CHAPTER 7. DISSOLVED OXYGEN TMDL

7.1 Introduction

This chapter presents the dissolved oxygen TMDL for the Shasta River. The analytical approach involved application of the River Modeling System (RMS) model. In addition, the Shasta River Benthic Algae Box Model (algae model) was applied in order to evaluate the effect of nutrient concentrations on primary production (photosynthesis and respiration of aquatic vegetation) in the Shasta River. The algae model application and nutrient sensitivity analysis results are presented in Section 7.2. The application and results of the RMS model are presented in Section 7.3 and 7.4. The dissolved oxygen TMDL and allocations are presented in Section 7.5.

7.2 Algae Box Model Application and Results

The Shasta River Benthic Algae Box Model was applied in order to evaluate the connection between nutrient concentrations and primary production (photosynthesis and respiration of aquatic vegetation) in the Shasta River, a dynamic not represented by RMS.

7.2.1 Model Implementation Values and Nutrient Sensitivity Results

The parameter values implemented for the algae model are tabulated in Table 7.1. These parameter values were selected to represent conditions typical of the Shasta River. The nutrient sensitivity results are summarized in Table 7.2, which tabulates annual biomass and percentage of baseline biomass associated with alternate parameter values.

For the nutrient sensitivity analysis, when the concentrations of both phosphate and nitrogen were decreased to the half-saturation constant[1] for that nutrient, the algal biomass decreased. Conversely, when the nutrient concentrations were increased to concentrations exceeding the half-saturation constant, the algal biomass increased.

The nutrient sensitivity analysis results indicate that if the modeling implementation nitrogen half-saturation constant of 0.014 mg/L is maintained, a total inorganic nitrogen (TIN - the sum of ammonia-nitrogen plus nitrate/nitrite-nitrogen) concentration of 0.02 mg/L (an order of magnitude lower than the model implementation value) would yield an average annual biomass equal to 10% of the baseline average annual biomass. A review of the Shasta River watershed nitrogen data presented in Tables 2.8, 2.9, 2.10, and 2.11 (in Chapter 2) shows that average ammonia plus nitrate/nitrite (TIN) concentrations exceed 0.1 mg/L in the Shasta River downstream of Dwinnell Dam, but are approximately 0.04 mg/L in the headwaters of the Shasta River. The analysis indicates that reductions in Shasta River TIN concentrations would likely limit the productivity of aquatic vegetation in the Shasta River.

[1] A nutrient half-saturation coefficient is the concentration of the nutrient at which the growth rate is one half of its maximum value.

Table 7.1: Shasta River algae box model implemented parameter values

Parameter	**Model Value**	**Units**
Time step	0.041667	day
Travel time of reach	0.042	day
Reach length, l	1609	meters
River width, w	9.1	meters
River depth, d	0.6	meters
River cross-sectional area, CS	13.9	m^2
Reach volume, V	22426.9	m^3
Reach flow in and flow out, Qin and Qout	538247	m^3/day
Reach bed area, A	7357.9	m^2
Reach velocity, vel	73.2	m/day
Initial bed algae biomass, P_i	0.001	g/m^2
Minimum bed algae biomass, P_{min}	0.1	g/m^2
maximum bed algae biomass, P_{max}	20	g/m^2
Solar radiation, SR	hourly	W/m^2
Global Shade Factor, GSF	0	-
Total inorganic nitrogen inflow concentration, $[TIN]_{in}$	0.2	mg/L
Phosphate inflow concentration, $[PO4]_{in}$	0.2	mg/L
Silica inflow concentration, $[Si]_{in}$	50	mg/L
Light half saturation coefficient, K_L	0.0009	Kcal/m^2s
Light extinction coefficient, Le	1.48	1/meter
Nitrogen half saturation coefficient, K_N	0.014	mg/L
Phosphate half saturation coefficient, K_P	0.003	mg/L
Silica half saturation coefficient, K_S	0.03	mg/L
Maximum growth rate, G	1.2	1/day
Respiration (and excretion) rate, R	0.14	1/day
Mortality rate, D	0.14	1/day
Grazing rate, Z	0.05	1/day
Algae settling rate, v	0	m/day
Scouring factor, s	0.00001	-
Theta, θ	1.040	-
Water Temperature, T	hourly	C
Reference water temperature, T_{ref}	20	C

Table 7.2: Nutrient sensitivity analysis results - annual total and annual average algae biomass

Varied Parameter(s)	Parameter(s) Value	Units	Annual Total Biomass (g/m^2)	Annual Ave Biomass (g/m^2)	% Baseline
None (Baseline Condition)	Implementation values	-	77913	8.87	100%
K_N	0.0014	mg/l	80976	9.22	104%
	0.14		7564	0.86	10%
K_P	0.0003	mg/l	77913	8.87	100%
	0.03		71489	8.14	92%
K_{Si}	0.003	mg/l	77913	8.87	100%
	0.3		77913	8.87	100%
K_N, K_P, K_{Si}	0.0014, 0.0003, 0.003	mg/l	81010	9.22	104%
	0.14, 0.03, 0.3		7564	0.86	10%
$[TIN]_{in}$	0.014	mg/l	1	0.00012	0.0014%
	0.02		7564	0.86	10%
	2		80976	9.22	104%
$[PO4]_{in}$	0.003	mg/l	1	0.00012	0.0014%
	0.02		71489	8.14	92%
	2		77913	8.87	100%
$[Si]_{in}$	5	mg/l	77913	8.87	100%
	500		77913	8.87	100%
$[TIN]_{in}$, $[PO4]_{in}$, $[Si]_{in}$	0.02, 0.02, 5.0	mg/l	7564	0.86	10%
	2.0, 2.0, 500.0		81010	9.22	104%
	1.1		67727	7.71	86.9%
	1.3		88193	10.04	113.2%
	1.4		95429	10.86	122.4%

When the modeling implementation phosphate half-saturation constant of 0.003 mg/L is maintained, a phosphate concentration of 0.02 mg/L (an order of magnitude lower than the model implementation value) would yield an average annual biomass equal to 92% of the baseline average annual biomass. A review of the Shasta River watershed phosphate data presented in Tables 2.8, 2.9, 2.10, and 2.11 (in Chapter 2), shows that average phosphate concentrations are well above 0.02 mg/L in the Shasta River above and below Lake Shastina, as well as in Shasta Valley springs (which account for much of the summer flow in the river downstream of Dwinnell). This analysis indicates that phosphate concentrations of the Shasta River watershed are biostimulatory and do not limit productivity.

7.2.2 Summary and Conclusions

Based on the algae model sensitivity analysis of nutrient half-saturation coefficients and nutrient concentrations, there are several conclusions that can be drawn from the algae model application:

- The model is mildly sensitive to phosphate half-saturation constants and concentrations;
- The model is sensitive to nitrogen half-saturation constants and concentrations;
- The concentrations of nitrogen and phosphorus in the Shasta River below Lake Shastina are biostimulatory; and
- If TIN concentrations in the Shasta River were maintained at levels comparable to those concentrations measured in the headwaters of the Shasta River, aquatic vegetation biomass would likely be reduced.

7.3 RMS Model Application

The analytical approach in developing the dissolved oxygen TMDL involved application of the RMS model 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 includes a suite of conditions that yields attainment of the minimum dissolved oxygen objective for the Shasta River at all times under critical conditions.

As discussed in Chapter 2, the Shasta River does not meet the dissolved oxygen objective during summer months. Therefore, as for the temperature analysis, the water quality 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 determination that these time periods represent "critical conditions" is discussed in Section 6.4.

7.3.1 Water Quality Compliance Scenario Conditions

The process used to develop the water quality compliance scenario involved separately evaluating the components identified in the dissolved oxygen source and linkage analysis (Chapter 4) that affect dissolved oxygen concentrations in the Shasta River watershed. The components that were evaluated included: photosynthetic and respiration rates; sediment oxygen demand rates; dissolved oxygen and NBOD concentrations of Lake Shastina outflow, key tributaries, and tailwater return flows; riparian shade; and flow.

The water quality compliance scenario for dissolved oxygen consists of the baseline condition with the following key modifications:

1. Reduced photosynthetic and respiration rates;
2. Reduced sediment oxygen demand (SOD) rates behind minor impoundments;
3. Reduced nitrogenous oxygen demand (NBOD) input concentrations;
4. Modified dissolved oxygen concentrations at key locations;
5. Increased riparian shade, represented as decreased percent transmittance on a river reach scale, as outlined in Section 6.2.1; and
6. Increased Shasta River flow.

These modifications are discussed below, with the exception of #5, decreased percent transmittance, which is discussed in Section 6.2.1.

7.3.2 Photosynthetic and Respiration Rates

As outlined in Section 5.3.2.2, the water quality model assigns photosynthesis and respiration rates of aquatic plants in units of gO_2/m^2-s. The assigned rates are exerted on the wetted area of the channel, assuming uniform biomass and distribution.

The photosynthetic and respiration rates assigned for the water quality compliance scenario were 50% of those for the existing (baseline) condition, as shown in Table 7.3. These reductions in photosynthetic and respiration rates assume a 50% reduction in aquatic vegetation standing crop during the simulation periods. Regional Water Board staff believe that such reductions in aquatic vegetation standing crop, and associated reductions in photosynthetic and respiration rates, are achievable in the Shasta River. In the field, the mechanisms that would result in these reductions include:

- Decreased light availability to aquatic vegetation via increased riparian shade, as outlined in Section 6.2.1;
- Reduced concentrations of biostimulatory nutrients (i.e. ammonia-nitrogen, nitrate-nitrogen, and ortho-phosphate-phosphorus) in the Shasta River achieved via controls targeting NBOD reductions from Lake Shastina outflow, irrigation return flows, and Yreka Creek, as outlined in Section 7.3.4;
- Reduced fine sediment inputs from irrigation return flows that can be achieved via controls targeting NBOD reductions, as outlined in Section 7.3.4; and
- Increased flushing flows to scour the channel of accumulated fine sediments that promote the establishment and proliferation of rooted aquatic macrophytes.
- Reduced stream temperatures, as outlined in Chapter 6.

7.3.3 Sediment Oxygen Demand Rates

The water quality model assigns SOD rates in units of gO_2/m^2-s, and the assigned SOD is exerted on the wetted area of the channel. For the water quality compliance scenario SOD rates were reduced by 50% of the existing (baseline) rates at river locations influenced by minor impoundments (flashboard dams), as shown in Table 7.4. Regional Water Board staff believe SOD reductions are achievable at these locations. In practice, SOD reductions would occur as a result of the following actions:

- Removal of the minor impoundments, or re-engineering them to minimize the opportunity for sediment and organic material accumulation;
- Reduced fine sediment and organic material inputs from irrigation return flows that can be achieved via controls targeting NBOD reductions, as outlined in Section 7.3.4; and

- Reduced concentrations of biostimulatory nutrients in the Shasta River that promote aquatic vegetation growth, which in turn exert a sediment oxygen demand when the organic material is decomposed. Reductions in nutrient concentrations can be achieved via controls targeting NBOD reductions from Lake Shastina outflow, irrigation return flows, and Yreka Creek, as outlined in Section 7.3.4.

Table 7.3: Photosynthetic and respiration rates for the July, August, and September water quality compliance scenarios

River Mile	July 2-8		Aug 29-Sep 4		Sep 17-23	
	Pmax	Resp	Pmax	Resp	Pmax	Resp
	(gO_2/m^2-hr)		(gO_2/m^2-hr)		(gO_2/m^2-hr)	
40.62	1.18	0.24	1.18	0.24	1.18	0.12
39.51	1.18	0.24	1.18	0.24	1.18	0.12
39.26	1.58	0.32	1.58	0.32	1.58	0.16
25.85	1.58	0.32	1.58	0.32	1.58	0.16
25.79	1.18	0.24	1.18	0.24	1.18	0.12
24.11	1.18	0.24	1.18	0.24	1.18	0.12
24.10	0.60	0.12	0.60	0.12	0.60	0.06
22.14	0.60	0.12	0.60	0.12	0.60	0.06
22.13	1.18	0.24	1.18	0.24	1.18	0.12
16.11	1.18	0.24	1.18	0.24	1.18	0.12
15.91	1.58	0.32	1.58	0.32	1.58	0.16
14.88	1.58	0.32	1.58	0.32	1.58	0.16
14.68	0.60	0.12	0.60	0.12	0.60	0.06
13.99	0.60	0.12	0.60	0.12	0.60	0.06
13.79	1.58	0.32	1.58	0.32	1.58	0.16
13.40	1.58	0.32	1.58	0.32	1.58	0.16
13.26	1.18	0.24	1.18	0.24	1.18	0.12
12.63	1.18	0.24	1.18	0.24	1.18	0.12
12.58	1.58	0.32	1.58	0.32	1.58	0.16
12.27	1.58	0.32	1.58	0.32	1.58	0.16
12.16	1.18	0.24	1.18	0.24	1.18	0.12
11.10	1.18	0.24	1.18	0.24	1.18	0.12
10.69	1.58	0.32	1.58	0.32	1.58	0.16
10.55	1.18	0.24	1.18	0.24	1.18	0.12
6.42	1.18	0.24	1.18	0.24	1.18	0.12
6.34	0.60	0.12	0.60	0.12	0.60	0.06
4.30	0.60	0.12	0.60	0.12	0.60	0.06
4.19	1.18	0.24	1.18	0.24	1.18	0.12
4.05	1.18	0.24	1.18	0.24	1.18	0.12
3.98	0.60	0.12	0.60	0.12	0.60	0.06
0.00	0.60	0.12	0.60	0.12	0.60	0.06

Table 7.4: Sediment oxygen demand (SOD) rates for existing (baseline) and water quality compliance scenarios

River Mile	Existing scenario SOD rate (gO_2/m^2-day)	Water quality compliant scenario SOD rate (gO_2/m^2-day)
40.62	0.2	0.2
39.94	0.2	0.2
38.65	0.5	0.5
32.03	0.5	0.5
30.65	**2.0**	**1.0**
27.50	0.2	0.2
25.79	0.1	0.1
24.10	0.1	0.1
19.11	0.1	0.1
17.78	**2.0**	**1.0**
15.40	**1.5**	**0.75**
14.68	**1.5**	**0.75**
13.74	**1.5**	**0.75**
13.16	**2.0**	**1.0**
12.50	0.2	0.2
11.10	0.2	0.2
10.69	0.2	0.2
8.65	0.2	0.2
6.42	0.1	0.1
1.05	0.1	0.1
0.72	0.1	0.1
0.00	0.1	0.1

Note: SOD rates are temperature corrected in RQUAL

7.3.4 Nitrogenous Oxygen Demand Concentrations

For the water quality compliance scenario NBOD concentrations were reduced at key input locations including Dwinnell Dam, distributed flows in accreting reaches of the river that include irrigation return flows, and Yreka Creek, as shown in Table 7.5. For both the existing (baseline) and water quality compliance scenarios the boundary conditions for NBOD were based on Total Kjeldahl Nitrogen (TKN) concentrations, according to the equation: NBOD = 4.57 * TKN (Chapra 1997), as discussed in Section 5.1.2 in Appendix E. The NBOD concentrations applied at the various input locations for both the existing (baseline) and water quality compliance scenario are identified in Table 7.5.

The NBOD concentration applied to Dwinnell Dam is based on the average TKN concentration in the Shasta River just upstream of Lake Shastina. The NBOD concentration applied to Yreka Creek is based on the average TKN concentration from all Yreka Creek monitoring locations above the City of Yreka wastewater treatment and disposal facility. The NBOD concentrations for distributed flows in accreting reaches of the river (which include irrigation return flows) were assigned the same NBOD concentration as the Shasta River at the model node closest to the mid-point of the distributed flow reach. In other words, this assumes that the NBOD concentrations of the irrigation return flows are equal to the reach average NBOD concentration of the Shasta River in the accretion reach. Regional Water Board staff believe these NBOD concentration reductions are achievable in the Shasta River watershed.

Table 7.5: Nitrogenous oxygen demand (NBOD) concentrations for existing (baseline) and water quality compliance scenarios

Location	Scenario	NBOD (mg/L)	Comments
Dwinnell Dam	Existing Condition	2.74	Based on average TKN concentrations at Riverside Drive.
	Water Quality Compliance	0.91	Based on average TKN concentrations just upstream of Lake Shastina.
Big Springs Creek	Existing Condition	0.91	Based on average TKN concentrations measured in Big Springs Lake.
	Water Quality Compliance	0.91	Due to lack of data at the mouth of Big Springs Creek, the same NBOD concentration was applied.
GID to Anderson Grade Road – (Accretions - Distributed Flows)	Existing Condition	5.53	Based on average TKN concentrations from tailwater return flow dataset.
	Water Quality Compliance	Variable	The model output NBOD concentrations of the Shasta River at the mid-points of the distributed flow reaches were applied.
Yreka Creek	Existing Condition	1.33	Based on average TKN concentrations at the mouth of Yreka Creek.
	Water Quality Compliance	0.91	Based on average TKN concentrations of Yreka Creek from locations upstream of the wastewater treatment and disposal facility.

7.3.5 Dissolved Oxygen Concentrations

The same dissolved oxygen concentrations were applied to the water quality compliance scenario as the existing (baseline) scenario (as presented in Section 5.1.2 of Appendix D), with the following exceptions. The dissolved oxygen concentrations for Big Springs Creek and Parks Creek were calculated at saturation based on reduced stream temperature (and atmospheric pressure). As described in Section 6.2.3, the temperatures attributed to the water quality compliance scenario for Big Springs Creek and Parks Creek were equal to the existing (baseline) temperature regime minus 4°C and 2°C, respectively. Finally, for the water quality compliance scenario the dissolved oxygen concentrations for accretions were assigned the river concentrations associated with the model output at the mid-point of the respective accretion reach.

7.3.6 Shasta River Flow

The water quality compliance scenario included Shasta River flows based on baseline conditions with a 50% increase in flow in the Shasta Riverdownstream of the Big Springs Creek confluence. The explanation and rationale for including this flow regime in the water quality compliance scenario is discussed in Sections 6.2.4 and 6.4.1.

7.4 RMS Model Simulations - Dissolved Oxygen Results and Discussion

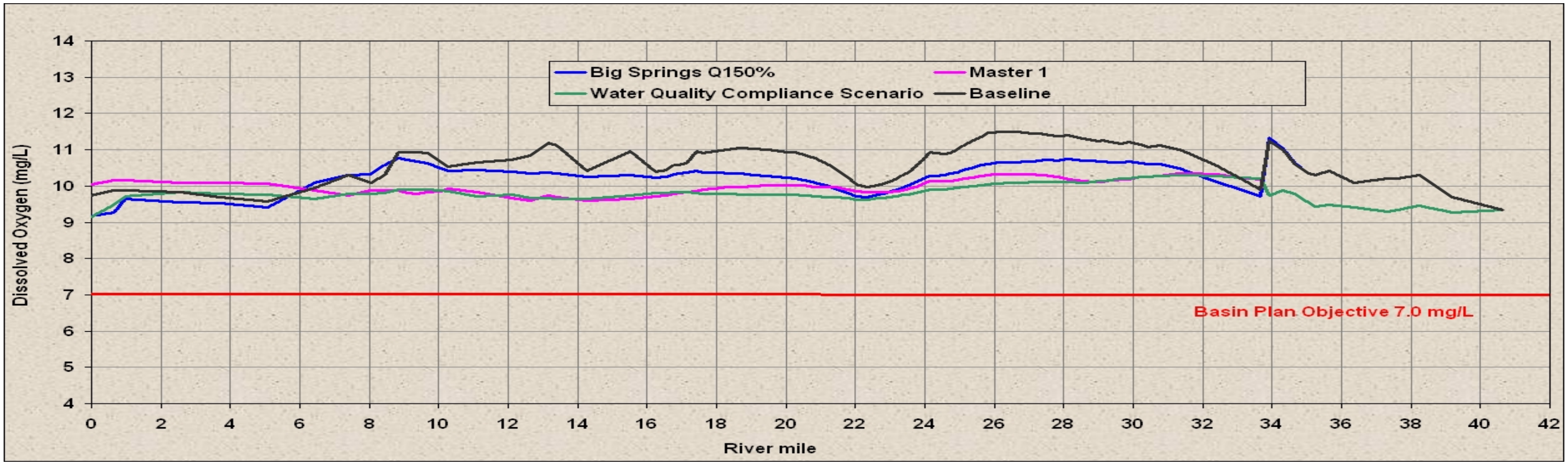
This section presents the RMS model dissolved oxygen results for the water quality compliance scenario. These results serve as the basis for dissolved oxygen TMDL allocations, as presented in Section 7.5.

7.4.1 Water Quality Compliance Scenario Dissolved Oxygen Results

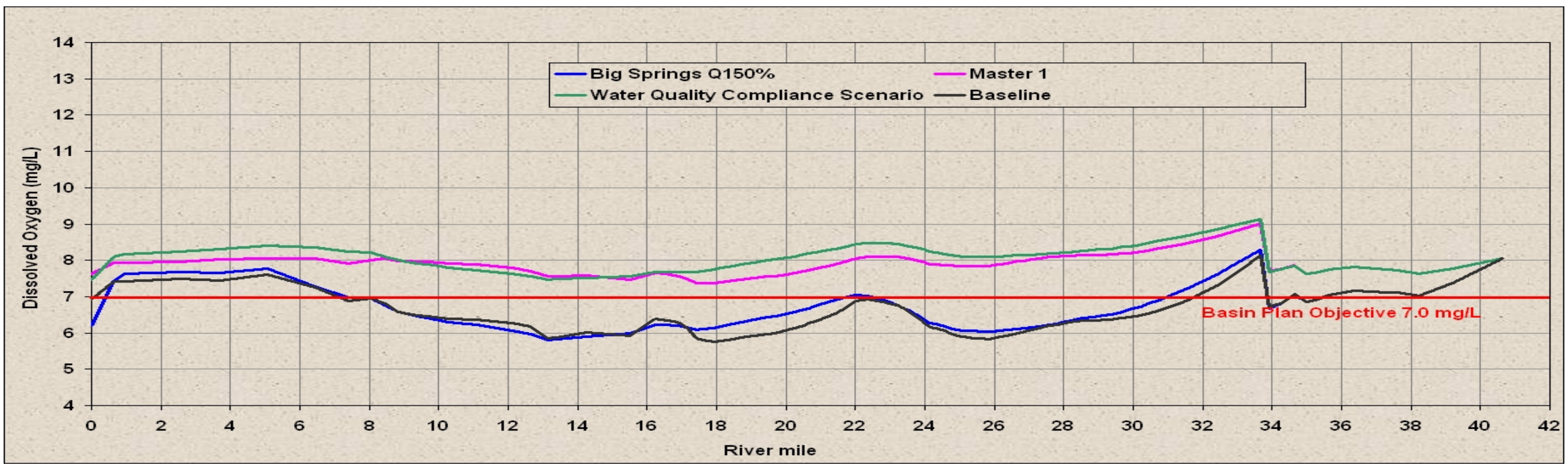
The dissolved oxygen results of the water quality compliance scenario are presented in Figure 7.1 and Table 7.6. Figure 7.1 shows the maximum and minimum dissolved oxygen concentrations in the Shasta River associated with the water quality compliance scenario. For comparison, Figure 7.1 also presents the maximum and minimum dissolved oxygen concentrations 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 dissolved oxygen concentrations for each of these simulations are presented in Table 7.6, and the increases or decreases in these concentrations compared with the baseline condition are identified.

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

- Increasing flow downstream of the Big Springs Creek confluence by 50% has a modest effect on maximum and minimum dissolved oxygen concentrations in the Shasta River compared with baseline conditions. Maximum dissolved oxygen concentrations are reduced up to 0.8 mg/L. Minimum dissolved oxygen concentrations are increased up to 0.4 mg/L;
- The water quality compliance scenario results in the greatest dissolved oxygen improvements (reductions in maximum and increase in minimum concentrations) compared with the other simulations;
- The magnitude of diel dissolved oxygen concentrations is reduced throughout the Shasta River under the water quality compliance scenario;
- Dissolved oxygen concentrations are *above* the Basin Plan minimum dissolved oxygen objective of 7.0 mg/L throughout the Shasta River under the water quality compliance scenario;
- The water quality compliance scenario results in attainment of the Basin Plan minimum dissolved oxygen objective for the Shasta River.
- The water quality compliance scenario results in reduced maximum and increased minimum dissolved oxygen concentrations in the Shasta River. Though the available data indicate that the 9.0 mg/L 50% lower limit dissolved oxygen objective is being met in the Shasta River (see Section 2.4.2), implementation of the factors represented in the water quality compliance scenario will likely lead to attainment of the 9.0 mg/L 50% lower limit dissolved oxygen objective more conclusively.
- The water quality compliance scenario appears to result in attainment of the Basin Plan biostimulatory substances objective, as nutrient load reductions result in attainment of the dissolved oxygen objective and non-nuisance level growth of aquatic plants.



(A)



(B)

Figure 7.1: Alternate scenarios, maximum (A) and minimum (B) dissolved oxygen results

Table 7.6: Alternate scenarios, dissolved oxygen results and change from baseline

Compliance Points	River Mile	Maximum Modeled Dissolved Oxygen Values				Maximum Modeled Differences in D. O. 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	9.35	9.35	9.35	9.35	0.00	0.00	0.00
Louie Road	33.93	11.27	11.34	9.74	9.74	0.07	(1.53)	(1.53)
GID	30.59	11.07	10.60	10.26	10.26	(0.47)	(0.81)	(0.81)
Highway A-12	24.11	10.75	10.20	10.07	9.85	(0.55)	(0.68)	(0.90)
Freeman Lane	19.23	11.03	10.31	10.00	9.76	(0.72)	(1.03)	(1.27)
M-G Road	15.52	10.96	10.30	9.65	9.73	(0.66)	(1.31)	(1.23)
Highway 3	13.16	11.18	10.38	9.74	9.67	(0.80)	(1.44)	(1.51)
Yreka Ager Road	10.91	10.66	10.43	9.82	9.72	(0.23)	(0.84)	(0.94)
Anderson Grade Road	8.03	10.09	10.33	9.88	9.79	0.24	(0.21)	(0.30)
Highway 263	7.30	9.94	10.08	9.88	9.64	0.14	(0.06)	(0.30)
"Salmon Heaven"	5.60	9.58	9.40	10.06	9.87	(0.18)	0.48	0.29
Mouth	0.66	9.87	9.64	10.17	9.71	(0.23)	0.30	(0.16)

Compliance Points	River Mile	Average Modeled Dissolved Oxygen Values				Average Modeled Differences in D. O. 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	8.72	8.72	8.72	8.72	0.00	0.00	0.00
Louie Road	33.93	8.56	8.55	8.61	8.60	(0.01)	0.06	0.05
GID	30.59	8.16	8.19	9.05	9.19	0.03	0.88	1.02
Highway A-12	24.11	7.98	7.79	8.85	8.89	(0.18)	0.87	0.91
Freeman Lane	19.23	7.91	7.85	8.55	8.73	(0.06)	0.64	0.82
M-G Road	15.52	7.88	7.68	8.33	8.49	(0.20)	0.45	0.61
Highway 3	13.16	7.92	7.58	8.32	8.36	(0.34)	0.40	0.44
Yreka Ager Road	10.91	8.12	7.84	8.58	8.55	(0.29)	0.46	0.42
Anderson Grade Road	8.03	8.30	8.20	8.82	8.80	(0.11)	0.52	0.50
Highway 263	7.30	8.52	8.35	8.88	8.85	(0.17)	0.36	0.33
"Salmon Heaven"	5.60	8.54	8.46	8.95	8.97	(0.07)	0.42	0.43
Mouth	0.66	8.64	8.50	8.98	8.93	(0.14)	0.34	0.29

Compliance Points	River Mile	Minimum Modeled Dissolved Oxygen Values				Minimum Modeled Differences in D. O. 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	8.06	8.06	8.06	8.06	0.00	0.00	0.00
Louie Road	33.93	6.72	6.67	7.71	7.68	(0.05)	0.99	0.96
GID	30.59	6.54	6.81	8.27	8.48	0.27	1.73	1.94
Highway A-12	24.11	6.30	6.39	7.95	8.30	0.09	1.65	2.00
Freeman Lane	19.23	5.91	6.36	7.51	7.94	0.45	1.60	2.03
M-G Road	15.52	5.93	6.00	7.47	7.57	0.07	1.54	1.64
Highway 3	13.16	5.84	5.80	7.56	7.47	(0.04)	1.72	1.63
Yreka Ager Road	10.91	6.36	6.22	7.88	7.73	(0.14)	1.52	1.37
Anderson Grade Road	8.03	6.95	6.94	8.00	8.21	(0.01)	1.05	1.26
Highway 263	7.30	7.26	7.28	8.04	8.36	0.02	0.78	1.10
"Salmon Heaven"	5.60	7.61	7.77	8.04	8.40	0.16	0.43	0.79
Mouth	0.66	7.41	7.62	7.94	8.17	0.21	0.53	0.76

7.4.2 Oxygen Load Calculations

As discussed in Chapter 4, there are a number of interacting processes affecting dissolved oxygen concentrations in the Shasta River watershed. Photosynthesis and reaeration add oxygen to the water, while respiration of aquatic vegetation, sediment oxygen demand, and carbonaceous and nitrogenous oxygen demands effectively remove dissolved oxygen from the water. In other words, absent other processes being exerted on the system, photosynthesis and reaeration cause an increase in dissolved oxygen concentrations, while respiration, sediment oxygen demand, and carbonaceous and nitrogenous oxygen demand cause a decrease in dissolved oxygen concentrations in the river.

The RMS model for dissolved oxygen allowed us to evaluate how changes to these oxygen-producing and oxygen-consuming processes affect dissolved oxygen concentrations in the river. The water quality compliance scenario represents a suite of conditions that result in dissolved oxygen concentrations above the water quality objective of 7.0 mg/L at all river locations under critical conditions. The difference between the rates and concentrations of the oxygen producing and consuming processes for the existing (baseline) condition and those for the water quality compliance scenario, therefore, represents the needed changes in order to achieve water quality standards compliance for the Shasta River.

The difference in the total dissolved oxygen load of the Shasta River for a 24-hour period under the existing (baseline) condition and the water quality compliance scenario equals the reduction in total oxygen demand that is required to achieve water quality compliance. The net dissolved oxygen load of the river can be calculated using a basic dissolved oxygen budget equation:

$$O_{2net} = P + R_{aer} - (R_{esp} + S + C_{deox} + N_{deox})$$

Where,

O_{2net} = Net oxygen load in pounds/day
P = Oxygen load from photosynthesis in pounds/day
R_{aer} = Oxygen load from reaeration in pounds/day
R_{esp} = Oxygen demand from aquatic plant respiration in pounds/day
S = Oxygen demand from sediment oxygen demand in pounds/day
C_{deox} = Oxygen demand from carbonaceous deoxygenation in pounds/day
N_{deox} = Oxygen demand from nitrogenous deoxygenation in pounds/day.

This dissolved oxygen budget equation was used to calculate the 24-hour net oxygen load for the fourth day of the August simulation period for both the existing (baseline) condition and water quality compliance scenario. Several factors were considered in selecting the simulation period for which to calculate the dissolved oxygen budget, including day length, flow, and stream temperature. Daylight hours decreased (and nighttime hours increased) progressively for the July, August, and September simulation periods. Longer daylight hours yield greater oxygen production from photosynthesis. Oxygen consumption from aquatic vegetation respiration is constant and occurs around the clock. For the August simulation period there were 13 hours of daylight and 11 nighttime hours. In addition, flows were lowest in the river during the August 2002 baseline simulation period. Considering these factors in combination, the August simulation period was selected because it represents a critical condition with respect to dissolved oxygen conditions in the river. Hydrodynamic and water quality models often show some instability during the first 72 hours or so of a model simulation. Therefore, the fourth day of the August simulation period was used for calculating 24-hour net oxygen load to avoid inaccuracies that could be associated with model instability during the first 72 hours.

Tables 7.7 and 7.8 present the dissolved oxygen budget calculation results for Shasta River reaches for both the daytime and nighttime periods for the existing (baseline) condition and for the water quality compliance scenario, respectively. The total pounds of oxygen produced (i.e. the total 24-hr productivity) and the total pounds of oxygen demanded (i.e. the total 24-hr demand) are presented at the bottom of Table 7.7 and Table 7.8. In addition, the oxygen demand associated with each of the oxygen demand components (i.e. respiration, SOD, CBOD, and NBOD) are presented at the bottom of Table 7.7 and Table 7.8. Table 7.7 and Table 7.8 also present the oxygen production and oxygen demand during daylight versus nighttime hours for specified reaches of the river. Calculations of oxygen production and oxygen demand for specified reaches allow for determination of reach-scale oxygen demand reductions necessary for dissolved oxygen objective compliance.

The total net daily oxygen demand (i.e. the sum of respiratory demand, sediment oxygen demand, nitrogenous oxygen demand, and biochemical oxygen demand) on the Shasta River (from Dwinnell Dam to the mouth) for the fourth day (24-hours) of the August simulation period is 20,622 pounds/day for the existing (baseline) condition and 12,353 pounds/day for the water quality compliance scenario. Based on these calculations, the net oxygen demand of the river must be reduced by 8,269 pounds/day (i.e. 20,622 – 12,353) in order to comply with water quality standards under critical conditions.

7.5 Dissolved Oxygen TMDL and Allocations

This section presents the dissolved oxygen TMDL and load allocations. As discussed in Section 6.5, 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.

Table 7.7: Calculated oxygen production and demands for the August existing (baseline) condition

REACH	Reach Length (mi)	*EXISTING (BASELINE) CONDITIONS*								
		PRODUCTIVITY or (DEMAND)					Daylight Demand (lbs/day)	Daylight Productivity (lbs/day)	Total Daylight Productivity (lbs/day)	Total Daylight Productivity (lbs/mi-day)
		SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)				
		Daylight Hours (for model time period - 13 hours)								
Dwinnell Reservoir - Riverside Drive	0.7	(0)	15	(3)	(3)	(6)	(154)	198	44	65
Riverside Drive - Parks Creek	5.0	(2)	285	(58)	(4)	(8)	(933)	3,710	2,777	555
Parks Creek - Big Springs Creek	1.3	(1)	92	(19)	(5)	(9)	(432)	1,199	767	604
Big Springs Creek - Highway A-12	9.6	(13)	1,078	(219)	(15)	(84)	(4,299)	14,016	9,716	1,016
Highway A-12 - Shasta River @ Freeman Lane	5.0	(1)	461	(93)	(28)	(25)	(1,912)	5,991	4,079	819
Shasta River @ Freeman Lane - DWR Weir	3.6	(6)	291	(59)	(4)	(4)	(948)	3,780	2,833	785
DWR Weir - Yreka-Ager Road	4.4	(6)	277	(56)	0	0	(808)	3,607	2,799	633
Yreka-Ager Road - Anderson Grade Road	3.1	(1)	252	(51)	0	0	(679)	3,282	2,603	853
Anderson Grade Road - Mouth	8.1	(1)	377	(76)	(0)	(0)	(1,006)	4,897	3,891	483

REACH	Reach Length (mi)	*EXISTING (BASELINE) CONDITIONS*								
		PRODUCTIVITY or (DEMAND)					Nighttime Demand (lbs/day)	Nighttime Productivity (lbs/day)	Total Nighttime Demand (lbs/day)	Total Nighttime Demand (lbs/mi-day)
		SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)				
		Nighttime Hours (for model time period - 11 hours)								
Dwinnell Reservoir - Riverside Drive	0.7	(0)	0	(3)	(3)	(6)	(130)	0	(130)	(192)
Riverside Drive - Parks Creek	5.0	(2)	0	(58)	(4)	(8)	(789)	0	(789)	(158)
Parks Creek - Big Springs Creek	1.3	(1)	0	(19)	(5)	(9)	(365)	0	(365)	(288)
Big Springs Creek - Highway A-12	9.6	(13)	0	(219)	(15)	(84)	(3,638)	0	(3,638)	(381)
Highway A-12 - Shasta River @ Freeman Lane	5.0	(1)	0	(93)	(28)	(25)	(1,618)	0	(1,618)	(325)
Shasta River @ Freeman Lane - DWR Weir	3.6	(6)	0	(59)	(4)	(4)	(802)	0	(802)	(222)
DWR Weir - Yreka-Ager Road	4.4	(6)	0	(56)	0	0	(684)	0	(684)	(155)
Yreka-Ager Road - Anderson Grade Road	3.1	(1)	0	(51)	0	0	(574)	0	(574)	(188)
Anderson Grade Road - Mouth	8.1	(1)	0	(76)	(0)	(0)	(851)	0	(851)	(106)

		SHASTA RIVER PRODUCTIVITY or (DEMAND)							
		SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)			
Shasta River (Daylight Hours - 13 hours)	Daily Productivity or Demand	(30)	3,129	(635)	(60)	(135)	**Total 24 Hour Productivity (lbs/day)**	**40,680**	**1,001**
Shasta River (Nightime Hours - 11 hours)		(30)	0	(635)	(60)	(135)	**Total 24 Hour Demand (lbs/day)**	**(20,622)**	**(508)**
Demand By Process	%	3.4%	0.0%	73.9%	6.9%	15.8%			

Table 7.8: Calculated oxygen production and demands for the August water quality compliance conditions

REACH	Reach Length (mi)	TMDL WATER QUALITY COMPLIANCE CONDITIONS								
		PRODUCTIVITY or (DEMAND)					Daylight Demand (lbs/day)	Daylight Productivity (lbs/day)	Total Daylight Productivity (lbs/day)	Total Daylight Productivity (lbs/mi-day)
		SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)				
		Daylight Hours (for model time period - 13 hours)								
Dwinnell Reservoir - Riverside Drive	0.7	(0)	8	(2)	(1)	(6)	(107)	99	(8)	(12)
Riverside Drive - Parks Creek	5.0	(2)	143	(29)	(1)	(8)	(519)	1,855	1,336	267
Parks Creek - Big Springs Creek	1.3	(1)	46	(9)	(2)	(9)	(267)	600	332	262
Big Springs Creek - Highway A-12	9.6	(8)	539	(110)	(15)	(84)	(2,815)	7,008	4,193	439
Highway A-12 - Shasta River @ Freeman Lane	5.0	(1)	230	(47)	(25)	(20)	(1,206)	2,995	1,789	359
Shasta River @ Freeman Lane - DWR Weir	3.6	(3)	145	(30)	(4)	(3)	(513)	1,890	1,377	382
DWR Weir - Yreka-Ager Road	4.4	(3)	139	(28)	0	0	(406)	1,803	1,398	316
Yreka-Ager Road - Anderson Grade Road	3.1	(1)	126	(26)	0	0	(345)	1,641	1,296	425
Anderson Grade Road - Mouth	8.1	(1)	188	(38)	(0)	(0)	(513)	2,449	1,935	240

REACH	Reach Length (mi)	TMDL WATER QUALITY COMPLIANCE CONDITIONS								
		PRODUCTIVITY or (DEMAND)					Nighttime Demand (lbs/day)	Nighttime Productivity (lbs/day)	Total Nighttime Demand (lbs/day)	Total Nighttime Demand (lbs/mi-day)
		SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)				
		Nighttime Hours (for model time period - 11 hours)								
Dwinnell Reservoir - Riverside Drive	0.7	(0)	0	(2)	(1)	(6)	(91)	0	(91)	(133)
Riverside Drive - Parks Creek	5.0	(2)	0	(29)	(1)	(8)	(439)	0	(439)	(88)
Parks Creek - Big Springs Creek	1.3	(1)	0	(9)	(2)	(9)	(226)	0	(226)	(178)
Big Springs Creek - Highway A-12	9.6	(8)	0	(110)	(15)	(84)	(2,382)	0	(2,382)	(249)
Highway A-12 - Shasta River @ Freeman Lane	5.0	(1)	0	(47)	(25)	(20)	(1,020)	0	(1,020)	(205)
Shasta River @ Freeman Lane - DWR Weir	3.6	(3)	0	(30)	(4)	(3)	(434)	0	(434)	(120)
DWR Weir - Yreka-Ager Road	4.4	(3)	0	(28)	0	0	(343)	0	(343)	(78)
Yreka-Ager Road - Anderson Grade Road	3.1	(1)	0	(26)	0	0	(292)	0	(292)	(96)
Anderson Grade Road - Mouth	8.1	(1)	0	(38)	(0)	(0)	(434)	0	(434)	(54)

		SHASTA RIVER PRODUCTIVITY or (DEMAND)							
		SOD (lbs/hr)	Pmax (lbs/hr)	RESP (lbs/hr)	NBOD (lbs/hr)	CBOD (lbs/hr)	Total 24 Hour Productivity (lbs/day)	20,340	501
Shasta River (Daylight Hours - 13 hours)	Daily Productivity or Demand (lbs/day)	(19)	1,565	(317)	(48)	(130)			
Shasta River (Nightime Hours - 11 hours)		(19)	0	(317)	(48)	(130)	Total 24 Hour Demand (lbs/day)	(12,353)	(304)
Demand By Process	%	3.8%	0.0%	61.7%	9.4%	25.2%			

7.5.1 Dissolved Oxygen Loading Capacity

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 dissolved oxygen TMDL the water quality objective of concern is the minimum dissolved oxygen objective of 7.0 mg/L for the Shasta River. There are no known point sources of oxygen-demanding constituents to the Shasta River and tributaries. Each of the components that exert an oxygen demand on the Shasta River is attributed to nonpoint sources. As outlined in Section 7.3.1, these oxygen demand components include respiration of aquatic plants, sediment oxygen demand, and nitrogenous oxygen demand (NBOD). The loading capacity for the Shasta River is, therefore, the total oxygen demand of the river under the water quality compliance scenario, as outlined in Section 7.4.1 and as presented in Table 7.8.

Therefore, the Shasta River dissolved oxygen TMDL is:

TMDL = Loading Capacity = 12,353 lbs O_2/day

7.5.2 Dissolved Oxygen Load Allocations

In accordance with EPA regulations, the TMDL (i.e., the 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 known point sources of oxygen-demanding constituents to the Shasta River and tributaries, and therefore no waste load allocations apply.

For the dissolved oxygen TMDL allocations are assigned to reaches of the Shasta River, as identified in Table 7.9. Responsibility for meeting these river-reach allocations is assigned to the landowners whose operations contribute to water quality conditions within the specified reaches. These load allocations are presented on an hourly and daily basis, and equal the total hourly and total daily oxygen demand for these river reaches. The difference between the total daily oxygen demand for the existing (baseline) condition and the total daily oxygen demand for the water quality compliance scenario condition represents the reductions in total oxygen demand needed to comply with the TMDL. These river-reach oxygen demand reductions needed for dissolved oxygen compliance are also presented in Table 7.9.

In addition to the river reach load allocations, NBOD allocations are applied to Dwinnell Dam, Yreka Creek, and tailwater return flows. These allocations are assigned as NBOD concentrations, not loads, as outlined in Table 7.10. The tailwater return flow NBOD concentration allocation is equal to the average Shasta River NBOD concentration in the water quality compliance scenario. 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”.

Table 7.9: Shasta River dissolved oxygen TMDL river-reach load allocations and total oxygen demand reductions needed to achieve dissolved oxygen compliance

REACH	Reach Length (mi)	Hourly Demand Existing (Baseline) Conditions (lbs/hr)	Hourly Demand Water Quality Compliance (Master 1 scenario) Conditions (lbs/hr)	Reduction In Oxygen Demand Needed To Achieve Water Quality Compliance	
				(lbs/hr)	%
Dwinnell Reservoir - Riverside Drive	0.7	(12)	(8)	4	30%
Riverside Drive - Parks Creek	5.0	(72)	(40)	32	44%
Parks Creek - Big Springs Creek	1.3	(33)	(21)	13	38%
Big Springs Creek - Highway A-12	9.6	(331)	(217)	114	35%
Highway A-12 - Shasta River @ Freeman Lane	5.0	(147)	(93)	54	37%
Shasta River @ Freeman Lane - DWR Weir	3.6	(73)	(39)	33	46%
DWR Weir - Yreka-Ager Road	4.4	(62)	(31)	31	50%
Yreka-Ager Road - Anderson Grade Road	3.1	(52)	(27)	26	49%
Anderson Grade Road - Mouth	8.1	(77)	(39)	38	49%

REACH	Reach Length (mi)	24 Hour Demand Existing (Baseline) Conditions (lbs/day)	24 Hour Demand Water Quality Compliance (Master 1 scenario) Conditions (lbs/day)	Reduction In Oxygen Demand Needed To Achieve Water Quality Compliance	
				(lbs/day)	%
Dwinnell Reservoir - Riverside Drive	0.7	(285)	(198)	87	30%
Riverside Drive - Parks Creek	5.0	(1,722)	(957)	765	44%
Parks Creek - Big Springs Creek	1.3	(797)	(494)	304	38%
Big Springs Creek - Highway A-12	9.6	(7,937)	(5,197)	2,741	35%
Highway A-12 - Shasta River @ Freeman Lane	5.0	(3,529)	(2,226)	1,303	37%
Shasta River @ Freeman Lane - DWR Weir	3.6	(1,749)	(947)	803	46%
DWR Weir - Yreka-Ager Road	4.4	(1,492)	(749)	743	50%
Yreka-Ager Road - Anderson Grade Road	3.1	(1,253)	(637)	616	49%
Anderson Grade Road - Mouth	8.1	(1,857)	(948)	909	49%

Table 7.10: Nitrogenous oxygen demand (NBOD) allocations

Location	NBOD Allocation (mg/L)
Dwinnell Dam	0.91
Yreka Creek	0.91
Tailwater return flows	0.85

7.6 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, which is the basis for the dissolved oxygen TMDL, includes a 50% reduction of sediment oxygen demand only at locations behind minor impoundments in the Shasta River. Fine sediment and organic material load reductions from irrigation return flows that can be achieved via controls targeting NBOD reductions would result in reductions in sediment oxygen demand in the entire river, not just behind impoundments. This represents a margin of safety.
- The water quality compliance scenario does not include CBOD concentration reductions. Controls targeting NBOD reductions from irrigation return flows, Dwinnell Dam outflow, and Yreka Creek would result in reductions in CBOD concentrations, and provide a margin of safety.