

# Upper Spokane River Model: Boundary Conditions and Model Setup, 2001



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# Table of Contents

<i>Table of Contents</i> .....	<i>i</i>
<i>List of Figures</i> .....	<i>ii</i>
<i>List of Table</i> .....	<i>iv</i>
<i>Acknowledgements</i> .....	<i>v</i>
<i>Introduction</i> .....	<b>6</b>
<i>Water Quality Data</i> .....	<b>7</b>
<b>Long Lake Vertical Profiles in 2001</b> .....	<b>12</b>
<b>Longitudinal Profiles in 2001</b> .....	<b>12</b>
<i>Model Forcing Data</i> .....	<b>14</b>
<b>Model Geometry</b> .....	<b>14</b>
Spokane River Bathymetry .....	14
Long Lake Bathymetry.....	15
<b>Grid Layout</b> .....	<b>15</b>
<b>Boundary Conditions</b> .....	<b>18</b>
Spokane River at state line .....	19
Long Lake outflow .....	24
<b>Tributaries</b> .....	<b>25</b>
Hangman Creek .....	25
Little Spokane River.....	30
Coulee Creek.....	35
<b>Reservoir Operations</b> .....	<b>36</b>
Upriver Dam and Reservoir .....	36
Upper Falls Dam and Reservoir .....	38
Nine mile Dam and Reservoir .....	40
Long Lake Dam and Reservoir .....	42
<b>Groundwater</b> .....	<b>44</b>
Spokane River .....	44
Spokane River groundwater quality .....	47
Long Lake .....	48
Long Lake groundwater quality .....	48
<b>Point Dischargers</b> .....	<b>49</b>
Kaiser Aluminum .....	50
Liberty Lake Wastewater Treatment Plant.....	54
Spokane Wastewater Treatment Plant.....	59
Inland Empire Paper Company .....	64
<b>Meteorological Data</b> .....	<b>70</b>
Spokane International Airport.....	70
Spokane Felts Field .....	73
Odessa, WA.....	76
<b>Periphyton Data</b> .....	<b>77</b>
<i>Summary</i> .....	<b>80</b>
<i>References</i> .....	<b>81</b>

<i>Appendix A: Vertical Profiles</i> .....	82
<i>Appendix B: Longitudinal Profiles</i> .....	90

## List of Figures

Figure 1. Model domain, WA-ID state line to Long Lake reservoir .....	7
Figure 2. Water quality monitoring sites along the Spokane River and Long Lake reservoir .....	8
Figure 3. Water quality monitoring sites at Long Lake Reservoir .....	8
Figure 4. Water quality monitoring sites along Nine Mile Reservoir.....	9
Figure 5. Water quality monitoring sites along the Spokane River near Upriver Dam (includes both surface water and well monitoring sites) .....	9
Figure 6. Water quality monitoring sites near the WA-ID state line (includes both surface water and well monitoring sites) .....	10
Figure 7. Temperature vertical profile in Long Lake .....	12
Figure 8. Temperature longitudinal profile, 2001.....	13
Figure 9. Plan view Spokane river grid. The arrows show the segment orientation. ....	15
Figure 10. Vertical layout of Spokane River grid.....	17
Figure 11. Long Lake volume-elevation comparison, data and model grid .....	18
Figure 12. Plan view grid layout including Long Lake .....	18
Figure 13. Spokane River flow at the state line, 2001 .....	21
Figure 14. Spokane River temperature at the state line, 2001 .....	21
Figure 15. Spokane River at the state line water quality conditions (Part 1).....	22
Figure 16. Spokane River at the state line water quality conditions (Part 2).....	23
Figure 17. Spokane River at the state line water quality conditions (Part 3).....	24
Figure 18. Long Lake Reservoir outflow, 2001.....	25
Figure 19. Hangman Creek flow, 2001.....	26
Figure 20. Hangman Creek water temperature, 2001 .....	27
Figure 21. Hangman Creek water quality conditions (Part 1) .....	28
Figure 22. Hangman Creek water quality conditions (Part 2) .....	29
Figure 23. Hangman Creek water quality conditions (Part 3) .....	30
Figure 24. Little Spokane River flow, 2001 .....	31
Figure 25. Little Spokane River temperature, 2001.....	32
Figure 26. Little Spokane River water quality conditions (Part 1).....	33
Figure 27. Little Spokane River water quality conditions (Part 2).....	34
Figure 28. Little Spokane River water quality conditions (Part 3).....	35
Figure 29. Coulee and Deep Creek flow, 2001.....	36
Figure 30. Upriver Dam total flow through all gates, 2001 .....	37
Figure 31. Upriver Dam flow through turbines, 2001 .....	38
Figure 32. Upper Falls Dam flow through turbines, 2001 .....	39
Figure 33. Upper Falls Dam flow over the spillway, 2001 .....	39
Figure 34. Upper Falls Dam Elevation, 2001 .....	40
Figure 35. Nine Mile Dam flow through turbines, 2001 .....	41
Figure 36. Nine Mile Dam flow over the spillway, 2001 .....	41
Figure 37. Nine-Mile Elevation, 2001 .....	42
Figure 38. Long Lake Flow through Turbines, 2001.....	43
Figure 39. Long lake Flow over Spillway, 2001 .....	43
Figure 40. Long Lake Elevation, 2001 .....	44
Figure 41. Long Lake Distributed Inflow, 2001 .....	48

Figure 42. Point Discharges to the Spokane River .....	50
Figure 43. Kaiser Aluminum discharge flow, 2001 .....	51
Figure 44. Kaiser Aluminum discharge temperature, 2001 .....	51
Figure 45. Kaiser Aluminum discharge water quality conditions (Part 1) .....	52
Figure 46. Kaiser Aluminum discharge water quality conditions (Part 2) .....	53
Figure 47. Kaiser Aluminum discharge water quality conditions (Part 3) .....	54
Figure 48. Liberty Lake WWTP discharge flow, 2001 .....	55
Figure 49. Liberty Lake WWTP discharge temperature, 2001 .....	56
Figure 50. Liberty Lake WWTP discharge water quality conditions (Part 1) .....	57
Figure 51. Liberty Lake WWTP discharge water quality conditions (Part 2) .....	58
Figure 52. Liberty Lake WWTP discharge water quality conditions (Part 3) .....	59
Figure 53. City of Spokane WWTP discharge flow, 2001 .....	60
Figure 54. City of Spokane WWTP discharge temperature, 2001 .....	61
Figure 55. City of Spokane WWTP discharge water quality conditions (Part 1) .....	62
Figure 56. City of Spokane WWTP discharge water quality conditions (Part 2) .....	63
Figure 57. City of Spokane WWTP discharge water quality conditions (Part 3) .....	64
Figure 58. Inland Empire Paper Co. discharge flow, 2001 .....	65
Figure 59. Inland Empire Paper Co. discharge temperature, 2001 .....	66
Figure 60. Inland Empire Paper Co. discharge water quality conditions (Part 1) .....	67
Figure 61. Inland Empire Paper Co. discharge water quality conditions (Part 2) .....	68
Figure 62. Inland Empire Paper Co. discharge water quality conditions (Part 3) .....	69
Figure 63. Meteorological stations near the Spokane River .....	70
Figure 64. Air temperature, °C, at the Spokane International Airport 2001 .....	71
Figure 65. Dew point temperature, °C, at the Spokane International Airport 2001 .....	71
Figure 66. Wind Speed, m/s, at the Spokane International Airport 2001 .....	72
Figure 67. Wind direction, degrees from North, at the Spokane International Airport, 2001 .....	72
Figure 68. Cloud Cover, x10, at the Spokane International Airport 2001 .....	73
Figure 69. Air temperature, °C, at Spokane Felts Field 2001 .....	74
Figure 70. Dew point temperature, °C, at Spokane Felts Field 2001 .....	74
Figure 71. Wind speed, m/s, at Spokane Felts Field 2001 .....	75
Figure 72. Wind direction, degrees from North, at Spokane Felts Field 2001 .....	75
Figure 73. Cloud Cover, x10, at Spokane Felts Field 2001 .....	76
Figure 74. Solar radiation at Odessa, WA 2001 .....	77
Figure 75. Vertical profiles Long Lake for temperature 8/8/2001 .....	82
Figure 76. Vertical profiles Long Lake for conductivity 8/8/2001 .....	83
Figure 77. Vertical profiles Long Lake for dissolved oxygen 8/8/2001 .....	84
Figure 78. Vertical profiles Long Lake for pH 8/8/2001 .....	85
Figure 79. Vertical profiles Long Lake for temperature 8/29/2001 .....	86
Figure 80. Vertical profiles Long Lake for conductivity 8/29/2001 .....	87
Figure 81. Vertical profiles Long Lake for dissolved oxygen 8/29/2001 .....	88
Figure 82. Vertical profiles Long Lake for pH 8/29/2001 .....	89
Figure 83. Longitudinal profiles in Spokane River for temperature 2001 .....	90
Figure 84. Longitudinal profiles in Spokane River for conductivity 2001 .....	91
Figure 85. Longitudinal profiles in Spokane River for Sp conductivity 2001 .....	92
Figure 86. Longitudinal profiles in Spokane River for pH 2001 .....	93
Figure 87. Longitudinal profiles in Spokane River for dissolved oxygen 2001 .....	94
Figure 88. Longitudinal profiles in Spokane River for NO <sub>2</sub> -NO <sub>3</sub> -N 2001 .....	95
Figure 89. Longitudinal profiles in Spokane River for NH <sub>3</sub> -N 2001 .....	96

Figure 90. Longitudinal profiles in Spokane River for TKN 2001.....	97
Figure 91. Longitudinal profiles in Spokane River for SRP 2001.....	98
Figure 92. Longitudinal profiles in Spokane River for TP 2001.....	99
Figure 93. Longitudinal profiles in Spokane River for turbidity 2001.....	100
Figure 94. Longitudinal profiles in Spokane River for TSS 2001.....	101
Figure 95. Longitudinal profiles in Spokane River for fecal coliform 2001.....	102
Figure 96. Longitudinal profiles in Spokane River for E. coli 2001.....	103
Figure 97. Longitudinal profiles in Spokane River for chlorophyll a 2001.....	104
Figure 98. Longitudinal profiles in Spokane River for hardness 2001.....	105
Figure 99. Longitudinal profiles in Spokane River for Ca hardness 2001.....	106
Figure 100. Longitudinal profiles in Spokane River for Cl 2001.....	107
Figure 101. Longitudinal profiles in Spokane River for alkalinity 2001.....	108
Figure 102. Longitudinal profiles in Spokane River for Field alkalinity 2001.....	109
Figure 103. Longitudinal profiles in Spokane River for DOC 2001.....	110
Figure 104. Longitudinal profiles in Spokane River for TOC 2001.....	111

## List of Table

Table 1. Water Quality Monitoring sites.....	10
Table 2. Long Lake vertical profile constituents plotted, 2001.....	12
Table 3. Longitudinal profile constituents plotted, 2001.....	13
Table 4. Layout of Branches for the Spokane River and Long Lake.....	15
Table 5. Water body-Branch Layout (see Cole and Wells, 2000).....	16
Table 6. Groundwater flow sections along the Spokane River.....	44
Table 7. Aquifer exchange estimate for each model branch.....	47
Table 8. Spokane River groundwater quality.....	48
Table 9. Water quality means of wells located around Long Lake.....	49
Table 10. Temperature and constituent concentrations used to characterize groundwater for Long Lake branch 12.....	49
Table 11. Point Source dischargers modeled.....	49
Table 12. Periphyton Data Sites.....	77
Table 13. August 2001 Site Mean Biomass from Natural Substrates.....	77
Table 14. August 2001 Site Mean Chlorophyll from Natural Substrates.....	78
Table 15. September 2001 Sites Mean Biomass from Natural Substrates.....	78
Table 16. September 2001 Site Mean Chlorophyll from Natural Substrates.....	78
Table 17. September 2001 Sites Mean Biomass, New Growth Over 28 days on Incubated Substrates.....	79
Table 18. September 2001 Site Mean Chlorophyll, New Growth Over 28 days on Incubated Substrates .....	79

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## Introduction

The Upper Spokane River system is located in the Northeastern part of Washington State and runs from the Stateline with Idaho, river mile (RM) 96.0, downstream to Long Lake dam at RM 32.5. Figure 1 shows a plan view of the river system model domain and an outline the boundaries of the City of Spokane.

The Washington Department of Ecology is interested in a water quality model for the Upper Spokane River system for use in developing Total Maximum Daily Loads (TMDLs). The goals of this modeling effort are to:

- Gather data to construct a computer simulation model of the Spokane River system including Long Lake Reservoir and the pools behind Nine Mile dam, Upper Falls dam and Upriver dam for 2001 based on the calibration conducted for 1991 and 2000 data sets, (Annear et al, 2001).
- Ensure that the model accurately represents the system hydrodynamics and water quality (flow, temperature, dissolved oxygen and nutrient dynamics) for the three simulation years;

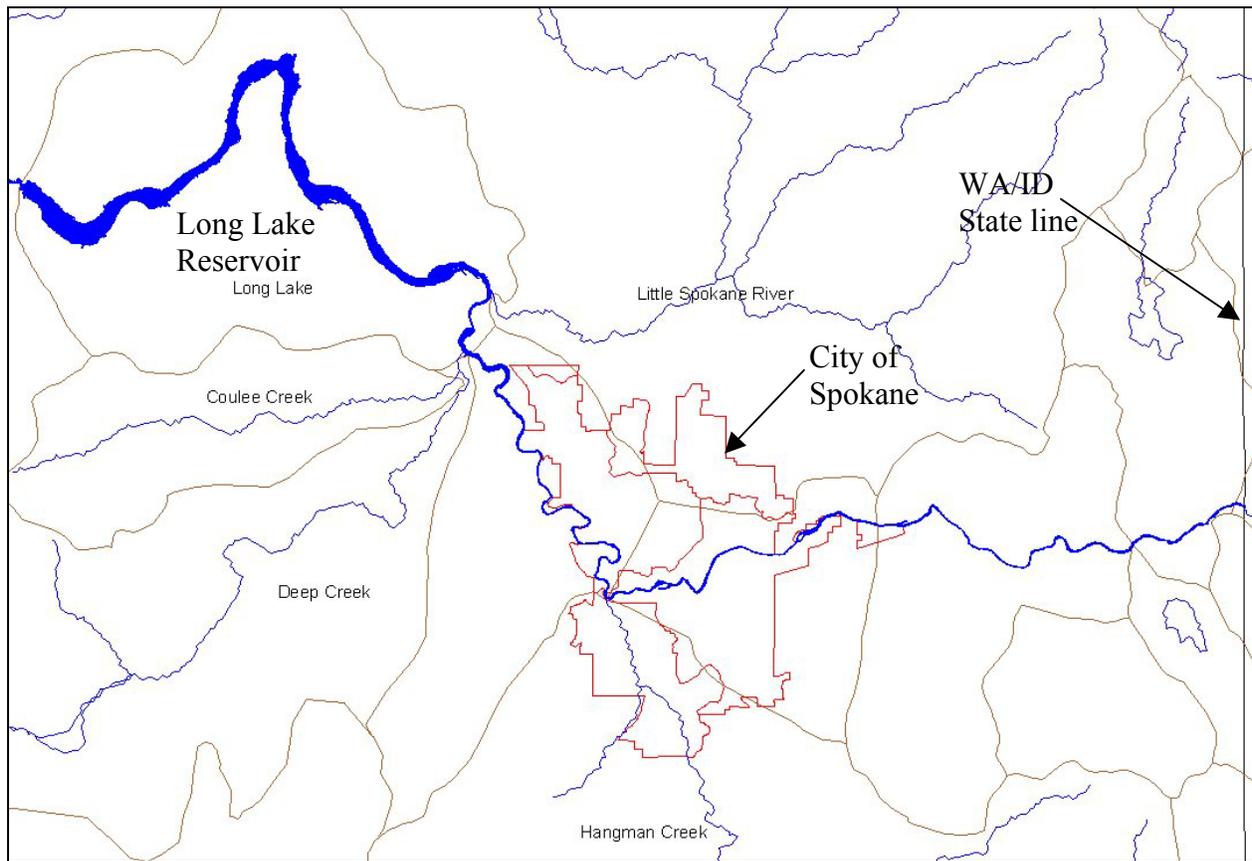
A hydrodynamic and water quality model, CE-QUAL-W2 Version 3 (Wells, 1997), is being applied to model the Spokane River system. CE-QUAL-W2 is a two dimensional (longitudinal-vertical), laterally averaged, hydrodynamic and water quality model that has been under development by the Corps of Engineers Waterways Experiment Station (Cole and Wells, 2000).

In order to model the system, the following data were required:

- Spokane River flow, water level and water quality data at the upstream system boundary (the State of Idaho boundary)
- Tributary inflows and water quality
- Meteorological conditions
- Bathymetry of the Spokane River, the dam pools along the river, and Long Lake Reservoir
- Point source (wastewater treatment plants, WWTPs) inflows and water quality characteristics

Data have been primarily collected from 1991 to 1992, during 2000, and more recently during 2001. This report summarizes the 2001 data used in the modeling effort to expand the model calibration period. Information provided in this report was organized in the following sections:

- Spokane River and Long Lake water quality data
- A summary of the model geometry for the Spokane River and reservoirs
- Spokane River flow and water level data
- Meteorological data
- Point Source flow and water quality data
- Tributary inflow and water quality data
- Groundwater flows and water quality data



**Figure 1. Model domain, WA-ID state line to Long Lake reservoir**

## Water Quality Data

Water quality data were provided by the Washington State Department of Ecology (DOE), the dischargers, Avista Corporation, and Spokane County. Additional flow, temperature and water quality data were provided by the USGS in WA and ID. The data were collected from January 2001 through December 2001. Figure 2 shows a map of the upper Spokane River region with the water quality monitoring sites. Figure 3 shows the water quality sites in Long Lake. Monitoring sites in the Spokane River just above Nine Mile dam to the Upper Falls dam are shown in Figure 4. Spokane River monitoring sites just below and above the Upriver dam facilities are shown in Figure 5. Figure 6 shows the remaining monitoring sites above Upriver dam to the state line with Idaho. Table 1 lists the water quality monitoring sites with their associated river mile.

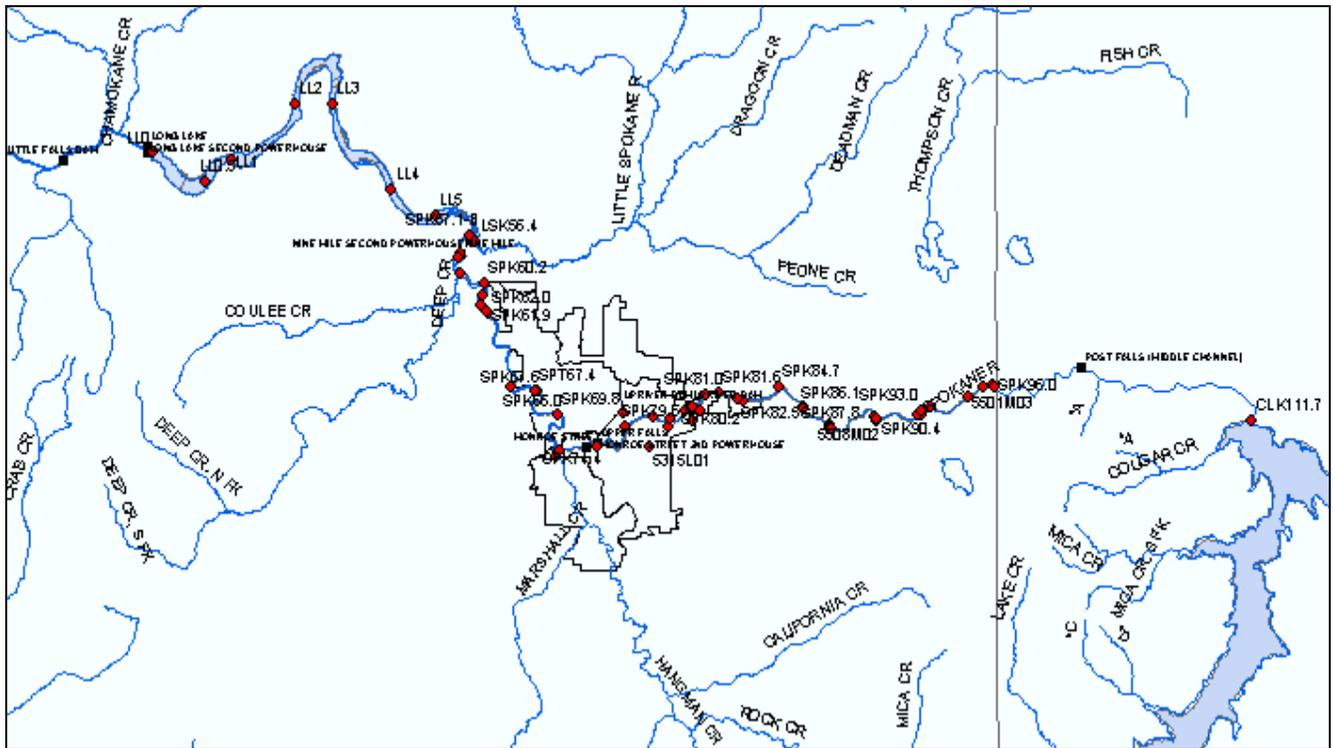


Figure 2. Water quality monitoring sites along the Spokane River and Long Lake reservoir

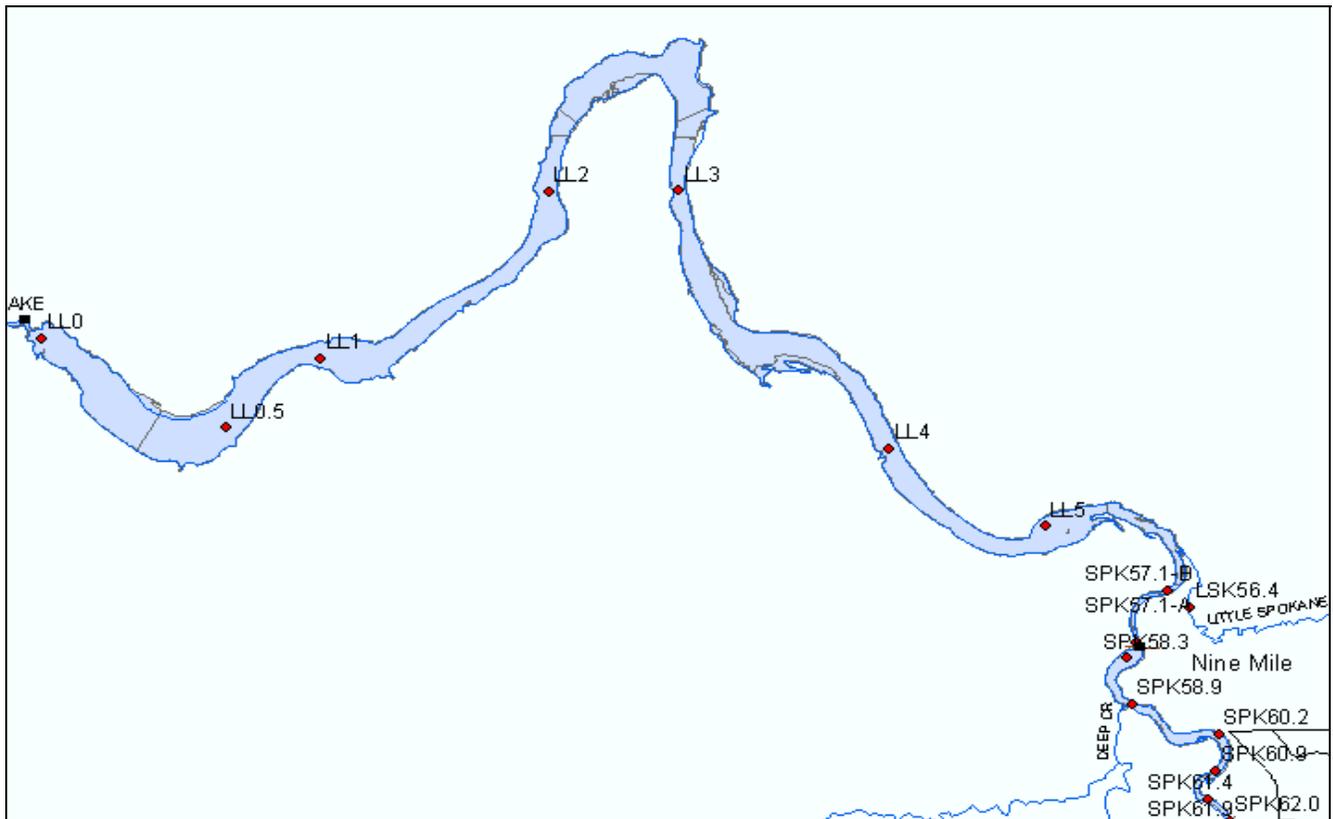
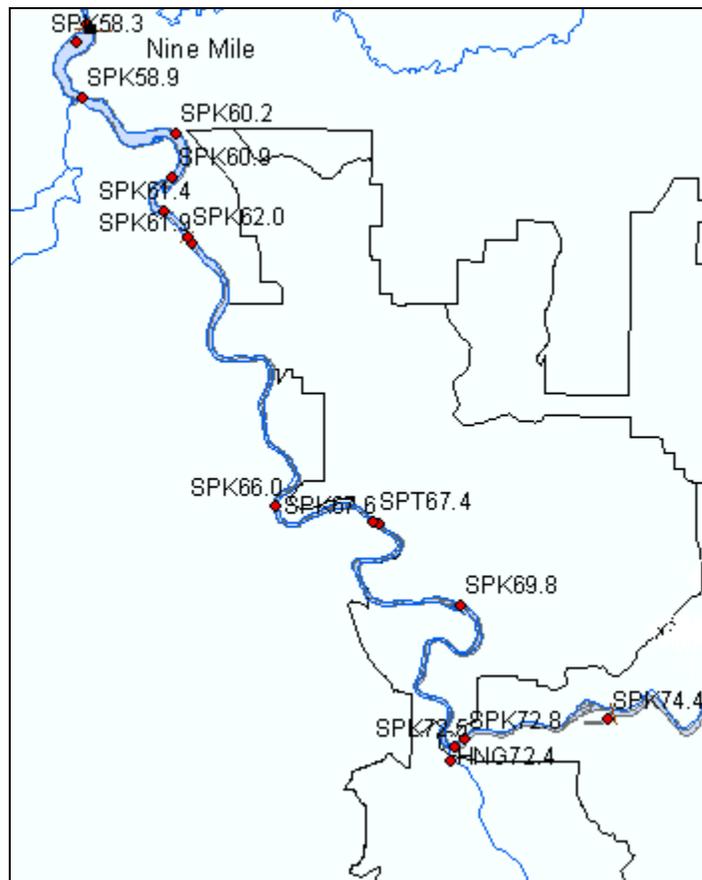
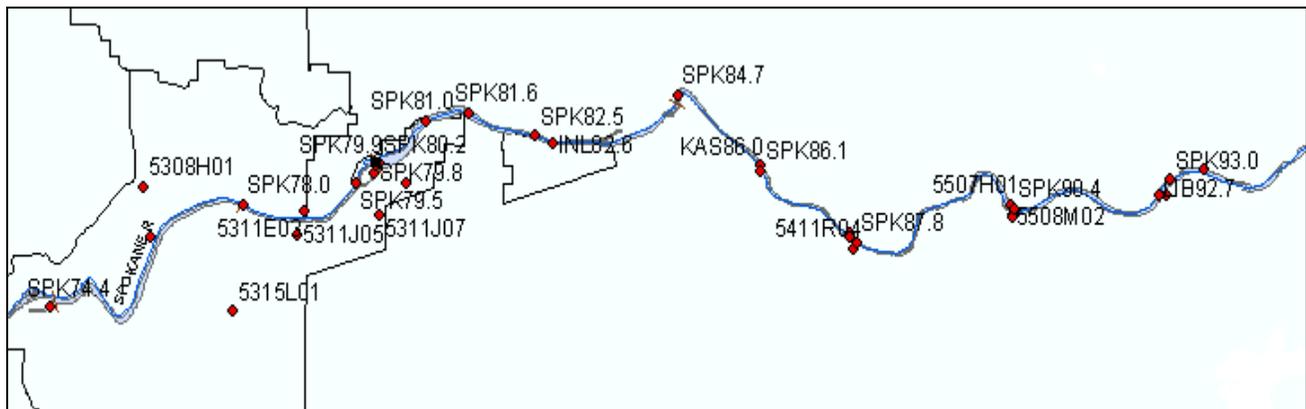


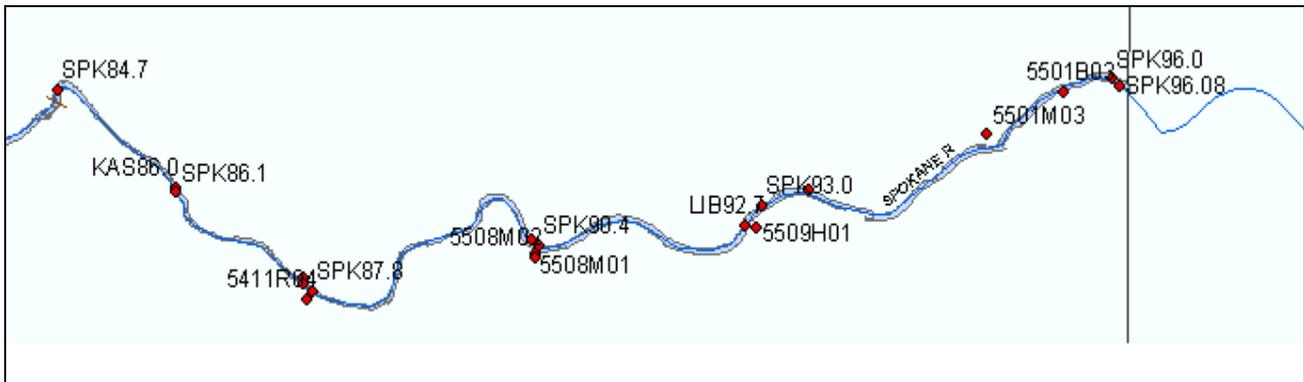
Figure 3. Water quality monitoring sites in Long Lake Reservoir



**Figure 4. Water quality monitoring sites along Nine Mile Reservoir**



**Figure 5. Water quality monitoring sites along the Spokane River near Upriver Dam (includes both surface water and well monitoring sites)**



**Figure 6. Water quality monitoring sites near the WA-ID state line (includes both surface water and well monitoring sites)**

<b>Table 1. Water Quality Monitoring sites</b>		
<b>Site ID</b>	<b>Description</b>	<b>RM</b>
USGS12419000	Spokane River at Post Falls, ID	100.52
LL0	Long Lake @ Station 0 (near dam)	32.66
LL0.5	Long Lake @ Station 0.5	35.90
LL1	Long Lake @ Station 1	37.62
LL2	Long Lake @ Station 2	42.06
LL3	Long Lake @ Station 3	46.42
LL4	Long Lake @ Station 4	51.47
LL5	Long Lake @ Station 5	54.20
LSK56.4	Little Spokane River @ Long Lake (near mouth): near HWY 291 Bridge.	56.40
SPK57.1-A	Spokane River at Long Lake: @ 1 mile downstream of Nine Mile Dam.	57.10
SPK57.1-B	Spokane River at Long Lake: @ 1 mile downstream of Nine Mile Dam.	57.10
SPK57.74	Spokane River Below 9 Mile Dam, Spokane River at 9 mile bridge	57.74
SPK58.1	Just d/s of Nine Mile Dam at Charles Road bridge, Spokane River below 9 mile dam	58.10
SPK58.3	Spokane River above Nine mile Dam: 0.2 miles upstream of Nine Mile Dam.	58.30
SPK58.9	Spokane River above Nine mile Dam: 0.8 miles upstream of Nine Mile Dam.	58.90
SPK60.2	Spokane River above Nine mile Dam: 2.1 miles upstream of Nine Mile Dam.	60.20
SPK60.9	Spokane River above Nine mile Dam: 2.8 miles upstream of Nine Mile Dam.	60.90
SPK61.4	Spokane River above Nine mile Dam: 3.3 miles upstream of Nine Mile Dam.	61.40
SPK61.9	Spokane River above Nine mile Dam: 3.8 miles upstream of Nine Mile Dam.	61.90
SPK62.0	Spokane River at Seven Mile Bridge	62.00
SPK66.0	Spokane River at Riverside State Park, at Bowl and Pitcher	66.00
SPT67.4	Spokane River AWTP effluent discharge	67.40
SPK67.6	Spokane R Upstream (above) Spokane AWTP	67.60
SPK69.8	Spokane River at Fort Wright Bridge	69.80
SPK69.8?	Spokane River at TJ Meenach	69.80
HNG72.4	Hangman Creek at mouth, upstream of confluence with the Spokane River	72.40
SPK72.5	Spokane River Upstream of Hangman Cr.	72.50
SPK72.8	Spokane River, 200 m downstream of Spokane River gage station	72.80
SPK73.4	Spokane River at Monroe Street Powerhouse, Post St. Bridge	73.40
SPK74.4	Spokane River at Walkbridge behind Spokane Center	74.40
SPK74.8	Spokane River at Division St Bridge	74.80

<b>Table 1. Water Quality Monitoring sites</b>		
<b>Site ID</b>	<b>Description</b>	<b>RM</b>
5315L01	Olive & Fiske monitoring well, NW corner Fiske & Olive	76.34
SPK76.5	Spokane River at Mission Street Bridge, 76.5	76.79
5309M04	Avista monitoring well near SE corner of Main Office, Avista MW4	76.87
5308H01	Denver & Marietta, City monitoring well	77.12
SPK78.0	Spokane River at Green St. Bridge	78.12
5310R01	GE MW-22	78.86
5311E03	Avista Beacon Substation 208 well	78.95
SPK79.5	Downstream of Upriver Dam Powerhouse	79.50
5311J07	Hale's Ale Nested Site, middle	79.65
5311J05	Hale's Ale Nested Site, east	79.65
SPK79.7	Spokane River at Upriver Dam, downstream, 79.5	79.78
SPK79.8	Spokane R Upstream Upriver Dam Powerhouse, Dam Forebay	79.86
SPK79.9	Spokane River above Upriver Dam: 0.1 miles upstream of Upriver Dam	79.90
SPK80.2	Spokane River above Upriver Dam: 0.4 miles upstream of Upriver Dam	80.20
5312C01	Felts Field City monitoring well	80.41
SPK81.0	Spokane River above Upriver Dam: 1.2 miles upstream of Upriver Dam	81.00
SPK81.6	Spokane River above Upriver Dam: 1.8 miles upstream of Upriver Dam	81.60
SPK82.5	Spokane River above Upriver Dam: 2.7 miles upstream of Upriver Dam	82.50
INL82.6	Inland Empire Paper Co discharge, IWTP	82.60
SPK84.7	Spokane River at Plantes Ferry Park Foot Bridge	84.70
KAS86.0	Kaiser Aluminum IWTP	86.00
SPK86.1	Spokane River Upstream Kaiser IWTP	86.10
5411R02	Sullivan Road and Centennial Trail, monitoring well, Spokane R @ Sullivan Rd, 200 ft N, SW corner Sullivan Park lower parking lot	87.44
5411R03	Sullivan Park North, monitoring well, Spokane R. @ Sullivan Rd, 100 ft N, Sullivan Park near bluff over river	87.46
5411R04	Sullivan Park South, monitoring well, Spokane R. @ Sullivan Rd, 100 ft S, County Row, W of Sullivan, S. of Trail	87.59
SPK87.8	Spokane River at Sullivan Rd. Bridge	87.80
5507H01	Barker Road north of river, monitoring well, Spokane R. @ Barker Rd, 100 ft N, W of Barker, N of River	90.24
5508M01	Barker Road Centennial Trail North, monitoring well, Spokane R. @ Barker Rd, 100 ft S, Barker Rd Cent Trail parking lot #1	90.34
5508M02	Barker Road Centennial Trail South, monitoring well, Spokane R. @ Barker Rd, 200 ft S, SW corner Cent Trail parking lot, Barker Rd	90.35
SPK90.4	Spokane River at Barker Rd. Bridge	90.40
5509H01	Monitoring well, USGS Well 5	92.42
LIB92.7	Liberty Lake POTW	92.70
SPK93.0	Spokane River at Harvard Rd. Bridge	93.00
5510C03	Monitoring well, USGS Well 18	93.06
5501M03	Monitoring well, USGS Well 10	94.94
5501B03	Monitoring well, USGS Well 3	95.75
SPK96.0	Spokane River at the Stateline Bridge, about 400 feet upstream of Stateline Bridge.	96.00
SPK96.08	Spokane River near the Stateline	96.10

## Long Lake Vertical Profiles in 2001

Vertical profiles were collected in Long Lake for two dates in August. The vertical profiles were collected at several locations in the lake on a given day. Table 2 indicates a list of the water quality constituents monitored, and Figure 7 shows an example of the water temperature profiles taken in Long Lake on August 8, 2001. Vertical profiles for additional dates and water quality constituents can be found in Appendix A: Vertical Profiles.

Table 2. Long Lake vertical profile constituents plotted, 2001			
Constituent	Constituent Name	Constituent	Constituent Name
Temp	Temperature, C	pH	pH
Conductivity	Conductivity, umhos/cm	DO	Dissolved Oxygen, mg/L

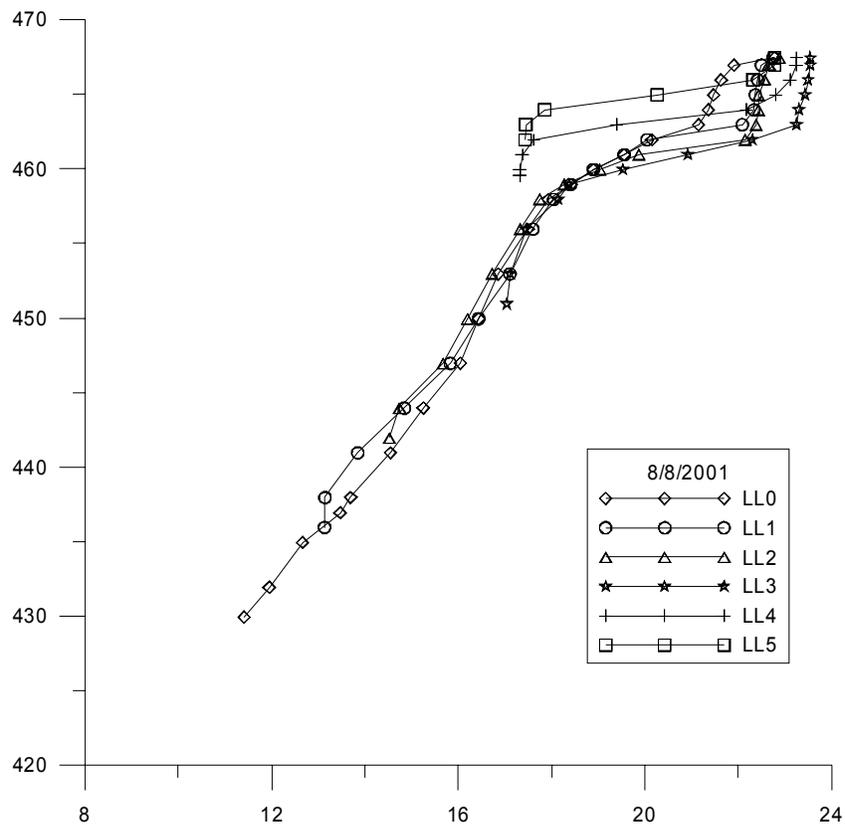


Figure 7. Temperature vertical profile in Long Lake

## Longitudinal Profiles in 2001

Grab samples were collected along the length of the Spokane River between the state line and Long Lake dam. Table 3 shows a list of the water quality constituents monitored and plotted in longitudinal profiles. Figure 8 shows an example of a longitudinal profile for water temperature. The figure also includes another plot indicating the location of specific features such as incoming tributaries, discharges and breaks in the river geometry. Additional figures for the remaining constituents listed in Table 3 can be found in Appendix B: Longitudinal Profiles.

Table 3. Longitudinal profile constituents plotted, 2001			
Constituent	Constituent Name	Constituent	Constituent Name
Temp	Temperature, C	Turb	Turbidity, NTU
Conductivity	Conductivity, umhos/cm	TSS	Total Suspended Solids, mg/L
pH	pH	Fecal Coliform	Fecal Coliform MPN/100 ml
DO	Dissolved Oxygen, mg/L	Chl a	Chlorophyll a, ug/L
NO3-NO2	Nitrate-Nitrite, mg/L	ALK	Alkalinity, mg/L
SpCond	Specific Conductivity, uS/cm	Field ALK	Field measured alkalinity, mg/L
NH4	Ammonium	Hardness	Hardness, mg/L
TKN	Total Kheldal Nitrogen, mg/L	CaHardness	Calcium Hardness, mg/L
TDS	Total dissolved solids, mg/L	Cl	Chloride, mg/L
SRP	Soluble Reactive Phosphorus, mg/L	DOC	DOC, mg/L
TP	Total Phosphorus, mg/L	TOC	TOC, mg/L
E. Coli	E Coli, MPN/100 ml		

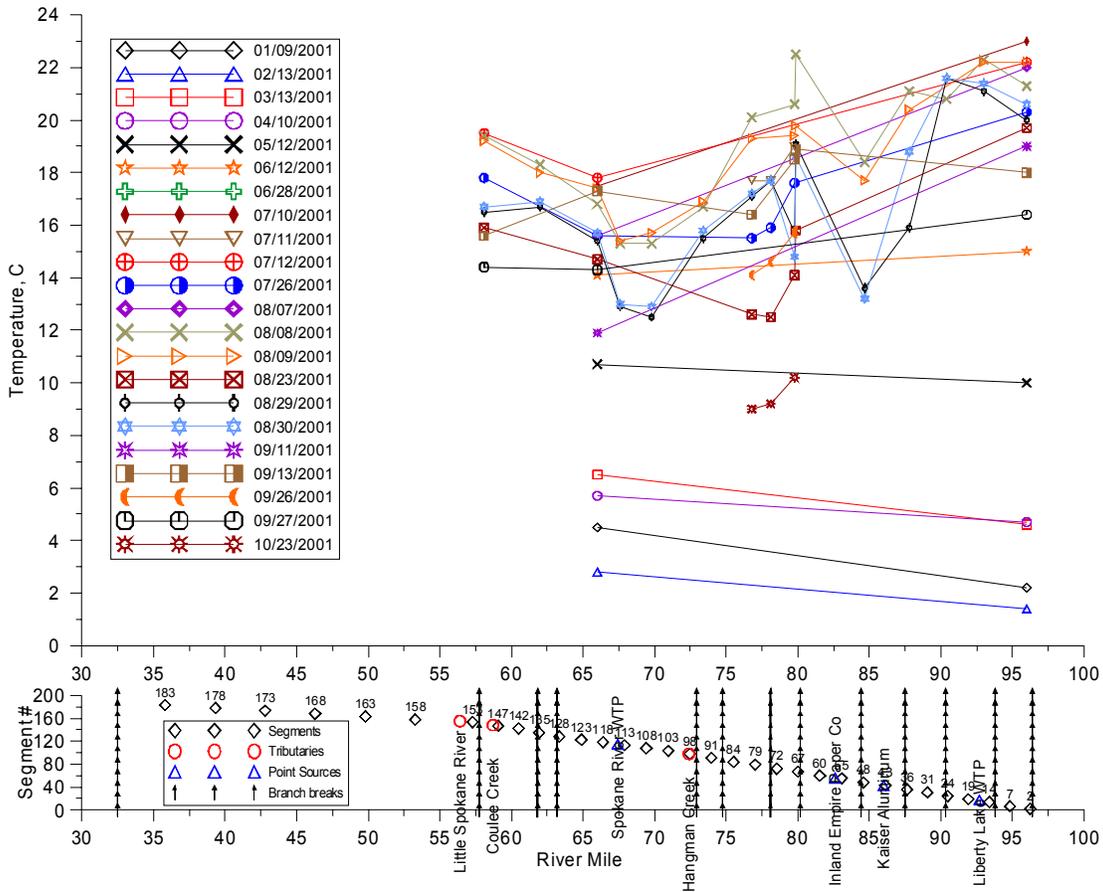


Figure 8. Temperature longitudinal profile, 2001

## **Model Forcing Data**

The model forcing data consists of the system bathymetry developed into the model grid; the boundary condition flow, temperature and water quality; the tributary and discharger flow, temperature and water quality; the groundwater flow, temperature, and water quality; and the system meteorology.

### ***Model Geometry***

#### **Spokane River Bathymetry**

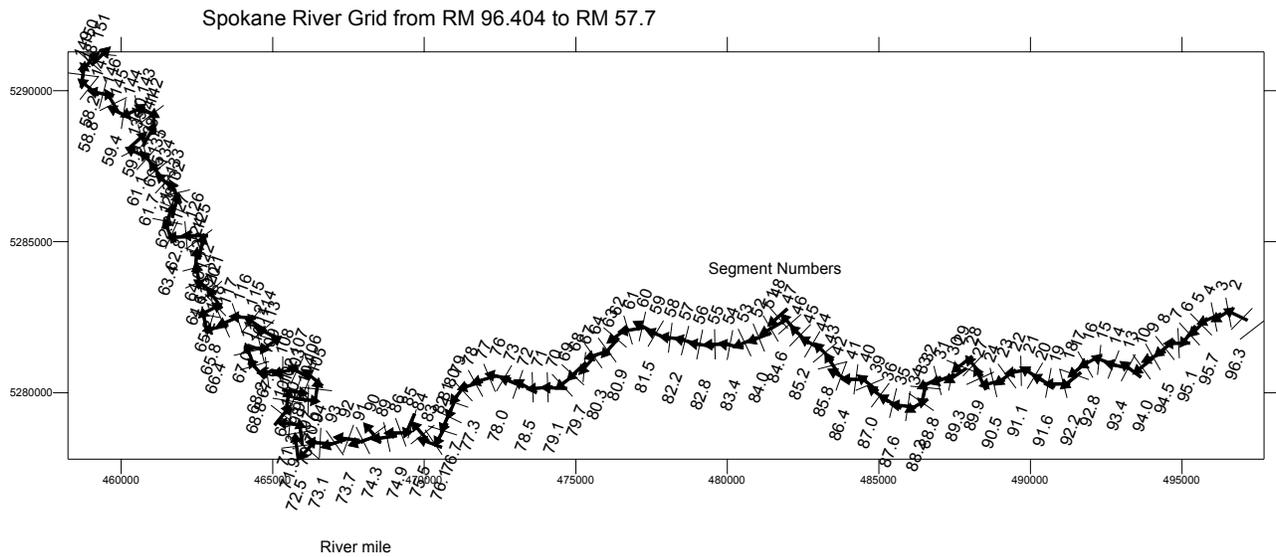
The river-reservoir system bathymetry was developed separately for the 39.2 miles of the Spokane River between the Washington-Idaho state line and Long Lake and Long Lake itself. The model grid used is the same as the model grid for the 1991 and 2000 calibrated model. A detailed description of the bathymetry development can be found in Annear et al, 2001.

## Long Lake Bathymetry

The Long Lake bathymetry was originally developed by the WA DOE based on bathymetric contour maps provided by Avista Corporation. The model grid used for 2001 is the same as the model calibrated using 1991 and 2000 data.

### Grid Layout

Figure 9 shows the plan view of the grid layout for the Spokane River, upstream of Long Lake, assuming the breakup of the river into water-bodies and branches as outlined in Table 4.



**Figure 9. Plan view Spokane river grid. The arrows show the segment orientation.**

The breaks in the model grid to form branches and water-bodies were based on (1) how groundwater inflow/recharge was computed for the Spokane River, (2) how the vertical slope changed from reach to reach, and (3) where there were pools or dams.

The vertical layout of the Spokane River, upstream of Long Lake, is shown in Figure 10. The figure also includes the locations of the branches, highest (red dots) and lowest (blue triangles) elevations recorded in a cross-section of the river, the water surface elevation from a GIS map (blue line), and a light blue line showing the elevations of the dam spillways or pools.

**Table 4. Layout of Branches for the Spokane River and Long Lake**

Comments	Start Branch (RM)	End Branch (RM)	Branch #	Distance m from upper boundary	Distance between, m	# of segment	DLX, m	Bottom Elev. Start, m	Bottom Elev. End, m
Stateline to Harvard Road Bridge	96.40	93.82	1	4154.52	4154.52	9	461.61	616	608.5
Harvard Road Bridge to Barker Road	93.82	90.34	2	9762.91	5608.39	12	467.37	608.5	600

**Table 4. Layout of Branches for the Spokane River and Long Lake**

<b>Comments</b>	<b>Start Branch (RM)</b>	<b>End Branch (RM)</b>	<b>Branch #</b>	<b>Distance m from upper boundary</b>	<b>Distance between, m</b>	<b># of segments</b>	<b>DLX, m</b>	<b>Bottom Elev. Start, m</b>	<b>Bottom Elev. End, m</b>
Bridge									
Barker Road Bridge to RM 87.50	90.34	87.50	3	14333.51	4570.59	10	457.06	600	585
RM 87.50 to The Islands Foot Bridge	87.50	84.45	4	19249.74	4916.24	10	491.62	585	578
The Islands Foot Bridge to Upriver Dam	84.45	80.18	5	26107.61	6857.87	14	489.85	571	571
Upriver Dam to Green Street Bridge	80.18	78.10	6	29459.92	3352.30	7	478.90	560	560
Green Street Bridge to Upper Falls Dam	78.10	74.75	7	34856.11	5396.20	11	490.56	560	560
Upper Falls Dam to Spokane USGS gage	74.75	72.93	8	37781.81	2925.69	6	487.62	525	517.5
Spokane USGS gage to Seven Mile	72.93	63.20	9	53441.04	15659.24	32	489.35	517.5	485
Seven Mile to RM61.813	63.20	61.813	10	55673.23	2232.19	5	446.44	481	481
RM 61.813 to Nine Mile Dam	61.81	57.77	11	62179.89	6506.66	14	464.76	481	481
Nine Mile Dam to Long Lake Dam			12						

The complexity of the model in the vicinity of Monroe Street and the Upper Falls dam has been simplified. The Monroe Street Dam is not explicitly modeled. Flow through the Upper Falls dam is modeled using the CE-QUAL-W2 selective withdrawal algorithm to simulate the turbines and spillway gates. After passing through the dam, water is placed in the model river segment downstream of the Upper Falls dam, neglecting the Monroe Street dam. The grid between Upper Falls Dam and the lower section where Monroe Street Dam is located has significant vertical fall (see Table 4 and the difference between Branch 7 and 8), which provided a natural point to break the bathymetry into separate branches. The vertical grid resolution for the Spokane River is 0.5 m.

In the CE-QUAL-W2 model, the model user must specify the characteristics and connectivity of the model grid. The following parameters were used in the Spokane-Long-Lake model (see Cole and Wells, 2000, for detailed explanation of model grid characteristics):

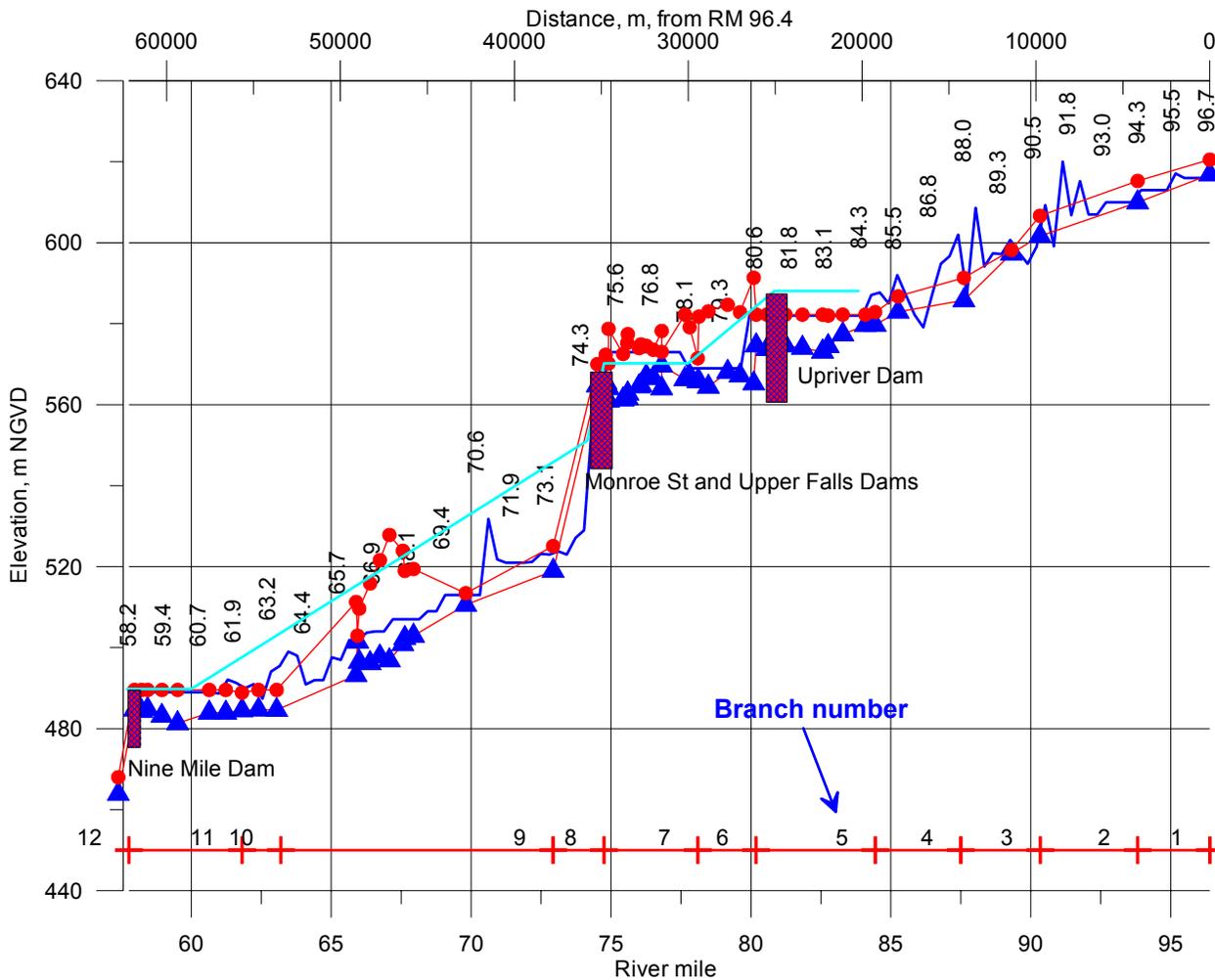
- IMP (# of segments): 189
- KMP (# of vertical layers): 47
- NWB (# of water-bodies): 6
- NBR (# of branches): 12

The branch layout was specified by these parameters for each branch (as specified in the w2\_con.npt control file – see Cole and Wells, 2000). The water-bodies included the following branches as shown in Table 5.

**Table 5. Water body-Branch Layout (see Cole and Wells, 2000)**

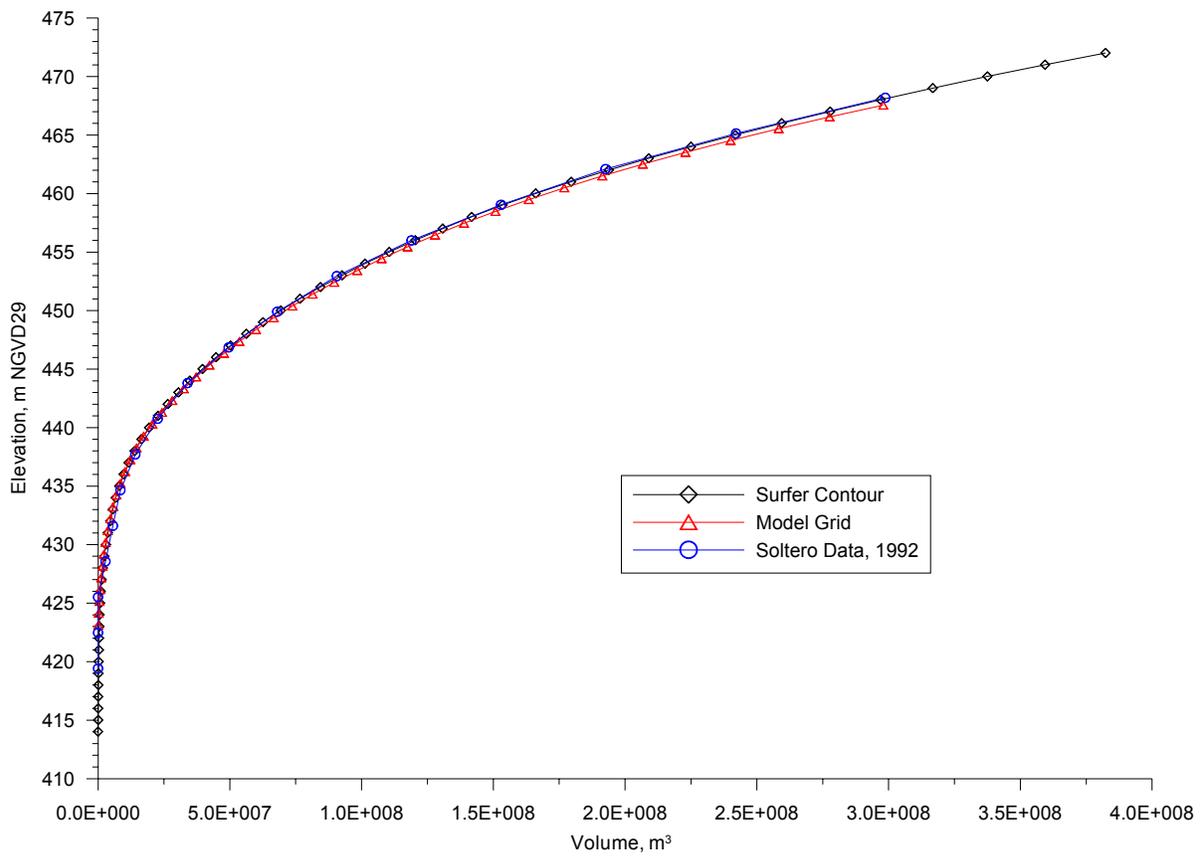
<b>Water body</b>	<b>Branch Start</b>	<b>Branch End</b>	<b>JBDN</b>
Jr 1 4 sloping branches above the pool of Upriver Dam	1	4	4
Jr 2 Pool of Upriver Dam	5	5	5
Jr 3 Pool of Upper Falls Dam	6	7	7
Jr 4 2 sloping branches above the Nine Mile Dam pool	8	9	9

Water body	Branch Start	Branch End	JBDN
Jr 5 Nine mile dam pool	10	11	11
Jr 6 Long Lake pool	12	12	12

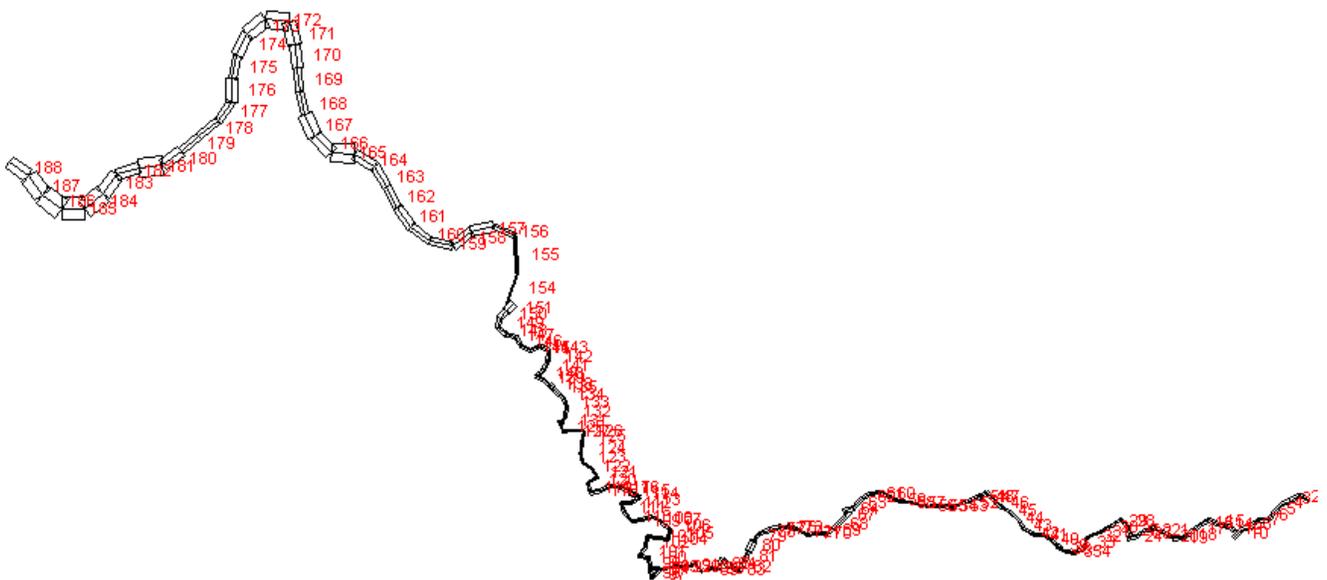


**Figure 10. Vertical layout of Spokane River grid.**

Figure 11 compares the volume-elevation data from Soltero (1992) with the SURFER contour program estimates and the W2 model grid for Long Lake. The figure shows close agreement between the model grid and data indicating the model grid is accurately representing the lake's volume as a function of elevation. A plan view of model grid layout is shown in Figure 12.



**Figure 11. Long Lake volume-elevation comparison, data and model grid**



**Figure 12. Plan view grid layout including Long Lake**

**Boundary Conditions**

The model upstream boundary condition is the Spokane River at the WA-ID state line and the downstream boundary condition is the outflow from Long Lake. The upstream boundary condition was characterized by flow, water temperature, and water quality. The downstream boundary condition was characterized by flow rate. The model used internal interpolation to fill in the boundary conditions between the data.

### Spokane River at state line

The upstream boundary condition on the Spokane River was set at the Washington-Idaho state line. The model time period is from January to December 2001. The boundary conditions consist of flow, water temperature and water quality characteristics. Figure 13 shows the flow at the state line and were developed by adjusting data obtained from the U.S. Geological Survey (USGS) gage station near Post Falls, ID (USGS: 12419000). The change in flow occurring between Post Falls and the state line was estimated by using flow data from Harvard Road (RM93.7). Flow rates at Harvard Road were typically less than those at Post Falls due to losses to the underlying aquifer. The flow difference between Post Falls and Harvard Road was then used to estimate the flow at the state line, which was 4.7 miles downstream of Post Falls. The total distance between Post Falls and Harvard Bridge is 7.7 miles, and the loss/gain to the aquifer occurring between Post Falls and the state line was estimated by multiplying the flow difference between Post Falls and Harvard Road by the fraction,  $f$ , of river miles between Post Falls and state line ( $f = 4.7 \text{ miles}/7.7 \text{ miles}$ ). The gain/loss to the aquifer  $Q_{\text{aquifer}}$  (typically a loss) between Post Falls and State Line was estimated from

$$Q_{\text{aquifer}} = (Q_{\text{Harvard}} - Q_{\text{Post Falls}}) \frac{4.7 \text{ miles}}{7.7 \text{ miles}}$$

which was then used to estimate the flow at state line  $Q_{\text{state line}}$  with

$$Q_{\text{state line}} = Q_{\text{Post Falls}} + Q_{\text{aquifer}}$$

The flow in 2001 was similar to the flow recorded in 1991. In both years, the flow reached a maximum of approximately  $550 \text{ m}^3/\text{s}$  near mid-May. However, 2001 flows remained low until mid-April and then rose rapidly. In 1991 flows increased steadily over the course of a few months.

As in 1991 and 2000 there was little temperature data available at the state line. The data consisted of periodic grab samples and some Hydrolab data monitored over a short period in the summer. Figure 14 shows the water temperature at the state line. The data show a seasonal warming and cooling trend similar to 1991 and 2000, with the peak stream temperature occurring in August.

Water quality files for 2001 were developed from data collected at the State Line Bridge (RM 96.0). If data for a particular constituent were not available, constituent concentrations were estimated from other relevant data.

Organic matter in the upstream boundary condition, tributaries, and point sources were simulated using CBOD ultimate data and multiple CBOD compartments in CE-QUAL-W2. Each point source was represented by a separate CBOD compartment and decay rate, and the upstream boundary condition and tributary BOD were grouped into a single CBOD compartment.

For the year 2001, data were available for the following constituents: conductivity, ammonia nitrogen, nitrite-nitrate nitrogen, phosphorus (soluble reactive phosphorus), fecal coliform, CBOD ultimate, and dissolved oxygen. Alkalinity and chloride concentrations were estimated using averages of data collected in the year 2000. Inorganic carbon concentrations were calculated from pH, alkalinity and temperature data using equations based on the carbonate-bicarbonate equilibrium reaction (Stumm and Morgan, 1981). Algae concentrations were estimated using chlorophyll *a* data and assuming a ratio of 35 µg/l chlorophyll *a* to 1 mg/l algae.

Organic matter from the upstream boundary condition and tributaries were simulated using a single combined CBOD compartment and CBOD ultimate data. The constituent concentrations of LDOM (labile dissolved organic matter), RDOM (refractory dissolved organic matter), LPOM (labile particulate organic matter) and RPOM (refractory particulate organic matter) were set to zero.

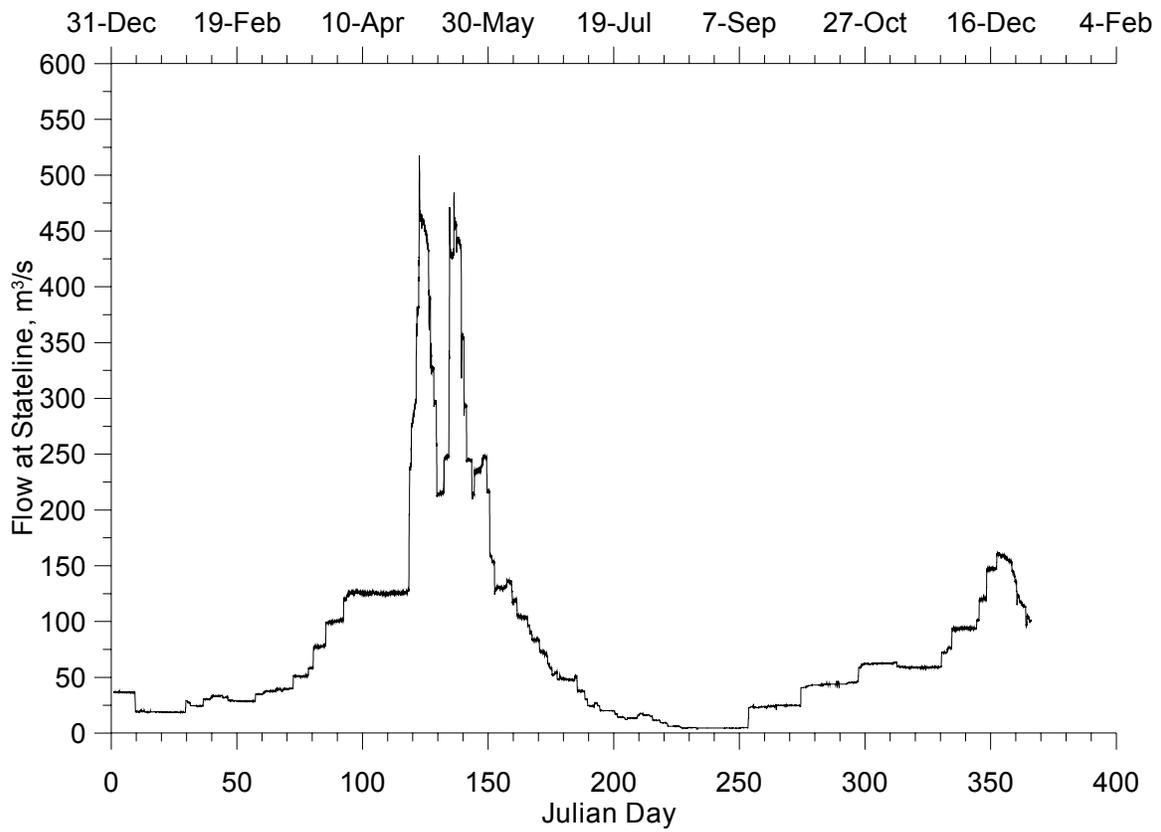
Concentration of inorganic suspended solids (ISS) were estimated by applying a mass balance between total suspended solids data (TSS), algae data, and estimated particulate organic matter (POM) concentration giving

$$\text{ISS} = \text{TSS} - \text{POM} - \text{algae}$$

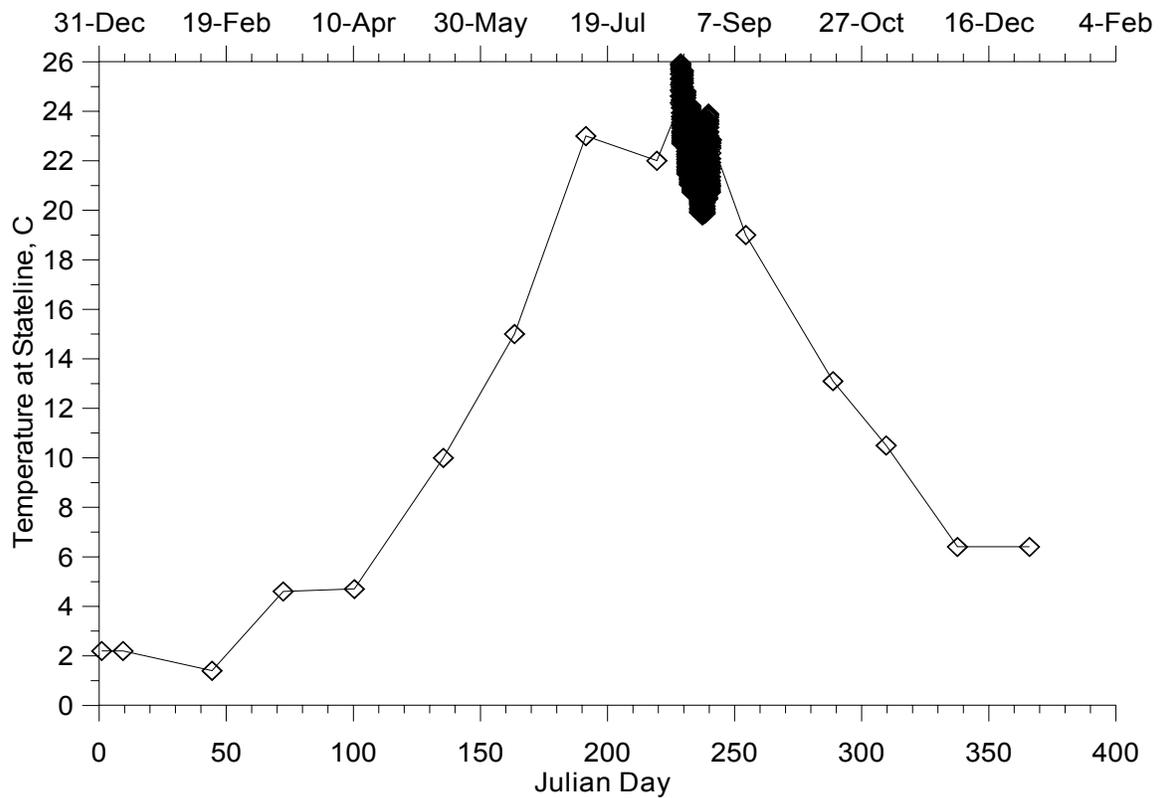
Particulate organic matter (POM) concentrations were estimated from dissolved organic carbon data (DOC), total organic carbon data (TOC), and algae data:

$$\text{POM} = \frac{\text{TOC} - \text{DOC}}{\delta_c} - \text{algae}$$

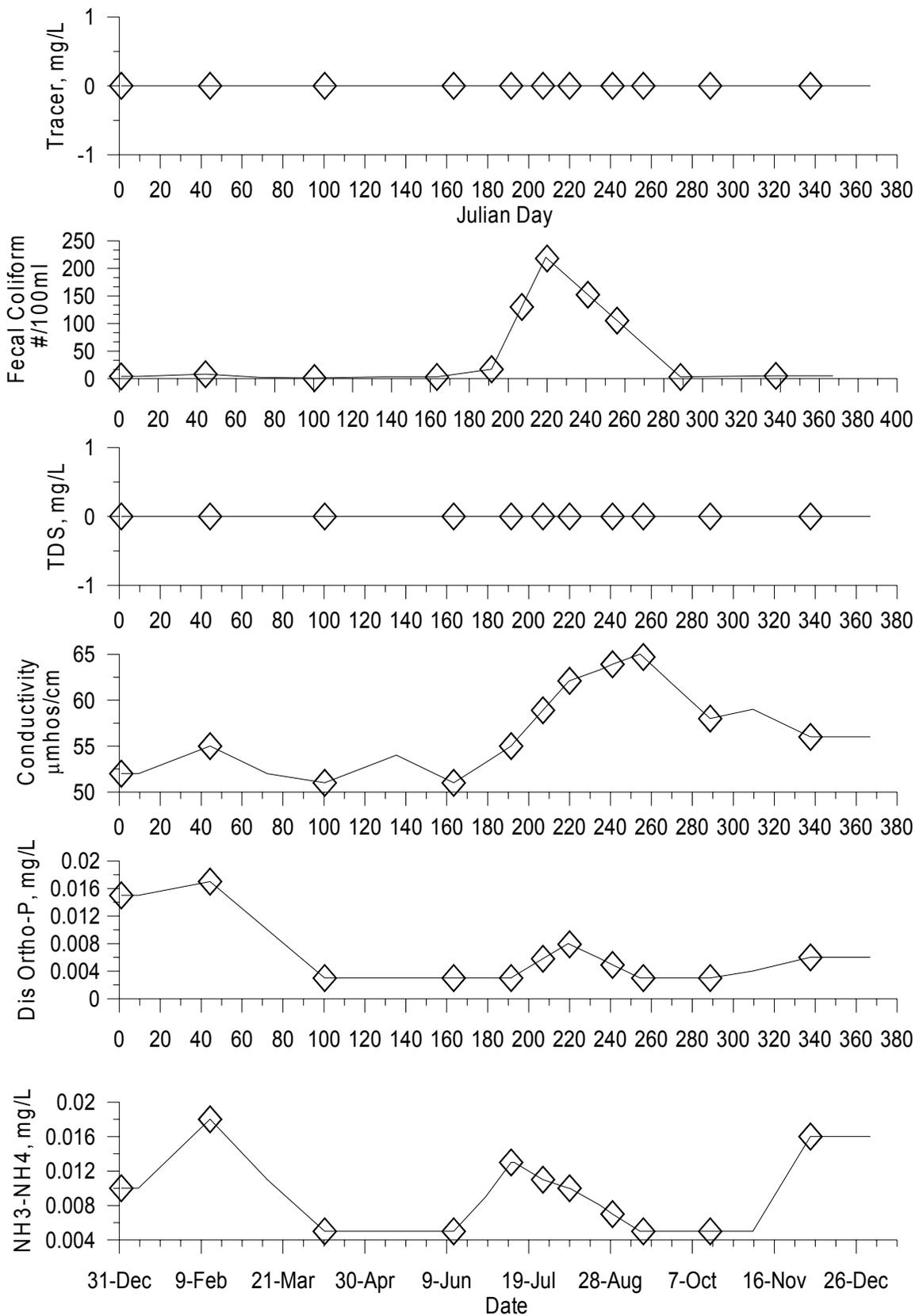
where  $\delta_c$  was the stoichiometric equivalent between organic matter and carbon. It was assumed that  $\delta_c=0.65$ . Figure 15, Figure 16 and Figure 17 show the plots of constituent concentrations for both years.



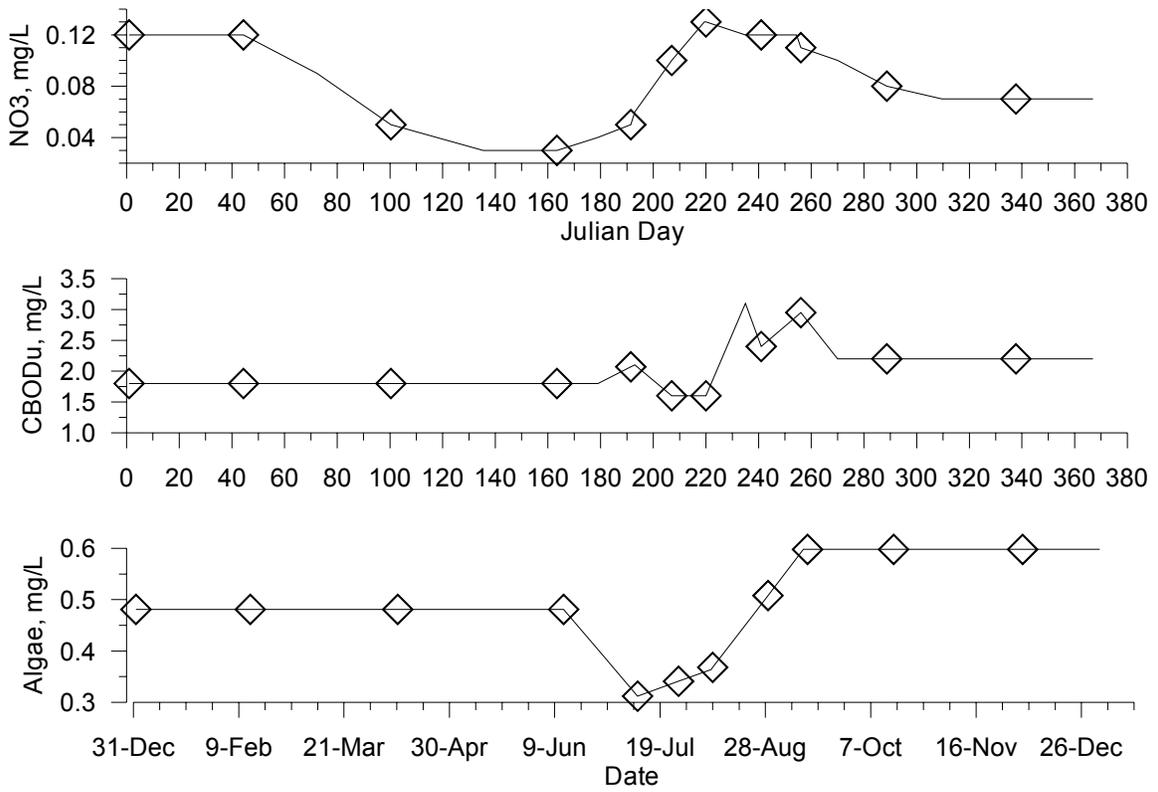
**Figure 13. Spokane River flow at the state line, 2001**



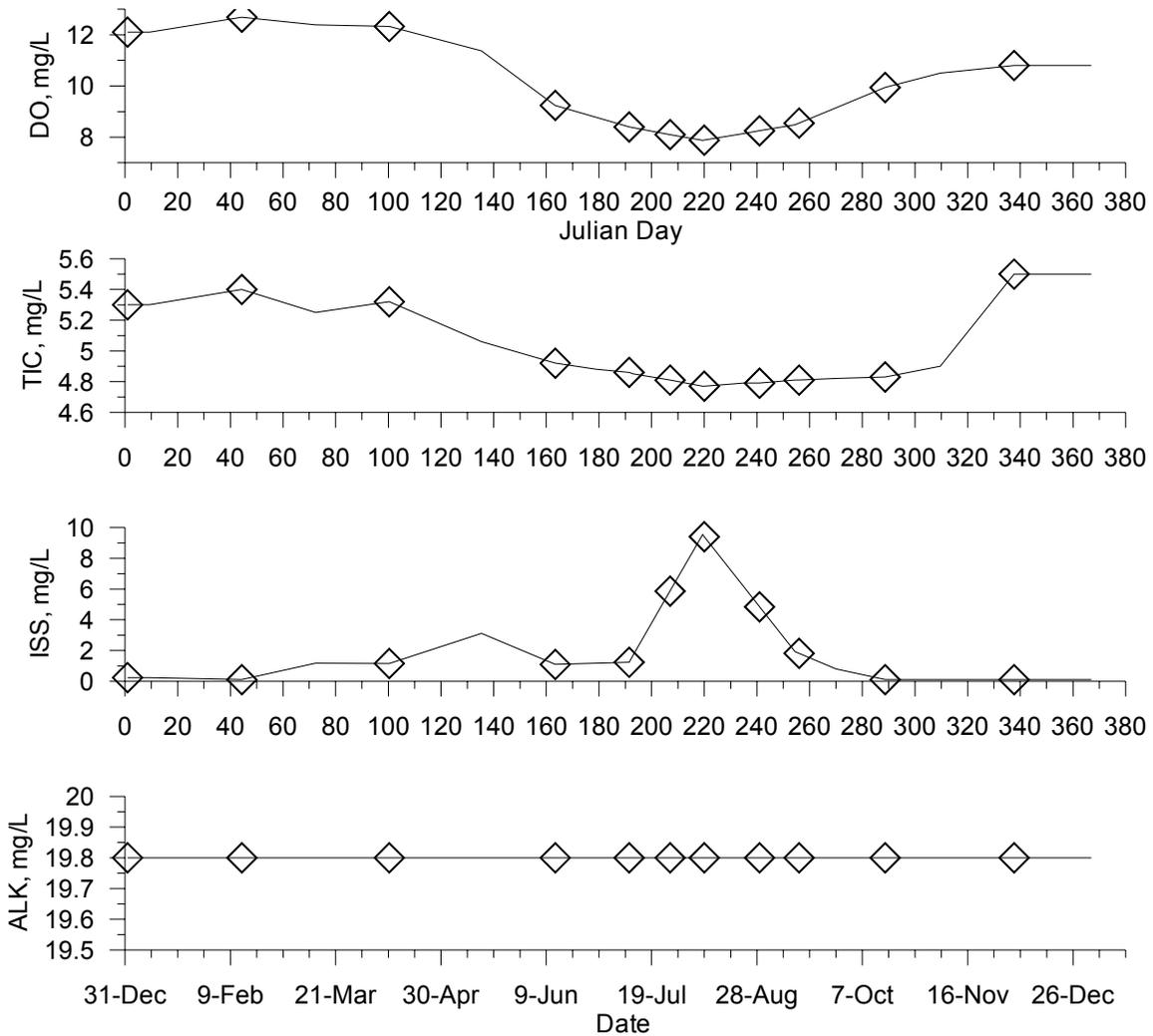
**Figure 14. Spokane River temperature at the state line, 2001**



**Figure 15. Spokane River at the state line water quality conditions (Part 1)**



**Figure 16. Spokane River at the state line water quality conditions (Part 2)**

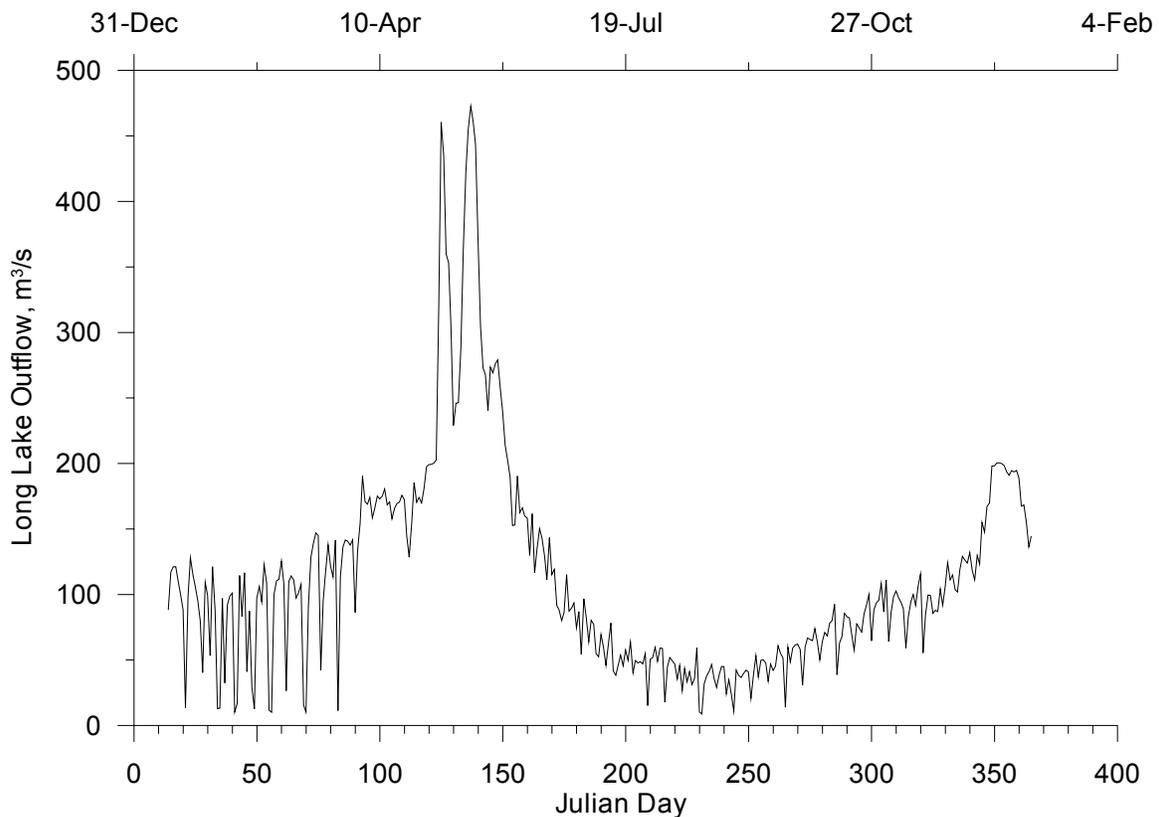


**Figure 17. Spokane River at the state line water quality conditions (Part 3)**

Long Lake outflow

The downstream boundary condition was the outflow from Long Lake. An outflow record was developed for the model as shown in Figure 18. The seasonal trend shown in this figure is similar to the seasonal trend at state line.

The Long Lake outflow temperature and water quality is dependent upon the location of water withdrawn from the reservoir using the CE-QUAL-W2 selective withdrawal algorithm. Turbine flow out of the dam was modeled as a point sink. Additionally the dam spillway was also modeled to incorporate any additional flow passed downstream.



**Figure 18. Long Lake outflow, 2001**

### ***Tributaries***

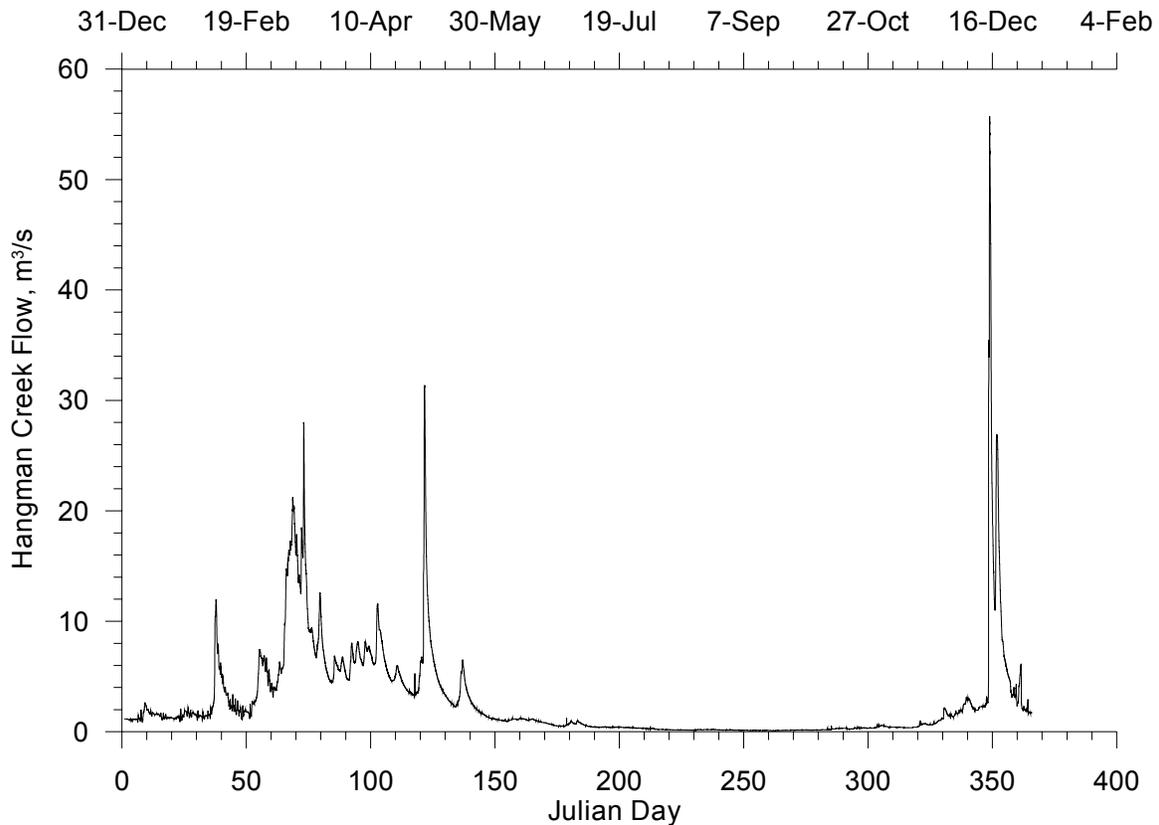
The three main tributaries contributing flow to the Spokane River and Long Lake are Hangman Creek (RM 72.4), Little Spokane River (RM 56.4), and Coulee Creek (RM 58.8). Each tributary was characterized by flow, temperature, and water quality. The model used internal interpolation to fill in the boundary conditions between the data. In many cases there was not much data available to characterize the water quality. The result is that some water quality constituents remained constant over 2001. This assumption should not have much influence on the water quality calibration due to the small magnitude of these inflows.

### **Hangman Creek**

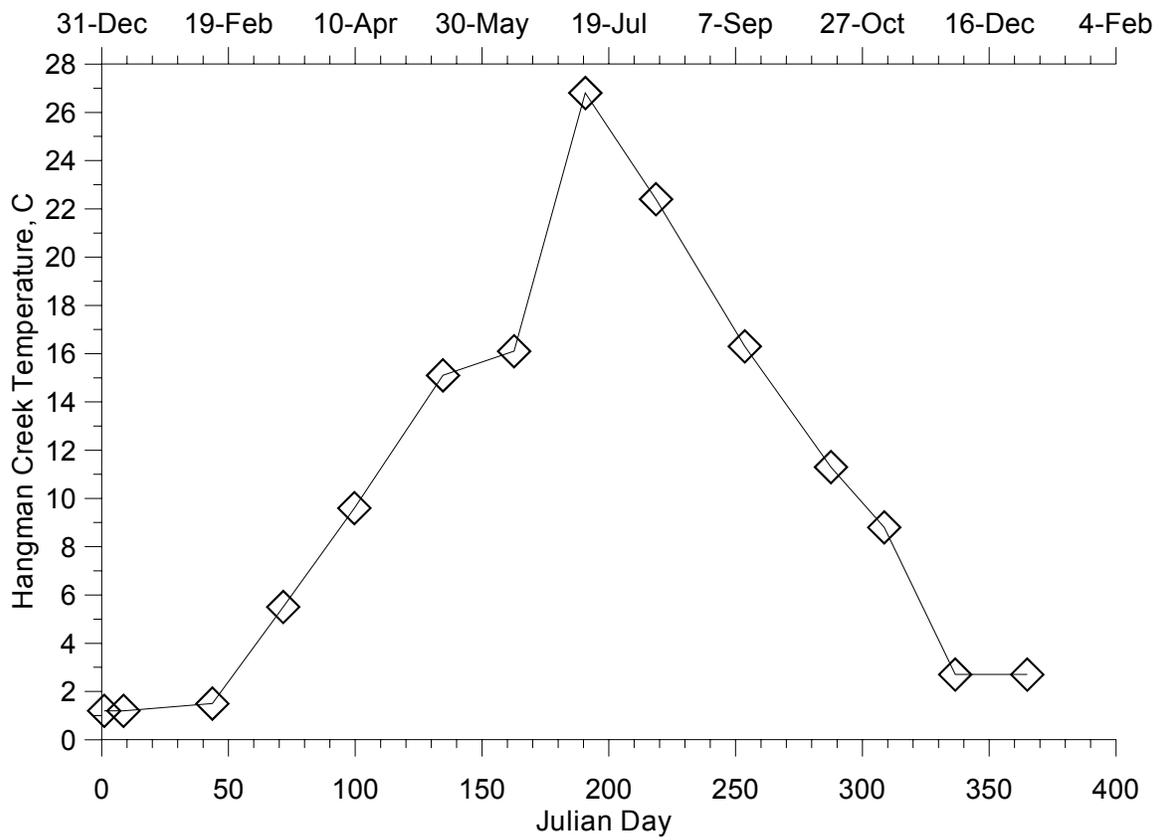
Hangman Creek inflows are shown in Figure 19. The peak flows were during the winter-spring freshet (February through April) and were considerably less than previously modeled years, reaching only 30 m<sup>3</sup>/s where in 1991 the flow rate was 190 m<sup>3</sup>/s and in 2000 it was 170 m<sup>3</sup>/s. Hangman Creek water temperatures are shown in Figure 20. The stream temperatures were slightly higher in 2001 than 1991 and 2000 due to lower flows.

The water quality characteristics for Hangman Creek were developed using data collected at the mouth of Hangman Creek. If data for a particular constituent was not available, constituent concentrations were estimated from other relevant data.

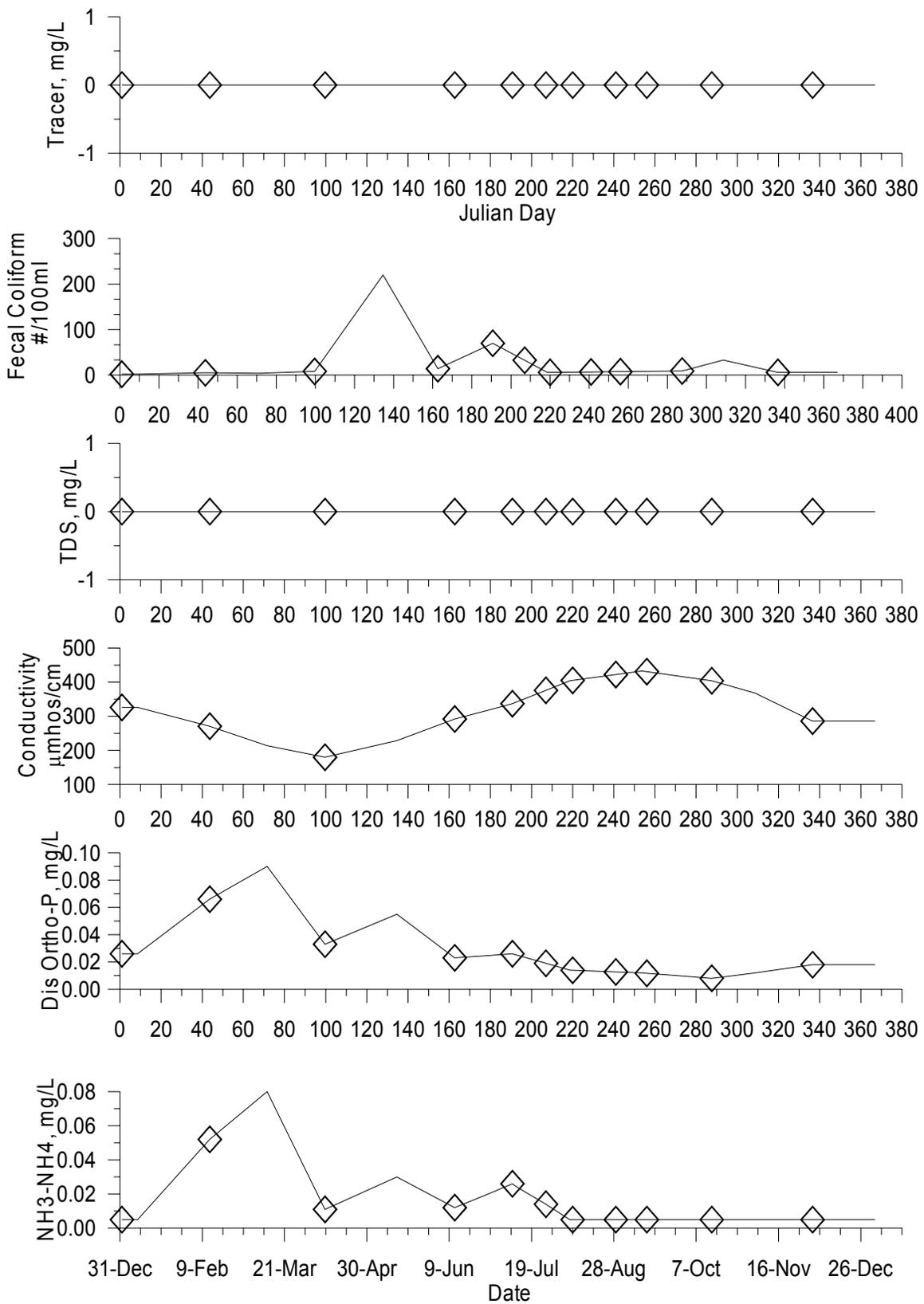
For the year 2001, data were available for the following constituents: conductivity, ammonia nitrogen, nitrite-nitrate nitrogen, phosphorus (soluble reactive phosphorus), fecal coliform, CBOD ultimate, and dissolved oxygen. Alkalinity and chloride concentration were estimated using the averages of data collected in the year 2000. Inorganic carbon concentrations were calculated from pH, alkalinity and temperature data using the method described above under the section titled “Spokane River at state line”. As was described in this section, organic matter originating from Hangman Creek, the upstream boundary condition, and other tributaries were modeled using CBOD ultimate data and a single CBOD compartment. The remaining water quality constituents for the model were developed using the same procedure outlined under Spokane River at state line. Figure 21, Figure 22, and Figure 23 show the plots of the constituent concentrations for both years.



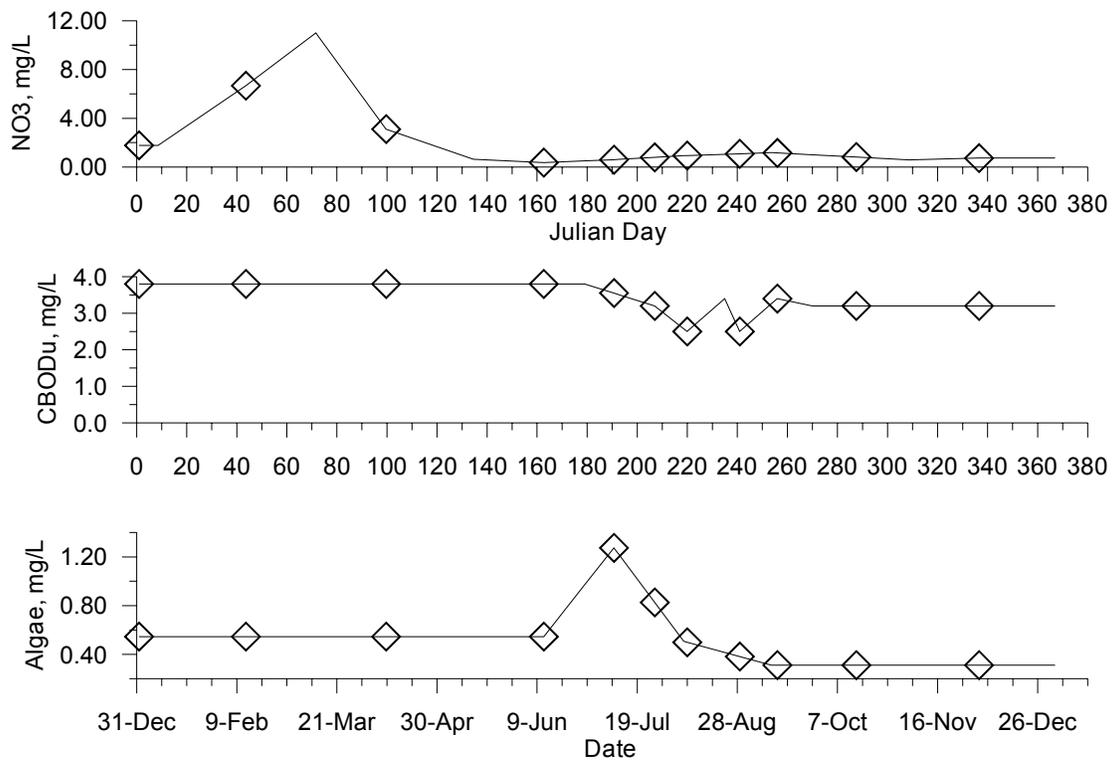
**Figure 19. Hangman Creek flow, 2001**



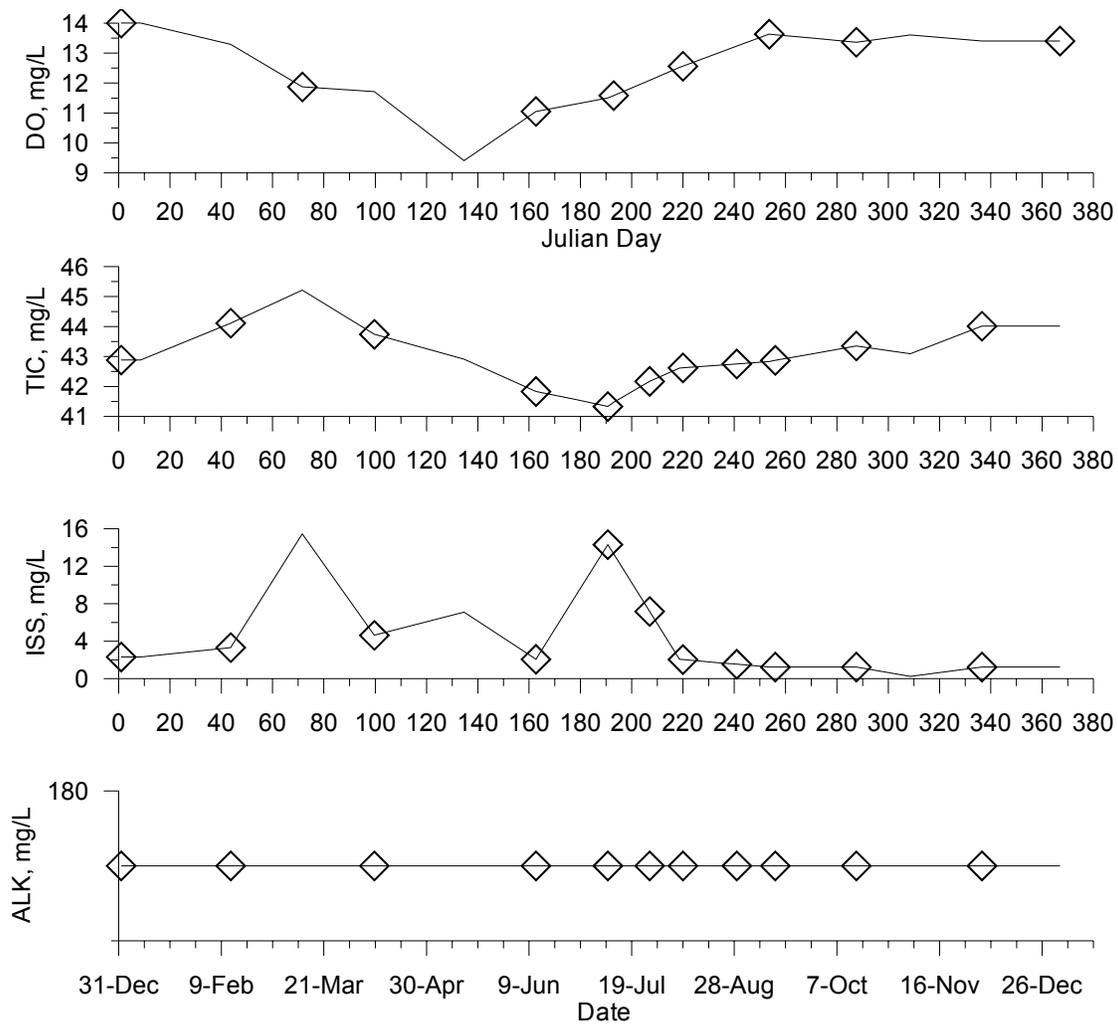
**Figure 20. Hangman Creek water temperature, 2001**



**Figure 21. Hangman Creek water quality conditions (Part 1)**



**Figure 22. Hangman Creek water quality conditions (Part 2)**



**Figure 23. Hangman Creek water quality conditions (Part 3)**

### Little Spokane River

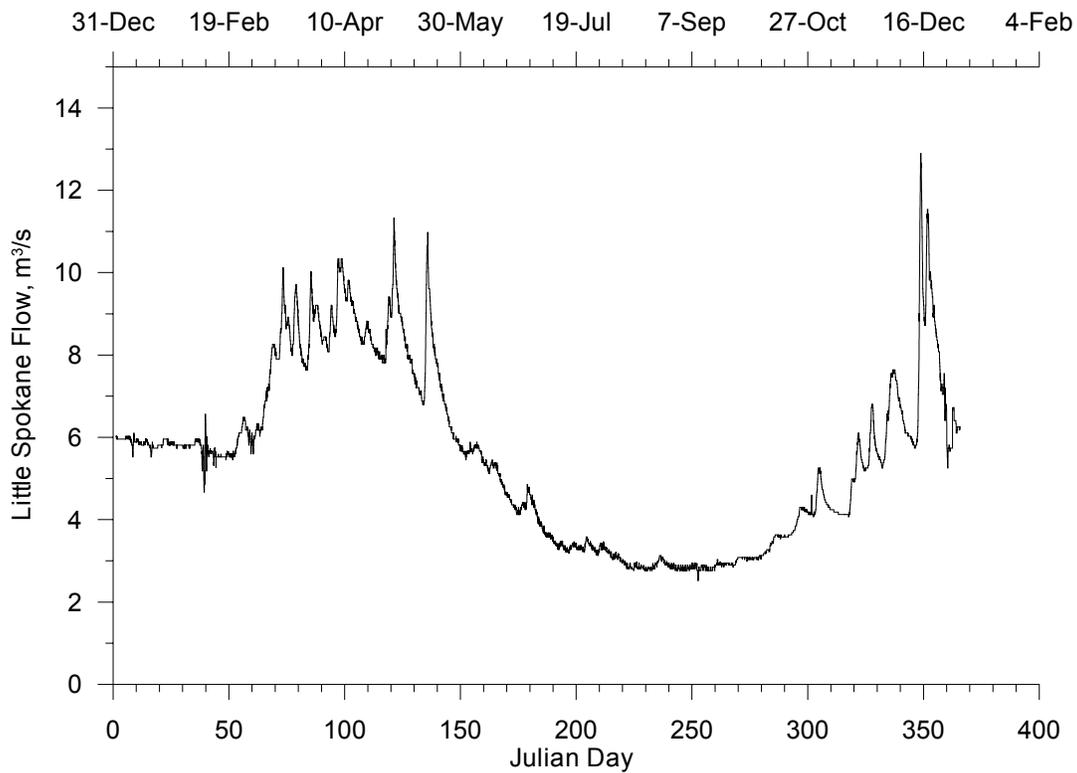
The Little Spokane River is located downstream of Nine Mile Dam and contributes flow directly to Long Lake. Approximately 7.7 miles upstream of the confluence with the lake the Little Spokane River flow is monitored at a USGS gage station at Dartford, WA (USGS: 12431000). As noted in Soltero et al. (1992), there is considerable groundwater inflow between the gage station and the river's confluence with Long Lake. Groundwater modeling by Bolke and Vaccaro (1981) and Patmont et al. (1985, 1987) indicate during the summer from June to October approximately 250 cfs should be added to the gage station flow to represent the total flow entering Long Lake. During the winter, November to May, the total flow was calculated based on Soltero et al. (1987):

$$\text{Little Spokane River at mouth} = (\text{gage } 12431000 \times 1.09) + 252 \text{ cfs}$$

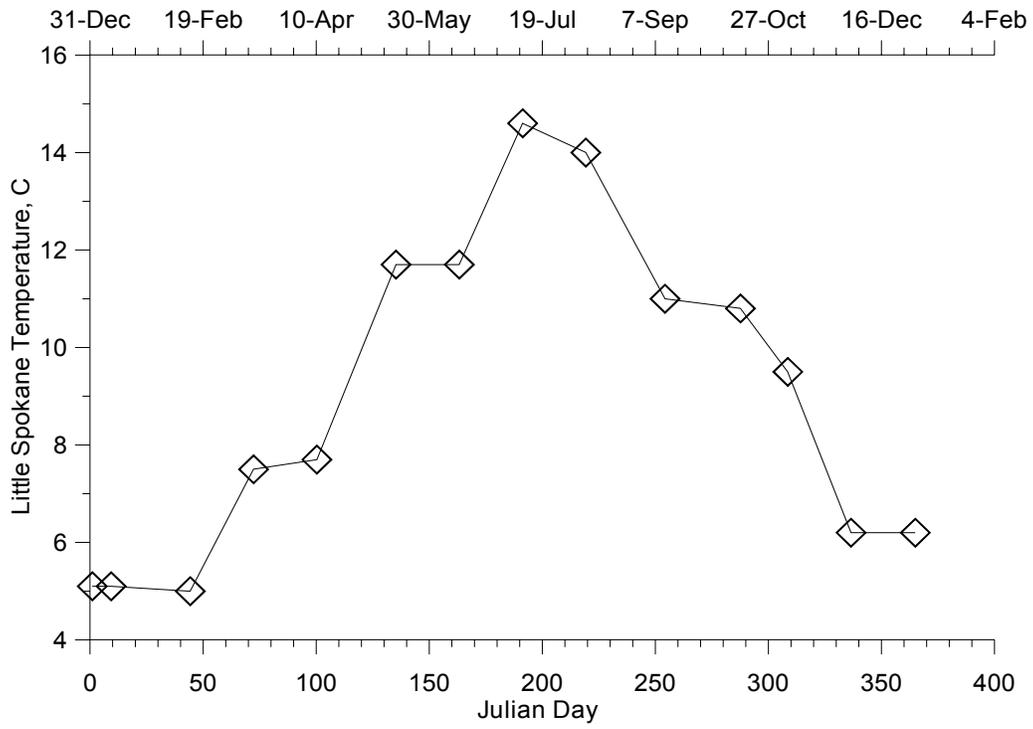
These relationships were used with the gage station flow to generate the Little Spokane River inflow to Long Lake. Figure 24 shows the total flow for the Little Spokane River. The figure shows increased flows in the spring caused by snow pack runoff and another increase in December resulting from increased precipitation. The peak flows for 2001 were the similar to the base flow levels for previously

modeled years. Water temperatures in the river show a typical seasonal trend. Summer highs were a couple of degrees less than in 2000.

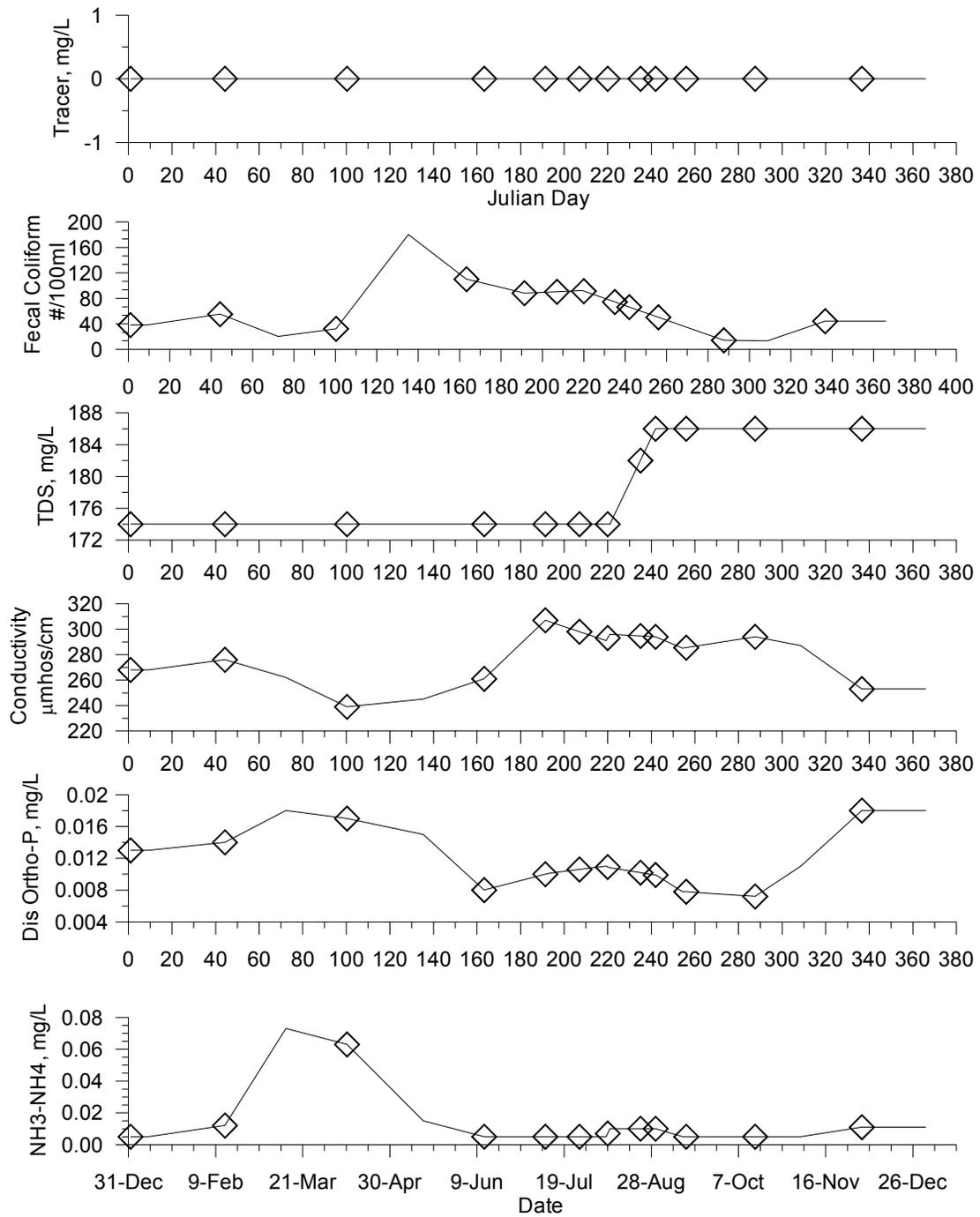
The method used to create water quality files representing the Little Spokane River inflows was identical to the one applied for the Spokane River at the state line (discussed above). Figure 26, Figure 27, and Figure 28 show the constituent concentrations for the Little Spokane River.



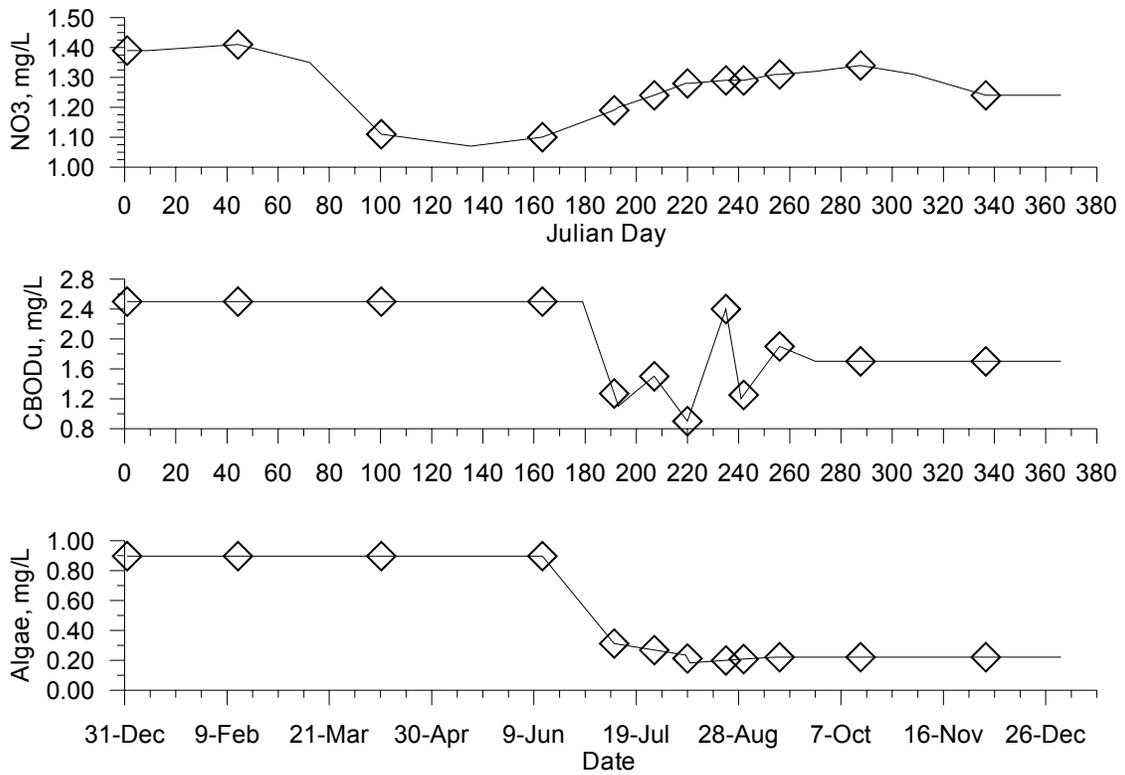
**Figure 24. Little Spokane River flow, 2001**



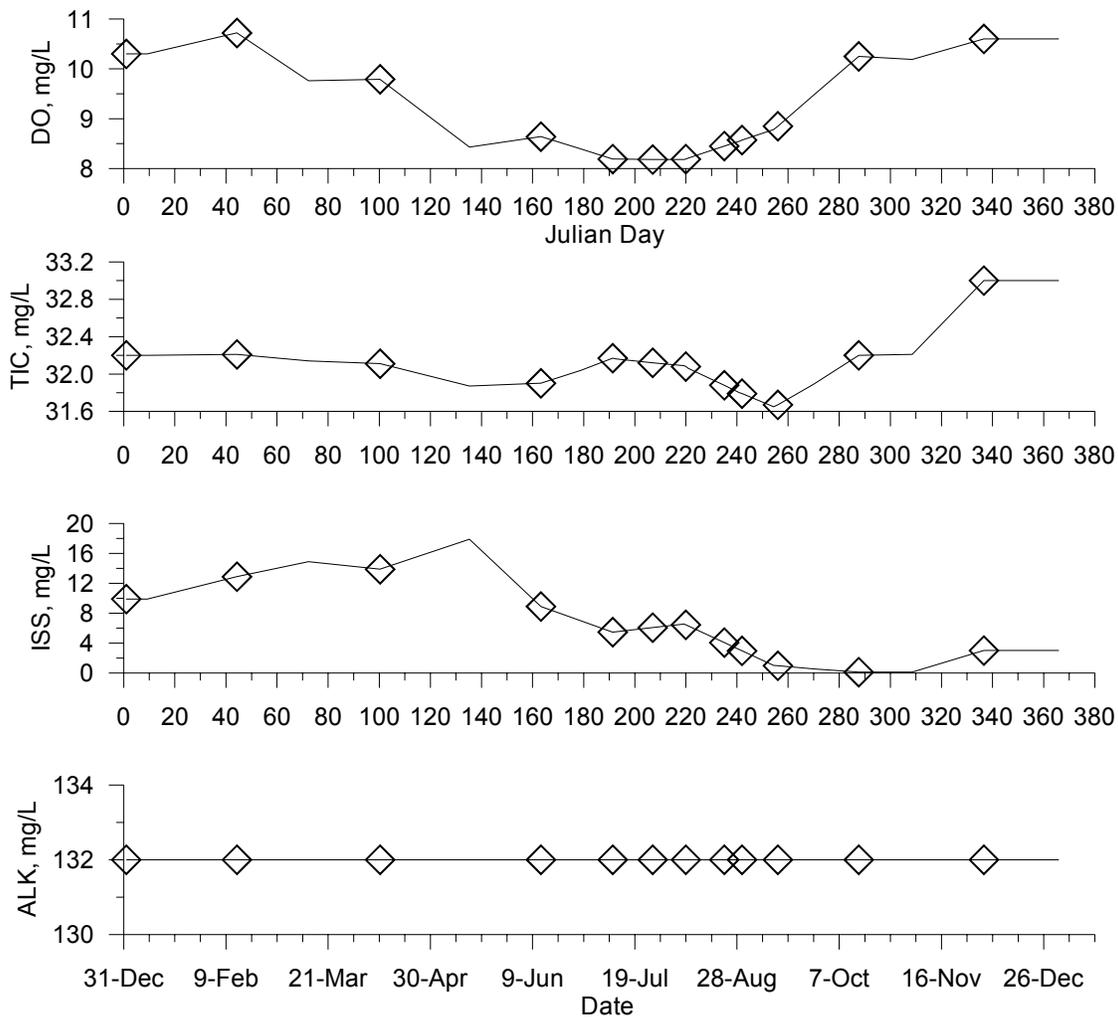
**Figure 25. Little Spokane River temperature, 2001**



**Figure 26. Little Spokane River water quality conditions (Part 1)**



**Figure 27. Little Spokane River water quality conditions (Part 2)**



**Figure 28. Little Spokane River water quality conditions (Part 3)**

### Coulee Creek

Adjacent to the Hangman Creek basin are the Coulee Creek and Deep Creek basins. Since there was no flow monitoring on either tributary, flow estimates were made by comparing basin areas with the Hangman Creek basin area and taking a fraction of the Hangman Creek flow:

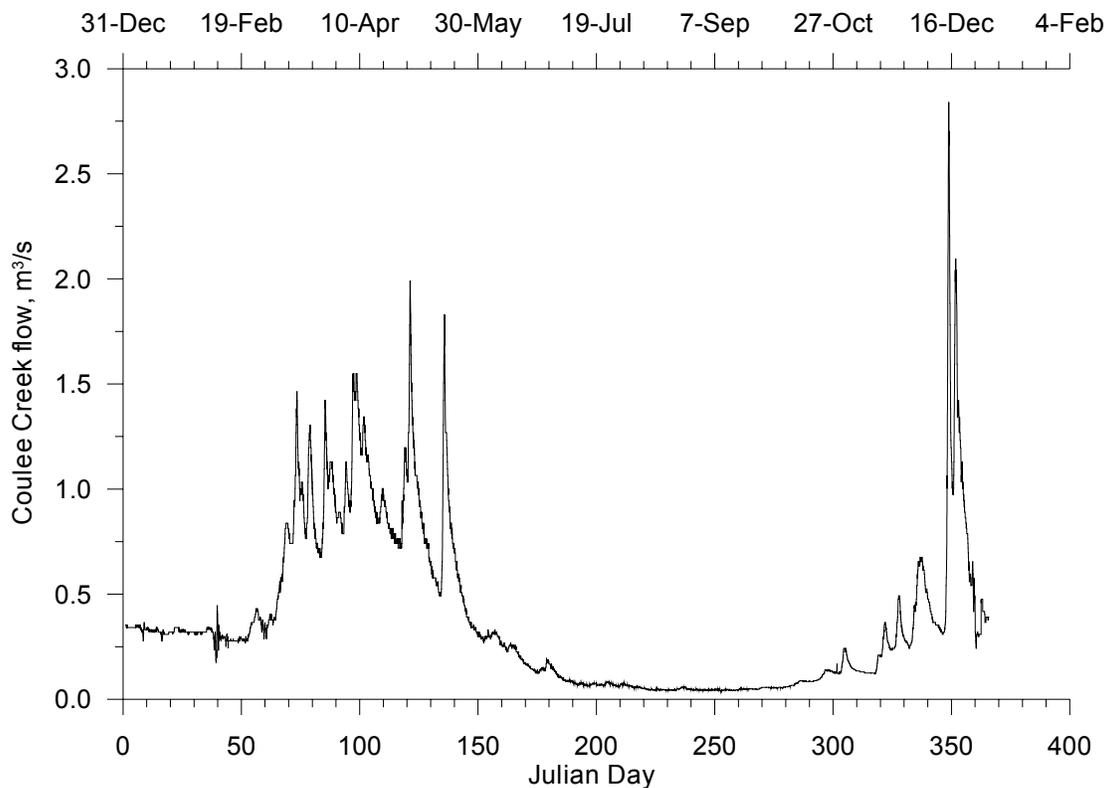
$$Coulee \ \& \ DeepCreekQ = \left( \frac{Coulee \ \& \ DeepCreek \ \_ \ basin \ \_ \ area}{HangmanCreek \ \_ \ basin \ \_ \ area} \right) HangmanCreekQ$$

The calculated flows for Coulee and Deep Creeks are plotted in Figure 29. Deep Creek is intermittent and, although it has a larger drainage basin than Coulee Creek, most of the flow that reaches the Spokane River is from the Coulee Creek basin (email correspondence with Stan Miller, Spokane County). Coulee Creek enters Deep Creek just before Deep Creek's confluence with the Spokane River. In the lower reaches of Deep Creek, the river flows across alluvial gravel for a considerable distance losing flow to groundwater. Additionally, it has been noted that the intermittent nature of Deep Creek may be the result of dewatering of the basalt interbeds by domestic wells and these interbeds feed springs which support the stream in its lower reaches (Stan Miller). Coulee Creek is believed to be the major source of water to the Spokane River because water has been seen entering the Spokane River

when Deep Creek was dry upstream, and Coulee Creek does not flow over the alluvial gravel for a very long distance. In general, it is also believed that a lot more water reaches the Spokane River in this stretch of river than is provided by the tributary inflow. As discussed later in this report, groundwater inflow and outflow files were developed for most of the river reaches to account for groundwater gains and losses

Since there was no active monitoring taking place on Coulee and Deep Creeks, stream temperatures were unknown. The calculated flows were much smaller than Hangman Creek and since temperatures were monitored in the adjacent Hangman Creek basin, the temperature records were used for the Deep and Coulee Creek inflows.

Because no water quality data were available, the constituent concentrations of Coulee Creek were assumed to be equivalent to that of Hangman Creek. The method and data used to characterize Hangman Creek water quality were described above.



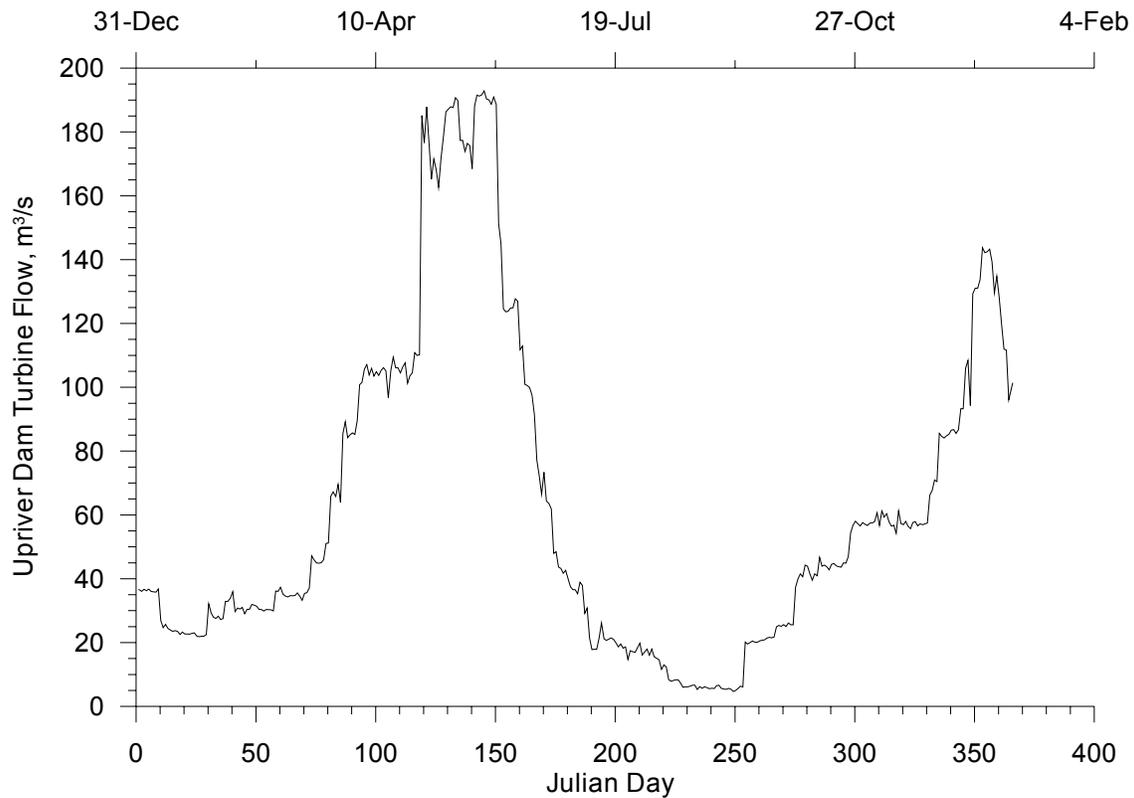
**Figure 29. Coulee and Deep Creek flow, 2001**

## ***Reservoir Operations***

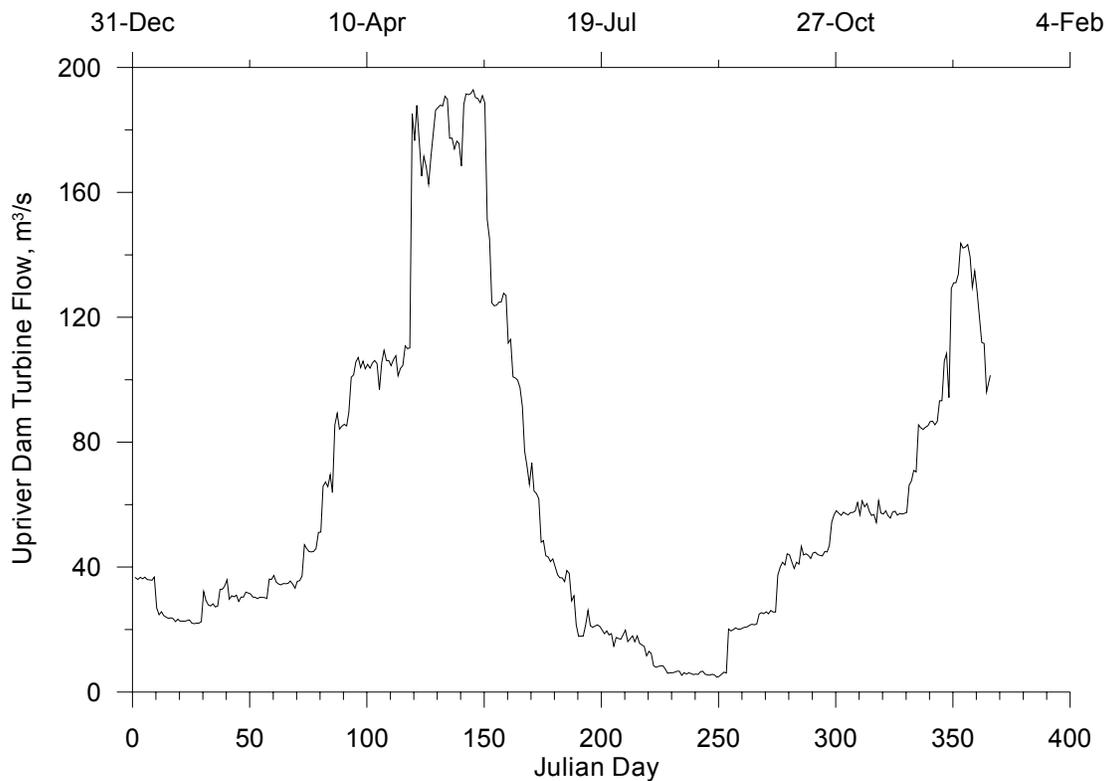
### **Upriver Dam and Reservoir**

Upriver Dam is located furthest upstream in the model domain at RM 80.2. The dam is operated as a run-of-the-river facility so the pool water level is maintained relatively constant at 1910.2 ft NGVD29 with a deviation of +/- 0.2 ft.

Figure 30 shows total gate flow for the Upriver Dam. Spring peak flow (May through June) was half of what it was in 2000 and a third of what it was in 1991. Figure 31 shows turbine flows for 2001, which were less than in previously modeled years.



**Figure 30. Upriver Dam total flow through all gates, 2001**

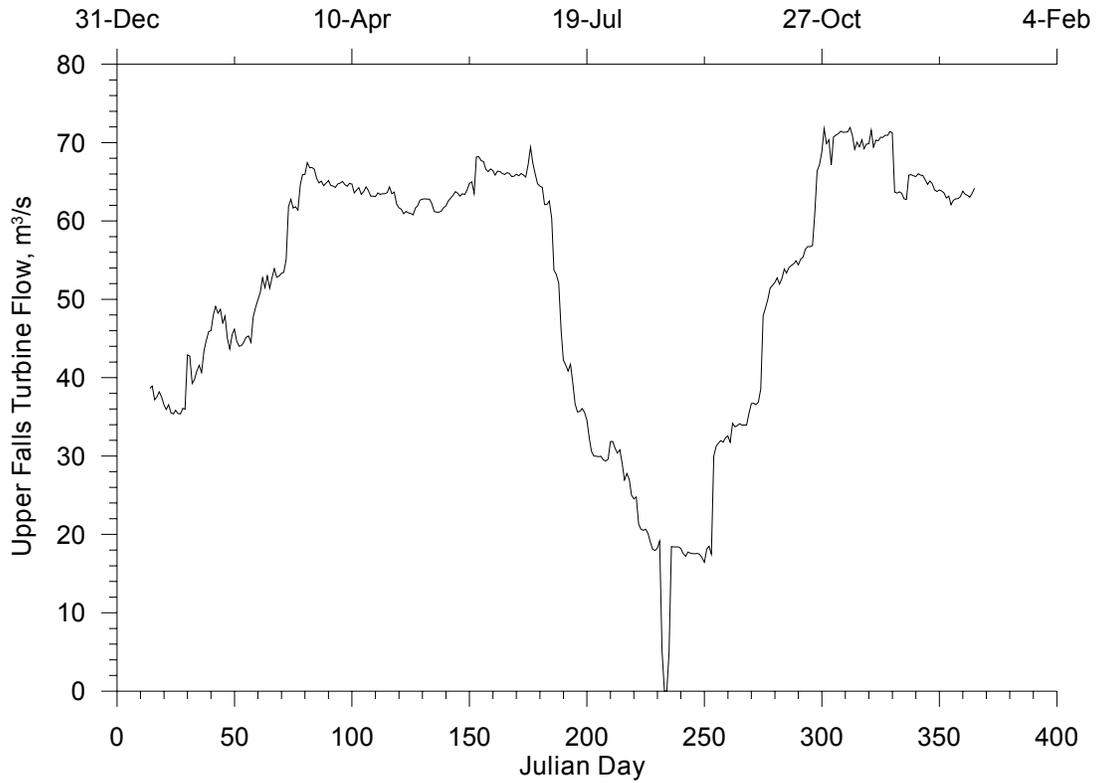


**Figure 31. Upriver Dam flow through turbines, 2001**

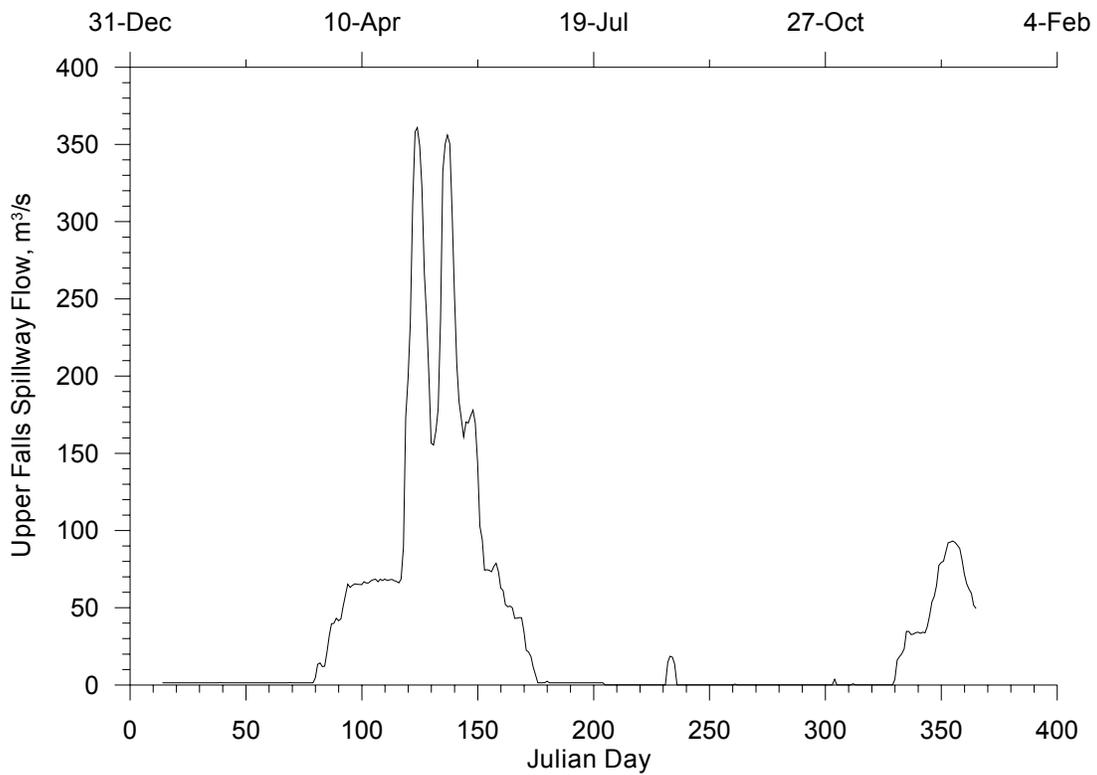
### Upper Falls Dam and Reservoir

The Spokane Falls area is a highly managed stretch of the Spokane River that passes through downtown Spokane. Upper Falls Dam is located at approximately RM 74.8 but most of the river water is diverted down a side channel to the south, which leads to the Upper Falls Powerhouse. During the summer the Upper Falls Dam continuously releases 300 cfs down the north branch of the river. During the winter, when much higher flows are expected, the water that cannot be passed through the powerhouse is spilled at this dam facility. Flow through the Upper Falls powerhouse is then diverted back to the Spokane River to a pool area just below the Spokane Falls Rapids. The Spokane Falls Rapids consist of two branches as well. The furthest north branch is only used when there is very high water whereas the south branch is used to pass the 300 cfs summer flow and normal winter flows. The outflow from the turbines and the flow from the Spokane Rapids meet in a pool area just downstream. Just below the pool and at the top of the Spokane Falls sits the Monroe St Dam and powerhouse. This facility is designed to pass flow through it over a short distance, bypassing the Spokane Falls. The predominant flow through all of these facilities during the summer is through the Upper Falls powerhouse before rejoining the Spokane River.

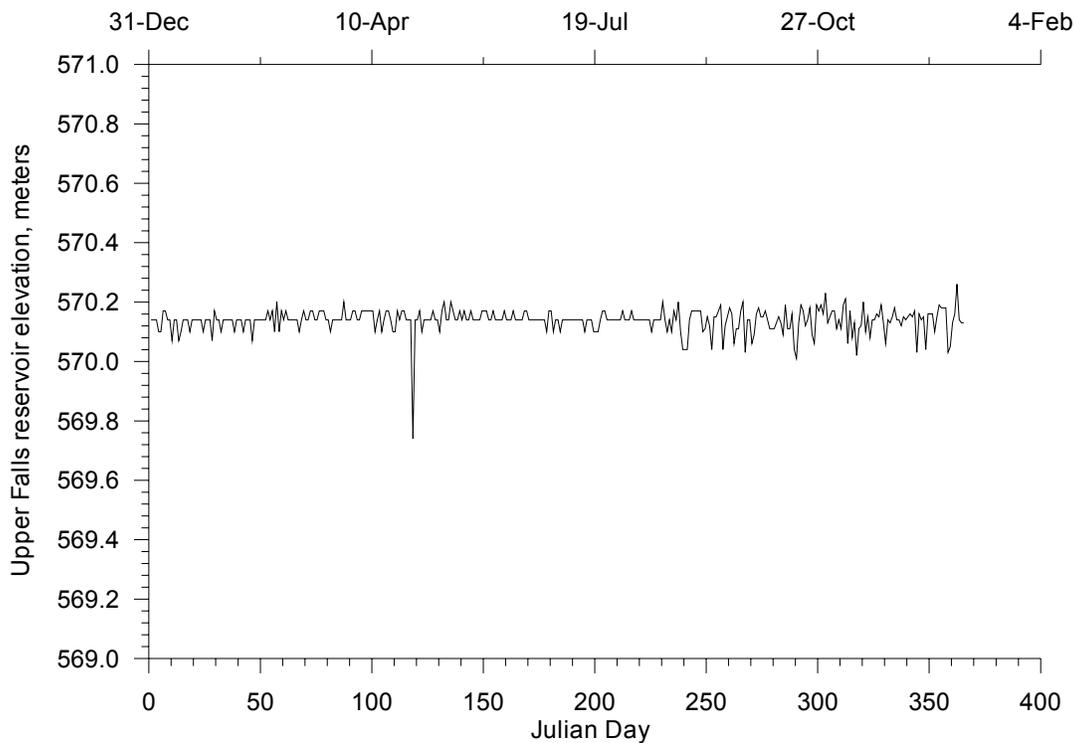
Figure 32 shows the Upper Falls Dam turbine flow. The 2001 winter flows were less than in 1991 and 2000, but the spring freshet flows were similar. During the summer flows typically decrease until fall but in 2001 the reduced flow lasted longer than in the previous years modeled. Figure 33 shows the flow over the spillway at Upper Falls Dam. Figure 34 shows the reservoir surface water elevation. The water surface elevation remained fairly constant throughout the year, with a slight decrease when spillway flows increased in April.



**Figure 32. Upper Falls Dam flow through turbines, 2001**



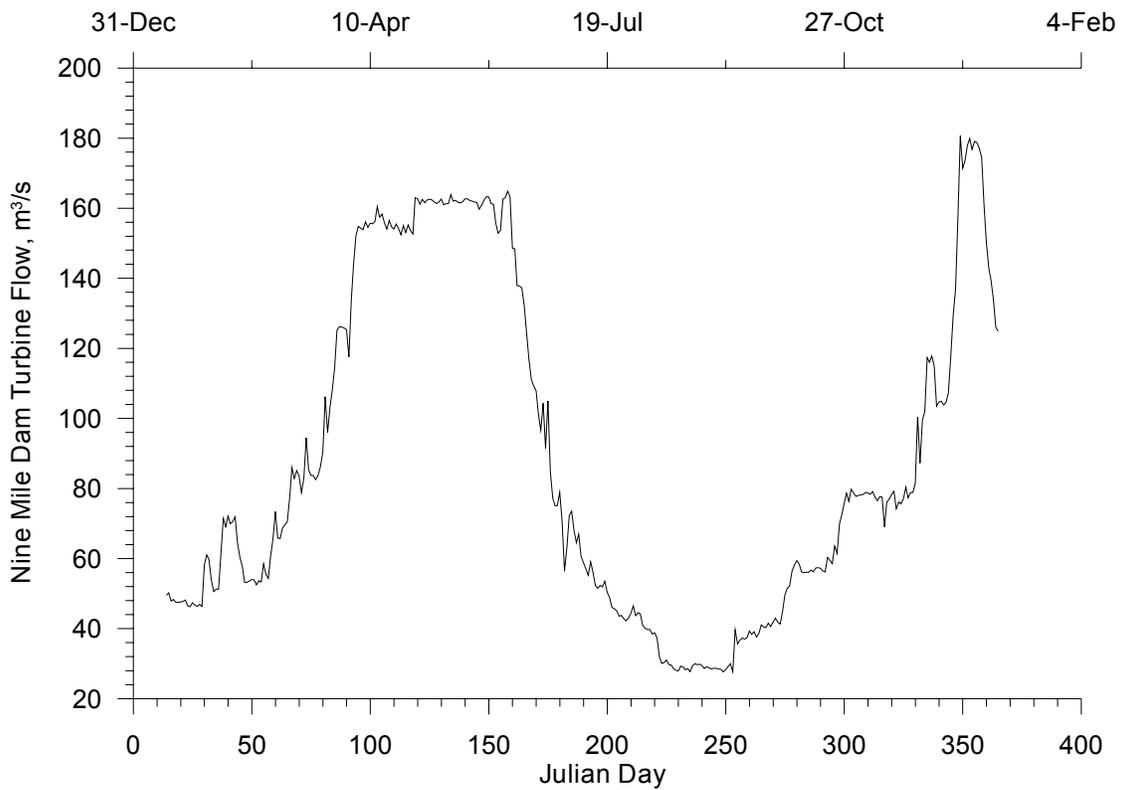
**Figure 33. Upper Falls Dam flow over the spillway, 2001**



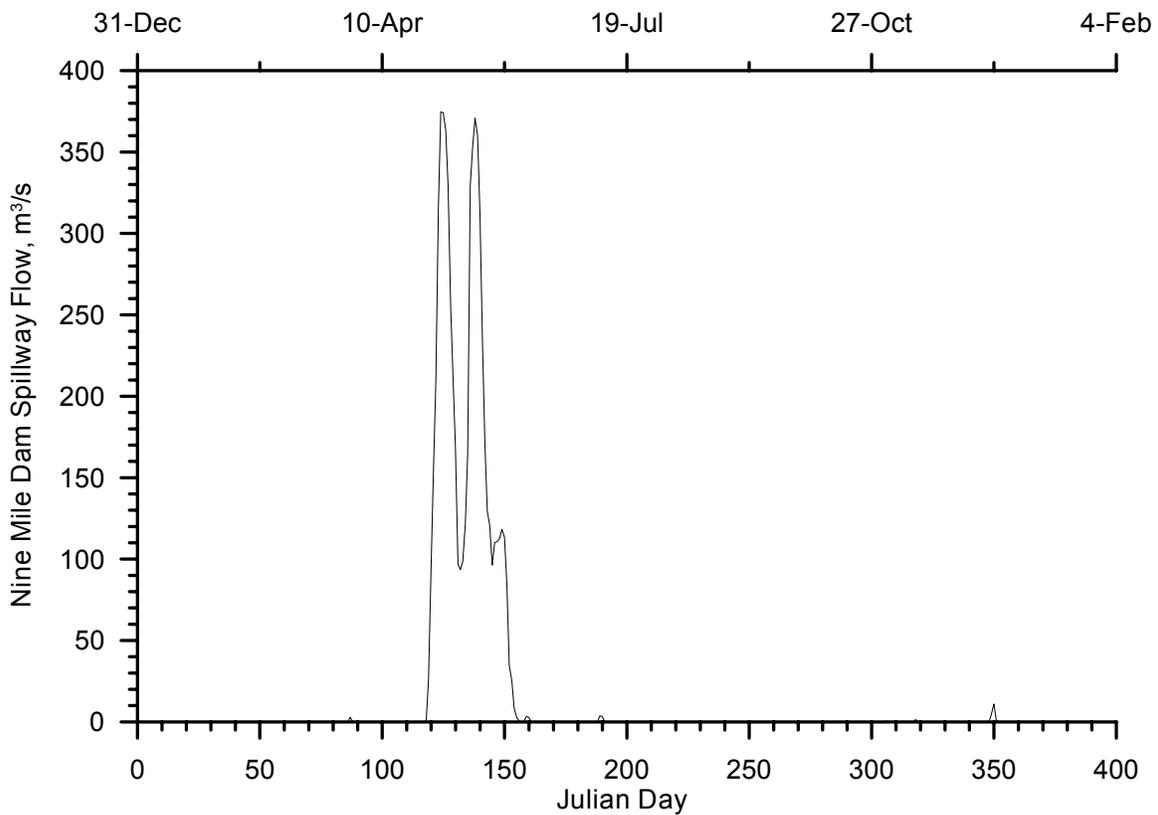
**Figure 34. Upper Falls Dam Elevation, 2001**

### Nine mile Dam and Reservoir

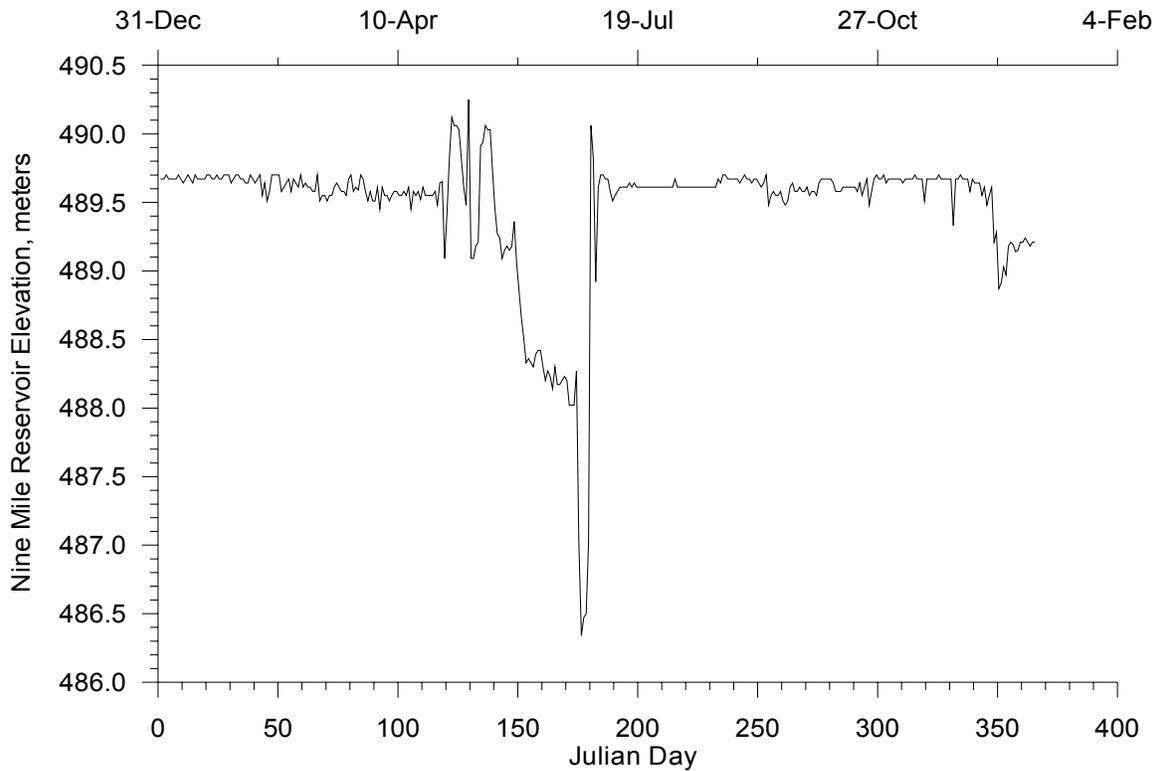
Nine Mile dam is located at RM 57.8 and consists of a spillway and a powerhouse with multiple turbines. Nine Mile Dam also serves as the headwaters to Long Lake Reservoir. Figure 35 shows the turbine flow in 2001. The 1991 and 2000 turbine flows showed a steady-flow from the beginning of the year until early July. In 2001 the flow through the turbines started lower and gradually increased to similar level around early April. As in 1991 and 2000, flows dropped near the end of June, but for 2001 flows did not increase again until October. Figure 36 shows the spillway flows in 2001. The spillway was only utilized during the month of May and a few days in April and June. Nine Mile Reservoir water level elevation is shown in Figure 37. The water surface remained relatively constant throughout the spring and winter with a large decrease during the summer.



**Figure 35. Nine Mile Dam flow through turbines, 2001**



**Figure 36. Nine Mile Dam flow over the spillway, 2001**

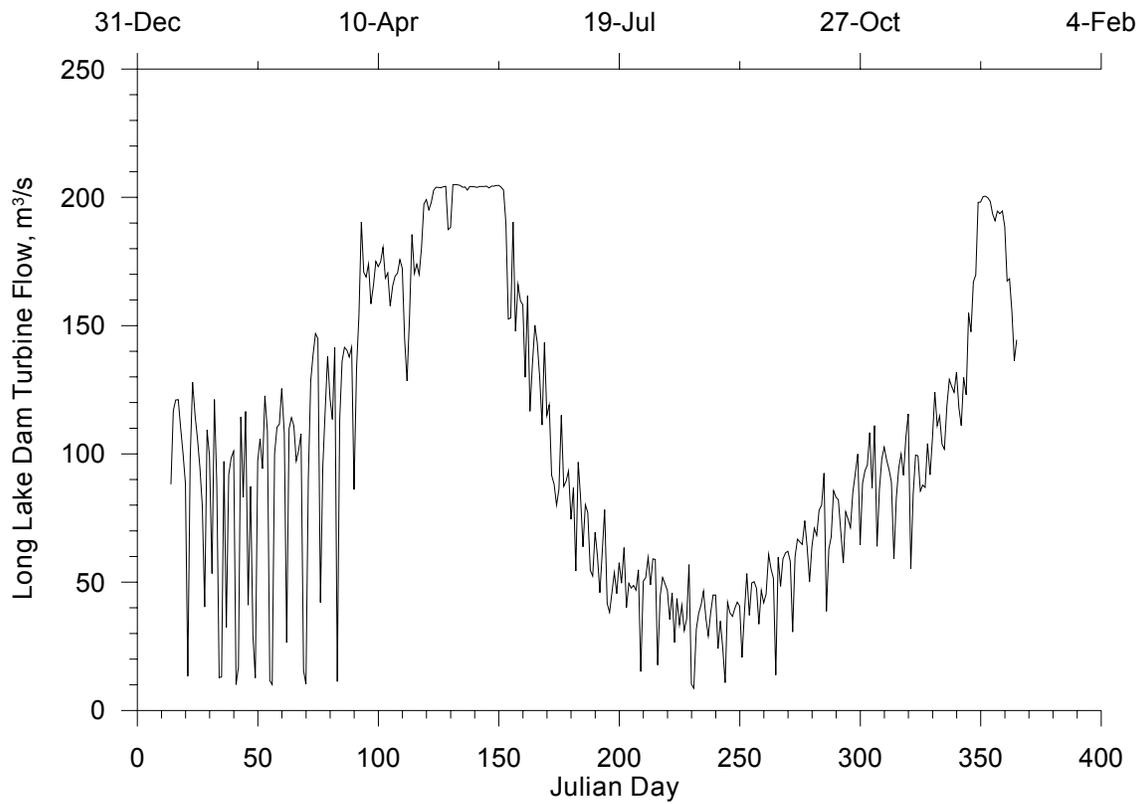


**Figure 37. Nine-Mile Elevation, 2001**

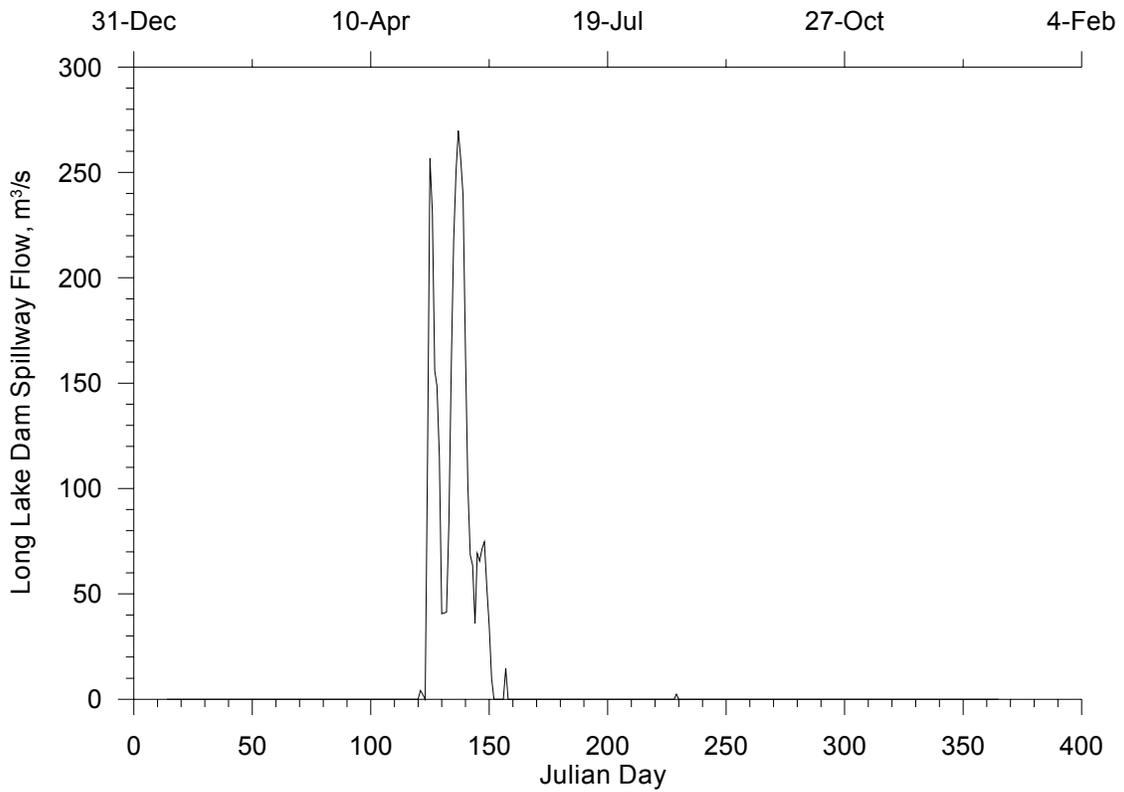
### Long Lake Dam and Reservoir

Long Lake Reservoir is located at the lower end of the modeled system. The dam facilities are located at approximately RM 32.5 and the lake backs up to one mile below Nine Mile Dam at RM 57.8. The Long Lake model includes from Nine Mile Dam to Long Lake Dam, depending on water level the upper most segments of the model may act like a river or lake. The lake has a maximum depth of 170 ft at a full pool elevation of 1536 ft NGVD29.

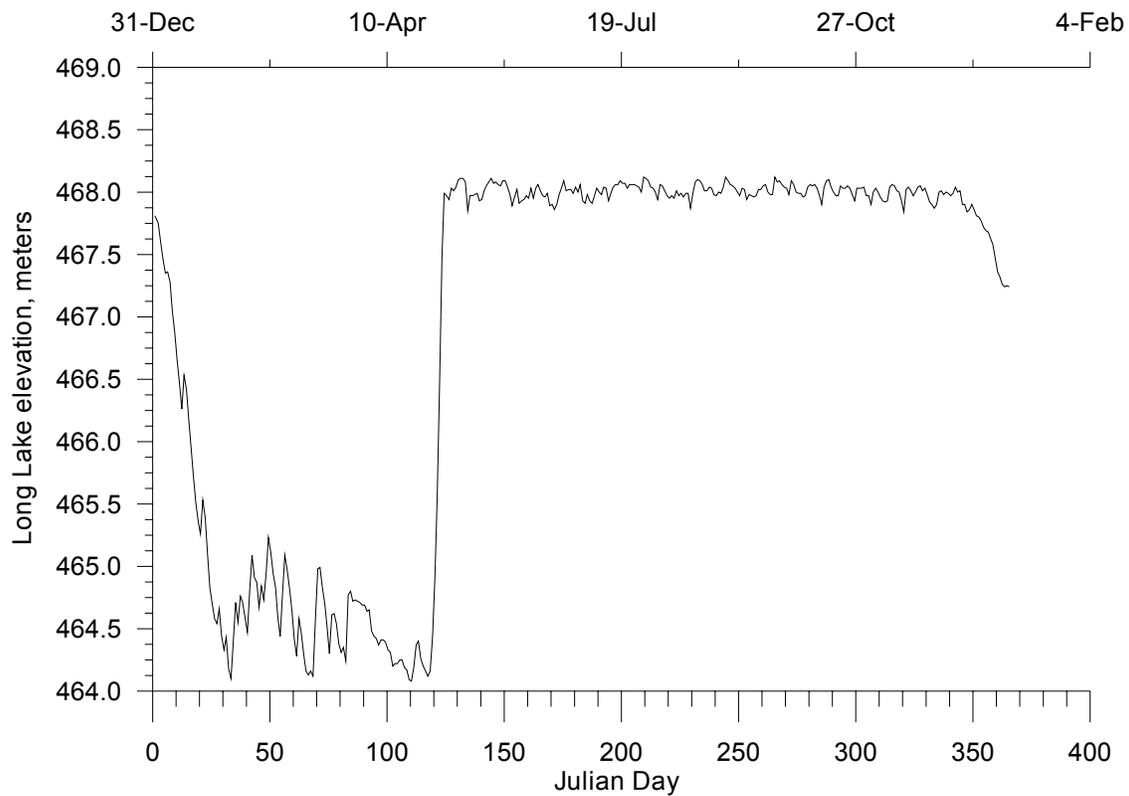
Figure 38 shows the flow that passed through the turbines in 2001. Figure 39 shows flow over the spillway. Figure 40 shows reservoir water surface elevation.



**Figure 38. Long Lake Flow through Turbines, 2001**



**Figure 39. Long lake Flow over Spillway, 2001**



**Figure 40. Long Lake Elevation, 2001**

### **Groundwater**

The groundwater to the model was characterized for individual reaches of the rivers system using the model grid branches. The groundwater was characterized by flow, water temperature, and water quality. The model did not use internal interpolation to fill in the boundary conditions between the data.

### **Spokane River**

Current and historical data suggest that there are specific inflow/outflow reaches in our study area can be grouped according to River Mile as shown in Table 6.

<b>Table 6. Groundwater flow sections along the Spokane River</b>		
<b>RM Range</b>	<b>Downstream Point</b>	<b>+ / -</b>
100.7 – 93.7	Harvard Rd. gauge	Outflow
93.7 – 90.4	Barker Rd. gauge	Outflow
90.4 – 87.8	Sullivan Rd. Bridge	Transition
87.8 – 85.3	Trent Rd. Bridge	Inflow
85.3 – 84.2	Plantes Ferry Footbridge	Inflow
84.2 – 82.6	Argonne Rd. Bridge	No change
82.6 – 79.8	Upriver Dam	Outflow
79.8 – 78.0	Green St. Bridge	Inflow
78.0 – 76.7	Mission St.	Outflow

<b>Table 6. Groundwater flow sections along the Spokane River</b>		
<b>RM Range</b>	<b>Downstream Point</b>	<b>+ / -</b>
76.7 – 74.1	Post St. Powerhouse	Outflow
74.1 – 72.9	Monroe St. gauge	Inflow
72.9 – 62.0	Seven Mile Bridge	Inflow
62.0 – 58.1	Nine Mile Dam	?

USGS began collecting current data at the historical gauging sites near Harvard Rd and Barker Rd in 1999. In addition, some recent data have been collected at the Plantes Ferry Park Footbridge (historical gauge near Trent Rd). USGS has collected some data at the Green St. gauge (another historical gauging site). Although USGS measured flow at these stations in the past (pre 1970), there were some significant changes in the flow characteristics of the river between the Post Falls (RM 100.7) and Monroe St (RM 72.9) gauges from before and after the late 1960s. Because of the changes, none of the pre-1970 data upstream of the Green St. gauge were used to develop flow relationships. Historical data (1948-1952) from the Green St gauge was used though because the relationship between Green St. and Monroe St was assumed not to have changed.

The following is a summary of what information was used to establish the flow for each river reach:

Post Falls (RM 100.7) to Harvard Rd. (RM 96.0)

- Groundwater flows were estimated by calculated by computing the difference between flows measured Post Falls and Harvard Road flows

Harvard Rd. (RM 96.0) to Barker Rd. (RM 90.4)

- Groundwater flows were estimated by calculated by computing the difference between flows measured at Post Falls and Harvard Road flows

Barker Rd. (RM 90.4) to Sullivan Rd. (RM 87.8)

- The river reach between Barker Rd. and Sullivan Rd (RM 87.8) has been identified as a “transition zone” from river outflow to inflow conditions. The higher the flow the closer the upstream boundary of the inflow zone is to Barker Rd. Conversely, at low flows the upstream boundary of the inflow zone is closer to Sullivan Rd.
- At low river flow conditions it has been estimated that only about 28 cfs is lost between Bark Rd and Sullivan Rd (Gearhart and Buchanan, 2000)
- Stan Miller suggests that the reach is probably loosing water to about Flora Rd. (RM 89.1)

Barker Rd./Flora Rd. (RM 90.4 - 89.1) to the Plantes Ferry Park Footbridge (RM 84.0)

- Current and historical data show that this is an inflow reach.
- Used flow data collected at the footbridge provided by Stan Miller to establish a mean inflow of 318 cfs for this reach (std. dev 130 cfs).
- The mean inflow was used because there were only eight data points.

Planters Ferry Foot Bridge (RM 84.0) to Argonne Rd. Bridge (RM 82.6)

- No change in river flow in this reach.

Argonne Rd. (RM 82.6) to Upriver Dam (RM 79.8)

- Used Upriver Dam flow data reported by Patmont et al. (1985) to establish a mean outflow for this reach of -256 cfs (std. dev 65 cfs).
- The mean outflow was used because there are only nine data points.

Upriver Dam (RM 79.8) to Green St. (RM 78.0)

- Historical data show that this is an inflow reach. Patmont et al. (1985) estimated the mean inflow for this reach to be 488 cfs (std. dev. 157 cfs).
- Used historical gauge data (1948-1952) to establish a regression estimate (Green St vs. Monroe St).

Green St. (RM 78.0) to Post St Powerhouse (RM 74.1)

- Well elevation data show that the river elevation is above the groundwater elevation in this reach.
- Historical data suggest that this is an outflow reach.
- Use turbine and spillway discharge estimates provided by Avista to provide estimated changes in river flow for this reach.

Post St. Powerhouse (RM 74.1) to Monroe St. (RM 72.9)

- Use Avista turbine and spillway discharge estimates and gauge data at Monroe St to determine flow balance.

Monroe St. (RM 72.9) to Seven Mile Br. (RM 62.0)

- Historical data show that this is an inflow reach.
- Used historical gauge data (1948-1952) to establish a regression estimate (Seven-Mile Br. vs. Monroe St).

Seven Mile Br. (RM 62.0) to Nine Mile Dam (RM 58.1)

- Used turbine and spillway discharge estimates provided by Avista to provide estimated changes in river flow for this reach.

Aquifer exchanges were modeled as distributed tributaries. CE-QUAL-W2 permits modeling of distributed tributaries on a branch-by-branch basis. The procedure to estimate flow for each model branch was summarized in Table 7.

**Table 7. Aquifer exchange estimate for each model branch.**

Branch #	Description	River Miles	Aquifer exchange flow estimate
1	Stateline to Harvard Road Bridge	96.40-93.82	Flow = Harvard Road Flow – State Line Flow <ul style="list-style-type: none"> <li>• Used Harvard Road flow data for 2000 from Julian Day 1 to 231, and 246 to 341</li> <li>• The calculation estimating state line flow is described above in the section discussing boundary conditions</li> </ul>
2	Harvard Road Bridge to Barker Road	93.82-90.34	Flow = Barker Road Flow-Harvard Road Flow – Liberty Lake Discharge
3-4	Barker Road Bridge to Islands Foot Bridge	90.34-84.45	Flow = 318 cfs
5	The Islands Foot Bridge to Upriver Dam	84.45-80.18	Flow = -256 cfs
6	Upriver Dam to Green Street Bridge	80.18-78.10	Flow = Green Street Flow – Upriver Dam Flow Green Street Flow estimated with $Q=(1.0026*\text{Spokane USGS gage } Q)-27.65$
7	Green Street Bridge to Upper Falls Dam	78.10-74.75	Flow = Upper Falls Flow – Green Street Flow
8	Upper Falls Dam to Spokane USGS gage	74.75-72.93	Flow= Spokane USGS Flow – Upper Falls Flow
9	Spokane USGS gage to Seven Mile Bridge	72.93-63.20	Flow = Seven Mile Bridge Flow – Spokane USGS gage Flow – Spokane WWTP Flow – Hangman Creek Flow <ul style="list-style-type: none"> <li>• Seven Mile Bridge Flow estimated with <math>Q=(0.9975684*\text{Spokane USGS gage } Q)+137.1542</math></li> </ul>
10-11	Seven Mile Bridge to Nine Mile Dam	63.20-57.77	Flow = Nine Mile Dam Flow – Seven Mile Bridge Flow

Spokane River groundwater quality

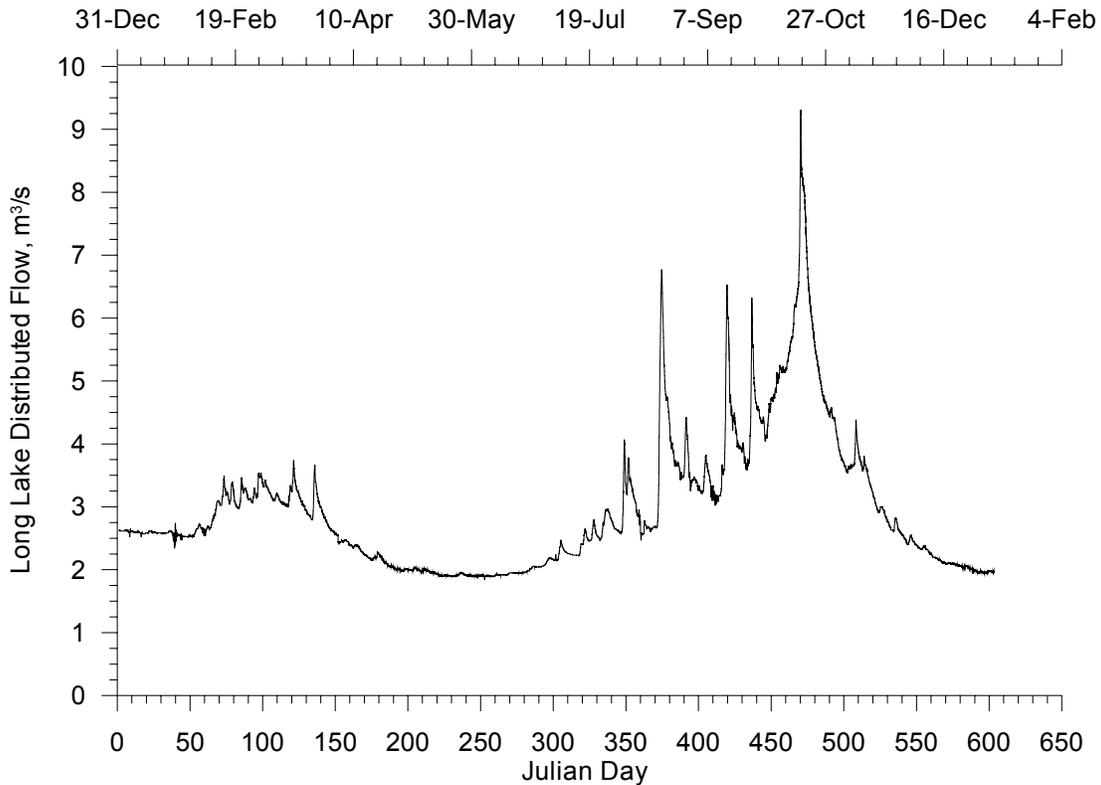
The 2001 Spokane River groundwater quality was developed using data collected from multiple wells located near the river. This was in contrast to 1991 and 2000 groundwater quality was developed with data from a cluster of 3 wells in pretty much the same location (near Sullivan Road, around RM 87.5). For year 2001, Sullivan well data only were used for branches 1 to 4 (river section between the state line and start of Upriver pool). Branch 1 was always an outflow reach, branch 2 both inflow and outflow, and branches 3 and 4 are strictly inflow reaches. Branch 5 (Upriver reservoir area) groundwater quality was based on data from the Felts Field monitoring well. However this branch was always an outflow reach, so the water quality used in the input file had no impact on model predictions. Branch 6 was a high inflow reach that extends from Upriver Dam to Green Street. Data were based on the average of two wells, the GE MW-22 (RM 78.86) and the Hale's Ale Nested Site east (RM 79.65). Branch 7 stretches from Green Street to Upper Falls dam and groundwater quality were estimated to be the average of 4 wells located along this reach. Branches 8 to 11, from Upper Falls to Nine Mile dam, did not have any nearby well data available, so water quality used the same as for branch 7. Table 8 summarizes groundwater quality data used for the 2001 simulation and also shows data used for the 1991 and 2000 simulations.

**Table 8. Spokane River groundwater quality**

	TDS	Conductivity (mhos/cm)	Chloride (mg/l)	PO4P (mg/l)	NH4N (mg/l)	NoxN (mg/l)	D. O. (mg/l)	TIC (mg/l)	ALK (mg/l)
Year 1991 and 2000									
All Branches	142.0	250.2	1.53	0.0060	0.0	1.00	7.50	29.60	118.00
Year 2001									
Branches 1 to 4	129.6	240.4	1.53	0.0060	0.0	0.89	8.22	18.31	71.67
Branch 5	117.1	207.9	1.53	0.0226	0.1	1.14	7.30	18.23	73.00
Branch 6	174.7	294.7	1.53	0.0074	0.1	1.44	8.64	26.52	104.33
Branches 7 to 11	137.9	242.7	1.53	0.0090	0.1	1.20	6.40	21.98	83.63

Long Lake

A distributed tributary was developed for Long Lake based on flows in the Little Spokane River basin. The ratio of the drainage area surrounding the lake was divided by the drainage area of the Little Spokane River basin and then multiplied by the Little Spokane River calculated flow. Figure 41 shows the estimated flow for the Long Lake distributed tributary.



**Figure 41. Long Lake Distributed Inflow, 2001**

Long Lake groundwater quality

The groundwater water quality flowing into Long Lake was characterized using well data described by Soltero et al. (1992). The groundwater quality and flow patterns about Long Lake are complex with areas where groundwater flows into the lake and other areas where reservoir water flows into the aquifer. Only data from wells where the gradient results in groundwater flow into Long Lake were used

to characterize the groundwater quality. Well data means of temperature, soluble reactive phosphorus, nitrate, nitrite, dissolved oxygen, ammonia-N, conductivity and chloride were summarized in Table 9.

**Table 9. Water quality means of wells located around Long Lake.**

Well	Temperature (Celsius)	Soluble Reactive P (mg/l)	NO3-N (mg/l)	NO2-N (mg/l)	D. O. (mg/l)	NH3-N (mg/l)	Chloride (mg/l)	Conductivity (µmhos/cm)
SW-1	11.9	0.019	3.34	0.084	2.2	0.12	5.32	490
SW-2	12.0	0.007	0.75	0.004	7.1	0.03	2.84	449
SW-3	12.5	0.006	2.96	0.003	6.8	0.07	9.93	551
SCE-1	12.1	0.017	1.11	0.044	8.4	0.06	3.90	513
TY-1	12.5	0.006	2.23	0.003	5.9	0.02	5.67	467
TY-2	12.0	0.005	0.23	0.002	2.7	0.04	3.90	308
C-1	10.9	0.123	2.91	0.023	7.4	0.02	3.55	253
C-2	12.1	0.008	4.91	0.133	3.4	0.04	9.57	476
C-3	10.4	0.035	2.79	0.006	8.7	0.05	4.96	423
Average	11.82	0.025	2.36	0.030	5.84	0.05	5.51	393

The averages of these wells were used to characterize groundwater quality for the Long Lake reach of the model. Soluble reactive phosphorus data were used as the bioavailable phosphorus input required by the model. Alkalinity, inorganic carbon, and total dissolved solids were assumed to be the same as listed above for the other Spokane River model branches.

**Table 10. Temperature and constituent concentrations used to characterize groundwater for Long Lake branch 12.**

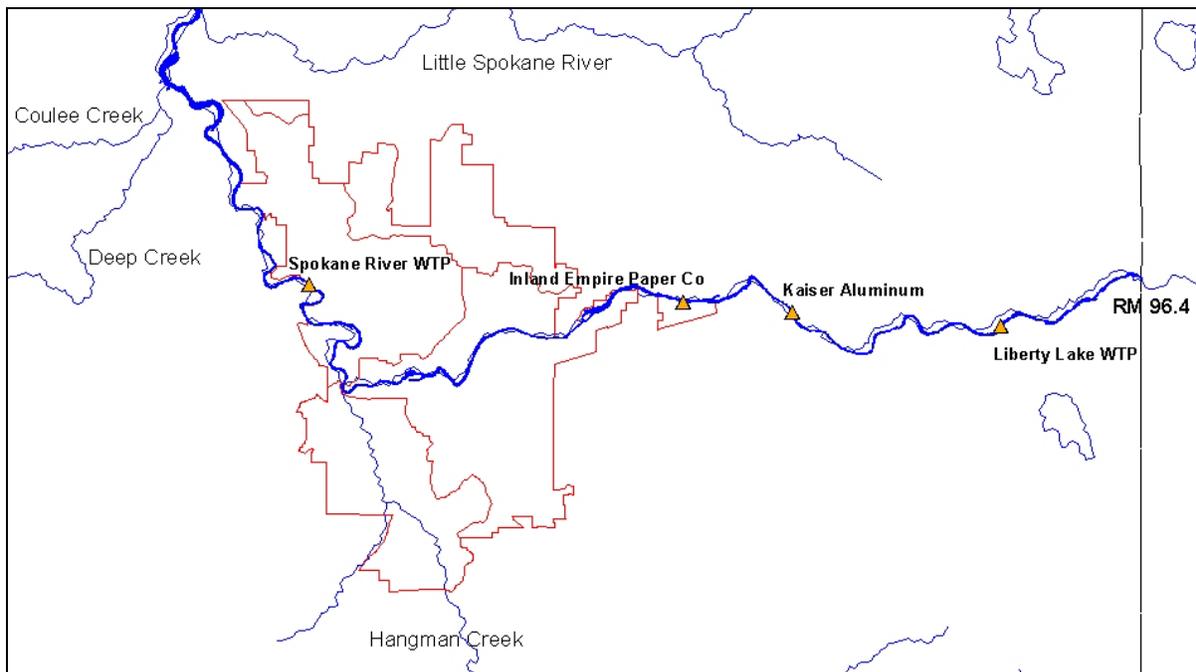
Parameter	Temp. (C)	Alkalinity (mg/l)	TDS (mg/l)	PO4-P (mg/l)	Nitrate-Nitrite (mg/l)	D. O. (mg/l)	NH4-N (mg/l)	Chloride (mg/l)	Inorganic Carbon (mg/l)	Conductivity (µmhos/cm)
Value	11.8	118	142	0.025	2.39	5.84	0.05	5.51	29.6	393

### Point Dischargers

There are four significant point sources along the Spokane River included in the modeling effort. Table 11 lists the sites and their river mile location. Figure 42 shows the location of the four dischargers along the river. The data were obtained from the National Pollutant Discharge Elimination System (NPDES) through the WA Department of Ecology or directly from the dischargers. Each point source is characterized by flow, temperature, and water quality constituent concentrations.

**Table 11. Point Source dischargers modeled**

Discharger Description	RM	Model Segment
Liberty Lake WWTP	92.7	18
Kaiser Aluminum	86.0	43
Inland Empire Paper Co	82.6	56
Spokane River WWTP	67.4	115



**Figure 42. Point Discharges to the Spokane River**

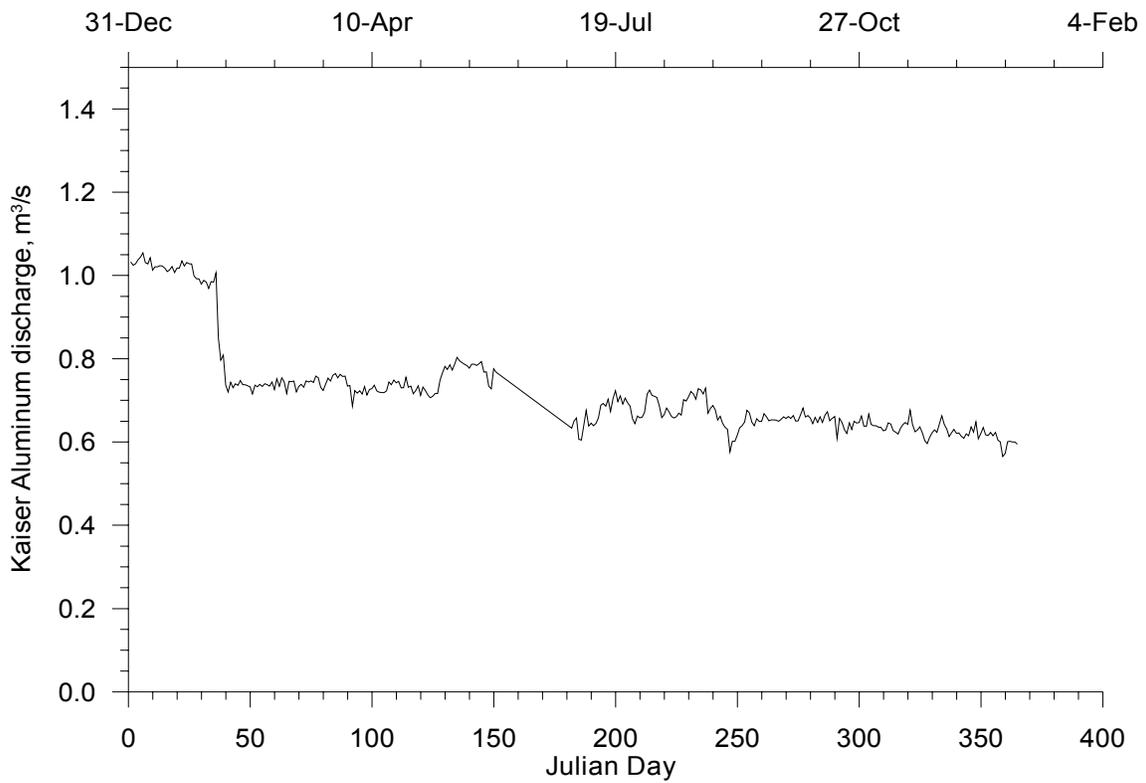
### Kaiser Aluminum

Kaiser Aluminum flow and temperature data were recorded daily. Figure 43 shows the discharge flow for 2001 and represents about two-thirds of the flows recorded in 2000. Figure 44 shows the discharge temperature for 2001, which was similar to 2000.

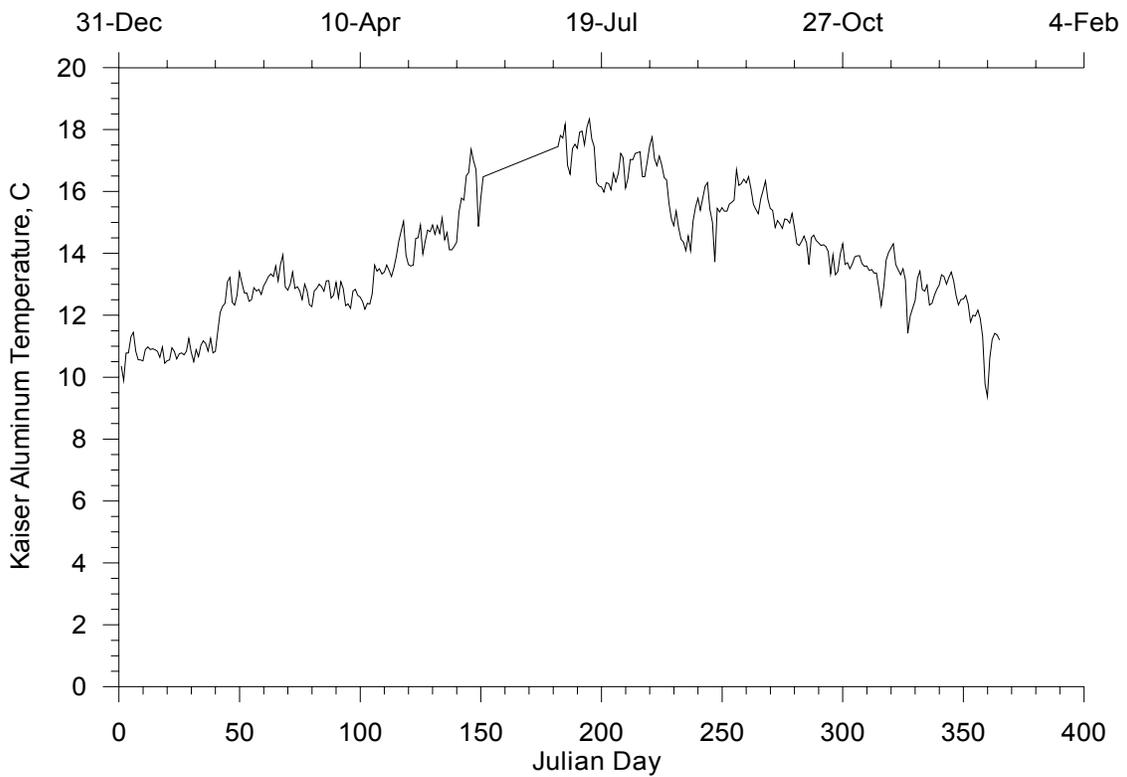
For 2001, the Kaiser Aluminum point source water quality was characterized using conductivity, total dissolved solids, chloride, ammonia nitrogen, nitrite-nitrate nitrogen, soluble reactive phosphorus, alkalinity, carbonaceous BOD ultimate (CBOD<sub>u</sub>), and total and dissolved organic carbon data. No coliform data were available and concentrations were assumed to be zero. Dissolved oxygen concentrations were set to 8.0 mg/l, which was the value used for the year 2000.

A separate CBOD compartment and CBOD ultimate data were used in the model to simulate organic matter originating from Kaiser Aluminum. Since organic matter was accounted for in the BOD compartment concentrations of LDOM, RDOM, LPOM, and RPOM concentrations were set to zero.

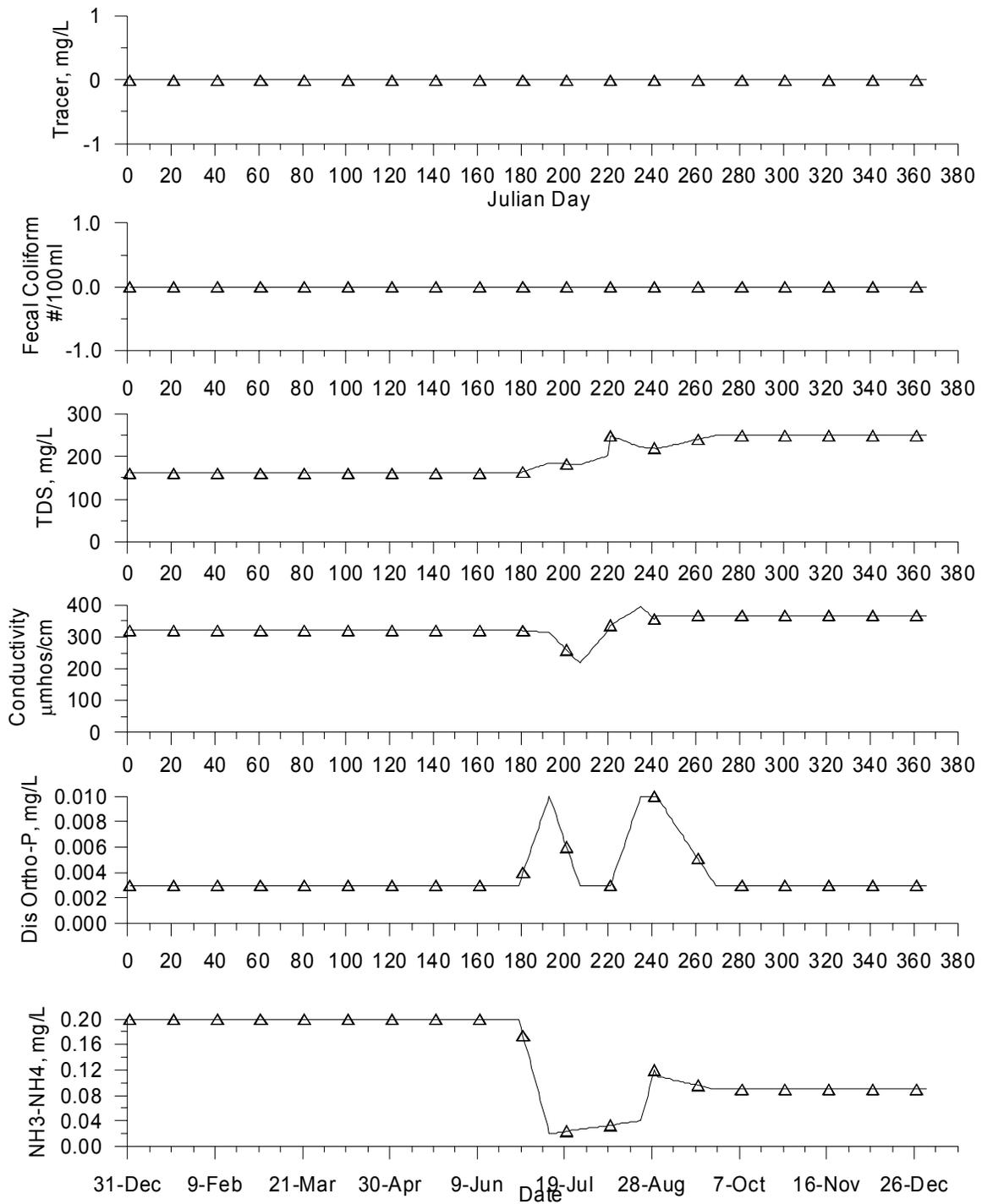
The inorganic carbon concentrations were estimated using alkalinity data and the method described above for the Spokane River at the state line. The pH was assumed to be 7.0. Inorganic suspended solids concentrations were estimated using the same procedure outlined for the Spokane River at the state line with the algae concentration as zero. The 2001 constituent concentrations of the Kaiser Aluminum point source were plotted in Figure 45, Figure 46, and Figure 47.



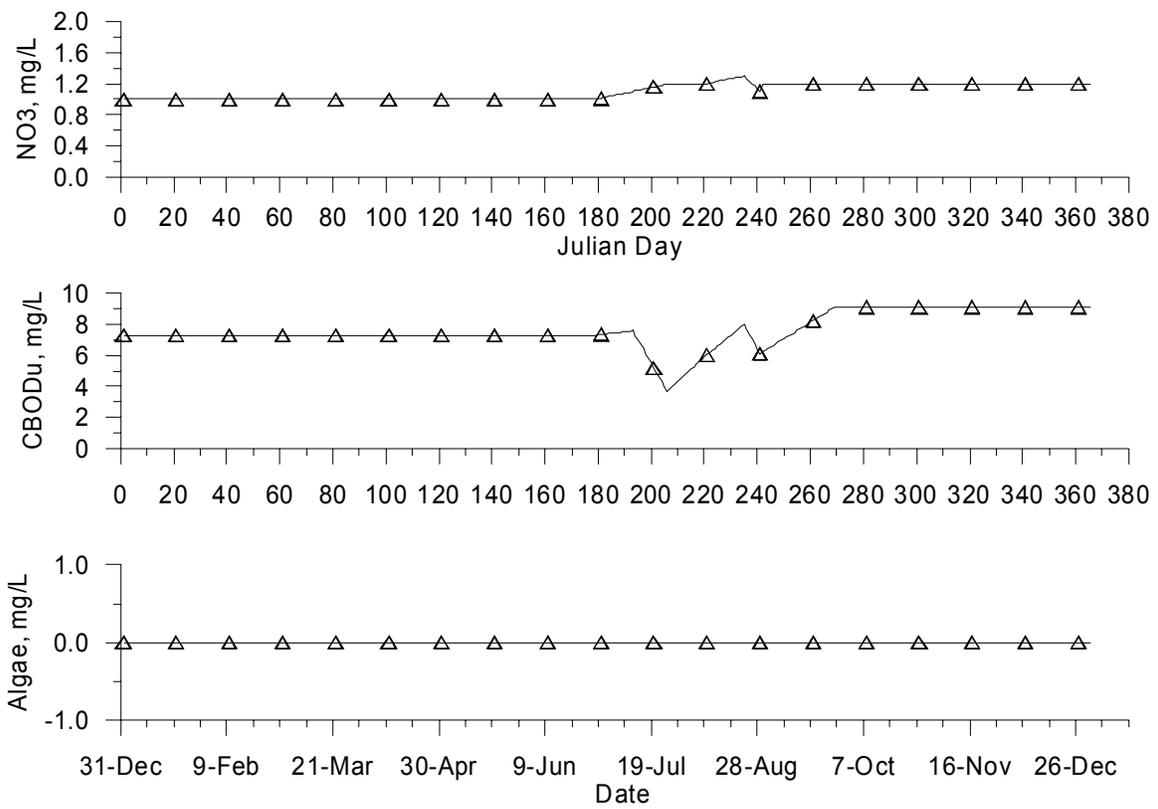
**Figure 43. Kaiser Aluminum discharge flow, 2001**



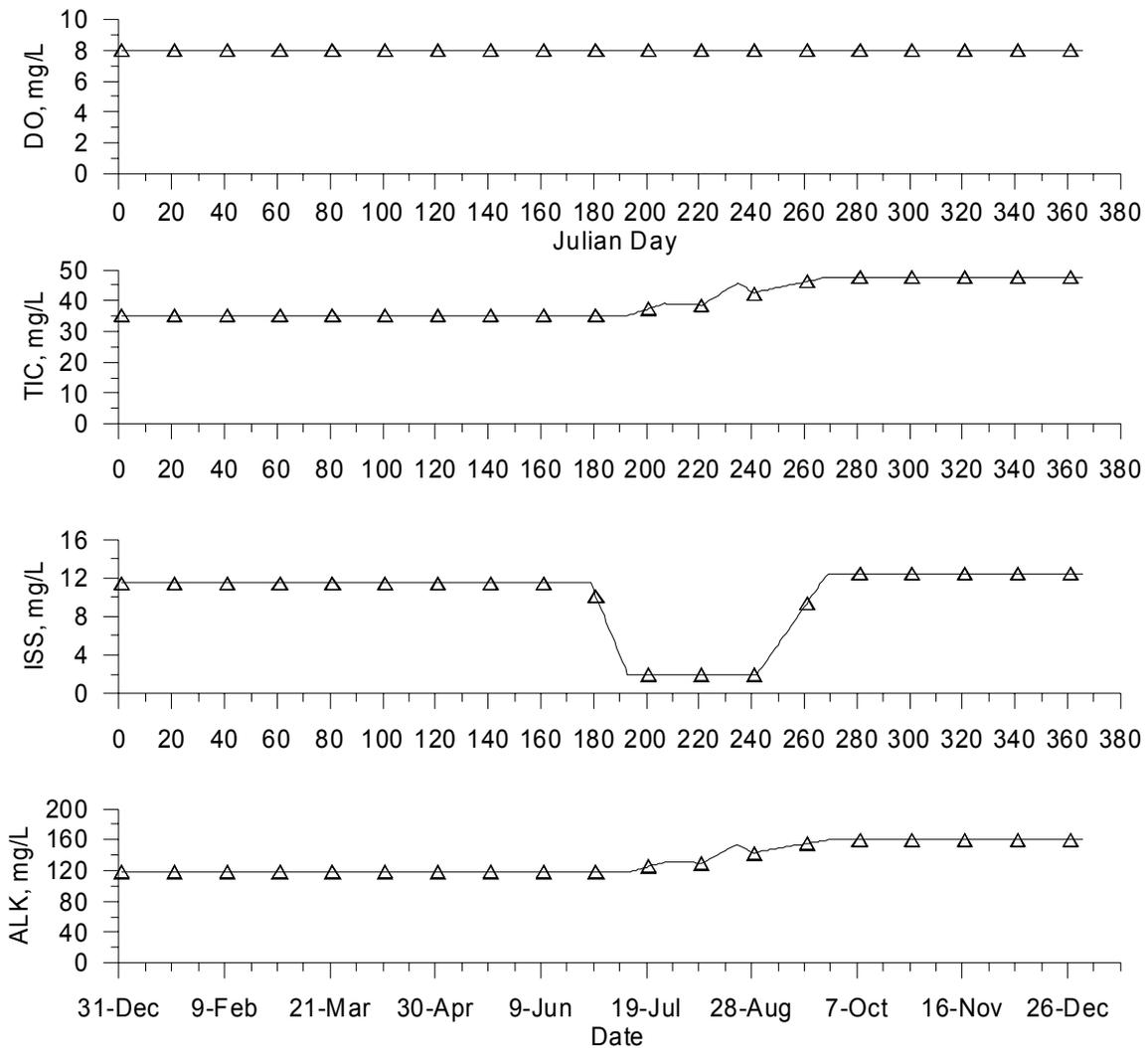
**Figure 44. Kaiser Aluminum discharge temperature, 2001**



**Figure 45. Kaiser Aluminum discharge water quality conditions (Part 1)**



**Figure 46. Kaiser Aluminum discharge water quality conditions (Part 2)**



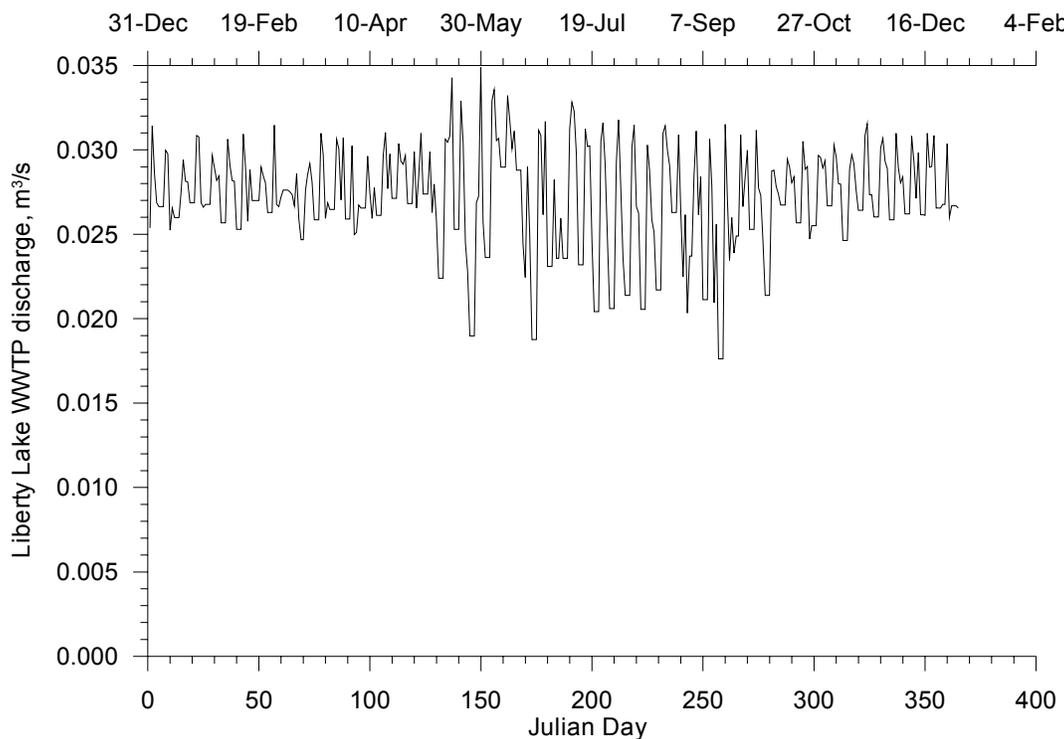
**Figure 47. Kaiser Aluminum discharge water quality conditions (Part 3)**

### Liberty Lake Wastewater Treatment Plant

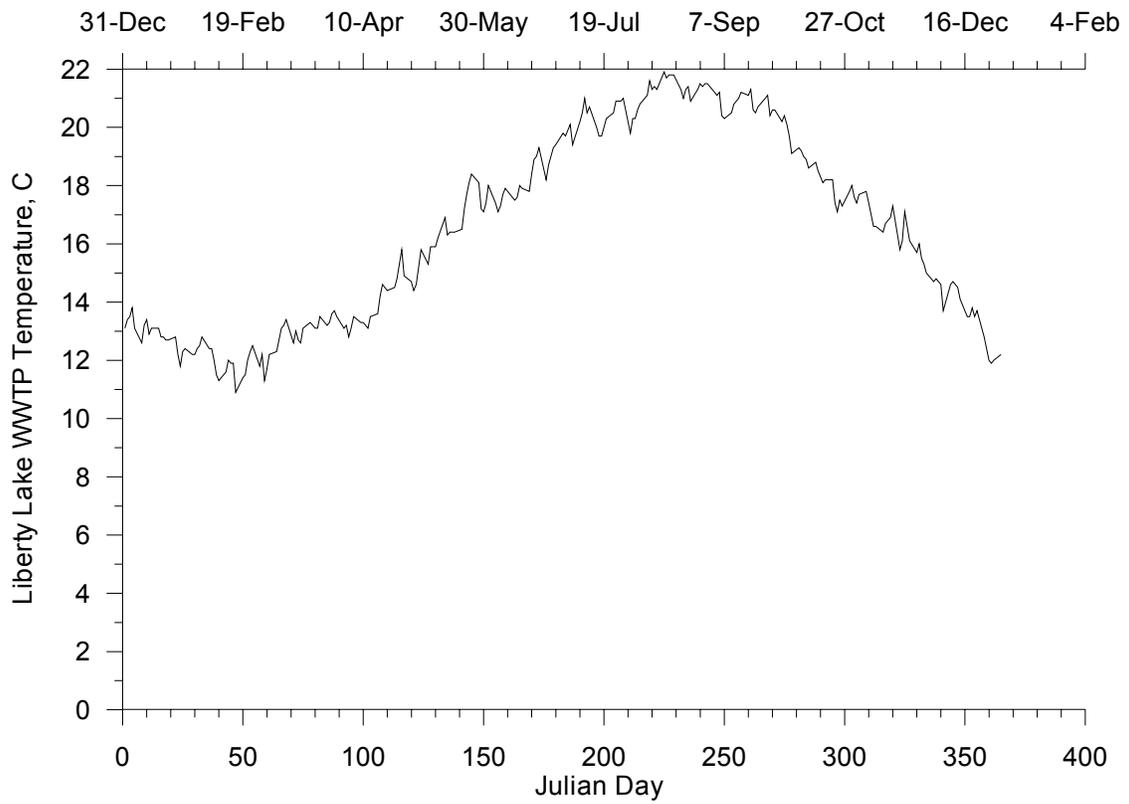
The Liberty Lake treatment plant discharge has low flows over the course of the year as shown in Figure 48. Figure 49 shows the discharge temperature. Flows and temperatures for 2001 were similar to 2000.

The 2001 Liberty Lake constituent inflow file was characterized using dissolved oxygen, ammonia nitrogen, conductivity, pH, chloride, nitrite-nitrate nitrogen, alkalinity, soluble reactive phosphorus, dissolved and total organic carbon, BOD5, carbonaceous BOD ultimate (CBOD<sub>u</sub>), fecal coliform, total dissolved solids, and total suspended solids data. The inorganic carbon concentrations were estimated using alkalinity and pH data and the method described above for the Spokane River at the state line. Using the same approach described above in the Kaiser Aluminum section, organic matter from Liberty Lake was modeled using a CBOD compartment and decay rate. When available carbonaceous BOD ultimate data were used for the CBOD compartment concentrations. During time periods when CBOD<sub>u</sub> data were sparse, CBOD<sub>u</sub> concentrations were estimated with BOD5 data and assuming a ratio of 4.25 mg/l CBOD<sub>u</sub> per 1 mg/l BOD5. This ratio was developed from Liberty Lake WTP discharge data collected in the Year 2001. Inorganic suspended solids concentrations were estimated using the same procedure outlined for the Spokane River at the state line with the algae concentration as zero.

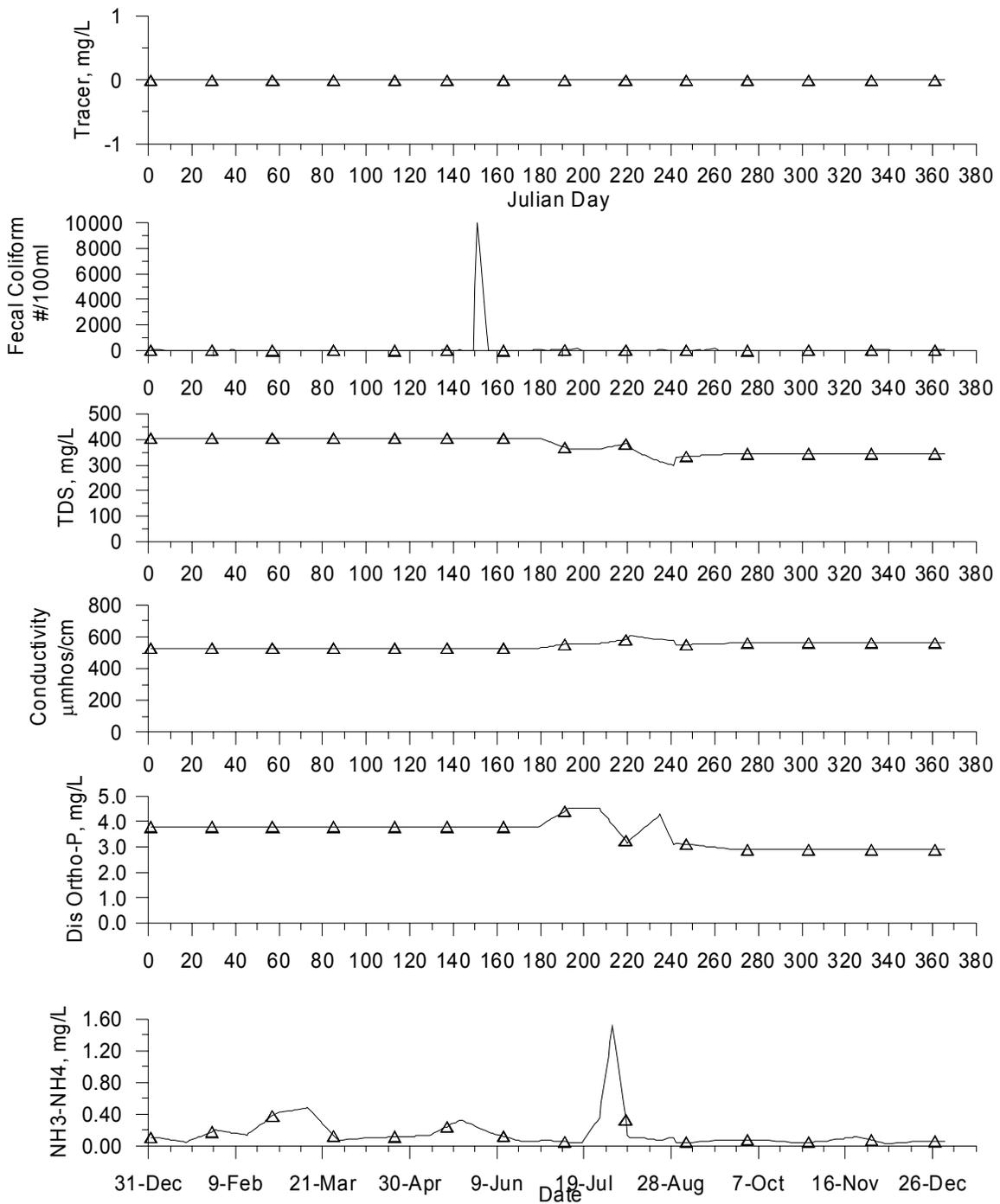
The concentrations of the Liberty Lake water quality constituents were plotted in Figure 50, Figure 51, and Figure 52. Some constituents had few data points so an average of the available data was used.



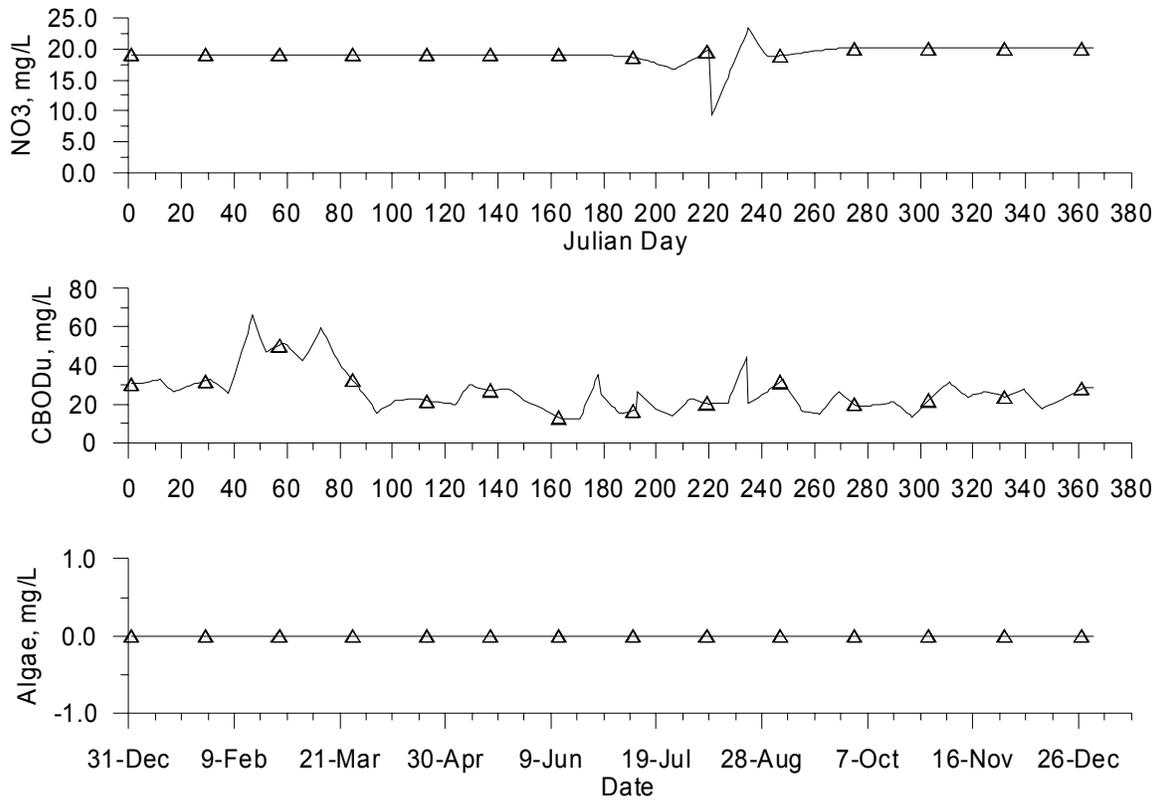
**Figure 48. Liberty Lake WWTP discharge flow, 2001**



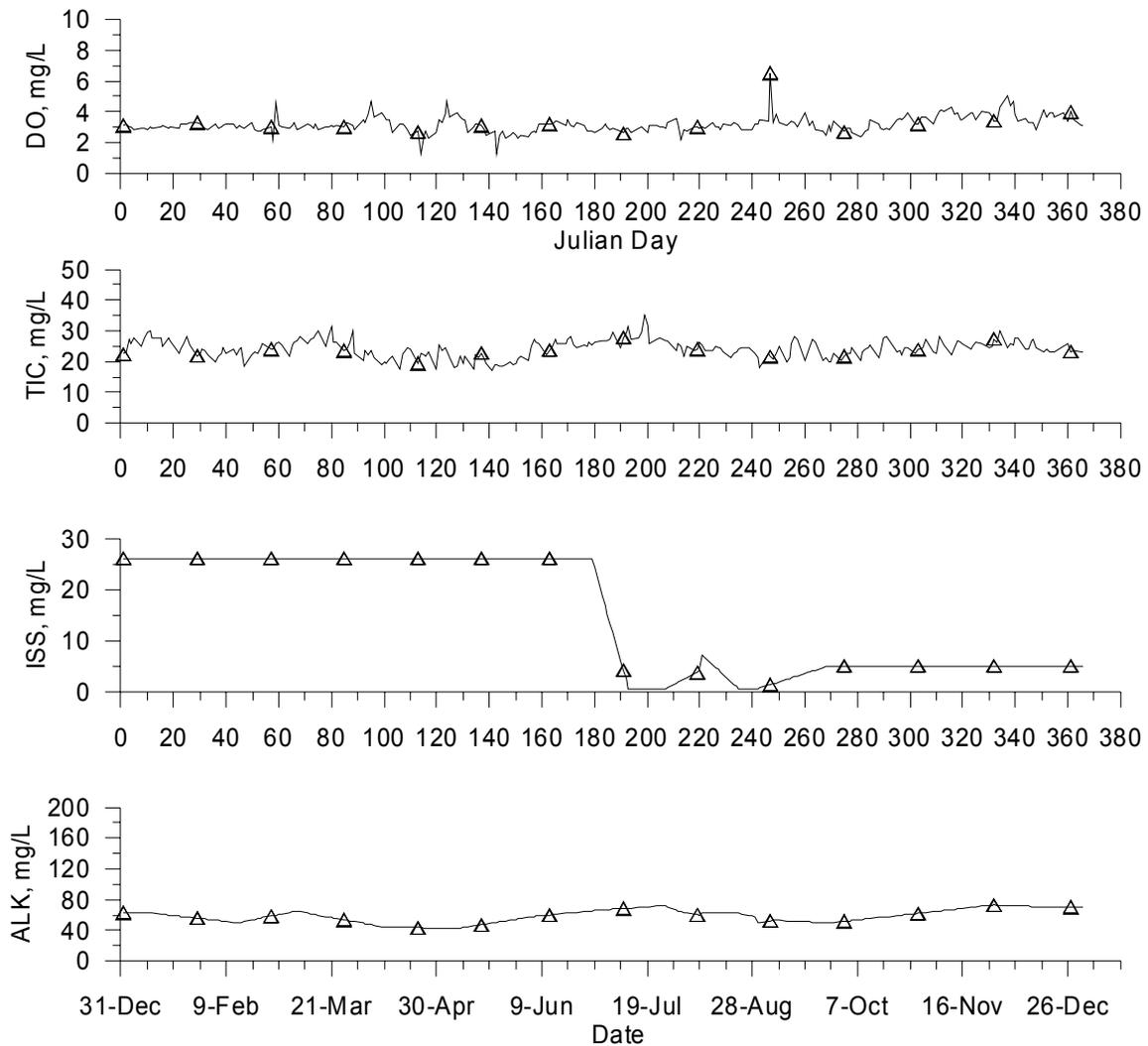
**Figure 49. Liberty Lake WWTP discharge temperature, 2001**



**Figure 50. Liberty Lake WWTP discharge water quality conditions (Part 1)**



**Figure 51. Liberty Lake WWTP discharge water quality conditions (Part 2)**



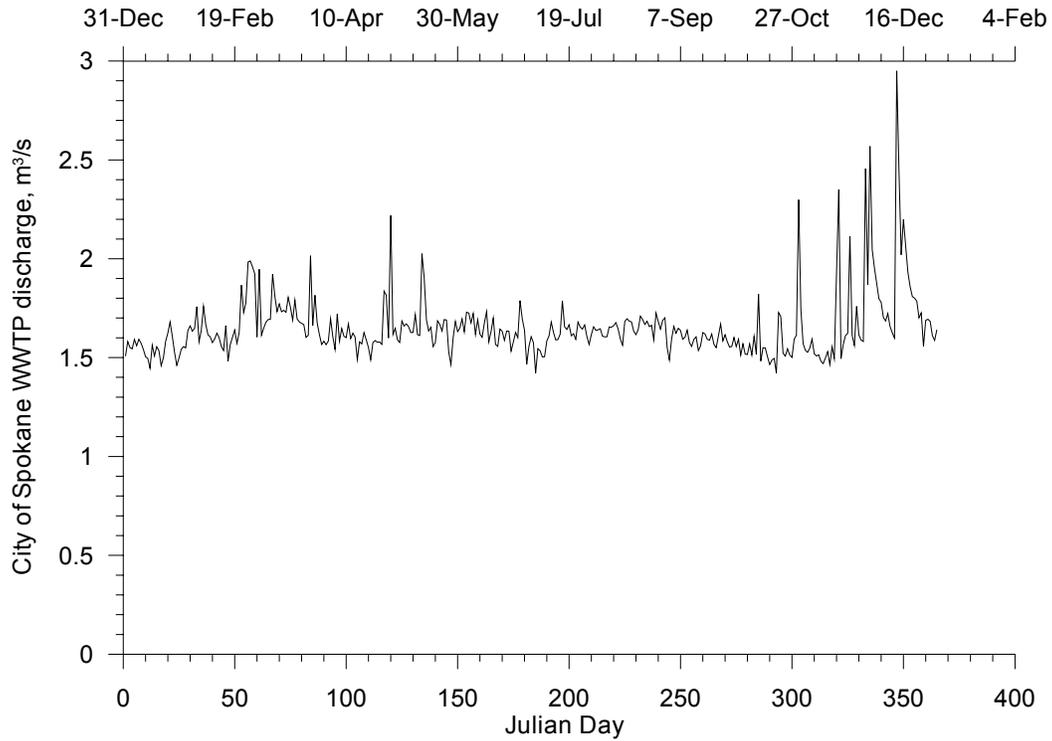
**Figure 52. Liberty Lake WWTP discharge water quality conditions (Part 3)**

### Spokane Wastewater Treatment Plant

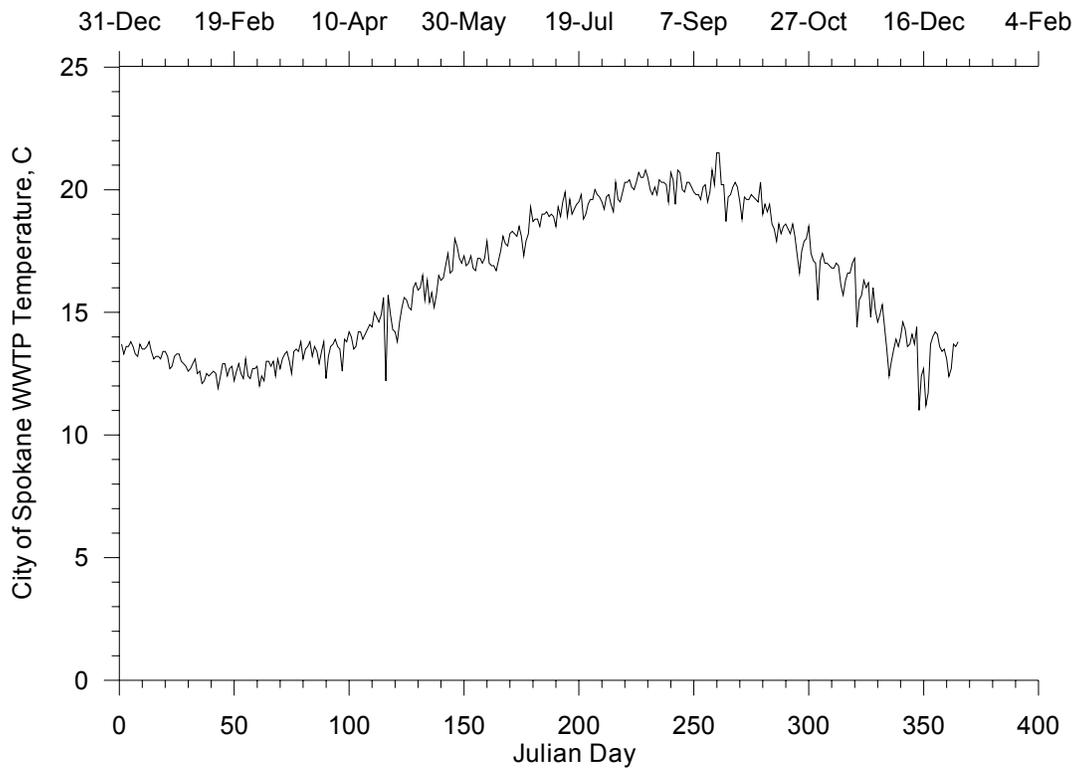
The City of Spokane wastewater treatment plant discharge was incorporated into the model. Figure 53 shows the discharge flow. Flows varied throughout the year, but remained close to 1.6 m<sup>3</sup>/s over most of the year and increased in the winter. Figure 54 shows the discharge temperatures. The seasonal trends shown were similar to the trends shown in 2000.

The 2001 constituent file was developed using dissolved oxygen, nitrite-nitrate nitrogen, pH, ammonia-nitrogen, fecal coliform, total dissolved solids, soluble reactive phosphorus, alkalinity, BOD<sub>5</sub>, carbonaceous BOD ultimate (CBOD<sub>u</sub>), conductivity and chloride data. Inorganic carbon concentrations were estimated using alkalinity and pH data and applying equations based on the carbonate-bicarbonate equilibrium reaction, which was described in Stumm and Morgan (1981). Inorganic suspended solid concentrations were estimated by subtracting volatile suspended solids data from suspended solids data. Soluble reactive phosphorus data were relatively sparse, so the daily total phosphorus data were used to estimate soluble reactive phosphorus data by applying a soluble reactive P to Total P ratio of 0.364 that was developed from 2001 Spokane WTP discharge data.

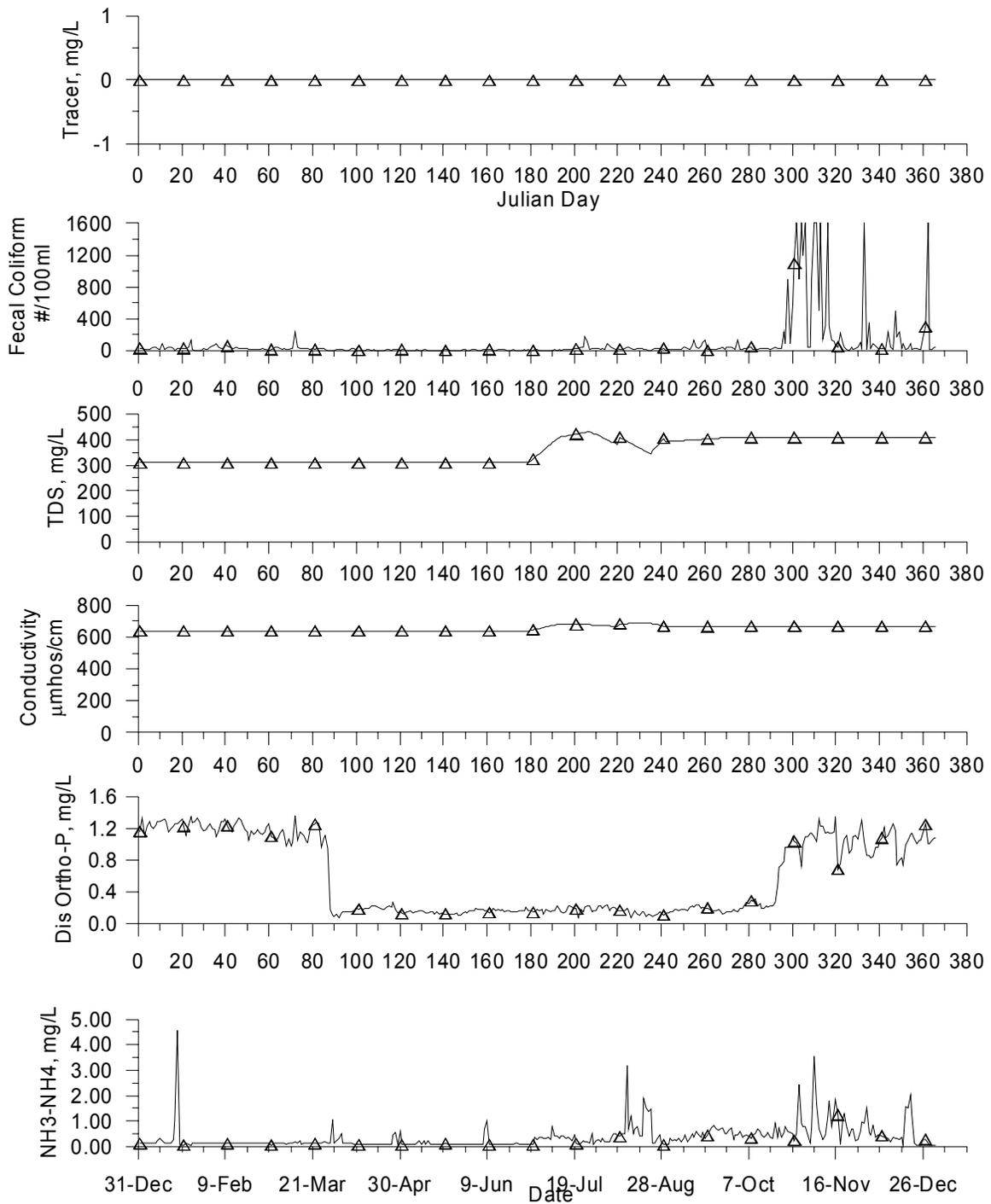
Using the same approach described above in the Kaiser Aluminum section, organic matter from the Spokane wastewater treatment plant was modeled using a CBOD compartment and decay rate. BOD5 data were much more frequent than CBOD<sub>u</sub> data, so BOD5 data were used to estimate CBOD<sub>u</sub> concentrations when CBOD<sub>u</sub> data were sparse. CBOD<sub>u</sub> was estimated using a ratio of 3.25 mg/l CBOD<sub>u</sub> to 1 mg/l BOD5. This ratio was based on 2001 Spokane WTP discharge data. The concentrations of the Spokane wastewater treatment plant constituents were plotted in Figure 55, Figure 56, and Figure 57. Some constituents had few data points so an average of the available data was used.



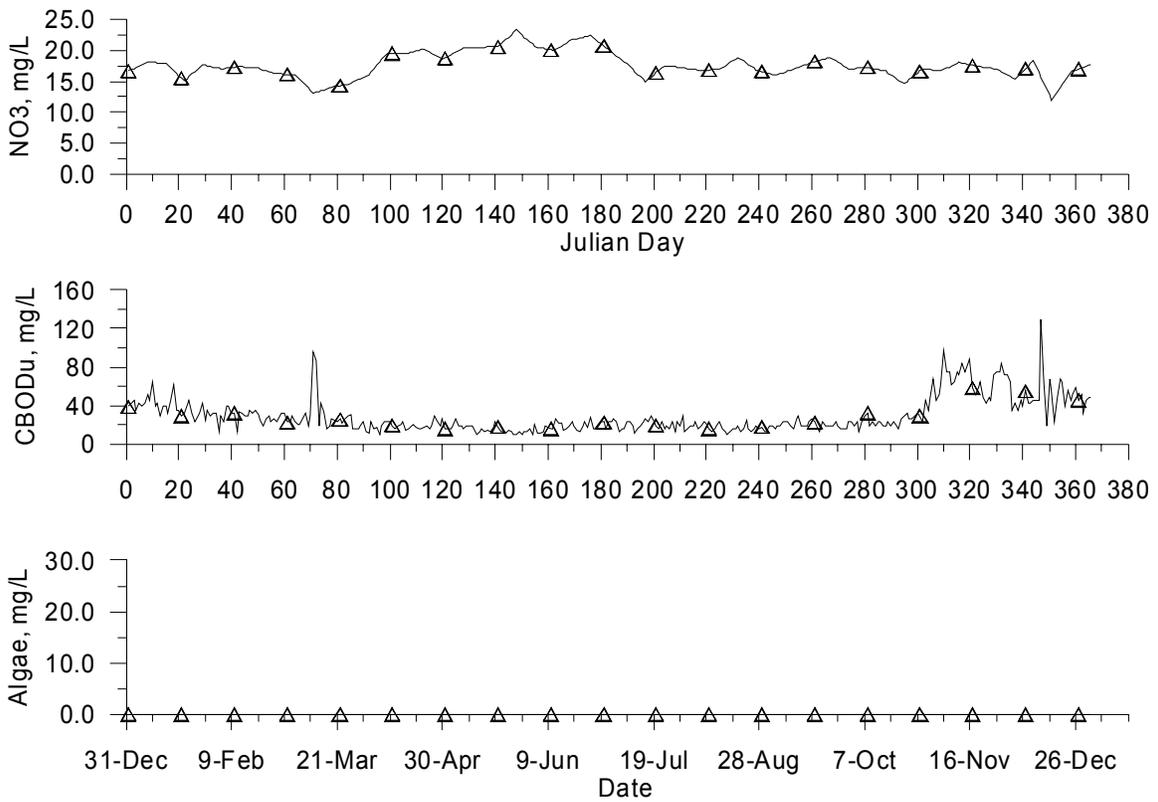
**Figure 53. City of Spokane WWTP discharge flow, 2001**



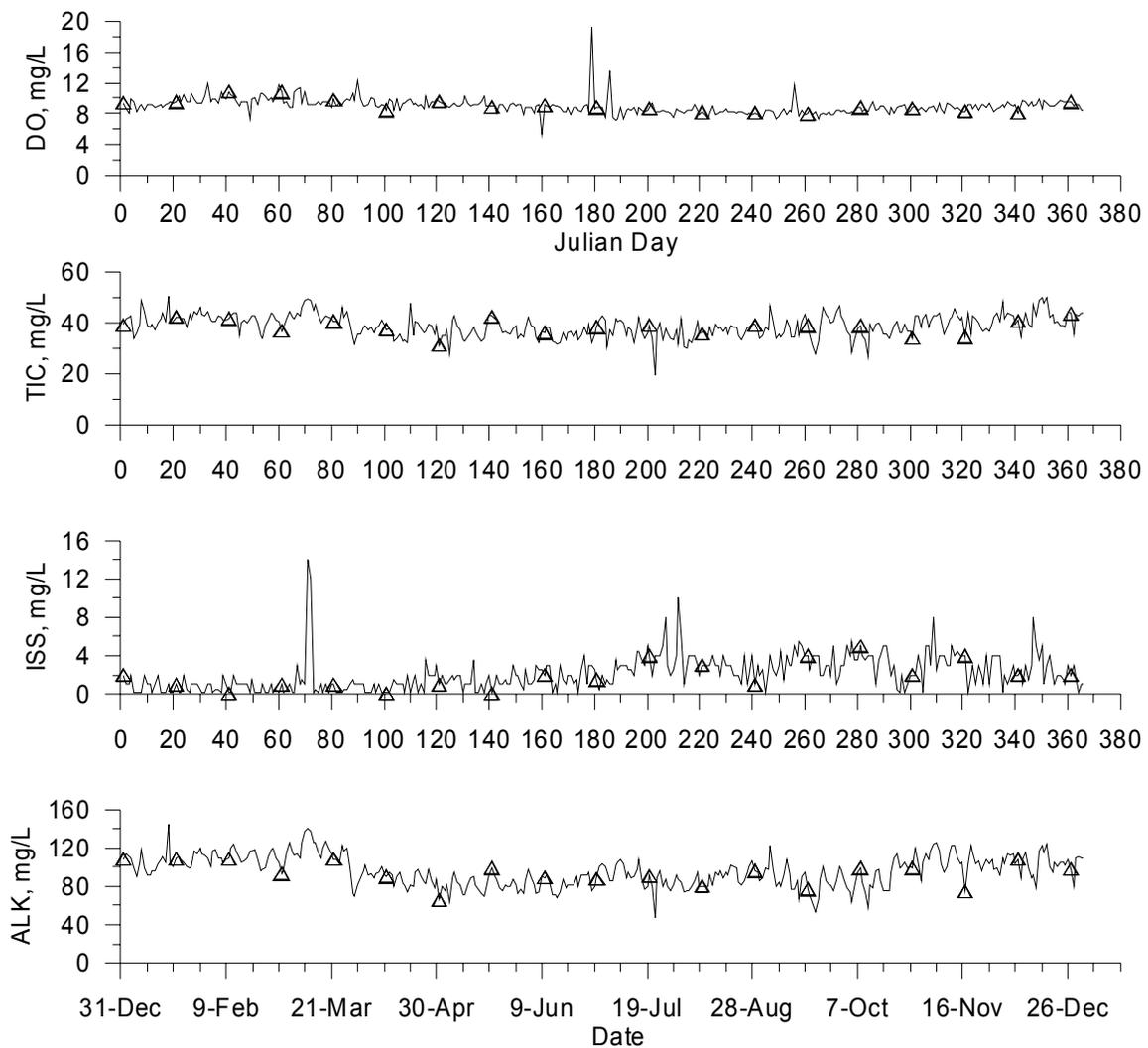
**Figure 54. City of Spokane WWTP discharge temperature, 2001**



**Figure 55. City of Spokane WWTP discharge water quality conditions (Part 1)**



**Figure 56. City of Spokane WWTP discharge water quality conditions (Part 2)**



**Figure 57. City of Spokane WWTP discharge water quality conditions (Part 3)**

### Inland Empire Paper Company

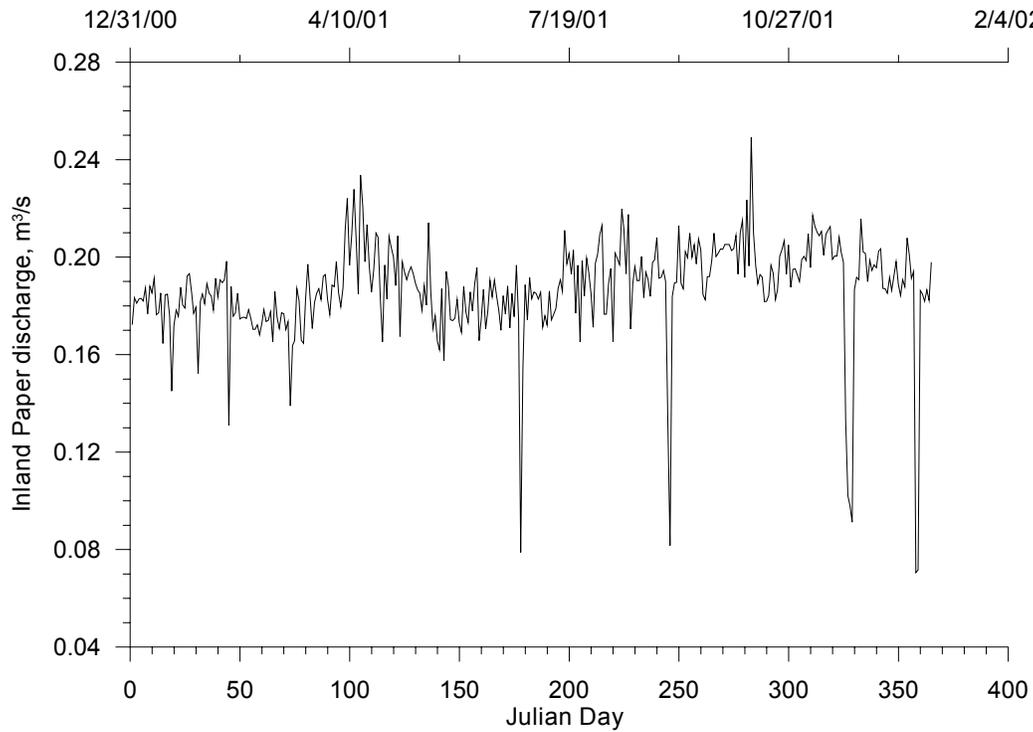
Inland Empire Paper Company discharges to the Spokane River upstream of Upriver Dam. Figure 58 shows the discharge. Flows remained relatively constant, with a few decreases over the year. Figure 59 shows the discharge temperatures. Temperatures were generally several degrees cooler than in 2000.

The 2001 water quality characteristics corresponding to the Inland Empire point source were developed using conductivity, chloride, nitrite-nitrate nitrogen, ammonia nitrogen, soluble reactive phosphorus, total organic carbon, total dissolved solids, pH, carbonaceous BOD ultimate (CBOD<sub>u</sub>), BOD5, dissolved organic carbon, alkalinity, and total suspended solids data. Dissolved oxygen concentrations were set to the average of the 1991 data. Due to lack of data, fecal coliform concentrations were set to zero. Inorganic suspended solids concentrations were developed using the method outlined for the Spokane River at the state line with algae concentration set to zero.

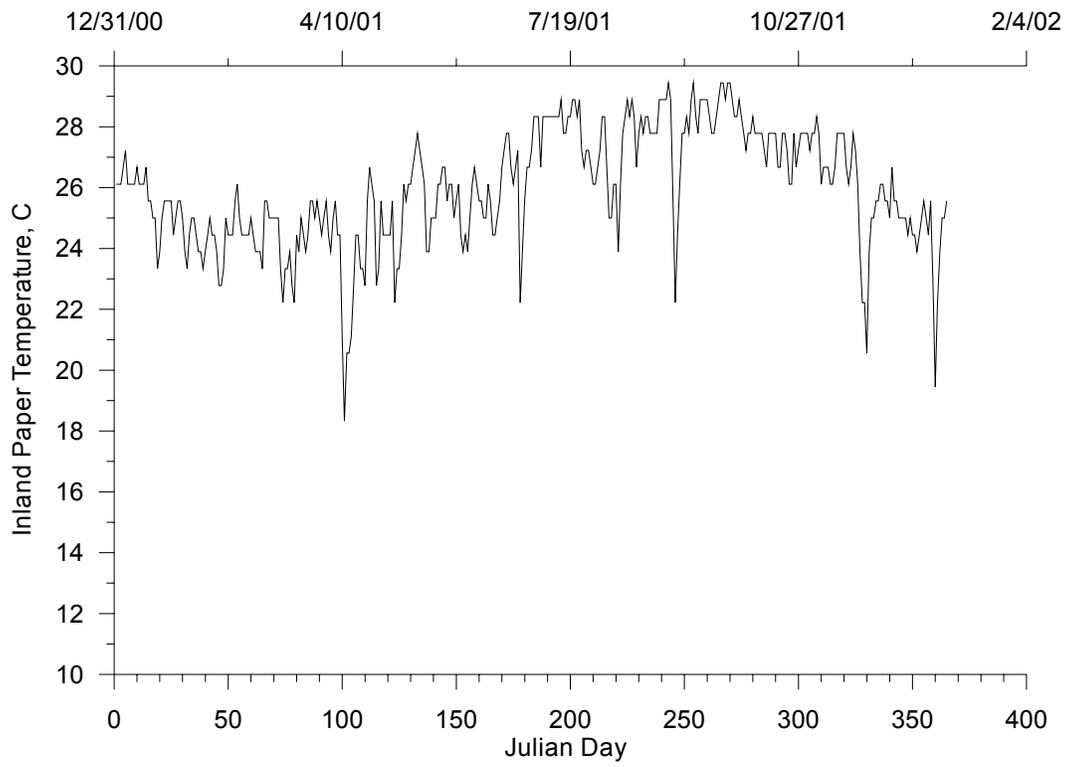
Using the same approach described above in the Kaiser Aluminum section, organic matter from the Inland Empire was modeled using a CBOD compartment and decay rate. The CBOD compartment was

modeled using carbonaceous BOD ultimate. When  $CBOD_u$  data were sparse,  $CBOD_u$  concentrations were estimated from  $BOD_5$  data assuming a ratio of  $CBOD_u$  to  $BOD_5$  of 9.47.

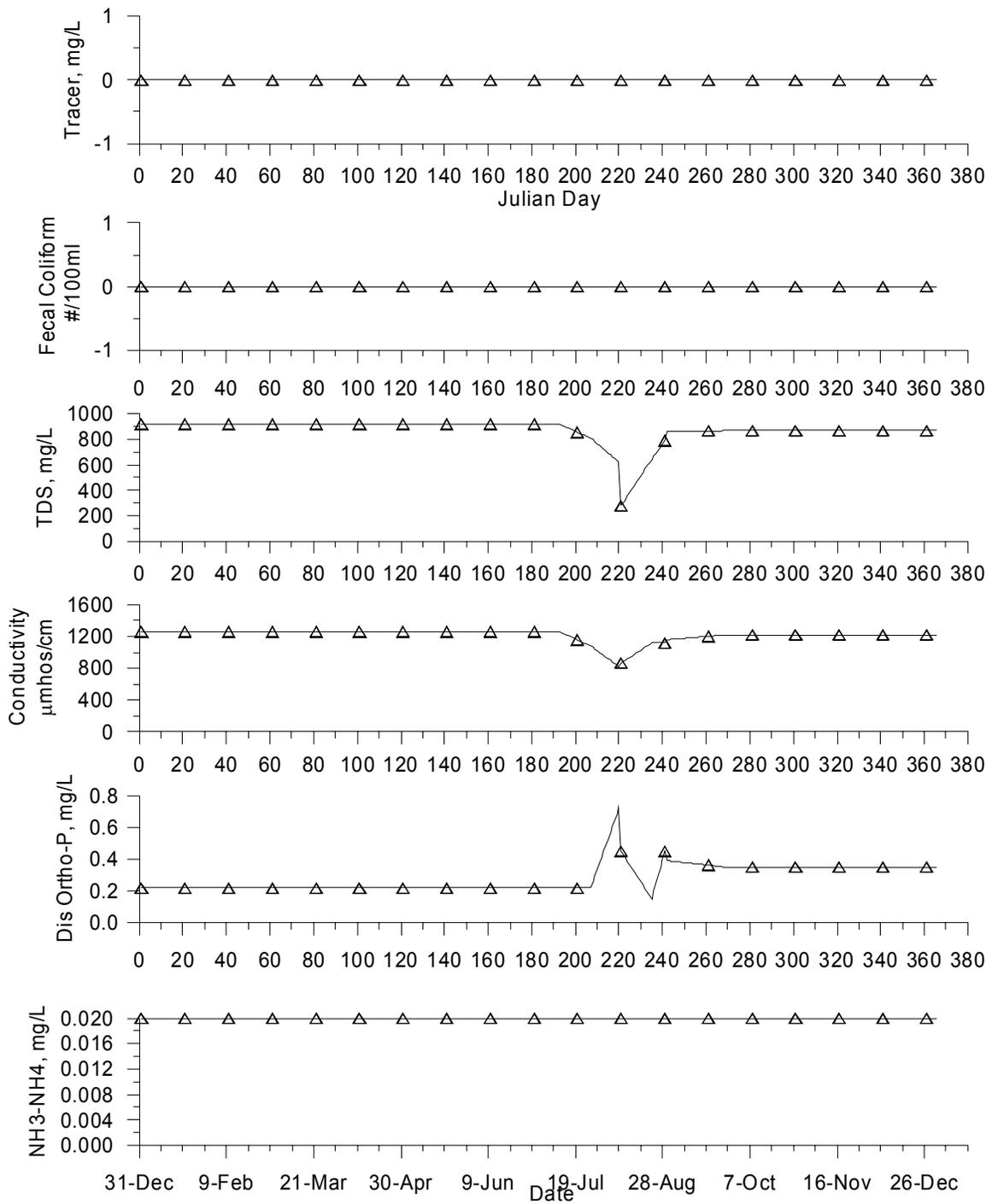
The concentrations of the Inland Paper Company constituents were plotted in Figure 60, Figure 61, and Figure 62. Some constituents had few data points so an average of the available data was used.



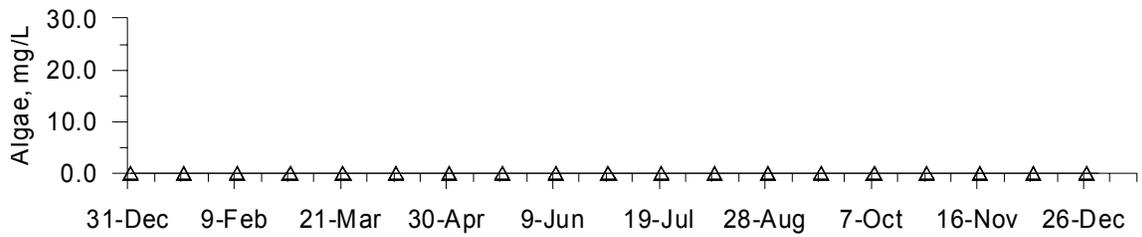
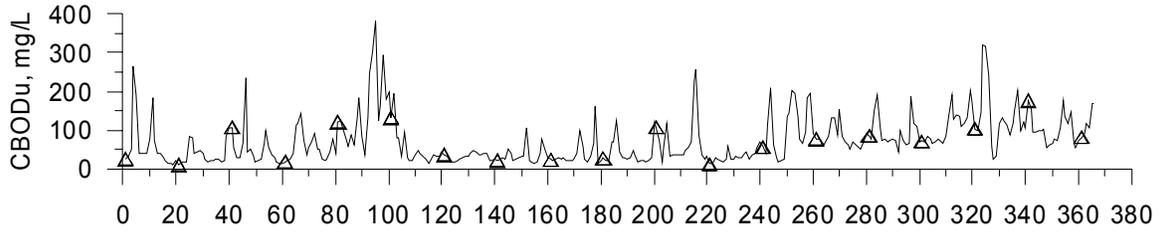
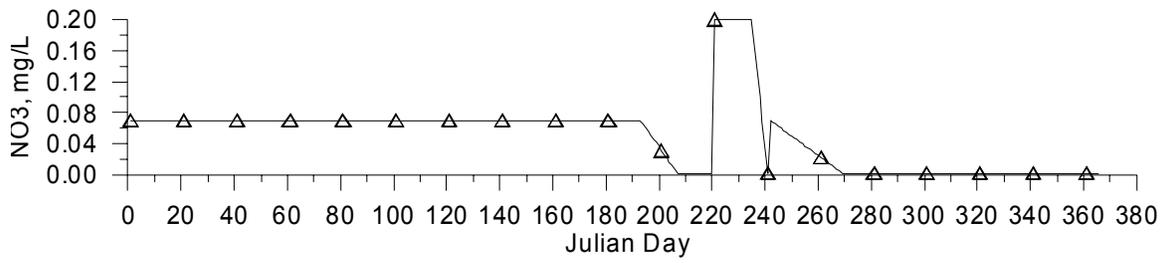
**Figure 58. Inland Empire Paper Co. discharge flow, 2001**



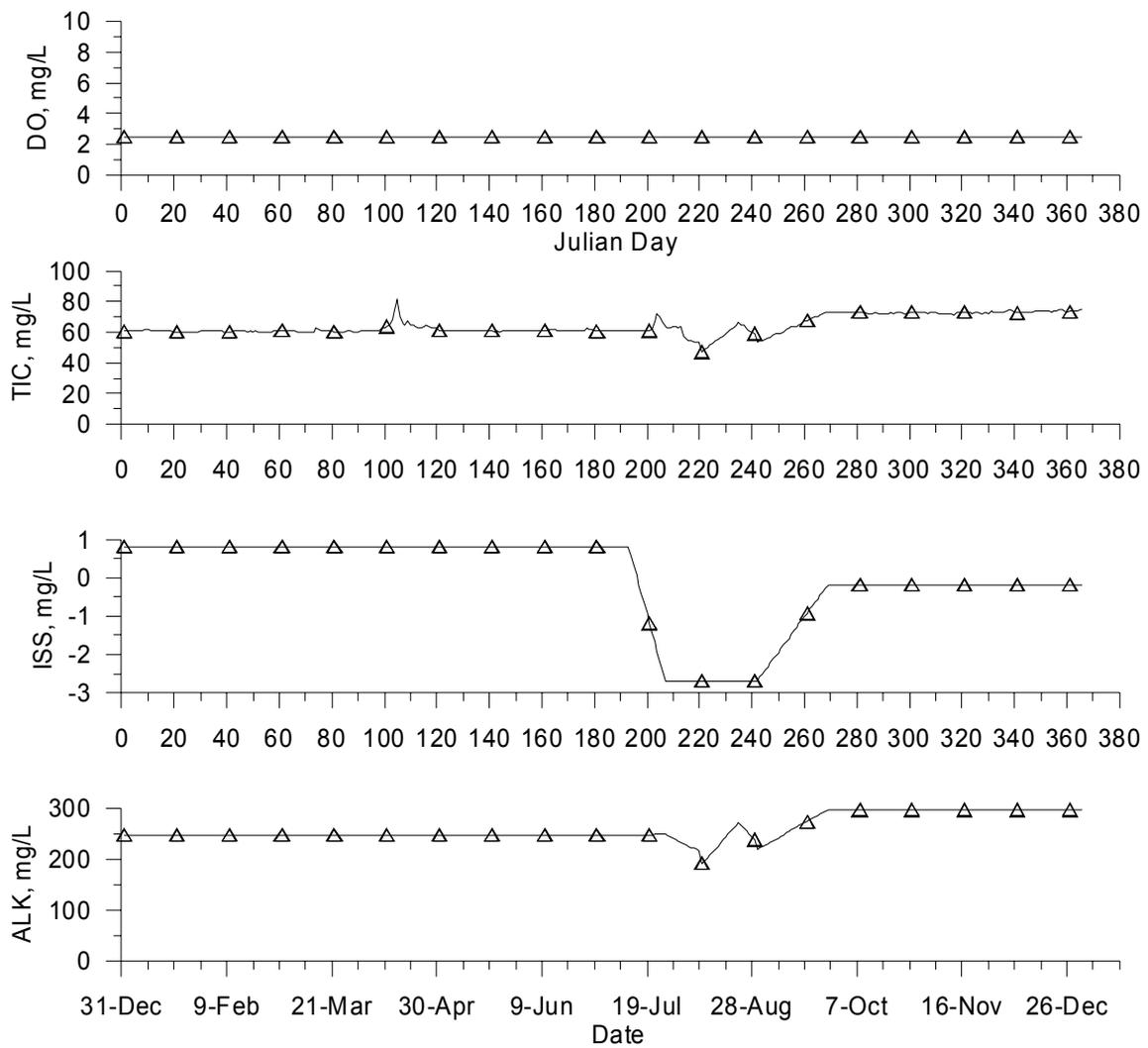
**Figure 59. Inland Empire Paper Co. discharge temperature, 2001**



**Figure 60. Inland Empire Paper Co. discharge water quality conditions (Part 1)**



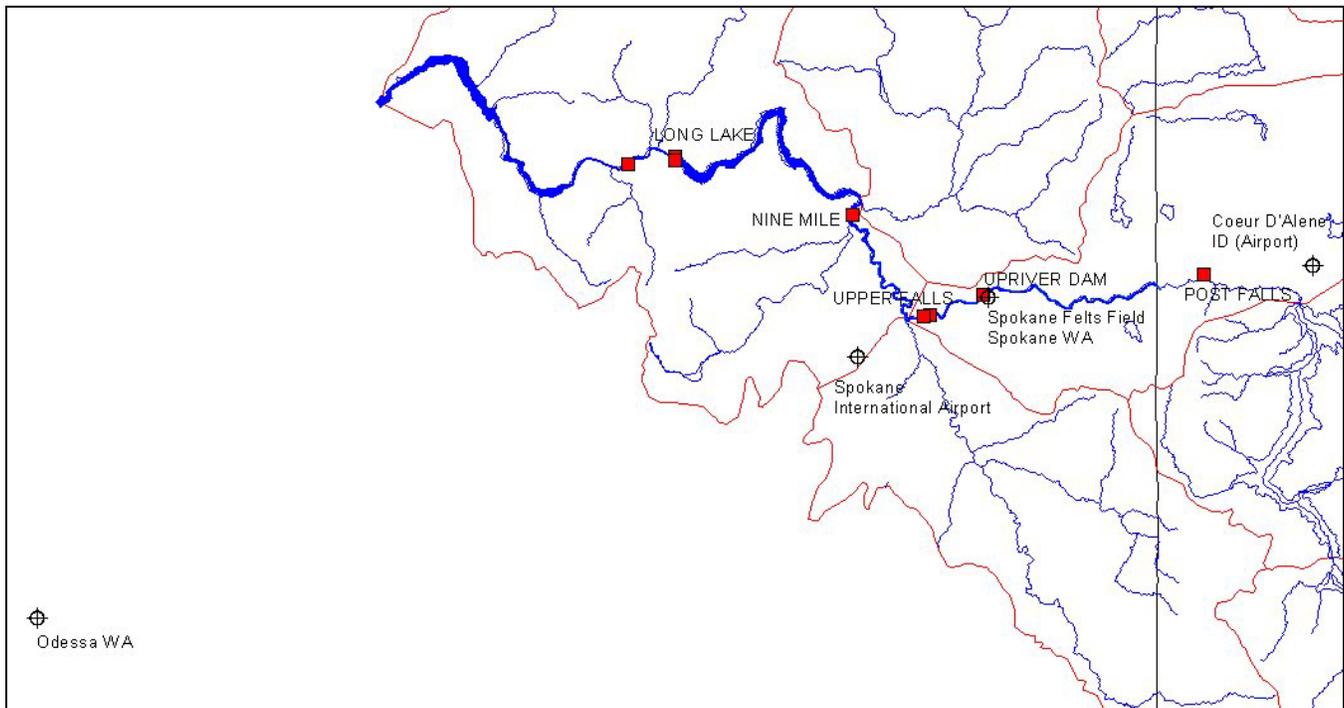
**Figure 61. Inland Empire Paper Co. discharge water quality conditions (Part 2)**



**Figure 62. Inland Empire Paper Co. discharge water quality conditions (Part 3)**

## **Meteorological Data**

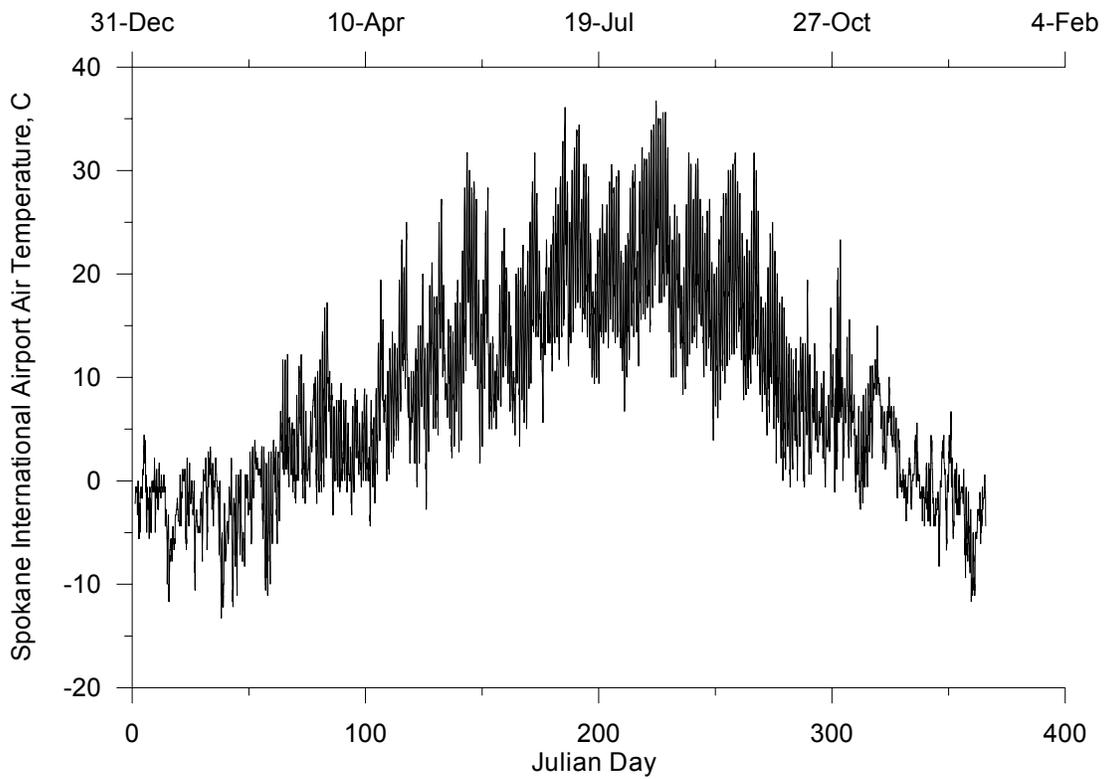
Meteorological data for the CE-QUAL-W2 model was taken from the Spokane International Airport and the Spokane Felts Field (Figure 63). The model utilizes air and dew point temperature, wind speed and direction, and cloud cover or solar radiation. The two airports did not have solar radiation data available, so solar radiation data from Odessa, WA was used. The cloud cover data collected is not very accurate because it is measured in only a few discrete increments. The model used internal interpolation to fill in the meteorological information between input data. Meteorological data from Coeur d'Alene, ID was not used because it was too far away from the model domain, located 12 miles from the Idaho-Washington state line.



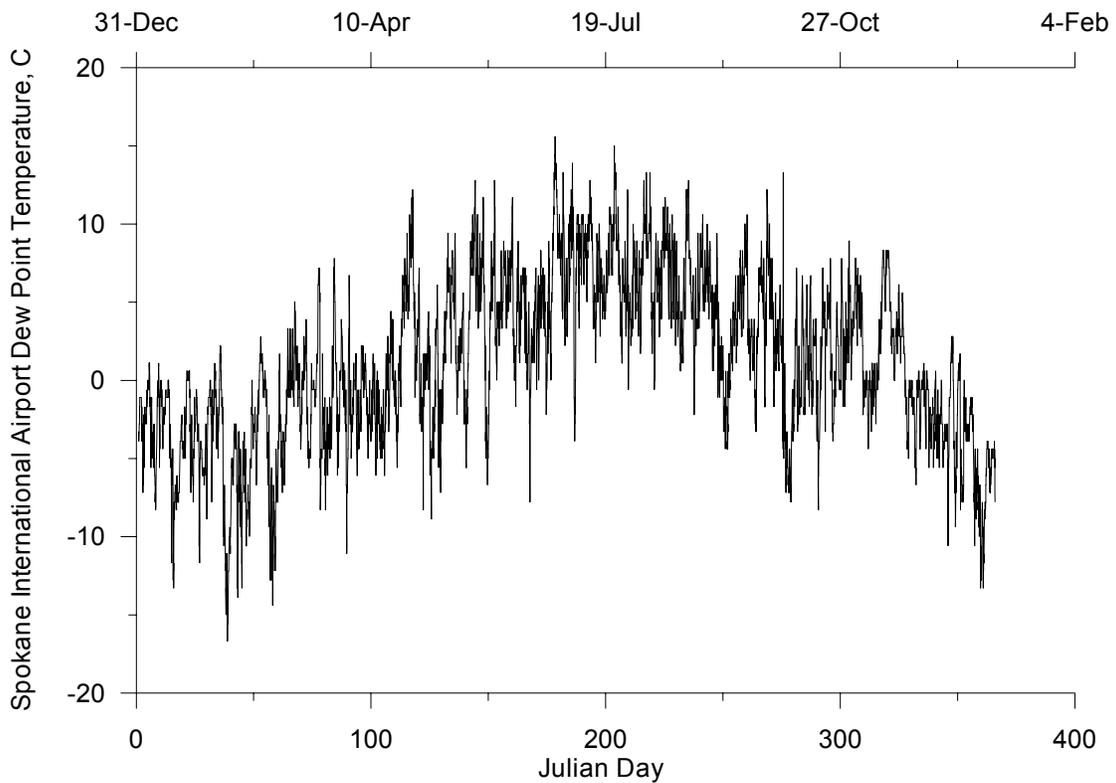
**Figure 63. Meteorological stations near the Spokane River**

### Spokane International Airport

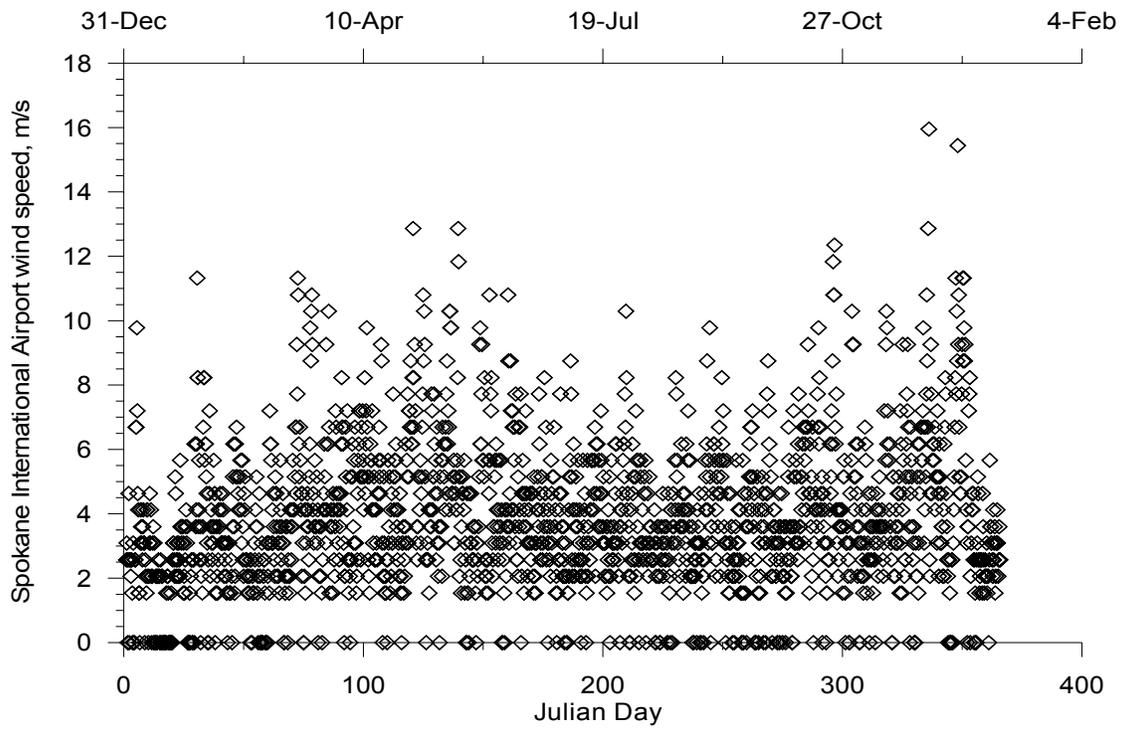
Air temperatures for 2001 are shown in Figure 64. Dew point temperatures are shown in Figure 65. Air and dew point temperatures were similar to 2000. Figure 66 shows wind speed and Figure 67 shows wind direction recorded at the airport for 2001. The Spokane International Airport uses a high-speed wind gauge that only records wind speeds greater than 1.5 m/s. Wind direction is only noted for speeds greater than 1.5 m/s. As in 1991 and 2000, the predominant wind directions were from 150 to 250 degrees from the North and from 0 to 70 degrees from the North. Figure 68 shows the cloud cover reported at the airport. It should be noted that the National Weather Service (NWS) started recording cloud cover differently in 1996. Prior to 1996 the NWS used a 0 to 10 scale for recording cloud density with 0 indicating no cloud cover and 10 indicating full cloud cover. After 1996, the scale was switched to 1 to 8. In order to compare the data to the previous data record, the cloud cover from 2001 was converted to a scale of 0 to 10. This change can influence the model temperatures.



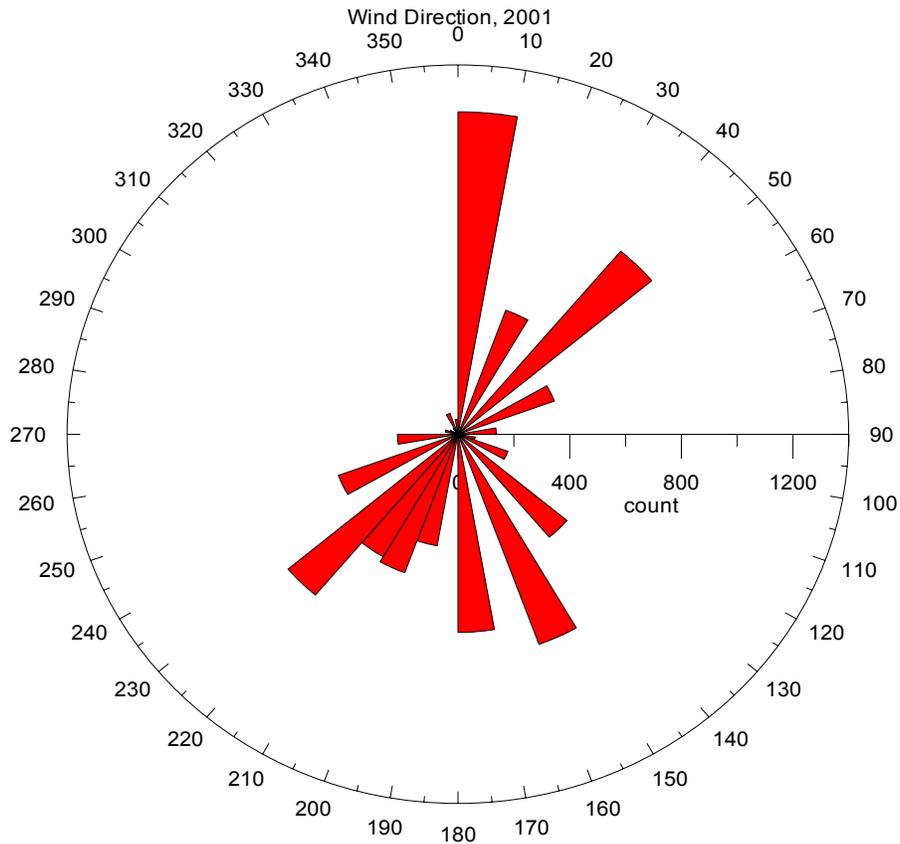
**Figure 64. Air temperature, °C, at the Spokane International Airport 2001**



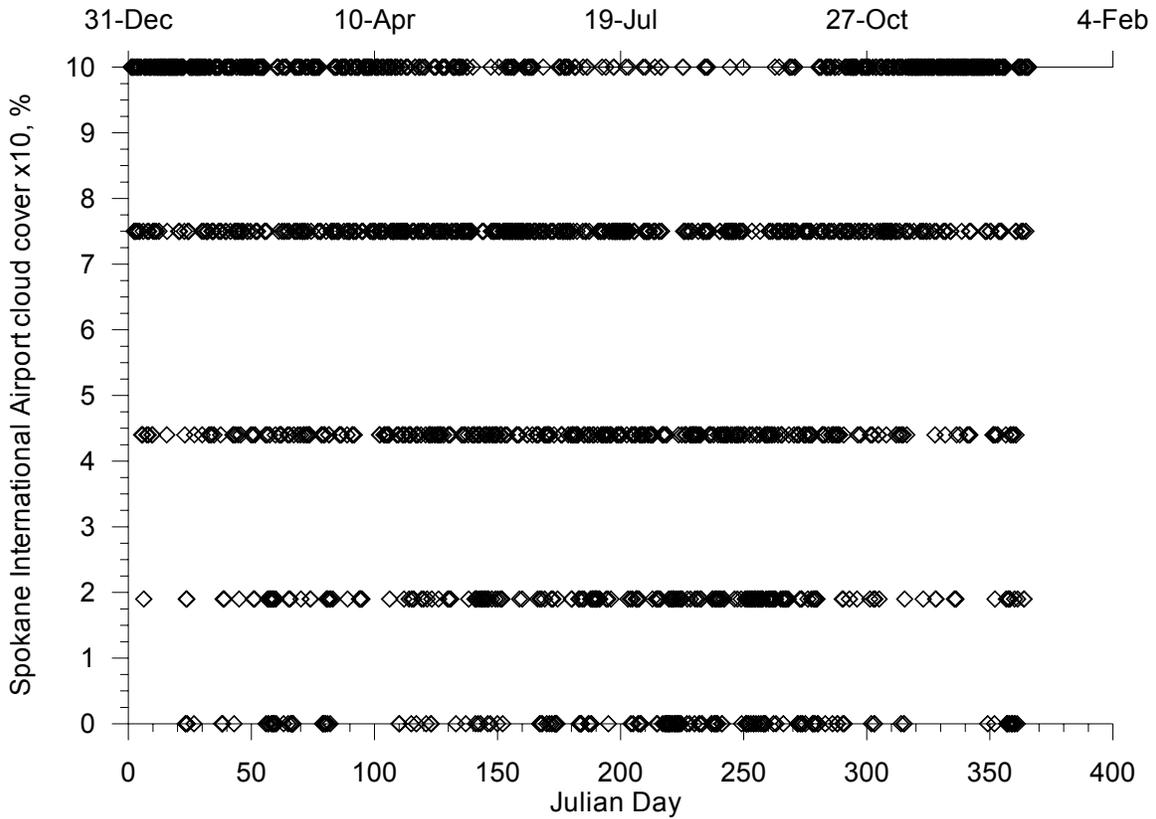
**Figure 65. Dew point temperature, °C, at the Spokane International Airport 2001**



**Figure 66. Wind Speed, m/s, at the Spokane International Airport 2001**



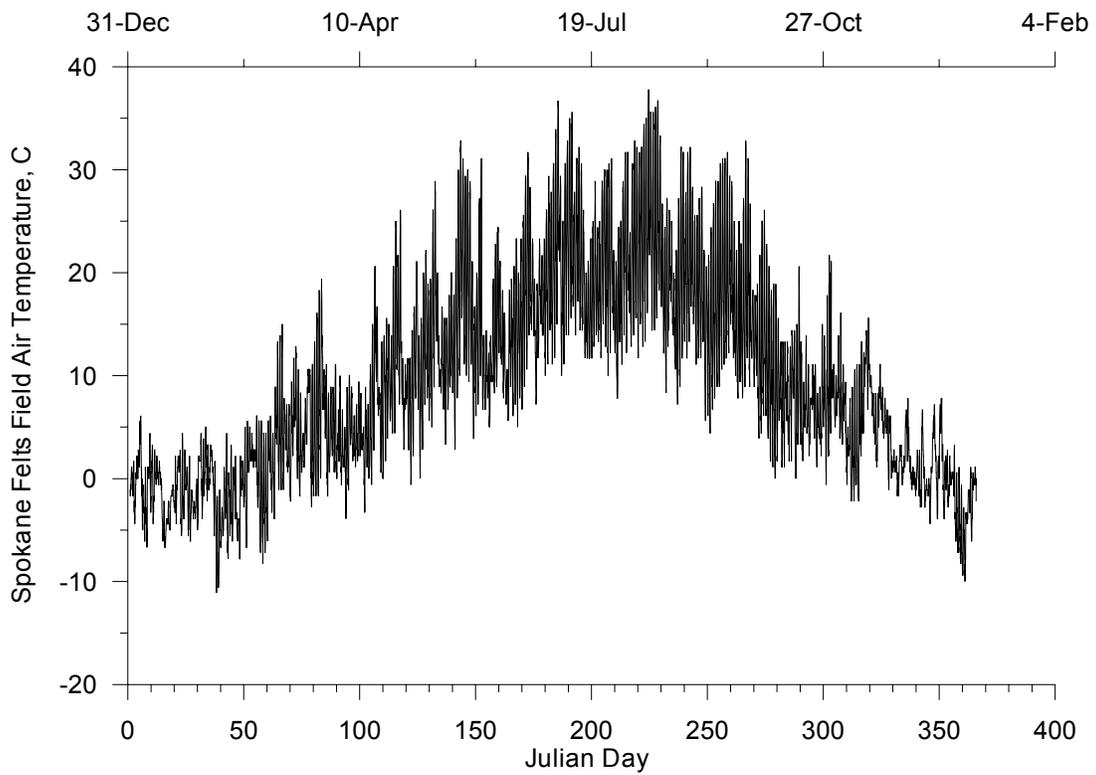
**Figure 67. Wind direction, degrees from North, at the Spokane International Airport, 2001**



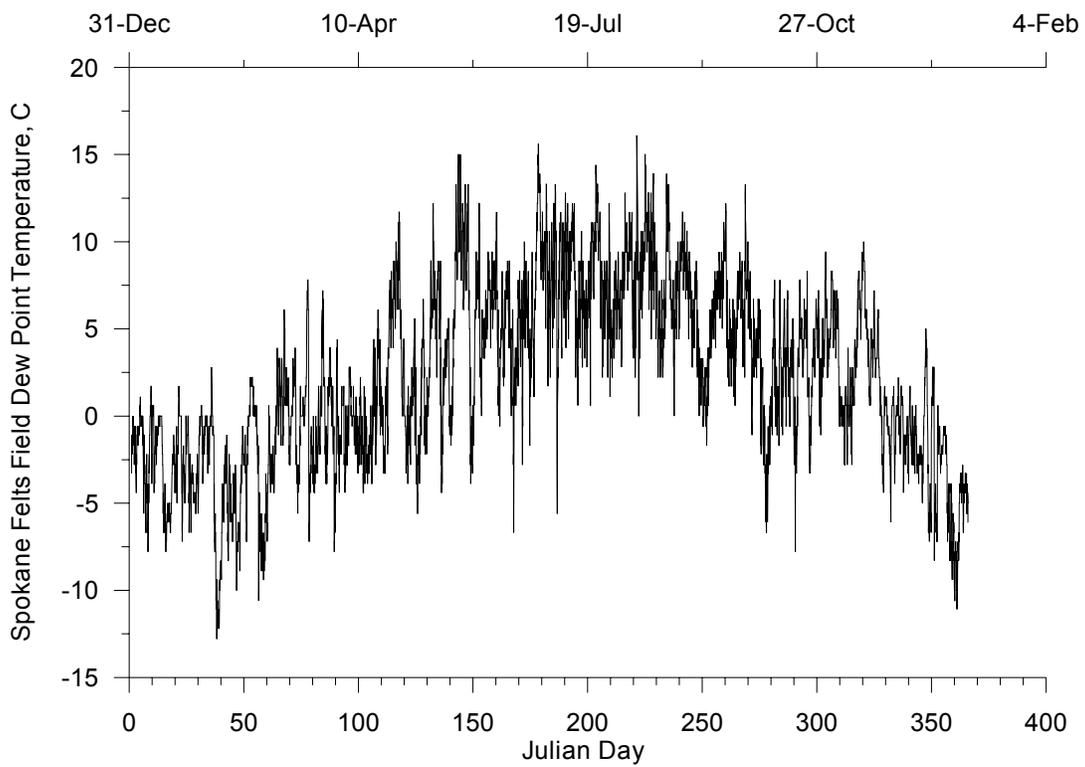
**Figure 68. Cloud Cover, x10, at the Spokane International Airport 2001**

Spokane Felts Field

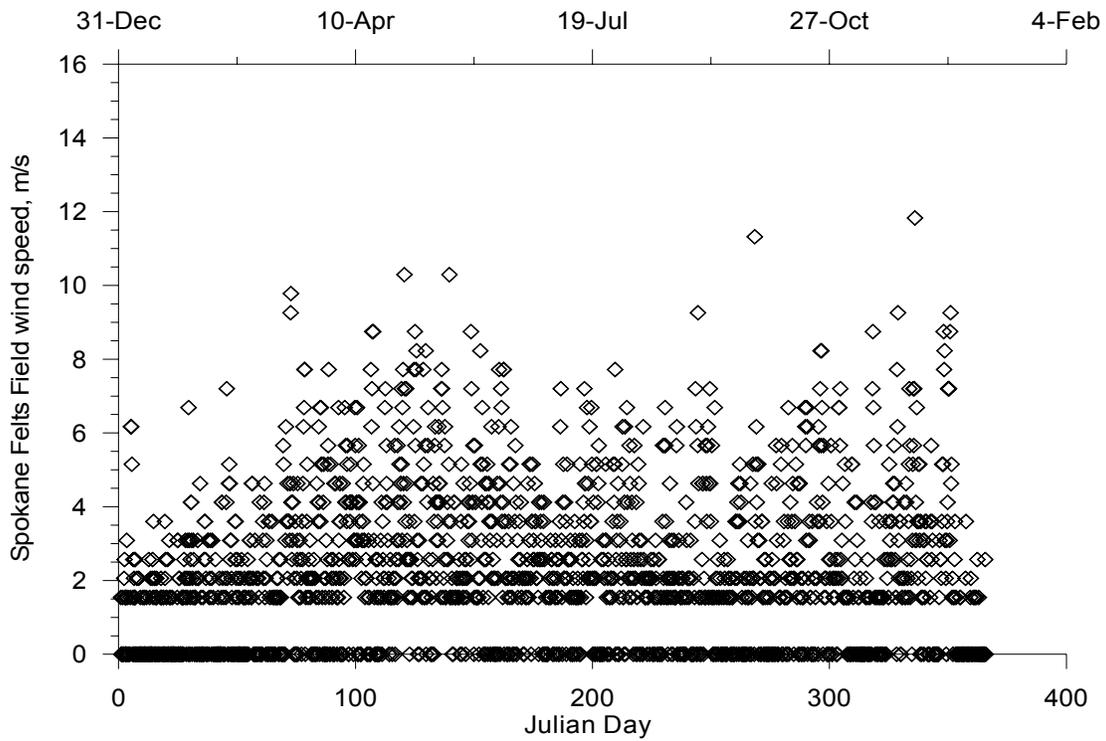
Air temperatures for 2001 are shown in Figure 69 with the highest temperatures in July and August similar to temperatures shown for the Spokane International Airport. Dew point temperatures are shown in Figure 70. Figure 71 shows the wind speeds, which were lower than wind speeds at the Spokane International Airport. Figure 72 shows a rose diagram of the wind directions recorded where the predominant wind direction was 170 to 260 degrees from the North. Figure 73 shows the cloud cover reported for the year. Felts Field has a high-speed wind gauge as well, only recording speeds greater than 1.5 m/s. Similar to the Spokane International Airport, the cloud cover data recorded by the National Weather Service (NWS) were switched to 1 to 8 scale after 1996. In order to compare data from years prior to 1996 and for use in the model, the cloud cover information from 2000 was converted to a scale of 0 to 10.



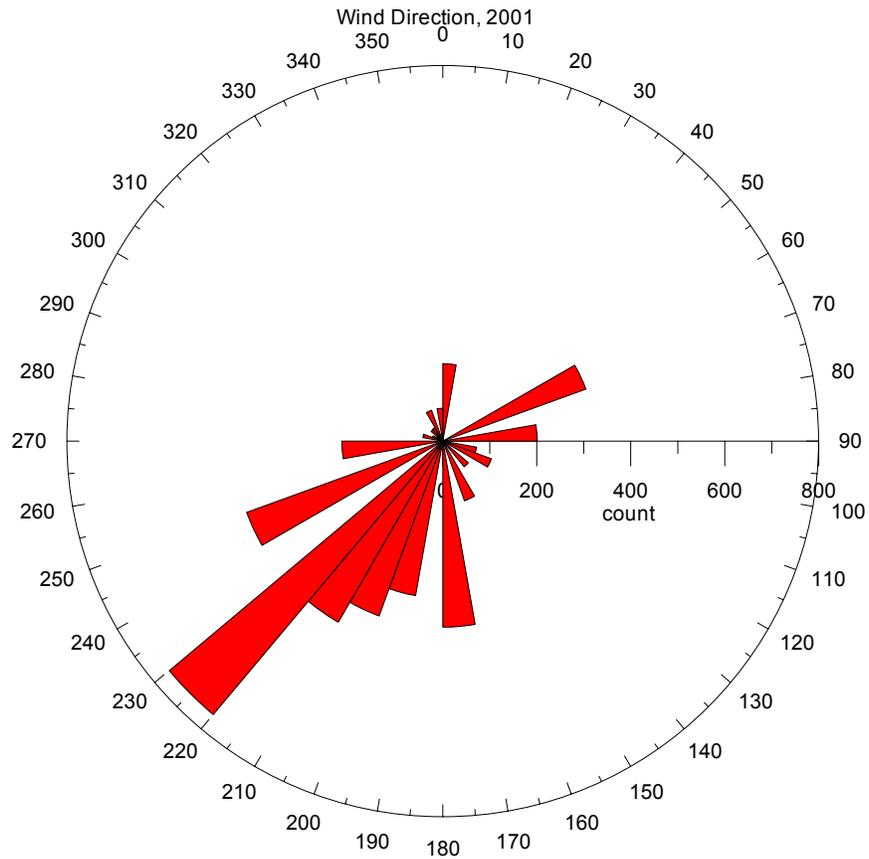
**Figure 69. Air temperature, °C, at Spokane Felts Field 2001**



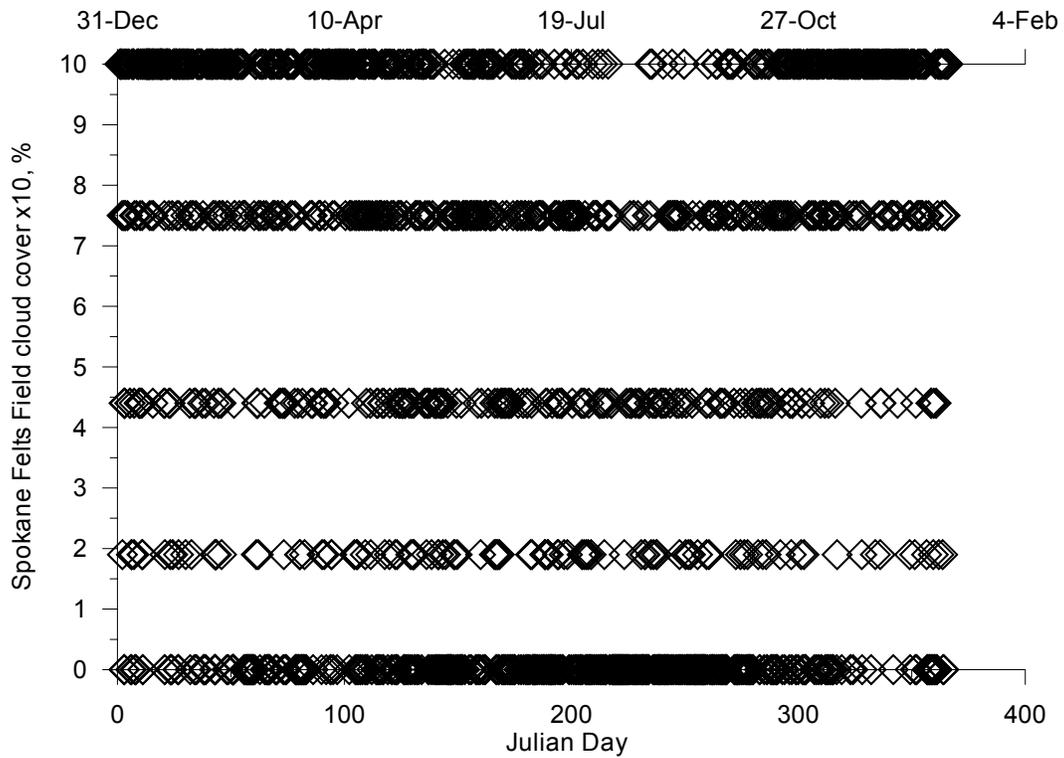
**Figure 70. Dew point temperature, °C, at Spokane Felts Field 2001**



**Figure 71. Wind speed, m/s, at Spokane Felts Field 2001**



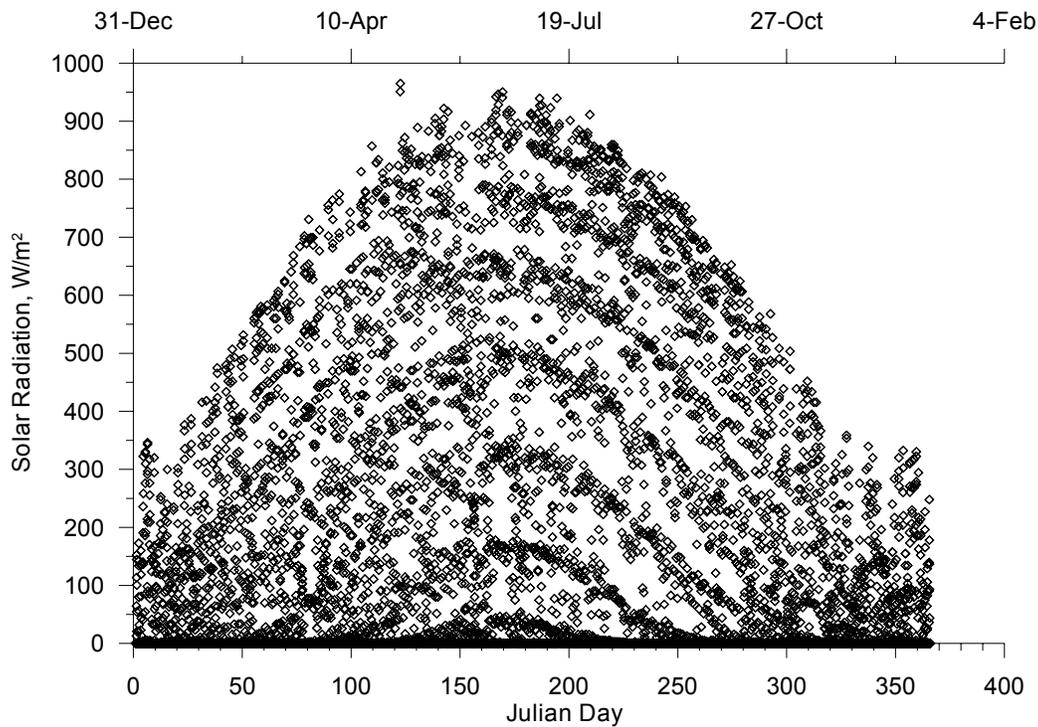
**Figure 72. Wind direction, degrees from North, at Spokane Felts Field 2001**



**Figure 73. Cloud Cover, x10, at Spokane Felts Field 2001**

Odessa, WA

Since there were no solar radiation data available at the Spokane International Airport or at the Spokane Felts Field, data were used from a meteorological site in Odessa, WA (see Figure 63). The solar radiation data collected at Odessa in 2001 is shown in Figure 74.



**Figure 74. Solar radiation at Odessa, WA 2001**

***Periphyton Data***

A periphyton algorithm was developed for the model to incorporate important nutrient and dissolved oxygen changes in the Spokane River. Samples were collected at 8 sites on the Spokane River as listed in Table 12 in August and September 2001. Table 13 and Table 14 show the mean biomass and chlorophyll data from August 2001 for each site based on several samples collected. Table 15 and Table 16 show the mean biomass and chlorophyll data from September 2001 for each site based on several samples collected. Table 17 and Table 18 show the mean biomass and chlorophyll data for each site based on new growth over 28 days from incubated substrates at each site.

<b>Table 12. Periphyton Data Sites</b>		
Site Code	Description	River Mile
SL	Stateline Bridge	96.0
BSB	Barker Road Bridge	90.4
TI	Trent Road Bridge	85.3
BGS	Green St. Bridge	78.0
CPS	Clark Pump Station	72.7
ASP	Above Spokane WWTP	67.6
BGC	Below Gun Club	64.6
BNM	Below Nine Mile Dam	58.1

<b>Table 13. August 2001 Site Mean Biomass from Natural Substrates</b>					
RM	Depth (m)	ODW (g/m <sup>2</sup> )	AFODW (g/m <sup>2</sup> )	Autotrophic Index (Mono)	Autotrophic Index (Tri)

				Chl a)	Chl a)
96.0	1.17	120.24	8.49	244.51	222.74
90.4	1.47	13.15	3.33	358.46	334.78
85.3	1.21	20.75	4.93	418.41	386.32
78.0	0.69	129.19	22.95	283.53	259.21
72.7	0.71	24.37	8.86	215.76	202.55
67.6	0.93	41.94	9.33	276.97	263.53
64.6	0.65	39.43	15.42	196.19	190.08
58.1	0.79	279.24	11.63	162.86	153.99

**Table 14. August 2001 Site Mean Chlorophyll from Natural Substrates**

RM	Temp. (C)	Elec. Cond. (m-siemens)	Depth (m)	Flow Velocity (ft/sec)	Mono-Chromatic Chl a (mg/m <sup>2</sup> )	Pheophyton (mg/m <sup>2</sup> )	Tri-Chromatic Chl a (mg/m <sup>2</sup> )	Tri-Chromatic Chl b (mg/m <sup>2</sup> )	Tri-Chromatic Chl c (mg/m <sup>2</sup> )
96.0	24.2	140	1.1	0.0	36.6	4.3	40.4	3.1	1.6
90.4	22.5	175	1.3	0.0	10.8	0.8	11.6	1.3	0.3
85.3	12.5	280	1.2	0.1	14.4	0.8	15.4	0.9	1.0
78.0	14.3	271	0.7	0.4	26.8	2.3	28.9	4.5	1.4
72.7	15.7	270	0.7	0.3	44.0	3.0	47.0	5.2	4.9
67.6	15.2	210	0.9	0.4	43.4	2.0	45.9	4.7	1.8
64.6	16.0	329	0.6	0.3	77.9	-0.1	80.6	1.6	4.9
58.1	18.1	326	0.8	0.0	80.0	4.8	85.7	2.1	5.5

**Table 15. September 2001 Sites Mean Biomass from Natural Substrates**

RM	Depth (m)	ODW (g/m <sup>2</sup> )	AFODW (g/m <sup>2</sup> )	Autotrophic Index (Mono Chl a)	Autotrophic Index (Tri Chl a)
96.0	1.39	172.10	9.46	236.79	211.01
90.4	1.78	21.61	5.08	413.41	382.36
85.3	0.97	36.75	5.01	436.66	404.29
78.0	0.78	67.81	8.59	312.56	288.26
72.7	0.62	75.91	8.15	347.10	303.12
67.6	0.79	26.88	8.80	320.92	292.22
64.6	0.72	47.65	19.89	192.81	185.45
58.1	0.68	557.08	12.21	306.63	278.79

**Table 16. September 2001 Site Mean Chlorophyll from Natural Substrates**

RM	Temp. (C)	Elec. Cond. (m-siemens)	Depth (m)	Flow Velocity (ft/sec)	Mono-Chromatic Chl a (mg/m <sup>2</sup> )	Pheophyton (mg/m <sup>2</sup> )	Tri-Chromatic Chl a (mg/m <sup>2</sup> )	Tri-Chromatic Chl b (mg/m <sup>2</sup> )	Tri-Chromatic Chl c (mg/m <sup>2</sup> )
96.0	20.5	135	1.5	0.0	44.2	7.4	50.0	5.4	1.9
90.4	17.5	90	1.8	0.0	11.6	1.0	12.6	1.7	0.6
85.3	10.7	240	1.0	0.1	12.6	1.2	13.6	1.8	0.6
78.0	11.5	230	0.8	0.5	30.3	2.3	32.4	5.3	1.0
72.7	13.4	250	0.6	0.2	27.9	5.4	32.0	3.7	2.0
67.6	14.0	220	0.8	0.3	29.4	2.9	32.0	3.0	1.8
64.6	13.9	240	0.7	0.1	103.3	1.7	107.7	6.4	4.4
58.1	15.1	268	0.7	0.1	43.9	3.3	47.3	3.1	2.6

**Table 17. September 2001 Sites Mean Biomass, New Growth Over 28 days on Incubated Substrates**

RM	Depth (m)	ODW (g/m <sup>2</sup> )	AFODW (g/m <sup>2</sup> )	Autotrophic Index (Mono Chl a)	Autotrophic Index (Tri Chl a)
96.0	1.39	96.87	15.42	176.35	153.27
90.4	1.65	21.18	2.96	362.73	284.44
85.3	0.97	34.29	4.60	327.87	301.46
78.0	0.77	40.79	9.08	276.48	256.77
72.7	0.62	19.94	5.86	291.91	266.61
67.6	0.79	22.90	5.05	351.24	308.10
64.6	0.71	29.81	10.43	180.35	172.28
58.1	0.61	68.20	7.31	200.76	185.50

**Table 18. September 2001 Site Mean Chlorophyll, New Growth Over 28 days on Incubated Substrates**

RM	Temp. (C)	Elec. Cond. (m-siemens)	Depth (m)	Flow Velocity (ft/sec)	Mono-Chromatic Chl a (mg/m <sup>2</sup> )	Pheophyton (mg/m <sup>2</sup> )	Tri-Chromatic Chl a (mg/m <sup>2</sup> )	Tri-Chromatic Chl b (mg/m <sup>2</sup> )	Tri-Chromatic Chl c (mg/m <sup>2</sup> )
96.0	20.5	135	1.5	0.0	90.2	18.1	103.5	13.9	4.0
90.4	17.5	90	1.6	0.0	9.0	2.1	10.5	2.1	0.0
85.3	10.7	240	1.0	0.1	14.9	1.6	16.3	2.5	0.7
78.0	11.5	230	0.8	0.6	34.9	2.4	37.2	5.8	1.7
72.7	13.4	250	0.6	0.2	20.9	2.2	22.9	1.2	1.5
67.6	14.0	220	0.8	0.3	16.4	1.1	17.5	1.1	1.6
64.6	13.9	240	0.7	0.1	67.2	0.5	69.9	1.6	4.1
58.1	15.1	268	0.6	0.1	43.4	3.5	46.9	3.1	3.2

## Summary

This report summarizes boundary conditions for the CE-QUAL-W2 Version 3.1 model of the Spokane River from the Idaho-Washington state-line to the outlet to Long Lake for 2001. This report is a companion report to the report written to summarize the data from 1991 and 2000 (Annear et. al., 2001). Since the CE-QUAL-W2 model allows the user to separate the river basin into separate branches (collections of model longitudinal segments or computational cells) and water bodies (collections of branches with similar kinetic coefficients, turbulence closure, and meteorological forcing) the W2 model was composed of both riverine and reservoir sections, such as

- The Spokane River
- Nine Mile Dam pool
- Upriver Dam pool
- Upper Falls Dam pool
- Long Lake

The system model required that boundary conditions and the topography of river and reservoir sections be determined. Data in support of this modeling effort were shown in this report. This includes data such as:

- Dynamic inflow/discharge rates
- Dynamic inflow/discharge temperatures
- Dynamic inflow/discharge water quality constituents
- Dynamic meteorological data (air temperature, dew point temperature, wind speed, wind direction and cloud cover or short wave solar radiation)
- Model bathymetry

In addition, this report includes a review of water quality data collected from 2001. In order to account for distributed flow into and out of the Spokane River, a groundwater algorithm was developed for predicting the dynamic groundwater flows for various reaches in the model.

Comparisons were also made of meteorological data in the Long Lake Spokane River area at the Spokane International Airport, Spokane Felts Field, and at Odessa, Washington.

A companion report, entitled: "Spokane River Model: Model Calibration, 2001" considers the calibration of the Long Lake – Spokane River system model for 2001.

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## Appendix A: Vertical Profiles

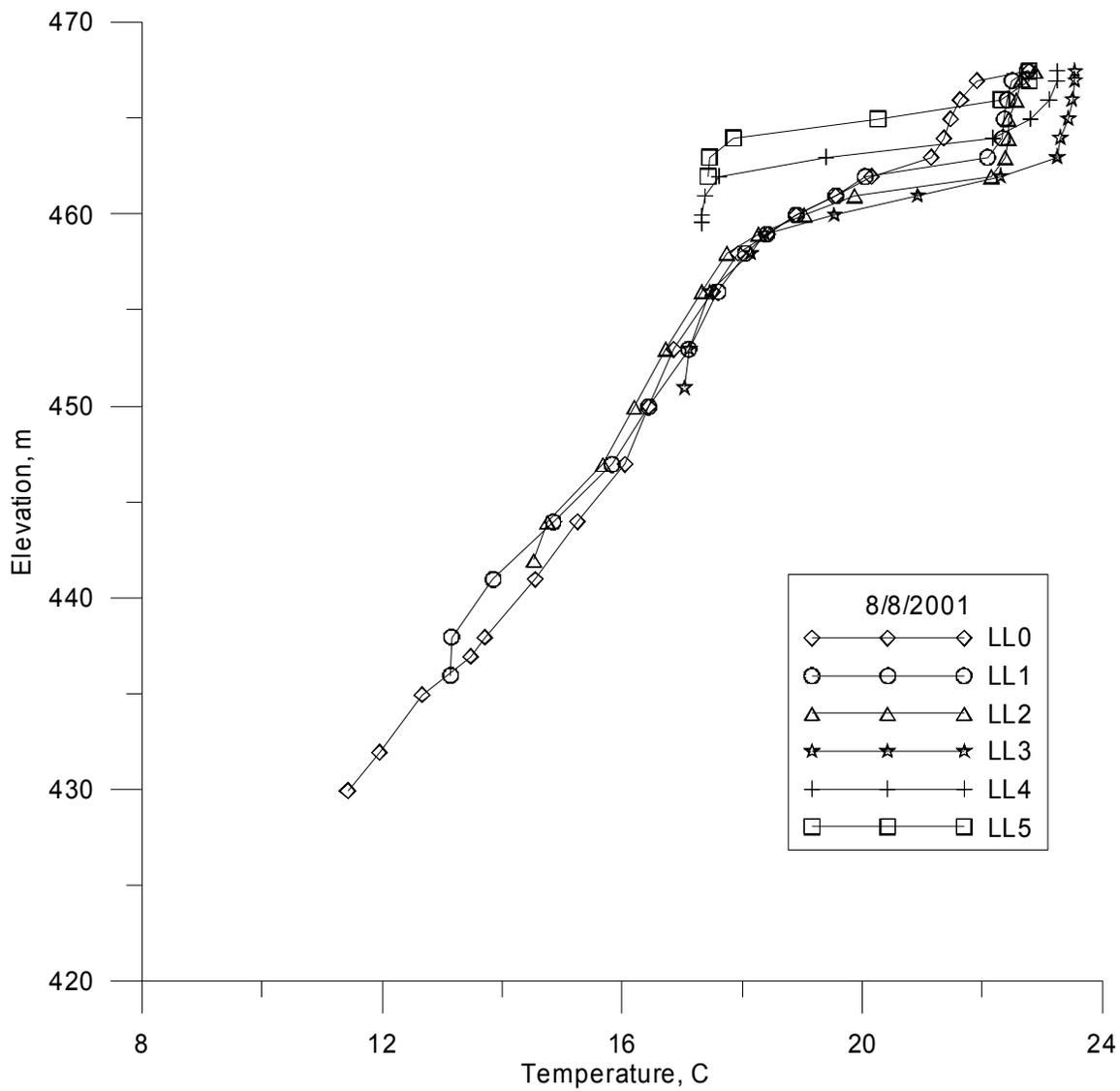
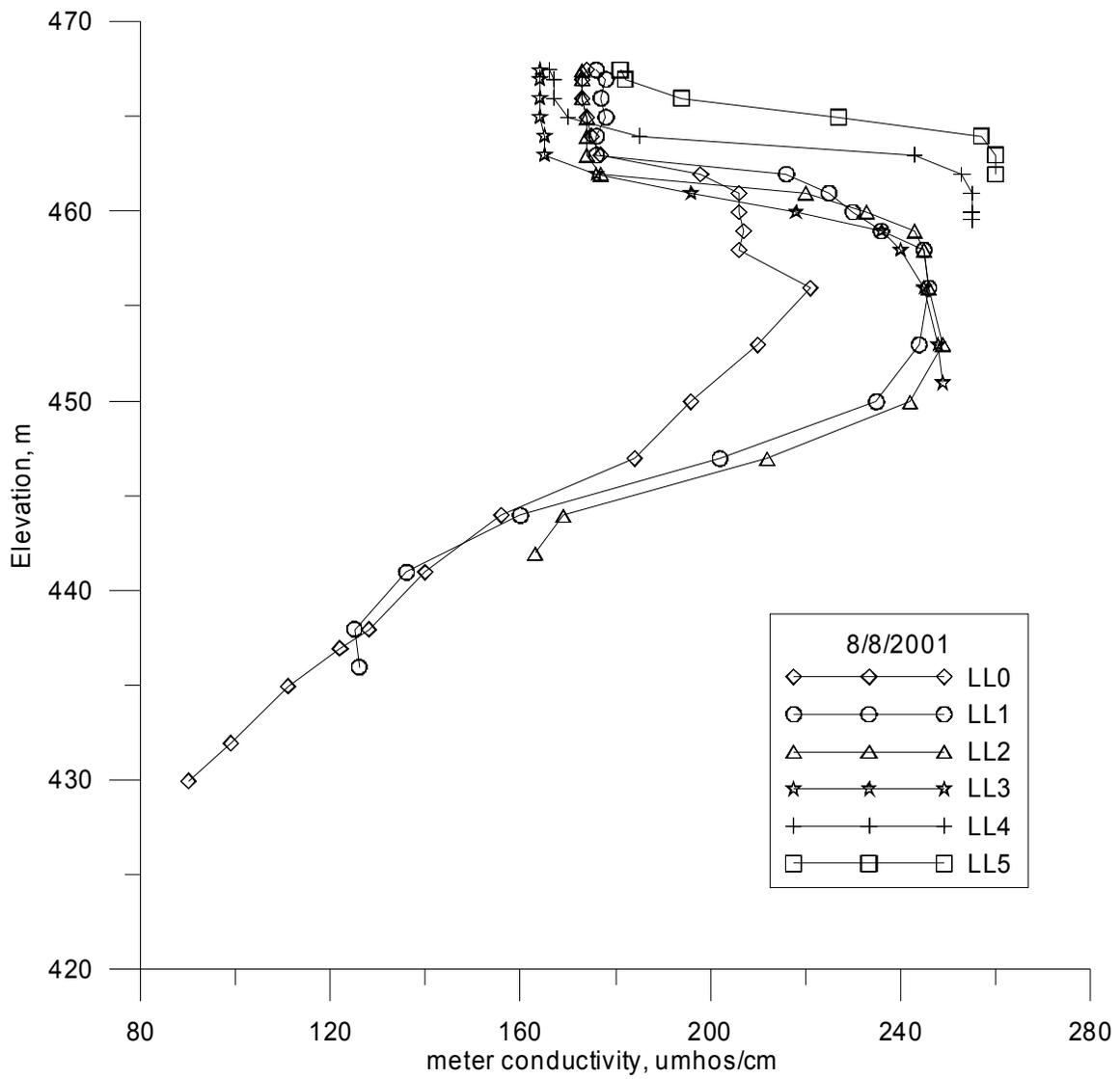
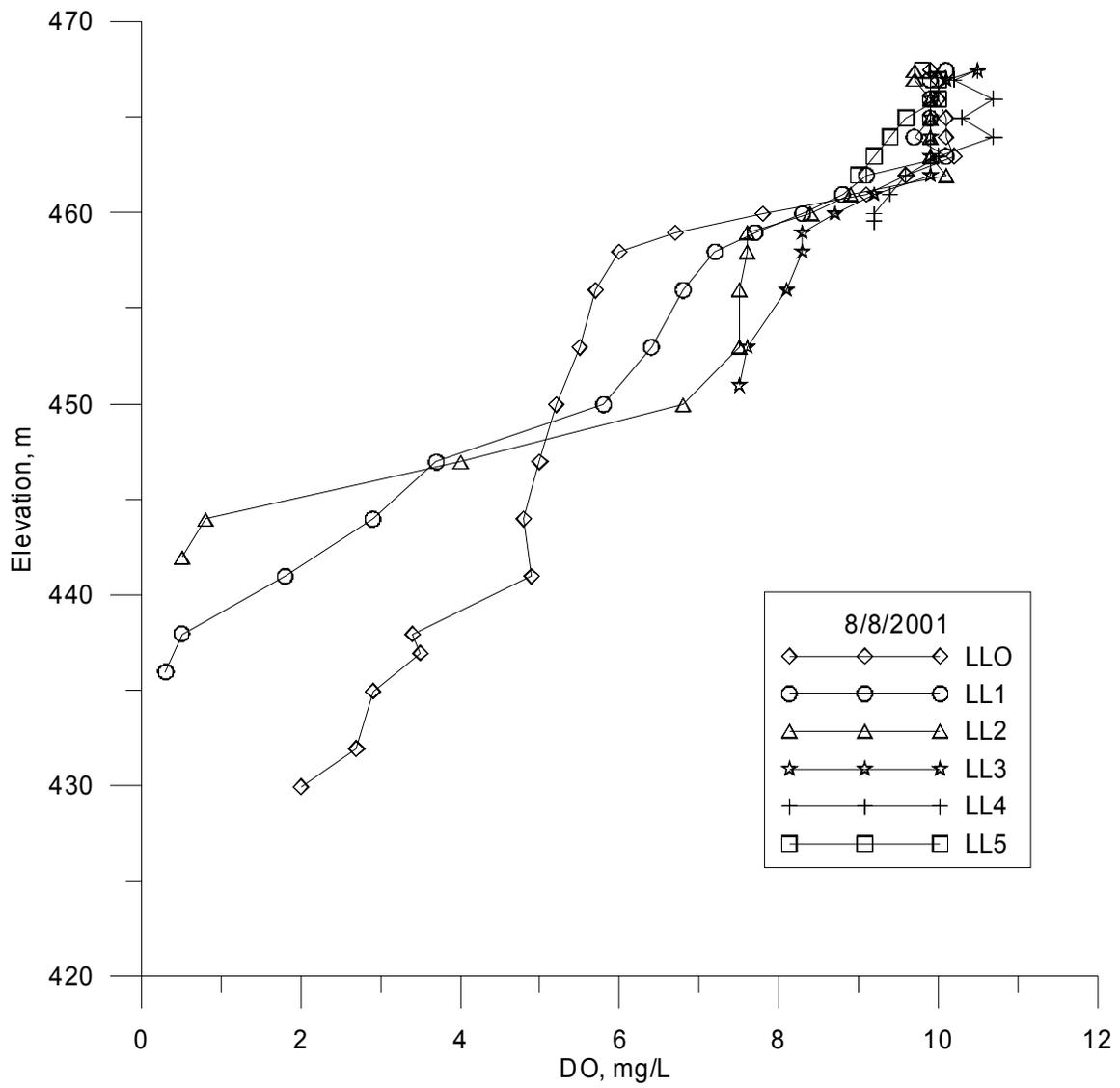


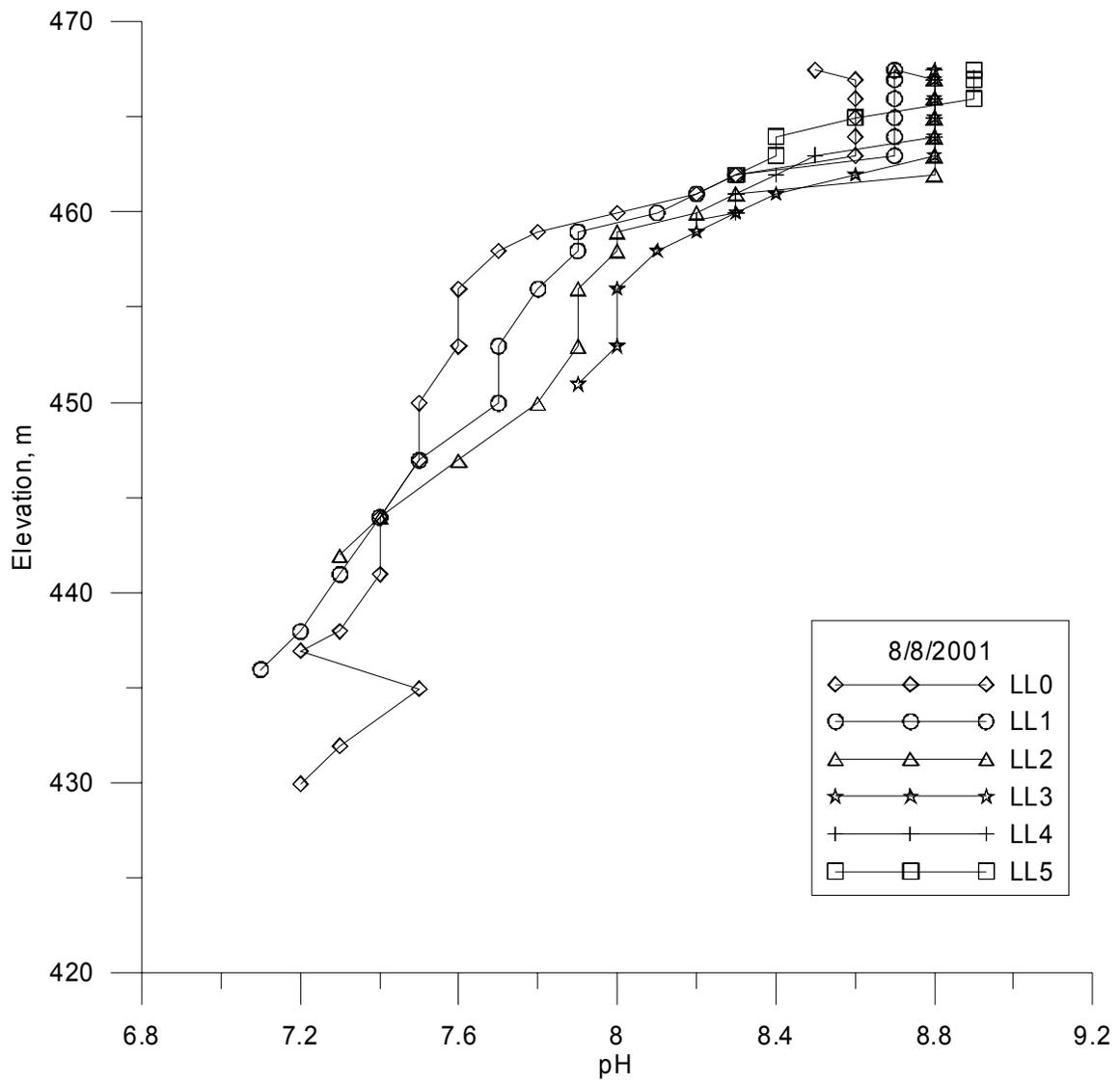
Figure 75. Vertical profiles Long Lake for temperature 8/8/2001



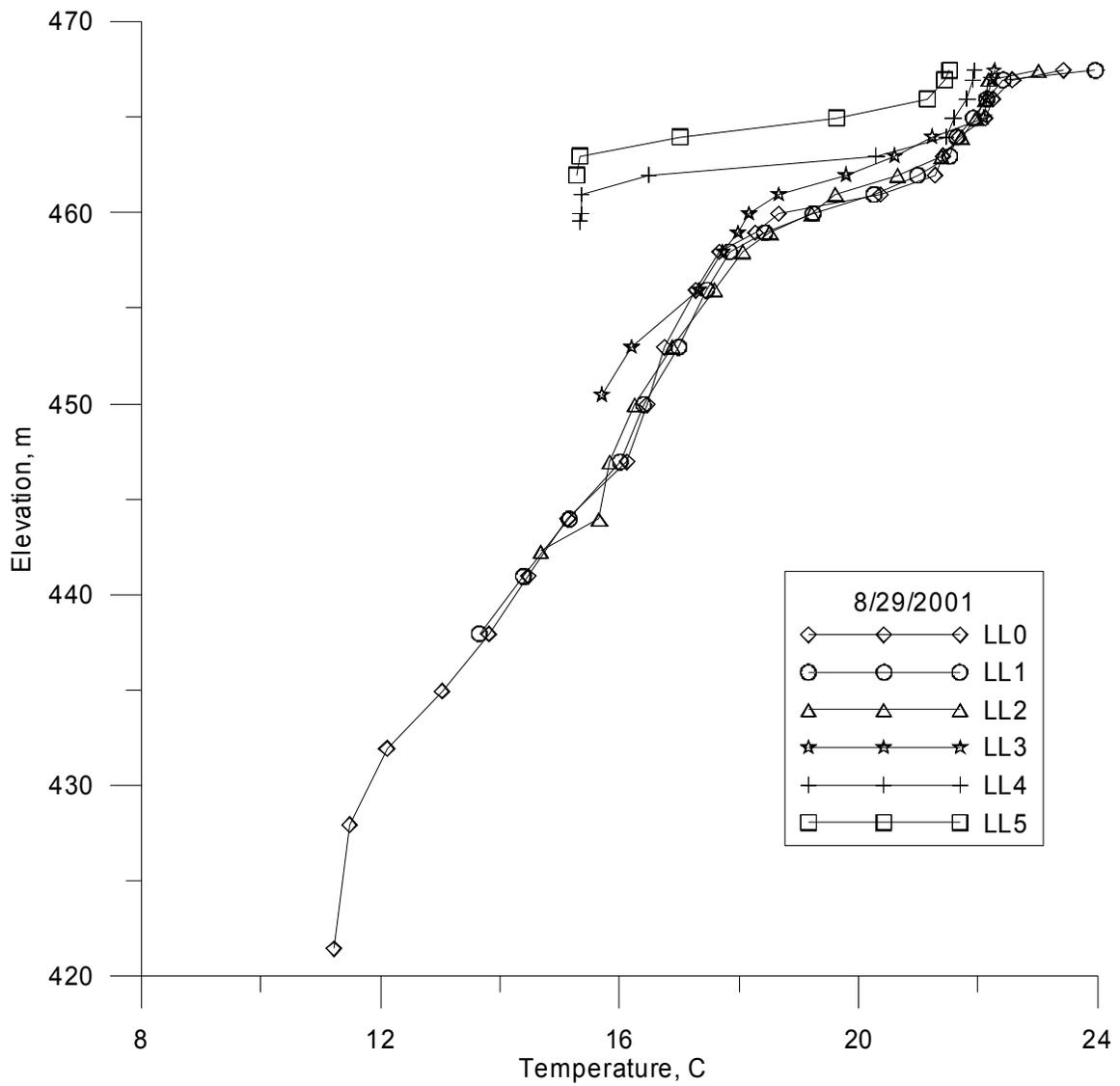
**Figure 76. Vertical profiles Long Lake for conductivity 8/8/2001**



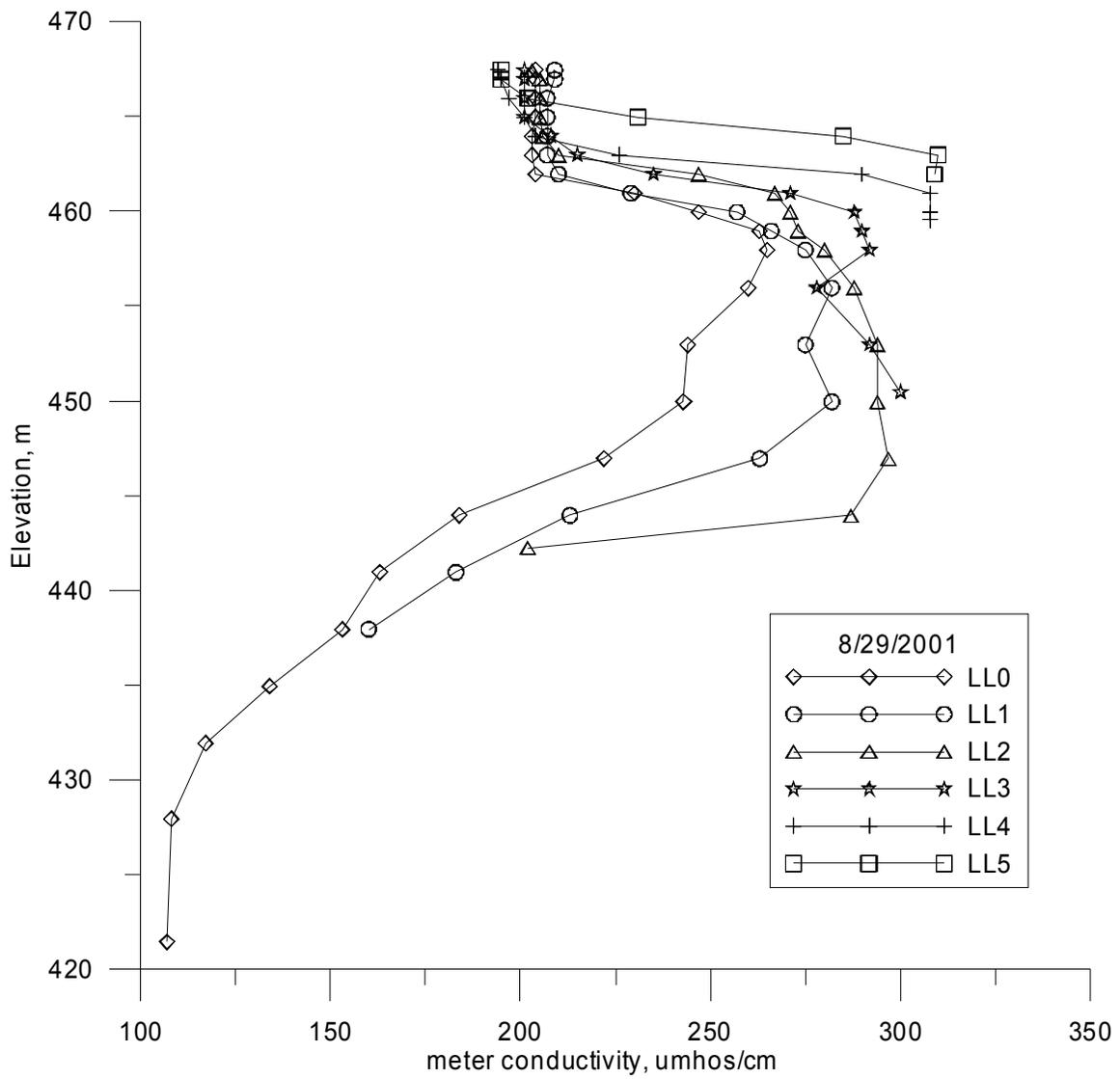
**Figure 77. Vertical profiles Long Lake for dissolved oxygen 8/8/2001**



**Figure 78. Vertical profiles Long Lake for pH 8/8/2001**



**Figure 79. Vertical profiles Long Lake for temperature 8/29/2001**



**Figure 80. Vertical profiles Long Lake for conductivity 8/29/2001**

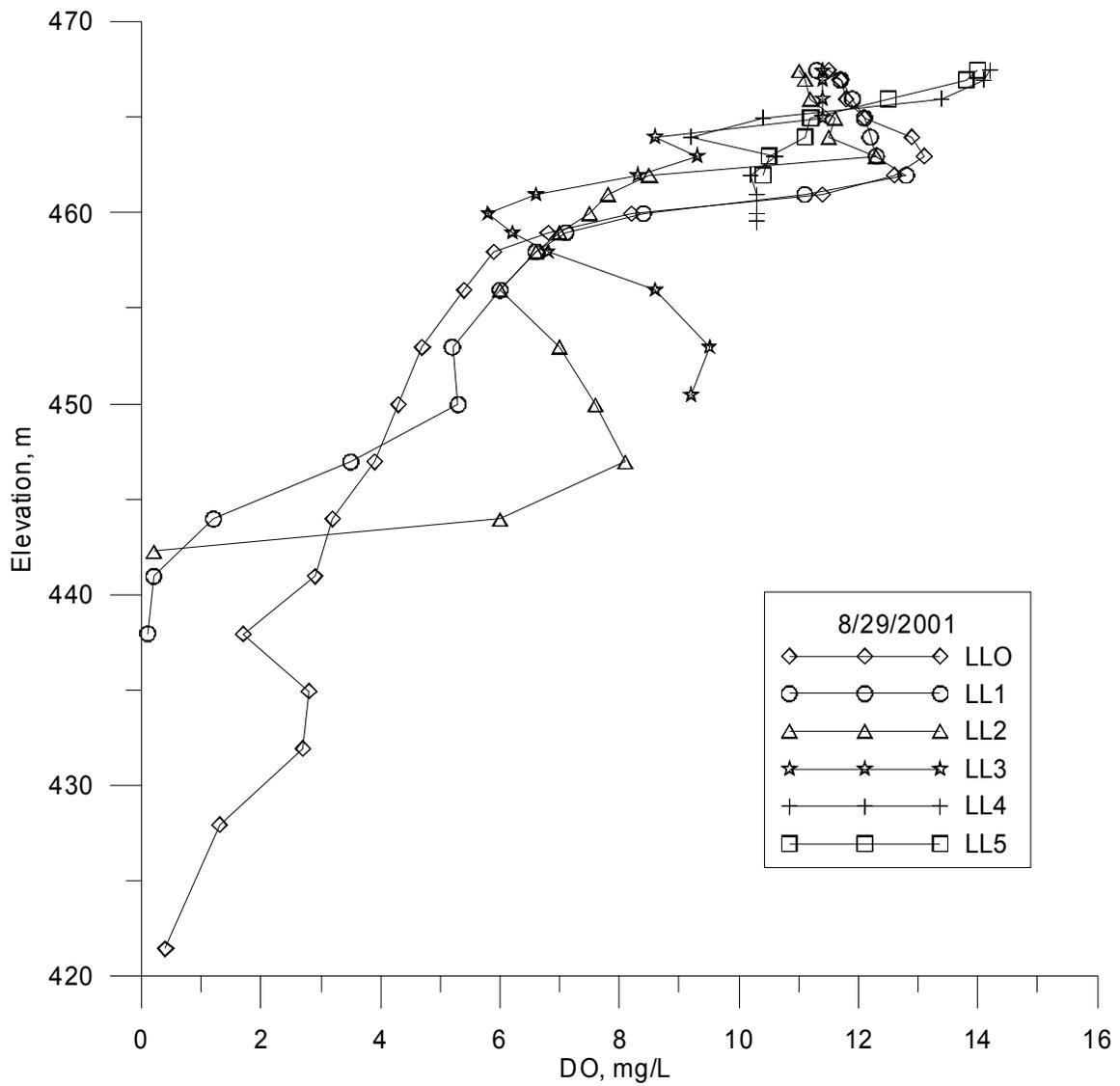


Figure 81. Vertical profiles Long Lake for dissolved oxygen 8/29/2001

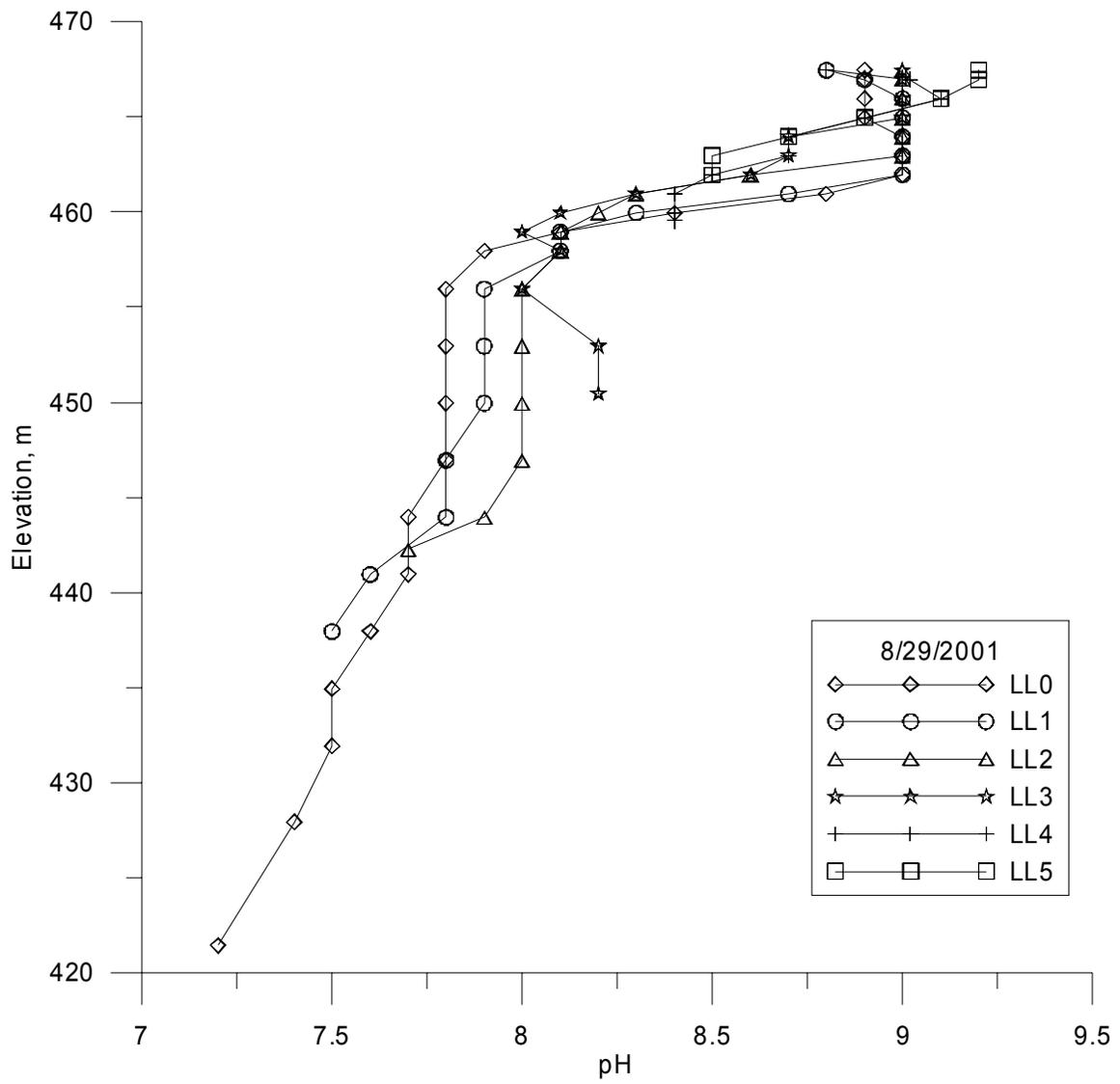


Figure 82. Vertical profiles Long Lake for pH 8/29/2001

## Appendix B: Longitudinal Profiles

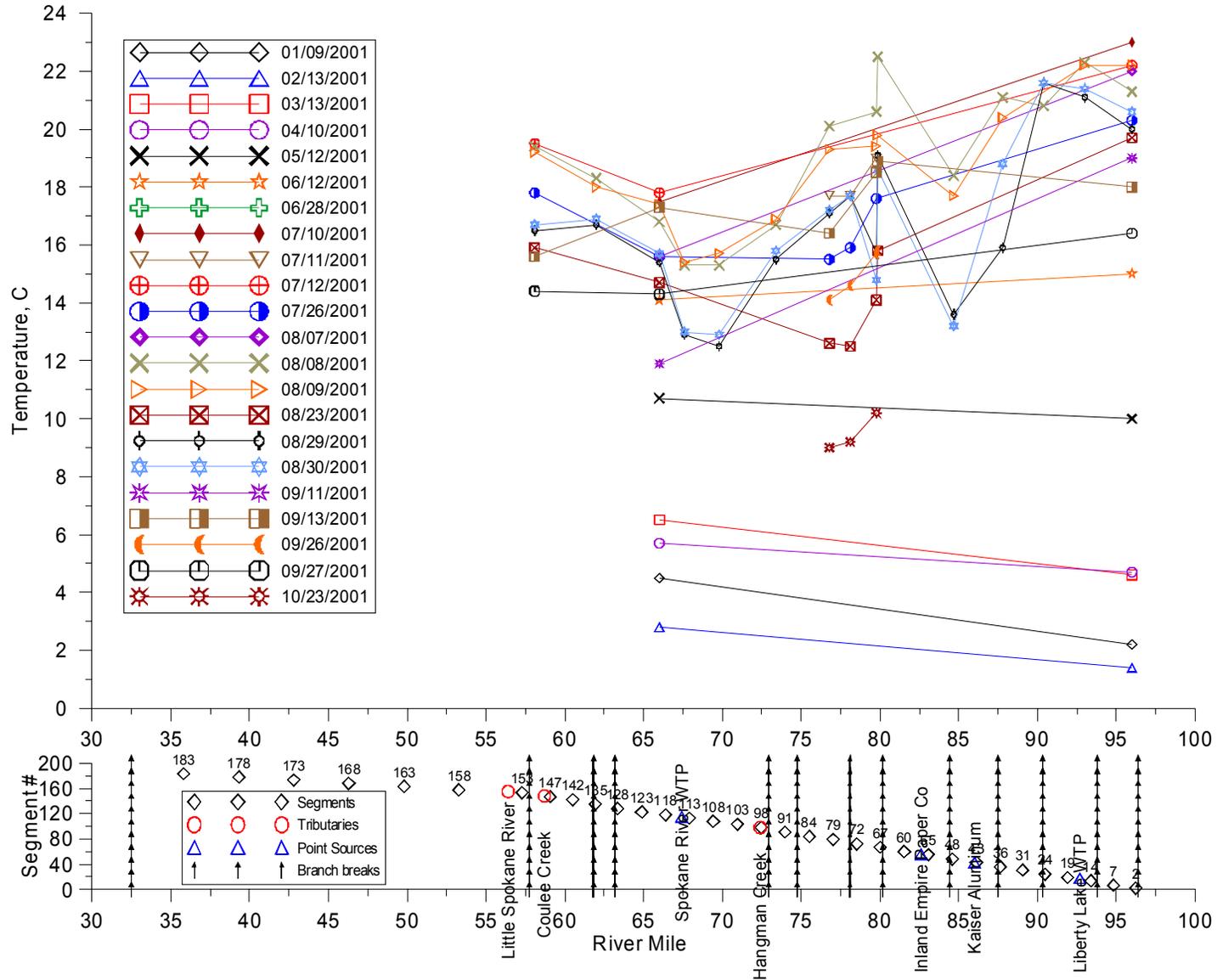


Figure 83. Longitudinal profiles in Spokane River for temperature 2001

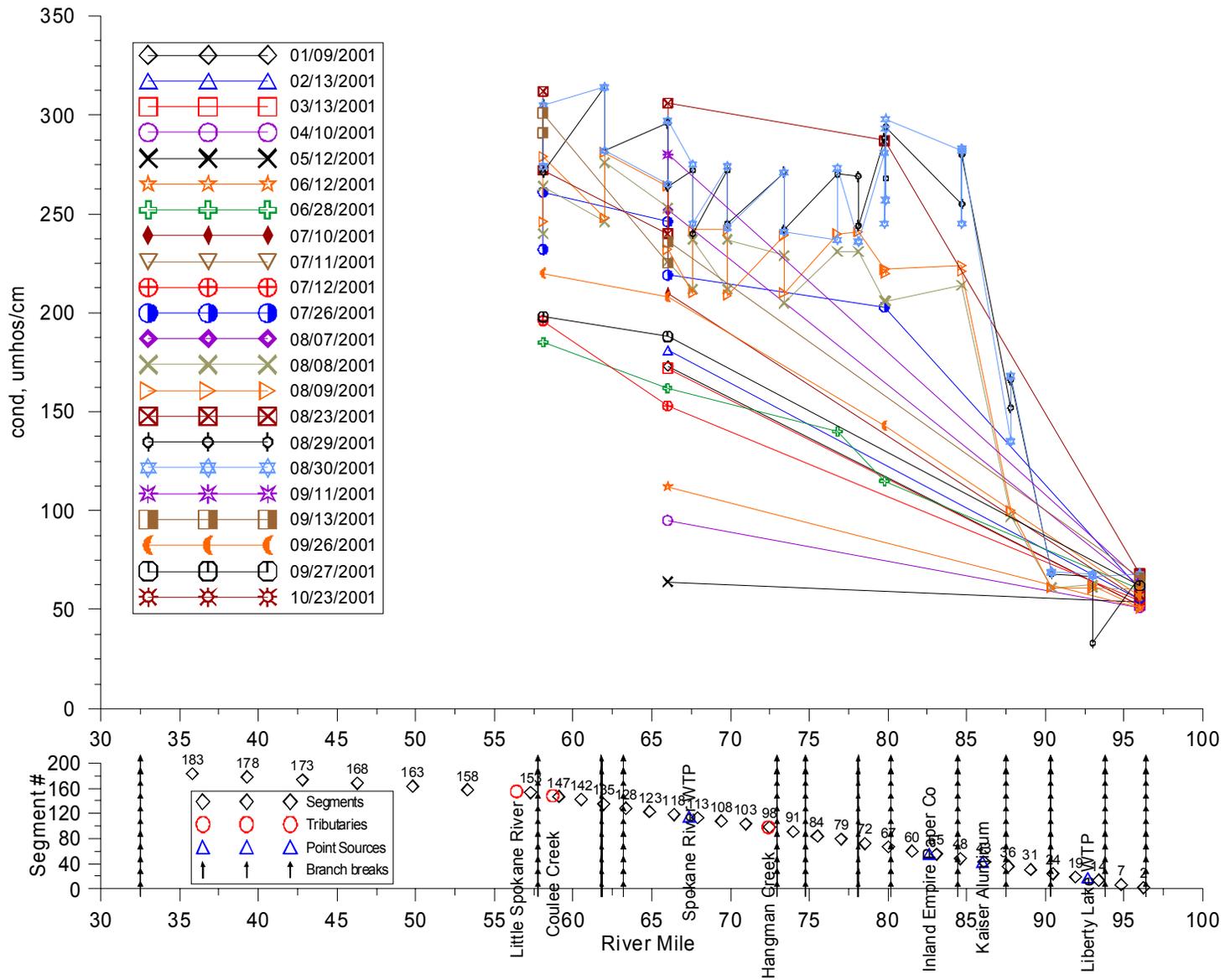
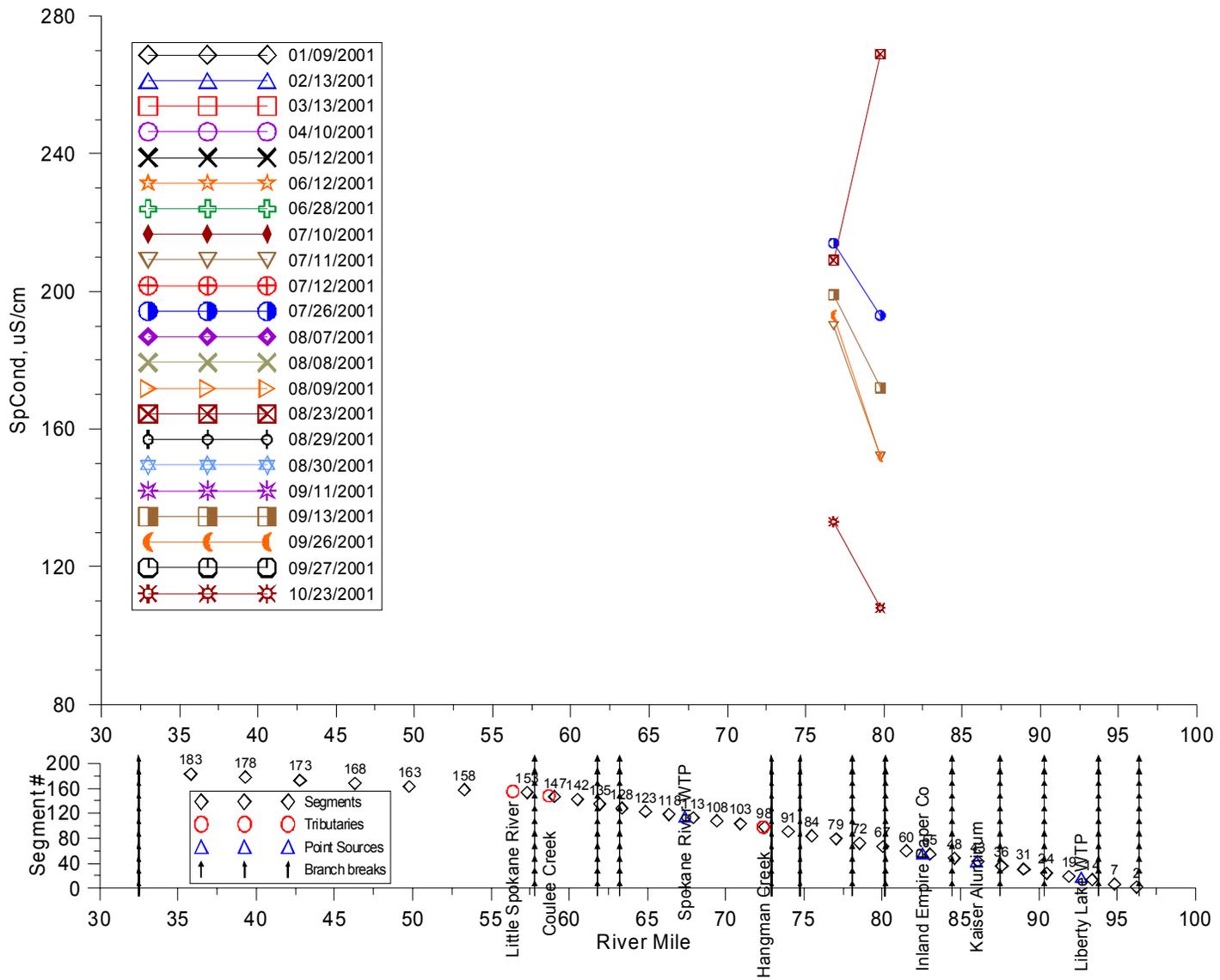
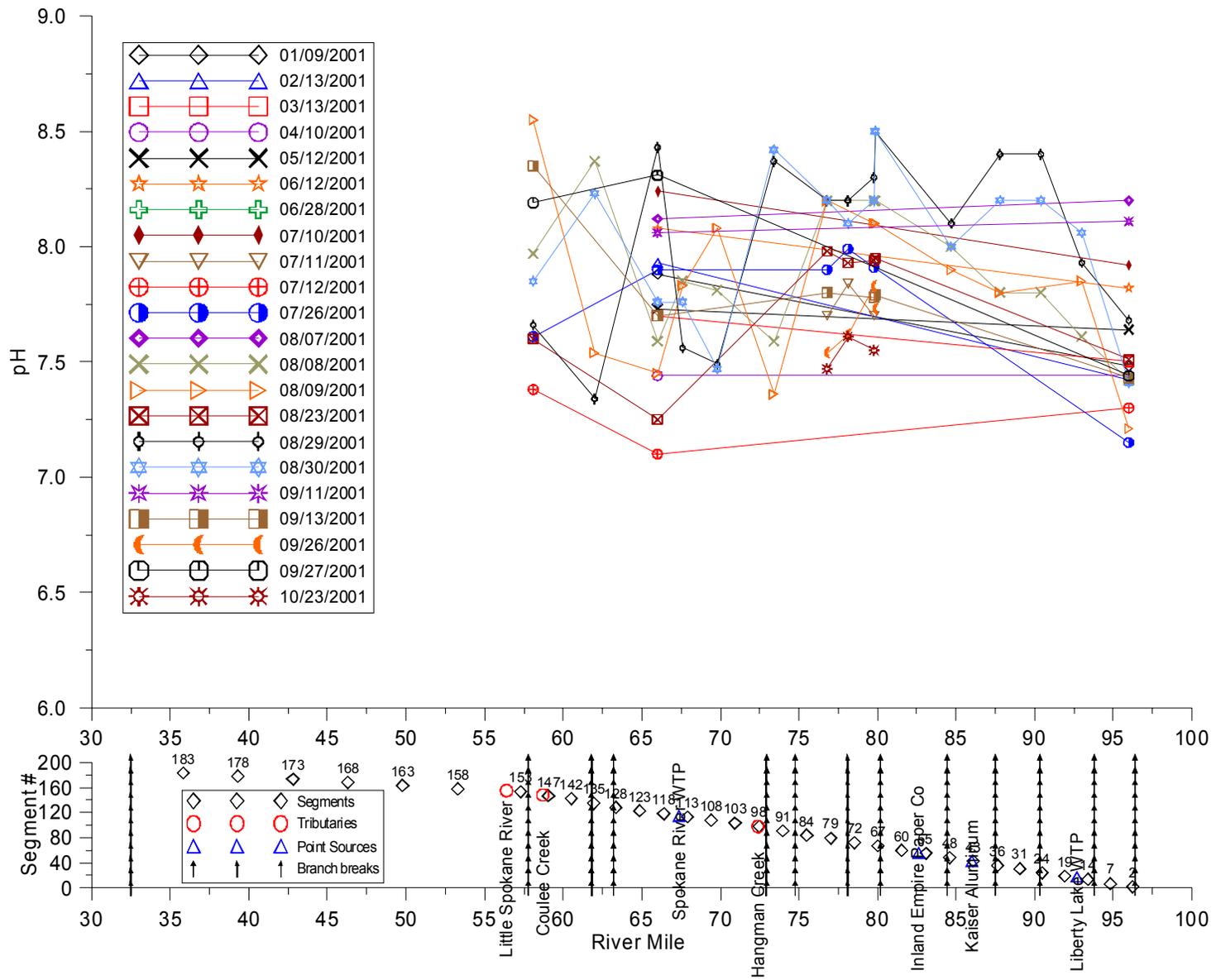


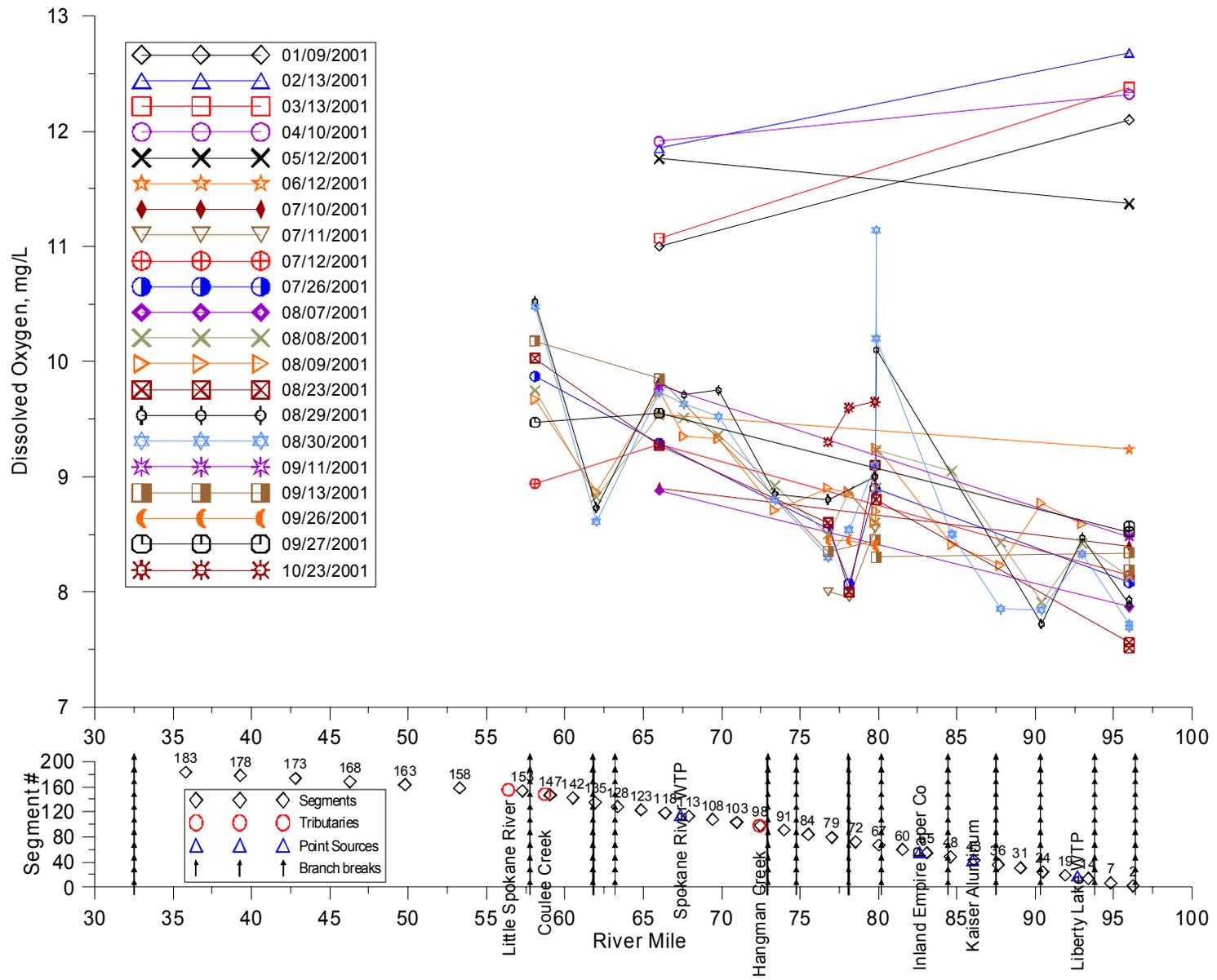
Figure 84. Longitudinal profiles in Spokane River for conductivity 2001



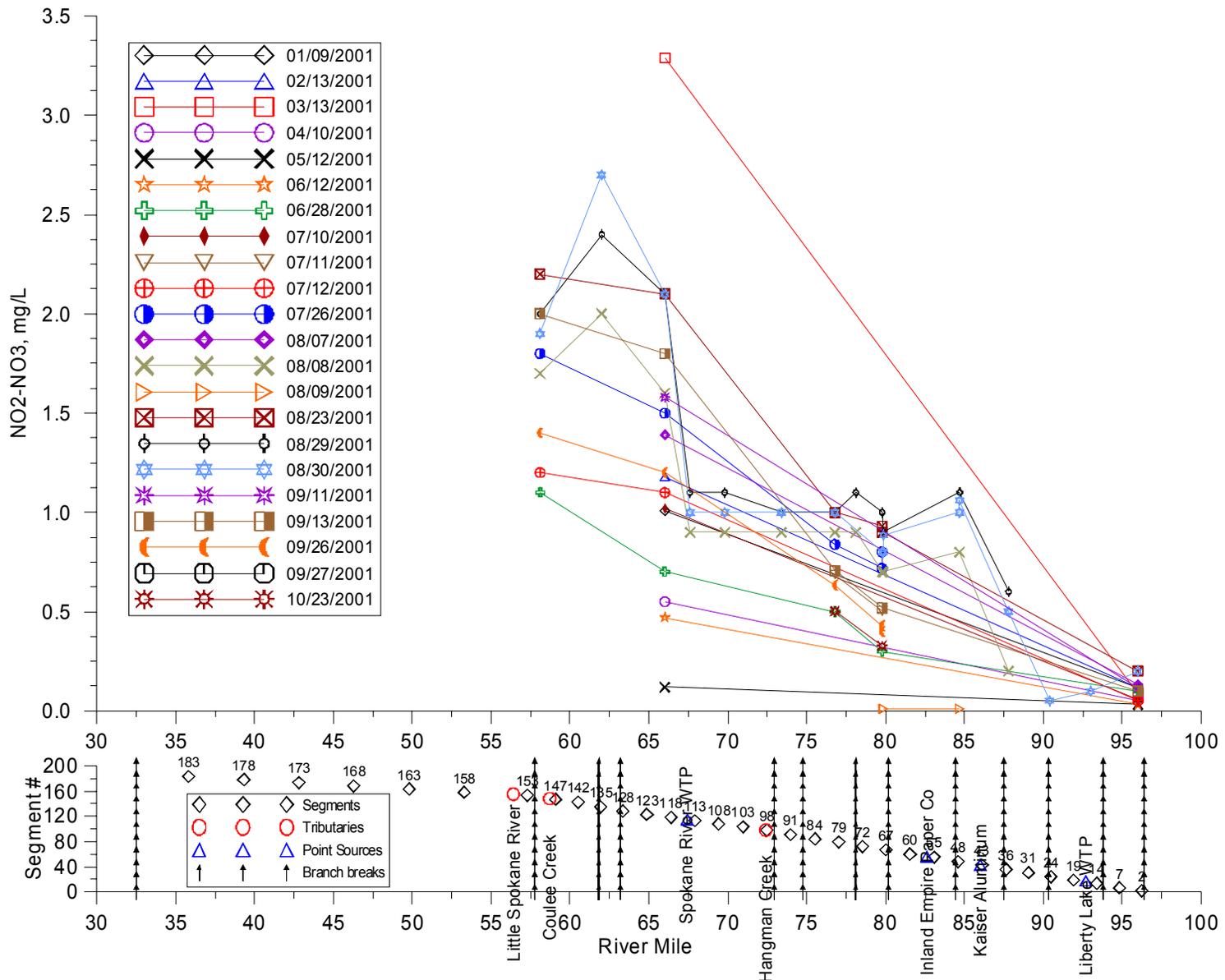
**Figure 85. Longitudinal profiles in Spokane River for Sp conductivity 2001**



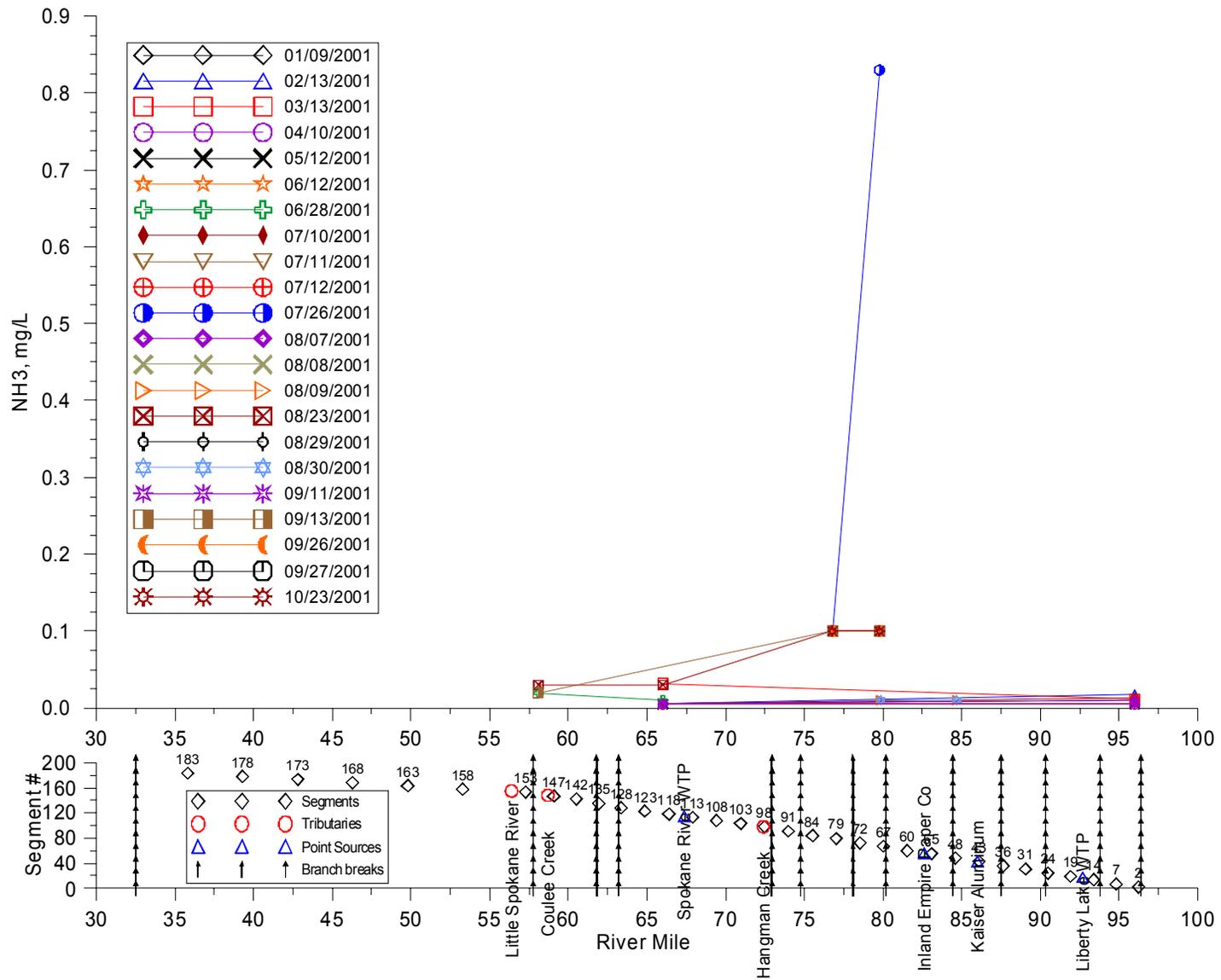
**Figure 86. Longitudinal profiles in Spokane River for pH 2001**

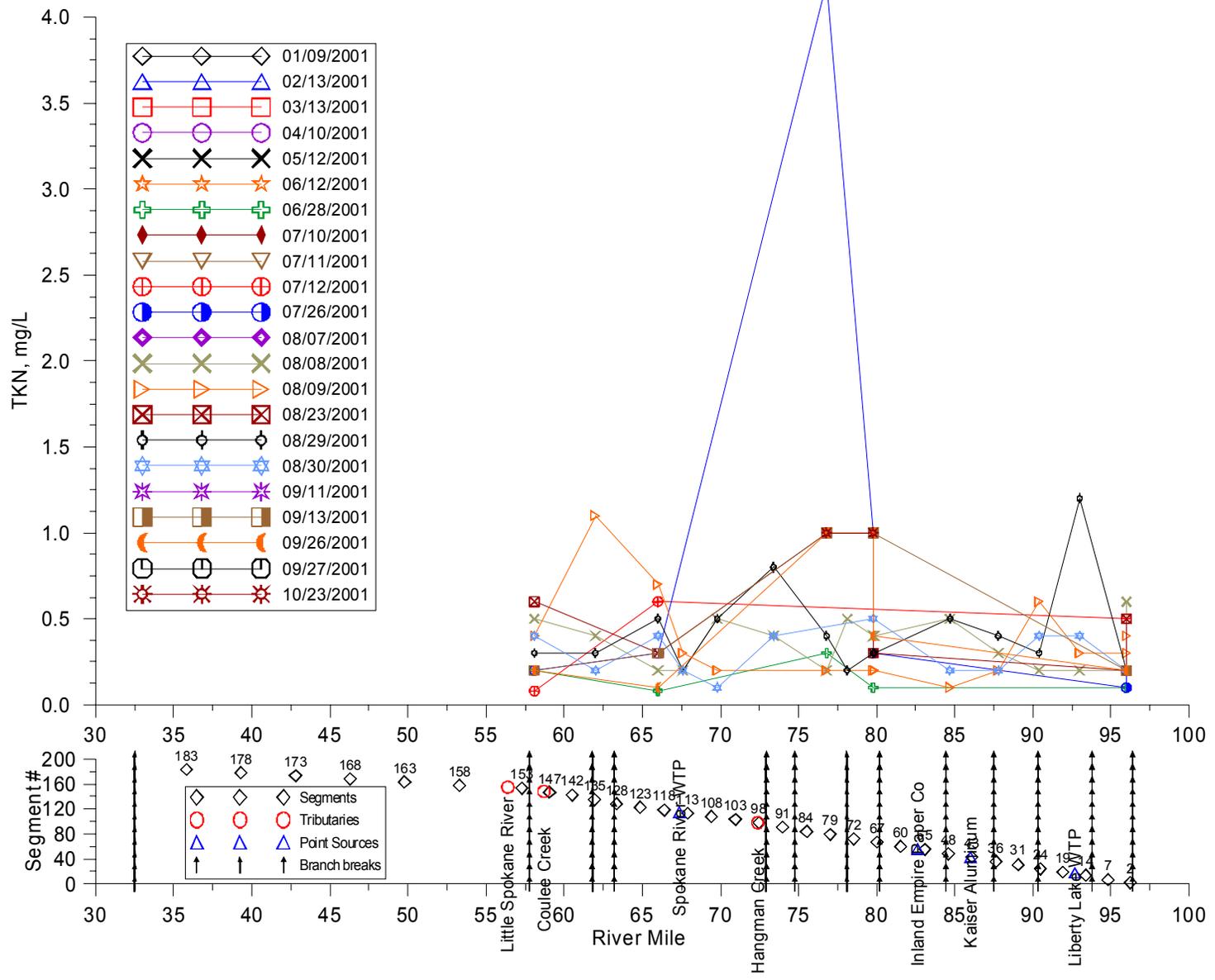


**Figure 87. Longitudinal profiles in Spokane River for dissolved oxygen 2001**



**Figure 88. Longitudinal profiles in Spokane River for NO<sub>2</sub>-NO<sub>3</sub>-N 2001**





**Figure 90. Longitudinal profiles in Spokane River for TKN 2001**

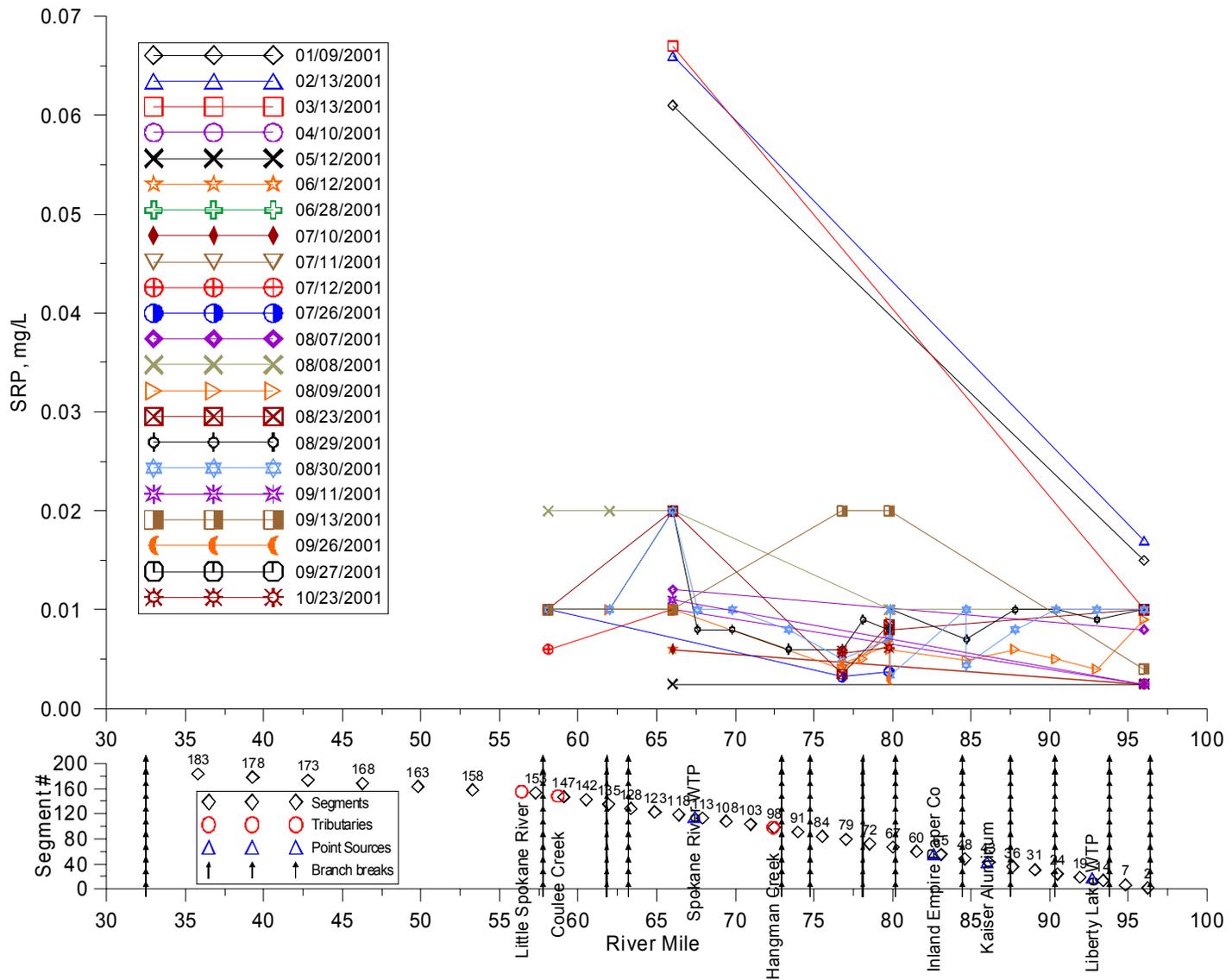


Figure 91. Longitudinal profiles in Spokane River for SRP 2001

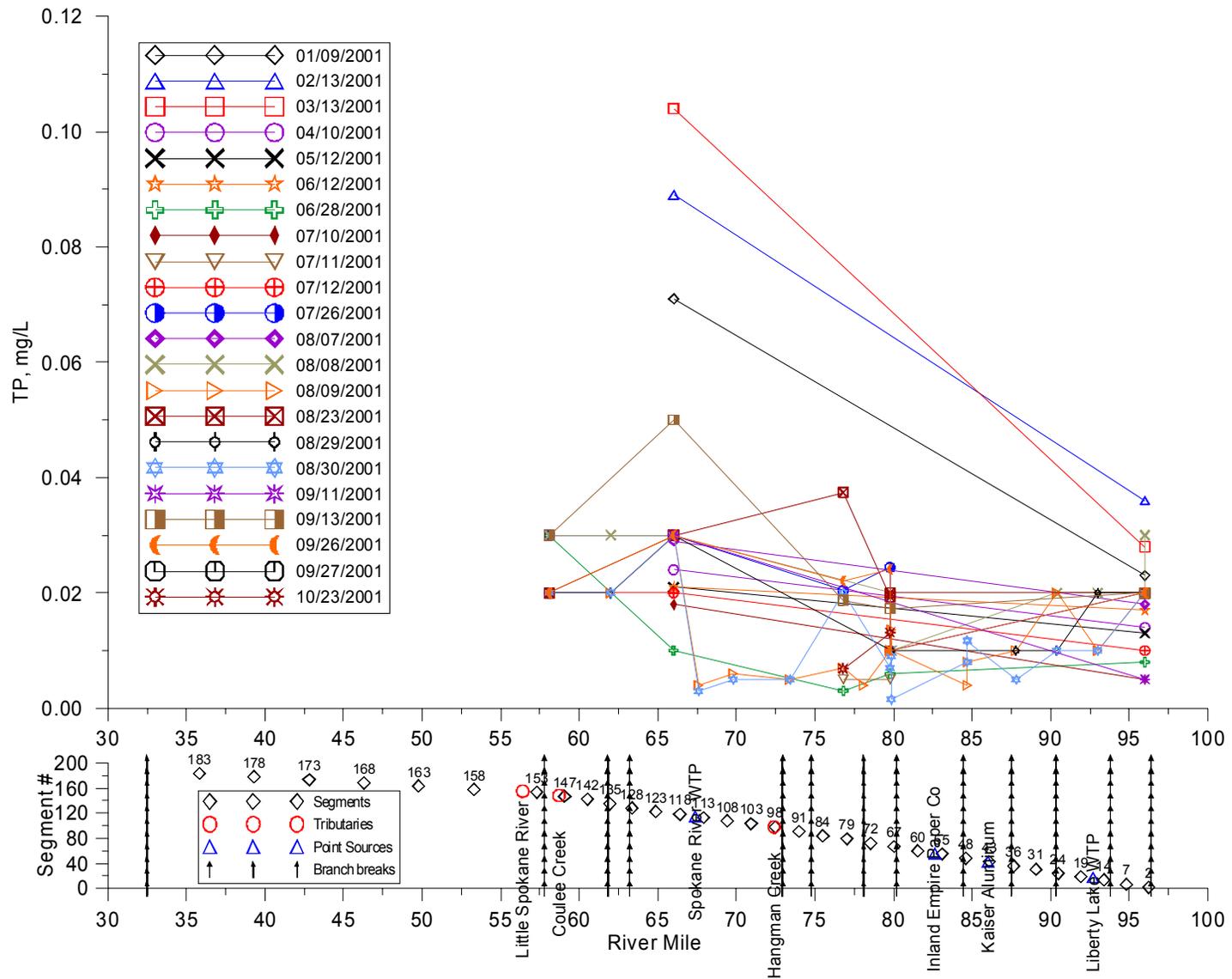
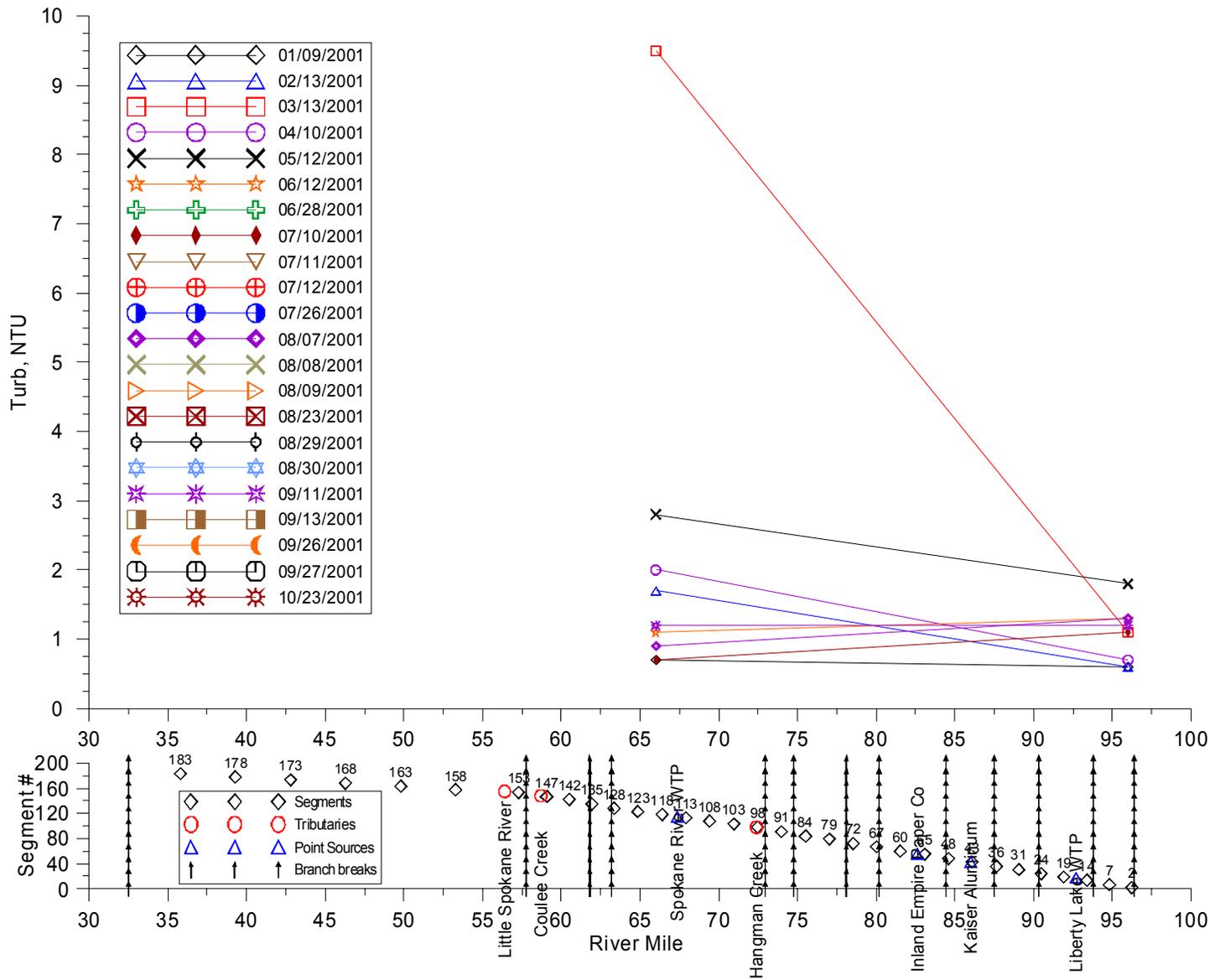
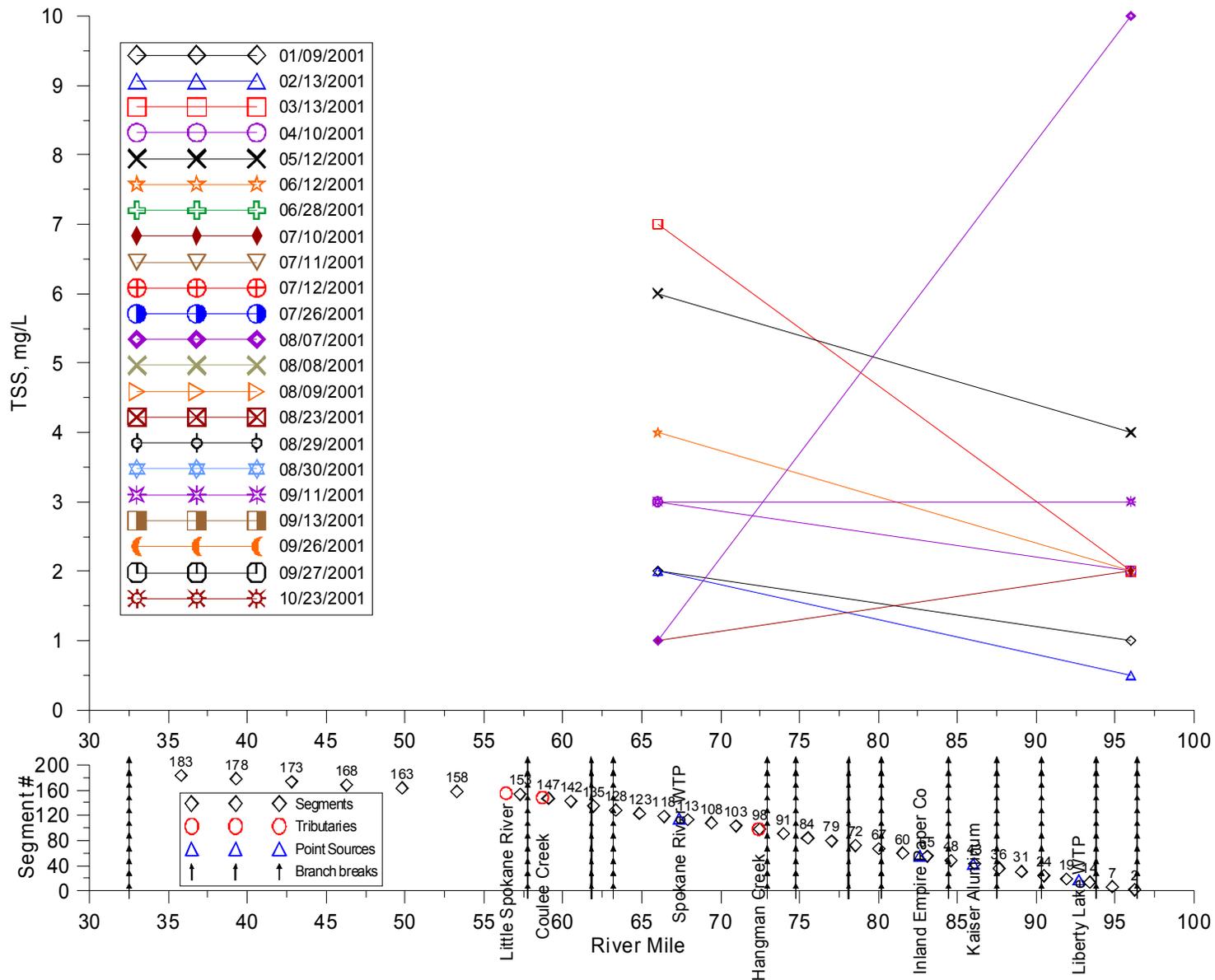


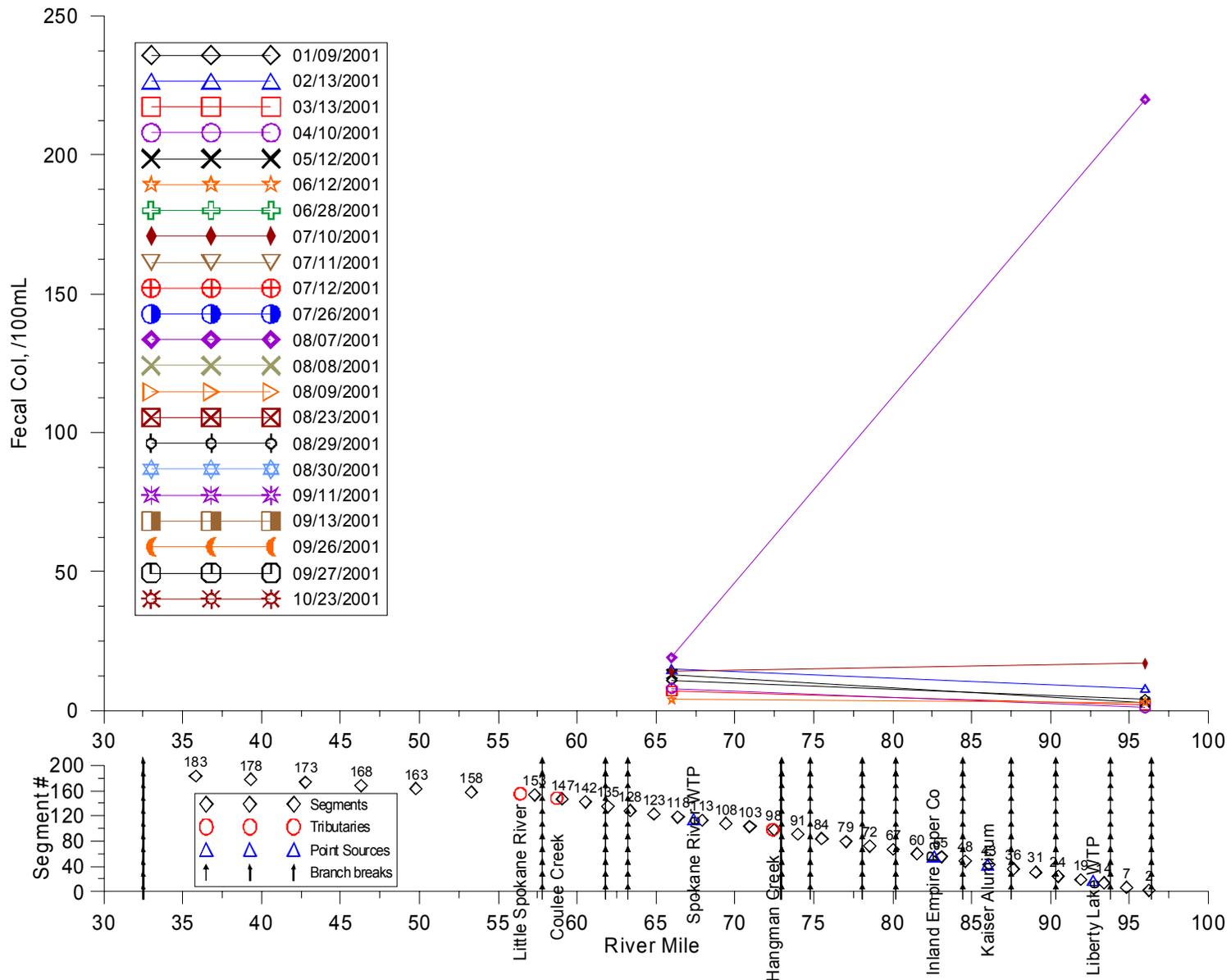
Figure 92. Longitudinal profiles in Spokane River for TP 2001



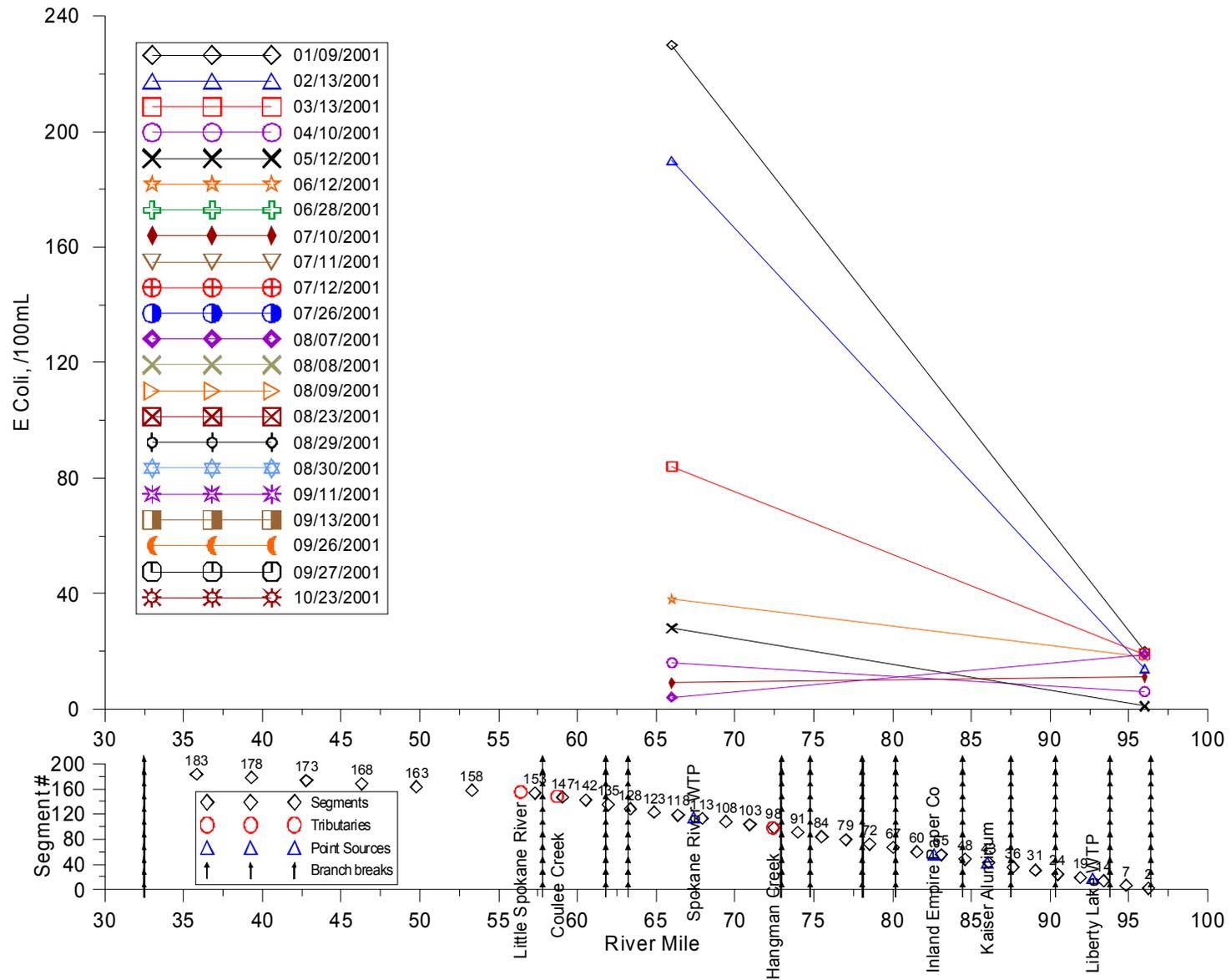
**Figure 93. Longitudinal profiles in Spokane River for turbidity 2001**



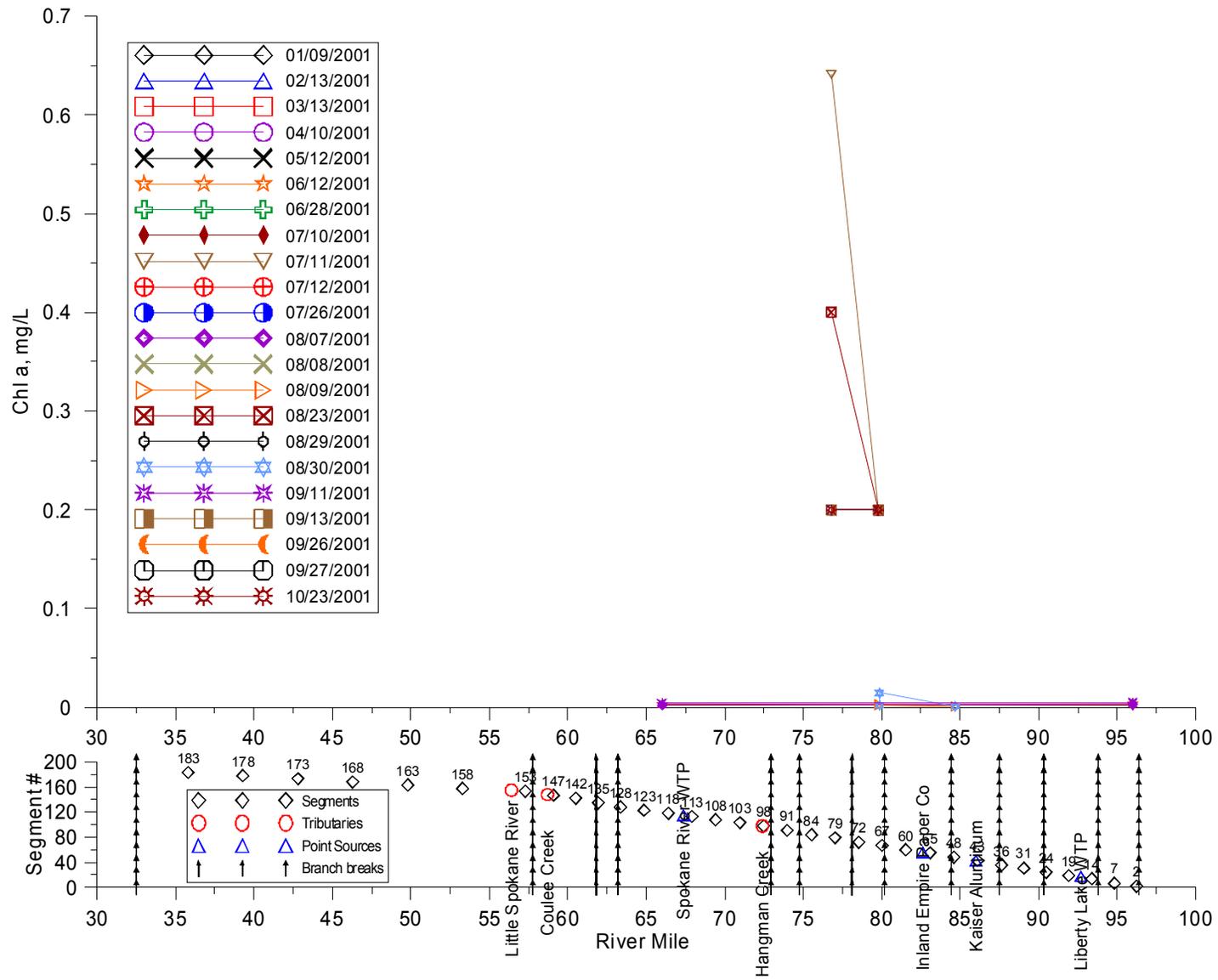
**Figure 94. Longitudinal profiles in Spokane River for TSS 2001**



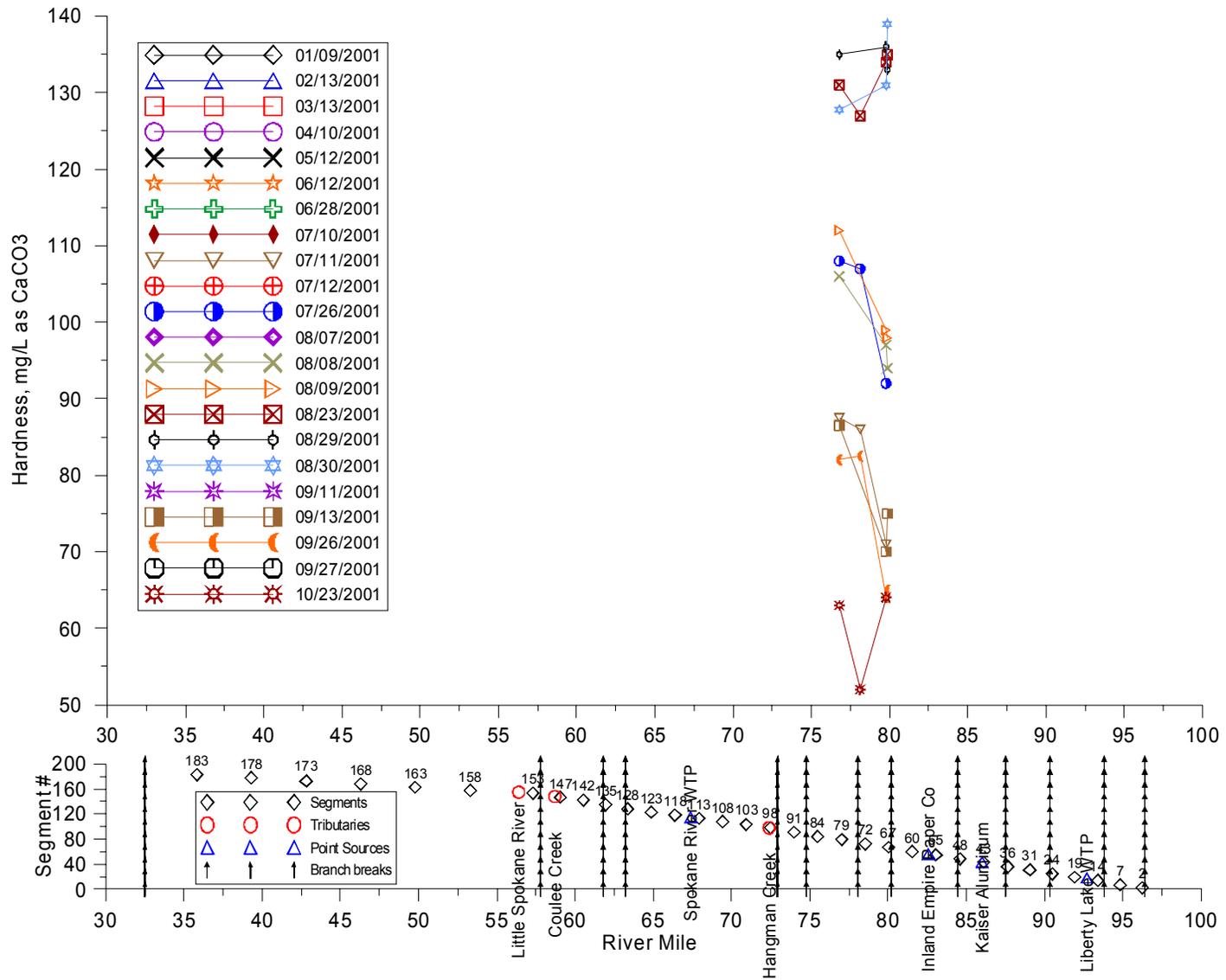
**Figure 95. Longitudinal profiles in Spokane River for fecal coliform 2001**



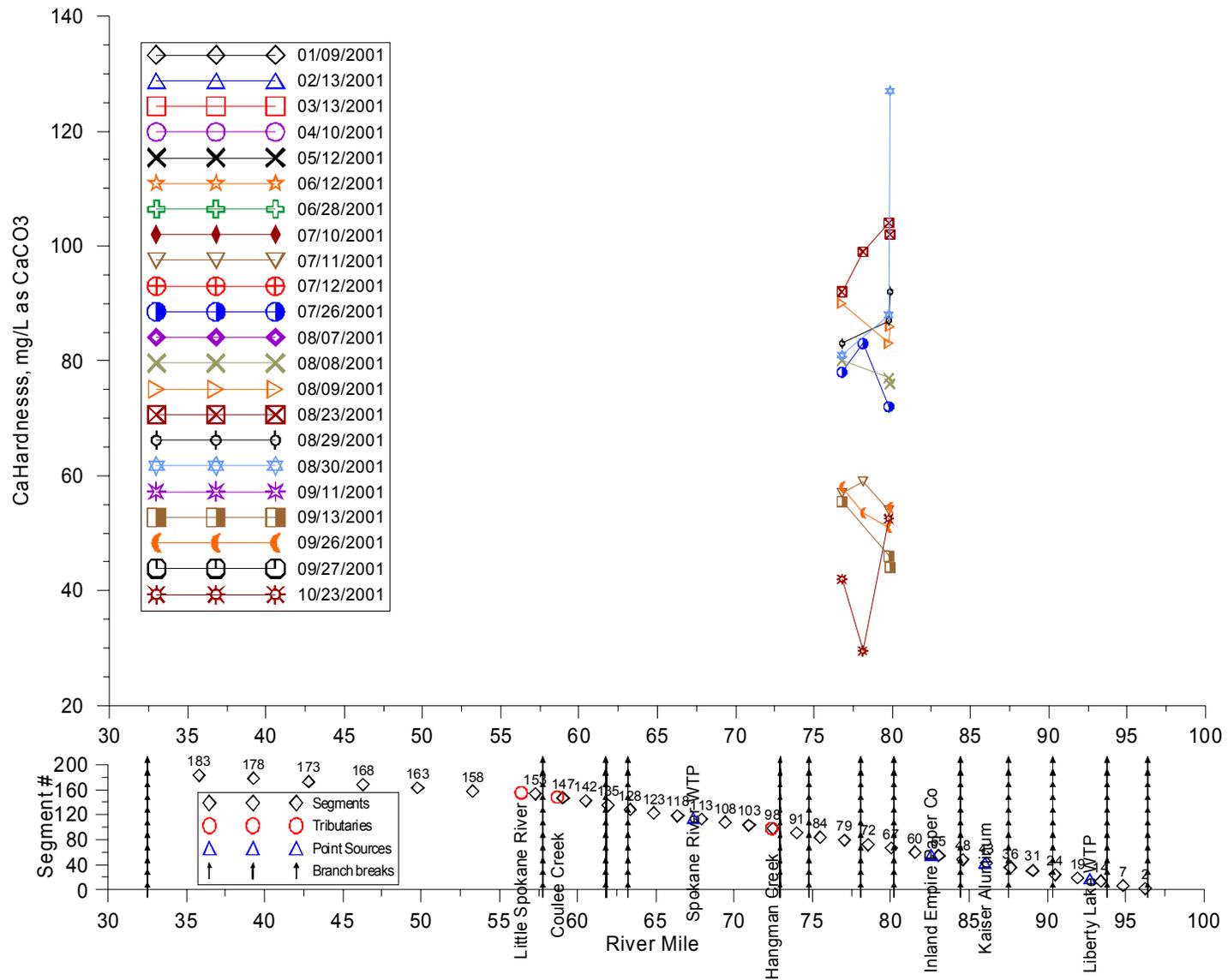
**Figure 96. Longitudinal profiles in Spokane River for E. coli 2001**

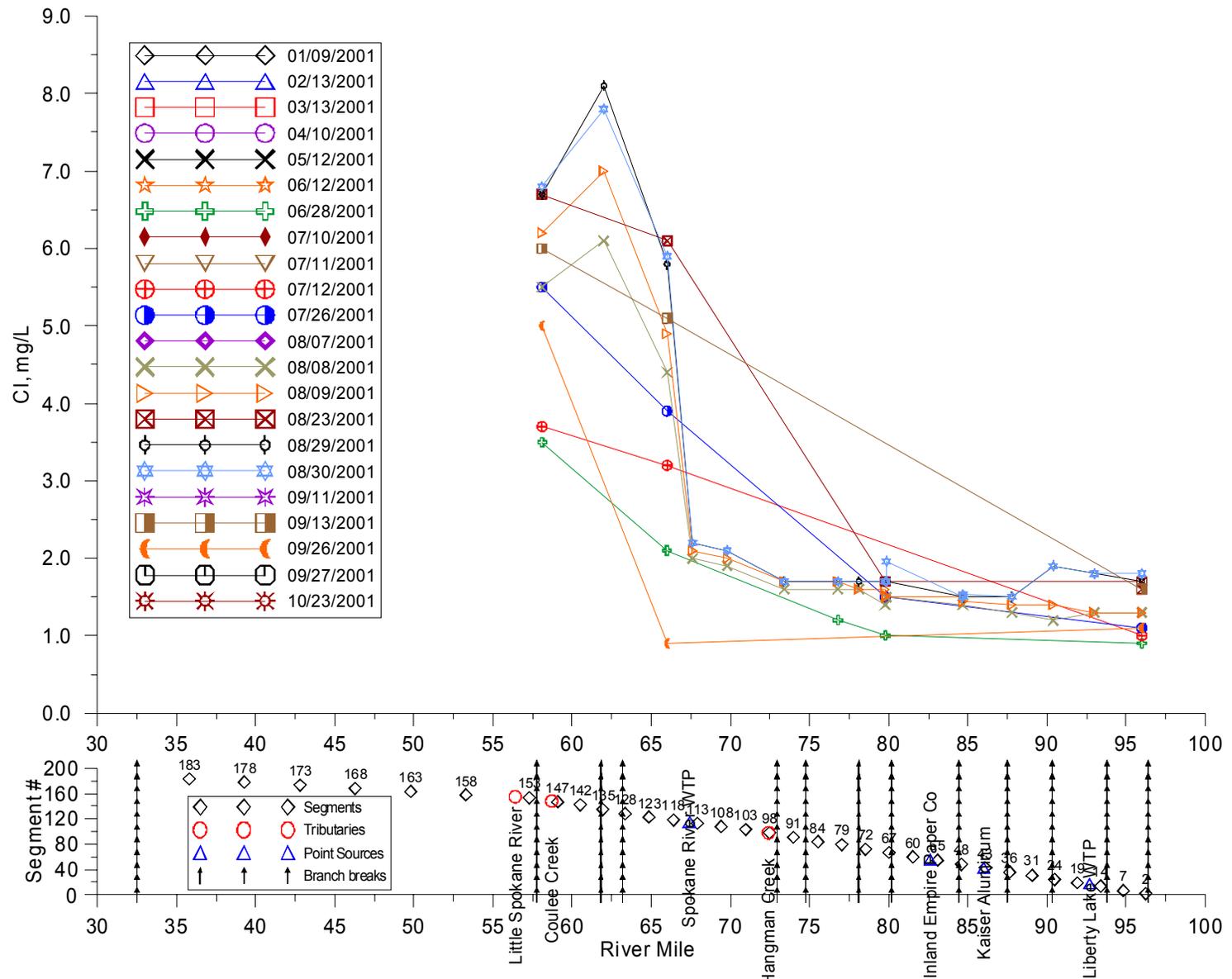


**Figure 97. Longitudinal profiles in Spokane River for chlorophyll a 2001**

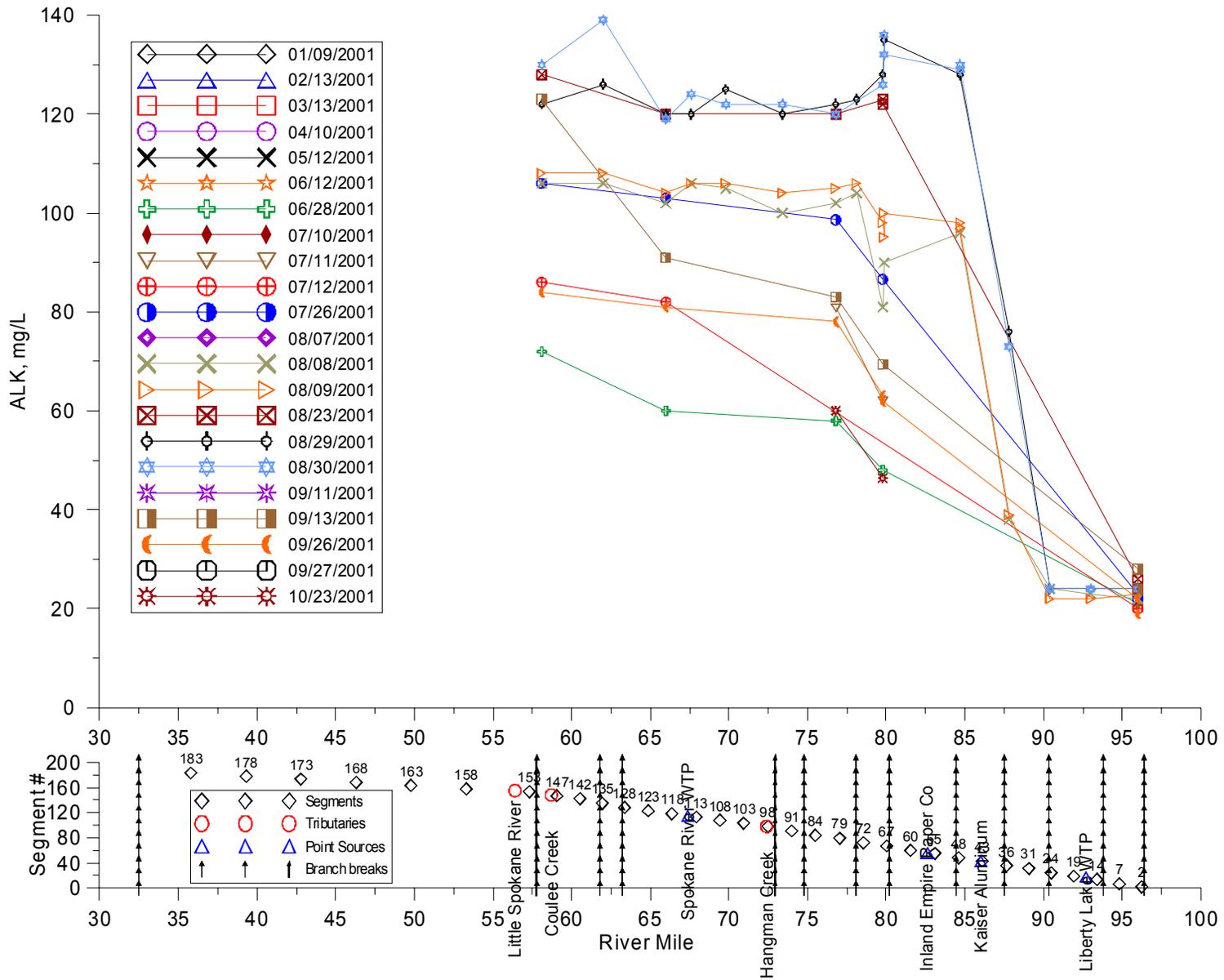


**Figure 98. Longitudinal profiles in Spokane River for hardness 2001**

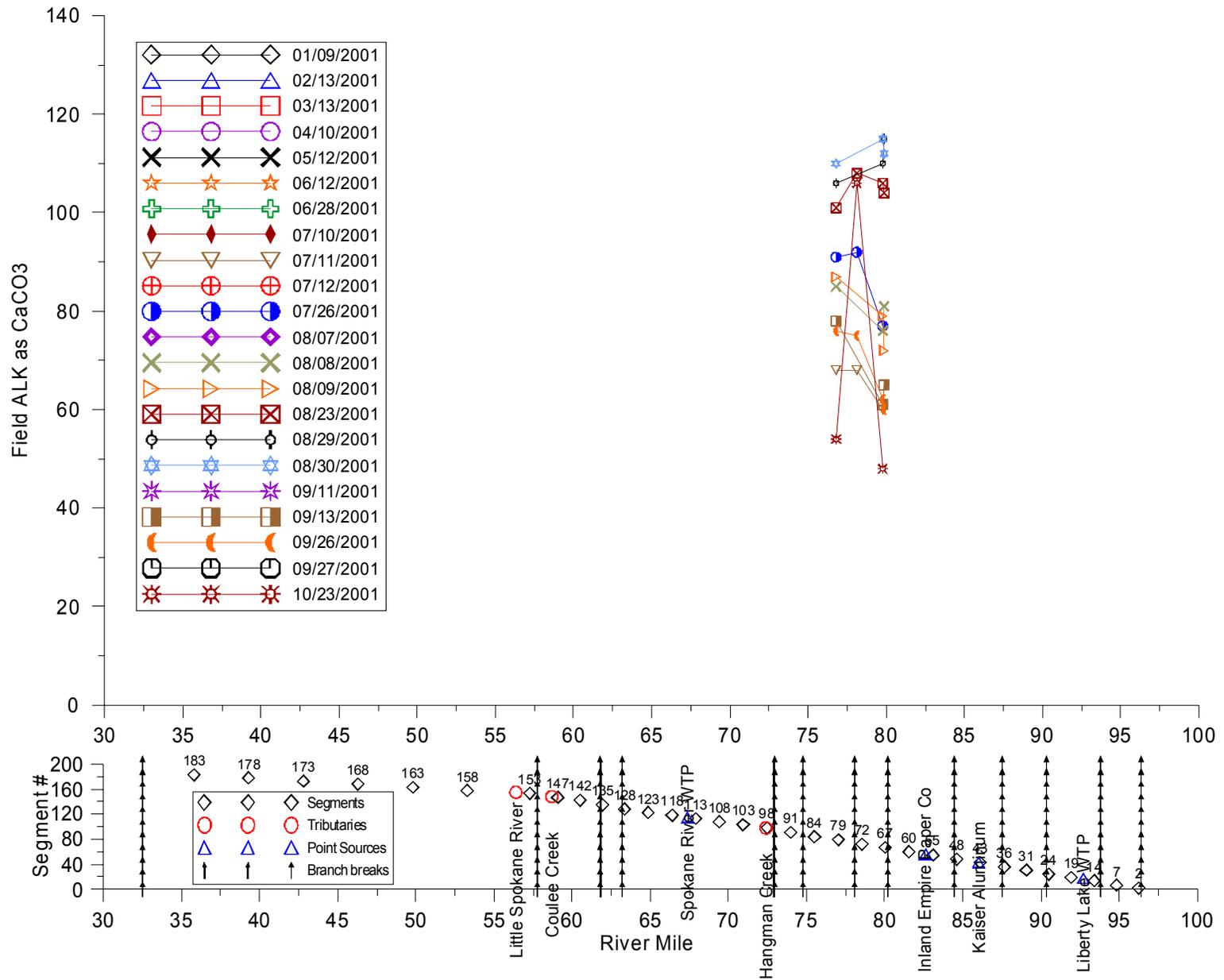




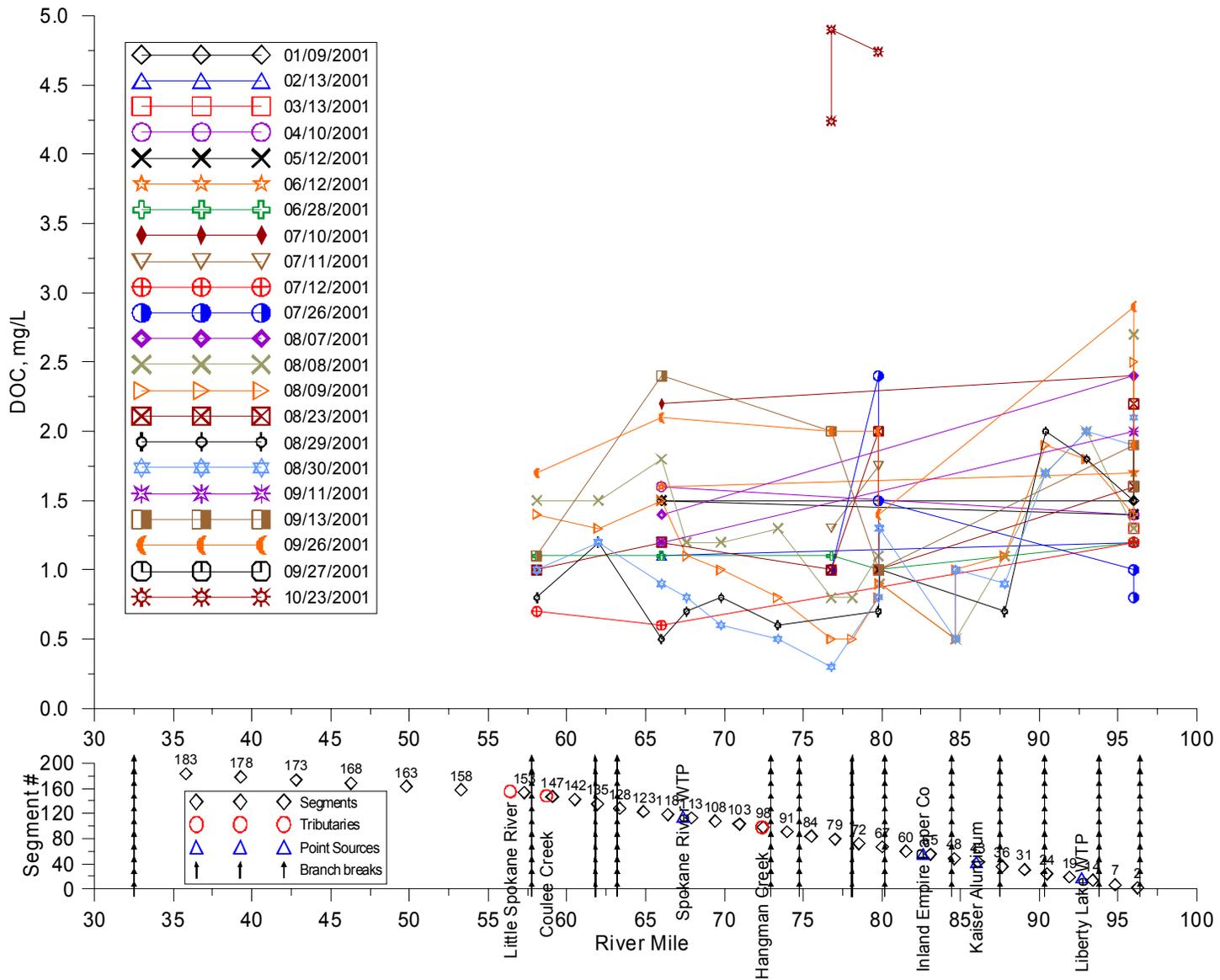
**Figure 100. Longitudinal profiles in Spokane River for CI 2001**



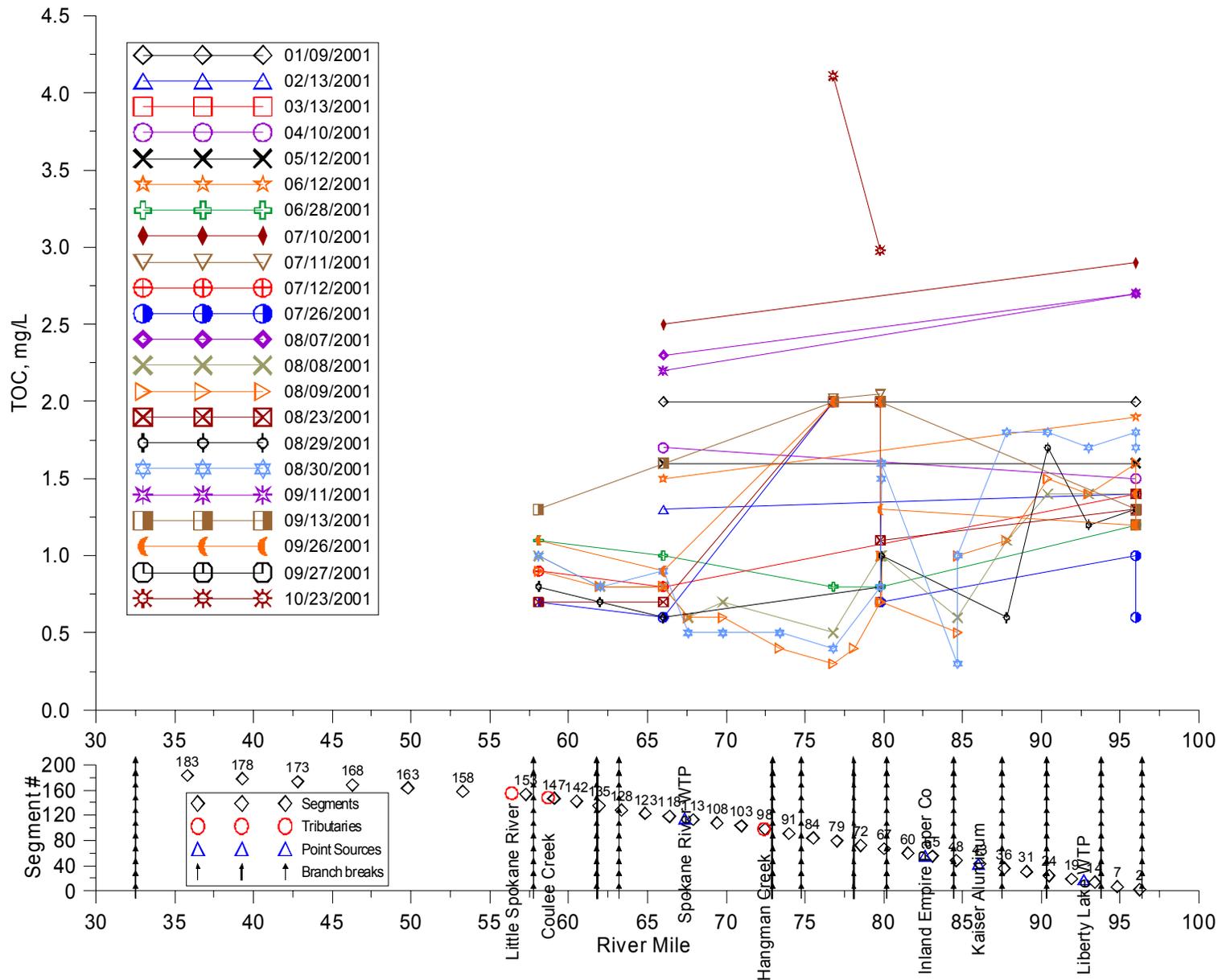
**Figure 101. Longitudinal profiles in Spokane River for alkalinity 2001**



**Figure 102. Longitudinal profiles in Spokane River for Field alkalinity 2001**



**Figure 103. Longitudinal profiles in Spokane River for DOC 2001**



**Figure 104. Longitudinal profiles in Spokane River for TOC 2001**