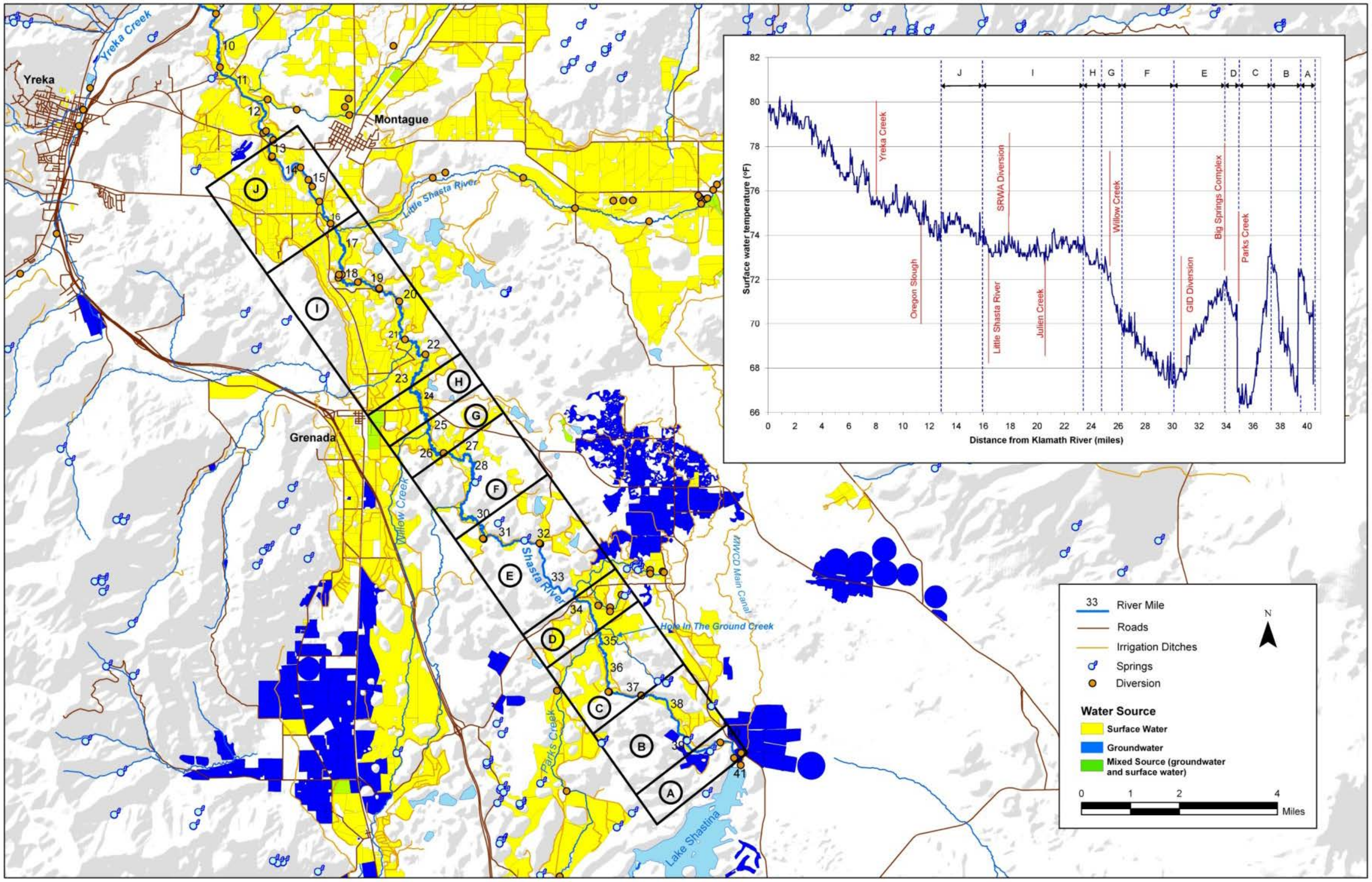

Figure 16 in large format (11x17)

Figure 17. Shasta River stream temperatures and surface geology

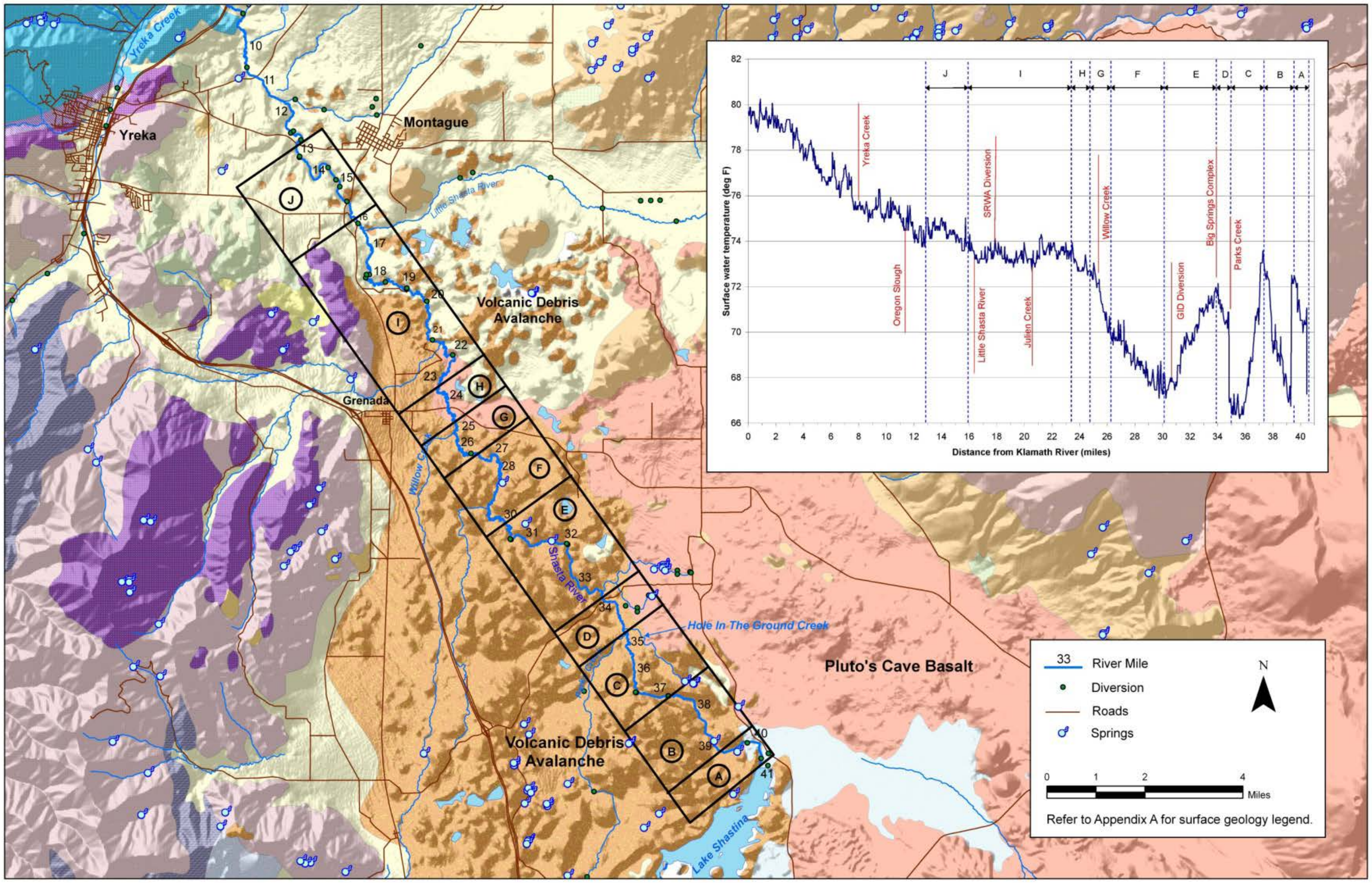

Figure 17 in large format (11x17)

Evaluation of the trends was conducted by dividing the temperature profile into river segments based on uniform rates of temperature change. When looked at in relation to other geographical data, several inferences can be made regarding the potential causes for the trends. The geographical data used in this evaluation were surface geology and land use data. The river segments are summarized in , which shows the reaches of each river segment in river miles and the rate of temperature change.

Table 11. Rates of temperature change along the Shasta River

River segment	River mile interval	Rate of temperature change (°F) per river mile
A	40.5 – 39.4	+2.5
B	39.4 – 37.2	+3.2
C	37.2 – 35.6 35.6 – 34.8	-3.9 +0.3
D	34.8 – 33.8	+1.7
E	33.8 – 30.0	-1.2
F	30.0 – 26.1	+0.8
G	26.1 – 24.7	+2.0
H	24.7 – 23.2	+0.6
I	23.2 – 15.9	Temperature stabilizes between 72.7 and 74.3 degrees
J	15.9 – 14.0 14.0 – 12.8	+0.3 -0.1

The following is a summary of stream temperatures, rates of temperature change, and their correlation to surface geology and land use activity along the different segments of the river. The river segments are defined by river mile (RM) and are shown in relation to surface geology and land and water use data in Figures 17 and 18 respectively.

River Segment A (RM 40.5 to RM 39.4). River flow is typically minimal along this reach, and active diversions are supplied by reservoir releases from Lake Shastina's Dwinnell Dam. It's not known if any reservoir release had occurred prior to or during the temperature survey. River flow in lieu of releases from Lake Shastina is primarily due to reservoir leakage, spring discharge, and irrigation water return flow.

The surface geology for this segment transitions from glacial outwash to volcanic debris avalanche deposits that do not appear to be a significant source of groundwater accretion to the river. Groundwater, however, is a source of irrigation water for fields adjacent to the river and northeast of Lake Shastina (Figure 17).

Watershed Sciences (2004) notes that the river temperature just below Dwinnell Dam as being a "cool region." This initial temperature may be the result of reservoir leakage. Over the remainder of this segment, river temperatures increase at a rate of 2.5 °F per river mile. The minimum flows along this reach likely result in increased solar and air conductance heating. The increase in temperature could also be due to warm irrigation water return flow. At RM 39.4, river temperatures decrease by 5.8 °F due to spring discharge to the river.

River Segment B (RM 39.4 to RM 37.2). River Segment B traverses block facies of the debris avalanche. At the beginning of the segment, river temperature is relatively cold due to spring discharge to the river. River temperature then increases at a rate of 3.2 °F per river mile. As shown in Figure 17, surface water is used for flood irrigation throughout most of this segment and may be a source of warm water return flows to the river. The rate of river flow along this reach is also low providing for increased solar and air conductance heating. Other than the initial spring discharge, groundwater accretion to the river does not appear to be significant.

River Segment C (RM 37.2 to RM 34.8). Flood irrigation occurs within this segment and may be a source of warm water return flow; however, river temperatures decrease from RM 37.2 to 35.6 at a rate of 3.9 °F per mile and stabilize at about 67 °F from RM 35.6 to 34.8. River flow also increases despite a lack of identifiable sources (Webb 2007).

A potential source of cold water that may contribute to increased flow and reduced temperature is the groundwater system feeding the Hole in the Ground spring complex located about 0.5 miles east of the river. Although blocks of the debris avalanche are located between the springs and the river, the orientation of the blocks may serve to convey groundwater to the river.

The river temperature increases sharply at RM 34.8 due to inflow from Parks Creek.

River Segment D (RM 34.8 to RM 33.8). This segment begins at the confluence of Parks Creek and Shasta River at RM 34.8 where river temperature increases sharply by 3.8 °F and then increases at a rate of 1.7 °F per river mile. As shown in Figure 17, flood irrigation with surface water occurs throughout this segment and may be a source of warm water return flow to the river.

River Segment E (RM 33.8 to RM 30.0). River flows increase within this segment due to groundwater discharge to the river from the Big Springs and Little Springs complex. The spring discharge temperature is 58 °F, and river temperatures decrease at a rate of 1.2 °F per river mile. The primary source of groundwater accretion for the rest of the segment is likely the Pluto’s Cave basalt aquifer. Very little irrigation occurs adjacent to the river, thus limiting the potential for warm water return flows.

River Segment F (RM 30.0 to RM 26.1). River temperatures along this segment increase at a rate of 0.8 °F per river mile. This steady increase in river temperature begins some distance downstream of the Grenada Irrigation District (GID) diversion. It’s unknown if water was being diverted at the time of the survey. Flood irrigation occurs within this reach and may be a source of warm water return flows; however, only a limited amount of irrigation occurs adjacent to the river. The rate of temperature increase is likely due to limited groundwater accretion.

River Segment G (RM 26.1 to RM 24.7). River temperatures along this segment increase at a rate of 2.0 °F per river mile. There is an increase in irrigated acreage adjacent to the river (relative to River Segment F) which may be a source of warm water return flows. At RM 25.1, the rate of temperature change begins to decrease near the Willow Creek confluence with the Shasta River. This may indicate an area of groundwater accretion to the river from Willow Creek channel deposits. Deposits of Pluto’s Cave basalt may also be a factor.

River Segment H (RM 24.7 to RM 23.2). River Segment H traverses the block facies of the debris avalanche and a portion of Pluto’s Cave basalt. River temperatures along this segment increase at a rate of approximately 0.6 °F per river mile. Land use near the river is flood-irrigated agriculture that may be a source of warm water return flows; however, the rate of river temperature increase is less than that observed within River Segment G. This may indicate groundwater accretion to the river from channel deposits of Willow Creek and deposits of Pluto’s Cave basalt. The basalt flow is believed to have followed the channel of an ancestral Shasta River that incised through avalanche deposits. Cooler groundwater accretion from basalt deposits may originate from the main body of basalt located east of debris avalanche deposits.

River Segment I (RM 23.2 to RM 15.9). River Segment I traverses deposits of the debris avalanche, Pluto’s Cave basalt, and alluvium. While there are a number of surface water diversions within this segment, most of them are relatively small (0.25 to 3.5 cfs) compared to the 42 cfs diversion at RM 17.8. Considering the diversions and the large amount of irrigated acreage, it would be expected that stream temperatures would increase from reduced flow and warm water return flows. The temperature profile for this reach shows that temperatures stabilize at approximately 73 °F. This may be due to groundwater accretion from several sources including Pluto's Cave basalt, sources of groundwater recharge, and Julien Creek channel deposits.

The most likely source of groundwater accretion to the river is Pluto's Cave basalt deposits. As shown in Figure 18, Shasta River follows deposits of Pluto's Cave basalt from RM 24 to downstream of RM 22. As noted above, the deposits may be a source of groundwater accretion to the river originating from the main body of basalt located east of debris avalanche deposits.

Recharge to groundwater within this segment occurs from flood irrigation and water conveyance ditch losses. Surface water is the primary source of irrigation water for lands along this river segment and for some distance away from the river. As sources of groundwater recharge, applied surface water and conveyance ditch losses may be factors in maintaining stream temperatures as groundwater accretion to the river.

The confluence of Julien Creek and Shasta River at RM 21.4 is another potential source of groundwater accretion to the river. Julien Creek is an ephemeral stream with deep channel deposits spread over a large area. The deposits likely contribute to both natural and irrigation-derived sub-surface flows to the river.

River Segment J (RM 15.9 to RM 11.9). River Segment J follows matrix facies deposits of the debris avalanche. River temperatures along this segment increase at a rate of 0.3 °F per mile from RM 37.2 to 34.8 and decrease at a rate of 0.1 °F per mile from RM 13.3 to 11.9. The main difference between these two reaches is that water conveyance ditches are in greater number and are closer to the river between RM 13.3 and 11.9. Conveyance ditch losses may be a source of groundwater recharge and groundwater accretion to the river.

3.2.2 Implications of Shasta River Temperature Trend Data

Groundwater discharge to the Shasta River from the Pluto's Cave basalt aquifer is the primary source of cold water inflow to the river during summer months and relatively warmer water in winter months; both are critically important to the fishery. Future urban and agricultural development within the Pluto's Cave Basalt sub-area and corresponding increases in groundwater usage could have an impact on groundwater discharge to the river and the cold water fishery. Reduction in the contribution of groundwater from the Pluto's Cave basalt aquifer to Shasta River base flow may also impact downstream surface water users, some of whom are already periodically restricted in most years due to inadequate flows.

Although spring discharges are the primary mechanism for sustaining river flows and water quality, irrigation water may also be contributing to river base flow by increasing groundwater recharge and accretion to the river. This source of recharge and its relative importance needs to be understood; otherwise, efforts to reduce up-stream diversions or implement water conservation measures may result in unexpected consequences without understanding the site-specific interconnectedness of groundwater and in-stream cold water flows.

Other areas of cold groundwater accretion to Shasta River may include the Julien Creek and the Willow Creek drainages located within the Gazelle/Grenada hydrologic sub-area. Characterization of these systems is necessary to determine their importance as cold groundwater inputs to the river.

4 Groundwater Data Needs

The following identifies several data needs to further define the groundwater resources of Shasta Valley. These data needs are recommended with the primary goal to identify sustainable levels of groundwater development. Generally, sustainable development of an aquifer is less than what is recharged naturally. The greatest challenge facing county planners and resource managers with respect to water is the need to define the limits of available supplies and find the appropriate balance to meet present and future water demands. Each hydrologic sub-area in the valley has different resource requirements.

An important finding of this assessment concerns the role that surface water plays with respect to groundwater. Irrigation with surface water has been a practice in the valley for over 150 years. The application of surface water by flood irrigation methods is a source of groundwater recharge that contributes to domestic supplies and groundwater accretion to the river. Future urban and rural residential development may reduce this source of groundwater recharge if development requires the conversion of farm land to other uses. Also, on-farm water conservation practices and efforts to reduce surface water conveyance ditch losses will also reduce this source of recharge. These actions are not necessarily detrimental to groundwater resources; however, future planning efforts need to take the reduction of this source of recharge into account. Aquifers most susceptible to future development or changes in land use are the hydrologic sub-areas of Yreka, Yreka East, Montague, Little Shasta Valley, and Gazelle/Grenada.

Another issue concerns the Pluto’s Cave basalt aquifer and the role it plays in regards to the cold water fishery. This aquifer system is the primary source of cold water inflow to the Shasta River below Dwinnell Dam during summer and fall months which is critically important to coho and other salmon. Groundwater extractions from this aquifer have historically impacted groundwater discharge to the river. Future residential and agricultural development—and corresponding increases in groundwater usage—may act to further reduce this source of cold water supply to the river.

In light of these issues, the most important data need is the collection of data in support of the development of groundwater budgets for each hydrologic sub-area. Groundwater budgets are needed to account for the different sources of recharge, discharge, and changes in groundwater volumes. Sources of recharge to aquifers include precipitation, snowmelt runoff, water conveyance ditch losses, applied irrigation water, and subsurface inflow from adjacent aquifers. Each of these sources contributes to the sustainability of groundwater resources and ultimately affects the volume, rate, and timing of groundwater accretion to surface water systems.

To support the development of groundwater budgets, or to further refine budgets as more data comes available, the following data collection efforts are recommended:

- Expanded groundwater level monitoring
- Aquifer performance testing
- Identification and quantification of the different sources of recharge
- Stream characterization
- Water Quality Assessments

4.1 Expanded Groundwater Level Monitoring

The number of wells currently monitored in the valley is limited for the hydrologic sub-areas of Yreka, Yreka East, Little Shasta Valley, Debris Flow, and Weed. This lack of data is important for areas where groundwater supplies might be impacted from urban and rural residential growth, changes in land use, or on-farm water conservation measures. Sub-areas where further development and changes in land use could impact groundwater resources include Yreka, Yreka East, Montague, Little Shasta Valley, and Grenada/Gazelle.

The groundwater level monitoring grid needs to be expanded with additional private wells or dedicated monitoring wells (wells constructed for the sole purpose of monitoring groundwater). Dedicated wells will provide additional subsurface geologic data for areas where data is insufficient to characterize the groundwater and surface water interaction for selected reaches of Shasta River and Little Shasta River. Dedicated wells could also help gauge the effects of groundwater recharge from applied surface water and provide the infrastructure necessary to monitor the impacts of water conservation and resource management strategies.

4.2 Aquifer Performance Testing

Aquifer performance testing can provide a better understanding of aquifer properties, which is necessary to characterize how groundwater and surface water interact, assess potential impacts of using groundwater instead of surface water for irrigation, and evaluate future measures for water use efficiency. Aquifer performance tests are needed for areas within the Gazelle/Grenada, Yreka East, and Pluto’s Cave basalt hydrologic sub-areas. More specifically, tests are needed for the region leading to the Willow Creek/Shasta River confluence, the Julien Creek drainage, and the region adjacent to River Segment I (Figures 17 and 18). In addition to assessing the interaction of groundwater and surface water, the test data will help define the impacts of conveyance ditch losses and how applied surface water affects groundwater levels, flow gradients, flow volumes, and timing of groundwater accretion to the river.

4.3 Identification and Quantification of Sources of Groundwater Recharge

Identifying and quantifying the varied sources of groundwater recharge will allow planners to gauge the relative importance of the different sources of recharge and assess the impact of proposed resource management strategies.

The role of Mount Shasta as a source of recharge to debris avalanche deposits is probably the greatest unknown and the most difficult to characterize. The quantity of recharge and recharge mechanics may never be fully understood; however, recharge from Mount Shasta may be an important source of groundwater for the Gazelle/Grenada hydrologic sub-area. Having a concept of recharge mechanics is necessary to adequately develop groundwater budgets for Gazelle/Grenada, Debris Flow, and Pluto’s Cave Basalt hydrologic sub-areas.

4.4 Stream Characterization

The temperature profile for the Shasta River (Figures 17 and 18) presents several implications in regards to groundwater discharge and land use, and their potential impacts to stream flow and temperature. The primary source of cold water flow in the river is the discharge of groundwater from the Pluto’s Cave basalt aquifer system. Several of the warming trends that are observed are likely due to warm water irrigation return flows. Characterization of stream flow and temperature, through a combination of field measurements and dedicated monitoring, is needed to assess the impacts of diversions, land use, and the discharge and accretion of groundwater to the river. Current stream temperature monitoring efforts need to be expanded with dedicated instrumentation (building on previous efforts by the Resource Conservation District) to identify principal sources of groundwater discharge and provide the clear temperature signatures that denote the various inputs and changes to river flows.

4.5 Water Quality Assessments

Water quality assessments need be part of data collection efforts to help characterize groundwater and surface water interaction. Areas where this is most applicable include Stream Segment I of the Shasta River (Figures 17 and 18) and the Little Shasta Valley hydrologic sub-area. One of the findings noted in the evaluation of existing water quality data was the potential for seasonal effects of applied irrigation water. As noted in Section 2.4.3 Groundwater Chemistry by Hydrologic Sub-area, groundwater samples collected in May and October from several groundwater wells show seasonal changes in groundwater chemistry and TDS concentrations – likely due to recharge from applied irrigation water. Used in conjunction with dedicated monitoring wells, additional water quality data will help gauge the effects of applied irrigation water and assist in defining aquifer parameters.

4.6 Data Needs Summary by Hydrologic Sub-area

Table 12 summarizes the data collection needs for each hydrologic sub-area. Objectives for data collection efforts have been provided together with groundwater assessment measures.

Table 12. Summary of data needs by hydrologic sub-area

Hydrologic Sub-area	Resource Data Objectives	Groundwater Assessment Measures
Debris Flow	• Define the interaction of groundwater and surface water in relation to the Shasta River at River Segment I. • Provide resource planning data necessary to identify impacts of management actions and to ensure cold water inflows to the Shasta River and other beneficial uses.	• Develop groundwater budget. • Assess water conveyance ditch losses. • Expand groundwater monitoring – private and dedicated wells. • Characterize groundwater recharge sources • Expand stream temperature monitoring. • Provide water quality testing in support of groundwater/surface water interaction assessment.
Gazelle/Granada	• Define the role of applied irrigation water with respect to groundwater recharge and sustainability of groundwater resources. • Assess the Willow Creek drainage and its role in conveying sub-surface flows to the Shasta River. • Assess the Julien Creek drainage and its role in conveying sub-surface flows to the Shasta River. • Provide resource planning data necessary to identify impacts of management actions.	• Develop groundwater budget. • Assess water conveyance ditch losses. • Expand groundwater monitoring – private and dedicated wells. • Characterize groundwater recharge sources. • Provide water quality testing in support of groundwater/surface water interaction assessment. • Conduct sub-surface investigations.
Little Shasta Valley	• Define the interaction of groundwater and surface water in relation to the Little Shasta River. • Define the role of applied irrigation water with respect to groundwater recharge and sustainability of groundwater resources.	• Develop groundwater budget. • Assess water conveyance ditch losses. • Expand groundwater monitoring – dedicated wells. • Characterize groundwater recharge sources.

Table 12. Summary of data needs by hydrologic sub-area

Hydrologic Sub-area	Resource Data Objectives	Groundwater Assessment Measures
	• Characterize sub-surface geology. • Provide resource planning data necessary to define future levels of development with respect to the sustainability of groundwater resources.	• Provide water quality testing in support of groundwater/surface water interaction assessment.
Montague	• Define the role of applied irrigation water with respect to groundwater recharge and sustainability of groundwater resources. • Provide resource planning data necessary to define future levels of development with respect to the sustainability of groundwater resources.	• Develop groundwater budget. • Assess water conveyance ditch losses. • Expand groundwater monitoring – private and dedicated wells. • Characterize groundwater recharge sources.
Plutos Cave Basalt	• Define the interaction of groundwater and surface water in relation to the Shasta River. • Identify and quantify the effects of land use and future development on groundwater discharge to the Shasta River.	• Develop groundwater budget. • Assess water conveyance ditch losses. • Expand groundwater monitoring – private and dedicated wells. • Expand stream temperature monitoring. • Provide water quality testing in support of groundwater/surface water interaction assessment.
Yreka	• Provide resource planning data necessary to define future levels of development outside of Yreka city limits with respect to groundwater sustainability.	• Develop groundwater budget.
Yreka East	• Define the interaction of groundwater and surface water in relation to the Shasta River. • Define the role of applied irrigation water with respect to recharge, the sustainability of groundwater resources, and cold groundwater accretion to the Shasta River. • Provide resource planning data necessary to define future levels of development with respect to groundwater sustainability.	• Develop groundwater budget. • Assess water conveyance ditch losses. • Expand groundwater monitoring – private and dedicated wells. • Provide water quality testing in support of groundwater/surface water interaction assessment.
Weed	• Identify sources of recharge and their relative contribution to groundwater.	• Develop groundwater budget.

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Glossary

Alluvial fans. These coarse fan deposits transition into finer floodplain deposits on the valley floor.

Anions. Includes bicarbonate (negatively charged) ions

Cations. Includes calcium, magnesium, and sodium (positively charged) ions

Chemical classifications of groundwater. A description of the primary ions (cations and anions) dissolved in the water. As an example, water that is classified as calcium bicarbonate has at least 50 percent calcium as the principal cation and at least 50 percent bicarbonate as the principal anion.

Cinders. Loose volcanic fragments

Evaporite deposits. Deposits left from the evaporation of a body of water

Geomorphology. A study of plate tectonics, volcanic processes, and erosional processes that have formed and reformed the structure of the valley and its different aquifer systems.

Hornbrook Formation. A sequence of marine sedimentary rocks ranging up to several thousand feet in thickness and deposited around 65 million years ago. The formation includes inter-layered beds of shale, sandstone, and conglomerate. These marine rocks underlie much of the younger alluvium and volcanic deposits on the valley floor.

Hydrologic area. Part of a geographic classification which includes (from largest to smallest) hydrologic regions, hydrologic units, hydrologic areas, and hydrologic sub-areas.

Isohyetal map. Shows the mean annual rainfall pattern

Paleozoic to late Mesozoic in age. Approximately 500 million to 65 million years ago

Pleistocene to Holocene in age. Approximately 1.8 million years ago to present

Pliocene to early Pleistocene eras. Approximately 5.3 million to 1.8 million years ago

Quartenary period. Includes two geologic epochs—the Pleistocene and the Holocene.

Tertiary. A geologic period that covers the geologic time scale from 1.6 million to about 65 million years ago

Water year. The period extending from October of the previous year through September

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Appendix. Geologic Cross-Sections and Plates

Cross-Section Develop Summary

Since 1960, the USGS report *Geology and Groundwater Features of Shasta Valley, Siskiyou County California* (Mack 1960) has been the only comprehensive evaluation of geology, hydrogeology, and groundwater resources within Shasta Valley. Since that time, our understanding of the region has changed with the reinterpretation of the Tertiary-age volcanic rocks (volcanic debris avalanche) that cover most of the western half of the valley. Crandell (1989) recognized that the deposits of volcanic rock were the result of a gigantic post-depositional landslide off the slopes of an ancestral Mount Shasta rather than in-place deposits. This changed many assumptions regarding the rocks that underlie the surficial deposits of the valley and their hydrogeologic properties.

Since its publication in 1960, more than 40 years of new subsurface data have become available in the form of well completion reports. In an effort to provide for a broader evaluation of sub-surface geology, the reports were assembled and plotted along original cross-section lines developed in the 1960 publication. The original cross-section lines were updated, and four additional transects were constructed. The original cross-section lines that are expanded from Mack (1960) are A-A’, B-B’, and C-C’. The location of these cross-sections and new cross-sections developed for the valley are illustrated in the Plate: Areal Geology and Geologic Cross Sections.

Geologic Cross-Sections

The geologic cross-sections shown in the plates that follow this appendix were developed with a highly exaggerated vertical scale (25 times) to adequately depict areas of shallow alluvium. A profile for each cross-section at a scale of 1:1 was also provided on each plate to illustrate the topography of the region. The cross-sectional areas are highly interpretive and present a simple diagrammatic view of what is known about subsurface contacts.

Cross-Section A-A’

This section line extends to the southeast from the vicinity of Montague and Yreka to the eastern edge of the valley. The cross-section begins in Paleozoic bedrock and crosses deposits of the volcanic debris avalanche and Pluto’s Cave basalt. The section line terminates in an up-faulted block of the Hornbrook Formation. Near the City of Montague, well data show that the Hornbrook Formation underlie debris avalanche deposits providing for the interpretation that Hornbrook Formation rocks also underlie the younger, surficial volcanic rocks along the section line. This differs from the 1960 interpretation where Western Cascade volcanic rocks were thought to underlie Pluto’s Cave basalt.

Cross-Section B-B’

This section line extends roughly west-to-east at the far northern end of the valley. The original Mack (1960) depiction shows a broad regional interpretation based more on geologic history and inferred structure rather than site specific data. Few wells are drilled in the area; however, three completion reports used in updating the cross-section indicate a thin soil underlain by a brown “claystone”, which, in turn, overlies the Hornbrook Formation. The surficial claystone horizon is interpreted as being the clay rich matrix facies of the debris avalanche.

Cross-Section D-D'

This section line trends roughly north-to-south along the western portion of the valley. Well completion reports for deeper wells constructed along this line encounter Paleozoic rocks. The Cretaceous Hornbrook Formation is not observed implying that these deposits were eroded or that there is some structure disruption from north-to-south which is covered by surficial deposits.

Cross-Section E-E'

This section line trends from west-to-east in the vicinity of the town of Gazelle. The western margin of the valley has several wells constructed within alluvial fan deposits, some of which also encounter Paleozoic bedrock or debris avalanche deposits. No wells located along this cross-section have been constructed to a depth which penetrates the base of debris avalanche deposits. As a result, the thickness of debris avalanche is unknown as well as the nature of the underlying strata towards the axis of the valley.

Cross-Section G-G'

This section line extends from west-to-east near the town of Granada. The cross-section shows the narrowing of the alluvial drainage along the west side of the valley, constrained to the east by debris avalanche deposits. Although no well completion reports are available to confirm the presence of Cretaceous Hornbrook Formation deposits underlying the volcanic debris avalanche and Pluto's Cave basalt, it's postulated that the Hornbrook Formation is in the subsurface conforming to Mack (1960) interpretation.

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