CHAPTER 6. TEMPERATURE TMDL

6.1 Introduction

This chapter presents the temperature TMDL for the Shasta River. The analytical approach in developing the temperature TMDL involved application of the RMS model of the Shasta River to determine a suite of conditions that result in water quality standards attainment under critical conditions. Regional Water Board staff developed a "water quality compliance" model scenario that characterizes Shasta River watershed conditions that reflects "natural receiving water temperatures" and result in water quality standards attainment.

6.2 Water Quality Compliance Scenario Conditions

The process used to develop the water quality compliance scenario involved separately evaluating the components identified in the temperature source and linkage analysis (Chapter 3) that affect Shasta River stream temperature. The components that were evaluated include riparian shade, tailwater return flow temperatures, the temperature regime of key tributaries, and flow.

The water quality compliance scenario for temperature represents baseline conditions with the following key modifications:

1. Increased riparian shade to represent site potential riparian conditions on a river-reach scale;
2. Modified temperature regime of tailwater return flows such that the return flows do not cause heating of the receiving water;
3. Modified temperature regime of key tributaries to reflect site potential shade conditions and elimination of receiving water heating by tailwater return flows; and
4. Increased Shasta River flows.

These modifications are presented below.

6.2.1 Shade

The objective of the shade modifications was to characterize riparian shade conditions that reflect site potential shade conditions. As outlined in Section 3.6 of Appendix D (Geisler and Watercourse Engineering, Inc 2005), riparian vegetation shading is represented in RMS by solar radiation transmittance. Solar radiation transmittance is defined as the amount of solar radiation that passes through the tree canopy and reaches the water surface. A value of 1.0 represents no shade and is equal to a percent transmittance of 100%, while a value of 0.0 would represent complete shade and is equal to a percent transmittance of 0%.

Regional Water Board staff developed depictions of site potential percent transmittance values by river reach based on available information about Shasta River riparian conditions. The information used in depicting site potential riparian shade conditions included:

- The Shasta River Woody Riparian Vegetation Inventory conducted by UC Davis for the Shasta Valley RCD (Deas et al. 1997);
- Riparian vegetation surveys and solar radiation measurements within the riparian corridor of the Shasta River conducted by Watercourse Engineering, Inc. in support of the Shasta River Flow and Temperature Modeling Project developed for the Shasta Valley RCD (Deas et al. 2003; Watercourse Engineering, Inc. 2004, Table 2-8);
- Riparian vegetation density characterization by Regional Water Board and UC Davis staff in 2004 (NCRWQCB and UCD AEAL 2005);
- Review of recent aerial photographs of the Shasta River, Big Springs Creek, and Parks Creek riparian corridor (Watershed Sciences, LLC 2004); and
- Assessment of soil conditions within the riparian corridor of the Shasta River based on USDA Soil Survey of Siskiyou County (USDA 1983), field observations, and anecdotal information about Shasta River riparian corridor soil conditions provided by local residents.

Based on this information, Regional Water Board staff defined reach-average percent transmittance values associated with varying riparian shade conditions (Table 6.1)

Table 6.1: Reach average percent transmittance associated with varying riparian shade conditions

Reach Average % Transmittance	Riparian Condition
10	Contiguous dense woody riparian with complete overhang across channel.
30	Contiguous dense woody riparian with near-complete overhang across channel. Or, patchy (70% of reach length) dense woody riparian with complete overhang.
50	Patchy (70% of reach length) woody riparian with near-complete overhang.
85	No woody riparian; near contiguous dense herbaceous (e.g. bulrush) growth. Or, disperse moderately dense patches of woody riparian, mixed with patches of herbaceous (e.g. bulrush) growth.
95	No woody riparian; patchy (10% or reach length) dense herbaceous (e.g. bulrush) growth.
100	No riparian vegetation provides measurable shade.

Using these reach-average percent transmittance to riparian condition relationships, Regional Water Board staff estimated *potential* riparian percent transmittance values for the Shasta River (Table 6.2). The potential riparian percent transmittance values presented in Table 6.2 account for natural riparian disturbance such as floods, wind throw, disease, landslides, and fire. These reach average percent transmittance values replaced the baseline percent transmittance values in the water quality compliance scenario. Considerations used in assigning the potential reach average percent transmittance values to the Shasta River reaches included: existing riparian vegetation condition, existing channel morphology, and soil conditions within the riparian corridor, based on the information cited above.

Table 6.2: Current and potential riparian reach-average percent transmittance values for the Shasta River

Reach	Upstream River Mile	Downstream River Mile	Reach Average Percent Transmittance[1]	
			Current	TMDL
Dwinnell Dam to Riverside Road	40.6	39.9	59	30
Riverside Road to u/s of A12	39.9	28.3	76	50
U/S of A12 to near DeSoza Lane	28.3	22.0	95	85
Near DeSoza Lane to u/s of Montague-Grenada Road	22.0	16.1	89	30
Near Montague-Grenada Road	16.1	14.6	90	10
D/S Montague-Grenada Road to Hwy 263	14.6	7.3	78	30
Hwy 263 to mouth	7.3	0	70 to 100	30 to 50[2]

[1] Daylight-hour average percent transmittance for given reach.
[2] Alternate between 30 and 50% every 10 percent of reach length.

6.2.2 Tailwater Return Flows

In the RMS model, tailwater return flows are depicted as a portion of total accretion flows within a model reach, and the model represents these accretions as distributed flows along a length of the reach (see Section 4.0 in Appendix D). For the existing condition (baseline) model runs, the temperatures assigned to these accretions, including tailwater return flows, were the temperatures of the Shasta River at Anderson Grade Road (see Section 5.1.1 of Appendix D). This decision was based on review of temperature data from 2001 and 2002, which indicated that river temperatures were approaching equilibrium temperature by the end of the Shasta Valley (i.e., near Anderson Grade). This assumes that the temperature of tailwater return flows are at equilibrium with air temperature, and the temperature time series at Anderson Grade Road was used as a surrogate.

For the water quality compliance scenario the temperatures for tailwater return flows were assigned the temperature of the Shasta River at the model node closest to the mid-point of the distributed flow reach. In other words, this assumes that the temperatures of the tailwater return flows are equal to the reach average temperature of the accretion reach. By attributing tailwater return flow temperatures in this manner, the water balance of the model was maintained, but the heat load from the tailwater return flows did not cause a change in the reach average temperature of the Shasta River.

6.2.3 Tributary Temperatures

The RMS model depicts inflows from Big Springs Creek, Parks Creek, and Yreka Creek as discrete inputs to the Shasta River. The other tributaries to the Shasta River are accounted for as a portion of total accretion flows within the appropriate river reach. The water quality compliance scenario involved modifying the temperature boundary conditions associated with the inputs from Big Springs Creek and Parks Creek to account for reductions in stream temperature that could occur given site potential riparian shade and modified heat load from tailwater return flows within these sub-watersheds. No change was applied to Yreka Creek stream temperature. The modifications assigned to Big Springs Creek and Parks Creek are presented below.

6.2.3.1 Big Springs Creek

Due to access limitations, no stream temperature data is available at the mouth of Big Springs Creek. Section 5.1.1 of Appendix D identifies the temperature boundary condition assigned to Big Springs Creek for the baseline condition, which average 17°C. For the water quality compliance scenario inflow temperatures from Big Springs Creek were set to baseline minus 4°C, for an average of 13°C.

Regional Water Board staff measured the water temperature of Big Spring proper (the spring at the eastern end of Big Springs Lake) and at the outlet of Big Spring Lake for 3-day periods in August and September 2003 (NCRWQCB 2004b). During these periods water temperature at Big Spring was constant, ranging from 11.26 to 11.31°C. The water temperature of Big Springs Lake at a depth of approximately 3 feet below water surface near the outlet of the lake ranged from 10.49°C to 12.86°C, averaging 11.7°C.

Big Springs Creek is approximately 2.3 miles long from the outlet of Big Springs Lake to its confluence with the Shasta River. The July 2003 thermal infrared (TIR) survey of Big Springs Creek showed that there are four springs that flow into Big Springs Creek within 0.4 miles downstream of the outlet of Big Springs Lake (Watershed Sciences, LLC 2004 [included as Appendix B of this report]). On the date of the TIR survey (July 27, 2003) the surface water temperature of Big Springs Creek dropped from ≈ 17.4°C near the outlet of Big Springs Lake to ≈15.6°C downstream of these springs. Further downstream of these springs, the surface temperature of Big Springs Creek increased 5.4°C within 1.2 miles, and then remained fairly constant for the remaining 0.7 miles before flowing into the Shasta River at ≈ 20.8°C. Based on these survey results, the overall rate of heating in Big Springs Creek is approximately 2.7°C/mile, with a maximum rate of heating of 4.5°C/mile. By contrast, based on July 27, 2003 TIR survey results, the rate of heating in the Shasta River in reaches not affected by surface water diversion was approximately 0.35°C/mile.

Aerial and TIR images of Big Springs Creek show there is no shade producing vegetation along Big Springs Creek, and that irrigation return flows contribute to heating of the creek. In addition aerial images show that the channel is quite wide, braided, and choked with aquatic vegetation.

Based on the information outlined above, Regional Water Board staff estimate that if riparian shade were at or near site potential conditions within the Big Springs Creek sub-watershed, and tailwater return flows did not cause heating of the receiving water, the rate of heating of Big Springs Creek could approximate 0.35°C/mile. Assuming an average temperature of 11.7°C at the outlet from Big Springs Lake, and applying the 0.35°C/mile rate of heating to the 2.3 miles of the Creek to the mouth, the resulting average temperature at the mouth would be approximately 12.5°C, rounded up to 13°C. Thirteen °C is equal to the average baseline temperature of 17°C minus 4°C. Therefore, for the water quality compliance scenario inflow temperatures from Big Springs Creek were set to baseline minus 4°C.

6.2.3.2 Parks Creek
Due to access limitations, stream temperature data at the mouth Parks Creek is limited. Section 5.1.1 of Appendix D identifies the temperature boundary condition assigned to Parks Creek for the baseline condition. For the water quality compliance scenario inflow temperatures from Parks Creek were set to baseline minus 2°C.

Based on the July 2003 TIR survey of the Shasta River, Parks Creek adds a heat load to the river that causes an increase in the surface temperature of the Shasta River of approximately 2°C just downstream of the confluence of Parks Creek (see Figure 3.1 in Chapter 3). On the day of the TIR survey the surface temperature at the mouth of Parks Creek was 26.6°C compared with a surface water temperature of the Shasta River just upstream of the confluence of 21.4°C (Watershed Sciences, LLC 2004).

Parks Creek is approximately 23 miles long. The headwaters flow from Mt. Eddy, and the creek is largely fed from snowmelt. From June through September 2003 the weekly average temperature in Parks Creek near its headwaters ranged from approximately 10°C to 17.5°C. From its headwaters Parks Creek traverses northeast through the Shasta Valley before entering the Shasta River. Aerial and TIR images show that the channel has almost no shade producing vegetation throughout the lower reaches in the Shasta Valley. In addition, the aerial and TIR images show that Parks Creek is characterized by multiple water withdraws, surface return flows, and tributary and spring seep inflows. On July 27, 2003, the day of the Parks Creek TIR survey, there was very little flow in some reaches of the creek, and the temperature of the creek appeared to respond dramatically to any mass transfers.

Based on this information it is apparent that the temperatures of Parks Creek are significantly affected by water management practices. Regional Water Board staff estimate that if riparian shade were at or near site potential conditions within the Parks Creek sub-watershed, if tailwater return flows did not cause heating of the receiving water, and if less cold water sources were diverted, the temperature regime at the mouth of Parks Creek could be reduced by at least 2°C from baseline.

6.2.4 Flow
To evaluate the effect of flow increases on Shasta River temperatures, a number of flow increase scenarios were applied. The simulations involved maintaining baseline conditions (i.e., none of the modifications outlined in Sections 6.2.1, 6.2.2, and 6.2.3 were applied), while increasing baseline flows by 50% at select locations in the Shasta River. The temperature assigned the increased flow was equal to the baseline temperature at the corresponding river location. The volume of water associated with the 50% flow increase was maintained to the mouth of the Shasta River. The Shasta River locations at which flows were increased by 50% included Dwinnell Dam, downstream of Big Springs Creek confluence, Grenada Irrigation District, Highway A12, Montague Grenada Road, and Anderson-Grade Road. The 50% flow increases were applied to these locations one at a time in a step-wise fashion. In other words, in the first simulation Dwinnell Dam flows were increased by 50% above baseline. In the second simulation

the Dwinnell Dam flows reverted to the baseline flow, and flows downstream of Big Springs Creek confluence were increased by 50%, and so on.

The baseline (i.e. 100%) and 150% flows in the Shasta River at the flow increase locations are presented in Table 6.3.

Table 6.3: Average baseline and 150% flows

Shasta River Location	Average Baseline flow (cfs)	Average 150% flow (cfs)
Dwinnell Dam	5	7.5
Downstream of Big Springs Creek confluence	93	138
Grenada Irrigation District	55	82
Highway A12	73	109
Montague Grenada Road	27	40
Anderson Grade Road	22	33

Before presenting the results of the flow increase simulations, the model simulation periods are identified with a discussion regarding critical conditions.

6.3 Model Simulation Periods, Critical Conditions, and Critical Locations

As discussed in Chapter 2, the Shasta River is impaired by high temperature and low dissolved oxygen during summer months. The model simulations were run using the meteorological conditions for the model calibration and validation time periods: July 2 - 8, 2002; August 29 – September 4, 2002, and September 17 – 23, 2002. The 50% flow increase simulations were run only for the August simulation period.

Table 6.4 compares the maximum daily air temperature for the 2002 model run periods to the average of the daily maximum air temperatures for the sixteen years of record at the USGS meteorological gauging station at Brazie Ranch, located west of the Shasta River near the City of Yreka. As identified in Section 5.2 of Appendix D, Brazie Ranch is the source of meteorological data used for the Shasta River temperature and dissolved oxygen model. Table 6.4 shows that the measured daily maximum air temperatures for the model run dates in 2002 consistently exceed the 16-year average of the daily maximum air temperatures for these same dates.

Figure 1.6 in Chapter 1 shows that the Shasta River annual discharge in 2002 was well below the average annual discharge during the period of record. Further, Figure 1.8 in Chapter 1 shows that in 2002 Shasta River flows rank the 19th lowest of the 67 years for which there is a complete flow record.

Based on a review of these air temperature and flow records, Regional Water Board staff determined that the model simulation periods represent critical conditions for the Shasta River with respect to stream temperature. Finally, the August simulation period was selected for the flow scenarios as flows were lowest during this time period in 2002, and therefore, represent a critical condition.

Table 6.4: Brazie Ranch air temperature data (degrees C)

Date	2002 Daily Maximum	16-Year Average Daily Maximum
July 2	94	73
July 3	86	79
July 4	84	80
July 5	90	80
July 6	91	83
July 7	85	81
July 8	88	84
August 29	92	78
August 30	90	82
August 31	90	81
September 1	95	76
September 2	96	71
September 3	87	70
September 4	77	70
September 17	70	67
September 18	81	69
September 19	89	72
September 20	89	73
September 21	88	73
September 22	91	74
September 23	94	74

Juvenile salmonids are known or suspected to rear in the following reaches of the Shasta River: Grenada Irrigation District pumps to Highway A-12, near Breceda Lane, and in the Shasta Canyon at a side channel known as “Salmon Heaven”. Based on this information, the following locations are considered temperature compliance locations, as they are at or near the downstream end of these critical summer rearing locations:

- Highway A-12 (RM 24.1),
- Montague-Grenada Road (RM 15.5), and
- “Salmon Heaven” (RM 5.6).

6.4 Model Simulation Temperature Results and Discussion

This section presents the RMS model simulation results. The temperature results of the flow increase simulations are presented in Section 6.4.1. The temperature results of the water quality compliance scenario are presented in Section 6.4.2.

6.4.1 Flow Increase Simulations

The RMS model predicts stream temperature at numerous locations in the Shasta River. Figure 6.1 identifies select model output locations. The temperature results of the six flow increase simulations and baseline condition are presented in Figure 6.2 and Table 6.5. Figure 6.2 shows the maximum and minimum temperatures in the Shasta River associated with each of the simulations. The maximum, minimum, and average water temperatures for the flow increase scenarios are presented in Table 6.5, and the increases or decreases in these temperatures compared with the baseline condition are identified.

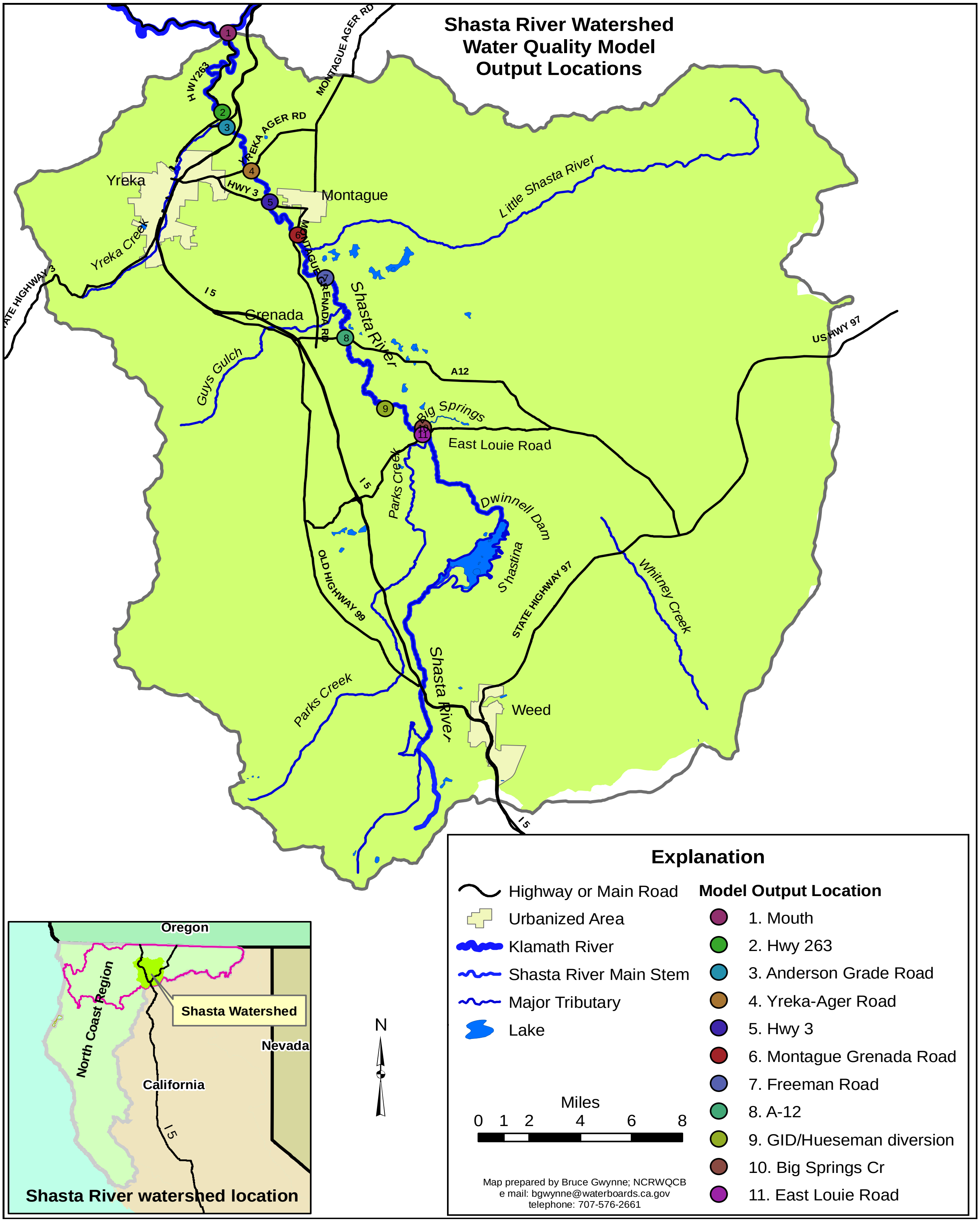
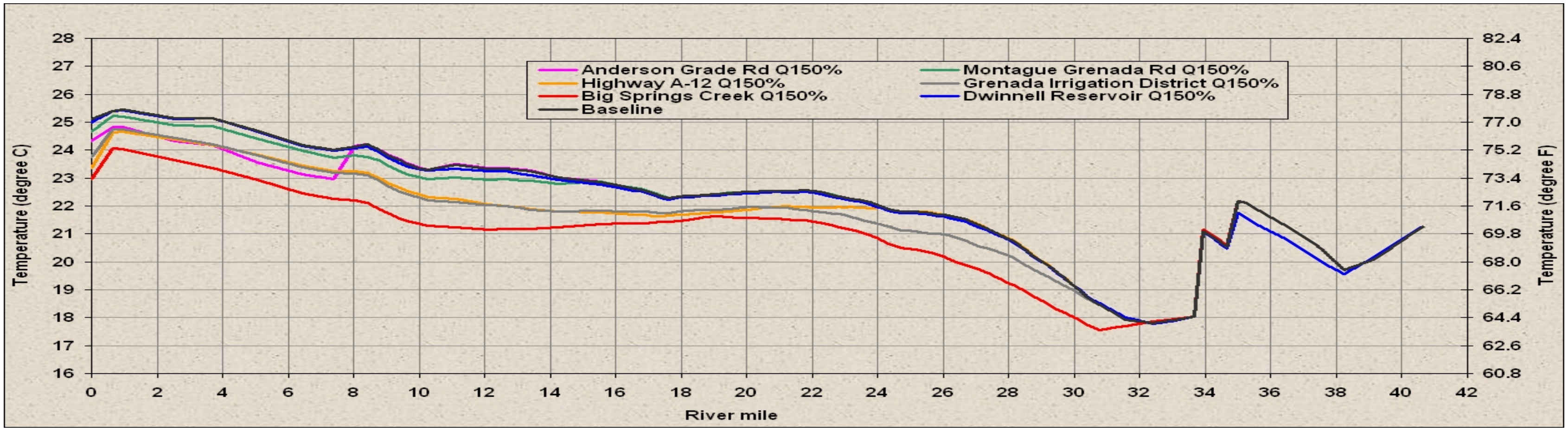
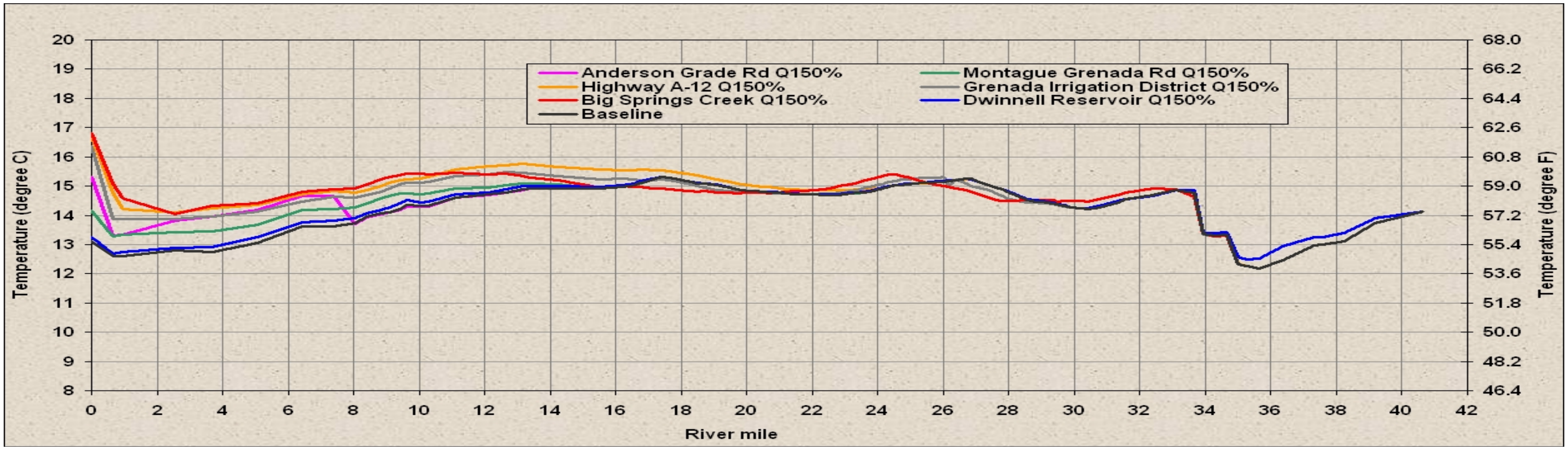


Figure 6.1: Shasta River flow, temperature, and dissolved oxygen model output locations



(A)



(B)

Figure 6.2: 50% flow increase simulations; Maximum (A) and minimum (B) temperature results

Table 6.5: 50% flow increase simulation temperature results and change from baseline

Compliance Points	River Mile	August Baseline	Maximum Modeled Temperature Values (August Baseline with increased incremental flows)						Maximum Modeled Differences in Stream Temperature compared to August Baseline (Increase or (decrease))					
			Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road	Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road
Dwinnell Dam	42.60	21.27	21.27	21.27	21.27	21.27	21.27	21.27	0.00	0.00	0.00	0.00	0.00	0.00
Louie Road	33.93	21.09	21.09	21.16	21.16	21.16	21.16	21.16	0.00	0.07	0.07	0.07	0.07	0.07
GID	30.59	18.68	18.72	17.74	18.65	18.69	18.69	18.69	0.04	(0.94)	(0.03)	0.01	0.01	0.01
Highway A-12	24.11	22.05	21.98	20.86	21.37	21.92	22.06	22.06	(0.07)	(1.19)	(0.68)	(0.13)	0.01	0.01
Freeman Lane	19.23	22.42	22.38	21.62	21.86	21.78	22.43	22.43	(0.04)	(0.80)	(0.56)	(0.64)	0.01	0.01
M-G Road	15.52	22.85	22.75	21.36	21.84	21.77	22.88	22.88	(0.10)	(1.49)	(1.01)	(1.08)	0.03	0.03
Highway 3	13.16	23.28	23.14	21.17	21.91	21.93	22.91	23.30	(0.14)	(2.11)	(1.37)	(1.35)	(0.37)	0.02
Yreka Ager Road	10.91	23.48	23.33	21.25	22.13	22.25	23.03	23.50	(0.15)	(2.23)	(1.35)	(1.23)	(0.45)	0.02
Anderson Grade Road	8.03	24.13	24.07	22.20	23.16	23.24	23.80	24.14	(0.06)	(1.93)	(0.97)	(0.89)	(0.33)	0.01
Highway 263	7.30	24.19	24.16	22.46	23.39	23.44	23.97	23.12	(0.03)	(1.73)	(0.80)	(0.75)	(0.22)	(1.07)
"Salmon Heaven"	5.60	24.68	24.67	22.93	23.80	23.83	24.41	23.57	(0.01)	(1.75)	(0.88)	(0.85)	(0.27)	(1.11)
Mouth	0.66	25.46	25.43	24.03	24.75	24.66	25.21	24.82	(0.03)	(1.43)	(0.71)	(0.80)	(0.25)	(0.64)

Compliance Points	River Mile	August Baseline	Average Modeled Temperature Values (August Baseline with increased incremental flows)						Average Modeled Differences in Stream Temperature compared to August Baseline (Increase or (decrease))					
			Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road	Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road
Dwinnell Dam	42.60	17.56	17.56	17.56	17.56	17.56	17.56	17.56	0.00	0.00	0.00	0.00	0.00	0.00
Louie Road	33.93	17.60	17.62	17.60	17.60	17.59	17.60	17.59	0.02	0.00	(0.00)	(0.00)	(0.00)	(0.00)
GID	30.59	16.87	16.89	16.65	16.85	16.87	16.87	16.87	0.02	(0.22)	(0.02)	(0.00)	(0.00)	(0.00)
Highway A-12	24.11	18.38	18.36	17.77	18.07	18.39	18.38	18.38	(0.02)	(0.61)	(0.31)	0.01	0.00	0.00
Freeman Lane	19.23	18.80	18.78	18.16	18.47	18.74	18.81	18.81	(0.03)	(0.65)	(0.33)	(0.07)	0.00	0.00
M-G Road	15.52	18.95	18.95	18.39	18.69	18.91	18.96	18.96	(0.01)	(0.57)	(0.26)	(0.04)	0.00	0.00
Highway 3	13.16	18.98	18.98	18.49	18.78	18.98	19.02	18.98	(0.01)	(0.50)	(0.21)	(0.01)	0.03	(0.00)
Yreka Ager Road	10.91	18.94	18.95	18.56	18.82	19.00	19.01	18.94	0.01	(0.39)	(0.13)	0.06	0.07	(0.00)
Anderson Grade Road	8.03	18.82	18.85	18.68	18.86	19.01	18.97	18.82	0.03	(0.14)	0.04	0.19	0.15	(0.00)
Highway 263	7.30	18.77	18.80	18.70	18.86	19.00	18.94	18.77	0.03	(0.07)	0.09	0.23	0.17	(0.00)
"Salmon Heaven"	5.60	18.73	18.77	18.77	18.90	19.03	18.93	18.74	0.04	0.04	0.17	0.30	0.20	0.01
Mouth	0.66	18.69	18.73	18.90	18.89	19.06	18.88	18.74	0.04	0.20	0.19	0.37	0.19	0.04

Compliance Points	River Mile	August Baseline	Minimum Modeled Temperature Values (August Baseline with increased incremental flows)						Minimum Modeled Differences in Stream Temperature compared to August Baseline (Increase or (decrease))					
			Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road	Dwinnell Dam	Big Springs	GID	Highway A-12	M-G Road	A-G Road
Dwinnell Dam	42.60	14.14	14.14	14.14	14.14	14.14	14.14	14.14	0.00	0.00	0.00	0.00	0.00	0.00
Louie Road	33.93	13.37	13.38	13.36	13.35	13.35	13.35	13.35	0.01	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
GID	30.59	14.21	14.25	14.47	14.22	14.21	14.21	14.21	0.04	0.26	0.01	0.00	0.00	0.00
Highway A-12	24.11	14.86	14.88	15.29	15.02	14.91	14.86	14.86	0.02	0.43	0.16	0.05	0.00	0.00
Freeman Lane	19.23	15.04	15.05	14.79	14.86	15.22	15.04	15.04	0.01	(0.25)	(0.18)	0.18	0.00	0.00
M-G Road	15.52	14.92	14.98	14.96	15.23	15.56	14.92	14.92	0.06	0.04	0.31	0.64	0.00	0.00
Highway 3	13.16	14.90	15.00	15.33	15.45	15.77	15.10	14.87	0.10	0.43	0.55	0.87	0.20	(0.03)
Yreka Ager Road	10.91	14.62	14.73	15.45	15.33	15.58	14.91	14.60	0.11	0.83	0.71	0.96	0.29	(0.02)
Anderson Grade Road	8.03	13.72	13.89	14.91	14.61	14.77	14.26	13.69	0.17	1.19	0.89	1.05	0.54	(0.03)
Highway 263	7.30	13.62	13.77	14.80	14.47	14.72	14.17	14.66	0.15	1.18	0.85	1.10	0.55	1.04
"Salmon Heaven"	5.60	13.05	13.24	14.40	14.13	14.36	13.68	14.17	0.19	1.35	1.08	1.31	0.63	1.12
Mouth	0.66	12.61	12.74	14.57	13.87	14.22	13.34	13.33	0.13	1.96	1.26	1.61	0.73	0.72

The following conclusions are drawn from the flow increase simulation results:

- Maximum stream temperatures are reduced from the baseline condition at all locations downstream of the flow increase location in the river for each of the six 50% flow increase simulations.
- Minimum stream temperatures are increased from the baseline condition downstream of approximately RM 15 for each of the six 50% flow increase simulations.
- The largest reduction in maximum stream temperature is associated with the 50% flow increase downstream of the Big Springs Creek confluence.
- The temperature associated with a 50% flow increase greatly influences the temperature results.
- The Big Springs Creek 50% flow increase simulation resulted in maximum stream temperature reductions of approximately 1°C to 2°C, with the largest reduction of 2.2°C at Yreka Ager Road (RM 10.9). At River Mile 5.6, an important location for summer rearing, the maximum stream temperature is reduced by approximately 1.8°C from baseline.
- The Big Springs Creek 50% flow increase simulation resulted in minimum stream temperature increases of approximately 0.2 to 2°C.

6.4.1.1 Big Springs Creek Flow

The 50% flow increase downstream of the Big Springs Creek confluence is attributed to a 45 cfs increase in flow from the Big Springs Creek complex. Appendix G summarizes the available information pertaining to current and historic (pre-diversion) flows in the Big Springs Creek complex. The Big Springs Creek complex refers to Big Springs proper (assumed to originate at the eastern end of Big Springs Lake), Big Springs Lake, Big Springs Creek, Little Springs and the channel between Little Springs and Big Springs Creek, and may include springs that extend into the Shasta River proper. Based on the information presented in Appendix G, it is estimated that historically (pre-diversion) the Big Springs Creek complex delivered on the order of 100 to 125 cfs to the Shasta River.

The flow from Big Springs Creek in the 50% flow increase simulation averaged 112 cfs. Based on the review of Big Springs Creek complex flow records, Regional Water Board staff believe the 45 cfs flow increase from Big Springs Creek complex is within the historic (pre-diversion) flow range.

6.4.1.2 Conclusions

Regional Water Board staff chose to include the 45 cfs flow increase from the Big Springs Creek complex as part of the water quality compliance scenario. This decision was based on:

- The uniquely cold water from Big Springs.
- The significant temperature improvements in the Shasta River downstream of Big Springs Creek, which, when coupled with the other components of the water quality compliance scenario, result in attainment of the narrative water quality objective for temperature; and

- The finding that the 45 cfs flow increase from Big Springs Creek complex is within the historic (pre-diversion) flow range.

6.4.2 Water Quality Compliance Scenario

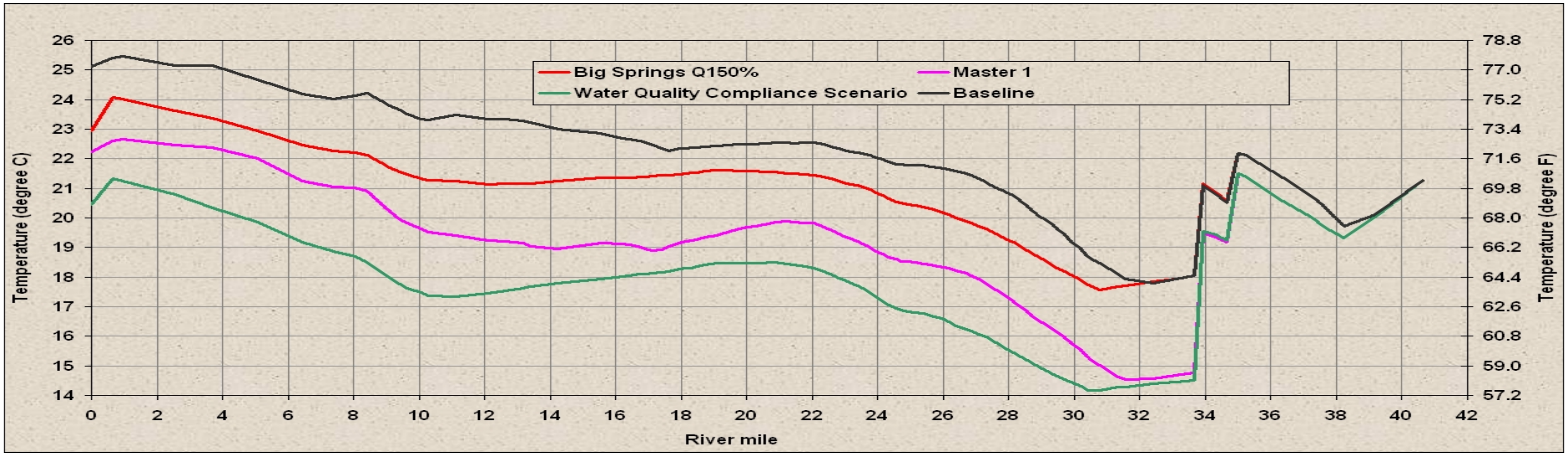
To summarize, the water quality compliance scenario included:

1. Increased riparian shade to represent site potential riparian conditions on a river-reach scale (as outlined in Section 6.2.1);
2. Modified temperature regime of tailwater return flows such that the return flows do not cause heating of the receiving water (as outlined in Section 6.2.2);
3. Big Springs Creek temperatures reduced by 4°C from baseline (as outlined in Section 6.2.3.1);
4. Parks Creek temperatures reduced by 2°C from baseline (as outlined in Section 6.2.3.2); and
5. Fifty percent increase in Shasta River flows downstream of the Big Springs Creek confluence, an increase of 45 cfs, (as outlined in Sections 6.2.4 and 6.4.1.1).

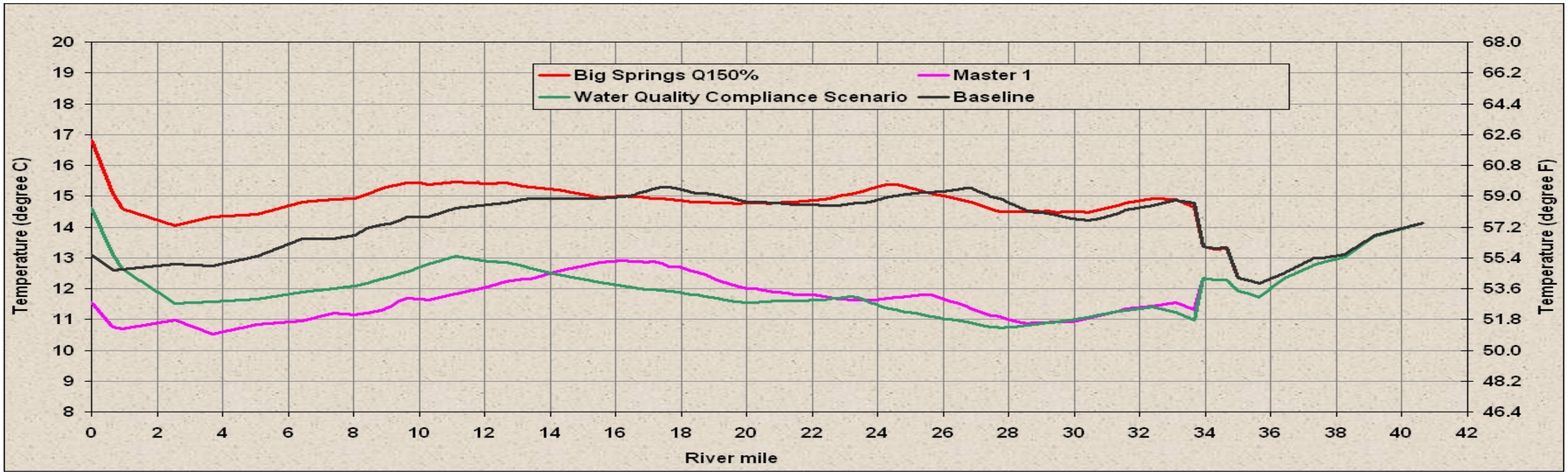
The temperature results of the water quality compliance scenario are presented in Figure 6.3 and Table 6.6. Figure 6.3 shows the maximum and minimum temperatures in the Shasta River associated with the water quality compliance scenario. For comparison, Figure 6.3 also presents the maximum and minimum temperatures for the following simulations: (1) baseline condition, (2) 50% flow increase in the Shasta River downstream of the Big Springs Creek confluence, and (3) the first four components of the water quality compliance scenario identified in the preceding paragraph (i.e. riparian shade, tailwater modifications, 4°C reduction from Big Springs Creek, and 2°C reduction from Parks Creek), identified as “Master 1”. The maximum, minimum, and average water temperatures for the water quality compliance scenario are presented in Table 6.6, and the increases or decreases in these temperatures compared with the baseline condition are identified. Table 6.7 identifies the average daily maximum temperatures for the baseline, Master 1, and water quality compliance scenario at select locations.

The following conclusions are drawn from these water quality model results:

- The water quality compliance scenario results in reductions in maximum stream temperature at all Shasta River locations.
- The largest reduction in maximum stream temperature exceeds 6°C at Yreka Ager Road, compared with the baseline condition.
- The water quality compliance scenario results in reductions in the minimum stream temperature at all Shasta River locations upstream of approximately River Mile 1.
- The largest reduction in minimum stream temperature was nearly 4°C at Highway A-12, compared with the baseline condition.
- Shasta River temperatures are below juvenile salmonid growth and rearing lethal temperature thresholds (see Table 2.4) during the August simulation period (which reflects critical conditions) under the water quality compliance scenario.



(A)



(B)

Figure 6.3: Alternate scenarios; Maximum (A) and minimum (B) temperature results

Table 6.6: Alternate scenarios, temperature results and change from baseline

Compliance Points	River Mile	Maximum Modeled Temperature Values				Maximum Modeled Differences in Temp. compared to August Baseline (Increase or (decrease))		
		August Baseline	Big Springs Q150%	Master 1	Water Quality Compliance	Big Springs Q150%	Master 1	Water Quality Compliance
Dwinnel Dam	42.60	21.27	21.27	21.27	21.27	0.00	0.00	0.00
Louie Road	33.93	21.09	21.16	19.48	19.56	0.07	(1.61)	(1.53)
GID	30.59	18.68	17.74	15.28	14.16	(0.94)	(3.40)	(4.52)
Highway A-12	24.11	22.05	20.86	18.87	17.34	(1.19)	(3.18)	(4.71)
Freeman Lane	19.23	22.42	21.62	19.41	18.47	(0.80)	(3.01)	(3.95)
M-G Road	15.52	22.85	21.36	19.16	17.93	(1.49)	(3.69)	(4.92)
Highway 3	13.16	23.28	21.17	19.14	17.62	(2.11)	(4.14)	(5.66)
Yreka Ager Road	10.91	23.48	21.25	19.41	17.33	(2.23)	(4.07)	(6.15)
Anderson Grade Road	8.03	24.13	22.20	21.03	18.69	(1.93)	(3.10)	(5.44)
Highway 263	7.30	24.19	22.46	21.24	19.19	(1.73)	(2.95)	(5.00)
"Salmon Heaven"	5.60	24.68	22.93	22.00	19.86	(1.75)	(2.68)	(4.82)
Mouth	0.66	25.46	24.03	22.67	21.25	(1.43)	(2.79)	(4.21)

Compliance Points	River Mile	Average Modeled Temperature Values				Average Modeled Differences in Temp. compared to August Baseline (Increase or (decrease))		
		August Baseline	Big Springs Q150%	Master 1	Water Quality Compliance	Big Springs Q150%	Master 1	Water Quality Compliance
Dwinnel Dam	42.60	17.49	17.49	17.49	17.47	0.00	0.00	(0.02)
Louie Road	33.93	17.59	17.60	16.40	16.38	0.00	(1.19)	(1.21)
GID	30.59	16.91	16.69	13.66	13.19	(0.22)	(3.25)	(3.73)
Highway A-12	24.11	18.44	17.83	15.17	14.28	(0.61)	(3.28)	(4.16)
Freeman Lane	19.23	18.87	18.23	16.06	15.05	(0.64)	(2.81)	(3.82)
M-G Road	15.52	19.02	18.45	16.23	15.35	(0.56)	(2.79)	(3.67)
Highway 3	13.16	19.05	18.56	16.17	15.44	(0.49)	(2.88)	(3.61)
Yreka Ager Road	10.91	19.01	18.62	16.12	15.55	(0.39)	(2.89)	(3.46)
Anderson Grade Road	8.03	18.90	18.75	16.29	15.90	(0.15)	(2.61)	(3.00)
Highway 263	7.30	18.86	18.77	16.31	15.99	(0.08)	(2.55)	(2.87)
"Salmon Heaven"	5.60	18.73	18.77	16.42	16.11	0.04	(2.31)	(2.62)
Mouth	0.66	18.77	18.96	16.53	16.49	0.19	(2.23)	(2.27)

Compliance Points	River Mile	Minimum Modeled Temperature Values				Minimum Modeled Differences in Temp. compared to August Baseline (Increase or (decrease))		
		August Baseline	Big Springs Q150%	Master 1	Water Quality Compliance	Big Springs Q150%	Master 1	Water Quality Compliance
Dwinnel Dam	42.60	14.14	14.14	14.14	14.14	0.00	0.00	0.00
Louie Road	33.93	13.37	13.36	12.33	11.49	(0.01)	(1.04)	(1.88)
GID	30.59	14.21	14.47	11.04	11.01	0.26	(3.17)	(3.20)
Highway A-12	24.11	14.86	15.29	11.64	10.92	0.43	(3.22)	(3.94)
Freeman Lane	19.23	15.04	14.79	12.27	11.68	(0.25)	(2.77)	(3.36)
M-G Road	15.52	14.92	14.96	12.84	12.19	0.04	(2.08)	(2.73)
Highway 3	13.16	14.90	15.33	12.30	12.73	0.43	(2.60)	(2.17)
Yreka Ager Road	10.91	14.62	15.45	11.82	12.67	0.83	(2.80)	(1.95)
Anderson Grade Road	8.03	13.72	14.91	11.14	11.68	1.19	(2.58)	(2.04)
Highway 263	7.30	13.62	14.80	10.96	11.50	1.18	(2.66)	(2.12)
"Salmon Heaven"	5.60	13.05	14.40	10.85	11.15	1.35	(2.20)	(1.90)
Mouth	0.66	12.61	14.57	10.69	12.62	1.96	(1.92)	0.01

- The 5-day average daily maximum temperatures for the water quality compliance scenario were 16.7°C, 17.5°C, and 18.9°C at Highway A-12 (RM 24.1), Montague-Grenada Road (RM 15.5) and at River Mile 5.6 (an important location for summer rearing), respectively. RM 24.1, RM 15.5, and RM 5.6 are compliance points for the temperature TMDL. The average daily maximum temperatures at these compliance points can be compared to the USEPA (2003) non-core juvenile rearing maximum weekly maximum temperature (MWMT) threshold of 18°C (see Table 2.3). Based on this comparison, the water quality compliance scenario results in maximum stream temperatures *below* the non-core juvenile rearing chronic temperature threshold at RM 24.1 and RM 15.5. The 5-day average daily maximum temperatures for the water quality compliance scenario at RM 5.6 was nearly 1°C above the threshold.
- The 5-day average daily maximum temperatures for the "Master 1" scenario were 18.1°C, 18.4°C, and 20.8°C at the temperature compliance points Highway A-12 (RM 24.1), Montague-Grenada Road (RM 15.5) and at River Mile 5.6, respectively. These temperatures are all above the USEPA (2003) non-core juvenile rearing MWMT threshold of 18°C.
- A comparison of the maximum temperatures for the water quality compliance scenario, Master 1 scenario, and baseline condition can be made to determine the relative proportions of the temperature reductions attributed to shade and tailwater management (Master 1) versus flow increase. This comparison indicates that approximately 30% of the maximum stream temperature reductions achieved by the water quality compliance scenario are attributed to the Big Springs Creek flow increase, and approximately 70% of the reductions are attributed to riparian shade increases and tailwater management.
- The water quality compliance scenario achieves compliance with the Basin Plan narrative temperature objective.

Table 6.7: 5-day average maximum temperatures for water quality compliance scenario and baseline condition

Compliance Points	RM	5-day Average Maximum Temperature		
		Baseline	Master 1	Water Quality Compliance Scenario
Highway A-12	24.11	21.07	18.1	16.71
Montague-Grenada Rd	15.52	21.53	18.4	17.49
"Salmon Heaven"	5.6	23.1	20.8	18.96

6.5 Temperature TMDL and Allocations

This section presents the temperature TMDL and load allocations. The starting point for the load allocation analysis is the equation that describes the Total Maximum Daily Load or loading capacity:

$$\text{TMDL} = \text{Loading Capacity} = \Sigma\text{WLAs} + \Sigma\text{LAs} + \text{Natural Background}$$

where Σ = the sum, WLAs = waste load allocations, and LAs = load allocations. Waste load allocations are contributions of a pollutant from point sources while load allocations are contributions from management-related non-point sources. There are no point source heat loads in the Shasta River watershed, and therefore no waste load allocations apply.

6.5.1 Development of Temperature Load Capacity and Surrogate Measures

Under the TMDL framework, and in this document, identification of the 'loading capacity' is a required step. The loading capacity represents the total loading of a pollutant that a water body can assimilate and still meet water quality objectives so as to protect beneficial uses. For the temperature TMDL the water quality objective of concern is the temperature objective, which prohibits the alteration of the natural receiving water temperature unless such alteration does not adversely affect beneficial uses. The loading capacity provides a reference for calculating the amount of pollutant load reduction needed to bring a water body into compliance with standards.

The Shasta River watershed temperature TMDL addresses the heat loads that arise from three sources:

1. Changes in riparian vegetation,
2. Tailwater return flows, and
3. Surface water flow.

The temperature loading capacity of the Shasta River and its tributaries equals the heat load associated with the potential riparian shade conditions, no net increase in receiving water temperature from tailwater return flows, and reductions in daily maximum temperatures achieved via flow increase, as detailed below.

6.5.1.1 Riparian Vegetation

In order to use the loading capacity that focuses on heat loads that arise from changes in streamside vegetation, and to be able to compare it to current conditions, a surrogate measure is proposed. EPA regulations (40 CFR §130.2(i)) allow for the use of other appropriate measures (surrogate measures) to allocate loads for conditions "when the impairment is tied to a pollutant for which a numeric criterion is not possible…(USEPA 1998)." Heat load can be measured as solar radiation transmittance (the amount of solar radiation that passes through the tree canopy and reaches the water surface, where a value of 1.0 represents no shade, and a value of 0.0 would represent complete shade). Also, solar radiation transmittance can be related to stream temperature conditions. Finally, solar radiation transmittance can be readily measured in the field. Therefore, for this temperature TMDL, the portion of the loading capacity associated with riparian shade is expressed as potential percent solar radiation transmittance for the mainstem Shasta River downstream of Dwinnell Dam, and is expressed as adjusted potential effective shade for tributaries to the Shasta River and the river upstream of Dwinnell Dam. Potential solar radiation transmittance is used for the Shasta River because the water quality model accounts for riparian shade with this metric. Adjusted potential effective shade is used for the tributaries to the Shasta River because the tributaries were not included in the water quality model and potential solar radiation transmittance values were not defined for the tributaries. Adjusted potential effective shade has been used for other temperature TMDLs in California.

6.5.1.2 Tailwater Return Flow

There is insufficient information to quantify the heat load associated with tailwater return flows in the Shasta River watershed. The loading capacity associated with tailwater return flow is no net increase in receiving water temperatures. In this document "tailwater return flow" refers to surface runoff of irrigation water to a surface water body, and is synonymous with "irrigation return flow".

6.5.1.3 Surface Water Flow

Approximately 30% of the maximum temperature reductions achieved in the water quality compliance scenario compared with the baseline condition are attributed to the 50% flow increase in the Shasta River downstream of the Big Springs Creek confluence. Regional Water Board staff have included this 45 cfs Big Springs Creek complex flow increase as part of the water quality compliance scenario because this flow increase simulation achieved the largest reductions in maximum stream temperatures compared with flow increases from other locations in the river, and results in attainment of the narrative water quality objective for temperature. Further, Regional Water Board staff estimate that the flow increase from the Big Springs Creek complex is within the historic (pre-diversion) flow range, as outlined in Section 6.4.1.1. The analysis presented in Section 6.4.1, however, demonstrates that temperature improvements are achievable due to flow increases at other locations in the Shasta River watershed. Therefore, although the loading capacity associated with flow is based on 45 cfs flow increase from the Big Springs Creek complex, Regional Water Board staff acknowledge that there are other sources of cold water in the watershed and alternative flow regimes may achieve the same temperature improvements. Additional sources of cold water in the watershed include, but are not limited to, the Parks Creek watershed, the Hole in the Ground Creek watershed, and springs within the Little Shasta River watershed.

The maximum stream temperature reductions attributed to flow increase are approximately 1.5°C, 1.2°C, and 2.1°C at RM 24.1, RM 15.5, and RM 5.6, the temperature compliance locations. Increased dedicated cold water instream surface flow[1] that results in temperature reductions of 1.5°C, 1.2°C, and 2.1°C at these compliance locations constitute the load allocation to flow.

6.5.1.4 Temperature Loading Capacity

In summary, the Shasta River watershed temperature TMDL loading capacity is equal to potential percent solar radiation transmittance for the mainstem Shasta River downstream of Dwinnell Dam, adjusted potential effective shade upstream of Dwinnell Dam and for the Shasta River tributaries, no net increase in receiving water temperature from tailwater

[1] Dedicated cold water instream flow is water remaining in the stream in a manner that the diverter, either individually or as a group, can ensure will result in water quality benefits. Temperature, length and timing are factors to consider when determining the water quality benefits of an instream flow.

return flows, and a Shasta River flow regime that results in reductions in maximum daily temperature of 1.5°C, 1.2°C, and 2.1°C at RM 24.1, RM 15.5, and RM 5.6, the temperature compliance locations. The TMDL equation becomes:

TMDL = Loading Capacity =
Potential Percent Solar Radiation Transmittance of the Shasta River
+ Adjusted potential Effective Shade of the Tributaries
+ No Net Increase in Temperature from Tailwater Return Flows
+ Flow Increases that achieved specific temperature reductions at compliance locations.

6.5.2 Temperature Load Allocations

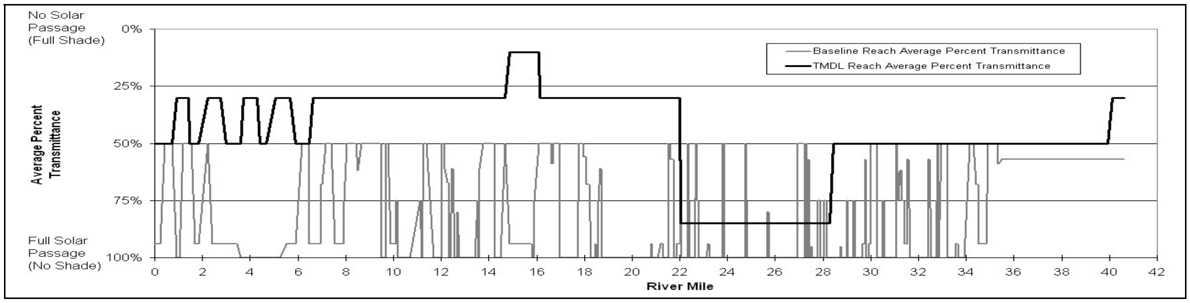
In accordance with EPA regulations, the TMDL (i.e., loading capacity) for a water body is to be allocated among the various sources of the targeted pollutant. The sum of the waste load and load allocations for the watershed is equivalent to the loading capacity for the watershed as a whole. There are no point source heat loads in the Shasta River watershed, and therefore no waste load allocations apply.

6.5.2.1 Riparian Shade

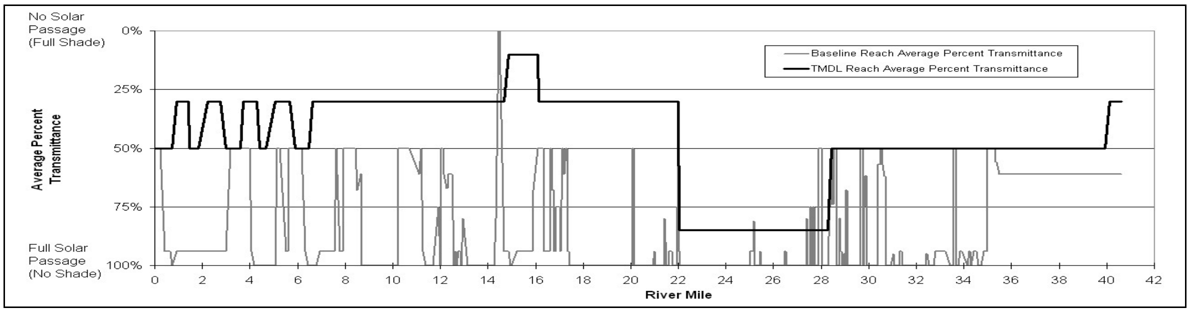
Load allocations to riparian shade are expressed differently for the Shasta River mainstem and tributaries in the Shasta River watershed temperature TMDL. For the mainstem Shasta River downstream of Dwinnell Dam the allocations are reach average potential solar radiation transmittance values. For Shasta River tributaries and upstream of Dwinnell Dam the allocations are adjusted potential effective shade.

Shasta River Potential Solar Radiation Transmittance

The potential solar radiation transmittance values for the Shasta River downstream of Dwinnell Dam were estimated by Regional Water Board staff, as outlined in Section 6.2.1. Both the potential and existing (baseline) solar radiation transmittance values for the Shasta River are presented in Figure 6.4. There is no difference assigned to the percent solar radiation transmittance between the right and left banks. The difference between existing (baseline) and potential solar radiation transmittance reflects the amount of effective shade increase (i.e. reduced solar transmittance) that is required to achieve natural receiving water temperatures in the Shasta River.



(A) Left Bank



(B) Right Bank

Figure 6.4: Existing (baseline) and potential solar radiation transmittance for the left bank (A) and right bank (B) of the Shasta River

Adjusted Potential Effective Shade of Shasta River Tributaries

This temperature TMDL analysis did not directly evaluate current or potential riparian conditions in Shasta River tributaries or the river upstream of Dwinnell Dam, nor was modeling used to calculate solar radiation heat load at streamside locations of the Shasta River tributaries. However, as discussed in Section 3.1.1, numerous studies have identified that solar radiation is the dominant heat exchange process affecting stream temperature, and that changes in solar radiation associated with riparian shade affect stream temperatures (Johnson 2004; ODEQ 2002; Sinokrot and Stefan 1993). Therefore, in order to achieve natural receiving water temperatures in the tributaries of the Shasta River and upstream of Dwinnell Dam, adjusted potential effective shade (shade resulting from topography and vegetation that reduces the heat load reaching the stream) must be achieved, and is used as a surrogate for solar energy to assess compliance. Adjusted potential effective shade is equal to 90% of site potential shade, to allow for natural riparian disturbance such as floods, wind throw, disease, landslides, and fire.

6.5.2.2 Tailwater Return Flow

The load allocation for tailwater return flows within the Shasta River watershed is no net increase in receiving water temperature.

6.5.2.3 Dedicated Cold Water Instream Flow

The load allocation for flow is reductions in the maximum daily stream temperatures of 1.5°C, 1.2°C, and 2.1°C from baseline at RM 24.1, RM 15.5, and RM 5.6, the temperature compliance locations.

6.5.2.4 Shasta River Watershed Temperature TMDL Load Allocations Summary
In summary, the temperature load allocations for the Shasta River watershed are presented in Table 6.8.

Table 6.8: Shasta River watershed temperature load allocations

Source	Allocation
Change in Riparian Vegetation	***Shasta River***: Reach average potential solar radiation transmittance, as presented in Table 6.2 and Figure 6.4. ***Tributaries***: Potential effective riparian shade = 90% of site potential shade.
Tailwater Return Flow	No net increase in receiving water temperature.
Surface Water Flow	Reductions in the maximum daily stream temperatures of 1.5°C, 1.2°C, and 2.1°C from baseline at RM 24.1, RM 15.5, and RM 5.6

6.6 Margin of Safety

The Clean Water Act Section 303(d) and the associated regulations at 40 CFR §130.7 require that TMDLs include a margin of safety that takes into account any lack of knowledge concerning the relationship between the pollutant loads and the desired receiving water quality. The margin of safety is often implicitly incorporated into conservative assumptions used in calculating loading capacities, waste load allocations, and load allocations (USEPA 1991). The margin of safety may also be incorporated explicitly as a separate component in the TMDL equation. For this TMDL analysis, conservative assumptions were made that account for uncertainties in the analysis.

- The water quality compliance scenario incorporated temperature reductions from Big Springs Creek and Parks Creek to account for improvements associated with riparian shade and tailwater management. The water quality compliance scenario did not incorporate temperature reductions from Yreka Creek and other small tributaries to the Shasta River and provides a margin of safety.
- Topographic shade was not considered in the temperature model and is likely a significant factor in the Shasta canyon, and provides a margin of safety.
- Some improvements in stream temperature that may result from reduced sedimentation are not quantified. Reduced sediment loads could lead to increased frequency and depth of pools, independent of changes in solar radiation input. These changes tend to result in lower stream temperatures overall and tends to increase the amount of lower-temperature pool habitat. These expected changes are not directly accounted for in the TMDL.
- The effects of changes to streamside riparian areas toward mature trees will tend to create microclimates that will lead to improvements in stream temperatures. These effects were not accounted for in the temperature analysis and provide a margin of safety.