Chehalis Best Management Practices Evaluation Project

1995-2000 Temperature Monitoring Data

November 2001

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1995-2000 Temperature Monitoring Data

by
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November 2001

Waterbody Numbers: (see Abstract)

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Table of Contents

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List of Appendices

List of Appendices (cont.)

List of Figures

Page

List of Figures (cont.)

List of Tables

Page

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Abstract

This report describes the 1995-2000 water temperature results for monitoring conducted in the Chehalis River basin.

Results are presented for long-term temperature monitoring in the upper Chehalis basin. The five monitoring sites were near the mouths of four tributaries to the Chehalis River – Black River, Lincoln Creek, South Fork Chehalis River, Newaukum River – as well as in the mainstem Chehalis River upstream of the Newaukum River. All sites showed water temperature violations, with three of the five sites exceeding temperatures of 25°C. Recommendations include continued monitoring and implementation of basin-wide riparian restoration activities.

Results are also presented for monitoring to determine the effectiveness of riparian shading practices in reducing water temperature. Results represent pre-shade conditions. Upstream and downstream sampling was conducted at seven monitoring sites: Mill Creek, North Fork Lincoln Creek, a tributary to Mohney Creek, south tributary of Salzer Creek, South Branch of Big Creek, Stillman Creek, and a tributary to Scatter Creek. Results show higher water temperatures downstream for most of the pre-restoration sites. Continued water temperature monitoring is recommended after riparian plantings have become effective in providing shade to the stream.

Waterbody Numbers:

WA-22-1015
WA-22-4045
WA-23-1015
WA-23-1018
WA-23-1019
WA-23-1020
WA-23-1023
WA-23-1070
WA-23-1106

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- Karol Erickson reviewed and provided comments on the final report.

- Joan LeTourneau formatted and edited the final report.

Introduction

This report presents the results of 1995-2000 water temperature monitoring conducted as a part of the Chehalis Best Management Practices Evaluation Project funded by U.S. Fish & Wildlife Service (USFWS). The purpose of the monitoring is to document surface water temperature change associated with shade tree restoration of riparian areas. Monitoring includes upstream-downstream evaluation of sites where planting has occurred as well as long-term ambient monitoring at the mouths of some of the major tributaries to the upper Chehalis River. Replanting of the stream corridor for shading is not expected to be fully effective for six to ten years after initial replanting. This monitoring provides baseline data for future temperature comparisons.

Background

In the Chehalis River basin, poor water quality has been identified as a threat to the fisheries resource (Hiss and Knudsen, 1993). In an effort to protect and enhance the fishery, the USFWS set up the Chehalis Fisheries Restoration Program (CFRP), which provides funding for projects to restore anadromous fish to the Chehalis basin. Types of projects funded by CFRP include habitat restoration and installation of best management practices (BMPs) to improve or protect water quality. The Washington State Department of Ecology received CFRP funding from 1994-2000 to determine if habitat restoration and BMPs are effective in improving water quality.

While CFRP provides funding for numerous restoration projects, only a few project areas were selected to demonstrate results. Trying to monitor all project areas would result in too dispersed an effort. Detecting water quality improvements is more effective if monitoring focuses on collecting samples at a relatively high frequency and analyzing them for a small number of relevant variables. The restoration projects chosen for monitoring were selected in consultation with USFWS.

For the CFRP monitoring project, several types of monitoring were conducted including water quality monitoring, benthic macroinvertebrate sampling, and water temperature monitoring for shade tree restoration of riparian areas. This report describes the results of the water temperature monitoring. These results will serve as a pre-BMP baseline to determine if the riparian restoration projects were successful.

Applicable Water Quality Criteria

The state water quality standards describe criteria for temperature for the protection of characteristic uses. The Chehalis River and tributaries sampled for this study are designated Class A. For Class A waters: *"Temperature shall not exceed 18.0°C…due to human activities. When natural conditions exceed 18.0°C… no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C."*

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Methods

Sampling was conducted as described by the Quality Assurance Project Plan (Sargeant, 1995). This section provides a general description of sampling methods. Detailed methods are included in the descriptions of individual project areas.

Site Selection

From 1995 through 2000, long-term monitoring occurred at the mouths of four major tributaries to the Chehalis River in the upper Chehalis Basin, as well as at the Chehalis River upstream of the Newaukum River. Sites were selected based on known temperature problems in a sub-basin. The five long-term sites are listed below and shown in Figure 1:

1. Black River
2. Lincoln Creek
3. South Fork Chehalis River
4. Newaukum River
5. Chehalis River upstream of the Newaukum River

Monitoring to determine the effectiveness of riparian shading to reduce water temperature occurred at seven sites. In consultation with USFWS, site selection was based on the timing and scope of the riparian restoration project. The riparian restoration locations are referred to in this document as best management practice (BMP) sites. The sites and monitoring years are as follows:

1.	Mill Creek	1995
2.	North Fork Lincoln Creek	1995-96
3.	A tributary to Mohney Creek	1995-98
4.	South tributary of Salzer Creek	1996-99
5.	South Branch of Big Creek	1998-99
6.	Stillman Creek	1998-2000
7.	A tributary to Scatter Creek	2000

Water and Air Temperature Monitoring

Water and air temperature monitoring were conducted using a StowAway™, Hobotemp™, or StowAway Tidbit™ temperature probe and data logger, hereafter referred to as a thermograph. Thermographs were checked for accuracy prior to deployment, and again at the conclusion of field season. Thermographs were field checked with a hand-held thermometer at all sites during thermograph deployment and retrieval.

Water and air temperature were monitored hourly at each location from June through September. Water thermographs were placed in a well-mixed location in the stream channel at 1/2 to 1/3 the depth from the bottom substrate. Air and water thermographs were placed in shaded locations, or shade was provided if no shade was available.

For the BMP sites upstream and downstream, air and water temperature monitoring was conducted for one to three years. Most of the BMP sites had little or no riparian shading. The upstream thermograph site was usually located in an area where there was some riparian cover to represent a more shaded condition.

Stream Flow

Stream flow measurements were obtained during low-flow conditions at the upstream and downstream thermograph sites for each BMP site. Instantaneous flow discharge measurements were obtained using a velocity meter and top-set wading rod. Flow measurements were not obtained for the tributary to Scatter Creek.

Photo Points and Shade Measurements

Shade was measured with a densiometer, and photo points were obtained at the following BMP sites: Mill Creek, North Fork Lincoln Creek, tributary to Mohney Creek, south tributary of Salzer Creek, and the South Branch of Big Creek.

Densiometer measurements were obtained every 25 meters for a minimum of 100 meters above the upstream and downstream thermograph. Photo points were obtained every 25 meters for 100 meters above of the downstream thermograph. Photos were taken with 200 ASA print film. A stadia rod or photo board was used to indicate a 25-meter distance upstream from the photographer. Where possible, photos were obtained upstream, downstream, and toward the right and left banks.

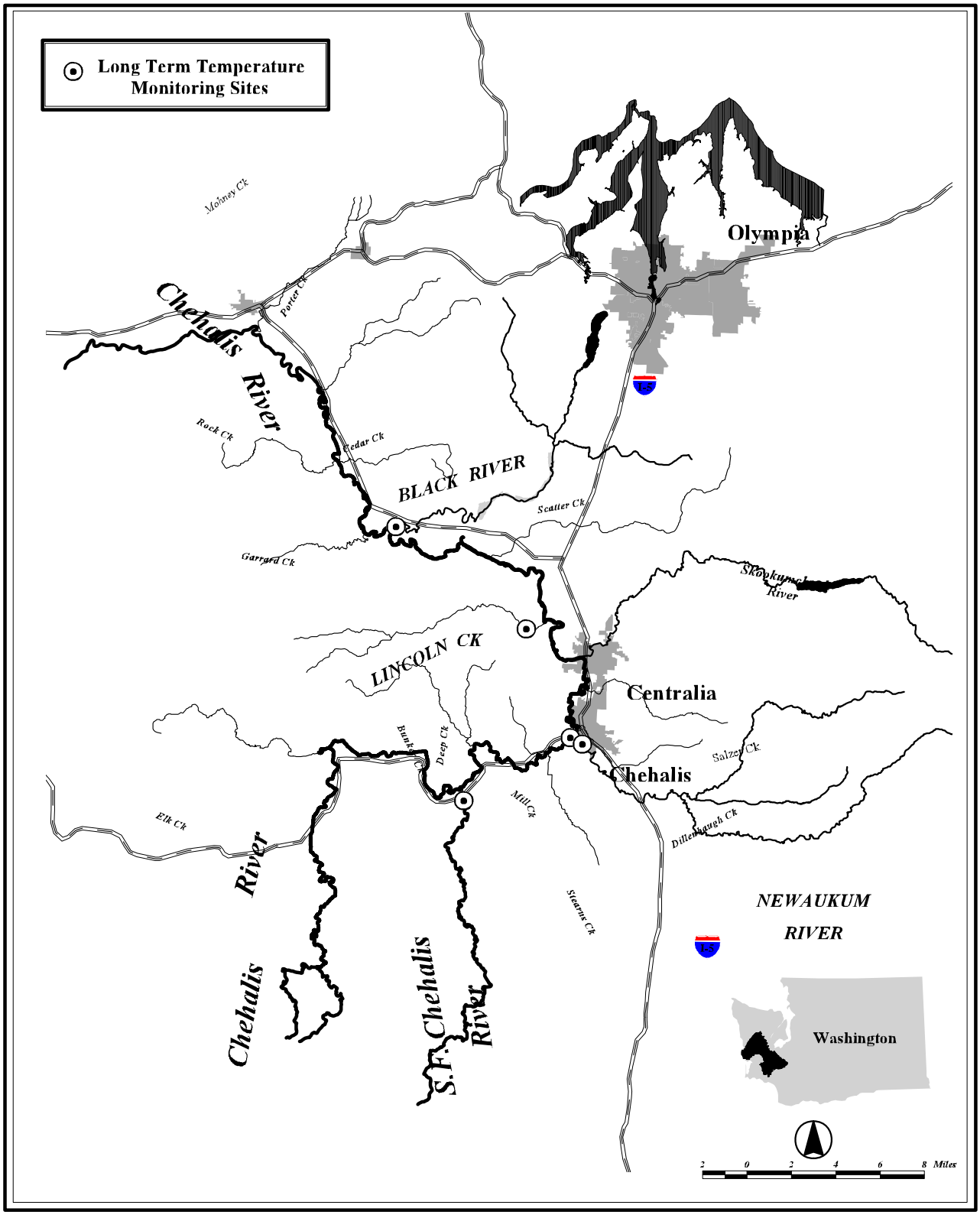

Figure 1. Chehalis Basin Long-Term Water Temperature Monitoring Sites.

Data Analysis

For each monitoring site, hourly temperature graphs are included in the appendices. For the long-term monitoring sites, graphs illustrate hourly, daily maximum, and daily mean water temperatures. For the BMP sites, graphs illustrate hourly water and air temperature when available for each site.

For the long-term monitoring sites, the box plots describe daily average and daily maximum temperatures for the warmest period of the year, July 15-August 15, for each year. For the BMP sites, box plots show daily maximum water and air temperatures for the warmest period of the year for each year. A key to interpreting notched box plots is included in Appendix A.

Where appropriate, paired t-tests were used to compare maximum daily temperature differences between upstream and downstream sites for July 15-August 15. A two-tailed test with a significance level of $\alpha = 0.05$ was used.

Data from all sites were compared to the numeric water quality temperature criterion.

Results

Long-term Trend Monitoring Sites

1. Black River

Water temperature monitoring was conducted on the Black River near Howanut Road from 1995 through 2000. Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate the Black River temperature data are of good quality.

Maximum, mean, and hourly water temperature graphs for the Black River are presented in Appendix B. Table 1 presents the monitoring period for each year and a summary of the water temperature data.

Table 1. Summary of water temperature data for the Black River at Howanut Road.

Year	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
1995	6/10/95 - 9/20/95	62 of 103	6/23/95 9/16/95	23.6°C	119 hours (7/17-7/22)
1996	6/12/96 – 8/26/96	47 of 76	6/30/96 8/26/96	22.9 °C	189 hours (7/23-7/31)
1997	6/28/97 – 9/8/97	59 of 73	7/3/97 9/8/97	22.2 °C	163 hours (8/2-8/9)
1998	7/16/98– 9/21/98	55 of 68	7/16/98 9/14/98	24.4 °C	352 hours (8/2-8/17)
1999	6/25/99 – 9/5/99	48 of 73	7/5/99 8/29/99	21.2 °C	64 hours (8/3-8/6) (8/9-8/12)
2000	6/27/00- 9/9/00	54 of 75	6/27/00 8/26/00	22.6 °C	116 hours (7/29-8/3)

Figures 2 and 3 are box plots illustrating hourly and maximum daily water temperature for each year, July 16 - August 15. Appendix A includes a key to interpreting notched box plots.

In both figures water temperature seems to increase from 1995 through 1998 with lower temperatures detected in 1999. The Black River site did not meet the numeric water temperature criterion of < 18.0°C for any of the years sampled.

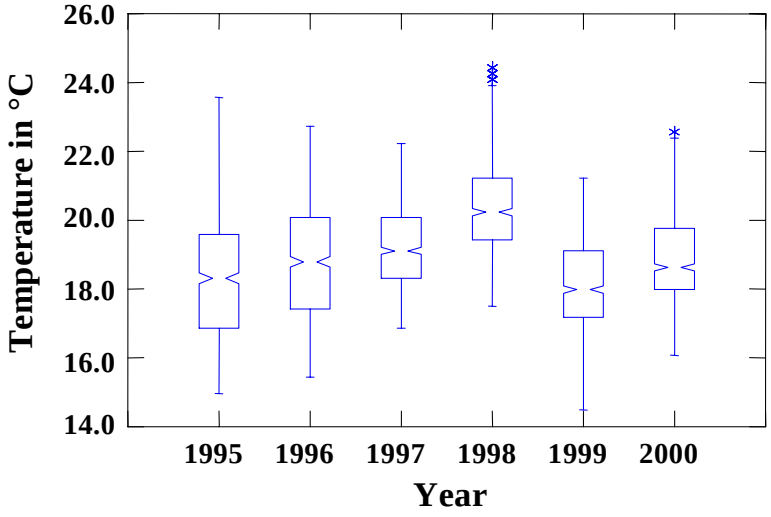

Figure 2. Black River Hourly Water Temperature for July 16-August 15, 1995-2000.

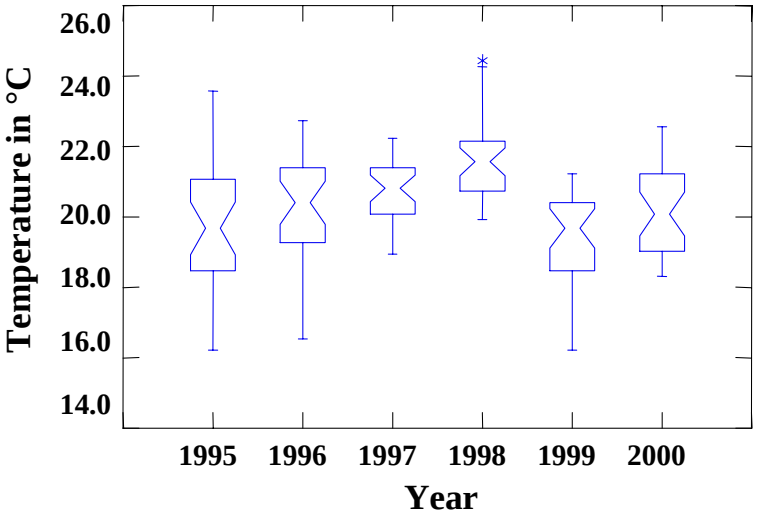

Figure 3. Black River Maximum Daily Water Temperature for July 16-August 15, 1995-2000.

2. Lincoln Creek

Water temperature monitoring was conducted on Lincoln Creek at the Lincoln Creek Road bridge near Galvin. Monitoring was conducted from 1995 through 2000. Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate the Lincoln Creek temperature data are of good quality.

Maximum, mean, and hourly water temperature graphs for Lincoln Creek are presented in Appendix C. Table 2 presents the monitoring period for each year and a summary of the water temperature data.

Table 2. Summary of water temperature data for the Lincoln Creek.

Year	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
1995	6/10/95 - 9/15/95	29 of 98	6/24/95 8/5/95	21.2 °C	183 hours (7/17-7/25)
1996	6/14/96 – 8/26/96	31 of 74	7/2/96 8/15/96	21.6 °C	209 hours (7/23 - 8/1)
1997	6/28/97 – 9/8/97	50 of 73	7/4/97 9/3/97	20.9 °C	136 hours (8/3 - 8/9)
1998	6/23/98 – 9/4/98	45 of 74	6/30/98 9/4/98	23.9 °C	402 hours (7/16 - 8/2)
1999	6/26/99 – 9/5/99	32 of 72	7/10/99 8/26/99	20.2 °C	59 hours (7/28 - 7/31)
2000	6/27/00 – 9/9/00	29 of 75	6/27/00 8/10/00	21.2 °C	117 hours (7/29 - 8/3)

Figures 4 and 5 are box plots illustrating hourly and maximum daily water temperature for each year, July 15 - August 15.

In both box plots, water temperature increases from 1995 through 1998 with lower temperatures detected in 1999, similar to the pattern seen in the Black River data. The Lincoln Creek site did not meet the numeric water temperature criterion of < 18.0°C for any of the years sampled.

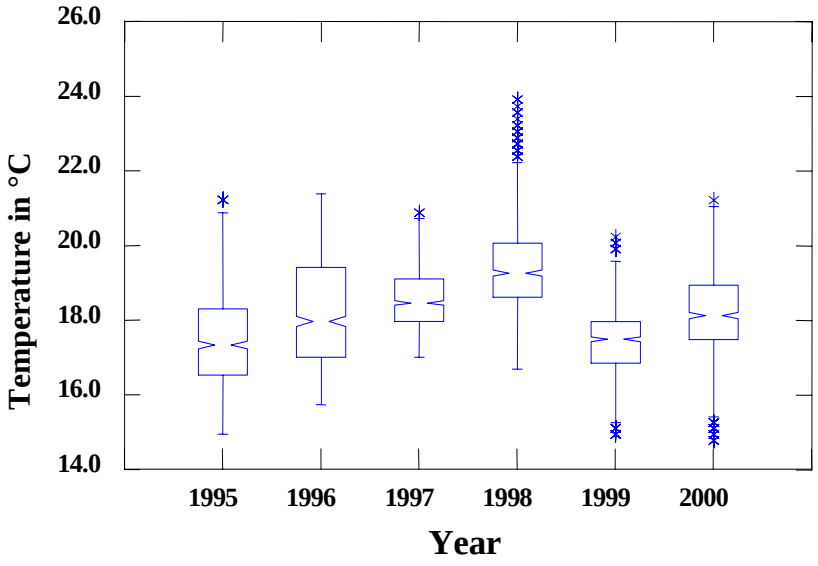

Figure 4. Lincoln Creek Hourly Water Temperature for July 15-August 15, 1995-2000.

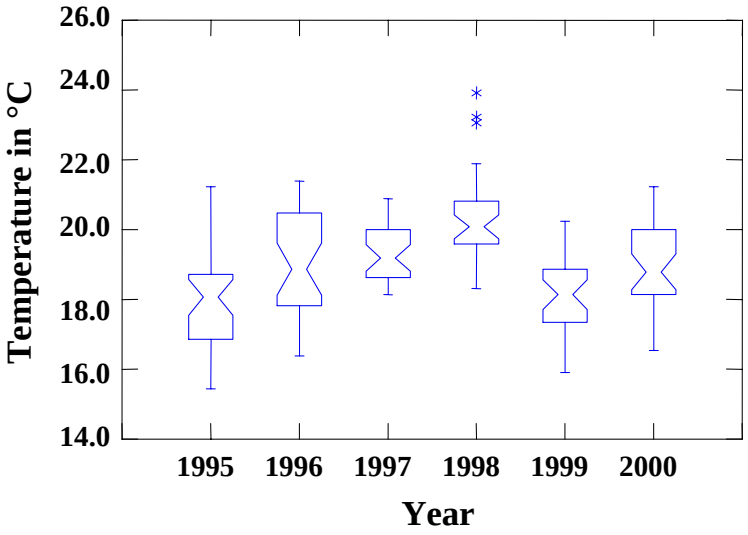

Figure 5. Lincoln Creek Maximum Daily Water Temperature for July 15-August 15, 1995-2000.

3. South Fork Chehalis River

From 1995 through 2000, water temperature monitoring was conducted on the South Fork of the Chehalis River 0.5 miles upstream of the mouth. Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate the South Fork Chehalis River temperature data are of good quality. For 1998 only a portion of the data is available, because the temperature monitoring probe was physically lost during the sample period and replaced on August 11, 1998.

Maximum, mean, and hourly water temperature graphs for the South Fork Chehalis River are presented in Appendix D. Only a portion of the data from 1998 is presented in these graphs due to missing data. Table 3 presents the monitoring period for each year and a summary of the water temperature data.

Table 3. Summary of water temperature data for the South Fork Chehalis River near the mouth.

Year	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
1995	6/10/95 - 10/1/95	88 of 114	6/10/95 9/21/95	26.5°C	329 hours (7/15-7/29)
1996	6/26/96 – 9/10/96	69 of 74	6/29/96 9/10/96	25.5 °C	332 hours (7/22-8/5)
1997	6/28/97 – 9/7/97	65 of 72	7/2/97 9/7/97	26.0 °C	829 hours (7/19-8/26)
1998	8/11/98– 9/20/98	41 of 41	8/11/98 9/20/98	26.2 °C	214 hours (8/28-9/6)*
1999	6/25/99 – 9/12/99	69 of 81	7/5/99 9/12/99	25.1 °C	283 hours (8/2-8/14)**
2000	6/22/00 – 9/27/00	76 of 98	6/25/00 9/21/00	25.1 °C	376 hours (7/27-8/12)

* Limited data set.

** Between July 26 and August 14, temperatures remained above 18.0 °C for 448 hours except for one hour on August 2 when the temperature was 17.98 °C.

Figures 6 and 7 are box plots illustrating hourly and maximum daily water temperature for each year, July 15 - August 15.

Of the tributaries sampled, the South Fork Chehalis River had some of the highest temperatures. In 1997 over a month of >18.0°C temperatures were recorded. This site did not meet the numeric water temperature criterion of < 18.0°C for any of the years sampled.

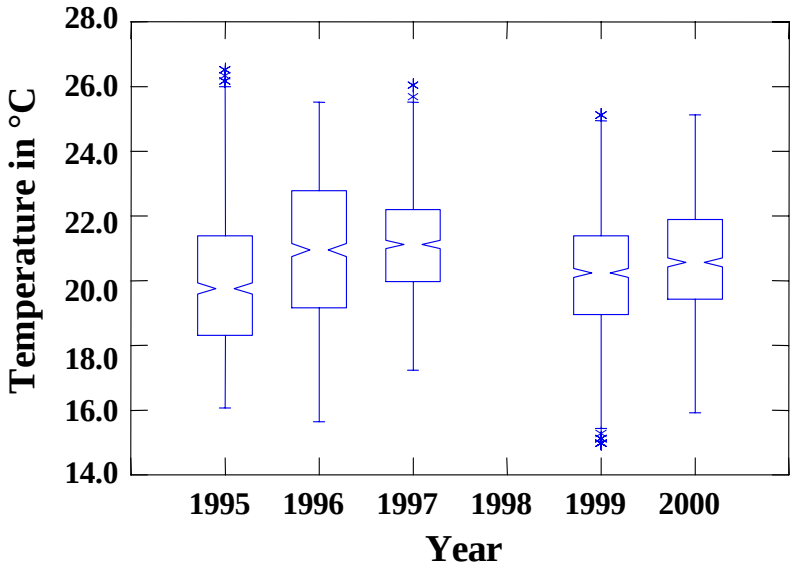

Figure 6. South Fork Chehalis River Hourly Water Temperature for July 15-August 15, 1995-1997, 1999-2000.

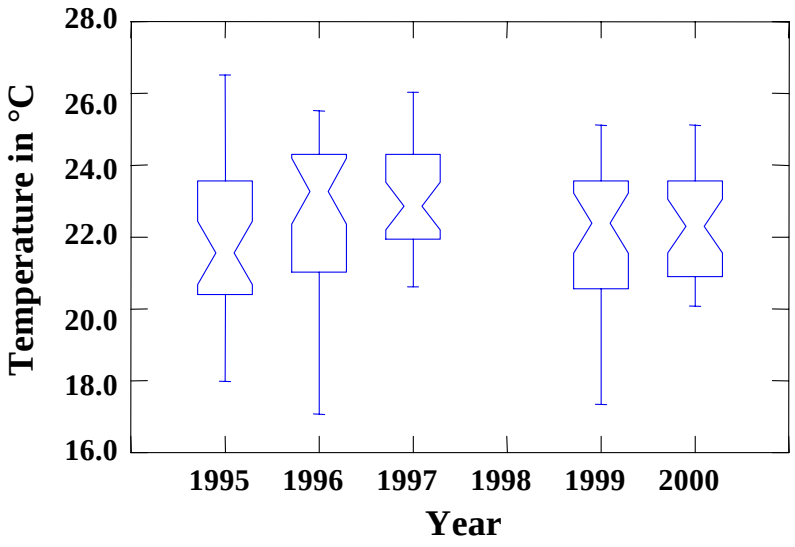

Figure 7. South Fork Chehalis River Maximum Daily Water Temperature for July 15-August 15, 1995-1997, 1999-2000.

4. Newaukum River

Water temperature monitoring was conducted at the mouth of the Newaukum River from1995 through 2000. Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate the Newaukum River temperature data are of good quality. No data are available for 1996, or for July 4 - August 12, 1997 and June 1 - August 19, 1998, because the thermograph was physically lost. Data from the critical period, July 15 - August 15, are unavailable for 1996 and 1997.

Maximum, mean, and hourly water temperature graphs for the Newaukum River are presented in Appendix E. Data from 1996 are not available, and 1997 and 1998 are partial data sets. Table 4 presents the monitoring period for each year and a summary of the water temperature data.

Table 4. Summary of water temperature data for the mouth of the Newaukum River.

Year	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
1995	6/9/95- 10/1/95	93 of 115	6/9/95 9/22/95	27.2°C	397 hours (6/23-7/10)
1996	No data probe missing				
1997	6/26-7/3/97 8/13-9/7/97	27 of 34	7/2/97 9/7/97	24.4 °C	327 hours (8/13-8/27)
1998	8/20/98– 9/20/98	31 of 32	8/20/98 9/20/98	23.4 °C	237 hours (8/27-9/6)
1999	6/24/99 – 9/20/99	71 of 89	7/6/99 9/20/99	23.5 °C	162 hours (7/26-8/2)
2000	6/27/00 – 9/27/00	72 of 94	6/27/00 9/21/00	25.0 °C	644 hours (7/16-8/12)

Figures 8 and 9 are box plots illustrating hourly and maximum daily water temperature for each year, July 15 - August 15.

The Newaukum River site did not meet the numeric water temperature criterion of < 18.0°C for any of the years sampled.

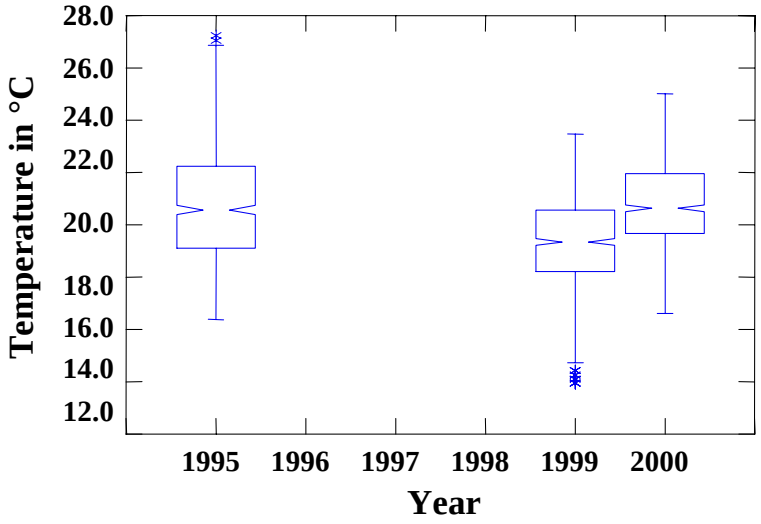

Figure 8. Newaukum River Hourly Water Temperature for July 15-August 15, 1995, 1999, and 2000.

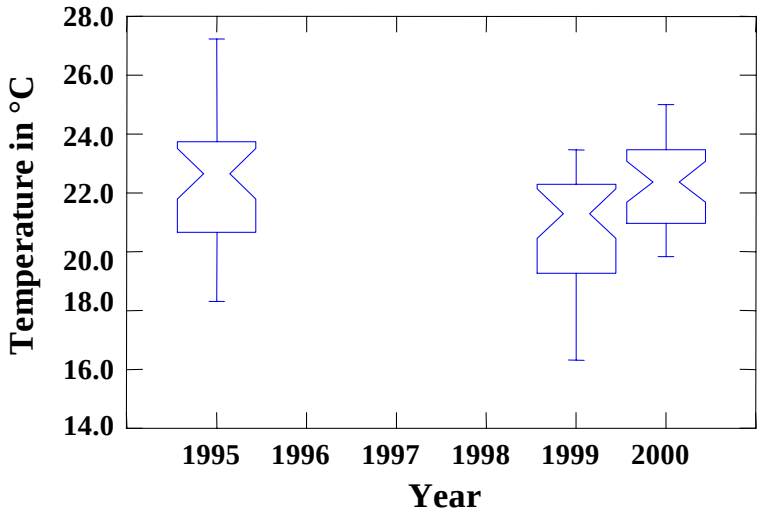

Figure 9. Newaukum River Daily Maximum Water Temperature for July 15-August 15, 1995, 1999, and 2000.

5. Chehalis River Upstream of the Newaukum River

Water temperature monitoring was conducted on the Chehalis River ¼ mile upstream from the Newaukum River from 1995 through 2000. Data from this probe are not considered representative of Chehalis River water temperatures. The Chehalis River is slow moving and deep in this stretch. Due to the water depth, the thermograph could not be placed in the thalweg. The thermograph was placed approximately one foot from the left bank 2/3 from the surface. Water depth was 3 feet at time of placement, but during several years water levels dropped so the thermograph was near the surface or out of the water. Data for the critical period, July 15 - August 15, are unavailable for 1996 and 1997 because the thermograph was out of the water.

Maximum, mean, and hourly water temperature graphs for the Chehalis River are presented in Appendix F. Table 5 presents the monitoring period for each year and a summary of the water temperature data.

Table 5. Summary of water temperature data for the Chehalis River upstream of the Newaukum River.

Year	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
1995	6/9/95-10/1/95	35 of 115	6/9/95 9/22/95	25.8°C	821 hours (7/11-8/14)
1996	6/29/96-7/13/96	15 of 15	6/29/96	25.7°C	Not available
1997	6/26/97-7/25/97	22 of 30	7/2/97	25.9°C	Not available
1997	8/13/97-9/7/97	26 of 26	8/13/97 9/7/97	25.0°C	Not available
1998	6/23/98-9/4/98	71 of 74	6/23/98 9/4/98	27.2°C	1451 hours (7/6-9/4)
1999	6/25/99-9/5/99	62 of 73	7/6/99 9/5/99	23.3°C	1045 hours (7/19-8/31)
2000	6/28/00-9/9/00	66 of 74	6/28/00 9/8/00	24.8°C	1001 hours (7/10-8/21)

Figures 10 and 11 are box plots illustrating hourly and maximum daily water temperature for each year, July 15 - August 15.

The Chehalis River at this site did not meet the numeric water temperature criterion of < 18.0°C for any of the years sampled. Although due to the position of the probe, data from this site do not represent true conditions in the river.

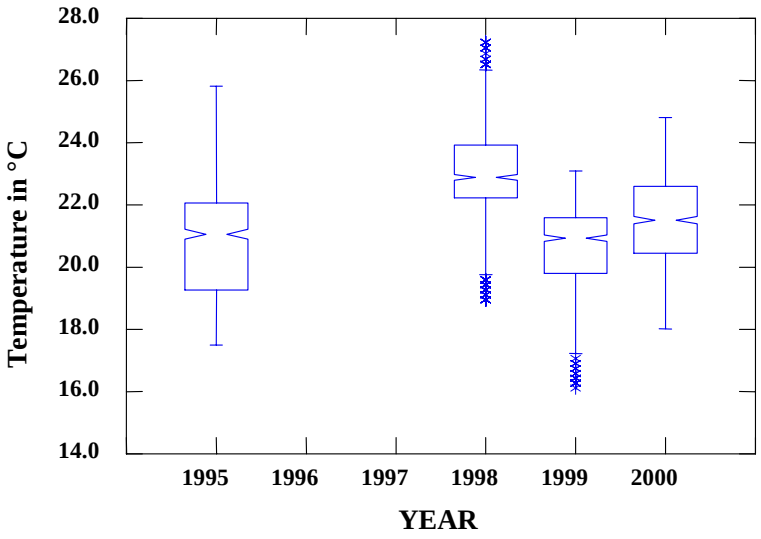

Figure 10. Chehalis River Hourly Water Temperature for July 15-August 15, 1995, 1998, 1999, and 2000.

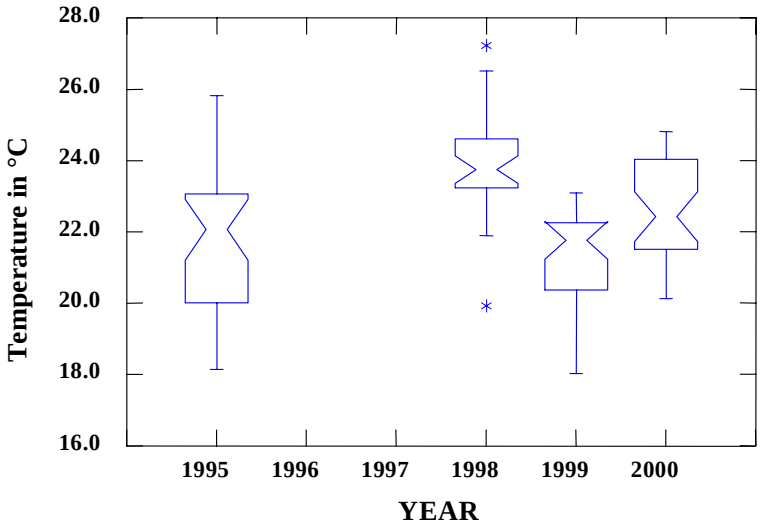

Figure 11. Chehalis River Daily Maximum Water Temperature for July 15-August 15, 1995, 1998, 1999, and 2000.

Best Management Practice Sites

1. Mill Creek

Mill Creek is located in Lewis County, four miles east of the town of Chehalis via Highway 6 (Figure 12). Mill Creek flows into the Chehalis from the north at Chehalis river mile (RM) 79.0. The Mill Creek BMP site extends from creek mile (CM) 1.7 to 2.6, and is located on privately owned land used for pasture. In early 1995 this site received treatment for riparian restoration including ash, cedar, and willow plantings, as well as livestock exclusion with 2000 feet of fencing on both sides of the creek (Edwards, 1996).

In 1995 three thermographs were deployed on Mill Creek. Two thermographs were installed downstream of the BMP site, one mid-channel and one adjacent to the mid-stream probe on the right bank. One thermograph was installed upstream of the BMP site at CM 2.9. Monitoring periods are shown in Table 6. Air temperature thermographs were also installed at the upstream and downstream sites.

Table 6. 1995 Summary of water temperature data for Mill Creek.

Monitoring Site	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
Upstream	6/9/95 - 8/18/95	21 of 71	6/27/95 8/5/95	20.9°C	41 hours 7/19-7/21
Downstream (mid channel)	6/9/95 - 9/30/95	27 of 104	6/24/95 8/6/95	20.8°C	135 hours 7/17-7/23
Downstream (right bank)	6/29/95- 9/30/95	27 of 104	6/29/95 8/6/95	21.6°C	137 hours 7/17-7/23

Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate the Mill Creek temperature data are of good quality.

The upstream thermograph ceased functioning on August 18, 1995 due to battery failure. No data are available for this site after that date.

On August 18, 1995, riparian canopy at the BMP site was evaluated. Spherical densiometer readings and photo points were obtained at 25-meter intervals for 100 meters upstream of the downstream thermograph site. The average densiometer reading for the BMP site was 20% cover, ranging from 1 to 54%. Field notes and photo points indicate riparian area consisted of primarily reed canary grass on both banks of the creek. Cover was not measured at the upstream site, but field notes indicate the thermograph was placed in an area of good riparian cover of deciduous trees and young conifers.

Flow discharge measurements were obtained on August 18, 1995 at the upstream and downstream sites. Flow discharge at both sites was 0.6 cfs, indicating no major surface water inputs between the upstream and downstream sites.

Appendix G includes hourly water and air temperature graphs for the upstream and downstream sites. Table 6 summarizes water temperature results. Figures 13 and 14 are box plots illustrating maximum daily water and air temperature for July 15 - August 15, 1995.

The air temperature graphs and box plot show that air temperature varies more downstream, and the daily maximum temperature is significantly higher. The downstream site receives more solar radiation than the upstream site due to the lack of riparian shading, while the upstream site is well shaded in the vicinity of the thermographs.

The daily maximum water temperature box plot shows no statistically significant differences in median temperature between the upstream and downstream sites. There is a water temperature lag between the upstream and downstream, with slightly higher water temperatures at the downstream sites.

The downstream site had significantly higher air temperatures without correspondingly high water temperatures. This could be due to several factors. The downstream riparian area was replanted in 1995, but the dominant plant species in and around the creek was a tall stand of reed canary grass. The reed canary grass may provide some shade to the creek in the vicinity of the BMP site. This shade may help maintain the water temperatures seen at the upper site. The more likely reason that higher water temperatures are not seen downstream is inadequate cover above the upstream thermograph. Densiometer readings were not obtained for the upstream site, so riparian cover upstream is unknown.

Temperature measurements were compared to the criterion of 18.0°C for freshwater. Both the upstream and downstream sites exceeded the numeric temperature criterion. The upstream and downstream maximum temperatures were 20.9°C and 21.6°C respectively.

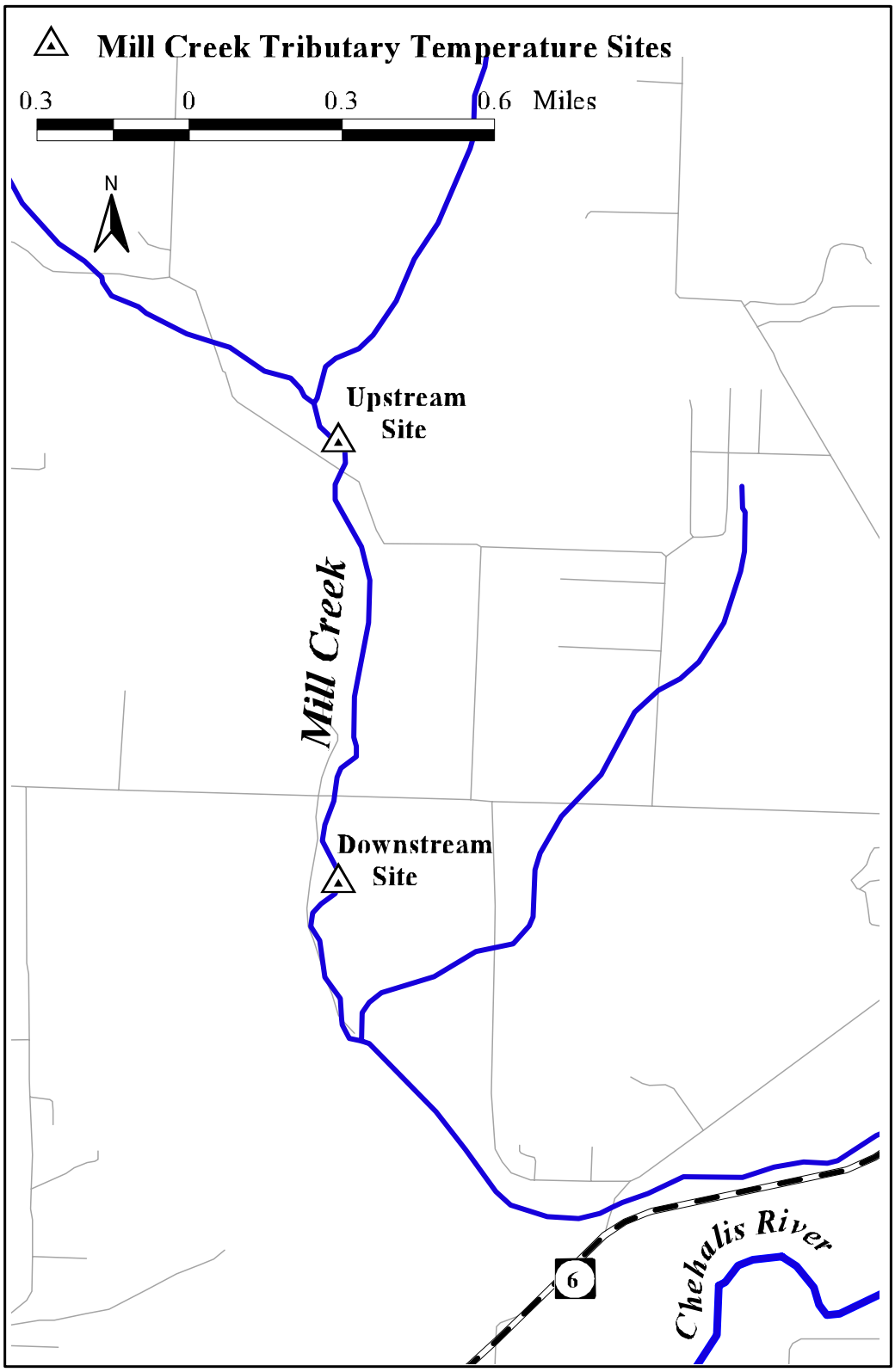

Figure 12. Mill Creek BMP Temperature Monitoring Sites.

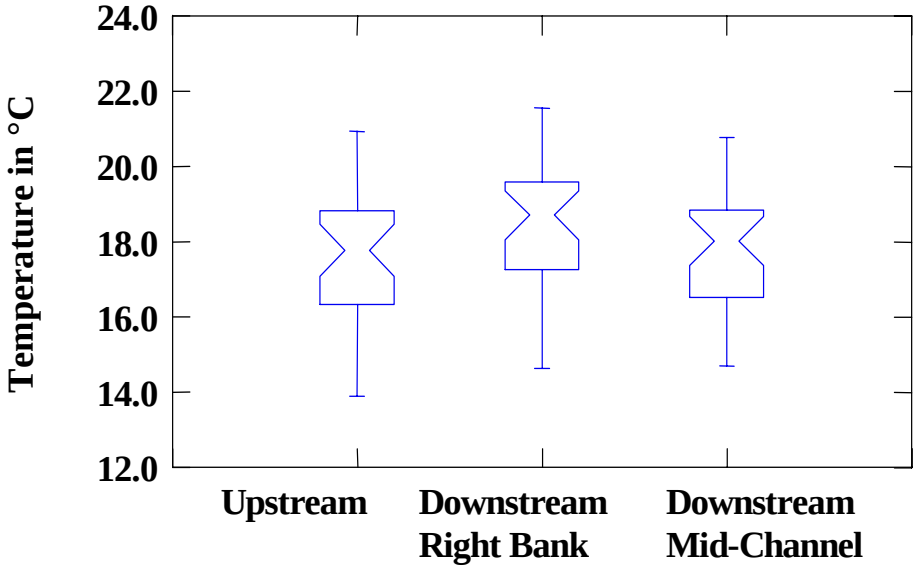

Figure 13. Mill Creek Maximum Daily Water Temperature for July 15-August 15, 1995.

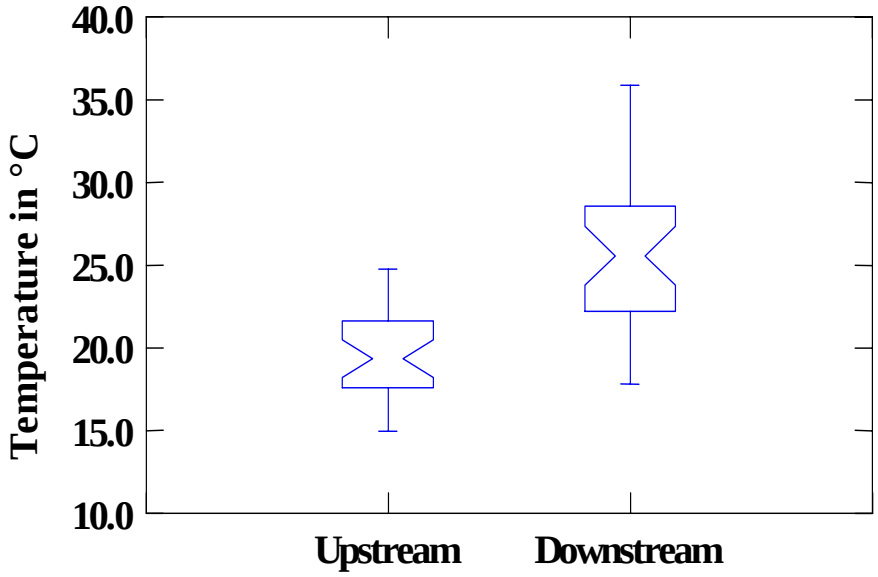

Figure 14. Mill Creek Maximum Daily Air Temperature for July 15-August 15, 1995.

2. North Fork Lincoln Creek

North Fork Lincoln Creek in Lewis County is a tributary to Lincoln Creek (Figure 15). Lincoln Creek flows into the Chehalis River from the west at RM 62 near the town of Galvin. The BMP site on the North Fork of Lincoln Creek is on state owned land that was formerly leased for agricultural purposes. In early 1995 this site received BMP treatment for erosion control and riparian replanting. Banks along the creek were stabilized using willow plantings and tree-revetments. A 10-80 foot buffer was re-planted with willow, red-osier dogwood, Douglas fir, and cedar along 1,200 feet of the south site of the creek (Edwards, 1996).

In 1995 three water temperature thermographs were deployed on North Fork Lincoln Creek. Two thermographs were installed at the downstream edge of the BMP site, one mid-channel and one near the right bank. The upstream thermograph was placed one mile upstream of the BMP site mid-channel. In 1995 two air thermographs were deployed at the upstream and downstream sites from July 21 - September 30 and July 1 - September 30 respectively. In 1996 air and water temperature sites remained the same, except only one water temperature probe was installed mid-stream at the downstream site. Monitoring periods are shown in Table 7.

Table 7. 1995-6 Summary of water temperature data for North Fork Lincoln Creek.

Monitoring Site	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
Upstream 1995	6/1/95-9/30/95	2 of 122	7/18/95 7/19/95	18.1°C	4 hours on 7/18/95
Downstream 1995	6/1/95-9/30/95	16 of 122	6/29/95 8/5/95	21.1°C	14 hours on 7/19/95
Upstream 1996	6/13/96-8/27/96	2 of 76	7/14/96 7/26/96	18.3°C	5 hours on 7/26/96
Downstream 1996	6/13/96-8/27/96	30 of 76	7/12/96 8/25/96	21.1°C	13 hours on 7/26/96

Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate the North Lincoln Creek temperature data are of good quality. In 1995 the downstream thermograph on the right bank was not functioning properly for most of the monitoring period. The upstream thermograph was not functioning from August 20-24, 1995 due to battery failure.

On August 24, 1995, the riparian canopy at the BMP site was evaluated: spherical densiometer readings and photo points were obtained at 25-meter intervals for 250 meters. The average densiometer reading for the BMP site was 23% cover, ranging from 1 to 60%. Field notes and photo points indicate riparian area consists of primarily reed canary grass on both banks of the creek. On September 12, 1996 the upstream site was evaluated using a spherical densiometer and photo points obtained at 25 meter intervals for 225 meters. The average densiometer reading was 92% cover, ranging from 89 to 95%. Field notes and photo points indicate riparian area

upstream consisted of mature deciduous and conifer along both banks. During the summer of 1996 a logging road was built along the upstream portion of the left bank.

Flow discharge measurements were obtained on August 24, 1995 at the upstream and downstream sites. Flow discharge at both sites was 0.6 cfs, indicating no major surface water inputs between the upstream and downstream sites.

Appendix H includes hourly water and air temperature graphs for the upstream and downstream sites. Table 7 summaries water temperature results. Figures 16 and 17 are box plots of 1995-6 maximum daily water temperature for July 15-August 15, and daily maximum air temperature for July 21 - August 21, 1995 1996.

The water and air temperature graphs and box plot show that air temperature varies more downstream and the daily maximum temperatures are higher. A paired t-test shows significantly higher water and air temperatures downstream. In 1996 air and water temperatures were higher than in 1995.

Temperature measurements were compared to the criterion of 18.0°C for freshwater. The upstream site had a few minor excursions to the temperature criterion, with a maximum temperature in 1996 of 18.3°C. The downstream station had more temperature violations and higher temperatures, with a maximum of 21.1°C in 1995 and 1996.

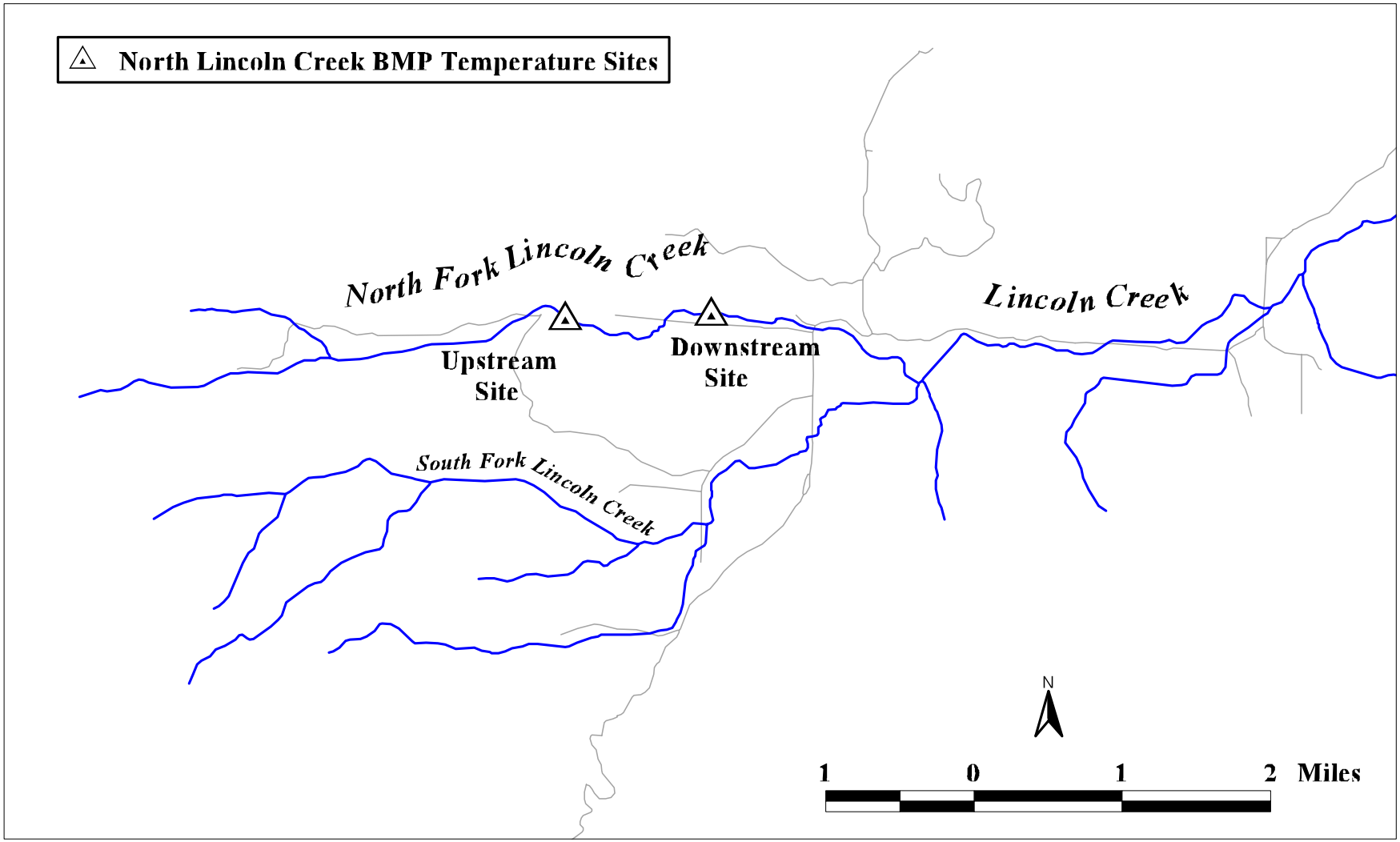

Figure 15. North Lincoln Creek BMP Temperature Monitoring Sites.

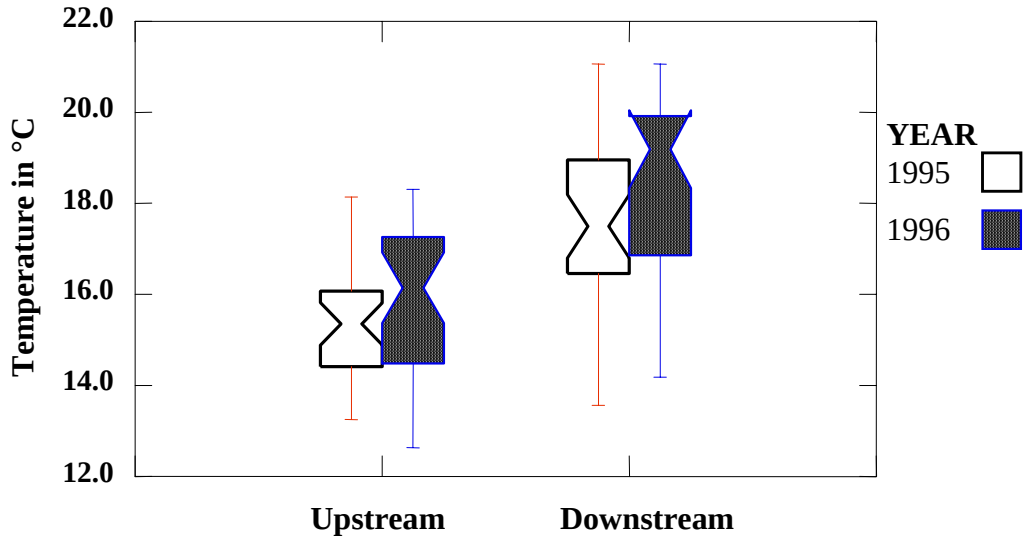

Figure 16. Lincoln Creek Maximum Daily Water Temperature for July 15-August 15, 1995-6.

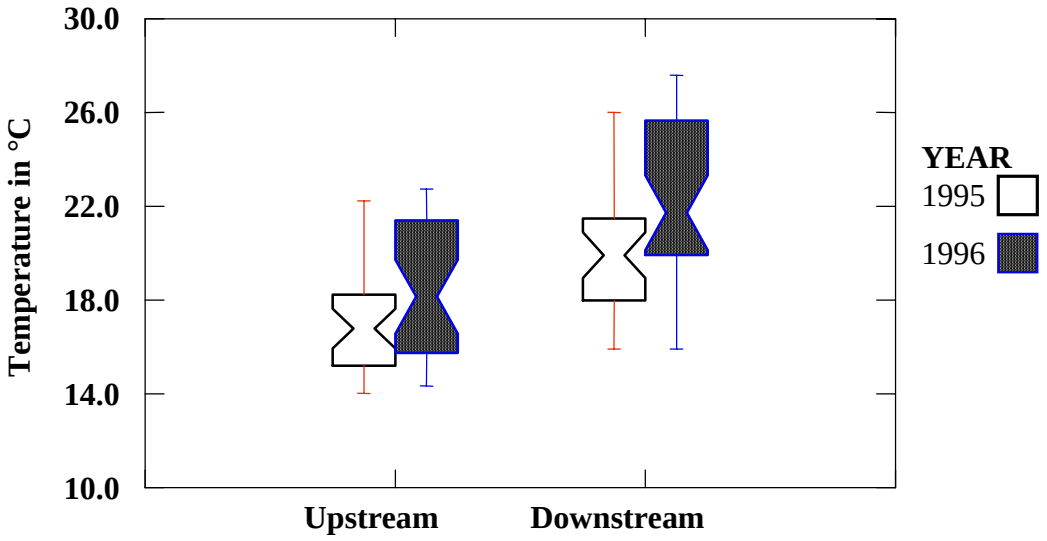

Figure 17. Lincoln Creek Maximum Daily Air Temperature for July 15-August 15, 1995-6.

3. Tributary to Mohney Creek

The Mohney Creek tributary is located in Mason County 1.5 miles northeast of McCleary (Figure 18). Mohney Creek tributary flows to the Chehalis via Mohney Creek, Wildcat Creek, Cloquallum Creek, then the Chehalis River at RM 25.2. The BMP site is on privately owned land used for agricultural purposes. In 1994 the BMP sites received BMP treatment for riparian restoration and livestock exclusion. Approximately 3000 feet of fencing (1500 feet on both sides) were installed, and the riparian area was replanted with native vegetation (Barnes, 1996).

From 1995-98 water and air temperature thermographs were deployed on a tributary to Mohney Creek. Air and water thermographs were installed just downstream of the BMP site and 0.25 miles upstream. Monitoring periods are shown in Table 8.

Table 8. Summary of water temperature data for the tributary to Mohney Creek.

Monitoring Site	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
1995 Upstream	8/18/95-9/30/95	0 of 44	N/A	14.2°C	N/A
1995 Downstream	8/18/95-9/30/95	11 of 44	8/20/95 9/15/95	19.2°C	6 hours 9/1/01
1996 Upstream	6/12/96-8/26/96	0 of 76	N/A	15.3°C	N/A
1996 Downstream	6/12/96-8/26/96	40 of 76	6/26/96 8/25/96	23.1°C	11 hours 7/14/96
1997 Upstream	6/28/97-9/9/97	0 of 74	N/A	14.9°C	N/A
1997 Downstream	6/28/97-9/9/97	15 of 74	7/4/97 8/22/97	19.8°C	5 hours 8/17/01
1998 Upstream	6/23/98-9/5/98	0 of 75	N/A	15.6°C	N/A
1998 Downstream	6/23/98-9/5/98	47 of 75	6/28/98 9/5/98	24.3°C	12 hours 7/27-8 + 8/13

Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate the temperature data are of good quality. In 1997 the upstream air temperature thermograph ceased functioning one day after deployment.

On August 8, 1996 riparian canopy was evaluated at the BMP site and upstream, using a spherical densiometer and photo points. Photo points and densiometer readings were taken at 25-meter intervals for 100 meters. The average densiometer reading for the BMP site was 0% cover, ranging from 0 to 1%. Field notes and photo points indicate riparian area consists of blackberries and grasses on both sides of the creek. Cover upstream of the BMP site was 94%, ranging from 92 to 96%. Field notes indicate mature deciduous canopy upstream with a wide riparian buffer on both sides of the creek.

Flow discharge measurements were obtained on August 8, 1996 and September 28, 1998 at the upstream and downstream sites. For 1996 flow discharge was 0.3 cfs at the upstream site and 0.2 cfs at the downstream site. In 1998 flow was 0.2 cfs at both sites. No major surface water inputs are noted between the upstream and downstream sites.

Appendix I includes hourly water and air temperature graphs for the upstream and downstream sites. Table 8 summarizes water temperature results. Figures 19 and 20 present box plots of maximum daily water and air temperature for July 15 - August 15, 1995. Box plots for 1995 are not included due to the late monitoring start in 1995.

The water temperature graphs and box plot show that water temperature varies more downstream, and the daily maximum temperatures are higher. A paired t-test shows significantly higher water temperatures downstream for July 15 - August 15 for all years sampled.

Temperature measurements were compared to the criterion of 18.0°C for freshwater. With a maximum temperature of 15.6°C in 1998, the upstream site met water quality standards. With a maximum temperature of 24.3°C in 1998, the downstream site did not meet numeric temperature criterion for any of the years sampled.

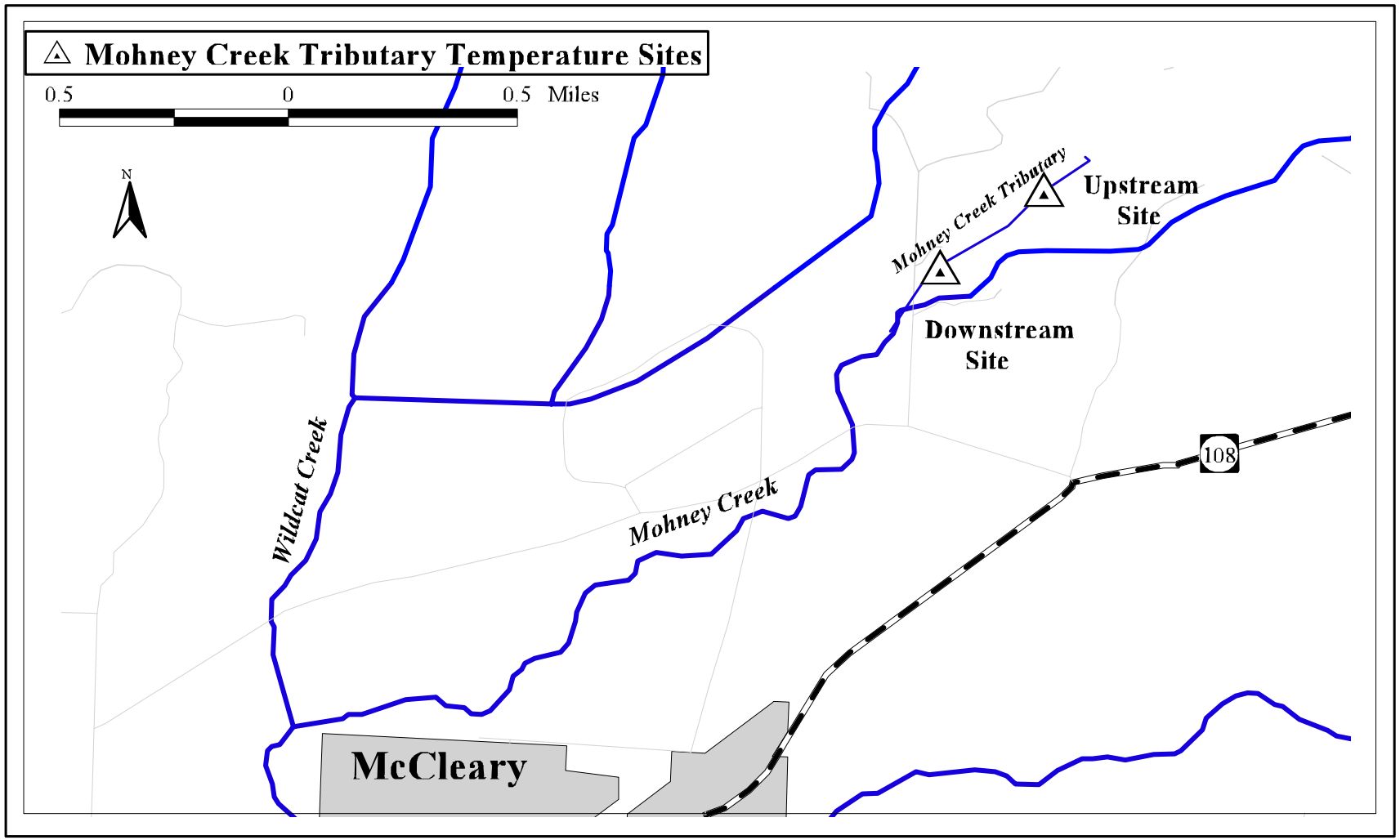

Figure 18. Mohney Creek tributary BMP Temperature Monitoring Sites.

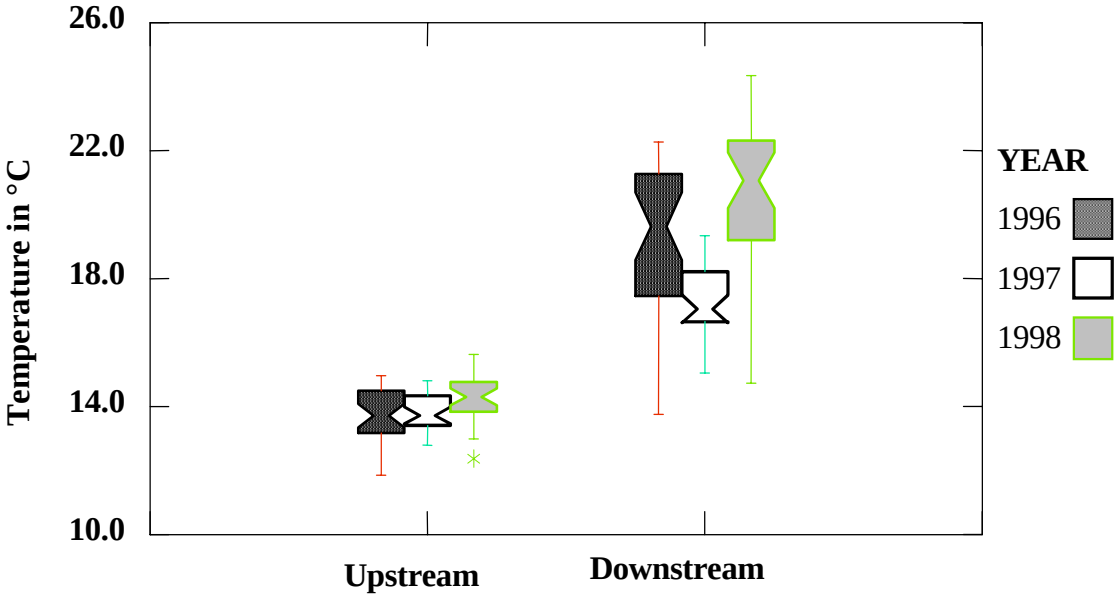

Figure 19. Mohney Creek Tributary Maximum Daily Water Temperature for July 15-August 15, 1996-98.

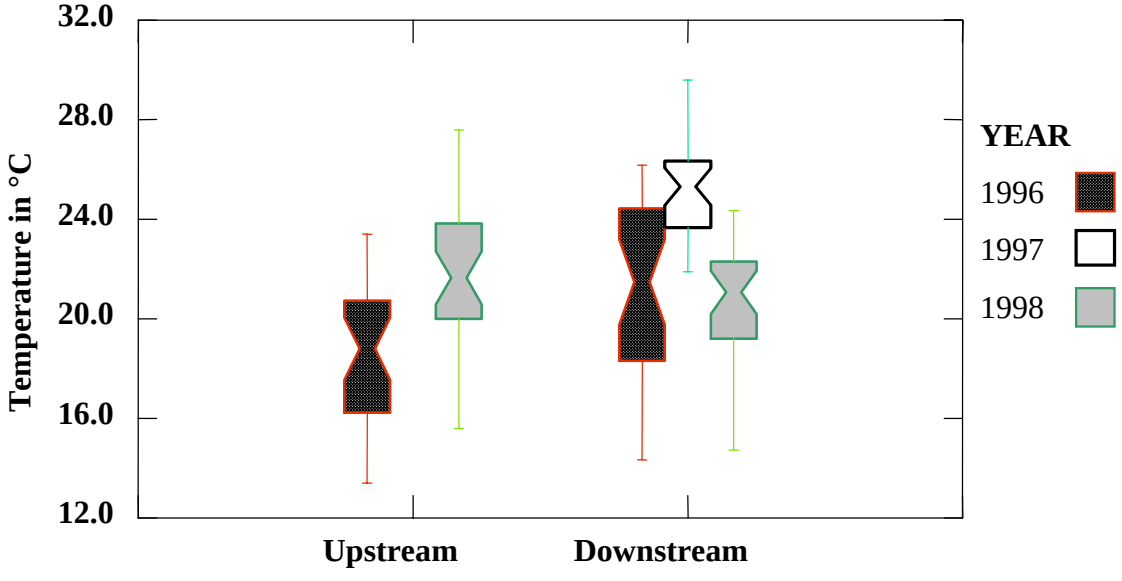

Figure 20. Mohney Creek Tributary Maximum Daily Air Temperature for July 15-August 15, 1996-98.

4. South Tributary to Salzer Creek

The south tributary to Salzer Creek is located in Lewis County four miles southeast of Centralia (Figure 21). Salzer Creek flows into the Chehalis River at RM 69.2. The BMP site is on privately owned land used for agricultural purposes. In 1996 the BMP site received treatment for riparian restoration and livestock exclusion. Approximately 3600 feet of fencing (1800 feet on both sides) was installed, and the riparian area was replanted with native vegetation (Mendoza, 1998). The riparian buffer averages 10 feet on both sides of the creek. Two cattle crossings were also installed.

From 1996-99 four water and air temperature thermographs were deployed on the south tributary to Salzer Creek. Air and water thermographs were installed just downstream of the BMP site and 0.5 miles upstream. Monitoring periods are shown in Table 9.

Table 9. Summary of water temperature data for the tributary to Salzer Creek.

Monitoring Site	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
1996 Upstream	7/19/96-9/12/96	0 of 56	N/A	16.9°C	N/A
1996 Downstream	7/19/96-9/12/96	41 of 56	7/21/96 9/10/96	22.9°C	117 hours 7/26-7/31
1997 Upstream	6/28/97-9/7/97	0 of 72	N/A	15.4°C	N/A
1997 Downstream	6/28/97-9/7/97	4 of 72	8/4/97 8/7/97	18.5°C	6 hours 8/5-8/6
1998 Upstream	6/22/98-9/4/98	0 of 75	N/A	16.3°C	N/A
1998 Downstream	6/22/98-9/4/98	28 of 75	7/16/98 8/15/98	21.5°C	92 hours 7/27-7/31
1999 Upstream	6/25/99-9/5/99	0 of 73	N/A	14.9°C	N/A
1999 Upstream	6/25/99-9/5/99	0 of 73	N/A	17.4°C	N/A

Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate the temperature data are of good quality.

On August 6, 1996 riparian canopy was evaluated upstream and at the BMP site using a spherical densiometer and photo points. Photo points and densiometer readings were taken at 25-meter intervals for 175 meters downstream and 225 meters upstream. The average densiometer reading for the BMP site was 2% cover, ranging from 0 to 9%. Field notes and photo points indicate riparian area consists of heavily grazed grass on both sides of the creek. Cover upstream of the BMP site was 62%, ranging from 25 to 88%. Field notes indicate mature deciduous canopy for 75 meters above the upstream thermograph; riparian cover then decreases

with reed canary grass and some deciduous trees on the left bank. The upstream thermograph is located in a wide slow moving portion of the creek; there may be a dam downstream of the upstream thermograph site.

Flow discharge measurements were obtained on August 6, 1996 at the upstream and downstream sites. Flow discharge was 0.7 cfs at both sites, indicating no major surface water inputs between the two sites.

Appendix J includes hourly water and air temperature graphs for the upstream and downstream sites. Table 9 summarizes water temperature results. Figures 22 and 23 present box plots of maximum daily water and air temperature for July 17 - August 17, 1995. The time period described in the Salzer Creek box plots is slightly different, because four years of data were available for that time.

The water temperature graphs and box plot show that water temperatures are much higher downstream. A paired t-test shows significantly higher water temperatures downstream for July 19 - August 19 for all years sampled. Air temperatures also tend to be higher downstream.

Temperature measurements were compared to the criterion of 18.0°C for freshwater. With a maximum temperature of 16.9°C in 1996, the upstream site met the numeric criterion for the four years sampled. The downstream site did not meet the numeric temperature criterion in 1996-1997, but met the criterion in 1998; the maximum temperature at the downstream site was 22.9°C in 1996.

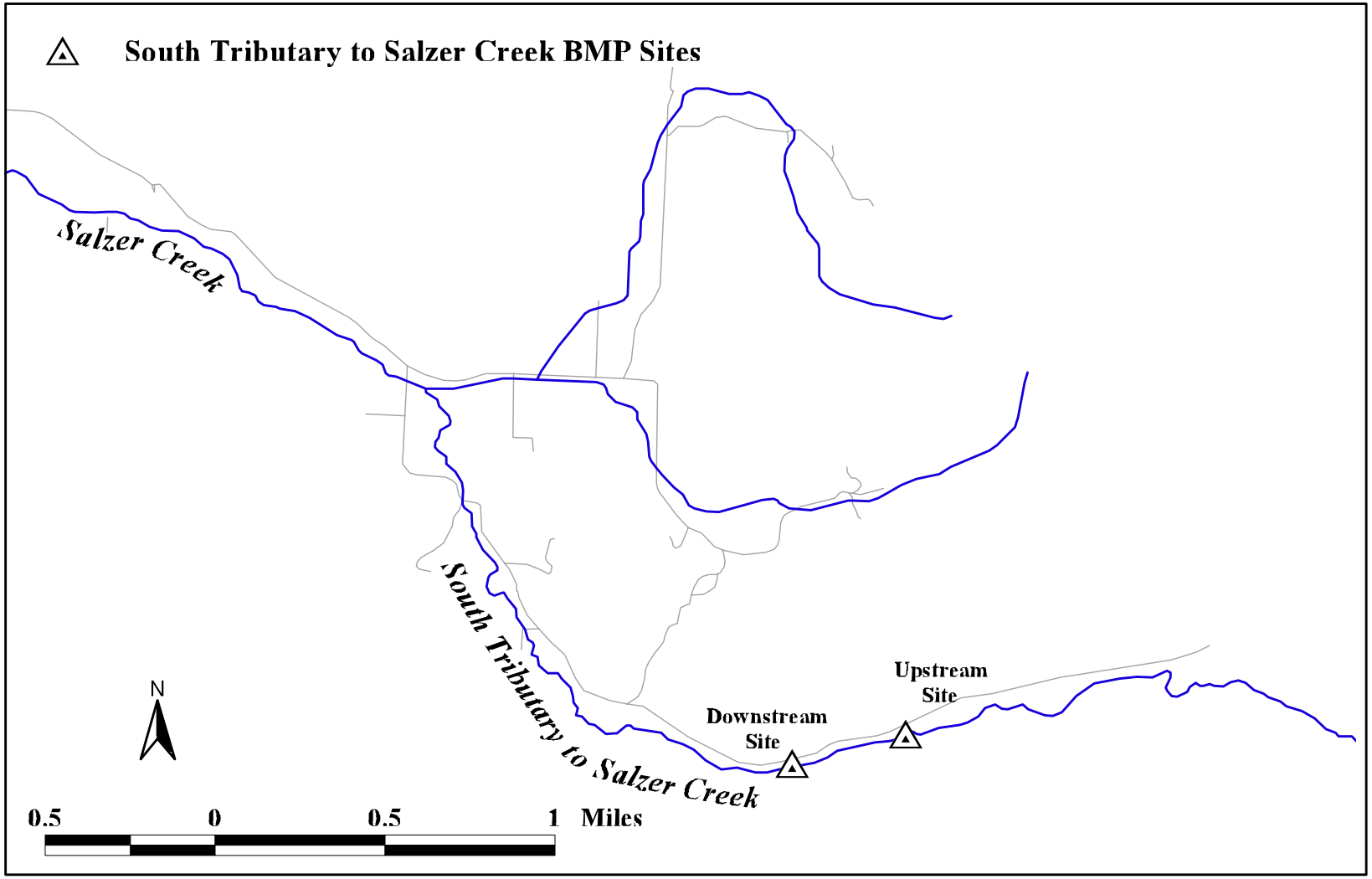

Figure 21. South Tributary to Salzer Creek BMP Temperature Monitoring Sites.

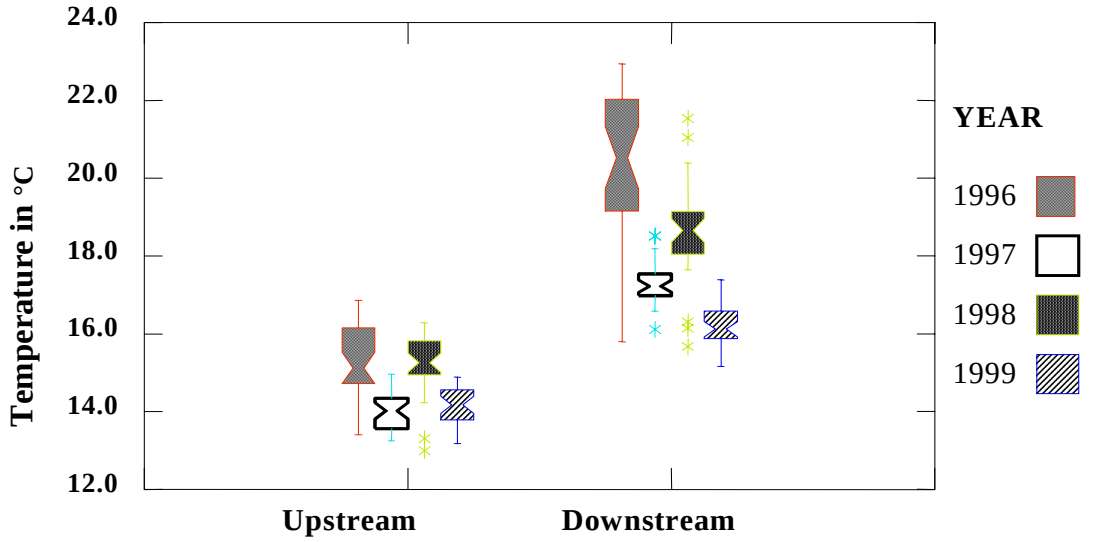

Figure 22. July 19-August 19, 1996-99 Maximum Daily Water Temperature for the Tributary to Salzer Creek.

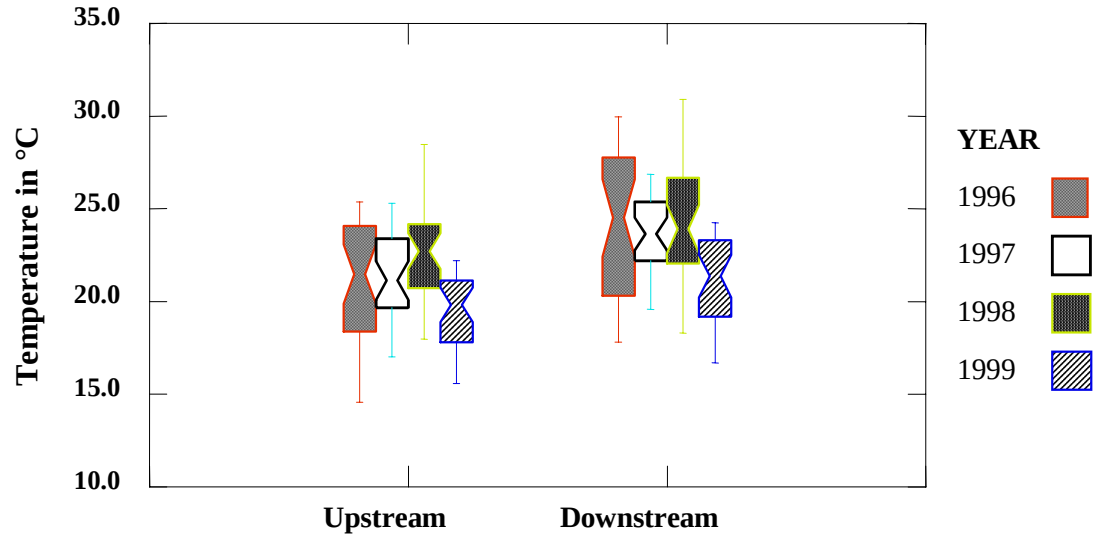

Figure 23. July 19-August 19, 1996-99 Maximum Daily Air Temperature for the Tributary to Salzer Creek.

5. South Branch of Big Creek

The South Branch of Big Creek is a small tributary to the Humptulips River, which flows into Grays Harbor in Grays Harbor County. The BMP site is located 12 miles north of Hoquiam and is owned by a private timber firm (Figure 24). In June 1998 deciduous and conifer seedlings were planted along both banks, and large woody debris in the form of multiple-log and single-log structures were placed along a one-mile stretch of the creek (Madril, 1999).

For monitoring purposes the study area was divided into three reaches. (1) The lower reach had the best riparian cover before BMP treatment, with a riparian buffer of mature conifers along both banks of the reach. Additional plantings did occur along the banks of the lower reach. (2) The mid-stream reach was logged and very little riparian cover remained. Replanting occurred along both banks of this reach. (3) The upper reach was under different ownership and did not receive BMP treatment. The upper reach was logged on both sides of the creek, with a 25-40 buffer of sparsely spaced Douglas fir. These provided little shading, as the only vegetation on the trees was a small crown near the top.

In 1998 three water temperature thermographs and one air thermograph were deployed. A suitable upstream or background site was not available. Water thermographs were placed at the downstream end of the lower reach, two at the downstream end of the mid-stream reach (one upstream and one downstream of a small tributary), and one air thermograph at the downstream site. On July 7, 1998 an additional water thermograph was placed at the upstream site. In 1999 the same sites were sampled again, and three air thermographs were deployed at the downstream, mid-stream, and upper reaches. Monitoring periods are shown in Table 10.

Table 10. 1998-9 Summary of water temperature data for the South Branch of Big Creek.

Monitoring Site	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
Upstream 1998	7/7/98-9/18/98	17 of 74	7/16/98 8/14/98	21.2°C	16 hours 7/27 + 7/28
Mid-Upstream 1998	6/23/98-9/6/98	0 of 76	N/A	16.7°C	N/A
Mid-Downstream 1998	6/23/98-9/6/98	0 of 76	N/A	17.9°C	N/A
Downstream 1998	6/23/98-9/6/98	1 of 76	7/27/98	18.1°C	2 hours 7/27
Upstream 1999	6/16/99-9/9/99	1 of 86	7/9/99	18.1°C	3 hours 7/9/99
Mid-Upstream 1999	6/16/99-9/9/99	0 of 86	N/A	14.6°C	N/A
Mid-Downstream 1999	6/16/99-9/9/99	0 of 86	N/A	15.8°C	N/A
Downstream 1999	6/16/99-9/9/99	0 of 86	N/A	15.6°C	N/A

Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate the temperature data are of good quality.

On August 10, 1998 the riparian cover for the three reaches was evaluated using a spherical densiometer and photo points. Densiometer readings and photo points were obtained at 25-meter intervals for 100 meters above each thermograph site. The average densiometer reading above the upstream thermograph site was 55% cover, ranging from 48 to 65%. Above the mid-stream thermographs the cover was 66%, ranging from 30 to 90%. Above the downstream thermograph the cover was 97%, ranging from 91 to 100%.

On September 9, 1998 flow discharge measurements were obtained at all three sites. Flows were <0.05 cfs for each site, indicating no major surface water inputs between sites.

Appendix K includes hourly water and air temperature graphs for all sites. Table 10 summarizes water temperature results. Figures 25 and 26 present box plots of 1998-9 maximum daily water temperature for July 15-August 15, and daily maximum air temperature for the same period where available.

The water temperature graphs and box plot show that in 1998 water temperature was higher and varied most at the upstream site. Paired t-tests show significantly higher water temperatures upstream as compared to the mid-upstream site. The two mid-stream sites reversed, with the mid-upstream probe having significantly higher temperatures in 1998, and the mid-downstream site having significantly higher temperatures in 1999. The downstream site had significantly higher temperatures in 1998, but lower temperature than the mid-downstream site in 1999. Differences seen in the downstream site may be due to the increase in temperature seen at the mid-downstream site. The air temperature was higher in 1998 than in 1999; in 1999 air temperatures were similar for all three sites.

Temperature measurements were compared to the criterion of 18.0°C for freshwater. In 1998 the upstream site did not meet the numeric criterion, and the downstream site had a minor excursion of 18.1°C for one day. In 1999 all the sites met the numeric criterion except the upstream site with a one-day exceedence from the standard, with a temperature of 18.1°C.

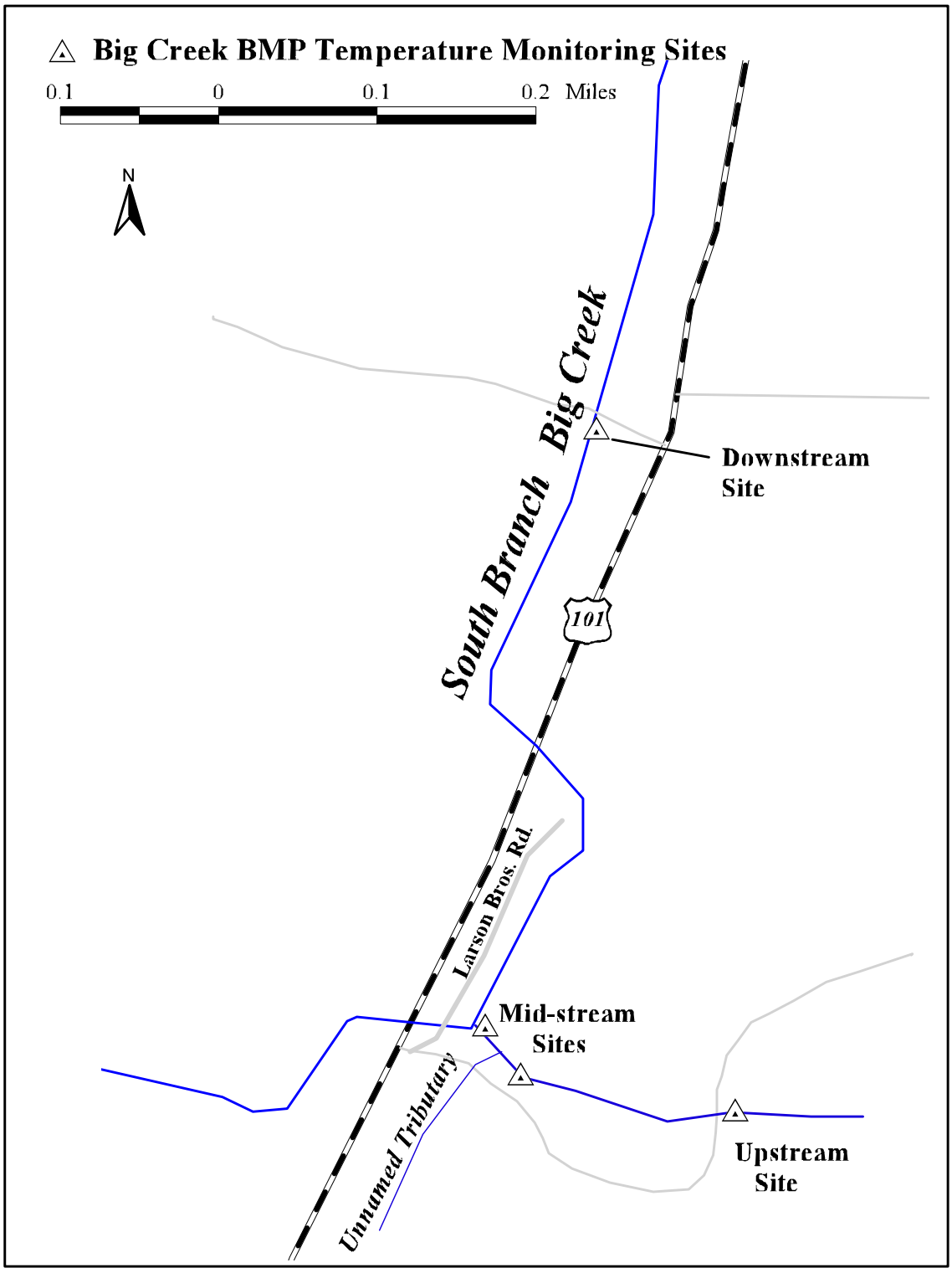

Figure 24. South Branch of Big Creek Temperature Monitoring Sites.

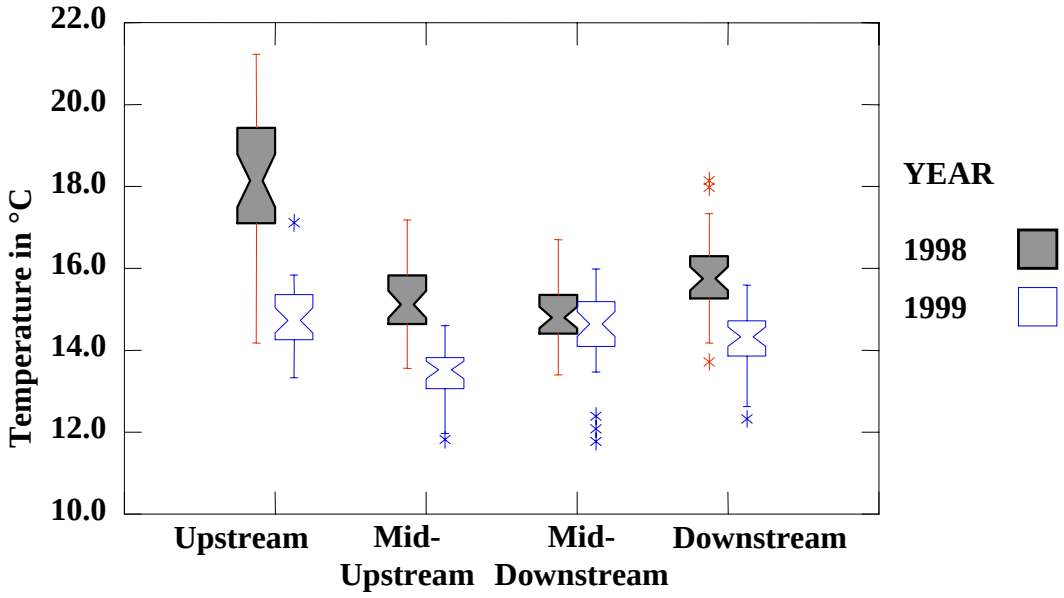

Figure 25. South Branch of Big Creek Maximum Daily Water Temperature for July 15-August 15, 1998-9.

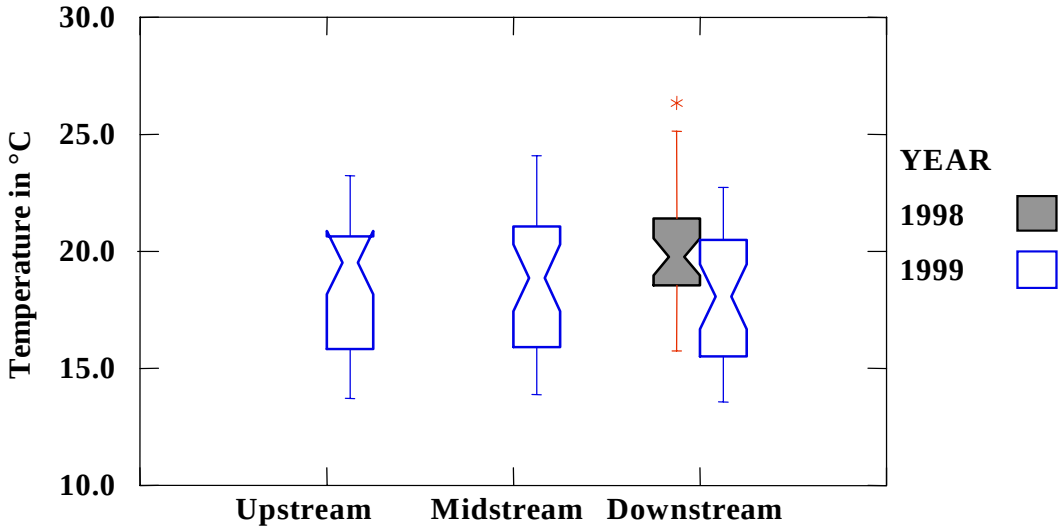

Figure 26. South Branch of Big Creek Maximum Daily Air Temperature for July 15-August 15, 1998-9.

6. Stillman Creek

Stillman Creek, a tributary of the South Fork Chehalis River, is located in Lewis County, eight miles southwest of Pe Ell (Figure 27). The upper watershed above CM 3.0 is primarily forestland owned by Weyerhaeuser timber company. Downstream of CM 3.0 land use is primarily agricultural. A Washington Forest Practices Watershed Analysis was conducted on Stillman Creek in 1994. The Watershed Analysis includes prescriptions for forestry practices in the upper watershed as well as voluntary management objectives for the agricultural lands.

In June 1994 Weyerhaeuser installed one air temperature gauge and 11 water temperature gauges in Stillman Creek and selected tributaries. Temperature data were collected using continuous recorders that collect daily maximum temperature. Summer peak water temperatures occurred on July 22, 1994. Maximum daily water temperatures ranged from 16.1°C in the upper reaches of Stillman Creek to 24.1°C within the lower reaches. The maximum air temperature that day was 34°C. Appendix L contains the Riparian Assessment portion of Weyerhaeuser's watershed analysis on Stillman Creek, including the stream temperature assessment (Weyerhaeuser, 1994).

From 1998-2000 water and air temperature thermographs were deployed at three sites on Stillman Creek. Water and air temperature thermographs were placed at CM 4.0 just downstream from Mill Creek, at CM 2.6 just downstream from Halfway Creek, and at CM 0.6 just upstream of Lost Creek. In 1998 the monitoring season did not begin until August 20. In 2000 an additional water thermograph was deployed upstream of Halfway Creek at CM 2.7. This probe was deployed to determine the temperature influence of Halfway Creek. Monitoring periods are shown in Table 11.

Table 11. 1998-2000 Summary of water temperature data for Stillman Creek.

Monitoring Site	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
Upstream 1998	8/20/98-9/20/98	2 of 32	9/1/98 9/3/98	18.4°C	4 hours 9/1
Mid-stream 1998	8/20/98-9/20/98	21 of 32	8/20/98 9/16/98	21.0°C	12 hours 8/31-9/1
Downstream 1998	8/20/98-9/20/98	21 of 32	8/20/98 9/14/98	20.5°C	20 hours 8/31-9/1
Upstream 1999	6/24/99-9/12/99	1 of 81	8/25/99	18.2°C	2 hours 8/25
Mid-stream 1999	6/24/99-9/12/99	41 of 81	7/6/99 9/3/99	21.3°C	11 hours 8/10
Upstream 2000	6/23/00-9/27/00	8 of 97	7/30/00 8/9/00	19.2°C	5 hours 7/30+7/31
Above Mid-stream 2000	6/23/00-9/27/00	27 of 97	6/27/00 9/14/00	21.2°C	10hours 7/30+7/31
Mid-stream 2000	6/23/00-9/27/00	31 of 97	6/27/00 9/16/00	21.5°C	11 hours 7/30+7/31

Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate Stillman Creek temperature data are of good quality.

In 1999 and 2000 the downstream thermograph at CM 0.6 was physically lost. No data for the warmer period, July 15-August 15, are available for this site

On August 20, 1998 flow discharge measurements were obtained at CM 4.0 and CM 2.6, with flows of 10.5 and 9.4 cfs respectively.

Appendix M includes hourly water and air temperature graphs for the upstream and downstream sites. Table 11 summarizes the water temperature results. Figures 28 and 29 present box plots of 1999-2000 maximum daily water and air temperature for July 15-August 15.

Figures 30 and 31 are box plots of 1998-2000 maximum daily water and air temperature for August 20-September 12. This was the only time period when data from all three water temperatures sites were available.

The water temperature graphs and box plots show that water temperature is higher at the mid-stream and downstream sites. A paired t-test shows significantly higher water temperatures from upstream to the mid-stream site for all years. In 2000 there was a small increase in temperature between CM 2.6 to 2.7, with a mean of 18.9°C and 19.1°C respectively. This increase is probably due to the influence of Halfway Creek. While 2000 appeared to have warmer air temperatures than 1999, water temperature from the mid-stream site did not differ significantly, while the upstream site had increased water temperatures in 2000.

Temperature measurements were compared to the criterion of 18.0°C for freshwater. The upstream and mid-stream sites did not meet the numeric temperature criterion for any of the years monitored, with a maximum temperature of 19.2°C upstream and a 21.2°C and 21.5°C maximum for the mid-stream sites in 2000. Temperature data collected for the downstream site in 1998 did not meet the numeric temperature criterion; data for this site from 1999 and 2000 are not available.

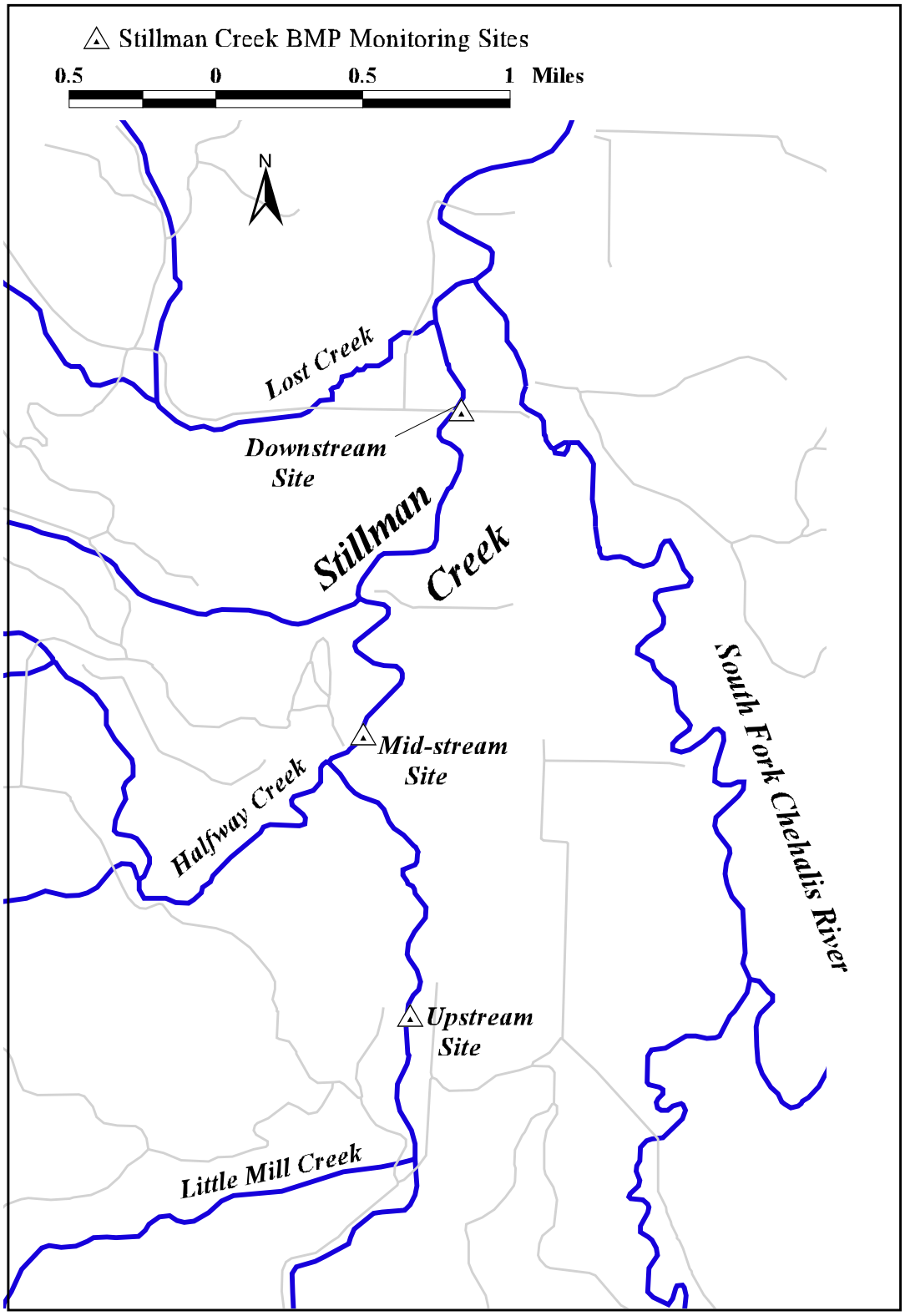

Figure 27. Stillman Creek Temperature Monitoring Sites.

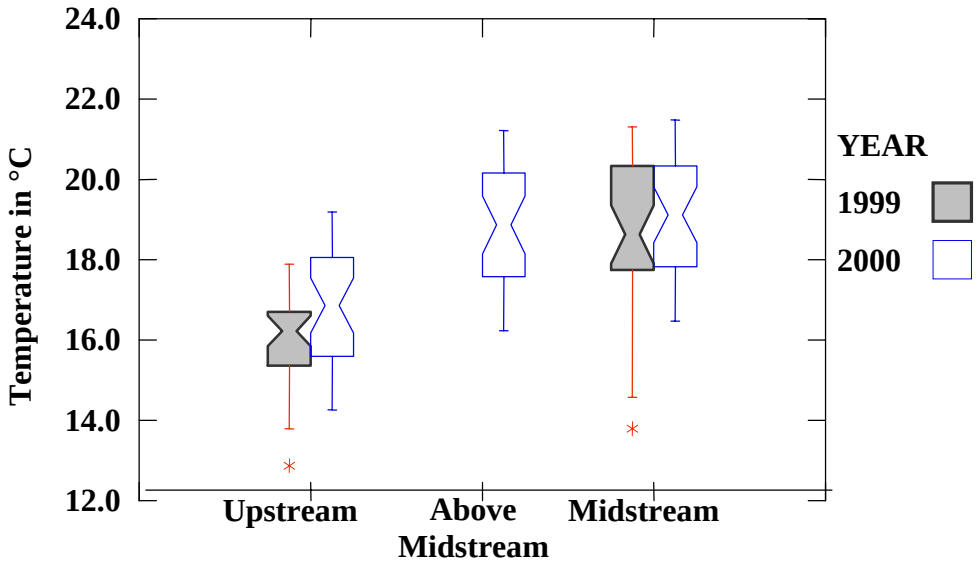

Figure 28. Stillman Creek Maximum Daily Water Temperature for July 15-August 15, 1999-2000.

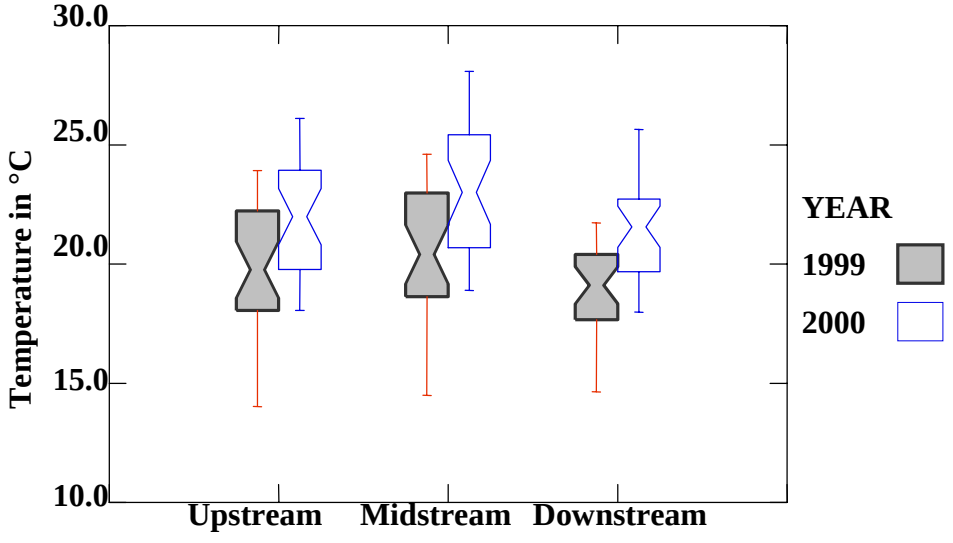

Figure 29. Stillman Creek Maximum Daily Air Temperature for July 15-August 15, 1998-2000.

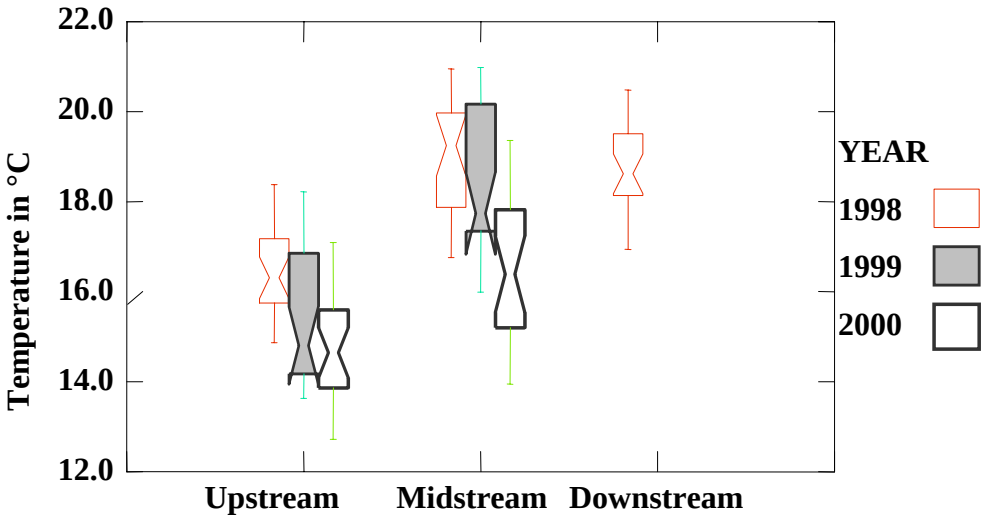

Figure 30. Stillman Creek Maximum Daily Water Temperature for August 20-September 12, 1998-2000.

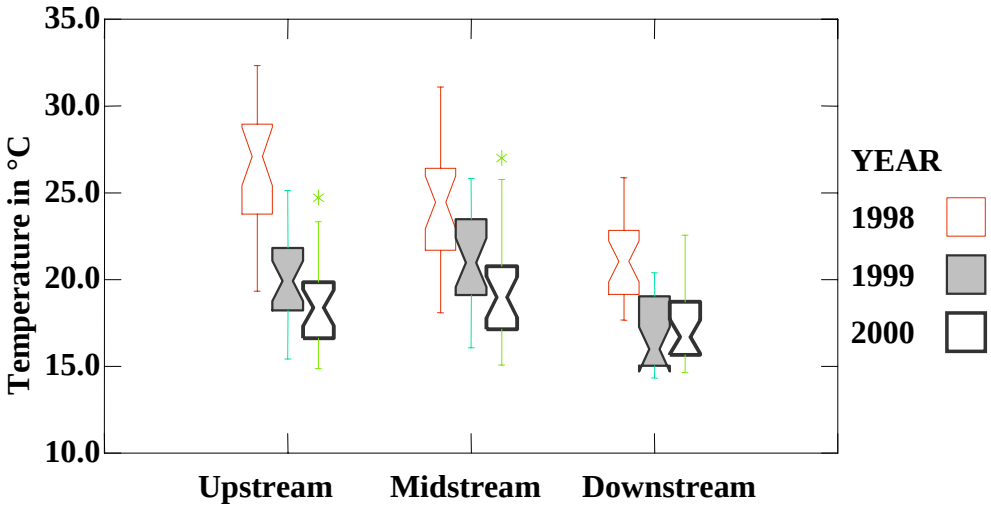

Figure 31. Stillman Creek Maximum Daily Air Temperature for August 20-September 12, 1998-2000.

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7. Tributary to Scatter Creek

The Scatter Creek tributary BMP site is located in Thurston County, 1.5 miles southeast of Tenino (Figure 32). Scatter Creek flows into the Chehalis River at RM 55.2. The BMP site is on privately owned land used for agricultural purposes. No BMPs were in place during monitoring. This site is slated for riparian replanting. Fencing was in place along most of the riparian at the BMP site.

In 2000 four water and three air temperature thermographs were deployed. One water temperature thermograph was installed upstream of the BMP site under a small walking bridge, and three thermographs were installed at the downstream end of the BMP site (one in a small tributary, one upstream of the tributary, and one downstream of the tributary). Air thermographs were installed at the upstream site, at the most downstream water thermograph site, and at the tributary. Monitoring periods are shown in Table 12.

Table 12. 2000 Summary of water temperature data for Scatter Creek tributary.

Monitoring Site	Dates monitored occurred	Days exceeding 18.0 °C out of number of days monitored	Dates of first and last violation during monitoring period	Maximum temperature	Maximum number of hours temperature > 18.0°C and dates
Upstream 2000	7/16/00-9/9/00	0 of 56	N/A	16.5°C	N/A
Mid-stream 2000	6/27/00-9/9/00	0 of 75	N/A	17.7°C	N/A
Tributary 2000	6/27/00-9/9/00	12 of 75	7/29/00 8/23/00	22.9°C	10 hours 7/30 + 7/31
Downstream 2000	6/27/00-9/9/00	4 of 75	8/1/00 8/25/00	19.4°C	5 hours 8/23

Quality control procedures, including hand-held thermometer readings and pre- and post-deployment checks of the thermographs, indicate the temperature data are of good quality.

Densiometer readings, photo points, and flow measurements were not obtained for this site.

Appendix N includes hourly water and air temperature graphs for all sites. Table 12 summarizes water temperature results. Figures 33 and 34 present box plots of the 2000 maximum daily water and air temperatures for July 16-August 16.

The water temperature graphs and the box plot show that water temperature was highest and most variable in the unnamed tributary. The lowest and steadiest water temperatures were seen at the most upstream site. This site also had the highest air temperatures. The upstream water site could be fed primarily by groundwater, accounting for the lower and steadier water temperatures. Paired t-tests showed a significant increase in water temperature from the upstream to the upper downstream site. There was not a significant change in water temperature from two downstream sites despite the higher water temperatures in the tributary.

Temperature measurements were compared to the criterion of 18.0°C for freshwater. The upstream and mid-stream sites met the numeric temperature criterion. The unnamed tributary and the downstream site did not meet the numeric criterion, with maximum temperatures of 22.9°C and 19.4°C respectively.

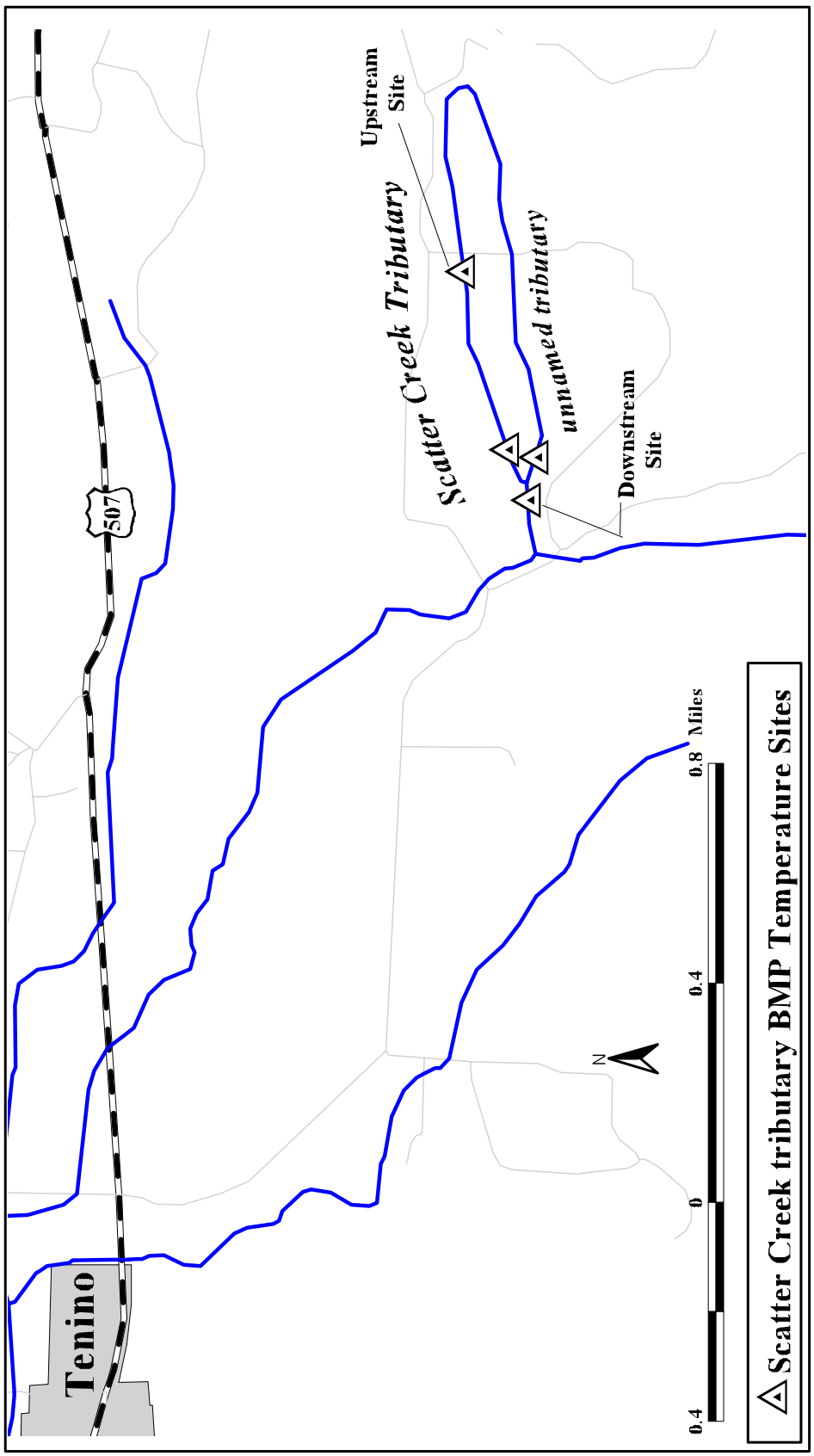

Figure 32. Scatter Creek Tributary Temperature Monitoring Sites.

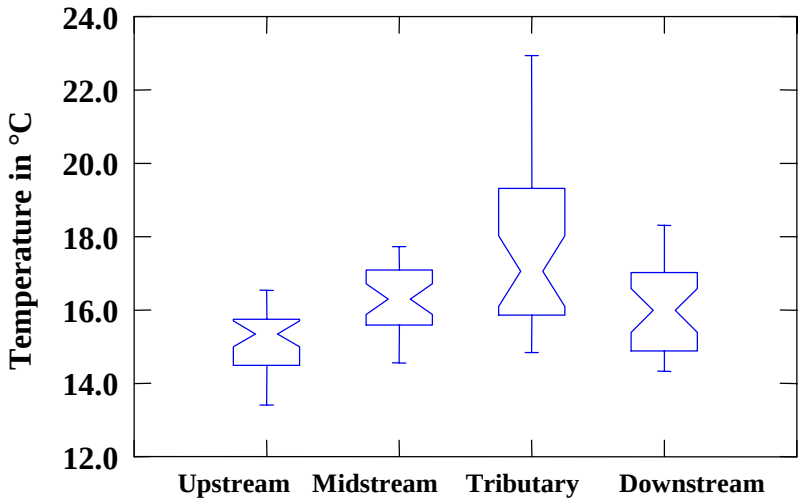

Figure 33. Scatter Creek Tributary Maximum Daily Water Temperature for July 16-August 16, 2000.

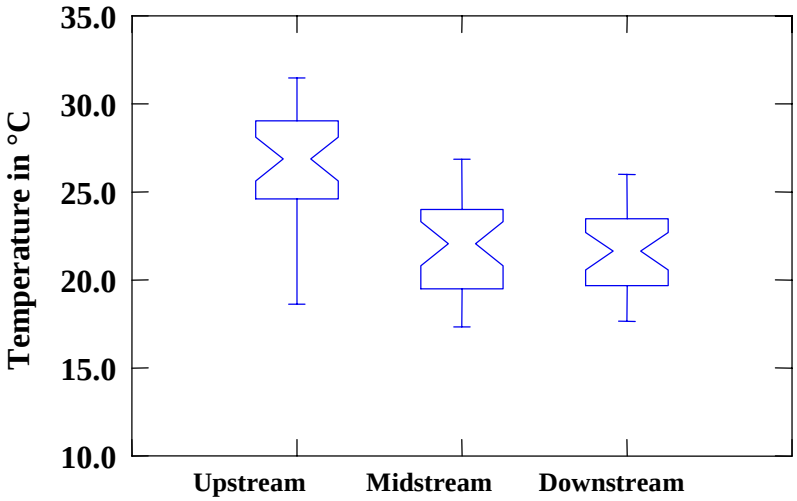

Figure 34. Scatter Creek Tributary Maximum Daily Air Temperature for July 16-August 16, 2000.

Conclusions and Recommendations

Long-term Trend Monitoring Sites

All five long-term temperature monitoring sites had water temperatures exceeding the numeric water temperature criterion of 18.0°C. The highest tributary temperatures were in the South Fork Chehalis River and the Newaukum River, with the next highest in the Black River, followed by Lincoln Creek. The Chehalis River upstream of the Newaukum River had some of the highest temperatures, but data from this site may not be representative of river conditions.

Three of the five sites – South Fork Chehalis River, Newaukum River, Chehalis River upstream of the Newaukum River – had temperatures exceeding 25.0°C, which is near the upper lethal temperature limit for salmonids (Brett, 1956).

Recommendations for these five sub-basins are:

- Install riparian shade best management practices where monitoring occurred, with high priority on the sites with salmonids.
- Conduct water temperature monitoring to determine reaches or tributaries contributing to high water temperatures.
- Continue long-term water temperature monitoring to determine progress.

Best Management Practice Sites

Monitoring showed lower upstream temperatures and minor exceedences in the water temperature standard upstream for four sites: North Lincoln Creek, Mohney Creek tributary, Salzer Creek south tributary, and Scatter Creek tributary.

Recommendations for these four sites are:

- Conduct periodic monitoring to determine the success of the BMPs (e.g., fence conditions and percent survivability of riparian plantings).
- Conduct post-BMP water and air temperature monitoring to begin when riparian plantings become effective in providing shade. Shade measurements and photo points should be obtained with post-BMP water temperature monitoring.

Higher upstream water temperatures were found at Mill Creek and the South Branch of Big Creek. This will make it difficult to determine the effectiveness of BMPs installed downstream.

The recommendation for these two sites is:

- Install riparian shade BMPs upstream of the site to lower upstream temperatures.

For Stillman Creek the recommendations are:

- Continue water temperature monitoring at the upstream site to determine the effectiveness of the forestry prescriptions.
- Install riparian shade BMPs in the lower reaches of Stillman Creek in an effort to lower water temperature.

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Appendices

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Appendix A.

Example of Notched Box Plots

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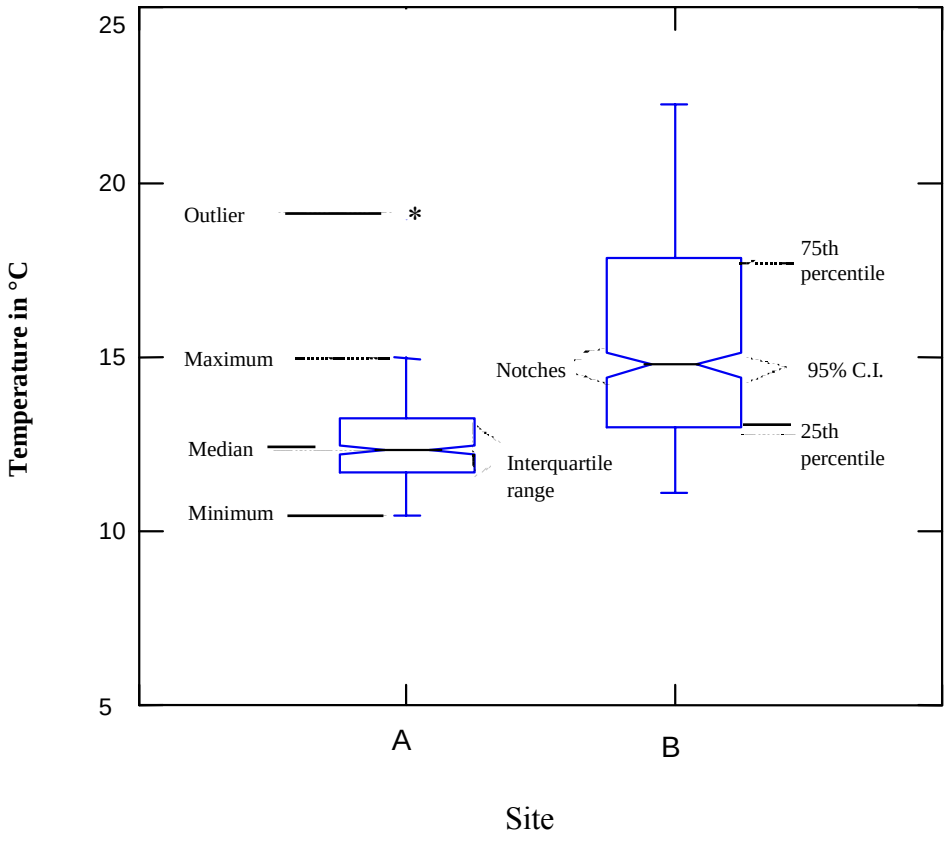
Appendix A. Example of Notched Box Plots.



Box plots are graphical displays of the distribution and characteristics of sample data. Fifty percent of the sample data lie within the box. The remainder of the data, except outliers, lie within the upper and lower tails. Symmetrical plots (see A, above) suggest that the data are normally distributed. Asymmetrical plots like B (unequal tails and median not equidistant between quartiles) may indicate a skewed distribution. Long whiskers indicate a wide range of data values. Small sample size or highly variable data tend to result in larger confidence intervals. Outliers lie within 1.5 to 3 times the interquartile range.

Notched box plots are useful for showing differences between two groups. The upper and lower notches mark the 95% confidence interval (C.I.) around the median. If the notches do not overlap, the site medians are significantly different. In the figure above, the 95% C.I.s of sites A and B do not overlap. Therefore, the median temperatures at the two sites are significantly different.

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Appendix B. Black River

Maximum, Mean, and Hourly Water Temperature

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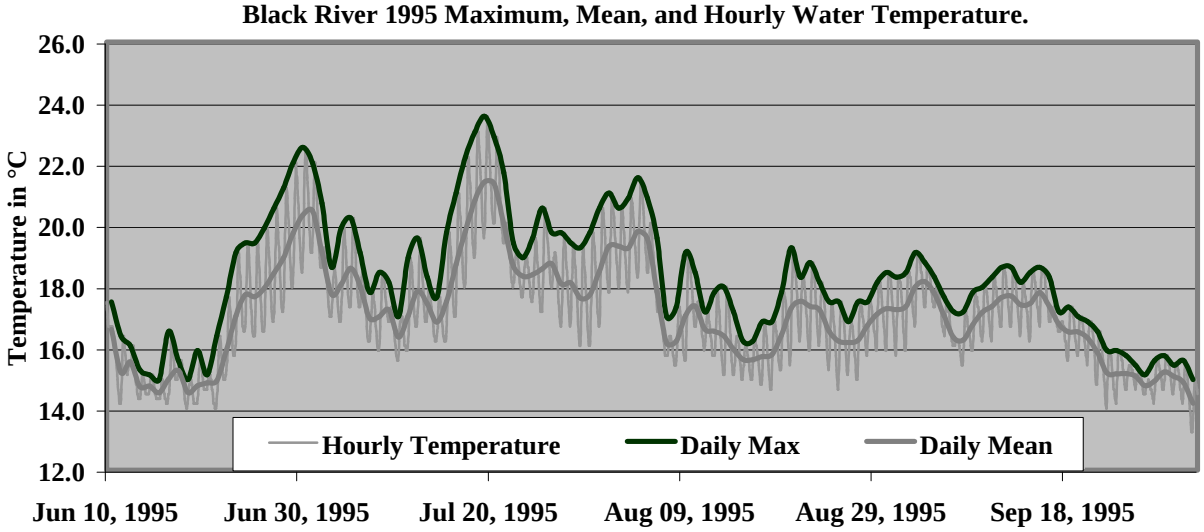
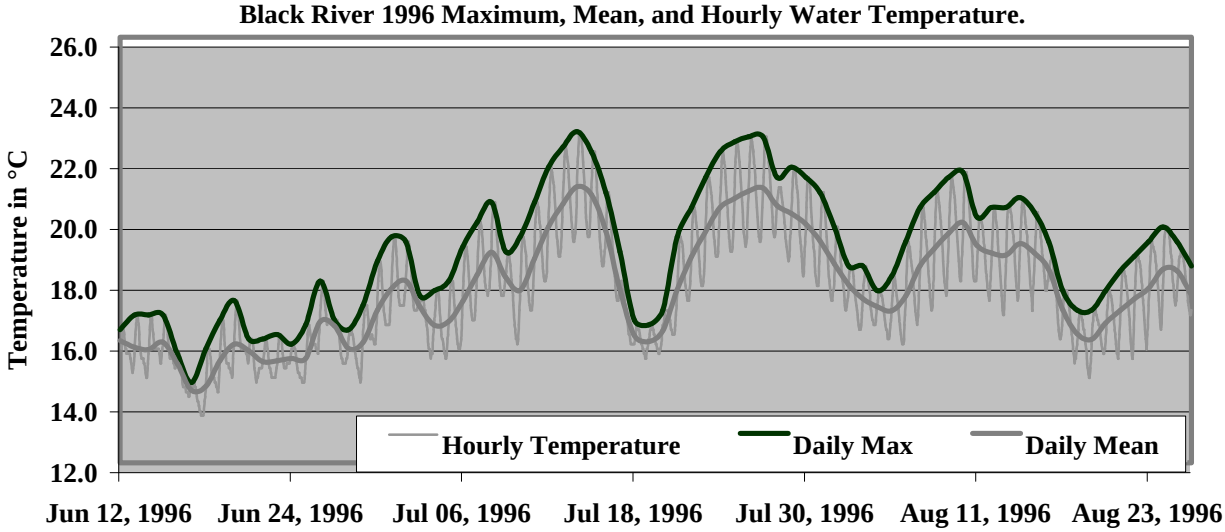
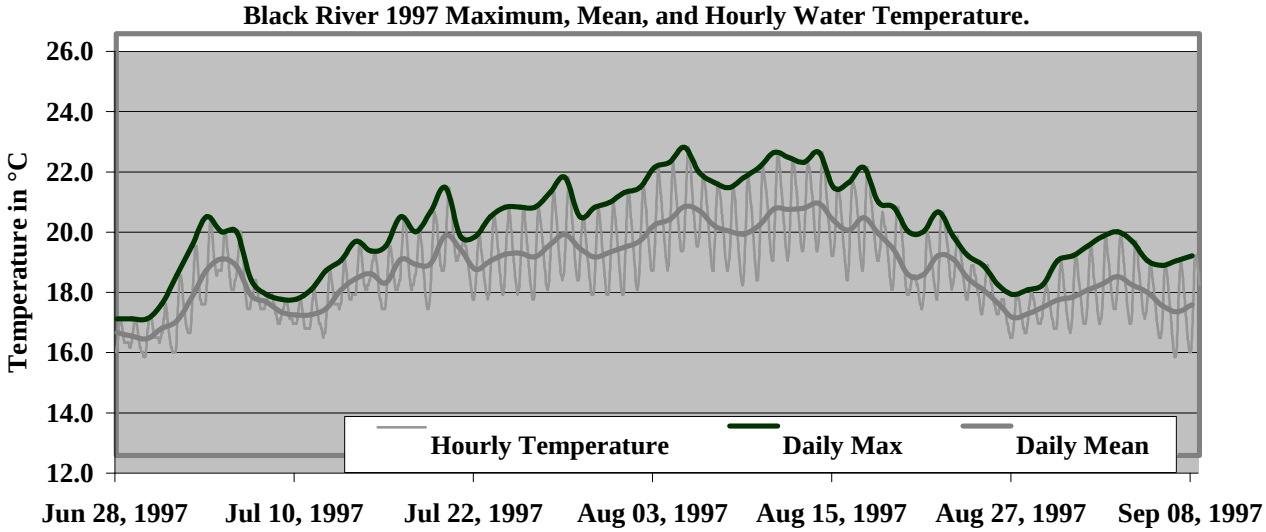
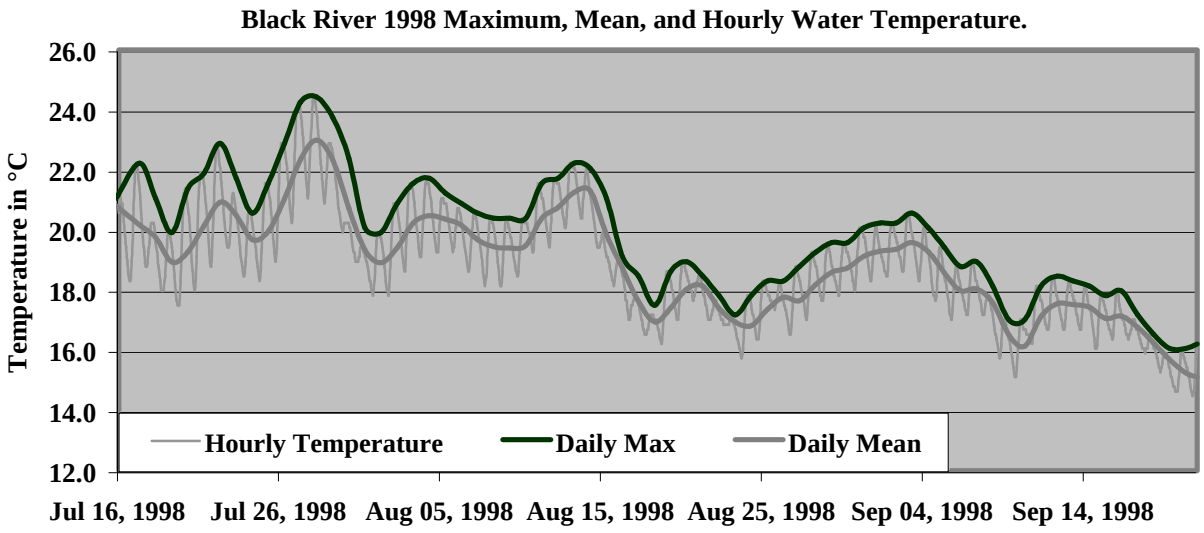
Appendix B. Black River Maximum, Mean, and Hourly Water Temperature.

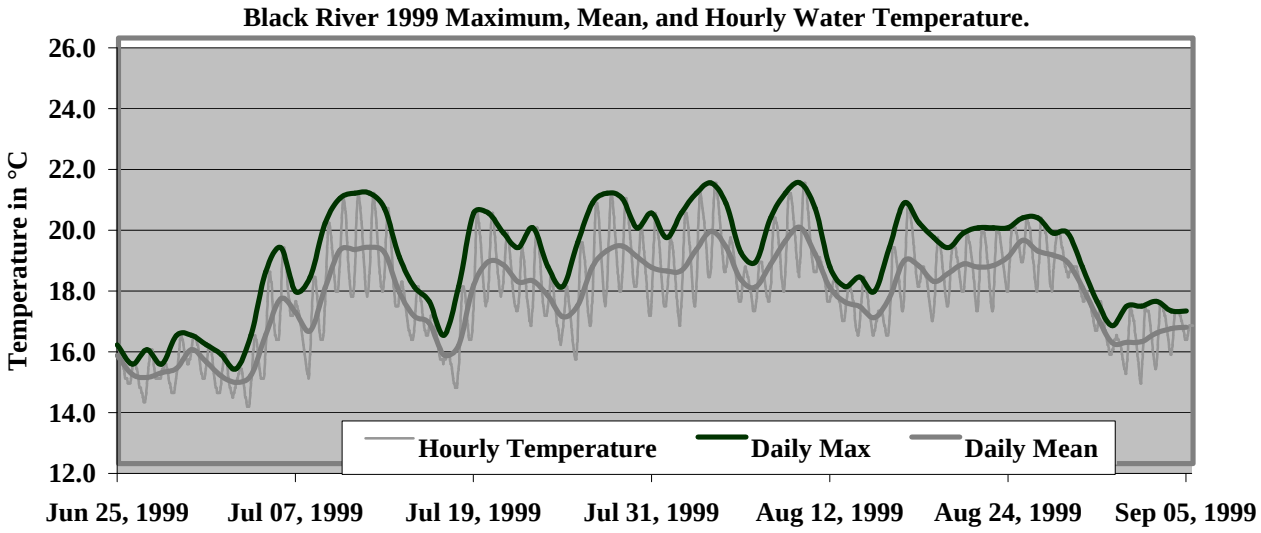


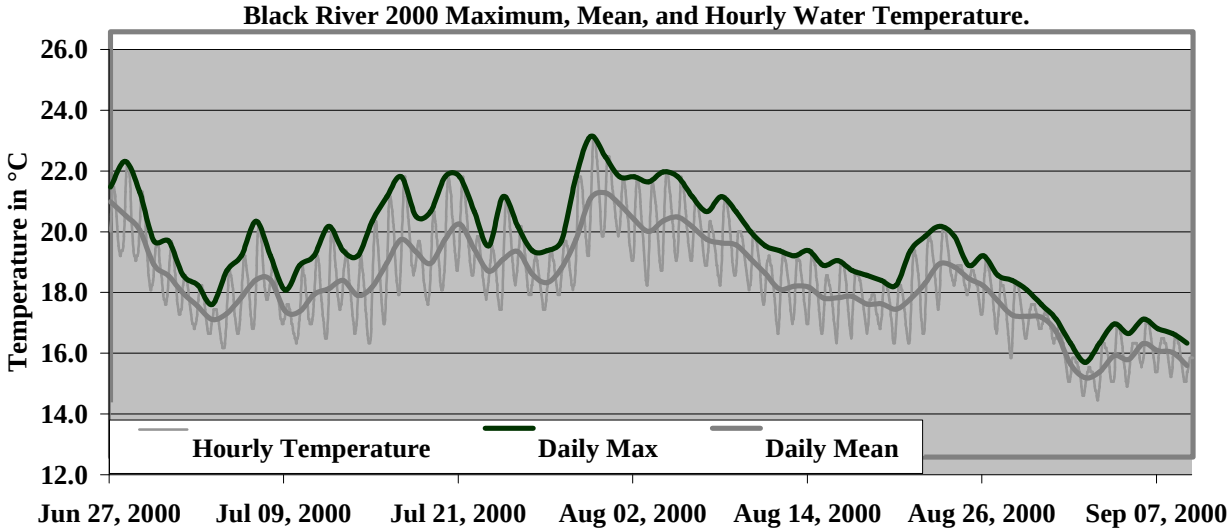




Appendix B. Black River Maximum, Mean, and Hourly Water Temperature.







Appendix C. Lincoln Creek

Maximum, Mean, and Hourly Water Temperature

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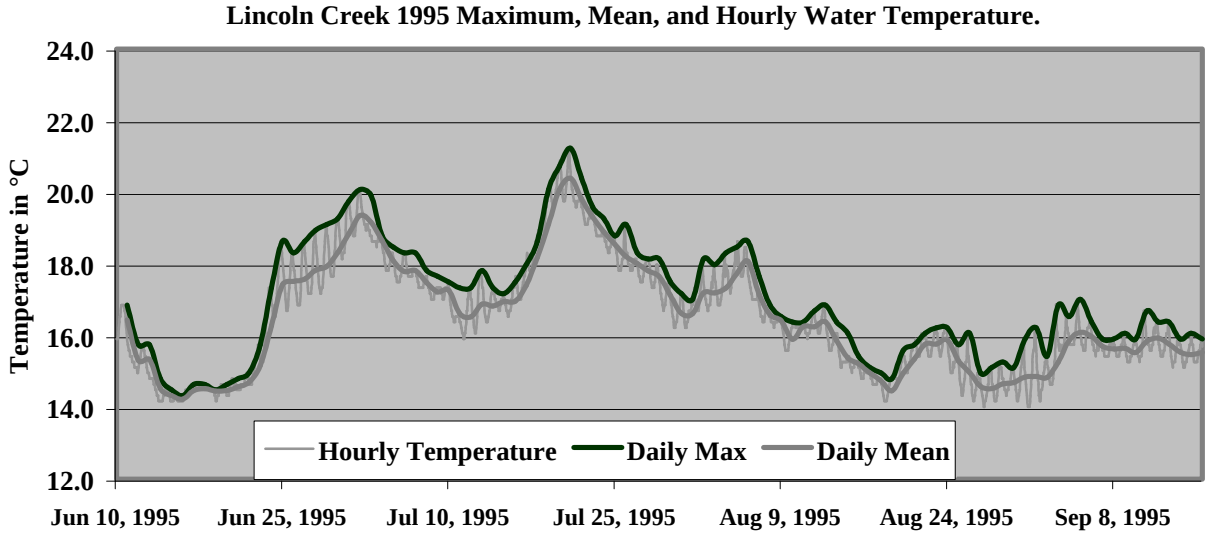
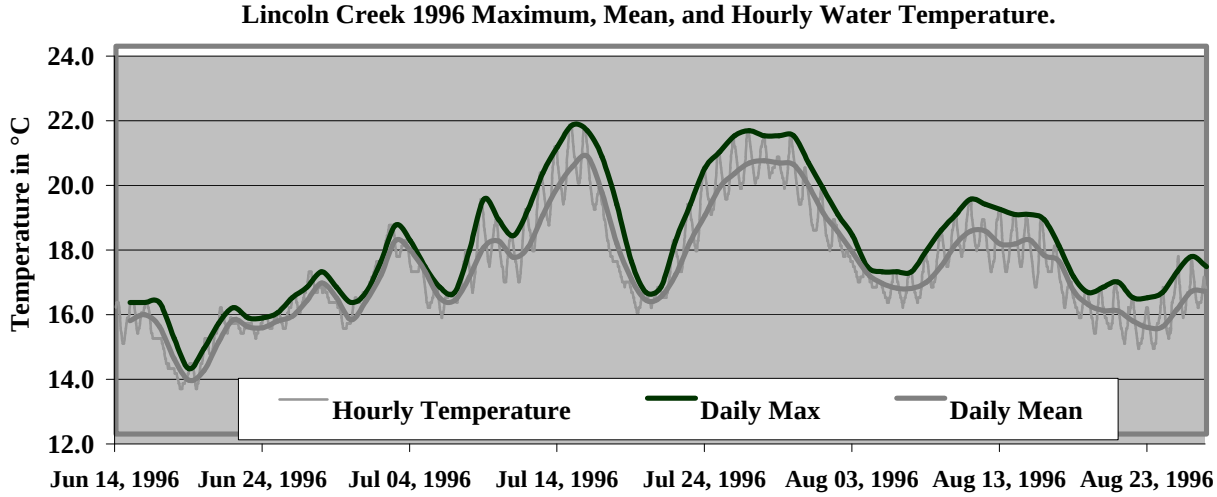
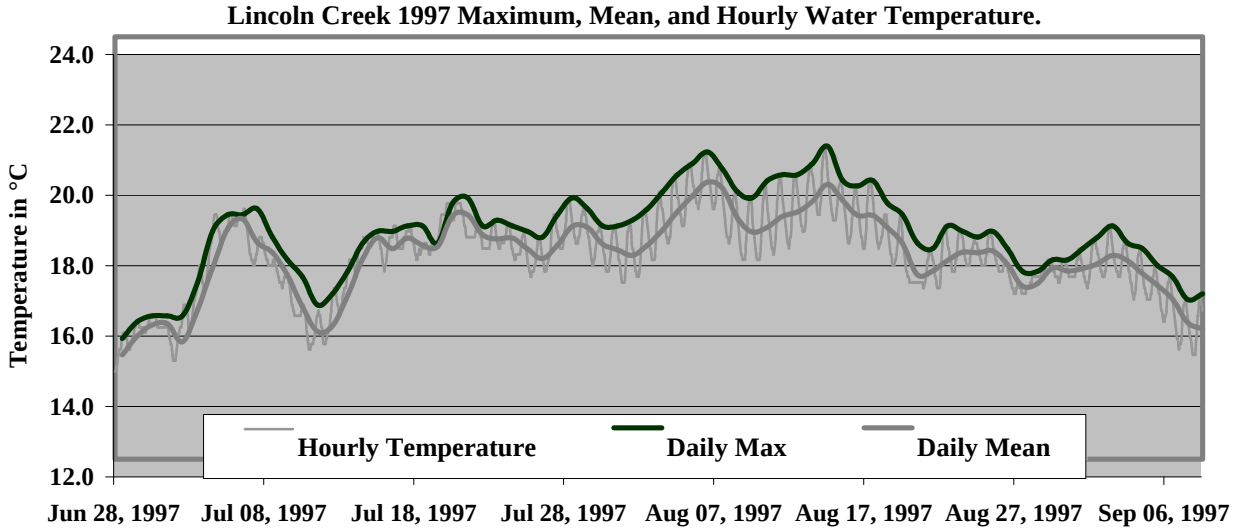
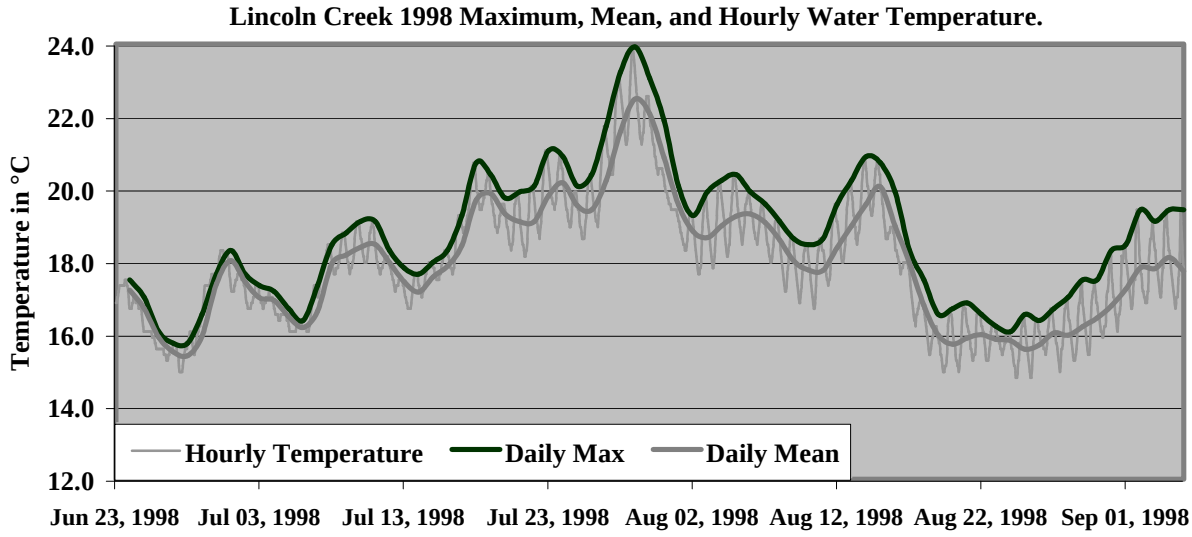
Appendix C. Lincoln Creek Maximum, Mean, and Hourly Water Temperature.

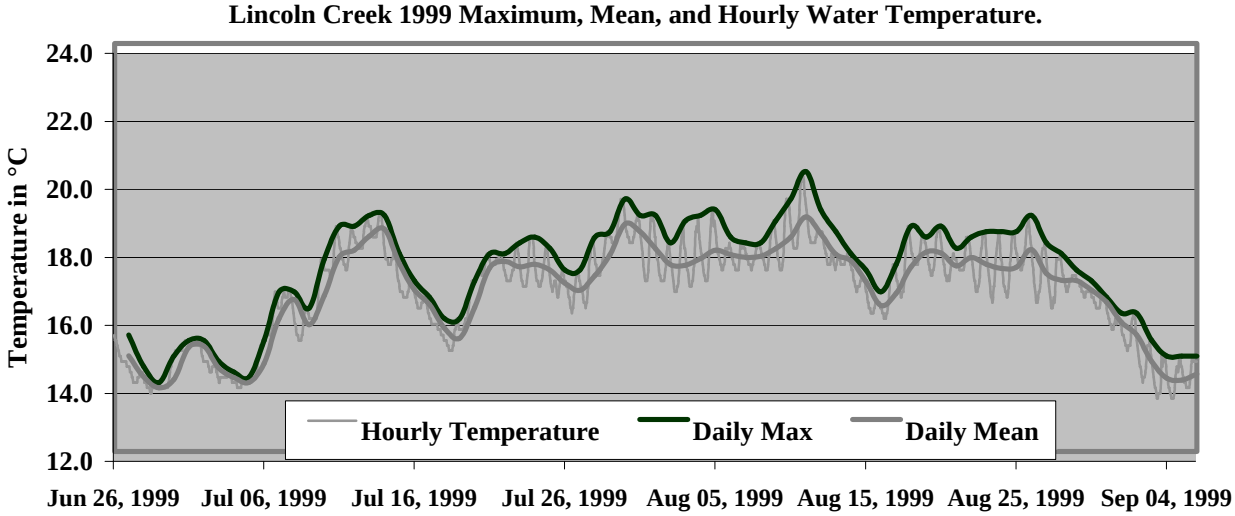


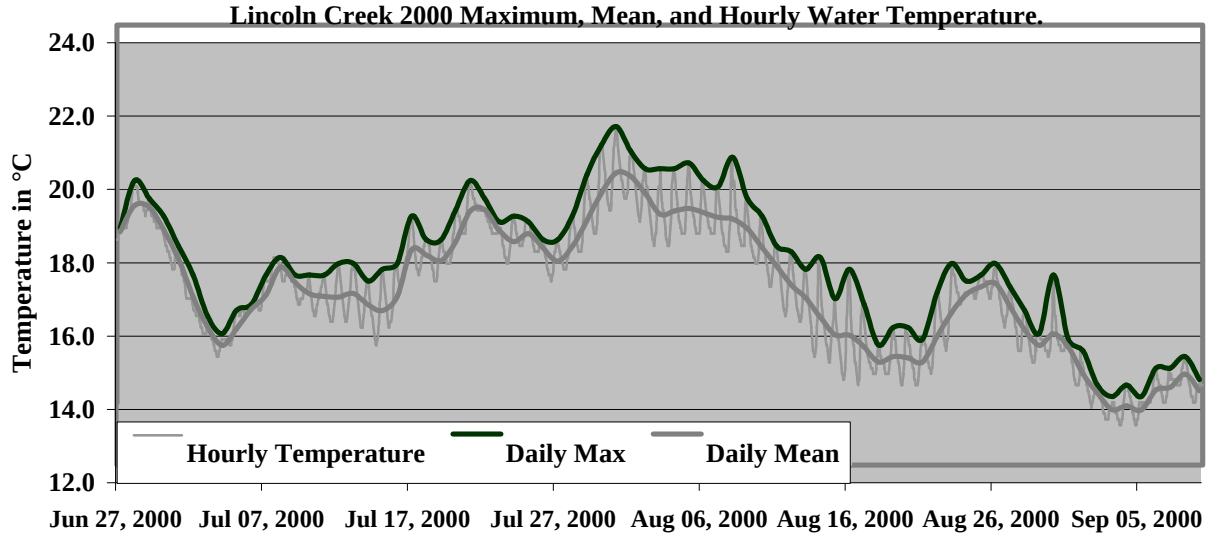




Appendix C. Lincoln Creek Maximum, Mean, and Hourly Water Temperature.







Appendix D. South Fork Chehalis

Maximum, Mean, and Hourly Water Temperature

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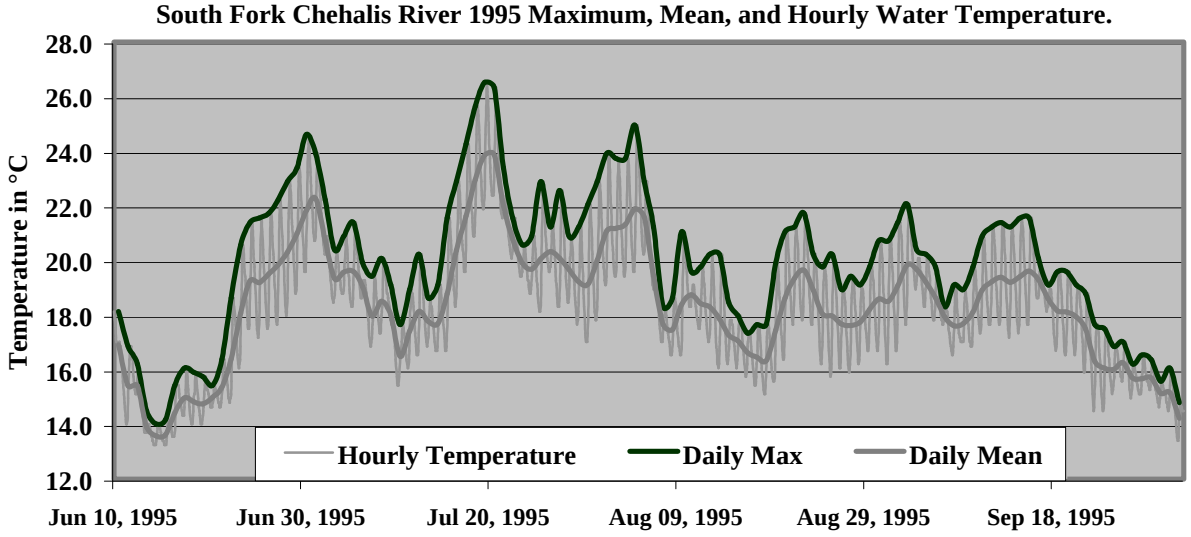
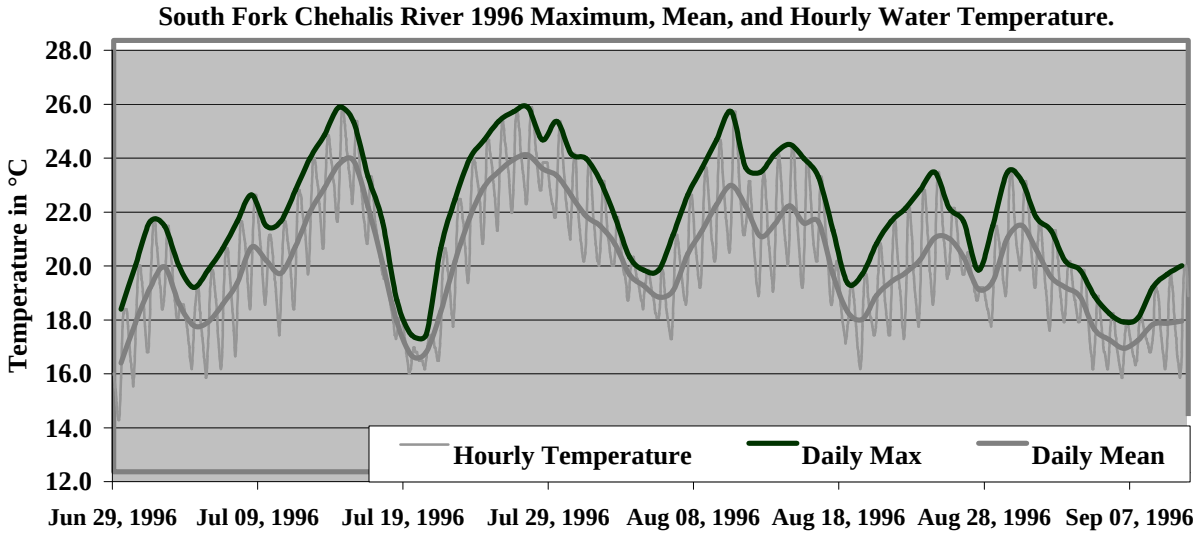
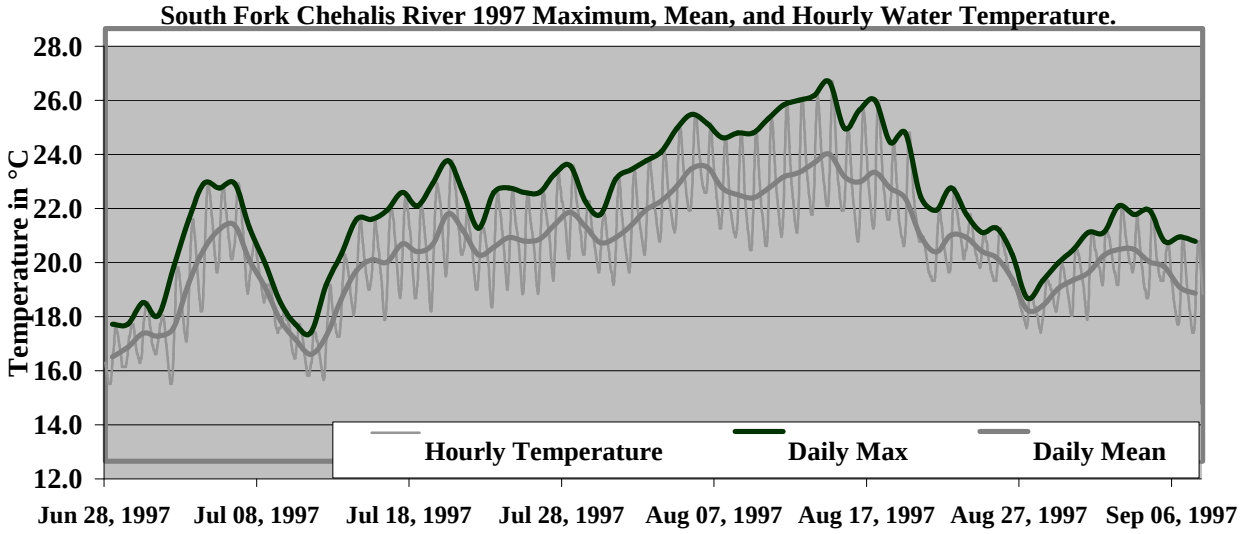
Appendix D. South Fork Chehalis River Maximum, Mean, and Hourly Water Temperature.

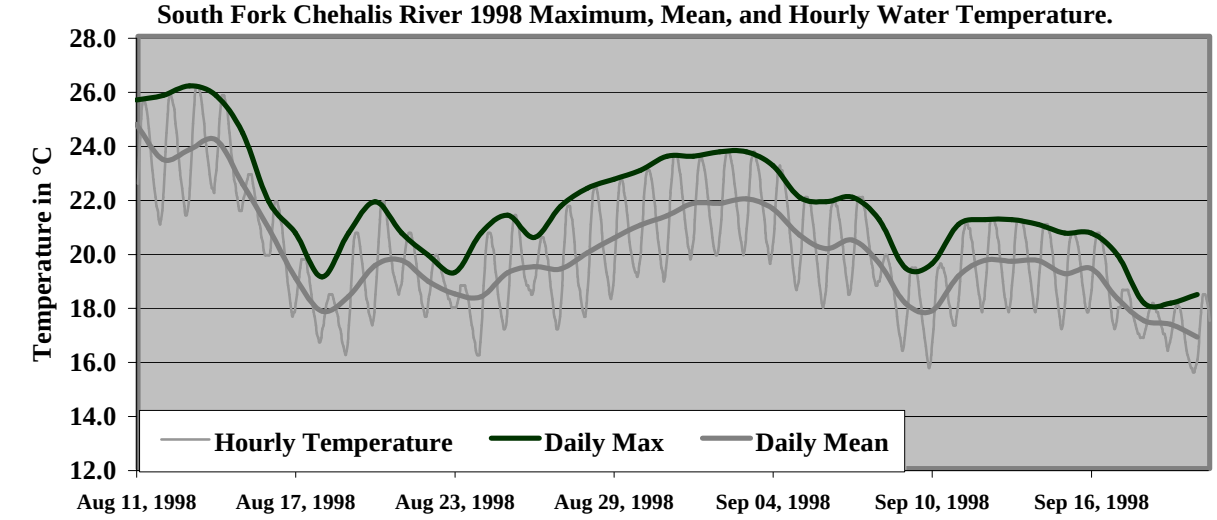




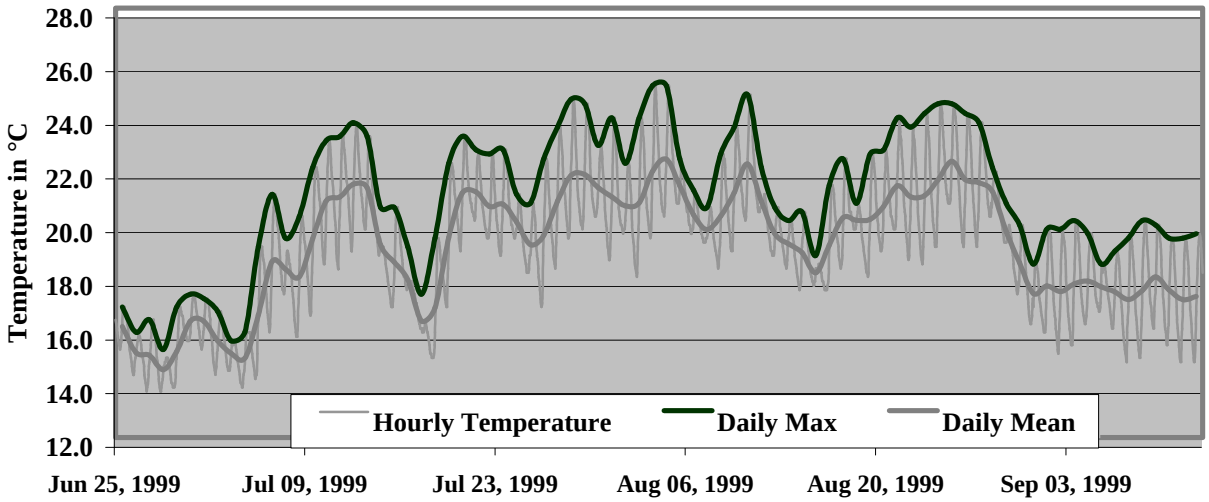


Appendix D. South Fork Chehalis River Maximum, Mean, and Hourly Water Temperature.

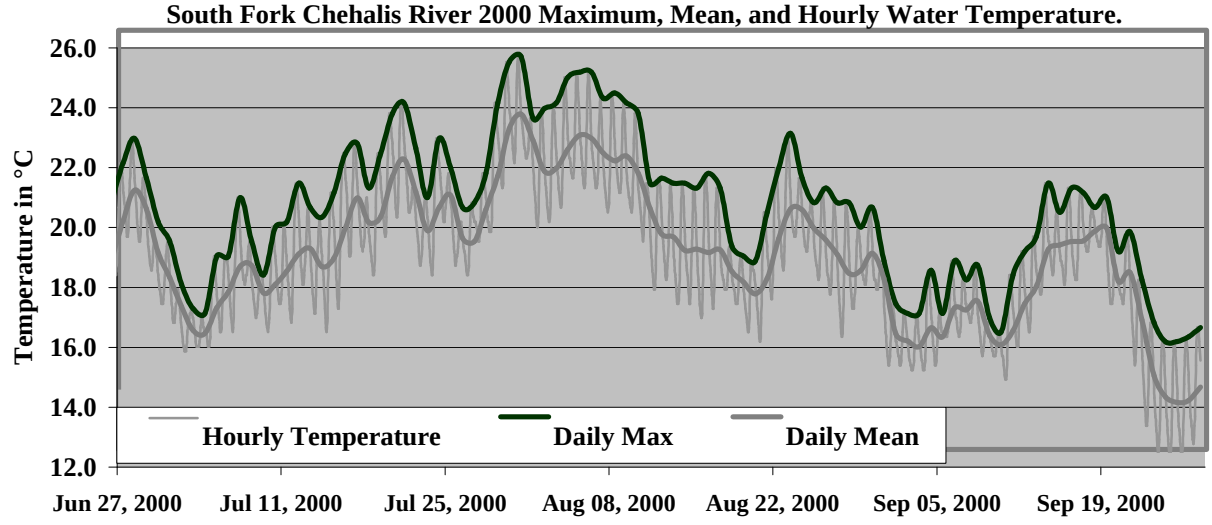
South Fork Chehalis River 1998 Maximum, Mean, and Hourly Water Temperature.



South Fork Chehalis River 1999 Maximum, Mean, and Hourly Water Temperature.



South Fork Chehalis River 2000 Maximum, Mean, and Hourly Water Temperature.



Appendix E. Newaukum River

Maximum, Mean, and Hourly Water Temperature

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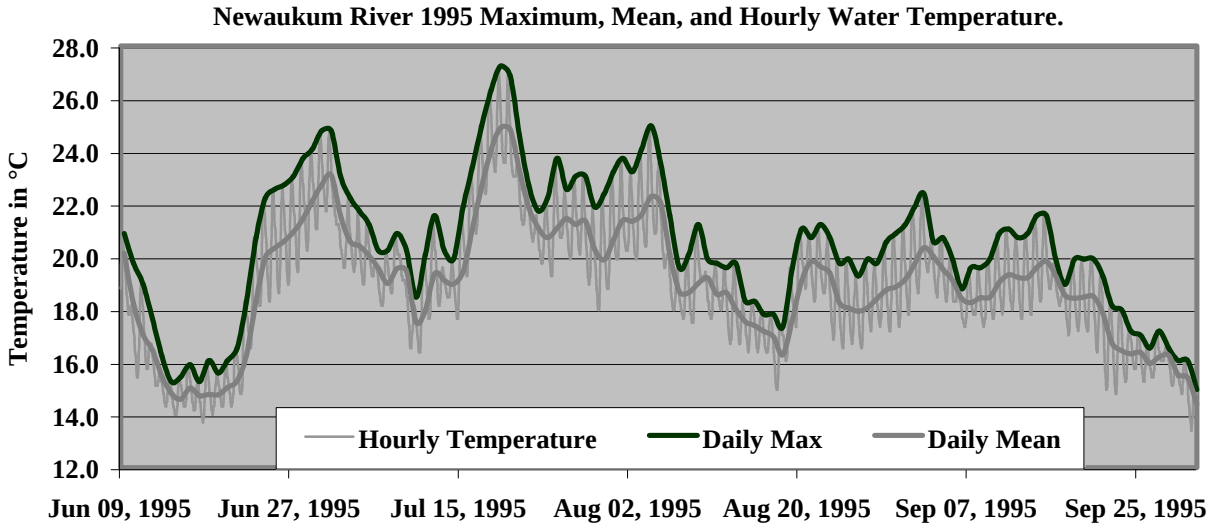
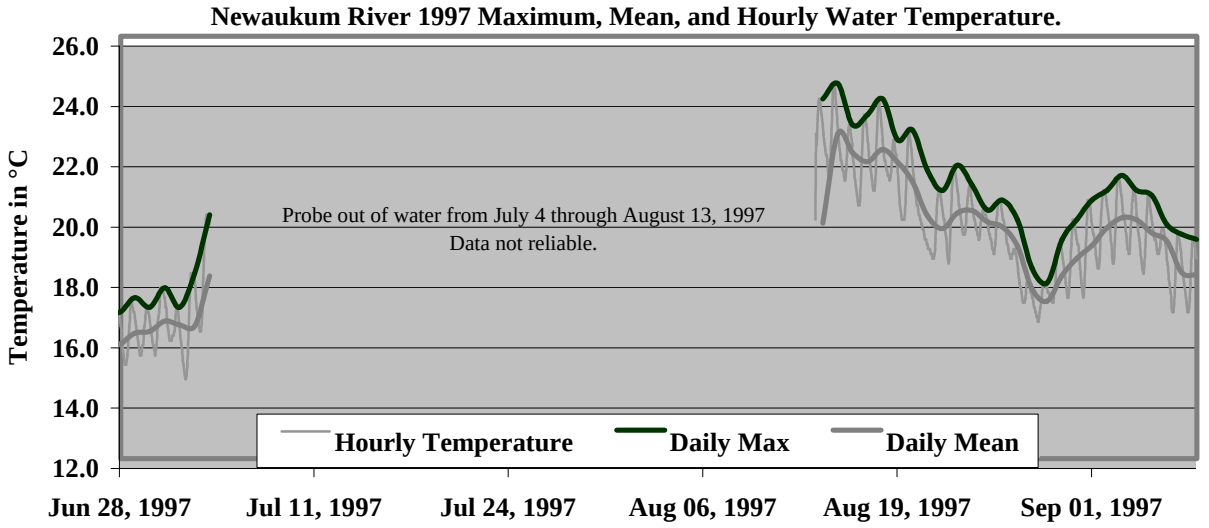
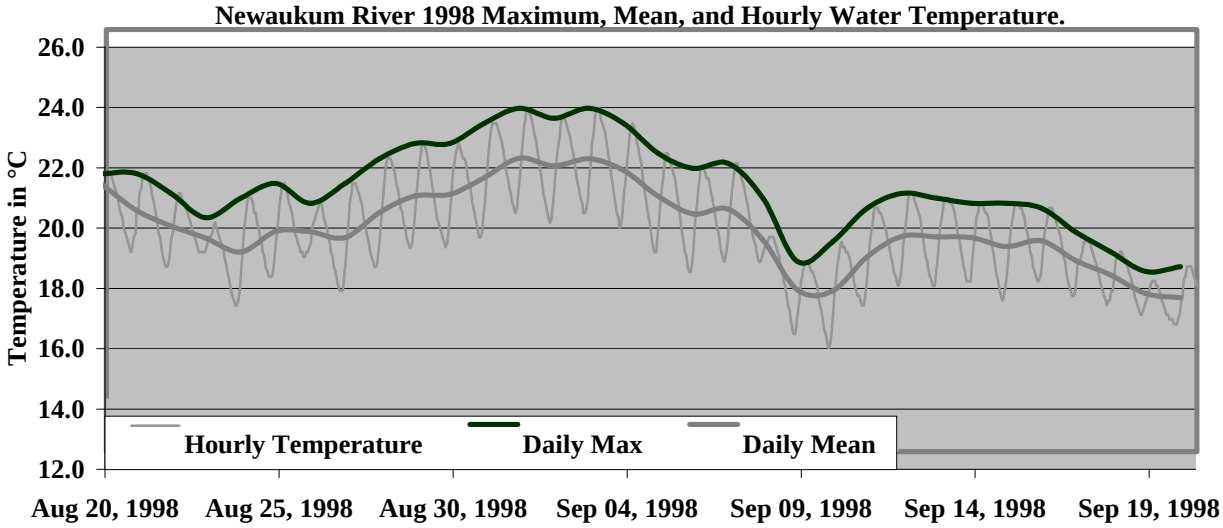
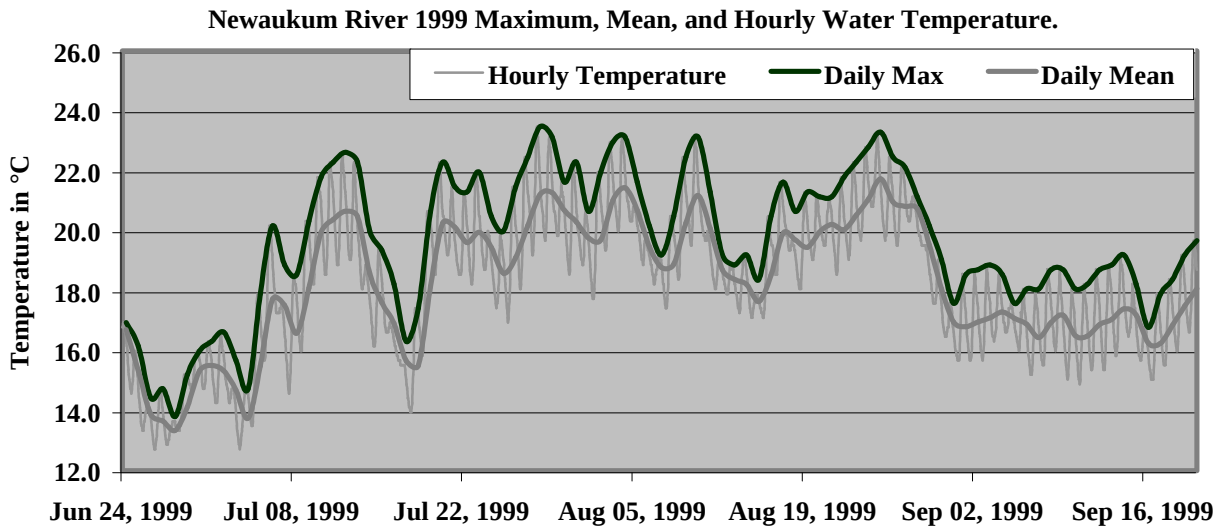
Appendix E. Newaukum River Maximum, Mean, and Hourly Water Temperature.

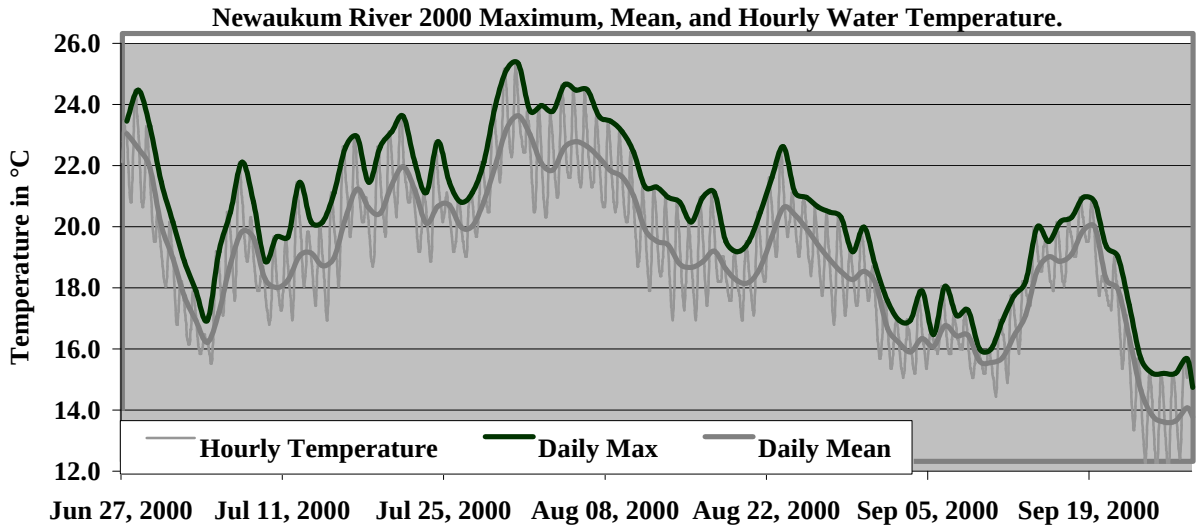






Appendix E. Newaukum River Maximum, Mean, and Hourly Water Temperature.





Appendix F. Chehalis River above the Newaukum River

Maximum, Mean, and Hourly Water Temperature

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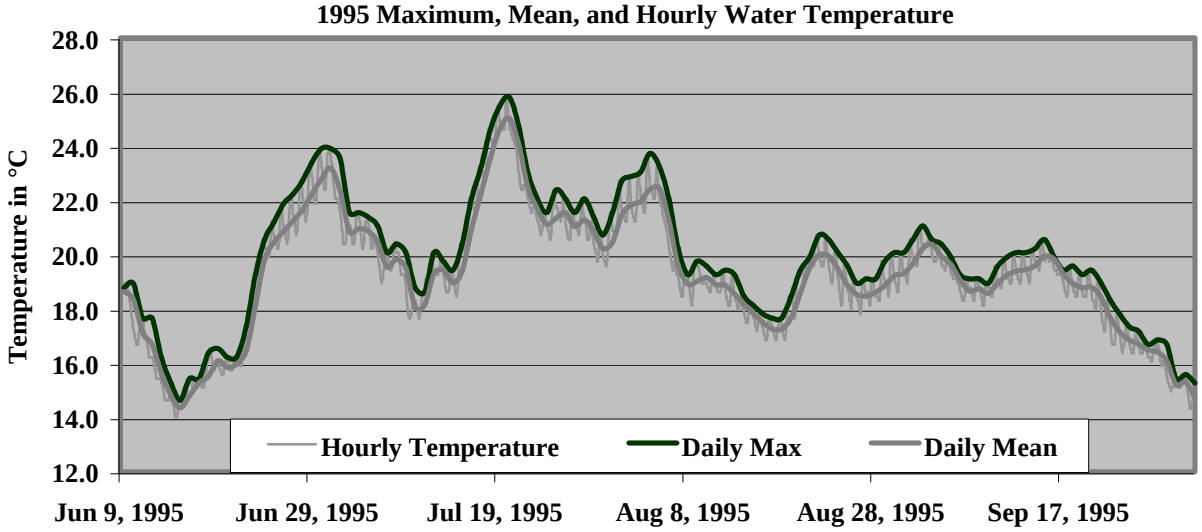
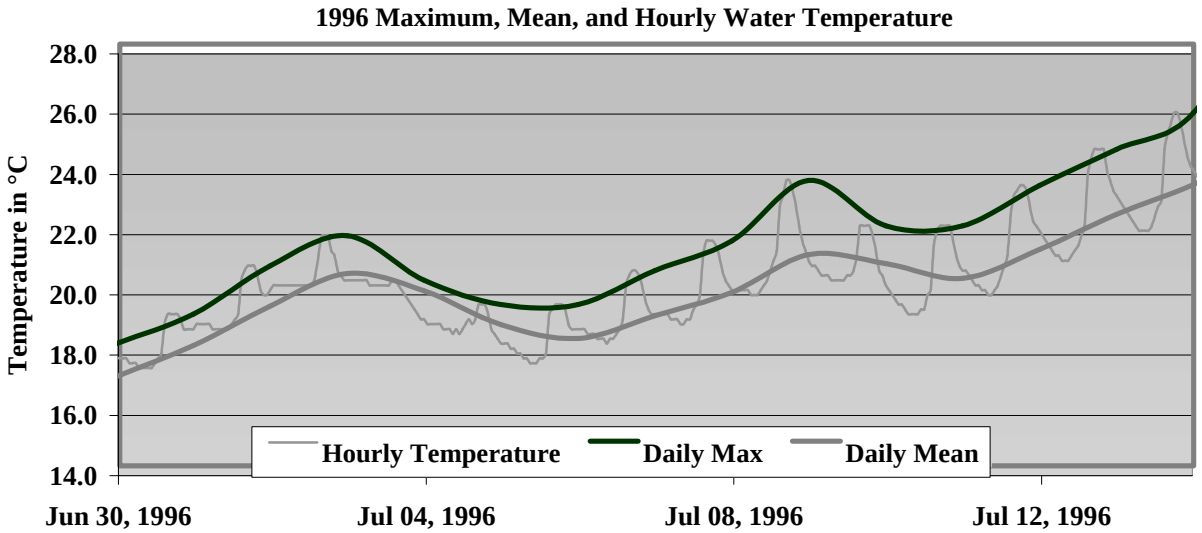
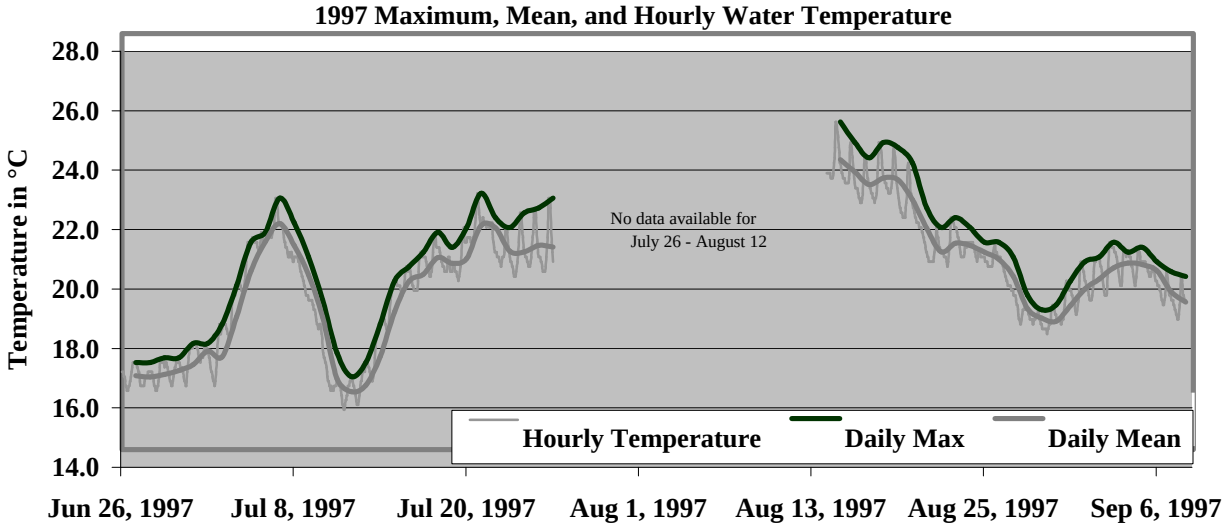
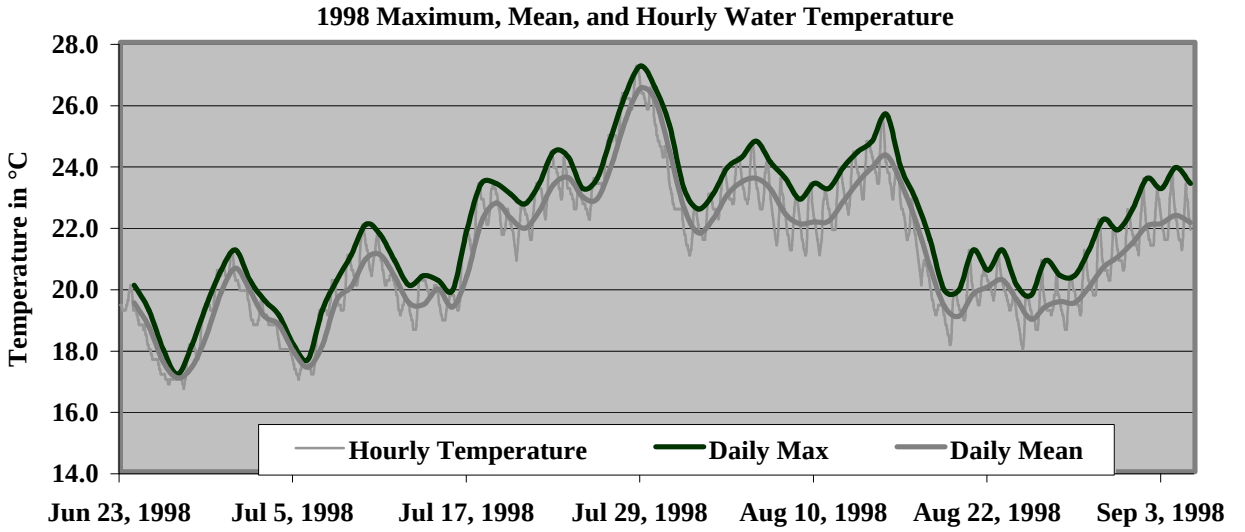
Appendix F. Maximum, Mean, and Hourly Water Temperature for the Chehalis River above the Newaukum River.

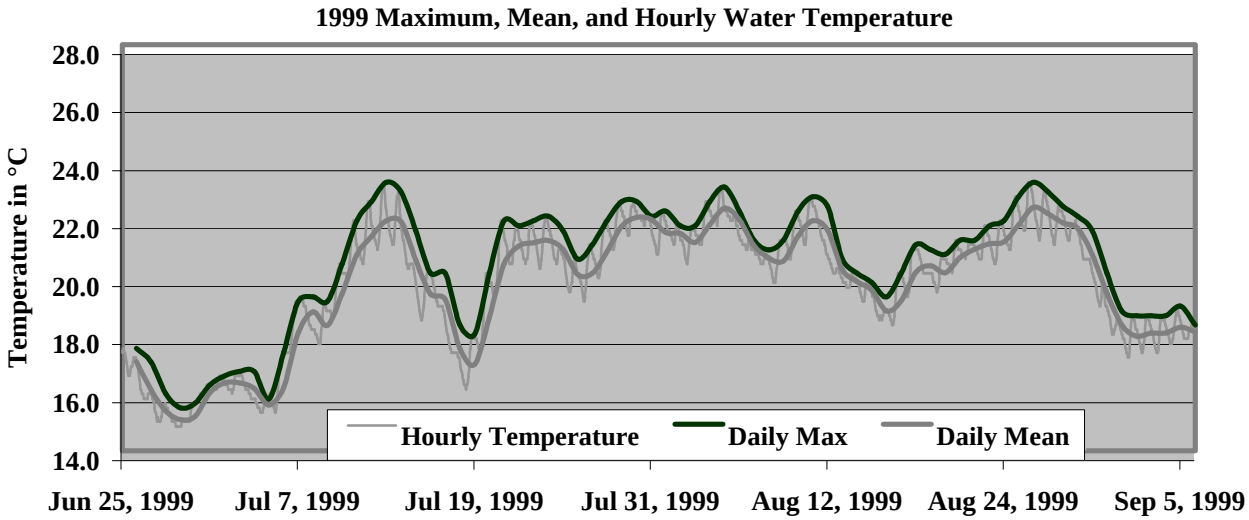


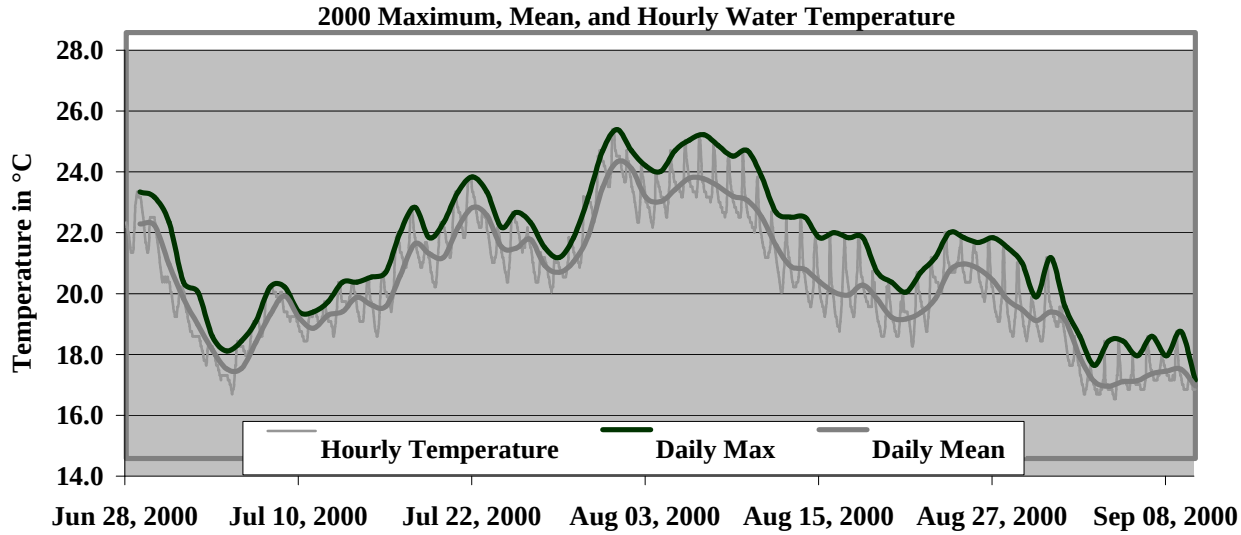




Appendix F. Maximum, Mean, and Hourly Water Temperature for the Chehalis River above the Newaukum River.







Appendix G. Mill Creek

1995 Hourly Water and Air Temperature Monitoring Data

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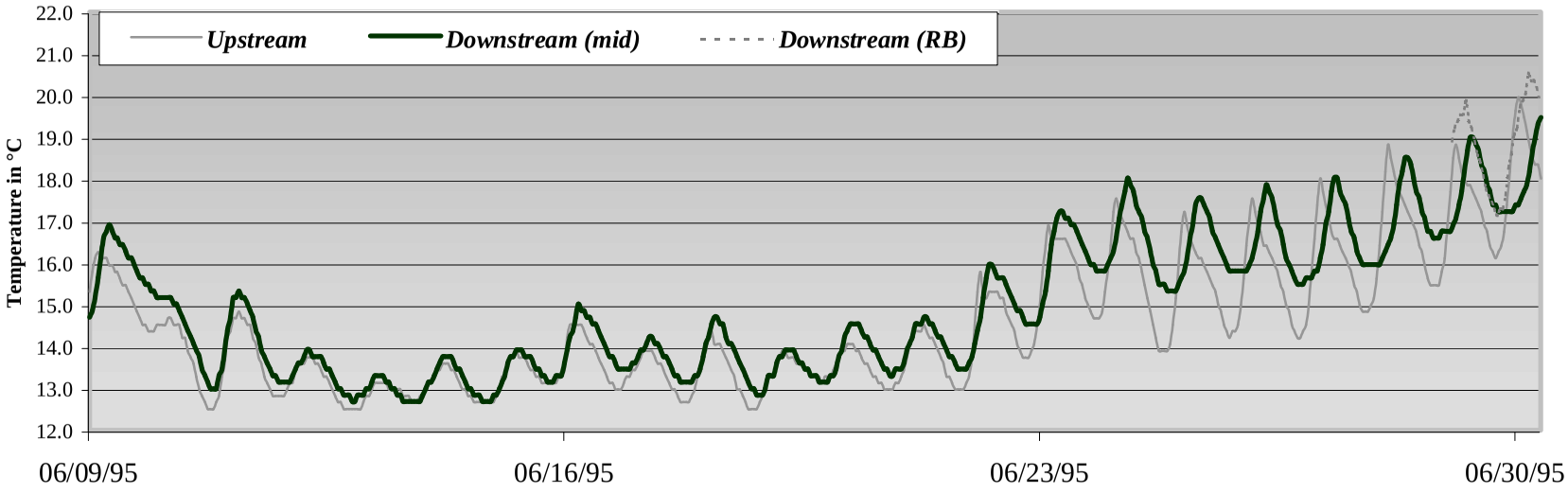
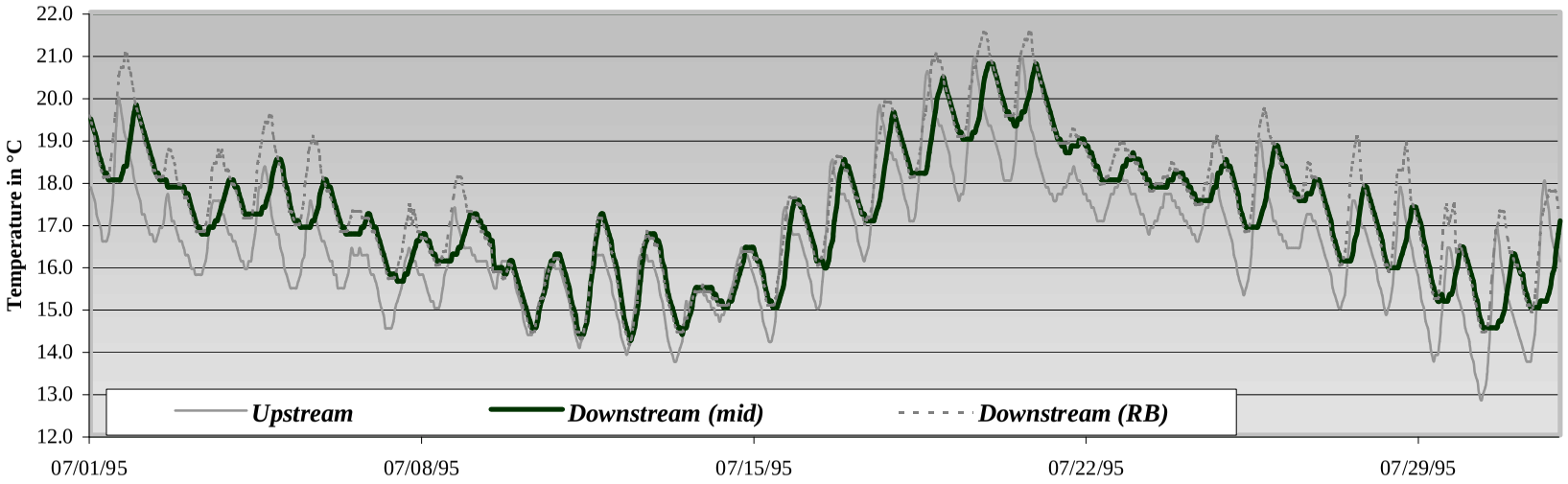
Appendix G: 1995 Hourly Water and Air Temperature Monitoring Data for Mill Creek BMP Site.

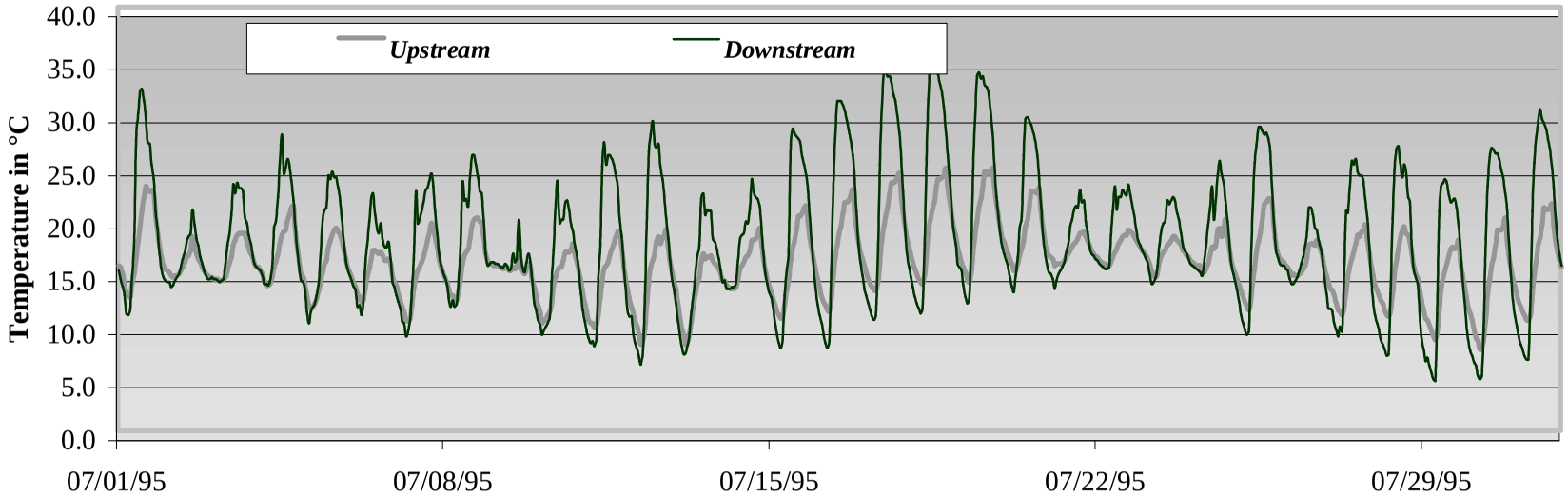


June 9-30, 1995 Hourly Water Temperature for Mill Creek.

Appendix G: 1995 Hourly Water and Air Temperature Monitoring Data for Mill Creek BMP Site.

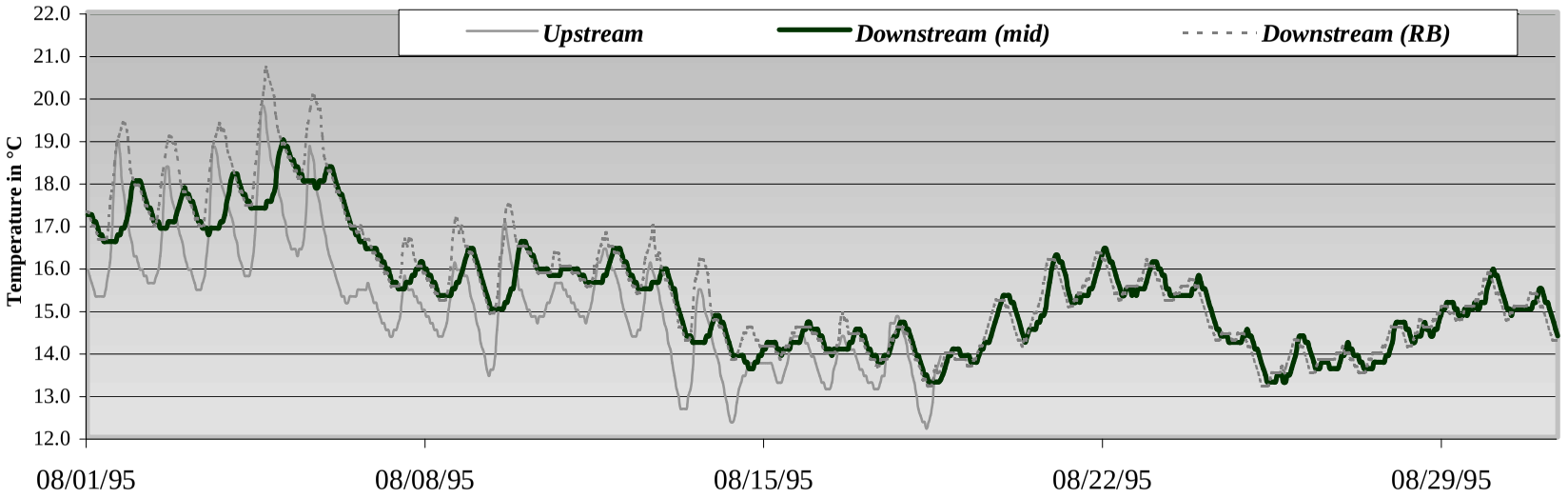


July 1-31, 1995 Hourly Water Temperature for Mill Creek.

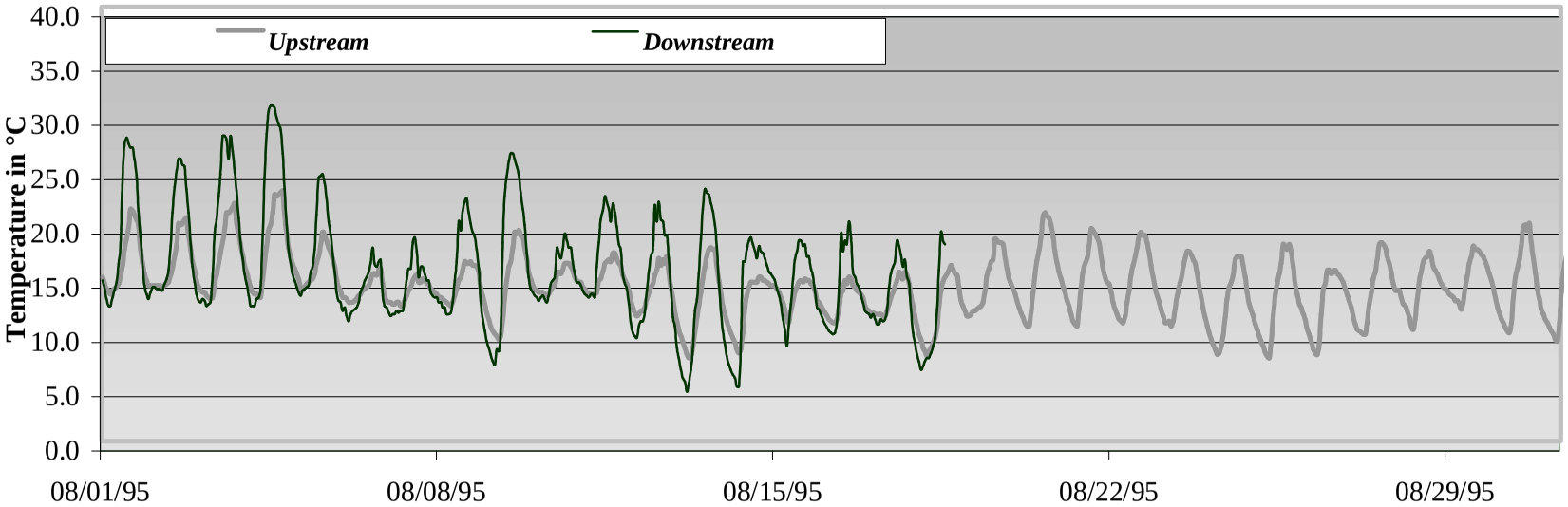


July 1-31, 1995 Hourly Air Temperature for Mill Creek.

Appendix G: 1995 Hourly Water and Air Temperature Monitoring Data for Mill Creek BMP Site.

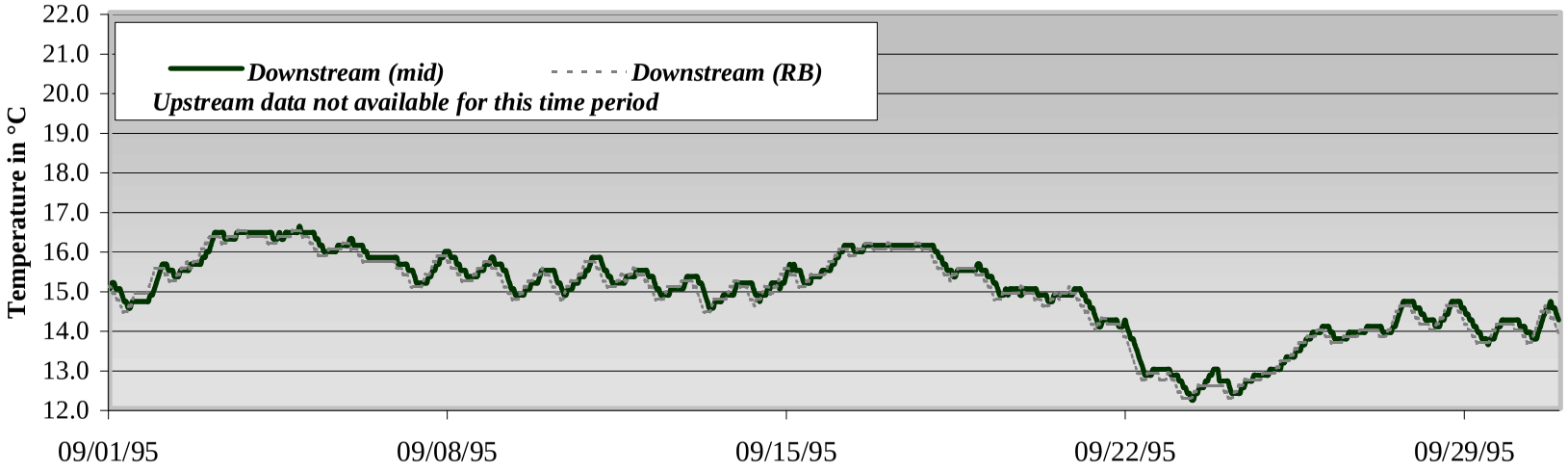


August 1-31, 1995 Hourly Water Temperature for Mill Creek.



August 1-31, 1995 Hourly Air Temperature for Mill Creek.

Appendix G: 1995 Hourly Water and Air Temperature Monitoring Data for Mill Creek BMP Site.



September 1-30, 1995 Hourly Water Temperature for Mill Creek.

Appendix H. North Fork Lincoln Creek

1995 Hourly Water and Air Temperature Monitoring Data
1996 Hourly Water and Air Temperature Monitoring Data

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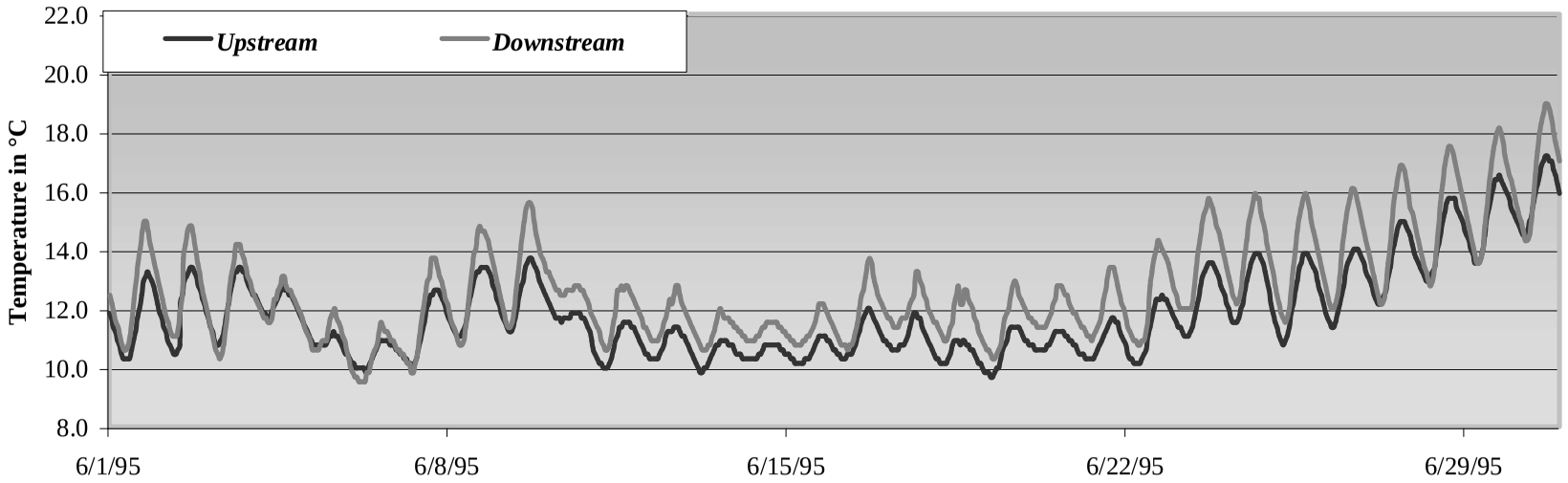
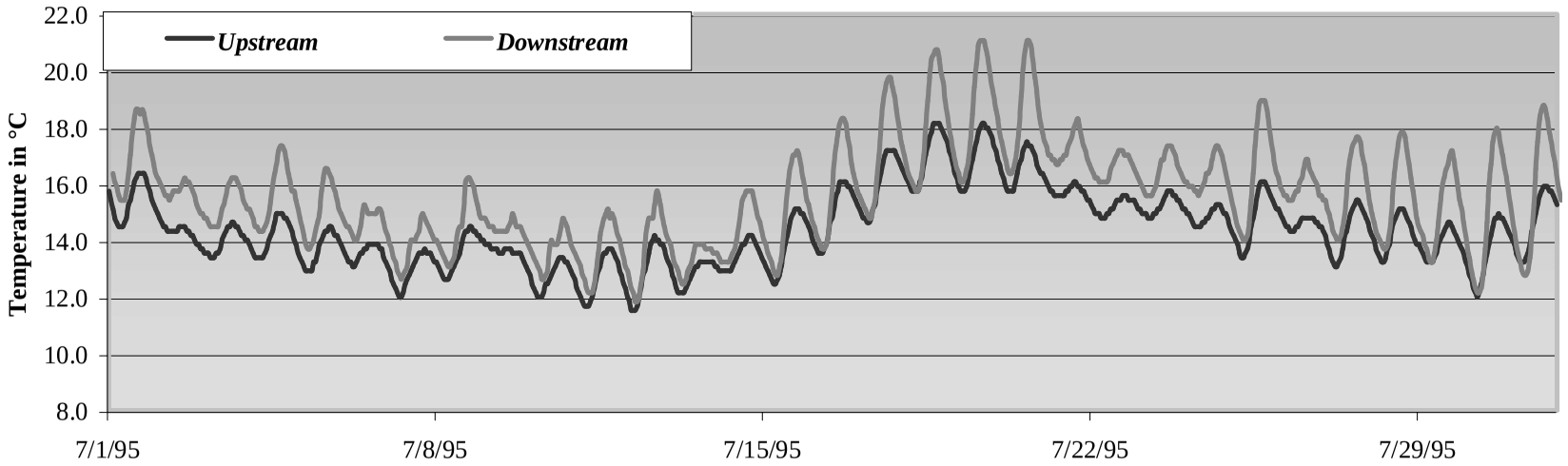
Appendix H: 1995 Hourly Water and Air Temperature Monitoring Data for North Fork Lincoln Creek BMP Site.

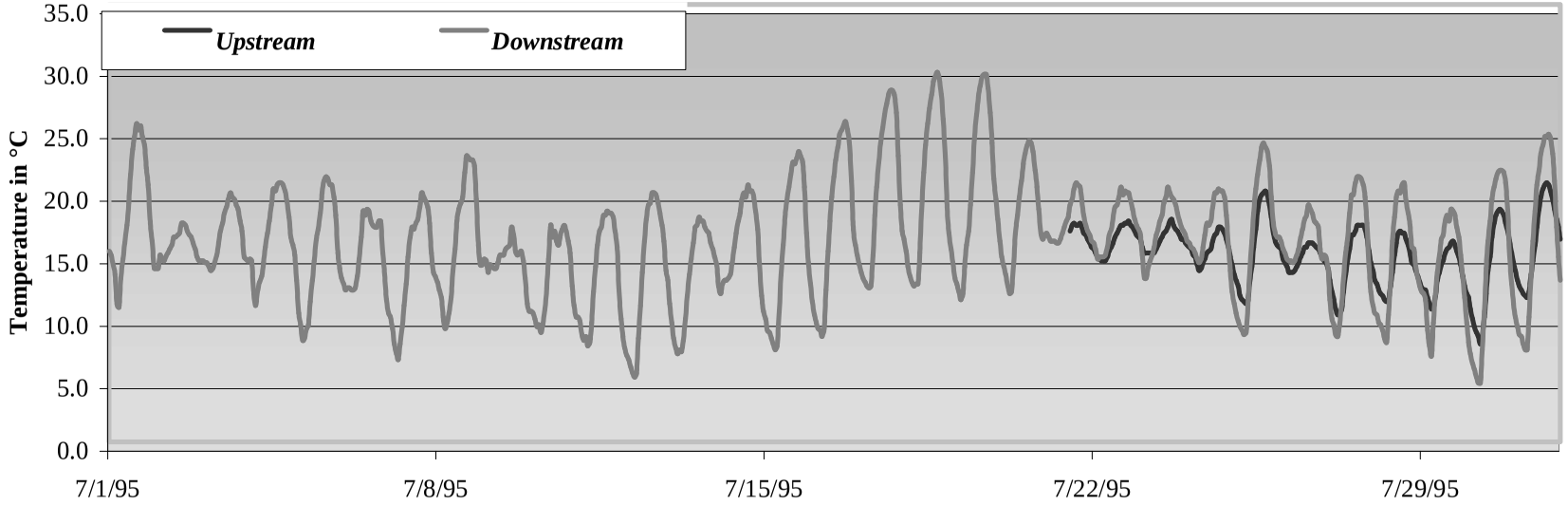


June 1-30, 1995 Hourly Water Temperature for North Fork Lincoln Creek.

Appendix H: 1995 Hourly Water and Air Temperature Monitoring Data for North Fork Lincoln Creek BMP Site.

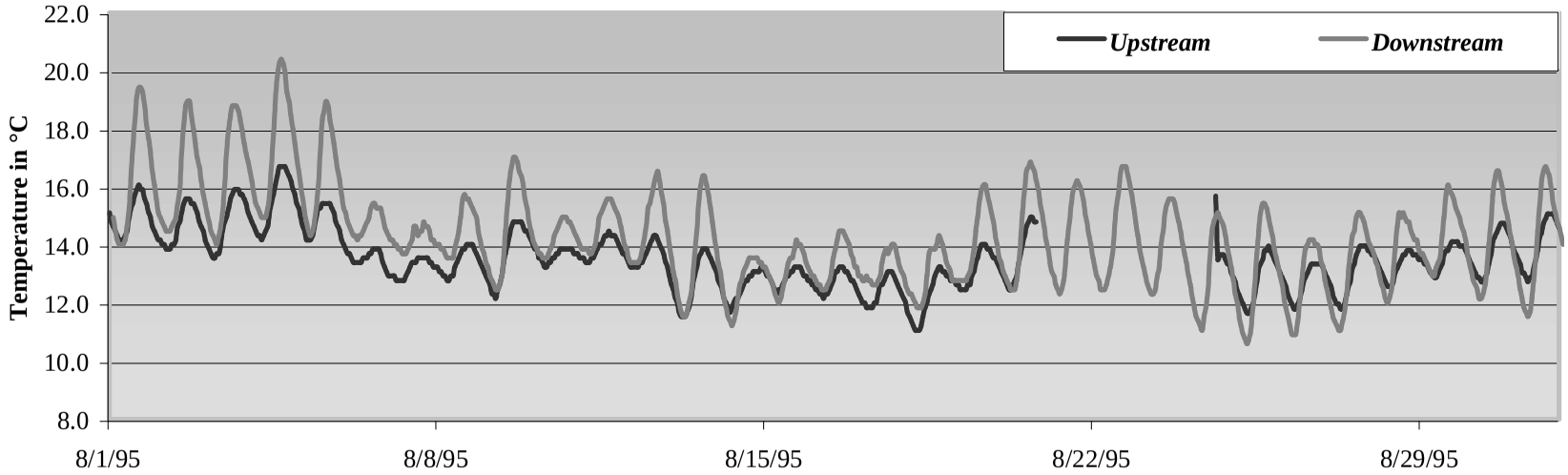


July 1-31, 1995 Hourly Water Temperature for North Fork Lincoln Creek.

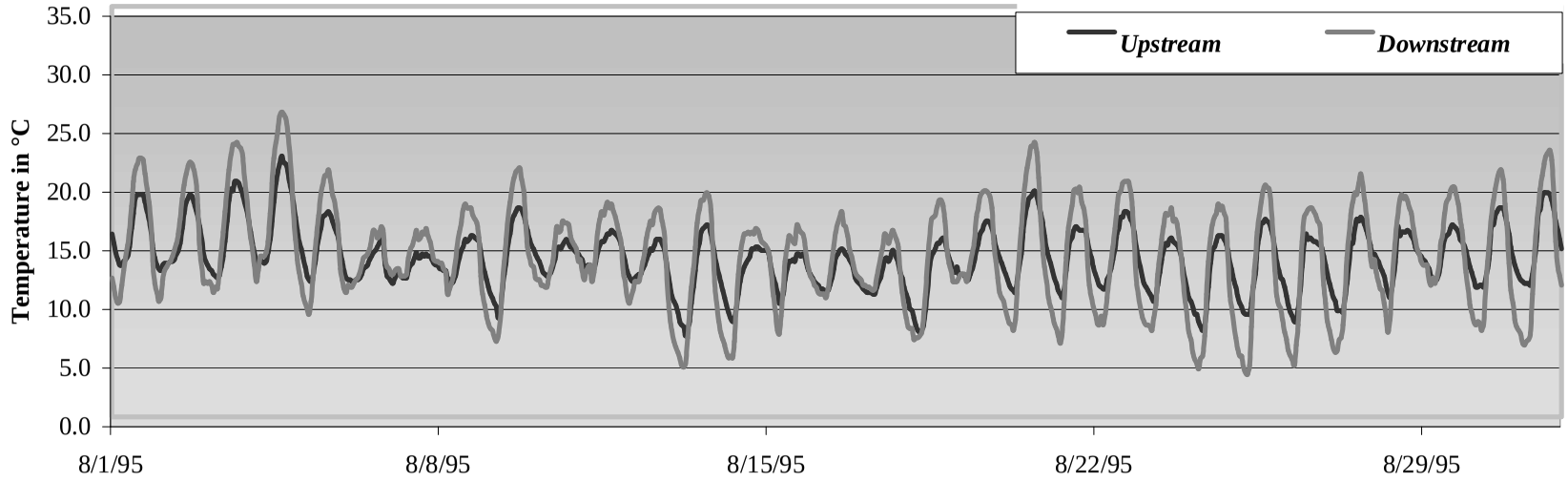


July 1-31, 1995 Hourly Air Temperature for North Fork Lincoln Creek.

Appendix H: 1995 Hourly Water and Air Temperature Monitoring Data for North Fork Lincoln Creek BMP Site.

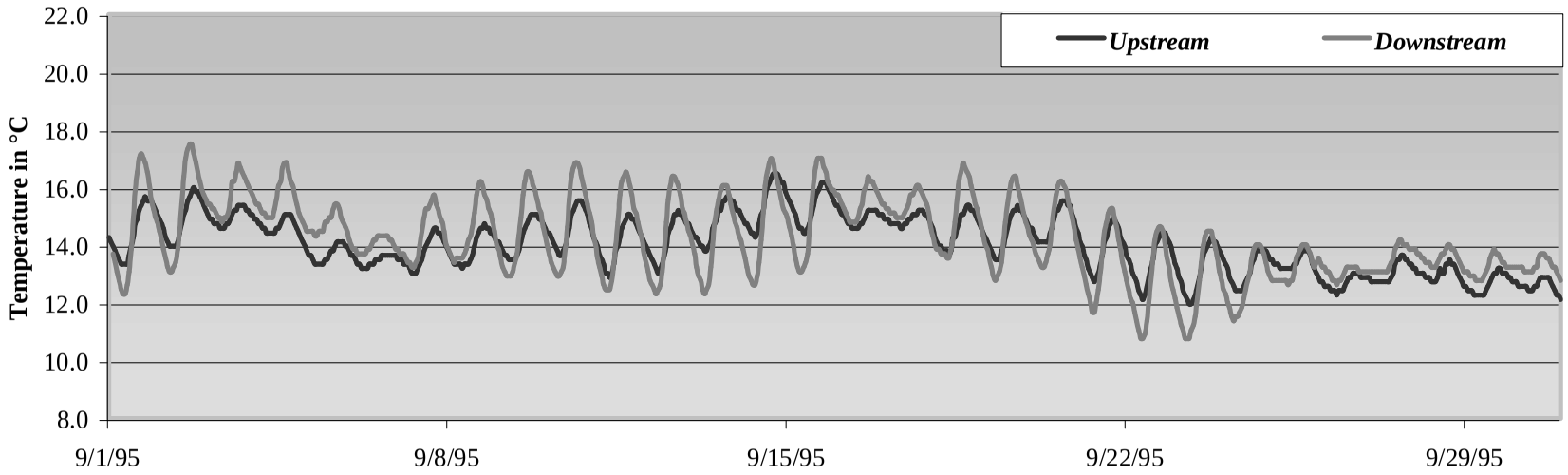


August 1-31, 1995 Hourly Water Temperature for North Fork Lincoln Creek.

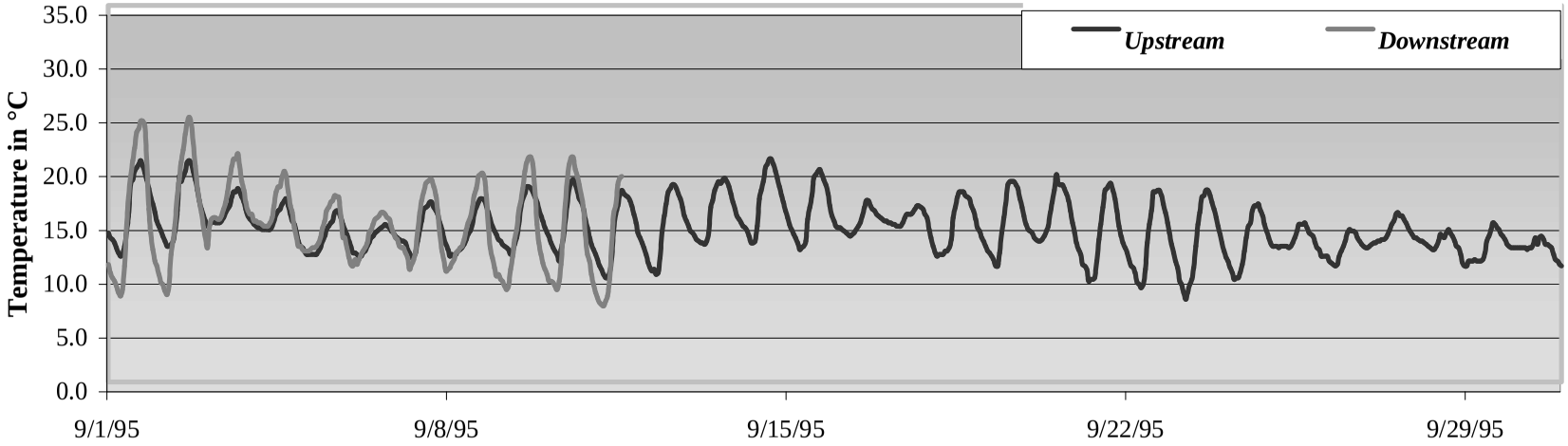


August 1-31, 1995 Hourly Air Temperature for North Fork Lincoln Creek.

Appendix H: 1995 Hourly Water and Air Temperature Monitoring Data for North Fork Lincoln Creek BMP Site.

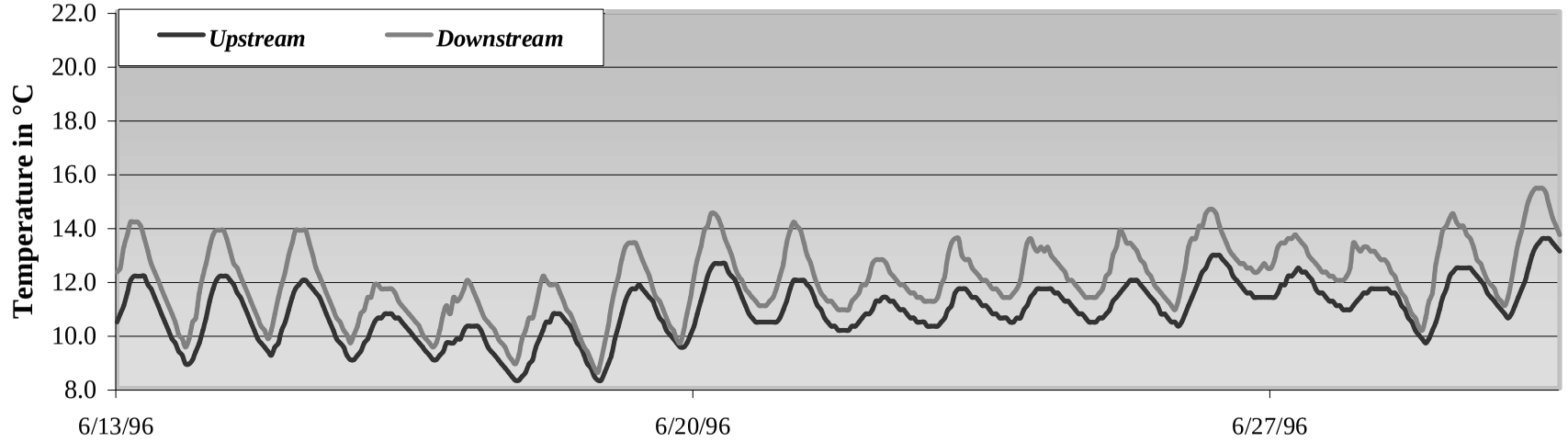


September 1-30, 1995 Hourly Water Temperature for North Fork Lincoln Creek.

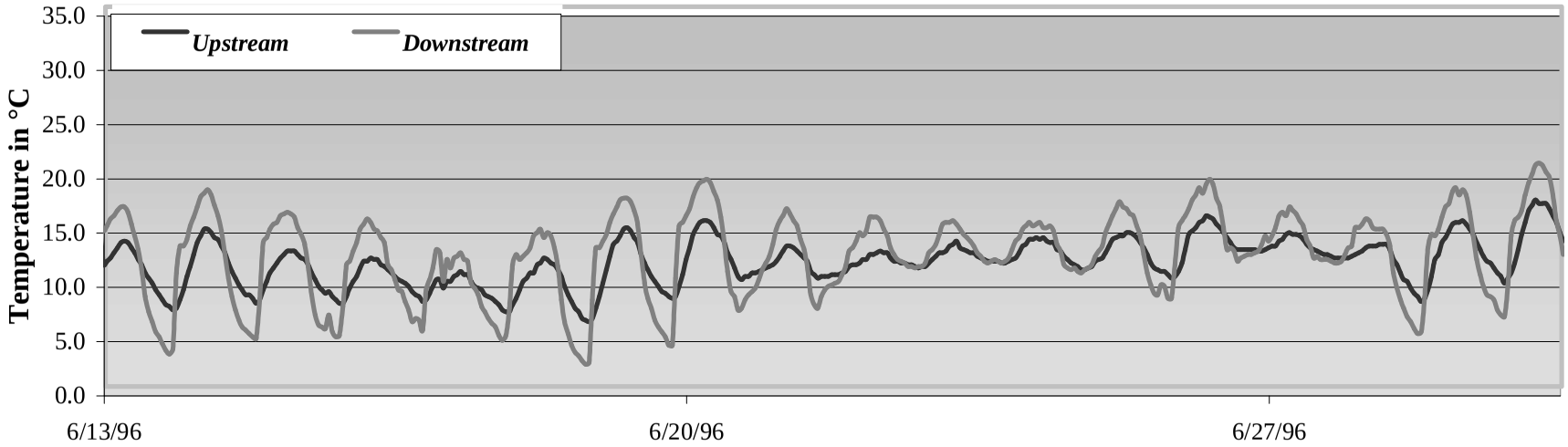


September 1-30, 1995 Hourly Air Temperature for North Fork Lincoln Creek.

Appendix H. 1996 Hourly Water and Air Temperature Monitoring Data for North Fork Lincoln Creek BMP Site.

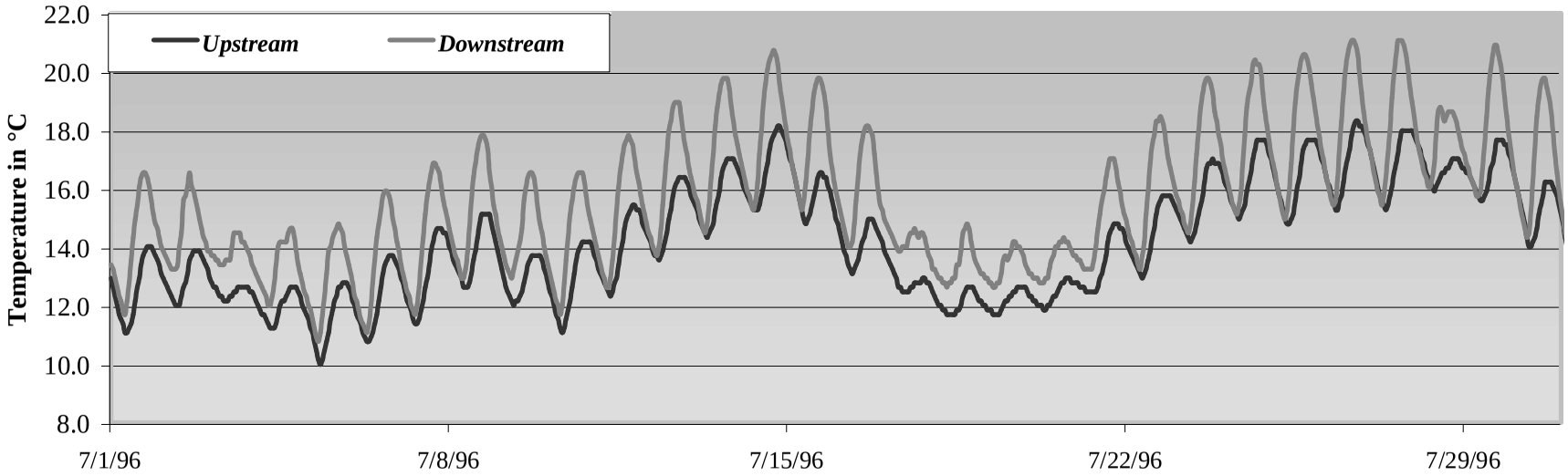


June 13-30, 1996 Hourly Water Temperature for North Fork Lincoln Creek.

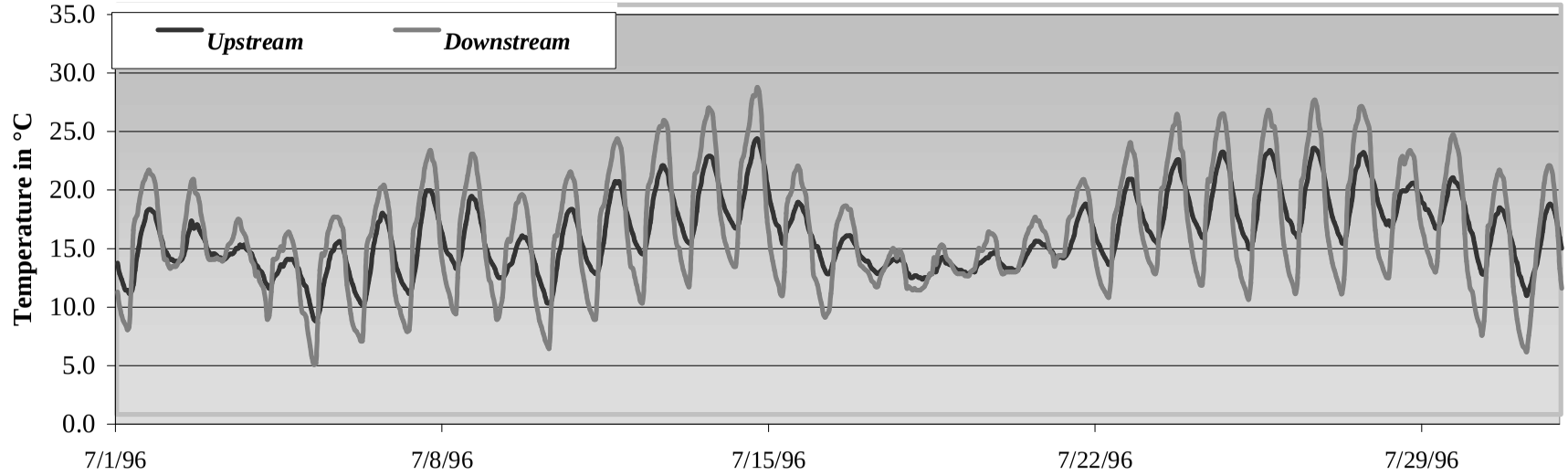


June 13-30, 1996 Hourly Air Temperature for North Fork Lincoln Creek.

Appendix H. 1996 Hourly Water and Air Temperature Monitoring Data for North Fork Lincoln Creek BMP Site.

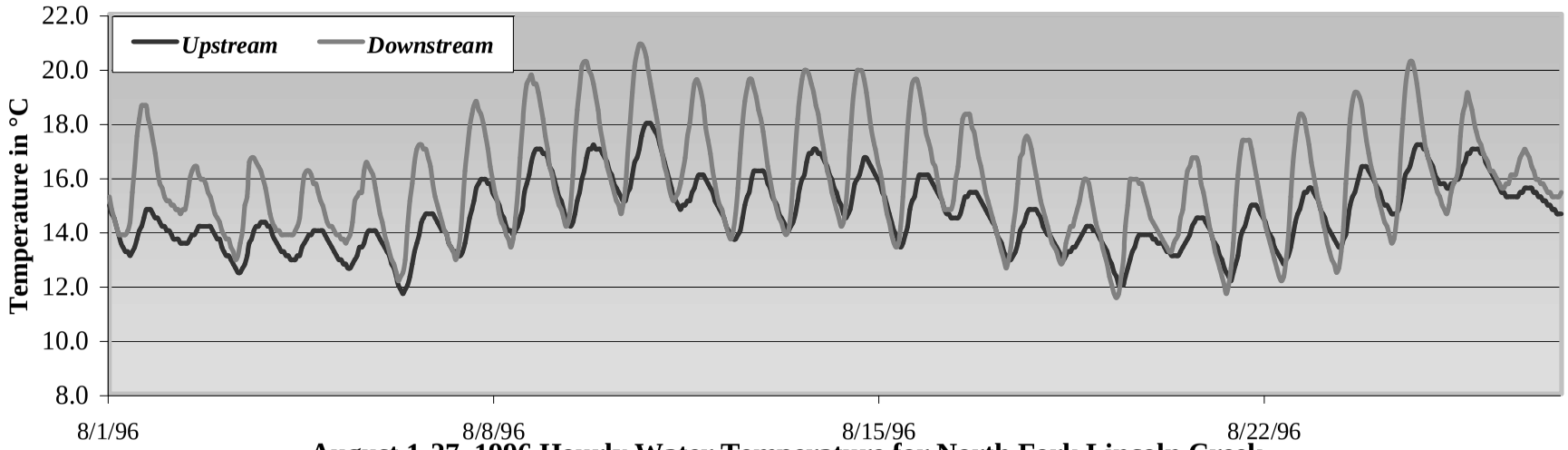


July 1-31, 1996 Hourly Water Temperature for North Fork Lincoln Creek.

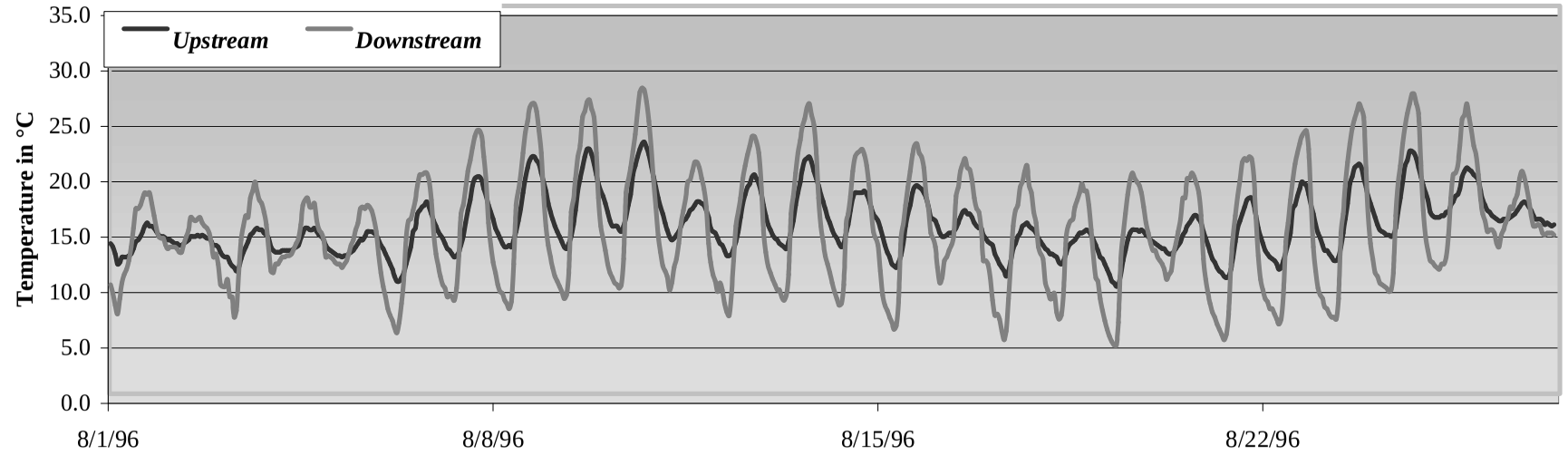


July 1-31, 1996 Hourly Air Temperature for North Fork Lincoln Creek.

Appendix H. 1996 Hourly Water and Air Temperature Monitoring Data for North Fork Lincoln Creek BMP Site.



August 1-27, 1996 Hourly Water Temperature for North Fork Lincoln Creek.



August 1-27, 1996 Upstream/Downstream Hourly Air Temperature for Lincoln Creek.

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Appendix I. Mohney Creek Tributary

1995 Hourly Water Temperature Monitoring Data
1996 Hourly Water and Air Temperature Monitoring Data
1997 Hourly Water and Air Temperature Monitoring Data
1998 Hourly Water and Air Temperature Monitoring Data

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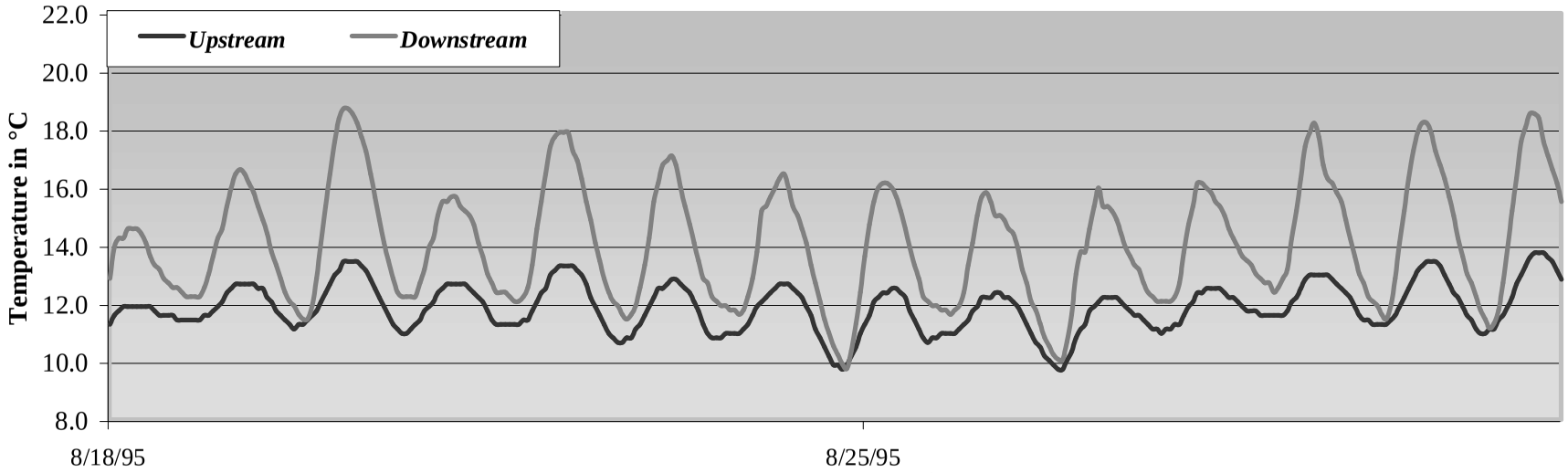
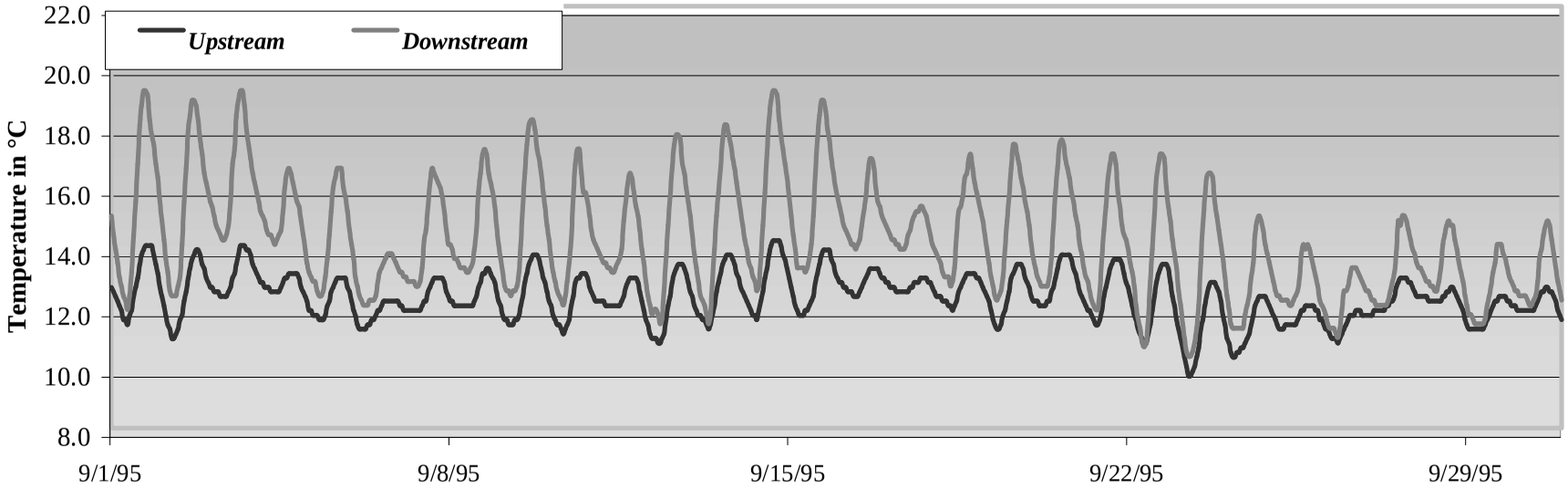
Appendix I: 1995 Hourly Water Temperature Monitoring Data for the Mohney Creek Tributary BMP Site.

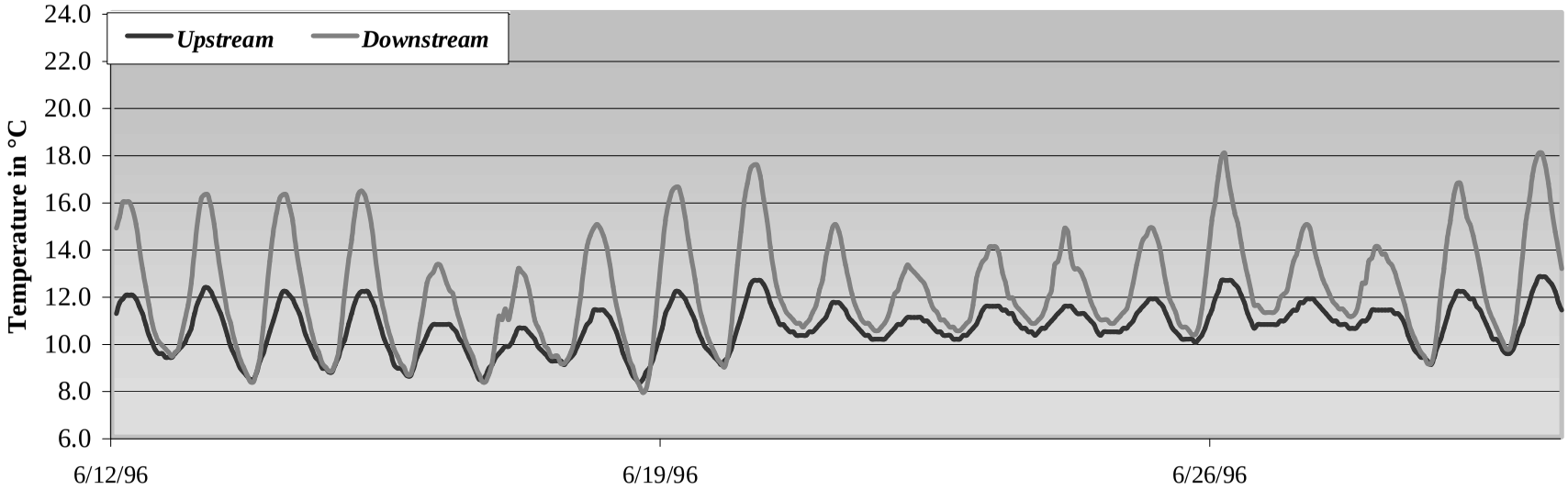


August 18-31, 1995 Hourly Water Temperature for Mohney Creek tributary.

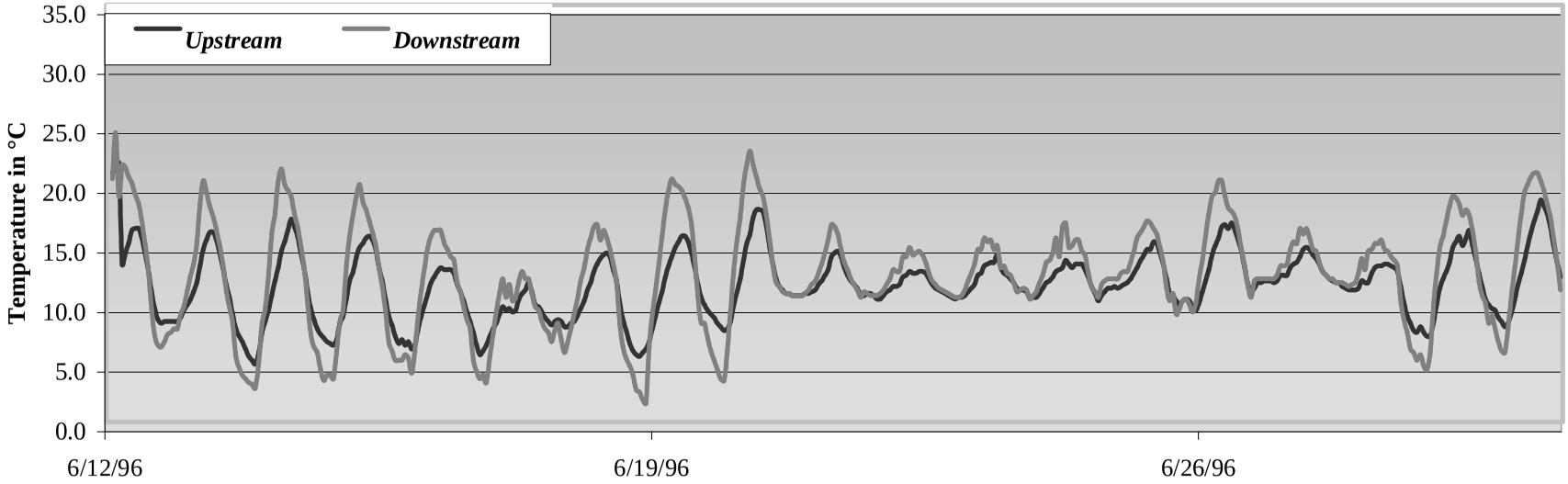


September 1 - 31, 1995 Hourly Water Temperature for Mohney Creek tributary.

Appendix I: 1996 Hourly Water and Air Temperature Monitoring Data for the Mohney Creek Tributary BMP Site.

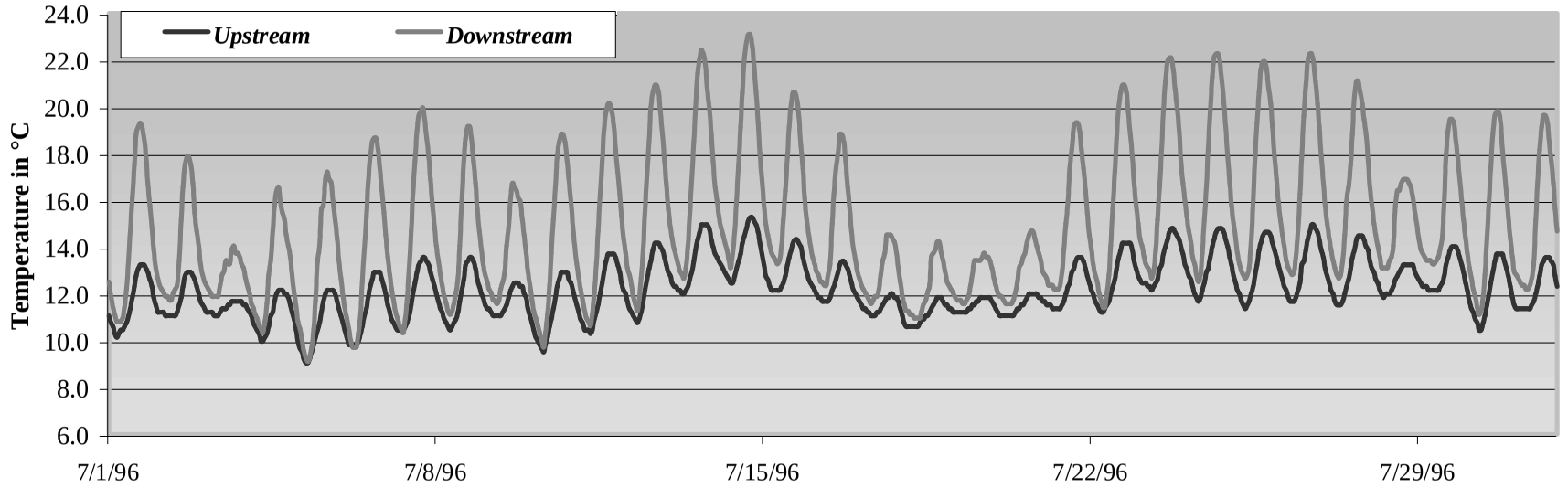


June 12-30, 1996 Hourly Water Temperature for Mohney Creek tributary.

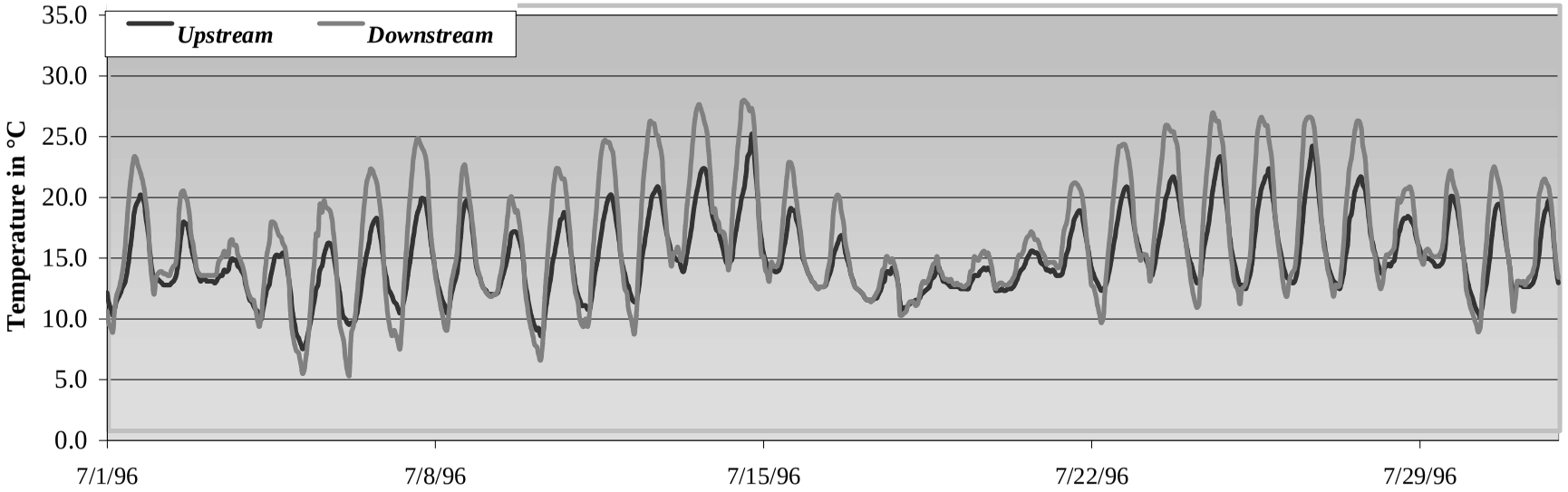


June 12-30, 1996 Hourly Air Temperature for Mohney Creek tributary.

Appendix I: 1996 Hourly Water and Air Temperature Monitoring Data for the Mohney Creek Tributary BMP Site.

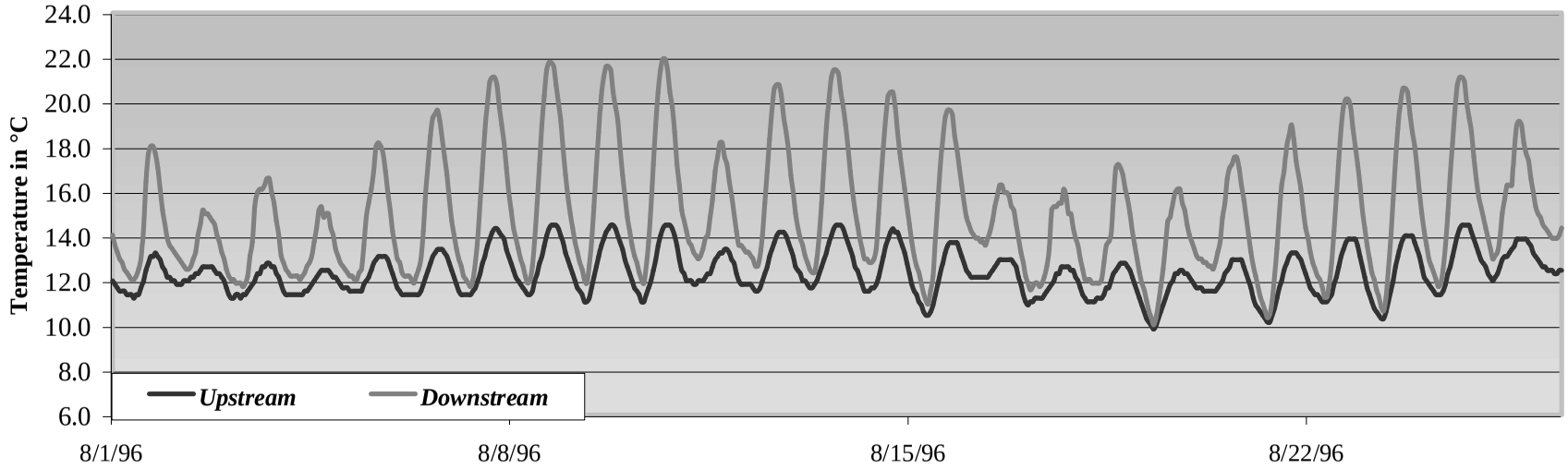


July 1-31, 1996 Hourly Water Temperature for Mohney Creek tributary.

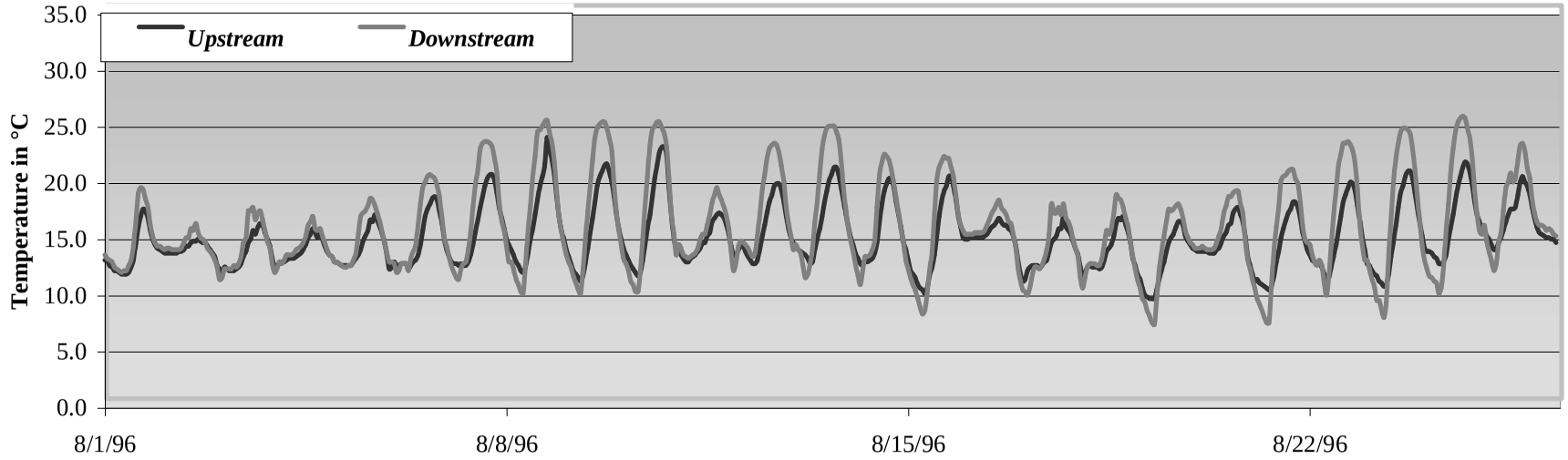


July 1-31, 1996 Hourly Air Temperature for Mohney Creek tributary.

Appendix I: 1996 Hourly Water and Air Temperature Monitoring Data for the Mohney Creek Tributary BMP Site.

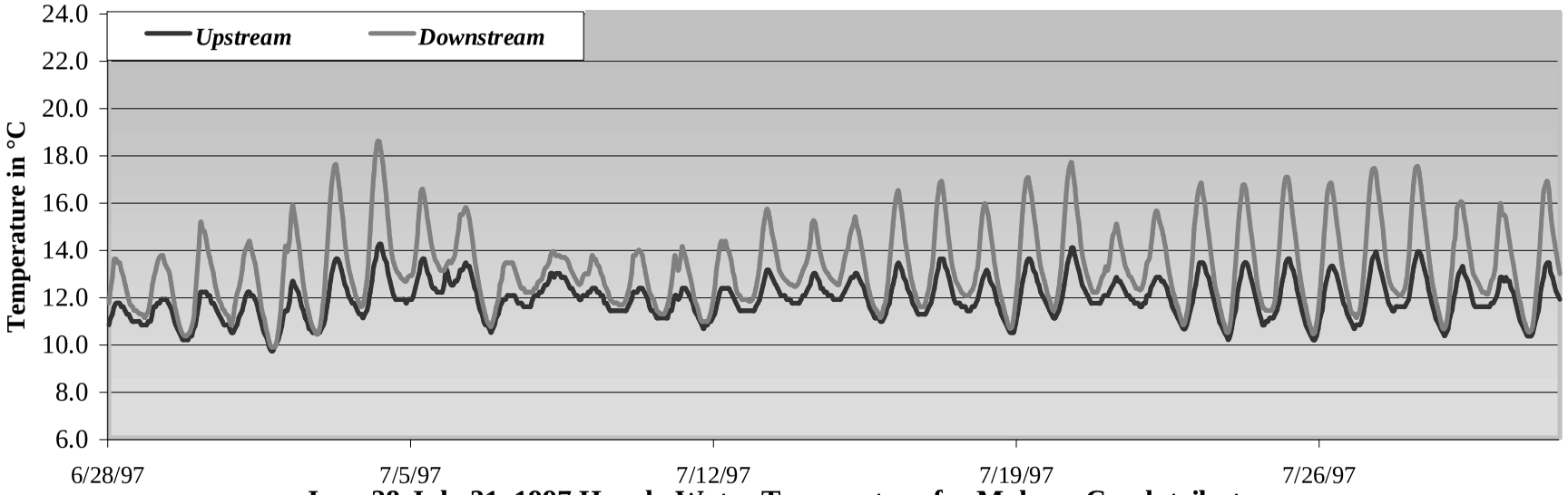


August 1-26, 1996 Hourly Water Temperature for Mohney Creek tributary.

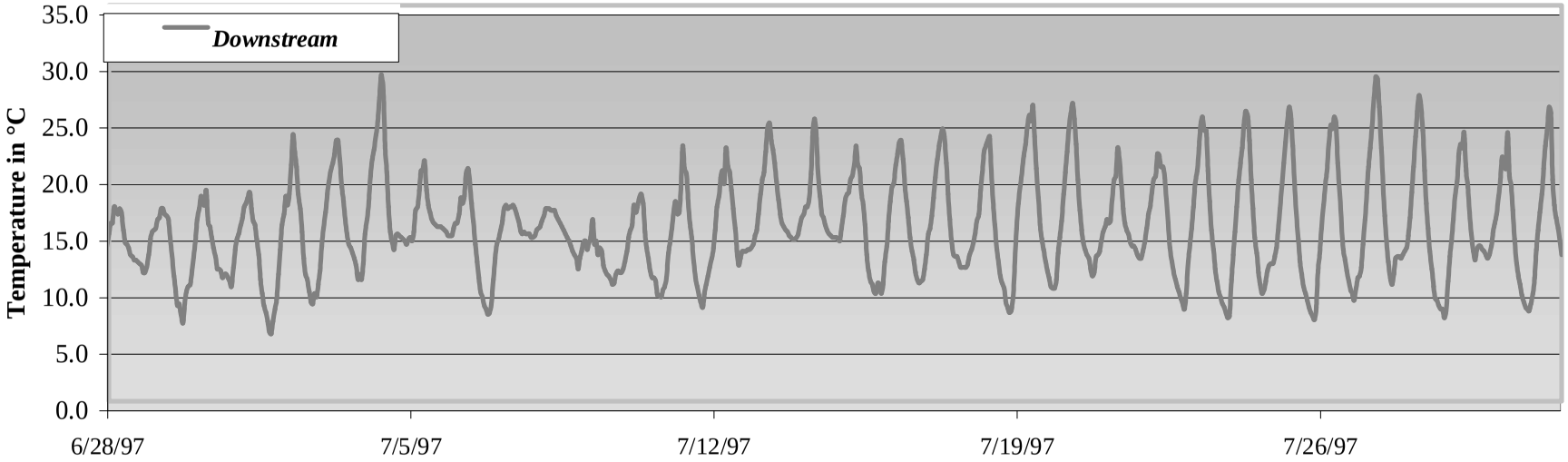


August 1-26, 1996 Hourly Air Temperature for Mohney Creek tributary.

Appendix I: 1997 Hourly Water and Air Temperature Monitoring Data for the Mohney Creek Tributary BMP Site.

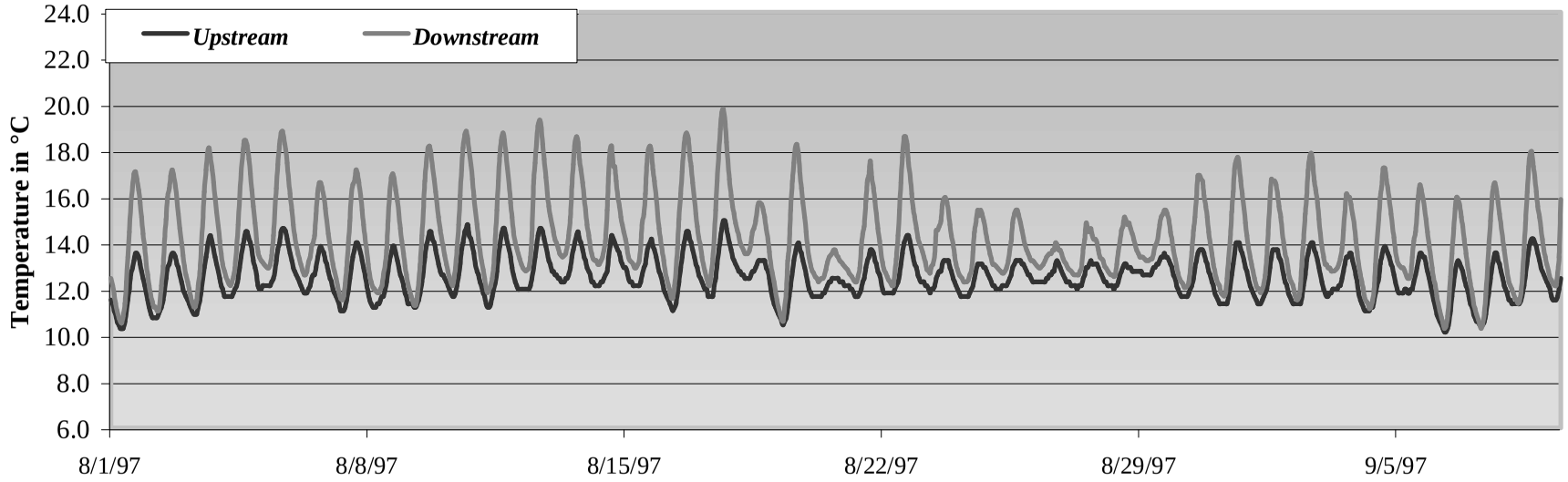


June 28-July 31, 1997 Hourly Water Temperature for Mohney Creek tributary.

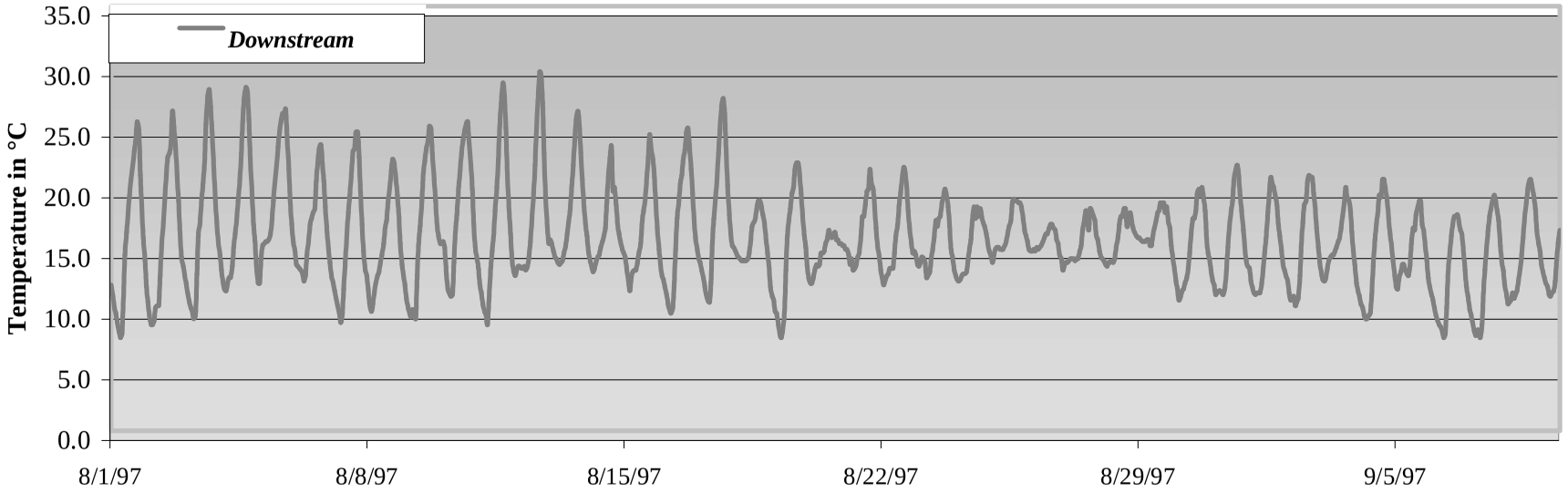


June 28-July 31, 1997 Hourly Air Temperature for Mohney Creek tributary.

Appendix I: 1997 Hourly Water and Air Temperature Monitoring Data for the Mohney Creek Tributary BMP Site.

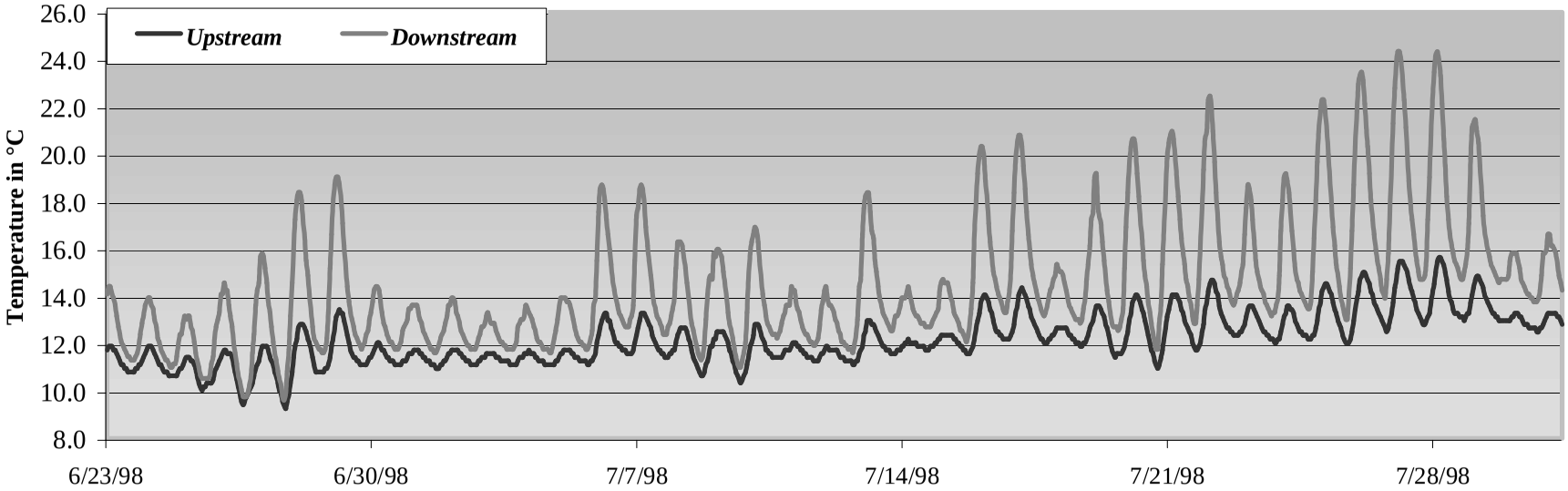


August 1- September 9, 1997 Hourly Water Temperature for Mohney Creek tributary.

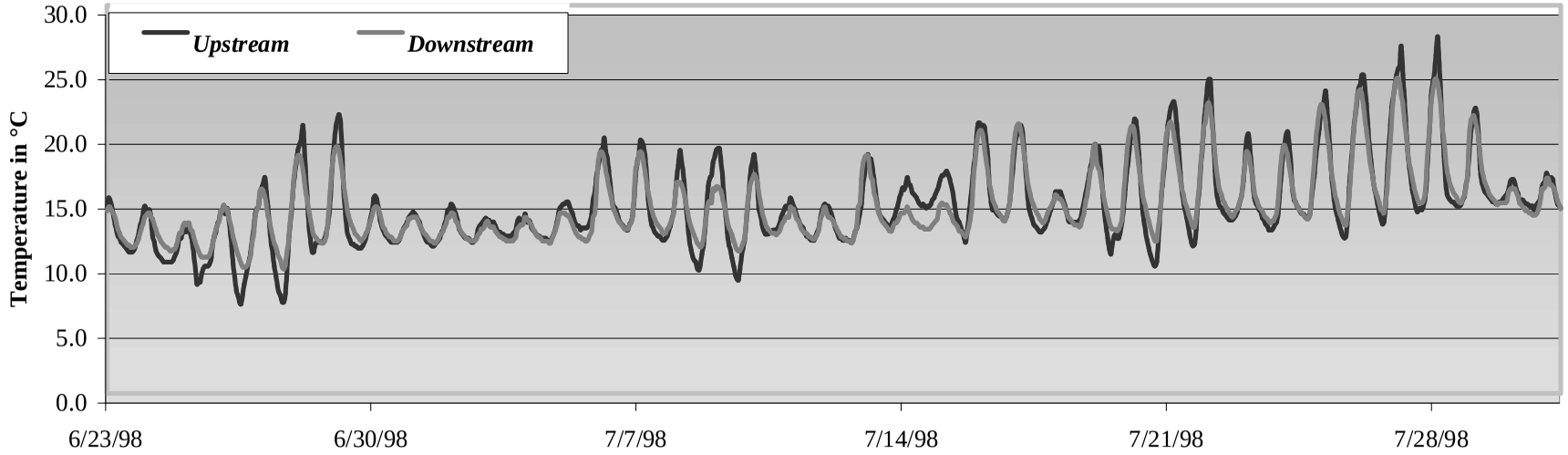


August 1- September 9, 1997 Hourly Air Temperature for Mohney Creek tributary.

Appendix I: 1998 Hourly Water and Air Temperature Monitoring Data for the Mohney Creek Tributary BMP Site.

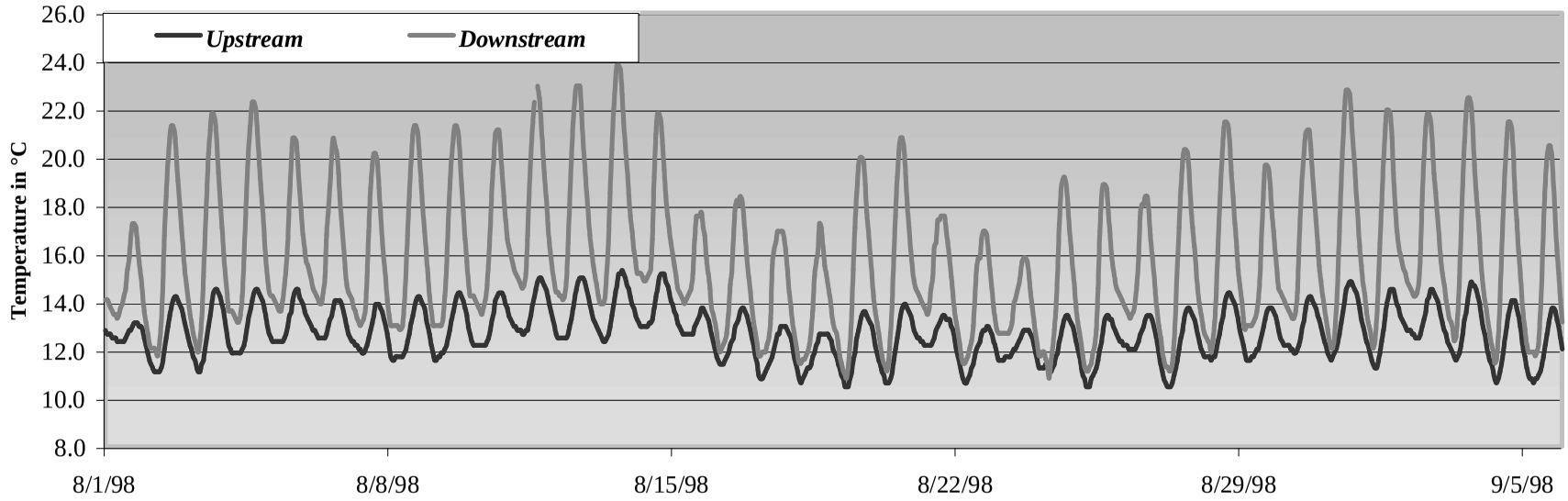


June 23-July 31, 1998 Hourly Water Temperature for Mohney Creek tributary.

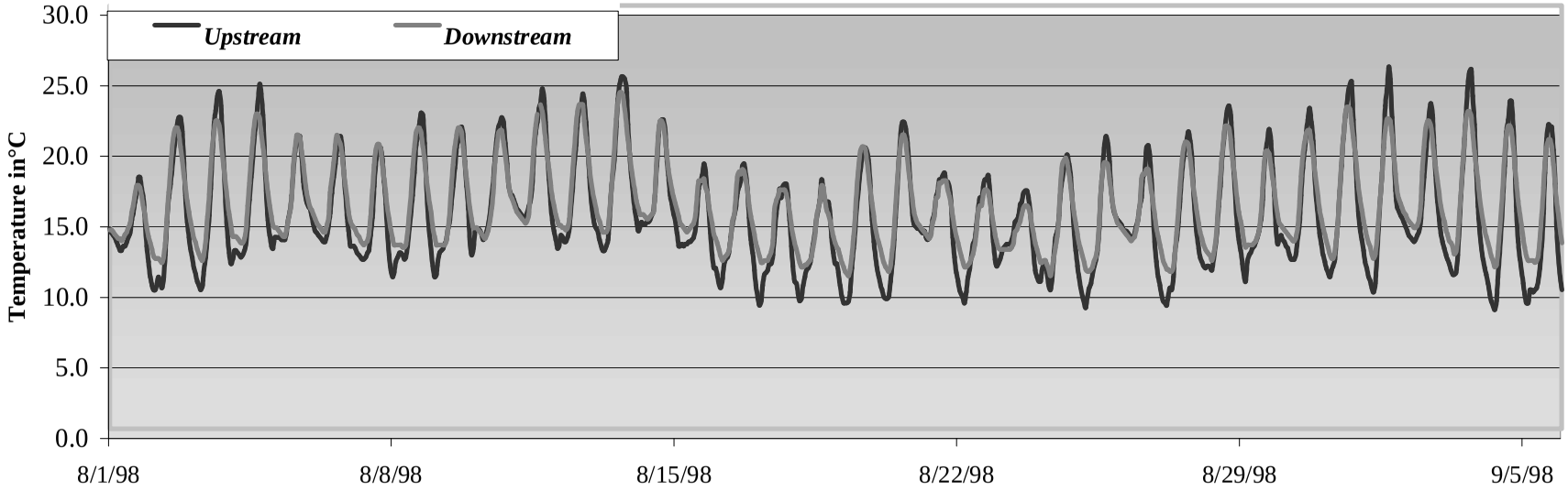


June 23-July 31, 1998 Air Temperature for Mohney Creek tributary.

Appendix I: 1998 Hourly Water and Air Temperature Monitoring Data for the Mohney Creek Tributary BMP Site.



August 1 - September 5, 1998 Hourly Water Temperature for Mohney Creek tributary.



August 1 - September 5, 1998 Hourly Air Temperature for Mohney Creek tributary.

Appendix J. South Tributary to Salzer Creek

1996 Hourly Water and Air Temperature Monitoring Data
1997 Hourly Water and Air Temperature Monitoring Data
1998 Hourly Water and Air Temperature Monitoring Data
1999 Hourly Water and Air Temperature Monitoring Data

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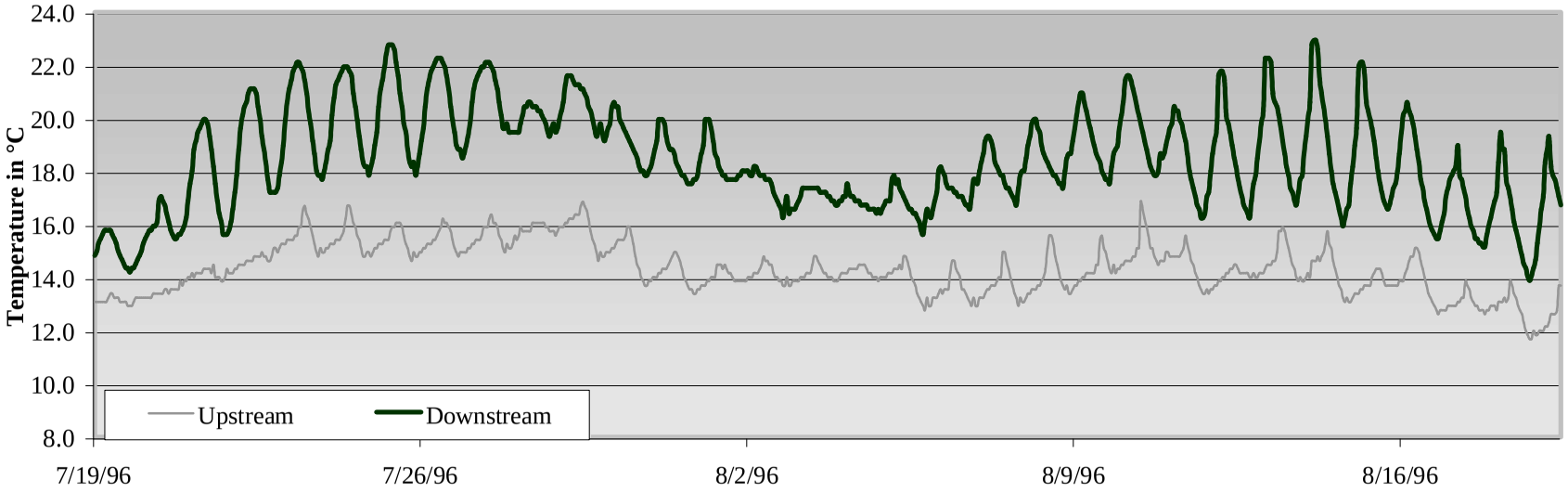
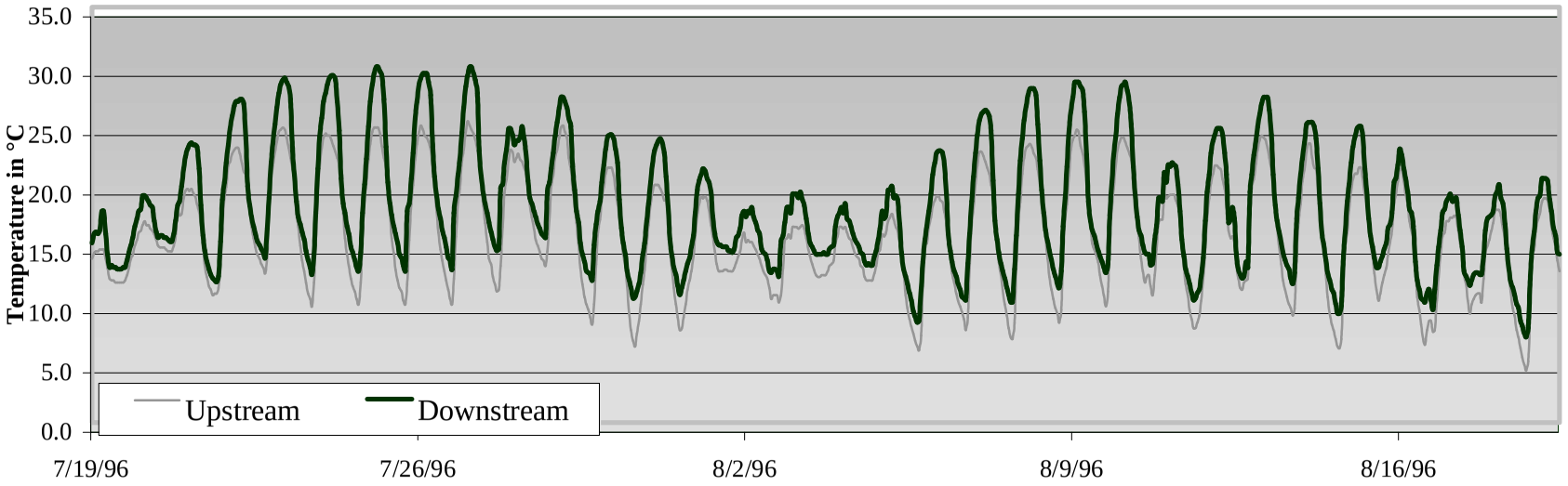
Appendix J: 1996 Hourly Water and Air Temperature Monitoring Data for the South Tributary to Salzer Creek BMP Site.

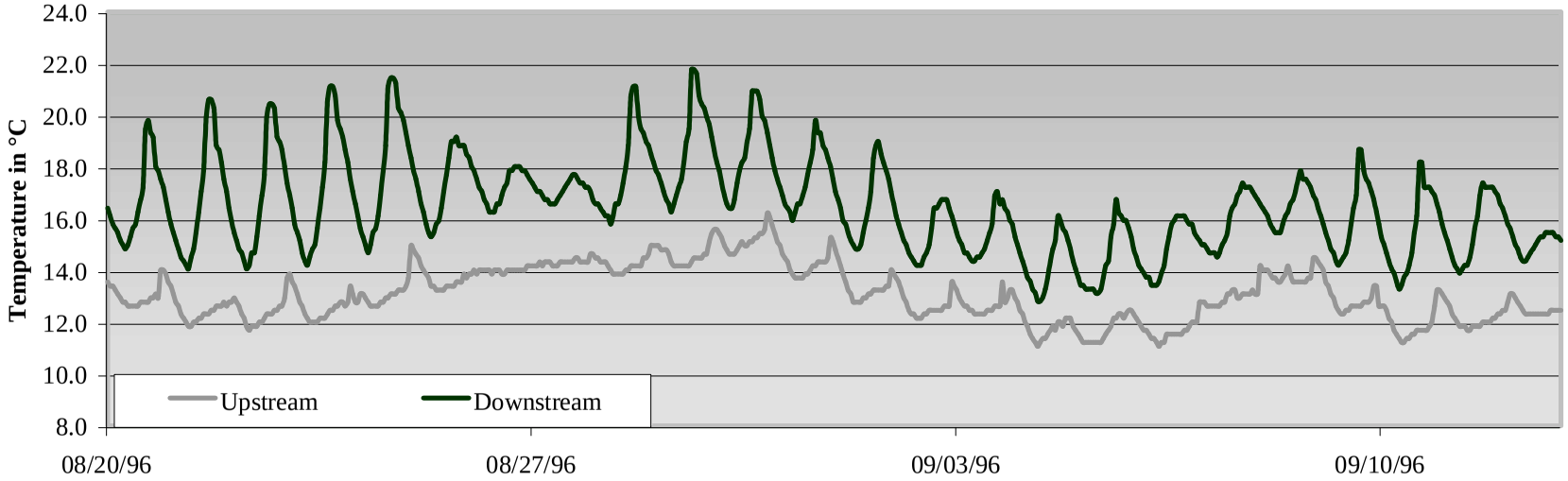


July 19 - August 19, 1996 Hourly Water Temperature for the Salzer Creek Tributary.

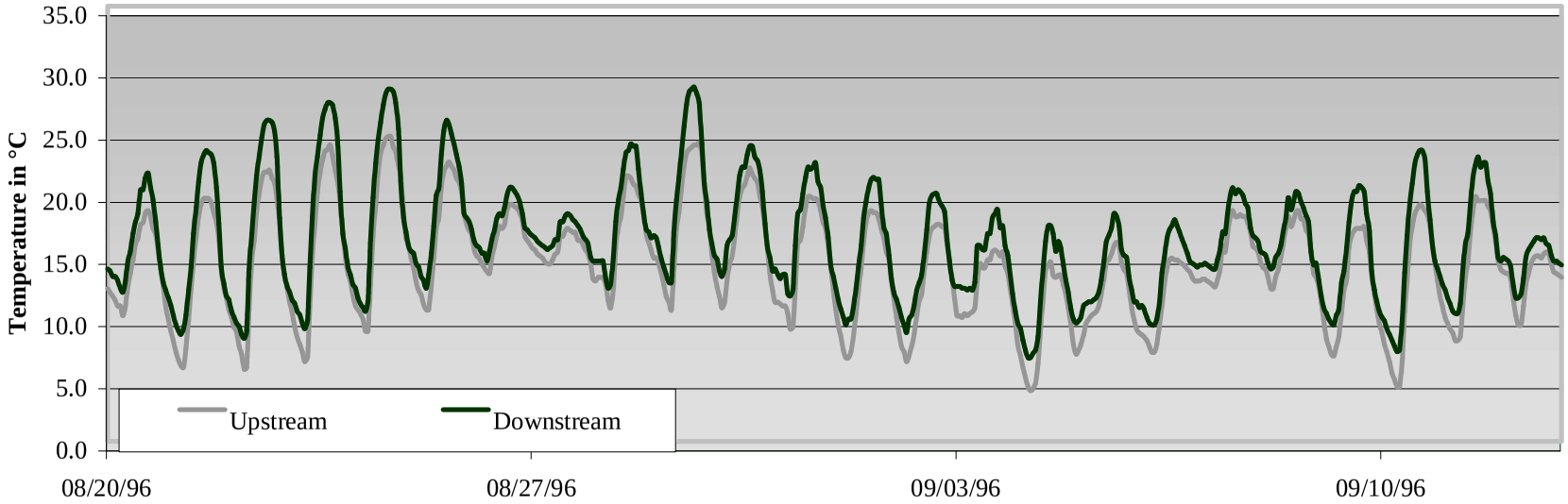


July 19 - August 19, 1996 Hourly Air Temperature for the Salzer Creek Tributary.

Appendix J: 1996 Hourly Water and Air Temperature Monitoring Data for the South Tributary to Salzer Creek BMP Site.

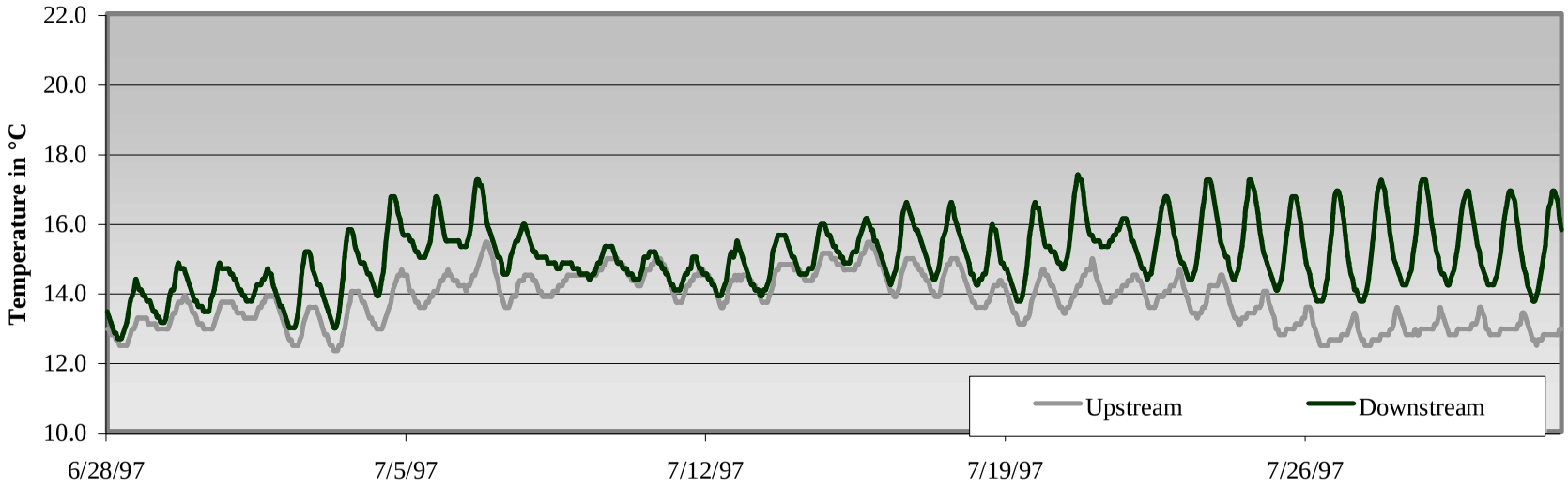


August 20 - September 12, 1996 Hourly Water Temperature for the Salzer Creek Tributary.

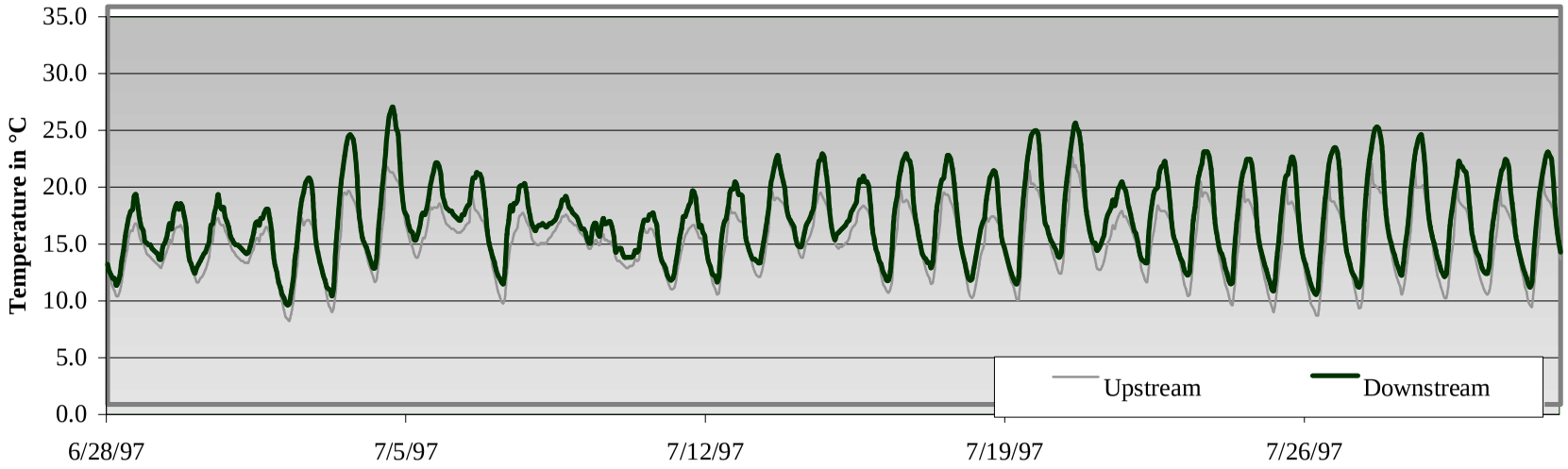


August 20 - September 12, 1996 Hourly Air Temperature for the Salzer Creek Tributary.

Appendix J: 1997 Hourly Water and Air Temperature Monitoring Data for the South Tributary to Salzer Creek BMP Site.

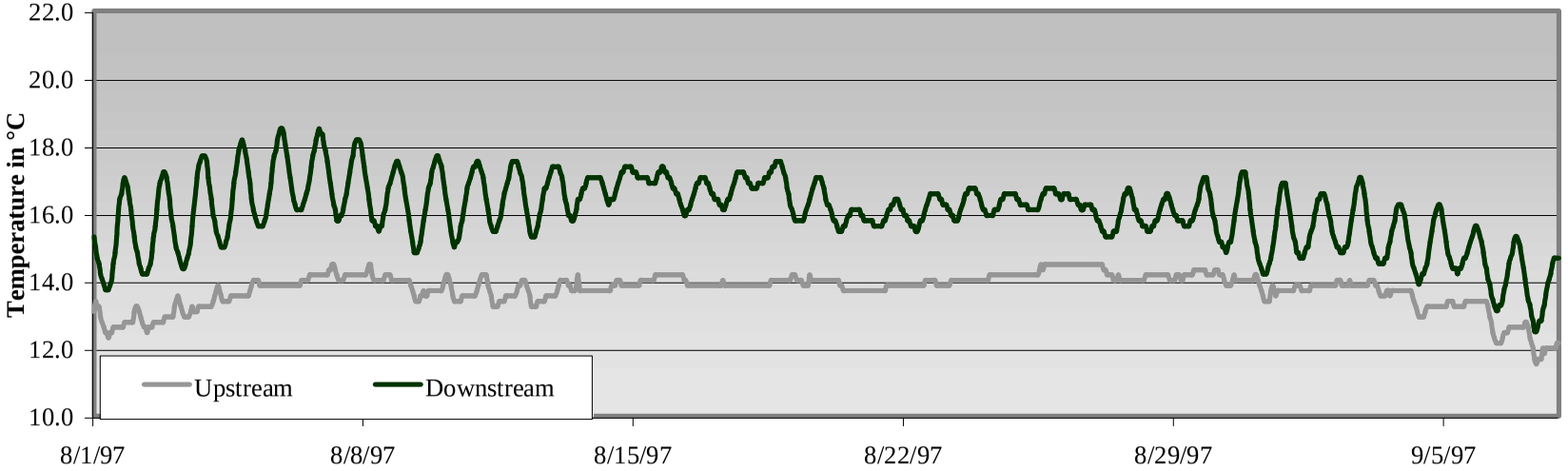


June 28 - July 31, 1997 Hourly Water Temperature for Salzer Creek Tributary.

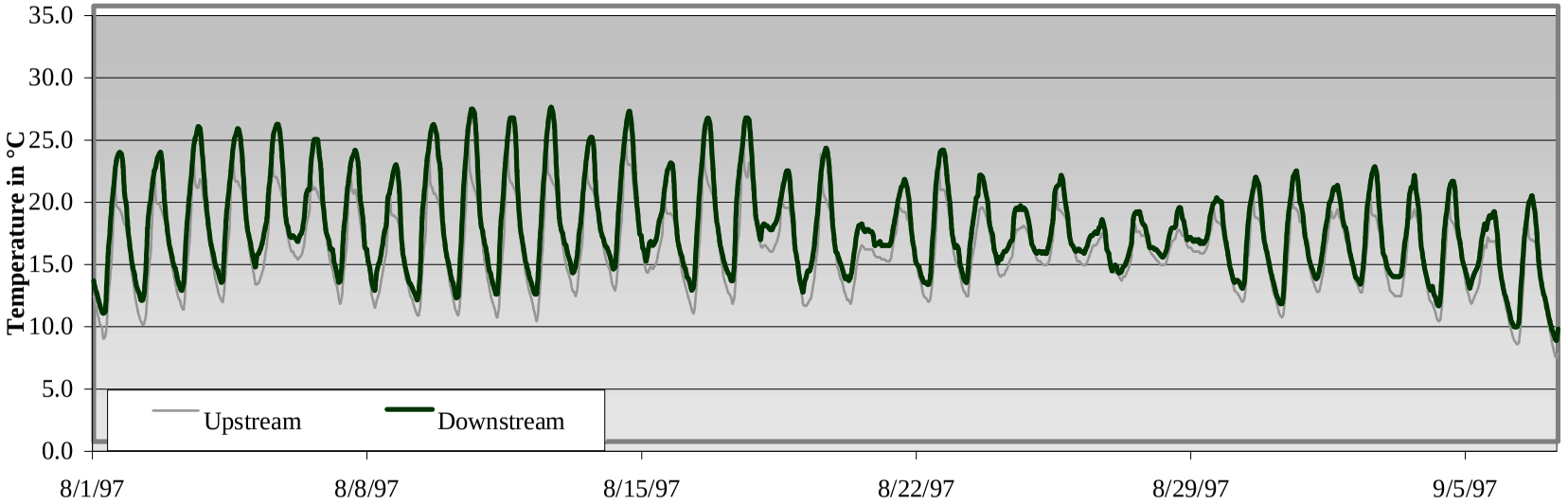


June 28 - July 31, 1997 Hourly Air Temperature for Salzer Creek Tributary.

Appendix J: 1997 Hourly Water and Air Temperature Monitoring Data for the South Tributary to Salzer Creek BMP Site.

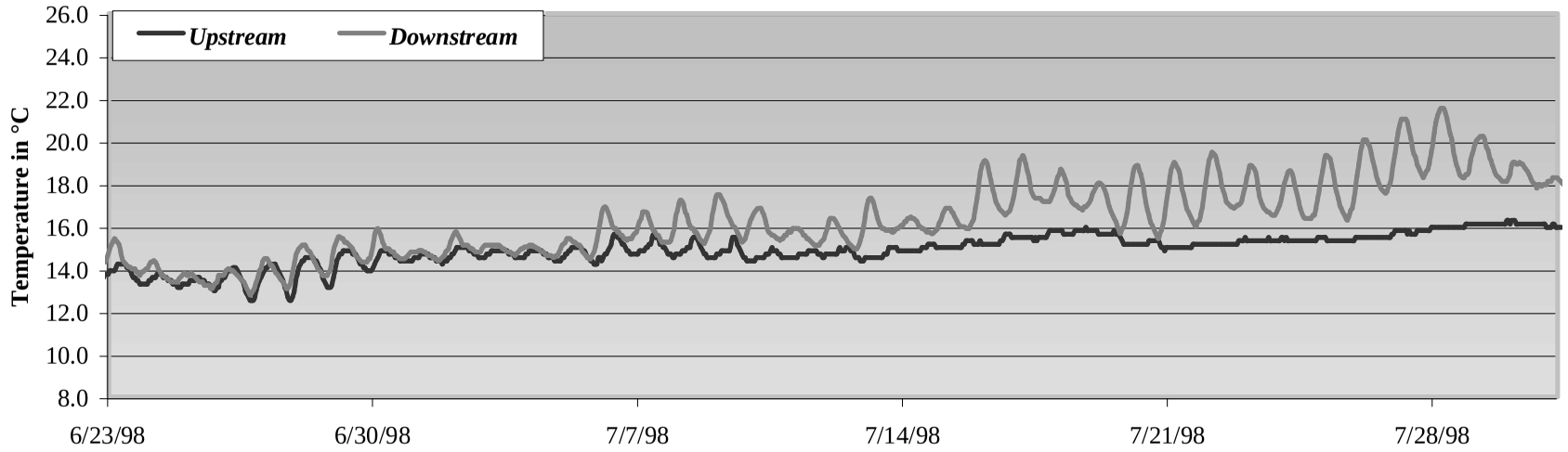


August 1 - September 7, 1997 Hourly Water Temperature for Salzer Creek Tributary.

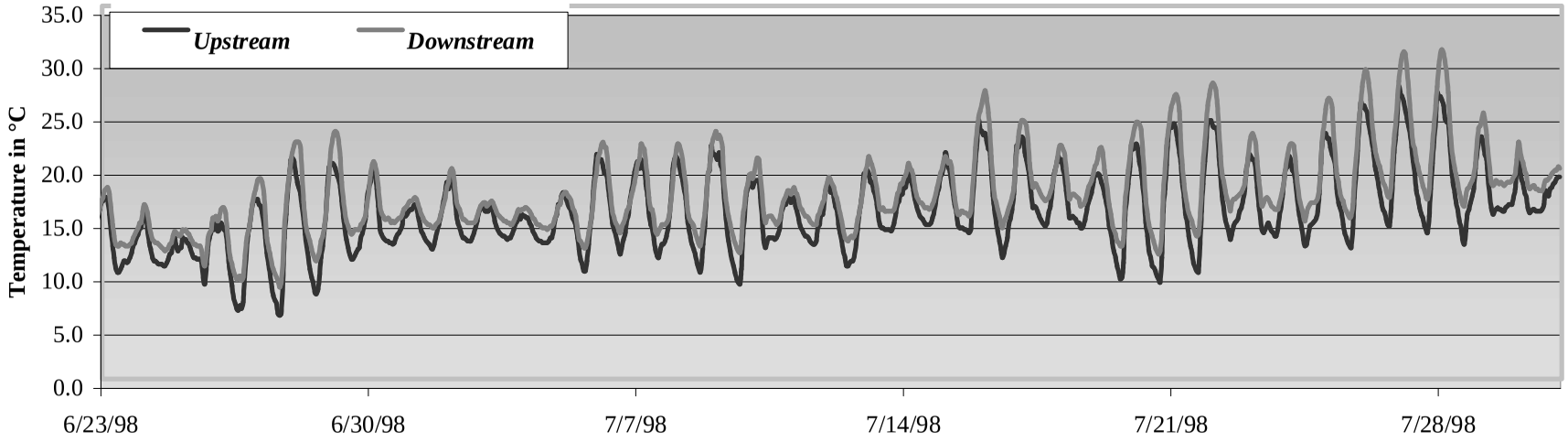


August 1 - September 7, 1997 Hourly Air Temperature for Salzer Creek Tributary.

Appendix J: 1998 Hourly Water and Air Temperature Monitoring Data for the South Tributary to Salzer Creek BMP Site.

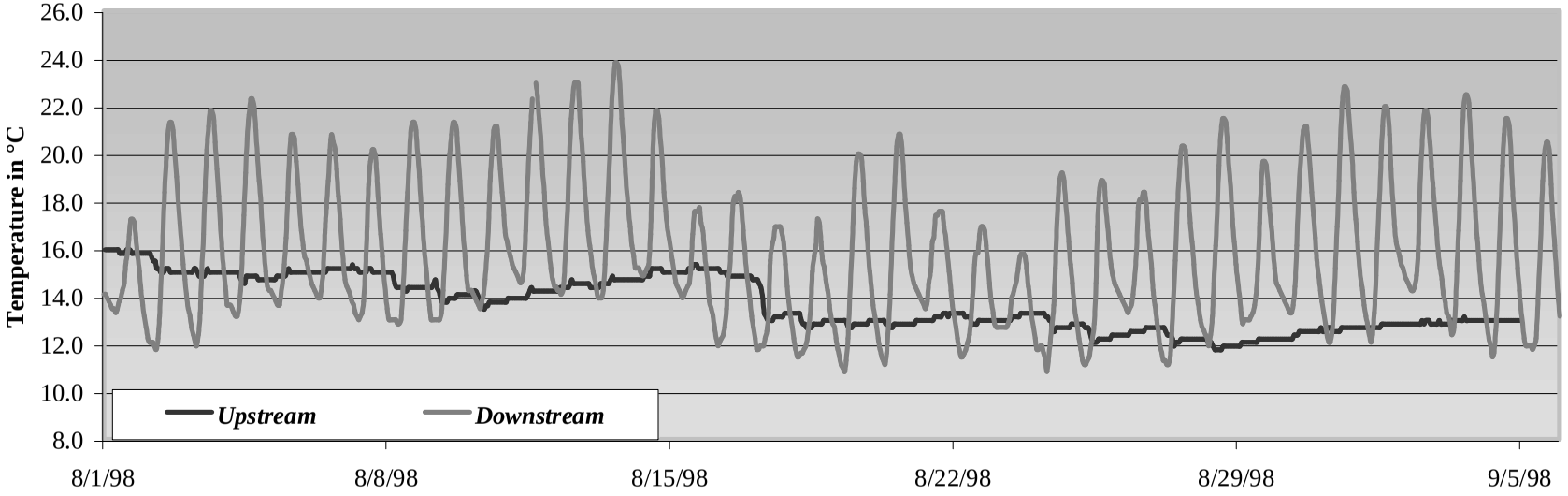


June 23-July 31, 1998 Hourly Water Temperature for Salzer Creek Tributary.

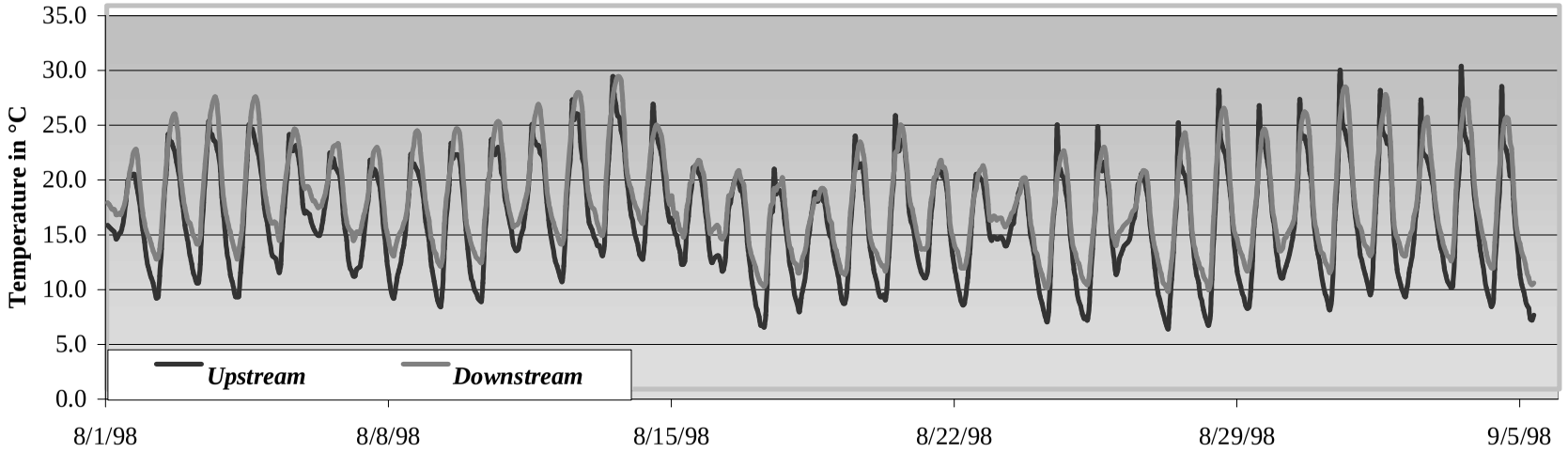


June 23-July 31, 1998 Hourly Air Temperature for Salzer Creek Tributary.

Appendix J: 1998 Hourly Water and Air Temperature Monitoring Data for the South Tributary to Salzer Creek BMP Site.

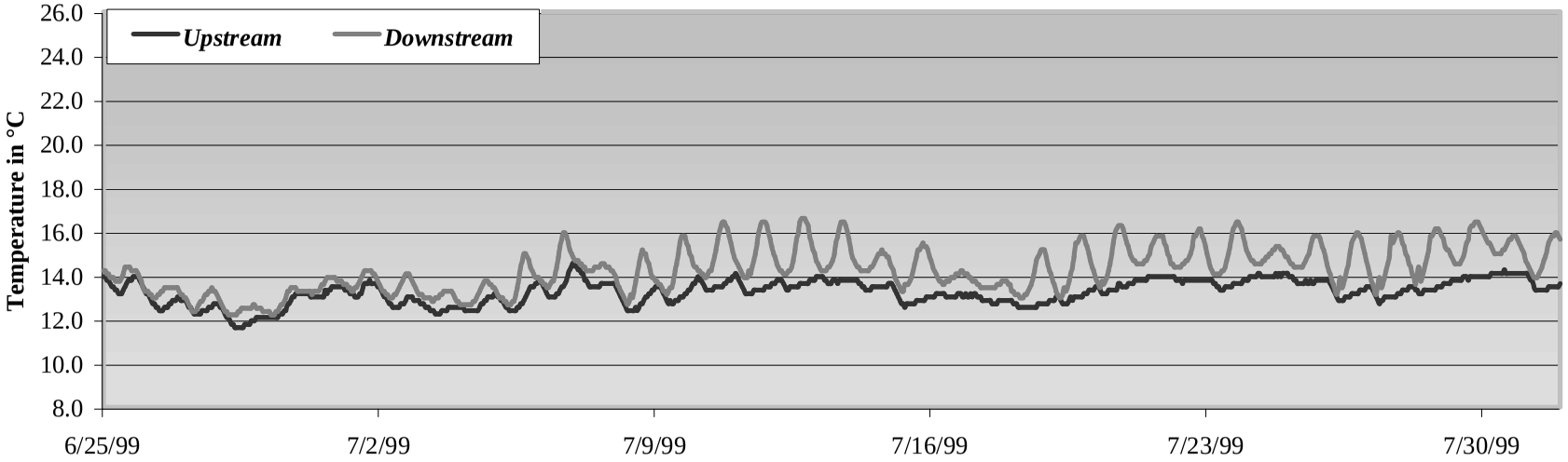


August 1-September 5, 1998 Hourly Water Temperature for Salzer Creek Tributary.

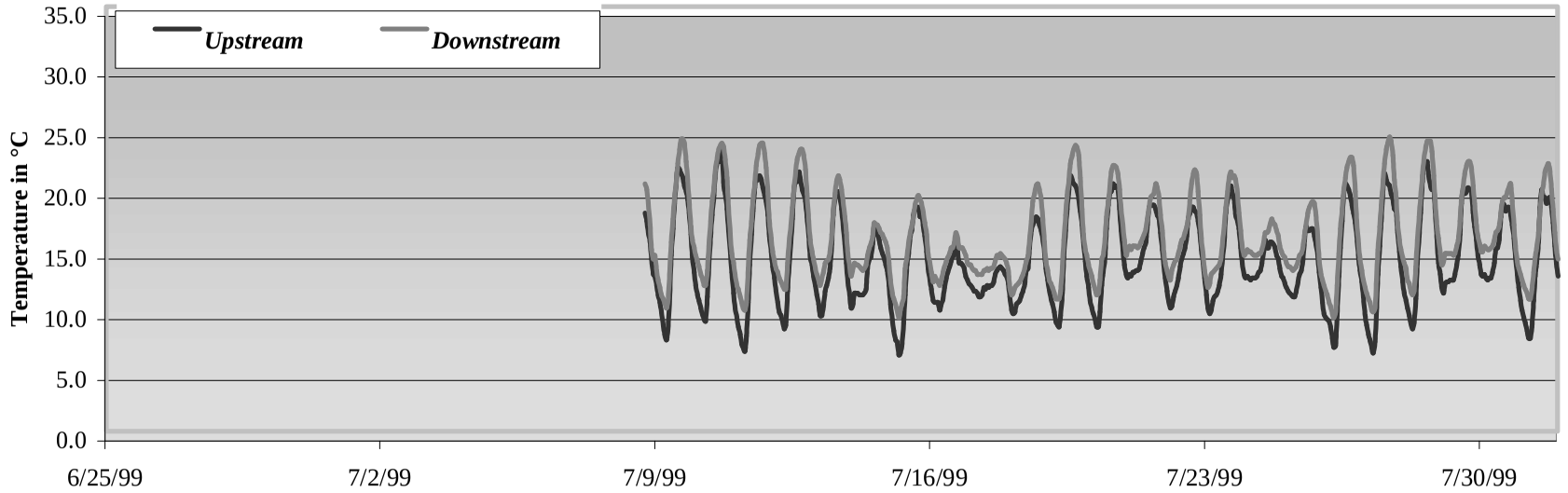


August 1-September 5, 1998 Hourly Air Temperature for Salzer Creek Tributary.

Appendix J: 1999 Hourly Water and Air Temperature Monitoring Data for the South Tributary to Salzer Creek BMP Site.

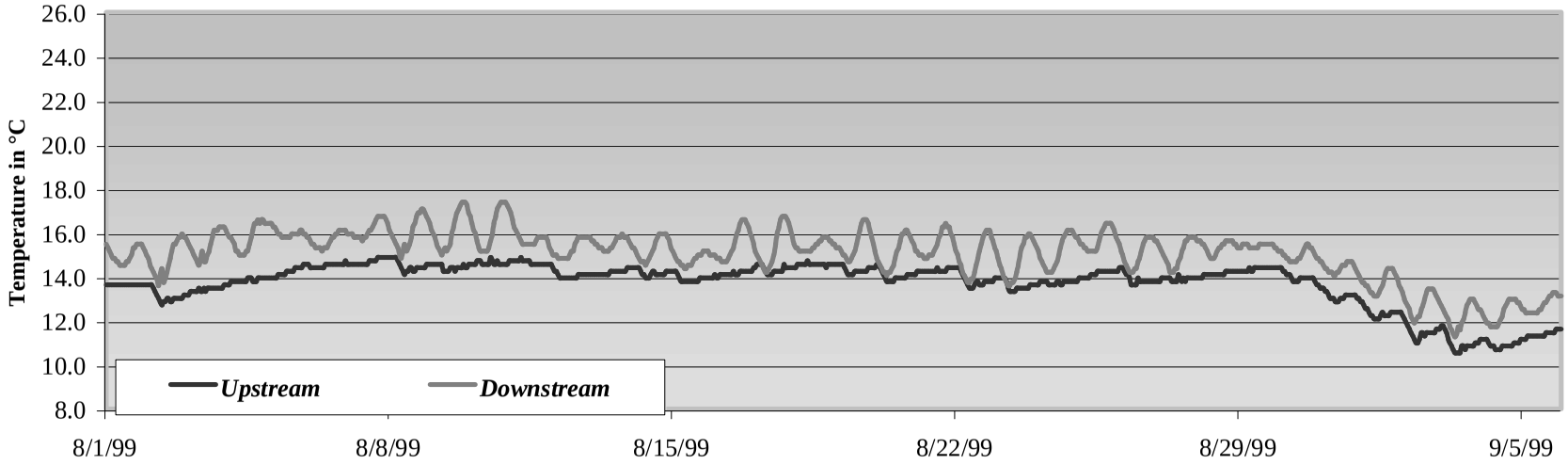


June 25-July 31, 1999 Hourly Water Temperature for Salzer Creek Tributary.

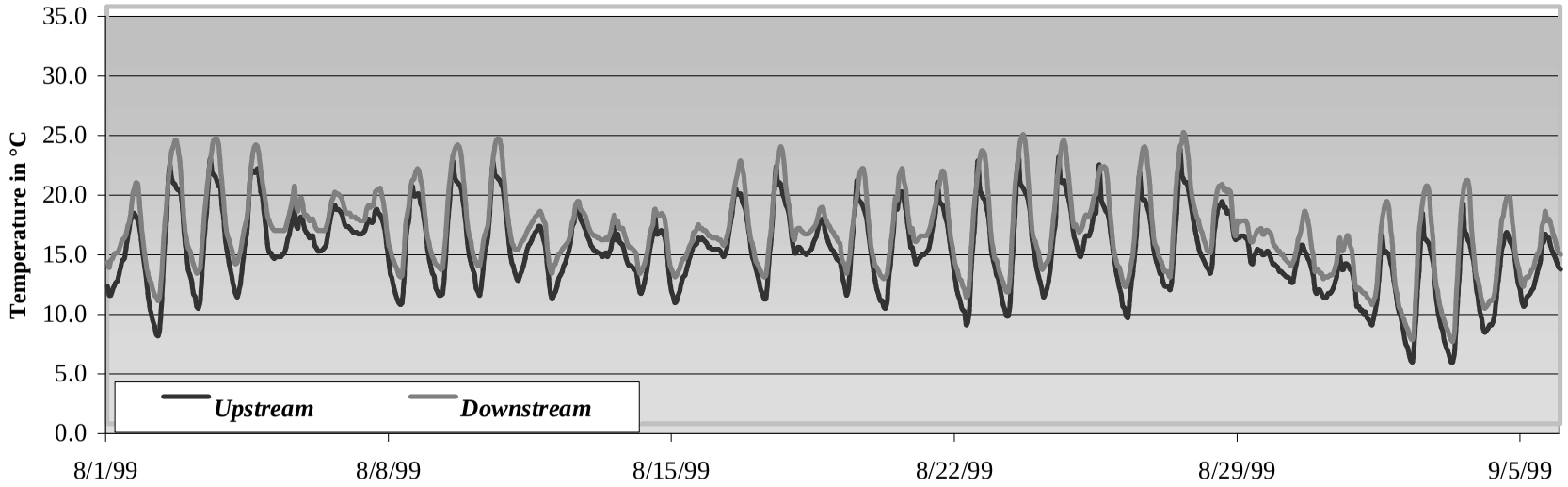


June 25-July 31, 1999 Air Temperature for Salzer Creek Tributary.

Appendix J: 1999 Hourly Water and Air Temperature Monitoring Data for the South Tributary to Salzer Creek BMP Site.



August 1-September 5, 1999 Hourly Water Temperature for Salzer Creek Tributary.



August 1-September 5, 1999 Hourly Air Temperature for Salzer Creek Tributary.

Appendix K. South Branch of Big Creek

1998 Hourly Water Temperature Monitoring Data
1999 Hourly Water and Air Temperature Monitoring Data

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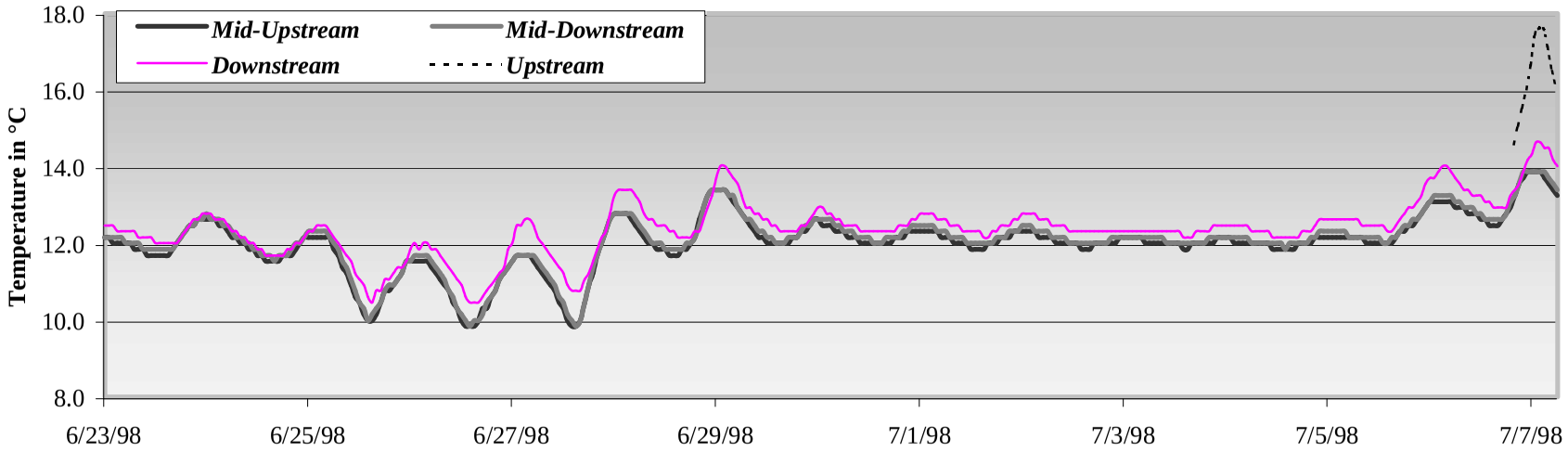
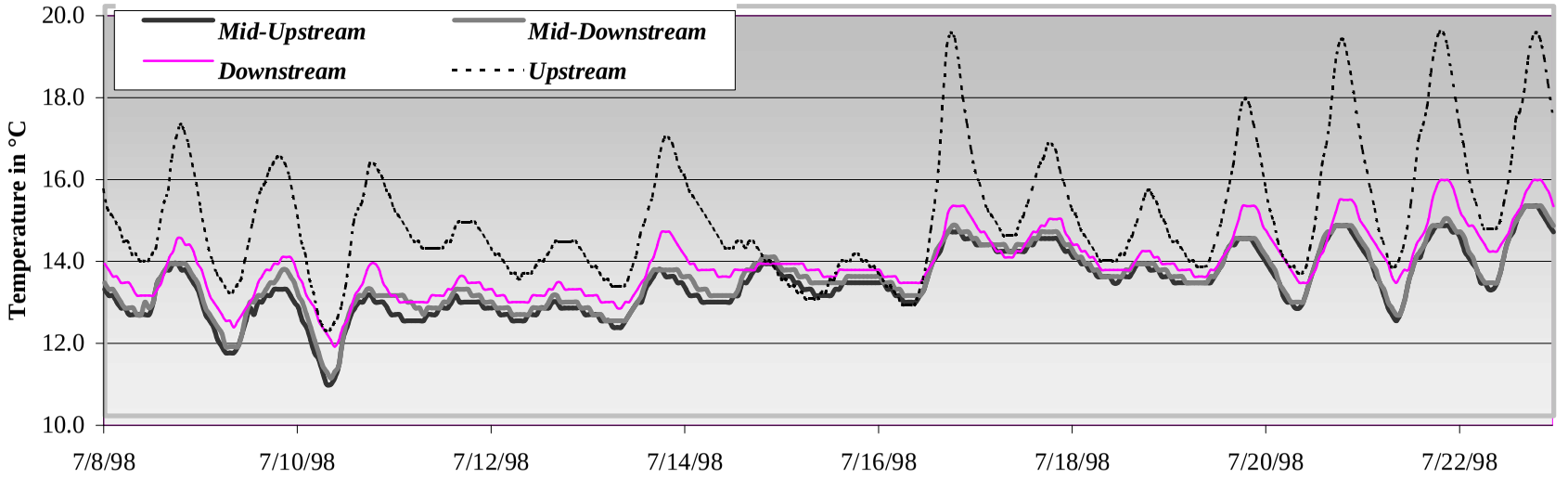
Appendix K: 1998 Hourly Water Temperature Monitoring Data for the South Branch of Big Creek BMP Site.

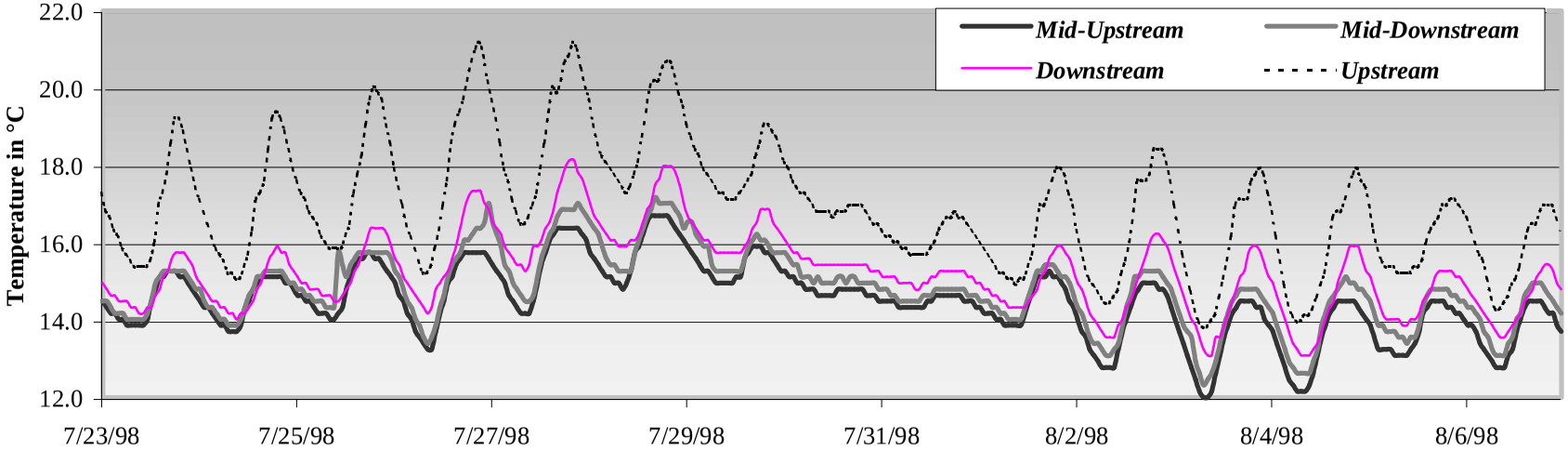


June 23-July 7, 1998 Hourly Water Temperature for South Branch of Big Creek.

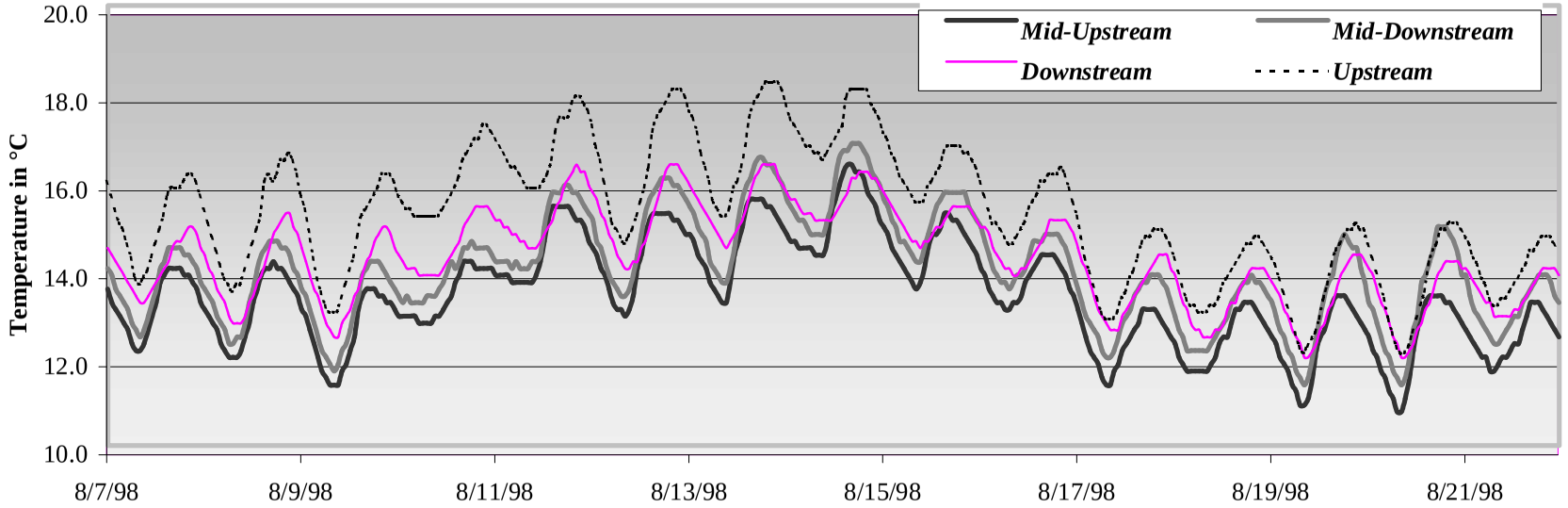


July 8-July 22, 1998 Hourly Water Temperature for South Branch of Big Creek.

Appendix K: 1998 Hourly Water Temperature Monitoring Data for the South Branch of Big Creek BMP Site.

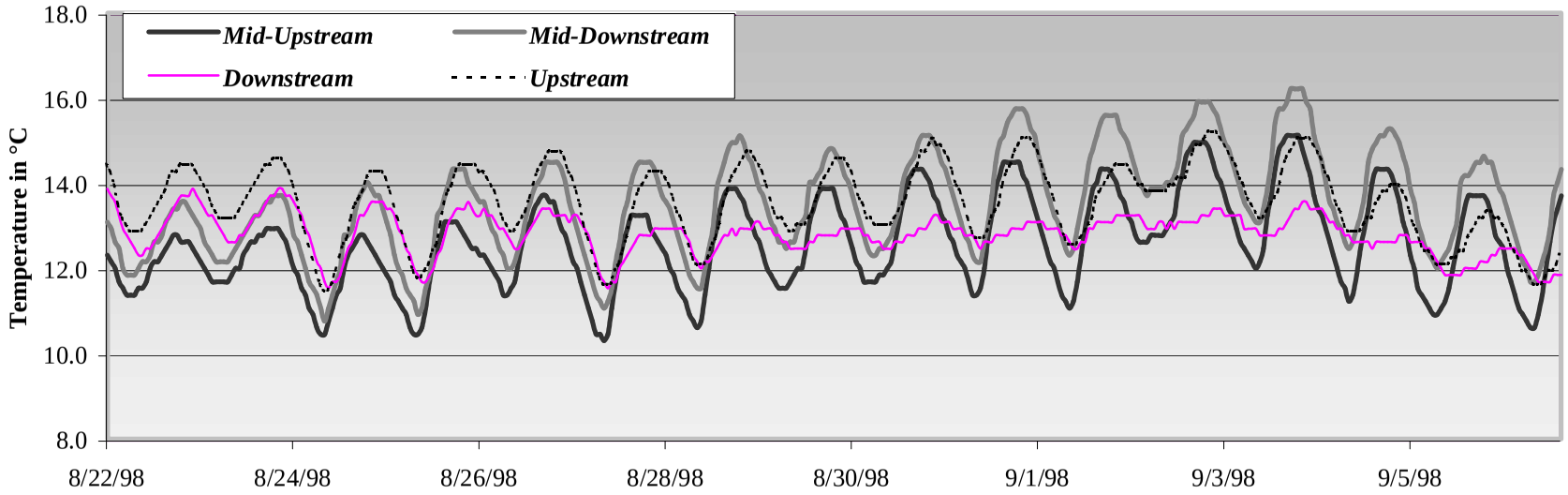


July 23-August 6, 1998 Hourly Water Temperature for South Branch of Big Creek.



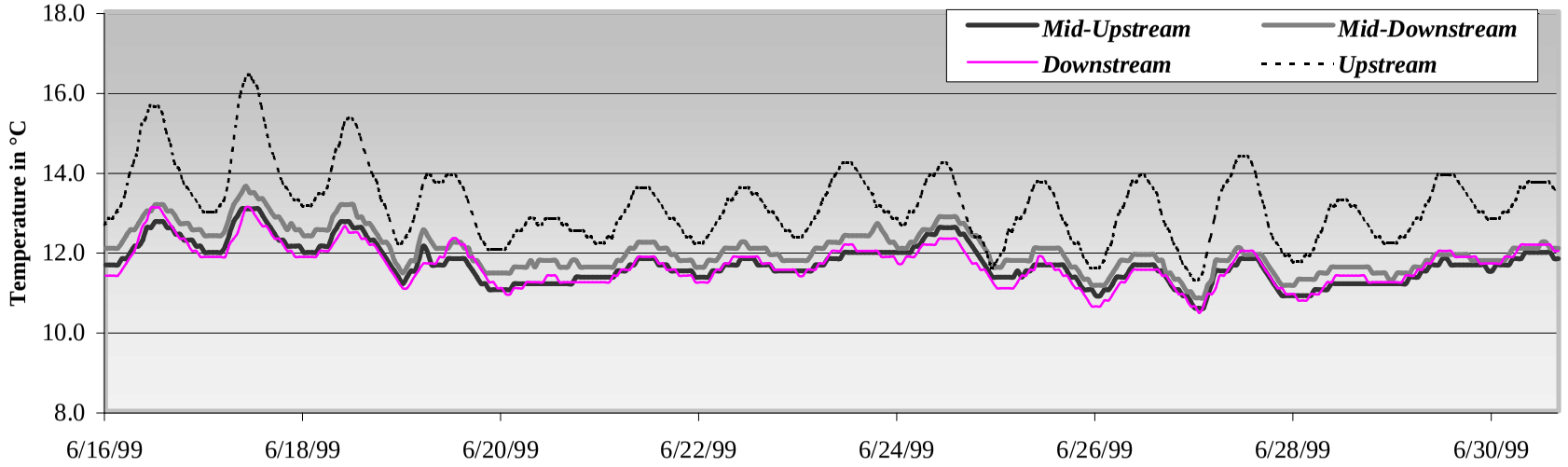
August 7-August 21, 1998 Hourly Water Temperature for South Branch of Big Creek.

Appendix K: 1998 Hourly Water Temperature Monitoring Data for the South Branch of Big Creek BMP Site.

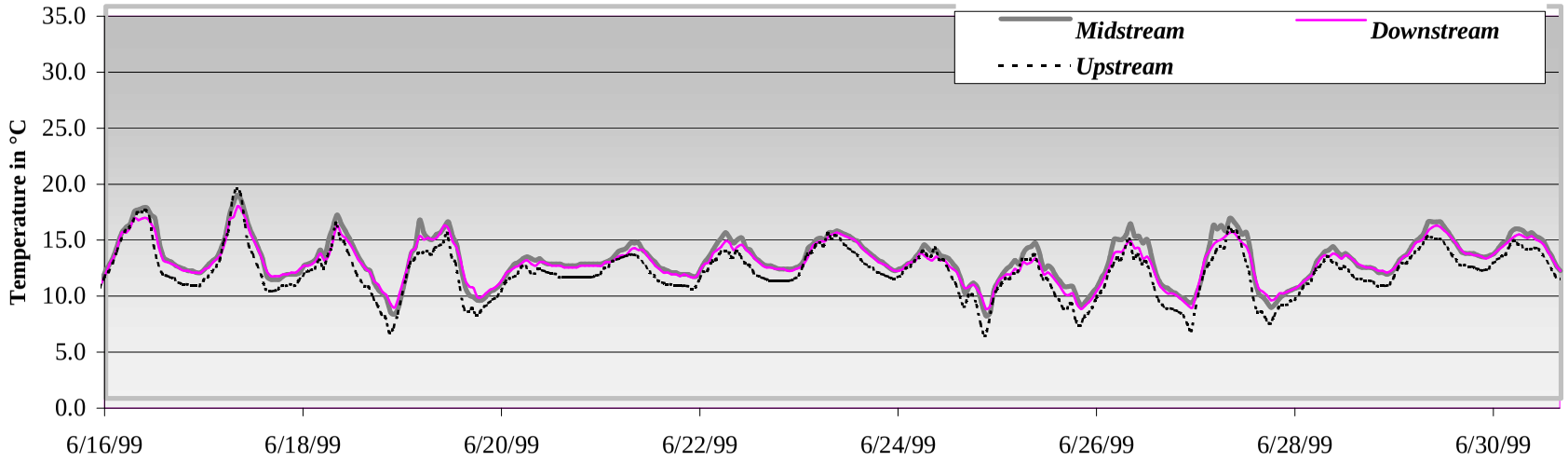


August 22-September 5, 1998 Hourly Water Temperature for South Branch of Big Creek.

Appendix K: 1999 Hourly Water and Air Temperature Monitoring Data for the South Branch of Big Creek BMP Site.

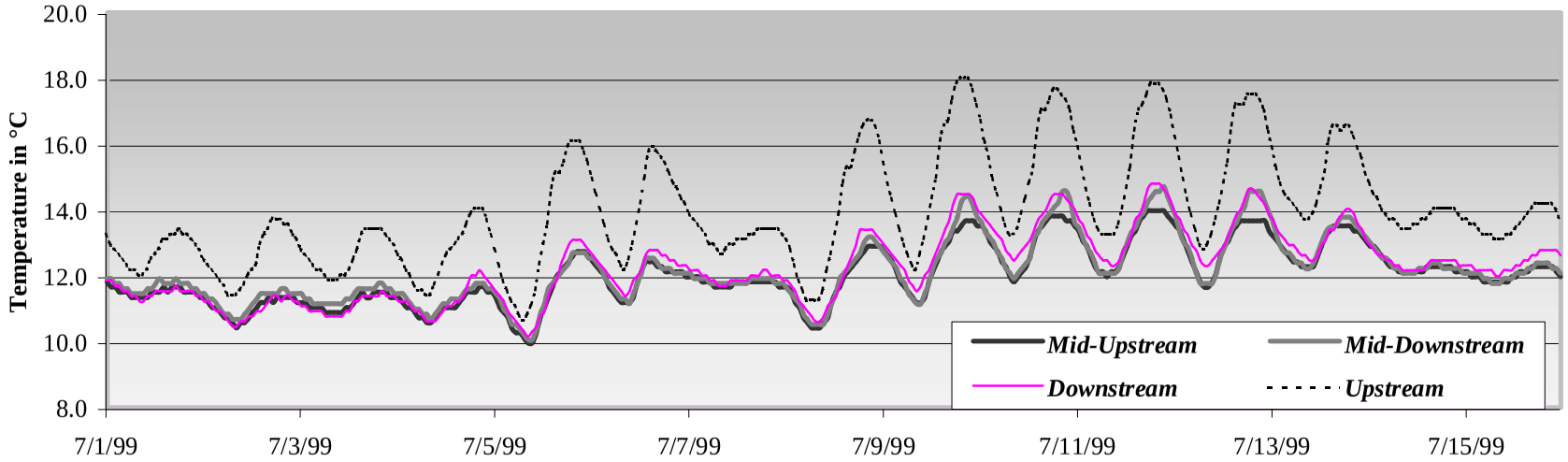


June 16-30, 1999 Hourly Water Temperature for South Branch of Big Creek.

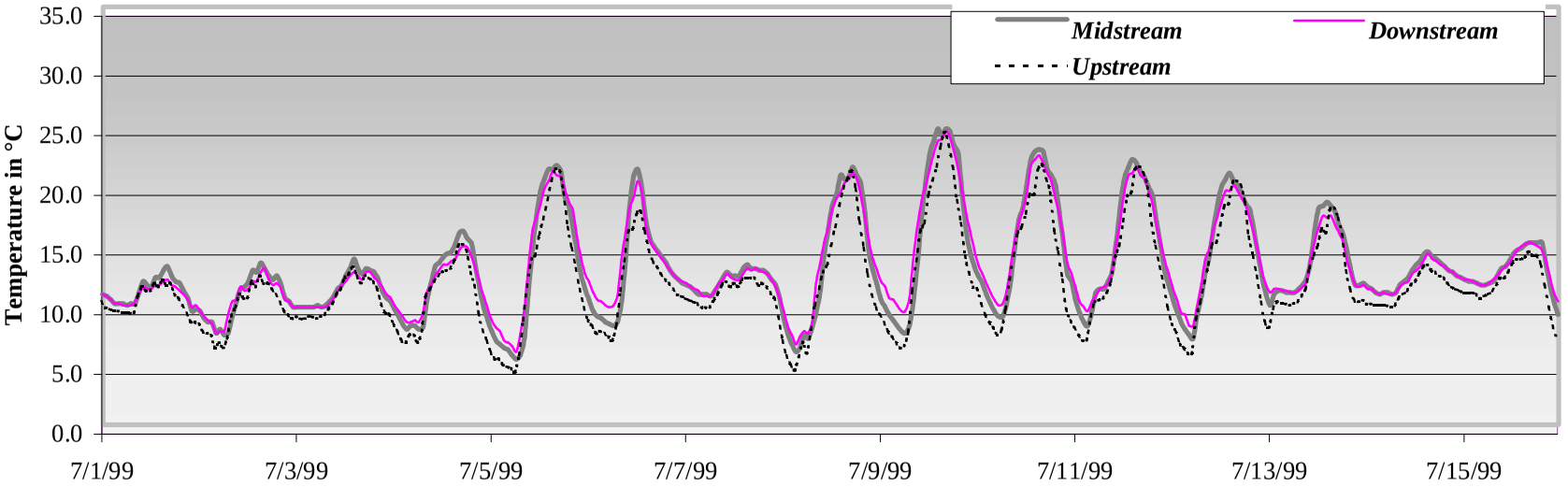


June 16-30, 1999 Hourly Air Temperature for South Branch of Big Creek.

Appendix K: 1999 Hourly Water and Air Temperature Monitoring Data for the South Branch of Big Creek BMP Site.

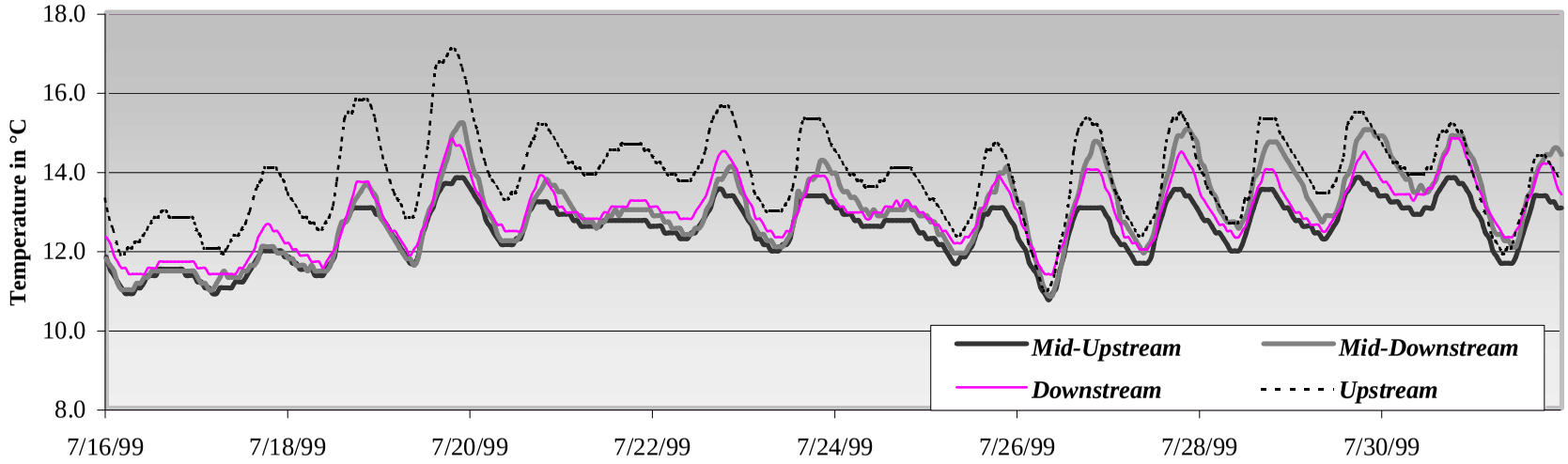


July 1-15, 1999 Hourly Water Temperature for South Branch of Big Creek.

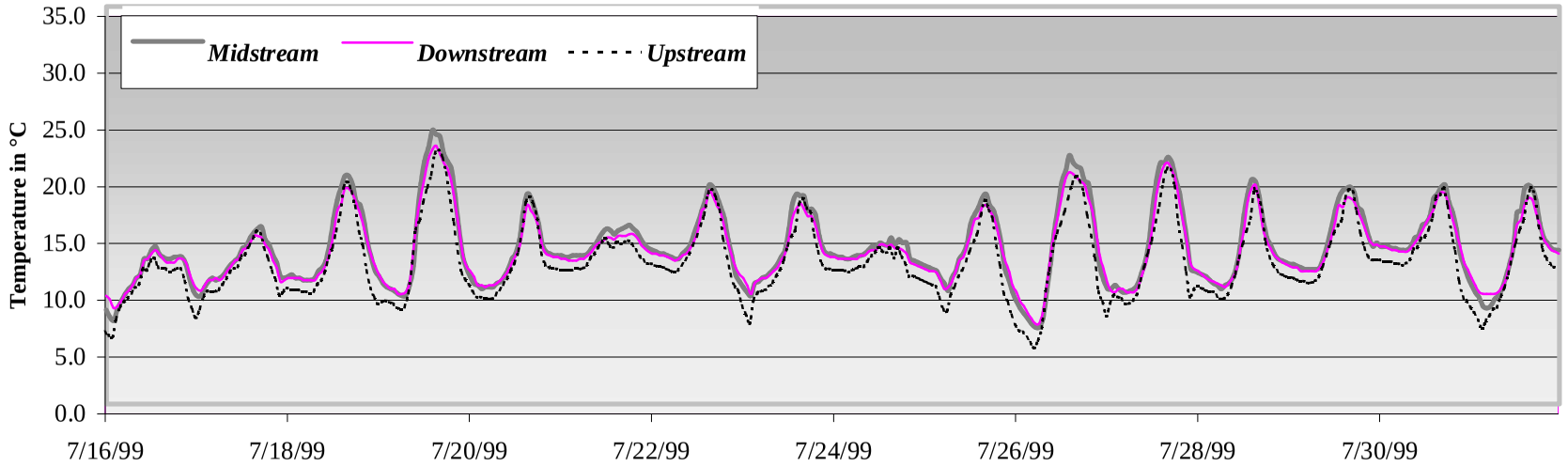


July 1-15, 1999 Hourly Air Temperature for South Branch of Big Creek.

Appendix K: 1999 Hourly Water and Air Temperature Monitoring Data for the South Branch of Big Creek BMP Site.

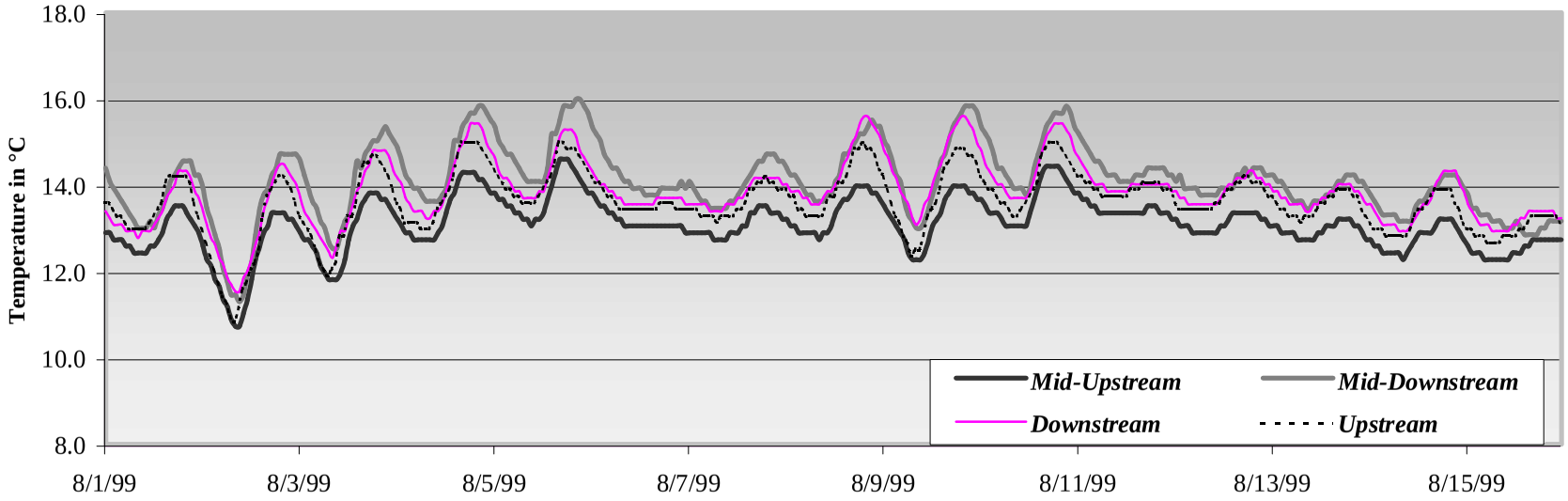


July 16-31, 1999 Hourly Water Temperature for South Branch of Big Creek.

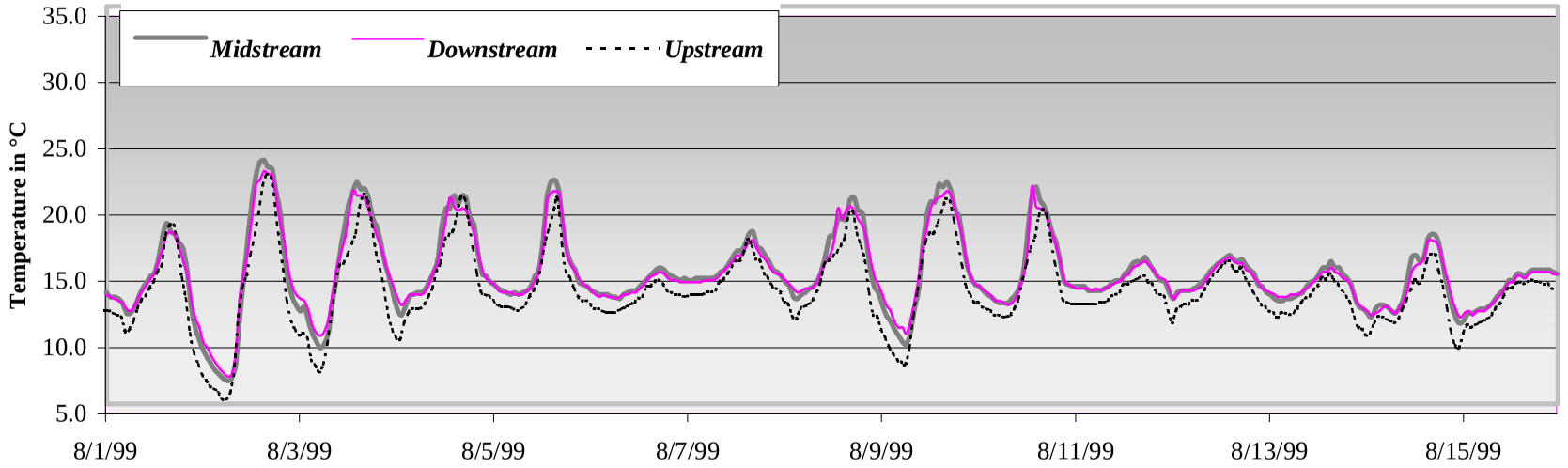


July 16-31, 1999 Hourly Air Temperature for South Branch of Big Creek.

Appendix K: 1999 Hourly Water and Air Temperature Monitoring Data for the South Branch of Big Creek BMP Site.

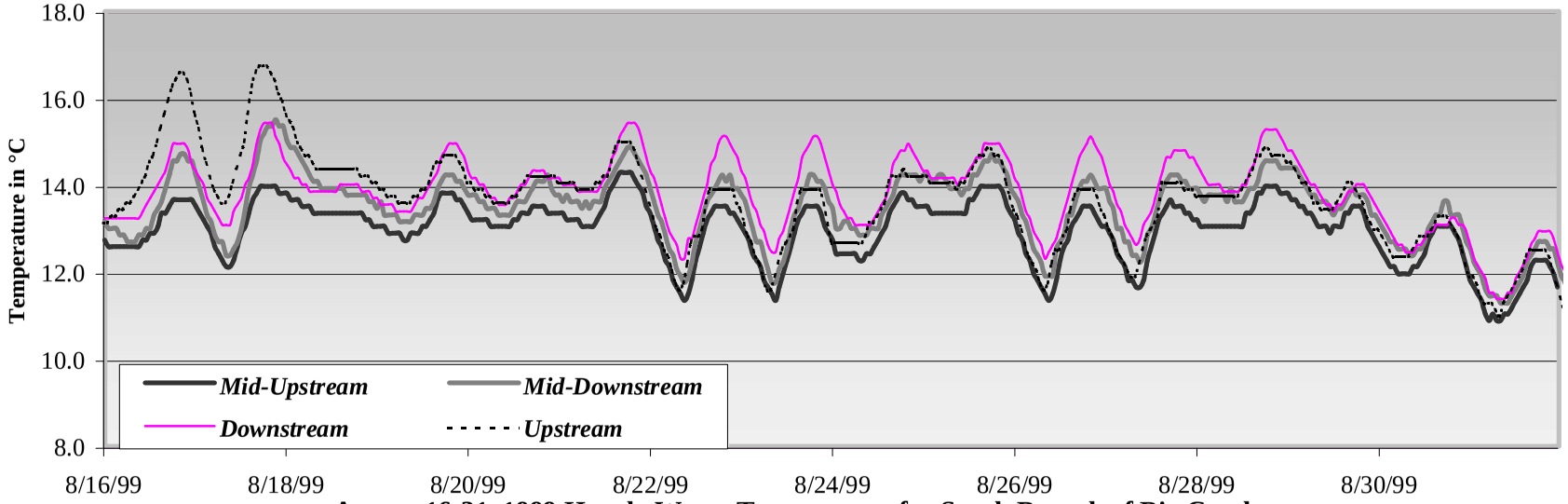


August 1-15, 1999 Hourly Water Temperature for South Branch of Big Creek.

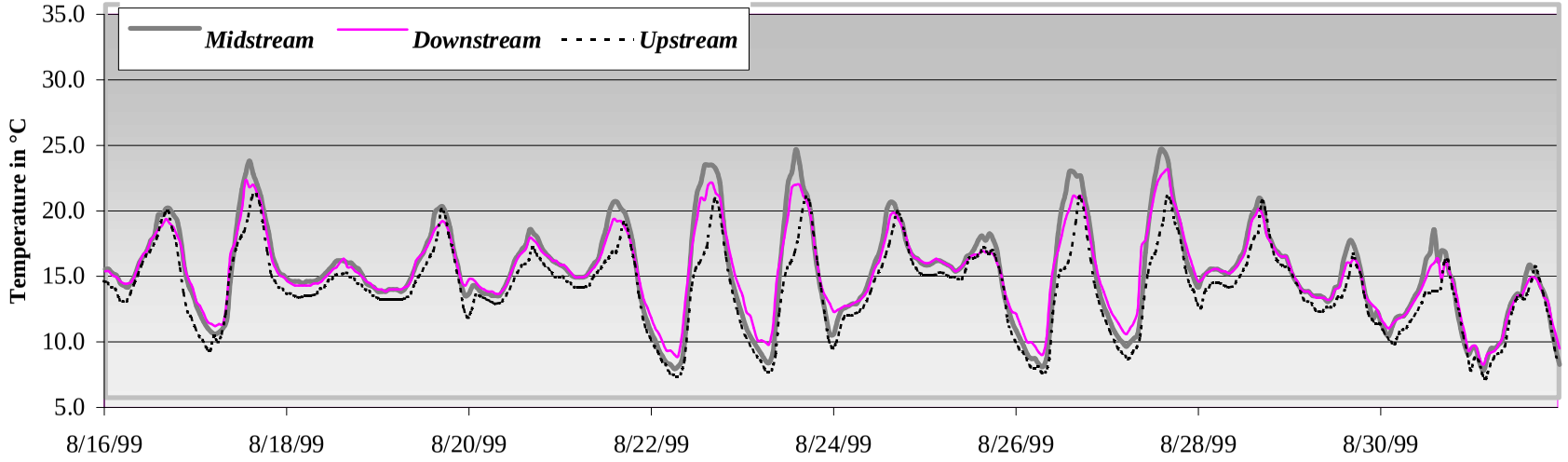


August 1-15, 1999 Hourly Air Temperature for South Branch of Big Creek.

Appendix K: 1999 Hourly Water and Air Temperature Monitoring Data for the South Branch of Big Creek BMP Site.

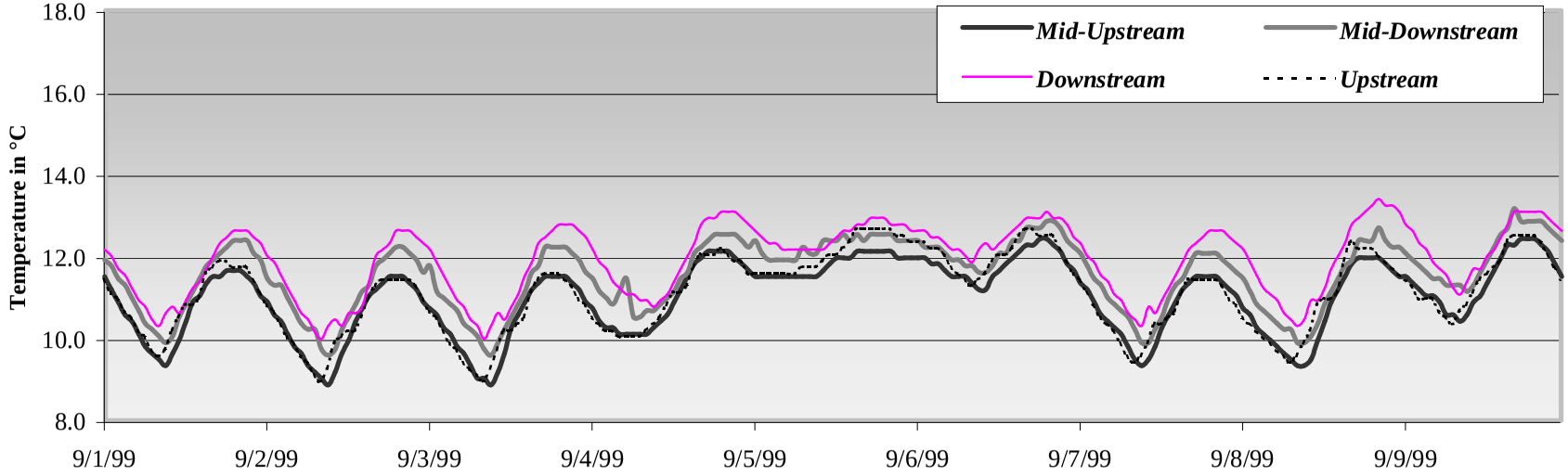


August 16-31, 1999 Hourly Water Temperature for South Branch of Big Creek.

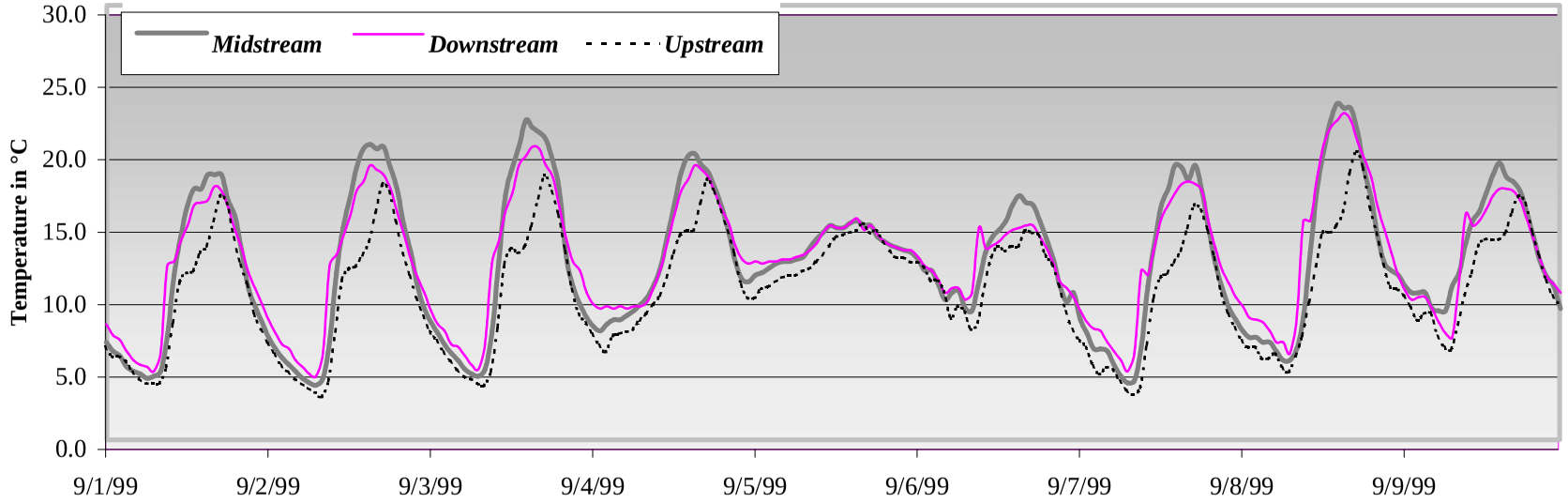


August 16-31, 1999 Hourly Air Temperature for South Branch of Big Creek.

Appendix K: 1999 Hourly Water and Air Temperature Monitoring Data for the South Branch of Big Creek BMP Site.



September 1-9, 1999 Hourly Water Temperature for South Branch of Big Creek.



September 1-9, 1999 Hourly Air Temperature for South Branch of Big Creek.

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Appendix L. Stillman Creek

Riparian Assessment
Stillman Creek Watershed Analysis
Weyerhaeuser Company

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Appendix M. Stillman Creek

1998 Hourly Water and Air Temperature Monitoring Data
1999 Hourly Water and Air Temperature Monitoring Data
2000 Hourly Water and Air Temperature Monitoring Data

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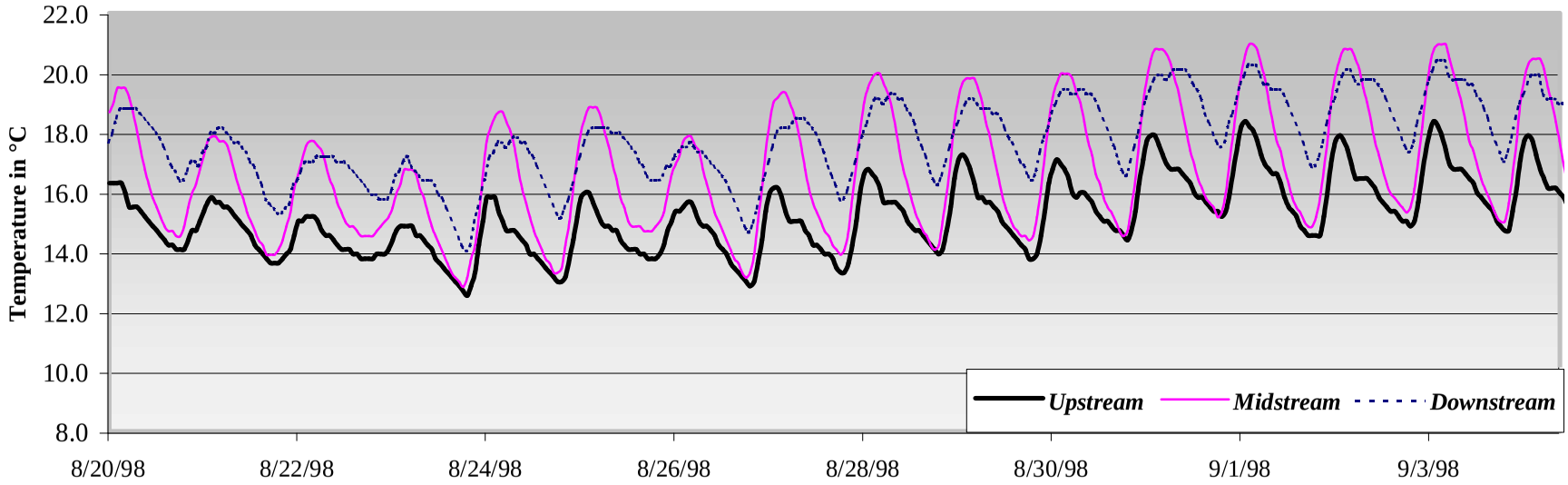
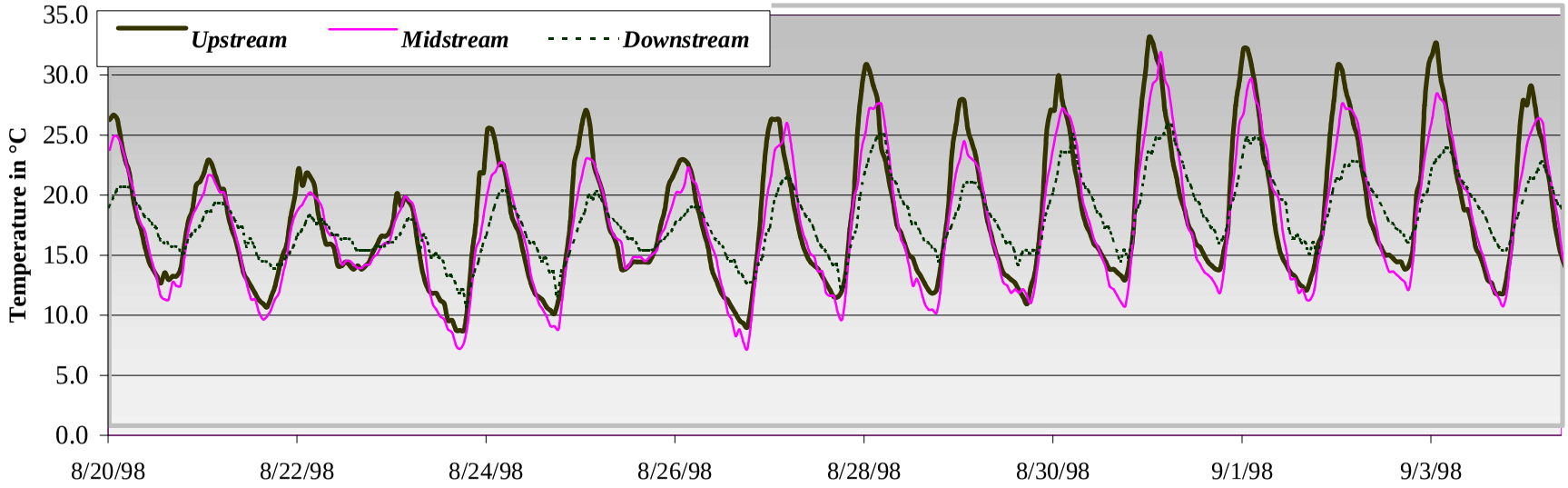
Appendix M: 1998 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

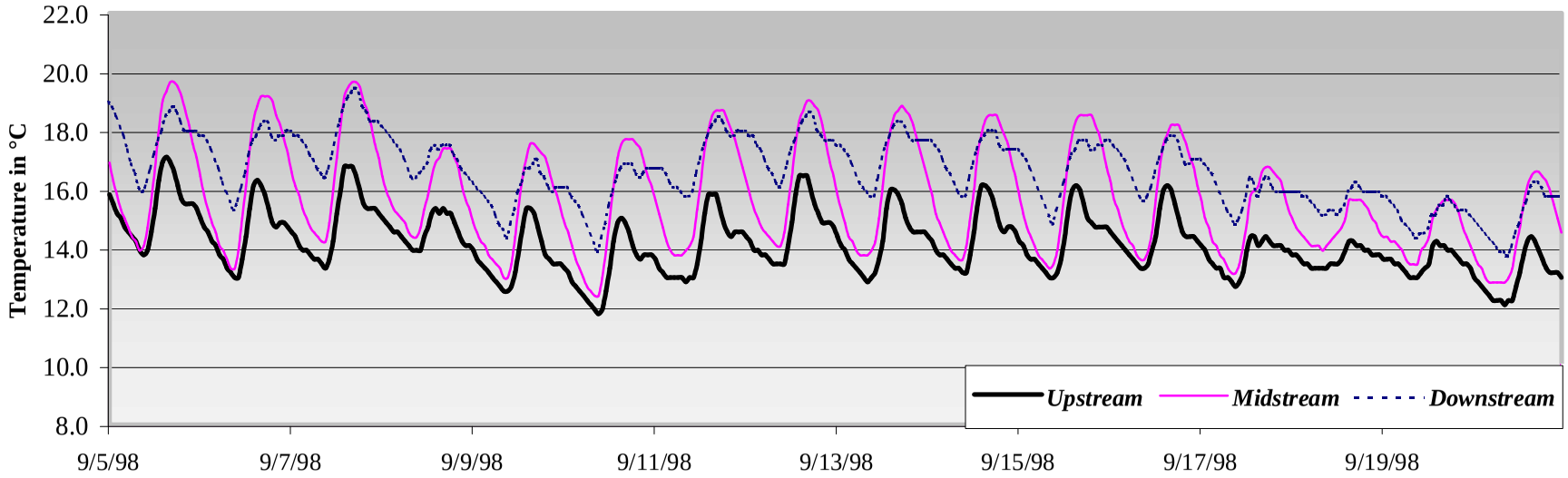


August 20 -September 4, 1998 Hourly Water Temperature for Stillman Creek.

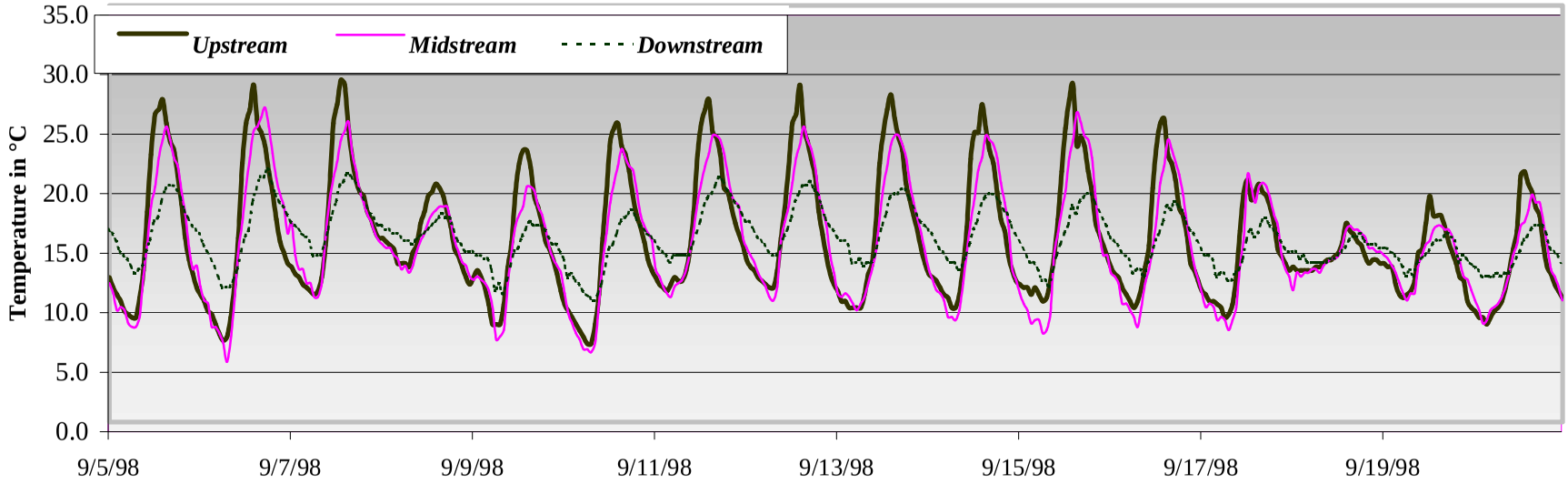


August 20 - September 4, 1998 Hourly Air Temperature for Stillman Creek.

Appendix M: 1998 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

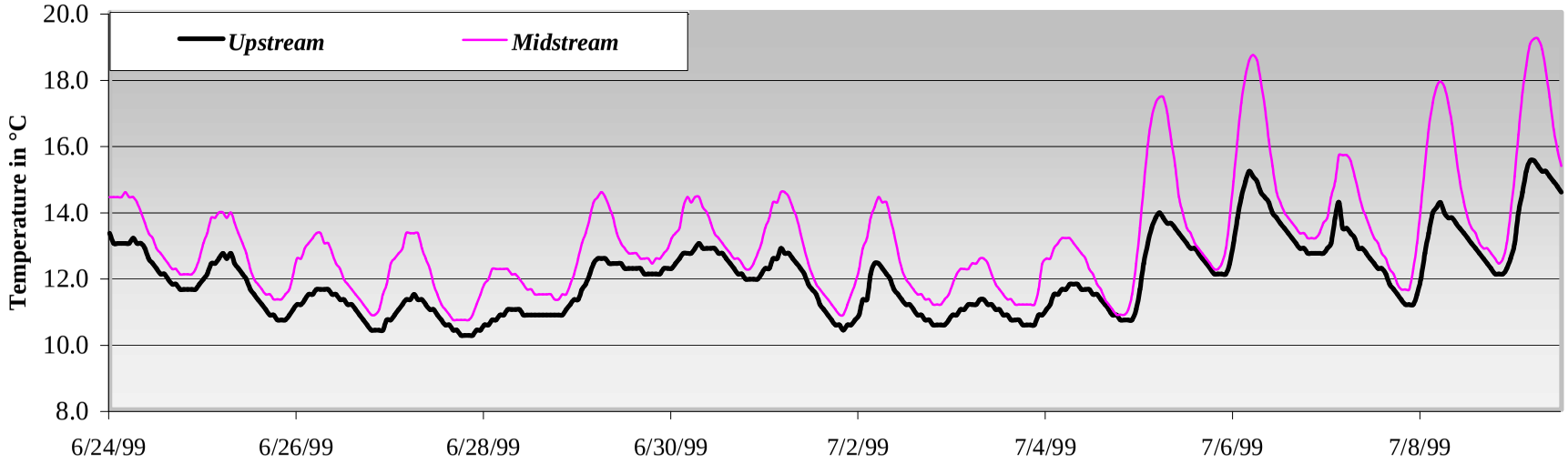


September 5 - 20, 1998 Hourly Water Temperature for Stillman Creek.

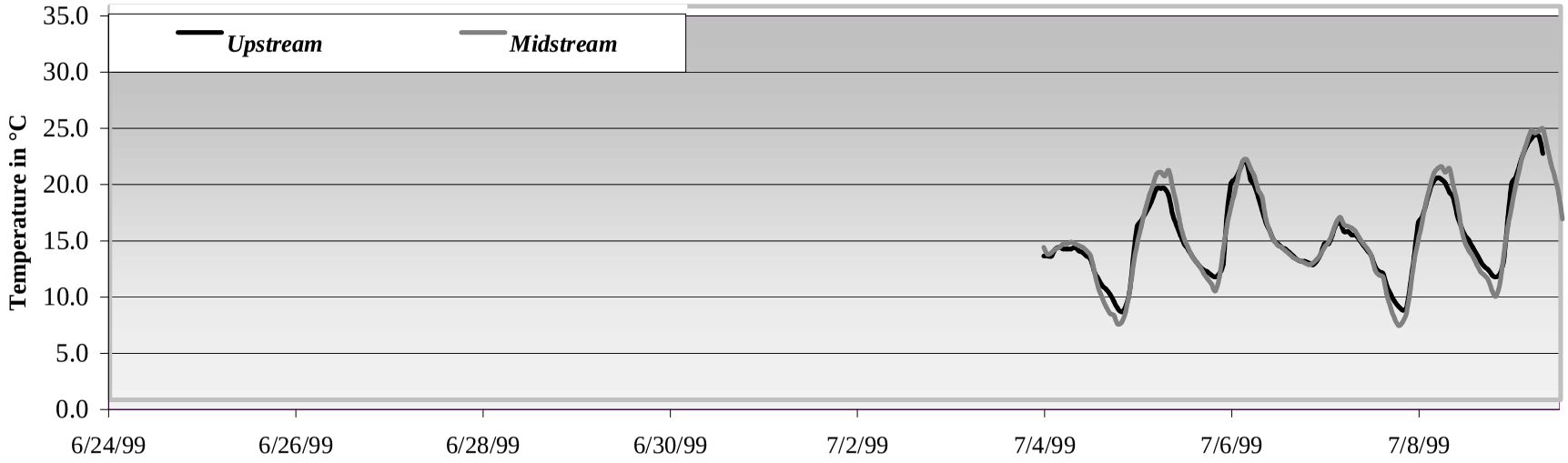


September 5 - 20, 1998 Hourly Air Temperature for Stillman Creek.

Appendix M: 1999 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

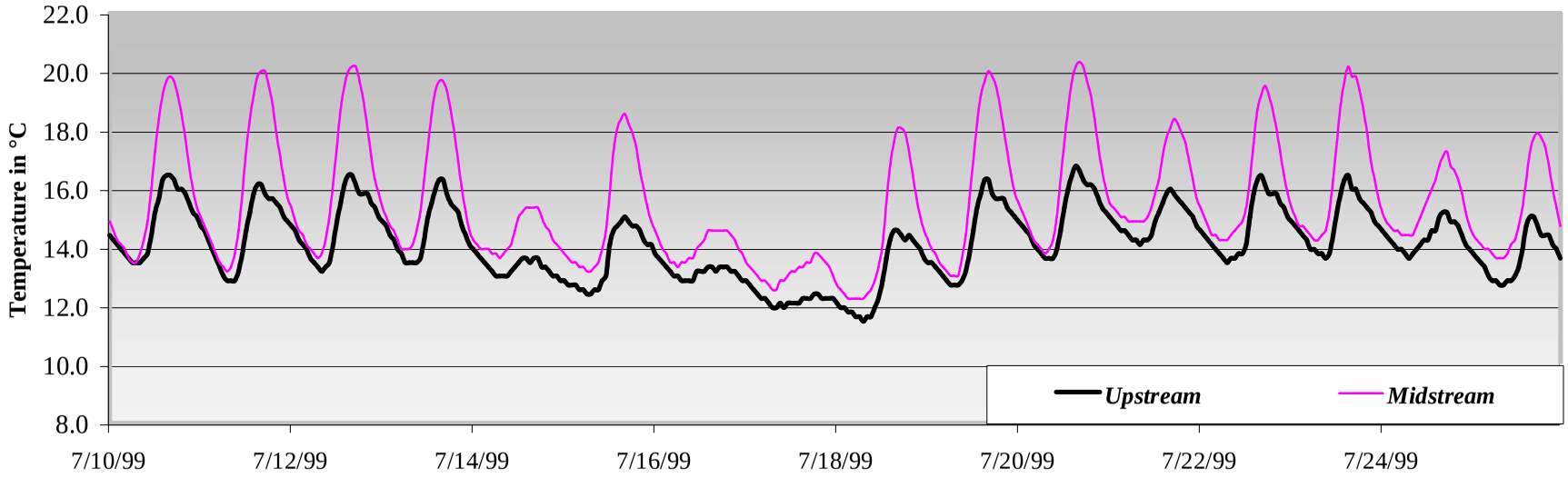


June 24-July 9, 1999 Hourly Water Temperature for Stillman Creek.

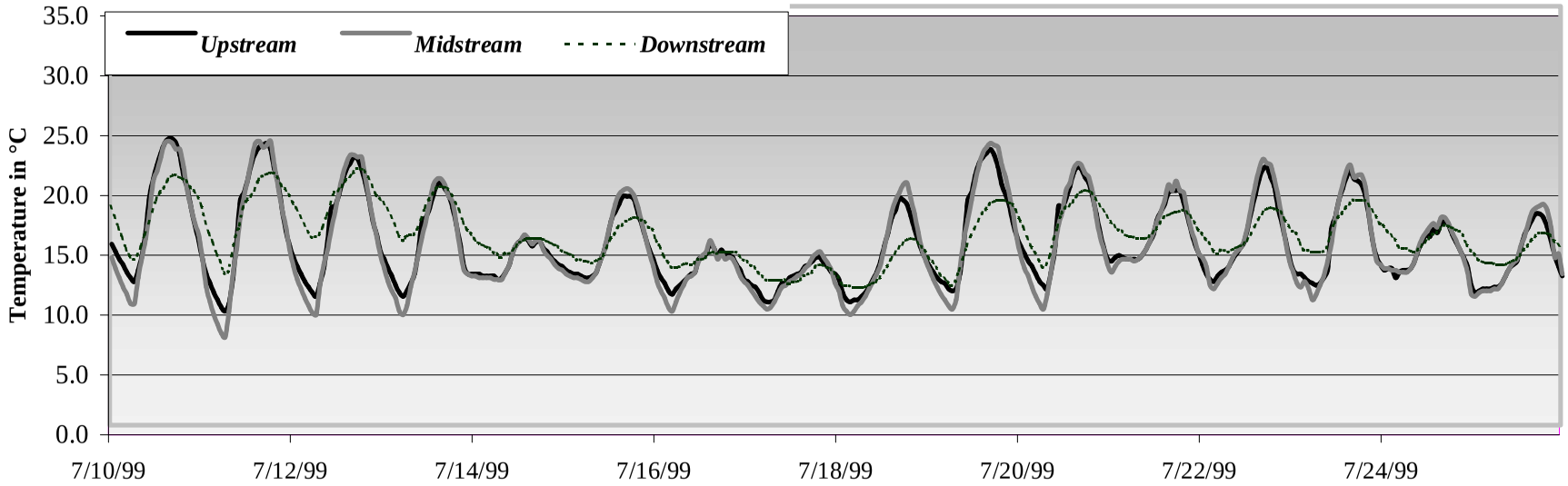


June 24-July 9, 1999 Hourly Air Temperature for Stillman Creek.

Appendix M: 1999 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

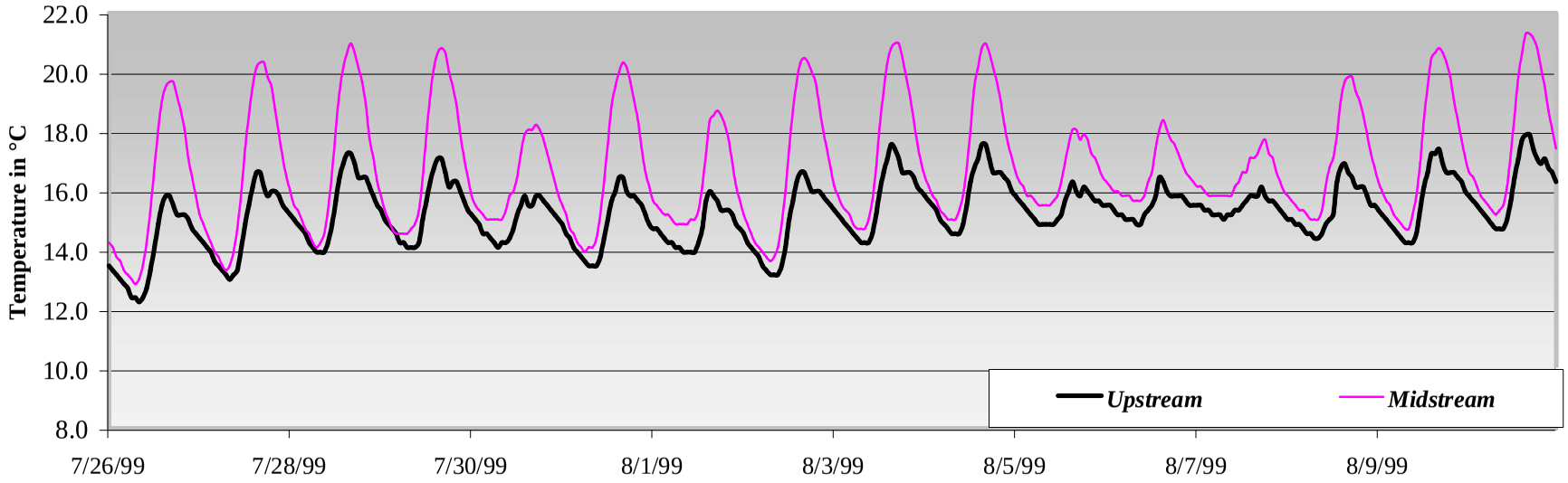


July 10 - 25, 1999 Hourly Water Temperature for Stillman Creek.

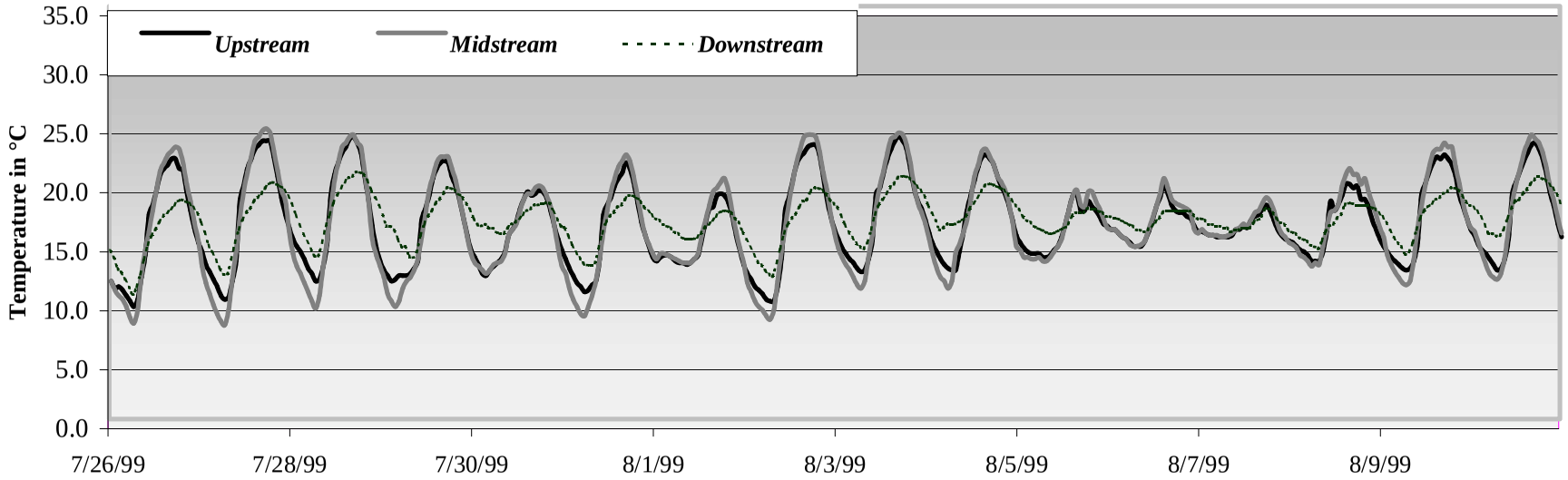


July 10 - 25, 1999 Hourly Air Temperature for Stillman Creek.

Appendix M: 1999 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

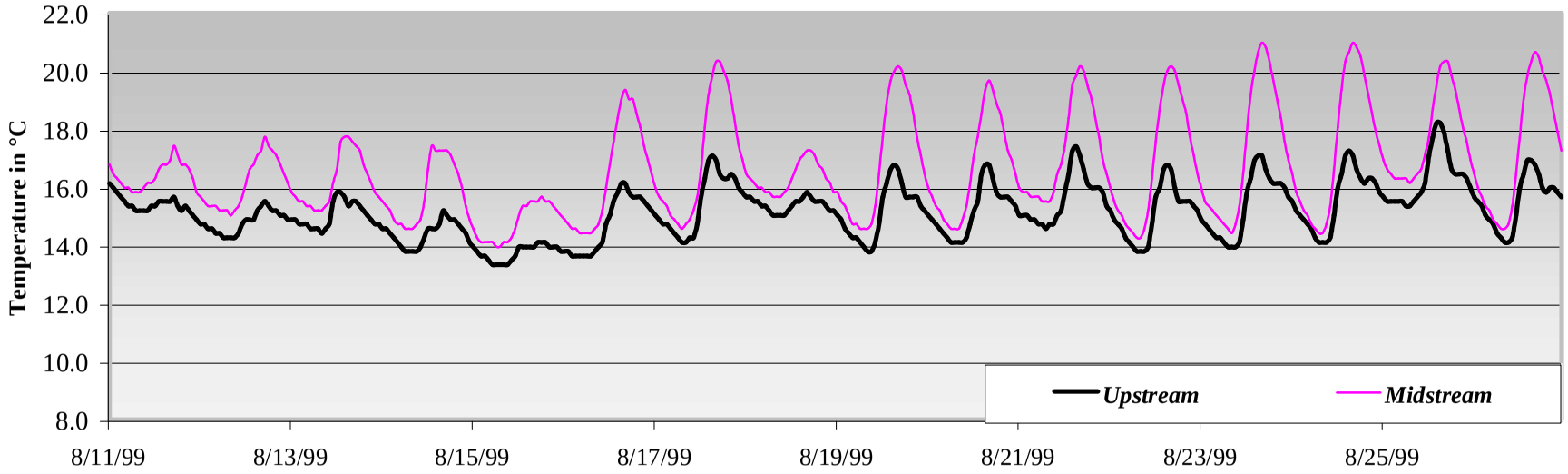


July 26-August 10, 1999 Hourly Water Temperature for Stillman Creek.

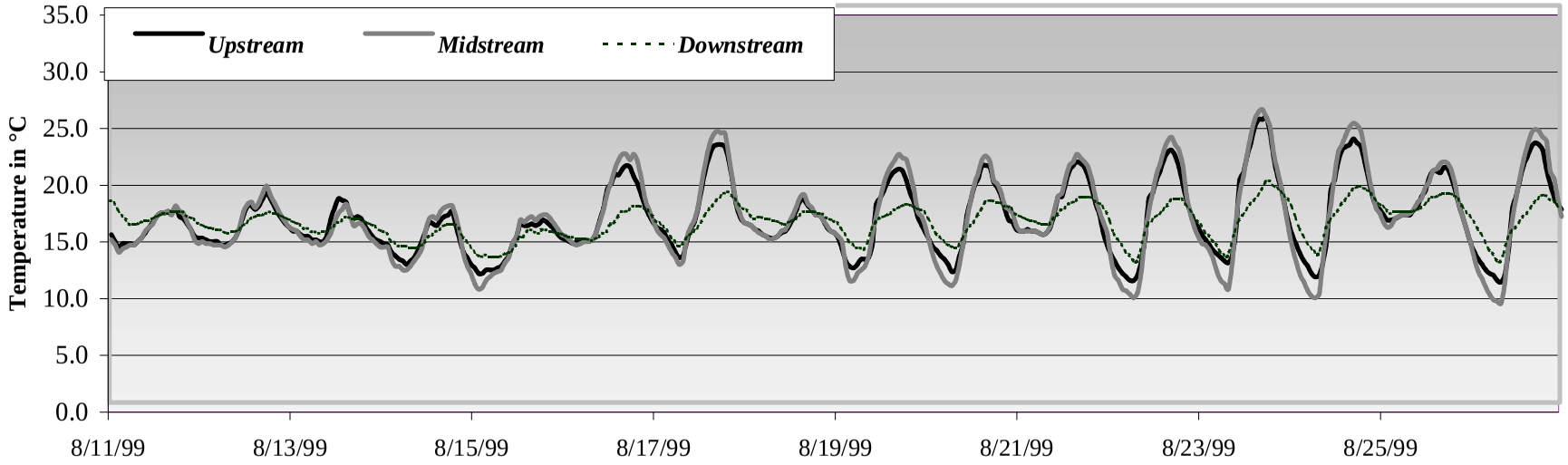


July 26-August 10, 1999 Hourly Air Temperature for Stillman Creek.

Appendix M: 1999 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

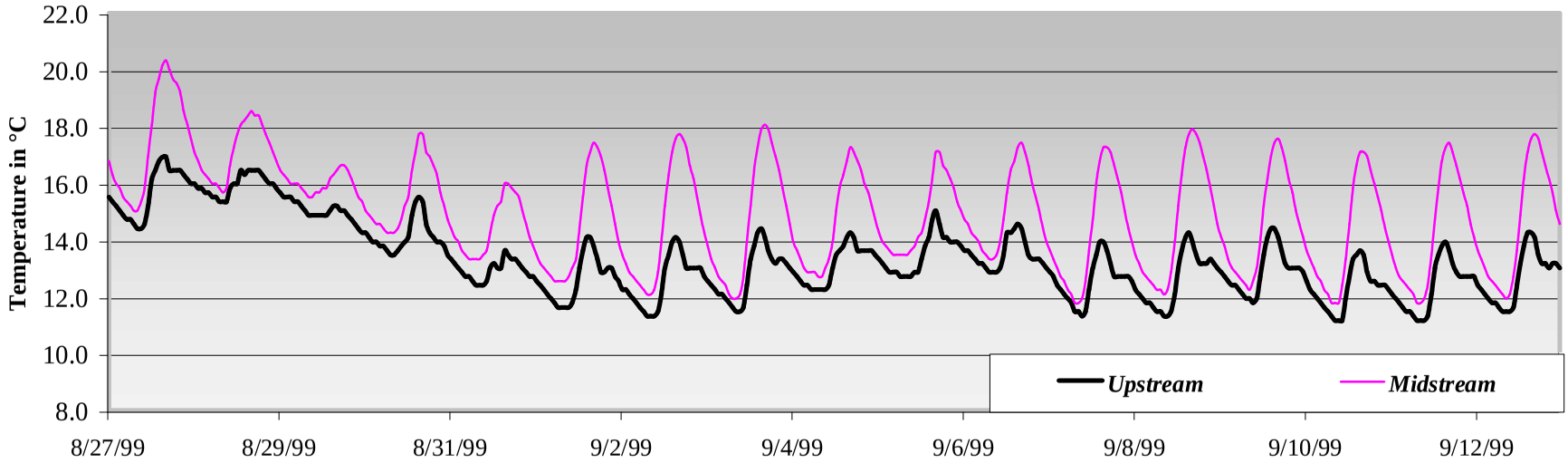


August 11 - 26, 1999 Hourly Water Temperature for Stillman Creek.

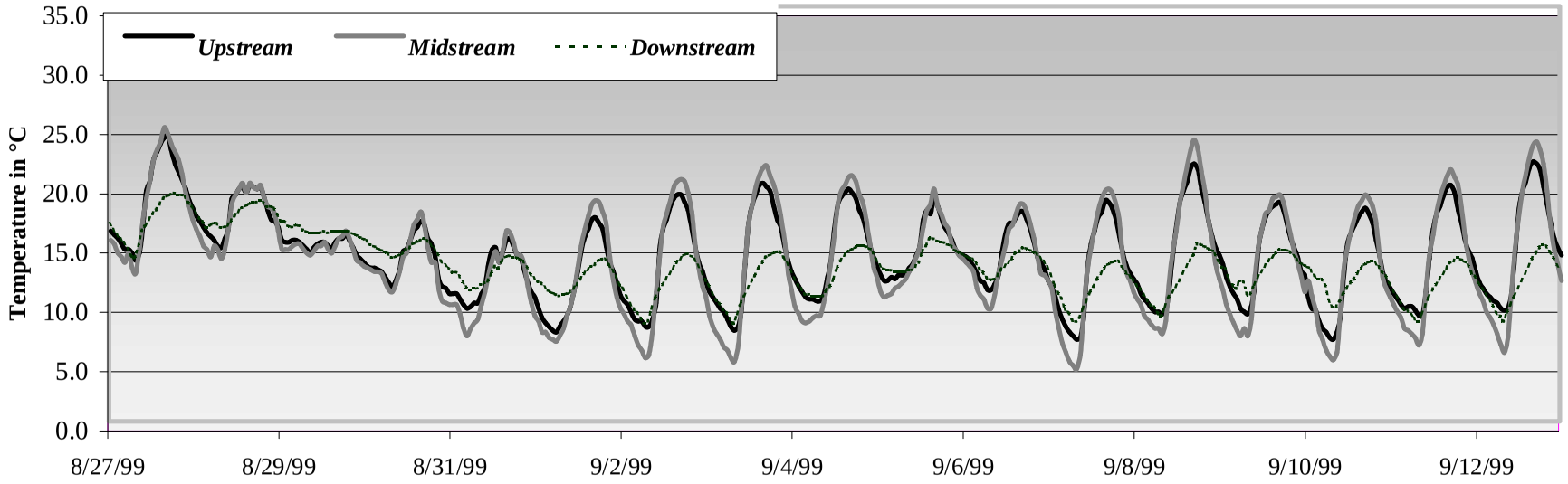


August 11 - 26, 1999 Hourly Air Temperature for Stillman Creek.

Appendix M: 1999 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

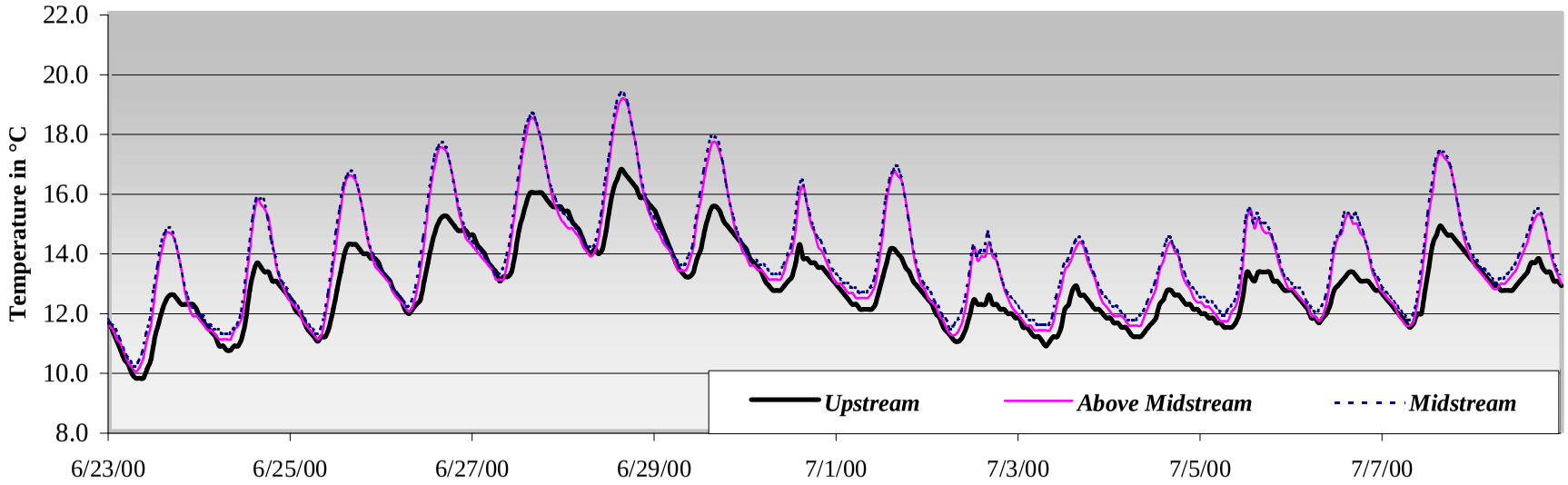


August 27-September 13, 1999 Hourly Water Temperature for Stillman Creek.

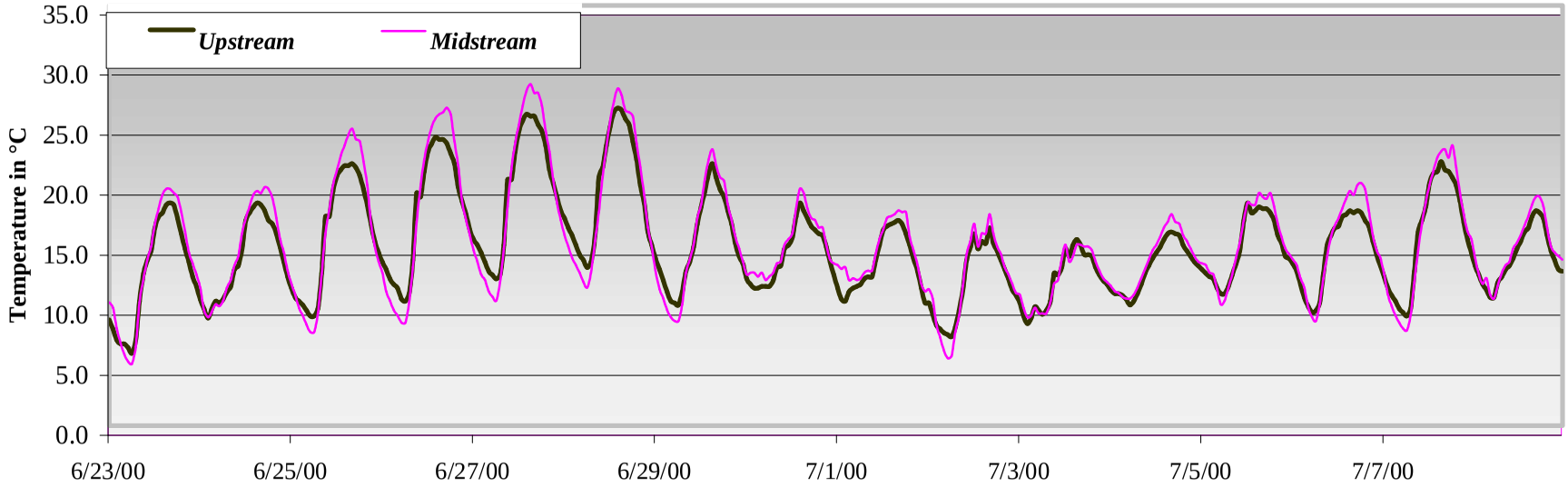


August 27-September 13, 1999 Hourly Air Temperature for Stillman Creek.

Appendix M: 2000 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

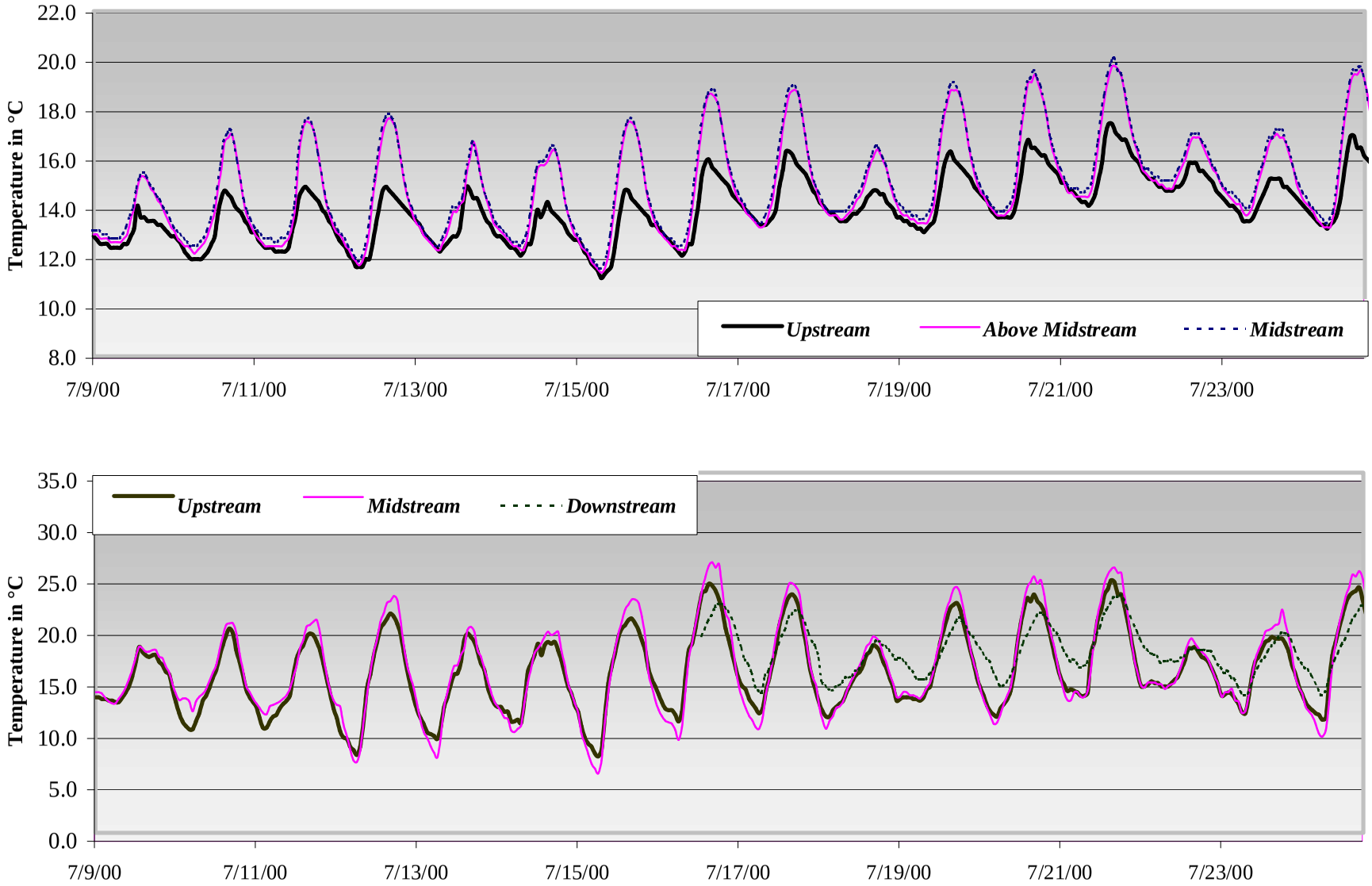


June 23 -July 8, 2000 Hourly Water Temperature for Stillman Creek.



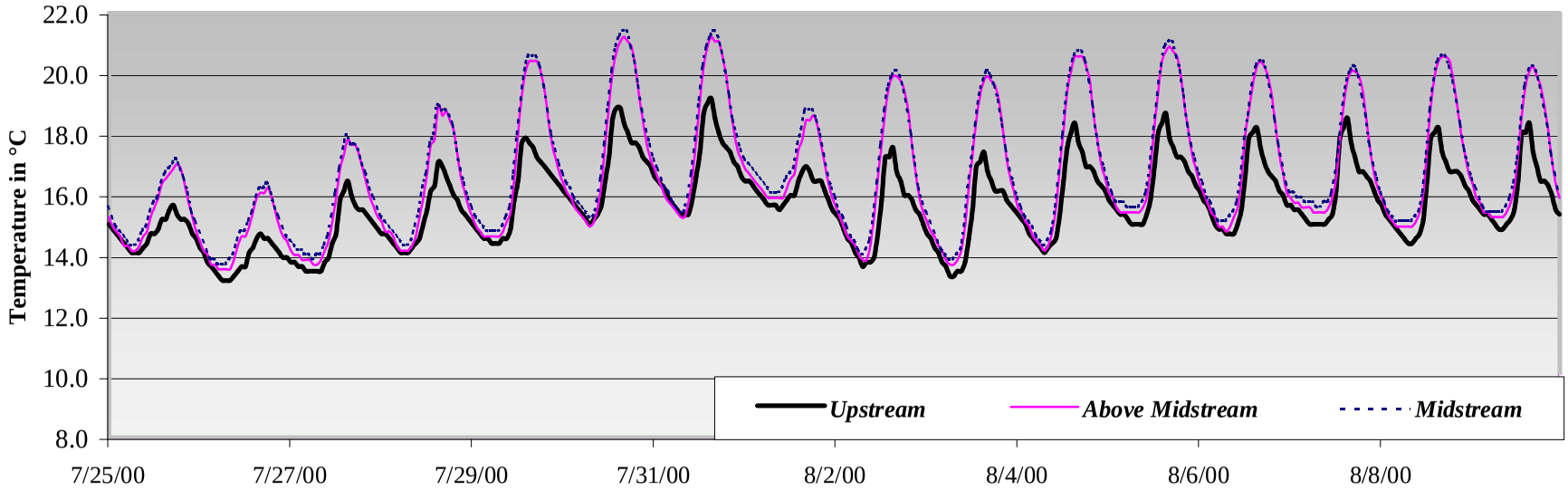
June 23 - July 8, 2000 Hourly Air Temperature for Stillman Creek.

Appendix M: 2000 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

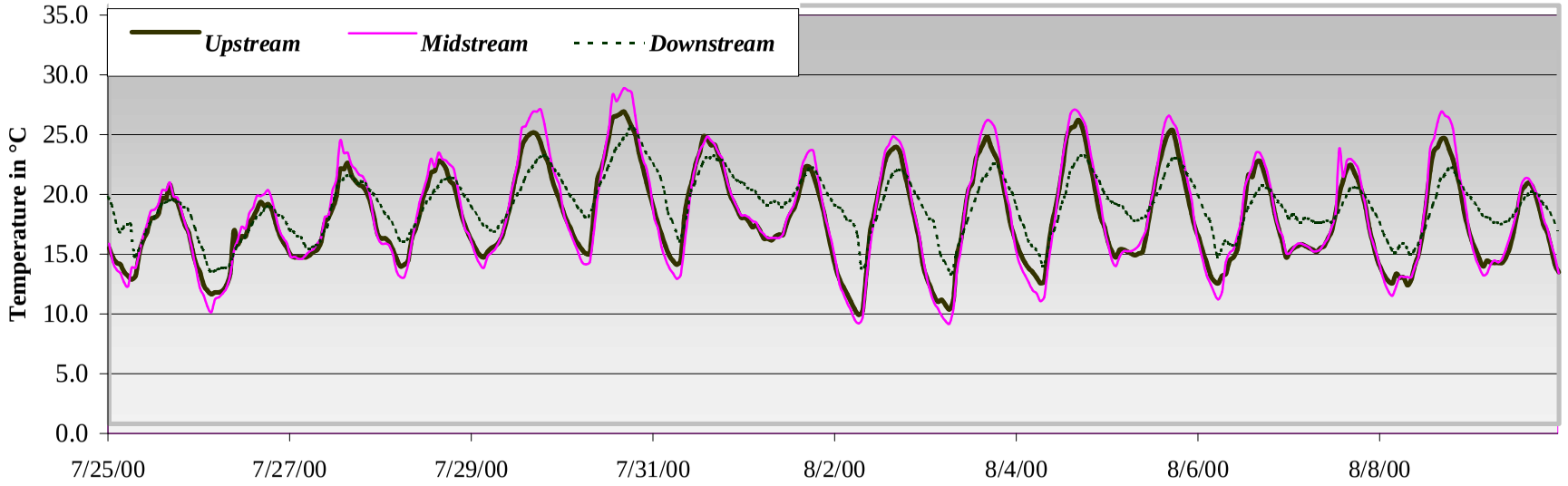


July 9 - 24, 2000 Hourly Air Temperature for Stillman Creek.

Appendix M: 2000 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

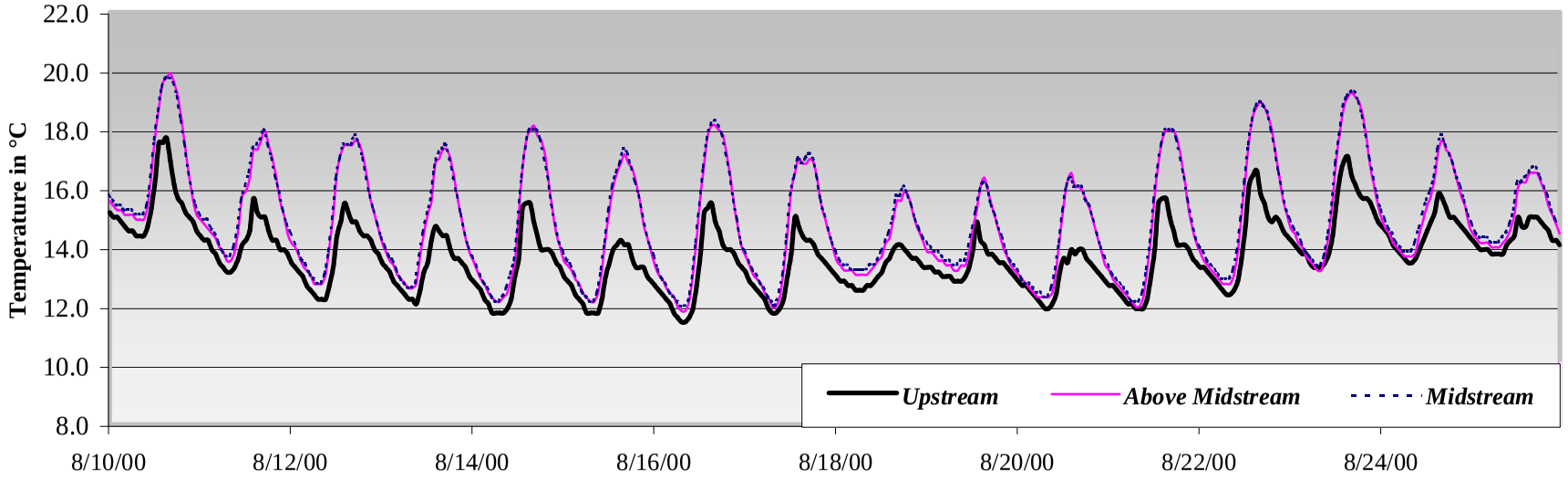


July 25 - August 9, 2000 Hourly Water Temperature for Stillman Creek.

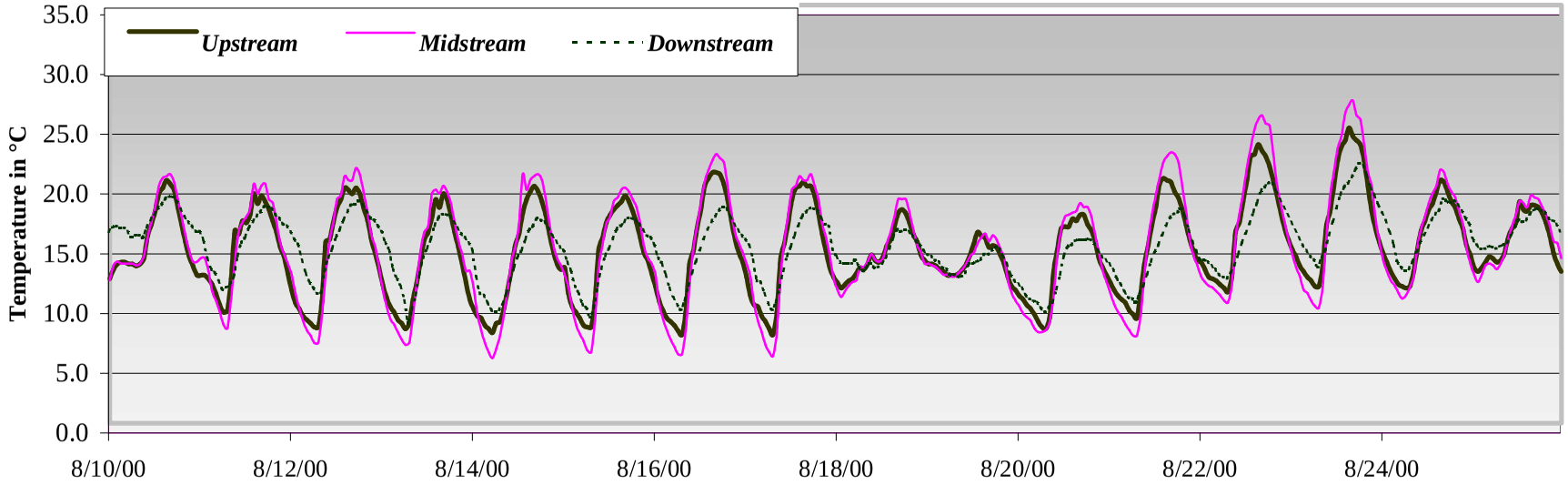


July 25 - August 9, 2000 Hourly Air Temperature for Stillman Creek.

Appendix M: 2000 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

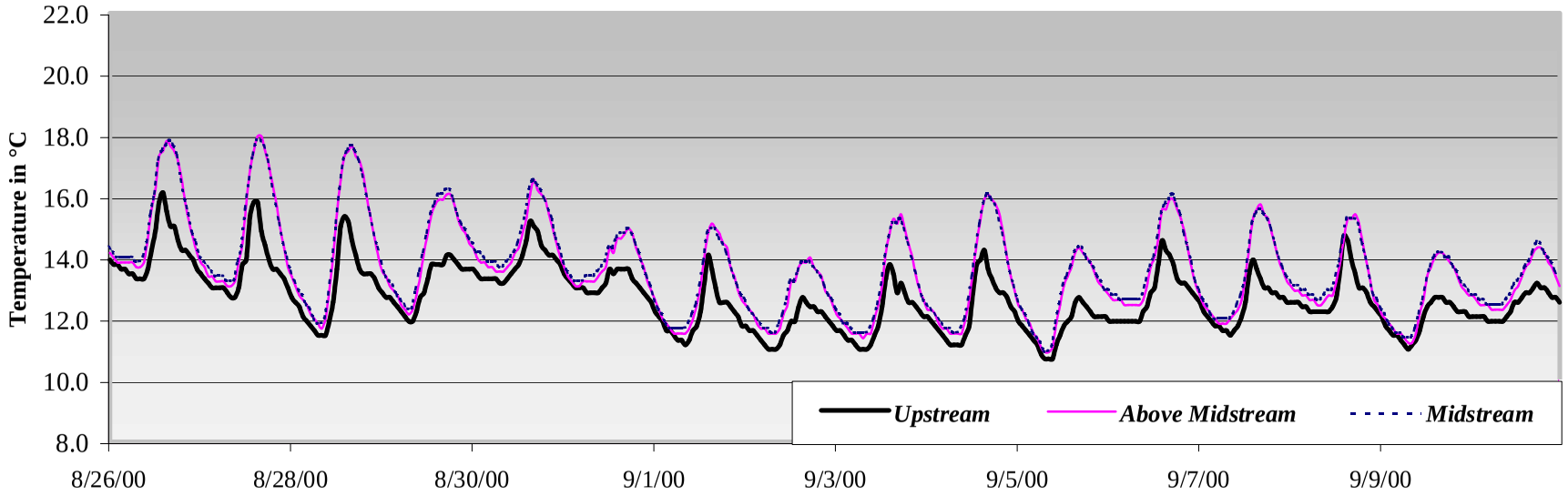


August 10 - 25, 2000 Hourly Water Temperature for Stillman Creek.

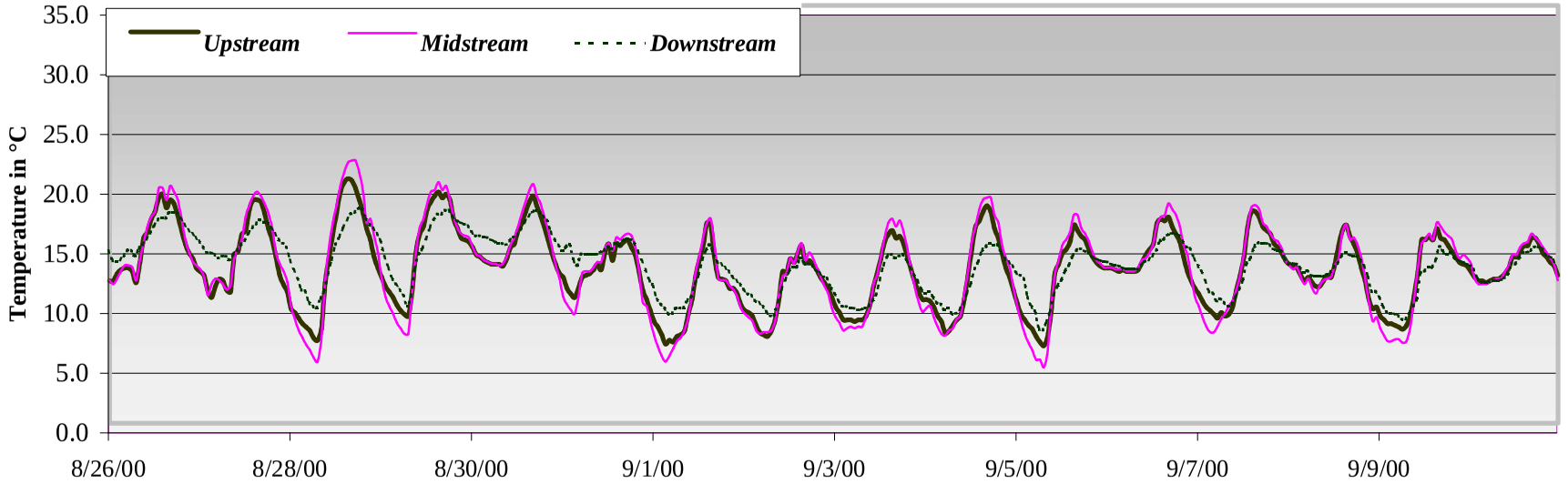


August 10 - 25, 2000 Hourly Air Temperature for Stillman Creek.

Appendix M: 2000 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.

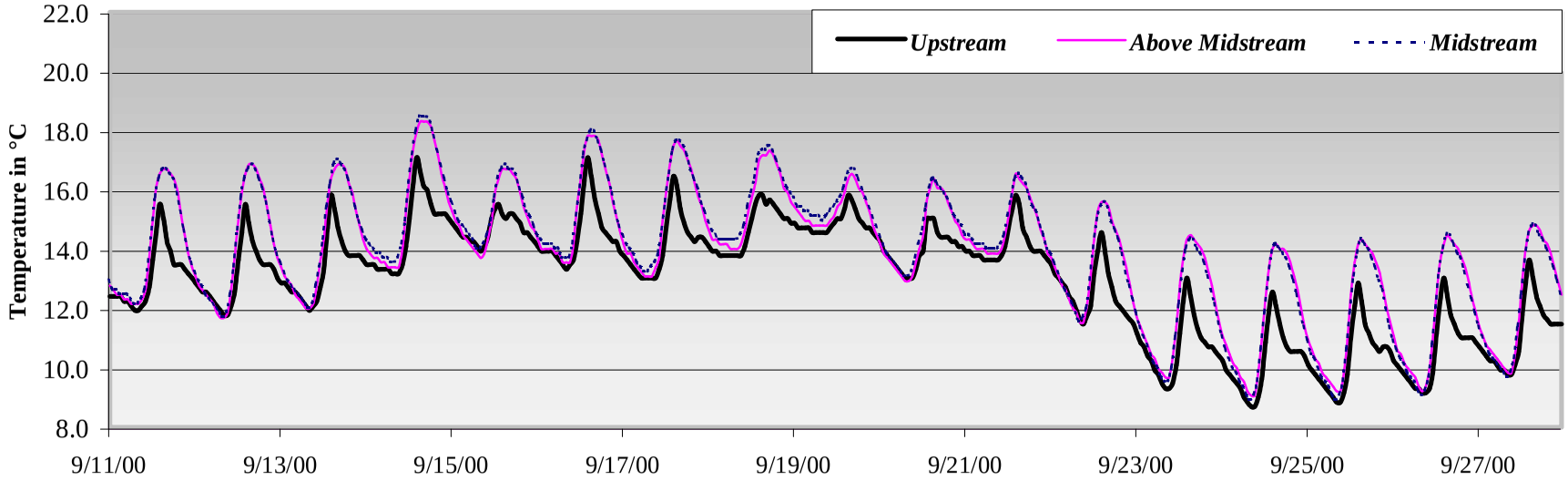


August 26 - September 10, 2000 Hourly Water Temperature for Stillman Creek.

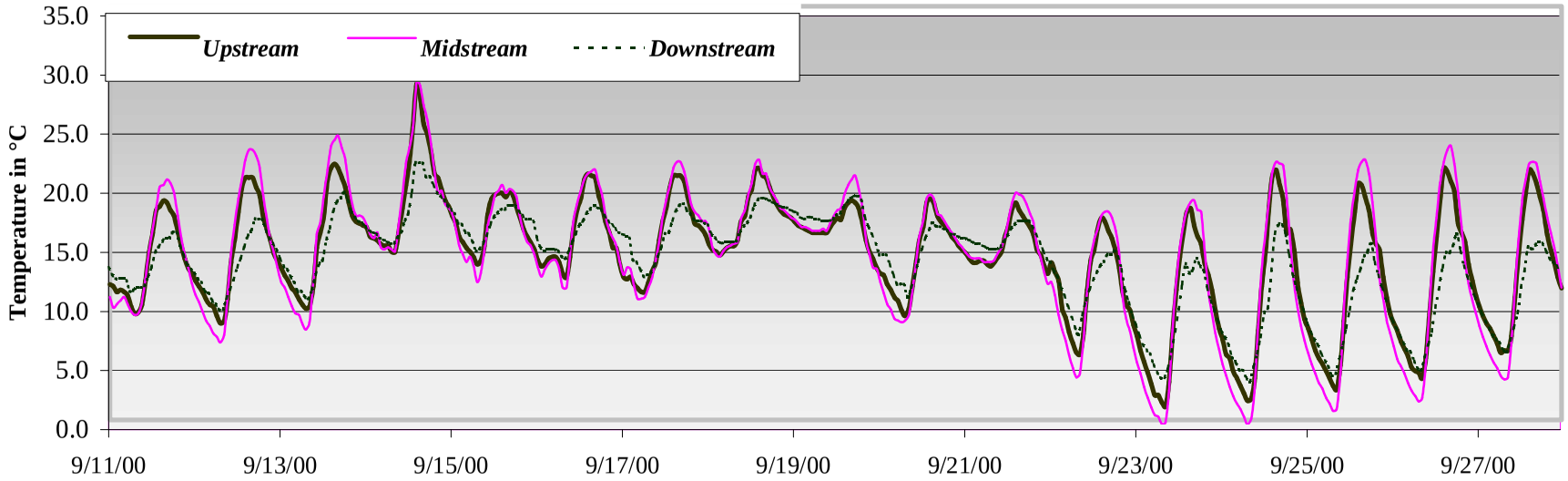


August 26 - September 10, 2000 Hourly Air Temperature for Stillman Creek.

Appendix M: 2000 Hourly Water and Air Temperature Monitoring Data for Stillman Creek.



September 11 - 27, 2000 Hourly Water Temperature for Stillman Creek.



September 11 - 27, 2000 Hourly Air Temperature for Stillman Creek.

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Appendix N. Scatter Creek Tributary

2000 Hourly Water and Air Temperature

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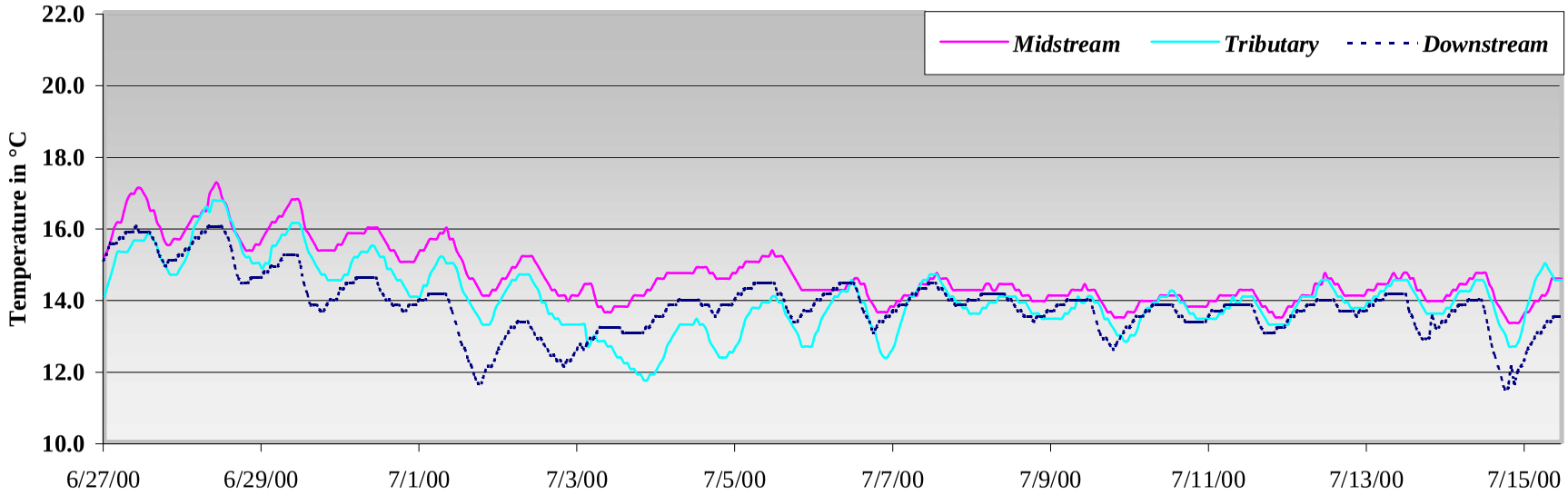
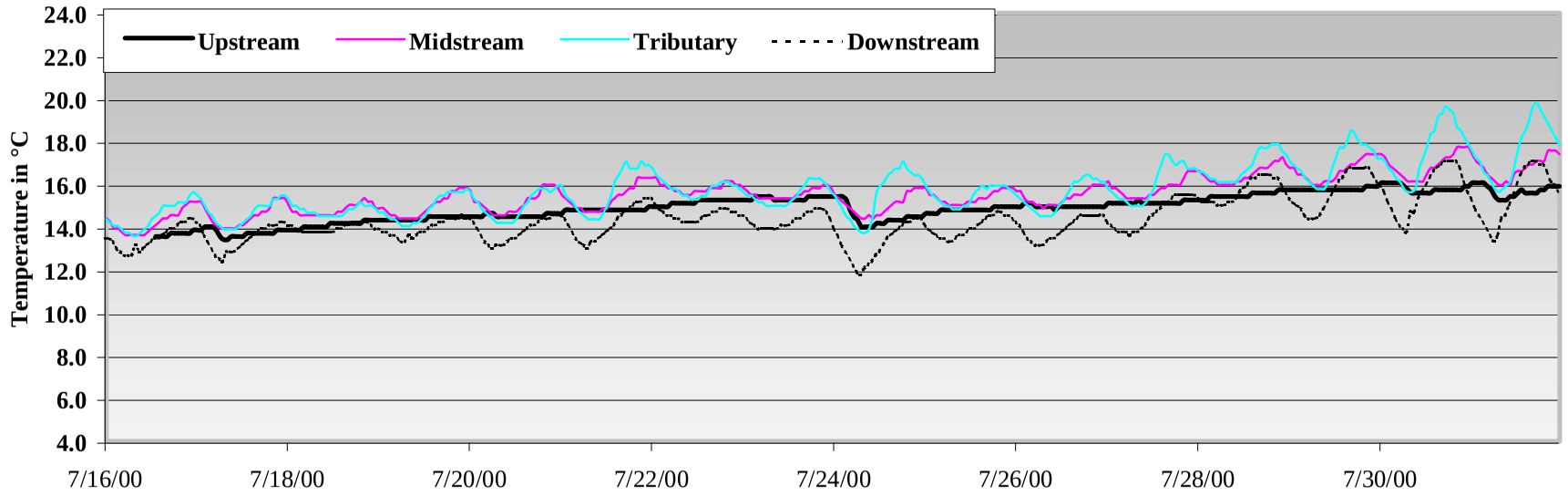
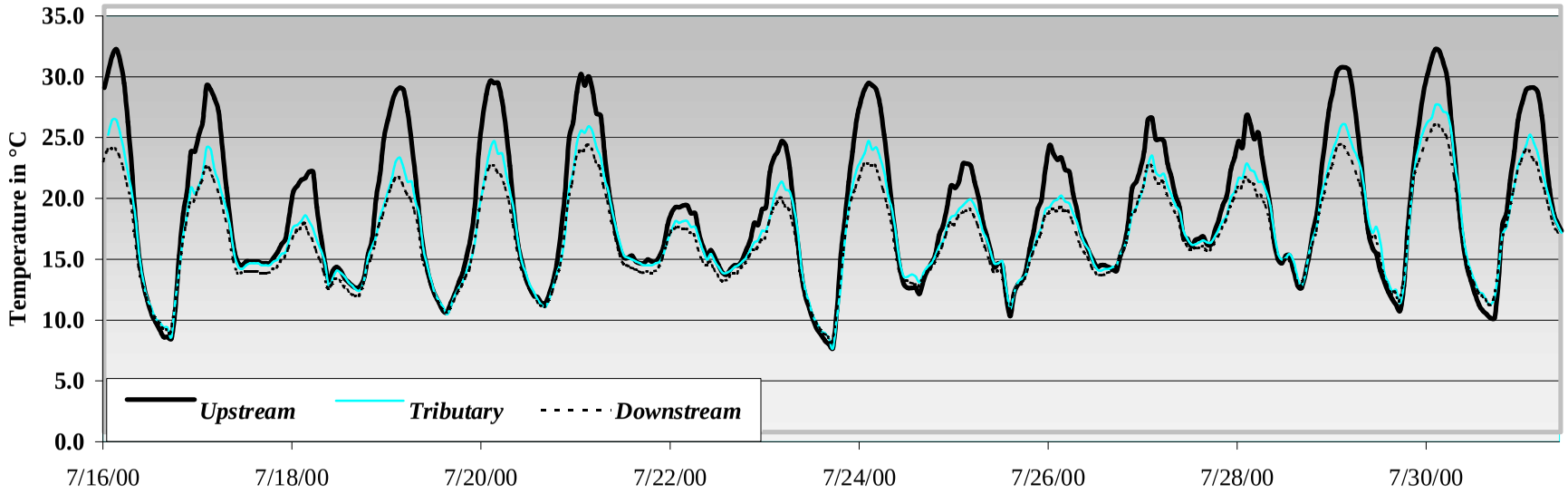
Appendix N: 2000 Hourly Water and Air Temperature for the Scatter Creek Tributary BMP Site.



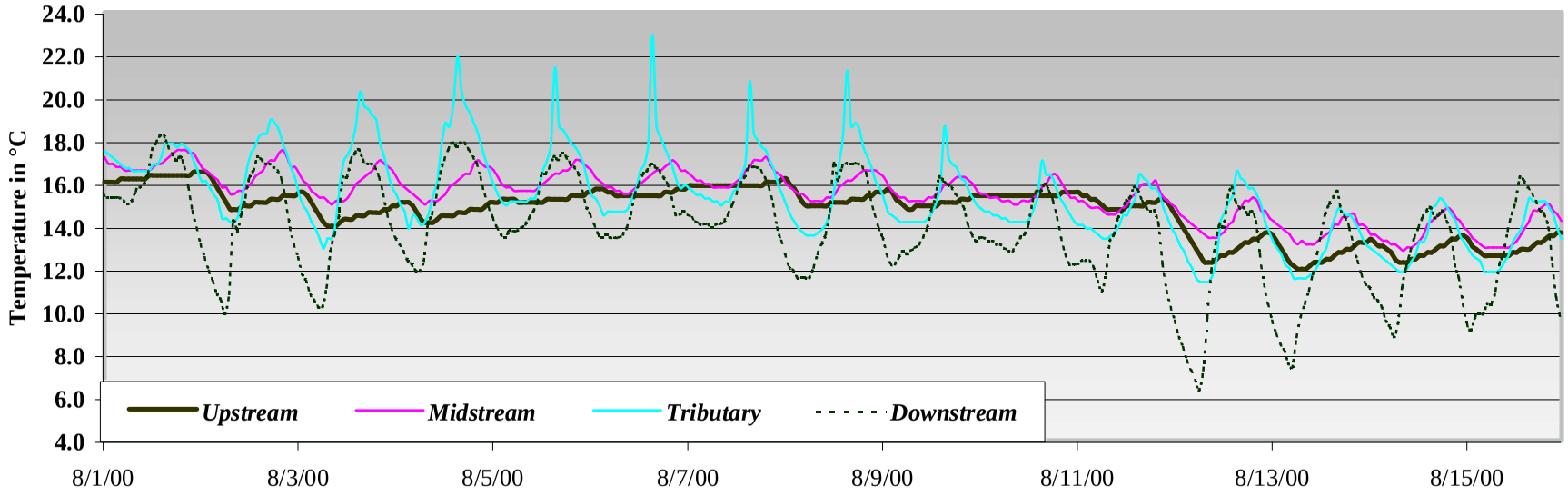
June 27 -July 15, 2000 Hourly Water Temperature for Scatter Creek Tributary.

Appendix N: 2000 Hourly Water and Air Temperature for the Scatter Creek Tributary BMP Site.

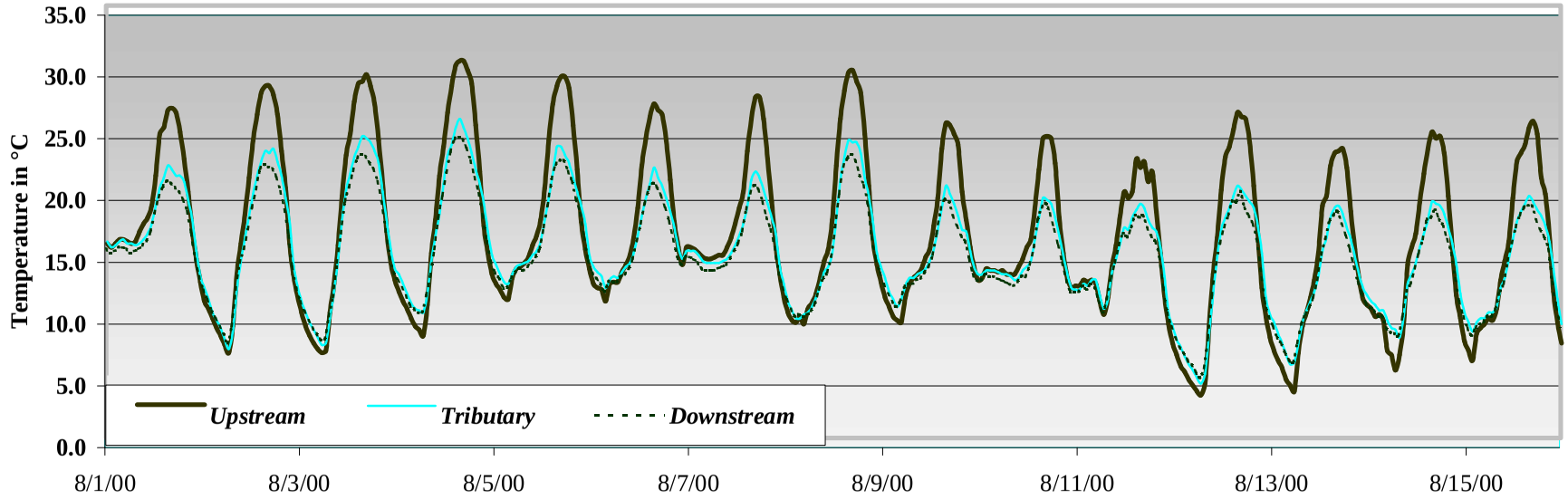




Appendix N: 2000 Hourly Water and Air Temperature for the Scatter Creek Tributary BMP Site.

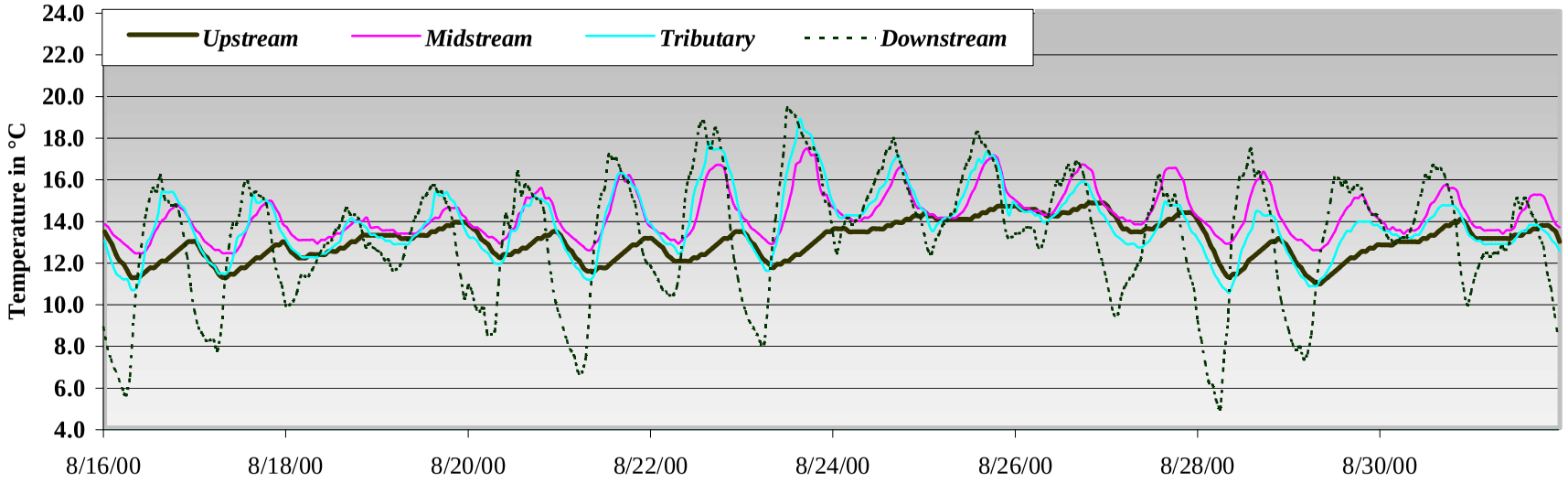


August 1-15, 2000 Hourly Water Temperature for Scatter Creek Tributary.

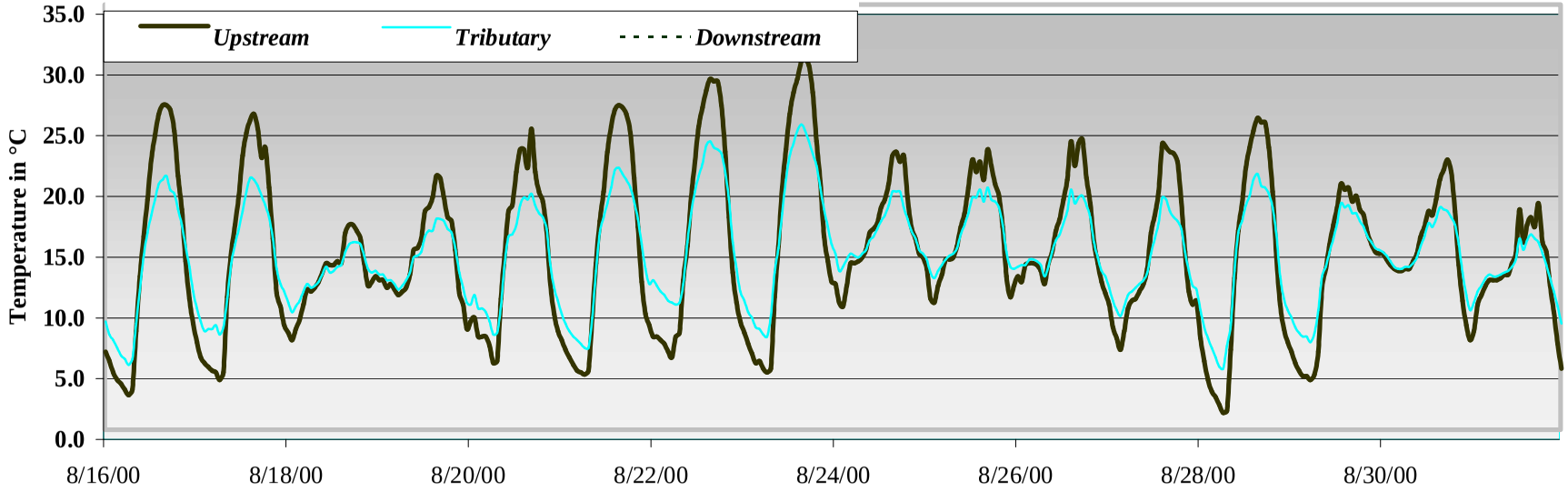


August 1-15, 2000 Hourly Air Temperature for Scatter Creek Tributary.

Appendix N: 2000 Hourly Water and Air Temperature for the Scatter Creek Tributary BMP Site.

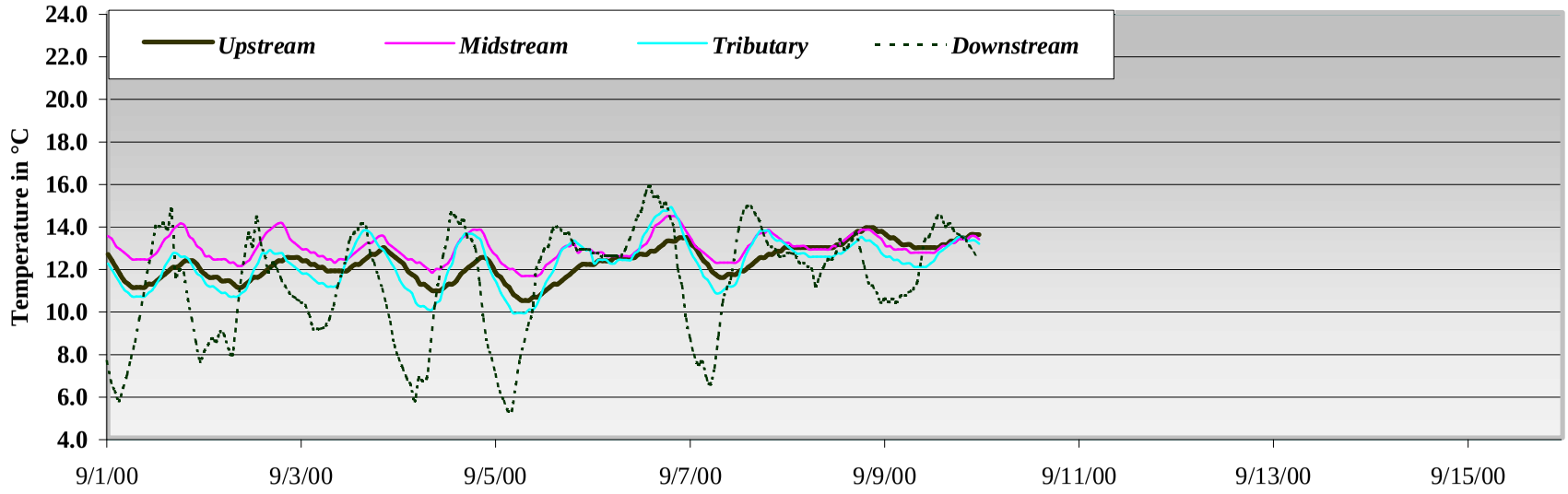


August 16-31, 2000 Hourly Water Temperature for Scatter Creek Tributary.

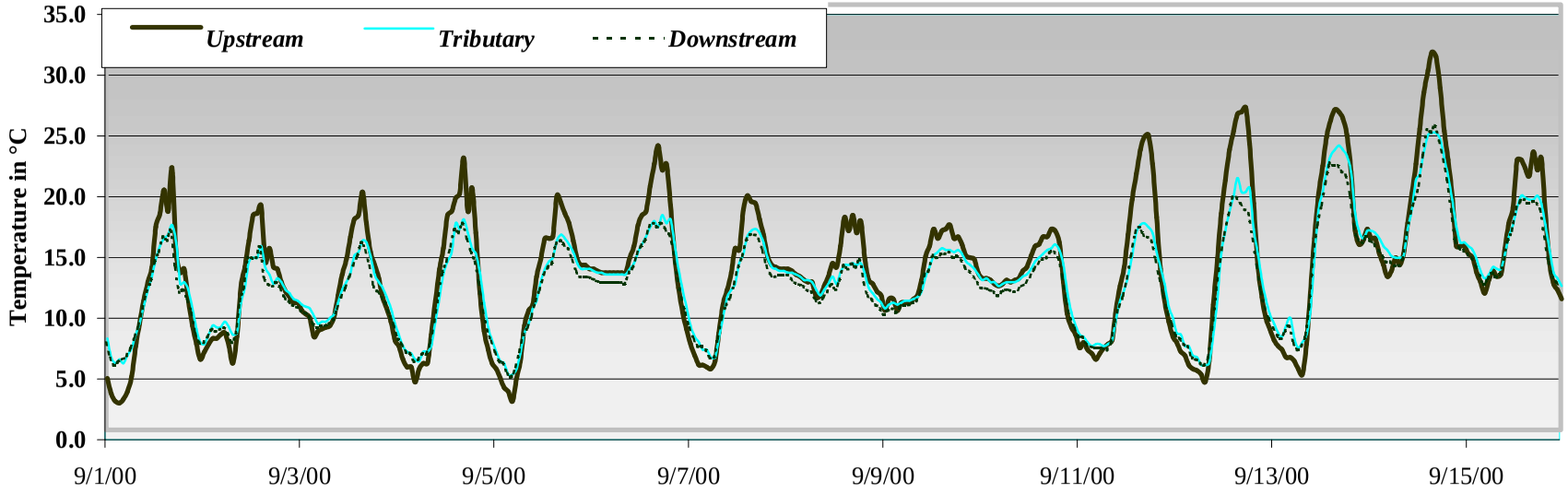


August 16-31, 2000 Hourly Air Temperature for Scatter Creek Tributary.

Appendix N: 2000 Hourly Water and Air Temperature for the Scatter Creek Tributary BMP Site.



September 1-9, 2000 Hourly Water Temperature for Scatter Creek Tributary.



September 1-15, 2000 Hourly Water Temperature for Scatter Creek Tributary.