3.0 MODEL CALIBRATION: 1995-1996 AND 2001-2002

This section of the report discusses issues relative to the calibration effort. Data input to the model as discussed in Section 2.0 is reviewed and revised as necessary during model calibration.

The calibration effort focused on model predictions of hydrodynamics (flow and water level), temperature, bacteria (fecal coliform), and eutrophication model parameters (such as nutrients, algae, dissolved oxygen, and organic matter). The model calibration periods were from May 25, 1995 to November 30, 1996 and April 1, 2001 to July 31, 2002.

3.1 Hydrodynamic Calibration

There is one flow and water level gage station along the sections of river being modeled. This is a USGS gage (12113000), located near Auburn at River Mile 31.30. Figure 263 shows the location of this station.

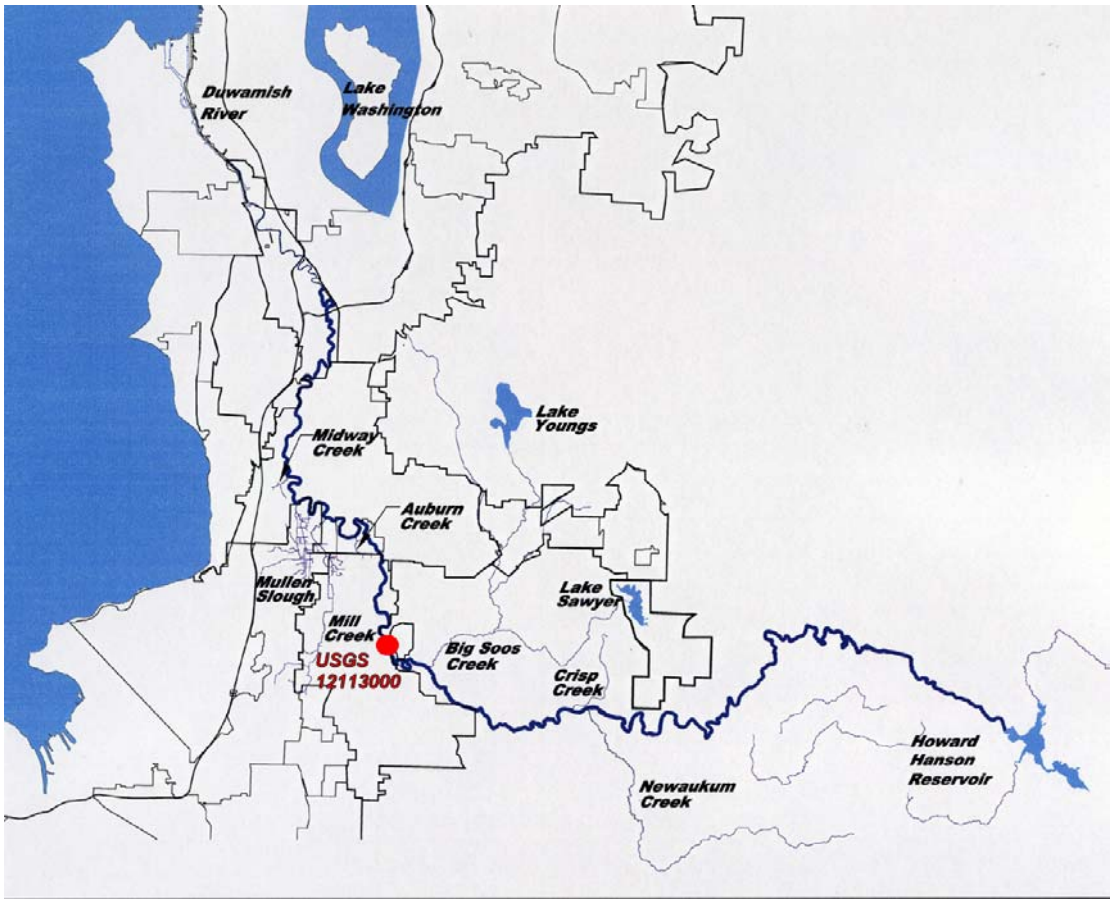


Figure 263: Flow and Water Level Calibration Station

3.1.1 2001-2002

A review of literature indicated there are many springs that contribute flow to the Green River, especially upstream of the upper project boundary (Luzier 1969, Woodward et. al. 1995). Luzier 1969 estimated average winter flow rates as 6.30 cms, and summer rates at 1.26 cms from flows in the Green River Gorge. To account for groundwater in the model, 6.30 cms was added to flow at the upstream boundary from October 1, 2001 to March 30, 2002, and 1.26 cms was added to the upstream flow from April 1, 2002 to July 31, 2002. Initial model results at Site 12113000 showed that flow was under-predicted during summer months and over-predicted during winter months.

Since groundwater contributions were approximated, it was assumed this was the source of the difference between model values and data. Flow data at the upstream boundary were adjusted to calibrate flow. Figure 264 shows the initial and revised flow added at the upstream boundary and shows the model values and data at Station 12113000. Table 10 shows the flow error statistics.

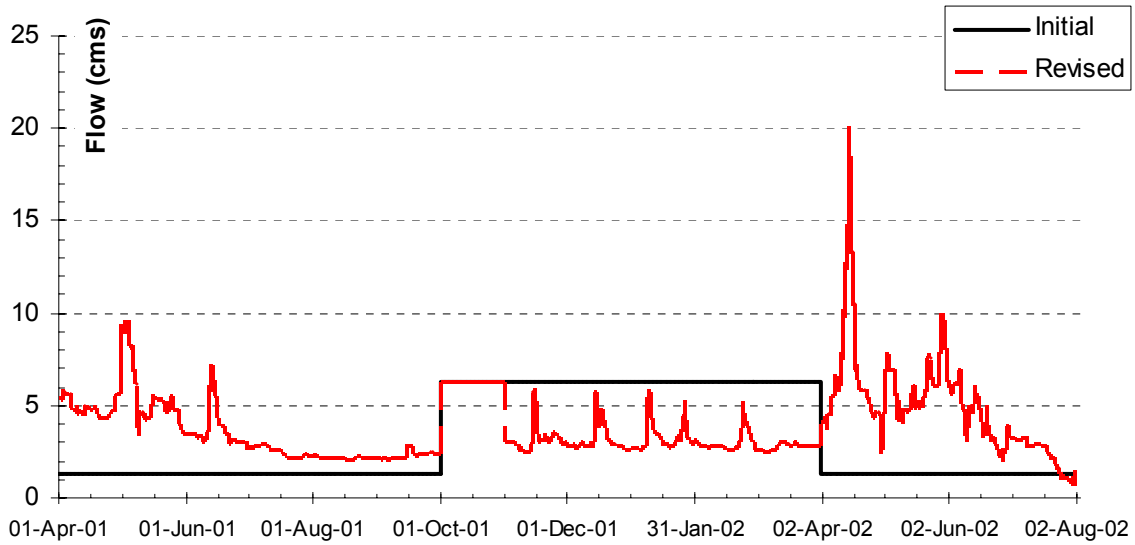


Figure 264: Initial and Revised Flow Additions at Upstream Boundary, 2001-2002

Table 10: Flow Error Statistics, 2001-2002 Model Run Period

No. of Data Comparisons	Mean Error (cms)	AME (cms)	RMS Error (cms)
11665	0.05	1.6	3.1

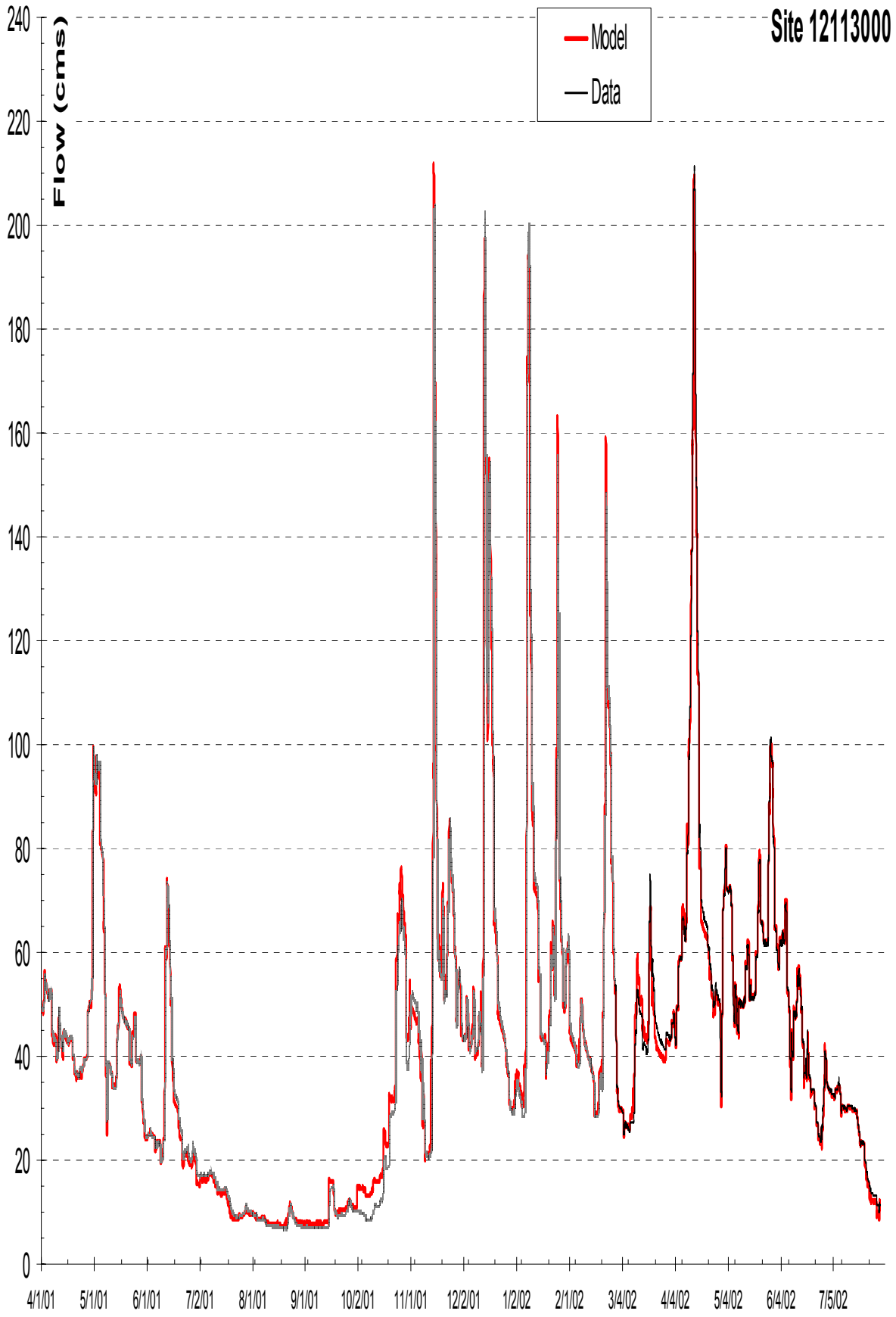

Site 12113000
Model
Data
Flow (cms)
240
220
200
180
160
140
120
100
80
60
40
20
0
4/1/01
5/1/01
6/1/01
7/2/01
8/1/01
9/1/01
10/2/01
11/1/01
12/2/01
1/2/02
2/1/02
3/4/02
4/4/02
5/4/02
6/4/02
7/5/02

Figure 265: Flow Comparison - April 2001-July 2002

Water level was also monitored at the same location on the Green River (USGS 12113000). Calibrating water surface elevation at this location required adjustments to the bathymetry and friction factor. Figure 266 shows the water surface elevation for the model calibration period, and Table 11 shows the error statistics.

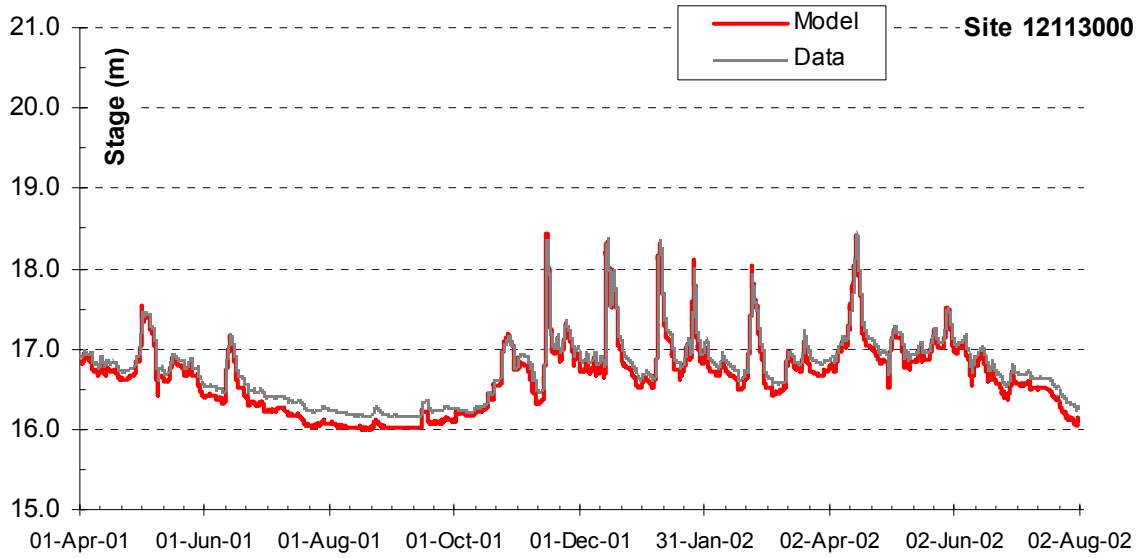


Figure 266: Water Surface Elevation Comparison - April 2001 - July 2002

Table 11: Water Surface Elevation Error Statistics, 2001-2002 Model Run Period

No. of Data Comparisons	Mean Error (m)	AME (m)	RMS Error (m)
11665	-0.11	0.11	0.12

3.1.2 1995-1996

As with the 2001-2002 model run period, water level and flow values were compared with data at USGS Station 12113000, near Auburn, Washington. Since groundwater inflows were approximated at the upstream boundary, these values were adjusted to calibrate model values with data at the USGS station. Figure 267 shows the initial and revised flow added at the upstream boundary,

Figure 268 shows the model results and data for flow, Figure 269 shows water surface elevation data and model results, and Table 12 shows the error statistics for this model calibration period.

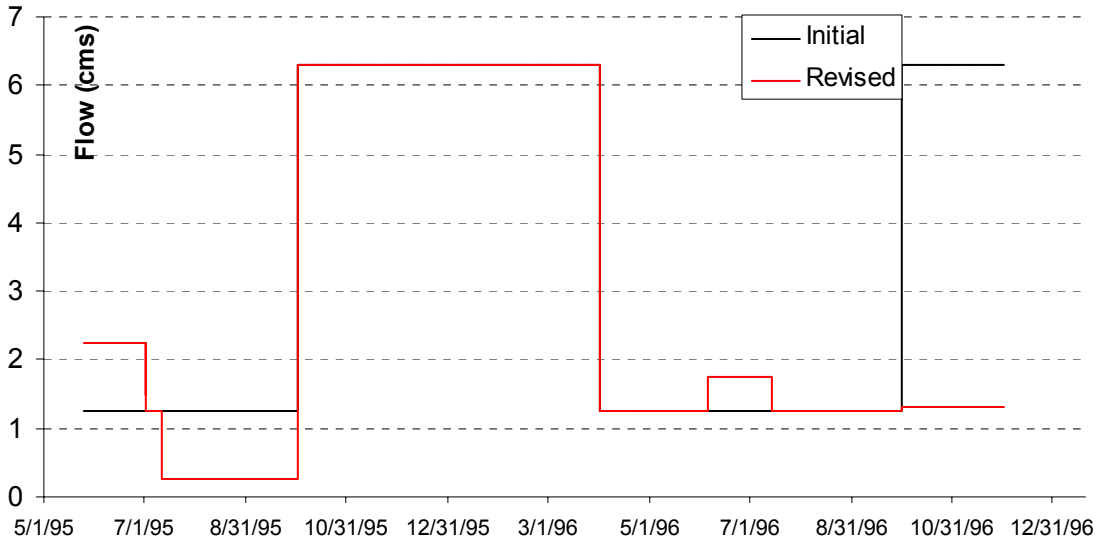


Figure 267: Initial and Revised Flow Additions at Upstream Boundary, May 25, 1995-Nov 1996

Table 12: Flow Error Statistics, 1995-1996 Model Run Period

No. of Data Comparisons	Mean Error (cms)	AME (cms)	RMS Error (cms)
13312	0.13	2.5	5.6

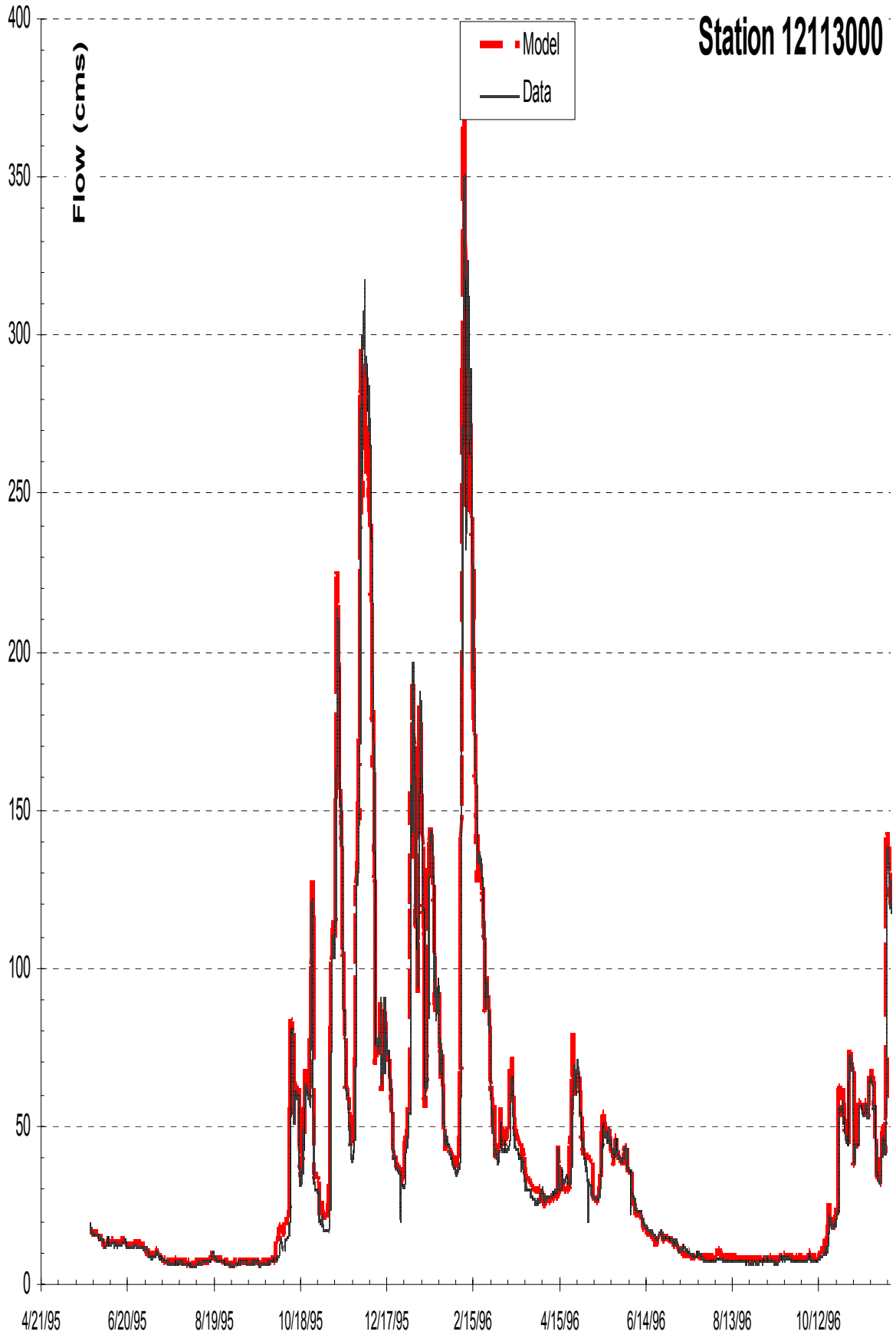


Figure 268: Flow Comparison - May 25, 1995 to November 1996

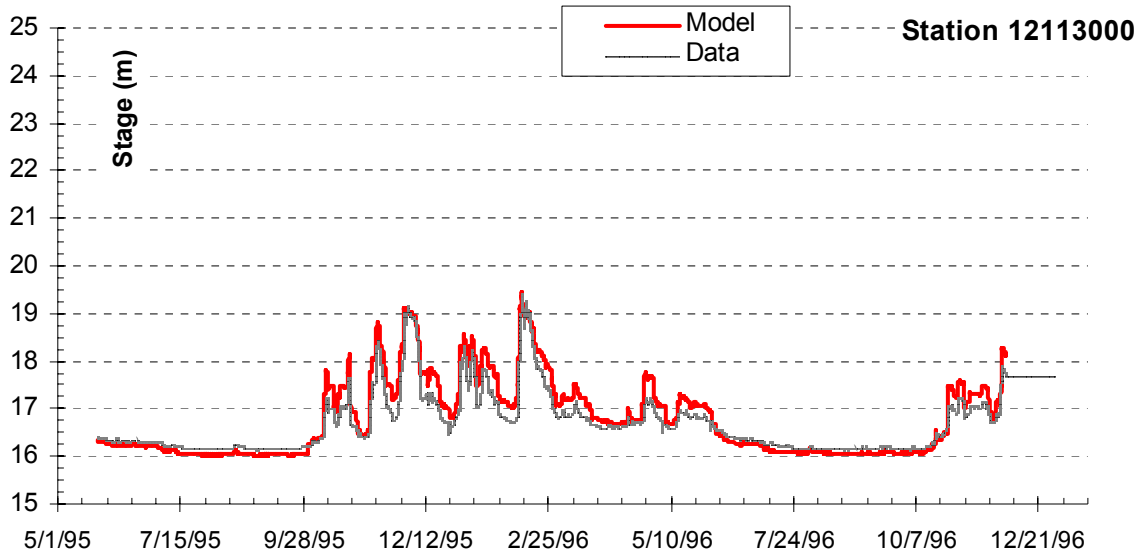


Figure 269: Water Surface Elevation Comparison - 1995-1996 Model Run Period

Table 13: Water Surface Elevation Error Statistics, 1995-1996 Model Run Period

No. of Data Comparisons	Mean Error (m)	AME (m)	RMS Error (m
13312	0.10	0.21	0.26

3.2 Temperature Calibration

3.2.1 2001-2002

Monitoring Sites

There were four locations available for temperature calibration during this run period. Figure 270 shows the site locations, and Table 14 lists the time periods of data sampling and the river mile of the sampling site.

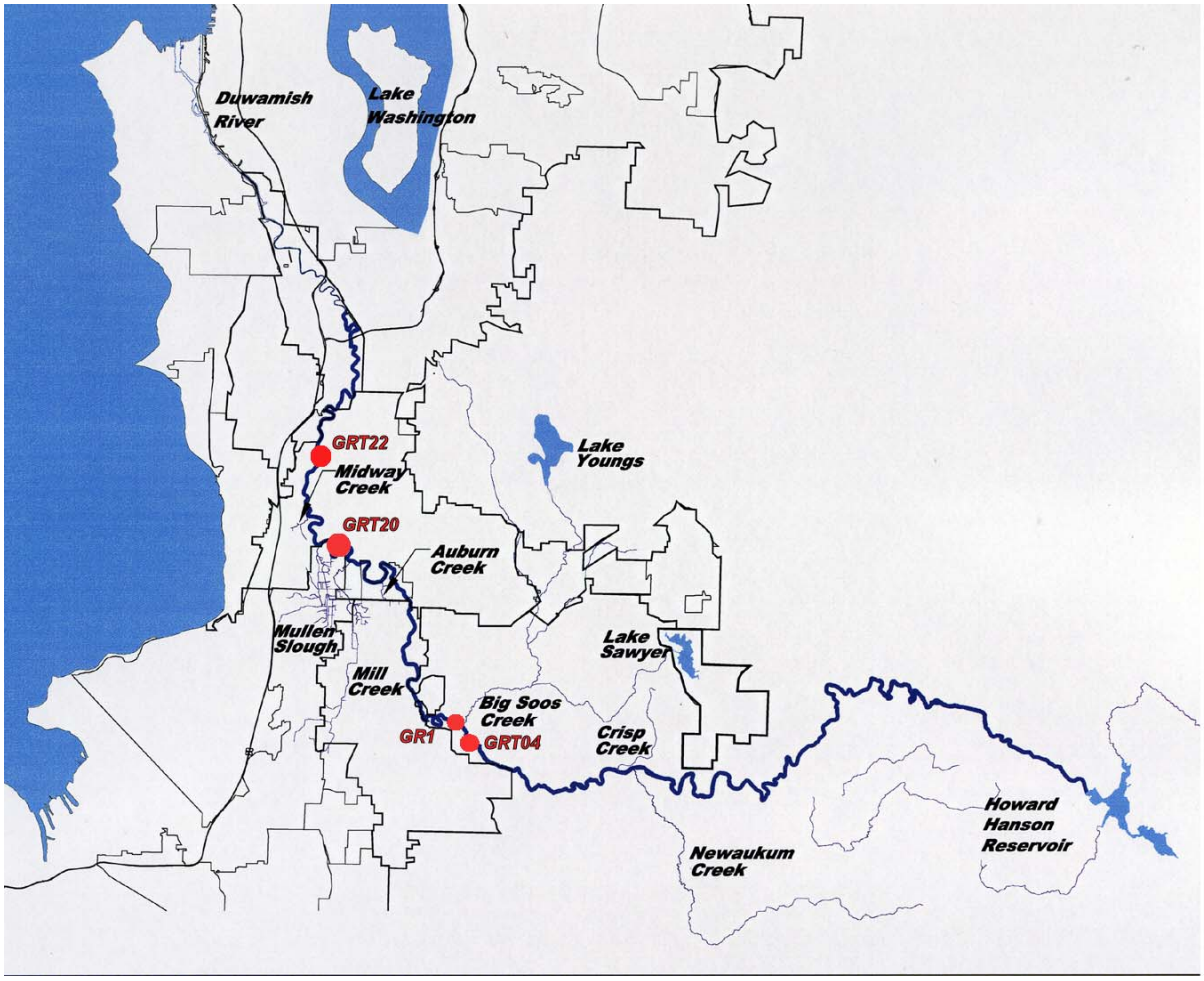


Figure 270: 2001-2002 Temperature Calibration Sites

Table 14: 2001-2002 Temperature Calibration Sites

Locator Station	Description	River Mile	Time Period of Data
GRT22	Van Doren's Landing	18.60	7/9/2002 – 7/31/2002
GRT20	Near Mill Creek	23.20	7/9/2002 – 7/31/2002
GR1	Near Big Soos Creek	33.80	4/1/2001 – 9/10/01 11/09/01 – 9/12/2002
GRT04	Porter Levee	34.40	7/27/2001 – 11/09/2001

Temperature adjustments were made by reviewing which model layers contained water during the summer months and adjusting the width of these layers at and upstream of the calibration segments. By decreasing segment widths, the depth was increased, and the area exposed to solar radiation was decreased, thus decreasing solar heating.

Figure 271 and Figure 272 shows model value and data temperature comparisons for Site GRT04, and Figure 273 and Figure 274 shows the same comparison for Site GR1 (See Figure 270 for site

locations). Error statistics can be found in Table 15

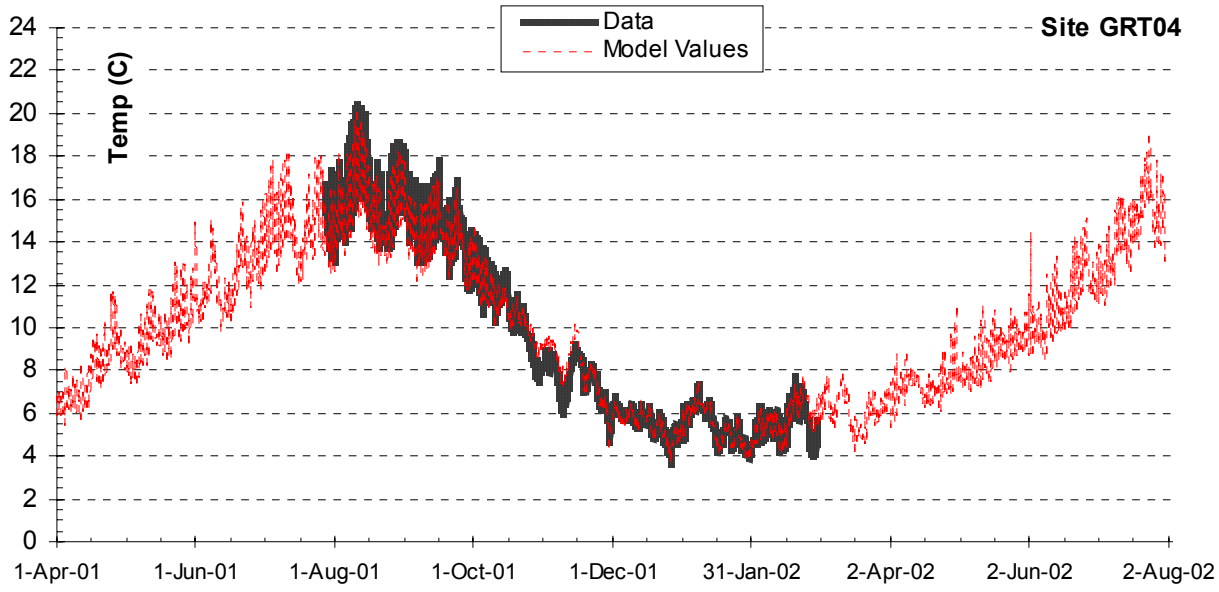


Figure 271: Temperature comparison at Site GRT04, 2001-2002 Model Run Period

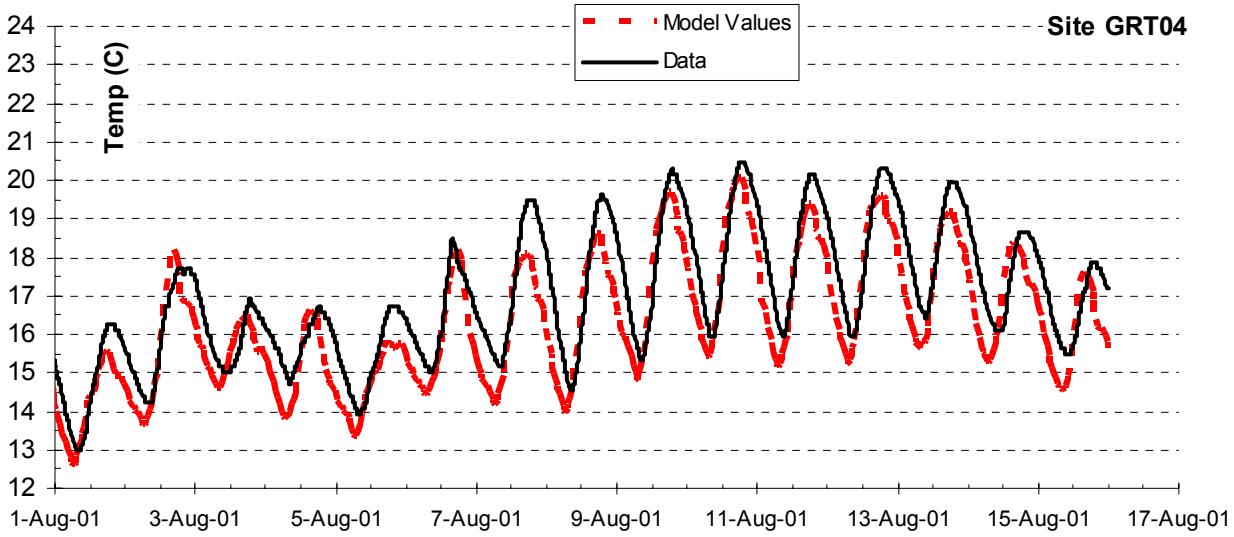


Figure 272: Temperature Comparison at Site GRT04, Aug 1-Aug 16, 2001

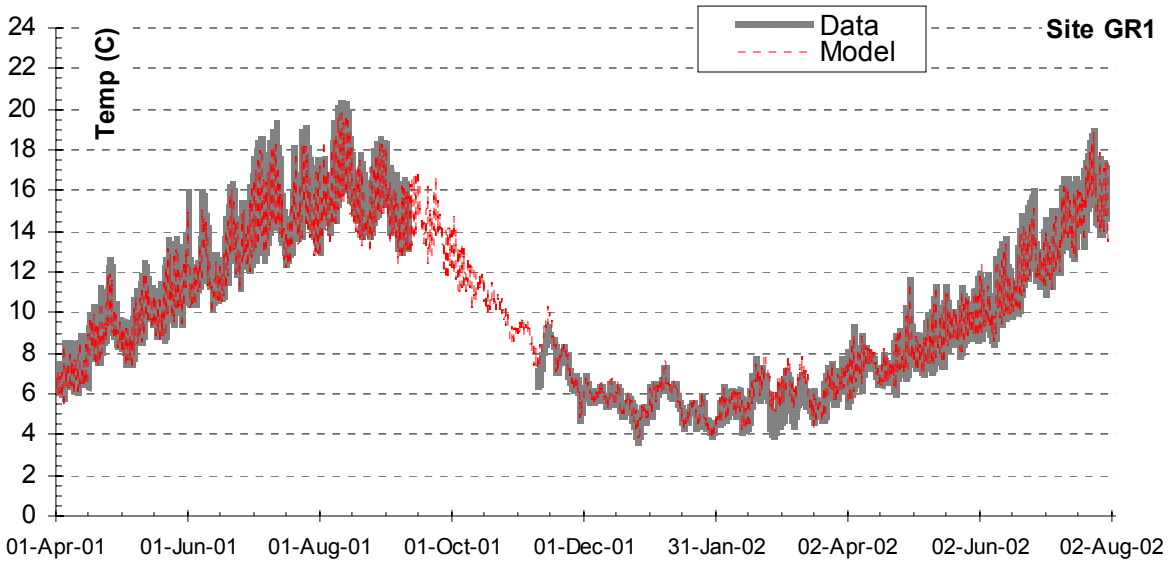


Figure 273: Temperature comparison at Site GR1, 2001-2002 Model Run Period

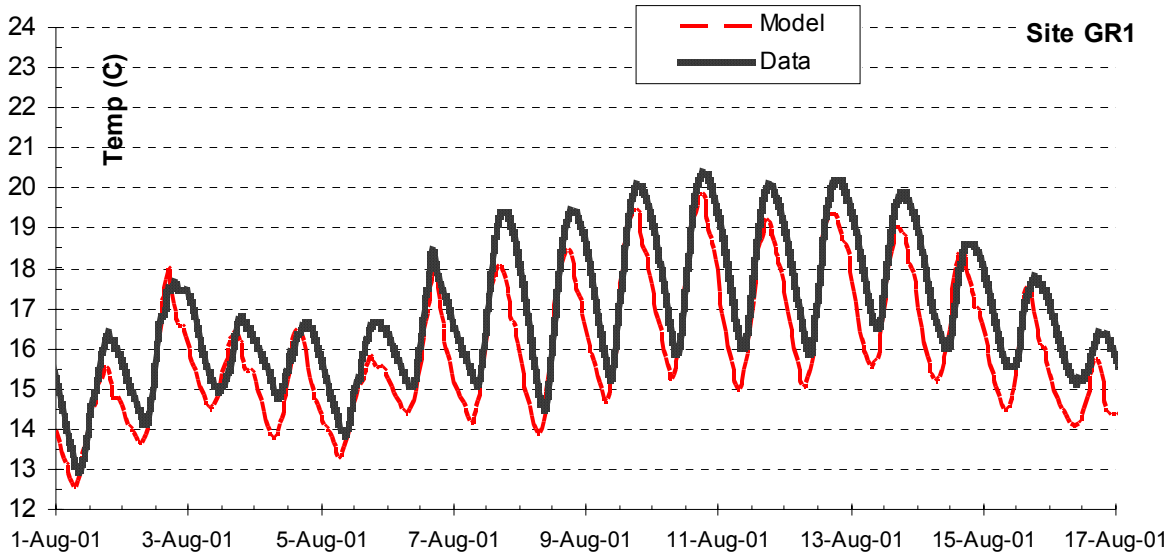


Figure 274: Temperature Comparison at Site GR1, Aug 1-Aug 16, 2001

Temperature was sampled in July 2002 at Sites GRT22 and GRT20 (See Figure 270 for site locations). Figure 275 and Figure 276 show the comparisons, and Table 15 shows the error statistics for all four sites.

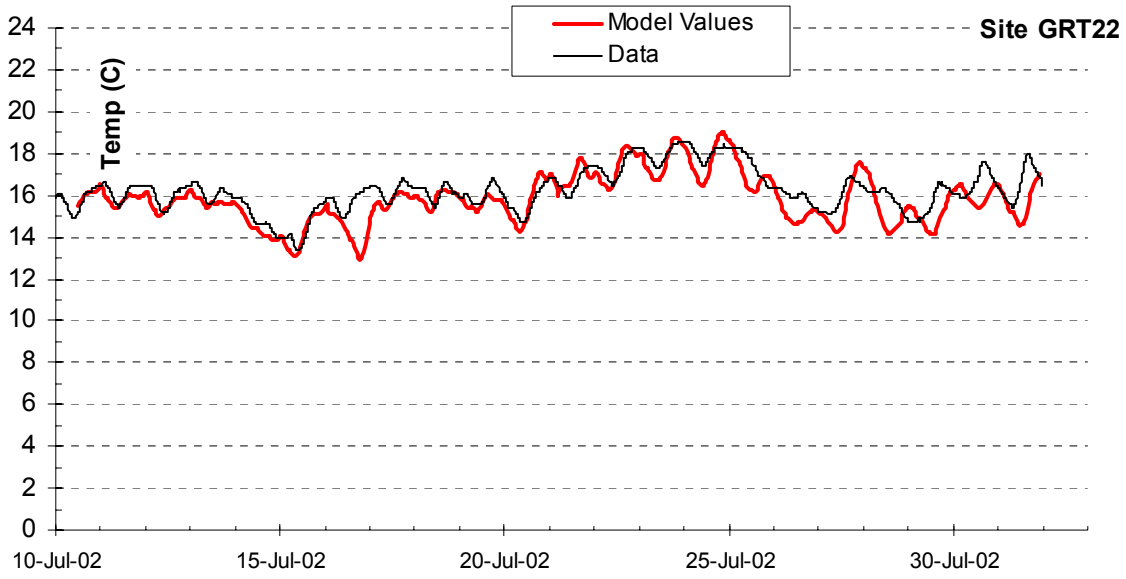


Figure 275: Temperature Comparison at Site GRT22, 2001-2002 Model Run Period

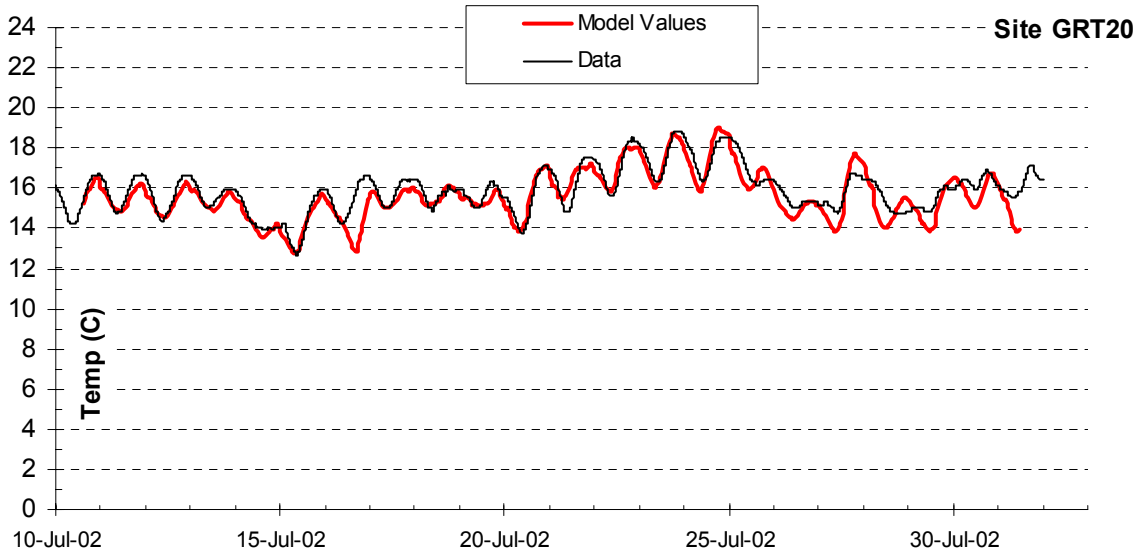


Figure 276: Temperature Comparison at Site GRT20, 2001-2002 Model Run Period

Table 15: Temperature Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error (ºC)	AME (ºC)	RMS Error (ºC)
GRT04	8517	0.009	0.4	0.6
GR1	10209	-0.3	0.4	0.6
GRT20	510	-0.2	0.5	0.6
GRT22	510	-0.4	0.6	0.8

3.2.2 1995-1996

Monitoring Sites

Figure 277 shows the temperature monitoring locations for the May 25, 1995 to November 30, 1996 calibration period and Table 16 lists the sites, including time period of available data and river mile location of the site.

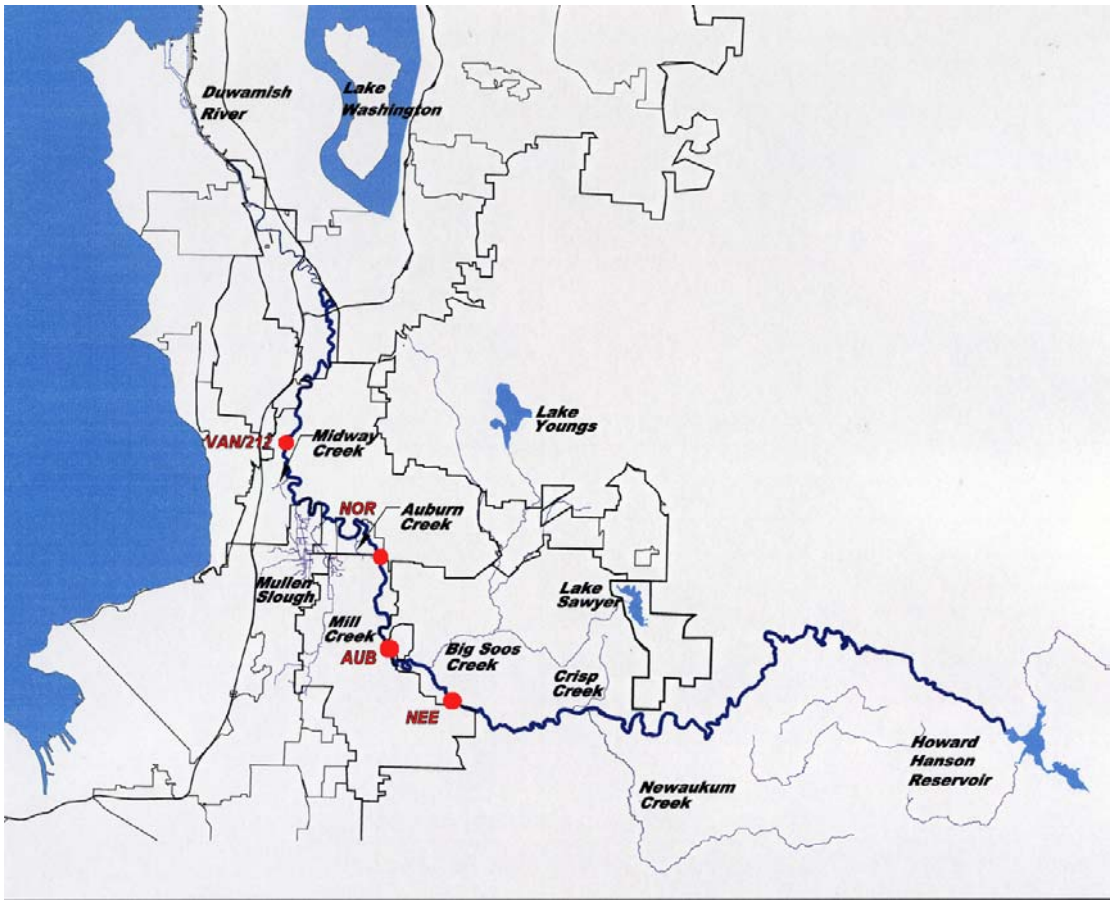


Figure 277: 1995-1996 Temperature Calibration Sites

Table 16: 1995-1996 Temperature Calibration Sites

Locator Station	Description	River Mile	Time Period of Data
VAN/212	Van Doren's Landing/ S. 212th Street	18.60	5/24/1995 – 11/2/1995 6/7/1996 – 11/2/1996
NOR	North Green River Park	27.50	5/25/1995 – 11/3/1995 6/7/1996 – 11/2/1996
AUB/2ND	Below Big Soos Creek/ NE 2nd Street	31.30	7/21/1995 – 10/17/1995 7/2/1996 – 9/5/1996
NEE	Neely Bridge	34.40	5/25/1995 – 11/3/1995 6/7/1996 – 10/29/1996

Figure 278 through Figure 281 show the comparison of model temperature values and data for the full model period, and Table 17 shows the model error statistics. As with the 2001-2002 model run period, bathymetry adjustments were used to calibrate temperature.

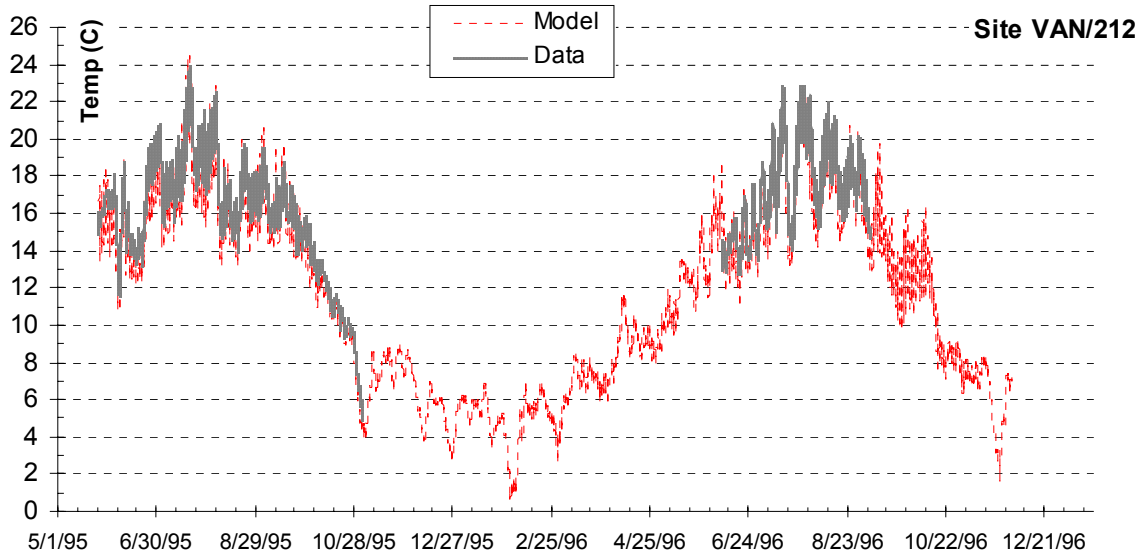


Figure 278: Temperature Comparison at Site VAN/212, May 25, 1995 - Nov 1996

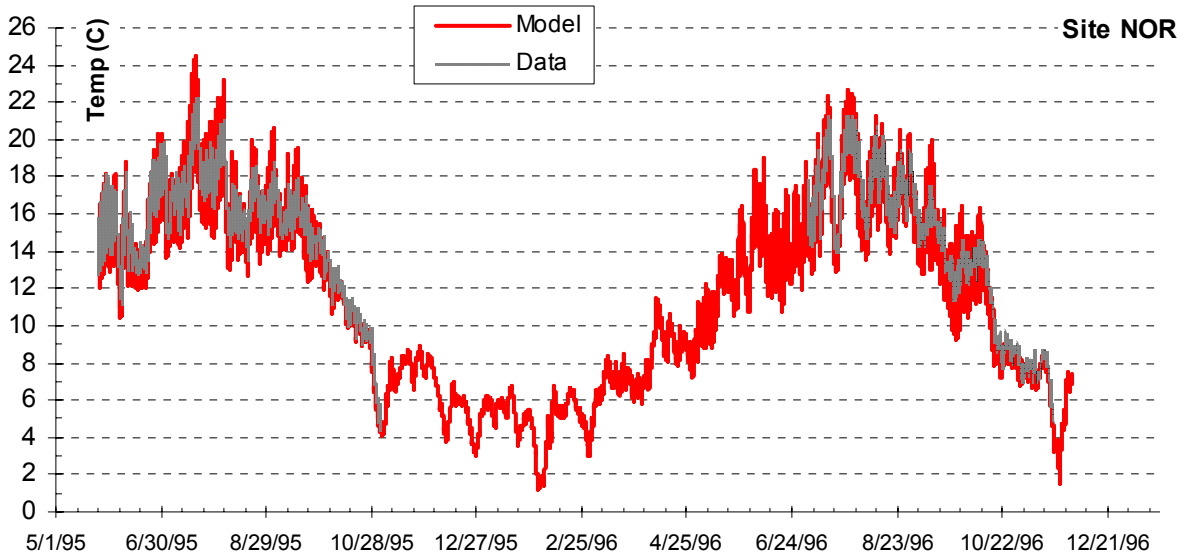


Figure 279: Temperature Comparison at Site NOR, May 25, 1995 - Nov 1996

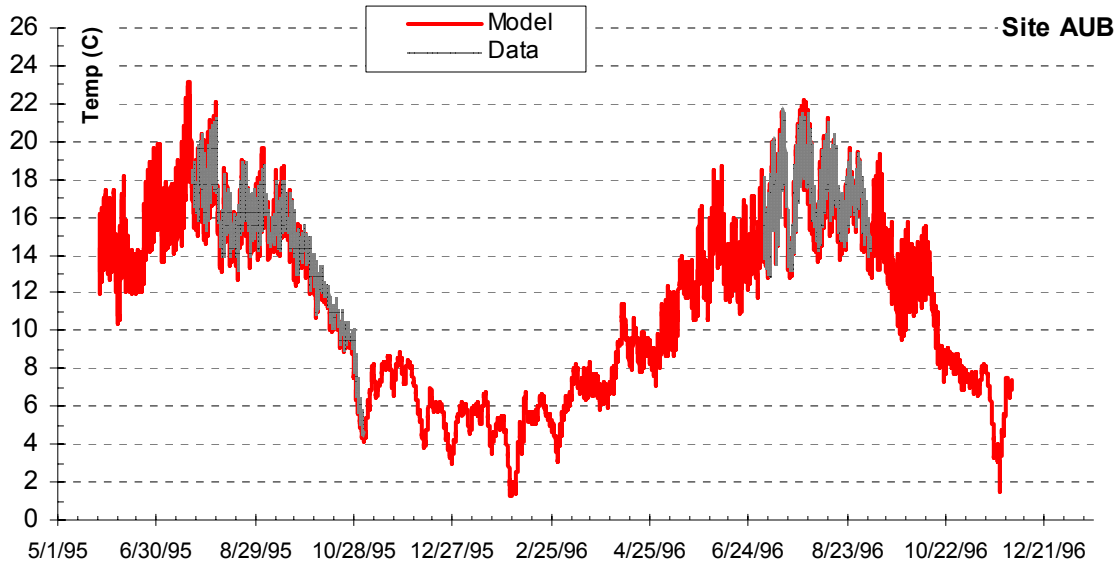


Figure 280: Temperature Comparison at Site AUB - May 25, 1995 - Nov. 1996

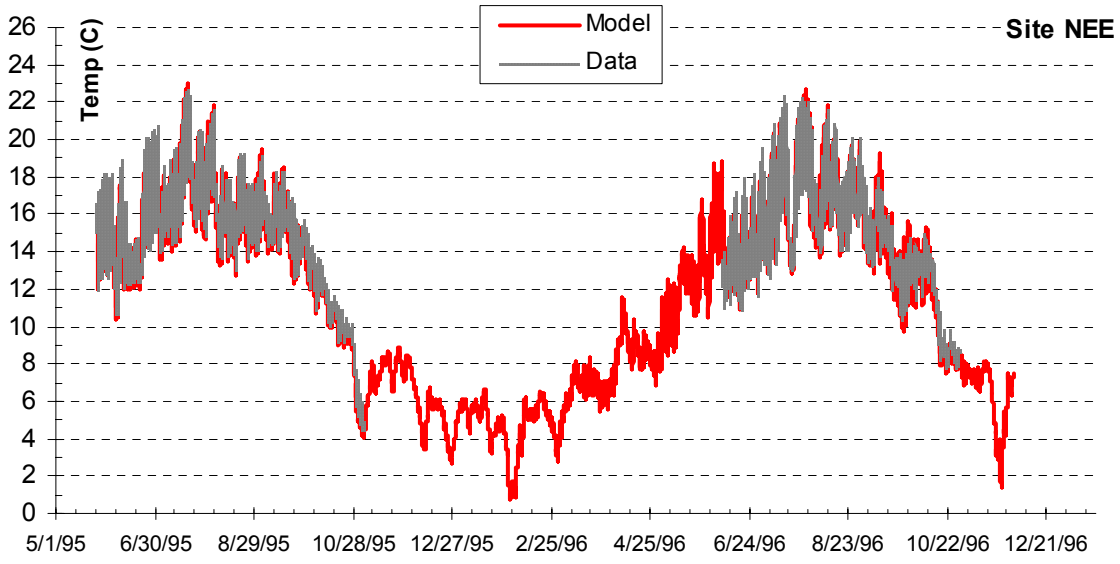


Figure 281: Temperature Comparison at Site NEE - May 25, 1995 - Nov. 1996

Figure 282 shows model and data temperature comparisons at Site NEE for August 1995, Figure 283 shows the same comparison for Site AUB, and Figure 284 shows the comparison at Site AUB for August 1996.

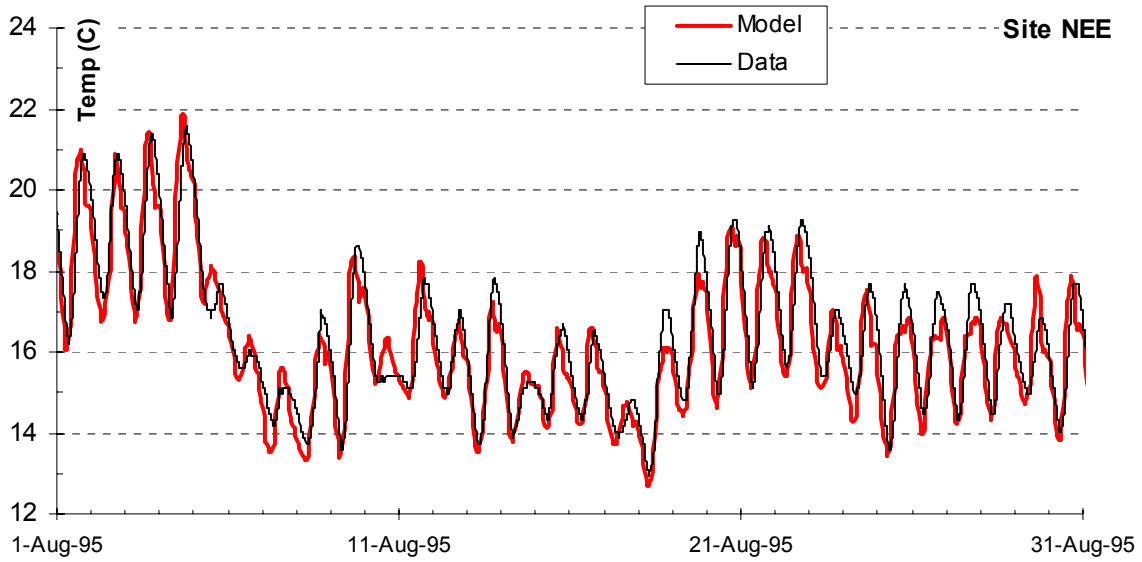


Figure 282: Temperature Comparison at Site NEE - August 1995

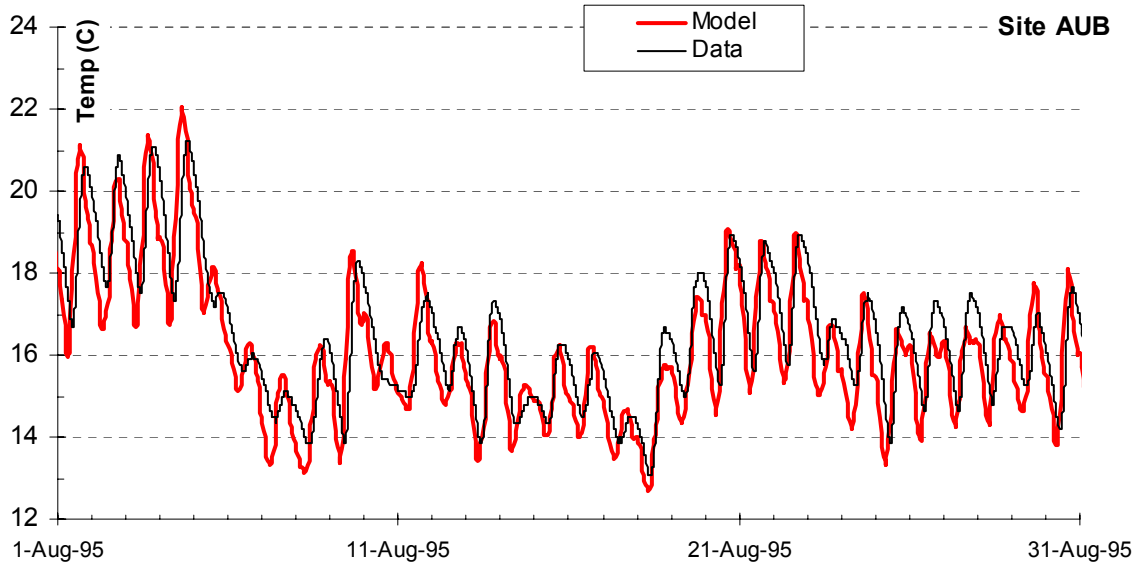


Figure 283: Temperature Comparison at Site AUB - August 1995

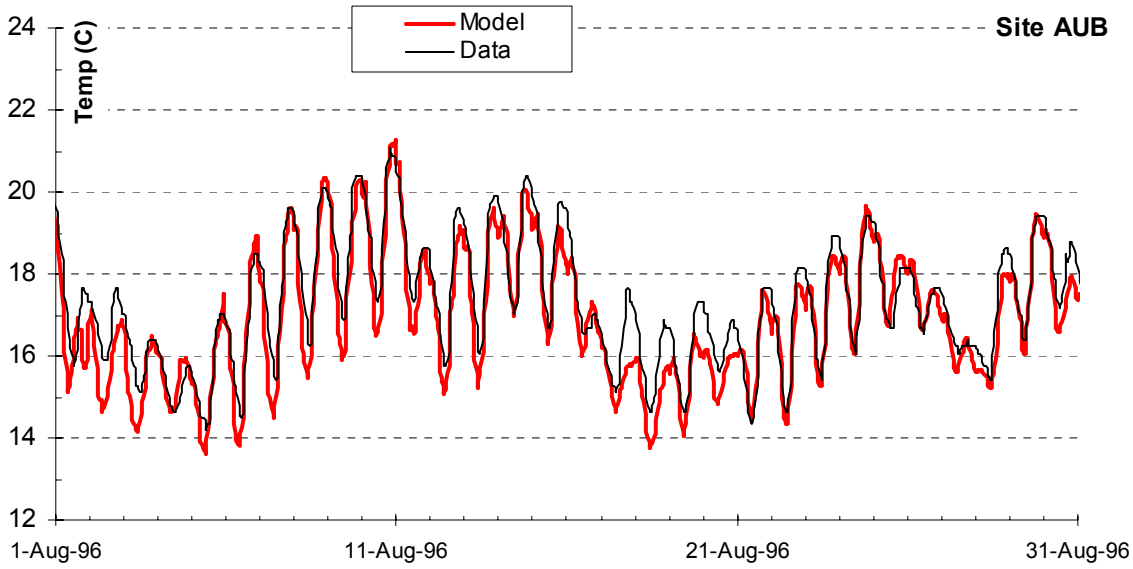


Figure 284: Temperature Comparison at Site AUB - August 1996

Table 17: Temperature Error Statistics, 1995-1996 Model Run Period

Site	No. of Data Comparisons	Mean Error (ºC)	AME (ºC)	RMS Error (ºC)
NEE	5599	0.1	0.7	0.9
AUB	3681	0.2	0.6	0.8
NOR	3584	0.2	0.9	1.0
VAN/212	3855	-0.7	0.9	1.1

3.3 Water Quality Calibration

Figure 285 shows the locations of the water quality monitoring sites on the river. Table 18 lists the sites, along with the periods of available data and river mile. Sites 0311 and A319 have data for both model run periods, and Site G319 has data beginning in January of 2002.

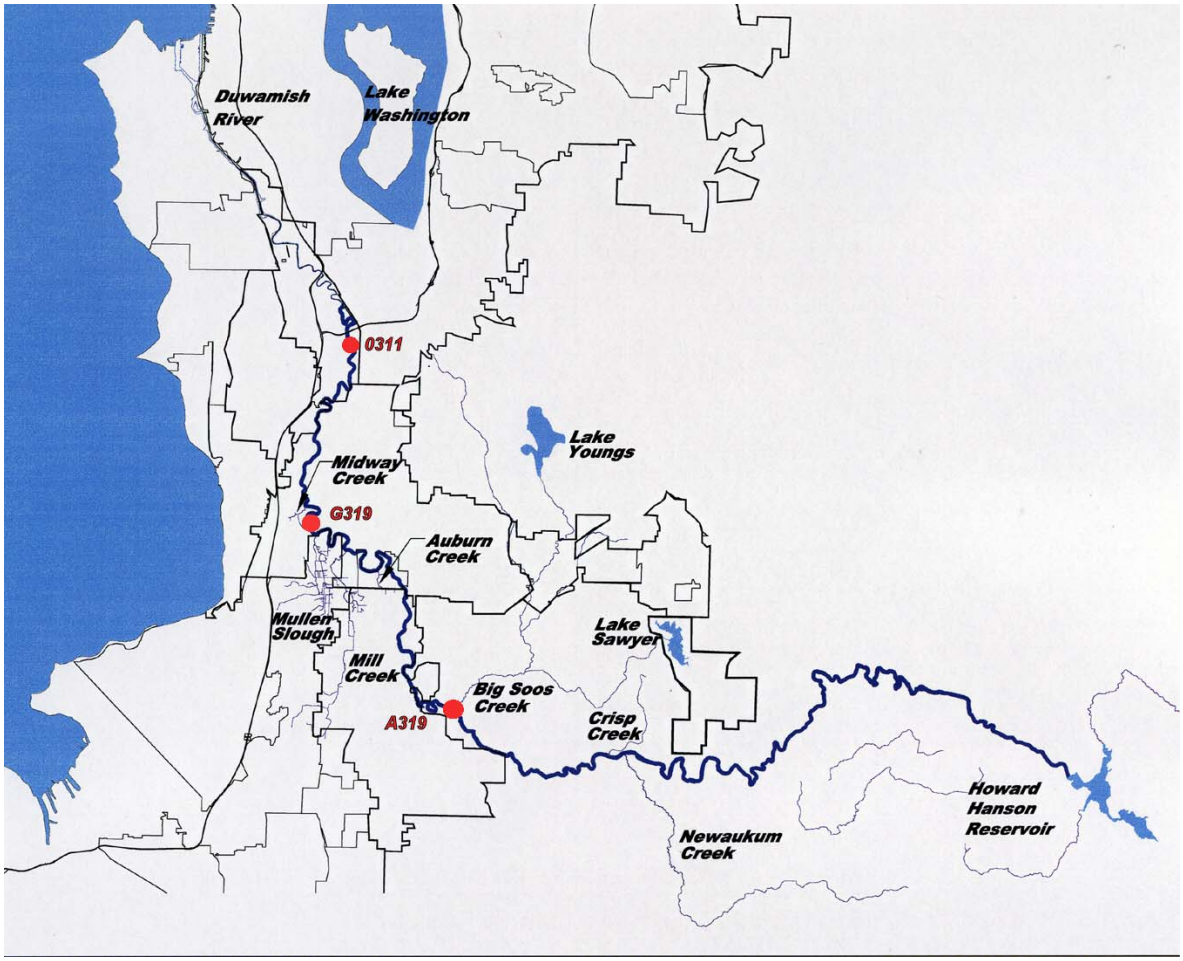


Figure 285: Water Quality Calibration Sites

Table 18: Water Quality Calibration Sites

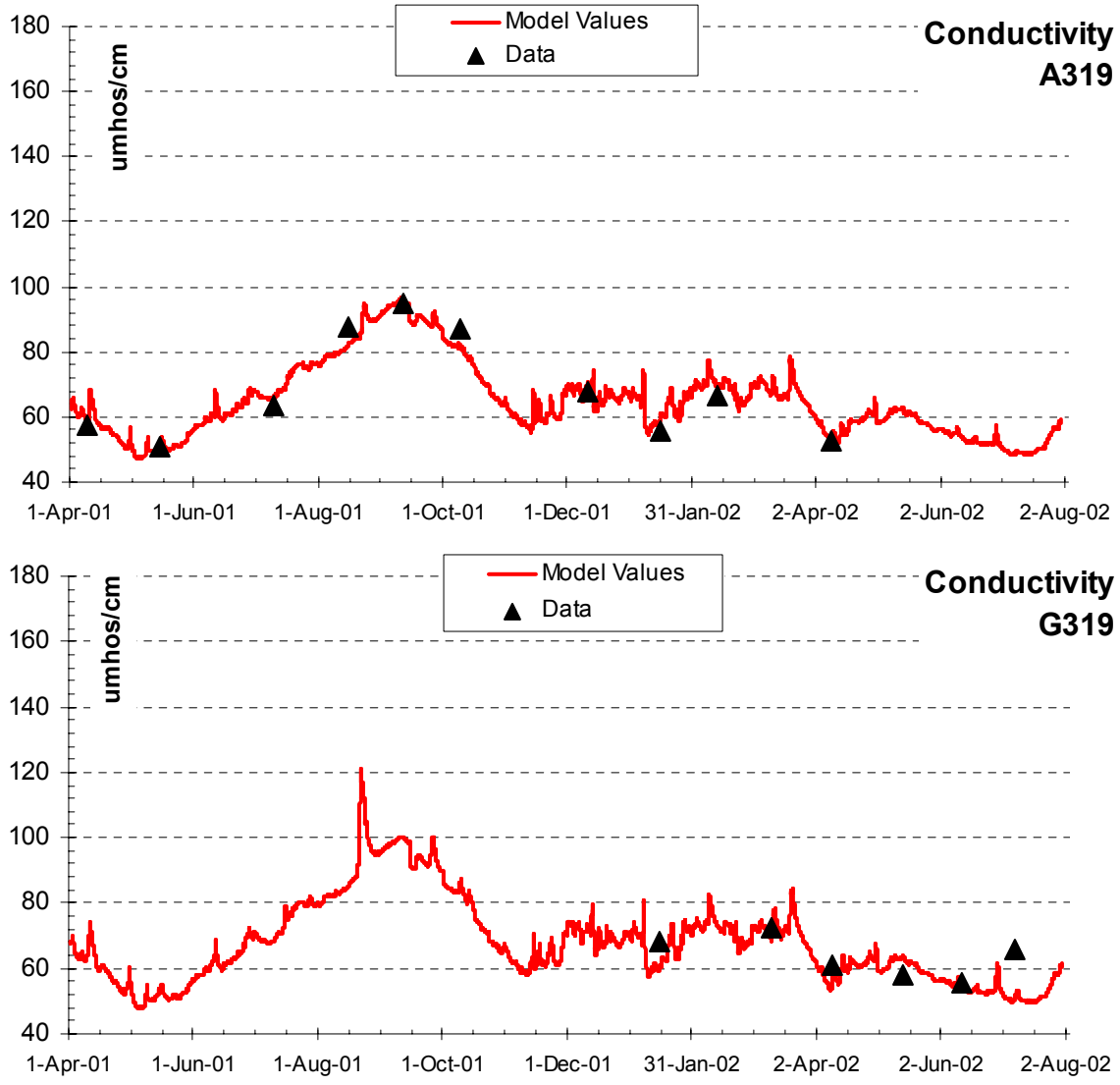
Locator Station	Description	River Mile
0311	Interurban Avenue	13.20
G319	Near Mullen Slough	21.30
A319	Auburn-Black Diamond Road	33.80

The water quality calibration section shows a comparison between model values and sampled data, and discusses calibration measures used to match model values with the sampled data. Each model run period is discussed separately.

3.3.1 2001-2002

Conductivity

Conductivity is modeled as a conservative constituent, with all rate terms set to zero. Figure 286 shows the comparison between sampled data and model results and Table 19 shows the model error statistics.



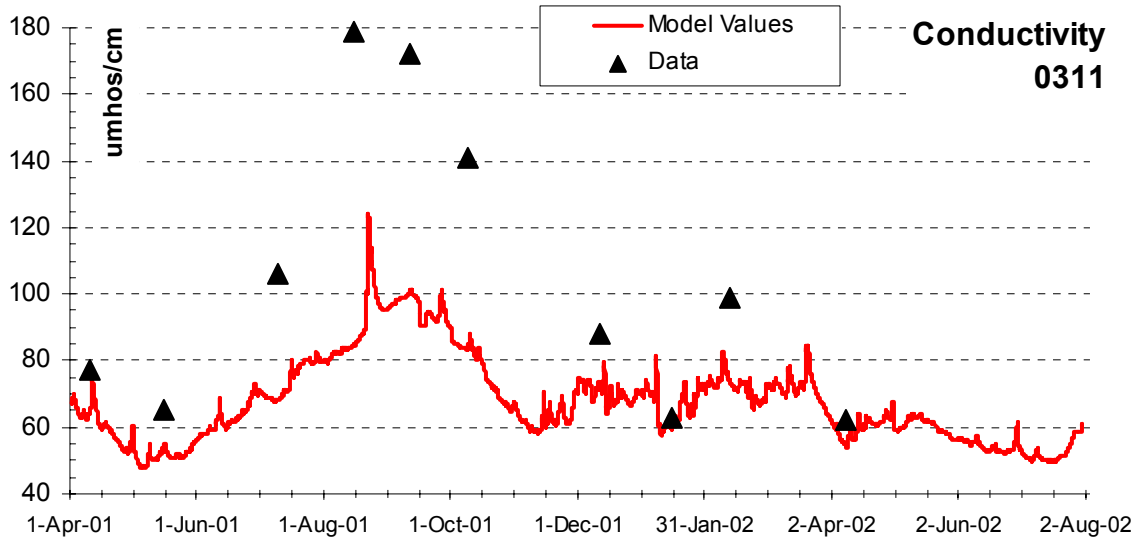


Figure 286: Conductivity comparison, 2001-2002 Model Run Period

Table 19: Conductivity Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error (umhos/cm)	AME (umhos/cm)	RMS Error (umhos/cm)
A319	10	0.26	2.48	3.04
G319	6	-4.22	6.15	7.62
0311	10	-33.40	33.40	44.4

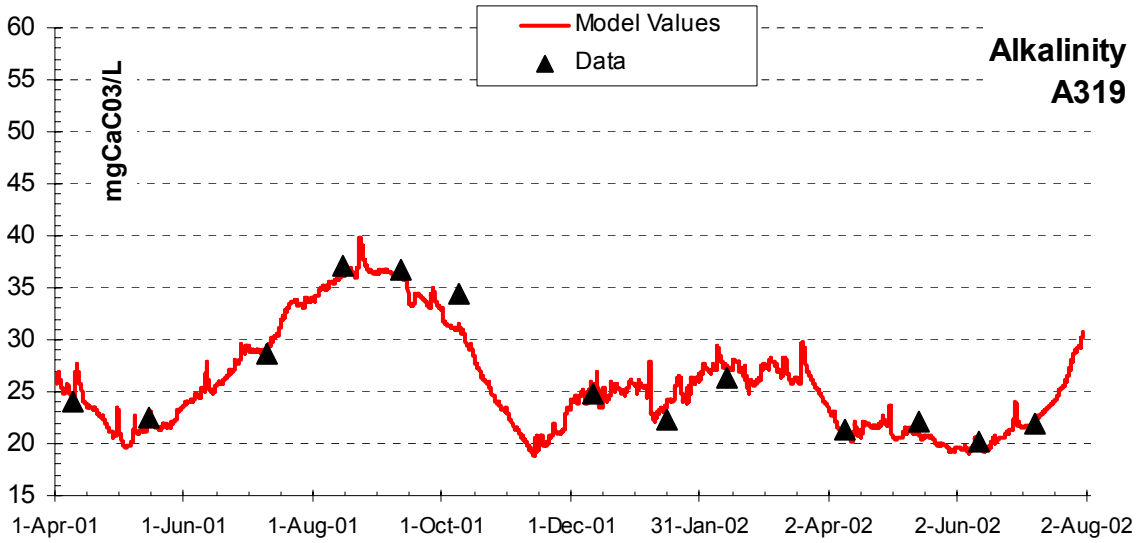
Model values and data compare well at Site A319, the farthest upstream site, and at Site G319, which is farther downstream, but do not compare well at the farthest downstream calibration site, Site 0311, during late summer and fall of 2001. Note that data were not available for comparison at Site G319 during the summer and fall of 2001.

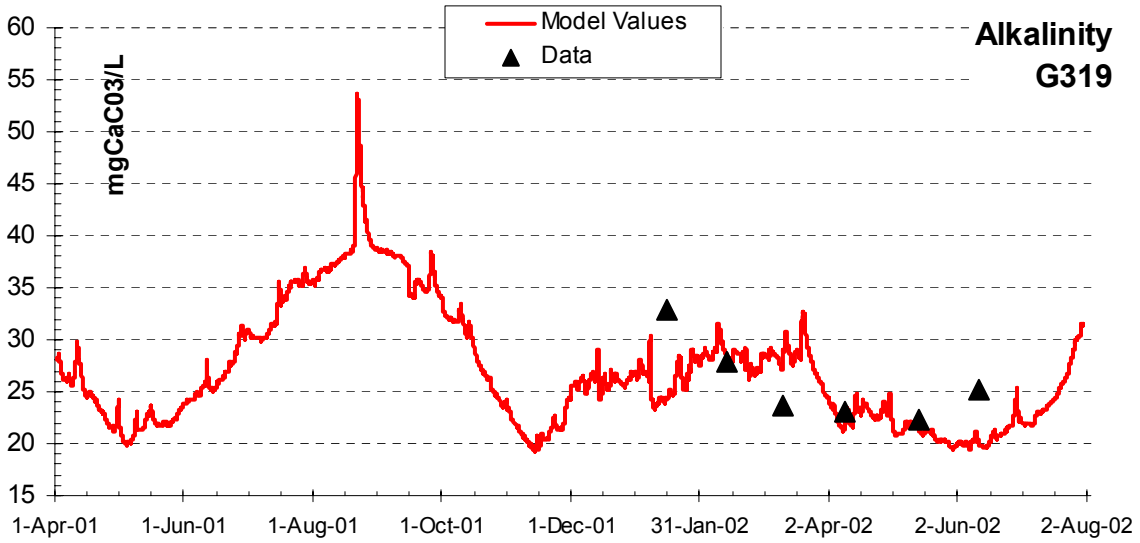
Since conductivity is a conservative constituent, the difference between model values and data is an issue with model data - there is a source of flow and conductivity missing from the model. This issue is discussed in more detail in the Summary and Conclusions section. An additional distributed tributary was added to the last branch of the model to simulate conditions needed to match the data at this location. This is discussed in the Sensitivity Analysis section.

Alkalinity

Alkalinity is a conservative constituent in the model and is used to calculate pH. Model values match well at Sites A319 and G319 for this model run period, but as with other constituents, model values do not compare as well at Site 0311 in the summer and fall of 2001. See the Summary and Conclusions section for a discussion, and the Sensitivity Analysis section for additional alkalinity added to the model to match data.

Figure 287 shows the comparisons for the three locations, and Table 20 shows the model error statistics.


Model Values
Data
Alkalinity
A319
mgCaC03/L
60
55
50
45
40
35
30
25
20
15
1-Apr-01
1-Jun-01
1-Aug-01
1-Oct-01
1-Dec-01
31-Jan-02
2-Apr-02
2-Jun-02
2-Aug-02


Model Values
Data
Alkalinity
G319
mgCaC03/L
60
55
50
45
40
35
30
25
20
15
1-Apr-01
1-Jun-01
1-Aug-01
1-Oct-01
1-Dec-01
31-Jan-02
2-Apr-02
2-Jun-02
2-Aug-02

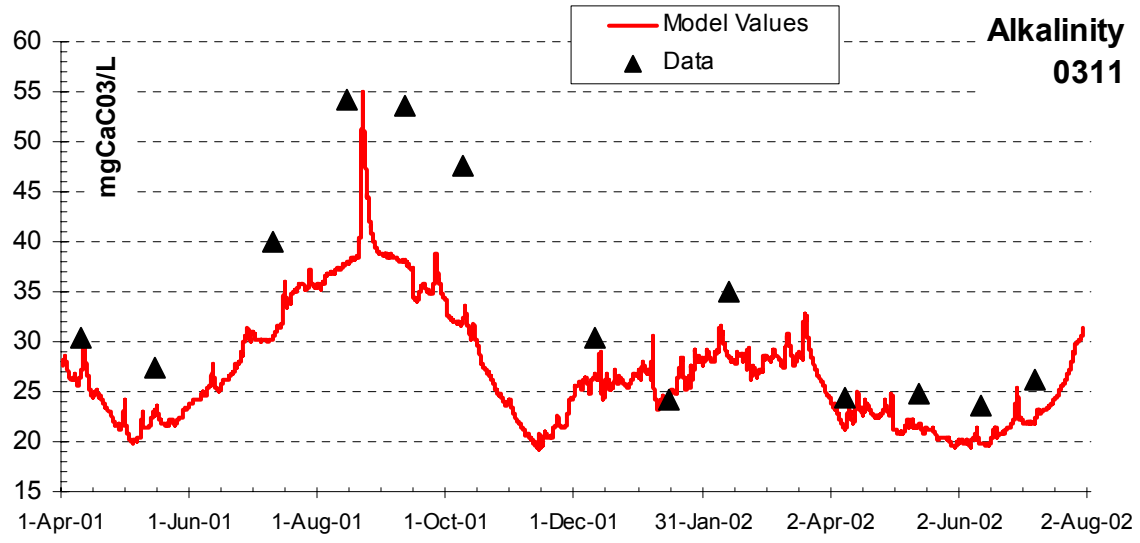

Model Values
Data
Alkalinity
0311
mgCaC03/L
60
55
50
45
40
35
30
25
20
15
1-Apr-01
1-Jun-01
1-Aug-01
1-Oct-01
1-Dec-01
31-Jan-02
2-Apr-02
2-Jun-02
2-Aug-02

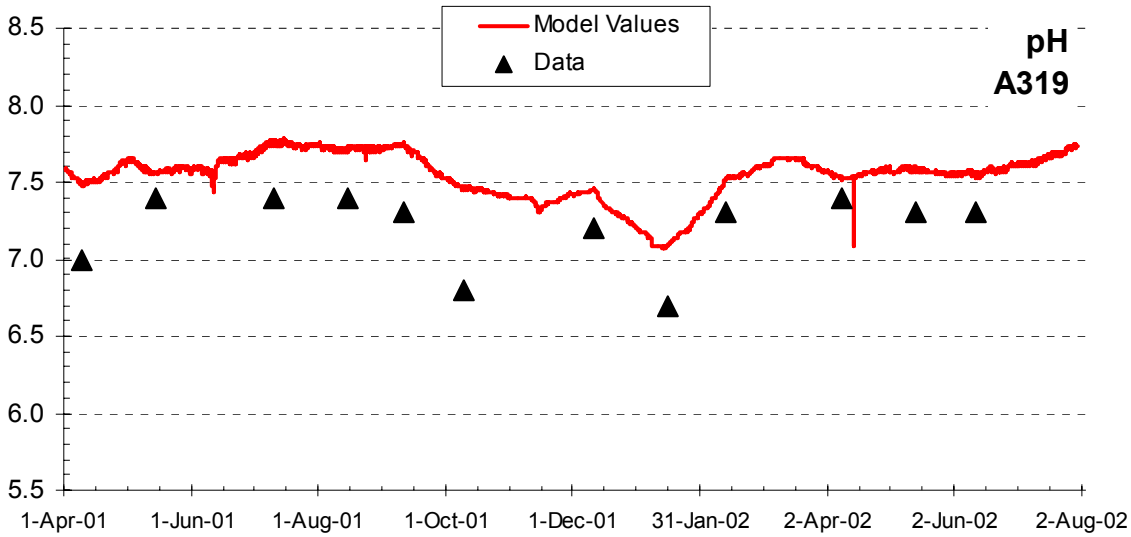
Figure 287: Alkalinity Comparison, 2001-2002 Model Run Period

Table 20: Alkalinity Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error (mgCaCO3/L)	AME (mgCaCO3/L)	RMS Error (mgCaCO3/L)
A319	13	-0.23	0.86	1.11
G319	6	-2.1	3.03	3.97
0311	13	-6.83	6.87	8.65

pH

pH is calculated in the model from total inorganic carbon (TIC), alkalinity, and temperature model values. Figure 288 shows the comparison between model values and sampled data for all three sites, and Table 21 shows the mean, AME and RMS model error statistics for each calibration site.



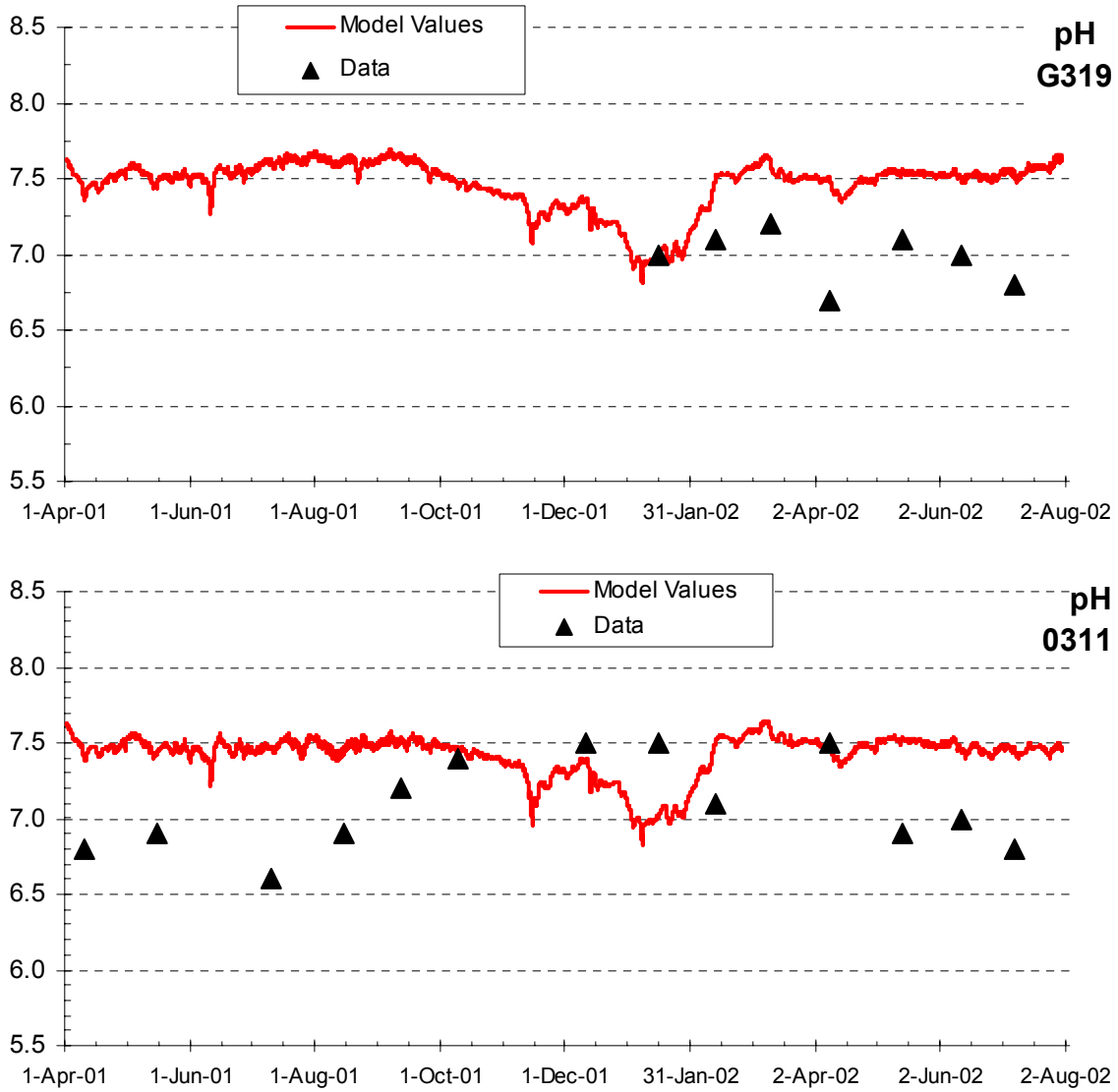


Figure 288: pH comparison, 2001-2002 Model Run Period

Table 21: pH Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error	AME	RMS Error
A319	7	0.33	0.33	0.31
G319	7	0.46	0.46	0.52
0311	13	0.35	0.44	0.50

pH model values do not compare well at at all three calibration sites. Model predictions of alkalinity match well with field data at Site A319, so TIC was calculated from temperature, alkalinity, and pH data at this site to compare with TIC values from the model. A graph comparing TIC from field data with model predictions is shown in Figure 289. A comparison of Figure 288 and Figure 289 shows

that the model is under-predicting TIC at the same time it's over-predicting pH. This shows that TIC is under-predicted in the model during the low flow end-of-summer months. The TIC model values in Figure 289 compare very closely with the TIC data used in the upstream boundary condition, therefore there is a source of high TIC below the upstream boundary, possibly in a groundwater source. This is reviewed in more detail in the Sensitivity Analysis Section. Please see Section 4.2 for more information.

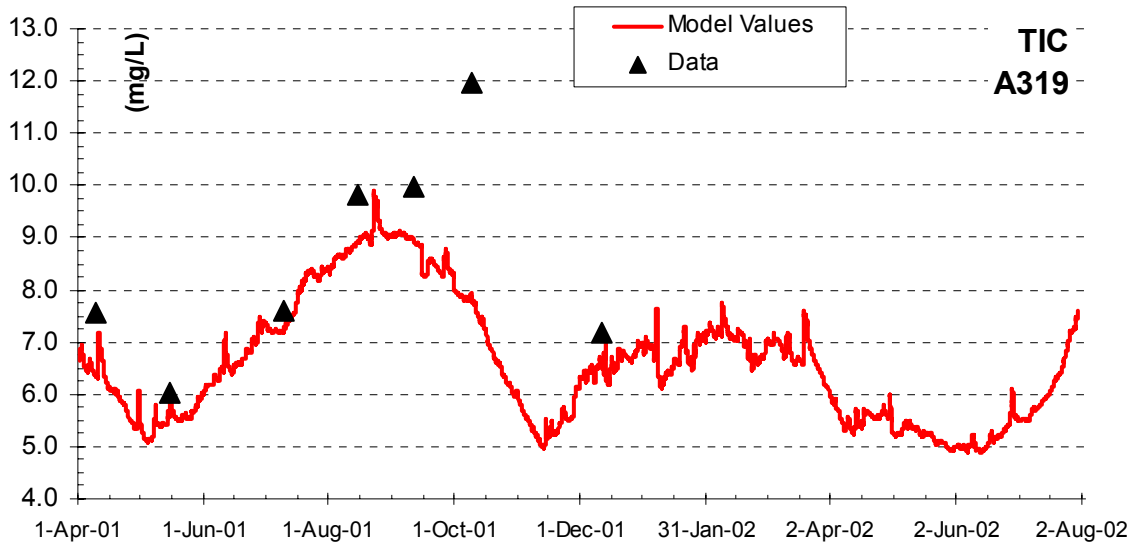


Figure 289: TIC Comparison, 2001-2002 Model Run Period

Total Suspended Solids

Total Suspended Solids is a derived constituent in CE-QUAL-W2, calculated by adding particulate organic matter, inorganic suspended solids, and algae. The model data for TSS consisted of monthly grab samples. CE-QUAL-W2 uses linear interpolation for values between the monthly data points. When a monthly sample with low TSS values is followed by a monthly sample with high values of TSS, the model predictions are affected by the interpolation between the low and high TSS values. Figure 290 shows model results using monthly data input. Although the values match close with data, the peaks in TSS are spread out over three months due to the linear interpolation of values.

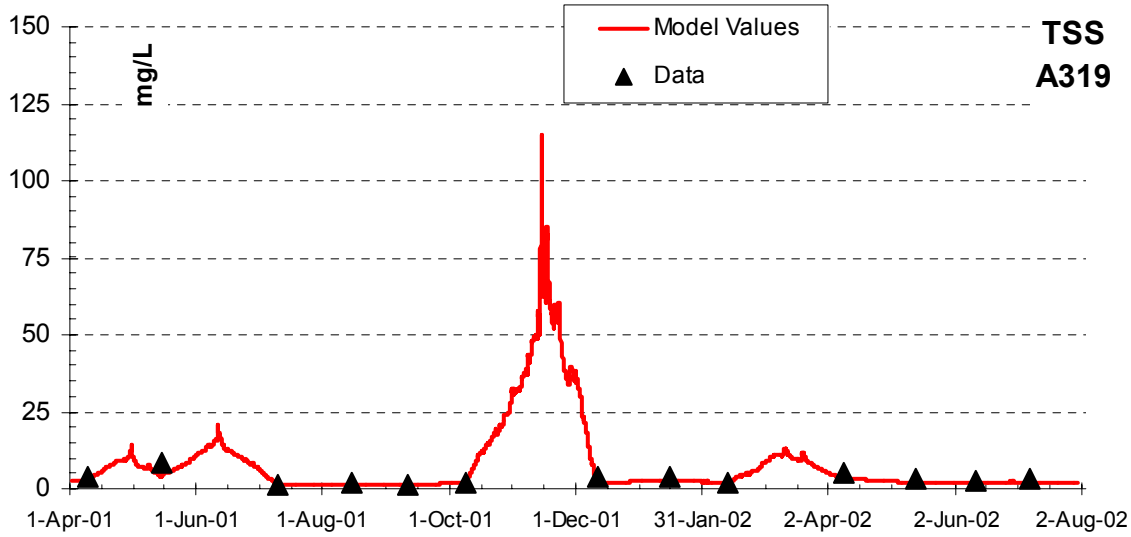
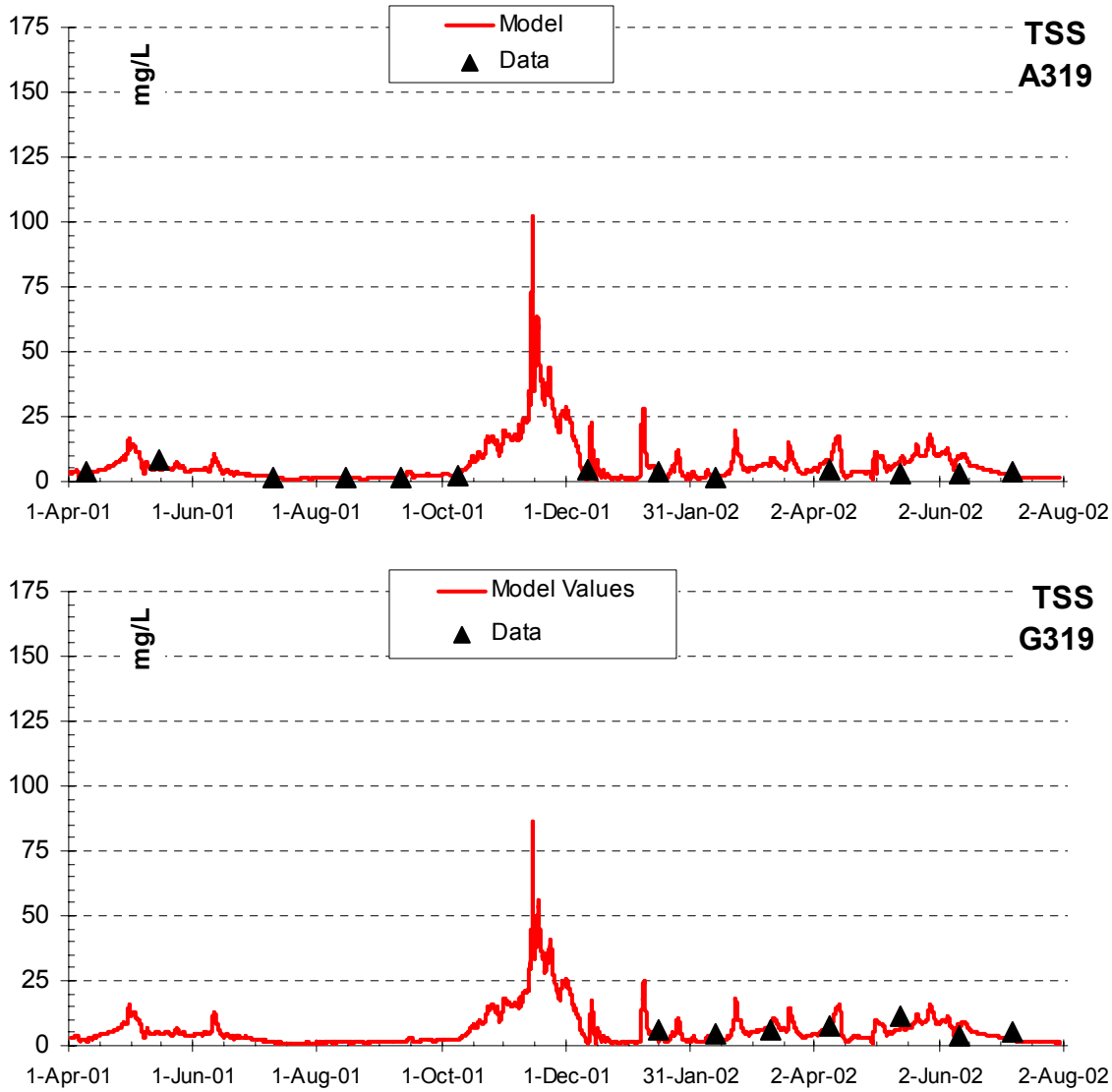


Figure 290: TSS Comparison with monthly grab samples, 2001-2002 Model Run Period

To address this, a regression equation was used to estimate model input between the monthly sampled data. Daily average TSS model data were estimated using flow data from the USGS gage at Palmer (Station No. 12108700), from flow data at the USGS gage near Auburn (12113000), and the Julian date. The following correlation was developed for the 2001-2002 model run period (R^2 = 0.88):

TSS = ABS[0.90*(Palmer flow) + 0.045*Log(Palmer flow) - 0.61*AUB flow-0.0007*Julian date - 265.62]

Model input at the upstream boundary was adjusted using this equation. The resulting graph of model values and data are shown in Figure 291, and the error statistics can be found in Table 22.



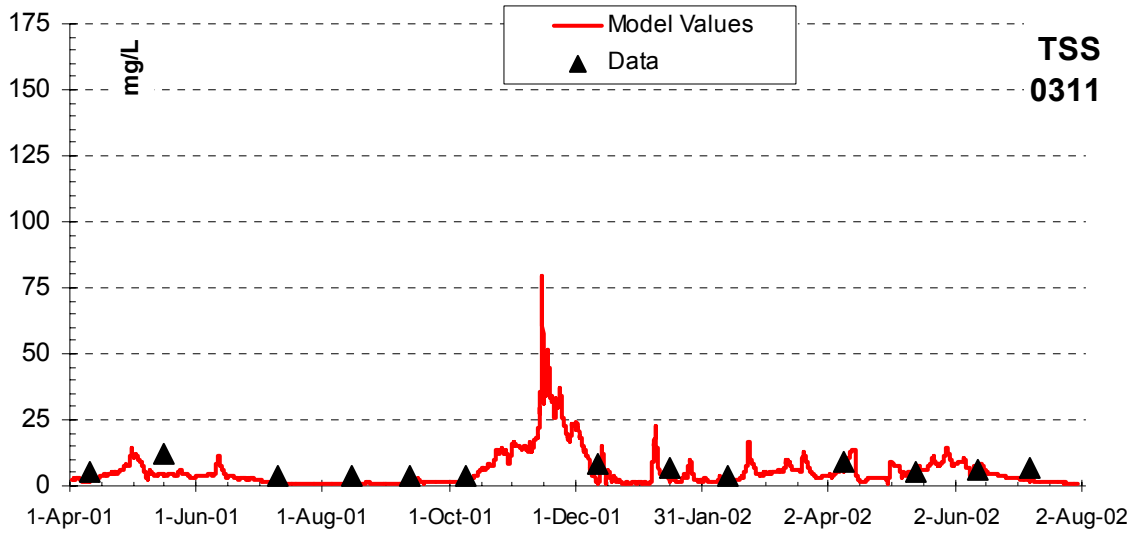


Figure 291: TSS Comparison using regression equation, 2001-2002 Model Run Period

Table 22: Total Suspended Solids Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	13	0.36	2.21	2.97
G319	7	-1.55	3.26	3.41
0311	13	-3.21	3.64	4.12

Dissolved Oxygen

CE-QUAL-W2 has nine separate reaeration formulations that can be used for river systems. The Melching and Flores (1999) equation applicable for channel control streams was used in both model runs. Zero order sediment oxygen demands were set at 1.0 g m^{-2} d^{-1} for the first two water bodies, and 3 g m^{-2} d^{-1} for Water Body three. Figure 292 shows the time series comparison of data and model values, and Table 23 shows the mean, AME, and RMS error statistics.

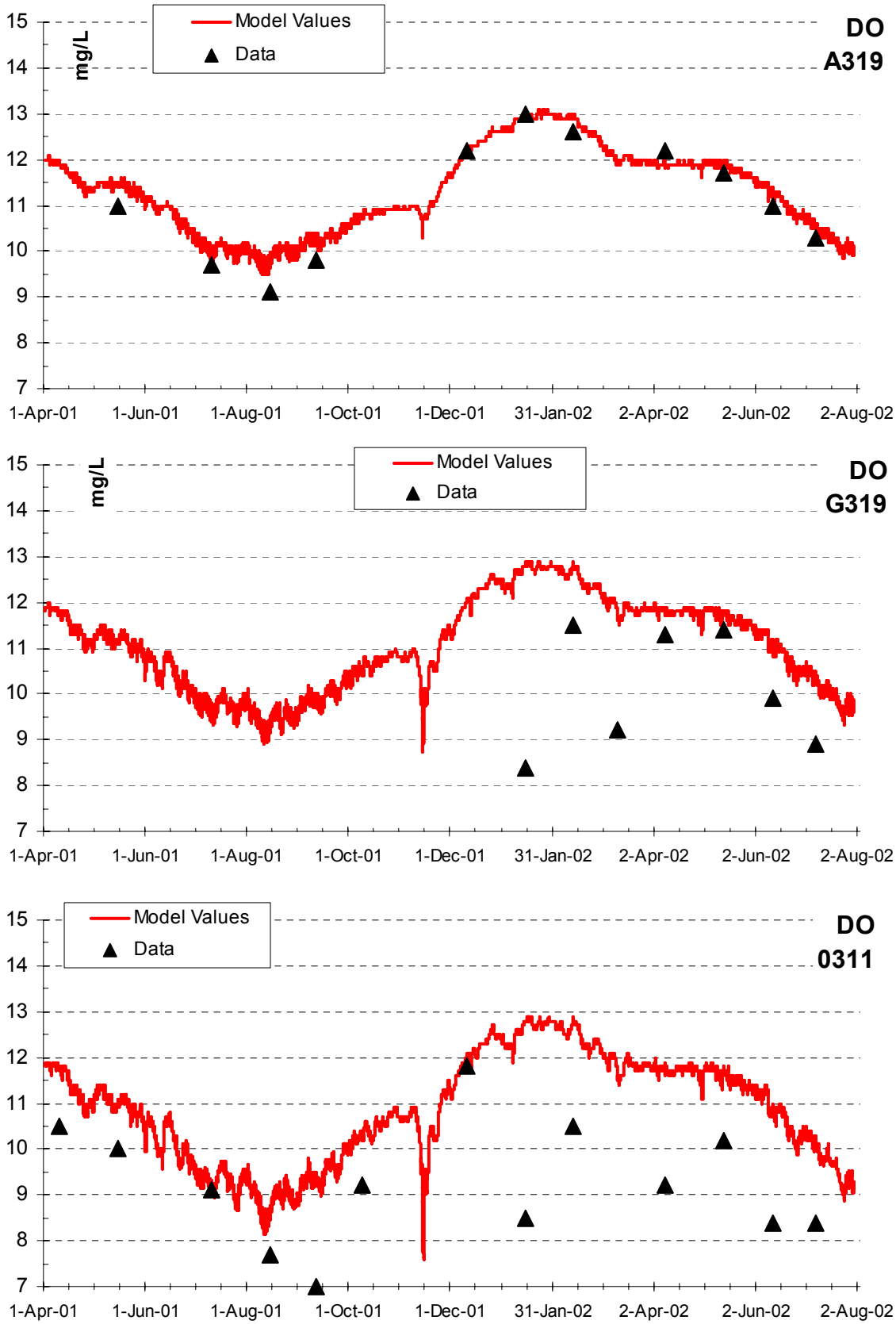


Figure 292: DO comparison, 2001-2002 Model Run Period

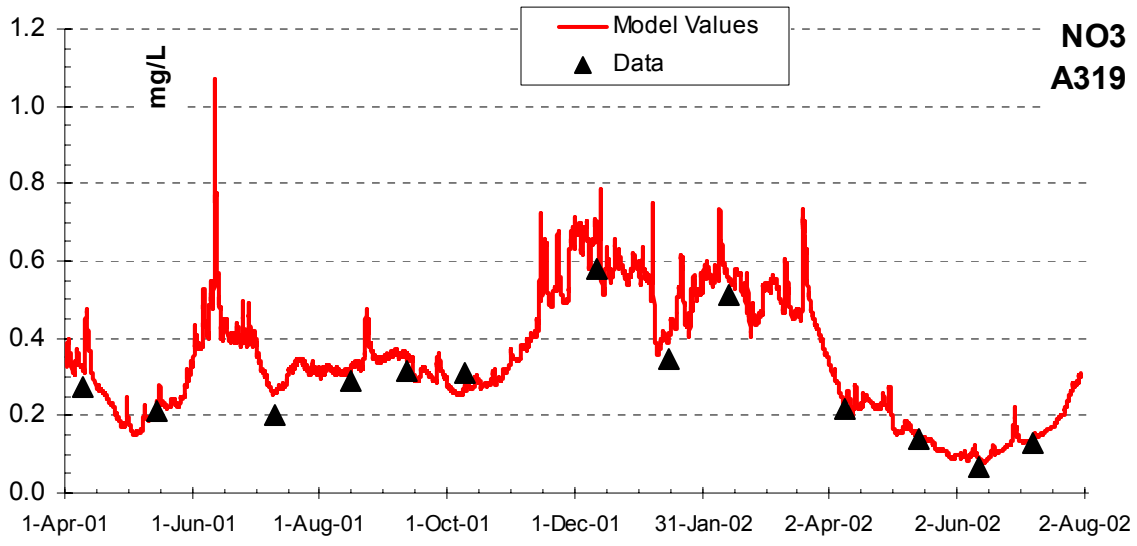
Table 23: Dissolved Oxygen Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	11	0.30	0.36	0.42
G319	7	1.67	1.67	2.13
0311	13	1.66	1.66	1.98

With dissolved oxygen, model values compare well at Site A319, but do not compare well at Site G319 and Site 0311. The model is predicting mostly saturated values, but data indicates lower DO for much of the model run period. The Summary and Conclusions section discusses possible reasons for the difference, and the Sensitivity Analysis section discusses model runs performed with additional data added to the Lower Green River to replicate sampled data.

Nitrite-Nitrate Nitrogen

Nitrite-Nitrate data were available for comparison with model-predicted values for all three sampling sites. Figure 293 compares field data to model values, and Table 24 shows the model error statistics.



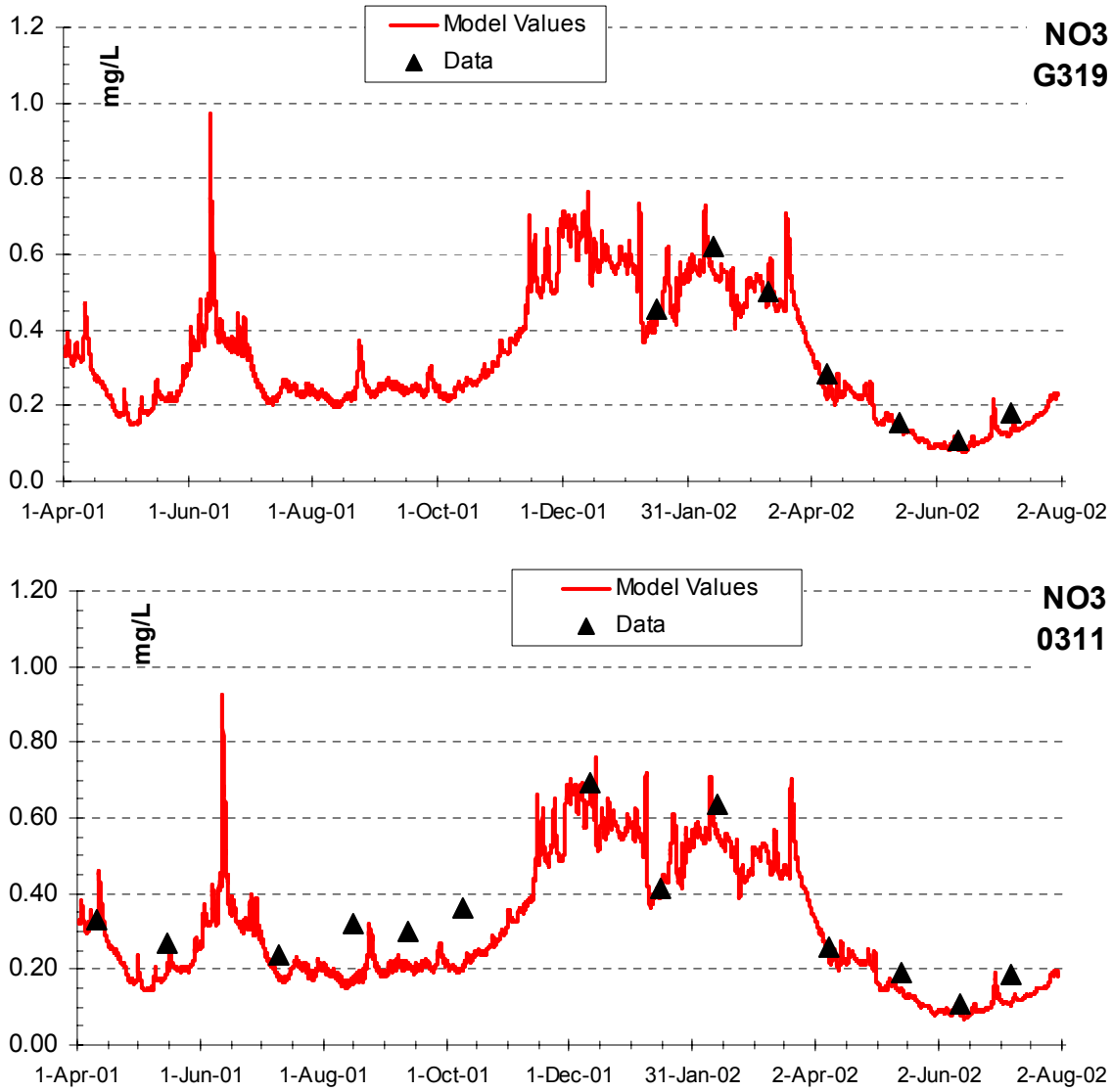


Figure 293: Nitrite-Nitrate comparison, 2001-2002 Model Run Period

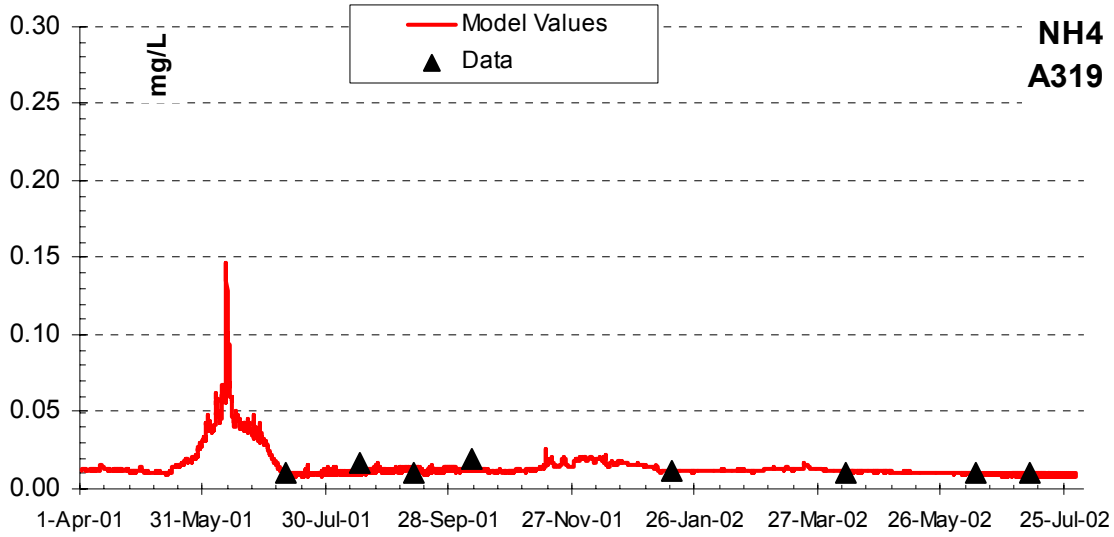
Table 24: Nitrite-Nitrate Nitrogen Error Statistics, 2001-2002 Model Run Period

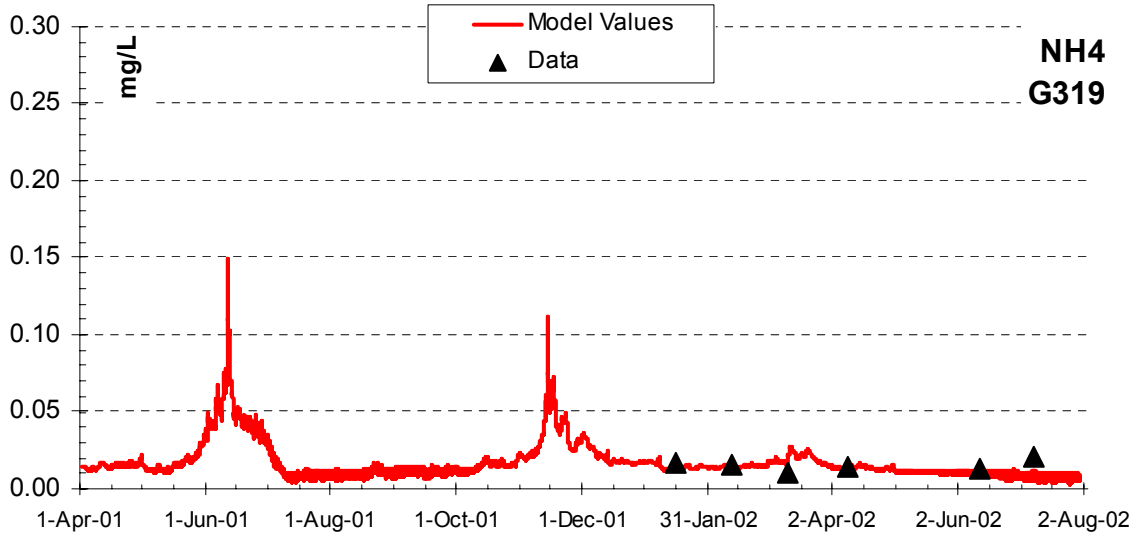
Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L
A319	13	0.032	0.039	0.046
G319	7	-0.039	0.039	0.044
0311	13	-0.064	0.064	0.080

Model values compare very well with data for Sites A319 and G319, and compare relatively well at Site 0311, except during late summer and early fall of 2001. It is assumed this discrepancy can also be attributed to missing inflows near the downstream boundary.

Ammonia Nitrogen

Ammonia Nitrogen data were available for comparison through most of this model run period for Sites A319 and G319, and for the entire run period for Site 0311. Figure 294 shows the comparison of sampled data and model values, and Figure 295 shows a comparison of values over a small time period at Site A319 to show the diurnal fluctuations predicted by the model. Table 25 shows the error statistics for all three sampling sites.





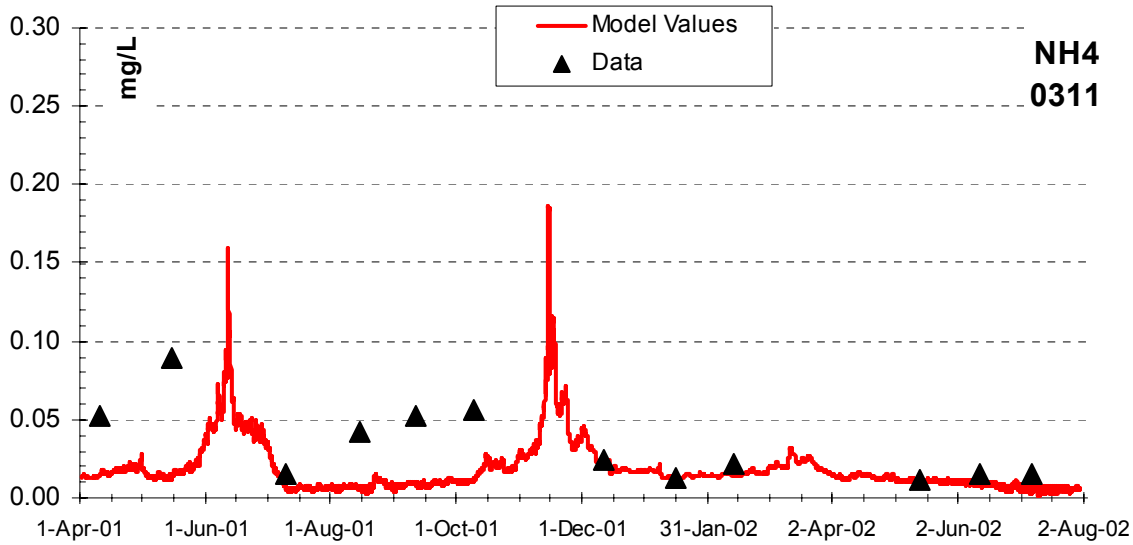


Figure 294: Ammonia Nitrogen Comparison, 2001-2002 Model Run Period

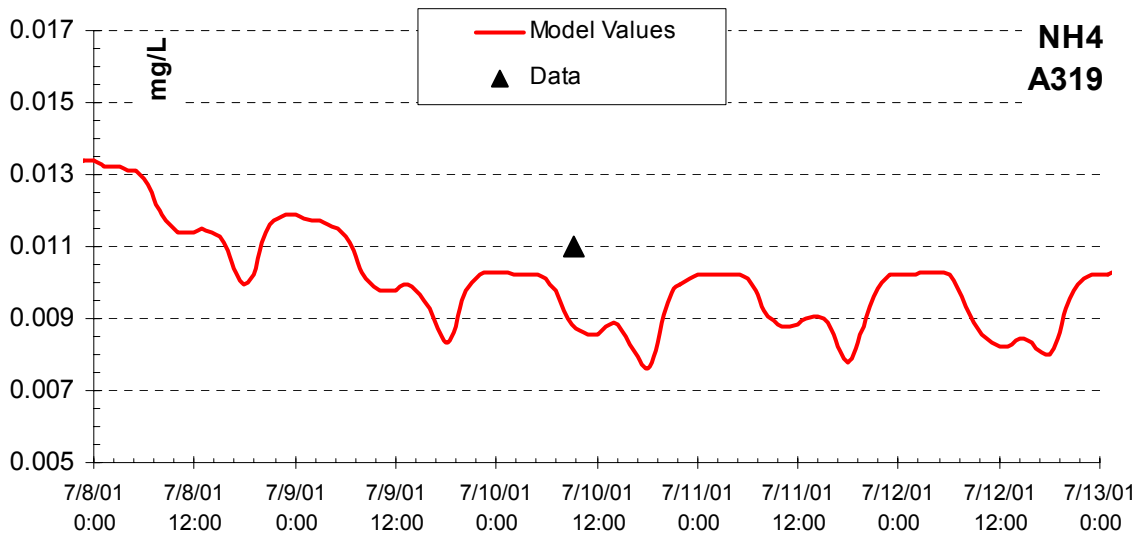


Figure 295: Diurnal Fluctuations in Ammonia Nitrogen

Table 25: Ammonia Nitrogen Error Statistics, 2001-2002 Model Run Period

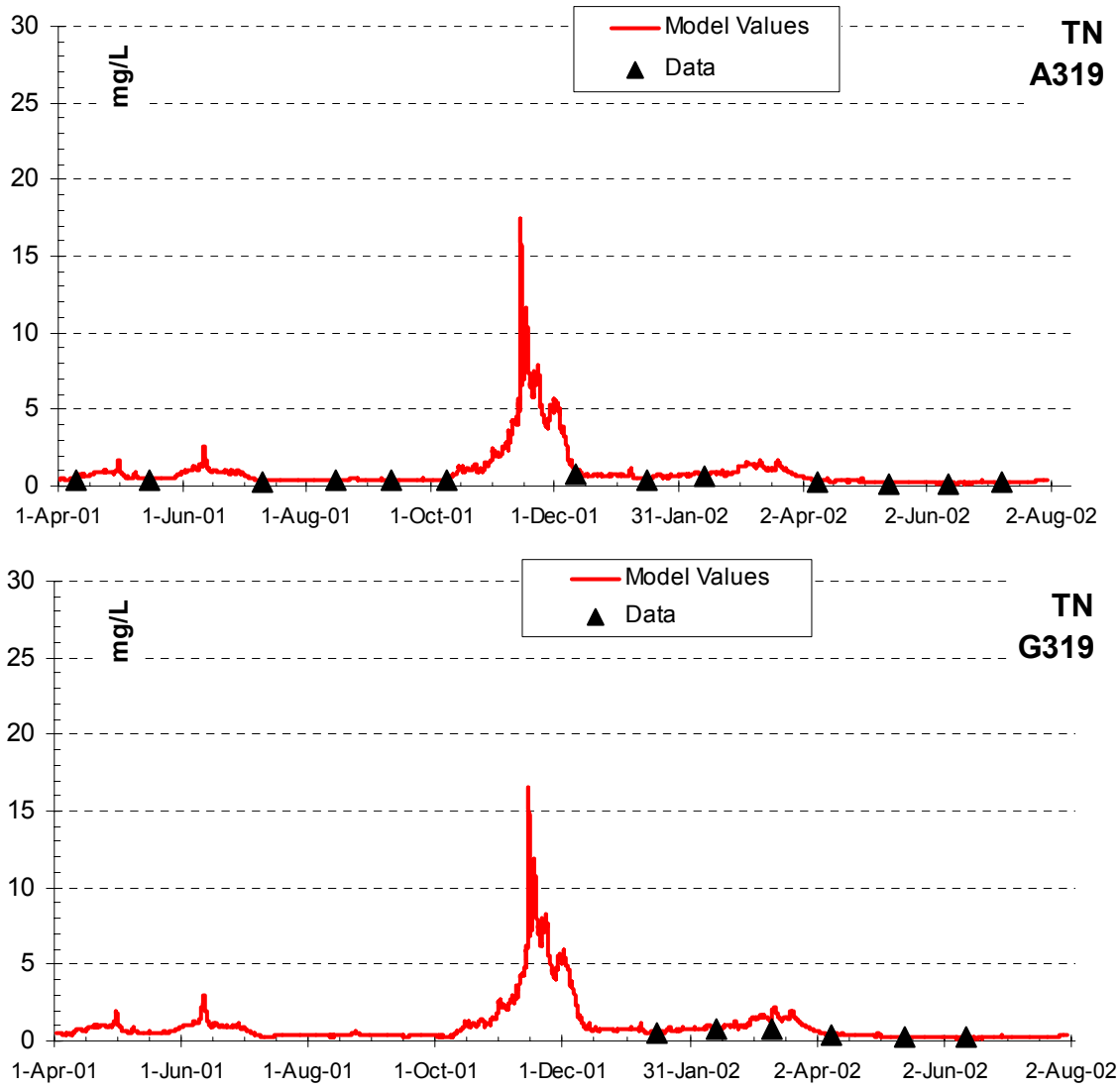
Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	8	-0.0020	0.0023	0.0034
G319	6	0.0017	0.0052	0.0065
0311	12	-0.023	0.023	0.032

Total Nitrogen

Total nitrogen data were available for comparison with model values for the entire model run period, and for all three sampling sites. Total Nitrogen values are calculated using ammonia nitrogen, nitrite-nitrate, and organic matter values. To calibrate Total Nitrogen to sampled data, the

procedures for establishing organic matter model input were reviewed and revised. For the 2001-2002 model run period initial organic matter model inputs were determined by estimation from two Total Organic Carbon samples from the summer of 2002. During model calibration the amount of organic matter in the system was calculated from its contribution to ammonia nitrogen (See Appendix F for more information on the calculation of these values). From these values the percentage of TSS that is organic matter was calculated. This percentage was then used to estimate organic matter input from the regression values of TSS used in the model (See TSS section above for more information on the regression). These estimates were revised during calibration to match data.

Figure 296 shows the comparison of field data with model values for all three sites, and Figure 297 shows the same time period, without the peak of large concentration from a mid-November storm to better show model value comparison with the field data. Table 26 shows the error statistics for the model run period.



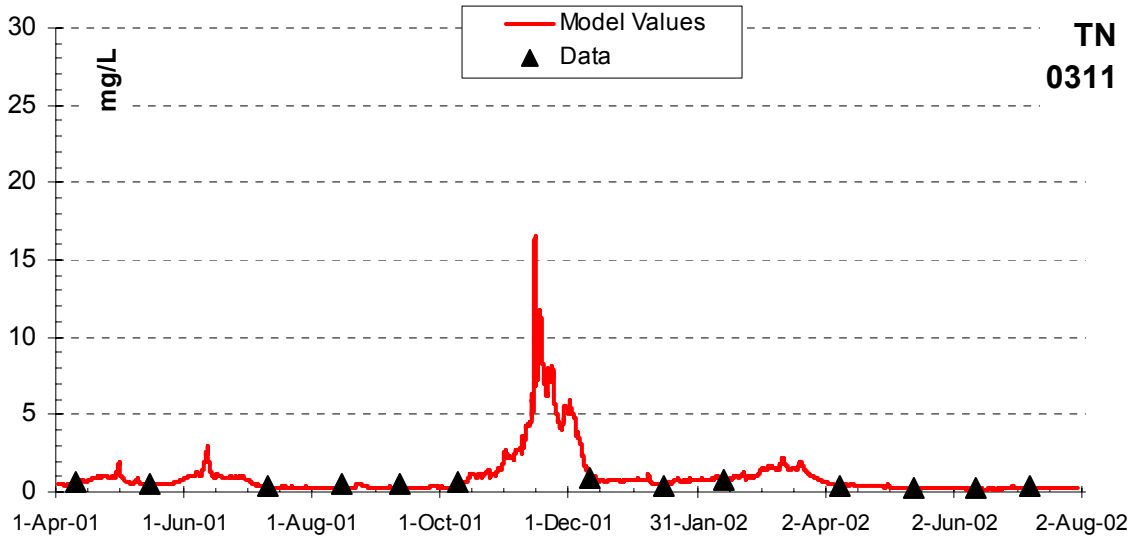
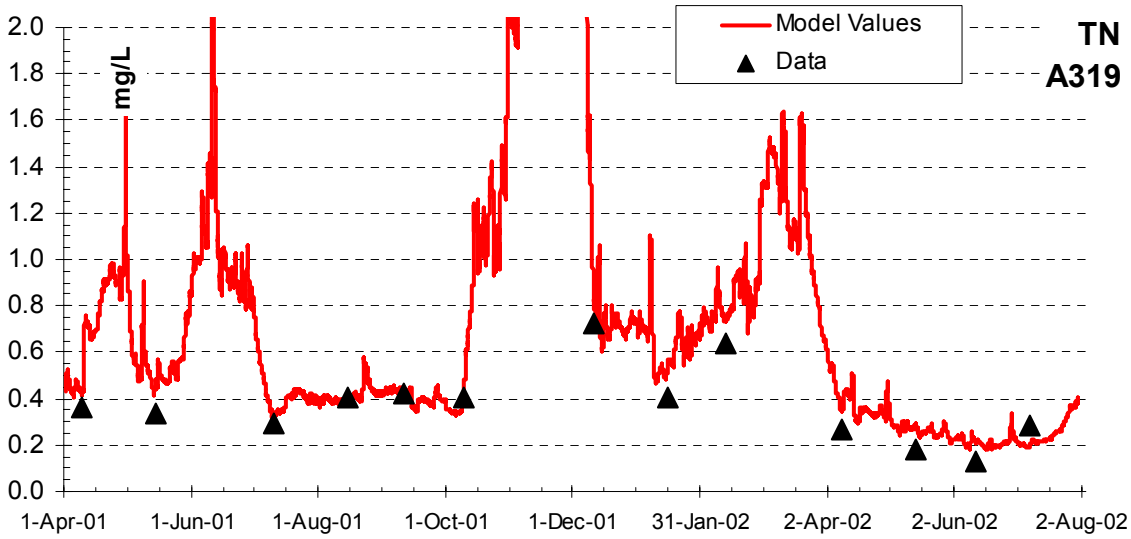
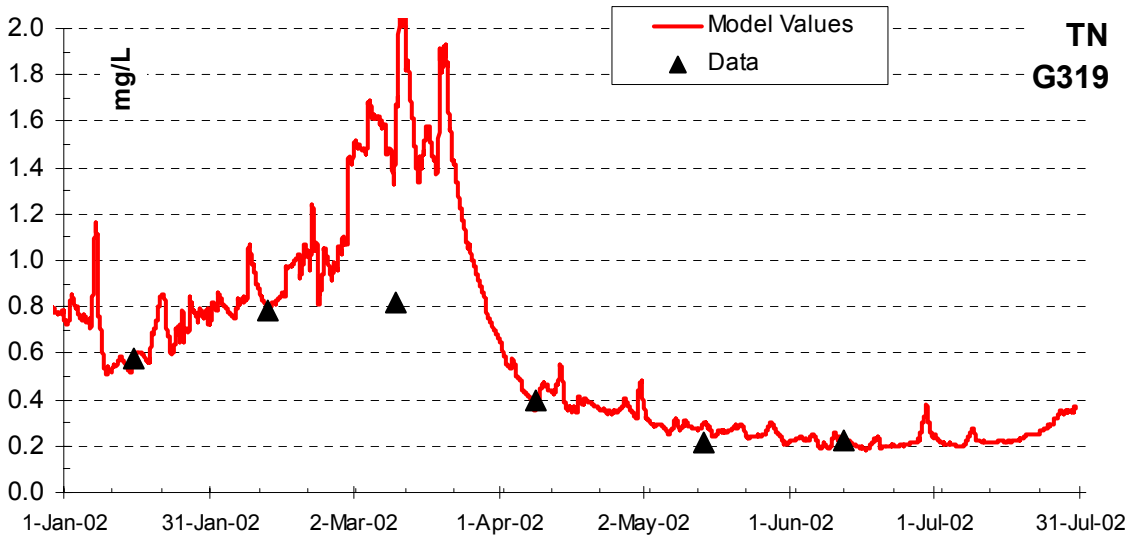


Figure 296: Total Nitrogen Comparison, 2001-2002 Model Run Period





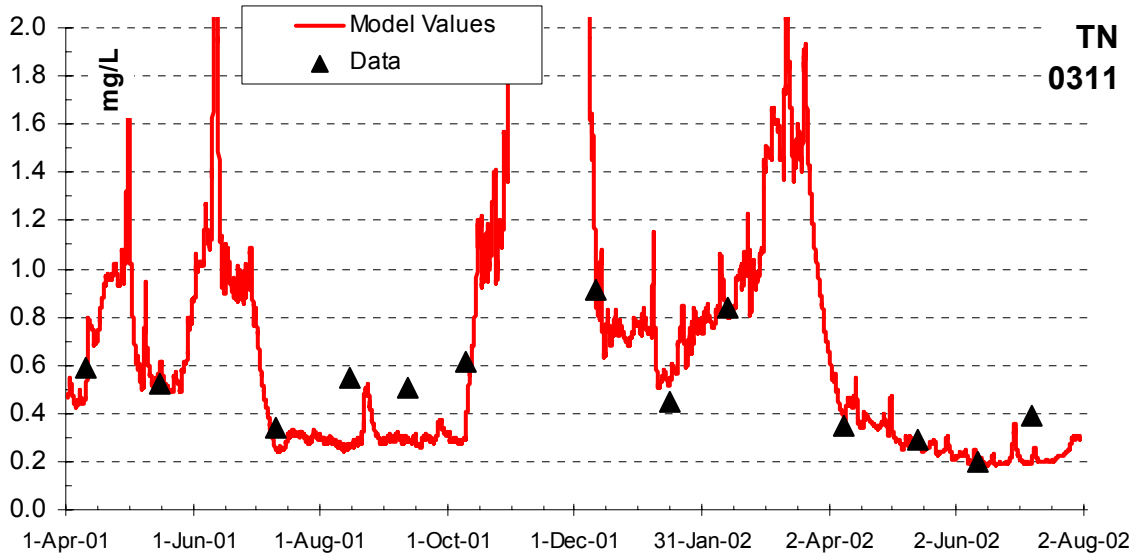


Figure 297: Reduced Scale Total Nitrogen Comparison, 2001-2002 Model Run Period

Table 26: Total Nitrogen Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	13	0.055	0.070	0.080
G319	6	0.10	0.18	0.33
0311	13	-0.090	0.11	0.15

Total Nitrogen values compare well with data at all three locations.

Ortho Phosphorus

Ortho phosphorus is a primary nutrient for algal growth, and is considered the limiting growth factor in many systems (Chapra, 1997). Data in Green River were sampled as Ortho Phosphorus, and this data were input in the model. Model values compare very closely with sampled data at all three locations. Figure 298 shows the data and model comparisons for all three locations, and Table 27 shows the error statistics.

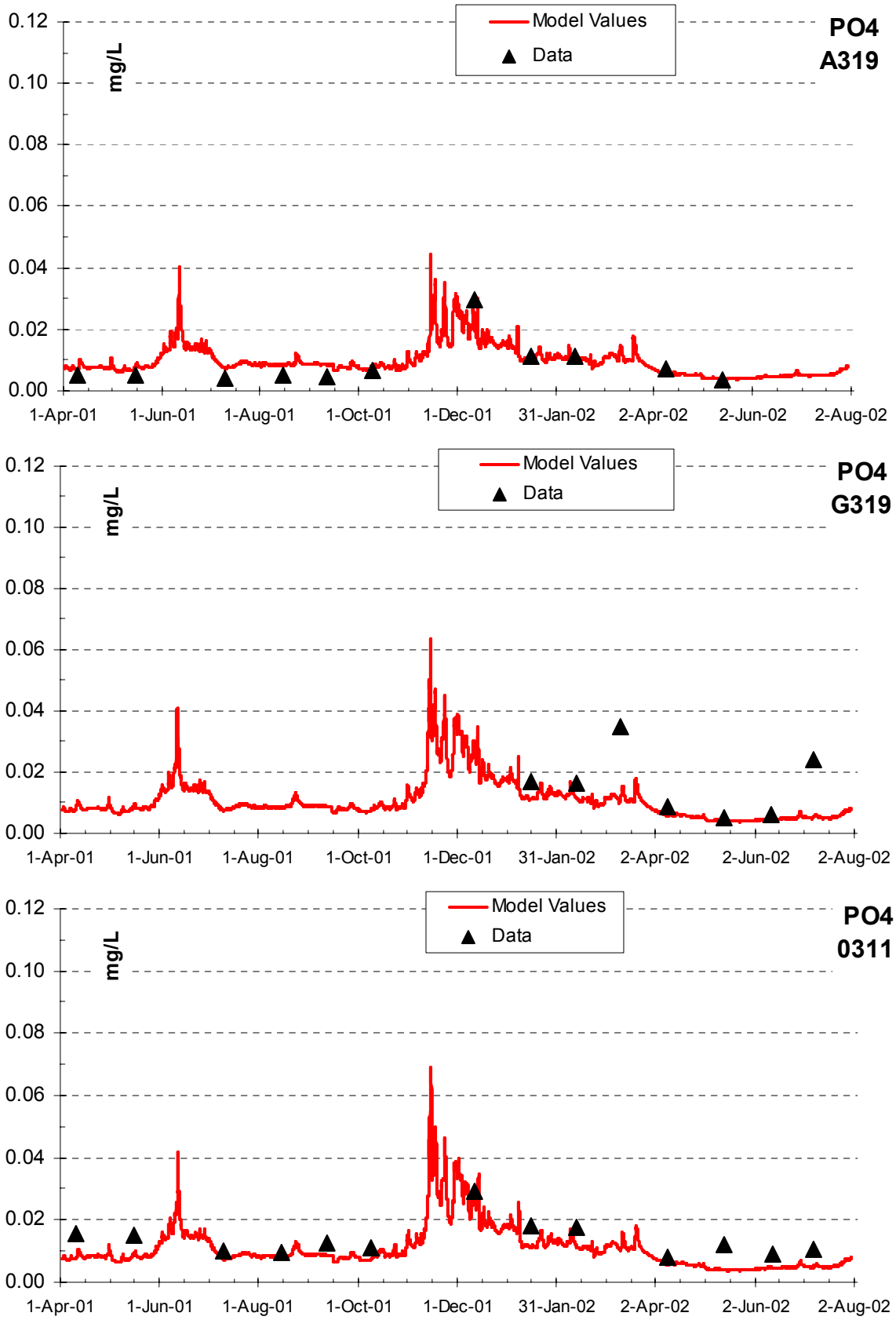


Figure 298: Ortho Phosphorus Comparison, 2001-2002 Model Run Period

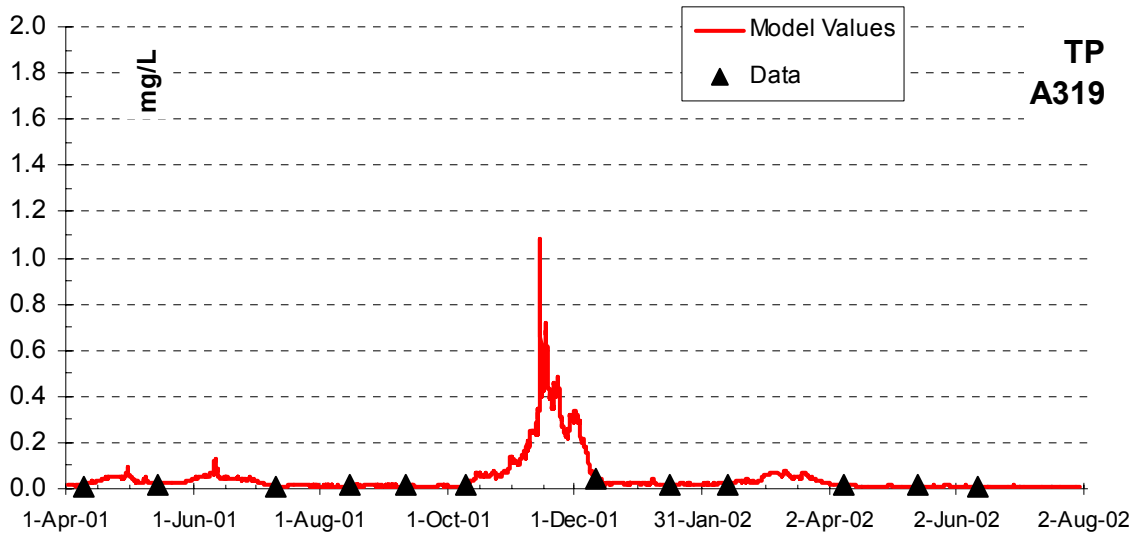
Table 27: Ortho Phosphorus Error Statistics, 2001-2002 Model Run Period				
Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	7	0.0006	0.0021	0.0025
G319	7	-0.0085	0.0085	0.012
0311	13	-0.0045	0.0045	0.0051

Total Phosphorus

Total Phosphorus is calculated by the model as the sum of all phosphorus compartments. Field data were available at all three sites, but only at Site 0311 for the entire model run period.

Total Phosphorus values are calculated using ortho phosphorus and organic matter. To calibrate Total Phosphorus to sampled data, the procedures for estimating organic matter input were reviewed and revised. For the 2001-2002 model run period initial organic matter model inputs were determined by estimation from two Total Organic Carbon samples from the summer of 2002. During model calibration the amount of organic matter in the system was calculated from its contribution to ammonia nitrogen (See Appendix F for more information on the calculation of these values). From these values the percentage of TSS that is organic matter was estimated. This percentage was then used to estimate organic matter input from the regression values of TSS used in the model (See TSS section above for more information on the regression). This percentage of organic matter was then adjusted to calibrate Total Phosphorus.

Figure 299 shows the data and model comparison for the model run period, and Table 28 shows the model error statistics.



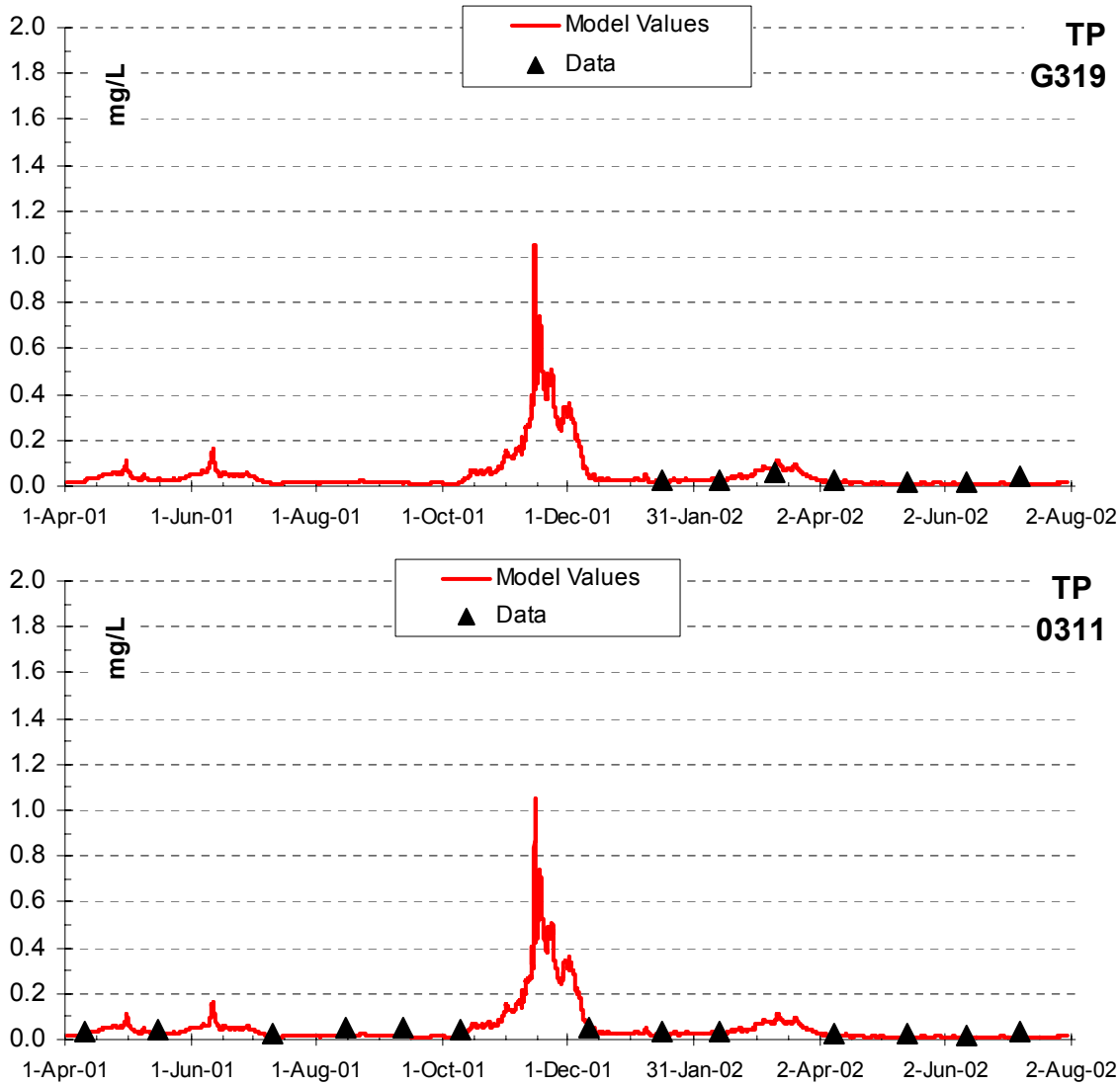


Figure 299: Total Phosphorus Comparison, 2001-2002 Model Run Period

Table 28: Total Phosphorus Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	7	-0.0035	0.0041	0.0042
G319	7	-0.006	0.012	0.016
0311	13	-0.018	0.018	0.021

Chlorophyll A

There were only two data points at Site A319 to compare to for this model period, in June and July of 2002. Figure 300 shows the model data for the model run period, and the sampled data points,

and Figure 301 shows the model and data comparison for June and July of 2002.

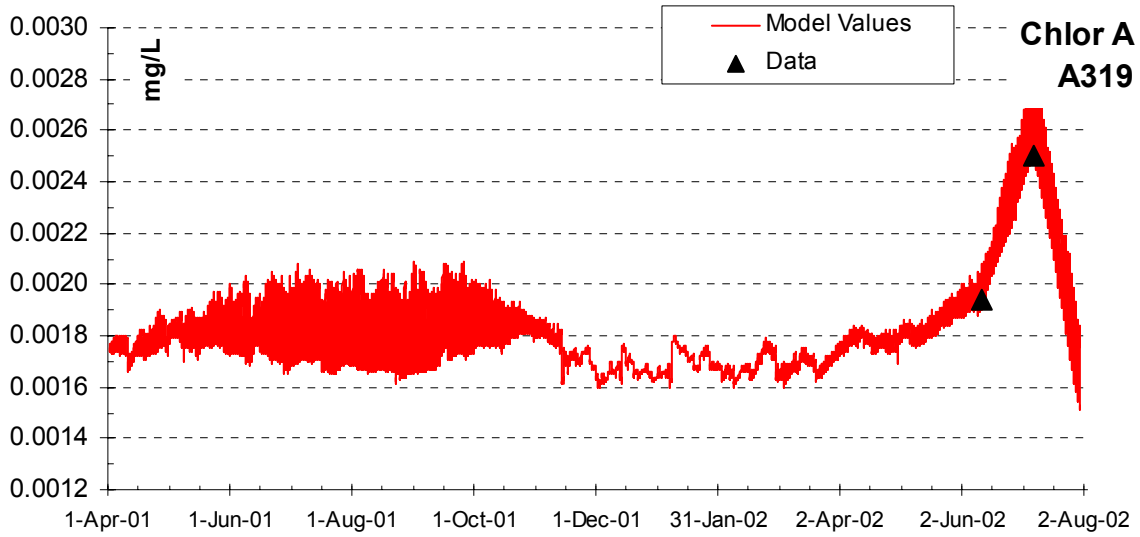


Figure 300: Chlorophyll a Comparison, 2001-2002 Model Run Period

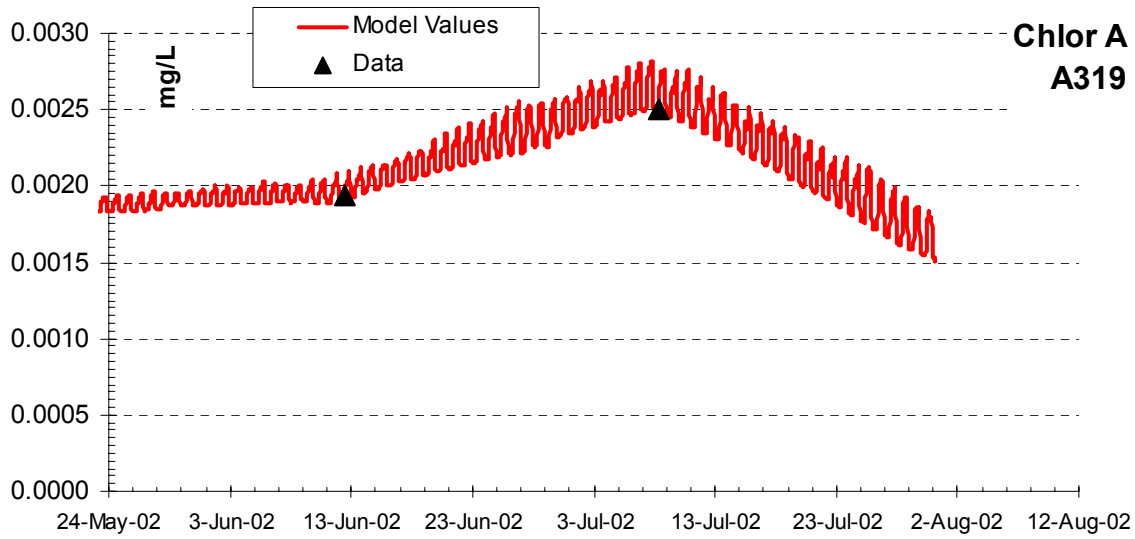


Figure 301: Chlorophyll a Comparison, June 10, 2002 to July 10, 2002

Table 29: Chlorophyll A Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error (ug/L)	AME (ug/L)	RMS Error (ug/L)
A319	2	0.065	0.065	0.05

The algae biomass to chlorophyll a ratio was used to calibrate the model to the sampled data. An algal to biomass ratio of 100 was used in the model, along with an algae growth rate of 2 d^{-1}.

Total Organic Carbon

Three data samples were available for comparison during the summer of 2002 at Site A319. Figure

302 shows the model values and data comparison, and Table 30 shows the error statistics.

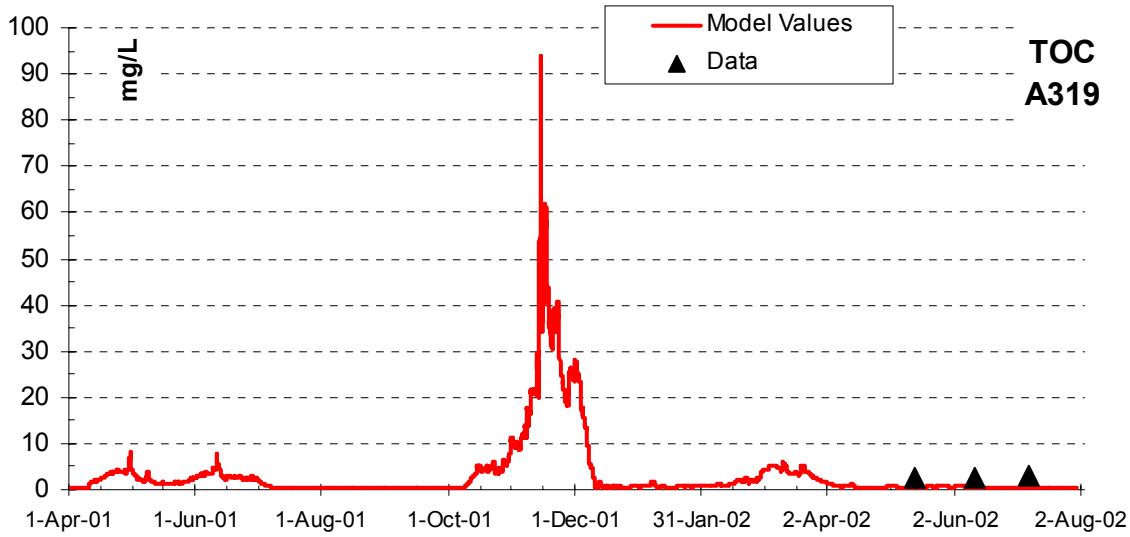


Figure 302: TOC Comparison, 2001-2002 Model Run Period

Table 30: Total Organic Carbon Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	3	-2.25	2.25	2.29

Dissolved Organic Carbon

Three data samples were available for comparison during the summer of 2002 at Site A319. Figure 303 shows the model values and data comparison, and Table 31 shows the error statistics.

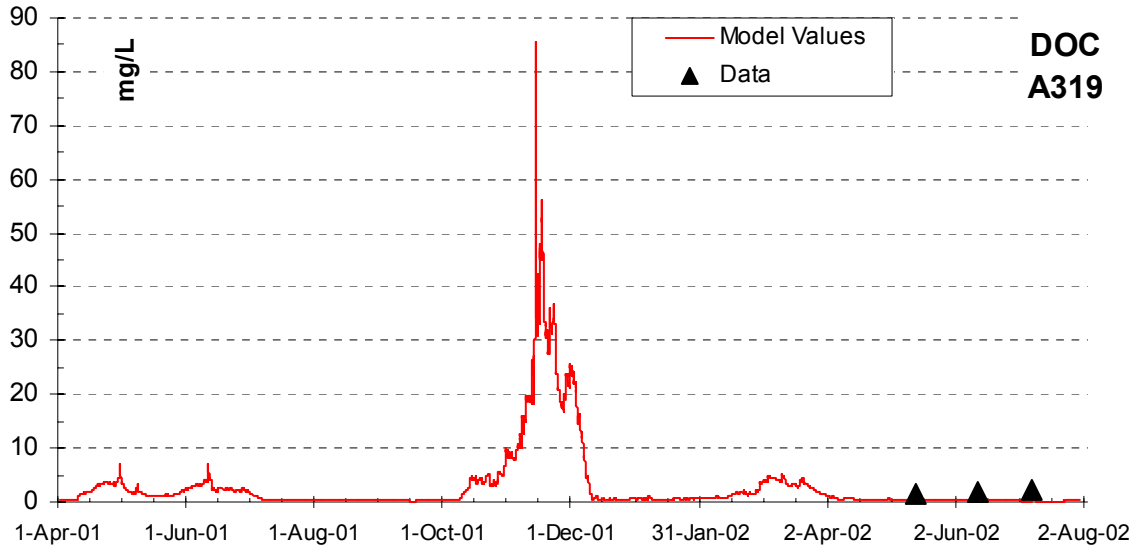


Figure 303: DOC Comparison, 2001-2002 Model Run Period

Table 31: Dissolved Organic Carbon Error Statistics, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	3	-1.59	1.59	1.62

Fecal Coliform

Fecal Coliform is modeled using a generic constituent. In CE QUAL-W2, decay rate and temperature multipliers can be individually set for generic constituents, but they do not interact with other constituents. The default variables of 1.04 for the Arrhenius Temperature Multiplier, and 0.20 d^{-1} for the first order decay rate were used in the model for Fecal Coliform.

Figure 304 shows the model value and data comparison, and Figure 305 shows the same time period, but does not include the high peak produced during a storm event of middle June 2001. The model values match well with field data.

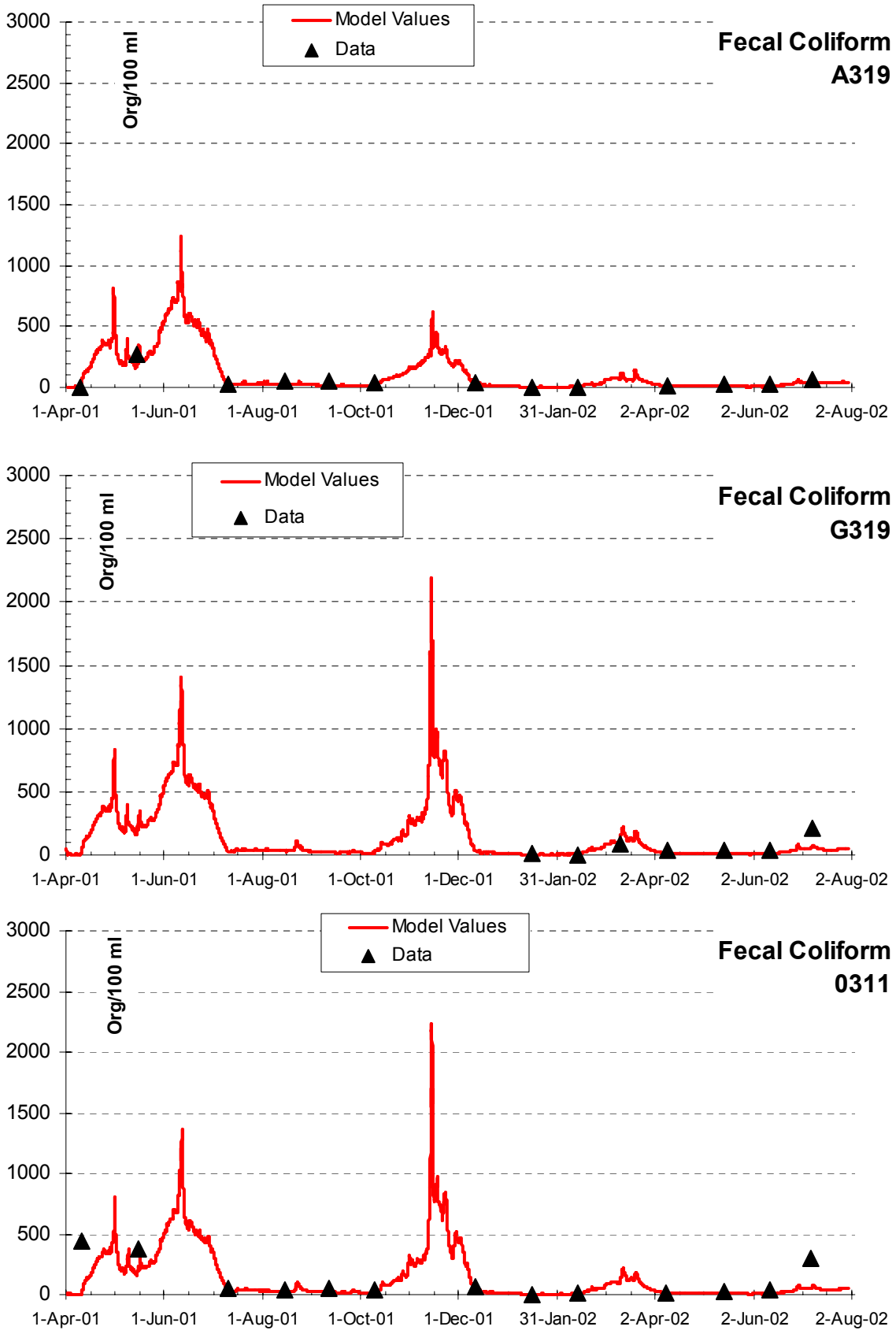


Figure 304: Fecal Coliform Comparison, 2001-2002 Model Run Period

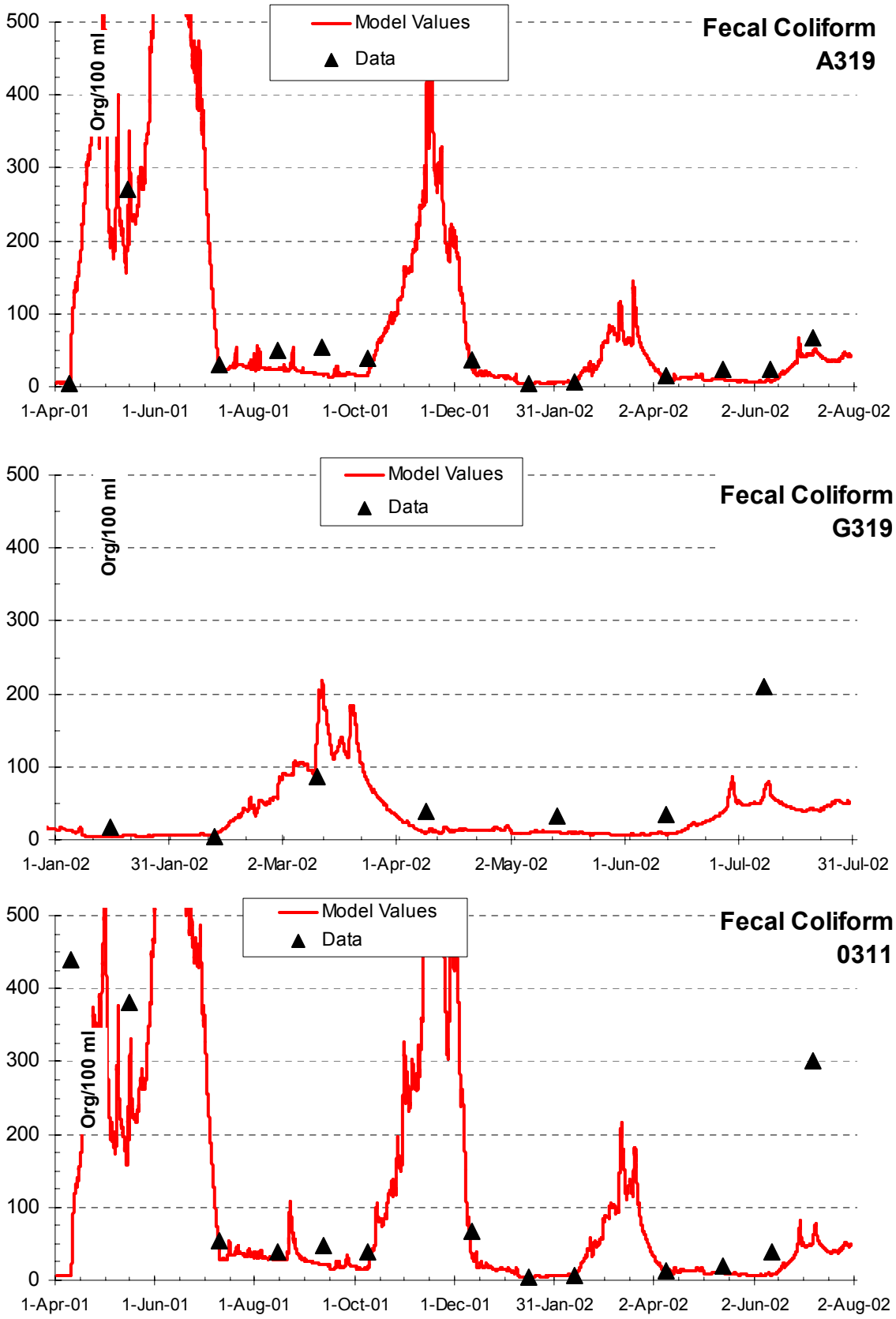


Figure 305: Reduced Scale Fecal Coliform Comparison, 2001-2002 Model Run Period

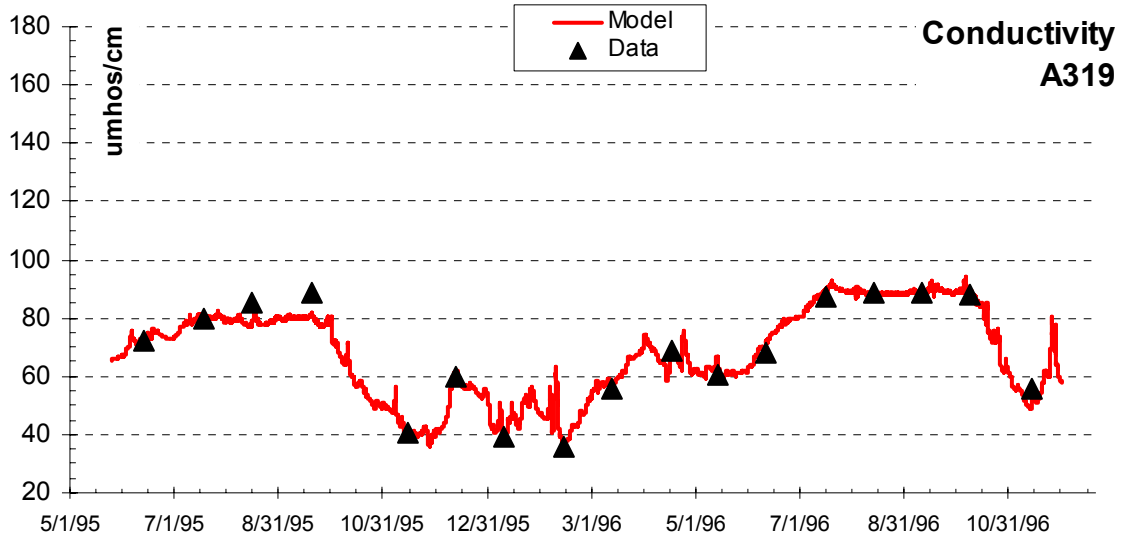
Table 32: Fecal Coliform Error Statistics, 2001-2002 Model Run Period				
Site	No. of Data Comparisons	Mean Error (ORG/100mL)	AME (Org/100 ml)	RMS Error (Org/100 ml)
A319	13	-13.85	14.01	18.00
G319	7	-26.70	40.00	59.60
0311	13	-75.80	75.80	145.4

3.3.2 1995-1996

Model data were compared with field values at two sites for this model run period: Site A319, which is about 18 km below the upstream project boundary at River Mile 33.8, and Site 0311, which is near the downstream boundary at River Mile 13.20. The model run period is from May 25, 1995 to November 30, 1996.

Conductivity

Conductivity is modeled as a conservative constituent, with all rate terms set to zero. Figure 306 shows the comparison between sampled data and model results and Table 33 shows the model error statistics. Note that the model values compare very well at Site A319, but, as with the 2001-2002 model run period, summer conductivity model values are lower than the data at Site 0311. Since conductivity is a conservative constituent, the most likely possibility is that a source of high conductivity flow in the Lower Green River is not represented in the model. This issue is discussed in more detail in the Summary and Conclusions analysis section. An additional distributed tributary was added to the last branch of the model to simulate conditions needed to match the data at this location. This is discussed in the Sensitivity Analysis section.



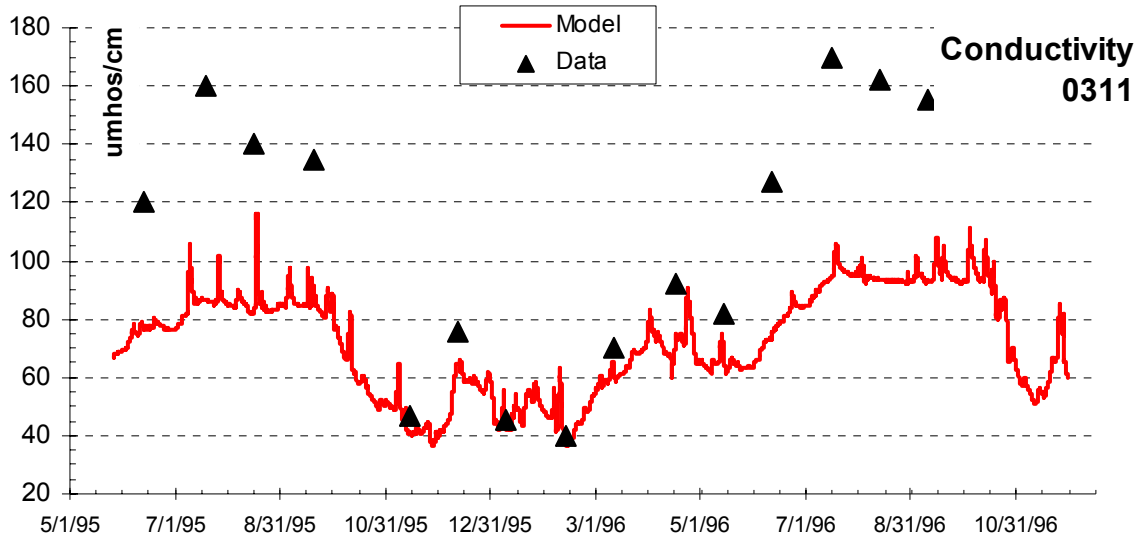


Figure 306: Conductivity Comparison, May 25, 1995 - Nov 1996 Model Run Period

Table 33: Conductivity Error Statistics, May 25, 1995 - Nov 1996 Model Run Period

Site	No. of Data Comparisons	Mean Error (umhos/cm)	AME (umhos/cm)	RMS Error (umhos/cm)
A319	17	-0.32	2.02	2.87
0311	16	-37.73	37.73	46.21

pH

pH is computed in the model from total inorganic carbon, alkalinity, and temperature model values. Figure 307 shows the comparison between model values and data for both sites, and Table 34 shows AME and RMS error statistics at each sampling site.

Alkalinity data were not available for the boundary conditions during this model run period, and an average from periods where data were available was used in the model. Since alkalinity is unknown, this was used as a calibration factor to match model values of pH with data.

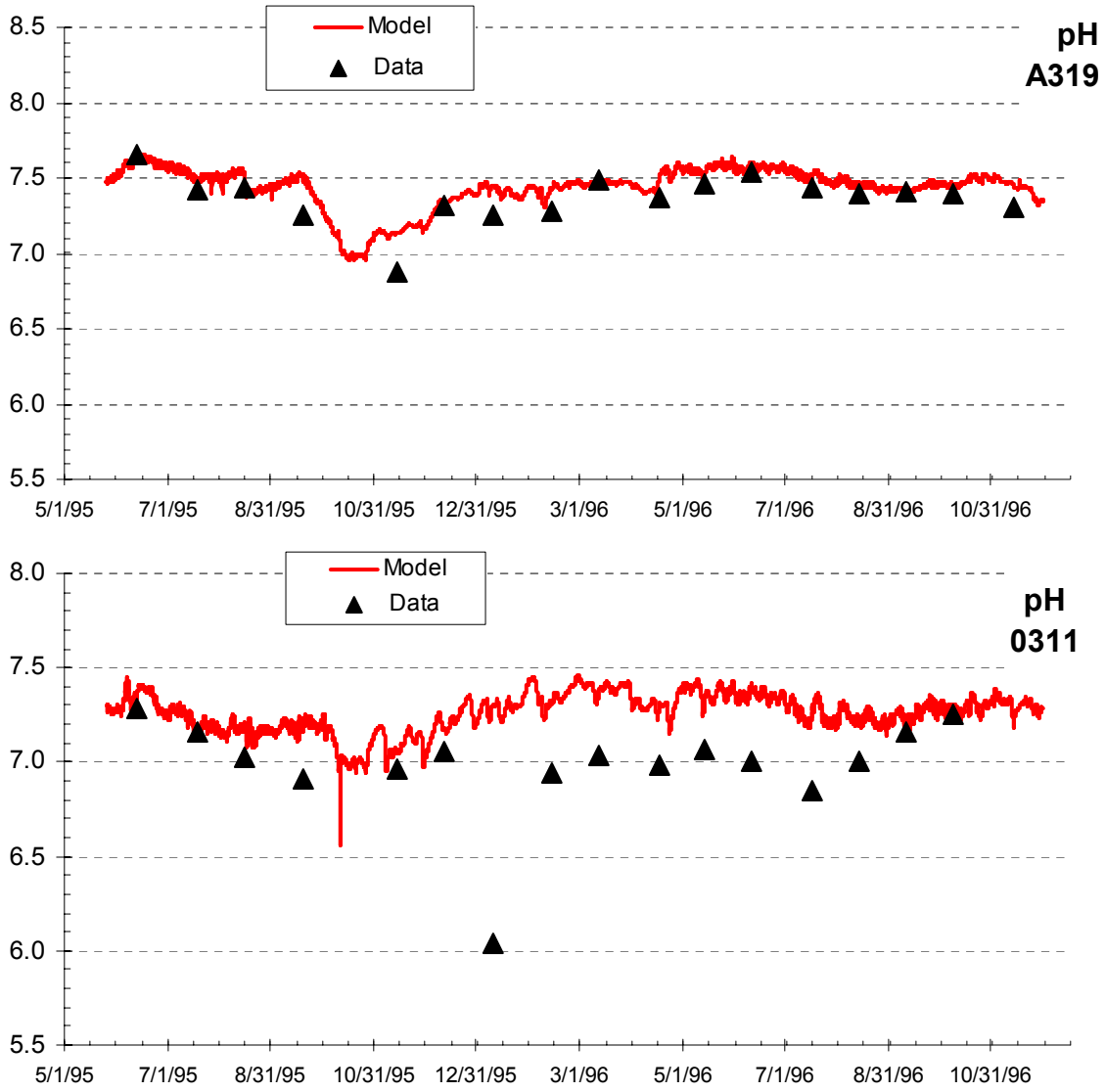


Figure 307: pH Comparison, May 25, 1995 - Nov 1996 Model Run Period

Table 34: pH Error Statistics, May 25, 1995 - Nov 1996 Model Run Period

Site	No. of Data Comparisons	Mean Error	AME	RMS Error
A319	17	0.10	0.10	0.13
0311	16	0.28	0.29	0.41

Total Suspended Solids

Total Suspended Solids is a derived constituent in CE-QUAL-W2, found by adding particulate organic matter, inorganic suspended solids, and algae. As with the 2001-2002 model run period regression was used to establish an equation that estimates model input between monthly sampling periods. Figure 308 shows the model results and data without the regression equation.

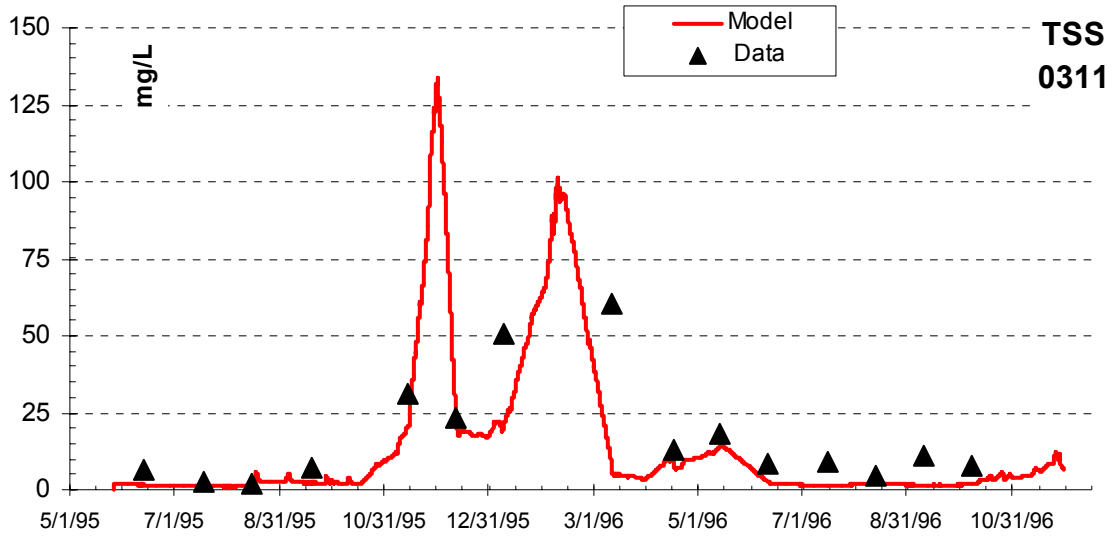
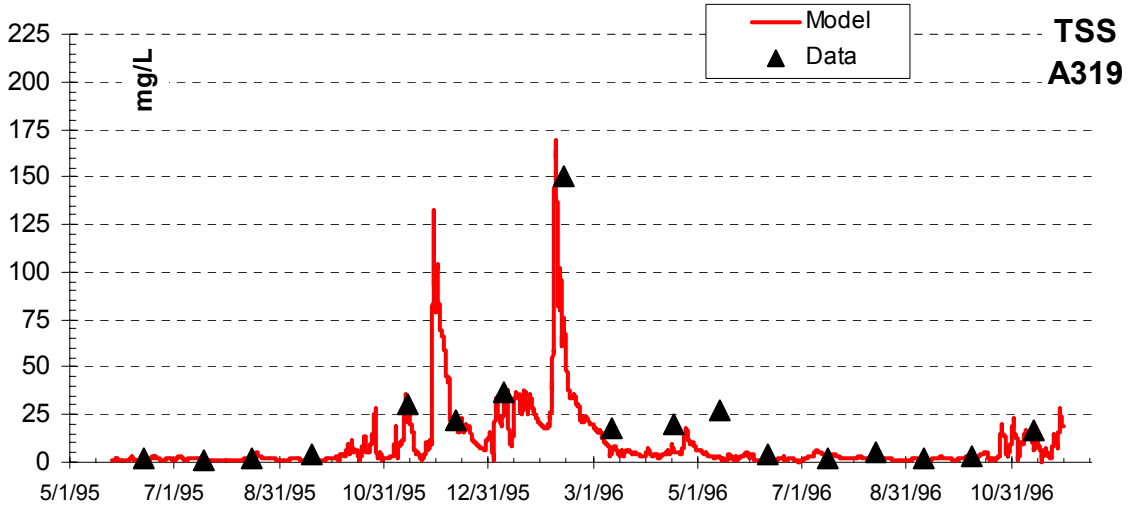


Figure 308: TSS Comparison with monthly grab samples, 1995-1996

Daily average TSS model values were estimated using flow data from the USGS gage at Palmer (Station No. 12108700), from flow data at the USGS gage near Auburn (12113000), and the Julian date. The following correlation was developed for the 2001-2002 model run period ($R^2 = 0.94$):

TSS = ABS[5.82 - 1.24*(Palmer flow) - 26.58*Log(Palmer flow) + 1.50*AUB flow-0.032*Julian date]

Model input at the upstream boundary was adjusted using this equation. The resulting graph of model values and data are shown in Figure 309, and the error statistics can be found in Table 35.



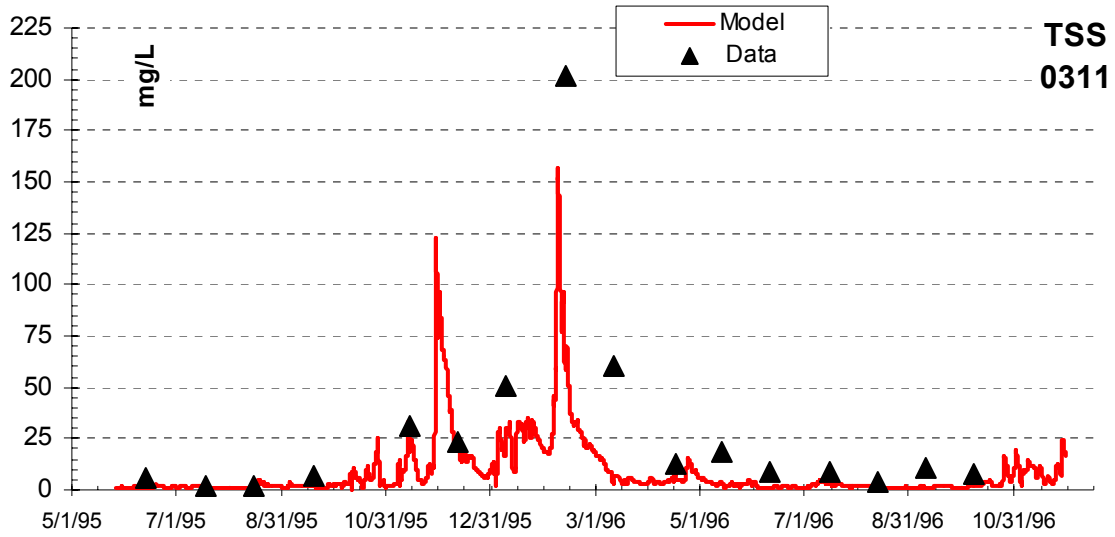


Figure 309: TSS Comparison, May 25, 1995 - Nov 1996 Model Run Period

Table 35: Total Suspended Solids Error Statistics, May 25, 1995 - Nov 1996 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	17	-9.30	9.81	20.8
0311	16	-18.11	18.11	36.9

Dissolved Oxygen

CE-QUAL-W2 has nine separate reaeration formulations that can be used for river systems. The Melching and Flores (1999) equation applicable for channel control streams was used. Zero order sediment oxygen demands were set at 1.0 g m^{-2} d^{-1} for Waterbody One and two, and 2 g m^{-2} d^{-1} for Water Body three. Figure 310 shows the time series comparison of data and model values, and Table 36 shows the AME and RMS error statistics.

As with conductivity, the model values compare very closely at Site A319, but do not compare as well at Site 0311. The Summary and Conclusions section discusses possible reasons for the difference, and the Sensitivity Analysis section discusses model runs made with additional data added to the Lower Green River to replicate sampled data.

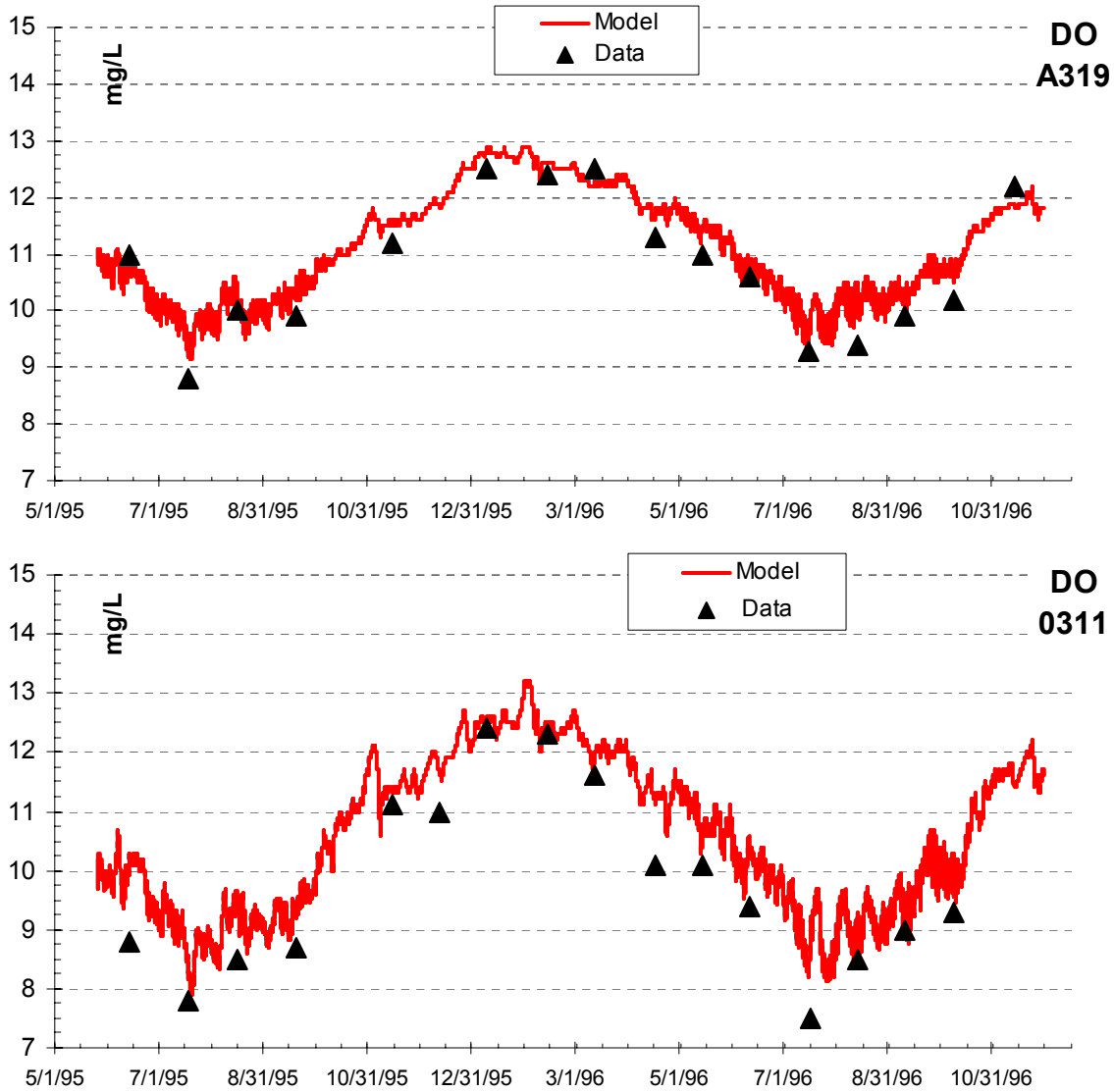


Figure 310: DO Comparison, May 25, 1995-Nov 1996 Model Run Period

Table 36: Dissolved Oxygen Error Statistics, May 25, 1995-Nov 1996 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	16	0.36	0.45	0.50
0311	16	0.59	0.59	0.68

Nitrite-Nitrate Nitrogen

Nitrite-Nitrate data were available for comparison with model-predicted values for both sampling sites. Figure 311 compares data to model values at both sampling sites, and Table 37 shows the model error statistics.

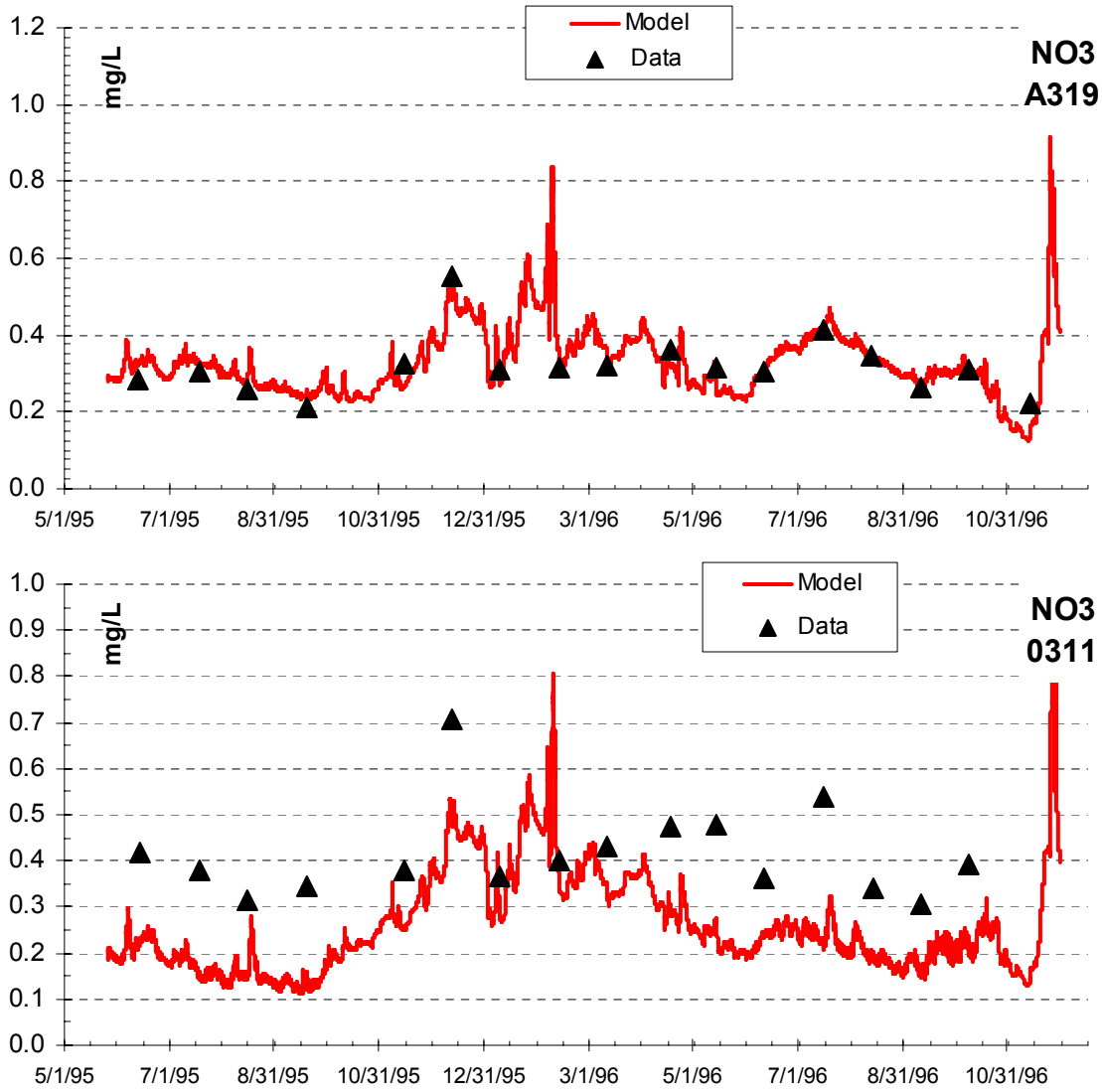


Figure 311: Nitrite-Nitrate Comparison, May 25, 1995 - Nov 1996 Model Run Period

Table 37: Nitrite-Nitrate Nitrogen Error Statistics, May 25, 1995 - Nov 1996 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	17	-0.005	0.026	0.031
0311	16	-0.17	0.17	0.18

As with the 2001-2002 model run period, nitrite-nitrate model values are under-predicted during summer periods at Site 0311. See the Sensitivity Analysis section for more information.

Ammonia Nitrogen

Ammonia Nitrogen data were available for comparison through the last half of this model run period for Site A319, and for the entire run period for Site 0311. Figure 312 shows the comparison of

sampled data and model values, and Table 38 shows the error statistics for both sampling sites.

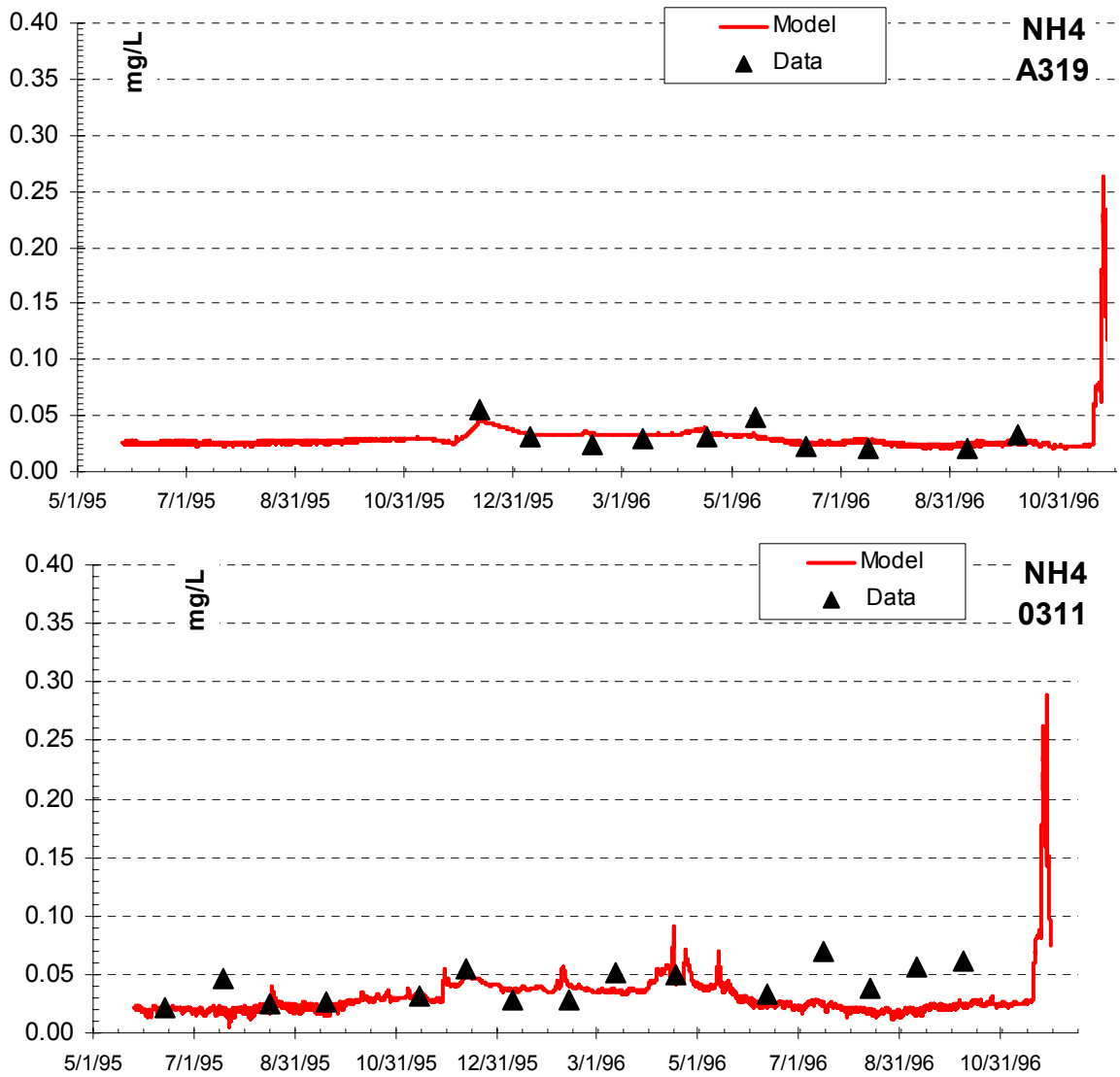


Figure 312: Ammonia Nitrogen Comparison, May 25, 1995 - Nov 1996 Model Run Period

Table 38: Ammonia Nitrogen Error Statistics, May 25, 1995 - Nov 1996 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L
A319	10	0.000	0.006	0.008
0311	15	-0.012	0.015	0.25

Total Nitrogen

Total nitrogen data were available for comparison with model values for the entire model run period, and for both sampling sites. Total Nitrogen values are calculated from nitrite-nitrate, ammonia nitrogen, and organic matter. To calibrate Total Nitrogen, the procedures for establishing organic matter input were reviewed and revised. For the 1995-1996 model run period initial organic matter model inputs were determined as a percentage of Total Suspended Solids. During model calibration

the amount of organic matter in the system was calculated from its contribution to ammonia nitrogen (See Appendix F for more information on the calculation of these values). From these values the percentage of TSS that is organic matter was calculated. This value was used to calculate organic matter input from the regression values of TSS used in the model (See TSS section above for more information on the regression). This percentage of TSS was then adjusted to calibrate Total Phosphorus.

Figure 313 shows the comparison of data with model values for both sites, and Figure 314 shows the same time period, without the peak of large concentration from two winter storms. Table 39 shows the error statistics for the model run period.

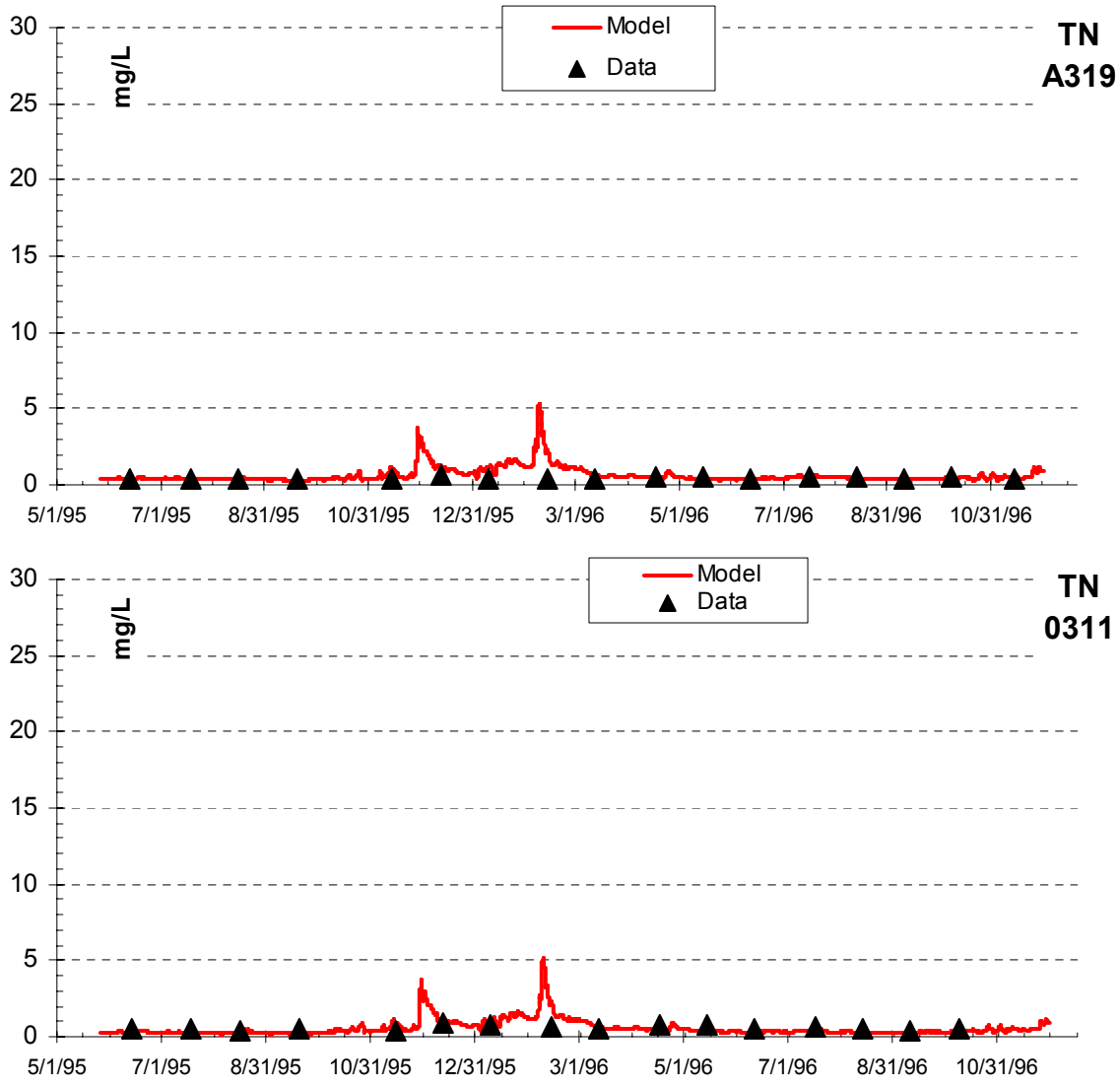


Figure 313: Total Nitrogen Comparison, May 25, 1995 - Nov 1996 Model Run Period

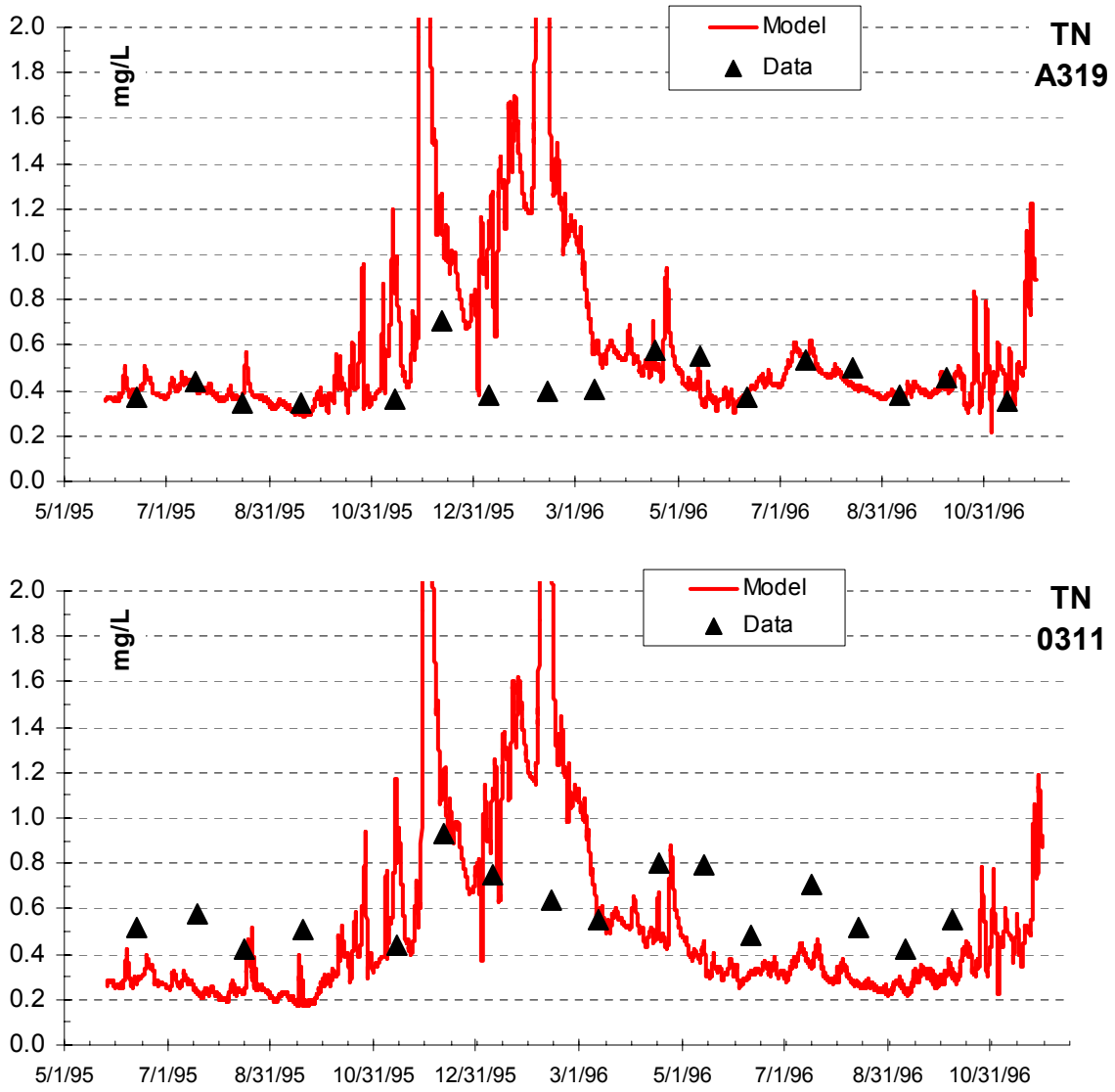


Figure 314: Reduced Scale Total Nitrogen Comparison, May 25, 1995 - Nov 1996 Model Run Period

Table 39: Total Nitrogen Error Statistics, May 25, 1995 - Nov 1996 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	17	0.21	0.26	0.53
0311	16	-0.013	0.35	0.50

Ortho Phosphorus

Ortho-phosphorus model values compare closely with sampled data at both locations. Figure 315 shows the data and model comparisons for all three locations, and Table 40 shows the error statistics.

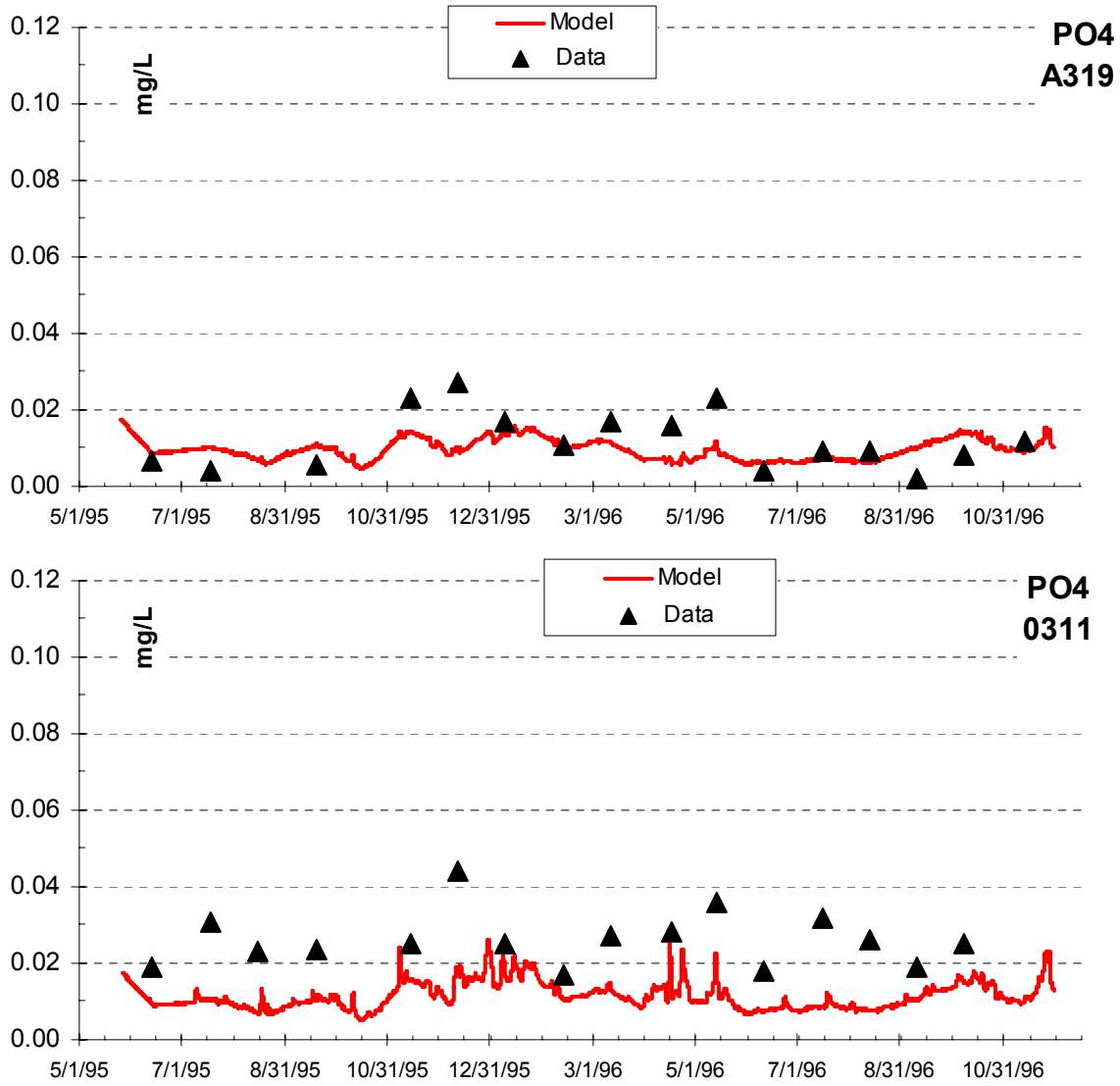


Figure 315: Ortho Phosphorus Comparison, May 25, 1995 - Nov 1996 Model Run Period

Table 40: Ortho Phosphorus Error Statistics, May 25, 1995 - Nov 1996 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L	RMS Error (mg/L
A319	16	-0.002	0.006	0.007
0311	16	-0.014	0.014	0.015

Total Phosphorus

Total Phosphorus is calculated by the model as the sum of all phosphorus compartments. Total Phosphorus values are calculated using ortho-phosphorus and organic matter. To calibrate Total Phosphorus, the procedures for establishing organic matter input were reviewed and revised. For the 1995-1996 model run period initial organic matter model inputs were estimated as a percentage of Total Suspended Solids. During model calibration this percentage was revised as described

previously and in Appendix F. Note that a regression equation has been established to determine average daily values of TSS. A percentage of these values were used as input for organic matter. Figure 316 shows the data and model comparison for the model run period. Figure 317 shows the same comparison at both sites, without the large peaks from winter storms. Table 41 shows the model error statistics.

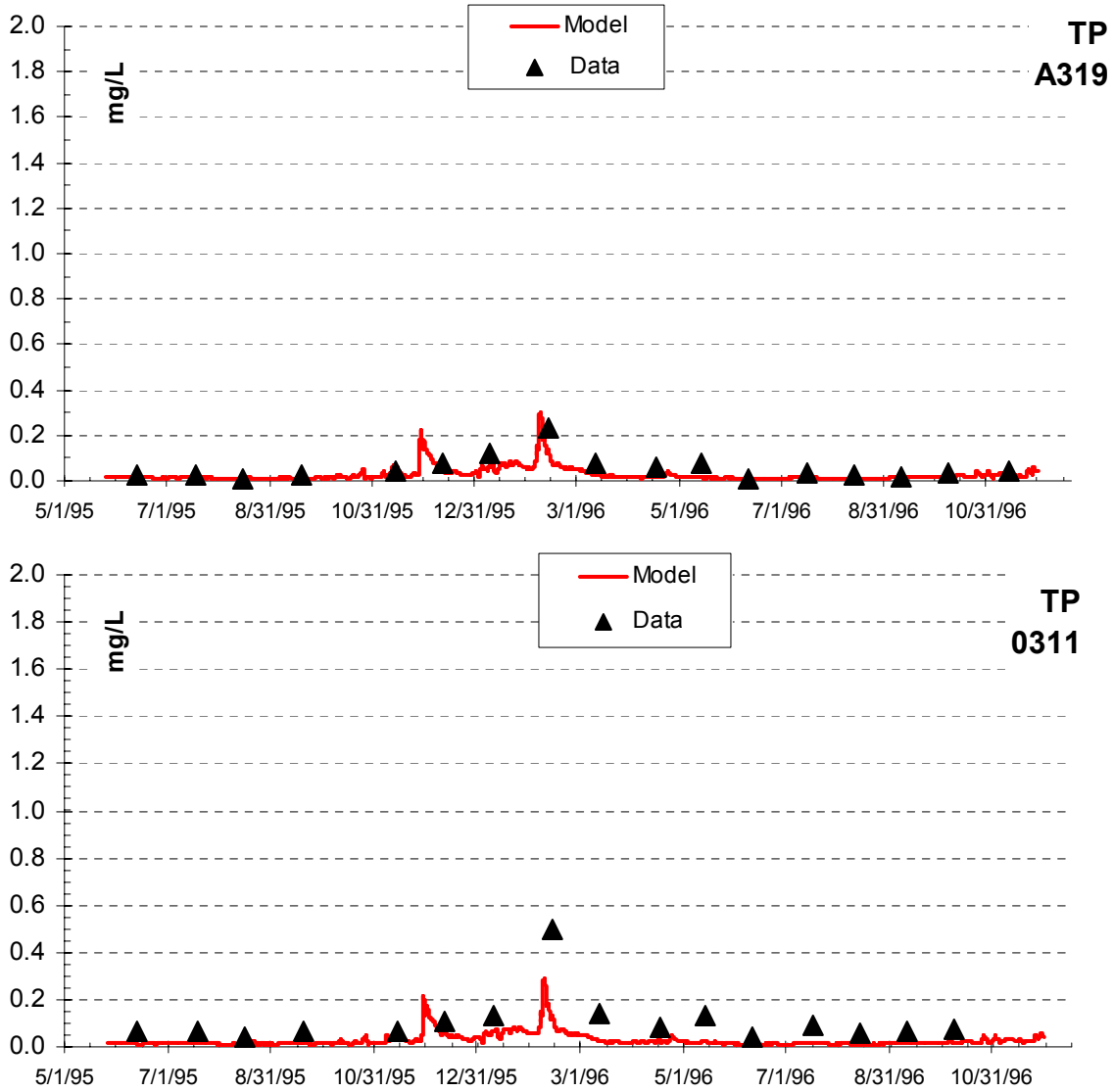


Figure 316: Total Phosphorus Comparison, May 25, 1995 - Nov 1996 Model Run Period

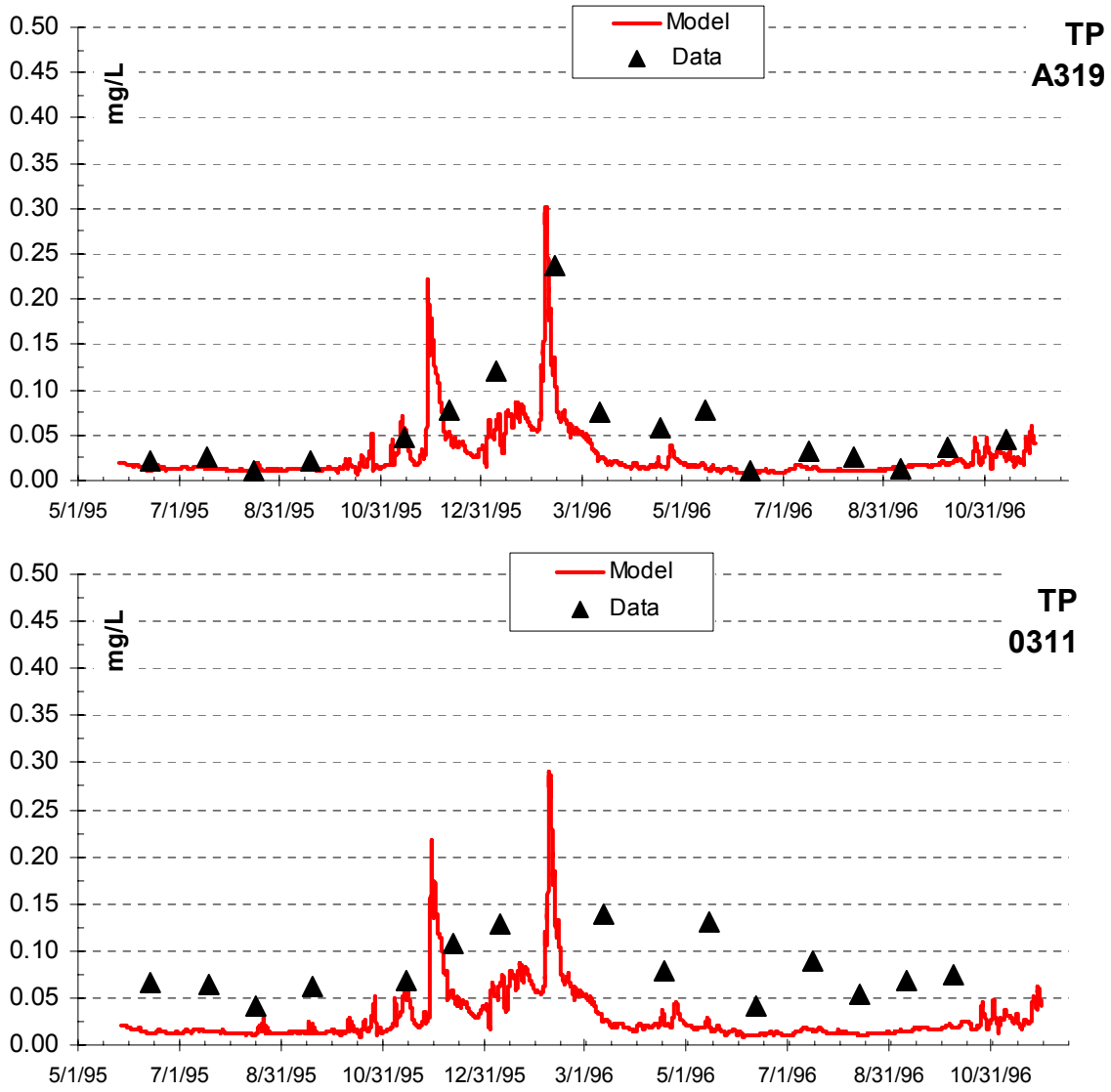


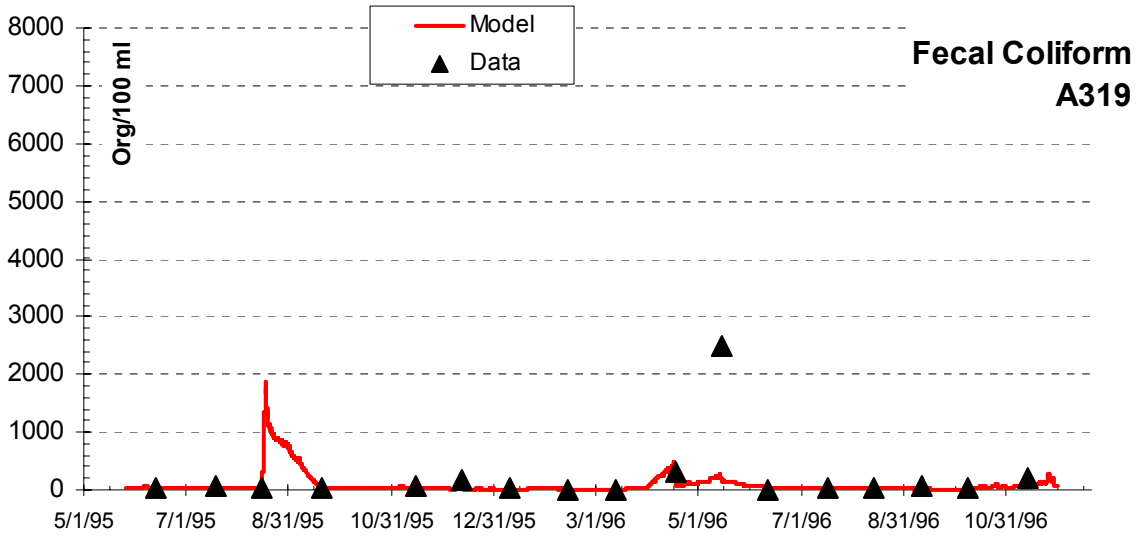
Figure 317: Reduced Scale Total Phosphorus Comparison, May 25, 1995 - Nov 1996 Model Run Period

Table 41: Total Phosphorus Error Statistics, May 25, 1995 - Nov 1996 Model Run Period

Site	No. of Data Comparisons	Mean Error (mg/L)	AME (mg/L)	RMS Error (mg/L)
A319	17	-0.026	0.027	0.039
0311	16	-0.076	0.076	0.108

Fecal Coliform

Fecal Coliform is set up as a generic constituent in the model. In CE QUAL-W2, decay rate and temperature multipliers can be individually set for generic constituents, but the constituents do not interact with other constituents. The default variables of 1.04 for the Arrhenius Temperature Multiplier, and 0.20 d^{-1} for the first order decay rate were used in the model for Fecal Coliform. Figure 318 shows the model value and data comparison, and Table 42 shows the error statistics.



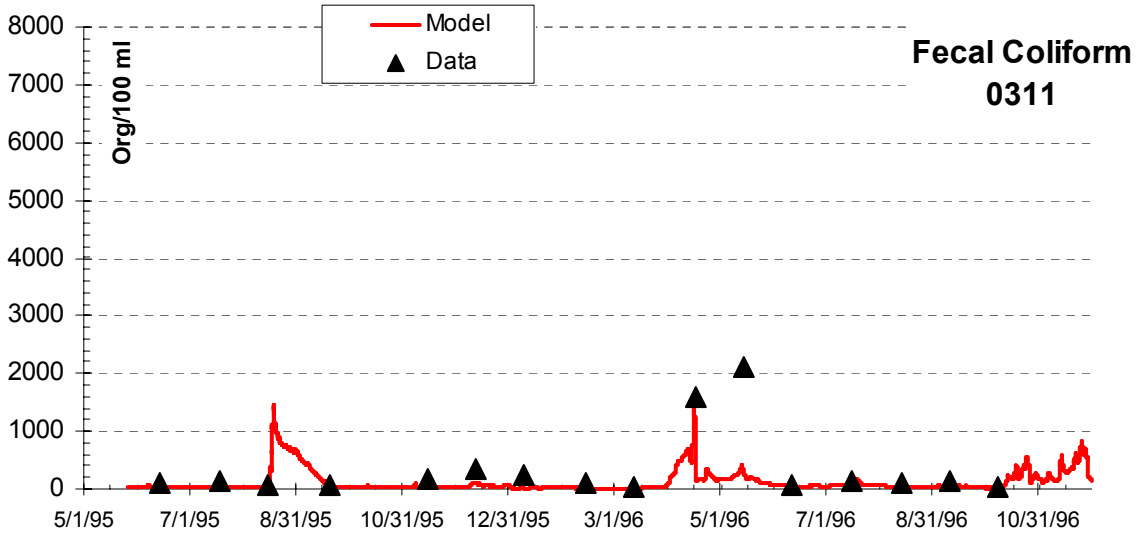
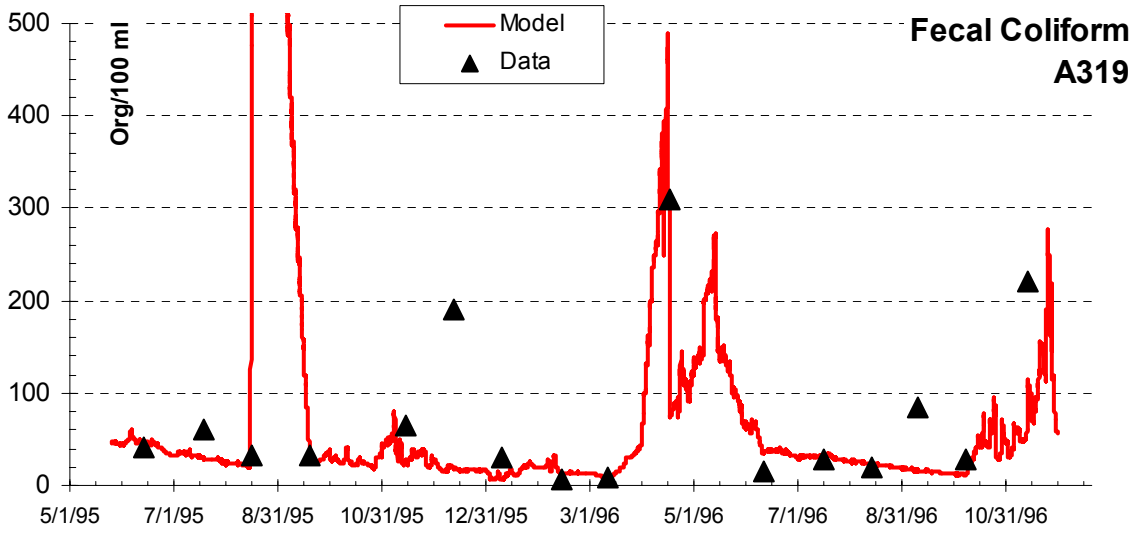


Figure 318: Fecal Coliform Comparison, May 25, 1995 - Nov 1996 Model Run Period



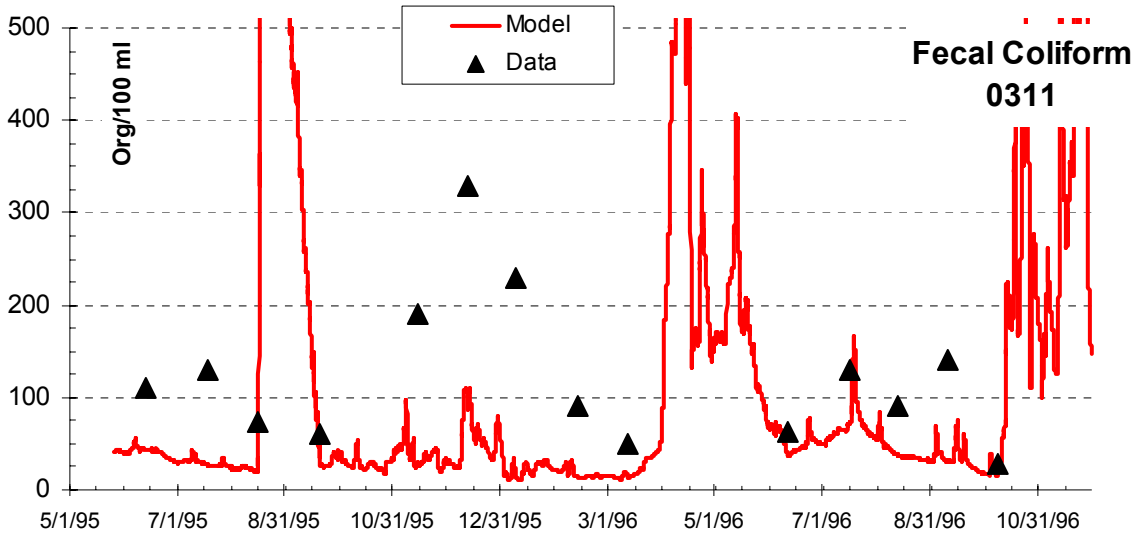


Figure 319: Reduced Scale Fecal Coliform Comparison, May 25, 1995 - Nov 1996 Model Run Period

Table 42: Fecal Coliform Error Statistics, May 25, 1995 - Nov 1996 Model Run Period

Site	No. of Data Comparisons	Mean Error (Org/100 ml)	AME (Org/100 ml)	RMS Error (Org/100 ml)
A319	17	-162	190.80	565.3
0311	16	-272.3	272.3	570

4.0 SENSITIVITY ANALYSES

4.1 Analysis of New Channel on Model Flow, Temperature, and Water Quality

In the winter of 1996 flooding created new channels in three locations on the river, with the most significant change located at River Mile 32.40 (See Figure 320). When assembling the model bathymetry this channel was to be included in the model; however there was no topographical information available. Since the topography is not known, and the effect of this new channel on the model is unknown, it was decided to leave it out of the model and perform separate model runs comparing results with and without the new channel.

For this model run a new branch was added to the model with two segments, connected upstream and downstream to the main river channel. Channel widths and bottom elevation were taken from model segments directly adjacent to the upstream and downstream end of the new channel. A spillway was used to spill water into the new channel. The model results were compared to each other and with field data. Flow data were compared at the downstream end of the new channel, and at Site 12113000, which is about 1.25 km downstream of the new channel. Model values for temperature were compared with each other at Site 12113000, and at the downstream end of the new channel. Temperature data were not collected at Site 12113000, but the only data collection sites downstream are GRT20 and GRT22, which is a long way downstream and only has data for July 2002. Water quality data were compared at the downstream end of the new channel, and at King County's water quality sampling site G319, which is approximately 20 km downstream of the new channel.

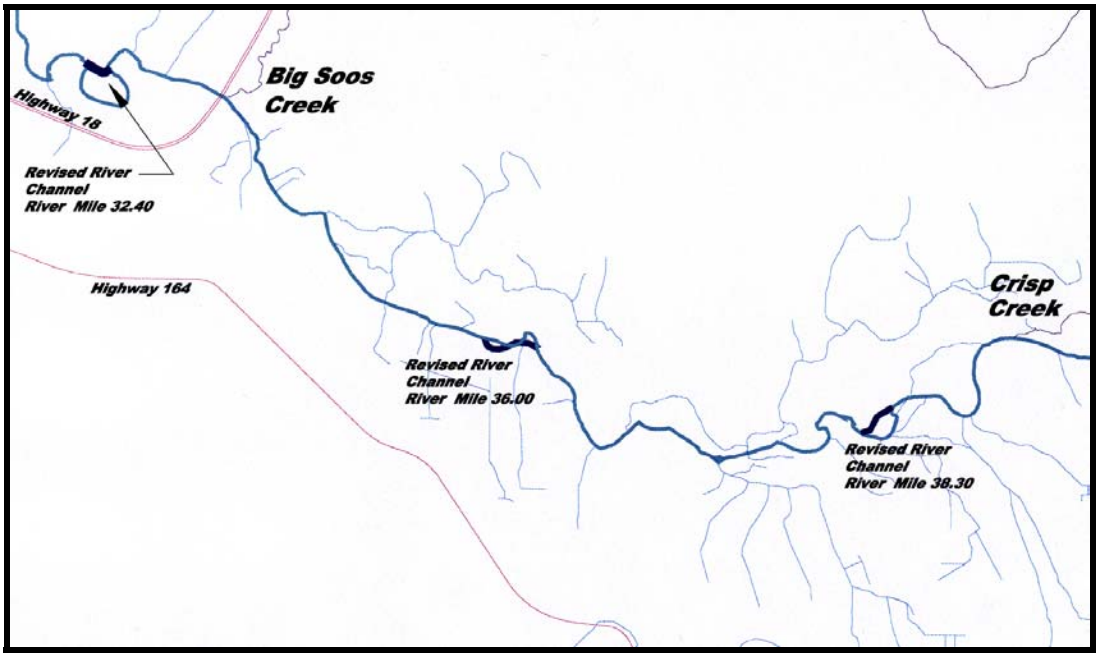


Figure 320: New Channel Locations

Figure 321 shows the comparison between model values of flow one segment downstream from where the new channel enters the main channel, and Figure 322 shows flow comparisons at Site 12113000. Model values for flow are the same with and without the channel at both locations.

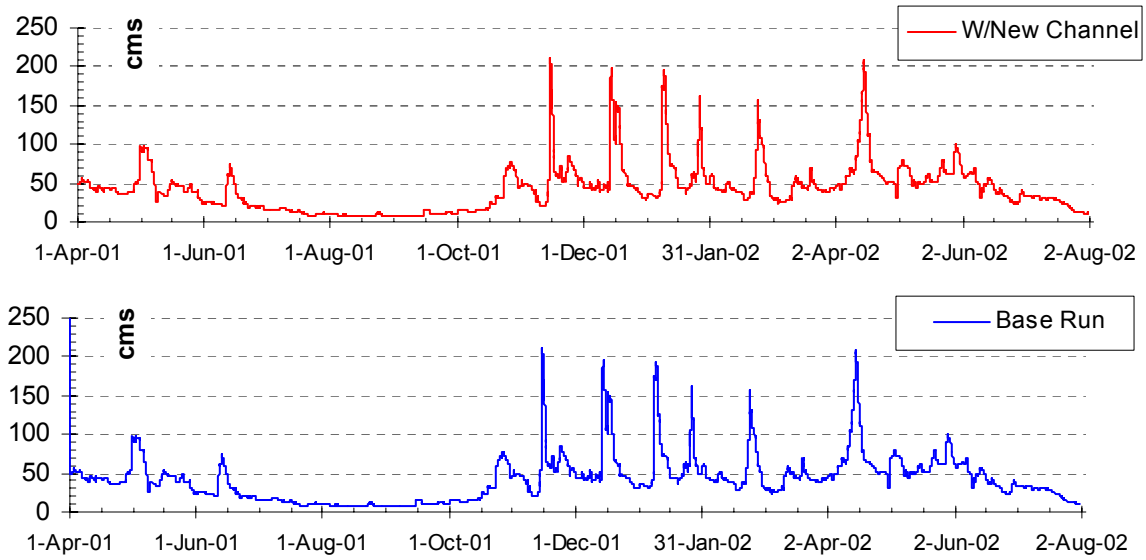


Figure 321: Flow Comparison at downstream end of new channel

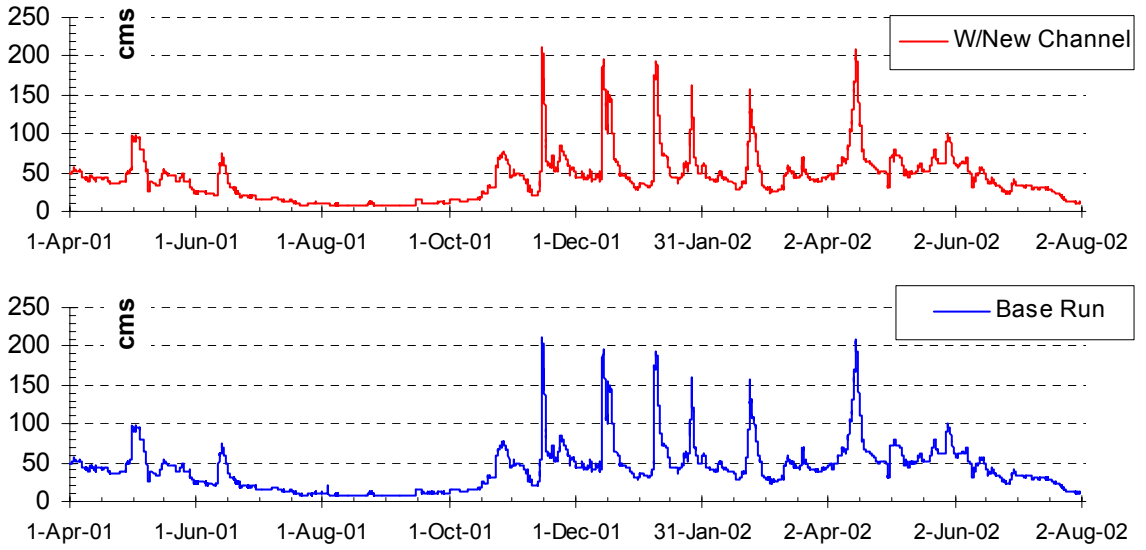


Figure 322: Flow Comparison at Site 12113000

Table 43 lists the error statistics between the model run without the side channel and the model run with the side channel.

Table 43: Flow Error Statistics with and without side channel

Site	Mean Error (cms)	AME (cms)	RMS (cms)
Downstream End (RM 34.0)	-0.0003	0.11	0.34
USGS Site 12113000 (RM 31.3)	0.0067	0.26	0.78

Figure 323 compares temperature model values at the first segment in the main channel downstream

of the new channel, and Figure 324 compares temperature model values at Site 12113000.

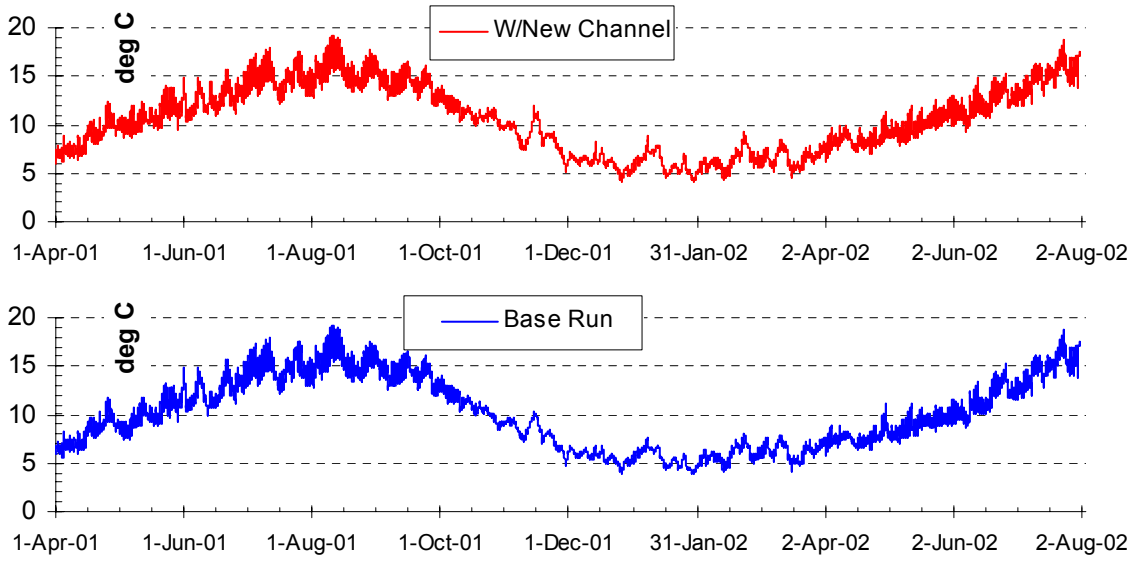


Figure 323: Temperature Comparison at downstream end of new channel

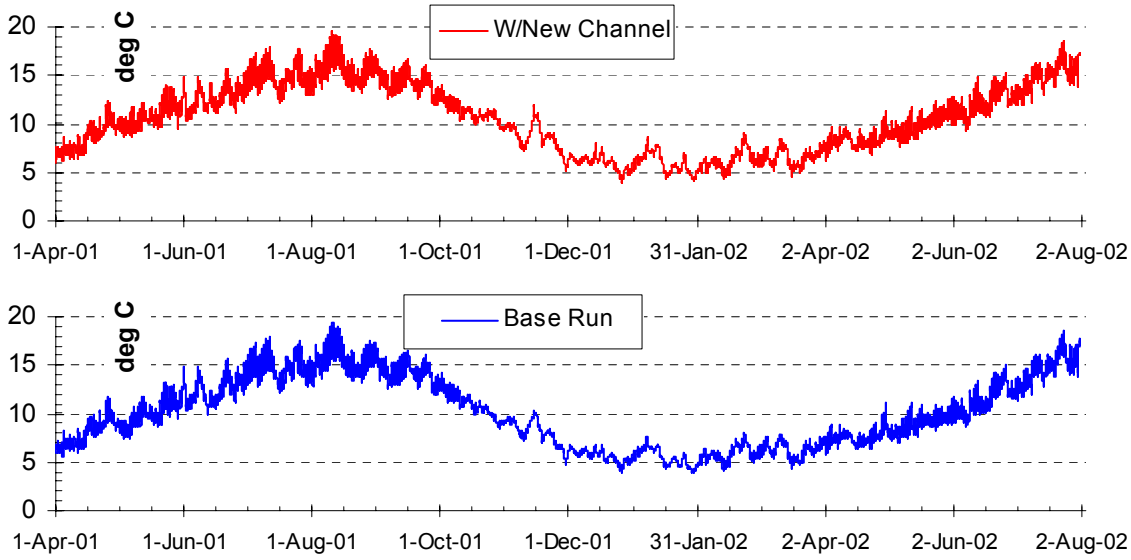


Figure 324: Temperature Comparison at Site 12113000

Figure 325 shows a comparison at the downstream end of the new channel for both model runs from mid-October 2001 through August of 2002. The run with the new channel has higher temperatures during this time period.

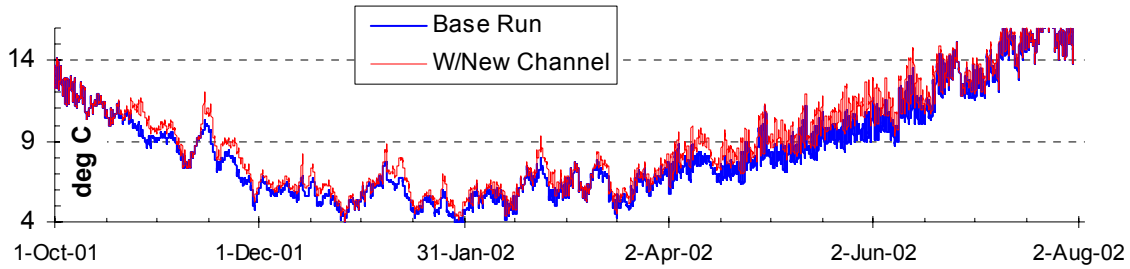


Figure 325: Side-by-side Temperature Comparison at downstream end of new channel

Temperature values with the new channel also ran higher during April and May of 2001. During other time periods model values match very closely with both runs. Table 44 lists the error statistics between the model run without the side channel and the model run with the side channel.

Table 44: Temperature Error Statistics with and without side channel

Site	Mean Error (C)	AME (C)	RMS (C)
Downstream End (RM 34.0)	0.43	0.43	0.61
USGS Site 12113000 (RM 31.3)	0.42	0.44	0.58

The median value of temperature for the base run is 9.56 C. The 95% confidence interval around this median is between 9.47 and 9.67 C. The median value of temperature for the model run with the additional channel is 10.38 C, and is outside the confidence interval for the median value.

Figure 326 through Figure 329 compares conductivity, pH, dissolved oxygen, and total suspended solids at Site G319, and Figure 330 through Figure 333 compares the same constituents at the downstream end of the new channel with and without the new channel included in the model.

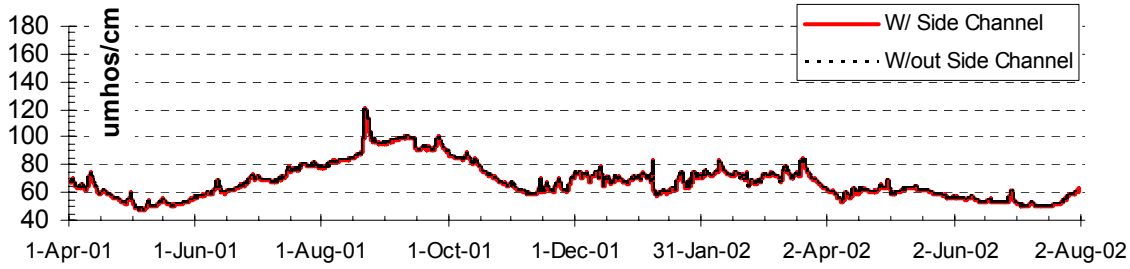


Figure 326: Conductivity Comparison at Site G319

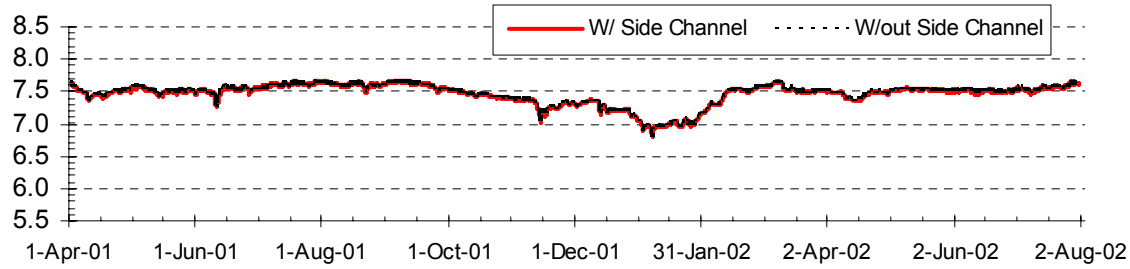


Figure 327: pH Comparison at Site G319

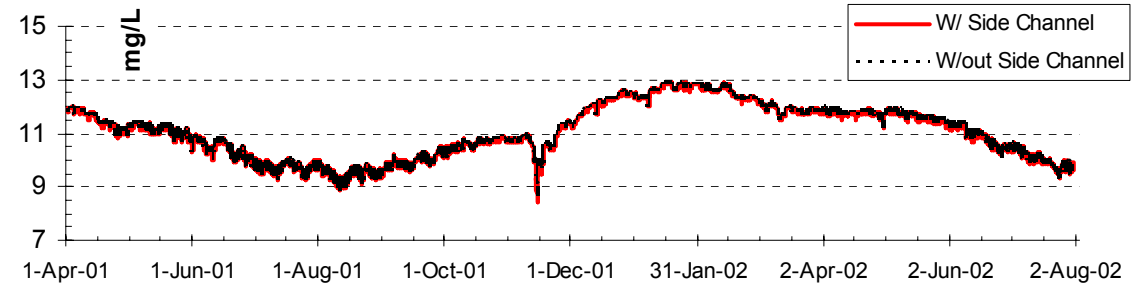


Figure 328: DO Comparison at Site G319

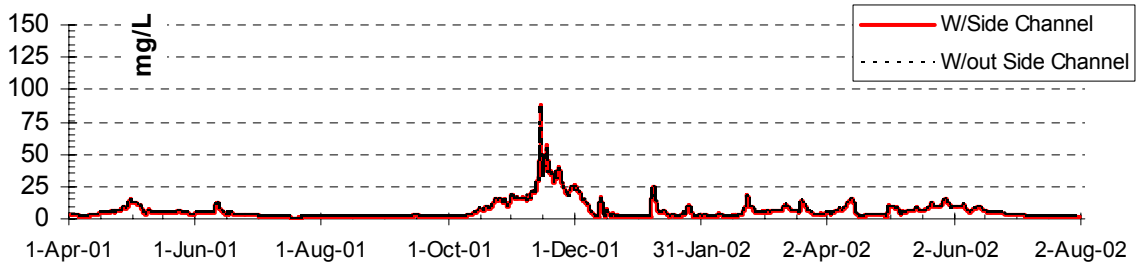


Figure 329: TSS Comparison at Site G319

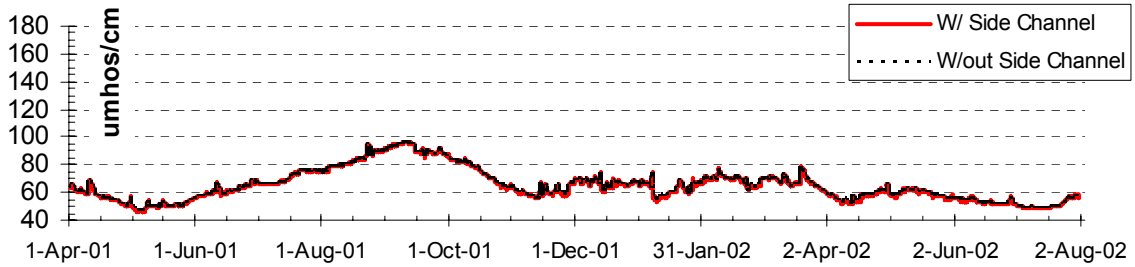


Figure 330: Conductivity Comparison Downstream of New channel

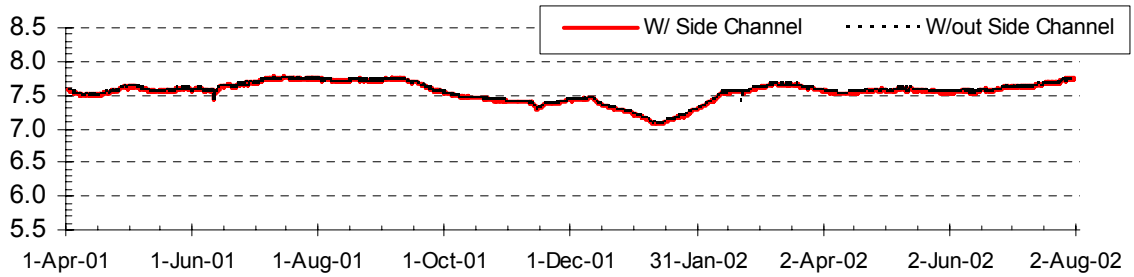


Figure 331: pH Comparison Downstream of New channel

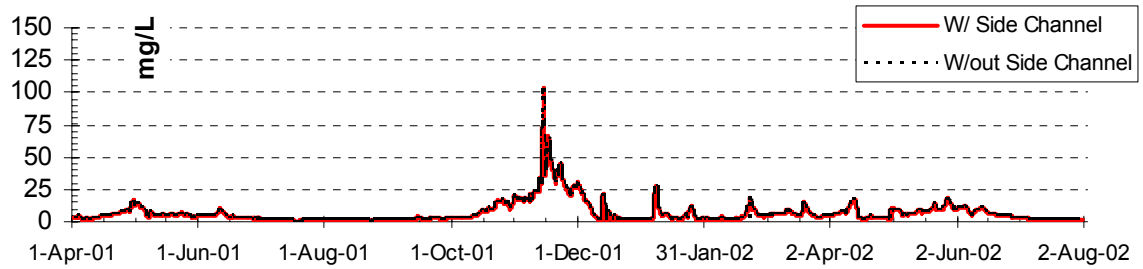


Figure 332: TSS Comparison Downstream of New channel

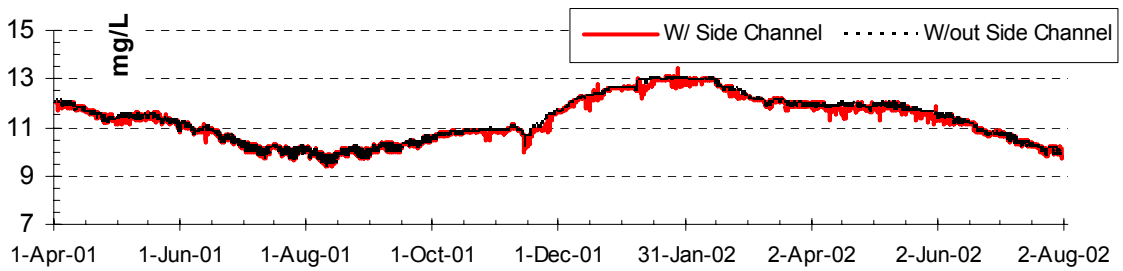


Figure 333: DO Comparison Downstream of New channel

Table 45 lists the error statistics between the model run without the side channel and the model run with the side channel.

Table 45:Water Quality Error Statistics with and without side channel

	Site	Mean Error (mg/L)	AME (mg/L)	RMS (mg/L)
CONDUCTIVITY	Downstream End (RM 34.0)	-0.16	0.24	0.43
	Site G319 (RM 21.3)	-0.027	0.058	0.15
pH	Downstream End (RM 34.0)	-0.0039	0.004	0.008
	Site G319 (RM 21.3)	-0.0038	0.0047	0.0077
DO	Downstream End (RM 34.0)	-0.039	0.046	0.094
	Site G319 (RM 21.3)	-0.027	0.029	0.054
TSS	Downstream End (RM 34.0)	-0.033	0.051	0.34
	Site G319 (RM 21.3)	0.0093	0.022	0.082

4.2 pH Calibration

pH model values differed from sampled data during late summer and early fall at all three water quality calibration sites and during both model run periods. For the 1995-1996 model run period alkalinity data were not available, so adjusting model input values of alkalinity was used to calibrate pH. Sample alkalinity data were available for the 2001-2002 model run period, so alkalinity values

were not adjusted.

Figure 334 shows the field sampled pH data at the upstream boundary, field sampled pH data at Site A319, which is 20 km downriver from the upstream boundary, and model values of pH at Site A319. This graph shows that model values at Site A319 were close to the sampled data at the upstream boundary - even higher during some time periods, whereas sampled data at the downstream sampling site shows that pH values have dropped at this location. Model runs were performed varying data in an attempt to reproduce the sampled data at the downstream sampling site.

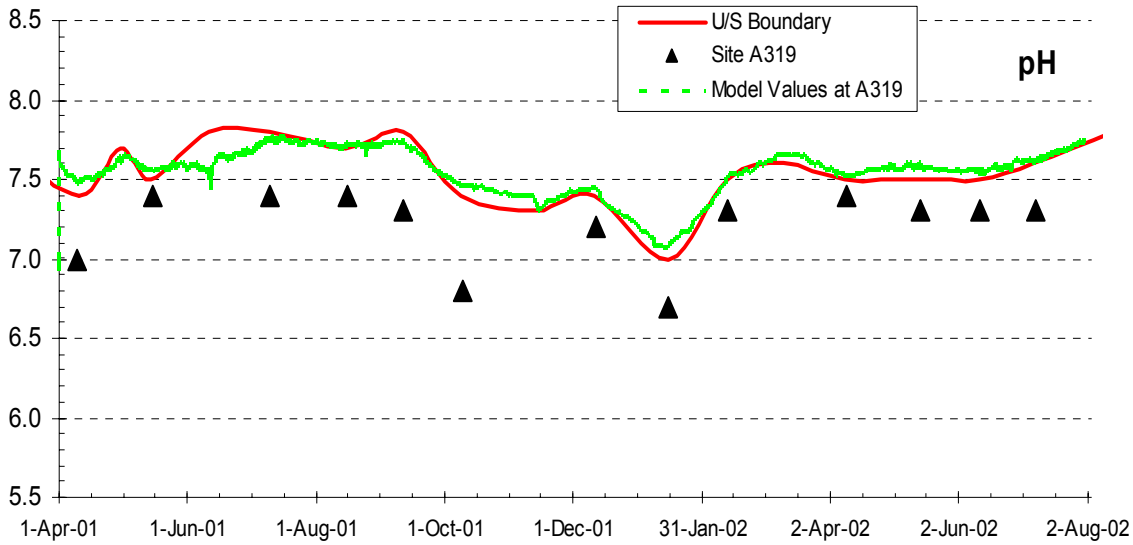
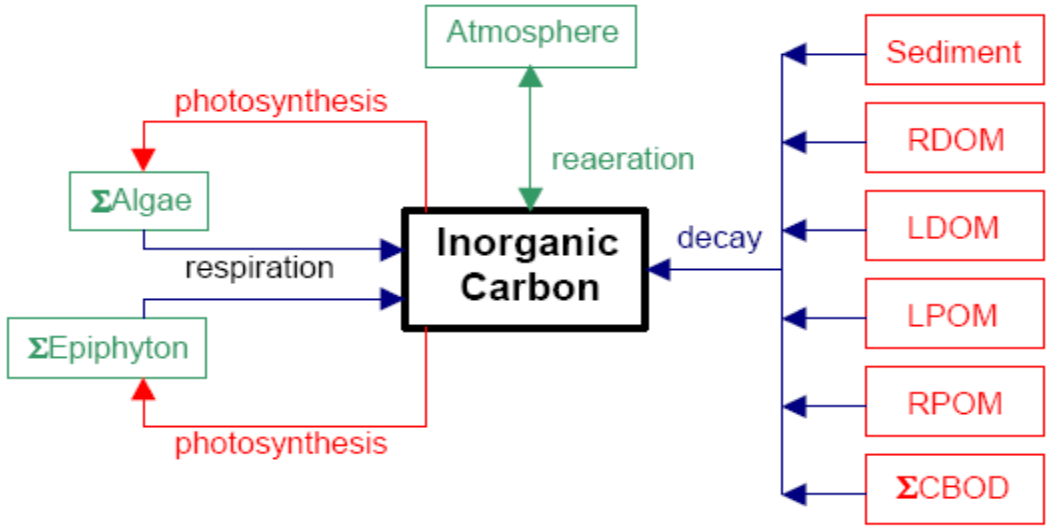


Figure 334: pH Comparison

pH is calculated in the model using temperature, alkalinity, and total inorganic carbon (TIC). Model temperature values and alkalinity values matched well with data when sampled data were available, so TIC values were reviewed. Low TIC values will result in higher calculated values for pH.

Figure 335 is a diagram from Cole (2002) which shows the sources and sinks for TIC. This figure shows how TIC is accumulated and lost in the model and provides a guideline for determining where additional sources of TIC might be produced.



SOURCE: Cole (2002)

Figure 335: CE-QUAL-W2 TIC MODEL

The following analyses were performed in an attempt to calibrate pH levels through adjusting the sources and sinks to TIC. Model runs were performed for August 2001 with the changes noted. This is a period of low-flow where pH values were noted to be different from sampled data.

- Adjusting SOD values. CE-QUAL-W2 allows different SOD values to be specified for each segment of the river. Adjusting these values was effective in reducing pH, but only by using very high SOD values. Using a SOD value of 5.0 g m^{-2} d^{-1} reduced model pH values very close to the sampled data at the calibration points.
- Reducing the algae growth rate. Algae growth consumes TIC, so reducing the growth rate of algae would reduce the amount of TIC consumed. This had little effect, mainly because of the small amounts of algae present in the river, especially in the upper reaches of the modeled section.
- Increasing the amount of organic matter in the system, and adjusting the percentage of labile and refractory organic matter. Total suspended solids data at boundaries and tributaries are divided between inorganic suspended solids and organic matter for input into the model. The percentage of organic matter was increased. Also, organic matter introduces TIC into the system when decaying, and labile organic matter has a higher decay factor than refractory organic matter. The percentage of labile organic matter was increased. However, these changes did not produce a significant increase in TIC.
- Turning on the first-order sediment compartment, which accumulates sediment and releases TIC based upon a 1st-order process. This change exhibited no effect on pH values.
- Changing the oxygen reaeration coefficient. The CO2 reaeration coefficient is determined as a percentage of the oxygen reaeration coefficient, so changing the oxygen reaeration coefficient will also change the reaeration of CO2 to the system. Oxygen reaeration values of 0.50, 1, 5, and 10 were used. Model runs showed improvement in pH model values with the reaeration coefficient set to 0.50.
- TIC values for the distributed tributaries were increased. Branches two and three have distributed tributaries. There were no water quality data available for these tributaries, so data from the Big Soos River was used. The amount of TIC input into the model for these distributed branches was increased. The amount of TIC need to be up over 200 mg /L to produce pH values close to sampled data at Site A319.
- Along with looking for sources of TIC, alkalinity changes were also tried. Alkalinity data for the distributed tributaries ranged from 41 to 55 mgCACO3/L. These model input values were reduced by 30 points for both tributaries. This had a small effect on lowering pH.

There is one other possible source of TIC that was not pursued. Increasing TIC and decreasing alkalinity values in the distributed tributaries had little affect because the flow rates used in the distributed tributaries are very low. When calibrating flow, additions or reductions were made to the upstream boundary when necessary, assuming the flow difference came from unknown flow contributions from springs above the upstream boundary. If the flow additions came from groundwater inflows below the upstream boundary, this would mean more flow added to the distributed tributaries. With additional flow, the changes in TIC and alkalinity would have a greater affect on model values of pH. The Summary and Conclusions section discusses recommendations

for future model development. One recommendation is to move the upstream boundary of the model. Moving the boundary condition upstream and adding additional calibration points on the Middle Green River would allow better characterization of groundwater inflows, and may provide better information on how groundwater inflows affect pH.

4.3 Lower Green River Model Calibration

Model values provided good comparisons with sampled data for most constituents at Site A319 (RM 33.80) matching data with model values was not as consistent at Site G319 (RM 21.30) and Site 0311 (RM 13.2) during the 2001-2002 model run period, and at Site 0311 for the 1995-1996 model run period.

Conductivity and alkalinity model values differ significantly from data at Site 0311 during summer months for both model run periods. These are conservative constituents, so this indicates a missing source with either significant flow or high concentrations.

Model values at Site G319 and Site 0311 showed significant differences from sampled data for dissolved oxygen throughout the 2001-2002 model run period. Model values for dissolved oxygen also differed significantly from data at Site 0311 during the 1995-1996 model run period.

pH model values differed from data at these sites for both model run periods.

To estimate missing data, a distributed tributary was added to a downstream branch of the model, and constituent data were added to replicate sampled data at the two sampling sites (G319 and 0311). The data and methods used differed for the two model run periods, so the two periods are addressed separately.

4.3.1 2001-2002 Model Run Period

A distributed inflow was added to Branch four, which extends approximately from RM 27 to RM 34. Flow values were set, and constituent input values to the model were adjusted to match data at both calibration sites. A BOD source was added to this distributed tributary to reduce dissolved oxygen values to match data. TIC data were adjusted to match pH values, and alkalinity and conductivity values were adjusted until model results produced values closer to data at both sites.

The distributed inflow was first added to Branch five, which is the branch that both Site G319 and Site 0311 are located in. However, the dissolved oxygen values did not respond to the BOD when used in Branch five. This distributed tributary was removed from Branch five and added to Branch four. This produced better results for dissolved oxygen, and did not affect results for the other constituents.

Figure 336 shows the flow used in the distributed tributary and Figure 337 through Figure 340 shows the combined flow/constituent values that were added to the model for the 2001-2002 model run period.

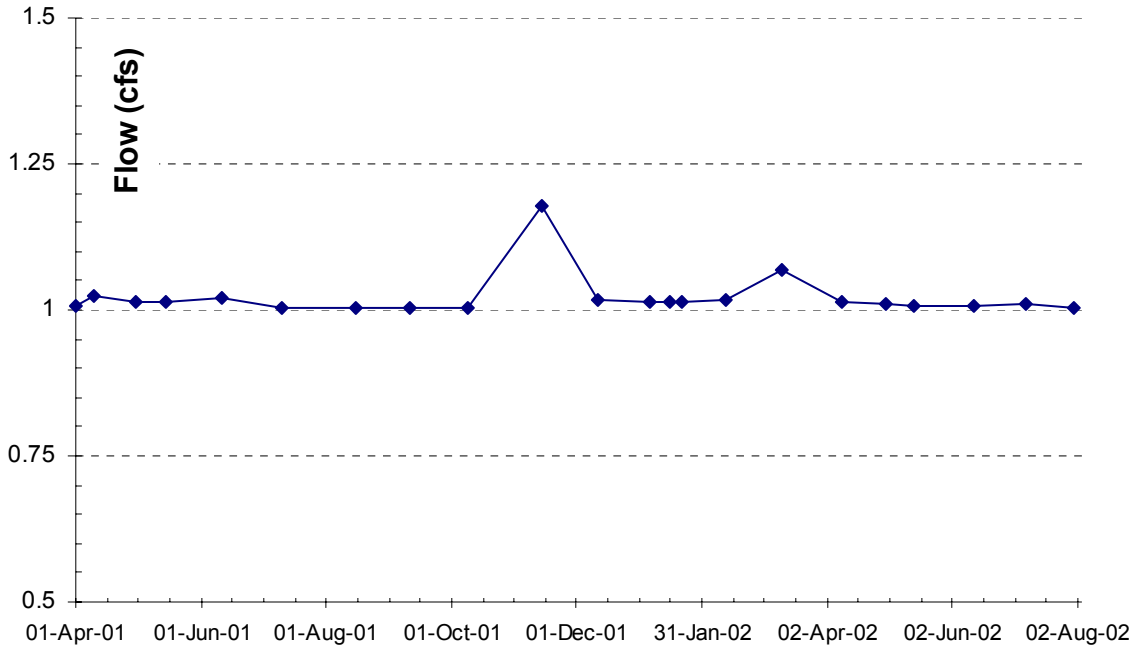


Figure 336: Flow Data for 2001-2002 Model Run Period - Branch 4 Distributed Tributary

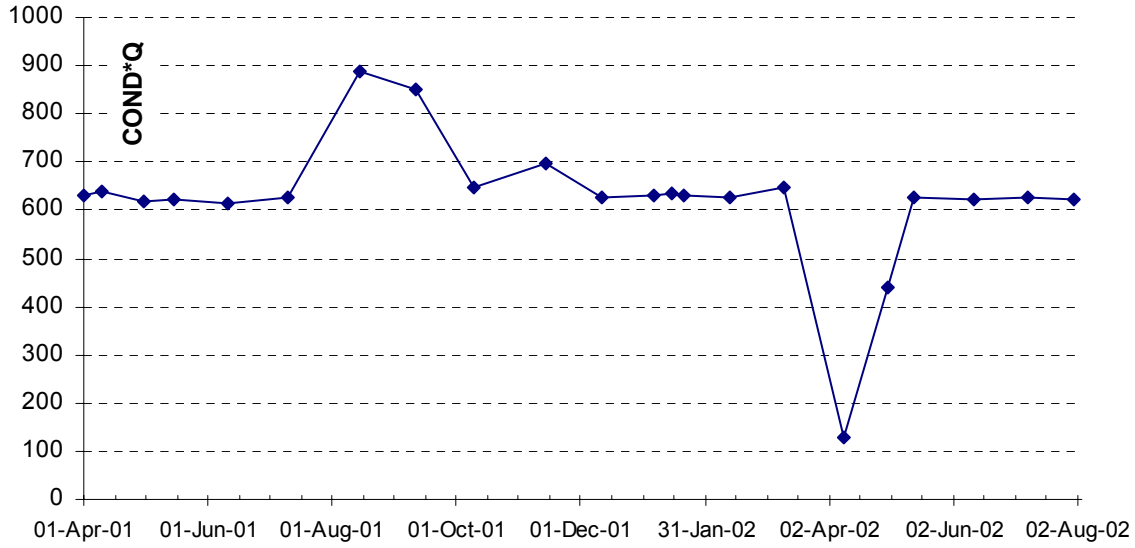


Figure 337: Flow and Conductivity Data for 2001-2002 Model Run Period - Branch 4 Distributed Tributary

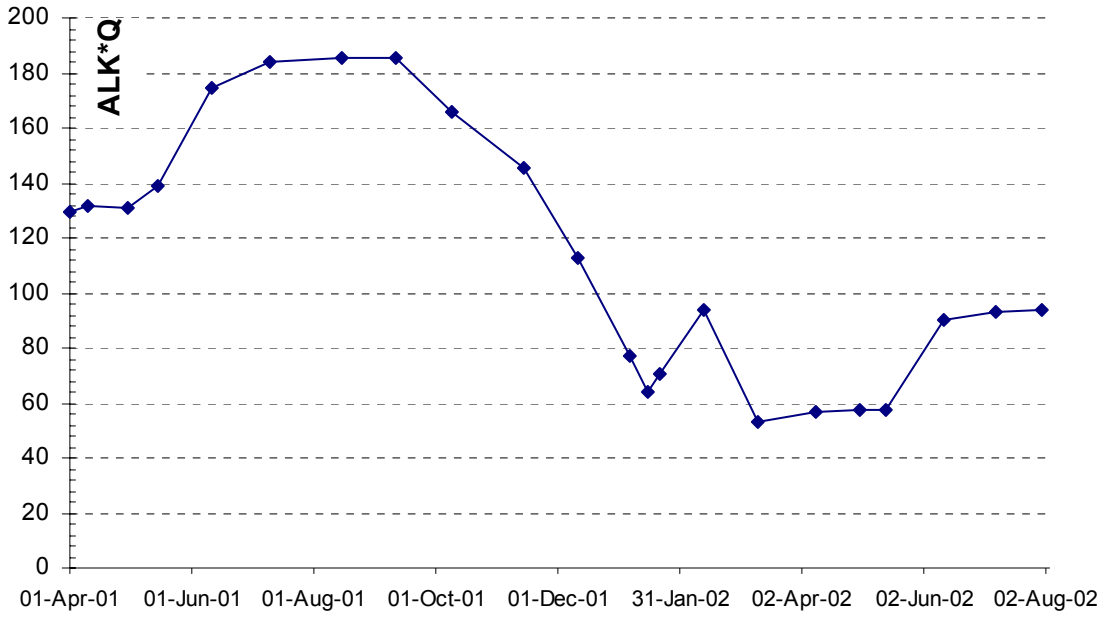


Figure 338: Flow and Alkalinity Data for 2001-2002 Model Run Period - Branch 4 Distributed Tributary

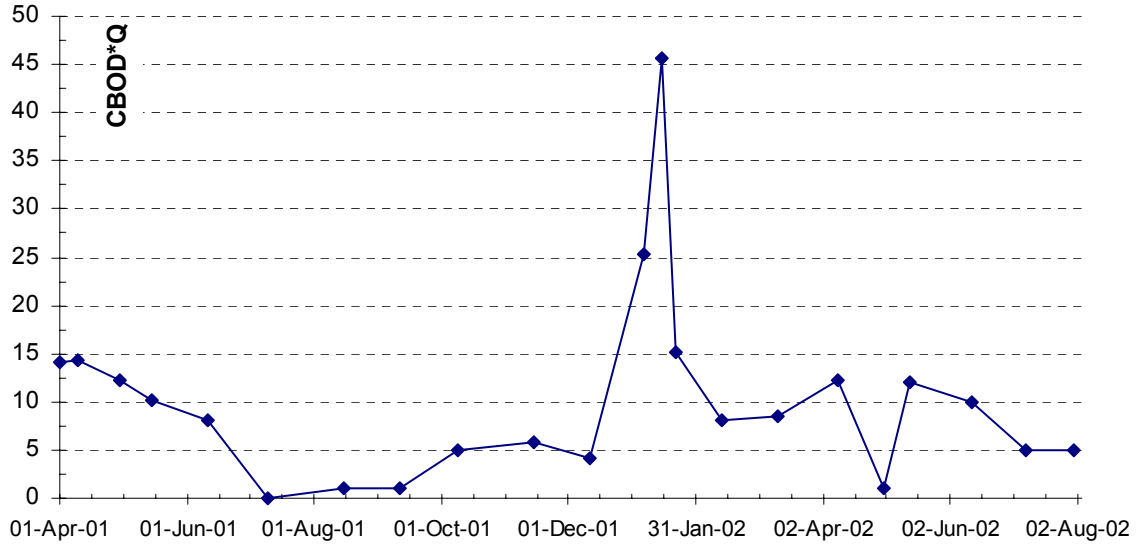


Figure 339: Flow and CBOD Data for 2001-2002 Model Run Period - Branch 4 Distributed Tributary

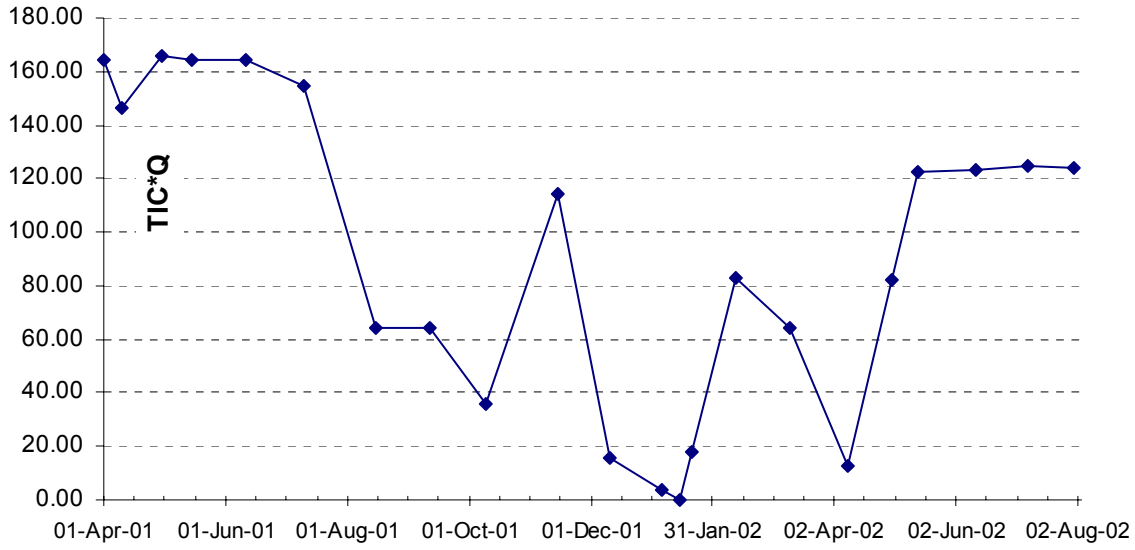


Figure 340: Flow and TIC Data for 2001-2002 Model Run Period - Branch 4 Distributed Tributary

Figure 341 through Figure 348 shows the model values and data with the distributed tributary for Sites 0311 and G319, and Table 46 through Table 49 shows the error statistics.The tables also show the error statistics without the additional data for comparison purposes.

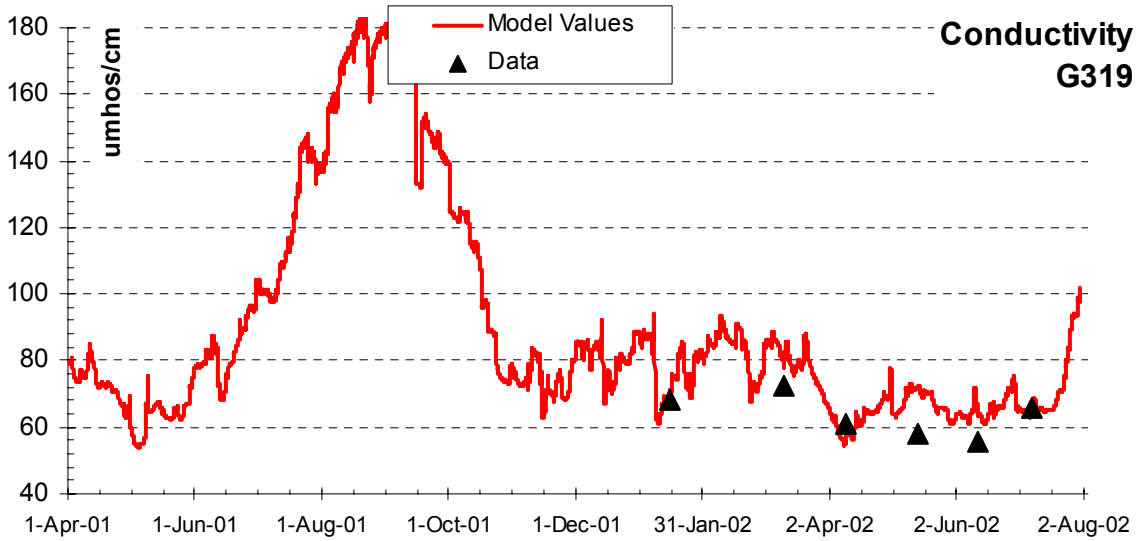


Figure 341: Conductivity Comparison with distributed tributary at Site G319 - 2001-2002 Model Run Period

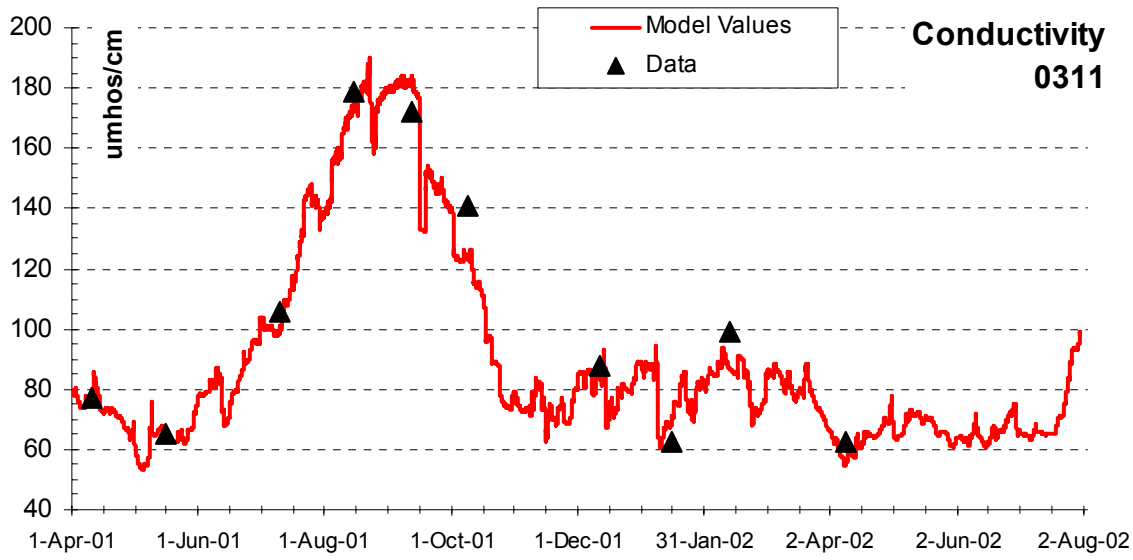


Figure 342: Conductivity Comparison with distributed tributary at Site 0311 - 2001-2002 Model Run Period

Table 46: Conductivity Error Statistics with distributed tributary, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error	AME	RMS Error
G319	6	4.51	6.88	8.33
0311	13	-3.58	7.34	8.79
Conductivity Error Statistics without distributed tributary, 2001-2002 Model Run Period				
G319	6	-4.22	6.15	7.6
0311	13	-33.4	33.4	44.4

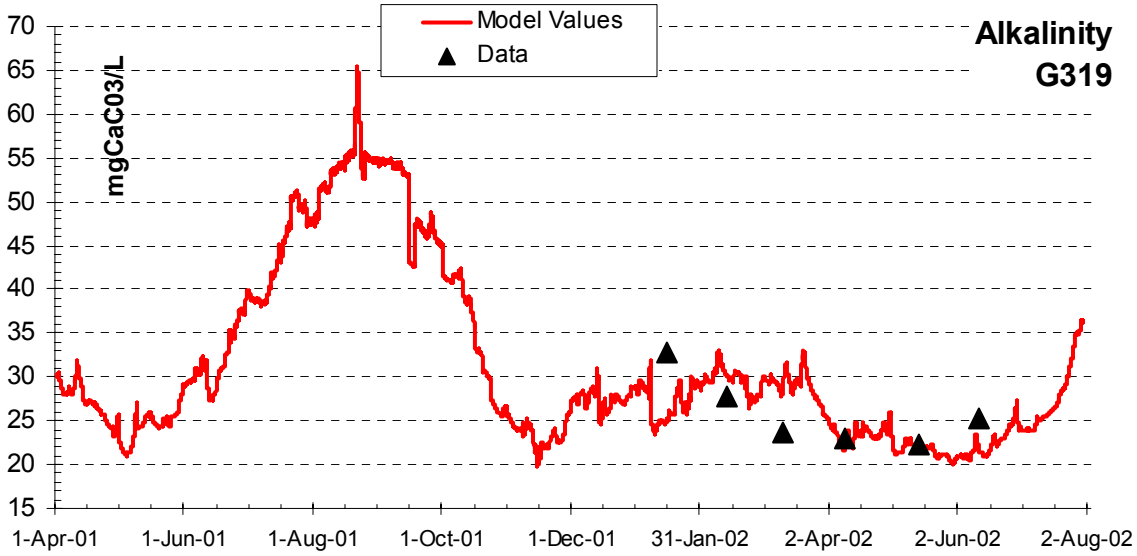


Figure 343: AlkalinityComparison with distributed tributary at Site G319 - 2001-2002 Model Run Period

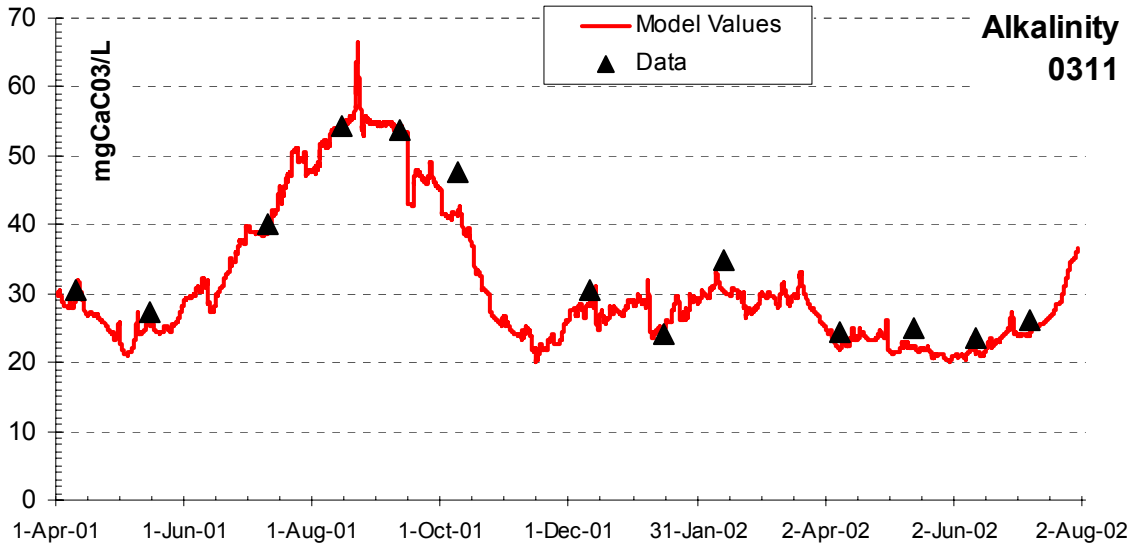


Figure 344: Alkalinity Comparison with distributed tributary at Site 0311 - 2001-2002 Model Run Period

Table 47: Alkalinity Error Statistics with distributed tributary, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error	AME	RMS Error
G319	6	-0.967	2.28	3.41
0311	13	-1.96	2.19	2.69
Alkalinity Error Statistics without distributed tributary, 2001-2002 Model Run Period				
G319	6	-2.1	3.0	4.0
0311	13	-6.83	6.87	8.65

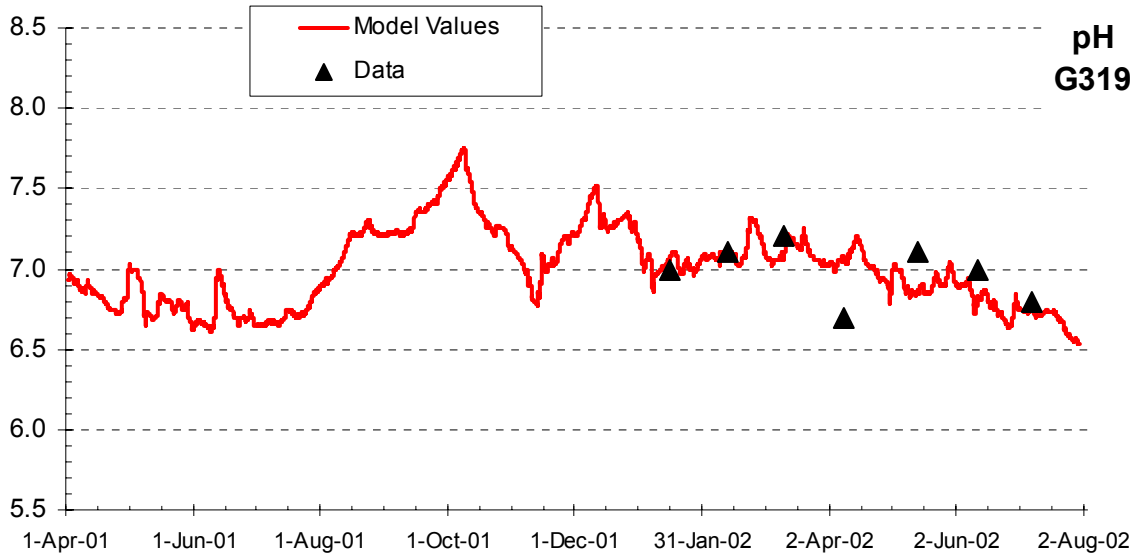


Figure 345: pH Comparison with distributed tributary at Site G319 - 2001-2002 Model Run Period

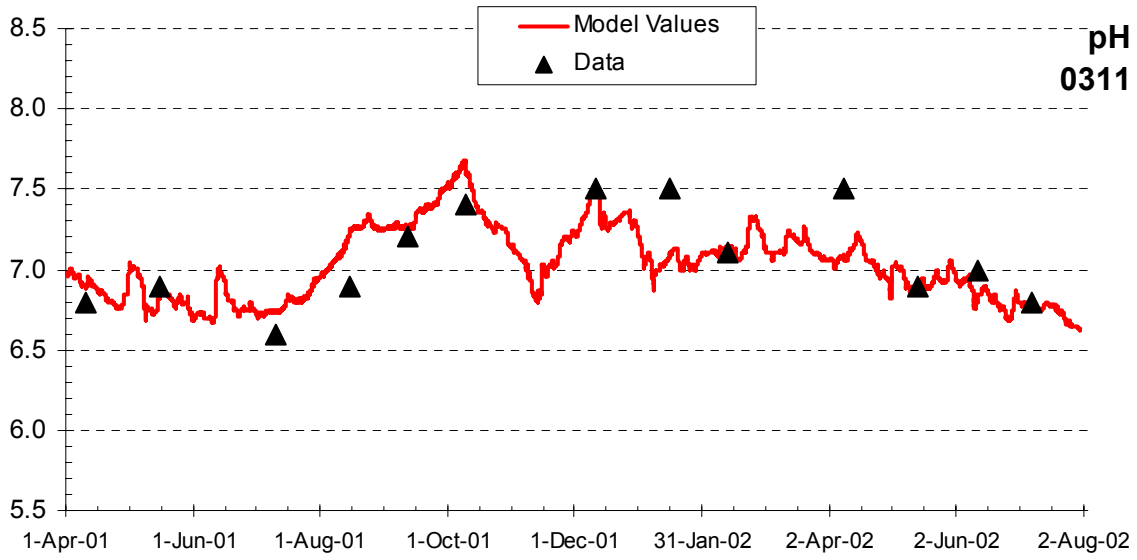


Figure 346: pH Comparison with distributed tributary at Site 0311 - 2001-2002 Model Run Period

Table 48: pH Error Statistics with distributed tributary, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error	AME	RMS Error
G319	7	-0.024	0.14	0.18
0311	13	-0.0062	0.16	0.21
pH Error Statistics without distributed tributary, 2001-2002 Model Run Period				
G319	7	0.46	0.46	0.52
0311	13	0.35	0.44	0.50

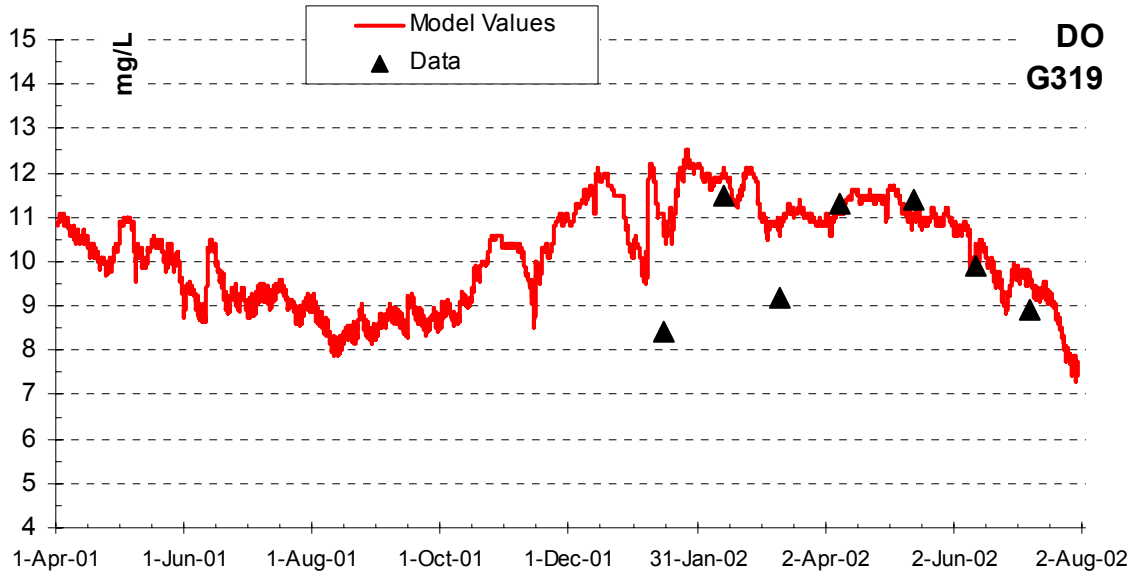


Figure 347: Dissolved Oxygen Comparison with distributed tributary at Site G319 - 2001-2002 Model Run Period

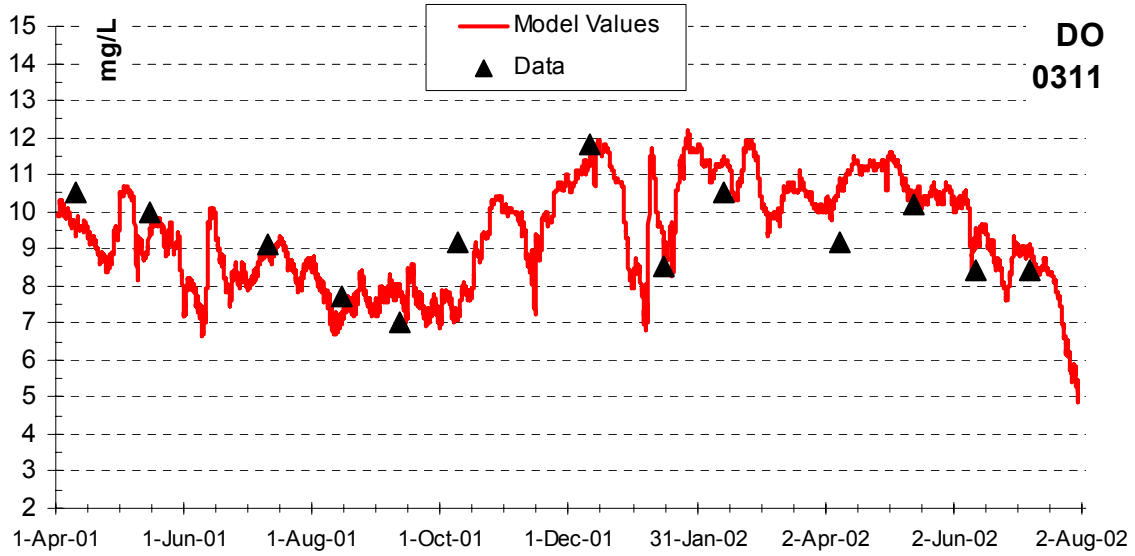


Figure 348: Dissolved Oxygen Comparison with distributed tributary at Site 0311 - 2001-2002 Model Run Period

Table 49: DO Error Statistics with distributed tributary, 2001-2002 Model Run Period

Site	No. of Data Comparisons	Mean Error	AME	RMS Error
G319	7	0.71	0.83	1.14
0311	13	0.07	0.80	0.96
DO Error Statistics without distributed tributary, 2001-2002 Model Run Period				
G319	7	1.67	1.67	2.13
0311	13	1.66	1.66	8.65

This analysis was meant to show that the model could reproduce the characteristics of the river, and to provide an estimate of the magnitude of the data missing from the model in the Lower Green River.

4.3.2 1995-1996 Model Run Period

A distributed inflow was added to Branch five. Flow values were set, and constituent values were adjusted to match data at Site 0311. A BOD source was not added during this model run because the large differences between model values and data were not seen at Site 0311 for this model run perod. TIC and alkalinity data were adjusted to match pH values, and conductivity values were adjusted until they matched data at Site 0311.

Figure 349 shows the flow used in the distributed tributary and Figure 350 through Figure 351 shows the combined flow/constituent values that were added to the model for the 2001-2002 model run period.

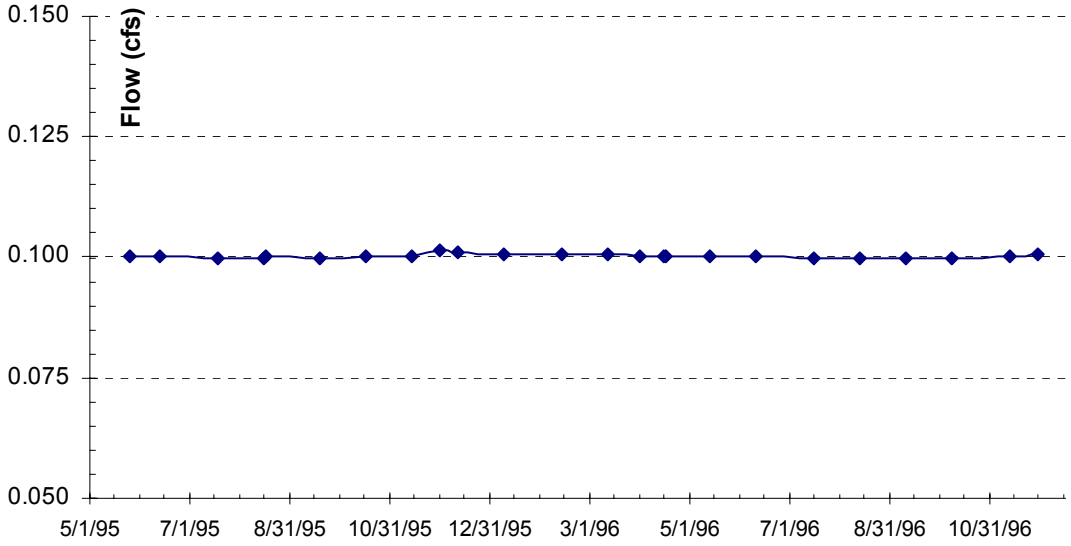


Figure 349: Flow Data for 1995-1996 Model Run Period - Branch 4 Distributed Tributary

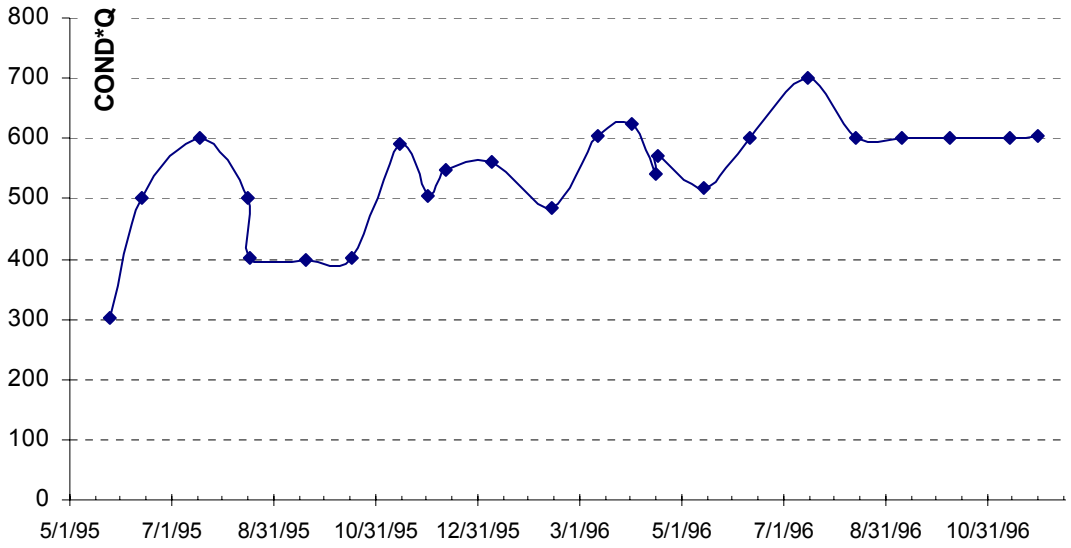


Figure 350: Flow and Conductivity Data for 2001-2002 Model Run Period - Branch 4 Distributed Tributary

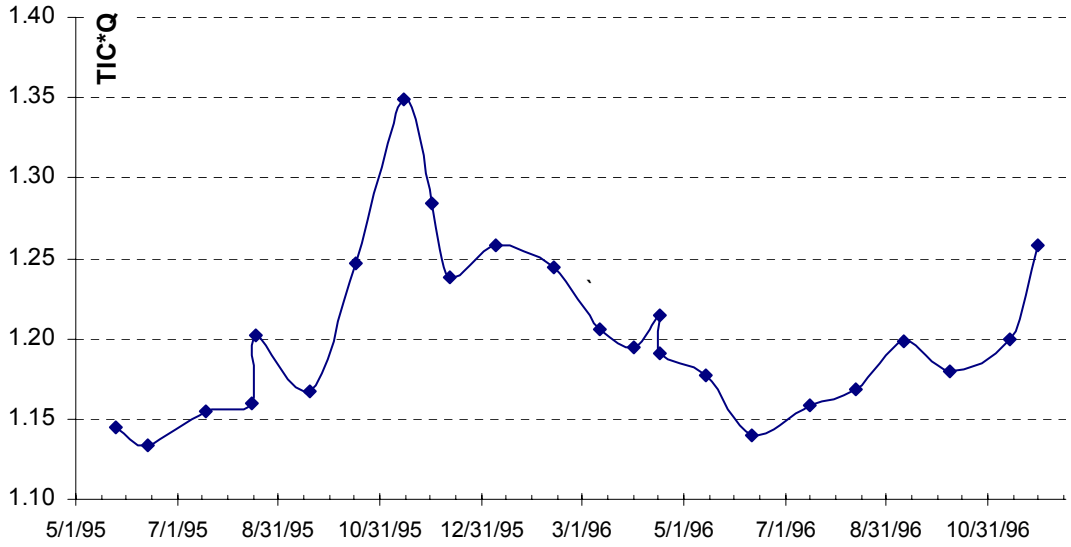


Figure 351 Flow and TIC Data for 2001-2002 Model Run Period - Branch 4 Distributed Tributary

Figure 352 through Figure 353 shows comparisons of data with model values with the distributed tributary, and Table 50 through Table 51 shows the error statistics. The tables also show the error statistics without the additional data for comparison purposes.

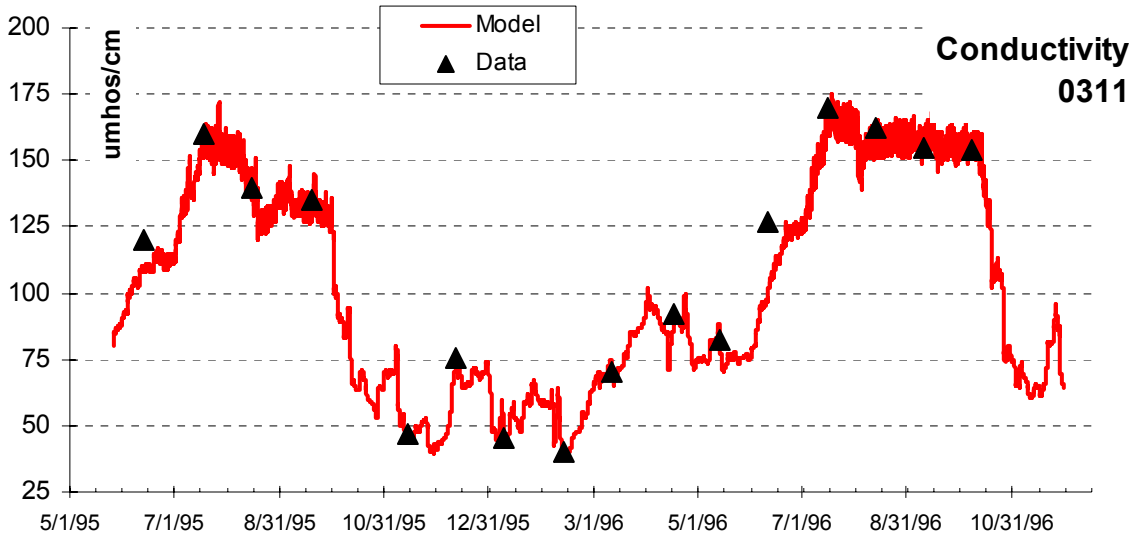


Figure 352: Conductivity Comparison with distributed tributary - 1995-1996 Model Run Period

Table 50: Conductivity Error Statistics with distributed tributary, 1995-1996 Model Run Period

Site	No. of Data Comparisons	Mean Error	AME	RMS Error
0311	13	-7.24	9.84	12.79
Conductivity Error Statistics without distributed tributary, 1995-1996 Model Run Period				
0311	13	-37.73	37.73	46.21

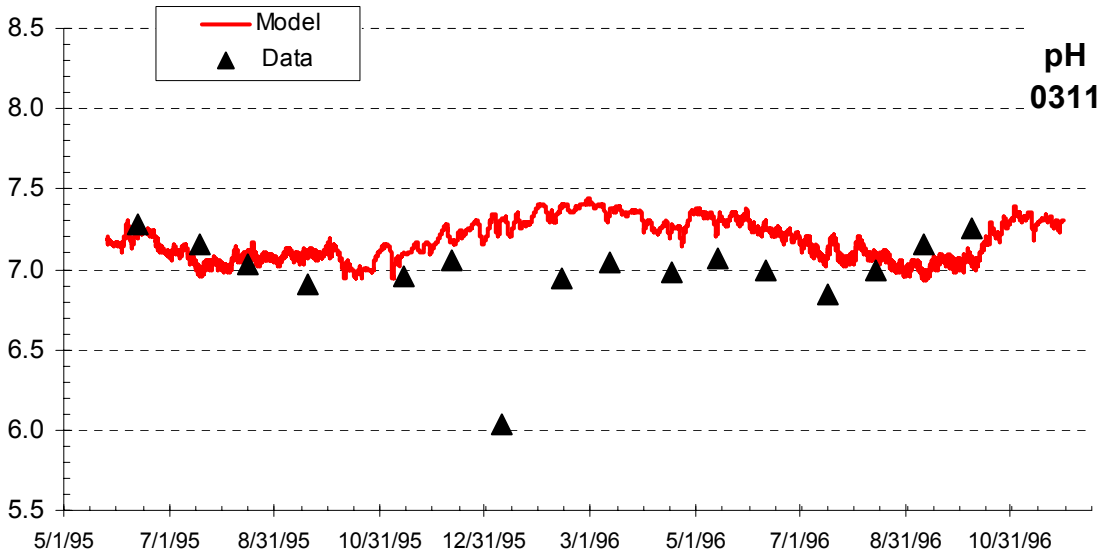


Figure 353: pH Comparison with distributed tributary - 1995-1996 Model Run Period

Table 51: pH Error Statistics with distributed tributary, 1995-1996 Model Run Period				
Site	No. of Data Comparisons	Mean Error	AME	RMS Error
0311	13	0.045	0.21	0.24
pH Error Statistics without distributed tributary, 1995-1996 Model Run Period				
0311	13	0.28	0.29	0.41

5.0 SUMMARY AND CONCLUSIONS

5.1 Model Summary

The water quality and hydrodynamic model CE-QUAL-W2, Version 3.1 (Cole and Wells, 2001), was applied to the Middle and Lower Green River from River Mile 45.0, near Flaming Geyser State Park to River Mile 11.20 in Tukwila, Washington. This model was calibrated to field data from May 25, 1995 to November 30, 1996, and from April 1, 2001 to July 31, 2002. A description of field data used in the model and the model set-up is described in Section 2.0 of this report, and the calibration of hydrodynamic, temperature and water quality constituents is discussed in Section 3.0. A sensitivity analysis examined model responses to various data input and is discussed in Section 4.0.

Flow and water level model results were compared to field data at one location on the river, and temperature model results were compared with data at four locations. Grab-sample water quality data were compared with model results at three locations for the 2001-2002 model run period, and at two locations for the 1995-1996 model run period. Table 52 lists the constituents that were compared with field data for each model run period, and Table 53 shows the locations of the water quality model-data comparison sites.

Table 52: Water Quality Constituents

2001-2002 Constituents	1995-1996 Constituents
Conductivity	Conductivity
pH	pH
Nitrite-Nitrate	Nitrite-Nitrate
Ammonia Nitrogen	Ammonia Nitrogen
Total Nitrogen	Total Nitrogen
Ortho Phosphorus	Ortho Phosphorus
Total Phosphorus	Total Phosphorus
Alkalinity	
Chlorophyll A	
Total Organic Carbon	
Dissolved Organic Carbon	
Fecal Coliform	Fecal Coliform
Total Suspended Solids	Total Suspended Solids

Table 53: Water Quality Calibration Sites

Locator Station	Description	River Mile
0311	Interurban Avenue	13.20
G319	Near Mullen Slough	21.30
A319	Auburn-Black Diamond Road	33.80

Data were available for model-data comparisons at all sites for the 2001-2002 model run period, but not at Site G319 during the 1995-1996 model run period. Table 54 shows the overall model-data statistics for both model run periods.

Table 54: Overall Error Statistics

	Overall Mean Error	Overall AME	Overall RMS Error
Water Level (m)	0.10	0.21	0.23
Flow (cms)	0.12	2.1	4.5
Temperature (ºC)	-0.14	0.63	0.80
Conductivity (umhos/cm)	-15.8	17.0	21.5
Alkalinity (mgCaCO3/L)	-3.05	3.6	4.6
pH	0.29	0.31	0.36
TSS (mg/L)	-7.6	8.5	16.2
DO (mg/L)	0.84	0.88	1.05
NO2-NO3 (mg/L)	-0.054	0.075	0.085
NH4 (mg/L)	-0.007	0.01	0.014
TN (mg/L)	0.061	0.22	0.36
PO4 (mg/L)	-0.0061	0.0075	0.0088
TP (mg/L)	-0.03	0.031	0.044
Chlor A (ug/L)	0.065	0.065	0.05
TOC (ug/L)	-2.25	2.25	2.29
DOC (ug/L)	-1.59	1.59	1.62
FC (Org/100 ml)	89.2	137.5	321.0

Model-data comparisons show that the model reproduced the river responses to known boundary conditions at Site A319 (excluding pH), but comparisons at Site 0311, and to a lesser extent at Site G319, indicate conditions in the river that are not represented in the model. The model results indicate that data for conservative constituents such as conductivity, are not represented correctly in the model for the Lower Green River. This is most likely due to a source of flow missing from the model in the Lower Green River. There was one location available for comparing flow data with model values. It is at USGS Gaging Station 12113000, which is 36 km above the downstream boundary.

One possible source of missing flow could be groundwater inflows in the Lower Green River not included in the model. Luzier (1969) and Woodward et al (1995) discussed groundwater inflows in the Lower Green River, but the estimated values were so small they were not considered in the model. Since groundwater inflows are small relative to the instream flows, constituent concentrations would need to be very high to reproduce the constituent data sampled at Site 0311.

A second possibility for missing model data could be tidal inflows from downstream. As river levels drop during summer months, there is more possibility of tidal flows pushing up to site 0311. The volume of water moving upstream with a tidal inflow would be closer to the same magnitude as flows coming down the river, so the constituent concentrations would not need to be nearly as high to produce the values field-sampled from the river. This option was considered, but discounted for

the following reasons:

- A review of flow data recorded at the downstream project boundary (USGS Site 12113350) between 1960 and 1987 did not show flow reversal.
- Two dye studies conducted in August and September of 1965 on the Lower Green River showed that dye did not flow upstream on the incoming tides (Santos 1972).
- Dye studies performed in 1968 (Fisher, 1968) showed that the tidal influence does not extend into the Lower Green River.
- Model results did not show flow reversals in the Lower Green River. The model was run with a new branch containing the last 10 segments of the model. The slope of the river was set to zero for this branch, and the bottom elevation of each model segment was set equal to the river elevation at the downstream boundary. The model results did not show flow reversal during these runs. Note that these model runs are reflective of the bathymetry used in the model. Both slope averaging the river bottom and the limitations of the bathymetry data available affect the ability of the model to reproduce river responses at the downstream boundary.

A sensitivity analysis was performed to determine the magnitude of constituent concentrations and flow necessary to produce the river response indicated by field data. A distributed tributary was added to the Lower Green River, and input data was adjusted until the model results produced values that matched closer with sampled data. The results of these model runs are discussed in the Sensitivity Analysis section.

The bathymetry for the Middle Green River came from a field survey of the river in 1995, supplemented with aerial photogrammetry. River channel cross-sections were surveyed approximately every 650 feet. Survey data for the Lower Green River was taken from a HEC2 river study originally done in the 1980s. This bathymetry was used for both model run periods. As was noted in this study, there were significant changes to the river channel during the 1996 floods. There have most likely been other changes to the river bathymetry since the 1980s, when the Lower Green River bathymetry was surveyed, and there have most likely been changes to the river between the two model run periods. Potential bathymetric changes may be large enough to influence model results.

5.2 Recommendations for further work

The following items have been identified where further work could improve model predictions.

- Additional gage stations measuring stage and discharge along the Lower Green River would provide more model calibration points and identify where groundwater is entering the system. It would also provide a better understanding of the flows and tidal influences at the downstream model boundary.
- Additional systematic data collection of BOD_5, COD, TOC, and Chl a could be used to determine if there is a source of oxygen depletion in the Lower Green River. Additional algae data will determine the significance of algal blooms in the lower reaches of the river.
- A dye study would verify model travel times and dispersion characteristics. This would allow a better check on the model predictive ability than currently exists. This study should be conducted at both high and low flows. Dye studies performed in 1965 (Santos 1975) and

in 1968 (Fisher 1968) do not cover the section of the river in this model domain.

- Moving the upstream boundary to the gage station just below the Howard Hanson Reservoir (USGS: 12106700) would provide a more accurate boundary condition with flow, temperature and water quality data. Additionally, it would allow model development and calibration to better characterize groundwater inflows to the river. Water quality, temperature, and flow data are available at this location, but bathymetry data would need to be aquired.

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