Little Shasta River
Hydrologic and Water Temperature Assessment: April to December 2015

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Introduction

The Shasta River of northern California provides critical spawning and rearing habitat for anadromous salmonids residing in the larger Klamath River Basin, including Chinook salmon (*Oncorhynchus tshawytscha*) and the federally threatened coho salmon (*Oncorhynchus kisutch*). Historical accounts (Wales 1951, NRC 2004) suggest cool, groundwater-derived river flows throughout the Shasta River Basin created nearly ideal habitat conditions for all stages of the salmonid life cycle. Modern data suggest stable spring flows rich in geologically-derived nutrients (Dahlgren et al. 2010) support robust food webs (Jeffres et al. 2009) and nearly ideal rearing conditions for juvenile salmonids.

Restoration of spring-fed tributaries to the Shasta River has become a prominent conservation objective. Near constant spring water temperatures provide ideal thermal habitat conditions for juvenile salmonids. Consequently, restoration and conservation activities have focused on actions needed to extend the downstream distance of the suitable thermal habitat provided by observed spring flows. As a result of regional geologic conditions, many of the large springs (> 5 ft^3/s) in the Shasta River Valley are located along the eastern edge of the valley. Prominent among these are the “Big Springs” and “Shastina Springs” complexes (Figure 1), where juvenile salmonids are known to congregate during the spring and summer periods (Chesney et al. 2009, Nichols et al. 2014). Numerous ecosystem assessment activities (e.g. Jeffres et al. 2009) have identified these two spring complexes as hydrologic features critical to the success of salmonids in the Shasta River Basin. Conservation actions have focused on understanding and managing these springs and downstream waterways.

The “Big Springs” and “Shastina Springs” complexes are located along the upper reaches of the Shasta River accessible to anadromous fish. Conservation actions in the vicinity of these spring complexes have greatly improved aquatic habitat conditions (e.g. Willis and Deas 2012, Willis et al. 2012) for salmonids. The only other large spring complex in the Shasta River Valley is located along the Little Shasta River (Figure 1). Uniquely, these springs are located more than 20 kilometers from the confluence between the Little Shasta and Shasta Rivers. Historical accounts identify spring flow to the Little Shasta River in excess of 20 ft^3/s (Adams et al. 1912). However, little is known about the character of these spring flows, or how they interact with seasonal rainfall and snowmelt-derived streamflows originating in the headwaters of the Little Shasta River (McBain & Trush 2013). The Little Shasta River is one of the few remaining tributaries with spring sources that may be valuable in the broader management strategy to restore cold water ecosystem function. Further, the Little Shasta River is located in the lower Shasta River Basin, where no alternative sources of cold water have been identified. However, prior to this study, limited data was available to assess the potential role this tributary might play in the portfolio of salmonid habitats throughout the Shasta River Basin.

This report provides a preliminary assessment of hydrologic and water temperature conditions along the lowest 20 kilometers of the Little Shasta River. First, the report summarizes publicly available hydrologic data for the Little Shasta River. Second, the report presents the first longitudinal assessment of streamflow and water temperature conditions in the Little Shasta River from data collected between April and December 2015. These data provide a foundation for assessing the feasibility of using targeted conservation and restoration actions to provide suitable spawning and rearing habitat for salmonids in the Little Shasta River.

Study Area

The Little Shasta River originates along the western flank of the Cascade Volcanic Range in Siskiyou County, California (Figure 1). The drainage area of the Little Shasta River watershed is approximately 330 km^2, with topographic elevations ranging from 2,523 m on Goosenest Mountain to 832 m at the confluence with the Shasta River. The Little Shasta River flows generally westward for approximately 39 kilometers, eventually reaching the Shasta River at river kilometer (RK) 26.3. The river exhibits three distinct channel reaches, easily distinguished by topographic slope. Generally, the steep headwater reach (~RK 39 to 30) transitions into a moderate gradient reach (~RK 30 to 20) in the foothills of the Cascades. The longest channel reach (RK 20 to 0) extends across the low-gradient Little Shasta River Valley (Figure 1).

Streamflow in the Little Shasta River is derived from both surface runoff (snowmelt and rainfall) and groundwater. While numerous groundwater springs and seeps contribute baseflow to the Little Shasta River and its tributaries, several prominent springs (e.g. Cleland Springs; also known as “Cold Spring”) are found near Table Rock (see Figure 1) at the eastern edge of the Shasta River Valley. These springs are generally oriented along geologic contacts between the porous volcanic rocks of the Western and High Cascades, as well as at the toes of recent lava flows that overlie less permeable Quaternary alluvium throughout the Little Shasta River Valley (Mack 1960). Surface runoff derived from seasonal rainfall and snowmelt augments spring-fed baseflows in the Little Shasta River.

Surface water (including spring flow) and groundwater are used to support domestic, agricultural, municipal and ecosystem water uses in the Little Shasta River Valley throughout the year. Consistent with other parts of the larger Shasta River Valley, the low gradient land areas adjacent to the Little Shasta River broadly support agricultural and ranching activities (NCRWQCB 2006). As of 2001, approximately 7,979 acres of land in the Little Shasta River Valley were irrigated with surface water sources (CADWR 2008). The Shasta Valley Wildlife Area occupies approximately 4,700 acres of riparian forests, seasonal wetlands and crop lands in the western portions of the Little Shasta River Valley. Most of the mountainous headwater areas of the Little Shasta River (generally above RK 30; see Figure 1) are located within the Klamath National Forest.

The Little Shasta River is generally assumed to support runs of anadromous salmonids (NCRWQCB 2006, McBain & Trush 2013). While the extent of salmonid anadromy in the Little Shasta River is not well known, natural passage barriers for juvenile and adult salmonids exist in the higher gradient foothill reaches of the Little Shasta River above RK 25 (see Figure 1). It is generally thought that Dry Creek/Gulch Falls near RK 26 may be the first impassable natural upstream barrier (McBain & Trush 2013).

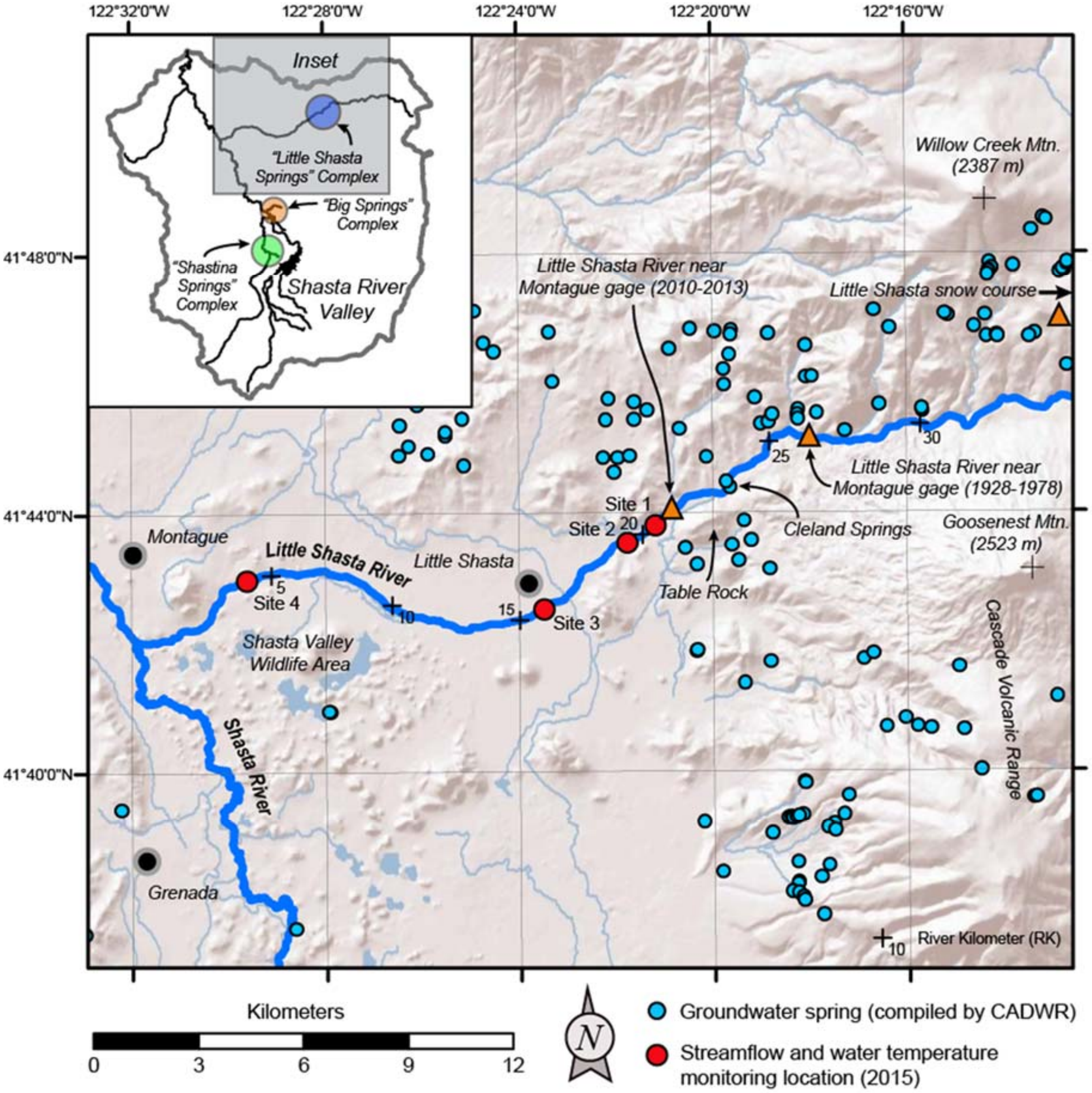


Figure 1. Little Shasta River watershed map. The Little Shasta River flows approximately 39 kilometers westward, joining the Shasta River at river kilometer (RK) 26.3. Streamflow and water temperature sampling sites are identified with red circles. Stream gaging sites previously maintained by the Watermaster/USGS (1928-1978) and DWR (2010-2013) are identified by orange triangles.

Little Shasta River Valley Water Resources Development

Water resources development in the Little Shasta River Valley has been ongoing for over 160 years, with the oldest water rights pertaining to the appropriation of surface waters from the Little Shasta River and nearby springs in March 1855 (CDPW 1932). The amount and priority date of each surface water right is formalized in the Shasta River Adjudication Proceeding Judgement and Decree (CDPW 1932), and a Watermaster organizes the diversion priorities. Figure 2 identifies surface water diversion locations, numerical designations and right priorities throughout the Little Shasta River Basin. Summer water rights to the Little Shasta River and its tributaries and springs extend from March 1 through October 31, while winter rights occur during the remaining months of the year (WMSA 2007).

The highest priority summer water rights in the Little Shasta River Basin are all located upstream from river kilometer 18.5 (see Figures 1 and 2). These water rights permit the diversion of surface water from both off-channel springs (e.g. Cleland/Cold Springs) and the Little Shasta River. During periods of low streamflow (e.g. summer), the cumulative total of these highest priority water rights can exceed the amount of available surface water. With minimal surface or groundwater inflows to the Little Shasta River below RK 18.5, the lower reaches of the river can run dry during low streamflow periods.

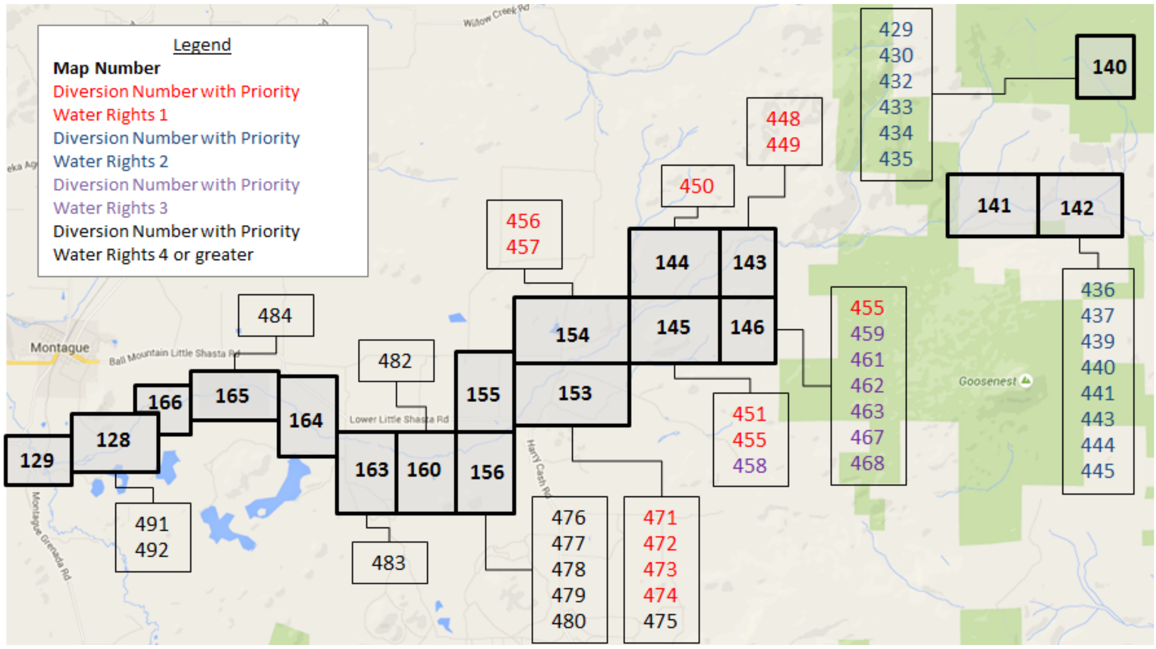


Figure 2. Little Shasta diversion locations by DWR map number (bold box). First, second, third, and fourth (and higher) priority water rights that occur within the DWR map units are shown by DWR diversion number (color coded by priority). (Original map divisions and numberings from http://www.californiaresourcecenter.org)

Historical Hydrologic Data

Available hydrologic data pertaining to the Little Shasta River Basin was reviewed to help understand temporal variation in hydrologic conditions prior to 2015. Historical streamflow data were found within Shasta River Watermaster reports, and archived with the United States Geological Survey (USGS) and California Department of Water Resources (DWR). Historical flow data are available for measurement points at three principal geographic locations in the Little Shasta River Basin: Cleland Springs (also known as “Cold Spring”) and two different gaging locations, both identified as the “Little Shasta River near Montague” (Figure 1). The Cleland Springs gage data captures streamflow emanating from the largest spring in the Little Shasta River Valley. It is unknown whether any spring-flow from Cleland Springs enters the Little Shasta River. The Little Shasta River near Montague gage operated by both the Watermaster (1928-1978) and the USGS (1957-1978) at RK 26 presents streamflow in the Little Shasta River upstream from Cleland Springs. The Little Shasta River near Montague gage operated by DWR at RK 22 from 2010 to 2013 presents streamflow in the Little Shasta River downstream from Cleland Springs.

Spring flow magnitudes at selected springs in the Little Shasta River Valley (Figure 3) are also presented in available historical documents. For example, a report on irrigation resources in California (Adams et al. 1912) identify Bassey Branch Spring and Martin Spring as each having a constant flow rate of approximately 3.5 ft^3/s, and Cleland Springs flowing at a rate of 13 ft^3/s. Existing Watermaster records (WMSA 2007) identify summer diversions from the following springs in the vicinity of Table Rock (Figure 1 and 3): Cleland Springs (10.12 ft^3/s); Martin Spring (2.63 ft^3/s); Bassey Spring (3.59 ft^3/s); Jims Spring (0.73 ft^3/s); Evans Spring (2.36 ft^3/s); and Kegg Spring (0.50 ft^3/s). Recognizing that spring discharge likely exhibits some annual variation, existing water rights suggest the combined spring flow from these large springs in the vicinity of Table Rock is approximately 20 ft^3/s. Much of this spring water appears diverted into irrigation canals. It is unknown how much of this spring flow enters the Little Shasta River during either the summer or winter periods.

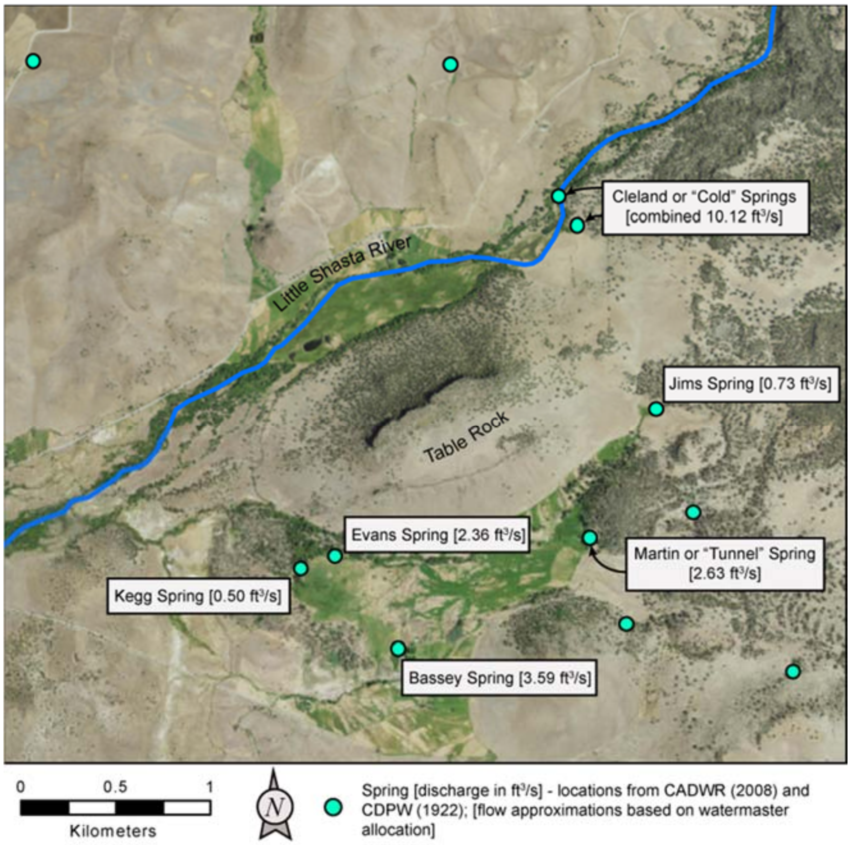


Figure 3. Spring locations mapped in the vicinity of Table Rock. Locations are derived from CADWR (2008) and CDPW (1922). Spring discharge magnitudes are derived from the summation of diversion rights specified by the Watermaster.

Little Shasta River near Montague (1928-1978)

Flow records from the Little Shasta River near Montague gage were recorded in annual Watermaster reports published by DWR between 1924 and 1978. Continuous daily flow records were also reported by the United States Geological Survey (USGS) at the same gaging site (USGS ID 11516900) between 1957 and 1978. These Watermaster and USGS data identify historical streamflows in the Little Shasta River above all large groundwater springs in Little Shasta River Valley, including Cleland Springs. As such, the streamflow records represent streamflows sourced from small springs in the Little Shasta River headwaters (see Figure 1), as well as seasonal runoff from rainfall and snowmelt.

Monthly Watermaster data for the Little Shasta River near Montague gage are plotted in Figures 4 and 6. During most years, streamflow data are only reported by the Watermaster for the March through October irrigation season. However, more detailed flow records were collected in the mid-1950s as part of separate water resource investigations conducted by the California Department of Water Resources (CADWR 1964, 1965). These DWR studies led to year-round daily records for the Little Shasta River near Montague flow gaging station from 1953-55 and extended records in 1957 and 1958. Daily discharge for the entire period of USGS monitoring (1957-1978) is presented in Figure 5, while mean monthly discharge for the period of record is presented in Figure 6.

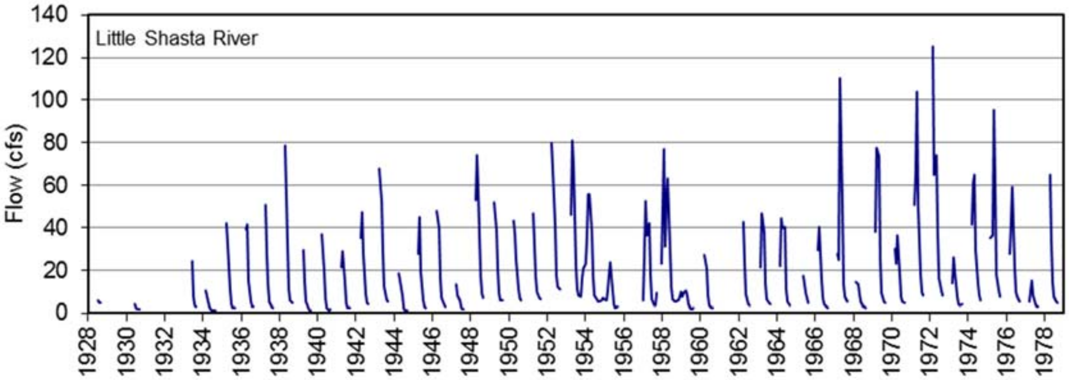


Figure 4. Time series of monthly flow data reported by the Watermaster for the Little Shasta River near Montague gaging station (1928 to 1978) (Deas et al. 2004)

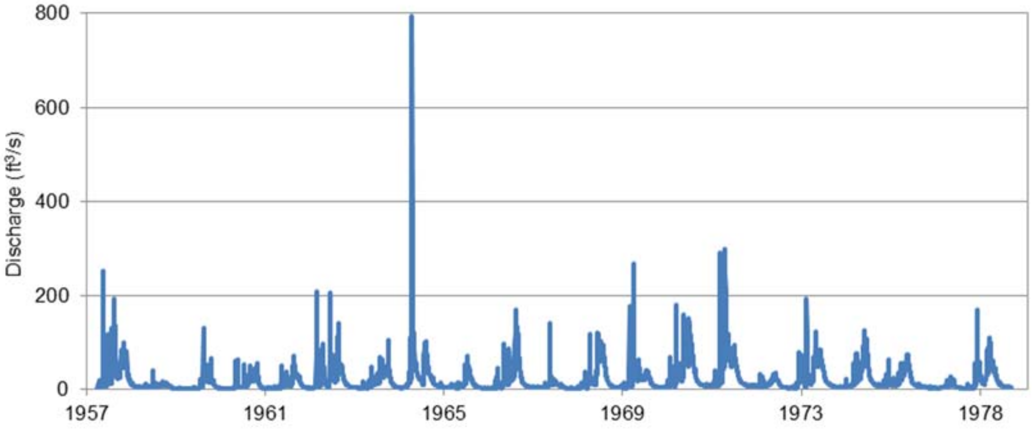


Figure 5. Daily discharge data measured by the USGS at the Little Shasta River near Montague gaging station (USGS site 11516900) between 1957 and 1978.

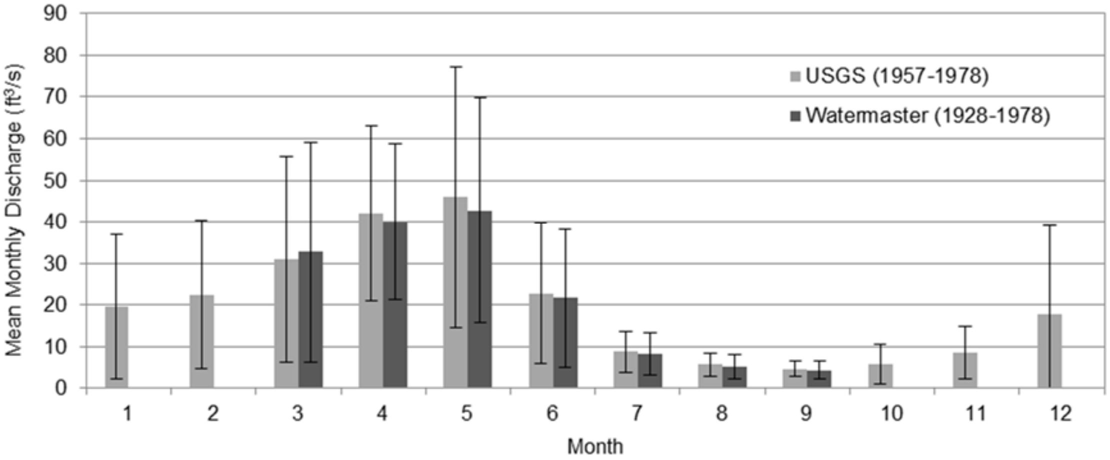


Figure 6. Mean monthly discharge (ft^3/s) measured by the USGS and Watermaster at the Little Shasta River near Montague stream gage (USGS site 11516900) between 1928 and 1978. Error bars represent ±1 SD.

Watermaster and USGS flow data identify distinct seasonal trends in streamflow in the Little Shasta River above the first (and highest) priority diversion points (see Figure 2) from the Little Shasta River and large spring locations that comprise the “Little Shasta Springs” complex. Small, second priority diversion points on Klamath National Forest lands are located upstream from the gage location (Figure 2). Peak daily streamflows (max = 794 ft^3/s on December 22, 1964) (Figure 5) occur in response to winter and spring rain events, while monthly average streamflows generally peak mid-spring of each year (mean = 46 ft^3/s) (Figures 4 and 6). Elevated springtime streamflows likely coincide with the timing of peak snowmelt in the mountainous headwaters of the Little Shasta River. Flows rapidly diminish during the late spring and early summer. Given the gaging location was upstream from all high priority stream diversions, the observed seasonal decrease in streamflows was likely in response to decreasing snowmelt-derived surface water runoff. Streamflows at the gaging site reach seasonal minimums (< 5 ft^3/s) in late summer.

A comparison of Little Shasta River flow records (Figures 5 and 6) and total appropriated water rights to the Little Shasta River (~70 ft^3/s) indicates the river may often be over appropriated. If water used by a water right holder were left instream (undiverted) as part of a flow transaction, there are other downstream water right holders who may divert that water from the Little Shasta River. Thus, instream dedications, or similar measures, would be required to maintain such water instream in downstream reaches of the Little Shasta River or Shasta River.

Cleland Springs (1928-1958)

Watermaster records also record monthly irrigation season streamflows discharging from Cleland Springs (Figure 1) during the period from 1928 to 1958 (Figure 7). Consistent with historical accounts (Adams et al. 1912), flow volumes discharging from Cleland Springs range from 6 to 14 ft^3/s, with an annual irrigation season average of 9.3 ft^3/s (Figure 8). It is unknown whether spring flow from Cleland Springs connects to the Little Shasta River at any period during a given water year.

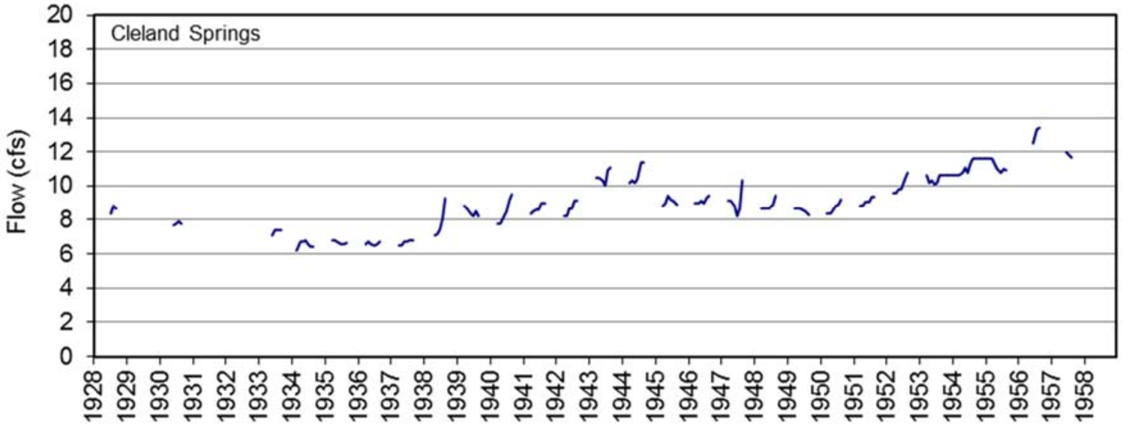


Figure 7. Hydrograph of monthly flow data from Cleland Springs (1928 to 1958) (Deas et al. 2004).

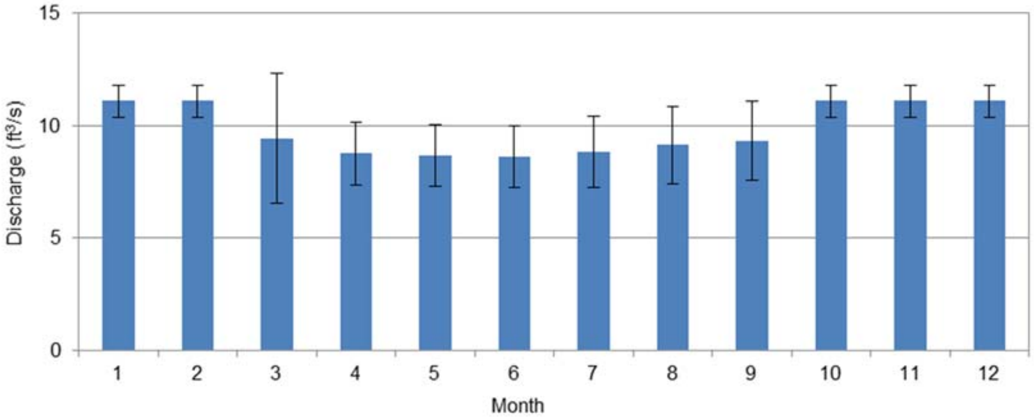


Figure 8. Mean monthly discharge measured at Cleland Springs (1928 to 1958).

Little Shasta River near Montague (2010-2013)

DWR operated a stream gage in the Little Shasta River between 2010 and 2013. Similar to the Little Shasta River gage historically maintained by the Watermaster and USGS, the gaging site is also named “Little Shasta River near Montague.” However, the gaging site is located approximately 5 kilometers downstream from the historic gaging location (see Figure 1). This DWR gage is located downstream from Cleland Springs.

Using publicly available, continuous river stage data (http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=LSR) and periodic discharge measurement data provided by DWR (personal communication, Mr. Joe Scott), a quantitative rating curve was created for the gaging location using standard rating methodologies (Rantz 1982a). Measured discharge (i.e. field measurements) used to rate the gage ranged from 12 to 162 ft^3/s. Calculated streamflows above and below these measured discharge magnitudes should be considered approximate. Similar to historical observations at the Little Shasta near Montague gaging station maintained by the Watermaster and USGS, peak streamflow during the period of record occurred following winter and spring precipitation events. Spring and early summer streamflows exhibited a springtime recession consistent with observations from many northern California streams receiving water from high-elevation snowmelt (Figure 9).

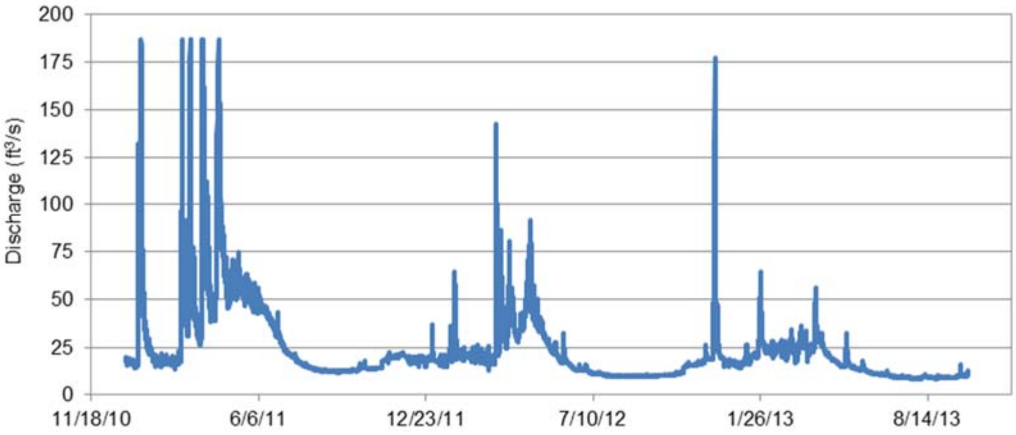


Figure 9. Continuous discharge data (15-minute intervals) measured by DWR at the Little Shasta River near Montague gaging station between 2010 and 2013. Available discharge measurements did not allow rating curve extrapolation beyond ~ 185 ft^3/s.

Irrigation season streamflow magnitudes at the Little Shasta River near Montague gage appear largely reliant on available snowpack in the Little Shasta River headwaters. Snow depth and snow-water equivalent data from the Little Shasta Snow Course (Figures 1, 6; Table 2) can help identify basic hydrologic year types ("wet", "normal", "dry"; year-typing methodology is discussed in more detail later in this report). Accordingly, hydrologic year types in 2011 ("wet") and 2013 ("dry") can be used to show the dependence of Little Shasta River streamflow on seasonal snowmelt. Mean monthly streamflow data presented in Table 1 illustrates that during a "wet" year (2011), between 200 to 300% more water was available for diversion from the Little Shasta River during the spring period (March through June) compared to a "dry" year (2013).

Table 1. Mean monthly discharge measured at the Little Shasta River at Montague gaging station in 2011 (wet year) and 2013 (dry year). Only months during the March through October irrigation season are presented.

Month	2011 ("wet")	2013 ("dry")
Mar	61	26
Apr	87	24
May	54	15
Jun	42	11
Jul	21	9
Aug	13	9
Sep	13	10
Oct	14	N/A

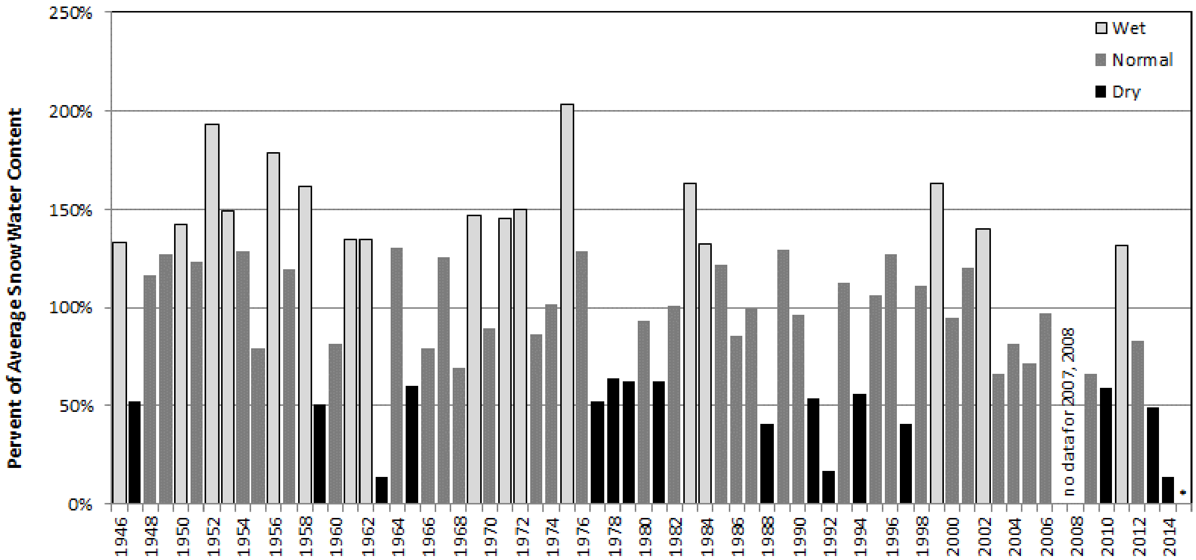
Little Shasta Snow Course (1946-present)

The Little Shasta snow course has been operated continuously from 1946 to present. Snow surveys are completed approximately monthly from first snow through April 1st; however, the period of monitoring may vary based on hydrologic year type (in some years, only April 1st information is provided). April 1st snow water content ranged from zero in 2015 to 36.7 inches in 1975 (Figure 10). Other basic statistics of the record are include in Table 2. This long record helps to identify the year-to-year hydrologic variability in the Little Shasta River Basin. The annual April 1st snow water content and long-term average April 1st snow water content was used in concert with 25th and 75th percentile statistics to develop a basic hydrologic year-type: April 1st snow water content less than 25th percentile was defined as "dry," between the 25th and 75th percentile was "normal," and above the 75th percentile was "wet." This initial breakdown of water year-types, or a more sophisticated approach, may be useful in future flow management assessment to identify periods of dry or wet years.

Table 2. April 1st snow water content, percent of average, for LSH 1946-2015.

Statistic	**April 1st Snow Water Content** (Inches)	**Snow Water Content (Percent of Average)*** (%)	**Year**
Minimum	0	0%	2015
Maximum	36.7	203%	1975
Average	18.08	100%	n/a
Mean (50%)	18.15	100%	1982, 1987
Lower Quartile (25%)	11.88	66%	n/a
Upper Quartile (75%)	23.55	130%	n/a

* Period of Record 1946-2015, excluding 2007, 2008 when no data were available



* zero snow water content for 2015

Figure 10. April 1st snow water content, percent of average, for LSH 1946 – 2015.

Little Shasta River field investigations: April through December 2015

Four streamflow and water temperature monitoring locations were established along the lower 20 kilometers of the Little Shasta River in 2015 (Sites 1 to 4; Figure 11; Table 3). Monitoring sites extended downstream from the lowest portions of the "foothill" reach of the Little Shasta River (Sites 1 and 2), through the low-gradient "valley" reach (Sites 3 and 4) of the river. All four monitoring locations were located downstream from Cleland Springs (~ RK 23). and both "Little Shasta River near Montague" historic stream gages (USGS/Watermaster = RK 26; DWR = RK 21).

At each monitoring location, a pressure transducer was placed in a vertical stilling well to record water temperature and river stage (m) at 15-minute sampling intervals between April 3 and December 15, 2015. Solinst Levelogger Junior pressure transducers were used between April 3 and November 5, 2015, while Hobo Water Level Loggers (U-20L-04) were used between November 5 and December 15, 2015. Solinst Levelogger Junior have an accuracy of 0.3 cm over a depth range of 0-5 m; HOBO Water Level Loggers have an accuracy of 0.8 cm over a depth range of 0-4 m.

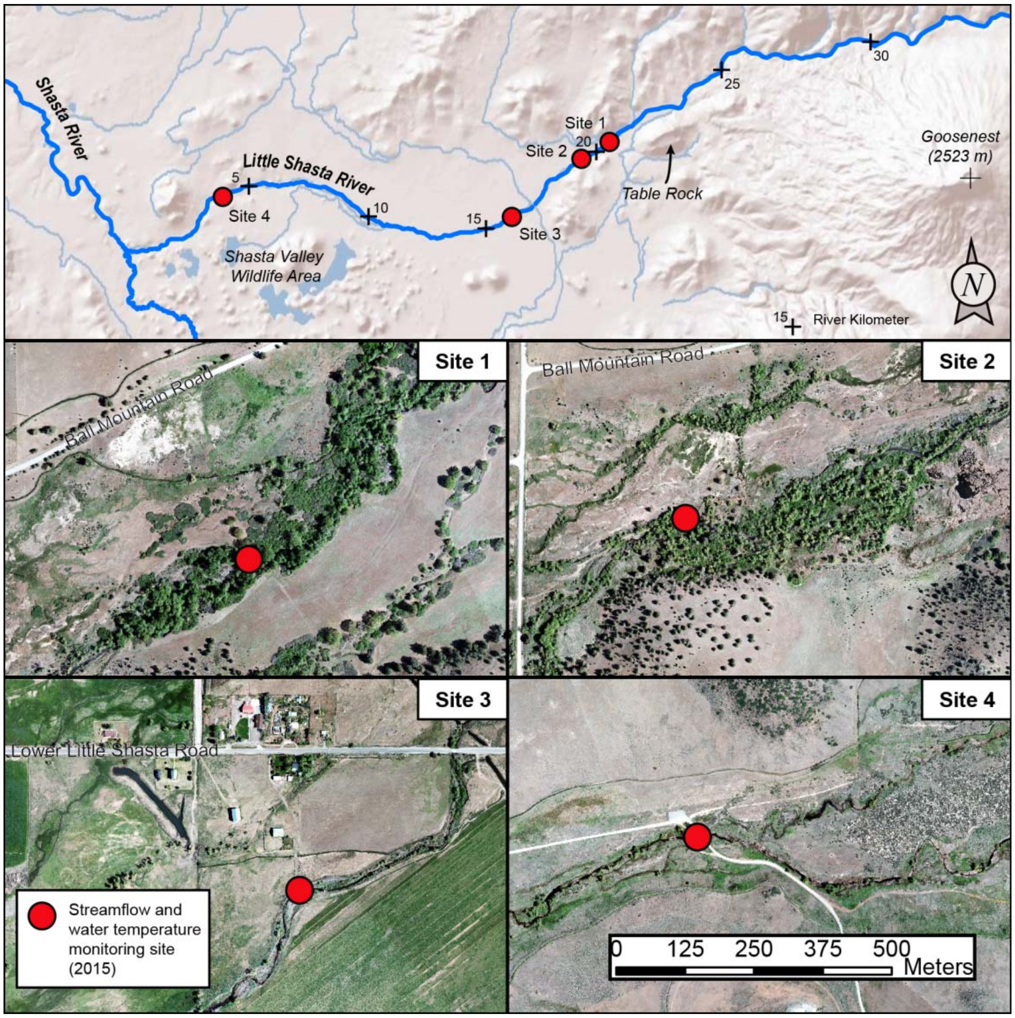


Figure 11. Little Shasta River streamflow and water temperature monitoring locations.

Table 3. Geographic location of Little Shasta River streamflow and water temperature monitoring locations in 2015.

Stream Gage Site	Latitude	Longitude	River Kilometer (RK)
1	41.7285	-122.3560	20.1
2	41.7255	-122.3661	19.1
3	41.7092	-122.3871	16.2
4	41.7162	-122.4951	4.3

Streamflow (2015)

Periodic discharge measurements were performed across the range of observed streamflows at each monitoring site (see Figure 12) following standard measurement and computational methods (Rantz 1982a, b). River stage-discharge relationships (Figure 11) were quantified using standard rating methodologies (Rantz 1982a), from which continuous streamflow time-series were generated (Figure 13). Measured river stages greater than those observed during periodic discharge measurements (and corresponding discharges) were excluded from the streamflow time series. Trendline fitting for data from Sites 2 and 3 resulted in computed discharges slightly in excess of measured discharges at the time of the peak flow measurement.

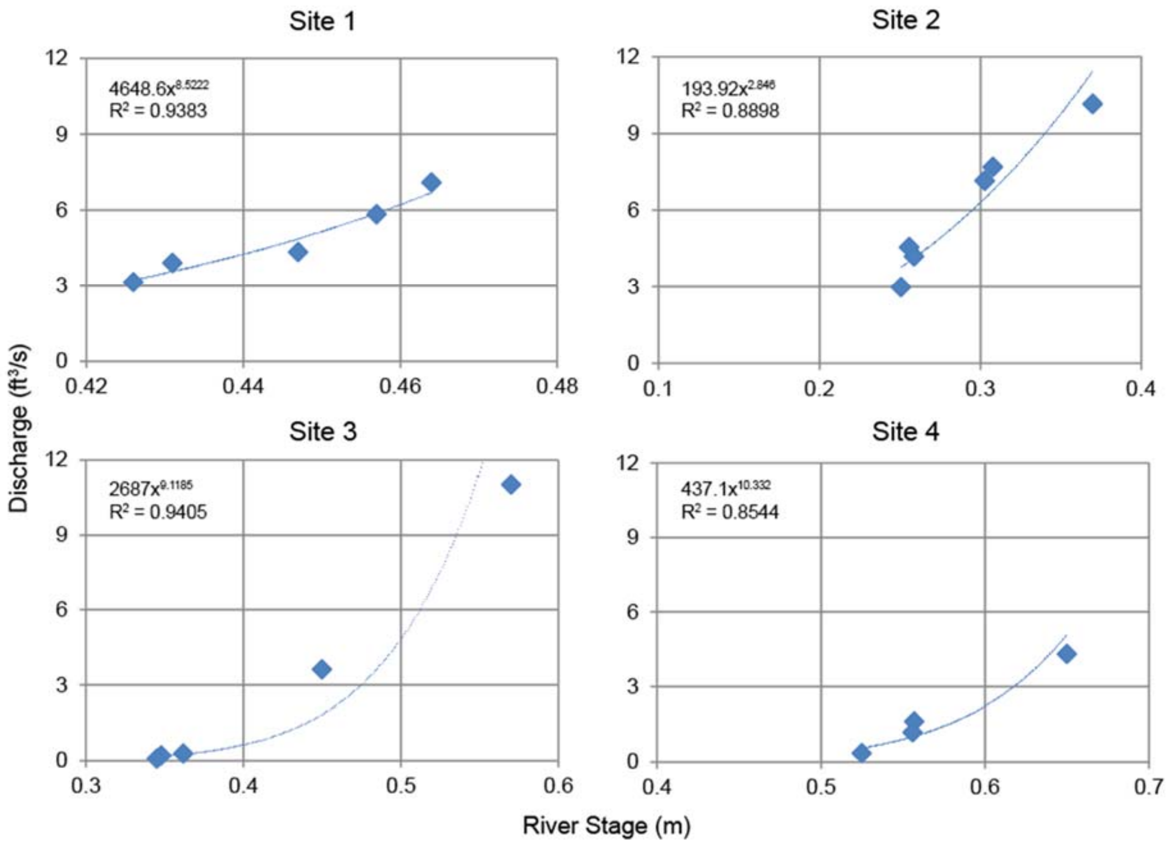


Figure 12. River stage-discharge relationships for monitoring sites 1 through 4 on the Little Shasta River.

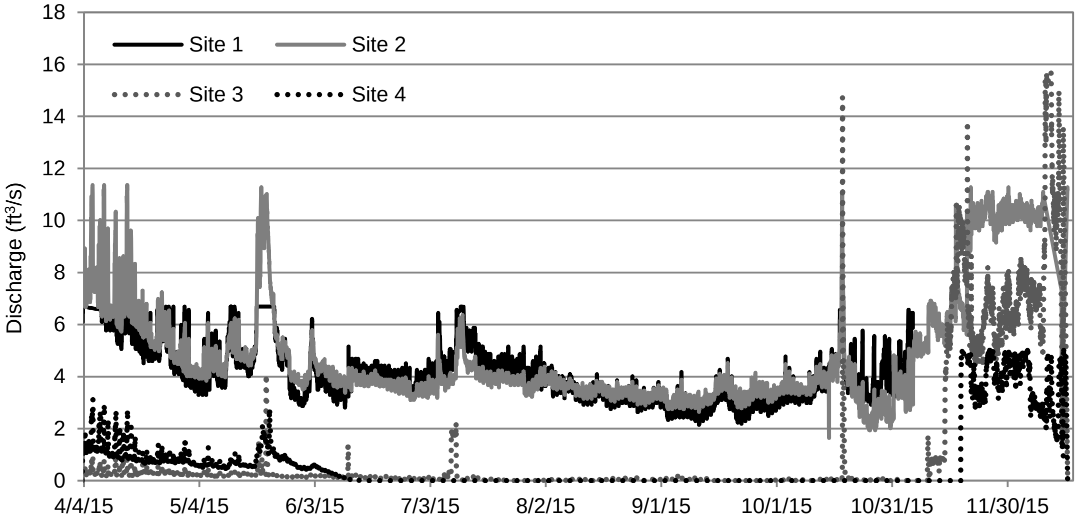


Figure 13. Hydrologic time series for the Little Shasta River streamflow monitoring sites (2015).

Table 4. Mean monthly discharge at each streamflow monitoring site in 2015.

	2015 Mean Monthly Discharge (ft^3/s)			
Month	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Apr	NA	6.20	0.31	1.07
May	4.12	4.72	0.25	0.77
Jun	3.91	3.87	0.14	0.12
Jul	4.48	4.00	0.13	0.00
Aug	3.41	3.49	0.04	0.00
Sep	2.88	3.24	0.03	0.00
Oct	3.67	3.48	0.04	0.00
Nov	NA	7.17	3.89	1.00
Dec	NA	10.29	6.97	3.25

Streamflow in the Little Shasta River exhibited spatial and temporal variability throughout the 2015 monitoring period. With no snow measured at the Little Shasta River snow course station on April 1, 2015 (see Table 2), streamflows observed in the Little Shasta River in 2015 were derived largely from surface flow (rainfall-derived), shallow subsurface flow and groundwater (diffuse and discrete springs). Interestingly, streamflows at all monitoring sites exhibited considerable diurnal variation during the spring months (April and May). During the spring period, maximum flows were often observed at night, suggesting that high elevation snowmelt (i.e. above the snow course) during the previous day (and downstream advection during the night) or nighttime reductions in evapotranspiration, influenced diurnal patterns in streamflow magnitude in the Little Shasta River.

Similar to observations from historical streamflow records, streamflows in the "foothill" reach of the Little Shasta River (Sites 1 and 2) gradually declined across the spring and summer of 2015 (Figure 13, Table 4). Streamflow at both sites showed remarkable similarity. On average, streamflow at Site 1 was 0.03 ft^3/s ($\sigma = 0.45$; max = 1.54) greater than that observed at Site 2.

Both sites exhibited clear hydrologic responses to spring and summer rainfall. Peak streamflows at Sites 1 and 2 were observed in April, with a maximum instantaneous magnitude of 11.36 ft^3/s observed on April 9. Streamflow at Sites 1 and 2 approached seasonal minimums in early June. From June through October, streamflow at both sites was relatively stable (Site 2 mean = 3.62 ft^3/s; $\sigma = 0.52$). Following the cessation of the irrigation season on November 1, 2015, streamflows at Site 2 began to gradually rise, ultimately stabilizing at approximately 10 ft^3/s in late November.

While Site 2 and 3 are less than 3 kilometers apart, they exhibited remarkably different streamflow characteristics during the 2015 monitoring period. Instantaneous streamflow at Site 3 never exceeded 4 ft^3/s. By early June 2015, observed streamflow was less than 0.25 ft^3/s, with "zero-flow" conditions (i.e. standing water in disconnected pools) reached by the middle of July. With the exception of short duration increases in streamflow during an early July water transaction (Willis and Nichols 2015) and a mid-October rainstorm, streamflow at Site 3 remained near zero until the middle of November. The rapid reduction in streamflow between Sites 2 and 3 during the entire monitoring period may be the result of upstream irrigation diversions at high priority diversion locations and/or bed loss (see Figure 11). Curiously, streamflow at Site 3 did not increase following the cessation of the irrigation season on November 1. It is possible that upstream winter diversions diverted the majority of available flow during the early part of November, until available water (from precipitation or additional spring flow) exceeded the quantity diverted.

Site 4 exhibited a fairly unique hydrograph during 2015. During the spring period, streamflows at Site 4 generally exceeded those observed upstream at Site 3 (Figure 13). This was possibly the result of the applied water returning to the river during a period where lower priority downstream water right holders were able to divert and use water from the Little Shasta River. However, by mid-June, streamflow at Site 4 ceased, and the river remained dry until the middle of November 2015. In early July 2015, approximately 3 ft^3/s of water was diverted into the Little Shasta River just upstream from Site 3. This water did not reach Site 4, likely due to seepage losses and potential diversions. Even during the late fall, flow at Site 4 was much less than that observed upstream at Sites 1 through 3. It is likely that winter diversions between Site 3 and 4 were responsible for the observed downstream reduction in streamflow.

Water Temperature (2015)

Though historic stream flow data was available for various locations throughout the Little Shasta River Basin, no associated water temperature data was available to help characterize historic water temperature conditions. As such, data collected during this study provides the first water temperature characterization of this watershed. Water temperatures in the Little Shasta River were examined for seasonal patterns to identify general periods of heating and cooling, as well as the distribution of water temperatures for each month during the monitoring period. For sites with sufficient seasonal flow (Sites 1 and 2), water temperatures exceeding 20°C were also examined. Previous studies have used 20°C [either as an instantaneous metric (USEPA 2003) or a weekly average maximum (Welsh et al. 2001)] as a guideline to distinguish between desirable and elevated water temperatures for salmonid cold-water aquatic habitat. On-going studies suggest that site-specific water temperature thresholds are strongly influenced by available food (i.e., macroinvertebrate) resources (Lusardi and Kiernan 2015); a separate, exploratory study is examining macroinvertebrates at discrete locations in the Little Shasta River Basin.

Water temperature was measured concurrent with stage monitoring at each of the four field monitoring sites (Figure 11). Solinst Levelogger Junior pressure transducers were used between April 3 and November 4, 2015, while HOBO Water Level Loggers were used between November 5 and December 15, 2015. Solinst Levelogger Junior pressure transducers have an accuracy of 0.1°C over the range of -20-80°C; HOBO Water Level Loggers have an accuracy of 0.44°C over the range of 0-50°C.

At Sites 1 and 2, water temperatures generally increased until June, then decreased (Figure 14). At Site 1, annual maximum water temperature was 21.7°C and occurred on June 8, 2015. In general, water temperatures ranged between 14.4 to 18.2°C (25th-75th percentile temperature range) at Site 1 during June. At Site 2, the annual maximum water temperature was 22.7°C, and also occurred on June 8, 2015. In general water temperatures at Site 2 during June ranged between 15.2 to 19.1°C (25th-75th percentile temperature range). Monthly average streamflow was 3.9 ft^3/s at both sites during this time.

Low flows and periods of zero flow and longitudinal flow disconnection prevent a characterization of water temperature conditions in the lower watershed for much of the 2015 monitoring period (Sites 3 and 4). Discharge records show that mean monthly discharge was generally <1 ft^3/s (Table 4). Water temperatures at these sites, particularly Site 4, are likely influenced primarily by ambient meteorological conditions and not of general water temperature trends. In addition, water temperatures in these low-flow, disconnected pools may also be influenced by local processes such as hyporheic flow. Riparian shade is negligible in these reaches, based on field observations. Due to the short period of record and low streamflow conditions, we would not recommend using the 2015 water temperature data to generally characterize water temperature patterns in these reaches.

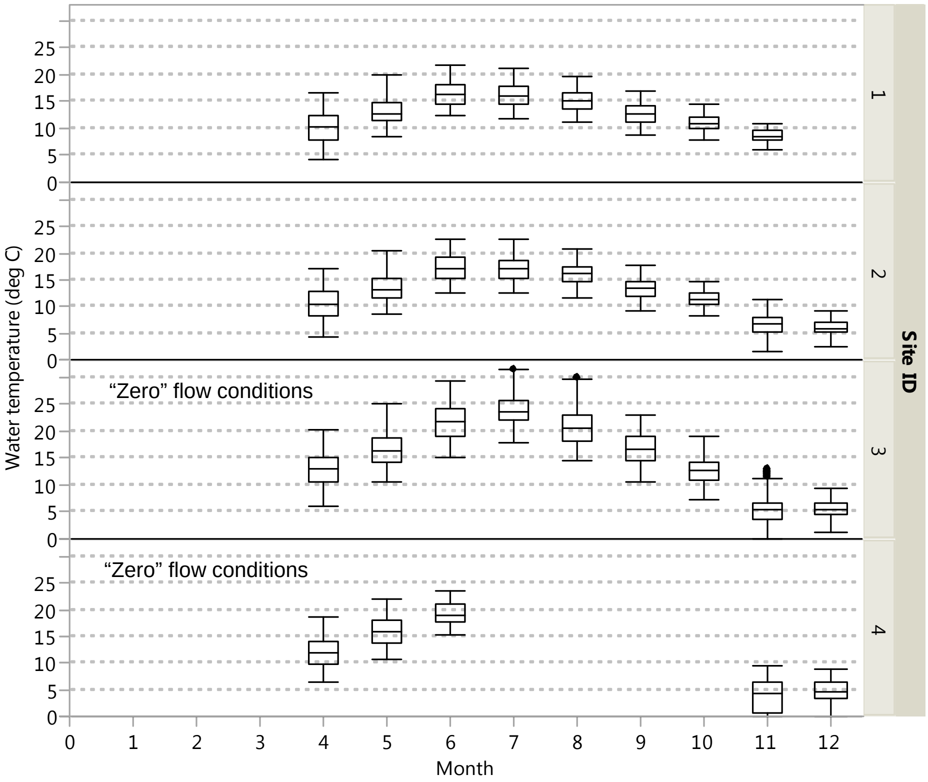


Figure 14. Interquartile distribution of water temperatures at each of the four monitoring sites, grouped by month. Outliers are identified with discrete dots. Due to insufficient streamflow at sites 3 and 4, 2015 water temperature data is not recommended to generally characterize water temperature patterns in these reaches.

The seasonal warming and cooling trend is similar to other streams in the Shasta River Basin (e.g., Big Springs Creek), where considerable vegetative cover/riparian shading exists by the end of June (Willis and Deas 2012). Overhead cover along the stream reach monitored at Sites 1 and 2 is provided by mature riparian tree canopy, which generally overhangs the low-flow channel. Time series photography shows that leaves begin to bud in April, with dense cover provided by the end of June (Figure 15). Additional monitoring is recommended to characterize the extent of riparian cover in this reach.

Figure 15. Photographs of shade provided by riparian cover at Site 1 at approximately 13:00 on April 21, 2015 and June 27, 2015. Leaves are beginning to bud in April (left), with dense leaf cover provided by the end of June (right). Daily average streamflow was 5.0 ft^3/s on April 21, 2015, and 3.7 ft^3/s on June 27, 2015.

Water temperatures at Sites 1 and 2 were also assessed for the number of days where maximum water temperatures exceeded 20°C. At Site 1, water temperatures exceeded 20°C for 16 days, with a maximum of four consecutive days over 20°C (Table 5). At Site 2, water temperatures exceeded 20°C for 34 days, with a maximum of 13 consecutive days. On average, maximum water temperatures increased 0.6°C from Site 1 to Site 2 between April and August, a relatively modest rate of heating given the remarkably low flows in the Little Shasta River.

Table 5. A summary of the number of days when water temperatures exceeded 20°C at Sites 1 and 2, the maximum number of consecutive days, and the annual maximum water temperature during the 2015 monitoring period.

Month	**Site 1**	**Site 2**
April	0 (0)	0 (0)
May	0 (0)	1 (1)
June	11 (4)*	20 (13)
July	5 (4)*	12 (8)*
August	0 (0)	1 (0)
Total	16	34
Maximum number of consecutive days (dates)	4 (June 29-July 2, 2015)	13 (June 6-June 18, 2015)
Annual maximum	21.7°C	22.7°C

*number of consecutive days overlapped June and July

Conclusions

Historical data sources indicate streamflows in the Little Shasta River are derived from surface runoff from snowmelt and direct precipitation, augmented by discrete spring sources (Little Shasta River Springs complex) and shallow subsurface flow. Approximately 20 ft^3/s of spring flow discharges from a group of springs surrounding Table Rock. It appears that most of this spring water is diverted for agricultural purposes. It is unclear whether any spring water from these springs reaches the Little Shasta River during a given water year.

The Little Shasta River is over-appropriated. Historical data indicate that summertime streamflows in the Little Shasta River at RK 26 are often less than the cumulative water rights of the first priority water right holders in the Little Shasta River Valley.

Modern streamflow observations (2015) largely mimic historical data trends. Even with minimal snowpack in the Little Shasta River watershed in 2015, streamflows at Sites 1 and 2 generally remained above 3 ft^3/s during the entire monitoring period. Qualitative observations suggest such flow volumes maintained suitable habitat for rearing salmonids. However, “zero-flow” conditions were reached at Sites 3 and 4 by early June, as a result of water diversions by highest-priority upstream water users. Streamflows did not return to Sites 3 and 4 until mid-November 2015.

Water temperature data gathered during this study provided the first insight to water temperature conditions in the Little Shasta River; no historic water temperature data was available. Where streamflow was sufficient, water temperatures were similar to water temperatures observed in other streams in the Shasta River Basin where juvenile salmon have been detected across all life-stages. These findings are especially remarkable in the context of seasonally low flows compounded by California's multi-year drought, of which 2015 was its fourth year and had the lowest snow water content of record at zero percent. The confluence of a "dry" water year and upstream water diversions precluded a detailed assessment of water temperature conditions in the lower Little Shasta River due to "zero-flow" conditions downstream from RK 18.5 in 2015.

While the findings of this study provide a useful first step to assessing the feasibility of targeted conservation actions in the Little Shasta River to support conservation of salmonids, additional data quantifying elements such as available physical habitat, nutrient contributions from springs, and food resources, will be critical to assessing the potential for a functioning cold-water aquatic ecosystem. Such data can help define the spatial and temporal boundaries of potential habitat for various salmonid lifestages, identify key limitations, and guide decisions as to the feasibility of an overall conservation strategy to diversify cold-water salmonid habitat into the Little Shasta River.

Recommendations

The 2015 study provides the first concurrent characterization of streamflow and water temperature in the Little Shasta River Basin. Given the "dry" water year context of this study and limited ability to characterize longitudinal streamflow and water temperature patterns, additional activities are recommended. Specifically, we recommend:

- Continued streamflow and water temperature monitoring efforts across multiple water year "types" (e.g. "wet", "dry", "normal") to improve understanding of spatial and temporal variability of streamflow and water temperature patterns in the Little Shasta River.
- Characterization of springs in the Little Shasta River to assess the quantity, persistence, temperature, and nutrient content of these waters. Also, identify whether these waters could be conveyed to the mainstem or to areas to where salmonid habitat may be available. Access may be limited to these private properties.
- Physical habitat characterization to identify habitat types and extent in reaches where desirable streamflow and water temperature conditions have been identified. This may include an assessment of the riparian canopy to quantify species present, solar radiation reduction, and percent cover.
- Macroinvertebrate monitoring to improve understanding of available food resources that may mitigate for short-term exposure to elevated water temperatures by juvenile coho; macroinvertebrates are also a useful indicator of habitat quality.

- Experimental flow transactions to provide insight into flow and water temperature patterns for targeted river reaches during critical juvenile salmonid migration and rearing periods. Specifically, experiments using water from the upper Little Shasta River (proximate to Sites 1 and 2), would improve understanding of the relationship between additional streamflow, water temperature magnitudes, and rates of heating throughout stream reaches downstream from RK 20. In additional, experimental flow transactions to explore the potential for connectivity during migratory periods. Data from such experiments would provide the foundation to assess the potential downstream limits of desirable thermal conditions along the lower reaches of the Little Shasta River, the potential to support migrating into and out of the Little Shasta River, and a more enhanced understanding of potential benefits of flow transactions.
- Continued or renewed support for existing gaging stations, including the Little Shasta River near Montague and the Little Shasta River snow course. At minimum, the Little Shasta River near Montague can be used to develop a long-term record for flow in the basin. This single gage will provide useful information for ongoing Watermaster service and support potential studies in the basin.
- An updated assessment of current Watermaster information, including diversion timing, quantity, and locations; seasonal water availability; and other factors. If Watermaster service does not currently identify the onset and termination of diversions (per priority), diversion rates, and similar operational and management activities, request that the Watermaster document these conditions. An improved understanding of these conditions will be invaluable in identifying the feasibility of restoration efforts in time and space to support both irrigated agriculture and instream habitat.

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