SHASTA RIVER WATER TEMPERATURE ASSESSMENT

1.0 Study Goals and Objectives

The overall goal of the study element is to acquire sufficient water temperature and metrological data in the Shasta River watershed to support the characterization of salmonid rearing habitat in the rivers and tributaries as a function of river flow, springs, channel hydraulics (width, depth, and velocity), and riparian shade. Because water temperature is likely a limiting factor for fish habitat quality, the connection between these variables will be an important factor in the successful implementation of fish habitat protection and restoration (McCullough 1999, Carter 2005). Once acquired, existing data will be reviewed and a determination made by reach that they are either adequate or inadequate for habitat characterization using either direct thermal patterns or water temperature modeling. If determined to be necessary, new data should be collected that would be compatible with either approach. Both approaches would create frameworks for predicting and interpreting the effects of potential restoration actions (e.g., altered instream flow or increased riparian shade) on water temperatures and aquatic habitat.

High water temperatures often occur under low flow conditions and are presumed to be major limitations for fish habitat in the Shasta River basin. Several large springs in the Shasta River watershed (e.g., Big Springs) have a moderating effect on downstream water temperatures due to their relatively constant temperature and can also function as thermal refugia, both in-channel and off-channel. Due in part to the abundance of permeable volcanic material, the Shasta River watershed has numerous cold water springs. If allowed to flow into the main stem Shasta River (and key tributaries such as Parks Creek, Big Springs, and the Little Shasta River) these springs can and do provide thermal refugia for rearing salmonids. The importance of these springs for fish habitat has recently been heightened by studies of juvenile coho salmon behavior and survival. Because spring discharge and water temperature have a significant localized effect on the water temperatures of the Shasta River, and the distribution of fish habitat, it is critical that a complete inventory of all springs in the watershed be conducted. This information is crucial for planning and managing stream temperatures and providing habitat for the recovery of listed species. Specifically, this task will also result in a series of maps and a database that documents where the springs are located, discharge, temperature, ownership, and water right.

The specific objectives of the study include:

- Acquiring and summarizing existing data on water temperatures over space and time,
- Developing empirical water temperature maps showing the presence and persistence of thermal refugia that may be used by rearing juvenile salmonids during seasons of high temperatures,
- Creating a database of all springs by location, temperature, flow, and known water rights,
- Acquiring physical and meteorological data sufficient for development and calibration of water temperature models, and
- Identifying specific water temperature models compatible with either existing or acquired data and capable of predicting thermal effects of restoration activities.

2.0 Review of Existing Information

Flows and water temperatures in the Shasta River watershed have been of great interest for fisheries resources for many years. Staff reports were prepared by North Coast Regional Water Quality Control Board (NCRWQCB) for the Shasta River temperature and dissolved oxygen TMDL determinations (NCRWQCB 2006). Several previous surveys, investigations, and modeling studies of flow and water temperatures (and effects on fish habitat) have been conducted in the Shasta River watershed (Deas et al. 2003, Deas et al. 2004a, Deas and Geisler 2004b, Nichols et al. 2013, Stenhouse et al. 2012, and Watershed Sciences 2004).

The Shasta River TMDL staff report provides an excellent analysis of the factors controlling water temperatures (e.g., flow, meteorology, stream geometry, shade, springs) and includes the most extensive flow and water temperature modeling efforts conducted in the Shasta River watershed. However, the data collection and flow and temperature modeling was confined to the 40 miles of Shasta River below Dwinnell Dam, with no analysis of the tributaries or the Shasta River above Dwinnell Dam.

Several recent studies of the restoration efforts for Big Springs Ranch undertaken by The Nature Conservancy (Chesney et al. 2011, Nichols et al. 2013, Null et al. 2009) have documented the effects of cool spring inflows on downstream water temperatures during the summer months. Optimal water temperatures for juvenile coho and Chinook rearing during the summer are 15°C, with a sub-optimum temperature range of 15-20°C. The existing summer temperatures of 25°C in portions of the Shasta River are near lethal and few salmonids are found in these warmer reaches (Stenhouse et al. 2012).

There are many sources of data and information on permanent or intermittent springs in the Shasta River watershed. These include the California Conservation Commission 1913, California Division of Water Resources Watermaster Reports (circa 1934-1965, e.g. 1945), Paulsen 1963, Wharton and Vinyard 1979, Nathenson et al. 2002, AquaTerra Consulting 2010, Jeffres et al. 2008; 2009, Davids Engineering 2011, Willis et al. 2013, and various United States Geological Survey quadrangle maps. In addition, there are water rights decree maps held by the Siskiyou County Superior Court, records of the Montague Water Conservation District, files at the Scott Valley and Shasta Valley Watermaster District offices, the pre-adjudication water supply and use report by the California Department of Public Works (CDPW 1925), and digitized maps created by the Northern Region of the California Department of Water Resources.

3.0 Study Areas

The Shasta River watershed has an area of approximately 795 square miles at the confluence with the Klamath River. Snowmelt percolating through the volcanic geology surrounding Mount Shasta contributes a constant source of spring flow to the Shasta River and its eastern tributaries. During project scoping, the Shasta River was segmented into study reaches using criteria such as hydrology, length, geomorphology, and others (Normandeau Associates 2013; Figures 1 and 2). Several water temperature monitoring projects are currently being conducted within the Shasta River basin (Table 1). There are several reaches of the Shasta River and tributaries where there are known springs that likely serve as thermal refugia. Table 2 identifies reaches to be surveyed to determine their potential suitability. Many reaches of the watershed are identified as needing data for water temperature modeling (Table 3). See Shasta River Potential Studies Matrix: http://www.normandeau.com/scottshasta/project_materials.asp).

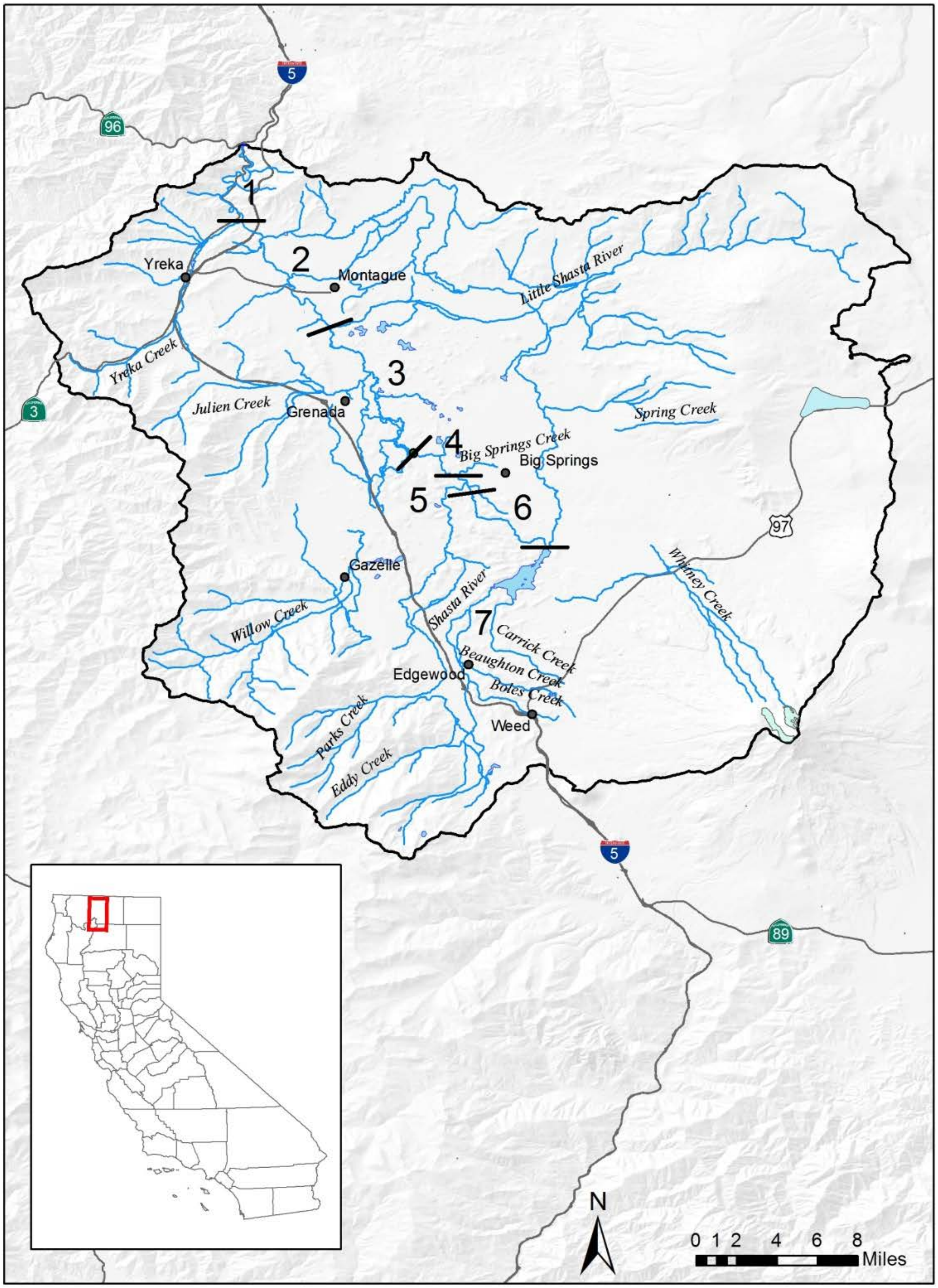

Figure 1. Shasta River Mainstem Reaches.

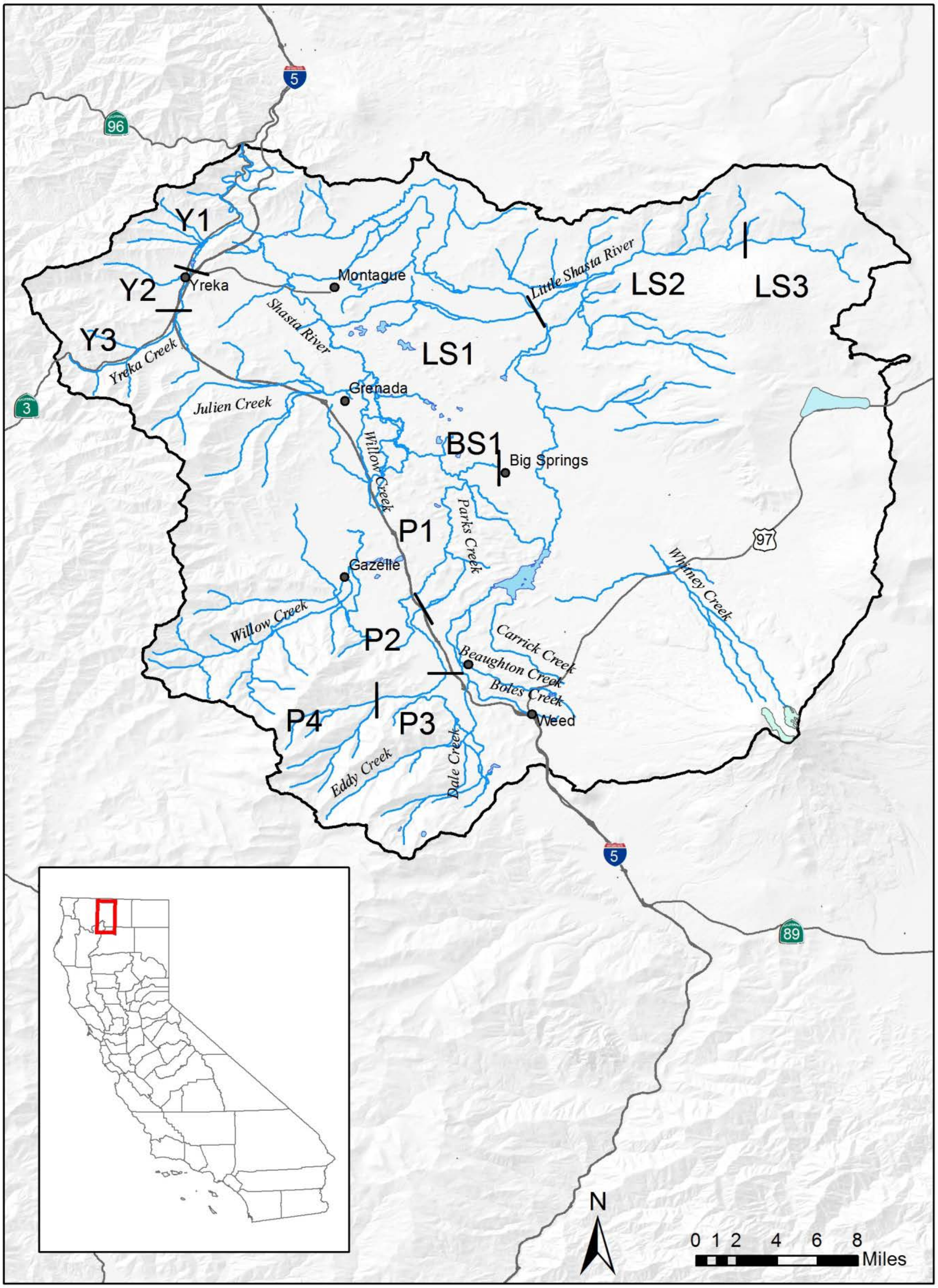

Figure 2. Shasta River Tributary Reaches. Little Springs Creek (Reach BS1a) is a tributary to Big Springs Creek and is not depicted due to its short relative length (0.7 miles).

Table 1. Reaches of the Shasta River and tributaries where water temperature monitoring is currently being conducted (see Table 4 for specific reaches).

REACH DESCRIPTION	Reference(s)	Studies Status
Mainstem Shasta River	CDFG 1997, 2004; Chesney et al. 2011; DWR 1964; Jeffres et al. 2008; M&T under review; Nichols et al 2010; Null 2008; Null et al. 2009; SRWCRMPC 1997; SVRCD, M&T 2013; Stenhouse et al. 2012	On-going
Shasta River Tributaries	CDFG 1997, 2004; Chesney et al. 2011, SVRCD, M&T 2013; Willis and Deas 2011, UC Davis 2015	On-going

Table 2. Reaches of the Shasta River and tributaries where areas of springs, groundwater accretion, and potential thermal refugia are to be identified and mapped.

REACH DESCRIPTION	Reference(s)	Studies Status
Shasta River (4,5,6)	Chesney et al. 2001; SVRCD and M&T 2013	Needed
Big Springs Creek (BS1)	Chesney et al. 2001; SVRCD and M&T 2013	Needed
Little Springs Creek (BS1a)	Chesney et al. 2001; SVRCD and M&T 2013	Needed
Little Shasta River (LS1-3)	Chesney et al. 2001; SVRCD and M&T 2013	Needed
Parks Creek (P1-4)	Chesney et al. 2001; SVRCD and M&T 2013	Needed

Table 3. Reaches of the Shasta River and tributaries where data suitable for predictive water temperature modeling will be acquired.

REACH DESCRIPTION	Reference(s)	Studies Status
Shasta River (1,2,3)	CDFG 1997, 2004; Chesney et al. 2011; DWR 1964; Jeffres et al. 2008; M&T under review; Nichols et al. 2010; Null 2008; Null et al. 2009; SRWCRMPC 1997; SVRCD and M&T 2013; Stenhouse et al. 2012	Partial
Yreka Creek (1,2,3)	CDFG 1997, 2004; Chesney et al. 2011; SVRCD and M&T 2013; Willis and Deas 2011	Partial

4.0 Study Methods

The thermal relationships in the Shasta River and tributaries between streamflow, spring inflow, and potential thermal refugia for rearing salmonids are to be assessed with three approaches:

1. Collect (compile) all previous water temperature measurements. Prepare watershed map(s) with stream reaches, spring locations, and riparian vegetation
2. Conduct multiple FLIR thermal overflights to locate sources of spring inflow and evaluate patterns of mixing or cool water retention in relation to streamflow
3. Validate the level of effectiveness of FLIR images at locating small seeps and springs by comparison to existing and new field measurements
4. Investigate the application of distributed temperature sensing (DTS) fiber optic technology for collecting water temperature data.
5. Collect physical and meteorological data sufficient for developing and calibrating water temperature models capable of predicting thermal effects of restoration activities.

All aspects of this study plan should be closely coordinated with the California Department of Fish and Wildlife (CDFW), the NCRWQCB, and their specified contractors who work on the Shasta River TMDL and other studies related to water temperature. In addition, this study plan should be coordinated where feasible with the *Shasta River Hydrology and Integrated Surface Water/Groundwater Modeling* study plan.

4.1 Water Temperature Data Compilation

All known sources of water temperature data for the Shasta River and tributaries are to be compiled and the data itself collated, analyzed, and summarized in a searchable electronic database. Water temperatures have been measured at many locations in the Shasta River watershed as an important variable to suitable fish habitat and significant in any attempt to recover endangered salmonids. Several agencies have established measurements stations, and numerous evaluations, monitoring programs, and modeling studies have already been undertaken. Table 4 identifies temperature measurements in the Shasta River, although not all of these stations have been consistently active.

Table 4. Water temperature sampling locations in the Shasta River.

Site	River Mile
USGS Gage	0.6
Highway 263	7.3
Yreka Creek	7.6
Anderson Grade Road	8.0
Interstate 5	8.6
Yreka-Ager Road	10.9
Oregon Slough	11.8
Highway 3	13.1
Montague-Grenada Road	15.5
Little Shasta River	16.3
Freeman Lane	19.2
Highway A-12	21.1
Willow Creek	25.1
GID	30.6
East Louie Road	33.9
Hole In the Ground	34.8
Riverside Drive	36.0

Measured seasonal Shasta River water temperature patterns at several locations are shown in Figure 3. Stream temperatures in the fall, winter and spring months are suitable for all life stages of anadromous fish (<15°C). However, in summer periods, certain reaches experience elevated temperatures, with weekly average temperatures exceeding 25°C. Additional information on water temperature and dissolved oxygen monitoring data should be available in a database developed as part of the Shasta River Stewardship Project, a collaborative restoration project (NCRWQCB and SVRCD 2014).

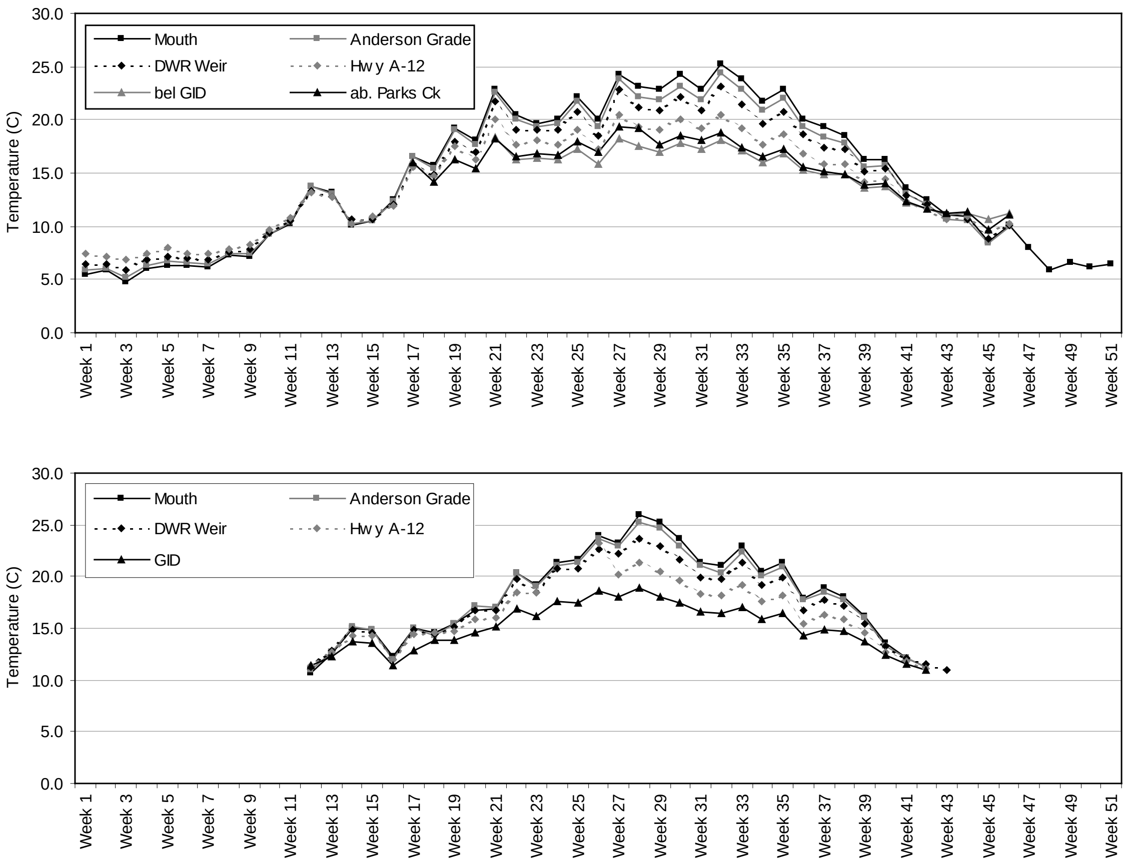

Figure 3. Weekly average temperatures at selected locations in the Shasta River for 2001 and 2002 (Source: Deas et al. 2004a)

4.2 Thermal Refugia Monitoring and Evaluation

Aerial thermal infrared imaging will be conducted using the latest available technology along each reach of the Shasta River and tributaries identified in Table 2. Image collection and data processing methods should be substantially the same as those used in previous surveys of the watershed by Watershed Sciences (2004) as part of the NCRWQCB TMDL process. The NCRWQCB funded a thermal infrared remote radiometry (TIR) survey of the Shasta River and select tributaries. As described in the TMDL report (NCRWQCB 2006), the Shasta River, Little Shasta River, Big Springs and Parks Creek were remote-imaged on July 26-27, 2003. These surveys should be repeated on two successive years under different summer flow and meteorological conditions to validate the results and confirm the conclusions of this report and others that thermal refugia are present and persistent. Results obtained from aerial imaging should be compared to existing and new field measurements of water temperature, including small springs and seeps, to validate the ability of remote sensing to detect such water sources. For example, the Yreka Creek Committee in 2005 “noted over 20 small spring[s], seeps or cold pools in the ~ 1.5 miles between HY 3 north of Yreka, and the Bottlingworks Mall” (SVRCD 2015). A reanalysis of FLIR data by the Department of Water Resources on the effect of diffuse springs on water temperature moderation should also be reviewed (DWR 2008).

Table 2. Reaches of the Shasta River and tributaries where areas of springs, groundwater accretion, and potential thermal refugia are to be identified and mapped.

REACH DESCRIPTION	Reference(s)	Studies Status
Shasta River (4,5,6)	Chesney et al. 2001; SVRCD and M&T 2013	Needed
Big Springs Creek (BS1)	Chesney et al. 2001; SVRCD and M&T 2013	Needed
Little Springs Creek (BS1a)	Chesney et al. 2001; SVRCD and M&T 2013	Needed
Little Shasta River (LS1-3)	Chesney et al. 2001; SVRCD and M&T 2013	Needed
Parks Creek (P1-4)	Chesney et al. 2001; SVRCD and M&T 2013	Needed

Evaluation should consist of mapping colder water pockets within springs, where spring runs join and merge with tributaries or the main stream, and where springs emerge from the stream bed or along stream banks, then relating the existence and areal extent of the pockets to stream flow. With five TIR surveys in three years (one completed and four planned), it should be possible to assess whether and what flows disrupt or disperse the pockets, and whether higher or lower net stream temperatures result. If higher flows increase instead of decrease stream temperatures in specific areas used as thermal refugia by rearing juvenile salmonids, riparian shade management might be preferred over flow enhancement in potential habitat restoration scenarios.

4.3 Water Temperature Data Collection for Modeling

In reaches of the Shasta River identified in Table 3 as needing a water temperature model capable of predicting thermal effects of restoration activities, sufficient physical and meteorological data should be collected for developing and calibrating such a model (or models). For any given reach, most water temperature models require continuous records of inflow, outflow, flow accretion (point or diffuse), starting and ending water temperatures, flow accretion water temperatures, air temperature, relative humidity, wind speed, and percent sun (or solar radiation). The continuous data may be in daily, hourly, or sub-hourly form, depending on the time-step requirements of the model. Model input requirements also include physical data on upstream and downstream topographic elevation, wetted channel widths in relation to streamflow, stream channel aspect by distance (coarse or fine scales), ground temperature, ground reflectivity, thermal gradient, dust coefficients, channel roughness (Manning's n), east and west topographic altitude, and riparian vegetation height, width, density, and offset.

Table 3. Reaches of the Shasta River and tributaries where data suitable for predictive water temperature modeling will be collected.

REACH DESCRIPTION	Reference(s)	Studies Status
Shasta River (1,2,3)	CDFG 1997, 2004; Chesney et al. 2011; DWR 1964; Jeffres et al. 2008; M&T under review; Nichols et al. 2010; Null 2008; Null et al. 2009; SRWCRMPC 1997; SVRCD and M&T 2013; Stenhouse et al. 2012	Partial
Yreka Creek (1,2,3)	CDFG 1997, 2004; Chesney et al. 2011; SVRCD and M&T 2013; Willis and Deas 2011	Partial

Existing data collected under study element 4.1 will need to be evaluated to determine if any reaches of the Shasta River and tributaries have sufficient information to populate a model, and if so, what type of model. Daily time-step models that calculate average, maximum, and minimum water temperatures can use daily average data and approximations of the physical input data, while more sophisticated, shorter time-step models need more detail, since they will be sensitive to short-term variability (afternoon thunderstorms, or diurnal snowmelt change, for example). A single year's data between May 1 and September 30 (the warmest part of the year coinciding with the juvenile salmonid rearing period) is less preferable than two or more years of data, because models are typically calibrated with one season or year and validated against another season or year. If the validation statistics (mean error, maximum error, bias, etc.) approximate the calibration statistics, the model would be suitable for simulation of restoration activities such as flow change and/or riparian vegetation enhancement.

For any reach that does not meet these data requirements, field data collection will be necessary and could be fairly elaborate, depending on the complexity of conditions within the reach. A simple reach with virtually the same rates of inflow and outflow and no diversions or irrigations returns would only require temperature recording devices at the upstream and downstream ends, along with a continuous stream gage recorder. Any significant change from these characteristics will require additional continuous monitoring data on both water temperature and flow volume by location, whether point or diffuse. Irrigation tailwater return areas will in particular require continuous temperature and flow data collection. Two years of comprehensive data suitable for detailed, seasonal water temperature modeling will be required. The feasibility of collecting water temperature data through the use of DTS technology should also be investigated (e.g. Hausner et al. 2011).

The most suitable meteorological station would be an hourly CIMIS station, used throughout California for irrigation management (tracking of evaporation and crop transpiration) based on soil moisture and crop needs. The direct measurements of solar radiation are particularly valuable for hourly water temperature estimates from heat transfer equations (and water depth). The two nearest CIMIS stations (active) are at McArthur in northern Shasta County at elevation 3310 feet, and Tulelake in Siskiyou County at elevation 4,035 feet. Data from these stations, in combination with the hourly weather stations at Callahan (no solar radiation) in Scott Valley and Weed (includes solar radiation) in Shasta Valley will likely be adequate for accurate water temperature modeling, but data quality should be reviewed.

4.4 Water Temperature Model Selection

A water temperature model should be recommended by reach as part of the Shasta River water temperature assessment. There are water temperature modeling packages available, such as SNTEMP (Bartholow 1999) developed by USGS, Heat Source (Boyd and Kasper 2003) currently maintained and used by the Oregon Department of Environmental Quality (http://www.deq.state.or.us/wq/tmdls/heatsource.htm), CE-QUAL-W2 from the Corps of Engineers (Cole and Wells 2006), RQUAL from the Tennessee Valley Authority (Hauser and Walters 1995), QUAL2K or QUALKw from the Environmental Protection Agency (Brown and Barnwell 1987, Chapra et al. 2008), TEMP (ICFI 2014), and W3T (Watercourse Engineering 2013), among others. The pros and cons of each model considered for application to the Shasta River watershed should be clearly described and the recommended model or models justified by accuracy, professional acceptability, data requirements, and the objectives of this study plan.

Determining the relationships between surface flow, groundwater inputs, riparian shade, channel geometry, and downstream water temperatures are the most important results from the water temperature modeling. There are sufficient historical temperatures for identifying tributary reaches that remain relatively cool (higher elevations with shade and higher flows or springs) and those valley reaches that warm to above suitable water temperatures for fish rearing (lower elevations with less shade and lower flows). Increased flows will likely provide more suitable habitat and will moderate the temperature warming in the valley sections of the tributaries. The water temperature model could be applied to determine minimum flows below each major diversion or to assess the effect of riparian vegetation enhancement that would maintain more suitable water temperatures for fish habitat.

5.0 Deliverables

The main products from the *Shasta River Water Temperature Assessment* Study Plan will be:

1) A searchable electronic data base containing all known water temperature data for the Shasta River and tributaries,
2) Four thermal image maps for identified reaches showing the location and persistence of potential thermal refugia, along with evaluation,
3) An inventory of all known or newly-identified springs along with location, temperature, average discharge, and decreed water right.
4) Two complete years of continuous data on water temperature and flow suitable for predictive water temperature modeling, and
5) A recommendation for a water temperature model capable of assessing the potential effect of surface flow and riparian vegetation enhancements.

6.0 Literature Cited

AquaTerra Consulting. 2010. Mt. Shasta springs 2009 summary report. Report prepared by AquaTerra Consulting, SGI Environmental, and UC Davis for California Trout. Draft dated January 1, 2010. 33 pp.

Bartholow, J.M. 1999. SSTEMP Version 1.1.0: As retrieved from USGS, Midcontinent Ecological Science Center website: .http://www.mesc.usgs.gov/ rsm/rsm_software.html

Boyd, M.S. 1996. Heat Source: stream temperature prediction: Master's Thesis, Departments of Civil and Bioresource Engineering, Oregon State University, Corvallis, Oregon.

Boyd, M., and Kasper, B. 2003. Analytical methods for dynamic open channel heat and mass transfer: Methodology for heat source model Version 7.0, 193 p.

Brown, L.C., and Barnwell, T.O. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS, EPA/600/3-87-007, U.S. Environmental Protection Agency, Athens, GA, 189 pp.

California Conservation Commission. 1913. Report of the Conservation Commission of the State of California. Transmitted to the Governor and the Legislature January 1, 1913, Sacramento, California, printed 1912. 502 pp + plates and accompanying map.

California Department of Fish and Game (CDFG). 1997 A Biological Needs Assessment for anadromous Fish in the Shasta River Siskyou County, California. California Department of Fish and Game, Northern California North Coast Region (Region 1), Northern Management Area (Area 2). Redding, CA.

California Department of Fish and Game (CDFG). 2003. Shasta and Scott River Pilot for Coho Salmon Recovery: with recommendations relating to Agriculture and Agricultural Water Use. Prepared by The Shasta-Scott Coho Recovery Team. 125 pp.

California Department of Fish and Game (CDFG). 2004. Recovery Strategy for California Coho Salmon. Report to the California Fish and Game Commission, Species Recovery Strategy 2004-1. California Department of Fish and Game, Native Anadromous Fish and Watershed Branch. Sacramento, CA.

California Department of Public Works, Division of Water Rights (CDPW). 1925. Shasta River Adjudication Proceedings: Report on Water Supply and Use of Water from Shasta River and Tributaries, Siskiyou County, California : Submitted as Evidence July 1, 1925. 368 pp.

California Division of Water Resources. 1945. Report on Water Master Service in Shasta River Watermaster Service Area, Siskiyou County, California: 1945 Season.

California Department of Water Resources (DWR). 1964. Bulletin No. 87. Shasta Valley Investigation.

California Department of Water Resources (DWR). 2008. Shasta Valley, Siskiyou County Groundwater Data Needs Assessment (Draft). California Department of Water Resources, Red Bluff, California.

Carter, K. 2005. The effects of temperature on steelhead trout, coho salmon, and Chinook salmon biology and function by life stage: implications for Klamath basin TMDLs:NCRWQCB, August, 2005.

Chapra, S.C., Pelletier, G.J. and Tao, H. 2008. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.11: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA

Chesney, W R., C.C. Adams, W.B. Crombie, H.D. Langendorf, S.A. Stenhouse and K.M. Kirkby. 2011. Shasta River Juvenile Coho Habitat & Migration Study. CDFG report prepared for BOR. 76 pp. + appendices.

Cole, T.M., and S.A. Wells. 2006. CE-QUAL-W2: A two-dimensional, laterally averaged, Hydrodynamic and Water Quality Model, Version 3.5, Instruction Report EL-06-1, US Army Engineering and Research Development Center, Vicksburg, MS.

Davids Engineering. 2011. Shasta Springs Ranch Irrigation Efficiency Study. Prepared by Davids Engineering, Inc., Davis, California, for the California Department of Fish and Game.

Deas, M., A. Abbott, and A. Bale. 2003. Shasta River Flow and Temperature Modeling Project. Watercourse Engineering, Inc. 119 pp. +appendix.

Deas, M.L., P.B. Moyle, J. Mount, J.R. Lund, C.L. Lowney, and S. Tanaka. 2004a. Priority Actions for Restoration of the Shasta River Technical Report. Watercourse Engineering, Inc and University of California Davis. Prepared for The Nature Conservancy. Dated June 11, 2004.

Deas, M. and L. Geisler. 2004b. Memorandum: Shasta River flow and temperature modeling implementation, testing, and calibration. Watercourse Engineering, Inc and University of California Davis. September 13, 2004. 22pp.

Flint, L.E., A.L. Flint, D.S. Curry, S.A. Rounds, and M.C. Doyle. 2005. Water-Quality Data from 2002 to 2003 and Analysis of Data Gaps for Development of Total Maximum Daily Loads in the Lower Klamath River Basin, California. U.S. Geological Survey Scientific Investigations Report 2004-5255. 77pp.

Geisler, L. and Watercourse Engineering, Inc. 2005. Shasta River Flow, Temperature, and Dissolved Oxygen Model Calibration Technical Report. Prepared for the Information Center for the Environment, University of California Davis Department of Environmental Science and Policy, and North Coast Regional Water Quality Control Board. 57pp.

Hauser, G.E. and Walters, M. 1995. User's Manual for One- Dimensional Unsteady Flow and Water Quality Modeling in River Systems with Dynamic Tributaries. WR28-3-590-135. TVA Engineering Laboratory. Norris, Tennessee. July.

Hausner, M.B., F. Suárez, K.E. Glander, N. van de Giesen, J.S. Selker, and S.W. Tyler. 2011. Calibrating Single-Ended Fiber-Optic Raman Spectra Distributed Temperature Sensing Data. Sensors 2011(11)10859-10879; doi:10.3390/s111110859.

ICF International. 2014. TEMP (Temperature Evaluation for Management and Protection): Development and assumptions for the Battle Creek daily hydrology and hourly water temperature model. ICF International, Sacramento, California.

Jeffres, C., E. Buckland, J. Kiernan, A. King, A. Nichols, S. Null, J. Mount, P. Moyle, and M. Deas. 2008. Baseline assessment of salmonid habitat and aquatic ecology of the Nelson Ranch, Shasta River, California, Water Year 2007. Prepared for the United States Bureau of Reclamation, Klamath Area Office.

Jeffres C.A., R.A. Dahlgren. M.L. Deas, J.D. Kiernan, A.M. King, R.A. Lusardi, J.M. Mount, P.B. Moyle, A.L. Nichols, S.E. Null, A.D. Tanaka, and A.D. Willis. 2009. Baseline Assessment of Physical and Biological Conditions Within Waterways on Big Springs Ranch, Siskiyou County, California. Prepared for California State Water Resources Control Board by U.C. Davis Center for Watershed Sciences and Watercourse Engineering, Inc. Available online (http://watershed.ucdavis.edu/pdf/Jeffres-et-al-SWRCB-2009.pdf).

Klamath Resource Information System (KRIS). 2005. KRIS Background, Geology and River Overviews: Shasta River, Shasta River Basin Geology, and Shasta River Hydrology. Available online at: http://www.krisweb.com.

McCullough, D.A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon: prepared for the U.S. Environmental Protection Agency, Region 10, Seattle, Wash., EPA 910-R-99-010, 279 p. Available online at: http://www.critfc.org/tech/EPAreport.htm

Nathenson, M., J.M. Thompson, and L.D. White. 2002. Slightly thermal springs and non-thermal springs at Mt. Shasta, California: chemistry and recharge elevations. Journal of Volcanology and Geothermal Research 2545 (2002) 1-17.

National Marine Fisheries Service (NMFS). 2012. Recovery Plan for the Southern Oregon Northern California Coast Evolutionary Significant Unit of Coho Salmon (Oncorhynchus kisutch). Volume II, Chapter 36, Scott River Population.

National Research Council. 2004. Endangered and Threatened Fishes in the Klamath River Basin. Available online at: http://www.krisweb.com/biblio/klamath_nsa_nrc_2003.pdf

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

Nichols, A. L., A.D. Willis, C.A. Jeffres, and M.L. Deas. 2013. Water temperature patterns below large groundwater springs: management implications for Coho salmon in the Shasta River, California. River Research and Applications. doi: 10.1002/rra.2655

Normandeau Associates, Inc. 2013. Scott River and Shasta River study reaches. 1 October 2013 final report submitted to California Department of Fish and Wildlife, Yreka, CA. 30 pp.

North Coast Regional Water Quality Control Board. 2006. Action Plan for the Shasta River Temperature and Dissolved Oxygen Total Maximum Daily Loads, June 2006. http://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/shasta_river/staff_report.shtml.

North Coast Regional Water Quality Control Board and Shasta Valley Resource Conservation District (NCRWQCB and SVRCD). 2014. Shasta River Stewardship Report. Draft under review by collaborating partners.

Null, S.E. 2008. Improving Managed Environmental Water Use Efficiency: Shasta River Flow and Temperature Modeling. U.C. Davis Ph.D. Dissertation. Geography Graduate Group. (Published in California Department of Water Resources' California Water Plan Update 2009, Vol. 4 – Environment Section 5. Available online: www.waterplan.water.ca.gov/docs/cwpu2009/0310final/v4c10a05_cwp2009.pdf)

Null, S.E., M.L. Deas, and J. R. Lund. 2009. Flow and water temperature simulation for habitat restoration in the Shasta River, California. River Research & Applications 26(6):663-681.

Paulsen, W.W. 1963. Geologic investigation for [Dwinell] reservoir leakage and groundwater development. Montague Irrigation District, Montague, California. 35 pp + figs.

Shasta River Watershed Coordinated Resource Management Planning Council (SRWCRMPC). 1997. Shasta Watershed Restoration Plan.

Shasta Valley Resource Conservation District and McBain and Trush, Inc (SVRCD and M&T). 2013. Study Plan to Assess Shasta River Salmon and Steelhead Recovery Needs. Prepared for USFWS, Arcata, CA. 151 pp.

Shasta Valley Resource Conservation District (SVRCD). 2015. Comment letter on the draft Shasta River Water Temperature Assessment Draft Study Plan, by Dave Webb, dated May 27, 2015.

Stenhouse, S.A., C.E. Bean, W.R. Chesney, and M.S. Pisano. 2012. Water temperature thresholds for coho salmon in a spring-fed river, Siskiyou County, California. California Fish and Game 98:19-37.

Sullivan, Kathleen, Martin, D.J., Cardwell, R.D., Toll, J.E., and Duke, Stephen. 2000. An analysis of the effects of temperature on salmonids of the Pacific Northwest with implications for selecting temperature criteria: Sustainable Ecosystems Institute, Portland, OR. 147 p. Available online at: http://www.sei.org/pub.html#reports

Theurer, F.D., K.A. Voos, and W.J. Miller. 1984. Instream water temperature model. Instream flow information paper 16. United States Fish and Wildlife Service. Washington D.C. 316 pp.

Torgersen, C.E., D.M. Price, H.W. Li, and B.A. McIntosh. 1999. Multiscale thermal refugia and stream habitat associations of Chinook salmon in northeastern Oregon. Ecological Applications 9:301–319.

U.C. Davis. 2015. Little Shasta River Monitoring Plan 2015. Report prepared by UC Davis Center for Watershed Sciences and Watercourse Engineering, Inc., Davis, CA, for the Nature Conservancy, dated March 2015. 4 pp.

Vignola, E. and M. Deas. 2005. Lake Shastina Limnology. Watercourse Engineering, Inc. Prepared for the Information Center for the Environment; Department of Environmental Science and Policy; University of California, Davis and North Coast Regional Water Quality Control Board. April 2005. 73pp.

Watercourse Engineering, Inc. 2004. Shasta River Field Monitoring Report 2001-2002. Napa, CA. 44 pp + appendices.

Watercourse Engineering, Inc. 2013. Water Temperature Transaction Tool (W3T): Technical and User's Guide (V1.0). A report for National Fish and Wildlife Foundation (NFWF) prepared by Watercourse Engineering, Inc., Davis, CA. Dated September 2013. 19 pp.

Watershed Sciences. 2004. Aerial surveys using thermal infrared and color videography: Scott River and Shasta River sub-basins. 26 February 2004 final report to the California North Coast Regional Water Quality Control Board and University of California at Davis Department of Environmental Science and Policy. 59 pp.

Wharton, R.A., and W.C. Vinyard. 1979. Summit thermal springs, Mt. Shasta, California. California Geology, Vol. 32. No. 2. pp. 38-41, February 1979.

Willis, A.D., Nichols, A.L., Jeffres, C.A., Deas, M.L., 2013. Water Resources Management Planning: Conceptual Framework and Case Study of the Shasta Basin. Report prepared for: National Fish and Wildlife Foundation. 61 pp.

Willis, A. and M. Deas. 2011. Technical Memorandum regarding preliminary investigation of macrophyte shade in Big Springs Creek. For TNC, September 6, 2011.