SHASTA RIVER IRRIGATION WATER MANAGEMENT AND WATERSHED STEWARDSHIP PROJECT
AGREEMENT NO. 13-501-251-2

ANNUAL MONITORING REPORT

2017

PREPARED AND SUBMITTED BY
Shasta Valley Resource Conservation District
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INTRODUCTION

The Shasta River is listed in the Shasta TMDL for high temperature and low dissolved oxygen (DO). Agricultural activities (livestock impacts, impoundments, and diversions) have been identified as the main source of these impairments (NCRWQCB 2007). Sizable diversions of water from the Shasta River and excessive irrigation return flows, or tailwater, returns to the river system degrade water quality and impact the *beneficial uses*, which include: 1) cold freshwater habitat (COLD) that supports migration, spawning and rearing (MIGR, SPWN) of salmonids including Chinook, steelhead and state and federally ESA-listed coho (RARE), 2) drinking water (MUN), 3) recreation (REC-1 & 2), 4) agricultural supply (AGR) and 5) groundwater recharge (GWR) (NCRWQCB 2007).

The Shasta Valley Resource Conservation District (SVRCD) has a contract with the State Water Resources Control Board (SWRCB) for irrigation and spring water management (Shasta River Irrigation Water Management and Watershed Stewardship, Agreement No. 13-501-251-2). Under the protocols established in the Monitoring Plan, QAPP and PAEP approved by the SWRCB, the SVRCD and AquaTerra Consulting are monitoring water quality on the Shasta River (and selected springs and tributaries). The goals of this monitoring effort are to assess progress in meeting TMDLs (temperature and DO) by monitoring Shasta River water quality and to identify future project locations that would improve water quality in the Shasta River. This project includes the implementation of water management projects (Kettle Spring Irrigation Efficiency and Control Structure Improvement Project) within a high priority area of the Shasta Basin (Shasta Springs Ranch), as well as implementing three projects (Flying L Connection Pipeline, 105SRHV Spring Connection Pipeline, and 105SRHV Tailwater Berms) identified through *the Assessment & Planning Analysis for Shasta River: Dwinnell to Parks Creek Project (Agreement No. 13-508-251-0)*.

This report summarizes the monitoring data from year four of four under this grant agreement, with general comparisons made to years one, two, and three where appropriate. In 2017, additional tailwater and spring monitoring locations were selected to help establish baseline (existing) conditions for proposed projects, as well as to supplement monitoring for projects completed during 2017. Access was acquired from private landowners through landowner agreements to monitor flow, temperature, and DO.

MONITORING LOCATIONS

Temperature, DO and/or discharge were measured from April 1st through October 1st, 2017 at 33 locations on the Shasta River and several tributaries and springs (Table 1). The study area spans approximately 40 river miles from Dwinnell Reservoir to the mouth of the Shasta River at its confluence with the Klamath River (Figure 1).

Table 1: Reach, Site ID, river mile, equipment deployed and measured metrics during the 2017 irrigation season (listed in order from upstream at the outlet of Dwinnell Reservoir to downstream at the mouth of the Shasta River). Tailwater and spring sites are listed in parentheses.

Reach	Reach Description	Site ID	River Mile	Equipment	Measurement
6	Dwinnell Outlet to Parks Creek	105DRE	39.8	DWR Gage	Reservoir Storage
		105SRXQ	39.8	DWR Gage	Discharge
		105DFBQ	39.8	DWR Gage	Discharge
		105SRHVRPOD	39.1	TidbiTs®	Temperature
		(105SRHVRFSRT)*	NA	Hach A-V + TidbiTs®	Discharge/Temperature
		(105SRUPPERS)*	NA	Hach A-V + TidbiTs®	Discharge/Temperature
		105SRHVSPL	38.1	TidbiTs®	Temperature
		105SRHVRALC	37.9	TidbiTs®	Temperature
		105SRU1DO	37.9	D-Opto	DO/Temperature
		(105SRHVSPG)*	37.9	Sontek-IQ Pipe	Discharge/Temperature
		105SRHVDSSPG	37.8	TidbiTs®	Temperature
		105SRU0IT	37.7	TidbiTs®	Temperature
		(105SR7191TW)*	37.3	Hach A-V + TidbiTs®	Discharge/Temperature
		105SR7163DS	36.9	TidbiTs®	Temperature
		105SRHIGF	36.6	TidbiTs®	Temperature
Parks Creek	Parks Creek	(105SRP1DO)*	SR 33.9 (PC 0.04)**	D-Opto	DO/Temperature
5	Parks Creek to Big Springs Creek	(105SRPCO) *	SR 33.1 (PCO 0.04)**	TidbiTs®	Temperature
4	Big Springs Creek to Willow Creek	105SRN1DO	30.9	D-Opto	DO/Temperature
		105SRV1DO	26.0	D-Opto	DO/Temperature
		105SRV4AT	25.2	TidbiTs®	Temperature
		105SRV4BT	24.3	TidbiTs®	Temperature
3	Willow Creek to Little Shasta River	105SRT1DO	23.0	D-Opto	DO/Temperature
		105SR5007DS	20.1	TidbiTs®	Temperature
		105SRS1DO	16.7	D-Opto	DO/Temperature
2	Little Shasta River to Yreka Creek	105SRMQ	14.6	DWR/USGS Gage	Discharge
		105SRM1DO	14.6	D-Opto	DO/Temperature
		105SR400T	12.3	TidbiTs®	Temperature
		105SRA1DO	11.8	D-Opto	DO/Temperature
		105SRA01T	10.2	TidbiTs®	Temperature
Yreka Creek	Yreka Creek	(105YCA01T)*	SR 7.3 (YC 0.6)**	TidbiTs®	Temperature
1	Yreka Creek to Shasta River Mouth	105SRTM01	5.3	TidbiTs®	Temperature
		105SRL1DO	0.6	D-Opto	DO/Temperature
		105SRYQ	0.1	USGS Gage	Discharge

* Parentheses indicate site was located on tributary to Shasta River

** Tributary river miles are provided both for where the tributary meets the mainstem as well as tributary river mile

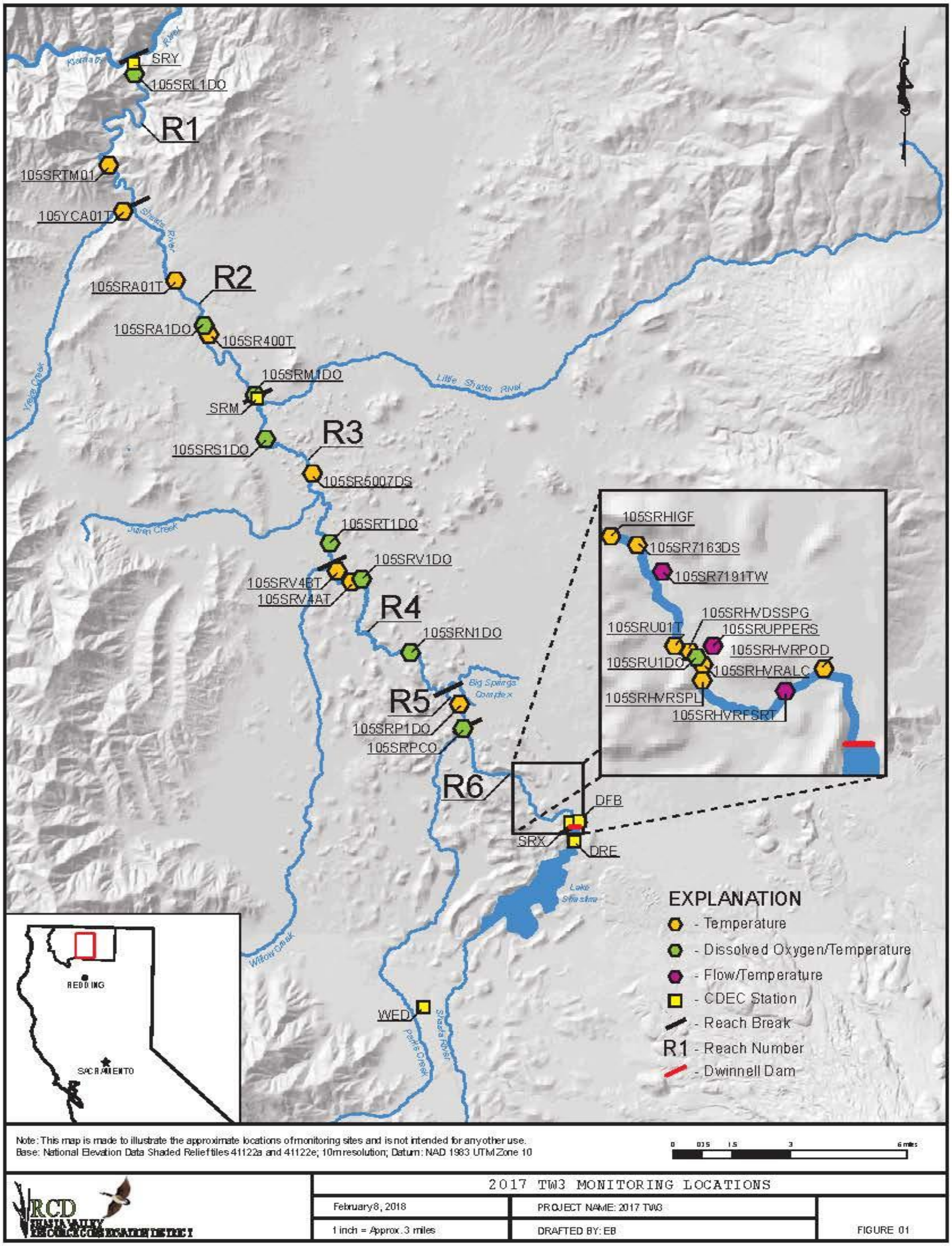

FIGURE 1. MAP OF 2017 TEMPERATURE, DO, FLOW AND CDEC MONITORING LOCATIONS.

EQUIPMENT AND MEASUREMENTS

DISSOLVED OXYGEN (W/TEMPERATURE)

Dissolved Oxygen (DO) and temperature were measured at nine sites (Table 1; Figure 1) with ZebraTech D-Opto Loggers, which use optical fluorescence sensing elements to measure DO in liquids. These DO loggers were housed in custom made canisters designed to suspend the logger above sediment in the benthic zone, and to maintain a stationary position in the river in high flow.

Where possible, DO loggers were placed in runs or pool tail-outs and within the thalweg or deepest part of the cross-section. D-opto loggers were downloaded, cleaned of bio-fouling and re-calibrated per manufacturer specifications every three weeks. Intervals of more than three weeks may have increased the risk of optical lens bio-fouling that may have caused the logger to record inaccurate measurements.

TEMPERATURE

Temperature loggers were deployed at 15 sites in the Shasta River in sets of two (paired for quality control) and housed in custom made canisters to protect them from direct sunlight. Where possible, temperature loggers were placed in runs or pool tail-outs and within the thalweg or deepest part of the cross-section.

In 2017, temperatures were recorded at 15-minute increments (D-Opto loggers and Onset® Tidbits®) at temperature monitoring locations as identified in Table 1 and on Figure 1. The 7-day average daily maximums (7-DAD Max) were calculated as the 7-day running average of daily maximum temperatures. Dates reported correspond with the last date of this running average.

In addition to the 7-DAD Maximum temperature graphs are an analysis of the Maximum Weekly Average Temperatures (MWAT) and Maximum Weekly Maximum Temperatures (MWMT) for each site. The use of MWAT values was first proposed by the National Academy of Sciences (NAS) in 1972 as a long-term standard for preventing chronic sub-lethal effects for a variety of fish species. However, the MWAT is not calculated consistently by all researchers and agencies. The MWAT, as reported by Carter (2005), is the highest single value of the seven-day moving average temperature. Likewise, the MWMT is the highest seasonal or yearly value of the daily maximum temperatures over a running seven-day consecutive period. This methodology for calculating MWAT and MWMT was followed in this report and calculated for the entire irrigation season. Additionally, the absolute maximum is calculated as the highest daily maximum temperature for the entire irrigation season.

The objective of the MWAT index is to provide an upper temperature standard that is protective of juvenile salmonids during the summer rearing period. The MWAT is a common measure of chronic (i.e. sub-lethal) exposure, the absolute maximum is a measure of acute (i.e. lethal) exposure, and the MWMT is a common measure of both chronic and acute effects (Carter 2005). The MWMT describes the maximum temperatures in a stream, but the value is not overly influenced by the maximum temperature of a single day. Table 2 describes the MWMT for the Shasta River during various life stages of coho salmon (Carter 2005). Refer to Carter (2005) for additional information regarding temperature effects on various life stages of Chinook and steelhead salmonids.

TABLE 2. MWMT FOR DIFFERENT LIFE STAGES OF COHO SALMON (REPRODUCED FROM CARTER 2005).

Coho Life Cycle						
	Adult Migration	**Spawning**	**Egg Incubation**	**Fry Emergence**	**Juvenile Rearing**	**Juvenile Out-migration**
Coho Periodicity	Sept 15 – Jan 31	Nov 1 – Jan 31	Nov 1 – Mar 31	Feb 1 – Apr 15	Jan 1 – Dec 31	Feb 15 – July 15
MWMT Criterion (°C)	20	13	13	13	18	18

In addition to water temperature collection, ambient air temperature (as well as rainfall and solar radiation) data were retrieved from Weed Airport (CDEC Station ID-WED) to inform water temperature and DO results in this study.

DISCHARGE

Discharge through culverts was measured at four sites at 105SRHV (Figure 1). HACH submerged AV9000 area-velocity flow meters with Hach Sigma 910 dataloggers were deployed by the SVRCD at three sites, and flow data was retrieved from an existing SonTek-IQ Pipe flow meter at one other site (Table 1). Hach and SonTek flow meters use acoustic doppler technology to measure velocity and pressure transducers to measure water level, which are then used to calculate discharge in cubic feet per second (cfs). Paired Onset® Hobo® TidbiT® temperature data loggers were installed near each flow meter.

In addition, velocity "spot checks" were performed using a handheld SonTek® FlowTrackerII® that utilizes acoustic doppler technology to measure velocity. These spot checks were done to verify the accuracy of velocity readings from Hach flow meters, as well as to measure flow in culverts that did not have continuous flow measurement devices installed.

Additional river discharge data and Dwinnell Reservoir storage and flow releases were retrieved from the California Data Exchange Center (CDEC). River discharge data was reviewed for the DWR maintained Cross-canal weir (CDEC Station ID – SRX), Dwinnell Dam instream flow releases (CDEC Station ID – DFB), as well as from the USGS maintained gages at the Montague-Grenada Road weir (Station ID - SRM) and Yreka weir gage (CDEC Station ID – SRY).

RESULTS AND DISCUSSION

METEOROLOGICAL CONDITIONS

Ambient air temperatures were examined to assist with analysis of seasonal and inter-annual river temperature trends. As air temperatures increase into the summer, water temperatures in the Shasta River generally increase as well. An exception to this trend is in the upper Shasta River and Big Springs Creek where extensive macrophyte growth during mid and late summer minimizes increases in water temperature (Jeffres et al. 2009). Additionally, tailwater returns to the river via overland flows are greatly affected by air and ground surface temperatures.

Temperature, rainfall, and solar radiation data from Weed Airport (CDEC Station ID-WED) helped to inform temperature and DO results in this study (Figure 2). Weather data display a typical warm-dry irrigation season with reduced solar radiation starting in late July due to smoke cover from a particularly active fire season.

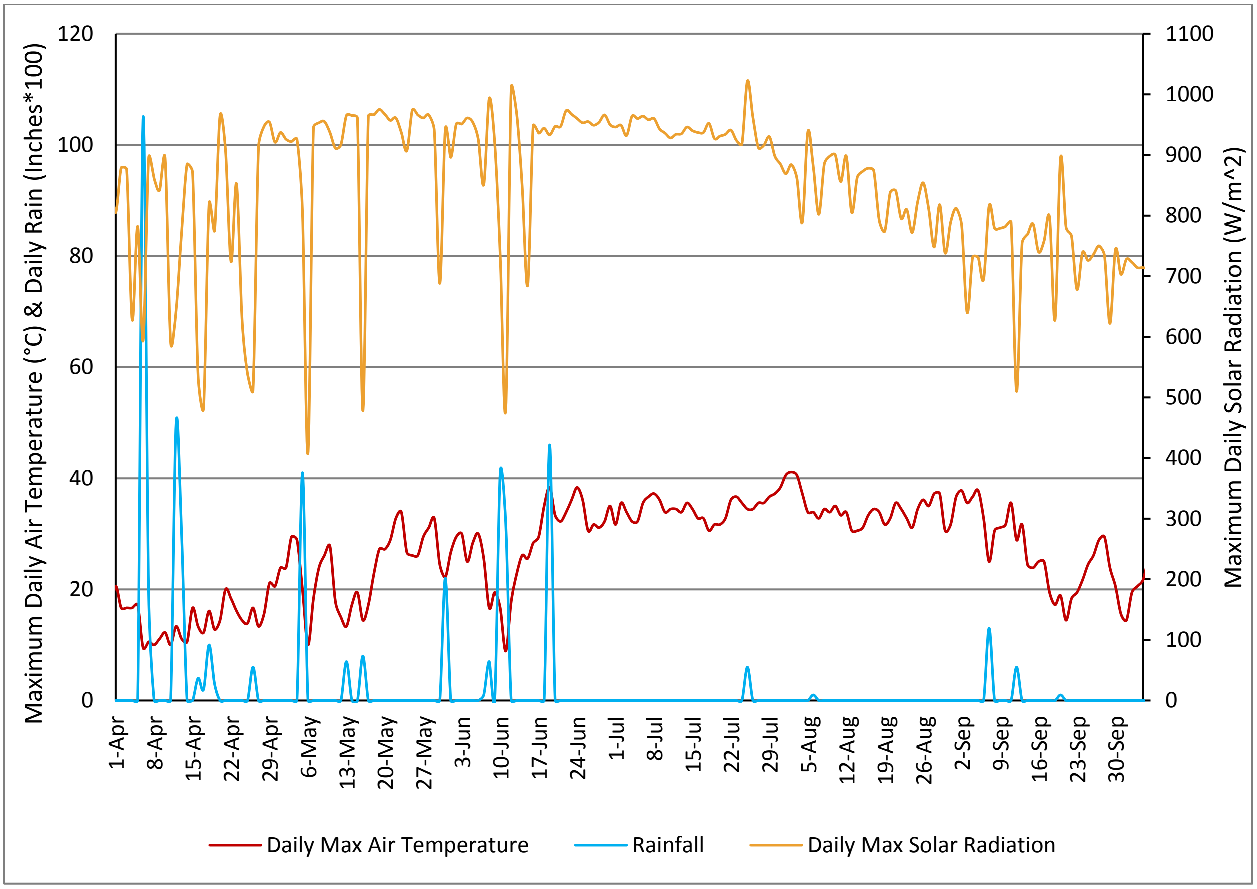

FIGURE 2. 2017 MAX DAILY AIR TEMPERATURE AND SOLAR RADIATION, AND DAILY RAINFALL*(100) DATA AT THE WEED AIRPORT.

DWINNELL RESERVOIR STORAGE AND SHASTA RIVER DISCHARGE

In 2017 monthly storage totals for Dwinnell Reservoir were examined in conjunction with river discharge data to assist with analysis of seasonal and inter-annual river temperature trends in the Shasta River. Monthly storage totals for Dwinnell Reservoir for water years 2013 through 2017 presented in Table 3 and Figure 3. The water year is defined as the 12-month period that starts October 1st and ends September 30th the following year. Figure 4 displays discharge into the Shasta River at the top of Reach 6 from Dwinnell Dam instream flow releases (DFB) and prior rights releases to the river from the cross canal below Dwinnell Dam (SRX). Figure 5 displays discharge of the Shasta River at the top Reach 2 at Montague (SRM) and in Reach 1 near Yreka (SRY). While the multi-water year trends among monthly storage data for Dwinnell Reservoir are reflective of differences in annual precipitation, climatological conclusions and their effect on the Shasta River cannot be explicitly derived from differences in monthly storage.

TABLE 3. DWINNELL RESERVOIR STORAGE (DRE) IN ACRE-FEET FOR WATER YEARS 2013 THROUGH 2017 FROM CEDEC.

Dwinnell Reservoir Storage (acre-ft)					
Water Year	**2013**	**2014**	**2015**	**2016**	**2017**
Oct	6705	2441	2745	2383	11764
Nov	10032	3389	3952	3339	15705
Dec	18711	4490	13914	6109	21205
Jan	21840	5559	15423	15519	31937
Feb	23636	7405	32440	21736	45905
Mar	24961	8928	30899	35487	47114
Apr	21693	5766	21902	34892	45909
May	17760	5149	17909	31063	43873
Jun	11101	4339	12655	25483	39485
Jul	4334	3012	7140	17780	29603
Aug	2586	1934	2964	10864	21346
Sep	1929	1628	658	7393	16367

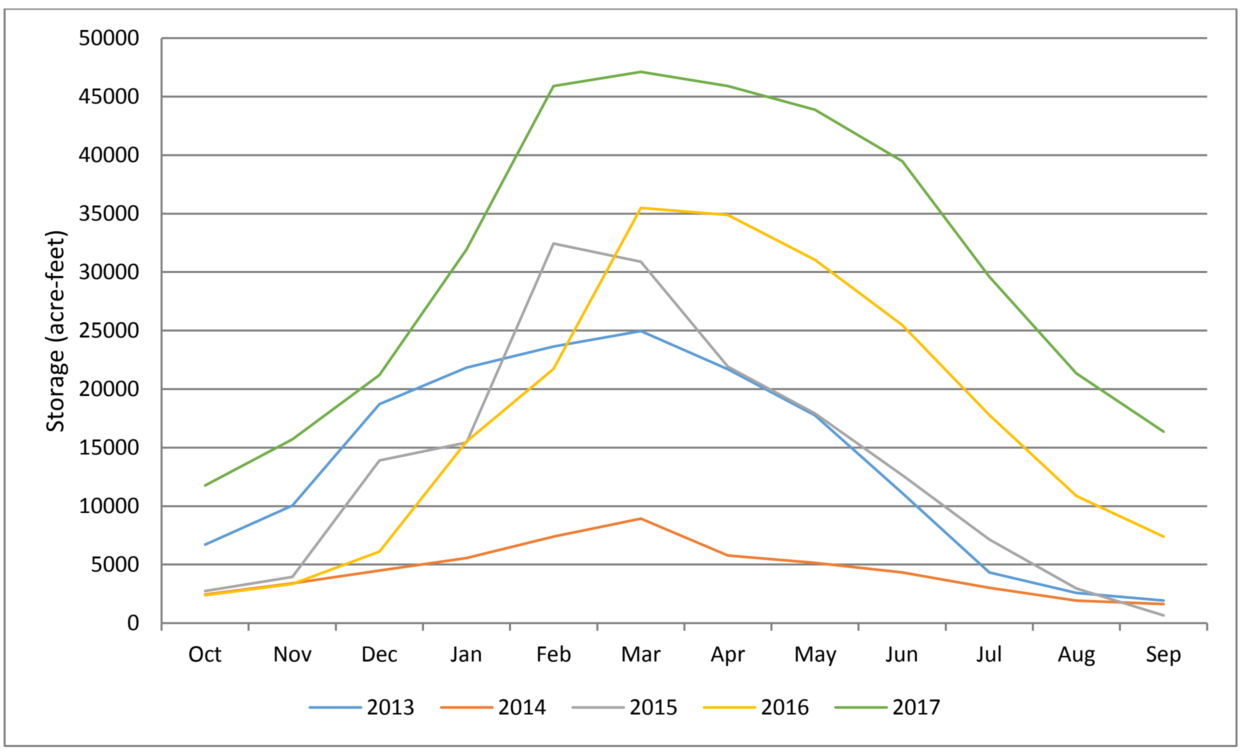

FIGURE 3. DWINNELL RESERVOIR STORAGE (DRE) IN ACRE-FEET FOR WATER YEARS 2013 THROUGH 2017 FROM CEDEC.

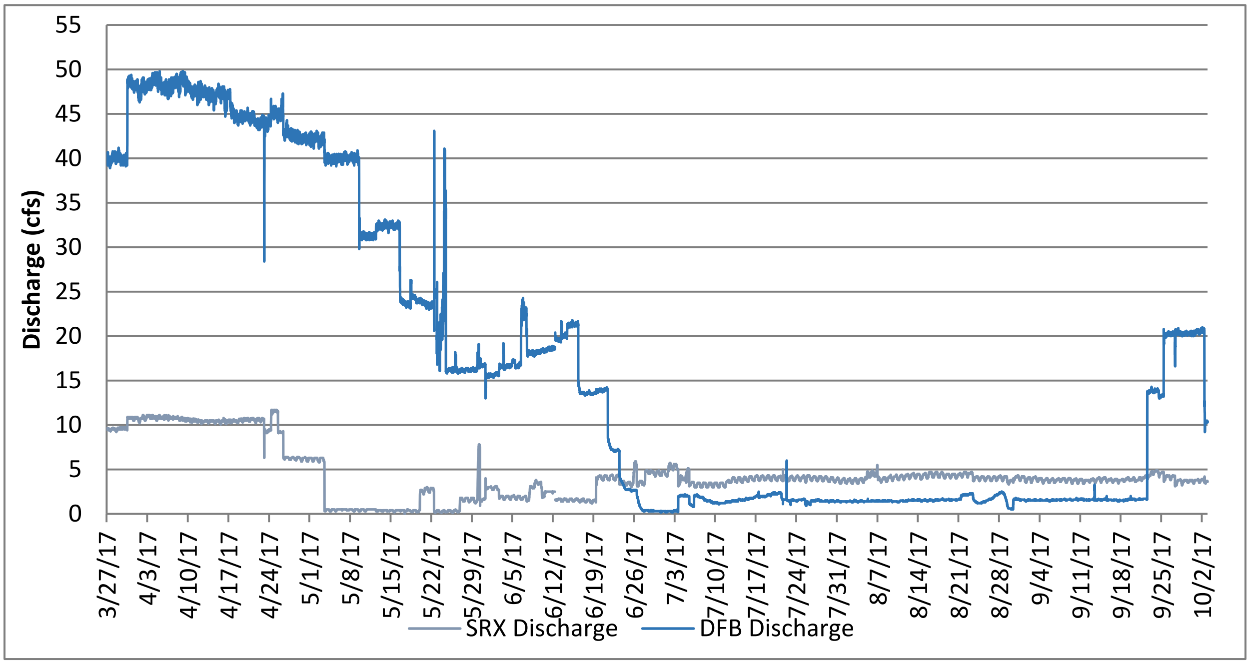

FIGURE 4. 2017 DISCHARGES INTO SHASTA RIVER AT THE TOP OF REACH 6 FROM 105SRXQ AND 105DFBQ.

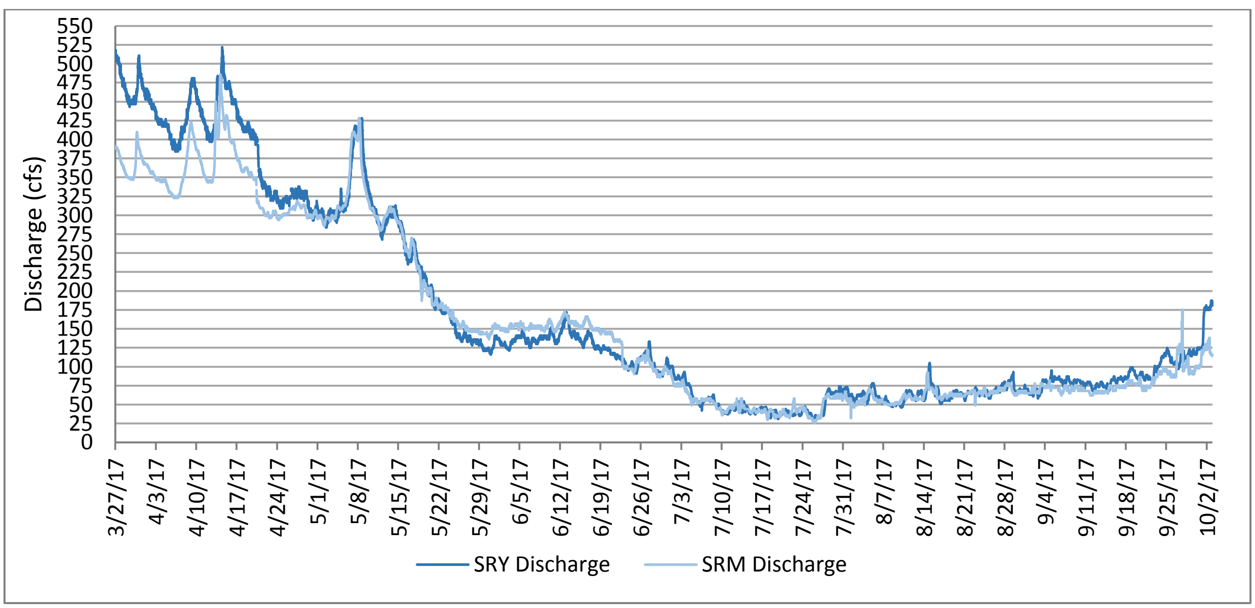

FIGURE 5. 2017 DISCHARGE FROM UNITED STATES GEOLOGICAL SURVEY OPERATED GAUGES IN THE SHASTA RIVER AT THE TOP REACH 2 AT MONTAGUE (SRM) AND IN REACH 1 NEAR YREKA (SRY).

TEMPERATURE MONITORING

Temperature was measured at 28 sites on the Shasta River and its tributaries in 2017. Temperatures in the Shasta River and its tributaries fluctuate daily and are moderated in comparison to air temperatures due to the high specific heat capacity of water.

WATER MANAGEMENT PROJECTS IN REACH 6

Two water management projects were completed at 105SRHV in early 2017: 1) 105SRHV Spring Connection Pipeline Project, and 2) 105SRHV Bunkhouse Tailwater Berm Project. Post project monitoring was performed at locations surrounding both sites.

105SRHV SPRING CONNECTION PIPELINE PROJECT

At 105SRHV, cold (approx. 14°C) water emanating from springs had been previously captured and primarily used for irrigation of pastures. The 105SRHV Spring Connection Pipeline now conveys a portion of this cold spring water directly into the Shasta River (Figure 6). The purpose of this project was to reduce temperatures and increase DO by providing a consistently cold source of spring water to the Shasta River at Reach 6. The project also improves water management and reduces the amount of tailwater produced on the ranch.

FIGURE 6. PHOTO A) 2017 PRE-PROJECT PHOTO OF NORTH AND SOUTH 105SRHV SPRING PIPELINE SITE; PHOTO B) 2017 POST-PROJECT PHOTO OF NORTH AND SOUTH 105SRHV SPRING PIPELINE OUTLETS (SEE BLACK ARROWS) DISCHARGING COLD (~14°C) SPRING WATER INTO THE SHASTA RIVER.

Discharge and temperature measurements made at 105SRUPPERS recorded the volume and temperature of spring water that continued to be used for irrigation (not conveyed directly to the river) in 2017 (Figure 7), while temperature and discharge of spring water diverted directly to the Shasta River was recorded from within the Spring Connection pipeline (Figure 8).

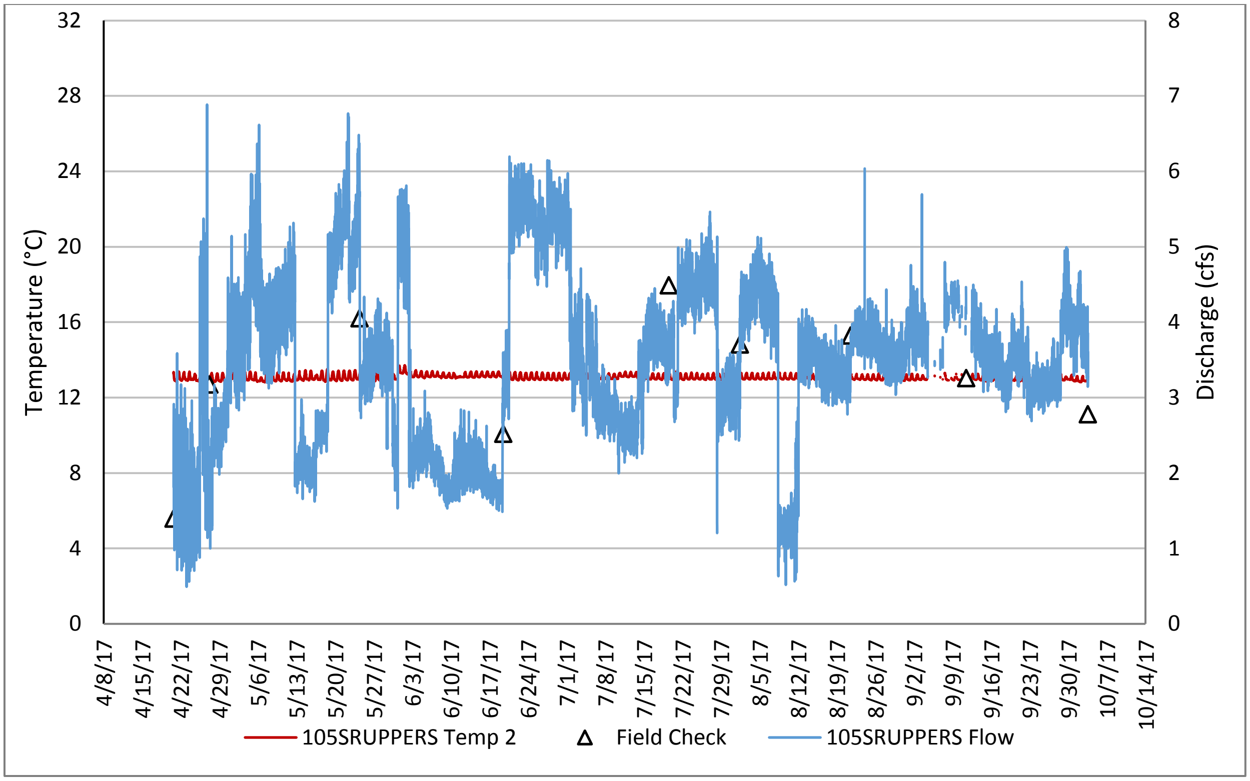

FIGURE 7. 2017 DISCHARGE AND TEMPERATURE DATA AT 105SRUPPERS.

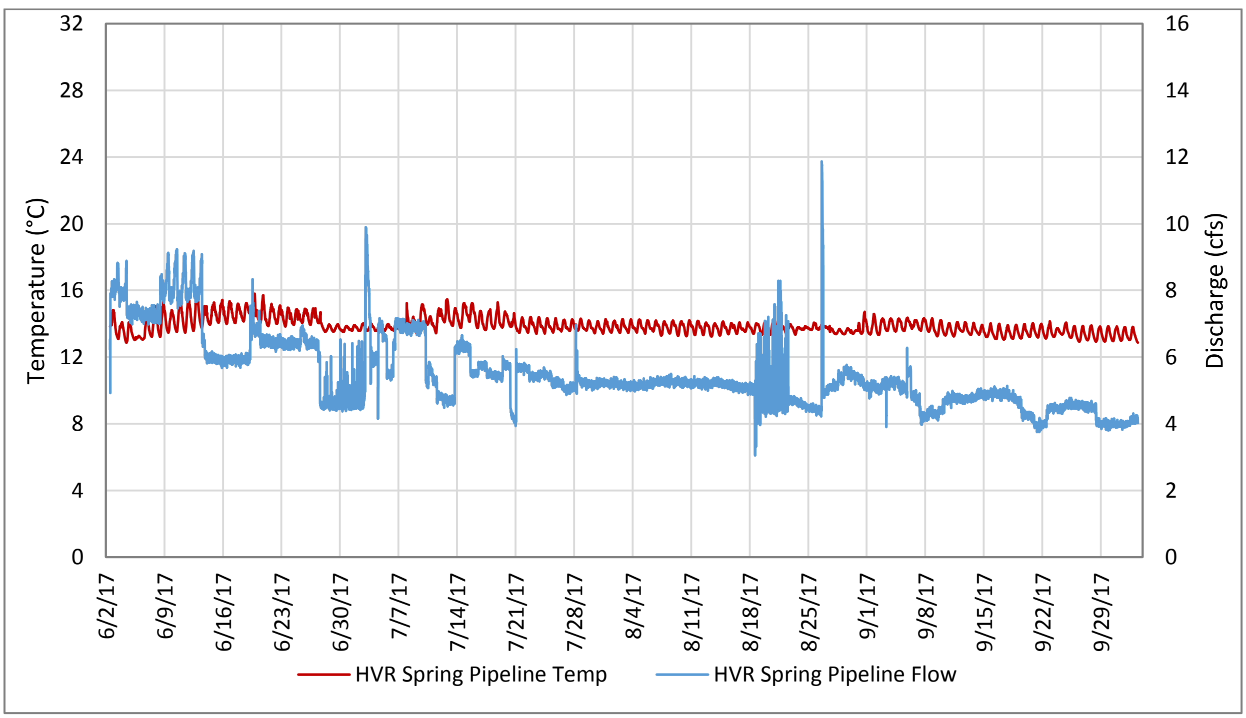

FIGURE 8. 2017 DISCHARGE AND TEMPERATURE DATA AT THE 105SRHV SPRING CONNECTION PIPELINE REAL-TIME STATION.

From June 2nd through October 3rd, 2017, the 105SRHV Spring Connection Pipeline provided a total of 1,335 acre-feet of water at an average rate of 5.5 cfs and an average temperature of 14°C. Table 4 provides a summary of 2016 and 2017 temperatures on the Shasta River above and below the Spring Pipeline outlets (where applicable). In 2016, MWMT's remained fairly consistent between 105SRU1DO and 105SRHIGF with a slight warming trend in the downstream direction. In 2017, cold Spring Pipeline inflows reduced Shasta River temperature from 23.9 °C just upstream of the pipeline outlets, to 18.3 °C at the nearest downstream site (105SRU1DO). Temperature reductions were detected at monitoring sites progressively further downstream, with the furthest one (105SRHIGF) more than 1.5 miles away from the pipeline outlets (Figure 9).

TABLE 4. 2017 SHASTA RIVER MWMTS ABOVE AND BELOW THE SPRING PIPELINE PROJECT, WITH 2016 MWMT COMPARISON.

105SRHV Spring Connection Pipeline River Temperature Impact Summary					
Site ID	Distance from Spring Pipeline Outflow (miles)	2016 MWMT (°C)	2017 MWMT (°C)	Difference 2017-2016 MWMT (°C)	2017 Temperature difference between 105SRHVSPL and all other sites (°C)
105SRHVSPL	-0.11	n/a	23.85	n/a	0
105SRHVRALC	0	n/a	14.42	n/a	-9.43
105SRU1DO	0.01	24.30	18.28	-6.01	-5.56
105SRHVDSSPG	0.03	n/a	19.32	n/a	-4.52
105SRU0IT	0.19	24.32	20.28	-4.04	-3.57
105SR7163DS	1.11	24.26	22.23	-2.03	-1.62
105SRHIFG	1.53	24.57	22.68	-1.89	-1.17

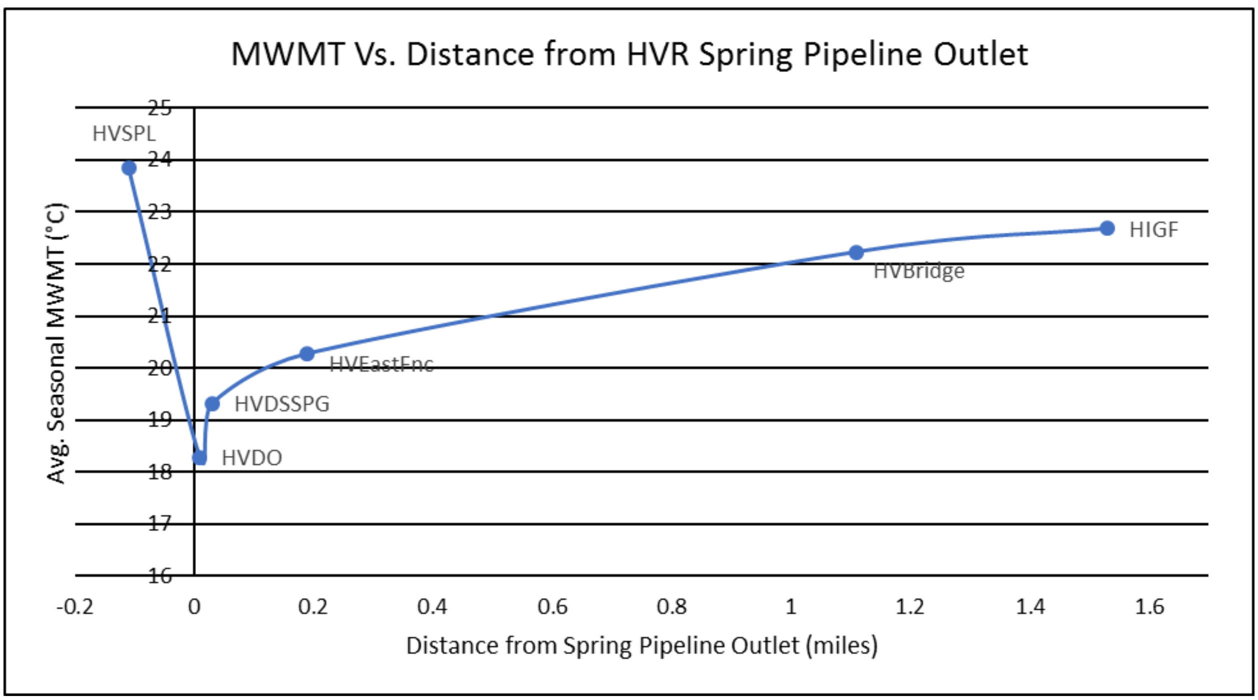

FIGURE 9. TEMPERATURE VS. DISTANCE FROM 105SRHV SPRING PIPELINE ON THE SHASTA RIVER. NEGATIVE DISTANCE VALUES REFER TO MILES UPSTREAM OF OUTLET; POSITIVE VALUES ARE DOWNSTREAM. TEMPERATURE OF SPRING WATER DISCHARGE IS 14.4 °C.

105SRHV BUNKHOUSE TAILWATER BERM PROJECT

The 105SRHV Tailwater Berm project is an engineered berm that can capture tailwater. In theory, the tailwater is collected and stored overnight, giving it time to cool before being returned to the Shasta River by opening a manually operated head gate. The purpose of this project was to improve instream conditions and habitat for endangered coho salmon by reducing temperatures of tailwater in the Shasta River at 105SRHV.

Tailwater flow events were characterized by intermittent flows ranging from approximately 0.01 to 3.3 cfs. The frequency of high flow tailwater releases was greatest during early to mid-May, and again from early July to early August. Tailwater flows greater than 0.2 cfs and the associated water temperatures were recorded for the 2017 irrigation season (Figure 11). Total tailwater returned to the Shasta River at 105SR7191TW during the 2017 irrigation season was 45.25 acre-feet.

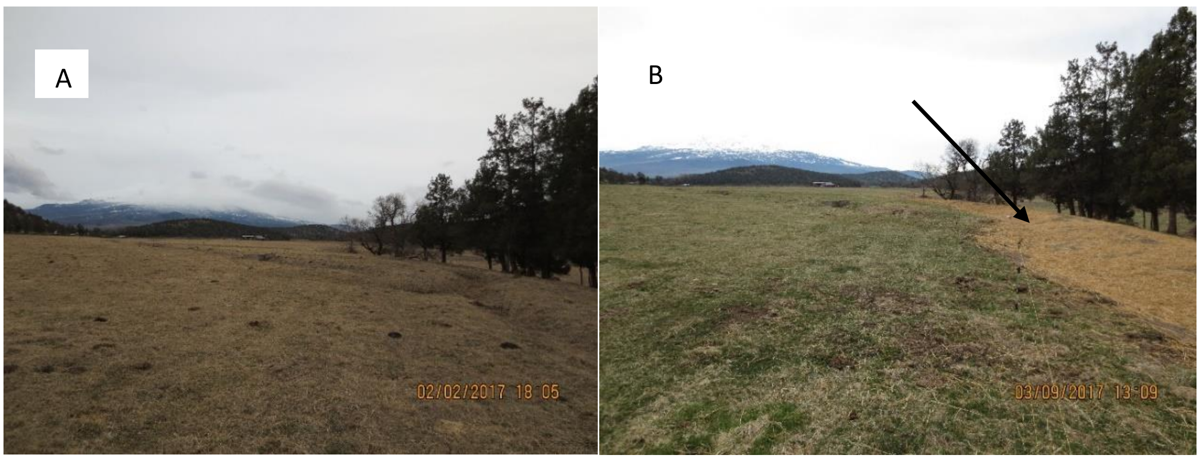

FIGURE 10. PHOTO A) 2017 PRE-PROJECT PHOTO OF 105SRHV BUNKHOUSE TAILWATER BERM PROJECT SHOWING EXISTING TAILWATER RETURN DITCH; PHOTO B) 2017 POST-PROJECT PHOTO OF 105SRHV BUNKHOUSE TAILWATER BERM PROJECT SHOWING THE RECENTLY COMPLETED TAILWATER BERM ON THE RIGHT SIDE OF THE PICTURE.

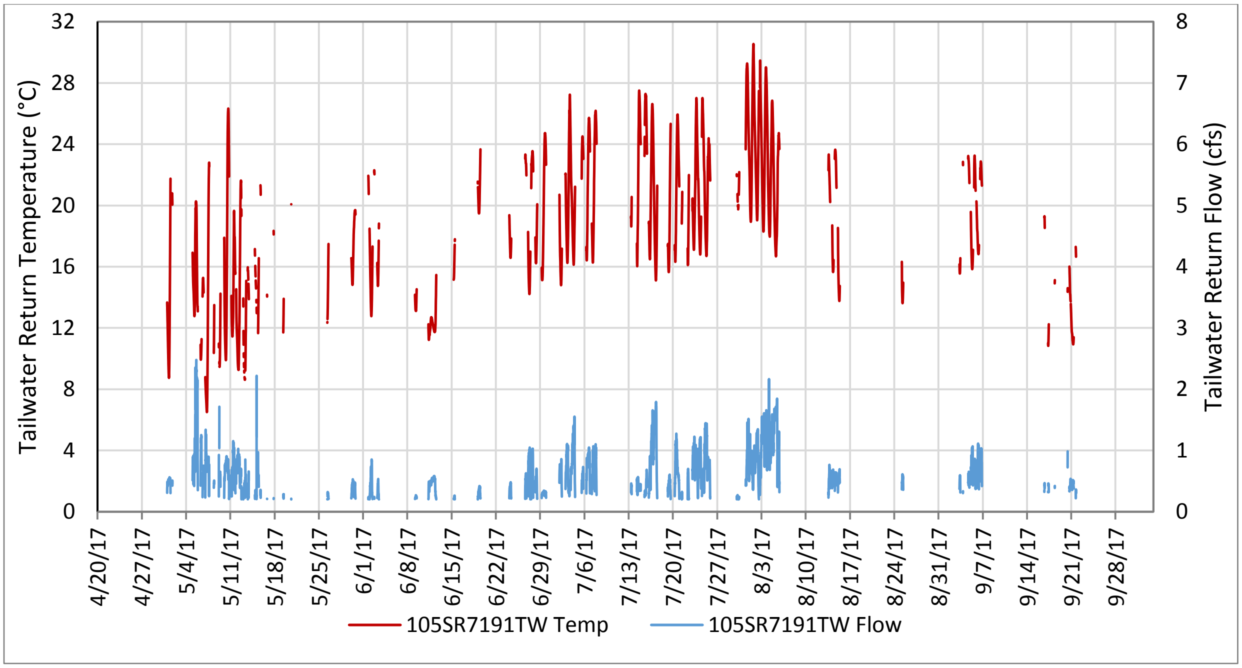

FIGURE 11. 2017 TEMPERATURE AND FLOW DATA FOR 105SR7191TW WITHIN SHASTA RIVER REACH 6.

For the purpose of evaluating the efficacy of the 105SRHV Tailwater Berm project, *optimal* tailwater return time is between the hours of 12:00am and 10:00am, when irrigation water is not warmed by the sun and has been cooled throughout the night. Conversely, the *suboptimal* tailwater return time is between the hours of 10:00am and 12:00am, when irrigation water has been warmed by the sun. Optimal and suboptimal tailwater return temperatures are assumed to be less than 20°C and greater than 20°C, respectively.

Figure 12 shows approximately 18.5 acre-feet of tailwater returned to the Shasta River at an optimal time and temperature compared to approximately 16.25 acre-feet of tailwater that returned at a suboptimal time and temperature. Approximately 7.75 acre-feet of tailwater returned during a suboptimal time at an optimal temperature, and approximately 2.75 acre-feet of tailwater returned during an optimal time at a suboptimal temperature (Figure 12). The proportions of tailwater returned at an optimal time and temperature versus a suboptimal time and temperature are roughly equal.

In summary, these data show that temperature impacts associated with tailwater can be minimized when the 105SRHV Bunkhouse Tailwater Berm is managed to release tailwater to the Shasta River between 12:00 am and 10:00 am.

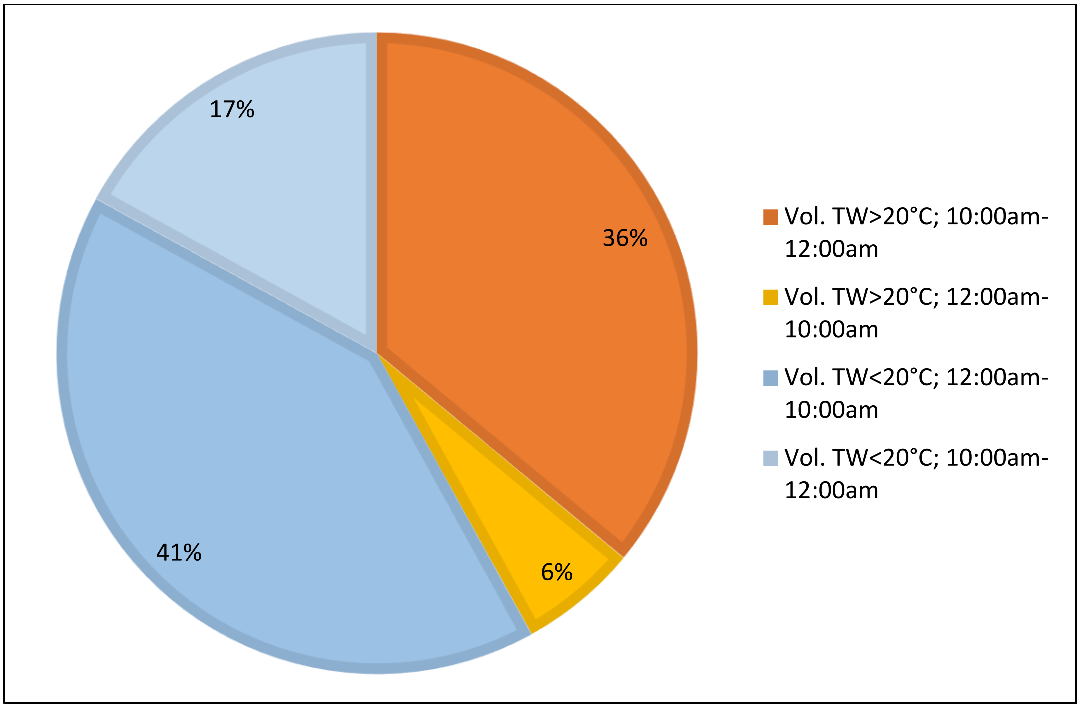

FIGURE 12. 2017 PERCENTAGE OF TOTAL VOLUME OF TAILWATER (45.25 ACRE-FT) DELIVERED AT OPTIMAL OR SUBOPTIMAL TIMES, AND GREATER OR LESS THAN 20°C, AT SITE 105SR7191TW.

REACH TEMPERATURE

REACH 6

Figure 13 displays MWMT criterion for juvenile coho salmon rearing and 7-DAD Maximum water temperatures at sites within Shasta River Reach 6. These sites are located downstream of Dwinnell Reservoir, which releases prior water rights into the upper Shasta River, affecting the amount of water instream, as well as the temperature of the water entering the river. In the early part of the season, when storage in the reservoir is generally at its greatest, water temperature is maintained throughout the day, allowing for the release of consistently cold water to Reach 6. Later in the year when storage has decreased and the water within the reservoir has warmed, warmer water is released into the river. This is evidenced in Figure 13 by 7-DAD Maximum temperatures prior to July 18th at 105SRHVRPOD and 105SRHVSPL that are cooler than downstream temperatures at 105SR7163DS and 105SRHIGF. On July 18th this trend is reversed, and water entering the Shasta River remains warmer until the end of the monitored period on October 3rd.

105SRHVRPOD also experiences a jump in 7-DAD Maximum temperatures beginning around June 18th that coincides with a reduction of instream flows from Dwinnell Reservoir (Figure 4) and increased air temperatures (Figure 2). 7-DAD Maximum temperatures at sites 105SRHVALC, 105SRU1DO, 105SRHVDSSPG, and 105SRU0IT are all cooler than upstream sites 105SRHVPOD and 105SRHVSPL, due to the fact that they are receiving cool spring water averaging approximately 14°C from the 105SRHV Spring Pipeline Project. Temperature of the spring water is recorded at 105SRUPPERS, situated near the inlet of the 105SRHV Spring Connection Pipeline and at 105SRHVRALC, situated just below the south outlet of the 105SRHV Spring Connection Pipeline.

All 7-DAD Maximum temperatures display a large dip corresponding with an early June weather event that brought approximately 0.75 inches of precipitation to the Shasta Valley. Data at 105SR7163DS and

105SRHIGF indicate an overall cooling trend in river temperature from mid-July until late-September, despite these typically being the warmest months of the year. This latter cooling trend may be correlated with the presence of heavy smoke from regional wildfires during mid-July through September which reduced solar intensity, and/or an increase in instream vegetation that can shade and maintain cool water temperatures throughout the day. The remainder of the sites are unaffected by reduced solar radiation due to their proximity to Dwinnell Reservoir or the 105SRHV Spring Pipeline.

The site with coolest 7-DAD Maximum temperatures within Reach 6 was 105SRHRVALC, which exceeded the MWMT criterion a total of 0 of 189 days monitored (0% of the time). These optimal water temperatures can be attributed to its location just below the outlet of the Spring Connection Pipeline. The site with the greatest number of days (113 of 189) exceeding the MWMT criterion is the downstream most site in Reach 6 (105SRHIGF). However, two sites above the Spring Connection Pipeline far surpassed temperatures at 105SRHIGF in mid-July and remained well above through the remainder of irrigation season. This demonstrates that the cooling effects of the Spring Pipeline achieve their greatest impact during months when air temperature is typically the warmest and water temperature released from Dwinnell Reservoir is potentially the warmest as well.

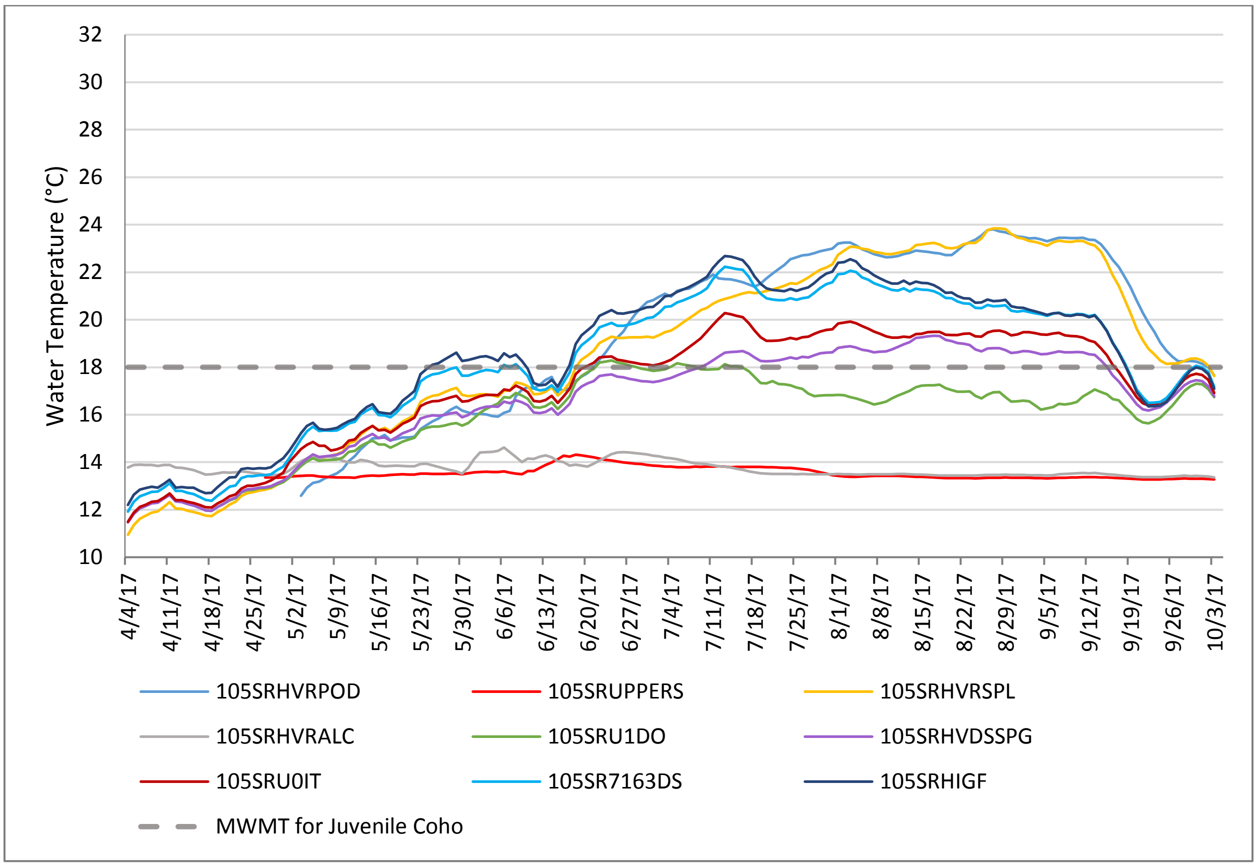

FIGURE 13. 2017 7-DAD MAX RIVER TEMPERATURES AT SITES WITHIN SHASTA RIVER REACH 6 AND MWMT FOR JUVENILE COHO.

REACH 5

In Reach 5, the Shasta River is supplemented by flows from Parks Creek (105SRP1DO), Hole in the Ground Creek (not measured), and Parks Creek overflow (105SRPCO). Parks Creek overflow is the historic Parks Creek channel, which primarily collects a mix of tailwater from one ranch and small ephemeral spring water inputs. The overflow is only connected to Parks Creek during high flow events, usually winter or early spring. This flow enters the Shasta River just north (downstream) of the Parks Creek confluence with the Shasta River. During irrigation season, Parks Creek overflow discharges up to 5 cfs into the Shasta River.

7-DAD Maximum temperatures from Parks Creek were typically 2-3°C warmer than our nearest Shasta River measurement site (105SRHIGF), while Parks Creek overflow 7-DAD Maximum temperatures were up to 8 degrees warmer during the warmest part of the season (Figure 14). Depending on flow rates, these warm inflows may increase water temperatures in the Shasta River. Inflow from Big Springs Creek reduces temperatures considerably at the bottom of Reach 5.

Coho salmon utilize Parks Creek for migration, spawning and juvenile rearing (Chesney et al. 2009). Figure 14 displays MWMT criterion for juvenile coho salmon rearing and 7-DAD Maximum water temperatures measured near the mouth of Parks Creek (105SRP1DO). Temperatures at the mouth of Parks Creek exceeded the MWMT for juvenile coho salmon a total of 129 of 176 days monitored (73% of the time). Coho use of the overflow channel has not been documented. However, temperatures in Parks Creek Overflow exceeded the MWMT for juvenile coho salmon a total of 145 of 170 days monitored (85% of the time).

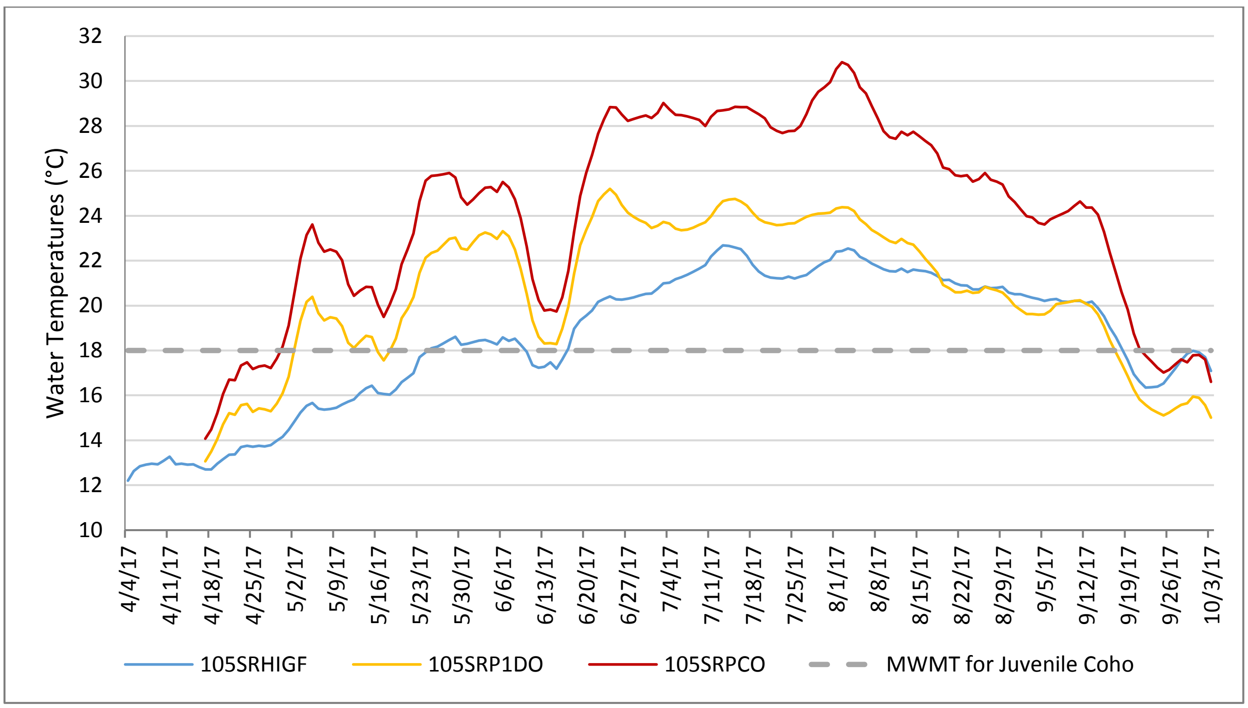

FIGURE 14. 2017 7-DAD MAX RIVER TEMPERATURES AT SITES WITHIN SHASTA RIVER REACH 5 AND MWMT FOR JUVENILE COHO. 105SRHIGF IS INCLUDED FOR REFERENCE.

REACH 4

Figure 15 displays MWMT criterion for juvenile coho salmon rearing and 7-DAD Maximum water temperatures at sites within Shasta River Reach 4. These sites are located downstream of the Big Springs Creek confluence, which adds a large volume (53 cfs average during July and August) of cold water to the Shasta River (Nichols et al. 2010). Consequently, 7-DAD Maximum water temperatures within this reach are consistently cooler throughout irrigation season than in all other reaches within the Shasta

River. 7-DAD Maximum temperatures display a large dip corresponding with an early June weather event that brought approximately 0.75 inches of precipitation to the Shasta Valley. 7-DAD Maximum temperatures display a cooling trend among all sites within the reach throughout the second half of the irrigation season. The highest 7-DAD Max temperatures were reached at 105SRN1DO and the MWMT criterion was exceeded 95 of 171 days monitored (56% of the time). The warmest overall site within Reach 4, 105SRV4AT, exceeded the MWMT criterion a total of 103 of 171 days monitored (60% of the time).

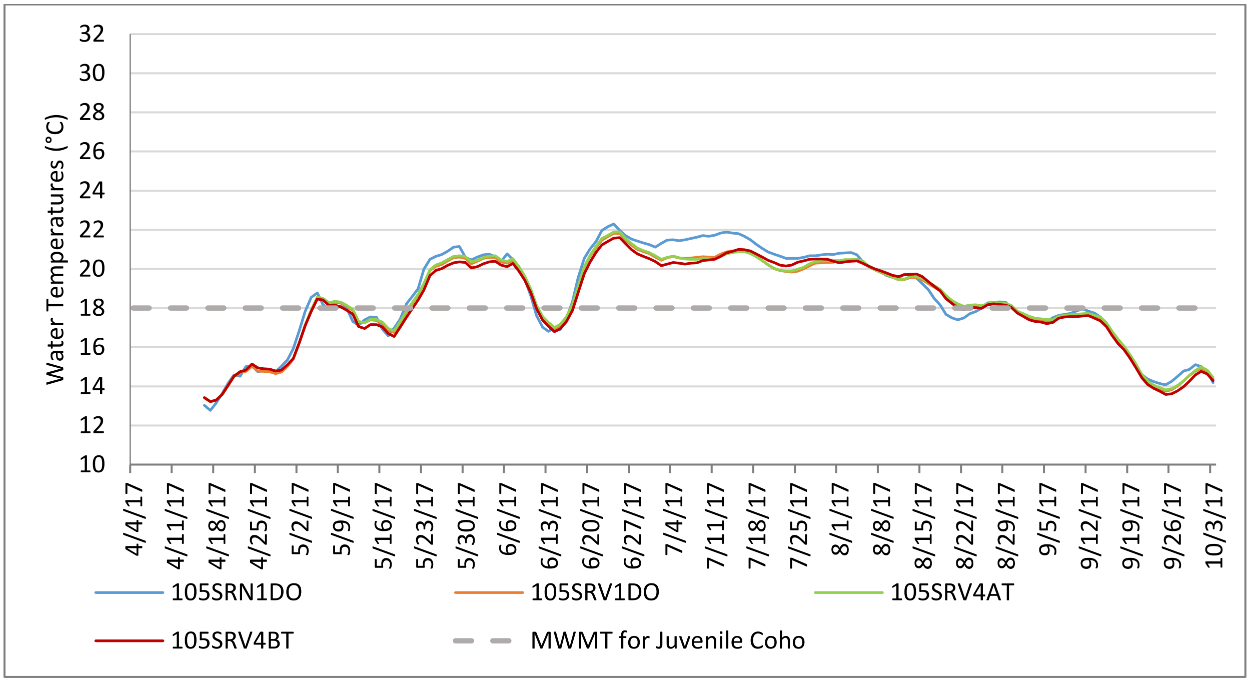

FIGURE 15. 2017 7-DAD MAX RIVER TEMPERATURES AT SITES WITHIN SHASTA RIVER REACH 4 AND MWMT FOR JUVENILE COHO.

REACH 3

Figure 16 displays MWMT criterion for juvenile coho salmon rearing and 7-DAD Maximum river temperatures at sites within Shasta River Reach 3. 7-DAD Maximum temperatures were cooler in the downstream direction from 105SRT1DO to 105SR5007DS through late June. The 15-minute water temperature data (not shown) exhibit much smaller diurnal fluctuations at 105SR5007DS through late June. This trend is consistent in previous years. It's possible that cold water inflows from Julien Creek and/or unknown springs may have produced anomalous (cooler than expected) temperatures at 105SR5007DS. Otherwise, 7-DAD Maximum temperatures increased in the downstream direction through all sites in this reach.

In general, a seasonal warming trend in the Shasta River occurred during the first half of the monitoring period, with the exception of two notable instances of rapid cooling in mid-May and mid-June corresponding with cool and precipitous weather events. 7-DAD Maximum temperatures for all sites remain above the MWMT criterion until mid-September, before dropping below the MWMT criterion for the remainder of the monitored period. Data indicate an overall cooling trend in 7-DAD Maximum river temperatures from mid-July until late-September, despite these typically being the warmest months of the year. This latter cooling trend correlates with the presence of heavy smoke from regional wildfires during mid-July through September that reduced solar intensity (Figure 2) and/or increased instream vegetation that can reduce river temperatures. The coolest site within Reach 3 (105SRT1DO) exceeded the MWMT criterion a total of 95 of 176 days monitored (54% of the time). The warmest site within Reach 3 (105SRS1DO) exceeded the MWMT criterion a total of 111 of 188 days monitored (59% of the time).

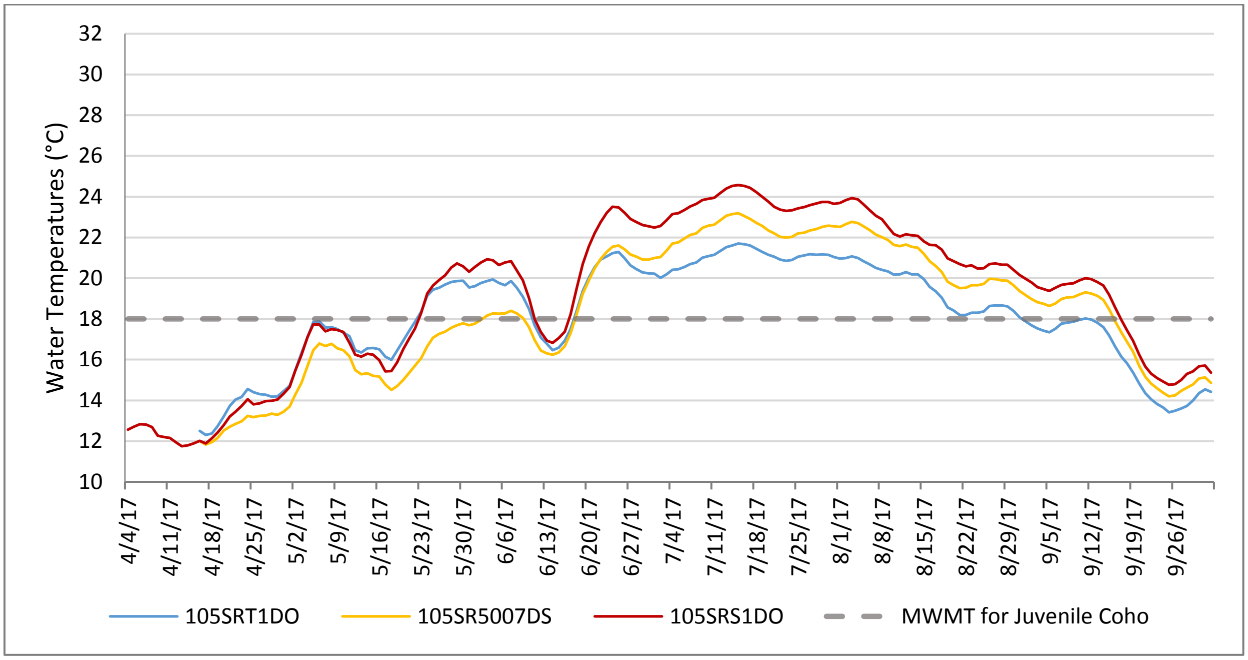

FIGURE 16. 2017 7-DAD MAX RIVER TEMPERATURES AT SITES WITHIN SHASTA RIVER REACH 3 AND MWMT FOR JUVENILE COHO.

REACH 2

Figure 17 displays MWMT criterion for juvenile coho salmon rearing and 7-DAD Maximum water temperatures at sites within Shasta River Reach 2. These sites are located downstream of the USGS operated Montague Weir (105SRMQ). 7-DAD Maximum temperatures at all sites within Reach 2 are generally consistent with one another with 7-DAD Maximum temperatures increasing only slightly in the downstream direction. All 7-DAD Maximum temperatures display a large dip corresponding with an early June weather event that brought approximately 0.75 inches of precipitation to the Shasta Valley. Data indicate an overall cooling trend in river temperature from mid-July until late-September, despite these typically being the warmest months of the year. This latter cooling trend correlates with the presence of heavy smoke from regional wildfires during mid-July through September that reduced solar intensity (Figure 2) and/or increased instream vegetation that can reduce river temperatures. The coolest site within Reach 3 (105SRM1DO) exceeded the MWMT criterion a total of 121 of 188 days monitored (64% of the time). The warmest site within Reach 2 (105SRA01T) exceeded the MWMT criterion a total of 123 of 188 days (65% of the time).

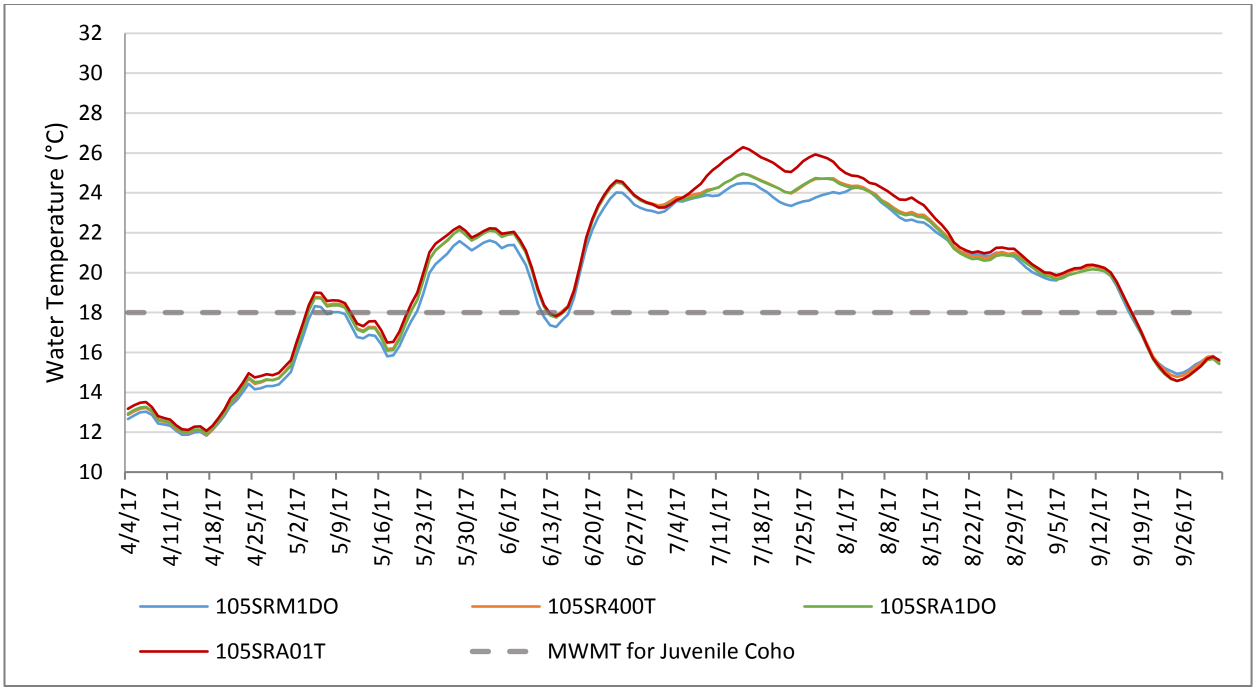

FIGURE 17. 2017 7-DAD MAX RIVER TEMPERATURES AT SITES WITHIN SHASTA RIVER REACH 2 AND MWMT FOR JUVENILE COHO.

REACH 1

Figure 18 displays MWMT criterion for juvenile coho salmon rearing and 7-DAD Max water temperatures at a site within the tributary Yreka Creek (105YCA01T) and sites downstream of the confluence of Yreka Creek within Shasta River Reach 1. 7-DAD Maximum temperatures at Yreka Creek are consistently cooler than all other sites within Reach 1 throughout the monitored period. The temperature gap between Yreka Creek and the Shasta River in Reach 1 widens substantially from mid-June through mid-August when Reach 1 7-DAD Maximum temperatures reach their maximums. Despite the cool water input from Yreka Creek, its flows are minimal, ranging from 2-5 cfs during the summer. 7-DAD Maximum temperatures throughout Reach 1 are generally consistent with each other, increasing only slightly in the downstream direction.

All 7-DAD Maximum temperatures display a large dip corresponding with an early June weather event that brought approximately 0.75 inches of precipitation to the Shasta Valley. Data indicate an overall cooling trend in river temperature from mid-July until late-September, despite these typically being the warmest months of the year. This latter cooling trend correlates with the presence of heavy smoke produced from regional wildfires during mid-July through September reduced solar intensity (Figure 2) and/or increased instream vegetation that can reduce river temperatures.

The coolest site measured within Reach 1 (105YCA01T) exceeded the MWMT criterion a total of 92 of 188 days monitored (49% of the time). The warmest site measured within Reach 1 (105SRL1DO) exceeded the MWMT criterion a total of 123 of 190 days monitored (65% of the time).

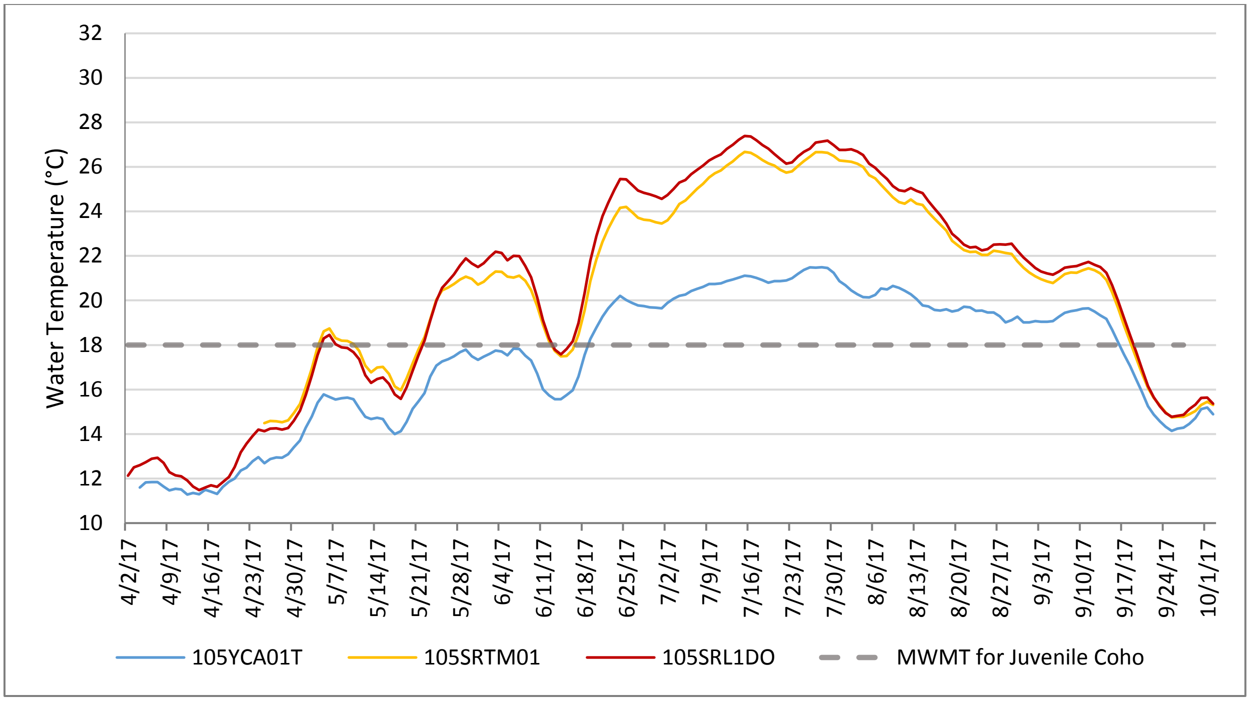

FIGURE 18. 2017 7-DAD MAX RIVER TEMPERATURES AT YREKA CREEK AND SITES WITHIN SHASTA RIVER REACH 1 AND MWMT FOR JUVENILE COHO.

TEMPERATURE CONCLUSIONS

Table 5 summarizes 2017 MWMT, MWAT, and Absolute Maximum temperatures recorded over the course of the period monitored at each site in the Shasta River, Parks Creek, and Yreka Creek. The general trend of 7-DAD Max temperatures among all sites measured is a continuous rise that appears to correlate with seasonal warming, and late season decreases that correlate with cooling temperatures and decreased solar radiation from regional wild fires and/or increased instream vegetation. All sites saw a peak in 7-DAD Max temperatures during the month of July, before the onset of the smoke. Exceptions to the late season cooling of the Shasta River are sites within Reach 6 in close proximity to Dwinnell Reservoir, and the 105SRHV Spring Pipeline Project which never experienced a warming trend.

Ambient air temperature plays a significant role in Shasta River water temperatures. Local factors that can buffer the effects of air temperature are riparian vegetation, topography (e.g., hill shade), cold water inflows, and structures that inhibit flows (e.g., weirs, flashboard dams and other impoundments) which may lead to reduced water velocity, greater water surface area and increased solar gains.

These data support continued efforts (e.g. riparian planting, tailwater reduction, spring-connection/enhancement projects, and impoundment removal) to decrease water temperatures in the Shasta River and its tributaries.

TABLE 5. SUMMARY TABLE OF 2017 RIVER TEMPERATURE RESULTS.

Reach	Site ID	River Mile	MWMT (°C)	MWAT (°C)	Absolute Max Temp (°C)
6	105DRE	39.8	n/a	n/a	n/a
	105SRXQ	39.8	n/a	n/a	n/a
	105DFBQ	39.8	n/a	n/a	n/a
	105SRHVRPOD	39.1	23.81	21.79	26.23
	105SRHVSPL	38.1	23.85	20.65	24.29
	105SRHVRALC	37.9	14.62	13.50	16.08
	105SRU1DO	337.9	20.28	17.55	21.103
	105SRHVDSSPG	37.8	19.32	17.06	19.75
	105SRU0IT	37.7	20.28	17.55	21.103
	105SR7163DS	36.9	22.23	18.52	23.16
	105SRHIGF	36.6	22.68	18.86	23.545
Parks Creek	(105SRP1DO)*	SR 33.9 (PC 0.04)**	25.20	22.66	26.05
Parks Creek Overflow	(105SRPCO)*	SR 33.1(PCO0.04)**	30.84	24.62	31.64
4	105SRN1DO	30.9	22.30	18.87	22.70
	105SRV1DO	26.0	22.62	19.74	26.89
	105SRV4AT	225.2	21.89	20.00	22.47
	105SRV4BT	24.3	21.60	20.21	22.23
3	105SRT1DO	23.0	21.70	20.50	27.58
	105SR5007DS	20.1	23.19	20.96	23.40
	105SRS1DO	16.7	24.57	21.72	24.89
2	105SRMQ	14.6	n/a	n/a	n/a
	105SRM1DO	14.6	24.48	22.26	24.91
	105SR400T	12.3	24.95	22.99	25.38
	105SRA1DO	11.8	24.97	23.04	25.39
	105SRA01T	10.2	26.93	23.55	33.78
Yreka Creek	(105YCA01T)*	SR 7.3 (YC 0.6)**	21.49	19.39	21.70
1	105SRTM01	5.3	26.67	23.97	27.24
	105SRL1DO	0.6	27.39	24.54	27.82
	105SRYQ	0.1	n/a	n/a	n/a

* Parentheses indicate that site was located on a tributary of the Shasta River
** Tributary river miles are provided both for where the tributary meets the mainstem as well as tributary river mile

DISSOLVED OXYGEN

Dissolved oxygen (DO) levels in surface waters are not constant, but change throughout the day as oxygen is added (by photosynthesis and reaeration) and removed (by carbonaceous and nitrogenous deoxygenation, sediment oxygen demand, and respiration) from the water. Salmonids such as coho and Chinook salmon are particularly sensitive to low DO concentrations as DO regulates metabolic activity in these and many fish species (Fry 1971). The 2015 North Coast Water Quality Control Plan states that the minimum dissolved oxygen concentration in the Shasta River should not fall below **6 mg/L**[1].

Diurnal DO fluctuations were recorded at nine monitoring sites on the Shasta River and its tributaries. Lowest DO concentrations were between 23:00 and 7:00 when respiration occurs without photosynthesis, while the highest concentrations of DO were between 12:00 and 15:00 when peak photosynthesis occurs.

DISSOLVED OXYGEN RESULTS

Figure 19 displays 2017 daily minimum dissolved oxygen measurements at all sites. The general trend among all sites measured was a continuous reduction in the daily minimum DO from early April through late July that correlates with seasonal warming, followed by increasing DO through early October that correlates with cooling temperatures, decreased solar radiation from regional wild fires and increased production of instream vegetation (e.g., macrophytes).

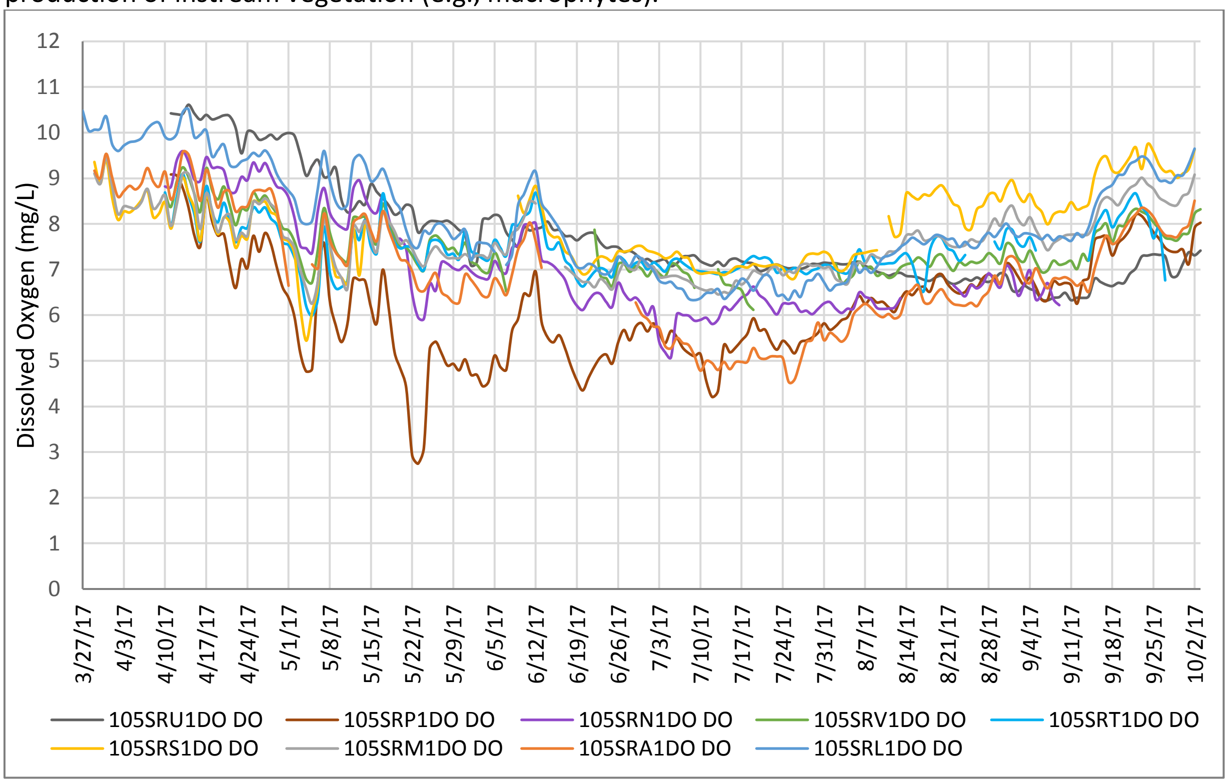

FIGURE 19. 2017 DAILY MINIMUM DO COMPARISON BETWEEN ALL SITES LISTED FROM LEFT TO RIGHT AND TOP TO BOTTOM IN ORDER OF UPSTREAM (REACH 6) TO DOWNSTREAM (REACH 1).

[1] Prior to the release of the 2015 standards, DO minimum was 7.0 mg/L.

Reach 6

DO measured in Reach 6 at 105SRU1DO did not fall below the NCWQCP minimum objective (6 mg/L DO) during the entire 176 days monitored (Figure 20).

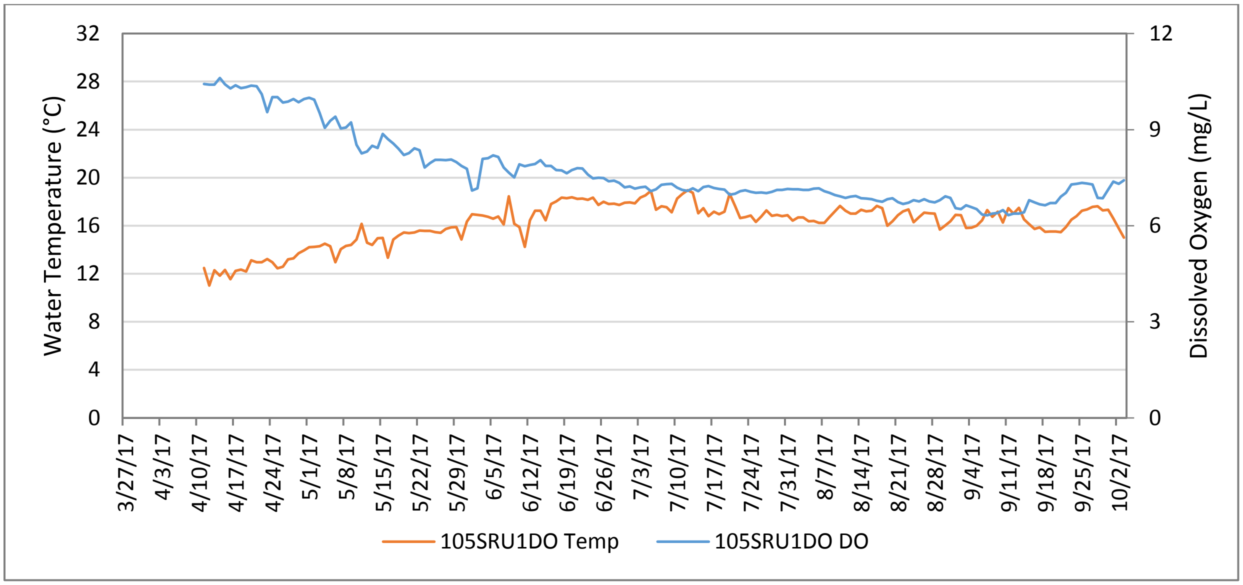

Figure 20. 2017 daily minimum DO and daily maximum water temperatures in Shasta River Reach 6 at 105SRU1DO.

Reach 5

DO measured in the mouth of Parks Creek 105SRP1DO fell below the NCWQCP minimum objective (6 mg/L DO) during 83 of 176 days monitored (47% of the time), reaching a low of 2.93 mg/l in May (Figure 21).

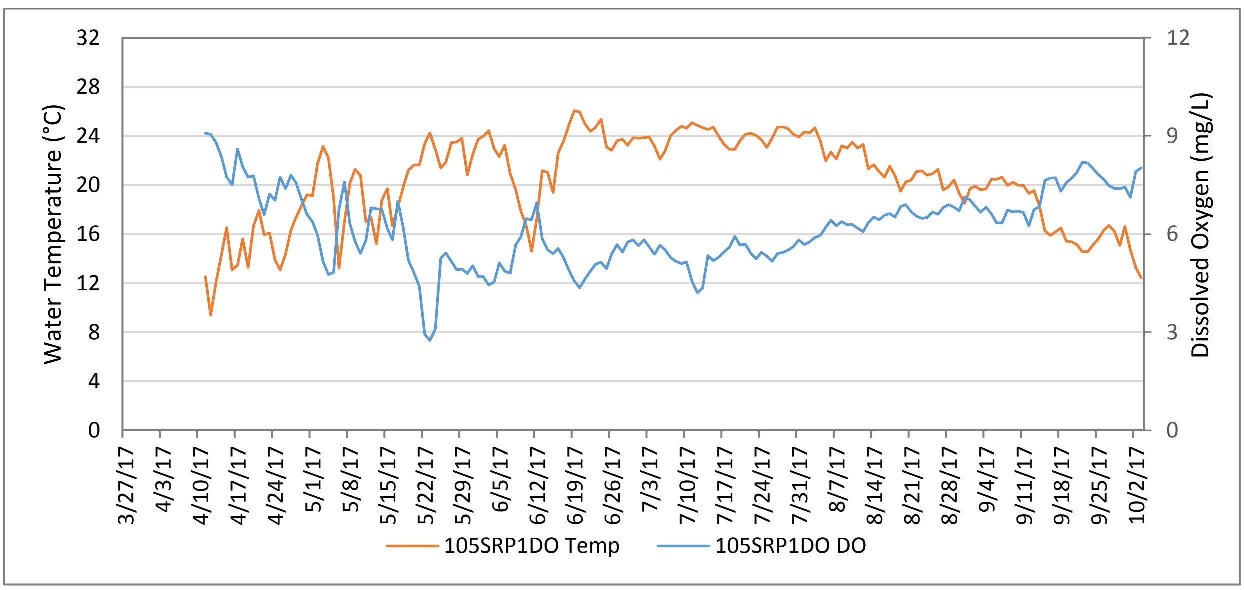

Figure 21. 2017 daily minimum DO and daily maximum temperatures in Parks Creek at 105SRP1DO.

REACH 4

DO in Reach 4 at 105SRN1DO fell below the NCWQCP minimum objective (6 mg/L DO) during 11 of 145 days monitored (7.6% of the time), and reached a low of 5.07 mg/l in early July (Figure 22). Data is missing August 14th[t] through August 24th, and September 10th through October 3rd, due to sensors obscured by vegetation and/or sediments.

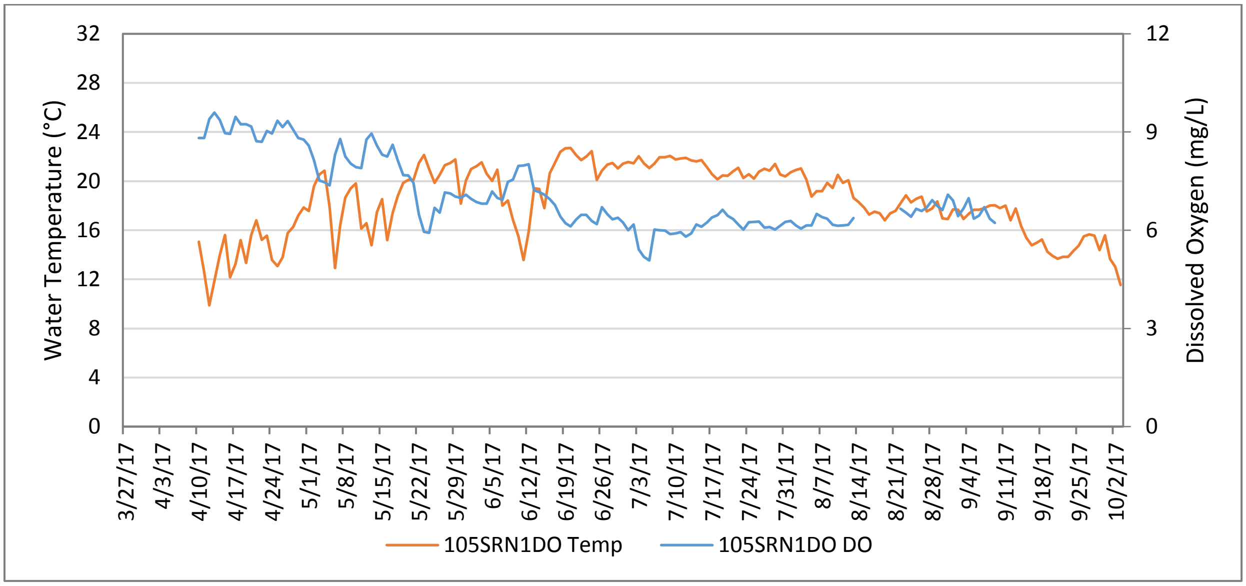

FIGURE 22. 2017 DAILY MINIMUM DO AND DAILY MAXIMUM TEMPERATURES IN SHASTA RIVER REACH 4 AT 105SRN1DO.

DO in Reach 4 at 105SRV1DO did not fall below the NCWQCP minimum objective (6 mg/L DO) during 147 days monitored (Figure 23). Data is missing June 8th through June 21st, July 10th through July 12th, and July 20th through August 1st due to sensors obscured by vegetation or sediments.

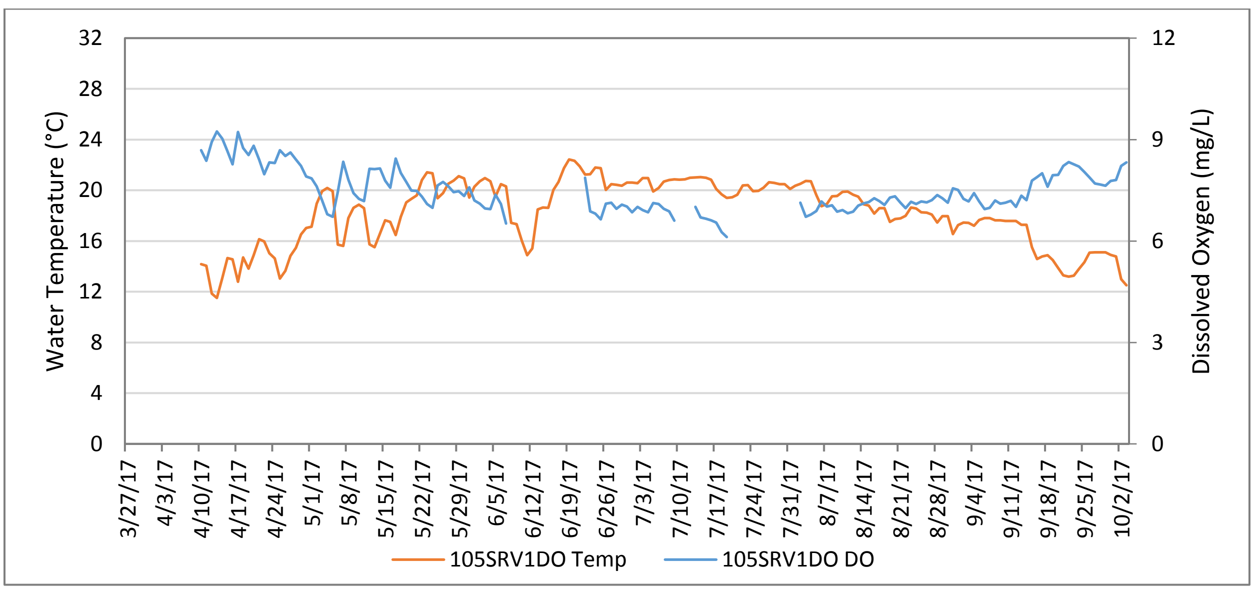

FIGURE 23. 2017 DAILY MINIMUM DO AND DAILY MAXIMUM TEMPERATURES IN SHASTA RIVER REACH 4 AT 105SRV1DO.

Reach 3

DO in Reach 3 at 105SRT1DO did not fall below the NCWQCP minimum objective (6 mg/L DO) during the entire 179 days monitored (Figure 24). Data is missing on August 25th through August 28th, September 6th through July 13th, due to sensors obscured by vegetation or sediments.

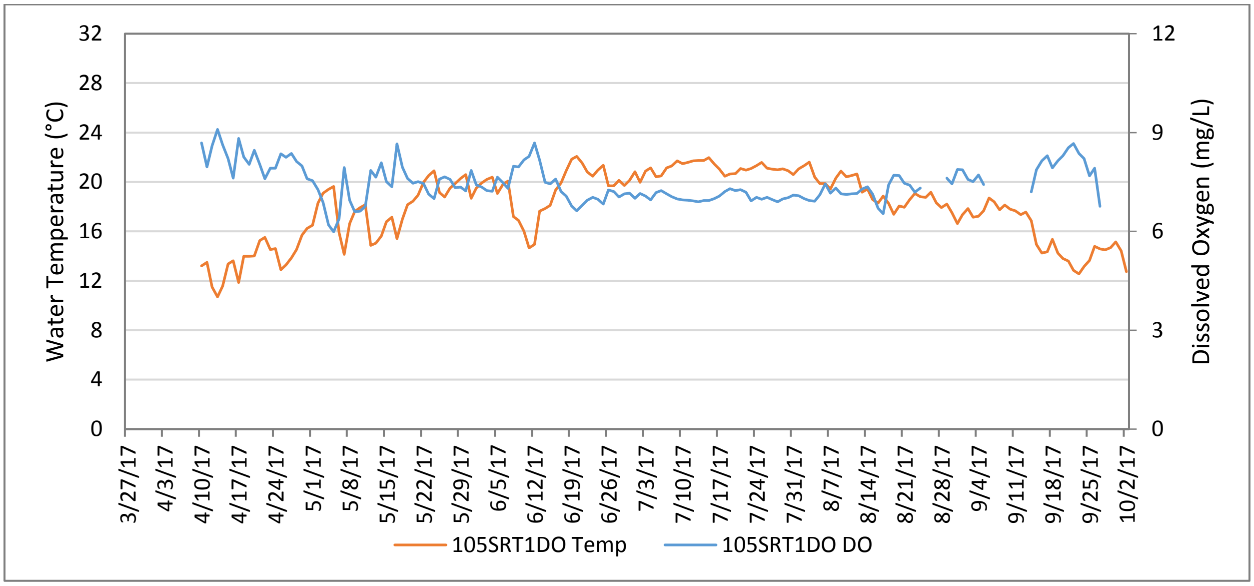

Figure 24. 2017 daily minimum DO and daily maximum temperatures in Shasta River Reach 3 at 105SRT1DO.

DO in Reach 3 at 105SRS1DO only fell below the NCWQCP minimum objective (6 mg/L DO) during 1 of 163 days monitored (0.6% of the time), reaching a low of 5.44 mg/l in early May (Figure 25). Data is missing on May 16th through June 8th due to equipment malfunctioning and on August 10th due to sensors obscured by vegetation or sediments.

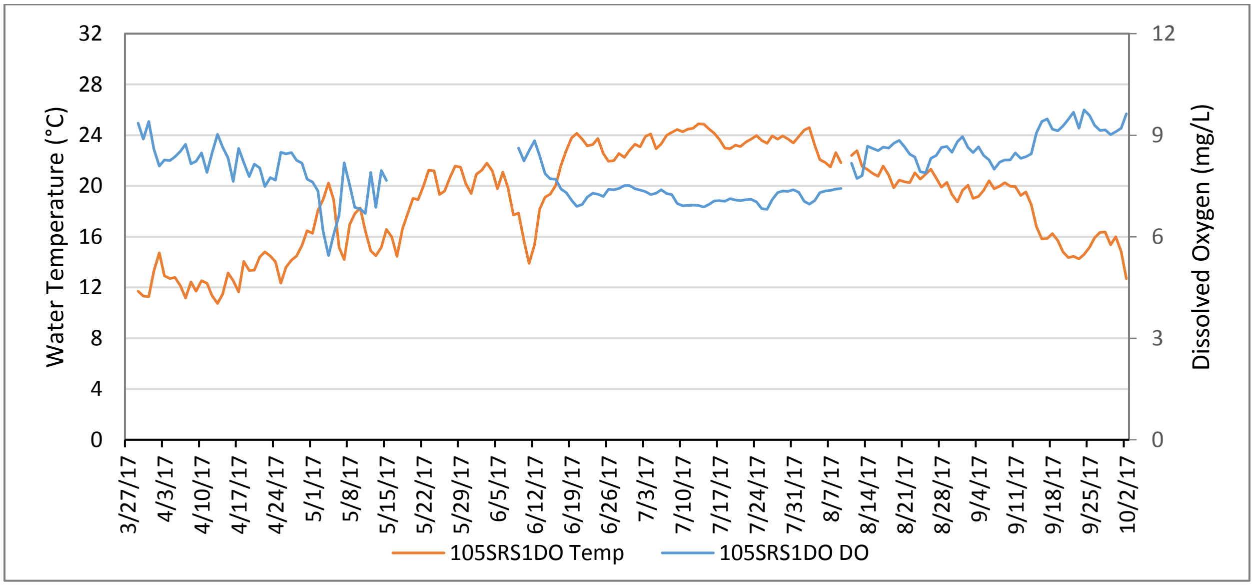

Figure 25. 2017 daily minimum DO and daily maximum temperatures in Shasta River Reach 3 at 105SRS1DO.

Reach 2

DO in Reach 2 at 105SRM1DO did not fall below the NCWQCP minimum objective (6 mg/L DO) during the 184 days monitored (Figure 26). Data is missing on June 13th through June 16th due to sensors obscured by vegetation or sediments.

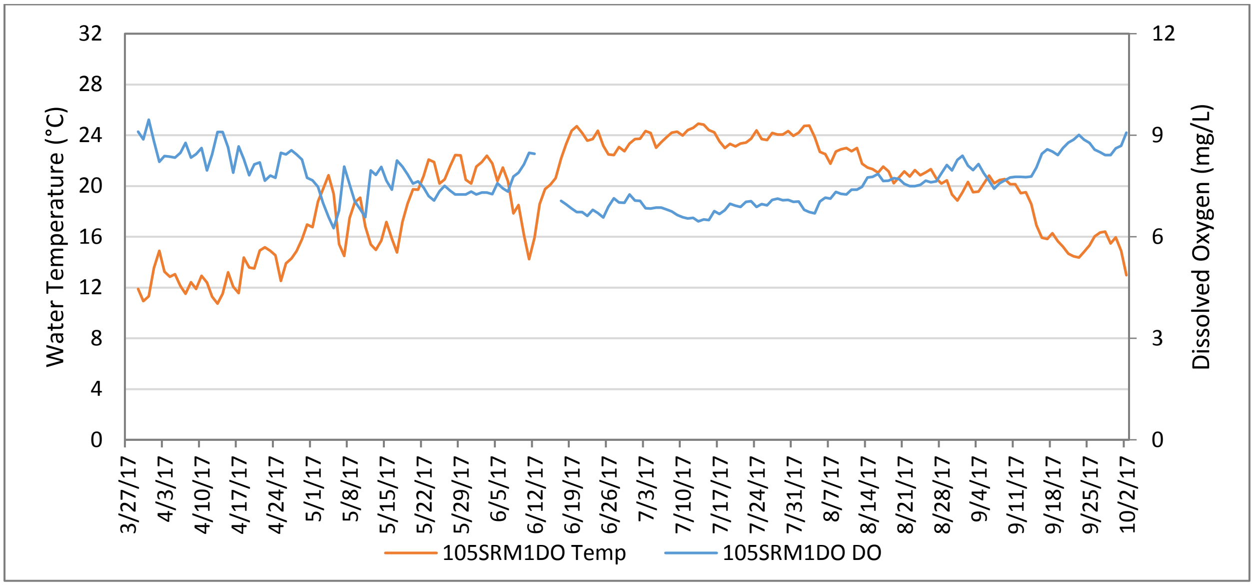

Figure 26. 2017 daily minimum DO and daily maximum temperatures in Shasta River Reach 2 at 105SRM1DO.

DO in Reach 2 at 105SRA1DO (Figure 27) fell below the NCWQCP minimum objective (6 mg/L DO) 37 of 170 days monitored (20% of the time), reaching a low of 4.56 mg/l in July. Data is missing on June 14th through June 28th due to sensors obscured by vegetation or sediment.

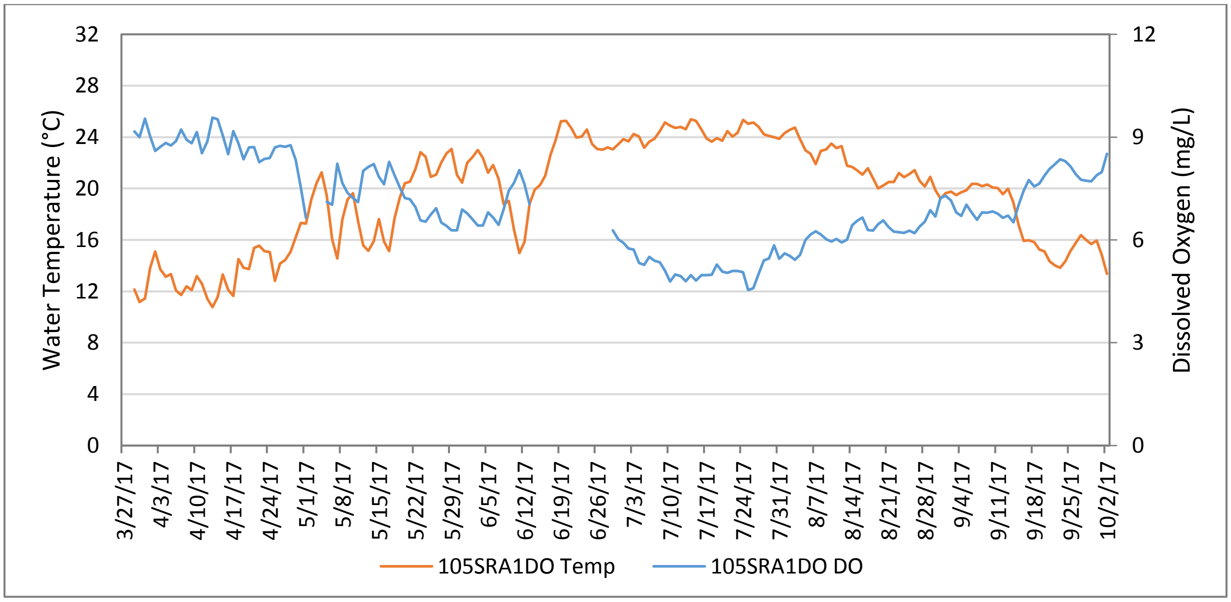

Figure 27. 2017 daily minimum DO and daily maximum temperatures in Shasta River Reach 2 at 105SRA1DO

REACH 1

DO in Reach 1 at 105SRL1DO did not fall below the NCWQCP minimum objective (6 mg/L DO) during the 189 days monitored (Figure 28). Data is missing on June 6th due to sensors obscured by vegetation or sediment.

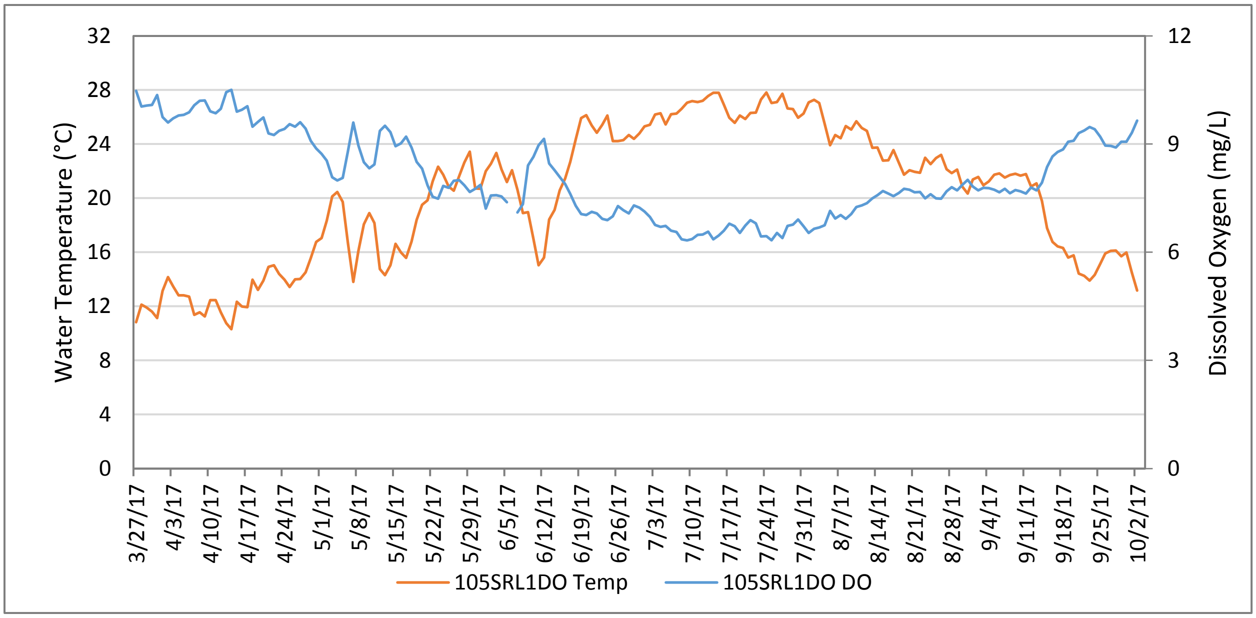

FIGURE 28. 2017 DAILY MINIMUM DO AND DAILY MAXIMUM TEMPERATURES IN SHASTA RIVER REACH 1 AT 105SRL1DO.

DISSOLVED OXYGEN CONCLUSION

In 2017, DO on the Shasta River fared well (above the minimum DO objective) in some areas and remained lower than minimum DO objectives in others. Reaches 3 and 6 recorded only one day during which DO fell below the minimum objective, and Reach 4 recorded 11 days below the objective at the upstream site (105SRN1DO) and 0 days below the objective at the downstream site (105SRV1DO). In Reach 2, DO was favorable at the upstream site (105SRM1DO) but fell below the minimum objective 37 days at the downstream site (105SRA1DO). The only monitoring site in Reach 5 is on Parks Creek tributary and this site had substantially higher DO than any Shasta River sites.

Irrigation system improvements and re-distribution of spring water on 105SRHV (Reach 6) decreased temperatures for at least 1.5 miles on the Shasta River, which likely contributed to increased DO levels at 105SRU1DO.

In Reach 4, a consistent flow of more than 50 cfs of cold spring water into the Shasta River from Big Springs Creek helped to generally keep DO levels above the minimum. However, wide and unshaded river conditions at 105SRN1DO, along with extensive macrophyte growth, which creates larger diurnal fluctuations and hence, lower minimum and higher maximum DO values, may explain why this site fell below the minimum DO objective 11 days.

Reach 3 experienced favorable DO conditions at both sites except for one day where DO fell below the minimum objective at the downstream site (105SRS1DO).

The upstream site in Reach 2 (105SRT1DO) experienced favorable DO conditions throughout the season while the downstream site (105SRA1DO) fell below the DO objective 37 days. Several factors that have not been investigated may explain the drop in DO at this site including: higher water temperatures due to lack of riparian shade, slower water velocities, higher sediment oxygen demand, less aquatic vegetation or a combination of all of these. More monitoring is needed to investigate low DO at 105SRA1DO.

105SRL1DO in Reach 1 likely experienced relatively high levels of DO due to aeration as the Shasta River tumbles through the canyon here and creates oxygen rich riffles. This site also experienced high temperatures that would typically lower DO levels as can be seen at 105SRA1DO in Reach 2. In addition to increased aeration through the canyon, another explanation for these higher than expected DO levels in Reach 1 could be the effect of increased macrophyte (aquatic vegetation) growth.

CONCLUSION

In general, temperature on the Shasta River exceeded TMDL and MWMT objectives in 2017, while DO levels were above minimum objectives at most sites but fell below those objectives at others. These mixed results suggest that, in general, DO and especially temperature did not meet NCWQCP objectives.

However, post-project monitoring results from projects completed at 105SRHV that included the Spring Pipeline which provides cold spring water into the Shasta River in Reach 6, and a tailwater berm designed to release tailwater during the coolest part of the day, demonstrated a reduction in temperature more than 1.5 miles downstream of the Spring Pipeline outlets (when compared to upstream sites); and an increase in DO over 2016 results at the same site.

The results from this annual monitoring report, as well as a multi-year analysis of temperatures and DO on the Shasta River that can be found in the 2018 Shasta River Watershed Stewardship Report, support continued efforts (e.g. riparian planting, tailwater reduction, spring-connection/enhancement projects, and impoundment removal) to decrease water temperatures and improve DO conditions in the Shasta River.

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