SHASTA RIVER HYDROLOGY AND INTEGRATED SURFACE WATER / GROUNDWATER MODELING

1.0 Study Goals and Objectives

The overall goal of the Shasta River hydrology and integrated surface water / groundwater modeling study plan is to: 1) quantify natural (unimpaired[1]) and regulated (with diversions) flows in the watershed; and 2) develop an integrated surface water / groundwater model that represents unimpaired flows, accretions and depletions, including diversions, within the Shasta River basin. The combined assessment of natural surface water runoff, groundwater, water storage, and diversions can then be used to evaluate alternative water management scenarios. The daily natural and regulated flows for each major tributary and river segment will be modeled for the 21-year period of water year 1991 – 2011.

The specific objectives of the study include:

1) Estimate the natural daily streamflow in each tributary and main river reach as a function of the rainfall and snowmelt runoff using a daily hydrologic model (e.g. HEC-HMS). The hydrologic model will apply daily rainfall and snowpack data from two or more precipitation stations (one for valley rainfall and one for higher elevation rainfall with snowpack) and will include representations of the soil moisture capacity (depth of water) and evapotranspiration losses, so that the direct surface runoff and groundwater infiltration and subsequent baseflow discharges can be estimated. The hydrologic model will be divided into tributary watersheds, so that the runoff from each tributary can be estimated. Tributary reach flow estimates will be provided at the upstream extent of fisheries habitat and at the downstream confluence with another tributary reach or with a main river reach, as well as the daily diversion flows at each diversion along the reach.

2) To understand the relationship between unimpaired flows (including high elevation snowmelt runoff), reservoir storage, spring flow accretions, percolation of surface water, changes in groundwater elevation, municipal and agricultural diversions, groundwater pumping, and other accretions / depletions, this study will include development of an integrated surface water / groundwater model using a tool such as MODFLOW 2005, which was developed by the U.S. Geological Survey (USGS), or the California Department of Water Resources' (DWR) Integrated Water Flow Model (IWFM). The integrated model will allow interested parties to evaluate operational alternatives within the basin.

2.0 Existing Information/Literature Review

The geology of the Shasta River watershed and Shasta Valley is dominated by volcanic formations, with high infiltration rates, damped storm response, and sustained baseflow. Snowmelt from Mount Shasta contributes significantly to surface runoff and groundwater hydrology. Water from melted snow percolates down through porous volcanic rocks and flows subsurface, eventually emerging as springs and seeps on the valley margin or floor. The

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[1] "Unimpaired Flow" represents the natural water production of a river basin, unaltered by upstream diversions, storage, or by export or import of water to or from other watersheds. Gauged flows at the given measurement points are increased or decreased to account for these upstream operations.

western side of the basin is underlain by more crystalline formations with shallow soils, which produce a more rapid response to storms, and baseflow that declines more rapidly through the summer. Groundwater moves generally northward in the southern part of the Shasta Valley and from the east and west, converging toward the Shasta River along the valley axis (Mack 1960). Annual precipitation ranges from less than 15 inches in parts of the Valley to over 45 inches in the Eddy and Klamath Mountains, while precipitation on Mount Shasta ranges from 85 to 125 inches. The wet season generally lasts from October to April and much of the winter precipitation falls as snow in the higher elevations. In general, the amount of precipitation at any place and the proportion of precipitation that falls as snow are related directly to elevation.

<u>Gaging</u>

The USFS weather station at Scott Mountain (5,500 feet) provides daily precipitation and daily snowpack depth, which can be used to estimate the effects of snow pack on reducing runoff during accumulation, and increasing runoff during melting. Daily weather stations near Yreka and Weed can be used to provide the valley rainfall estimates. Data from the following stations are available from the USGS, DWR Water Data Library or CDEC websites:

Station Name	Data Source (Type)	Station ID	Period of Record
Shasta River near Yreka, CA	USGS (stream flow)	11517500	12/14/1944 – 9/1/2014
Shasta River near Montague, CA	USGS (stream flow) CDEC (stream flow)	11517000 SRM	10/1/2001 – 9/1/2014 7/14/1999 – 9/1/2014
Shasta River near Granada	WDL (stream flow)	F21370	1/26/2005 – 9/30/2005
Shasta River at Granada Pumping Plant	CDEC (stream flow)	SPU	7/3/2013 – 1/14/2014
Dwinnell Reservoir near Edgewood	CDEC (storage)	DRE	9/1/2005 – 9/1/2014
Shasta River near Edgewood	WDL (stream flow)	F21700 F21675	No data after WY 1991 10/1/2004 – 9/30/2005
MWCD Parks Ck Diversion	WDL (canal flow) CDEC (stream flow) CDEC (canal flow)	F21940 MPD	10/15/2004 – 9/30/2006 11/18/2012 – 5/19/2013 11/14/2005 – 10/25/2011 10/31/2011 – 9/1/2014
Little Shasta River near Montague	WDL (stream flow)	F21300	No data after WY 1978
Parks Creek above Yreka Ditch	DWR Watermaster	n/a	Daily data during diversion season through 1998
Weed Airport (2930 ft)	CDEC (daily precip.)	WED	1/1/1984 – 9/1/2014
Brazie Ranch (3020 ft)	CDEC (daily precip.)	BZR	1/1/1984 – 9/1/2014
Mount Shasta City (3590 ft)	CDEC (daily precip.)	MSC	1/1/1989 – 8/4/2014
Parks Creek (6700 ft)	CDEC (mon. snow)	PRK	3/1/1939 – Present

Mount Shasta (7900 ft)	CDEC (mon. snow)	MSH	2/1/1930 – Present

Other flow measurement stations have been operated for various periods by Shasta River Watershed Council (SRWC), North Coast Regional Water Quality Control Board (NCRWQCB), US Forest Service (USFS) and Shasta Valley RCD. The operations of Lake Shastina (MWCD) and the major springs must also be included in the hydrology and water balance models for the Shasta River basin.

Groundwater

The most recent study of the Shasta Valley groundwater was a draft report (DWR 2007) that updated the previous USGS (Mack 1960) and DWR reports (DWR 1964).

Groundwater elevations vary considerably in the different types of material underlying the valley. In the vicinity of Big Springs the water surface in the Plutos Cave basalt slopes to the west at about 25 feet per mile. Hydraulic gradients in the volcanic rocks of the western Cascades average about 25-30 feet per mile throughout most of the valley. Immediately west of Dwinnell Reservoir (Lake Shastina), however, the gradient in these rocks steepens, sloping to the northwest at about 100 feet per mile. This steepening may reflect sizable seepage to the volcanic rocks from Dwinnell Reservoir. Hydraulic gradients in the Gazelle-Grenada alluvial belt and in Little Shasta Valley also average about 25-30 feet per mile. The depth to the water table varies throughout Shasta Valley. The depth to water is greatest at the south end of the valley near its eastern and western margins. The depth to water is least near the Shasta River, where surface water may interact with groundwater (i.e., seepage or recharge). Near Plutos Cave the water table lies at a depth of about 300 feet. Northward and westward the land surface declines rapidly and many large springs issue from the basaltic lava. In Little Shasta Valley the water table locally intersects the land surface and ponds and meadows occupy the depressions (Mack 1960).

The volcanic debris avalanche deposits which are below the Pluto's Cave basalt redirects the natural flow of groundwater to the Shasta River, which is sustained by several large springs – the largest of which is the Big Springs complex. The avalanche deposits resulted in a barrier to the subsequent flow and deposition of the Pluto's Cave basalt. The less permeable avalanche deposits impede the flow of groundwater from the basalt -- giving rise to numerous springs (including Big Springs) along the line of contact between the formations.

Precipitation on the valley floor is not sufficient to contribute much recharge to ground water, except during above-average precipitation. Recharge from irrigation water (seepage from canals and infiltration of excess applied water was estimated to be about 25% of the applied surface water of 60,000 acre-feet (af) in 1953 (Mack 1960). Ground-water discharge from springs and seepage and groundwater pumping was roughly estimated to be about 130,000 af (average flow of 175 cfs) in 1953 (Mack 1960). The Big Springs Irrigation District historically pumped 30 cfs from Big Springs Lake, but replaced this diversion with groundwater pumping in 1986.

The annual amount of recharge is important for determining the seasonal changes in groundwater elevations within the sub-areas of the Shasta Valley groundwater basin. The stream percolation to groundwater will be highest in alluvial fan areas (generally where tributaries enter the valley) when the tributary flows are highest. Surface diversions for irrigation, storage in Lake Shastina, and irrigation canals provide a substantial portion of the Shasta Valley groundwater recharge. For example, Lake Shastina apparently has a large seepage rate to the groundwater basin beneath the Shasta River to the northwest. The Montague canal from Lake Shastina also has a high seepage rate (estimated as 25% of the canal flow) that recharges the groundwater between Lake Shastina and Montague (Pluto's Cave Basalt sub-area). There is also considerable recharge (25% of applied surface water) from the irrigated pastures and alfalfa fields in other parts of Shasta Valley

3.0 Study Areas

The Shasta River study area is bounded to the north by the Siskiyou Range, to the west by the Klamath Mountains, to the east by the Cascade Range, and to the south by Mount Shasta and Mount Eddy. Mount Shasta, elevation about 14,000 feet, is the dominant topographic feature in the watershed and contributes significantly to the hydrology of the basin.

3.1 Shasta River Study Area

The study areas for the Shasta River hydrology, groundwater, and water balance modeling are presented in Table 1 (see Shasta River Potential Studies Matrix; http://www.normandeau.com/scottshasta/ project materials.asp), Figure 1 (Shasta River Mainstem Reaches, and Figure 2 (Shasta River Tributary Reaches).

Table 1. Reaches of the Shasta River and tributaries where a hydrology, groundwater, and water balance model needs to be developed.

REACH DESCRIPTION	Reference(s)	Studies Status
Mainstem Shasta River, Dwinnell Dam to mouth	CDFG 2004; Jeffres et al. 2008; Nichols 2008; Nichols et al. 2010; SRWCRMPC 1997, SVRCD, M&T 2013	Partial
Shasta River Tributaries, including Little Shasta River, Parks Creek, and above Lake Shastina	CDFG 2004, SVRCD, M&T 2013	Partial

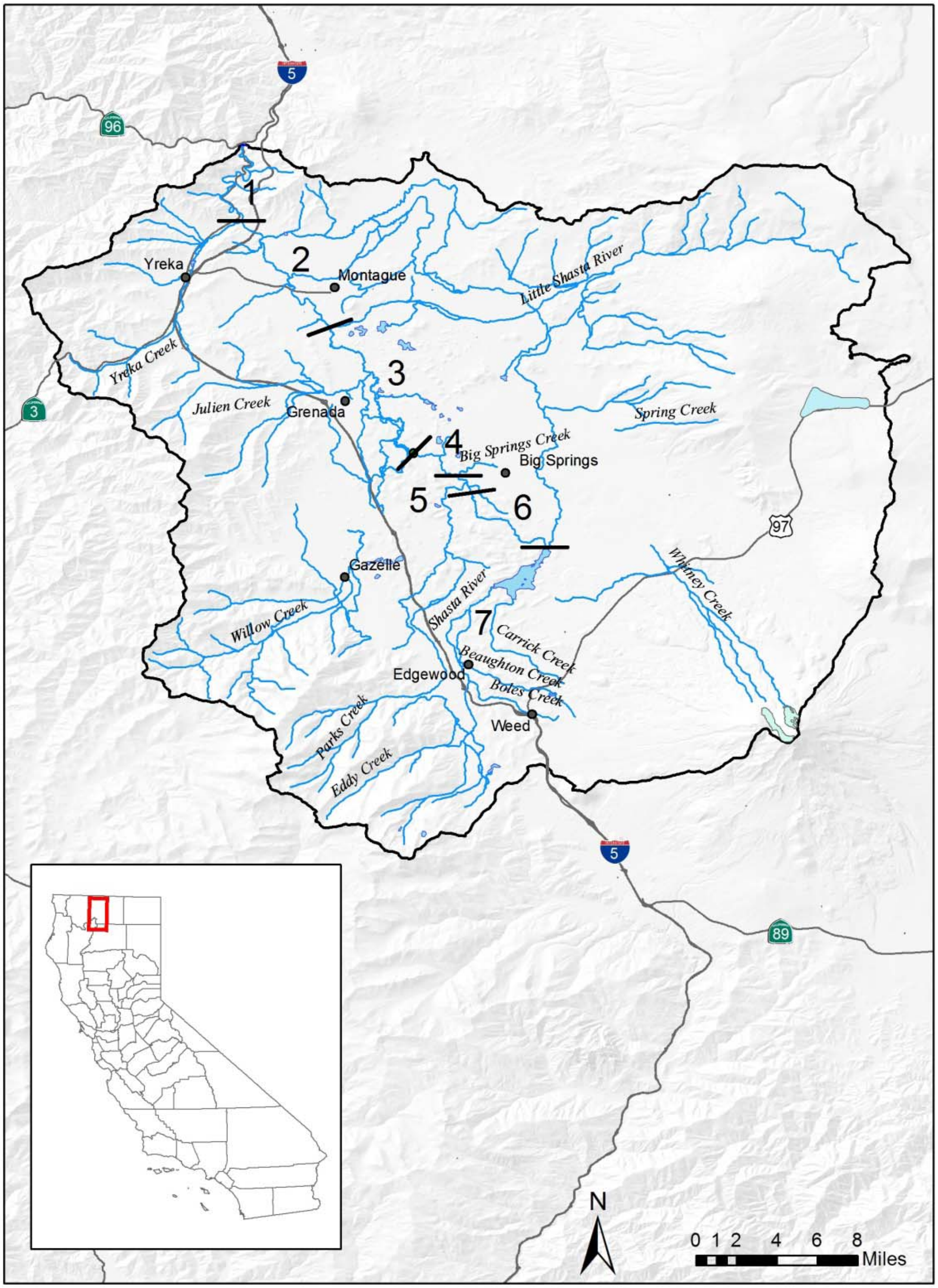

Figure 1. Shasta River Mainstem Reaches.

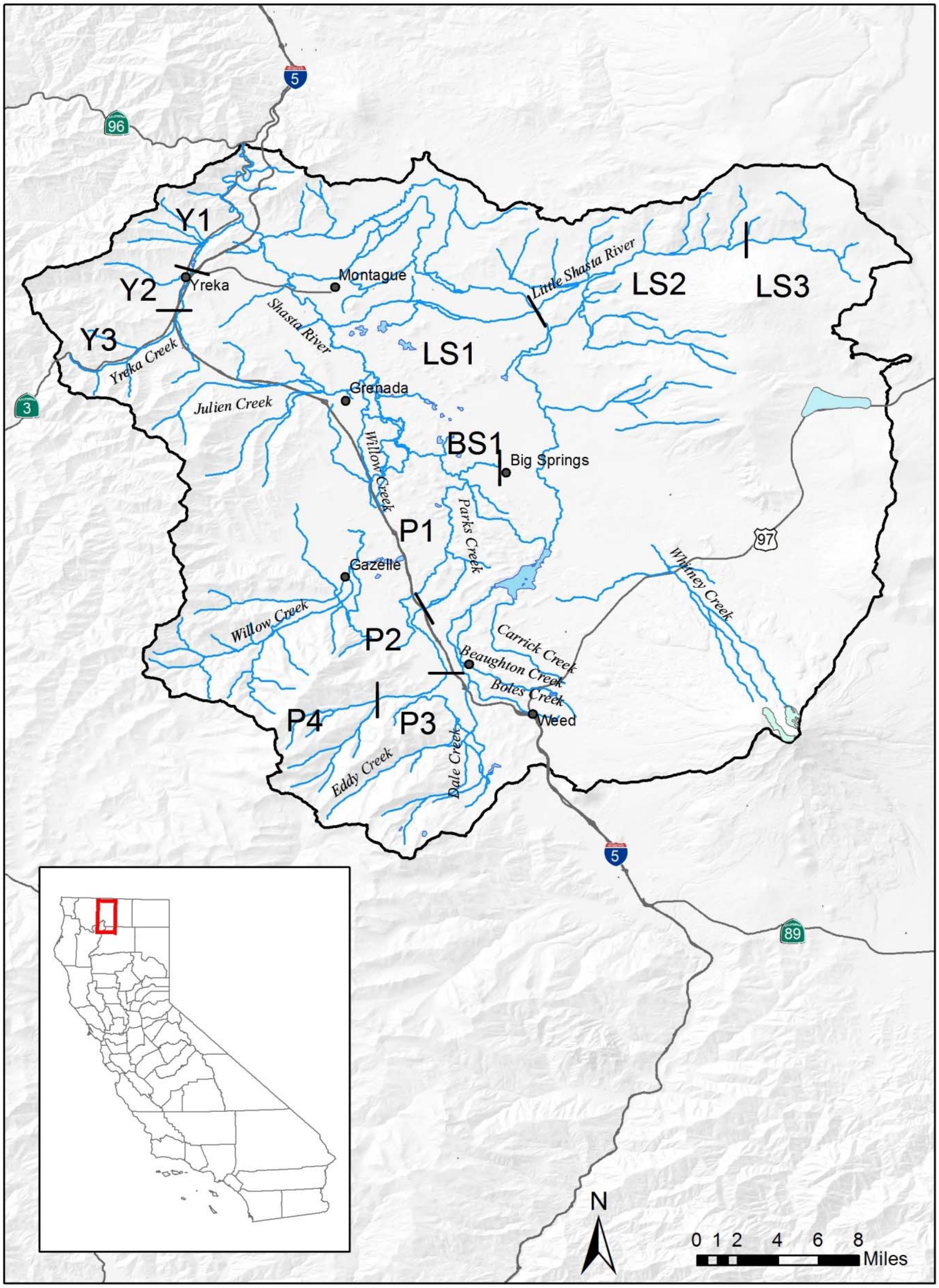

Figure 2. Shasta River Tributary Reaches. Little Springs Creek (Reach BS1a) is a tributary to Big Springs Creek and is not depicted due to its short relative length (0.7 miles).

3.2 Shasta Valley Groundwater Sub-Areas

Figure 3 shows the Shasta River Valley groundwater basin and the nine sub-areas identified by DWR (DWR 2007). The groundwater in each of the sub-regions should be separately described and quantified. A summary of the approximately 2,200 wells within the Shasta Valley (DWR 2007) indicates that most (1,825) are domestic wells, generally with yields of 20 gallons per minute (gpm) and there are about 200 irrigation wells and about 25 municipal or industrial wells, with median reported yields of about 150 gpm. The average depth for most wells is about 150 feet. Most of the groundwater pumping is for irrigation and municipal wells. The average water use for 1984-1994 ranged from 100,000 to 160,000 af, with groundwater pumping of about 25,000 af (Balance Hydrologics, 1998). Groundwater use in each of the sub-areas identified in Figure 3 should be confirmed from the irrigated acreages not supplied by surface diversions.

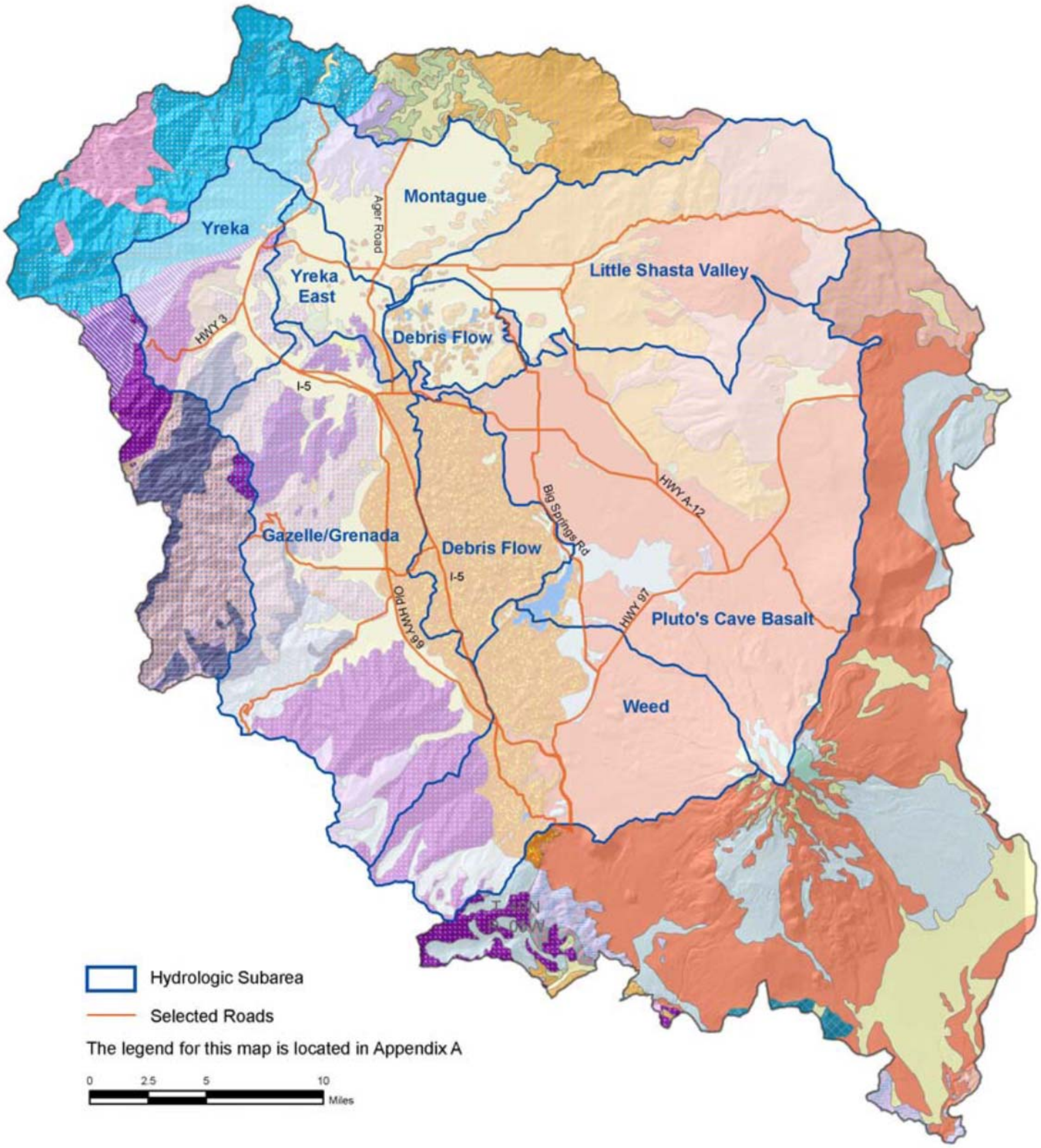

Figure 3. Surface Geology of the Shasta Valley Hydrological Sub-areas (Source: DWR 2007)

4.0 Study Methods

Task 1. Evaluate and Summarize Background Information

1. Review previous reports on the springs, groundwater, hydrology, and water management for the Shasta River basin (e.g. Mack 1960, DWR 1964, DWR 2007, and others). Compile all publically available streamflow, precipitation, snowpack, and appropriate meteorological data within the Shasta River watershed. Obtain or prepare maps with topography, geological features, spring locations, and irrigation well locations (excluding domestic wells). Acquire the results on spring location and flow magnitude from the *Shasta River Water Temperature Assessment Study Plan*.

2. Determine the upstream boundary for fish habitat in each tributary and identify the upstream watershed areas for each reach boundary.

Task 2. Develop Unimpaired Hydrology

1. Identify all springs, stream inflows, and diversions along each reach, so that the flows can be accurately estimated along the stream channel (with river mile locations). This information, along with global positioning s ystem waypoints should be included as a table with the deliverables.

2. When it is necessary to determine the spring flows, measure the streamflow immediately above and immediately below each spring source on a monthly basis for one year. Estimate the spring flow as the difference between the upstream and downstream flow measurements.

3. Where it is necessary to determine diversion flows, measure the streamflow immediately above and immediately below each diversion on a monthly basis for one year. Estimate the diverted flow as the difference between the upstream and downstream flow measurements.

4. Using the information complied and evaluated under Task 1 and the previous steps of Task 2, develop a daily rainfall-snowmelt-runoff hydrologic model (e.g., HEC-HMS, Sharffenberg 2013) that includes soil moisture, evaporation and shallow groundwater infiltration and seepage (baseflow, springs) for the basin.

5. Calibrate the model against an appropriate dataset, and subsequently validate the model against a separate, recent, dataset. Apply the hydrologic model to estimate the streamflow at all reach boundaries for an appropriate time period.

Task 3. Compile Data to Support Groundwater Modeling

1. Identify the connections with the basin groundwater, such as a) stream infiltration to the groundwater along the alluvial fan sections of tributary streams, b) recharge from irrigation water canals, and c) seepage from the shallow groundwater to the river channel in the irrigated valley reaches.

2. Evaluate the available groundwater elevation data, including data from the major agricultural pumping areas in the Shasta Valley (in cooperation with DWR and SVRCD), and determine whether the data is adequate to support the development of a groundwater model.

3. If the data is not adequate to support model development, prepare a groundwater level monitoring plan that recommends specific monitoring locations and durations that will support model development.

4. In cooperation with DWR and SVRCD, determine the annual pumping volumes for irrigation in each sub-area of the Shasta Valley. Compare historical monitoring well data (spring and fall water elevations) to determine the effects of seasonal pumping volumes and seasonal recharge volumes for the major irrigation areas within the Shasta valley. If necessary, estimate pumping volumes based on the water needs of the specific crops supplied by groundwater.

5. In cooperation with DWR and SVRCD, determine the effective surface area for the aquifers in the sub-areas of the Shasta Valley. In addition, determine the hydraulic conductivity in each sub-area identified in Figure 3 using pump tests and slug tests conducted in accordance with the standard analysis methods identified by Dawson and Istok (1991).

6. Estimate the magnitude of tributary percolation to groundwater and canal percolation losses as a function of the stream flow or canal flow. Estimate the seepage losses from Lake Shastina and the deep percolation from surface irrigated areas, based on the applied water depth (acre-feet applied per acre).

Task 4. Develop an Integrated Surface Water / Groundwater Model

1. Prepare a groundwater map using GIS techniques that includes the watershed topography (DEM with 10-foot contour resolution in the valley), the stream network, Lake Shastina and the major surface canal networks, and that identifies all irrigation and municipal wells (>50 gpm), all springs (>1 cfs, 450 gpm), and other know accretion / depletion locations. The map should include the areal extent of the groundwater (aquifers) with a saturated depth of more than 25 feet. All known wells should be located within these aquifer boundaries.

2. Using the information compiled and evaluated under Tasks 1, 2, and 3, develop an integrated surface water / groundwater model for the sub-areas of the Shasta Valley groundwater basin using a tool such as MODFLOW, developed by the USGS, or DWR's Integrated Water Flow Model.

3. Develop and apply operating rules for each diversion and pumping location that reflects recent historic conditions, if known, or the water rights decrees if recent historic operations are not known.

4. Validate the model against the observed record compiled in Task1.

5. Develop a base-case simulation in consultation with interested participants.

5.0 Deliverables

Deliverables from this study plan include: a technical memorandum summarizing the pertinent background information (Task 1); a technical memorandum documenting the development of unimpaired hydrology, including the estimates of the regulated and unimpaired flow at specific locations of the Shasta River watershed depicted in Figures 1 and 2 (Task 2); a technical memorandum describing the data compiled to support groundwater modeling (Task 3); and an integrated surface water / groundwater model that can be used to evaluate flow management alternatives (Task 4); and a Final Report that documents the development of the integrated surface water / groundwater model, including calibration and validation efforts.

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