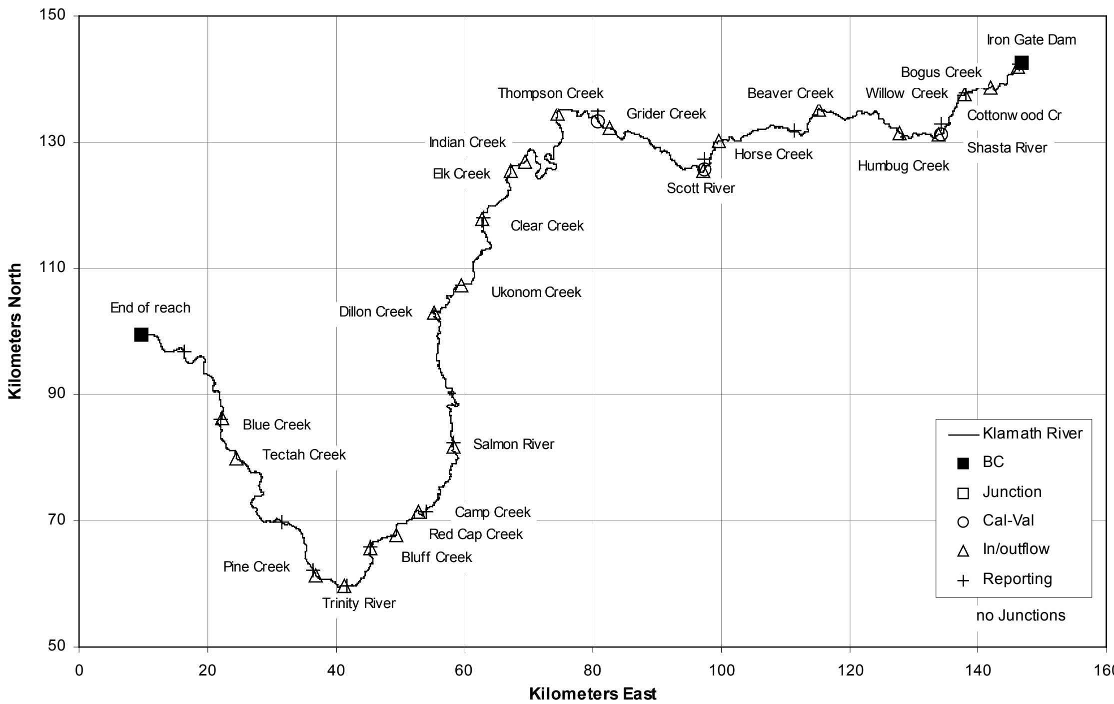
APPENDIX 4A

KLAMATH RIVER MODELING FRAMEWORK

Klamath River Modeling Framework to Support the PacifiCorp Federal Energy Regulatory Commission Hydropower Relicensing Application



Prepared for PacifiCorp

Watercourse Engineering, Inc.
1732 Jefferson Street, Suite 7
Napa, CA 94559

November 14, 2003

Table of Contents

Unit Abbreviations

Acre-feet	ac-ft
Cubic feet per second	cfs
Day	d
Degree Celsius	°C
Degree Fahrenheit	°F
Degree Kelvin	K
Feet	ft
Fluid ounce	fl oz
Gallon	gal
Gram	g
Hectare	ha
Hour	hr
Inch	in
Joule	J
Kilogram	kg
Kilometer	km
Liter	L
Meter	m
Microgram	μg
Micromhos	μmhos
Mile	mi
Millibar	mb
Milliliter	ml
Microgram	μg
Milligram	mg
Millimeter	mm
Ounce	oz
Parts per billion	ppb
Parts per million	ppm
Parts per thousand	ppt
Pascal	Pa
Pounds per square inch	psi
Second	s
Watt	W
Yard	yd

Unit Conversions

Class	Multiply	By	To Obtain
Area	acre	4047.0	m^2
	acre	0.4047	ha (10 000 m^2)
	ft^2	0.0929	m^2
	yd^2	0.8361	m^2
	mi^2	2.590	km^2
Length	ft	0.3048	m
	in	25.4	mm
	mi	1.6093	km
	yd	0.9144	m
Volume	ft^3	0.0283	m^3
	gal	3.785	L
	fl oz	29.575	mL
	yd^3	0.7646	m^3
	acre-feet	1233.49	m^3
Mass	oz	28.35	g
	lb	0.4536	kg
Concentration	□g/l	1.0	ppb
	□g/l	1.0	mg/m^3
	□g/l	0.001	mg/l
	mg/l	1.0	ppm
	mg/l	1.0	g/m^3
	mg/l	0.001	g/L
	g/l	1.0	ppt
	g/l	1.0	kg/m^3
Density	lb/ft^3	6894.7	kg/m^3
Velocity	ft/s	0.3048	m/s
	mi/hr	0.4470	m/s
	mi/hr	1.6093	km/h
Flow Rate	cfs	0.0283	cms
Temperature	°F	$T_{°C} = (T_{°F} - 32.0)/1.8$	°C

Temperature Conversion Table

Temperature °C	Temperature °F	Temperature °C	Temperature °F
0.0	32.0	25.0	77.0
1.0	33.8	26.0	78.8
2.0	35.6	27.0	80.6
3.0	37.4	28.0	82.4
4.0	39.2	29.0	84.2
5.0	41.0	30.0	86.0
6.0	42.8	31.0	87.8
7.0	44.6	32.0	89.6
8.0	46.4	33.0	91.4
9.0	48.2	34.0	93.2
10.0	50.0	35.0	95.0
11.0	51.8	36.0	96.8
12.0	53.6	37.0	98.6
13.0	55.4	38.0	100.4
14.0	57.2	39.0	102.2
15.0	59.0	40.0	104.0
16.0	60.8	41.0	105.8
17.0	62.6	42.0	107.6
18.0	64.4	43.0	109.4
19.0	66.2	44.0	111.2
20.0	68.0	45.0	113.0
21.0	69.8	46.0	114.8
22.0	71.6	47.0	116.6
23.0	73.4	48.0	118.4
24.0	75.2	49.0	120.2

Julian Days (2000 Leap Year)

1-Jan-00	1	**1-Mar-00**	61	**1-May-00**	122	**1-Jul-00**	183	**1-Sep-00**	245	**1-Nov-00**	**306**
2-Jan-00	2	2-Mar-00	62	2-May-00	123	2-Jul-00	184	2-Sep-00	246	2-Nov-00	307
3-Jan-00	3	3-Mar-00	63	3-May-00	124	3-Jul-00	185	3-Sep-00	247	3-Nov-00	308
4-Jan-00	4	4-Mar-00	64	4-May-00	125	4-Jul-00	186	4-Sep-00	248	4-Nov-00	309
5-Jan-00	5	5-Mar-00	65	5-May-00	126	5-Jul-00	187	5-Sep-00	249	5-Nov-00	310
6-Jan-00	6	6-Mar-00	66	6-May-00	127	6-Jul-00	188	6-Sep-00	250	6-Nov-00	311
7-Jan-00	7	7-Mar-00	67	7-May-00	128	7-Jul-00	189	7-Sep-00	251	7-Nov-00	312
8-Jan-00	8	8-Mar-00	68	8-May-00	129	8-Jul-00	190	8-Sep-00	252	8-Nov-00	313
9-Jan-00	9	9-Mar-00	69	9-May-00	130	9-Jul-00	191	9-Sep-00	253	9-Nov-00	314
10-Jan-00	10	10-Mar-00	70	10-May-00	131	10-Jul-00	192	10-Sep-00	254	10-Nov-00	315
11-Jan-00	11	11-Mar-00	71	11-May-00	132	11-Jul-00	193	11-Sep-00	255	11-Nov-00	316
12-Jan-00	12	12-Mar-00	72	12-May-00	133	12-Jul-00	194	12-Sep-00	256	12-Nov-00	317
13-Jan-00	13	13-Mar-00	73	13-May-00	134	13-Jul-00	195	13-Sep-00	257	13-Nov-00	318
14-Jan-00	14	14-Mar-00	74	14-May-00	135	14-Jul-00	196	14-Sep-00	258	14-Nov-00	319
15-Jan-00	15	15-Mar-00	75	15-May-00	136	15-Jul-00	197	15-Sep-00	259	15-Nov-00	320
16-Jan-00	16	16-Mar-00	76	16-May-00	137	16-Jul-00	198	16-Sep-00	260	16-Nov-00	321
17-Jan-00	17	17-Mar-00	77	17-May-00	138	17-Jul-00	199	17-Sep-00	261	17-Nov-00	322
18-Jan-00	18	18-Mar-00	78	18-May-00	139	18-Jul-00	200	18-Sep-00	262	18-Nov-00	323
19-Jan-00	19	19-Mar-00	79	19-May-00	140	19-Jul-00	201	19-Sep-00	263	19-Nov-00	324
20-Jan-00	20	20-Mar-00	80	20-May-00	141	20-Jul-00	202	20-Sep-00	264	20-Nov-00	325
21-Jan-00	21	21-Mar-00	81	21-May-00	142	21-Jul-00	203	21-Sep-00	265	21-Nov-00	326
22-Jan-00	22	22-Mar-00	82	22-May-00	143	22-Jul-00	204	22-Sep-00	266	22-Nov-00	327
23-Jan-00	23	23-Mar-00	83	23-May-00	144	23-Jul-00	205	23-Sep-00	267	23-Nov-00	328
24-Jan-00	24	24-Mar-00	84	24-May-00	145	24-Jul-00	206	24-Sep-00	268	24-Nov-00	329
25-Jan-00	25	25-Mar-00	85	25-May-00	146	25-Jul-00	207	25-Sep-00	269	25-Nov-00	330
26-Jan-00	26	26-Mar-00	86	26-May-00	147	26-Jul-00	208	26-Sep-00	270	26-Nov-00	331
27-Jan-00	27	27-Mar-00	87	27-May-00	148	27-Jul-00	209	27-Sep-00	271	27-Nov-00	332
28-Jan-00	28	28-Mar-00	88	28-May-00	149	28-Jul-00	210	28-Sep-00	272	28-Nov-00	333
29-Jan-00	29	29-Mar-00	89	29-May-00	150	29-Jul-00	211	29-Sep-00	273	29-Nov-00	334
30-Jan-00	30	30-Mar-00	90	30-May-00	151	30-Jul-00	212	30-Sep-00	274	30-Nov-00	335
31-Jan-00	31	31-Mar-00	91	31-May-00	152	31-Jul-00	213	**1-Oct-00**	275	**1-Dec-00**	336
1-Feb-00	32	**1-Apr-00**	92	**1-Jun-00**	153	**1-Aug-00**	214	2-Oct-00	276	2-Dec-00	337
2-Feb-00	33	2-Apr-00	93	2-Jun-00	154	2-Aug-00	215	3-Oct-00	277	3-Dec-00	338
3-Feb-00	34	3-Apr-00	94	3-Jun-00	155	3-Aug-00	216	4-Oct-00	278	4-Dec-00	339
4-Feb-00	35	4-Apr-00	95	4-Jun-00	156	4-Aug-00	217	5-Oct-00	279	5-Dec-00	340
5-Feb-00	36	5-Apr-00	96	5-Jun-00	157	5-Aug-00	218	6-Oct-00	280	6-Dec-00	341
6-Feb-00	37	6-Apr-00	97	6-Jun-00	158	6-Aug-00	219	7-Oct-00	281	7-Dec-00	342
7-Feb-00	38	7-Apr-00	98	7-Jun-00	159	7-Aug-00	220	8-Oct-00	282	8-Dec-00	343
8-Feb-00	39	8-Apr-00	99	8-Jun-00	160	8-Aug-00	221	9-Oct-00	283	9-Dec-00	344
9-Feb-00	40	9-Apr-00	100	9-Jun-00	161	9-Aug-00	222	10-Oct-00	284	10-Dec-00	345
10-Feb-00	41	10-Apr-00	101	10-Jun-00	162	10-Aug-00	223	11-Oct-00	285	11-Dec-00	346
11-Feb-00	42	11-Apr-00	102	11-Jun-00	163	11-Aug-00	224	12-Oct-00	286	12-Dec-00	347
12-Feb-00	43	12-Apr-00	103	12-Jun-00	164	12-Aug-00	225	13-Oct-00	287	13-Dec-00	348
13-Feb-00	44	13-Apr-00	104	13-Jun-00	165	13-Aug-00	226	14-Oct-00	288	14-Dec-00	349
14-Feb-00	45	14-Apr-00	105	14-Jun-00	166	14-Aug-00	227	15-Oct-00	289	15-Dec-00	350
15-Feb-00	46	15-Apr-00	106	15-Jun-00	167	15-Aug-00	228	16-Oct-00	290	16-Dec-00	351
16-Feb-00	47	16-Apr-00	107	16-Jun-00	168	16-Aug-00	229	17-Oct-00	291	17-Dec-00	352
17-Feb-00	48	17-Apr-00	108	17-Jun-00	169	17-Aug-00	230	18-Oct-00	292	18-Dec-00	353
18-Feb-00	49	18-Apr-00	109	18-Jun-00	170	18-Aug-00	231	19-Oct-00	293	19-Dec-00	354
19-Feb-00	50	19-Apr-00	110	19-Jun-00	171	19-Aug-00	232	20-Oct-00	294	20-Dec-00	355
20-Feb-00	51	20-Apr-00	111	20-Jun-00	172	20-Aug-00	233	21-Oct-00	295	21-Dec-00	356
21-Feb-00	52	21-Apr-00	112	21-Jun-00	173	21-Aug-00	234	22-Oct-00	296	22-Dec-00	357
22-Feb-00	53	22-Apr-00	113	22-Jun-00	174	22-Aug-00	235	23-Oct-00	297	23-Dec-00	358
23-Feb-00	54	23-Apr-00	114	23-Jun-00	175	23-Aug-00	236	24-Oct-00	298	24-Dec-00	359
24-Feb-00	55	24-Apr-00	115	24-Jun-00	176	24-Aug-00	237	25-Oct-00	299	25-Dec-00	360
25-Feb-00	56	25-Apr-00	116	25-Jun-00	177	25-Aug-00	238	26-Oct-00	300	26-Dec-00	361
26-Feb-00	57	26-Apr-00	117	26-Jun-00	178	26-Aug-00	239	27-Oct-00	301	27-Dec-00	362
27-Feb-00	58	27-Apr-00	118	27-Jun-00	179	27-Aug-00	240	28-Oct-00	302	28-Dec-00	363
28-Feb-00	59	28-Apr-00	119	28-Jun-00	180	28-Aug-00	241	29-Oct-00	303	29-Dec-00	364
29-Feb-00	60	29-Apr-00	120	29-Jun-00	181	29-Aug-00	242	30-Oct-00	304	30-Dec-00	365
		30-Apr-00	121	30-Jun-00	182	30-Aug-00	243	31-Oct-00	305	31-Dec-00	366
						31-Aug-00	244				

Julian Days (2001)

1-Jan-01	1	**1-Mar-01**	60	**1-May-01**	121	**1-Jul-01**	182	**1-Sep-01**	244	**1-Nov-01**	**305**
2-Jan-01	2	2-Mar-01	61	2-May-01	122	2-Jul-01	183	2-Sep-01	245	2-Nov-01	306
3-Jan-01	3	3-Mar-01	62	3-May-01	123	3-Jul-01	184	3-Sep-01	246	3-Nov-01	307
4-Jan-01	4	4-Mar-01	63	4-May-01	124	4-Jul-01	185	4-Sep-01	247	4-Nov-01	308
5-Jan-01	5	5-Mar-01	64	5-May-01	125	5-Jul-01	186	5-Sep-01	248	5-Nov-01	309
6-Jan-01	6	6-Mar-01	65	6-May-01	126	6-Jul-01	187	6-Sep-01	249	6-Nov-01	310
7-Jan-01	7	7-Mar-01	66	7-May-01	127	7-Jul-01	188	7-Sep-01	250	7-Nov-01	311
8-Jan-01	8	8-Mar-01	67	8-May-01	128	8-Jul-01	189	8-Sep-01	251	8-Nov-01	312
9-Jan-01	9	9-Mar-01	68	9-May-01	129	9-Jul-01	190	9-Sep-01	252	9-Nov-01	313
10-Jan-01	10	10-Mar-01	69	10-May-01	130	10-Jul-01	191	10-Sep-01	253	10-Nov-01	314
11-Jan-01	11	11-Mar-01	70	11-May-01	131	11-Jul-01	192	11-Sep-01	254	11-Nov-01	315
12-Jan-01	12	12-Mar-01	71	12-May-01	132	12-Jul-01	193	12-Sep-01	255	12-Nov-01	316
13-Jan-01	13	13-Mar-01	72	13-May-01	133	13-Jul-01	194	13-Sep-01	256	13-Nov-01	317
14-Jan-01	14	14-Mar-01	73	14-May-01	134	14-Jul-01	195	14-Sep-01	257	14-Nov-01	318
15-Jan-01	15	15-Mar-01	74	15-May-01	135	15-Jul-01	196	15-Sep-01	258	15-Nov-01	319
16-Jan-01	16	16-Mar-01	75	16-May-01	136	16-Jul-01	197	16-Sep-01	259	16-Nov-01	320
17-Jan-01	17	17-Mar-01	76	17-May-01	137	17-Jul-01	198	17-Sep-01	260	17-Nov-01	321
18-Jan-01	18	18-Mar-01	77	18-May-01	138	18-Jul-01	199	18-Sep-01	261	18-Nov-01	322
19-Jan-01	19	19-Mar-01	78	19-May-01	139	19-Jul-01	200	19-Sep-01	262	19-Nov-01	323
20-Jan-01	20	20-Mar-01	79	20-May-01	140	20-Jul-01	201	20-Sep-01	263	20-Nov-01	324
21-Jan-01	21	21-Mar-01	80	21-May-01	141	21-Jul-01	202	21-Sep-01	264	21-Nov-01	325
22-Jan-01	22	22-Mar-01	81	22-May-01	142	22-Jul-01	203	22-Sep-01	265	22-Nov-01	326
23-Jan-01	23	23-Mar-01	82	23-May-01	143	23-Jul-01	204	23-Sep-01	266	23-Nov-01	327
24-Jan-01	24	24-Mar-01	83	24-May-01	144	24-Jul-01	205	24-Sep-01	267	24-Nov-01	328
25-Jan-01	25	25-Mar-01	84	25-May-01	145	25-Jul-01	206	25-Sep-01	268	25-Nov-01	329
26-Jan-01	26	26-Mar-01	85	26-May-01	146	26-Jul-01	207	26-Sep-01	269	26-Nov-01	330
27-Jan-01	27	27-Mar-01	86	27-May-01	147	27-Jul-01	208	27-Sep-01	270	27-Nov-01	331
28-Jan-01	28	28-Mar-01	87	28-May-01	148	28-Jul-01	209	28-Sep-01	271	28-Nov-01	332
29-Jan-01	29	29-Mar-01	88	29-May-01	149	29-Jul-01	210	29-Sep-01	272	29-Nov-01	333
30-Jan-01	30	30-Mar-01	89	30-May-01	150	30-Jul-01	211	30-Sep-01	273	30-Nov-01	334
31-Jan-01	31	31-Mar-01	90	31-May-01	151	31-Jul-01	212	**1-Oct-01**	274	**1-Dec-01**	335
1-Feb-01	32	**1-Apr-01**	91	**1-Jun-01**	152	**1-Aug-01**	213	2-Oct-01	275	2-Dec-01	336
2-Feb-01	33	2-Apr-01	92	2-Jun-01	153	2-Aug-01	214	3-Oct-01	276	3-Dec-01	337
3-Feb-01	34	3-Apr-01	93	3-Jun-01	154	3-Aug-01	215	4-Oct-01	277	4-Dec-01	338
4-Feb-01	35	4-Apr-01	94	4-Jun-01	155	4-Aug-01	216	5-Oct-01	278	5-Dec-01	339
5-Feb-01	36	5-Apr-01	95	5-Jun-01	156	5-Aug-01	217	6-Oct-01	279	6-Dec-01	340
6-Feb-01	37	6-Apr-01	96	6-Jun-01	157	6-Aug-01	218	7-Oct-01	280	7-Dec-01	341
7-Feb-01	38	7-Apr-01	97	7-Jun-01	158	7-Aug-01	219	8-Oct-01	281	8-Dec-01	342
8-Feb-01	39	8-Apr-01	98	8-Jun-01	159	8-Aug-01	220	9-Oct-01	282	9-Dec-01	343
9-Feb-01	40	9-Apr-01	99	9-Jun-01	160	9-Aug-01	221	10-Oct-01	283	10-Dec-01	344
10-Feb-01	41	10-Apr-01	100	10-Jun-01	161	10-Aug-01	222	11-Oct-01	284	11-Dec-01	345
11-Feb-01	42	11-Apr-01	101	11-Jun-01	162	11-Aug-01	223	12-Oct-01	285	12-Dec-01	346
12-Feb-01	43	12-Apr-01	102	12-Jun-01	163	12-Aug-01	224	13-Oct-01	286	13-Dec-01	347
13-Feb-01	44	13-Apr-01	103	13-Jun-01	164	13-Aug-01	225	14-Oct-01	287	14-Dec-01	348
14-Feb-01	45	14-Apr-01	104	14-Jun-01	165	14-Aug-01	226	15-Oct-01	288	15-Dec-01	349
15-Feb-01	46	15-Apr-01	105	15-Jun-01	166	15-Aug-01	227	16-Oct-01	289	16-Dec-01	350
16-Feb-01	47	16-Apr-01	106	16-Jun-01	167	16-Aug-01	228	17-Oct-01	290	17-Dec-01	351
17-Feb-01	48	17-Apr-01	107	17-Jun-01	168	17-Aug-01	229	18-Oct-01	291	18-Dec-01	352
18-Feb-01	49	18-Apr-01	108	18-Jun-01	169	18-Aug-01	230	19-Oct-01	292	19-Dec-01	353
19-Feb-01	50	19-Apr-01	109	19-Jun-01	170	19-Aug-01	231	20-Oct-01	293	20-Dec-01	354
20-Feb-01	51	20-Apr-01	110	20-Jun-01	171	20-Aug-01	232	21-Oct-01	294	21-Dec-01	355
21-Feb-01	52	21-Apr-01	111	21-Jun-01	172	21-Aug-01	233	22-Oct-01	295	22-Dec-01	356
22-Feb-01	53	22-Apr-01	112	22-Jun-01	173	22-Aug-01	234	23-Oct-01	296	23-Dec-01	357
23-Feb-01	54	23-Apr-01	113	23-Jun-01	174	23-Aug-01	235	24-Oct-01	297	24-Dec-01	358
24-Feb-01	55	24-Apr-01	114	24-Jun-01	175	24-Aug-01	236	25-Oct-01	298	25-Dec-01	359
25-Feb-01	56	25-Apr-01	115	25-Jun-01	176	25-Aug-01	237	26-Oct-01	299	26-Dec-01	360
26-Feb-01	57	26-Apr-01	116	26-Jun-01	177	26-Aug-01	238	27-Oct-01	300	27-Dec-01	361
27-Feb-01	58	27-Apr-01	117	27-Jun-01	178	27-Aug-01	239	28-Oct-01	301	28-Dec-01	362
28-Feb-01	59	28-Apr-01	118	28-Jun-01	179	28-Aug-01	240	29-Oct-01	302	29-Dec-01	363
		29-Apr-01	119	29-Jun-01	180	29-Aug-01	241	30-Oct-01	303	30-Dec-01	364
		30-Apr-01	120	30-Jun-01	181	30-Aug-01	242	31-Oct-01	304	31-Dec-01	365
						31-Aug-01	243				

1 Introduction

Watercourse Engineering, Inc. (Watercourse) was retained by PacifiCorp to design and implement a flow and water quality modeling framework for the Klamath River from Link Dam (River Mile (RM) 255) to Turwar (RM 5). The modeling framework provides a key tool for the analysis of water quality for the Federal Energy Regulatory Commission relicensing of PacifiCorp's Klamath Hydroelectric Project. The basis for the modeling framework and supporting documentation are found in the attached appendices. Outlined herein are three specific tasks:

1) Model Implementation
2) Calibration and Validation
3) Model Application

Model implementation is the process of gathering the appropriate data (geometry, flow, water quality, meteorology) and formatting it for input into the selected models. Also included in this step is selection of default model parameters and general model testing. The end result of model implementation is a running, but uncalibrated model. Model calibration and validation is the stage wherein model parameters are modified to fit the model to field observations – calibration. The model is then tested on an independent set of data to illustrate that the model can replicate field conditions for the parameter values determined in calibration. The final stage is model application, wherein the calibrated models are applied to selected management strategies or scenarios. Such scenarios may vary flow or water quality conditions, or may include the addition or removal of project facilities to identify potential effects and outcomes. Data sets for model implementation, calibration and application may vary and are noted in the text.

This report is arranged as per the three specific modeling tasks outlined above, plus appendices. The appendix includes the modeling framework originally proposed with additions and changes included, as well as other supporting information.

2 Model Implementation

2.1 Model Selection

Flow and water quality conditions in the Klamath River basin vary dramatically in the approximately 250 river miles (RM) from Link Dam (RM 255), near Klamath Falls Oregon, and Turwar (RM 6), California. There are a wide range of natural and anthropogenic influences in the Klamath River system throughout this region: inflows at Link Dam originate in hypereutrophic Upper Klamath Lake; there are four major reservoirs on the mainstem Klamath River; diversions and return flows for agriculture, as well as municipal and industrial use occur in the reach between Link Dam and Keno Dam; and the river receives considerable inflow from tributaries as it flow towards the Pacific Ocean..

To address these diverse characteristics discrete river models and reservoir models were selected. The river models consist of a suite of models produced by RMA. The flow component is represented with RMA-2, a finite element hydrodynamic model capable of modeling highly dynamic flow regimes at short space and time steps. The output from this model, velocity, depth, a representative surface and bed areas are passed to the water quality model RMA-11. RMA-11 is a full water quality finite element model, simulating the fate and transport of a wide range of physical, chemical, and biological constituents based on information produced by RMA-2. The suite of river models is applied on a sub-daily time step to capture the short-term response of parameters such as temperature and dissolved oxygen. The RMA models are applied in one-dimension for the river reaches. For this application the variations along the longitudinal axis of the stream are represented, with the vertical and lateral directions averaged.

The two dimensional longitudinal/vertical hydrodynamic and water quality model CE-QUAL-W2 is applied to system reservoirs (Copco 2 is a small reservoir and is not modeled within the framework). Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow water bodies exhibiting longitudinal and vertical water quality gradients, but can be applied to a wide range of physical configurations. The model is capable of representing a wide range of water quality processes include physical, chemical, and biological processes. The model can simulate selective withdrawal, sediment nutrient release dynamics, nitrogen inhibition under anoxic conditions, internal weirs and curtains, as well as other useful options to assess a wide range of existing and possible future conditions. To interface with the river model, sub-daily simulation results on the same time scale of the river models are employed.

2.2 Model Implementation

The river and reservoir models were implemented for discrete river reaches. The nine reaches are presented in Table 1 and graphically in Figure 1. The model implementation process includes constructing appropriate system geometry, flow and water quality conditions (boundary conditions, initial conditions, calibration/validation data), meteorological data and other model parameters.

- Geometry data include a description of the river location, i.e., latitude and longitude, UTM, or similar coordinate system; bed slope, and cross section data. For reservoirs bathymetric information, and facilities information (such as stage-volume data; intake structure configurations, elevations; locations of diversions structures and return points) are required.
- Flow and water quality information include system inflow (mainstem points, tributaries, return flows, etc.), outflow (diversions), reservoir storage change, and facilities operations. Water quality data for all inflows as well as in-river and reservoir conditions are required.
- Meteorological data include standard parameters for heat budget calculation within the numerical models, e.g., air temperature, wet bulb temperature (or dew point temperature), solar radiation, cloud cover, wind speed, and/or barometric pressure.
- Other model parameters include selection of time step, spatial resolution, identified periods of analysis, and selection of default model constants and coefficients.

Table 1. River reaches and representation in the modeling framework

Reach	Existing Representation	Model(s)
Link River	River	RMA-2/RMA-11
Lake Ewauna-Keno Dam	Reservoir	CE-QUAL-W2
Keno Dam to JC Boyle Reservoir	River	RMA-2/RMA-11
JC Boyle Reservoir	Reservoir	CE-QUAL-W2
Bypass Reach[a]	River	RMA-2/RMA-11
Peaking Reach[a]	River	RMA-2/RMA-11
Copco Reservoir[b]	Reservoir	CE-QUAL-W2
Iron Gate Reservoir	Reservoir	CE-QUAL-W2
IG Dam to Turwar	River	RMA-2/RMA-11

[a] The Bypass and Peaking reaches are modeled as a single reach

[b] Copco 2 is not represented in the framework

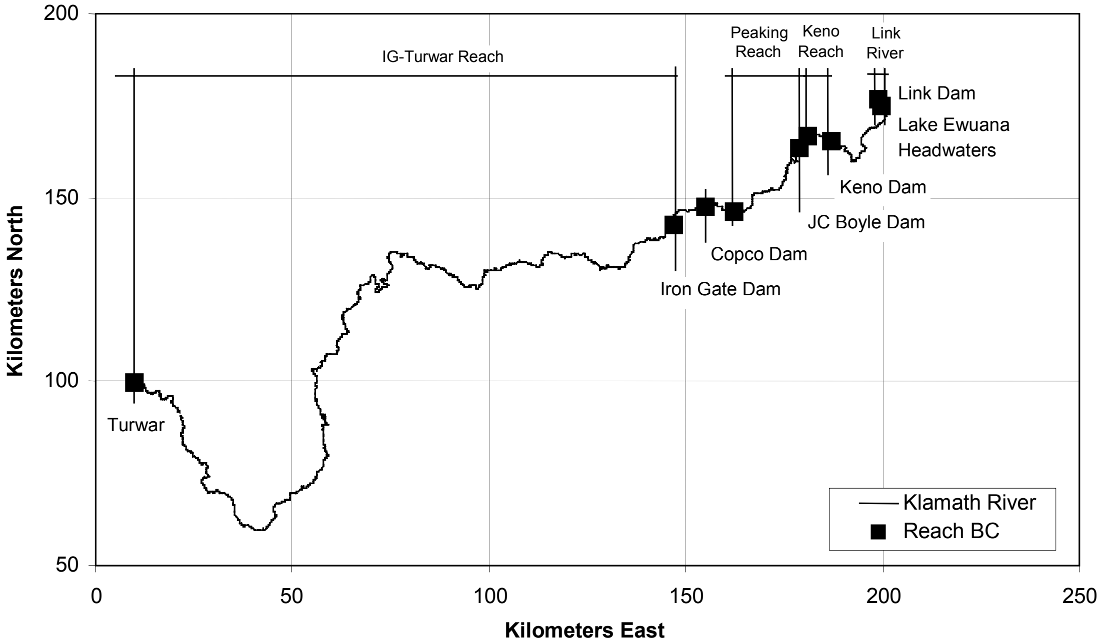


Figure 1. Designated river reaches and reservoirs

For system-wide simulation the models are applied in series, starting with upper most reach – Link River – and passing the output from one reach to the next. Thus the outputs from the river models (RMA models) form the upstream boundary condition for the CE-QUAL-W2 representation of Lake Ewauna/Keno Reservoir. Similarly, the output from CE-QUAL-W2 forms the headwater boundary condition for the river models representing the Klamath River reach from Keno Dam to JC Boyle Dam, and so on down the river. The flow conditions are generally not passed from reach to reach. That is, historical flows are used as headwater boundary conditions for most reaches. Where there is no upstream flow record (i.e., measured flow) above Copco Reservoir, the hydrodynamic model is used to route peaking flows on an hourly basis down to Copco Reservoir – these flows are then used in the CE-QUAL-W2 simulation of Copco Reservoir. For certain scenarios (e.g., without project), flows are passed from one modeled reach to the next because flow conditions cannot be explicitly specified. Further details of the flow records used in each reach are outlined in the model implementation section.

Water quality is passed downstream between all simulated river reaches. The river models (RMA) and the reservoir model (CE-QUAL-W2) do not represent all water quality parameters in the same fashion. The river models represent organic matter as organic nitrogen and organic phosphorous, while the reservoir model represents organic matter as refractory and labile dissolved and particulate organic matter. Stoichiometric equivalents are used to convert the appropriate information for passing from one model to the next. Details are addressed in model application.

2.3 River-Reservoir Reaches

Model implementation for each reach is outlined herein, with a description of geometric data, flow and water quality conditions, and meteorological conditions.

2.3.1 Link River

The Link River reach starts at Link Dam and terminates at Lake Ewauna. There are two powerhouses which discharge into this reach. The geometry, flow and water quality data, meteorological conditions and other model parameters are outlined below. Flow is modeled with RMA-2 and water quality with RMA-11.

2.3.1.1 River Geometry

River Location

The x-y coordinates describing the river location were defined using a digitized version of the 1:24,000 USGS topographic quadrangles provided by CH2M Hill, as discussed in Appendix C. This information was translated into a network of nodes and elements for use by the numerical model (Figure 2). Important locations within the reach, i.e., those of boundary conditions, are presented in Table 2.

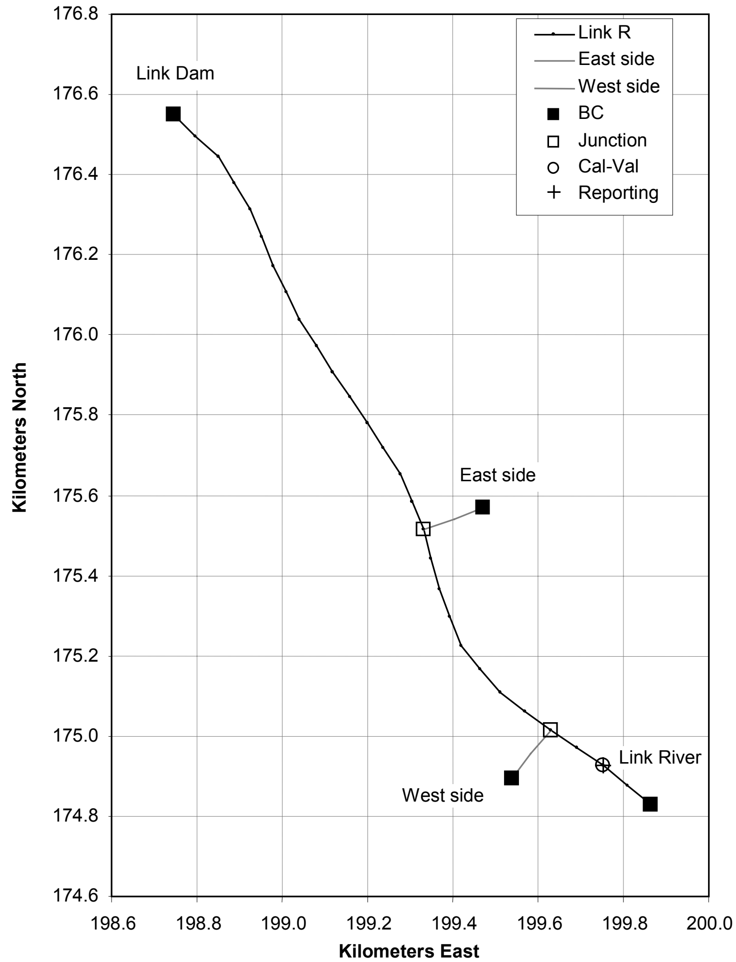


Figure 2. Map of Link River representation

Table 2. Geometry information for Link River

Location	Node	Element	x-coord	y-coord	Site type	Inflow Angle, radians [a]
Link Dam	1	1	198.745	176.550	BC	-0.790
End Link R reach	29	14	199.865	174.828	BC	-
East Side	17	9	199.471	175.57	BC	-
West Side	25	13	199.538	174.895	BC	-
East Side	30	15	199.333	175.514	Junction, inflow	3.527
West Side	34	16	199.631	175.015	Junction, inflow	0.911
Link River above Lake Ewauna	25	-	-	-	Reporting Point	-

[a] : Radians are measured counter-clockwise from due east

River Width

Link River widths were obtained from 1:7,500 scale aerial photos taken July 21, 1988, with an associated daily flow of 920 cfs. Width measurements were taken 6 locations within the short river reach. The cross section within the model is a trapezoid with twenty-to-one side slopes for the main stem and one-to-one side slopes for the junctions.

Bed Elevations/Slope

Bed slope for the reach was estimated from USGS topographic maps and Lake Ewauna elevations. The upstream reach elevation was 4130.5 ft msl (1259 m) and the downstream reach elevation was 4084.6 ft msl (1245 m). Elevations were estimated from land surface topographic contours and do not represent the river bed elevations, but the general slope of the river is preserved.

Table 3. Link River Geometry Summary

Node spacing	75 meters
Number of nodes	29 nodes in length; 37 nodes total including junctions
Length	1.31 miles from RM 252.57-253.88
Elevations	Range: 1245-1259 meters
Widths	Constant widths: 5 meters main stem; 20 meters junction elements
Side slopes	20:1 main stem; 1:1 junctions
Data sources	UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps.
Notes	2 junctions: East side, West side; Nodes 30-33 at East side; 34-37 at West side

2.3.1.2 Flow Data

Inflows and Outflows

Water enters the Link River reach via releases from Link Dam. Two diversions are made from Upper Klamath Lake at Link Dam: one along the west side of the river through a canal and short penstock to the West Side power house and one along the East Side of the River to the East Side power house. The East Side powerhouse returns to the river above the west side powerhouse return. Between the East Side and West Side powerhouses is the USGS Gage (11507500 Link River at Klamath Falls, OR). There are no outflows represented in this reach.

Flow entering the reach at the upstream most element (Link Dam) is termed the Link Bypass flow. East Side Turbine flows were calculated as the difference between the Link River USGS gage 11507500 and the Link Bypass flow. PacifiCorp measures West Side Turbine flows.

East Side and West Side powerhouses are represented by junction elements in the model. To properly account for momentum in the hydrodynamic model, the angle at which these flows enter the river is required. The inflow angles are measured counterclockwise from due east and the model calculates the angle with respect to the main stem element. Values are presented in Table 2.

There are no tributaries or accretions included as element side flows in the Link River reach. (Tributaries and inflows can be represented in several fashions in RMA-2. When such inflows form a large percentage of the baseflow in the main stem, a junction is added to the model as a small branch, which represents the inflow location. This type of inflow is placed at a single point in the model – a node. When inflows to the mainstem are relatively modest, they are included in the model as element side flows. In this case the inflow is placed into the geometry network over the length of a single element.)

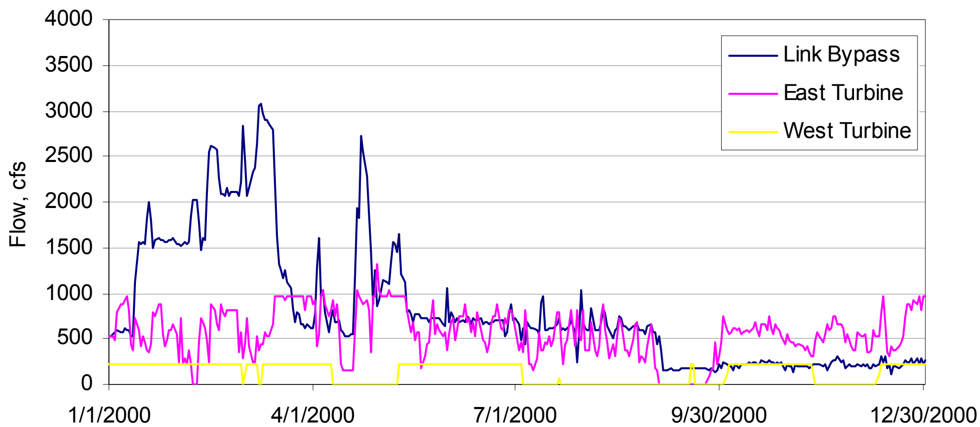


Figure 3. Link River inflows for Link River model

Downstream Boundary Condition

The downstream boundary condition for the hydrodynamic model is represented by stage in Lake Ewauna. This approach resulted in a variable stage downstream boundary condition, thus replicating backwater conditions within the reach. Stage in the Lake Ewauna / Keno Reservoir reach is assumed, the elevations measured by PacifiCorp in the vicinity of Highway 97 are applied at the headwaters of Lake Ewauna. As the x-y coordinates from the CH2M Hill maps provided locations of river reaches and elevations from Upper Klamath Lake to Iron Gate Dam, elevations for the river reaches were estimated from the CH2M Hill maps (above Iron Gate Dam) and USGS topographic maps (below Iron Gate Dam), which were of twenty foot contour lines. Therefore the elevations in the river reaches were approximate, but nonetheless representative. When resolving river and reservoir elevation (reservoir elevations are absolute), adjustments were made to the downstream reservoir elevation boundary conditions to represent the river discharge into the impoundment within the river elevation representation and framework. The elevations used in the model input file for the Link River reach were calculated to be the Keno Reservoir elevations plus 3 meters (9.84 feet).

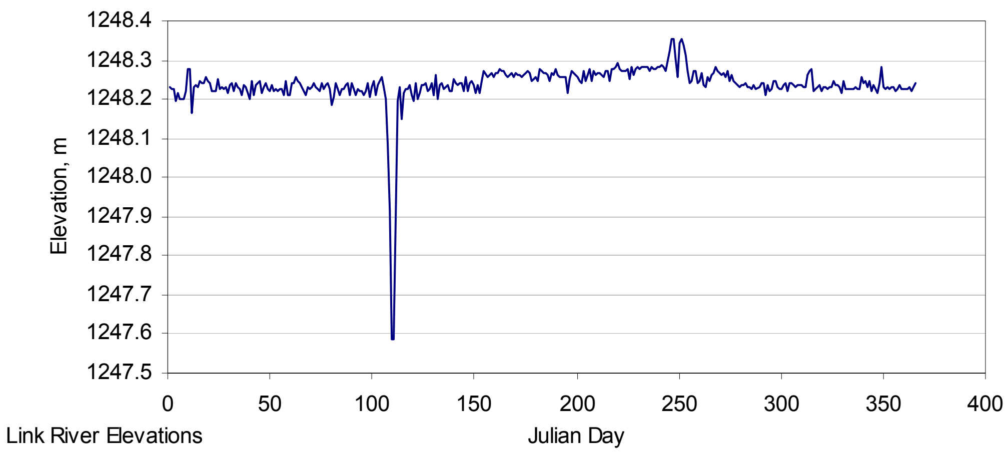


Figure 4. Input elevations for Link River model

2.3.1.3 Water Quality Data

Water quality data for the Link River reach was derived from multiple sources. Little data exists at Link Dam prior to 2001. Grab samples at Fremont Bridge 1994 to 2001 supplied by the Klamath Tribes were used to form seasonal water quality conditions at the upstream boundary. The return flows from East Side and West Side powerhouses were assumed to have the same water quality as the releases to Link River from Link Dam. Data sources are outlined in Table 4.

Table 4. Data sources for boundary conditions to the Link River reach

Data	Source	Type
Water quality parameters[1]	Klamath Tribes	Seasonal estimates
Temperature	U.S. Bureau of Reclamation	Hourly, seasonal estimates
Dissolved Oxygen	U.S. Bureau of Reclamation	Hourly, seasonal estimates

[1] Water quality parameters include pH, conductivity, total phosphorus, orthophosphates, total nitrogen, nitrate + nitrite, ammonia, chlorophyll-a and phaeophytin.

Temperature

A-Canal USBR monitoring temperatures, 2000-2001 were used to construct a composite of hourly inflow temperatures for the Link River. 2000 temperatures were available from Julian day 133 though Julian day 333. 2001 temperatures were used from Julian day 26 through Julian day 133. Temperatures from Julian day 1 through 26 and from 333 through 367 were estimated by assuming that the temperature on Julian day 1 and Julian day 367 was 2 ºC. The East Side and West Side Turbines were assumed to have the same water source as the flows at Link Dam, the same temperatures were used for all three water sources in the Link River reach.

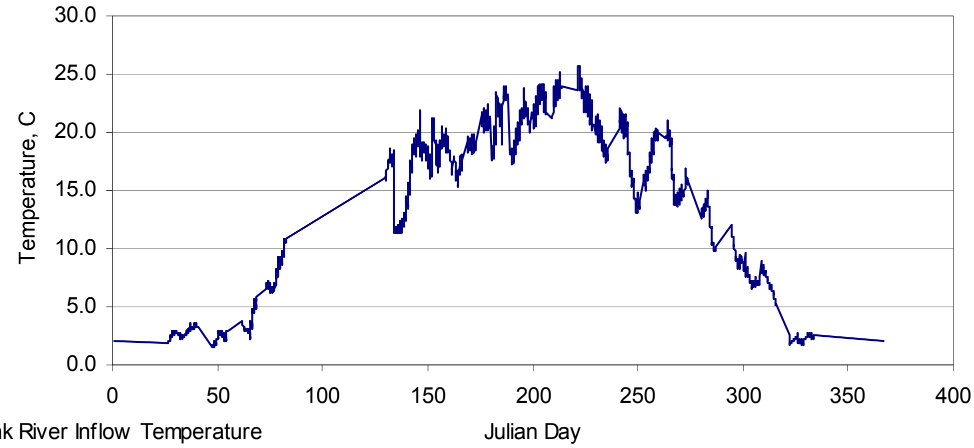


Figure 5. Link River inflow temperature for Link Bypass, East Turbine and West Turbine for Link River model

Constituent Concentrations

Dissolved Oxygen: Limited field data are available for Link Dam. Hourly dissolved oxygen saturation concentrations, calculated from USBR water quality probe temperatures for A-Canal during 2000-2001, were used to construct a composite of hourly inflow for the Link River reach. 2000 dissolved oxygen saturation values were available from Julian day 133 though Julian day 333. 2001 temperatures used from Julian day 26 through Julian day 133. Dissolved oxygen concentrations from Julian day 1 through 26 and from 333 through 367 were estimated as the saturation values of the inflow temperatures. The East Side and West Side Turbines have the same water source as the flows at Link Dam, therefore the same dissolved oxygen were used for all three water sources in the Link River reach.

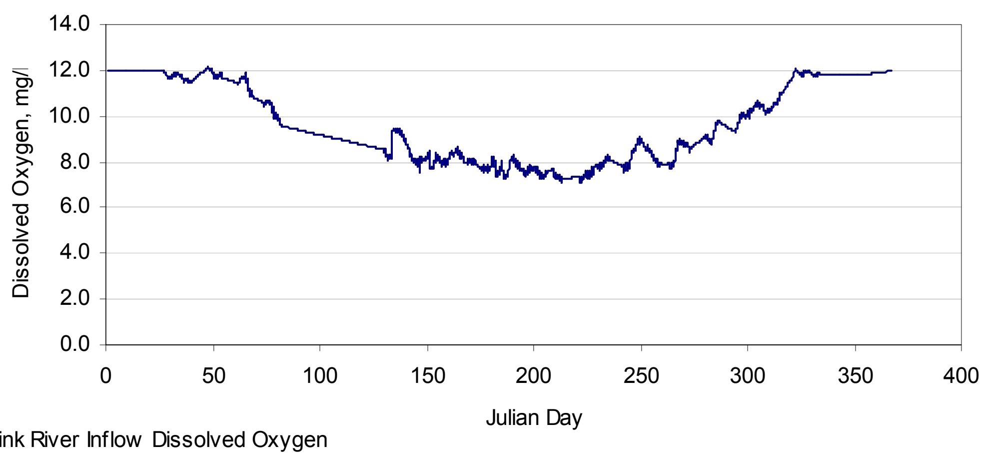


Figure 6. Link River inflow dissolved oxygen concentrations for Link Bypass, East Turbine and West Turbine for model implementation

<u>BOD</u>: There was no biochemical oxygen demand data available for 2000. BOD levels were estimated based on available data from the 2002 sampling program completed by USBR. Samples were collected at two-week intervals from late April through September. BOD concentrations for Link Dam prior to April were assumed to be 2.0 mg/l. The USBR sampling effort suggests that BOD levels remain elevated through the end of September. BOD was assumed to be 10 mg/l on October 15^{th}, 3 mg/l on November 15^{th}, and 2 mg/l after December 15^{th}.

<u>Nutrients and Algae</u>: The water quality boundary conditions for the Link River were calculated from Upper Klamath Lake grab sample data collected by the Klamath Tribes from 1994-2001 at the Fremont Bridge (Kann, 2001). The Fremont Bridge location in Upper Klamath Lake was selected because of the proximity to the Link Dam.

Between 1994 and 2001 there were approximately 60 grab samples with nutrient concentrations (at multiple depths). Because there were insufficient samples in 2000 to identify a boundary condition for the Link River reach, a composite of all data were used to create monthly average concentrations that represented general seasonal conditions.

Comparison of field data suggested that conditions in the Fremont Bridge area were generally well mixed (i.e., minimal vertical variation for the selected water quality constituents). Thus all samples were used in the determination of monthly average concentrations. Data were sorted by Julian day and averaged. Monthly averages were calculated from the daily data. The first and last days of the year were given concentrations that were the average of the January and December monthly average concentrations. Values were assigned to the 15^{th} of each month, and are presented in Table 5. Organic nitrogen and phosphorus were calculated as the total forms minus the inorganic forms of each nutrient.

Table 5. Link Dam inflow concentrations for the Link River reach simulation

Julian Day	BOD_5, mg/l	Organic N (mg/l)	Ammonia, mg/l	Nitrite, mg/l	Nitrate, mg/l	Organic P (mg/l)	Phosphate, mg/l	Algae, mg/l
1	2.0	0.88	0.61	0.0	0.21	0.06	0.03	2.2
47	2.0	0.88	0.07	0.0	0.11	0.06	0.03	7.2
75	2.0	0.80	0.05	0.0	0.05	0.05	0.03	2.8
106	2.0	0.80	0.06	0.0	0.05	0.05	0.03	1.3
136	4.0	0.80	0.06	0.0	0.05	0.05	0.03	2.1
166	6.0	0.96	0.12	0.0	0.05	0.06	0.03	14.9
197	10.0	1.12	0.16	0.0	0.05	0.07	0.06	22.8
228	12.0	1.20	1.02	0.0	0.05	0.08	0.07	22.2
259	12.0	1.12	0.05	0.0	0.05	0.07	0.03	16.0
289	10.0	1.04	0.29	0.0	0.05	0.07	0.03	10.2
321	3.0	0.96	0.16	0.0	0.05	0.06	0.03	4.1
350	2.0	0.88	0.84	0.0	0.23	0.06	0.03	3.0
366	2.0	0.88	0.61	0.0	0.21	0.06	0.03	2.2

2.3.1.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

The meteorological data for the Link River reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure was calculated based on elevation (4100 ft (1250 m)) and assumed constant throughout the simulation period (870 mb). Wet bulb temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

All times within the modeling effort are Pacific Standard Time. Daylight Saving Time is not used.

2.3.2 Lake Ewauna to Keno Dam

The Lake Ewauna to Keno Dam reach extends from where Link River enters Lake Ewauna (RM 253) to Keno Dam (RM 233). The impoundment is generally a broad, shallow body of water. System width ranges from several hundred to over 1000 feet (over 300 meters), and a maximum depth of roughly 20 feet (approximately 6 meters). There are several discharges and withdrawals in this reach. The physical (e.g., geometry), flow and water quality data, meteorological conditions, and other model parameters are outlined below. The reach is modeled with CE-QUAL-W2.

2.3.2.1 Reservoir Physical Data

The primary purpose of Keno Dam operations is to provide a regulated water surface for irrigation project diversions within the reach. A total of eighteen discharges and seven withdrawals were represented in the model.

Keno Dam Features

The Keno Dam spillway, with an invert elevation of 4070 feet, includes six Taintor gates. There are three additional outlets include a sluice conduit, the fish attraction outlet, and the fish ladder exit to the reservoir. The details of these outlets are summarized in Table 6.

Table 6. Keno Dam outlet features

Outlet	Invert Elevation	Dimension	Operation
Sluice Conduit	4,073.0 ft	36 inch diameter	Manual gate
Fish Attraction Outlet	4,075.0 ft	30 inch diameter	Manual gate
Fish Ladder	4,078.5 ft	60 inch width	Stop logs
Spillway	4,070.0 ft	6 gates @ 40 ft width each	Remote control on three gates
Sources:	PacifiCorp (2002), PacifiCorp (2000)		

Reservoir Bathymetry for CE-QUAL-W2

The bathymetry for the Lake Ewauna to Keno Dam section of the Klamath River was partially derived from the existing bathymetry created by Dr. Wells (1996), and partially derived from x-y coordinates created by processing the latitudes and longitudes given in the 1:24,000 USGS topographic quadrangles provided by CH2MHill to created approximately equidistant segments.

The existing number of segments, number of layers, segment lengths, layer widths per segment and water surface elevation from the Dr. Wells (1996) simulation were supplemented by new segment orientations calculated from the x-y coordinates (note – new bathymetry was implemented in 2003). The orientation of individual river segments was updated because the original file orientations contained discrepancies when applied to the newer versions of CE-QUAL-W2. The model representation is shown in Figure 7.

In addition to the segment and layer specifications, bottom roughness was represented by a Manning coefficient of 0.04 for each segment. The volume generated by the model representation was larger than the available reservoir bathymetry from PacifiCorp. Because the PacifiCorp volumes are used primarily for operating within a small range of storage elevations and limited additional information, the bathymetry from Wells (1996) was retained.

The CE-QUAL-W2 representation of Lake Ewauna to Keno reach has two branches. Branch 1 has 106 active segments, all 1000.0 ft (304.8 m) in length. Branch 2 has three active segments, each 800.0 ft (243.8 m) in length. There are fifteen active layers in Lake Ewauna all 2.00 ft (0.61 m) thick. Branch 2 starts at Branch 1 Segment 14 and ends at Branch 1 Segment 18. A total of eighteen discharges and seven withdrawals were represented in the model (Table 7). Branch 2 has no external inflows or outflows. The modeled and observed stage-volume curve is shown in Figure 8.

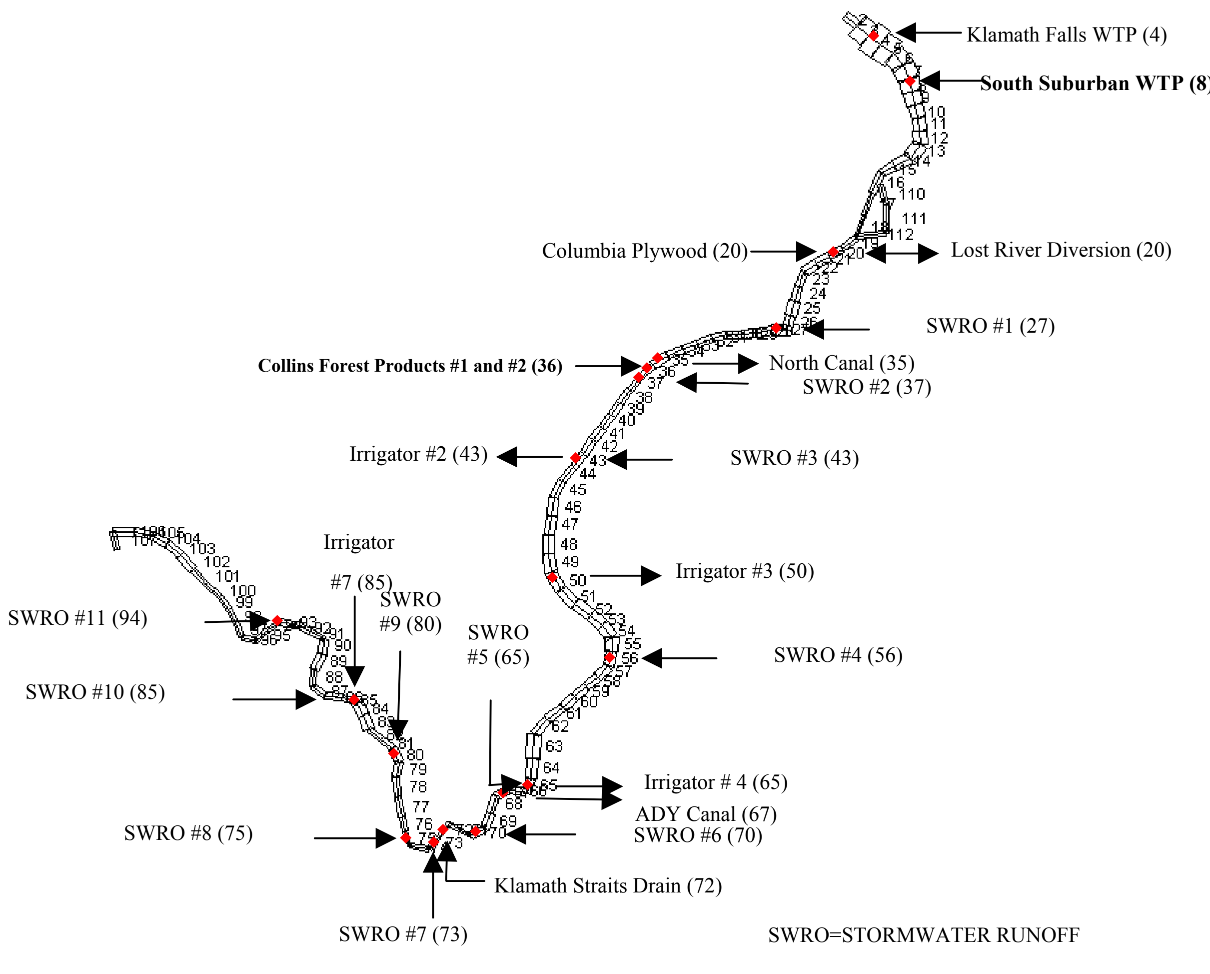


Figure 7. Map of Lake Ewauna to Keno Dam CE-QUAL-W2 representation, identifying inputs and withdrawals

Table 7. Modeled inflows and outflows in the Lake Ewauna to Keno Dam reach

Name	Type	River Bank [a]	Approximate RM [b]	Model Segment
Klamath Falls Wastewater Treatment Plant	Inflow	Left	253	4
South Suburban Sanitation District	Inflow	Left	252	8
Columbia Plywood	Inflow	Right	250	20
Lost River Diversion	Inflow / Outflow	Left	250	20
Collins Forest Products #1	Inflow	Right	247	36
Collins Forest Products #2	Inflow	Right	247	36
Klamath Straits Drain	Inflow	Left	240	72
Stormwater Runoff #1	Inflow	NA	249	27
Stormwater Runoff #2	Inflow	NA	247	37
Stormwater Runoff #3	Inflow	NA	246	43
Stormwater Runoff #4	Inflow	NA	243	56
Stormwater Runoff #5	Inflow	NA	242	65
Stormwater Runoff #6	Inflow	NA	241	70
Stormwater Runoff #7	Inflow	NA	240	73
Stormwater Runoff #8	Inflow	NA	240	75
Stormwater Runoff #9	Inflow	NA	239	80
Stormwater Runoff #10	Inflow	NA	238	85
Stormwater Runoff #11	Inflow	NA	236	94
North Canal	Outflow	Left	247	35
ADY Canal	Outflow	Left	241	67
Irrigator #1	Outflow	NA	246	43
Irrigator #2	Outflow	NA	244	50
Irrigator #3	Outflow	NA	242	65
Irrigator #4	Outflow	NA	238	85

[a] : The river bank is given for reference only. The model does not discriminate between river bank when simulating flows.

[b] : The river miles are approximate as each model segment is 1000 ft in length.

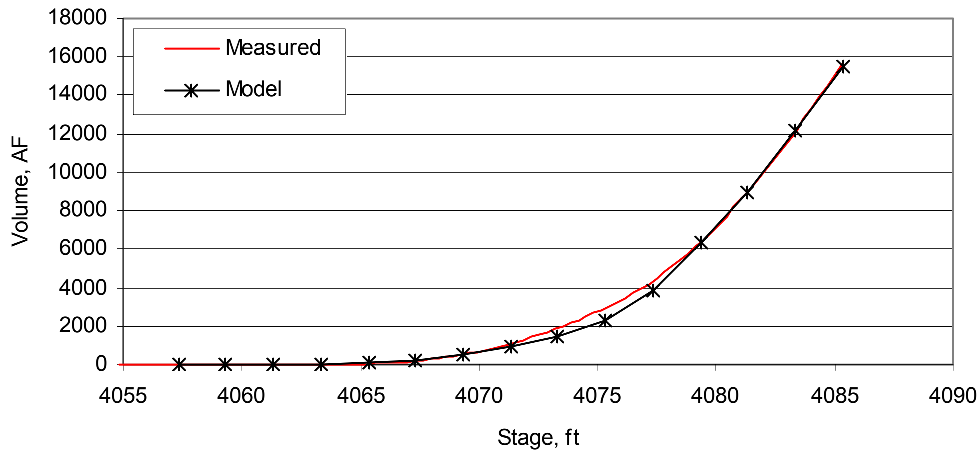


Figure 8. Comparison of measured and model representation of Lake Ewauna stage-volume (S-V) relationships

2.3.2.2 Flow Data

Flow data required for the model application includes the upstream boundary condition representing water flowing into Lake Ewauna from Link River. In addition there are a series of discrete withdrawals and inflows along the reach. Finally, there is an accretion/depletion flow, representing un-quantified losses and gains within the reach. This is represented as a distributed tributary within CE-QUAL-W2. Typically flow data are recorded in cubic feet per second or million gallons per day – all flows were converted to cubic meters per second for model input. Each flow component is addressed below.

Link River Inflow

The USGS Gage at Link River is upstream of the Westside Powerhouse return. Thus, the branch inflow flow rates for the Lake Ewauna to Keno reach were determined by subtracting the PacifiCorp West Turbine Gage from the USGS Gage 11507500. Flow rates for 2000 are presented in Figure 9.

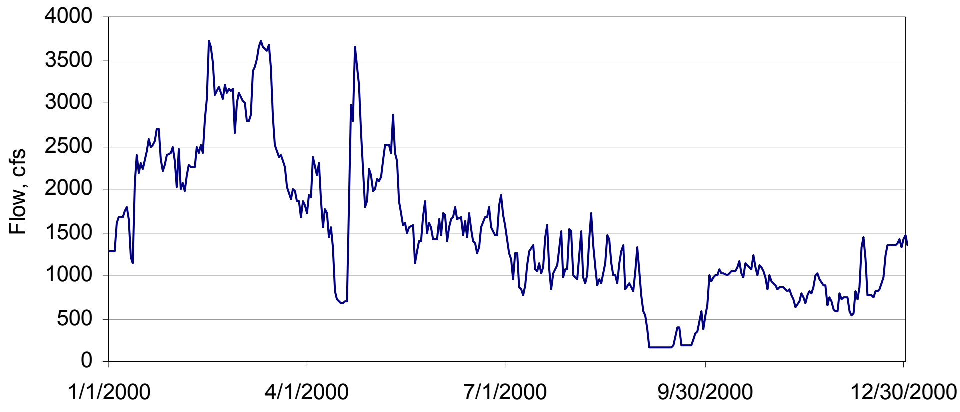


Figure 9. Lake Ewauna main inflow rates for Lake Ewauna to Keno Dam reach model

Tributary Inflows

Storm water Runoff

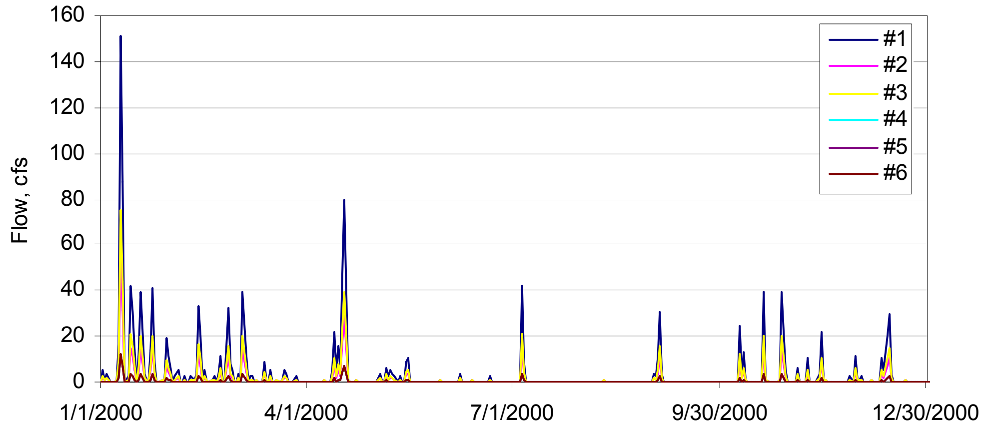
The storm water runoff flow for the Dr. Wells 1992 simulation (1996) was compared to 1992 rainfall data recorded at the KFLO meteorological station. A relationship for the 1992 data was determined between the total storm water runoff flow rate and the daily precipitation using linear regression.

$$SWRO = 12.129 \times R \qquad (r^2=1)$$

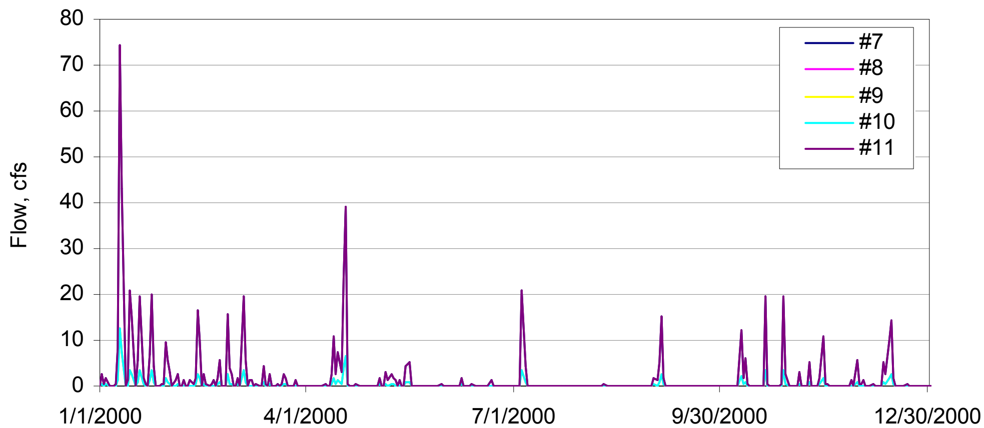
Where: SWRO = Total stormwater runoff, cms

R = precipitation, inches

An average percent of total stormwater runoff flow for each of the eleven locations was determined for each rainfall event in 1992. 2000 daily precipitation from KFLO and the relationships determined from the 1992 data were used to calculate each of the eleven storm water runoff flow rates for 2000. The placement of stormwater runoff flows is as per Wells (1996) (Figure 10).



(a)



(b)

Figure 10. Storm water runoff flow for Lake Ewauna to Keno Dam reach model: (a) Runoff input locations #1 through #6, (b) Runoff input locations #7 through #11

Columbia Plywood

An average monthly flow for Columbia Plywood was calculated from the maximum monthly flows recorded on the plant's monthly monitoring reports submitted to ODEQ. The average for calendar year 2000 was 0.01 cfs (0.0004 cms) and was applied throughout the year.

Klamath Falls Water Treatment Plant

The daily flows for the Klamath Falls Wastewater Treatment Plant were provided by the daily flows recorded in the monthly monitoring reports submitted to ODEQ (presented in Figure 11. Daily flow was input into the model after being converted to the appropriate units.

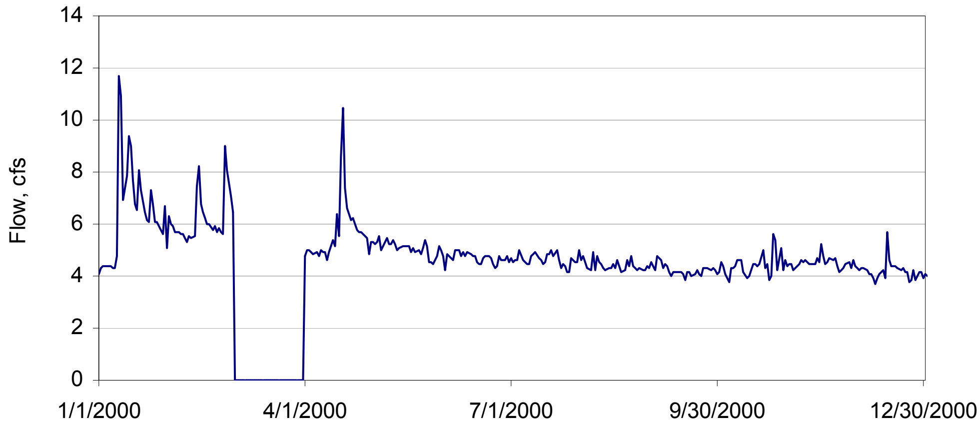


Figure 11. Klamath Falls Wastewater Treatment Plant flow for Lake Ewauna to Keno Dam reach model

South Suburban Sanitation District

The daily flow for the South Suburban Sanitation District were derived from flows recorded five times a week in the monthly monitoring reports the District submitted to the ODEQ. Because plant discharge varied little from day to day and were relatively small, input flows for 2000 were monthly averages based on measured data and are presented in Table 8.

Table 8. South Suburban Sanitation District flow for Lake Ewauna to Keno Dam reach model

Julian Day	Flow, cfs
1	3.53
15	3.85
46	4.24
75	3.88
106	3.60
136	3.00
167	2.19
197	2.83
228	2.37
259	2.51
289	2.61
320	3.07
350	3.32
367	3.53

Collins Forest Products #1 and #2

Daily inflows from Collins Forest Products discharge #1 and #2 were provided in the monthly monitoring reports submitted to ODEQ (presented in Figure 12). The daily measured data was directly input into the model.

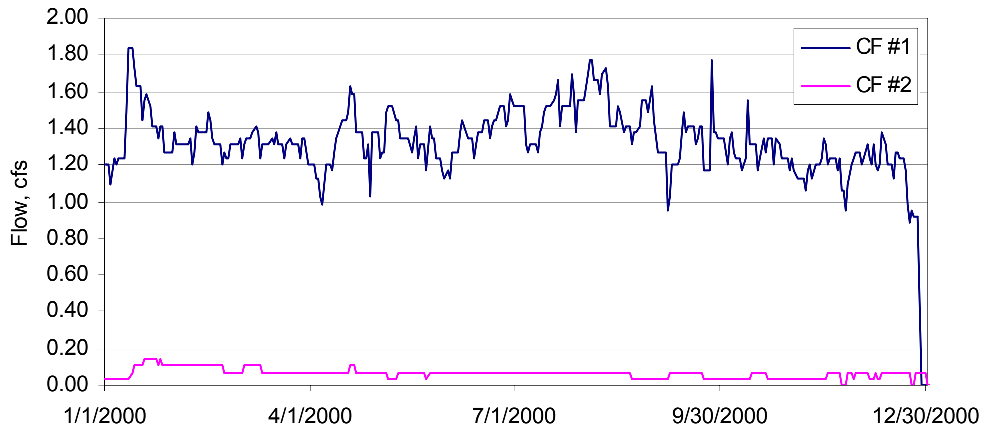


Figure 12. Collins Forest Product flows #1 and #2 for Lake Ewauna to Keno Dam reach model

Lost River Diversion Channel

The daily inflows into Lake Ewauna from the Lost River Diversion Channel are gauged by USBR (presented in

Figure 13). These records were used to define both the Lost River discharge to and withdrawal from Lake Ewauna to Keno Reach (for diversion from Lake Ewauna to Keno reach see the withdrawal section below).

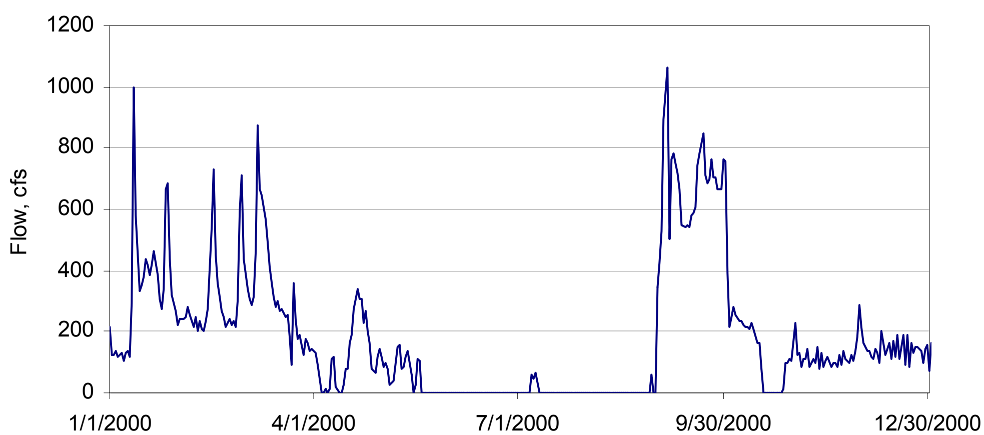


Figure 13. Lost River Diversion Channel inflows to Lake Ewauna for Lake Ewauna to Keno Dam reach model

Klamath Straits Drain

Inflow to Lake Ewauna from the Klamath Straits Drain is gauged by USBR (presented in Figure 14). Daily input flows were taken directly from the recorded information.

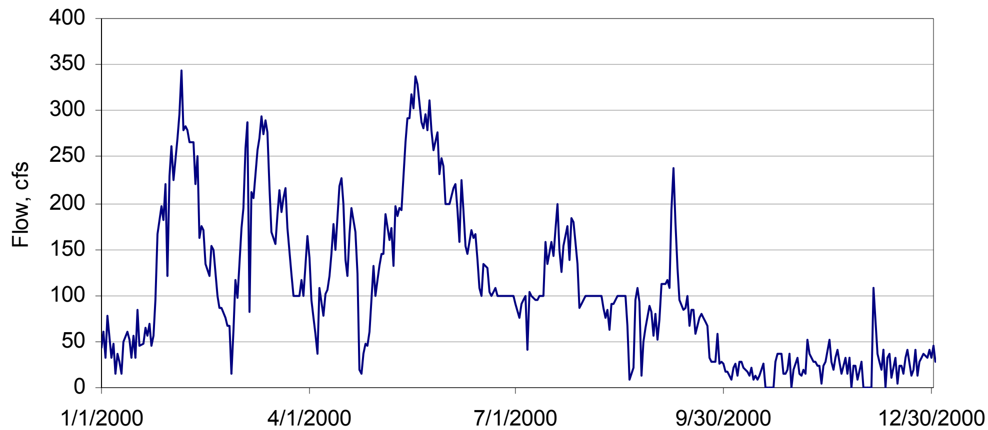


Figure 14. Klamath Straits Drain flow for Lake Ewauna to Keno Dam reach model

Withdrawals

Klamath Reclamation Project Diversions

There are three withdrawals within Lake Ewauna for the Klamath Reclamation Project: the Lost River, North Canal and ADY Canal. All three withdrawals were daily flows, gauged by USBR (presented in Figure 15).

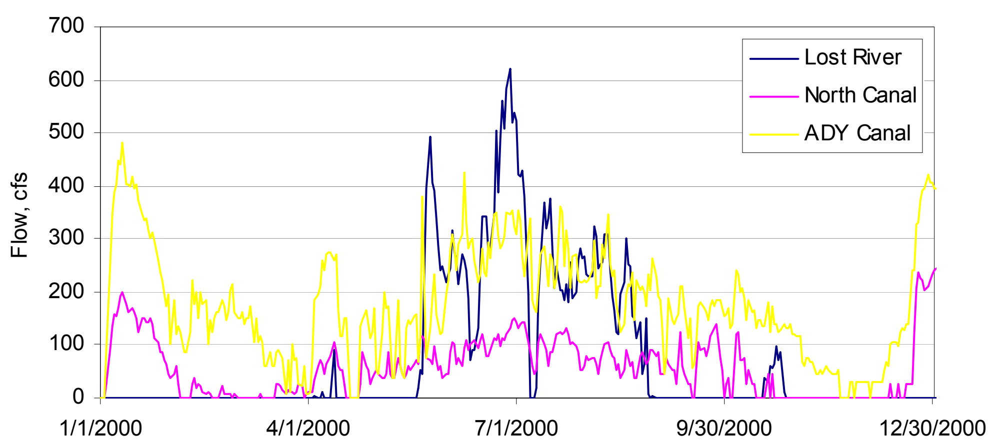


Figure 15. Klamath reclamation project diversions for Lake Ewauna to Keno Dam reach model

Non-Reclamation Irrigation Diversions

Due to a lack of available non-USBR irrigation records, daily withdrawal rates from 1992 (Wells 1996) were applied on the same schedule for 2000 (presented in Figure 16). The irrigation season was assumed to extend from May 30, 2000 (Julian day 152) to September 30, 2000 (Julian day 274). Prior to and after the irrigation season flows were assumed to be zero for all four irrigation withdrawals.

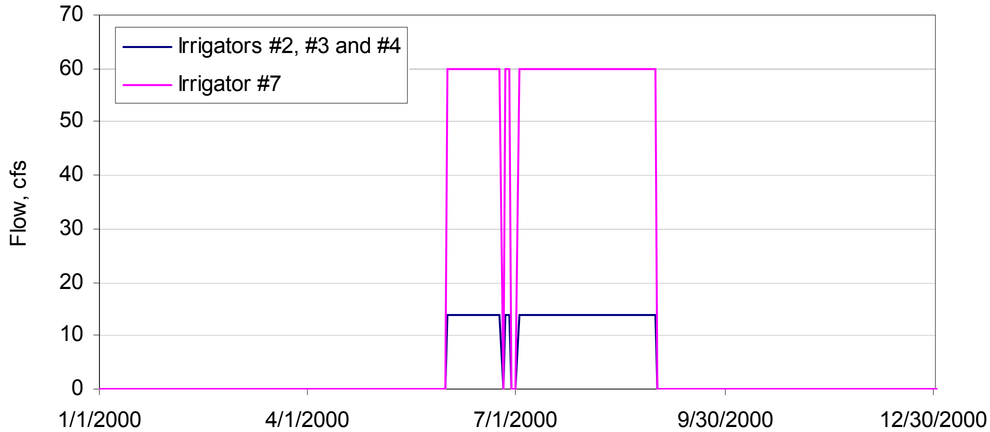


Figure 16. Irrigator withdrawals for Lake Ewauna to Keno Dam reach model

Keno Dam Outflow

The hourly flow rate at Keno Dam was taken from the data recorded at USGS Gage 11509500, Klamath River near Keno, Oregon. The flows are presented in Figure 17.

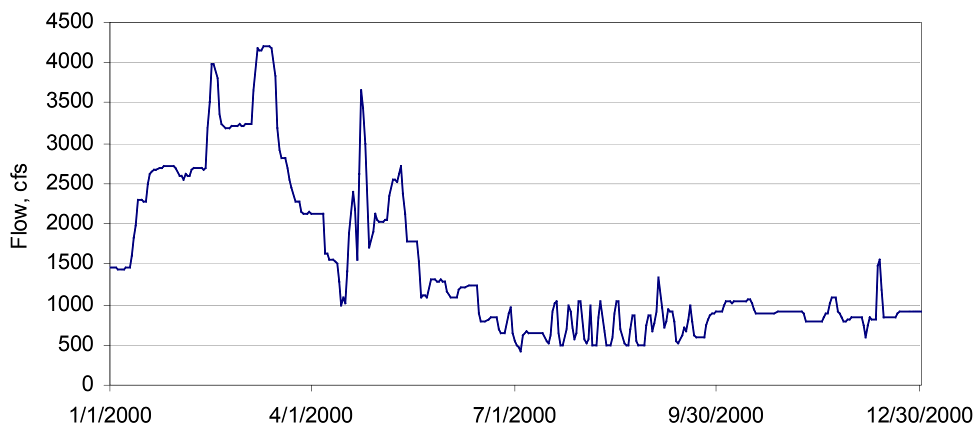


Figure 17. Keno Dam outflow for Lake Ewauna to Keno Dam reach model

Accretion / Depletion (Distributed Tributary) Inflow

A flow representing net un-gauged accretions and depletions from the system was determined using a water balance based on the aforementioned inflows and outflows and change in storage recorded at Keno Dam (provided by PacifiCorp). This flow was represented in CE-QUAL-W2 as a distributed tributary, applied over the entire reach and is presented in Figure 18.

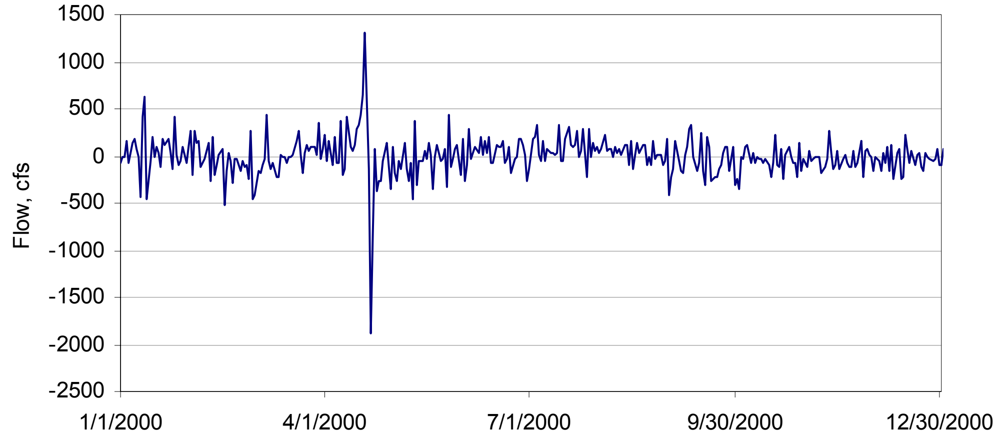


Figure 18. Accretion / depletion flow (distributed tributary) for Lake Ewauna to Keno Dam reach model

2.3.2.3 Water Quality Data

Water quality data for the main inflow to the Lake Ewauna to Keno Dam reach model implementation is presented below. However, during calibration and application, Link River reach simulation output was used to provide all water quality data for the main inflow to the Lake Ewauna to Keno Dam reach.

Temperature

In CE-QUAL-W2, only model inflows are required to have assigned water quality data. All withdrawals from the system assume the temperature or water quality at the point of withdrawal. The inflow locations, data sources, and data and model resolution are summarized in Table 9, followed by descriptions of each data set.

Table 9. Temperature data for inflow locations, including data source, and data and model resolution

Location	Source	Data Resolution	Model Input Resolution
Link River	USBR	Hourly, other	Hourly, other [a]
Distributed tributary	Estimated	n/a	Annual
Stormwater	Estimated	n/a	Annual
Columbia Plywood	ODEQ	monthly	Monthly
KFWTP	ODEQ / estimated	Daily	Daily
South Suburban Sanitation District	ODEQ	Daily	Monthly

Collins Forest Products #1, 2	ODEQ	Daily	Daily
Lost River	USBR	Semi-monthly	Semi-monthly
Klamath Straits Drain	USBR	hourly	daily, other [a]

[a] : Hourly data was not available for all periods.

Link River Temperature

For model implementation, hourly temperatures from Link Dam (A-Canal) recorded by USBR were used as input temperatures, as presented in Figure 5. For calibration and application, simulated hourly temperatures from the Link River reach simulation were used as hourly input temperatures for the Lake Ewauna reach simulation.

Distributed Tributary Temperature

The distributed tributary was assumed to represent groundwater exchange within the reach. A constant inflow temperature of 12.0^{o}C was assumed for the entire 2000 simulation.

Tributary Temperatures

Storm water Runoff

The temperatures for the storm water runoff in 2000 were assumed constant 12.0^{o}C for the entire year, which is the same as the temperature assigned to storm water runoff in the 1992 simulation (Wells, 1996).

Columbia Plywood

Monthly values provided in the Columbia Plywood monitoring reports to ODEQ were used as model input and are presented in Table 10.

Table 10. Columbia Plywood inflow temperatures for Lake Ewauna to Keno Dam reach model

Julian Day	Inflow Temperature, C
1	13.61
15	13.33
46	13.89
75	14.44
106	16.11
136	17.22
167	18.89
197	21.11
228	20.56
259	18.33

289	15.56
320	13.33
350	13.89
367	13.61

Klamath Falls Wastewater Treatment Plant

The Klamath Falls Wastewater Treatment Plant (KFWTP) was not required to report their effluent temperature prior to July 2001. However, after 2001, the daily effluent temperature was reported as well as the daily blowdown temperature, and the daily combined effluent and blowdown temperature. Blowdown is the water used as coolant at the cogeneration plant. Blowdown temperatures were not available prior to July 2001, because effluent was not being used at the cogeneration plant as cooling water. Using the existing data set, a linear regression relationship between the daily influent and effluent temperatures was determined based on data from July 2001 through February 2002. All temperatures in the relationship are in Fahrenheit.

$$T_{effluent} = 0.8952(T_{influent}) + 8.1293 \qquad (r^2 = 0.89)$$

This relationship was used to calculate the effluent temperatures for 2000 for the KFWTP, which were then converted to degrees Celsius. Resulting temperatures are presented in Figure 19.

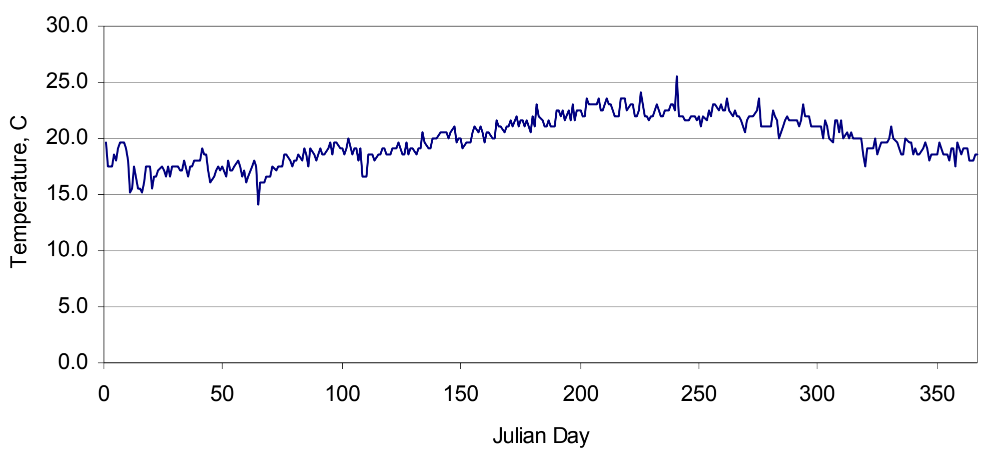


Figure 19. Klamath Falls Wastewater Treatment Plant inflow temperatures for Lake Ewauna to Keno Dam reach model

South Suburban Sanitation District

Water temperature for the South Suburban Sanitation District were monthly averages calculated from measured data gathered five times a week reported in the monthly monitoring reports submitted to ODEQ (presented in Table 11).

Table 11. South Suburban Sanitation District inflow temperatures for Lake Ewauna to Keno Dam reach model implementation

Julian Day	Inflow Temperature, C
1	2.5
15	2.4
46	4.2
75	6.8
106	11.9
136	14.5
167	19.0
197	20.6
228	20.7
259	16.3
289	10.9
320	4.5
350	2.9
367	2.5

Collins Forest Products #1 and #2

Daily measured temperatures for the #1 and #2 discharge from Collins Forest Products were reported in the monthly monitoring reports submitted to ODEQ and were used for model input.

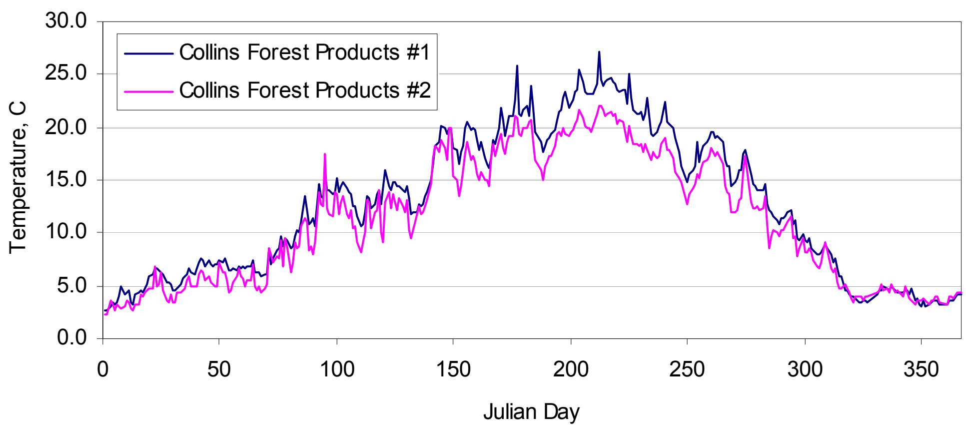


Figure 20. Collins Forest Products #1 and #2 inflow temperature for Lake Ewauna to Keno Dam reach model

Lost River Diversion

Temperatures for the Lost River Diversion input were estimated from bimonthly measurements taken in the Lost River at Wilson Reservoir by USBR between December 28, 1999 and December 18, 2000 and are presented in Table 12.

Table 12. Lost River Diversion inflow temperatures for Lake Ewauna to Keno Dam reach model

Julian Day	Inflow Temperature, C
1	3.87
13	2.2
25	5.28
41	7.16
62	6.11
75	8.01
89	9.22
103	14.97
118	15.31
131	12.6
145	22.38
159	29.98
242	19.39
277	17.26
284	12.17
298	8.35
312	6.63
326	3.85
340	3.43
353	1.9
367	1.9

Klamath Straits Drain

The temperature record for the Klamath Straits Drain is a composite of hourly temperatures measured by USBR at both the mouth of KSD and KSD at Stateline for 2000 averaged to daily temperatures. First, daily temperatures were calculated for each location. Data was available at the mouth from 1/15/00 to 3/16/00, 4/6/00 to 4/19/00 and 5/2/00 to 11/22/00. Data from the Stateline location was used to fill the data gaps for 3/20/00 to 4/5/00. Daily air temperatures from KFLO 2000 were used to fill the data gaps from 1/1/00 to 1/14/00 and from 11/23/00 to 12/31/00. If a daily average air temperature was less than 0.0 ºC, a water temperature of 0.0 ºC was used. The composite temperature record is shown in Figure 21.

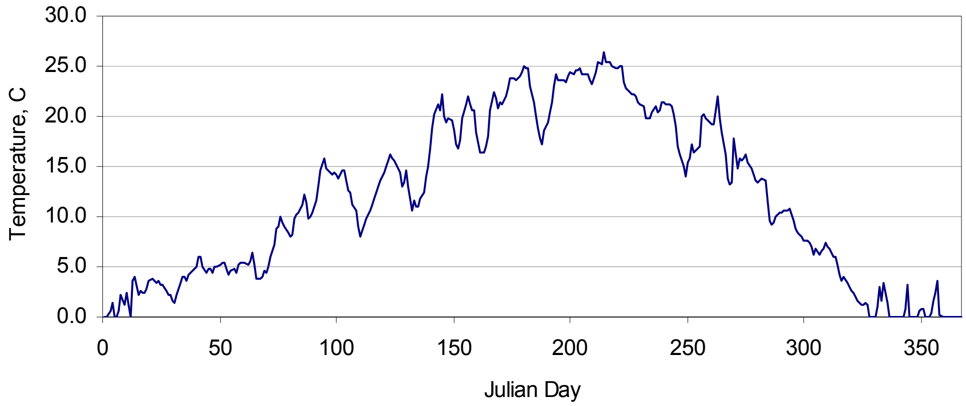


Figure 21. Klamath Straits Drain inflow temperatures for Lake Ewauna to Keno Dam reach model

<u>Constituent Concentrations</u>

Link River Concentrations

For model implementation, concentrations used in the Link River implementation were used in the Lake Ewauna to Keno reach (see Table 5). Not all parameters modeled in CE-QUAL-W2 are modeled in RMA-11. Total dissolved solids, suspended solids, total inorganic carbon, and alkalinity are not represented in the river model. Values from Wells (1996) were used for these parameters. Labile dissolved organic matter (LDOM) was estimated from organic nitrogen and phosphorous concentrations output by RMA-11 by using the stoichiometric equivalence for the nitrogen and phosphorous partitioning in the CE-QUAL-W2 model parameter set. Calibration – validation and model application used Link River simulated results to construct the input file.

Distributed Tributary Concentrations

The constituent concentrations from the 1992 simulation (Wells, 1996) were applied to the 2000 simulation. Prior to Julian day 274, the concentrations were assumed to be equal to the concentrations on Julian day 152 in the 1992 simulation, and after Julian day 274, the concentrations were assumed to be equal to those on day 274. (The 1992 simulation period in Wells (1996) included the period from Julian day 152 to 274.) Assumed distributed tributary values are shown in Table 13.

Table 13. Distributed tributary concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	25.0	0.0	0.0	0.1	0.05	1.0	0.0	0.0	0.0	1.0	0.0	3.0	20.2	80.0
274	25.0	0.0	0.6	0.1	0.05	1.0	0.0	0.0	0.0	1.0	0.0	3.0	20.2	80.0
367	25.0	0.0	0.6	0.1	0.05	1.0	0.0	0.0	0.0	1.0	0.0	3.0	20.2	80.0

"Tracer" is a conservative constituent that does not decay or react with time or space. Can be used to check conservation of mass within the model framework.

Tributary Concentrations

Storm water Runoff

The 1992 simulation (Wells, 1996) concentrations were applied directly to the 2000 simulation (Table 14). The concentrations were constant throughout entire year.

Table 14. Storm water runoff concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	25.0	0.0	5.0	0.05	0.05	0.1	0.0	3.0	0.0	0.7	0.0	9.0	15.9	52.0
367	25.0	0.0	5.0	0.05	0.05	0.1	0.0	3.0	0.0	0.7	0.0	9.0	15.9	52.0

Columbia Plywood

The monthly monitoring reports submitted by Columbia Plywood to ODEQ generally provide average monthly pH, biological oxygen demand (BOD) and total suspended solids (TSS). A single sample was available for 2000 (December) and eight samples in 2001. An average of the December 2000 through December 2001 period was used to represent a constant annual input value of 8 mg/l of BOD. TSS was similarly estimated to be 16 mg/l. Inputs for the other water quality parameters were taken from the 1992 simulation (Wells, 1996) for Columbia Plywood. Final values used for Columbia Plywood inflows are included in Table 15.

Table 15. Columbia Plywood inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	25.0	0.0	16.0	0.15	0.15	0.24	0.0	5.0	0.0	8.0	0.0	7.0	15.8	52.0
367	25.0	0.0	16.0	0.15	0.15	0.24	0.0	5.0	0.0	8.0	0.0	7.0	15.8	52.0

Klamath Falls Water Treatment Plant

Constituent concentrations for the Klamath Falls Water Treatment Plant were based on both 2000 monthly ODEQ report data and the 1992 simulation (Wells, 1996).

Because reported daily dissolved oxygen and suspended solids values showed modest variation, monthly average values were calculated for model input. Monthly BOD concentrations were estimated from samples collected at biweekly intervals. All other data are monthly estimates based on the 1992 simulation (Wells, 1996). The average monthly inflow concentrations are shown in Table 16.

Table 16. KFWTP inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	5.0	14.0	50.0
15	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	5.0	14.0	50.0
46	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	5.0	14.0	50.0
75	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	4.5	14.0	50.0
106	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	4.5	14.0	50.0
136	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	4.0	14.0	50.0
167	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	4.0	14.0	50.0
197	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	4.0	14.0	50.0
228	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	4.0	14.0	50.0
259	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	4.5	14.0	50.0
289	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	4.5	14.0	50.0
320	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	4.5	14.0	50.0
350	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	5.0	14.0	50.0
366	200.0	0.0	8.0	3.0	6.0	1.5	0.0	0.0	0.0	11.0	0.0	5.0	14.0	50.0

South Suburban Sanitation District

South Suburban Sanitation District reports dissolved oxygen, BOD, TSS, total phosphorus, ammonia, nitrate and pH to ODEQ. The frequency of reporting varied for each parameter, with dissolved oxygen and pH reported 5 times a week, BOD and TSS reported twice a week. All nutrients were reported once a month. All data was converted to monthly averages. Orthophosphate was estimated as 50 percent of total phosphorous concentrations because no data were available. The pH and temperature monthly averages were used to estimate alkalinity and TIC monthly values (Snoeyink and Jenkins, 1980). TDS was estimated to be 200 mg/l (same as 1992 simulation (Wells, 1996)). Several parameters were set to zero because there was no available information. These parameters included the tracer, iron, refractory and labile particulate organic matter, and algae concentration. All values are included shown in Table 17.

Table 17. SSSD inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	42.5	0.0	9.4	0.0	0.0	0.0	0.0	28.6	0.0	10.5	0.0	24.3
15	200.0	0.0	35.0	0.0	12.0	0.0	0.0	0.0	0.0	26.6	0.0	7.5	0.0	13.4
46	200.0	0.0	49.4	0.0	13.0	0.0	0.0	0.0	0.0	28.6	0.0	9.2	0.0	26.5
75	200.0	0.0	58.7	0.0	17.0	0.0	0.0	0.0	0.0	30.7	0.0	8.5	0.0	29.0
106	200.0	0.0	29.4	0.0	8.0	0.0	0.0	0.0	0.0	28.0	0.0	3.9	0.0	8.6
136	200.0	0.0	30.6	1.6	9.5	1.6	0.0	0.0	0.0	30.3	0.0	4.9	0.0	12.4
167	200.0	0.0	40.1	1.6	1.4	2.0	0.0	0.0	0.0	30.4	0.0	4.6	0.0	10.8
197	200.0	0.0	31.4	2.4	17.0	1.0	0.0	0.0	0.0	28.9	0.0	3.1	0.0	9.8
228	200.0	0.0	36.3	1.9	3.6	0.6	0.0	0.0	0.0	25.9	0.0	3.5	0.0	11.3
259	200.0	0.0	42.1	1.8	10.5	3.3	0.0	0.0	0.0	42.9	0.0	4.6	0.0	9.0
289	200.0	0.0	41.0	2.4	4.4	2.2	0.0	0.0	0.0	33.9	0.0	5.5	0.0	8.7
320	200.0	0.0	31.9	0.0	5.4	0.0	0.0	0.0	0.0	35.6	0.0	10.8	0.0	23.8
350	200.0	0.0	50.4	0.0	6.8	0.0	0.0	0.0	0.0	30.7	0.0	13.7	0.0	48.6
366	200.0	0.0	42.5	0.0	9.4	0.0	0.0	0.0	0.0	28.6	0.0	10.5	0.0	24.3

Collins Forest Products (Weyerhauser #1 and #3)

Constituent concentrations for Collins Forest Products #1 and #2 were estimated from the monthly water quality reports submitted to ODEQ. These reports provided daily flow and temperature. BOD and TSS were reported twice a week. The other constituent concentrations were estimated from the 1992 simulation (Wells 1996) input files for Weyerhauser #1 and #3 (Collins Forest Products is the current owner of the same facilities that Weyerhauser owned in 1992). Estimated monthly values are shown in Table 18 and Table 19.

Table 18. Collins Forest Products #1 inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	11.6	0.2	0.2	0.2	0.0	0.0	0.0	29.8	0.0	3.5	12.2	50.0
15	200.0	0.0	12.8	0.2	0.2	0.2	0.0	0.0	0.0	20.1	0.0	3.5	12.2	50.0
46	200.0	0.0	9.8	0.2	0.2	0.2	0.0	0.0	0.0	23.6	0.0	3.5	12.2	50.0
75	200.0	0.0	6.0	0.2	0.2	0.2	0.0	0.0	0.0	17.5	0.0	3.5	12.2	50.0
106	200.0	0.0	1.6	0.2	0.2	0.2	0.0	0.0	0.0	17.3	0.0	3.5	12.2	50.0
136	200.0	0.0	3.4	0.2	0.2	0.2	0.0	0.0	0.0	15.0	0.0	3.5	12.2	50.0

167	200.0	0.0	8.9	0.2	0.2	0.2	0.0	0.0	0.0	13.7	0.0	3.5	12.2	50.0
197	200.0	0.0	5.9	0.2	0.2	0.2	0.0	0.0	0.0	13.3	0.0	3.5	12.2	50.0
228	200.0	0.0	6.8	0.2	0.2	0.2	0.0	0.0	0.0	15.6	0.0	3.5	12.2	50.0
259	200.0	0.0	9.9	0.2	0.2	0.2	0.0	0.0	0.0	17.2	0.0	3.5	12.2	50.0
289	200.0	0.0	14.7	0.2	0.2	0.2	0.0	0.0	0.0	26.1	0.0	3.5	12.2	50.0
320	200.0	0.0	13.0	0.2	0.2	0.2	0.0	0.0	0.0	30.4	0.0	3.5	12.2	50.0
350	200.0	0.0	10.5	0.2	0.2	0.2	0.0	0.0	0.0	39.4	0.0	3.5	12.2	50.0
366	200.0	0.0	11.6	0.2	0.2	0.2	0.0	0.0	0.0	29.8	0.0	3.5	12.2	50.0

Table 19. Collins Forest Products #2 concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	20.7	3.0	3.0	0.5	0.0	0.0	0.0	15.0	0.0	3.5	11.9	50.0
15	200.0	0.0	23.8	3.0	3.0	0.5	0.0	0.0	0.0	20.4	0.0	3.5	11.9	50.0
46	200.0	0.0	65.4	3.0	3.0	0.5	0.0	0.0	0.0	29.1	0.0	3.5	11.9	50.0
75	200.0	0.0	38.3	3.0	3.0	0.5	0.0	0.0	0.0	23.5	0.0	3.5	11.9	50.0
106	200.0	0.0	27.0	3.0	3.0	0.5	0.0	0.0	0.0	27.8	0.0	3.5	11.9	50.0
136	200.0	0.0	32.7	3.0	3.0	0.5	0.0	0.0	0.0	25.5	0.0	3.5	11.9	50.0
167	200.0	0.0	25.9	3.0	3.0	0.5	0.0	0.0	0.0	16.2	0.0	3.5	11.9	50.0
197	200.0	0.0	12.6	3.0	3.0	0.5	0.0	0.0	0.0	9.9	0.0	3.5	11.9	50.0
228	200.0	0.0	7.8	3.0	3.0	0.5	0.0	0.0	0.0	6.7	0.0	3.5	11.9	50.0
259	200.0	0.0	6.6	3.0	3.0	0.5	0.0	0.0	0.0	4.2	0.0	3.5	11.9	50.0
289	200.0	0.0	3.6	3.0	3.0	0.5	0.0	0.0	0.0	5.9	0.0	3.5	11.9	50.0
320	200.0	0.0	2.6	3.0	3.0	0.5	0.0	0.0	0.0	3.1	0.0	3.5	11.9	50.0
350	200.0	0.0	17.6	3.0	3.0	0.5	0.0	0.0	0.0	10.7	0.0	3.5	11.9	50.0
366	200.0	0.0	20.7	3.0	3.0	0.5	0.0	0.0	0.0	15.0	0.0	3.5	11.9	50.0

Lost River Diversion

The Lost River Diversion constituent concentrations (Table 20) were estimated from bimonthly data collected by USBR at Wilson Reservoir in 2000, Klamath Straits data from 2000 (for dissolved oxygen), Link Dam 2002 grab samples, and from the 1992 simulation (Wells, 1996) input files. Wilson Reservoir data were used only during periods when the Lost River diversion channel was flowing to the Klamath River. ************* UPDATE (*Check with Deas on this update*)

Table 20. Wilson Reservoir 2000 Data

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	15.0	0.7	11.0	23.0	140.0
13	175.0	0.0	10.0	0.4	0.4	0.7	0.0	0.0	0.0	15.0	4.1	10.3	23.0	190.0
25	175.0	0.0	10.0	0.2	0.2	0.1	0.0	0.0	0.0	15.0	3.6	9.5	23.0	170.0
41	175.0	0.0	10.0	0.1	0.2	1.3	0.0	0.0	0.0	15.0	0.7	10.7	23.0	190.0
62	175.0	0.0	10.0	0.1	0.2	1.5	0.0	0.0	0.0	15.0	0.7	9.3	23.0	140.0
75	175.0	0.0	10.0	0.1	0.1	0.7	0.0	0.0	0.0	15.0	0.7	9.4	23.0	170.0
89	175.0	0.0	10.0	0.1	0.1	0.7	0.0	0.0	0.0	15.0	0.7	9.6	23.0	170.0
103	175.0	0.0	10.0	0.1	0.1	0.2	0.0	0.0	0.0	15.0	3.3	10.7	23.0	130.0
118	175.0	0.0	10.0	0.1	0.1	0.4	0.0	0.0	0.0	15.0	2.9	9.7	23.0	140.0
131	175.0	0.0	10.0	0.1	0.1	0.1	0.0	0.0	0.0	15.0	0.7	8.3	23.0	130.0
145	175.0	0.0	10.0	0.1	0.1	0.1	0.0	0.0	0.0	15.0	1.7	10.6	23.0	120.0
159	175.0	0.0	10.0	0.2	0.1	0.1	0.0	0.0	0.0	15.0	1.5	8.9	23.0	120.0
242	175.0	0.0	10.0	0.5	0.8	0.1	0.0	0.0	0.0	15.0	0.7	1.4	23.0	140.0
277	175.0	0.0	10.0	0.2	0.3	0.2	0.0	0.0	0.0	15.0	3.0	6.7	23.0	110.0
284	175.0	0.0	10.0	0.2	0.3	0.4	0.0	0.0	0.0	15.0	0.9	6.2	23.0	120.0
298	175.0	0.0	10.0	0.1	0.2	0.6	0.0	0.0	0.0	15.0	1.2	9.0	23.0	180.0
312	175.0	0.0	10.0	0.1	0.3	0.5	0.0	0.0	0.0	15.0	1.6	9.0	23.0	160.0
326	175.0	0.0	10.0	0.1	0.1	0.6	0.0	0.0	0.0	15.0	0.7	11.3	23.0	150.0
340	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	15.0	0.7	11.5	23.0	160.0
353	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	15.0	0.9	11.1	23.0	150.0
366	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	15.0	0.9	11.0	23.0	150.0

Klamath Straits Drain

Monthly model input values were identified for all water quality constituents at the Klamath Straits Drain. Dissolved oxygen and total dissolved solids values were calculated from USBR datasonde data for Klamath Straits Drain during 2000. The sonde was deployed from January through November, with several periods of missing data (the largest data gaps are from March 16, 2000 through April 6, 2000 and April 19, 2000 through May 2, 2000). Monthly estimates for ammonia, nitrate, orthophosphate, algae, and alkalinity concentrations were based on USBR grab samples collected in 2000. All other necessary data was estimated from the 1992 simulation (Wells, 1996). Final constituent concentrations for this inflow are presented in Table 21.

Table 21. KSD inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	354.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
15	374.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
46	316.0	0.0	24.0	0.2	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
75	365.0	0.0	24.0	0.2	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
106	409.0	0.0	24.0	0.4	0.3	0.5	0.0	10.0	0.0	5.0	1.0	4.7	37.0	150.0
136	423.0	0.0	24.0	0.5	0.5	0.5	0.0	13.0	0.0	5.0	1.0	6.8	37.0	150.0
167	319.0	0.0	24.0	0.5	0.5	0.5	0.0	15.0	0.0	5.0	1.0	3.5	37.0	150.0
197	266.0	0.0	24.0	0.5	0.5	1.0	0.0	15.0	0.0	5.0	1.0	2.4	37.0	150.0
228	252.0	0.0	24.0	0.3	0.5	1.3	0.0	13.0	0.0	5.0	1.0	1.9	37.0	150.0
259	296.0	0.0	24.0	0.2	1.0	2.0	0.0	10.0	0.0	5.0	1.0	2.8	37.0	150.0
289	376.0	0.0	24.0	0.2	1.5	0.3	0.0	10.0	0.0	5.0	1.0	3.3	37.0	150.0
320	294.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.1	37.0	150.0
350	334.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
366	354.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0

2.3.2.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10) and atmospheric pressure.

The meteorological data for the Klamath River Lake Ewauna to Keno Dam reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure is calculated within CE-QUAL-W2 (elevation of Keno Reservoir: 4085 ft (1245 m)). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

2.3.3 Keno Reach

The Keno reach extends from Keno Dam to the headwaters of JC Boyle Reservoir. There are no appreciable streams tributary to this reach. The physical description (e.g., geometry), flow and water quality data, meteorological conditions and other model parameters are outlined below. This reach uses RMA-2 to represent flow and RMA-11 to represent water quality.

2.3.3.1 River Physical Description

River Location

The x-y coordinates describing the river location were defined using a digitized version of the 1:24,000 USGS topographic quadrangles provided by CH2M Hill, as discussed in Appendix C. Key locations in the reach are presented in Table 22 and a model representation of the reach is shown in Figure 22.

Table 22. Klamath River, Keno reach geometry information for the RMA-2 and RMA-11 models

Location	Node	Element	x-coord	y-coord	Site type	Inflow Angle, radians [a]
Keno Dam	1	1	186.791	165.422	BC, upper	-1.185
	37	18			A/D	-
End Keno R reach	117	58	180.990	166.913	BC, lower	-
1/4 mi abv JC Boyle	110	56	181.439	166.884	Cal/Val and Reporting	-

BC – boundary condition (flow, constituent concentration, stage)

Reporting – model output location

[a] : Radians are measured counter-clockwise from due east

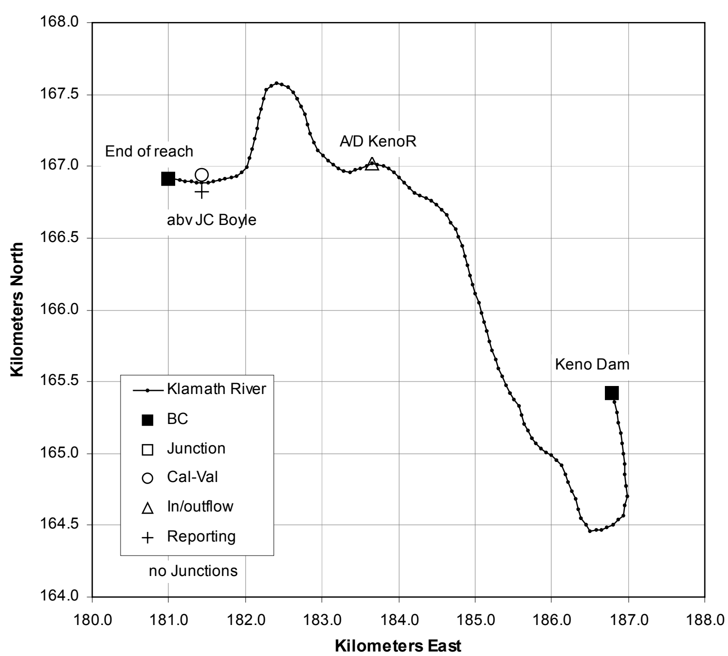


Figure 22. Klamath River, Keno reach representation

River Width

Keno reach widths were obtained from habitat surveys conducted by Tom Payne and Associates. Measurements were completed at roughly eight locations per mile. These measurements were not necessarily uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were assigned to the nearest x-y coordinate. Trapezoidal river cross sections were constructed at evenly spaced intervals of 75 meters. Side slopes were assumed to be 1:1 and river width was based on a seven times running average of measured widths.

Bed Elevation/Slope

Bed slope for the reach was estimated from USGS topographic maps and known elevations at Keno Dam and JC Boyle water surface elevations. Reach elevations range from approximately 3796 ft msl (1157 m) to 4019 ft msl (1225 m). Elevations were estimated from land surface topographic contours and do not represent the river bed elevations.

Table 23. Klamath River, Keno reach geometry summary

Node spacing	75 meters
Number of nodes	117 nodes in length
Length	5.37 miles from RM228.69-234.06
Elevations	Range: 1157-1225 meters
Widths	Range: 21-57 meters
Side slopes	1:1
Data sources	UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps.
Notes	n/a

2.3.3.2 Flow Data

Inflows and Outflows

Inflow to the Keno reach was based on daily flows measured by the USGS gage near Keno (No. 11509500), shown in Figure 23. No appreciable tributary contributions or diversions have been identified for this relatively short reach and accretions/depletions between Keno Dam and JC Boyle Dam were assigned to the JC Boyle Reservoir reach. However, an element inflow location and small inflow (0.1 cms) has been included at element 37.

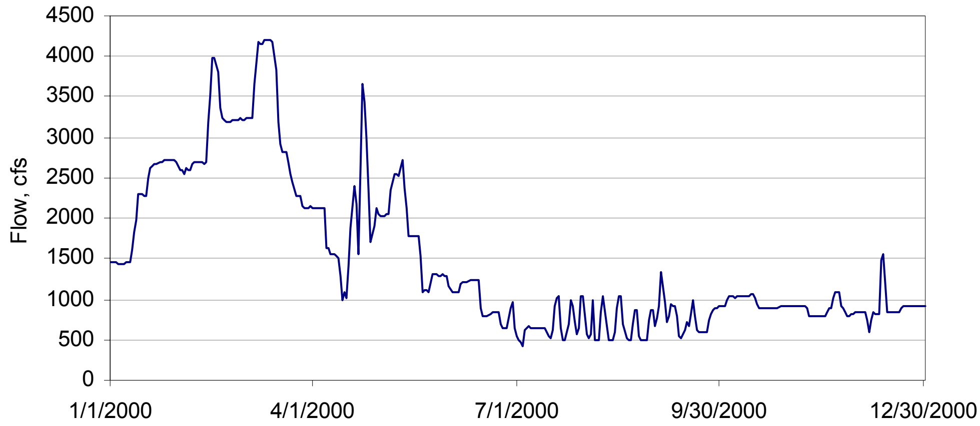


Figure 23. Keno Dam inflow for Keno reach model

Downstream Boundary Condition

The measured elevations at JC Boyle dam were used to calculate the downstream elevations for the Keno reach simulation. This approach resulted in a variable stage downstream boundary condition and replicated backwater conditions within the reach. As the x-y coordinates from the CH2M Hill maps gave locations of river reaches and elevations from Upper Klamath Lake to Iron Gate Dam, elevations for the river reaches were estimated from the CH2MHill maps (above Iron Gate Dam) and USGS topographic maps (below Iron Gate Dam), which were of twenty foot contour lines. Therefore the elevations in the river reaches were approximate, but nonetheless representative. When resolving river and reservoir elevation (reservoir elevations are absolute), adjustments were made to the downstream reservoir elevation boundary conditions to represent the river discharge into the impoundment within the river elevation representation and framework. Elevations were calculated as measured plus 10.2 ft (3.11 m) for the Keno reach (presented in Figure 24).

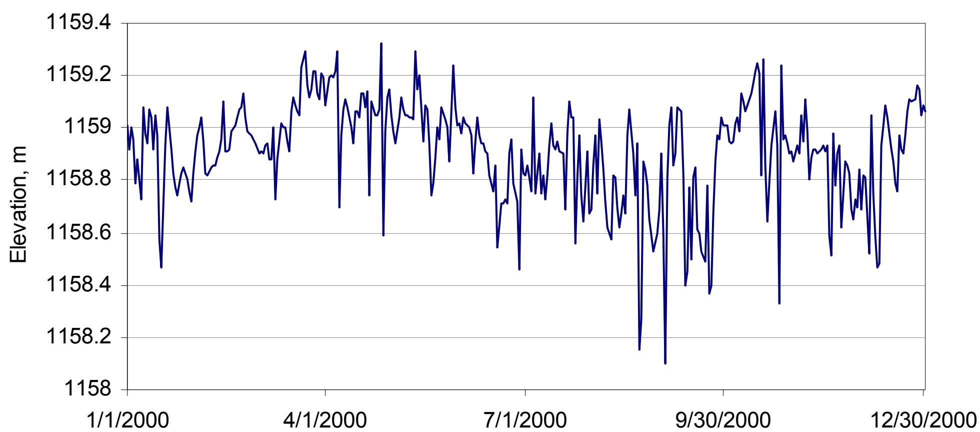


Figure 24. Downstream elevations for Keno reach model

2.3.3.3 Water Quality Data

Temperature

Hourly simulated temperatures from the Lake Ewauna CE-QUAL-W2 simulation were used as the temperatures in the Keno reach and are presented in Figure 25.

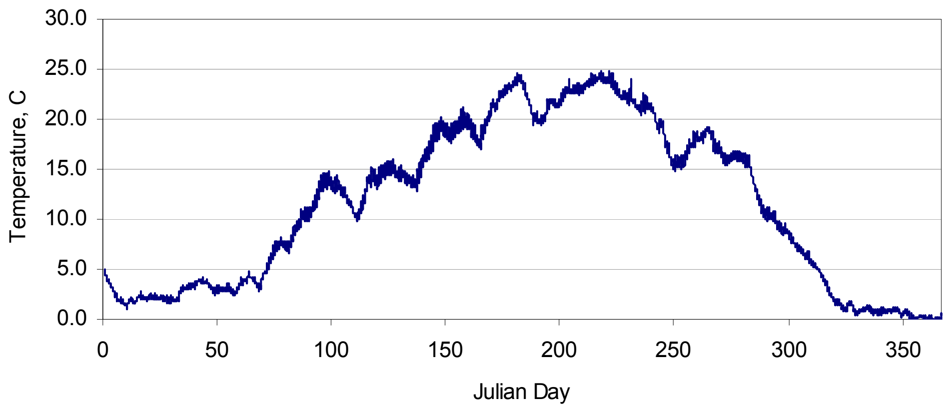
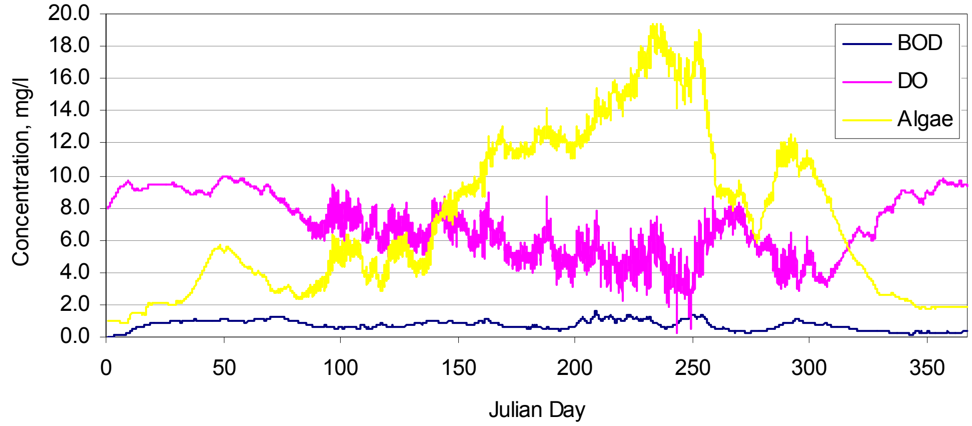


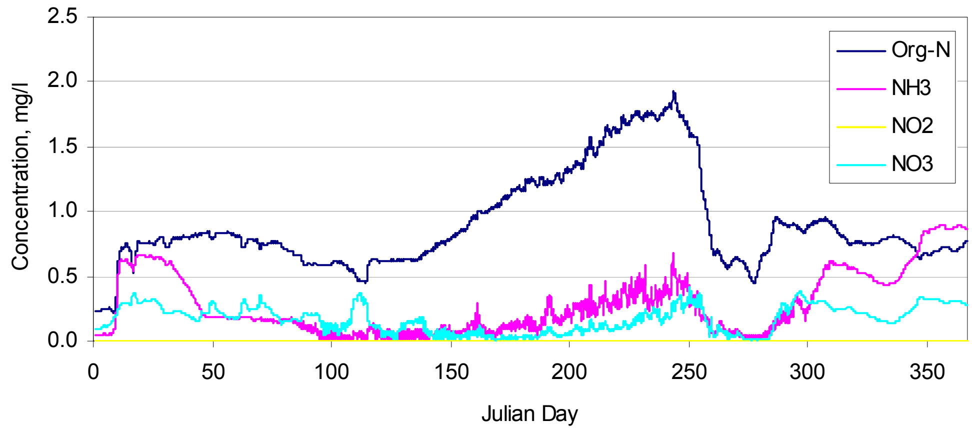
Figure 25. Keno inflow temperature for Keno reach model

Constituent Concentrations

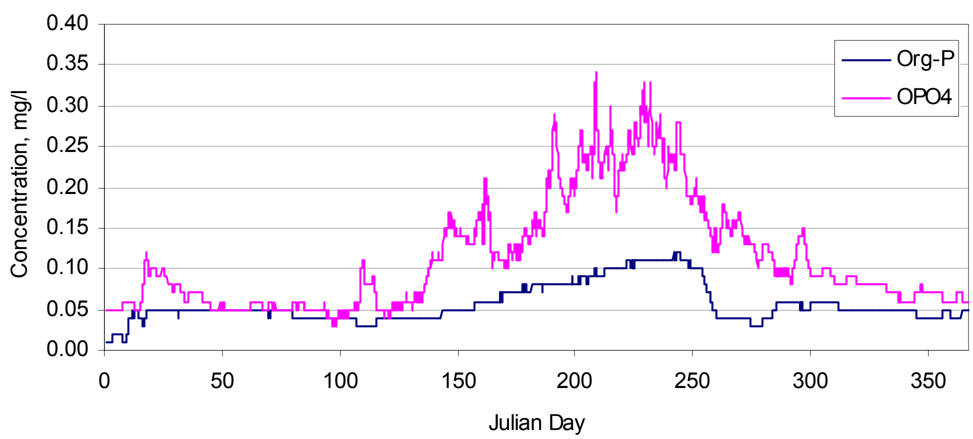
Hourly simulated constituent concentrations from the Lake Ewauna CE-QUAL-W2 simulation were used as the constituent concentrations in the Keno reach. CE-QUAL-W2 provides total organic and dissolved organic forms of nitrogen and phosphorous as derived output values. To maintain the total mass of organic nitrogen and phosphorous in the system, total organic nitrogen and total organic phosphorous are passed to the downstream river model (RMA-11). Because CE-QUAL-W2 includes the algae fraction in organic nitrogen and organic phosphorus, the algal component of each nutrient subtracted from the total. Inflow constituent concentrations used in model implementation are presented in Figure 26.



(a)



(b)



(c)

Figure 26. Inflow constituent concentrations for Keno reach model: (a) BOD, dissolved oxygen, algae; (b) nitrogen forms; (c) phosphorus forms

2.3.3.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

The meteorological data for the Klamath River Keno reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure was calculated based on elevation at JC Boyle (3800 ft (1158 m)) and assumed constant throughout the simulation period (880 mb). Wet bulb temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

2.3.4 JC Boyle Reservoir

The JC Boyle Reservoir primarily serves to regulate peaking flows for the JC Boyle Powerhouse (RM 220.4). The reservoir reach extends from the JC Boyle headwaters (the end of the Keno reach) to JC Boyle Dam (RM 224.7). There is one tributary represented in the model, located at Spencer Creek. The physical date, flow and water quality data, meteorological conditions and other model parameters are outlined below.

2.3.4.1 Reservoir Physical Data

JC Boyle Dam Features

JC Boyle Dam has four primary outlets: a spillway, fish ladder, and two outlets into the waterway intake (fish screen bypass and waterway pipeline). There are two additional low level culverts that were used during dam construction – these have been filled with concrete. The details of these outlets are summarized in Table 24.

Table 24. JC Boyle Dam outlet features

Outlet	Invert Elevation	Dimension	Operation
Fish ladder	3780.0 ft	24 inch diameter	Manual
Fish Screen Bypass	3757.0 ft	24 inch diameter	Manual
Waterway pipeline	3775.0 ft	14 foot diameter	**
Spillway	3782.0 ft	3 radial gates @ 35 ft width each	Remote control on one gate

Sources: PacifiCorp (2002), PacifiCorp (2000)
PacifiCorp drawing: Exhibit L-4

Reservoir Bathymetry Representation

Unlike the Lake Ewauna to Keno Dam Reservoir reach, there was no previous modeling effort of JC Boyle using CE-QUAL-W2. Reservoir geometry was derived from bathymetric data provided by JC Headwaters. Segment length, segment orientation, layer thickness and width were required for the reservoir model. Segments were identified based on changes in the reservoir morphology and widths. The reservoir was divided into sixteen active segments. Segments varied in length from approximately 135 ft (roughly 40 m) to 1600 ft (roughly 490 m). While capturing the general shape of JC Boyle Reservoir, the chosen segments also captured pertinent features of the reservoir such as the deep hole in the northwest corner of the reservoir and the discontinuity in the reservoir bed near the dam (Figure 27).

Cross sections were defined by roughly bisecting each segment and determining the depths as measured from river left to river right (looking downstream). These measurements were used to determine the number of active layers and the layer widths for each segment. The layer thickness used was one meter. There were twelve active layers of varying widths determined from this method. Although a finer resolution representation was attempted, the peaking hydropower operations produced a dynamic water surface elevation and simulations times were long (on the order of a day) because the model was continually adding and subtracting both layers and segments. The 1 meter layer thickness produced reasonable results and the simulation time was approximately 10 minutes.

The Manning's friction factor for each segment was assumed to be 0.04. A stage-volume curve was generated from the bathymetry data and compared to the measured stage-volume curve of the reservoir. Adjustments were made as necessary to ensure the simulated reservoir stage-volume relationship was consistent with the observed stage-volume relationship. The second active segment (segment 3) layer widths were increased slightly to increase the volume within that segment because the model experienced solution difficulties due to the characteristics of the accretion/depletion at Spencer Creek. A comparison of modeled and measured stage-volume relationships is shown in Figure 28.

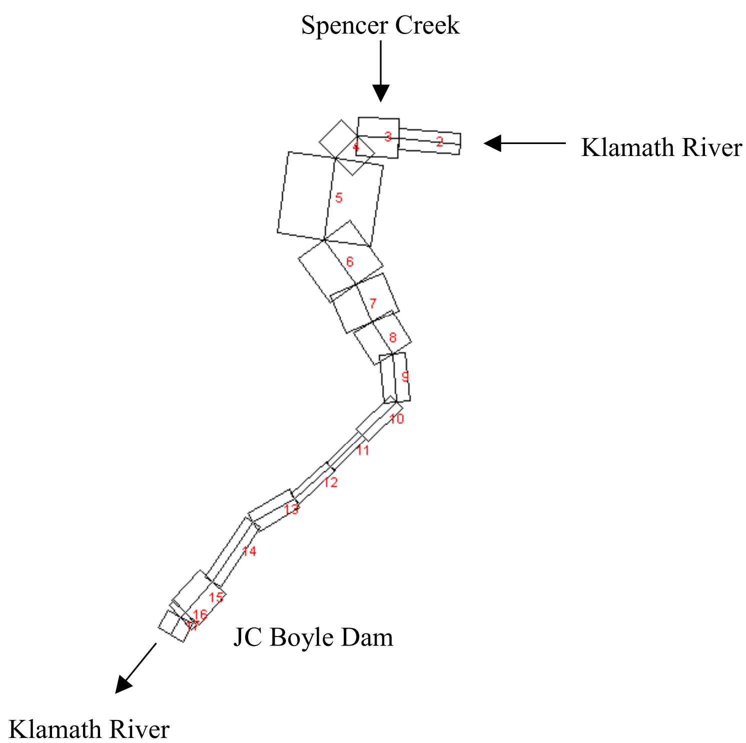


Figure 27. Representation of JC Boyle Reservoir in CE-QUAL-W2

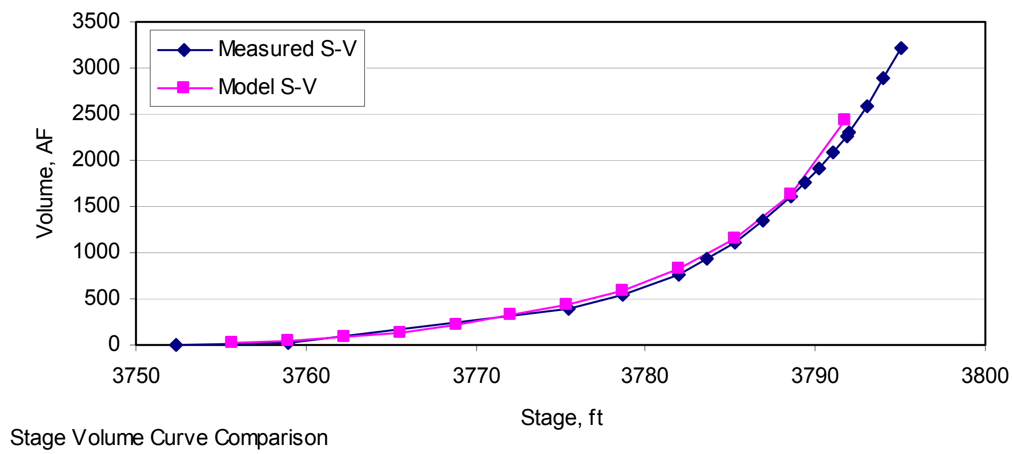


Figure 28. Comparison of measured and model representation of JC Boyle Reservoir stage-volume (S-V) relationships

2.3.4.2 Flow Data

Klamath River Inflow

Klamath River inflow to J.C. Boyle Reservoir is not directly measured. A water balance between Keno Dam and J.C. Boyle Dam suggest that accretions within this reach are generally modest. Thus, daily flow rates from the Klamath River near Keno USGS gage 11509500 were used as inflow into JC Boyle Reservoir and are presented in Figure 29.

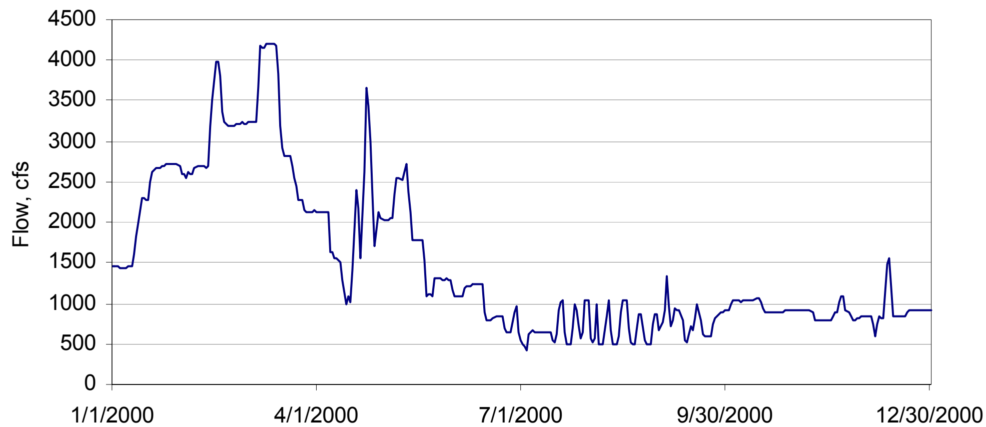


Figure 29. JC Boyle inflow rates for JC Boyle Reservoir reach model

Spencer Creek Inflow

Limited Spencer Creek inflow information was available. The net reservoir accretion/depletion was calculated as the difference between the daily average outflow from J.C. Boyle Dam and the daily average inflow (which was derived from the USGS Gage Klamath River near Keno). This accretion/depletion for the reservoir was located at Spencer Creek and is presented in Figure 30.

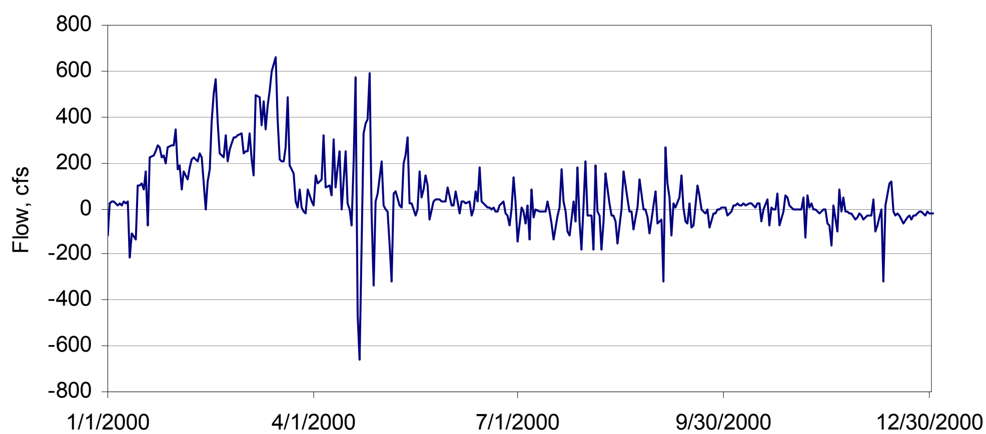


Figure 30. Accretion / depletion inflow (at Spencer Creek) for JC Boyle Reservoir reach model

JC Boyle Dam Outflow

The outflow from the J.C. Boyle Reservoir was calculated as the sum of the release to the powerhouse canal, spill from the dam, bypass releases, and fish ladder releases. Hourly data for power canal flows and spill were derived from PacifiCorp records and are presented in Figure 31. Fish ladder and bypass releases were assumed constant at 80 cfs and 20 cfs, respectively.

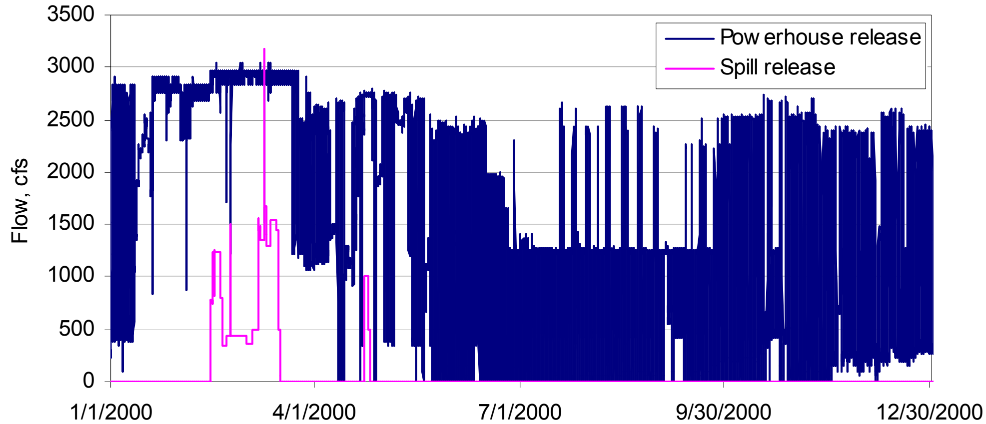


Figure 31. JC Boyle Dam powerhouse and spill releases for JC Boyle Reservoir reach model

2.3.4.3 Water Quality Data

Temperature

Klamath River Inflow

Inflow temperatures to J.C. Boyle Reservoir are derived from hourly temperatures simulated by RMA-11 (Keno Reach simulation at Node 110) and presented in Figure 32.

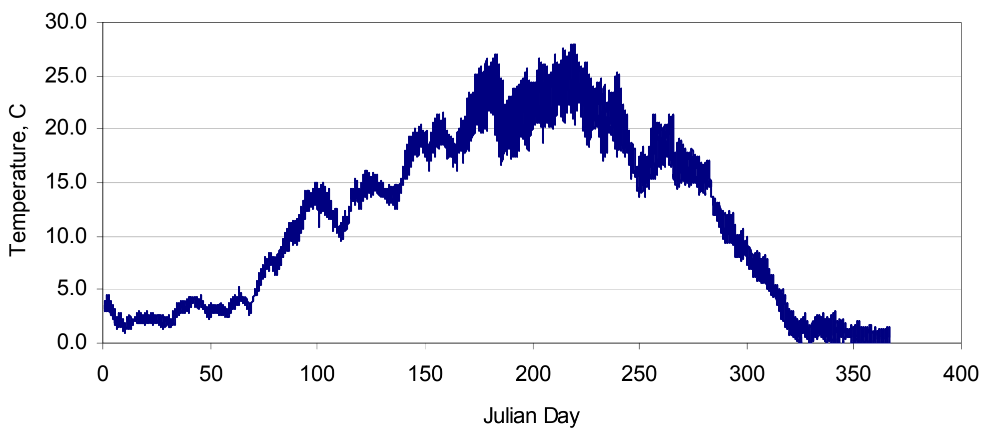


Figure 32. Inflow temperature for JC Boyle Reservoir reach model

Spencer Creek Inflow (Accretion/Depletion)

Temperatures for the inflow at Spencer Creek were made of a composite of hourly field data recorded by PacifiCorp using Tidbits in 2001 and 2002. Data was available for 2001 from 5/11 to 12/31 and for 2002 from 1/1 to 5/5. Missing data was linearly interpolated. Hourly values were input into the model (presented in Figure 33).

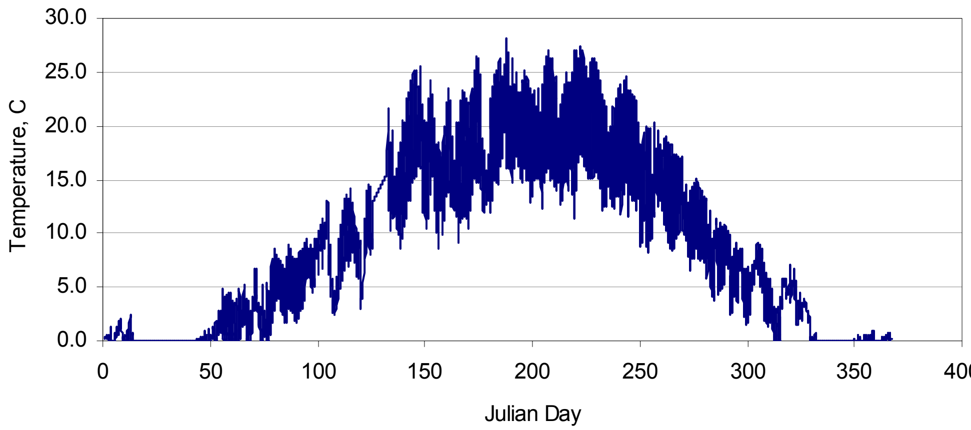
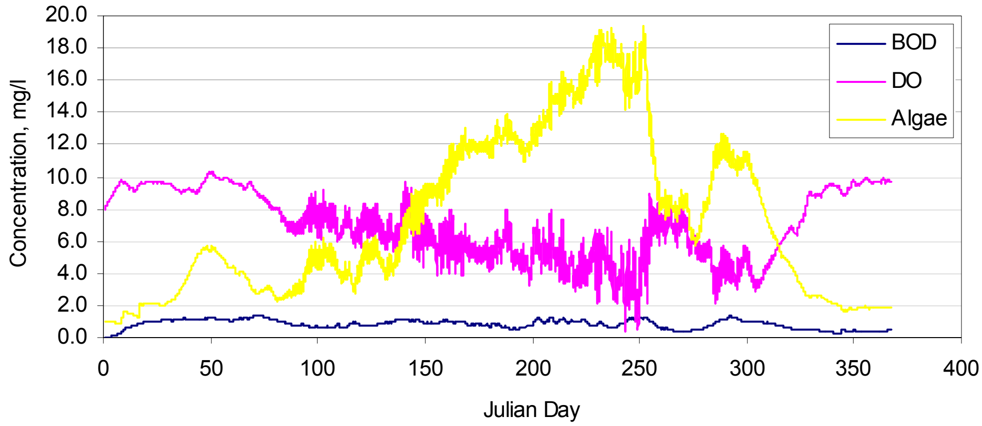


Figure 33. Spencer Creek inflow temperature for JC Boyle Reservoir reach model

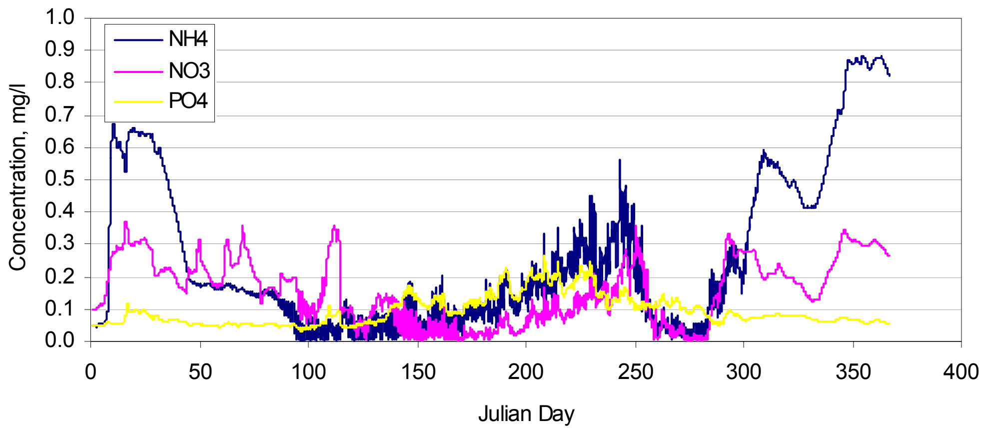
Constituent Concentrations

Klamath River Inflow

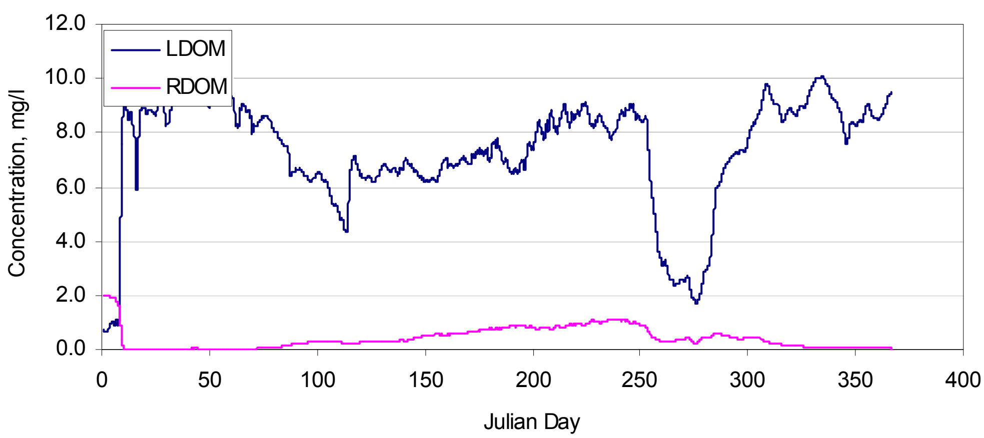
For model implementation, the hourly constituent concentrations used are from the CE-QUAL-W2 outflow file from the Lake Ewauna implementation simulation. Selected constituent concentrations are presented in Figure 34. For calibration and application, hourly constituent concentrations from the Keno reach were used and are presented in the calibration section of this document.



(a)



(b)



(c)

Figure 34. Selected inflow constituent concentrations for JC Boyle Reservoir reach model

Spencer Creek Inflow

The concentrations for the required constituents at Spencer Creek were estimated from 2002 grab samples (Table 25). Nine dates were input into the model, representing the seven grab sample dates and the first and last day of the year. Labile dissolved organic matter (LDOM) was estimated from the calculation:

$$LDOM = \frac{TotalPhosphorus - Phosphate}{0.005}$$

This method was used because the 2002 grab samples included both total phosphorus and phosphate concentrations. The value of 0.005 is a stoichiometric equivalence between phosphate and organic matter.

Table 25. Spencer Creek constituent concentrations for the JC Boyle Reservoir reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	20	0	10	0.05	0.14	0.05	0	10	0	3	2	11	15	60
85	20	0	10	0.05	0.07	0.05	0	15	0	3	2	11	15	38
106	20	0	10	0.09	0.05	0.05	0	15	0	3	2	10	15	23
142	20	0	10	0.06	0.05	0.05	0	10	0	3	2	9	15	40
169	20	0	10	0.08	0.03	0.05	0	11	0	3	2	8	15	58
197	20	0	10	0.07	0.03	0.05	0	10	0	3	2	9	15	64
225	20	0	10	0.06	0.04	0.05	0	10	0	3	2	10	15	66
253	20	0	10	0.13	0.21	0.05	0	10	0	3	2	11	15	62
366	20	0	10	0.05	0.14	0.05	0	10	0	3	2	11	15	60

Phosphate, ammonia, nitrate, LDOM, BOD, DO and alkalinity from 2002 Spencer Creek grab samples. All other parameters estimated.

2.3.4.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10) and atmospheric pressure.

The meteorological data for the JC Boyle Reservoir reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure is calculated within CE-QUAL-W2 (elevation of JC Boyle Reservoir: 3793 ft (1156 m)). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

2.3.5 Bypass and Peaking Reach

The Bypass and Peaking reach extends from JC Boyle Dam to the headwaters of Copco Reservoir. Noteworthy features of the reach include diversion of mainstem flows at J.C. Boyle Dam for hydropower production, the powerhouse penstock return roughly five miles downstream from J.C. Boyle Dam, a large springs complex in the bypass section, and hydropower peaking operations downstream of the powerhouse. There are few small streams entering the reach, the most significant being Shovel Creek. The geometry, flow and water quality data, meteorological conditions and other model parameters are outlined below.

2.3.5.1 River Physical Description

River Location

The x-y coordinates describing the river location were defined using a digitized version of the 1:24,000 USGS topographic quadrangles provided by CH2M Hill, as discussed in Appendix C. This information was translated into a network of nodes and elements for use by the numerical model (Figure 35). Important locations within the reach, i.e., those of boundary conditions, are presented in Table 26.

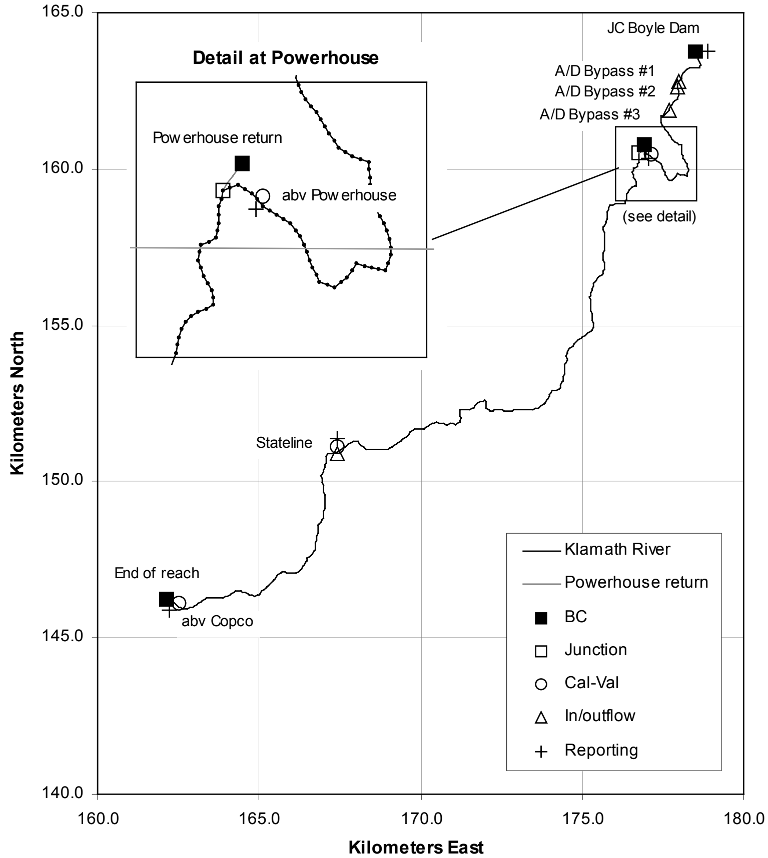


Figure 35. Bypass - Peaking reach representation

Table 26. Geometry information for the Bypass - Peaking reach EC simulation

Location	Node	Element	x-coord	y-coord	Site type	Inflow Angle, radians [a]
JC Boyle Dam	1	1	178.679	163.748	BC, upper	4.026
End Peaking reach	453	226	162.151	146.244	BC, lower	-
JC Boyle Powerhouse	95	48	176.945	160.764	BC	-
Simulated Powerhouse Return	97	49	176.777	160.516	Junction, inflow	4.106
1/4 mi abv Powerhouse	91	46	177.130	160.377	Cal-Val	-
1/4 mi abv Shovel Cr	389	195	166.264	147.155	Cal-Val	-
1/4 mi abv Copco	447	224	162.499	145.990	Cal-Val	-
CA-OR Stateline	331	166	167.418	151.100	Cal-Val, A/D	-
A/D Bypass #1	21	11	177.978	162.789	A/D	-
A/D Bypass #2	23	12	177.951	162.644	A/D	-
A/D Bypass #4	35	18	177.680	161.865	A/D	-

BC – boundary condition

A/D – accretion/depletion location

Cal-Val – calibration and validation location

[a] : Radians are measured counter-clockwise from due east.

River Width

Bypass and Peaking reach widths were obtained from habitat surveys completed by Tom Payne and Associates. Measurements were completed at roughly eight locations per mile. These measurements were not necessarily uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were assigned to the nearest x-y coordinate. Trapezoidal river cross sections were constructed at evenly spaced intervals of 75 meters. Side slopes were assumed to be 1:1 and river width was based on a seven times running average of measured widths.

Bed Elevation/Slope

Bed slope for the reach was estimated from USGS topographic maps and known elevations at J.C. Boyle Dam and Copco Reservoir water surface elevations. Reach elevations range from approximately 2565 ft msl (782 m) to 3760 ft msl (1146 m). Elevations were estimated from land surface topographic contours and do not represent the river bed elevations.

Table 27. Klamath River, Bypass-Peaking Reach geometry summary

Node spacing	75 meters
Number of nodes	459 nodes in length
Length	20.81 miles from RM204.72-225.53
Elevations	Range: 782-1146 meters
Widths	Range: 19-64 meters
Side slopes	1:1
Data sources	UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps.
Notes	1 junction: JCB Powerhouse; Nodes 97, 458, 459

2.3.5.2 Flow Data

Inflows and Outflows

The Bypass-Peaking reach has two inflows: releases from J.C. Boyle Dam directly to the Klamath River (Bypass flow) and inflow at the J.C. Boyle Powerhouse tailrace (both presented in Figure 36). Measured releases from JC Boyle Dam during the 2000 calendar year were obtained from PacifiCorp and used to designate both flows. The springs, located in the bypass reach are represented by three element inflows at elements 11, 12 and 18. The springs were assigned a constant flow of 75 cfs (2.12 cms) each for the entire simulation (a total of 225 cfs (6.36 cms) for that section). A single accretion/depletion is located at Stateline in the Peaking portion of the reach (element 168). This accretion/depletion was placed at Stateline because there are several inflows in this vicinity, as well as diversions for agriculture. The accretion/depletion (shown in Figure

37) was calculated using seven day average values to average out day to day variations in operations in the peaking reach.

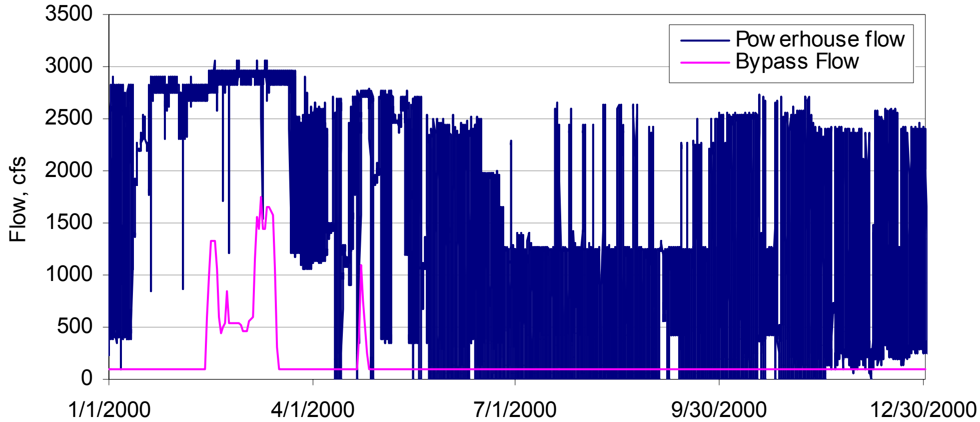


Figure 36. Powerhouse inflow and Bypass inflow rates for Bypass / Peaking reach model

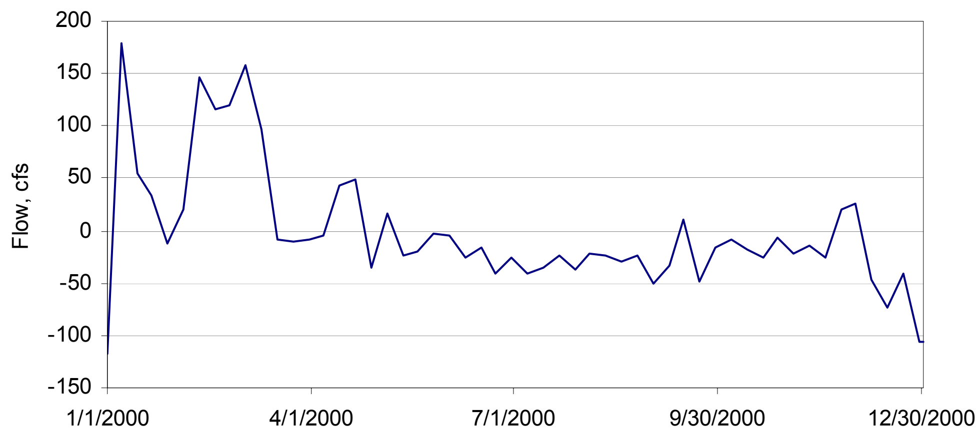


Figure 37. Accretion / depletion flow for Bypass / Peaking reach model

Downstream Boundary Condition

The downstream boundary condition at Copco Reservoir was represented by reservoir elevation. This approach resulted in a variable stage downstream boundary condition and replicated backwater conditions within the reach. Elevations were determined by subtracting 39.21 ft (11.95 m) from the measured Copco Dam water surface elevations, to match the Peaking reach datum and the Copco Reservoir datum.

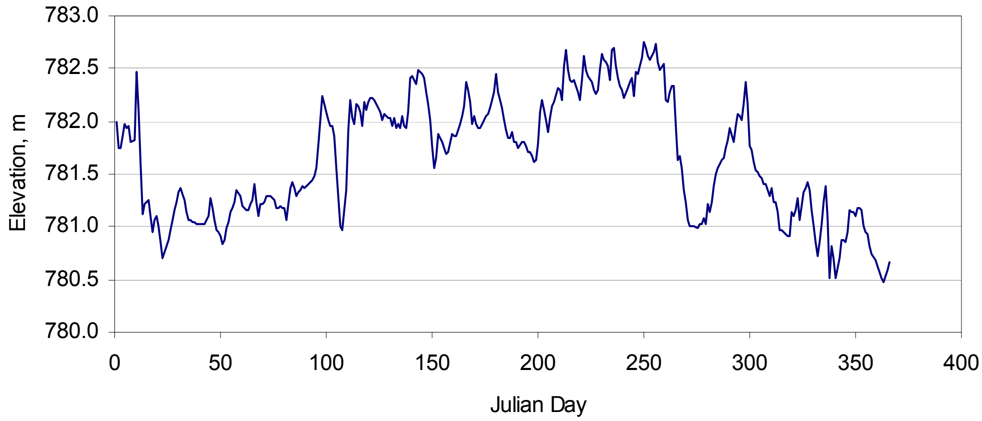


Figure 38. Downstream elevations for Bypass / Peaking reach model

2.3.5.3 Water Quality Data

Temperature

Both the JC Boyle Dam release to the Bypass reach and via the Powerhouse were assigned the simulated hourly temperature releases at J.C. Boyle Dam (from CE-QUAL-W2, presented in Figure 39). It was assumed that the transit time between JC Boyle Dam and the powerhouse tailrace, roughly three miles, was approximately twenty minutes at Peaking (T. Olson personal communication). Thus, Powerhouse release temperatures were not lagged.

The springs were assigned constant temperatures of 11.0°C. The A/D at Stateline was not assigned a temperature.

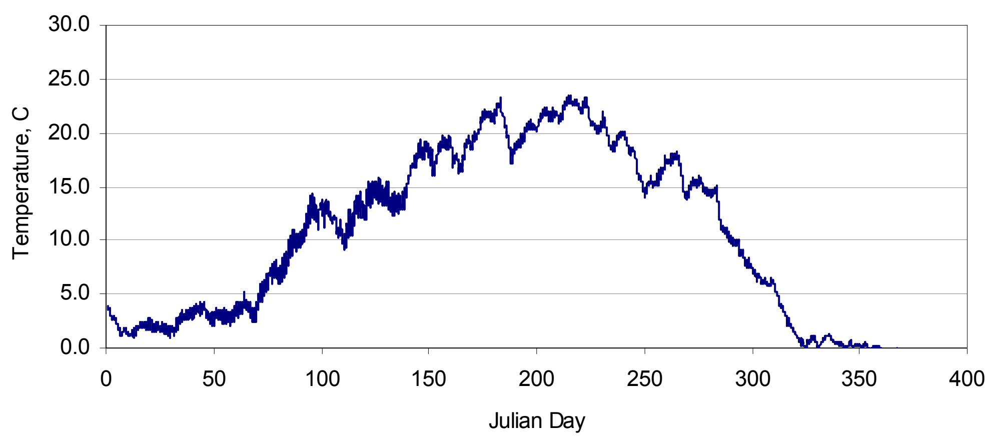
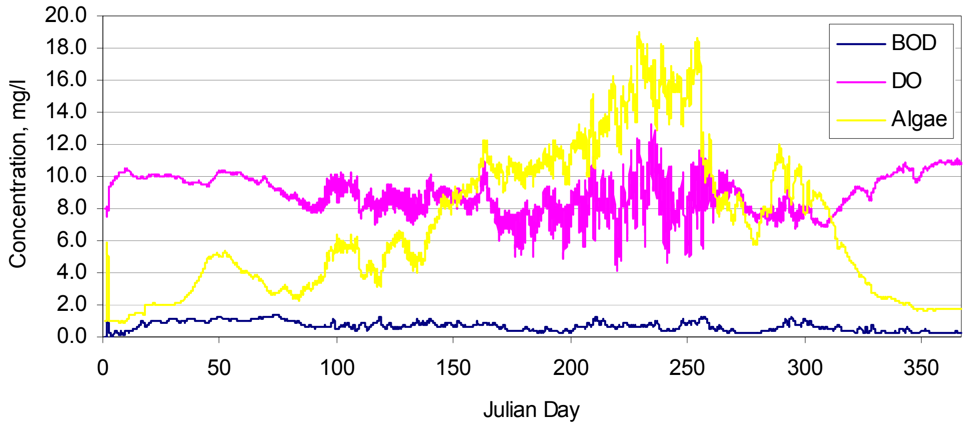


Figure 39. Bypass and Powerhouse inflow temperatures for Bypass / Peaking reach model implementation

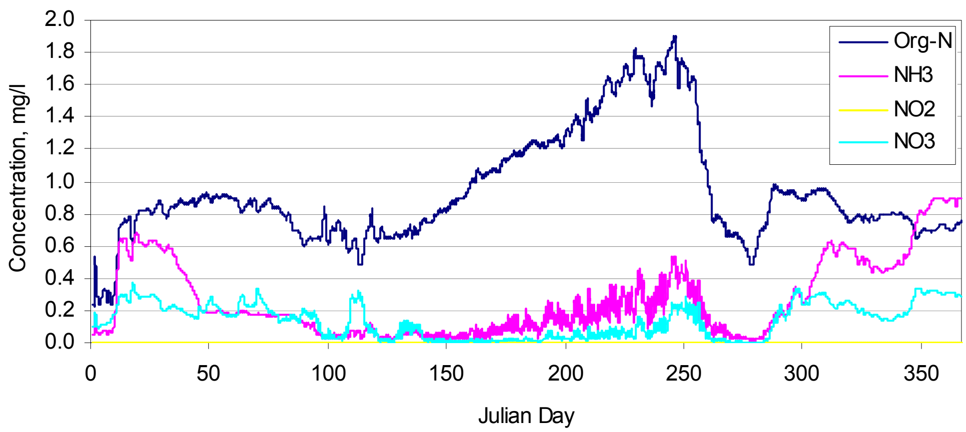
Constituent Concentrations

Both the JC Boyle Dam release to the Bypass and the Powerhouse were assigned the simulated hourly constituent concentrations releases at J.C. Boyle Dam (from CE-QUAL-W2 and presented in Figure 40). It was assumed that the transit time between JC Boyle Dam and the powerhouse tailrace, roughly three miles, was approximately twenty minutes. Thus, Powerhouse release constituent concentrations were not lagged.

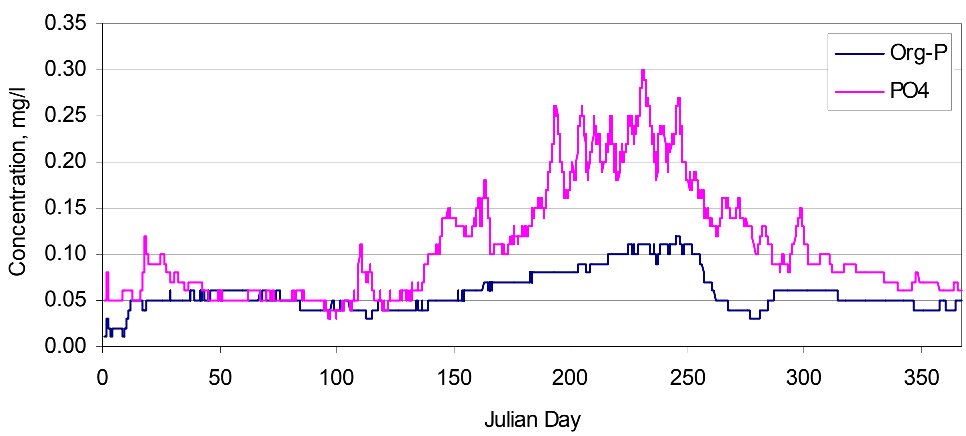
The springs were assigned constant concentrations of 9.7 mg/l estimated as dissolved oxygen saturation at elevation 3600 ft and water temperature of 11°C. All constituent concentrations were assumed zero except nitrate and orthophosphate, which were assumed at 0.15 mg/l. The A/D at Stateline was not assigned water quality characteristics.



(a)



(b)



(c)

Figure 40. Bypass and Powerhouse inflow constituent concentrations for Bypass / Peaking reach model: (a) BOD, dissolved oxygen and algae; (b) nitrogen forms; (c) phosphorus forms

2.3.5.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

The meteorological data for the Klamath River Klamath River Bypass and Peaking reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Barometric pressure was calculated based on mean reach elevation of approximately 3160 ft (963 m), and was constant at 904 mb. The methods of determination and calculation of necessary model parameters are outlined in Appendix E.

2.3.6 Copco Reservoir

The Copco Reservoir reach extends from Copco Reservoir headwaters (RM 203.1) to Copco Dam (RM 198.6). There are no tributaries represented in the model: the only inflow represented is Klamath River inflow to the reservoir. The physical data, flow and water quality data, meteorological conditions and other model parameters are outlined below.

2.3.6.1 Reservoir Physical Data

Copco Dam Features

Copco Dam has two primary outlets: a spillway and two waterway intakes that feed Unit 1 and Unit 2 at Copco No. 1 powerhouse. The two penstock intakes are treated as a single outlet in CE-QUAL-W2. The details of these outlets are summarized in Table 28.

Table 28. Copco Dam outlet features

Outlet	Invert Elevation	Dimension	Operation
Penstock Intake (Unit 1)	2575 ft	Two, 10-foot diameter	Remote Operation
Penstock Intake (Unit 2)	2575 ft	14 foot diameter	Remote Operation
Spillway	2594 ft	3 radial gates @ 35 ft width each	Remote control on one gate, others by motorized hoist

Sources: PacifiCorp (2002), PacifiCorp (2000)

Reservoir Bathymetry

Reservoir geometry was derived from bathymetric data of Copco Reservoir provided by JC Headwaters. Segment length, segment orientation, layer thickness and width were required for the reservoir model. Segments were identified based on changes in the reservoir morphology and widths. The reservoir was divided into twenty active segments.

Segments varied in length from approximately 470 ft (roughly 140 m) to 2340 ft (roughly 715 m) . While capturing the general shape of Copco Reservoir, the segment layout also captured the some of the pertinent features of the reservoir such as the deep hole near the dam.

Cross sections were defined by roughly bisecting each segment and determining the depths as measured from river left to river right (looking downstream). These measurements were used to determine the number of active layers and the layer widths for each segment. The layer thickness used was 6.6 ft (2.0 m). There were sixteen active layers of varying widths determined from this method. The 6.6 ft (2.0 m) layer thickness produced reasonable results and the simulation time was approximately 10 minutes. The final CE-QUAL-W2 representation is shown in Figure 41, and the computed versus measured stage-volume relationships are compared in Figure 42.

The Manning's friction factor for each segment was assumed to be 0.04. A stage-volume curve was generated from the bathymetry data and compared to the measured stage-volume curve of the reservoir to ensure proper volume and storage representation.

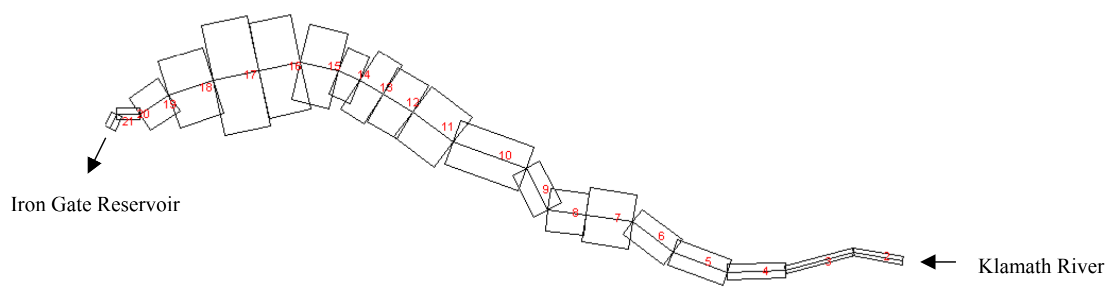


Figure 41. Representation of Copco Reservoir in CE-QUAL-W2

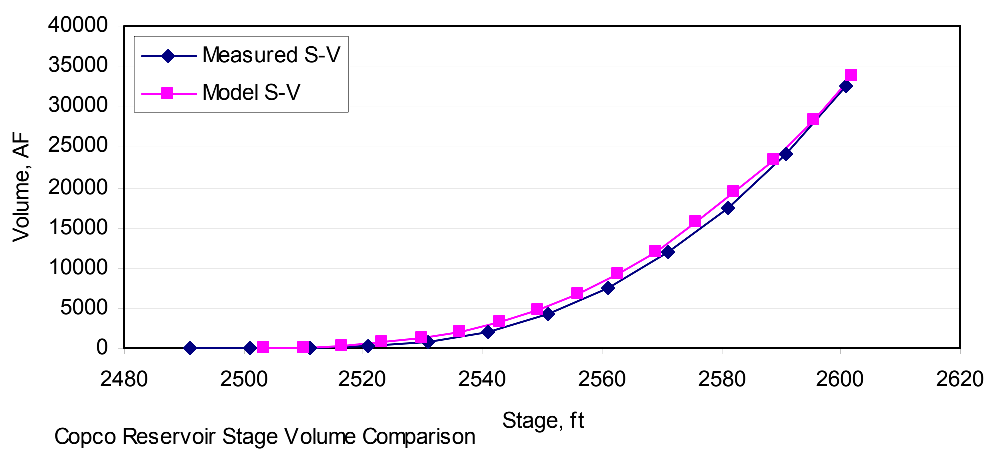


Figure 42. Comparison of measured and model representation of Copco Reservoir stage-volume (S-V) relationships

2.3.6.2 Flow Data

Klamath River Inflow and Accretion/Depletion

The hourly inflows for Copco Reservoir are represented as the sum of the inflow into the reservoir and the estimated accretion / depletion for the reservoir. The inflow into the reservoir used was the hourly flows from the Bypass-Peaking reach simulation (RMA-2 output: Node 453): there is no flow measurement station immediately above Copco Reservoir. The hourly accretion / depletion was calculated as sum of the daily change in storage in Copco and the daily average outflow from Copco, subtracting the daily average inflows from the Peaking Reach. Then a 7-day average accretion/depletion was calculated. This 7-day average accretion/depletion was expanded to hourly flows as a step function (no linear interpolation was used) and added Klamath River inflows. The total inflow rates are presented in Figure 43.

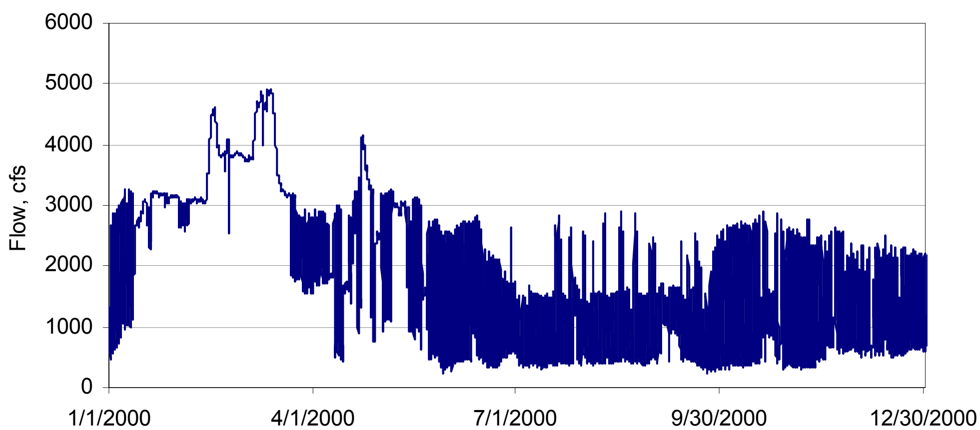


Figure 43. Copco inflow rates for Copco Reservoir reach model

Copco Dam Outflow

Hourly outflow for both the powerhouse and the spillway were available from PacifiCorp and were used as the Copco Reservoir outflow flows for model implementation. The two powerhouse units were treated as a single outlet, with a single elevation (2581.04 feet (786.70 meters)).

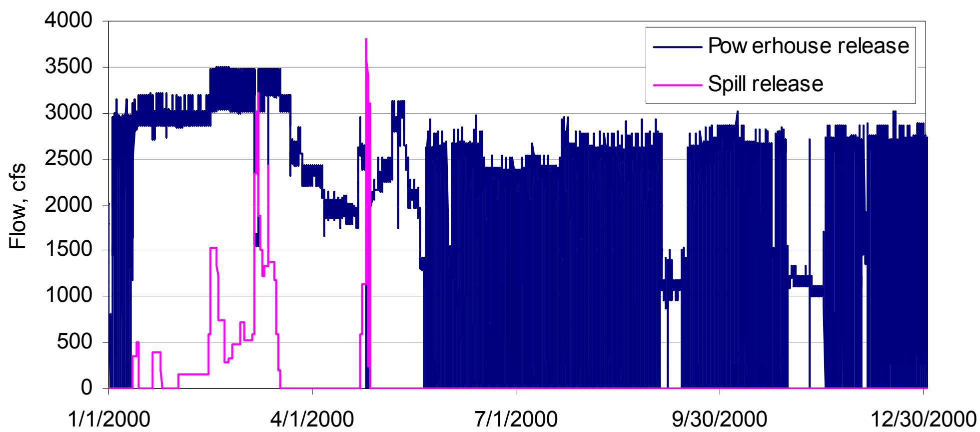


Figure 44. Copco Dam outflow for Copco Reservoir reach model

2.3.6.3 Water Quality Data

Temperature

Klamath River Inflow

Inflow temperatures for Copco Reservoir were the hourly temperatures from the Bypass-Peaking reach (RMA-11: Node 453).

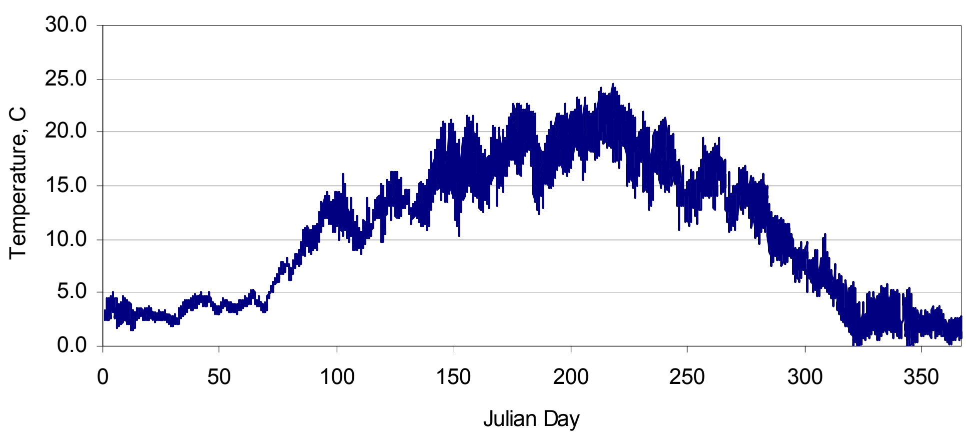


Figure 45. Inflow temperatures for Copco Reservoir reach model

Constituent Concentrations

Klamath River Inflow

For model implementation and application, the hourly constituent concentrations from the RMA-11 output file are used. Not all parameters modeled in CE-QUAL-W2 are modeled in RMA-11. Total dissolved solids, suspended solids, total inorganic carbon, and alkalinity are not represented in the river model. Labile dissolved organic matter (LDOM) was estimated from organic nitrogen and phosphorous concentrations output by RMA-11 by using the stoichiometric equivalence for the nitrogen and phosphorous partitioning in the CE-QUAL-W2 model parameter set and accounting for the algal component of organic nitrogen and phosphorus.

Suspended solids, iron, and tracer concentrations were set to reference levels (these parameters are included in the simulation, but are not used in assessment). Final input values are shown in Table 29.

Table 29. Inflow constituent concentrations for the Copco Reservoir model

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1.00	112.00	0.00	5.00	0.16	0.08	0.31	0.00	0.00	0.00	3.00	0.30	10.02	75.00	75.00
130.00	102.00	0.00	5.00	0.23	0.10	0.19	0.00	0.25	0.00	3.00	0.39	10.02	70.00	70.00
144.00	183.00	0.00	5.00	0.13	0.23	0.25	0.00	0.50	0.00	3.00	0.12	8.65	127.00	127.00
158.00	176.00	0.00	5.00	0.26	0.10	0.30	0.00	0.60	0.00	3.00	0.83	7.96	113.00	113.00
172.00	96.00	0.00	5.00	0.39	0.21	0.57	0.00	0.93	0.10	3.00	0.87	7.86	70.00	70.00
193.00	104.00	0.00	5.00	0.16	0.05	0.41	0.00	1.26	0.10	3.00	0.29	8.04	75.00	75.00
207.00	144.00	0.00	5.00	0.25	0.08	0.42	0.00	1.59	0.10	3.00	0.29	9.49	78.00	78.00
220.00	129.00	0.00	5.00	0.17	0.05	0.61	0.00	1.92	0.10	3.00	3.34	8.11	76.00	76.00
235.00	136.00	0.00	5.00	0.05	0.05	0.36	0.00	2.25	0.10	3.00	0.29	9.53	74.00	84.00
256.00	164.00	0.00	5.00	0.10	0.05	0.38	0.00	1.80	0.10	2.00	2.90	9.71	103.00	112.00
270.00	115.00	0.00	5.00	0.12	0.05	0.31	0.00	1.35	0.10	3.00	0.15	10.97	108.00	108.00
291.00	156.00	0.00	5.00	0.09	0.05	0.68	0.00	0.90	0.10	3.00	0.15	10.86	83.00	83.00
305.00	109.00	0.00	5.00	0.05	0.05	0.49	0.00	0.45	0.00	3.00	0.15	10.75	75.00	75.00
319.00	122.00	0.00	5.00	0.08	0.05	0.43	0.00	0.00	0.00	3.00	0.15	11.38	79.00	79.00
367.00	112.00	0.00	5.00	0.16	0.08	0.31	0.00	0.00	0.00	3.00	0.30	10.02	75.00	75.00

2.3.6.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10) and atmospheric pressure.

The meteorological data for the Copco Reservoir reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure is calculated within CE-QUAL-W2 (elevation of Copco Reservoir: 2607 ft (765 m)). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

Because Copco Reservoir is roughly 1500 feet lower than Klamath Falls, the air temperature was adjusted to accommodate for the change in elevation. A lapse rate of 3.0 °C, based on data from Klamath Falls and a meteorological station at Iron Gate Dam (see Appendix E). Air temperature was adjusted according to the following formula, based on Linacre (1992).

$$T_1 = T_2 + 0.003h$$

Where: T1 = temperature at site 1

T2 = temperature at site 2

h = $E_2 - E_1$, meters

E_1 = Elevation of site 1

E_2 = Elevation of site 2

For the purposes of this study an average elevation of Copco and Iron Gate Reservoirs was applied (2450 ft (746.8 m)). Based on a meteorological station at Copco Village, it was apparent that wind speed was moderated near the headwaters of Copco Reservoir. A second field season of data is being collected to better understand local conditions. For this effort the remaining meteorological parameters from the KFLO station were not modified.

2.3.7 Iron Gate Reservoir

The Iron Gate Reservoir reach extends from the headwaters of Iron Gate Reservoir to Iron Gate Dam. The small Copco #2 Reservoir and river reach between Copco and Iron Gate reservoirs are not represented in the modeling framework (the exception is the Without Project scenario, discussed in the application section). There are three tributaries represented in the Iron Gate Reservoir CE-QUAL-W2 applications: Camp Creek, Jenny Creek, and Fall Creek. The spillway for the dam is modeled as a withdrawal in the last active segment as the spillway structure draws water to the side of the dam, not over or through the dam. Also, due to the shape of the reservoir, two branches were created. Branch one is the main branch, and receives water from Klamath River (i.e., releases from Copco Reservoir). The Camp Creek arm of Iron Gate Reservoir is represented with a separate branch. The geometry, flow and water quality data, meteorological conditions and other model parameters are outlined below.

2.3.7.1 Reservoir Physical Data

Iron Gate Dam Features

Iron Gate Dam has four primary outlets: a spillway, penstock, and two fish hatchery intakes. The details of these outlets are summarized in Table 30.

Table 30. Iron Gate Dam outlet features

Outlet	Invert Elevation	Dimension	Operation
Upper Fish Hatchery	2293 ft	24 inch diameter	Manual
Penstock Intake	2309 ft	12 foot diameter	Remote operation
Lower Fish Hatchery	2253 ft	24 inch diameter	Manual
Spillway	2328 ft	Side channel (727 feet in length)	Overflow
Sources: PacifiCorp (2002), PacifiCorp (2000)			

Reservoir Bathymetry

Reservoir geometry was derived from bathymetric data of Iron Gate Reservoir provided by JC Headwaters. Segments were identified based on changes in the reservoir orientations and widths. Using this method, two branches were created. Branch 1 had twenty-six active segments and Branch 2 had four active segments. The segment length for the entire reservoir varies from approximately 121 ft (roughly 40 m) to approximately 1680 ft (roughly 510 m). Branch 2 had an external upstream boundary and ended at Branch 1 Segment 20 (Figure 46).

Once the segments were determined, each segment was roughly bisected and the changes in depth across each segment were measured from river left to river right (looking downstream). These measurements were used to determine the number of active layers and the layer widths for each segment. The layer thickness was 8.2 ft (2.5 m) and there were 18 active layers.

Also determined from the bathymetric map of Iron Gate Reservoir were the orientations of each segment. Segment length, segment orientation, layer thickness and width were all used to construct the bathymetry file. The Manning’s friction factor for each segment was assumed to be 0.04. A stage-volume curve was generated from the bathymetry data and adjusted to match the measured stage-volume curve of the reservoir (Figure 8).

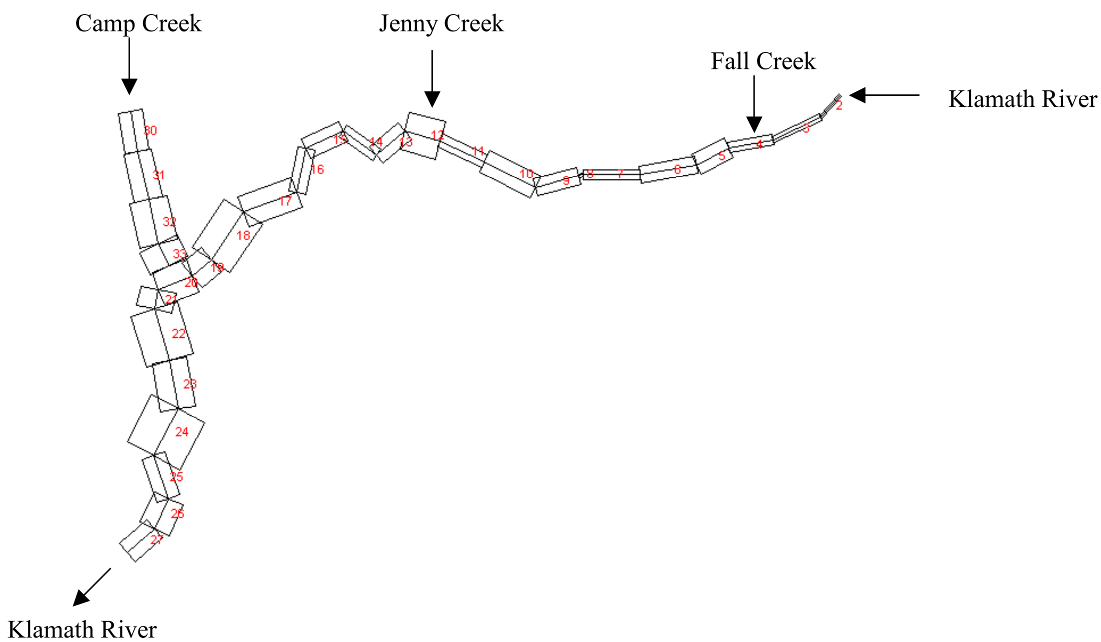


Figure 46. Representation of Iron Gate Reservoir for CE-QUAL-W2

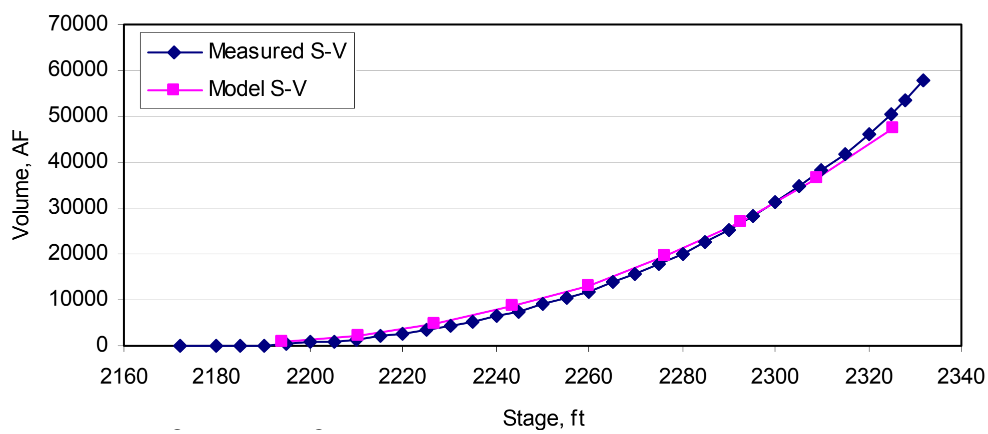


Figure 47. Comparison of measured and model representation of Iron Gate Reservoir stage-volume (S-V) relationships

2.3.7.2 Flow Data

Iron Gate Reservoir Inflow

There is no gage to measure flow into Iron Gate Reservoir; however, hourly flows from the Copco Reservoir were used as representative inflows. Hydropower peaking at Copco No. 1 and No. 2 results in periods when releases to the Klamath River downstream are insignificant. During these periods a flow of 0.035 cfs (0.001 cms) was assumed. The main inflows for Iron Gate Reservoir are presented in Figure 48.

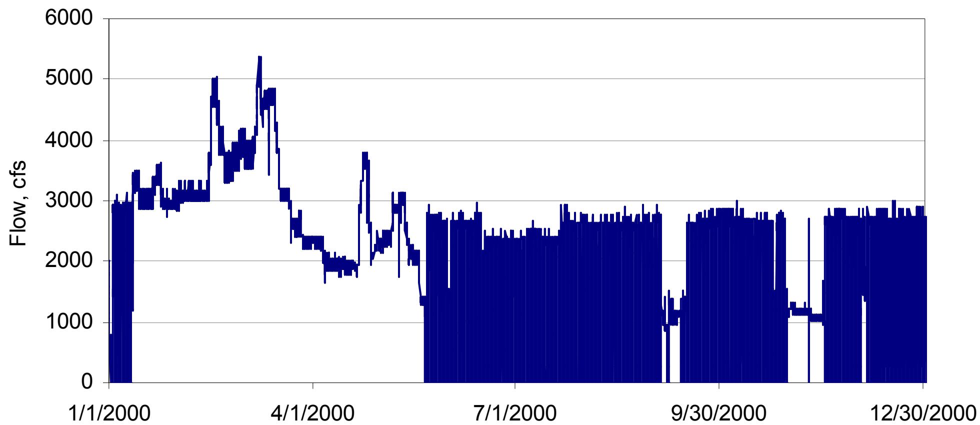


Figure 48. Main inflow rates for Iron Gate Reservoir reach model

Accretion/Depletion and Tributary Inflow

The hourly accretion/depletion was calculated as sum of the daily inflow to, outflow from, and change in storage in Iron Gate Reservoir. A 7-day running average accretion/depletion was determined from the daily values (Figure 49).

Because limited flow information was available for any of the creeks (Camp, Jenny, and Fall Creeks) flowing into Iron Gate Reservoir, the accretion/depletion was placed at Jenny Creek inflow location (Segment 12). Camp Creek (segment 10) and Fall Creek (segment 4) are active in the model, but flows are set to small numbers or zero, effectively rendering them insignificant. Camp Creek, because it is a branch inflow, was assigned a value of 0.0035 cfs (0.0001 cms) for the entire year. Fall Creek inflow was set to zero.

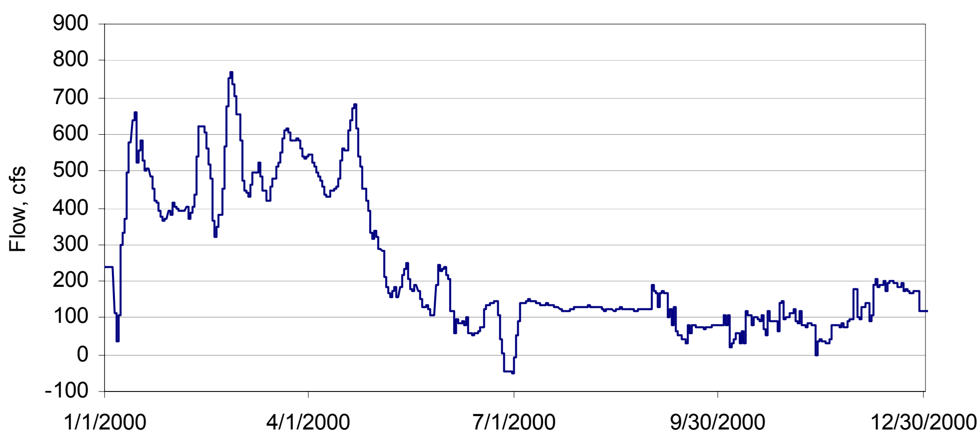


Figure 49. Accretion / depletion flow rates (placed at Jenny Creek) for Iron Gate Reservoir reach model

Iron Gate Dam Outflow

Outflow from Iron Gate Reservoir was determined from PacifiCorp daily flow records for the Powerhouse release and spill, and estimates of fish hatchery releases (presented in Figure 50). A constant flow of 50 cfs (1.42 cms) was assumed for the lower fish hatchery release. The upper fish hatchery release was assumed zero.

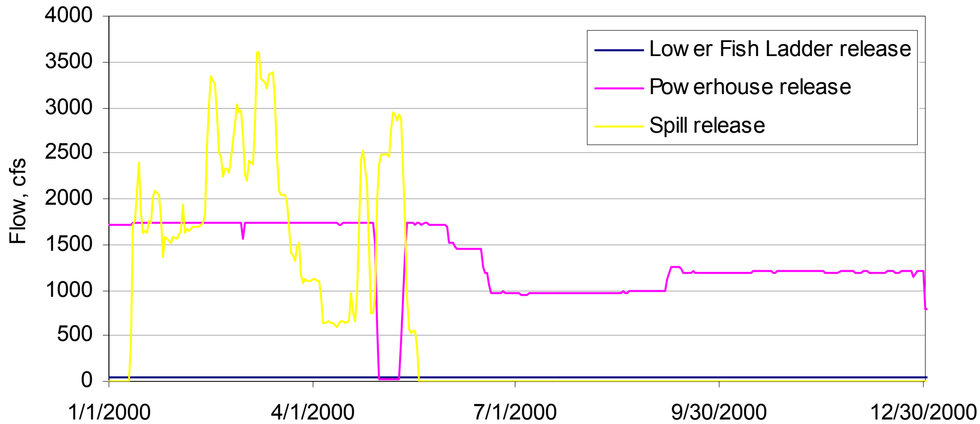


Figure 50. Iron Gate dam release for Iron Gate Reservoir reach model

2.3.7.3 Water Quality Data

Temperature

Copco Dam Inflow

Hourly Iron Gate Reservoir inflow temperatures were assigned based on simulated Copco Reservoir outflow values produced by CE-QUAL-W2. During off peak hours, the small inflow was assigned the water quality of the last time step there was a release from Copco. Inflow temperatures are presented in Figure 51.

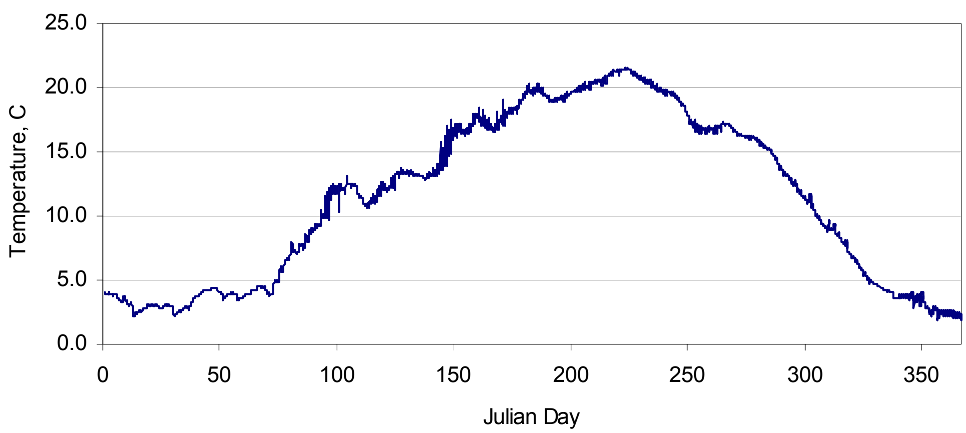


Figure 51. Main inflow temperatures for Iron Gate Reservoir reach model

Accretion/Depletion and Tributary Inflow Quality

The accretion/depletion for this reach was located at Jenny Creek. However, Jenny Creek has not been monitored for temperature historically. Water temperatures assigned to Jenny Creek flows were monthly estimated temperatures for Bogus Creek (located in the Iron Gate to Turwar reach) and are presented in Table 31. The same water temperature is assigned at Fall and Camp Creeks; however, because there are very small or no flows assigned at these tributaries, the impact is negligible.

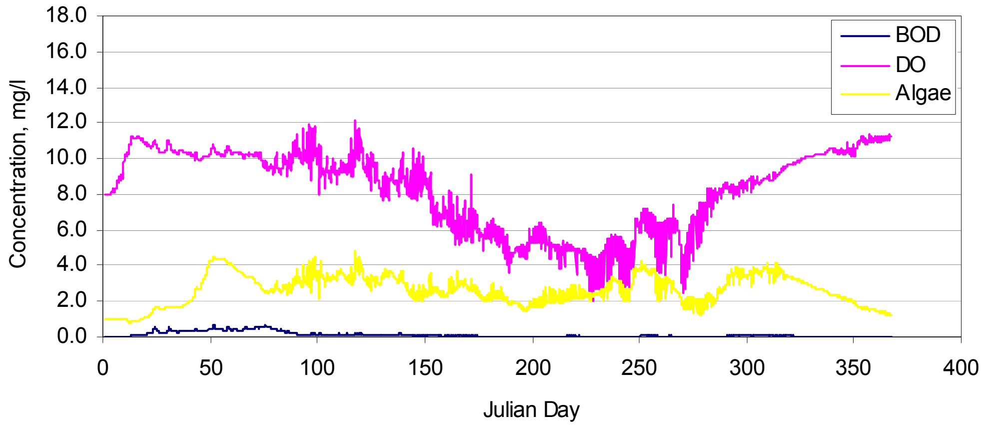
Table 31. Jenny Creek inflow temperatures for Iron Gate Reservoir reach model implementation

Julian Day	Inflow Temperature, ºC
1	0.13
15	0.19
46	0.52
75	3.39
106	7.79
136	12.43
167	12.76
197	14.06
228	14.5
259	12.43
289	8.31
320	2.87
350	0.06
366	0.13
367	0.13

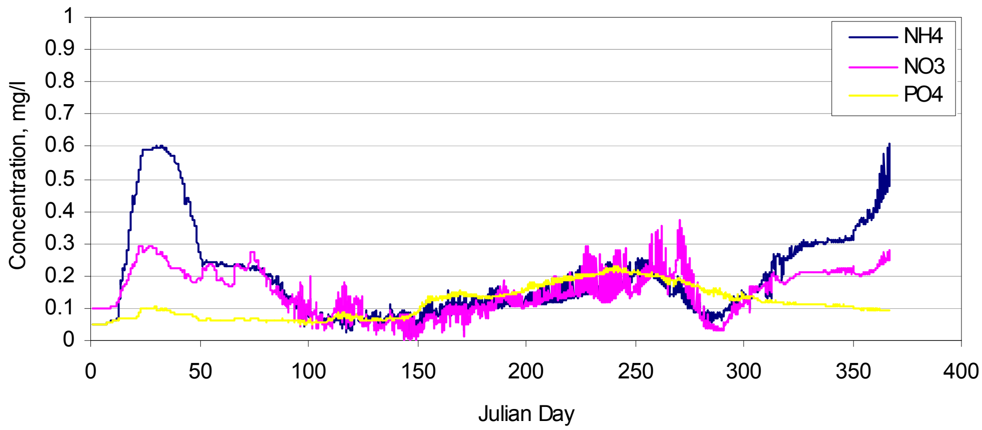
Constituent Concentrations

Copco Dam Inflow

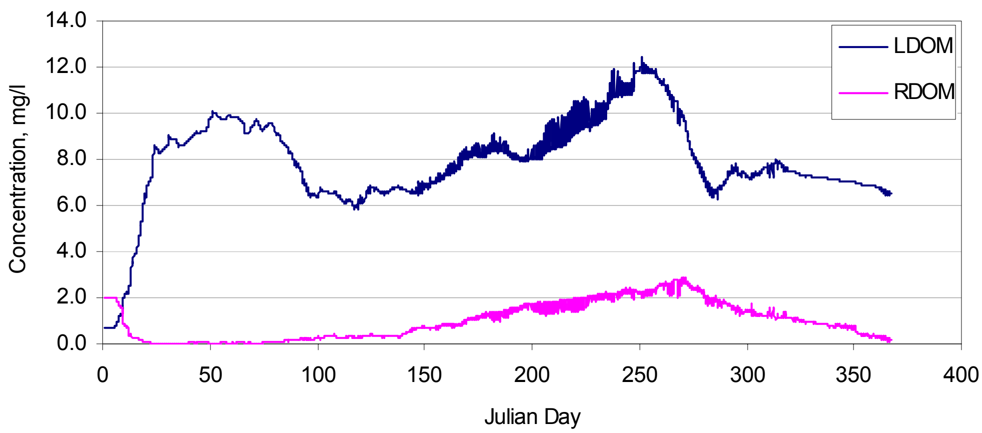
Hourly Iron Gate Reservoir inflow quality was assigned based on simulated Copco Reservoir outflow values produced by CE-QUAL-W2. During off peak hours, the small inflow was assigned the water quality of the last time step there was a release from Copco. Selected constituent concentrations are presented in Figure 52.



(a)



(b)



(c)

Figure 52. Selected main inflow constituent concentrations for Iron Gate Reservoir reach model

Accretion/Depletion and Tributary Inflow Quality

The accretion/depletion for this reach was located at Jenny Creek. Bogus Creek monthly estimated water quality was assigned to the accretion/depletion at Jenny Creek. The same water quality is assigned at Fall and Camp Creeks; however, because there are very small or no flows assigned at these tributaries, the impact is negligible. Estimated constituent concentrations for these boundary conditions are included in Table 32.

Table 32. Estimated constituent concentrations and temperature for the Iron Gate Reservoir accretion/ depletion located at Jenny Creek

Julian Day	Total Dissolved Solids	Inorganic Suspended Solids	Orthophosphate	Ammonia	Nitrate	Labile Dissolved Organic Matter	Refractory Dissolved Organic Matter	Labile Particulate Organic Matter	Refractory Particulate Organic Matter	Biological Oxygen Demand	Algal Biomass	Dissolved Oxygen	Total Inorganic Carbon	Total Alkalinity	Water Temperature
1	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	13.75	13.8	58	0.13
15	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	13.72	13.8	58	0.19
46	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	13.60	13.8	58	0.52
75	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	12.57	13.8	58	3.39
106	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	11.23	13.8	58	7.79
136	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	10.06	13.8	58	12.43
167	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	9.99	13.8	58	12.76
197	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	9.70	13.8	58	14.06
228	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	9.61	13.8	58	14.5
259	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	10.06	13.8	58	12.43
289	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	11.09	13.8	58	8.31
320	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	12.74	13.8	58	2.87
350	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	13.78	13.8	58	0.06
366	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	13.75	13.8	58	0.13
367	100	2	0.05	0.05	0.05	1.875	0	0	0	2	0.5	13.75	13.8	58	0.13

2.3.7.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10) and atmospheric pressure.

The meteorological data for the Iron Gate Reservoir reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure is calculated within CE-QUAL-W2 (elevation of Iron Gate Reservoir: 2,328 ft (710 m)). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

Because Iron Gate Reservoir is roughly 1700 feet lower than Klamath Falls, the air temperature was adjusted to accommodate for the change in elevation. A lapse rate of 3.0 °C, based on data from Klamath Falls and a meteorological station at Iron Gate Dam (see Appendix E). Air temperature was adjusted according to the following formula, based on Linacre (1992).

$$T_1 = T_2 + 0.003h$$

Where: T1 = temperature at site 1

T2 = temperature at site 2

h = $E_2 - E_1$, meters

E_1 = Elevation of site 1

E_2 = Elevation of site 2

For the purposes of this study an average elevation of Copco and Iron Gate Reservoirs was applied (2450 ft (746.77 m)). Field data did not suggest any additional relationships between the Klamath Falls and Iron Gate Reservoir site. Thus, the remaining meteorological parameters from the KFLO station were not modified.

2.3.8 Iron Gate Dam to Turwar

The Iron Gate Dam to Turwar reach extends from Iron Gate Dam to the mouth of the Klamath River. There are several main tributaries flowing into the reach: Shasta River, Scott River, Salmon River, and Trinity River. Several creeks are also included within the simulation. The geometry, flow and water quality data, meteorological conditions and other model parameters are outlined below.

2.3.8.1 River Physical Description

River Location

The x-y coordinates describing the river location were defined using a digitized version of the 1:24,000 USGS topographic quadrangles provided by CH2M Hill, as discussed in Appendix C. This information was translated into a network of nodes and elements for use by the numerical model (Figure 53). Important locations within the reach, i.e., those of boundary conditions or reporting / output locations, are presented in Table 33. Two model grids were developed for the reach, one with roughly 245-foot (75 meter) node spacing and one with 490 foot (150 meter) node spacing. The more refined model grid was constructed first and used for calibration and validation. When longer simulation periods were identified (e.g., months versus days), a coarser grid was constructed to reduce simulation times. Results from the two grids were compared and differences were negligible.

Table 33. Geometry information for the IG-Turwar reach (150 meter grid)

Location	Node	Element	x-coord	y-coord	Site type	Inflow Angle, Radians [a]
Iron Gate Dam	1	1	146.747	142.634	BC, upper	4.040
End IG-Turwar reach	2081	1040	9.821	99.506	BC, lower	-
Bogus Creek	7	4	146.141	142.022	A/D	-
Willow Creek	55	28	142.035	138.739	A/D	-
Cottonwood Creek	86	43	137.904	137.535	A/D	-
Shasta River	144	72	133.963	131.178	A/D	-
Humbug Creek	204	102	127.848	131.402	A/D	-
Beaver Creek	319	160	115.190	135.232	A/D	-
Horse Creek	468	234	99.597	130.180	A/D	-
Scott River	513	257	97.299	125.428	A/D	-
Grider Creek (A/D Scott to Seiad)	656	328	82.714	132.246	A/D	-
Thompson Creek	735	368	74.440	134.626	A/D	-
Indian Creek	906	453	69.371	126.831	A/D	-
Elk Creek	925	463	67.209	125.507	A/D	-
Clear Creek	1000	500	62.733	117.818	A/D	-
Ukonom Creek	1098	549	59.559	107.347	A/D	-
Dillon Creek	1162	581	55.209	102.905	A/D	-
Salmon River	1357	679	58.333	81.788	A/D	-
Camp Creek	1466	733	52.865	71.474	A/D	-
Red Cap Creek	1511	756	49.403	67.773	A/D	-
Bluff Creek	1547	774	45.339	65.584	A/D	-
Trinity River	1609	805	41.415	59.672	A/D	-
Pine Creek	1644	822	36.954	61.269	A/D	-
Tectah Creek	1850	925	24.557	79.833	A/D	-
Blue Creek	1908	954	22.306	86.220	A/D	-
1/4 mi bl Iron Gate	4	2	146.419	142.345	reporting	-
1/4 mi ab Cottonwood	84	42	138.117	137.743	reporting	-
1/4 mi ab Shasta	142	71	134.262	131.198	reporting	-
Walker Bridge	369	185	111.329	131.759	reporting	-
1/4 mi ab Scott	511	256	97.348	125.720	reporting	-
USGS Gage at Seiad Valley	672	336	80.887	133.289	reporting	-
1/4 mi ab Clear Cr.	998	499	62.908	118.058	reporting	-
1/2 mi ab Salmon (Ishi Pishi)	1352	676	58.231	82.372	reporting	-
USGS Gage at Orleans	1454	727	54.016	71.457	reporting	-
1/4 mi ab Bluff Cr.	1545	773	45.357	65.876	reporting	-
1/4 mi ab Trinity	1607	804	41.692	59.692	reporting	-
Martin's Ferry	1651	826	36.505	62.187	reporting	-
Young's Bar	1722	861	31.541	69.894	reporting	-
1/4 mi ab Blue Cr.	1906	953	22.177	85.992	reporting	-
USGS Gage nr Turwar	2024	1012	16.341	96.868	reporting	-

[a] : Radians are measured counter-clockwise from due east

River Width

Klamath River widths from Iron Gate Dam to Turwar were estimated from Meso-habitat surveys completed by US Fish and Wildlife Service. This data set included a reach by reach description of habitat unit type, width, and maximum depth (a total of 1741 units). These measurements were not uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were assigned to the nearest x-y coordinate. Trapezoidal river cross sections were constructed at evenly spaced intervals of 75 meters. Side slopes were assumed to be 1:1 and river width was based on a seven times running average of measured widths.

River Bed Elevation

Bed slope for the reach was estimated from USGS topographic maps and known elevations at Iron Gate Dam. Reach elevations range from approximately sea level to roughly 2200 ft msl (671 m). Elevations were estimated from land surface topographic contours and do not represent the river bed elevations.

Table 34. Klamath River, Iron Gate Dam to Turwar Reach geometry summary

Node spacing	75 meters/150 meters
Number of nodes	2082 nodes/4161 nodes in length
Length	190.54 miles from RM0.00-190.54
Elevations	Range: 0-671 meters
Widths	Range: 29- meters
Side slopes	1:1
Data sources	UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps.
Notes	n/a

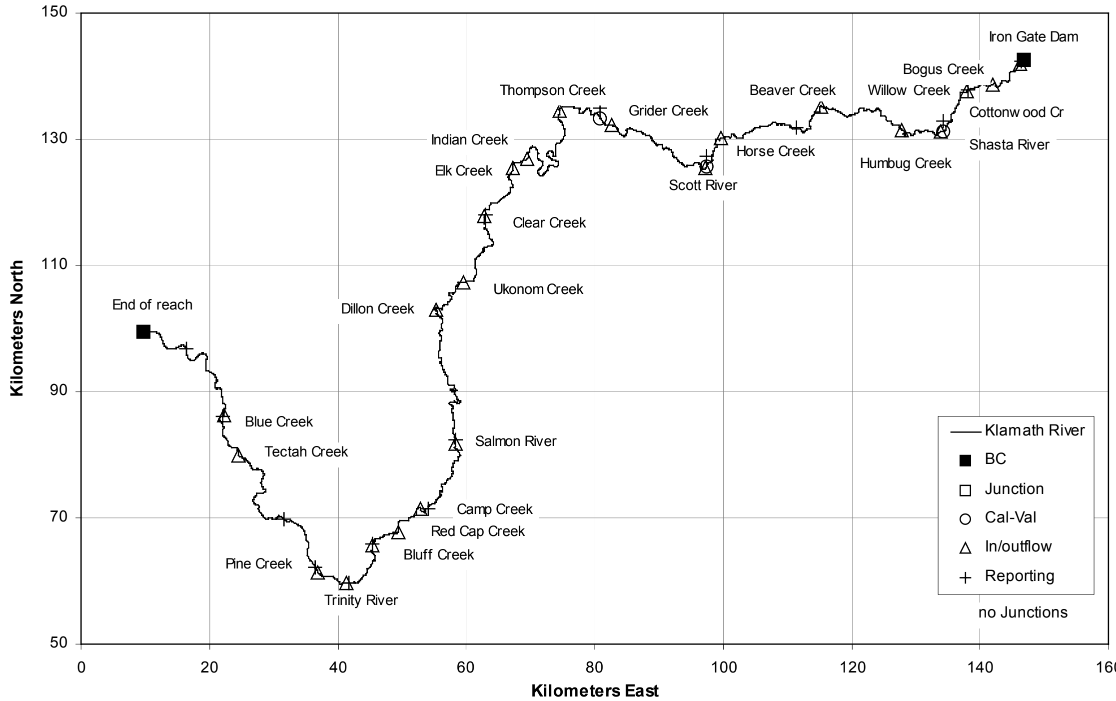


Figure 53. Iron Gate Dam to Turwar reach representation showing tributary names

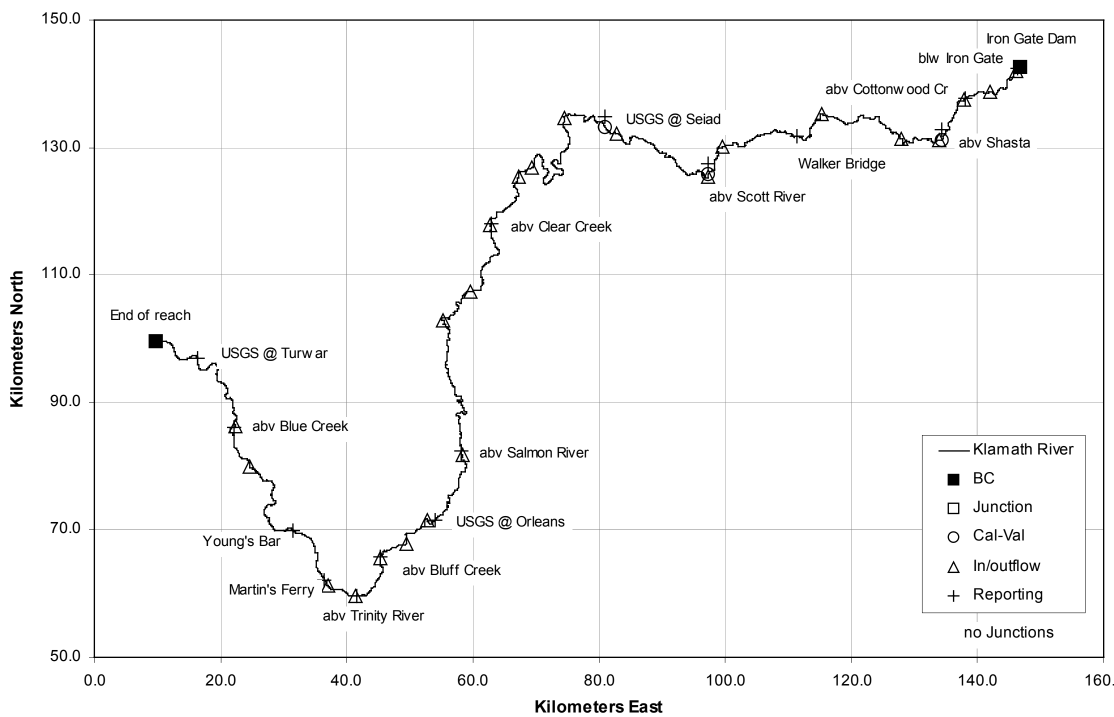


Figure 54. Iron Gate Dam to Turwar reach representation showing reporting location names

2.3.8.2 Flow Data

Inflows

The Iron Gate Dam to Turwar reach includes 23 inflows in addition to the headwater boundary condition at Iron Gate Dam. Measured releases from Iron Gate during the 2000 calendar year as provided by PacifiCorp were used to designate operations (presented in Figure 55).

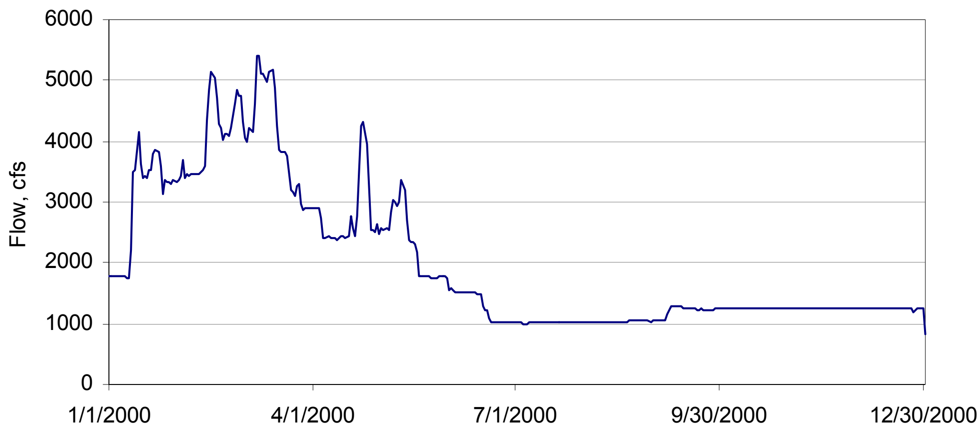


Figure 55. Iron Gate Dam release rates for Iron Gate to Turwar reach model

Observed field data were used for those tributaries that are actively gauged, including the Shasta, Scott, Salmon, and Trinity Rivers, and Indian Creek. The inflows for minor tributaries were defined and quantified based on USGS (1995). The details of the USGS methodology are included in Appendix D. All tributaries in this reach are treated as element inflows.

Element flows (ELM)

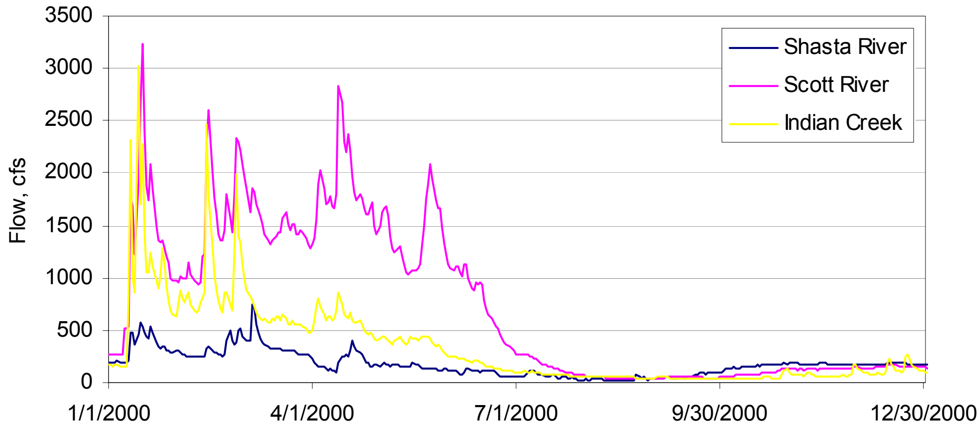
There are 23 element flows in the IG-Turwar reach. Tributary contributions were assigned daily data based on USGS gages or 7-day average flows based on accretion calculations. Table 35 summarizes the locations, model node and element information, and type of record employed.

Table 35. Element flow information for the IG-Turwar EC simulation

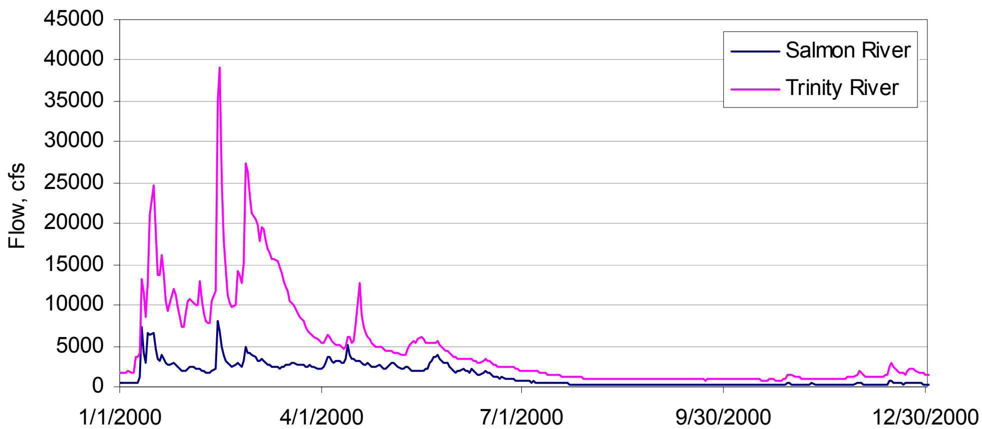
Location	Node	Element	Flow Type
Bogus Creek	7	4	7 day average
Willow Creek	55	28	7 day average
Cottonwood Creek	86	43	7 day average
Shasta River	144	72	Daily measured
Humbug Creek	204	102	7 day average
Beaver Creek	319	160	7 day average
Horse Creek	468	234	7 day average
Scott River (+ A/D Ft. Jones to Klamath)	513	257	Daily calculated
Grider Creek (A/D Scott to Seiad)	656	328	7 day average
Thompson Creek	735	368	7 day average
Indian Creek	906	453	Daily measured
Elk Creek	925	463	7 day average
Clear Creek	1000	500	7 day average
Ukonom Creek	1098	549	7 day average
Dillon Creek	1162	581	7 day average
Salmon River	1357	679	Daily measured
Camp Creek	1466	733	7 day average
Red Cap Creek	1511	756	7 day average
Bluff Creek	1547	774	7 day average
Trinity River (+ A/D Hoopa to Klamath)	1609	805	Daily calculated
Pine Creek	1644	822	7 day average
Tectah Creek	1850	925	7 day average
Blue Creek	1908	954	7 day average

The Shasta River daily flows were from USGS gage 11517500. The Scott + A/D daily flows were calculated from USGS gage 11519500 (Scott River daily flows) and A/D described in Appendix D. The daily Indian Creek flows were from USGS gage 11521500. The Salmon River daily flows were from USGS gage 11522500. The Trinity + A/D daily flows were calculated from USGS gage 11530000 (Trinity River daily flows) and the A/D described below.

The 7 day accretion / depletion calculations are described in Appendix D. Daily A/D flows were calculated and then averaged over 7 days, except for the Scott River and Trinity River A/D, which were added to their respective river daily flows. The daily inflows are presented in Figure 56. The 7 day average inflows are presented in Figure 57.



(a)



(b)

Figure 56. Major tributary inflows for Iron Gate to Turwar reach model: (a) Shasta River, Scott River and Indian Creek; (b) Salmon River and Trinity River

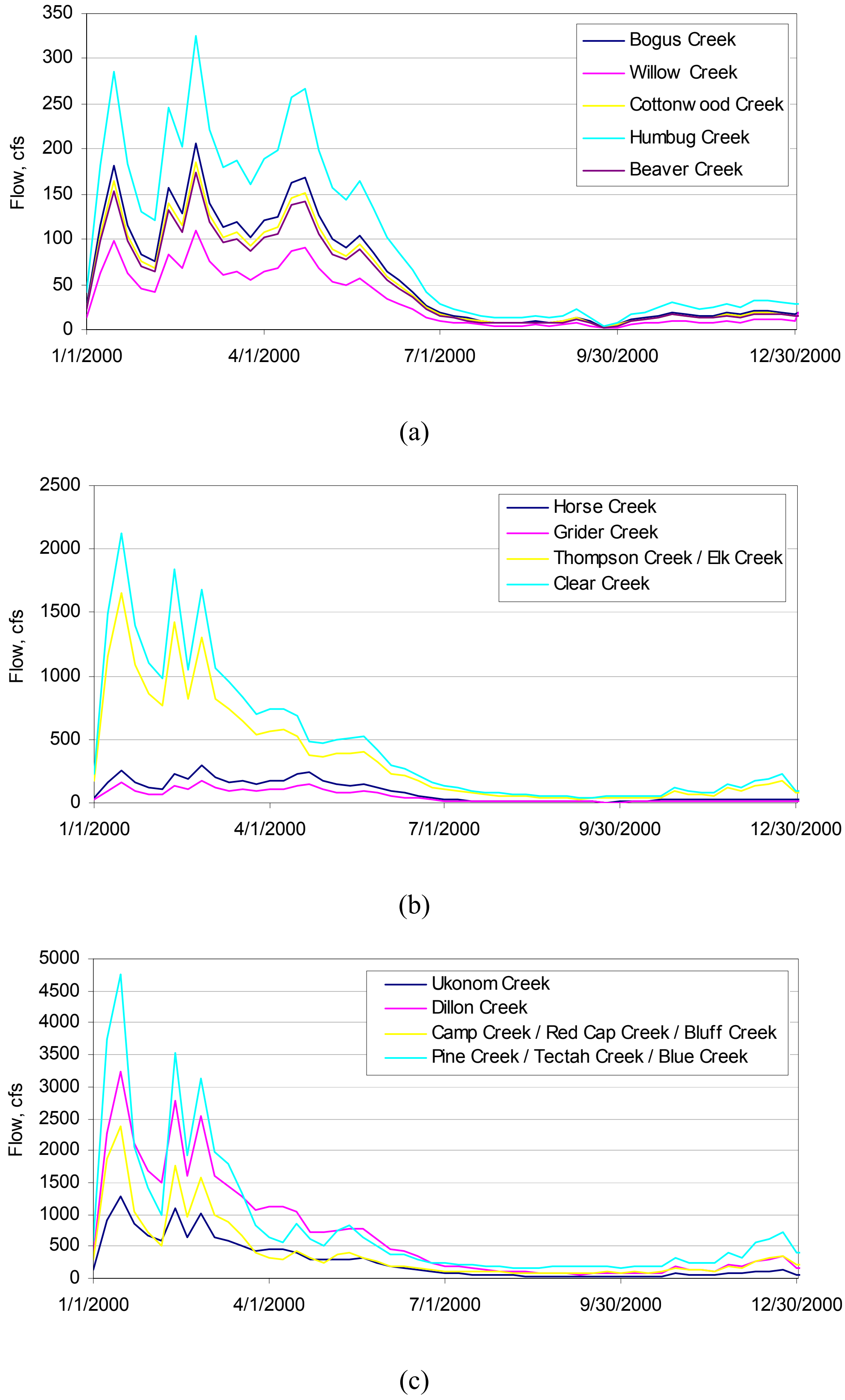


Figure 57. Minor tributary inflows for Iron Gate to Turwar reach model

Downstream Boundary Condition

The downstream boundary for the model is placed at River Mile (RM) 0. There is tidal influence at Turwar (RM 5), but this dynamic condition is neglected in the model application. Instead a stage-discharge boundary condition of the form

$$Q = A_1 + A_2(E - E_o)^C$$

is applied, where

Q = flow rate (m^3/s)

A_1 = 0.0

A_2 = 39.481

E = simulated water surface elevation (representing depth) (m)

E_o = water surface elevation datum (m)

C = 2.2974

The coefficients for the stage discharge relationship were derived from the rating curve available for the Klamath River at Turwar USGS gage (15530500) corrected for tidal influence.

2.3.8.3 Water Quality Data

Temperature

Tributary water temperature data for calendar year 2000 in the Iron Gate Dam to Turwar reach were largely unavailable, with the exception of major tributaries, including the Shasta, Scott, Salmon, and Trinity Rivers. However, even these records exhibited significant data gaps. Inflow temperatures for the upstream boundary condition include simulated hourly temperatures in the Iron Gate Reservoir (shown in Figure 58). The source of records and final model inputs for major and minor tributaries are outlined below.

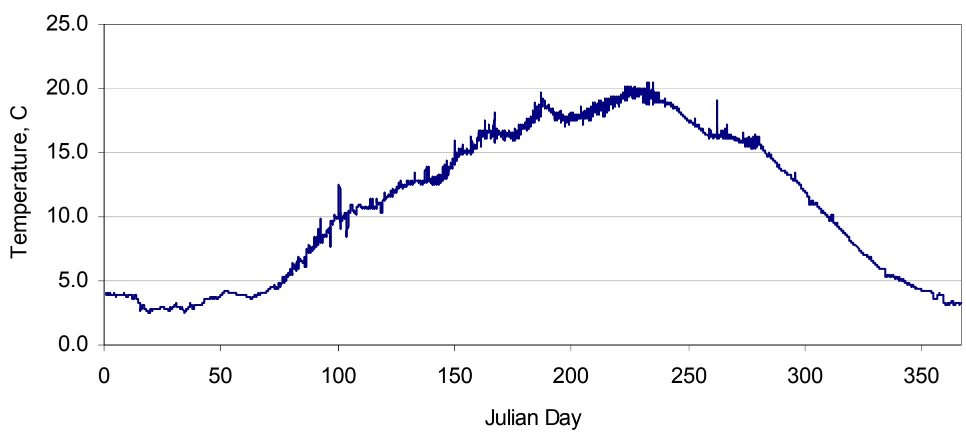


Figure 58. Main inflow temperatures for Iron Gate to Turwar reach model

Major Tributaries

A complete water temperature record for the Shasta River during 2000 was not available. Thus, hourly temperatures were represented with a composite records constructed from multiple sources (presented in Figure 59). Data from USBR (2003) was used from 3/22/00 – through 11/6/00, while California Department of Fish and Game (Shasta River at Mouth temperatures) data was used from 1/1/01 to 3/23/01 and 11/6/00 to 12/31/00.

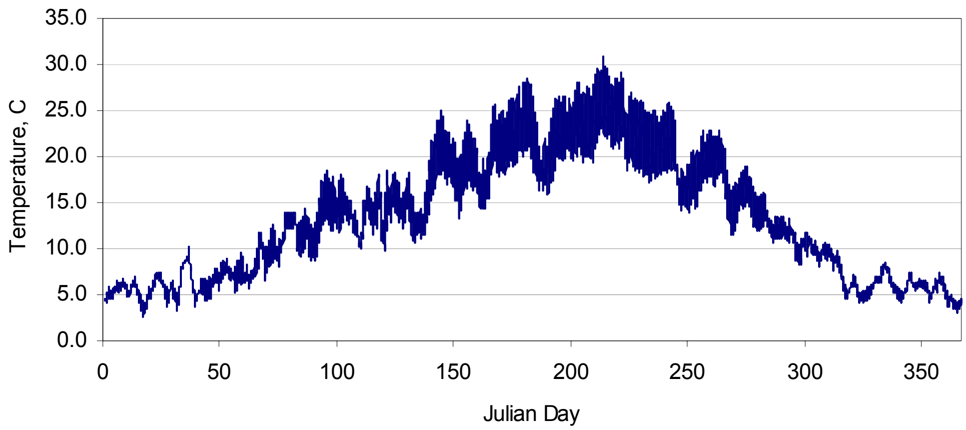


Figure 59. Shasta River inflow temperatures for Iron Gate to Turwar reach model

Scott River hourly temperatures were derived primarily from a datasonde deployed at the mouth of the Scott River from March through November 2000 by USBR. However, there were some gaps in that data. These data gaps were filled with data from the Shasta River composite temperatures that was corrected to match the existing Scott River temperatures. The Scott River composite temperature record is presented in Figure 60.

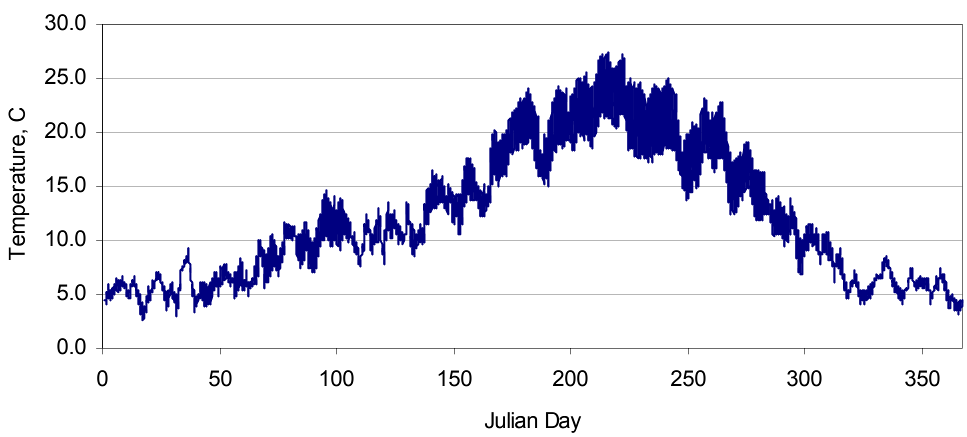


Figure 60. Scott River inflow temperatures for Iron Gate to Turwar reach model

Salmon River was assigned hourly temperatures from a composite (presented in Figure 61). Some 2000 data was available for the Salmon River from USBR. The composite was made of 3/22/00 - 4/13/00, 5/2/00 - 5/22/00, and 5/30/00 - 11/13/00 Salmon River temperatures and 1/1/00 - 3/22/00, 5/22/00 - 5/30/00 and 11/13/00 - 12/31/00 Trinity River temperatures.

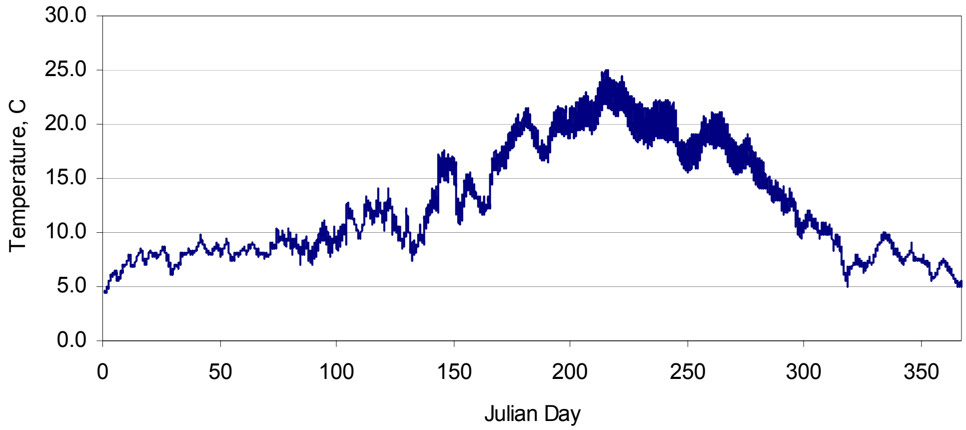


Figure 61. Salmon River inflow temperatures for Iron Gate to Turwar reach model

The Trinity River hourly water temperatures (presented in Figure 62) were obtained from the California Department of Water Resources, California Data Exchange Center (CDEC): site name for Trinity River at Hoopa (HPA).

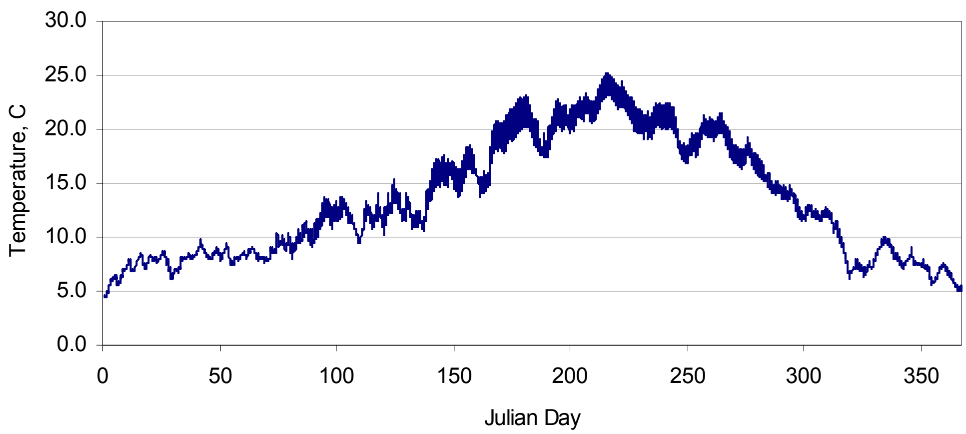


Figure 62. Trinity River inflow temperatures for Iron Gate to Turwar reach model

<u>Minor Tributaries</u>

The tributary water temperatures were based on hourly (generally) data collected by U.S. Forest Service (USFS) between 1994 and 2001. The exception was Blue Creek data which was supplied by the Yurok Tribe. The USFS temperature.mdb database contains all of the stream temperature records available in the Klamath National Forest stream temperature database, as of Oct. 17, 2002. This includes almost 650,000 individual stream records total. Generally, the USFS monitoring efforts did not provide long-term data sets at any one location, but rather several locations were monitored for intermittent periods. To provide representative temperature for the various tributaries composite hourly temperature traces were identified for each creek. These composite data sets were used to calculate monthly average temperatures for each tributary. Certain tributaries lacked data or provided little summer time flow volume and thus were not assigned a water temperature at this time. A brief discussion of each inflow temperature for tributary is outlined below and the monthly temperatures are presented in Table 36.

Bogus Creek had no temperature data available. Shovel Creek composite monthly temperatures were used for Bogus Creek. Shovel Creek composite monthly temperatures were estimated as follows. No winter data for Shovel Creek was available. No 2000 data was available. Observed 2001 hourly temperatures (available for 5/9/01 to 10/15/01) were filled with composite Spencer Creek hourly data. Composite Shovel Creek hourly data was then aggregated to daily and then to monthly averages.

Willow, Cottonwood, and Humbug Creeks were not assigned temperatures.

Beaver Creek: No 2000 data was available. A composite temperature record was made of 6/30/99 - 9/13/99 Beaver Creek daily temperatures, and 1/1 - 6/29 and 9/14 - 12/31 composite Elk Creek daily temperatures, and then aggregated to monthly average temperatures.

Horse Creek: No 2000 data was available. A composite temperature record was made of 7/1/99 - 9/14/99 Horse Creek daily temperatures and 1/1 - 6/30 and 9/15 - 12/31 composite Elk Creek daily temperatures, and then aggregated to monthly average temperatures.

Grider Creek: Only summer 2000 temperatures were available for Grider Creek. A composite temperature record was made of 7/1/00 - 10/13/00 Grider Creek daily temperatures, and 1/1 - 6/29 and 10/14 - 12/31 composite Elk Creek daily temperatures. Elk Creek temperatures were used because both creeks had sources in the Marble Mountains. The daily composite Grider Creek temperature record was aggregated to monthly average temperatures.

Thompson Creek: No 2000 data was available. An incomplete record available was for 2001. After comparing the existing Thompson Creek data to other creeks' records, Blue Creek 2000 temperatures were chosen because the small amount of existing Thompson Creek temperature record matched the 2000 Blue Creek temperatures. The composite Thompson Creek temperatures were aggregated to monthly average temperatures.

Blue Creek: Only summer 2000 temperatures were available for Indian Creek. A composite temperature record was made up of 7/1/00 - 9/27/00 Indian Creek daily temperatures, and 1/1 - 6/30 and 9/28 - 12/31 composite Clear Creek daily temperatures. Clear Creek temperatures were used because the sources for both creeks are adjacent to each other in the Siskiyou Mountains. The composite Indian creek daily temperatures were aggregated to monthly average temperatures.

Elk Creek: Only summer 2000 temperatures were available for Elk Creek. However, there were other years available. A composite temperature record was made up of 1/1/93 - 6/30/93, 7/1/00 - 10/3/00 and 10/4/93 - 12/31/93 Elk Creek daily temperatures. The composite Elk Creek data was aggregated to monthly average temperatures.

Clear Creek: No 2000 temperature data was available for Clear Creek near the mouth. A composite temperature record was made of 1993 Clear Creek daily temperatures, which were aggregated to monthly average temperatures.

Ukonom Creek: No 2000 temperature data was available. A composite temperature record was made of 1993 Ukomon Creek daily temperatures, which were aggregated to monthly average temperatures.

Dillon Creek: No 2000 temperature data was available. A composite temperature record was made of 1/1/94 - 9/30/94 and 10/1/92 - 12/31/92 Dillon Creek daily temperatures, which were aggregated to monthly average temperatures.

Camp Creek: No 2000 temperature data was available. A composite temperature record was made up of 2000 Blue Creek daily temperatures. Blue Creek temperatures were chosen because the existing record for Camp Creek matched the 2000 record for Blue Creek. The composite Camp creek daily temperatures were aggregated to monthly average temperatures.

Red Cap Creek: No 2000 temperature data was available. A composite temperature record was made of 1/1 - 7/30 composite Dillon Creek daily temperatures, and 7/31/92 - 12/31/92 Red Cap Creek daily temperatures. Dillon Creek temperatures were chosen because the two creeks are somewhat adjacent to each other and their sources share the same approximate elevation. The composite Red Cap Creek daily temperatures were aggregated to monthly average temperatures.

Bluff Creek: There was no temperature data available for Bluff Creek. A composite temperature record for Bluff Creek was created using Blue Creek daily temperatures. Blue Creek temperatures were chosen because they were a complete record. The composite daily Bluff Creek temperatures were aggregated to monthly average temperatures.

Pine Creek: There was no temperature data available for Pine Creek. A composite temperature record for Pine Creek was created using Blue Creek daily temperatures. Blue Creek temperatures were chosen because they were a complete record. The composite daily Pine Creek temperatures were aggregated to monthly average temperatures.

Tectah Creek: Some 2000 data was available. A composite temperature record was made of 4/29/00 - 9/15/00 Tectah Creek daily temperatures and 1/1 - 4/28 and 9/16 - 12/31 Blue Creek daily temperatures. The composite daily Tectah Creek temperatures were aggregated to monthly average temperatures.

Blue Creek: Blue Creek had daily temperatures available for 2000. No composite record was necessary. The daily Blue Creek temperatures were aggregated to monthly average temperatures.

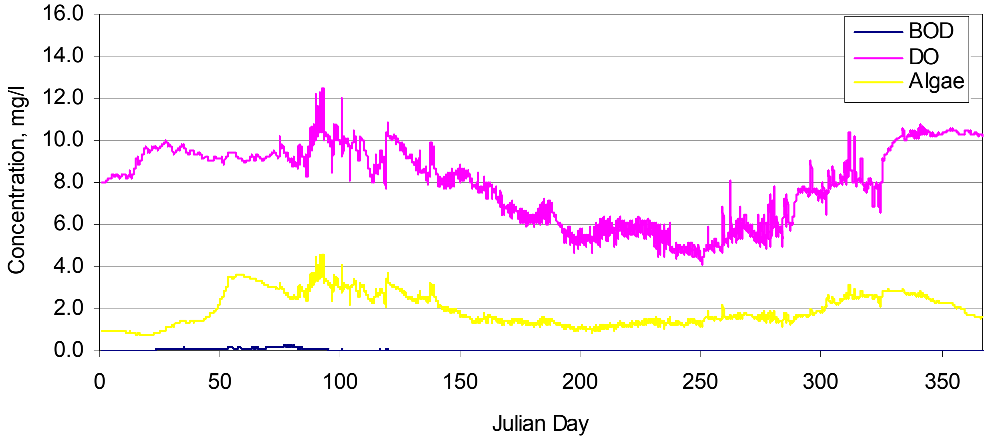
Table 36. Minor tributary inflow temperatures for Iron Gate to Turwar reach model

	Temperature, ºC														
JDAY	1	15	46	75	106	136	167	197	228	259	289	320	350	366	367
Bogus Creek	0.13	0.19	0.52	3.39	7.79	12.43	12.76	14.06	14.50	12.43	8.31	2.87	0.06	0.13	0.13
Beaver Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.16	14.03	15.55	14.31	11.09	4.79	4.04	4.00	4.00
Horse Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	13.13	14.08	13.64	11.09	4.79	4.04	4.00	4.00
Grider Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	16.31	16.82	13.95	10.80	4.79	4.04	4.00	4.00
Thompson Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Indian Creek	5.00	5.11	5.55	6.76	7.33	8.74	11.61	16.88	18.41	15.69	12.08	5.74	4.60	5.00	5.00
Elk Creek	4.00	4.25	4.85	6.98	7.79	8.68	11.09	17.62	18.15	14.95	11.09	4.79	4.04	4.00	4.00
Clear Creek	5.00	5.13	5.50	6.95	7.39	8.76	11.96	15.78	17.29	15.06	11.83	5.45	4.56	5.00	5.00
Ukonom Creek	5.00	5.05	5.26	6.74	7.38	8.17	10.71	13.05	13.95	12.37	10.66	5.52	4.88	5.00	5.00
Dillon Creek	5.00	6.93	6.19	7.67	9.52	12.46	15.49	20.21	18.58	16.92	11.80	7.63	4.93	5.00	5.00
Camp Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Red Cap Creek	6.50	6.93	6.19	7.67	9.52	12.46	15.49	20.30	19.37	16.62	13.06	9.22	6.23	6.50	6.50
Bluff Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Pine Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89
Tectah Creek	7.90	7.76	8.26	8.18	9.94	10.02	12.51	13.73	14.10	14.48	13.50	9.98	8.03	7.90	7.90
Blue Creek	7.89	7.76	8.25	8.23	10.00	10.96	14.10	15.37	16.79	15.79	13.35	9.91	8.01	7.89	7.89

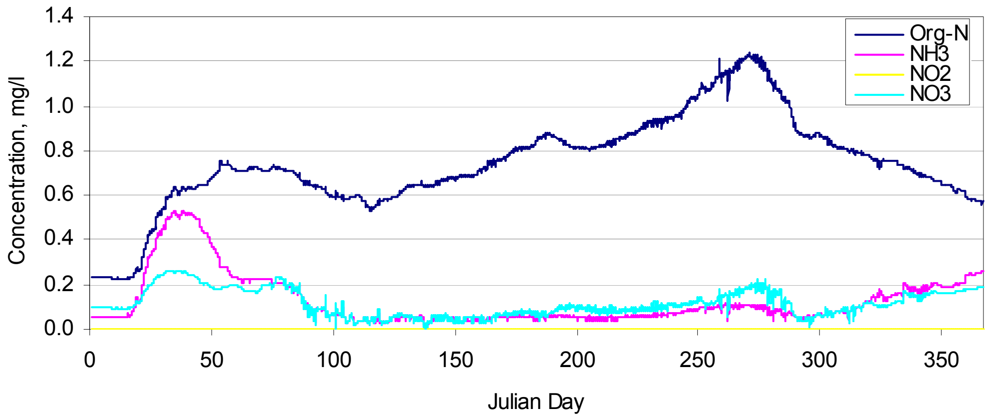
Constituent Concentrations

Constituent concentrations for the tributary inflows between Iron Gate Dam and the Pacific Ocean were assigned for all streams identified in Table 35 with the exception of Willow, Cottonwood, and Humbug Creeks. There was not data available for these tributaries and they contribute only minor flow in the summer months.

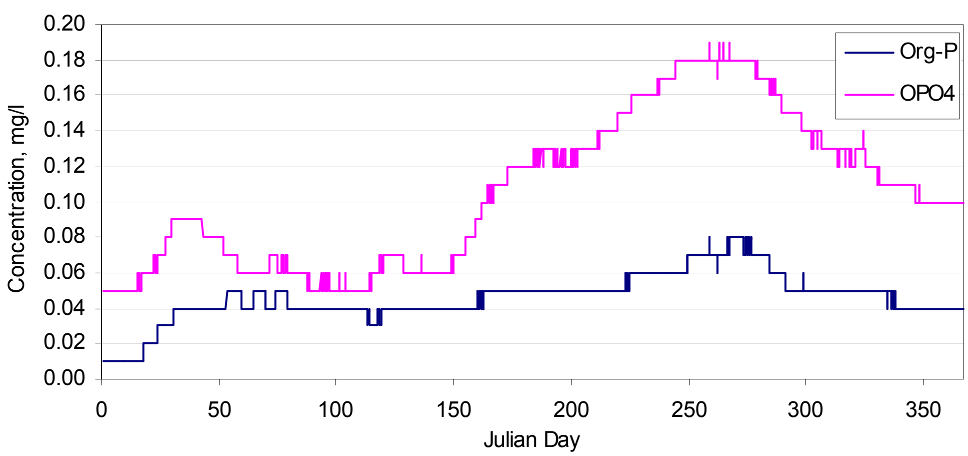
Constituent concentrations for the upstream boundary condition were provided by the Iron Gate Reservoir CE-QUAL-W2 simulation, and passed to the Iron Gate to Turwar reach in the manner described for the Keno reach. Constituent concentrations for the main inflow for Iron Gate to Turwar reach are presented in Figure 63.



(a)



(b)



(c)

Figure 63. Main inflow constituent concentrations for Iron Gate to Turwar reach model: (a) BOD, dissolved oxygen and algae; (b) nitrogen forms; (c) phosphorus forms

Dissolved oxygen at all tributaries was estimated assuming 100 percent saturated conditions. This assumption is based on most of these streams reach the Klamath River after flowing

- through step canyon reaches that are several miles long
- through watersheds that have little or no water resources development and/or
- through watersheds where organic loads and other oxygen demanding processes are minimal.

Review of available data (USBR, 2003) indicates this is a reasonable assumption for modeling applications. However, any diurnal variations due to primary production are not represented.

Dissolved oxygen concentrations were based on the hourly (Shasta, Scott, Salmon, and Trinity Rivers) or monthly (all remaining tributaries) temperature data identified above and atmospheric pressure corrected for elevation. Hourly dissolved oxygen concentrations are presented in Figure 64 through Figure 67. Monthly dissolved oxygen concentrations are presented in Table 37. Because the atmospheric correction through the study reach was small, average elevations for three sub-reaches were used in the calculation. The average elevation from Iron Gate Dam to the USGS Gage at Seiad Valley (1759.9 ft (536.4 m)) was used to correct atmospheric pressure for all tributaries within that reach. Likewise, the average elevation for USGS Gage at Seiad Valley to Trinity River reach (810.0 ft (246.9 m)) and from the Trinity River to the end of the IG-Turwar reach (150.0 ft (45.7 m)) were used to correct atmospheric pressure for all tributaries within those reaches. The methodology for dissolved oxygen saturation calculation and atmospheric pressure correction are included in Appendix F.

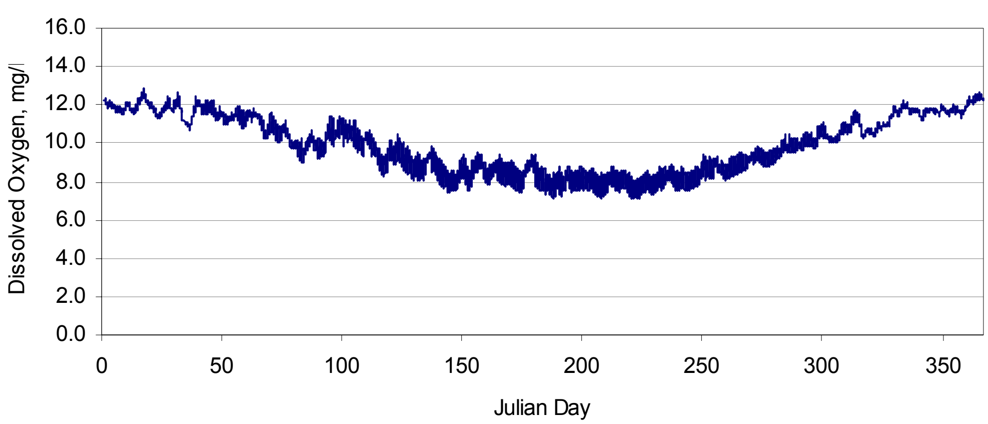


Figure 64. Shasta River inflow dissolved oxygen concentrations for Iron Gate to Turwar reach model

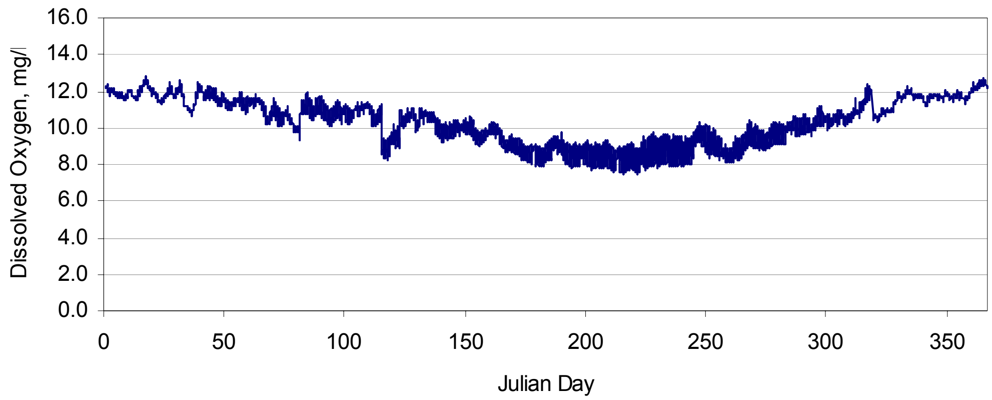


Figure 65. Scott River inflow dissolved oxygen concentrations for Iron Gate to Turwar reach model

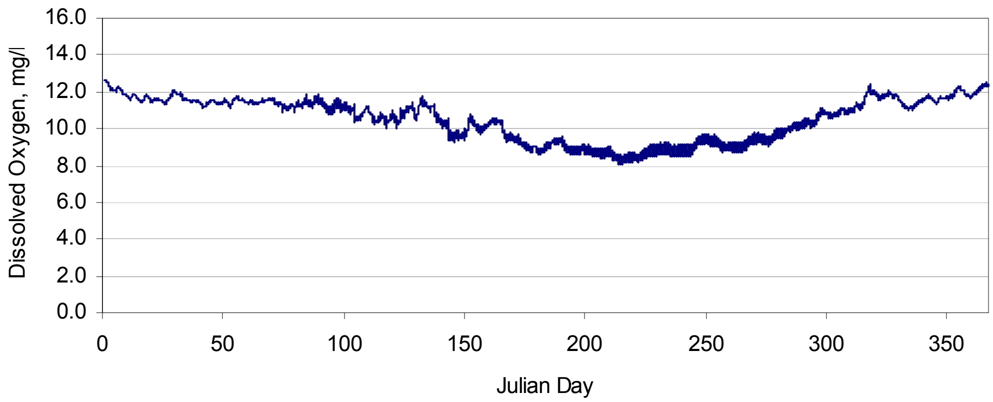


Figure 66. Salmon River inflow dissolved oxygen concentrations for Iron Gate to Turwar reach model

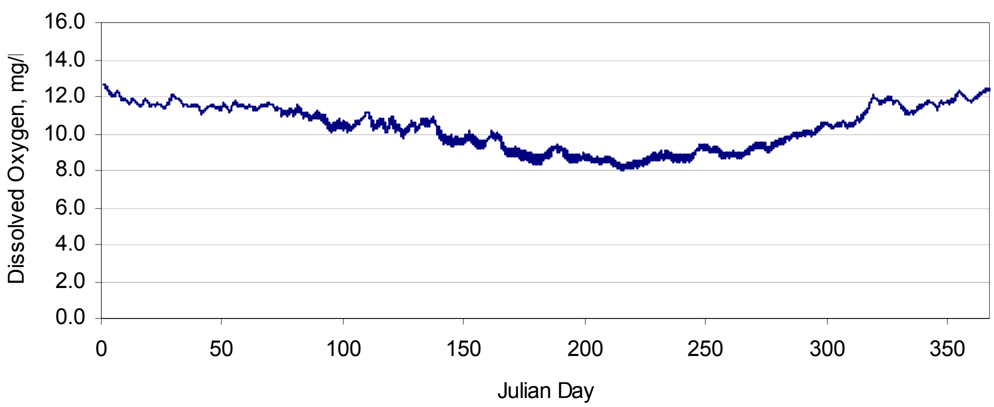


Figure 67. Trinity River inflow dissolved oxygen concentrations for Iron Gate to Turwar reach model

Table 37. Minor tributary inflow dissolved oxygen concentrations for Iron Gate to Turwar reach model

	Dissolved Oxygen, mg/l														
JDAY	1	15	46	75	106	136	167	197	228	259	289	320	350	366	367
Bogus Creek	13.75	13.72	13.60	12.57	11.23	10.06	9.99	9.70	9.61	10.06	11.09	12.74	13.78	13.75	13.75
Beaver Creek	12.37	12.29	12.09	11.46	11.23	10.99	10.36	9.71	9.39	9.65	10.38	12.12	12.35	12.37	12.37
Horse Creek	12.37	12.29	12.09	11.46	11.23	10.99	10.38	9.91	9.70	9.79	10.38	12.12	12.35	12.37	12.37
Grider Creek	12.37	12.29	12.09	11.46	11.23	10.99	10.38	9.24	9.14	9.73	10.45	12.12	12.35	12.37	12.37
Thompson Creek	11.59	11.62	11.49	11.49	11.01	10.77	10.03	9.76	9.47	9.67	10.20	11.04	11.55	11.59	11.59
Indian Creek	12.46	12.43	12.29	11.92	11.75	11.35	10.61	9.45	9.15	9.69	10.49	12.23	12.60	12.46	12.46
Elk Creek	12.79	12.71	12.51	11.85	11.61	11.37	10.74	9.30	9.20	9.85	10.74	12.53	12.78	12.79	12.79
Clear Creek	12.46	12.42	12.30	11.86	11.73	11.34	10.52	9.67	9.37	9.82	10.55	12.32	12.61	12.46	12.46
Ukonom Creek	12.46	12.45	12.38	11.92	11.73	11.51	10.83	10.27	10.06	10.42	10.84	12.30	12.50	12.46	12.46
Dillon Creek	12.46	11.87	12.09	11.65	11.14	10.40	9.73	8.83	9.12	9.44	10.56	11.66	12.49	12.46	12.46
Camp Creek	11.59	11.62	11.49	11.49	11.01	10.77	10.03	9.76	9.47	9.67	10.20	11.04	11.55	11.59	11.59
Red Cap Creek	11.99	11.87	12.09	11.65	11.14	10.40	9.73	8.81	8.98	9.50	10.26	11.22	12.08	11.99	11.99
Bluff Creek	11.59	11.62	11.49	11.49	11.01	10.77	10.03	9.76	9.47	9.67	10.20	11.04	11.55	11.59	11.59
Pine Creek	11.86	11.89	11.75	11.76	11.27	11.02	10.26	9.98	9.69	9.89	10.43	11.29	11.82	11.86	11.86
Tectah Creek	11.85	11.89	11.75	11.77	11.28	11.26	10.63	10.35	10.26	10.18	10.40	11.27	11.82	11.85	11.85
Blue Creek	11.86	11.89	11.75	11.76	11.27	11.02	10.26	9.98	9.69	9.89	10.43	11.29	11.82	11.86	11.86

Representation of chemical constituents (e.g., nutrients, BOD, and algae) was based largely on USFWS (1999), USBR (2003), and EPA (1997). Overall, there was little data available for most tributaries, and the minor tributaries generally had no available water quality data of this type. The Shasta and Scott Rivers had sufficient data from USBR (2003) to represent seasonal variations. Table 38 summarizes the estimated water quality boundary conditions for the Shasta and Scott Rivers, as well as other major and minor tributaries. As noted above, many of these tributary watersheds are lightly populated, have minimal water resources development, and although several areas reside within active timber management areas, the water quality out of most tributaries is of good quality.

Table 38. Water quality boundary conditions for constituent concentrations for Klamath River tributaries between Iron Gate Dam and Turwar

Parameter		Shasta R.		Scott R [a]		All Other Tributaries [b]
		1/1- 7/15	7/16-12/31	1/1- 7/15	7/16-12/31	1/1-12/31
Organic N (D [c])	(mg/l)	0.45	0.45	0.20	0.20	0.15
NH_4^+	(mg/l)	0.15	0.05	0.15	0.05	0.05
NO_2^-	(mg/l)	0.00	0.00	0.00	0.00	0.00
NO_3^-	(mg/l)	0.05	0.05	0.15	0.05	0.05
Organic P (D [c])	(mg/l)	0.05	0.05	0.05	0.05	0.05
PO_4^{3-}	(mg/l)	0.45	0.15	0.10	0.05	0.05
BOD	(mg/l)	2.00	2.00	2.00	2.00	2.00
Algae	(mg/l)	1.00	1.00	1.00	1.00	1.00
Dissolved Oxygen	(mg/l)	Based on saturation dissolved oxygen				

[a] based on synoptic at mouth

[b] Including Salmon River, Trinity River and all minor tributaries

[c] D – Dissolved

2.3.8.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

The meteorological data for the Klamath River Iron Gate to Turwar reach was derived from meteorological observations near Klamath Falls, OR; however, it is clear that atmospheric conditions vary appreciably throughout the study reach due to elevation, orographic features, proximity to the Pacific Ocean, and the shear size of the study area. To more effectively address local meteorological conditions with data collected at a distance location, an assessment of available observations at several locations throughout the reach was completed to determine meteorological variability throughout the basin and, to the extent feasible, adjust parameters to more fully represent local conditions.

Air temperature, dew point (for wet bulb), and wind speed were examined at several locations and lapse rates for air temperature and dew point identified. No clear relationship was identified for relating wind speed at different locations. Adjustments to air temperature and dew point for the Iron Gate Dam to Turwar reach are shown in Table 39 and Table 40. Appendix E contains additional details on comparison of meteorological conditions throughout the study area.

Table 39. Air temperature corrections, based on month for Klamath River temperature modeling

Month	Correction: Klamath Falls (°C)	Correction: Iron Gate to Orleans (°C)	Correction: Orleans to Turwar (°C)
January	0.0	0.0	3.5
February	0.0	0.0	3.5
March	0.0	0.0	2.5
April	0.0	2.5	1.5
May	0.0	2.5	0.5
June	0.0	2.5	0.0
July	0.0	2.5	0.0
August	0.0	2.5	0.5
September	0.0	2.5	1.5
October	0.0	2.5	2.5
November	0.0	2.5	3.5
December	0.0	0.0	3.5
Positive corrections are added to the KFLO data to arrive at local conditions			

Table 40. Dew point temperature corrections, based on month for Klamath River temperature modeling

Month	Correction: Klamath Falls (°C)	Correction: Iron Gate to Orleans (°C)	Correction: Orleans to Turwar (°C)
January	0.0	0.0	8.0
February	0.0	0.0	8.0
March	0.0	0.0	8.0
April	0.0	0.0	8.0
May	0.0	0.0	5.5
June	0.0	0.0	4.0
July	0.0	0.0	4.0
August	0.0	0.0	5.5
September	0.0	0.0	5.5
October	0.0	0.0	8.0
November	0.0	0.0	8.0
December	0.0	0.0	8.0
Positive corrections are added to the KFLO data to arrive at local conditions			

3 Model Calibration and Validation

Model calibration and validation is the stage wherein model parameters are adjusted to fit model results to field observations (calibration), and then the model is tested on an independent set of data (often termed validation). This process provides a means to test the model and quantify its ability to replicate field conditions for the selected parameter values. The results of model calibration and validation, as well as the final set of model parameters are presented for each river reach.

The reservoir reaches were not formally calibrated for flow. Inflows and outflows are specified as input values in CE-QUAL-W2 and these were determined based on changes in observed or assumed storage. Existing data are insufficient to test the actual hydrodynamic performance of these models. Probably the most useful method of assessing hydrodynamic performance would be the implementation of a dye study, but this is beyond the scope of this project. The river reaches were calibrated for flow. The specific approach is outlined in the Flow Calibration section included below.

All river and reservoirs reaches were formally calibrated for water temperature and dissolved oxygen. The models were not specifically calibrated for nutrients, phytoplankton, or benthic algae. There was insufficient data in most cases (the exception is the Klamath River below Iron Gate Dam) to test the models rigorously for simulation of nutrient concentrations. However, these data were not discounted. Available nutrient data were plotted versus simulation results to ensure the model produced realistic response to system conditions. Temperature, dissolved oxygen, nutrients and algae data are all presented herein.

Although the reservoir models were all applied over a calendar year during calibration, there was generally little or no data between late fall and mid spring. Model results are presented for the entire year, but late fall to mid spring calibration and validation was not completed for this analysis.

3.1 Flow Calibration

Hydrodynamic calibration typically requires varying channel roughness (e.g., Manning coefficient, n) through a range of values while comparing simulated transit time and river stage with measured data. Transit time can be estimated from stream velocity measurements or tracking changes in river stage under varying flow conditions. Although USGS gages are located near Seiad Valley (RM 129), Orleans (RM 56), and Turwar (RM5), travel time was difficult to ascertain accurately due to the long distance and uncertainty in ungaged tributary flows and other accretions.

To overcome limitations of independent calibration of flow, Deas and Orlob (1997) present a method for iterative calibration wherein both the hydrodynamic and water quality models were used jointly. Application requires modeling on a sub-daily time step and availability of associated sub-daily water temperature data (e.g., hourly). Both criteria were fulfilled for this project. The method is outlined below in the context of the Klamath River.

3.1.1 Iterative Calibration: Background

Iterative calibration of flow and temperature was completed for the Keno, JC Boyle to Copco Reservoir, and Iron Gate Dam to Turwar Reaches. The Link River reach was deemed too short for effective application of the methodology. The upstream boundary conditions for these three reaches (Keno Dam, JC Boyle Dam and powerhouse release, and Iron Gate Dam) provide unique temperature signals that can be identified in downstream reaches. Because the heat budget is driven primarily by solar energy, river temperature downstream of the reservoir responds to daily cycles of heating and cooling. In response to this cycle, a characteristic diurnal temperature pattern is produced, the advective transport of which serves as a "tracer" of the flow. Thus, diurnal variations in water temperature provide a signal similar to that of a conservative tracer that is superimposed on the mean daily thermal profile. This signal is effectively reproduced in model results, and can be "fit" to measured data in the process of model calibration. This approach is not generally applicable to unregulated rivers.

Calibration parameters for the hydrodynamic model include bed roughness (Manning coefficient) and turbulent exchange coefficients, although in this exercise longitudinal mixing was assumed minimal (i.e., turbulent exchange coefficients were not varied). In the water quality model, temperature calibration parameters include evaporative cooling coefficients, where evaporation, E, is represented by

$$E = (a+bW)(e_s-e_a) \qquad (6.1)$$

where a and b are empirical evaporation coefficients, W is wind velocity, e_s is saturation vapor pressure, and e_a is actual atmospheric vapor pressure.

The calibration technique requires that the hydrodynamic model initially be applied to simulate a flow field that is then used as input to the water quality model. Computed hourly water temperature data are then compared to measured field data. Three possible relationships between phase and amplitude of computed and measured values may occur: (1) both phase and amplitude are correct; (2) phase is correct, but amplitude is incorrect; and, (3) phase is incorrect. The calibration technique is represented schematically in Figure 68.

Phase of the diurnal temperature variation is directly related to travel time. Travel time, in turn, is determined by water velocity, and is thus a function of bed roughness. The amplitude of diurnal temperature variations is affected by two processes: travel time (i.e., exposure time), and evaporation coefficients. The possible outcomes and model steps of the calibration process are described below.

Case 1: Phase correct, amplitude correct - If the simulated phase and amplitude of the diurnal variation in water temperature match measured data, the calibration is complete.

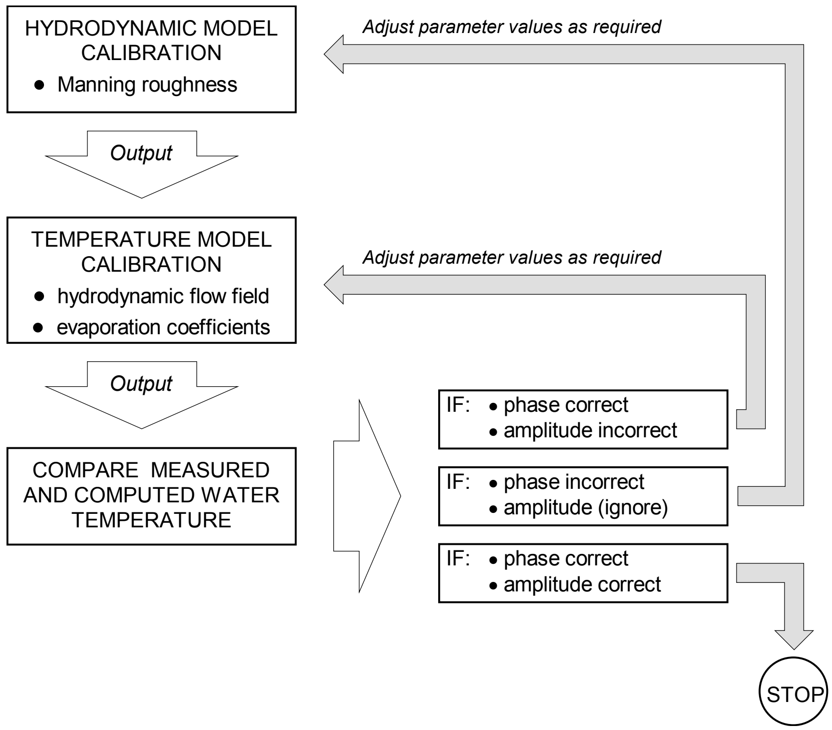


Figure 68. Schematic of iterative hydrodynamic and water temperature model calibration process

Case 2: Phase correct, amplitude incorrect - If the phase of simulated diurnal temperature variation matches measured data, but amplitude is incorrect, the applied Manning roughness coefficient is representative and hydrodynamic calibration is complete. Subsequently, evaporation coefficients (*a* and *b*) may be adjusted to improve/calibrate diurnal temperature amplitude.

Case 3: Phase incorrect - If the phase of simulated diurnal temperature variation does not coincide with measured field data, transit time in the river has been compromised. For excessive roughness values, average river velocities are reduced and transit time is increased; the converse is true for roughness values that are too small. The result is a temperature tracer signal that is displaced upstream or downstream, respectively. Amplitude of the signal is ignored because replication of the phase is necessary prior to assessing the amplitude, i.e., increased or decreased travel time will lead to greater or lesser heating of river water, directly affecting amplitude. Under these conditions, the Manning coefficient must be modified appropriately and both the hydrodynamic and water quality models re-run. Water quality model calibration coefficients remain unchanged because amplitude calibration cannot be completed until the phase of the tracer signal is correctly determined.

The steps of calibrating for phase and subsequently calibrating for amplitude are illustrated for an idealized example in Figure 69. The initial simulated temperatures illustrate both a phase shift and amplitude error. Calibration of channel roughness corrects for phase and, because travel time has been changed, also affects amplitude error. Subsequently, the amplitude is calibrated with evaporation coefficients. In practice, simulated phase and amplitude may not consistently match measured data due to short-term variations in upstream operations, local meteorology, and tributary influences.

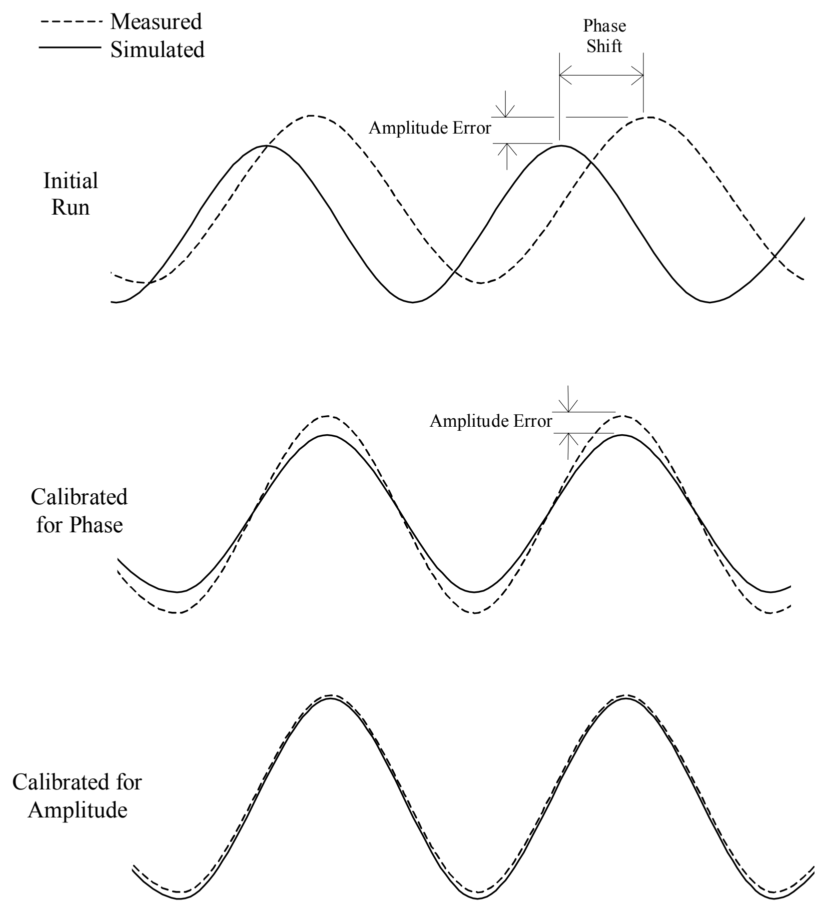


Figure 69. Example calibration of phase and amplitude for diurnal temperature trace

The final values for Manning roughness and evaporative heat flux coefficients are included for each reach in the summary table at the end of the calibration presentation.

3.1.2 Slope Factor

Preliminary runs, with a water surface slope based on the elevation of the upstream and downstream end of each reach (gross slope), showed that model results in the steep river reaches were not effectively represented. The water surface slope of steep rivers is generally significantly less than the overall gross slope of the river profile. Further, steep rivers are typically not uniform in slope, but consist of short cascades or riffles, combined with intermediate pools and runs. RMA-2 includes a slope factor (SF) and associated logic that reduces the effective bed slope of the stream and assumes travel time through the short cascade sections is negligible compared to the transit time through runs or pools. Figure 70 shows a schematic of initial model application (Case 1; SF = 0) and model application with slope factor applied (Case 2: 1>SF>0). For cases 1 and 2 the stream reaches have equivalent vertical elevation change (z) and horizontal distance. But, by neglecting the short cascade reach the transit time in the river is more closely simulated.

To estimate slope factor, uniform flow was assumed and Manning's equation applied.

$$Q = [1.49AR^{2/3}S^{1/2}] / n \qquad (4.2)$$

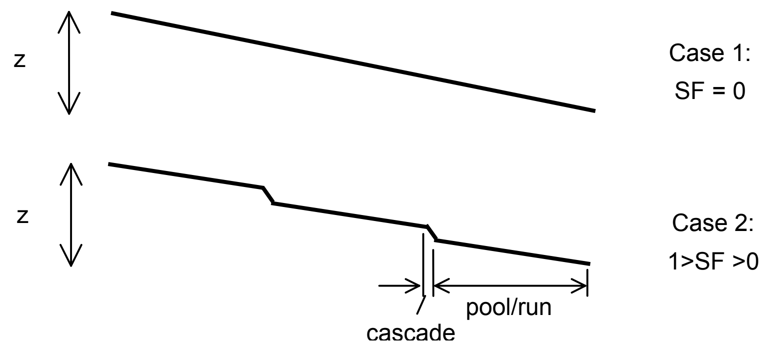


Figure 70. Slope factor application for a representative river reach

Where Q is flow rate, A is cross sectional area, R is hydraulic radius, S is bed slope (or water surface slope), and n is a channel roughness coefficient. Using this equation for a known cross sectional area, hydraulic radius, and an estimated value of Manning n, the slope required to deliver a known flow rate can be determined.

Based on typical summer flow rates the slope factor for the Link and Keno reaches was set at 0.90, the bypass and peaking reaches slope factor was 0.95, and the factor for the Klamath River from Iron Gate Dam to Turwar was set at 0.80. These value were not changed throughout calibration. The assumption is that small discrepancies in the slope factor can be accommodated in selection of an appropriate Manning coefficient. For this reason, use of the Manning coefficient determined herein for application in other flow models should be done with great consideration and care.

3.1.3 Calibration Measures and Methods

Calibration required comparison of several alternative parameter sets. Selecting final parameter values may include professional judgment, graphical comparisons of simulated versus measured data, and statistical analysis of simulated and measured data, to name a few. Though each measure has merits and demerits, statistical analyses were used as the primary method to select final calibration parameters for the flow and temperature models. Graphical comparisons and professional judgment were used to assess general model performance and provided significant insight, but proved difficult to quantify differences over long time periods and at multiple locations along the river. Thus, several basic statistics were applied to the simulated temperature data and associated error to provide additional insight into model performance and to quantify model uncertainty: bias, mean absolute error, and root mean squared error.

These summary statistics are presented in the temperature calibration section for each river reach. The final values of channel roughness and other hydrodynamic parameters are included in the summary table that concludes each calibration section.

3.2 Link River

The RMA suite of models for Link River was calibrated and validated for May 21-23, 2002 and July 16-18, 2002, respectively. Water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) data were collected during field season 2002 to support the modeling task.

3.2.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the mainstem (calibration/validation points) were required.

3.2.1.1 Boundary Conditions

The boundary condition data was derived from samples collected at Link Dam. Calibration and validation flow for Link River, East Turbine and West Turbine are presented in Figure 71 and Figure 72, respectively. Water temperature and dissolved oxygen data were available from water quality probes at hourly intervals. Grab samples were collected once per day for three days. Due to the inherent variability and infrequent sampling interval of the grab data, the boundary condition values for nutrients, BOD, and algae were assumed to be a constant value for the calibration and validation period, based on the grab sample data from 2002 (Appendix F).

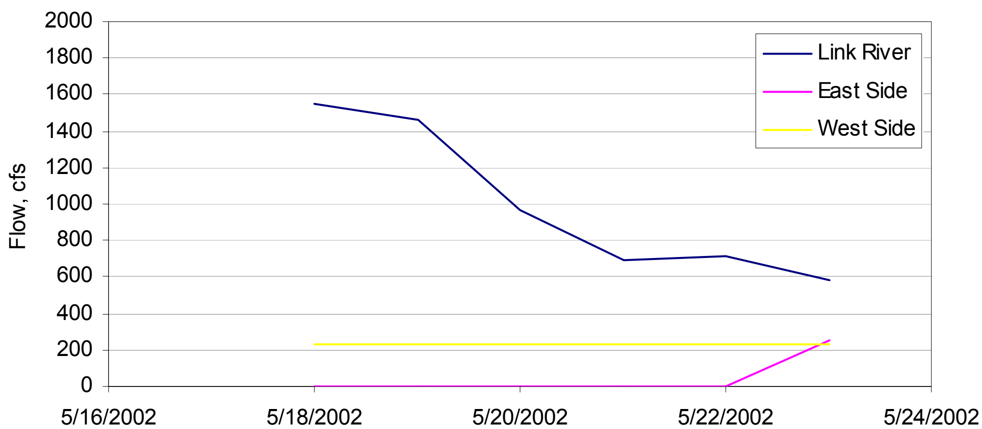


Figure 71. Flow in Link River, East Side and West Side for Link River calibration

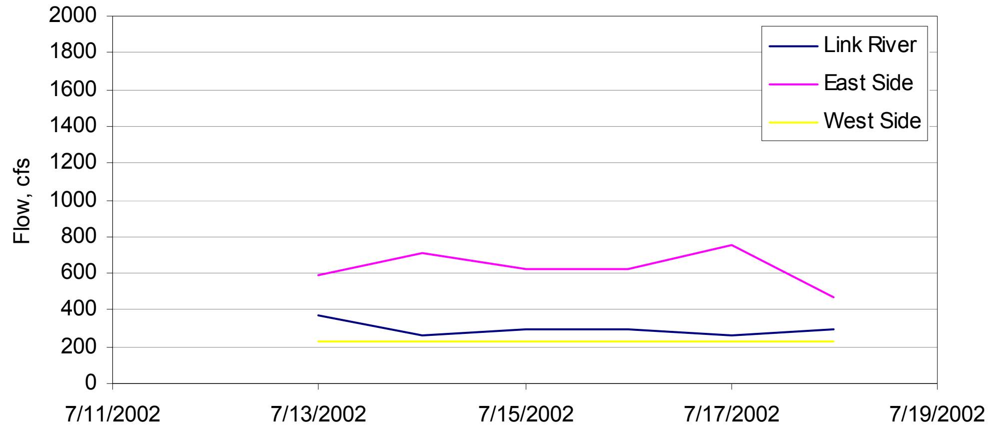


Figure 72. Flow in Link River, East Side and West Side for Link River validation

The water quality boundary conditions derived for Link Dam were also applied to the return flows at East Side and West Side powerhouse. The water quality values for the calibration and validation period are shown in Table 41 and Figure 73 and Figure 74.

Table 41. Link River reach calibration and validation water quality boundary conditions

		Dates	
Parameter	**Units**	5/21/02 - 5/23/02	7/16/02 - 7/18/02
BOD	mg/l	3.0	5.0
DO	mg/l	variable	Variable
Org N	mg/l	0.70	1.80
NH_4^+	mg/l	0.10	0.25
NO_2^-	mg/l	0.00	0.00
NO_3^-	mg/l	0.05	0.10
Org P	mg/l	0.25	0.40
PO_4^{3-}	mg/l	0.10	0.10
Algae	mg/l	2.0	22.0
Tw	°C	variable	variable

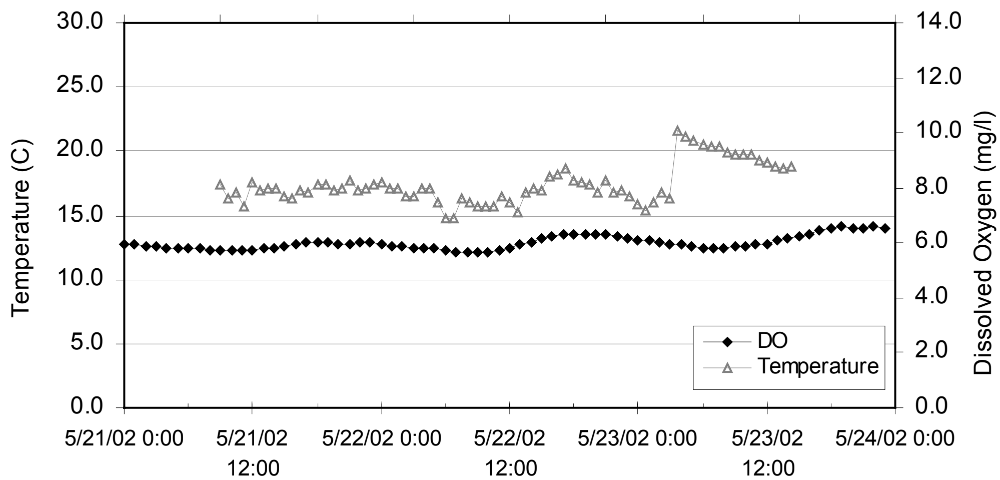


Figure 73. Link River reach temperature and dissolved oxygen calibration boundary conditions

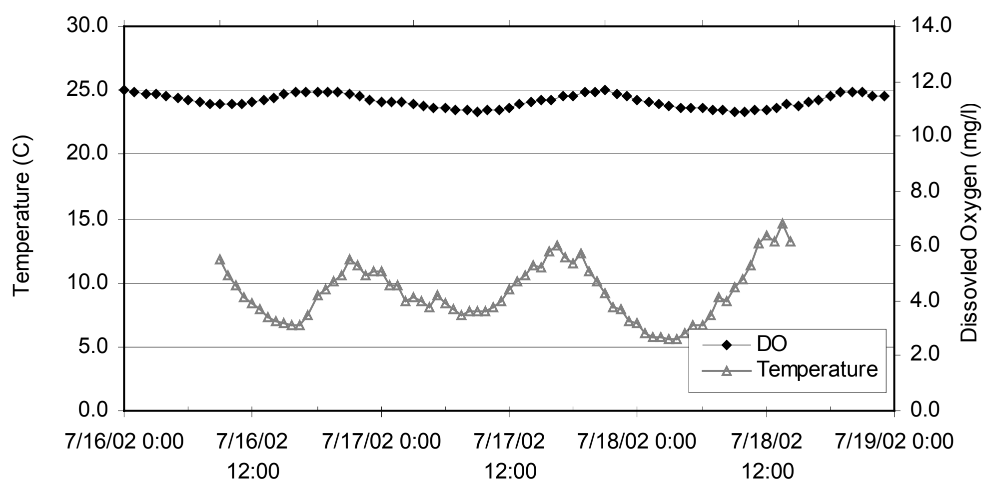


Figure 74. Link River reach temperature and dissolved oxygen validation boundary conditions

3.2.1.2 Initial conditions

The model was run for three days prior to both the calibration and validation periods to provide an initial condition for simulation. The initial bed algae mass was estimated at 5 g/m^2.

3.2.1.3 Calibration and Validation Points

The calibration and validation point for the Link River reach was Link River at Lake Ewauna. These data are displayed in the following section with model results.

3.2.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled once per day, resulting in sparse data that are not readily amenable for such statistical analysis. All model parameters for the Link River reach are summarized in Table 44 at the end of this section.

3.2.2.1 Water Temperature

Water temperature calibration required varying evaporation heat flux coefficients (presented in Table 44) that govern the mass transfer formulation represented in the numerical model heat budget. No other parameters were varied. The hourly results are presented graphically in Figure 75 and Figure 76. The diurnal range and phase is well represented for spring temperatures in the neighborhood of 12°C-14°C, as well as in the summer period, when temperatures reach almost 25°C. Tabulated statistics (Table 42) illustrate that simulated results on an hourly and daily basis are within about 0.2°C of observations. These results are not unexpected given the short river reach.

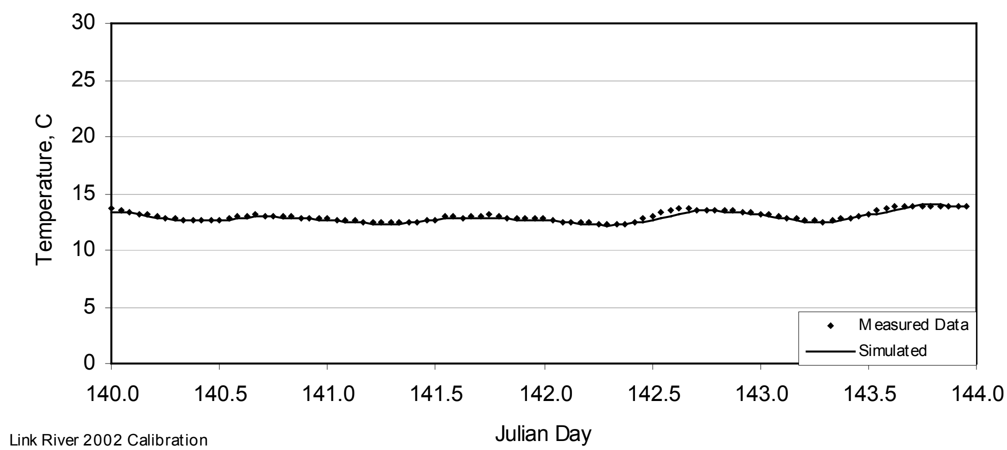


Figure 75. Link River simulated versus measured water temperature, May 20-23, 2002

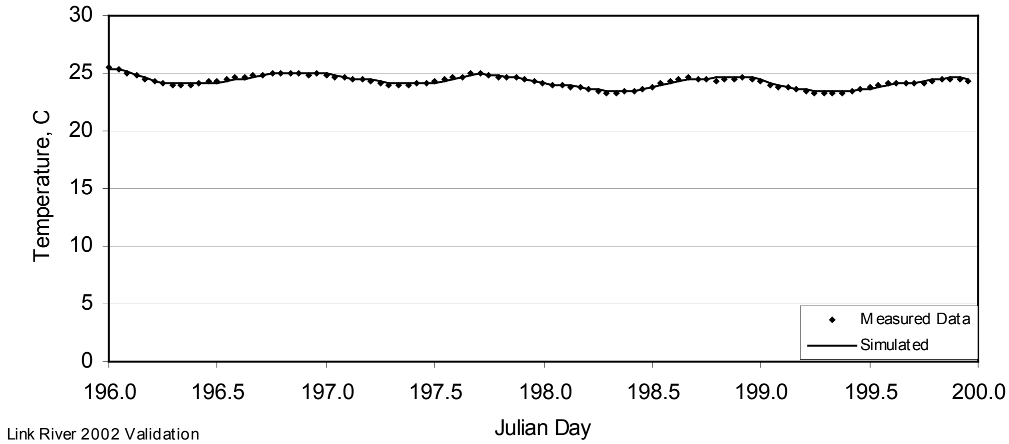


Figure 76. Link River simulated versus measured water temperature, July 15-18, 2002

Table 42. Link River hourly and daily calibration and validation period statistics for water temperature

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	°C	-0.11	0.02	-0.11	0.02
Mean absolute error (MAE)	°C	0.13	0.11	0.11	0.03
Root mean squared error (RMSE)	°C	0.16	0.12	0.12	0.03
n	-	95	96	4	4

[a] Mean bias = simulated – measured

3.2.2.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates, and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeled in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from Upper Klamath Lake, growth rates were set to very low numbers in river reaches.

The hourly results are presented graphically in Figure 77 and Figure 78. The diurnal range and phase is well represented for spring dissolved oxygen (DO) conditions in the neighborhood of 8-10 mg/l, as well as in the summer period, when DO concentrations vary from about 4 to 6 mg/l. Tabulated statistics (Table 43) illustrate that simulated results on an hourly and daily basis are within about 1 mg/l of observed values. Some of the disparity between simulated and observed values is probably due to Link Dam dissolved oxygen conditions being imposed as boundary conditions at East and West Side powerhouses.

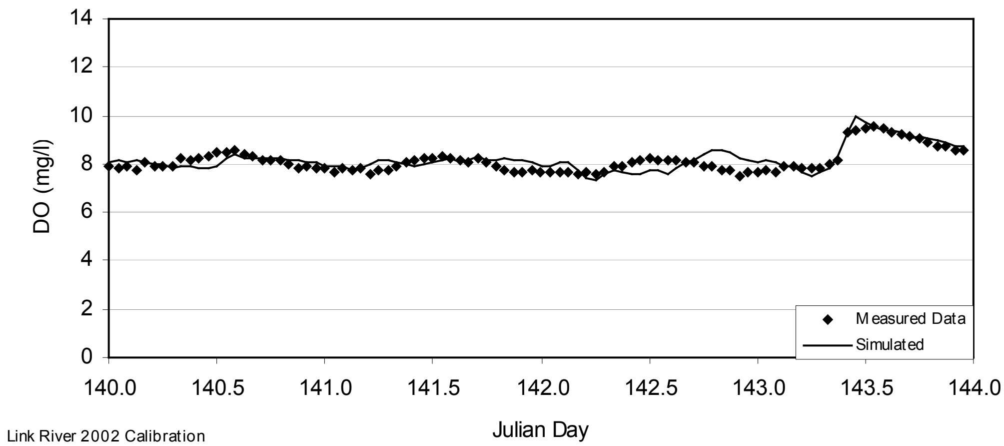


Figure 77. Link River simulated versus measured dissolved oxygen, May 20-23, 2002

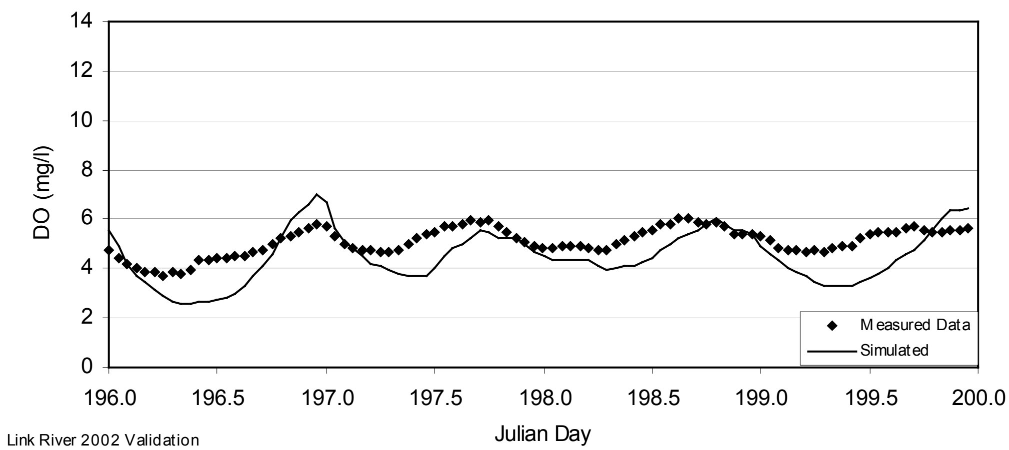


Figure 78. Link River simulated versus measured dissolved oxygen, July 15-18, 2002

Table 43. Link River hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics	Unit	Hourly Calib.	Hourly Valid.	Daily Calib.	Daily Valid.
Mean Bias	mg/l	0.08	-0.60	0.08	-0.60
Mean absolute error (MAE)	mg/l	0.25	0.80	0.08	0.60
Root mean squared error (RMSE)	mg/l	0.31	0.95	0.10	0.61
n	-	95	95	4	4

[a] Mean bias = simulated – measured

3.2.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Link River reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 79 through Figure 84. Simulated concentrations for ammonia, nitrate, and orthophosphate were consistent with field observations.

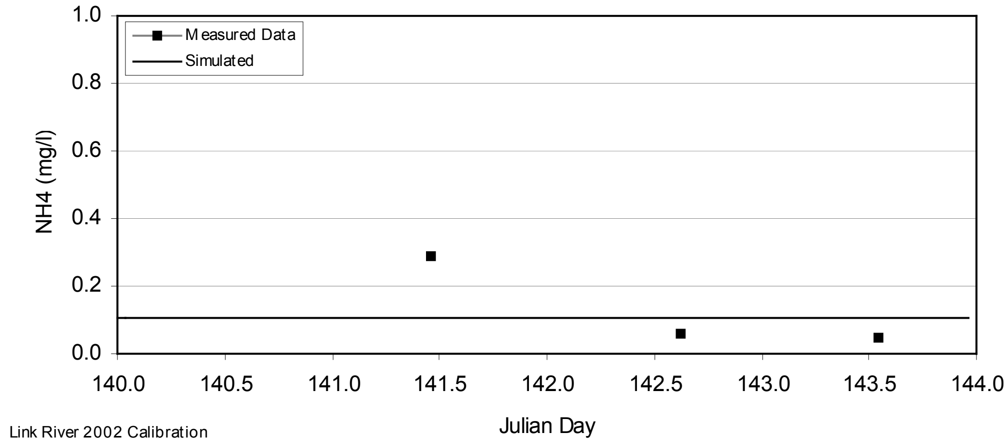


Figure 79. Link River simulated versus measured ammonia, May 20-23, 2002

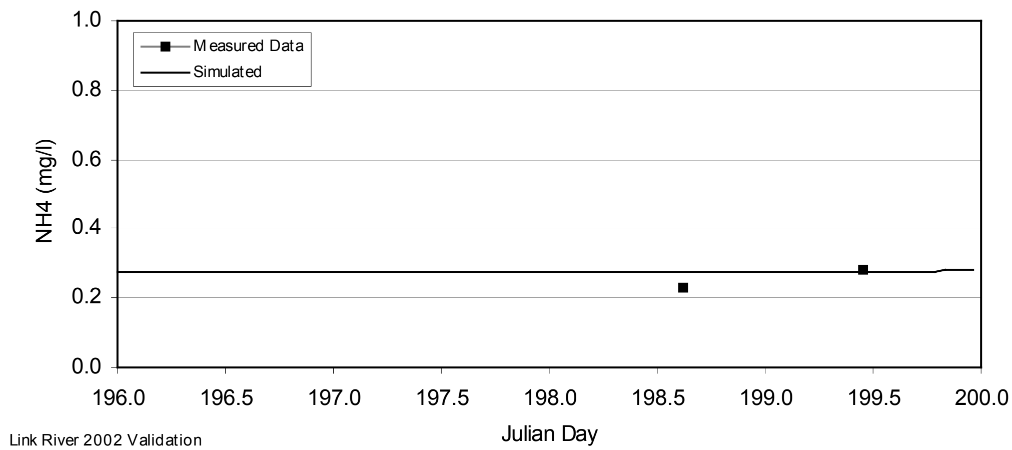


Figure 80. Link River simulated versus measured ammonia, July 15-18, 2002

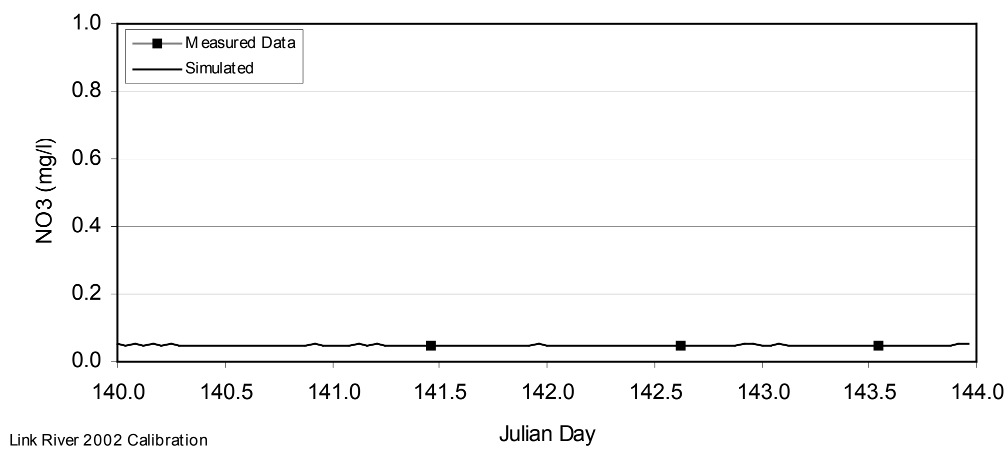


Figure 81. Link River simulated versus measured nitrate, May 20-23, 2002

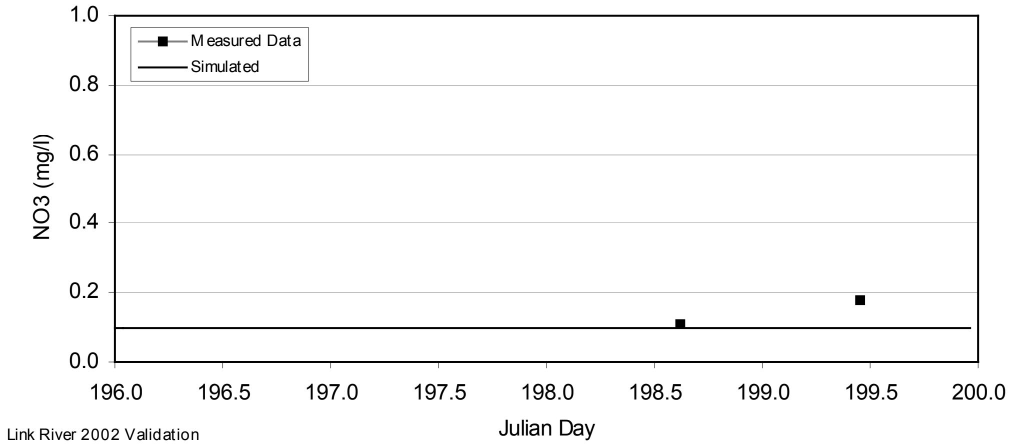


Figure 82. Link River simulated versus measured nitrate, July 15-18, 2002

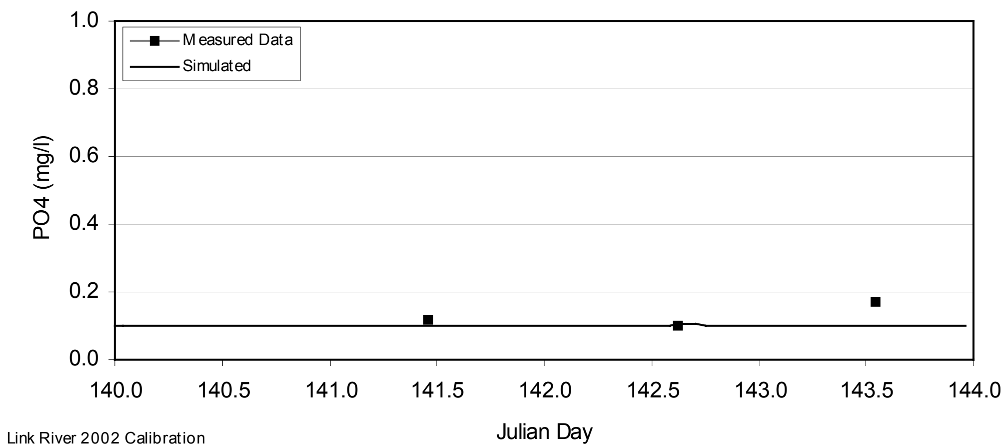


Figure 83. Link River simulated versus measured orthophosphate, May 20-23, 2002

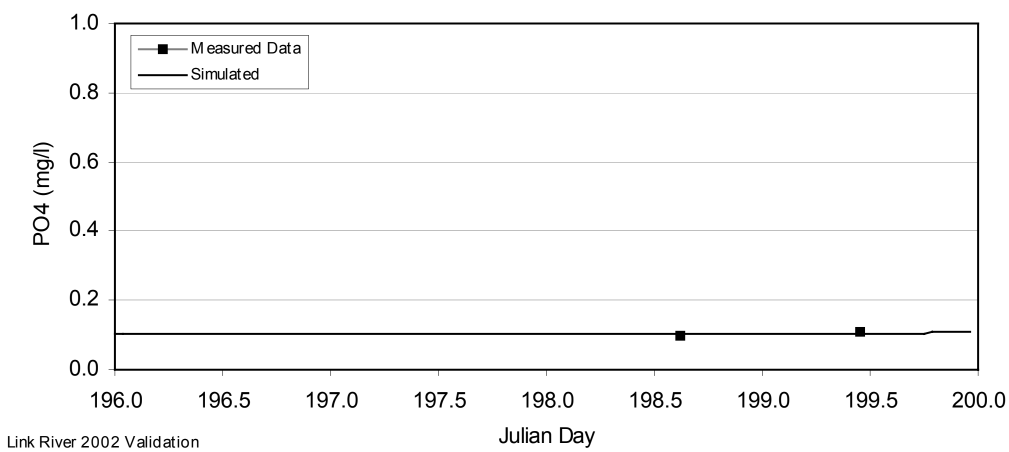


Figure 84. Link River simulated versus measured orthophosphate, July 15-18, 2002

3.2.2.4 Summary of Parameters

Table 44. RMA-2 and RMA-11 Model , rates, coefficients, constants for the Link River reach

Variable Name	Description, units	Value
	Time step, hr	1.0
	Space step, m	75
	Manning roughness coefficient	0.04
	Turbulence factor, Pascal-sec	100
	Longitudinal diffusion scale factor	0.10
	Slope Factor	0.80
ELEV	Elevation of site, m	1192.0
LAT	Latitude of site, degrees	41.5
LONG	Longitude of site, degrees	122.45
EVAPA	Evaporative heat flux coefficient a, m hr^{-1} mb^{-1}	0.000015
EVAPB	Evaporative heat flux coefficient b, m hr^{-1} mb^{-1} $(m/h)^{-1}$	0.000005
EXTINC	Light Extinction coefficient, used when algae is not simulated, 1/m	1.5
ALP0	Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A	67
ALP1	Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A	0.072
ALP2	Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A	0.010
LAMB1	Linear algal self-shading coefficient, phytoplankton, 1/m	n/a
LAMB2	Non-linear algal self shading coefficient, phytoplankton, 1/m	n/a
MUMAX	Maximum specific growth rate, phytoplankton, 1/d	0.01
RESP	Local respiration rate of algae, phytoplankton, 1/d	0.05
SIG1	Settling rate of algae, phytoplankton, 1/d	0.0
KLIGHT	Half saturation coefficient for light, phytoplankton, KJ m^{-2} s^{-1}	0.01
KNITR	Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l	0.01
KPHOS	Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l	0.001
PREFN	Preference factor for NH3-N, phytoplankton	0.6
ABLP0	Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A	50
ABLP1	Fraction of algal biomass that is nitrogen, bed algae, mg/l	0.07
ABLP2	Fraction of algal biomass that is phosphorus, bed algae, mg/l	0.01
LAMB1	Linear algal self shading coefficient, bed algae, 1/m	n/a
LAMB2	Non-linear self shading coefficient, bed algae, 1/m	n/a
MUMAX	Maximum specific growth rate, bed algae, 1/d	1.0
RESP	Local respiration rate of algae, bed algae, 1/d	0.60
MORT	Mortality, bed algae, 1/d	0.0
KBNITR	Half-saturation coefficient for nitrogen, bed algae, mg/l	0.01
KBPHOS	Half-saturation coefficient for phosphorus, bed algae, mg/l	0.002
KBLIGHT	Half-saturation coefficient for light, bed algae, KJ m^{-2} s^{-1}	0.01
PBREFN	Preference factor for NH3-N, bed algae	0.75
BET1	Rate constant: biological oxidation NH3-N, 1/d	0.3
BET2	Rate constant: biological oxidation NO2-N, 1/d	0.5
BET3	Rate constant: hydrolysis Org N to NH3-N, 1/d	0.3
BET4	Rate constant: transformation Org P to P-D, 1/d	0.3
KNINH	First order nitrification inhibition coefficient, mg^{-1}	n/a
ALP3	Rate O_2 production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A	1.6
ALP4	Rate O_2 uptake per unit of algae respired, phytoplankton, mg-O/mg-A	1.6
ABLP3	Rate O_2 production per unit of algal photosynthesis, bed algae, mg-O/mg-A	1.6
ABLP4	Rate O_2 uptake per unit of algae respired, bed algae, mg-O/mg-A	1.6
ALP5	Rate O_2 uptake per unit NH3-N oxidation, mg-O/mg-N	3.43
ALP6	Rate O_2 uptake per unit NO2-N oxidation, mg-O/mg-N	1.14
K1	Deoxygenation rate constant: BOD, 1/d	0.3
-	Minimum reaeration rate constant (Churchill formula applied), 1/d	3.0
SIG6	BOD settling rate constant, 1/d	0.0

n/a – not applicable

Table 45. RMA-11 model temperature factors for the Link River reach

Variable Name	Description	Value
Water Column		
THET1	Algal growth rate temperature factor	1.047
THET2	Algal respiration rate temperature factor	1.047
THET3	Algal settling rate temperature factor	1.047
THET4	Organic nitrogen decay rate temperature factor	1.047
THET5	Organic nitrogen settling rate temperature factor	1.024
THET6	Ammonia nitrogen decay rate temperature factor	1.083
THET7	Ammonia nitrogen benthic sources rate temperature factor	1.074
THET8	Nitrite nitrogen decay rate temperature factor	1.047
THET9	Organic phosphorous decay rate temperature factor	1.047
THET10	Organic phosphorous settling rate temperature factor	1.024
THET11	Orthophosphate benthic sources rate temperature factor	1.074
THET12	BOD decay rate temperature factor	1.047
THET13	BOD settling rate temperature factor	1.024
THET14	DO benthic demand rate temperature factor	1.000
THET15	DO reaeration rate temperature factor	1.024
Bed		
BTHET1	Bed algae growth rate temperature factor	1.047
BTHET2	Bed algae respiration rate temperature factor	1.047
BTHET3	Bed algae settling rate temperature factor	1.000
BTHET4	Bed organic nitrogen decay rate temperature factor	1.000
BTHET5	Bed organic nitrogen settling rate temperature factor	1.000
BTHET6	Bed ammonia nitrogen decay rate temperature factor	1.000
BTHET7	Bed ammonia nitrogen benthic sources rate temperature factor	1.000
BTHET8	Bed nitrite nitrogen decay	1.000
BTHET9	Bed organic phosphorous decay rate temperature factor	1.000
BTHET12	Bed BOD decay rate temperature factor	n/a

3.3 Lake Ewauna-Keno Dam Reach

The CE-QUAL-W2 model for the Lake Ewauna to Keno Dam reach was calibrated for 2001 and tested using 2000 data. Water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) data were collected at multiple locations during the 2001 field season and at three locations (Klamath River at Miller Island, Klamath River at Highway 66 bridge, and Klamath Straits Drain at Highway 97) during the 2000 field season by the U.S. Bureau of Reclamation.

The Lake Ewauna-Keno Reach is a complex reach with multiple inputs and outputs. The headwater boundary condition is Link River, which essentially represents Upper Klamath Lake – a highly dynamic hypereutrophic body of water. Other inputs include municipal waste water treatment plant effluent, industrial (primarily wood processing) discharges, agricultural discharges, and stormwater runoff. Although variable in size, the persistence and long-term nature of these discharges into this impoundment have created a water quality condition that is wholly uncommon in rivers of this size in the western United States. Namely, persistent and extreme anoxia, elevated nutrient levels, highly variable (in space and time) algal standing crop, appreciable BOD, and SOD demands. Available data have lead to a preliminary characterization of pertinent system processes.

Additional field work and model testing completed during the summer of 2003 has identified that this reach is dominated by the inflow quantity and quality at Upper Klamath Lake. Further, this boundary condition is highly variable in time, presumably in response to conditions in Upper Klamath Lake during late spring through fall periods, including but not limited to primary production (algal standing crop, blooms and die-offs), storage, flow conditions, and meteorological conditions (incident solar radiation, wind conditions). Because there is a measurable current throughout much of Keno Reservoir, the inputs from Upper Klamath Lake are actively transported downstream, impacting water quality throughout the reservoir length. This current, coupled with the shallow nature of the impoundment and intermittent winds, preclude strong thermal stratification of the system. The reservoir does stratify on a diurnal basis under calm conditions. The water velocity is not sufficient to preclude the development of large densities of phytoplankton, which actively colonize the top few feet of the water body. The high level of primary production, coupled with the large load of organic matter (living and dead algal tissue), creates a system that is almost wholly anoxic in the aphotic zone and experiences large diurnal variation in dissolved oxygen concentration in the photic zone. At certain locations there have been periods where the entire water column experiences dissolved oxygen concentrations less than 1 mg/l.

The large load of nutrients and organic matter from Upper Klamath Lake, imparts an appreciable oxygen demand on the system, wherein the system experiences a severe and persistent dissolved oxygen sag in the region from Lake Ewauna to below the Klamath Straits drain. The river system tends to recover somewhat by the time it reaches the Keno area, but concentrations often remain well below saturation in summer months. The role of sediment oxygen demand has been briefly explored with the CE-QUAL-W2 model and appears to play a modest role compared to the impacts of Upper Klamath Lake inflows.

U.S. Bureau of Reclamation operations occasionally have a dramatic affect on the water quality of the reservoir. Namely, there are periods where Link Dam releases are reduced and Lost River diversion channel inputs are increased. For example, in the fall of 2000 Link Dam releases were reduced to about 100 cfs and the Lost River diversion channel flows increased to around 700 cfs. During these operations the reservoir water quality was dominated by Lost River diversion channel water inflow. Another condition that can affect water quality in the Klamath River downstream of the Lost River Diversion Channel is when diversions to the Reclamation project occur. If large amounts of water are diverted the residence time downstream of this point can potentially increase depending on the operations of the other withdrawal points and the Klamath Straits Drain. These may be short term events, but they can have impacts on water quality. The Klamath Straits Drain rarely exceeds 200 cfs in discharge and plays a lesser role; however, the drain experiences a more persistent flow regime, while the Lost River diversion channel is often off line or diverting water from the river to the Reclamation Project.

Lake Ewauna/Keno Reservoir is a complex system and although significant improvements in characterizing the system have been identified, more studies will be required to improve the water quality simulation of the system. Probably the most important issue is characterizing the boundary conditions (primarily Link Dam, but also Lost River diversion channel and Klamath Straits Drain) on a timescale sufficiently short to capture the dynamics of the system – probably on the order of several days to a week.

3.3.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the mainstem (calibration/validation points) were required.

3.3.1.1 Boundary Conditions

The upstream and downstream flow boundary conditions utilized 2000 and 2001 existing conditions. The upstream boundary conditions for temperature and constituent concentrations were passed from the calibrated Link River model simulation, and are presented in Figure 85 and Figure 86 for 2000 and Figure 87 and Figure 88 for 2001. All other boundary conditions were derived as documented in the model implementation section. (Note: boundary condition data for 2001 and presented in Appendix H in graphical or tabular form.)

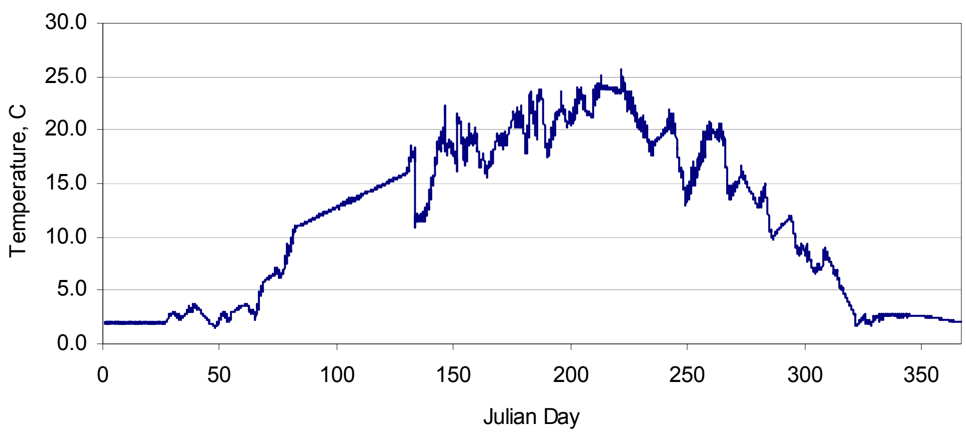
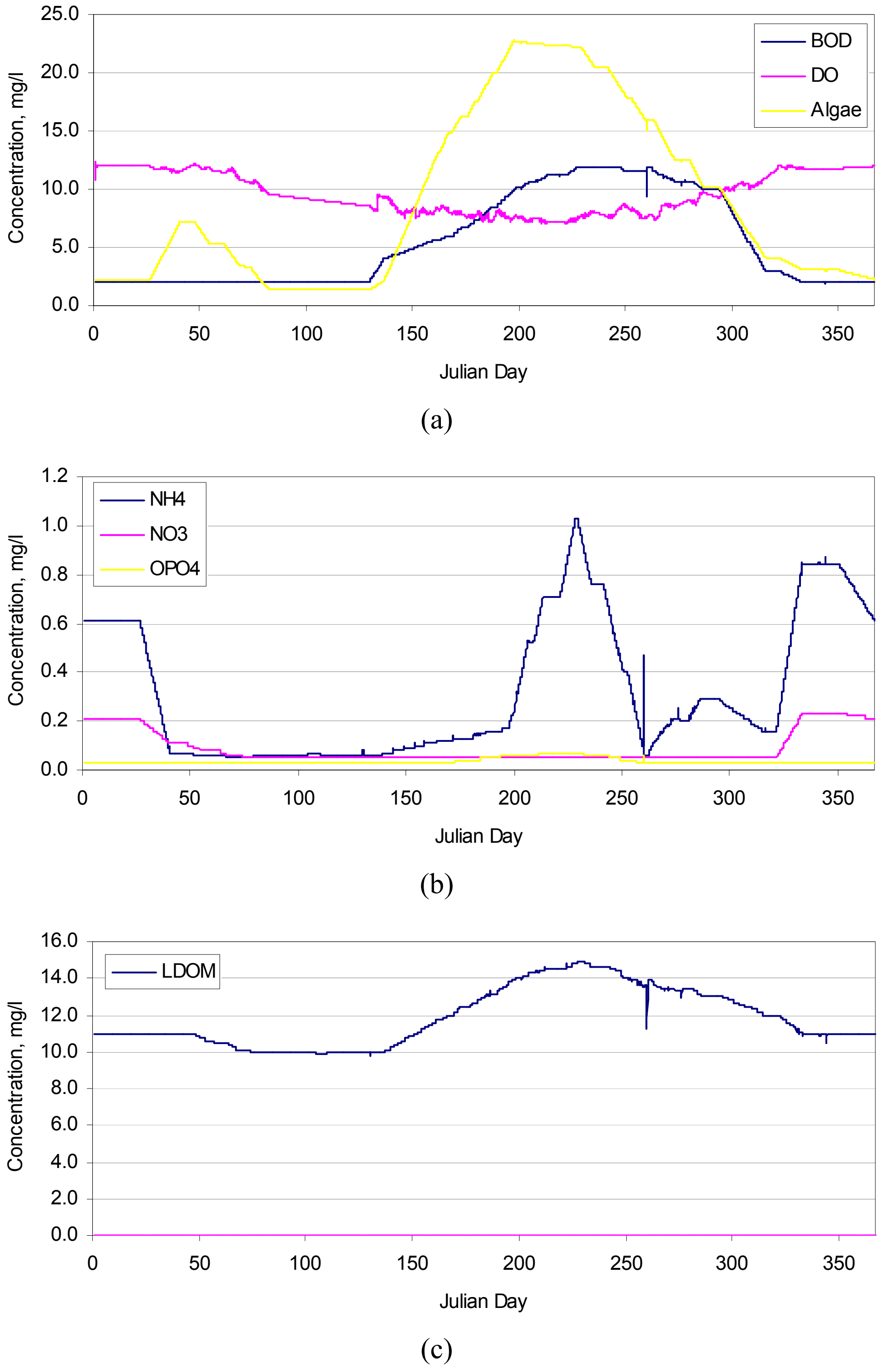


Figure 85. Link River inflow temperature for Lake Ewauna to Keno Dam reach 2000



(a)

(b)

(c)

Figure 86. Selected Link River inflow constituent concentrations for Lake Ewauna to Keno Dam reach 2000: (a) BOD, dissolved oxygen, algae; (b) ammonia, nitrate, orthophosphate; (c) labile dissolved organic matter (refractory dissolved organic matter inflow concentrations are zero)

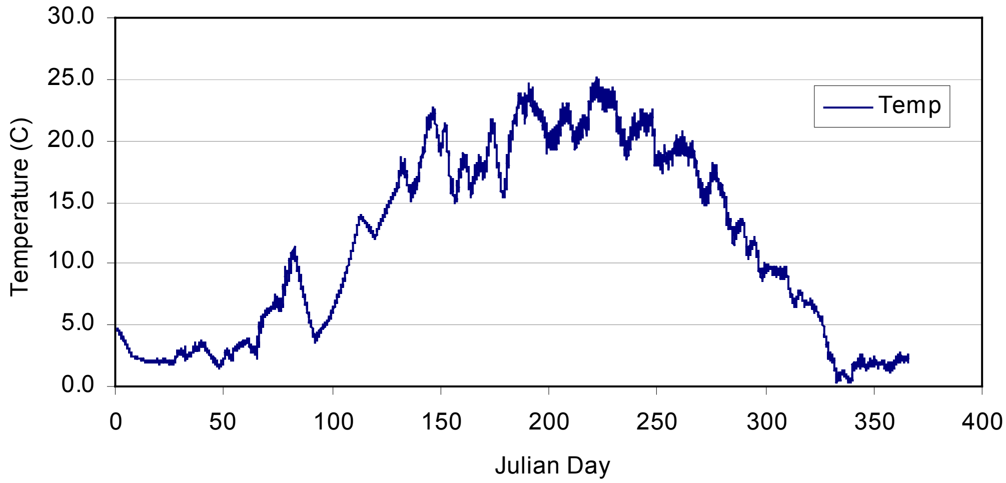


Figure 87. Link River inflow temperature for Lake Ewauna to Keno Dam reach 2001

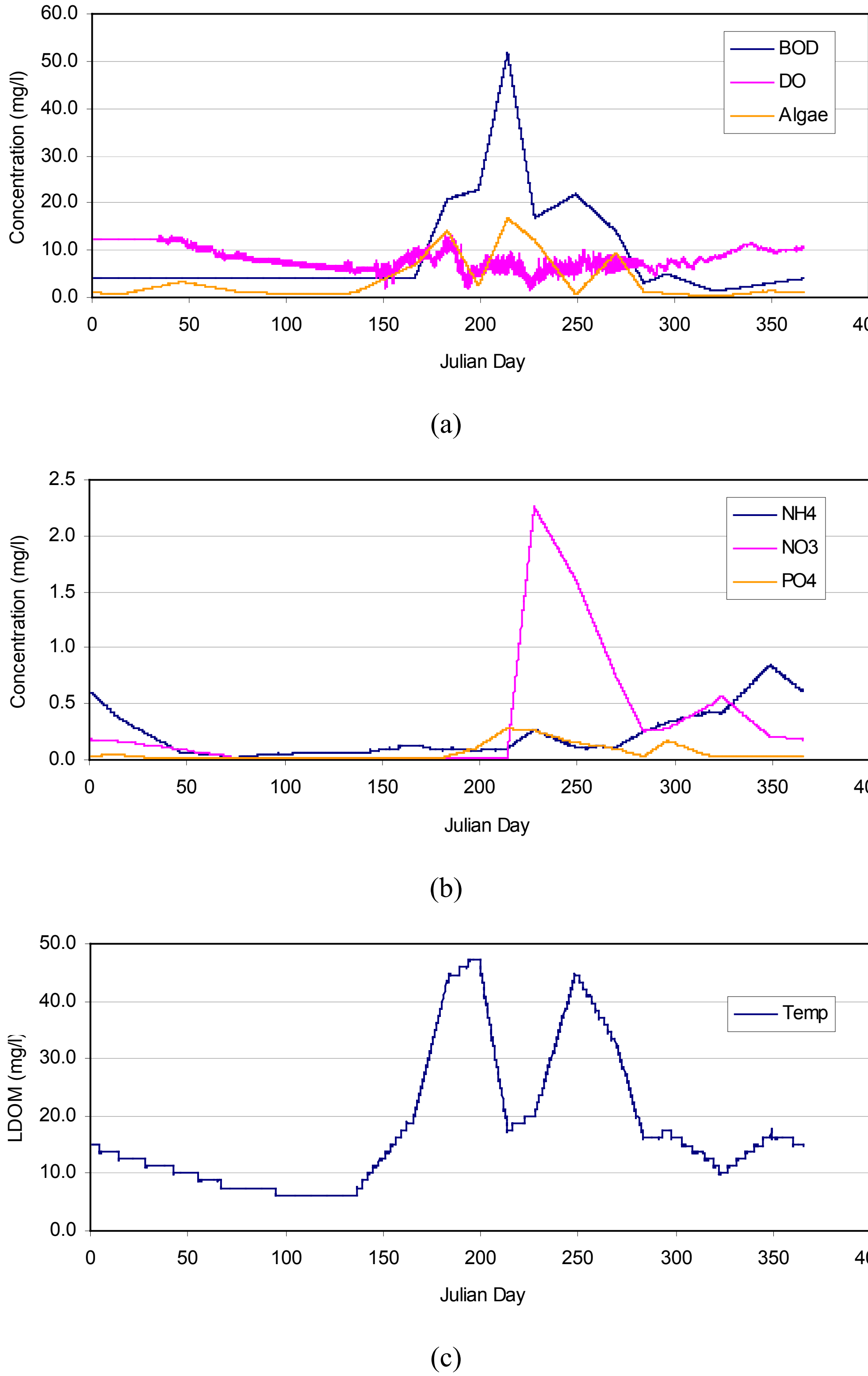


Figure 88. Selected Link River inflow constituent concentrations for Lake Ewauna to Keno Dam reach 2001: (a) BOD, dissolved oxygen, algae; (b) ammonia, nitrate, orthophosphate; (c) labile dissolved organic matter (refractory dissolved organic matter inflow concentrations are zero)

3.3.1.2 Initial conditions

The residence time in the reach is approximately 10 days, thus the first half of January is used to “warmed up” the model and results from this period are not applicable to analysis for both 2000 and 2001.

3.3.1.3 Calibration Points

There are two calibration and validation points within the Lake Ewauna to Keno Dam reach for the simulated years. The first is located at the Miller Island boat ramp. The second is located in the Keno Reservoir at the Highway 66 Bridge. These data are displayed in the following section with model results.

3.3.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. The model was run for the entire calendar year (2000 and 2001). Model performance was evaluated for the first week of the months of June through October to cover a wide range of seasons. Graphical presentation of these weekly periods also includes the 10 days prior to and 10 days following the selected week. This information, although not included in the statistical summary, provides insight into any trends the model is or is not representing in this dynamic and complex reach.

Field observations for temperature and dissolved oxygen were available from water quality probes on an hourly interval, allowing for summary statistics to be calculated on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled monthly or semimonthly; resulting in sparse data that are not readily amenable for such statistical analysis. All model parameters for the Lake Ewauna to Keno Dam reach are summarized in Table 54 at the end of this section.

3.3.2.1 Water Temperature

Water temperature calibration included varying the three wind speed evaporation coefficients specified by the user in CE-QUAL-W2. CE-QUAL-W2 simulated seasonal variations in water temperature effectively at both Miller Island (approximate river mile and Highway 66 near Keno. CE-QUAL W-2 was applied to this reach for the entire year. Residence time ranges from a few days to roughly two weeks and the system does not seasonally stratify.

Miller Island

The entire calendar year was simulated and temperature results for the first week of the months June through October 2000 and 2001 are shown in Figure 90 and Figure 91 and Figure 92 and Figure 93, respectively. Seasonal trends and short-term meteorological conditions are reflected in the model simulations. Summary statistics for the first week of each month for 2000 and 2001 are provided in Table 46 and Table 47, respectively.

The simulated hourly and mean daily temperature is represented to within about 1°C for 2000, and generally well under 1°C for 2001. The model matched short term variations as well as seasonal trends. However, simulated results did not reproduce a component of the diurnal variation evident in field observations. It is important to note that in 2000 the US Bureau of Reclamation datasonde was deployed at the Miller Island boat ramp dock in approximately 4 feet of water. This location did not represent actual mid-channel conditions. Further, the location was subject to mixing due to boat launching activities. Close examination of the trace shows increases in water temperatures on the order of 7°C within an hour (see Julian Day 173), which is highly unlikely. Thus attempting to calibrate to the peak daily temperatures was not appropriate. Associated dissolved oxygen data, pH and electrical conductivity also suggest that this location was not desirable. During the 2001 field season, the Bureau of Reclamation moved the sampling location to mid-channel, suspending the sonde from a buoy. The 2001 data, while still illustrating mid- to late-afternoon peaks, do not exhibit such drastic deviations.

Upon close examination, the daily temperature peaks are actually deviations from a smother sinusoidal temperature trace. Figure 89 illustrates the observed temperature at Miller Island (at a depth of approximately 1 meter) with an estimated sinusoidal signal sketched in on Julian days 207, 208, and 212. These deviations occur in the late afternoon, and after observing conditions at Miller Island and Keno, as well as other locations, in the summer of 2003 it is postulated that this upward deviation is due to late afternoon wind mixing. Local meteorological data suggest that during summer periods afternoon winds are typical, especially in the vicinity of Keno where the river cuts through the Cascades. During these afternoon wind events, the mixing energy is presumed to be sufficient to overcome at least a portion of the diurnal stratification wherein surface waters are mixed downward by wind, possibly aided by local velocities (current) within the reservoir. Field data from August 2003 suggest there are considerable temperature differences in the top meter: in the vicinity of Miller Island surface waters (depth of 0.1 m) were 28°C, while at 0.5 and 1.0 meters water temperatures were 25.1°C and 22.5°C, respectively. Towards sunset the thermal loading drastically diminishes and winds die down and water temperatures return to the typical smooth sinusoidal pattern. Examination of the observed data at Highway 66 suggests this occurs at Keno as well. Attempts to refine the model to address these afternoon deviations were not attempted.

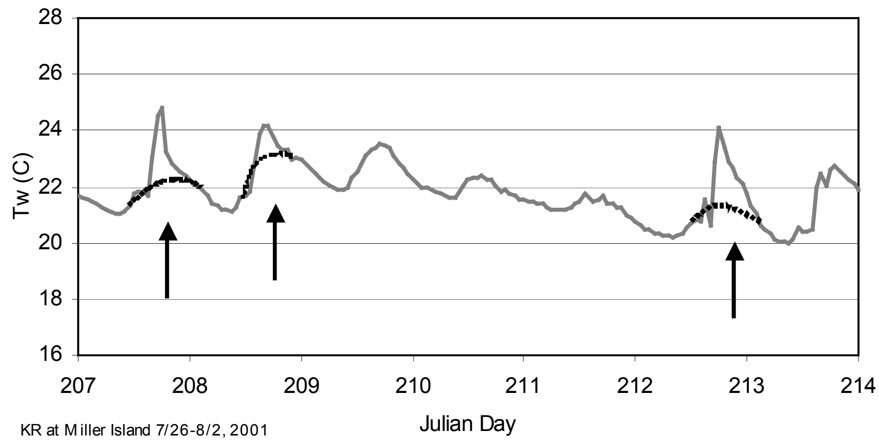
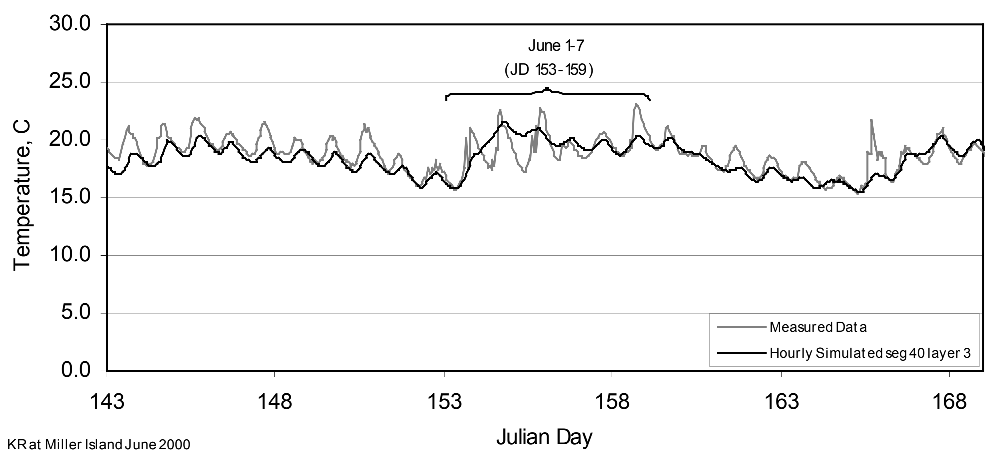
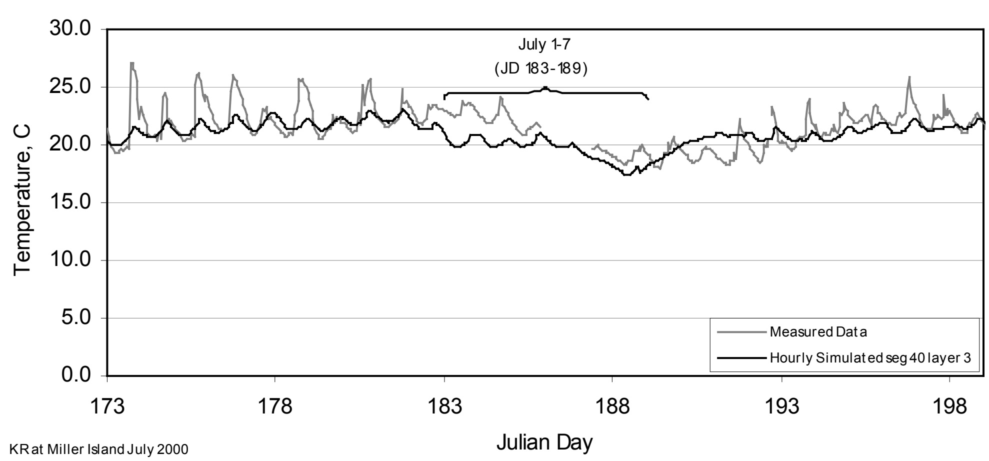


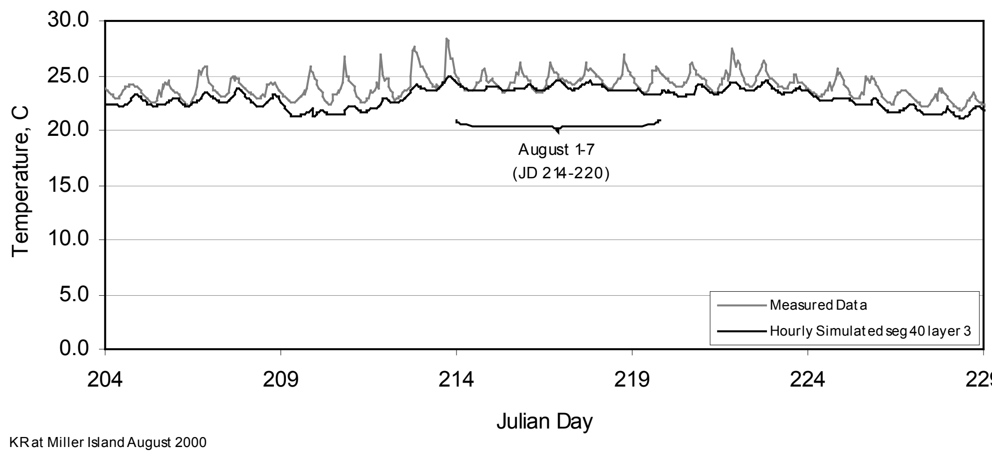
Figure 89. Observed water temperature at Miller Island (2001) showing afternoon deviations from the typical sinusoidal pattern of water temperatures (estimated with the dashed line and marked by arrows)



(a)

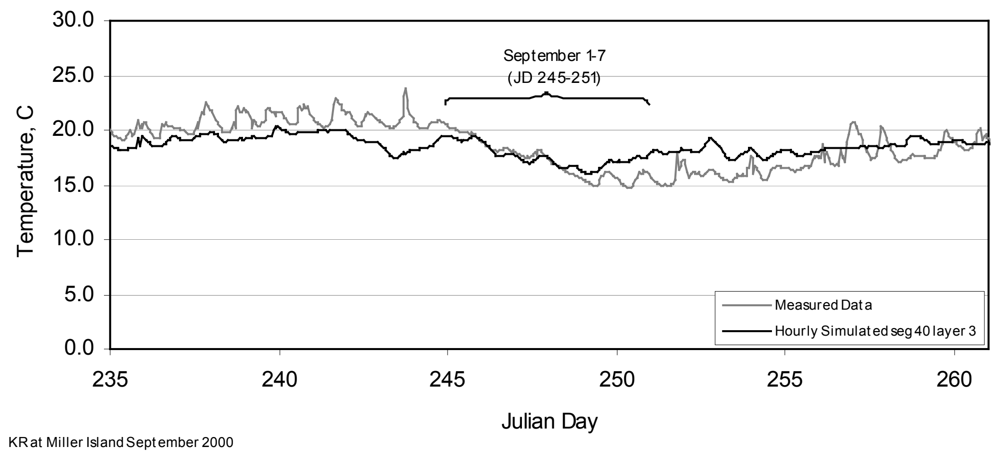


(b)

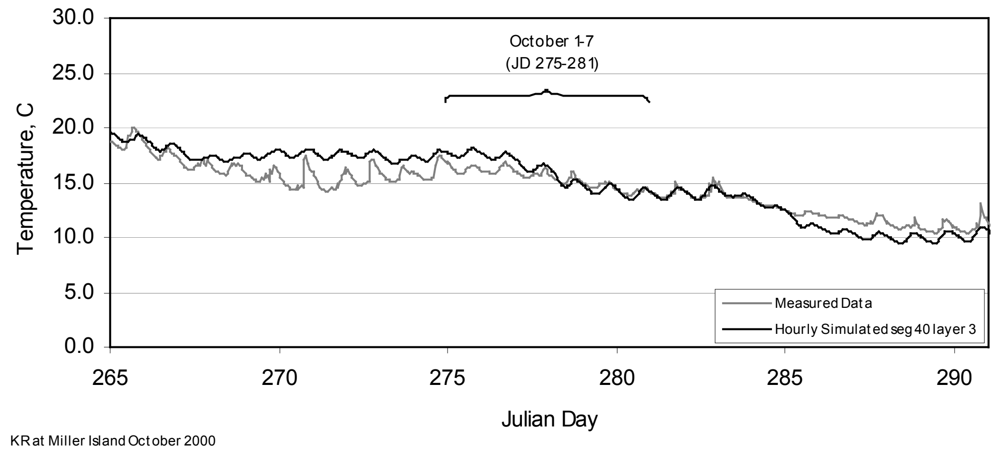


(c)

Figure 90. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000



(a)

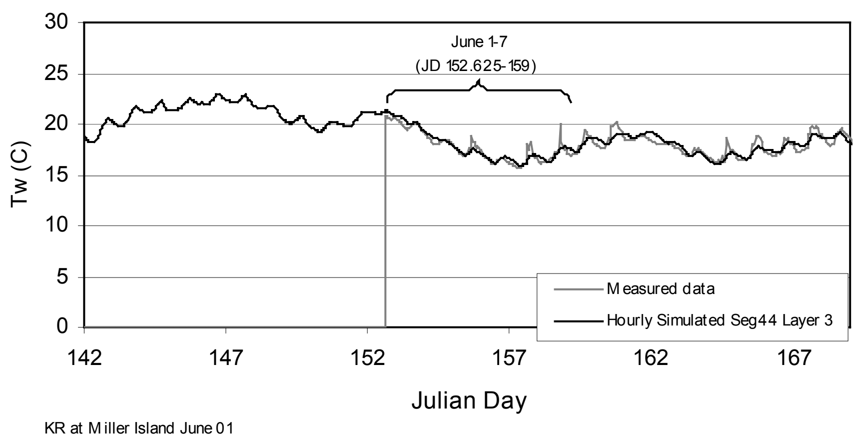


(b)

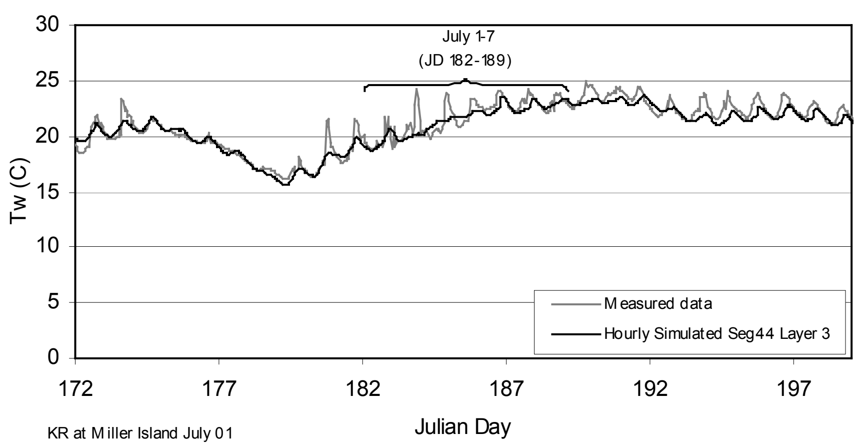
Figure 91. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2000

Table 46. Lake Ewauna-Keno Reach hourly and daily calibration period statistics for temperature at Miller Island 2000

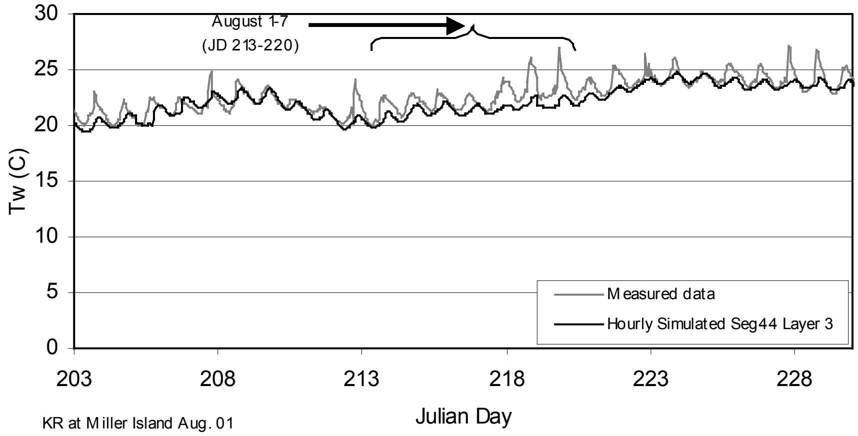
Statistic	Unit	Jun 1-7	Jul 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	°C	0.09	-1.48	-0.80	0.65	0.39
Mean absolute error (MAE)	°C	0.94	1.53	0.83	1.01	0.63
Root mean squared error (RMSE)	°C	1.26	1.78	1.08	1.34	0.82
N	-	168	131	168	168	168
Daily						
Mean Bias	°C	0.09	-1.62	-0.80	0.65	0.91
Mean absolute error (MAE)	°C	0.66	1.62	0.80	0.99	0.56
Root mean squared error (RMSE)	°C	0.78	1.88	0.85	1.69	0.77
N	-	7	4	7	7	7



(a)

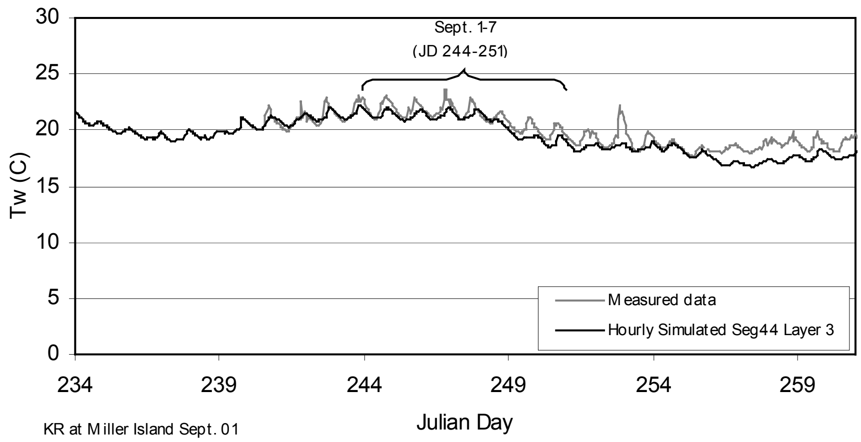


(b)

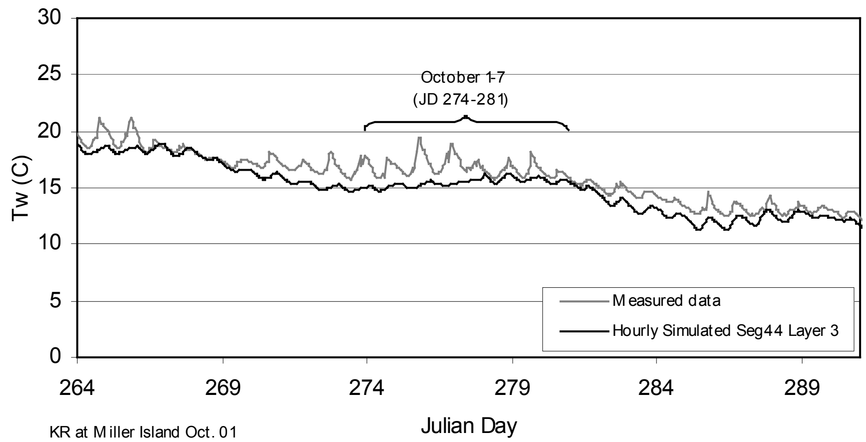


(c)

Figure 92. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001



(a)



(b)

Figure 93. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2001

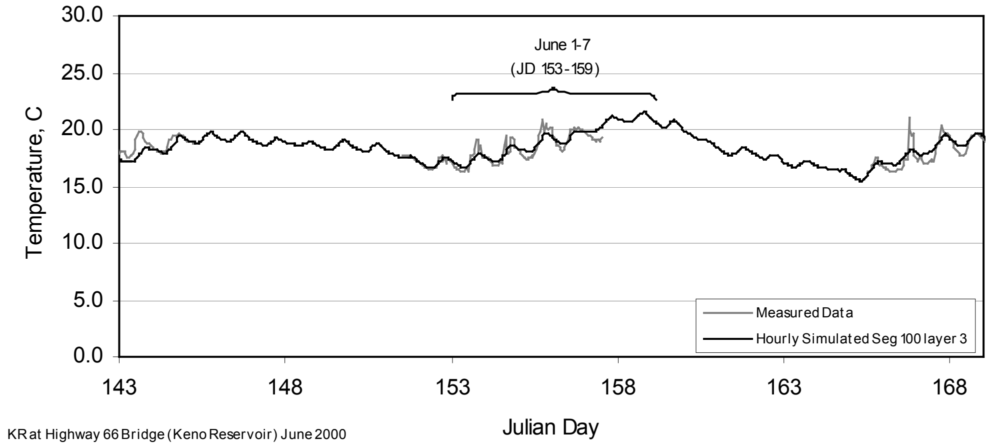
Table 47. Lake Ewauna-Keno Reach hourly and daily calibration period statistics for temperature at Miller Island 2001

Statistic	Unit	Jun 1-7	Jul 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	°C	0.08	-0.29	-1.06	-0.56	-1.31
Mean absolute error (MAE)	°C	0.32	0.61	1.06	0.61	1.31
Root mean squared error (RMSE)	°C	0.45	0.86	1.35	0.75	1.56
N	-	153	168	168	168	168
Daily						
Mean Bias	°C	0.05	-0.32	-1.07	-0.56	-1.31
Mean absolute error (MAE)	°C	0.15	0.33	1.07	0.56	1.31
Root mean squared error (RMSE)	°C	0.19	0.39	1.15	0.60	1.43
N	-	6	7	7	7	7

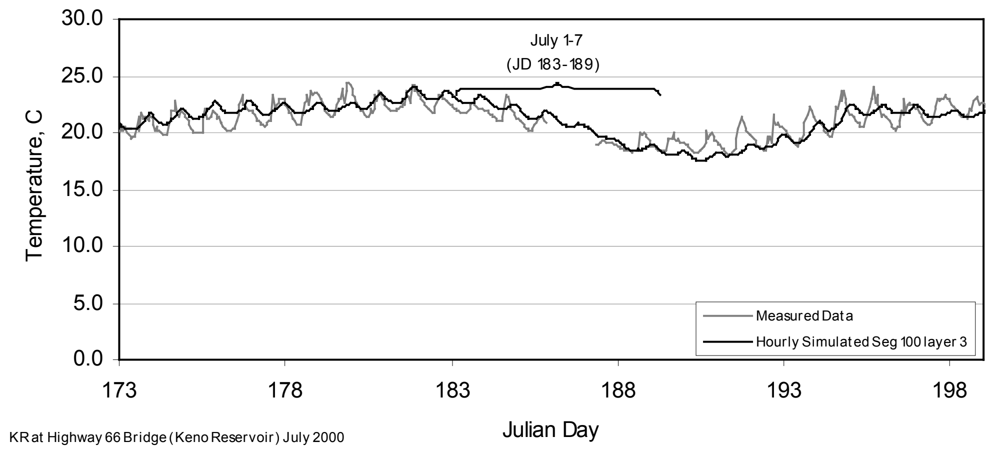
Highway 66 Bridge near Keno

Both 2000 and 2001 were simulated for the calendar year and results shown in Figure 94 through Figure 97. Hourly and daily summary statistics are included in Table 48 and Table 49 for 2000 and 2001, respectively. Seasonal trends and short-term meteorological conditions are clearly reflected in the model results and the models are within 1°C if observed values for all calibration periods. The US Bureau of Reclamation data sonde at Highway 66 has was suspended from a buoy in both 2000 and 2001. Windy conditions, similar to Miller Island are also present in the Keno area.

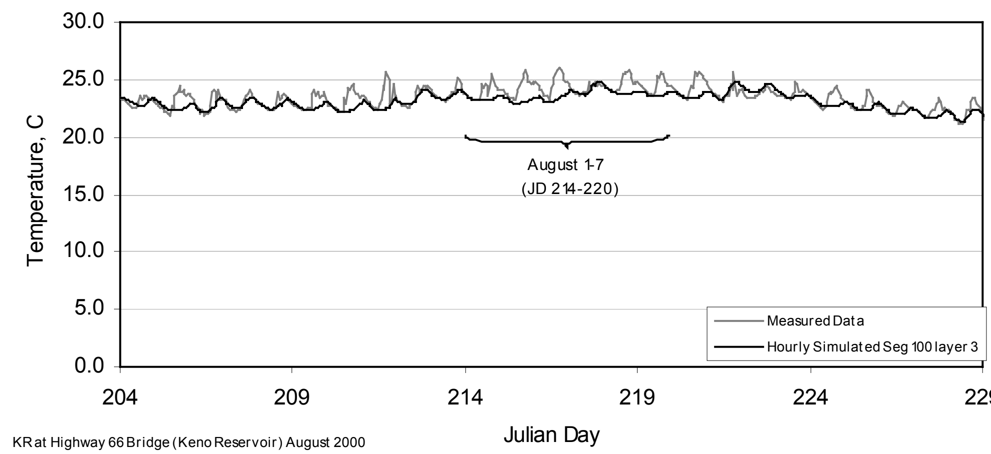
In general the models perform well over a wide range of conditions at both Miller Island and at Highway 66 near Keno.



(a)

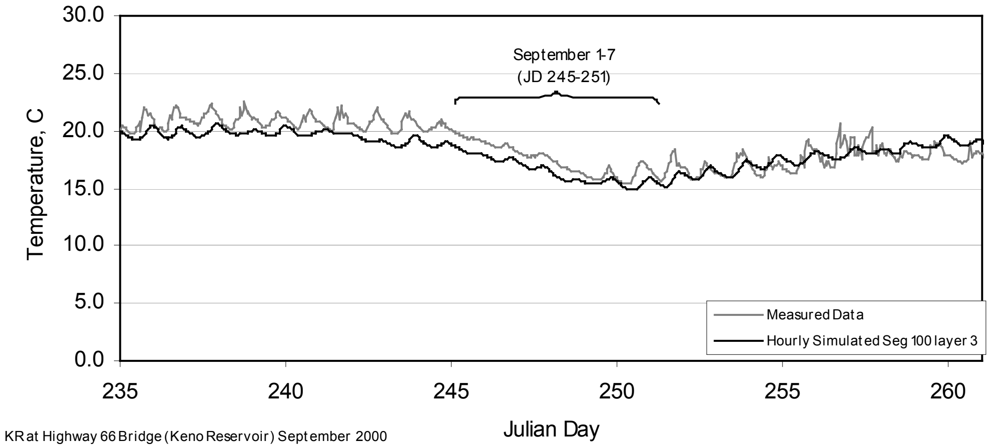


(b)

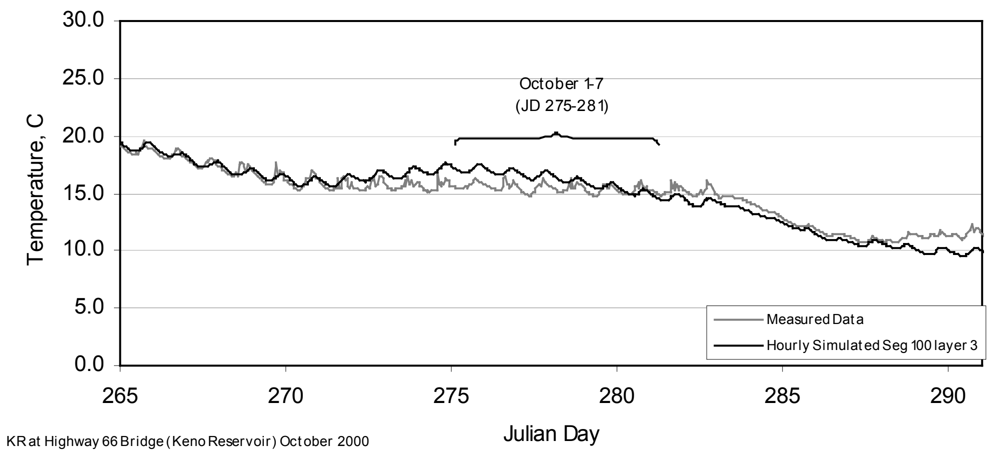


(c)

Figure 94. Temperature simulation results for Lake Ewauna to Keno Reach for Klamath River at Highway 66 bridge (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000



(a)



(b)

Figure 95. Temperature simulation results for Lake Ewauna to Keno for Klamath River at Highway 66 (a) September 1-7 and (b) October 1-7, 2000

Table 48. Lake Ewauna-Keno Reach hourly and daily period statistics for temperature at Highway 66, 2000

Statistic	Unit	June 1-7	July 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	°C	0.06	0.27	-0.75	-0.97	0.60
Mean absolute error (MAE)	°C	0.46	0.70	0.79	0.97	0.85
Root mean squared error (RMSE)	°C	0.56	0.83	1.08	1.07	0.98
N	-	110	132	168	168	168
Daily						
Mean Bias	°C	-0.03	0.14	-0.75	-0.97	0.29
Mean absolute error (MAE)	°C	0.03	0.58	0.75	0.97	0.82
Root mean squared error (RMSE)	°C	0.03	0.61	0.83	1.32	0.93
N	-	4	4	7	7	7

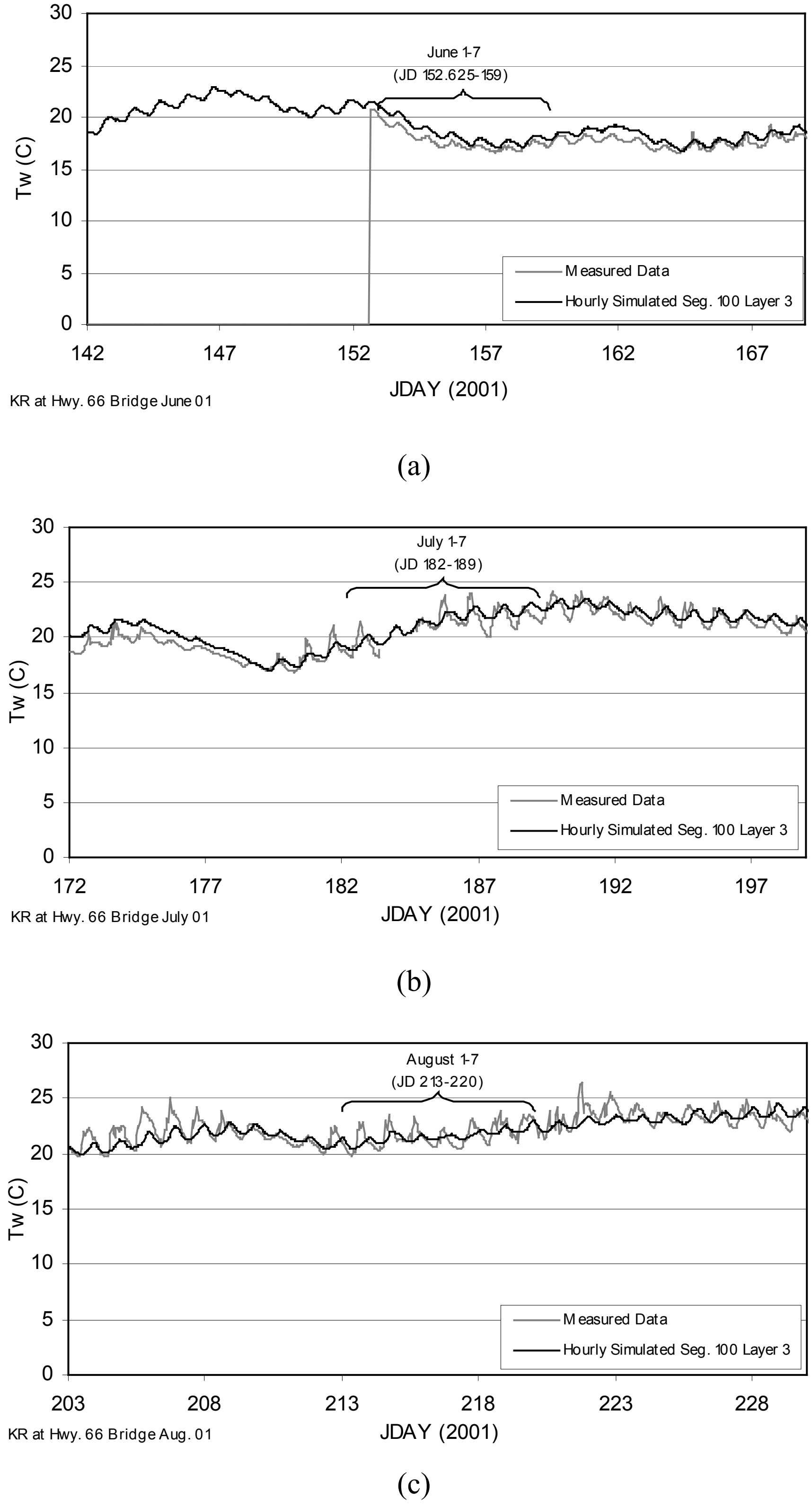
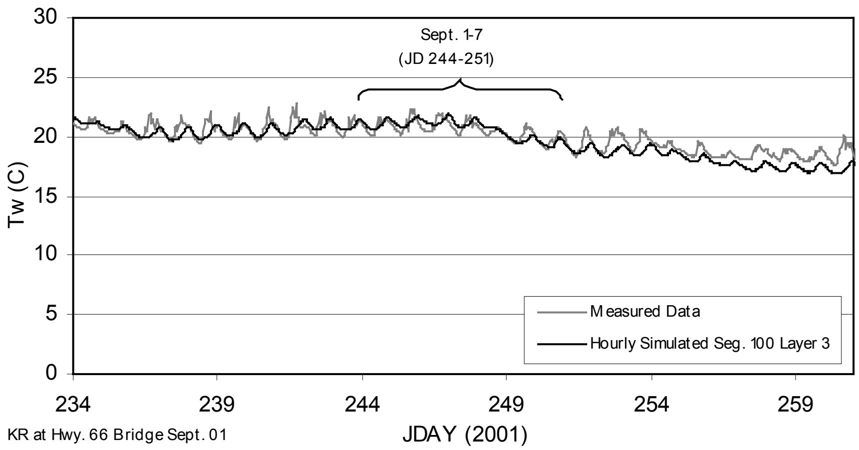
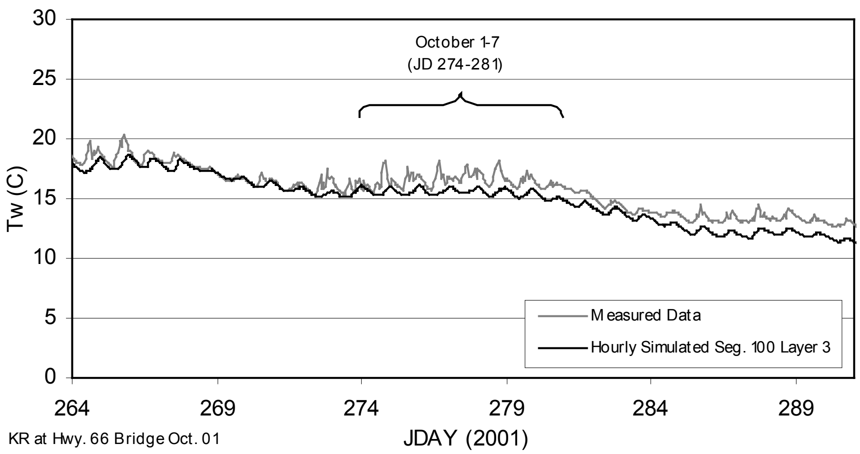


Figure 96. Temperature simulation results for Lake Ewauna to Keno Reach for Klamath River at Highway 66 bridge (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001



(a)



(b)

Figure 97. Temperature simulation results for Lake Ewauna to Keno for Klamath River at Highway 66 (a) September 1-7 and (b) October 1-7, 2001

Table 49. Lake Ewauna-Keno Reach hourly and daily period statistics for temperature at Highway 66, 2001

Statistic	Unit	June 1-7	July 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	°C	0.76	0.27	-0.09	0.06	-1.03
Mean absolute error (MAE)	°C	0.76	0.66	0.65	0.41	1.04
Root mean squared error (RMSE)	°C	0.81	0.80	0.80	0.49	1.17
N	-	153	138	168	168	168
Daily						
Mean Bias	°C	0.76	0.19	-0.10	0.06	-1.04
Mean absolute error (MAE)	°C	0.76	0.34	0.19	0.21	1.04
Root mean squared error (RMSE)	°C	0.81	0.40	0.21	0.22	1.05
N	-	6	5	7	7	7

3.3.2.2 Dissolved Oxygen

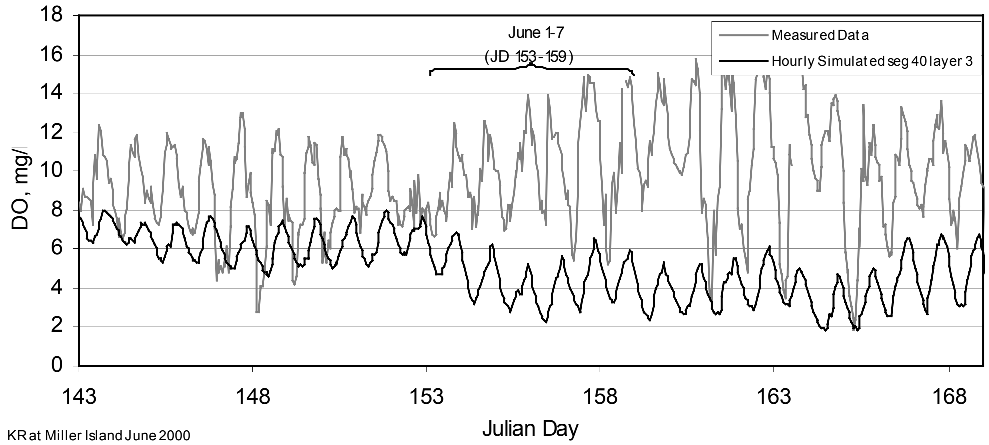
Dissolved oxygen response of Lake Ewauna to Keno Dam is unique for a river system of this size and morphology. The system receives appreciable organic loads from Upper Klamath Lake as well as small, but low quality return flows from municipal, industrial, and agricultural sources. However, an overriding system condition is the severe, persistent anoxia that develops within the system from near the bottom of Lake Ewauna proper to near Keno Dam. Although there are a suite of parameters available for model calibration, including algal growth, respiration and mortality rates, nutrient decay rates, organic matter decay rates, and SOD (zero order), the critical factor is the considerable organic load from Upper Klamath Lake – and the characterization of that boundary condition at Link Dam.

Initial model calibration identified the need for additional field information and year 2001 was added to the analysis. Results for both 2000 and 2001 suggest that general seasonal trends are represented, as are diurnal variations and periods of anoxia. Further, trends in dissolved oxygen concentration for many of the multi-week periods shown in the figures are well represented. However, the model performance is spotty with certain periods not well represented. Simulated results at Highway 66 are notably better than those at Miller Island. Based on field data and model simulations, it is postulated that the region of extreme water quality conditions originates in the stretch from Lake Ewauna to somewhere in the vicinity of Miller Island – a reach of roughly seven or eight miles. Thus results at the upper site – Miller Island – are more directly impacted than those at the lower River site near Keno Dam. The dynamic nature of the Lake Ewauna/Keno reach is primarily driven by the organic load originating in Upper Klamath Lake. The long, narrow aspect of Keno Reservoir results in a much reduced surface area for primary production to occur versus the broad aspect of Upper Klamath Lake. Given the large organic load (dead algae, as well as living algae that flows into the narrow Lake Ewauna/Keno reach and resides below the photic zone and subsequently dies) and the measurable current, it appears that the reservoir experiences an oxygen sag with the largest oxygen deficits occurring between Lake Ewauna to downstream of Miller Island and then showing modest recovery by the time waters reach Keno.

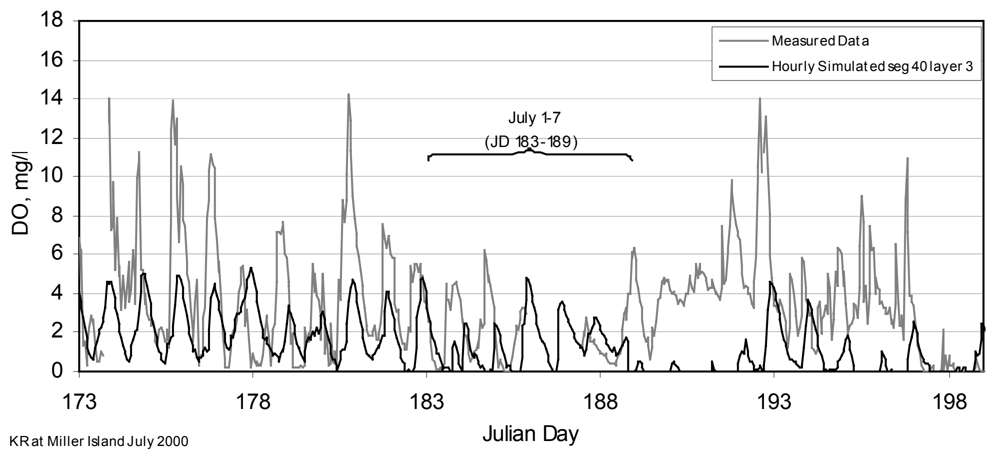
A limited amount of model testing was completed with CE-QUAL-W2 to determine the sensitivity of dissolved oxygen to influent algae and BOD concentrations from Link Dam and the model is quite sensitive to short term variations in these parameters at the upstream boundary conditions. It is estimated that improved results could be obtained if water quality information were collected on a more frequent basis (e.g. twice weekly) to more completely represent water quality conditions of waters leaving Upper Klamath Lake.

Additional model simulations were completed to determine if algal populations, and thus dissolved oxygen, would be affected if respiratory requirements were not met during anoxic periods. The model was modified to limit algal growth based on respiratory needs of phytoplankton. Specifically, if there was insufficient dissolved oxygen in the water column to support respiration of algae, algal mortality was increased.

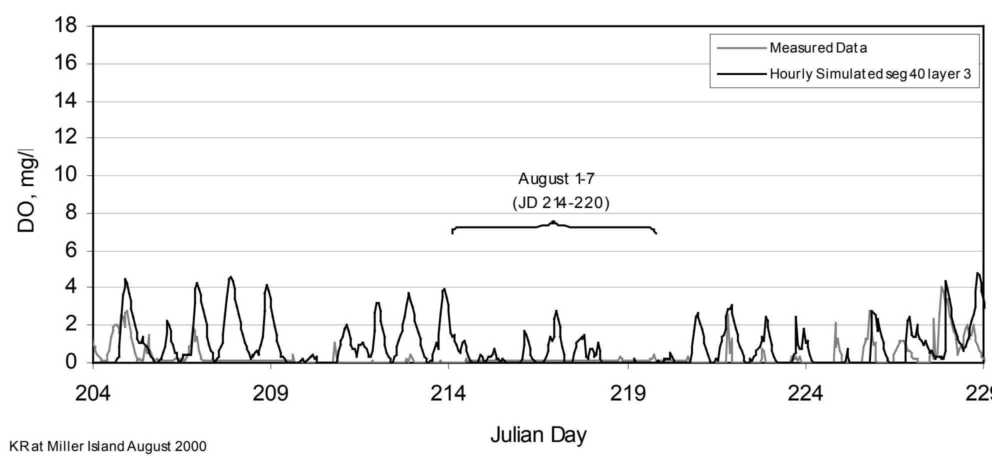
While there was no field data to test the model logic, sensitivity testing of the model parameters while assessing phytoplankton, DO, and nutrient level responses indicated that algal respiratory requirements is probably not the primary factor behind the persistent anoxia, elevated nutrients and low algal counts that are prone to occur in this reach. Advection from upstream reaches tends to re-colonize downstream reaches on the order of days. Further research into this issue has focused on algal inhibition by one of several factors, potentially including impacts of pharmaceutical/human health and personal care products in municipal treated effluent, phenolic compounds associated with organic matter – including that within the sediments (source: tannins, humic substances, lignin), production of hydrogen peroxide, other chemical constituents or reactions that may lead to inhibition or toxicity. Additional analyses and field studies have been completed in 2003 to refine model representation of dissolved oxygen, as well as other factors, in this reach; however, additional studies are needed to more fully characterize the complex dynamics of this reach and its relationship with Upper Klamath Lake..



(a)

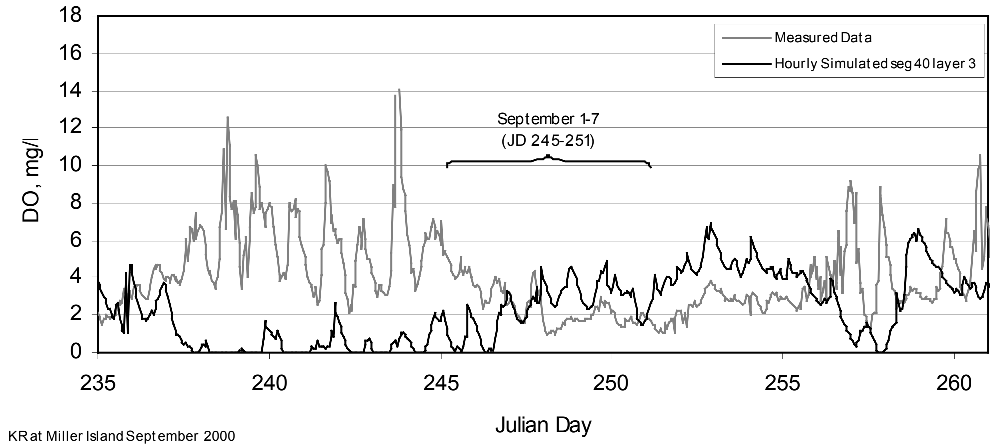


(b)

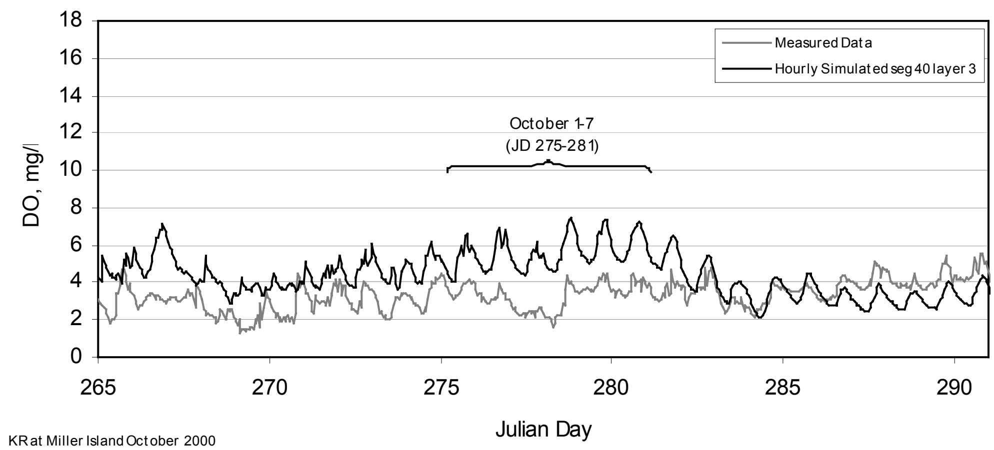


(c)

Figure 98. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000



(a)

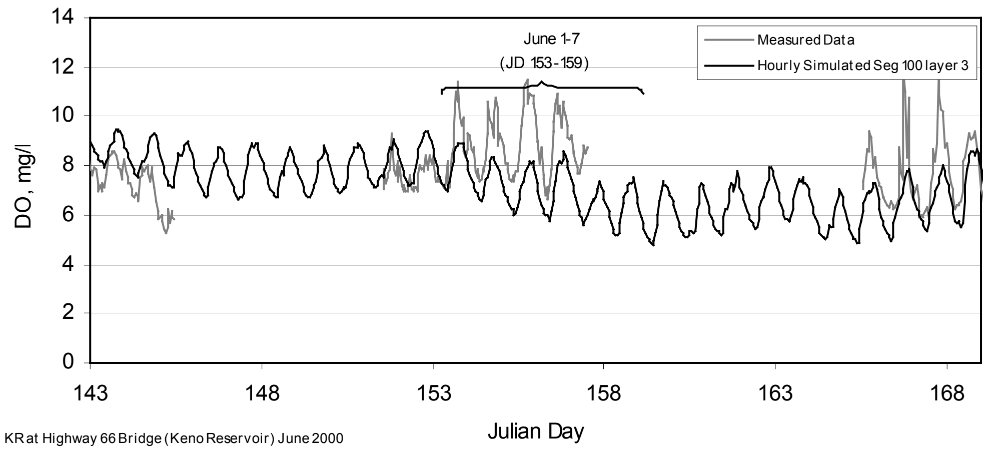


(b)

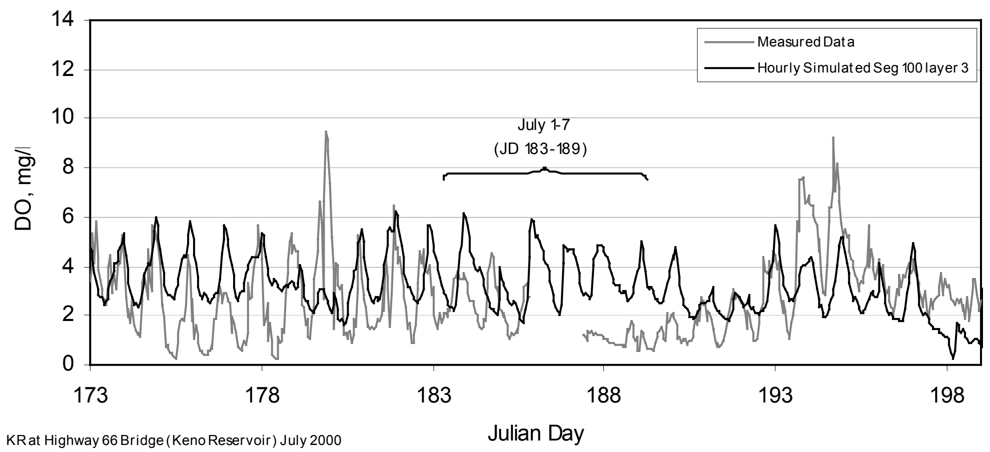
Figure 99. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2000

Table 50. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Miller Island, 2000

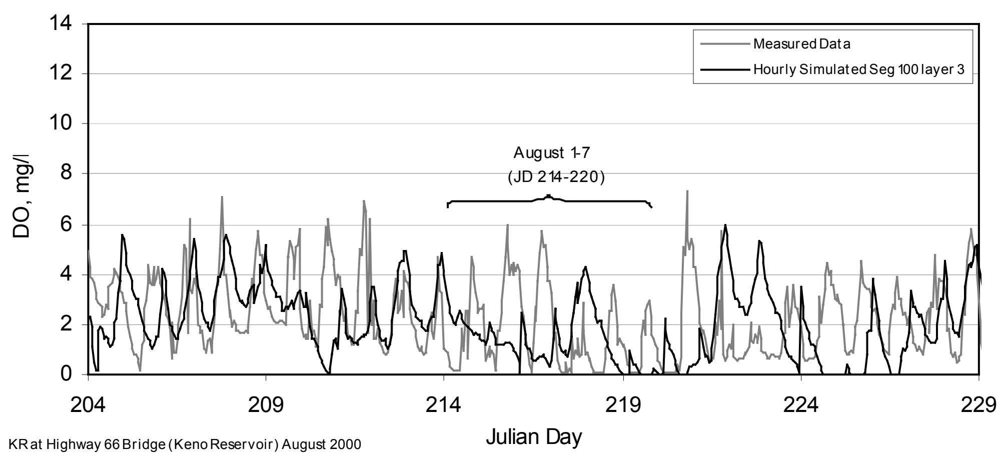
Statistic	Unit	Jun 1-7	Jul 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	mg/l	-5.94	-1.41	0.20	0.05	2.25
Mean absolute error (MAE)	mg/l	5.94	1.95	0.33	1.79	2.25
Root mean squared error (RMSE)	mg/l	6.40	2.56	0.57	2.13	2.36
N	-	168	126	152	168	168
Daily						
Mean Bias	mg/l	-5.89	-1.80	0.30	0.05	2.25
Mean absolute error (MAE)	mg/l	5.89	1.80	0.34	1.72	2.25
Root mean squared error (RMSE)	mg/l	6.07	1.99	0.43	1.98	2.30
N	-	7	4	7	7	7


June 1-7
(JD 153-159)
Measured Data
Hourly Simulated Seg 100 layer 3
DO, mg/l
Julian Day
KR at Highway 66 Bridge (Keno Reservoir) June 2000

(a)

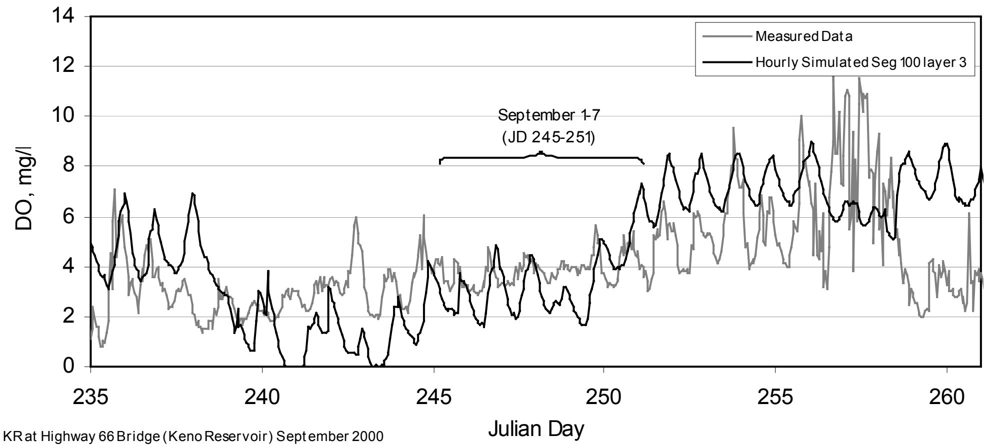

July 1-7
(JD 183-189)
Measured Data
Hourly Simulated Seg 100 layer 3
DO, mg/l
Julian Day
KR at Highway 66 Bridge (Keno Reservoir) July 2000

(b)

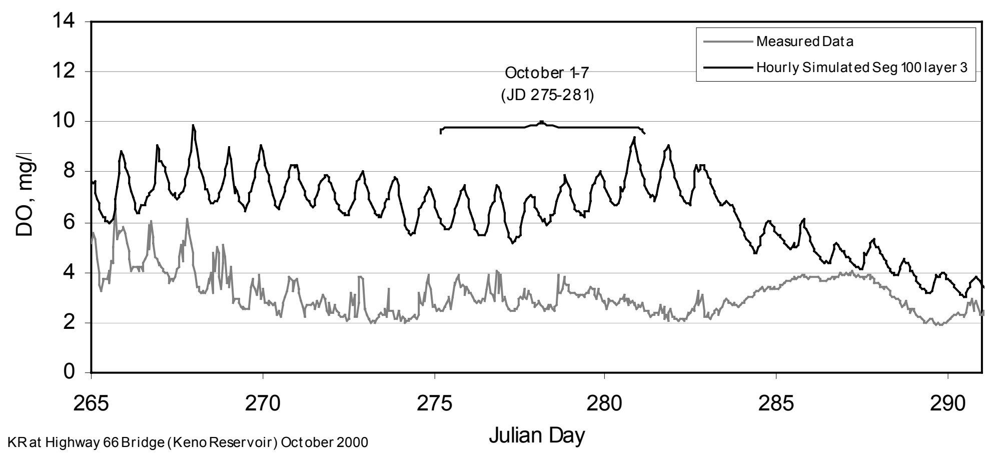

August 1-7
(JD 214-220)
Measured Data
Hourly Simulated Seg 100 layer 3
DO, mg/l
Julian Day
KR at Highway 66 Bridge (Keno Reservoir) August 2000

(c)

Figure 100. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000



(a)



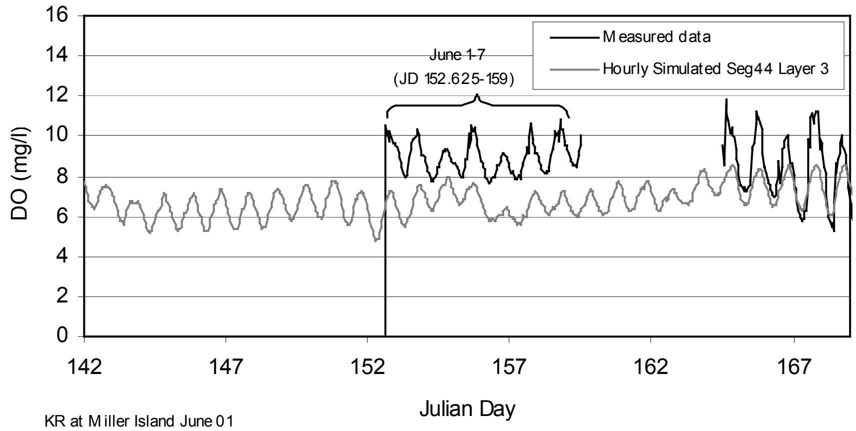
(b)

Figure 101. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) September 1-7, (b) October 1-7, 2000

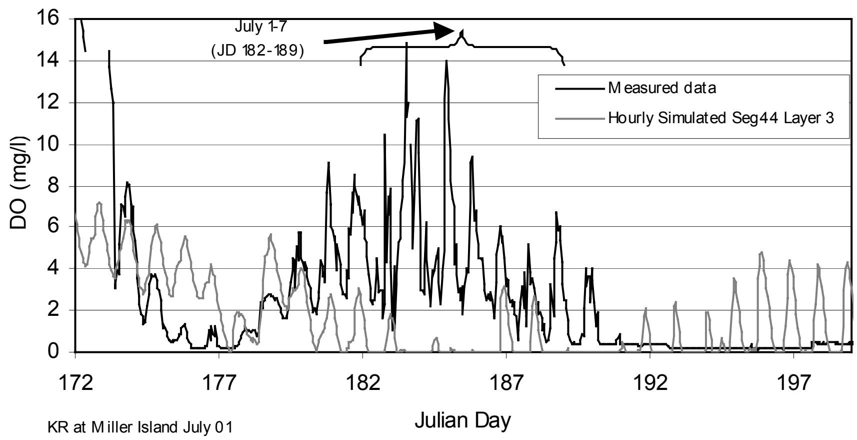
Table 51. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Highway 66, 2000

Statistic	Unit	June 1-7	July 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	mg/l	-1.50	1.54	-0.48	-0.24	3.96
Mean absolute error (MAE)	mg/l	1.55	1.86	1.80	1.15	3.96
Root mean squared error (RMSE)	mg/l	1.78	2.06	2.26	1.38	4.09
N	-	110	132	168	168	168
Daily						
Mean Bias	mg/l	-1.42	1.55	-0.48	-0.24	3.96
Mean absolute error (MAE)	mg/l	1.42	1.55	1.15	1.00	3.96

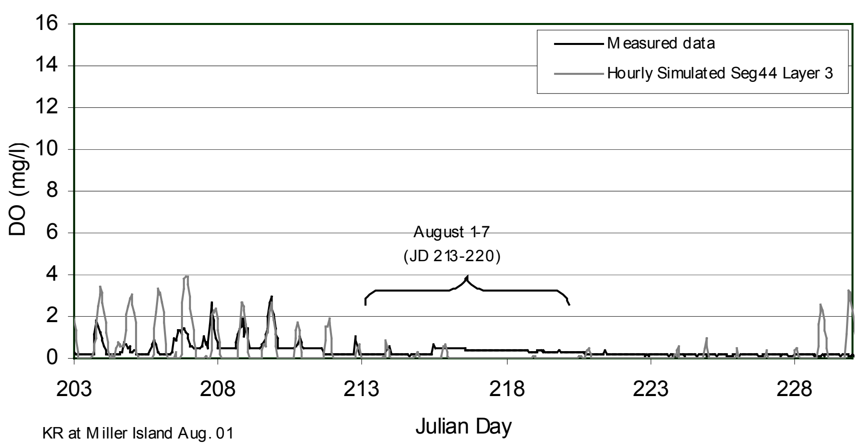
Root mean squared error (RMSE)	mg/l	1.56	1.72	1.27	1.11	4.05
N	-	4	4	7	7	7



(a)

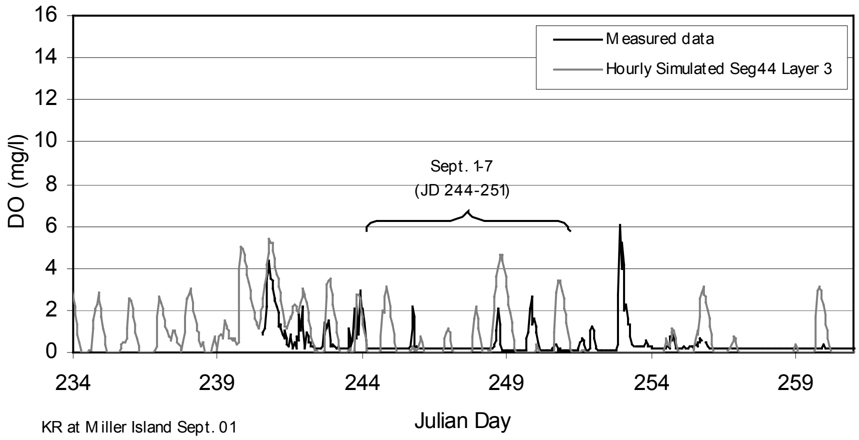


(b)

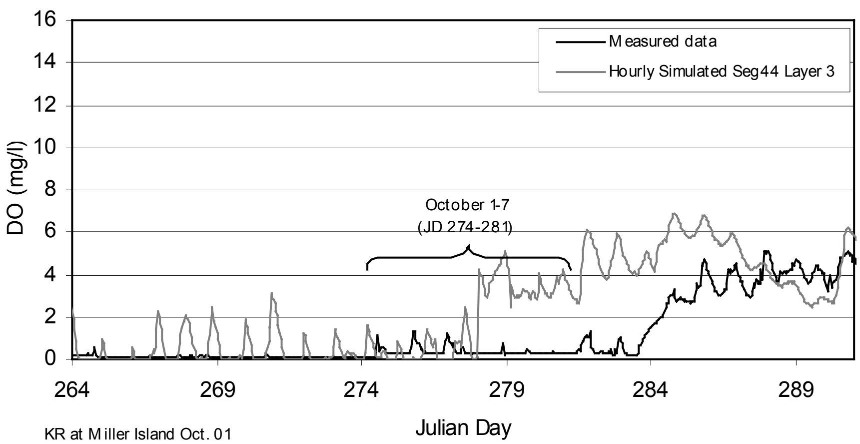


(c)

Figure 102. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001



(a)



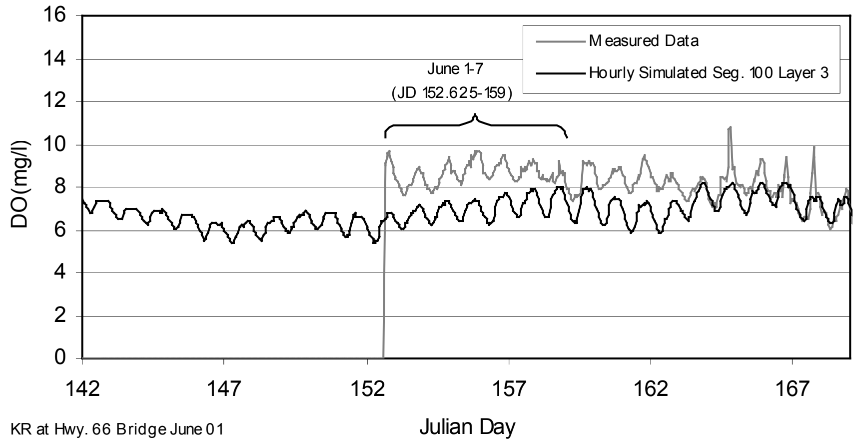
(b)

Figure 103. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2001

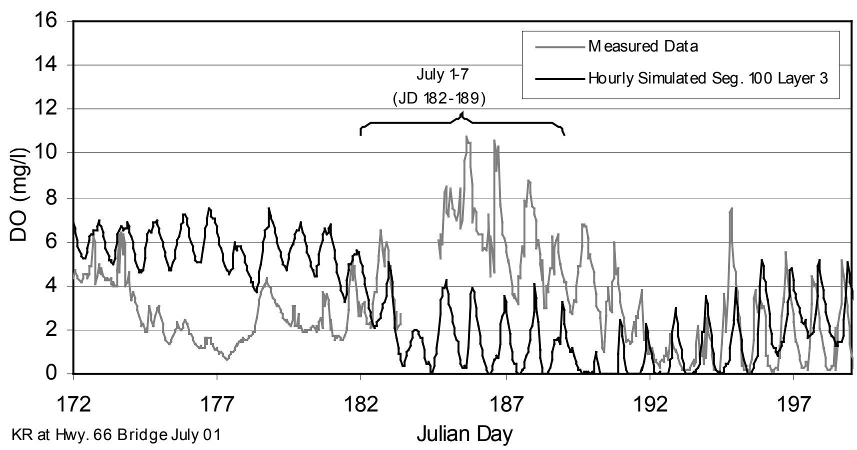
Table 52. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Miller Island, 2001

Statistic	Unit	Jun 1-7	Jul 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	mg/l	-2.26	-4.19	-0.29	0.42	1.41
Mean absolute error (MAE)	mg/l	2.26	4.20	0.30	0.82	1.70
Root mean squared error (RMSE)	mg/l	2.34	5.13	0.32	1.33	2.24
N	-	144	167	168	168	168
Daily						
Mean Bias	mg/l	-2.26	-4.21	-0.29	0.42	1.41

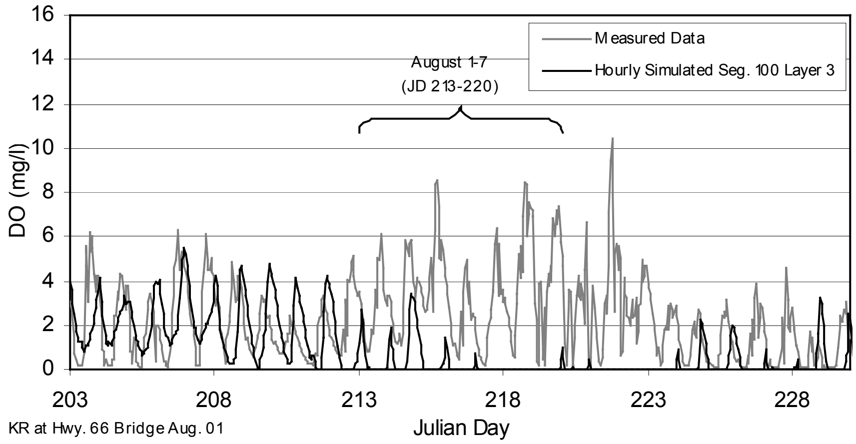
Mean absolute error (MAE)	mg/l	2.26	4.21	0.29	0.46	1.51
Root mean squared error (RMSE)	mg/l	2.29	4.53	0.30	0.68	2.14
N	-	6	7	7	7	7



(a)

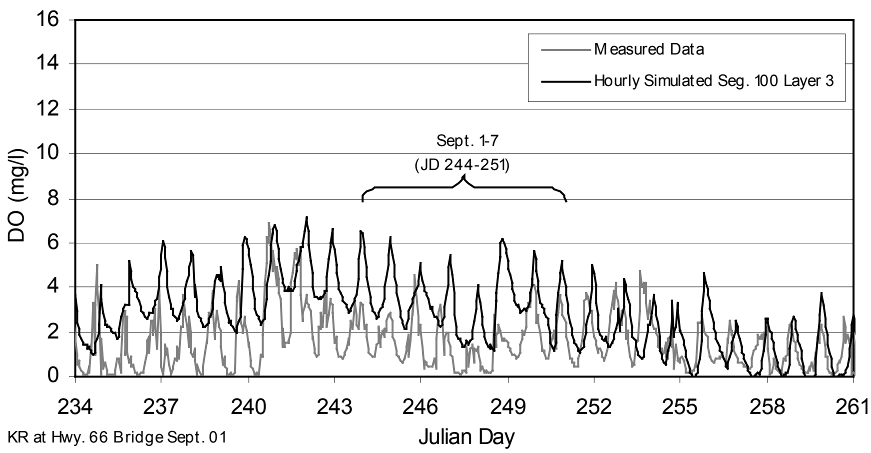


(b)

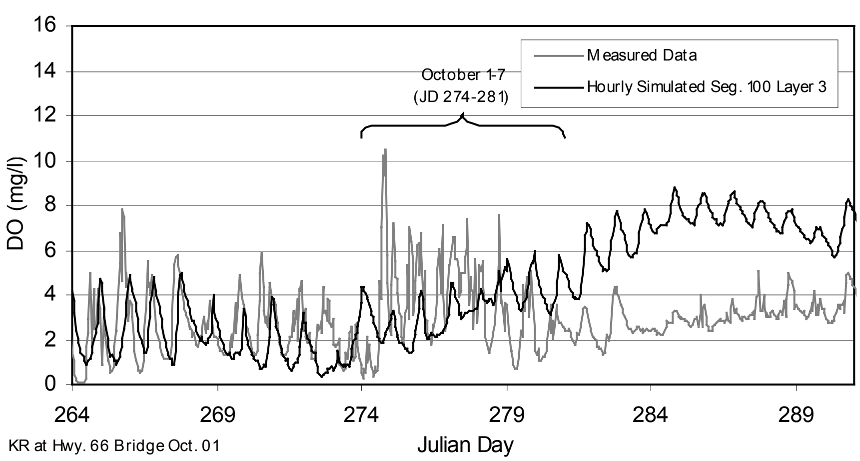


(c)

Figure 104. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001



(a)



(b)

Figure 105. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) September 1-7, (b) October 1-7, 2001

Table 53. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Highway 66, 2001

Statistic	Unit	June 1-7	July 1-7	Aug 1-7	Sept 1-7	Oct 1-7
Hourly						
Mean Bias	mg/l	-1.50	1.54	-0.48	-0.24	3.96
Mean absolute error (MAE)	mg/l	1.55	1.86	1.80	1.15	3.96
Root mean squared error (RMSE)	mg/l	1.78	2.06	2.26	1.38	4.09
N	-	110	132	168	168	168
Daily						
Mean Bias	mg/l	-1.42	1.55	-0.48	-0.24	3.96
Mean absolute error (MAE)	mg/l	1.42	1.55	1.15	1.00	3.96
Root mean squared error (RMSE)	mg/l	1.56	1.72	1.27	1.11	4.05
N	-	4	4	7	7	7

3.3.2.3 Nutrients and Phytoplankton

Nutrient concentrations were not formally calibrated in the Lake Ewauna to Keno Dam reach; however, examination of model performance was compared with limited available field data.

As noted previously, the upstream boundary condition at Link Dam plays a critical role in the water quality response of Lake Ewauna/Keno Reservoir during spring through fall periods. Most sampling programs to date have either collected data infrequently (e.g., semi-monthly, monthly, quarterly). A limited amount of daily monitoring was done in 2002 (two periods of three days each). However, observations of data sonde data at Link Dam, Link River at Lake Ewauna, and other downstream locations, as well as the infrequent grab sample data suggest that past monitoring efforts do not sufficiently represent the dynamic water quality conditions present at Link Dam. The transit time through the reservoir during summer periods ranges from approximately 7 to 14 days depending on time of year, local operations, and water year type. Thus monitoring programs that span either a few days or multiple weeks are insufficient to fully characterize the spatial and temporal conditions between Link River and Keno Dam. The monitoring and modeling effort has provided critical insight into the temporal and spatial variability and response of system processes, including thermal, dissolved oxygen, and nutrient conditions. The model has been used to assess variable boundary conditions at Link Dam, Lost River, and Klamath Straits drain and has identified the need for more detailed Link Dam and Lost River inflow water quality conditions.

When anoxia occurs within this reach, algal concentrations decline, and a corresponding increase in nutrients occurs. It is apparent from field observations that under anoxia there is decreased phytoplankton present reducing the opportunity of increased oxygen levels through photosynthesis, as well as elevated nutrient levels. Field observations also indicate that pH falls from a range of 8.5 to 9.5 under aerobic conditions to around 7 during periods of severe anoxia (Watercourse, 2003), further indicating the absence of algal production in this weakly buffered system.

The model generally under-predicted orthophosphate during the first part of the season, but was in general agreement after July. Ammonia was well represented throughout the simulation, while nitrate was systematically under predicted. The model over predicted algal biomass, especially in the Keno region. Further model and field studies are planned for 2003 to refine model representation of system conditions in this reach.

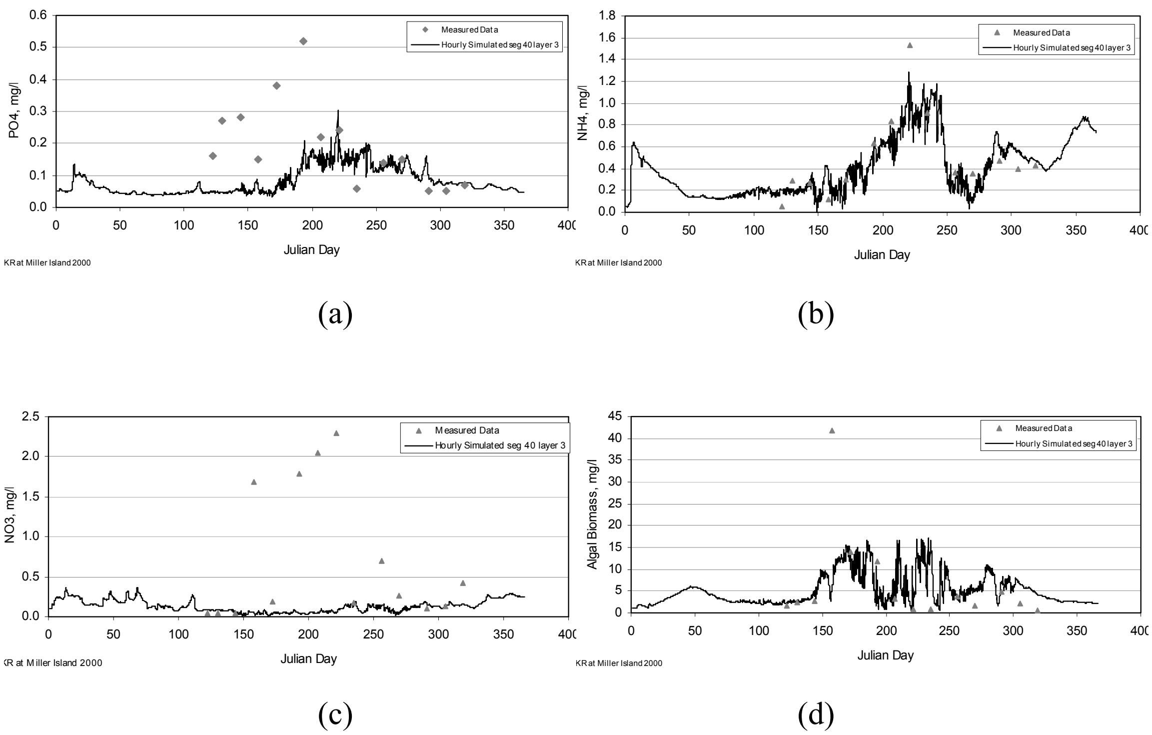


Figure 106. Simulated (line) and observed (triangles) nutrients and algal biomass for Klamath River at Miller Island in the Lake Ewauna to Keno Dam reach. (a) phosphate; (b) ammonia; (c) nitrate; (d) algal biomass

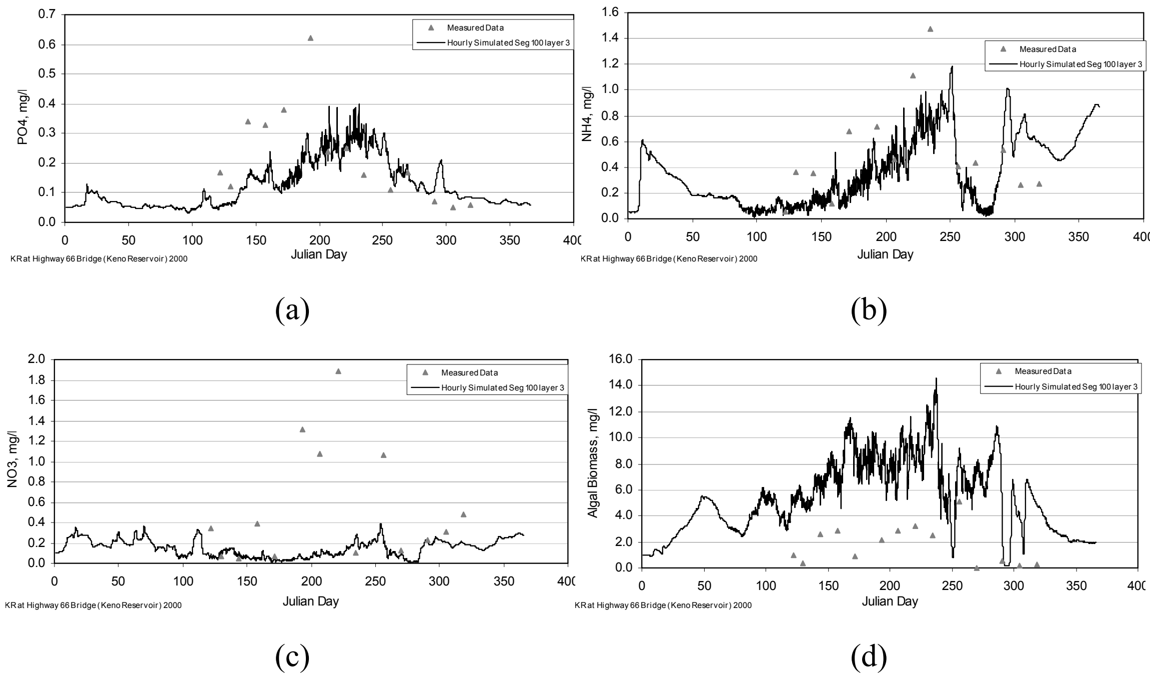


Figure 107. Simulated (line) and observed (triangles) nutrient and algal biomass for Klamath River at Highway 66 bridge in the Lake Ewauna to Keno Dam reach. (a) phosphate; (b) ammonia; (c) nitrate; (d) algal biomass.

3.3.2.4 Summary of Parameters

Table 54. Significant control file parameters for the Lake Ewauna to Keno Dam reach calibration

Parameter Name	Description	EC Lake Ewauna Value	Default Value
DLT MIN	Minimum timestep, sec	5.0	N/A
DLT MAX	Maximum timestep, sec	500	N/A
SLOPE	Waterbody bottom slope	0.0	N/A
LAT	Latitude, degrees	42.13	N/A
LONG	Longitude, degrees	121.95	N/A
EBOT	Bottom elevation of waterbody, m	1236.25	N/A
CFW	C coefficient in the wind speed formulation	1.0	2.0
WINDH	Wind speed measurement height, m	2.0	N/A
TSED	Sediment (ground) Temperature, C	12.0	N/A
FI	Interfacial friction factor	0.04	N/A
TSEDF	Heat lost to sediments that is added back to water column, fraction	0.01	N/A
EXH2O	Extinction for pure water, m^{-1}	0.25	0.25 (for full WQ sim)
CGQ10 (Tracer)	Arhennius temperature rate multiplier	0	0
CG0DK (Tracer)	0-order decay rate, 1/day	0	0
CG1DK (Tracer)	1^{st}-order decay rate, 1/day	0	0
CGS (Tracer)	Settling rate, m/day	0	0
CGQ10 (Age)	Arhennius temperature rate multiplier	0	0
CG0DK (Age)	0-order decay rate, 1/day	-1.0	-1.0
CG1DK (Age)	1^{st}-order decay rate, 1/day	0	0
CGS (Age)	Settling rate, m/day	0	0
CGQ10 (Coliform)	Arhennius temperature rate multiplier	1.04	N/A
CG0DK (Coliform)	0-order decay rate, 1/day	0	N/A
CG1DK (Coliform)	1^{st}-order decay rate, 1/day	1.4	N/A
CGS (Coliform)	Settling rate, m/day	1.0	N/A
AG	Maximum algal growth rate, 1/day	3.0	2.0
AR	Maximum algal respiration rate, 1/day	0.05	0.04
ASAT	Light saturation intensity at a maximum photosynthetic rate, W/m^2	100.0	75.0
AT1	Lower temperature for algal growth, C	5.0	5.0
PO4R	Sediment release rate of phosphorus, fraction of SOD	0.03	0.001
PARTP	Phosphorus partitioning coefficient for suspended solids	0.001	0.0
NH4REL	Sediment release rate of ammonium, fraction of SOD	0.07	0.001
NH4DK	Ammonium decay rate, 1/day	0.1	0.12
NO3DK	Nitrate decay rate, 1/day	0.1	0.03
NO3S	De-nitrification rate from sediments, m/day	0	1.0
CO2REL	Sediment carbon dioxide release rate, fraction of SOD	0.01	0.1
O2AR	Oxygen stoichiometry for algal respiration	1.4	1.1
O2AG	Oxygen stoichiometry for algal primary production	1.5	1.4
SOD	Zero-order sediment oxygen demand for each segment, $g\ O_2\ /\ m^2 day$	2.0 (for each segment)	N/A

3.4 Keno Reach

The Keno reach extends from Keno Dam to the headwaters of JC Boyle Reservoir, a distance of about 5.4 miles. The RMA suite of models for the Klamath River Keno reach was calibrated and validated using data from the periods of May 21-23, 2002 and September 10-12, 2002, respectively.

3.4.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and observations in the Klamath River above JC Boyle were required (calibration/validation points). There were no intermediate locations within this short reach that required inflow for outflow boundary condition or that were used for calibration and validation.

3.4.1.1 Boundary Conditions

The boundary condition data was derived from samples collected at Keno Dam and Highway 66. Hourly water temperature and dissolved oxygen data were available from water quality probes deployed by the US Bureau of Reclamation at Highway 66 near Keno. Grab samples were collected once per day for three days below Keno Dam. Due to the inherent variability and infrequent sampling interval of the grab data, the boundary condition values for nutrients, BOD, and algae were assumed to be a constant value for the calibration and validation period, based on the grab sample data from 2002 (Appendix F). The water quality values for the calibration and validation period are shown in Table 41 and Figure 73 and Figure 74.

Table 55. Keno Dam to JC Boyle Reservoir, Klamath River reach calibration and validation water quality boundary conditions

		Dates	
Parameter	**Units**	5/21/02 - 5/23/02	9/10/02 – 9/12/02
BOD	mg/l	3.0	5.0
DO	mg/l	variable	variable
Org N	mg/l	0.80	1.50
NH_4^+	mg/l	0.10	0.15
NO_2^-	mg/l	0.00	0.00
NO_3^-	mg/l	0.10	0.20
Org P	mg/l	0.30	0.05
PO_4^{3-}	mg/l	0.20	0.20
Algae	mg/l	2.0	4.2
Tw	°C	variable	variable

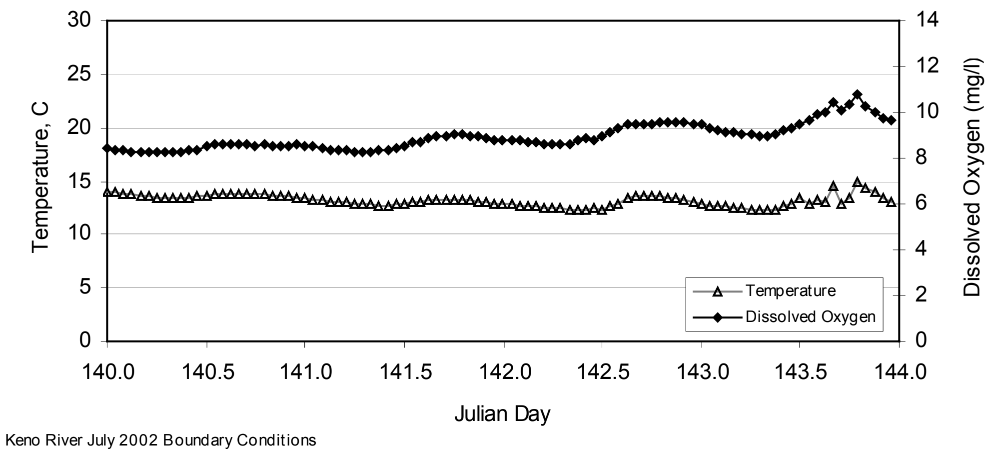


Figure 108. Keno Dam temperature and dissolved oxygen calibration boundary conditions

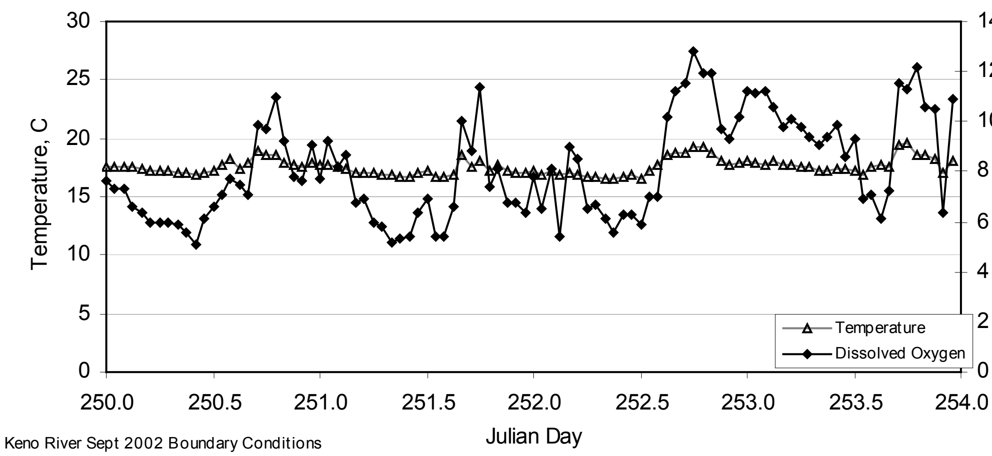


Figure 109. Keno Dam temperature and dissolved oxygen validation boundary conditions

3.4.1.2 Initial conditions

The model was run for one day prior to both the calibration and validation periods to provide an initial condition for simulation. The initial bed algae mass was estimated at 5 g/m^2.

3.4.1.3 Calibration and Validation Points

The calibration and validation point for the Keno reach was Klamath River above JC Boyle Reservoir. During May and July water quality probes and tidbit temperature devices were employed to represent conditions above JC Boyle Reservoir. These data are displayed in the following section with model results.

3.4.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The exception is validation during the September period: grab sample temperatures and dissolved oxygen data were available, but the sonde deployed during the data gathering effort malfunctioned and hourly data were not available. The nutrient data were primarily derived from field data, which were sampled once per day. All model parameters for the Keno reach are summarized in Table 58 at the end of this section.

3.4.2.1 Water Temperature

Water temperature calibration required varying evaporation heat flux coefficients (presented in Table 58) that govern the mass transfer formulation represented in the numerical model heat budget. No other parameters were varied. The hourly results are presented graphically in Figure 110 through Figure 112. Summary statistics are included in Table 56. The diurnal range and phase is well represented for spring temperatures in the neighborhood of 12°C-15°C. Limited data for the September period late summer period was available for temperature. To further test the model available data from mid-July were used to test the model. Phase and diurnal range are well represented under conditions when observations conditions exceeded 25°C. Hourly bias for the July simulation was –0.19°C with a mean absolute error of 0.54°C. Tabulated statistics (Table 56) illustrate that simulated results on an hourly and daily basis are within 1°C of observations.

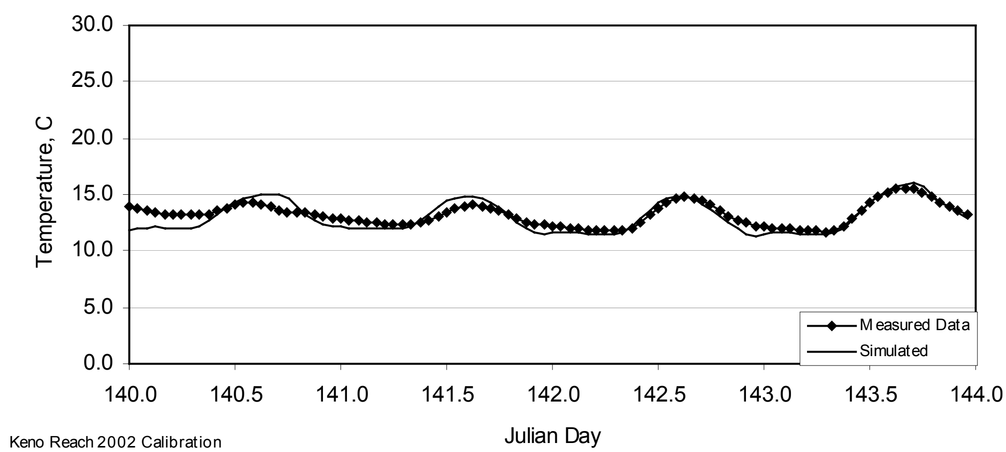


Figure 110. Klamath River, Keno to JC Boyle, simulated versus measured water temperature, May 20-23, 2002

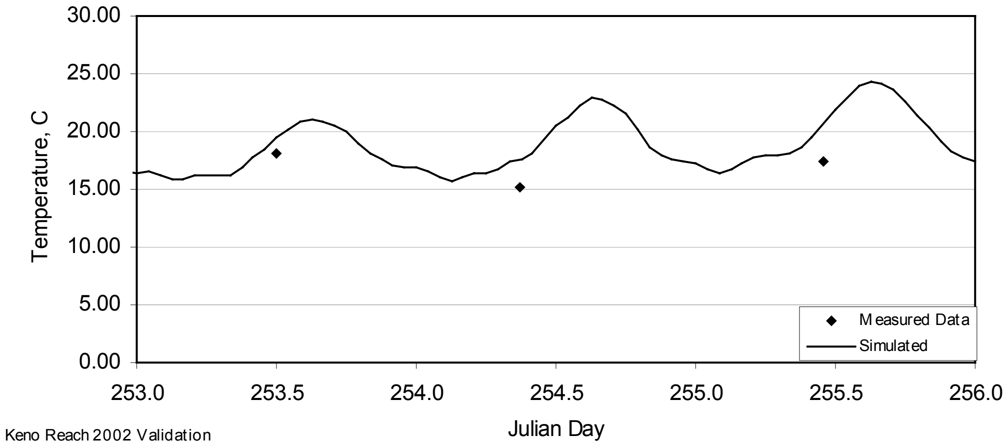


Figure 111. Klamath River, Keno to JC Boyle, simulated versus measured water temperature, September 10-12, 2002

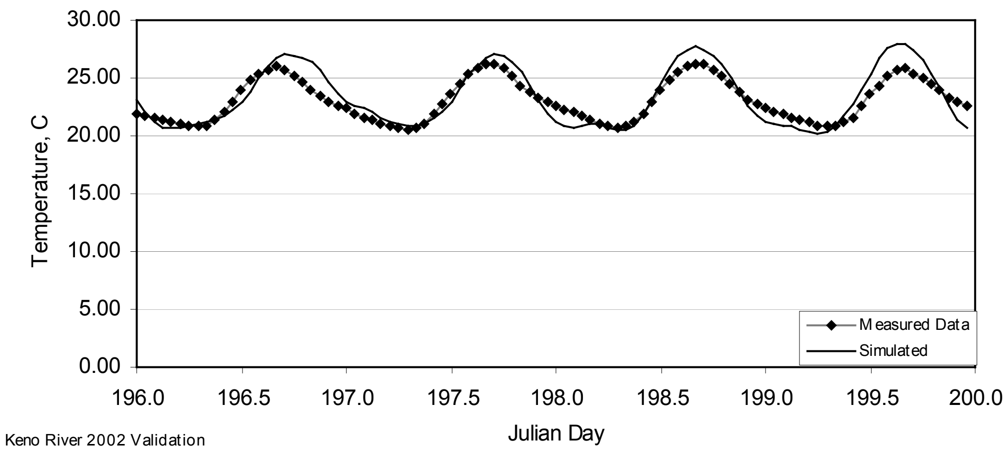


Figure 112. Klamath River, Keno to JC Boyle, simulated versus measured water temperature, July 14-17, 2002

Table 56. Klamath River, Keno to JC Boyle, hourly and daily calibration and validation period statistics for temperature

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	°C	-0.19	n/a	-0.17	n/a
Mean absolute error (MAE)	°C	0.54	n/a	0.17	n/a
Root mean squared error (RMSE)	°C	0.68	n/a	0.23	n/a
n	-	96	n/a	4	n/a

[a] Mean bias = simulated – measured

3.4.2.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates, and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeled in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from upstream of Keno Dam, growth rates for plankton were set to very low numbers in river reaches.

The hourly results are presented graphically in Figure 113 and Figure 114. Field observations suggest a moderated diurnal range in this reach, and the model replicates these conditions as well as overall magnitude of dissolved oxygen concentrations. The hourly bias of –0.46 mg/l and the mean absolute error of 0.50 mg/l presented in Table 57 illustrate that simulated results on an hourly and daily basis are within about 1 mg/l of observed values.

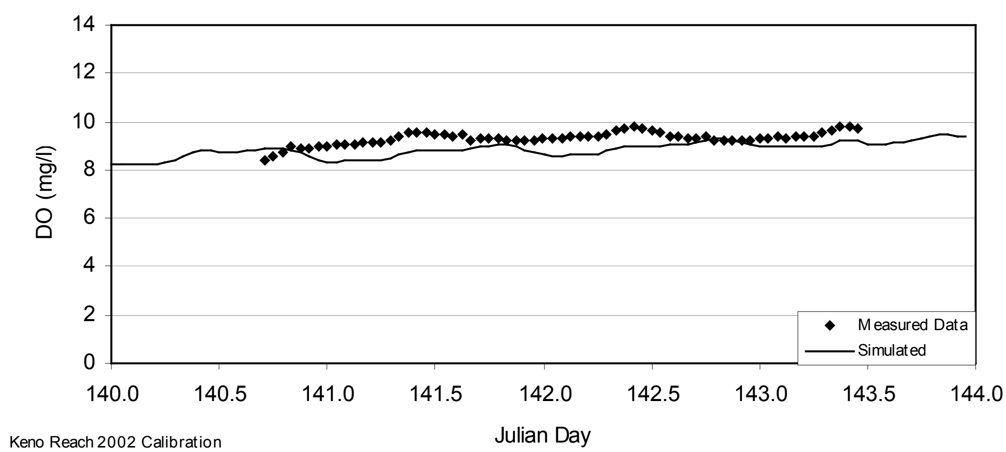


Figure 113. Klamath River, Keno to JC Boyle, simulated versus measured dissolved oxygen, May 20-23, 2002

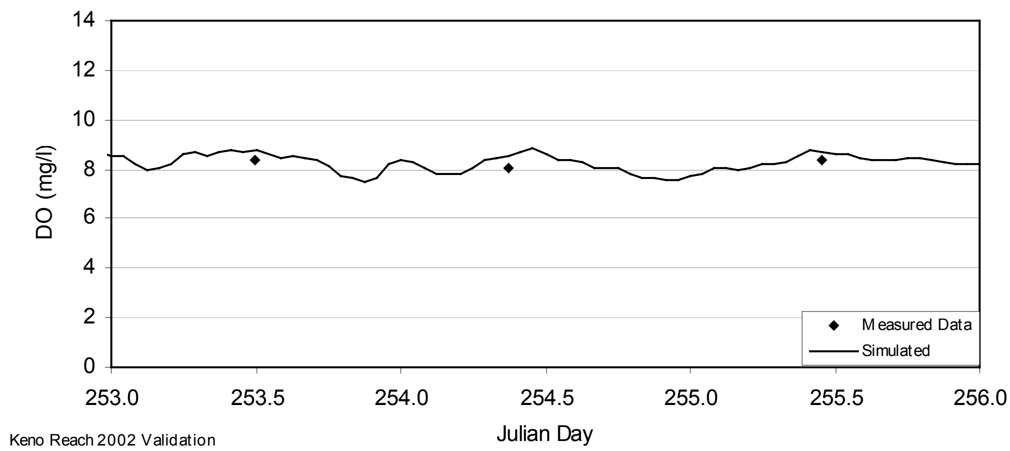


Figure 114. Klamath River, Keno to JC Boyle, simulated versus measured dissolved oxygen, September 10-12, 2002

Table 57. Klamath River, Keno to JC Boyle, hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	-0.46	n/a	-0.47	n/a
Mean absolute error (MAE)	mg/l	0.50	n/a	0.47	n/a
Root mean squared error (RMSE)	mg/l	0.55	n/a	0.48	n/a
n	-	67	n/a	3	n/a

[a] Mean bias = simulated – measured

3.4.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Keno reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 115 through Figure 120. Simulated concentrations for ammonia, nitrate, and orthophosphate were consistent with field observations. There is some scatter in the observed data that is not replicated within the model. Because upstream boundary conditions were maintained at constant values for these simulations, such results in a short reach are not unexpected.

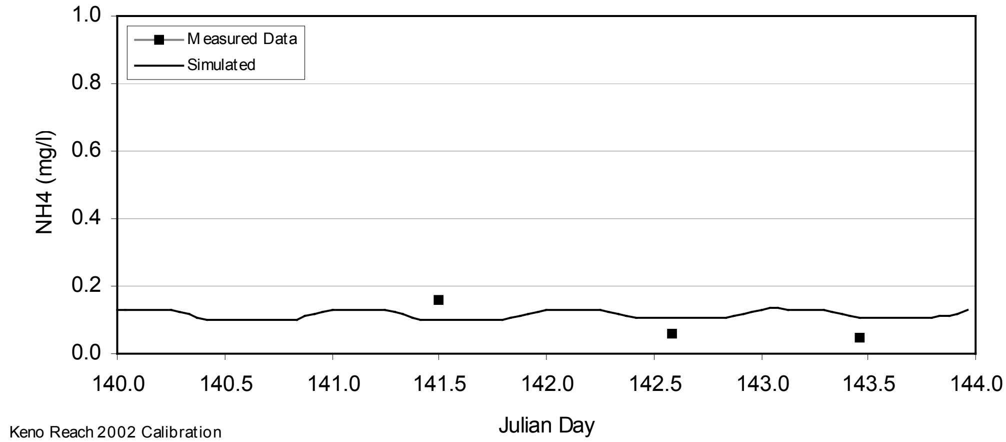


Figure 115. Klamath River, Keno to JC Boyle, simulated versus measured ammonia, May 20-23, 2002

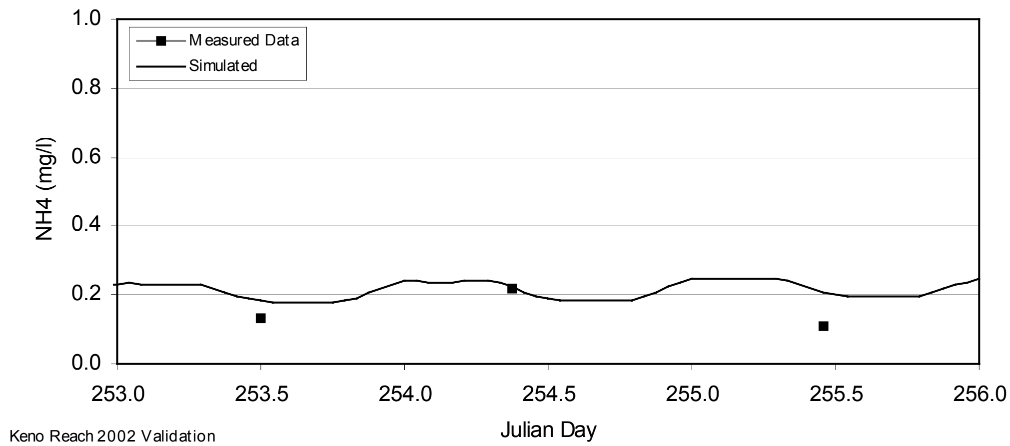


Figure 116. Klamath River, Keno to JC Boyle, simulated versus measured ammonia, September 10-12, 2002

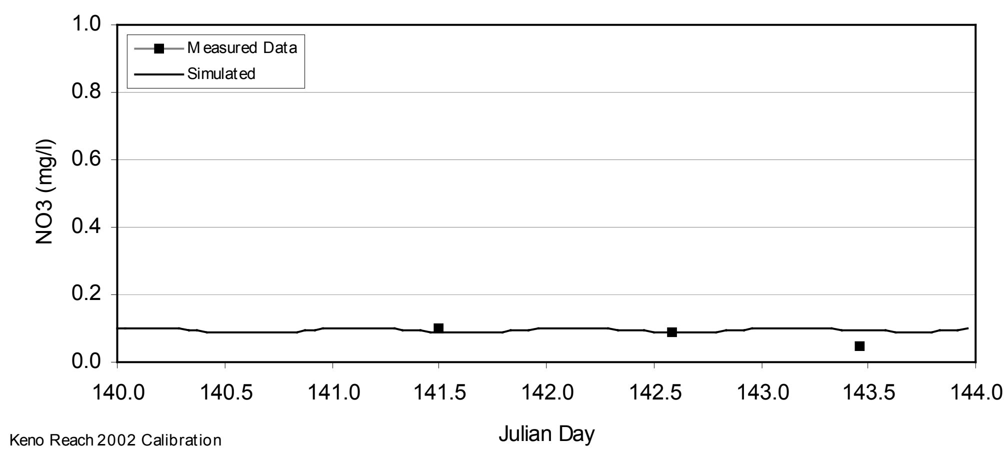


Figure 117. Klamath River, Keno to JC Boyle, simulated versus measured nitrate, May 20-23, 2002

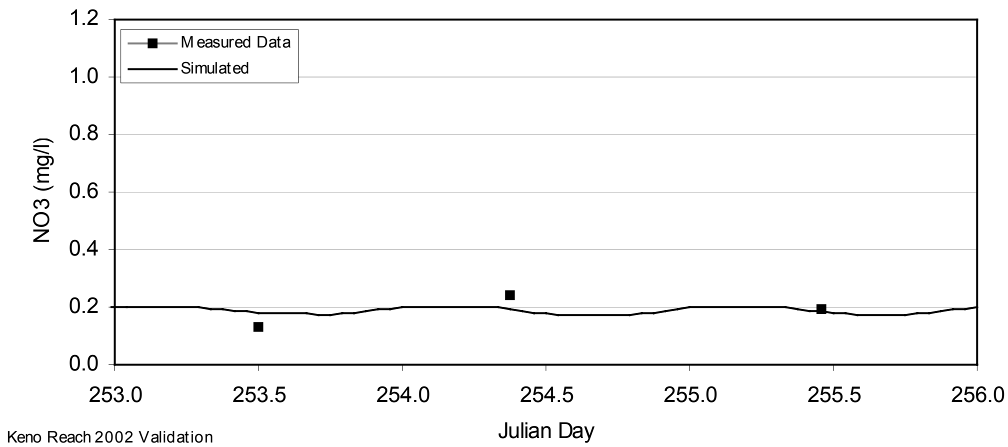


Figure 118. Klamath River, Keno to JC Boyle, simulated versus measured nitrate, September 10-12, 2002

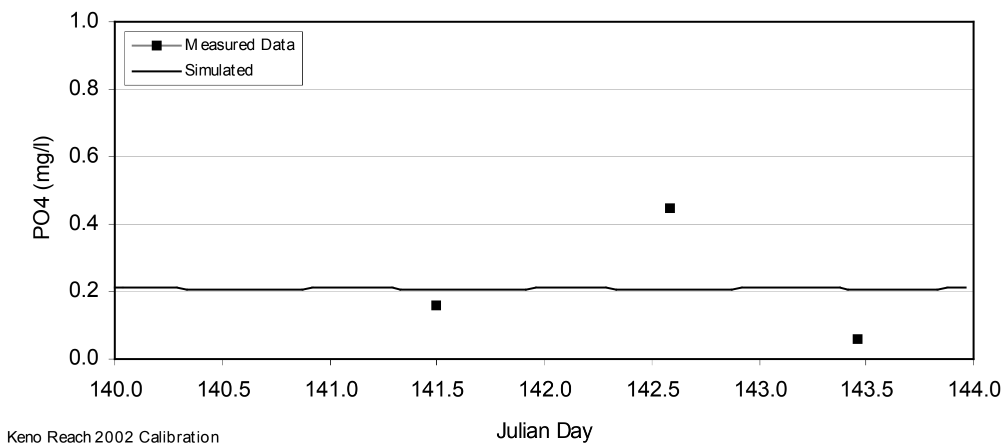


Figure 119. Klamath River, Keno to JC Boyle, simulated versus measured orthophosphate, May 20-23, 2002

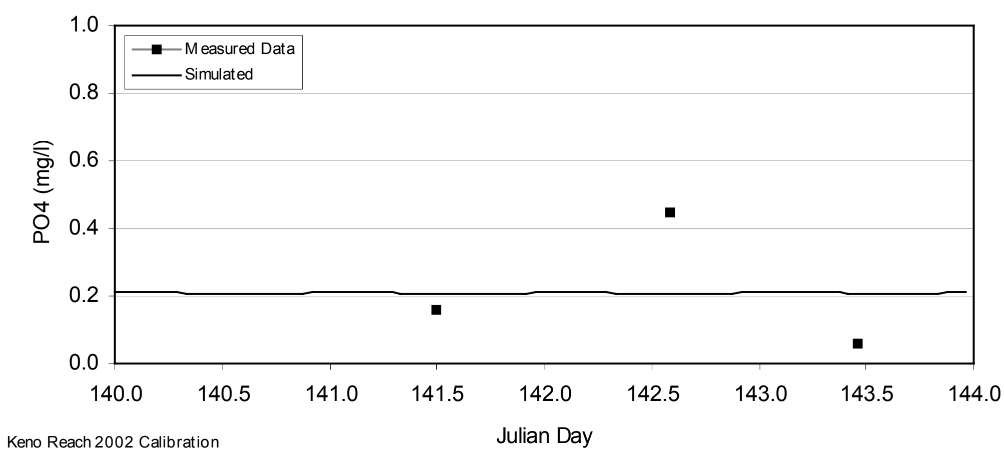


Figure 120. Klamath River, Keno to JC Boyle, simulated versus measured orthophosphate, September 10-12, 2002

3.4.2.4 Summary of Parameters

Table 58. RMA-2 and RMA-11 Model , rates, coefficients, constants for the Keno reach

Variable Name	Description, units	Value
	Time step, hr	1.0
	Space step, m	75
	Manning roughness coefficient	0.04
	Turbulence factor, Pascal-sec	100
	Longitudinal diffusion scale factor	0.10
	Slope Factor	0.90
ELEV	Elevation of site, m	1192
LAT	Latitude of site, degrees	41.5
LONG	Longitude of site, degrees	122.45
EVAPA	Evaporative heat flux coefficient a, m hr^{-1} mb^{-1}	0.000015
EVAPB	Evaporative heat flux coefficient b, m hr^{-1} mb^{-1} $(m/h)^{-1}$	0.000010
EXTINC	Light Extinction coefficient, used when algae is not simulated, 1/m	1.5
ALP0	Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A	67
ALP1	Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A	0.072
ALP2	Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A	0.010
LAMB1	Linear algal self-shading coefficient, phytoplankton, 1/m	n/a
LAMB2	Non-linear algal self shading coefficient, phytoplankton, 1/m	n/a
MUMAX	Maximum specific growth rate, phytoplankton, 1/d	0.01
RESP	Local respiration rate of algae, phytoplankton, 1/d	0.05
SIG1	Settling rate of algae, phytoplankton, 1/d	0.0
KLIGHT	Half saturation coefficient for light, phytoplankton, KJ m^{-2} s^{-1}	0.01
KNITR	Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l	0.01
KPHOS	Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l	0.001
PREFN	Preference factor for NH3-N, phytoplankton	0.6
ABLP0	Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A	50
ABLP1	Fraction of algal biomass that is nitrogen, bed algae, mg/l	0.07
ABLP2	Fraction of algal biomass that is phosphorus, bed algae, mg/l	0.01
LAMB1	Linear algal self shading coefficient, bed algae, 1/m	n/a
LAMB2	Non-linear self shading coefficient, bed algae, 1/m	n/a
MUMAX	Maximum specific growth rate, bed algae, 1/d	1.0
RESP	Local respiration rate of algae, bed algae, 1/d	0.60
MORT	Mortality, bed algae, 1/d	0.0
KBNITR	Half-saturation coefficient for nitrogen, bed algae, mg/l	0.01
KBPHOS	Half-saturation coefficient for phosphorus, bed algae, mg/l	0.002
KBLIGHT	Half-saturation coefficient for light, bed algae, KJ m^{-2} s^{-1}	0.01
PBREFN	Preference factor for NH3-N, bed algae	0.75
BET1	Rate constant: biological oxidation NH3-N, 1/d	0.3
BET2	Rate constant: biological oxidation NO2-N, 1/d	0.5
BET3	Rate constant: hydrolysis Org N to NH3-N, 1/d	0.3
BET4	Rate constant: transformation Org P to P-D, 1/d	0.3
KNINH	First order nitrification inhibition coefficient, mg^{-1}	n/a
ALP3	Rate O_2 production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A	1.6
ALP4	Rate O_2 uptake per unit of algae respired, phytoplankton, mg-O/mg-A	1.6
ABLP3	Rate O_2 production per unit of algal photosynthesis, bed algae, mg-O/mg-A	1.6
ABLP4	Rate O_2 uptake per unit of algae respired, bed algae, mg-O/mg-A	1.6
ALP5	Rate O_2 uptake per unit NH3-N oxidation, mg-O/mg-N	3.43
ALP6	Rate O_2 uptake per unit NO2-N oxidation, mg-O/mg-N	1.14
K1	Deoxygenation rate constant: BOD, 1/d	0.3
-	Minimum reaeration rate constant (Churchill formula applied), 1/d	3.0
SIG6	BOD settling rate constant, 1/d	0.0

n/a – not applicable

3.5 JC Boyle Reservoir

The CE-QUAL-W2 model of JC Boyle Reservoir was calibrated for 2000. Although the reservoir has a relatively short residence time and could be calibrated and validated using two periods within a single year, it is proposed to continue testing the model on an independent year for validation. The primary calibration data are monthly profiles and a second year of analysis will provide additional data. Although this reach has not been formally validated, it has been represented under various levels of spatial discretization in CE-QUAL-W2 and results compared with the application of the one-dimensional model WQRRS. Thus, there is a good level of confidence in model results.

Water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) data were collected during field season 2000 just upstream from the dam to support the modeling task (additional profiles were collected in the vicinity of the Highway 66 bridge and conditions were found to be similar to those near the dam).

3.5.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the mainstem (calibration/validation points) were required.

3.5.1.1 Boundary Conditions

Because no upstream data were available, the upstream boundary conditions were derived from simulated output using the calibrated Keno reach model. Upstream boundary conditions are presented in Figure 121 through Figure 123. Hourly inflow and outflow from JC Boyle Reservoir were used, thus peaking operations at JC Boyle Powerhouse were reflected in the operations. The accretion / depletion boundary conditions were those defined in model implementation of JC Boyle Reservoir.

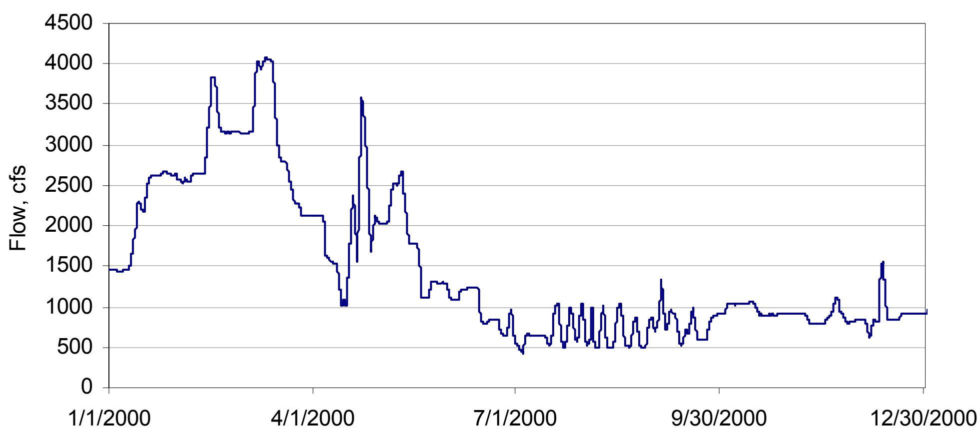


Figure 121. Inflow rates for JC Boyle Reservoir reach calibration

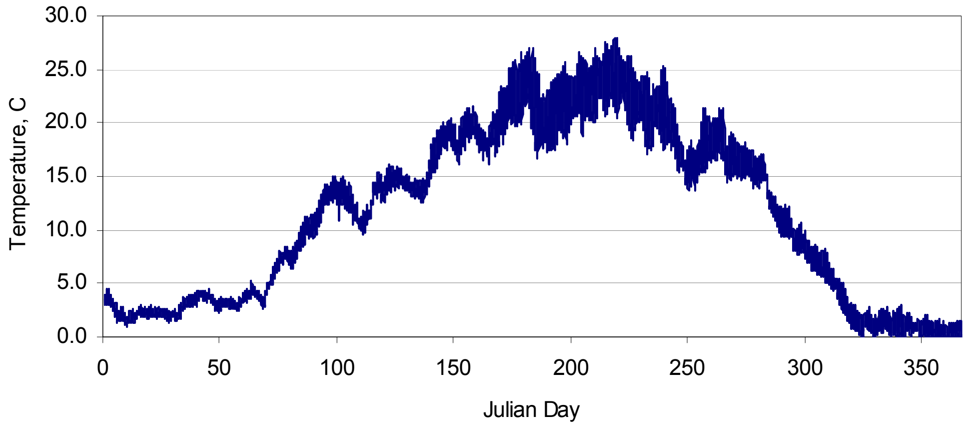
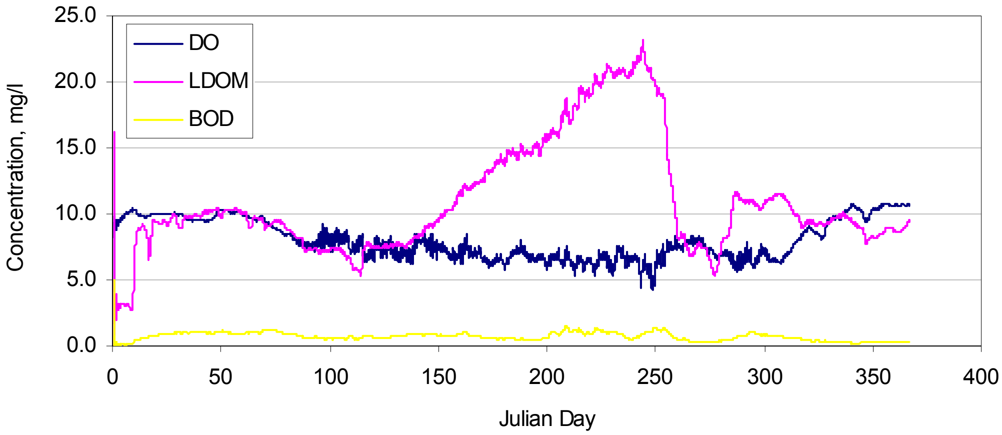
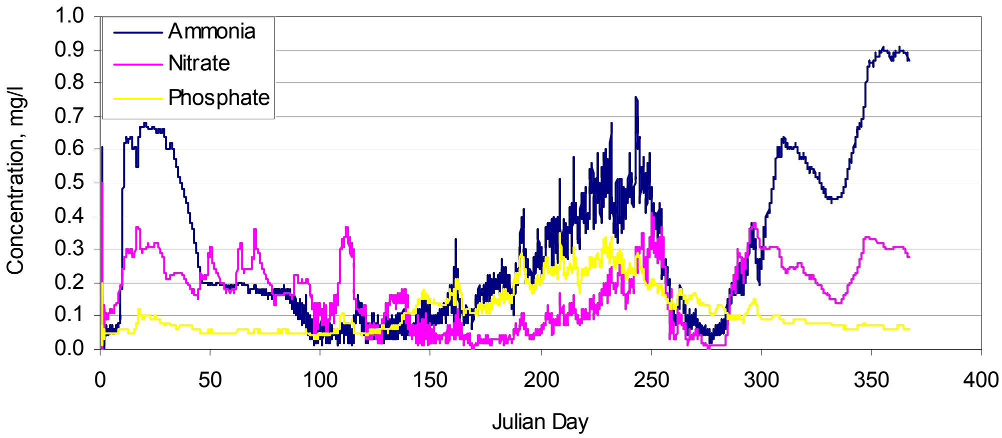


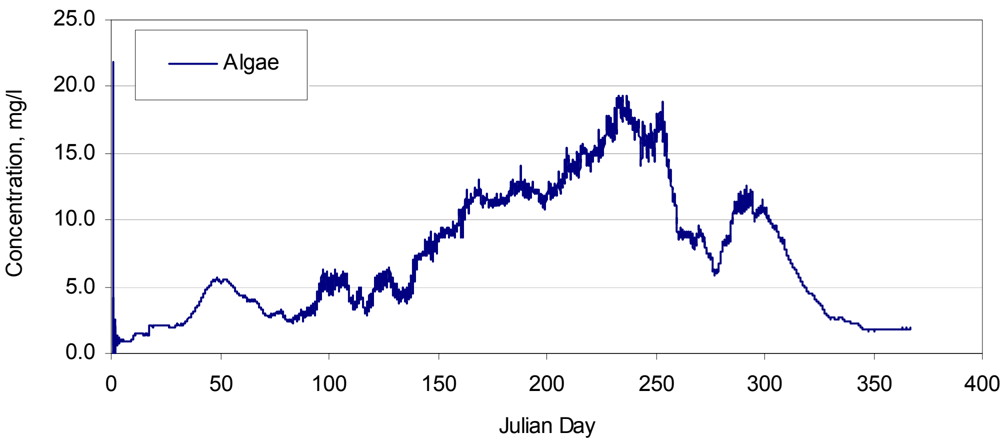
Figure 122. Inflow temperatures for JC Boyle Reservoir reach calibration



(a)



(b)



(c)

Figure 123. Inflow concentrations for selected constituents for JC Boyle Reservoir reach calibration: (a) dissolved oxygen, labile dissolved organic matter and BOD; (b) ammonia, nitrate and phosphate; (c) algae

3.5.1.2 Initial conditions

Initial conditions for the JC Boyle Reservoir were assumed to wash out within the first few days of January, due to the short residence time and isothermal conditions of the reservoir.

3.5.2 Results

Calibration was completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from monthly profiles. The nutrient data were primarily derived from field data, which were typically sampled once per month at two depths within the reservoir. All model parameters for the JC Boyle Reservoir reach are summarized in Table 61 at the end of this section.

3.5.2.1 Water Temperature

The water temperature was calibrated using the three user specified wind evaporation coefficients available in CE-QUAL-W2. Results are shown in Figure 124 and summary statistics are included in Table 59. JC Boyle Reservoir experiences weak, intermittent stratification. The model does replicate this to some degree. The profile bias ranged from 0.03°C to –1.46°C and the mean absolute error ranged from 0.21°C to 1.46°C. Overall the model is within about 1.5°C of observations. Because JC Boyle Reservoir residence time is on the order of a day or two, water temperature is strongly influenced by the temperature of river inflows.

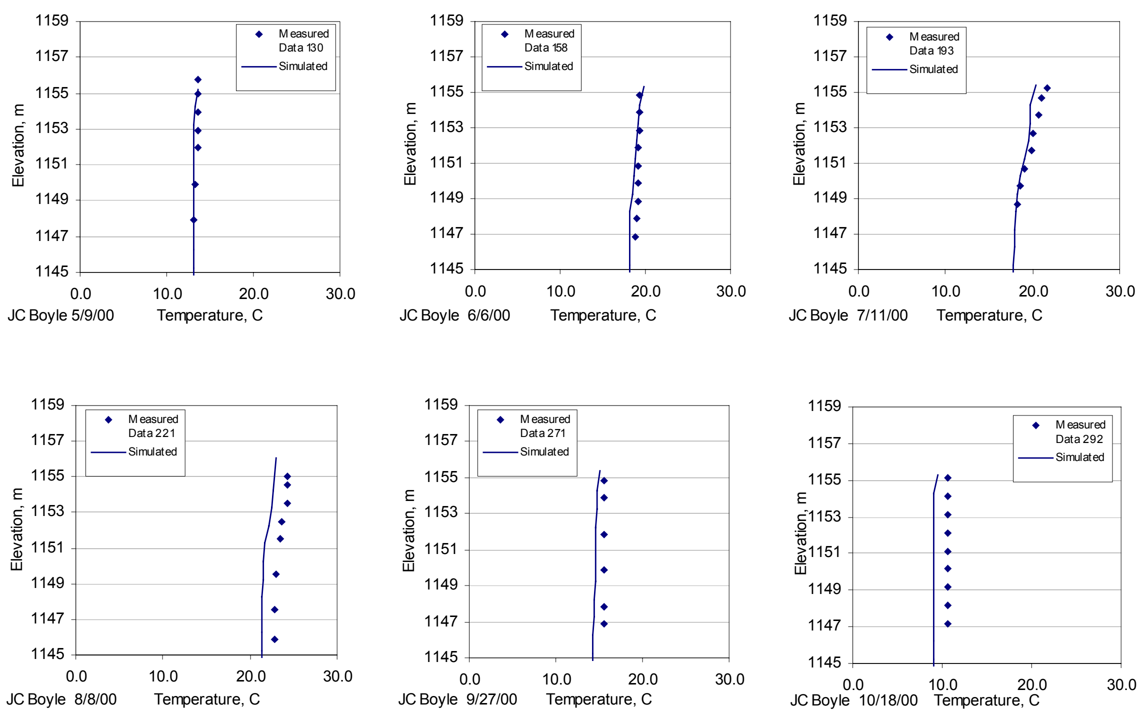


Figure 124. JC Boyle Reservoir thermal profiles, simulated versus measured monthly values: 2000

Table 59. JC Boyle Reservoir thermal profile summary statistics: simulated versus measured

Date	Mean Bias[a] (°C)	Mean Absolute Error (°C)	Root Mean Squared Error (°C)	n
April 12, 2000	-2.44	2.44	2.45	8
May 9, 2000	-0.29	0.29	0.34	6
June 6, 2000	-0.41	0.47	0.54	9
July 11, 2000	-0.63	0.63	0.79	8
August 8, 2000	-1.53	1.53	1.54	8
September 28, 2000	-0.94	0.94	0.97	6
October 18, 2000	-1.55	1.55	1.56	9

[a] Mean bias = simulated – measured

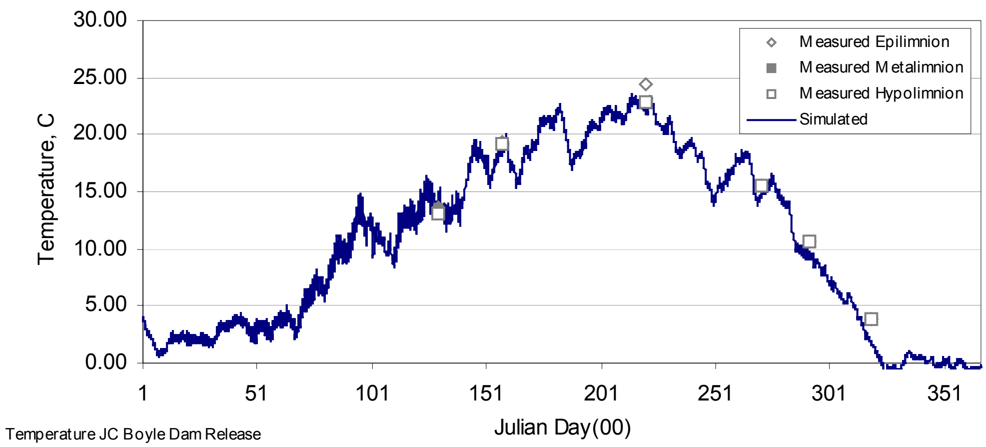


Figure 125. JC Boyle Reservoir simulated release temperatures compared with in-pool grab samples near JC Boyle Dam

3.5.2.2 Dissolved Oxygen

The dissolved oxygen was calibrated by varying several different parameters, including algal rates, organic matter decay rates and nutrient decay rates. Also zero order SOD was employed in calibrating dissolved oxygen.

Results are shown in Figure 126 and summary statistics are included in Table 60. The profile bias ranged from –1.87 mg/l to 3.75 mg/l while the mean absolute error ranged from 0.30 mg/l to 3.75 mg/l. The model performed well through about mid-June. Thereafter, dissolved oxygen concentrations were over predicted in surface waters. Simulated dissolved oxygen concentration in JC Boyle release is compared with in-pool grab samples in Figure 127. Because the reservoir is only weakly stratified and has a short residence time, boundary conditions can play an important role in model performance. Additional simulations using data from subsequent years are planned to improve model representation and to provide a validation step.

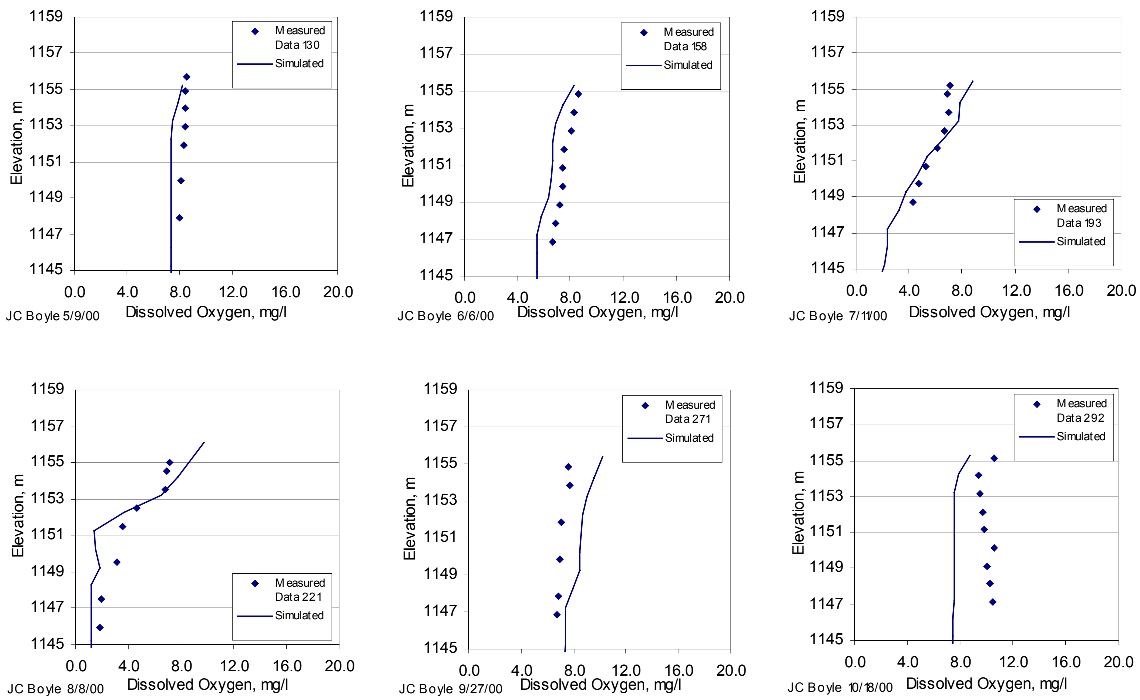


Figure 126. JC Boyle Reservoir dissolved oxygen profiles, simulated versus measured monthly values: 2000

Table 60. JC Boyle Reservoir dissolved oxygen profile summary statistics: simulated versus measured.

Date	Mean Bias[a] (mg/l)	Mean Absolute Error (mg/l)	Root Mean Squared Error (mg/l)	n
April 12, 2000	0.54	0.54	0.57	8
May 9, 2000	-0.74	0.74	0.78	6
June 6, 2000	-1.01	1.01	1.03	9
July 11, 2000	0.29	0.74	0.88	8
August 8, 2000	-0.27	0.90	1.06	8
September 28, 2000	1.47	1.47	1.57	6
October 18, 2000	-2.33	2.33	2.38	9

[a] Mean bias = simulated – measured

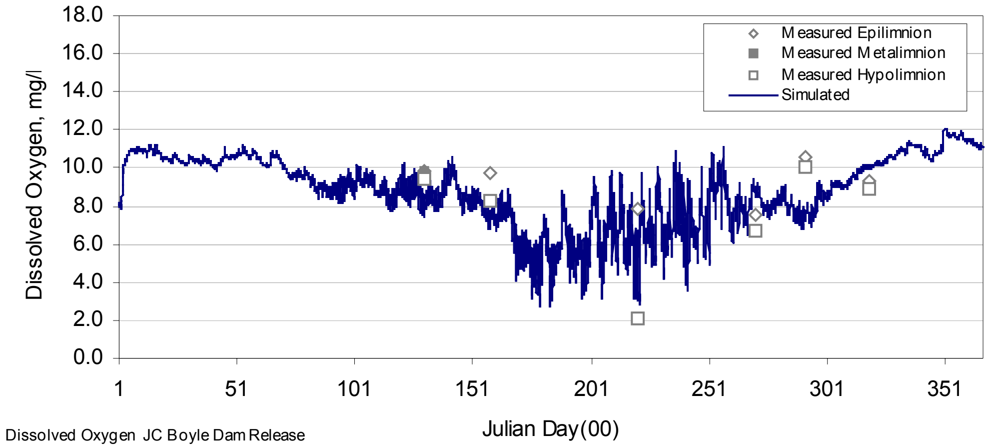


Figure 127. JC Boyle Reservoir simulated release dissolved oxygen concentration compared with in-pool grab samples near JC Boyle Dam

3.5.2.3 Nutrients

Nutrient concentrations were not actively calibrated in the JC Boyle Reservoir reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the DO calibration were not modified, and other parameters were set at default values. Results are presented for orthophosphate, ammonia, nitrate, and chlorophyll a (algae) in Figure 128 through **Error! Reference source not found.**, respectively. These results, similar to dissolved oxygen, are impacted by the assumed upstream boundary condition. Additional simulations planned using data from subsequent years to improve model representation.

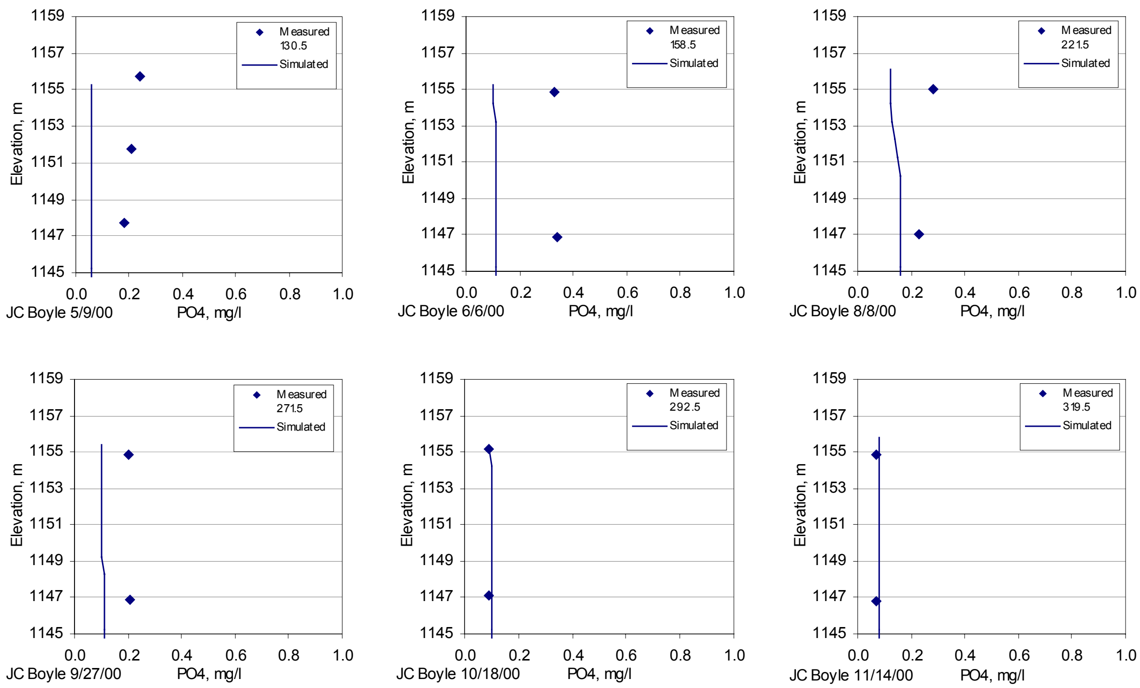


Figure 128. JC Boyle Reservoir orthophosphate profiles, simulated versus measured monthly values: 2000

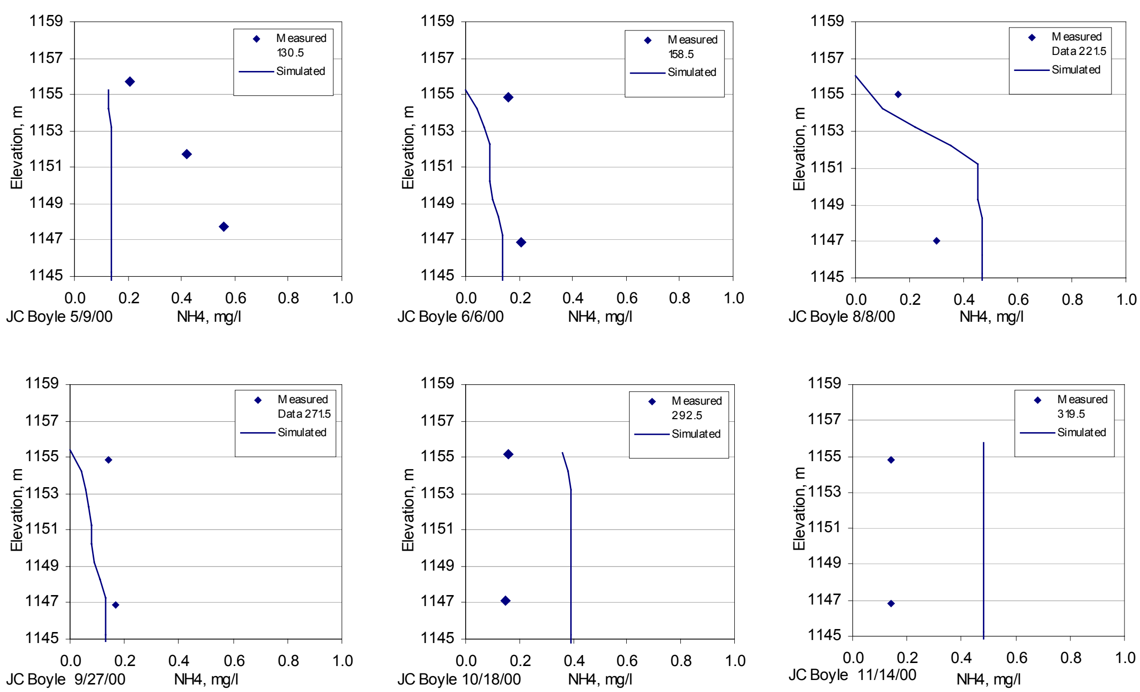


Figure 129. JC Boyle Reservoir ammonia profiles, simulated versus measured monthly values: 2000

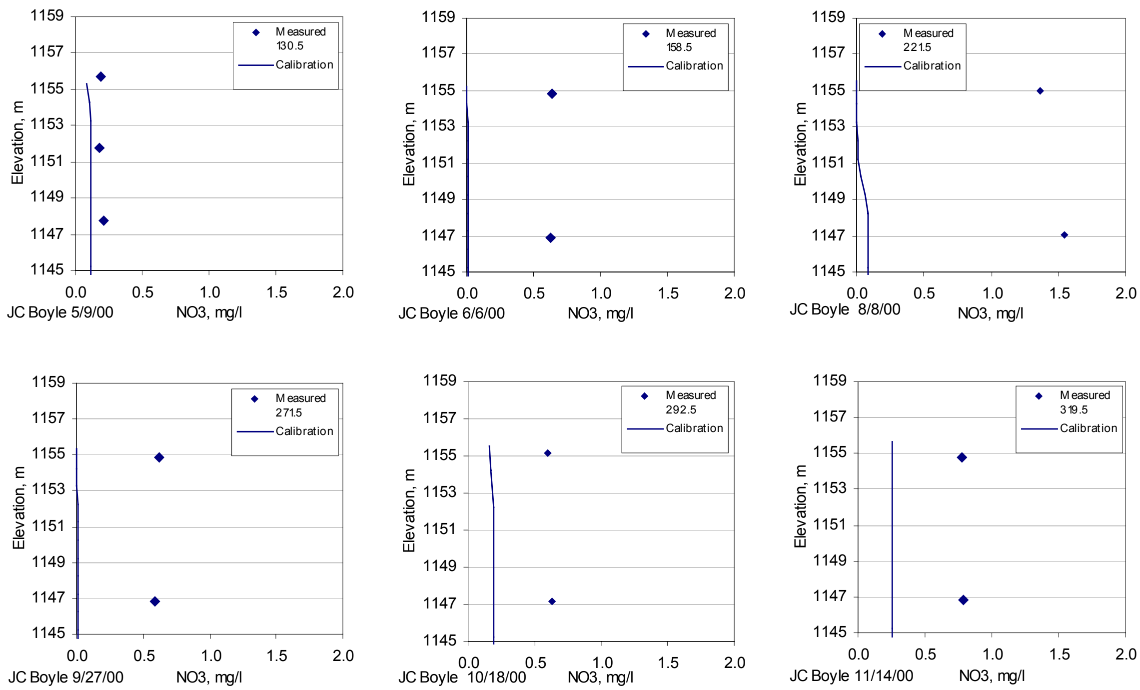


Figure 130. JC Boyle Reservoir nitrate profiles, simulated versus measured monthly values: 2000

3.5.2.4 Summary of Parameters

Table 61. Significant control file parameter values for the JC Boyle Reservoir EC simulation

Parameter Name	Description	EC JC Boyle Value	Default Values
DLT MIN	Minimum timestep, sec	5.0	N/A
DLT MAX	Maximum timestep, sec	500	N/A
SLOPE	Waterbody bottom slope	0.0	N/A
LAT	Latitude, degrees	42.12	N/A
LONG	Longitude, degrees	122.05	N/A
EBOT	Bottom elevation of waterbody, m	1143.75	N/A
AFW	A coefficient in the wind speed formulation	18.0	9.2
WINDH	Wind speed measurement height, m	2.0	N/A
TSED	Sediment (ground) temperature, C	12.0	N/A
FI	Interfacial friction factor	0.04	N/A
TSEDF	Heat lost to sediments that is added back to water column, fraction	0.01	N/A
EXH20	Extinction for pure water, m^{-1}	0.25	0.25 (for full WQ sim)
CGQ10 (Tracer)	Arrhenius temperature rate multiplier	0	0
CG0DK (Tracer)	0-order decay rate, 1/day	0	0
CG1DK (Tracer)	1^{st}-order decay rate, 1/day	0	0
CGS (Tracer)	Settling rate, m/day	0	0
CGQ10 (Age)	Arrhenius temperature rate multiplier	0	0
CG0DK (Age)	0-order decay rate, 1/day	-1.0	-1.0
CG1DK (Age)	1^{st}-order decay rate, 1/day	0	0
CGS (Age)	Settling rate, m/day	0	0

CGQ10 (Coliform)	Arrhenius temperature rate multiplier	1.04	N/A
CG0DK (Coliform)	0-order decay rate, 1/day	0	N/A
CG1DK (Coliform)	1st-order decay rate, 1/day	1.4	N/A
CGS (Coliform)	Settling rate, m/day	1.0	N/A
AG	Maximum algal growth rate, 1/day	3.0	2.0
AT1	Lower temperature for algal growth, C	5.0	5.0
PO4R	Sediment release rate of phosphorus, fraction of SOD	0.03	0.001
PARTP	Phosphorus partitioning coefficient for suspended solids	0.001	0.0
NH4REL	Sediment release rate of ammonium, fraction of SOD	0.07	0.001
NH4DK	Ammonium decay rate, 1/day	0.1	0.12
NO3DK	Nitrate decay rate, 1/day	0.1	0.03
NO3S	De-nitrification rate from sediments, m/day	0.0	1.0
CO2REL	Sediment carbon dioxide release rate, fraction of sediment oxygen demand	0.01	0.1
O2AR	Oxygen stoichiometry for algal respiration	1.4	1.1
O2AG	Oxygen stoichiometry for algal primary production	1.5	1.4
SOD	Zero-order sediment oxygen demand for each segment, g O_2 / m^2 day	3.0 (for each segment)	N/A

3.6 Bypass Reach and Peaking Reach

The RMA suite of models for the Klamath River Bypass and Peaking reach was calibrated and validated during May 20 – 23, 2003 and July 15 – 18, 2003 respectively. The Bypass and Peaking Reach extends from JC Boyle Dam to the headwaters of Copco Reservoir and encompasses the JC Boyle Powerhouse tailrace.

3.6.1 Data

Water quality conditions of water flowing into the reach (boundary conditions at JC Boyle Dam and JC Boyle Powerhouse return), initial status of the system (initial conditions), and observations in the Klamath River (calibration/validation points at Klamath River above JC Boyle Powerhouse tailrace, Stateline and above Copco Reservoir) were required.

3.6.1.1 Boundary Conditions

The boundary condition data was derived from samples collected at JC Boyle Dam Reservoir. Water temperature and dissolved oxygen data were available from water quality probes and water temperature loggers at hourly intervals. Grab samples were collected once per day for three days. Due to the inherent variability and infrequent sampling interval of the grab data, the boundary condition values for nutrients, BOD, and algae were assumed to be a constant value for the calibration and validation period, based on the grab sample data from 2002 (Appendix F).

The upstream boundary condition for temperature and dissolved oxygen were obtained from water quality probes during the May and July calibration and validation periods. Sondes were deployed above the JC Boyle Dam, but were used to represent temperature and dissolved oxygen in both the direct JC Boyle Dam release into the river and the JC

Boyle Powerhouse tailrace release into the river. Grab samples were also collected above the dam, providing concentrations of nutrients at JC Boyle Dam, as well as the boundary condition for the JC Boyle Powerhouse tailrace. These boundary conditions were assumed equivalent because they are both drawn from JC Boyle Reservoir.

There is a lag time from JC Boyle Dam to the powerhouse, but it is well under one hour (approximately 15 minutes at 600 cfs, 8 minutes at 3000 cfs; pers. comm. T. Olson) and is thus neglected.

The water quality values for the calibration and validation period are shown in Table 62, Table 63, Figure 131 and Figure 132.

Table 62. Bypass/Peaking Klamath River reach calibration and validation water quality boundary conditions for JC Boyle Dam and JC Boyle Powerhouse return

Parameter	Units	Dates 5/21/02 - 5/23/02	Dates 7/16/02 - 7/18/02
BOD	mg/l	3.0	3.0
DO	mg/l	variable	Variable
Org N	mg/l	0.60	1.30
NH_4^+	mg/l	0.10	0.20
NO_2^-	mg/l	0.00	0.00
NO_3^-	mg/l	0.10	0.80
Org P	mg/l	0.20	0.10
PO_4^{3-}	mg/l	0.20	0.30
Algae	mg/l	2.0	22.0
Tw	°C	variable	variable

Table 63. Bypass/Peaking Klamath River reach calibration and validation water quality boundary conditions for the Bypass Reach spring inflow

Parameter	Units	Dates 5/21/02 - 5/23/02	Dates 7/16/02 - 7/18/02
BOD	mg/l	0.0	0.0
DO	mg/l	9.7	9.7
Org N	mg/l	0.00	0.00
NH_4^+	mg/l	0.00	0.00
NO_2^-	mg/l	0.00	0.00
NO_3^-	mg/l	0.15	0.15
Org P	mg/l	0.00	0.00
PO_4^{3-}	mg/l	0.15	0.15
Algae	mg/l	0.0	0.0
T_w	°C	11.0	11.0

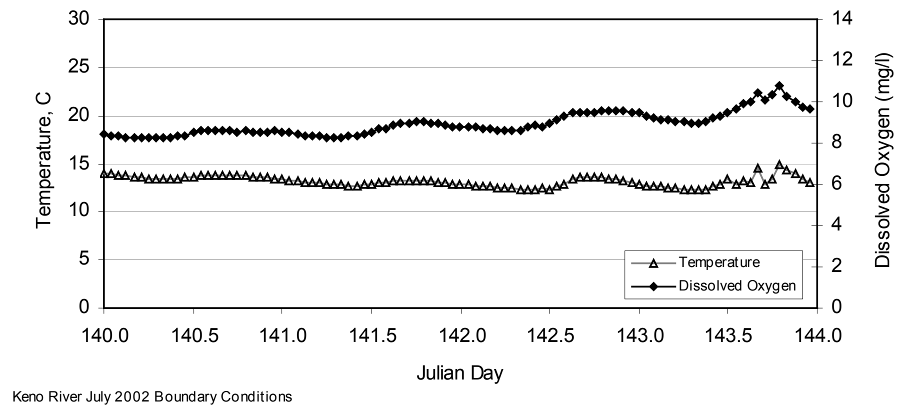


Figure 131. Temperature and dissolved oxygen calibration boundary conditions at both JC Boyle Dam and JC Boyle Powerhouse

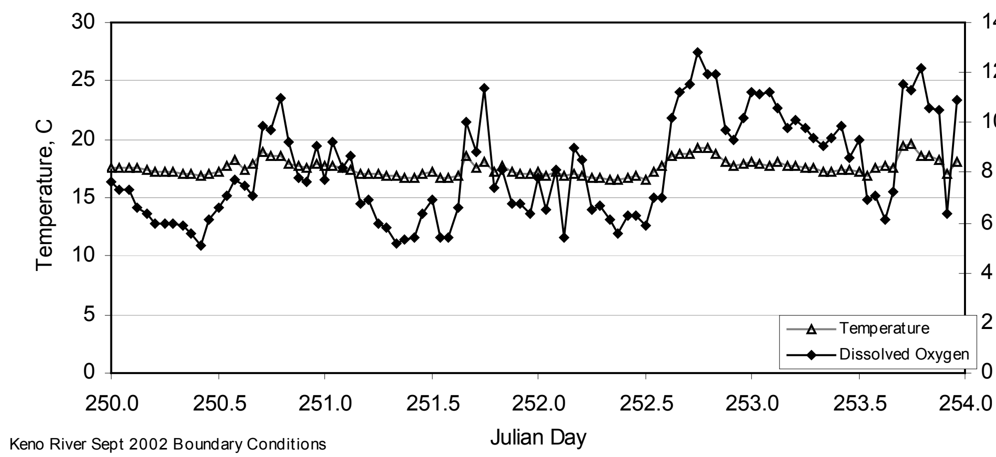


Figure 132. Temperature and dissolved oxygen validation boundary conditions at both JC Boyle Dam and JC Boyle Powerhouse

3.6.1.2 Initial conditions

The model was run for three days prior to both the calibration and validation periods to provide an initial condition for simulation. The initial bed algae mass was estimated at 5 g/m^2.

3.6.1.3 Calibration and Validation Points

The calibration and validation points for the Bypass / Peaking reach were Klamath River above JC Boyle Powerhouse tailrace, Klamath River at Stateline and Klamath River above Copco Reservoir. These data are displayed in the following section with model results.

3.6.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. An exception was at Klamath River above the JC Boyle Powerhouse tailrace site during the July (validation) period only temperature was available on an hourly interval. Dissolved oxygen was only available from field data collected once a day, and thus dissolved oxygen summary statistics are not available for that location in July. The nutrient data were primarily derived from field data, which were sampled once per day. All model parameters for the Bypass / Peaking reach are summarized in Table 70 at the end of this section.

3.6.2.1 Water Temperature

Water temperature calibration required varying evaporation heat flux coefficients (presented in Table 70) that govern the mass transfer formulation represented in the numerical model heat budget. No other parameters were varied. The hourly results are presented graphically in Figure 133 through Figure 138 . Summary statistics for both calibration and validation periods (May 20-23, 2002 and July 15-18, 2002, respectively) are included in Table 64 through Table 66.

At Klamath River above JC Boyle Powerhouse tailrace, the phase was well represented while the range was moderated slightly. Hourly bias for the May period (calibration) was 0.14 °C and the mean absolute error was 0.87 °C. Hourly bias for the July period (validation) was –0.23 °C and the mean absolute error was 0.91 °C. Both the calibration and validation simulation results were within 1 °C of observations.

At Klamath River at Stateline, the diurnal phase was approximately reproduced while the diurnal range was well represented. Hourly bias for the May period (calibration) was –0.39 °C and the mean absolute error was 0.67 °C. Hourly bias for the July period (validation) was –0.48 °C and the mean absolute error was 1.11 °C. Both the calibration and validation simulation results were within approximately 1.5 °C of observations.

At Klamath River above Copco Reservoir, the diurnal phase was approximately represented in May, but not represented well in July, while the diurnal range for both periods was well represented. Hourly bias for the May period (calibration) was –0.35 °C and the mean absolute error was 0.61 °C. Hourly bias for the July period (validation) was –0.05 °C and the mean absolute error was 1.10 °C. Both the calibration and validation simulation results were generally within 1.5 °C of observations.

Apparent in both the observed and simulated temperature time series is the influence of peaking operations. During off peak hours, water of a significantly different quality (from the bypass reach) markedly alters water temperature. The timing and magnitude of peaking operations create unique temperature traces at downstream locations. Figure 138 illustrates the thermal response of the Klamath River above Copco and, although shifted slightly in phase, the model replicates such conditions.

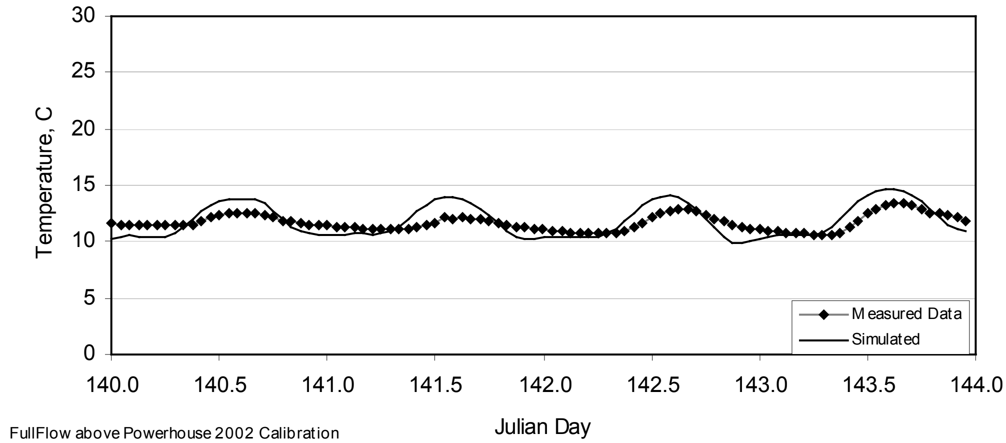


Figure 133. Klamath River, above JC Boyle PH tailrace, simulated versus measured water temperature, May 20-23, 2002

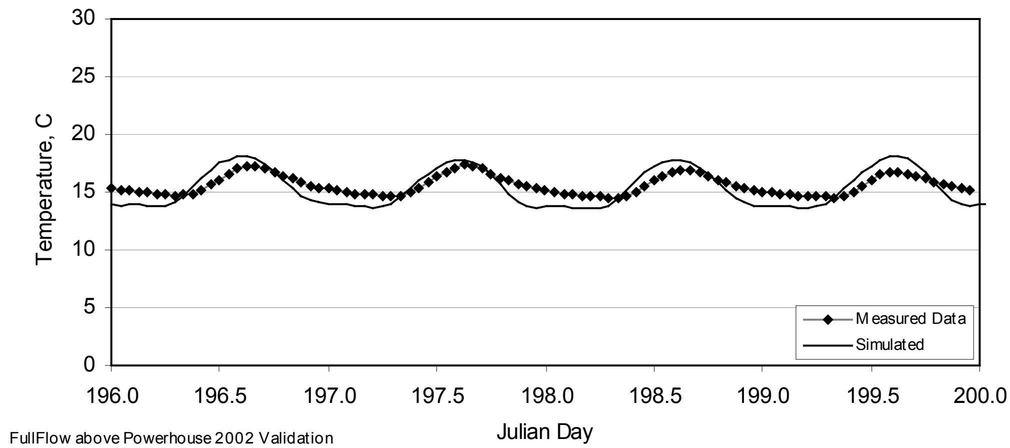


Figure 134. Klamath River, above JC Boyle PH tailrace, simulated versus measured water temperature, July 15-18, 2002

Table 64. Klamath River, above JC Boyle PH tailrace, hourly and daily calibration and validation period statistics for temperature

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	°C	0.14	-0.23	0.14	-0.23
Mean absolute error (MAE)	°C	0.87	0.91	0.18	0.23
Root mean squared error (RMSE)	°C	0.99	1.01	0.22	0.27
N	-	96	96	4	4

[a] Mean bias = simulated – measured

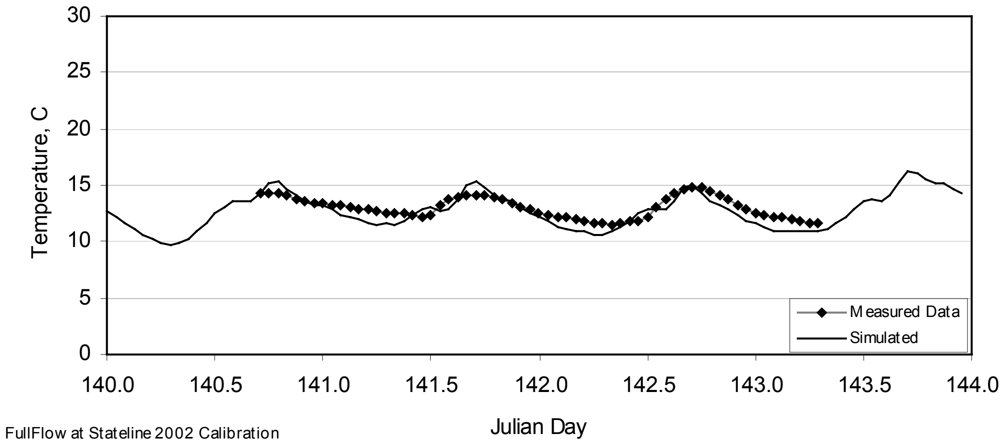


Figure 135. Klamath River, at Stateline, simulated versus measured water temperature, May 20-23, 2002

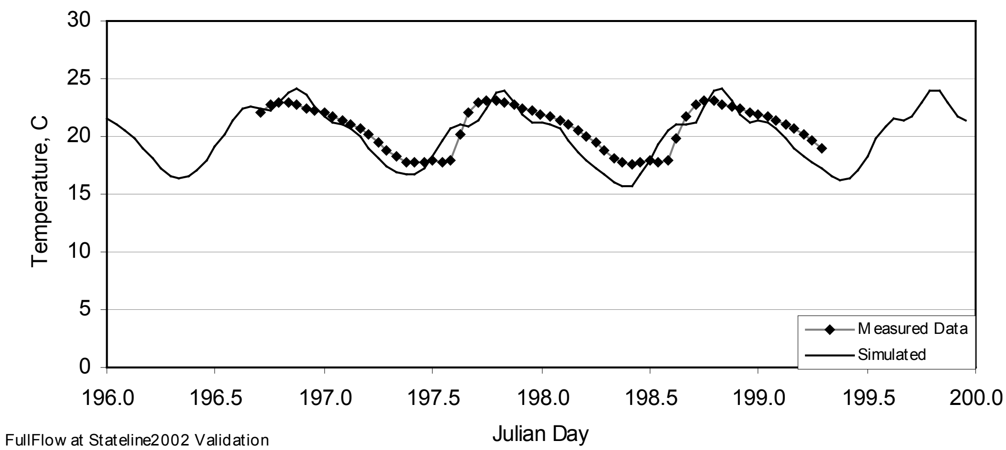


Figure 136. Klamath River, at Stateline, simulated versus measured water temperature, July 15-18, 2002

Table 65. Klamath River, at Stateline, hourly and daily calibration and validation period statistics for temperature

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	°C	-0.39	-0.48	-0.40	-0.49
Mean absolute error (MAE)	°C	0.67	1.11	0.40	0.49
Root mean squared error (RMSE)	°C	0.77	1.29	0.42	0.51
n	-	63	63	2	2

[a] Mean bias = simulated – measured

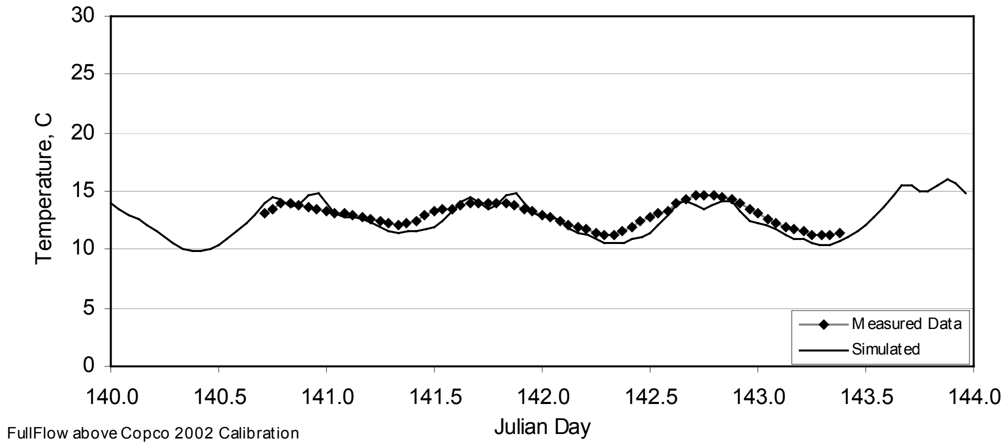


Figure 137. Klamath River, above Copco Reservoir, simulated versus measured water temperature, May 20-23, 2002

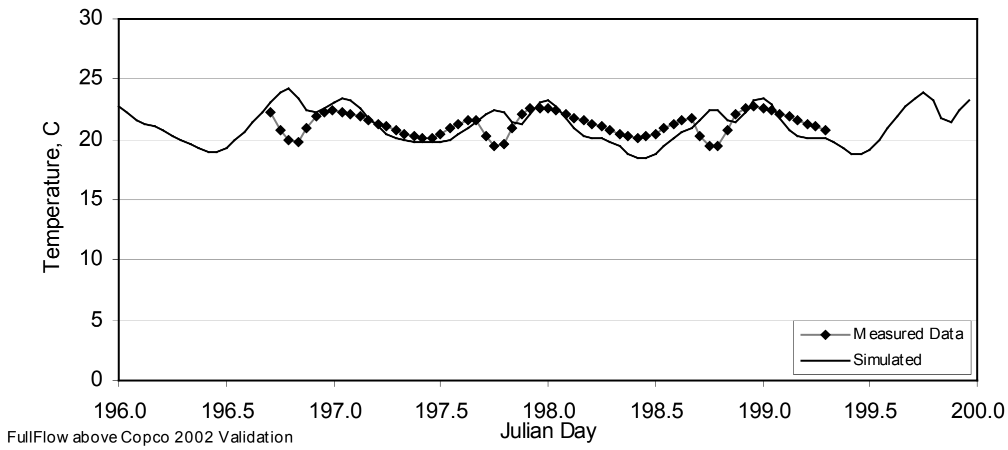


Figure 138. Klamath River, above Copco Reservoir, simulated versus measured water temperature, July 15-18, 2002

Table 66. Klamath River, above Copco Reservoir, hourly and daily calibration and validation period statistics for temperature

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	°C	-0.35	0.05	-0.41	-0.12
Mean absolute error (MAE)	°C	0.61	1.10	0.41	0.29
Root mean squared error (RMSE)	°C	0.71	1.39	0.46	0.31
n	-	65	63	2	2

[a] Mean bias = simulated – measured

3.6.2.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeling in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from upstream of Keno Dam, growth rates were set to very low numbers in river reaches. The results are presented both graphically, in Figure 139 through Figure 144, and using summary statistics, in Table 67 through

Table 69.

At Klamath River above JC Boyle Powerhouse tailrace, the model reproduced dissolved oxygen concentrations and the moderated diurnal signal. For July, the simulated concentrations are very similar to the field data. Hourly bias for the May period (calibration) was –0.07 mg/l and the mean absolute error was 0.28 mg/l. Hourly bias and mean absolute error for the July period (validation) were not available. The calibration and simulation results were within 1 mg/l of observations.

At Klamath River at Stateline, the May phase and range were approximately represented. For July the phase and range were well represented, but the magnitude was over-represented. Hourly bias for the May period (calibration) was 0.37 mg/l and the mean absolute error was 0.39 mg/l. Hourly bias for the July period (validation) was 1.17 mg/l and the mean absolute error was 1.17 mg/l. Both the calibration and validation simulation results were within 1.5 mg/l of observations.

At Klamath River above Copco Reservoir, the overall magnitude was well represented, but the diurnal range was not. In July, both the diurnal phase and range were well represented, as was the magnitude. Hourly bias for the May period (calibration) was 0.00 mg/l and the mean absolute error was 0.59 mg/l. Hourly bias for the July period (validation) was 0.56 mg/l and the mean absolute error was 0.56 mg/l. While the summary statistics of both the calibration and validation indicate the simulation results were within 1 mg/l of observations, a visual inspection of the May graph indicates that the simulation results for that period were within 2 mg/l.

Uncertainty in organic matter and algae inputs may be the cause for elevated simulation values in July at Klamath River at Stateline. Additionally, the distribution of benthic algae and biomass is largely unknown, as are the temporal and spatial variability of light extinction, and could impact model results.

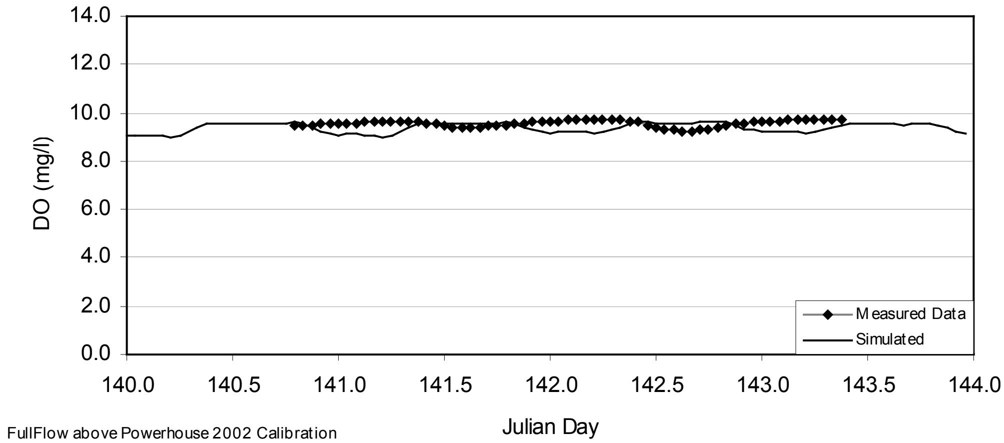


Figure 139. Klamath River, above JC Boyle PH tailrace, simulated versus measured dissolved oxygen, May 20-23, 2002

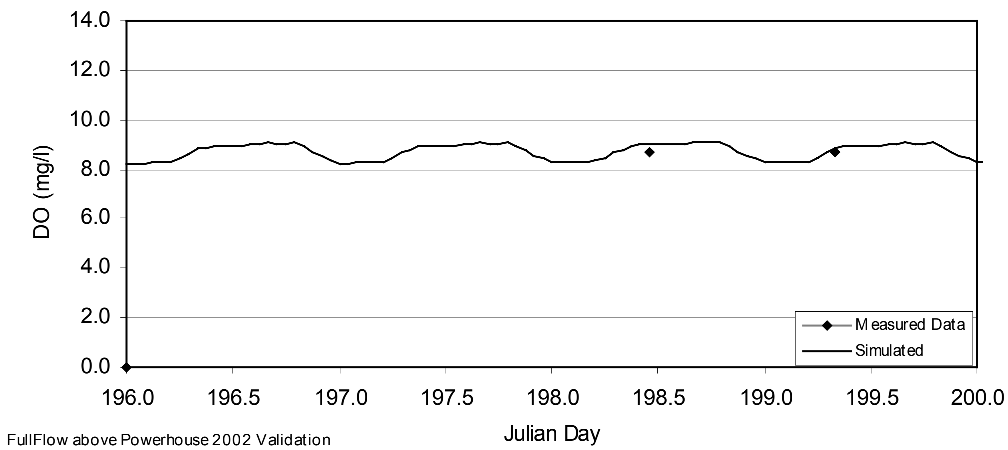


Figure 140. Klamath River, above JC Boyle PH tailrace, simulated versus measured dissolved oxygen, July 15-18, 2002

Table 67. Klamath River, above JC Boyle PH tailrace, hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	-0.07	n/a	-0.02	n/a
Mean absolute error (MAE)	mg/l	0.28	n/a	0.04	n/a
Root mean squared error (RMSE)	mg/l	0.30	n/a	0.04	n/a
N	-	63	n/a	2	n/a

[a] Mean bias = simulated – measured

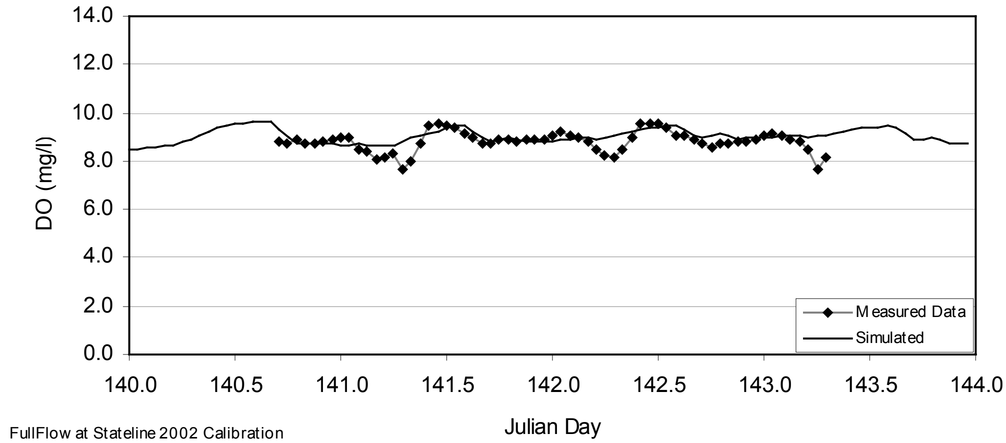


Figure 141. Klamath River, at Stateline, simulated versus measured dissolved oxygen, May 20-23, 2002

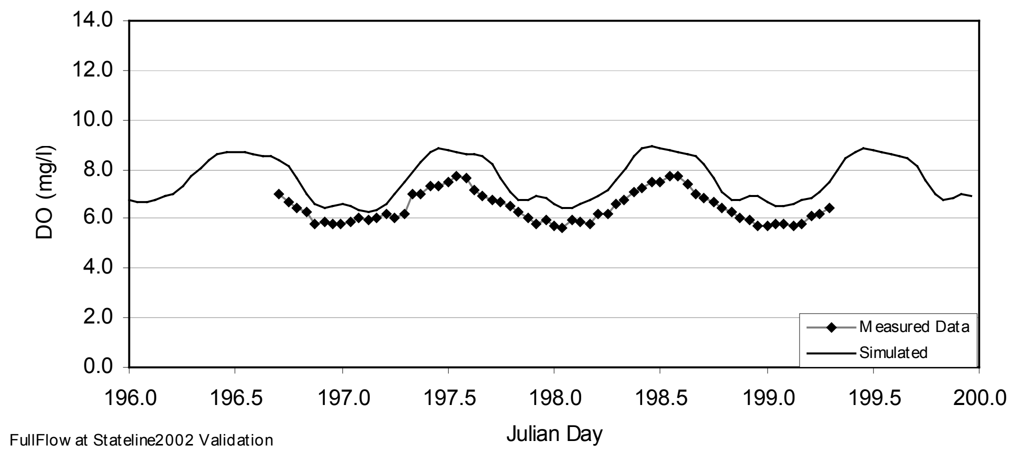


Figure 142. Klamath River, at Stateline, simulated versus measured dissolved oxygen, July 15-18, 2002

Table 68. Klamath River, at Stateline, hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	0.37	1.17	0.36	1.19
Mean absolute error (MAE)	mg/l	0.39	1.17	0.36	1.19
Root mean squared error (RMSE)	mg/l	0.51	1.22	0.36	1.19
n	-	63	63	2	2

[a] Mean bias = simulated – measured

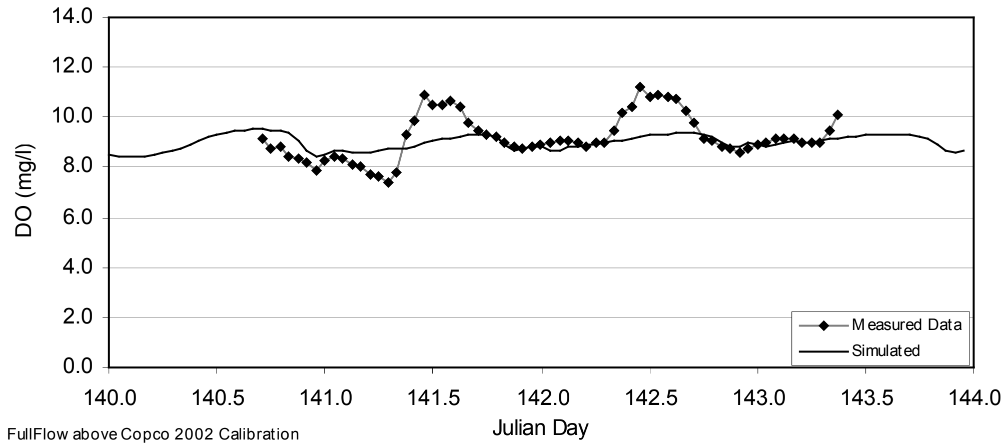


Figure 143. Klamath River, above Copco Reservoir, simulated versus measured dissolved oxygen, May 20-23, 2002

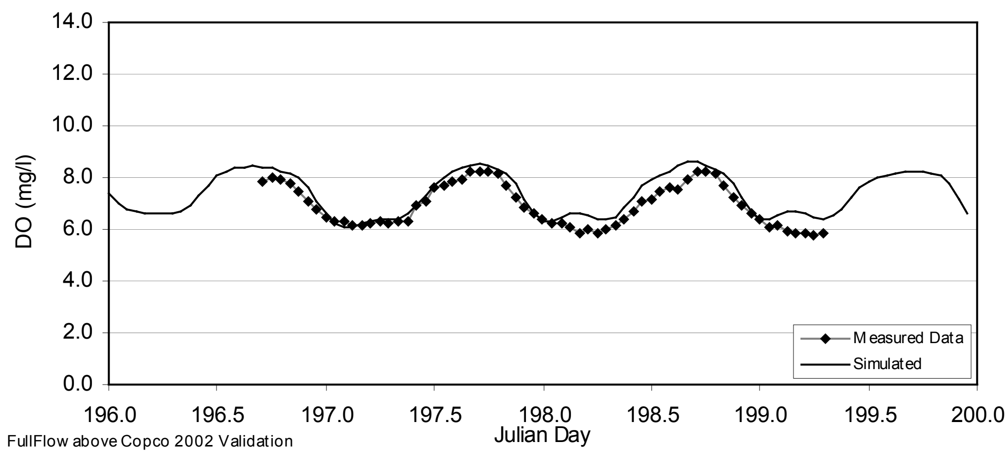


Figure 144. Klamath River, above Copco Reservoir, simulated versus measured dissolved oxygen, July 15-18, 2002

Table 69. Klamath River, above Copco Reservoir, hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		Hourly		Daily	
	Unit	Calib.	Valid.	Calib.	Valid.
Mean Bias[a]	mg/l	0.00	0.56	-0.13	0.52
Mean absolute error (MAE)	mg/l	0.59	0.56	0.18	0.52
Root mean squared error (RMSE)	mg/l	0.75	0.62	0.22	0.54
n	-	65	63	2	2

[a] Mean bias = simulated – measured

3.6.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Bypass / Peaking reach. That is, values for nutrient interactions (e.g. stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 145 through Figure 162. Simulated concentrations for ammonia, nitrate and orthophosphate were consistent with field observations. Although there is some scatter in the observed data that is not replicated within the model, the variations in water quality in response to peaking operations are well represented for certain constituents (e.g. nitrate, Figure 154 and Figure 160).

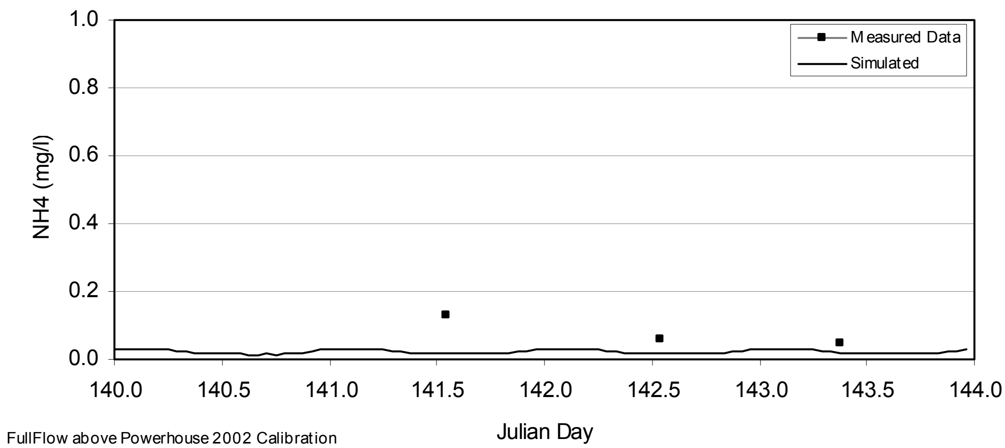


Figure 145. Klamath River, above JC Boyle PH tailrace, simulated versus measured ammonia, May 20-23, 2002

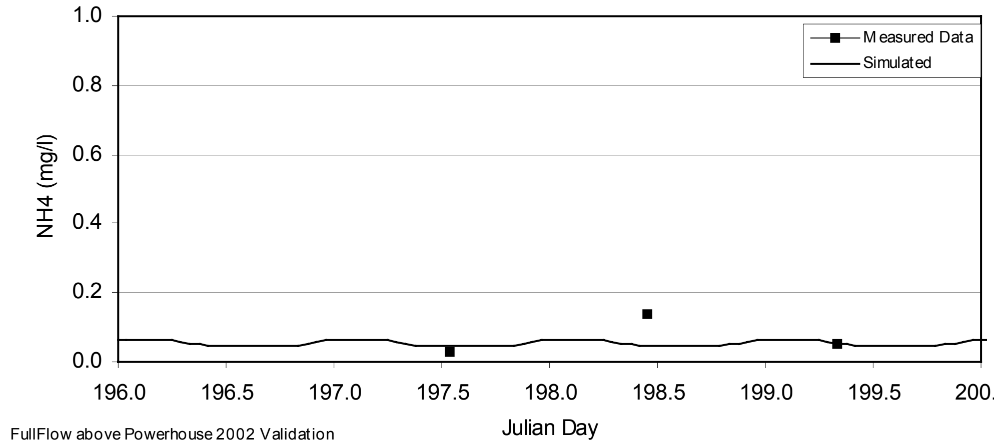


Figure 146. Klamath River, above JC Boyle PH tailrace, simulated versus measured ammonia, July 15-18, 2002

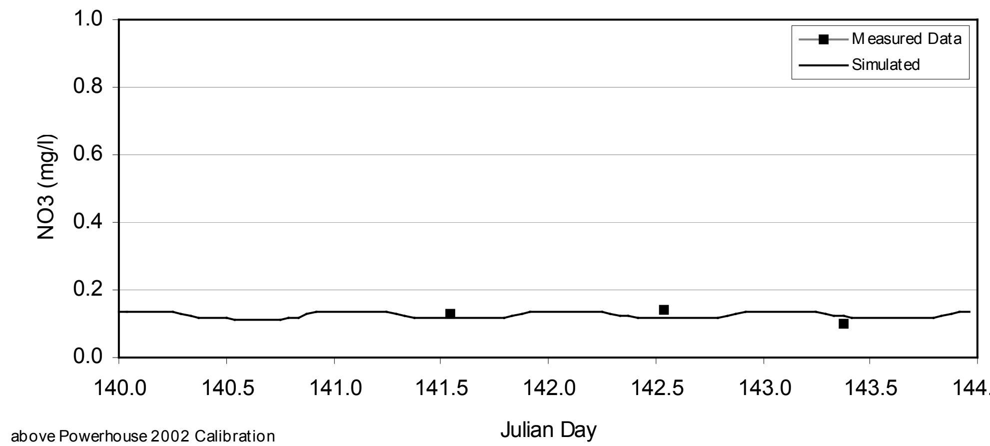


Figure 147. Klamath River, above JC Boyle PH tailrace, simulated versus measured nitrate, May 20-23, 2002

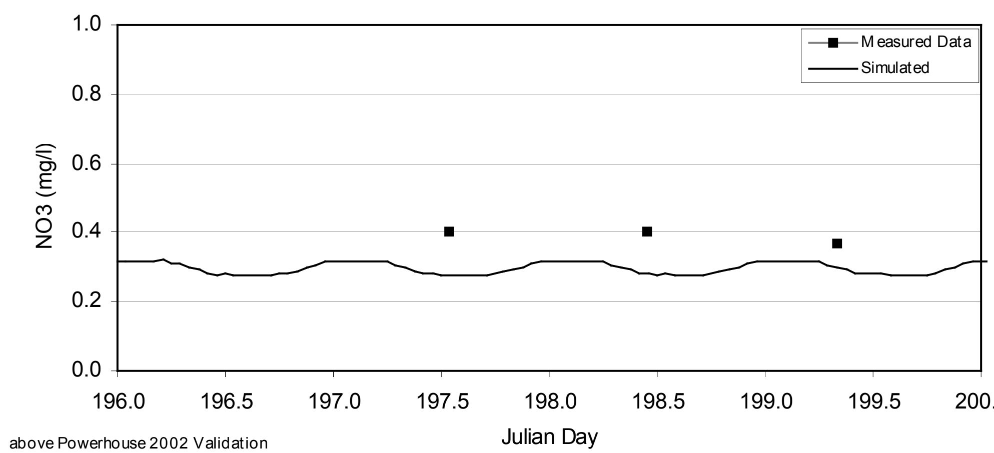


Figure 148. Klamath River, above JC Boyle PH tailrace, simulated versus measured nitrate, July 15-18, 2002

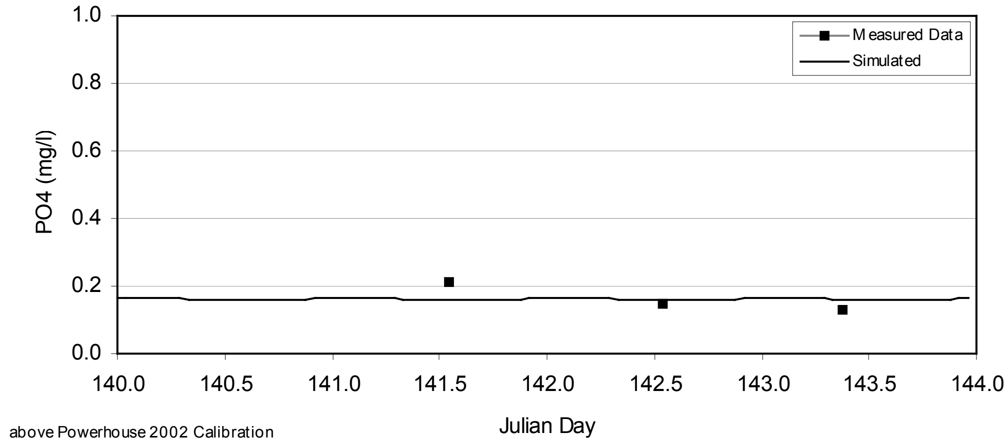


Figure 149. Klamath River, above JC Boyle PH tailrace, simulated versus measured orthophosphate, May 20-23, 2002

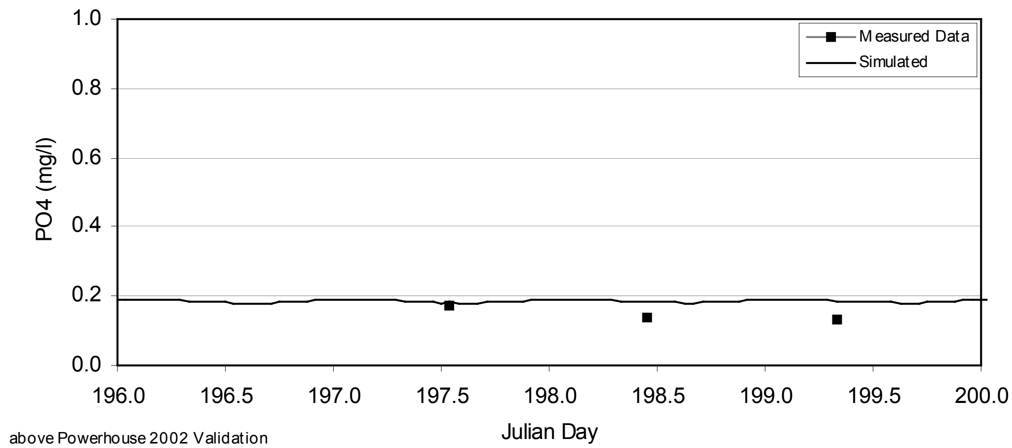


Figure 150. Klamath River, above JC Boyle PH tailrace, simulated versus measured orthophosphate, July 15-18, 2002

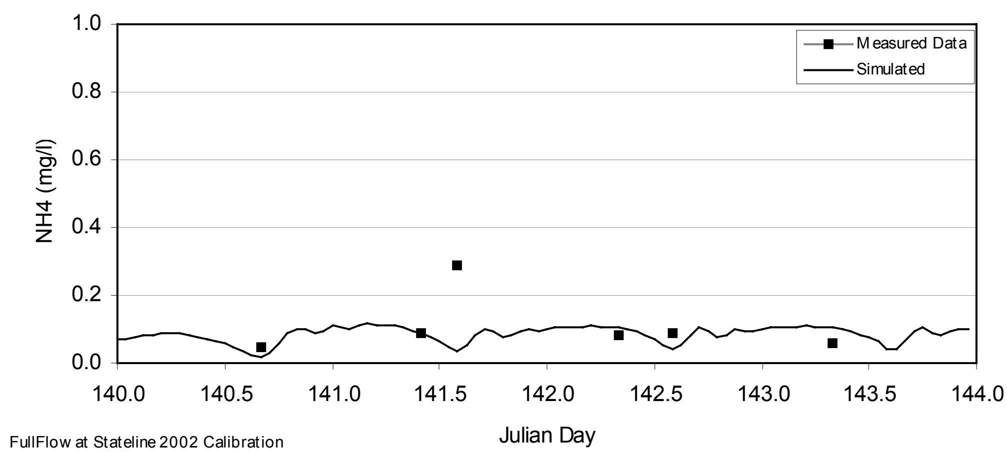


Figure 151. Klamath River, at Stateline, simulated versus measured ammonia, May 20-23, 2002

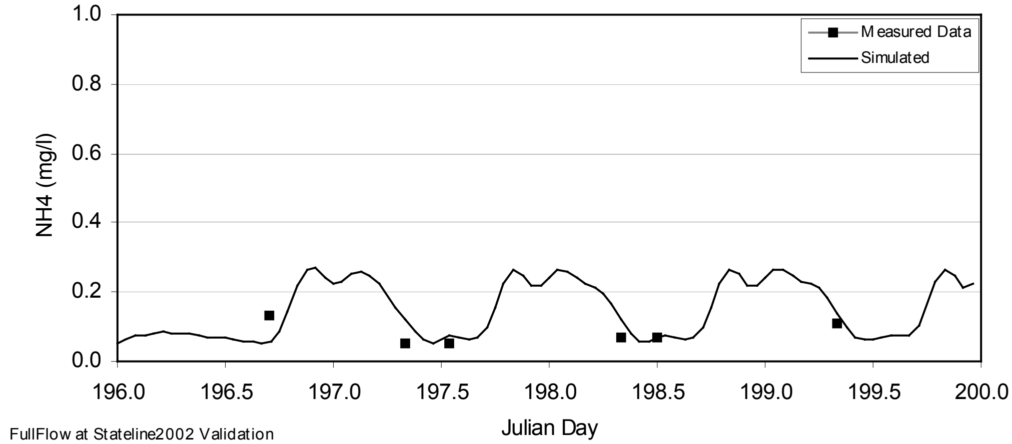


Figure 152. Klamath River, at Stateline, simulated versus measured ammonia, July 15-18, 2002

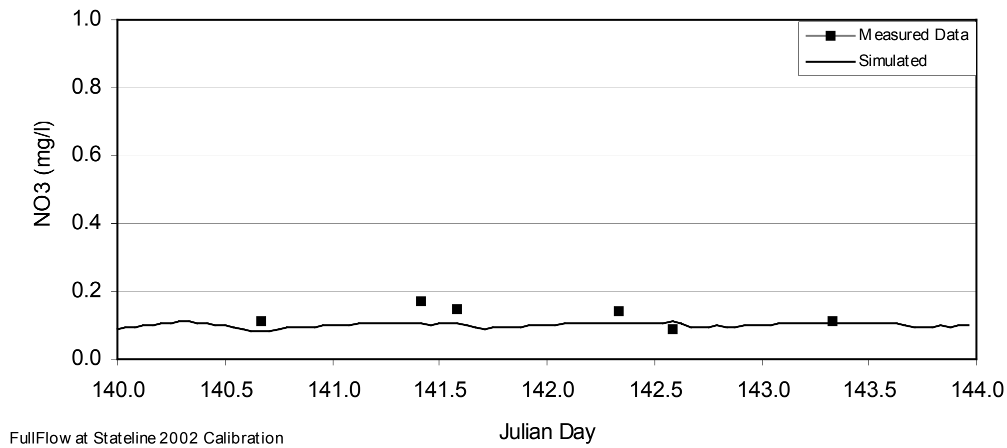


Figure 153. Klamath River, at Stateline, simulated versus measured nitrate, May 20-23, 2002

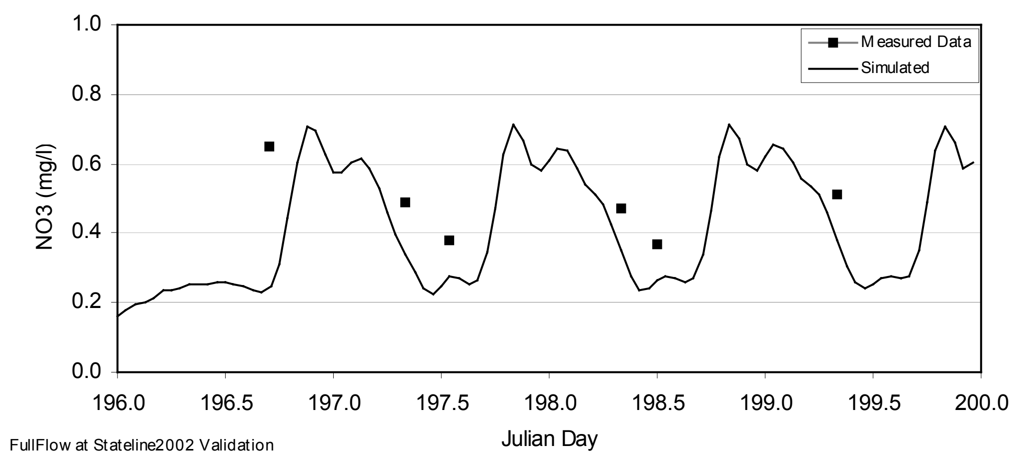


Figure 154. Klamath River, at Stateline, simulated versus measured nitrate, July 15-18, 2002

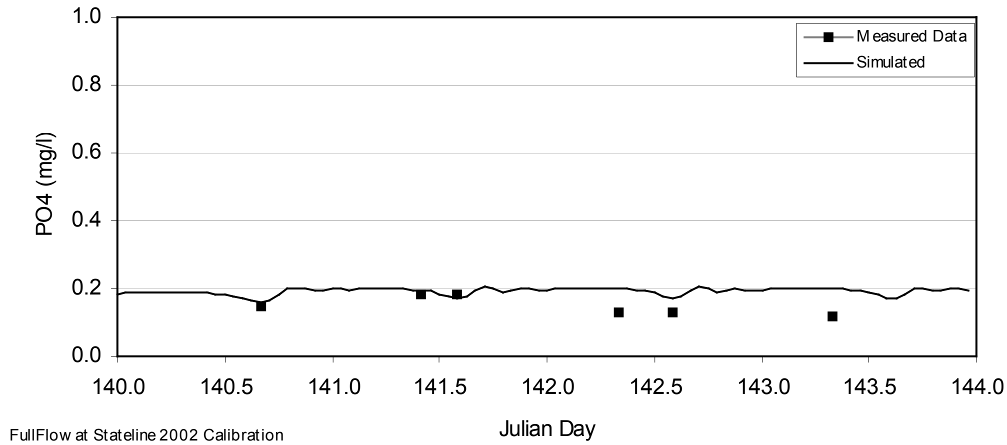


Figure 155. Klamath River, at Stateline, simulated versus measured orthophosphate, May 20-23, 2002

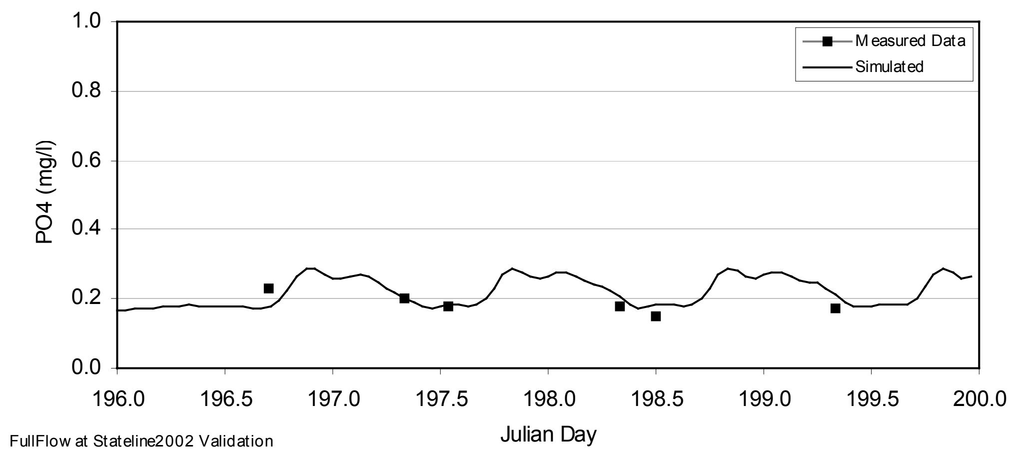


Figure 156. Klamath River, at Stateline, simulated versus measured orthophosphate, July 15-18, 2002

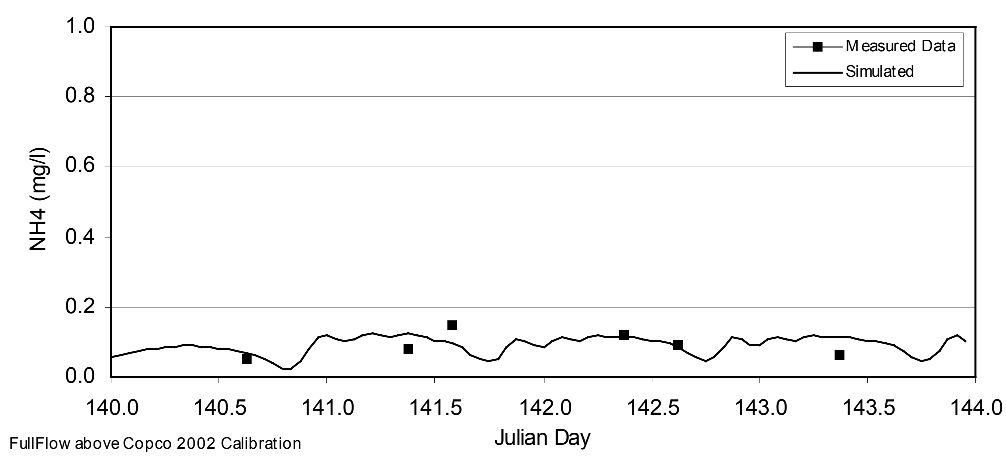


Figure 157. Klamath River, above Copco Reservoir, simulated versus measured ammonia, May 20-23, 2002

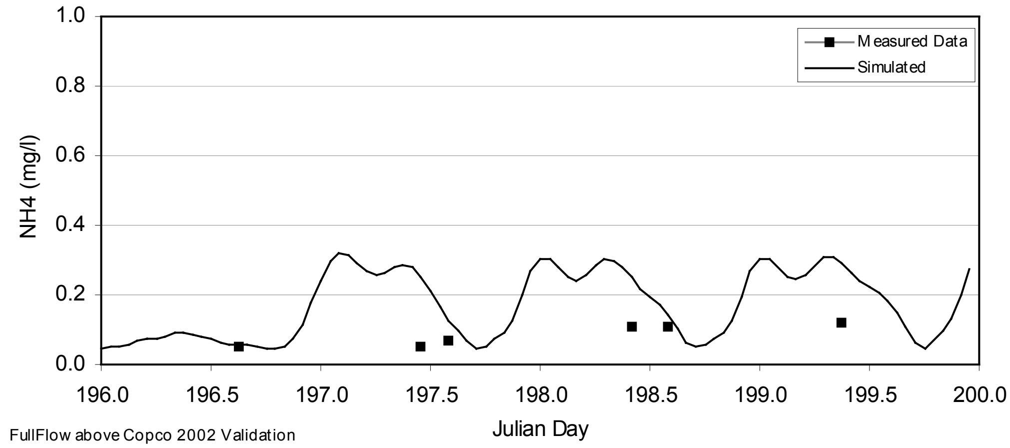


Figure 158. Klamath River, above Copco Reservoir, simulated versus measured ammonia, July 15-18, 2002

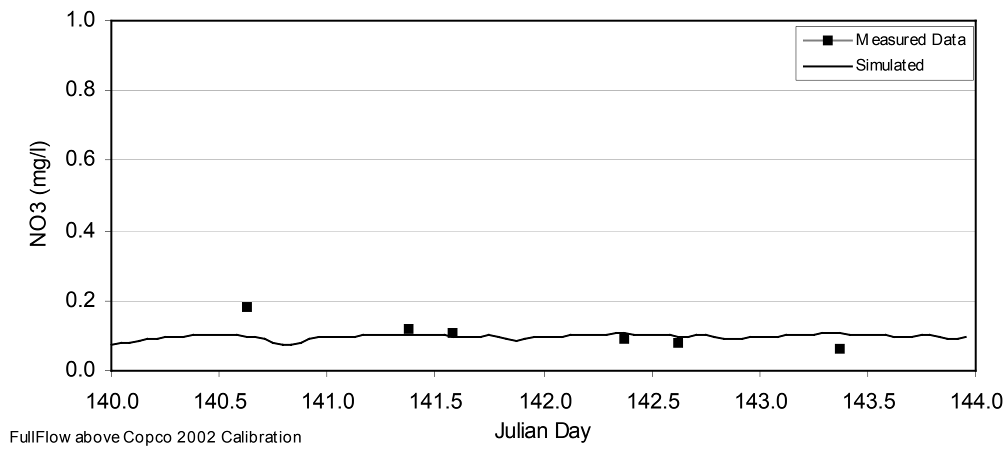


Figure 159. Klamath River, above Copco Reservoir, simulated versus measured nitrate, May 20-23, 2002

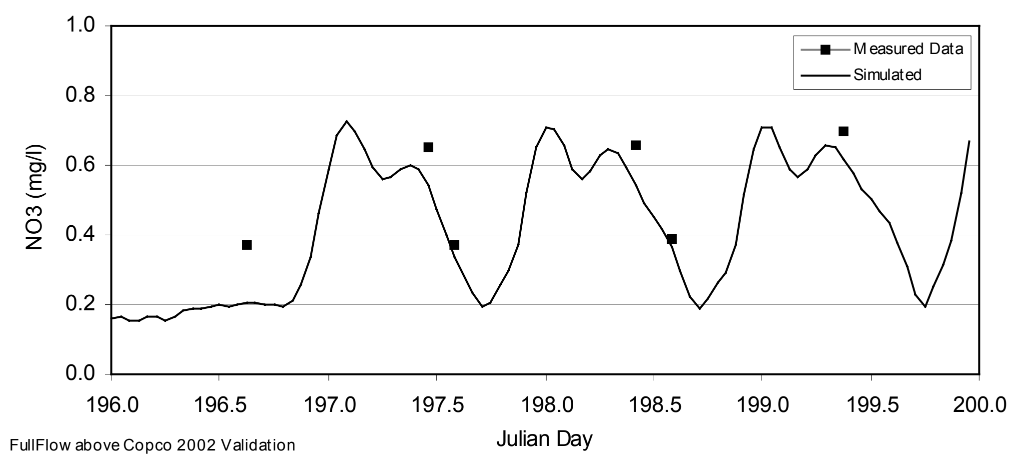


Figure 160. Klamath River, above Copco Reservoir, simulated versus measured nitrate, July 15-18, 2002

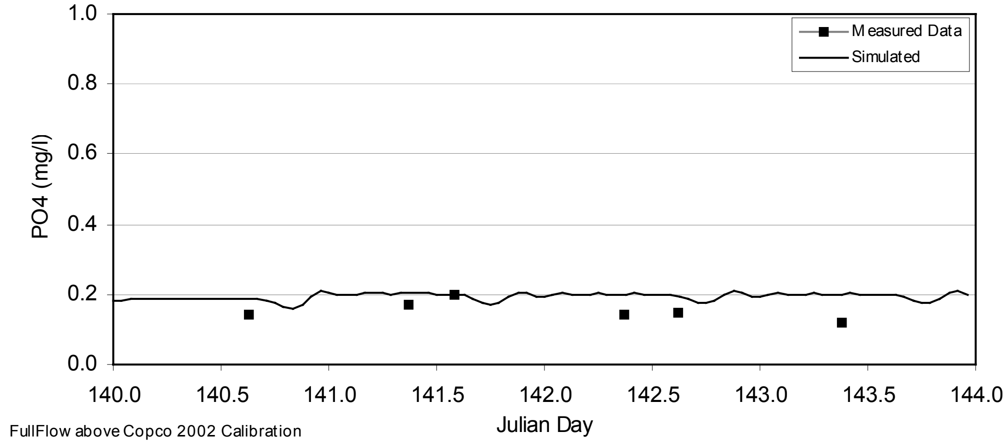


Figure 161. Klamath River, above Copco Reservoir, simulated versus measured orthophosphate, May 20-23, 2002

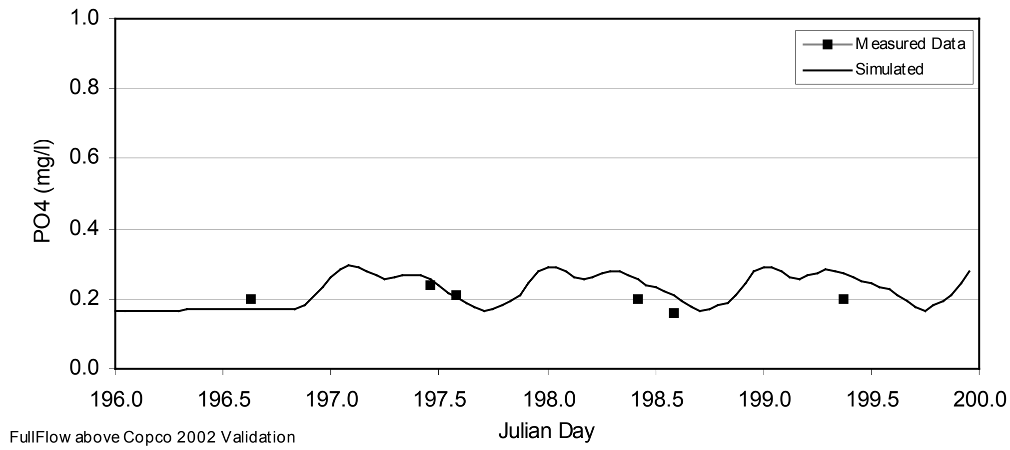


Figure 162. Klamath River, above Copco Reservoir, simulated versus measured orthophosphate, July 15-18, 2002

3.6.2.4 Summary of Parameters

Table 70. RMA-2 and RMA-11 Model rates, coefficients and constants for the Bypass / Peaking reach

Variable Name	Description, units	Value
	Time step, hr	0.25 (RMA-2)
		1.0 (RMA-11)
	Space step, m	75
	Manning roughness coefficient	0.04
	Turbulence factor, Pascal-sec	100
	Longitudinal diffusion scale factor	0.10
	Slope Factor	0.95
ELEV	Elevation of site, m	964.00
LAT	Latitude of site, degrees	41.5
LONG	Longitude of site, degrees	122.45
EVAPA	Evaporative heat flux coefficient a, m hr^{-1} mb^{-1}	0.000010
EVAPB	Evaporative heat flux coefficient b, m hr^{-1} mb^{-1} $(m/h)^{-1}$	0.000010
EXTINC	Light Extinction coefficient, used when algae is not simulated, 1/m	1.5
ALP0	Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A	67
ALP1	Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A	0.072
ALP2	Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A	0.010
LAMB1	Linear algal self-shading coefficient, phytoplankton, 1/m	n/a
LAMB2	Non-linear algal self shading coefficient, phytoplankton, 1/m	n/a
MUMAX	Maximum specific growth rate, phytoplankton, 1/d	0.01
RESP	Local respiration rate of algae, phytoplankton, 1/d	0.05
SIG1	Settling rate of algae, phytoplankton, 1/d	0.0
KLIGHT	Half saturation coefficient for light, phytoplankton, KJ m^{-2} s^{-1}	0.01
KNITR	Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l	0.01
KPHOS	Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l	0.001
PREFN	Preference factor for NH3-N, phytoplankton	0.6
ABLP0	Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A	50
ABLP1	Fraction of algal biomass that is nitrogen, bed algae, mg/l	0.07
ABLP2	Fraction of algal biomass that is phosphorus, bed algae, mg/l	0.01
LAMB1	Linear algal self shading coefficient, bed algae, 1/m	n/a
LAMB2	Non-linear self shading coefficient, bed algae, 1/m	n/a
MUMAX	Maximum specific growth rate, bed algae, 1/d	1.0
RESP	Local respiration rate of algae, bed algae, 1/d	0.60
MORT	Mortality, bed algae, 1/d	0.0
KBNITR	Half-saturation coefficient for nitrogen, bed algae, mg/l	0.01
KBPHOS	Half-saturation coefficient for phosphorus, bed algae, mg/l	0.002
KBLIGHT	Half-saturation coefficient for light, bed algae, KJ m^{-2} s^{-1}	0.01
PBREFN	Preference factor for NH3-N, bed algae	0.75
BET1	Rate constant: biological oxidation NH3-N, 1/d	0.3
BET2	Rate constant: biological oxidation NO2-N, 1/d	0.5
BET3	Rate constant: hydrolysis Org N to NH3-N, 1/d	0.3
BET4	Rate constant: transformation Org P to P-D, 1/d	0.3
KNINH	First order nitrification inhibition coefficient, mg^{-1}	n/a
ALP3	Rate O_2 production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A	1.6
ALP4	Rate O_2 uptake per unit of algae respired, phytoplankton, mg-O/mg-A	1.6
ABLP3	Rate O_2 production per unit of algal photosynthesis, bed algae, mg-O/mg-A	1.6
ABLP4	Rate O_2 uptake per unit of algae respired, bed algae, mg-O/mg-A	1.6
ALP5	Rate O_2 uptake per unit NH3-N oxidation, mg-O/mg-N	3.43
ALP6	Rate O_2 uptake per unit NO2-N oxidation, mg-O/mg-N	1.14
K1	Deoxygenation rate constant: BOD, 1/d	0.3
-	Minimum reaeration rate constant (Churchill formula applied), 1/d	3.0
SIG6	BOD settling rate constant, 1/d	0.0

n/a – not applicable

3.7 Copco Reservoir

Copco Reservoir reach extends from the headwaters of Copco Reservoir to Copco Dam. Copco Reservoir was modeled using CE-QUAL-W2 and was calibrated at selected dates for 2000.

3.7.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the mainstem (calibration/validation points) were required.

3.7.1.1 Boundary Conditions

The flow and temperature boundary conditions for the main inflow both passed from the Peaking reach (presented in Figure 163 and Figure 164) and constituent concentrations were estimated from field data (presented in Table 71). The accretion / depletion flow for the Copco Reservoir reach is included in the river inflow, and therefore is assumed to have the same temperature and constituent concentrations as the main inflow.

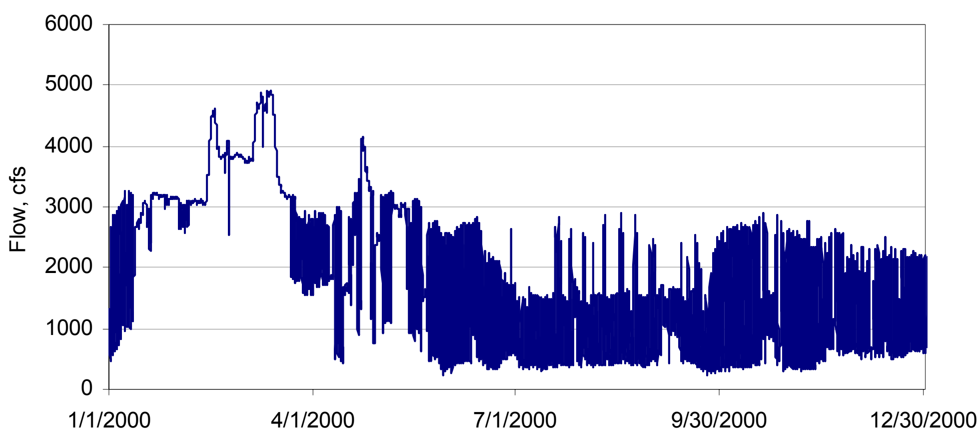


Figure 163. Main inflow rates for Copco Reservoir reach calibration (includes accretion / depletion flow)

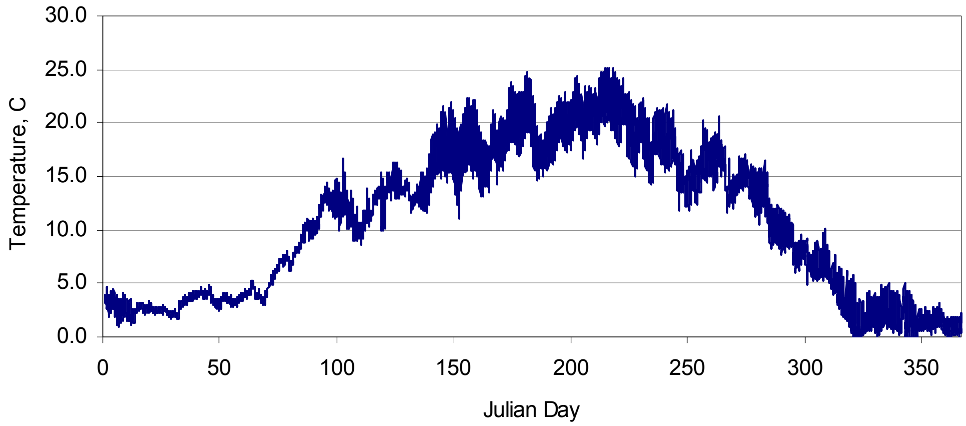


Figure 164. Main inflow temperatures for Copco Reservoir reach calibration

Table 71. Main inflow constituent concentrations for Copco Reservoir reach calibration

Julian Day	Total Dissolved Solids, mg/l	Total Suspended Solids, mg/l	Orthophosphate, mg/l	Ammonia, mg/l	Nitrate, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD, mg/l	Algal Concentration, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, eq/l
1	112	5	0.16	0.08	0.31	0	0	0.01	0.3	10.02	75	75
130	102	5	0.23	0.1	0.19	0.25	0	0.01	0.39	10.02	70	70
144	183	5	0.13	0.23	0.25	0.5	0	0.01	0.12	8.65	127	127
158	176	5	0.26	0.1	0.3	0.6	0	0.01	0.83	7.96	113	113
172	96	5	0.39	0.21	0.57	0.93	0.1	0.01	0.87	7.86	70	70
193	104	5	0.16	0.05	0.41	1.26	0.1	0.01	0.29	8.04	75	75
207	144	5	0.25	0.08	0.42	1.59	0.1	0.01	0.29	9.49	78	78
220	129	5	0.17	0.05	0.61	1.92	0.1	0.01	3.34	8.11	76	76
235	136	5	0.05	0.05	0.36	2.25	0.1	0.01	0.29	9.53	74	84
256	164	5	0.1	0.05	0.38	1.8	0.1	0.01	2.9	9.71	103	112
270	115	5	0.12	0.05	0.31	1.35	0.1	0.01	0.15	10.97	108	108
291	156	5	0.09	0.05	0.68	0.9	0.1	0.01	0.15	10.86	83	83
305	109	5	0.05	0.05	0.49	0.45	0	0.01	0.15	10.75	75	75
319	122	5	0.08	0.05	0.43	0	0	0.01	0.15	11.38	79	79
367	112	5	0.16	0.08	0.31	0	0	0.01	0.3	10.02	75	75

3.7.1.2 Initial conditions

During the winter the Copco Reservoir Can have a residence time of less than 10 days. Thus initial conditions under this short residence time and isothermal conditions are presumed to wash out of the system in a few weeks.

3.7.2 Results

Calibration was completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled once per day. All model parameters for the Copco Reservoir reach are summarized in Table 74, at the end of this section.

3.7.2.1 Water Temperature

The water temperature was calibrated using the three user specified wind evaporation coefficients available in CE-QUAL-W2. Results are shown in Figure 165 and summary statistics are included in Table 72. Copco Reservoir experiences seasonal stratification, and the model replicates these conditions. The profile bias ranged from 0.44°C to –1.11°C and the mean absolute error ranged from 0.45°C to 1.15°C. Overall the model is within about 1.5°C of observations, except at the bottom of the reservoir where simulated data indicate the presence of a cold water pocket not shown in the observations.

Table 72. Copco Reservoir thermal profile summary statistics: simulated versus measured

Date	Mean Bias[a] (°C)	Mean Absolute Error (°C)	Root Mean Squared Error (°C)	n
April 12, 2000	0.32	1.06	1.20	18
May 9, 2000	0.44	0.47	0.66	18
June 6, 2000	0.23	0.46	0.52	18
July 11, 2000	0.10	0.52	0.65	18
August 8, 2000	-0.50	0.83	1.00	17
September 10, 2000	-0.08	0.46	0.62	9
September 27, 2000	-1.11	1.15	1.77	9
October 18, 2000	0.28	0.45	0.54	18

[a] Mean bias = simulated – measured

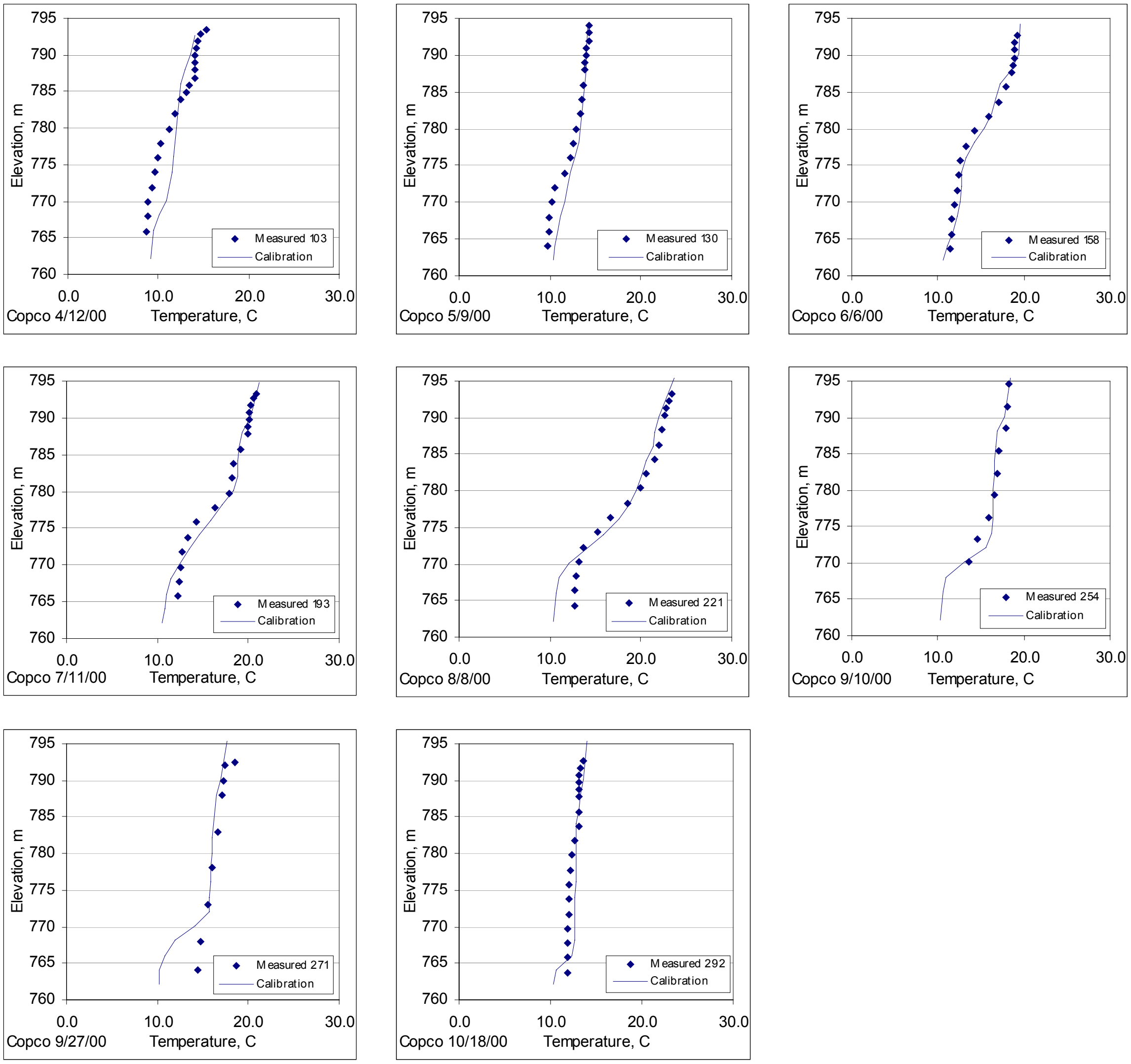


Figure 165. Copco Reservoir thermal profiles, simulated versus measured monthly values: 2000

3.7.2.2 Dissolved Oxygen

The dissolved oxygen was calibrated using several different parameters, including algal rates, organic matter decay rates and nutrient decay rates. Also, zero order SOD was employed in calibrating dissolved oxygen. Results are shown in Figure 166 and summary statistics are included in Table 73. The profile bias ranged from –3.00 mg/l to 5.73 mg/l while the mean absolute error ranged from 0.44 mg/l to 3.00 mg/l.

Conditions are generally well represented, with spring and fall conditions most variable. The October 18 simulated profile suggests that the lake had not attained isothermal condition, while observed data presented in Figure 165 identifies that the lake had turned over.

Table 73. Copco Reservoir dissolved oxygen profile summary statistics: simulated versus measured

Date	Mean Bias[a] (mg/l)	Mean Absolute Error (mg/l)	Root Mean Squared Error (mg/l)	n
April 12, 2000	0.09	0.53	0.64	18
May 9, 2000	1.39	1.40	2.10	18
June 6, 2000	-0.11	0.44	0.61	18
July 11, 2000	-0.61	0.78	1.13	18
August 8, 2000	-1.62	1.62	2.16	17
September 27, 2000	-1.87	1.87	2.29	9
October 18, 2000	-3.00	3.00	4.32	18

[a] Mean bias = simulated – measured

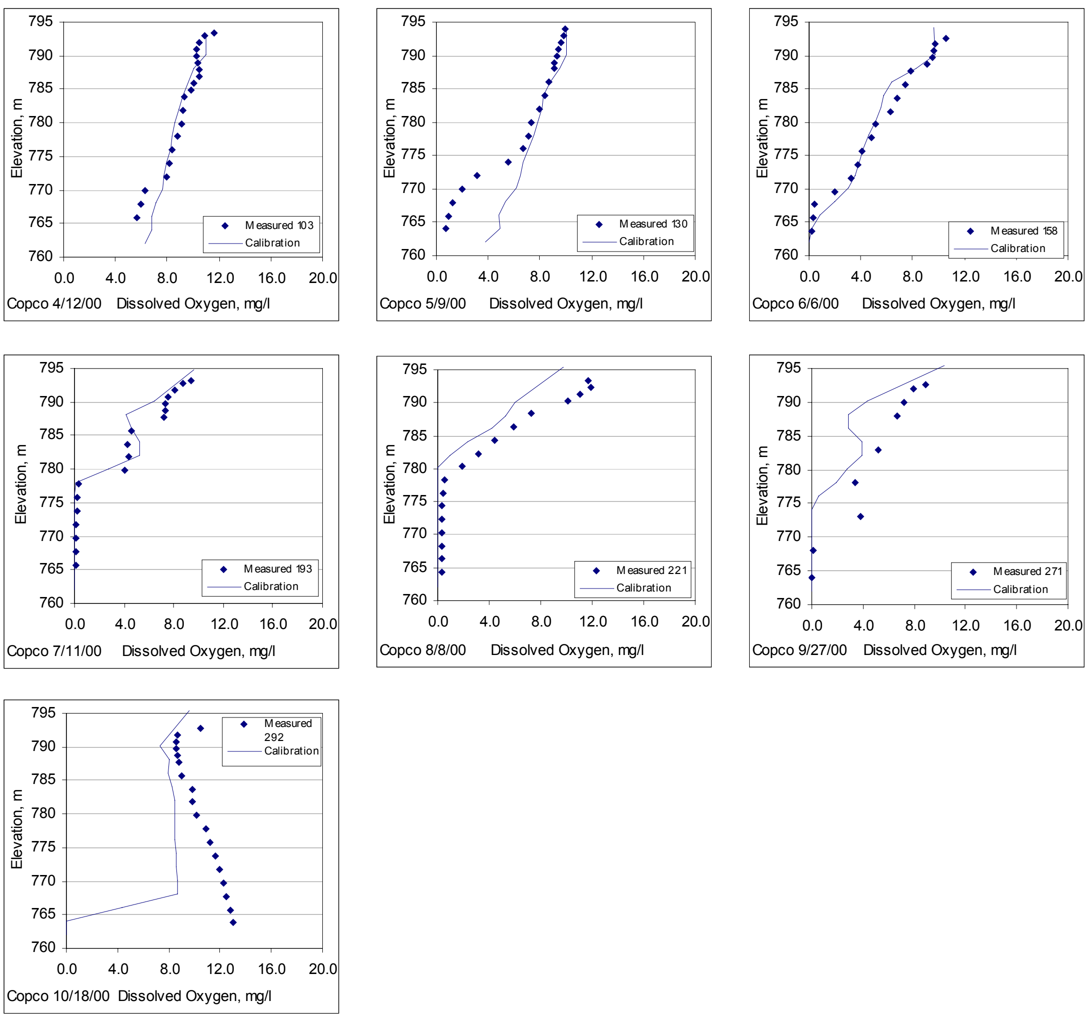


Figure 166. Copco Reservoir dissolved oxygen profiles, simulated versus measured monthly values: 2000

3.7.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Copco Reservoir reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the DO calibration were not modified, and other parameters were set at default values. Graphical results are presented in Figure 167 through Figure 170. Simulated coditions generally follow seasonal trends.

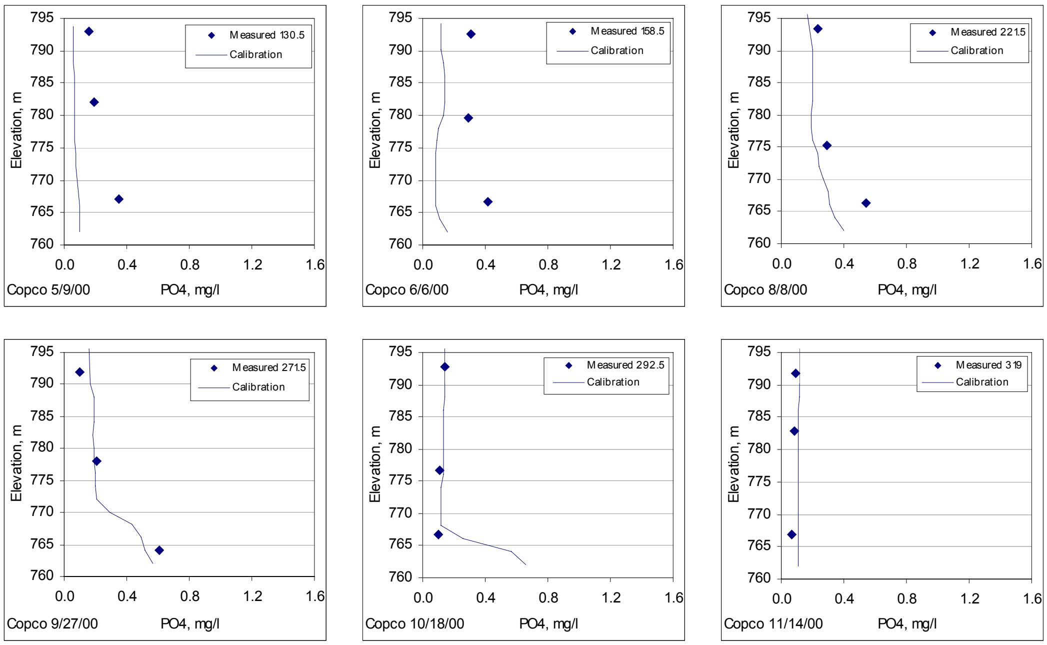


Figure 167. Copco Reservoir phosphate profiles, simulated versus measured monthly values: 2000

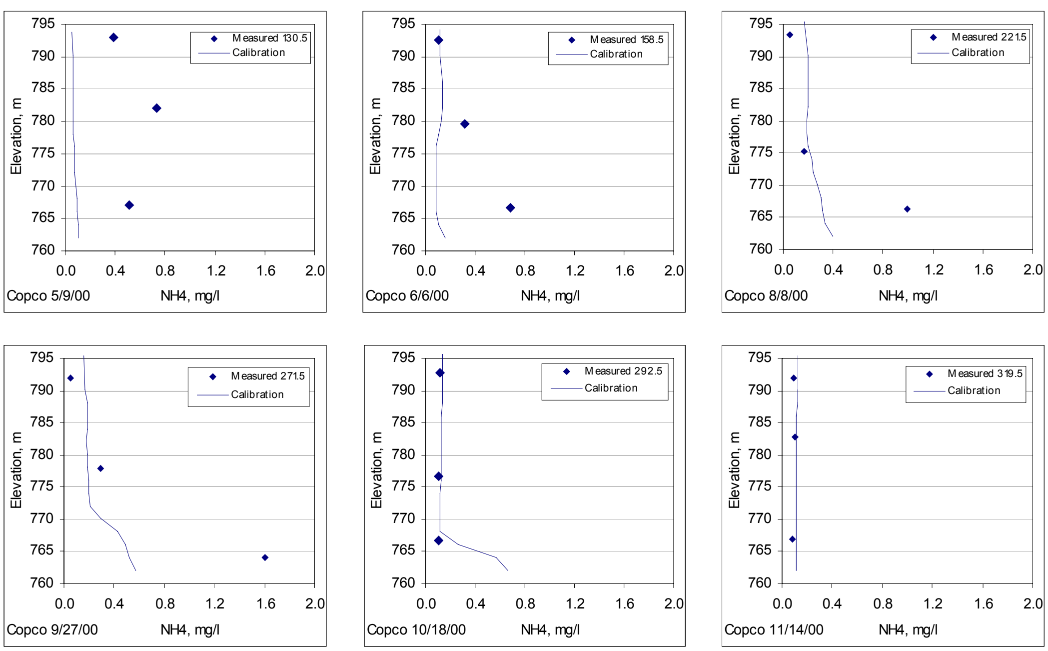


Figure 168. Copco Reservoir ammonia profiles, simulated versus measured monthly values: 2000

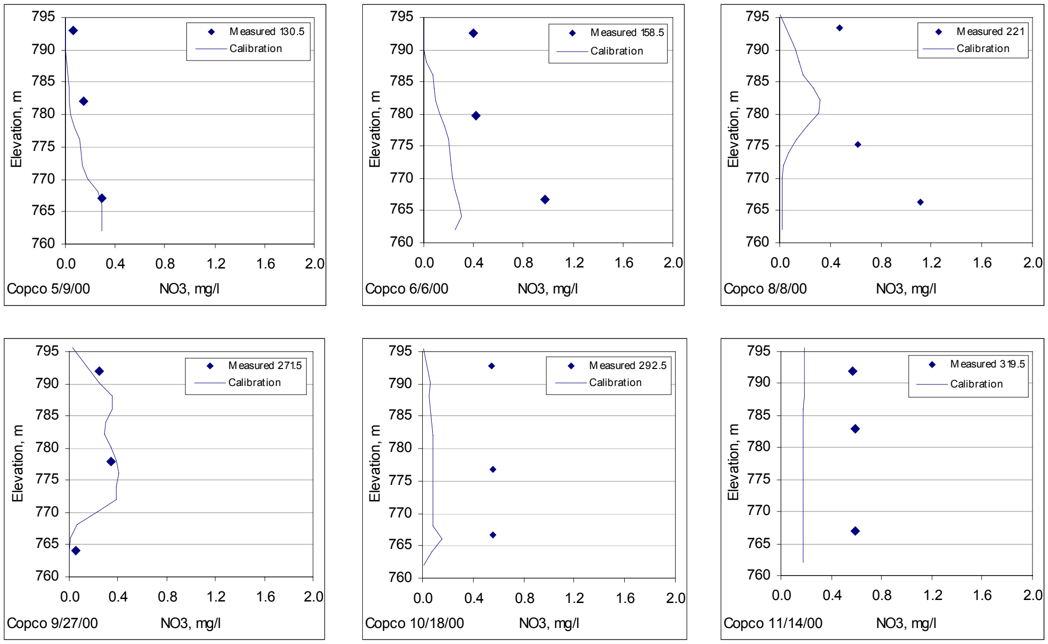


Figure 169. Copco Reservoir nitrate profiles, simulated versus measured monthly values: 2000

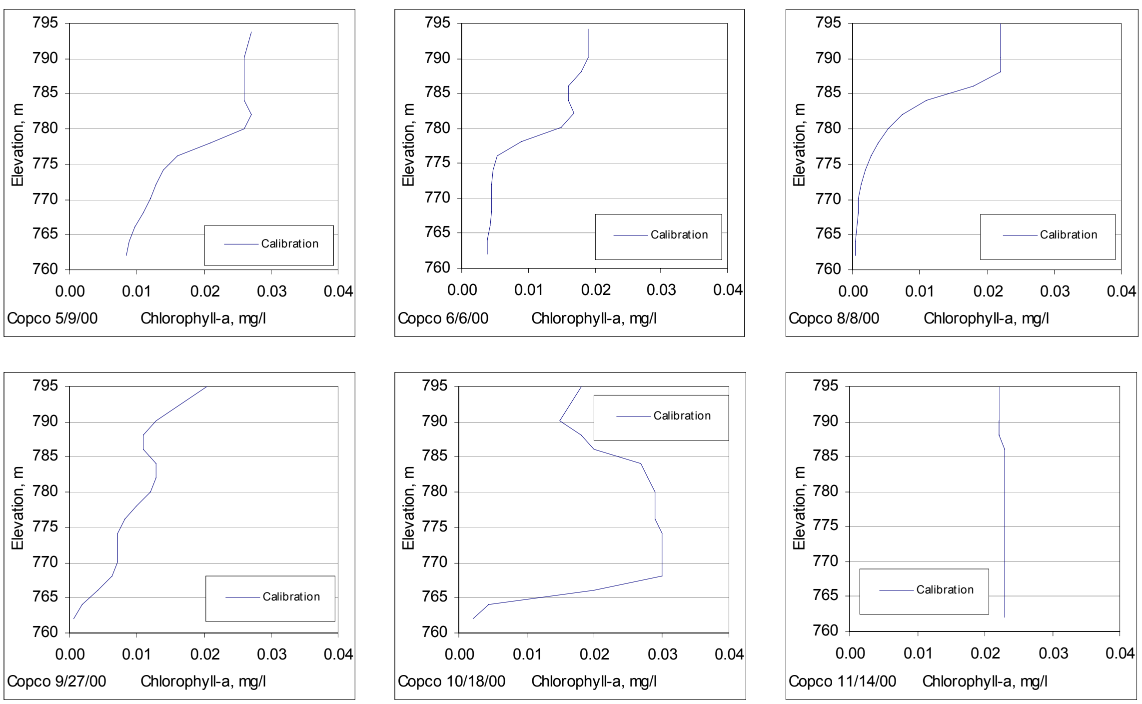


Figure 170. Copco Reservoir chlorophyll-a profiles, simulated concentrations only: 2000

3.7.2.4 Summary of Parameters

Table 74. Significant control file parameters for the Copco Reservoir reach calibration

Parameter Name	Description	EC Copco Value	Default Values
DLT MIN	Minimum timestep, sec	5.0	N/A
DLT MAX	Maximum timestep, sec	500	N/A
SLOPE	Waterbody bottom slope	0.0	N/A
LAT	Latitude, degrees	42.12	N/A
LONG	Longitude, degrees	122.33	N/A
EBOT	Bottom elevation of waterbody, m	761.09	N/A
CFW	C coefficient in the wind speed formulation	1.0	2.0
WINDH	Wind speed measurement height, m	2.0	N/A
CBHE	Coefficient of bottom heat exchange, W/m^2sec	3.0	7.0E-8
TSED	Sediment (ground) Temperature, C	10.0	N/A
FI	Interfacial friction factor	0.04	N/A
TSEDF	Heat lost to sediments that is added back to water column, fraction	0.01	N/A
EXH20	Extinction for pure water, m^{-1}	0.25	0.25 (Full WQ sim)
CGQ10 (Tracer)	Arhennius temperature rate multiplier	0	0
CG0DK (Tracer)	0-order decay rate, 1/day	0	0
CG1DK (Tracer)	1^{st}-order decay rate, 1/day	0	0
CGS (Tracer)	Settling rate, m/day	0	0
CGQ10 (Age)	Arhennius temperature rate multiplier	0	0
CG0DK (Age)	0-order decay rate, 1/day	-1.0	-1.0
CG1DK (Age)	1^{st}-order decay rate, 1/day	0	0
CGS (Age)	Settling rate, m/day	0	0
CGQ10 (Coliform)	Arhennius temperature rate multiplier	1.04	N/A
CG0DK (Coliform)	0-order decay rate, 1/day	0	N/A
CG1DK (Coliform)	1^{st}-order decay rate, 1/day	1.4	N/A
CGS (Coliform)	Settling rate, m/day	1.0	N/A
AG	Maximum algal growth rate, 1/day	3.0	2.0
AT1	Lower temperature for algal growth, C	5.0	5.0
PO4R	Sediment release rate of phosphorus, fraction of SOD	0.03	0.001
PARTP	Phosphorus partitioning coefficient for suspended solids	0.001	0.0
NH4REL	Sediment release rate of ammonium, fraction of SOD	0.07	0.001
NH4DK	Ammonium decay rate, 1/day	0.1	0.12
NO3DK	Nitrate decay rate, 1/day	0.1	0.03
NO3S	De-nitrification rate from sediments, m/day	0.0	1.0
CO2REL	Sediment carbon dioxide release rate, fraction of sediment oxygen demand	0.01	0.1
O2AR	Oxygen stoichiometry for algal respiration	1.4	1.1
O2AG	Oxygen stoichiometry for algal primary production	1.5	1.4
SOD	Zero-order sediment oxygen demand for each segment, g O_2 / m^2 day	2.0 (for each segment)	N/A

3.8 *Iron Gate Reservoir*

Iron Gate Reservoir was modeled using CE-QUAL-W2. Calibration occurred at selected dates in 2000. Validation has not occurred. Iron Gate Reservoir reach extends from the headwaters of Iron Gate Reservoir to Iron Gate Dam.

3.8.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the mainstem (calibration/validation points) were required.

3.8.1.1 Boundary Conditions

The boundary condition information for Iron Gate Reservoir is passed from the Copco Reservoir reach simulation (presented in Figure 171 through Figure 173). The accretion / depletion, located at Jenny Creek, has the same concentrations as presented in the model implementation section.

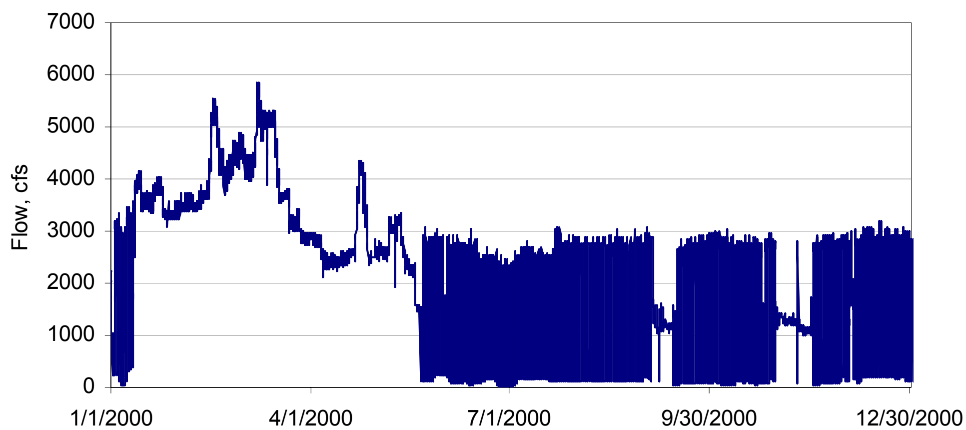


Figure 171. Main inflow rates for Iron Gate Reservoir reach calibration

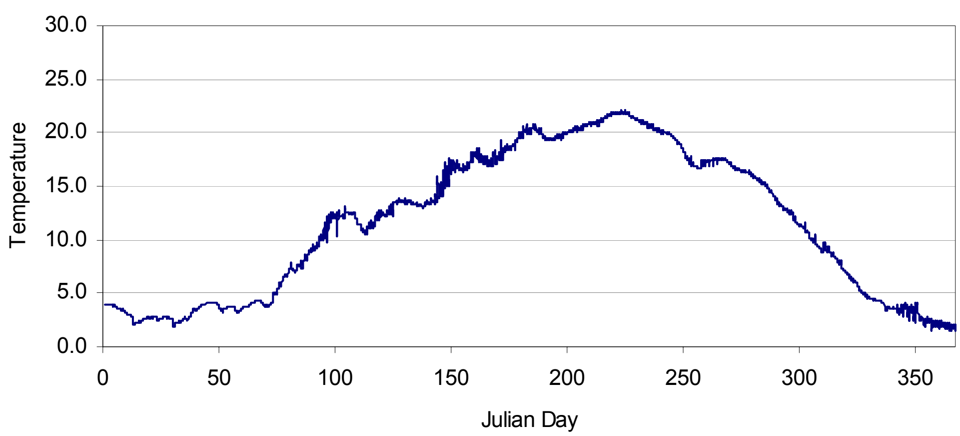
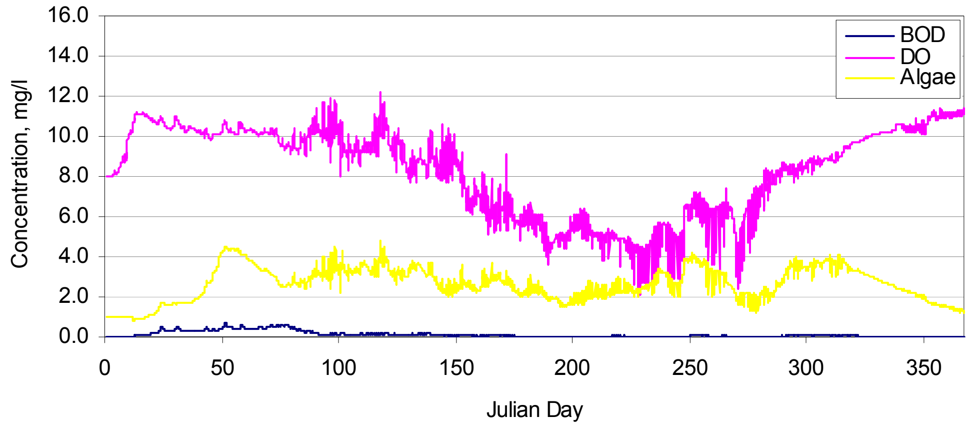
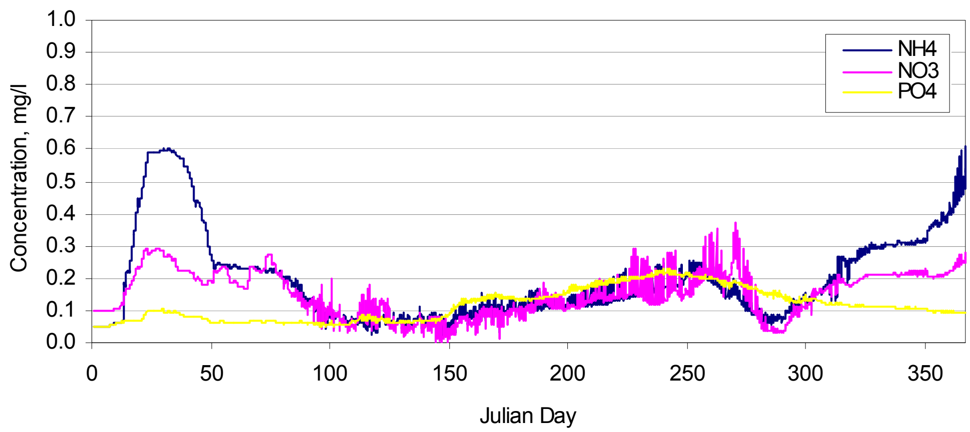


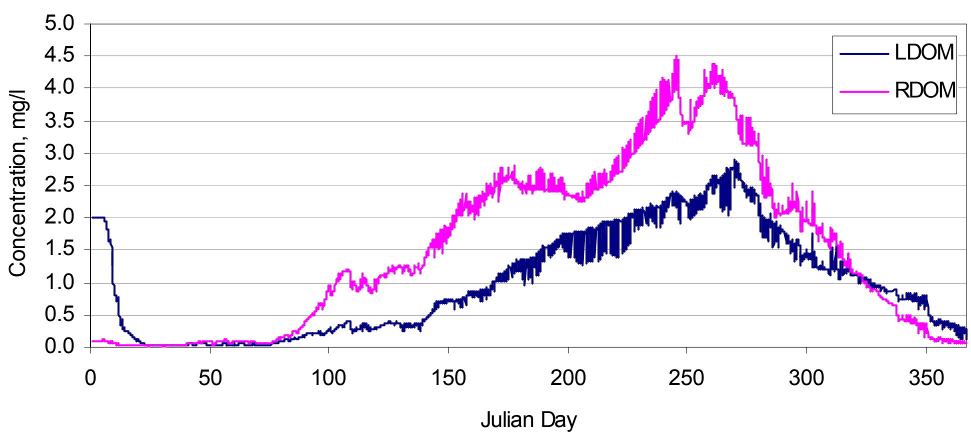
Figure 172. Main inflow temperature for Iron Gate Reservoir reach calibration



(a)



(b)



(c)

Figure 173. Selected inflow constituent concentrations for Iron Gate Reservoir reach calibration: (a) BOD, dissolved oxygen, algae; (b) nutrients; (c) dissolved organic matter

3.8.1.2 Initial conditions

The residence time for Iron Gate Reservoir is approximately 10 days in the winter. Thus initial conditions under this short residence time and isothermal conditions are presumed to wash out of the system in a few weeks.

3.8.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled once per day. All model parameters for the Iron Gate Reservoir reach are summarized in Table 77, at the end of this section.

3.8.2.1 Water Temperature

The water temperature was calibrated using the three user specified wind evaporation coefficients available in CE-QUAL-W2. Results are shown in Figure 174 and summary statistics are included in Table 75. Iron Gate Reservoir experiences seasonal stratification and the model replicates this stratification. The profile bias ranged from –1.06°C to 1.42°C and the mean absolute error ranged from 0.46°C to 1.42°C. Overall the model is within about 2°C of observations.

Table 75. Iron Gate Reservoir thermal profile summary statistics: simulated versus measured

Date	Mean Bias[a] (°C)	Mean Absolute Error (°C)	Root Mean Squared Error (°C)	n
April 12, 2000	0.24	1.16	1.28	26
May 9, 2000	1.06	1.06	1.22	24
June 6, 2000	1.42	1.42	1.70	23
July 11, 2000	0.26	0.46	0.50	23
August 8, 2000	0.53	0.75	0.91	23
September 10, 2000	0.34	0.93	1.21	12
September 27, 2000	-0.80	0.91	1.26	19
October 18, 2000	-1.06	1.06	1.31	22

[a] Mean bias = simulated – measured

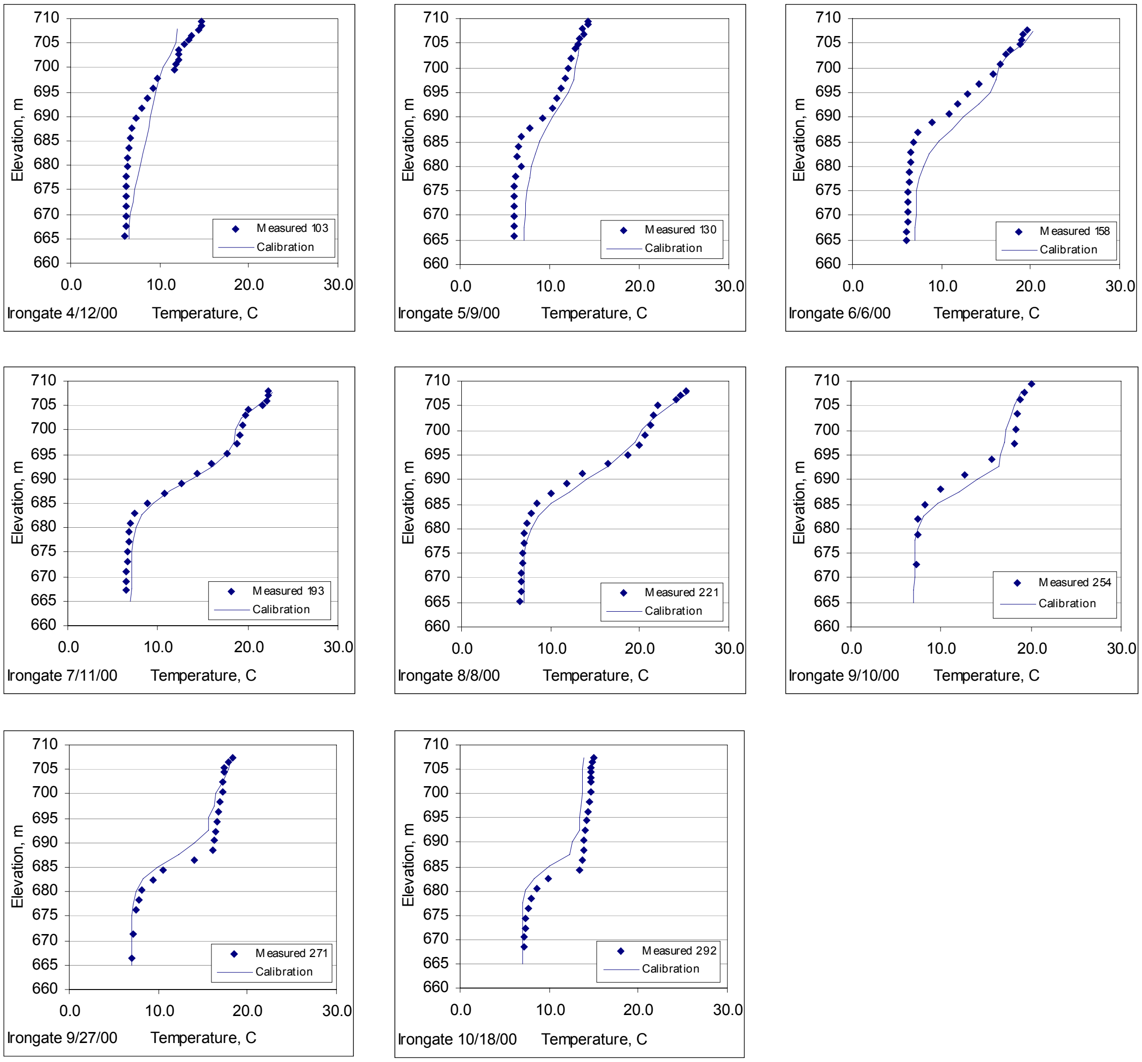


Figure 174. Iron Gate Reservoir thermal profiles, simulated versus measured monthly values: 2000

3.8.2.2 Dissolved Oxygen

The dissolved oxygen was calibrated using several different parameters, including algal rates, organic matter decay rates and nutrient decay rates. A zero order SOD representation was employed in calibrating dissolved oxygen. Results are shown in Figure 175 and summary statistics are included in Table 76. Iron Gate Reservoir dissolved oxygen concentrations experience significant seasonal deviations from saturated conditions. The seasonal anoxia in timing and extent is well represented in simulated results, with the exception of October when anoxia persists longer than the last observed data suggest. The profile bias ranged from –1.12 mg/l to 3.20 mg/l and the mean absolute error ranged from 0.94 mg/l to 3.20 mg/l. Overall the model is within about 5 mg/l of observations.

Table 76. Iron Gate Reservoir dissolved oxygen profile summary statistics: simulated versus measured

Date	Mean Bias[a] (mg/l)	Mean Absolute Error (mg/l)	Root Mean Squared Error (mg/l)	n
April 12, 2000	-1.12	1.51	1.74	26
May 9, 2000	0.54	0.94	1.07	24
June 6, 2000	0.17	0.94	1.09	23
July 11, 2000	0.02	1.00	1.26	23
August 8, 2000	0.25	1.77	2.38	23
September 10, 2000	3.20	3.20	4.61	12
September 27, 2000	1.00	1.40	2.15	19
October 18, 2000	0.66	2.53	2.81	22

[a] Mean bias = simulated – measured

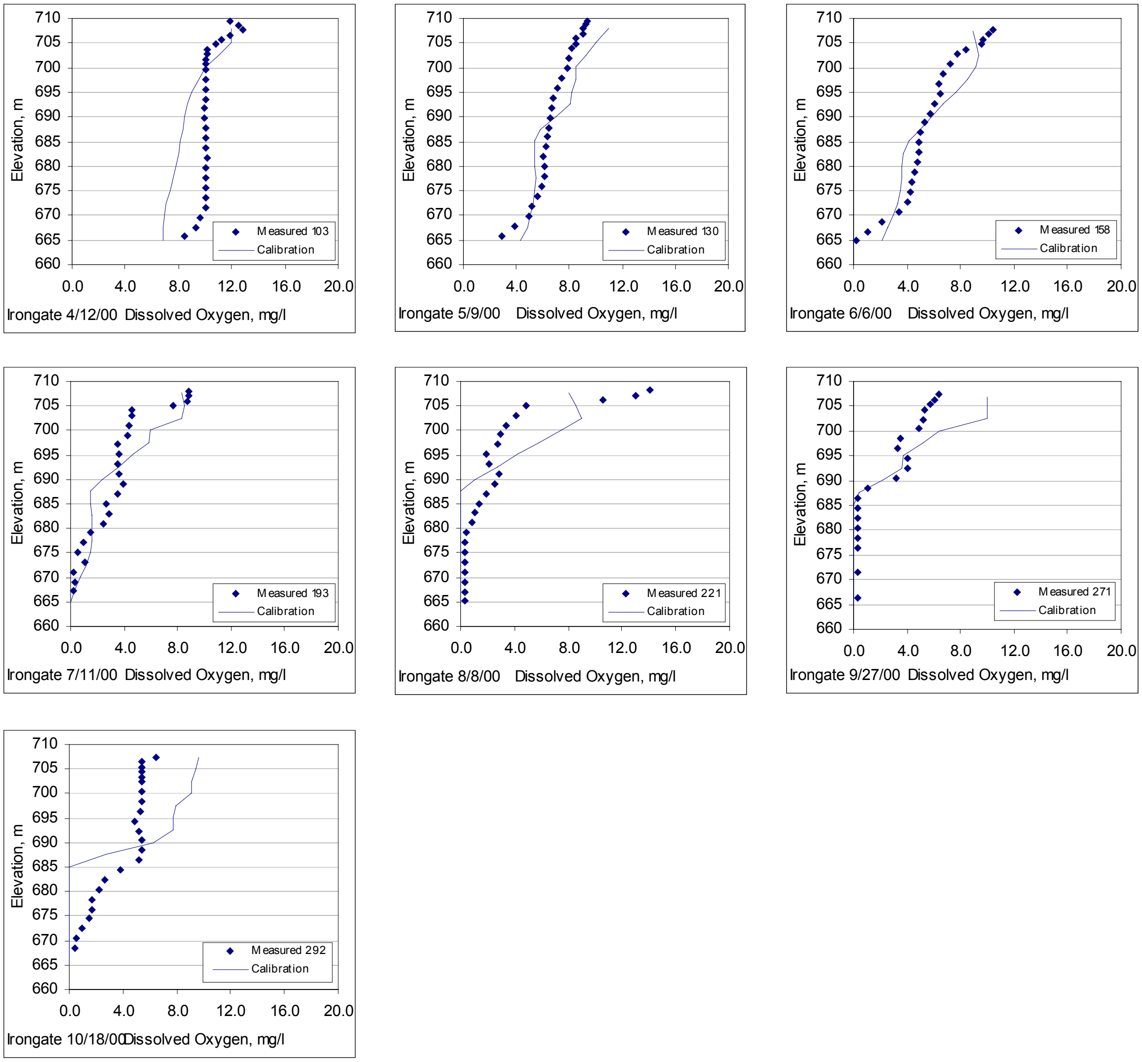


Figure 175. Iron Gate Reservoir dissolved oxygen profiles, simulated versus measured monthly values: 2000

3.8.2.3 Nutrients

Nutrient concentrations were not actively calibrated in the Iron Gate Reservoir reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the DO calibration were not modified, and other parameters were set at default values.

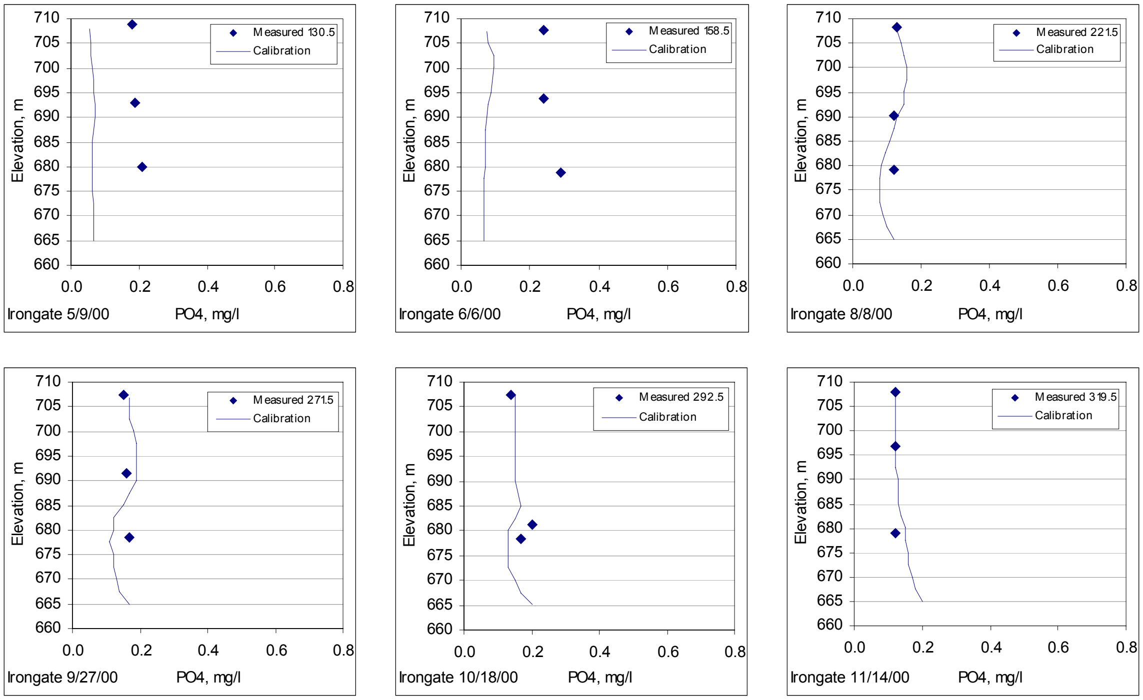


Figure 176. Iron Gate Reservoir phosphate profiles, simulated versus measured monthly values: 2000

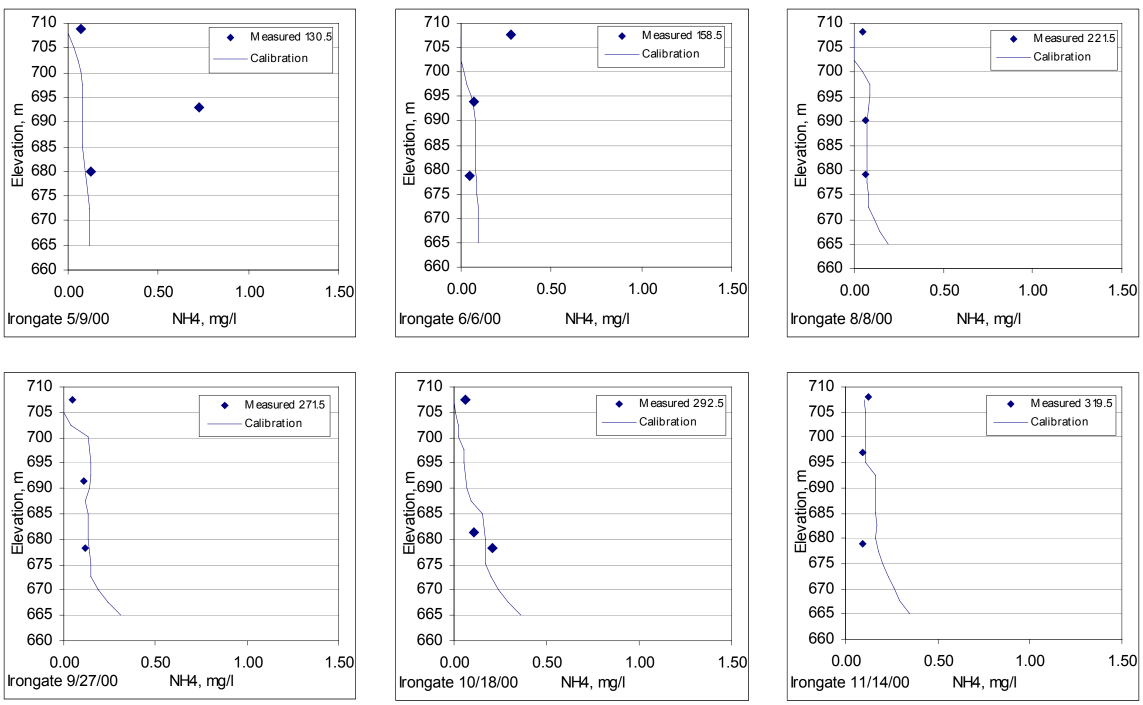


Figure 177. Iron Gate Reservoir ammonia profiles, simulated versus measured monthly values: 2000

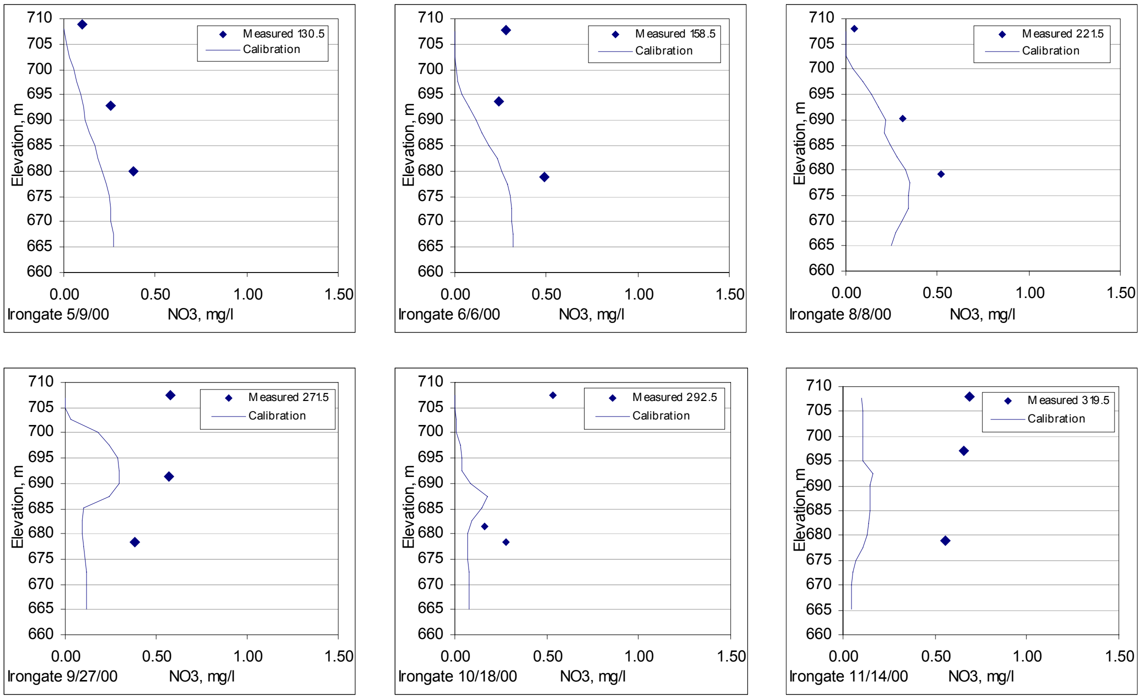


Figure 178. Iron Gate Reservoir nitrate profiles, simulated versus measured monthly values: 2000

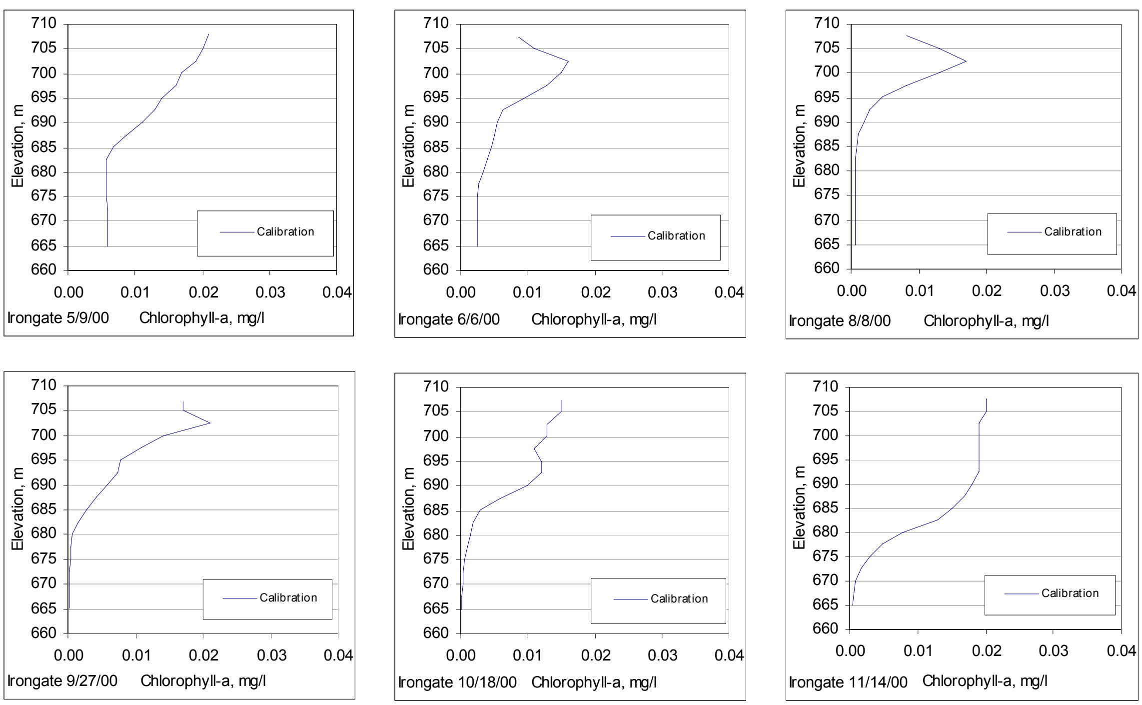


Figure 179. Iron Gate Reservoir chlorophyll-a profiles, simulated concentrations only: 2000

3.8.2.4 Summary of Parameters

Table 77. Significant control file parameters in the Iron Gate Reservoir calibration

Parameter Name	Description	EC Iron Gate Value	Default Value
DLT MIN	Minimum timestep, sec	5.0	N/A
DLT MAX	Maximum timestep, sec	500	N/A
SLOPE	Waterbody bottom slope	0.0	N/A
LAT	Latitude, degrees	42.97	N/A
LONG	Longitude, degrees	122.42	N/A
EBOT	Bottom elevation of waterbody, m	663.78	N/A
AFW	A coefficient in the wind speed formulation	6.0	
CFW	C coefficient in the wind speed formulation	1.0	2.0
WINDH	Wind speed measurement height, m	2.0	N/A
CBHE	Coefficient of bottom heat exchange, W/m^2sec	17.14	7.0-8
TSED	Sediment (ground) Temperature, C	7.0	N/A
FI	Interfacial friction factor	0.04	N/A
TSEDF	Heat lost to sediments that is added back to water column, fraction	0.01	N/A
EXH20	Extinction for pure water, m^{-1}	0.25	0.25 (for Full WQ sim)
CGQ10 (CG1)	Arhennius temperature rate multiplier	0	0
CG0DK (CG1)	0-order decay rate, 1/day	0	0
CG1DK (CG1)	1st-order decay rate, 1/day	0	0
CGS (CG1)	Settling rate, m/day	0	0
CGQ10 (CG2)	Arhennius temperature rate multiplier	0	0
CG0DK (CG2)	0-order decay rate, 1/day	-1.0	-1.0
CG1DK (CG2)	1st-order decay rate, 1/day	0	0
CGS (CG2)	Settling rate, m/day	0	0
CGQ10 (CG3)	Arhennius temperature rate multiplier	1.04	N/A
CG0DK (CG3)	0-order decay rate, 1/day	0	N/A
CG1DK (CG3)	1st-order decay rate, 1/day	1.4	N/A
CGS (CG3)	Settling rate, m/day	1.0	N/A
AG	Maximum algal growth rate, 1/day	3.0	2.0
AT1	Lower temperature for algal growth, C	5.0	5.0
PO4R	Sediment release rate of phosphorus, fraction of SOD	0.03	0.001
PARTP	Phosphorus partitioning coefficient for suspended solids	0.001	0.0
NH4REL	Sediment release rate of ammonium, fraction of SOD	0.07	0.001
NH4DK	Ammonium decay rate, 1/day	0.1	0.12
NO3DK	Nitrate decay rate, 1/day	0.1	0.03
NO3S	De-nitrification rate from sediments, m/day	0.0	1.0
CO2REL	Sediment carbon dioxide release rate, fraction of sediment oxygen demand	0.01	0.1
O2AR	Oxygen stoichiometry for algal respiration	1.4	1.1
O2AG	Oxygen stoichiometry for algal primary production	1.5	1.4
SOD	Zero-order sediment oxygen demand for each segment, g O_2 / m^2 day	3.0 (for each segment)	N/A

3.9 Iron Gate Dam to Turwar

The RMA suite of models for the Klamath River from Iron Gate Dam (RM 190) to Seiad Valley (RM 129) was initially calibrated for June 5-7, 2000 (Julian Day 157-159) and August 7-9, 2000 (JD 220-222), respectively. To calibrate the lower river and further test the model, field data was collected from 12 locations between Iron Gate Dam and Turwar, including major tributaries, in 2003. Field data was collected June 9-12, 2003 (JD 160-164) and August 18-21, 2003 (JD 230-234). The 2003 period was used as the final calibration data set; however, 2000 results are included to illustrate model performance over a wider range of conditions. The 2000 data are presented in less detail following the 2003 results.

3.9.1 Data: 2003

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and observations in the Klamath River at several points were required (calibration / validation points).

3.9.1.1 Boundary Conditions: 2003

Boundary conditions were required for all inflows into the reach, including the main inflow from Iron Gate Dam and twenty of the twenty-three tributaries modeled in the reach (three tributaries were not assigned temperature, dissolved oxygen or constituent concentrations due to their relatively small size, especially in summer: Willow, Cottonwood, and Humbug Creeks). Flow, temperature, dissolved oxygen and other water quality conditions for the 2003 period are presented below.

Flow

The Iron Gate Dam to Turwar reach includes 23 inflows in addition to the headwater boundary condition at Iron Gate Dam. Measured gage flow at Klamath River below Iron Gate Dam (USGS gage 11516530) during the 2003 recalibration periods was used to designate flow from Iron Gate Dam (presented in Figure 55).

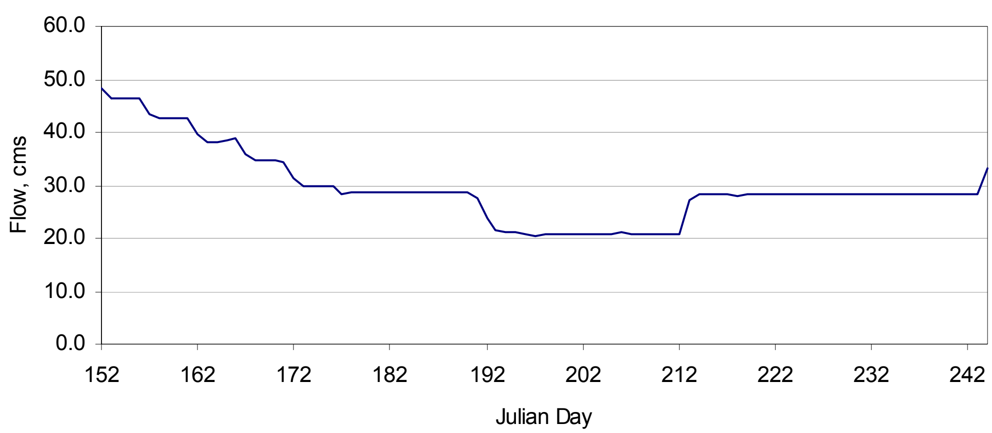


Figure 180. Gauged flow at Klamath River below Iron Gate Dam for Iron Gate to Turwar reach model 2003 calibration

There are 23 tributary flows in the IG-Turwar reach. Tributary contributions were assigned daily data based on USGS gages or daily average calculated flows based on accretion calculations. Table 35 summarizes the locations, model node and element information, and type of record employed.

Table 78. Element flow information for the IG-Turwar EC simulation

Location	Node	Element	Flow Type
Bogus Creek	7	4	Daily average
Willow Creek	55	28	Daily average
Cottonwood Creek	86	43	Daily average
Shasta River	144	72	Daily measured
Humbug Creek	204	102	Daily average
Beaver Creek	319	160	Daily average
Horse Creek	468	234	Daily average
Scott River (+ A/D)	513	257	Daily calculated
Grider Creek	656	328	Daily average
Thompson Creek	735	368	Daily average
Indian Creek	906	453	Daily measured
Elk Creek	925	463	Daily average
Clear Creek	1000	500	Daily average
Ukonom Creek	1098	549	Daily average
Dillon Creek	1162	581	Daily average
Salmon River	1357	679	Daily measured
Camp Creek	1466	733	Daily average
Red Cap Creek	1511	756	Daily average
Bluff Creek	1547	774	Daily average
Trinity River (+ A/D)	1609	805	Daily calculated
Pine Creek	1644	822	Daily average
Tectah Creek	1850	925	Daily average
Blue Creek	1908	954	Daily average

The Shasta River daily flows were from USGS gage 11517500. The Scott + A/D daily flows were calculated from USGS gage 11519500 (Scott River daily flows) and A/D described below. The daily Indian Creek flows were from USGS gage 11521500. The Salmon River daily flows were from USGS gage 11522500. The Trinity + A/D daily flows were calculated from USGS gage 11530000 (Trinity River daily flows) and the A/D described below. For input into the water quality input file for RMA-11, the daily average flows were disaggregated to hourly flows using linear interpolation. Daily A/D flows were calculated as those for implementation of the reach, but were not averaged over 7 days. Weekly A/D flows were also calculated for use in the water quality input file for RMA-11. The daily inflows for the gauged tributaries are presented in Figure 56. The daily inflows for the minor tributaries are presented in Figure 182. The weekly inflows for the minor tributaries are presented in Table 79.

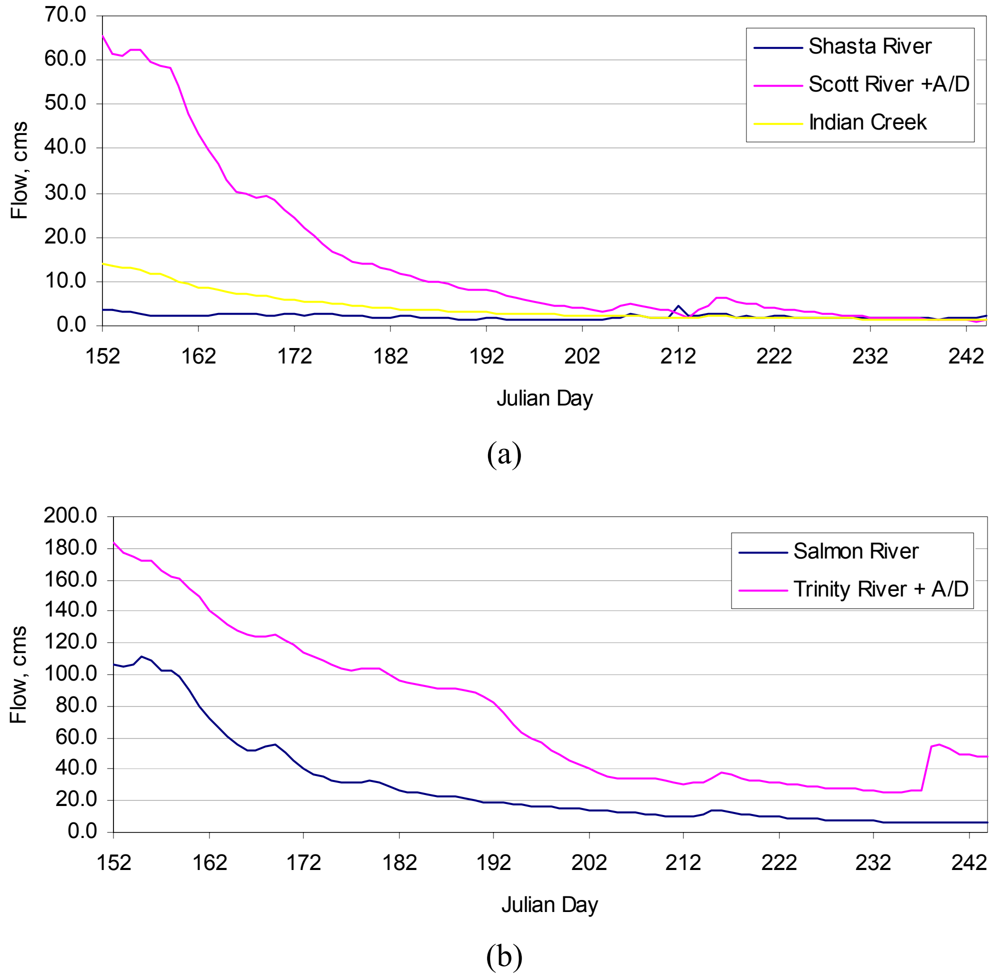
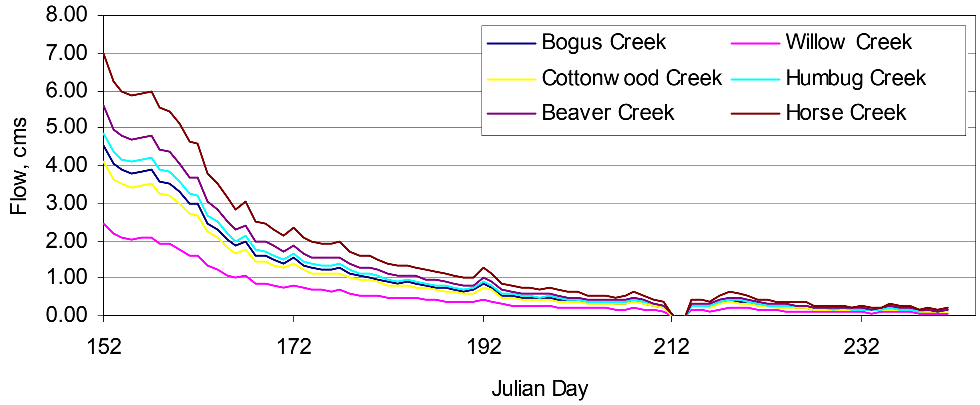
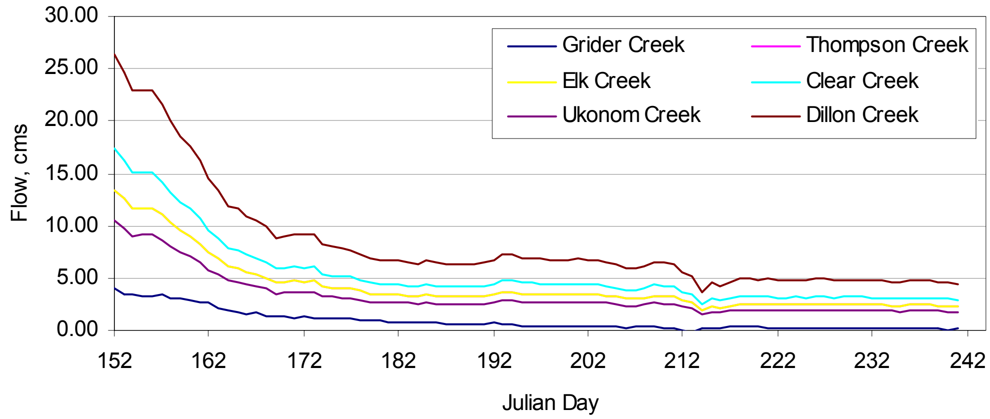


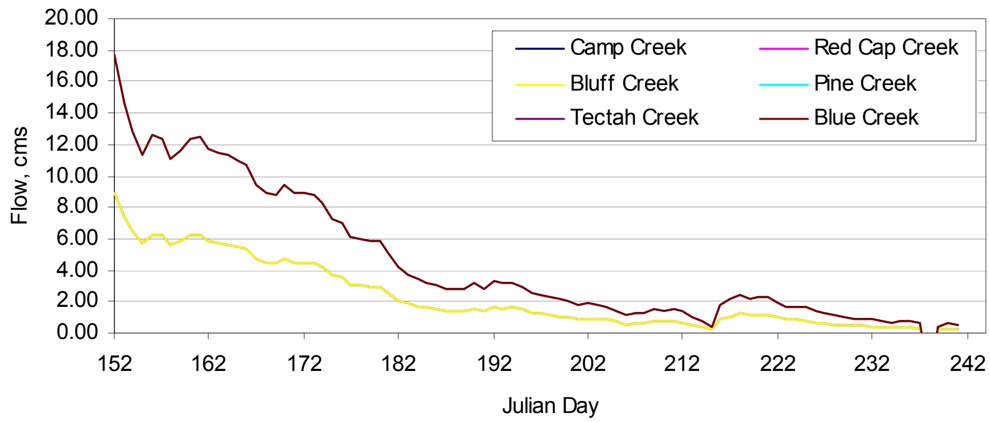
Figure 181. Gauged tributary inflows for Iron Gate to Turwar reach model 2003 calibration: (a) Shasta River, Scott River and Indian Creek; (b) Salmon River and Trinity River



(a)



(b)



(c)

Figure 182. Minor tributary inflows for Iron Gate to Turwar 2003 calibration: (a) above Scott River; (b) between the Scott and the Salmon Rivers; (c) between the Salmon River and the mouth of the Klamath River.

Table 79. Weekly average minor tributary inflows for Iron Gate to Turwar reach model, for use in the water quality input files for RMA-11

	Flow, cms												
Julian Day	**152**	**158**	**165**	**172**	**179**	**186**	**193**	**200**	**207**	**214**	**221**	**228**	**235**
Bogus Creek	3.94	3.94	2.80	1.64	1.22	0.90	0.73	0.49	0.36	0.19	0.32	0.23	0.17
Beaver Creek	4.85	4.85	3.45	2.02	1.50	1.11	0.90	0.60	0.45	0.24	0.40	0.28	0.21
Horse Creek	6.07	6.07	4.32	2.52	1.88	1.39	1.12	0.75	0.56	0.30	0.50	0.35	0.26
Grider Creek	3.42	3.42	2.43	1.42	1.06	0.78	0.63	0.42	0.31	0.17	0.28	0.20	0.14
Thompson Creek	11.77	11.77	7.57	4.94	4.02	3.37	3.34	3.49	3.27	2.91	2.41	2.44	2.42
Indian Creek	12.78	12.78	9.03	6.62	5.06	3.84	3.16	2.67	2.22	1.93	2.05	1.76	1.55
Elk Creek	11.77	11.77	7.57	4.94	4.02	3.37	3.34	3.49	3.27	2.91	2.41	2.44	2.42
Clear Creek	15.18	15.18	9.76	6.37	5.18	4.34	4.31	4.50	4.21	3.75	3.10	3.15	3.12
Ukonom Creek	9.15	9.15	5.89	3.84	3.12	2.62	2.60	2.71	2.54	2.26	1.87	1.90	1.88
Dillon Creek	23.05	23.05	14.83	9.67	7.86	6.59	6.54	6.83	6.40	5.69	4.71	4.79	4.74
Camp Creek	6.63	6.63	5.86	4.67	3.54	2.05	1.49	1.27	0.79	0.63	0.97	0.76	0.41
Red Cap Creek	6.63	6.63	5.86	4.67	3.54	2.05	1.49	1.27	0.79	0.63	0.97	0.76	0.41
Bluff Creek	6.63	6.63	5.86	4.67	3.54	2.05	1.49	1.27	0.79	0.63	0.97	0.76	0.41
Pine Creek	13.22	13.22	11.67	9.30	7.06	4.09	2.97	2.53	1.57	1.26	1.94	1.51	0.83
Tectah Creek	13.22	13.22	11.67	9.30	7.06	4.09	2.97	2.53	1.57	1.26	1.94	1.51	0.83
Blue Creek	13.22	13.22	11.67	9.30	7.06	4.09	2.97	2.53	1.57	1.26	1.94	1.51	0.83

The downstream boundary for the Iron Gate to Turwar reach was not altered from the downstream boundary used in implementation of the reach.

Temperature

Inflow temperatures for the upstream boundary condition were the hourly and half-hourly temperatures recorded by sondes deployed below Iron Gate Dam in June and August (shown in Figure 58 and Figure 184). The first full day of data is repeated for the four days previous to deployment to provide main inflow temperatures for the "warm up" period of the model. The source of records and final model inputs for major and minor tributaries are outlined below.

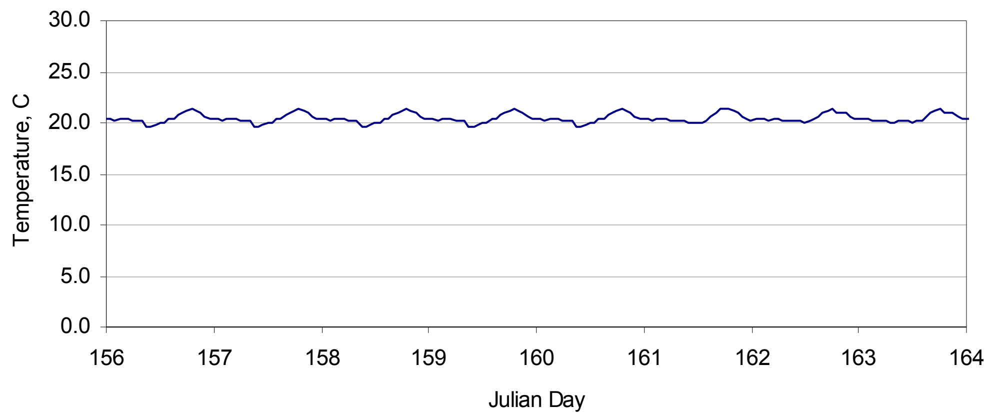


Figure 183. Main inflow temperatures for Iron Gate to Turwar reach model (June 2003)

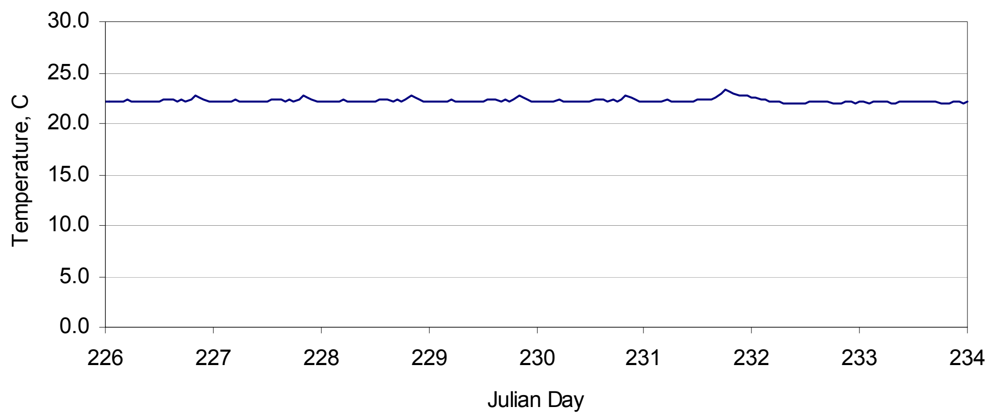


Figure 184. Main inflow temperatures for Iron Gate to Turwar reach model (August 2003)

Major Tributaries

Sonde data collected in June and August in the Shasta River, Scott River, Salmon River and Trinity River provided hourly temperatures for recalibration of the Iron Gate Dam to Turwar reach (presented in Figure 59 through Figure 60). To provide data for the four days of model simulation that occur prior to the deployment of the sondes, the first day temperatures are repeated until the time of deployment for all major tributaries. The Scott River had some missing data due to deployment difficulties in June. The following day's temperatures were used to fill in the missing temperatures. The simulation periods last until midnight of the last day of deployment, although many of the sondes were not deployed at that point in time. If there was missing data, the temperatures were filled in with the last recorded temperature for the particular hour of the day until midnight was reached.

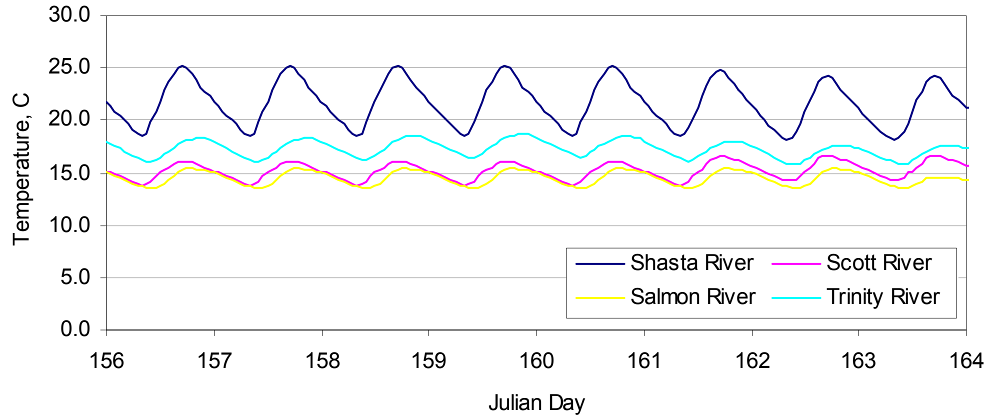


Figure 185. Major tributary inflow temperatures for Iron Gate to Turwar reach model 2003 calibration (June 2003)

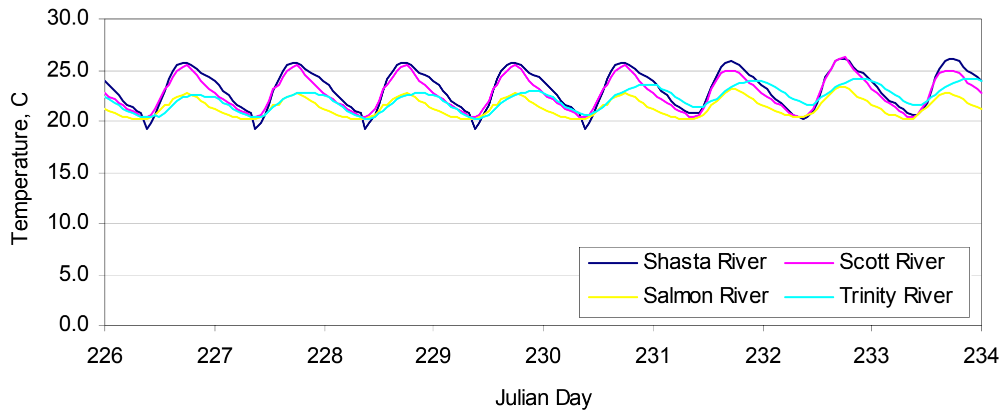


Figure 186. Major tributary inflow temperatures for Iron Gate to Turwar reach model 2003 calibration (August 2003)

<u>Minor Tributaries</u>

The minor tributary temperatures used for the 2003 calibration of the Iron Gate to Turwar reach were those used for the 2000 calibration and are presented in the main model documentation. The monthly average temperatures used in the previous calibration were disaggregated to weekly averages using linear interpolation for use in the 2003 calibration. The weekly average temperatures are presented in Table 80.

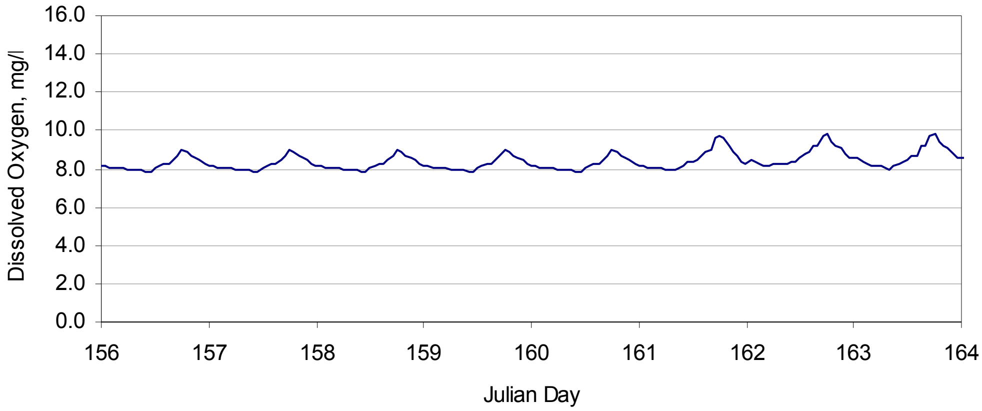
Table 80. Minor tributary inflow temperatures for Iron Gate to Turwar reach 2003 model calibration

	Temperature, °C												
Julian Day	**152**	**158**	**165**	**172**	**179**	**186**	**193**	**200**	**207**	**214**	**221**	**228**	**235**
Bogus Creek	12.60	12.66	12.74	12.98	13.28	13.58	13.89	14.10	14.20	14.30	14.40	14.50	14.03
Beaver Creek	9.96	10.44	11.00	11.64	12.31	12.98	13.65	14.18	14.52	14.86	15.21	15.55	15.27
Horse Creek	9.92	10.39	10.93	11.43	11.91	12.38	12.86	13.22	13.44	13.65	13.87	14.08	13.98
Grider Creek	9.92	10.39	10.93	11.96	13.18	14.40	15.61	16.36	16.47	16.59	16.70	16.82	16.17
Thompson Creek	12.58	13.19	13.90	14.31	14.61	14.90	15.20	15.51	15.83	16.15	16.47	16.79	16.56
Indian Creek	10.22	10.78	11.42	12.49	13.72	14.95	16.18	17.03	17.37	17.72	18.06	18.41	17.80
Elk Creek	9.92	10.39	10.93	12.18	13.70	15.23	16.75	17.67	17.79	17.91	18.03	18.15	17.43
Clear Creek	10.41	11.03	11.75	12.60	13.49	14.38	15.27	15.93	16.27	16.61	16.95	17.29	16.79
Ukonom Creek	9.48	9.97	10.55	11.10	11.65	12.19	12.74	13.14	13.34	13.54	13.75	13.95	13.59
Dillon Creek	14.02	14.61	15.29	16.28	17.38	18.48	19.58	20.05	19.68	19.32	18.95	18.58	18.21
Camp Creek	12.58	13.19	13.90	14.31	14.61	14.90	15.20	15.51	15.83	16.15	16.47	16.79	16.56
Red Cap Creek	14.02	14.61	15.29	16.29	17.41	18.54	19.66	20.21	20.00	19.79	19.58	19.37	18.75
Bluff Creek	12.58	13.19	13.90	14.31	14.61	14.90	15.20	15.51	15.83	16.15	16.47	16.79	16.56
Pine Creek	12.58	13.19	13.90	14.31	14.61	14.90	15.20	15.51	15.83	16.15	16.47	16.79	16.56
Tectah Creek	11.31	11.79	12.35	12.71	13.00	13.28	13.57	13.77	13.85	13.93	14.02	14.10	14.19
Blue Creek	12.58	13.19	13.90	14.31	14.61	14.90	15.20	15.51	15.83	16.15	16.47	16.79	16.56

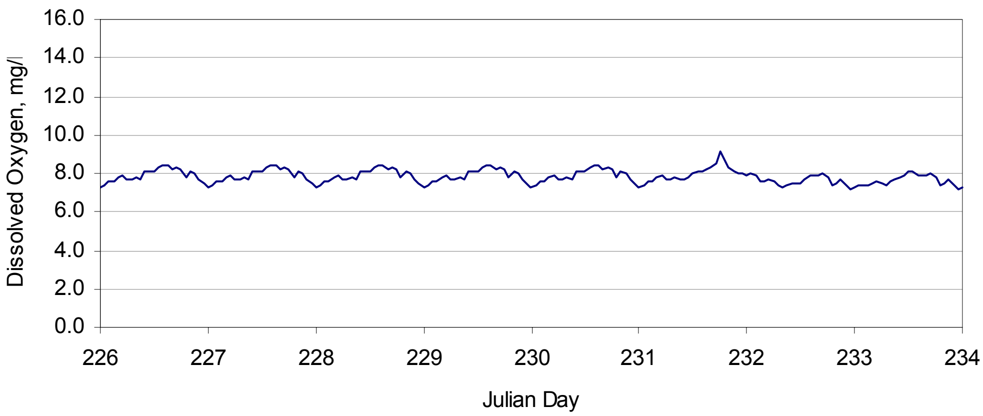
Constituent Concentrations

Constituent concentrations for the tributary inflows between Iron Gate Dam and the Pacific Ocean were assigned for all streams identified in Table 35 with the exception of Willow, Cottonwood, and Humbug Creeks. There was no data available for these tributaries and they contribute only minor flow in the summer months.

Dissolved oxygen concentrations were recorded by sonde below Iron Gate Dam. The first four days of model data are the first day of recorded data repeated to provide dissolved oxygen concentrations for the main inflow during the "warm up" period of the model. The model input dissolved oxygen concentrations are presented in Figure 63.



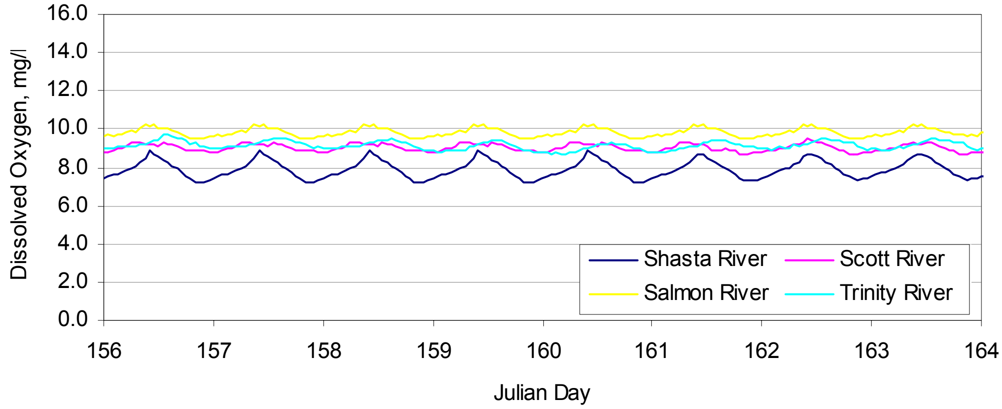
(a)



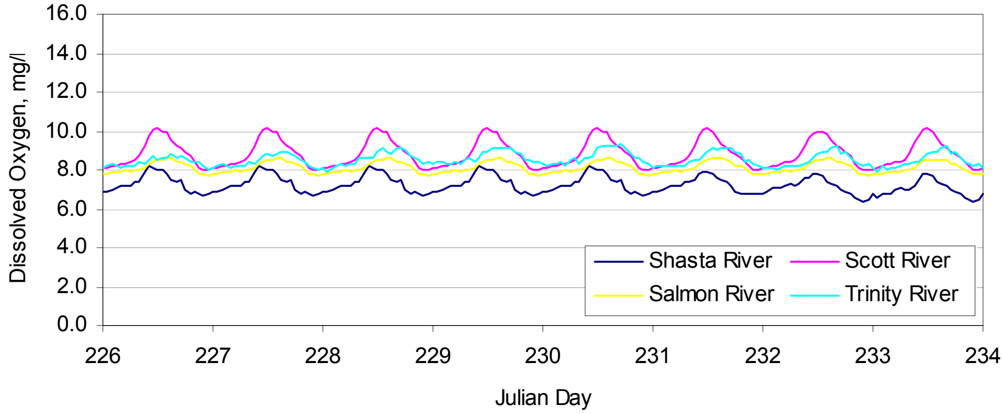
(b)

Figure 187. Klamath River below Iron Gate Dam dissolved oxygen concentrations for: (a) June 2003; (b) August 2003

Dissolved oxygen concentrations for the 2003 were those recorded by sondes for the major tributaries on the hourly (Shasta, Scott, Salmon, and Trinity Rivers) or those calculated in model implementation for the minor tributaries (all remaining tributaries). The dissolved oxygen concentrations recorded by sonde were adjusted for biofouling when appropriate (as discussed in Technical Memorandum 6). The calculated monthly average dissolved oxygen concentrations were disaggregated to weekly averages by linear interpolation. Hourly dissolved oxygen concentrations are presented in Figure 64. Weekly average dissolved oxygen concentrations are presented in Table 37.



(a)



(b)

Figure 188. Major tributary dissolved oxygen concentrations for Iron Gate to Turwar reach model calibration: (a) June 2003; (b) August 2003

Table 81. Minor tributary inflow dissolved oxygen concentrations for Iron Gate to Turwar reach model

	Dissolved Oxygen, mg/l												
Julian Day	**152**	**158**	**165**	**172**	**179**	**186**	**193**	**200**	**207**	**214**	**221**	**228**	**235**
Bogus Creek	10.02	10.01	9.99	9.94	9.87	9.81	9.74	9.69	9.67	9.65	9.63	9.61	9.71
Beaver Creek	10.66	10.54	10.40	10.25	10.10	9.95	9.80	9.68	9.61	9.53	9.46	9.39	9.45
Horse Creek	10.68	10.56	10.42	10.30	10.19	10.08	9.97	9.89	9.84	9.79	9.75	9.70	9.72
Grider Creek	10.68	10.56	10.42	10.19	9.92	9.66	9.39	9.23	9.21	9.19	9.16	9.14	9.27
Thompson Creek	10.39	10.24	10.08	9.99	9.92	9.86	9.80	9.73	9.67	9.60	9.54	9.47	9.52
Indian Creek	10.97	10.82	10.66	10.42	10.15	9.88	9.60	9.42	9.35	9.29	9.22	9.15	9.27
Elk Creek	11.04	10.92	10.78	10.50	10.16	9.83	9.49	9.29	9.27	9.25	9.22	9.20	9.35
Clear Creek	10.92	10.76	10.57	10.38	10.18	9.98	9.78	9.64	9.57	9.51	9.44	9.37	9.47
Ukonom Creek	11.16	11.03	10.87	10.74	10.61	10.48	10.34	10.25	10.20	10.15	10.11	10.06	10.14
Dillon Creek	10.05	9.92	9.77	9.58	9.37	9.16	8.95	8.86	8.92	8.99	9.05	9.12	9.19
Camp Creek	10.39	10.24	10.08	9.99	9.92	9.86	9.80	9.73	9.67	9.60	9.54	9.47	9.52
Red Cap Creek	10.05	9.92	9.77	9.58	9.36	9.15	8.93	8.83	8.86	8.90	8.94	8.98	9.10
Bluff Creek	10.39	10.24	10.08	9.99	9.92	9.86	9.80	9.73	9.67	9.60	9.54	9.47	9.52
Pine Creek	10.63	10.48	10.31	10.21	10.15	10.08	10.02	9.95	9.89	9.82	9.76	9.69	9.74
Tectah Creek	10.93	10.81	10.67	10.58	10.52	10.45	10.39	10.34	10.32	10.30	10.28	10.26	10.24
Blue Creek	10.63	10.48	10.31	10.21	10.15	10.08	10.02	9.95	9.89	9.82	9.76	9.69	9.74

Other constituent concentrations for the main inflow and major tributaries were either based on grab samples taken during the summer of 2003 or were those concentrations used in the previous calibration effort. Concentrations based on 2003 grab samples are presented in Table 82 and Table 83.

Table 82. Main inflow and major tributary constituent concentrations based on 2003 grab sample data, June 2003

	Ammonia as N	Nitrate as N	Ortho Phosphate as P	Organic Nitrogen	Organic Phosphorus	Algae	BOD
Site Name	**mg/L**	**mg/L**	**mg/L**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
KR below Iron Gate Dam	0.10	0.15	0.08	0.93	0.06	0.28	2
Shasta River	0.10	0.01	0.17	1.01	0.04	0.02	2
Scott River	0.10	0.11	0.05	0.79	0.00	0.03	2
Salmon River	0.10	0.01	0.05	0.86	0.00	0.00	2
Trinity River	0.10	0.01	0.05	0.84	0.00	0.02	2

Table 83. Main inflow and major tributary constituent concentrations based on 2003 grab sample data, August 2003

Site Name	Ammonia as N mg/L	Nitrate as N mg/L	Ortho Phosphate as P mg/L	Organic Nitrogen mg/l	Organic Phosphorus mg/l	Algae mg/l	BOD mg/l
KR below Iron Gate Dam	0.10	0.27	0.12	0.65	0.02	0.30	5
Shasta River	0.10	0.01	0.20	0.45	0.00	0.02	2
Scott River	0.10	0.14	0.05	0.40	0.00	0.03	2
Salmon River	0.10	0.01	0.05	0.40	0.00	0.00	2
Trinity River	0.10	0.01	0.05	0.40	0.00	0.02	2

Other constituent concentrations for minor tributaries were those used for model implementation and the previous calibration effort and are presented in the main model documentation.

3.9.1.2 Initial Conditions

The model was run for four days prior for the 2003 period (approximate travel time to mouth) to provide an initial condition for simulations. The initial bed algae mass was estimated at 5 g/m^2. Where field data were unavailable, the conditions of the first day of available field data were applied.

3.9.1.3 Meteorological Data

The meteorological data for the 2003 calibration was processed in the same manner as identified above under model implementation, using 2003 meteorological data from the KLFO station in Klamath Falls, Oregon.

3.9.2 Model Output Locations: 2003

The calibration locations for the Iron Gate to Turwar reach are presented in Table 84. There was additional temperature and dissolved oxygen collected from deployed sondes during June at Klamath River at Aikens Hole, but that data was not used for formal calibration of the reach. The recorded data are presented in the following section with model results.

All water quality probes and grab samples were collected from near-shore areas and although all efforts were made to identify locations that were deemed consistent with overall main stem conditions (e.g., areas that readily exchanged water with main flow in the river), several factors could result in potential deviation main stem conditions. The primary factor is probably the rapidly descending hydrographs in the June sampling periods which changed local conditions at some sampling locations and required successive re-deployment of water quality probes as water levels fell.

Table 84. Calibration and other data gathering locations in the Klamath River for 2003

Site	River Mile	Elevation, ft	Node	Location Type
Klamath River above Shasta River	177.46	2002.0	141	Cal / Val
Klamath River above Scott River	143.61	1560.0	369	Cal / Val
Klamath River at Seiad Valley	129.04	1320.0	672	Cal / Val
Klamath River at Clear Creek	99.00	937.0	994	Cal / Val
Klamath River above Salmon River	67.05	491.2	1354	Cal / Val
Klamath River at Aikens Hole	50.00	310.0	1545	Additional Information
Klamath River above Trinity River	43.50	302.0	1609	Cal / Val
Klamath River at Martins Ferry / Tully Creek	39.50	273.0	1649	Cal / Val
Klamath River at Blue Creek	16.95	100.0	1901	Cal / Val
Klamath River at Turwar	5.63	6.0	1974	Cal / Val

3.9.3 Results 2003

3.9.3.1 Water Temperature

Mean absolute error was less than 1.0°C for all sites for both June and August conditions with the exception of Klamath River above Salmon River in June (MAE = 1.44°C). Tabulated statistics illustrate that simulated results on a daily basis were within 1.0°C of observations, with the exception of the above noted site. Further, observation of the diurnal phase and amplitude were generally well represented at the individual locations.

Summary statistics include bias (average error), mean absolute error, and root mean square error. The error is computed as simulated values minus measured values, and the summary statistics are determined based on the period of available data. Daily statistics are calculated based on whole days, while hourly statistics utilize portions of days when data is available. The statistics represent performance over the period observed data.

The hourly results are presented graphically in Figure 189 through **Error! Reference source not found.**. Summary statistics are included in Table 89. Representation of diurnal phase as well as diurnal range was a calibration objective.

At Klamath River above Shasta River, the diurnal phase for both June and August was well represented, as well as the shape of the diurnal temperature trace. The maximum and minimum daily temperatures closely matched observed temperatures. Hourly bias for the June period was –0.40°C with a mean absolute error of 0.47 °C. Hourly bias for the August period was 0.81°C with a mean absolute error of 0.81°C.

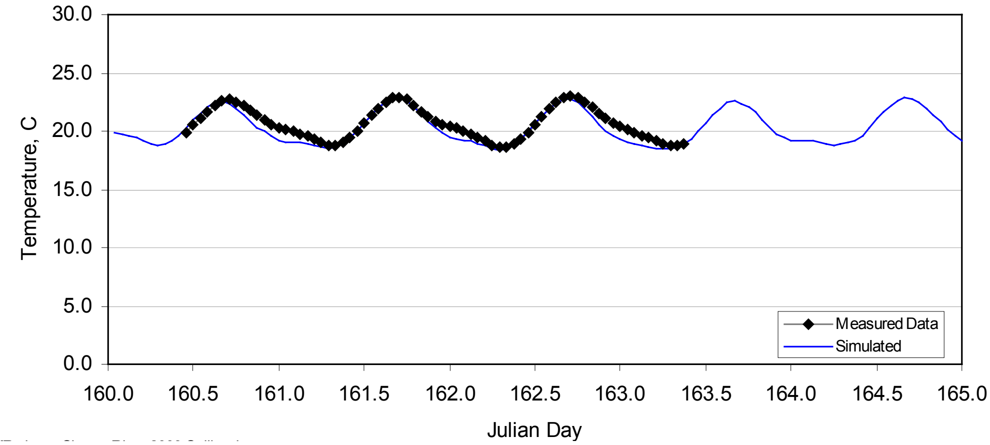


Figure 189. Klamath River ab Shasta River simulated versus measured water temperature, June 9-12, 2003

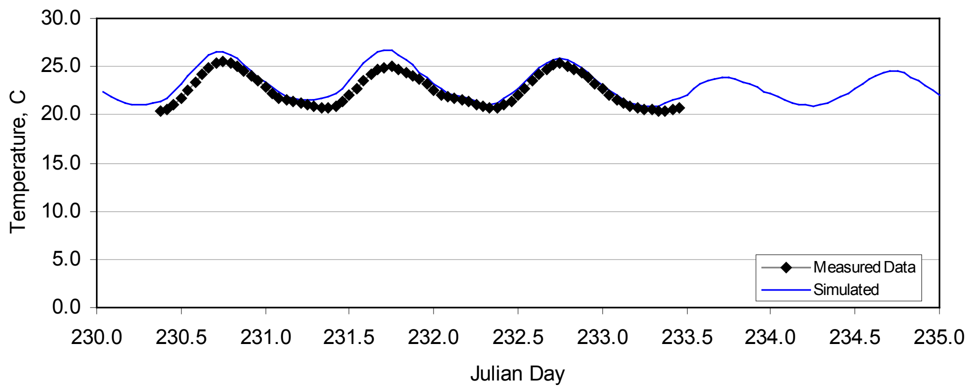


Figure 190. Klamath River ab Shasta River simulated versus measured water temperature, August 18-21, 2003

At Klamath River above Scott River, the diurnal phase and range for both June and August periods was well represented. Hourly bias for the June period was -0.11°C with a mean absolute error of 0.51°C. Hourly bias for the August period was 0.91°C with a mean absolute error of 0.91°C.

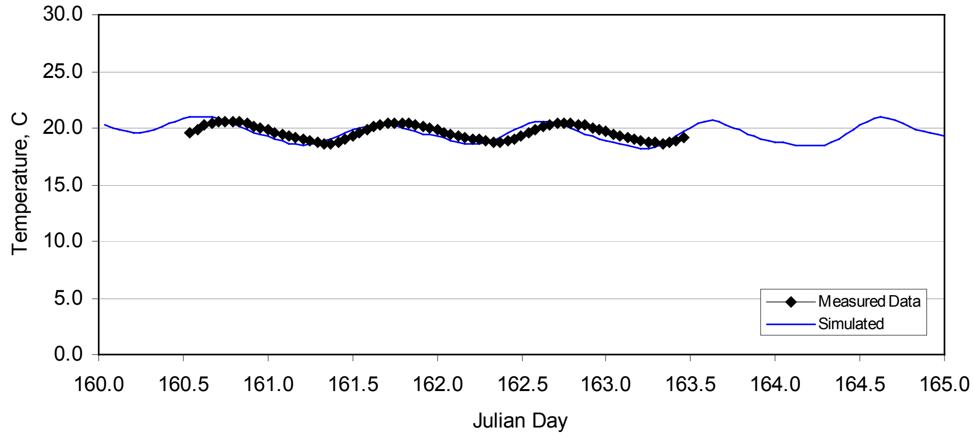


Figure 191. Klamath River above Scott River versus measured water temperature, June 9-12, 2003

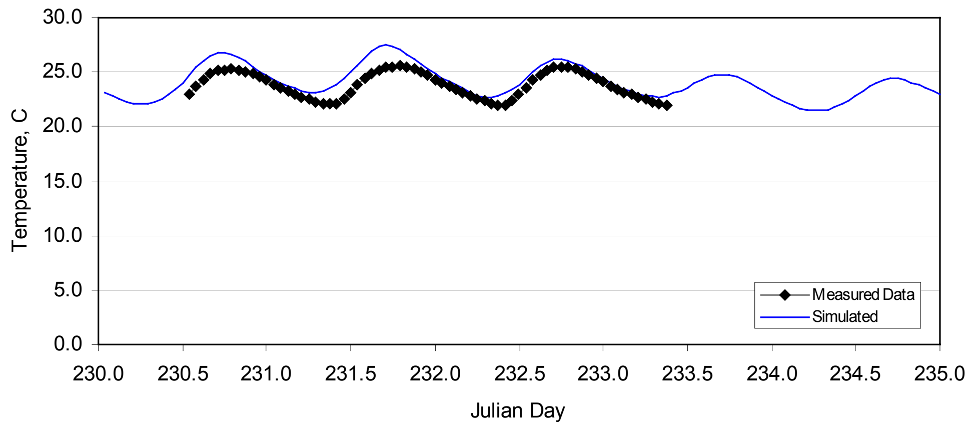


Figure 192. Klamath River above Scott River simulated versus measured water temperature, August 18-21, 2003

At Klamath River near Seiad Valley, the diurnal phase was well represented in both June and August periods. The diurnal range was adequately represented in both periods, with the maximum simulated temperatures slightly higher than observed temperatures. Hourly bias for the June period was 0.05°C with a mean absolute error of 0.13°C, and the shape of the diurnal signal is well represented. Hourly bias for the August period was 0.92°C with a mean absolute error of 0.92°C.

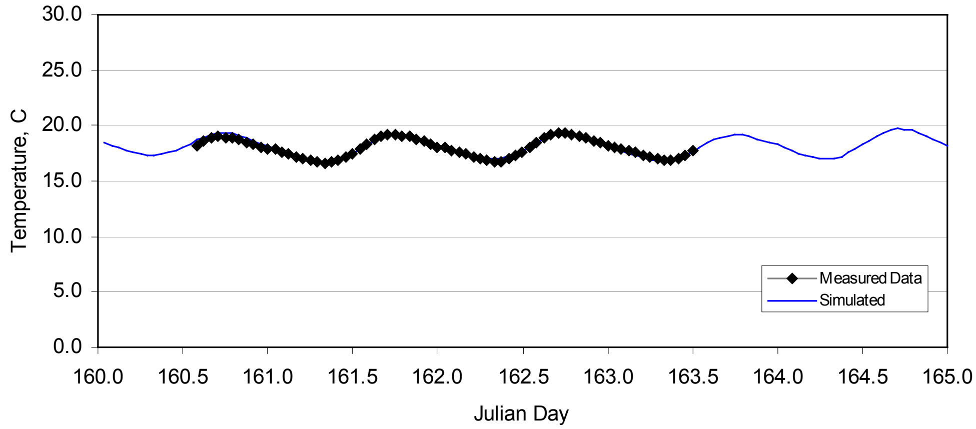


Figure 193. Klamath River near Seiad Valley simulated versus measured water temperature, June 9-12, 2003

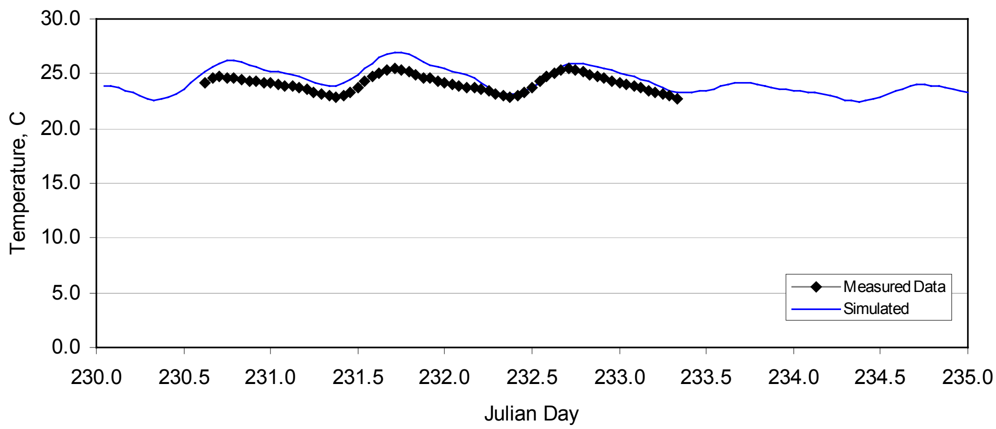


Figure 194. Klamath River near Seiad Valley simulated versus measured water temperature, August 18-21, 2003

At Klamath River above Clear Creek, observations for June were unavailable. The diurnal range for August was well represented. The hourly bias for August was 0.13°C with a mean absolute error of 0.47°C.

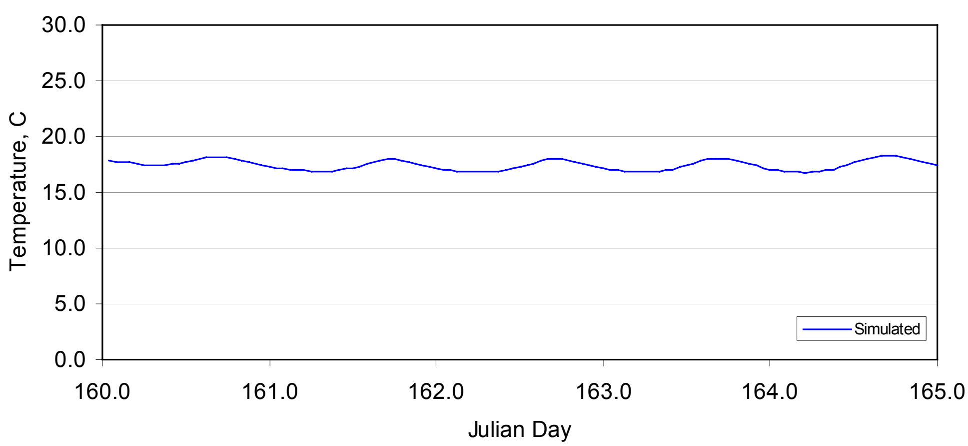


Figure 195. Klamath River ab Clear Creek simulated water temperature, June 9-12, 2003

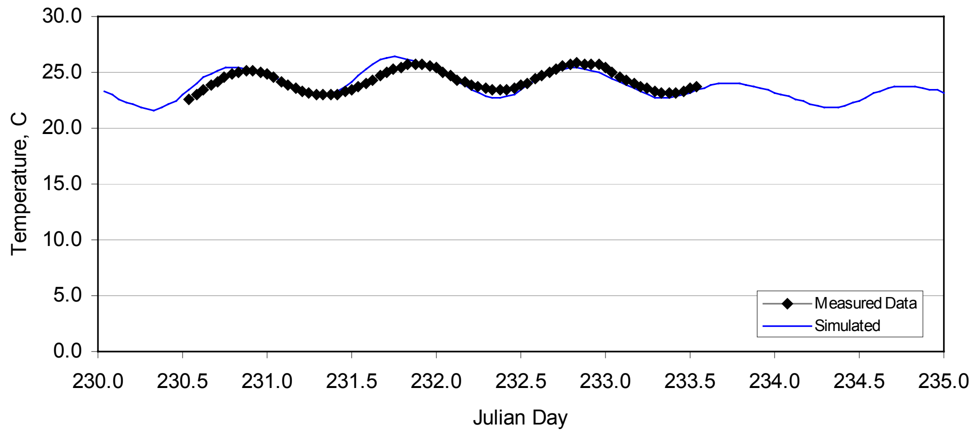


Figure 196. Klamath River ab Clear Creek simulated versus measured water temperature, August 18-21, 2003

At Klamath River above the Salmon River, the diurnal phase was well represented in both June and August periods; however June period simulated temperatures were under predicted. The diurnal range was well represented in both periods. Hourly bias for the June period was -1.44°C with a mean absolute error of 1.44°C. Hourly bias for the August period was 0.15°C with a mean absolute error of 0.43°C.

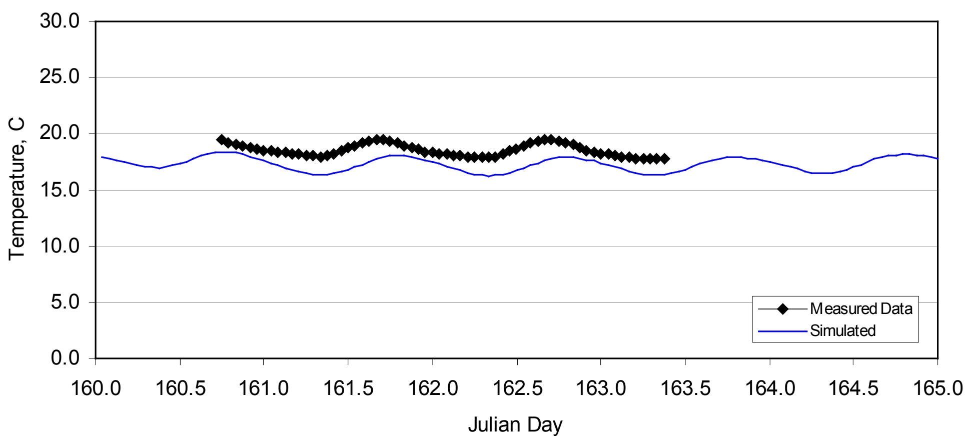


Figure 197. Klamath River ab Salmon River simulated versus measured water temperature, June 9-12, 2003

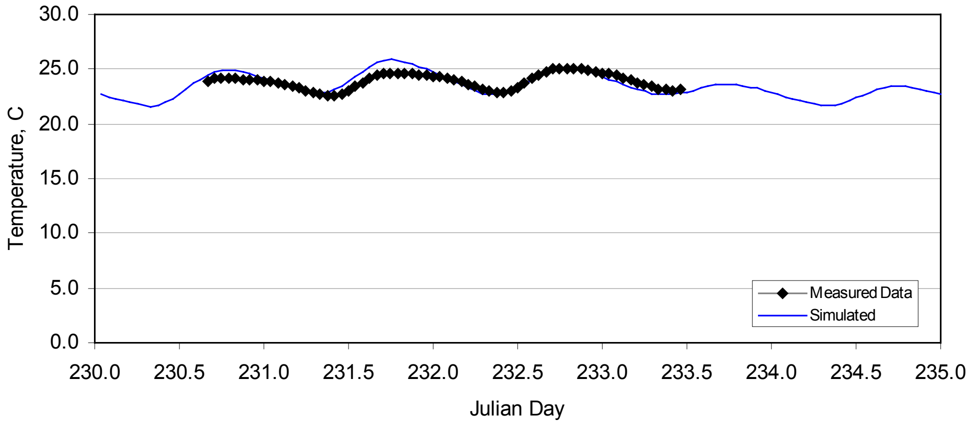


Figure 198. Klamath River ab Salmon River simulated versus measured water temperature, August 18-21, 2003

At Klamath River above the Trinity River the diurnal range was under represented in June, but matched well in August. The diurnal phase for August was generally well represented. Hourly bias for the June period was -0.98°C with a mean absolute error of 0.98°C. Hourly bias for the August period was 0.55°C with a mean absolute error of 0.67°C.

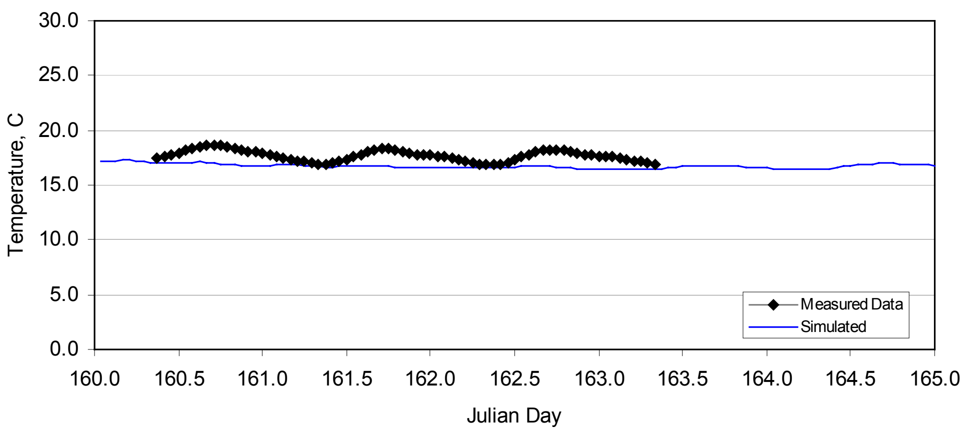


Figure 199. Klamath River ab Trinity River simulated versus measured water temperature, June 9-12, 2003

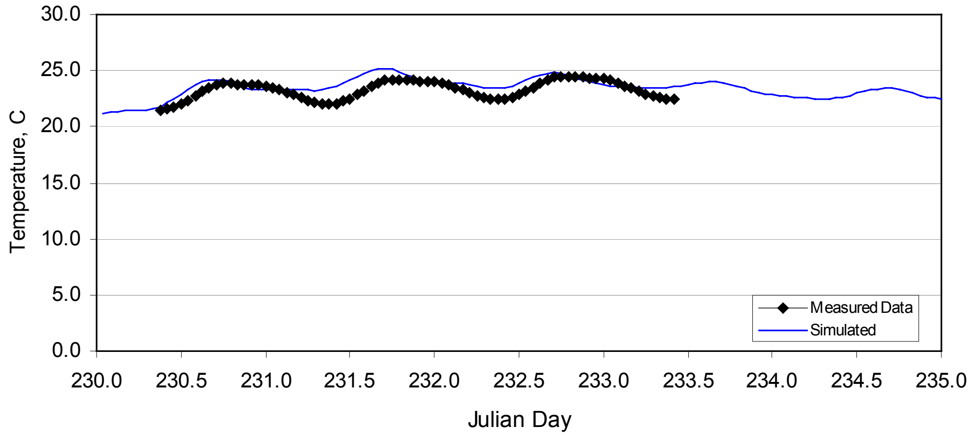


Figure 200. Klamath River ab Trinity River simulated versus measured water temperature, August 18-21, 2003

At Klamath River below the Trinity River in the vicinity of Martins Ferry was assessed at two locations due to movement of the sampling location: Martins Ferry in June and Tully Creek in August. Similar to the site above the Trinity, the simulated diurnal range was largely absent in the June results; however, the mean daily temperature was well represented (MAE = 0.63°C). The moderated diurnal range and phase was replicated in August. Hourly bias for the June period was -0.63°C with a mean absolute error of 0.63°C. Hourly bias for the August period was 0.43°C with a mean absolute error of 0.47°C.

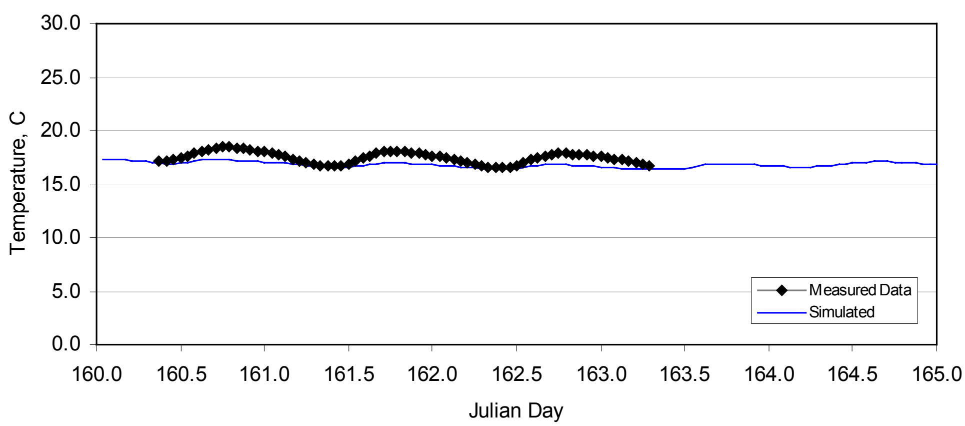


Figure 201. Klamath River ab Martins Ferry simulated versus measured water temperature, June 9-12, 2003

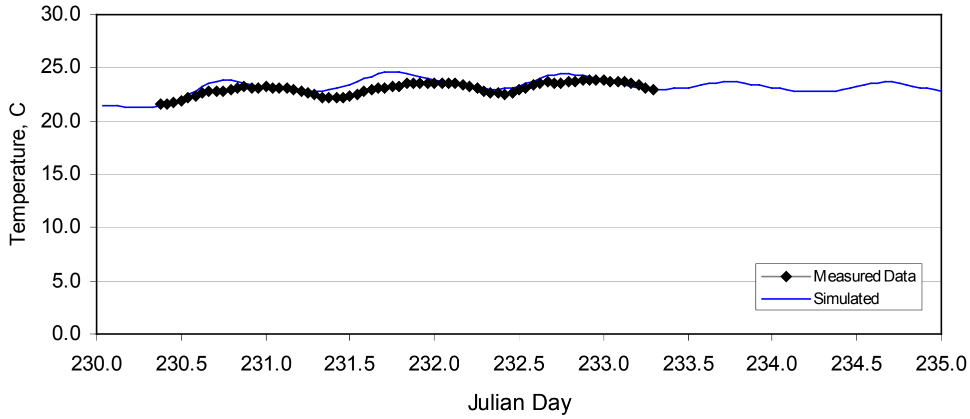


Figure 202. Klamath River ab Tully Creek simulated versus measured water temperature, August 18-21, 2003

At Klamath River below in the lowest reaches was assessed at two locations due to lack of data at Turwar in August: Turwar in June and Blue Creek in August. The June diurnal range was under represented in June, while the diurnal range and phase was generally replicated in August at Blue Creek. Hourly bias for the June period was -0.57°C with a mean absolute error of 0.68°C. Hourly bias for the August period was 0.86°C with a mean absolute error of 0.86°C.

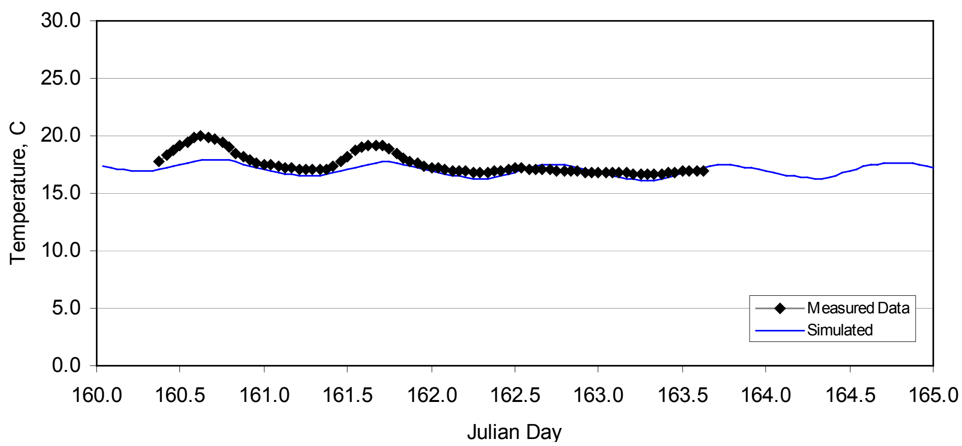


Figure 203. Klamath River at Turwar simulated versus measured water temperature, June 9-12, 2003

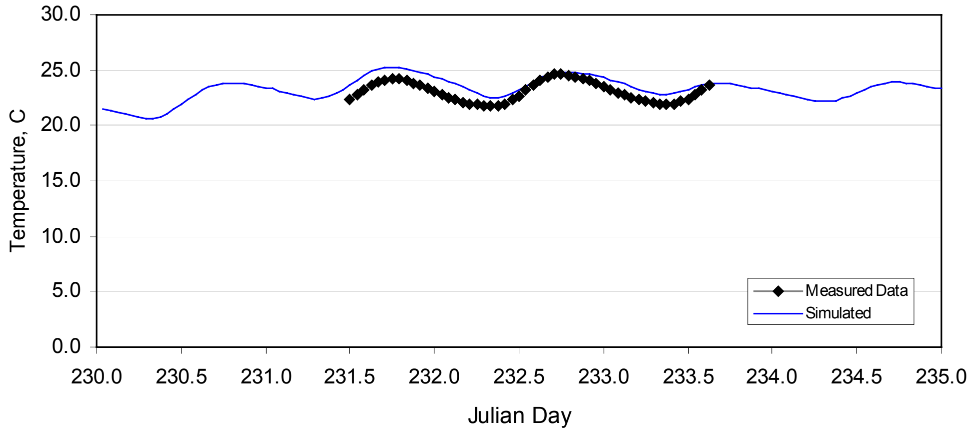


Figure 204. Klamath River ab Blue Creek simulated versus measured water temperature, August 18-21, 2003

Table 85. Klamath River hourly and daily calibration statistics for water temperature 2003

Calibration / Validation Statistics		Hourly		Daily	
	Unit	June	August	June	August
Klamath River ab Shasta River					
Mean Bias[a]	˚C	-0.40	0.81	-0.39	0.80
Mean absolute error (MAE)	˚C	0.47	0.81	0.39	0.80
Root mean squared error (RMSE)	˚C	0.59	0.93	0.39	0.84
n	-	71	75	2	2
Klamath River ab Scott River					
Mean Bias[a]	˚C	-0.11	0.91	-0.12	0.92
Mean absolute error (MAE)	˚C	0.51	0.91	0.12	0.92
Root mean squared error (RMSE)	˚C	0.57	1.08	0.12	0.98
n	-	71	69	2	2
Klamath River near Seiad Valley					
Mean Bias[a]	˚C	0.05	0.92	0.04	0.88
Mean absolute error (MAE)	˚C	0.13	0.92	0.04	0.88
Root mean squared error (RMSE)	˚C	0.17	1.02	0.04	0.94
n	-	71	66	2	2
Klamath River above Clear Creek					
Mean Bias[a]	˚C	na	0.03	na	0.03
Mean absolute error (MAE)	˚C	na	0.47	na	0.41
Root mean squared error (RMSE)	˚C	na	0.59	na	0.41
n	-	na	73	na	2
Klamath River above Salmon River					
Mean Bias[a]	˚C	-1.44	0.15	-1.44	0.23
Mean absolute error (MAE)	˚C	1.44	0.43	1.44	0.33
Root mean squared error (RMSE)	˚C	1.49	0.56	1.44	0.40
n	-	48	68	2	2
Klamath River above Trinity River					
Mean Bias[a]	˚C	-0.98	0.55	-0.93	0.66
Mean absolute error (MAE)	˚C	0.98	0.67	0.93	0.66
Root mean squared error (RMSE)	˚C	1.08	0.80	0.93	0.69
n	-	72	74	2	2
Klamath River at Martins Ferry/Tully Ck[b]					
Mean Bias[a]	˚C	-0.67	0.43	-0.63	0.53
Mean absolute error (MAE)	˚C	0.67	0.47	0.63	0.53
Root mean squared error (RMSE)	˚C	0.75	0.61	0.63	0.55
N	-	71	71	2	2
Klamath River at Blue Creek/Turwar[c]					
Mean Bias[a]	˚C	-0.57	0.86	-0.46	0.71
Mean absolute error (MAE)	˚C	0.68	0.86	0.46	0.71
Root mean squared error (RMSE)	˚C	0.84	0.94	0.57	0.71
n	-	79	52	2	1

[a] Mean bias = simulated – measured

[b] June, Martins Ferry; August, Tully Creek

[c] June, Turwar; August, Blue Creek

na – not available

3.9.3.2 Dissolved Oxygen

Mean absolute error was within 1.0 mg/l for all sites for both June and August conditions with the exception of Klamath River above Salmon River in August, which was just over 1.0 mg/l. Tabulated statistics illustrate that simulated results on a daily basis were also within approximately 1.0 mg/l of observations, with the exception of the above noted site. Further, observation of the diurnal phase and amplitude were generally well represented at the individual locations. The hourly results are presented graphically in Figure 189 through **Error! Reference source not found.**. Summary statistics are included in Table 89.

At Klamath River above Shasta River, the diurnal phase is well represented; however, in June the amplitude is moderated in model simulations. The maximum and minimum daily temperatures closely matched observed temperatures. Hourly bias for the June period was 0.64 mg/l with a mean absolute error of 0.84 mg/l. Hourly bias for the August period was 0.69 mg/l with a mean absolute error of 0.69 mg/l.

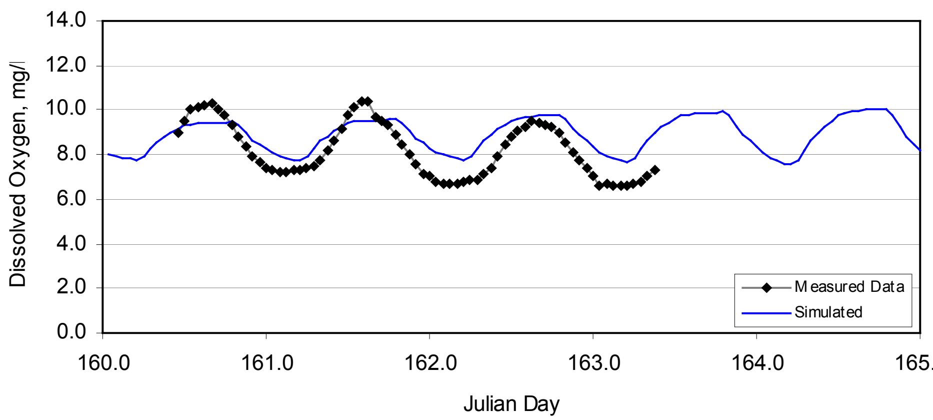


Figure 205. Klamath River above Shasta River simulated versus measured dissolved oxygen, June 9-12, 2003

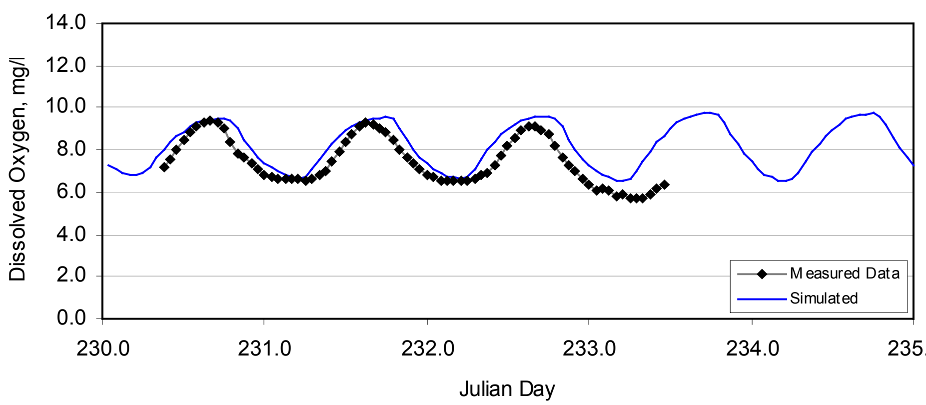


Figure 206. Klamath River above Shasta River simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River above Scott River, the diurnal phase is well represented. The diurnal range is replicated in June, with the model over predicting daily minimum values. In August the maximum values are under represented. Hourly bias for the June period was 0.63 mg/l with a mean absolute error of 0.64 mg/l. Hourly bias for the August period was -0.26 mg/l with a mean absolute error of 0.36 mg/l.

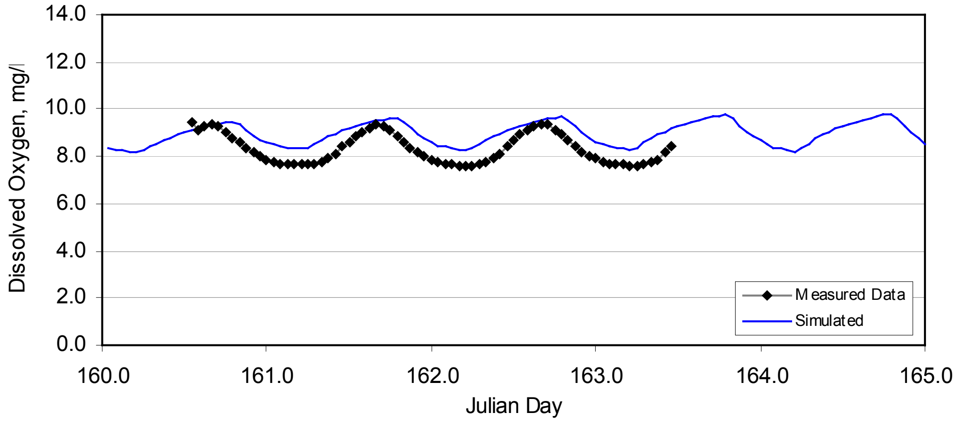


Figure 207. Klamath River above Scott River simulated versus measured dissolved oxygen, June 9-12, 2003

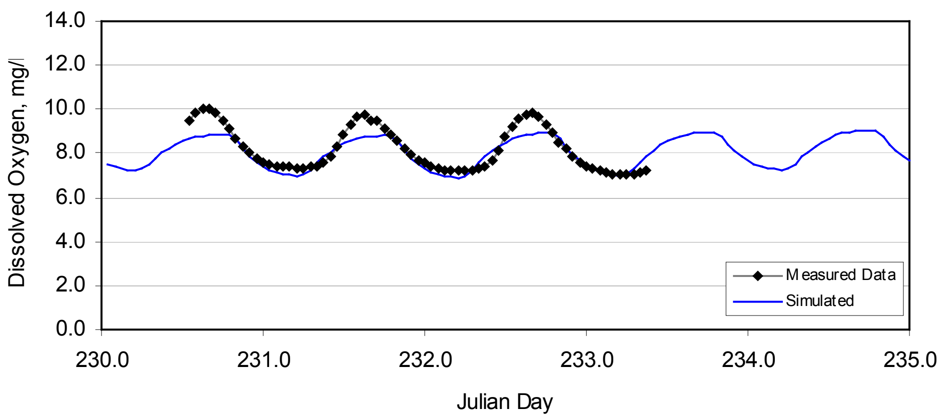


Figure 208. Klamath River above Scott River simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River near Seiad Valley, the diurnal phase is shifted by approximately an our, but the amplitude is well represented in June. In August the maximum values are under represented. Hourly bias for the June period was 0.13 mg/l with a mean absolute error of 0.18 mg/l. Hourly bias for the August period was -0.42 mg/l with a mean absolute error of 0.52 mg/l.

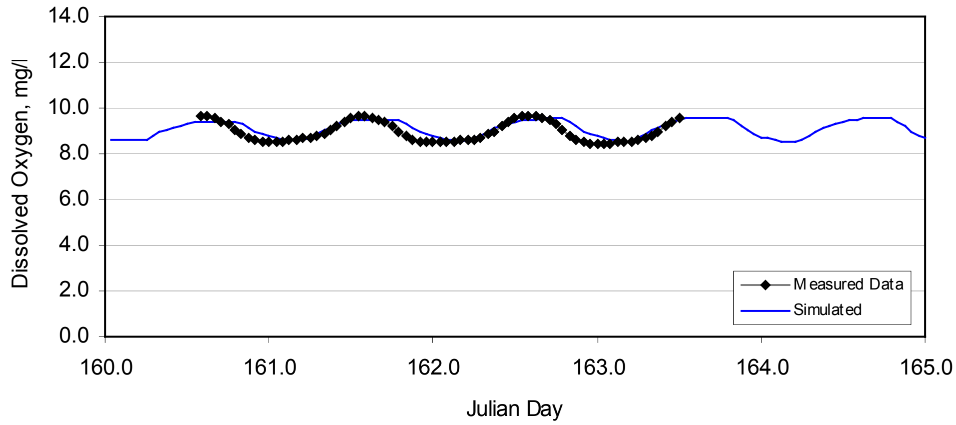


Figure 209. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, June 9-12, 2003

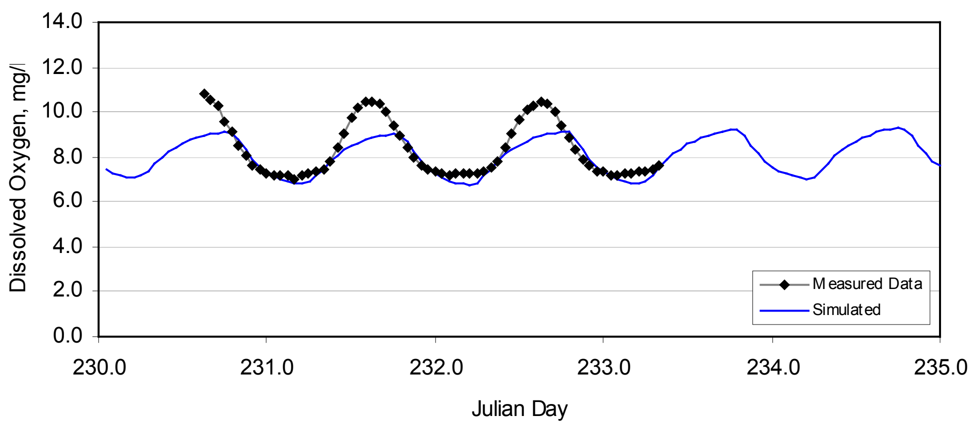


Figure 210. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River above Clear Creek, no data were available for June and August phase and diurnal range are generally well represented; however, the model results are overall lower than the observed values. Hourly bias for the August period was -0.73 mg/l with a mean absolute error of 0.73 mg/l.

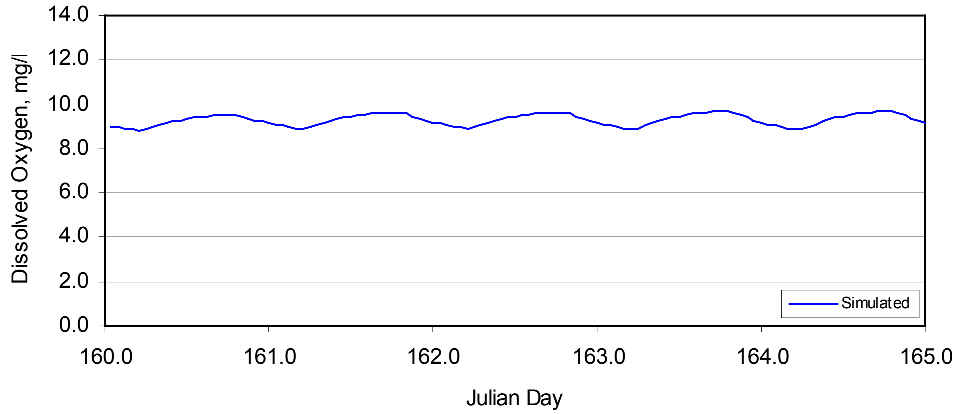


Figure 211. Klamath River above Clear Creek simulated versus measured dissolved oxygen, June 9-12, 2003

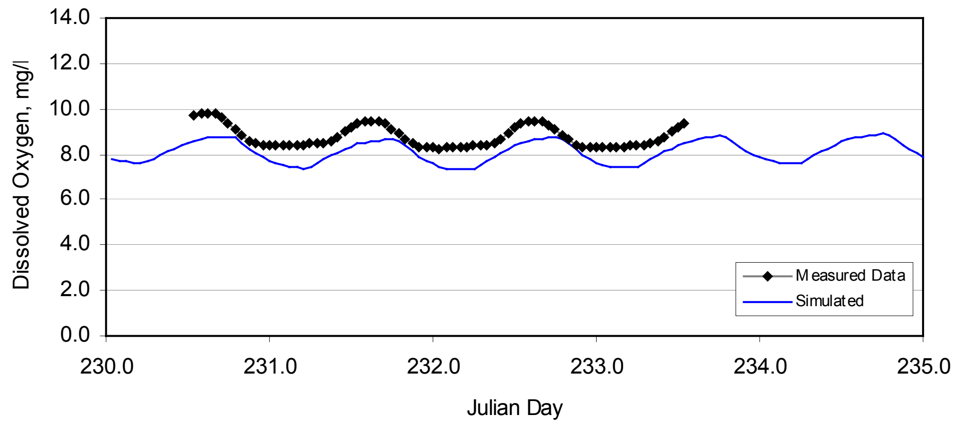


Figure 212. Klamath River above Clear Creek simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River above Salmon River, both the moderated June diurnal signal and larger August diurnal range is replicated by the model; however the model results are lower than the observed values by about 1.0 mg/l. Hourly bias for the June period was 0.13 mg/l with a mean absolute error of 0.18 mg/l. Hourly bias for the August period was -0.42 mg/l with a mean absolute error of 0.52 mg/l.

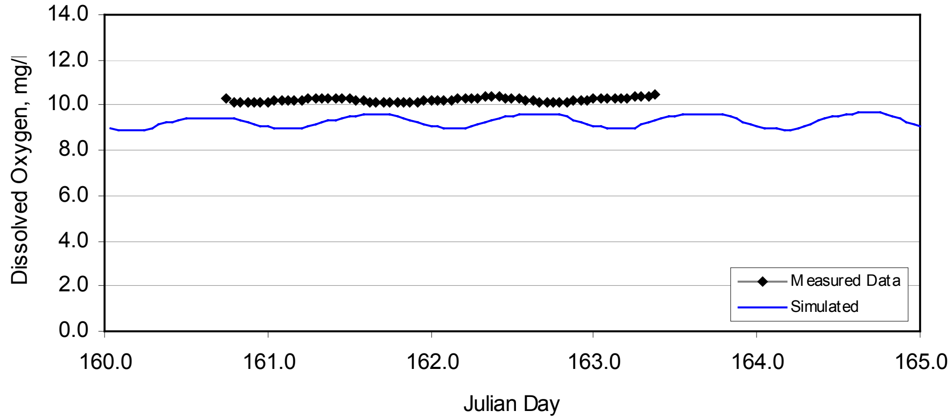


Figure 213. Klamath River above Salmon River simulated versus measured dissolved oxygen, June 9-12, 2003

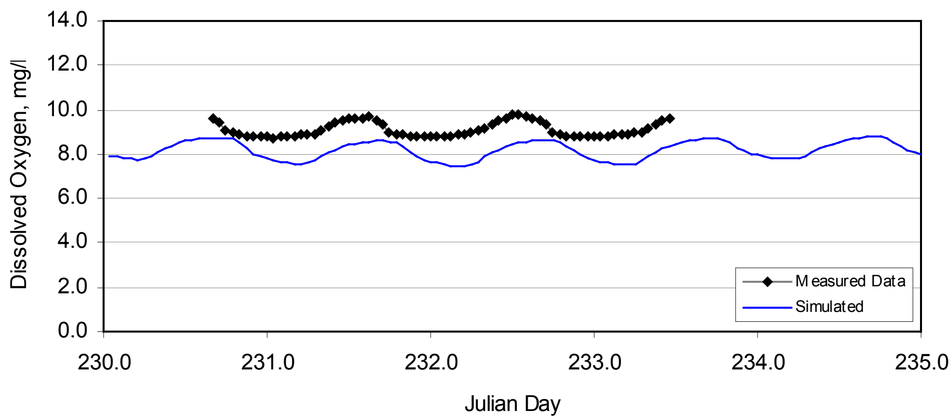


Figure 214. Klamath River above Salmon River simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River above Trinity River, both the moderated June diurnal signal and larger August diurnal range is replicated by the model; however the model results are higher than observations in June and the August diurnal signal is smaller than observed values. Hourly bias for the June period was 0.67 mg/l with a mean absolute error of 0.67 mg/l. Hourly bias for the August period was 0.29 mg/l with a mean absolute error of 0.50 mg/l.

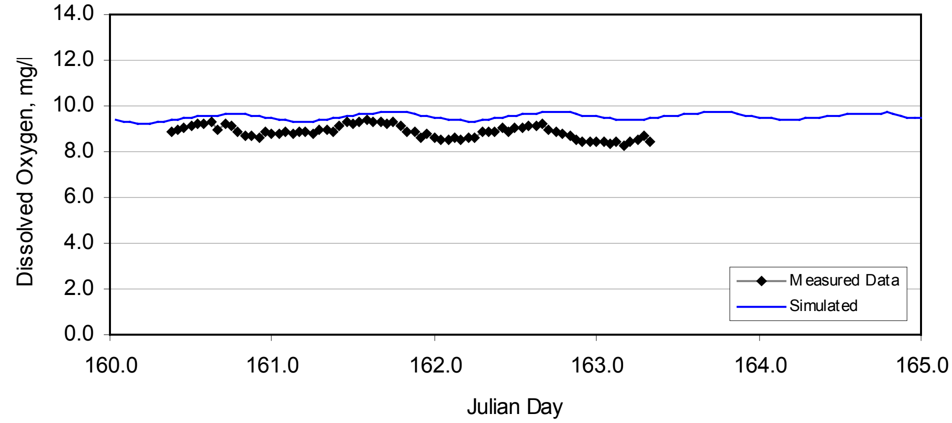


Figure 215. Klamath River above Trinity River simulated versus measured dissolved oxygen, June 9-12, 2003

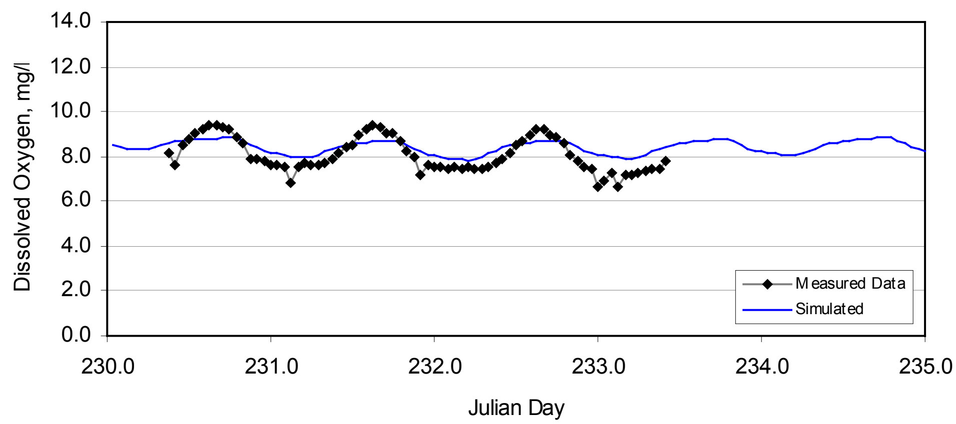


Figure 216. Klamath River above Trinity River simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River nears Martins Ferry as represented by Martins Ferry and Tully Creek, both the moderated June diurnal signal and larger August diurnal range is replicated by the model; however the model results are slightly higher than observations in June and the August diurnal signal is smaller than observed values. Hourly bias for the June period was 0.51 mg/l with a mean absolute error of 0.51 mg/l. Hourly bias for the August period was 0.02 mg/l with a mean absolute error of 0.29 mg/l.

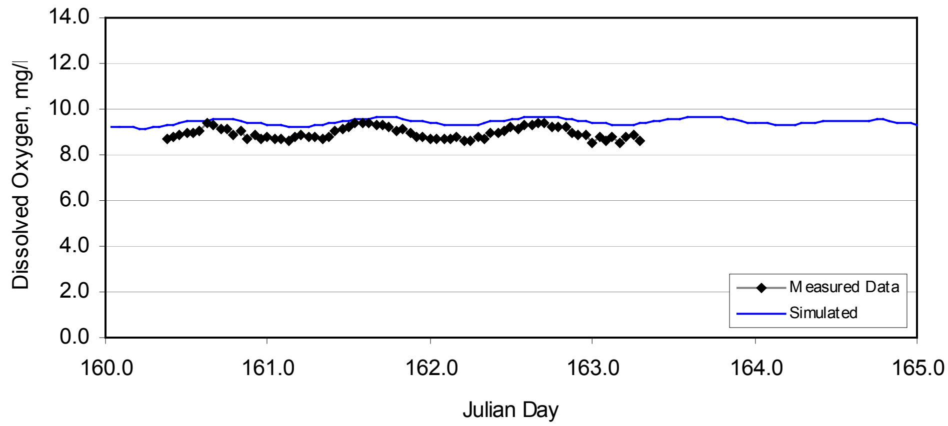


Figure 217. Klamath River at Martins Ferry simulated versus measured dissolved oxygen, June 9-12, 2003

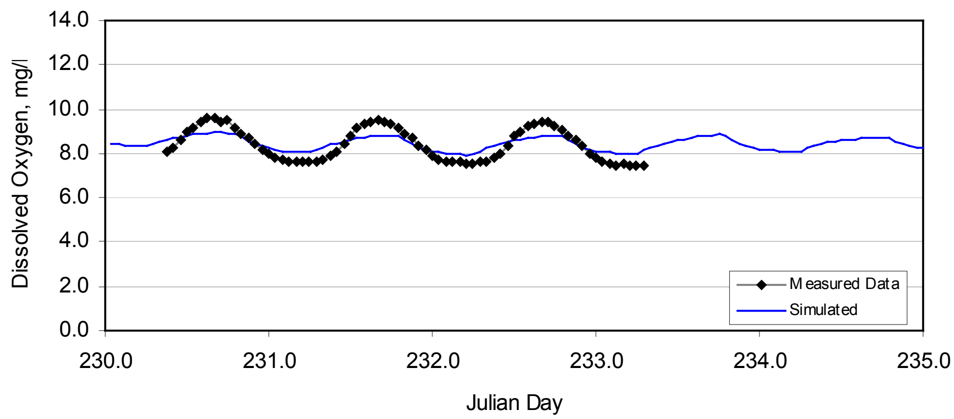


Figure 218. Klamath River at Tully Creek simulated versus measured dissolved oxygen, August 18-21, 2003

At Klamath River in the extreme lower river as represented by Turwar and Blue Creek the Turwar site has a wider diurnal range than the model (this may be due to deployment location), while the August phase and range are generally well represented at Blue Creek. Hourly bias for the June period was -0.27 mg/l with a mean absolute error of 0.41 mg/l. Hourly bias for the August period was 0.25 mg/l with a mean absolute error of 0.47 mg/l.

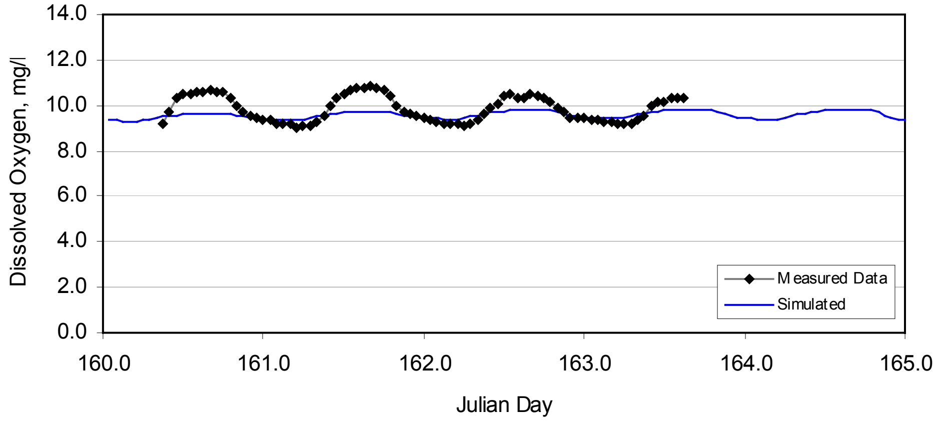


Figure 219. Klamath River at Turwar simulated versus measured dissolved oxygen, June 9-12, 2003

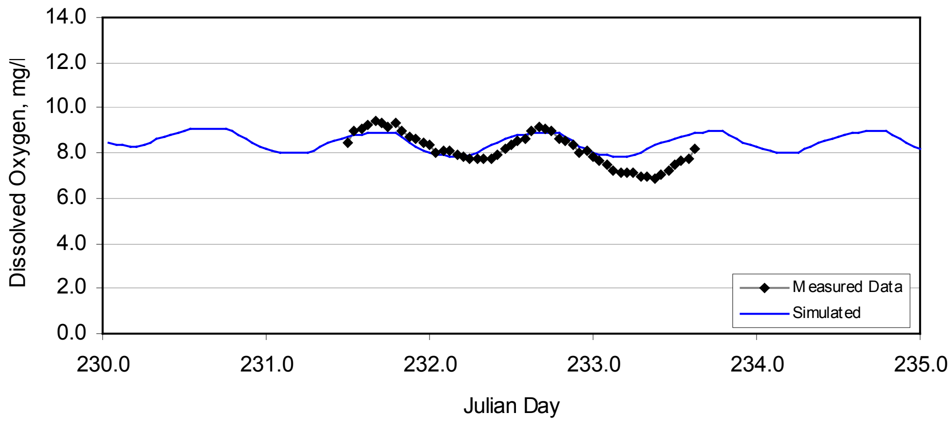


Figure 220. Klamath River at Blue Creek River simulated versus measured dissolved oxygen, August 18-21, 2003

Table 86. Klamath River hourly and daily calibration statistics for dissolved oxygen 2003

Calibration / Validation Statistics		Hourly		Daily	
	Unit	June	August	June	August
Klamath River ab Shasta River					
Mean Bias[a]	˚C	0.64	0.69	0.69	0.60
Mean absolute error (MAE)	˚C	0.84	0.69	0.69	0.60
Root mean squared error (RMSE)	˚C	0.94	0.84	0.75	0.60
n	-	71	75	2	2
Klamath River ab Scott River					
Mean Bias[a]	˚C	0.63	-0.26	0.65	-0.25
Mean absolute error (MAE)	˚C	0.64	0.36	0.65	0.25
Root mean squared error (RMSE)	˚C	0.68	0.49	0.65	0.25
n	-	71	69	2	2
Klamath River near Seiad Valley					
Mean Bias[a]	˚C	0.13	-0.42	0.13	-0.44
Mean absolute error (MAE)	˚C	0.18	0.52	0.13	0.44
Root mean squared error (RMSE)	˚C	0.24	0.73	0.13	0.44
n	-	71	66	2	2
Klamath River above Clear Creek					
Mean Bias[a]	˚C	na	-0.73	na	-0.71
Mean absolute error (MAE)	˚C	na	0.73	na	0.71
Root mean squared error (RMSE)	˚C	na	0.77	na	0.71
n	-	na	73	na	2
Klamath River above Salmon River					
Mean Bias[a]	˚C	-0.96	-1.03	-0.91	-1.05
Mean absolute error (MAE)	˚C	0.96	1.03	0.91	1.05
Root mean squared error (RMSE)	˚C	1.00	1.08	0.91	1.05
n	-	64	68	2	2
Klamath River above Trinity River					
Mean Bias[a]	˚C	0.67	0.29	0.64	0.23
Mean absolute error (MAE)	˚C	0.67	0.50	0.64	0.23
Root mean squared error (RMSE)	˚C	0.71	0.57	0.65	0.23
n	-	72	74	2	2
Klamath River at Martins Ferry/Tully Ck[b]					
Mean Bias[a]	˚C	0.51	0.02	0.50	0.00
Mean absolute error (MAE)	˚C	0.51	0.39	0.50	0.01
Root mean squared error (RMSE)	˚C	0.54	0.43	0.50	0.01
N	-	71	71	2	2
Klamath River at Blue Creek/Turwar[c]					
Mean Bias[a]	˚C	-0.27	0.25	-0.24	0.50
Mean absolute error (MAE)	˚C	0.41	0.47	0.24	0.50
Root mean squared error (RMSE)	˚C	0.53	0.60	0.26	0.67
n	-	79	52	2	2

[a] Mean bias = simulated – measured
[b] June, Martins Ferry; August, Tully Creek
[c] June, Turwar; August, Blue Creek
na – not available

3.9.3.3 Nutrients

Inorganic forms of nitrogen (ammonia, NH_4^+; nitrate, NO_3^-) and phosphorous (orthophosphate, PO_4^{3-}) were sampled once per day during the June and August 2003 monitoring program at the identified sampling sites for calibration. The sites at Blue Creek and at Turwar were not sampled for nutrients and are not included herein. The model results indicate that for all nutrients the bias is within ±0.10 mg/l and the MAE is les than 0.10 mg/l. These values are close to the reporting limits for these nutrients. Results are presented graphically in Figure 221 and Figure 262 and tabulated in Table 87.

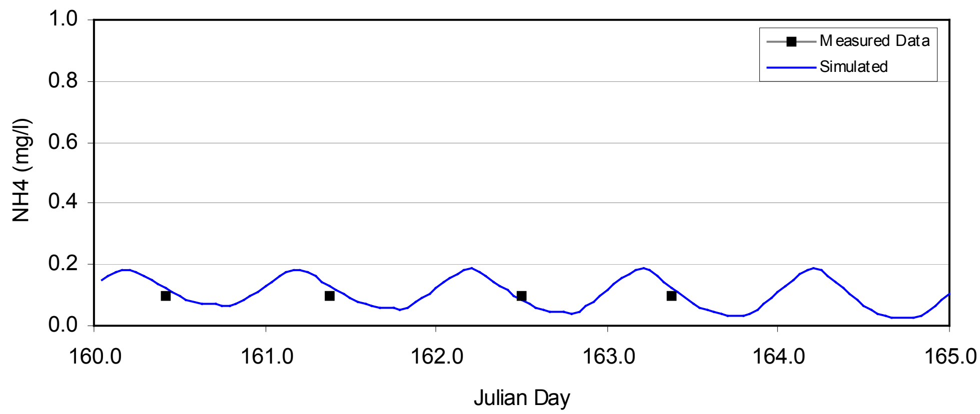


Figure 221. Klamath River above Shasta River simulated versus measured ammonia, June 9-12, 2003

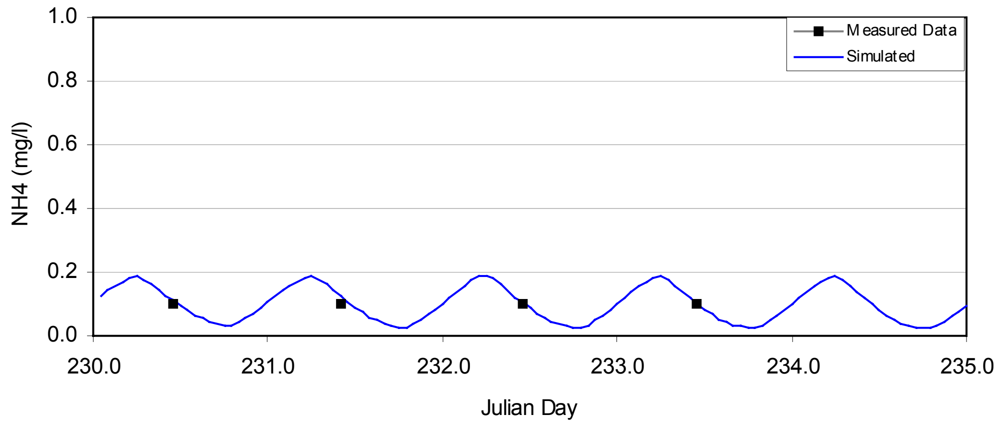


Figure 222. Klamath River above Shasta River simulated versus measured ammonia, August 18-21, 2003

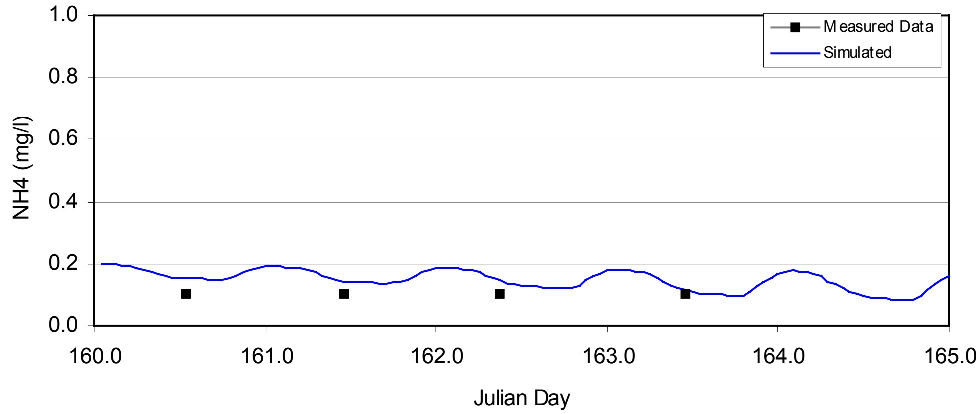


Figure 223. Klamath River above Scott River simulated versus measured ammonia, June 9-12, 2003

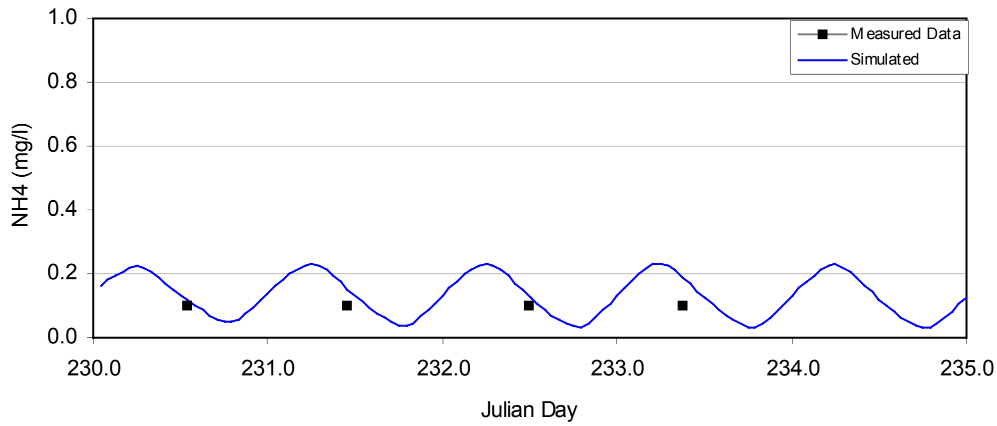


Figure 224. Klamath River above Scott River simulated versus measured ammonia, August 18-21, 2003

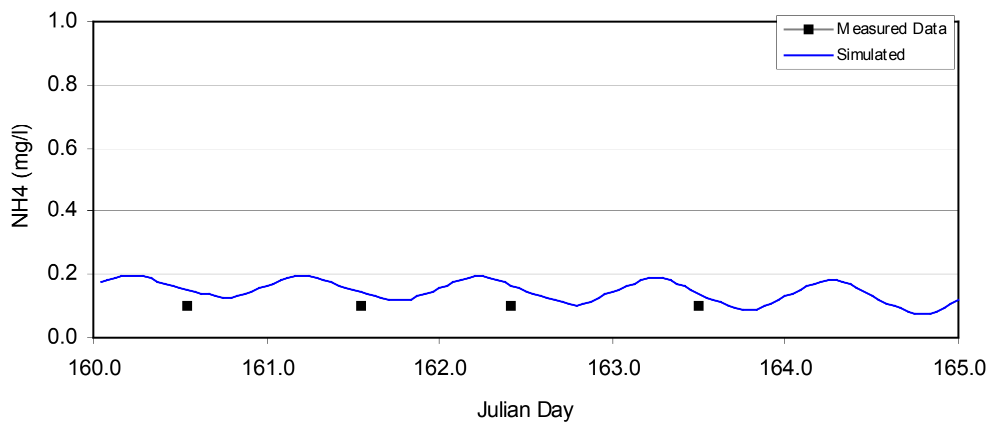


Figure 225. Klamath River near Seiad Valley simulated versus measured ammonia, June 9-12, 2003

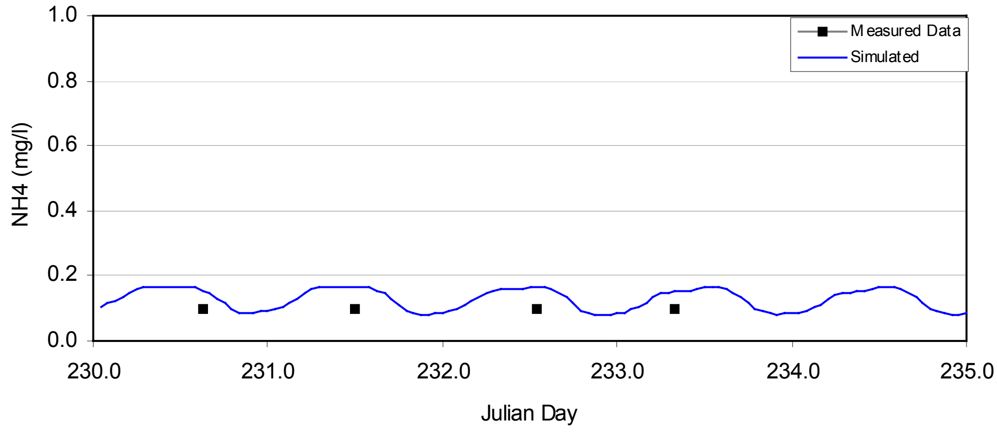


Figure 226. Klamath River near Seiad Valley simulated versus measured ammonia, August 18-21, 2003

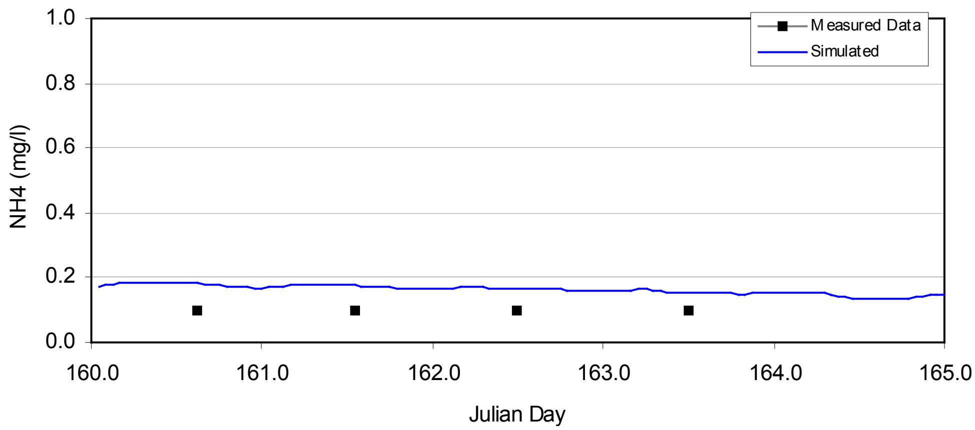


Figure 227. Klamath River above Clear Creek simulated versus measured ammonia, June 9-12, 2003

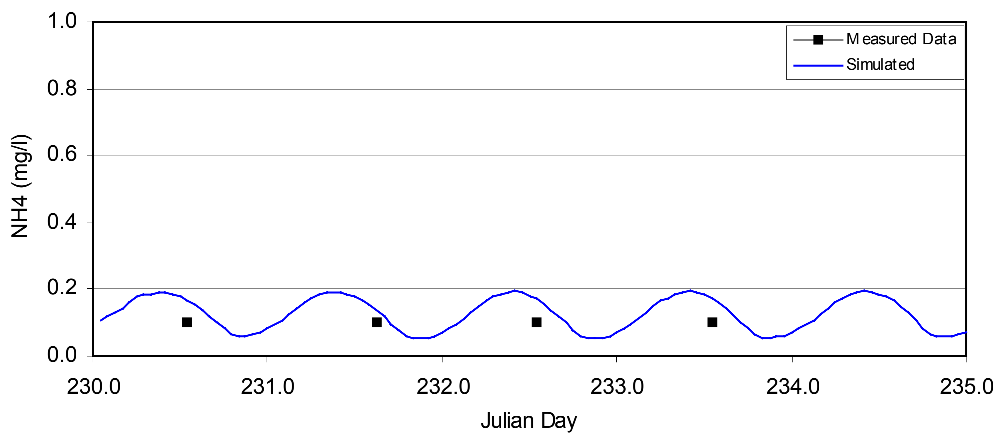


Figure 228. Klamath River above Clear Creek simulated versus measured ammonia, August 18-21, 2003

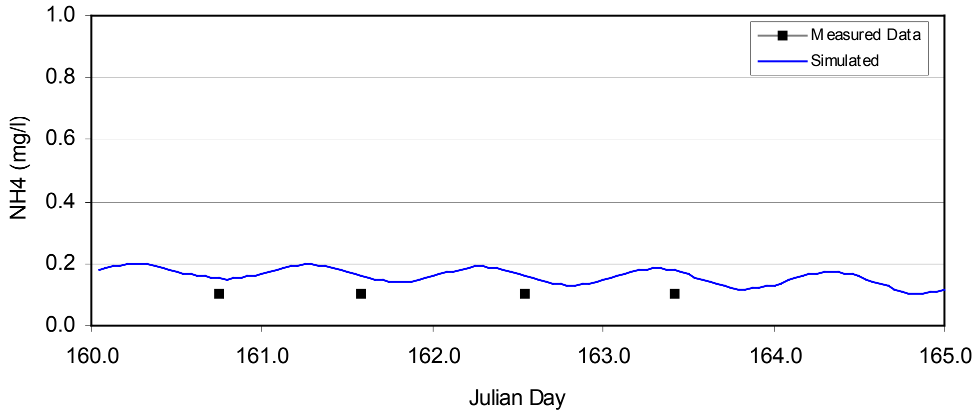


Figure 229. Klamath River above Salmon River simulated versus measured ammonia, June 9-12, 2003

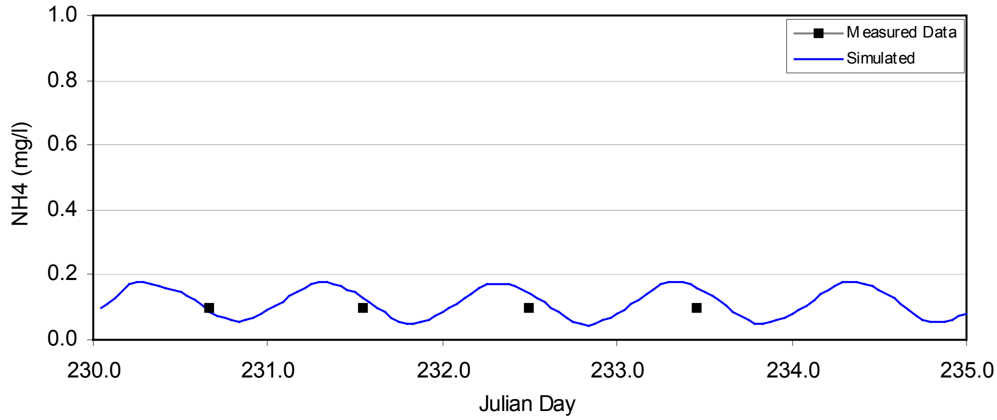


Figure 230. Klamath River above Salmon River simulated versus measured ammonia, August 18-21, 2003

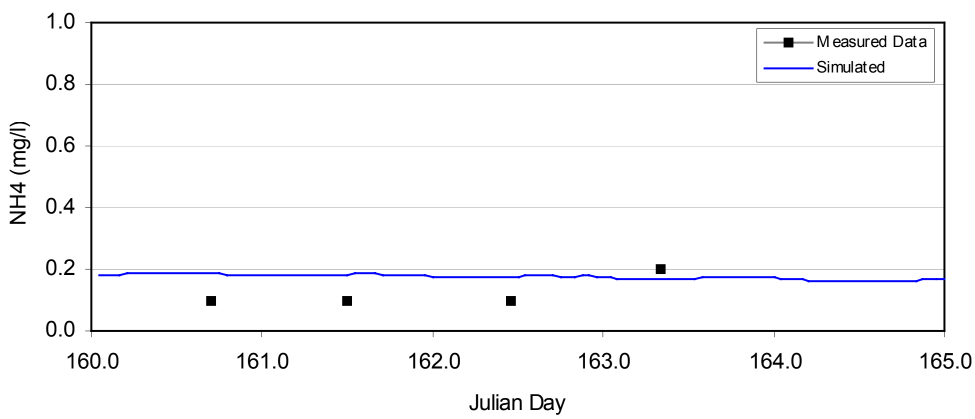


Figure 231. Klamath River above Trinity River simulated versus measured ammonia, June 9-12, 2003

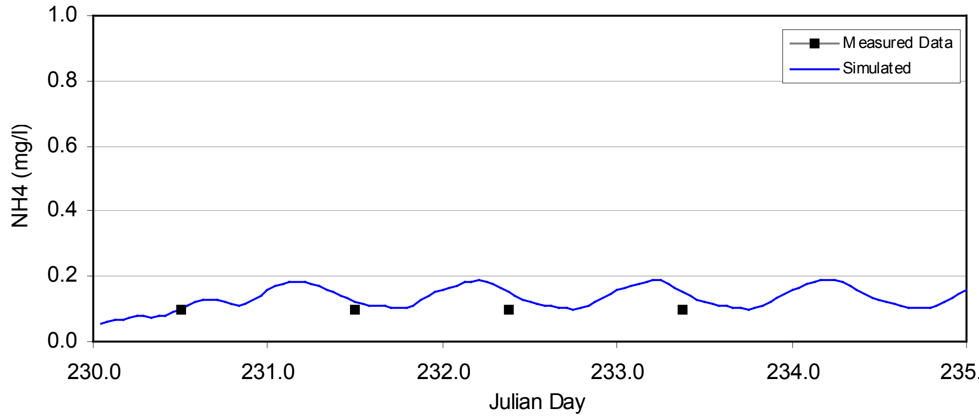


Figure 232. Klamath River above Trinity River simulated versus measured ammonia, August 18-21, 2003

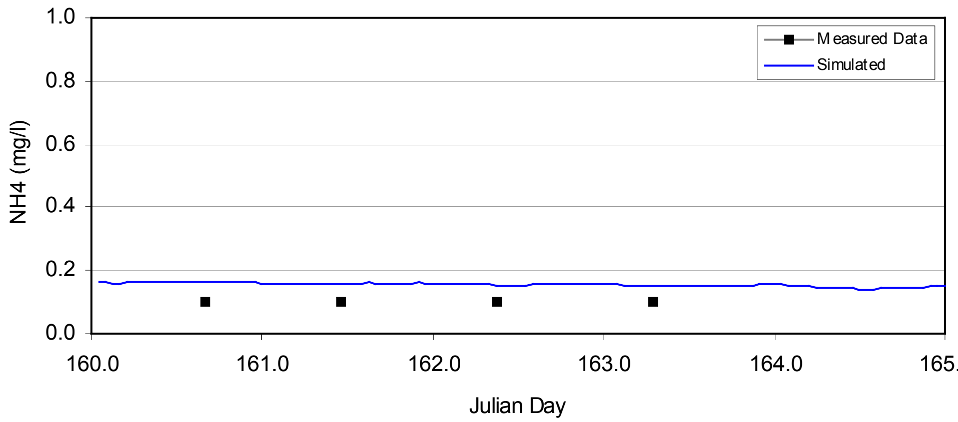


Figure 233. Klamath River at Martins Ferry simulated versus measured ammonia, June 9-12, 2003

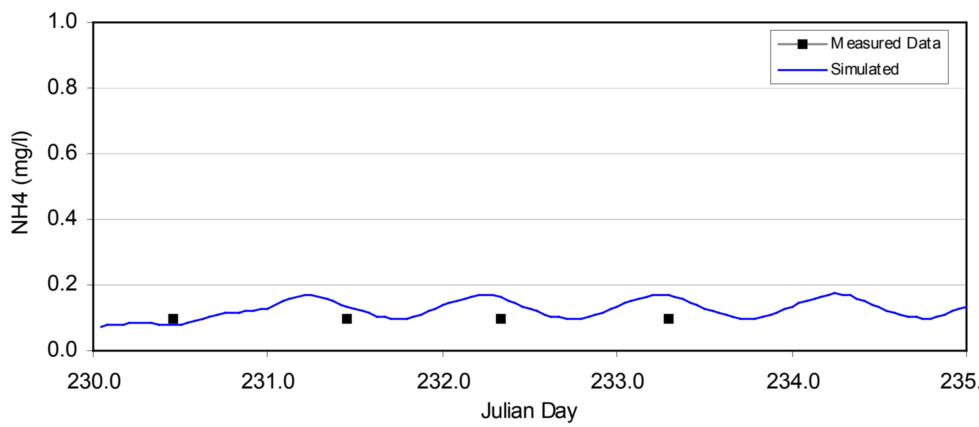


Figure 234. Klamath River at Tully Creek simulated versus measured ammonia, August 18-21, 2003

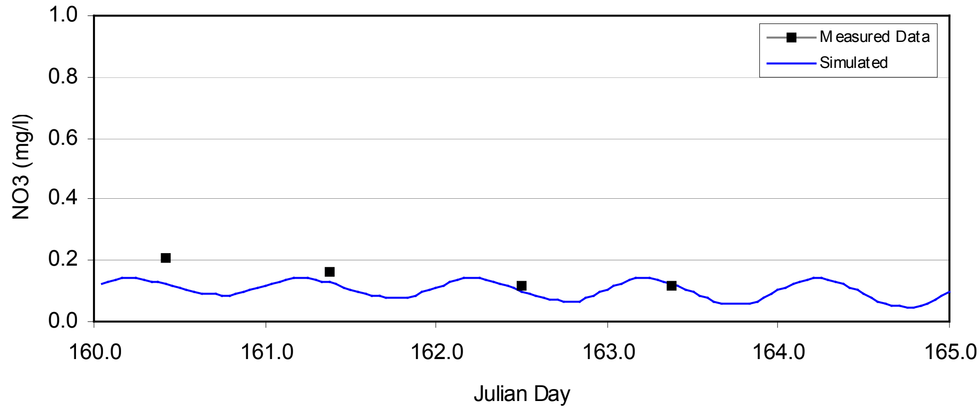


Figure 235. Klamath River above Shasta River simulated versus measured nitrate, June 9-12, 2003

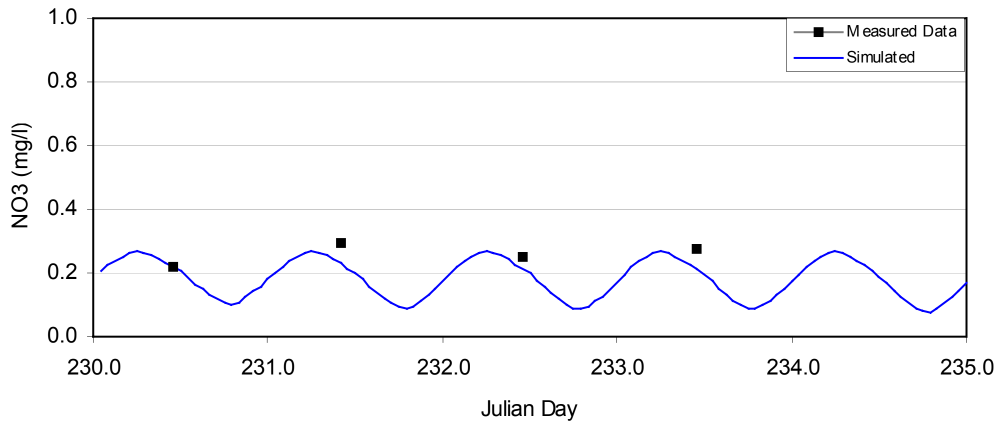


Figure 236. Klamath River above Shasta River simulated versus measured nitrate, August 18-21, 2003

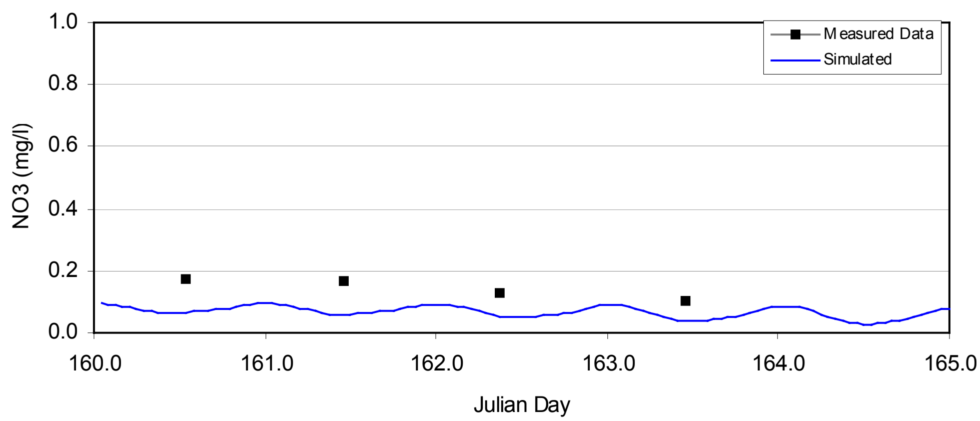


Figure 237. Klamath River above Scott River simulated versus measured nitrate, June 9-12, 2003

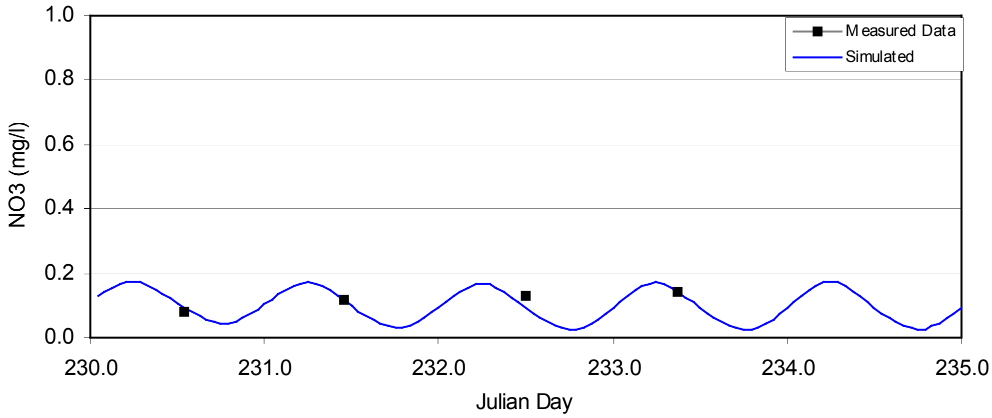


Figure 238. Klamath River above Scott River simulated versus measured nitrate, August 18-21, 2003

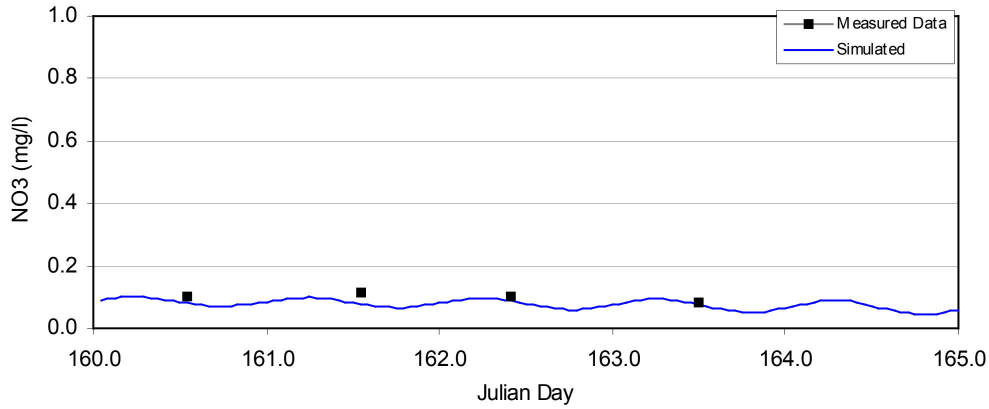


Figure 239. Klamath River near Seiad Valley simulated versus measured nitrate, June 9-12, 2003

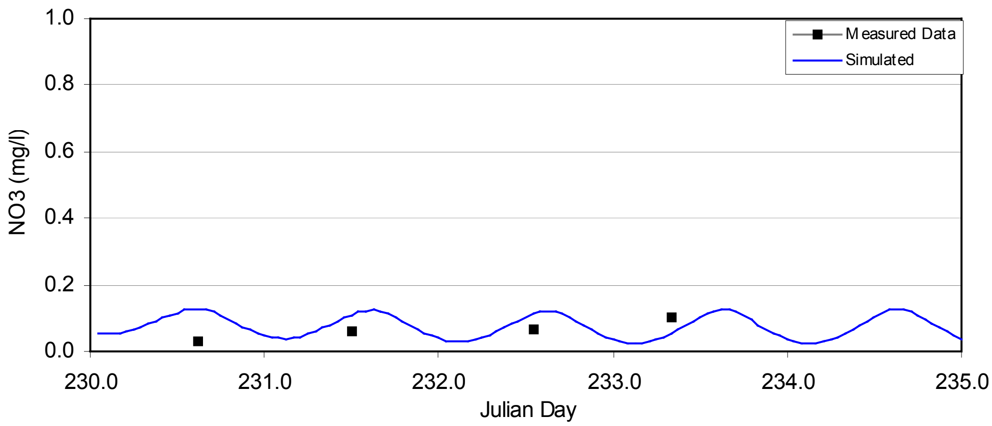


Figure 240. Klamath River near Seiad Valley simulated versus measured nitrate, August 18-21, 2003

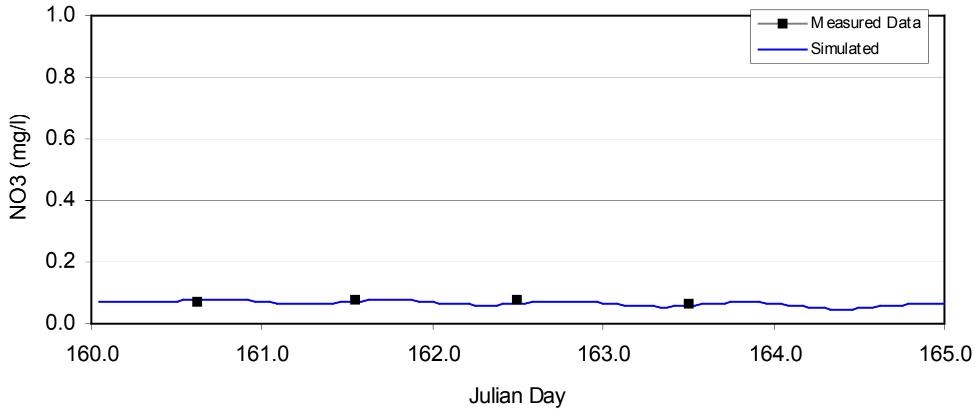


Figure 241. Klamath River above Clear Creek simulated versus measured nitrate, June 9-12, 2003

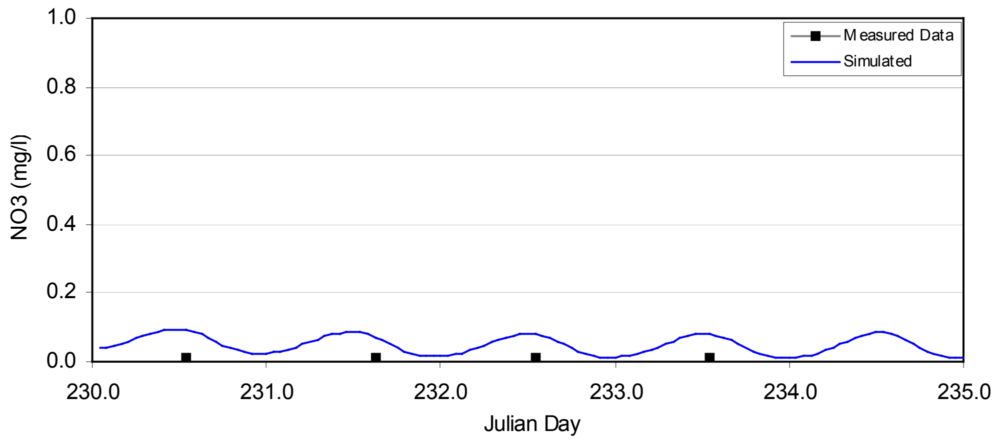


Figure 242. Klamath River above Clear Creek simulated versus measured nitrate, August 18-21, 2003

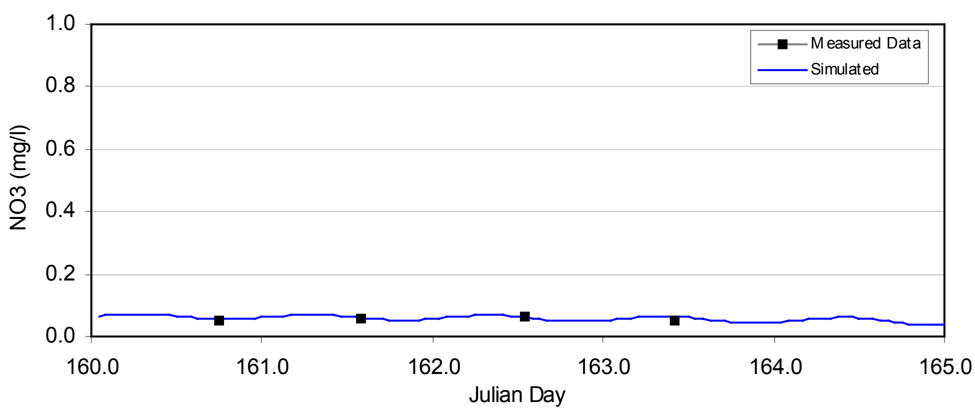


Figure 243. Klamath River above Salmon River simulated versus measured nitrate, June 9-12, 2003

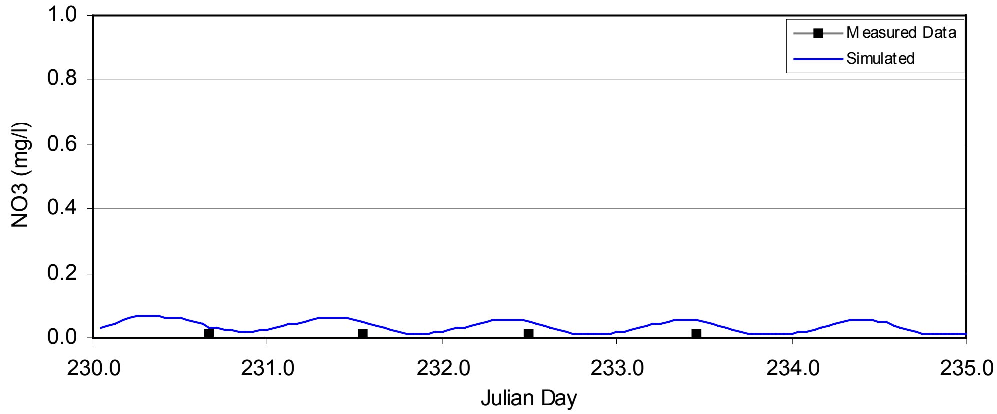


Figure 244. Klamath River above Salmon River simulated versus measured nitrate, August 18-21, 2003

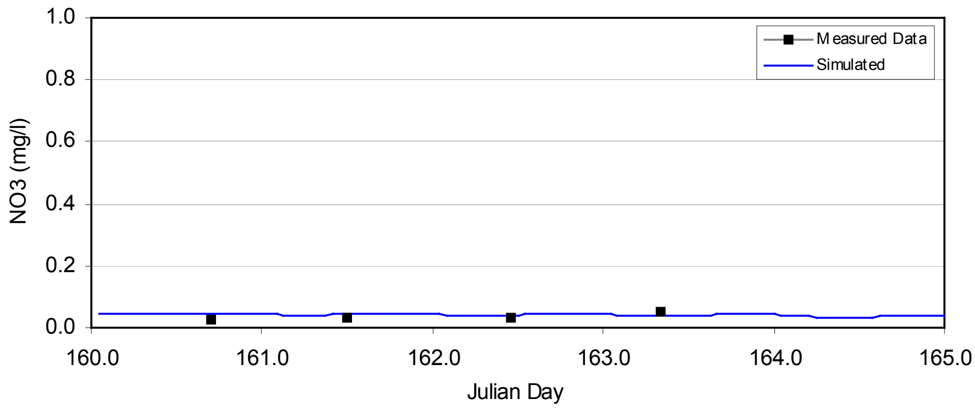


Figure 245. Klamath River above Trinity River simulated versus measured nitrate, June 9-12, 2003

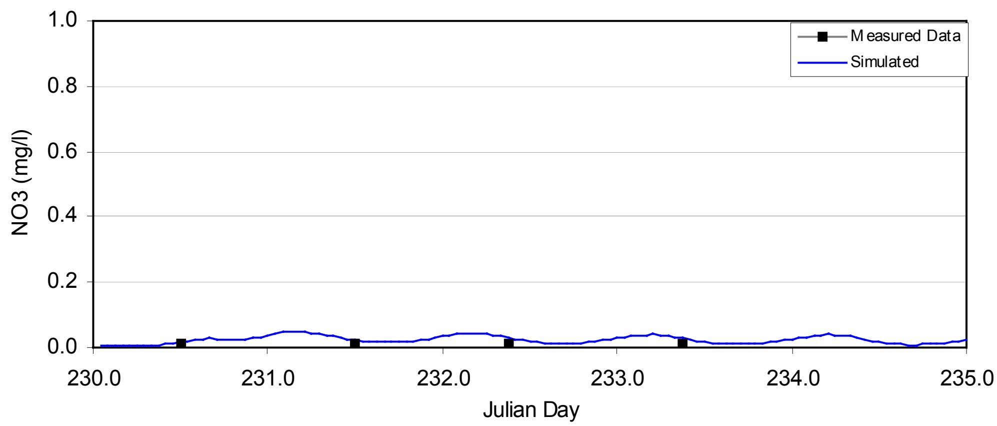


Figure 246. Klamath River above Trinity River simulated versus measured nitrate, August 18-21, 2003

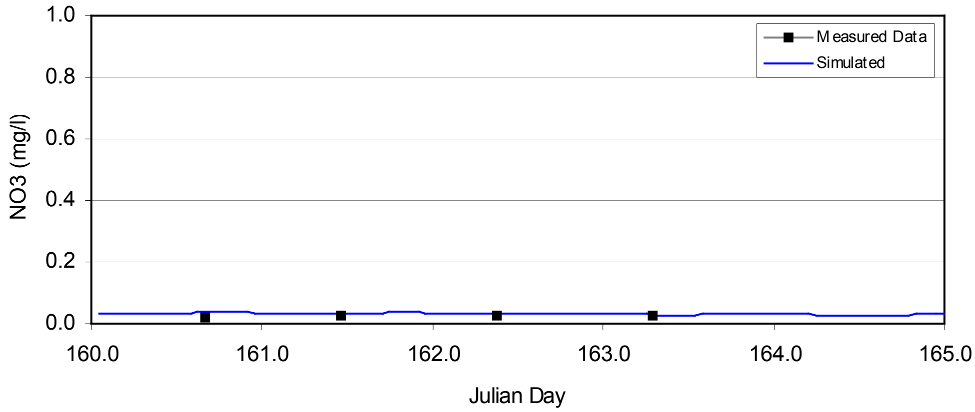


Figure 247. Klamath River at Martins Ferry simulated versus measured nitrate, June 9-12, 2003

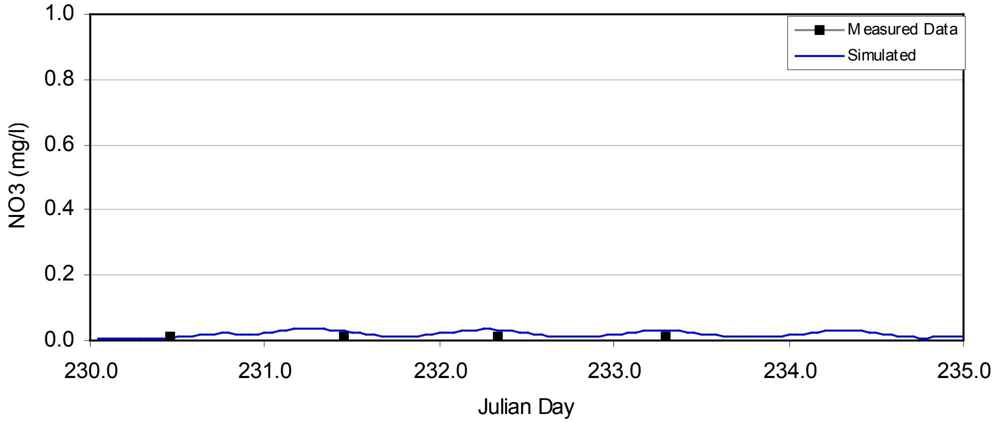


Figure 248. Klamath River at Tully Creek simulated versus measured nitrate, August 18-21, 2003

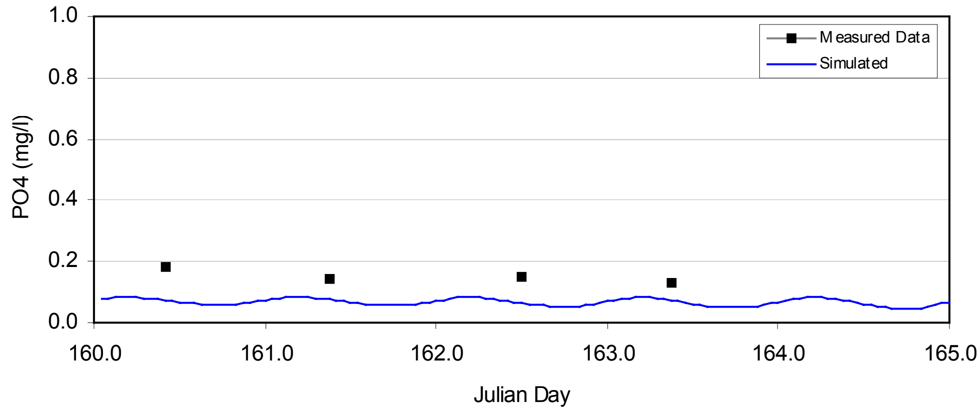


Figure 249. Klamath River above Shasta River simulated versus measured orthophosphate, June 9-12, 2003

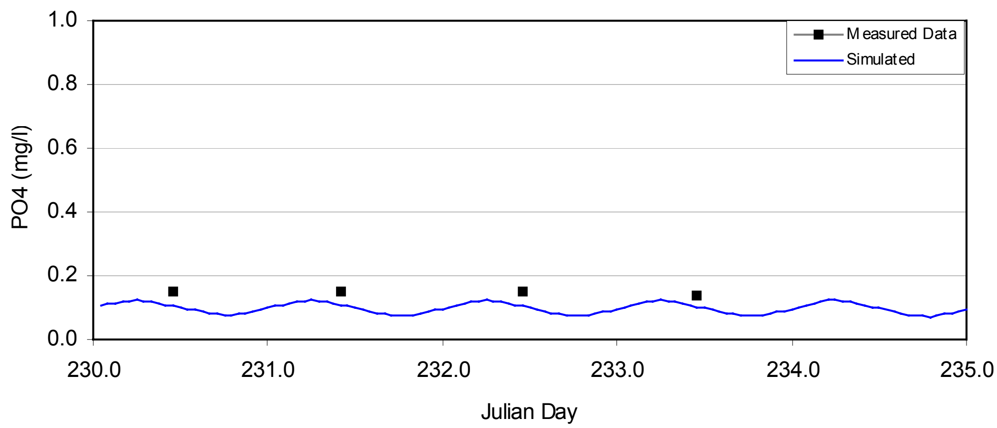


Figure 250. Klamath River above Shasta River simulated versus measured orthophosphate, August 18-21, 2003

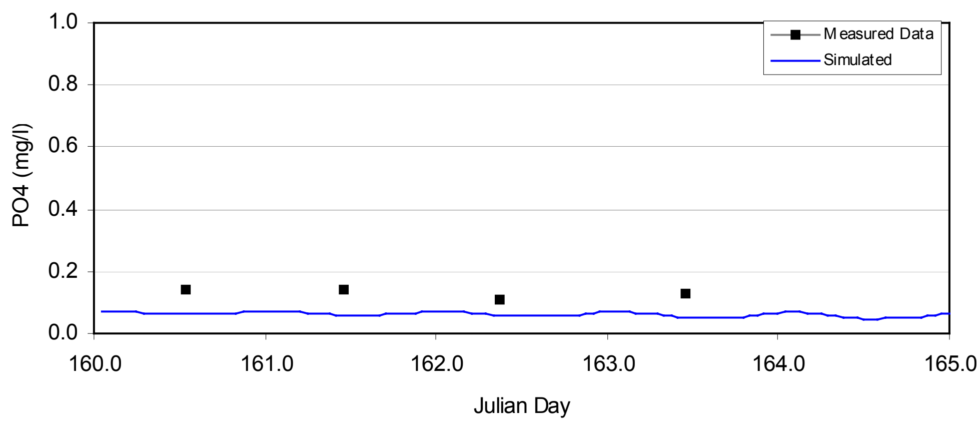


Figure 251. Klamath River above Scott River simulated versus measured orthophosphate, June 9-12, 2003

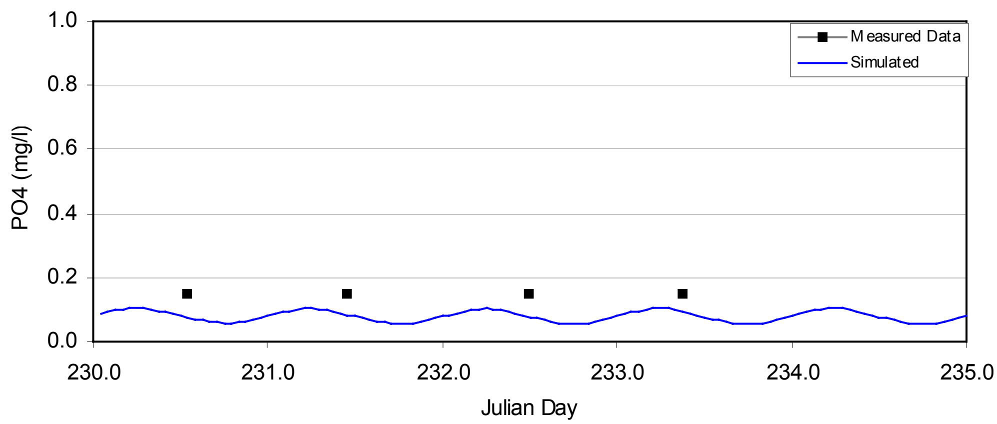


Figure 252. Klamath River above Scott River simulated versus measured orthophosphate, August 18-21, 2003

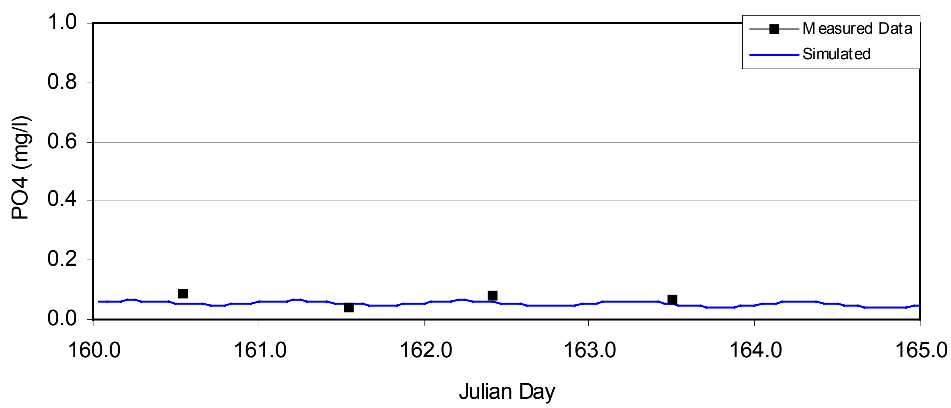


Figure 253. Klamath River near Seiad Valley simulated versus measured orthophosphate, June 9-12, 2003

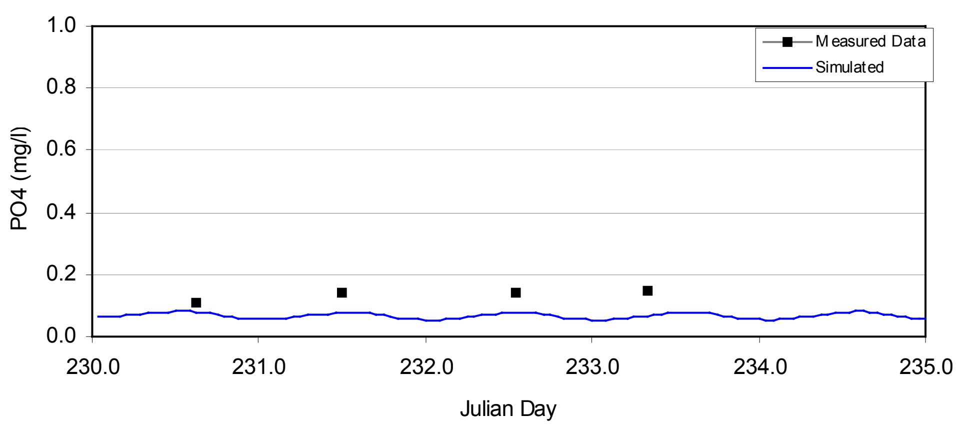


Figure 254. Klamath River near Seiad Valley simulated versus measured orthophosphate, August 18-21, 2003

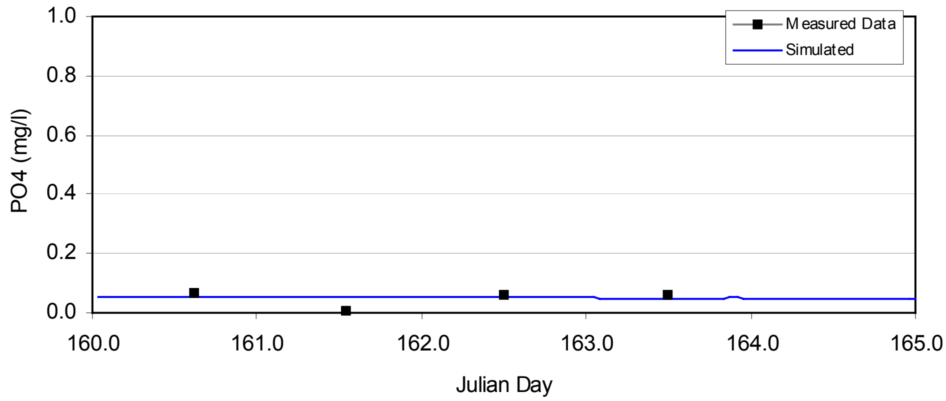


Figure 255. Klamath River above Clear Creek simulated versus measured orthophosphate, June 9-12, 2003

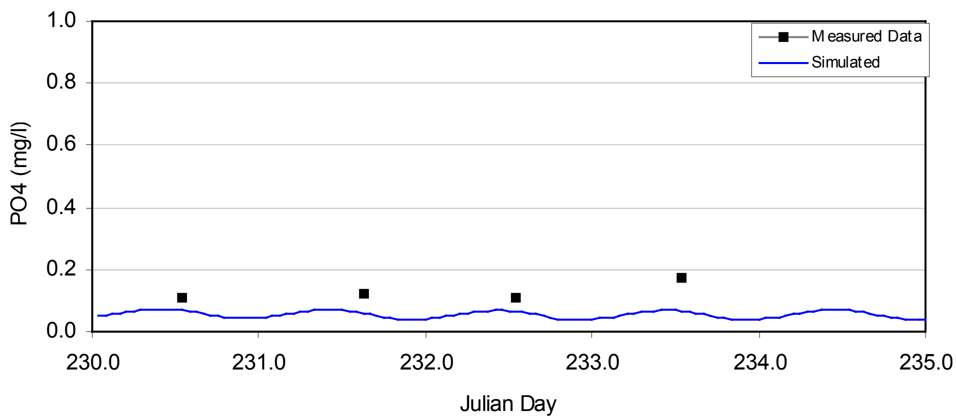


Figure 256. Klamath River above Clear Creek simulated versus measured orthophosphate, August 18-21, 2003

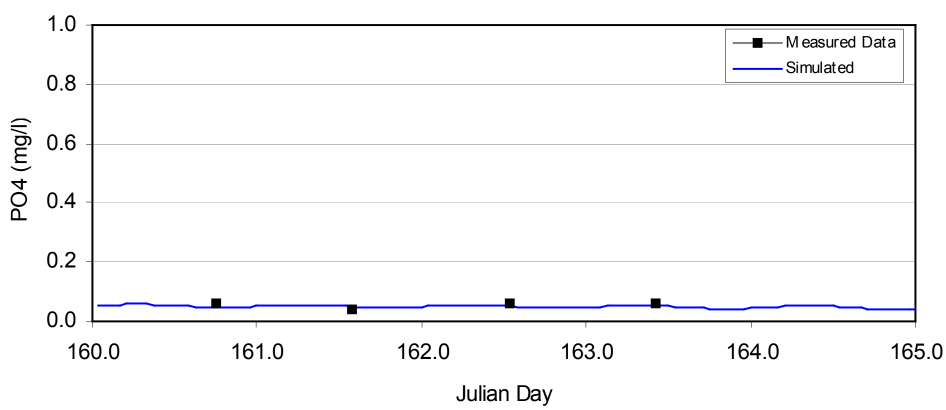


Figure 257. Klamath River above Salmon River simulated versus measured orthophosphate, June 9-12, 2003

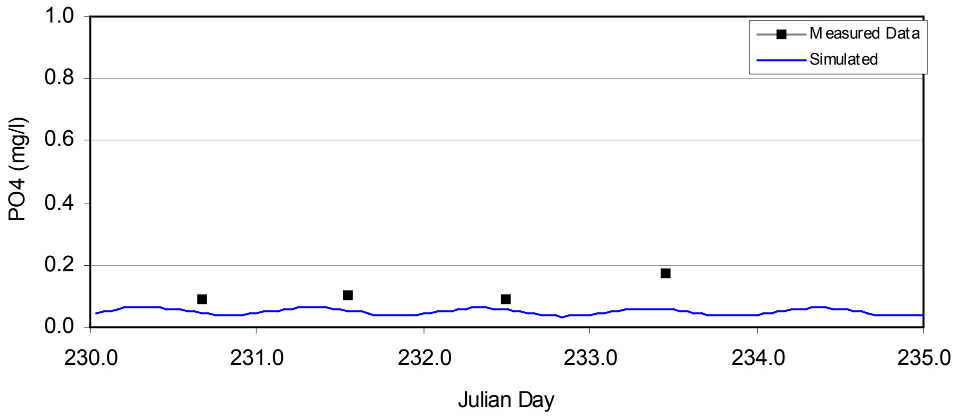


Figure 258. Klamath River above Salmon River simulated versus measured orthophosphate, August 18-21, 2003

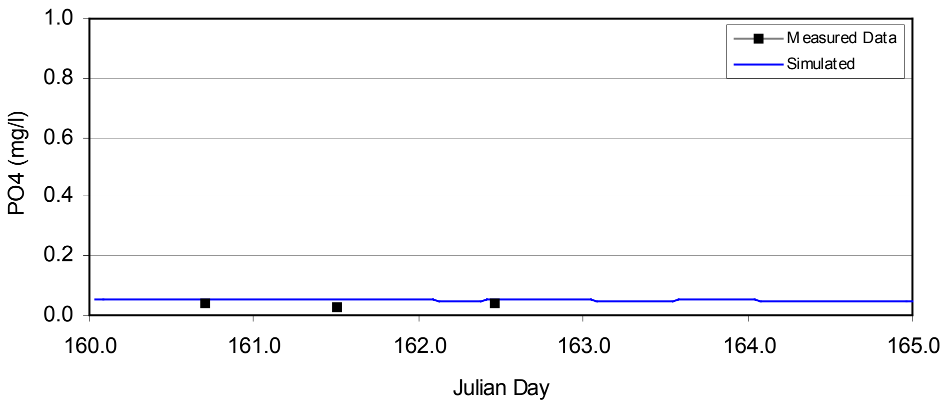


Figure 259. Klamath River above Trinity River simulated versus measured orthophosphate, June 9-12, 2003

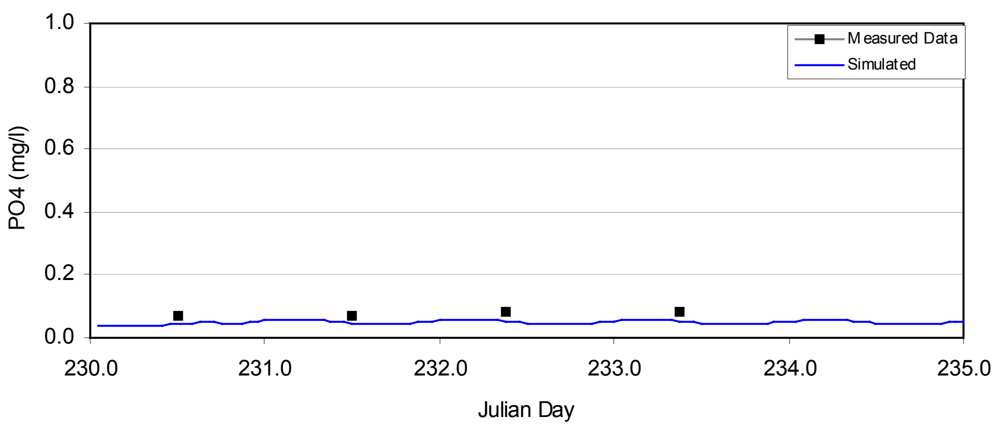


Figure 260. Klamath River above Trinity River simulated versus measured orthophosphate, August 18-21, 2003

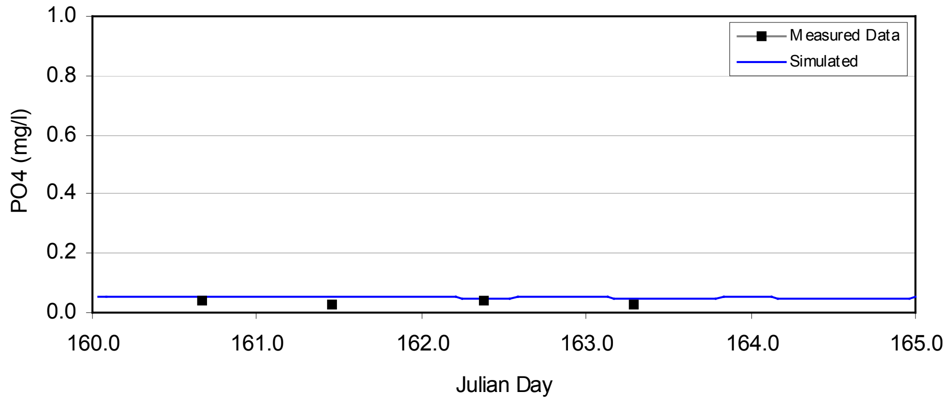


Figure 261. Klamath River at Martins Ferry simulated versus measured orthophosphate, June 9-12, 2003

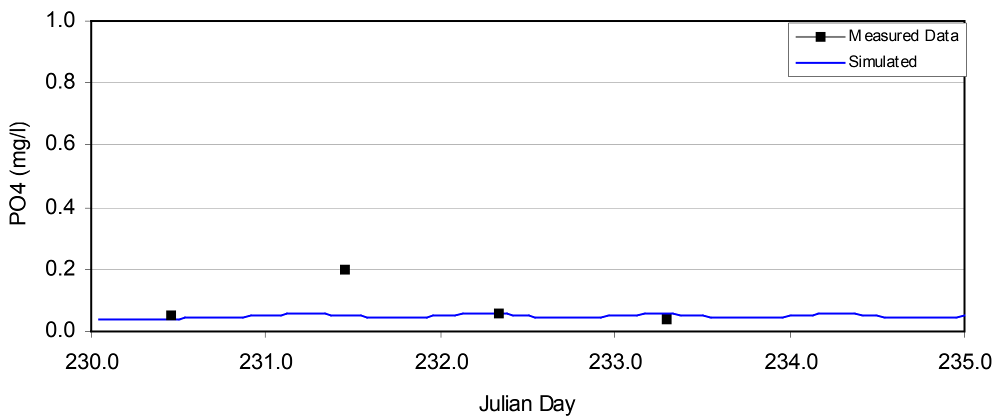


Figure 262. Klamath River at Tully Creek simulated versus measured orthophosphate, August 18-21, 2003

Table 87. Klamath River hourly and daily calibration statistics for nutrients 2003

Ammonia, NH_4^+

JUNE	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	Near Martins Ferry
Bias	0.02	0.04	0.05	0.07	0.06	0.05	0.06
MAE	0.02	0.04	0.05	0.07	0.06	0.07	0.06
RMSE	0.03	0.05	0.05	0.07	0.06	0.07	0.06
n	4	4	4	4	4	4	4

AUGUST	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	At Tully Ck
Bias	0.01	0.05	0.06	0.06	0.03	0.03	0.04
MAE	0.01	0.05	0.06	0.06	0.04	0.03	0.05
RMSE	0.01	0.06	0.06	0.06	0.03	0.04	0.05
n	4	4	4	4	4	4	4

Nitrate, NO_3^-

JUNE	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	Near Martins Ferry
Bias	-0.03	-0.09	-0.02	-0.01	0.01	0.01	0.01
MAE	0.04	0.09	0.02	0.01	0.01	0.01	0.01
RMSE	0.05	0.10	0.03	0.01	0.00	0.02	0.01
n	4	4	4	4	4	4	4

AUGUST	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	At Tully Ck
Bias	-0.04	0.00	0.04	0.07	0.04	0.01	0.02
MAE	0.04	0.01	0.06	0.07	0.04	0.01	0.02
RMSE	0.04	0.01	0.06	0.07	0.03	0.02	0.02
n	4	4	4	4	4	4	4

Orthophosphate, PO_4^{3-}

JUNE	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	Near Martins Ferry
Bias	-0.08	-0.07	-0.02	0.00	0.00	0.02	0.02
MAE	0.08	0.07	0.02	0.02	0.01	0.02	0.02
RMSE	0.08	0.07	0.03	0.03	0.01	0.02	0.02
n	4	4	4	4	4	3	4

AUGUST	Above Shasta	Above Scott	Near Seiad	Above Clear Ck	Above Salmon R	Above Trinity R	At Tully Ck
Bias	-0.04	-0.07	-0.06	-0.06	-0.06	-0.03	-0.04
MAE	0.04	0.07	0.06	0.06	0.06	0.03	0.04
RMSE	0.04	0.07	0.06	0.05	0.04	0.03	0.07
n	4	4	4	4	4	4	4

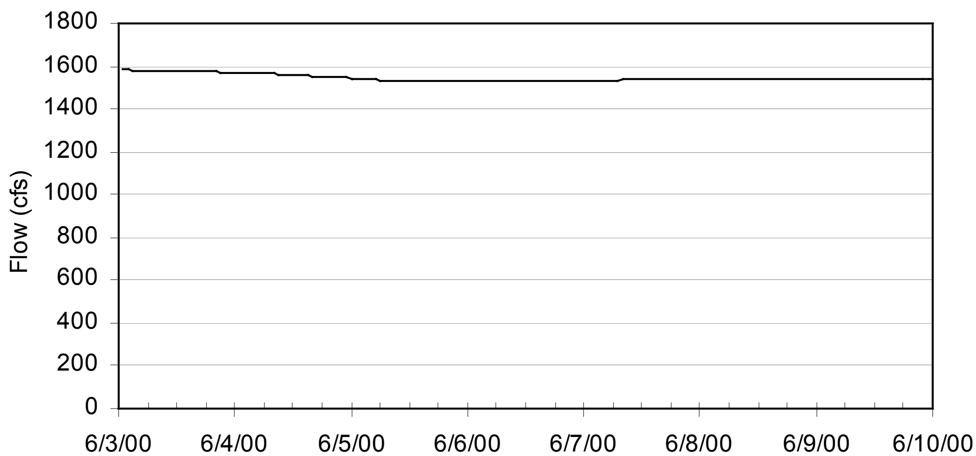
3.9.4 Model Application for 2000

The model was applied to the 2000 period and compared with available data: June 5-7, 2000 (Julian Day 157-159) and August 7-9, 2000 (JD 220-222). The process of identifying initial conditions, boundary conditions, and calibration data were the same as in 2003. These data are briefly discussed below, but the graphical and tabular presentation is not presented for sake of brevity.

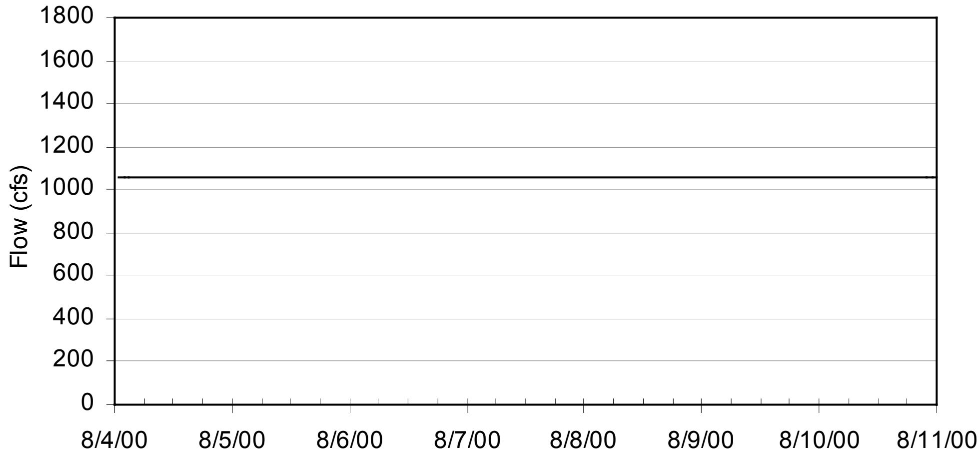
3.9.4.1 Data: 2000

Boundary Conditions at Iron Gate Dam

Flow data were derived in a similar fashion to 2003. The temperature and dissolved oxygen boundary conditions data for Iron Gate Dam were derived from hourly data recorded by sondes deployed in 2000 by USBR at Klamath River below Iron Gate Dam. The constituent concentration boundary condition data for the Iron Gate Dam was derived from 2000 grab samples (USBR, 2003), which were collected three times per day during the June and August periods. The concentrations were averaged for each period and the average was applied to the calibration or validation period as a constant boundary condition (Table 88). All boundary conditions for the tributaries were those used in model implementation, as described in section 2.3.8, and are not revisited herein.



(a)



(b)

Figure 263. Gauged flow at Klamath River below Iron Gate Dam for Iron Gate to Turwar reach model 2000: (a) June, (b) August

Table 88. Water quality constituent boundary conditions for the Klamath River below Iron Gate Dam: June and August 2000

Constituent	Unit	June	August
Temp	C	hourly	hourly
DO	mg/l	hourly	hourly
BOD	mg/l	2.00	2.00
OrgN	mg/l	0.70	0.55
NH4	mg/l	0.10	0.10
NO2	mg/l	0.00	0.00
NO3	mg/l	0.06	0.30
OrgP	mg/l	0.05	0.00
PO4	mg/l	0.25	0.15
Chlor_a	mg/m^3	10.00	10.00

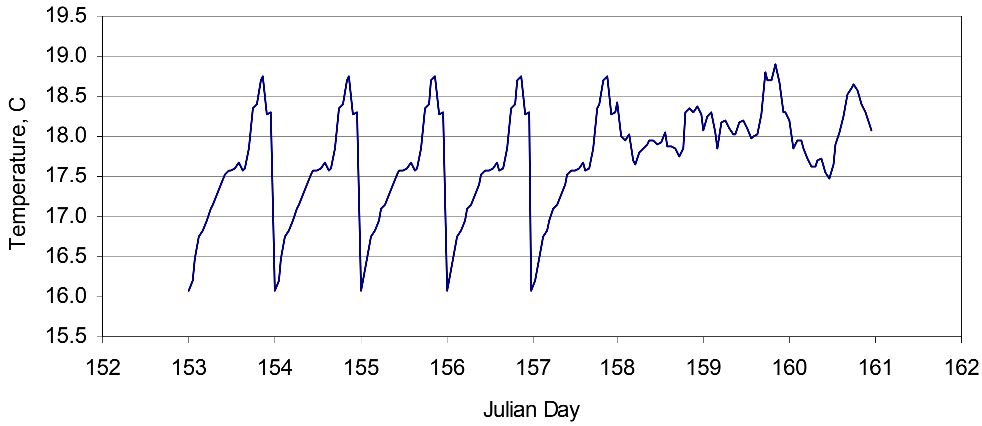


Figure 264. Klamath River below Iron Gate water temperature: June 1-9, 2000 (JD 153-161)

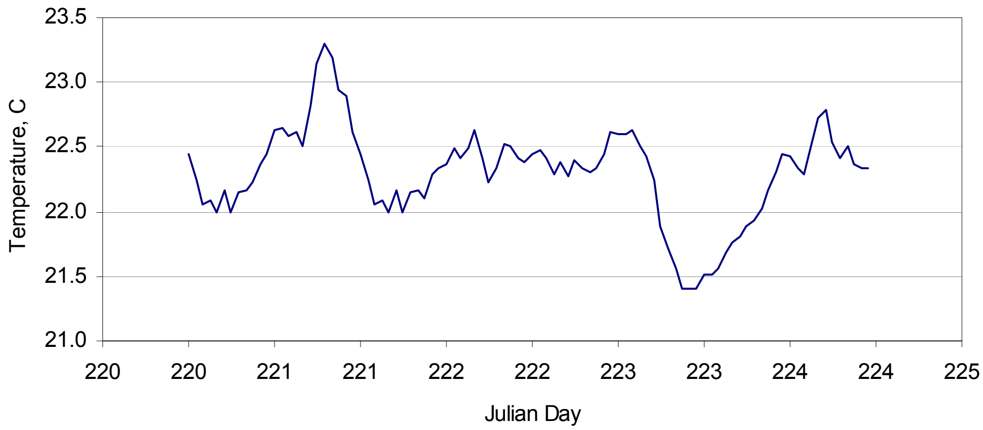


Figure 265. Klamath River below Iron Gate water temperature : August 7-15, 2000 (JD 220-224)

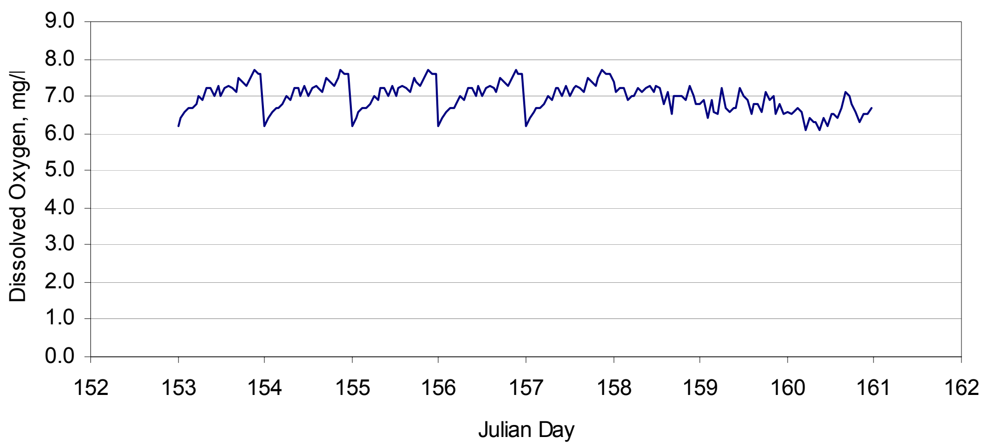


Figure 266. Klamath River below Iron Gate dissolved oxygen: June 1-9, 2000 (JD 153-161)

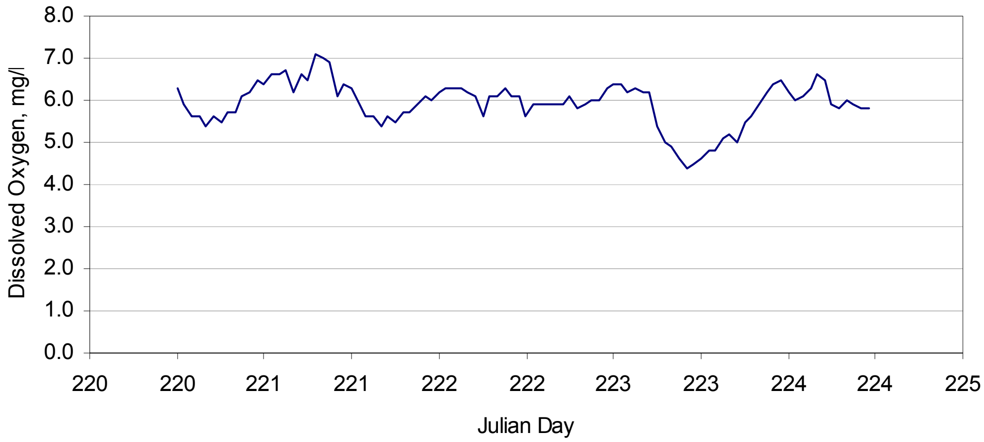


Figure 267. Klamath River below Iron Gate dissolved oxygen: August 7-15, 2000 (JD 220-224)

Initial Conditions

The model was run for two days prior to the 2000 calibration period (approximate travel time from Iron Gate to Seiad Valley) to provide an initial condition for simulations. The initial bed algae mass was estimated at 5 g/m^2. Where field data were unavailable, the conditions of the first day of available field data were applied.

Model Output Locations

For the 2000 simulation, model output was compared with observations at: Klamath River above Shasta River, above Walker Road Bridge, above Scott River, and near Seiad Valley. For dissolved oxygen there was only sufficient data for the Klamath River above the Shasta River and near Seiad Valley. Water quality probes and/or temperature loggers were employed to record conditions at the identified locations, and grab samples were available from USBR (2003). These data are displayed in the following section with model results.

All water quality probes and grab samples were collected from near-shore areas and although all efforts were made to identify locations that were deemed consistent with overall main stem conditions (e.g., areas that readily exchanged water with main flow in the river), several factors could result in potential deviation main stem conditions. The primary factor is probably the rapidly descending hydrographs in the June sampling periods which changed local conditions at some sampling locations and required successive re-deployment of water quality probes as water levels fell.

3.9.5 Results 2000

Results of year 2000 simulations were complete for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents (i.e., summary statistics were not computed). Field observations for temperature and dissolved oxygen were available from water quality probes on an hourly interval for June and August 2000 at multiple sites from Iron Gate Dam to Seiad Valley allowing for summary statistics to be calculated both on hourly and daily basis.

3.9.5.1 Water Temperature

Overall simulated results indicate that phase and amplitude were well represented during the 2000 periods and the mean absolute error between hourly simulated and observed value was less than 1.2°C at all locations. The mean absolute error in daily averaged values was 1.0°C or less at all locations. Simulated and observed temperatures results for each location are presented below.

At Klamath River above Shasta River, the diurnal range and phase were well represented in both periods of examination. Hourly bias for the June period was –0.17°C with a mean absolute error of 1.19°C. Hourly bias for the August period was 0.54°C with a mean absolute error of 0.70°C.

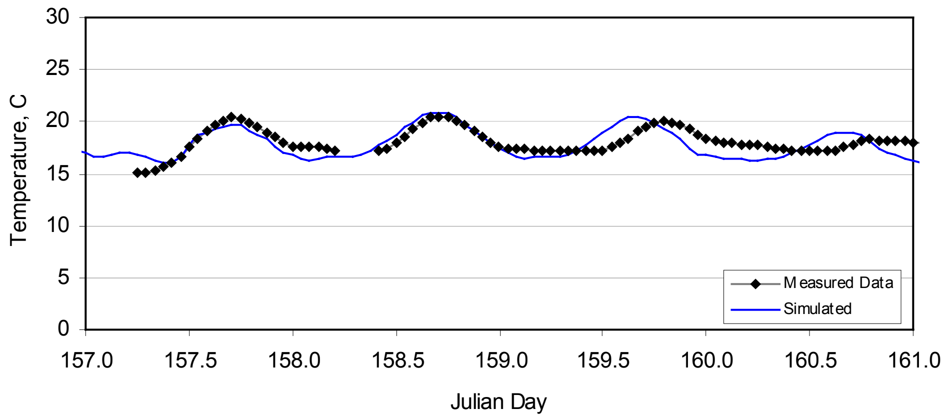


Figure 268. Klamath River above Shasta River simulated versus measured water temperature, June 5-7, 2000

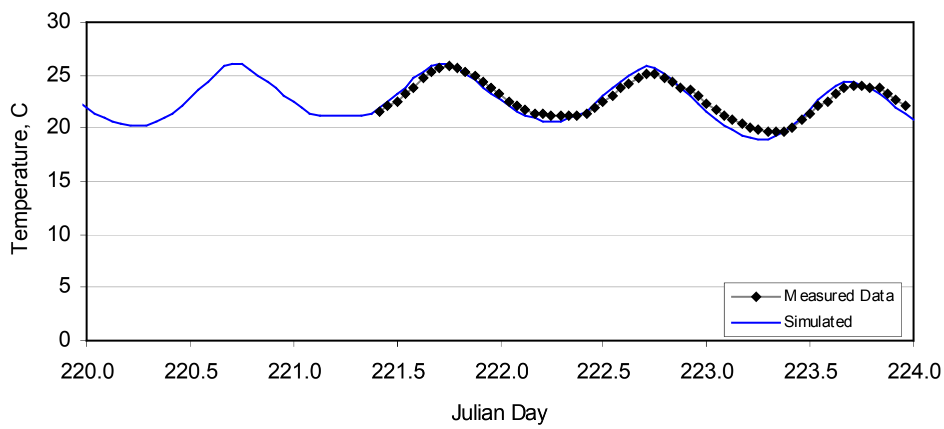


Figure 269. Klamath River above Shasta River simulated versus measured water temperature, August 7-9, 2000

At Klamath River at Walker Road Bridge, the moderated diurnal phase associated with the node of minimum diurnal variation due to Iron Gate Dam operations was well represented for both June and August periods. Hourly bias for the June period was 0.26°C with a mean absolute error of 0.47°C. Hourly bias for the August period was -0.25°C with a mean absolute error of 0.75°C.

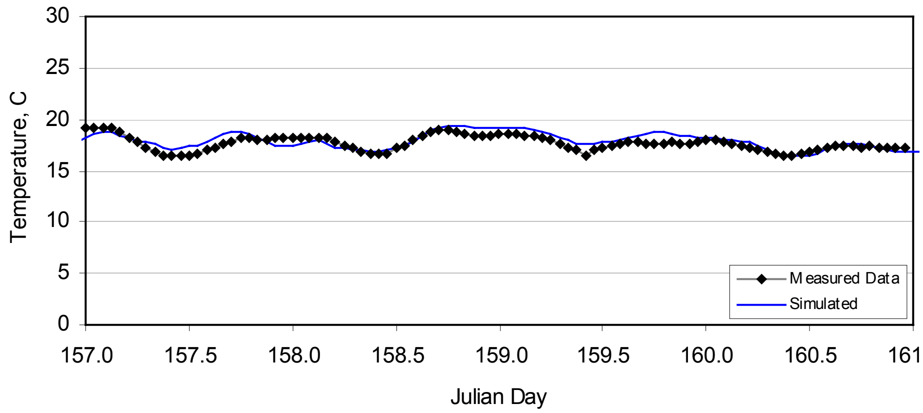


Figure 270. Klamath River above Walker Road Bridge (RM 156) simulated versus measured water temperature, June 5-7, 2000

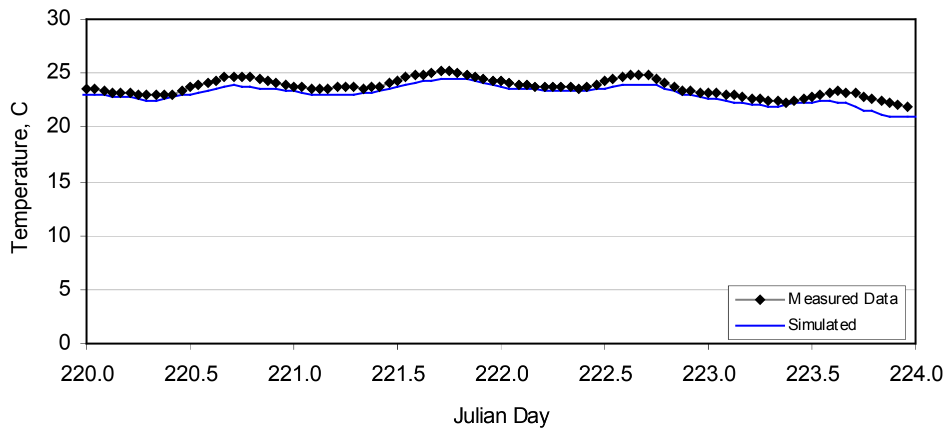


Figure 271. Klamath River above Walker Road Bridge (RM 156) simulated versus measured water temperature, August 7-9, 2000

At Klamath River above Scott River, the diurnal range and phase were generally well represented in both periods of examination. Hourly bias for the June period was 0.02°C with a mean absolute error of 0.51°C. Hourly bias for the August period was -0.53°C with a mean absolute error of 0.98°C.

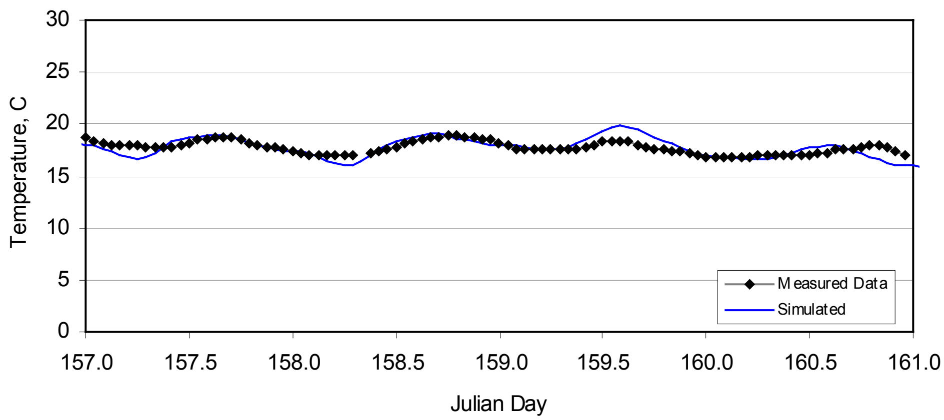


Figure 272. Klamath River above Scott River versus measured water temperature, June 5-7, 2000

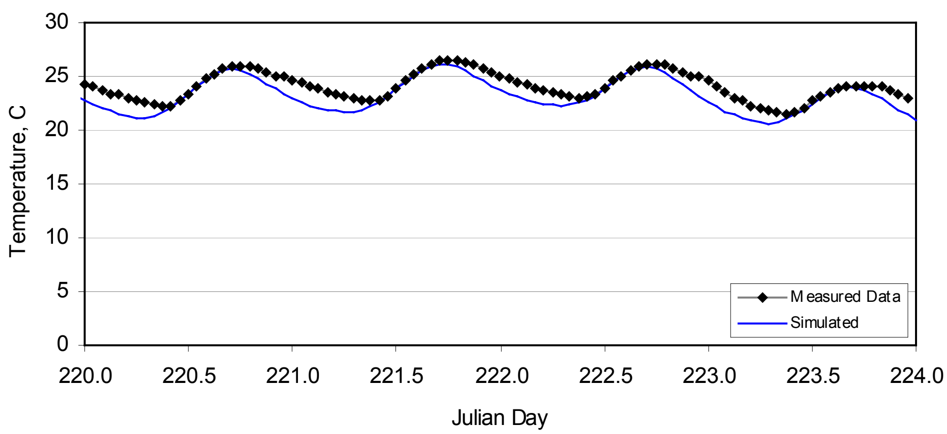


Figure 273. Klamath River above Scott River simulated versus measured water temperature, August 7-9, 2000

At Klamath River near Seiad Valley, the diurnal range and phase were well represented in both periods of examination; however, the model systematically under predicts in August. Hourly bias for the June period was -0.04°C with a mean absolute error of 0.38°C. Hourly bias for the August period was -0.78°C with a mean absolute error of 1.06°C.

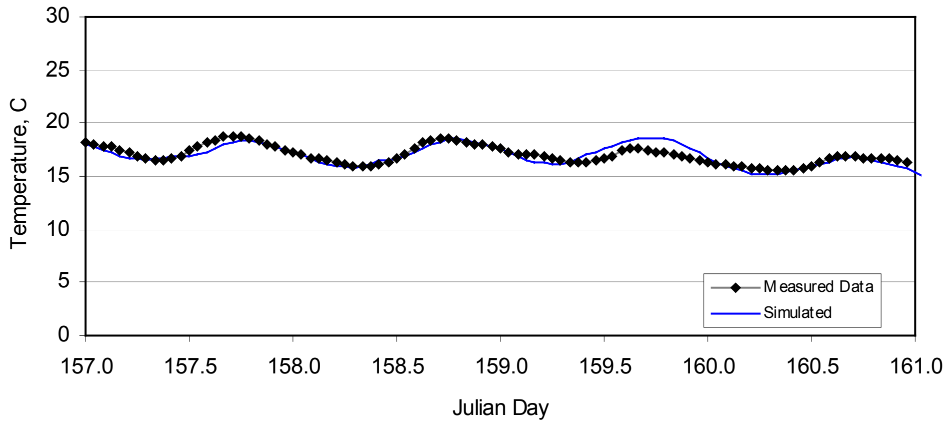


Figure 274. Klamath River near Seiad Valley versus measured water temperature, June 5-7, 2000

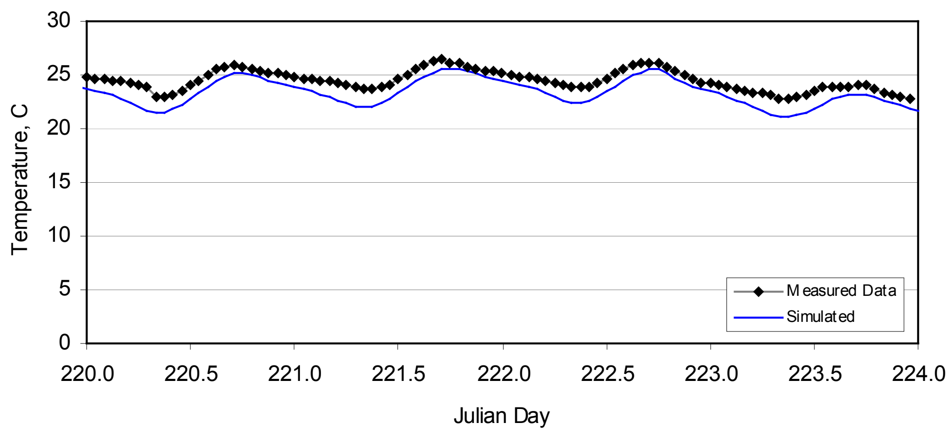


Figure 275. Klamath River near Seiad Valley versus measured water temperature, August 7-9, 2000

Table 89. Klamath River hourly and daily calibration and validation period statistics for water temperature 2000

Calibration / Validation Statistics		Hourly		Daily	
	Unit	June	August	June	August
Klamath River ab Shasta River					
Mean Bias[a]	˚C	-0.17	0.54	-0.25	0.68
Mean absolute error (MAE)	˚C	1.19	0.70	0.25	0.68
Root mean squared error (RMSE)	˚C	1.48	0.87	0.26	0.77
n	-	92	62	3	2
Klamath River at Walker Road Bridge					
Mean Bias[a]	˚C	0.26	-0.25	0.26	-0.25
Mean absolute error (MAE)	˚C	0.47	0.75	0.26	0.67
Root mean squared error (RMSE)	˚C	0.56	0.84	0.36	0.74
n	-	96	96	4	4
Klamath River ab Scott River					
Mean Bias[a]	˚C	0.02	-0.53	0.01	-0.53
Mean absolute error (MAE)	˚C	0.51	0.98	0.31	0.87
Root mean squared error (RMSE)	˚C	0.67	1.19	0.36	0.92
n	-	95	96	4	4
Klamath River near Seiad Valley					
Mean Bias[a]	˚C	-0.04	-0.78	-0.04	-0.78
Mean absolute error (MAE)	˚C	0.38	1.06	0.26	1.00
Root mean squared error (RMSE)	˚C	0.50	1.21	0.30	1.08
n	-	96	96	4	4

[a] Mean bias = simulated – measured

3.9.5.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates, and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeled in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from upstream Iron Gate Reservoir, growth rates were set to very low numbers in river reaches.

The hourly results are presented graphically in Figure 276 through Figure 280. Tabulated statistics are presented in Table 90.

At Klamath River above Shasta River, the diurnal phase is well represented during both June and August periods. However, the diurnal range in June is under represented and the shape of the daily cycle deviates from observed data. Hourly bias for the June period was 0.29 mg/l with a mean absolute error of 0.46 mg/l. Hourly bias for the August period was 0.48 mg/l with a mean absolute error of 0.56 mg/l.

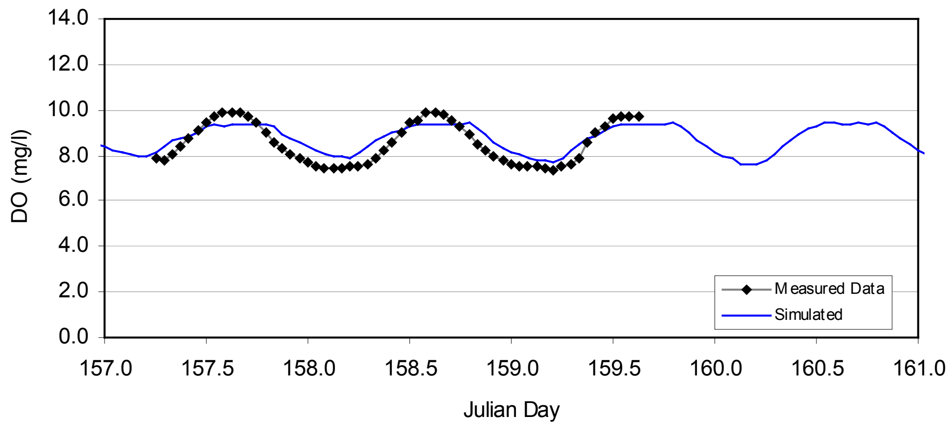


Figure 276. Klamath River above Shasta River simulated versus measured dissolved oxygen, June 5-7, 2000

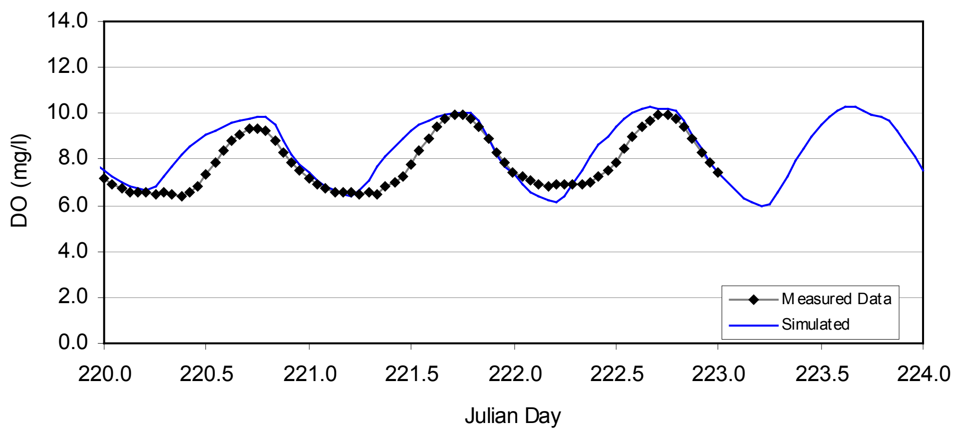


Figure 277. Klamath River above Shasta River simulated versus measured dissolved oxygen, August 7-9, 2000

There were no dissolved oxygen observations at Klamath River at Walker Road Bridge.

At Klamath River above Scott River, dissolved oxygen observations were only available during the August period (June data were unavailable). While the diurnal phase and range were well represented, the simulated values were offset approximately 1.5 mg/l higher than observations. Saturated dissolved oxygen concentration, included in the figure, suggest that the observed data were well below saturation, while model results are much more consistent with saturation dissolved oxygen values on a daily basis. Hourly bias for the August period was 1.50 mg/l with a mean absolute error of 1.50 mg/l.

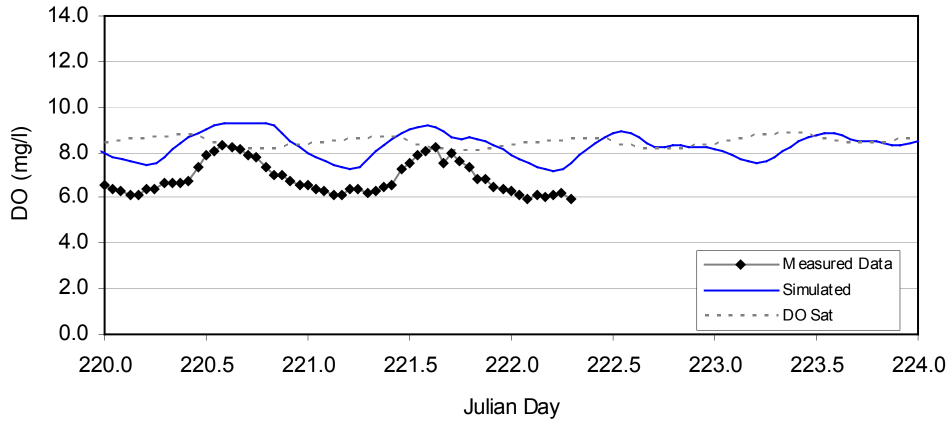


Figure 278. Klamath River above Scott River simulated versus measured dissolved oxygen, August 7-9, 2000

At Klamath River near Seiad Valley, during both June and August the diurnal phase and range were well represented; however, the simulated August values were offset by over 1.0 mg/l higher than observations. Saturated dissolved oxygen concentration, included in the figure, suggest that the observed data were well below saturation, while model results are much more consistent with saturation dissolved oxygen values on a daily basis. Hourly bias for the June period (calibration) was 0.19 mg/l with a mean absolute error of 0.27 mg/l. Hourly bias for the August period (validation) was 1.19 mg/l with a mean absolute error of 1.19 mg/l.

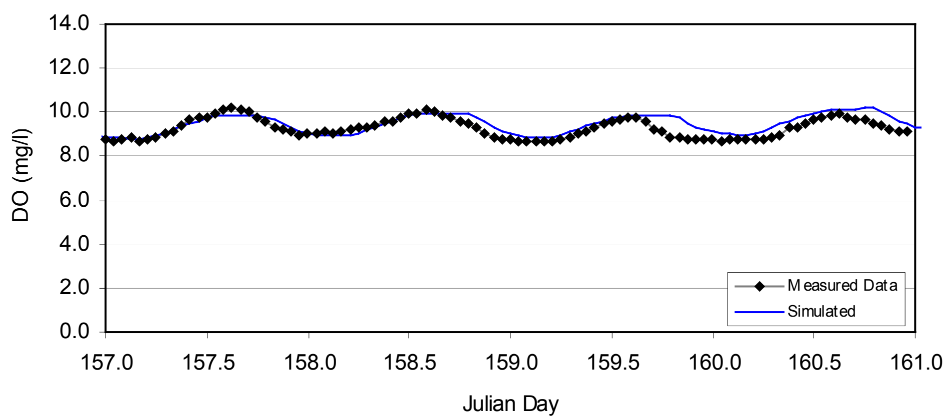


Figure 279. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, June 5-7, 2000

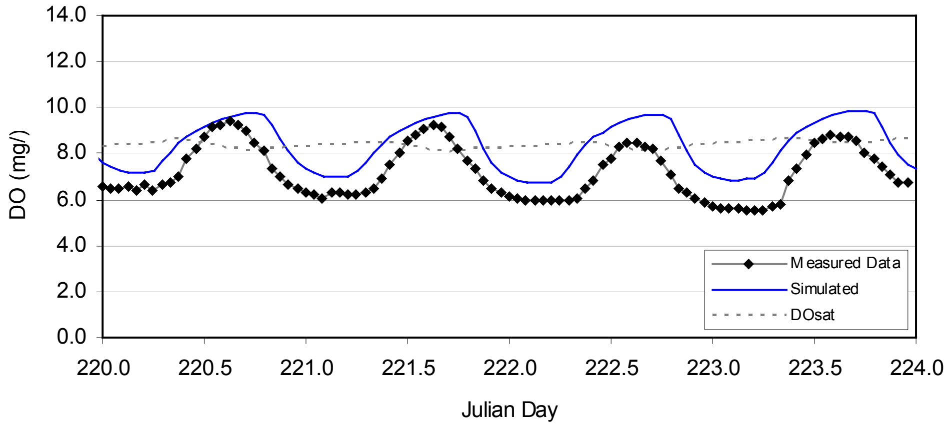


Figure 280. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, August 7-9, 2000

Table 90. Klamath River hourly and daily calibration and validation period statistics for dissolved oxygen

Calibration / Validation Statistics		**Hourly**		**Daily**	
	Unit	Calib.	Valid.	Calib.	Valid.
Klamath River ab Shasta River					
Mean Bias[a]	mg/l	0.29	0.48	0.35	0.49
Mean absolute error (MAE)	mg/l	0.46	0.56	0.35	0.49
Root mean squared error (RMSE)	mg/l	0.51	0.76	0.35	0.52
n	-	52	73	1	3
Klamath River ab Scott River					
Mean Bias[a]	mg/l	n/a	1.50	n/a	1.51
Mean absolute error (MAE)	mg/l	n/a	1.50	n/a	1.51
Root mean squared error (RMSE)	mg/l	n/a	1.54	n/a	1.51
n	-	n/a	56	n/a	2
Klamath River near Seiad Valley					
Mean Bias[a]	mg/l	0.19	1.19	0.19	1.19
Mean absolute error (MAE)	mg/l	0.27	1.19	0.19	1.19
Root mean squared error (RMSE)	mg/l	0.34	1.29	0.26	1.21
n	-	96	96	4	4

[a] Mean bias = simulated – measured

3.9.5.3 Nutrients

Nutrient concentrations were not formally calibration in the Iron Gate to Turwar reach. That is, values for nutrient interactions (e.g. stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 281 through Figure 298. Simulated concentrations for ammonia, nitrate, and orthophosphate were consistent with field observations. There is some scatter in the observed data that is not replicated within the model.

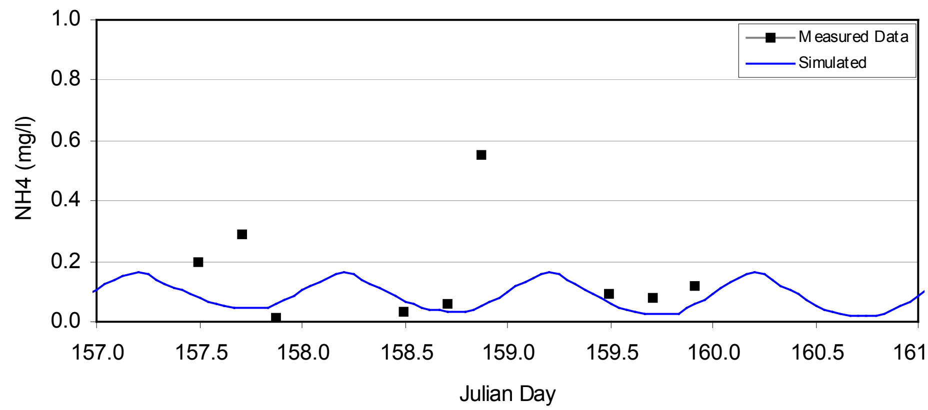


Figure 281. Klamath River above Shasta River simulated versus measured ammonia, June 5-7, 2000

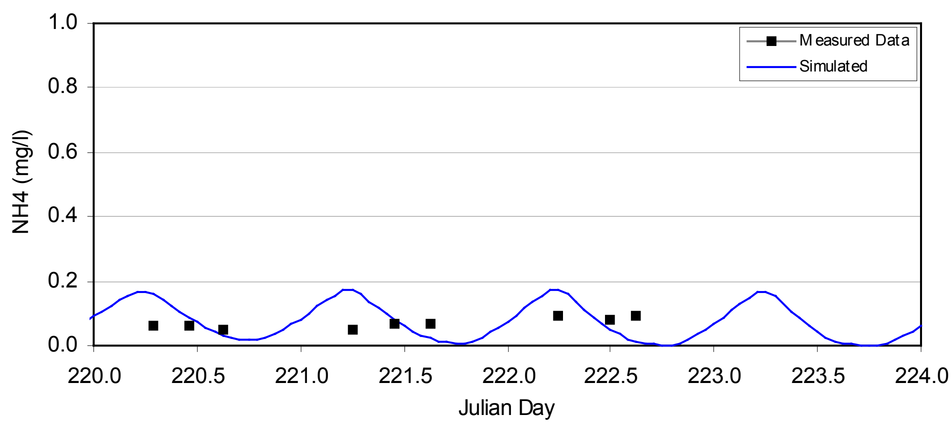


Figure 282. Klamath River above Shasta River simulated versus measured ammonia, August 7-9, 2000

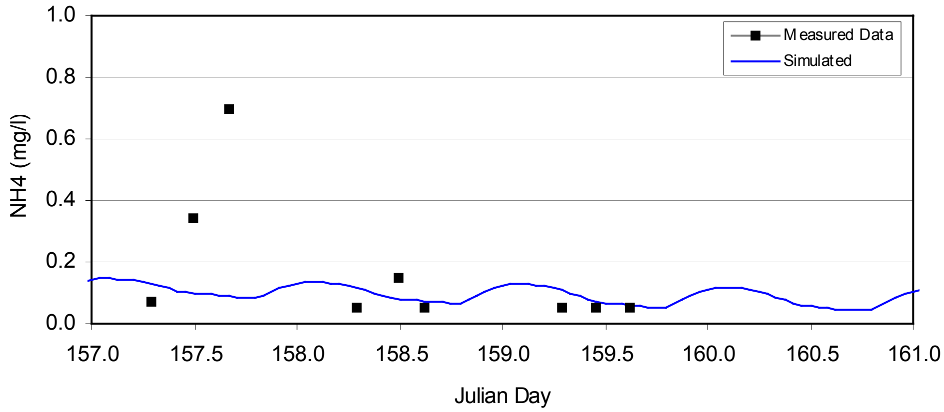


Figure 283. Klamath River above Scott River simulated versus measured ammonia, June 5-7, 2000

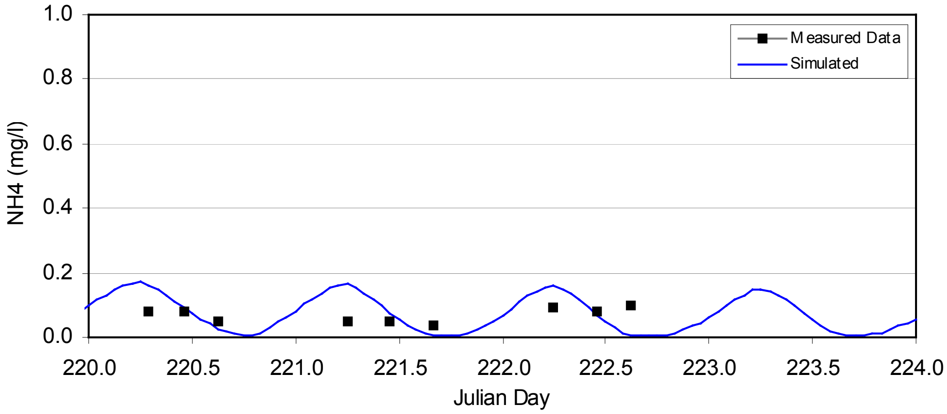


Figure 284. Klamath River above Scott River simulated versus measured ammonia, August 7-9, 2000

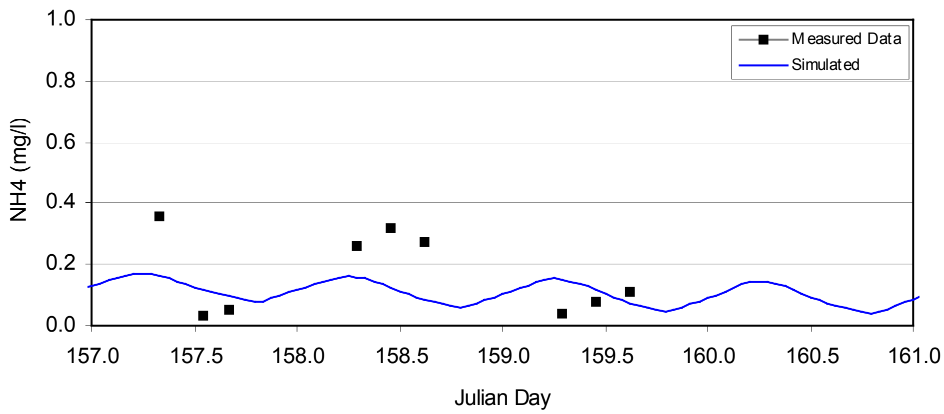


Figure 285. Klamath River near Seiad Valley simulated versus measured ammonia, June 5-7, 2000

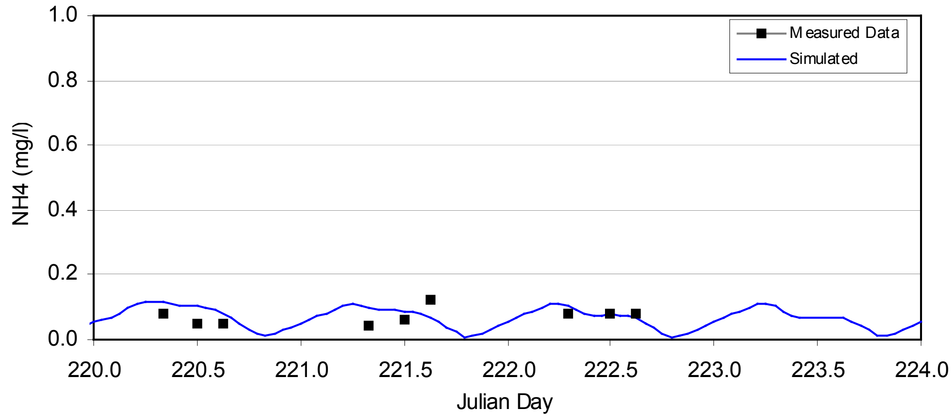


Figure 286. Klamath River near Seiad Valley River simulated versus measured ammonia, August 7-9, 2000

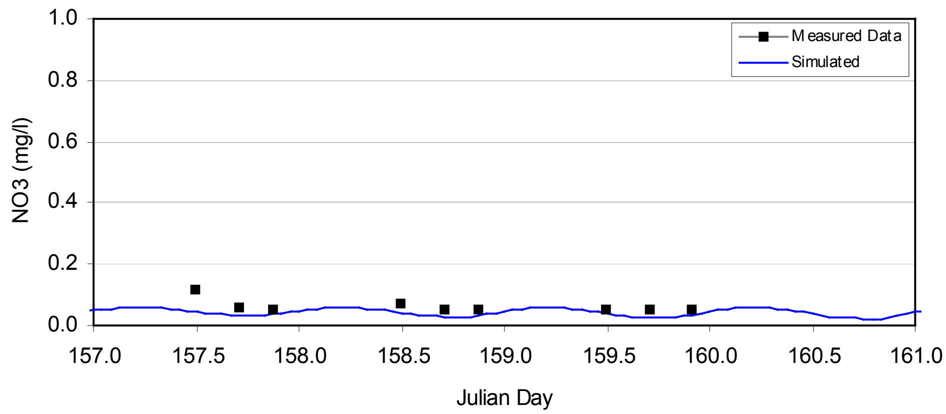


Figure 287. Klamath River above Shasta River simulated versus measured nitrate, June 5-7, 2000

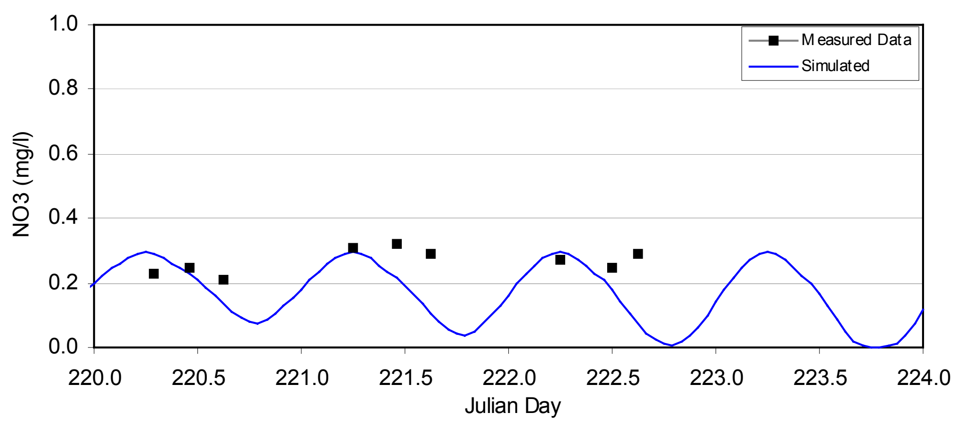


Figure 288. Klamath River above Shasta River simulated versus measured nitrate, August 7-9, 2000

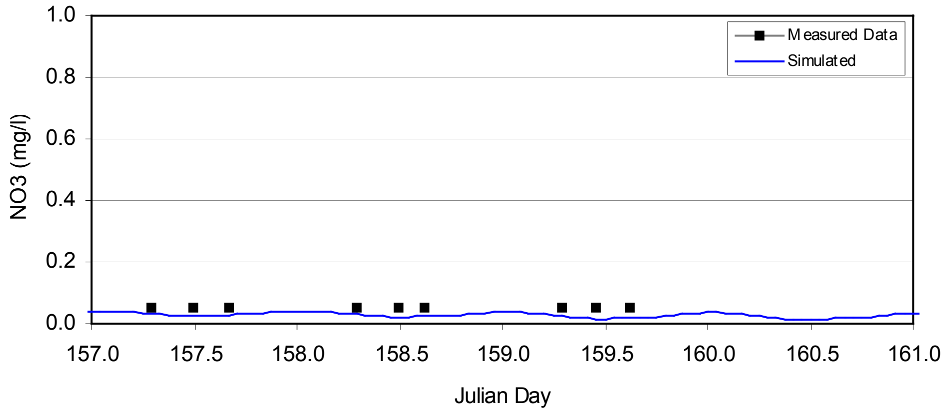


Figure 289. Klamath River above Scott River simulated versus measured nitrate, June 5-7, 2000

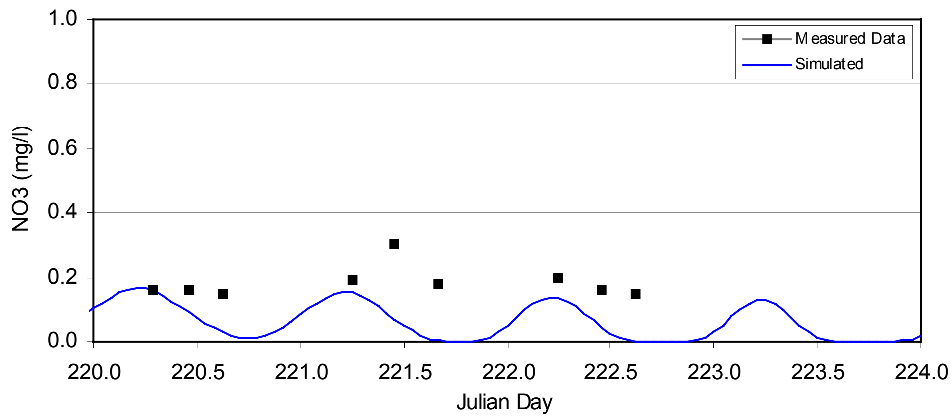


Figure 290. Klamath River above Scott River simulated versus measured nitrate, August 7-9, 2000

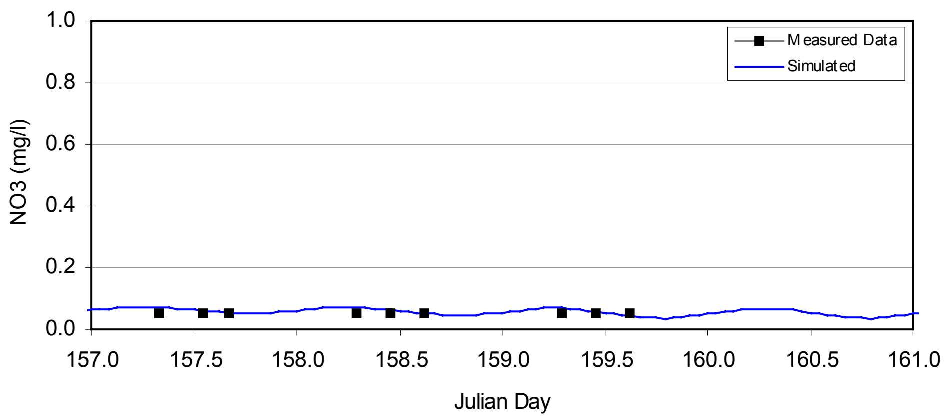


Figure 291. Klamath River near Seiad Valley simulated versus measured nitrate, June 5-7, 2000

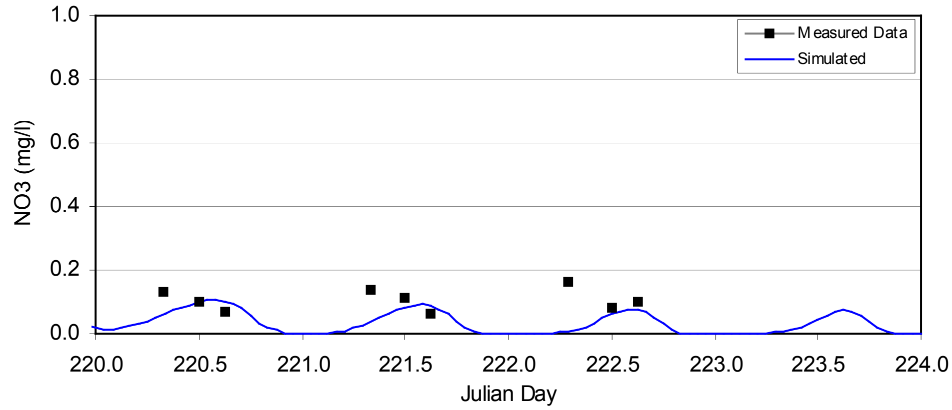


Figure 292. Klamath River near Seiad Valley simulated versus measured nitrate, August 7-9, 2000

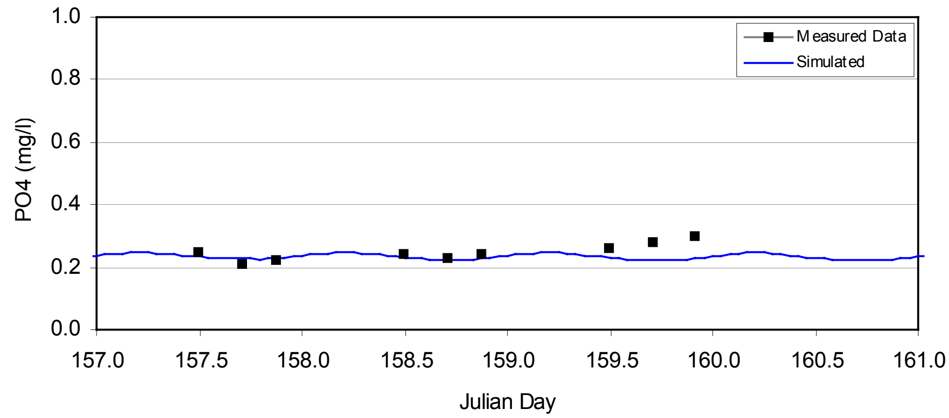


Figure 293. Klamath River above Shasta River simulated versus measured orthophosphate, June 5-7, 2000

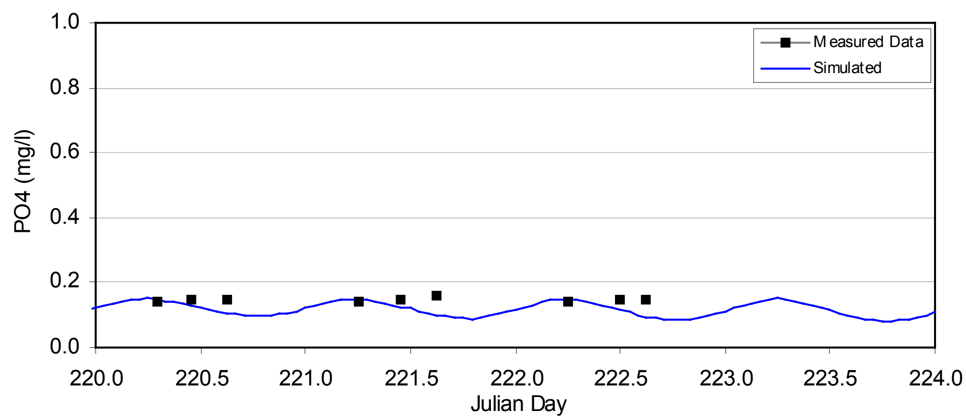


Figure 294. Klamath River above Shasta River simulated versus measured orthophosphate, August 7-9, 2000

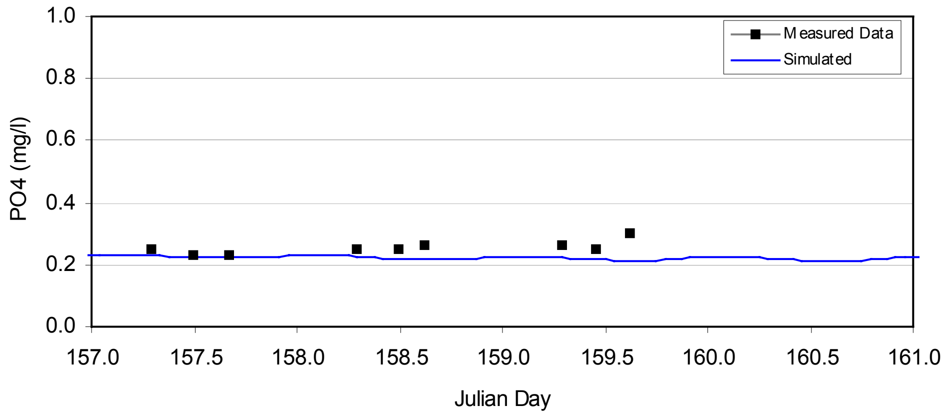


Figure 295. Klamath River above Scott River simulated versus measured orthophosphate, June 5-7, 2000

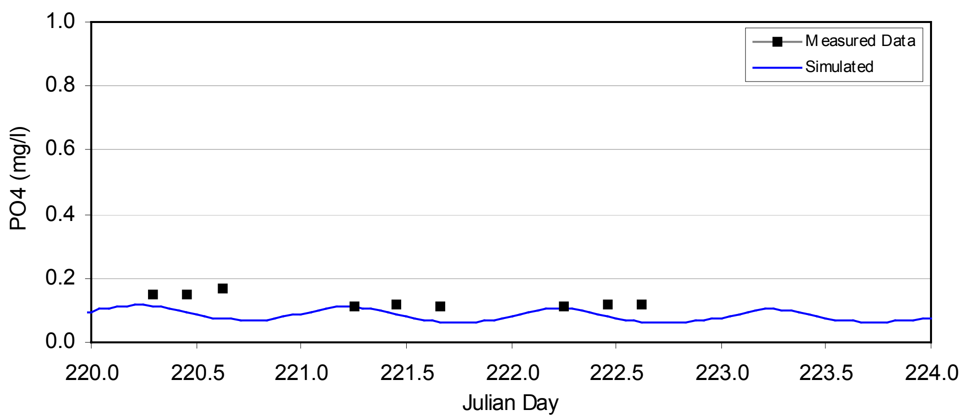


Figure 296. Klamath River above Scott River simulated versus measured orthophosphate, August 7-9, 2000

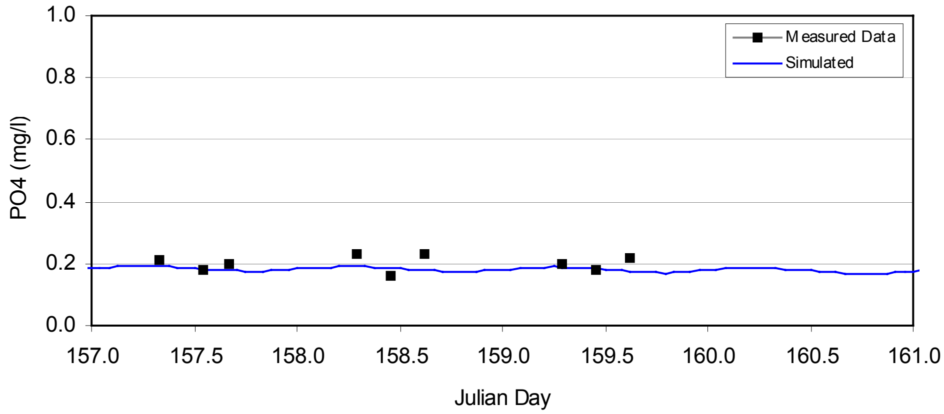


Figure 297. Klamath River near Seiad Valley simulated versus measured orthophosphate, June 5-7, 2000

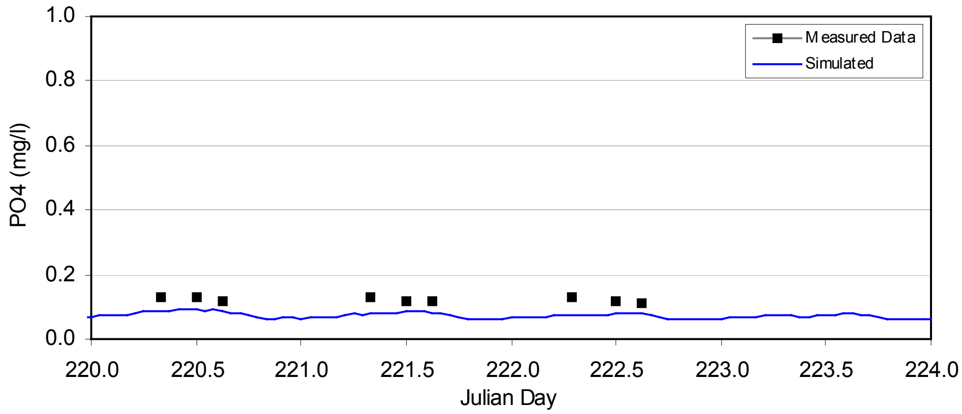


Figure 298. Klamath River near Seiad Valley simulated versus measured orthophosphate, August 7-9, 2000

3.9.6 Summary of Parameters

Table 91. RMA-2 and RMA-11 Model rates, coefficients and constants for the Iron Gate Dam to Turwar

Variable Name	Description, units	Value
	Time step, hr	1.0
	Space step, m	75 (cal)
		150 (application)
	Manning roughness coefficient	0.04
	Turbulence factor, Pascal-sec	100
	Longitudinal diffusion scale factor	0.10
	Slope Factor	0.80
ELEV	Elevation of site, m	520.00
LAT	Latitude of site, degrees	41.5
LONG	Longitude of site, degrees	122.45
EVAPA	Evaporative heat flux coefficient a, m hr^{-1} mb^{-1}	0.000015
EVAPB	Evaporative heat flux coefficient b, m hr^{-1} mb^{-1} $(m/h)^{-1}$	0.000010
EXTINC	Light Extinction coefficient, used when algae is not simulated, 1/m	0.25
ALP0	Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A	67
ALP1	Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A	0.072
ALP2	Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A	0.010
LAMB1	Linear algal self-shading coefficient, phytoplankton, 1/m	n/a
LAMB2	Non-linear algal self shading coefficient, phytoplankton, 1/m	n/a
MUMAX	Maximum specific growth rate, phytoplankton, 1/d	0.01
RESP	Local respiration rate of algae, phytoplankton, 1/d	0.05
SIG1	Settling rate of algae, phytoplankton, 1/d	0.0
KLIGHT	Half saturation coefficient for light, phytoplankton, KJ m^{-2} s^{-1}	0.01
KNITR	Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l	0.01
KPHOS	Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l	0.001
PREFN	Preference factor for NH3-N, phytoplankton	0.6
ABLP0	Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A	50
ABLP1	Fraction of algal biomass that is nitrogen, bed algae, mg/l	0.07
ABLP2	Fraction of algal biomass that is phosphorus, bed algae, mg/l	0.01
LAMB1	Linear algal self shading coefficient, bed algae, 1/m	n/a
LAMB2	Non-linear self shading coefficient, bed algae, 1/m	n/a
MUMAX	Maximum specific growth rate, bed algae, 1/d	1.5
RESP	Local respiration rate of algae, bed algae, 1/d	0.60
MORT	Mortality, bed algae, 1/d	0.10
KBNITR	Half-saturation coefficient for nitrogen, bed algae, mg/l	0.01
KBPHOS	Half-saturation coefficient for phosphorus, bed algae, mg/l	0.002
KBLIGHT	Half-saturation coefficient for light, bed algae, KJ m^{-2} s^{-1}	0.01
PBREFN	Preference factor for NH3-N, bed algae	0.75
BET1	Rate constant: biological oxidation NH3-N, 1/d	0.3
BET2	Rate constant: biological oxidation NO2-N, 1/d	0.5
BET3	Rate constant: hydrolysis Org N to NH3-N, 1/d	0.3
BET4	Rate constant: transformation Org P to P-D, 1/d	0.3
KNINH	First order nitrification inhibition coefficient, mg^{-1}	n/a
ALP3	Rate O_2 production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A	1.6
ALP4	Rate O_2 uptake per unit of algae respired, phytoplankton, mg-O/mg-A	1.6
ABLP3	Rate O_2 production per unit of algal photosynthesis, bed algae, mg-O/mg-A	1.6
ABLP4	Rate O_2 uptake per unit of algae respired, bed algae, mg-O/mg-A	1.6
ALP5	Rate O_2 uptake per unit NH3-N oxidation, mg-O/mg-N	3.43
ALP6	Rate O_2 uptake per unit NO2-N oxidation, mg-O/mg-N	1.14
K1	Deoxygenation rate constant: BOD, 1/d	0.3
-	Minimum reaeration rate constant (Churchill formula applied), 1/d	3.0
SIG6	BOD settling rate constant, 1/d	0.0

n/a – not applicable

3.10 Model Sensitivity

A sensitivity analysis is the test of a model in which the value of a single variable or parameter is changed (while the others remain constant) and the impact of this change on the independent variable is observed. Such analyses can be used to identify the characteristics of importance in a system. Uses of sensitivity analysis include:

- serving as an aid to confirming that the model is consistent with theory
- indicating the effects of errors in each of the variables and parameters, on the dependent variables
- identifying sensitive parameters or variables that must be reliably estimated
- indicating the relationship between control variables and decision variables to help ensure that a change in control variable can have a desirable effect on the decision variables, and
- identifying regions of "design invariance" where desirable levels of the decision variables are insensitive to possible errors of estimation in the model variables and parameters.

Other methods of quantifying uncertainty include first order analysis, Monte Carlo simulations and Kaman filtering, and are based on aggregate error terms and determine the total estimation (or prediction) error in a particular variable (Reckhow and Chapra, 1983). These multivariate methods are beyond the scope of this project.

Selected model parameters in both the RMA and CE-QUAL-W2 models were examined to determine relative sensitivity. There were too many variables to explore, and because many were not altered from default values, only those that were explored during calibration were examined. The input data sets, field observations or estimated values for flow and water quality boundary conditions and meteorological parameters, were not altered.

This qualitative assessment determined the general sensitivity of a particular parameter, (e.g., low, moderate, or high sensitivity, or insensitive), provided insight on model performance (e.g., was model consistent with theory), and to indicate the effects of modifying said parameters on the dependent variables. Many of the changes were carried out over modest ranges in parameter value, i.e., testing the model over extreme ranges for each parameter was not considered. Findings for the RMA models (RMA-2 and RMA-11) and CE-QUAL-W2 are outlined below. Sensitivity identified herein for the Klamath River system may not represent other responses encountered in other systems, i.e., not all of these analysis may be transferable to other river basins.

3.10.1 RMA parameters studied for sensitivity

Sensitivity was completed for the RMA-2 and RMA-11 models for selected parameters. In most cases literature values or default values for model constants and coefficients were applied. Through calibration and application of the models it was determined that certain parameters were sensitive. These parameters were explored further to determine the general sensitivity to perturbation.

Conditions are highly variable throughout the system and sensitivity varied by season (cooler periods or periods when there was more or less water in the system) and location. Also, longer river reaches (e.g., Klamath River from Iron Gate Dam to Turwar), where impacts could occur over long distance and long travel times may show more sensitivity than short reaches where water quality changes little from upstream to downstream (e.g. Link River). The parameters discussed herein include:

- n - Manning roughness coefficient
- SF - Slope Factor fraction to reduce bed slope of river to approximate water surface slope in solution of flow equations
- EVAPA, EVAPB – Evaporative heat flux coefficients
- IREAER* – (Minimum reaeration rate)
- MUMAX – nominal bed algae growth
- RESP – bed algae respiration rate
- EXTINC – non-algal light extinction
- EA – atmospheric pressure
- PBREFN –algal preference for ammonia

For a full description of model parameters the reader is referred to the user's manual for RMA-2 and RMA-11.

Table 92 outlines the general findings of the sensitivity testing. Generally temperature was sensitive to bed roughness and slope factor – both parameters that directly impact travel time (akin to residence time) through the river reaches. Likewise, temperature was highly sensitive to the evaporative heat flux parameters.

Dissolved oxygen was sensitive to the minimum reaeration value specified for the river reaches (thus the ultimate value was set relatively low), and highly sensitive to algal growth and respiration parameters.

Nutrients were generally moderately sensitive or experienced low sensitivity to algal growth parameters; however, the ammonia preference factor suggested sensitivity for ammonia and nitrate. The nutrients were moderately sensitive to extinction in certain river reaches – under high extinction rates benthic algal growth was light limited and nutrient uptake suppressed. Algae was very sensitive to growth and respiration rates as well as light extinction.

In addition temperature was examined under different geometric representations of the system. Specifically, temperature output from several reaches was examined while varying river width as well as side slope. The impacts were generally modest, with the exception that marked changes in river width can dramatically impact travel time and thus water temperature. Finally, the river models were run with node-to-node distances of 150 meters and 75 meters, with minimal differences in results. The exception being the hydrodynamic model required the 75 meter grid and fifteen minute time steps to retain stability under the highly variable flow regime of the peaking reach.

Table 92. RMA-11 water quality constituent sensitivity to different modeling parameters

Parameter	Sensitivity to Parameter					
	Temperature	DO	PO4	NH4	NO3	Algae
Manning n	H	-	-	-	-	-
SF	H	-	-	-	-	-
EVAPA	H	L	-	-	-	-
EVAPB	H	L	-	-	-	-
IREAER*	N	H	N	L	M	-
MUMAX	N	H	N	L	M	H
RESP	N	H	N	-	-	H
PBREFN	N	-	N	M	M	L
EXTINC	N	M	-	L	L	H
EA	N	L	-	-	-	-
Bathymetry	M	L	-	-	-	-

N – not sensitive

L – low sensitivity

M – moderate sensitive

H – high sensitivity

If there is no letter in the space, the constituent was not tested for sensitivity to the parameter.

3.10.2 CE-QUAL-W2 Parameters studied for sensitivity

Sensitivity was completed for the CE-QUAL-W2 models for selected parameters using the several reservoir applications. In most cases literature values or default values for model constants and coefficients were applied. Through calibration and application of the model to the various reservoirs it was determined that certain parameters were sensitive. These parameters were explored further to determine the general sensitivity to perturbation.

Conditions are highly variable throughout the system reservoirs and sensitivity varied by season (cooler periods or periods when there was more or less water in the system) and location. Response to varying model parameters varied among the shallow Lake Ewauna-Keno Reservoir, the short residence time JC Boyle reservoir, and the deep, longer residence time reservoirs of Copco and Iron Gate. The parameters discussed herein include:

- AFW, BFW, and CFW - Evaporative heat flux coefficients
- AG - Algal Growth Rate:
- AR - Algal Respiration Rate: AR
- AM - Algal Mortality Rate:
- ASAT - Algal light saturation intensity at the maximum photosynthetic rate.

- SOD- Sediment Oxygen Demand
- CBHE - Bed heat conduction coefficient
- TSED - Specified bed temperature: TSED
- EXSS Light Extinction due to inorganic suspended solids:
- EXOM - Light extinction due to organic matter
- EXH20 - Light extinction due to water
- EXA - Light extinction due to algae
- BETA - Solar radiation absorption fraction: the BETA parameter is the fraction of incident solar radiation absorbed at the water surface
- LDOMDK - Labile organic matter decay rate
- POMS - Particulate organic matter settling rate
- NH4DK - Ammonia decay rate
- NO3DK - Nitrate decay rate
- O2LIM - Aerobic/anaerobic oxygen Limit: user defined oxygen limit refers to the concentration below which anaerobic processes begin to be simulated.

Table 93 outlines the general findings of the sensitivity testing. Generally temperature was sensitive to the evaporative heat flux parameters. In the deeper reservoirs the impacts were observed over longer periods than in the shallow reservoirs. IN the deeper reservoirs with longer residence time, the bed heat exchange coefficient was modestly sensitive in bottom water temperature.

Dissolved oxygen was sensitive to algal growth, respiration, and mortality parameters, and parameters associated with algal growth such as the various light extinction parameters. The organic matter decay rates also impacted dissolved oxygen concentrations to some degree: the impact was larger in the long residence time reservoirs. Dissolved oxygen sensitivity to ammonia decay rate was low.

Nutrients were generally moderately sensitive or experienced low sensitivity to algal growth parameters (and associated parameters such as extinction); however, nitrate was notably more sensitive to these parameters than ammonia. Algae was very sensitive to growth and respiration rates as well as light extinction.

Two aspects of the reservoir geometric representation were explored: layer thickness and bathymetric representation. The layer thickness in Lake Ewauna-Keno Reservoir was set at 0.61 meters are per Wells (1996). The layer thickness in JC Boyle Reservoir was initially set at 0.61 meters; however simulation time exceeded 20 hours (1.2 GHz processor) due to the model frequently dropping and adding segments and layers in this small hydropower peaking reservoir.

The layer resolution was increased to 1.0 meters and the simulation time dropped to approximately 15 minutes, with no significant changes in model output. The 1.0 meter layer thickness was retained. Tests were completed in Iron Gate Reservoir at layer thicknesses of 5 meters, 2.5 meters, and 1 meter. Results between the 5 meter and 2.5 meter layer thickness cases varied considerably; however, the differences between the 2.5 meter and one meter layer thicknesses was insignificant. Iron Gate representation utilized 2.5 meter layer thickness to accommodate run time considerations (approximately 2 hours for a 1.2 GHz processor).

Finally, Lake Ewauna-Keno Reservoir was modeled under multiple bathymetric representations: the original work from Wells (1996), a fictitious bathymetry to determine if model results were sensitive to a different geometry, and utilizing a new bathymetric survey from 2003. The findings suggest that results are sensitive to bathymetry and that using the best available data is important in effective representation – the 2003 data is currently used in the model.

Table 93. CE-QUAL-W2 water quality constituent sensitivity to different modeling parameters

Parameter	Sensitivity to Parameter					
	Temperature	DO	PO4	NH4	NO3	Algae
AFW	M	-	-	-	-	-
BFW	M	-	-	-	-	-
CFW	L	-	-	-	-	-
AG	N	L	L	L	H	H
AR	N	M	L	L	M	H
AM	N	M	L	L	M	H
ASAT	-	-	-	-	-	-
SOD	N	M	M	N	N	L
CBHE	M	-	-	-	-	-
EXSS / EXOM	N	H	L	L	M	H
EXH2O	N	H	M	L	M	H
BETA	N	H	M	L	M	H
EXA	N	H	L	L	H	H
LDOMDK	N	M	L	L	L	N
POMS	N	L	L	L	L	N
NH4DK	N	L	N	L	L	N
NO3DK	N	N	N	N	M	N
O2LIM	N	N	M	N	L	N
Bathymetry	H	H	H	H	H	H

N – not sensitive
L – low sensitivity
M – moderate sensitive
H – high sensitivity

If there is no letter in the space, the constituent was not tested for sensitivity to the parameter.

The water quality model parameters most sensitive in the prediction of temperature and dissolved oxygen are similar for both RMA-11 and CE-QUAL-W2:

- Evaporative heat flux parameters for temperature

- Algal growth dynamics and light extinction for dissolved oxygen and algae.

It is useful to note that these are common calibration parameters in water quality modeling.

3.11 Summary – Model Calibration and Validation

All system components have been calibrated. There are a few notable reaches where additional information and model testing is recommended; however, the modeling framework is, by and large, complete. Although additional data needs and model testing has been identified, the framework and its individual components have been extremely effective at illustrating flow and water quality processes throughout the system. The exercise of system characterization, model implementation, sensitivity testing, and calibration have resulted in a dramatically improved understanding of Klamath River flow and water quality issues, as well as identifying need for additional data. Available data precluded formal calibration of the models during the winter months. Brief synopses of each reach, plus identified recommendations are outlined below.

3.11.1 Link River

This short river reach is fairly insensitive to model conditions, with the exception when Link Dam bypass flows are low and most of the water is passed through the East Side and West Side powerhouses. However, any variability imparted on Link Dam releases by conditions within Link River is quickly overwhelmed in the Lake Ewauna to Keno Dam reach. This reach has been calibrated.

Recommendations: Because Link Dam forms a critical boundary condition for all downstream reaches it is recommended that a formal monitoring program be considered to characterize water quality conditions and more completely characterize the short term variability at the head of Link River.

3.11.2 Lake Ewauna-Keno Dam

The Lake Ewauna-Keno Dam reach is a dynamic and complex reach to model for water quality. This reach is intensively developed for water resources and related activities. There are multiple diversions from the system for industrial and agricultural use, as well as their associated return flows. The Klamath River also is a receiving water for municipal discharge of treated wastewater. Land use practices, predominately agricultural, but also municipal and industrial activities, occur adjacent to the river throughout much of this reach. Finally, review of available literature and discussions with stakeholders suggest historical log rafting and timber industry practices have left considerable organic matter throughout the upper portion of this reach.

Other water resources development of importance include the impoundment of Upper Klamath Lake for diversion to the Reclamation project, as well as impoundment of the reach in question by Keno Dam. The operations of Link Dam, namely actively managing storage in Upper Klamath Lake for summer application within the Reclamation Project, has reduced the frequency, and to some degree the magnitude, of winter flows through the Lake Ewauna to Keno Dam reach. This coupled with impoundment at Keno Dam has created a slow moving waterway that allows primary production (as phytoplankton versus riverine forms of algae) to occur as well as favors deposition. Upstream inputs from hypereutrophic Upper Klamath Lake, as well as historical and continued inputs from municipal, industrial, agricultural, and non-point discharges lead to considerable oxygen demands within this reach.

Additional field work in 2003, as well as review of previous data collection efforts suggests that the advective nature of the reservoir – there is a notable current at mid-channel throughout the reach (on the order of 0.2-0.3 feet per second) – coupled with the daily weak stratification and wind dynamics creates a complex conditions within this reach that directly impact water quality. By and large, the Lake Ewauna-Keno Reach is very sensitive to influent conditions from Upper Klamath Lake for dissolved oxygen, nutrients, and algae. All downstream reaches are likewise impacted by outflow water quality conditions at Link Dam. (The exception is water temperature which is only moderately affected in downstream reaches because waters in Upper Klamath Lake are near equilibrium temperature.)

Given the level of complexity encountered within this reach, model application to this dynamic reach was by-and-large successful for temperature. For dissolved oxygen, nutrients, and algae, it was apparent that the resolution (i.e., monitoring frequency) of upstream boundary condition (actually conditions at Link Dam) governed processes within this reach. Sensitivity testing Link Dam as well as other boundary conditions, including sediment oxygen demand supported finding. As such, the model replicates seasonal dissolved oxygen response, but short term conditions are not always well represented. Model performance for nutrients varies dramatically between 2000 and 2001 applications. With the more complete data set of 2001, the model replicates observed conditions appreciably better than in 2000, when composite upstream boundary conditions were applied. The model has undergone a wide range of testing to assess variable conditions and response to modifying model parameters, and, given the level of available data can be considered preliminarily calibrated for dissolved oxygen and nutrients. Recommendations for additional studies are outlined below.

<u>Recommendations</u>: Several of the field studies completed in 2003 were not completed prior to the calibration of the model. These include sediment studies (SOD), and limited field studies. It is recommended that the results of these studies be reviewed and, as necessary, incorporated into the modeling effort. In addition, should a more refined calibration be required, additional field studies should be designed to further characterize conditions throughout the Lake Ewauna-Keno Reach. Field studies should include sampling of appropriate parameters to address nutrient conditions, biochemical oxygen demand, organic matter, algae, and pH, as well as temperature, dissolved oxygen, and other physical parameters. Such field studies should recognize the spatial and temporal scales of critical processes identified herein. If completed, results of these studies should be used to further refine the model application. The recommendation for the Link River reach – improving the information (boundary condition) at the Link Dam is imperative to this effort.

3.11.3 Keno Dam to JC Boyle

The Keno Dam to JC Boyle reach is fairly short with a transit time of a few hours. The models performed well in this steep river reach, replicating temperature and dissolved oxygen well, as well as nutrient concentrations.

Recommendations: Continue monitoring upstream and downstream water quality conditions as necessary.

3.11.4 JC Boyle Reservoir

JC Boyle Reservoir is a small reservoir and experiences residence times of less than a day to about 3 days. As such it is heavily influenced by inflow water quantity and quality. The system was modeled with CE-QUAL-W2 under several levels of detail and has been tested for a wide range of conditions using calendar year 2000 data. (The system was also modeled with WQRRS prior to applying CE-QUAL-W2.) The model performs well and is calibrated, but results are sensitive to influent conditions, which are ultimately driven by the boundary condition at Link Dam.

Recommendations: Continue reservoir monitoring.

3.11.5 Bypass / Peaking Reach

The bypass reach experiences a highly dynamic flow regime and variable water quality due to peaking operations and the influence of a large springs complex. Modeling this reach required representing the physical features of this steep reach as well as the short duration hydropower operations. The models performed well for all parameters. This reach is calibrated.

Recommendations: Exploratory field work was carried out in 2003 to assess the benthic algae community. If further model refinement is necessary it is recommended that a more comprehensive survey of benthic algae and the role it may play in dissolved oxygen concentration dynamics as well as nutrient conditions within the reach should be explored.

3.11.6 Copco Reservoir

Copco Reservoir receives a peaking flow regime from upstream Klamath River inflows as well as providing peaking flows at Copco Dam for a significant portion of the year. The reservoir was modeled for calendar year 2000 and performance was generally good for both temperature and dissolved oxygen. The model is considered calibrated; however it is sensitive to the upstream boundary condition – inflow from the Klamath River – which is in turn somewhat sensitive to the conditions at Link Dam.

Recommendations: Data from the 2003 field season included more detailed vertical profiles of the reservoir. This data collection and processing was not completed in time to be included herein. If additional model refinement is required, it is recommended that these data be reviewed and, as necessary, used to refine model calibration. Update SOD as information becomes available.

3.11.7 Iron Gate Reservoir

Iron Gate Reservoir receives a peaking flow regime from upstream Copco Reservoir and re-regulated the river to provide a steady flow regime below Iron Gate Dam for a significant portion of the year. The reservoir was modeled for calendar year 2000 and performance was generally good for both temperature and dissolved oxygen. The model is considered calibrated; however it is sensitive to the upstream boundary condition – inflow from Copco Reservoir – which is in turn somewhat sensitive to the conditions at Link Dam.

Recommendations: Data from the 2003 field season included more detailed vertical profiles of the reservoir. This data collection and processing was not completed in time to be included herein. If additional model refinement is required, it is recommended that these data be reviewed and, as necessary, used to refine model calibration. Update SOD as information becomes available.

3.11.8 Iron Gate Dam to Turwar

The Iron Gate Dam to Turwar reach is the longest single reach in the modeling framework. Multiple tributaries and variable meteorological conditions add complexity to this generally steep reach. Sufficient information was available to calibrate the models throughout the reach for water temperature, dissolved oxygen, and inorganic nutrients.

Recommendations: During 2003 benthic algae surveys were completed providing information on the distribution and approximate biomass at multiple locations within this reach. This information was important in improving the understanding of algal dynamics. Expansion of this information, coupled with the appropriate water quality conditions, could further improve the application of the model.

3.11.9 Additional Recommendations

General recommendations, some of which are addressed above, include the maintenance of the long term reservoir monitoring programs (profiles), thermistor deployment throughout the project area, maintenance of existing meteorological stations at main stem reservoirs, as well as ongoing reporting of flow, storage, and operations at project facilities. Long-term studies to improve understanding of the system are encouraged on an as needed basis.

4 Model Application

4.1 Introduction

Upon completion of model calibration, the models were applied to four system-wide scenarios: existing conditions, steady-flow, and two without project scenarios (I and II). These scenarios were intended to bracket the range of potential physical and operational conditions within the project area. Further, these analyses were completed for the years 2000 and 2001.

For each scenario the models were applied for a full calendar year, which allowed the larger reservoirs to attain stratified conditions from an initial isothermal state, as well as exhibit fall turnover. System conditions from Link Dam to the Klamath River at Turwar were simulated – a distance of approximately 250 miles. The existing condition scenario represents the baseline status and is used for comparing conditions without peaking hydropower operations (steady flow scenario) and a river system without hydropower facilities (without project scenario). The without project I scenario simply assumes conditions in the absence of hydropower facilities. Because Project reservoir storage is assumed absent, this scenario results in significant flow fluctuations (particularly in the Keno reach) from US Bureau of Reclamation irrigation project operations. The without project II scenario attempted to smooth river flows to produce a hydrograph that did not exhibit these fluctuations due to US Bureau of Reclamation project operations.

These analyses are intended to examine large scale system response over periods when critical water quality conditions tend to occur (spring – fall) in the Klamath River basin. More detailed analysis focusing on critical reaches, specific operations, and limited time periods are addressed separately. Basic assumptions for each scenario are discussed below and presented in Table 94.

Table 94. Basic scenario assumptions

Scenario	Geometry / Bathymetry	Meteorology	Hydrology for Boundary Conditions	Water Quality for Boundary Conditions	Operations
Existing Conditions (EC)	Base	Base	Base	Base	Base
Steady Flow (SF)	Base	Base	Base	Base	Modified
Without Project I (WOP)	Modified	Base	Base	Base	No Operations
Without Project II (WOPII)	Modified	Base	Modified[a]	Base	No Operations

Base – refers to baseline conditions or those applied to the existing condition scenario

Modified – identifies if any basic data information was modified for the identified scenario

Modified[a] – modified from Iron Gate Dam to Keno Dam

The basic output extracted from each scenario was hourly time series data at multiple locations for temperature and dissolved oxygen, although all other parameters are available at the hourly output frequency. The output locations from the models (nodes or segments) and the corresponding physical locations are presented in Table 97. Processed output for all three scenarios included daily mean data, daily maximum data, daily minimum data, monthly mean data, and 7 day maximum average data.

4.2 Model Coordination

The models are applied in series, starting with upper most reach – Link River – and passing the output from one reach to the next. The flow conditions are generally not passed from reach to reach. Exceptions include reaches where there is no upstream flow record (i.e., measured flow) above Copco Reservoir, wherein the hydrodynamic model is used to route peaking flows on an hourly basis down to Copco Reservoir – these flows are then used in the CE-QUAL-W2 simulation of Copco Reservoir. For certain scenarios (e.g., without project), flows are passed from one modeled reach to the next because flow conditions cannot be explicitly specified.

Water quality is passed downstream between all simulated river reaches. The river models (RMA) and the reservoir model (CE-QUAL-W2) do not represent all water quality parameters in the same fashion. The river models represent organic matter as organic nitrogen and organic phosphorous, while the reservoir model represents organic matter as refractory and labile dissolved and particulate organic matter. A stoichiometric equivalent is used to convert the fraction of organic matter or nutrients when passing information from one model to the next. Specifically, organic nitrogen from RMA-11 is converted to dissolved labile organic matter for input to CE-QUAL-W2 (the nitrogen fraction of organic matter is assumed to be 0.08 (USACOE-HEC, 1986)). No attempt is made to partition the organic matter among the refractory and labile or the dissolved and particulate compartments due to a lack of sufficient field data. When passing information from CE-QUAL-W2 to RMA-11, the derived constituent for total organic nitrogen and total organic phosphorous are employed; however, the algal component of organic nitrogen and phosphorous are removed from this value so as not to double count the algal fraction (the nitrogen and phosphorous fractions of algae is assumed to be 0.08 and 0.005, respectively (Cole and Wells, 2002)).

4.3 Existing Conditions Scenario (EC)

The existing conditions scenario models the actual conditions in the Klamath River during 2000 and 2001. All projects were assumed to be in place and operating under historical 2000 and 2001 conditions. All input information are those recorded in, calculated from records, or estimated for 2000 and 2001 conditions.

The models used in this scenario were RMA2 / RMA11 for the river reaches and CEQUALW2 for the reservoirs.

4.3.1 Geometry

The geometry (or bathymetry) for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

4.3.2 Meteorology

The meteorology for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

4.3.3 Hydrology

The hydrology for boundary conditions for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

4.3.4 Water Quality

The water quality data for boundary conditions for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

4.3.5 Operations

The project operations for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

4.4 Steady Flow Scenario (SF)

The steady flow scenario models alternative flows to those recorded in 2000 and 2001. All projects were assumed to be in place and but were not assumed to be operating under historical 2000 and 2001 conditions.

The models used in this scenario were RMA2 / RMA11 for the river reaches and CEQUALW2 for the reservoirs.

4.4.1 Geometry

The geometry (or bathymetry) for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

4.4.2 Meteorology

The meteorology for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

4.4.3 Hydrology

The hydrology for boundary conditions for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

4.4.4 Water Quality

The water quality data for boundary conditions for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

4.4.5 Operations

The project operations for each reach of the steady flow scenario were not the same as those described in the basic modeling framework. In the steady flow scenario, the reservoirs were operated with approximately no change in water surface elevation for the entire year. Calculations started by assuming the dam releases from Iron Gate Reservoir were the same as those used in the existing conditions scenario, calculating overall smoothed existing conditions accretions/depletions for each reach and then moving upstream using a water balance method between each reservoir up to Link Dam. The smoothing method used for the accretion/depletion calculation was to take the average flow of the flow for the day of interest and the following six days. In Table 95 the calculations for the un-smoothed accretion/depletion are presented. In Table 96 the steady flow scenario dam release calculations are presented. Spring flows in the JC Boyle bypass reach were assumed to be a constant 225 cubic feet per second for these calculations. Fish releases from Iron Gate and JC Boyle reservoirs were assumed to be 50 and 100 cfs respectively. The East Side and West Side turbine flows were calculated as a percentage of daily flow from Upper Klamath Lake. The percentage of daily flow was determined per day from existing conditions flows.

As these calculations assumed no daily change in storage in each of the reservoirs, the starting and ending elevations of the reservoirs were those recorded in each reservoir on January 1st, 2000 and 2001.

Below Iron Gate Reservoir, all flows were assumed to be the same as those used in the existing conditions scenario.

Table 95. Calculation of un-smoothed accretion/depletions by reach

Accretion Depletion	Calculation
Copco to Iron Gate	Iron Gate Out $_{PacifiCorp}$ – Copco Out $_{PacifiCorp}$ + Storage Change in Iron Gate
JC Boyle to Copco	Copco Out $_{PacifiCorp}$ - USGS 11510700 + Storage Change in Copco
Copco	½ JC Boyle to Copco A/D
Fullflow	½ JC Boyle to Copco A/D
JC Boyle	Assumed to be zero
Keno to JC Boyle	JC Boyle Out $_{PacifiCorp}$ - USGS 11509500 + Storage Change in JC Boyle
Lake Ewauna to Keno	USGS 11509500 – (USGS 11507500 + West Turbine $_{PacifiCorp}$ + Net Lost River $_{USBR}$ + Klamath Straits Drain $_{USBR}$ – North Canal $_{USBR}$ – ADY Canal $_{USBR}$) + Storage Change in Keno

Table 96. Calculation of steady flow dam releases by reach

Release	Calculation
Iron Gate Dam	Actual 2000 or 2001 release
Copco Dam	Irongate Dam release – “A/D Copco to Irongate”
JC Boyle Dam	Copco Dam release – “A/D JC Boyle to Copco” – Fullflow Spring flow
Keno Dam	JC Boyle Dam release – “A/D JC Boyle” – “A/D Keno to JC Boyle”
Link Dam	Keno Dam releases – “A/D Lake Ewauna to Keno” – East Side – West Side Turbines.

4.5 Without Project Scenario (WOP)

The without project scenario models the Klamath River as if there are projects in the Klamath River downstream of Link Dam.

The models used in this scenario were RMA2 / RMA11.

4.5.1 Geometry

The geometry for the river reaches of the without project scenario followed the basic modeling framework outlined in the implementation documentation. The reservoirs were replaced with river reaches, with the geometry of the reaches estimated from the deepest points in the reservoir bathymetries. River widths within the reservoirs were a linear interpolation between the river width in the element immediately preceding the reservoir and the river width in the element immediately following the reservoir. This process is illustrated in Figure 299, Figure 300, Figure 301 and . All other river widths were the same as those used in the existing conditions scenario. Figure 303 illustrates the method used to create element orientations for the reservoir sections of the without project grid. Other element information, such as element length, was not determined in this way as a uniform grid was used, creating elements of the same length for the entire river. Through this process the existing condition river miles were preserved, except for in Copco Reservoir, where the river was lengthened to capture the sinuosity of the old river bed under the reservoir.

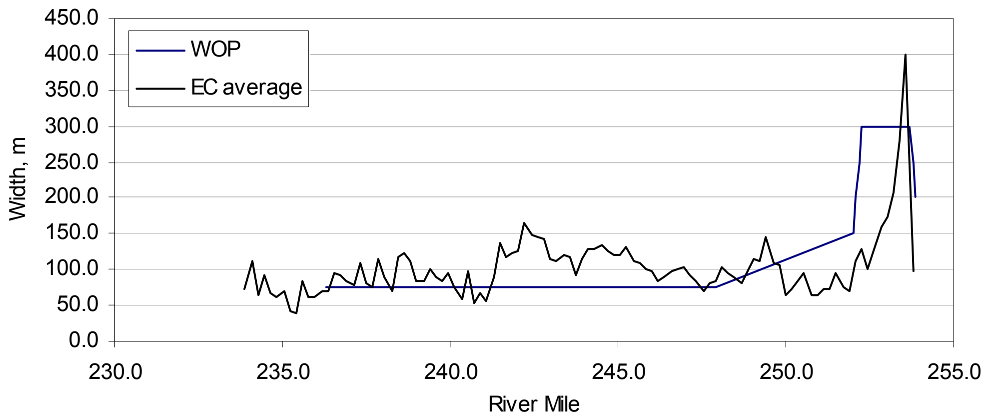


Figure 299. WOP scenario river widths for the Lake Ewauna to Keno Dam river reach

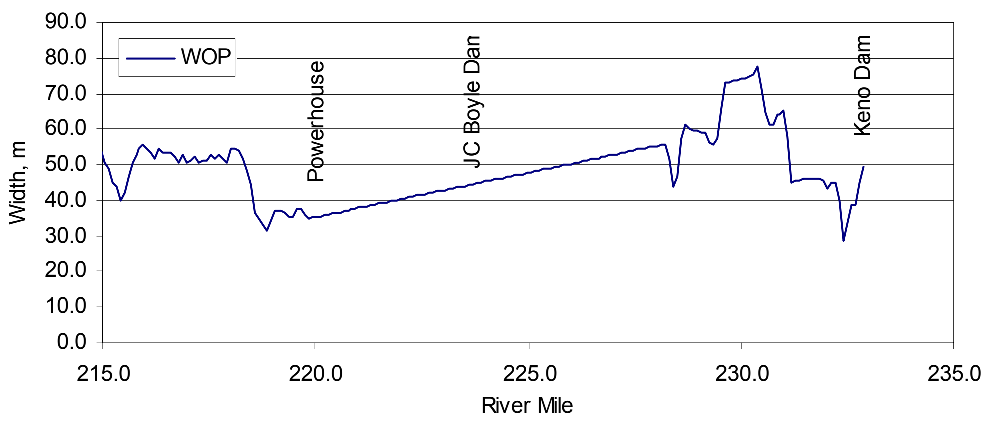


Figure 300. WOP river widths for JC Boyle Reservoir and surrounding river reaches

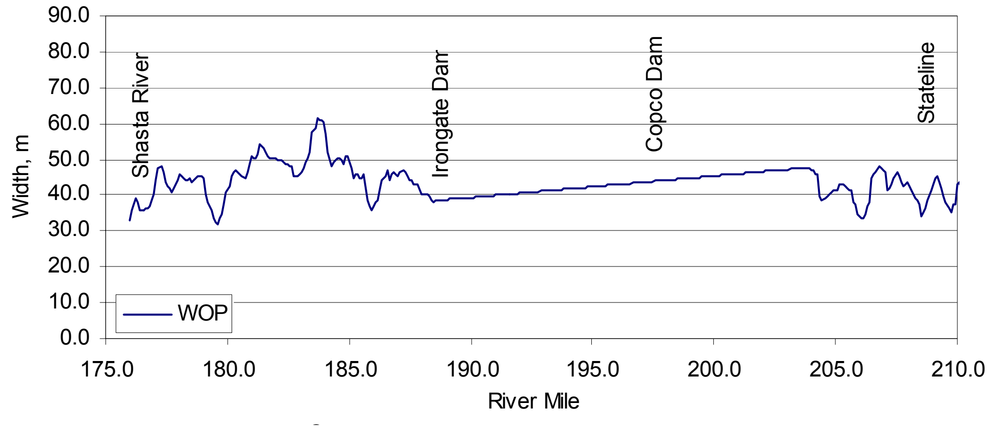


Figure 301. WOP river widths for Copco Reservoir, Iron Gate Reservoir and surrounding river reaches

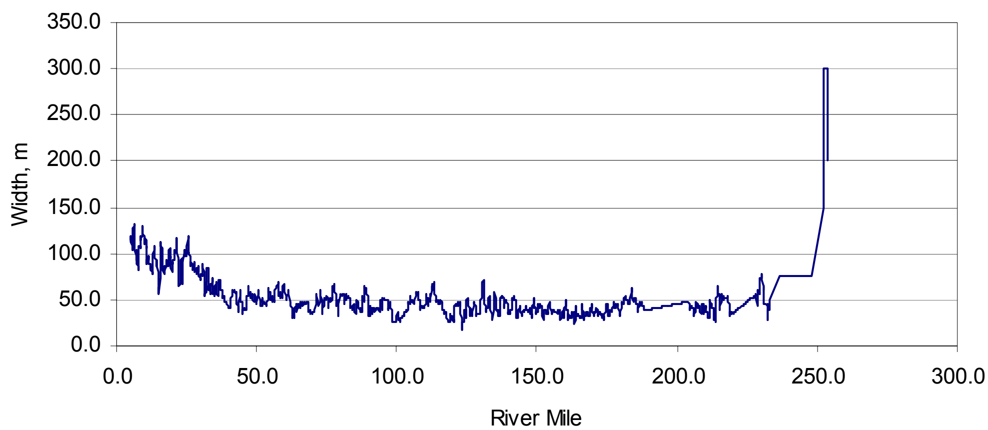


Figure 302. WOP river widths from Link Dam to Turwar

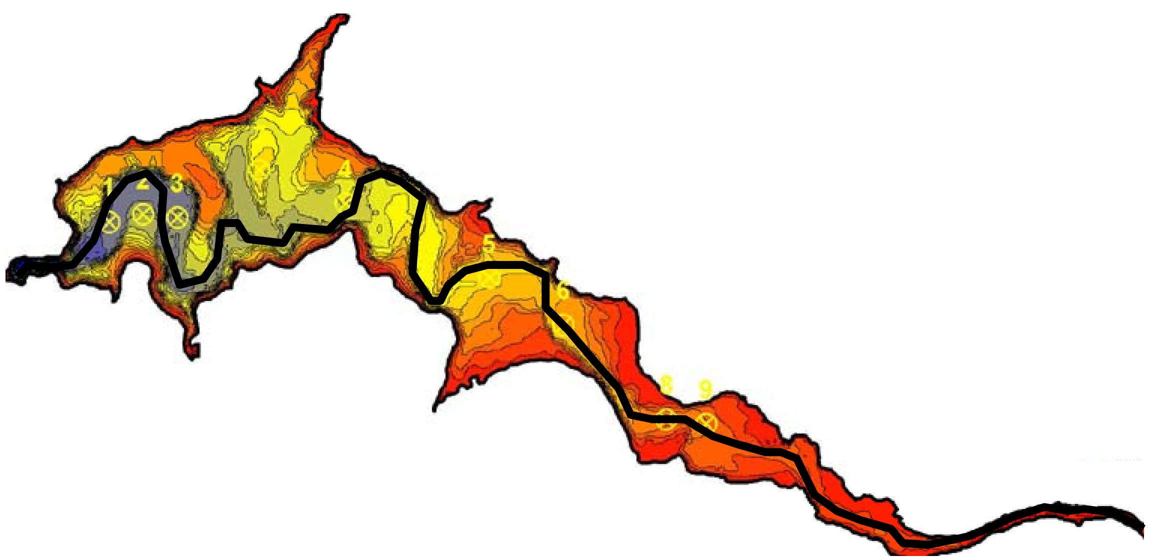


Figure 303. Example of river element orientation from Copco Reservoir bathymetry. Note the black line running through the reservoir in the deepest parts.

4.5.2 Meteorology

The meteorology for each reach of the without project scenario followed the basic modeling framework outlined in the implementation documentation.

4.5.3 Hydrology

The hydrology for boundary conditions for each reach of the without project scenario followed the basic modeling framework outlined in the implementation documentation.

4.5.4 Water Quality

The water quality data for boundary conditions for each reach of the without project scenario followed the basic modeling framework outlined in the implementation documentation.

4.5.4.1 Sediment Oxygen Demand

Unlike the sediment oxygen demand exerted in the reservoirs, there is little oxygen demand in the river bed due to scouring. Therefore the SOD which is present in the Existing Conditions scenario is not present in the form of bed BOD in the WOP scenario. Sensitively testing using the modeling framework illustrates that low dissolved oxygen conditions in the Lake Ewauna/Keno reach are most likely due to the oxygen demand imparted on the system from Upper Klamath Lake, and the response is more akin to an oxygen sag in this reach than overwhelming SOD load. SOD plays a role in water quality conditions; however, at this time it is generally presumed to be modest compared to inputs from Upper Klamath Lake.

4.5.5 Operations

No project operations were present in the without project scenario as all projects had been removed.

4.6 Without Project II Scenario (WOPII)

All conditions in the without project II scenario are the same as the WOP scenario with exception of the hydrology. The primary purpose of this scenario was to smooth out the flow variability that was being routed down the river during summer periods (Figure 304). These variations, which are most prominent between Julian day 200 and 250, are born out of US Bureau of Reclamation project operations and maintenance of Keno Reservoir at a stable water surface elevation during operations. The fluctuation over the span of a few days can exceed 500 cfs. The original WOP scenario assumed that all US Bureau of reclamation project operations were consistent with historic conditions – in which case the flow variations that occurred were historically “re-regulated” by system reservoirs were routed down the river. Stakeholder input identified this as an unrealistic without project operation and requested that attempts be made to smooth the hydrograph that was routed down the river.

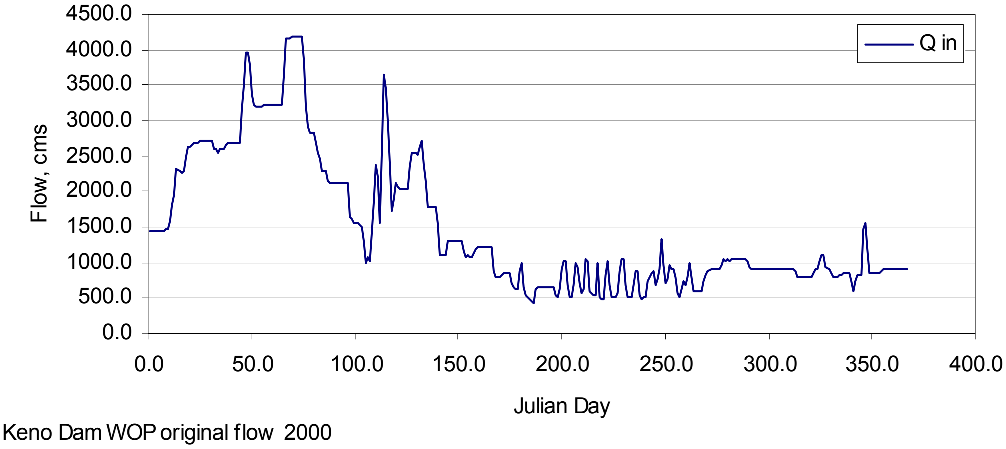


Figure 304. Keno Dam WOP flow, 2000

To address this issue, a seven day running average flow was calculated at Keno Dam (Figure 305). Using a water balance on the Link Dam to Keno Dam reach, several attempts were made to identify flow boundary conditions within this reach to achieve a smooth hydrograph at Keno Dam. These attempts failed to attain a hydrograph that was acceptable. Challenges include the variable transit times through the reach from the various inflow points (Link Dam, Lost River Diversion Channel, Klamath Straits Drain, return flow location), a process further confounded by the impacts on transit time due to diversions from various points. Lumping inputs and outputs was initially considered to simplify the transit time issue, but due to the variable timing and water quality of the various waters, this was deemed unacceptable because the results would be difficult to interpret and the results could not be readily compared with the other global scenarios.

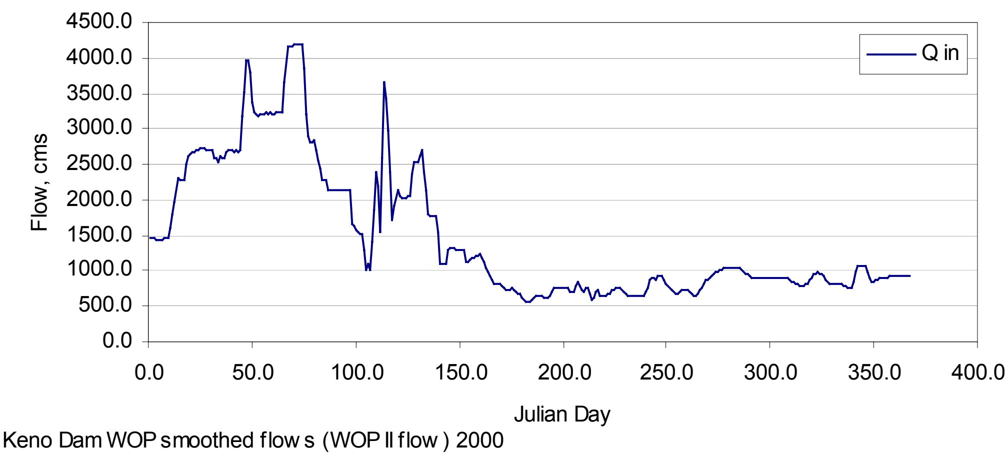


Figure 305. Keno Dam WOPII flow (smoothed), 2000

In the interest of time, and with stakeholder input, it was decided to use WOP scenario water quality conditions at Keno Dam and route those results down the river from Keno

Dam to Turwar using the smoothed hydrograph presented in Figure Y. This assumption presumes that the results with a smoothed hydrograph are similar to those without smoothing. (The flow and water quality results for all locations above Keno Dam are identical). It is critical that the reader understand this assumption and interpret the results accordingly.

WOP and WOPII flows at Keno Dam for 2001 are presented in Figure 306 and Figure 307. The impacts of smoothing in 2001 were modest because US Bureau of Reclamation operations were offline.

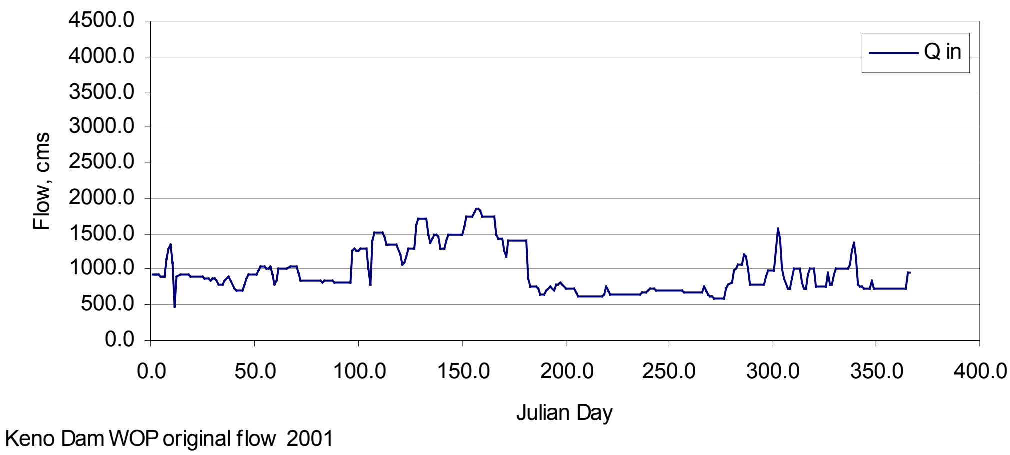


Figure 306. Keno Dam WOP flow, 2001

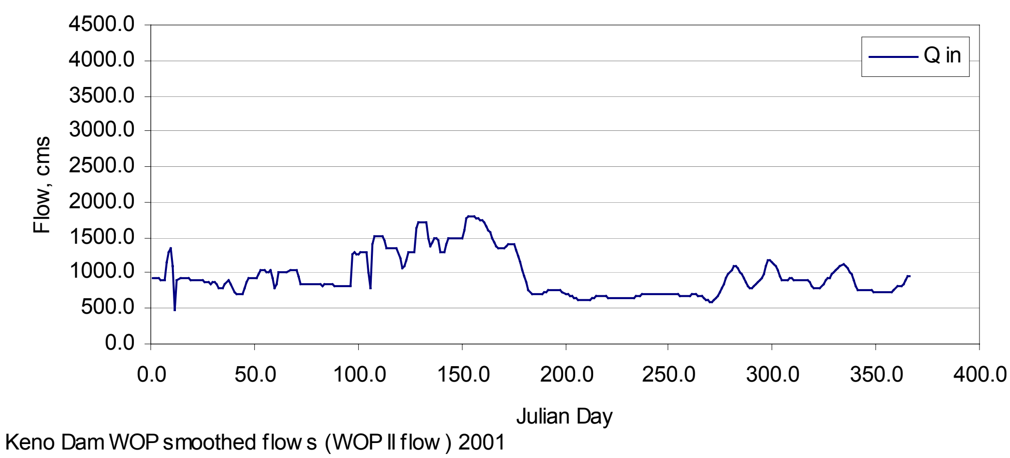


Figure 307. Keno Dam WOPII flow (smoothed), 2001

4.7 Presentation of Results

The model framework produces a substantial amount of information. To effectively provide information to the stakeholders, regulators, and various analysts, input was solicited via monthly meetings with the Water Quality Work Group (established as part of the stakeholder consultation process for the relicensing). Specific locations were identified where model output was desired, as well as parameters and summary statistics. Data was produced for 29 locations, primarily for flow, water temperature, and dissolved oxygen. The reporting locations are presented in Table 97. The information is available in tabular form and graphical form. The current graphical output includes:

For Existing Condition, Steady Flow, and Without Project:

- time series (one-hour data) of water temperature and dissolved oxygen
- daily maximum, mean, and minimum of water temperature and dissolved oxygen
- Longitudinal profiles for river reaches (Bypass/Peaking and Iron Gate Dam to Turwar) for the first of each month from April through November) of water temperature and dissolved oxygen
- Daily mean flow and water temperature (double y-axis plot)
- Daily mean flow and dissolved oxygen (double y-axis plot)

Comparisons of:

- Daily mean water temperature (EC vs. other scenarios)
- Daily mean dissolved oxygen (EC vs. other scenarios)
- Longitudinal profiles for the entire river from Link Dam to the Klamath River near Turwar for the first of each month from April through November) of water temperature and dissolved oxygen.

Table 97. Reporting locations for the Klamath River model simulations

Reach	Location	River Mile	Node (Seg) for EC and SF	Node For WOP
Link River	Link Dam	253.9	1	1
	Link River at Lake Ewauna	252. 7	25	10
Lake Ewauna to Keno Dam Reach	Link River at Lake Ewauna	252.7	(2)	77
	RM 248	248.0	(26)	131
	RM 243	243.0	(53)	185
	RM238	238.0	(79)	227
	Keno Dam	232.9	(107)	
Keno River	Keno Dam	232.9	1	1
	Above JC Boyle	227.6	110	55
JC Boyle Reservoir	JC Boyle Dam	224.3	-	94
Bypass / Peaking Reach	bel JC Boyle Dam	224.3	1	94
	Above Powerhouse	220.0	94	138
	Below Powerhouse	221.0	103	144
	Stateline	209.2	332	259
	Above Copco	203.6	448	309
	Copco Reservoir headwaters		453	
Copco Reservoir	Copco Dam	198.6	-	387
Iron Gate Reservoir	Irongate Dam	190.5	-	473
Irongate to Turwar Reach	Irongate Dam	190.5	1	1
	Above Shasta River	177.5	141	141
	At Walker Bridge	156.6	369	369
	Above Scott River	143.6	510	510
	At Seiad Valley	129.0	672	672
	Above Clear Creek	99.0	994	994
	Above Salmon River	67.1	1354	1361
	At Orleans	57.6	1441	1441
	Above Bluff Creek	50.0	1545	1545
	Above Trinity River	43.5	1609	1609
	At Martins Ferry	39.5	1649	1649
	At Blue Creek	16.9	1901	1901
	At Turwar	5.6	1974	1974

5 References

American Public Health Assc., American Water Works Assc., and Water Environment Federation (APHA). (1995) *Standard Methods for the examination of water and wastewater*, 19th Ed. Editors. A.E. Eaton, L.S. Clesceri, and A.E. Greenberg. Washington D.C.

Bowie, G.L. W.B. Mills, D.B. Porcella, C.L. Campbell, J.R. Pagenkopf, G.L. Rupp, K.M. Johnson, P.W. Chan, and S.A. Gherini. (1985) *Rates, constants and kinetics formulations in surface water quality modeling*, 2nd Ed. EPA/600/3-87/700. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA. May.

Chapra, S.C. (1997) *Surface Water-Quality Modeling*. McGraw-Hill, Inc.. New York. 843 pp.

Cole, T.M. and S.A. Wells (2002) *CE-QUAL-W2: A Two-Dimensional Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.1: User Manual*. Instruction Report EL-2002-1. U.S. Army Engineering and Research Development Center, Vicksburg, MS.

Deas, M.L. and G.T. Orlob. (1999) *Klamath River Modeling Project*. Sponsored by the United States Fish and Wildlife Service Klamath Basin Fisheries Task Force. Project No. 96-HP-01. December.

Handbook of Hydrology (1993) Ed. David Maidment. McGraw Hill Inc. New York.

Horne, A. J., and Goldman, C. R. (1994) *Limnology*. 2nd ed. McGraw-Hill, New York. 576 pp.

JC Headwaters, Joe Eilers

Kalff, J. (2002) *Limnology*. Prentice Hall, New Jersey. 592 pp.

Kann, J. (2001) *Compilation of Klamath Tribes Upper Klamath Lake Water Quality Data, 1990-2001*. Prepared for the Klamath Tribes Natural Resources Department and U.S. Bureau of Reclamation Cooperative Studies. May 3.

Linacre, E. (1992) *Climate Data and Resources: A reference guide*. Routledge. London. 366 pp.

Martin, J.L. and S.M. McCutcheon (1999) *Hydrodynamics and Transport for Water Quality Modeling*. Lewis Publishers, Boca Raton FL. 794 pp.

Reckhow, K.H., and S.C. Chapra. 1983. Engineering Approaches for Lake Management. Volume 1: Data Analysis and Empirical Modeling. Butterworth Publishers. Boston. 340 pp.

PacifiCorp (2002) *Explanation of Facilities and Operational Issues Associated with PacifiCorp's Klamath Hydroelectric Project*. Portland Oregon. May 1.

PacifiCorp (2000). First Stage Consultation Document and Appendices: Klamath Hydroelectric Project (FERC Project No. 2082). PacifiCorp, Portland Oregon. December 15, 2000.

Thomann, R.V. and J.A. Mueller (1987) *Principles of Surface Water Quality Modeling and Control*. Harper-Collins Publishers, Inc. New York. 644 pp.

Tchobanoglous, G and E.D. Schroeder (1985) *Water Quality*. Addison-Wesley Publishing Co., Inc. Menlo Park, CA.

United States Army Corps of Engineers - Hydrologic Engineering Center (USACOE-HEC). (1986) *WQRRS Water Quality for River-Reservoir Systems: User's Manual*. Document CPD-8. December.

United States Environmental Protection Agency (EPA). 1997. *Technical guidance manual for developing total maximum daily loads*. Book 2: Streams and rivers, Part 1: Biochemical oxygen demand/dissolved oxygen and nutrients/eutrophication. 823-B-97-002. March.

United States Environmental Protection Agency (EPA). (1976) *Quality Criteria for Water (Red Book)*. Washington D.C. July.

United States Geological Survey (USGS). (1997) 1997 *Completion Report: Water Quantity Model Development*. Prepared for the Technical Work Group of the Klamath Basin Fisheries Task Force by M. Flug and J. Scott. Fort Collins, CO. May.

United States Geological Survey (USGS). (1995) "Klamath River Basin Characterization of Hydrology Data from U.S.G.S. Records," in *Compilation of Phase I reports for the Klamath River Basin*. Prepared for the Technical Work Group of the Klamath Basin Fisheries Task Force. Fort Collins, CO. May.

University of California - Cooperative Extension. (____) *Converting humidity expressions with computers and calculators*, Leaflet 21372.

Watercourse Engineering, Inc.(Watercourse) (2003) *Klamath River Water Quality 2000 Monitoring Program: Project Report*. Sponsored by the U.S. Bureau of Reclamation, Klamath Area Office, with support from PacifiCorp. January.

Wetzel, R.G. (2001) Limnology: Lake and River Ecosystems, 3rd Ed. Academic Press, San Diego. 1006 pp.

Personal Communications

Todd Olson, PacifiCorp

Klamath River Modeling Framework to Support the PacifiCorp Federal Energy Regulatory Commission Hydropower Relicensing Application

- Appendices -

Watercourse Engineering, Inc.
1732 Jefferson Street, Suite 7
Napa, CA 94559
November 14, 2003

Table of Contents

6 Klamath River Water Quality Modeling Framework[1]

6.1 Introduction

As identified in subtask 1.3, Water Quality Analysis and Modeling Needs Assessment and Scoping Process, the objectives of water quality analysis and modeling are to:

- Determine what analysis and modeling tools are needed to assess Project water quality effects and compliance with water quality standards and objectives
- Determine the appropriate geographic scope for the needed analysis and modeling tools
- Clarify specifically how water quality compliance will be determined for the Project using such tools
- Develop plans for completing this analysis and modeling
- Ensure appropriate analytical coordination with larger-scale analyses and modeling that PacifiCorp assumes will be conducted by the agencies as a key part of TMDL water quality
- management planning in the basin
- Support subsequent assessment (including in other studies or during license application preparation) of the Project's potential effects on water quality and possible measures to protect, enhance, and mitigate where necessary.

In response to these objectives, as well as feedback from other stakeholders and interested parties in the Klamath River system a modeling framework has been developed, and is presented herein.

6.2 Klamath River Modeling Framework

The Klamath River system from Upper Klamath Lake to below Iron Gate Dam is a complex of river reaches and reservoirs. There are four major impoundments: Lake Ewuana/Keno Reservoir, JC Boyle Reservoir, Copco Reservoir, and Iron Gate Reservoir. Free-flowing river reaches occur between the impoundments with the exception of Copco Dam and Iron Gate Reservoir (Figure 1).

The diversity among the reservoir operations, inflows and diversions, morphology, and water quality characteristics is considerable. The river reaches vary in a similar manner. To effectively represent the flow and water quality characteristics of these reservoir and river reaches the models must be able to accommodate a wide range of conditions.

[1] This is the original framework submitted as part of subtask 1.3. Modifications have been made. Although not comprehensive, notes have been added to this section to identify significant changes.

Outlined herein are the general characteristics of each reservoir and river reach, the selected model, modeling parameters, and data needs. The framework of models is adaptable to modeling system components individually or as an integrated system, and is capable of representing a without project condition. An appendix includes descriptions of the various model attributes.

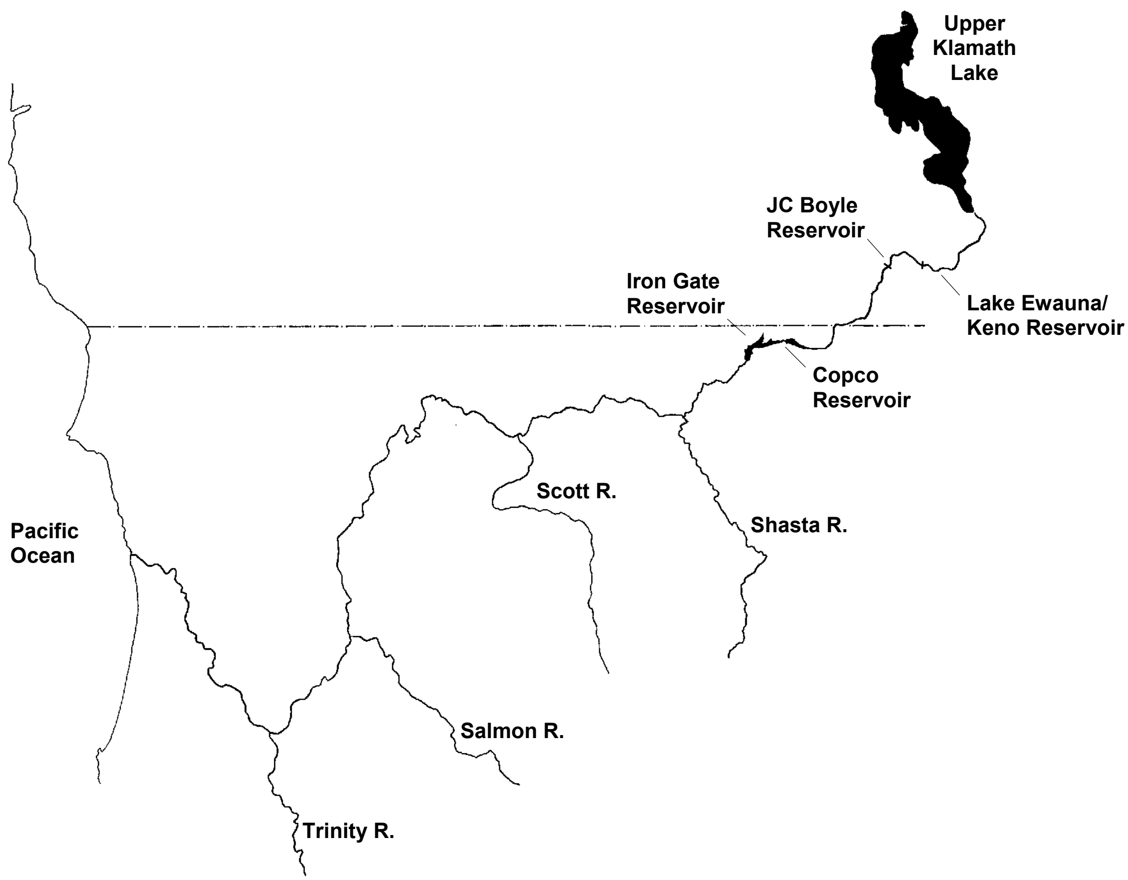


Figure 1. Klamath River System

6.2.1 Models

Four models are proposed for use to represent the various reservoir and river reaches in the Klamath Basin throughout the study area: CE-QUAL-W2, WQRRS[2], RMA-2 and RMA-11. These models are full water quality models capable of simulating water temperature as well as a wide range of water quality parameters in reservoirs and rivers. Although there are a range of models available, these were selected for several reasons

---

[2] WQRRS was not selected as a final model for includion in the modeling framework. CE-QUAL-W2 was used for all reservoir systems.

- They are physically-based numerical models capable of simulating a wide range of water quality conditions under dynamic conditions
- The models have been widely applied and have been widely tested
- They have been or are actively being used in the Klamath Basin
- The codes are not proprietary and are thus readily available for review

The reservoir models that will be used include the U.S. Army Corps of Engineers (USACE) model CEQUAL-W2, and the USACE model WQRRS. CEQUAL-W2 is a two dimensional, longitudinal and vertical representation of a water body. WQRRS is a one-dimensional vertical representation for stratified or well-mixed reservoirs. The river reaches will be modeled with a set of models, RMA-2 will be used to represent the hydrodynamic flow regime and the output (velocity, depth, etc.) will be used as input for the stream water quality model RMA-11.

The reservoir models will run on daily and/or sub-daily time steps. Certain reaches have been identified as requiring time steps on the order of an hour (e.g., JC Boyle full flow reach).

Model descriptions and general information is included in the appendix. It is presumed that these more complex models will be supported with simpler process-based or statistical models.

Interfacing the Models

Modeling the Klamath River reaches and reservoirs will be completed using different models for reservoir and river reaches. The process of interfacing or linking the models is a matter of writing separate computer programs to process the output from one model (e.g., river model) such that it forms the input to the subsequent model (e.g., reservoir model): a necessary, but straightforward task[3]. The end result is a model framework that can be used to examine individual reaches, or larger sections of the river and reservoir system.

6.2.2 Analyses

The system will be modeled for flow and water quality throughout the study area. Table 98 identifies the specific parameters that will be simulated in each reach. Physical, chemical, or biological information is unavailable or system response unknown in certain reaches. The selected models are capable of addressing these issues and can be used to

---

[3] This task was not funded, thus no formal software was developed to interface the models. Data transfer was done via spreadsheet manipulation.

test sensitivity of these processes and parameters as well as identify the need for additional data collection.

Table 98 Water quality parameters selected for simulation in each reach of the study area, and selected model for sub-reach

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	SOD	Phyto-plankton	Attached Algae[2]	Model
Link R	●	●	●	●	●		TBD	●	RMA-2/11
Lake Ewauna/Keno	●	●	●	●	●	●	●		CE-QUAL-W2
Keno Dam to JC Boyle	●	●	●	●	●		TBD	●	RMA-2/11
JC Boyle	●	●	●	●	●	●	●		WQRRS[3]/ RMA-2/11
Bypass Reach	●	●	●	●	●			●	RMA-2/11
JC Boyle Full Flow Reach	●	●	●	●	●			●	RMA-2/11
Copco Reservoir	●	●	●	●	●	●	●		WQRRS[3]
Iron Gate Reservoir	●	●	●	●	●	●	●		WQRRS[3]
Klamath River below IGD	●	●	●	●	●			●	RMA-2/11

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Attached algae modeling will be completed if required to simulate system response. In some of the short reaches it may not be necessary

[3] Final model applied to these systems was CE-QUAL-W2 (Update: Change from original framework)

Other water quality processes may be represented as well, e.g., specific conductance.

6.3 Model Representations and Required Information

A brief description of each reach, modeling approach, data requirements, and additional field studies for all of the study reaches are outlined below. Much of the data required to implement, test, and calibrate/validate the model will come from existing data sets. Additional seasonal monitoring and multiple day synoptic surveys are planned to provide other necessary information.

6.3.1 Link River

The Link River reach extends 1.2 miles from Link Dam to Lake Ewauna. This short river reach has no tributaries and a moderate gradient. Flows are generally stable, but can vary over short time periods. Water quality in the reach is dominated by upstream Upper Klamath Lake conditions. The transit time is on the order of hours.

6.3.1.1 Modeling Approach

This river reach will be modeled with river models RMA-2 (flow) and RMA-11 (water quality).

6.3.1.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature, wind speed, atmospheric pressure)

Geometry

- channel cross sections (estimate, previous field work)
- bed slope (USGS)
- UTM or Lat/Long description of reach (USGS, GIS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), if any (USGS, GIS)

Initial Conditions

- initial algal biomass if benthic algae is modeled
- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Calibration/Validation Data

Model calibration and validation will use data from the Link River above Lake Ewauna site, as well as the appropriate powerhouse return flow. Boundary conditions and calibration/validation data are summarized in Table 99.

Table 99 Link River boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae[2]	Other[3]	Boundary Condition	Cal/Val Site
Link Dam	H/D	H	H/D	G	G	G		Yes	No
Powerhouse #1 and #2[4]	H/D	H	H/D	G	G	G		Yes	No
Link R ab. Lake Ewauna	H/D	H	H/D	G				Yes[5]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Benthic algae modeling will be completed if required to simulate system response. Phytoplankton may be represented in this reach to reflect influx from Upper Klamath Lake.

[3] Other water quality constituents may be represented as well, e.g., specific conductance.

[4] Powerhouse return flow quality will be estimated using Link Dam data

[5] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

6.3.1.3 Additional Field Studies

- Synoptic surveys to characterize conditions for model calibration and validation

6.3.2 Link River to Keno Dam

Lake Ewauna/Keno Reservoir are formed by Keno Dam. Lake Ewauna is a wide, relatively shallow body of water from about RM 251 to 253, while Keno reservoir is a narrower reach between RM 233 and 251. The impoundment is approximately 20 miles in length and served both as a supply and discharge point for municipal, industrial, and agricultural uses. This reach experiences a wide range of water quality conditions and is one of the more complex and least understood system in the study area.

6.3.2.1 Modeling Approach

Lake Ewauna/Keno Reservoir will be modeled with CE-QUAL-W2.

6.3.2.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature, wind speed, atmospheric pressure)

Geometry

- Bathymetric survey of reach (PacifiCorp)
- UTM or Lat/Long description of reach (USGS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), (USGS)

Initial Conditions

- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Calibration/Validation Data

Model calibration and validation will use data at a minimum of five locations within the study reach. Boundary conditions and calibration/validation data are summarized in Table 99.

6.3.2.3 Additional Field Studies

The US Bureau of Reclamation will be sampling Lake Ewauna and Keno Reservoir at two week intervals at roughly a dozen locations. It is expected that these data may be augmented with additional studies, possibly including sediment analysis and phytoplankton studies. These special studies are still under consideration.

Table 100 Lake Ewauna/Keno Reservoir boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae	Other[2]	Boundary Condition	Cal/Val Site
Link R ab. Lake Ewauna	H/D	H	H	G	G	G		Yes	No
Municipal and Industrial Use	D							Yes	No
Municipal and Industrial Discharge	D	D	D	D				Yes	No
Agricultural Diversion	D							Yes	No
Agricultural Discharge	D	H/D	H/D	G				Yes	No
Lake Ewauna[3]	D	H	H	G		G			Yes
Miller Island	D	H	H	G		G			Yes
Teeters Landing	D	H	H	G		G			Yes
Additional sites[4]	D	H	H	G		G			Yes
Keno Dam	D	H	H	G		G		Yes[5]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Other water quality constituents may be represented as well, e.g., specific conductance.

[3] USBR has 3 sites in Lake Ewauna that may be used to support model applications

[4] USBR has several additional sites between Lake Ewauna and Keno Dam that may be used for model application

[5] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

6.3.3 Keno Dam to JC Boyle Reservoir

The Klamath River between Keno Dam and JC Boyle Reservoir is a characterized by a steep gradient with moderate to high velocities. This relatively short river reach has no major tributaries but experiences an undetermined, but probably small spring flow accretion. There are no major withdrawals or discharges into the reach. Although Keno Dam releases are relatively constant (essentially operated as a “run-of-river” facility), short-term fluctuations in flow are evident at times. Such fluctuations are due mainly to the effects of diversions from and return flows to Lake Ewauna/Keno Reservoir in response to irrigation operations.

The reach is dominated by upstream water quality. Further, the reach is relatively short, with transit time being well under one day. Although the diurnal range of temperature and dissolved oxygen is somewhat moderated by releases from Keno Reservoir, by the time water reaches the end of this reach there is a diurnal signal is observable. Overall, little is known about the water quality response of this reach.

6.3.3.1 Modeling Approach

This river reach will be modeled with river models RMA-2 (flow) and RMA-11 (water quality).

6.3.3.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature, wind speed, atmospheric pressure)

Geometry

- channel cross sections (estimate, previous field work)
- bed slope (USGS)
- UTM or Lat/Long description of reach (USGS, GIS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), if any (USGS, GIS)

Initial Conditions

- initial algal biomass if benthic algae is modeled
- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Validation Data

Calibration and validation of the model will be completed using data from the site above JC Boyle Reservoir. Boundary conditions and calibration/validation data are summarized in Table 101.

Table 101 Keno Dam to JC Boyle Reservoir boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae[2]	Other[3]	Boundary Condition	Cal/Val Site
Keno Dam	H	H	H	G	G	G		Yes	No
Accretions	D/W	D/G	G	G	G*	G*		Yes	No
KR above JC Boyle	H	H	H	G				Yes[4]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Benthic algae modeling will be completed if required to simulate system response.

[3] Other water quality constituents may be represented as well, e.g., specific conductance.

[4] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

6.3.3.3 Additional Field Studies

- synoptic water quality study (3 periods – 3 days each): to characterize short-term variability in the reach and for model calibration and validation
    - continuously monitoring probes (physical parameters - hourly) at the top and bottom of reach
    - grab samples 2 times once day for three days at the top and bottom of reach to coincide with the continuously monitoring probe deployment
- field reconnaissance to identify potential spring flow accretion location, quantity and quality

6.3.4 JC Boyle Reservoir

The J.C. Boyle reservoir reach includes the portion of the mainstem Klamath River from J.C. Boyle dam (RM 224.7) to the upper end of the J.C. Boyle reservoir (RM 228) near the mouth of Spencer Creek. The reservoir is relatively shallow and typically experiences a short residence time and is prone to weak stratification.

6.3.4.1 Modeling Approach

This reach can be modeled in two ways. It can be represented in WQRRS as a weakly stratified to mixed reservoir system. It also can be modeled as a slow deep river using the river models RMA-2 (flow) and RMA-11 (water quality). Both approaches will be explored to potentially investigate both longitudinal and vertical characteristics of the water body. (Ultimately CE-QUAL-W2 was the selected model for this application. This is an update: Change from original framework.)

6.3.4.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature, wind speed, atmospheric pressure)

Geometry

- Bathymetric survey of reach (PacifiCorp)
- UTM or Lat/Long description of reach (USGS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), (USGS)

Initial Conditions

- initial reservoir stage
- initial water quality profile
- initial organic sediment mass
- for river models, initial condition will be developed using the models

Boundary Conditions and Validation Data

For WQRRS calibration and validation will utilize data from the vertical profile site JC Boyle Dam. If the river models are implemented, data from synoptic surveys (to be completed) will be necessary. Both models would be calibrated to effectively simulate outflow conditions as well. Boundary conditions and calibration/validation data are summarized in Table 102.

Table 102 JC Boyle Reservoir boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae	Other[2]	Boundary Condition	Cal/Val Site
KR above JC Boyle	H	H	H	G	G	G		Yes[3]	No
JC Boyle Reservoir Profile/Synoptic	D	H/M (P)	M (P)	M (2 Depths)	M (2 Depths)	M (2 Depths)		No	Yes
JC Boyle Release (below Boyle)	H/D	H/D	G	G	G	G		Yes[4]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Other water quality constituents may be represented as well, e.g., specific conductance.

[3] Shovel Creek and other accretions may be combined with Klamath River above JC Boyle

[4] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly, M(P) refers to a monthly profile

G – Grab sample (frequency varies from sub-daily to monthly)

6.3.4.3 Additional Field Studies

- synoptic water quality study (3 periods – 3 days each): to characterize short-term variability in the reach and for model calibration and validation
  - continuously monitoring probes (physical parameters) at the headwaters and in the reservoir release
  - monitor vertical profiles of temperature, dissolved oxygen, pH, specific conductance, and oxidation-reduction potential (ORP) at two intermediate points in the reservoir twice per day
  - grab samples 1 time per day for 3 days at the headwaters and in the reservoir release, as well as two intermediate points (coincident with the above noted profiles). These grab samples should occur at two depths in the reservoir, corresponding to roughly 1meter deep and 1 meter off the bottom.
  - algal species identification
- sediment sampling to determine sediment oxygen demand (SOD) and possibly nutrient release. One set of samples (cores) during the summer season
- collect samples to identify algal species
- field reconnaissance to quantify potential accretions and depletions to/from reservoir (e.g., Spencer Creek)

6.3.5 JC Boyle Bypass Reach

The JC Boyle bypass reach is 4.3 miles long, extending from JC Boyle Dam to the JC Boyle Powerhouse. Minimum FERC releases from JC Boyle dam are 100 cfs. Although there are no major tributaries, there are significant spring flow accretions. The reach is steep and transit time appears to be on the order of hours. Spring flow accretion quantity and quality, as well as location are under represented in available data.

6.3.5.1 Modeling Approach

This river reach will be modeled with river models RMA-2 (flow) and RMA-11 (water quality).

6.3.5.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature, wind speed, atmospheric pressure)

Geometry

- channel cross sections (estimate, previous field work)
- bed slope (USGS)
- UTM or Lat/Long description of reach (USGS, GIS)

- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), if any (USGS, GIS)

Initial Conditions

- initial algal biomass if benthic algae is modeled
- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Validation Data

Calibration and validation of the model will be completed using data from the site above JC Boyle penstock return. Boundary conditions and calibration/validation data are summarized in Table 103.

6.3.5.3 Additional Field Studies

- synoptic water quality study (3 periods – 3 days each): to characterize short-term variability in the reach and for model calibration and validation
    - continuously monitoring probes (physical parameters - hourly) at the top and bottom of reach
    - grab samples 1 time per day for at the top and bottom of reach to coincide with the continuously monitoring probe deployment
- field reconnaissance to locate spring inflow locations and to collect representative water quality samples
- estimate spring inflow quantity in bypass reach

Table 103 JC Boyle Dam to penstock return (bypass reach) boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae[2]	Other[3]	Boundary Condition	Cal/Val Site
JC Boyle Release to KR	H/D	H/D	G	G	G	G		Yes	No
Accretions	D	D/G	G	G	G	G		Yes	No
KR above Penstock Return	H/D	H	H	G	G	G		Yes[4]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Benthic algae modeling will be completed if required to simulate system response.

[3] Other water quality constituents may be represented as well, e.g., specific conductance.

[4] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

6.3.6 JC Boyle Full Flow[4] Reach

The JC Boyle bypass reach is 16.4 miles long, extending from JC Boyle penstock return to the Copco Reservoir. During peaking periods flow rates vary on a subdaily basis between about 350 cfs (inflow from the bypass reach) to approximately 3000 cfs. Several small tributaries occur in this reach, the largest of which is Shovel Creek. The reach is steep and experiences a highly dynamic flow regime. The transit time is typically less than a day.

6.3.6.1 Modeling Approach

This river reach will be modeled with river models RMA-2 (flow) and RMA-11 (water quality).

6.3.6.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)

[4] This is now referred to as the Peaking Reach

- Brazie Ranch (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)

Geometry

- channel cross sections (estimate, previous field work)
- bed slope (USGS)
- UTM or Lat/Long description of reach (USGS, GIS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), if any (USGS, GIS)

Initial Conditions

- initial algal biomass if benthic algae is modeled
- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Validation Data

Calibration and validation of the model will be completed using data from the site at Klamath River above Shovel Creek and an intermediate location between Shovel Creek and the penstock return (to be determined). Boundary conditions and calibration/validation data are summarized in Table 104.

Table 104 JC Boyle Dam penstock return to Copco Reservoir (full flow reach) boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae[2]	Other[3]	Boundary Condition	Cal/Val Site
KR above Penstock Return	H/D	H	H	G	G	G		Yes	No
Penstock Return	H	H	H	G	G	G		Yes	No
Intermediate Location TBD		H	H	G	G	G		No	Yes
KR ab Shovel Ck	H	H	H	G	G	G		Yes[4]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Benthic algae modeling will be completed if required to simulate system response.

[3] Other water quality constituents may be represented as well, e.g., specific conductance.

[4] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

6.3.6.3 Additional Field Studies

- synoptic water quality study (3 periods – 3 days each):
    - continuously monitoring probes (physical parameters - hourly) at top, middle, and bottom of reach
    - grab samples 2 times per day at top, middle, and bottom of reach to coincide with the continuously monitoring probe deployment locations. Ideally, samples to be collected prior to peaking and after full flows occur.
    - monitor Shovel Creek and any other identified accretions that are deemed significant for temperature (logger) and one grab sample per day
- field reconnaissance to characterize river reach (cross section and slope), identify potential accretions (location and quantity), examine benthic algae conditions, and to locate intermediate sampling point for calibration and validation
- field studies to examine benthic algae conditions for model representation
- additional full meteorological station (Copco Village)

6.3.7 Copco Reservoir

Copco Reservoir is 5.4 miles long with a storage capacity of 46,867 acre-feet[5]. The reservoir has a residence time that ranges from two weeks to a month at typical summer flows and is subject to thermal stratification. Reservoir inflow, other than the Klamath River, is restricted to minor tributaries and spring flows.

6.3.7.1 Modeling Approach

The reservoir will be modeled with WQRRS. (Ultimately, CE-QUAL-W2 was the selected model for this application. This is an update: Change from original framework.)

6.3.7.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)
- Brazie Ranch (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)

Geometry

- Bathymetric survey of reach (PacifiCorp)

[5] Updated Copco Reservoir bathymetric surveys completed in 2001 identified that actual reservoir storage is approximately 40,000 acre-feet.

- UTM or Lat/Long description of reach (USGS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), (USGS)

Initial Conditions

- initial reservoir stage
- initial water quality profile
- initial organic sediment mass
- for river models, initial condition will be developed using the models

Boundary Conditions and Validation Data

For WQRRS calibration and validation will utilize data from the vertical profile site near Copco Dam. The model will be calibrated to effectively simulate outflow conditions as well. Boundary conditions and calibration/validation data are summarized in Table 105.

6.3.7.3 Additional Field Studies

- synoptic water quality study (3 times – one day each): to characterize longitudinal variability in reservoir
    - monitor vertical profiles of temperature, dissolved oxygen, pH, specific conductance, and oxidation-reduction potential (ORP) at a minimum of three points in the reservoir.
    - grab samples at above locations. The grab samples should occur at two or three depths in the reservoir, depending on total reservoir depth and thermal profile
    - algal species identification (sample each day at all three sites)
- sediment sampling to determine sediment oxygen demand (SOD) and nutrient release. One set of samples (cores) during the summer season.
- collect samples to identify algal species (monthly at dam site)
- field reconnaissance to quantify potential accretions and depletions to/from reservoir (e.g., springs)
- additional full meteorological station (Copco Village)

Table 105 Copco Reservoir boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae	Other[2]	Boundary Condition	Cal/Val Site
KR ab Shovel Ck	H/D	H/D	H/D	G	G	G	Synoptic	Yes	No
Copco Reservoir Profile	H/D	H/M (P)	M(P)	M (3 Depths)	M (3 Depths)	M (3 Depths)	Sediment Algae species	No	Yes

Copco Release (below Copco)	H/D	H/D	G	G	G	G	Yes[3]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Other water quality constituents may be represented as well, e.g., specific conductance.

[3] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

6.3.8 Iron Gate Reservoir

Iron Gate Reservoir is 7 miles long with a storage capacity of approximately 58,000 acre-feet. Iron Gate Reservoir acts as a reregulating reservoir for Copco Reservoir hydropower releases. The reservoir has a residence time that ranges from three weeks to over a month at typical summer flows and is subject to thermal stratification. Reservoir inflow, other than the Klamath River, is restricted to minor tributaries and spring flows.

6.3.8.1 Modeling Approach

The reservoir will be modeled with WQRRS. (Ultimately, CE-QUAL-W2 was the selected model for this application. This is an update: Change from original framework.)

6.3.8.2 Data Requirements

Meteorological Conditions

- Klamath Falls (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)
- Brazie Ranch (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)

Geometry

- Bathymetric survey of reach (PacifiCorp)
- UTM or Lat/Long description of reach (USGS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), (USGS)

Initial Conditions

- initial reservoir stage
- initial water quality profile
- initial organic sediment mass

- for river models, initial condition will be developed using the models

Boundary Conditions and Validation Data

For WQRRS calibration and validation will utilize data from the vertical profile site near Iron Gate Dam. The model will be calibrated to effectively simulate outflow conditions as well. Boundary conditions and calibration/validation data are summarized in Table 106.

Table 106 Iron Gate Reservoir boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae	Other[2]	Boundary Condition	Cal/Val Site
Copco Release (below Copco)	H/D	H/D	G	G	G	G		Yes	Yes
Iron Gate Reservoir Profile	H/D	H/M (P)	M (P)	M (3 Depths)	M (3 Depths)	M (3 Depths)	Sediment Algae	No	Yes
Iron Gate Release to KR (below IG)	H/D	H/D	G	G	G	G		Yes[3]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Other water quality constituents may be represented as well, e.g., specific conductance.

[3] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

6.3.8.3 Additional Field Studies

- synoptic water quality study (3 times – one day each): to characterize longitudinal variability in reservoir
  - monitor vertical profiles of temperature, dissolved oxygen, pH, specific conductance, and oxidation-reduction potential (ORP) at a minimum of three points in the reservoir.
  - grab samples at above locations. The grab samples should occur at two or three depths in the reservoir depending on total depth and thermal structure
  - algal species identification
- sediment sampling to determine sediment oxygen demand (SOD) and nutrient release. One set of samples (cores) during the summer season.

- collect samples to identify algal species
- more completely represent fish hatchery operations
- additional full meteorological station (Iron Gate Dam or Copco Village)

6.3.9 Klamath River below Iron Gate Dam

The Klamath River below Iron Gate Dam is regulated by upstream reservoir operations. Major tributaries downstream of the dam include the Shasta and Scott River. The reach is moderate to steep and experiences stable flow regime. The transit time between Iron Gate Dam (RM 190) and Seiad Valley (RM 129) during summer flow conditions ranges from one to two days.

6.3.9.1 Modeling Approach

This river reach will be modeled with river models RMA-2 (flow) and RMA-11 (water quality).

6.3.9.2 Data Requirements

Meteorological Conditions

- Brazie Ranch (solar radiation, dry bulb temperature, wet bulb temperature (or dew point), wind speed, atmospheric pressure)

Geometry

- channel cross sections (estimate, previous field work)
- bed slope (USGS)
- UTM or Lat/Long description of reach (USGS, GIS)
- locations of inputs (accretions, tributaries, and return flows) and withdrawals (diversions), if any (USGS, GIS)

Initial Conditions

- initial algal biomass if benthic algae is modeled
- model will be used to formulate initial flow and water quality conditions

Boundary Conditions and Validation Data

Calibration and validation of the model will be completed using data from the site at Klamath River above Shasta River and near Seiad Valley, and possibly an additional intermediate location (to be determined). Boundary conditions and calibration/validation data are summarized in Table 107.

6.3.9.3 Additional Field Studies

- synoptic water quality study (3 periods – 3 days each):): to characterize short-term variability in the reach and for model calibration and validation

  - continuously monitoring probes (physical parameters - hourly) at top and bottom of reach, as well as up to two intermediate locations (above Shasta River and one site to be determined)
  - grab samples one time per day at top, middle, and bottom of reach to coincide with the continuously monitoring probe deployment
  - monitor Shasta River and any other identified tributaries and accretions that are deemed significant for temperature (logger) and one grab sample per day
- field studies to examine benthic algae conditions for model representation
- additional full meteorological station (Iron Gate Dam)

Table 107 Below Iron Gate Dam to Seiad Valley boundary conditions and calibration/validation data

	Flow/ Stage	Tw	DO	Nutrients[1]	BOD	Algae[2]	Other[3]	Boundary Condition	Cal/Val Site
Iron Gate Release to KR (below IG)	H/D	H/D	H	G	G			Yes	No
KR above Shasta River		H	H	G	G			No	Yes
Shasta River inflow	H/D	H/D	H/D	G	G			Yes	No
Scott River inflow	H/D	H/D	H/D	G	G			Yes	No
Seiad Valley	H/D	H	H	G	G			Yes[4]	Yes

[1] Nutrients: Org N, NH_4^+, NO_2^-, NO_3^-, Org P, PO_4^{3-} (models may represent different collections of nutrient processes, all models include dominant inorganic forms)

[2] Benthic algae modeling will be completed if required to simulate system response.

[3] Other water quality constituents may be represented as well, e.g., specific conductance.

[4] A flow or stage boundary condition will be required at this location

Sampling Frequency:

H – hourly

D – Daily

M – Monthly

G – Grab sample (frequency varies from sub-daily to monthly)

7 Model Descriptions

7.1 CE-QUAL-W2

CE-QUAL-W2 (v3.1) is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. The model has been applied to rivers, lakes, reservoirs, and estuaries.

The model predicts water surface elevations, velocities, and temperatures. Temperature is included in the hydrodynamic calculations because of its effect on water density. The water quality algorithms incorporate 21 constituents in addition to temperature including nutrient/phytoplankton/dissolved oxygen (DO) interactions during anoxic conditions. Any combination of constituents can be simulated. Selective relationships pertinent to this application are shown in Figure 308. The effects of salinity or total dissolved solids/salinity on density and thus hydrodynamics are included only if they are simulated in the water quality module. The water quality algorithm is modular, allowing constituents to be easily added as additional subroutines. Selective withdrawal, the representations of internal curtains and weirs, and other features of this model allow the assessment of a wide range of configurations.

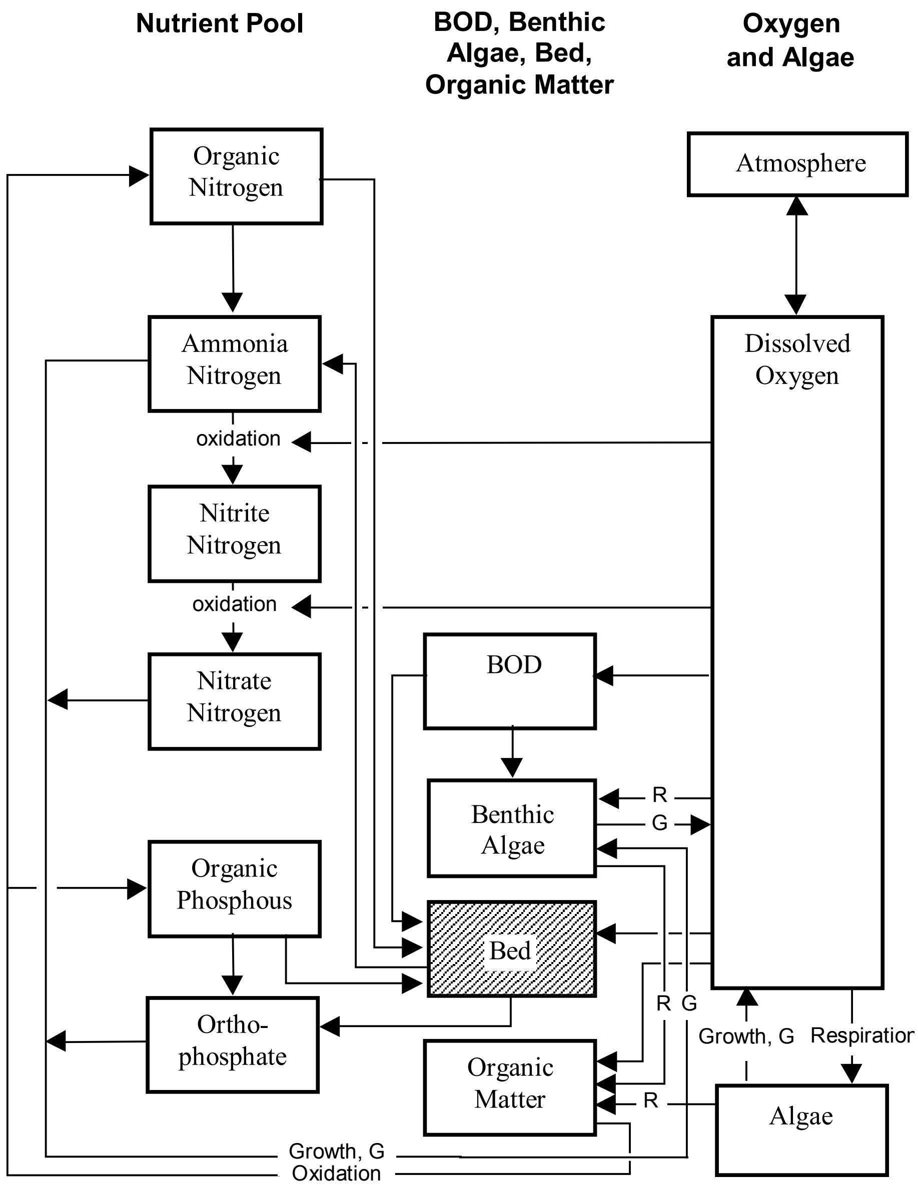


Figure 308. Selected water quality relationships for CE-QUAL-W2

7.2 RMA Models: Hydrodynamics and Water Quality

As with a handful of other numerical models, RMA-2 solves the full flow equations known as the St. Venant Equations, also called the shallow water equations. These equations utilize all terms of the conservation of momentum formulation and provide the most complete description of dynamic flow conditions. Several features of this model that make it a particularly useful tool for the Klamath River include:

- the model is a finite element model and the space-time criteria (e.g., Peclet number) for stability in the numerical solution of the governing equations is a necessary consideration

- the model has an option to represent steep river systems without utilizing unrealistic bed roughness parameters. This steep river system formulation is critical in representing proper transit times, which is paramount to modeling water quality
- the model has been widely applied (it is one of the most used full hydrodynamic model in the United States) to a variety of river and estuary systems in the United States as well as internationally. The model author is available for support.

RMA-11 solves the advection-diffusion equation to determine the fate and transport of up to 16 constituents. Selected process pertinent to this application are illustrated in Figure 309. The water quality algorithm is modular allowing constituents to be added. Other features include:

- the model interfaces directly with the geometry and output of RMA-2
- all standard water quality routines are from QUAL2E. These routines have been tested and reviewed for completeness and correctness
- Additional processes have been added to the model to simulate attached algae

The RMA-2 and RMA-11 Combination

Fundamental to effectively modeling water quality is the proper representation of the flow regime (hydrodynamics). The two models RMA-2 and RMA-11 provide a complete hydrodynamic model with a comprehensive water quality model, creating a powerful tool for assessing flow and water quality response in complex river systems. Although this model resides in the private sector, the source code is supplied with the executable when purchased. That is, these are open codes (as opposed to many proprietary codes where the source code is unavailable to the user). Further, many of the model applications have occurred in the public sector (government agencies, universities, etc.) and the RMA-2 code has undergone intensive peer review.

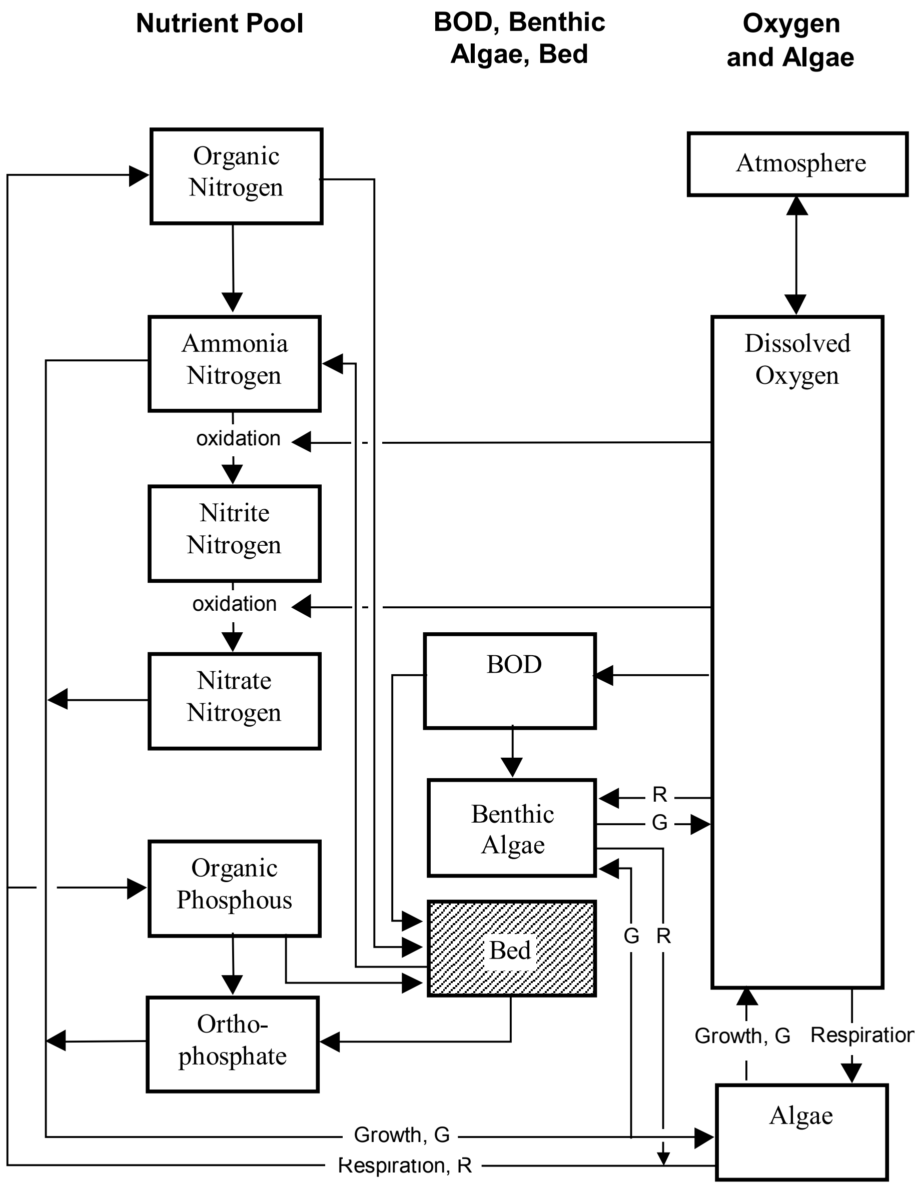


Figure 309. Selected water quality relationships for RMA-11

7.3 WQRRS (Reservoir Module)[6]

The model WQRRS is an Army Corps of Engineers river and reservoir system model, but the river and reservoir modules can be modeled separately. For this application the reservoir module is applied. Some of the attributes that are unique to WQRRS include the fact that is essentially an ecological model, representing not only water quality but also trophic levels from primary production, zooplankton predation, up to fish. Although

[6] The WQRRS model was replaced with CE-QUAL-W2 at JC Boyle, Iron Gate, and Copco Reservoirs.

all these processes are not deemed necessary for this application, because of its more comprehensive treatment of primary production it allows more flexibility, (e.g., benthic algae and phytoplankton, two species of phytoplankton, grazing by zooplankton). Further, the model readily allows for the simulation of selective withdrawal. The model has a few modifications/updates that may be pertinent to the Klamath River mainstem reservoirs, including

1) sediment nutrient release dynamics for ammonia and phosphorous
2) the ability of the analyst to examine the impacts of hypolimnetic oxygenation
3) seasonal evaporation coefficients

7.4 Interfacing the Models

Modeling the Klamath River reaches and reservoirs would require use of different models for reservoir and river reaches. The process of interfacing or linking the models is a matter of writing separate computer programs to process the output from one model (e.g., river model) such that it forms the input to the subsequent model (e.g., reservoir model). A necessary, but straightforward task. The end result is a model framework that can be used to examine individual reaches, or larger sections of the river and reservoir system.

7.5 Model Contact Information

7.5.1 CEQUAL-W2

U.S. Army Corps of Engineers, Waterways Experiment Station

Environmental Laboratory
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180
Contact: Thomas M. Cole(tcole@lasher.wes.army.mil)

7.5.2 RMA-2/RMA-11

Resource Management Associates PTY LTD

9 Dumaresq Street

Gordon

NSW 2071

Contact: Dr. Ian King (I.King@UNSW.EDU.AU)

7.5.3 WQRRS: Water Quality for River-Reservoir Systems

US Army Corps of Engineers – Hydrologic Engineering Center

609 2nd Street

Davis, CA 95616

Contact: none

8 River Geometry

8.1 River Location Description

The x-y coordinates describing the river location were defined using a digitized version of the 1:24,000 USGS topographic quadrangles provided by CH2M Hill. The coordinates provided were Eastings and Northings in the UTM Zone 10 NAD 83 projection (meters) rather than in degrees/minutes/seconds. The USGS hydro coverage did not cover the reservoirs in the upper basin, these were digitized by CH2M Hill. A centerline was used to depict the line of the river through the reservoirs. The dataset provided by CH2M Hill had and a length of 257.08 river miles (from Link Dam to the mouth) and coordinates that were irregularly spaced. This data set was processed using a program called "Make River" that uses linear interpolation to produce an evenly spaced set of coordinates, and consequently shortens the river slightly. The coordinates were processed to 150-meter intervals, with a new river length 253.88 miles. This corresponded more closely with the most commonly used river mile index developed by the USGS. Once completed, this geometry was used to define the individual reaches as well as the description of the "without project" scenario.

9 Flow Data

9.1 Tributaries from Iron Gate Dam to Turwar

Accretions from Iron Gate Dam to Turwar were defined and quantified according to the methodology identified by USGS (1995, 1997). In sum, the river was divided into multiple segments (reaches) based on available gages with full coverage between 1961 and 1922. USGS used monthly averages to determine accretions and depletions for each reach based on the differences in gage readings. These accretions and depletions were then assigned to individual tributaries based on estimated basin area (individual sub-basin contributions were obtained from personal communication with Mr. M. Flug). Not all tributaries to the Klamath River were included.

For this exercise, 7-day average values were used to identify accretions and depletions for identified tributaries. The same tributaries identified by USGS (1997) were used herein. The methodology is outlined below.

Total Accretion from Iron Gate Dam to Seiad Valley. Accretion value is equal to the flow at gage 11520500 (Klamath River nr. Seiad Valley) minus the sum of the flows at gages 11516530 (KR below Iron Gate Dam), 11517500 (Shasta River nr. Yreka), 11519500 (Scott River nr Fort Jones). This reach accretion is further sub-divided into shorter sub-reaches by according to the following criteria.

<u>Klamath River from Iron Gate Dam to the confluence of the Shasta River</u>. Accretion equals 24.2% of the total area accretion.

This accretion is distributed between the following creeks as determined by watershed area:

Bogus Creek – 41%

Willow Creek – 22%

Cottonwood Creek – 37%

<u>Klamath River from the confluence of the Shasta River to the confluence of the Scott River</u>.

Accretion equals 38.2% of the total area accretion.

This accretion is distributed between the following creeks as determined by watershed area:

Humbug Creek – 28%

Beaver Creek – 32%

Horse Creek – 40%

<u>Scott River from Ft. Jones to the confluence of the Klamath River</u>.

Accretion equals 29.0% of the total area accretion.

Klamath River from the confluence of the Scott River to Seiad valley. Accretion equals 8.6% of the total area accretion. This accretion is applied at Grider Creek.

Total Accretion from Klamath River from Seiad Valley to Orleans. Accretion equals the flow at gage 11523000 (Klamath River at Orleans) minus the sum of the flows at gages 11520500 (Klamath River nr Seiad Valley), 11522500 (Salmon River at Somes Bar, Ca), and 11521500 (Indian Cr nr Happy Camp).

This accretion is distributed between the following creeks as determined by watershed area:

Thompson Creek – 16.6%

Elk Creek – 16.6%

Clear Creek – 21.4%

Ukonom Creek – 12.9%

Dillon Creek – 32.5%

Total Accretion from Klamath River from Orleans to the Mouth. Accretion equals gage 15530500 (KR nr Klamath (Turwar), CA) minus gage 15523000 (KR at Orleans) and 11530000 (Trinity River at Hoopa).

Klamath River from Orleans to the confluence of the Trinity River.

Accretion equals 29.3% of the total area accretion.

This accretion is distributed between the following creeks as determined by watershed area:

Camp Creek – 33.3%

Red Cap Creek – 33.3%

Bluff Creek – 33.3%

Trinity River from Hoopa to the confluence with the Klamath River. Accretion equals 12.3% of the total area accretion.

Klamath River from the confluence of the Trinity River to the mouth. Accretion equals 58.4% of total area accretion.

This accretion is distributed between the following creeks as determined by watershed area:

Pine Creek – 33.3%

Tectah Creek – 33.3%

Blue Creek – 33.3%

10 Meteorological Data

The required hourly information for the meteorological input file consists of: air temperature (^oC), dew point temperature (^oC), wind speed (m/s), wind direction (radians), cloud cover (scale 0-10) and solar radiation (W/m^2). The Agrimet station located in Klamath Falls, Oregon, (KFLO) provided all of these parameters except for cloud cover. Wind speed and wind direction had to be converted to the units consistent with model requirements. The station provided hourly cumulative solar radiation. The difference between the cumulative solar radiation at each hour was determined and converted to the necessary units. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. This ratio was then converted to the appropriate scale for input into the model. It should be noted that this scale, from 0-10 is different from the scale required for RMA modeling, which is a scale from 0-1. Both sets of cloud cover were calculated from the same solar radiation data. Atmospheric pressure was unavailable, and was calculated based on elevation and a constant sea level pressure of 1013 mb.

Klamath Falls data was used throughout the modeling domain, i.e., from Link Dam (RM 255) to the mouth (RM 0) because it was the most complete and consistently avaiable record. However, it is clear that atmospheric conditions vary appreciably throughout the study reach due to elevation, orographic features, proximity to the Pacific Ocean, and the shear size of the study area. Meteorological observations within the basin are limited and non-uniformly distributed. Further, available parameters vary among stations. To overcome some of the challenges with representing meteorological conditions system-wide, PacifiCorp installed two additional weather stations (at Iron Gate Dam and Copco Village) to gather additional information within the project area. These stations, coupled with the station at Klamath Falls, the station maintained by the Yurok Tribe at Weitchpec, and observation locations in the Shasta Valley (National Weather Service at Montague and California Department of Forestry at Brazie Ranch) were examined to determine meteorological variability throughout the basin and, to the extent feasible, adjust parameters to more fully represent local conditions.

Klamath Falls (KFLO) meteorological data was used directly for the following reaches

- Link River
- Lake Ewauna to Keno Dam
- Klamath River from Keno Dam to JC Boyel Reservoir
- JC Boyle Reservoir
- JC Boyle Dam to Copco Reservoir

The only variations herein included modifying atmospheric pressure for elevation. Adjustment to meteorological parameters for Copco and Iron Gate Reservoirs, as well as the Klamath River reach from Iron Gate Dam to the mouth are presented below.

10.1 Copco and Iron Gate Reservoirs

Because Copco and Iron Gate Reservoir are roughly 1500 feet and 1700 feet, respectively, lower than Klamath Falls, the air temperature was adjusted to accommodate for the change in elevation. A lapse rate of 3.0 °C, based on data from Klamath Falls and a meteorological station at Iron Gate Dam. Air temperature was adjusted according to the following formula, based on Linacre (1992).

$$T_1 = T_2 + 0.003h \quad (1)$$

Where: T1 = temperature at site 1

T2 = temperature at site 2

h = $E_2 - E_1$, meters

E_1 = Elevation of site 1

E_2 = Elevation of site 2

the purposes of this study an average elevation of Copco and Iron Gate Reservoirs was applied (2450 ft (746.77 m)). Field data did not suggest any additional relationships between the Klamath Falls and Iron Gate Reservoir site. Thus, the remaining meteorological parameters from the KFLO station were not modified.

10.2 Meteorological Conditions below Iron Gate Dam

A review of available meteorological data at multiple locations in the Klamath River basin suggests variable meteorological conditions throughout the study area. Meteorological data are available in various forms, formats, frequencies, and for selected parameters at the several meteorological stations in the basin. Six stations were identified for meteorological data comparison and assessment for the 2002 field season (Table 1).

Table 108 Inventory of full meteorological stations located within the project area.

Station Name	Agency	Installation Date	Parameters	Elevation (ft)	Lat/Long
Klamath Falls	U.S. Bureau of Reclamation	3/31/99-present	S,W,Ta,P, RH,DP	4100	42°01' 53"N 121°45' 18"W
Copco Reservoir	PacifiCorp	6/7/02-present	S,W,Ta,P, RH,DP	2625 (approx)	n/a

Iron Gate Reservoir	PacifiCorp	6/7/02-present	S,W,Ta,P, RH,DP	2350 (approx)	n/a
Brazie Ranch	California Dept. of Forestry	1995/2000-present	S,W,Ta,RH	3020	41.6870N 122.6000W
Montague	National Weather Service	1930-present*	W,Ta,RH, DP,P	2518.4	41°44'N 122°33'W
Weitchpec	Yurok Tribe	2/11/02-present	S,W,Ta,RH,DP, P	300 (approx)	

* Data not archived until 2001. Sub-daily data not available prior to April 2001.

S – Solar Radiation
P – Atmospheric pressure
W – Wind Speed
RH – Relative humidity
Ta – Air temperature
DP – Dew point temperature

As illustrated in Table 1, meteorological monitoring is not consistent and the records are not particularly long. To include as many years as possible for analysis, Klamath Falls (KFLO) was used as the base data set, providing 3 full years of meteorological data. This data set was then compared with available records for 2002 to determine if there were clear relationships between Klamath Falls and the middle and lower Klamath basin regions. Common parameters used for comparison included air temperature (dry bulb), dew point temperature, and wind speed.

10.2.1 Air Temperature

Monthly mean air temperature was compared at each site from May through December (Figure 1). Lapse rates from Linacre (1992) were on the order of 6°C per 1000 meters of elevation change. Based on the available data, this rate of change appeared excessive. A lapse rate of 3°C per 1000 meters of elevation change was selected as a maximum.

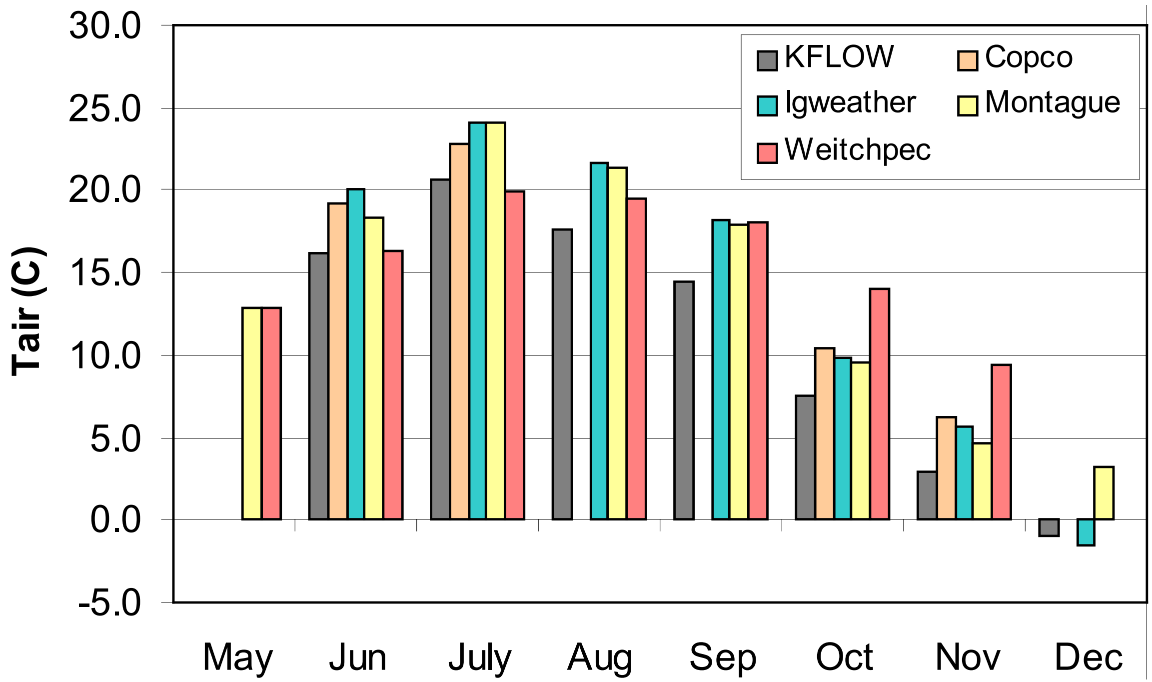


Figure 1 Air temperature at five locations in the Klamath Basin

The lapse rate for air temperature varied seasonally. The higher elevations around Klamath Falls (elevation >4000 ft) experience cold winters and relatively mild summer air temperatures. The coastal area experiences cool winters, with few days below freezing, and mild summers, similar to those found around Klamath Falls, followed by warm fall conditions. Finally the middle Klamath Basin experiences cold winters, hot summer, and warm fall conditions. The corrections based on the identified lapse rates are shown in Table 2.

Table 109 Air temperature corrections, based on month for Klamath River temperature modeling

Month	Correction: Klamath Falls (°C)	Correction: Iron Gate to Orleans (°C)	Correction: Orleans to Turwar (°C)
January	0.0	0.0	3.5
February	0.0	0.0	3.5
March	0.0	0.0	2.5
April	0.0	2.5	1.5
May	0.0	2.5	0.5
June	0.0	2.5	0.0
July	0.0	2.5	0.0
August	0.0	2.5	0.5
September	0.0	2.5	1.5
October	0.0	2.5	2.5
November	0.0	2.5	3.5
December	0.0	0.0	3.5

Positive corrections are added to the KFLO data to arrive at local conditions

10.2.2 Dew Point

Monthly mean dew point temperature was compared at each site from May through December (Figure 2). Although most locations were quite similar, Weitchpec showed a marked deviation.

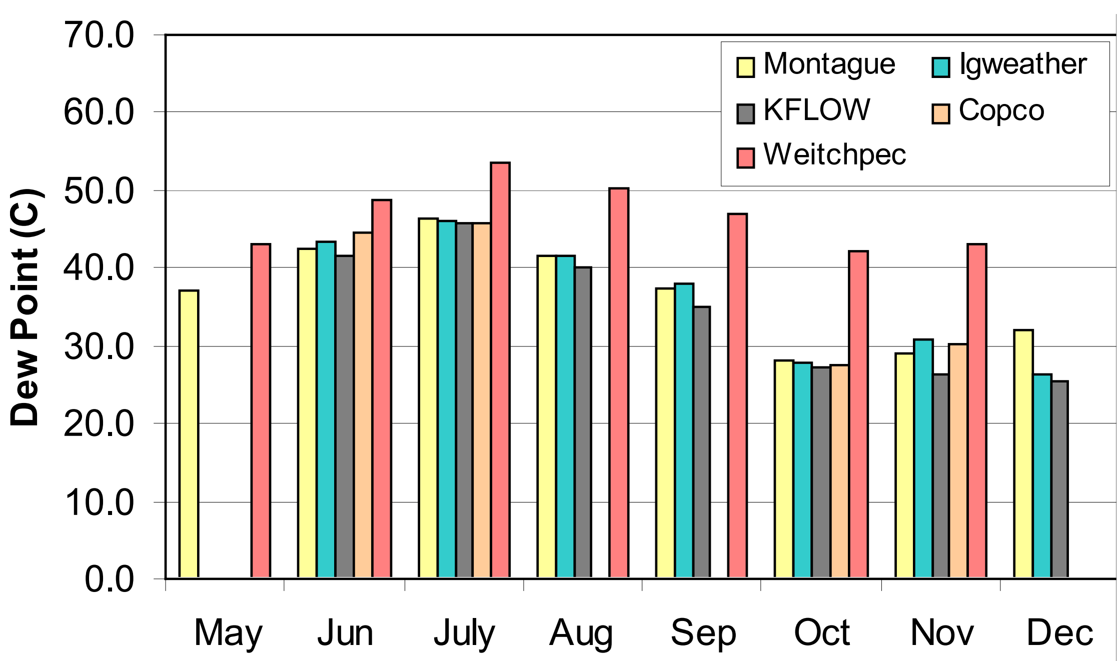


Figure 2 Dew point temperature at five locations in the Klamath Basin

A lapse rate of 6.9°C per 1000 meters of elevation change was selected as a maximum for dew point temperature. This lapse rate was only applied to the lower river region – below Orleans. Further the correction was applied seasonally as shown in Table 3. Dew Point temperatures were used to determine wet bulb temperatures for use in the model.

Table 110 Dew point temperature corrections, based on month for Klamath River temperature modeling

Month	Correction: Klamath Falls (°C)	Correction: Copco and Iron Gate Res. (°C)	Correction: Iron Gate to Orleans (°C)	Correction: Orleans to Turwar (°C)
January	0.0	0.0	0.0	8.0
February	0.0	0.0	0.0	8.0
March	0.0	0.0	0.0	8.0
April	0.0	0.0	0.0	8.0
May	0.0	0.0	0.0	5.5
June	0.0	0.0	0.0	4.0
July	0.0	0.0	0.0	4.0
August	0.0	0.0	0.0	5.5
September	0.0	0.0	0.0	5.5
October	0.0	0.0	0.0	8.0
November	0.0	0.0	0.0	8.0
December	0.0	0.0	0.0	8.0

Positive corrections are added to the KFLO data to arrive at local conditions

10.2.3 Wind Speed

Monthly mean wind speed was compared at each site from May through December (Figure 3).

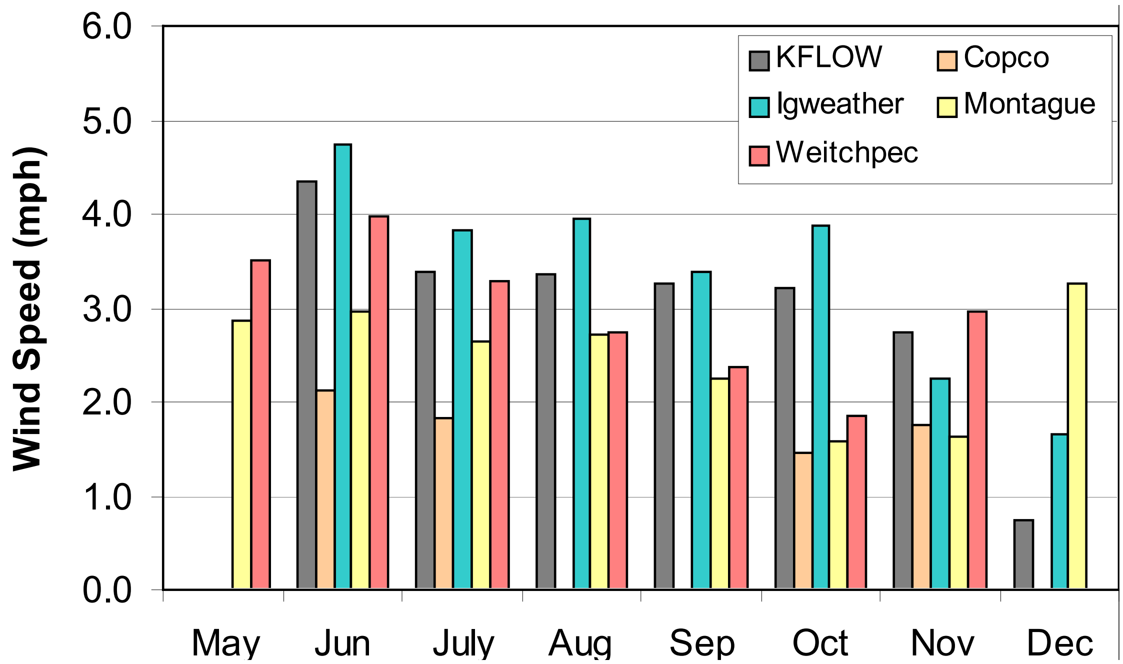


Figure 3 Wind speed at five locations in the Klamath Basin

Although seasonal variations are apparent in the mean monthly data, there was no clear trend (with the exception of Copco Reservoir, which due to a short record was not adjusted) or methods to make adjustments to wind. All sites utilized the KFLO wind data.

10.2.4 Atmospheric Pressure

Atmospheric pressure was corrected for elevation or calculated based on elevation.

10.2.5 Solar Radiation

Solar Radiation from Klamath Falls was used at all locations.

10.2.6 Summary

Based on air temperature the basin was divided into three meteorological "regions" (Figure 4). The upper basin extends from Link Dam to Copco Reservoir and utilizes Klamath Falls meteorological data. The middle region extends from Iron Gate Dam to Orleans The lower region, from Orleans to Turwar. Each reach is summarized below, data are summarized in Table 4.

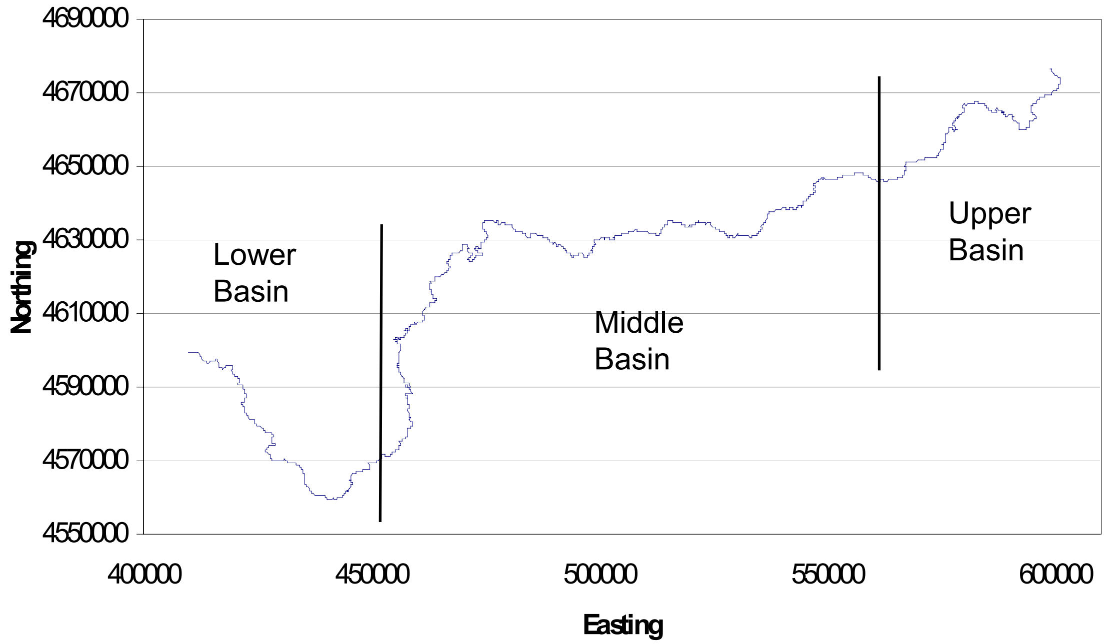


Figure 4 Meterological regions in the study area.

<u>Iron Gate Dam to Orleans</u>

The Klamath River from Iron Gate Dam to Orleans was modeled with RMA-11 for water temperature. The meteorological data set used for these models was based on KFLO data with the air temperature and atmospheric pressure corrected for elevation difference based on an elevation of 1320 at Seiad Valley. No modification was made to dew point temperatures, wind speed, or solar radiation. Dew point was converted to wet bulb temperatures for use in RMA-11.

<u>Orleans to Turwar</u>

The Klamath River from Orleans to Turwar was modeled with RMA-11 for water temperature. The meteorological data set used for these models was based on KFLO data with the air temperature, dew point, and atmospheric pressure corrected for elevation difference based on an elevation of 300 ft near the Trinity River. No modification was made to wind speed, or solar radiation. Dew point was converted to wet bulb temperatures for use in RMA-11.

Table 111 Meteorological Data used in model simulations

Location	Representative Elevation	Solar	Tair	Dew Point	Wind Speed	Barometric Pressure
Upper Basin	Klamath Falls	KFLO	KFLO	KFLO	KFLO	f(elevation)
Middle Basin*	Seiad Valley and Copco/Iron Gate*	KFLO	KFLO Corrected[1]	KFLO	KFLO	f(elevation)

Lower Basin	Weitchpec	KFLO	KFLO Corrected[2]	KFLO Corrected[3]	KFLO	f(elevation)

[1] Lapse Rate of 3.0°C per 1000 m of elevation change: April 1-Dec. 1

[2] Lapse Rate of 3.0°C per 1000 m of elevation change: seasonally

[3] Lapse Rate of 6.9°C per 1000 m of elevation change: seasonally

* For Existing Condition and Steady Flow scenarios, CE-QUAL-W2 representations of Copco and Iron Gate Reservoir use lapse rates and atmospheric pressure calculated on the average elevation of these two reservoirs. For the Without Project Scenario, KFLO data is used, without modification, from Link Dam to Iron Gate Dam. For all simulations between Iron Gate Dam and Orleans, Seiad Valley is used as the elevation for lapse rate and atmospheric pressure calculations.

11 Water Quality Data

The 2002 field work was divided into two types of sample collection: monthly sampling and synoptic surveys. E&S Environmental performed the monthly sampling and both E&S and Watercourse Engineering, Inc. performed the synoptic surveys. There were nine monthly sampling sessions and three synoptic surveys performed during the 2002 collection. Field personnel collected four hundred twenty one sets of water samples from twenty two sites along the Klamath River from March 26 through November 13, 2002. The water sample sets were sent to Basic Laboratory in Redding, CA to be analyzed for total alkalinity, total Kjedhal nitrogen, ammonia, nitrate/nitrite, total phosphorus, ortho-phosphate, and biological oxygen demand. These parameters will be used to characterize the water quality in the main stem of the Klamath River, to identify water quality parameters of concern within selected river reaches, and to estimate input parameters for water quality models. Watercourse Engineering, Inc, in Napa, CA is responsible for ensuring the reliability of the data. In order to ensure data reliability, field personnel incorporated external quality assurance samples (QA samples) with the production samples as per the Quality Assurance Project Plan (QAPP) adopted by PacifiCorp and the U.S. Bureau of Reclamation (USBR).

The 2002 field data are attached in the following table.

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
3/26/2002	1012		Klamath R below JC Boyle Dam	65	0.9	0.14	0.27	0.51	0.11	<3	7.52	11.54	128	8.02
3/26/2002	1057		Klamath R Bypass Reach above Powerhouse	68	0.2	0.09	0.23	0.33	0.12	<3	9.29	11.89	108	8.21
3/26/2002	1113		JC Boyle Powerhouse Release	65	1.0	0.11	0.24	0.31	0.10	3	7.79	11.75	128	7.89
3/26/2002	1206		Spencer Creek	38	1.0	0.07	<0.05	0.15	0.05	<3	4.21	11.26	42	7.80
3/26/2002	1237		Klamath R above JC Boyle Reservoir	65	1.0	0.13	0.18	0.48	0.12	<3	8.86	10.32	126	7.92
3/26/2002	1355	1	JC Boyle Reservoir at Dam	61	1.0	0.11	0.21	0.30	0.10	<3	8.21	10.16	127	7.80
3/26/2002	1407	8	JC Boyle Reservoir at Dam	60	1.2	0.12	0.20	0.37	0.11	3	7.20	9.83	129	7.75
3/26/2002	1443		JC Boyle Reservoir upper	62	1.2	0.09	0.25	0.37	0.10	4	9.11	10.54	127	7.84
3/26/2002	1543		Klamath R below Keno Dam	64	1.0	0.12	0.12	0.50	0.10	3	8.19	10.85	126	7.90
3/27/2002	1051		Klamath R above Shovel Creek	64	0.8	<0.05	0.32	0.67	0.17	<3	7.78	11.36	119	8.04
3/27/2002	1103		Shovel Creek	43	<0.2	<0.05	<0.05	0.46	0.27	<3	5.93	11.25	60	8.05
3/27/2002	1213	1	Copco Reservoir at Dam	69	0.7	<0.05	0.23	0.70	0.24	<3	8.98	11.82	127	8.08
3/27/2002	1233	18	Copco Reservoir at Dam		0.8	0.06	0.31	0.70	0.13		6.16	9.81	121	7.77
3/27/2002	1237	25	Copco Reservoir at Dam	69	0.9	0.11	0.31	0.30	0.40	<3	6.03	9.57	120	7.68
3/27/2002	1321		Fall Creek	74	<0.2	0.05	0.07	0.25	0.25	<3	9.93	10.73	96	8.25
3/27/2002	1358		Klamath R above Irongate Reservoir	69	0.6	0.06	0.26	0.41	0.37	3	7.97	10.69	123	7.89
3/27/2002	1415		Jenny Creek	47	0.2	<0.05	<0.05	0.30	0.24	<3	7.67	12.59	62	7.99
3/27/2002	1452	1	Irongate Reservoir above Dam	70	0.8	<0.05	0.23	0.39	0.32	<3	8.97	13.58	123	8.17
3/27/2002	1509	14	Irongate Reservoir above Dam	70	0.8	0.08	0.39	0.50	0.38	<3	6.80	11.04	120	7.76
3/27/2002	1516	30	Irongate Reservoir above Dam	71	0.6	0.11	0.43	0.45	0.34	<3	6.45	10.82	118	7.70
3/27/2002	1607		Klamath R below Irongate Dam	70	0.7	0.07	0.23	0.38	0.36	3	8.65	12.37	123	8.10
3/27/2002	1654		Shasta R	161	0.4	0.06	<0.05	0.87	0.68	7	14.44		409	8.87
4/16/2002	915		Klamath R below JC Boyle Dam	54	0.9	0.11	0.13	0.18	0.16	<3	12.04	9.85	108	7.91
4/16/2002	1104		Klamath R Bypass Reach above Powerhouse	61	0.2	<0.05	0.15	0.53	0.20	<3	10.60	10.67	99	8.33
4/16/2002	1113		JC Boyle Powerhouse Release	53	0.8	0.14	0.14	0.24	0.17	<3	12.22	9.35	108	7.85
4/16/2002	1140		Spencer Creek	23	<0.2	<0.05	<0.05	0.20	0.09	<3	4.71	11.35	28	7.89
4/16/2002	1220		Klamath R below Keno Dam	72	1.0	0.14	0.13	0.42	<0.03	4	11.94	9.74	175	7.75
4/16/2002	1255		Klamath R above JC Boyle Reservoir	69	0.9	0.07	0.31	0.36	0.19	<3	12.17	10.10	177	8.06
4/16/2002	1443	1	JC Boyle Reservoir at Dam	54	0.7	0.10	0.13	0.27	0.16	<3	12.28	8.58	108	7.90
4/16/2002	1452	8	JC Boyle Reservoir upper	57	0.9	0.12	0.18	0.41	0.20	<3	11.88	8.62	112	7.79

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
4/16/2002	1528		JC Boyle Reservoir at Dam	66	0.8	<0.05	0.26	0.32	0.19	<3	11.21	9.55	160	7.86
4/16/2002	1604		Klamath R above Shovel Creek	60	0.8	0.06	0.25	0.41	0.20	<3	11.35	10.40	133	8.10
4/16/2002	1609		Shovel Creek	32	0.2	0.06	<0.05	0.25	0.17	<3	4.75	11.89	38	8.08
4/16/2002	1815		Shasta R	264	0.5	0.06	<0.05	0.41	0.32	4	11.52	10.85	382	8.79
4/17/2002	1045	1	Copco Reservoir at Dam	65	0.7	0.07	0.20	0.31	0.17	<3	13.15	9.14	137	8.15
4/17/2002	1104	15	Copco Reservoir at Dam	64	0.8	0.16	0.23	0.35	0.15	<3	9.33	7.60	124	7.74
4/17/2002	1110	25	Copco Reservoir at Dam	69	1.0	0.27	0.28	0.49	0.24	<3	7.12	5.93	124	7.48
4/17/2002	1200		Klamath R above Irongate Reservoir	65	0.8	<0.05	0.21	0.27	0.15	<3	12.33	9.45	132	7.82
4/17/2002	1210		Fall Creek	72	<0.2	<0.05	0.05	0.21	0.11	<3	8.75	11.34	95	8.15
4/17/2002	1230		Jenny Creek	44	<0.2	<0.05	<0.05	0.22	0.09	<3	5.35	12.24	56	8.10
4/17/2002	1342	1	Irongate Reservoir above Dam	60	0.7	0.07	0.13	0.39	0.09	<3	12.57	9.97	122	8.02
4/17/2002	1358	12	Irongate Reservoir above Dam	62	0.6	0.09	0.20	0.19	0.12	<3	9.85	8.64	119	7.79
4/17/2002	1412	30	Irongate Reservoir above Dam	66	0.7	<0.05	0.60	0.36	0.15	<3	6.45	7.60	118	7.52
4/17/2002	1515		Klamath R below Irongate Dam	60	0.5	0.05	0.14	0.20	0.12	<3	12.48	9.95	124	7.86
5/20/2002	1500		Klamath R above Copco		0.8	0.05	0.18	0.21	0.14		14.23b	9.8b	230b	8.81b
5/20/2002	1600		Klamath River at State Line		1.1	0.05	0.11	0.26	0.15		14.25b	8.91b	254b	8.4b
5/21/2002	900		Klamath R above Copco		0.6	0.08	0.12	0.16	0.17		12.23	9.34	254	8.17
5/21/2002	1000		Klamath River at State Line		0.6	0.09	0.17	0.53	0.18		12.44	9.45	250	8.31
5/21/2002	1028		Klamath Lake above Link Dam		0.8	0.21	<0.05	0.49	0.13		12.20	9.20	137	8.20
5/21/2002	1045		Mouth of Link R		0.8	0.29	<0.05	0.41	0.12		12.50	9.70	105	8.20
5/21/2002	1125		Shovel Creek		<0.2	0.07	<0.05	0.65	0.15					
5/21/2002	1141		Klamath R below Keno Dam		0.9	0.17	<0.05	0.63	0.14		13.00	9.40	166	8.60
5/21/2002	1209		Klamath R above JC Boyle Reservoir		<0.2	0.16	0.10	0.43	0.16		13.60	9.30	155	8.50
5/21/2002	1234		Spencer Creek		<0.2	0.10	<0.05	0.21	0.09		9.20	10.20	71	8.60
5/21/2002	1303		Klamath R Bypass Reach above Powerhouse		0.3	0.13	0.13	0.33	0.21		12.20	10.00	151	8.70
5/21/2002	1306		JC Boyle Powerhouse Release		0.9	0.24	0.10	0.45	0.17		13.90	8.80	190	8.40
5/21/2002	1330		Klamath River at State Line		0.7	0.29	0.15	0.30	0.18		13.51	9.17	246	8.54
5/21/2002	1350		Klamath R below JC Boyle Dam		0.8	0.18	0.12	0.43	0.16		13.80	9.00	209	8.40
5/21/2002	1415		Klamath R above Copco		0.6	0.15	0.11	0.47	0.20		13.48a	10.54a	228a	8.88a
5/21/2002	1455	1	JC Boyle Reservoir at Dam		0.9	0.22	0.11	0.48	0.16		14.00	8.70	229	8.20

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC μS/cm	pH
5/21/2002	1500	8	JC Boyle Reservoir at Dam		0.8	0.29	0.11	0.37	0.16		13.20	8.60	185	7.80
5/22/2002	810		Klamath River at State Line		0.8	0.08	0.14	0.24	0.13		11.54t	8.52t	240t	8.13t
5/22/2002	850		Shovel Creek	36	0.2	0.06	<0.05	0.19	0.10	<3				
5/22/2002	920		Klamath R above Copco		0.7	0.12	0.09	0.26	0.14		11.74b	10.22b	231b	8.55b
5/22/2002	1043	1	JC Boyle Reservoir at Dam	60	0.7	0.08	0.09	0.20	0.13	<3	13.60	11.84	174	7.70
5/22/2002	1045		Klamath R above Shovel Creek	64	0.7	0.08	0.11	0.18	0.14	<3				
5/22/2002	1048	8	JC Boyle Reservoir at Dam	58	0.8	0.11	0.09	0.20	0.13	<3	12.80	11.26	158	7.60
5/22/2002	1143		Klamath R above Irongate Reservoir	67	0.6	0.08	<0.05	0.13	0.11	<3	14.62	8.99	151	8.24
5/22/2002	1205		Klamath R below JC Boyle Dam	60	0.9	0.09	0.11	0.25	0.14	<3	13.30	10.10	168	8.60
5/22/2002	1213		Fall Creek	75	<0.2	<0.05	0.06	0.44	0.11	<3	10.24	10.72	103	8.15
5/22/2002	1233		Jenny Creek	60	0.2	0.05	<0.05	0.10	0.09	<3	10.75	10.80	93	8.23
5/22/2002	1238		Klamath R Bypass Reach above Powerhouse	69	0.3	0.06	0.14	0.20	0.15	<3	12.50	11.00	143	9.40
5/22/2002	1247		JC Boyle Powerhouse Release	60	0.8	0.08	0.09	0.24	0.13	<3	13.30	10.00	166	9.00
5/22/2002	1303		Klamath R below Irongate Dam	65	0.6	0.06	<0.05	0.19	0.10	<3	14.67	10.55	139	8.53
5/22/2002	1318		Spencer Creek	40	0.1	<0.05	<0.05	0.08	0.06	<3	11.90	10.60	70	9.70
5/22/2002	1344		Klamath R above JC Boyle Reservoir	56	0.8	0.06	0.09	0.24	0.45	<3	14.70	11.10	155	9.40
5/22/2002	1350		Klamath River at State Line		0.7	0.09	0.09	0.19	0.13		13.76t	9.1t	228t	8.68t
5/22/2002	1415		Klamath R below Keno Dam	60	0.9	0.06	<0.05	0.28	0.14	<3	13.10	10.70	161	8.70
5/22/2002	1425		Shasta R	292	0.7	0.06	<0.05	0.48	0.31	<3	16.66	11.97	483	8.83
5/22/2002	1445		Mouth of Link R	45	0.8	0.06	<0.05	0.17	0.10	<3	13.40	10.60	103	9.20
5/22/2002	1455		Klamath R above Copco		0.6	0.09	0.08	0.25	0.15		13.95t	10.71t	218t	9.01t
5/22/2002	1500		Klamath R above Shasta	68	0.7	0.06	<0.05	0.16	0.10	<3	17.03	11.22	151	8.81
5/22/2002	1507		Klamath Lake above Link Dam	43	0.7	<0.05	<0.05	0.12	0.08	<3	13.60	10.50	102	9.10
5/23/2002	325	25	Copco Reservoir at Dam	64	1.0	0.33	0.24	0.38	0.25	4	9.51	1.10	130	7.16
5/23/2002	557	1	Copco Reservoir at Dam	66	0.7	<0.05	<0.05	0.21	0.09	<3	14.88	9.60	151	8.64
5/23/2002	612	12	Copco Reservoir at Dam	65	0.5	0.07	0.08	0.22	0.11	<3	13.57	7.48	146	7.93
5/23/2002	656	1	JC Boyle Reservoir at Dam		0.8	0.07	0.09	0.27	0.14		13.40	12.40	156	8.00
5/23/2002	702	8	JC Boyle Reservoir at Dam		0.7	0.05	0.10	0.16	0.07		13.10	11.10	154	7.70
5/23/2002	745		Klamath River at State Line		0.7	0.06	0.11	0.22	0.12		11.57b	8.36b	225b	8.08b
5/23/2002	752	1	Irongate Reservoir above Dam	66	0.6	<0.05	<0.05	0.44	0.08	<3	15.01	10.39	142	8.79

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
5/23/2002	807	12	Irongate Reservoir above Dam	65	0.4	<0.05	0.15	0.27	0.15	<3	13.57	7.48	146	7.93
5/23/2002	815	30	Irongate Reservoir above Dam	32	0.7	<0.05	0.34	0.24	0.15	<3	9.47	0.78	130	7.13
5/23/2002	822		Klamath R below JC Boyle Dam		0.8	<0.05	<0.05	0.21	0.08		13.20	9.30	156	8.10
5/23/2002	830		Shovel Creek		0.3	0.05	<0.05	0.24	0.09					
5/23/2002	856		Klamath R Bypass Reach above Powerhouse		0.7	<0.05	0.10	0.25	0.13		10.90	10.80	139	9.10
5/23/2002	900		JC Boyle Powerhouse Release		0.3	<0.05	0.14	0.35	0.14		13.10	10.20	154	8.80
5/23/2002	900		Klamath R above Copco		0.9	0.06	0.06	0.21	0.12		11.41	10.09	219	8.44
5/23/2002	1058		Spencer Creek		0.9	0.10	0.08	0.23	0.13		9.40	10.70	71	9.40
5/23/2002	1128		Klamath R above JC Boyle Reservoir		0.2	<0.05	<0.05	0.16	0.06		14.00	9.90	229	9.80
5/23/2002	1205		Klamath R below Keno Dam		0.9	<0.05	0.11	0.24	0.16		13.00	10.10	248	9.80
5/23/2002	1249		Mouth of Link R		1.1	<0.05	<0.05	0.30	0.17		13.40	10.30	103	9.40
5/23/2002	1304		Klamath Lake above Link Dam		0.7	<0.05	<0.05	0.22	0.09		13.10	9.80	101	9.60
6/18/2002	1015		Klamath R below JC Boyle Dam	88	1.1	0.15	0.24	0.38	0.25	<3	19.09	8.12	225	8.34
6/18/2002	1113		Klamath R Bypass Reach above Powerhouse	74	0.8	0.12	0.23	0.24	0.16	<3	13.80	9.78	139	8.23
6/18/2002	1119		JC Boyle Powerhouse Release	97	1.8	0.20	0.26	0.35	0.24	<3	18.97	7.53	227	8.12
6/18/2002	1154		Spencer Creek	58	0.2	0.03	<0.05	0.14	0.08	4	17.16	8.67	98	8.11
6/18/2002	1219		Klamath R above JC Boyle Reservoir	93	1.3	0.07	0.27	0.36	0.24	4	18.88	8.80	233	8.66
6/18/2002	1255		Klamath R below Keno Dam	92	1.6	0.15	<0.05	0.38	0.21	6	18.33	8.76	228	8.87
6/18/2002	1427	1	JC Boyle Reservoir at Dam	88	1.0	0.08	0.17	0.35	0.23	4	20.56	9.19	227	8.78
6/18/2002	1436	8	JC Boyle Reservoir at Dam	92	1.3	0.17	0.27	0.36	0.24	3	18.46	6.76	234	8.10
6/19/2002	1043		Klamath R above Shovel Creek	88	1.2	0.11	0.24	0.32	0.22	<3	16.66	10.18	197	8.46
6/19/2002	1207	1	Copco Reservoir at Dam	77	1.1	0.12	<0.05	0.37	0.17	5	20.11	9.12	182	8.58
6/19/2002	1219	9	Copco Reservoir at Dam	75	1.0	0.18	0.07	0.30	0.14	2	18.13	7.19	174	8.22
6/19/2002	1231	25	Copco Reservoir at Dam	71	1.1	0.24	0.43	0.36	0.29	<3	11.09	0.27	135	7.20
6/19/2002	1340		Klamath R above Irongate Reservoir	78	1.0	0.11	0.08	0.34	0.18	<3	19.41	9.16	177	8.43
6/19/2002	1352		Fall Creek	76	0.5	0.10	0.09	0.21	0.07	<3	12.71	10.19	95	8.15
6/19/2002	1406		Jenny Creek	82	0.1	0.10	<0.05	0.14	0.03	<3	16.72	9.44	143	8.40
6/19/2002	1501	1	Irongate Reservoir above Dam	77	1.0	0.10	<0.05	0.32	0.15	3	22.21	9.70	190	8.58
6/19/2002	1507	15	Irongate Reservoir above Dam	72	1.0	0.10	0.06	0.19	0.14	4	18.28	7.52	172	8.16
6/19/2002	1530	30	Irongate Reservoir above Dam	70	1.0	0.13	0.69	0.26	0.18	<3				

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
6/19/2002	1645		Klamath R below Irongate Dam	68	1.1	0.10	<0.05	0.21	0.13	3	20.13	9.41	184	8.23
6/19/2002	1822		Klamath R above Shasta	78	1.0	0.04	<0.05	0.24	0.13	<3	22.22	10.25	186	9.11
6/19/2002	1845		Shasta R	284	1.0	0.04	<0.05	0.47	0.32	3	23.72	7.98	556	8.76
7/15/2002	1445		Klamath R above Copco		0.5	0.05	0.37	0.18	0.20		22.20	7.20	113	8.37
7/15/2002	1630		Klamath River at State Line		0.8	0.13	0.65	0.23	0.23		21.44	6.46	111	8.26
7/16/2002	815		Klamath River at State Line		<0.2	0.04	0.49	0.16	0.20		18.29	6.84	110	7.62
7/16/2002	900		Klamath R above Shovel Creek	62	0.6	0.05	0.62	0.26	0.23	3	19.80	7.19	114	8.06
7/16/2002	1032	1	Copco Reservoir at Dam	73	1.2	0.04	<0.05	0.21	0.18	8	23.33	11.61	181	9.16
7/16/2002	1040		Klamath R above Copco		0.6	0.05	0.65	0.17	0.24		20.96	7.56	117	8.25
7/16/2002	1056	13	Copco Reservoir at Dam	80	0.4	0.09	0.33	0.71	0.29	3	17.80	1.89	2	7.60
7/16/2002	1056	25	Copco Reservoir at Dam	72	0.7	0.42	0.07	0.46	0.45	5	11.60	0.11	141	7.12
7/16/2002	1102	1	JC Boyle Reservoir at Dam	58	1.0	0.12	0.72	0.29	0.27	3				
7/16/2002	1110	8	JC Boyle Reservoir at Dam	58	1.2	0.23	0.75	0.28	0.27	4				
7/16/2002	1136		Klamath R above Irongate Reservoir	71	0.7	0.06	0.14	0.19	0.22	4	21.76	7.60	182	8.53
7/16/2002	1138		Klamath R below JC Boyle Dam	58	1.1	0.27	0.76	0.27	0.28	5	23.90		132	
7/16/2002	1201		Fall Creek	74	0.2	<0.05	0.06	0.11	0.10	4	12.51	10.57	111	8.18
7/16/2002	1230		Klamath River at State Line		0.3	0.05	0.38	0.14	0.18		18.05	7.45	106	8.26
7/16/2002	1233		Jenny Creek	90	<0.2	<0.05	<0.05	<0.05	0.09	2	20.80	8.99	187	8.25
7/16/2002	1257		Klamath R Bypass Reach above Powerhouse	64	0.2	0.03	0.40	0.15	0.17	<3	16.40		139	
7/16/2002	1304		JC Boyle Powerhouse Release	58	1.1	0.21	0.78	0.27	0.27	3	23.90		130	
7/16/2002	1315		Shovel Creek	58	<0.2	0.09	0.08	0.09	0.12	<3	17.04	7.91	71	7.89
7/16/2002	1321	1	Irongate Reservoir above Dam	79	0.5	<0.05	<0.05	0.12	0.14	4	26.22	10.53	217	9.04
7/16/2002	1338	12	Irongate Reservoir above Dam	66	0.3	0.11	0.17	0.13	0.13	3	15.14	3.79	151	7.54
7/16/2002	1352	30	Irongate Reservoir above Dam	66	0.4	<0.05	0.61	0.14	0.19	<3	7.05	1.84	125	7.24
7/16/2002	1405		Spencer Creek	64	<0.2	<0.05	<0.05	<0.05	0.07	<3	22.90		114	
7/16/2002	1415		Klamath R above Copco		0.5	0.07	0.37	0.21	0.21		21.00	6.86	110	8.49
7/16/2002	1431		Klamath R above JC Boyle Reservoir	56	1.0	0.11	0.91	0.25	0.25	3				
7/16/2002	1510		Klamath R below Keno Dam	60	2.3	0.48	0.05	0.31	0.18	5	24.10			
7/16/2002	1513		Klamath R below Irongate Dam	77	0.6	0.06	0.10	0.18	0.18	3	22.16	9.13	196	8.38
7/16/2002	1550		Klamath R above Shasta	75	0.4	0.06	0.07	0.15	0.18	4	24.92	10.71	207	8.81

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
7/16/2002	1619		Shasta R	246	0.5	0.08	<0.05	0.30	0.38	3	28.57	8.49	578	8.77
7/17/2002	815		Klamath River at State Line		0.5	0.07	0.47	0.19	0.18		18.08	7.50	110	7.64
7/17/2002	930	1	JC Boyle Reservoir at Dam		1.4	0.15	0.69	0.42			24.20	5.90		
7/17/2002	934	9	JC Boyle Reservoir at Dam		1.3	0.24	0.75	0.37	0.24		23.00	3.90		
7/17/2002	945		Klamath R above Copco		0.8	0.11	0.66	0.23	0.20		20.63	7.90	120	7.98
7/17/2002	1004		Klamath R below JC Boyle Dam		1.3	0.15	0.74	0.53	0.23		23.50			
7/17/2002	1109		Klamath R Bypass Reach above Powerhouse		0.4	0.14	0.40	0.29	0.14		16.30	8.70		
7/17/2002	1112		JC Boyle Powerhouse Release		1.3	0.18	0.76	0.51	0.27		23.10	6.10		
7/17/2002	1201		Klamath R above JC Boyle Reservoir		1.2	<0.05	0.98	0.50	0.21		24.20			
7/17/2002	1230		Klamath R below Keno Dam		1.4	0.68	0.05	0.42	0.16		23.80	6.60		
7/17/2002	1250		Klamath River at State Line		0.5	0.07	0.37	0.13	0.15		17.95	7.89	105	8.42
7/17/2002	1415		Klamath R above Copco		0.5	0.11	0.39	0.17	0.16		21.07	8.09	110	8.63
7/17/2002	1500		Klamath Lake above Link Dam		2.0	0.25	0.06	0.62	0.11		24.00	5.70		
7/17/2002	1515		Mouth of Link R		2.0	0.23	0.11	0.55	0.10		24.80	6.40		
7/18/2002	625	1	JC Boyle Reservoir at Dam		1.6	0.12	0.67	0.30	0.21		24.20	6.70		
7/18/2002	628	9	JC Boyle Reservoir at Dam		1.6	0.26	0.75	0.30	0.24		22.70	4.30		
7/18/2002	715		Klamath R below JC Boyle Dam		1.5	0.21	0.76	0.28	0.24		22.80			
7/18/2002	755		JC Boyle Powerhouse Release		1.7	0.28	0.76	0.33	0.23		21.80	5.30		
7/18/2002	800		Klamath River at State Line		0.6	0.11	0.51	0.57	0.17		18.62	6.84	104	7.67
7/18/2002	805		Klamath R Bypass Reach above Powerhouse		0.5	0.05	0.37	0.16	0.13		14.50	8.70		
7/18/2002	915		Klamath R above Copco		0.8	0.12	0.70	0.54	0.20		20.57	7.35	119	8.06
7/18/2002	930		Klamath R above JC Boyle Reservoir		1.8	0.11	1.05	0.30	0.23		21.70	7.20		
7/18/2002	1017		Klamath R below Keno Dam		<0.2	0.60	0.08	0.27	0.19		23.20	6.30		
7/18/2002	1100		Mouth of Link R		2.0	0.28	0.18	0.18	0.11			6.20		
7/18/2002	1127		Klamath Lake above Link Dam		2.1	0.24	0.10	0.18	0.09		24.70	5.00		
8/13/02	915		Klamath R below JC Boyle Dam	72	1.7	0.27	0.82	0.30	0.30	3	20.09	7.85	184	7.94
8/13/02	1018		Klamath R Bypass Reach above Powerhouse	65	0.5	0.10	0.36	0.15	0.19	3	13.92	9.74	127	8.26
8/13/02	1024		JC Boyle Powerhouse Release	70	1.6	0.22	0.73	0.29	0.29	4	19.34	7.35	179	7.86
8/13/02	1122		Spencer Creek	66	0.1	0.04	<0.05	0.05	0.06	<3	16.90	8.66	108	8.21
8/13/02	1148		Klamath R above JC Boyle Reservoir	72	1.8	0.09	0.71	0.28	0.29	5	21.01	8.36	199	8.48

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
8/13/02	1221		Klamath R below Keno Dam	75	2.1	0.64	0.13	0.28	0.24	5	20.56	7.46	203	8.15
8/13/02	1316	1	JC Boyle Reservoir at Dam	72	1.7	0.39	0.66	0.30	0.29	5	22.19	6.64	196	7.91
8/13/02	1331	8	JC Boyle Reservoir at Dam	73	1.7	0.45	0.76	0.25	0.30	5	18.85	4.80	183	7.66
8/14/2002	1025		Klamath R above Shovel Creek	66	0.6	0.10	0.49	0.11	0.20	<3	18.00	10.12	150	8.38
8/14/2002	1037		Shovel Creek	61	0.1	0.07	<0.05	0.06	0.12	<3	14.86	9.88	98	8.10
8/14/2002	1151	1	Copco Reservoir at Dam	71	0.9	0.14	0.35	0.14	0.18	4	21.84	9.25	163	8.60
8/14/2002	1209	17	Copco Reservoir at Dam	74	0.2	0.33	0.05	0.29	0.58	3	16.62	1.16	159	7.58
8/14/2002	1216	25	Copco Reservoir at Dam	70	1.2	1.04	<0.05	0.53	0.18	7	11.90	0.09	149	7.23
8/14/2002	1306		Klamath R above Irongate Reservoir	70	0.7	0.21	0.38	0.17	0.22	3	20.34	6.97	159	8.10
8/14/2002	1321		Fall Creek	73	0.2	0.08	0.07	0.03	0.08	7	13.33	10.56	113	8.04
8/14/2002	1339		Jenny Creek	70	0.3	0.08	<0.05	<0.05	0.07	<3	20.68	8.95	182	8.63
8/14/2002	1427	1	Irongate Reservoir above Dam	70	2.1	0.12	<0.05	0.17	0.11	14	25.09	16.85	190	9.70
8/14/2002	1442	12	Irongate Reservoir above Dam	70	0.7	0.11	0.45	0.17	0.25	<3	19.05	0.53	172	7.60
8/14/2002	1457	30	Irongate Reservoir above Dam	70	0.6	0.09	0.69	0.11	0.19	<3	7.14	0.10	125	7.25
8/14/2002	1557		Klamath R below Irongate Dam	72	1.2	0.14	0.15	0.16	0.15	8	22.42	10.50	177	9.16
8/14/2002	1642		Klamath R above Shasta	75	0.9	0.13	0.22	0.12	0.18	5	23.79	10.39	158	8.80
8/14/2002	1701		Shasta R	302	0.7	0.11	<0.05	0.28	0.41	4	27.62	9.32	667	8.91
9/9/2002	1400		Klamath River at State Line		0.4	0.09	0.16	0.14	0.42		14.90	9.45	176	8.14
9/9/2002	1515		Klamath R above Copco		0.5	0.08	0.16	0.12	0.41		13.72	9.01	178	7.88
9/10/2002	815		Klamath River at State Line		0.6	0.07	0.18	0.03	0.27		13.28	7.81	191	7.58
9/10/2002	910		Klamath R above Shovel Creek	70	0.9	0.08	0.13	0.16	0.14	2	14.00	8.47	224	7.78
9/10/2002	915	1	Copco Reservoir at Dam	78	0.7	0.07	0.26	0.23	0.19	5	18.51	7.66	202	8.50
9/10/2002	925	25	Copco Reservoir at Dam	84	1.4	0.95	<0.05	0.69	0.59	8	12.42	0.10	201	7.38
9/10/2002	930	14	Copco Reservoir at Dam	80	0.8	0.32	0.26	0.27	0.23	6	16.85	2.22	208	7.79
9/10/2002	950		Klamath R Bypass Reach above Powerhouse	80	<0.2	0.05	0.16	0.12	0.09	<3	12.20	9.65	137	8.21
9/10/2002	1005		JC Boyle Powerhouse Release	94	1.2	0.12	0.16	0.27	0.15	3	14.60	8.64	203	8.38
9/10/2002	1020		Klamath R above Irongate Reservoir	80	0.8	0.11	0.31	0.25	0.18	6	18.10	7.18	108	8.05
9/10/2002	1035		Klamath R above Copco		0.9	0.09	0.14	0.13	0.29		15.00	8.58	246	7.86
9/10/2002	1035		Klamath R below JC Boyle Dam	100	1.7	0.14	0.14	0.28	0.19	<3	16.80	8.78	248	8.48
9/10/2002	1045		Fall Creek	74	<0.2	0.09	0.07	0.03	<0.03	2	10.10	11.39	143	8.31

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
9/10/2002	1100		Jenny Creek	92	0.1	0.08	<0.05	0.08	<0.03	<3	13.04	10.60	192	8.51
9/10/2002	1135		Spencer Creek	62	0.3	0.04	<0.05	0.08	<0.03	<3	10.60	10.16	77	8.04
9/10/2002	1158	1	Irongate Reservoir above Dam	74	1.1	0.08	0.13	0.16	0.16	3	20.51	10.32	180	9.10
9/10/2002	1159		Klamath R above JC Boyle Reservoir	102	2.1	0.13	0.13	0.23	0.19	3	18.10	8.33	256	8.78
9/10/2002	1220		Klamath River at State Line		0.5	0.06	0.15	0.15	0.26		13.56	7.74	176	8.03
9/10/2002	1225	30	Irongate Reservoir above Dam	72	0.6	0.20	0.43	0.14	<0.03	3	7.34	0.06	193	7.36
9/10/2002	1230	16	Irongate Reservoir above Dam	90	0.4	0.08	0.19	0.21	0.15	6	14.97	0.15	188	7.51
9/10/2002	1234		Klamath R below Keno Dam	104	2.0	0.21	<0.05	0.29	0.17	5	17.40	8.97	250	8.98
9/10/2002	1300		Shovel Creek	64	0.1	0.07	0.05	0.07	0.26	<3	13.75	8.75	80	7.56
9/10/2002	1340		Klamath R below Irongate Dam	74	0.7	0.08	0.24	0.17	0.12	3	19.34	8.69	181	8.36
9/10/2002	1352	1	JC Boyle Reservoir at Dam	104	2.2	0.29	0.05	0.29	0.20	5	19.10	11.45	264	8.99
9/10/2002	1358	7	JC Boyle Reservoir at Dam	104	2.1	0.21	0.12	0.27	0.19	3	16.30	6.66	244	8.37
9/10/2002	1400		Klamath R above Shasta	76	0.6	0.19	0.23	0.17	0.13	<3	20.10	11.14	181	8.44
9/10/2002	1430		Klamath R above Copco		0.6	0.10	0.14	0.17	0.27		15.48	8.52	181	8.58
9/10/2002	1445		Shasta R	260	0.4	<0.05	0.05	0.26	0.19	4	19.62	10.37	567	8.75
9/11/2002	800		Klamath River at State Line		0.9	0.09	0.17	0.15	0.14		14.49	6.58	251	7.24
9/11/2002	838		Klamath R above JC Boyle Reservoir		1.5	0.22	0.24	0.27	0.19		15.20	8.08	234	8.14
9/11/2002	906		Klamath R below JC Boyle Dam		1.5	0.31	0.10	0.26	0.21		16.60	8.33	249	8.58
9/11/2002	945		Klamath R above Copco		1.1	0.09	0.11	0.17	0.13		15.00	7.61	281	7.95
9/11/2002	950	1	JC Boyle Reservoir at Dam		1.6	0.50	0.05	0.30	0.18		17.20	10.23	252	8.93
9/11/2002	958	7	JC Boyle Reservoir at Dam		1.6	0.43	0.09	0.22	0.18		16.40	6.21	248	8.33
9/11/2002	1113		Klamath R Bypass Reach above Powerhouse		0.4	0.08	0.15	0.12	0.08		13.00	9.76	142	8.34
9/11/2002	1120		JC Boyle Powerhouse Release		1.1	0.41	0.10	0.20	0.18		16.10	10.20	216	8.73
9/11/2002	1158		Klamath R below Keno Dam		2.0	0.22	<0.05	0.26	0.18		17.40	8.58	240	9.03
9/11/2002	1200		Klamath River at State Line		0.4	0.07	0.16	0.09	0.10		14.68	7.79	190	7.86
9/11/2002	1232		Mouth of Link R		1.8	0.23	0.06	0.17	0.12		18.20	8.89	92	9.55
9/11/2002	1250		Klamath Lake above Link Dam		1.9	0.23	<0.05	0.18	0.15		17.50	11.03	90	9.49
9/11/2002	1345		Klamath R above Copco		0.8	0.26	0.11	0.17	0.14		17.28	8.72	260	8.69
9/12/2002	800		Klamath River at State Line		0.4	0.13	0.13	0.14	0.21		13.34	6.55	181	8.09
9/12/2002	817	1	JC Boyle Reservoir at Dam		1.5	0.29	<0.05	0.21	0.18		17.40	11.85	252	7.58

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
9/12/2002	822	8	JC Boyle Reservoir at Dam		1.5	0.26	0.08	0.19	0.17		16.40	5.98	251	8.31
9/12/2002	852		Klamath R below JC Boyle Dam		1.6	0.24	0.08	0.23	0.18		16.80	8.32	251	8.64
9/12/2002	915		Klamath R above Copco		0.5	0.09	0.11	0.12	0.21		14.47	8.57	184	8.13
9/12/2002	1020		Klamath R Bypass Reach above Powerhouse		0.3	0.05	0.15	0.08	0.08		12.60	9.78	140	8.27
9/12/2002	1030		JC Boyle Powerhouse Release		0.9	0.21	0.10	0.23	0.18		16.20	8.41	235	8.53
9/12/2002	1122		Klamath R above JC Boyle Reservoir		1.5	0.11	0.19	0.17	0.20		17.40	8.38	236	8.42
9/12/2002	1154		Klamath R below Keno Dam		1.6	0.14	<0.05	0.23	0.21		17.70	8.49	235	9.03
9/12/2002	1226		Mouth of Link R		2.2	0.17	0.08	0.14	0.14		19.40	8.66	96	9.52
9/12/2002	1245		Klamath Lake above Link Dam		2.1	0.17	0.05	0.11	0.13		18.60	11.74	93	9.54
10/8/2002	1027	1	JC Boyle Reservoir at Dam	80	2.1	0.27	0.54	0.22	0.08	6	13.70	8.72	222	7.11
10/8/2002	1030	8	JC Boyle Reservoir at Dam	77	1.6	0.40	0.53	0.21	0.10	5	12.70	7.35	195	7.11
10/8/2002	1150		Klamath R Bypass Reach above Powerhouse	73	1.1	0.15	0.65	0.11	0.09	<3	13.00	8.24	162	7.40
10/8/2002	1244		Klamath R below JC Boyle Dam	75	1.7	0.34	0.57	0.19	0.09	5	13.80	7.90	182	7.40
10/8/2002	1350		Spencer Creek	61	<0.2	<0.05	<0.05	<0.05	<0.03	5	10.10	8.64	115	7.50
10/8/2002	1446		Klamath R above JC Boyle Reservoir	72	1.7	0.26	0.59	0.15	0.09	4	14.80	7.14	165	7.40
10/8/2002	1629		Klamath R below Keno Dam	72	2.5	0.37	0.13	0.03	0.05	7	14.40	7.99	131	7.70
10/9/2002	925		Klamath R above Shovel Creek	73	0.8	0.07	0.76	0.11	0.10	5	11.70	9.04	163	7.50
10/9/2002	1000		Shovel Creek	82	0.1	0.03	0.08	0.06	0.05	<3	8.60	9.73	118	7.40
10/9/2002	1112		Klamath R below Irongate Dam	81	0.5	0.08	0.17	0.18	0.16	<3	16.10	6.94	204	7.50
10/9/2002	1215	1	Irongate Reservoir above Dam	100	0.6	0.07	0.09	0.16	0.12	<3	17.20	12.20	184	8.40
10/9/2002	1225	8	Irongate Reservoir above Dam	<10	0.7	0.13	0.23	0.20	0.17	3	15.70	6.31	183	8.30
10/9/2002	1235	30	Irongate Reservoir above Dam	72	0.5	0.20	0.43	0.17	0.18	<3	7.90	0.17	157	8.40
10/9/2002	1411		Klamath R above Irongate Reservoir	83	0.8	0.14	0.25	0.23	0.20	<3	14.90	5.98	204	7.40
10/9/2002	1424		Fall Creek	74	0.2	0.10	0.09	0.06	0.04	<3	11.10	8.64	138	7.50
10/9/2002	1505	1	Copco Reservoir at Dam	84	0.8	0.08	0.26	0.16	0.17	3	16.50	9.66	186	8.57
10/9/2002	1510	10	Copco Reservoir at Dam	80	0.7	0.10	0.26	0.15	0.12	<3	14.60	6.82	180	8.46
10/9/2002	1515	26	Copco Reservoir at Dam	84	1.5	1.01	<0.05	0.58	0.62	5	12.90	0.32	176	8.53
10/9/2002	1615		Jenny Creek	99	0.1	0.06	<0.05	<0.05	0.04	4	13.10	8.52	194	7.70
10/9/2002	1820		Shasta R	214	0.3	0.21	0.11	0.19	0.18	<3	15.60	7.20	435	7.60
10/9/2002	1845		Klamath R above Shasta	80	0.5	0.09	0.21	0.15	0.16	3	17.30	8.16	202	7.70

Date Sampled	Time	Depth, m	Site Name	Total Alk mg/L	Total Kjeldahl Nitrogen mg/L	Ammonia as N mg/L	Nitrate+Nitrite as N mg/L	Total Phos-phorous as P mg/L	Ortho Phosphate as P mg/L	Bio-chemical Oxygen Demand mg/L	Tw C	DO mg/L	EC µS/cm	pH
11/12/2002	820		Klamath R below Keno Dam	62	1.5	0.55	0.22	0.14	0.12	4	5.35	11.94	144	7.75
11/12/2002	845		Klamath R above JC Boyle Reservoir	58	1.2	0.20	0.73	0.17	0.11	<3	5.33	12.07	143	7.84
11/12/2002	912		Spencer Creek	55	0.2	0.03	<0.05	0.04	<0.03	<3	3.07	12.73	105	7.73
11/12/2002	948		Klamath R Bypass Reach above Powerhouse	63	0.4	0.07	0.43	0.09	0.07	<3	9.01	11.89	144	8.07
11/12/2002	1002		JC Boyle Powerhouse Release	58	1.2	0.29	0.65	0.13	0.08	<3	6.28	11.35	144	7.68
11/12/2002	1052		Klamath R below JC Boyle Dam	55	1.0	0.30	0.72	0.16	0.12	<3	5.78	12.49	144	7.76
11/12/2002	1237	1	JC Boyle Reservoir at Dam	54	1.3	0.31	0.69	0.14	0.10	3	5.95	11.00	144	7.72
11/12/2002	1242	8	JC Boyle Reservoir at Dam	58	1.3	0.32	0.64	0.19	0.11	<3	5.64	11.11	144	7.68
11/13/2002	811		Klamath R above Shovel Creek	60	0.7	0.08	0.78	0.11	0.11	6	6.73	11.34	146	7.87
11/13/2002	815		Shovel Creek	63	<0.2	0.04	<0.05	0.07	0.06	<3	6.69	11.22	124	7.86
11/13/2002	1036	1	Copco Reservoir at Dam	74	0.8	0.15	0.48	0.14	0.12	5	8.53	10.06	181	7.83
11/13/2002	1041	10	Copco Reservoir at Dam	75	0.9	0.16	0.48	0.21	0.12	<3	8.27	9.95	181	7.83
11/13/2002	1046	28	Copco Reservoir at Dam	71	0.9	0.21	0.52	0.15	0.13	<3	7.65	9.14	175	7.68
11/13/2002	1200		Klamath R above Irongate Reservoir	75	0.7	0.20	0.51	0.15	0.15	3	8.35	10.78	180	7.77
11/13/2002	1221		Fall Creek	76	<0.2	0.03	<0.05	0.05	0.05	5	8.91	11.74	145	8.15
11/13/2002	1245		Jenny Creek	91	0.1	0.05	<0.05	0.03	0.02	<3	7.18	12.18	205	8.27
11/13/2002	1342	1	Irongate Reservoir above Dam	78	0.7	0.15	0.60	0.16	0.16	<3	10.68	8.04	197	7.72
11/13/2002	1347	10	Irongate Reservoir above Dam	78	1.0	0.17	0.29	0.15	0.16	<3	9.89	8.04	198	7.70
11/13/2002	1352	30	Irongate Reservoir above Dam	76	0.6	0.22	0.34	0.20	0.17	<3	8.85	5.38	191	7.45
11/13/2002	1540		Klamath R below Irongate Dam	78	0.7	0.16	0.30	0.18	0.16	<3	9.95	10.18	197	7.68
11/13/2002	1617		Klamath R above Shasta	82	0.7	0.10	0.33	0.20	0.17	<3	10.56	12.05	198	8.44
11/13/2002	1638		Shasta R	219	0.3	0.06	0.25	0.25	0.28	<3	9.80	11.24	485	8.51

FLAG = *: No flow from JC Boyle PH at time of sample

t = sonde measurement from the top of hour

b = sonde measurement from the bottom of hour was used

a = the average of the top and bottom of hour sonde measurement is presented

12 Data Processing for Calibration/Validation

12.1 Computation of Dissolved Oxygen Saturation

Dissolved oxygen saturation concentration is a function of water temperature, atmospheric pressure, and concentration of dissolved solids. The APHA (1985) formulation, namely

$$\ln(O_{sn}) = -139.34411 + (1.575701\times10^{5}/T) - (6.642308\times10^{7}/T^{2}) + (1.243800\times10^{10}/T^{3}) - (8.621949\times10^{11}/T^{4})$$

where

O_{sn} = saturation dissolved oxygen at 1 atmosphere (mg l^{-1})
T = water temperature (K)

To correct for atmospheric pressure at elevations less than roughly 4000 feet

$$O_s = O_{sn} P$$

Where

O_s = equilibrium dissolved oxygen concentration at non-standard pressure (mg $^{l-1}$)
P = atmospheric pressure (atm)

To correct for atmospheric pressure at elevations greater than roughly 4000 feet

$$O_s = O_{sn} P [(1-(P_{wv}/P)](1- \phi P) / [(1-P_{wv}) (1-\phi)]$$

where

P_{wv} = partial pressure of water vapor (atm) computed from,
$\ln(P_{wv}) = 11.8571 - 3840.70/(T_{a'}) - 216961/(T_{a'})^2$
where $T_{a'}$ is air temperature (K), and
$\phi = 0.000975 - 1.425\times10^{-5} (T_a) + 6.436\times10^{-8}(T_a)^2$
where T_a is air temperature (°C)
and other parameters are previously defined.

The former representation, for elevations less than approximately 4000 feet, was used in these analyses. Salinity (dissolved solids) can be incorporated in the above formulation, but was not addressed in this analysis.

Daily atmospheric pressure was corrected for elevation using assumed a constant sea level value of 1013 mb as per

$$P = 1013 - 3.436(E/100) - 0.0029(E/100)^2 + 0.0001(E/100)^3$$

Where E is elevation in feet and P is barometric pressure in millibars (U.C. Cooperative Extension, ___).

12.2 Correction for Biofouling Effects on Dissolved Oxygen Observations

Dissolved oxygen data for the calibration period was available from USBR (2003). The data clearly show that biofouling affected field observations (Figure 1). Probes were changes

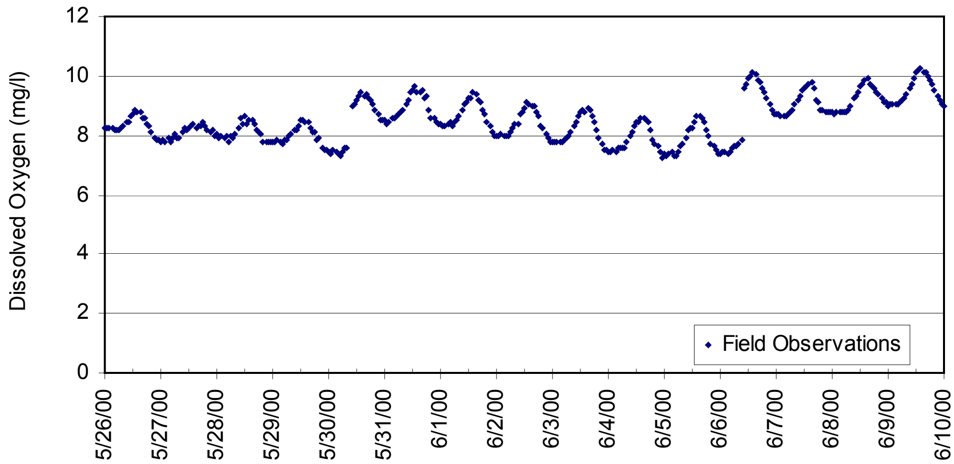


Figure 1. Observed dissolved oxygen at Seiad Valley, May-June 2000

To adjust the observed dissolved oxygen trace it was assumed that upon deployment the "fresh" probes are reading correctly. Using the difference form the last reading on the retrieved probe and the first reading deployed probe the traces were adjusted to provide a reasonable estimate of actual conditions. This method, which distributes the error over the entire period assumes that biolfouling affects probes uniformly from the hour of deployment to the hour of retrieval. Figure 2 shows the final results for the week of May 30 through June 6, 2000. Figure 3 shows the results for August 1-14, 2000.

Similar conditions occurred at the Klamath River at Youngs Bar and were addressed in the same fashion (Figures 4 and 5).

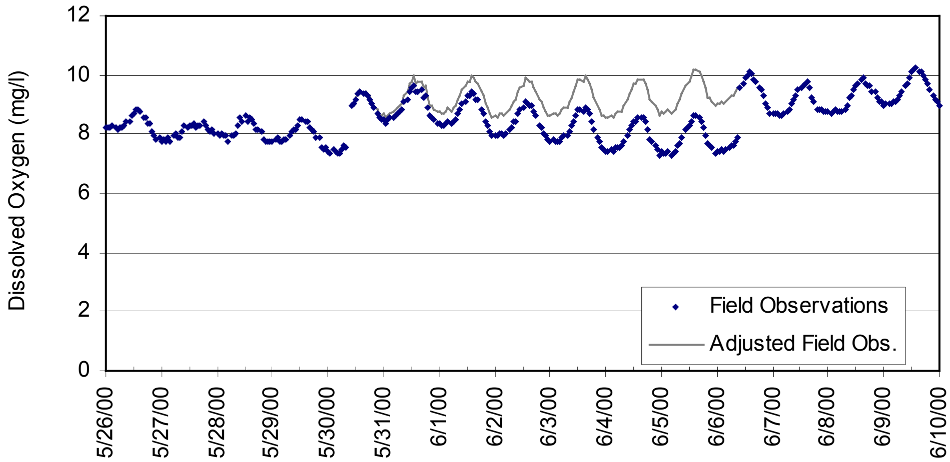


Figure 2. Observed and adjusted dissolved oxygen at Seiad Valley, May-June 2000

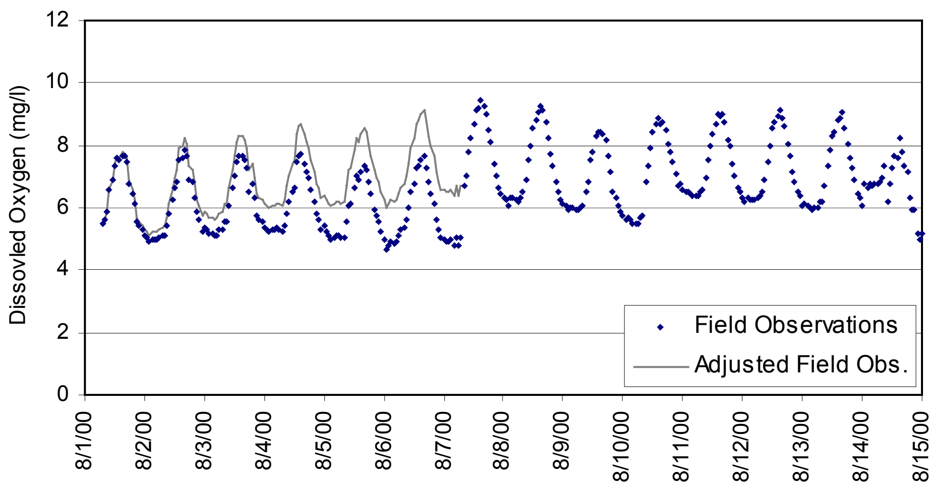


Figure 3. Observed and adjusted dissolved oxygen at Seiad Valley, August 2000

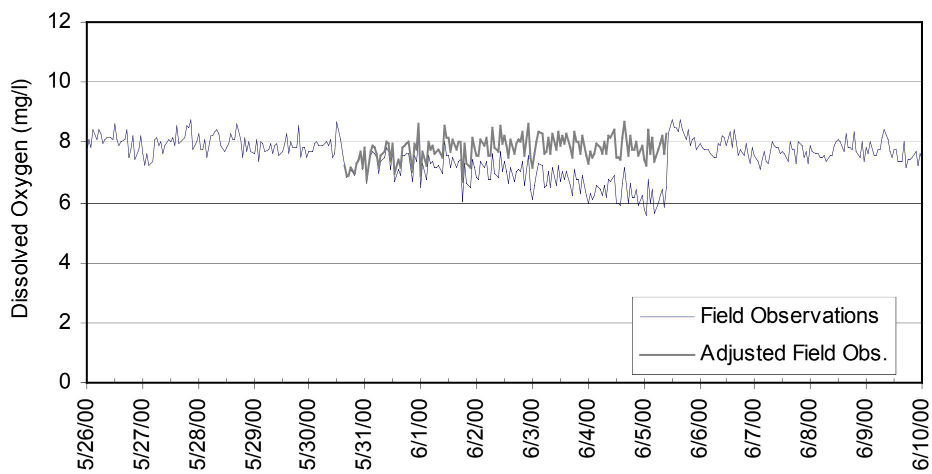


Figure 4. Observed dissolved oxygen at Youngs Bar, May-June 2000

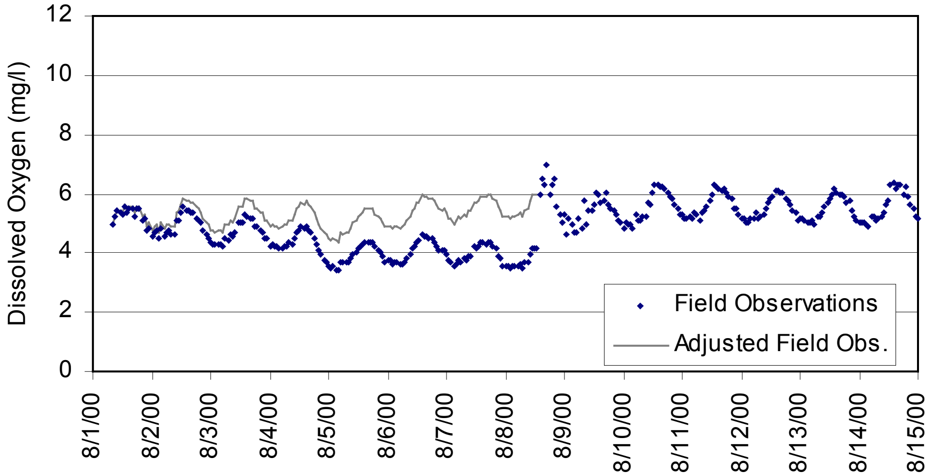


Figure 5. Observed and adjusted dissolved oxygen at Youngs Bar, August 2000

13 2001 Lake Ewauna/Keno Reach Boundary Conditions – Graphical and Tabular Presentation

The data to support the 2001 application of CE-QUAL-W2 to the Lake Ewauna/Keno Reservoir reach was not completed in a time to be included in the main documentation. The reader is referred to the main documentation, section 2.3.2 for the definitions of the various boundary conditions. Certain data are the same for 2001 and for 2000 and are not replicated herein.

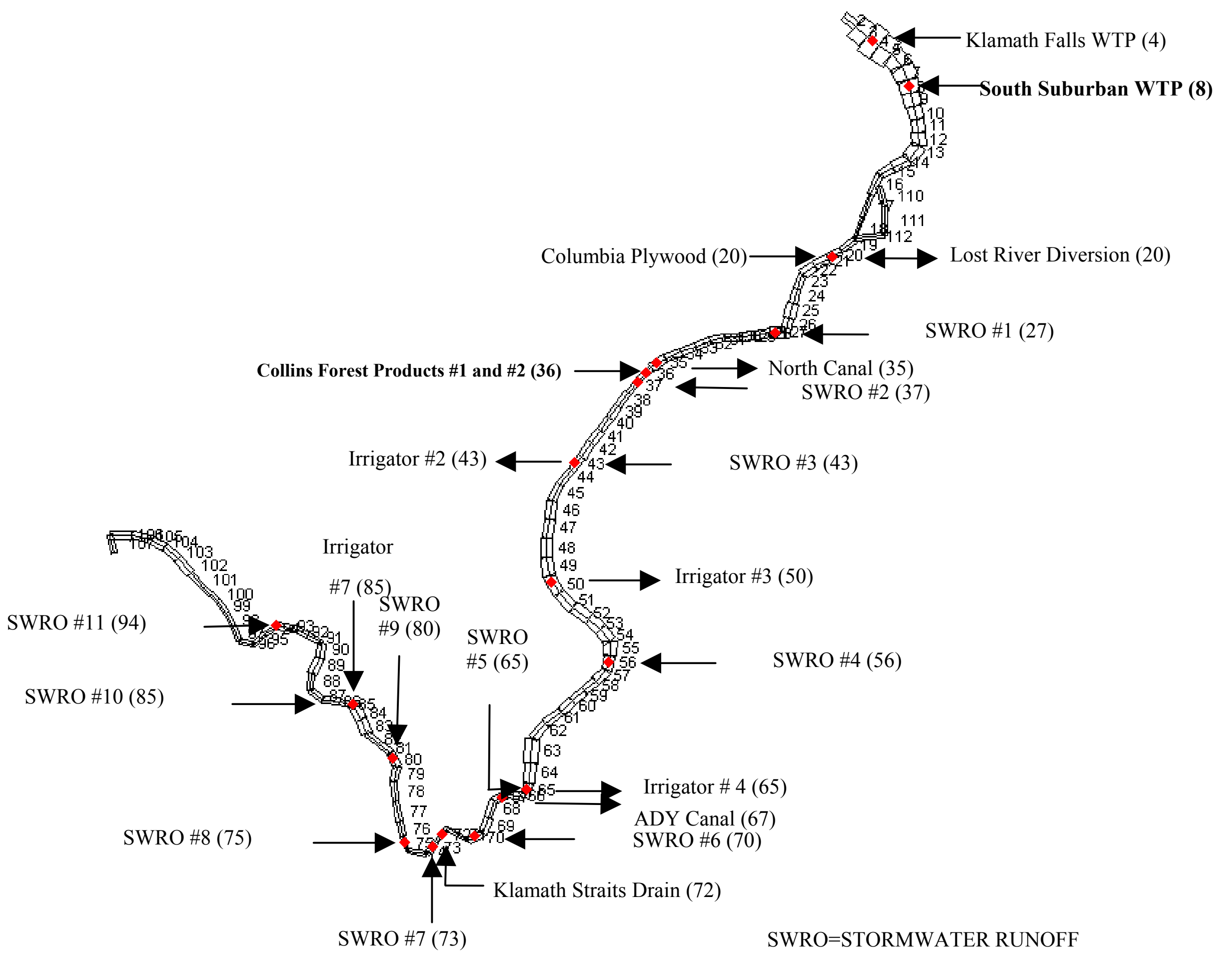


Figure 1. Map of Lake Ewauna to Keno Dam CE-QUAL-W2 presentation, identifying inputs and withdrawals

Link River Inflow

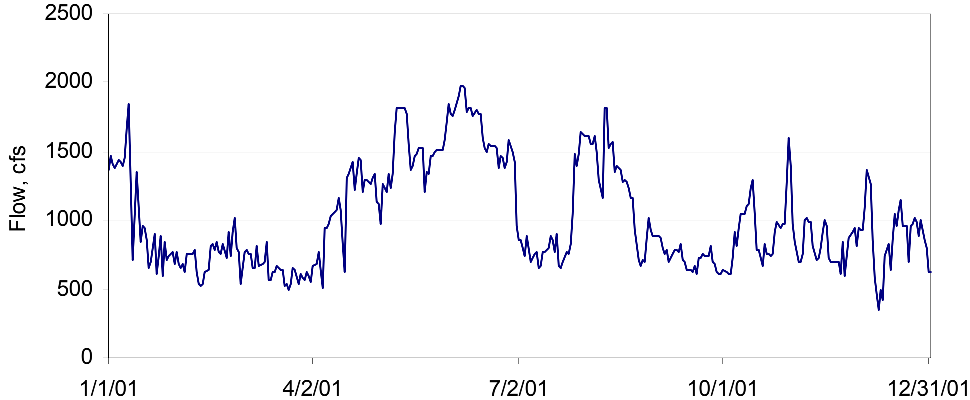
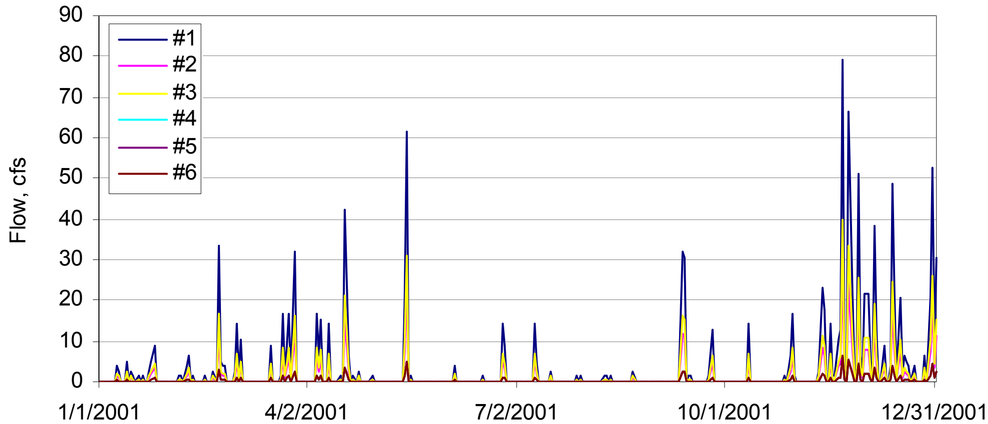


Figure 2. Lake Ewauna inflow at Link River for Lake Ewauna to Keno Dam reach model, 2001

Tributary Inflows



(a)

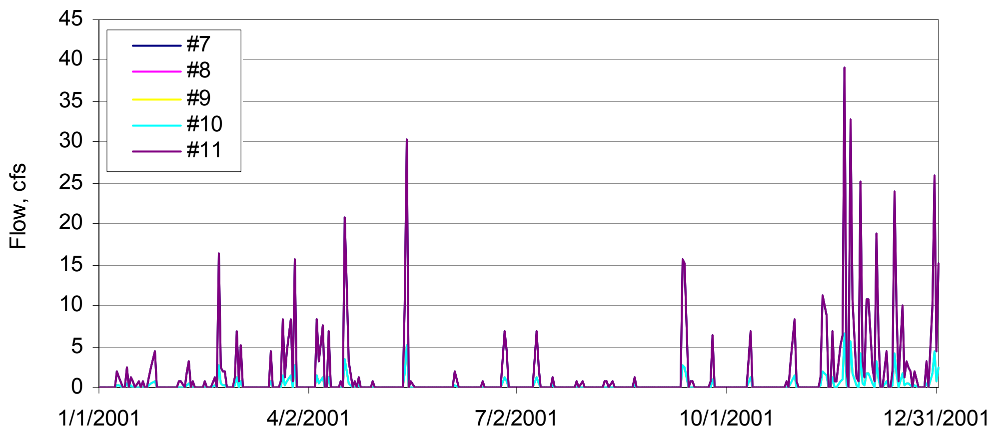


Figure 3. Storm water runoff flow for Lake Ewauna to Keno Dam reach model: (a) Runoff input locations #1 through #6, (b) Runoff input locations #7 through #11

Columbia Plywood

Table 112. Columbia Plywood inflow temperatures for Lake Ewauna to Keno Dam reach model, 2001

Julian Day	Inflow Temperature, C
1	13.61
15	13.33
46	13.89
74	14.44
105	16.11
135	17.22
166	18.89
196	21.11
227	20.56
258	18.33
288	15.56
319	13.33
349	13.89
366	13.61

Klamath Falls Water Treatment Plant

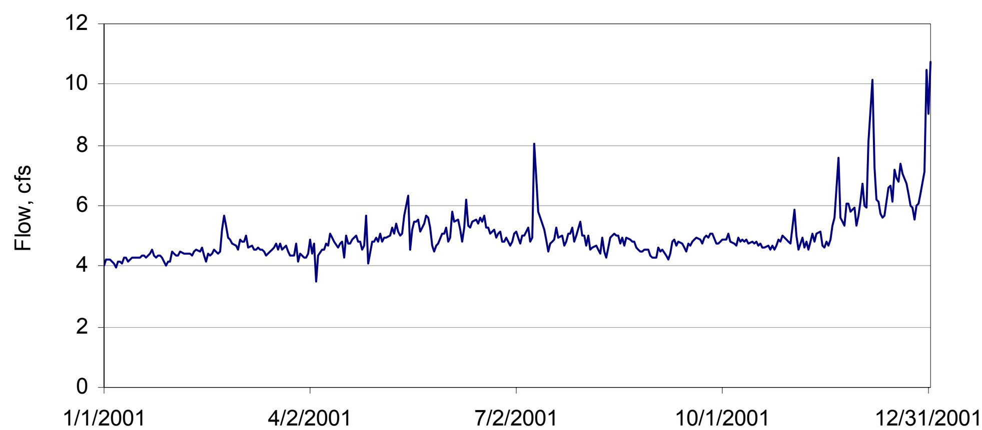


Figure 4. Klamath Falls Wastewater Treatment Plant for Lake Ewauna to Keno Dam reach model, 2001

South Suburban Sanitation District

Table 2. South Suburban Sanitation District flow for Lake Ewauan to Keno Dam reach model, 2001

Julian Day	Flow, cfs
1	3.11
15	2.98
46	2.69
75	3.00
106	2.68
136	0.86
167	0.96
197	1.03
228	1.58
259	2.18
289	2.06
320	2.46
350	4.92
366	5.09

Collins Forest Products

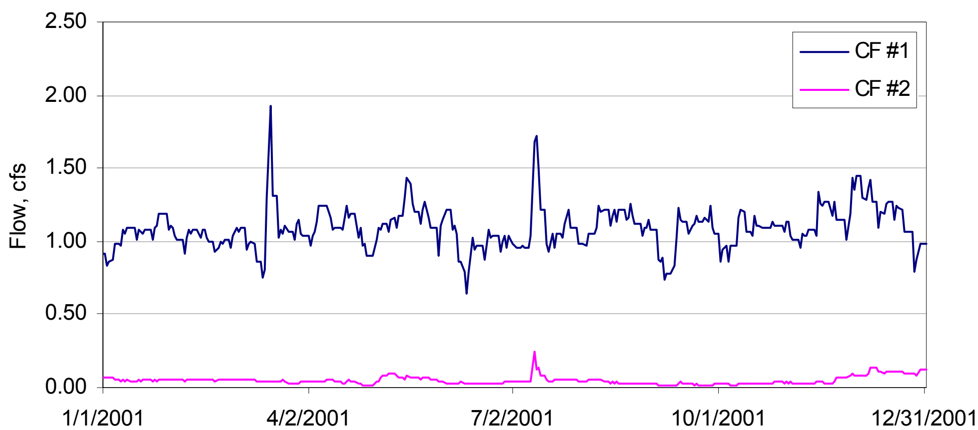


Figure 5. Collins Forest Product flows #1 and #2 for Lake Ewauna to Keno Dam reach model

Lost River Diversion Channel

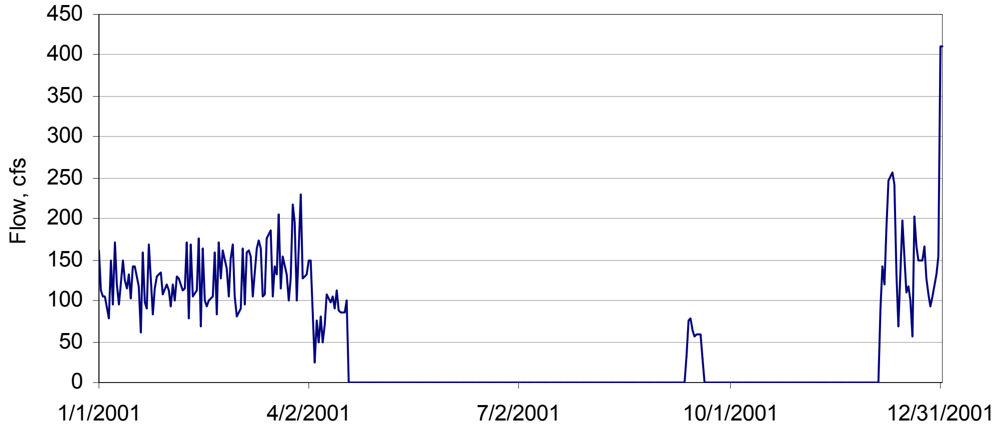


Figure 6. Lost River Diversion Channel inflows to Lake Ewauna for Lake Ewauna to Keno Dam reach model

Klamath Straits Drain

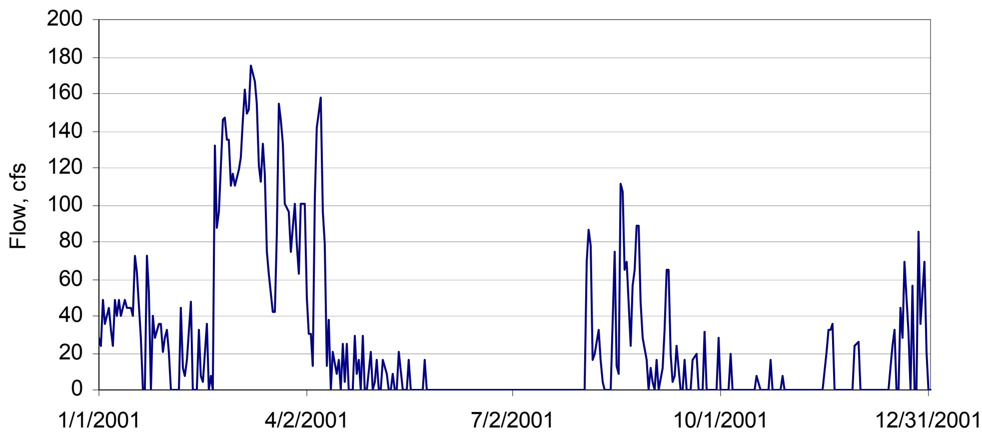


Figure 7. Klamath Straits Drain flow for Lake Ewauna to Keno Dam reach model

Withdrawals

Klamath Reclamation Project Diversions

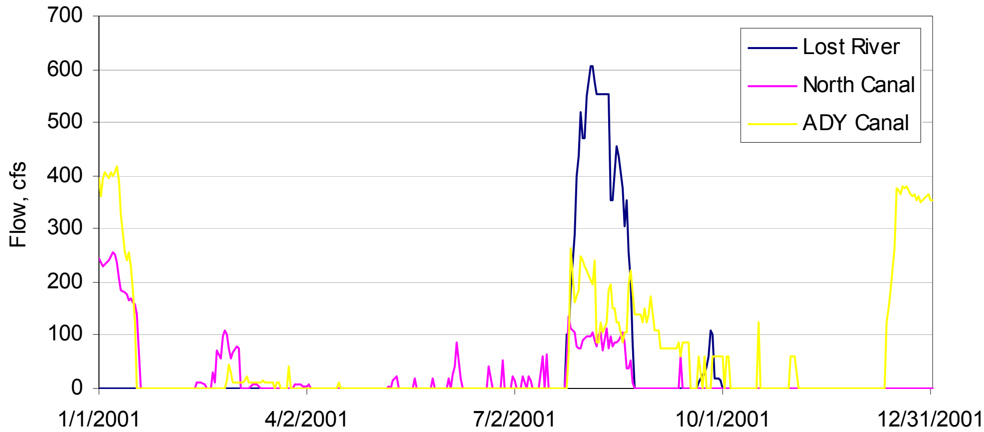


Figure 8. Klamath reclamation project diversions for Lake Ewauna to Keno Dam reach model, 2001

Non-Reclamation Irrigation Diversions

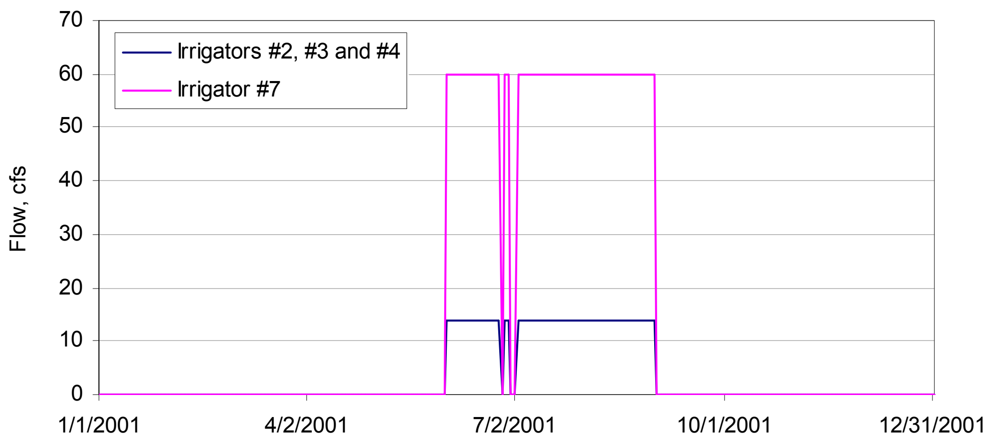


Figure 9. Irrigator withdrawals for Lake Ewauna to Keno Dam reach model, 2001

Keno Dam Outflow

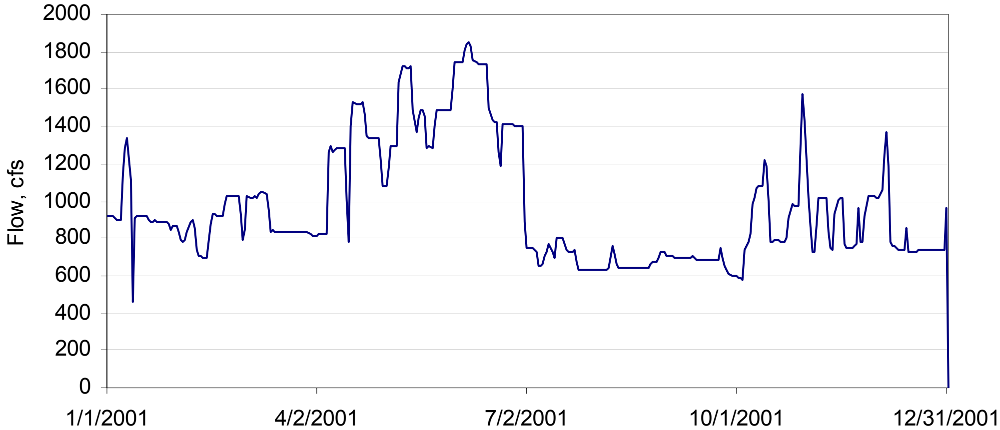


Figure 10. Keno Dam outflow for Lake Ewauna to Keno Dam reach model, 2001

Accretion/Depletion

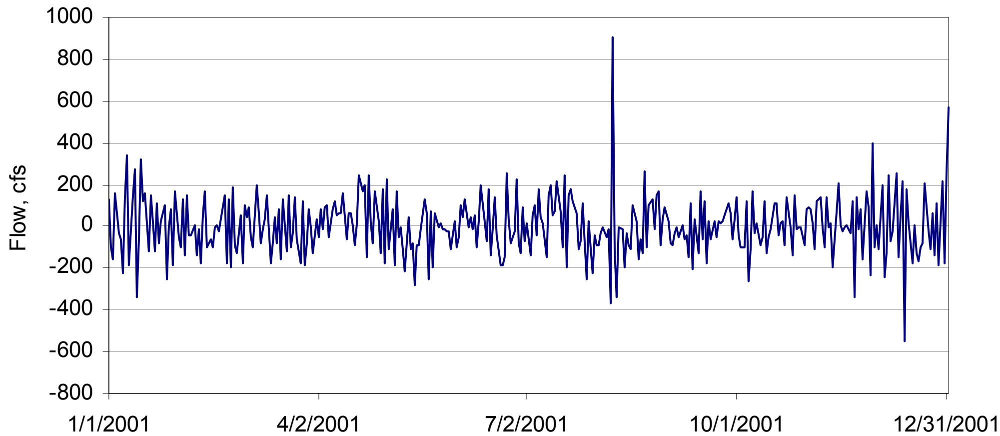


Figure 11. Accretion / depletion flow (distributed tributary) for Lake Ewauna to Keno Dam reach model, 2001

Tributary Temperatures

Klamath Falls Wastewater Treatment Plant Inflow Temperatures

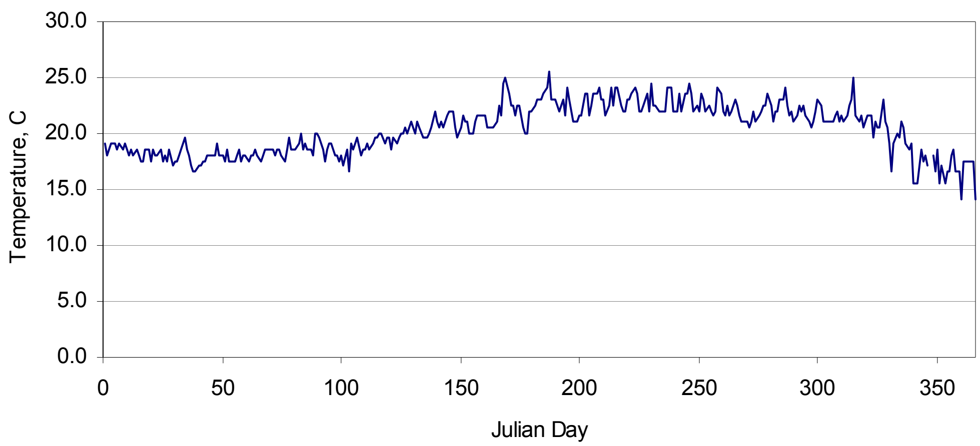


Figure 12. Klamath Falls Wastewater Treatment Plant inflow temperatures for Lake Ewauna to Keno Dam reach model

South Suburban Inflow Temperatures

Table 3. South Suburban Sanitation District inflow temperatures for Lake Ewauna to Keno Dam reach model implementation

Julian Day	Inflow Temperature, C
1	3.5
15	2.7
46	2.6
75	7.4
106	10.0
136	14.7
167	17.0
197	20.3
228	20.6
259	17.1
289	11.3
320	5.3
350	1.0
366	2.2

Lost River Inflow Temperatures

Table 4. Lost River Diversion inflow temperatures for Lake Ewauna to Keno Dam reach model

Julian Day	Inflow Temperature, C
1	3.62
4	3.62
17	1.74
37	5.95
52	5.20
66	7.98
192	26.21
205	25.19
221	26.75
235	18.28
247	20.48
275	19.42
289	12.62
303	9.22
317	7.14
366	7.14

Collins Forest Products Inflow Temperatures

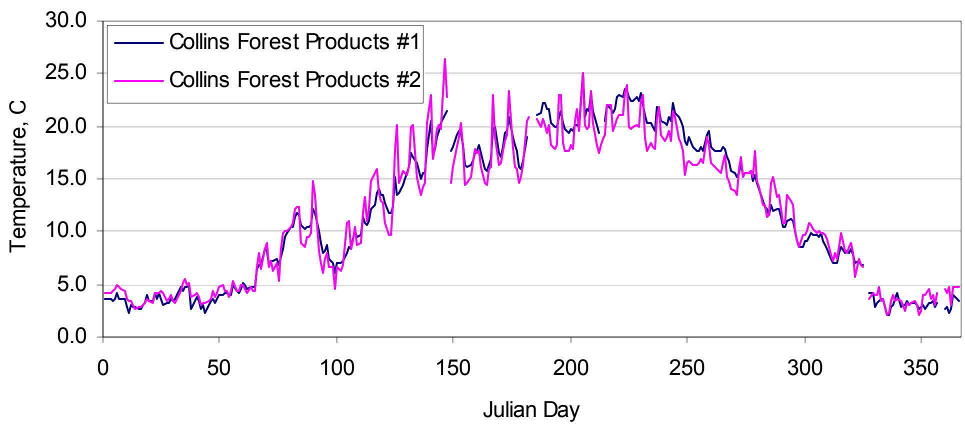


Figure 13. Collins Forest Products #1 and #2 inflow temperature for Lake Ewauna to Keno Dam reach model

Klamath Straits Drain Inflow Temperatures

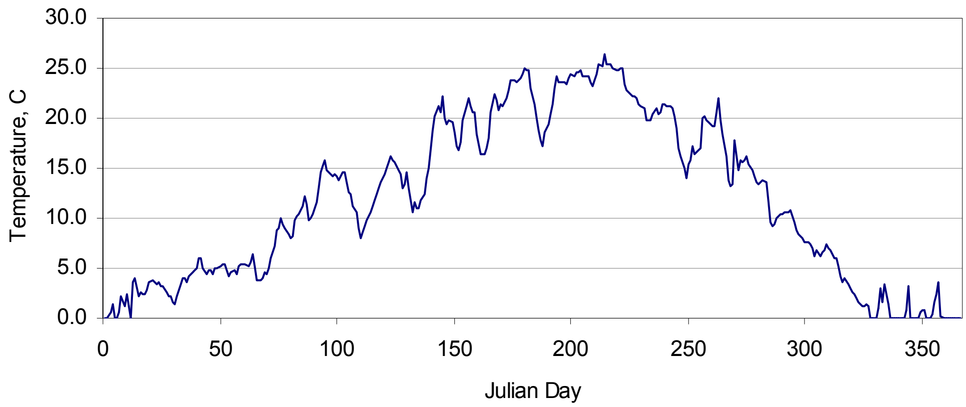


Figure 14. Klamath Straits Drain inflow temperatures for Lake Ewauna to Keno Dam reach model

Tributary Water Quality

Klamath Falls Wastewater Treatment Plant

Table 5. KFWTP inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	4.0	3.0	6.0	1.5	0.0	0.0	0.0	14.0	0.0	3.9	14.0	50.0
15	200.0	0.0	9.3	3.0	6.0	1.5	0.0	0.0	0.0	9.1	0.0	4.5	14.0	50.0
46	200.0	0.0	14.4	3.0	6.0	1.5	0.0	0.0	0.0	9.6	0.0	4.6	14.0	50.0
74	200.0	0.0	25.6	3.0	6.0	1.5	0.0	0.0	0.0	30.5	0.0	4.2	14.0	50.0
105	200.0	0.0	13.5	3.0	6.0	1.5	0.0	0.0	0.0	12.3	0.0	4.6	14.0	50.0
135	200.0	0.0	5.5	3.0	6.0	1.5	0.0	0.0	0.0	3.9	0.0	4.5	14.0	50.0
166	200.0	0.0	6.1	3.0	6.0	1.5	0.0	0.0	0.0	3.4	0.0	4.4	14.0	50.0
196	200.0	0.0	3.5	3.0	6.0	1.5	0.0	0.0	0.0	3.0	0.0	4.1	14.0	50.0
227	200.0	0.0	5.7	3.0	6.0	1.5	0.0	0.0	0.0	3.5	0.0	3.8	14.0	50.0
258	200.0	0.0	2.4	3.0	6.0	1.5	0.0	0.0	0.0	3.5	0.0	3.8	14.0	50.0
288	200.0	0.0	3.1	3.0	6.0	1.5	0.0	0.0	0.0	7.1	0.0	4.3	14.0	50.0
319	200.0	0.0	3.4	3.0	6.0	1.5	0.0	0.0	0.0	3.1	0.0	4.5	14.0	50.0
349	200.0	0.0	2.3	3.0	6.0	1.5	0.0	0.0	0.0	3.4	0.0	4.1	14.0	50.0
366	200.0	0.0	3.0	3.0	6.0	1.5	0.0	0.0	0.0	2.0	0.0	5.0	14.0	50.0

South Side Sanitation District

Table 6. SSSD inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	42.5	0.0	9.4	0.0	0.0	0.0	0.0	28.6	0.0	15.0	0.0	61.2
15	200.0	0.0	73.8	0.0	11.5	0.0	0.0	0.0	0.0	26.6	0.0	14.0	0.0	41.1
46	200.0	0.0	80.9	0.0	21.0	0.0	0.0	0.0	0.0	28.6	0.0	12.5	0.0	37.2
75	200.0	0.0	50.9	0.0	18.0	0.0	0.0	0.0	0.0	30.7	0.0	7.9	0.0	21.7
106	200.0	0.0	26.8	0.0	25.0	0.0	0.0	0.0	0.0	28.0	0.0	3.8	0.0	8.6
136	200.0	0.0	30.5	2.8	15.0	0.2	0.0	0.0	0.0	30.3	0.0	4.7	0.0	11.5
167	200.0	0.0	45.2	1.9	5.5	2.0	0.0	0.0	0.0	30.4	0.0	4.8	0.0	8.6
197	200.0	0.0	37.8	2.5	2.8	1.3	0.0	0.0	0.0	28.9	0.0	4.5	0.0	10.6
228	200.0	0.0	46.5	2.7	6.3	0.3	0.0	0.0	0.0	25.9	0.0	5.4	0.0	41.5
259	200.0	0.0	70.0	2.2	8.8	1.7	0.0	0.0	0.0	42.9	0.0	6.0	0.0	74.2
289	200.0	0.0	38.8	2.2	3.3	0.6	0.0	0.0	0.0	33.9	0.0	7.9	0.0	75.6
320	200.0	0.0	30.9	0.0	6.5	0.0	0.0	0.0	0.0	35.6	0.0	10.3	0.0	37.1
350	200.0	0.0	30.6	0.0	4.5	0.0	0.0	0.0	0.0	30.7	0.0	13.8	0.0	67.6
366	200.0	0.0	42.5	0.0	9.4	0.0	0.0	0.0	0.0	28.6	0.0	12.1	0.0	30.6

Lost River Diversion Channel

Table 7. Wilson Reservoir 2001 Data

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	2.0	0.9	9.7	23.0	140.0
4	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	2.0	1.0	11.5	23.0	120.0
17	175.0	0.0	10.0	0.1	0.1	0.4	0.0	0.0	0.0	2.0	0.4	13.2	23.0	140.0
37	175.0	0.0	10.0	0.1	0.1	0.3	0.0	0.0	0.0	2.0	0.4	12.1	23.0	140.0
52	175.0	0.0	10.0	0.1	0.2	0.4	0.0	0.0	0.0	2.0	0.4	10.1	23.0	130.0
66	175.0	0.0	10.0	0.1	0.1	0.1	0.0	0.0	0.0	2.0	0.7	10.3	23.0	140.0
192	175.0	0.0	10.0	0.4	0.0	0.2	0.0	0.0	0.0	5.4	1.7	6.7	23.0	132.0
205	175.0	0.0	10.0	0.2	0.0	0.1	0.0	0.0	0.0	5.7	1.0	5.9	23.0	135.0
221	175.0	0.0	10.0	0.3	0.1	0.0	0.0	0.0	0.0	6.2	1.2	8.0	23.0	139.0
235	175.0	0.0	10.0	0.3	0.1	0.3	0.0	0.0	0.0	6.6	1.2	3.8	23.0	132.0
247	175.0	0.0	10.0	0.2	0.0	0.0	0.0	0.0	0.0	6.9	0.8	4.2	23.0	142.0
275	175.0	0.0	10.0	0.1	0.1	0.0	0.0	0.0	0.0	7.7	0.7	7.9	23.0	153.0
289	175.0	0.0	10.0	0.2	0.0	0.0	0.0	0.0	0.0	7.6	0.5	8.9	23.0	164.0
303	175.0	0.0	10.0	0.1	0.1	0.0	0.0	0.0	0.0	6.6	0.1	9.2	23.0	146.0
317	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	5.6	0.3	9.7	23.0	156.0
366	175.0	0.0	10.0	0.1	0.2	0.5	0.0	0.0	0.0	2.0	0.9	9.7	23.0	150.0

Columbia Plywood

Table 8. Columbia Plywood inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	25.0	0.0	16.0	0.15	0.15	0.24	0.0	5.0	0.0	8.0	0.0	7.0	15.8	52.0
366	25.0	0.0	16.0	0.15	0.15	0.24	0.0	5.0	0.0	8.0	0.0	7.0	15.8	52.0

Collins Forest Products

Table 9. Collins Forest Products #1 inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	11.6	0.2	0.2	0.2	0.0	0.0	0.0	29.8	0.0	3.5	12.2	50.0
15	200.0	0.0	12.5	0.2	0.2	0.2	0.0	0.0	0.0	34.3	0.0	3.5	12.2	50.0
46	200.0	0.0	14.6	0.2	0.2	0.2	0.0	0.0	0.0	51.4	0.0	3.5	12.2	50.0
75	200.0	0.0	19.9	0.2	0.2	0.2	0.0	0.0	0.0	38.8	0.0	3.5	12.2	50.0
106	200.0	0.0	12.1	0.2	0.2	0.2	0.0	0.0	0.0	32.1	0.0	3.5	12.2	50.0
136	200.0	0.0	6.6	0.2	0.2	0.2	0.0	0.0	0.0	18.7	0.0	3.5	12.2	50.0
167	200.0	0.0	8.0	0.2	0.2	0.2	0.0	0.0	0.0	11.1	0.0	3.5	12.2	50.0
197	200.0	0.0	6.2	0.2	0.2	0.2	0.0	0.0	0.0	10.6	0.0	3.5	12.2	50.0
228	200.0	0.0	2.3	0.2	0.2	0.2	0.0	0.0	0.0	7.2	0.0	3.5	12.2	50.0
259	200.0	0.0	2.6	0.2	0.2	0.2	0.0	0.0	0.0	9.5	0.0	3.5	12.2	50.0
289	200.0	0.0	18.4	0.2	0.2	0.2	0.0	0.0	0.0	18.8	0.0	3.5	12.2	50.0
320	200.0	0.0	28.6	0.2	0.2	0.2	0.0	0.0	0.0	27.8	0.0	3.5	12.2	50.0
350	200.0	0.0	34.9	0.2	0.2	0.2	0.0	0.0	0.0	28.5	0.0	3.5	12.2	50.0
366	200.0	0.0	11.6	0.2	0.2	0.2	0.0	0.0	0.0	29.8	0.0	3.5	12.2	50.0

Table 10. Collins Forest Products #2 concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	200.0	0.0	20.7	3.0	3.0	0.5	0.0	0.0	0.0	15.0	0.0	3.5	11.9	50.0
15	200.0	0.0	32.5	3.0	3.0	0.5	0.0	0.0	0.0	12.6	0.0	3.5	11.9	50.0
46	200.0	0.0	42.5	3.0	3.0	0.5	0.0	0.0	0.0	17.1	0.0	3.5	11.9	50.0
75	200.0	0.0	38.0	3.0	3.0	0.5	0.0	0.0	0.0	18.1	0.0	3.5	11.9	50.0
106	200.0	0.0	35.8	3.0	3.0	0.5	0.0	0.0	0.0	23.6	0.0	3.5	11.9	50.0
136	200.0	0.0	24.3	3.0	3.0	0.5	0.0	0.0	0.0	14.1	0.0	3.5	11.9	50.0
167	200.0	0.0	5.3	3.0	3.0	0.5	0.0	0.0	0.0	5.9	0.0	3.5	11.9	50.0
197	200.0	0.0	7.6	3.0	3.0	0.5	0.0	0.0	0.0	7.6	0.0	3.5	11.9	50.0
228	200.0	0.0	3.2	3.0	3.0	0.5	0.0	0.0	0.0	6.3	0.0	3.5	11.9	50.0
259	200.0	0.0	2.9	3.0	3.0	0.5	0.0	0.0	0.0	8.0	0.0	3.5	11.9	50.0
289	200.0	0.0	2.1	3.0	3.0	0.5	0.0	0.0	0.0	5.1	0.0	3.5	11.9	50.0
320	200.0	0.0	10.9	3.0	3.0	0.5	0.0	0.0	0.0	8.0	0.0	3.5	11.9	50.0
350	200.0	0.0	31.1	3.0	3.0	0.5	0.0	0.0	0.0	16.1	0.0	3.5	11.9	50.0
366	200.0	0.0	20.7	3.0	3.0	0.5	0.0	0.0	0.0	15.0	0.0	3.5	11.9	50.0

Klamath Straits Drain

Table 113. KSD inflow concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	354.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
15	374.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
46	316.0	0.0	24.0	0.2	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
75	365.0	0.0	24.0	0.2	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
106	409.0	0.0	24.0	0.4	0.3	0.5	0.0	10.0	0.0	5.0	1.0	4.7	37.0	150.0
136	423.0	0.0	24.0	0.5	0.5	0.5	0.0	13.0	0.0	5.0	1.0	6.8	37.0	150.0
167	319.0	0.0	24.0	0.5	0.5	0.5	0.0	15.0	0.0	5.0	1.0	3.5	37.0	150.0
197	266.0	0.0	24.0	0.5	0.5	1.0	0.0	15.0	0.0	5.0	1.0	2.4	37.0	150.0
228	252.0	0.0	24.0	0.3	0.5	1.3	0.0	13.0	0.0	5.0	1.0	1.9	37.0	150.0
259	296.0	0.0	24.0	0.2	1.0	2.0	0.0	10.0	0.0	5.0	1.0	2.8	37.0	150.0
289	376.0	0.0	24.0	0.2	1.5	0.3	0.0	10.0	0.0	5.0	1.0	3.3	37.0	150.0
320	294.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.1	37.0	150.0
350	334.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0
366	354.0	0.0	24.0	0.1	0.3	0.3	0.0	10.0	0.0	5.0	1.0	9.0	37.0	150.0

Distributed Tributary

Table 12. Distributed tributary concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	25.0	0.0	0.0	0.1	0.05	1.0	0.0	0.0	0.0	1.0	0.0	3.0	20.2	80.0
274	25.0	0.0	0.6	0.1	0.05	1.0	0.0	0.0	0.0	1.0	0.0	3.0	20.2	80.0
366	25.0	0.0	0.6	0.1	0.05	1.0	0.0	0.0	0.0	1.0	0.0	3.0	20.2	80.0

“Tracer” is a conservative constituent that does not decay or react with time or space. Can be used to check conservation of mass within the model framework.

Stormwater Runoff

Table 13. Storm water runoff concentrations for the Lake Ewauna-Keno Reach

Julian Day	Total Dissolved Solids, mg/l	Tracer, mg/l	Suspended Solids, mg/l	Phosphate, mg/l	Ammonia, mg/l	Nitrate-Nitrite, mg/l	Iron, mg/l	Labile Dissolved Organic Matter, mg/l	Refractory Dissolved Organic Matter, mg/l	BOD_5, mg/l	Algae, mg/l	Dissolved Oxygen, mg/l	Total Inorganic Carbon, mg/l	Alkalinity, meq/l
1	25.0	0.0	5.0	0.05	0.05	0.1	0.0	3.0	0.0	0.7	0.0	9.0	15.9	52.0
366	25.0	0.0	5.0	0.05	0.05	0.1	0.0	3.0	0.0	0.7	0.0	9.0	15.9	52.0