12-2001

Lower Willamette River Model: Model Calibration

Chris Berger
Portland State University

Robert Leslie Annear
Portland State University

Scott A. Wells
Portland State University

Citation Details

Berger, C., Annear, R. L., & Wells, S. A. (2001). Lower Willamette River Model: Model Calibration. Technical Report EWR-2-01, Department of Civil Engineering, Portland State University, Portland, Oregon.

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By

Chris Berger

Robert L. Annear Jr.

And

Scott A. Wells

Technical Report EWR-2-01

School of Engineering and Applied Science
Department of Civil Engineering
Portland State University
Portland, Oregon 97201-0751

Prepared for Water Environment Services, Inc. on behalf of Richwine Environmental Inc.

December 2001

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Acknowledgements

The Willamette River Project Managers, Dale Richwine of Richwine Environmental, Inc. and Ted Kyle of Water Environment Services of Clackamas County, provided key support during the modeling study.

Chris Nygaard, an undergraduate student at Portland State University, was valuable in conducting data compilation and analyses to gain a better understanding of the Lower Willamette River and Columbia River system. Also, other staff at Water Environment, the City of Portland, and other organizations provided valuable field data for calibrating the model.

Introduction

The Willamette River consists of an 11,500 mi^2 watershed that drains through the Willamette valley. The Lower Willamette River between RM 0 (mouth of Columbia River) to RM 35 (Canby Ferry) was the region of interest in this modeling study (see Figure 1). The Willamette River passes through the Portland metropolitan area before its confluence with the Columbia River at Columbia RM 106. The Columbia River is tidally influenced from the Pacific Ocean to the tailrace of the Bonneville Dam at RM 145. As a result, the Lower Willamette River is also tidally influenced from RM 0 (confluence with the Columbia) to the Oregon City Falls at RM 26.8.

Water Environment Services of Clackamas County is in the process of planning upgrades on several of its wastewater treatment plants (WWTPs) which discharge into the Lower Willamette River. The goals of the modeling effort were to:

- Gather data to construct a computer simulation model of the Lower Willamette River system in order to evaluate the impact of the WWTP discharges on water quality,
- Ensure that the model accurately represents the system physics and chemistry (flow, temperature, dissolved oxygen and nutrient dynamics) by model calibration, and
- Use the model to evaluate how to meet various future discharge scenarios for Water Environment Services of Clackamas County.

Prior reports prepared for this modeling study include:

- Wells (2000) evaluated the use of CE-QUAL-W2 Version 3 for the Lower Willamette River. CE-QUAL-W2 Version 3 (Wells, 1997) is a two dimensional, laterally averaged, hydrodynamic and water quality model that was chosen for the model development.
- Rodriguez et al. (2001) summarized background data for the modeling effort such as
    1. Inflows, temperatures, and water quality
    2. Meteorological conditions in the watershed
    3. Bathymetry of the Willamette River and Columbia River and the model grid
    4. Willamette Falls hydraulic elements: spillways, withdrawal structures, weirs, fish ladder

This report evaluates the model calibration and discusses issues relative to that calibration effort. The calibration effort focused on model predictions of hydrodynamics (flow and water level), temperature, and eutrophication model parameters (such as nutrients, algae, dissolved oxygen, organic matter, coliform).

This information is divided into the following sections in this report:

- Hydrodynamic Calibration
- Temperature Calibration
- Water Quality Calibration
    - Summary and Conclusions

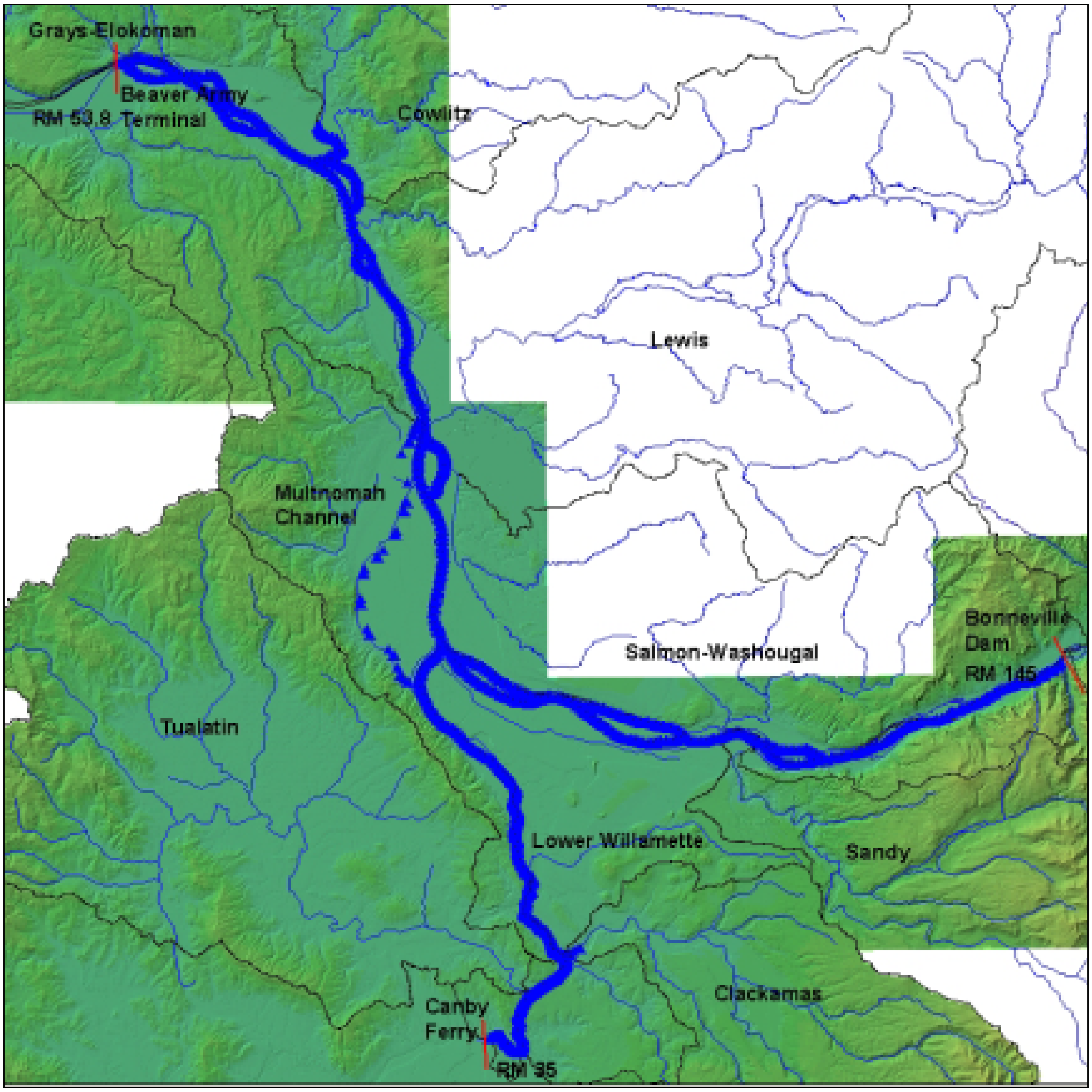


Figure 1. Lower Willamette and Columbia River model region

Hydrodynamic Calibration

The process of calibration of the hydrodynamics includes having accurate dynamics flow and head boundary conditions, good model bathymetry, and adjusting model friction using in this case the Manning's friction factor. For these model comparisons, once the model bathymetry and boundary conditions were established, the model friction factors were adjusted until there was reasonable model-data agreement in water level and flow rate. Manning's *n*, or friction coefficient, was the only model coefficient used for calibrating water level and flow rate predictions with data. For all simulation years Mannings *n* was calibrated to a value of 0.025 for the whole model domain.

The following sections show model predictions compared to data for water level and flow rate in the Willamette and Columbia River reaches.

Willamette River

The first step in the calibration process was to ensure that the model correctly predicted water levels and flow rates at measuring stations in the Willamette and Columbia River. The Willamette River has both water level and flow data, which can be used to compare with model results. The hydrodynamic calibration was conducted for the same model period established in Rodriguez et al. (2000) as the summers from May 1 to Oct 1 for 1993, 1994, 1997, 1998 and 1999. Table 1 shows the gage stations where water level and flow data were collected.

Table 1. Willamette River hydrodynamic calibration sites

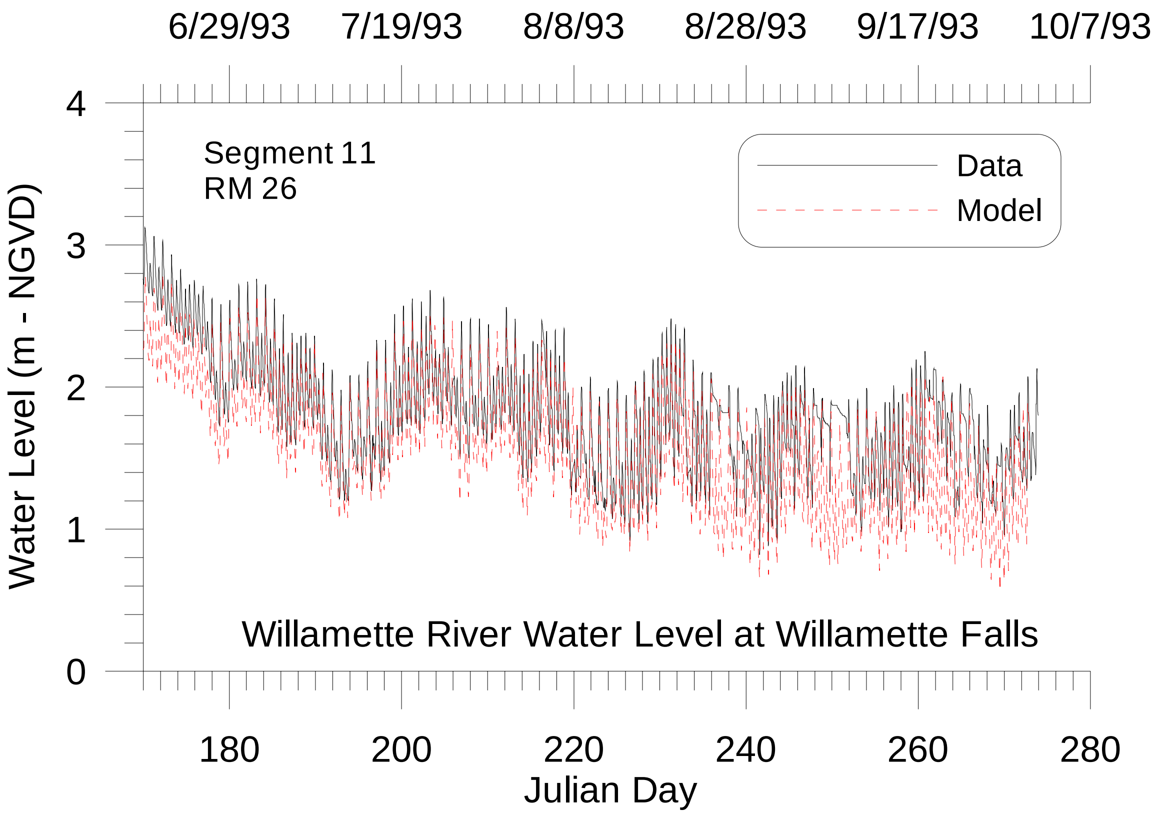
Site ID	Site Description	River Mile	Model Segment
14211720	Willamette River at Portland, OR	12.8	75
14207770	Willamette River Below Willamette Falls	26.2	11

Water Level

Model predictions compared to field data for 1993, 1994, 1995, 1997, 1998, and 1999 for the 2 stations in Table 1 are shown in Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6, respectively. Model-data errors are shown in Table 2.

Table 2. Model - data errors in water level for the Willamette River for 1993, 1994 and 1997-1999.

Year	RM 12.8 Segment #75			RM 26.2 Segment #11		
	n, # of data comparisons	AME, m	RMS error, m	n, # of data comparisons	AME, m	RMS error, m
1993	1515	0.157	0.221	1515	0.405	0.500
1994	1515	0.263	0.337	1515	0.447	0.569
1997	NA	NA	NA	1515	0.332	0.436
1998	1515	0.103	0.170	1515	0.248	0.348
1999	1515	0.121	0.178	1515	0.269	0.336



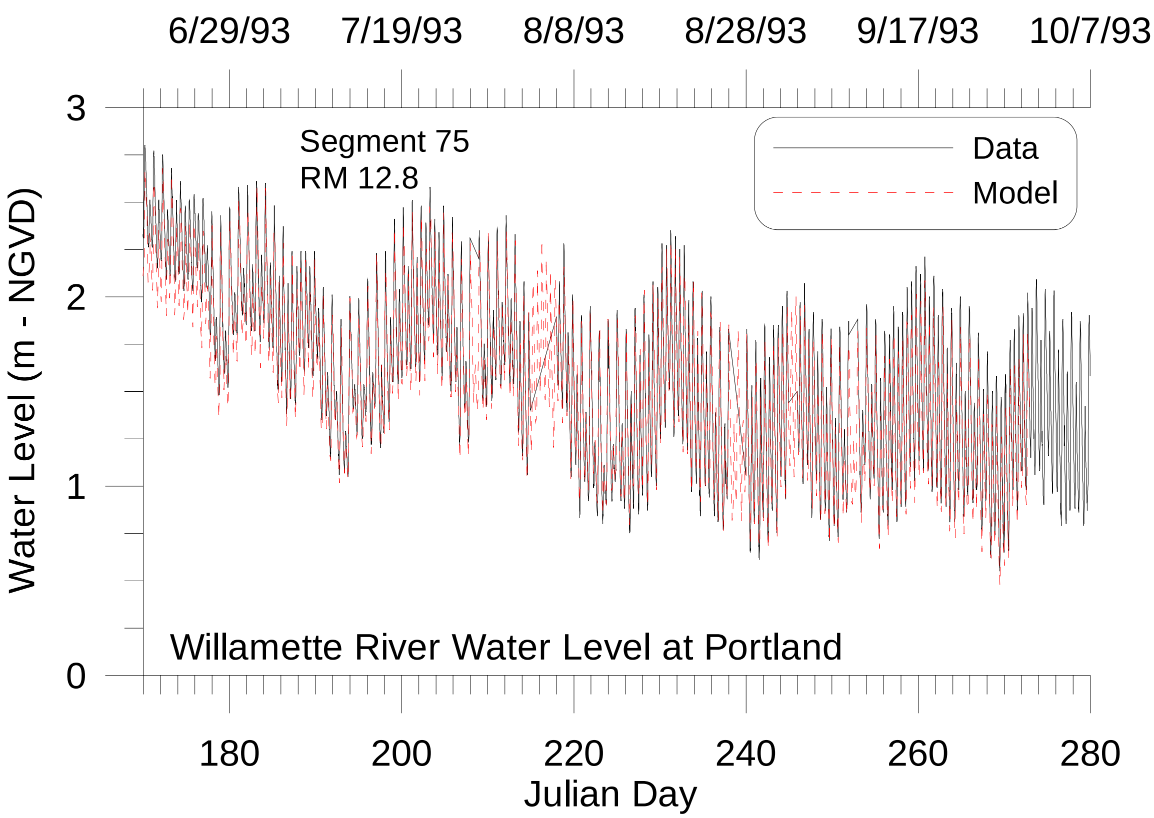
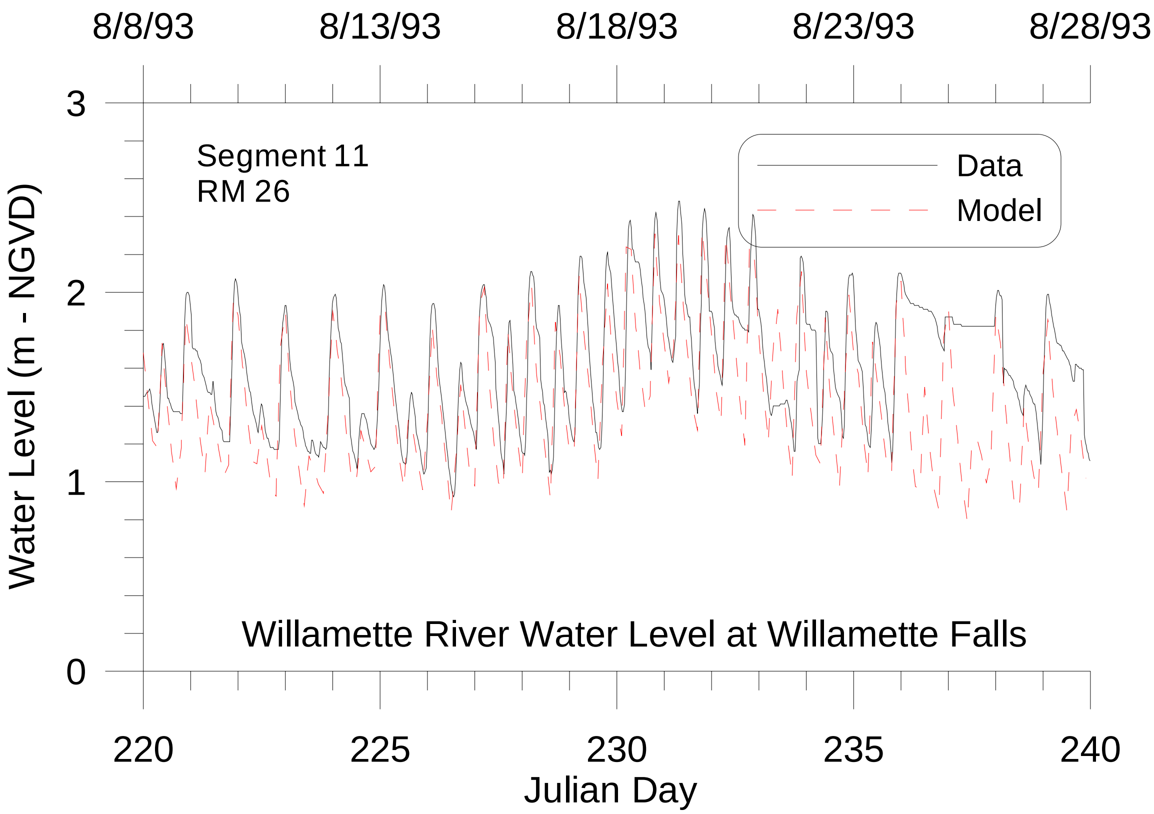


Figure 2. Water level data versus model predictions for Portland and below Willamette Falls during 1993.



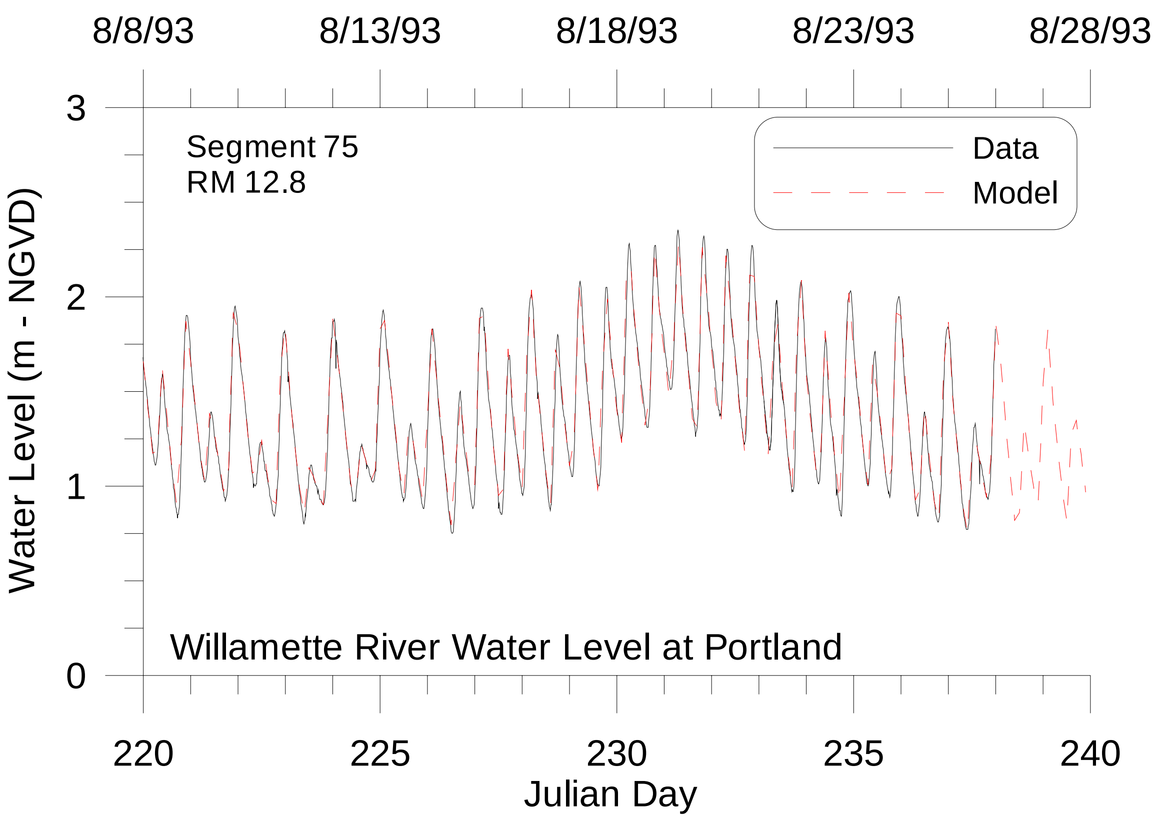


Figure 3. Water level data versus model predictions for Portland and below Willamette Falls during a 20-day period in 1993.

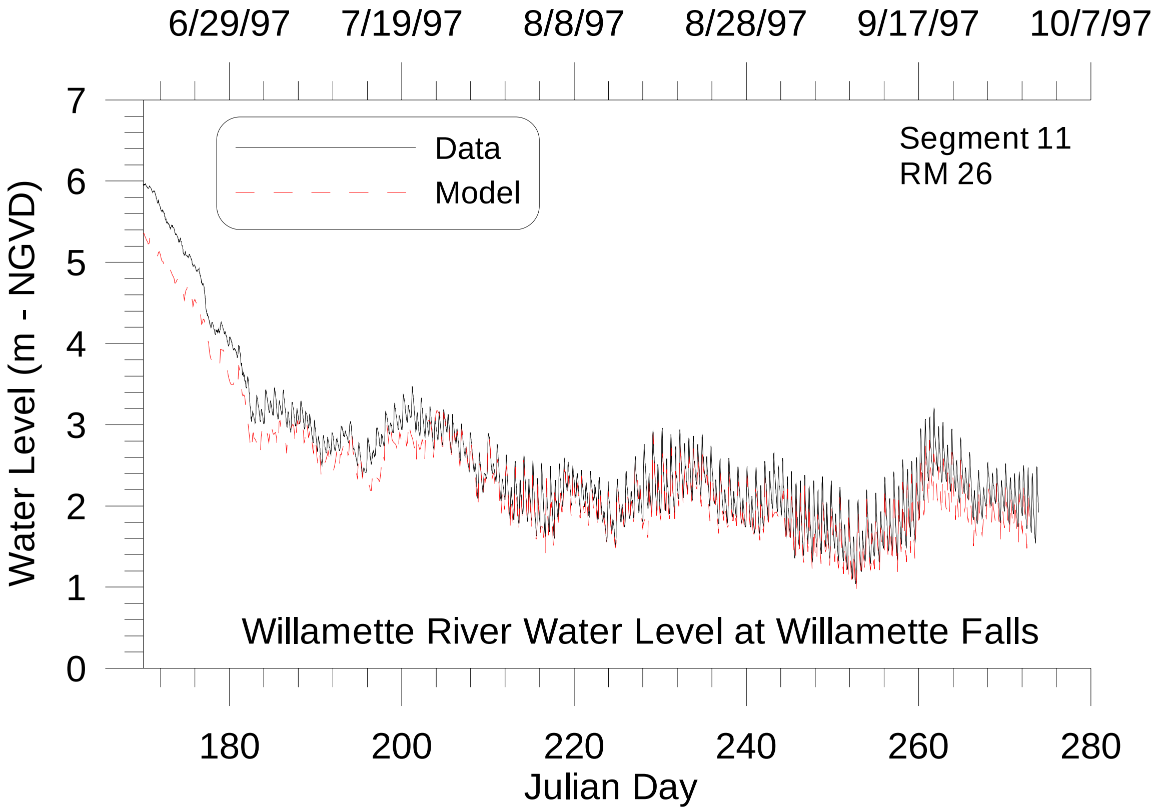
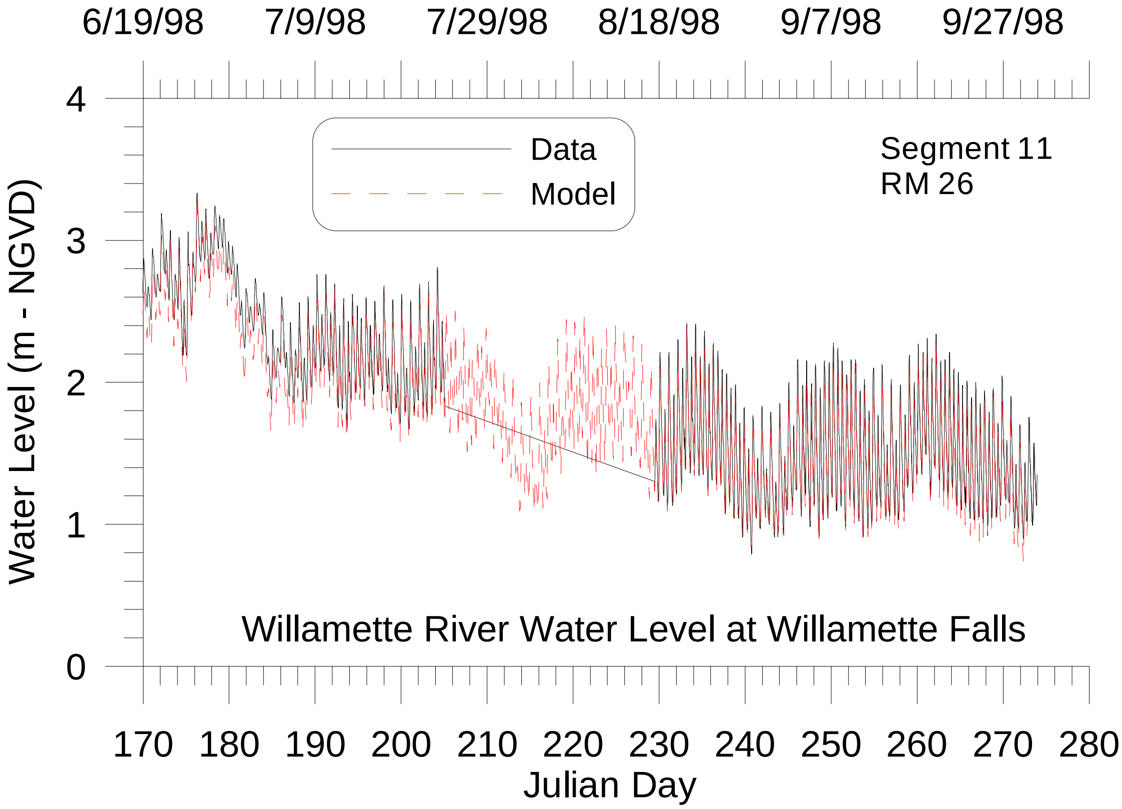


Figure 4. Water level data versus model predictions for Willamette Falls during 1997.



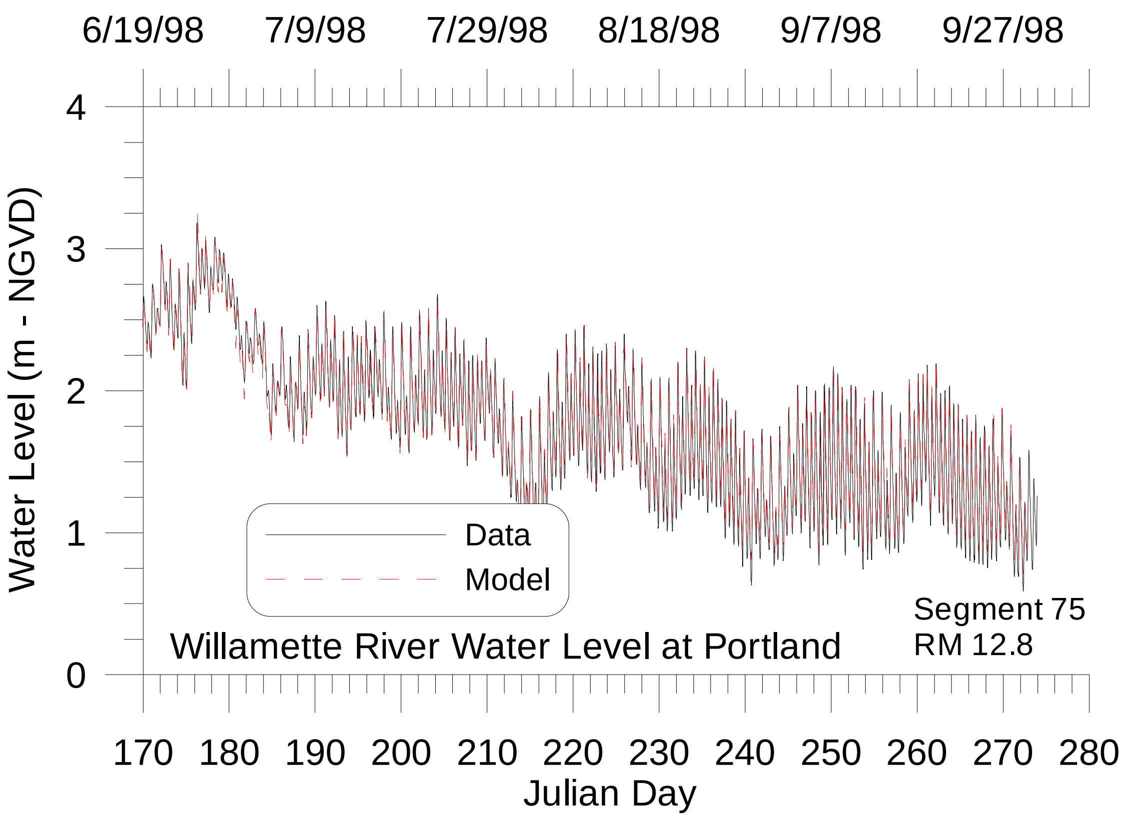


Figure 5. Water level data versus model predictions for Portland and below Willamette Falls during 1998.

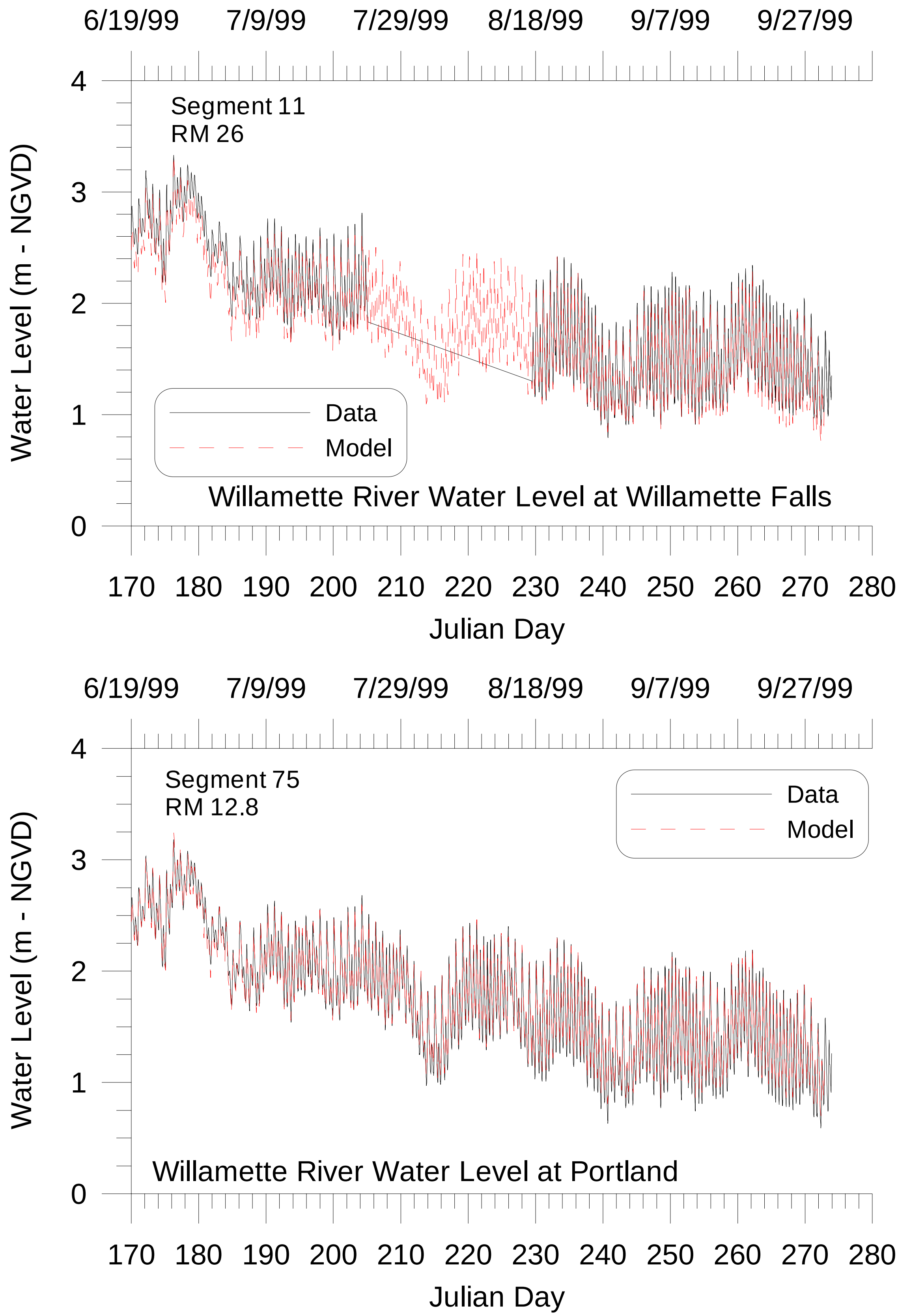


Figure 6. Water level data versus model predictions for Portland and below Willamette Falls during 1999.

Flow

Model predictions compared to field data for 1993 at RM 12.8 are shown in Figure 7, (a more detailed graph of these flow rates are shown in Figure 8). Model predictions compared to field data for 1994 at RM 12.8 are shown in Figure 9. Model-data errors are shown in Table 3.

Table 3. Model - data errors in flow rate for the Willamette River for 1993, 1994 and 1997-1999 at RM12.8 (model segment 75).

Year	RM 12.8 Segment #75			RM 26.2 Segment #11		
	n, # of data comparisons	AME, m^3/s	RMS error, m^3/s	n, # of data comparisons	AME, m^3/s	RMS error, m^3/s
1993	1515	135.60	197.68	1515	27.91	51.70
1994	1515	181.45	289.48	1515	13.09	18.09
1997	NA	NA	NA	1515	19.17	36.95
1998	NA	NA	NA	1515	29.73	53.47
1999	NA	NA	NA	1515	18.16	30.31

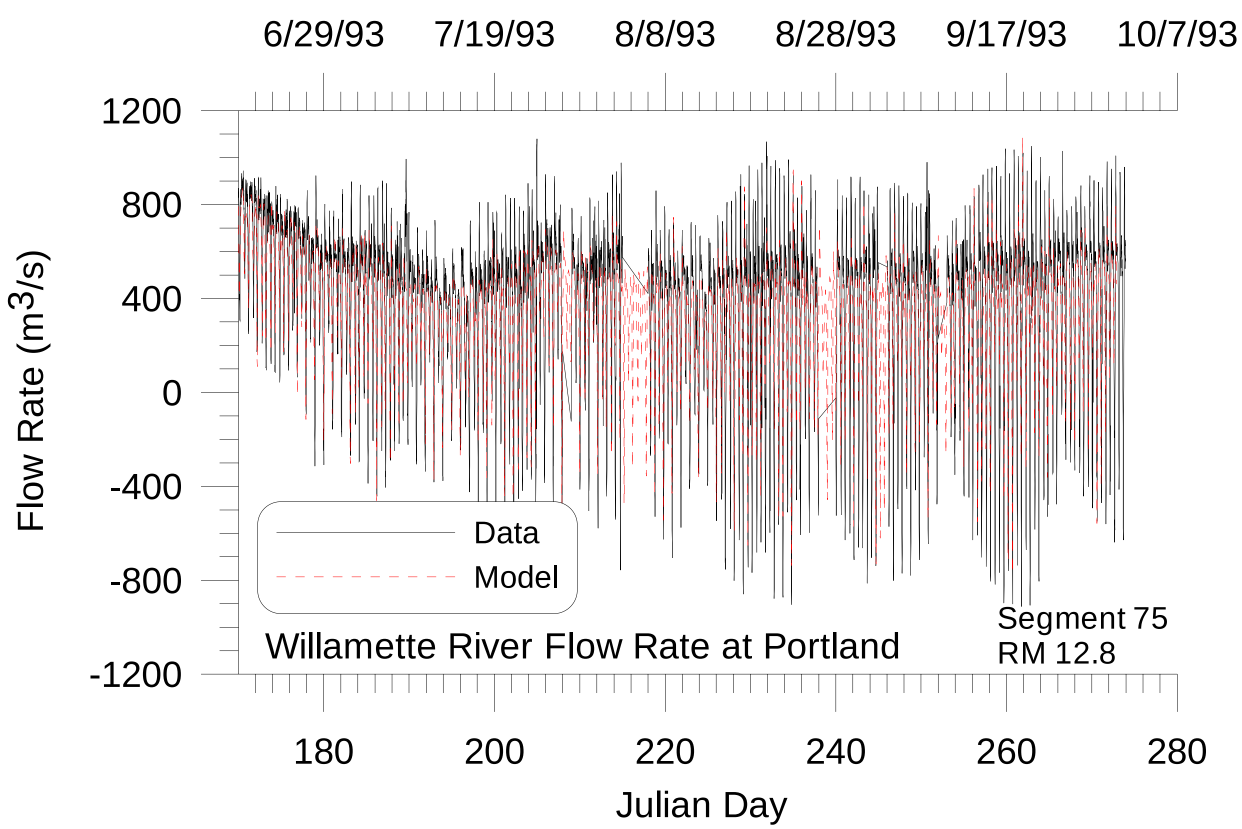


Figure 7. Model flow predictions versus data for 1993 at Portland.

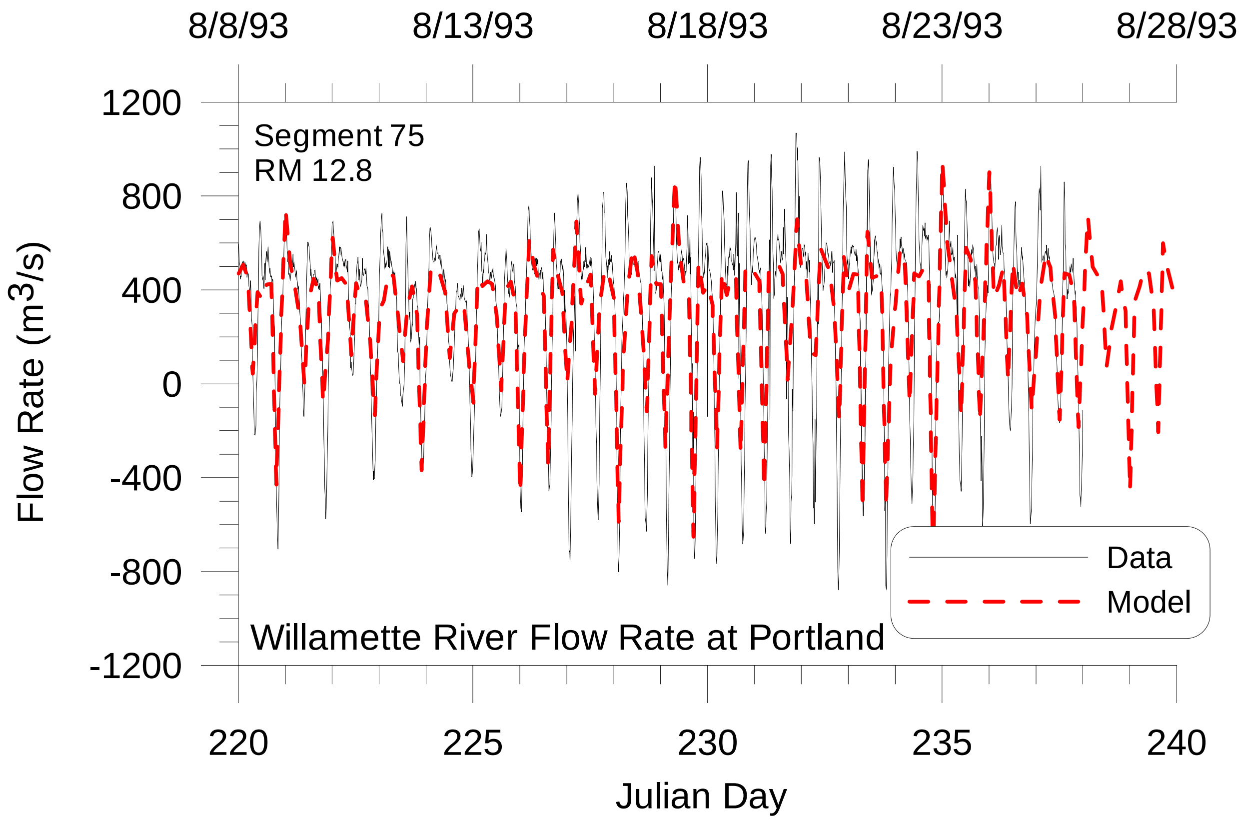


Figure 8. Model flow predictions versus data during a 20-day period during 1993 at Portland.

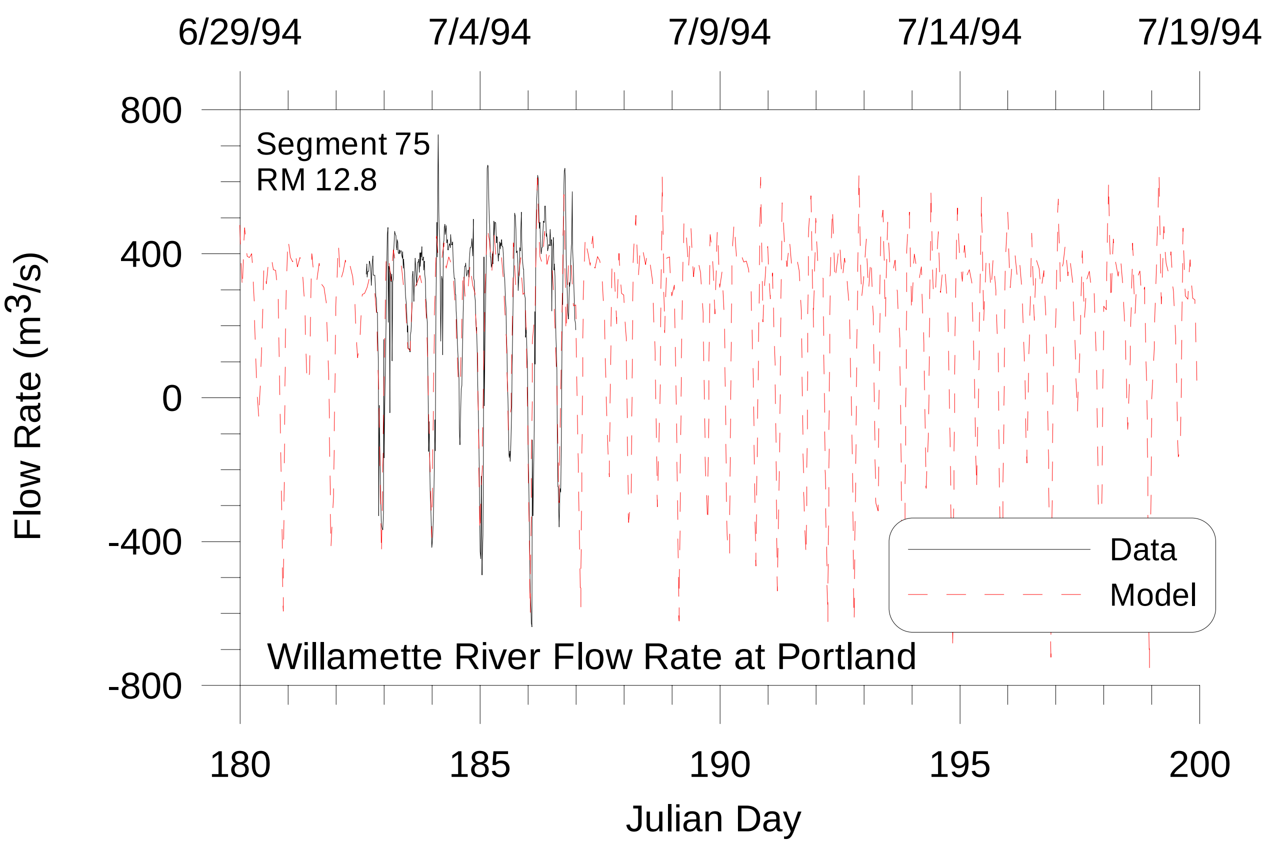


Figure 9. Model flow predictions versus data for 1994 at Portland.

Columbia River

Water level and flow data on the Columbia River were acquired form the USGS and from the US Army Corps of Engineers to compare with model results. Comparisons were made in the summers of 1993 and 1994 and 1997 through 1999 when data were available. Table 4 shows a list of gage stations on the Columbia River that had water level data and in some cases flow data.

Table 4. Columbia River hydrodynamic calibration sites

Site ID	Site Description	River Mile	Model Segment
LOPW1	Columbia River at Longview, WA	66.6	324
SHNO3	Columbia River at St. Helens, OR	85.7	279
14144700	Columbia River at Vancouver, WA	106.5	232
14246900	Columbia River at Beaver Army Terminal, nr Quincy, OR	53.8	356
14128870	Columbia River below Bonneville Dam, OR	144.5	127

Water Level

Model predictions compared to field data for 1993 at Columbia River Mile 144.5 (near Bonneville) and RM 106 (Vancouver) are shown in Figure 10. A more detailed 20-day comparison of model data versus predictions for this same period and locations is shown in Figure 11. Model predictions compared to field data for 1993 at Columbia River Mile 66.6 (Longview) are shown in Figure 12. A more detailed 20-day comparison of model data versus predictions for this same period and locations is shown in Figure 13.

Model predictions compared to field data for 1994 at Columbia River Mile 144.5 (near Bonneville) and RM 106 (Vancouver) are shown in Figure 14. Model predictions compared to field data for 1994 at Columbia River Mile 66.6 (Longview) are shown in Figure 15.

Model predictions compared to field data for 1997 at Columbia River Mile 144.5 (near Bonneville) and RM 106 (Vancouver) are shown in Figure 16. Model predictions compared to field data for 1997 at Columbia River Mile 66.6 (Longview) and Columbia River Mile 86 (St. Helens) are shown in Figure 17.

Model predictions compared to field data for 1998 at Columbia River Mile 144.5 (near Bonneville) and RM 106 (Vancouver) are shown in Figure 18. Model predictions compared to field data for 1998 at Columbia River Mile 66.6 (Longview) and Columbia River Mile 86 (St. Helens) are shown in Figure 19.

Model predictions compared to field data for 1999 at Columbia River Mile 144.5 (near Bonneville) and RM 106 (Vancouver) are shown in Figure 20. Model predictions compared to field data for 1999 at Columbia River Mile 66.6 (Longview) and Columbia River Mile 86 (St. Helens) are shown in Figure 21.

Model-data errors are shown in Table 5.

Table 5. Model - data errors in water level for the Columbia River for 1993, 1994 and 1997-1999.

Year	Location	Water level errors		
		n, # of data comparisons	AME, m	RMS error, m
1993	RM144.5 Segment #127	1515	0.143	0.196
1994		1515	0.138	0.171
1997		1515	0.148	0.224
1998		1515	0.130	0.214
1999		1515	0.087	0.147
1993	RM106.5 Segment #232	1515	0.138	0.211
1994		1515	0.071	0.118
1997		1515	0.252	0.381
1998		1515	0.101	0.167
1999		1515	0.124	0.176
1993	RM 85.7 Segment #279	1515	NA	NA
1994		1515	NA	NA
1997		1515	0.310	0.400
1998		1515	0.161	0.251
1999		1515	0.145	0.215
1993	RM 66.6 Segment #324	1515	0.125	0.184
1994		1515	0.262	0.400
1997		1515	0.282	0.341
1998		1515	0.163	0.205
1999		1515	0.240	0.267
1993	RM 53.8 Segment #356	1515	0.014	0.018
1994		1515	0.013	0.015
1997		1515	0.018	0.036
1998		1515	0.014	0.016
1999		1515	0.014	0.016

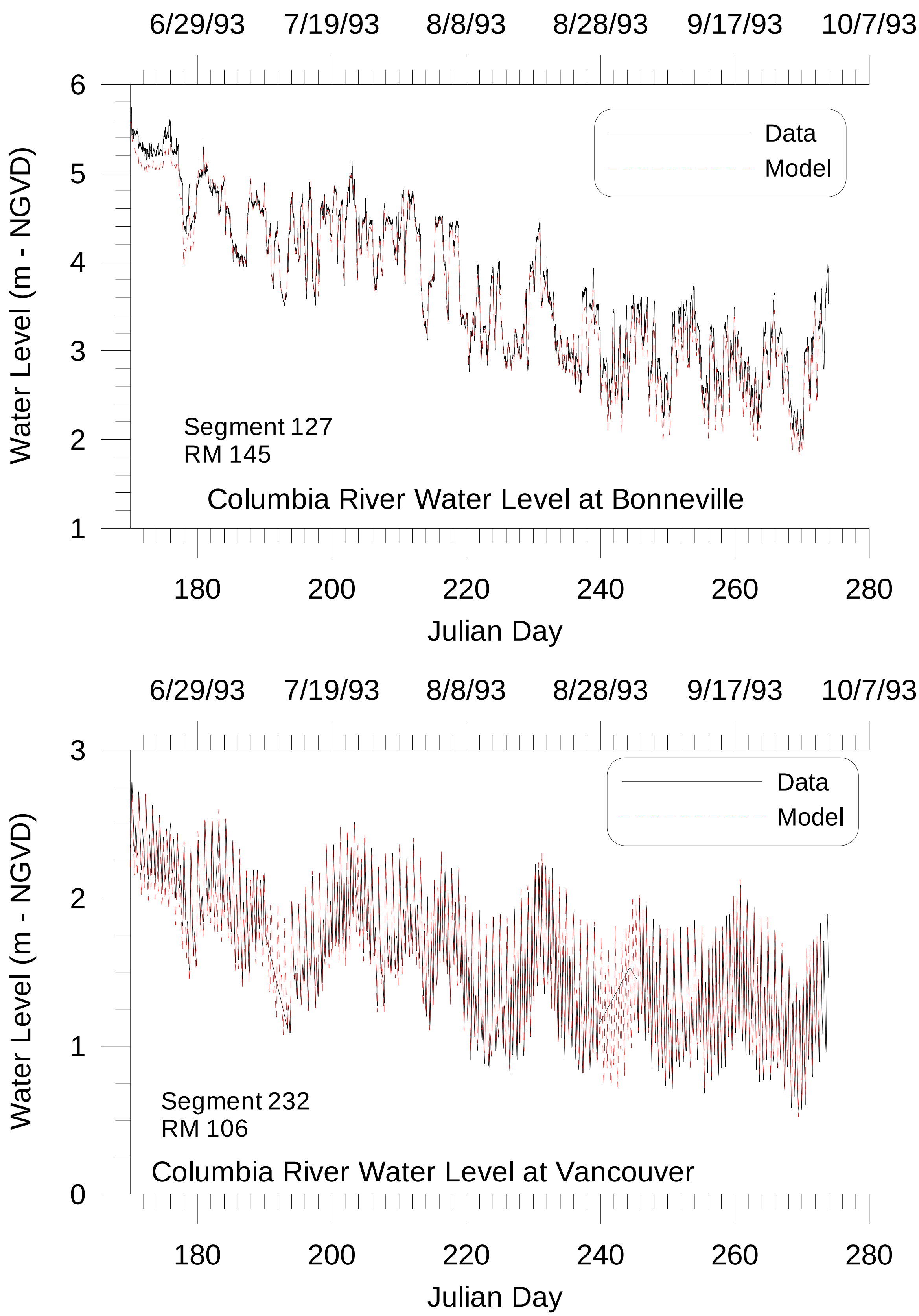
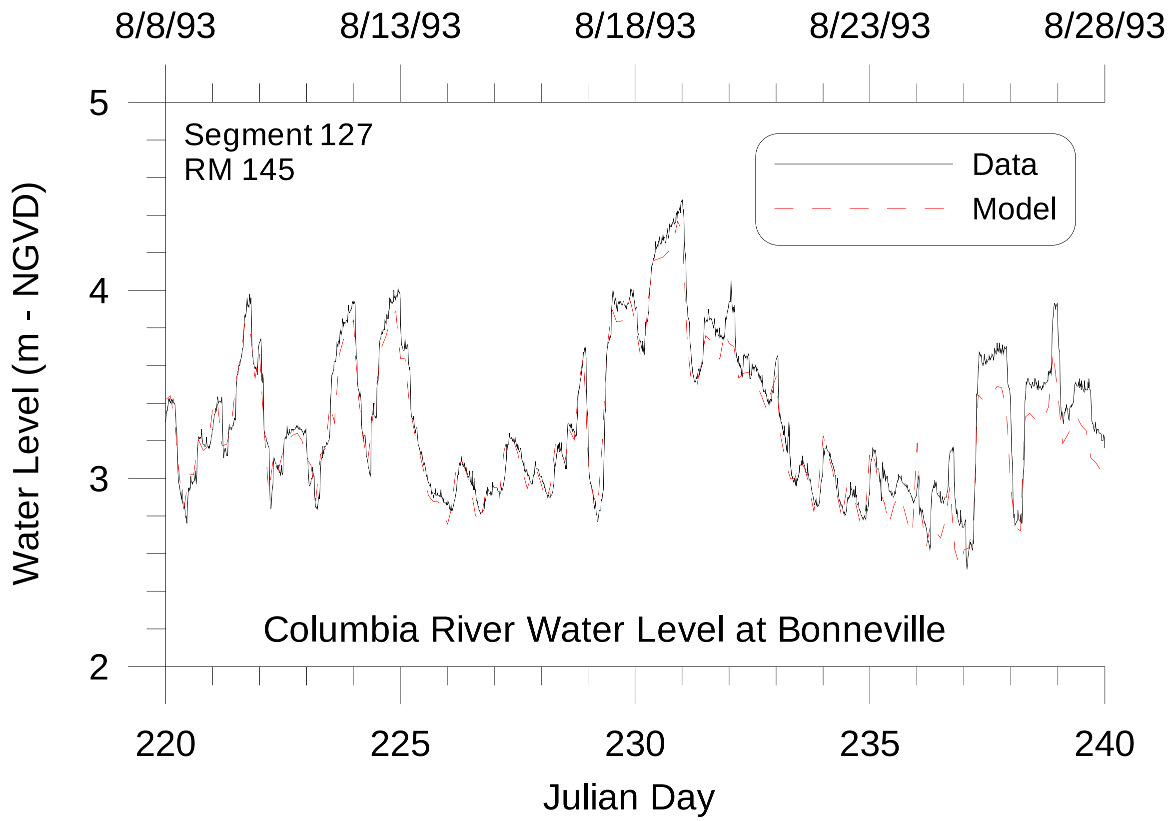


Figure 10. Water level data versus model predictions for Bonneville Dam and Vancouver, WA during 1993.



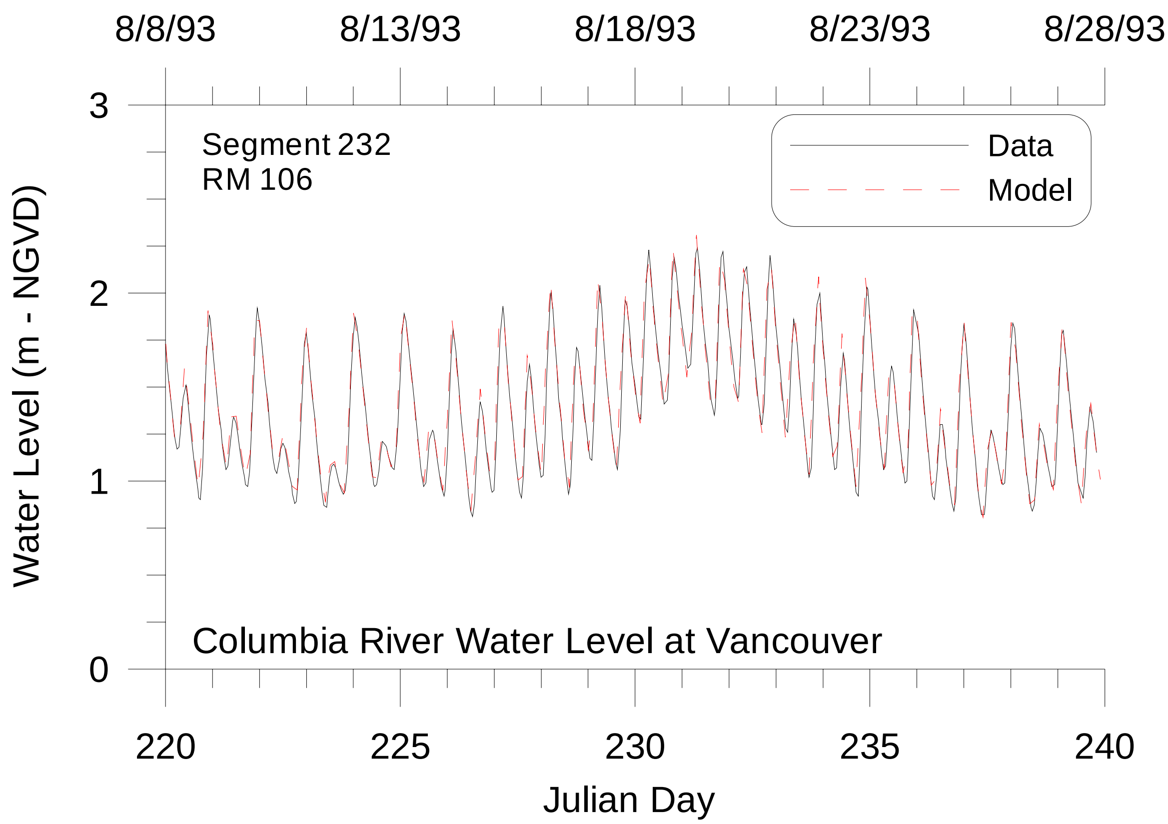


Figure 11. Water level data versus model predictions for Bonneville Dam and Vancouver, WA during a 20-day period in 1993.

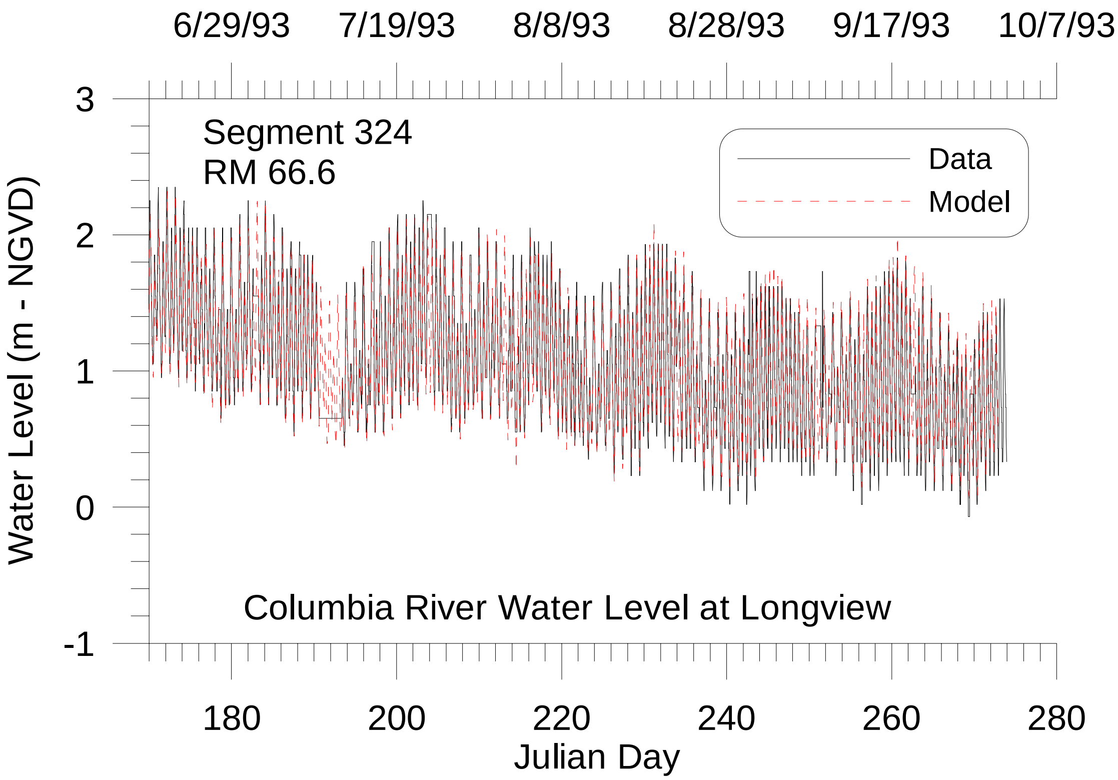


Figure 12. Water level data versus model predictions for Longview, WA during 1993.

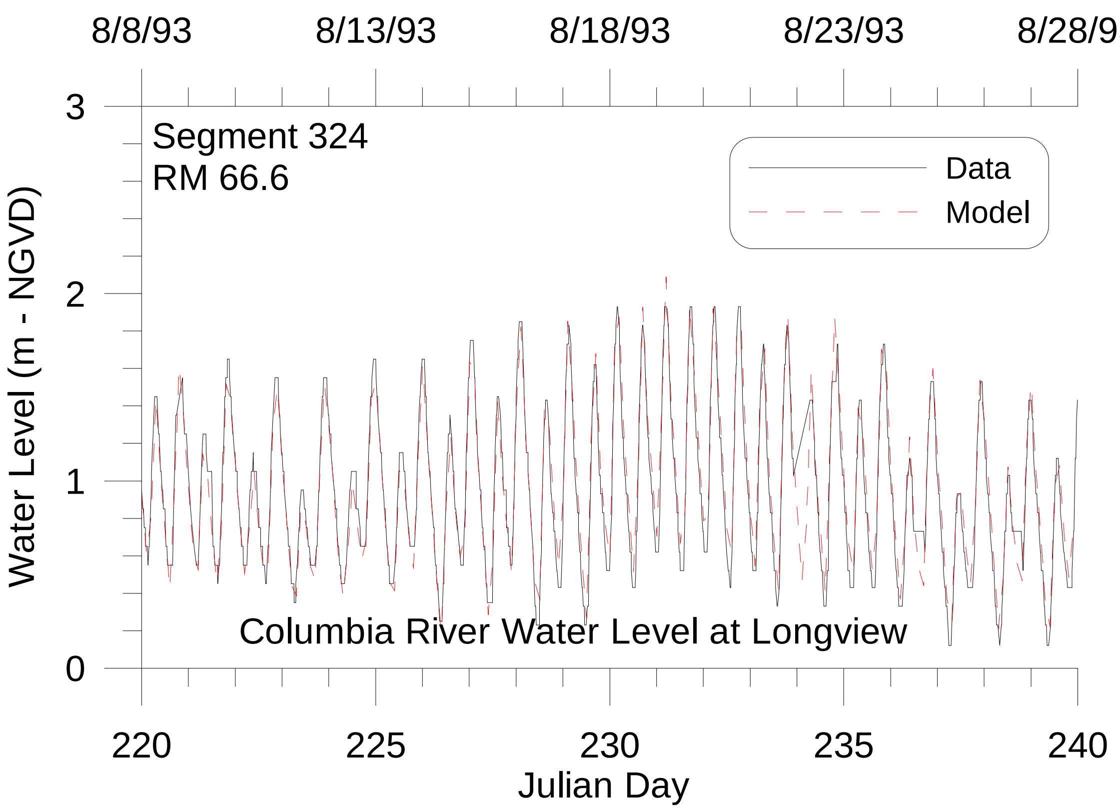


Figure 13. Water level data versus model predictions for Longview, WA during a 20-day period in 1993.

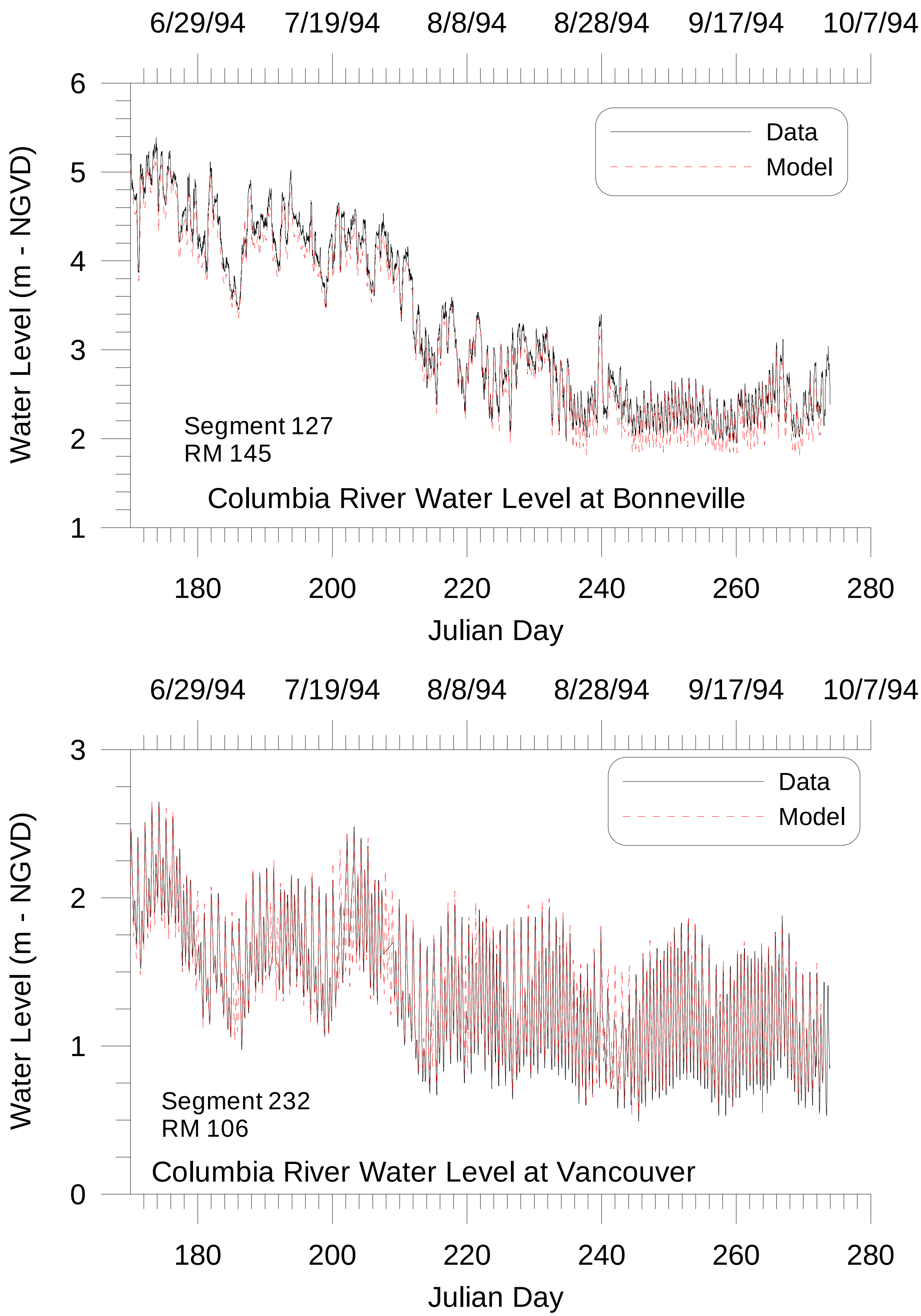


Figure 14. Water level data versus model predictions for Bonneville Dam and Vancouver, WA during 1994.

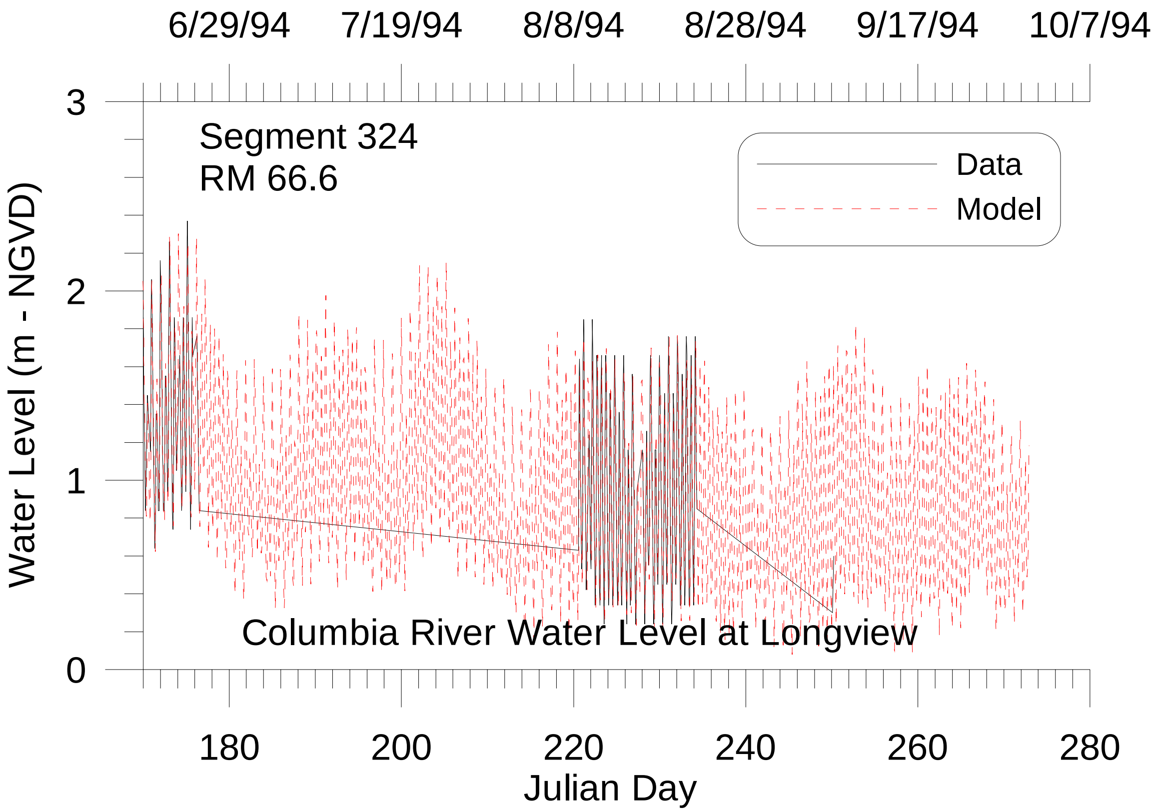
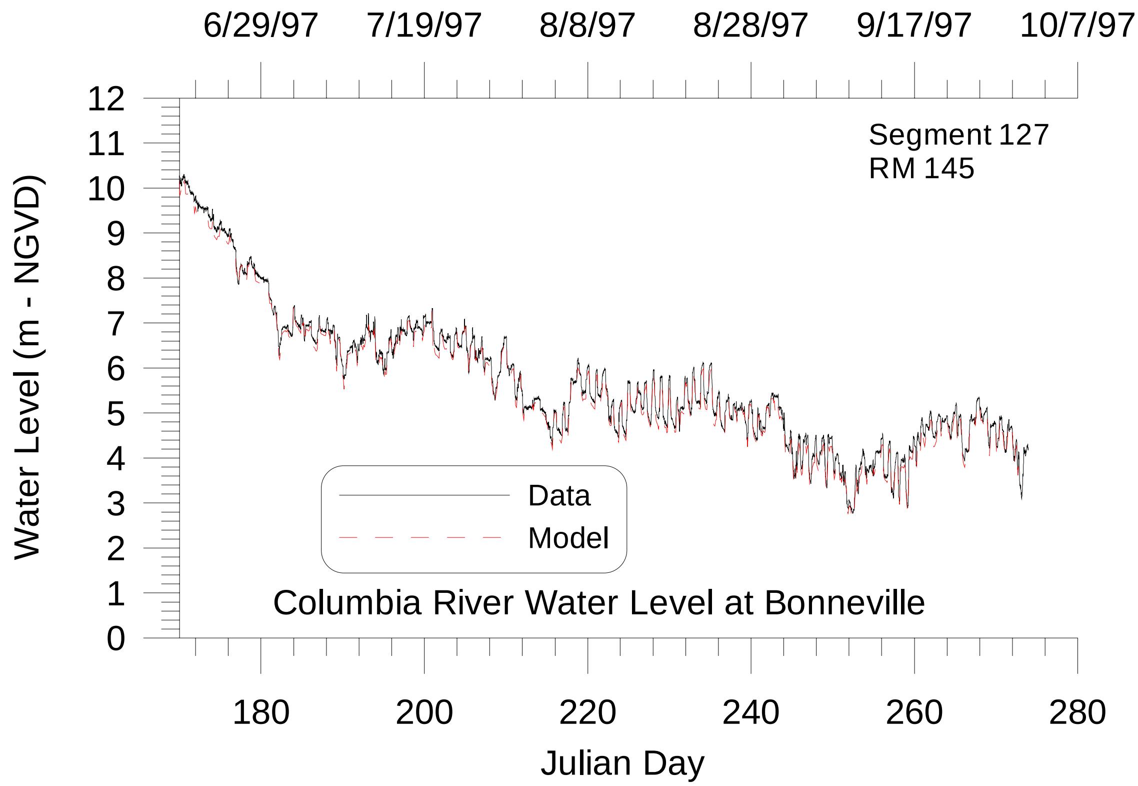


Figure 15. Water level data versus model predictions for Longview, WA during 1994.



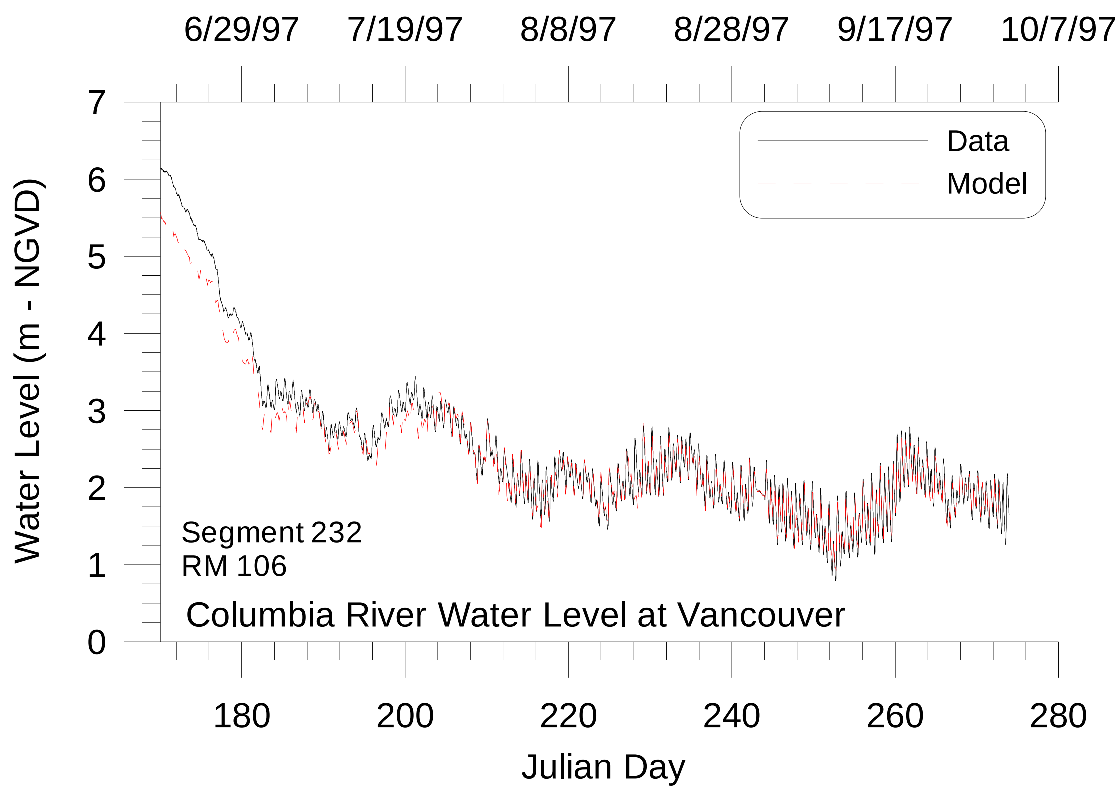
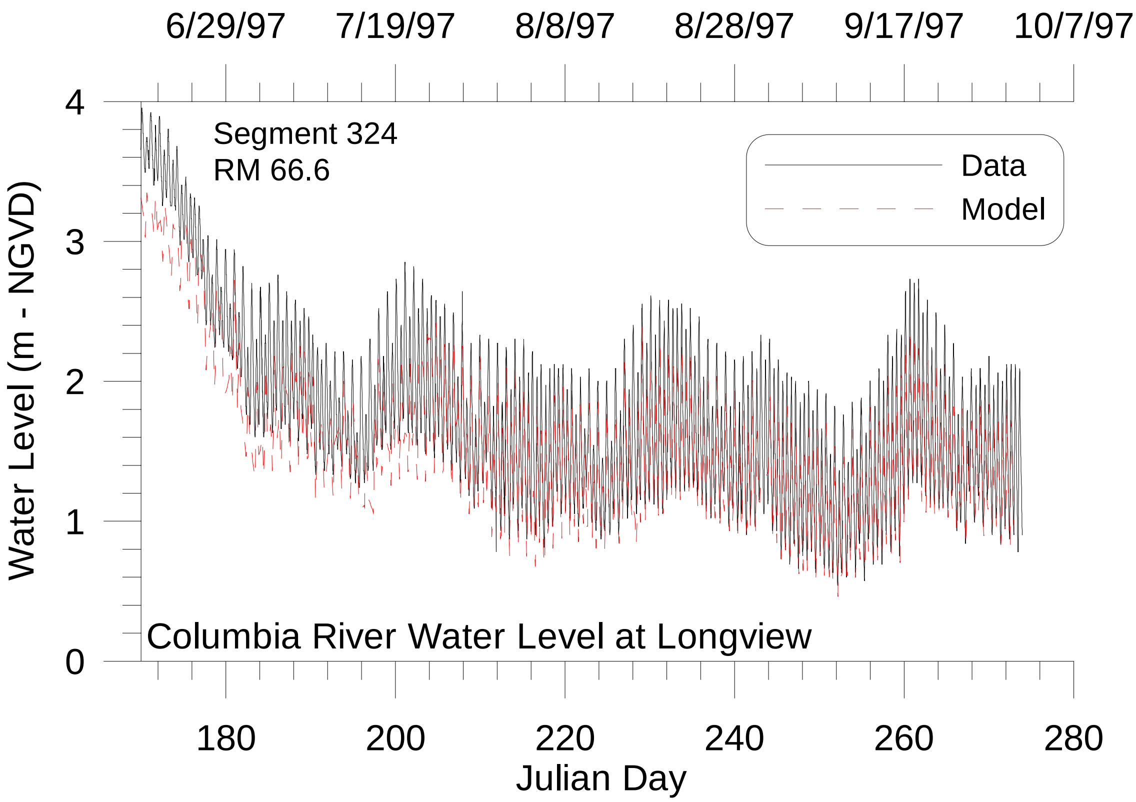


Figure 16. Water level data versus model predictions for Bonneville Dam and Vancouver, WA during 1997.



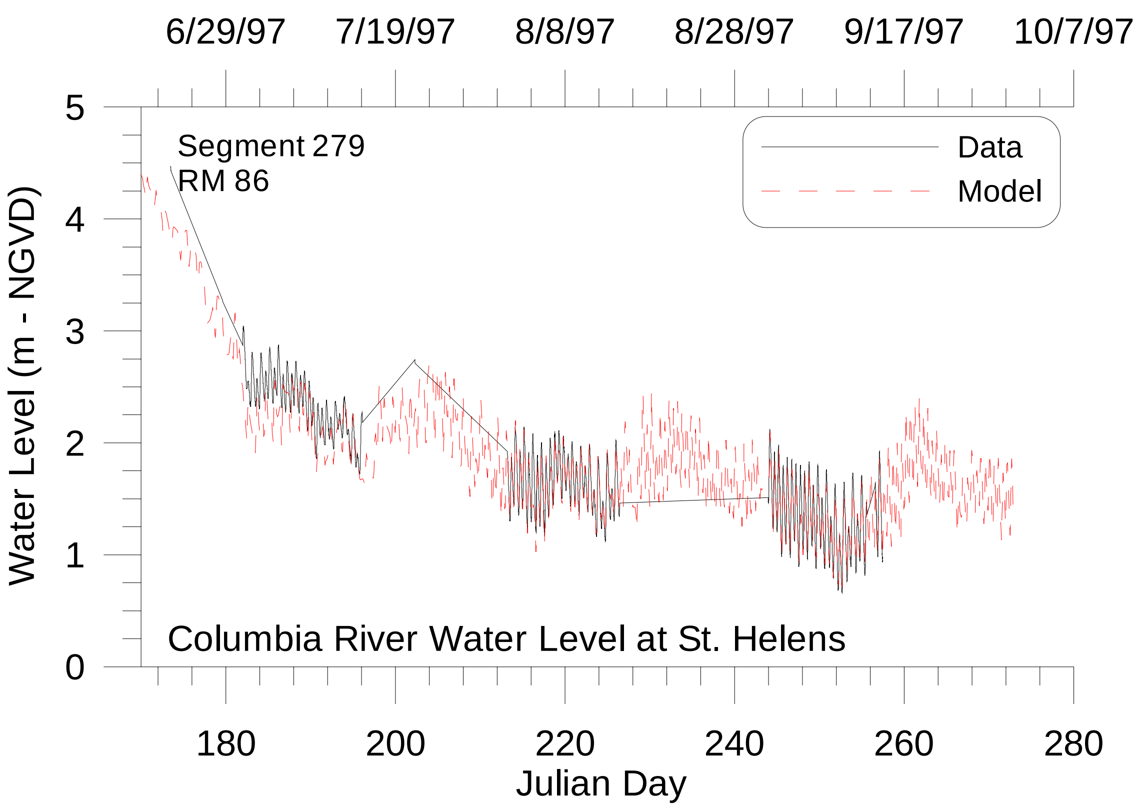


Figure 17. Water level data versus model predictions for Longview, WA and St. Helens, OR during 1997.

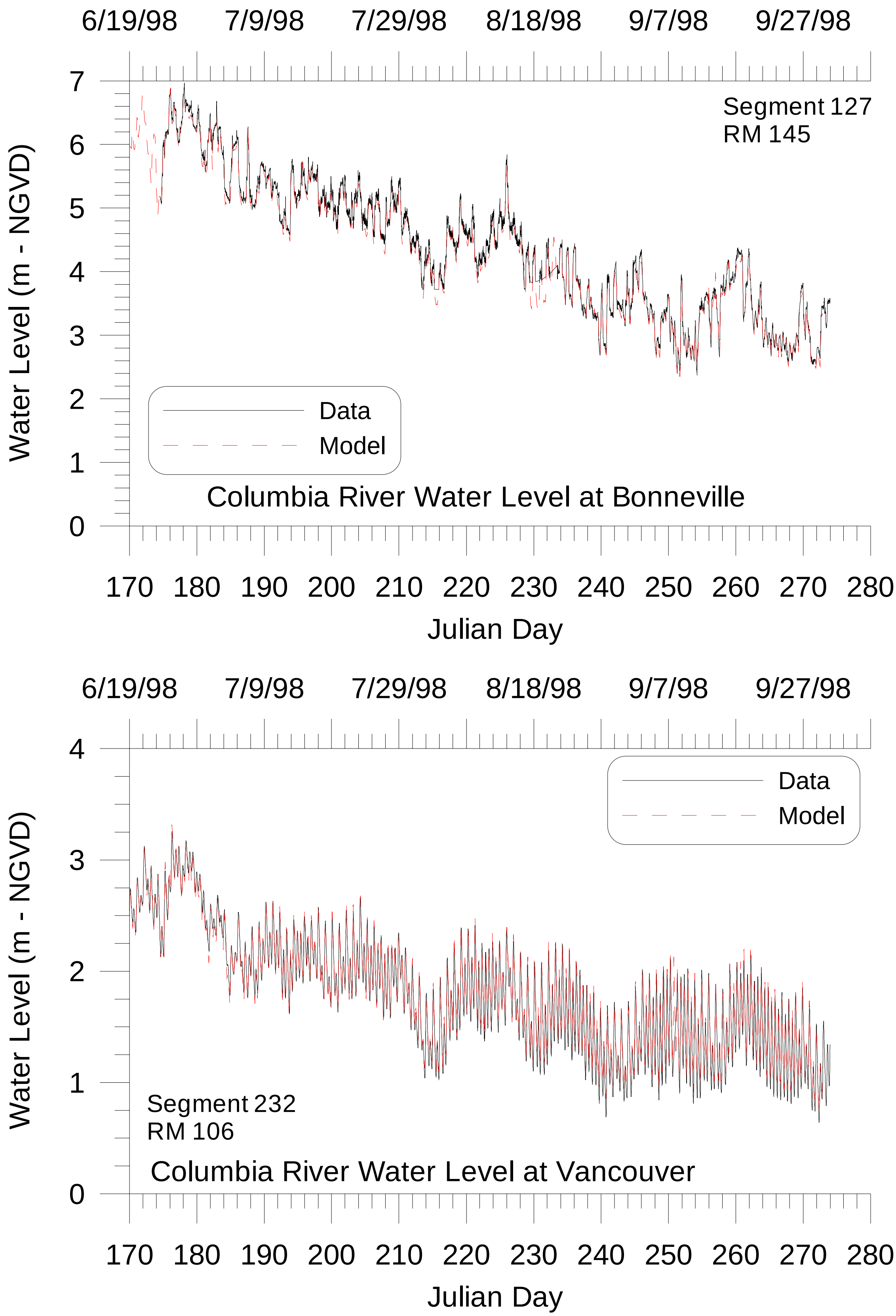


Figure 18. Water level data versus model predictions for Bonneville Dam and Vancouver, WA during 1998.

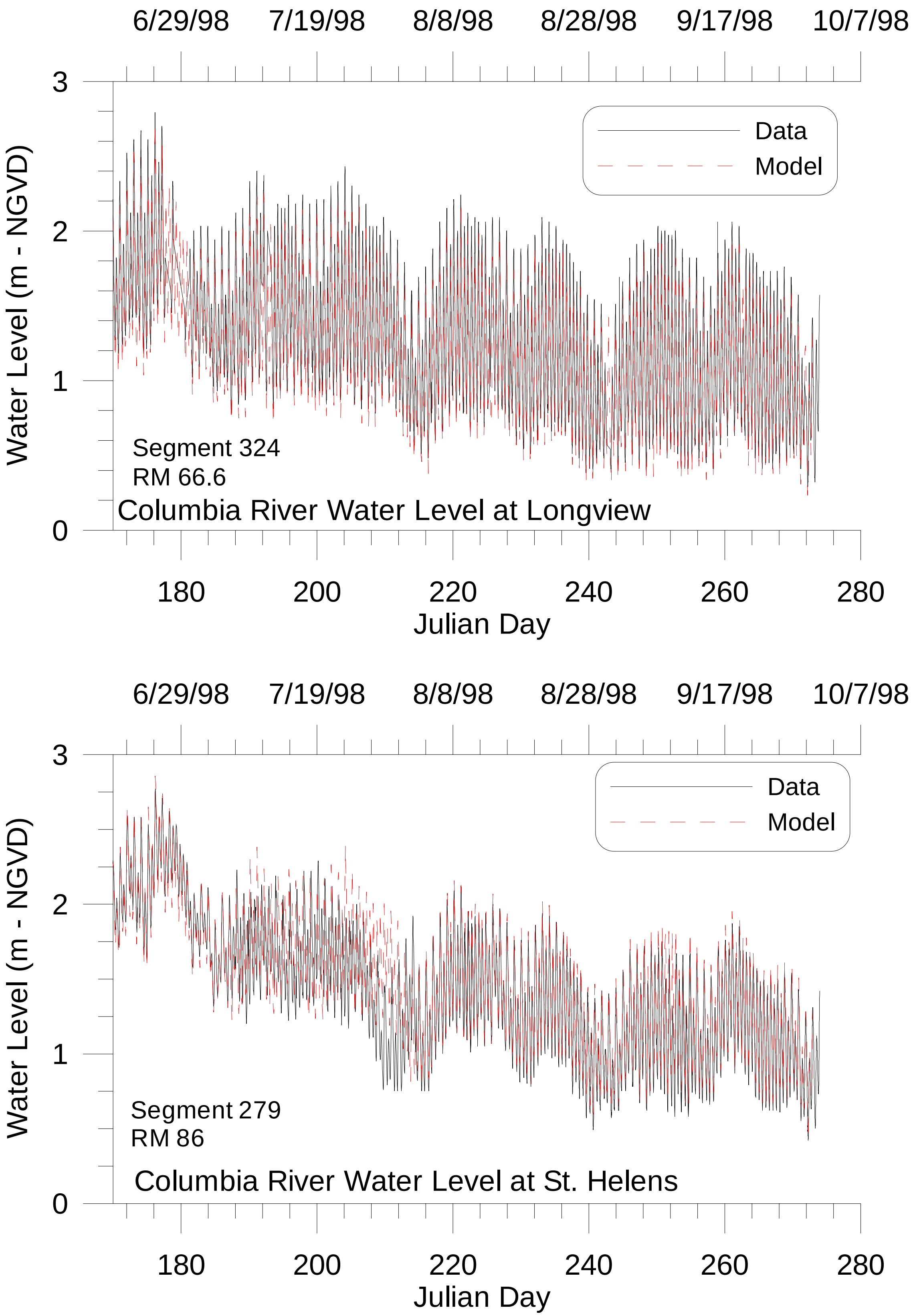


Figure 19. Water level data versus model predictions for Longview, WA and St. Helens, OR during 1998.

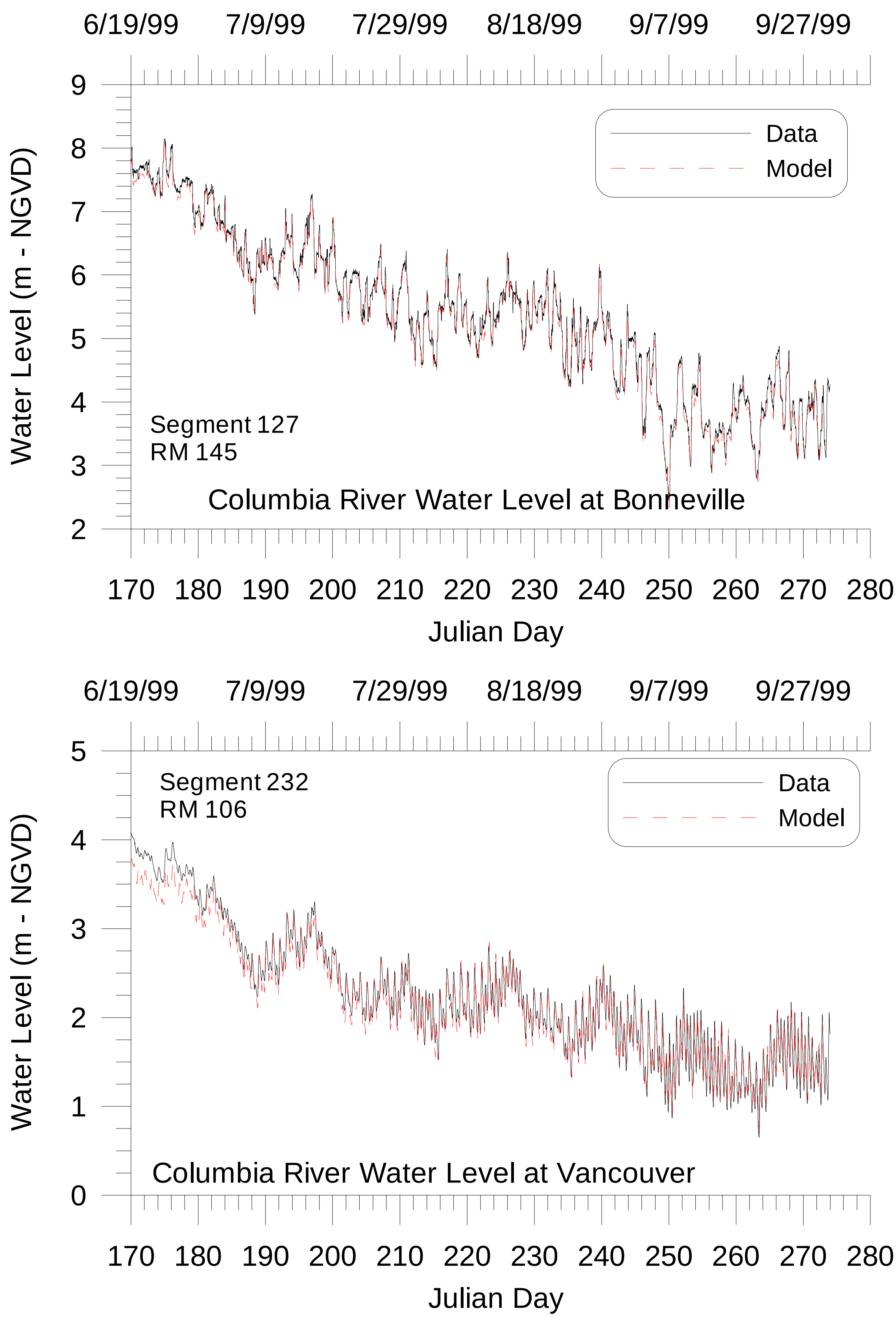
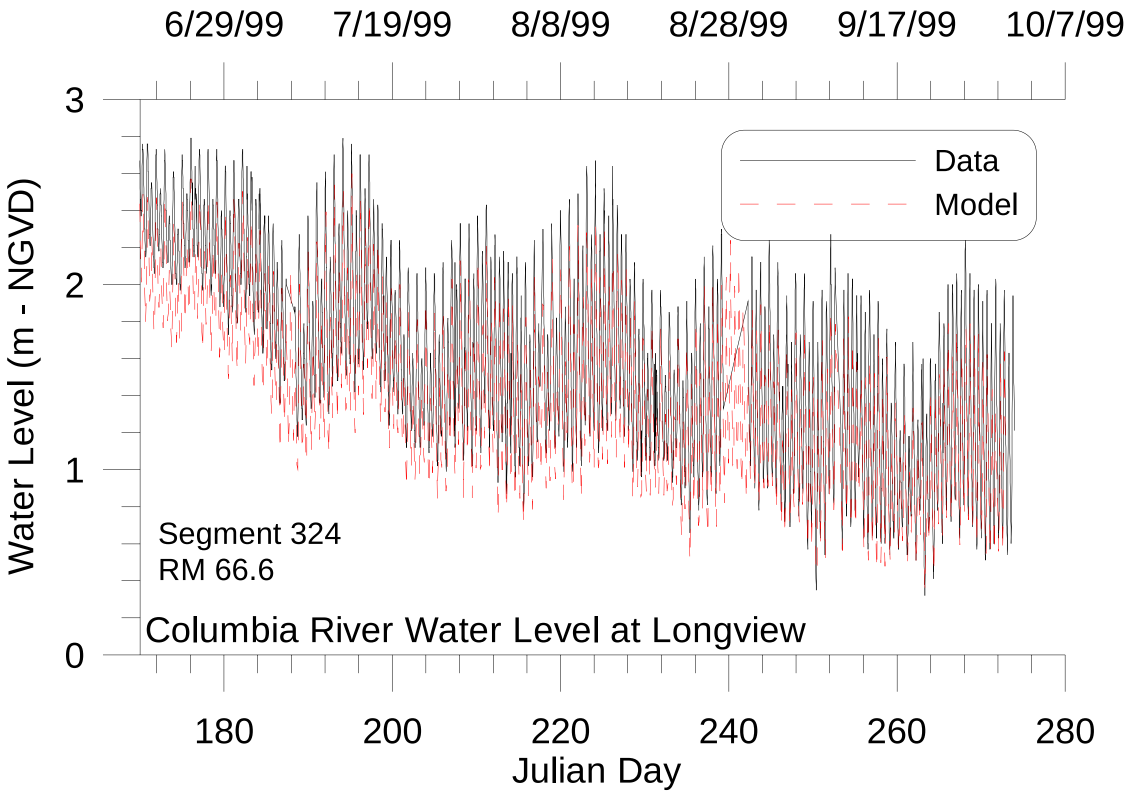


Figure 20. Water level data versus model predictions for Bonneville Dam and Vancouver, WA during 1999.



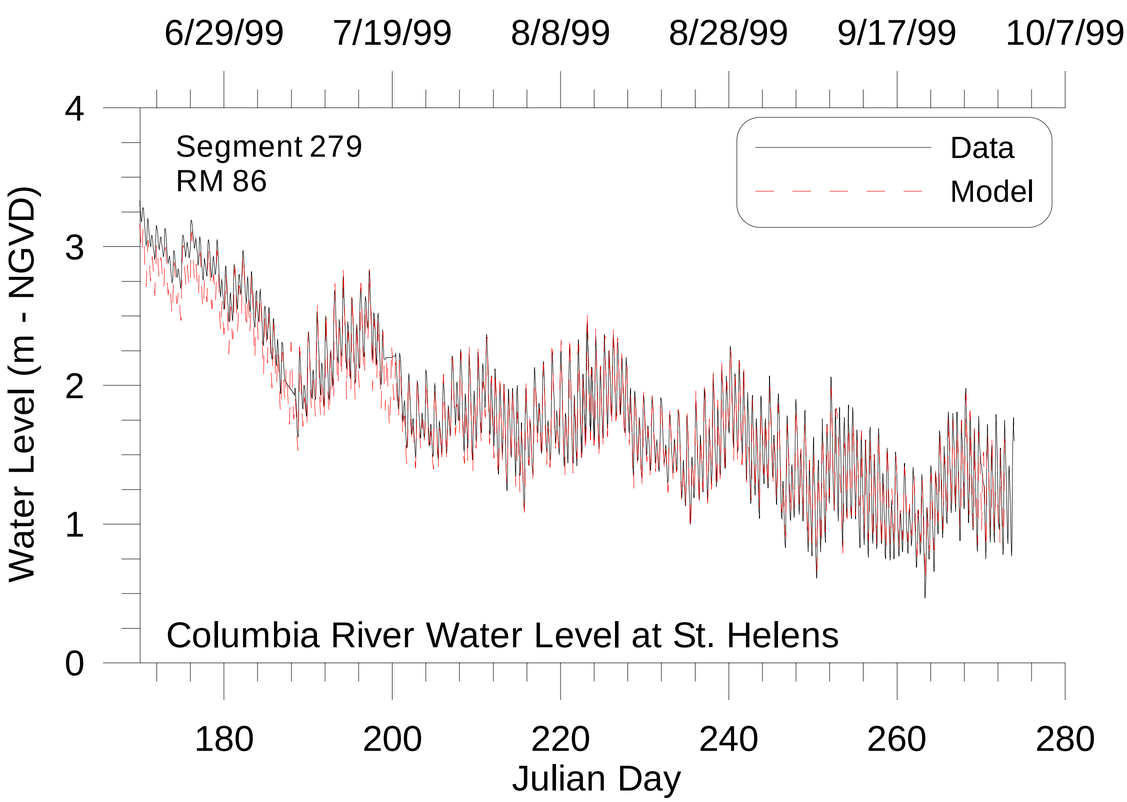


Figure 21. Water level data versus model predictions for Longview, WA and St. Helens, OR during 1999.

Flow

Model predictions of flow rate compared to field data for 1998 at Columbia River Mile 53.8 (Beaver Army Terminal) are shown in Figure 22. A more detailed 20-day comparison of model data versus predictions for this same period and locations is shown in Figure 23. Model predictions compared to field data for 1999 at Columbia River Mile 53.8 (Beaver Army Terminal) are shown in Figure 24.

Model-data errors for flow rate are shown in Table 6.

Table 6. Model - data errors in flow rate for the Columbia River for 1998 and 1999.

Year	Location	Flow rate errors		
		n, # of data comparisons	AME, m^3/s	RMS error, m^3/s
1998	RM 53.8 Segment #356	1299	1212.1	1479.9
1999		1205	1088.2	1435.8

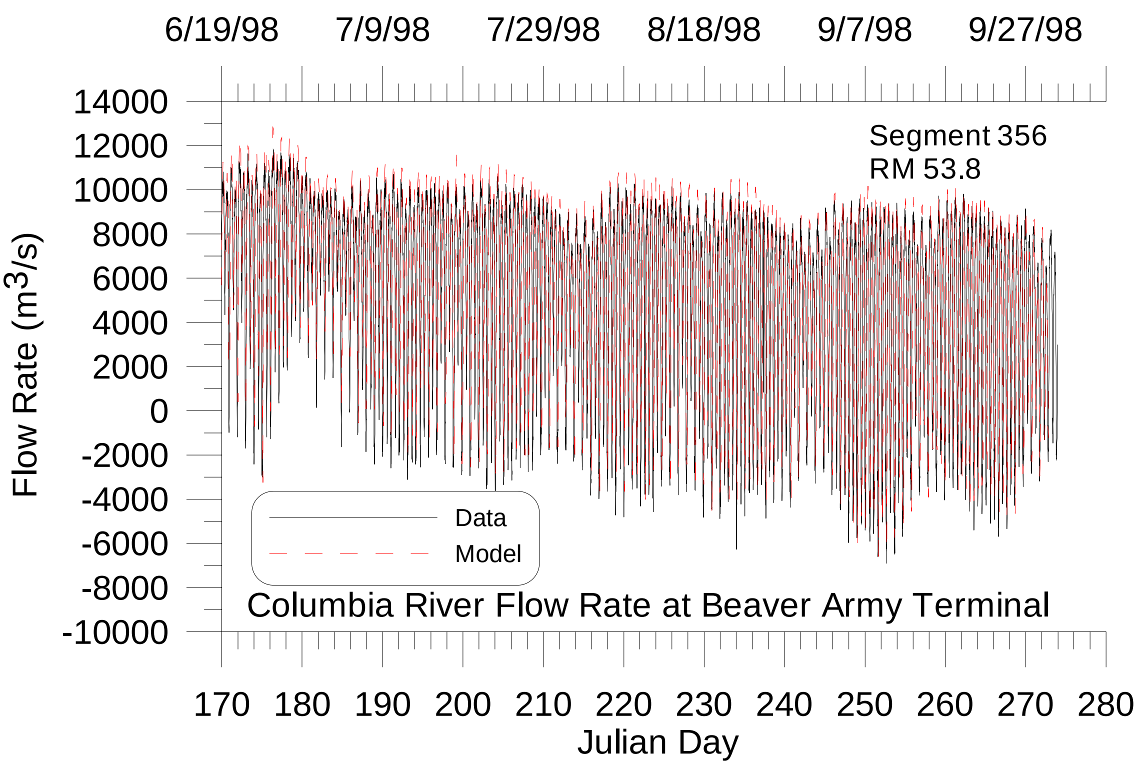


Figure 22. Model flow predictions versus data for 1998 at Beaver Army Terminal near Quincy, OR.

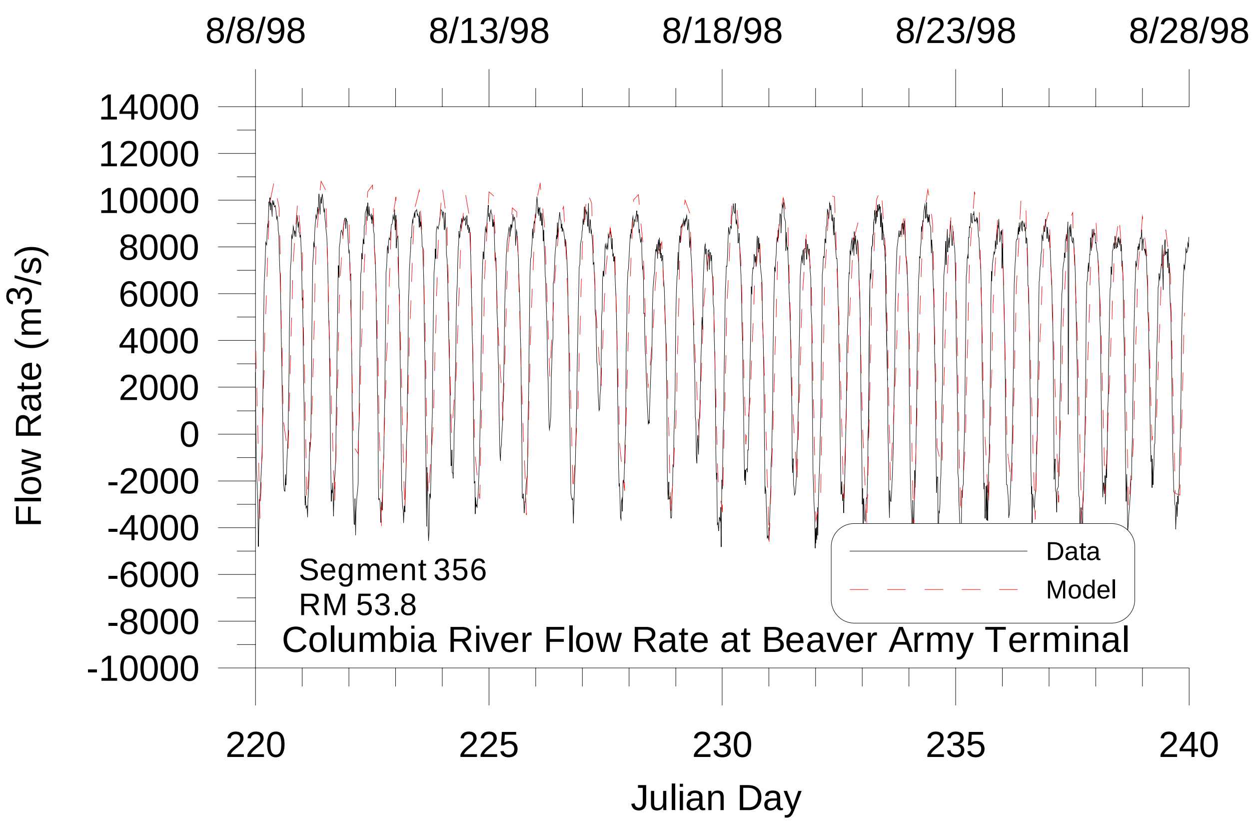


Figure 23. Model flow predictions versus data for a 20-day period during 1998 at Beaver Army Terminal near Quincy, OR.

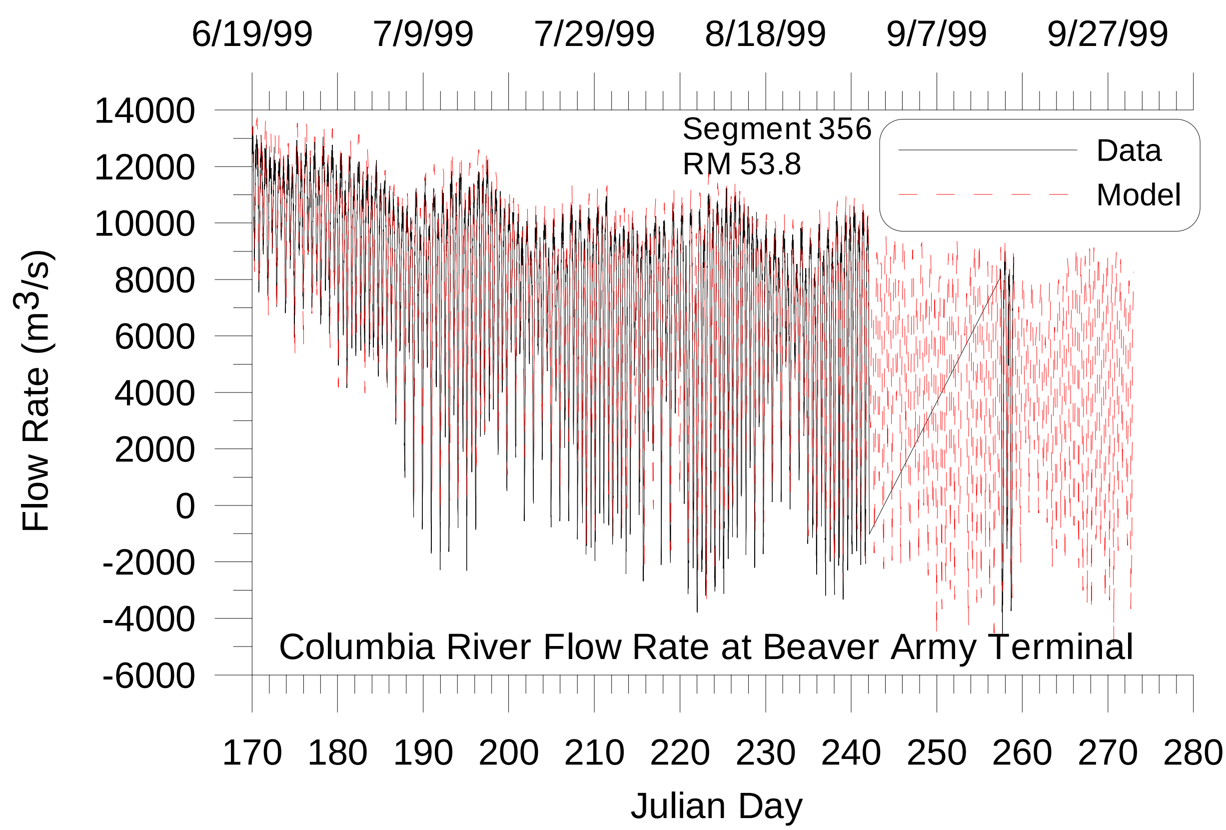


Figure 24. Model flow predictions versus data for 1999 at Beaver Army Terminal near Quincy, OR.

Temperature

Model calibration for temperature also depended on good upstream boundary conditions and meteorological data. Model parameters affecting the temperature calibration are shown below in Table 7.

Table 7. Model parameters affecting temperature calibration.

Parameter	Typical values*	Calibration Values	Description/Comments
Light extinction coefficient for water	0.25	0.20	EXH2O
Fraction of incident solar radiation absorbed at the water surface	0.45	0.45	BETA
Evaporation model coefficients	A=9.20 B=0.46 C=2.00	A=9.20 B=0.46 C=2.00	Default value from Cole and Wells (2000)
Wind sheltering coefficient	0.85	0.85	WSC
Coefficient of bottom heat exchange (Wm^2/sec)	7.0 x 10-8	7.0 x 10-8	CBHE
Sediment (ground) temperature (^oC)	12.8	14.0	TSED

Model results for the Willamette and Columbia data collection sites are shown in the following sections.

Willamette River

Crucial to adequately predicting temperatures in the Willamette was a good upstream boundary condition. The temperature boundary condition for the upstream end of the main stem Willamette River was estimated using data collected at Willamette Falls (RM 27). Temperature data collected at Canby were too sparse to adequately represent the boundary condition during the simulation years 1993, 1998, and 1999. Temperatures were estimated using the following 1-dimensional longitudinal model that neglects dispersion and utilizes the equilibrium temperature concept (Thomann and Mueller, 1987):

$$T_{Canby} = T_E + \left(T_{Falls} - T_E\right)\exp\left(\frac{kt}{H}\right)$$

where

T_{Canby} - temperature prediction for Canby (Celsius)

T_E - equilibrium temperature (Celsius)

T_{Falls} - temperature data from the Falls

t - time of travel (s)

H - mean depth (m)

k - kinematic surface exchange coefficient (m/s)

The kinematic surface heat exchange coefficient k and the equilibrium temperature T_E were calculated using the heat algorithm from CE-QUAL-W2 (Cole and Wells, 2000). Meteorological data was collected at Portland International Airport for 1993 and at Aurora for 1998 and 1999. Based on CE-QUAL-W2 model predictions, travel time t was assumed to be 1 day and mean depth H was assumed to be 3 meters. Figure 25 shows the estimated temperatures used for the 1993 input file compared to the

Willamette Falls data. The 1998 and 1999 input files and Falls data are shown in Figure 26 and Figure 27, respectively.

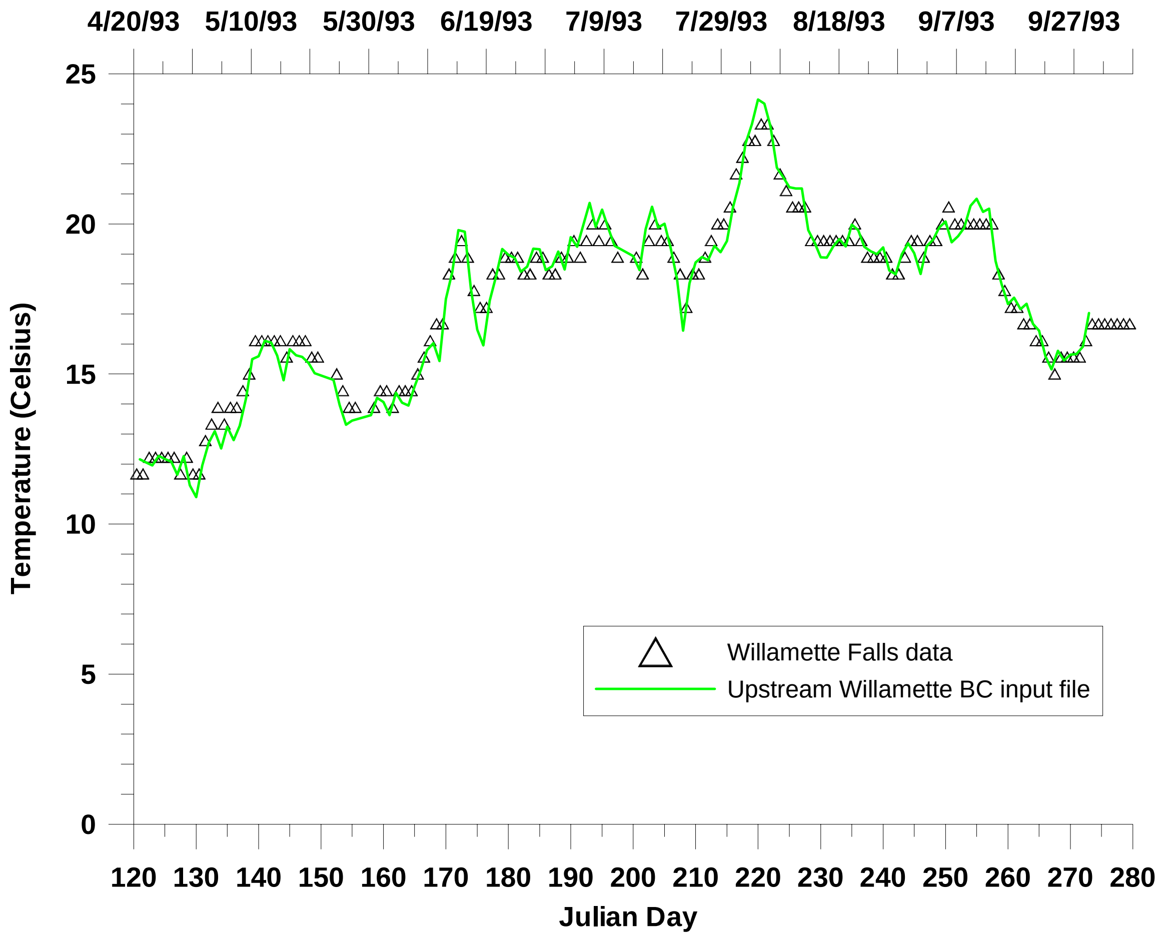


Figure 25. Plot of the temperature input file used for the 1993 Canby temperature boundary condition and the Willamette Falls data.

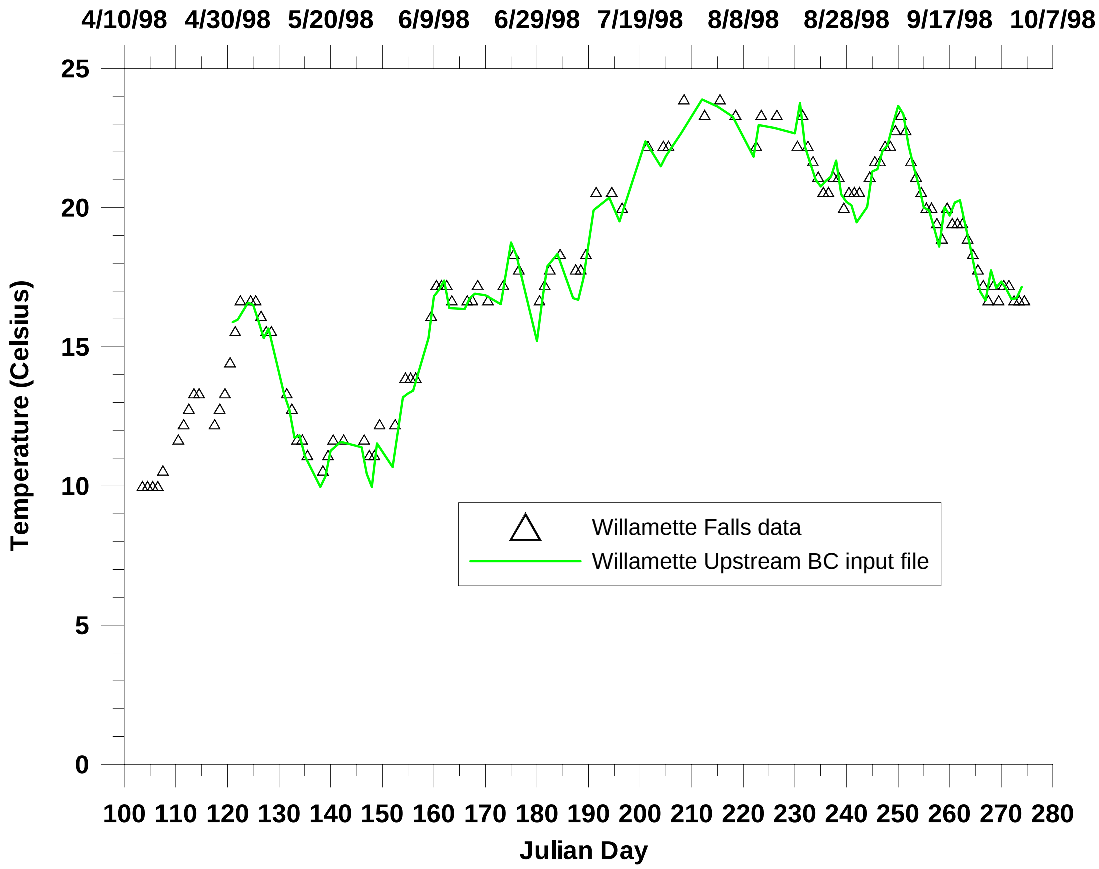


Figure 26. Plot of the temperature input file used for the 1998 Canby temperature boundary condition and the Willamette Falls data.

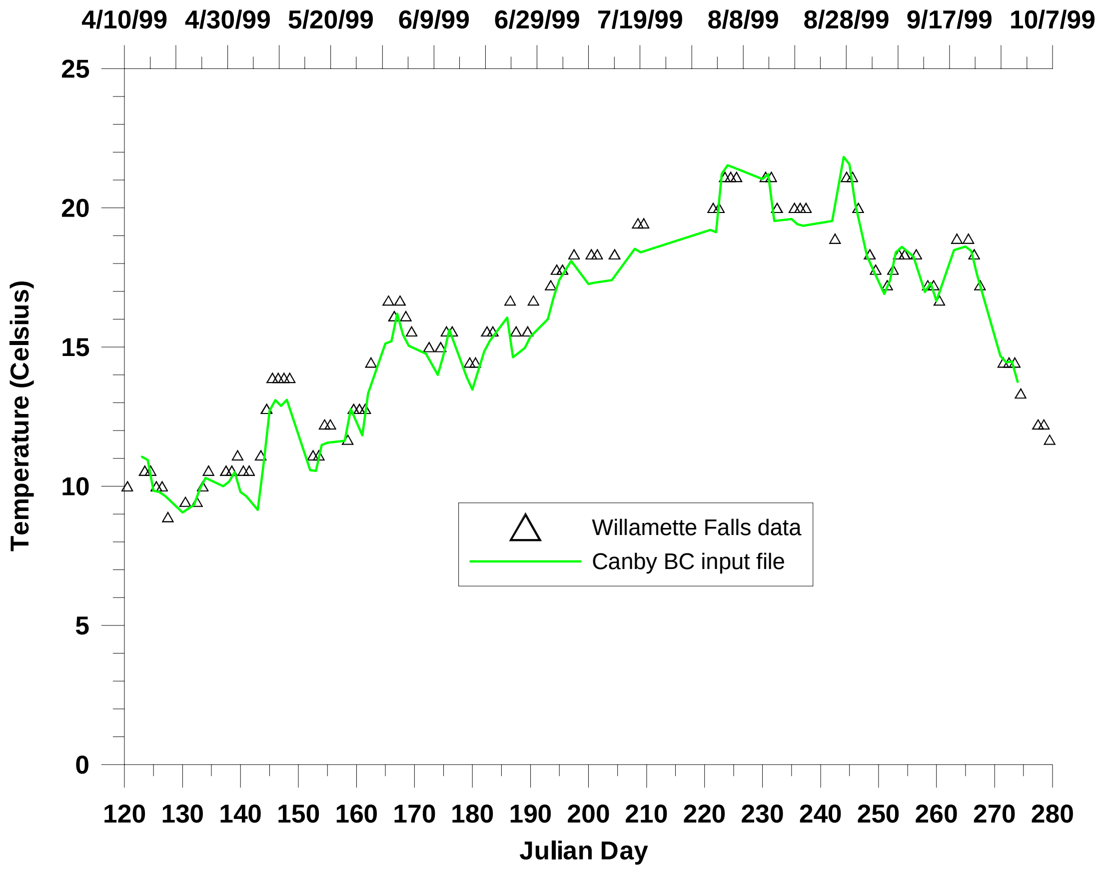


Figure 27. Plot of the temperature input file used for the 1999 Canby temperature boundary condition and the Willamette Falls data.

Table 8 lists the sites and frequency of temperature data collected on the Willamette River and used for comparison with model results.

Table 8. Willamette River temperature calibration sites

Site ID	Site Description	River mile	Model Segment	Data Type
A	Willamette River at Tryon Creek Railroad Bridge	20.0	45	Grab samples
C, SJRB	Willamette at St. John's Railroad Bridge	6.3	92	Continuous and Grab samples
D	Willamette River at South Kelly Point Park	1.1	105	Grab samples
E	Willamette River at Swan Island	8.8	88	Grab samples
F, WCC	Willamette River at Waverly Country Club	17.9	60	Continuous and Grab samples
B, ORSTORET	Willamette River at Portland, Oreg. (Morrison St Bridge)	12.7	75	Grab samples
ORSTORET	Willamette River at Hawthorne Bridge	13.1	73	Grab samples

Model predictions of surface temperatures compared to grab sample field data at Willamette River site A (RM 20.0) and site B (RM 12.7) for 1993, 1994, and 1997 are shown in Figure 28, Figure 29, and Figure 30, respectively.

Model predictions of surface temperatures compared to continuous field data at Willamette River near Waverly Country Club (RM 17.9) and St. John's Railway Bridge (RM 6.8) for 1998 and 1999 are shown in Figure 31 and Figure 32, respectively.

Model prediction errors are shown in Table 9.

Table 9. Model - data errors in temperature for the Willamette River between 1993 and 1999.

Year	Location	Temperature errors		
		n, # of data comparisons	AME, ^oC	RMS error, ^oC
1993	RM 20.0 Segment #45	9	0.466	0.568
1994		18	0.380	0.474
1997		19	0.861	1.018
1998		19	0.523	0.657
1999		22	0.782	1.025
1993	RM17.9 Segment #60	NA	NA	NA
1994		NA	NA	NA
1997		276	0.576	0.650
1998		6624	0.495	0.622
1999		5990	0.712	0.936
1993	RM 13.1 Segment #73	5	0.941	1.054
1994		7	1.400	2.427
1997		5	0.856	0.985
1998		6	2.126	3.472
1999		NA	NA	NA
1993	RM 12.7 Segment #75	14	0.537	0.695
1994		23	0.447	0.535
1997		19	0.821	0.957
1998		19	0.606	0.718
1999		22	0.754	0.933
1993	RM 8.8 Segment #88	NA	NA	NA
1994		18	0.932	1.891
1997		19	0.864	0.996
1998		19	0.491	0.589
1999		22	0.625	0.784
1993	RM 6.8 Segment #92	9	0.560	0.731
1994		18	0.616	0.776
1997		276	0.602	0.720
1998		6588	0.347	0.445
1999		5962	0.636	0.832
1993	RM 1.1 Segment #105	9	0.396	0.499
1994		NA	NA	NA
1997		19	0.711	0.851
1998		19	0.417	0.515
1999		17	1.304	3.261

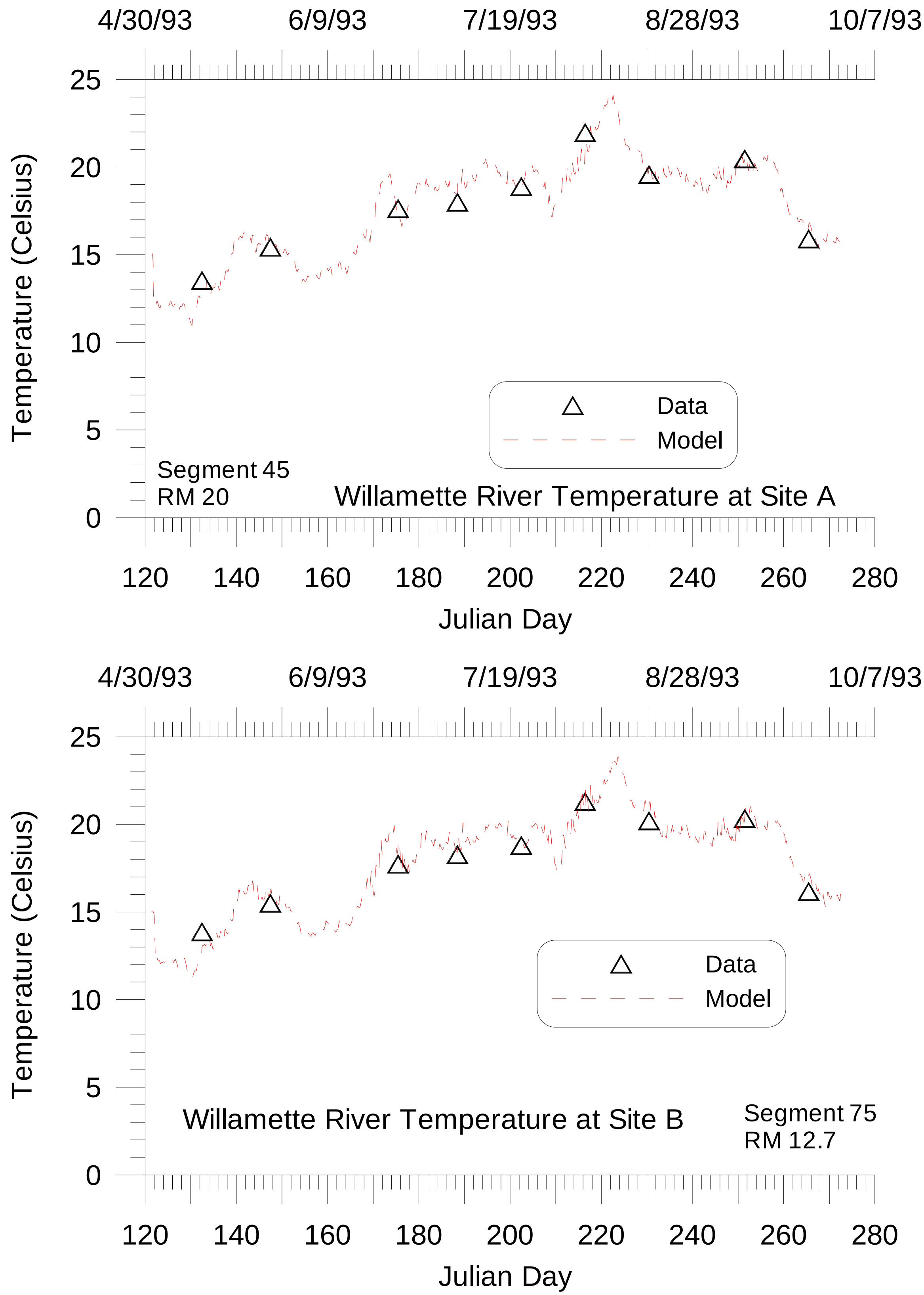


Figure 28. Comparison between model temperature predictions and data for Willamette River Sites A (RM 20) and B (RM 12.7) during 1993.

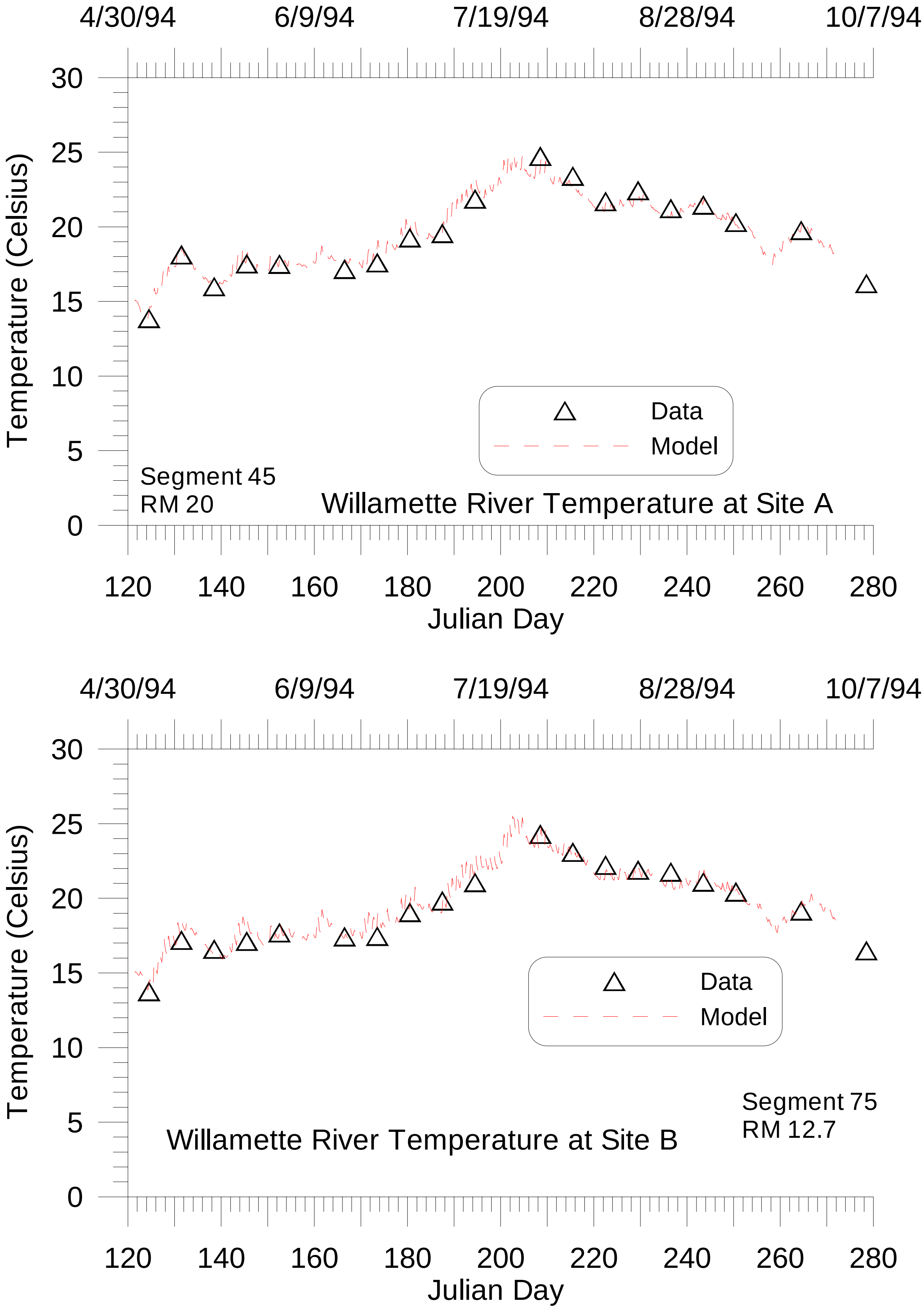
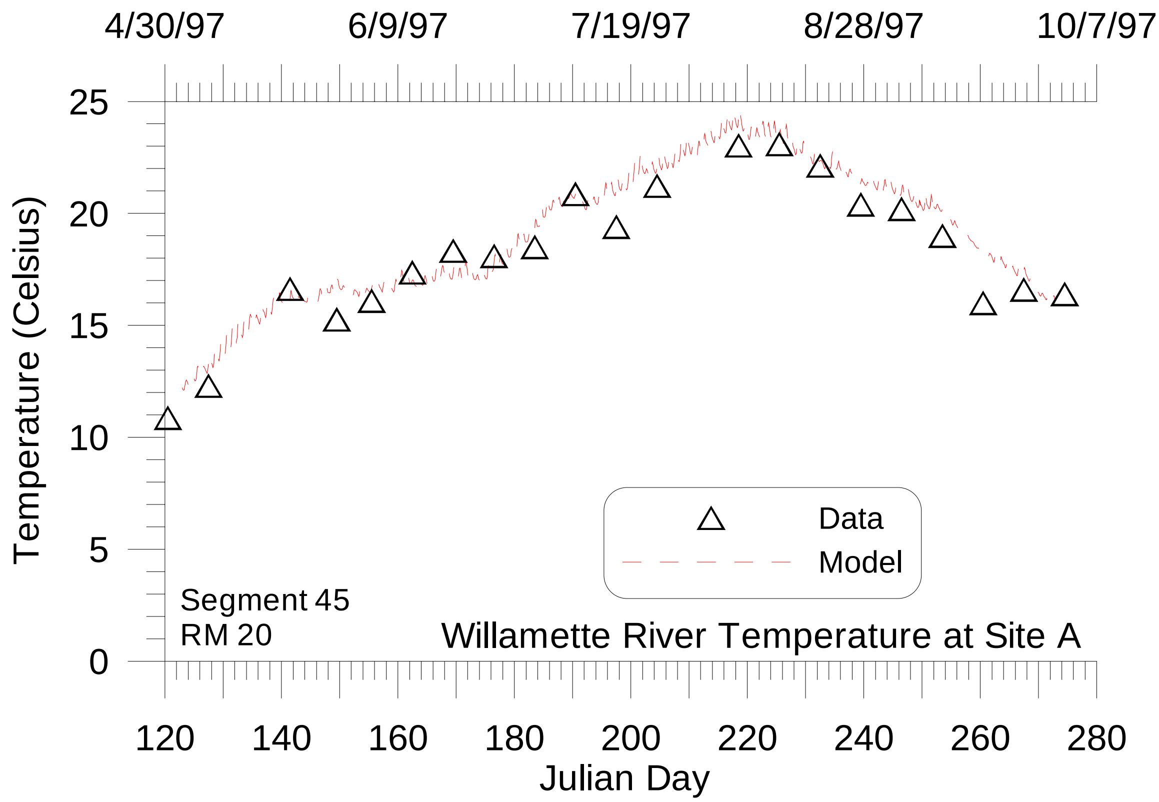


Figure 29. Comparison between model temperature predictions and data for Willamette River Sites A (RM 20) and B (RM 12.7) during 1994.



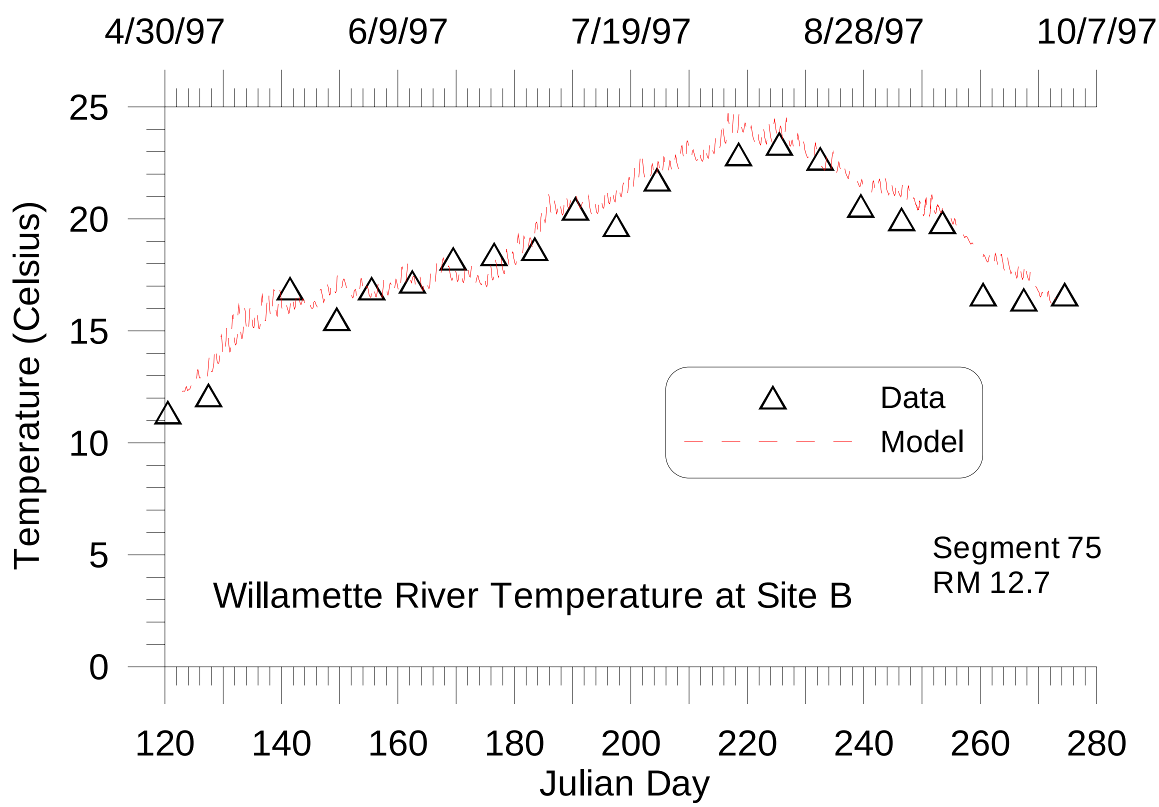
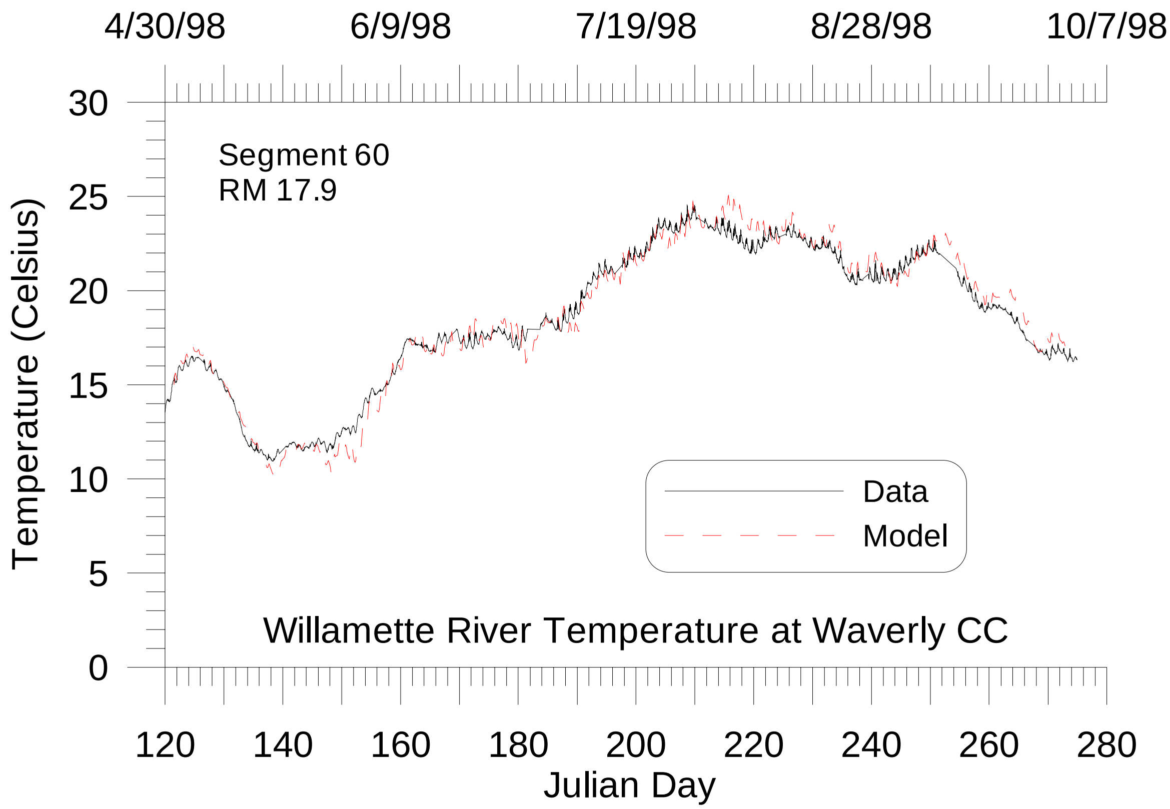


Figure 30. Comparison between model temperature predictions and data for Willamette River Sites A (RM 20) and B (RM 12.7) during 1997.



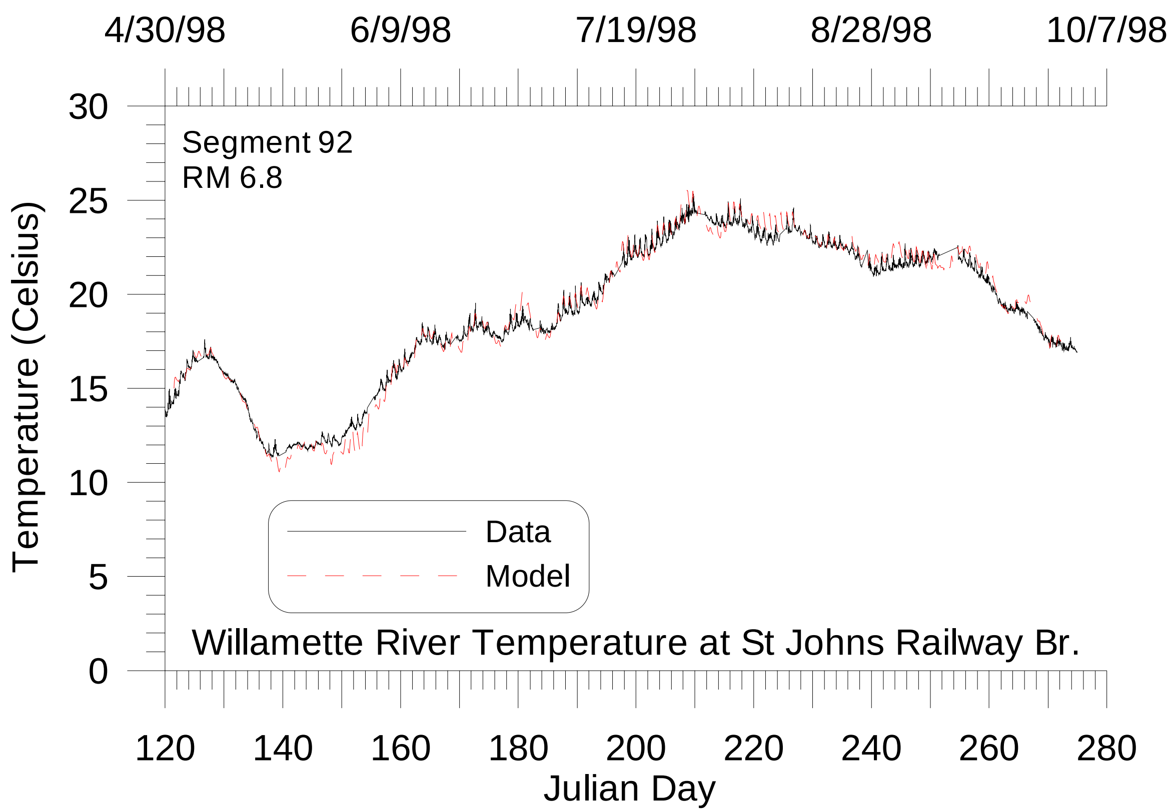


Figure 31. Comparison between model temperature predictions and data for Willamette River locations Waverly Country Club (RM 17.9) and St Johns Railway Bridge (RM 6.8) during 1998.

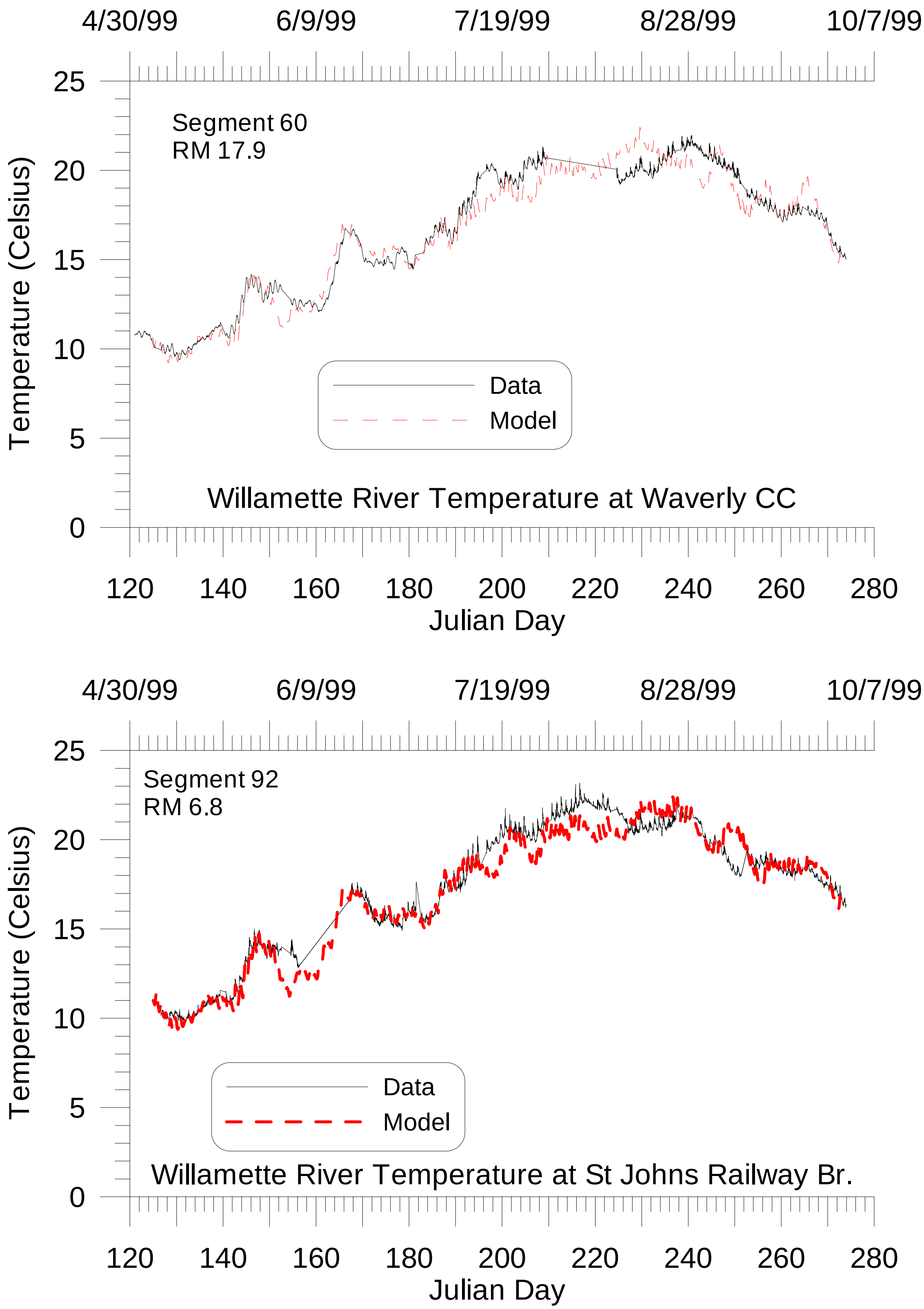


Figure 32. Comparison between model temperature predictions and data for the Willamette River at Waverly Country Club (RM 17.9) and St Johns Railway Bridge (RM 6.8) during 1999.

Columbia River

Table 4 identifies the temperature sampling sites on the Columbia River, which were compared with modeling results.

Table 10. Columbia River temperature calibration sites

Site ID	Site Description	River mile	Model Segment	Data Type
14128910	Columbia River at Warrendale, WA	141.0	141	Grab samples
ORSTORET	Columbia River near Columbia City, OR	82.0	288	Grab samples
ORSTORET	Columbia River RM 102 DS of Hayden Island	102.1	242	Grab samples
ORSTORET	Multnomah Channel near mouth at St. Helens, OR	0.9	123	Grab samples
453439122223900	Columbia River right bank at Washougal, WA	121.6	197	Continuous
455903122500000	Columbia River right bank near Kalama, WA	76.8	301	Continuous
453651122022200	Columbia River right bank near Skamania, WA	140.4	143	Continuous
453630122021400	Columbia River left bank near Dodson, OR	140.4	143	Continuous

Model predictions of surface temperatures compared to grab sample field data at Columbia River near Hayden Island (RM 102) and at Columbia City (RM 82) for 1994 are shown in Figure 33.

Model predictions of surface temperatures compared to continuous field data at Columbia River on the left and right banks of the river at Skamania, WA and Dodson, OR (RM 140.5) for 1998 and 1999 are shown in Figure 34 and Figure 35, respectively. These data also show that there is no significant lateral variability in temperatures in the Columbia River at this River mile.

Model predictions of surface temperatures compared to continuous field data at Columbia River at Kalama, WA (RM 76.8) for 1998 are shown in Figure 36.

Model prediction errors are shown in Table 14.

Table 11. Model - data errors in temperature for the Columbia River between 1994 and 1999.

Year	Location	Temperature errors		
		n, # of data comparisons	AME, °C	RMS error, °C
1994	RM 0.9 Segment #123	6	0.298	0.369
1994	RM 141 Segment #141	5	0.041	0.060
1997		4	0.100	0.106
1997	RM 140.4 Segment #143 Skamania	2292	0.097	0.263
1998		3239	0.036	0.054
1999		3450	0.046	0.088
1997	RM 140.4 Segment #143 Dodson	2358	0.269	0.372
1998		3623	0.059	0.084
1999		3611	0.095	0.154
1997	RM 121.6 Segment	2324	0.447	1.346
1998		3280	0.164	0.239

<table>
<tr><td>1999</td><td>#197</td><td>3434</td><td>0.179</td><td>0.310</td></tr>
<tr><td>1994</td><td>RM 102.1
Segment
#242</td><td>7</td><td>0.578</td><td>0.677</td></tr>
<tr><td>1994</td><td>RM 82.0
Segment
#288</td><td>5</td><td>0.629</td><td>0.654</td></tr>
<tr><td>1997</td><td rowspan="2">RM 76.8
Segment
#301</td><td>2359</td><td>0.334</td><td>0.593</td></tr>
<tr><td>1998</td><td>3304</td><td>0.186</td><td>0.298</td></tr>
</table>

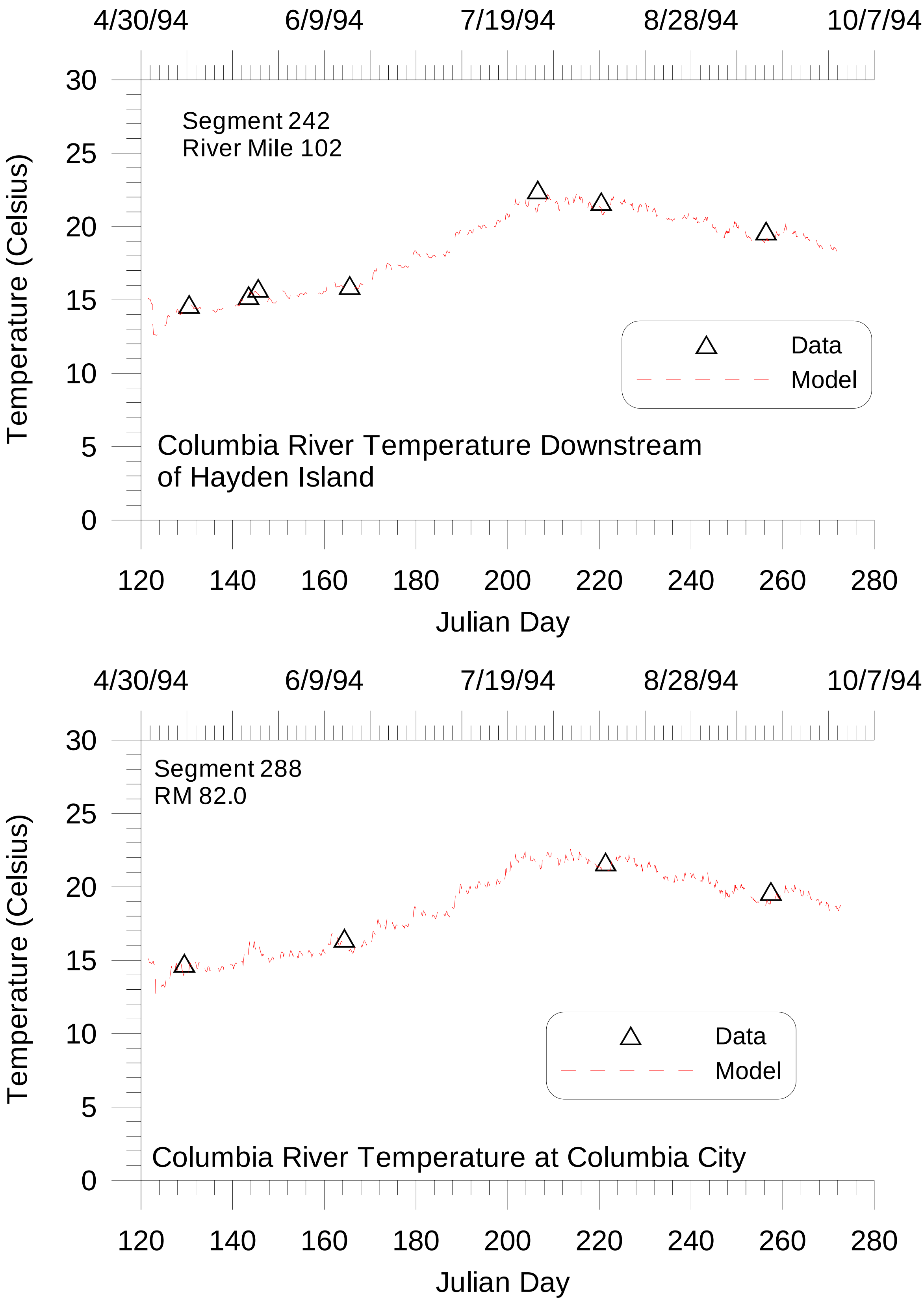
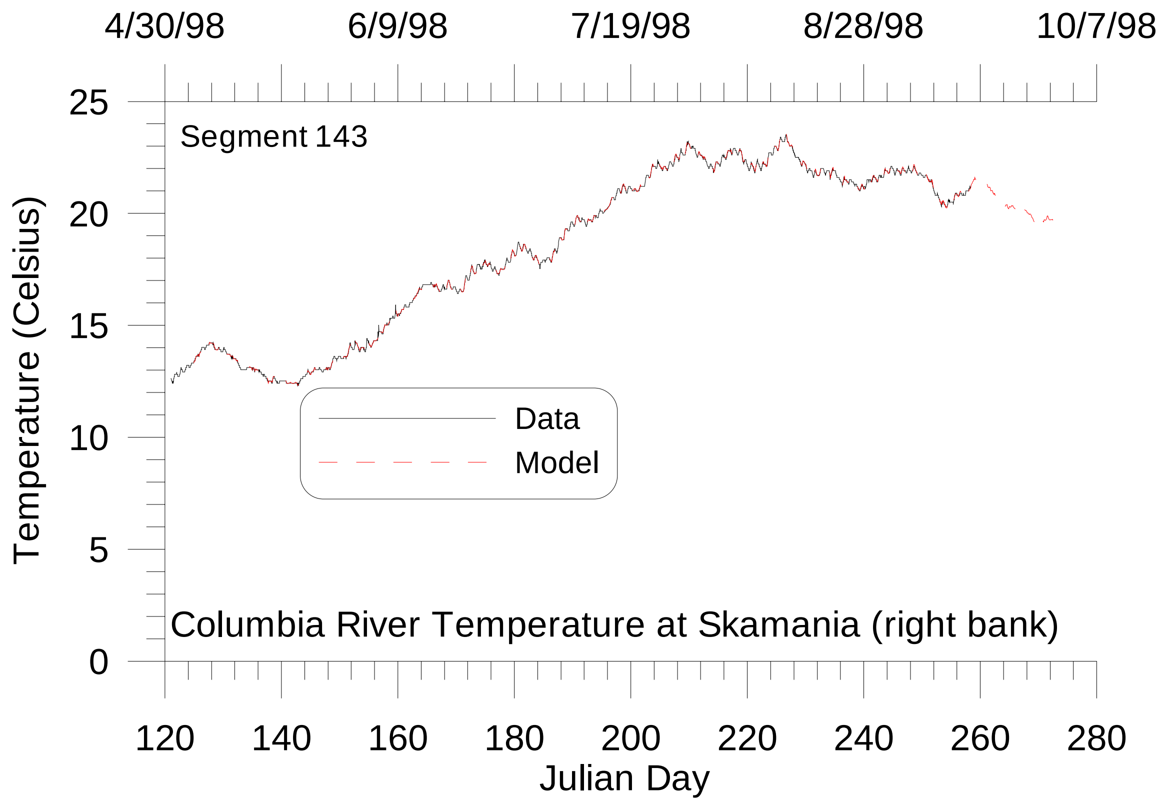


Figure 33. Comparison between model temperature predictions and data near Hayden Island (RM 102) and Columbia City (RM 82) during 1994.



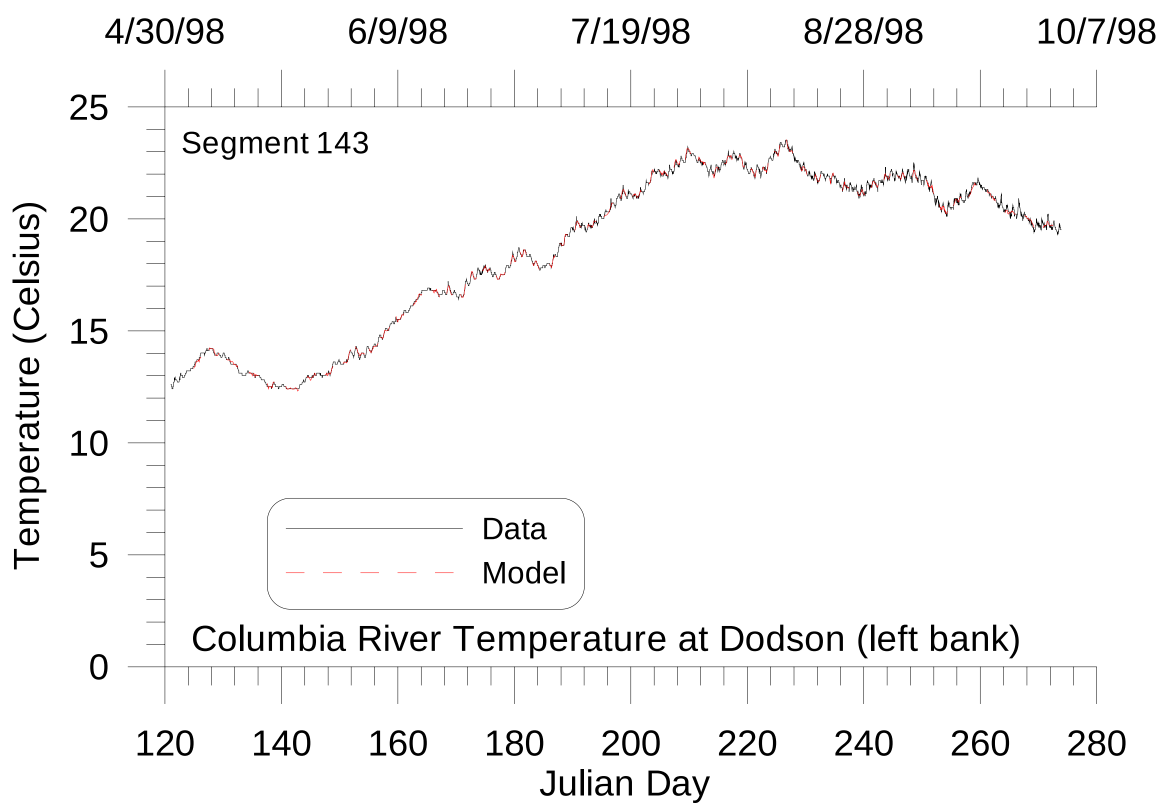
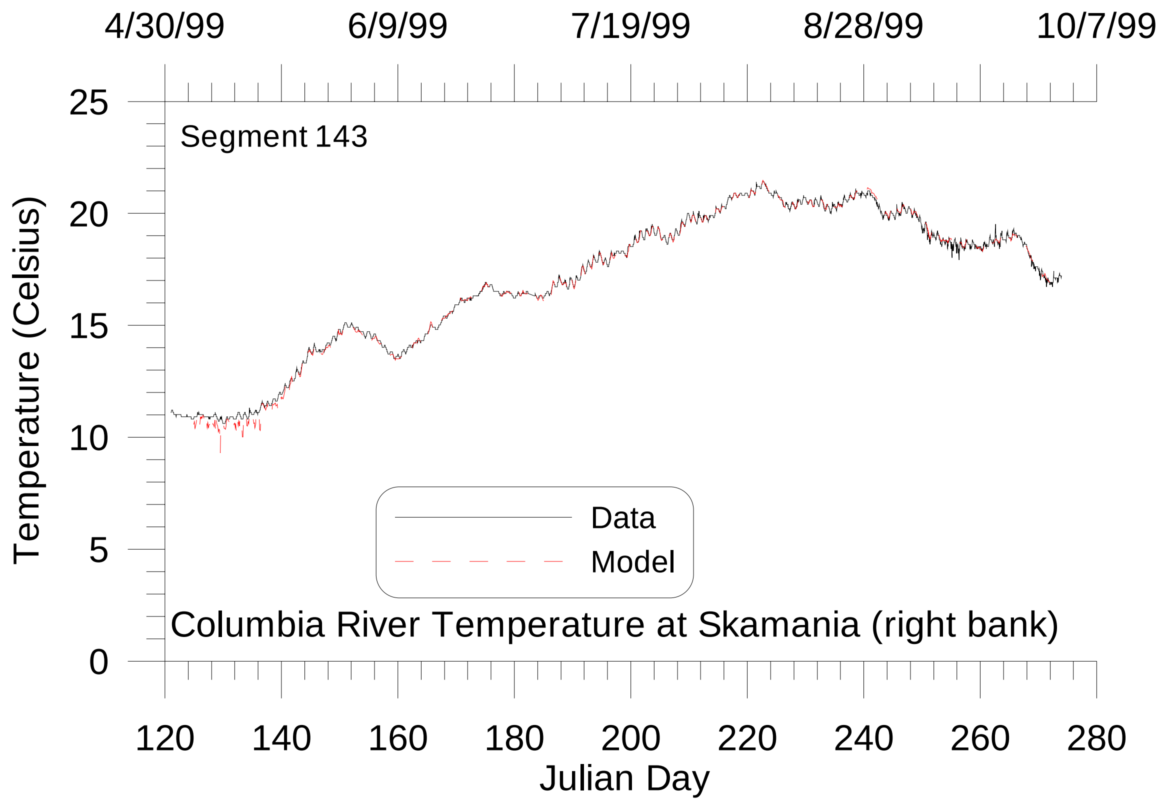


Figure 34. Comparison between model temperature predictions and data for Columbia River locations Skamania, WA and Dodson, OR (RM 140.5) during 1998.



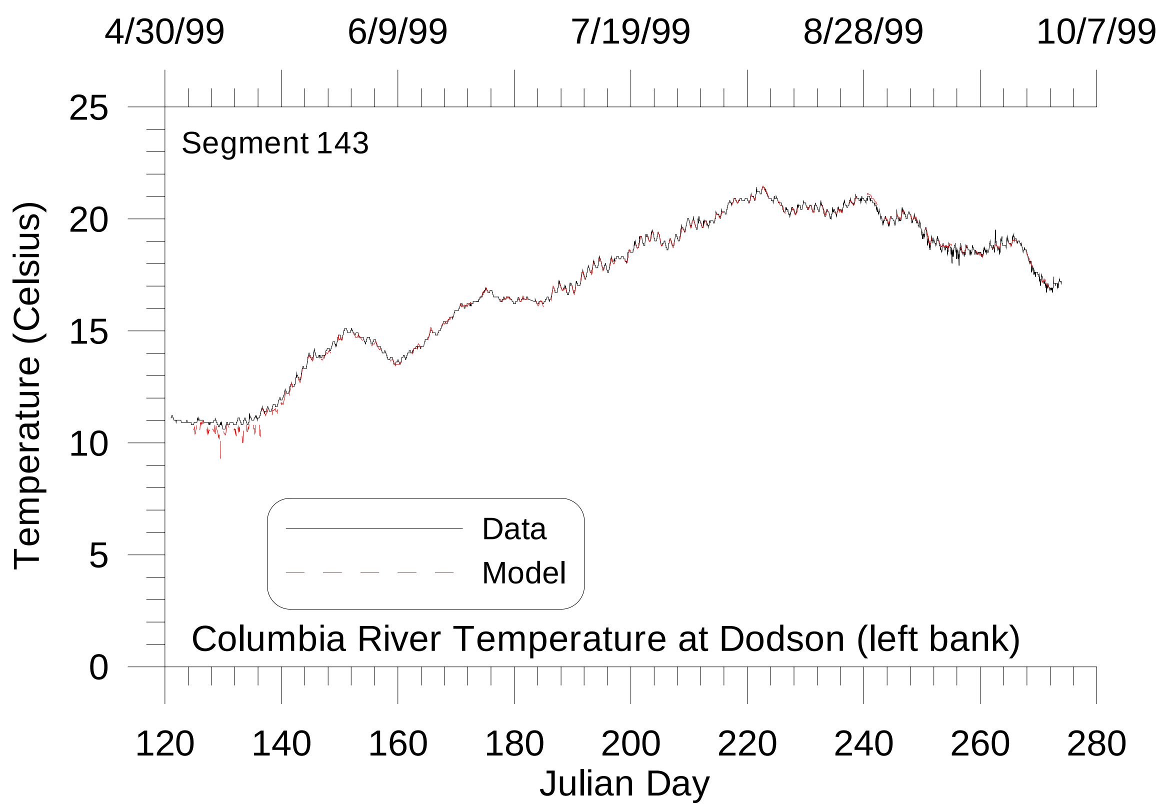


Figure 35. Comparison between model temperature predictions and data for Columbia River locations Skamania, WA and Dodson, OR (RM 140.4) during 1999.

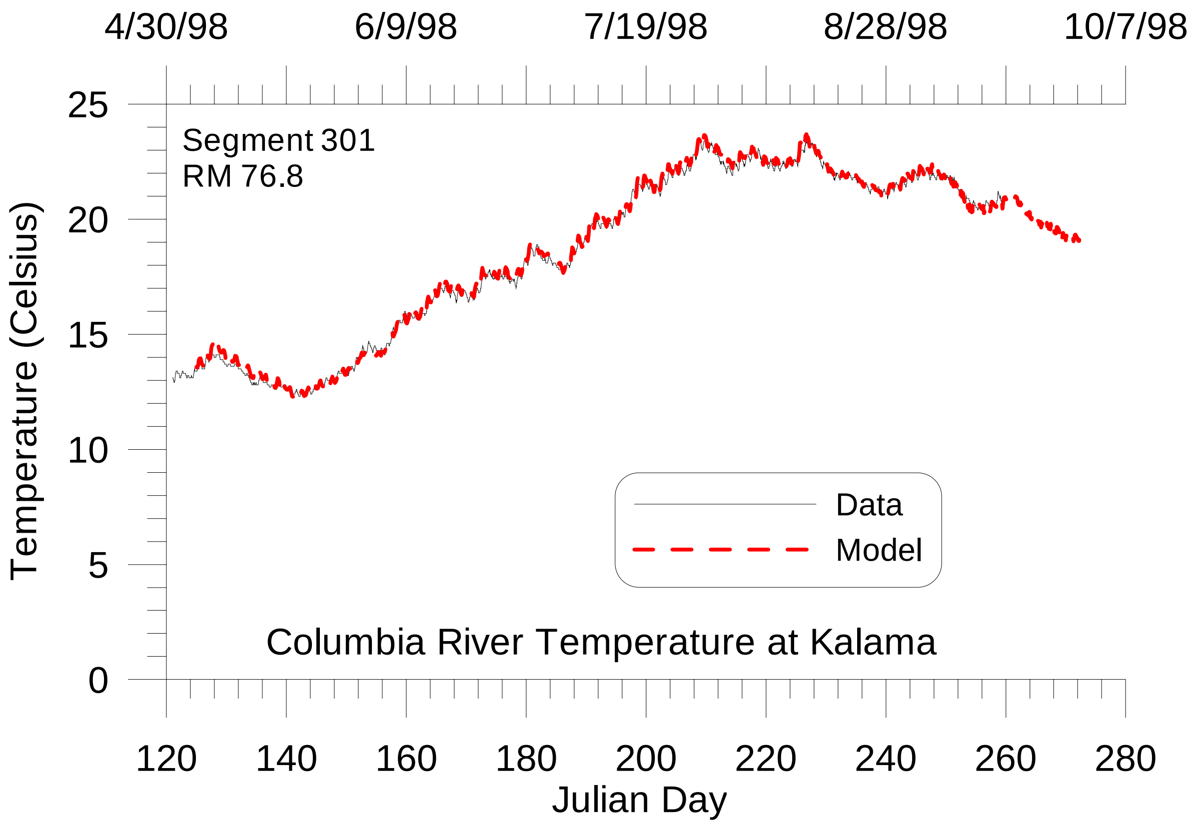


Figure 36. Comparison between model temperature predictions and data for the Columbia River at Kalama, WA during 1998.

Water Quality

Water quality data was obtained from the City of Portland, Bureau of Environmental Services, The US Geological Survey and the Oregon Department of Environmental Quality STORET program to compare with model results.

Water quality model parameters used during the calibration are shown in Table 12. Boundary conditions, algae growth rates, rearation equation, and sediment oxygen demand were particularly important for model calibration. Zeroth order sediment oxygen demand was set to 1.4 g/m^2 in segments above Willamette Falls and 1.8 g/m^2 for segments below. These values were based on measurements made in 1994 by the U. S. Geological Survey (Caldwell and Doyle, 1995). The rearation equation applied in the model was the Thomann and Fitzpatrick (1982) estuary equation where the rearation K_a (d^{-1}) was calculated using

$$K_a = \frac{0.728W^{0.5} - 0.317W + 0.0372W^2}{H} + 3.93\frac{\sqrt{U}}{H^{1.5}}$$

and U (m/s) was the water velocity, W (m/s) was the wind velocity, and H (m) was the depth. An equation appropriate to estuaries equation was chosen because the Lower Willamette River is tidally influenced. An algae maximum growth rate of 2.4 d^{-1} was used for model simulation years 1993, 1994 and 1997 and a maximum growth rate of 2.3 d^{-1} was used for 1998 and 1999. Adjustments to boundaries conditions were also important for model calibration and these modifications are discussed below.

Table 12. W2 Model Water Quality Parameters.

Variable	Description	Units	Typical values*	Calibration Values
Hydrodynamics and Longitudinal Transport				
AX	Longitudinal eddy viscosity (for momentum dispersion)	m^2/sec	1	1
DX	Longitudinal eddy diffusivity (for dispersion of heat and constituents)	m^2/sec	1	1
CHEZY	Chezy coefficient	m$^{1/2}$/sec	70	NA (MANN)
Temperature				
CBHE	Coefficient of bottom heat exchange	Wm^2/sec	7.0 x 10-8	7.0 x 10-8
TSED	Sediment (ground) temperature	^{o}C	12.8	14.0
WSC	Wind sheltering coefficient		0.85	0.85
BETA	Fraction of incident solar radiation absorbed at the water surface		0.45	0.45
Water Quality				
EXH20	Extinction for water	/m	0.25	0.20
EXSS	Extinction due to inorganic suspended solids	m^3/m/g	0.01	0.01
EXOM	Extinction due to organic suspended solids	m^3/m/g	0.17	0.01
SSS	Suspended solids settling rate	m/day	2	1.5
AG1	Algal growth rate for algal type 1	/day	1.1	2.3-2.4
AM1	Algal mortality rate for algal type 1	/day	0.01	0.05
AE1	Algal excretion rate for algal type 1	/day	0.01	0.02
AR1	Algal dark respiration rate for algal type 1	/day	0.02	0.40

Variable	Description	Units	Typical values*	Calibration Values
AS1	Algal settling rate for algal type 1	/day	0.14	0.10
ASAT1	Saturation intensity at maximum photosynthetic rate for algal type 1	W/m^2	150	75
APOM1	Fraction of algal biomass lost by mortality to detritus for algal type 1		0.8	
AT11	Lower temperature for algal growth for algal type 1	^oC	10	5
AT21	Lower temperature for maximum algal growth for algal type 1	^oC	30	10
AT31	Upper temperature for maximum algal growth for algal type 1	^oC	35	24
AT41	Upper temperature for algal growth for algal type 1	^oC	40	30
AK11	Fraction of algal growth rate at ALGT1 for algal type 1		0.1	0.1
AK21	Fraction of maximum algal growth rate at ALGT2 for algal type 1		0.99	0.99
AK31	Fraction of maximum algal growth rate at ALGT3 for algal type 1		0.99	0.99
AK41	Fraction of algal growth rate at ALGT4 for algal type 1		0.1	0.01
BIOP-A1	Stoichiometric equivalent between organic matter and phosphorus for algal type 1		0.011	0.005
BION-A1	Stoichiometric equivalent between organic matter and nitrogen for algal type 1		0.08	0.08
BIOC-A1	Stoichiometric equivalent between organic matter and carbon for algal type 1		0.45	0.45
LDOMDK	Labile DOM decay rate	/day	0.12	0.12
LRDDK	Labile to refractory decay rate	/day	0.001	0.001
RDOMDK	Maximum refractory decay rate	/day	0.001	0.001
LPOMDK	Labile Detritus decay rate	/day	0.06	0.08
POMS	Detritus settling rate	m/day	0.35	0.10
RPOMDK	Refractory Detritus decay rate	/day		0.001
OMT1	Lower temperature for organic matter decay	^oC	4	4
OMT2	Lower temperature for maximum organic matter decay	^oC	20	30
OMK1	Fraction of organic matter decay rate at OMT1		0.1	0.1
OMK2	Fraction of organic matter decay rate at OMT2		0.99	0.99
SDK	Sediment decay rate	/day	0.06	0.10
PARTP	Phosphorous partitioning coefficient for suspended solids		1.2	0.0
AHSP	Algal half-saturation constant for phosphorous	g/m	0.009	0.01
NH4DK	Ammonia decay rate (nitrification rate)	/day	0.12	0.40
AHSN	Algal half-saturation constant for ammonia	g/m^3	0.014	0.01
NH4T1	Lower temperature for ammonia decay	^oC	5	5
NH4T2	Lower temperature for maximum ammonia decay	^oC	20	20
NH4K1	Fraction of nitrification rate at NH4T1		0.1	0.1

Variable	Description	Units	Typical values*	Calibration Values
NH4K2	Fraction of nitrification rate at NH4T2		0.99	0.99
NO3DK	Nitrate decay rate (denitrification rate)	/day	0.102	0.05
NO3T1	Lower temperature for nitrate decay	^oC	5	5
NO3T2	Lower temperature for maximum nitrate decay	^oC	20	25
NO3K1	Fraction of denitrification rate at NO3T1		0.1	0.1
NO3K2	Fraction of denitrification rate at NO3T2		0.99	0.99
O2NH4	Oxygen stoichiometric equivalent for ammonia decay		4.57	4.57
O2OM	Oxygen stoichiometric equivalent for organic matter decay		1.4	1.4
O2AR	Oxygen stoichiometric equivalent for dark respiration		1.4	1.1
O2AG	Oxygen stoichiometric equivalent for algal growth		1.4	1.4
BIOP	Stoichiometric equivalent between organic matter and phosphorus		0.011	0.005
BION	Stoichiometric equivalent between organic matter and nitrogen		0.08	0.08
BIOC	Stoichiometric equivalent between organic matter and carbon		0.45	0.45
O2LIM	Dissolved oxygen concentration at which anaerobic processes begin	g/m^3	0.05	0.01
* Cole and Wells (2000)				

Willamette River

Table 13 shows a list of water quality monitoring sites in the Willamette River, many of which were used for comparison with model results (the shaded ones).

Table 13. Willamette River water quality calibration sites

Site ID	Site Description	River mile	Model Segment	Data Type
C, SJRB	Willamette at St. John's Railroad Bridge	6.8	92	Continuous and grab samples
ORSTORET	Willamette R upstream of St Johns Bridge	6.3	94	Grab samples
ORSTORET	Willamette River @ Meldrum Bar Boat Ramp	24.2	18	Grab samples
ORSTORET	Willamette River 100 Yds D/S Oswego Cr. Mouth	21.0	41	Grab samples
ORSTORET	Willamette River 100 Yds U/S Oswego Cr. Mouth	21.3	40	Grab samples
ORSTORET	Willamette River at Hawthorne Bridge	13.1	73	Grab samples
WRR	Willamette River at mouth of Columbia Slough	1.1	105	Grab samples
B, ORSTORET	Willamette River at Portland, Oreg. (Morrison St Bridge)	12.7	75	Grab samples
D	Willamette River at South Kelly Point Park	1.1	105	Grab samples
ORSTORET	Willamette River at SP&S Bridge (Portland)	6.9	92	Grab samples
E	Willamette River at Swan Island	8.8	88	Grab samples
A	Willamette River at Tryon Creek Railroad Bridge	20	45	Grab samples
F, WCC	Willamette River at Waverly Country Club	17.9	60	Continuous and grab samples

Willamette River Boundary Condition modifications

Because the frequency of dissolved oxygen data measured at Canby (RM 35) was inadequate to describe the upstream boundary condition, downstream data were used to back calculate upstream conditions. A Streeter-Phelps dissolved oxygen model was used to estimate dissolved oxygen concentration at Canby given grab sample data measured at Waverly Country Club (RM 17.9) and Tryon Street Bridge (RM 20). The form of the Streeter-Phelps equation applied was:

$$c = c_s - \left\{ \frac{(K_d)_T}{(K_a)_T - (K_r)_T} \left[\exp\left(-(K_r)_T \frac{x}{U} \right) - \exp\left(-(K_a)_T \frac{x}{U} \right) \right] \right\} L_0 - (c_s - c_0) \exp\left(-(K_a)_T \frac{x}{U} \right)$$

where:

c is the DO concentration at distance x (mg/l)

c_s is the saturation concentration of DO (mg/l)

c_0 is the DO concentration at the upstream boundary (mg/l)

K_d : effective deoxygenation rate of the CBOD (d^{-1})

K_a : the rearation coefficient (d^{-1})

K_r : the overall loss rate (d^{-1}) of CBOD from the water column due to both settling and oxidation of soluble BOD

The Streeter-Phelps equation was rearranged to solve for c_o yielding the following equation:

$$c_0 = \frac{1}{\exp\left(-K_a \frac{x}{U} \right)} \left(c - c_s + \left\{ \frac{-K_r}{K_a - K_r} \left[\exp\left(-K_r \frac{x}{U} \right) - \exp\left(-K_a \frac{x}{U} \right) \right] \right\} L_0 + c_s \exp\left(-K_a \frac{x}{U} \right) \right)$$

The effective deoxygenation rate for CBOD K_d (T^{-1}) was calculated from $K_d = 10.3 Q^{-0.49}$ (Write and McDonnell, 1979) and temperature corrected using $(K_d)_T = (K_d)_{20} 1.047^{T-20}$

Rearation K_a was calculated using O'Connor and Dobbins (1958) formulation $K_a = \frac{D_{O_2} U^{1/2}}{H^{3/2}}$ where D_{O_2} is the molecular diffusion coefficient for water. K_a was temperature corrected with $(K_a)_T = (K_a)_{20} 1.024^{T-20}$

Because this part of the model was not located near any large point sources for BOD, it was assumed that little CBOD settled from the water column and that K_r was considered to be equal to K_d.

The amount of pH data at Canby was also insufficient to describe the upstream boundary condition. PH data measured at sampling Site A (RM 20) along with alkalinity data were used to estimate inorganic carbon concentrations at Canby by applying equations based on the carbonate-bicarbonate equilibrium reaction (Stumm and Morgan, 1981).

Dissolved Oxygen

Model predictions of dissolved oxygen compared to filed data at Willamette River site A (RM 20) and site B (RM 12.7) for 1993, 1994, and 1997 are shown in Figure 37, Figure 38 and Figure 39, respectively.

Continuous and grab sample dissolved oxygen data are compared with model predictions at Waverly Country Club (RM 17.9) and St. John's Railway Bridge (RM 6.8) for 1998 and 1999 in Figure 40 and

Figure 41, respectively. There were obvious calibration problems with the continuous oxygen sensor during at the Waverly site in 1999.

Model prediction errors are shown in Table 14.

Table 14. Model - data errors in dissolved oxygen for the Willamette River between 1993 and 1999.

Year	Location	Dissolved Oxygen errors		
		n, # of data comparisons	AME, mg/L	RMS error, mg/L
1993	RM 20.0 Segment #45	8	0.230	0.285
1994		18	0.846	1.917
1997		19	0.214	0.250
1998		19	0.396	0.589
1999		22	0.369	0.419
1993	RM17.9 Segment #60	NA	NA	NA
1994		NA	NA	NA
1997		276	0.132	0.164
1998		5403	0.446	0.557
1999		4113	0.365	0.460
1993	RM 13.1 Segment #73	7	0.750	0.950
1994		8	0.602	0.682
1997		5	0.447	0.552
1998		6	0.876	1.403
1999		NA	NA	NA
1993	RM 12.7 Segment #75	13	0.281	0.340
1994		22	0.633	0.914
1997		24	0.342	0.454
1998		25	0.339	0.493
1999		26	0.388	0.435
1993	RM 8.8 Segment #88	NA	NA	NA
1994		17	1.696	3.595
1997		19	0.334	0.398
1998		19	0.374	0.468
1999		NA	NA	NA
1993	RM 6.8 Segment #92	8	0.395	0.463
1994		17	1.233	1.811
1997		276	0.281	0.327
1998		6597	0.439	0.550
1999		5390	0.496	0.682
1993	RM 1.1 Segment #105	8	0.489	0.549
1994		16	2.221	3.925
1997		19	0.635	0.746
1998		19	0.867	1.172
1999		NA	NA	NA

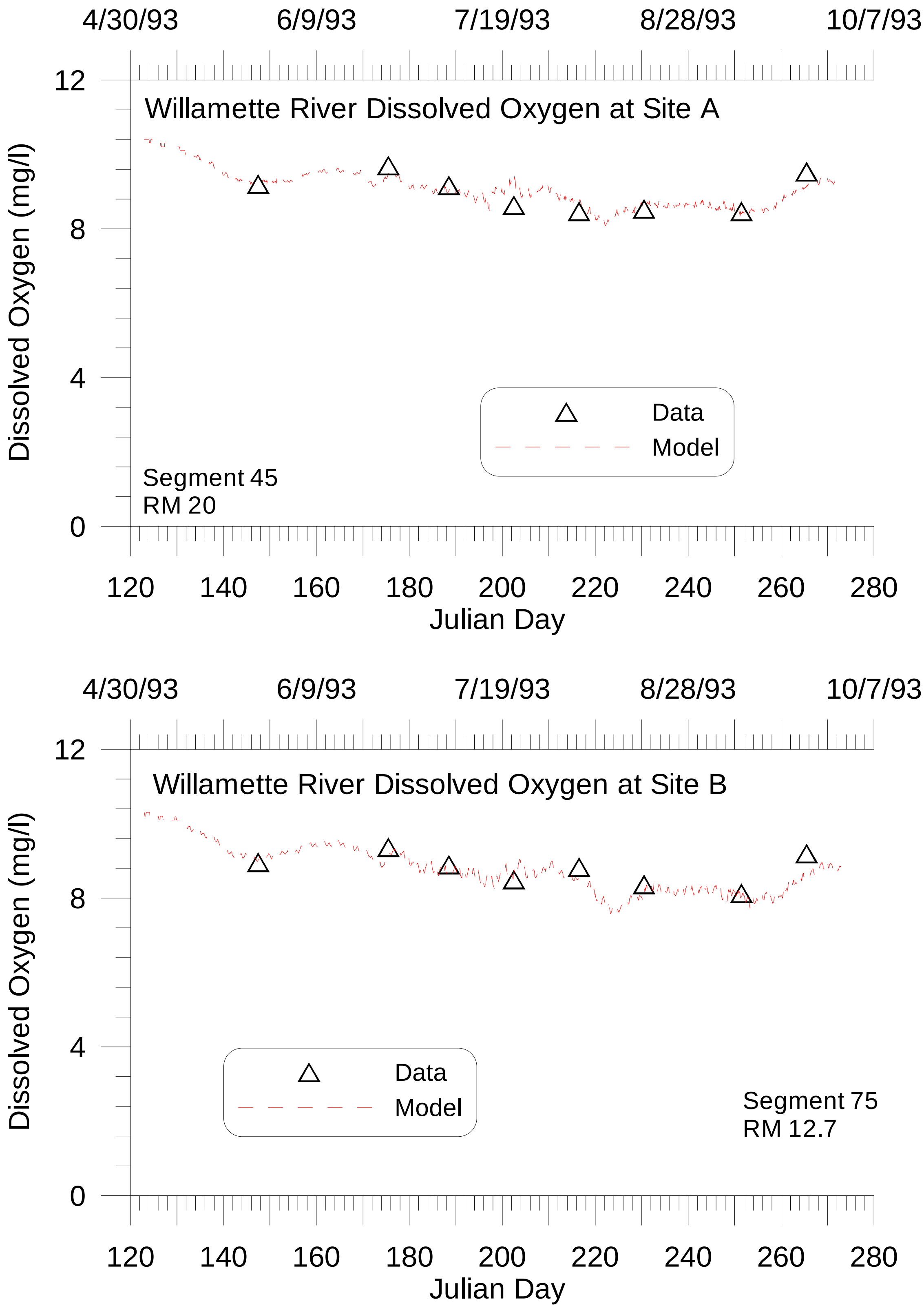


Figure 37. Comparison between model dissolved oxygen predictions and data for Willamette River Sites A (RM 20) and B (RM 12.7) during 1993.

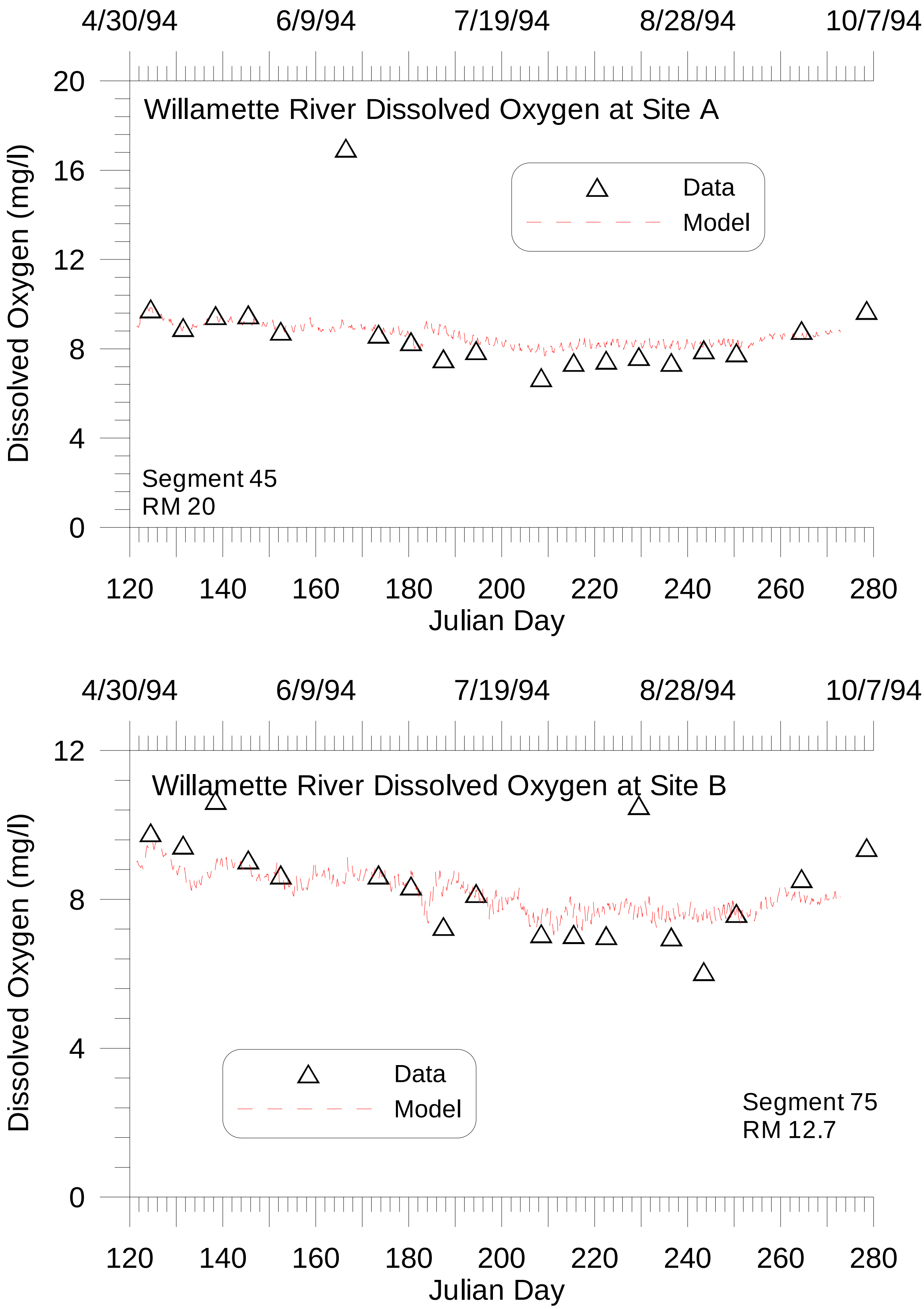


Figure 38. Comparison between model predicted dissolved oxygen concentrations and data for the Willamette River at site A (RM 20) and site B (RM 12.7) during 1994.

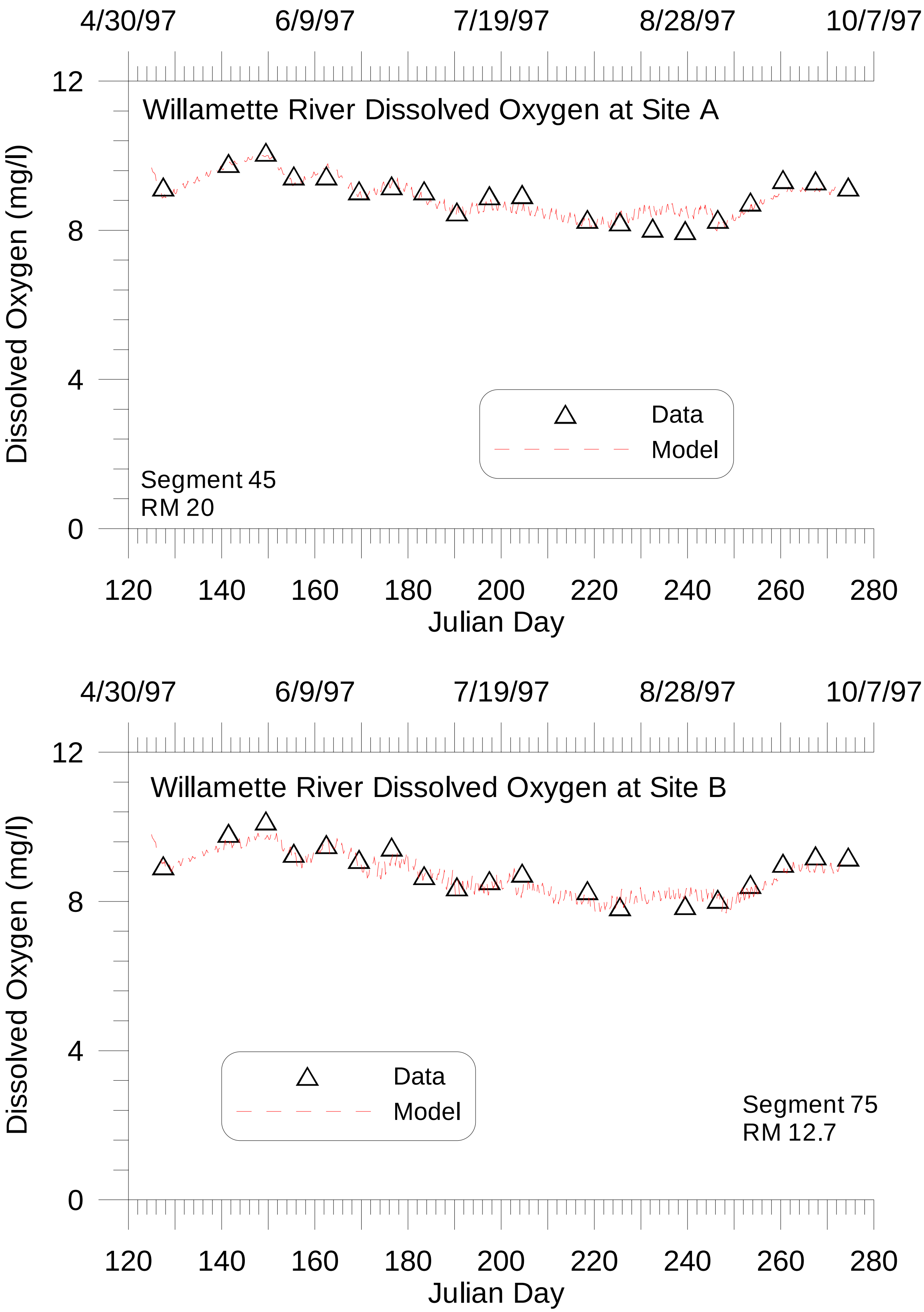
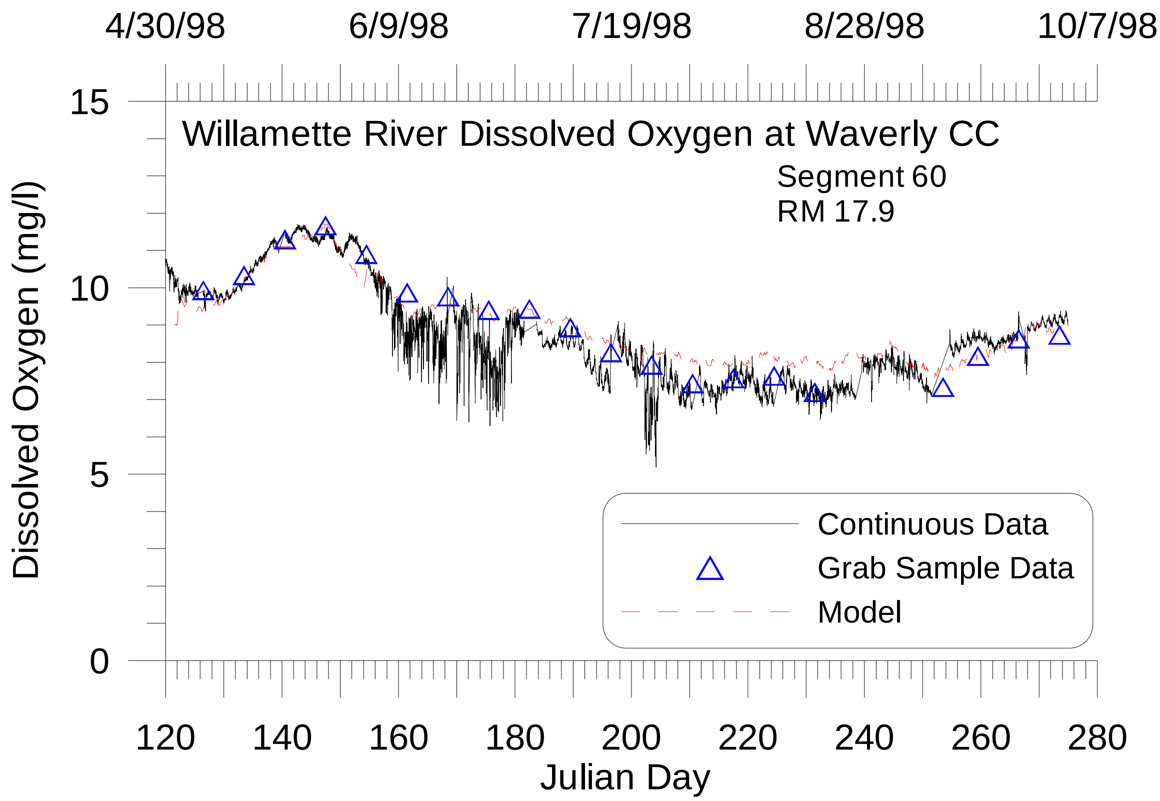


Figure 39. Comparison between model predicted dissolved oxygen concentrations and data for the Willamette River at site A (RM 20) and site B (RM 12.7) during 1997.



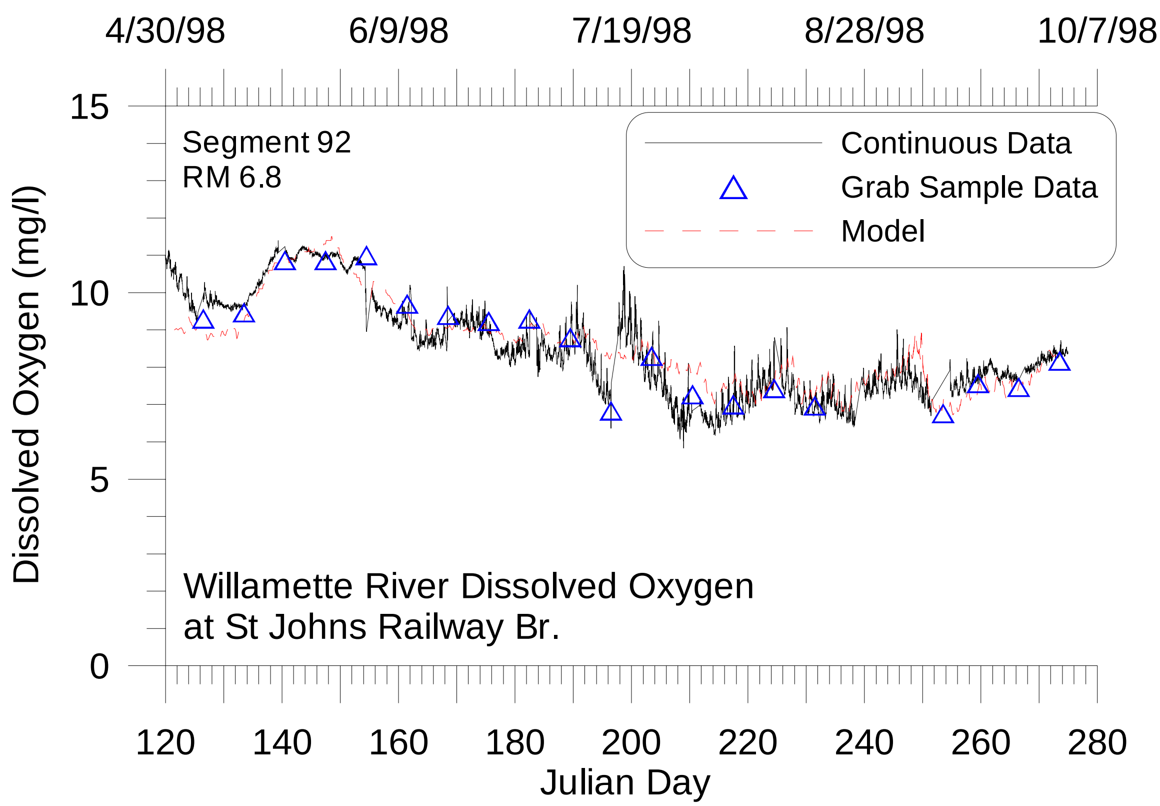


Figure 40. Comparison between model predicted dissolved oxygen concentrations and data for the Willamette River at Waverly Country Club (RM 17.9) and at St. Johns Railway Bridge (RM 6.8) during 1998.

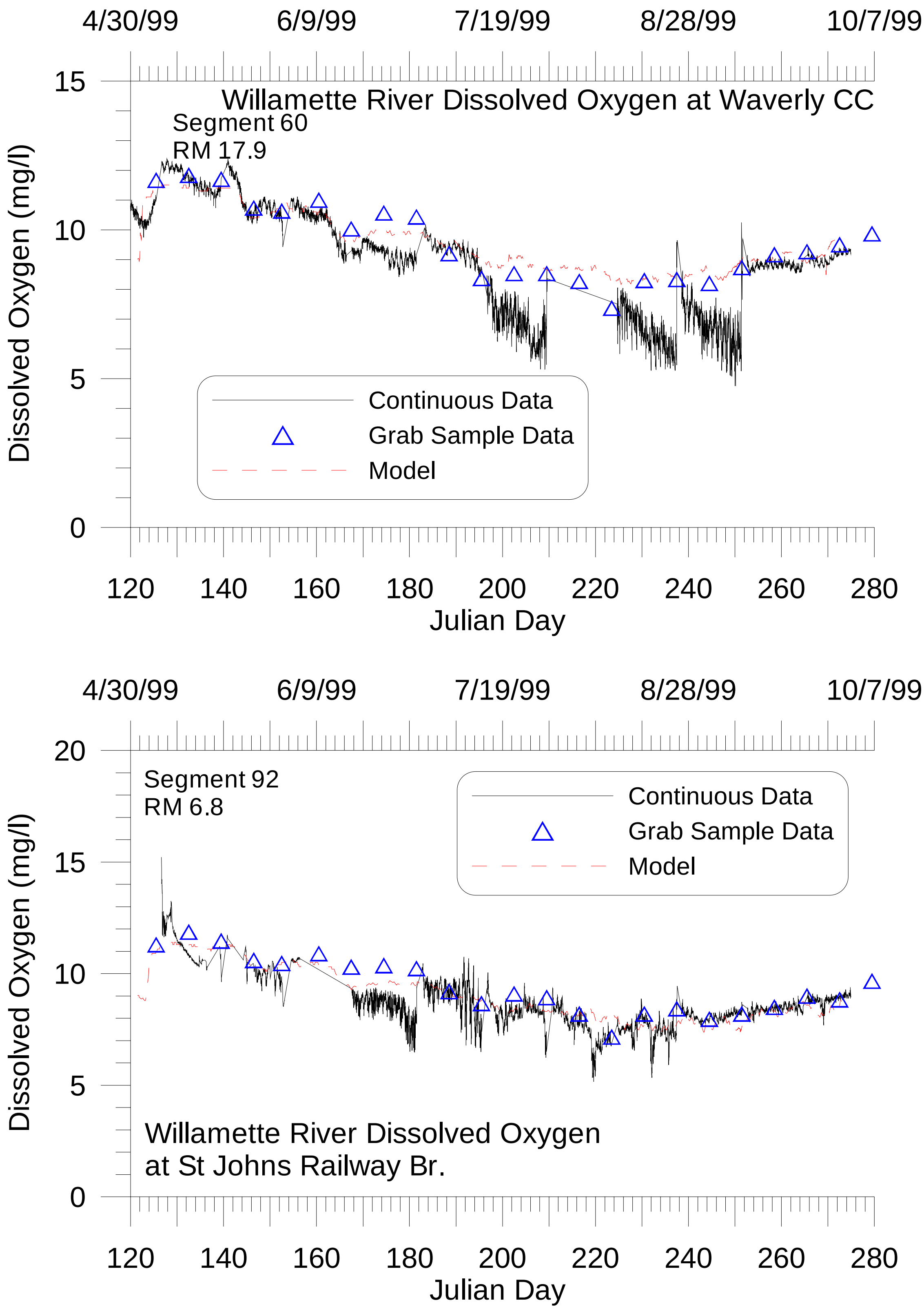


Figure 41. Comparison between model predicted dissolved oxygen concentrations and data for the Willamette River at Waverly Country Club (RM 17.9) and at St. Johns Railway Bridge (RM 6.8) during 1999.

Chlorophyll a

Comparisons of model predictions and field data of chlorophyll a in 1993 from the Hawthorne Bridge (RM 13.1) to the mouth of the Columbia Slough (RM 1.1) are shown in Figure 42 through Figure 44. Model predictions and field data comparisons of chlorophyll a in 1994 from the Hawthorne Bridge (RM 13.1) to the mouth of the Columbia Slough (RM 1.1) are shown in Figure 45 through Figure 48. Lower flow rates and longer detention times occurring in 1994 resulted in higher predicted algae growth near the downstream end of the Lower Willamette. During calibration the maximum algae growth rates were kept relatively consistent between years with values of 2.3 or 2.4 d^{-1}. To illustrate model sensitivity to algae growth rate for 1994, the chlorophyll a predictions at the mouth of the Columbia using a maximum algal growth rate half the calibrated value (1.2 d^{-1}) is shown in Figure 49. The average trends are well predicted, being based on upstream boundary conditions. A comparison of model predictions and field data of chlorophyll a in 1997 at the Hawthorne Bridge (RM 13.1) to the mouth of the Columbia Slough (RM 1.1) is shown in Figure 50 through Figure 53. Comparisons of model predictions and field data of chlorophyll a in 1998 at the Hawthorne Bridge (RM 13.1) and at the SP&S Bridge (RM 6.9) are shown in Figure 54 and Figure 55, respectively. No chlorophyll a data were available in the lower Willamette from 1999.

Model prediction errors are shown in Table 15. Statistics were not done for 1994 because of concern that chlorophyll a data collected at the mouth of the Columbia Slough were representative of Columbia Slough water quality rather than that for the Willamette River.

Table 15. Model - data errors in chlorophyll a for the Willamette River between 1993 and 1999.

Year	Location	Chlorophyll a model-data error		
		n, # of data comparisons	AME, ug/L	RMS error, ug/L
1993	RM 13.1 Segment #73	5	2.2	2.6
1997		5	14.9	15.5
1998		5	4.9	5.2
1993	RM 12.7 Segment #75	NA	NA	NA
1997		2	25.5	25.5
1998		NA	NA	NA
1993	RM 6.8 Segment #92	1	5.1	5.1
1997		2	17.5	17.8
1998		2	2.8	3.7
1993	RM 1.1 Segment #105	6	5.9	7.7
1997		6	13.3	18.4
1998		NA	NA	NA

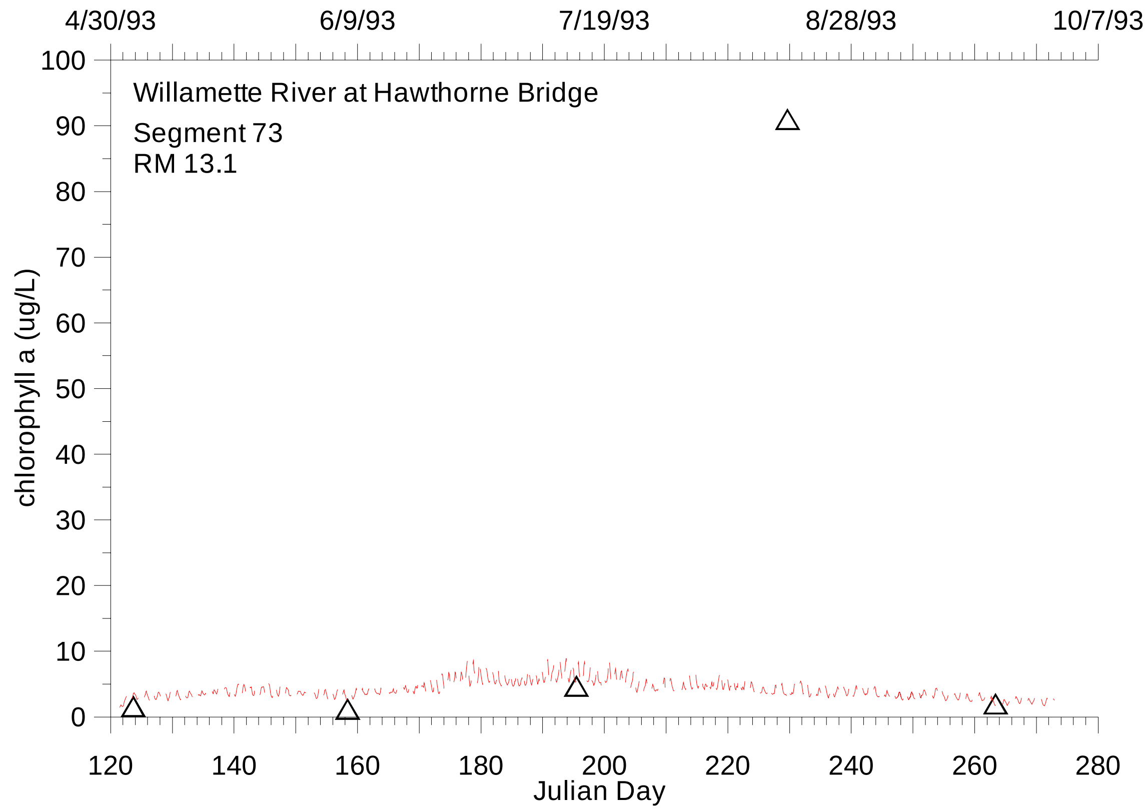


Figure 42. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the Hawthorne Bridge (RM 13.1) during 1993.

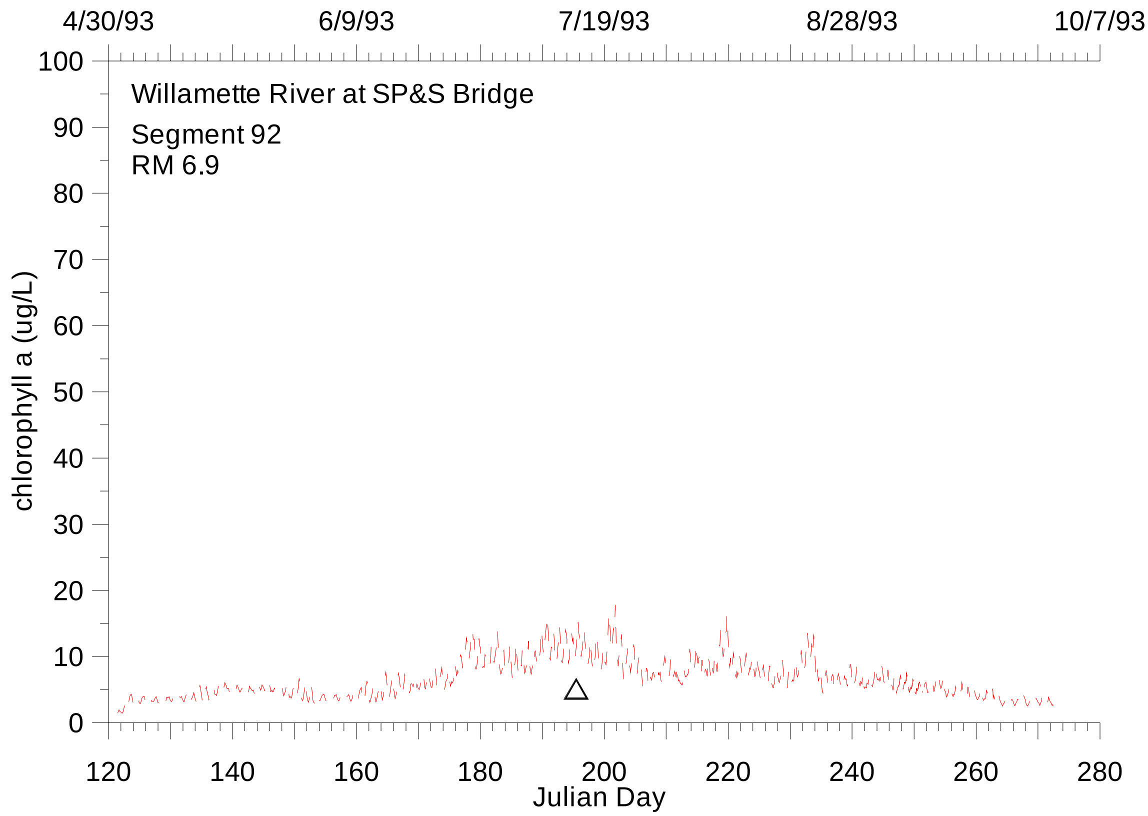


Figure 43. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the SP&S Bridge (RM 6.9) during 1993.

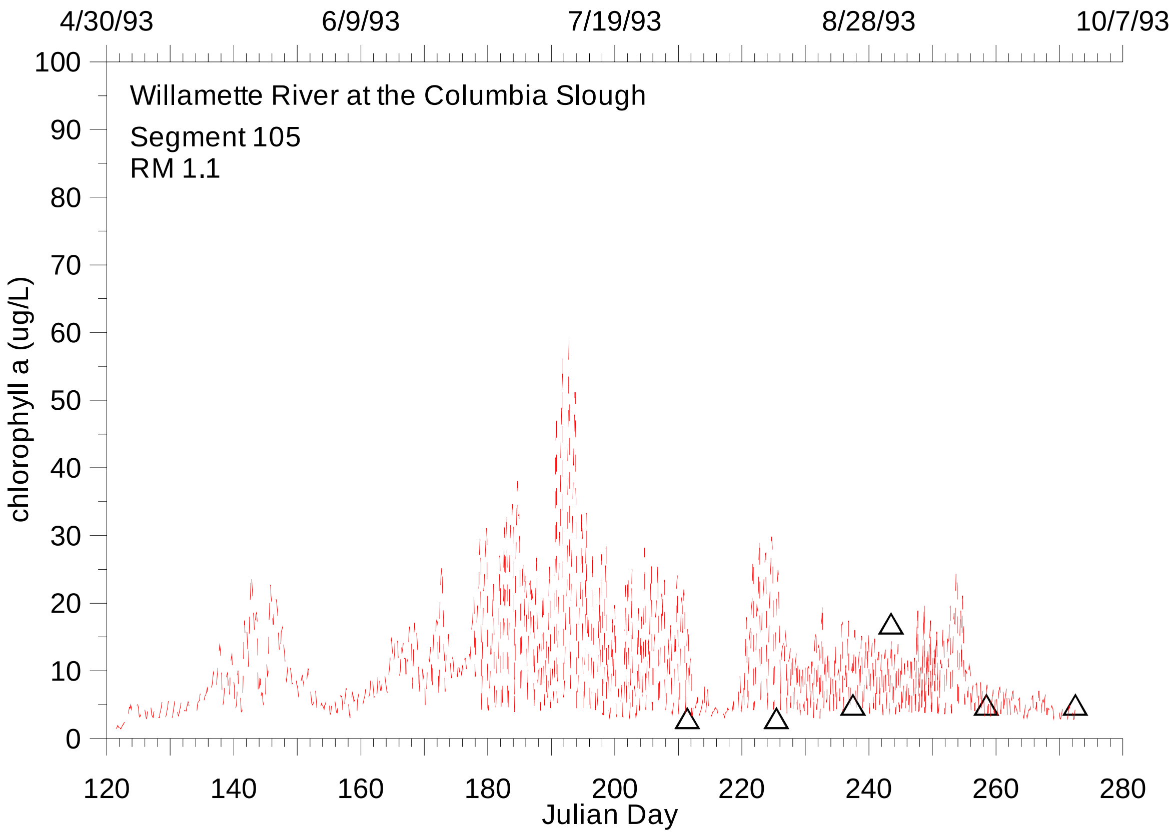


Figure 44. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the Columbia Slough (RM 1.1) during 1993.

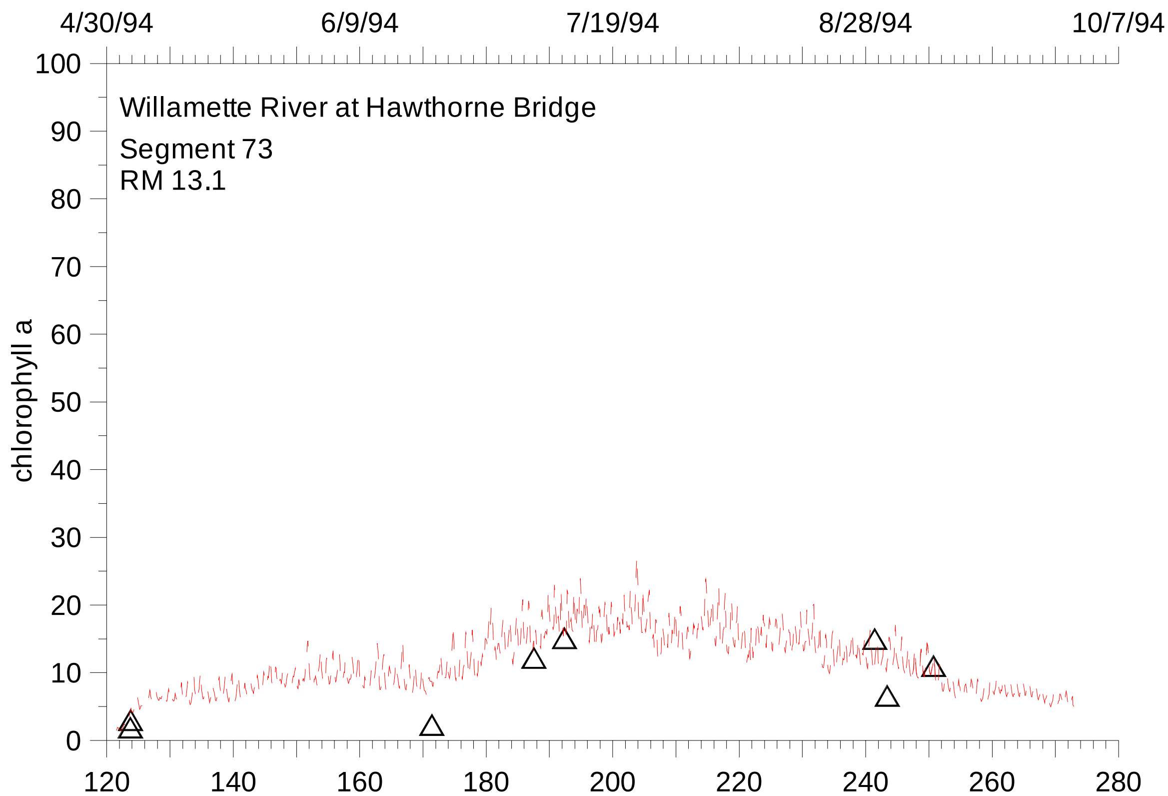


Figure 45. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the Hawthorne Bridge (RM 13.1) during 1994.

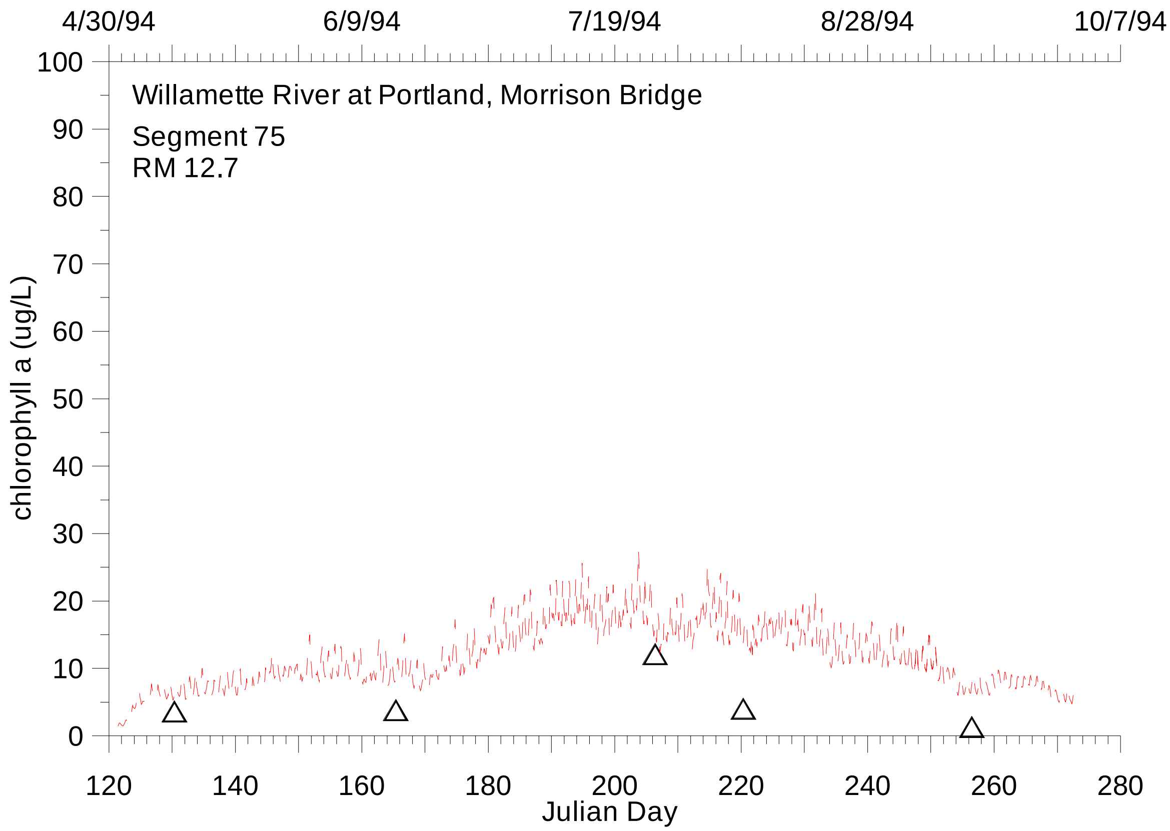


Figure 46. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the Morrison Bridge (RM 12.7) during 1994.

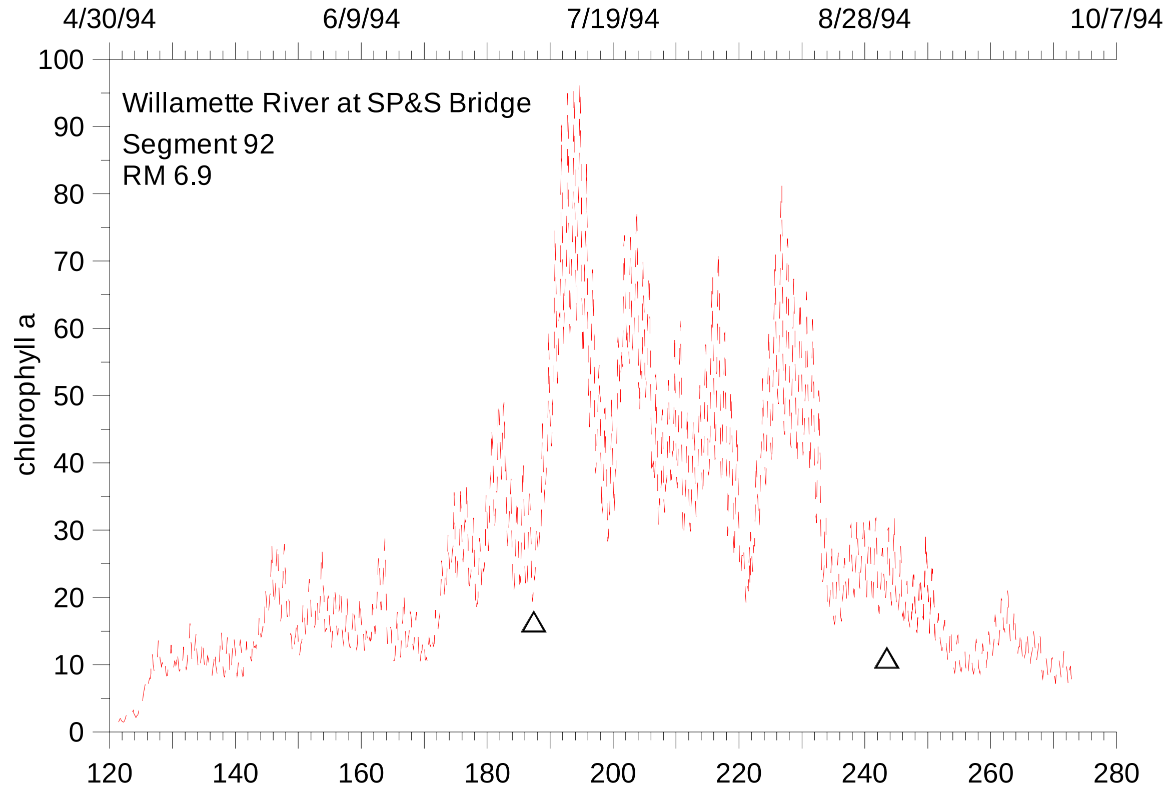


Figure 47. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the SP&S Bridge (RM 6.9) during 1994.

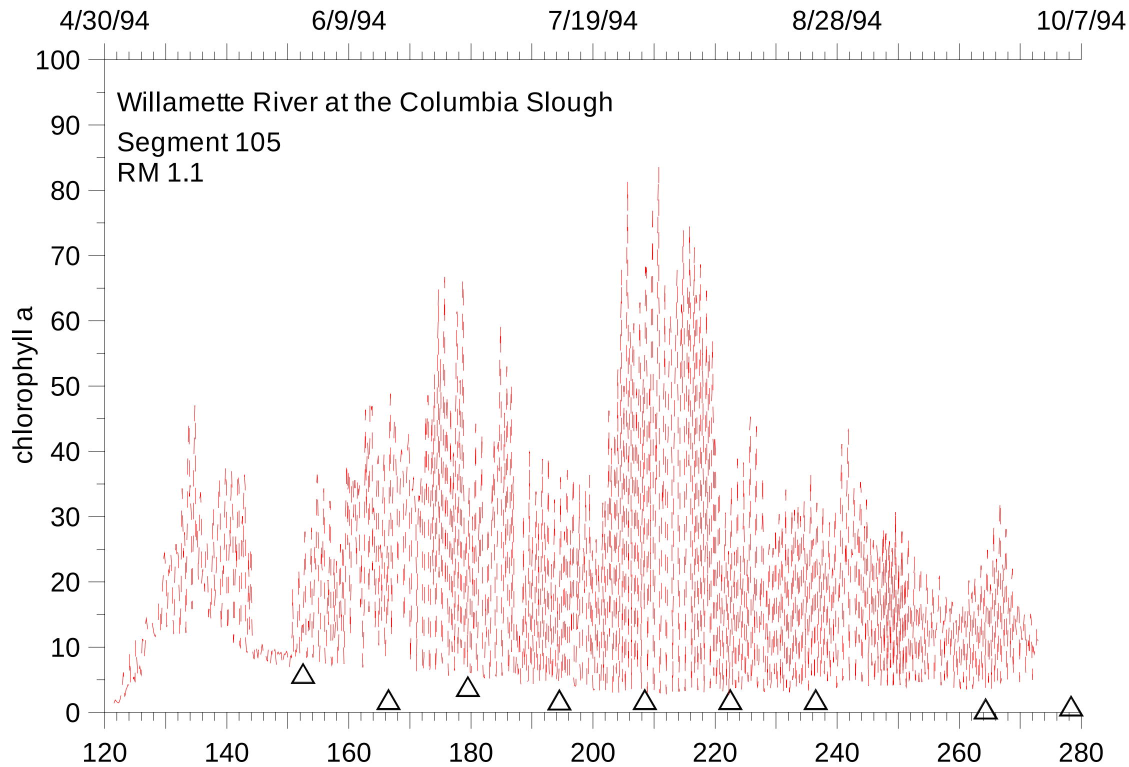


Figure 48. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the Columbia Slough (RM 1.1) during 1994.

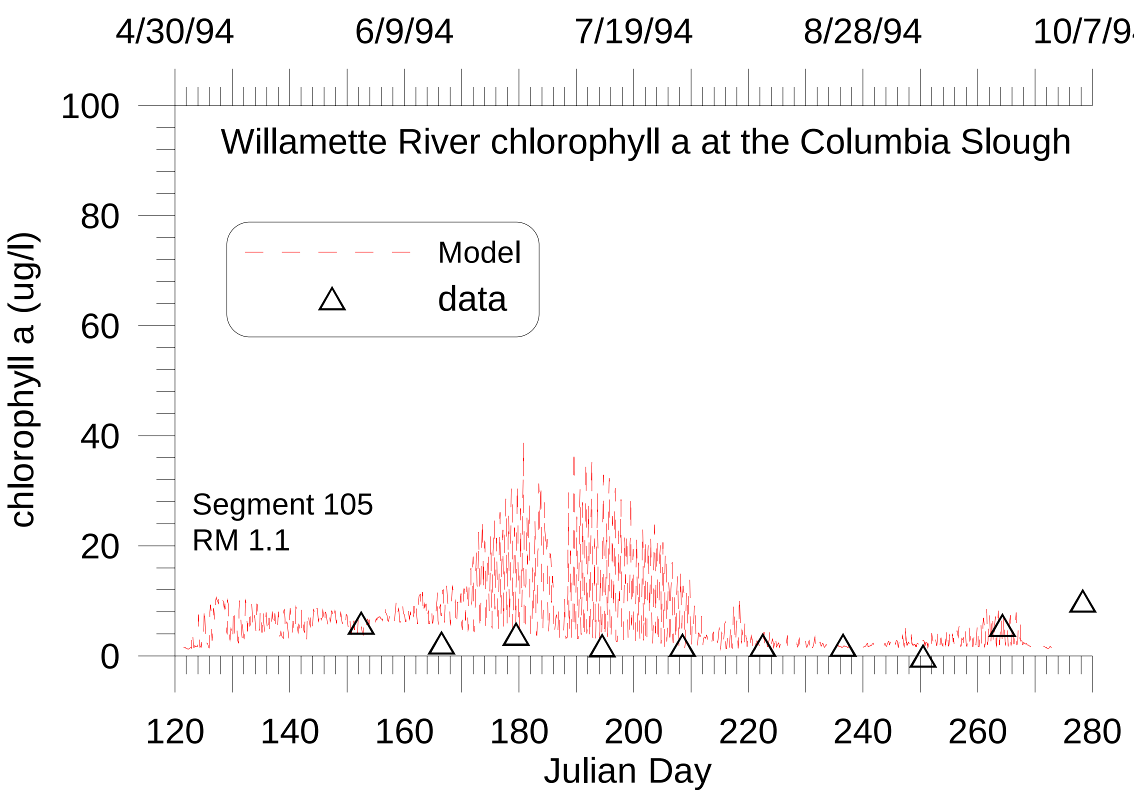


Figure 49. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the Columbia Slough (RM 1.1) during 1994 using a algal maximum growth rate of 1.2 d^{-1}.

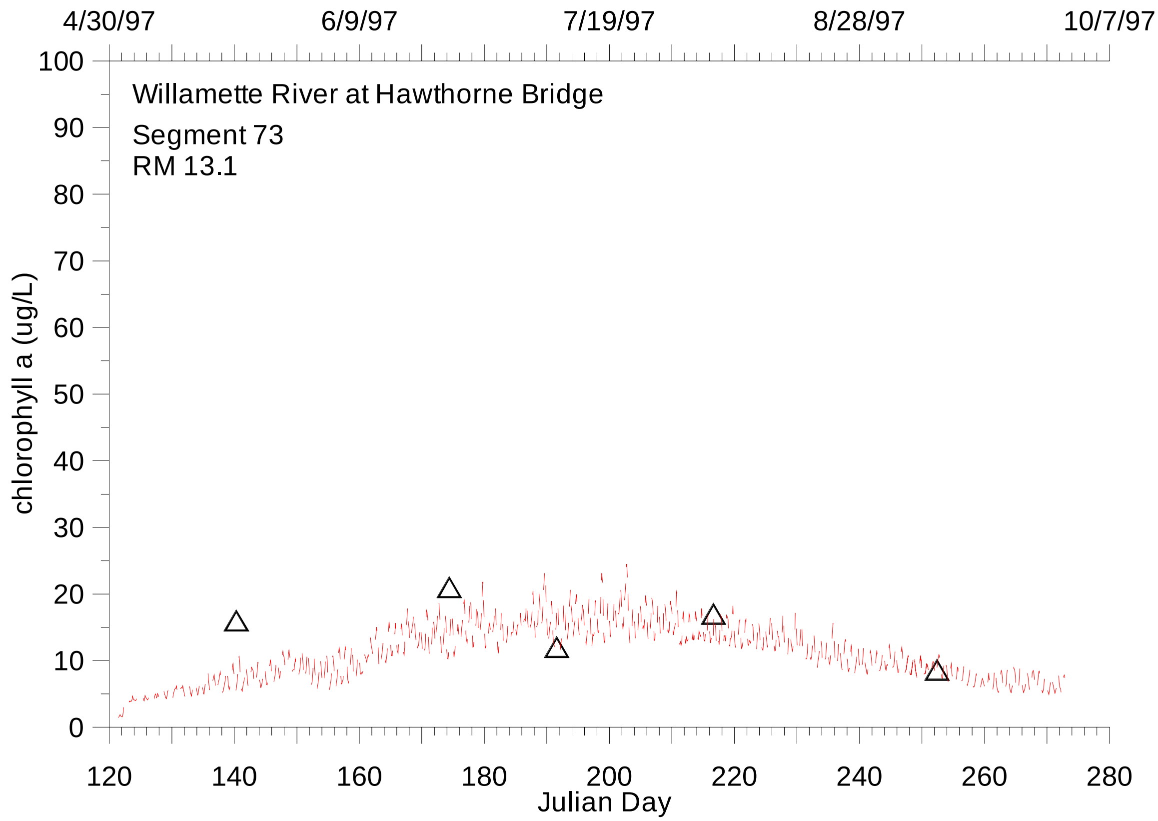


Figure 50. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the Hawthorne Bridge (RM 13.1) during 1997.

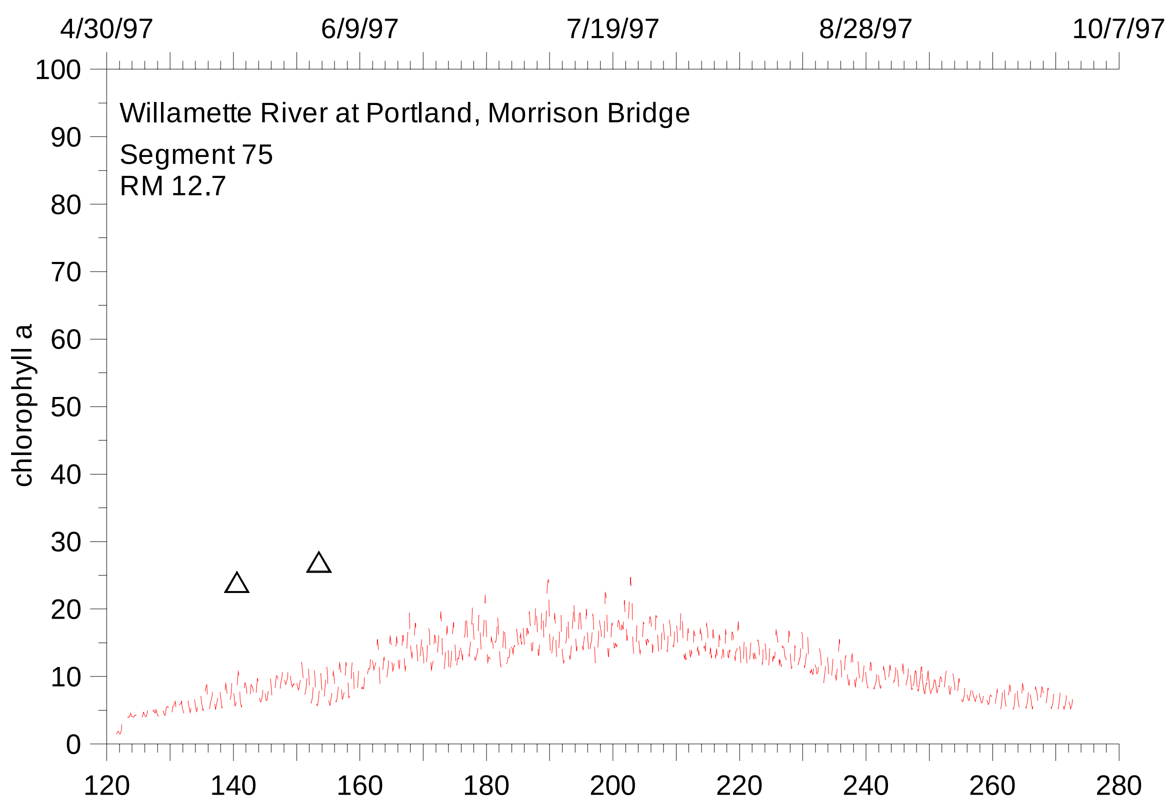


Figure 51. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the Morrison Bridge (RM 12.7) during 1997.

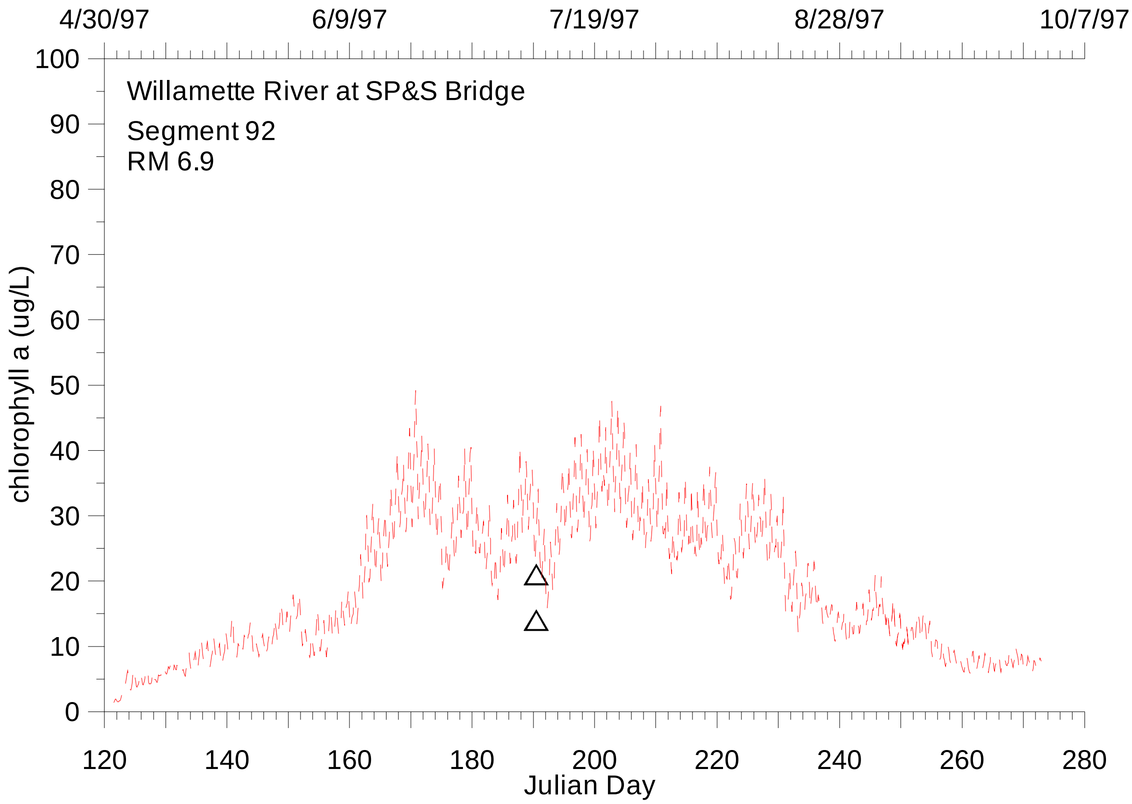


Figure 52. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the SP&S Bridge (RM 6.9) during 1997.

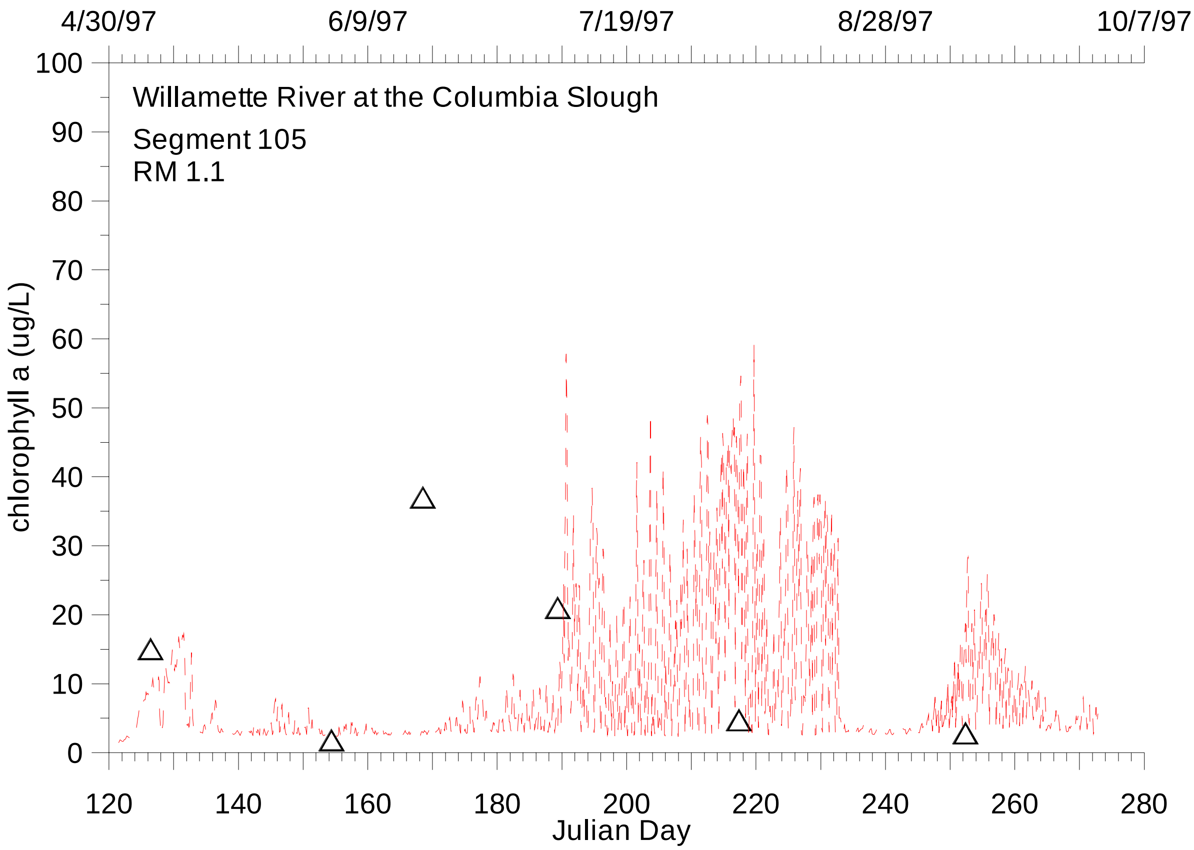


Figure 53. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the Columbia Slough (RM 1.1) during 1997.

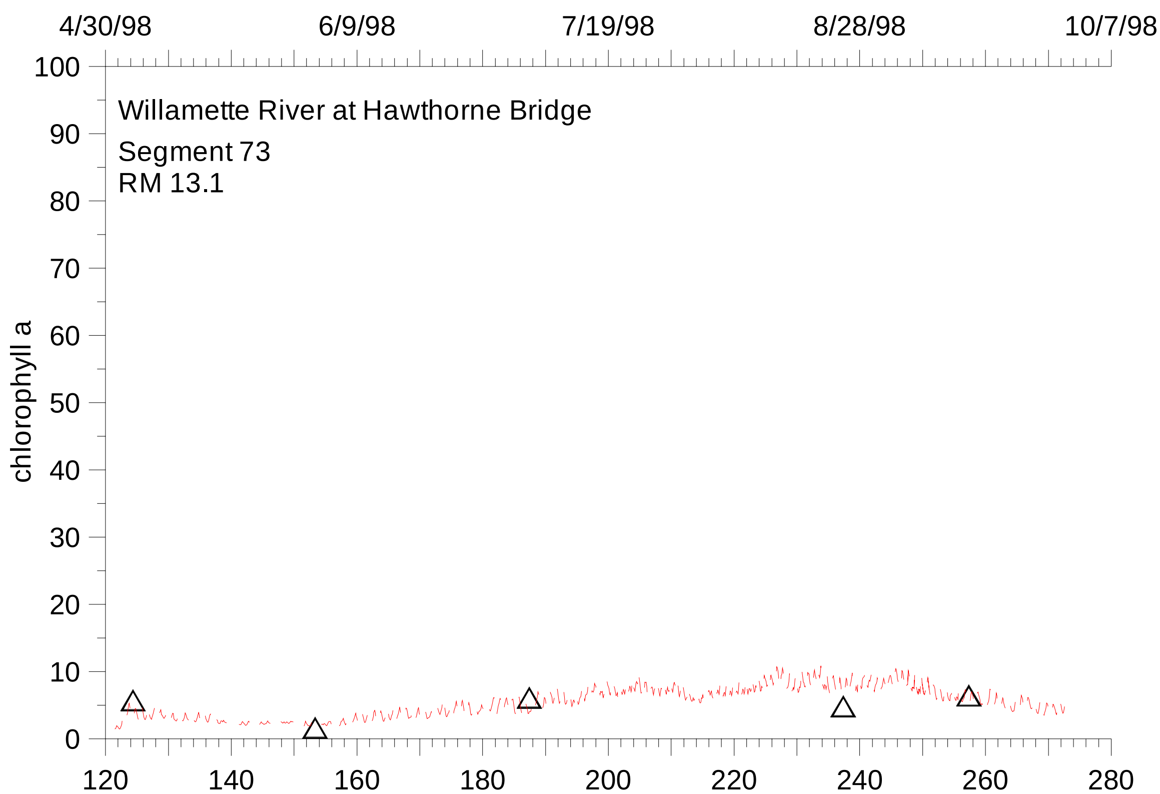


Figure 54. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the Hawthorne Bridge (RM 13.1) during 1998.

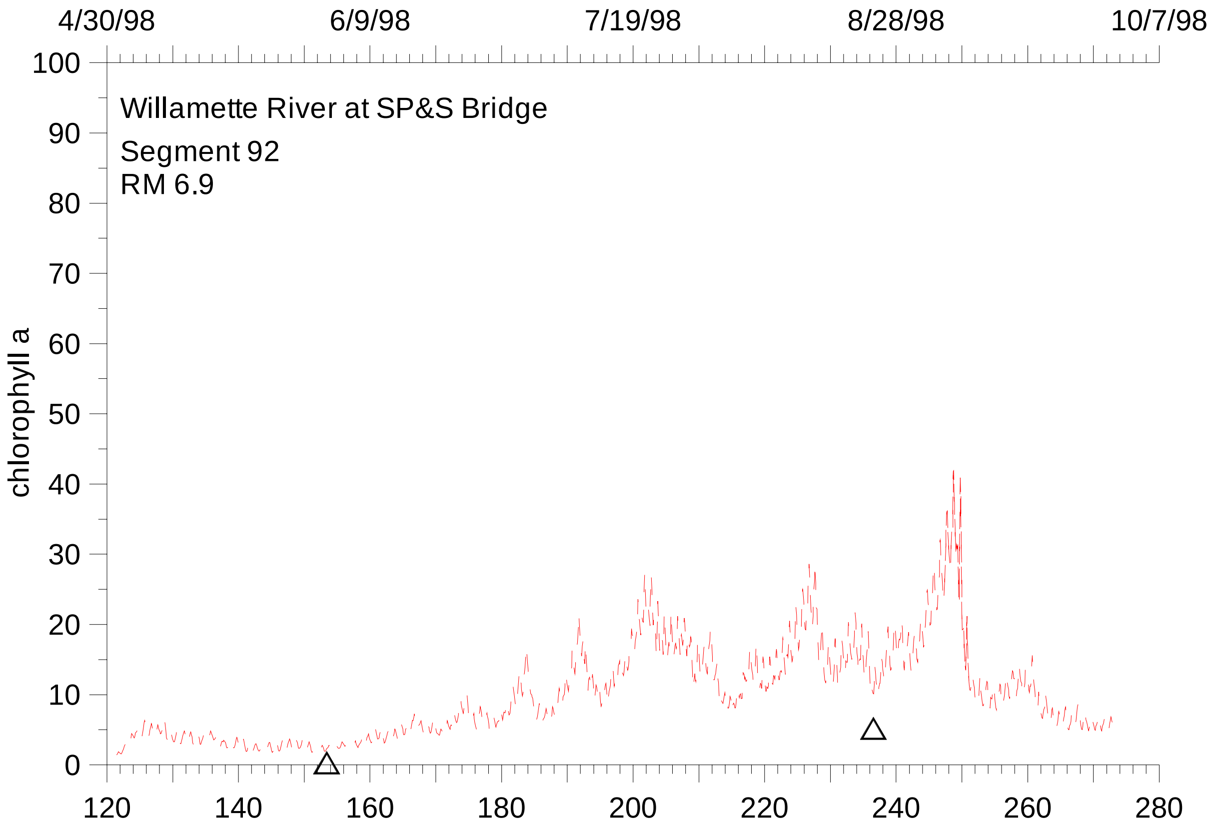


Figure 55. Comparison between model predicted chlorophyll a concentrations and data for the Willamette River at the SP&S Bridge (RM 6.9) during 1998.

pH

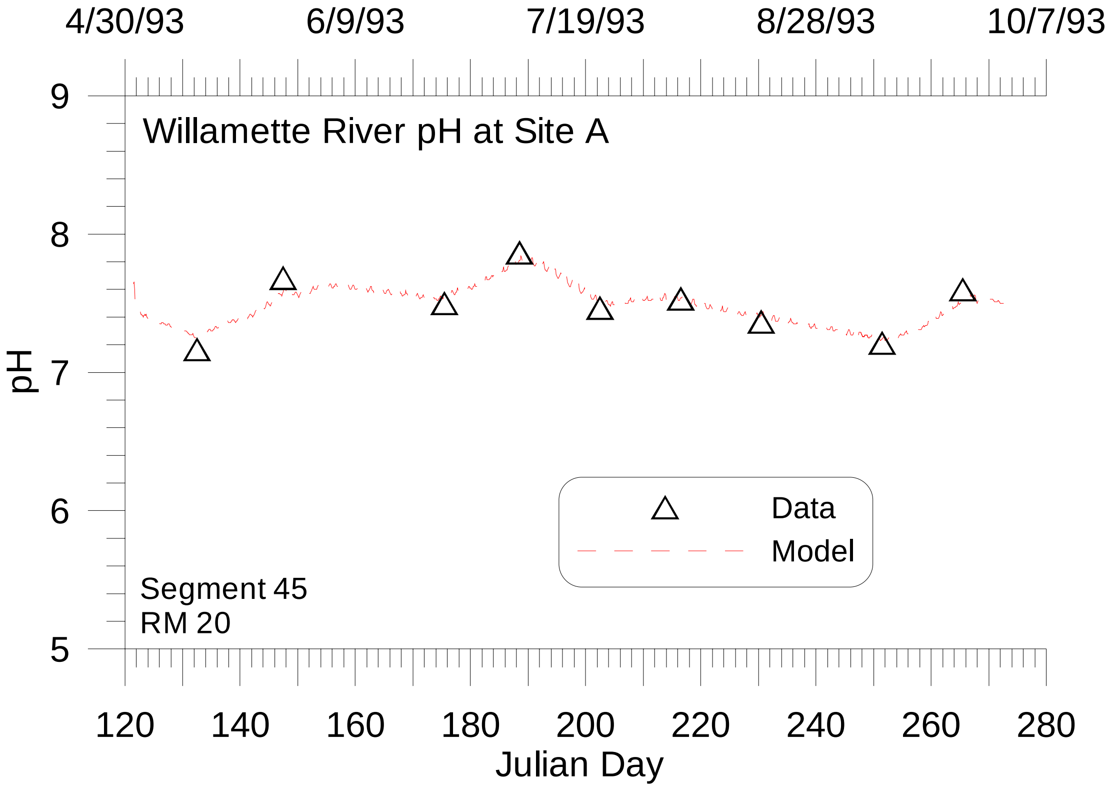
Adjustment of pH required accurately knowing the upstream concentration of TIC (total inorganic carbon) and alkalinity. In many cases, if alkalinity and pH were known, TIC was computed using principles of equilibrium chemistry from Stumm and Morgan (1981).

Comparisons of model predictions and grab sample field data of pH in 1993 and 1997 at the Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) are shown in Figure 56 and Figure 57, respectively. Comparisons of model predictions and continuous and grab sample field data of pH in 1998 and 1999 at the Waverly Country Club (RM 3.1) and at St. John's Railroad Bridge (RM 6.8) are shown in Figure 58 and Figure 59, respectively. The model tracked well the variation in grab sample data. Comparing grab sample and continuous pH data, some of the continuous data may not have been in proper calibration.

Model prediction errors are shown in Table 16.

Table 16. Model - data errors in pH for the Willamette River between 1993 and 1999.

Year	Location	pH errors		
		n, # of data comparisons	AME	RMS
1993	RM 20.0 Segment #45	9	0.054	0.061
1994		18	0.555	0.706
1997		19	0.050	0.056
1998		19	0.051	0.058
1999		22	0.105	0.118
1993	RM17.9 Segment #60	NA	NA	NA
1994		NA	NA	NA
1997		276	0.066	0.079
1998		6576	0.189	0.296
1999		6021	0.160	0.200
1993	RM 13.1 Segment #73	7	0.207	0.228
1994		8	0.147	0.183
1997		5	0.258	0.276
1998		6	0.237	0.453
1999		NA	NA	NA
1993	RM 12.7 Segment #75	14	0.145	0.172
1994		23	0.222	0.304
1997		24	0.111	0.134
1998		25	0.085	0.107
1999		27	0.087	0.129
1993	RM 8.8 Segment #88	NA	NA	NA
1994		18	0.189	0.243
1997		19	0.171	0.212
1998		19	0.113	0.133
1999		NA	NA	NA
1993	RM 6.8 Segment #92	9	0.190	0.201
1994		18	0.280	0.427
1997		276	0.283	0.315
1998		6557	0.238	0.298
1999		5910	0.172	0.234
1993	RM 1.1 Segment #105	9	0.301	0.345
1994		17	0.386	0.460
1997		19	0.187	0.241
1998		19	0.241	0.315
1999		NA	NA	NA



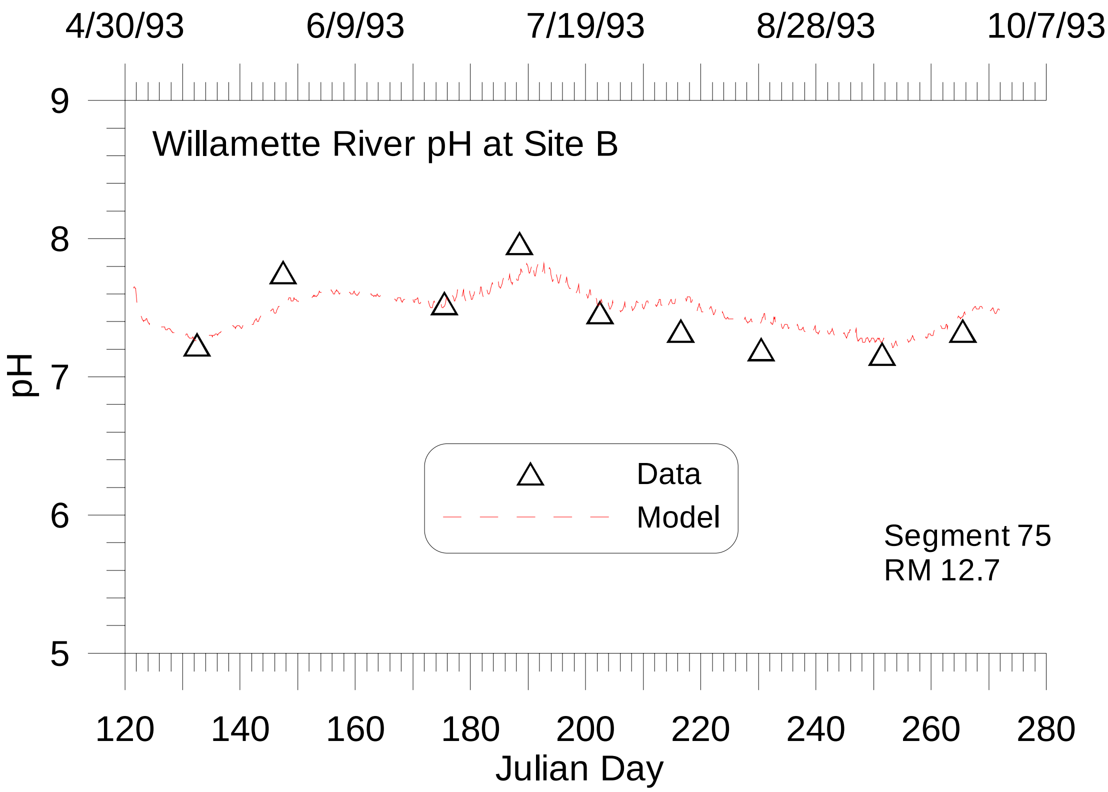


Figure 56. Comparison between model predicted pH and data for the Willamette River at site A (RM 20) and site B (RM 12.7) during 1993.

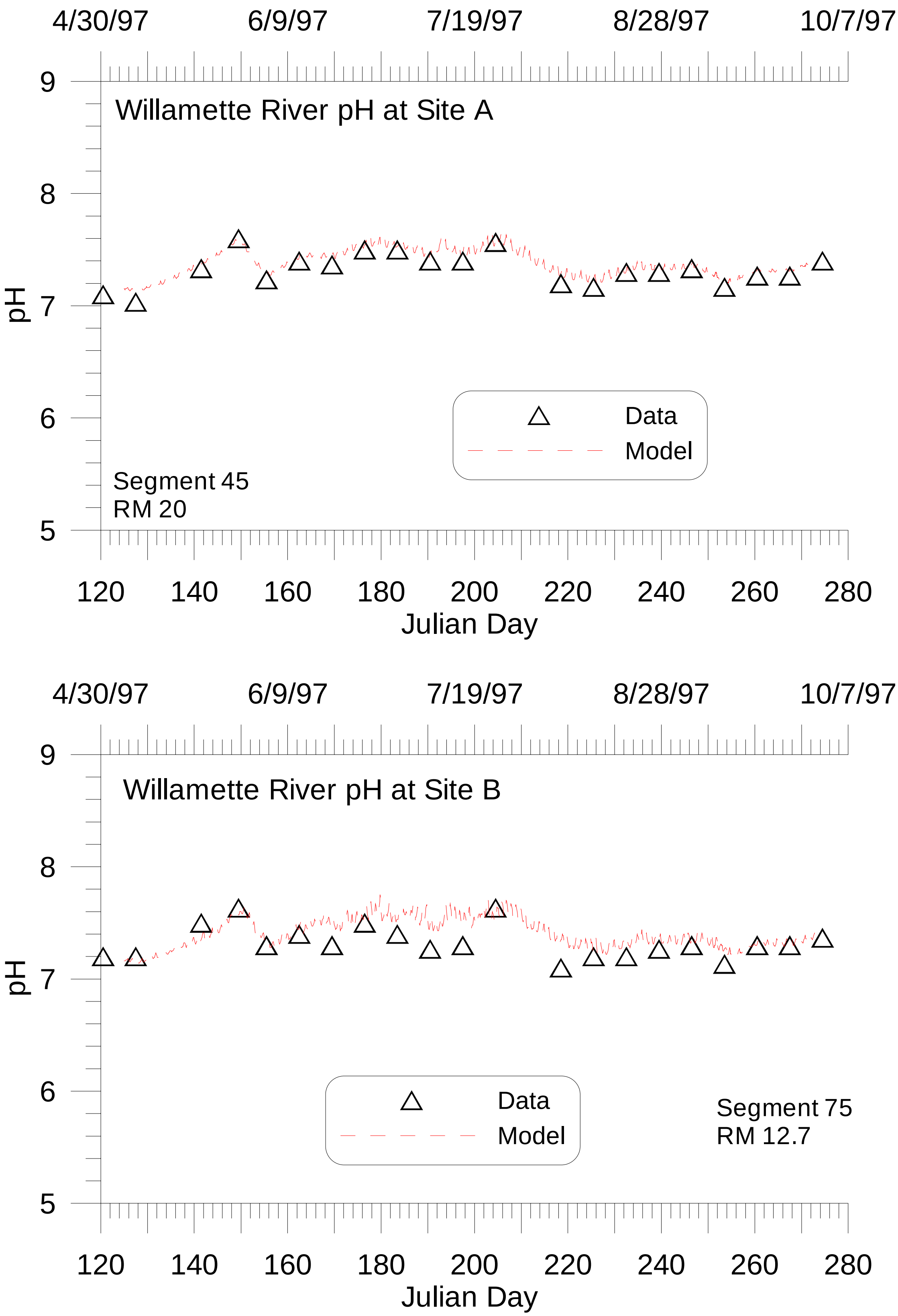
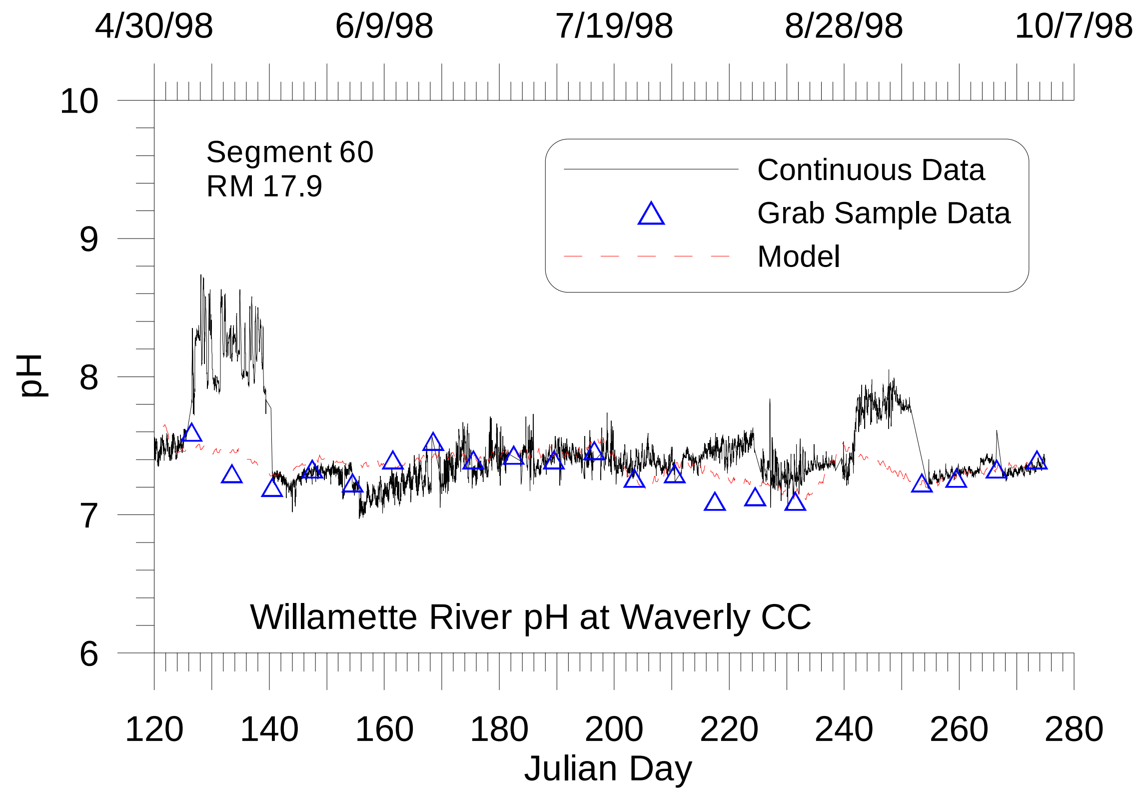


Figure 57. Comparison between model predicted pH and data for the Willamette River at site A (RM 20) and site B (RM 12.7) during 1997.



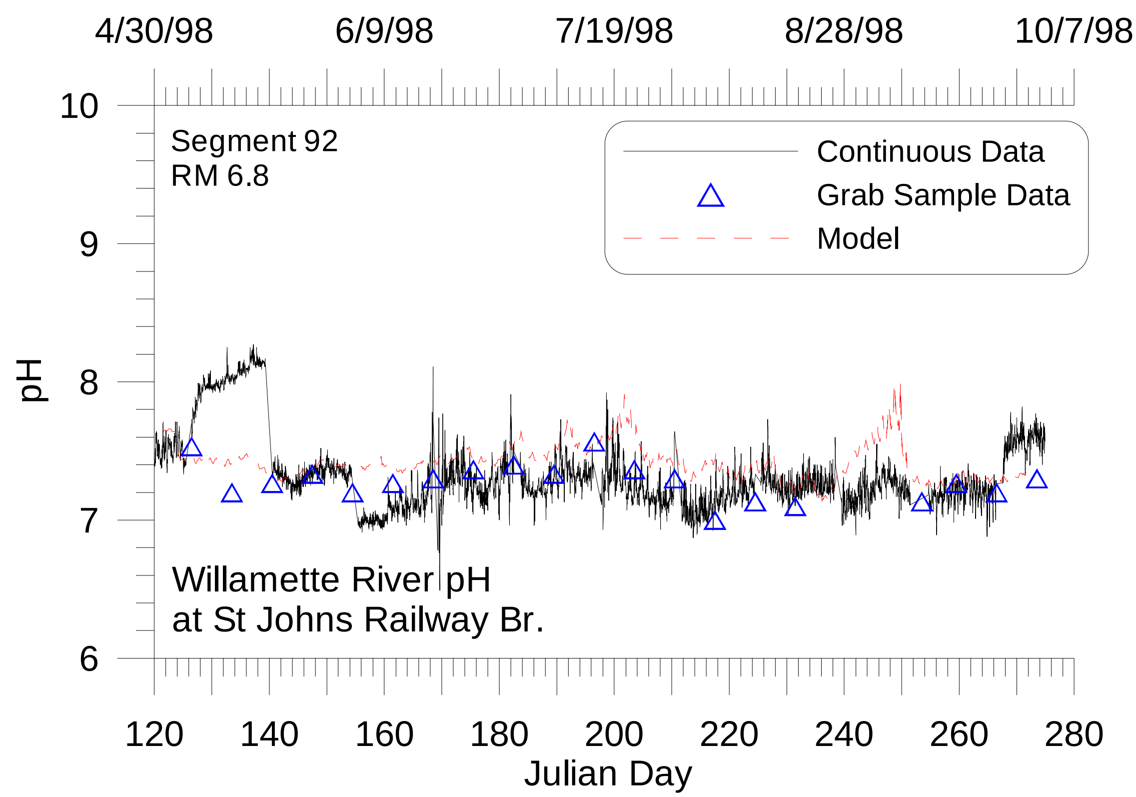


Figure 58. Comparison between model predicted pH and data for the Willamette River at Waverly Country Club (RM 17.9) and at St. Johns Railway Bridge (RM 6.8) during 1998.

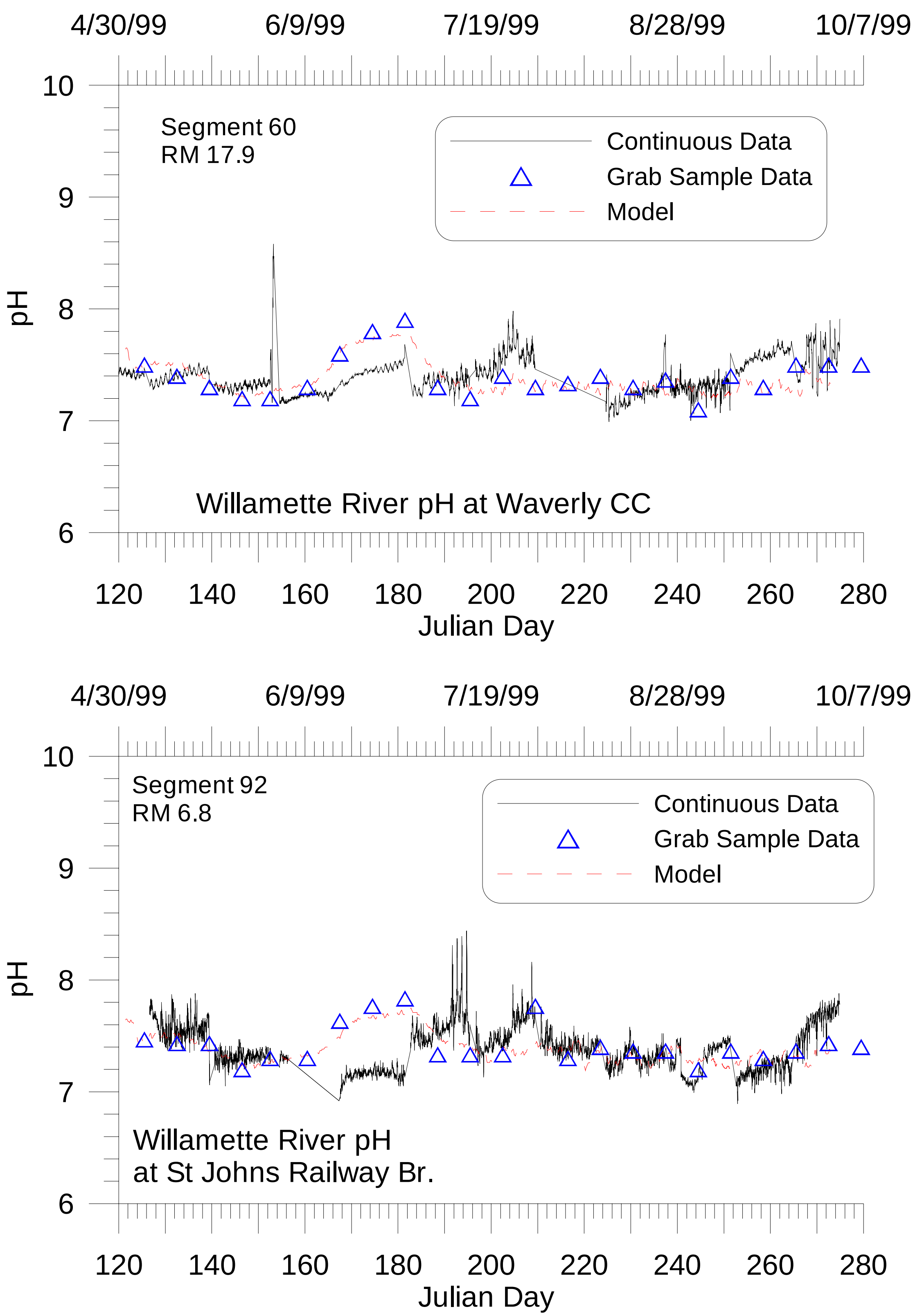


Figure 59. Comparison between model predicted pH and data for the Willamette River at Waverly Country Club (RM 17.9) and at St. Johns Railway Bridge (RM 6.8) during 1999.

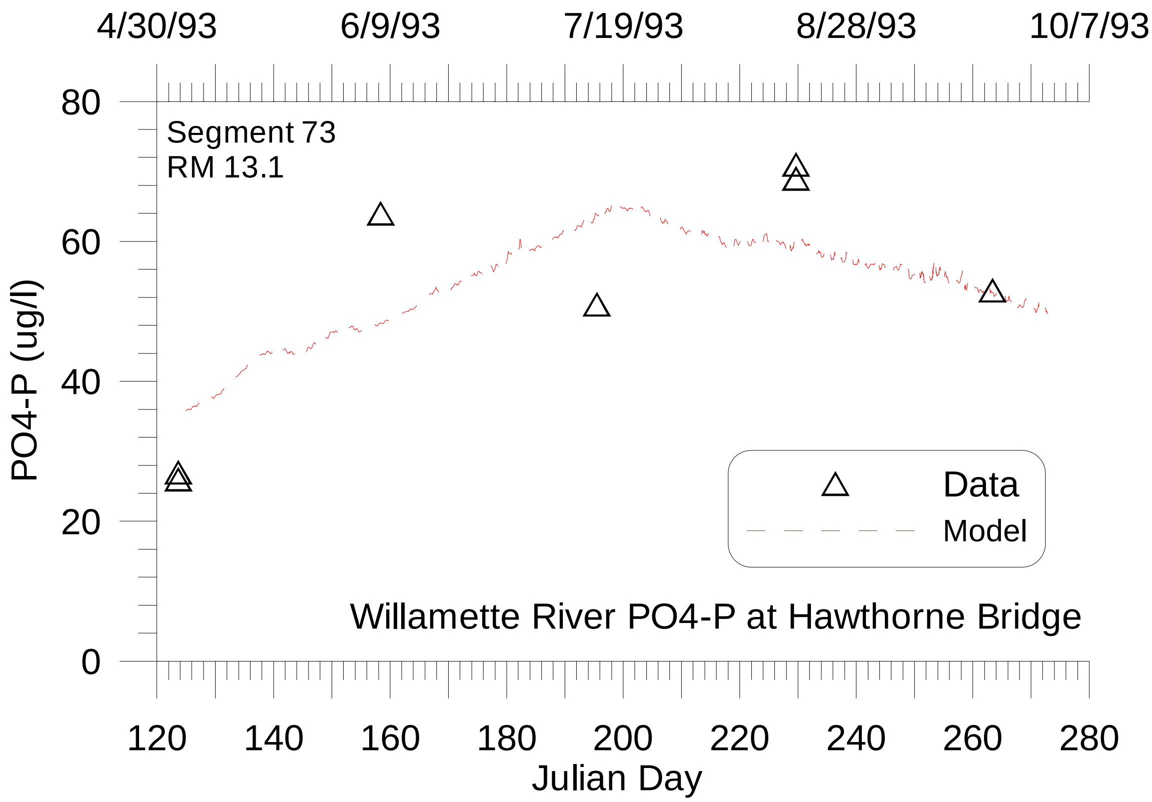
Ortho-Phosphorus

Comparisons of model predictions and grab sample field data of PO_4-P in 1993, 1994, 1997, and1998 at the Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) are shown in Figure 60, Figure 61, Figure 62, and Figure 63, respectively. Comparisons of model predictions and grab sample field data of PO_4-P in 1999 at Hawthorne Bridge (RM 13.1) are shown in Figure 64.

Model prediction errors are shown in Table 17.

Table 17. Model - data errors in PO_4-P for the Willamette River between 1993 and 1999.

Year	Location	PO_4-P model-data error		
		n, # of data comparisons	AME, ug/L	RMS, ug/L
1993	RM 13.1 Segment #73	7	9.6	10.6
1994		8	6.1	9.1
1997		5	6.9	8.1
1998		6	4.5	5.6
1993	RM 12.7 Segment #75	14	12.2	12.7
1994		5	8.9	11.7
1997		5	6.8	8.2
1998		6	4.8	5.2
1999		5	6.9	7.2



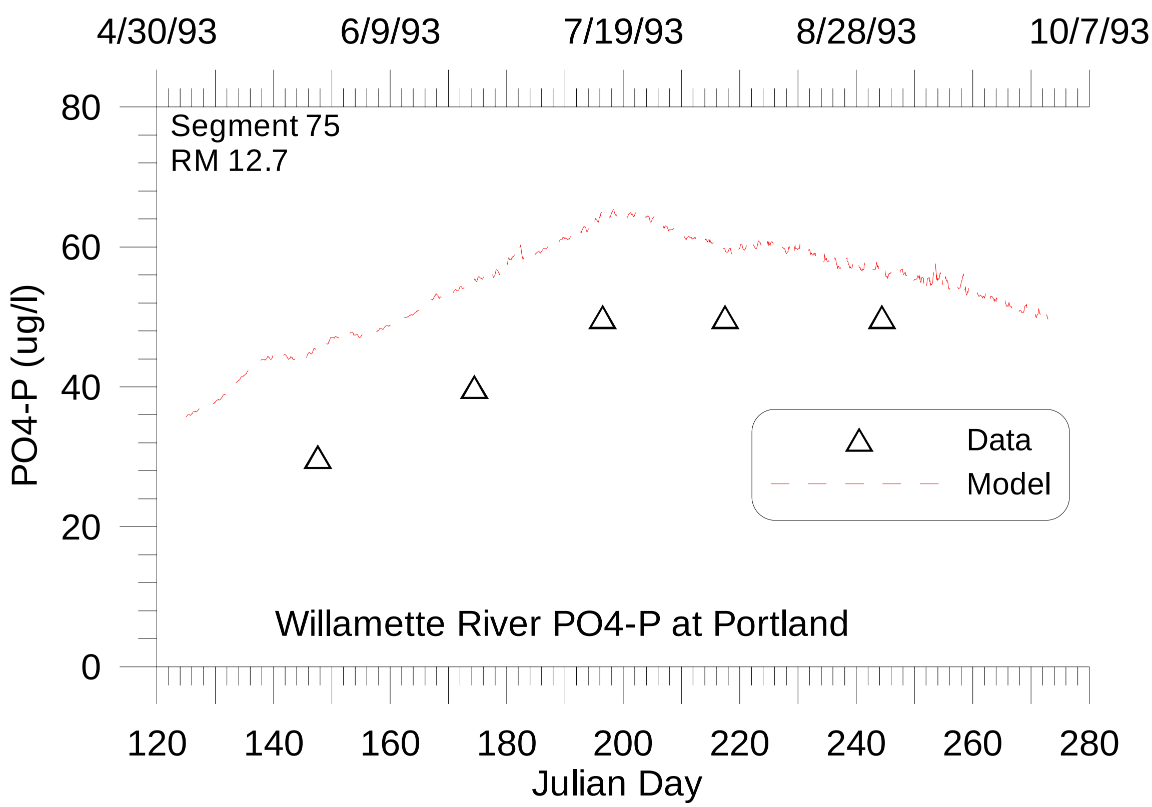
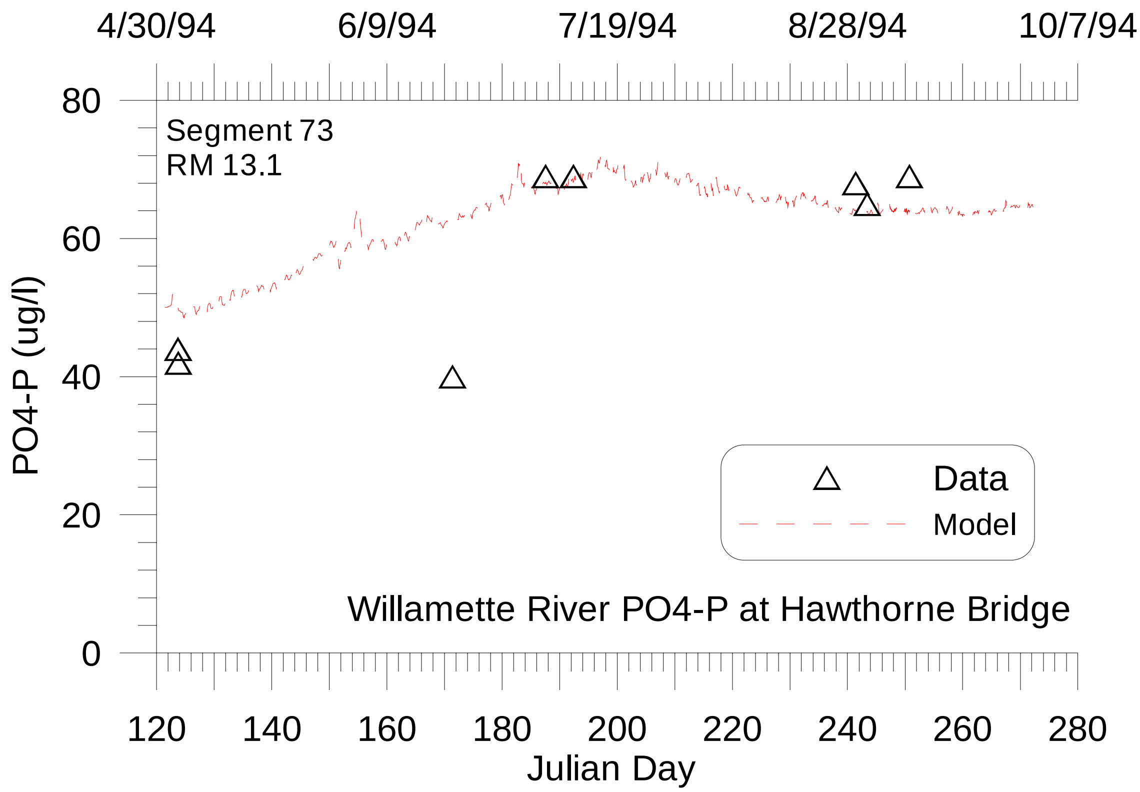


Figure 60. Comparison between model predicted ortho-phosphorus concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1993.



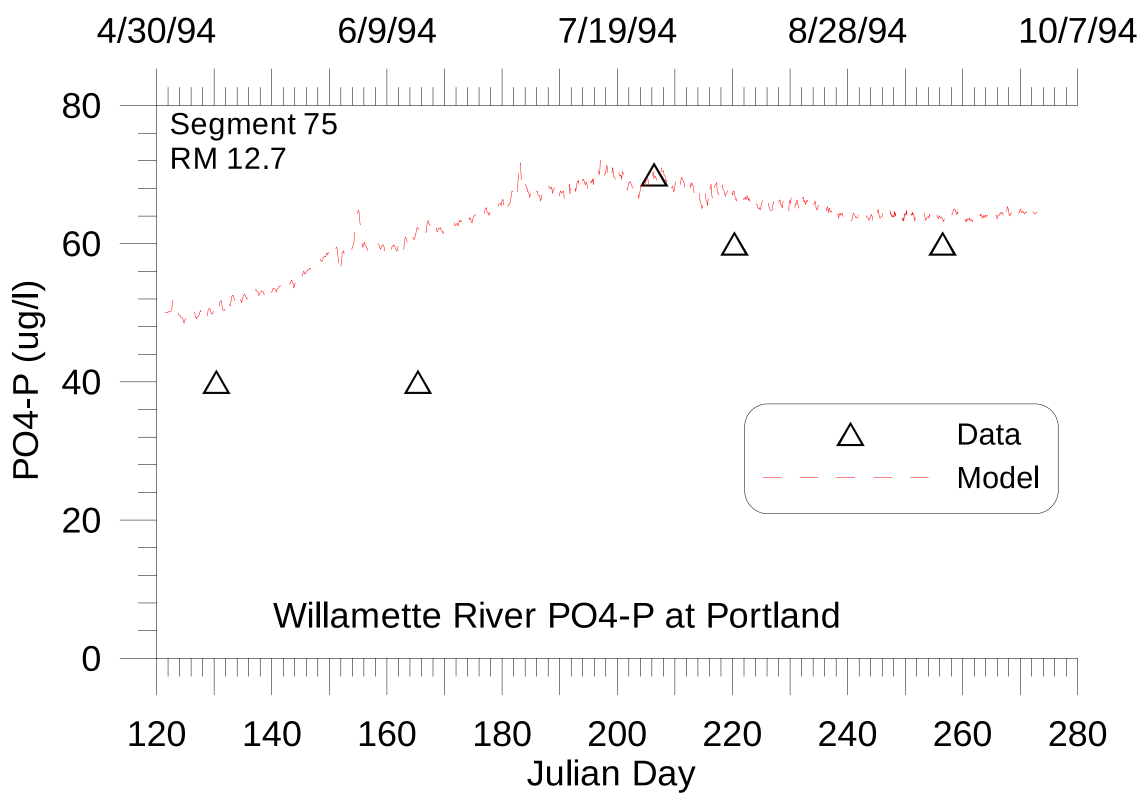


Figure 61. Comparison between model predicted ortho-phosphorus concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1994.

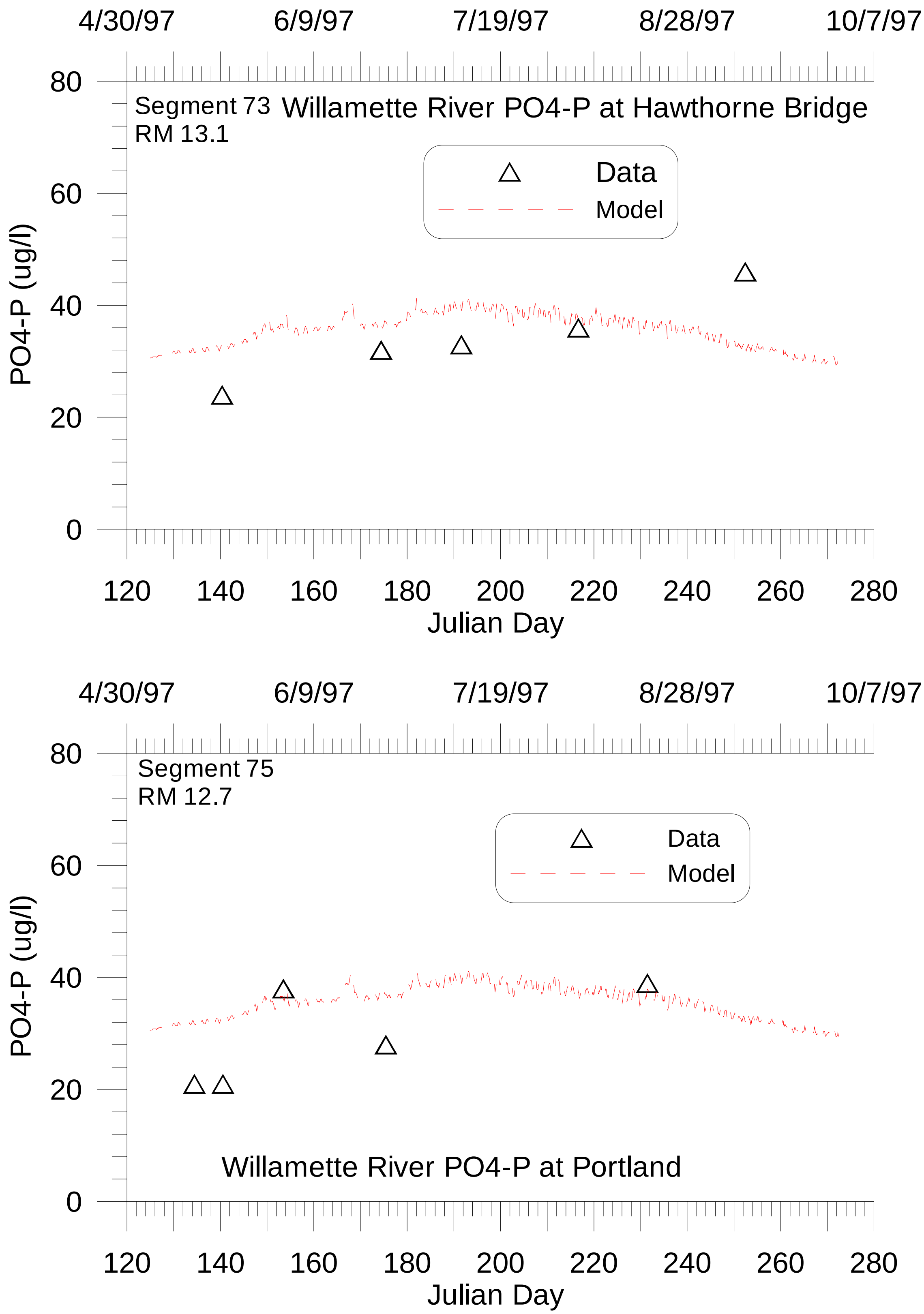


Figure 62. Comparison between model predicted ortho-phosphorus concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1997.

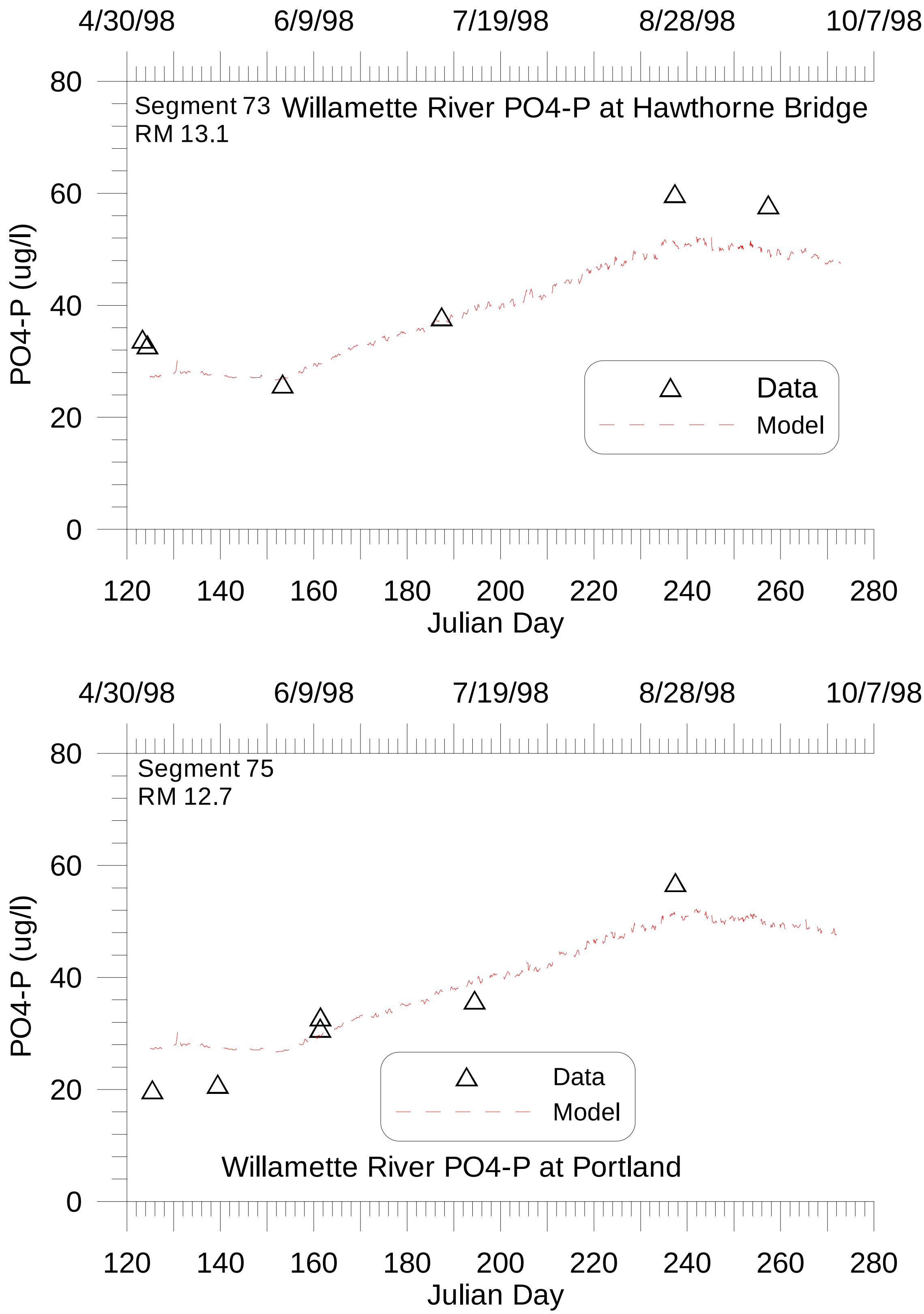


Figure 63. Comparison between model predicted ortho-phosphorus concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1998.

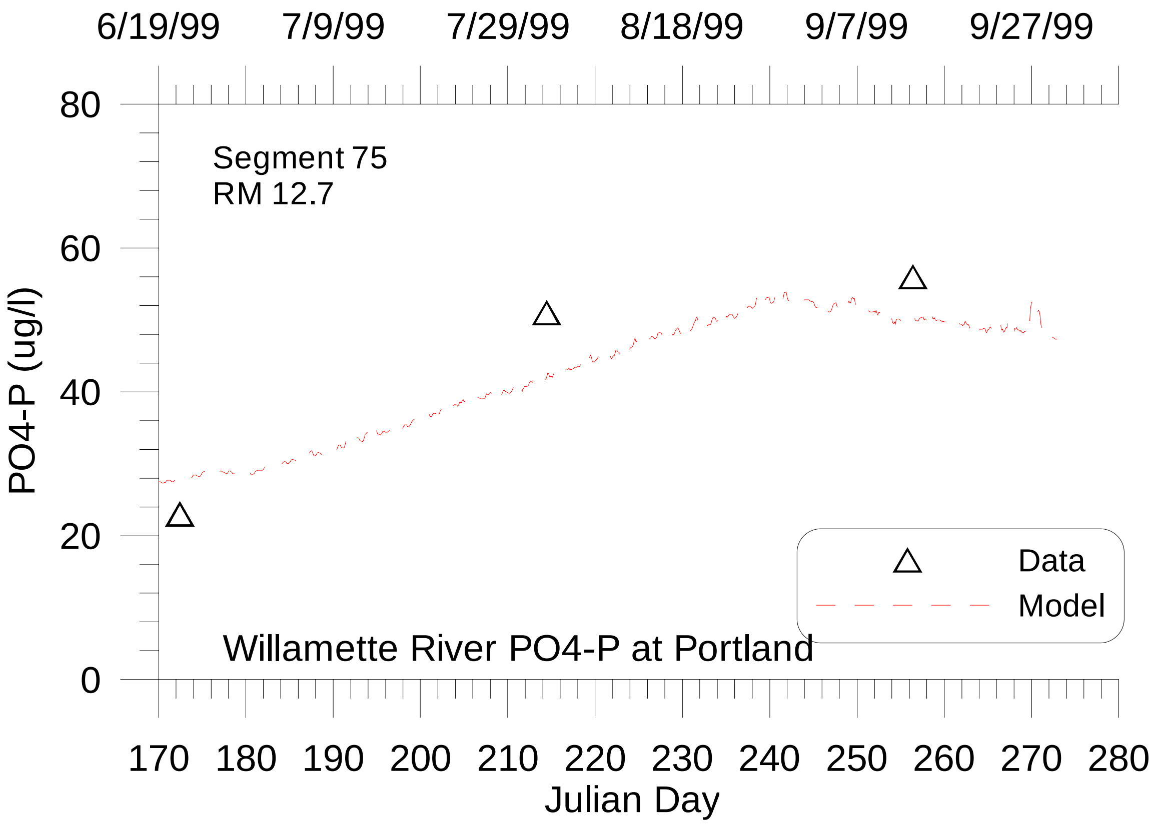


Figure 64. Comparison between model predicted ortho-phosphorus concentrations and data for the Willamette River at Portland (RM 12.7) during 1999.

Total Phosphorus

CE-QUAL-W2 does not use Total Phosphorus as a state variable, but computes it by summing up all the P in the following state variables: algae, PO_4-P, dissolved organic matter, and particulate organic matter. The calculation of TP depends primarily (as it does with the other water quality variables used in this model) on the upstream boundary conditions. Whenever field data were taken infrequently, the model interpolates between such low frequency data. In many cases, the error in the model prediction in the model domain are a result of the boundary conditions since model parameters are largely insensitive to variability in Total P.

Comparisons of model predictions and grab sample field data of Total P in 1993, 1994, 1997 and 1998 at the Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) are shown in Figure 65, Figure 66, Figure 67, and Figure 68, respectively. Figure 69 shows the 1999 model-data comparison for Total P at Portland (RM 12.7) only.

Model prediction errors are shown in Table 18.

Table 18. Model - data errors in Total P for the Willamette River between 1993 and 1998.

Year	Location	Total P model-data error		
		n, # of data comparisons	AME, ug/L	RMS, ug/L

1993	RM 20.0 Segment #45	4	10.9	12.5
1993	RM 13.1 Segment #73	7	19.0	22.9
1994		8	15.5	17.5
1997		5	18.1	20.3
1998		6	25.1	26.0
1993	RM 12.7 Segment #75	5	14.0	17.2
1994		5	16.4	17.0
1997		5	16.4	20.3
1998		6	15.2	21.8
1999		5	7.8	11.9
1993	RM 6.8 Segment #92	6	17.7	25.2
1993	RM 1.1 Segment #105	4	25.5	37.2

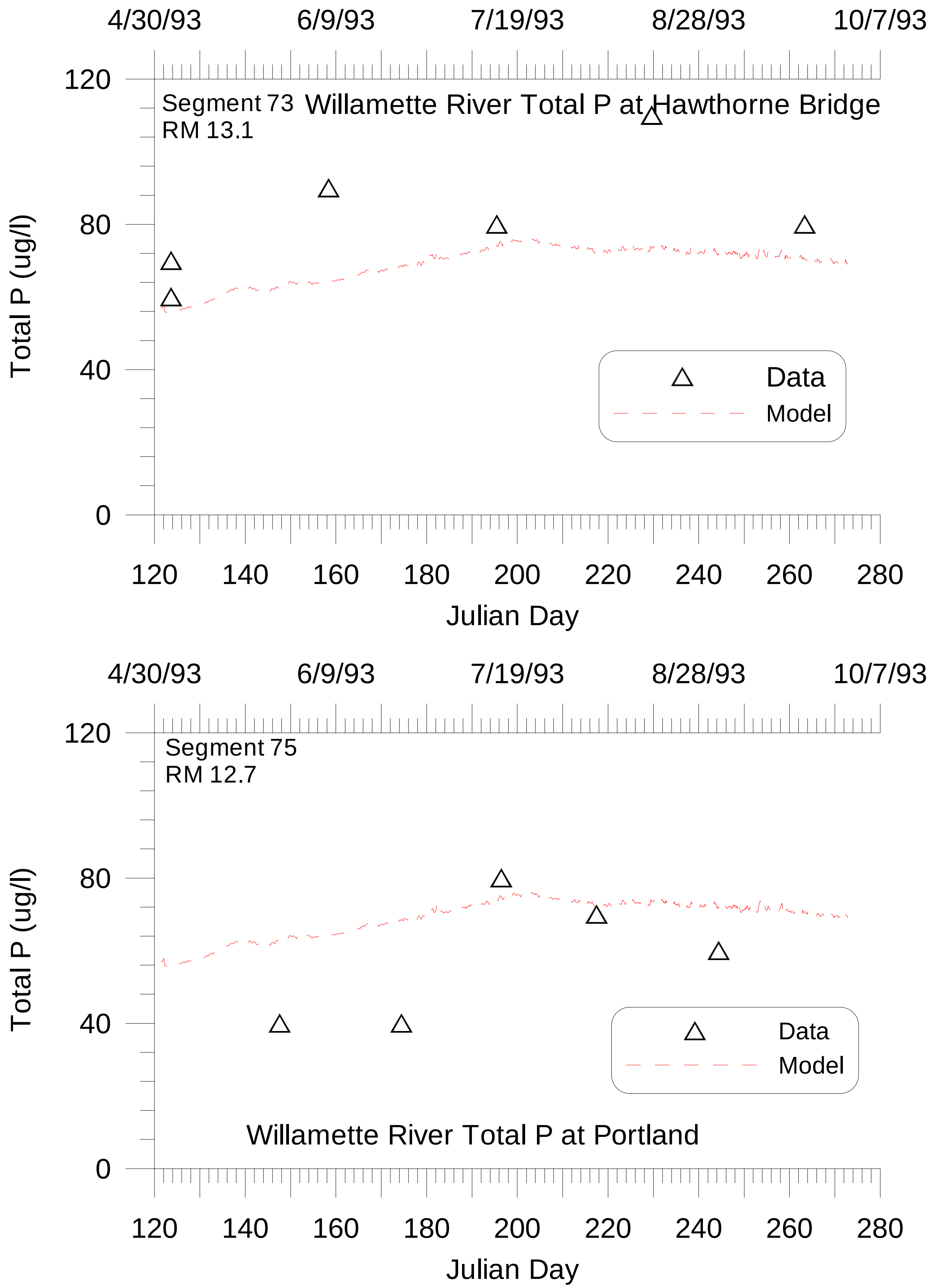
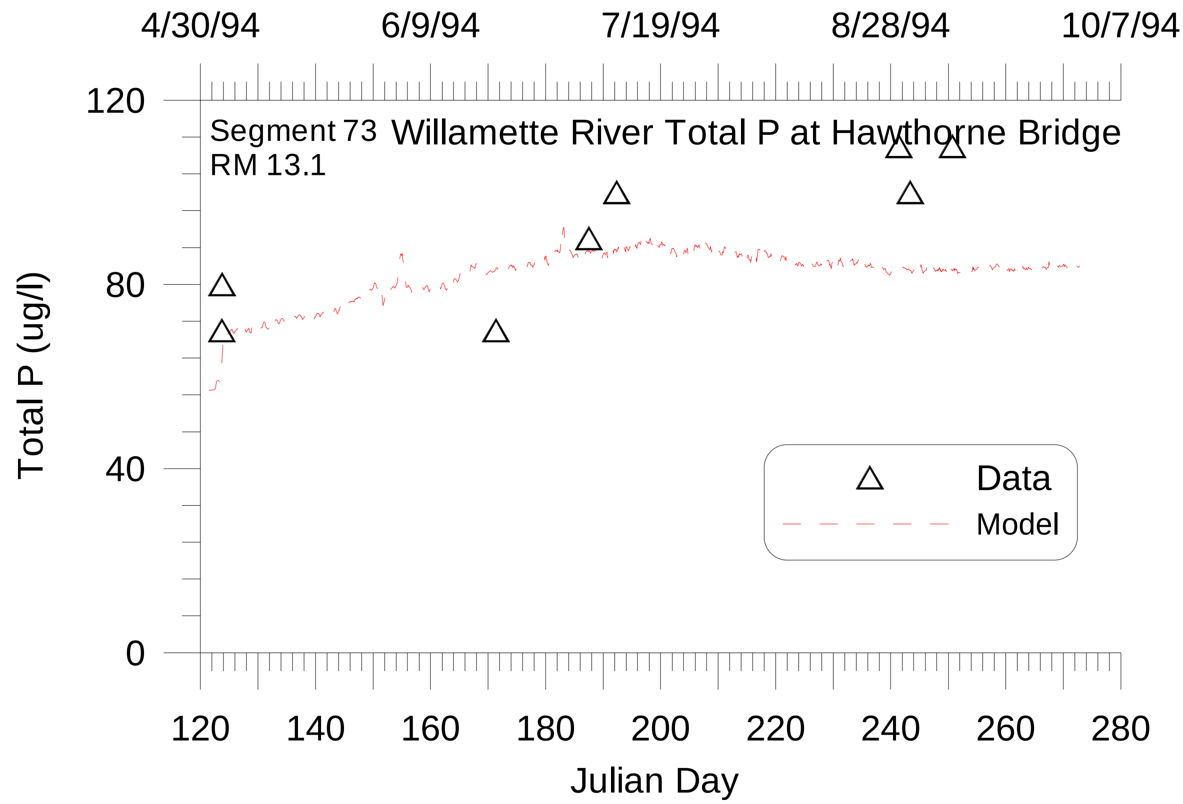


Figure 65. Comparison between model predicted total phosphorus concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1993.



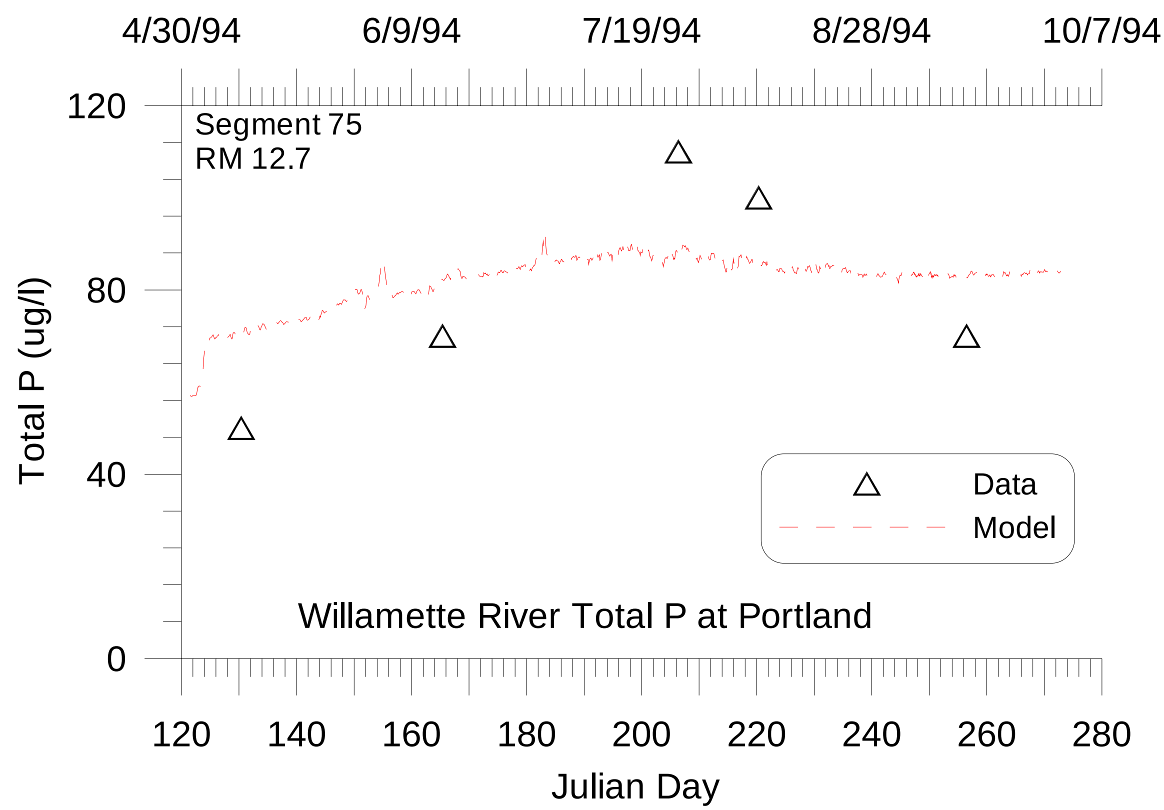
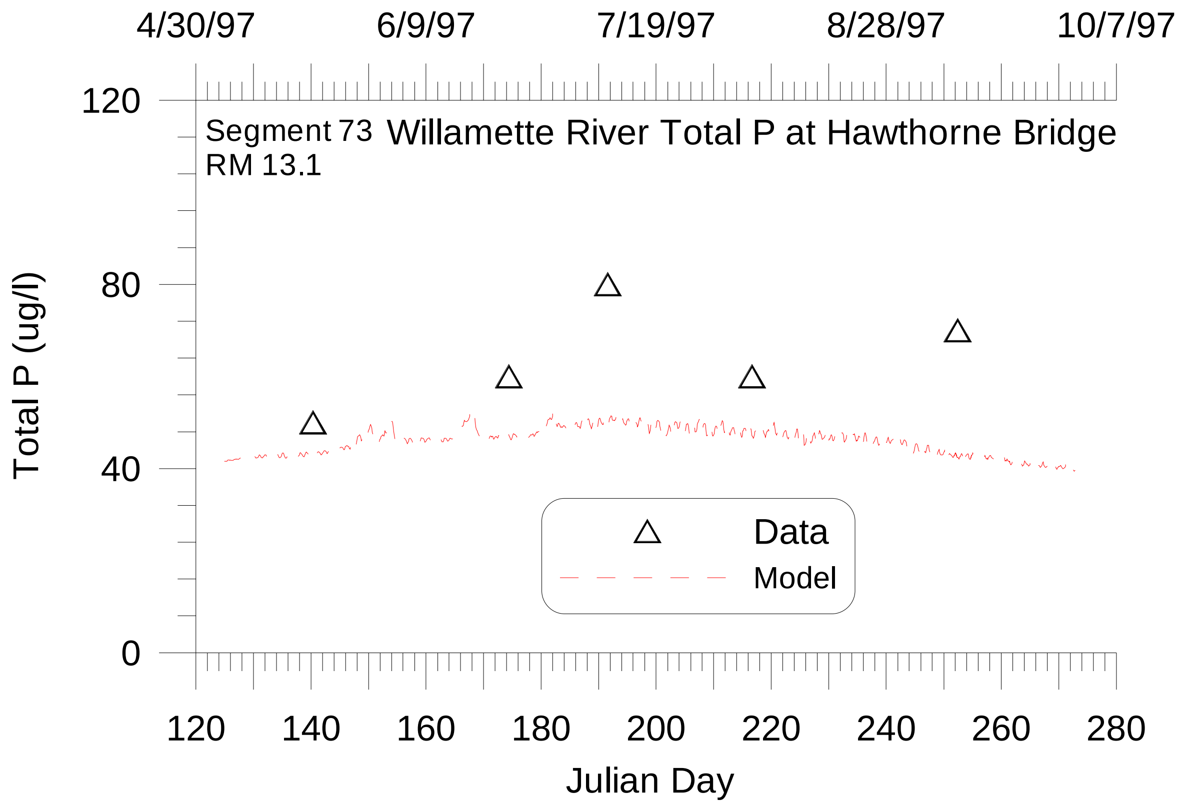


Figure 66. Comparison between model predicted total phosphorus concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1994.



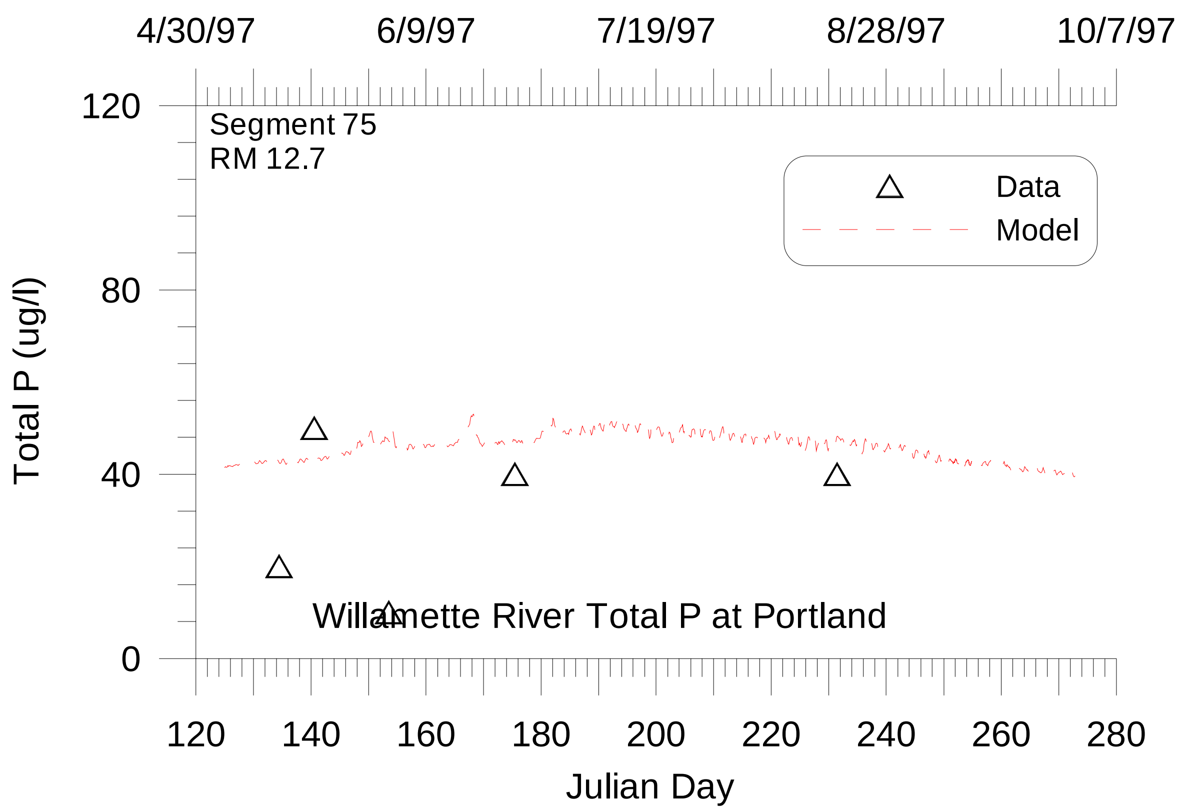


Figure 67. Comparison between model predicted total phosphorus concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1997.

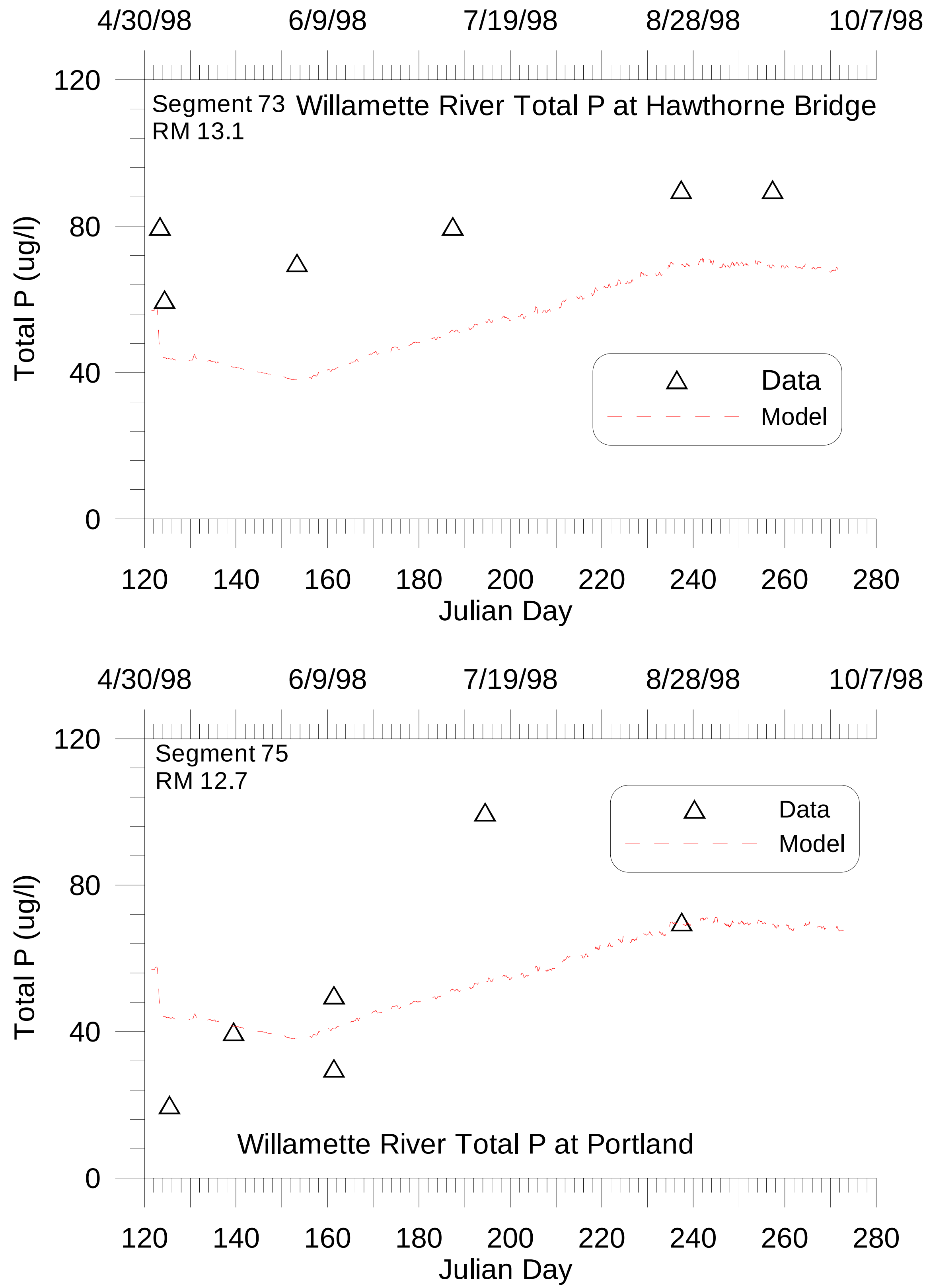


Figure 68. Comparison between model predicted total phosphorus concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1998.

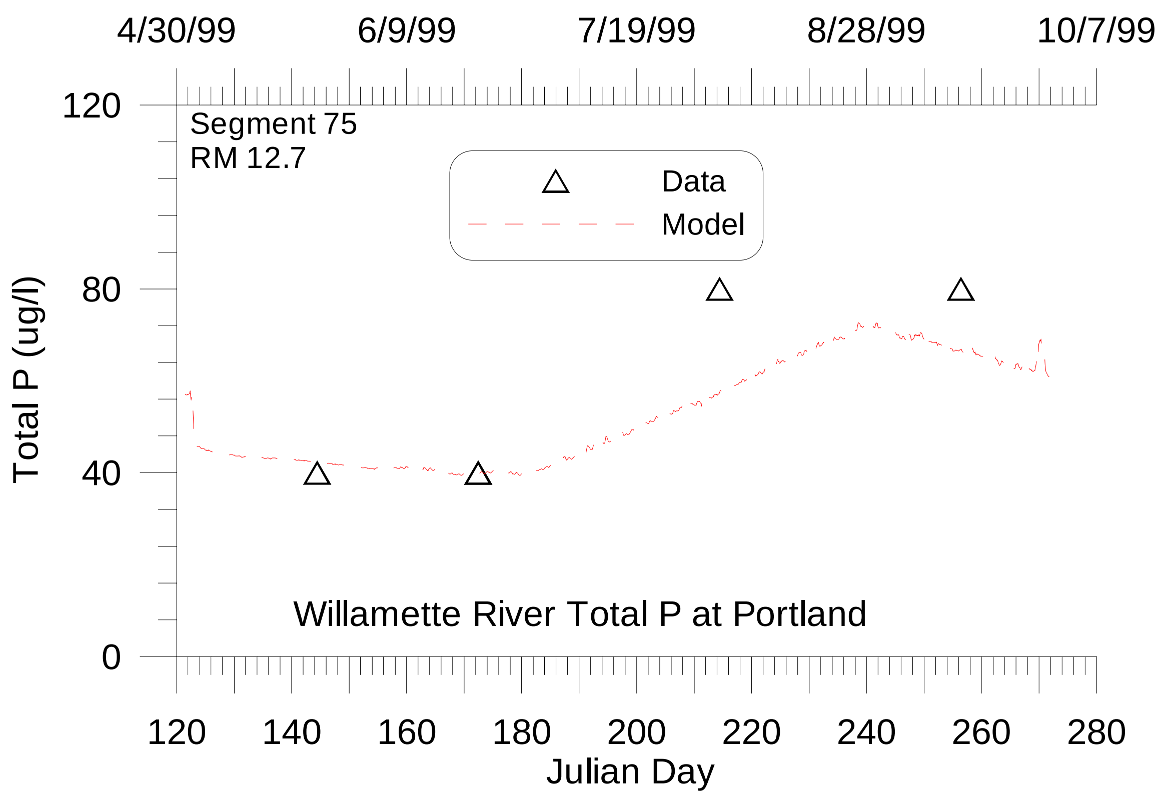


Figure 69. Comparison between model predicted total phosphorus concentrations and data for the Willamette River at Portland (RM 12.7) during 1999.

<u>Ammonia-Nitrogen</u>

Comparisons of model predictions and grab sample field data of NH_4-N in 1993, 1994, 1997, 1998 and 1999 at Portland (RM 12.7) are shown in Figure 70, Figure 71, Figure 72, Figure 73, and Figure 74, respectively.

Model prediction errors are shown in Table 19.

Table 19. Model - data errors in NH_4-N for the Willamette River between 1993 and 1999.

Year	Location	NH4-N model-data error		
		n, # of data comparisons	AME, ug/L	RMS, ug/L
1993	RM 20.0 Segment #45	9	32.5	37.9
1993	RM 13.1 Segment #73	7	25.0	32.0
1994		8	14.7	19.2
1997		5	21.6	27.4
1998		6	22.8	29.0
1993	RM 12.7 Segment #75	5	16.4	21.5
1994		5	21.4	26.6
1997		5	39.3	40.3
1998		6	17.3	23.0

1999		5	10.1	11.8
1993	RM 6.8 Segment #92	9	8.0	11.1
1993	RM 1.1 Segment #105	9	7.1	9.1

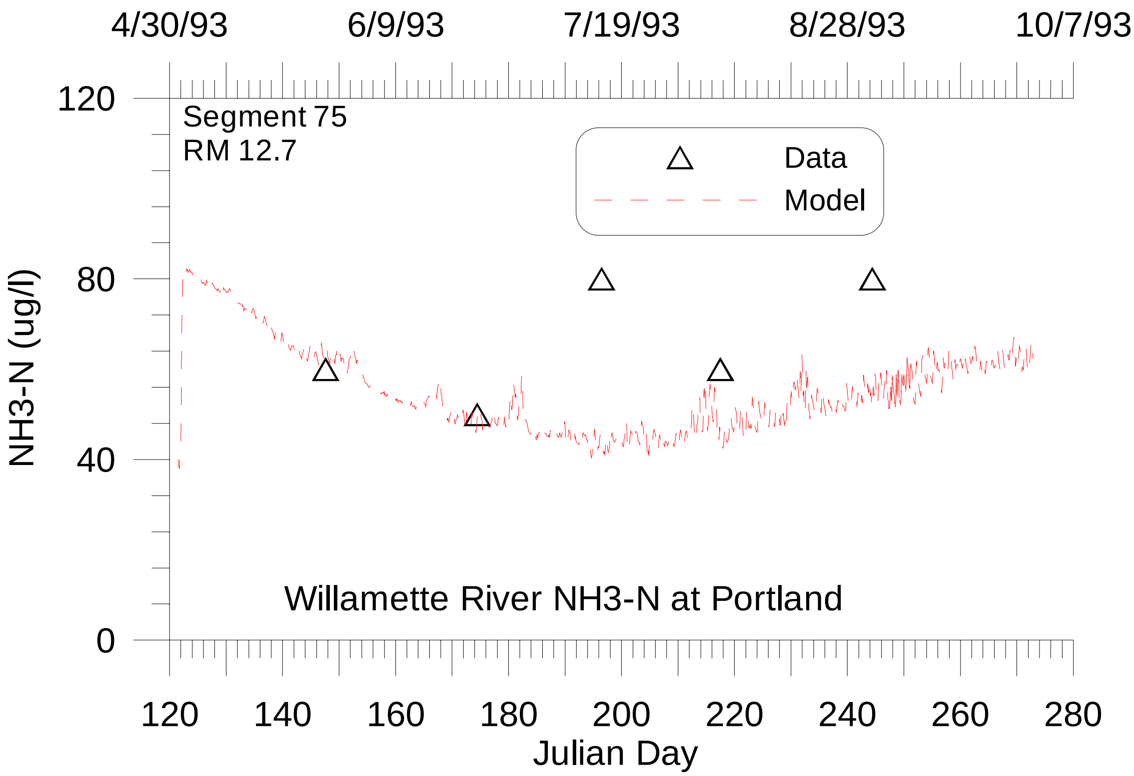


Figure 70. Comparison between model predicted ammonia-nitrogen concentrations and data for the Willamette River at Portland (RM 12.7) during 1993.

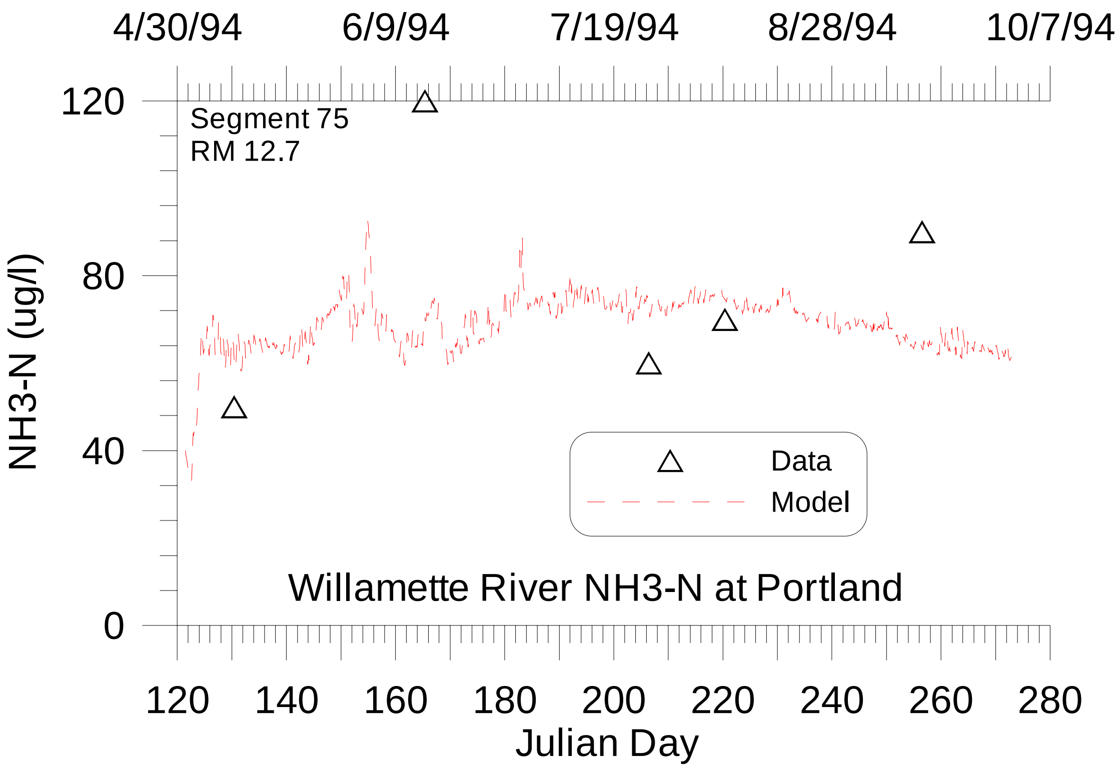


Figure 71. Comparison between model predicted ammonia-nitrogen concentrations and data for the Willamette River at Portland (RM 12.7) during 1994.

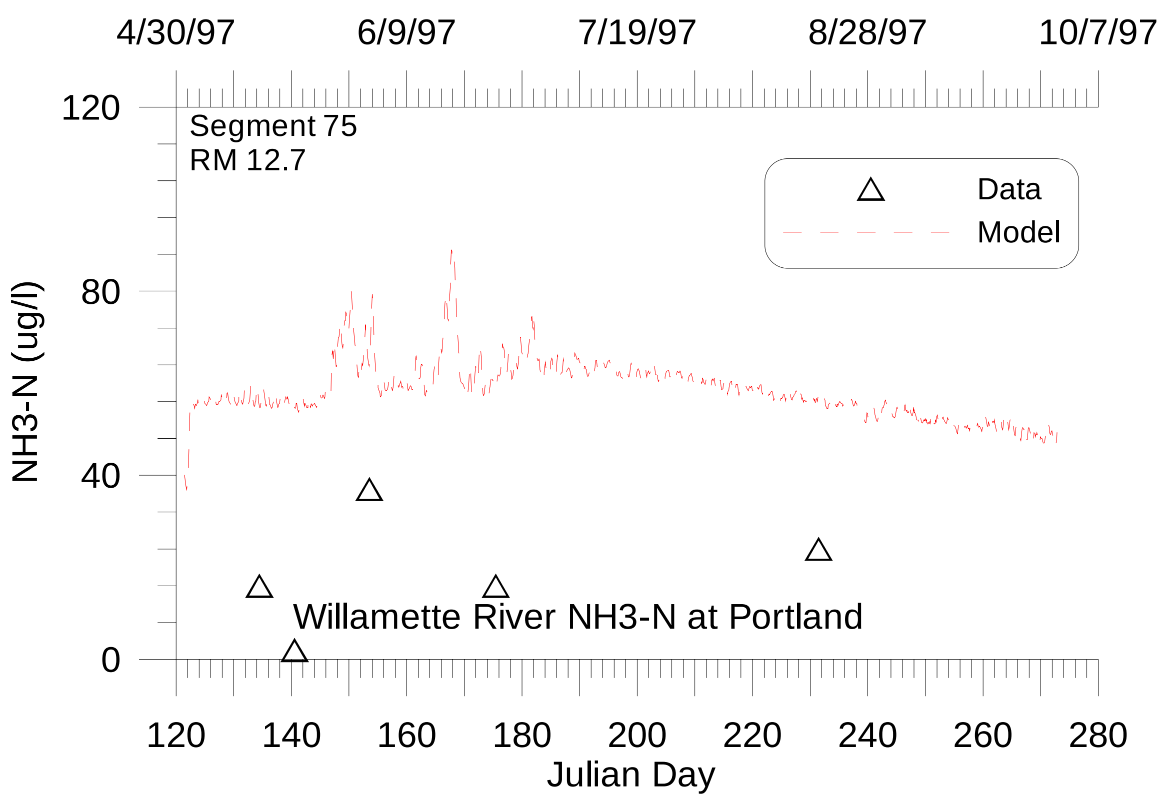


Figure 72. Comparison between model predicted ammonia-nitrogen concentrations and data for the Willamette River at Portland (RM 12.7) during 1997.

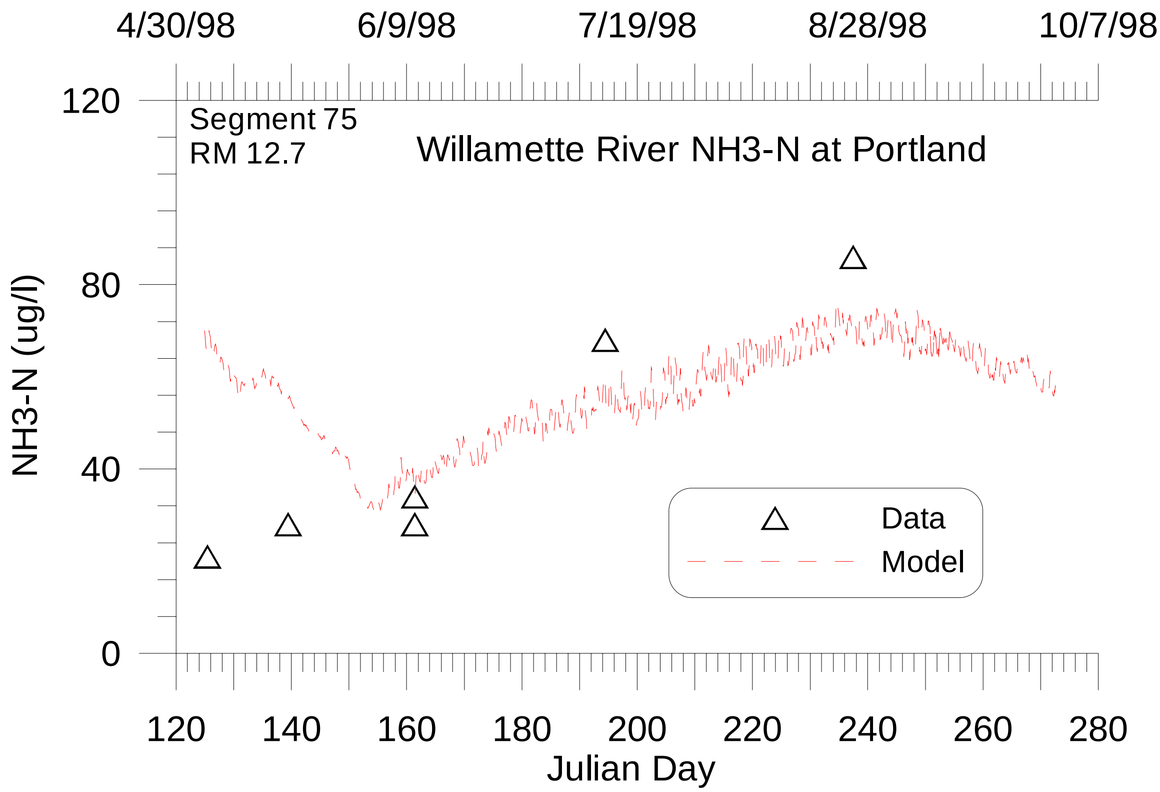


Figure 73. Comparison between model predicted ammonia-nitrogen concentrations and data for the Willamette River at Portland (RM 12.7) during 1998.

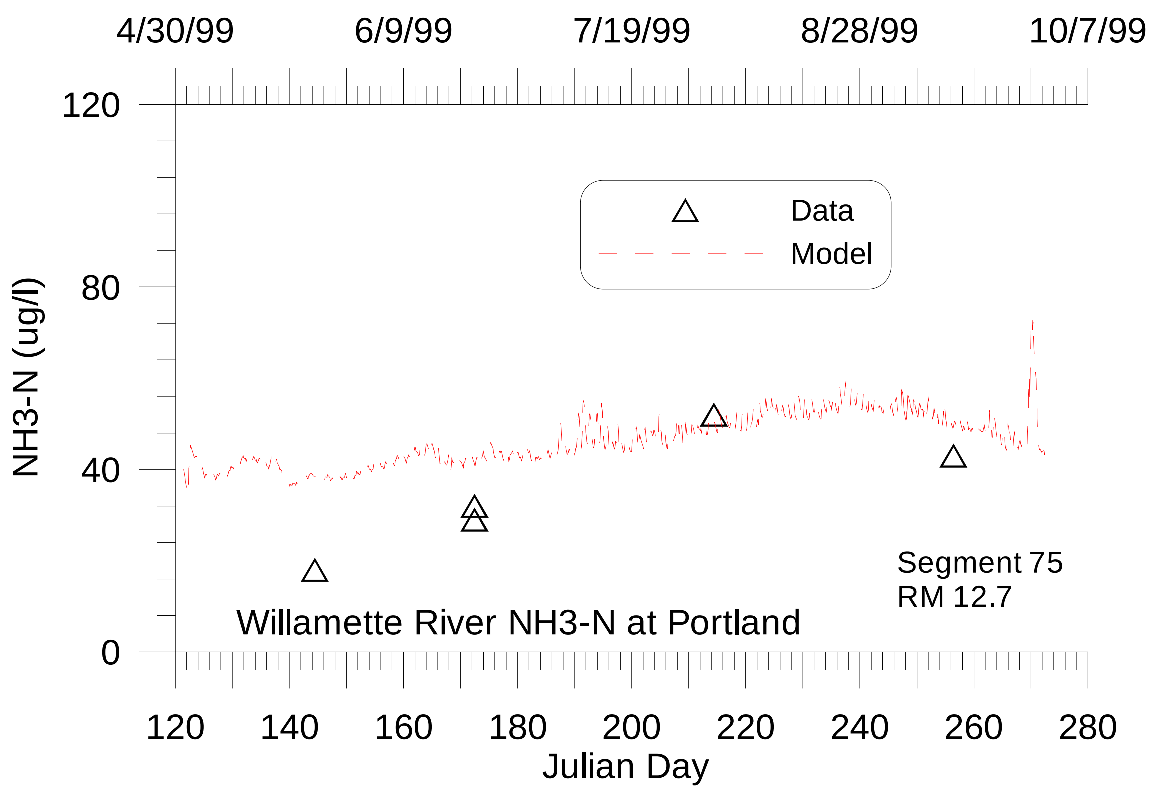


Figure 74. Comparison between model predicted ammonia-nitrogen concentrations and data for the Willamette River at Portland (RM 12.7) during 1999.

Nitrate & Nitrite-Nitrogen

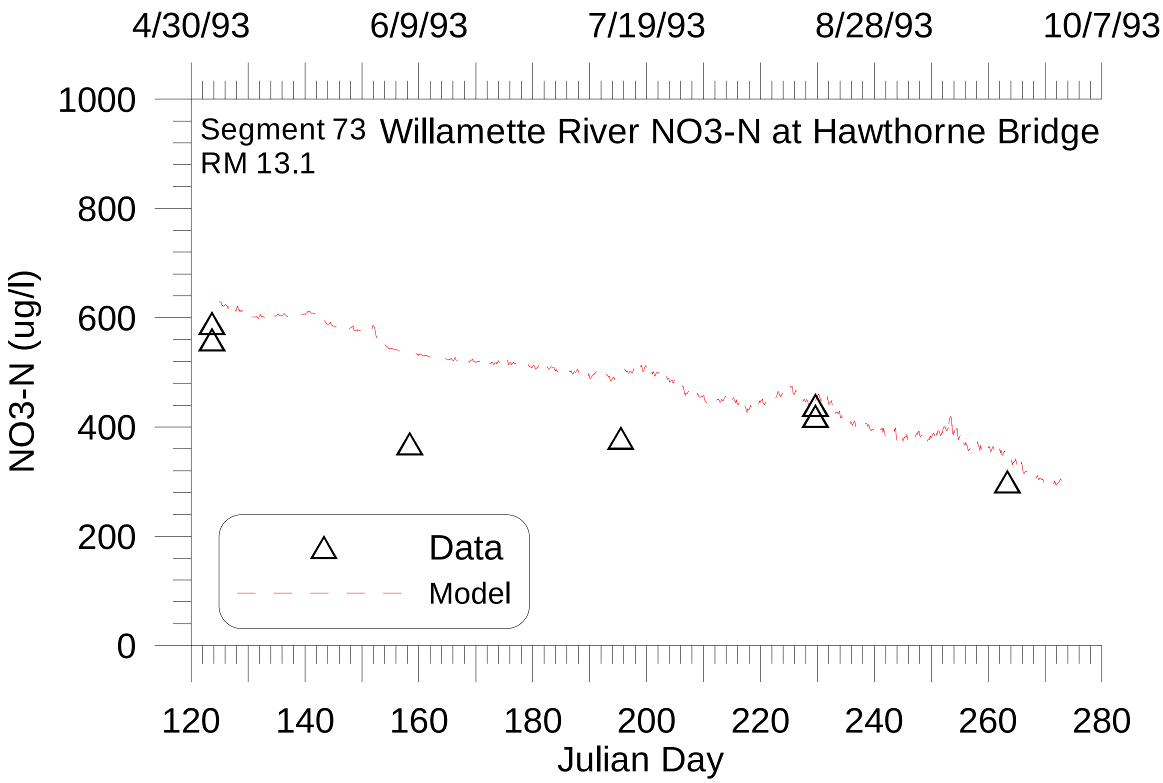
Comparisons of model predictions and grab sample field data of NO_3+NO_2-N in 1993, 1997, and 1998 and 1999 at Hawthorne Bridge (RM 13.1) at Portland (RM 12.7) are shown in Figure 75, Figure 76, and Figure 77, respectively.

Comparisons of model predictions and grab sample field data of NO_3+NO_2-N in 1999 at Portland (RM 12.7) are shown in Figure 78.

Model prediction errors are shown in Table 20.

Table 20. Model - data errors in NO_3-N +NO_2-N for the Willamette River between 1993 and 1999.

Year	Location	NO_3-N +NO_2-N model-data error		
		n, # of data comparisons	AME, ug/L	RMS, ug/L
1993	RM 20.0 Segment #45	9	239.3	316.0
1993	RM 13.1 Segment #73	7	68.1	84.6
1994		8	85.6	115.2
1997		5	153.8	161.5
1998		6	100.3	123.5
1993	RM 12.7 Segment #75	5	125.0	150.9
1994		6	87.8	102.9
1997		5	187.5	197.3
1998		5	234.0	248.5
1999		5	68.1	79.3
1993	RM 6.8 Segment #92	9	197.7	233.1
1993	RM 1.1 Segment #105	9	187.7	225.0



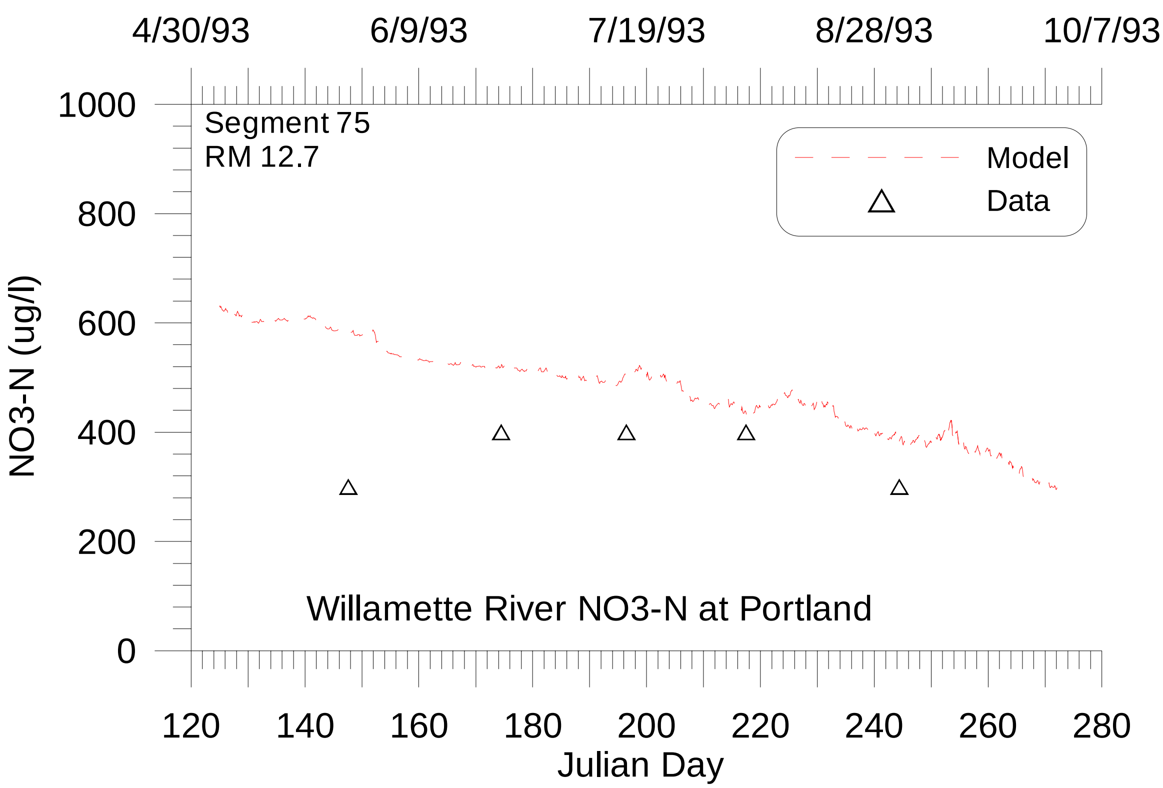
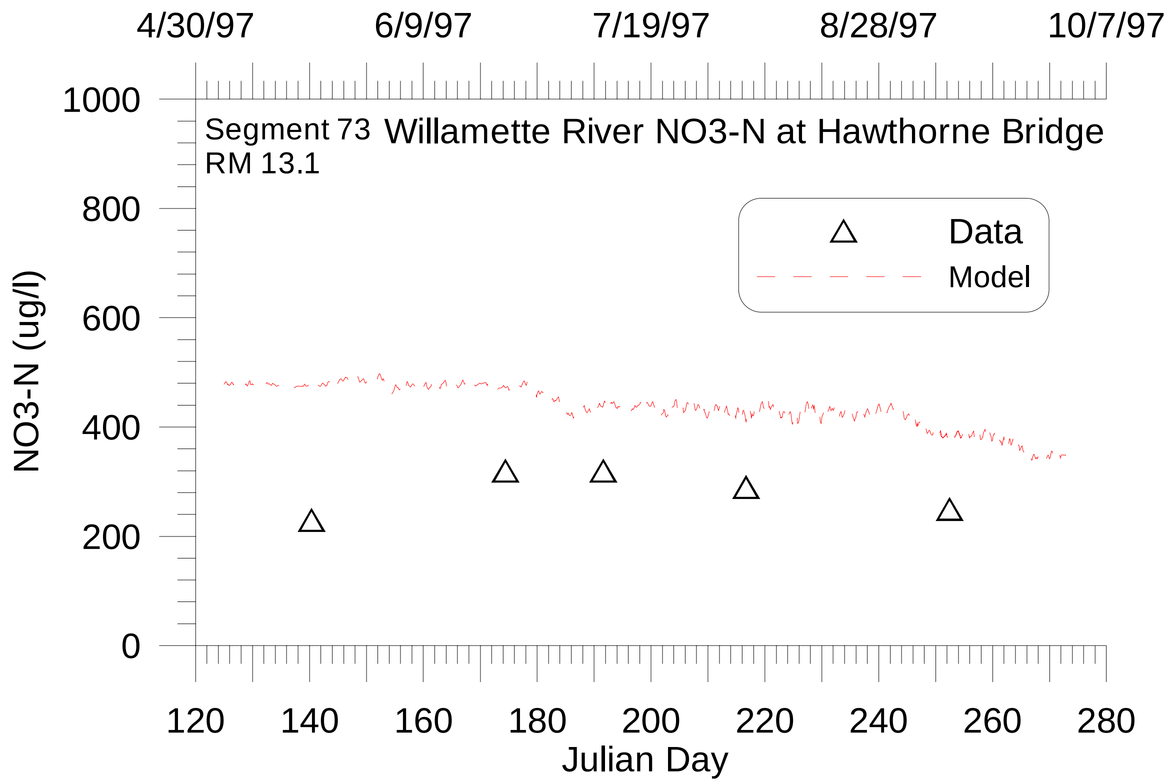


Figure 75. Comparison between model predicted nitrate+nitrite nitrogen concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1993.



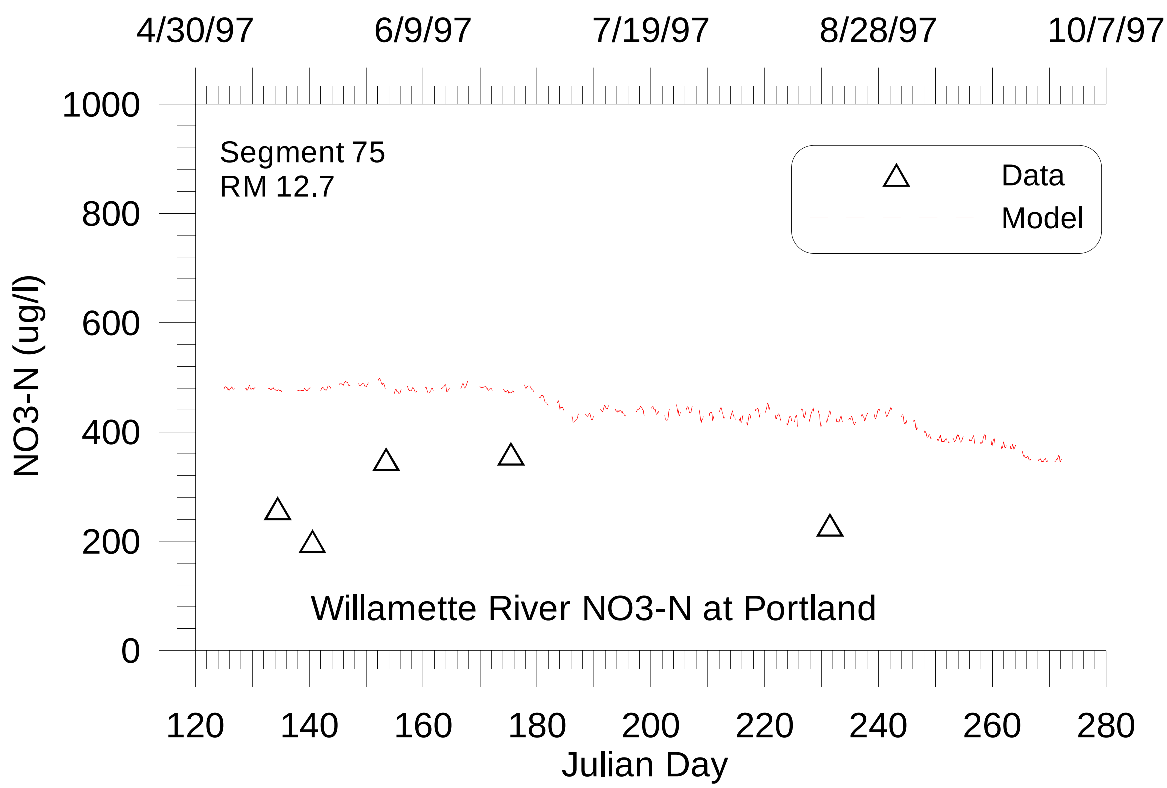


Figure 76. Comparison between model predicted nitrate+nitrite nitrogen concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1997.

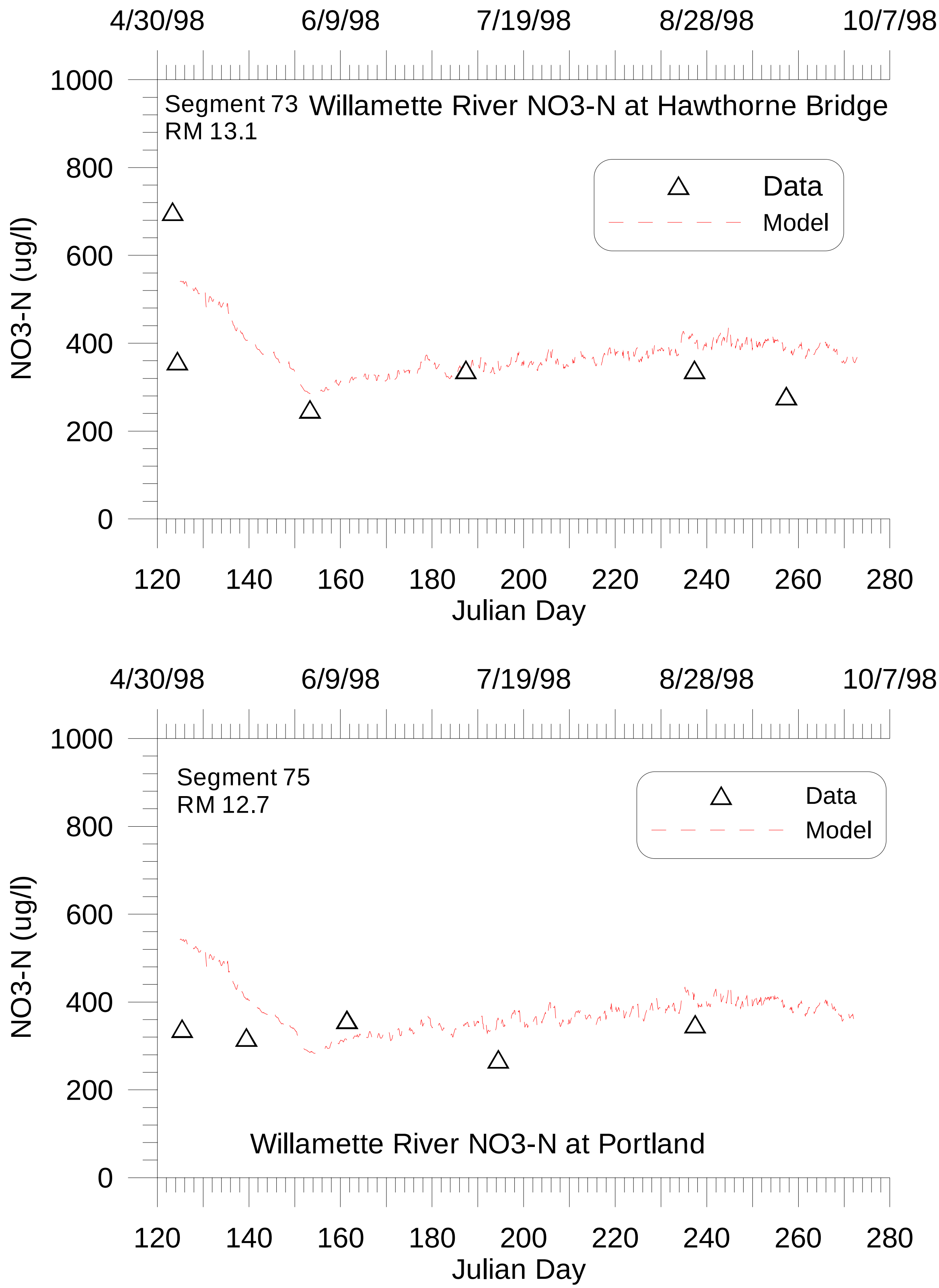


Figure 77. Comparison between model predicted nitrate+nitrite nitrogen concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1998.

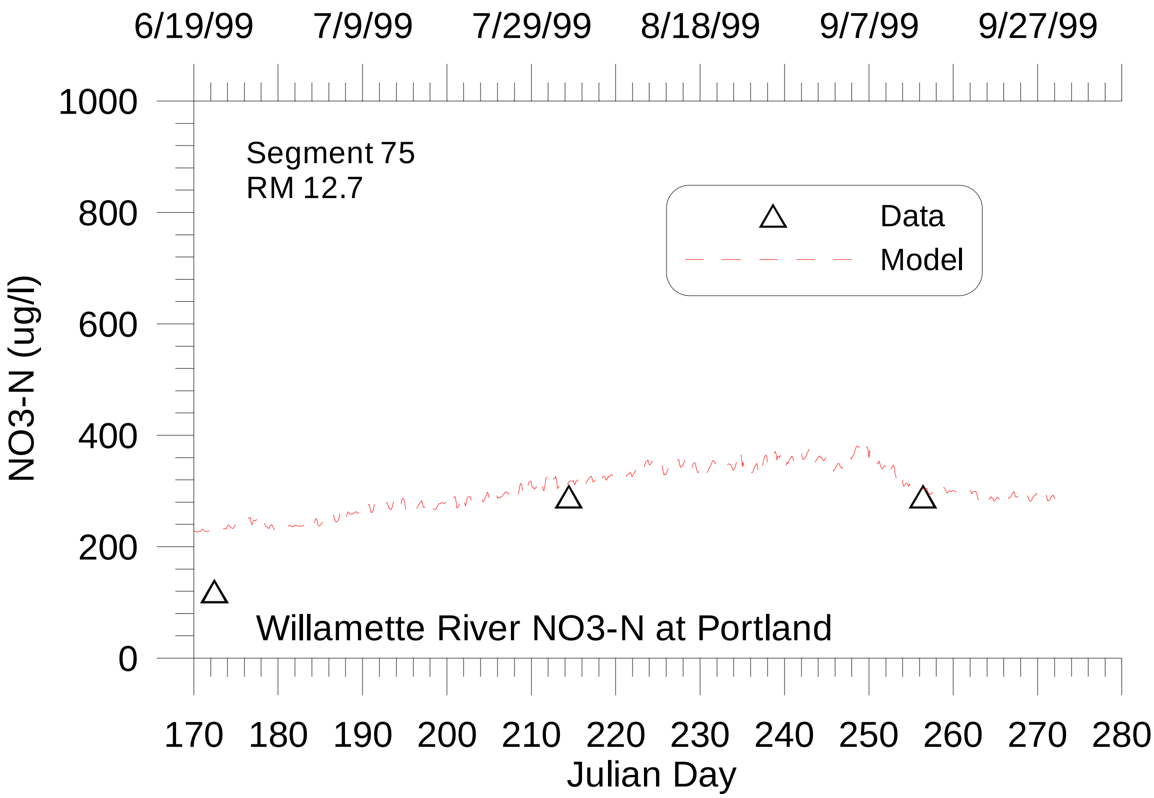


Figure 78. Comparison between model predicted nitrate+nitrite nitrogen concentrations and data for the Willamette River at Portland (RM 12.7).

Total Kjeldahl Nitrogen

TKN is not a state variable of CE-QUAL-W2 but is computed by summing up N in the following state variables: NH_4-N, algae, dissolved and particulate organic matter.

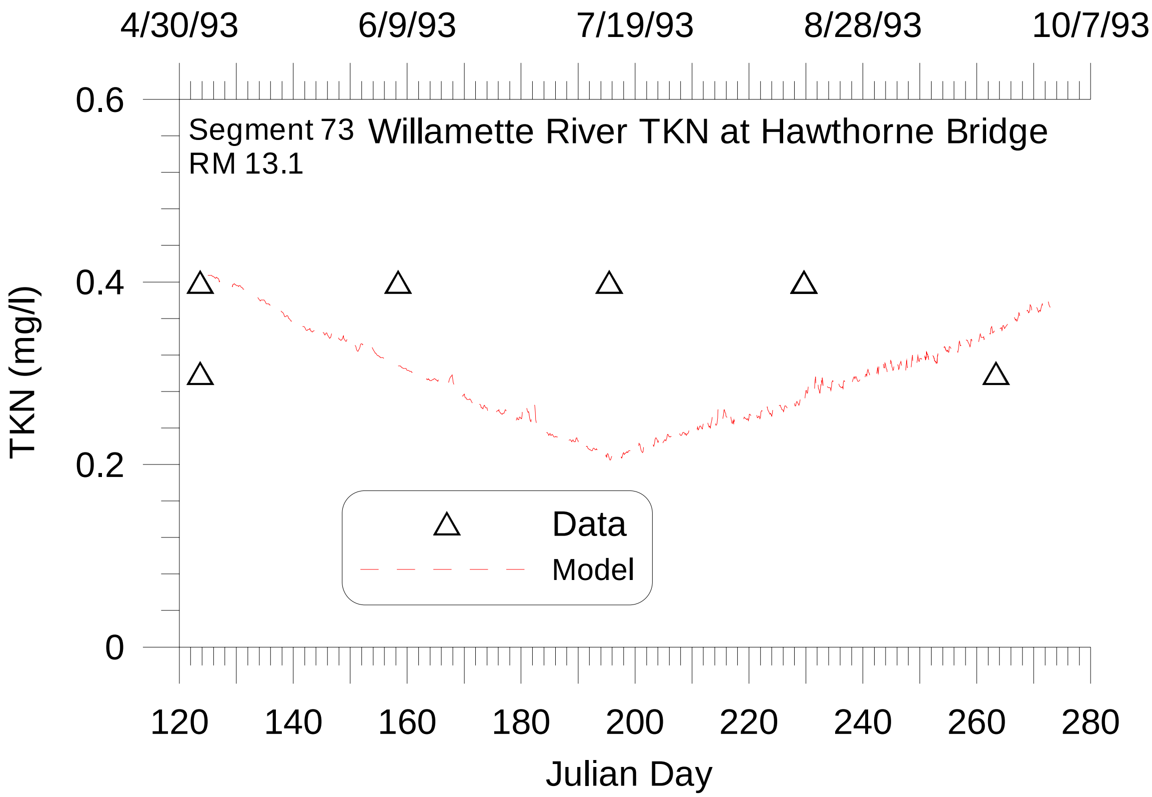
Comparisons of model predictions and grab sample field data of TKN in 1993, 1994, 1997 and 1998 at Hawthorne Bridge (RM 13.1) at Portland (RM 12.7) are shown in Figure 79, Figure 80, Figure 81, and Figure 82, respectively.

Model prediction errors are shown in Table 21.

Table 21. Model - data errors in TKN for the Willamette River between 1993 and 1998.

Year	Location	TKN model-data error		
		n, # of data comparisons	AME, mg/L	RMS, mg/L
1993	RM 13.1 Segment #73	7	0.10	0.12
1994		8	0.07	0.09
1997		5	0.12	0.13
1998		6	0.06	0.07
1993	RM 12.7 Segment	5	0.09	0.09
1994		6	0.12	0.13

1997	#75	5	0.03	0.03
1998		5	0.07	0.10
1999		5	0.09	0.11



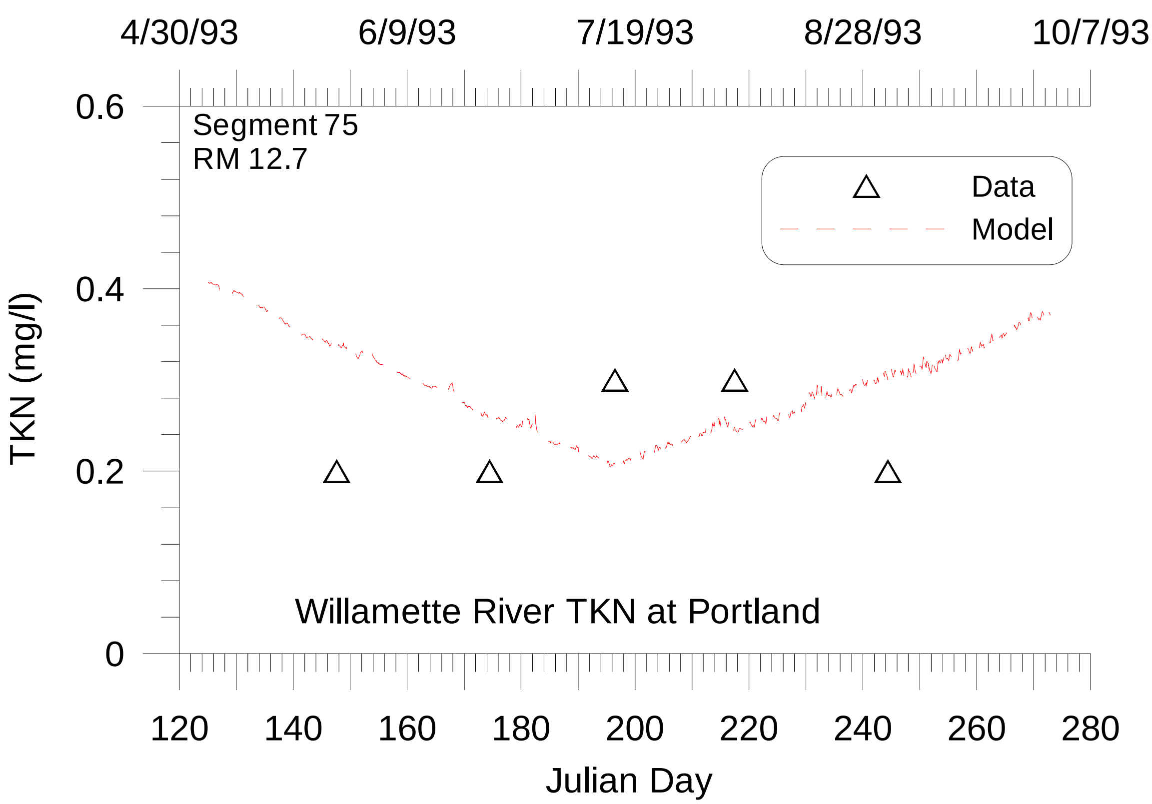


Figure 79. Comparison between model predicted total Kjeldahl nitrogen concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1993.

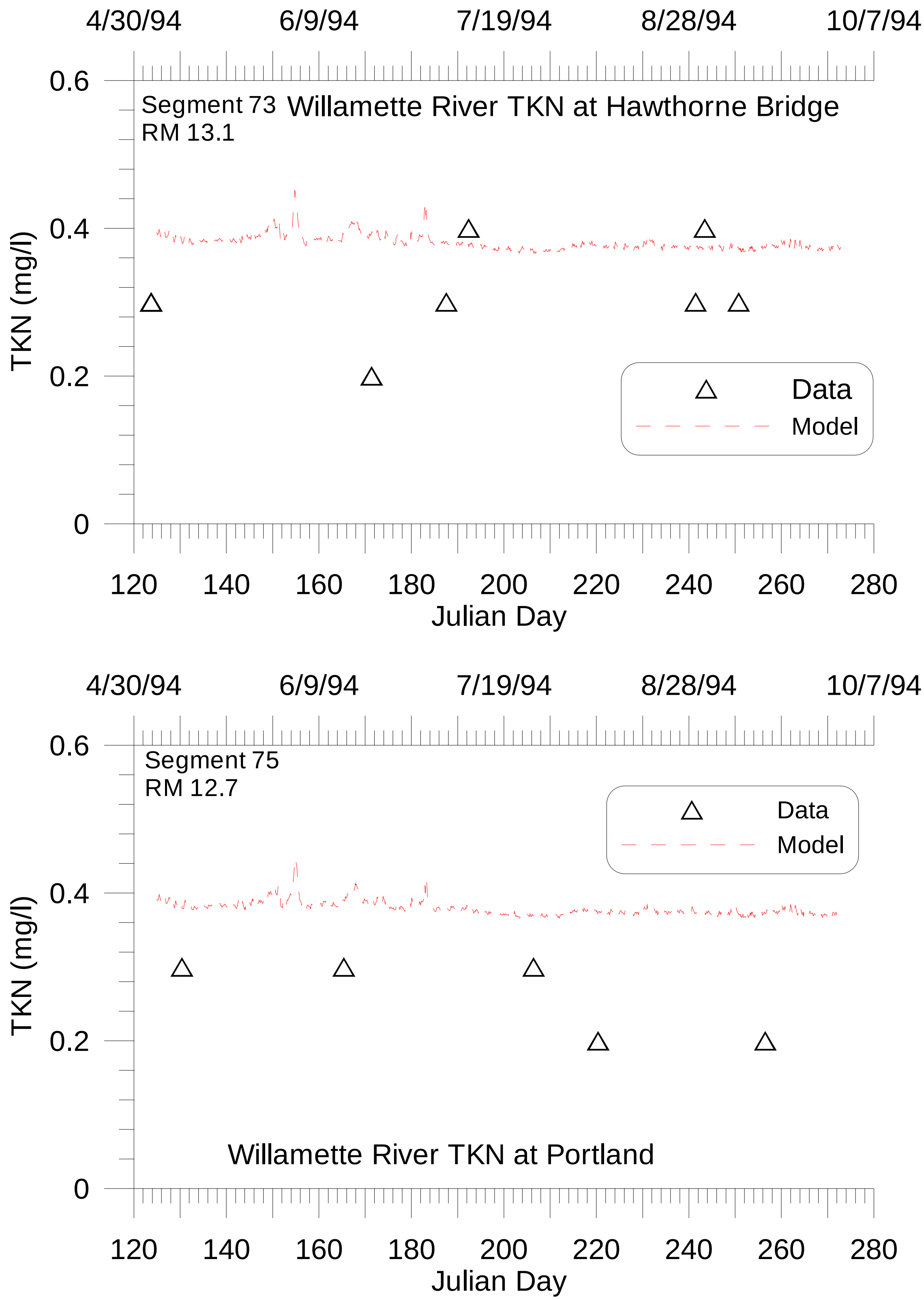


Figure 80. Comparison between model predicted total Kjeldahl nitrogen concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1994.

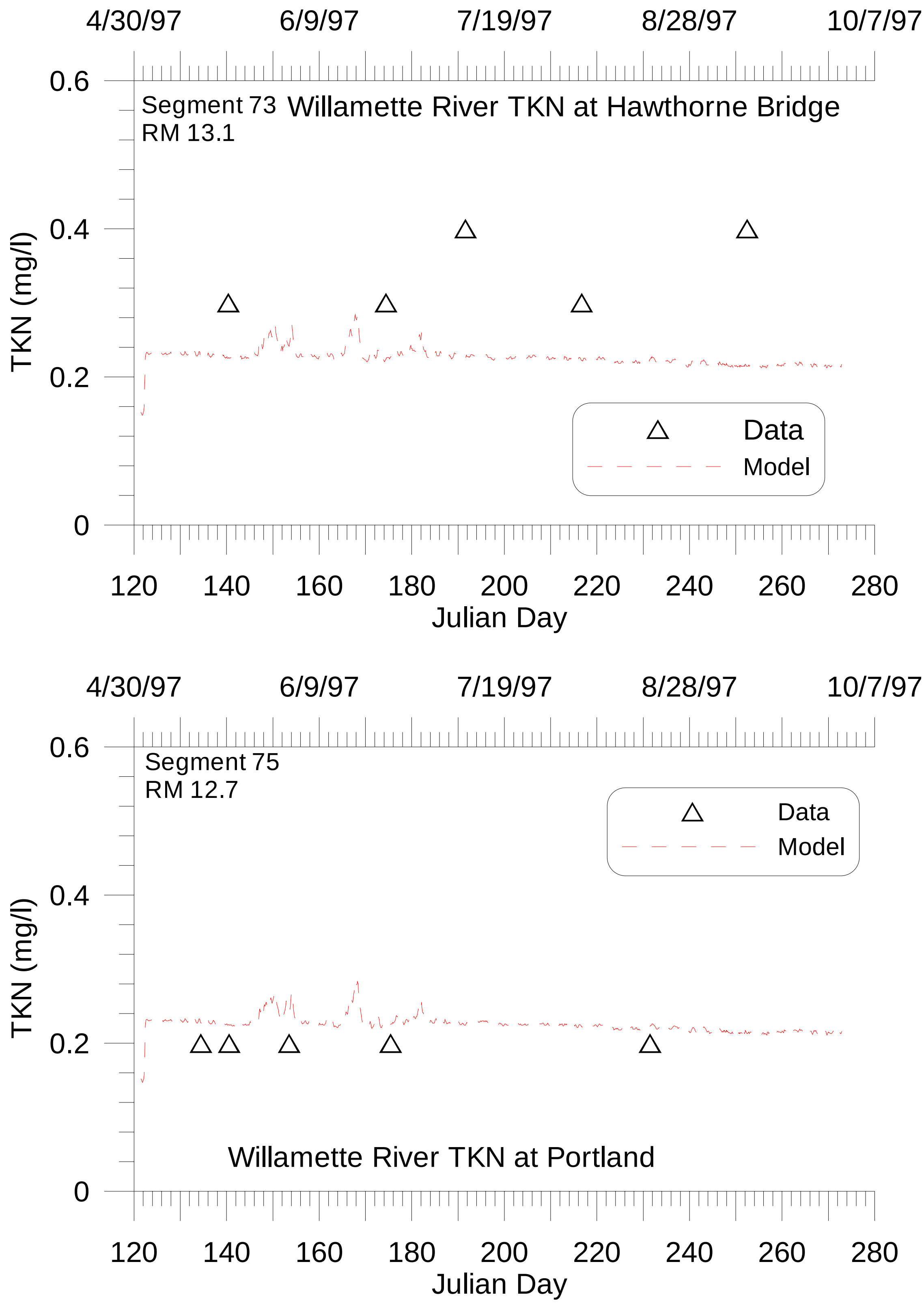
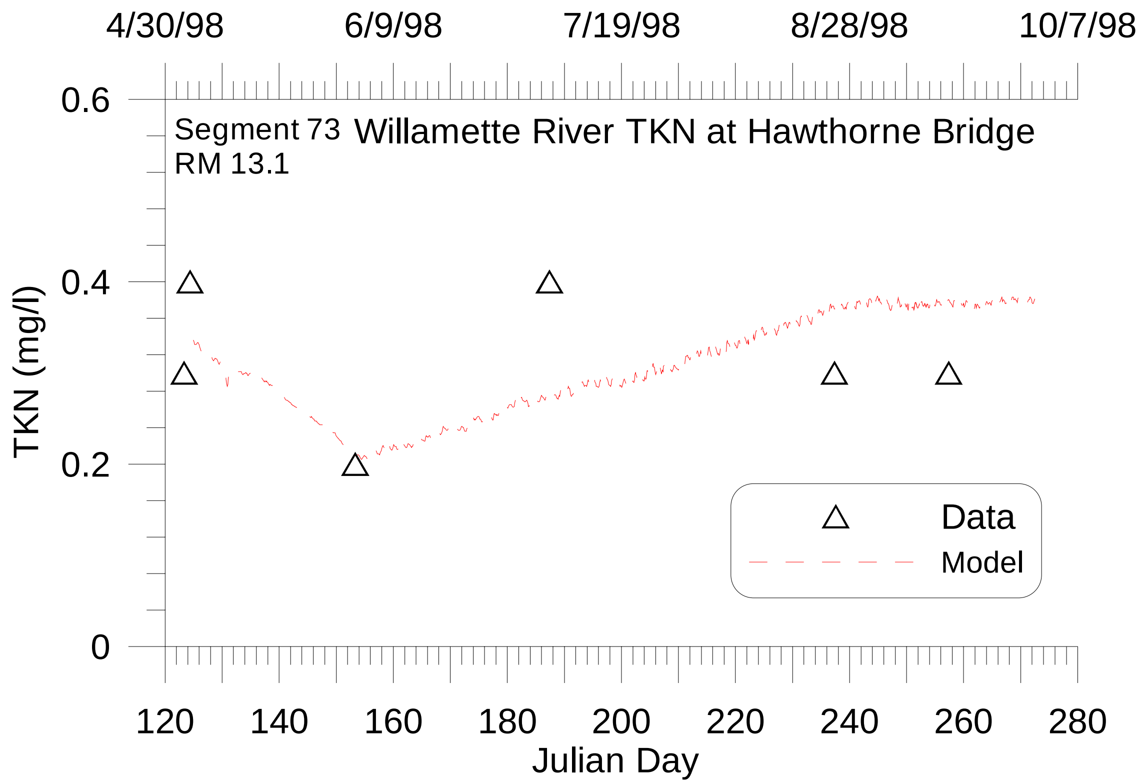


Figure 81. Comparison between model predicted total Kjeldahl nitrogen concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1997.



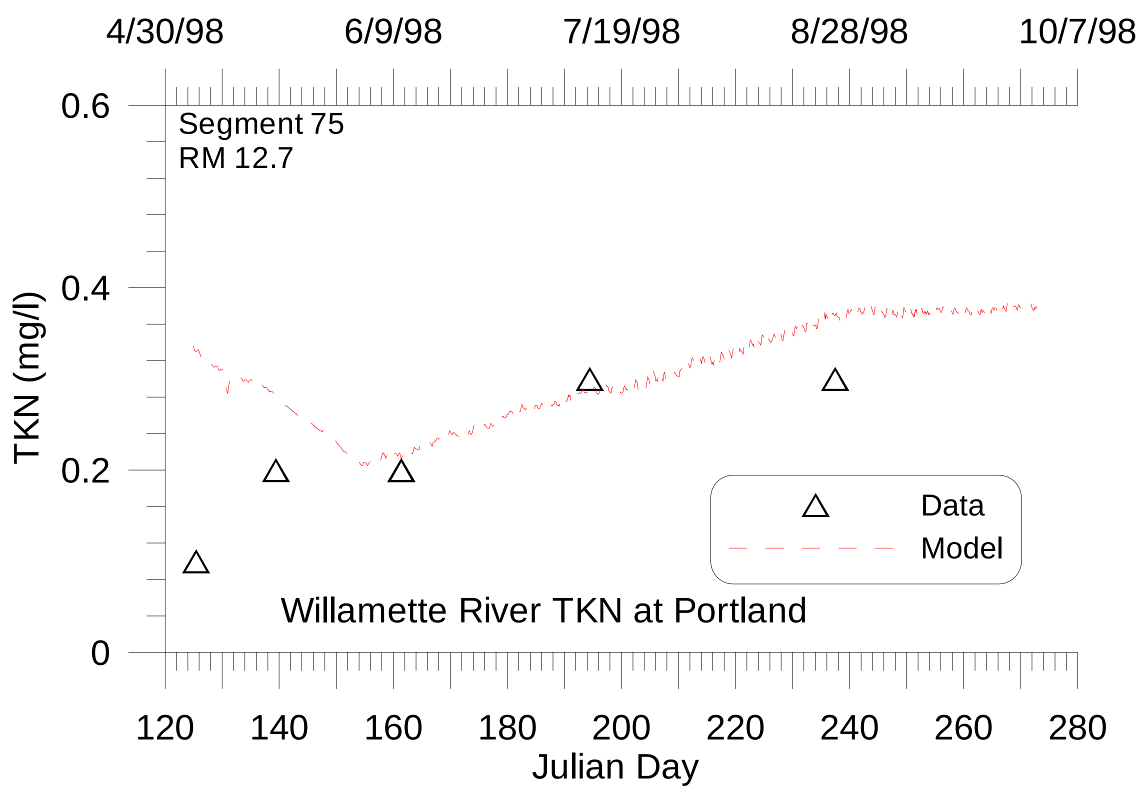


Figure 82. Comparison between model predicted total Kjeldahl nitrogen concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and at Portland (RM 12.7) during 1998.

Organic Carbon

Total Organic Carbon (TOC) is not a state variable of CE-QUAL-W2 but is computed by summing up C in the following state variables: algae, dissolved and particulate organic matter. Dissolved Organic Carbon (DOC) is also not a state variable of CE-QUAL-W2 but is computed by summing up C in dissolved organic matter (both labile and refractory).

Comparisons of model predictions and grab sample field data of TOC at the Hawthorne Bridge (RM 13.1) and grab sample DOC at Portland (RM 12.7) in 1993, 1994, 1997 and 1998 are shown in Figure 83, Figure 84, Figure 85, and Figure 86, respectively.

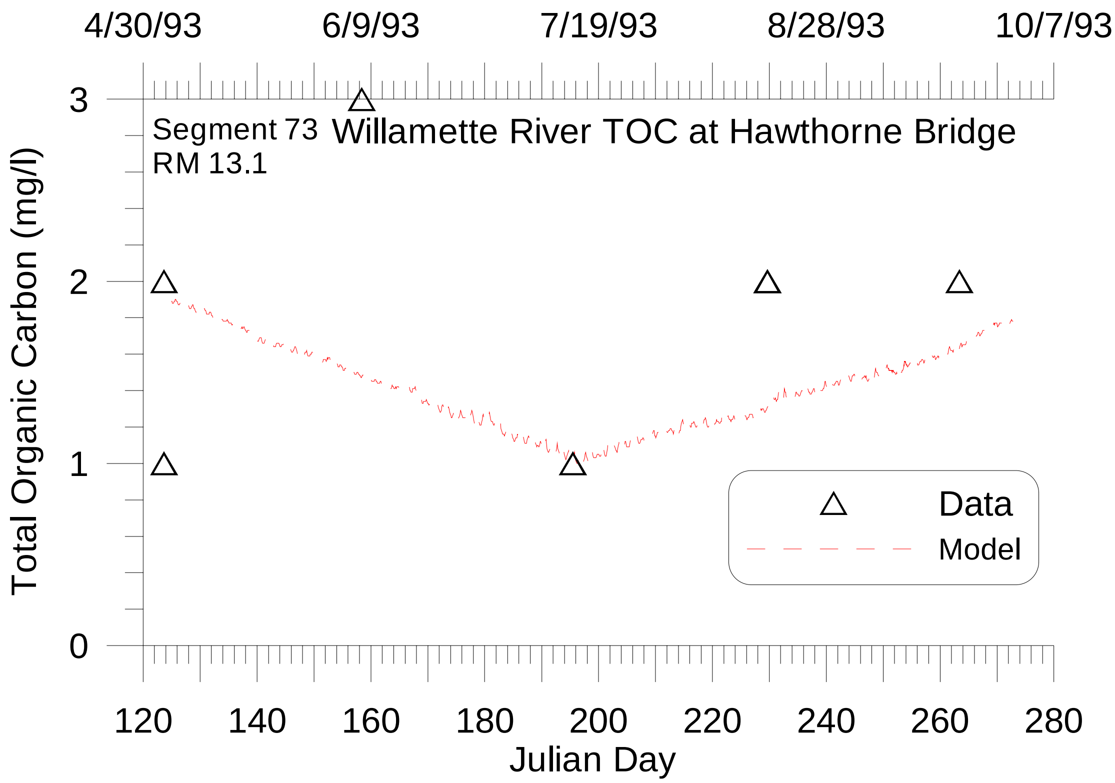
Comparisons of model predictions and grab sample field data of DOC at Portland (RM 12.7) in 1999 are shown in Figure 87.

Model prediction errors are shown in Table 22.

Table 22. Model - data errors in TOC and DOC for the Willamette River between 1993 and 1999.

Year	Location	Total Organic Carbon model-data error		
		n, # of data comparisons	AME, mg/L	RMS, mg/L
1993	RM 13.1 Segment #73	7	0.62	0.78
1994		8	0.47	0.62
1997		5	0.29	0.44
1998		6	0.67	0.91
1993	RM 12.7 Segment #75	5	0.65	0.69
1994		4	0.48	0.61
1997		5	0.69	0.75
1998		6	0.55	0.57
1999		5	0.29	0.34

Year	Location	Dissolved Organic Carbon model-data error		
		n, # of data comparisons	AME, mg/L	RMS, mg/L
1993	RM 12.7 Segment #75	5	0.45	0.48
1994		4	0.30	0.48
1997		5	0.45	0.48
1998		6	0.39	0.41
1999		5	0.27	0.27



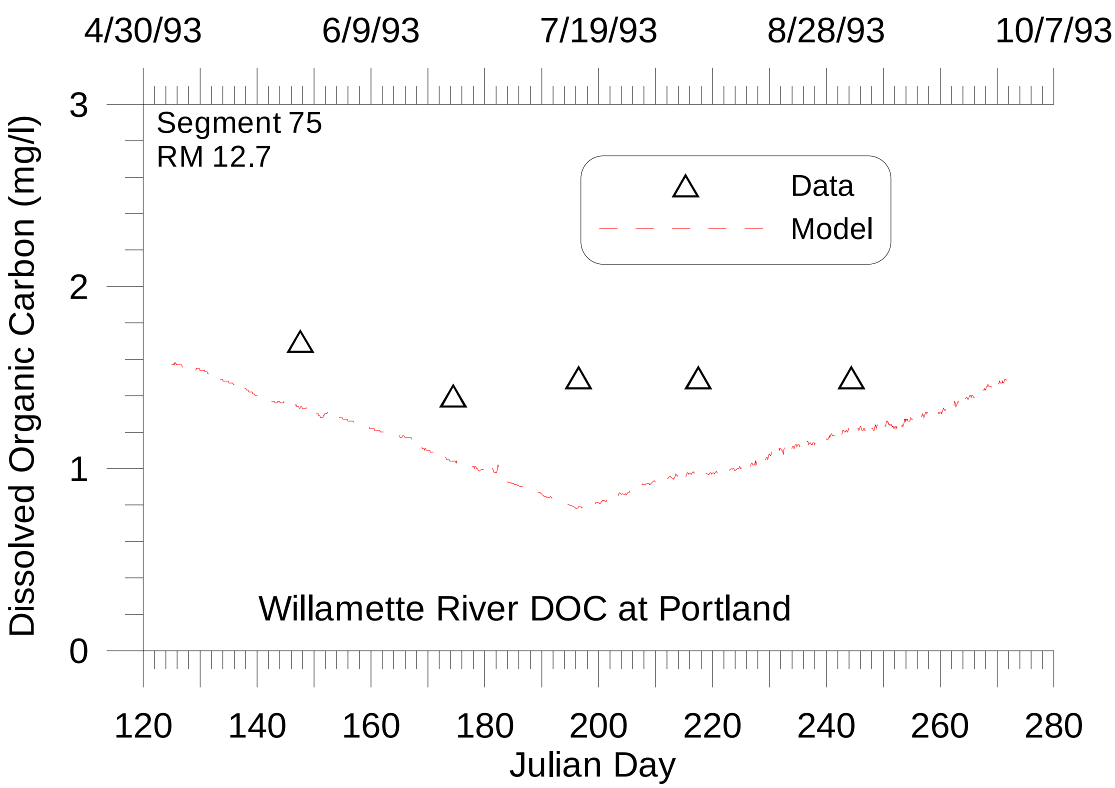


Figure 83. A comparison between model predicted total organic carbon concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and a comparison between dissolved organic carbon concentrations and data at Portland (RM 12.7) during 1993.

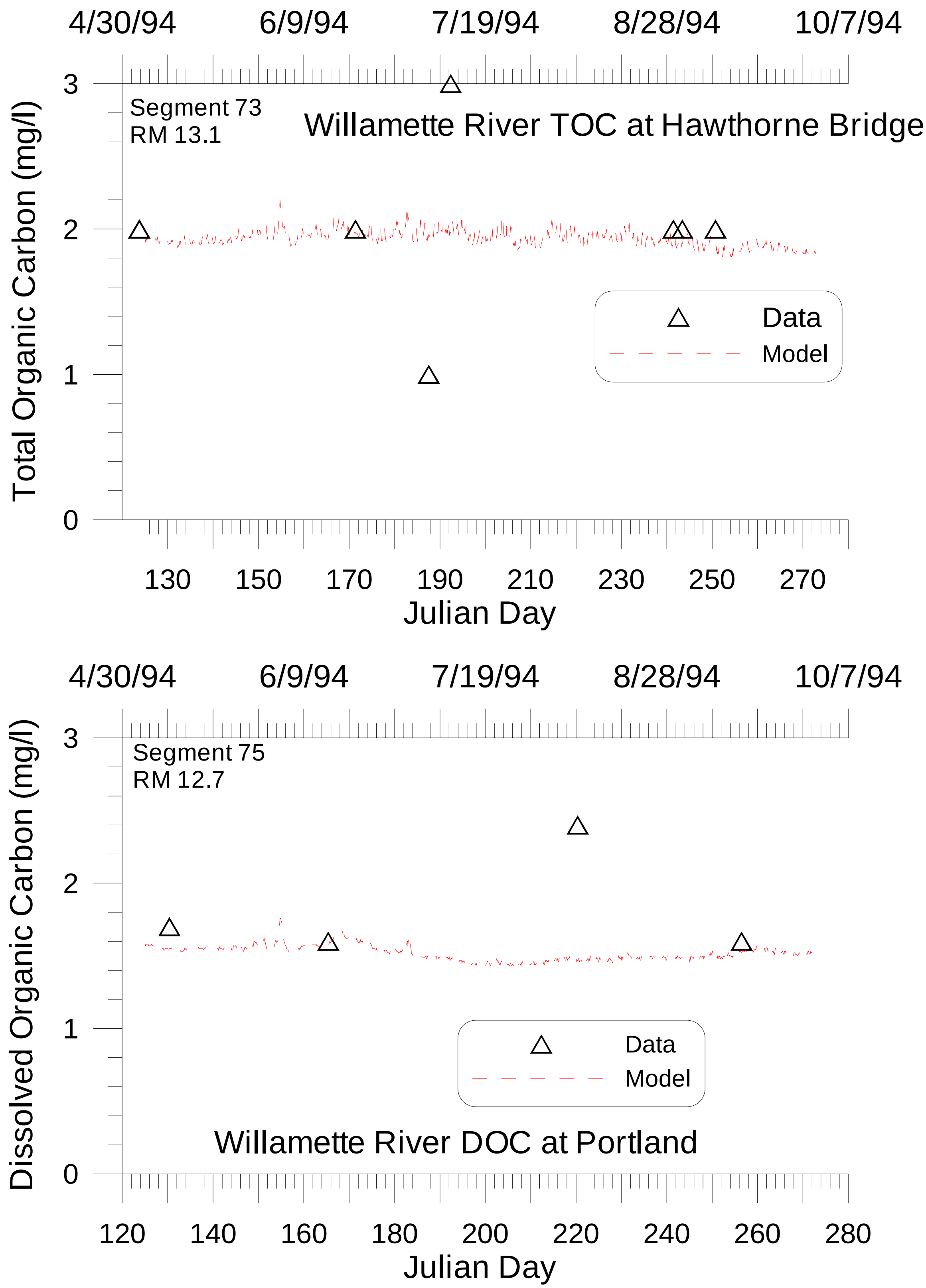
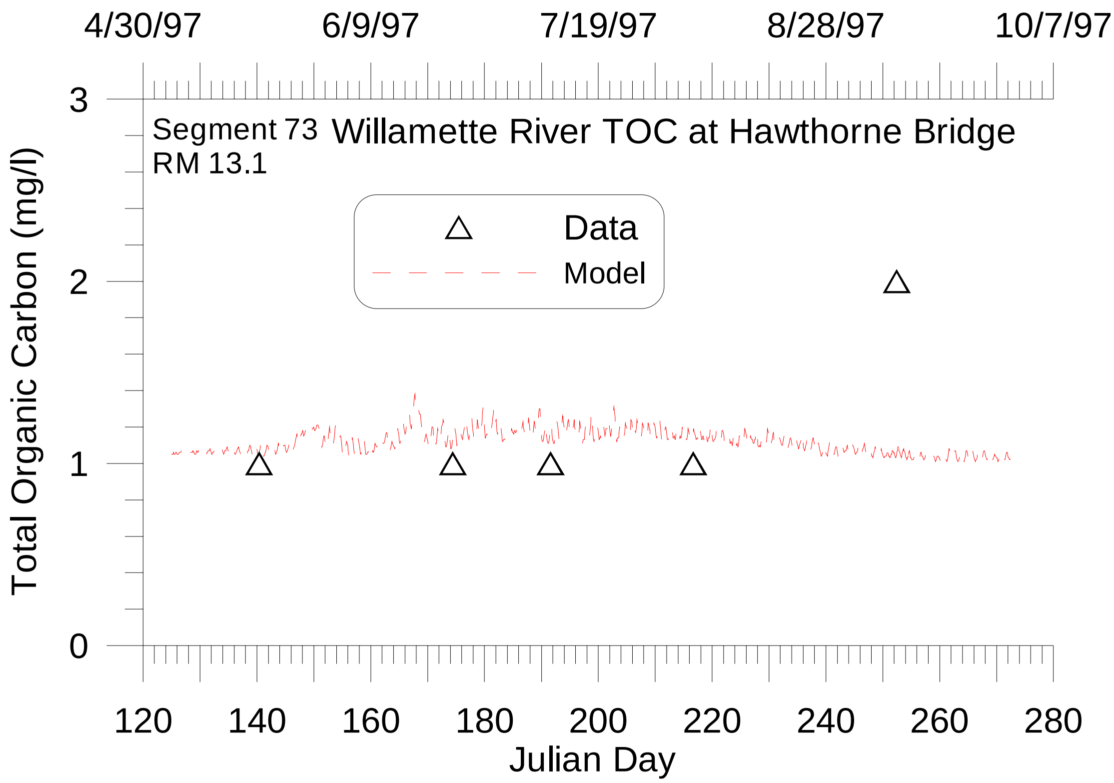


Figure 84. A comparison between model predicted total organic carbon concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and a comparison between dissolved organic carbon concentrations and data at Portland (RM 12.7) during 1994.



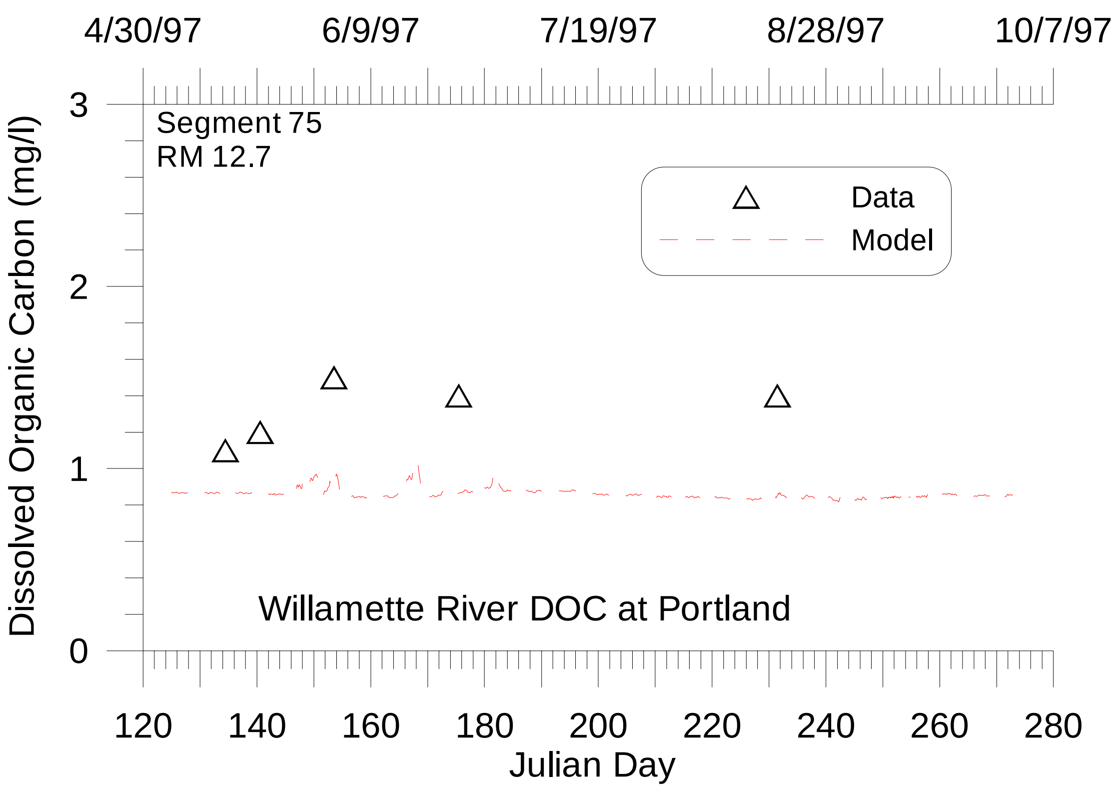
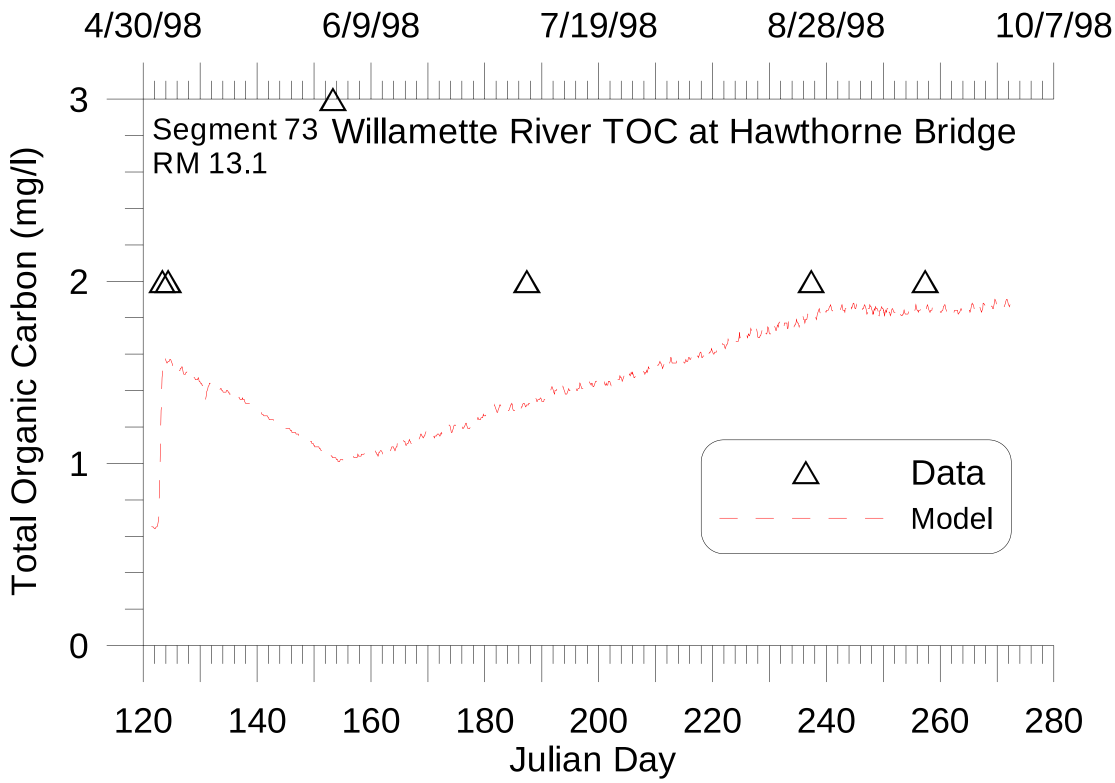


Figure 85. A comparison between model predicted total organic carbon concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and a comparison between dissolved organic carbon concentrations and data at Portland (RM 12.7) during 1997.



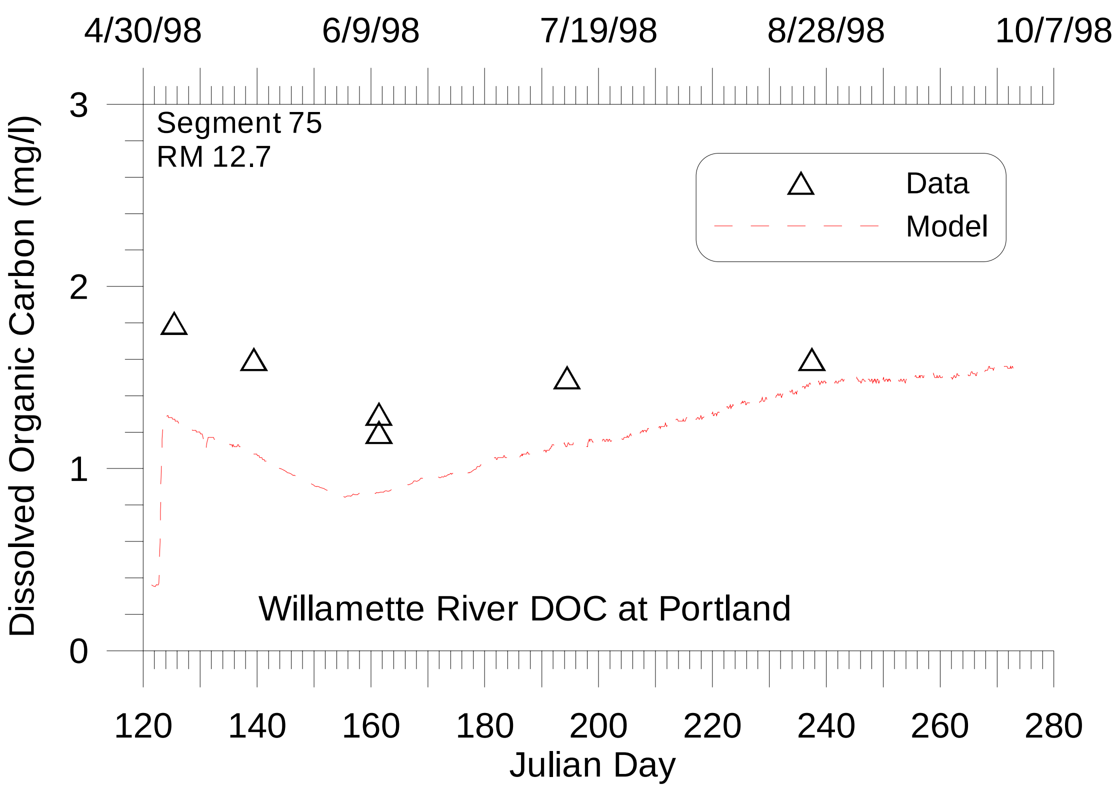


Figure 86. A comparison between model predicted total organic carbon concentrations and data for the Willamette River at Hawthorne Bridge (RM 13.1) and a comparison between dissolved organic carbon concentrations and data at Portland (RM 12.7) during 1998.

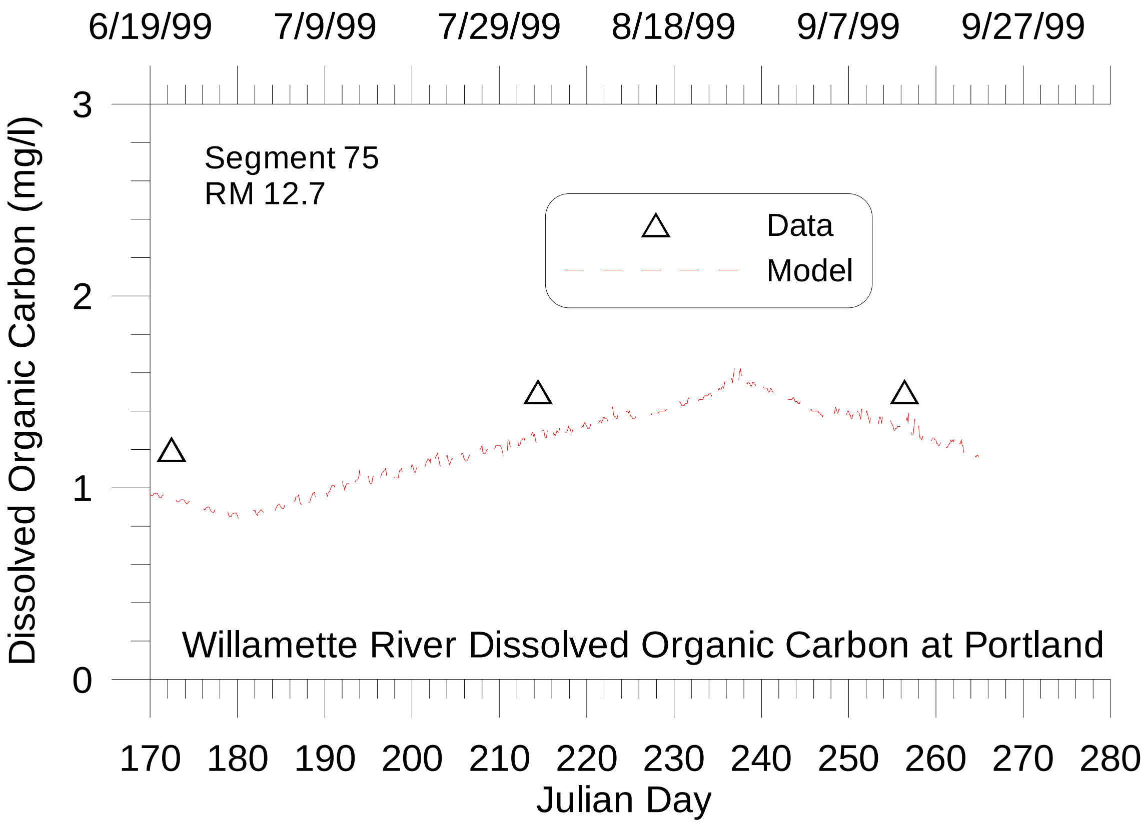


Figure 87. A comparison between dissolved organic carbon concentrations and data at Portland (RM 12.7) during 1999.

Columbia River

Sites along the Columbia River where water quality data exist is shown in Table 23. Several of these sites where used to compare model predictions to field data for dissolved oxygen and chlorophyll a. Since the main interest in this modeling study were water quality conditions in the Willamette River, these comparisons were made just to check the overall model predictive ability in the Columbia. The Columbia was modeled primarily to provide the proper flow and tidal height conditions for the Willamette River.

Table 23. Columbia River water quality calibration sites

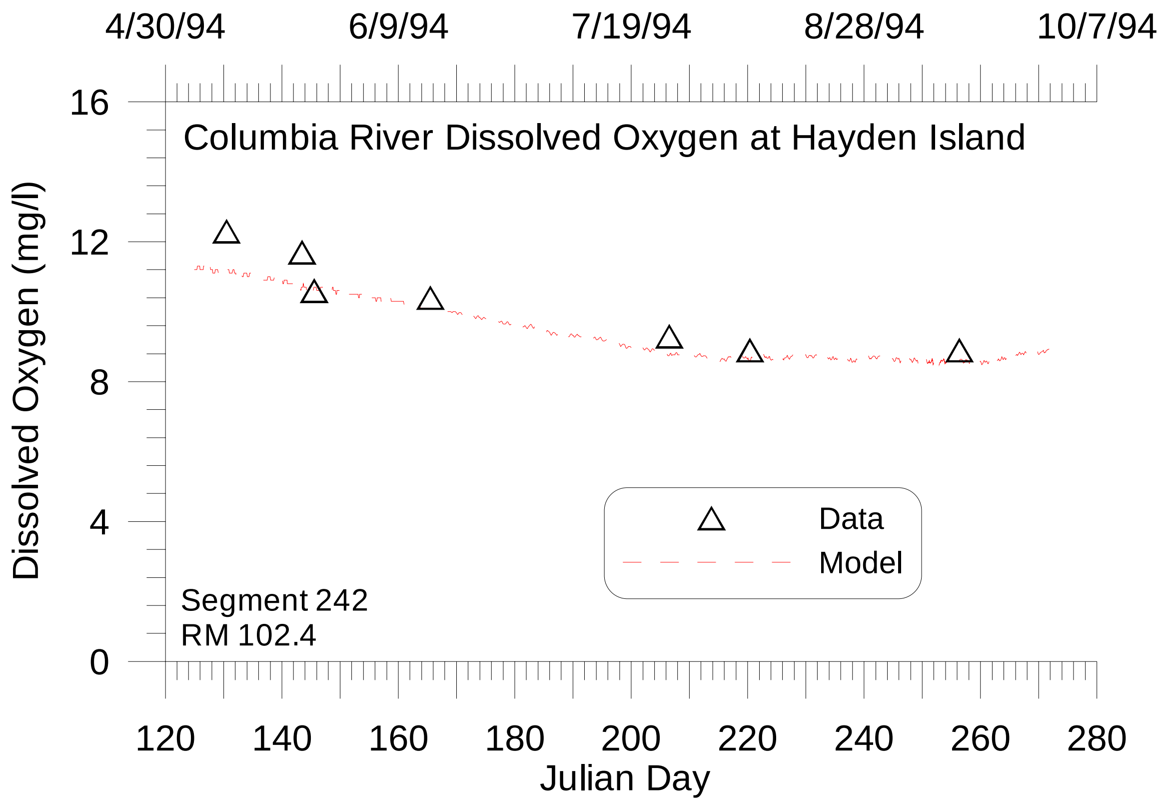
Site ID	Site Description	River mile	Model Segment	Data Type
ORSTORET	Columbia River near Columbia City, OR	82.0	288	Grab samples
ORSTORET	Columbia River, RM 102 DS of Hayden Island, OR	102.4	242	Grab samples

<u>Dissolved Oxygen</u>

Comparisons of model predictions and field data of dissolved oxygen at Hayden Island (Columbia River Mile 102.4) and at Columbia City, OR (RM 82.0) for 1994 are shown in Figure 88.

Chlorophyll a

Comparisons of model predictions and field data of chlorophyll a at Hayden Island (Columbia River Mile 102.4) and at Columbia City, OR (RM 82.0) for 1994 are shown in Figure 89.



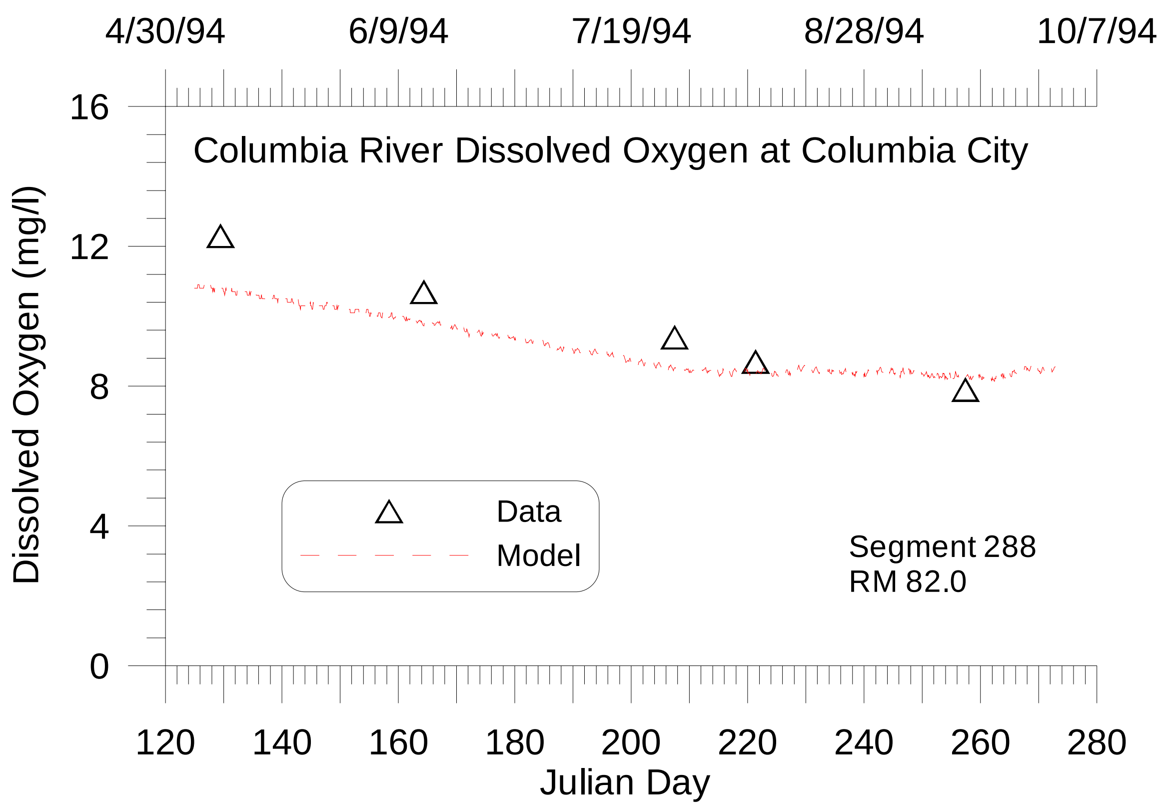
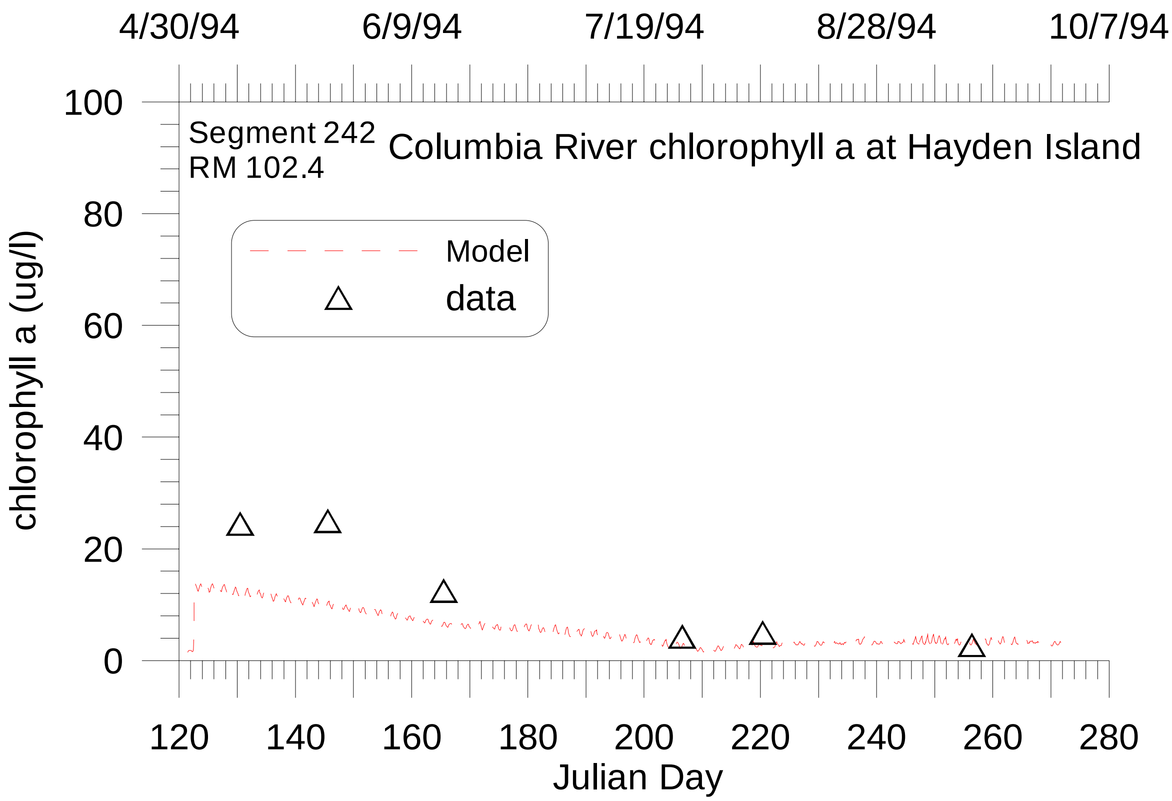


Figure 88. Comparison between model predicted dissolved oxygen concentrations and data for Columbia River at Hayden Island (RM 102.4) and at Columbia City, OR (RM 82.0) during 1994.



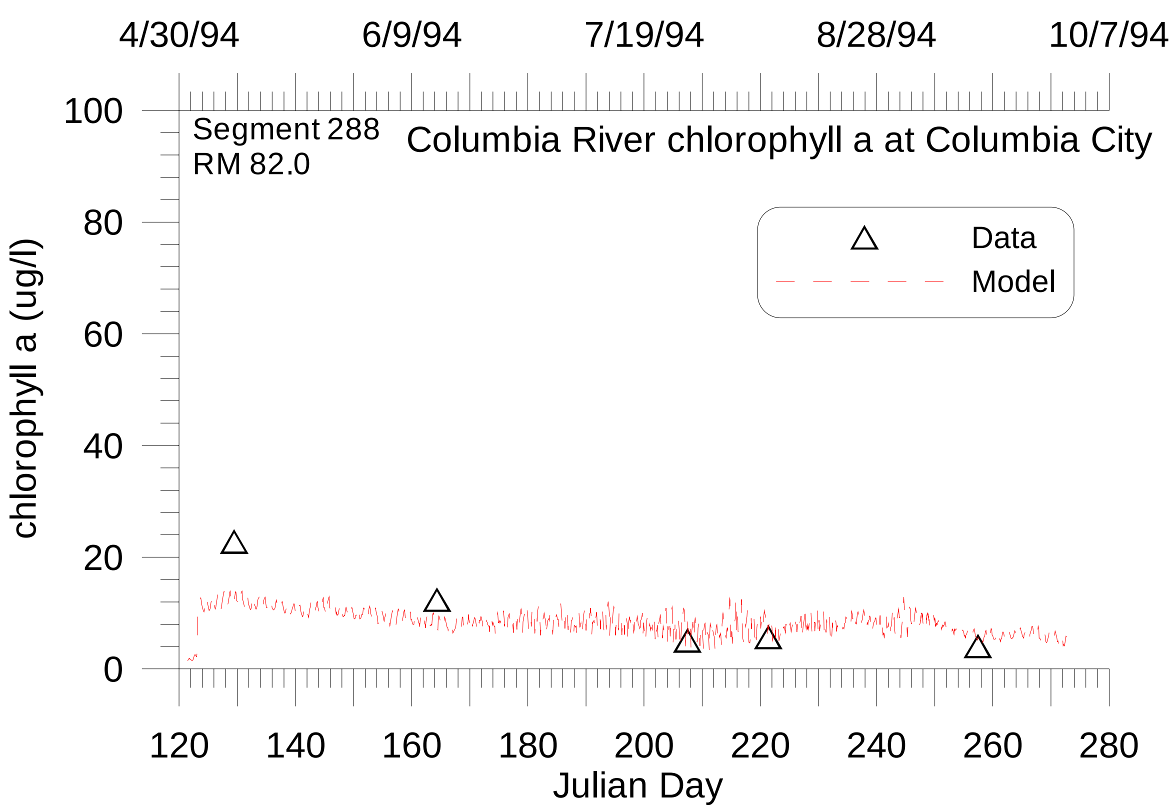


Figure 89. Comparison between model predicted chlorophyll a concentrations and data for Columbia River at Hayden Island (RM 102.4) and at Columbia City, OR (RM 82.0) during 1994.

Previous modeling work Compared with CE-QUAL-W2

Because earlier modeling studies using the 1-D hydrodynamic model DYNHYD and the 1-D steady-state model QUAL2EU were preformed during the same calibration period as the CE-QUAL-W2 modeling studies, it was deemed instructive to compare model predictions by CE-QUAL-W2 with those of the earlier studies. Comparisons of model predictions to field data are shown below for flow rates and dissolved oxygen and chlorophyll a concentrations.

DYNHYD model

An investigation of the Lower Willamette and the tidal influence on the combined sewer overflow (CSO) area was conducted by Limno-Tech, Inc. using DYNHYD for the City of Portland, Bureau of Environmental Services (Limno-Tech, Inc., 1997). DYNHYD (Ambrose et al. 1988) is a one-dimensional, unsteady hydraulic model with no water quality modeling capabilities. This study also investigated the magnitude of flows through Multnomah Channel. Unfortunately, in order to calibrate the flow model, the location of the Oregon City Falls was moved 75 miles upstream and the location of the Bonneville Dam was also moved 39 miles upstream. Moving the head of tide for both the Willamette and Columbia Rivers, even though they improved model-data agreement, was not appropriate and reflected more serious errors in the model set-up, probably in the DYNHYD model bathymetry.

DYNHYD results were compared with flow data in the Willamette River at the Morrison St Bridge (Figure 3, pg 16, Limno-Tech, Inc., 1997) in June 1994. Flow data was recorded at the USGS gage station #14211720 at the Morrison St Bridge for June 1994 except for a few data gaps. Flow rate errors (model – field data) were compared between the DYNHYD model flow results from the Tetra Tech Report Figure 3 and CE-QUAL-W2 model results in Figure 90. The average error in flow for the DYNHYD model was 15.3 m^3/s and for CE-QUAL-W2 was –7.0 m^3/s.

QUAL2EU model

A water quality model of the Willamette River mainstem (RM 0 to 187) was developed by Tetra Tech, Inc. (Tetra Tech, Inc., 1995) using QUAL2EU for the Oregon Department of Environmental Quality (ODEQ). QUAL2EU (Brown and Barnwell, 1987) is a one-dimensional, steady state, hydraulic and water quality model.

The QUA2E steady-state model results were compared to field data from August 1994. It was not clear though from the Tetra-Tech Report how the field data were averaged or used to compare to steady-state model predictions. The work compared dissolved oxygen and chlorophyll a model longitudinal profile results with data collected by ODEQ and USGS. Model results from QUAL2EU were obtained from Figure 2-2, pg. 2-11 (Tetra Tech, Inc., 1995). In examining the ODEQ data presented in the plot, it was determined that the dissolved oxygen data were collected by ODEQ on August 31, 1994. The chlorophyll a data were collected by ODEQ on August 29, and August 31. The data collected by USGS and presented in Figure 2-2 were collected upstream of the model boundary condition on the Willamette River at RM 35.0. Figure 91 compares the QUAL2EU and CE-QUAL-W2 model results with ODEQ data collected for dissolved oxygen. Figure 92 compares the two model results with ODEQ data for chlorophyll a on August 31, 1994. The CE-QUAL-W2 model results represent an average for results from 10 am to noon on August 31, 1994. The QUAL2EU plot line represents steady state model results.

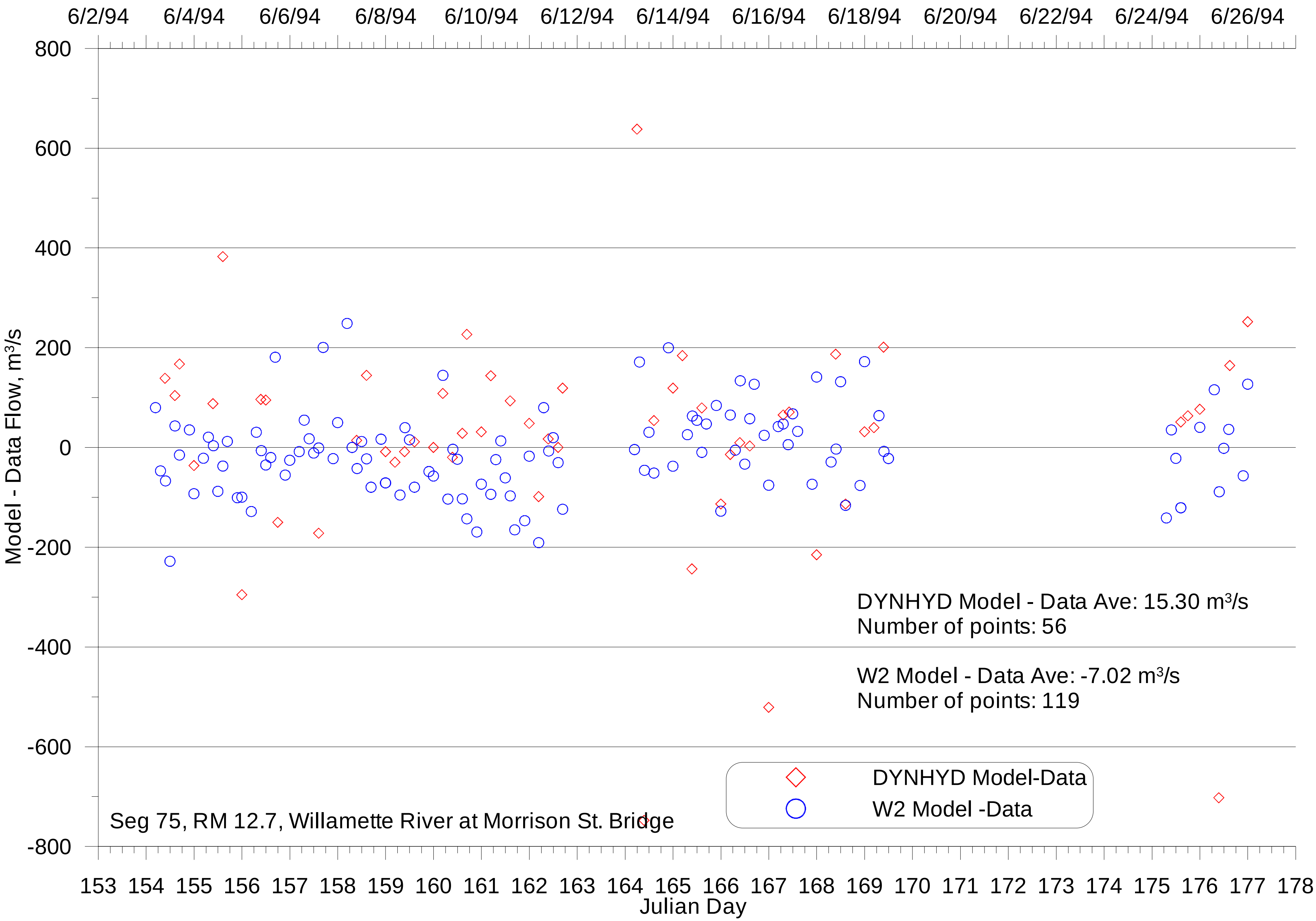


Figure 90. DYNHYD Model and CE-QUAL-W2 Model results compared with data, June 1994

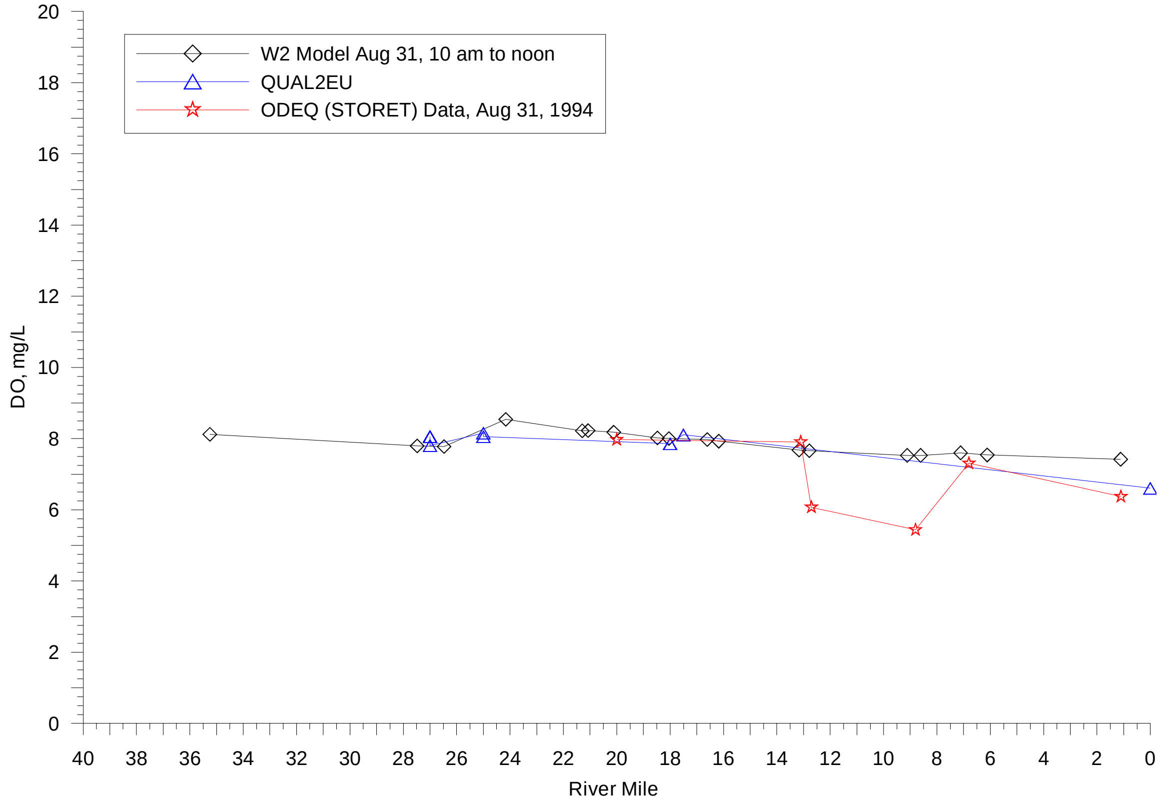


Figure 91. QUAL2EU and CE-QUAL-W2 model results compared with data for Dissolved Oxygen, August 31, 1994

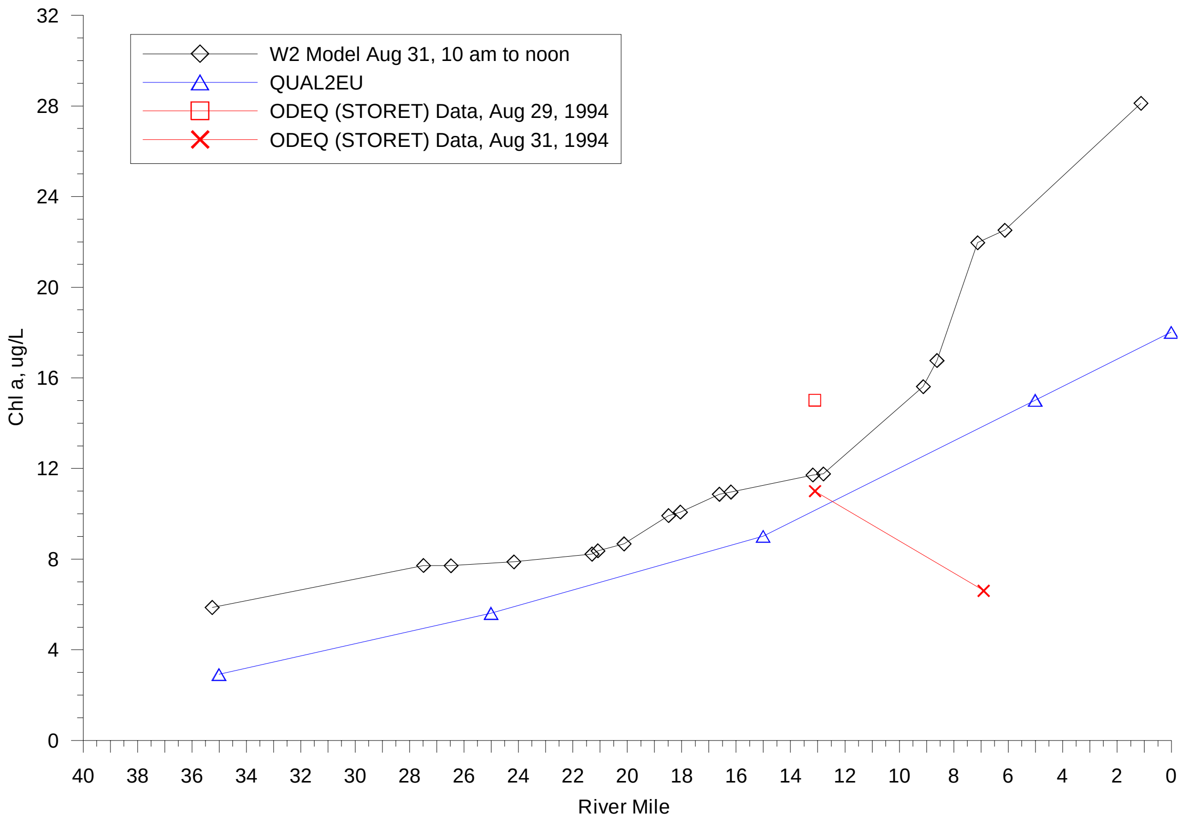


Figure 92. QUAL2EU and CE-QUAL-W2 model results compared with data for Chlorophyll a, August 31, 1994

Time of Travel

The CE-QUAL-W2 model also predicts "water age." The water age is a way of accounting for how long a water parcel has been in the model domain. Any water entering the model domain from tributaries or from the model boundaries (Canby Ferry on the Willamette River and Beaver Army Terminal and Bonneville Dam on the Columbia River) is assigned a water age of zero on entering the model domain.

Figure 93, Figure 94, Figure 95, Figure 96, and Figure 97 show model predictions from April to October for 1993, 1994, 1997, 1998, and 1999, respectively, for water age (or residence time), water level and flow rate at RM 20 on the Willamette River. Figure 98, Figure 99, Figure 100, Figure 101, and Figure 102 show model predictions from April to October for 1993, 1994, 1997, 1998, and 1999, respectively, for water age (or residence time), water level and flow rate at RM 12.7 (Morrison Street Bridge) on the Willamette River. These figures show that in general, the travel time from the upstream model boundary condition on the Willamette River (RM 35.5 Canby Ferry) to RM 20 (near the Tryon Creek Railroad Bridge) is less than 0.5 day during high flow conditions and less than 2 days during low summer flow conditions. From Canby Ferry (RM 35) to RM 12.7 (Morrison Street Bridge), travel times are on the order of less than a day during high flow periods and less than 4.5 days during summer low-flow conditions.

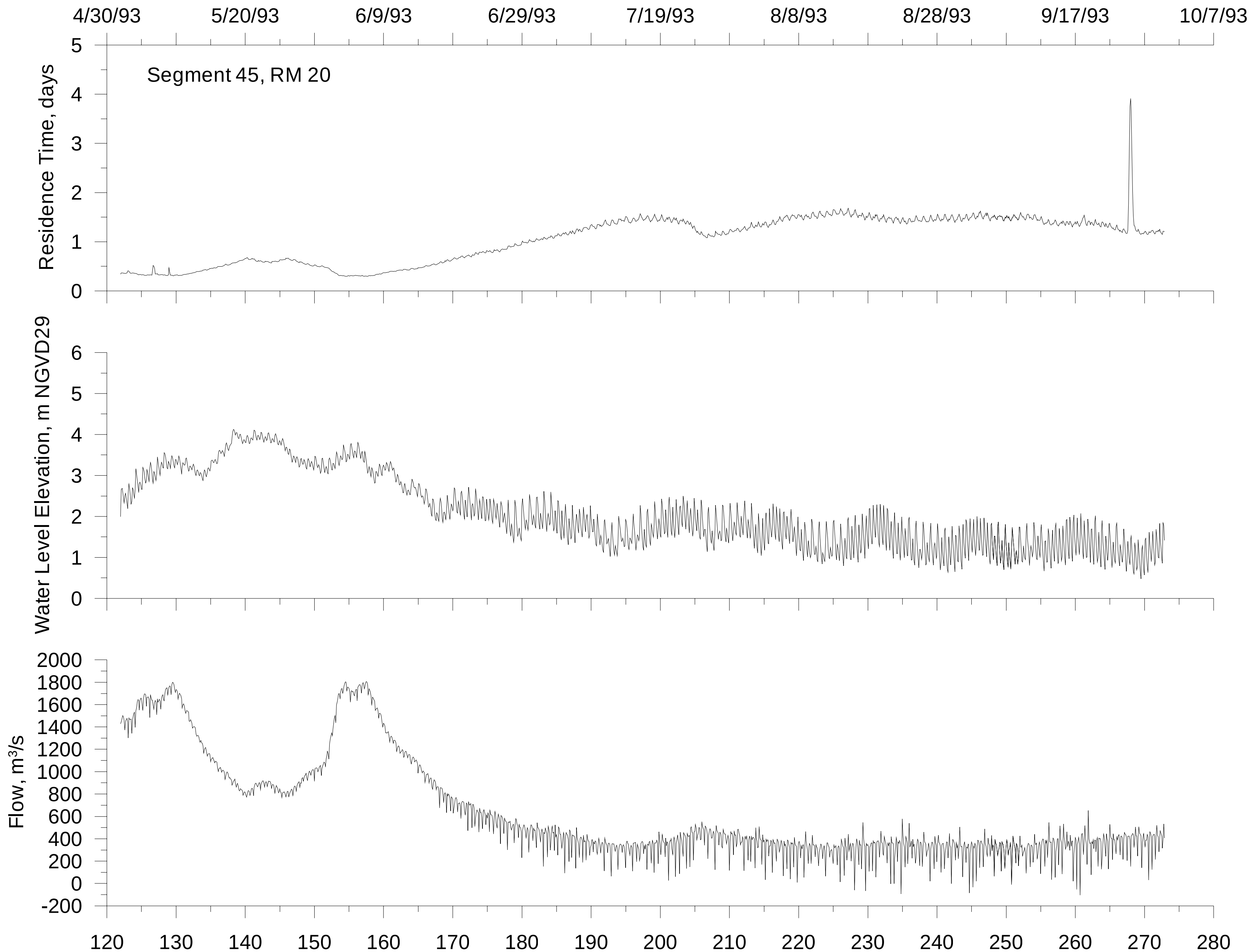


Figure 93. Residence Time, Flow and Water Level Elevation at RM 20, 1993

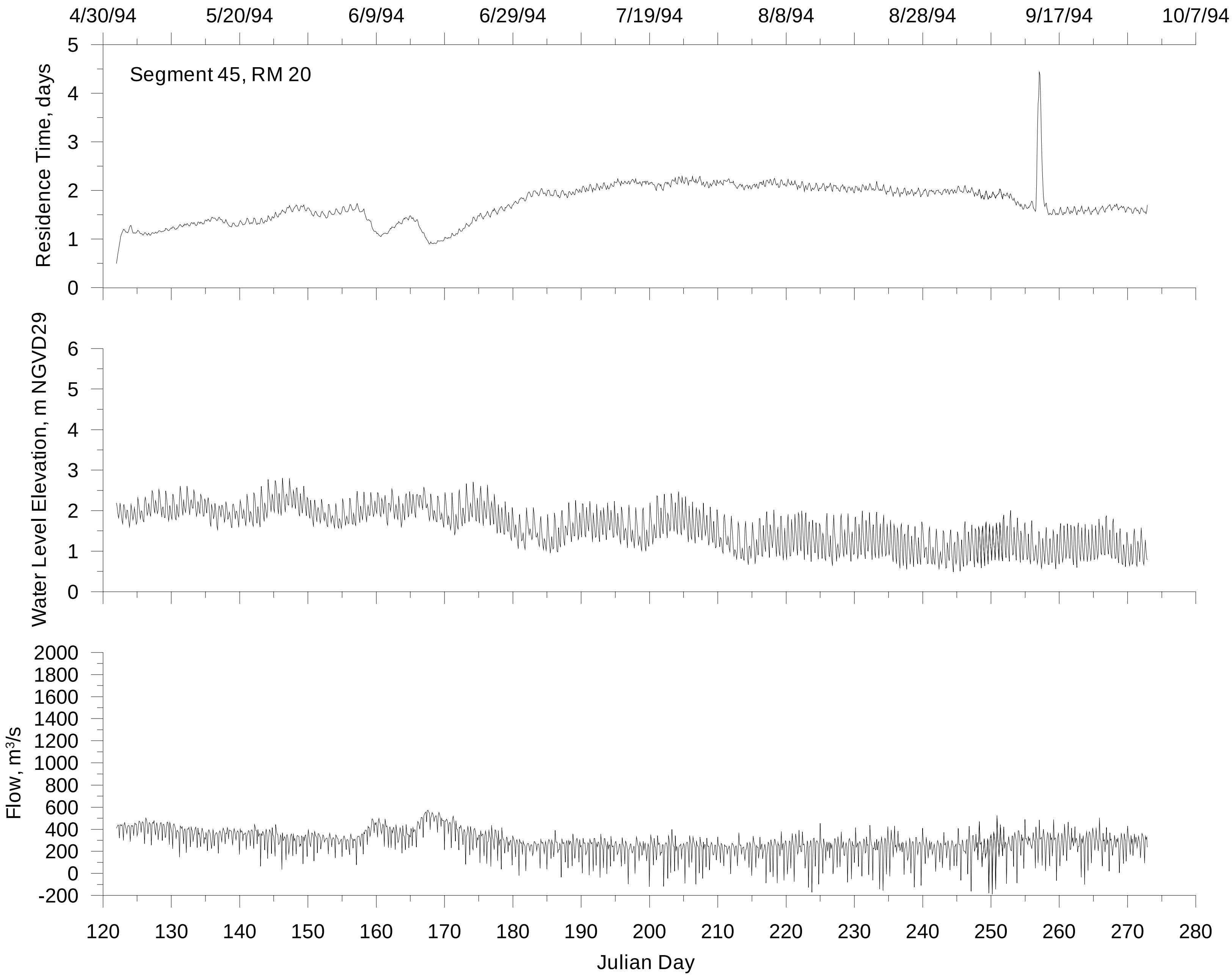


Figure 94. Residence Time, Flow and Water Level Elevation at RM 20, 1994

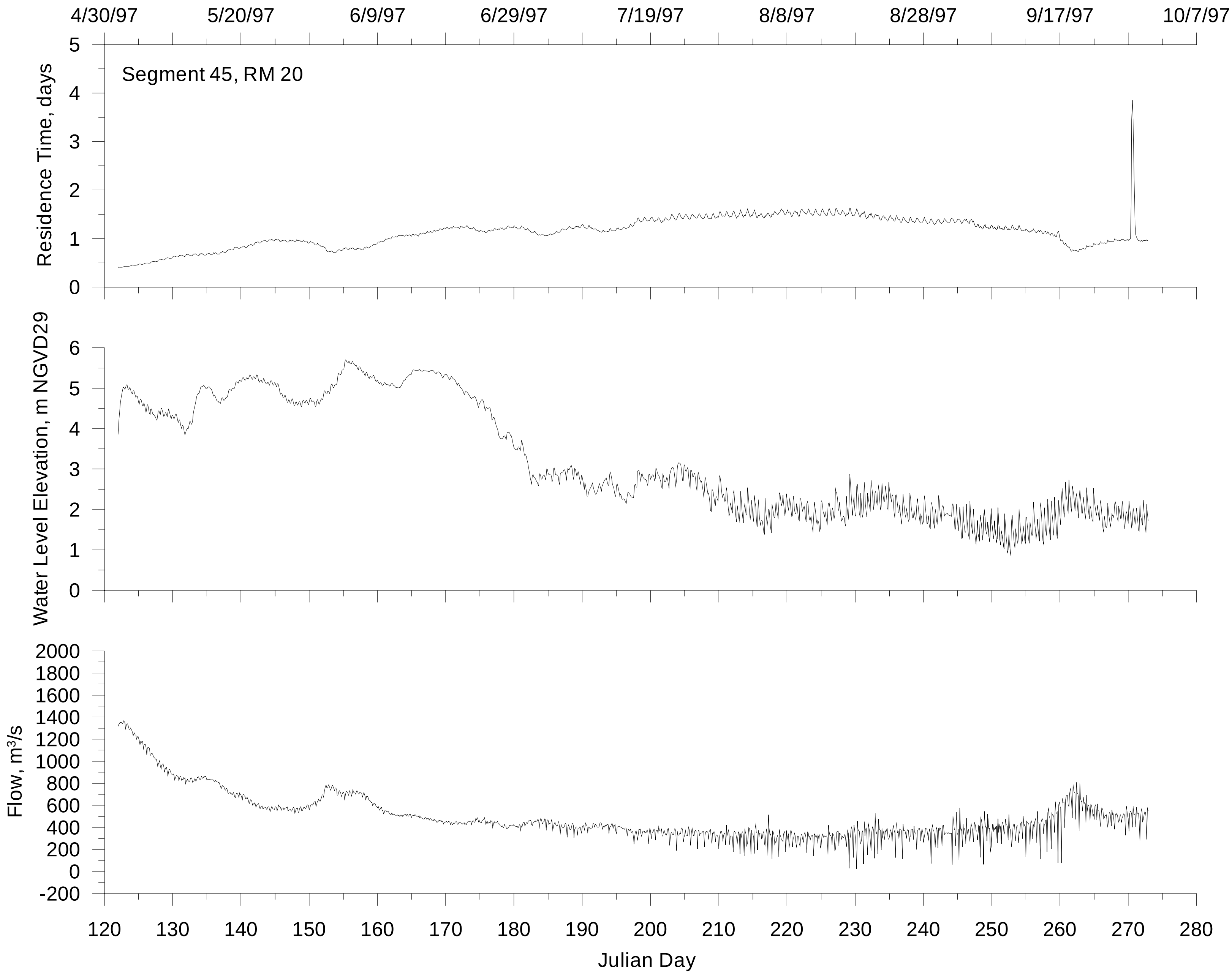


Figure 95. Residence Time, Flow and Water Level Elevation at RM 20, 1997

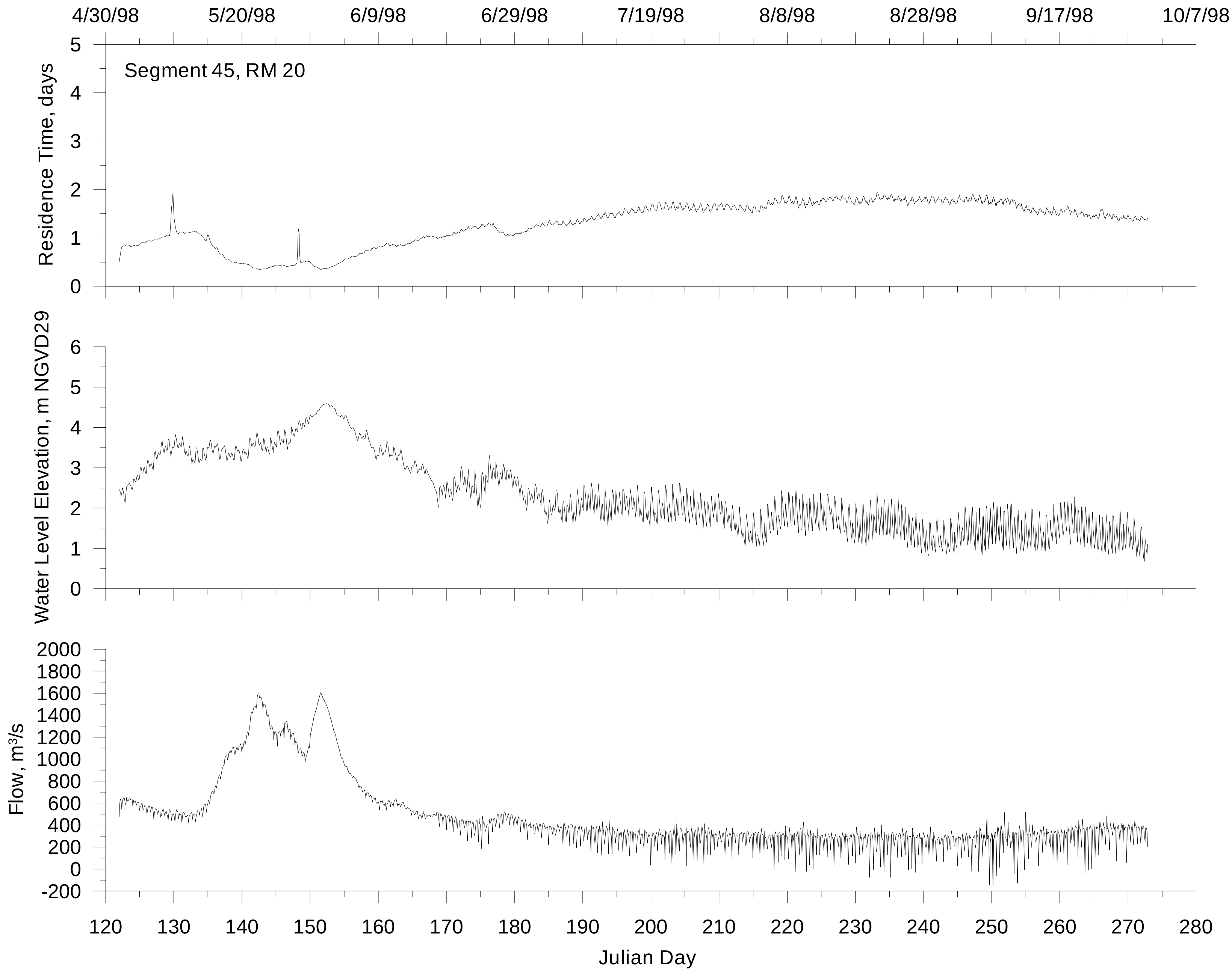


Figure 96. Residence Time, Flow and Water Level Elevation at RM 20, 1998

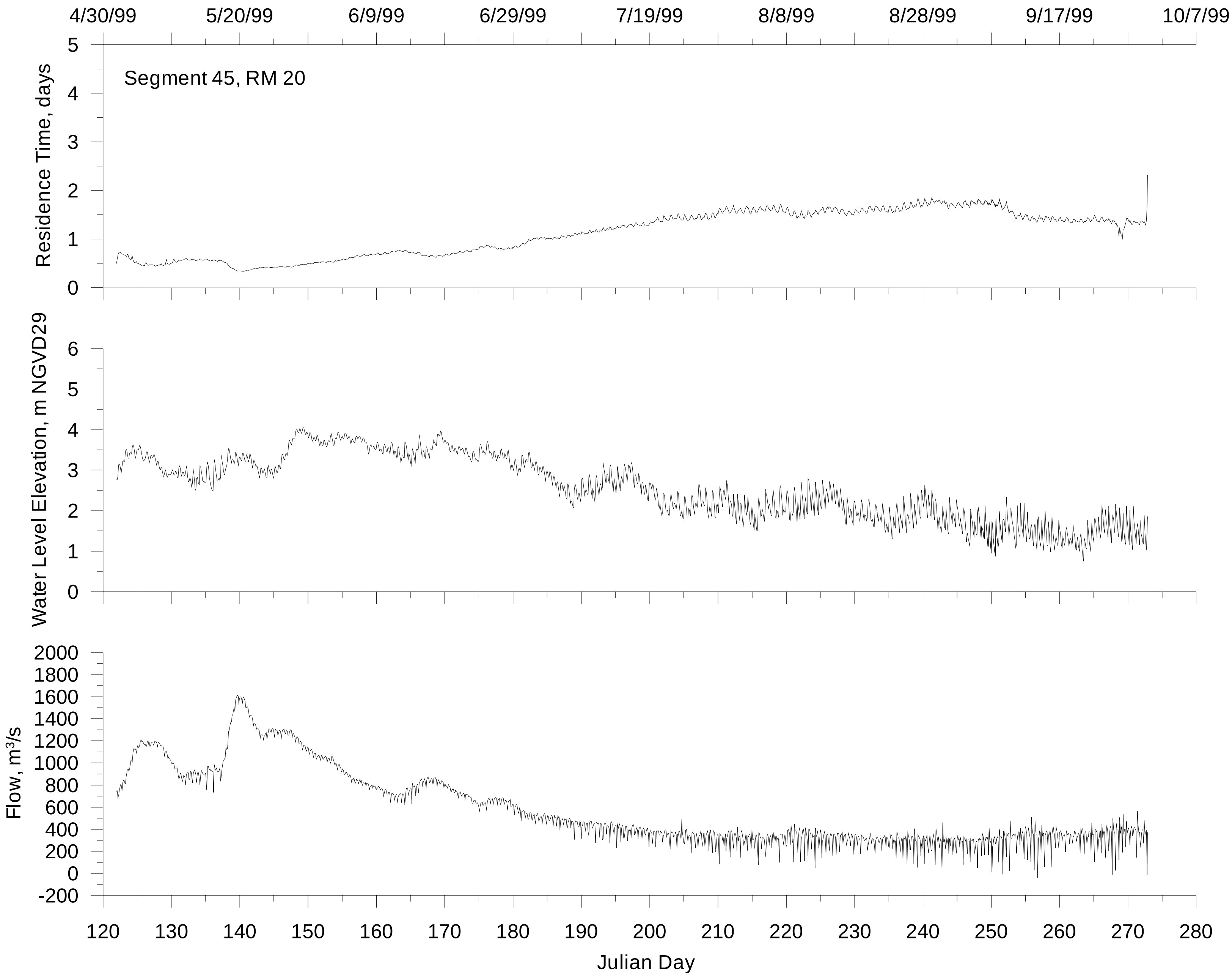


Figure 97. Residence Time, Flow and Water Level Elevation at RM 20, 1999

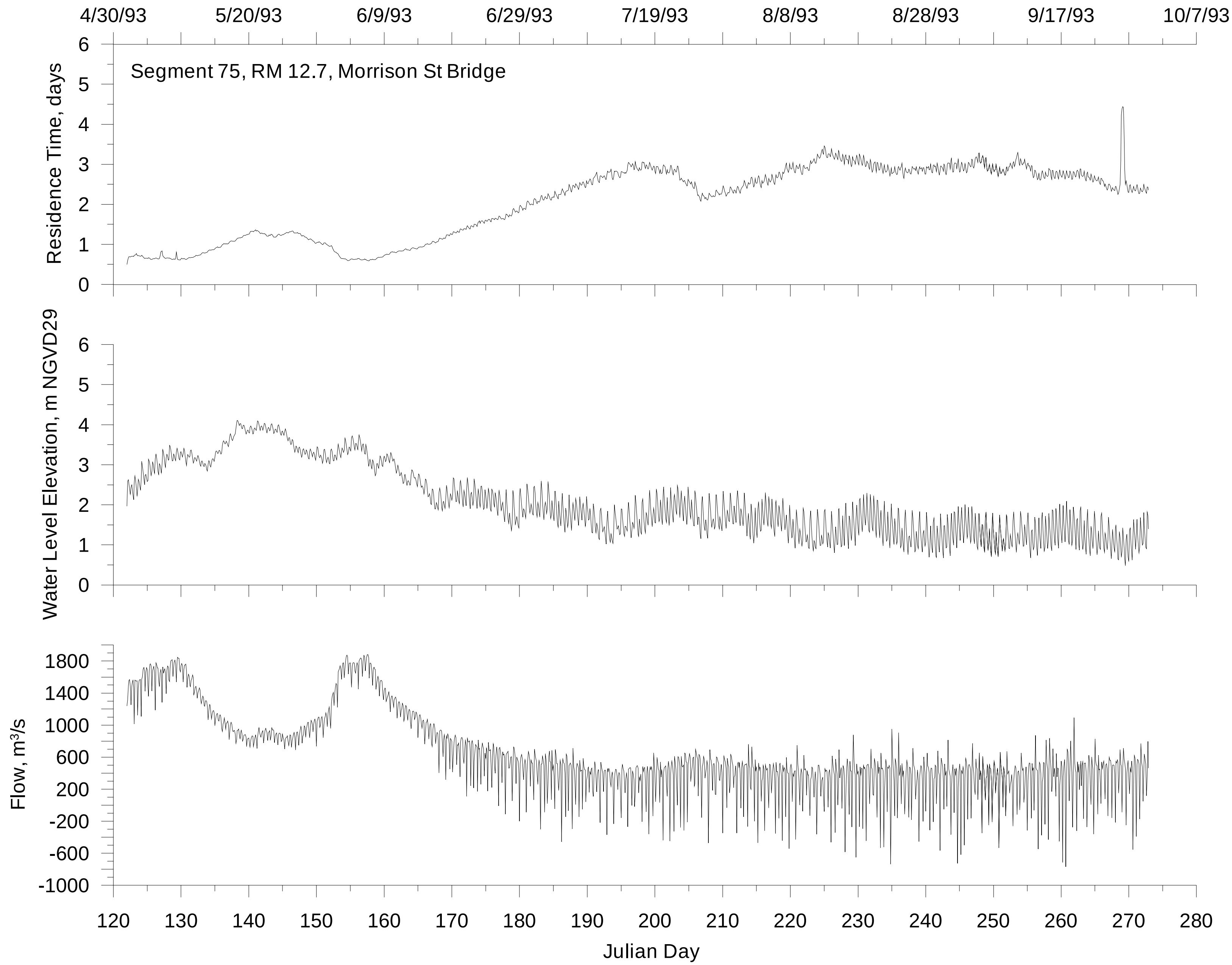


Figure 98. Residence Time, Flow and Water Level Elevation at RM 12.7, 1993

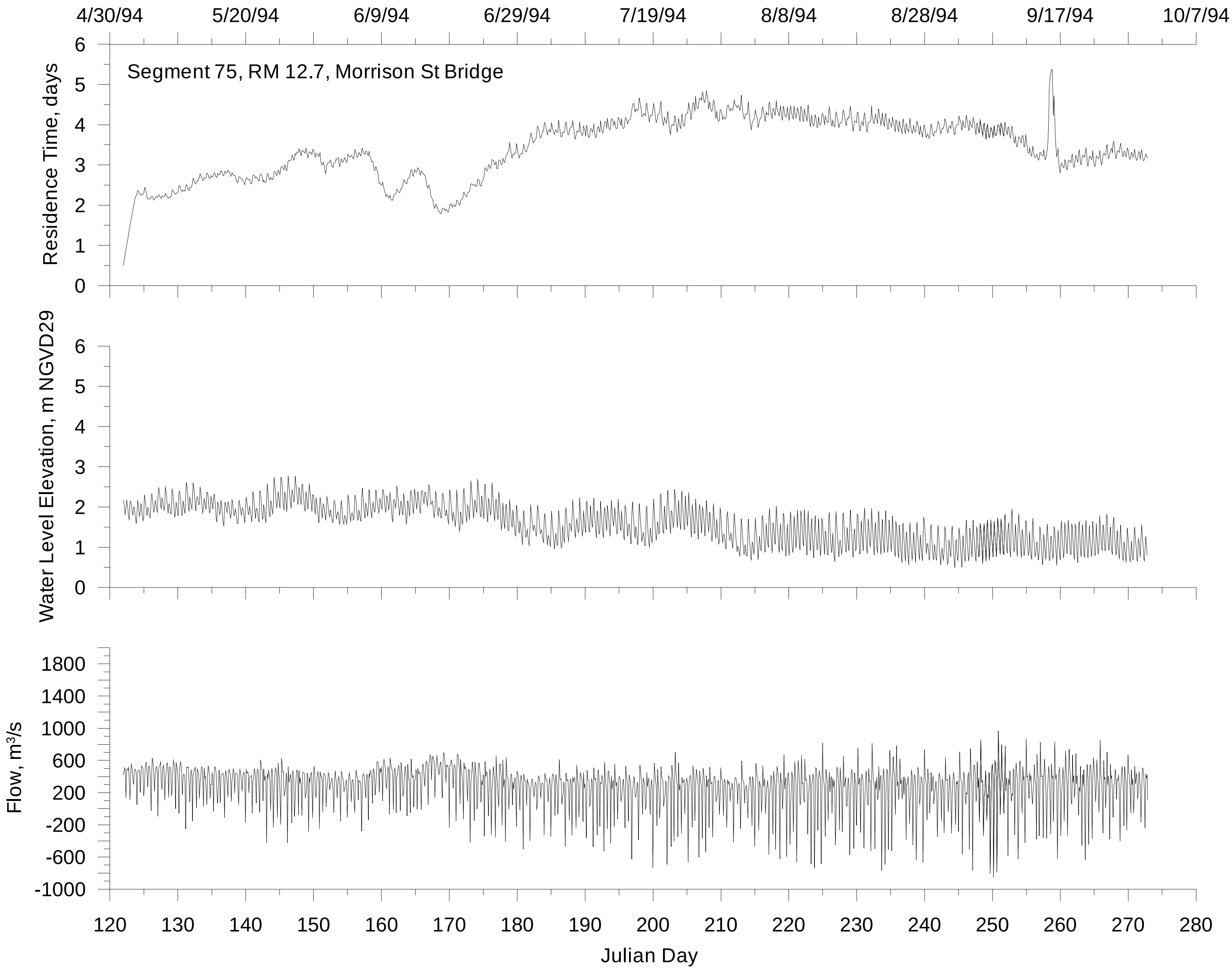


Figure 99. Residence Time, Flow and Water Level Elevation at RM 12.7, 1994

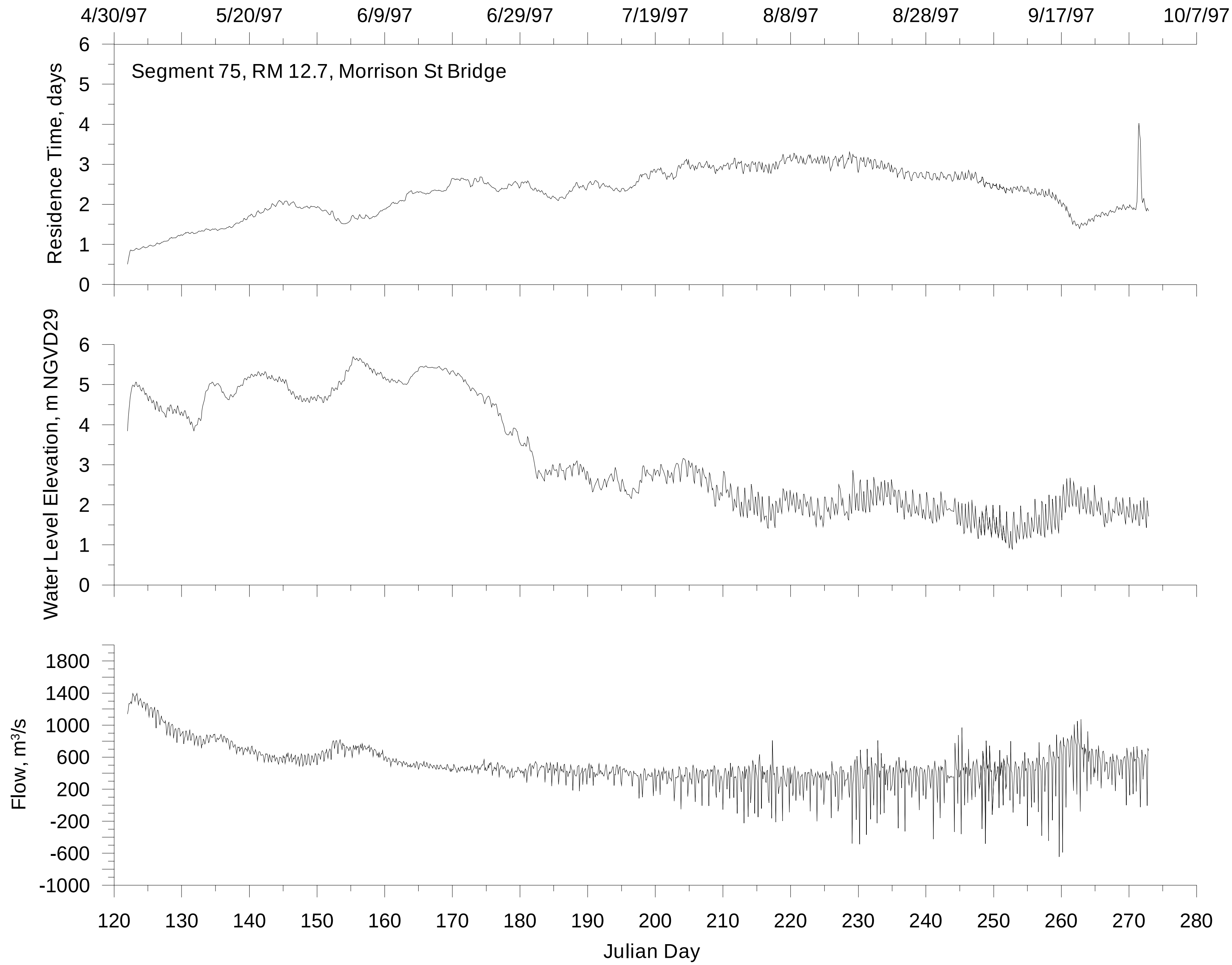


Figure 100. Residence Time, Flow and Water Level Elevation at RM 12.7, 1997

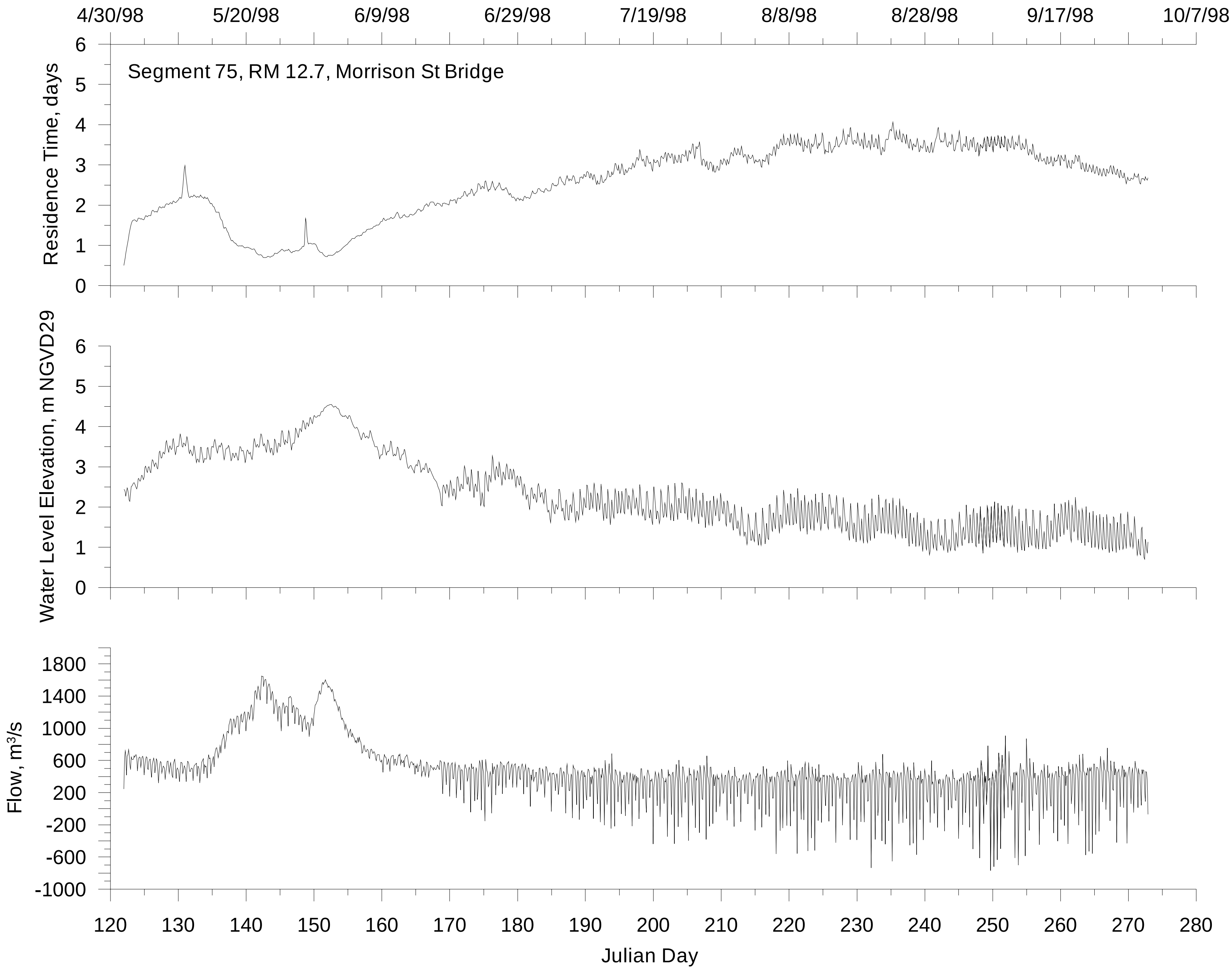


Figure 101. Residence Time, Flow and Water Level Elevation at RM 12.7, 1998

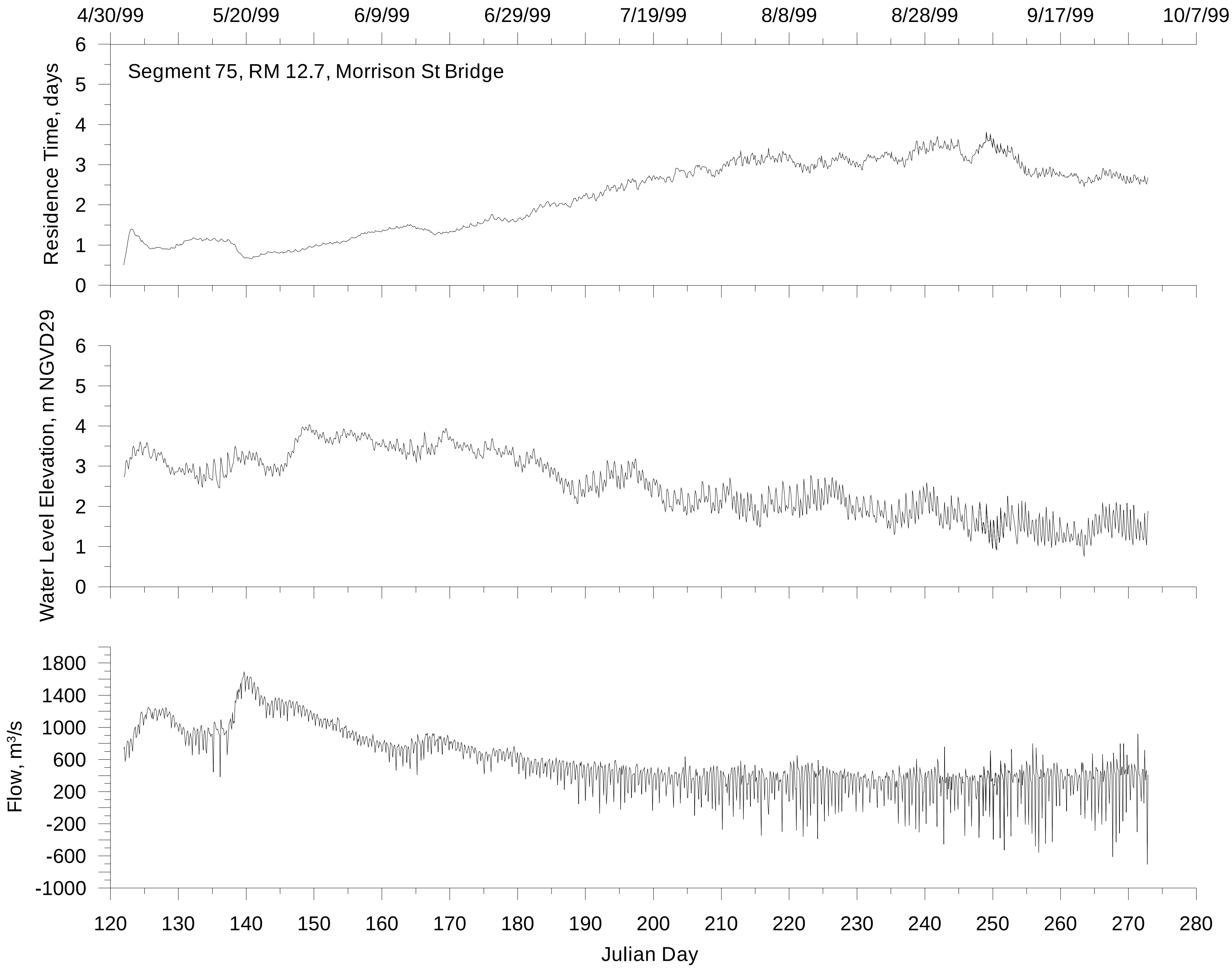


Figure 102. Residence Time, Flow and Water Level Elevation at RM 12.7, 1999

Sensitivity Analysis

In order to assess the model's sensitivity to different kinetic parameter values, model grid, and time step, model simulations were made to assess whether model results were a function of the model grid or time step and to assess whether model coefficients themselves drastically affected model predictions. Table 24 shows a list of model parameters used in the sensitivity analysis. In this set of model simulations, the calibrated model was run from July 1 to July 15, 1998 in order to assess differences in model results.

Table 24. Sensitivity Analysis Simulations, July 1 to July 15, 1998

Sensitivity Group	Simulation	Description
Algal Growth Rate	BaseCase	AG = 2.30
	1	AG = 1.15
	2	AG = 3.45
	3	AG = 4.60
Willamette River Boundary Condition	BaseCase	Algal Concentration =data
	4	0.5 x data
	5	2.0 x data
	6	4.0 x data
Reaeration Equation	BaseCase	Estuary, Eqn 1
	7	River, Eqn 1
	8	River, Eqn 2
	9	River, Eqn 7
	10	Lake, Eqn 6
Organic Decay Rate	BaseCase	LDOMDK = 0.12, LPOMDK = 0.08
	11	LDOMDK = 0.06, LPOMDK = 0.04
	12	LDOMDK = 0.18, LPOMDK = 0.12
	13	LDOMDK = 0.24, LPOMDK = 0.16
Grid density	BaseCase	Lower Willamette Grid, 97 segments
	14	Double grid, 194 segments
	15	Half grid, 49 segments
Maximum Time Step	BaseCase	DLTMAX=360 seconds
	16	50%, DLTMAX=180 seconds
	17	10%, DLTMAX=36 seconds

Algal Growth Rate

The impact on dissolved oxygen predictions using the algae growth rate were evaluated by decreasing the base value by 50% and increasing the base value by 50% and 100%. Model dissolved oxygen predictions with these algal growth rates are shown in Figure 103 and Figure 104 at RM 17.9 and RM 12.7 in the Willamette River, respectively. These figures show the sensitivity is dependent on the travel time from the upstream boundary condition at Canby Ferry. And since travel times during the summer can be up to 4.5 days from Canby Ferry to RM 12.7, adjustment of the algal growth rate can significantly affect model results. But in general, most algal population dynamics are well described by growth rates between 1 and 2 day^{-1}. In comparing the model base value to a reduction of 50%, dissolved oxygen differences were very small - much less than 0.5 mg/l dissolved oxygen. Differences between 50% less than and 50% greater than the base value resulted in dissolved oxygen variations at most of 0.5 mg/l at RM 12.7.

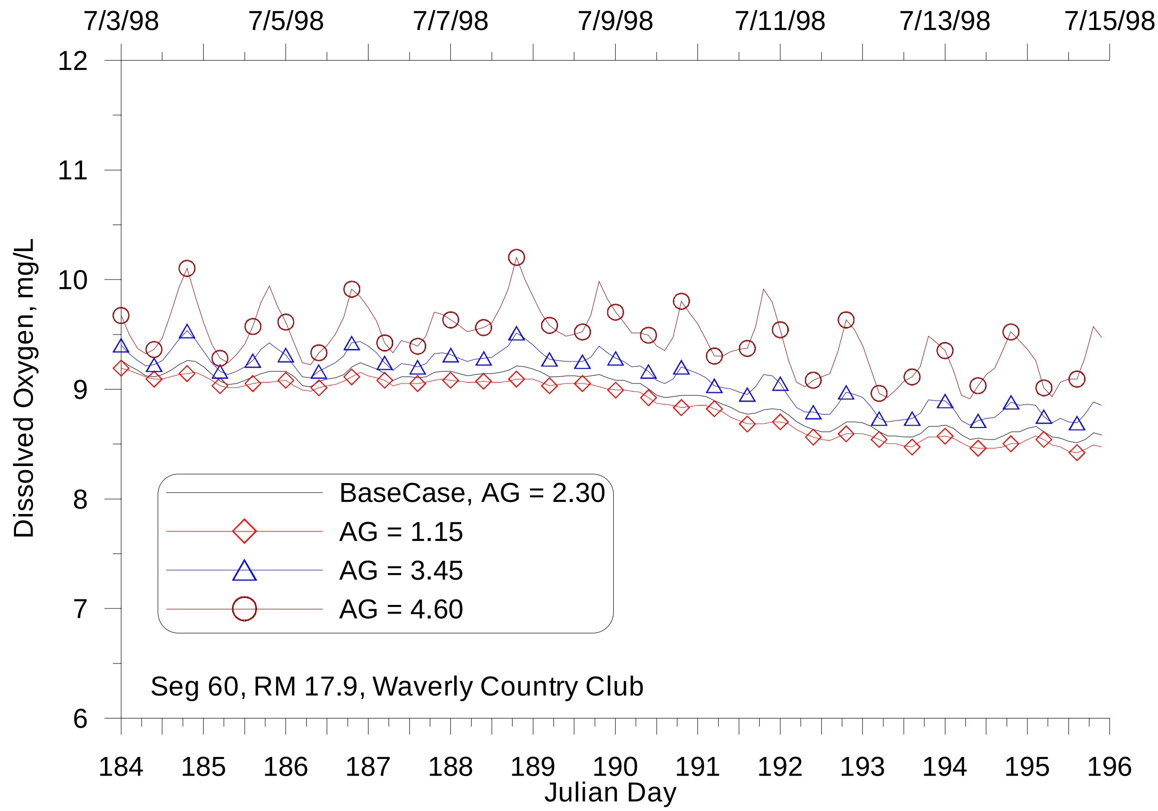


Figure 103. Sensitivity analysis, algal growth rate, dissolved oxygen at Waverly Country Club

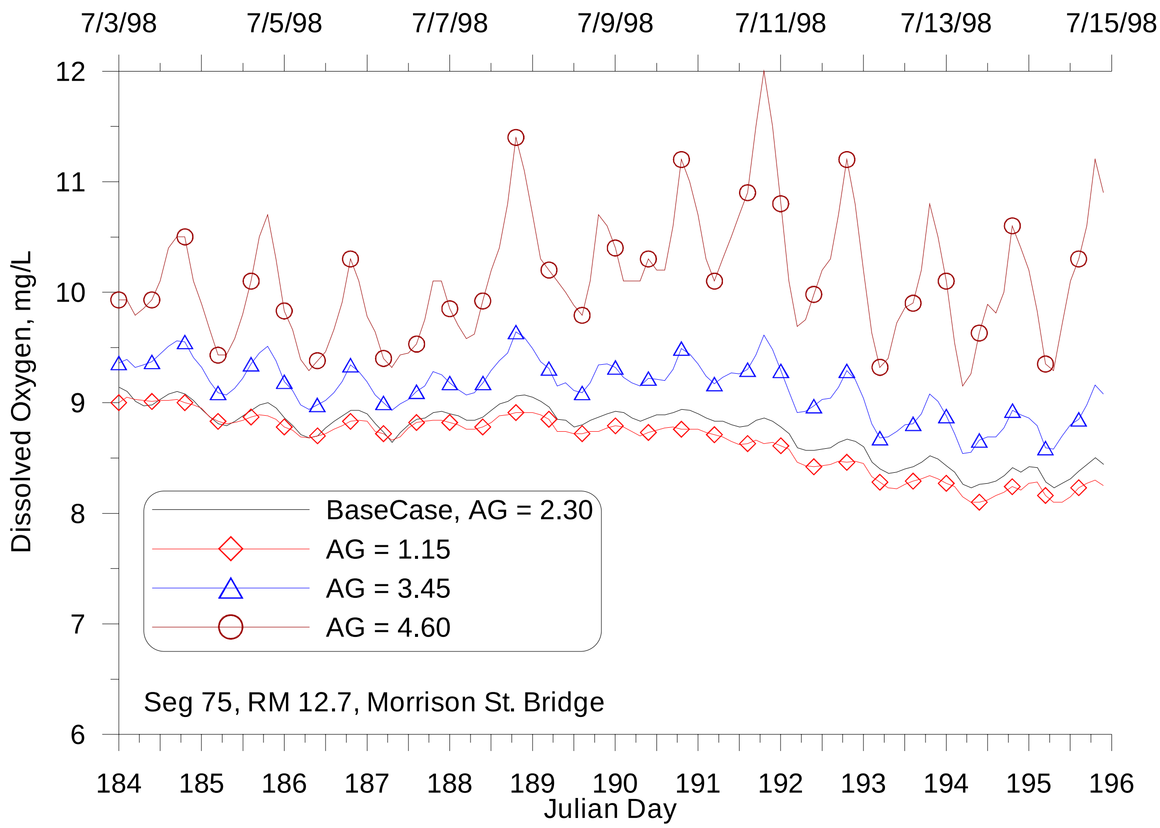


Figure 104. Sensitivity analysis, algal growth rate, dissolved oxygen at Morrison St. Bridge

Willamette River Boundary Condition

Another sensitivity check was to vary the inflow algae biomass concentration by 50%, 200% and 400% of field data used during model calibration. The model predictions of dissolved oxygen with these variations in the inflow algae biomass are shown in Figure 105 and Figure 106 for Willamette RM 17.9 and 12.7, respectively. Dissolved oxygen differences were at most less than 0.5 mg/l at RM 12.7 for the entire range of values used in the upstream boundary condition at Canby Ferry.

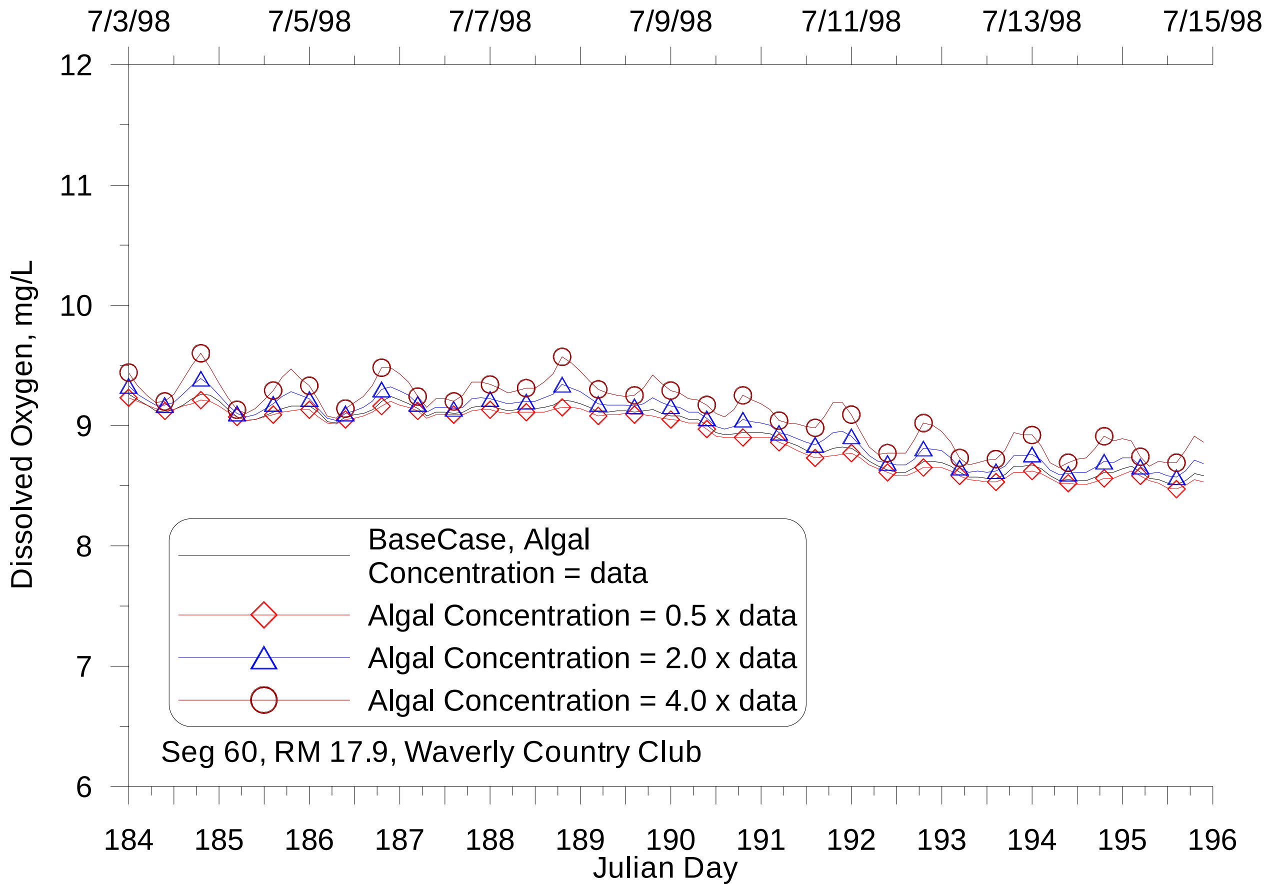


Figure 105. Sensitivity analysis, algal concentration in boundary condition, dissolved oxygen at Waverly Country Club

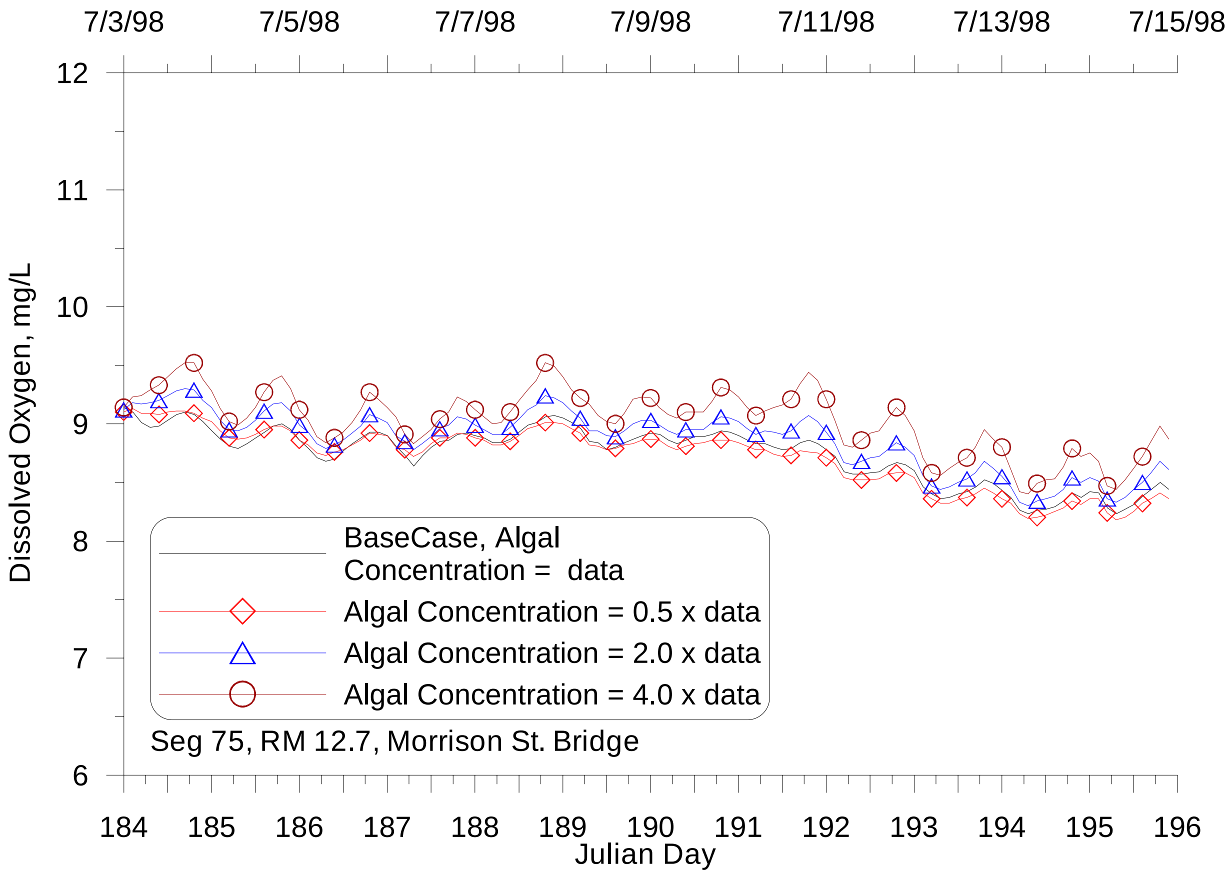


Figure 106. Sensitivity analysis, algal concentration in boundary condition, dissolved oxygen at Morrison St. Bridge

Reaeration Equation

CE-QUAL-W2 has several different formulations for reaeration that the model user can choose (Cole and Wells, 2000). An estuary model formulation (Equation 1 for Estuaries – see Cole and Wells, 2000) was used for the lower Willamette River that includes reaeration effects from wind and tidal currents. This reaeration model was compared to other reaeration models: O'Connor and Dobbins (River Eqn 1), Churchill, Elmore and Buckingham (River Eqn 2), and a typical Lake model (Lake Equation 6 – used in CE-QUAL-W2 Version 2 for reservoirs). The River Equation 1 and 2 are typical values used in river reaeration studies. The Lake model was used to show that surface layer turbulence that results in reaeration is also reasonably well described only by wind mixing in contrast to only boundary shear (River Eqn 1 and 2). Figure 107 and Figure 108 show the predicted dissolved oxygen at RM 17.9 and RM 12.7. Differences in reaeration formulae resulted in differences in dissolved oxygen predictions of at most 0.1 mg/l.

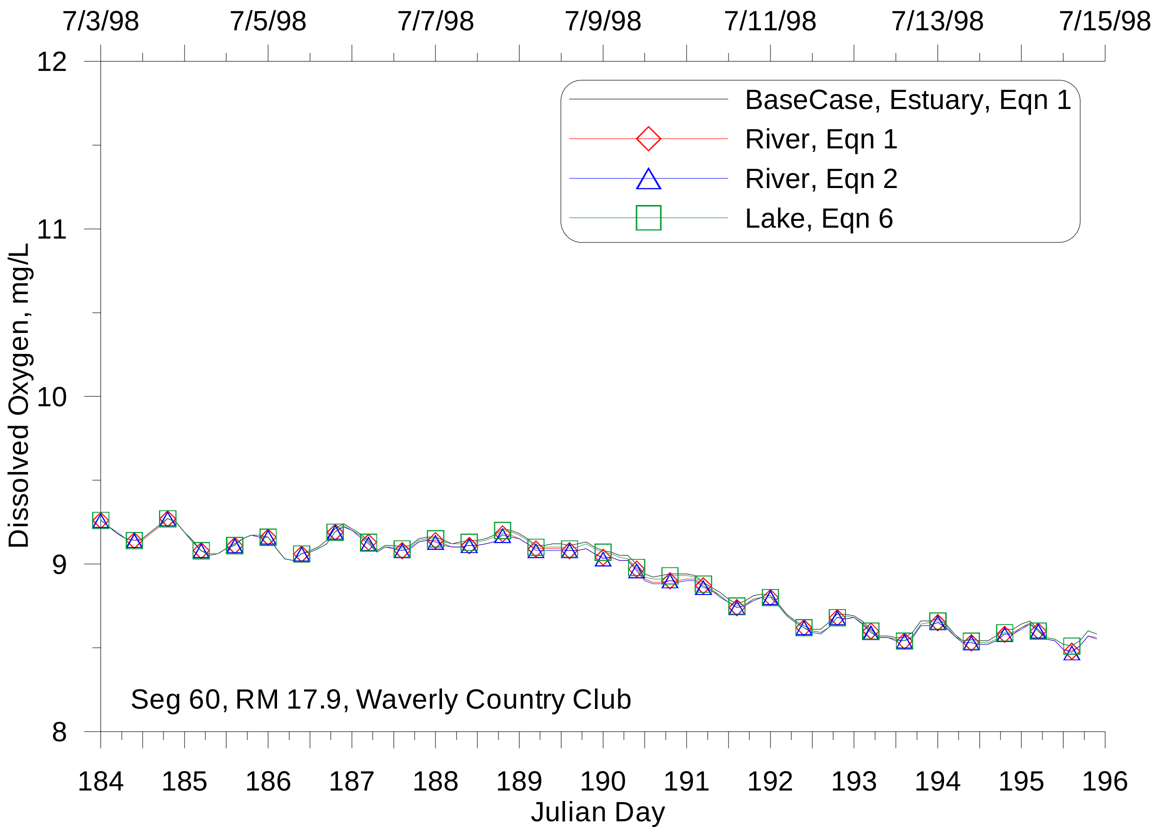


Figure 107. Sensitivity analysis, reaeration equation, dissolved oxygen at Waverly Country Club

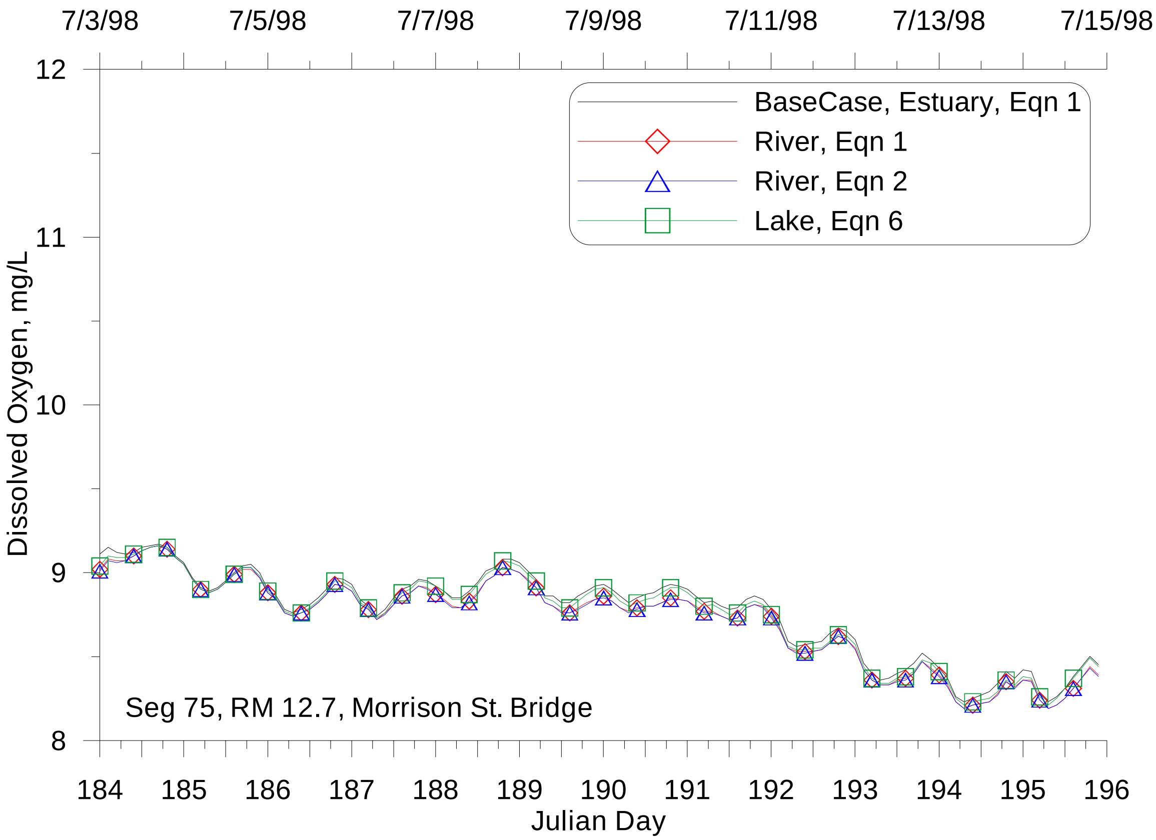


Figure 108. Sensitivity analysis, reaeration equation, dissolved oxygen at Morrison St. Bridge

Organic Decay Rate

The organic decay rate controls the kinetics of organic matter degradation. Sensitivity of this decay rate to model predictions of dissolved oxygen were made by changing the dissolved organic matter decay rate (DOM) and the particulate organic matter decay rate (POM) by 50%, 150%, and 200% from its base or calibrated value. Figure 109 and Figure 110 show model predictions of dissolved oxygen at Willamette River Mile 17.9 and 12.7, respectively, for the range of values of DOM and POM kinetic parameters. Note that even though these parameter values affected dissolved oxygen by at most 0.5 mg/l at RM 12.7, the sensitivity runs were conducted varying both POM and DOM rates at the same time.

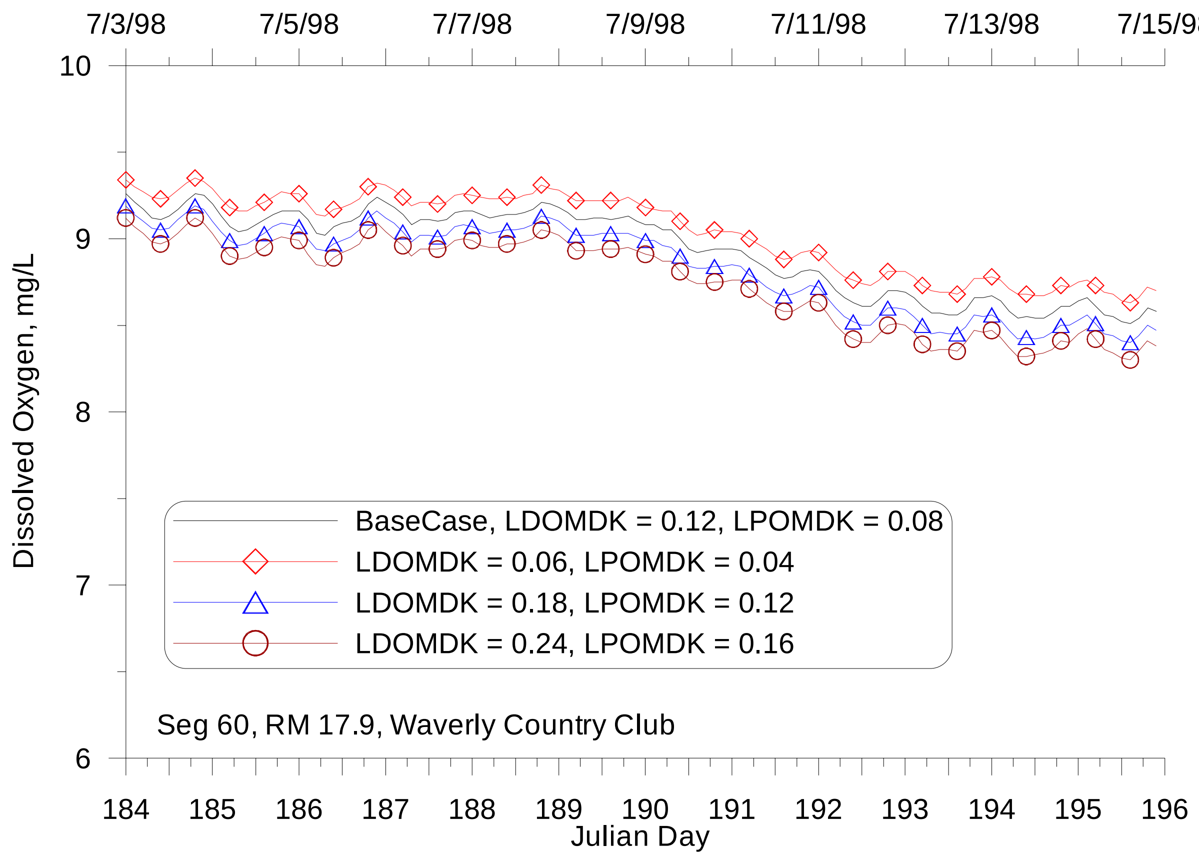


Figure 109. Sensitivity analysis, organic decay rate, dissolved oxygen at Waverly Country Club

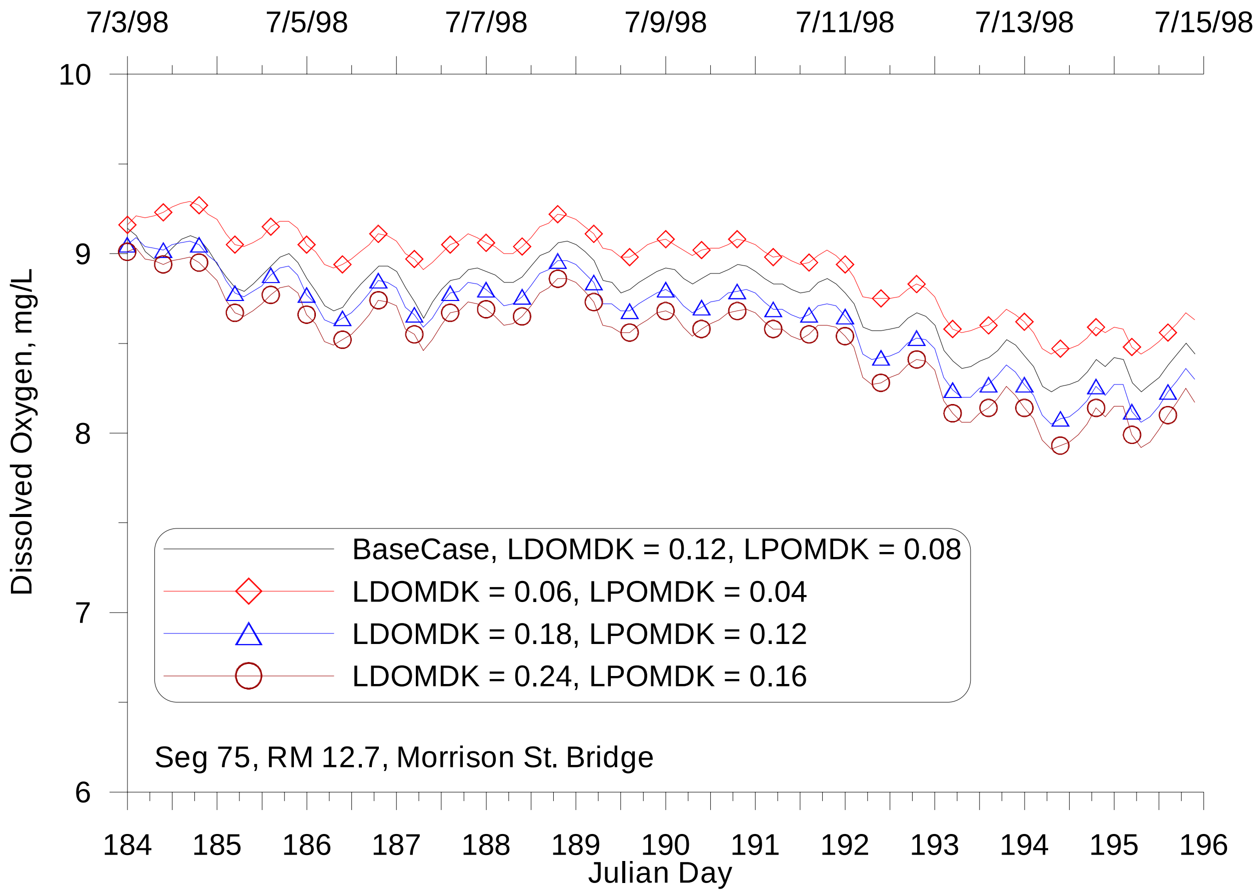


Figure 110. Sensitivity analysis, organic decay rate, dissolved oxygen at Morrison St. Bridge

Grid density

In many studies it is important to establish that the model result is not dependent on the model grid. In the two simulations below, the model grid was coarsened and halved. This means that the number of model segments was reduced by a factor of 2 and doubled from the base of the Willamette River Falls to the junction with the Columbia River. Model predictions with these 2 grids are shown in Figure 111 and Figure 112 at RM 17.9 and RM 12.7, respectively showing the model results are largely grid insensitive.

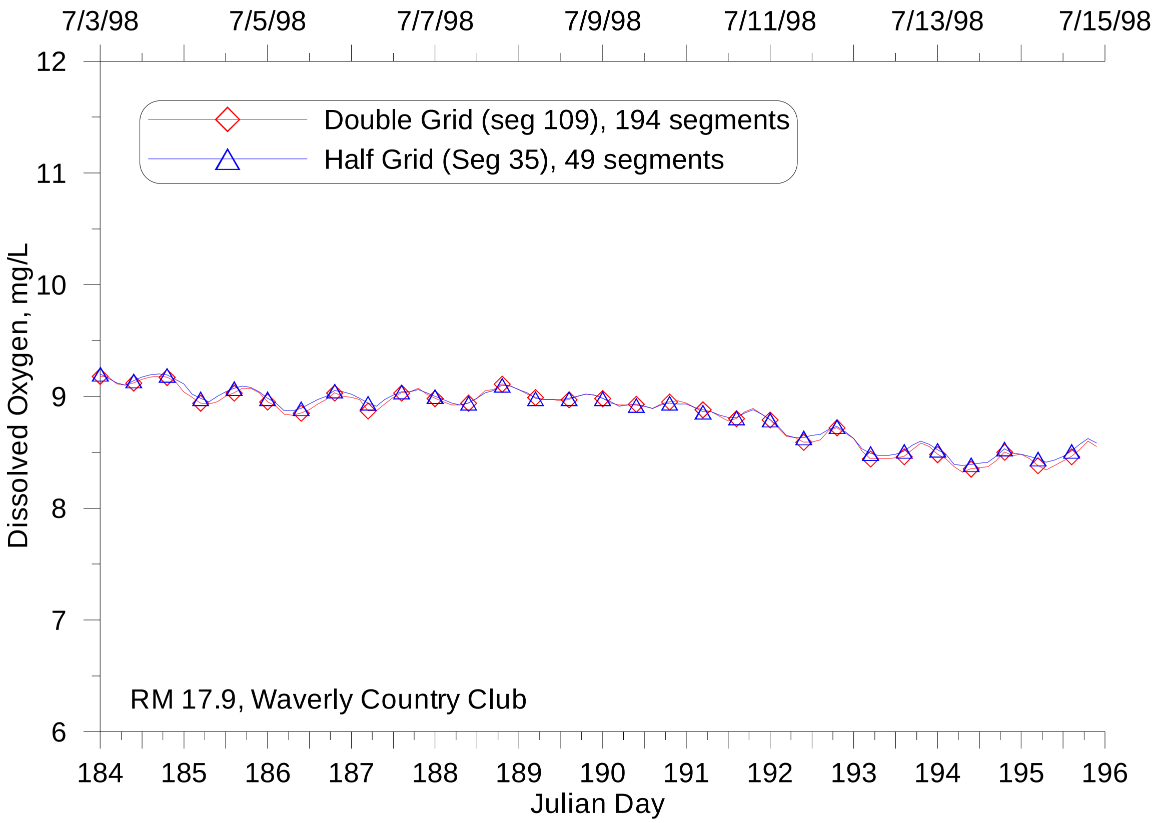


Figure 111. Sensitivity analysis, grid density, dissolved oxygen at Waverly Country Club

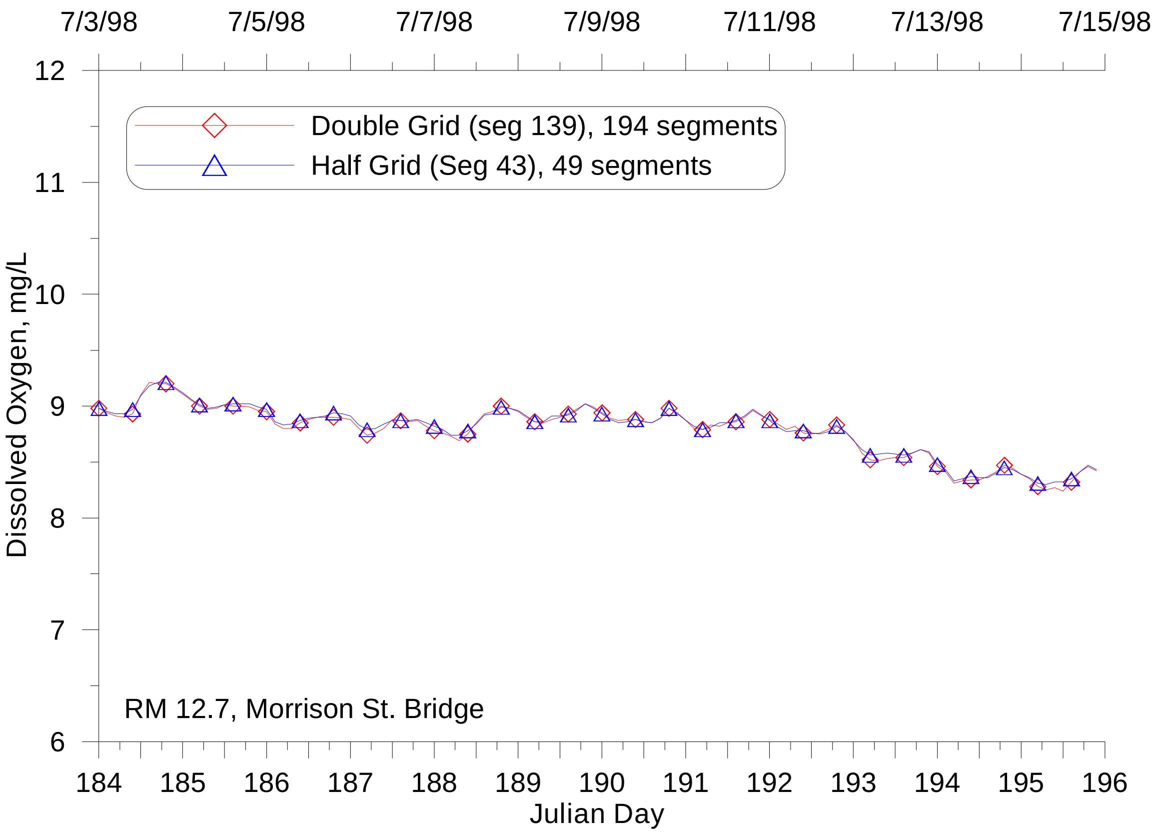


Figure 112. Sensitivity analysis, grid density, dissolved oxygen at Morrison St. Bridge

Maximum Time Step

Because CE-QUAL-W2 uses an implicit numerical solution to the water surface equation, there is a potential for numerical errors to creep into the model results for the water surface and thereby affect model hydrodynamics and ultimately water quality. CE-QUAL-W2 has a maximum model time step that is set by the model user. In these series of runs, the maximum model time step was reduced to determine if model predictions of dissolved oxygen were affected. Figure 113 and Figure 114 show model results of dissolved oxygen at a maximum time steps of 360 s (base case), 180 s, and 36 s at Willamette River RM 17.9 and RM 12.7, respectively. Hence, model results were largely insensitive to smaller maximum time steps.

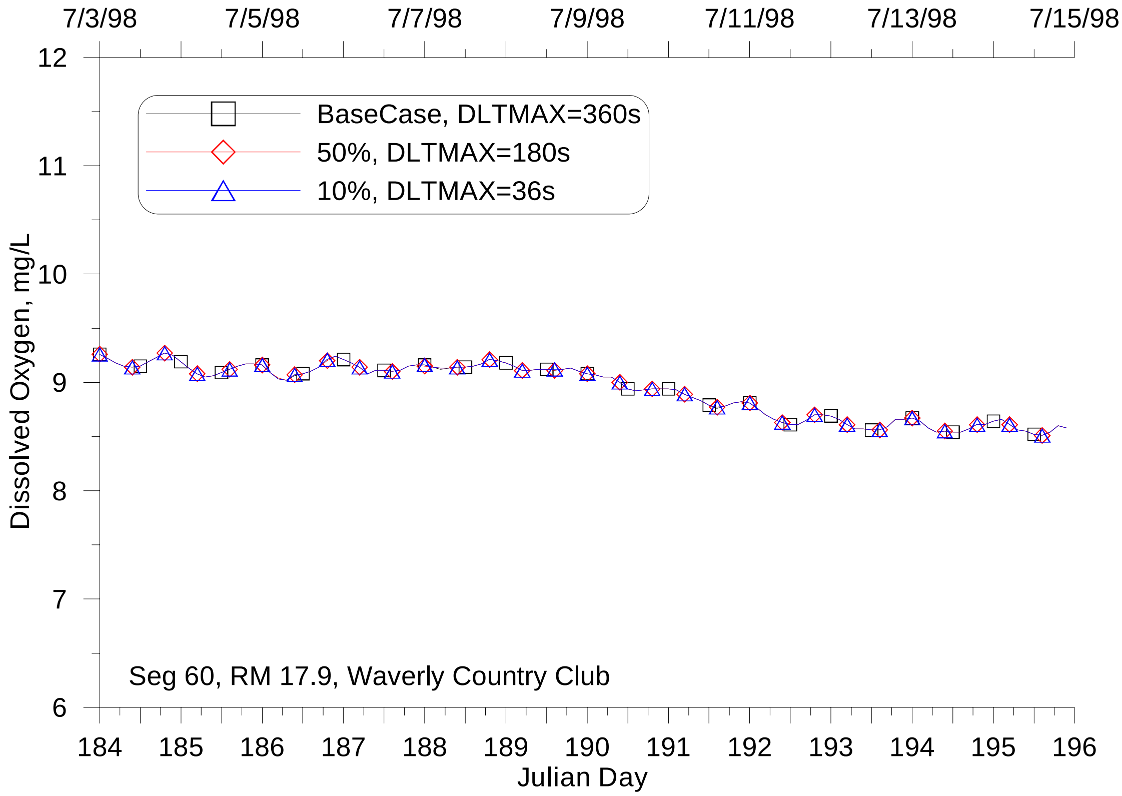


Figure 113. Sensitivity analysis, maximum time step, dissolved oxygen at Waverly Country Club

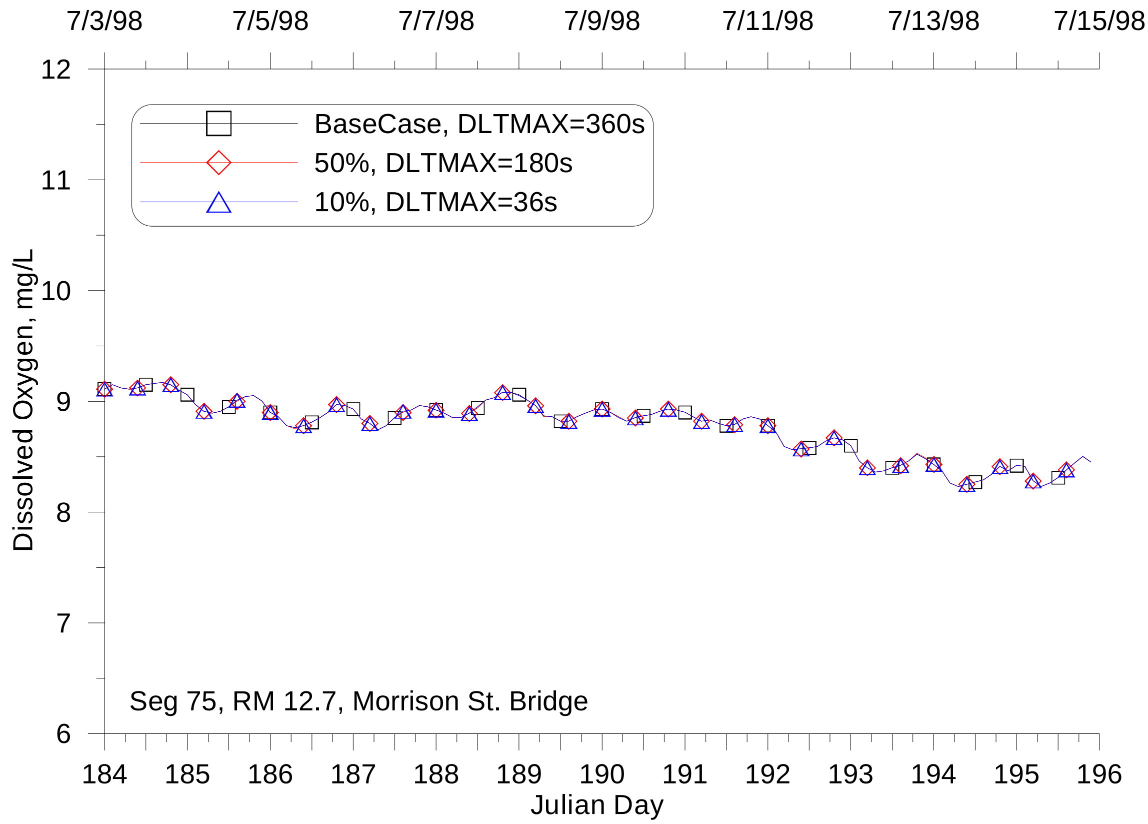


Figure 114. Sensitivity analysis, maximum time step, dissolved oxygen at Morrison St. Bridge

Summary

A CE-QUAL-W2 Version 3 model (Cole and Wells, 2000) was set-up to model the Lower Willamette River in order to assess the impact of the wastewater treatment plant discharges on water quality. The model was set-up for the summer periods (May 1-October 1) of 1993, 1994, 1997, 1998, and 1999. The model boundaries on the Columbia River extended from the Beaver Army Terminal (a downstream head boundary condition) to Bonneville Dam. On the Willamette River they included the confluence with the Columbia River to Canby Ferry at RM 35. The model set-up was discussed in Rodriguez et al. (2001). The model was compared to hydrodynamic field data (water level and flow rate data), temperature data, and water quality data (dissolved oxygen, chlorophyll a, pH, PO_4-P, NH_4-N, NO_3-N, TKN, TOC) at various stations in the Willamette and Columbia Rivers.

Model calibration showed that in general the model reproduced the hydrodynamics and water quality well during the May-October period despite the fact that many dynamic storm water dischargers were not used in the model. A summary of model errors in the Lower Willamette is shown in Table 25.

Table 25. Typical model errors in the Lower Willamette River.

Parameter	Typical Average Mean Error in the Lower Willamette River	Typical range in variable
Water level, m	0.1-0.25 m	±1.1 m
Flow rate, m^3/s	20 –130 m^3/s	1200 m^3/s
Temperature, ^oC	0.3-0.9^oC	10-24^oC
Dissolved oxygen, mg/l	0.3-1.0 mg/l	7-10 mg/l
Chlorophyll a, ug/l	2-15 ug/l	5-40 ug/l
pH	0.1-0.3	7-8
PO_4-P, ug/l	5-8 ug/l	20-65 ug/l
Total P, ug/l	10-20 ug/l	40-100 ug/l
Ammonia-N, ug/l	10-25 ug/l	40-100 ug/l
Nitrate-N, ug/l	80-100 ug/l	200-600 ug/l
TKN, mg/l	0.03-0.1 mg/l	0.2-0.4 mg/l
TOC, mg/l	0.3-0.5 mg/l	1-2 mg/l

The temperature and water quality model predictions are very dependent on upstream boundary conditions as evidenced by short travel times from the Canby Ferry to the Morrison Street bridge (from 1-4 days). Also, the ability to reduce model water level and flow rate errors is very dependent on having accurate and precise bathymetry data in the model system.

The following conclusions can be made evaluating regarding the modeling effort:

- Interpolating upstream boundary condition data between field sampling every 2 or 3 weeks made it difficult to predict conditions in the Lower Willamette when the data within the model domain was taken at a higher data frequency. It is recommended that future studies consider the use of continuous water quality monitoring devices (such as temperature, dissolved oxygen, and pH) so continuous boundary condition data can be obtained for the Willamette River

- In the W2 model, one algal type with the same kinetic parameters were used for all the years of record. There is probably a basis for using multiple algal types in the model or different algal growth rate kinetics year-by-year but limited data exist making such an effort merely an effort to match chlorophyll a data, which in itself can vary depending not only on algal species but time of year and the laboratory that did the analysis.

In general, hydrodynamic and water quality features of the system are well reproduced in the model. The use of the model to postulate impacts of increased BOD mass loadings from point sources would be a reasonable use of the calibrated model. Most improvements in model calibration would probably be based on improving boundary conditions for the model, especially the boundary condition for water quality parameters at the Canby Ferry at RM 35.

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Appendix 1: W2 Control File

```
                                  River Basin Model Version 3
INPUT PARAM  IMP     KMP     NRP     NBP
              84      85       2       4

TITLE C ..............................TITLE.....................................
jr1     Bull Run Reservoir 1 and 2 System Model
        JR=1 Reservoir 1
        Default hydraulic coefficients
        Default light absorption/extinction coefficients
        Temperature and water quality simulation
        Scott Wells - PSU  368-920
jr2     Bull Run Reservoir 1 and 2 System Model
        JR=1 Reservoir 1
        Default hydraulic coefficients
        Default light absorption/extinction coefficients
        Temperature and water quality simulation
        Scott Wells - PSU  368-920

TIME CON  TMSTRT   TMEND    YEAR
           368.5  1379.9    1996

DLT CON      NDT  DLTMIN
               1    01.0

DLT DATE    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
           368.0   593.0   595.0  1090.0

DLT MAX   DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
          100.00    10.0  400.00    10.0

DLT FRN     DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
            0.90    0.90    0.90    0.90

DLT LIMIT   VISC    CELC
              ON      ON

BRANCH G      US      DS     UHS     DHS      NL   slope
Br     1       2      30       0       0       1 0.00000
Br     2      33      37       0      27       1 0.00000
Br     3      40      74     -30       0       1 0.00000
Br     4      77      83       0      64       1 0.00000

LOCATION     LAT    LONG    EBOT      BS      BE    JBDN
jr1        45.44  122.18  266.50       1       2       1
jr2        45.44  122.18  228.00       3       4       3

INIT CND     T2I    ICEI  WTYPEC
jr 1         4.0     0.0   FRESH
jr 2         4.0     0.0   FRESH

CALCULAT     VBC     EBC     MBC   PQINC     EVC     PRC
              ON      ON      ON     OFF      ON     OFF

INTERPOL   QINIC    TRIC   DTRIC    HDIC  QOUTIC    WDIC   METIC
              ON      ON      ON      ON     OFF      ON      ON

DEAD SEA   WINDC    QINC   QOUTC   HEATC
              ON      ON      ON      ON

HEAT EXCH  SLHTC
            TERM

RAD&EVAP    SROC     AFW     BFW     CFW   WINDH RH_EVAP
JR1          OFF   10.51    1.31    1.00     2.0     OFF
JR2          OFF   10.51    1.31    1.00     2.0     OFF

ICE COVER   ICEC  SLICEC  ALBEDO   HWICE    BICE    GICE  ICEMIN   ICET2
JR1          OFF  DETAIL    0.25    10.0     0.6    0.07    0.05     3.0
JR2          OFF  DETAIL    0.25    10.0     0.6    0.07    0.05     3.0
```

```
TRANSPORT  SLTRC   THETA
        ULTIMATE    0.50

WSC NUMB    NWSC
jr 1          19
jr 2          21

WSC DATE    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD
jr1        368.0   440.0   455.0   500.0   570.0   600.0   620.0   767.0   830.0
           930.0   950.0  1000.0  1010.0  1050.0  1180.0  1190.0  1260.0  1315.0
          1320.0
jr2        368.0   390.0   415.0   460.0   515.0   560.0   630.0   670.0   700.0
           710.0   800.0   840.0   895.0   940.0   965.0   990.0  1050.0  1145.0
          1175.0  1270.0  1300.0

WSC COEF     WSC     WSC     WSC     WSC     WSC     WSC     WSC     WSC     WSC
jr1         0.80    0.55    0.75    0.80    0.85    0.90    0.65    0.55    0.30
            0.60    0.70    0.80    1.00    0.75    0.65    0.30    0.40    0.90
            0.65
jr2         0.70    1.00    0.60    0.25    0.40    0.60    0.20    0.70    0.60
            1.00    0.50    0.20    0.40    0.50    0.20    0.20    1.00    0.50
            0.20    0.40    0.20

HYD COEF      AX      DX    CBHE    TSED      FI TSEDFAC
JR1          1.0     1.0  1.0E-8    10.0    0.01    0.00
JR2          1.0     1.0  1.0E-8    10.0    0.01    0.00

AZ        AZFORM   AZMAX  AZCALC
jr1           W2 0.00010     EXP
jr2           W2 0.00010     EXP

FRICTION    TYPE
            MANN

N STRUC     NSTR
BR1            3
BR2            0
BR3            2
BR4            0

STR TOP    ESTRT   ESTRT   ESTRT   ESTRT   ESTRT   ESTRT   ESTRT   ESTRT   ESTRT
Br 1          10      10      10
Br 2
br 3          10      10
br4

STR BOT    ESTRB   ESTRB   ESTRB   ESTRB   ESTRB   ESTRB   ESTRB   ESTRB   ESTRB
Br 1          84      84      84
Br 2
br3           84      84
br4

SINK TYPE  SINKC   SINKC   SINKC   SINKC   SINKC   SINKC   SINKC   SINKC   SINKC
Br 1       POINT   POINT   POINT   POINT   POINT   POINT   POINT
Br 2
br3        POINT   POINT
br4

E STRUC     ESTR    ESTR    ESTR    ESTR    ESTR    ESTR    ESTR    ESTR    WSTR
Br 1       312.4  303.28  292.61
Br 2
br3        231.6  230.28
br4

W STRUC     WSTR    WSTR    WSTR    WSTR    WSTR    WSTR    WSTR    WSTR    WSTR
Br 1        10.0    10.0    10.0
Br 2
br3         10.0    10.0
br4

PIPES      NPIPE
               0

PIPE       IUSEG   IDSEG   INV-U   INV-D     DIA  LENGTH  FRIC_N  MIN_FR
pipe 1        30      33    20.0   22.00     1.0    50.0   0.045    0.10
```

```
PIPE-U     TRIBPL TRIBTOP TRIBBOT   KWTOP   KWBOT
pipe 1      DISTR                       2      24

PIPE-D     TRIBPL TRIBTOP TRIBBOT   KWTOP   KWBOT
pipe 1      DISTR

NWEIR       NWEIR
                1

SPWEIR      IUSEG   IDSEG    ZSPW      A1      B1      A2      B2
spill1         74       0  262.13 252.910     1.5       0     0.0

SP-U       TRIBPL TRIBTOP TRIBBOT   KWTOP   KWBOT
spill1    DENSITY                      15      60

SP-D       TRIBPL TRIBTOP TRIBBOT   KWTOP   KWBOT
spill1    DENSITY                       5      65

SP-GAS     ON/OFF    EQN#    AGAS    BGAS    CGAS
spill1        OFF       1   0.120  105.61

NGATE       NGATE
               12

GATE       IUGSEG  IDGSEG     ZGT     A1G     B1G     G1G     A2G     B2G     G2G
gate1          30      40  315.78  22.430   1.500   0.000   00.00    0.00    0.00
gate2          30      40  315.78  22.430   1.500   0.000   00.00    0.00    0.00
gate3          30      40  315.78  22.430   1.500   0.000   00.00    0.00    0.00
gate4          30      40  272.80 0.06627    0.50  0.9315    0.00    0.00  271.28
gate5          30      40  272.80 0.06627    0.50  0.9315    0.00    0.00  271.28
gate6          30      40  272.80 0.06627    0.50  0.9315    0.00    0.00  271.28
gate7          30      40  283.47 0.06627    0.50  0.9315    0.00    0.00  271.28
gate8          30      40  283.47 0.06627    0.50  0.9315    0.00    0.00  271.28
gate9          30      40  283.47 0.06627    0.50  0.9315    0.00    0.00  271.28
gate10         30      40  294.14 0.06627    0.50  0.9315    0.00    0.00  271.28
gate11         30      40  294.14 0.06627    0.50  0.9315    0.00    0.00  271.28
gate12         30      40  294.14 0.06627    0.50  0.9315    0.00    0.00  271.28

GATE WEIR     GA1     GB1     GA2     GB2
gate1      22.430     1.5    0.00     0.0
gate2      22.430     1.5    0.00     0.0
gate3      22.430     1.5    0.00     0.0
gate4         0.0     0.0      0.      0.
gate5         0.0     0.0      0.      0.
gate6         0.0     0.0      0.      0.
gate7         0.0     0.0      0.      0.
gate8         0.0     0.0      0.      0.
gate9         0.0     0.0      0.      0.
gate10        0.0     0.0      0.      0.
gate11        0.0     0.0      0.      0.
gate12        0.0     0.0      0.      0.

GT-U       TRIBPL TRIBTOP TRIBBOT   KWTOP   KWBOT
gate1       DISTR                      10      84
gate2       DISTR                      10      84
gate3       DISTR                      10      84
gate4       DISTR                      10      84
gate5       DISTR                      10      84
gate6       DISTR                      10      84
gate7       DISTR                      10      84
gate8       DISTR                      10      84
gate9       DISTR                      10      84
gate10      DISTR                      10      84
gate11      DISTR                      10      84
gate12      DISTR                      10      84

GT-D       TRIBPL TRIBTOP TRIBBOT   KWTOP   KWBOT
gate1       DISTR                       2      20
gate2       DISTR                       2      20
gate3       DISTR                       2      20
gate4       DISTR                       2      20
gate5       DISTR                       2      20
gate6       DISTR                       2      20
gate7       DISTR                       2      20
```

```
gate8      DISTR                       2      20
gate9      DISTR                       2      20
gate10     DISTR                       2      20
gate11     DISTR                       2      20
gate12     DISTR                       2      20

GT-GAS    ON/OFF    EQN#    AGAS     BGAS    CGAS
gate1        OFF
gate2        OFF
gate3        OFF
gate4        OFF
gate5        OFF
gate6        OFF
gate7        OFF
gate8        OFF
gate9        OFF
gate10       OFF
gate11       OFF
gate12       OFF

NWLC      NWLCON
               0

WL CON1   IUGSEG  IDGSEG   ZPUMP   START     END    WLON   WLOFF    FLOW
wlc1          30      40    312.  2000.0  2001.0  315.78  315.17     30.

WL CON2   TRIBPL TRIBTOP TRIBBOT   KWTOP   KWBOT
wlc1       DISTR                      10      84

INT WEIR     NWR
               0

WEIR SEG     IWR     IWR     IWR     IWR     IWR     IWR     IWR     IWR     IWR


WEIR TOP    EWRT    EWRT    EWRT    EWRT    EWRT    EWRT    EWRT    EWRT    EWRT


WEIR BOT    EWRB    EWRB    EWRB    EWRB    EWRB    EWRB    EWRB    EWRB    EWRB


N WDRWAL     NWD
               0

W SEGMNT     IWD     IWD     IWD     IWD     IWD     IWD     IWD     IWD     IWD
              74

W EL         EWD     EWD     EWD     EWD     EWD     EWD     EWD     EWD     EWD
           231.0

W TOP       KWDT    EWDT    EWDT    EWDT    EWDT    EWDT    EWDT    EWDT    EWDT
              15

W BOT       KWDB    EWDB    EWDB    EWDB    EWDB    EWDB    EWDB    EWDB    EWDB
              84

PUMPBACK     JBG     KTG     KBG     JBP     KTP     KBP


N TRIBS      NTR
               6

TRIB PLACE  PTRC    PTRC    PTRC    PTRC    PTRC    PTRC    PTRC    PTRC    PTRC
           DISTR   DISTR   DISTR   DISTR   DISTR   DISTR

TRIB SEG     ITR     ITR     ITR     ITR     ITR     ITR     ITR     ITR     ITR
              10      11      22      21      43      54

TRIB TOP    ETRT    ETRT    ETRT    ETRT    ETRT    ETRT    ETRT    ETRT    ETRT


TRIB BOT    ETRB    ETRB    ETRB    ETRB    ETRB    ETRB    ETRB    ETRB    ETRB


DST TRIB    DTRC
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BR1           ON
BR2          OFF
BR3           ON
BR4          OFF

PRINTER      LJC
              IV

HYD PRINT   HPRC    HPRC    HPRC    HPRC    HPRC    HPRC    HPRC    HPRC    HPRC
              ON      ON      ON      ON     OFF      ON     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF

SNP PRINT   SNPC    NSNP   NISNP
jr 1          ON       1      30
jr 2          ON       1      39

SNP DATE    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD
jr 1       368.0
jr 2       368.0

SNP FREQ    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF
jr 1      7.5000
jr 2      7.5000

SNP SEG     ISNP    ISNP    ISNP    ISNP    ISNP    ISNP    ISNP    ISNP     ISN
jr 1           2       3       4       5       6       7       8       9      10
              11      12      13      14      15      16      17      18      19
              20      21      24      25      26      27      28      29      30
              35      36      37
jr 2          40      41      42      43      44      45      46      47      48
              49      50      51      52      53      54      55      56      57
              58      59      60      61      62      63      64      65      66
              67      68      69      70      71      72      73      74      80
              81      82      83

SCR PRINT   SCRC    NSCR
jr 1          ON       1
jr 2         OFF       1

SCR DATE    SCRD    SCRD    SCRD    SCRD    SCRD    SCRD    SCRD    SCRD    SCRD
jr 1       368.5
jr 2       368.5

SCR FREQ    SCRF    SCRF    SCRF    SCRF    SCRF    SCRF    SCRF    SCRF    SCRF
jr 1      0.4000
jr 2      0.4000

PRF PLOT    PRFC    NPRF   NIPRF
jr 1          ON       1       3
jr 2          ON       1       4

PRF DATE    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD
jr 1       368.5
jr 2       368.5

PRF FREQ    PRFF    PRFF    PRFF    PRFF    PRFF    PRFF    PRFF    PRFF    PRFF
jr 1         1.0
jr 2         1.0

PRF SEG     IPRF    IPRF    IPRF    IPRF    IPRF    IPRF    IPRF    IPRF    IPRF
jr 1           6      21      30
jr 2          50      55      73      82

SPR PLOT    SPRC    NSPR   NISPR
jr 1         OFF       0       0
jr 2         OFF       0       0

SPR DATE    SPRD    SPRD    SPRD    SPRD    SPRD    SPRD    SPRD    SPRD    SPRD
jr 1
jr 2

SPR FREQ    SPRF    SPRF    SPRF    SPRF    SPRF    SPRF    SPRF    SPRF    SPRF
jr 1
jr 2
```

```
SPR SEG     ISPR    ISPR    ISPR    ISPR    ISPR    ISPR    ISPR    ISPR    ISPR
jr 1
jr 2

TSR PLOT    TSRC    NTSR
jr 1          ON       1
jr 2          ON       1

TSR DATE    TSRD    TSRD    TSRD    TSRD    TSRD    TSRD    TSRD    TSRD    TSRD
jr 1       368.5
jr 2       368.5

TSR FREQ    TSRF    TSRF    TSRF    TSRF    TSRF    TSRF    TSRF    TSRF    TSRF
jr 1        0.10
jr 2        0.10

KTTSR      KTTSC   KTTSD   KTTSI
             OFF       1       6

KTTSR DATE   KTD     KTD     KTD     KTD     KTD     KTD     KTD     KTD     KTD
            60.0

KTTSR FREQ   KTF     KTF     KTF     KTF     KTF     KTF     KTF     KTF    KTSF
            0.01

KTTSR SEG   KTSI    KTSI    KTSI    KTSI    KTSI    KTSI    KTSI    KTSI    KTSI
              14      19      48      60      76      85

WITH OUT   WDOUT  NWDOUT  NWFREQ
              ON       2    0.50

WITH SEG  IWDOUT  IWDOUT  IWDOUT  IWDOUT  IWDOUT  IWDOUT  IWDOUT  IWDOUT  IWDOUT
              74      30

VPL PLOT    VPLC    NVPL
jr 1         OFF       1
jr 2         OFF       1

VPL DATE    VPLD    VPLD    VPLD    VPLD    VPLD    VPLD    VPLD    VPLD    VPLD
jr 1        63.5     64.
jr 2

VPL FREQ    VPLF    VPLF    VPLF    VPLF    VPLF    VPLF    VPLF    VPLF    VPLF
jr 1         0.1      1.
jr 2

CPL PLOT    CPLC    NCPL
jr 1          ON       1
jr 2          ON       1

CPL DATE    CPLD    CPLD    CPLD    CPLD    CPLD    CPLD    CPLD    CPLD    CPLD
jr 1       368.5
jr 2       368.5

CPL FREQ    CPLF    CPLF    CPLF    CPLF    CPLF    CPLF    CPLF    CPLF    CPLF
jr 1       1.000
jr 2       1.000

FLUXES      FLXC    NFLX
jr 1         OFF       0
jr 2         OFF       0

FLX DATE    FLXD    FLXD    FLXD    FLXD    FLXD    FLXD    FLXD    FLXD    FLXD
jr 1
jr 2

FLX FREQ    FLXF    FLXF    FLXF    FLXF    FLXF    FLXF    FLXF    FLXF    FLXF
jr 1
jr 2

RESTART     RSOC    NRSO    RSIC
             OFF       1     OFF

RSO DATE    RSOD    RSOD    RSOD    RSOD    RSOD    RSOD    RSOD    RSOD    RSOD
           120.0
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```
RSO FREQ    RSOF    RSOF    RSOF    RSOF    RSOF    RSOF    RSOF    RSOF    RSOF
           300.0

CST COMP     CCC     PHC      KF
              ON     OFF       9

CST ACTIVE   CAC     CAC     CAC     CAC     CAC     CAC     CAC     CAC     CAC
             OFF      ON     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF

CST DERIVE   CDC     CDC     CDC     CDC     CDC     CDC     CDC     CDC     CDC
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF

CST FLUX     CFC     CFC     CFC     CFC     CFC     CFC     CFC     CFC     CFC
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF

CST ICON     C2I     C2I     C2I     C2I     C2I     C2I     C2I     C2I     C2I
jr1          0.0     0.0     0.0     0.0     0.0   0.001   0.002    0.14     0.1
             0.1     0.0     0.7   2.022    0.10    0.10     0.0    0.25     1.0
            0.05     1.0     0.0     0.0     0.0     0.0     0.0    0.00     0.0
            0.05     1.0     0.0     0.0     0.0     0.0     0.0
jr2          0.0     0.0     0.0     0.0     0.0   0.001   0.002    0.14     0.1
             0.1     0.0     0.7   2.022    0.10    0.10     0.0    0.25     1.0
            0.05     1.0     0.0     0.0     0.0     0.0     0.0    0.00     0.0
            0.05     1.0     0.0     0.0     0.0     0.0     0.0

CST PRINT   CPRC    CPRC    CPRC    CPRC    CPRC    CPRC    CPRC    CPRC    CPRC
             OFF      ON     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF

CIN CON    CINAC   CINAC   CINAC   CINAC   CINAC   CINAC   CINAC   CINAC   CINAC
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF

CTR CON    CTRAC   CTRAC   CTRAC   CTRAC   CTRAC   CTRAC   CTRAC   CTRAC   CTRAC
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF

CDT CON    CDTAC   CDTAC   CDTAC   CDTAC   CDTAC   CDTAC   CDTAC   CDTAC   CDTAC
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF

CPR CON    CPRAC   CPRAC   CPRAC   CPRAC   CPRAC   CPRAC   CPRAC   CPRAC   CPRAC
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF

EX COEF    EXH2O    EXSS    EXOM    BETA
JR1         0.45    0.01    0.01    0.45
JR2         0.45    0.01    0.01    0.45

ALG EX      EXA1    EXA2    EXA3    EXA4    EXA5    EXA6
             0.2     0.2     0.2

COLIFORM  COLQ10   COLDK
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JR1         1.04     1.4
JR2         1.04     1.4

C_ARBIT C_ARBQ10 C_ARBDK  C_ARBS
JR1         1.04    0.25    0.50
JR2         1.04    0.25    0.50

S SOLIDS     SS1     SS2     SS3     SS4     SS5     SS6     SS7     SS8     SS9
             1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0

ALGAL RATE    AG      AR      AE      AM      AS    AHSP    AHSN   AHSSI    ASAT
Alg1         1.5    0.02    0.02    0.05    0.04   0.003   0.014   0.003    75.0
Alg2         2.5    0.02    0.02    0.05    0.10   0.003   0.014   0.000    75.0
Alg3         0.5    0.02    0.02    0.01    0.02   0.003   0.010   0.000    75.0
Alg4         0.8    0.02    0.02    0.01    0.05   0.003   0.012   0.000    75.0
Alg5         0.8    0.02    0.02    0.01    0.15   0.009   0.015   0.000    75.0
Alg6         3.5    0.02    0.02    0.01    0.01   0.003   0.010   0.000    75.0

ALGAL TEMP   AT1     AT2     AT3     AT4     AK1     AK2     AK3     AK4
Alg1         5.0    18.0    20.0    24.0     0.1    0.99    0.99    0.01
Alg2        10.0    30.0    35.0    40.0     0.1    0.99    0.99    0.01
Alg3        10.0    35.0    40.0    50.0     0.1    0.99    0.99    0.01
Alg4        10.0    35.0    40.0    50.0     0.1    0.99    0.99    0.01
Alg5        10.0    20.0    25.0    30.0     0.1    0.99    0.99    0.01
Alg6        15.0    20.0    22.0    25.0     0.1    0.99    0.99    0.01

ALG STOICH  ALGP    ALGN    ALGC   ALGSI   ACHLA
Alg1       0.005    0.08    0.45    0.18    65.0
Alg2       0.005    0.08    0.45    0.00    65.0
Alg3       0.005    0.08    0.45    0.00    65.0
Alg4       0.005    0.08    0.45    0.00    65.0
Alg5       0.005    0.08    0.45    0.00    65.0
Alg6       0.005    0.08    0.45    0.00    65.0

DOM       LDOMDK  RDOMDK   LRDDK
jr1         0.12   0.001   0.001
jr2         0.12   0.001   0.001

POM       LPOMDK  RPOMDK   LRPDK    POMS    APOM
jr1         0.08   0.001   0.001     0.5     0.8
jr2         0.08   0.001   0.001     0.5     0.8

OM STOICH   ORGP    ORGN    ORGC   ORGSI
jr1        0.005    0.08    0.45    0.18
jr2        0.005    0.08    0.45    0.18

OM RATE     OMT1    OMT2    OMK1    OMK2
jr1          4.0    30.0     0.1    0.99
jr2          4.0    30.0     0.1    0.99

CBOD        KBOD    TBOD    RBOD
jr1         0.25  1.0147    1.85
jr2         0.25  1.0147    1.85

PHOSPHOR    PO4R   PARTP
jr1        0.015     0.3
jr2        0.015     0.3

AMMONIUM    NH4R   NH4DK
jr1         0.08    0.12
jr2         0.08    0.12

NH4 RATE   NH4T1   NH4T2   NH4K1   NH4K2
jr1          5.0    25.0     0.1    0.99
jr2          5.0    25.0     0.1    0.99

NITRATE    NO3DK
jr1         0.05
jr2         0.05

NO3 RATE   NO3T1   NO3T2   NO3K1   NO3K2
jr1          5.0    25.0     0.1    0.99
jr2          5.0    25.0     0.1    0.99

SILICA      DSIR    PSIS   PSIDK  PARTSI
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```
jr1             0.1     0.0     0.3     0.2
jr2             0.1     0.0     0.3     0.2

IRON            FER     FES
jr1             0.1     0.0
jr2             0.1     0.0

SED CO2        CO2R
jr1             0.1
jr2             0.1

STOICHMT   O2NH4    O2OM    O2AR    O2AG
jr1         4.57     1.4     1.1     1.4
jr2         4.57     1.4     1.1     1.4

O2 LIMIT   O2LIM
            0.00

SEDIMENT    SEDC   PRNSC   SEDCI    SEDK    FSOD
JR1          OFF      ON     0.0    0.10     1.0
JR2          OFF      ON     0.0    0.10     1.0

SOD RATE   SODT1   SODT2   SODK1   SODK2
jr1          4.0    30.0     0.1    0.99
jr2          4.0    30.0     0.1    0.99

SHIFT DECAY  SDC
jr1          OFF
jr2          OFF

S DEMAND     SOD     SOD     SOD     SOD     SOD     SOD     SOD     SOD     SOD
             0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3
             0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3
             0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3
             0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3
             0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3
             0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3
             0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3
             0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3
             0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3     0.3
             0.3     0.3     0.3

REAERATION  type    EQN#   COEF1   COEF2   COEF3   COEF4
jr1         LAKE       6
jr2         LAKE       6

RSI FILE..............................RSIFN...................................
        rsi.npt

QWD FILE..............................QWDFN...................................
        qseep_r2.npt

BTH FILE..............................BTHFN...................................
jr 1    bth_res1.npt
jr 2    bth_res2b.npt

MET FILE..............................METFN...................................
jr 1    pdxmet.npt
jr 2    pdxmet2.npt

VPR FILE..............................VPRFN...................................
jr 1    vpr.npt
jr 2    vpr2.npt

LPR FILE..............................LPRFN...................................
jr 1    lpr1.npt
jr 2    lpr2.npt

QIN FILE..............................QINFN...................................
Br 1    BULLRQ.npt
Br 2    BEARQ.NPT
br 3    not_used
br 4    southq.npt

TIN FILE..............................TINFN...................................
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Br 1    BULLRT.npt
Br 2    BEART.NPT
br 3    not_used
br 4    southt.npt

CIN FILE..............................CINFN...................................
Br 1    cin_br1.npt
Br 2    cin_br2.npt
br 3    not_used
br 4    cin_br4.npt

QOT FILE..............................QOTFN...................................
Br 1    ph1q.npt
Br 2    not_used
br 3    ph2q3.npt
br 4    not_used

QGT FILE..............................QGATE...................................
        qgate12.npt

QTR FILE..............................QTRFN...................................
Tr 1    fircrkq.npt
Tr 2    northq.npt
Tr 3    deerq.npt
Tr 4    cougarq.npt
tr 5    fivemq.npt
tr 6    campq.npt

TTR FILE..............................TTRFN...................................
Tr 1    fircrkt.npt
Tr 2    northt.npt
Tr 3    deert.npt
Tr 4    cougart.npt
tr 5    fivemt.npt
tr 6    campt.npt

CTR FILE..............................CTRFN...................................
Tr 1    ctr_tr1.npt
Tr 2    ctr_tr2.npt
Tr 3    ctr_tr3.npt
Tr 4    ctr_tr4.npt
tr 5    ctr_tr5.npt
tr 6    ctr_tr6.npt

QDT FILE..............................QDTFN...................................
Br 1    qwbR1_11.npt
Br 2
br 3    qwbR2_34.npt
br 4

TDT FILE..............................TDTFN...................................
Br 1    r1distT.npt
Br 2
br 3    r2distT.npt
br 4

CDT FILE..............................CDTFN...................................
Br 1    cwbal.npt
Br 2
br 3    cwbal2.npt
br 4

PRE FILE..............................PREFN...................................
Br 1    pre_br1.npt - not used
Br 2
Br 3
Br 4

TPR FILE..............................TPRFN...................................
Br 1    tpr_br1.npt - not used
Br 2
Br 3
Br 4

CPR FILE..............................CPRFN...................................
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```
Br 1    cpr_br1.npt - not used
Br 2
Br 3
Br 4

EUH FILE..............................EUHFN...................................
Br 1
Br 2
Br 3
Br 4

TUH FILE..............................TUHFN...................................
Br 1
Br 2
Br 3
Br 4

CUH FILE..............................CUHFN...................................
Br 1
Br 2
Br 3
Br 4

EDH FILE..............................EDHFN...................................
Br 1    edh_br1.npt
br 2    edh_br1.npt
br 3
br 4

TDH FILE..............................TDHFN...................................
Br 1    tdh_br1.npt
Br 2    tdh_br1.npt
br 3
br 4

CDH FILE..............................CDHFN...................................
Br 1    cdh_br1.npt
Br 2    cdh_br1.npt
br 3
br 4

SNP FILE..............................SNPFN...................................
jr 1    snp1.opt
jr 2    snp2.opt

TSR FILE..............................TSRFN...................................
jr 1    tsr1.opt
jr 2    tsr2.opt

PRF FILE..............................PRFFN...................................
jr 1    prf1.opt
jr 2    prf2.opt

TKT FILE..............................TSRKTFN.................................
        tsrkt.opt

VPL FILE..............................VPLFN...................................
jr 1    vpl1.opt
jr 2    vpl2.opt

CPL FILE..............................CPLFN...................................
jr 1    cpl1.opt
jr 2    cpl2.opt

SPR FILE..............................SPRFN...................................
jr 1    spr1.opt
jr 2    spr2.opt

FLX FILE..............................KFLFN...................................
jr 1    kfl1.opt
jr 2    kfl2.opt

WSF FILE..............................WSFFN...................................
jr 1    wsf1.opt
jr 2    wsf2.opt
```