Attachment A – Temperature Analysis and Modeling of 303(d) List Streams in the Blackfoot River Watershed, Montana

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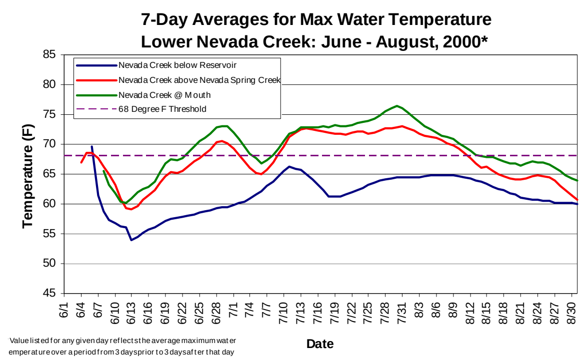

July 31, 2006

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1. Introduction

This document presents the results of an assessment of thermal conditions on 303(d) temperature listed streams of the Nevada Creek and Middle Blackfoot TMDL Planning Areas. This includes analysis of temperature data, methods and results of shade data development, and temperature model results for the Nevada Creek and Middle Blackfoot TMDL Planning Areas. Analysis of water temperature data identified reaches with high water temperatures and allowed selection of data from the warmest summer periods for temperature modeling. Shade data development provided critical temperature modeling input and identifies areas where reduced shade may cause high stream temperatures. Finally, results of SNTEMP, a stream network model that simulates water temperatures, indicates the amount of improvement in shade required to meet temperature targets for TMDLs.

This project departs from typical methods for temperature TMDLs utilized in other Montana watersheds. Typically, developing temperature TMDLs for streams in Montana using a numeric model requires collecting the necessary stream temperature, flow, and shade data during a typically warm summer period. In the Blackfoot River watershed, Montana FWP maintains a database of stream temperature data collected from numerous sites between 1994 and 2004. In addition, stream condition (base parameter) data collected in 2004 (DTM and AGI, 2005) includes detailed vegetation transects that can be used as a surrogate for shade measurements. Finally, stream gage data collected by the USGS and Montana DNRC, augmented by instantaneous flow measurements and visual flow estimates from July 2004 provide stream flow data. These datasets allowed development of numeric temperature models using SNTEMP and SSTEMP. In addition, since temperature data collected by Montana FWP span several years, it was possible to identify and analyze data from the warmest periods for this analysis.

1.1. Goals and Objectives

The primary goals of this project are to provide Montana DEQ and the Blackfoot Challenge an assessment of summer stream temperature conditions, develop additional datasets necessary to construct and utilize a numeric temperature models (SNTEMP and SSTEMP), construct and calibrate the temperature models, and run a series of simulations ranging from current conditions to natural conditions. The results will allow development of temperature TMDLs for the eight temperature listed streams. The following tasks define the scope of this project:

- compile, analyze, and summarize existing temperature data to determine locations and magnitudes of temperature;
- develop shade parameter data from existing base parameter data collected in 2004 (DTM and AGI, 2005);
- construct and calibrate a series of SNTEMP and SSTEMP models;
- run model simulations assessing stream temperature changes under various scenarios; and,
- report results.

1.2. Background Information

The Blackfoot River watershed covers 1,479,071 acres (2,311 square miles) and is broken into four TMDL planning areas: the Upper Blackfoot, Nevada Creek, Middle Blackfoot, and Lower Blackfoot planning areas. These areas contain over 50 rivers and streams on Montana's 303(d) list, compiled by the Montana DEQ. Eight streams in the in the Blackfoot River watershed are listed for temperature impairments (Figure 1-1, Table 1-1), and have a total length of 179 miles. Waters identified on the 303(d) list require development of water quality restoration plans and TMDLs to address the causes of impairment.

Stream	***TMDL Planning Area***	***Length (miles)***
Cottonwood Creek	Nevada Creek	7. 45
Murray Creek	Nevada Creek	8.6
Douglas Creek	Nevada Creek	26. 91
Nevada Creek	Nevada Creek	55
Kleinschmidt Creek	Middle Blackfoot	5. 13
Elk Creek	Lower Blackfoot	15. 5
Union Creek	Lower Blackfoot	24. 2
Blackfoot River	Middle and Lower Blackfoot	44. 78

Table 1-1. Streams listed for temperature in the Blackfoot River Watershed.

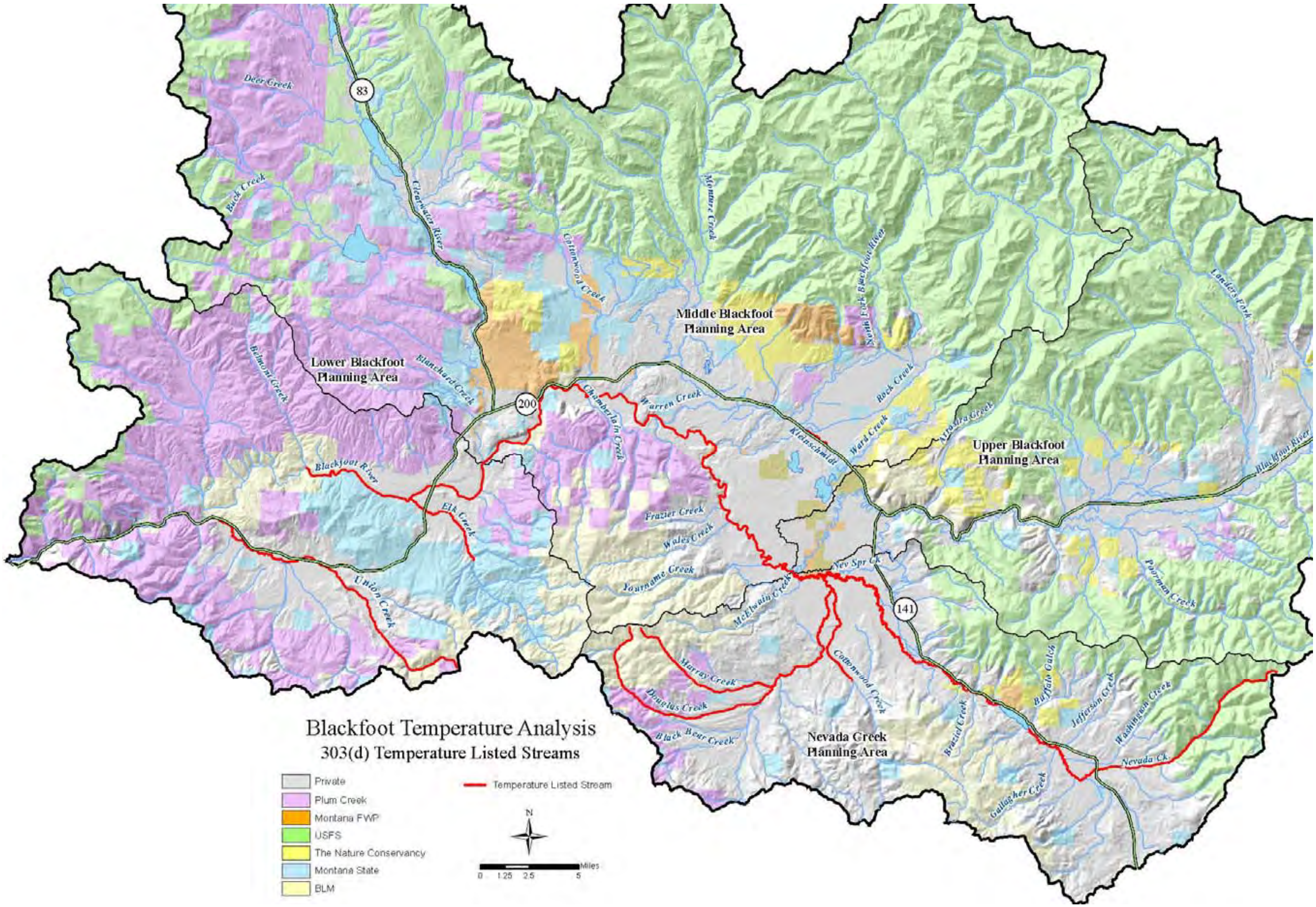


Figure 1-1. The Blackfoot River watershed and streams on the 303(d) list for temperature.

2. Methods

The following sections describe methods used for analysis of existing temperature data, development of input data sets, and construction of SNTEMP and SSTEMP models.

2.1. Temperature Data Analysis

The following sections describe existing temperature data sets and analysis of these data. The results of the data analysis allowed the identification of the locations and magnitudes of high summer water temperatures on 303(d) listed streams and several key tributaries. These results also guided selection of data for use in four SNTEMP models and one SSTEMP model that simulate existing conditions and restoration scenarios.

2.1.1. Available Temperature Data

Available sources of water temperature data for streams in the Blackfoot River watershed include the following:

- A Montana FWP database of continuous summer temperature data from numerous sites from 1994-2004,
- USGS instantaneous temperature measurements from several sites at irregular intervals,
- USFS continuous summer temperature data from the Clearwater River and tributaries (2004),
- DNRC summary temperature data for Blanchard Creek and tributaries (2004), and
- Instantaneous sampling of Nevada Creek and tributaries, and Kleinschmidt Creek in 2003 and 2005 by Hydrometrics, Inc.

The Montana FWP database is the most complete in terms of spatial and temporal coverage, and provides sufficient data for the temperature assessment. One USGS site, located at the mouth of Nevada Creek, does have relevant data, including 3348 records of maximum, minimum and average daily temperatures between 2001 and 2004. All of the other datasets lack sufficient data during critical warm periods.

2.1.2. Montana FWP Temperature Database

The Montana FWP temperature database consists of stream temperature measurements collected continuously every one to two hours over various summer seasons at 122 sites throughout the Blackfoot River watershed. Through 2004, this database contained nearly one million temperature records.

Only a portion of the FWP temperature data is relevant to peak summer temperatures. Of the 122 sites in the database, 49 are located on temperature listed 303(d) streams or important tributary streams (Table 2-1). At several of these sites, temperature records are not available for every summer. Comparison of data between sites required grouping sites by year and area. Table 2-1 lists site names, sites chosen for analysis, and available data by year.

Table 2-1. Montana FWP temperature data analyzed for this project, from upstream to downstream. Sites in bold are on 303(d) streams, others are tributaries. X indicates data chosen for analysis.

303(d) Stream	***Site***	***Sampling Year***										
		1994	***1995***	***1996***	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***
Upper Nevada Creek	**Nevada Creek above Shingle Mill Creek**								**X**			
	Mitchell Creek	√							**X**			
	Halfway Creek near mouth								**X**			
	Nevada Creek below Halfway Creek								**X**			
	Washington Creek at Hwy 141	√							**X**			
	Jefferson Creek at HWY 141								**X**			
	Nevada Creek above Reservoir	√						√	**X**			
	Buffalo Creek near Mouth								**X**			
Cottonwood Creek	**Cottonwood Creek above Pole Creek**	√						**X**				
	Cottonwood Creek above Douglas Creek	√						**X**				
Douglas Creek	**Douglas Creek Upstream Reservoirs**					**X** [3]						
	Douglas Creek Downstream Reservoirs	√				**X** [3]						
	Douglas Creek at Mouth of Chimney Creek	√						**X**				
	Douglas Creek above Cottonwood Creek	√						**X**				
Lower Nevada Creek	**Nevada Creek below Reservoir**	√	√	√		**X**	√	**X**				
	Nevada Creek near Helmville, MT					**X**						
	Wasson Creek near Mouth										**X**[2]	√
	Nevada Creek above Nevada Spring Creek	√						**X**			√	**X**
	Nevada Spring Creek at Mouth	√	√					**X**	√		√	**X**
	Cottonwood Creek above Douglas Creek	√						**X**				
	Douglas Creek above Cottonwood Creek	√						**X**				
	Nevada Creek below Nevada Spring Creek	**X**[2]	√									**X**
	McElwaine Creek at Ovando-Helmville Road							**X**	√	√		
	Nevada Creek at Mouth	√						**X**	√	√	√	
Kleinschmidt Creek	**Kleinschmidt Creek**	√				√	√		√	√	√	√
Union Creek	**Union Creek (Upper)**									**X**		
	Washoe Creek at Mouth									**X**		

303(d) Stream	***Site***	***Sampling Year***										
		1994	***1995***	***1996***	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***
	Union Creek at HWY 200 Potomac									**X**		
	Camas Creek									**X**		
	Ashby Creek									**X**		
	Union Creek at Morrison Lane									**X**		
	Union Creek at Mouth								√	**X**		
Elk Creek	**Elk Creek at Cap Wallace**									**X**	√	
	Elk Creek at Sunset Hill Road	√	√	√	√			√		**X**	√	
	Elk Creek at HWY 200	√	√	√	√		√	√	√	**X**		
	Elk Creek at Mouth	√	√	√				√			**X** [4]	
Blackfoot River	Blackfoot River at Cutoff Bridge	√	√			√	√	**X**	√	√	√	√
	Nevada Creek at Mouth	√						**X**	√	√	√	
	Yourname Creek at Wales Creek Road	√						**X**	√	√	√	√
	Wales Creek at Mouth	√						**X**	√		√	
	Blackfoot River at Raymond Bridge	√				√	√	**X**	√	√	√	√
	Frazier Creek									√	**X** [1]	
	North Fork Blackfoot River at Ovando-HelmvilleRoad	√				√	√	**X**	√	√	√	√
	Warren Creek near Mouth	√						**X**	√	√	√	√
	Monture Creek at Mouth						**X** [1]					
	Blackfoot River at Scotty Brown Bridge	√				√	√	**X**	√	√	√	√
	Chamberlain Creek near Mouth	√					√	**X**				
	Cottonwood Creek at HWY 200				√		√		√	√	√	√
	Clearwater River at Mouth					√				√	**X** [1]	√
	Elk Creek at Mouth	√	√	√				**X**			√	
	Blackfoot River at Corrick River Bend	√					√	**X**				
	Blackfoot River above Belmont Creek				√		√		√	√	√	√
	Belmont Creek at Mouth	√	√	√	√	√	√		√	√	√	√

Bold X (**X**) indicates data chosen for analysis. **X** [1] indicates substitute data used for year 2000 Blackfoot River analysis. **X**[2] indicates substitute data used in analysis of 2000 Lower Nevada Creek temperature data. **X** [3] indicates substitute data used in analysis of 2000 Douglas Creek temperature data. **X** [4] indicates data used in analysis of 2002 Elk Creek temperature data.

Air temperature and precipitation data also helped with the selection of Montana FWP temperature data for analysis. The ideal temperature data for this analysis is a continuous dataset through the summer months from a warm, dry summer (Figure 2-1 and Figure 2-2).

For example, on Lower Nevada Creek, Montana FWP stream temperature measurements are sporadic, with incomplete data from three years. Analysis of these data covers all three years (1998, 2000, and 2004). However, for modeling purposes, data from 2000 provided a reasonably complete dataset.

In some cases, modeling required using temperature data from two different years. This was possible only if the two years were similar climatically. Analysis of temperature data on lower Nevada Creek, Douglas Creek, the mainstem Blackfoot River, and Elk Creek all include some data from an alternate year (Table 2-1). Table 2-2 summarizes the data analyzed for each stream and the climatic conditions for those years.

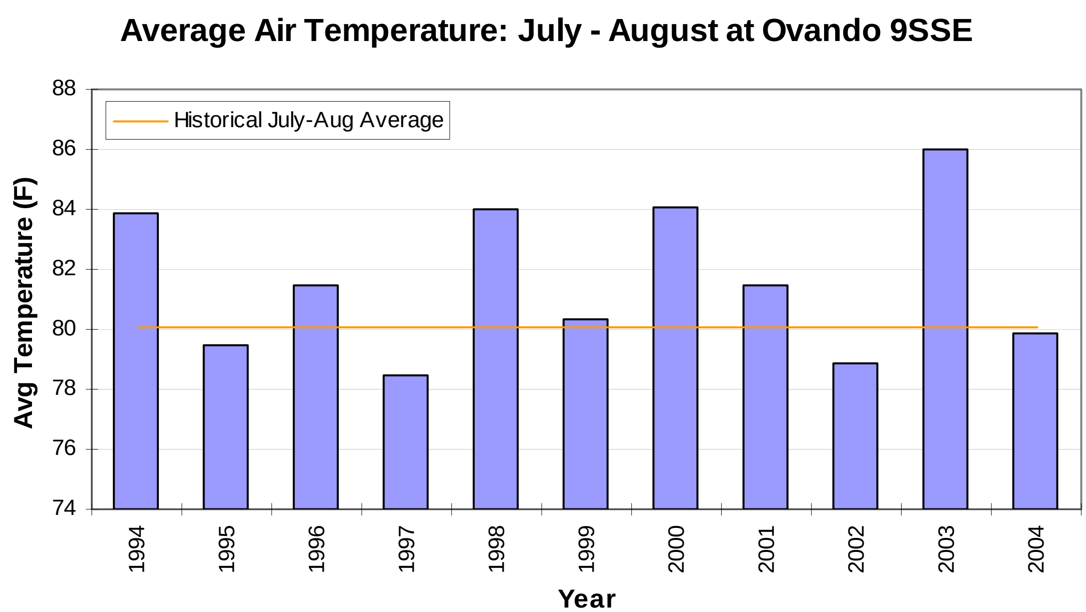


Figure 2-1. Average air temperature for July–August, 1994–2004.

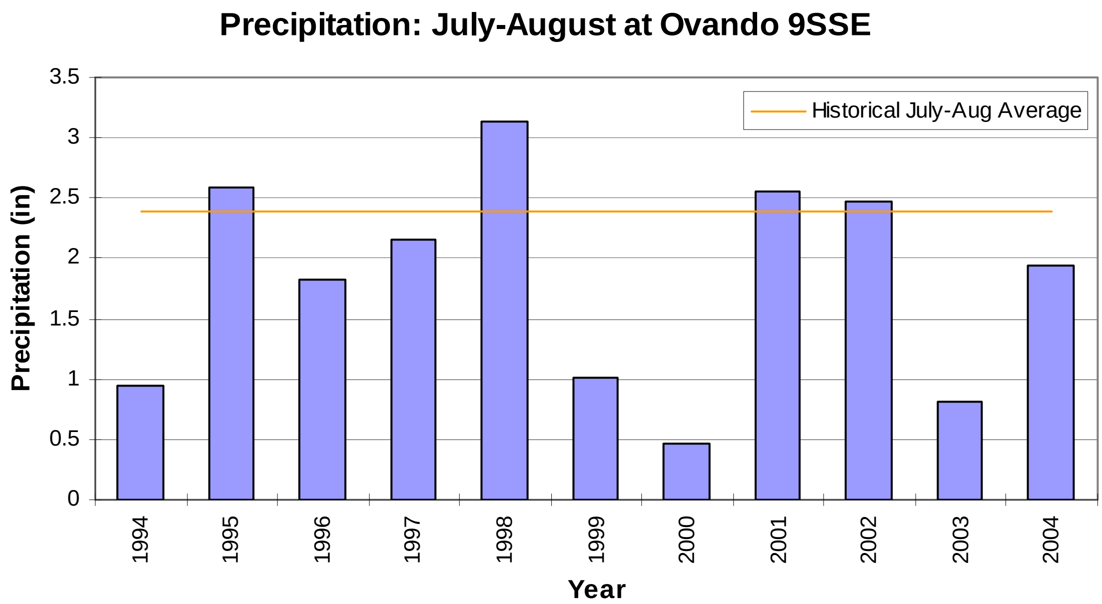


Figure 2-2. Precipitation for July–August, 1994–2004.

Stream	***TMDL Planning Area***	***Model***	***Analysis Year***	***Temperature***	***Precip***
Upper Nevada Creek	Nevada Creek	Upper Nevada	**2001**	Average	Average
Lower Nevada Creek	Nevada Creek	Lower Nevada	1998	Warm	Wet
			2000	Warm	Dry
			2004	Average	Dry
Lower Douglas Creek	Nevada Creek	Lower Nevada	**2000**	Warm	Dry
Cottonwood Creek	Nevada Creek		2000	Warm	Dry
Upper Douglas Creek	Nevada Creek	Upper Douglas	**1998**	Warm	Wet
Kleinschmidt Creek	Middle Blackfoot	Kleinschmidt	2004	Warm	Dry
Blackfoot River	Middle, Lower Blackfoot	Blackfoot	**2000**	Warm	Dry
Elk Creek	Lower Blackfoot		**2002**	Average	Average
Union Creek	Lower Blackfoot		**2002**	Average	Average

Table 2-2. Summary of data selected for analysis and modeling. Primary modeling data year is bold.

2.1.3. Temperature Data Trends

Analysis of temperature data consisted of displaying hourly temperature data, the range of temperature measurements, and seven-day average maximum water temperatures in a series of graphs and box and whisker plots. The hourly temperature data throughout the summer illustrates the timing of temperature increases as well as the diurnal fluctuation in temperature. The box and whisker plots illustrate changes in temperature between sites, and the seven-day average maximum temperature graphs show which sites have the highest temperatures and their duration. Maps showing the seven-day average maximum at each temperature monitoring location helped visualize the spatial distribution of high water temperatures. Together, these figures provide temporal, statistical, and spatial descriptions of summer water temperatures in the Blackfoot River watershed.

Sections three and four contain graphs of hourly summer water temperature for the 24 selected sites on 303(d) streams and important tributaries. Each graph represents one year of data for one site. The continuous temperature graphs also show the effect of weather patterns on stream temperature. For example, the drop in water temperature beginning around July 29th 2001 seen in the upper Nevada Creek graphs corresponds to a cool and rainy storm cycle. Comparison of these graphs illustrates the stream segments that have relatively high temperatures, as well as tributaries that contribute warm or cool water.

Box and whisker plots and seven-day average maximum graphs are also included in sections three and four. Box and whisker plots show the statistical distribution of summer temperatures for sites on 303(d) streams and their tributaries. These plots display the sites from upstream to downstream, and allow comparison of temperature between sites and identify sites with the highest temperatures. Seven-day average maximum graphs plot maximum temperatures over the summer months to illustrate the timing and duration of high temperatures.

Analysis of these graphs and plots allows an upstream to downstream assessment of temperature variability for each stream. Together with information from prior studies on these streams, these data also allow determination of potential sources of temperature gains such as:

- Increased solar input due to lack of shade from degradation or removal of riparian vegetation,
- Reduced stream flow from diversion of water, or
- Increased stream width from channel modifications

2.2. Shade Parameter Development

The quantitative assessment of 303(d) listed thermal impairments in the Nevada Creek and Middle Blackfoot planning areas using the SNTEMP model requires several input datasets. One of the required datasets describes the total amount of shade on a channel cross section on a given day. This section provides a summary of the methods used to quantify shading influences for stream segments included in the models.

The SNTEMP model requires a total shade value for each reach of interest. Model construction requires either entering a total shade parameter or the individual components comprising total shade. If the components are entered individually, the model will calculate the total shade value (Table 2-3, Figure 2-3). This series of shade components describe vegetation character and extent, stream width, stream orientation, and local topography. Calculating total shade based on each of these contributing factors provides a more accurate estimate of overall shade than a total shade input value (Bartholow, 2004).

For this effort, quantification of the individual shade components for each modeled stream segment allowed calculation of a single total shade value (Table 2-3). The data used to derive the shading estimates include aerial photography, digital elevation data, base parameter assessment data, field photos, aerial assessment results, and existing literature. In addition to the parameters shown in Figure 2-3, low flow channel width, stream azimuth, and topographic shade values were developed for each reach using available data.

Table 2-3. Data sources utilized to define topographic, morphologic, and riparian shading parameters.

Type of Shade	***Parameter***	***Definition***	***Data Source***
Topographic	Stream Reach Azimuth	The average departure angle of the stream reach from a north-south reference line when looking south.	Calculated in the GIS
	Topographic Altitude Angle	The vertical angle from a level line at the streambank to the general top of the local terrain when looking at a right angle to the reach azimuth.	Calculated from a Digital Elevation Model (DEM)
Riparian	Height of Vegetation (Vh)	The average maximum height of the overstory riparian vegetation above the water surface.	Base Parameter Assessment Data, Field Photos
	Crown Measurement (Vc)	The average maximum diameter of the riparian vegetation immediately adjacent to the stream.	Base Parameter Assessment Data, Field Photos
	Crown Offset (Vo)	The average distance of the tree trunks from the water's edge.	Base Parameter Assessment Data, Field Photos
	Vegetation Density (Vd)	Measure of sunlight screening. Equal to percent bank length of vegetation times percent of sunlight screened by shading vegetation. (***Pct bank length multiplied by filter factor***)	Base Parameter Assessment Data, Field Photos, Aerial Assessment Results, Literature
Channel Morphology	Low Flow Channel Width	Topwidth of wetted channel under low flow modeled conditions	Base Parameter Assessment Data, Field Photos, Aerial Photographs

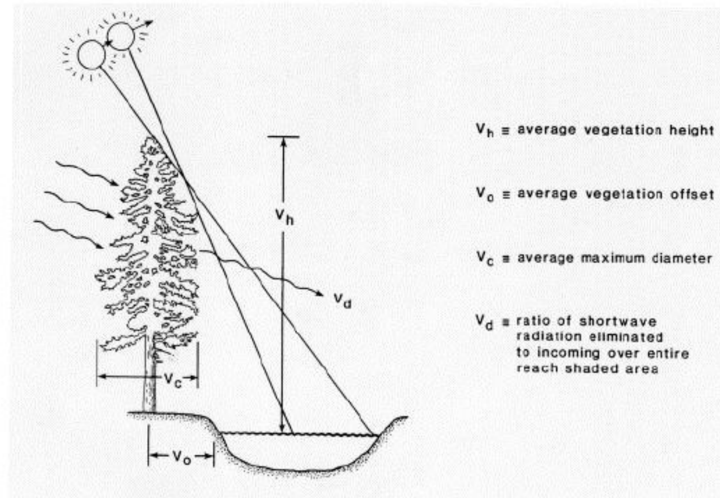


Figure 2-3. Schematic diagram of riparian shading components (Theurer et al, 1984).

2.2.1. Topographic Shade

The two components of topographic shade include stream reach azimuth and topographic altitude angle. The project GIS provided a tool for measuring these parameters for each of the reaches located within the modeling network.

The general stream reach azimuth is a measure of the average departure angle of the reach from a North-South reference line looking south. The direction of flow has no effect on determining the azimuth. The average reach azimuth was calculated in the GIS using a straight line between reach boundaries.

Topographic altitude angle is the angle from the stream bottom to the nearest topographic feature that forms the highest point perpendicular to the stream corridor. In general, this reflects the valley wall of the stream corridor. Points on each valley wall that reflect the topographic shape of the valley wall, and corresponding points on the stream bottom define topographic angle lines perpendicular to the direction of stream flow. Elevations of the two points and the distance between them allowed calculation of the topographic altitude angles (rise over run) for both left and right banks of the channel.

2.2.2. Channel Width

Stream topwidth is a required input parameter in the temperature models. In assessed reaches, the base parameter data includes measurements of bankfull channel width. These widths reflect channel topwidth dimensions at relatively high flows, and likely overestimate the channel width during low flow model conditions. Viewing field photographs helped estimate the ratio of low flow to bankfull width. Channels that are symmetrical and U shaped tend to have similar topwidths under both bankfull and low flow conditions. However, channels that are asymmetric, such as those with point bars tend to have low flow widths that are significantly less than bankfull.

On several reaches in the Nevada Creek planning area and for all of the mainstem Blackfoot River reaches, measuring the visible channel width from aerial photos allowed determination of the low flow channel width. In some areas of the Nevada Creek planning area where the channel is obscured or too small to measure, width information from adjacent assessed reaches and field photos helped refine the air photo estimates. Width measurements developed from the air photos reflect an average of multiple random measurements from each reach.

2.2.3. Riparian Vegetation

Within the modeled stream networks of the Nevada Creek planning area, numerous reaches have base parameter field assessment data that include measurements of vegetation type, extent, and channel cross section. For each of these reaches, queries of the base parameter database extracted the necessary riparian vegetation mapping and cross section data. For reaches without base parameter data, examination field photos helped define a series of vegetation types, with each type assigned an average vegetation height (Vh), canopy diameter (Vc), and offset (Vo). Filtering values were also developed for each vegetation category based on field photos and available literature. Bankline vegetation was then digitized in the GIS for the entire reach extent. This allowed calculation of a weighted average for each reach of the shade parameters based on the relative extent of the various vegetation types. These results combined with channel width and topographic shade measurements allowed calculation of a single shade value for each reach.

2.3. Pilot SSTEMP Modeling

Prior to construction of the SNTEMP models for this project, a pilot modeling effort using SSTEMP, the Stream Segment Temperature Model, was undertaken. The purpose of the pilot model was to determine if the developed input data would yield results requiring reasonable parameter adjustment for calibration. The results were favorable allowing the project to proceed with development of SNTEMP models.

2.4. SNTEMP Modeling

The utilization of a temperature model allowed simulation of stream temperatures under varying conditions. Simulations included current conditions, natural conditions based on higher levels of streambank vegetation, and vegetation conditions between current and natural conditions. In addition, preliminary simulations of increased flow or decreased channel width demonstrated the changes in temperature associated with these scenarios (Appendix C).

SNTEMP, the Stream Network Temperature Model, is a mechanistic heat transport model that predicts daily mean and maximum water temperatures at the end of a stream network (Theurer et al., 1984, Bartholow, 2004). Model simulations occur over a single time step, such as a day, and evaluate the effects of changing shade, stream geometry, and flow on instream temperature. The model requires inputs describing stream geometry, hydrology, meteorology, and stream shading.

SNTEMP expands upon SSTEMP by modeling multiple, linked stream segments to predict water temperature at the end of the network and at points within the network. Because SNTEMP models multiple stream segments, it allows for variability in flow, shade, and other factors at multiple locations within the modeled stream. Effects on stream temperature from one set of stream conditions can then propagate downstream to a stream segment with different conditions. This allows for more comprehensive modeling of stream temperatures than SSTEMP.

2.4.1. Model Construction

Analysis of the temperature data allowed assessment of the distribution of temperature monitoring sites and the periods of data collection. From this, it was apparent that five models were necessary to address temperature impairments on the 303(d) listed streams (Figure 2-4). The models are:

- Upper Nevada Creek,
- Lower Nevada Creek (includes Douglas Creek and Cottonwood Creek),
- The Blackfoot River
- Kleinschmidt Creek, and
- Upper Douglas Creek.

The Upper Nevada Creek, lower Nevada Creek, and Blackfoot River models are large, multi-segment, SNTEMP models. The lower Nevada Creek model simulates temperatures in three 303(d) listed streams: lower Nevada Creek, Douglas Creek, and Cottonwood Creek. Kleinschmidt Creek is a smaller SNTEMP model. The Upper Douglas Creek model uses SSTEMP and simulates temperatures for a section of Douglas Creek consisting of two short stream segments between irrigation reservoirs. The three reservoirs themselves were addressed through a simple surface area approach.

Input Data

A basic suite of input data describing stream conditions and other factors during the modeling period is required. Three broad categories of input data are required in SNTEMP: meteorology, stream geometry, and hydrology.

Local weather stations at Ovando and Helmville supplied the meteorological data. Meteorologic data are mean values for the modeling period, and consists of:

- Air temperature
- Relative humidity
- Wind speed
- Cloud cover, presented as a percent of possible sunshine
- Solar Radiation

Values for solar radiation were not available for the modeling periods from the local weather stations. In lieu of solar radiation values, the model calculates solar radiation if values for dust coefficient and ground reflectivity are available. Dust coefficient and ground reflectivity values representative of the season and ground cover for the modeling period were used (Tennessee Valley Authority, 1972).

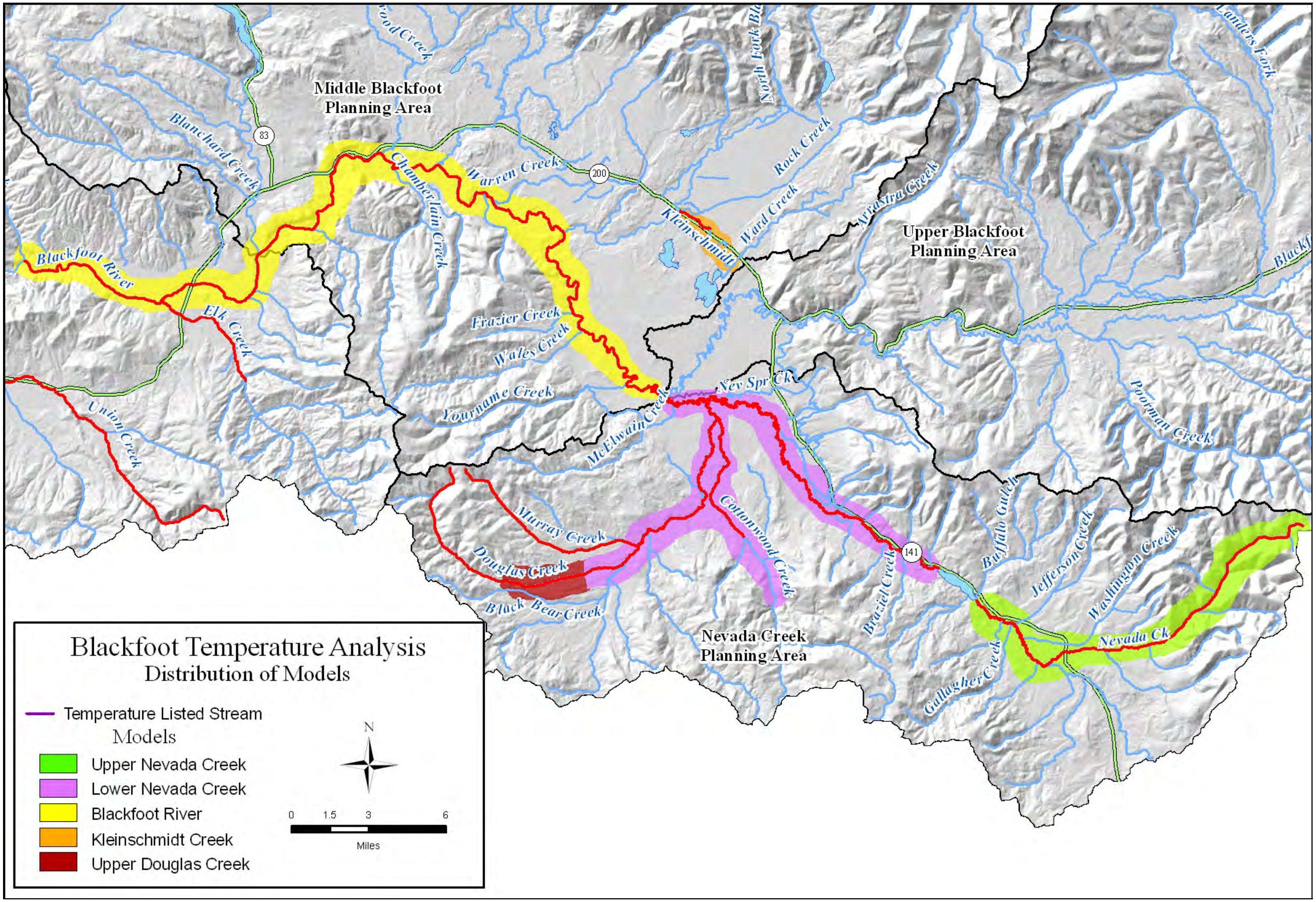


Figure 2-4. Distribution of temperature models in the Blackfoot River and Nevada Creek planning areas.

Hydrologic data are mean values for the modeling period, and include stream discharge throughout the system and water temperature. USGS gages, instantaneous flow measurements associated with water quality sampling, and visual flow estimates from July 2004 supplied flow data, while the FWP database supplied the temperature data. Initial flow at the beginning of the modeled stream, surface and ground water flow, point sources into the stream, and any flow diversions characterize flow throughout the system. Water temperature is input into the model at the beginning of the network, at any locations where additional flow enters the network, and at calibration points.

Other input data includes:

- shade,
- stream width,
- site elevations, and
- Manning's n.

Sections three and four contain tables specifying input data for each of the five models These sections describe meteorological, hydrological, and stream geometry input data for each model. Conditions represent the modeling period.

Model Networks

Each model required development of a spatial model network consisting of multiple stream segments. Each stream segment is unique and has homogenous characteristics such as length, stream width, slope, channel roughness (Manning's n), shade, and flow. Delineation of each segment occurs through identification of a series of nodes along the model network, and these nodes specify values for some or all of the segment characteristics (Table 2-4).

Node Type	***Input Stream Characteristics***
Headwater	Latitude, elevation, stream distance, water temperature, flow, stream width, Manning's n, shade
Segment	Latitude, elevation, stream distance, stream width, flow, Manning's n, shade
Point	Stream distance, water temperature, flow
Diversion	Stream distance, flow
Calibration	Stream distance, water temperature
Temperature Output	Stream distance
Flow	Stream distance, flow
End	Stream distance, flow

Table 2-4. SNEMP model network nodes and stream characteristics described with each node.

Headwater and segment nodes define the upstream point at which a stream segment begins, and that segment's stream characteristics. Segment nodes also define the downstream extent of a stream segment, but not its characteristics. Point nodes are additions of flow to the modeled stream, and can define the location and flow of important tributaries. Diversion nodes specify flow removed from the network. Flow nodes redefine the quantity of instream flow, and account for lateral flow such as groundwater. The Kleinschmidt model employed flow nodes to account for significant groundwater input to the stream. End nodes define the downstream extent of a stream or the network. Temperature predictions occur at these nodes. Additionally, temperature predictions occur at any point in the network where a temperature output node exists.

Sections three and four contain figures illustrating the model network for each of the models. These figures, and the input data, describe the distribution of model nodes and stream segments within each model network and allow spatial identification of characteristics such as shade, flow, and temperature.

2.4.2. Model Calibration

After model construction, calibration of simulated water temperatures with observed water temperature data is necessary. The goal of calibration is to ensure that the temperatures simulated with SNTEMP match well with observed conditions. The model is then suitable for assessing potential restoration efforts and conditions related to TMDLs.

To calibrate each model, observed daily mean and maximum water temperatures are assigned to calibration nodes at the end of each network and at various points within the network. A comparison of observed temperatures with simulated daily mean and maximum water temperatures at those points allows for an assessment of how well the model is simulating temperatures. For SNTEMP, a model is accurate if the difference between observed and simulated temperatures is no greater than 0.5^{o} C (0.9^{o} F) (Bartholow, 1989).

Calibration of simulated to observed water temperatures is accomplished by changing model input parameters in successive calibration iterations until simulated temperatures match observed temperatures. Parameters can be modified singly or in combination. Parameters modified include those described in SNTEMP literature (Bartholow, 1989, Bartholow, 2004) and fit with the project team's knowledge of the modeled streams. The parameters considered for modification during calibration were:

- relative humidity,
- cloud Cover,
- wind,
- dust coefficient,
- ground reflectivity,
- thermal gradient, and
- Manning's n (for maximum temperatures only).

Sections three and four contain tables specifying the parameters modified and the simulated temperatures for each calibration run. These sections also describe the rationale for each change in parameters. Calibration results at multiple nodes in a model network illustrate the accuracy of the model at multiple locations within each network.

2.4.3. Model Simulation

Once calibrated, the models can simulate resultant changes in water temperature from varying shade, flow, or channel width. Since lack of riparian shade is a large contributor to high temperatures in the modeled streams most simulations focused on this parameter.

Predicted temperatures from multiple simulations for each model determined the amount of shade required to meet temperature targets. Simulations typically include:

- current stream conditions,
- natural stream conditions (defined by Montana DEQ, usually 95% streambank vegetation and corresponding increase in shade),
- several simulations between current and natural conditions, and
- one simulation of the target values for shade.

The temperature targets are for mean daily temperatures due to uncertainty in the model's ability to simulate maximum daily temperatures. The target simulation simulates a mean temperature that is no more than one degree Fahrenheit warmer than the simulated mean temperature under the defined natural conditions. However, simulation results for maximum temperatures are reported as well. Sections three and four contain tables and graphs listing which parameters were changed in each simulation, the degree of change, and the resulting temperatures for each simulation.

3. Results: Nevada Creek Planning Area

The following sections describe the results of temperature data analysis, shade parameter development, and temperature modeling for the 303(d) temperature impaired streams in the Nevada Creek Planning Area. The results are presented by stream although in some cases multiple streams are part of a temperature model.

3.1. Shade

The following section presents the results of the shade parameter development for modeled reaches on the Nevada Creek Planning Area. These values are a function of shading vegetation type and extent, topographic conditions, and channel width. Section 2.2 describes the methods used to calculate each of these parameters.

3.1.1. Riparian Vegetation

For the modeled segments of the Nevada Creek Planning area, base parameter assessment data (DTM and AGI, 2005) and field photos allowed definition of the vegetation categories along the streams of interest. For each of these categories, field photos and notes provided the data for estimates of vegetation offset (Vo), diameter (Vd), and height (Vh). The median values of these estimates define typical conditions for each vegetation type. The greatest range in estimated values of height, crown diameter, and offset is the conifer or deciduous/conifer vegetation type (Figure 3-1 through Figure 3-3). However, in all modeled reach segments, this vegetation type occupied less than 10 percent of the total bank length. In general, the most extensive vegetation type mapped is willows/shrubs, which has a relatively small range in Vo, Vh, and Vc values. A summary of the median values measured for height, crown diameter, and offset are in Table 3-1.

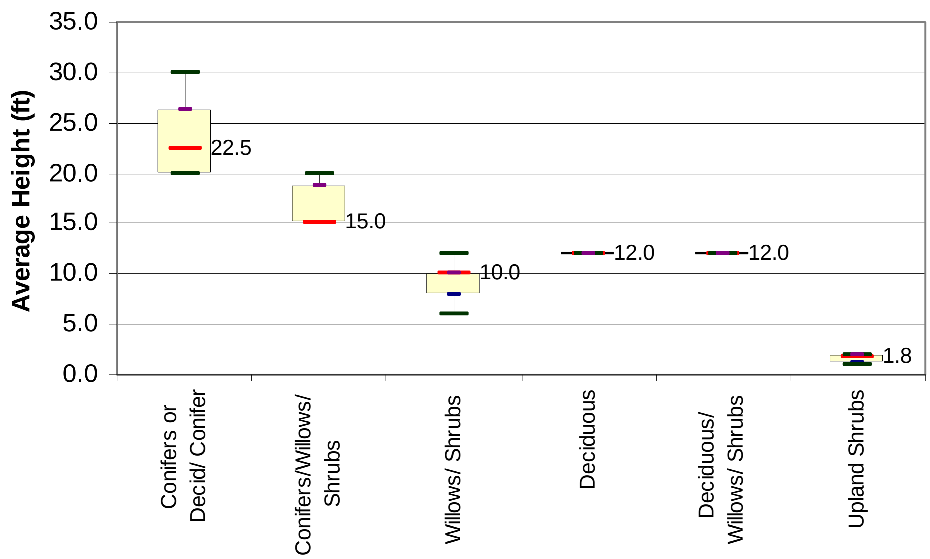


Figure 3-1. Estimated average heights for each vegetation type with median values labeled.

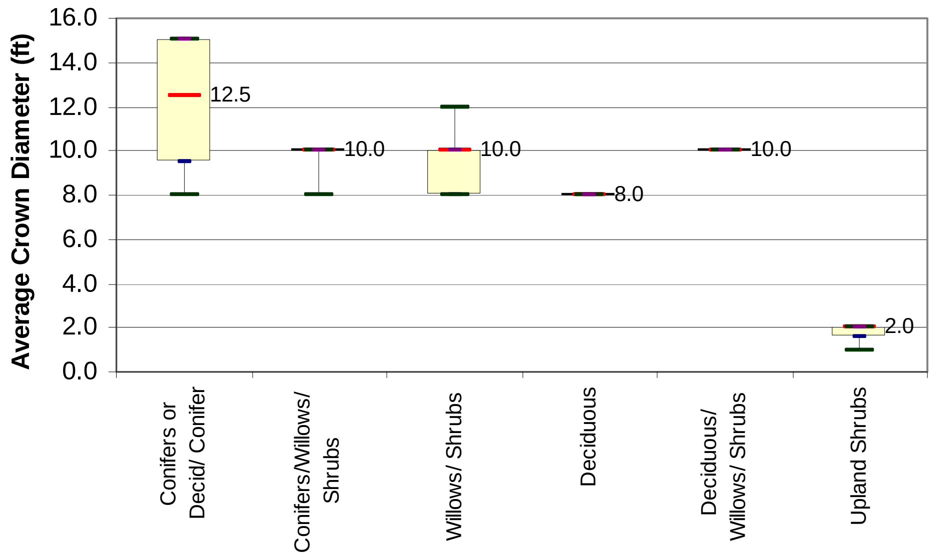


Figure 3-2: Estimated average crown diameter for each vegetation type with median values labeled.

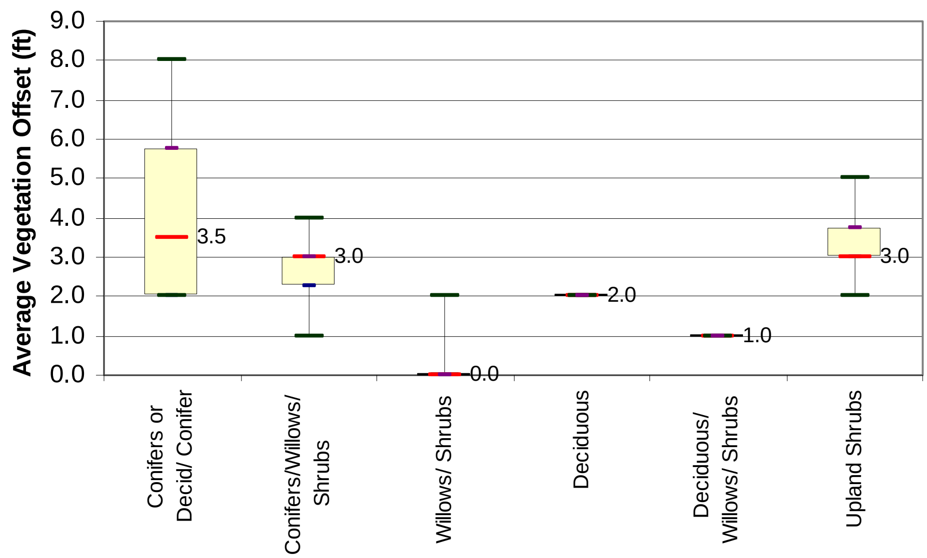


Figure 3-3: Estimated average offset for each vegetation type with median values labeled.

Table 3-1. Shade parameter values utilized for each vegetation category.

Vegetation Type	*Filtering*	*Vh: Crown Height (ft)*	*Vd: Crown Diameter (ft)*	*Vo: Offset (ft)*
Conifer or Deciduous/Conifer	0.6	22.5	12.5	3.5
Conifer/Willow/ Shrub	0.7	15.0	10.0	3.0
Willow/Shrub	0.7	10.0	10.0	0.0
Deciduous	0.6	12.0	8.0	2.0
Deciduous/Willow/ Shrub	0.7	12.0	10.0	1.0
Upland Shrub	0.2	1.8	2.0	3.0

Vegetation density (Vd) is a key input parameter into SSTEMP, for running both existing conditions and potential restoration scenarios. This parameter is the product of the vegetation's sunlight filtering capacity (filtering value) and its extent (percent coverage). Filtering values depend on the structure of the vegetation type. Available literature guided the selection of appropriate values for the vegetation categories mapped in the area (Manoukian and Marlow, 2002; Risley, 1997; Bartholow, 2004). The filtering values range in value from 0.2 to 0.7 (Table 3-1).

The shading parameter value developed for reaches without base parameter data reflects woody vegetation in each reach as measured on 1995 DOQQ and 2005 NAIP imagery. Within the GIS, line segments representing topbank vegetation were digitized and attributed with bank (right or left) and vegetation type. Summarizing the line segment attributes allow calculation of the total length of each vegetation type within each reach. From the extent of the various vegetation types, weighted averages of vegetation height, offset, crown diameter, and filtering value were calculated. Within the reach segments of the modeling network that do not have base parameter data, virtually all of the vegetation mapped was willow/shrub communities in the open valley bottoms.

3.1.2. Topographic Shade

In general, most of the modeled stream segments of the Nevada Creek Planning Area flow through open valleys that provide little topographic shade during summer months. However, some headwater areas, as well as entrenched stream segments, do receive significant shading from local topography. Table 3-2 presents topographic shade values for each reach.

3.1.3. Channel Width

Measured cross section data, air photos, and field photos provided the data to estimate channel width under low flow conditions for each modeled reach segment. Measured cross section data and field photos were available for all of the reach segments with base parameter data. These values, in combination with measurements from air photos helped estimate low flow widths in reaches without field data. Table 3-2 lists the estimated low flow width values for each reach.

3.1.4. Total Shade Calculations

The total shade value is the sum of the topographic and vegetation shade. Using the input parameters described above, a total shade value was calculated for each reach located within a modeling network (Table 3-2, Figure 3-4). Figure 3-5 shows the spatial distribution of shading values by reach and highest 7-day average maximum water temperature by site. These total shade values are a sum of the shade contributions from topography and vegetation typical of the reach during the modeling period. Total shade values range from less than one percent to 58 percent.

Table 3-2. Calculated topographic, vegetation, and total shading parameter for August 15, Nevada Creek Planning Area assessment reaches.

Model	Stream	Reach	B.P. Data	Reach Length (ft)	Pct Shaded Bank	Low Flow Width (ft)	Stream Azimuth (deg)	Crown Diam (ft)	Tree Height (ft)	Offset (ft)	Shade Density Decimal	% SHADE		
												Topo-graphic %	Vege-tation %	Total %
Upper Nevada Creek	Nevada Creek	Nev1		23018	83	5.0	57.4	10.0	14.5	2.7	0.6	1.64	55.23	56.87
		Nev2	√	10108	86	16.6	37.3	10.0	10.0	0.0	0.60	9.07	38.11	47.18
		Nev2b	√	10108	89	16.4	37.3	10.3	12.4	1.0	0.61	9.74	39.44	49.18
		Nev3	√	9666	81	16.0	46.5	8.9	8.9	0.5	0.51	8.60	29.17	37.78
		Nev4		12061	97	16.0	79.6	10.0	10.0	0.0	0.7	0.19	44.77	44.95
		Nev5b	√	33181	30	13.1	-86.3	10.0	10.0	0.0	0.21	0.01	11.13	11.15
		Nev5c	√	33181	0	13.4	-86.3	0.0	0.0	0.0	0.00	0.01	0.00	0.01
		Nev6	√	22204	20	14.2	-50.2	10.0	10.0	0.0	0.14	0.62	11.11	11.74
		Nev6b	√	22204	0	10.8	-50.2	0.0	0.0	0.0	0.00	0.62	0.00	0.62
	Washington Creek	Wash3b		11365	3	5.5	75.9	10	10	0.0	0.02	.02	1.98	2.00
Lower Nevada Creek	Nevada Creek	Nev7	√	22749	0	26.0	-65	0.0	0.0	0.0	0.00	0.72	0.00	0.72
		Nev8	√	18867	42	19.1	-53.8	10.0	10.0	0.0	0.29	0.80	18.40	19.20
		Nev9	√	18803	98	18.4	-48.9	9.1	9.1	0.3	0.63	0.07	38.52	38.59
		Nev10		21720	58	18.0	-31.8	10.0	10.0	0.0	0.4	0.10	28.06	28.15
		Nev11		8048	28	18.0	-26.8	10.0	10.0	0.0	0.2	0.00	13.88	13.88
		Nev12	√	18971	57	14.9	-26.7	10.0	10.0	0.0	0.40	0.00	31.19	31.19
		Nev12b	√	18971	62	9.2	-26.7	10.0	10.0	0.0	0.43	0.00	40.21	40.21
		Nev13	√	22779	34	34.1	-26.7	10.0	10.0	0.0	0.24	0.00	10.20	10.20
		Nev14	√	38527	35	39.2	-85.8	10.0	10.0	0.0	0.25	0.00	6.66	6.66
		Nev14		38527	27	39	-85.8	10	10	0.0	0.19	0.00	5.19	5.19
	Cottonwood Creek	CttnNev1		10201	45	8.0	-42.5	10.0	10.3	0.1	0.3	0.57	29.71	30.29
		CttnNev2	√	16331	25	7.3	10.2	9.5	9.5	0.2	0.17	0.07	15.93	16.00
		CttnNev2b	√	16331	21	9.3	10.2	10.0	10.0	0.0	0.15	0.07	13.53	13.60
		CttnNev3		15317	31	8.0	-14.6	10.0	10.0	0.0	0.2	0.07	20.68	20.75
	Douglas Creek	Doug3g		8896	9	5.9	75.5	10.0	10.0	0.0	0.06	0.11	6.23	6.34
		Doug5	√	17447	32	10.8	62.7	9.5	9.5	0.2	0.21	0.62	18.48	19.10
		Doug6		14486	80	10.0	17.3	10.0	10.0	0.0	0.6	0.55	50.43	50.98
		Doug7	√	10705	44	8.7	10.9	9.8	9.8	0.1	0.30	0.02	28.12	28.13
		Doug7		10705	38	8.7	10.9	10.0	10.0	0.0	0.27	0.02	25.22	25.24

Model	Stream	Reach	B.P. Data	Reach Length (ft)	Pct Shaded Bank	Low Flow Width (ft)	Stream Azimuth (deg)	Crown Diam (ft)	Tree Height (ft)	Offset (ft)	Shade Density Decimal	% SHADE Topo-graphic %	Vege-tation %	Total %
		Doug8		15002	4	10	12.3	10.0	10.0	0.0	0.0	0.00	2.78	2.78
		Doug9		7933	32	12	-23	10.0	10.0	0.0	0.2	0.00	18.86	18.86
Upper Douglas Creek	Douglas Creek	Doug3a		1891	45	5.9	75.5	10.0	10.0	0.0	0.31	0.11	31.26	31.37
		Doug3c		2840	54	5.9	75.5	10.0	10.0	0.0	0.38	0.11	37.92	38.03
		Doug3e		6783	34	5.9	75.5	10.0	10.0	0.0	0.24	0.11	23.55	23.67
		Doug3g		8896	9	5.9	75.5	10.0	10.0	0.0	0.06	0.11	6.23	6.34
None	Murray Creek	Murr1		18108	88	7	-46.5	10.0	15.0	3.0	0.6	4.69	53.44	58.13
		Murr2		10937	60	7	-55.2	10.0	15.0	3.0	0.4	0.44	38.43	38.87
		Murr3		20299	39	6	85.7	10.0	10.7	0.4	0.3	0.10	27.43	27.53

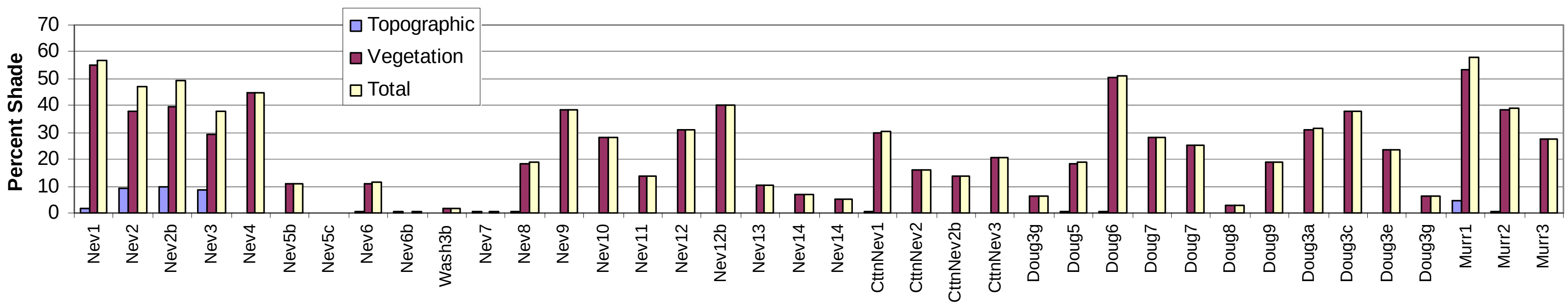
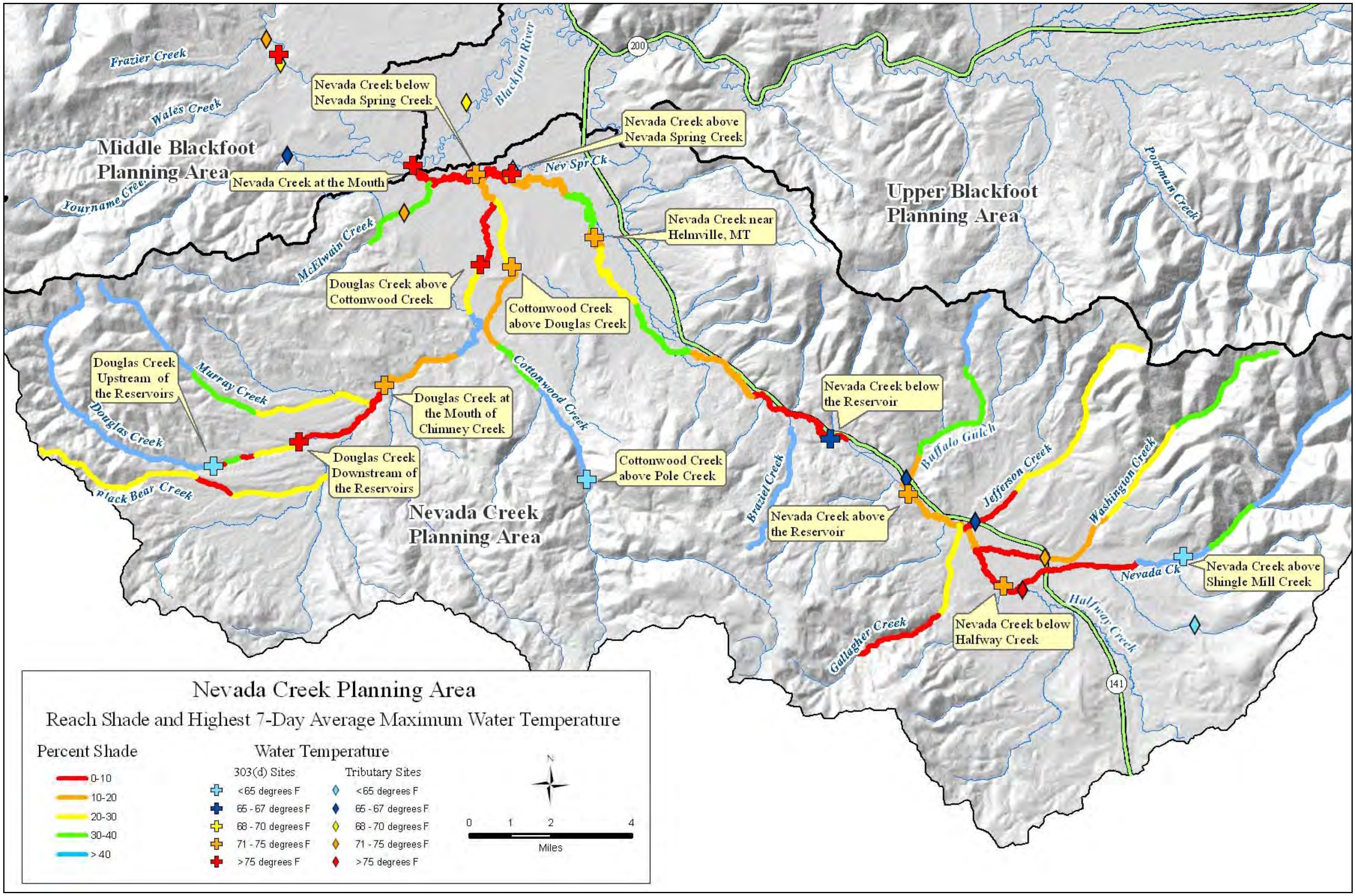


Figure 3-4. Total shade values calculated for modeled reaches, Nevada Creek Planning Area

Figure 3-5: Nevada Creek planning area map showing vegetation shade by reach and temperature at monitoring sites.



3.2. Temperature Conditions

The following sections describe the stream temperature conditions for each 303(d) listed stream in the Nevada Creek Planning Area. This includes important tributaries to these streams.

3.2.1. Upper Nevada Creek

Above Nevada Reservoir, the only stream on the 303(d) list for temperature impairments is Nevada Creek. However, tributary streams also contribute warm water. The Montana FWP temperature database contains data collected in 2001 for three sites on upper Nevada Creek and for four sites on tributary streams. Figure 3-6 through Figure 3-12 (upstream to downstream) display continuous water temperature readings collected at the seven monitoring sites during the summer of 2001. These figures illustrate that the daily range in water temperatures (diurnal fluctuation) is around 10- 15 ^{o} F. The drop in temperature around July 30 at all sites corresponds with a cool and rainy period (Figure 3-14).

Figure 3-13 shows the distribution of summer temperatures during 2001 at the seven monitoring sites. This figure allows comparison of temperature between sites. For example, Nevada Creek temperatures increase significantly between the site above Shingle Mill Creek and the site below Halfway Creek, with Halfway Creek itself having the highest temperatures of all the sites.

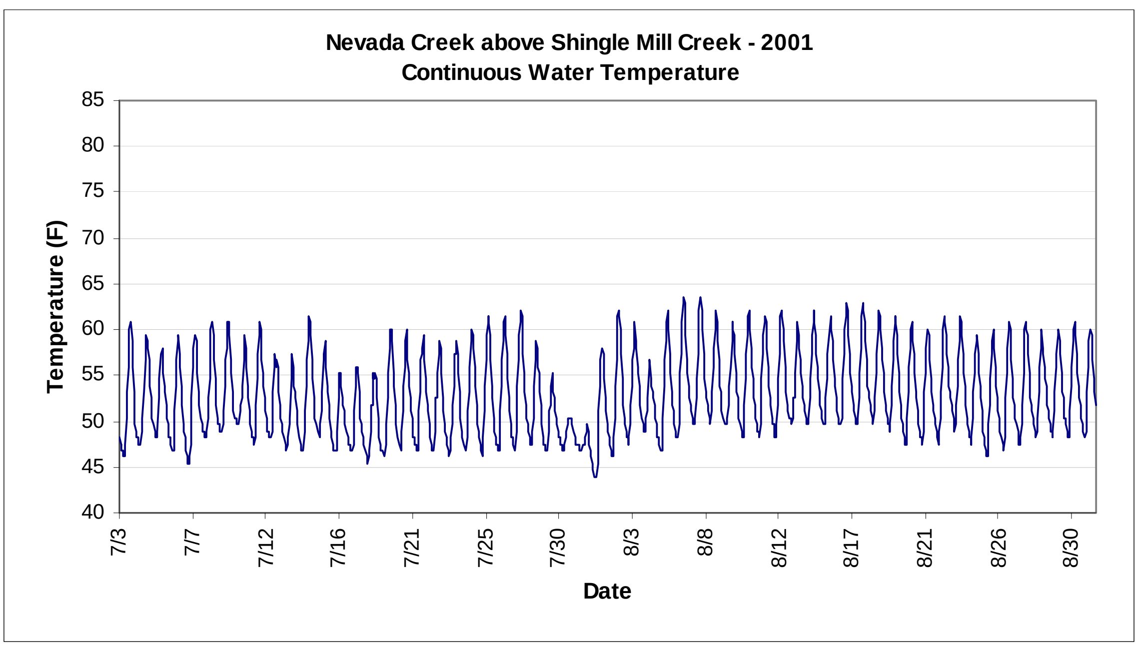


Figure 3-6: Continuous water temperature, Nevada Creek above Shingle Mill Creek, 2001.

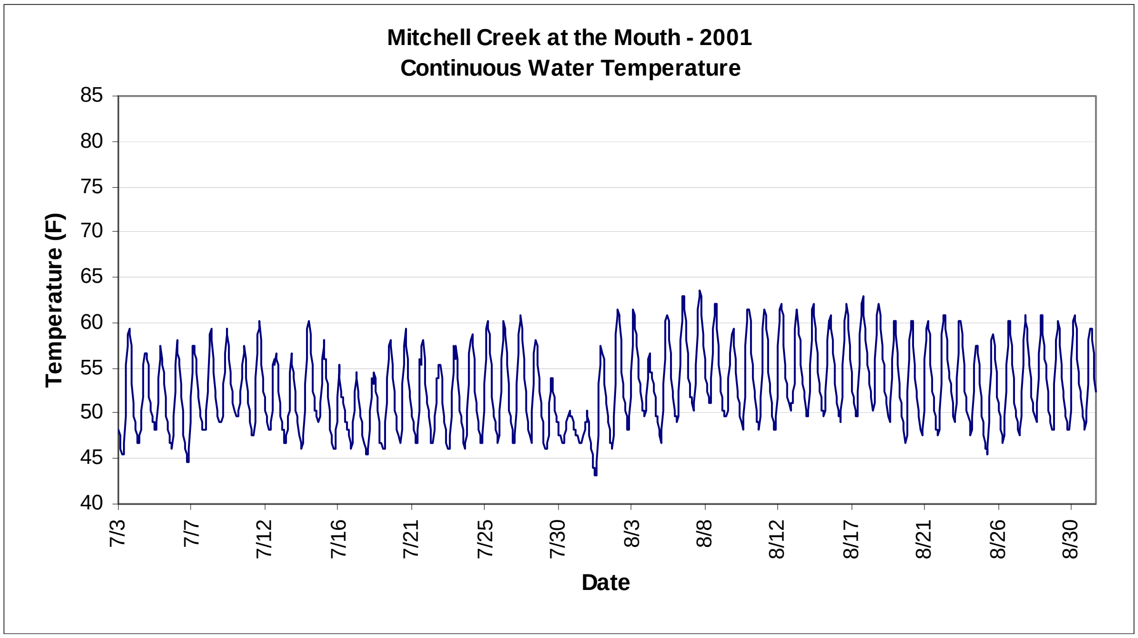


Figure 3-7: Continuous water temperature, Mitchell Creek at the mouth, 2001.

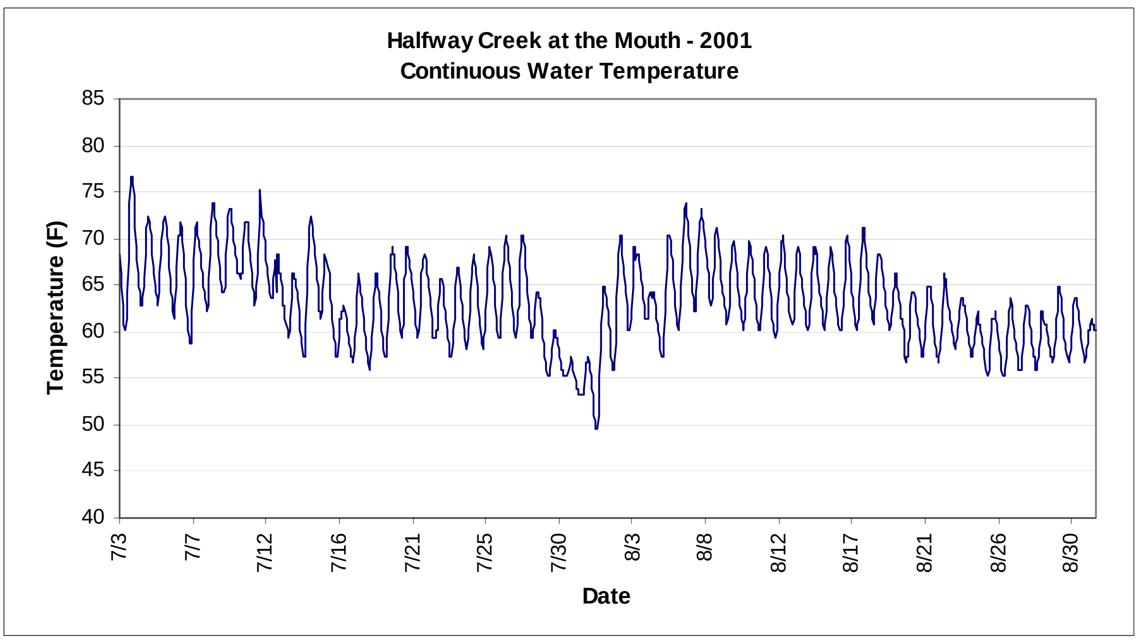


Figure 3-8: Continuous water temperature, Halfway Creek at the mouth, 2001.

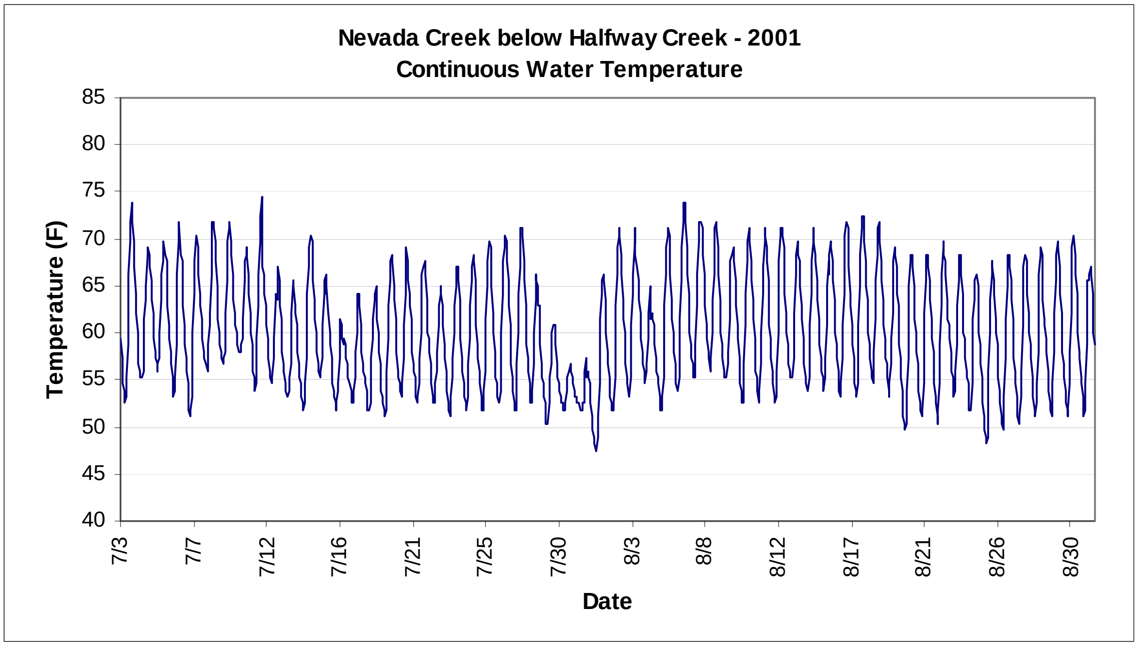


Figure 3-9. Continuous water temperature, Nevada Creek below Halfway Creek, 2001.

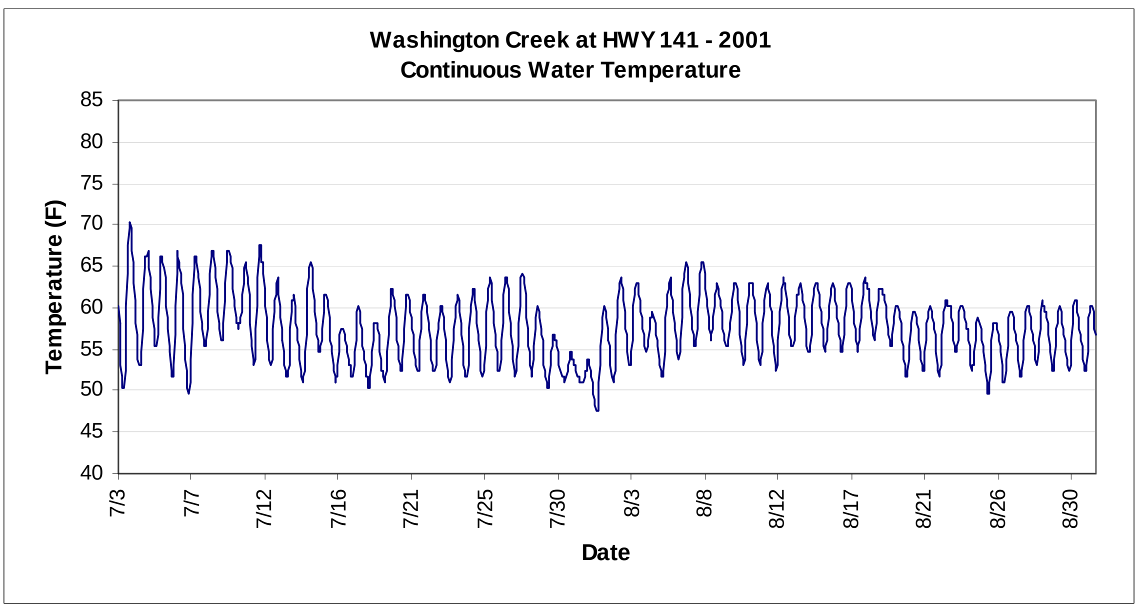


Figure 3-10. Continuous water temperature, Washington Creek at Highway 141, 2001.

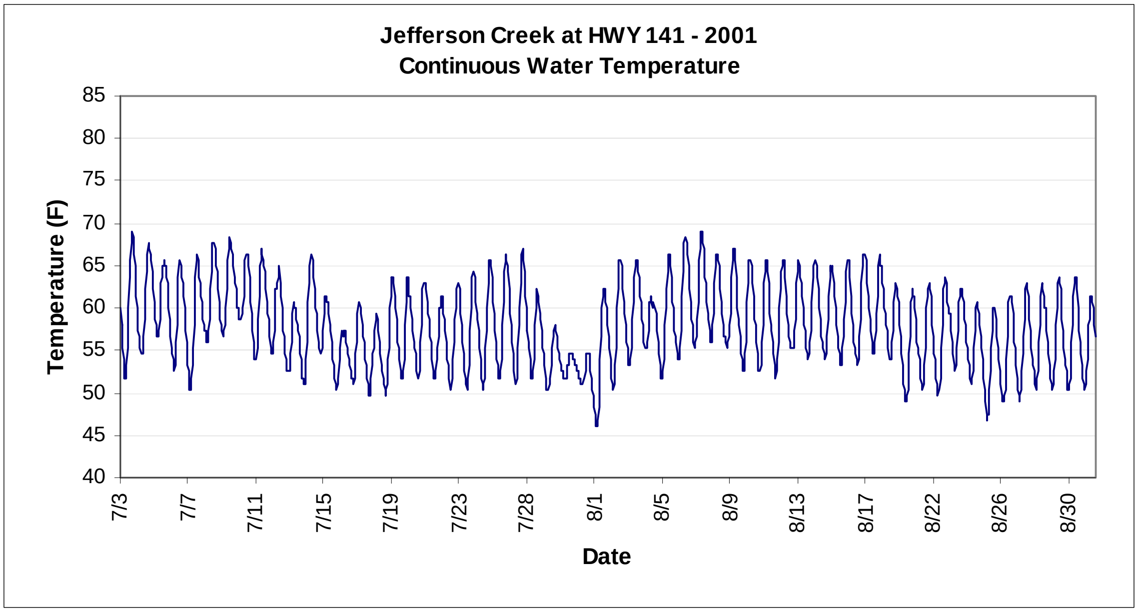


Figure 3-11. Continuous water temperature, Jefferson Creek at Highway 141, 2001.

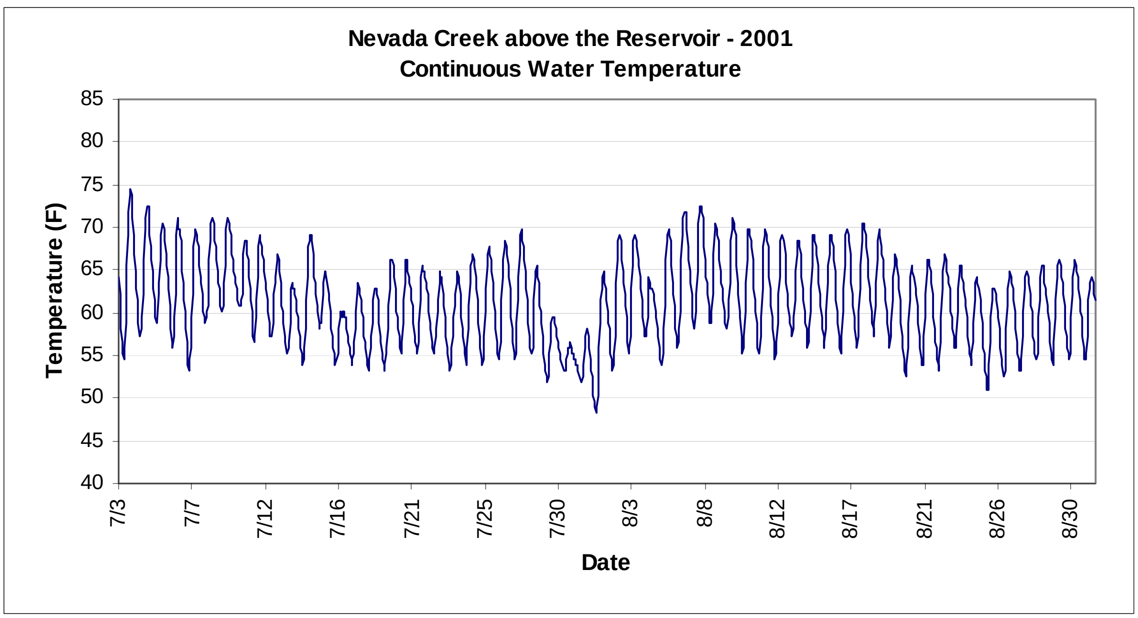


Figure 3-12: Continuous water temperature, Nevada Creek above the reservoir, 2001.

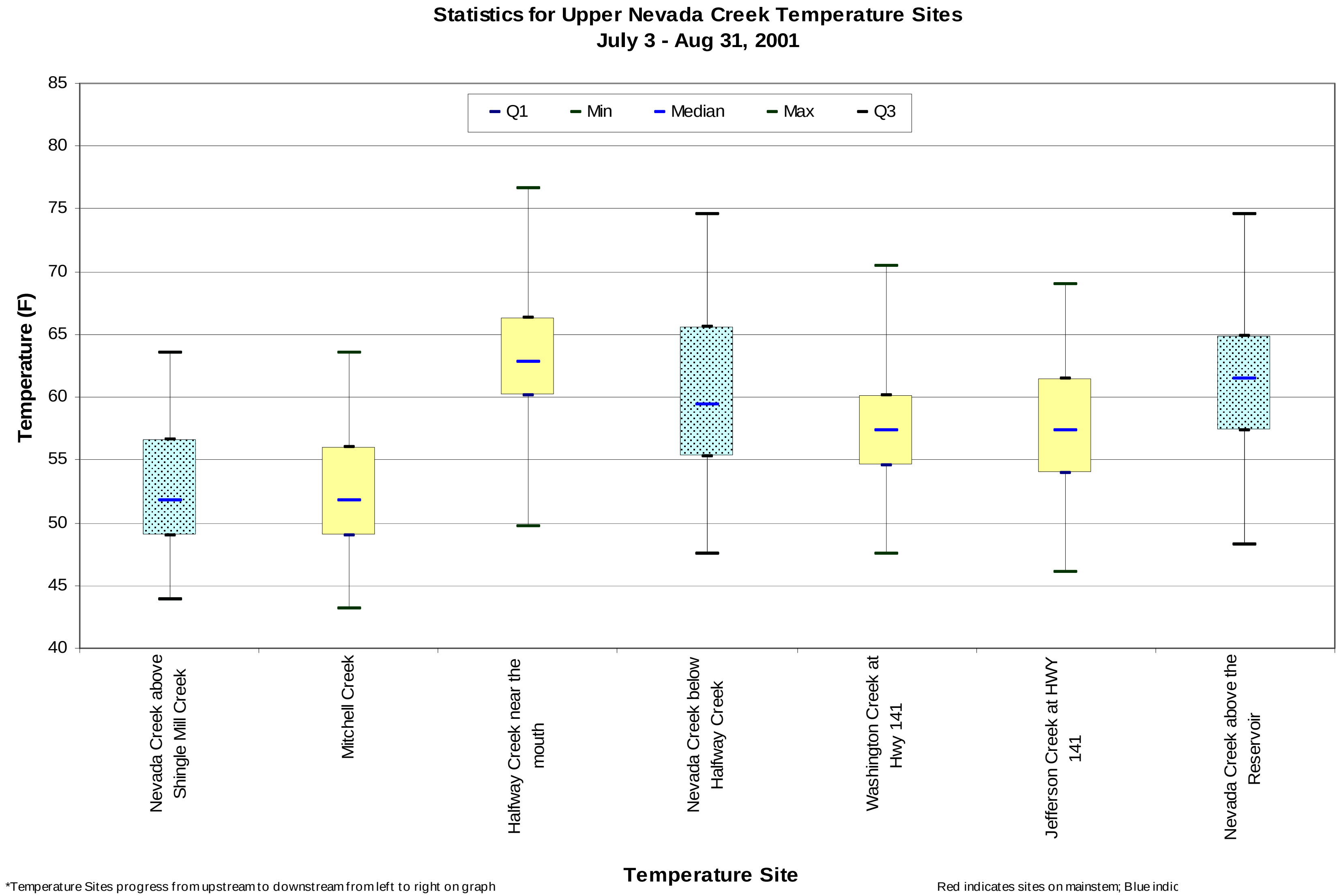


Figure 3-13. Upstream to downstream temperature variation, upper Nevada Creek, 2001.

Figure 3-14 and Figure 3-15 display the daily maximum and seven-day average maximum temperatures, respectively, at the three monitoring sites on upper Nevada Creek during the summer of 2001. Precipitation and air temperature plotted on the maximum daily water temperature graph illustrates that these factors strongly influence water temperature, as water temperatures fluctuate with changes in air temperature. The seven-day average maximum temperature graph shows that high temperatures occur at the two downstream monitoring sites in early July and for an extended period during the first three weeks in August.

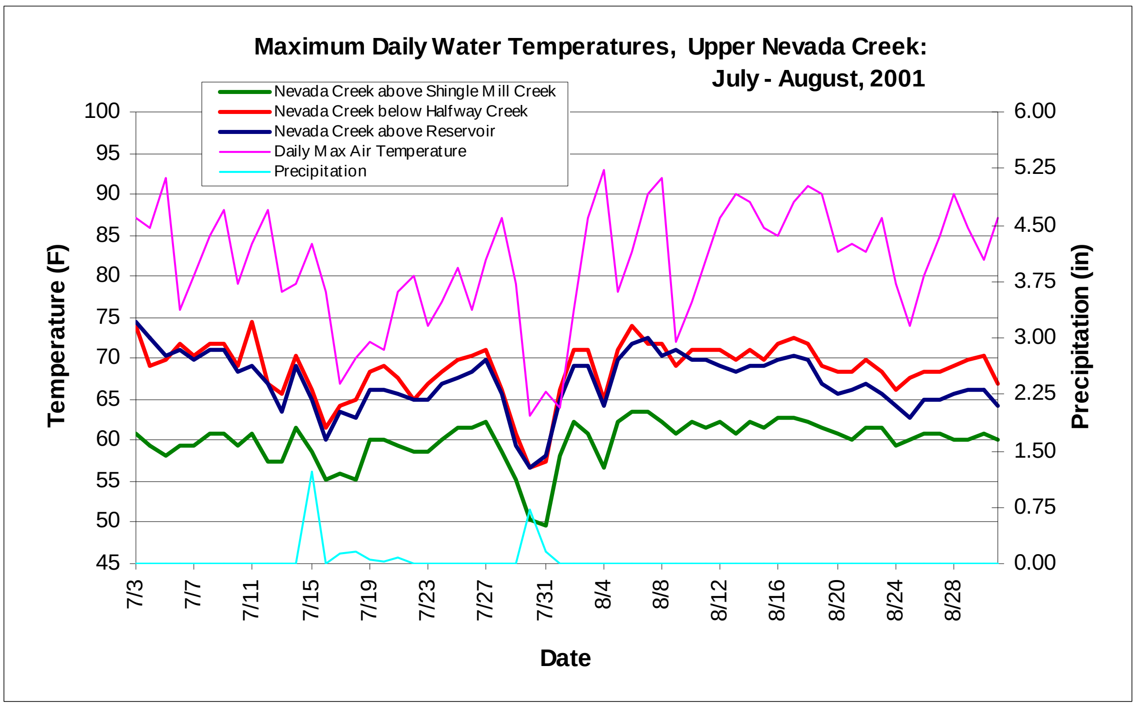


Figure 3-14: Maximum daily water temperature, air temperature, and precipitation, upper Nevada Creek, 2001.

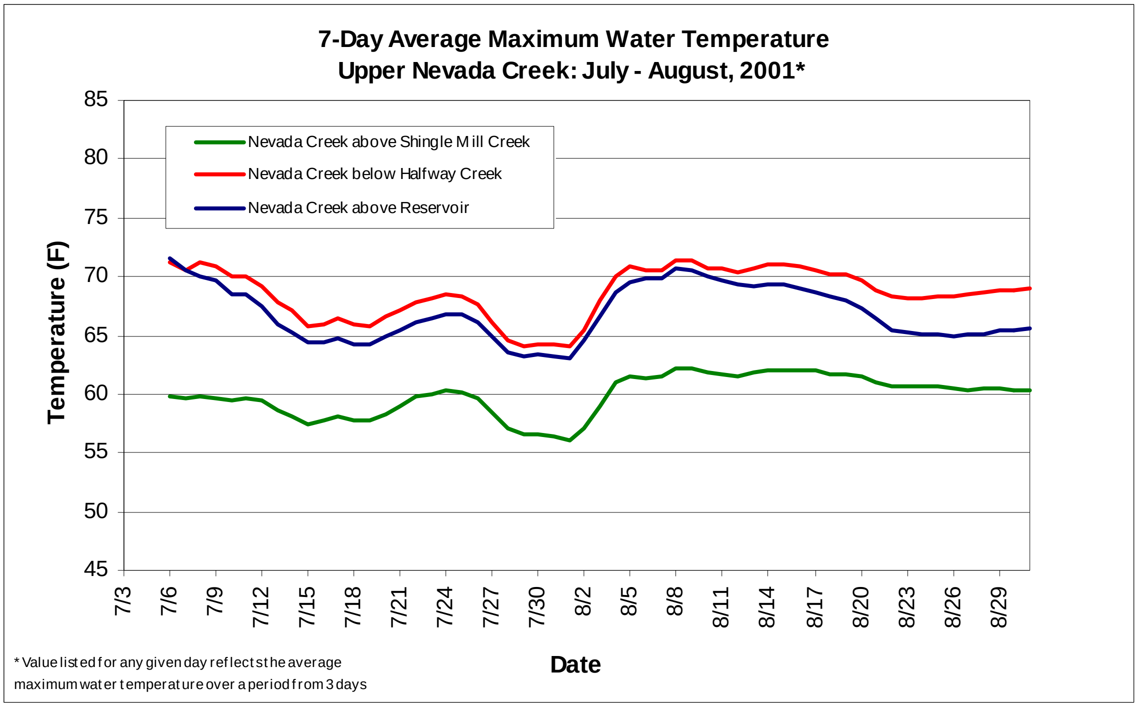


Figure 3-15: 7-day average maximum daily temperatures, Upper Nevada Creek, 2001.

Together, these graphs and plots assist with an upstream to downstream assessment of temperature variability in upper Nevada Creek. Relatively cool water temperatures measured at Nevada Creek above Shingle Mill Creek and Mitchell Creek reflect cold inflows from the headwater areas of Nevada Creek (Figure 3-6). Nevada Creek temperatures increase below the confluence of Halfway Creek, indicating a contribution of relatively warm water from that tributary. Air photos and base parameter assessment data (DTM and AGI, 2005) depict a lack of riparian shading on much of Halfway Creek, as well as on Nevada Creek above Halfway Creek. Both of these reaches likely experience large thermal gains during hot summer days, which results in warm stream temperatures in Nevada Creek below Halfway Creek. Farther downstream, Washington Creek is slightly warm at the Highway 141 crossing, which is approximately two miles upstream of its confluence with Nevada Creek. Between the measuring site and the confluence, the stream temperatures on Washington Creek likely experience substantial gains due to a lack of riparian vegetation on lower Washington Creek. Jefferson Creek contributes water slightly cooler than Washington Creek, and this may in part be due to groundwater inputs. Between the Halfway Creek confluence and Nevada Reservoir, the Nevada Creek corridor is also sparsely vegetated and significant solar warming of water is likely in the reach, as indicated by warm temperatures measured just above the reservoir.

Diversion of water for irrigation occurs in the early summer in upper Nevada Creek since water rights in this area allow diversion until late June. Note that the water temperatures at the start of the monitoring period (July 3) are relatively warm, and may reflect warm return flows from the early summer flood irrigation.

3.2.2. Lower Nevada Creek

The year chosen for temperature analysis and modeling for lower Nevada Creek is 2000. This year had the most consistent temperature dataset for the largest group of sites in the area. This section also includes temperature data for Nevada Spring Creek collected in 2004. Nevada Spring Creek underwent significant restoration in 2001, resulting in significantly reduced channel width. Comparison of the 2000 with 2004 continuous temperature graphs for Nevada Spring Creek indicates a significant improvement in stream temperatures since restoration (Figure 3-19 and Figure 3-20).

Figure 3-16, Figure 3-18 through Figure 3-19, and Figure 3-21 (upstream to downstream) display continuous water temperature readings collected for lower Nevada Creek during the summer of 2000. Figure 3-17 displays water release dat from Nevada Reservoir. Note that dam releases drop significantly around the July 4^{th} first cutting of hay and the corresponding increase in diurnal fluctuation in water temperature. Figure 3-22 displays temperature statistics for lower Nevada Creek and tributary sites. Note that the temperature data from Douglas and Cottonwood creeks is from significantly upstream of their confluence with Nevada Creek. Therefore, the actual contribution from these tributaries is likely warmer.

The range in diurnal temperature is low immediately below Nevada Reservoir, but increases downstream above Nevada Spring Creek and more so at the mouth of Nevada Creek. Temperatures also increase from upstream to downstream in Nevada Creek.

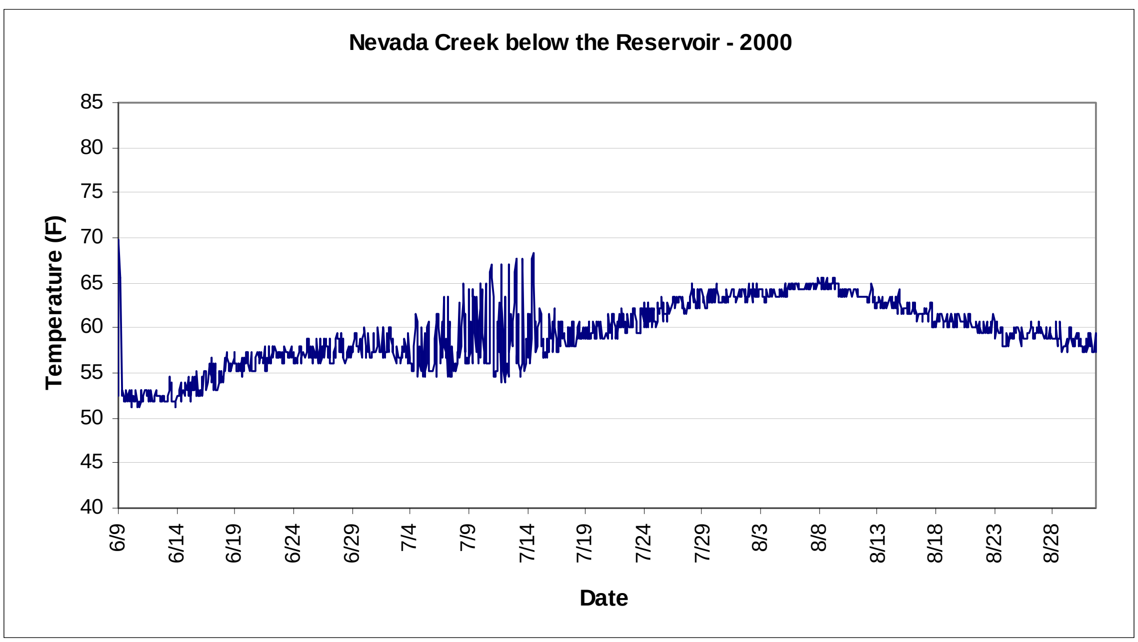


Figure 3-16. Continuous water temperature, Nevada Creek below the reservoir, 2000.

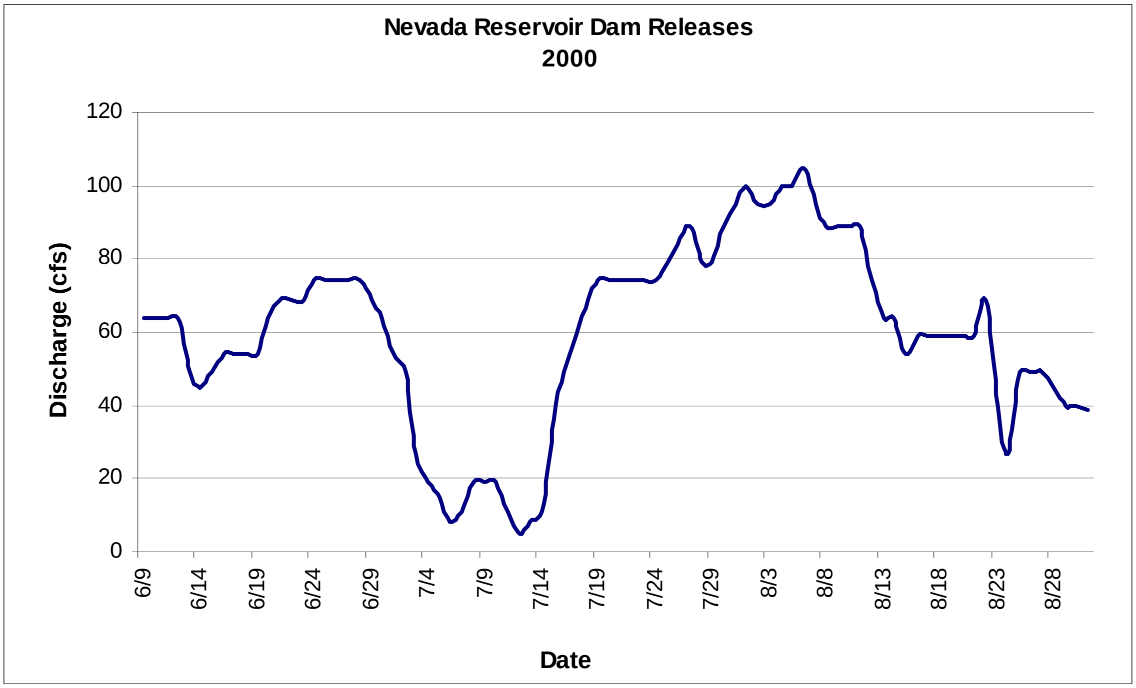


Figure 3-17. Flow below Nevada Reservoir, 2000.

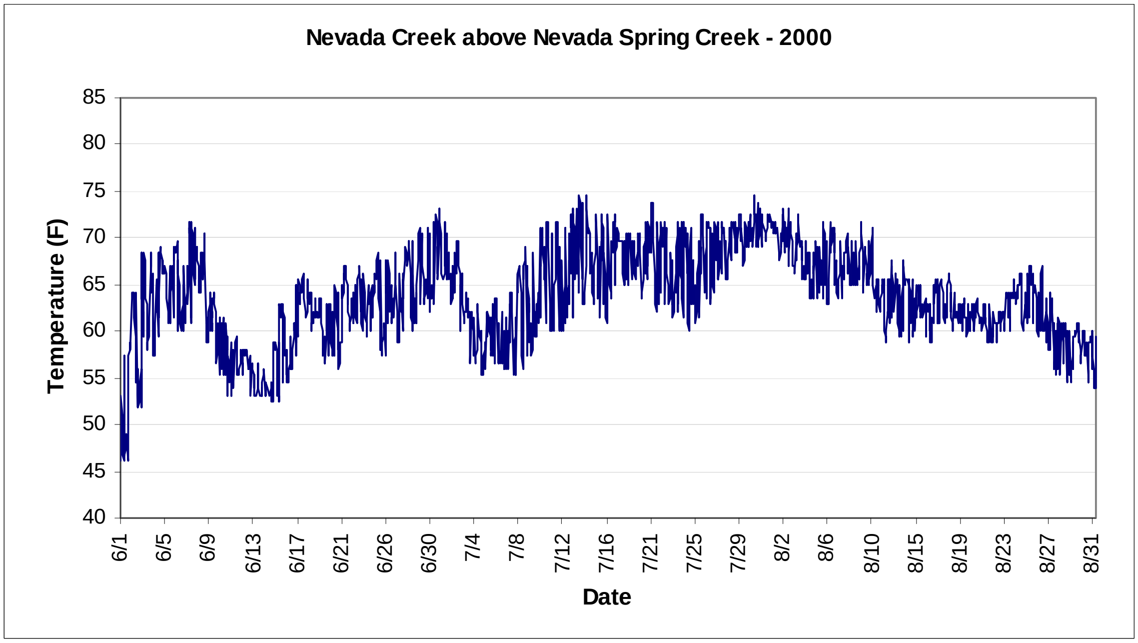


Figure 3-18. Continuous water temperature, Nevada Creek above Nevada Spring Creek, 2000.

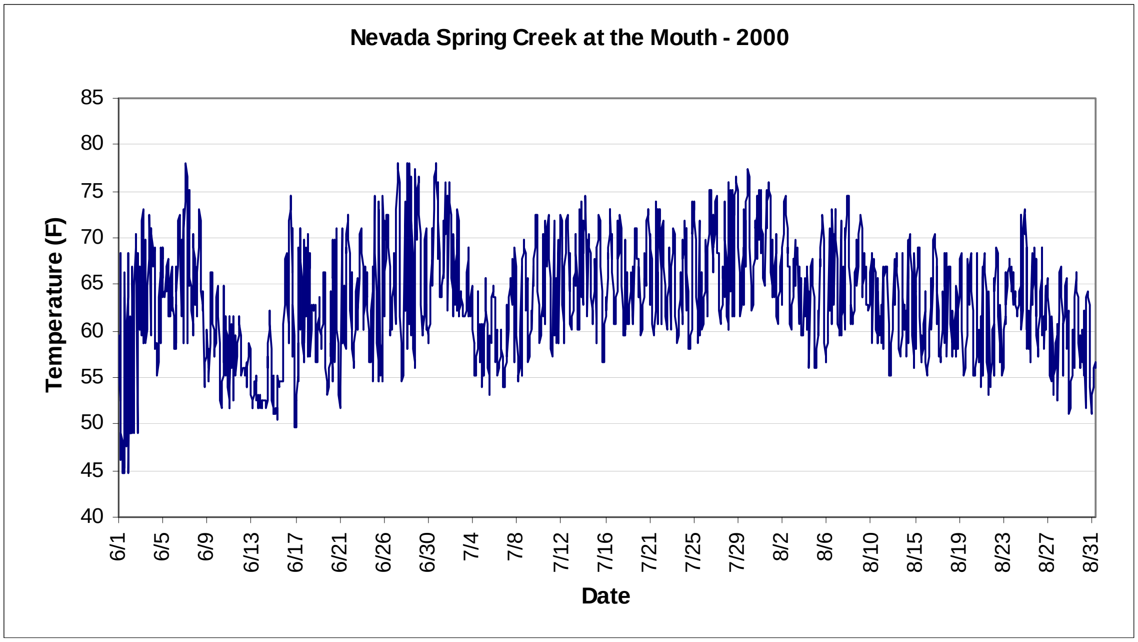


Figure 3-19. Continuous water temperature, Nevada Spring Creek, 2000.

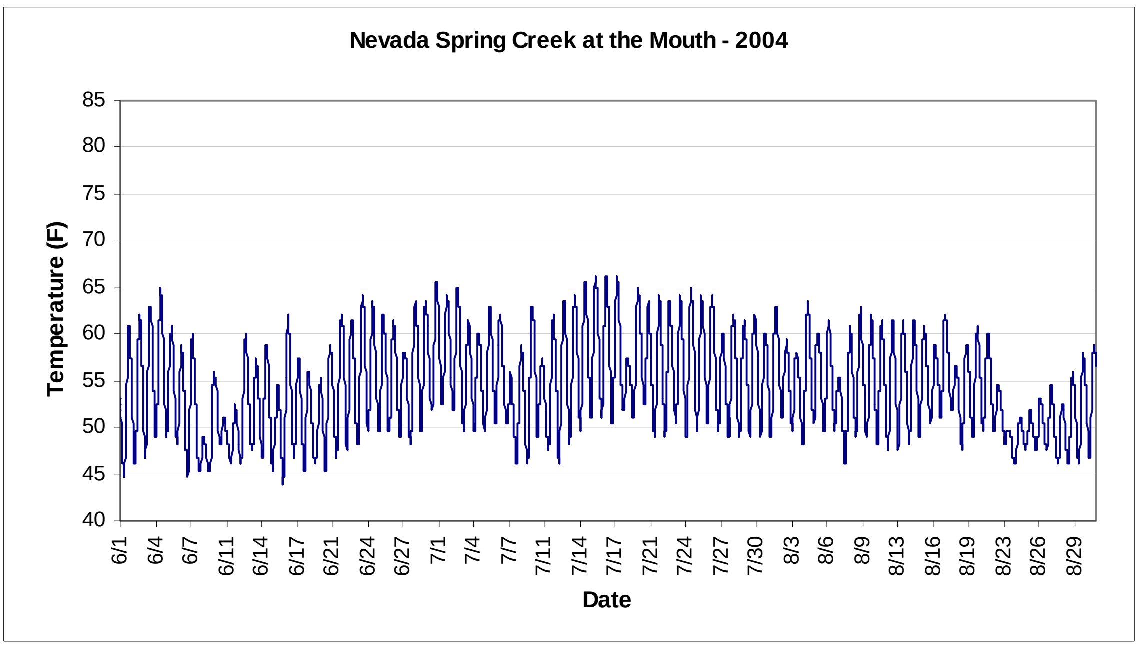


Figure 3-20: Continuous water temperature, Nevada Spring Creek at the mouth, 2004.

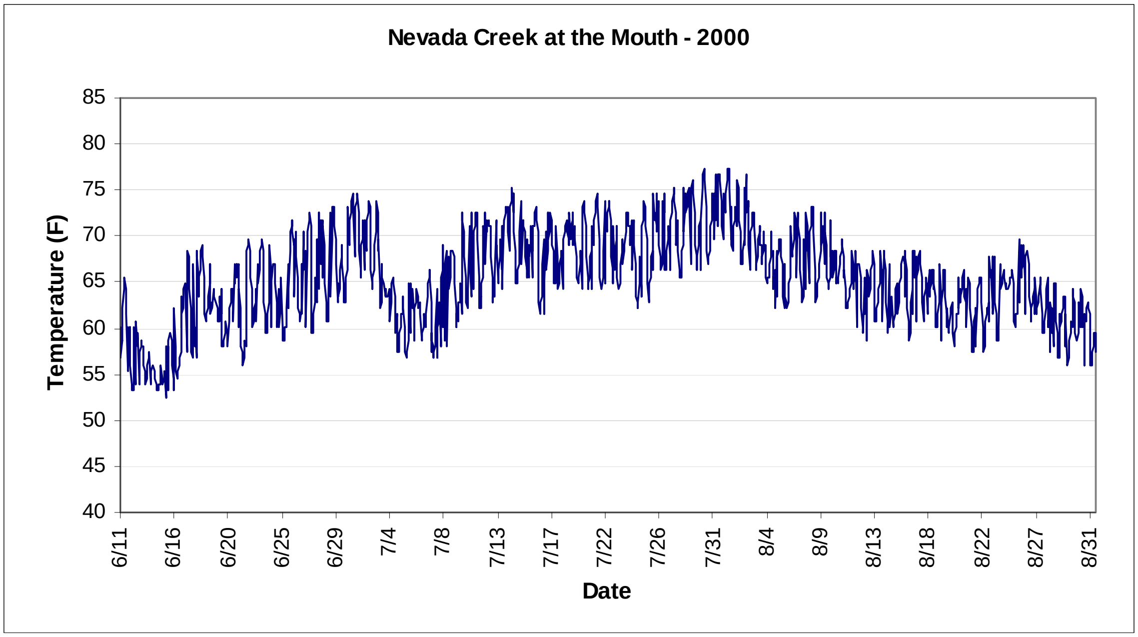


Figure 3-21: Continuous water temperature, Nevada Creek at the mouth, 2000.

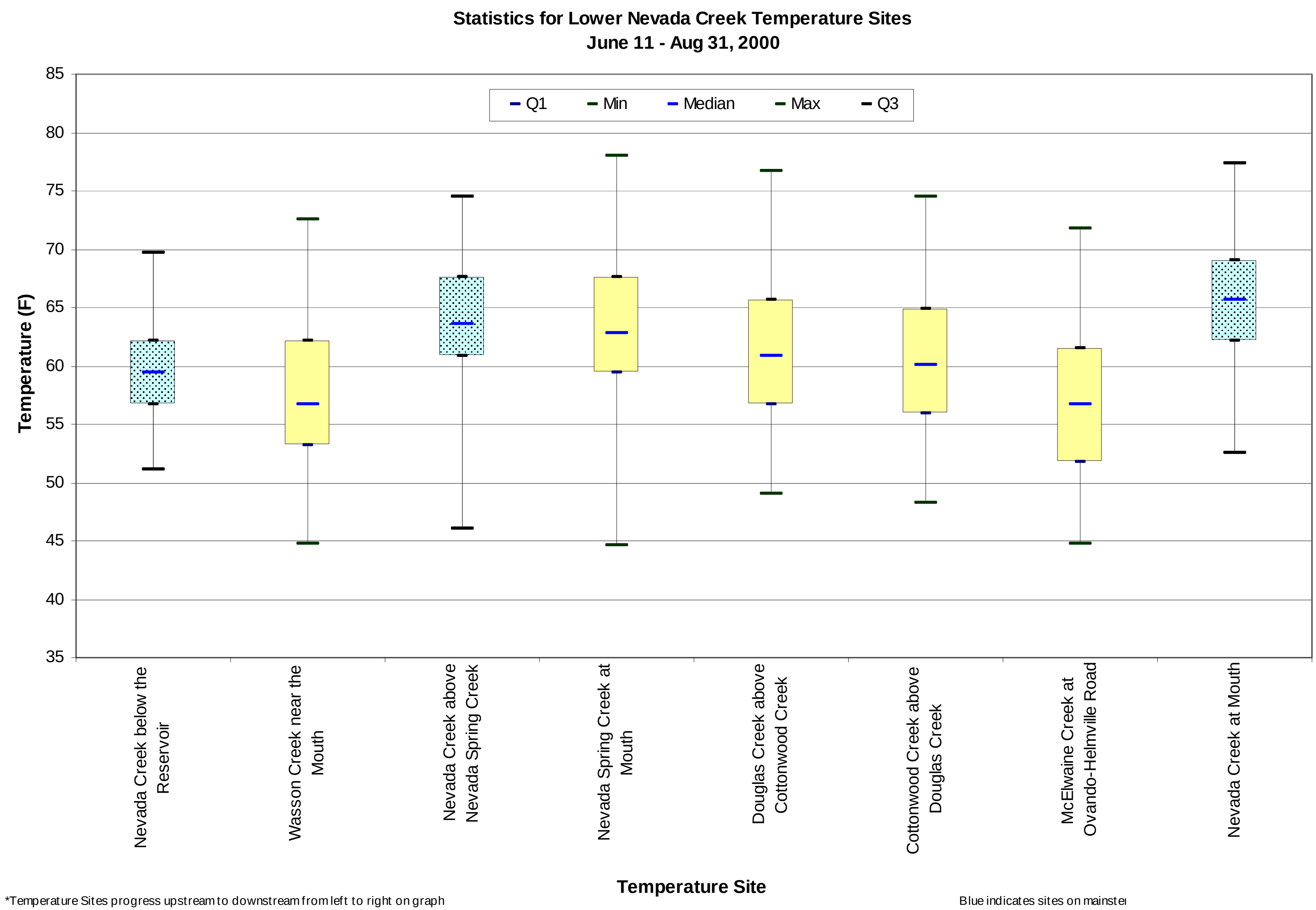


Figure 3-22. Upstream to downstream temperature variation, lower Nevada Creek, 2000.

Figure 3-23 and Figure 3-24 display the daily maximum and seven-day average maximum temperatures, respectively, at three monitoring sites on lower Nevada Creek during the summer of 2000. Precipitation and air temperature plotted on the maximum daily water temperature graph illustrates that these factors strongly influence water temperature. The seven-day average maximum temperature graph shows that maximum temperatures increase from upstream to downstream, with the highest temperatures occurring from mid July through early August before dropping off steadily in late August.

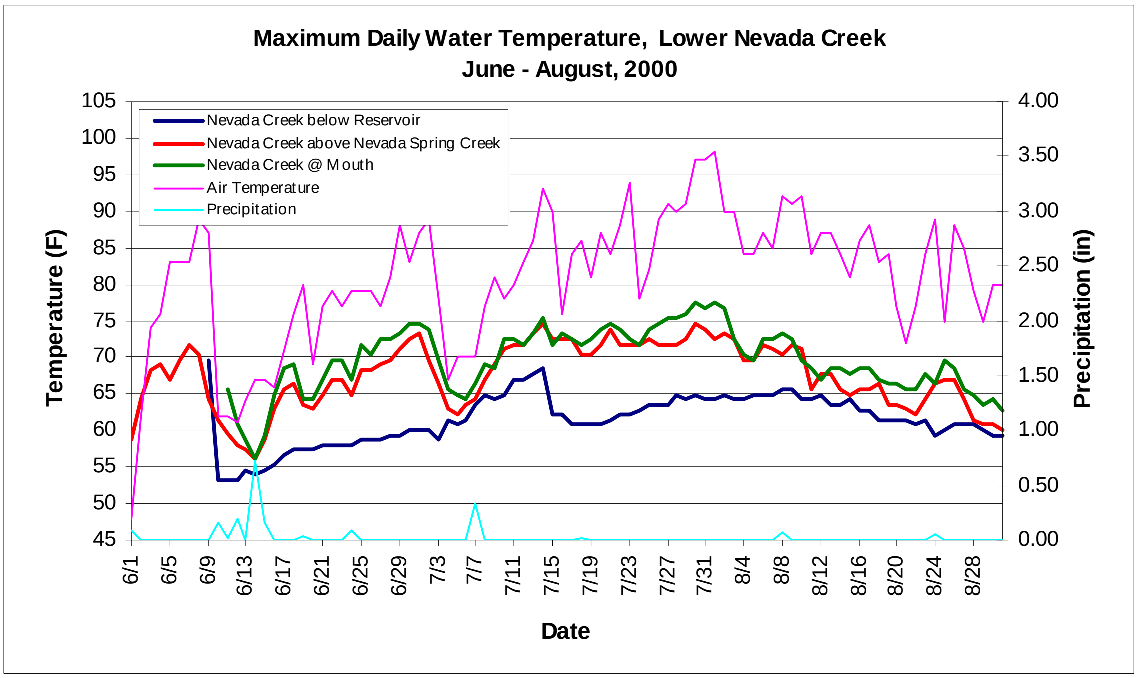


Figure 3-23. Maximum daily water temperature, air temperature, and precipitation, lower Nevada Creek, 2000.

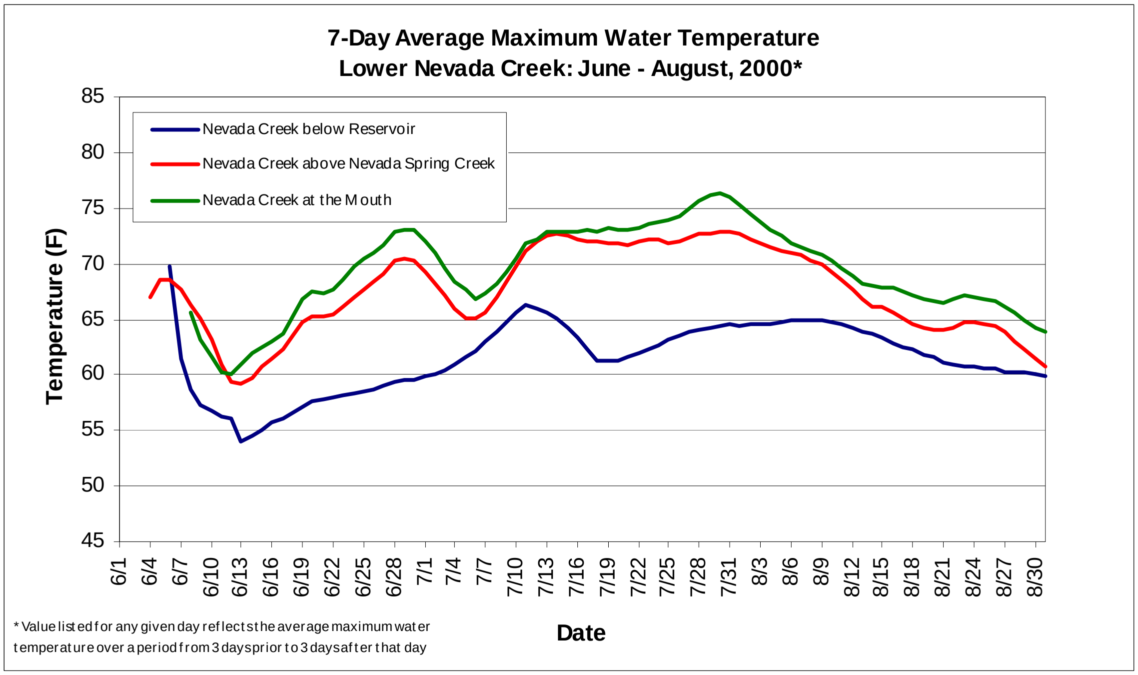


Figure 3-24. 7-day average maximum daily temperatures, lower Nevada Creek, 2000.

Lower Nevada Creek begins at the outlet of Nevada Reservoir. Here, cool water from the bottom of Nevada Reservoir is released (Figure 3-16). Between July 4 and July 15, temperatures increase below the reservoir. This reflects reduced water releases from Nevada Reservoir (Figure 3-17). Downstream, measured temperatures above Nevada Spring Creek reflect a significant temperature increase in Nevada Creek between the reservoir and Nevada Spring Creek. This reach of Nevada Creek notably lacks riparian shading and contains two major irrigation diversions. These conditions all contribute to the large thermal gains during hot summer days on this reach. Downstream, at the mouth of Nevada Creek, temperature readings indicate that Nevada Creek experiences thermal gains from Nevada Spring Creek to its confluence with the Blackfoot River. Several factors contributed to significant warming of streamflow in this reach in 2000 including warm water from Nevada Spring Creek prior to restoration, warm water from Douglas Creek, and a lack of shade and high channel width between Nevada Spring Creek and the mouth.

3.2.3. Cottonwood Creek

Temperature data for Cottonwood Creek is available for two years, 1994 and 2000. Temperature analysis and modeling for Cottonwood Creek is for the year 2000, as this is the most complete dataset. In addition, using the 2000 data allows including Cottonwood Creek in the lower Nevada Creek temperature model. Figure 3-25 and Figure 3-26 (upstream and downstream) display continuous water temperature readings collected at the two monitoring sites on Cottonwood Creek during the summer of 2000. Figure 3-27 shows the statistical distribution of summer temperatures at the two monitoring sites. The continuous temperature graphs show that temperatures fluctuate around 10-15^{o} F each day. The drop in temperatures around July 3rd indicates a cooler weather period and coincides with the drop in temperatures on lower Nevada Creek during the same period (Figure 3-16 through Figure 3-21). This may also be partly due to reduced irrigation withdrawals during hay cutting. The plots shows that temperatures are much higher downstream, although the range between maximum and minimum temperatures is similar.

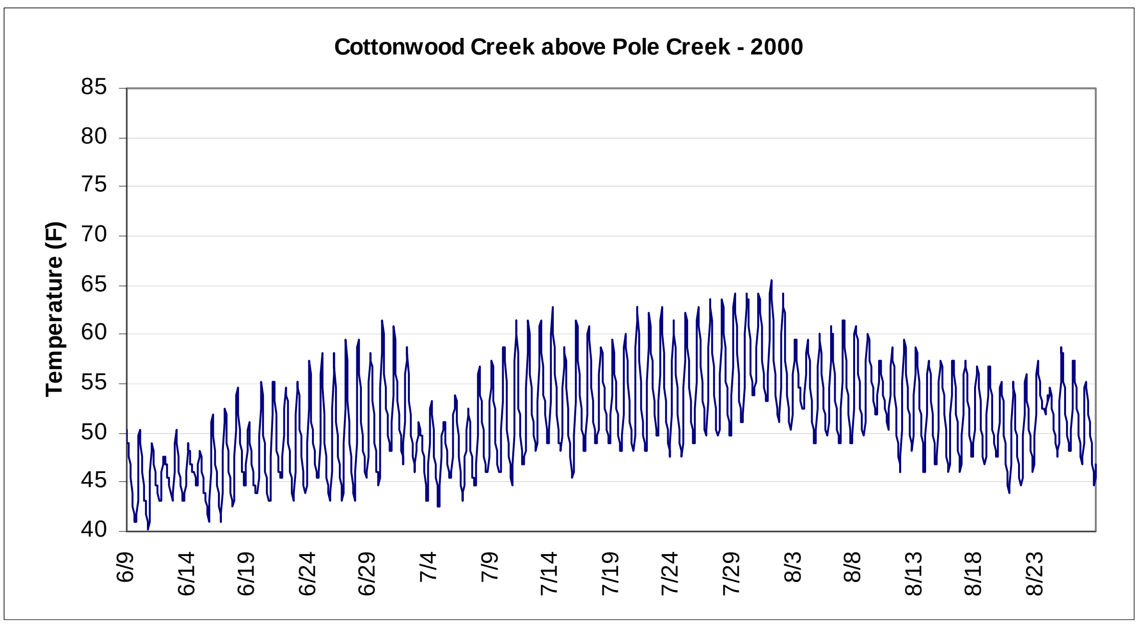


Figure 3-25: Continuous water temperature, Cottonwood Creek above Pole Creek, 2000.

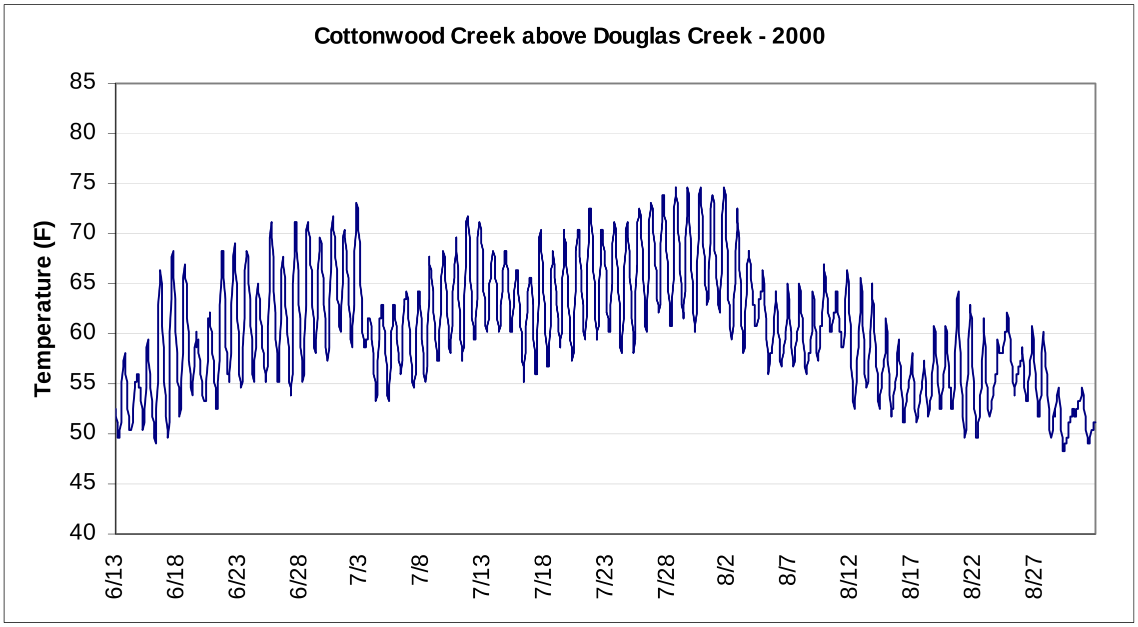


Figure 3-26: Continuous water temperature, Cottonwood Creek above Douglas Creek (Ovando-Helmville Road), 2000.

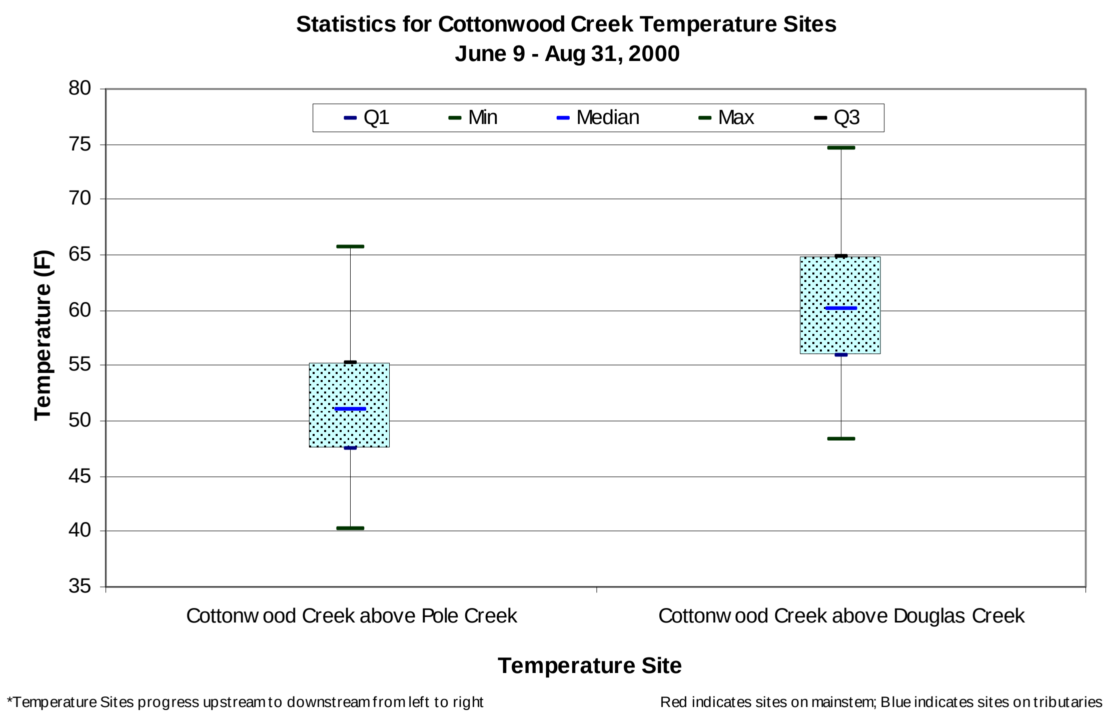


Figure 3-27. Upstream to downstream temperature variation, Cottonwood Creek, 2000.

Figure 3-28 and Figure 3-29 display the daily maximum and seven-day average maximum temperatures, respectively, at the two monitoring sites on Cottonwood Creek during the summer of 2000. As seen in other areas, precipitation and air temperature strongly influence water temperature. The seven-day average maximum temperature graph shows that maximum temperatures increase from upstream to downstream, and the highest temperatures occur in late July before dropping off steadily through August.

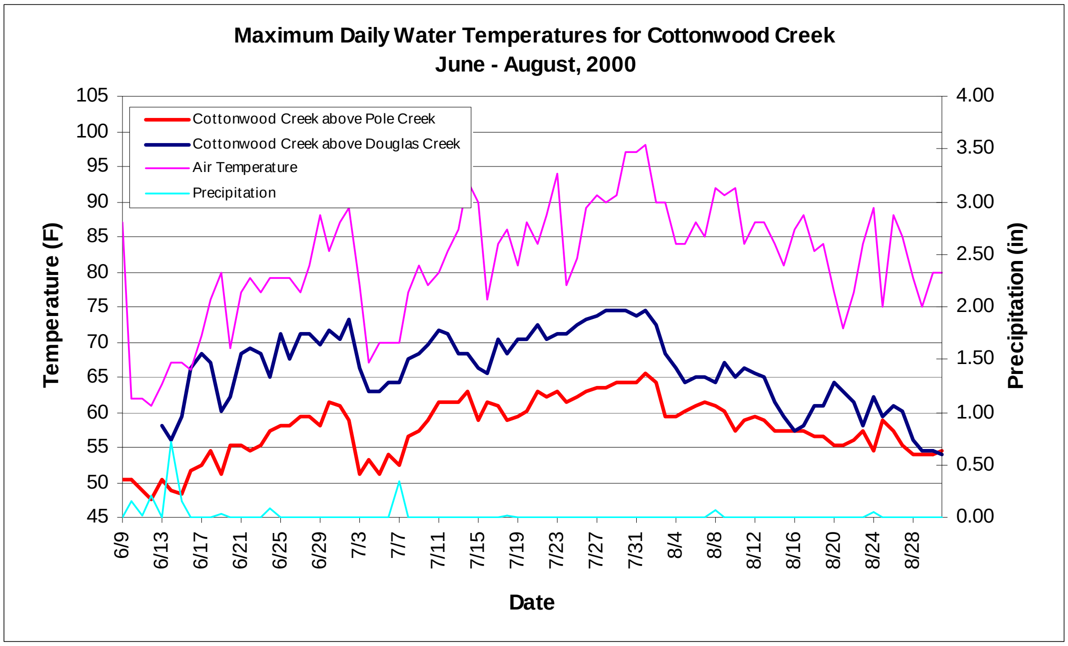


Figure 3-28. Maximum daily water temperature and climate Cottonwood Creek, 2000.

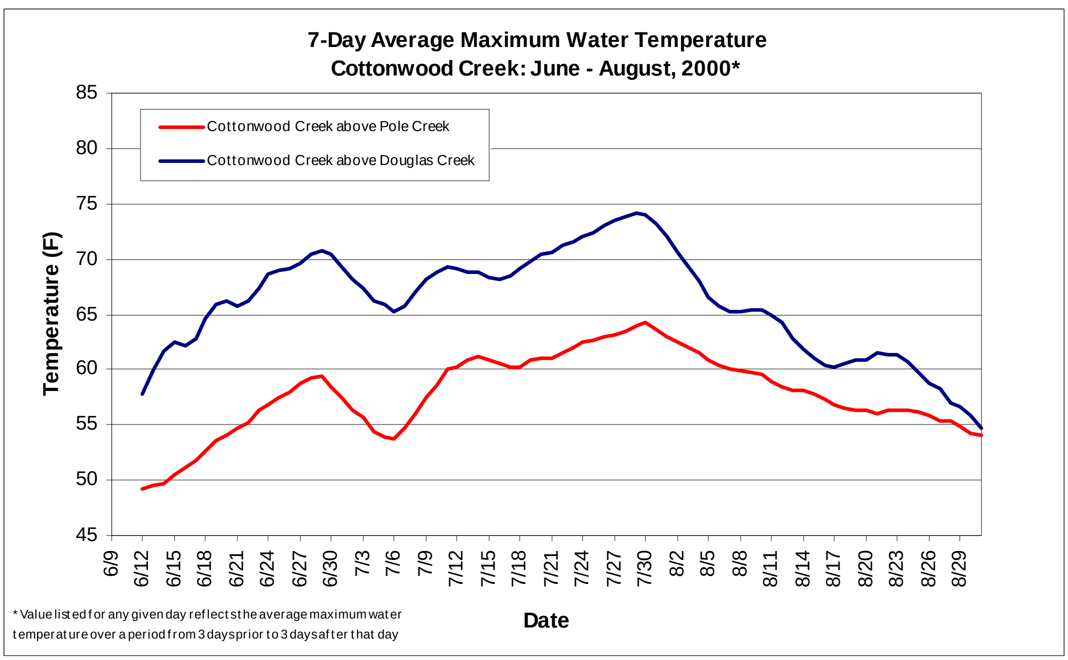


Figure 3-29. 7-day average maximum daily temperatures, Cottonwood Creek, 2000.

Cottonwood Creek above Pole Creek has cool water throughout the summer. However, Cottonwood Creek temperatures increase significantly by the time Cottonwood Creek reaches Ovando-Helmville Road, suggesting large thermal gains in the reach between these two sites. Air photos and water rights data show that below the South Fork of Cottonwood Creek, irrigation diversions reduce flow in Cottonwood Creek. About halfway between the South Fork Cottonwood Creek and Ovando-Helmville Road, riparian vegetation is sparse. Much of the thermal gain realized on hot summer days in Cottonwood Creek is attributable to these factors.

3.2.4. Douglas Creek

The Montana FWP temperature database contains temperature data collected at four sites on Douglas Creek, but not for all four sites in any year. The two upstream sites have data from 1998, while for the two sites downstream have data from 2000. However, similarities in climate (Figure 2-1 and Figure 2-2) between these two years allowed comparison of temperature data between all four sites. The 2000 data also allows inclusion of Douglas Creek in the temperature model for lower Nevada Creek.

Figure 3-30 through Figure 3-33 (upstream to downstream) display continuous water temperature readings collected at the four monitoring sites during the summers of 1998 and 2000. The lower temperatures in Douglas Creek above the reservoirs is due to much of this water sourcing from springs in Madison limestone in the Douglas Creek headwaters. The wide range in daily temperatures at the sites below the reservoirs indicates large thermal gain from both the reservoirs and stream segments separating the reservoirs.

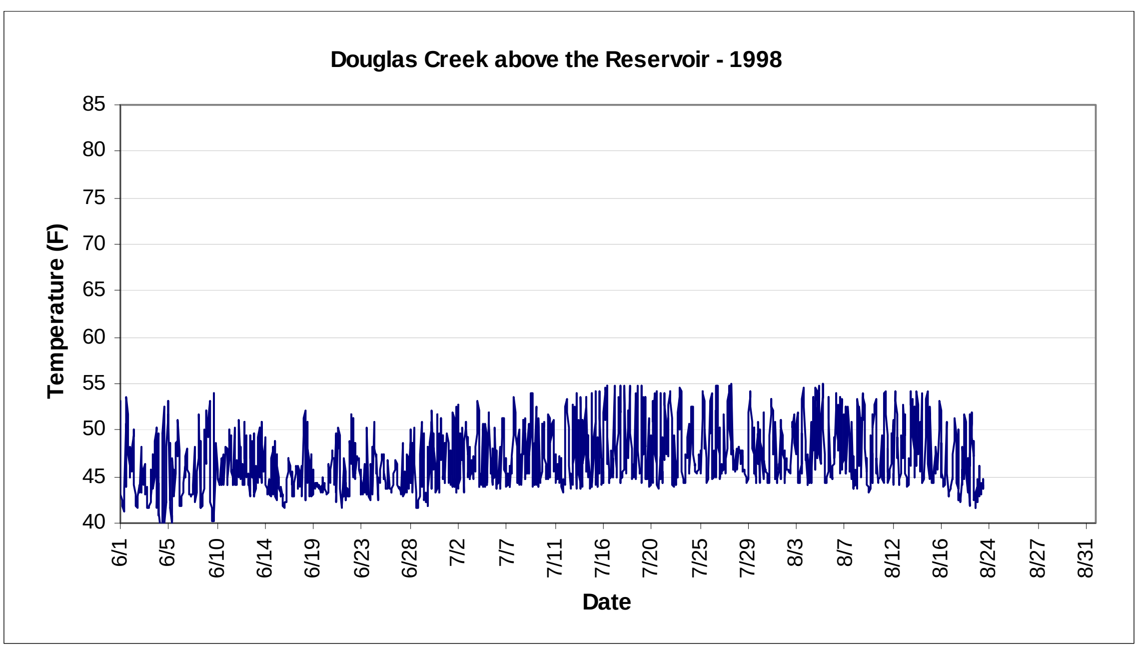


Figure 3-30: Continuous water temperature, Douglas Creek above the reservoirs, 1998.

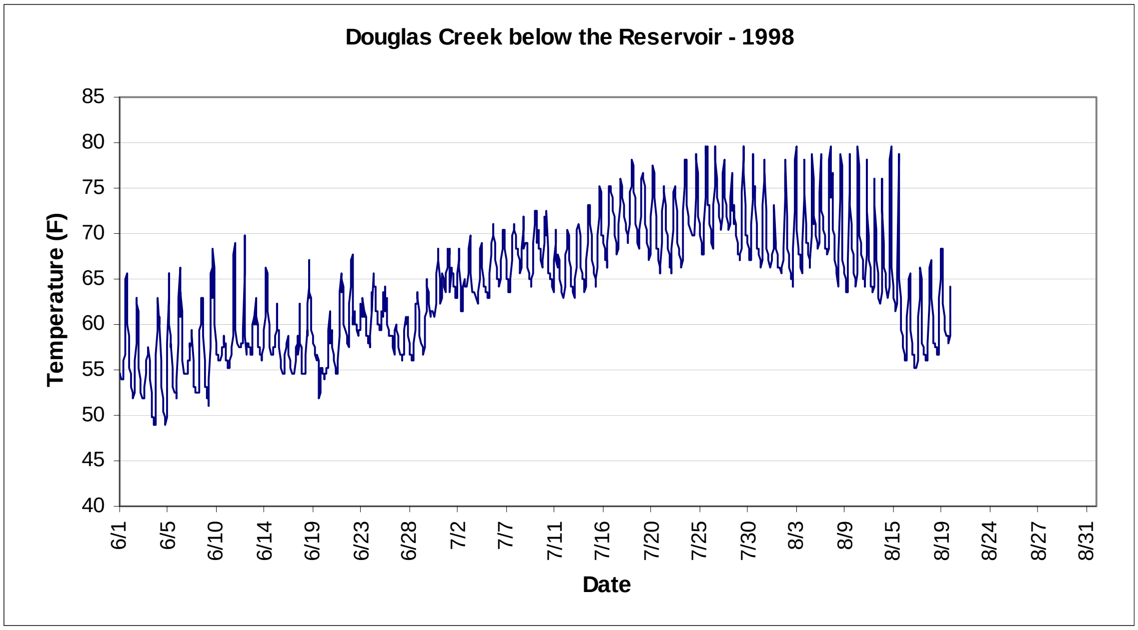


Figure 3-31: Continuous water temperature, Douglas Creek below the reservoirs, 1998.

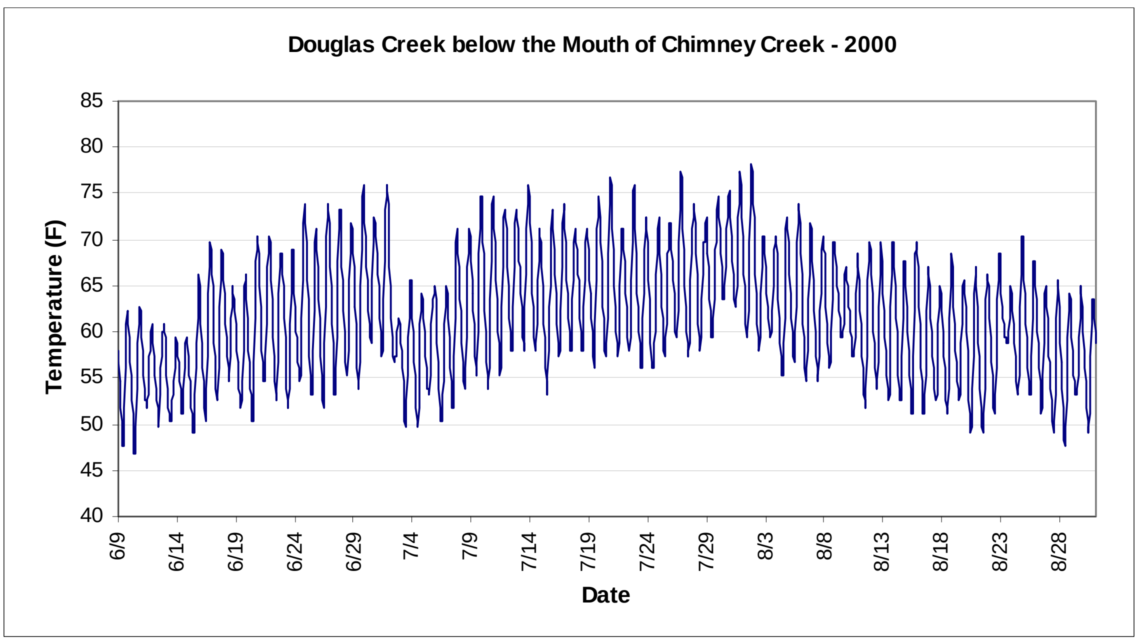


Figure 3-32: Continuous water temperature, Douglas Creek below Chimney Creek, 2000.

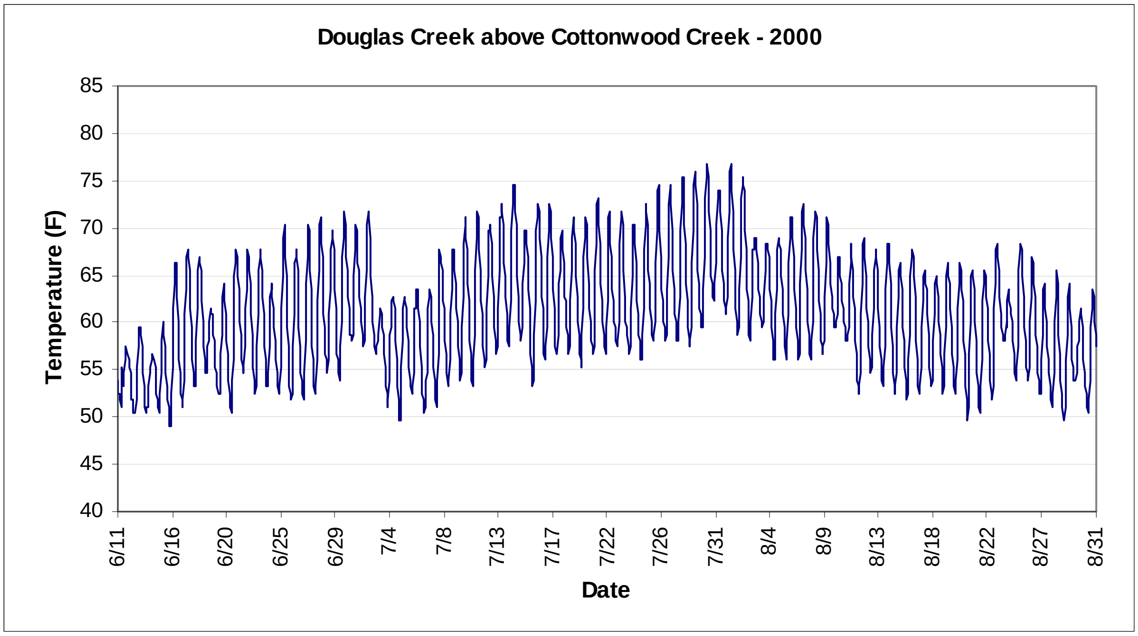


Figure 3-33: Continuous water temperature, Douglas Creek above Cottonwood Creek (Ovando-Helmville Road), 2000.

Figure 3-34 shows the statistical distribution of summer temperatures at the four monitoring sites. This figure illustrates the low temperatures at the site above the reservoir and high range in temperatures at the sites below the reservoir. Temperatures also decrease slightly downstream from the reservoir to the site above Cottonwood Creek due to cool water inflow from Chimney Creek.

The daily maximum and seven-day average maximum temperature graphs show that the highest maximum temperatures occur at the site below the reservoir. Similar to other areas, the highest temperatures at all sites occur in late July before dropping off steadily through August (Figure 3-35 and Figure 3-36). The increase in maximum temperatures of 20 to 25^{o} F between the sites above and below the reservoirs represents a substantial increase in temperature over a very short distance. As is the case for other streams, precipitation and air temperature strongly influence water temperature as illustrated in the daily maximum temperature graph (Figure 3-35).

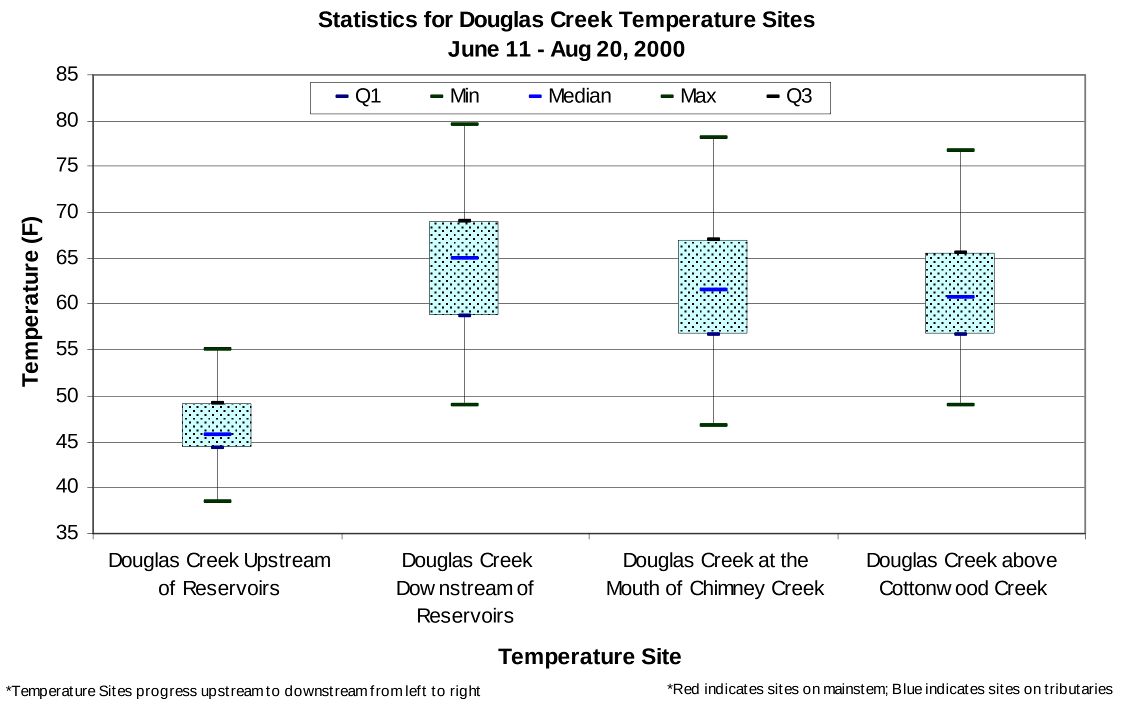


Figure 3-34. Upstream to downstream temperature variation, Douglas Creek, 2000.

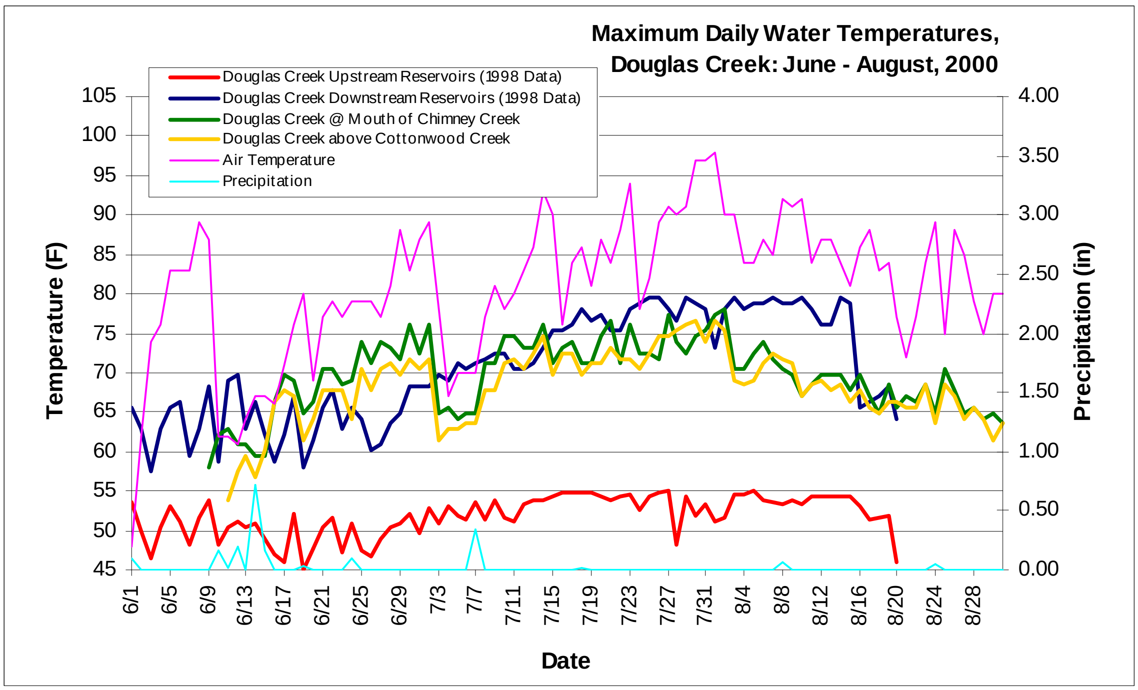


Figure 3-35. Maximum daily water temperature, air temperature, and precipitation, Douglas Creek, 2000.

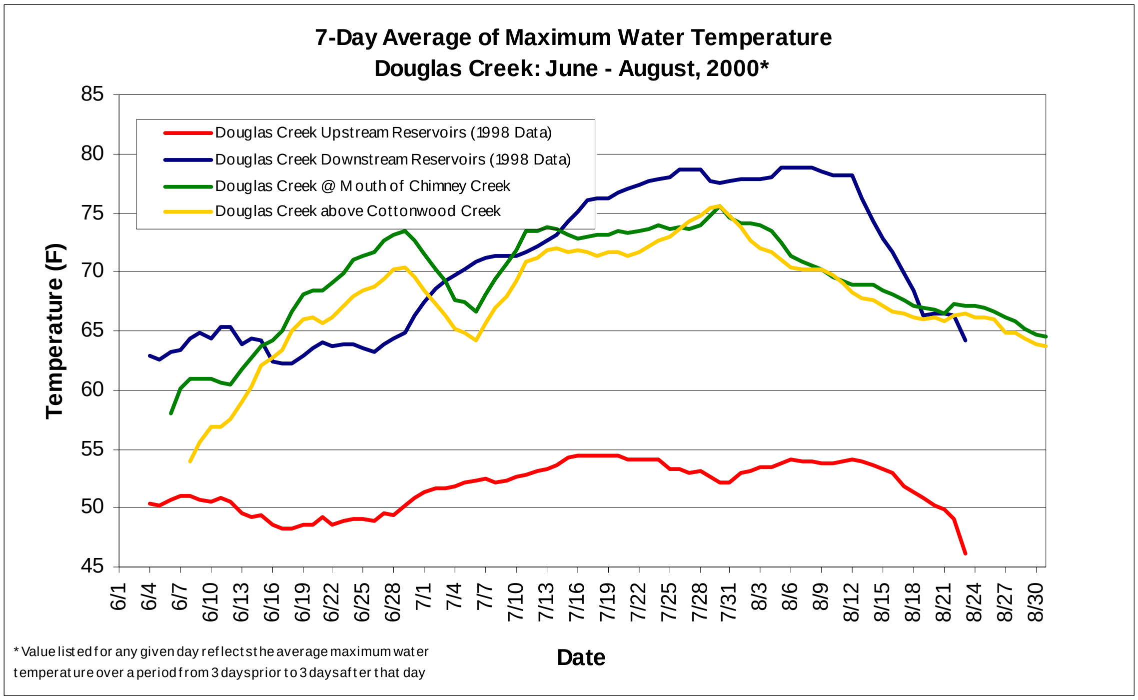


Figure 3-36. 7-day average maximum daily temperatures, Douglas Creek, 2000.

Douglas Creek above the reservoirs has cold headwaters emanating from springs in Madison limestone. The mean summer temperature of 46 ^{o} F is the coldest water measured in the Nevada Creek watershed. Measured Douglas Creek temperatures increase by as much as 25 ^{o} F below the reservoirs, indicating that the reservoirs heat the water significantly. Field observations from the base parameter assessment (DTM and AGI, 2005) suggest that the reservoirs are relatively shallow, resulting in rapid solar heating of reservoir water. Downstream, water temperatures at the monitoring site below Chimney Creek are slightly lower than below the reservoir, indicative of cooler water contributed by Chimney Creek. Temperatures then slightly decrease downstream to the site above Cottonwood Creek at Ovando-Helmville Road. In this reach Douglas Creek and the Douglas Creek Canal are coincident for ¼ mile. In this section, Douglas Creek mixes with cooler canal water, resulting in the observed temperature reduction and dampening of diurnal variation. No temperature data is available below Ovando-Helmville Road. However, a diversion that removes a large proportion of Douglas Creek's flow and the contribution of warm water from Cottonwood Creek suggests that temperatures likely increase in the reach downstream from Ovando-Helmville road to the confluence with Nevada Creek.

3.3. Temperature Modeling

The following sections describe temperature modeling for each of the 303(d) listed streams in the Nevada Creek Planning Area. SNTEMP simulated temperatures for upper and lower Nevada Creek, Douglas Creek, and Cottonwood Creek, while temperatures for the reservoirs section of upper Douglas Creek were simulated with SSTEMP.

3.3.1. Upper Nevada Creek Model

The upper Nevada Creek model simulated temperatures for Nevada Creek above Nevada Reservoir and included sections of two streams, Nevada creek and Washington Creek (Figure 3-37). Nevada Creek extends for 11.7 miles from a point above Shingle Mill Creek downstream to above Nevada Reservoir. Washington Creek is a 2.2-mile long segment extending from Highway 141 to its confluence with Nevada Creek. Modeling of Washington Creek allowed simulation of temperatures in Washington Creek and resulting effects on Nevada Creek.

Construction

Nodes in the model identify where hydrology, stream geometry, and temperature data are input in the stream network. Mitchell Creek, Halfway Creek, and Jefferson Creek are included in the model as point sources to Nevada Creek (Figure 3-37). An additional point source below Jefferson Creek accounted for groundwater flow from the Jefferson Creek drainage. Two calibration points are located in the stream network, below Halfway creek and above the reservoir. No diversion of flow occurred during the modeling period since water rights allow diversion only until late June.

Modeling of upper Nevada Creek is for the period August 5 – 7, 2001. A three-day modeling period ensured that water completed travel from the top to the bottom of the network. Table 3-3 lists stream geometry and general vegetation characteristics for the upper Nevada Creek model. About 25 percent of Nevada Creek has woody streambank vegetation, while Washington Creek is largely absent of woody vegetation.

Stream	***Modeling Period***	***Length (mi)***	***Average Low Flow Width (ft)***	***Streambank Vegetation (%) ****	***Current Shade (%)***
Nevada Creek	Aug 5-7, 2001	11.7	12.5	24.1	13.1
Washington Creek	Aug 5-7, 2001	2.2	5.5	2.6	2.8

*Streambank vegetation is percent of total stream bank in model that consists of vegetation that produces shade. Shade is percent of total stream surface area covered by shade.

Table 3-3. Current stream characteristics for the upper Nevada Creek SNTEMP model.

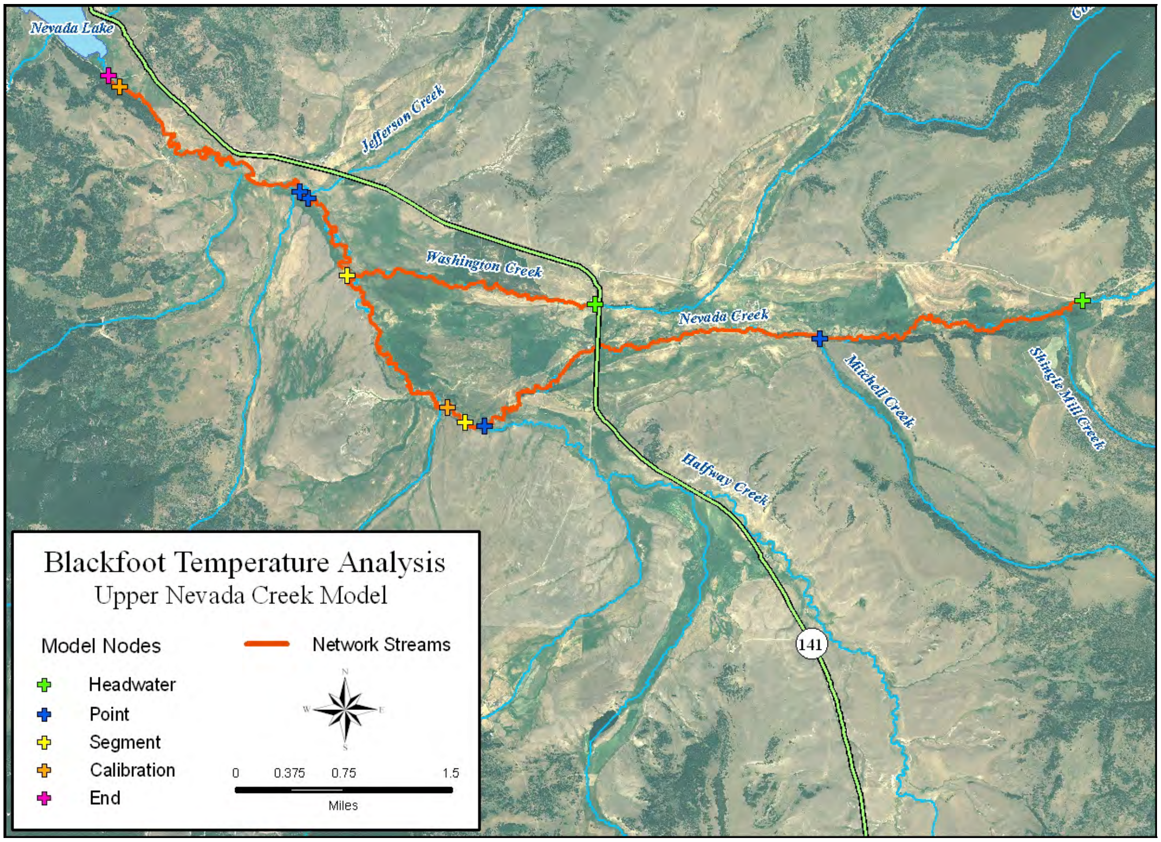


Figure 3-37. Schematic of the Upper Nevada Creek model network and model nodes.

For the modeling period, stream geometry and hydrology data was input into the model for all segments and nodes in the upper Nevada Creek network (Table 3-4). For each segment, flow, width, Manning's-n, and shade are defined. The table illustrates that the segment of Nevada Creek from Shingle Mill Creek to Halfway Creek accounts for most of the streambank vegetation and shade in the model. Woody vegetation is largely absent in Nevada Creek from Halfway Creek to the reservoir, and in Washington Creek. The Manning's n value, (a measure of water friction flowing over a streambed) of 0.062 is representative of the streams substrate, planform, and vegetation. Halfway Creek, with a mean water temperature of 65.9 ^{o} F, has the highest temperature water input in the model. The groundwater temperature of 55 ^{o} F to Nevada Creek below Jefferson Creek reflects historical summertime well and spring temperature measurements from the Nevada Creek watershed. Along with Mitchell Creek at 55.1 ^{o} F, these waters are the lowest temperature contributions to the model.

Table 3-4. Input data for the upper Nevada Creek model.

Stream	Segment	Node	Stream Mile	Water Temperature Mean (F)	Flow (cfs)	Stream Width (ft)	Manning's n	Streambank Veg (%)	Shade (%)	Comments
Nevada Creek	Shingle Mill to Halfway Ck	Headwater*	46.2	54.5	8.1	13.1	0.062	48.0	25.7	Above Shingle Mill Creek
		Point	43.8	55.1	1.5					Mitchell Creek
		Point	40.6	65.9	1.8					Halfway Creek
	Halfway Ck to Washington Ck	Segment	40.5		11.4	13.4	0.062	0.0	0.0	Below Halfway Creek
		Calibration	40.2	62.6	11.4					Temperature site below Halfway Ck
	Washington Ck to the Reservoir	Segment	38.4		15.4	11.3	0.062	3.0	2.1	Confluence with Washington Ck
		Point	37.3	60.5	2.3					Jefferson Ck
		Point	37.2	55.0	1.0					Point source return flow
		Calibration	34.6	63.8	18.7					Temperature site above reservoir
		End	34.5		18.7					Above Nevada Reservoir
Washington Creek	HWY 200 to Nevada Ck	Headwater*	40.6	59.0	4.0	5.5	0.062	2.6	2.8	At Highway 141
		End	38.4		4.0					Confluence with Nevada Creek

*Headwater is the starting point of each stream in the model network. Water temperature and flow for point nodes represent temperature of water and amount of water contributed to Nevada Creek from point source. Flow for all other nodes represents flow in the stream.

Meteorological data for the modeling period August 5 - 7, 2001 were summarized and input into the model (Table 3-5). These data are representative of the hot and dry conditions that cause water temperature extremes. The average daily maximum air temperature for this period of 88.3 ^{o} F represents one of the hotter periods of the summer of 2001.

Modeling Period	*Air Temperature (F)*		*Relative Humidity (%)*	*Wind (mph)*	*Possible Sun (%)*	*Dust Coefficient*	*Ground Reflectivity*
	Daily Mean	*Daily Maximum**					
Aug 5 - 7, 2001	68.0	88.3	57.1	2.4	95	0.05309	0.27086

* Daily maximum temperature is not an input into model but is included for comparison purposes.

Table 3-5. Meteorological input data for the upper Nevada Creek SNTEMP model.

Calibration

Model runs for Nevada Creek required little calibration. The first model run for Nevada Creek simulated temperatures that were too high. Simulated mean daily temperatures were 1.93^{o} and 3.28^{o} F greater than observed mean temperatures at the locations below Halfway Creek and above the reservoir, respectively (Table 3-6 through Table 3-7).

Meteorological data was least reliable in terms of characterizing conditions found on the stream, as the weather stations that provided data are located off the stream. To calibrate the model, wind speed was increased to 6.72 mph. The resulting simulated mean temperatures were still too high. Adjusting relative humidity to 40% lowered temperatures further. This yielded simulated mean daily temperatures lower than observed temperatures by 0.39^{o} F below Halfway Creek and higher by 0.33^{o} F above the reservoir. These values were well within the margin of 0.9^{o} F for calibration.

Calibration Iteration	*Temperature (F)*		*Difference from Observed Temp (F)*		*Parameter Changed / Rational*
	Mean	*Max*	*Mean*	*Max*	
Observed Temperature	62.58	72.23	NA	NA	NA
Initial Model Run	64.51	76.05	1.93	3.82	Default Parameter Values
1	64.00	73.94	1.42	1.71	Wind Speed - increased to 6.72 mph
2	62.19	72.34	-0.39	0.11	Wind Speed - increased to 6.72 mph Relative Humidity - decreased to 40%

Table 3-6: Initial model and calibration results for upper Nevada Creek below Halfway Creek.

Calibration Iteration	***Temperature (F)***		***Difference from Observed Temp (F)***		***Parameter Changed / Rational***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	63.82	71.31	NA	NA	NA
Initial Model Run	67.10	75.00	3.28	3.69	Default Parameter Values
1	66.11	73.15	2.29	1.84	Wind Speed - increased to 6.72 mph
2	64.15	71.35	0.33	0.04	Wind Speed - increased to 6.72 mph Relative Humidity - decreased to 40%

Table 3-7: Initial model and calibration results for upper Nevada Creek above the reservoir.

Simulations

After calibration, model simulations evaluated the effect different levels of riparian shade had on stream temperatures. Increased flow and channel width were not relevant for the simulations for upper Nevada Creek. Riparian shade is presented as percent of streambank with woody vegetation.

Five SNTEMP simulations assessed the effect of riparian shade on stream temperatures. One simulation was the calibrated model with current streambank vegetation conditions (19%). A second simulation modeled natural conditions. Montana DEQ defined natural conditions as 95% of streambanks with woody vegetation for this project. Two additional simulations modeled streambank vegetation at levels between current and natural conditions. A final simulation assessed the amount of vegetation required to keep temperatures within one degree Fahrenheit of the natural condition scenario. The one-degree allowable increase is the temperature target established by Montana DEQ (ARM, 2006).

For natural conditions, the model simulated a mean daily temperature of 60.66^o F (Table 3-8 and Figure 3-38). This value is lower than temperature simulated with current stream conditions by 3.49^o F. A simulation that increases streambank vegetation to 20% reduced mean temperature by 0.14^o F, while simulating streambank vegetation increased to 60% reduced mean temperature by 1.94^o F. A linear relationship between the results for these three simulations established a target value for streambank vegetation of 73%. Using this target value, the model simulated a mean daily temperature of 61.61^o F. This is 2.54^o F less than the mean daily temperature with current conditions, and 0.95^o F greater than the temperature for natural conditions. This falls within the one-degree allowable increase from with natural conditions.

These results indicate that meeting temperature targets in Nevada Creek above the reservoir requires increasing woody vegetation to 73% along Nevada Creek and Washington Creek modeled streambanks.

Model Run	***Temperature (F)***		***Difference from Calibration (F)***		***Comments***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	63.82	71.31	NA	NA	NA
Calibrated Temperature	64.15	71.35	NA	NA	Simulated temperature above the reservoir with current stream conditions
Simulation 1	64.00	70.59	-0.14	-0.76	20% of bank with woody vegetation cover
Simulation 2	62.24	67.60	-1.91	-3.75	60% of bank with woody vegetation cover
Target Conditions	61.61	66.74	-2.54	-4.61	73% of bank with woody vegetation cover
Natural Conditions	60.66	64.98	-3.49	-6.37	95% of bank with woody vegetation cover

Table 3-8. Simulation results for upper Nevada Creek above the reservoir.

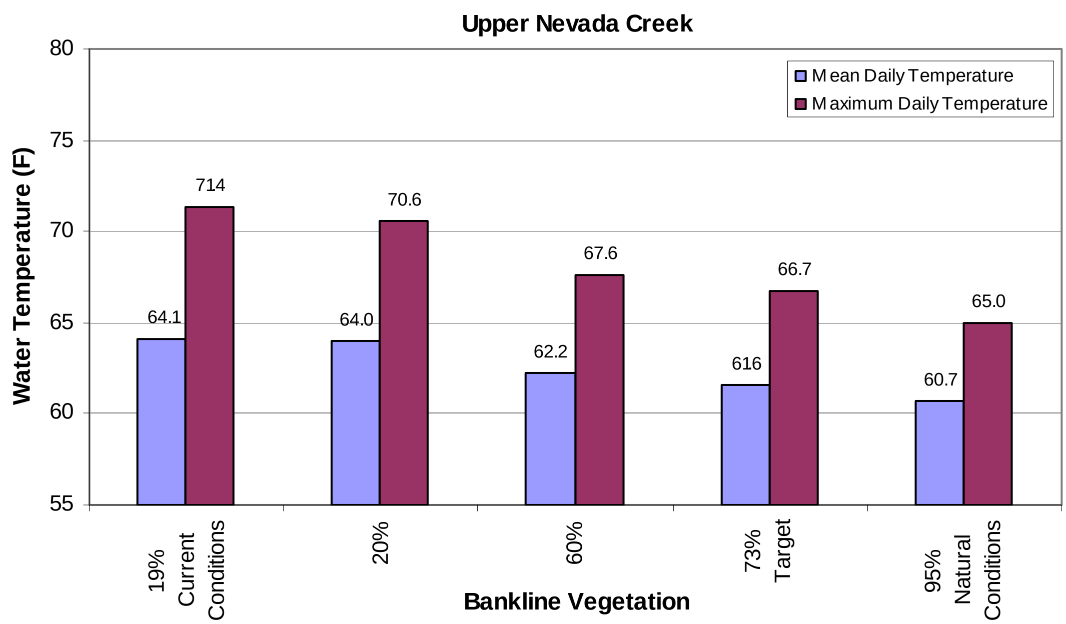


Figure 3-38. Simulated mean and maximum temperature with change in bankline vegetation for Upper Nevada Creek.

3.3.2. Lower Nevada Creek Model

The lower Nevada Creek model simulated temperatures for three connected 303(d) list streams; Cottonwood Creek, Douglas Creek, and lower Nevada Creek (Figure 3-39). Nevada Creek extends for 31.5 miles from below Nevada Reservoir downstream to its confluence with the Blackfoot River. Cottonwood Creek is an 11.1-mile long segment extending from above Pole Creek to its confluence with Douglas Creek. Douglas Creek is a 16 miles long from below the reservoirs to its confluence with Nevada Creek.

Construction

Nodes in the model identify where hydrology, stream geometry, and temperature data are input in the stream network. Point sources from tributary streams in the model include Nevada Spring Creek, Sturgeon Creek, Chimney Creek, and Murray Creek. An additional point source into Douglas Creek below Chimney Creek and subsequent removal downstream accounted for mixing of Douglas Creek canal water with Douglas Creek water. Calibration points for Nevada Creek are above Nevada Spring Creek and at the mouth. Cottonwood Creek and Douglas Creek had calibration points at the Ovando-Helmville Road. An additional calibration point for Douglas Creek is located below Chimney Creek. All streams had water diversion points. For Nevada Creek, four diversion points were located along a nine mile stretch downstream of Braziel Creek. These include the Douglas Creek and North Helmville canals. Cottonwood Creek had two diversion points, below the North Fork Cottonwood Creek and downstream below the Ovando-Helmville Road, while Douglas Creek also had water diverted below the Ovando-Helmville Road.

Modeling of lower Nevada Creek is for the period July 27 – August 2, 2000. A seven-day modeling period ensured that water completed travel from the top to the bottom of the network. Table 3-9 lists stream geometry and general vegetation characteristics for the lower Nevada Creek model. About 44 percent of the Nevada and Cottonwood creek streambanks have woody vegetation, while Douglas Creek has woody vegetation on about 30 percent of its streambanks. Cottonwood Creek is the narrowest stream with an average low flow width of only 5.2 feet.

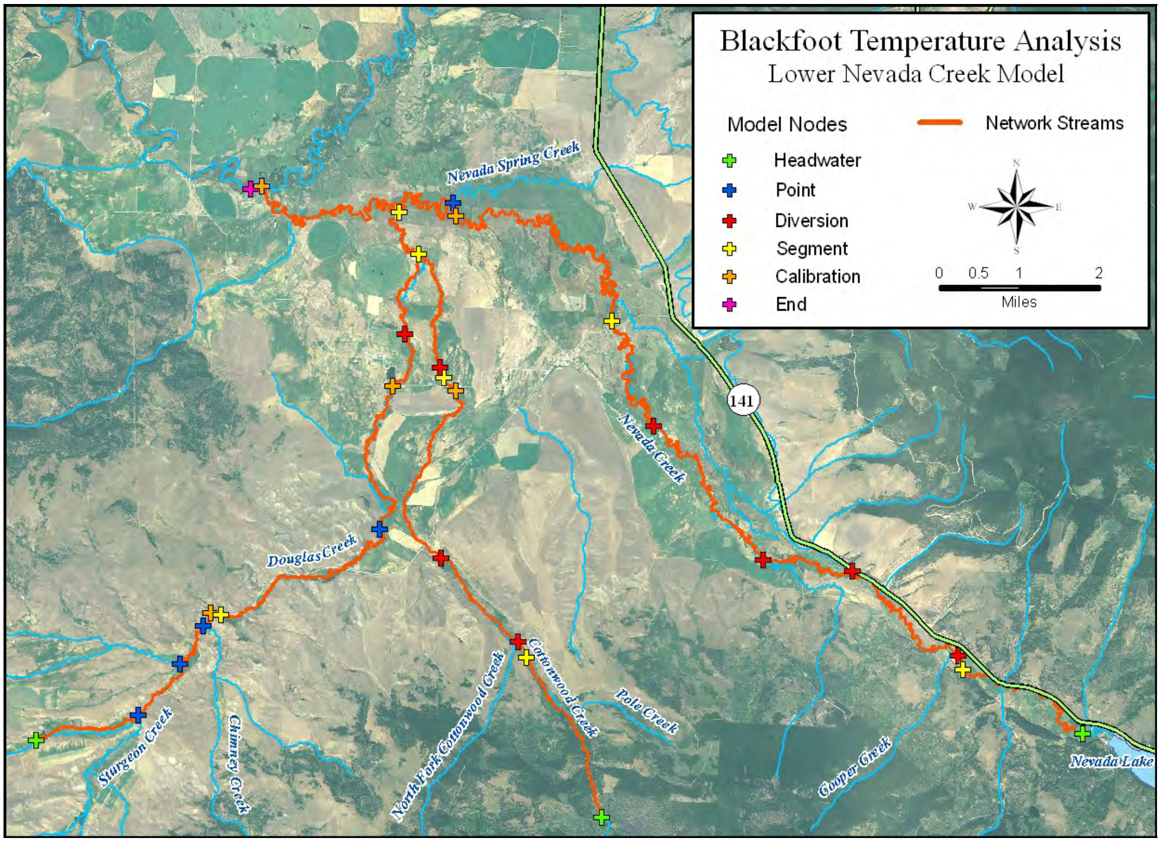


Figure 3-39. Schematic of the Lower Nevada Creek model network and model nodes.

Stream	***Modeling Period***	***Length (mi)***	***Average Low Flow Width (ft)***	***Streambank Vegetation (%)***	***Average Shade (%)***
Cottonwood Creek	July 27 - Aug 2, 2000	11.1	5.2	43.8	30.0
Douglas Creek	July 27 - Aug 2, 2001	16.0	9.1	29.9	18.8
Nevada Creek	July 27 - Aug 2, 2001	31.5	20.1	44.0	12.2

*Streambank vegetation is percent of total stream bank in model that consists of vegetation capable of producing shade. Shade is percent of total stream surface area covered by shade.

Table 3-9. Stream conditions for the lower Nevada Creek SNTEMP model.

Table 3-10 lists data input into the model. For each segment and headwater node, flow, width, Manning's-n, and shade must be designated, while water temperature is required for headwater nodes. All other nodes require only water temperature and/or flow data.

Table 3-10. Input data for the lower Nevada Creek model.

Stream	Segment	Node	Stream Mile	Water Temperature (F)	Flow (cfs)	Stream Width (ft)	Manning's n	Streambank Veg (%)	Shade (%)	Comments
Nevada Creek	Reservoir to above Cooper Ck	Headwater*	31.5	63.3	89.0	26.0	0.062	0.0	0.8	Below the reservoir
	Cooper Ck to Above Nevada Spring Creek	Segment	28.8		89.0	18.9	0.062	57.5	24.5	Above Cooper Creek
		Diversion	28.6		30.0					
		Diversion	25.5		30.0					
		Diversion	23.4		10.0					
		Diversion	19.2		10.0					
	Above Nevada Spring Creek to Douglas Ck	Segment	15.3		9.0	11.3	0.062	42.0	2.1	Above Lincoln Slough
		Calibration	7.3	70.4	9.0					Site above Nev Spg Ck
		Point	7.2	55.7	9.0					Nevada Spring Creek
	Douglas Ck to the Mouth	Segment	4.8		22.0	39.2	0. 062	35.0	6.0	Confluence with Douglas Ck
		Calibration	0.1	71.9	22.0					Site at the mouth of Nevada Ck
		End	0.0		22.0					Confluence with Blackfoot River

Stream	Segment	Node	Stream Mile	Water Temperature (F)	Flow (cfs)	Stream Width (ft)	Manning's n	Bankline Veg (%)	Shade (%)	Comments
Douglas Creek	Below the Reservoir to Chimney Ck	Headwater*	20.8	70.6	1.0	5.9	0.062	7.1	5.2	Above Shingle Mill Creek
		Point	18.9	66.0	2.0					Sturgeon Creek
		Point	17.7	70.0	1.0					Murray Creek
		Point	16.8	65.0	2.0					Chimney Creek
		Calibration	16.7	67.4	6.0					Site below Chimney Creek
	Chimney Ck to Cottonwood Ck	Segment	16.6		6.0	10.0	0.062	38.9	24.3	Below Halfway Creek
		Point	12.5	64.0	2.0					Canal return
		Calibration	9.2	66.9	8.0					Site at Ovando-Helmville Rd
		Diversion	8.0		5.0					Below Ovando-Helmville Rd
	Cottonwood Ck to Mouth at Nevada Ck	Segment	6.3		3.0	12.0	0.062	32.0	18.7	Confluence with Cottonwood Ck
		End	4.8		2.3					Confluence with Nevada Ck
Cottonwood Creek	Above Pole Ck to the South Fork	Headwater*	17.4	56.7	4.0	6.0	0. 062	80.0	56.2	Above Pole Creek
	South Fork to Ovando-Helmville Road	Segment	14.7		4.0	5.0	0.062	32.8	21.5	South Fork Cottonwood Ck
		Diversion	14.4		1.0					Below South Fork
		Diversion	12.6		1.0					
		Calibration	9.3	67.5	2.0					Site at Ovando-Helmville Rd
	Ovando-Helmville Road to Douglas Ck	Segment	9.1		2.0	5.0	0.062	31.0	21.6	Below Ovando-Helmville Rd
		Diversion	8.8		1.0					
		End	6.3		1.0					Confluence with Douglas Ck

*Headwater is the starting point of each stream in the model network

Meteorological data for the modeling period July 27 – August 2, 2000 were summarized and input into the model (Table 3-11). These data are representative of hot and dry conditions that cause water temperature extremes. The average daily maximum temperature, 90.7° F, represents a hot period in the summer of 2000.

Modeling Period	***Air Temperature (F) (mean)***	***Relative Humidity (%) (mean)***	***Wind (mph) (mean)***	***Possible Sun (%)***	***Dust Coefficient***	***Ground Reflectivity***
July 27 - Aug 2, 2000	69	43.2	3.6	94	0.05103	0.27690

Table 3-11. Meteorological input data for the lower Nevada Creek SNTEMP model.

Calibration

Calibration for the lower Nevada Creek model required adjusting parameters sequentially for three streams, Cottonwood Creek, Douglas Creek, and Nevada Creek. Since Cottonwood Creek terminates at and contributes its water to Douglas Creek, temperature at the outlet of Cottonwood Creek influences Douglas Creek. Therefore, calibration on Cottonwood Creek commenced first. Calibration for Douglas Creek occurred next as this stream contributes water to Nevada Creek. Nevada Creek simulated temperatures were the last calibrated.

Cottonwood Creek

Model runs for Cottonwood Creek required little calibration. The first model run simulated a mean and maximum daily temperature of 67.10° and 77.74° F, respectively (Table 3-12). The mean temperature was 0.38° F lower than observed mean temperature at this site, within the requirements for calibration. However, the maximum temperature was 3.7° F warmer than the observed maximum temperature.

To improve the model's performance for maximum temperature, Manning's n was increased from 0.062 to 0.080. Manning's n was adjusted because changes in this parameter only effects maximum temperatures in the model. The SNTEMP model uses the Manning's n parameter to capture the appropriate mixing depth and travel time of the stream. The result of changing Manning's n to 0.080 "speeds up" the stream and lowers simulated maximum temperature by 0.54° F, 3.16° F above the observed maximum temperature. However, higher values for Manning's n are unrealistic. In addition, there is uncertainty in the capability of SNTEMP to predict daily maximum temperatures accurately (Bartholow, 2004).

Location: Cottonwood Creek at Ovando-Helmville Road					
Calibration Iteration	Temperature (F)		Difference from Observed Temp (F)		Parameter Changed
	Mean	Max	Mean	Max	
Observed Temperature	67.48	74.04	NA	NA	NA
Initial Model Run	67.10	77.74	-0.38	3.70	Default Parameter Values
1	67.10	77.20	-0.38	3.16	Manning's n - Increase to 0.080

Table 3-12. Initial model and calibration results for Cottonwood Creek at Ovando-Helmville Road.

Douglas Creek

The Douglas Creek model required little calibration. The initial model run for Douglas Creek simulated mean daily temperatures 0.83^o F and 1.63^o F greater than observed temperatures at the locations below Chimney Creek and below Ovando-Helmville Road, respectively (Table 3-13 through Table 3-14). The difference between simulated and observed mean temperature at the site below Chimney Creek was within the margin for calibration of 0.9^o F and no further calibration was required for the upstream portion of the model. However, additional calibration was necessary for the site below Ovando-Helmville Road.

Since the lower Nevada Creek SNTEMP model includes Douglas Creek and Cottonwood Creek, adjustment of meteorological parameters would also affect results of these streams. The excellent calibration results for Cottonwood Creek would be degraded by adjusting meteorology input. Calibrating temperatures at the node at Ovando-Helmville Road without affecting Cottonwood Creek and Nevada Creek therefore required adjustment of a segment specific parameter.

Field observations suggest that some of the flow in Douglas Creek upstream from the Ovando-Helmville Road is subsurface and interacts with groundwater. A suppressed diurnal temperature variation in the FWP data supports this observation (Figure 3-34). Thermal gradient is a segment specific parameter that is a measure of thermal exchange between the streambed and water in joules/meter^{2}second/^{o}C (Bartholow, 2004). Streams that interact with groundwater typically have a higher thermal gradient and a suppressed diurnal temperature variation. Based on this information, thermal gradient was increased for calibration and yielded satisfactory results (Table 3-13 and Table 3-14).

Location: Douglas Creek below Chimney Creek					
Calibration Iteration	***Temperature (F)***		***Difference from Observed Temp (F)***		***Parameter Changed***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	67.37	75.6	NA	NA	NA
Initial Model Run	68.20	77.22	0.83	1.62	Default Parameter Values Thermal gradient = 1.65 joules/meter^{2}second/^{o}C
1	67.87	76.64	0.50	1.04	Thermal Gradient - Increase to 2.65
2	67.77	76.44	0.40	0.84	Thermal Gradient - Increase to 3.00

Table 3-13. Initial model and calibration results for Douglas Creek below Chimney Creek.

Location: Douglas Creek at Ovando-Helmville Road					
Calibration Iteration	***Temperature (F)***		***Difference from Observed Temp (F)***		***Parameter Changed***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	66.91	75.50	NA	NA	NA
Initial Model Run	68.54	75.90	1.63	0.40	Default Parameter Values
1	67.80	75.04	0.89	-0.46	Thermal Gradient - Increase to 2.65
2	67.55	74.75	0.64	-0.75	Thermal Gradient - Increase to 3.00

Table 3-14. Initial model and calibration results for Douglas Creek at Ovando-Helmville Road.

Lower Nevada Creek

The lower Nevada Creek model required little calibration (Table 3-15 and Table 3-16). The initial model run simulated mean daily temperatures of 70.92^{o} and 71.74^{o} F above Nevada Spring Creek and at the mouth, respectively. When compared to observed mean temperatures at these locations, both of these temperatures were within the 0.9^{o} F requirement for calibration. However, simulated maximum temperatures were 5.5 and 1.43^{o} F higher than observed temperatures at the two sites. The high, simulated maximum temperatures are explained by proximity to Nevada Reservoir. Water released from the reservoir has minimal diurnal variation in temperature since it is a bottom release dam. The lack of diurnal temperature fluctuation propagates downstream, resulting in over prediction of diurnal variation and maximum temperatures.

Similar to Cottonwood Creek, Manning's n was increased from 0.062 to 0.080 to calibrate for maximum temperature on Nevada Creek. This lowered the simulated maximum temperature to 77.74^{o} F above Nevada Spring Creek, and to 77.18^{o} F at the mouth. The simulated temperature above Nevada Spring Creek was still high, while the simulated maximum temperature at the mouth was 0.78^{o} higher than the observed temperature, within the required range for calibration. Since higher values for Manning's n are unrealistic and the suppressed diurnal variation of reservoir water causes SNTEMP to over-predict temperatures, no addition calibration was necessary.

Location: Nevada Creek Above Nevada Spring Creek					
Calibration Iteration	***Temperature (F)***		***Difference from Observed Temp (F)***		***Parameter Changed / Rational***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	70.36	72.85	BNA	NA	NA
Initial Model Run	70.92	78.35	0.56	5.50	Default Parameter Values
1	70.92	77.74	0.56	4.89	Manning's n - Increase to 0.080

Table 3-15. Initial model and calibration results for lower Nevada Creek above Nevada Spring Creek.

Location: Nevada Creek Above the Confluence with the Blackfoot River					
Calibration Iteration	***Temperature (F)***		***Difference from Observed Temp (F)***		***Parameter Changed / Rational***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	71.91	76.40	NA	NA	NA
Initial Model Run	71.74	77.83	-0.17	1.43	Default Parameter Values
1	71.74	77.18	-0.17	0.78	Manning's n - Increase to 0.080

Table 3-16. Initial model and calibration results for lower Nevada Creek at the mouth.

Simulations

Simulations for Cottonwood Creek, Douglas Creek, and Nevada Creek evaluated the effect different levels of shade have on stream temperatures. Shade is expressed as percent of streambank with woody vegetation.

Five SNTEMP simulations modeled the effect of shade on stream temperatures. One simulation was the calibrated model for current conditions. A second simulation modeled natural conditions, defined by Montana DEQ as 95% of streambank having woody vegetation. Two additional simulations assessed streambank vegetation at levels between current and natural condition. A final simulation determined the one-degree allowable increase from natural conditions as the TMDL target vegetation value.

Since Cottonwood Creek flows into Douglas Creek and Douglas Creek flows into Nevada Creek, the target streambank vegetation simulations proceeded from upstream to downstream. For example, initial simulations defined the vegetation target for Cottonwood Creek at 87% streambank woody vegetation. The water temperature resulting from this simulation served as input to develop the Douglas Creek vegetation target. Douglas Creek water temperature at target vegetation levels then served as input for Nevada Creek.

Initially, simulations for Nevada Creek included channel narrowing in the lower reaches of Nevada Creek and flow augmentation of 15 percent by either reduced irrigation withdrawal or increased reservoir releases. However, results indicated minimal improvements in mean daily water temperature from these scenarios. Requiring a larger amount of flow augmentation could place large burdens on landowners and would be difficult politically. Therefore, all simulations focus on increased shade from increased streambank vegetation. Preliminary simulation results including flow and channel width are in Appendix C.

Cottonwood Creek

Results illustrate that for natural conditions (95% streambank woody vegetation); the model simulated a mean temperature of 62.67^{o} F at the mouth of Cottonwood Creek

(Table 3-17 and Figure 3-40). This value is lower than temperatures simulated with current stream conditions (33% streambank woody vegetation) by 6.88° F. A reduction in streambank vegetation to 20% increases water temperatures. A simulation that increases streambank vegetation to 60% reduces mean temperature by 4.43° F. Simulating 87% of streambank with woody vegetation is within the one-degree allowable increase from natural conditions and is the target condition.

Model Run	*Temperature (F)*		*Difference from Calibration (F)*		*Comments*
	Mean	*Max*	*Mean*	*Max*	
Calibrated Model	69.55	79.05	NA	NA	Simulated temperature at output of creek with current stream conditions (33% streambank vegetation)
Simulation 1	70.97	81.03	1.42	1.98	20% of bank with vegetation cover
Simulation 2	66.70	74.62	-2.84	-4.43	60% of bank with vegetation cover
Target Conditions	63.59	69.85	-5.96	-9.20	87% of bank with vegetation cover
Natural Conditions	62.67	68.40	-6.88	-10.66	95% of bank with vegetation cover

Table 3-17. Simulation results for Cottonwood Creek at the confluence with Douglas Creek.

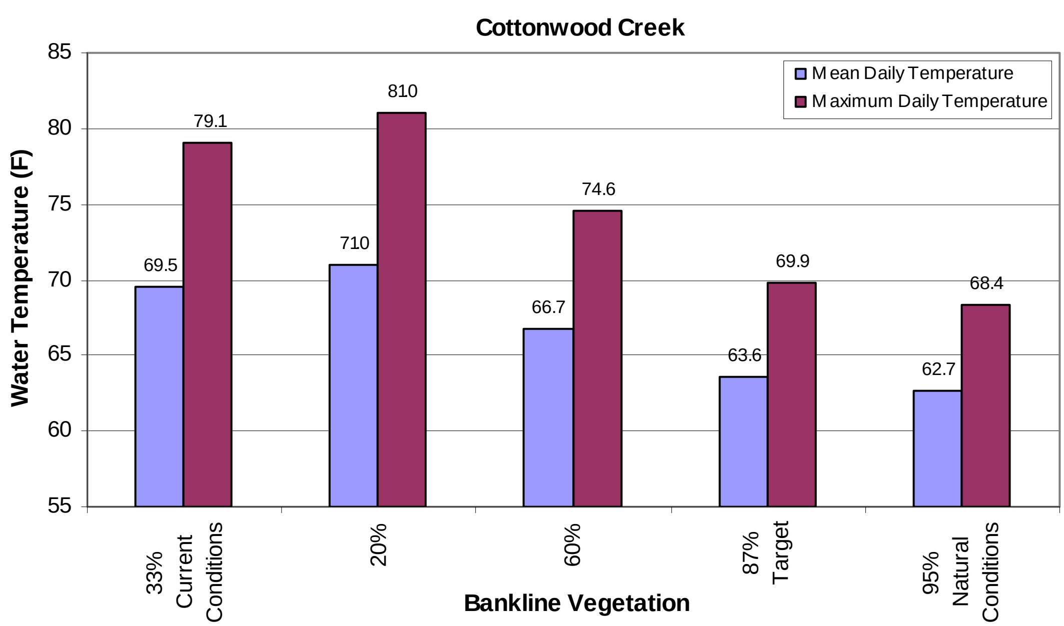


Figure 3-40. Simulated mean and maximum temperature with change in bankline vegation for Cottonwood Creek .

Douglas Creek

The difference in simulated mean temperature in Douglas Creek between current and natural conditions is 5.92° F (Table 3-18 and Figure 3-41). Simulating 84 percent streambank woody vegetation yields the one-degree allowable increase from the natural conditions scenario.

Model Run	*Temperature (F)*		*Difference from Calibration (F)*		*Comments*
	Mean	*Max*	*Mean*	*Max*	
Calibrated Model	69.30	78.22	NA	NA	Simulated temperature at output of creek with current stream conditions (23% bankline woody vegetation)
Simulation 1	69.55	79.23	0.25	1.01	20% of bank with vegetation cover Cottonwood Creek target vegetation
Simulation 2	66.38	74.03	-2.92	-4.19	60% of bank with vegetation cover Cottonwood Creek target vegetation
Target Conditions	64.36	70.74	-4.93	-7.49	84% of bank with vegetation cover Cottonwood Creek target vegetation
Natural Conditions	63.37	69.12	-5.92	-9.11	95% of bank with vegetation cover

Table 3-18. Simulation results for Douglas Creek at the confluence with Nevada Creek.

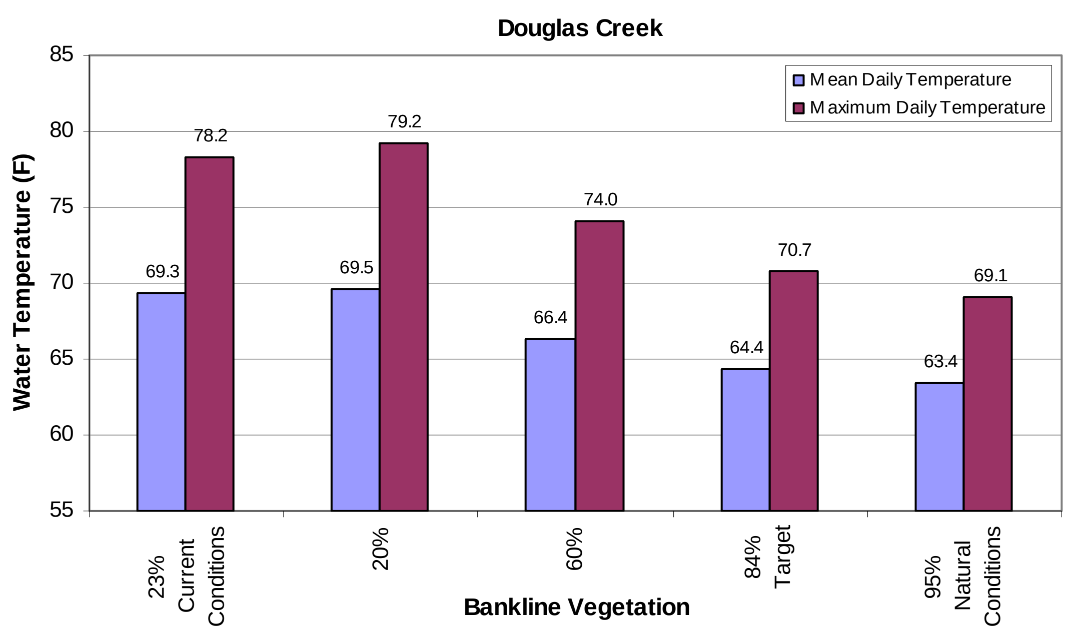


Figure 3-41. Simulated mean and maximum temperature with change in bankline vegetation for Douglas Creek.

Lower Nevada Creek

At the mouth of Nevada Creek, the difference between simulation of current and natural conditions for mean temperature is 2.12^{o} F and 2.57^{o} F for maximum temperature (Table 3-19 and Figure 3-42). Simulating 65 percent streambank woody vegetation along lower Nevada Creek (as well as target vegetation conditions for Cottonwood and Douglas creeks) yields the one-degree allowable increase in mean daily water temperature from natural conditions. The 65 percent value for streambank woody vegetation is therefore the target for lower Nevada Creek.

Note that the model utilized 2004 input water temperatures for Nevada Spring Creek for the 2001 modeling period. This accounts for the improvement in water temperature (1.3^{o} F mean daily) already realized from post 2001 restoration of Nevada Spring Creek.

Model Run	*Temperature (F)*		*Difference from Updated Calibration*		*Comments*
	Mean	*Max*	*Mean*	*Max*	
Observed Temperature	71.91	76.40	NA	NA	Observed Temperature in 2000 above the confluence with Blackfoot River
Calibrated Temperature	71.71	77.18	1.30	1.13	Simulated temperature with current stream conditions
Updated Calibration	70.41	76.05	NA	NA	Simulated temperature with current stream conditions and 2004 Nevada Spring Creek temperature data
Simulation 1	70.66	76.44	0.25	0.40	20% of bank with woody vegetation cover; Cottonwood and Douglas Creek with target bankline vegetation
Simulation 2	69.44	74.89	-0.97	-1.15	60% of bank with woody vegetation cover; Cottonwood and Douglas Creek with target bankline vegetation
Target Conditions	69.28	74.68	-1.13	-1.37	65% of bank with woody vegetation cover; Cottonwood and Douglas Creek with target bankline vegetation
Natural Conditions	68.29	73.47	-2.12	-2.57	95% of bank with vegetation cover

Table 3-19. Simulation results for lower lower Nevada Creek at the mouth.

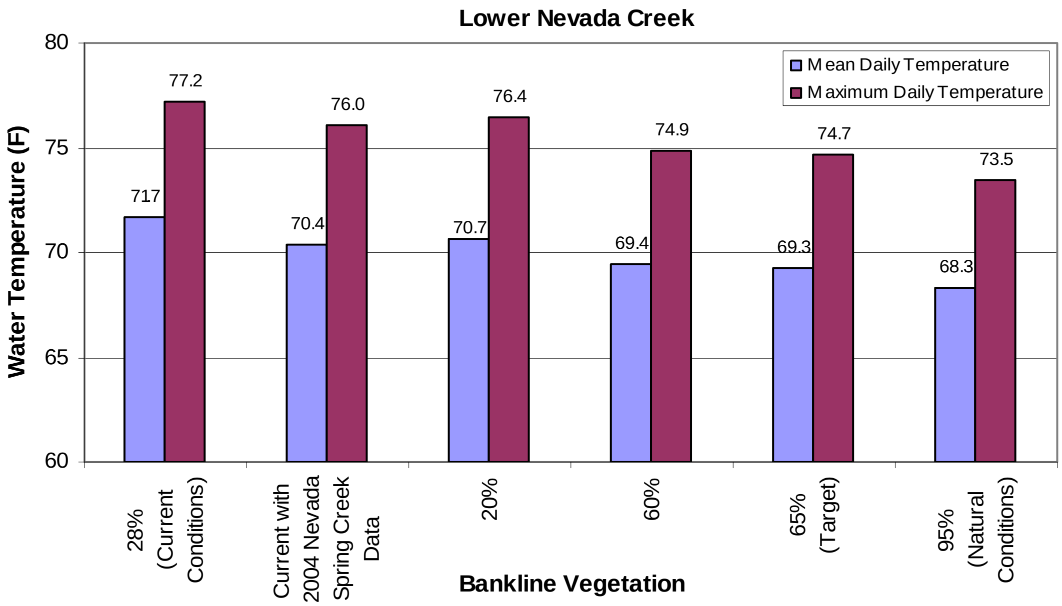


Figure 3-42. Simulated mean and maximum temperature with change in bankline vegetation for lower Nevada Creek.

3.3.3. Upper Douglas Creek Model

The upper Douglas Creek model consists of two short stream segments of Douglas Creek between three reservoirs (Figure 3-43). The observed change in temperature from above to below the reservoirs is approximately 20^{o} F (Table 3-22). Since SSTEMP or SNTEMP cannot simulate water temperatures in reservoirs, the SSTEMP model for upper Douglas Creek only simulated thermal conditions for the stream segments. The remaining thermal gain is therefore attributable to the three reservoirs.

Construction

The modeled portion of Douglas Creek extends for 1.82 miles between the reservoirs (Figure 3-43 and Table 3-20). Temperature monitoring sites located above the upper reservoir on Douglas Creek provided input temperature data for the model. Since temperature data from below the reservoirs include the heating impact of the reservoirs, no observed data was available for comparison with simulated output temperatures.

Modeling for upper Douglas Creek is for the period August 11, 1998. Table 3-20 lists stream geometry and general vegetation characteristics for Douglas Creek during the modeling period. About 40 percent of Douglas Creek has woody vegetation along its streambanks producing shade.

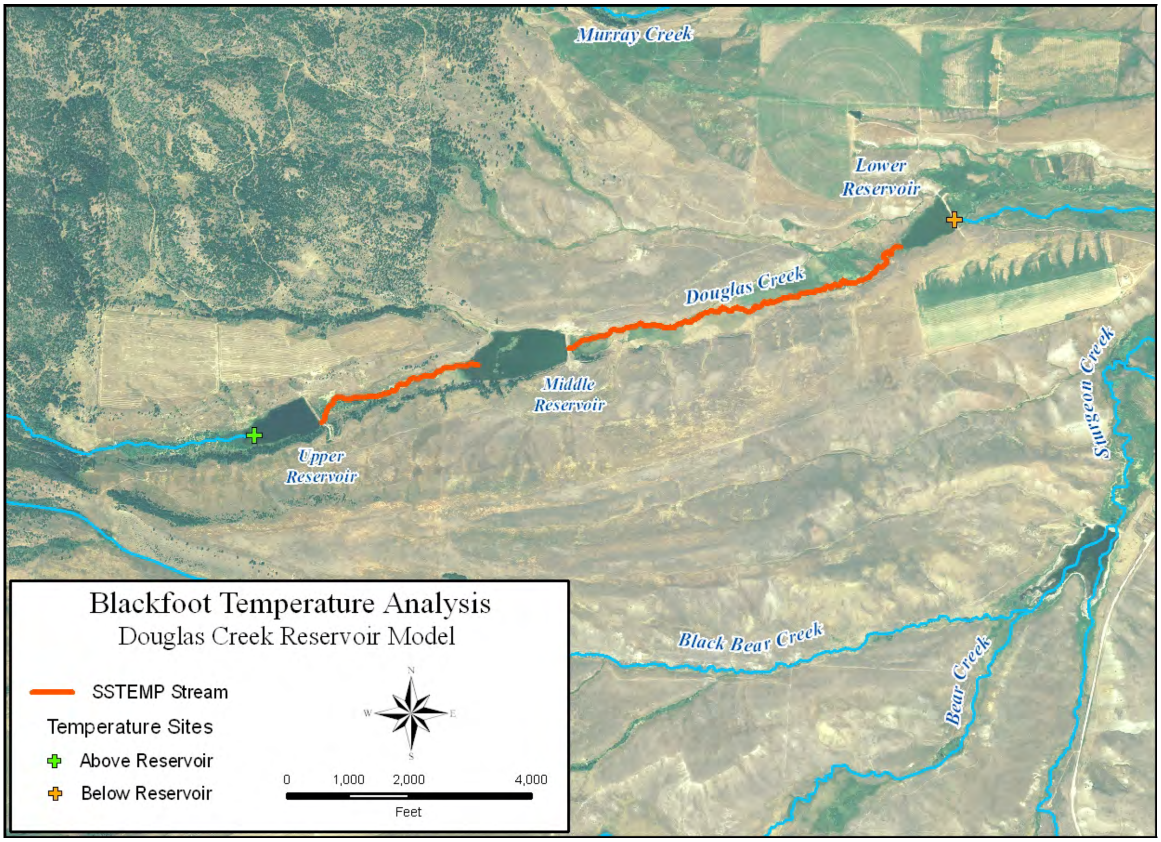


Figure 3-43. Schematic of the upper Douglas Creek SSTEMP model.

Stream	*Modeling Period*	*Length (mi)*	*Average Low Flow Width (ft)*	*Average Bankline Vegetation (%)*	*Average Shade (%)*
Douglas Creek	August 11, 1998	1.82	5.9	39.9	27.9

Table 3-20. Current stream conditions for the upper Douglas Creek SSTEMP model.

Meteorological data for August 11, 1998 (Table 3-21) reflect hot and dry conditions that lead to extreme maximum temperatures. The maximum temperature for this day, 88^{o} F, was one of the warmer temperatures in the summer of 1998.

Modeling Period	*Mean Air Temperature (F)*	*Mean Relative Humidity (%)*	*Mean WindSpeed (mph)*	*Possible Sun (%)*	*Dust Coefficient*	*Ground Reflectivity*
August 11, 1998	66	60	3.0	90	0.055	0.27

Table 3-21. Meteorological input data for the upper Douglas Creek SSTEMP model.

The Montana FWP temperature data for the modeling period indicates that Douglas Creek experiences large thermal gains of approximately 20^{o} F from above the reservoirs to below the reservoirs (Table 3-22). Input flow values are estimates. The mean water temperature above the reservoirs is 48.25^{o} F, the coldest temperature tributary stream water observed in the Nevada Creek watershed. The observed mean water temperature below the third reservoir is 68.37^{o}. SSTEMP simulated the mean temperature at the end of the stream segments (without the reservoirs) at approximately 53.4^{o} F. Therefore, the stream segments accounts for approximately 5^{o} F of the 20^{o} F observed temperature increase.

Segment	Date	Flow in (cfs)	Flow out (cfs)	Water Temperature above Reservoir		Water Temperature below Reservoir	
				Mean	Max	Mean	Max
Douglas Creek from above to below the reservoirs	August 11, 1998	3	3	48.25	54.2	68.37	78.10

Table 3-22. Hydrologic data for Upper Douglas Creek Model.

Calibration

The presence of reservoirs in upper Nevada Creek precluded using the same calibration methods used for the other models. Therefore, a bracketed calibration method provided a pseudo calibration. With this method, multiple model simulations using the typical ranges of meteorological and Manning's n parameter values used for the lower Nevada Creek model provided calibration guidelines (Table 3-23). The first SSTEMP model run for upper Douglas Creek simulated temperatures based on unadjusted meteorological data. Three more simulations evaluated changing meteorological and/or Manning's n values to cover a possible range of conditions. This series of simulations yields a range of simulated temperature increases in the stream segments ranging from 3.8^{o} to 6.2^{o} F. The final SSTEMP calibration simulation used typical parameter values from the SNTEMP model created for lower Nevada Creek, lower Douglas Creek and Cottonwood Creek.

Model Run	Manning's n	Relative Humidity	Wind Speed (mph)	% Sun	Dust	Ground Reflectivity	Simulated Temperature	
							Mean (F)	Max (F)
1	0.062	60	3	90	0.055	0.27	54.42	68.05
2	0.062	45	5	80	0.075	0.20	53.38	65.05
3	0.062	30	7	70	0.100	0.18	52.05	62.06
4	0.080	30	7	70	0.100	0.19	52.05	61.36
Final*	0.080	45	5	80	0.075	0.20	53.38	64.18

*Represents the model used to simulate current and natural conditions on the stream portion of the upper Doulgas Creek model.

Table 3-23. Model iterations and temperature results used to establish parameters for Douglas Creek SSTEMP model.

Simulations

Three simulations for upper Douglas Creek evaluated the effect different levels of riparian shade have on stream temperatures. Note that these simulations only address the stream segment portion of upper Douglas Creek. The first simulation modeled current streambank vegetation conditions, (40% streambank vegetation). A second simulation modeled natural conditions, defined by Montana DEQ as 95% of the streambanks having woody vegetation. A final simulation determined the one-degree allowable increase from natural conditions as the TMDL target for streambank vegetation.

Results illustrate that for current conditions, SSTEMP simulated an increase in Douglas Creek mean water temperature of 5.13 degrees F (Table 3-24). With natural conditions, the simulated mean temperature in Douglas Creek is 51.87 degrees F. This is 4.48 degrees F less than temperatures with current conditions. Simulating 69% streambank vegetation yields the one-degree allowable increase from natural conditions. This requires an increase from 40% to 69% of streambanks having woody vegetation cover.

Model Run	***Temperature (F)***		***Difference from Calibration***		***Comments***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	NA	NA	NA	NA	No observed temperature data due to the presence of reservoirs.
Calibrated Temperature	53.38	64.18	NA	NA	Bracketed calibration (described above)
Simulation 1	53.38	64.18	0.00	0.00	Current conditions, 40% streambank woody vegetation (same as bracketed calibration)
Target Conditions	52.85	60.72	-0.53	-3.46	69% streambank woody vegetation
Natural Conditions	51.87	57.45	-1.51	-6.73	95% streambank woody vegetation

*SSTEMP simulation results are for the stream segments only. The reservoirs are discussed below.

Table 3-24. Simulation results for the upper Douglas Creek temperature model.

Reservoirs

The reservoirs on upper Douglas Creek cause much of the temperature gain between the FWP temperature monitoring sites above and below the reservoirs. Temperature data indicate that the increase in stream temperature between these sites is approximately 20^{o} F. SSTEMP modeling indicates that the stream segments between the reservoirs contribute approximately 5^{o} F (25%) of this increase. Therefore, the reservoirs are responsible for approximately 15^{o} F (75%) of the increase in temperature.

Reasonable agricultural practices fall within the natural conditions defined by Montana DEQ. However, in upper Douglas Creek, the temperature gains are excessive. Modifications to the water storage and delivery system that would improve stream temperatures are possible based on field observations and air photo assessment of the irrigation system. These data suggest that the lowermost reservoir has the smallest surface area and is the shallowest (Table 3-25). Locations of the reservoirs and the conveyance to irrigated areas suggest that if the lowermost reservoir were consolidated with the upper and middle reservoirs, overall water availability would still be adequate to meet agricultural requirements. This would effectively reduce the total reservoir surface area by approximately 20 percent and temperature gain from the reservoirs by a similar amount. This results in a further 3^o F reduction in temperature (15^o F X 20%). The lowermost reservoir is shallower than the upper and middle reservoirs and may heat faster as a result. Therefore, the temperature improvements realized from consolidating the reservoirs may be larger than 3^o F.

Reservoir	***Area (acres)***	***% of Reservoir Area***
Upper	11.10	27.8%
Middle	20.88	52.3%
Lower	7.91	19.8%

Table 3-25. Reservoir sizes, upper Douglas Creek.

4. Results: Middle Blackfoot Planning Area

This section contains results for the Blackfoot River and Kleinschmidt Creek in the Middle Blackfoot planning area. Results include development of shade parameter data, temperature data analysis, and temperature modeling.

4.1. Shade

The shading value applied to each segment of the mainstem Blackfoot River modeling network is a function of topographic conditions, channel width, and shading vegetation type and extent. Section 2.2 describes the methods used to calculate each of these parameters.

4.1.1. Riparian Vegetation

For the modeled segments of the Nevada Creek Planning area, base parameter assessment data (DTM and AGI, 2005) and field photos allowed definition of the vegetation categories along the streams of interest. For each of these categories, field photos and notes provided the data for estimates of vegetation offset (Vo), diameter (Vd), and height (Vh). The median values of these estimates define typical conditions for each vegetation type. (Figure 4-1 through Figure 4-3; Table 4-1).

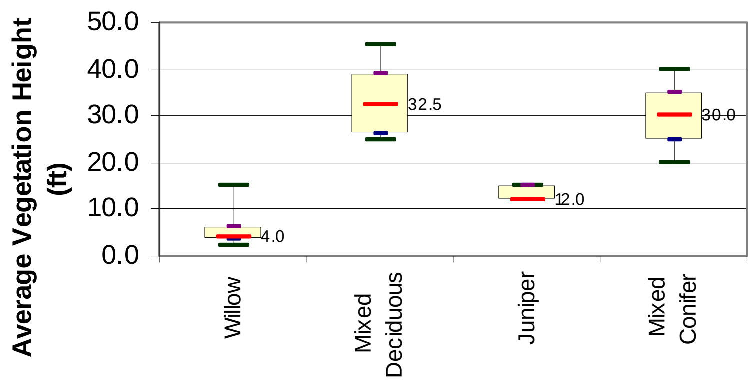


Figure 4-1. Estimated average heights for each vegetation type with median values labeled.

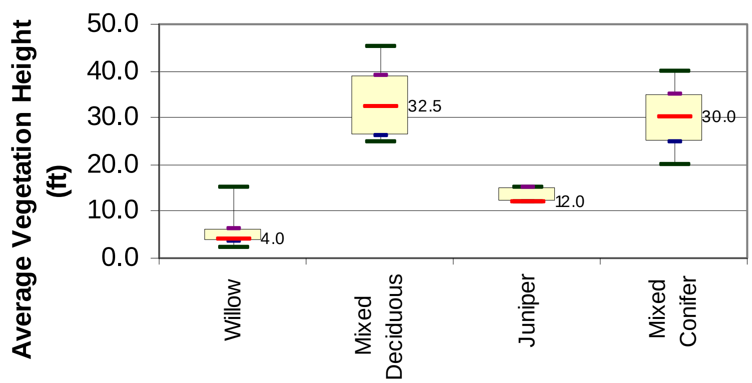


Figure 4-2 Estimated average crown diameter for each vegetation type with median values labeled.

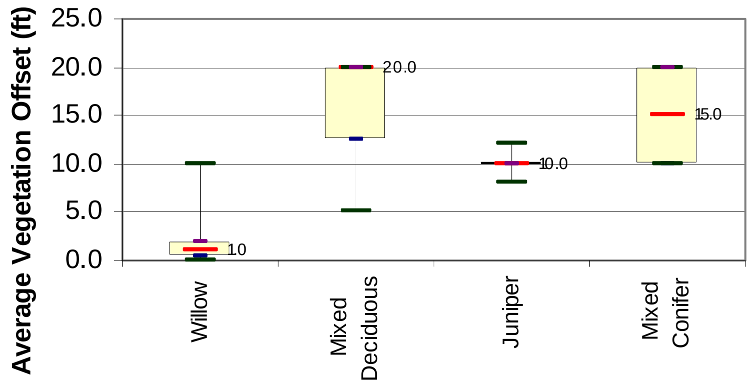


Figure 4-3. Estimated average offset for each vegetation type with median values labeled.

Calculation of filtering values for each stream segment requires a filtering value for each vegetation type in addition to vegetation density. Vegetation density (Vd) is equal to the filtering value multiplied by the percent of shaded bank length within a reach. Preliminary default filtering values used for each vegetation type ranged from 0.2 to 0.7 (Table 4-1). Literature that addressed similar vegetation types (Manoukian and Marlow, 2002; Risley, 1997; Bartholow, 2004) guided the selection of the filtering values.

Table 4-1. Shade parameter values utilized for each vegetation category.

Vegetation Type	*Filtering*	*Vh: Crown Height (ft)*	*Vd:Crown Diameter (ft)*	*Vo: Offset (ft)*
Willow	0.5	4	5	1
Mixed Deciduous	0.7	32.5	11.0	20.0
Juniper	0.8	12.0	10.0	10.0
Mixed Conifer	0.7	30.0	12.0	15.0

4.1.2. Topographic Shade

The mainstem Blackfoot River flows through canyon sections that provide some topographic shade to the river. However, the extent of shading contributed by topography during the modeling period is less than six percent for all reaches, and less than two percent for the vast majority of reaches. Topographic shade values calculated for each reach of the mainstem Blackfoot River are in Table 4-2.

4.1.3. Channel Width

Channel width under low flow conditions was estimated from NAIP 2005 color air photos. Ten channel widths were measured at random locations throughout each reach, and the mean of that value represents the reach. The measured widths for each reach are quite variable; however, the overall trend shows downstream widening (Figure 4-4).

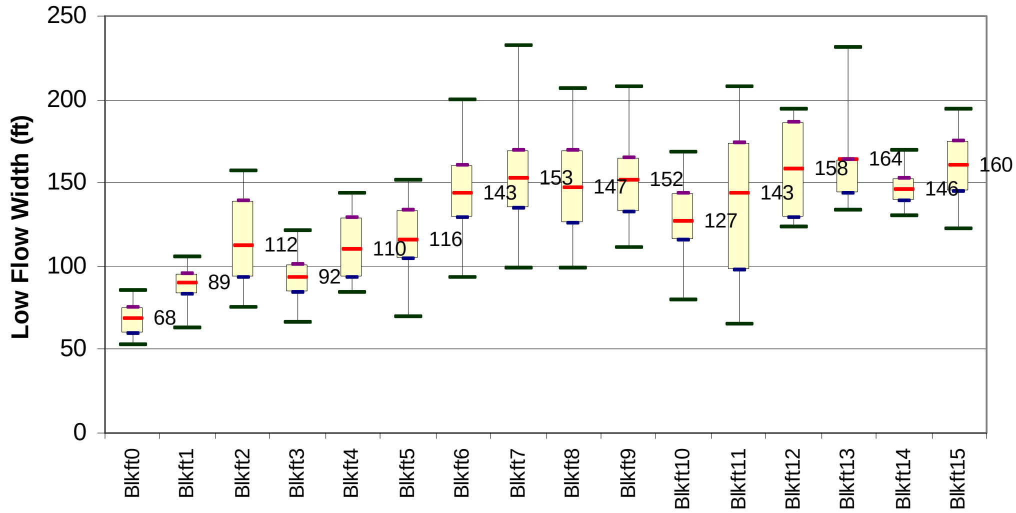


Figure 4-4. Measured low flow widths from aerial photography, mainstem Blackfoot River.

4.1.4. Total Shade Calculations

Using the input parameters described above, a total shade value for the modeling period was calculated for each reach (Figure 4-5 and Table 4-2). The total shade value is the sum of the topographic and vegetation shade. The tree height, offset, diameter, and shade density values all reflect weighted averages that account for all vegetation types identified. Note that all values are below 12 percent shading due to large channel widths. In addition, reaches with in excess of 70 percent streambank woody vegetation had no more than 8.75% shade due to large channel widths.

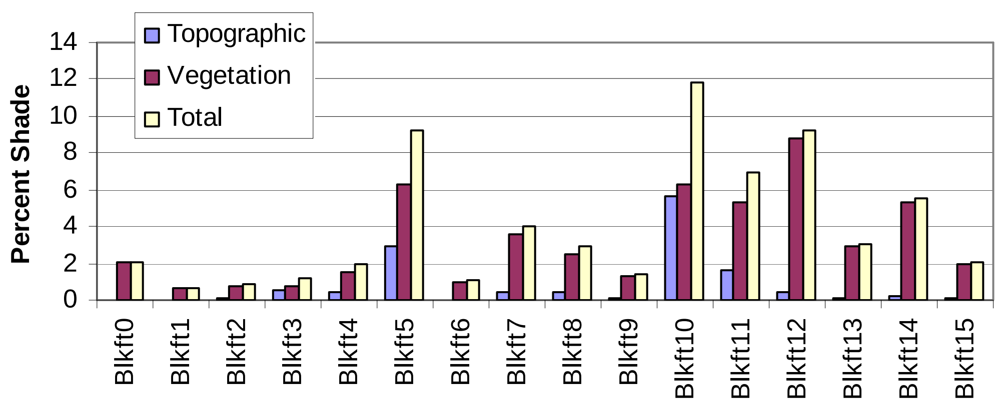


Figure 4-5. Total shade values calculated for modeled reaches, Middle Blackfoot Planning Area.

Table 4-2. Calculated topographic, vegetation, and total shading parameter for August 15, Middle Blackfoot Planning Area modeled assessment reaches.

Reach	Reach Length (ft)	Pct Shaded Bank	Est Low Flow Wid (ft)	Stream Azimuth Degrees	West Topo Degrees	East Topo Degrees	Crown Diameter (ft)	Tree Height (ft)	Offset Distance (ft)	Shade Density decimal	% SHADE		
											Topographic %	Vegetation %	Total %
Blkft0	26945	19.8	68	36.3	0.00	0.00	8.4	14.2	9.2	0.15	0.00	2.10	2.10
Blkft1	8432	21.0	89	-78.1	2.65	1.10	10.7	25.6	16.6	0.07	0.01	0.61	0.62
Blkft2	15225	13.0	112	-35.1	3.69	2.53	10.0	12.0	10.0	0.10	0.12	0.74	0.86
Blkft3	12182	9.2	92	-47.2	9.19	6.34	11.0	21.2	12.6	0.07	0.51	0.73	1.24
Blkft4	9517	14.3	110	-35.6	6.72	4.97	12.0	30.0	15.0	0.04	0.44	1.49	1.93
Blkft5	26441	51.4	116	-4.6	13.77	9.07	11.9	30.1	15.3	0.34	2.97	6.29	9.26
Blkft6	15232	23.3	143	-72.2	8.13	2.48	11.7	30.8	16.5	0.08	0.04	1.02	1.06
Blkft7	17604	79.8	153	-68	13.31	9.67	11.1	26.7	13.2	0.51	0.45	3.55	3.99
Blkft8	9091	41.7	147	-33.3	0.75	6.13	8.7	17.9	8.5	0.37	0.41	2.53	2.94
Blkft9	22565	43.9	152	-84.9	2.86	5.30	9.3	22.2	12.1	0.23	0.08	1.35	1.43
Blkft10	10485	70.9	127	19	15.78	17.69	11.8	29.2	14.6	0.59	5.62	6.26	11.88
Blkft11	24852	69.1	143	54.5	15.56	11.15	12.0	30.0	15.0	0.63	1.62	5.30	6.92
Blkft12	10065	79.9	158	14.3	3.00	6.29	12.0	30.0	15.0	0.68	0.44	8.74	9.18
Blkft13	13311	69.4	164	-76.4	3.31	4.50	12.0	30.0	15.0	0.35	0.08	2.97	3.06
Blkft14	8072	79.2	146	60.8	5.71	9.46	12.0	30.0	15.0	0.61	0.23	5.34	5.57
Blkft15	35686	56.9	160	-72.8	14.23	3.30	7.6	13.7	6.2	0.29	0.07	1.95	2.03

4.2. Temperature Conditions

The following sections describe the stream temperature conditions for each 303(d) listed stream in the Nevada Creek Planning Area. This includes important tributaries to these streams.

4.2.1. Kleinschmidt Creek

The Montana FWP temperature database has 2001 and 2004 temperature measurements for one site on Kleinschmidt Creek above its confluence with Rock Creek (Figure 4-6). In addition to temperature data, BBCTU collected flow data in 2004 at three locations on Kleinschmidt Creek (Blackfoot Challenge, 2004). These data served as input to the SNTEMP temperature model for Kleinschmidt Creek.

Kleinschmidt Creek underwent significant restoration downstream of Highway 200 from 1990 through 2001, resulting in significantly reduced channel width and surface area, and increased channel sinuosity (Hydrometrics, 2005). The majority of restoration took place in 2000-2001.

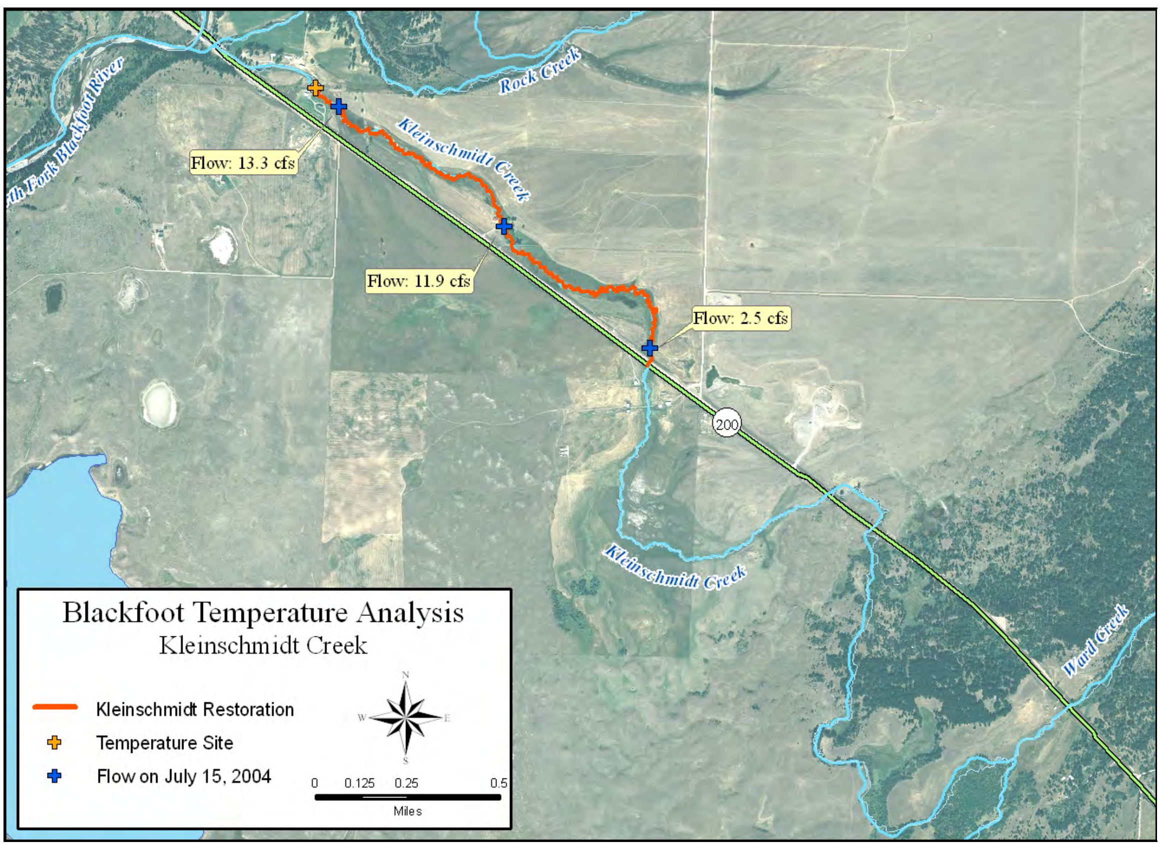


Figure 4-6. Kleinschmidt Creek and related data.

A comparison of 2001 with 2004 continuous temperature graphs for Kleinschmidt Creek indicates significant improvement in stream temperatures after 2001 restoration (Figure 4-7 and Figure 4-8). Minimum temperatures are similar; however, maximum temperatures and the amount of diurnal fluctuation are much lower in 2004.

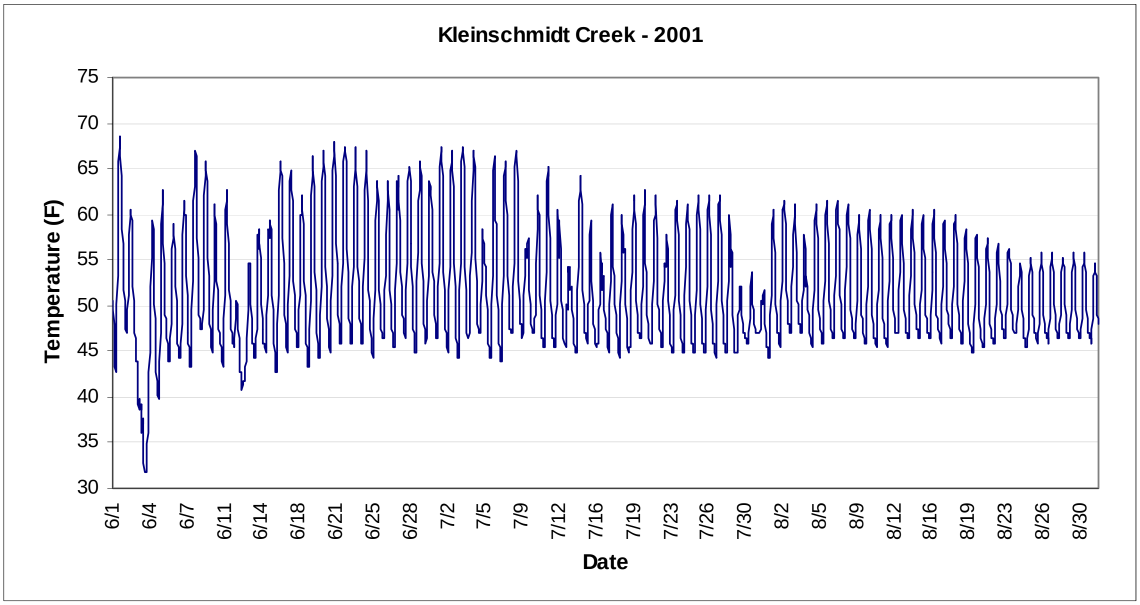


Figure 4-7. Continuous water temperature, Kleinschmidt Creek, 2001.

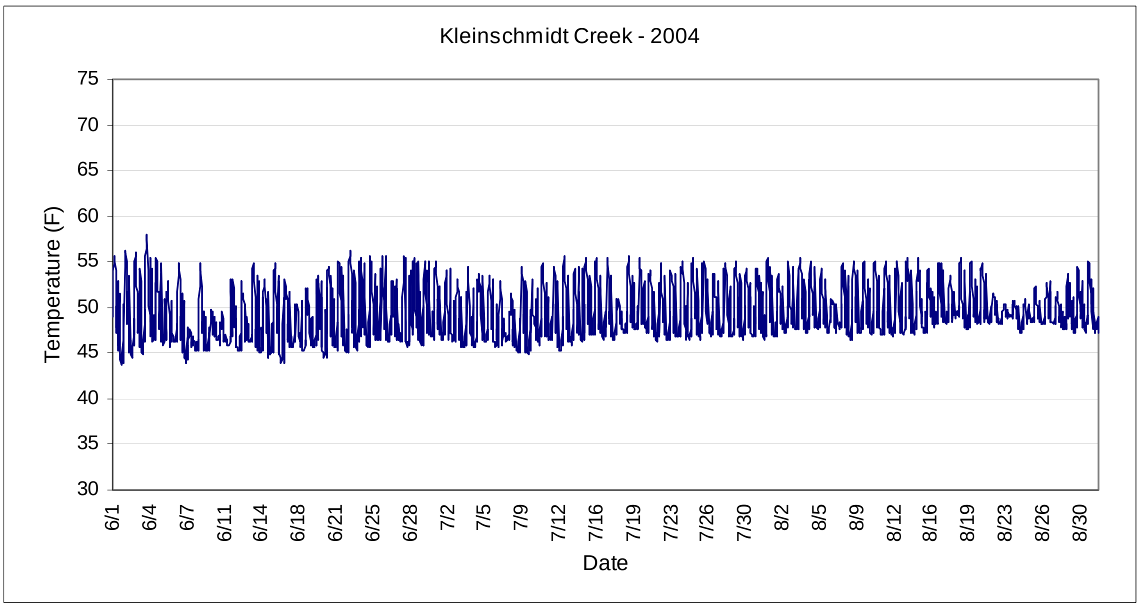


Figure 4-8. Continuous water temperature, Kleinschmidt Creek, 2004.

Figure 4-9 shows the difference in summer temperatures between 2001 and 2004 at the monitoring site above Rock Creek. This plot illustrates that the range in summer temperatures decrease dramatically post-restoration. Fifty percent of the temperature readings over the summer of 2004 fall within a 5° F range, centered on 50° F.

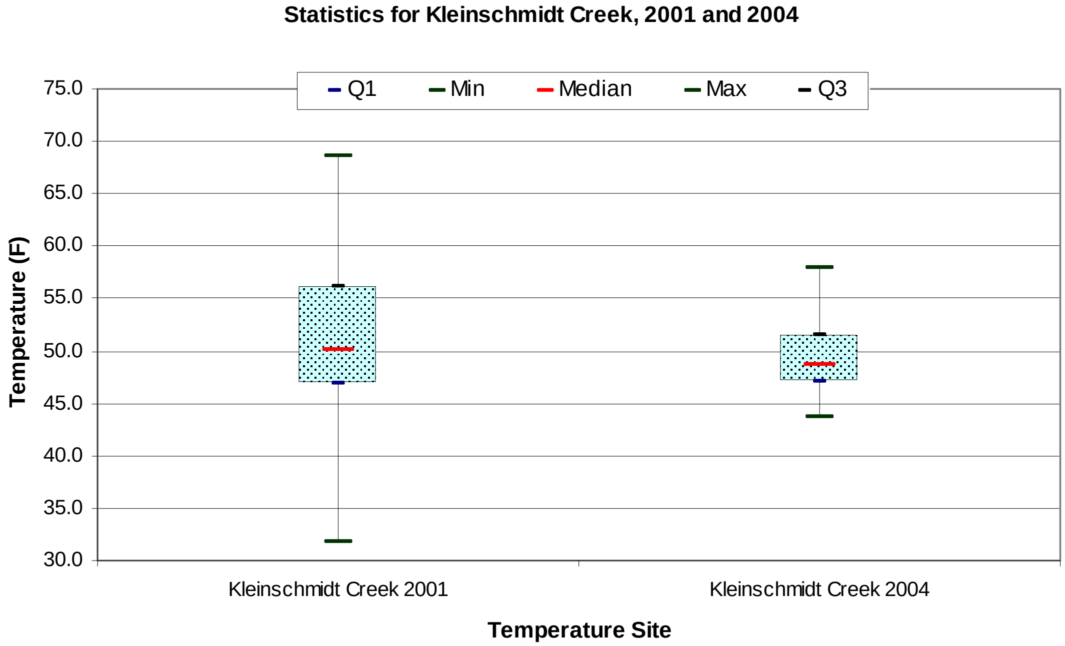


Figure 4-9. Temperature variation between years 2001 and 2004, Kleinschmidt Creek.

Figure 4-10 through Figure 4-13 display the daily maximum and seven-day average maximum temperatures at the monitoring site on Kleinschmidt Creek during the summers of 2001 and 2004. A comparison of 2001 and 2004 data shows that maximum water temperatures frequently are in the low to upper 60s F in 2001, while temperatures rarely exceed 55° F in 2004. Maximum water temperatures also fluctuate more in 2001 than in 2004. Precipitation and air temperature plotted on the maximum daily water temperature graph illustrate their influence on water temperature in both 2001 and 2004, although the degree of influence is smaller in 2004 than in 2001.

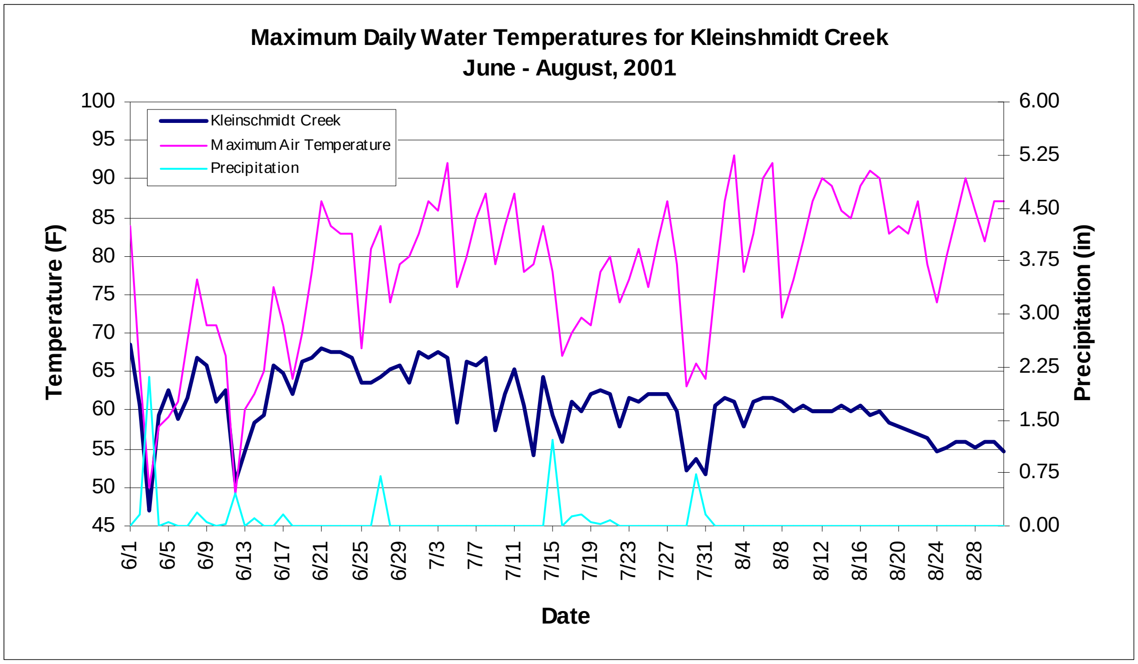


Figure 4-10. Maximum daily water temperature, air temperature, and precipitation, Kleinschmidt Creek, 2001.

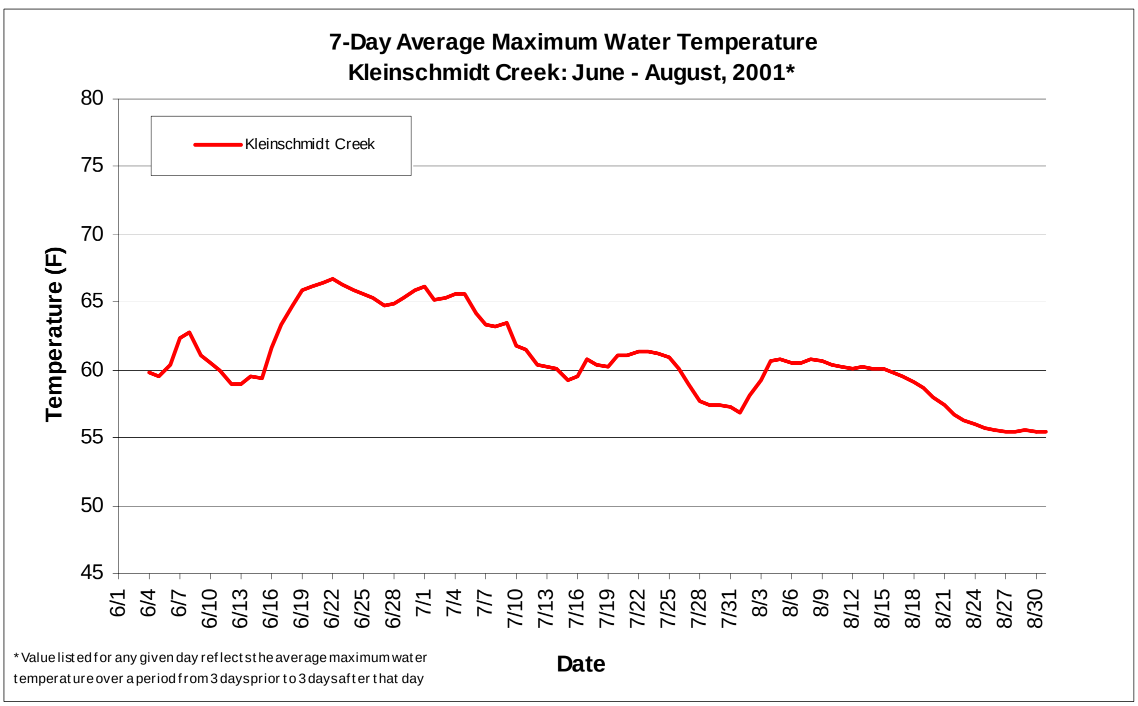


Figure 4-11. 7-day average maximum daily temperatures, Kleinschmidt Creek, 2001.

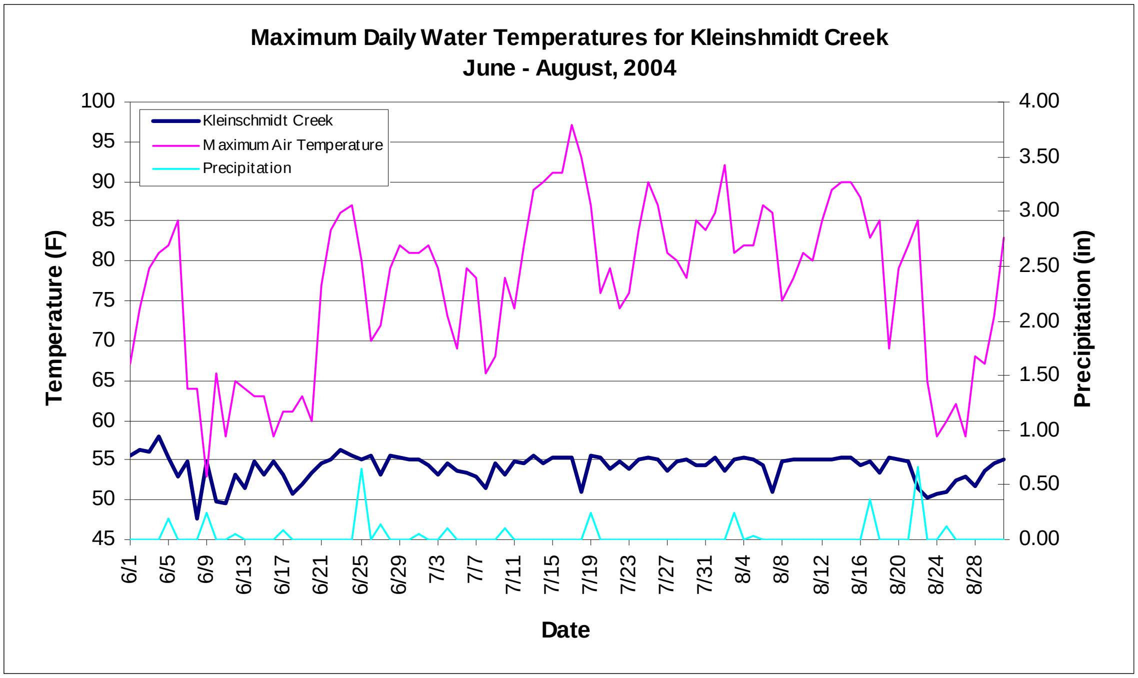


Figure 4-12. Maximum daily water temperature, air temperature, and precipitation, Kleinschmidt Creek, 2004.

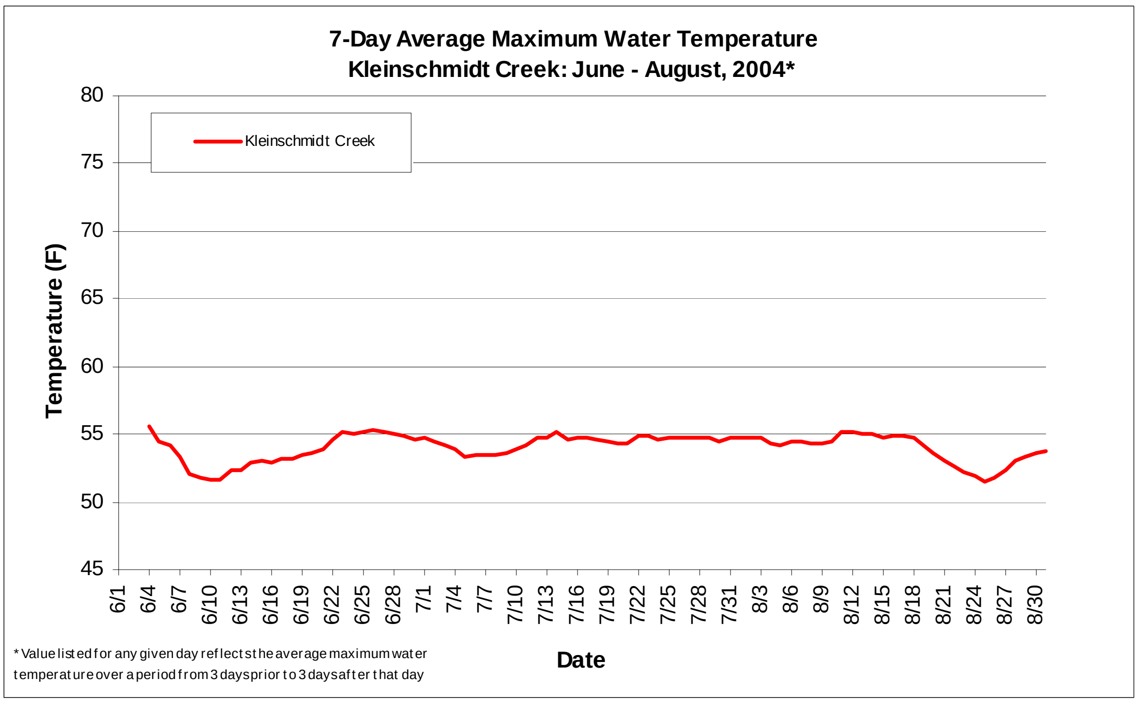


Figure 4-13. 7-day average maximum daily temperatures, Kleinschmidt Creek, 2004.

Kleinschmidt Creek originates in a riparian meadow where Ward Creek splits into the continuation of Ward Creek towards Browns Lake and Kleinschmidt Creek (Figure 4-6). Kleinschmidt Creek then continues through a conifer riparian zone for approximately ½ mile before it enters a highly degraded valley bottom area where it crosses Highway 200 three times. Thermal gains are likely in this area. Below Highway 200, abundant cold groundwater reduces stream temperature. 2004 flow data shows an increase in flow from 2.5 cfs at the third Highway 200 crossing to 11.9 cfs less than a mile downstream (Figure 4-6). This reach is located at the toe of the large deposit of glacial outwash that makes up Kleinschmidt Flat and thus gains water from groundwater traveling through the outwash.

4.2.2. Blackfoot River

The Montana FWP temperature database contains data collected in 2000 for four sites on the Blackfoot River and eight sites on tributary streams in the Midddle and Lower Blackfoot TMDL planning areas. In addition, the database contains data collected in other years for two key tributaries, Monture Creek (1999) and the Clearwater River (2003). Figure 4-14 through Figure 4-27 (upstream to downstream) display continuous water temperature readings collected at the twelve monitoring sites during the summer of 2000, and for Monture Creek in 1999 and the Clearwater River in 2003. These figures illustrate that for all sites in 2000, temperatures peak around July 30. The drop in water temperature around July 5, 2000 corresponds to a cool and rainy storm cycle.

Figure 4-9 shows the statistical distribution of summer temperatures during 2000 for the four sites on the Blackfoot River and tributaries. From the plot, it is apparent that temperatures are coolest on the Blackfoot River at the site at Cutoff Bridge, and increase dramatically at Raymond Bridge, site of the warmest temperatures on the Blackfoot River. Nevada Creek, Elk Creek, and the Clearwater River all contributed warm water to the Blackfoot River during the summer of 2000, with water temperatures reaching greater than 75^{o} F during that summer. However, the volumes of warm water are small compared to the Blackfoot. The North Fork of the Blackfoot River and Monture Creek are cold-water streams, and contributed significant volumes of cold water to the Blackfoot River with temperatures topping out in the mid-60s F for both streams.
Yourname, Wales, Creek

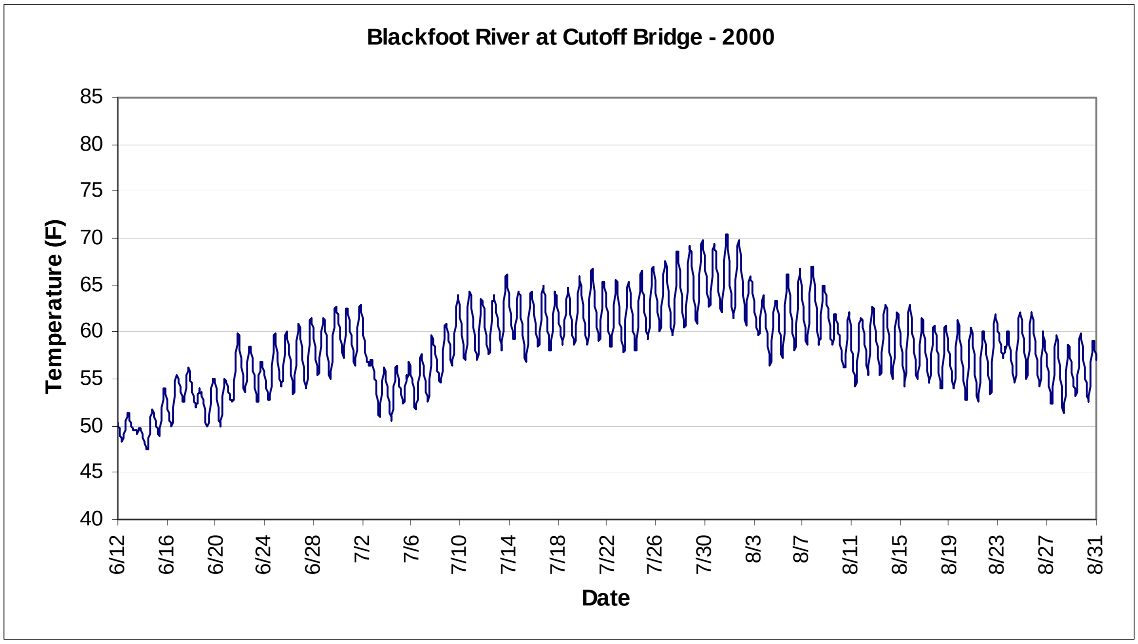


Figure 4-14. Continuous water temperature, Blackfoot River at Cutoff Bridge, 2000.

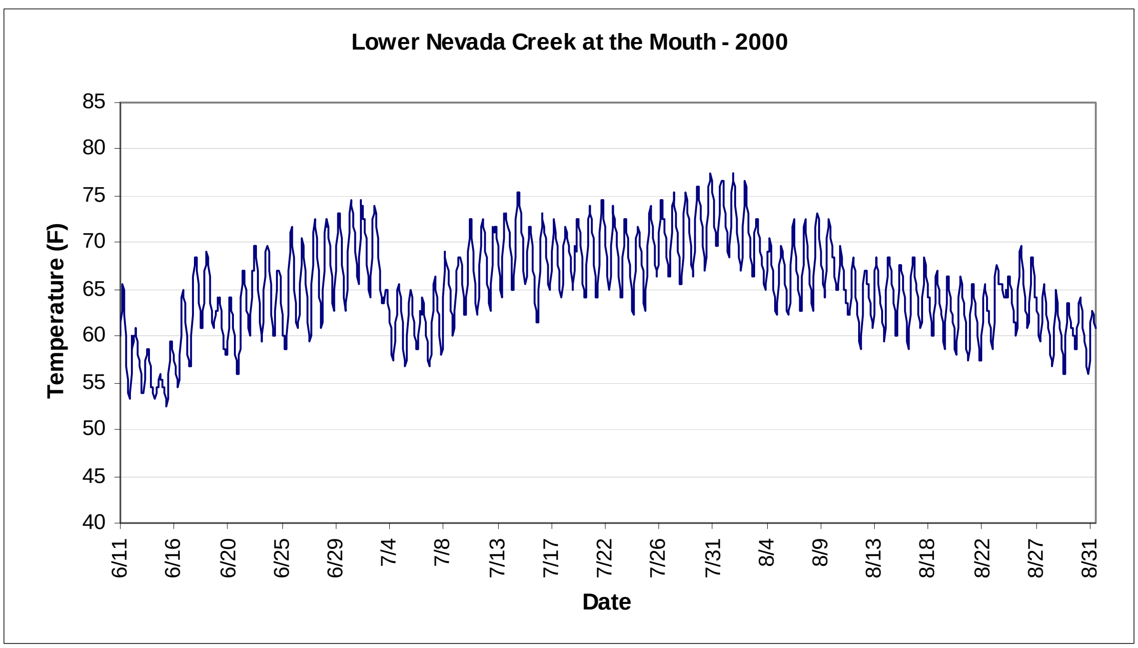


Figure 4-15.. Continuous water temperature, lower Nevada Creek at the mouth, 2000.

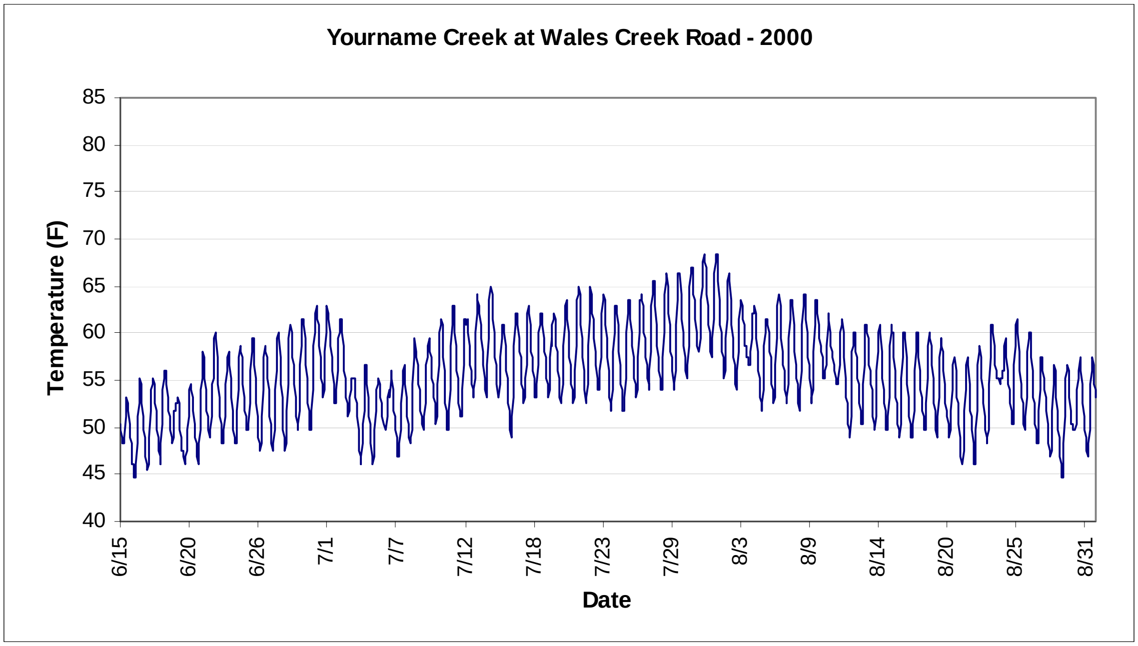


Figure 4-16. Continuous water temperature, Yourname Creek at Wales Creek Road, 2000.

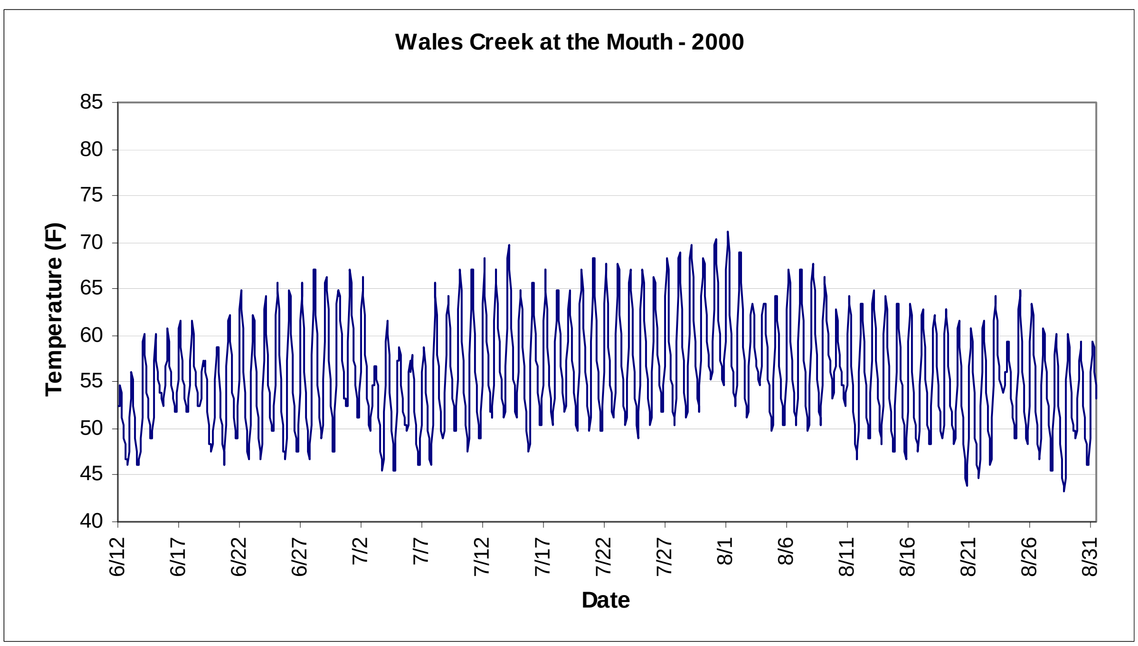


Figure 4-17. Continuous water temperature, Wales Creek at the mouth, 2000.

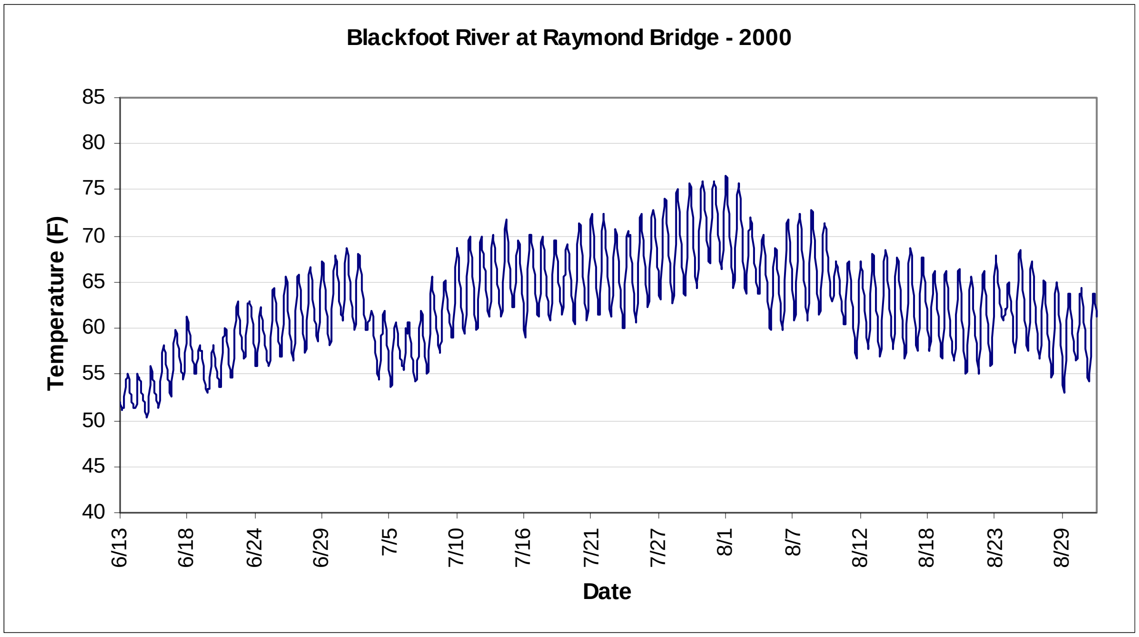


Figure 4-18. Continuous water temperature, Blackfoot River at Raymond Bridge, 2000.

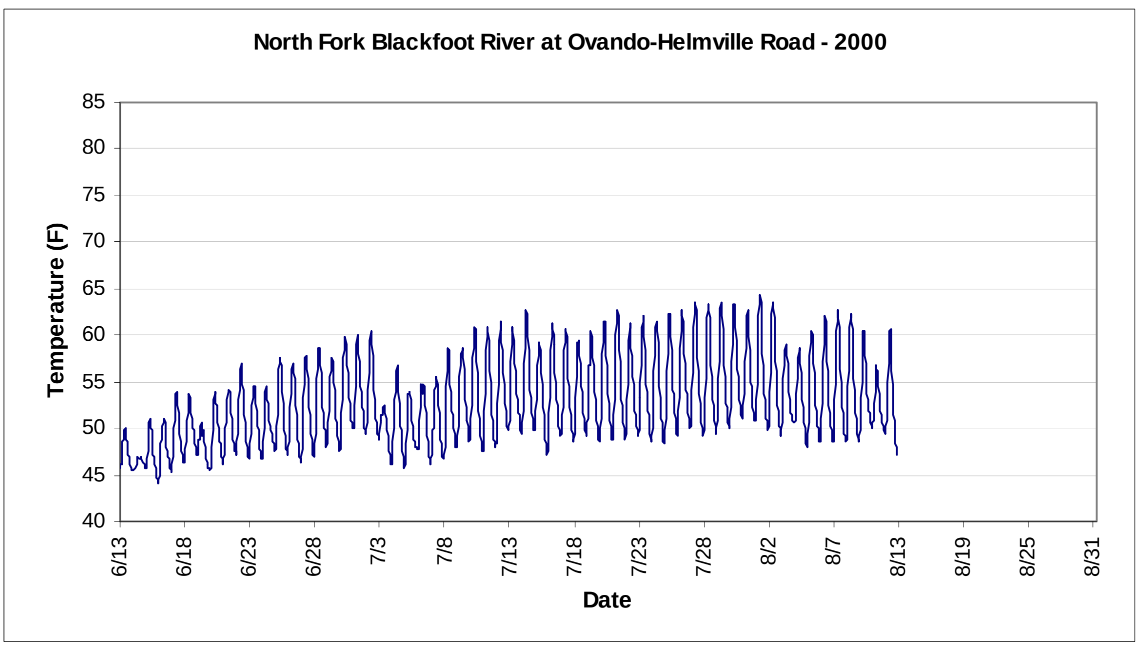


Figure 4-19. Continuous water temperature, North Fork Blackfoot River, 2000.

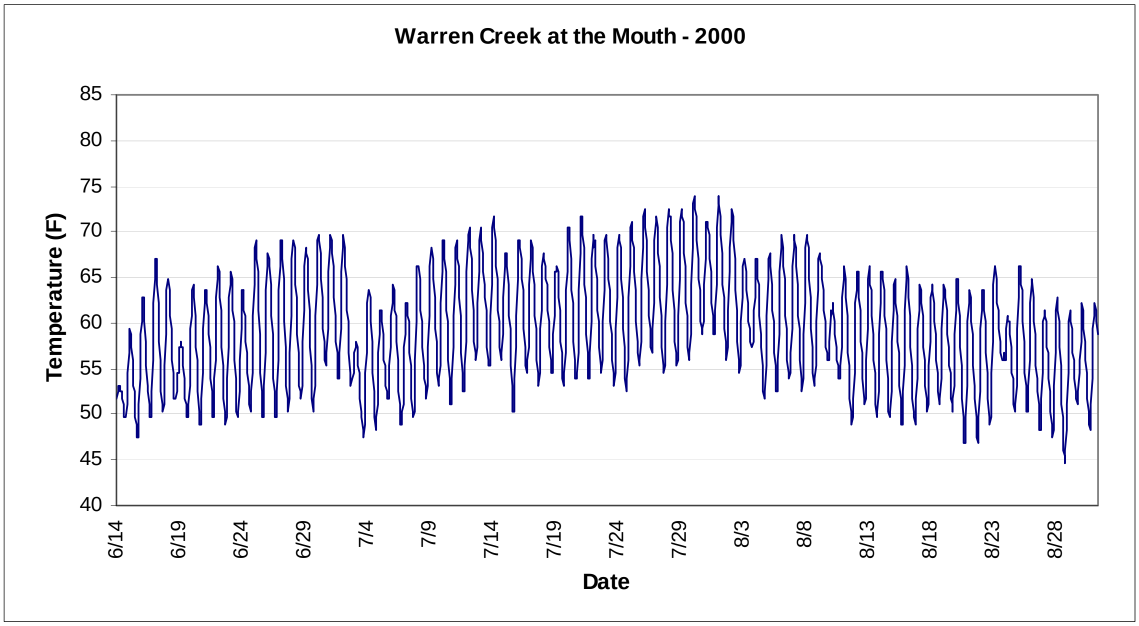


Figure 4-20. Continuous water temperature, Warren Creek at the mouth, 2000.

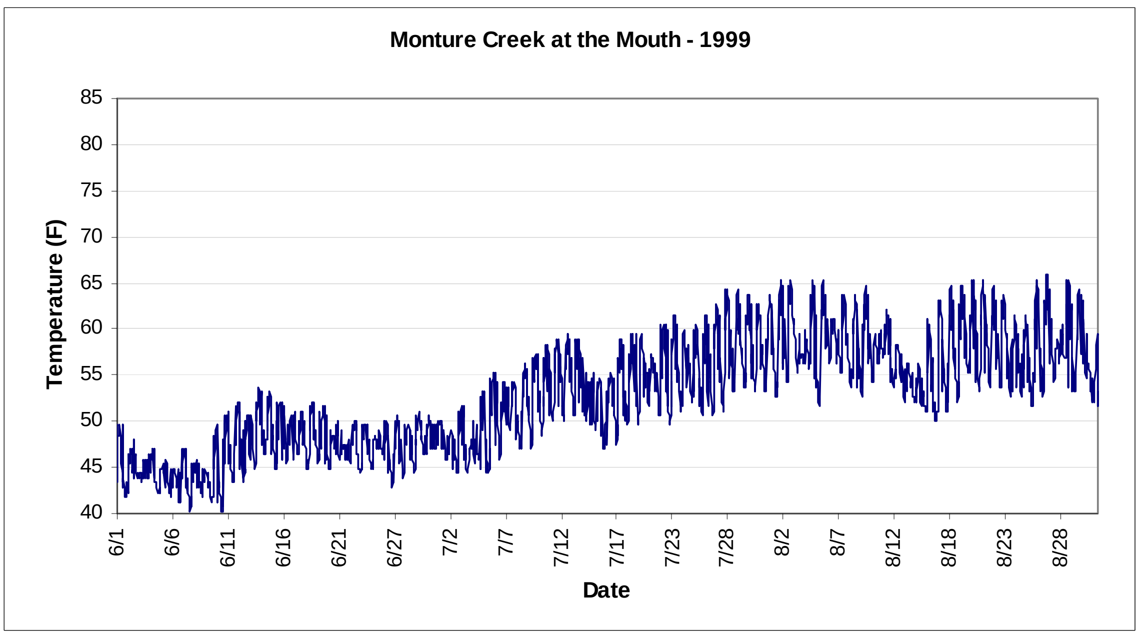


Figure 4-21. Continuous water temperature, Monture Creek, 1999.

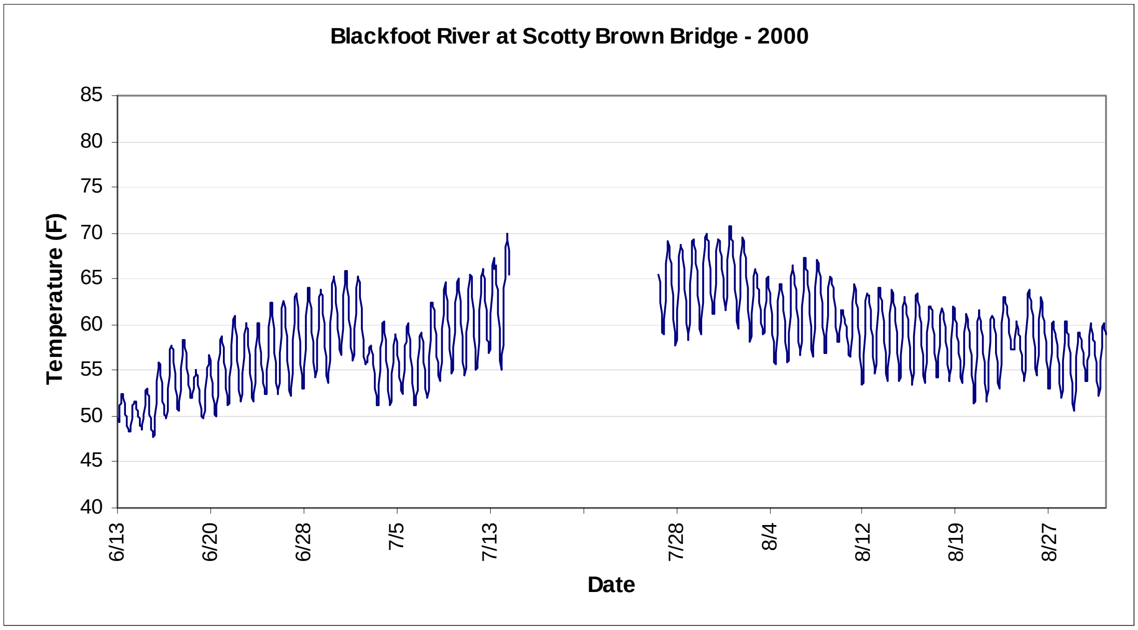


Figure 4-22. Continuous water temperature, Blackfoot River at Scotty Brown Bridge, 2000.

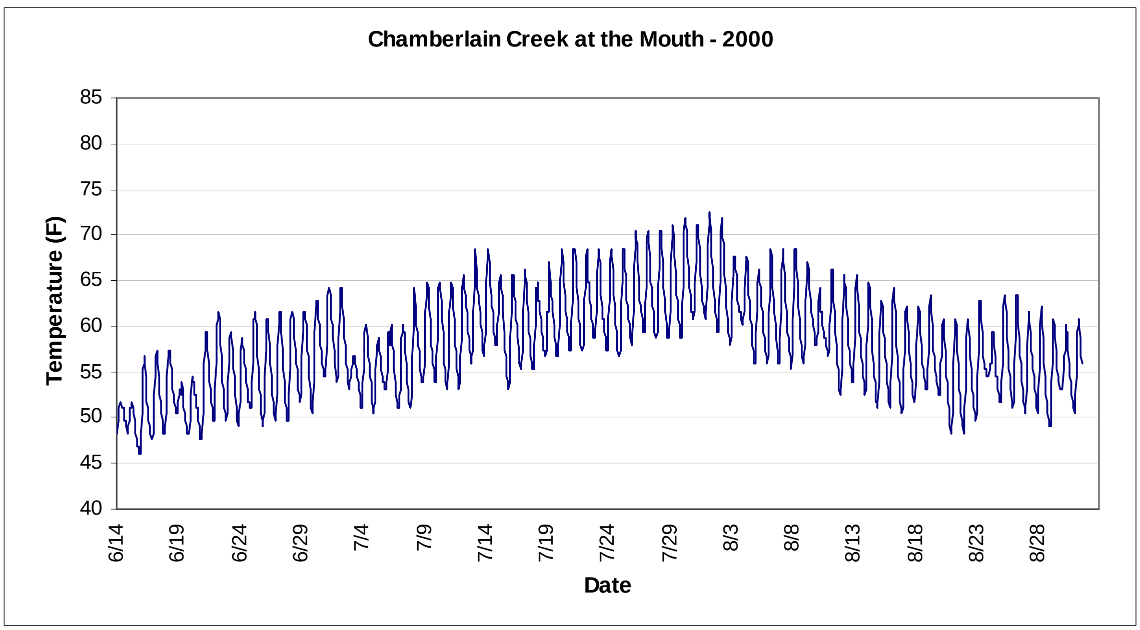


Figure 4-23. Continuous water temperature, Chamberlain Creek at the mouth, 2000.

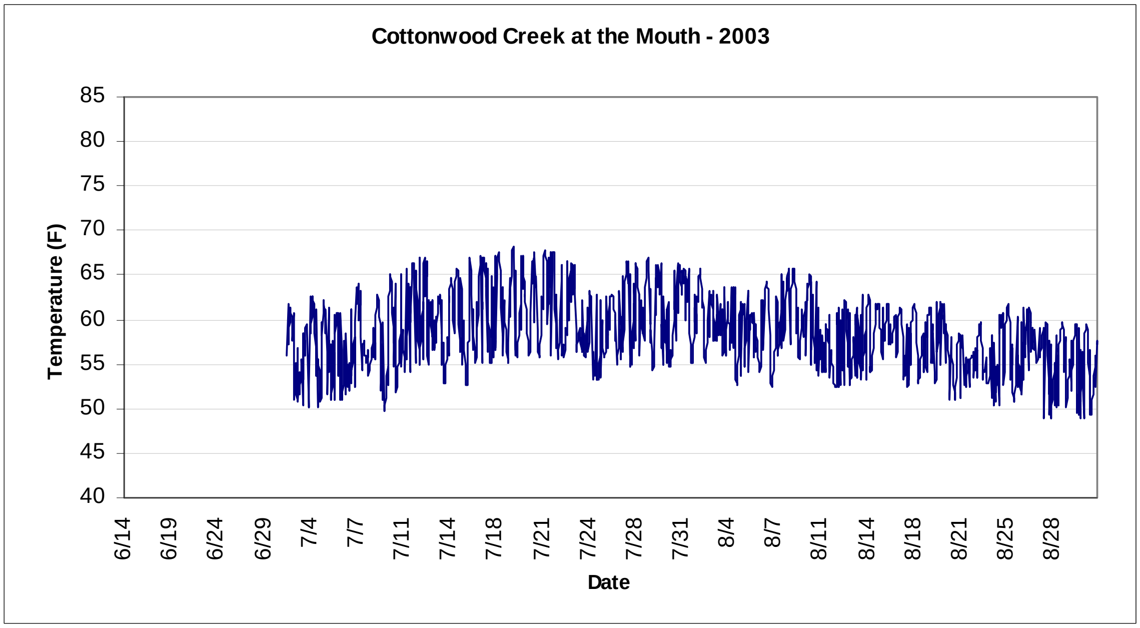


Figure 4-24: Continuous water temperature, Cottonwood Creek at the mouth, 2003.

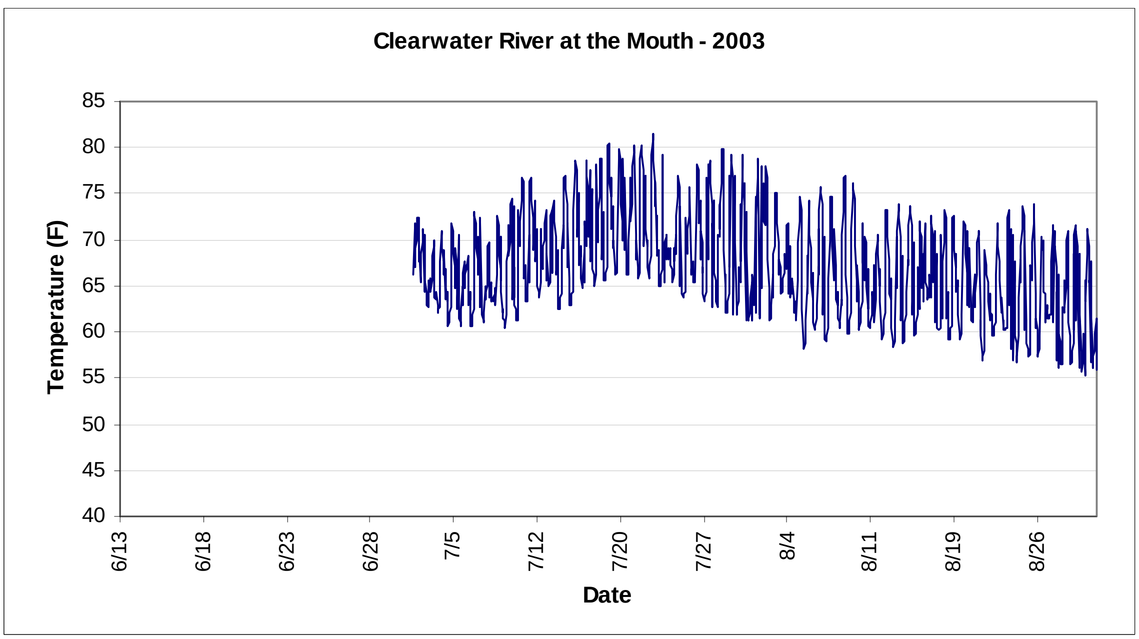


Figure 4-25. Continuous water temperature, Clearwater River at the mouth, 2003.

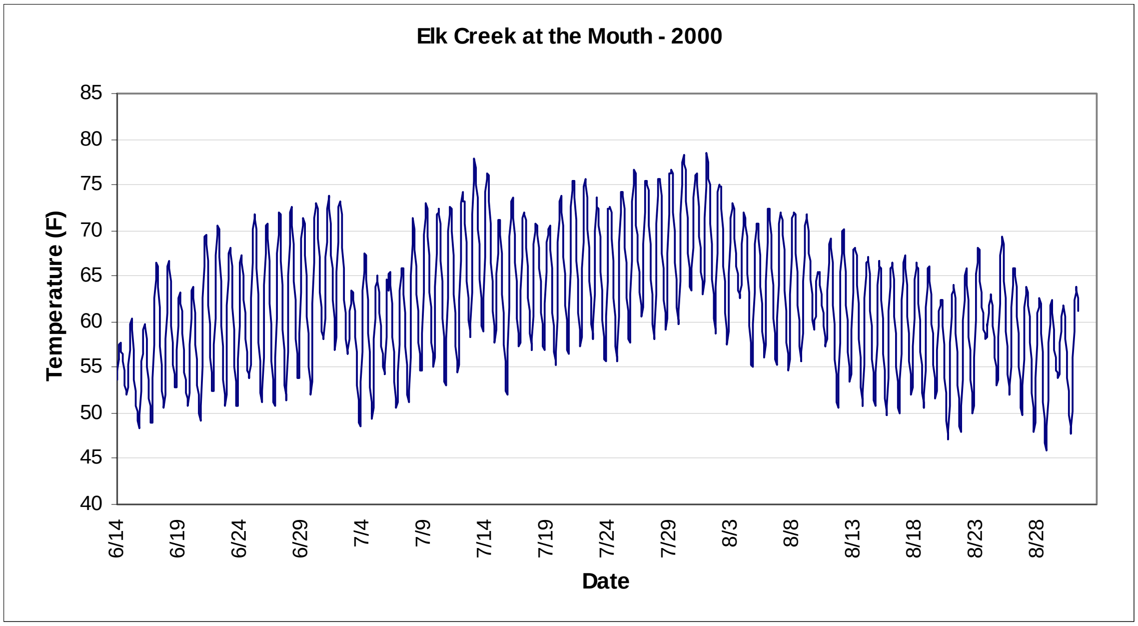


Figure 4-26. Continuous water temperature, Elk Creek at the mouth, 2000.

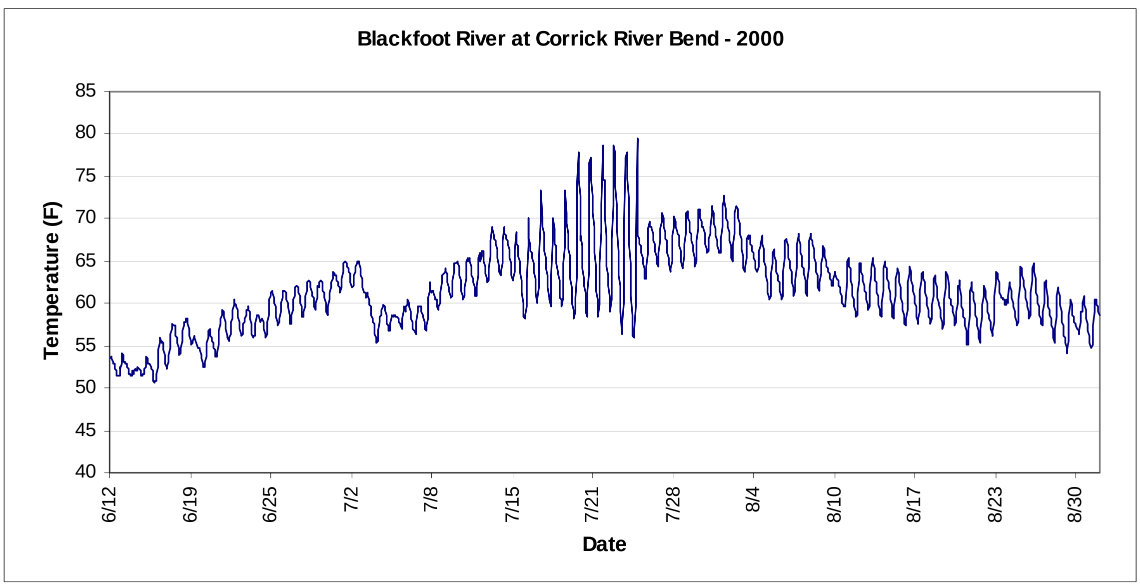


Figure 4-27. Continuous water temperature, Blackfoot River at Corrick River Bend, 2000.

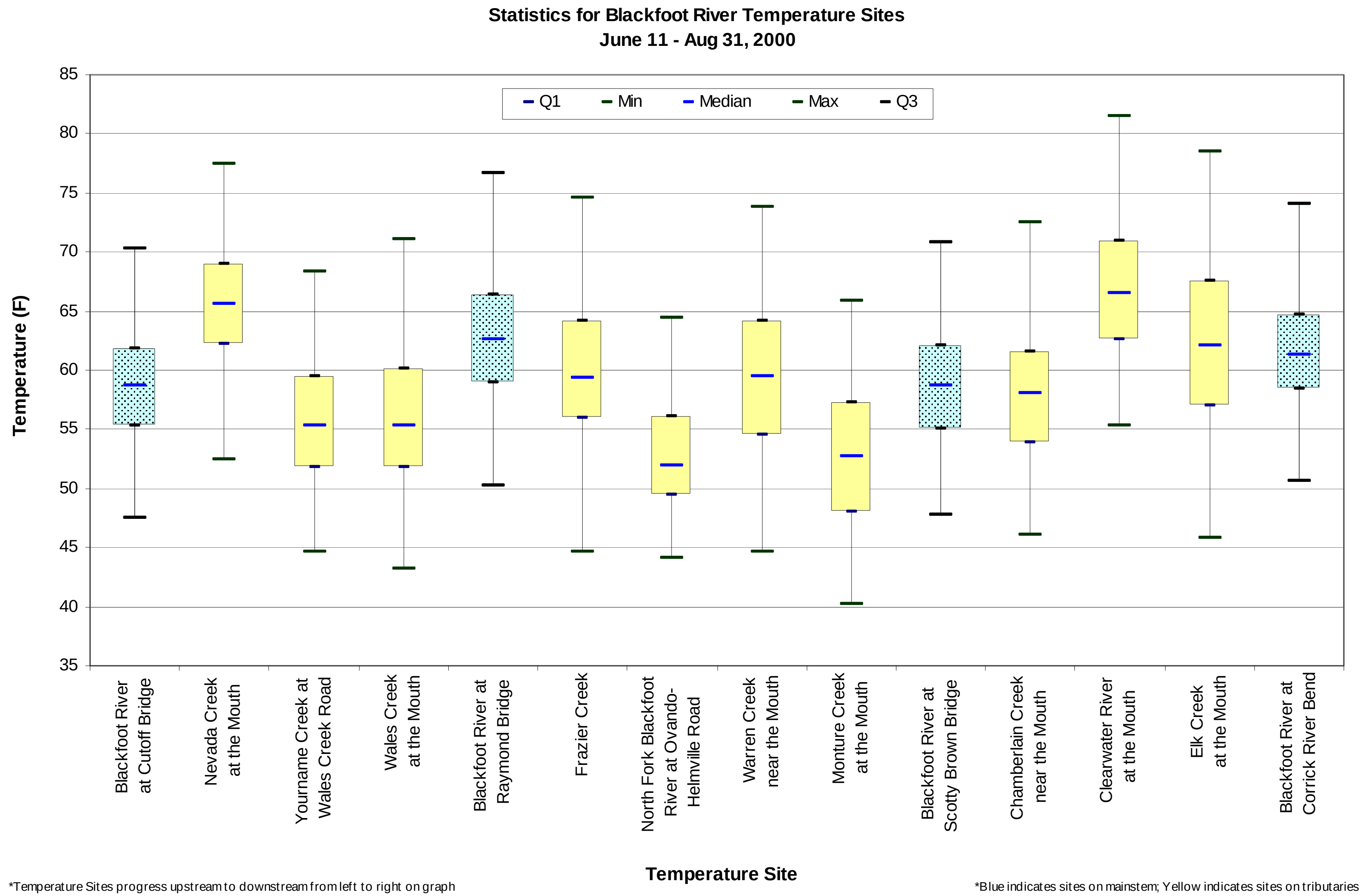


Figure 4-28. Upstream to downstream temperature variation, Blackfoot River, 2000.

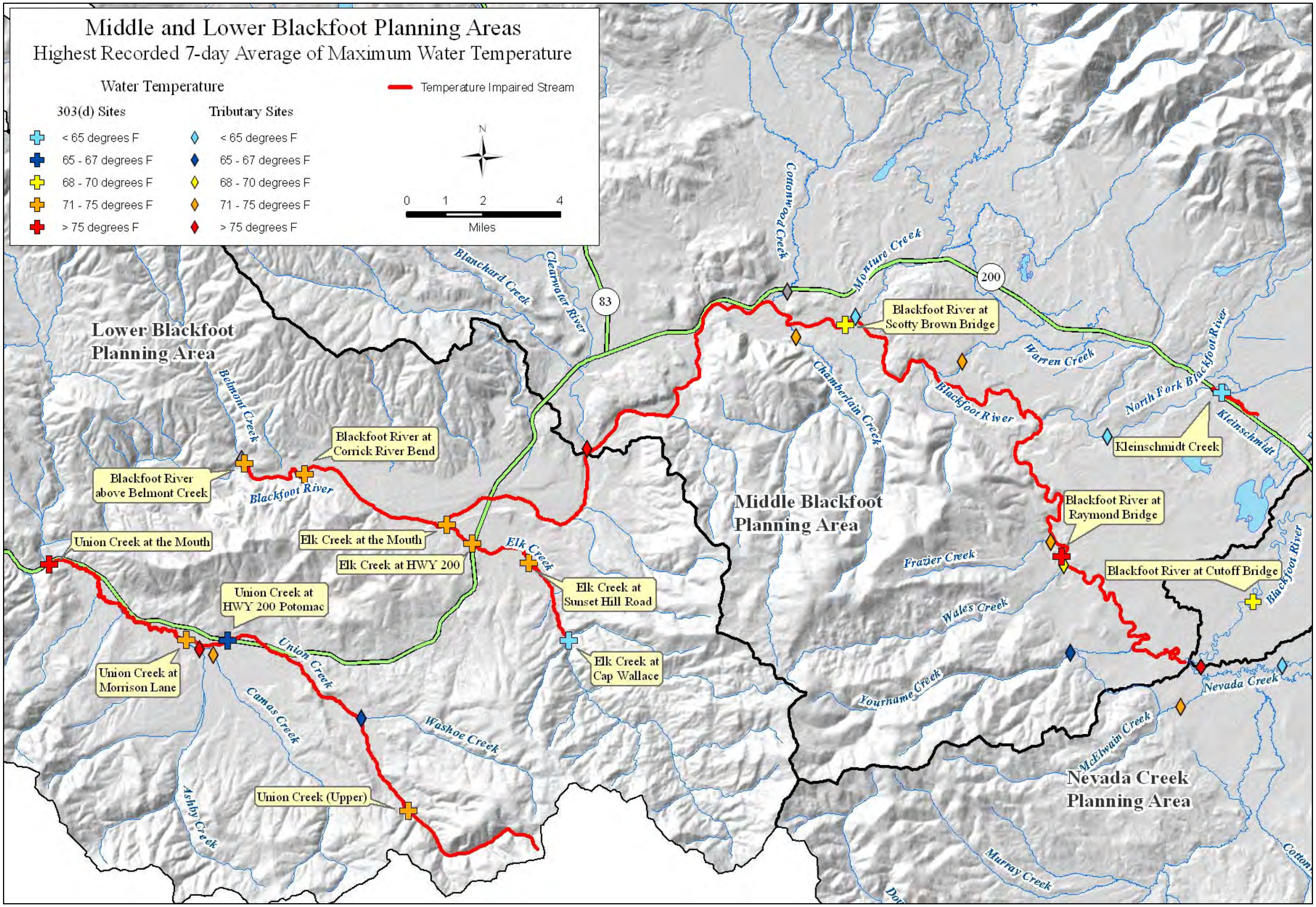


Figure 4-29: Highest 7-day average maximum temperature, Middle Blackfoot planning area, 2000.

Figure 4-30 and Figure 4-31 display the daily maximum and seven-day average maximum temperatures respectively at the four monitoring sites on the Blackfoot River during the summer of 2000. The site at Cutoff Bridge had the coolest maximum temperature throughout the summer, while the site at Raymond Bridge had the warmest maximum temperature for most of the summer. Maximum temperatures are slightly cooler at the other two sites at Scotty Brown Bridge and at Corrick River Bend. Figure 4-29, which displays the highest maximum temperature recorded during the summer of 2000 at all the sites, shows that Raymond Bridge is located upstream from these two sites. Thus, the largest increase in water temperatures on the Blackfoot River occurs between Cutoff Bridge and Raymond Bridge

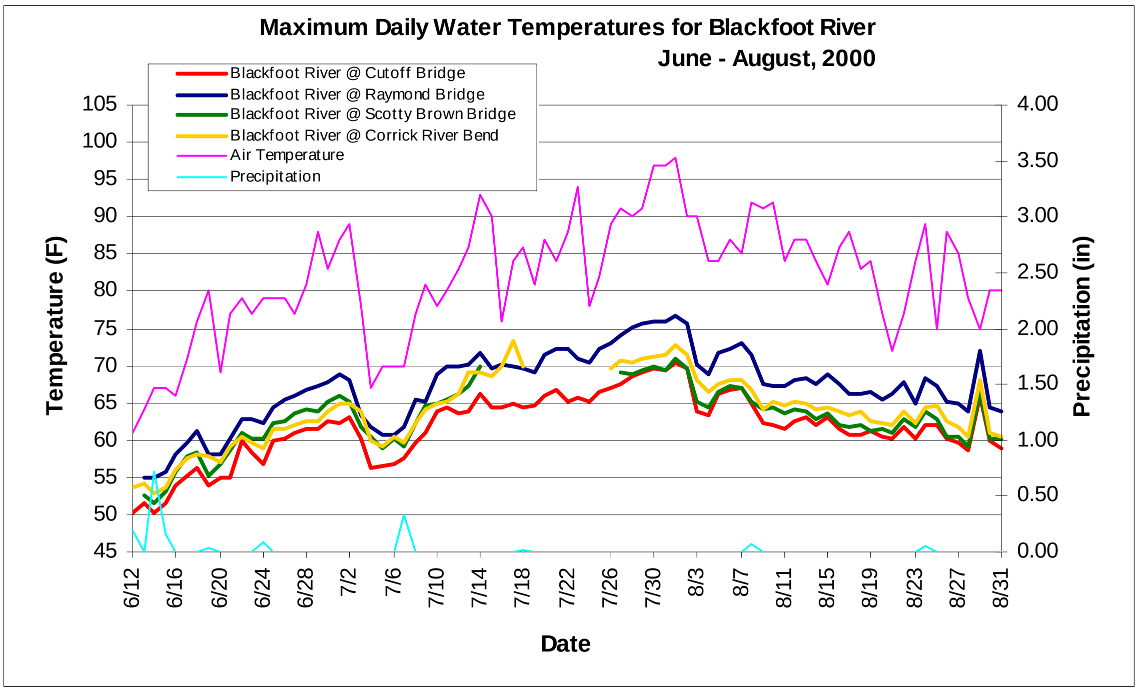


Figure 4-30. Maximum daily water temperature, air temperature, and precipitation, Blackfoot River, 2000.

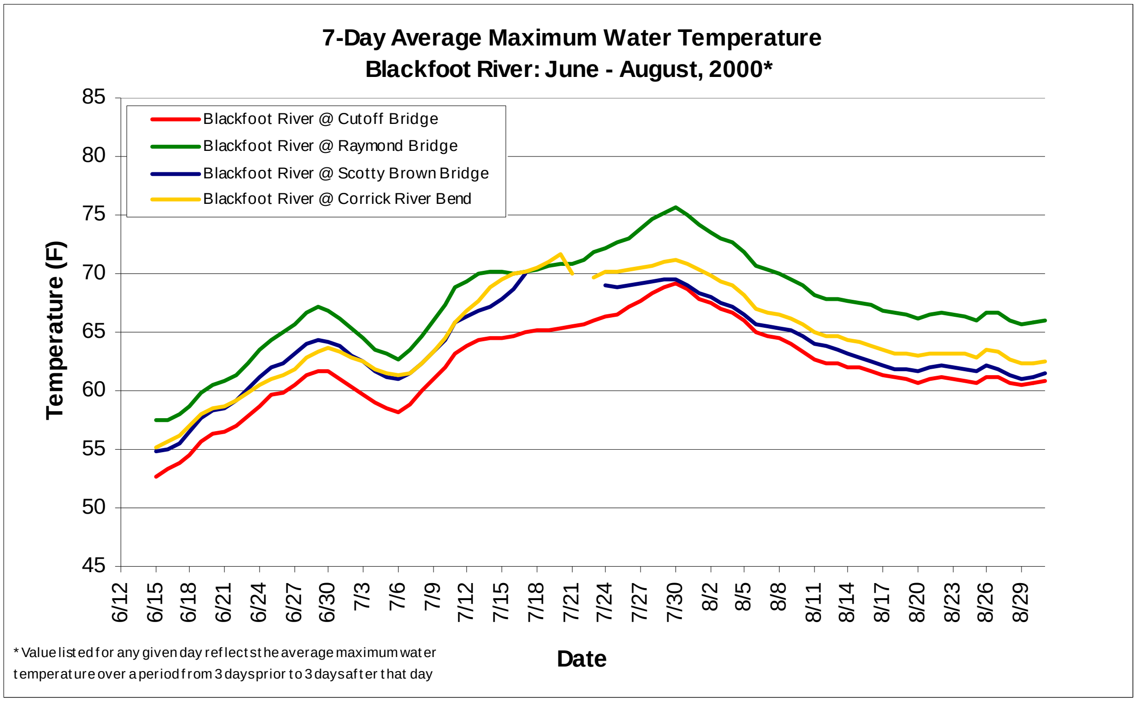


Figure 4-31. 7-day average maximum daily temperatures, Blackfoot Rvier, 2000.

Water temperatures measured at Cutoff Bridge, located above the confluence with Nevada Creek in the upper Blackfoot planning area, are relatively cool for much of the summer of 2000. Flow is 180 cfs during the late July 2000 modeling period. Water temperatures increased moderately at this site from late July through early August. Interpretation of aerial photos indicates that irrigation diversions near this site reduce flow in this reach, resulting in thermal gains during hot summer periods. The Blackfoot then meets Nevada Creek, which contributes approximately 22 cfs of relatively warm water. Because 22 cfs is only 12% of the Blackfoot River flow of 180 cfs, the increase in Blackfoot River temperature is relatively small. However, the Blackfoot then travels through a wide, un-shaded reach with irrigation withdrawals, where thermal gains are significant. By the time water reaches the Raymond Bridge, it has warmed significantly.

Farther downstream, cooler Blackfoot River water temperatures measured at Scotty Brown Bridge are indicative of cold-water contribution from the North Fork of the Blackfoot River and Monture Creek. Both of these streams contribute large volumes of cool water to the Blackfoot River throughout the summer. Between the site at Scotty Brown Bridge and the site downstream at Corrick River Bend the Clearwater River has the highest water temperatures of any Blackfoot River tributary and contributes a substantial amount of water. This is reflected in slightly warmer temperatures on the Blackfoot River at Corrick River Bend.

4.2.3. Elk Creek

The Montana FWP temperature database has temperature data collected at four sites on Elk Creek. However, not all four sites have available data for any one year. Three of the sites have data from 2002, while one site at the mouth of Elk Creek has data from 2003. Figure 4-32 through Figure 4-35 display continuous water temperature readings collected at the four monitoring sites during the summers of 2002 and 2003. For all sites, the highest water temperatures of the summer occur around mid-July. Note the increased range in diurnal temperature variation from the site at Cap Wallace downstream to the site at Highway 200, while minimum temperatures remain similar. This reflects an increase in maximum daily temperatures from site to site, upstream to downstream. The range in diurnal temperature is similar between the Highway 200 site and the next site downstream at the mouth of Elk Creek.

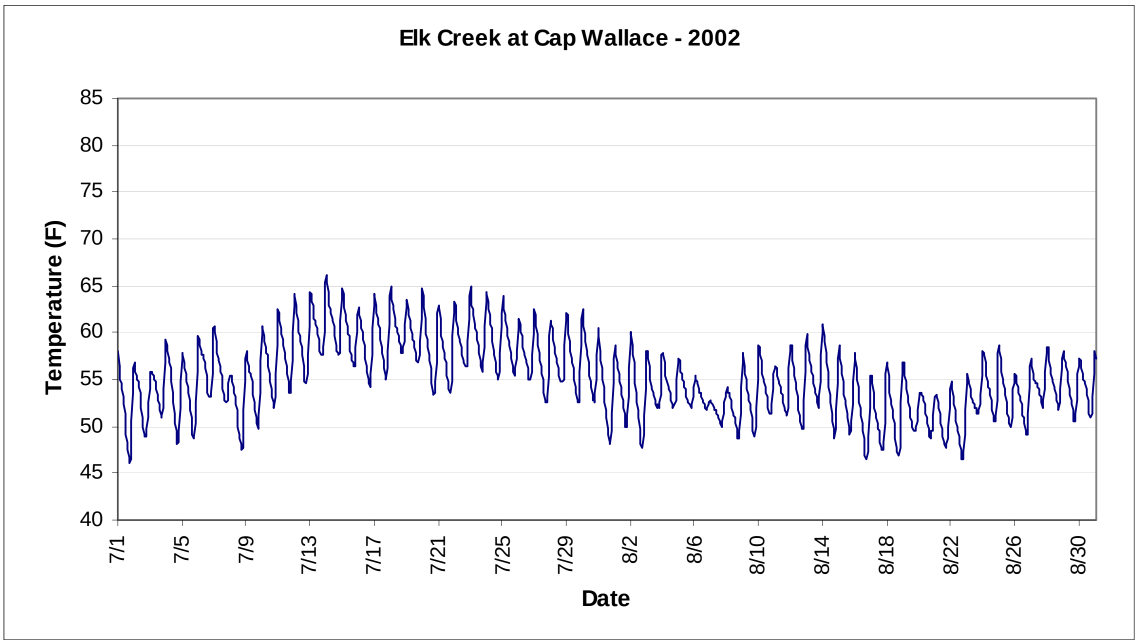


Figure 4-32. Continuous water temperature, Elk Creek at Cap Wallace, 2002.

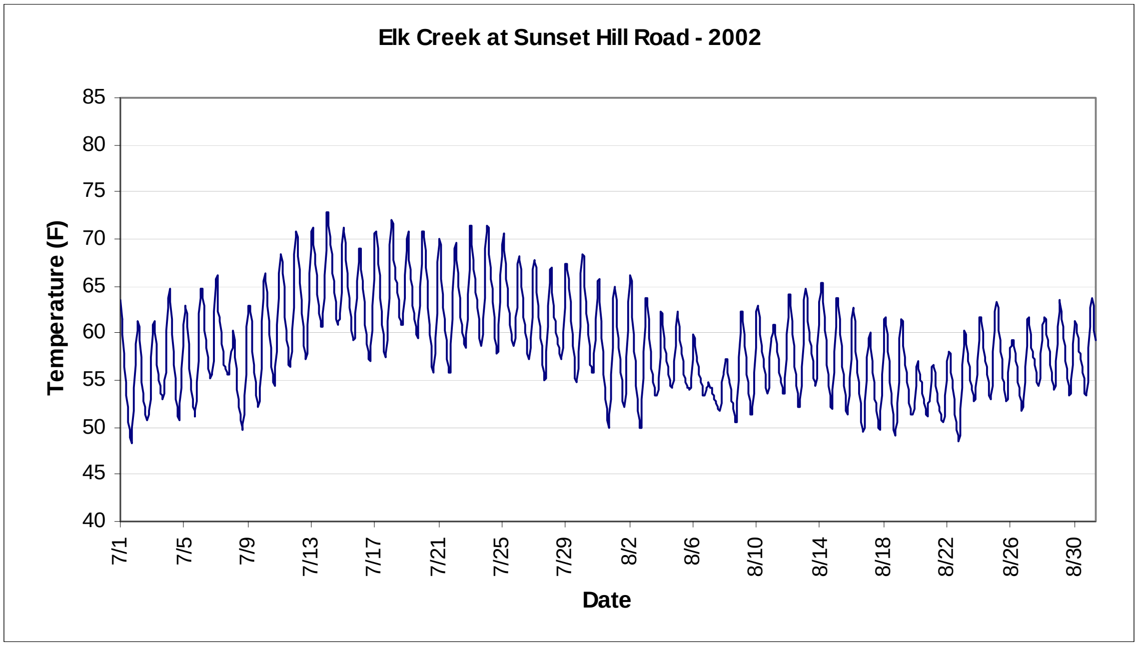


Figure 4-33. Continuous water temperature, Elk Creek at Sunset Hill Road, 2002.

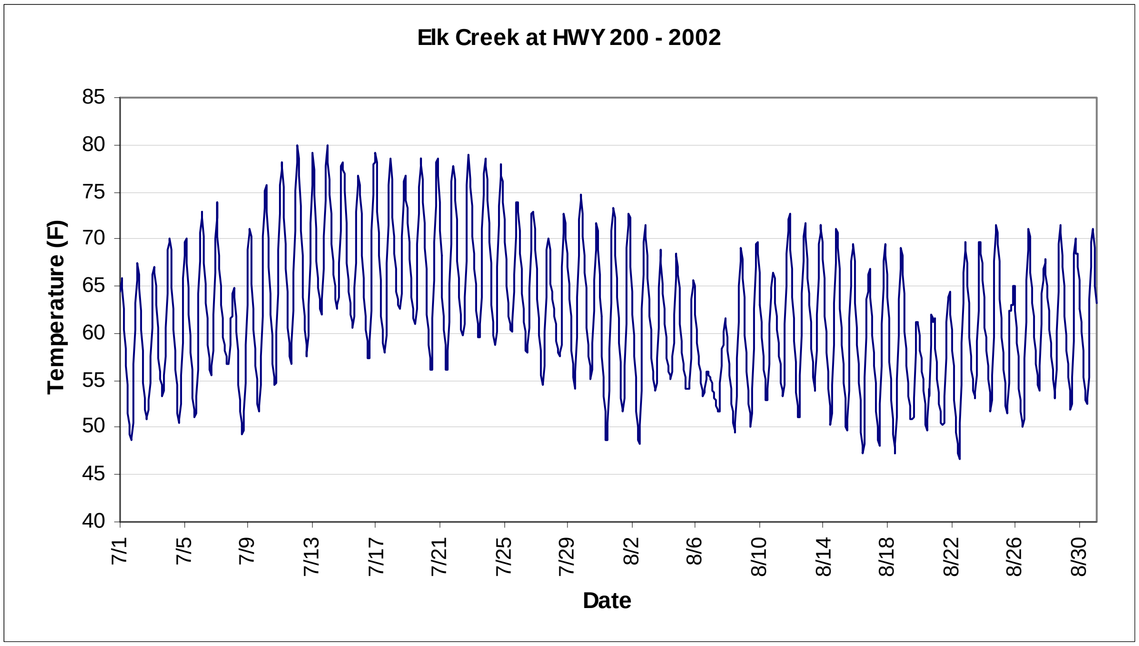


Figure 4-34. Continuous water temperature, Elk Creek at Highway 200, 2002.

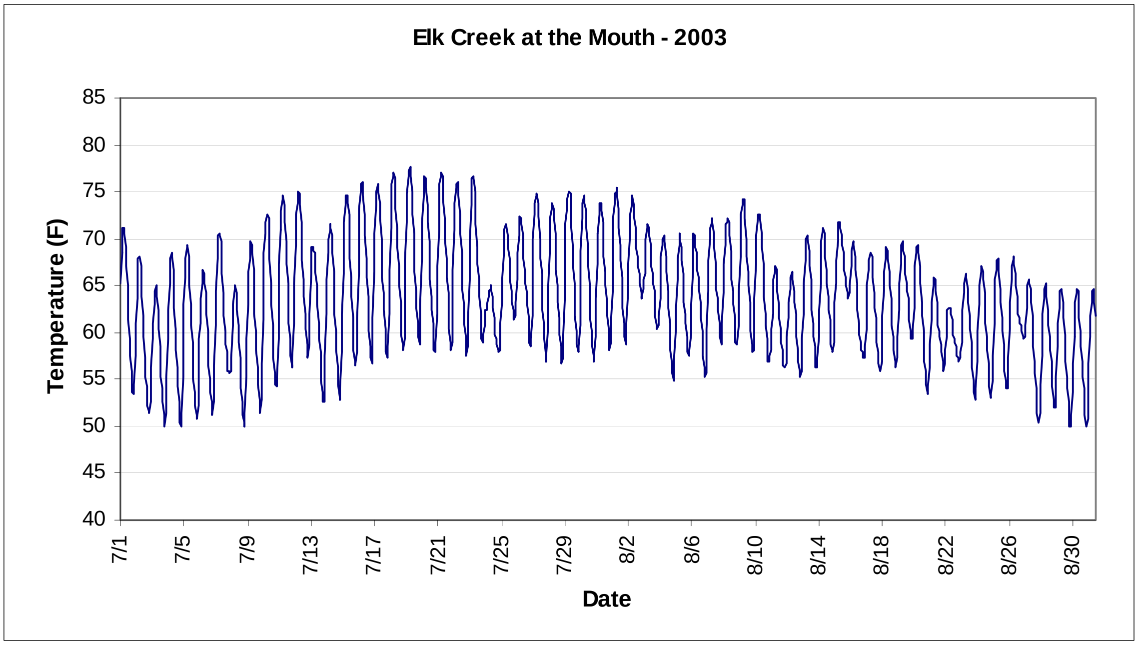


Figure 4-35. Continuous water temperature, Elk Creek at the mouth, 2003.

The statistical distribution of temperatures at the four monitoring sites also illustrates the trends seen in the daily temperatures graphs (Figure 4-36).

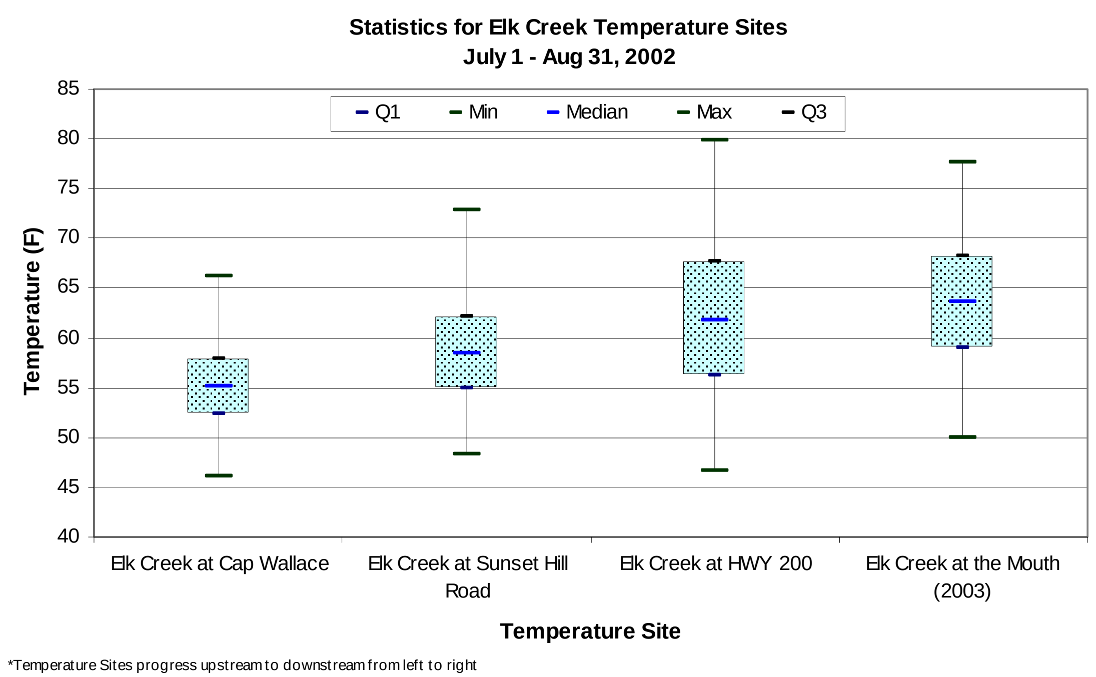


Figure 4-36. Upstream to downstream temperature variation, Elk Creek, 2002.

Daily maximum and seven-day average maximum temperatures at the four monitoring sites on Elk Creek during the summer of 2002 and 2003 also show the coolest maximum water temperatures recorded at the upstream site, Cap Wallace. The warmest maximum water temperatures are at Highway 200 or the mouth of Elk Creek. Maximum water temperatures increase steadily from upstream to downstream, and were highest during the summer in mid-July for all sites.

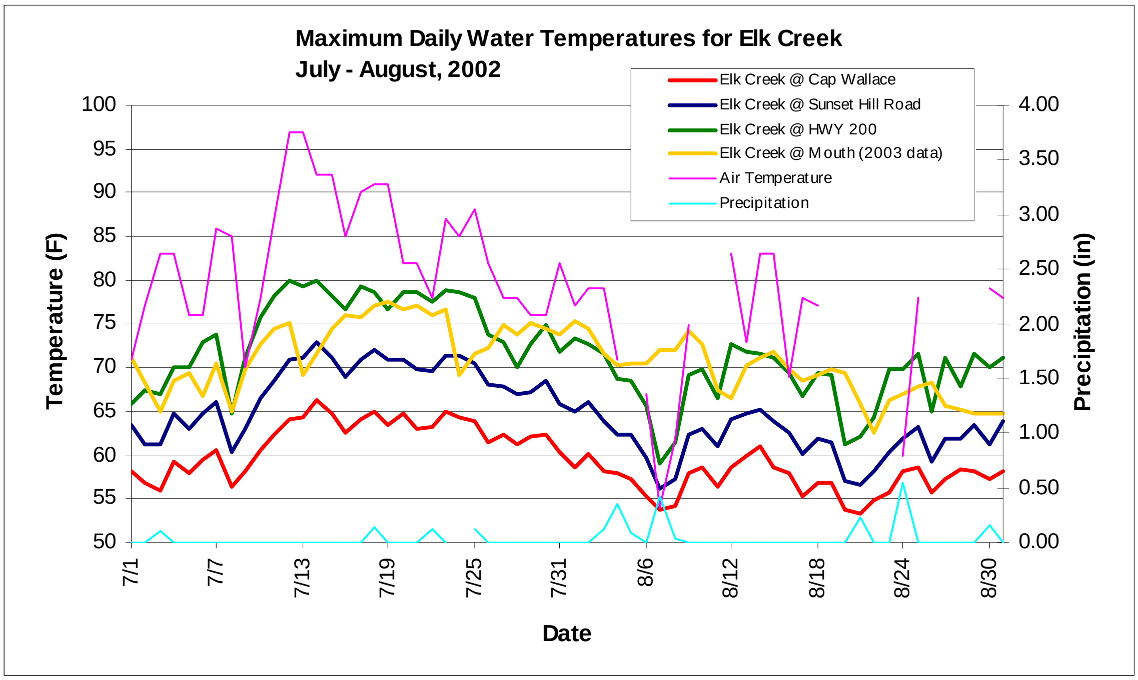


Figure 4-37. Maximum daily water temperature, air temperature, and precipitation, Elk Creek, 2002.

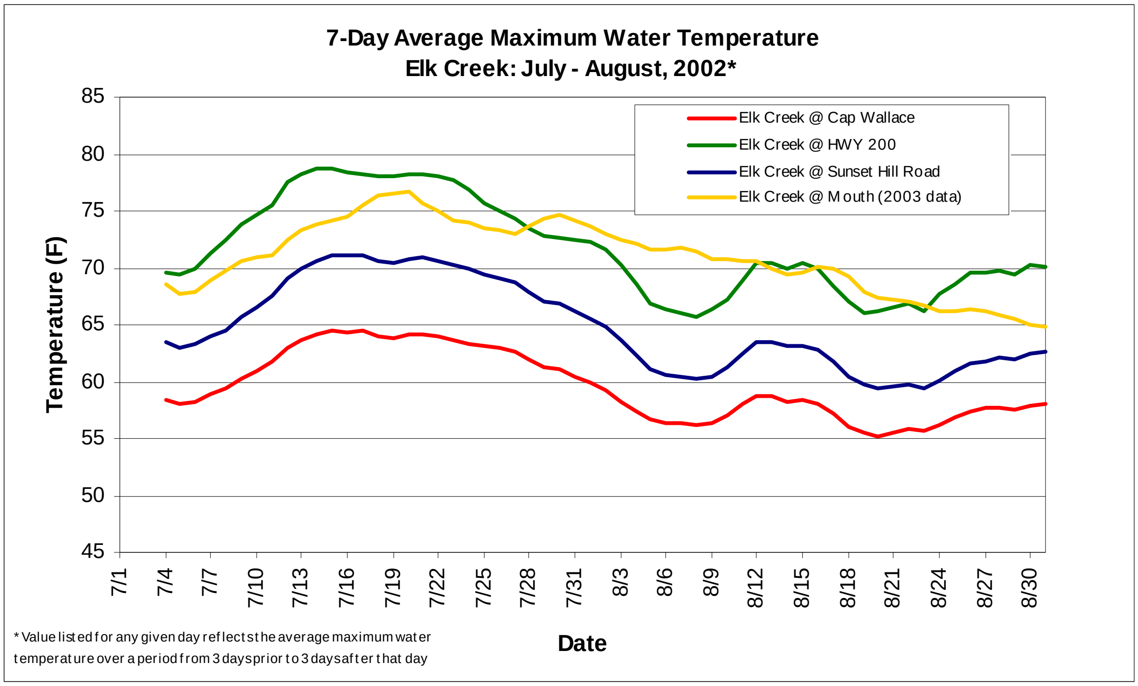


Figure 4-38. 7-day average maximum daily temperatures, Elk Creek, 2002.

Above Cap Wallace Gulch, Elk Creek is cold from headwater streams that flow through drainages with dense coniferous forests. Downstream from Cap Wallace, the valley widens considerably, and air photos depict a lack of riparian shading on much of Elk Creek downstream to Highway 200. This likely produces large thermal gains during hot summer days, as confirmed by warm stream temperature measurements on Elk Creek at Sunset Hill Road and at Highway 200. Further downstream, temperatures measured at the mouth of Elk Creek are similar to temperatures measured Highway 200. Although these data represent different years, air photos and field reconnaissance conducted during the summer of 2006 indicate that this reach of Elk Creek has a high density of woody vegetation that shades much of Elk Creek. This suggests that Elk Creek incurs little or no solar warming downstream of Highway 200.

4.2.4. Union Creek

Union Creek, like Elk Creek, is located within the Lower Blackfoot Planning Area. Although no tributaries of Union Creek are on the 303(d) list for temperature impairments, temperature data is available for some tributaries that contribute water to Union Creek. The Montana FWP temperature database contains data collected in 2002 for four sites on Union Creek and for three sites on tributary streams. Figure 4-39 through Figure 4-45 display continuous water temperature data collected at the seven monitoring sites during the summer of 2002. These figures illustrate that for all the sites the warmest temperatures during the summer of 2002 occurred in mid-July, although for some sites water temperatures in mid-August were also high. The drop in temperature around Aug 8 at all sites indicates a cool and rainy period (Figure 4-47).

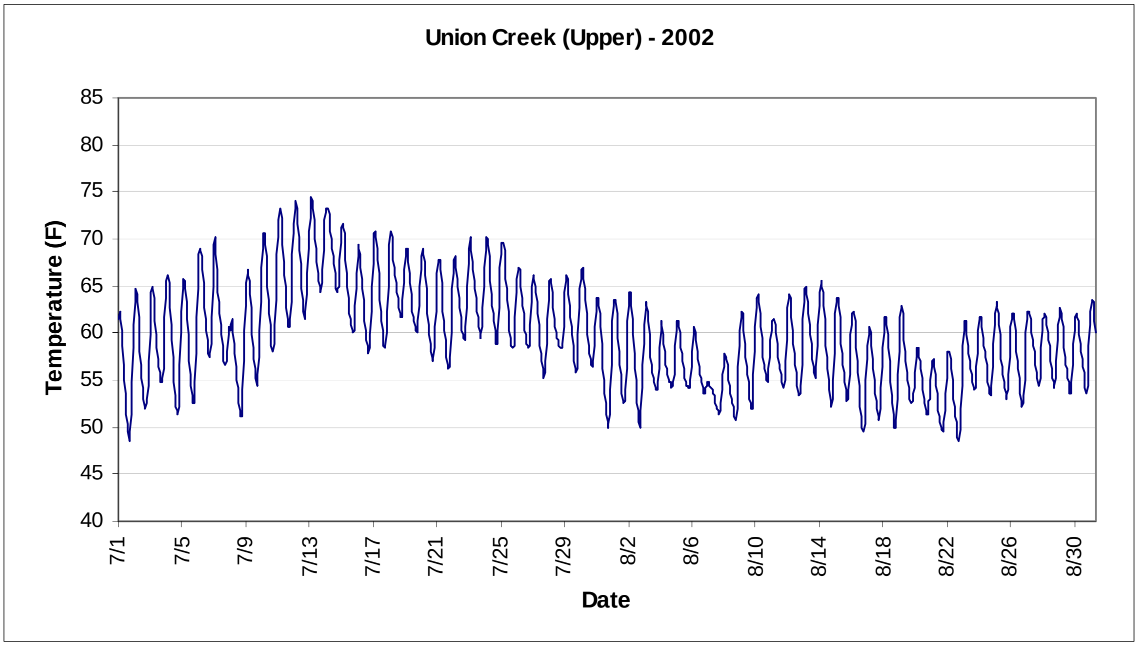


Figure 4-39. Continuous water temperature, Union Creek (Upper), 2002.

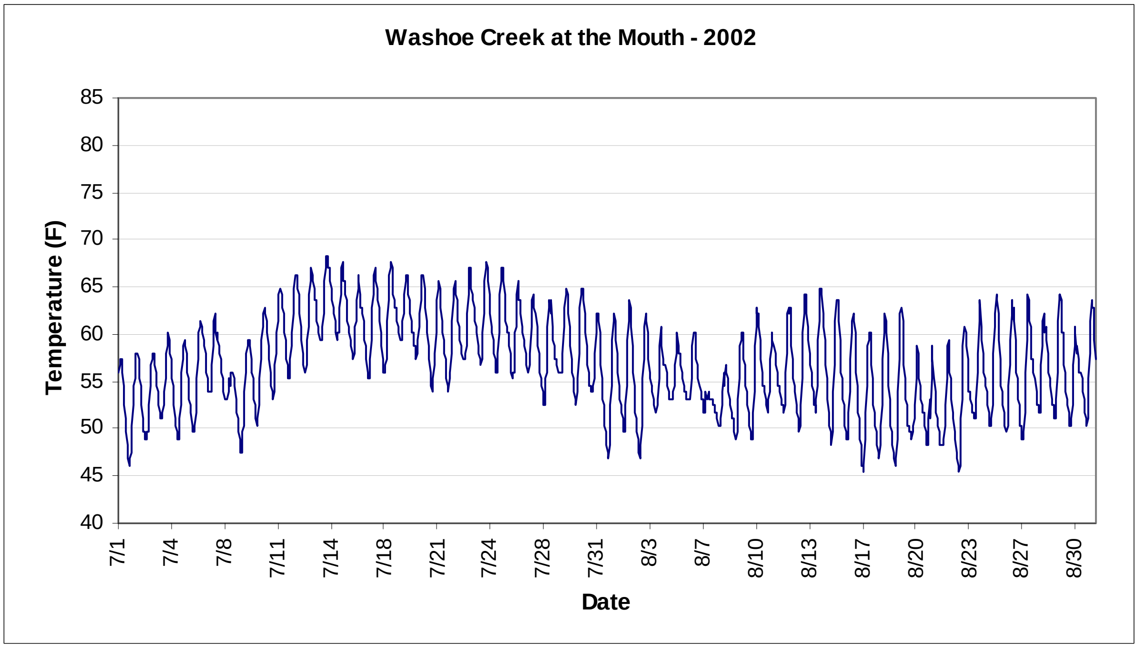


Figure 4-40. Continuous water temperature, Washoe Creek at the mouth, 2002.

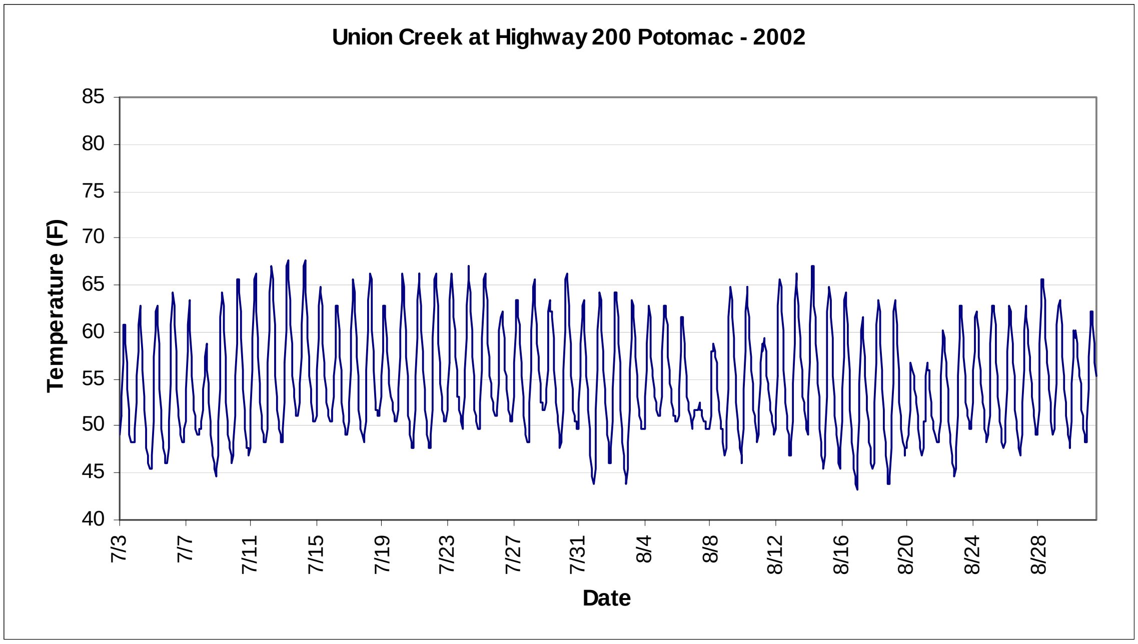


Figure 4-41. Continuous water temperature, Union Creek at Highway 200 Potomac, 2002.

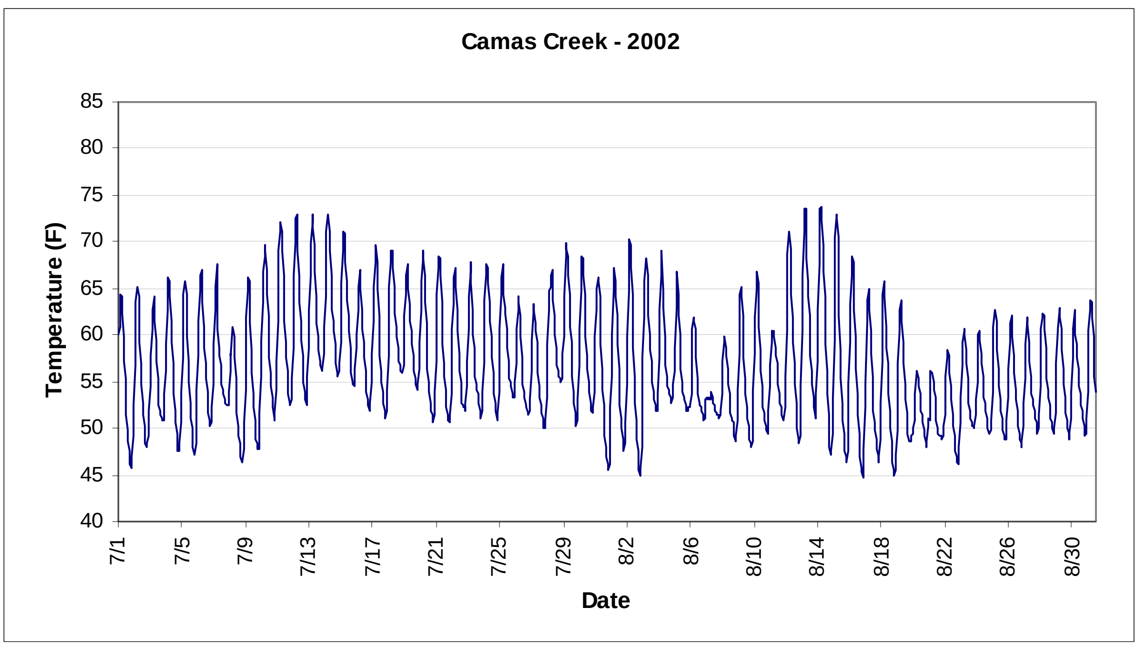


Figure 4-42 Continuous water temperature, Camas Creek, 2002.

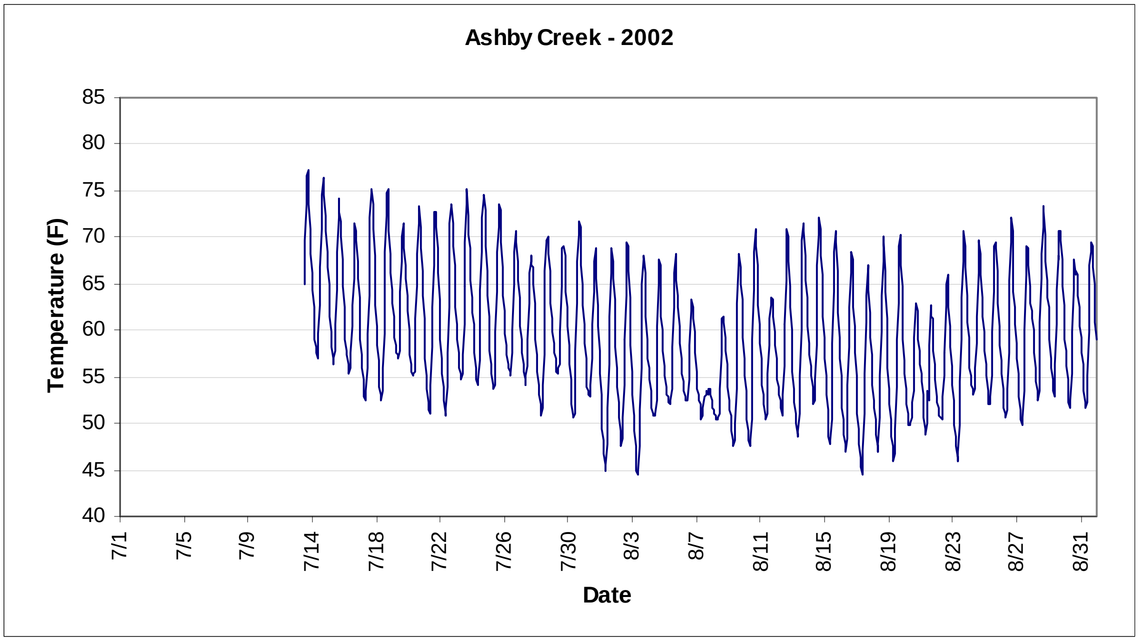


Figure 4-43. Continuous water temperature, Ashby Creek, 2002.

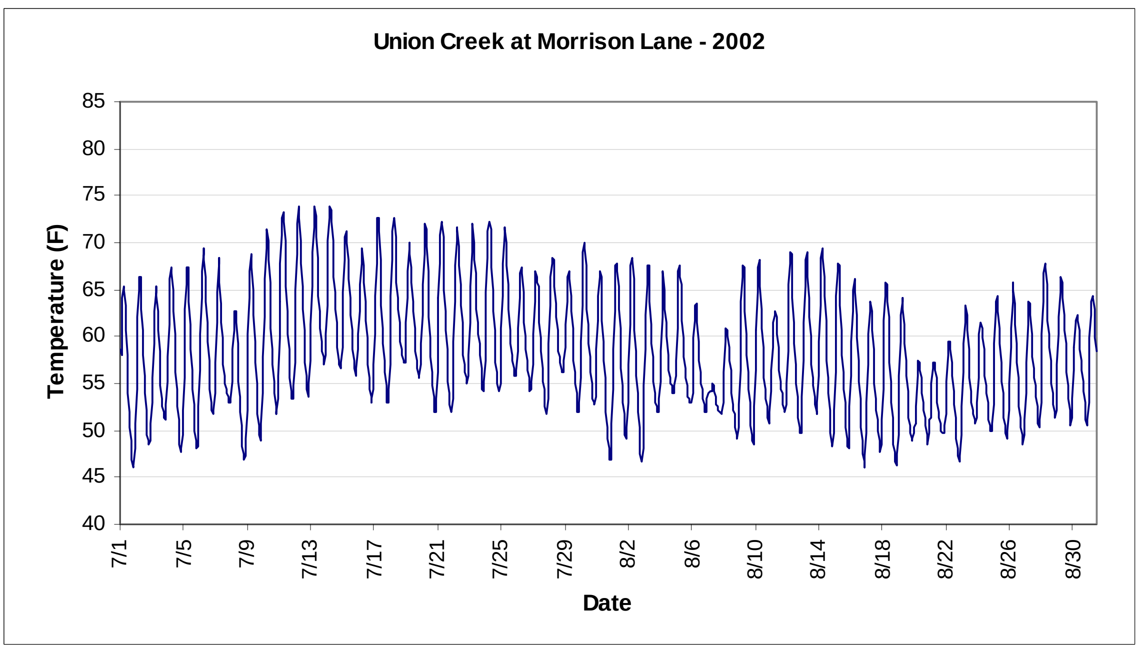


Figure 4-44. Continuous water temperature, Union Creek at Morrison Lane, 2002.

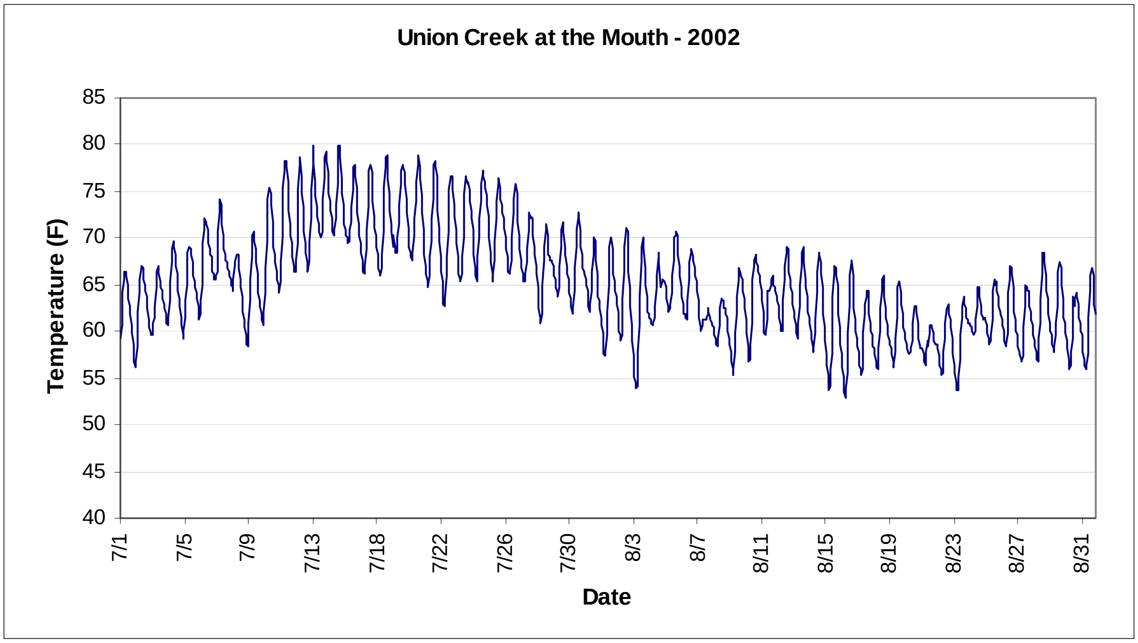


Figure 4-45. Continuous water temperature, Union Creek at the mouth, 2002.

The plot of the distribution of summer temperatures shows that upper Union Creek has a wide range of water temperatures and high daily maximum temperatures (Figure 4-46). The maximum temperature and range in measured temperatures decreases slightly at Highway 200 before increasing again at Morrison Lane and at the mouth of Union Creek. Tributary streams Camas Creek and Ashby Creek both had high maximum temperatures and a wide range in measured temperatures. Washoe Creek has a much narrower range in measured water temperatures and a lower measured maximum water temperature.

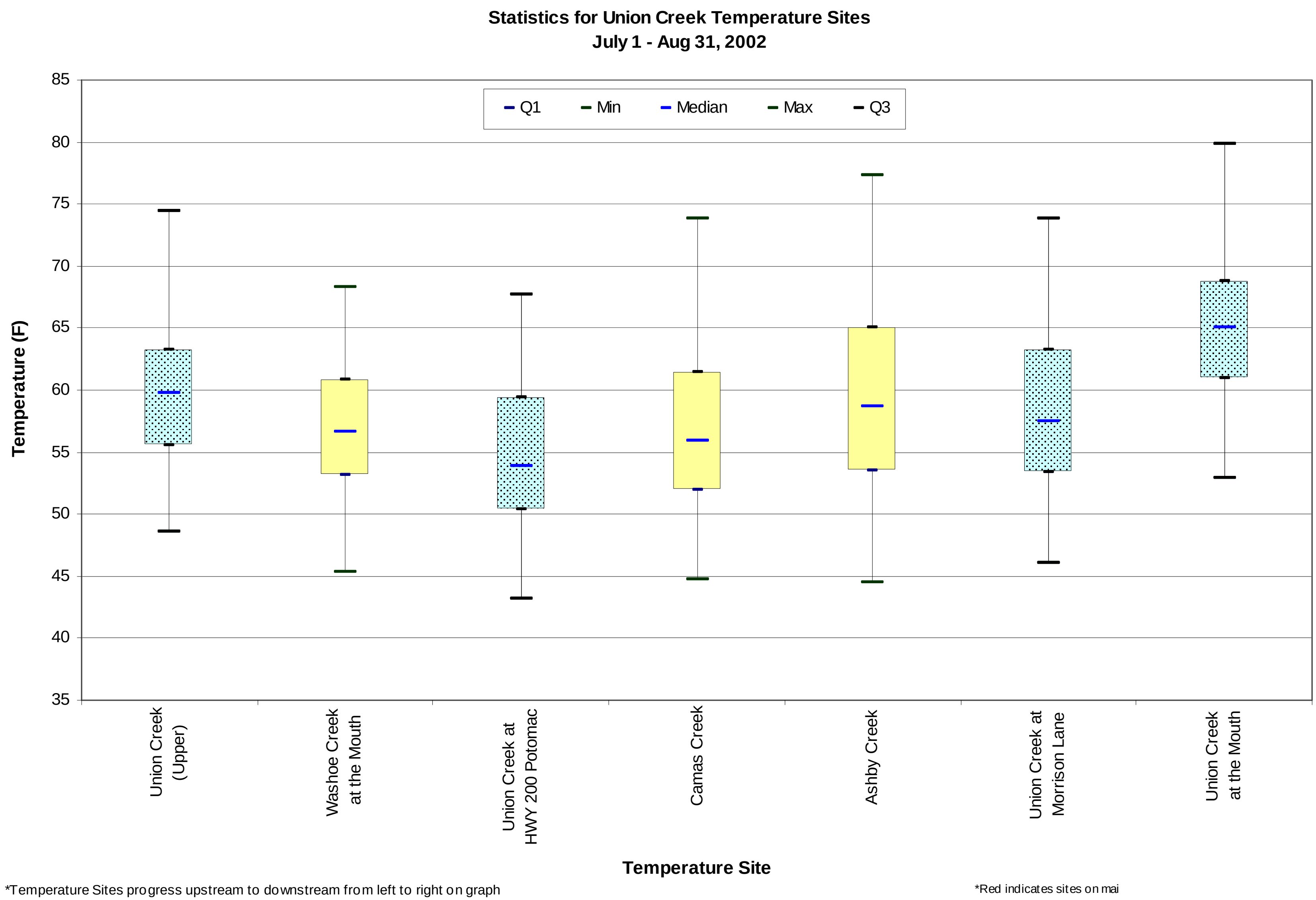


Figure 4-46. Upstream to downstream temperature variation, Union Creek, 2002.

The daily maximum and seven-day average maximum temperature graphs show that the highest temperatures in mid July, concurrent with sustained warmest air temperatures (Figure 4-47 and Figure 4-48). Unlike the other streams on the 303(d) list, however, the site farthest upstream, located in upper Union Creek, does not have the lowest maximum temperature. Maximum temperatures decrease downstream from this site at Morrison Lane, before rising again further downstream at Highway 200. The site at the mouth of Union Creek has the highest maximum temperatures for much of the summer of 2002.

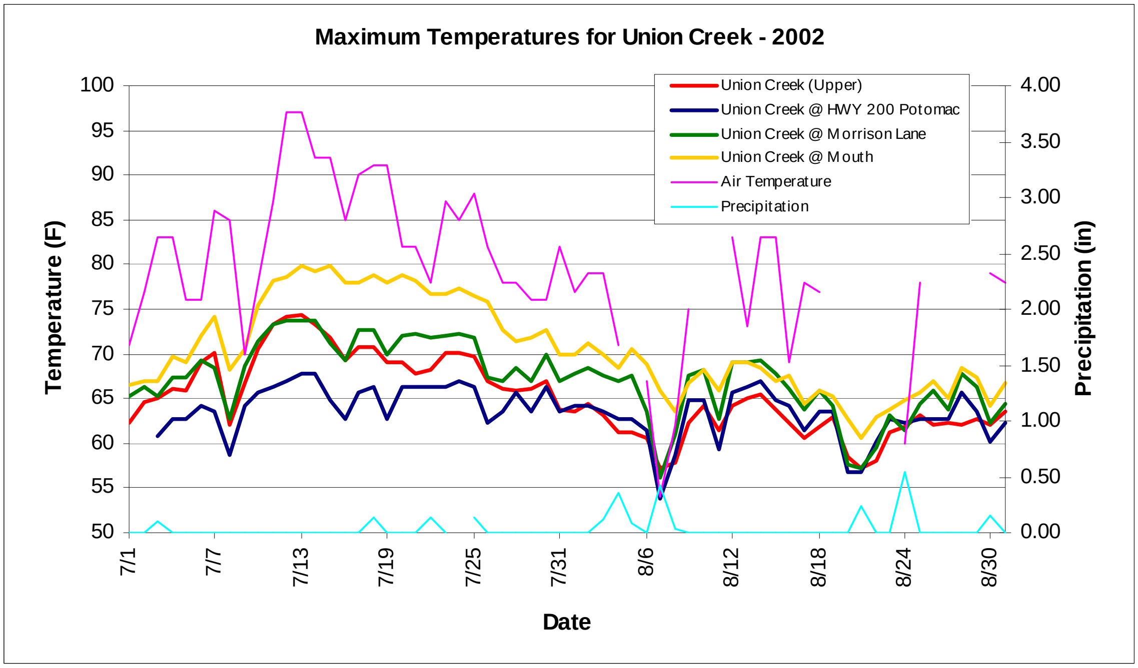


Figure 4-47. Maximum daily water temperature, air temperature, and precipitation, Union Creek, 2002.

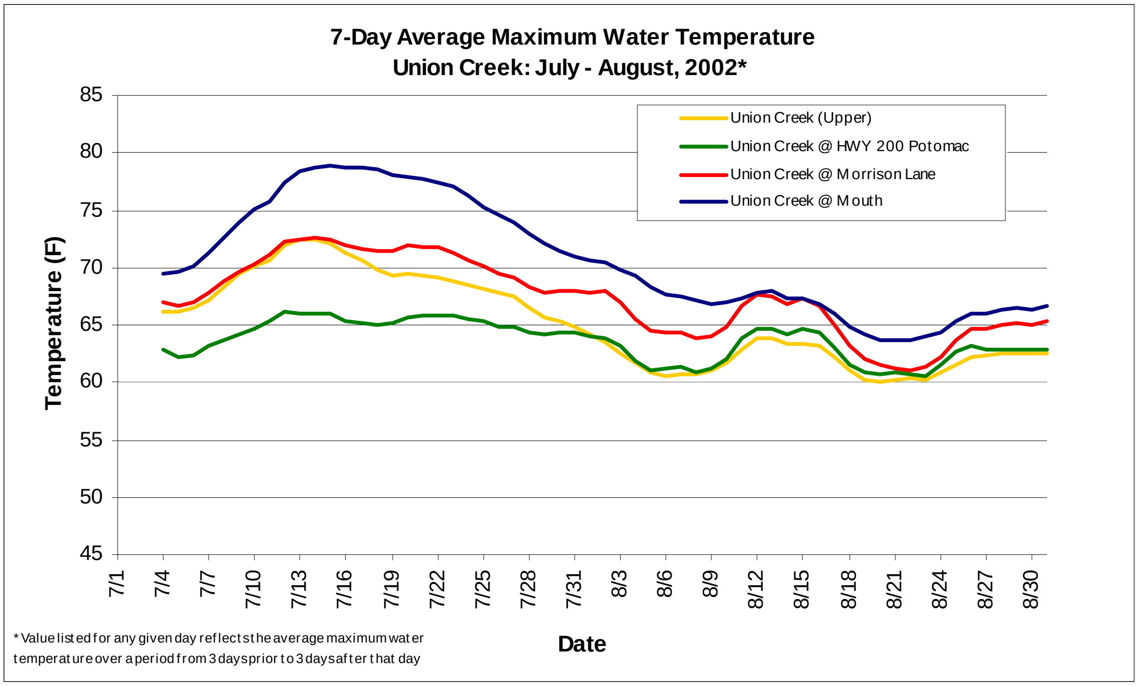


Figure 4-48. 7-day average maximum daily temperatures, Union Creek, 2002.

Warm water temperatures measured at the upper Union Creek site are not typical of other headwater streams in this study. Air photos depict extensive timber harvest in the area above this site. The reduction in vegetation cover may result in increased solar heating of Union Creek and other tributaries. In addition, the geology of the headwaters area of Union Creek consists mostly of Proterozoic sedimentary rocks that are less likely to host springs than Paleozoic sedimentary rocks or Cretaceous granitic rocks in nearby drainages. Therefore, the higher headwater temperatures in Union Creek may be natural, anthropogenic, or a combination.

Union Creek enters a wide agricultural valley bottom area after it leaves its headwaters area. Several irrigation diversions remove flow and numerous ranchettes with horse pastures cause habitat, sediment, temperature, and nutrient impairments. Union Creek receives cool water from Washoe Creek that partially mitigates these impacts. About one mile further downstream, Union Creek passes through a small canyon constricted by Proterozoic bedrock. Groundwater upwelling in this area likely provides additional cool water. Downstream of this canyon, Union Creek is a losing stream until about ½ mile past the first Highway 200 crossing where it picks up cold groundwater from Tertiary sedimentary rocks to the north. By the second crossing, one mile further downstream, Union Creek has gained considerable flow. Between the second Highway 200 crossing and Morrison Lane, Union Creek flows through a highly impacted agricultural valley bottom where lack of shade contributes to higher water temperatures. In addition, Camas Creek and Ashby Creek contribute warm water to Union Creek in this reach. Downstream from Morrison Lane, air photos depict a lack of riparian shading on much of Union Creek. In addition to limited riparian vegetation, irrigation diversions reduce flow in these reaches. This likely results in large thermal gains during hot summer days, as seen in warm stream temperature measurements at the mouth of Union Creek.

4.3. Temperature Modeling

The following sections describe the SNTEMP temperature modeling conducted for the Blackfoot River and Kleinschmidt Creek in the Middle Blackfoot Planning Area.

4.3.1. Blackfoot River

The Blackfoot River model simulated temperatures for the Blackfoot River within the Middle Blackfoot planning area by modeling the Blackfoot River from Cutoff Bridge to Corrick River Bend. This section of the Blackfoot River extends for 49.8 miles (Figure 4-49). However, Corrick River Bend is located in the Lower Blackfoot planning area . To model temperatures for the Blackfoot River only in the Middle Blackfoot planning area, temperatures were simulated at a location below the Clearwater River.

Construction

Point, calibration, diversion, segment, and temperature output nodes are included in the Blackfoot River model (Figure 4-49). All tributaries in the model are included as point sources to the Blackfoot River. An additional point source below Chamberlain Creek accounted for return flow from the prairie pothole area around the mouth of Cottonwood Creek. Three calibration points in the network are located at Raymond Bridge, Scotty Brown Bridge, and at the end of the network at Corrick River Bend. Only one diversion point is in the model, below Yourname Creek to account for several irrigation pumps.

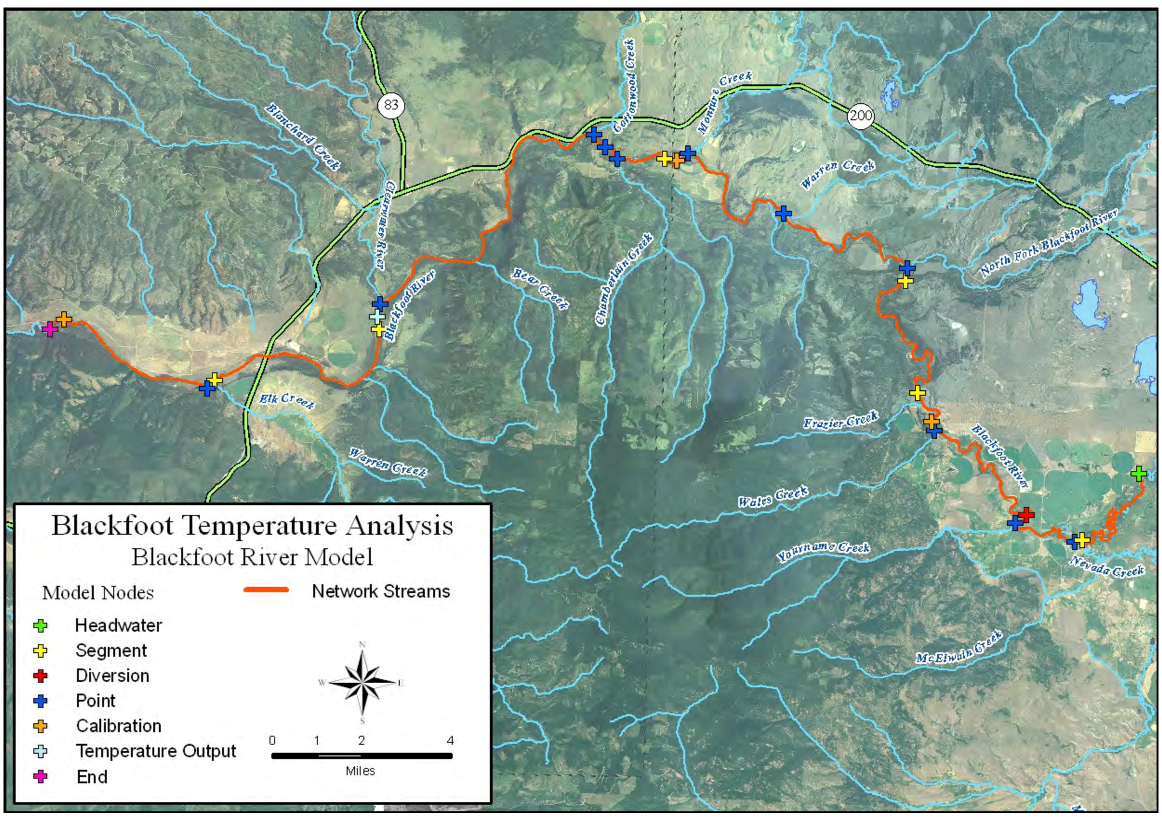


Figure 4-49. Schematic of the Blackfoot River model network and model nodes.

Modeling for the Blackfoot River is for the period July 27 – 29, 2000. A three-day modeling period ensured that water completed travel through the network during the modeling period. Table 4-3 lists stream geometry and general vegetation characteristics for the Blackfoot River model. About 47 percent of the Blackfoot River has streambank woody vegetation. However, since the Blackfoot River is wide, with an average low flow width of 130 feet, this vegetation provides little shade (maximum of 8.74% in reach Blkft12).

Stream	*Modeling Period*	*Length (mi)*	*Average Low Flow Width (ft)*	*Average Streambank Vegetation (%)*	*Average Shade (%)*
Blackfoot River	July 27 - 29, 2000	47.7	129.6	46.7	3.9

*Streambank vegetation is percent of total stream bank in model that consists of vegetation capable of producing shade. Shade is percent of total stream surface area covered by shade.

Table 4-3. Current stream conditions for the Blackfoot River SNTEMP model.

Stream geometry and hydrology data for the modeling period were input into the model (Table 4-5). For each segment and headwater node, flow, width, Manning's-n, and shade are input, while water temperature is required for headwater nodes. All other nodes receive only water temperature and/or flow data.

Water temperature input to the model at the Cutoff Bridge is 64.1^{o} F. Warm water contributions include Nevada Creek (70.9^{o} F) and the Clearwater River (69.9^{o} F). Monture Creek and the North Fork of the Blackfoot River contribute large volumes of cool water at 58.0^{o} F and 55.7^{o} F, respectively.

Meteorological data for the modeling period of July 27 – 29, 2000 were summarized and input into the model (Table 3-11). These data are representative of hot and dry conditions that lead to temperature extremes in the stream. The average daily maximum air temperature, 90.7^{o} F, was one of the hotter periods in the summer of 2000.

Modeling Period	*Air Temperature (F) (mean)*	*Relative Humidity (%) (mean)*	*Wind (mph) (mean)*	*Possible Sun (%)*	*Dust Coefficient*	*Ground Reflectivity*
July 27 - July 29, 2000	90.7	47.3	3.8	95	0.05103	0.27690

Table 4-4. Meteorological input data for the Blackfoot River SNTEMP model.

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Table 4-5. Input data for the Blackfoot River model.

Segment	Node	Stream Mile	Water Temperature (F)	Flow (cfs)	Stream Width (ft)	Manning's n	Bankline Veg (%)	Shade (%)	Comments
Cutoff Bridge to Nevada Ck	Headwater*	71.5	64.1	180	68.0	0.062	19.8	2.0	Network initiation at Cutoff Bridge
Nevada Ck to Frazier Ck	Segment	66.5	32.0	180	102.5	0.062	13.4	1.0	Above Nevada Creek
	Point	66.5	70.9	22					Nevada Creek
	Point	64.6	59.9	5					Yourname Creek
	Diversion	64.0		8					Below Yourname Ck
	Point	59.6	59.1	4					Wales Creek
	Calibration	59.3	69.0	203					Temperature site at Raymond Brdg
Frazier Ck to above North Fork Blackfoot River	Segment	58.3		203	116.0	0.062	51.4	9.2	Segment within canyon section
Above North Fork to below Monture Ck	Segment	53.3	32.0	203	148.0	0.062	50.6	2.6	Segment break above North Fork
	Point	53.3	55.7	219					North Fork Blackfoot River
	Point	49.2	63.9	8					Warren Creek
	Point	45.3	58.0	81					Monture Creek
	Calibration	45.1	64.2	511					Site at Scotty Brown Bridge
Below Monture Ck to below Clearwater River	Segment	45.0		511	143.3	0.062	60.3	5.7	Segment break below calibration
	Point	43.5	64.2	5					Chamberlain Creek
	Point	42.9	55.0	20					Point source return flow
	Point	42.5	60.8	27					Cottonwood Creek
	Point	34.4	69.9	73					Clearwater River
	Output	34.3		636					Middle Blackfoot temperature output

Segment	***Node***	***Stream Mile***	***Water Temperature (F)***	***Flow (cfs)***	***Stream Width (ft)***	***Manning's n***	***Bankline Veg (%)***	***Shade (%)***	***Comments***
Below Clearwater River to Elk Ck	Segment	34.2		636	157.4	0.062	75.3	5.5	Segment break below the Middle Blackfoot planning area
Elk Ck to Corrick River Bend	Segment	28.5		636	160.0	0.062	56.9	1.9	Segment break above Elk Ck
	Point	28.4	68.4	15					Elk Creek
	Calibration	24.0	67.4	651					Site at Corrick River Bend
	End	23.9		651					End of network

*Headwater is the starting point of each stream in the model network

Calibration

Model calibration used three sites on the Blackfoot River. The model required no calibration for the first two upstream sites, at Raymond Bridge and at Scotty Brown Bridge, since simulated and observed temperatures were within the required calibration tolerance (Table 4-6 and Table 4-7). However, calibration was necessary for the site at Corrick River Bend, with initial simulated mean and maximum temperatures 1.56^{o} F and 2.85^{o} F greater, respectively, than observed temperatures.

To calibrate temperatures at Corrick River Bend, the thermal gradient for the model segment from Scotty Brown Bridge to Corrick River Bend was adjusted (Table 4-8). Thermal gradient is a segment specific parameter that is a measure of thermal exchange between the streambed and water in joules/meter^{2}second/^{o}C (Bartholow, 2004). Streams that interact with groundwater typically have a higher thermal gradient and a suppressed diurnal temperature variation. Field observations suggest the between Monture Creek and Cottonwood Creek, the Blackfoot River receives and interacts with cool groundwater coming from the prairie pothole topography to the north of this reach. Increasing thermal gradient helped account for groundwater/surface water interactions and yielded satisfactory calibration results (Table 4-8).

Location: Blackfoot River at Raymond Bridge					
Calibration Iteration	***Temperature (F)***		***Difference from Observed Temp (F)***		***Parameter Changed***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	69.04	74.96	NA	NA	NA
Initial Model Run	68.65	74.12	-0.39	-0.84	Default Parameter Values

Table 4-6. Initial model and calibration results for the Blackfoot River at Raymond Bridge.

Location: Blackfoot River at Scotty Brown Bridge					
Calibration Iteration	***Temperature (F)***		***Difference from Observed Temp (F)***		***Parameter Changed***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	64.19	69.03	NA	NA	NA
Initial Model Run	64.53	69.80	0.34	0.77	Default Parameter Values

Table 4-7. Initial model and calibration results for the Blackfoot River at Scotty Brown Bridge.

Location: Blackfoot River at Corrick River Bend (End of Network)					
Calibration Iteration	***Temperature (F)***		***Difference from Observed Temp (F)***		***Parameter Changed***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	67.43	70.59	NA	NA	NA
Initial Model Run	68.99	73.44	1.56	2.85	Default Parameter Values Thermal gradient = 1.65
1	68.59	72.93	1.16	2.34	Thermal Gradient - Increase to 2.65
2	68.36	72.34	0.89	1.75	Thermal Gradient - Increase to 3.25
3	68.20	72.45	0.77	1.35	Thermal Gradient - Increase to 3.65 Manning's n – Increase to 0.080

Table 4-8. Initial model and calibration results for the Blackfoot River at Corrick River Bend.

Simulations

The mainstem Blackfoot River covered by this model does not suffer from significant riparian degradation or channel widening. In addition, reaches of the Blackfoot that have up to 79% woody bankline vegetation only have up to 8.74% shade due the large channel width. Therefore, targets for vegetation are not applicable for the Blackfoot River. Temperature targets focused on Nevada Creek water temperatures input to the Blackfoot.

Two SNTEMP simulations were conducted for the Blackfoot River. One simulation was the calibrated model under current conditions. A second simulation modeled natural conditions, defined as current vegetation conditions with reduced Nevada Creek input temperatures to meet targets for that stream. The target for the mouth of Nevada Creek is to reduce mean daily temperature from 71.9^o to 69.2^o F. The results of this simulation show negligible change (0.23^o F) in Blackfoot River temperatures at Raymond Bridge (Table 4-9). Below the Clearwater River, the temperature reduction is negligible (Table 4-10).

Since Nevada Creek is the only known source of temperature impairments addressable by TMDLs and is currently causing less than a 0.5^o F increase in temperature in the Blackfoot River, then the Blackfoot River does not fit the TMDL temperature impaired criteria.

Model Run	Temperature (F)		Difference from Calibration (F)		Comments
	Mean	Max	Mean	Max	
Observed Temperature	69.04	74.96	NA	NA	NA
Calibrated Temperature	68.66	74.19	NA	NA	Simulated temperature with current stream conditions
Simulation 1	68.43	73.99	-0.23	-0.20	Natural Conditions: Reduce Nevada Creek temperature to 69.2° F

Table 4-9: Simulation results for the Blackfoot River at Raymond Bridge.

Model Run	Temperature (F)		Difference from Calibration (F)		Comments
	Mean	Max	Mean	Max	
Calibrated Model	66.60	70.14	NA	NA	Simulated temperature below the Clearwater River with current stream conditions
Natural Conditions	66.58	70.12	-0.02	-0.02	Current stream conditions; Nevada Creek input under natural conditions

Table 4-10. Simulation results for the Blackfoot River below the Clearwater River.

4.3.2. Kleinschmidt Creek

The Kleinschmidt Creek model is 5.65 miles long from Ward Creek downstream to Rock Creek. The model simulated temperatures at two locations in Kleinschmidt Creek, at Highway 200 and further downstream at Rock Creek (Figure 4-50). The section of Kleinschmidt Creek above Highway 200 extends for 3.4 miles, while the lower section of Kleinschmidt Creek below Highway 200 is 2.3 miles long.

Construction

Nodes in the model identify where hydrology, stream geometry, and temperature data are input in the stream network. No point sources are present in the Kleinschmidt Creek model. However, three flow points below Highway 200 reassign flow, accounting for diffuse groundwater contributions. A calibration point and end of the model network is above the confluence with Rock Creek. To simulate the temperature in the upper section of Kleinschmidt Creek, a temperature output point is in the model below Highway 200. No flow diversions are in the model.

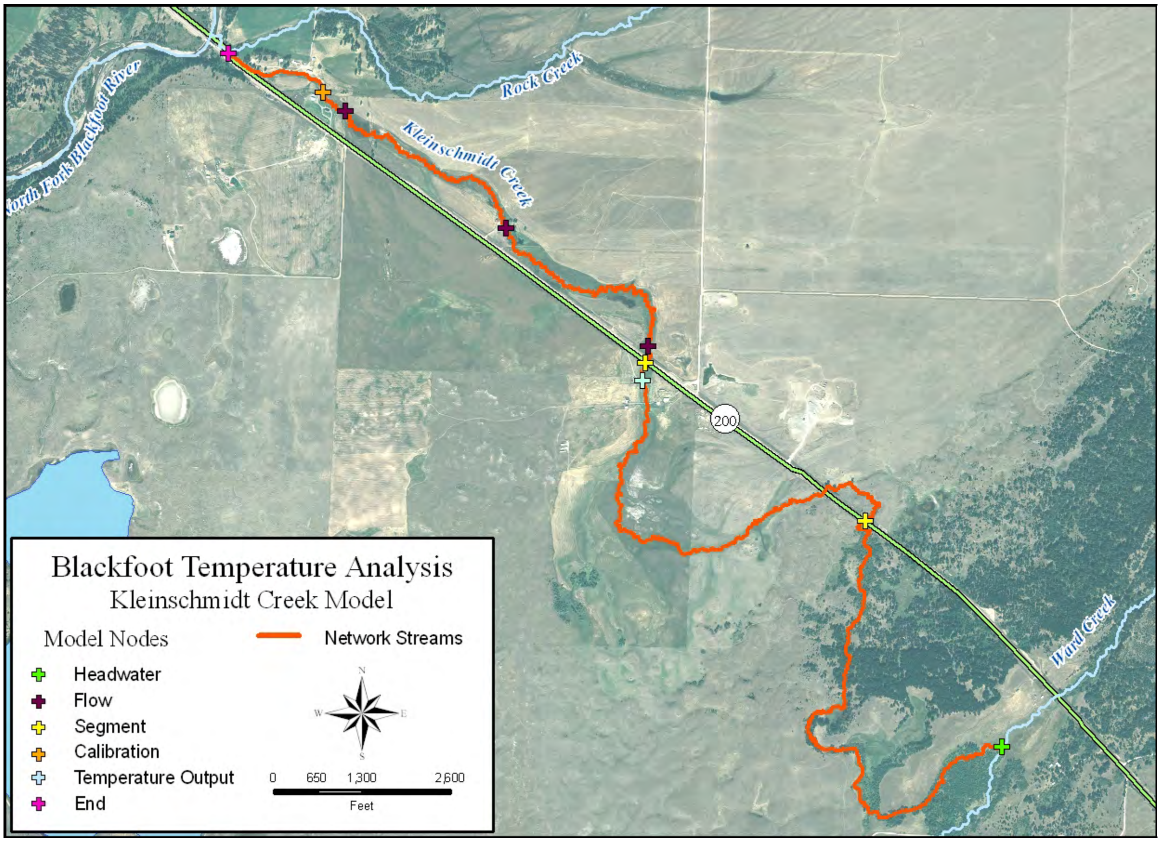

Figure 4-50. Schematic of the Kleinschmidt Creek model network and model nodes.

Modeling for Kleinschmidt Creek is for July 15, 2004. Table 4-11 lists stream geometry and general vegetation characteristics for the Kleinschmidt Creek model. About 23 percent of Kleinschmidt Creek has woody streambank vegetation. Because the width of Kleinschmidt is relatively narrow, this translates to approximately 15 percent shade.

Stream	***Modeling Period***	***Length (mi)***	***Average Low Flow Width (ft)***	***Average Streambank Vegetation (%)***	***Average Shade (%)***
Kleinschmidt Creek	July 15, 2004	5.8	3.0	23.3	14.7

*Streambank vegetation is percent of total stream bank in model that consists of vegetation capable of producing shade. Shade is percent of total stream surface area covered by shade.

Table 4-11. Current stream conditions for the Kleinschmidt Creek SNTEMP model.

Table 4-13 lists data input into the model. For each segment and headwater node, flow, width, Manning's n, and shade must be designated, while water temperature is required for headwater nodes. All other nodes receive only water temperature and/or flow data.

Kleinschmidt Creek from Ward Creek to the first Highway 200 crossing has 63 percent of streambank woody vegetation cover. The remainder of Kleinschmidt Creek downstream is largely devoid of streambank vegetation.

Kleinschmidt Creek flow increases from 2.5 cfs at Highway 200 to 14.4 cfs less than two miles downstream due to groundwater inputs (Blackfoot Challenge, 2005). The groundwater temperature input in the model is 47^{o} F. This temperature is the average of several historical summertime well and spring temperature measurements from this area.

Meteorological data for the July 15, 2004 modeling period were summarized and input into the model (Table 4-12). These data are representative of hot and dry conditions that lead to temperature extremes in the stream. The maximum air temperature this day, 91^{o} F, is one of the hotter days of the summer of 2004.

Modeling Period	***Air Temperature (F) (mean)***	***Relative Humidity (%) (mean)***	***Wind (mph) (mean)***	***Possible Sun (%)***	***Dust Coefficient***	***Ground Reflectivity***
July 15, 2004	70	37.3	8.2	80	0.05865	0.28677

Table 4-12. Meteorological input data for the Kleinschmidt Creek model.

Table 4-13. Input data for the Kleinschmidt Creek model.

Segment	*Node*	*Stream Mile*	*Water Temperature (F)*	*Flow (cfs)*	*Stream Width (ft)*	*Manning's n*	*Bankline Veg (%)*	*Shade (%)*	*Comments*
Ward Ck to HWY 200 (1st crossing)	Headwater[1]	5.8	63.7	2.5	3.0	0.062	63.0	39.8	Divergence of Ward Creek
To HWY 200 (Third Crossing)	Segment	4.0		2.5	3.0	0.062	6.0	4.1	First Highway 200 crossing
	Output	2.4		2.5					Above third HWY 200 crossing
HWY 200 to Rock Ck	Segment	2.3		2.5	3.0	0.062	5.0	3.0	At third HWY 200 crossing
	Flow	2.2	47.0	2.8*					Below HWY 200 crossing
	Flow	1.3	47.0	11.9*					At Tom Rue's house
	Flow	0.5	47.0	14.4*					At Rue/Friede fence
	Calibration	0.4	50.3	14.4					Above Rock Creek
	End	0.1		13.2**					Segment within canyon section

Headwater[1] is the starting point of the model network. * indicates flow adjustment from ground water recharge in reach above this point at a temperature of 47 degrees F. ** indicates flow adjustment from loss of stream flow to ground water.

Calibration

Initial model runs for Kleinschmidt Creek required little calibration (Table 4-14). The first model run simulated a mean and maximum daily temperature within the margin of 0.9° F for calibration. One small adjustment to possible sun percent improved the results slightly.

Location: Kleinschmidt Creek above Rock Creek					
Calibration Iteration	***Temperature (F)***		***Difference from Observed Temp (F)***		***Parameter Changed***
	Mean	***Max***	***Mean***	***Max***	
Observed Temperature	50.34	55.38	NONE	NONE	NONE
Initial Model Run	50.83	55.90	0.49	0.52	Default Parameter Values
1	50.72	55.42	0.38	0.04	Sunshine % - Decrease to 80%

Table 4-14. Initial model and calibration results for Kleinshmidt Creek above Rock Creek.

Simulations

Five SNTEMP simulations evaluated the effect of shade on stream temperatures in the upper and lower sections of Kleinschmidt Creek. Shade is expressed as percent of streambanks with woody vegetation. One simulation was the calibrated model that used current streambank vegetation conditions. A second simulation modeled natural conditions defined by Montana DEQ (ARM, 2006) as 95% streambank woody vegetation. Two additional simulations modeled streambank vegetation at levels between current and natural condition. A final simulation assessed the amount of vegetation required to keep temperatures within the one degree F allowable increase from natural conditions.

Kleinschmidt Creek above Highway 200

For Kleinschmidt Creek from Ward Creek downstream to Highway 200, the model simulated a mean temperature of 62.53° F under natural conditions (Table 4-15 and Figure 4-51). This value is lower than the temperature simulated with current stream conditions by 2.52° F. Increasing streambank vegetation to 60 percent reduces mean temperature by 1.17° F from current conditions, while reducing streambank vegetation to 20 percent increases mean temperature by 0.36° F. Simulating 69 percent streambank woody vegetation resulted in a simulated mean temperature of 63.52° F. This is the one-degree allowable increase from natural conditions, and is the target for Kleinschmidt Creek above Highway 200.

Model Run	***Temperature (F)***		***Difference from Calibration (F)***		***Comments***
	Mean	***Max***	***Mean***	***Max***	
Calibrated Model	65.05	72.99	NA	NA	Simulated temperature with current stream conditions
Simulation 1	65.41	72.43	0.36	-0.56	20% of bank with vegetation cover
Simulation 2	63.88	68.88	-1.17	-4.11	60% of bank with vegetation cover
Target	63.52	68.09	-1.53	-4.90	69% of bank with vegetation cover
Natural Conditions	62.53	65.84	-2.52	-7.15	95% of bank with vegetation cover

Table 4-15. Simulation results for Kleinschmidt Creek above Highway 200.

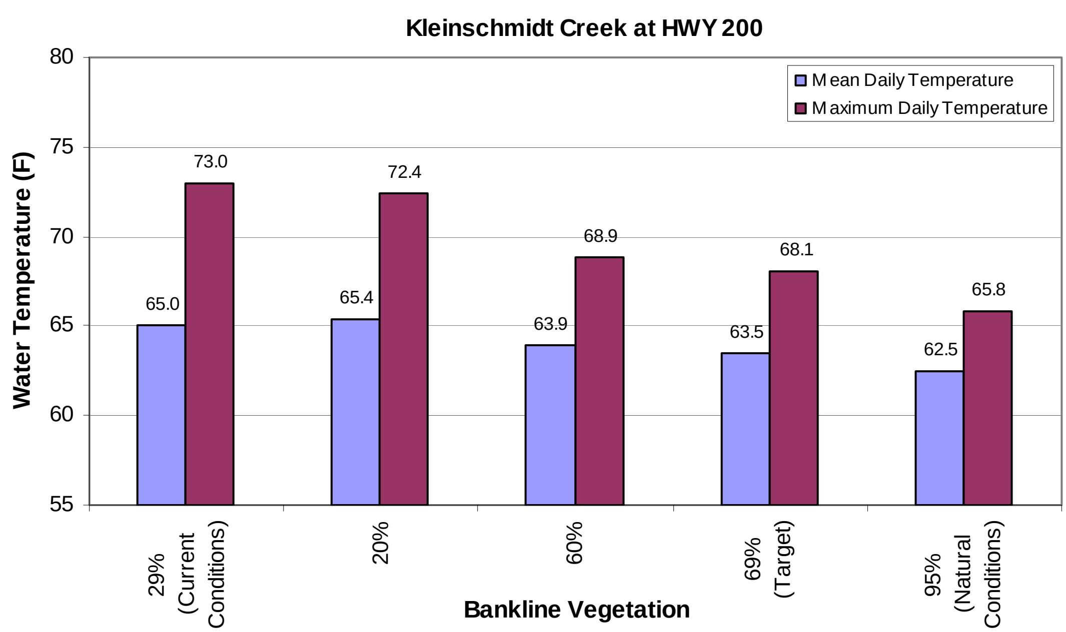

Figure 4-51. Simulated mean and maximum temperature with change in bankline vegation for Kleinschmidt Creek above Highway 200.

Kleinschmidt Creek below Highway 200

For natural conditions, the model simulated a mean temperature of 50.04° F for Kleinschmidt Creek at Rock Creek (Table 4-16 and Figure 4-52). This value is lower than temperatures simulated with current stream conditions by 0.84° F, indicating that current temperatures fall within the one-degree allowable increase from natural conditions established by Montana DEQ (ARM, 2006).

Model Run	Temperature (F)		Difference from Calibration (F)		Comments
	Mean	Max	Mean	Max	
Calibrated Model	50.88	55.78	NA	NA	Simulated temperature with current stream conditions
Simulation 1	50.83	55.26	-0.05	-0.52	20% of bank with vegetation cover
Simulation 2	50.40	53.65	-0.48	-2.13	60% of bank with vegetation cover
Natural Conditions	50.04	52.34	-0.84	-3.44	95% of bank with vegetation cover

Table 4-16. Simulation results for Kleinschmidt Creek above Rock Creek.

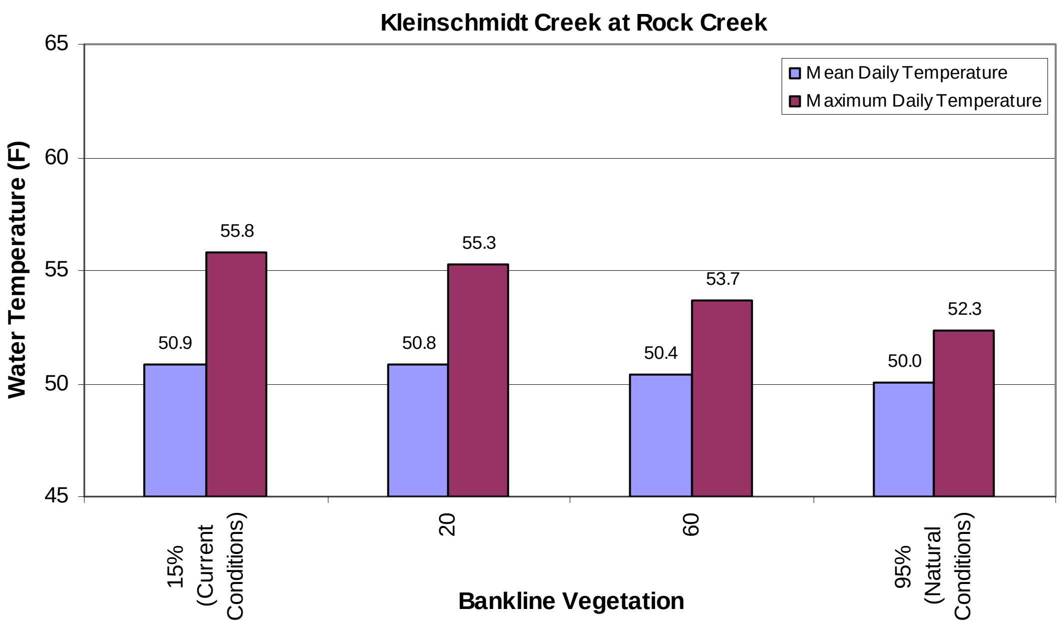

Figure 4-52. Simulated mean and maximum temperature with change in bankline vegation for Kleinschmidt Creek above Rock Creek.

These results indicate that Kleinschmidt Creek from Highway 200 downstream to Rock Creek currently does not fit the TMDL temperature impairment criteria. Restoration efforts on Kleinschmidt Creek downstream from Highway 200 reduced stream surface area and improved temperatures over prior conditions (see Section 4.2.1). Above Highway 200, establishment of woody vegetation on 69 percent of Kleinschmidt Creek reduces temperature in the SNTEMP simulations by 1.53^{o} F, highlighting the difference between the two reaches.

5. Summary

The Montana FWP database was a robust source of input and calibration temperature data for the models. The base parameter field data and filed photos provided a reliable data source from which to derive shade data necessary for the models. Hydrologic gage data, instantaneous flow measurements, and visual estimates from July 2004 provided acceptable flow data for input to the models. Combined, these data sources allowed modeling of stream temperatures using SNTEMP and provided the results necessary to establish temperature targets for 303(d) list streams in the Blackfoot River watershed. Table 5-1 below summarizes the results of the SNTEMP modeling and presents the targets that provide the necessary data for TMDL development.

Table 5-1: Temperature and target summary, Nevada Creek and Middle Blackfoot planning areas.

Model	*Stream*	*Sources of Temperature Impairment*	*Current Conditions Mean Daily Temperature °F*	*Natural Condition*	*Natural Conditions Mean Daily Temperature °F*	*TMDL Target*	*Comments*
Upper Nevada SNTEMP	Upper Nevada Creek	Lack of shade	64.15	95% bankline vegetation	60.66	73% streambank woody vegetation	Results indicate 1° F allowable increase in mean temperature requires 73% bankline vegetation
Lower Nevada SNTEMP	Lower Nevada Creek	Lack of shade, irrigation withdrawals, channel widening	70.41	95% bankline vegetation,	68.29	65% streambank woody vegetation	15% reduction in irrigation withdrawals gave minimal improvement in temperature, channel narrowing is not a natural condition
	Cottonwood Creek	Lack of shade, irrigation withdrawals	69.55	95% bankline vegetation	62.67	87% streambank woody vegetation	15% reduction in irrigation withdrawals gave minimal improvement in temperature
	Lower Douglas Creek	Lack of shade, irrigation withdrawals	69.30	95% bankline vegetation	63.37	84% streambank woody vegetation	15% reduction in irrigation withdrawals gave minimal improvement in temperature

Model	***Stream***	***Sources of Temperature Impairment***	***Current Conditions Mean Daily Temperature °F***	***Natural Condition***	***Natural Conditions Mean Daily Temperature °F***	***TMDL Target***	***Comments***
Upper Douglas SSTEMP	Upper Douglas Creek	Lack of shade, irrigation withdrawals, large reservoir surface area	68.37	95% bankline vegetation on stream segments, reduced reservoir surface area by 20% (consolidation into 2 reservoirs)	63.87	65% streambank woody vegetation (-1.5° F) and 20% reduction in thermal heating from reservoirs (-3° F)	SSTEMP results indicate that ~5° F of the 20° F temperature increase in this area is attributable to lack of shade. The remaining 15° F is from reservoir heating.
Kleinschmidt SNTEMP	Kleinschmidt Creek	Lack of shade	50.88	95% bankline vegetation	50.04	69% streambank woody vegetation in reach above 3rd Highway 200 crossing	Natural condition scenarios in the upper part of Kleinschmidt Creek (above Hwy 200) improve temperature. Below Hwy 200, groundwater influx lowers temperature.
Blackfoot SNTEMP	Blackfoot River	Tributary inputs	66.60	Nevada Creek input under natural conditions scenario	66.58	Anthropogenic temperature increases on the Blackfoot River are less than the 1° F allowable increase. No target required.	Natural condition scenario in Nevada Creek improves mainstem water temp by only 0.23° F at the Raymond Bridge. Suggests the Blackfoot is not impaired for temperature

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A. Appendix A: Additional Continuous Water Temperature Graphs

Upper Nevada Creek – 2001

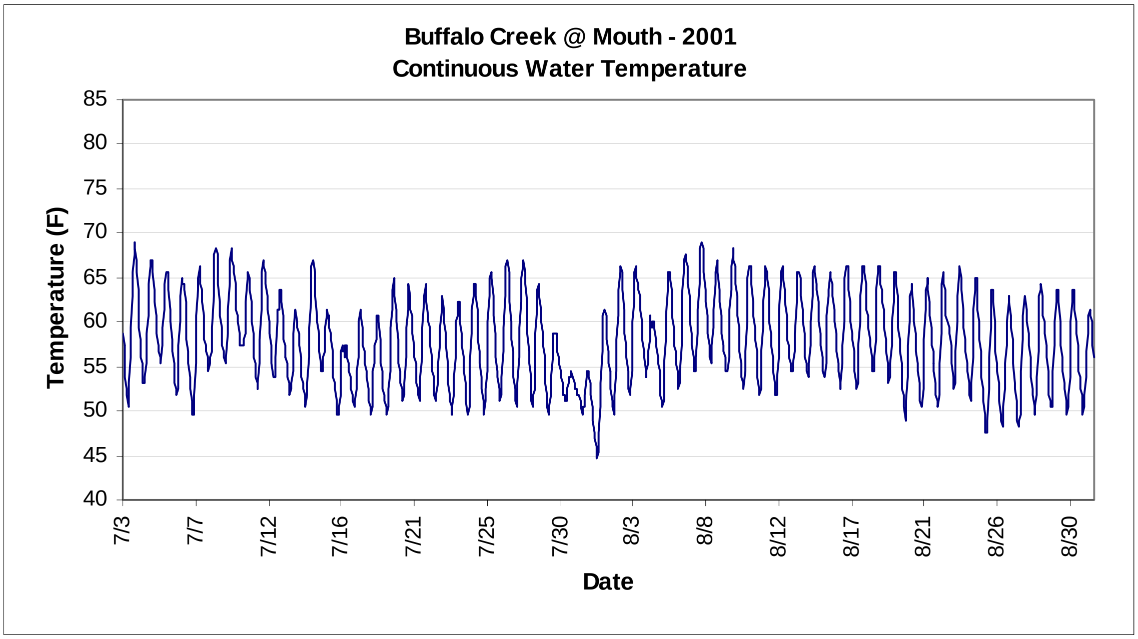


Figure A-1. Continuous water temperature, Buffalo Creek, July 3 – August 31, 2001.

Lower Nevada Creek – 2004

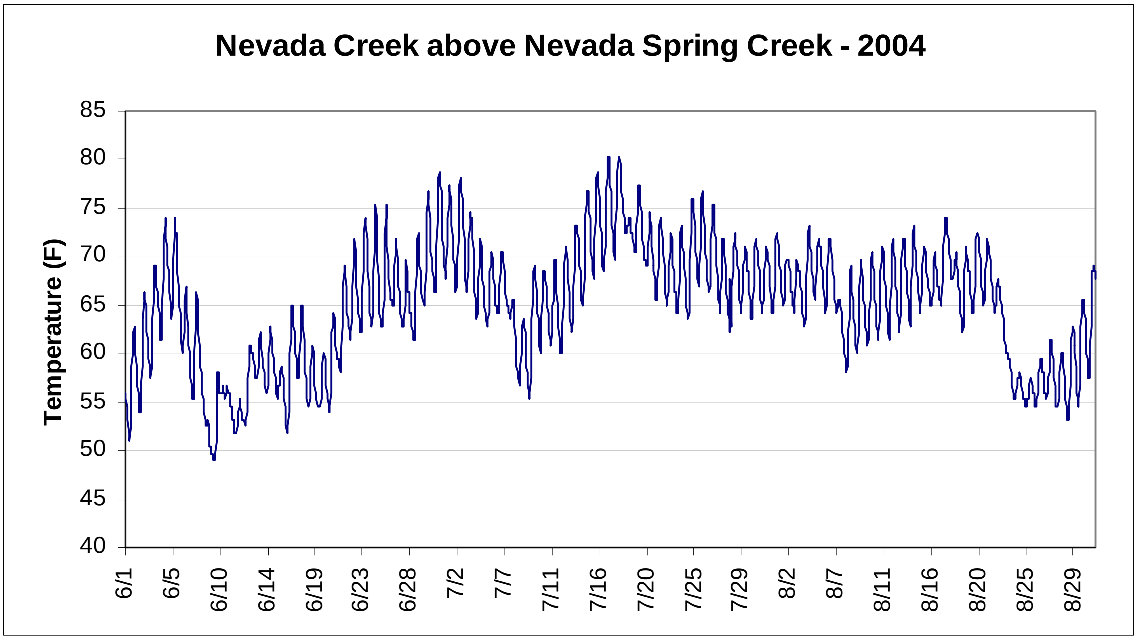


Figure A-2. Continuous water temperature, Nevada Creek above Nevada Spring Creek, June 1 – August 31, 2004.

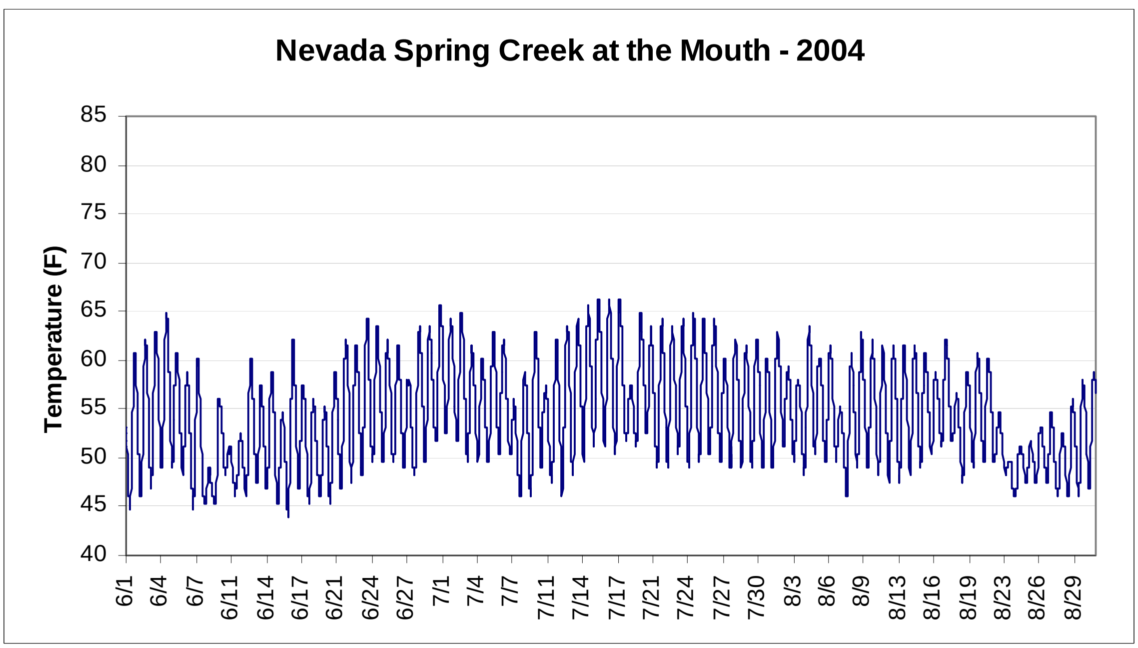


Figure A-3. Continuous water temperature, Nevada Spring Creek, MT, June 1 – August 31, 2004.

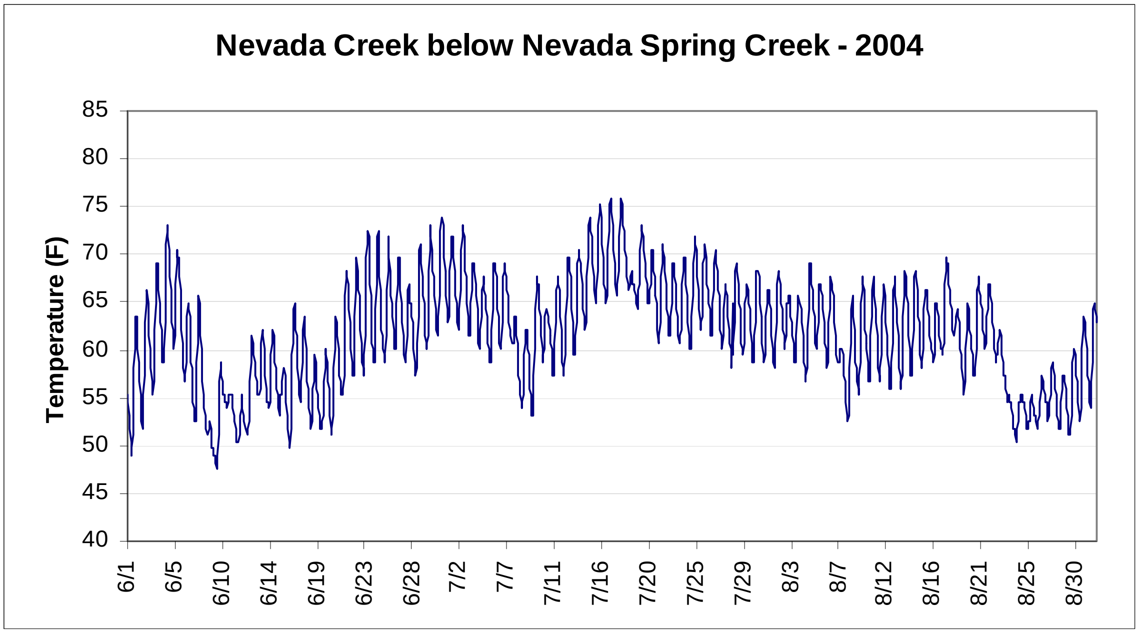


Figure A-4. Continuous water temperature, Nevada Creek below Nevada Spring Creek, June 1 – August 31, 2004.

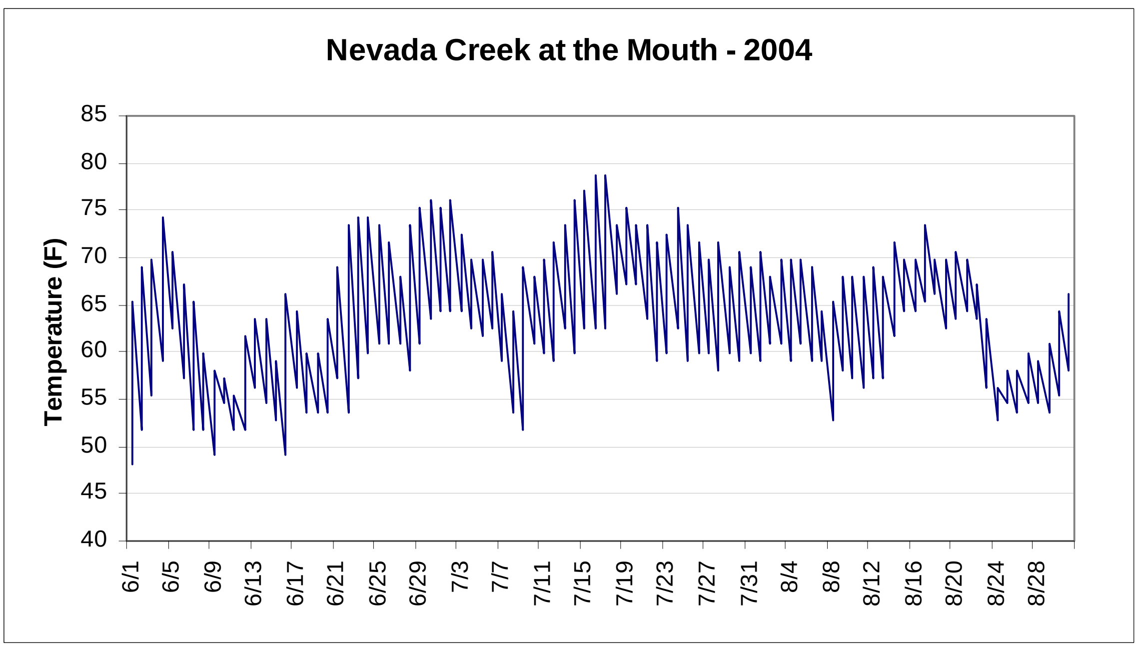


Figure A-5. Continuous water temperature, Nevada Creek at the mouth, June 1 – August 31, 2004.

Lower Nevada Creek – 1998

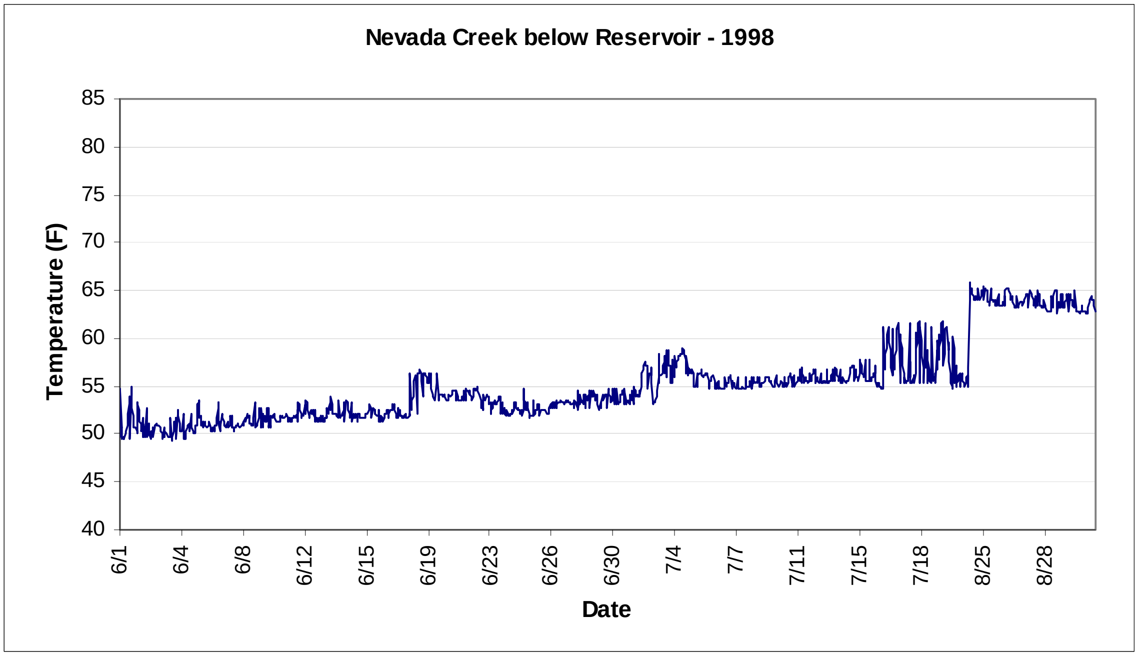


Figure A-6. Continuous water temperature, Nevada Creek below the reservoir, June 1 – August 31, 1998.

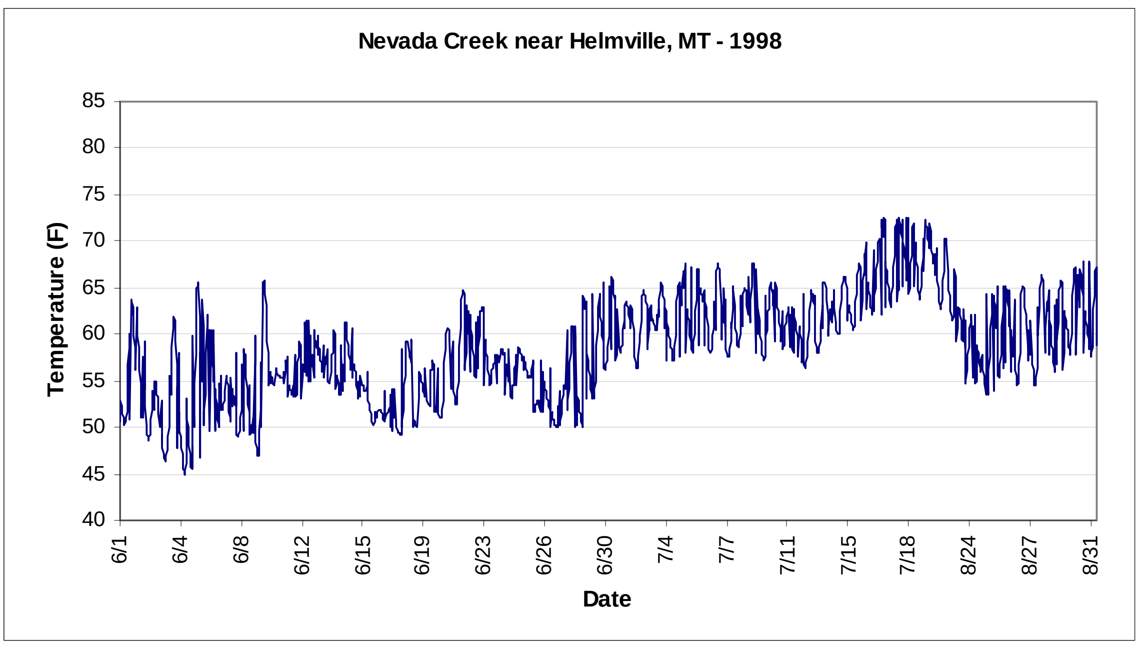


Figure A-7. Continuous water temperature, Nevada Creek near Helmville, June 1 – August 31, 1998.

Kleinschmidt Creek

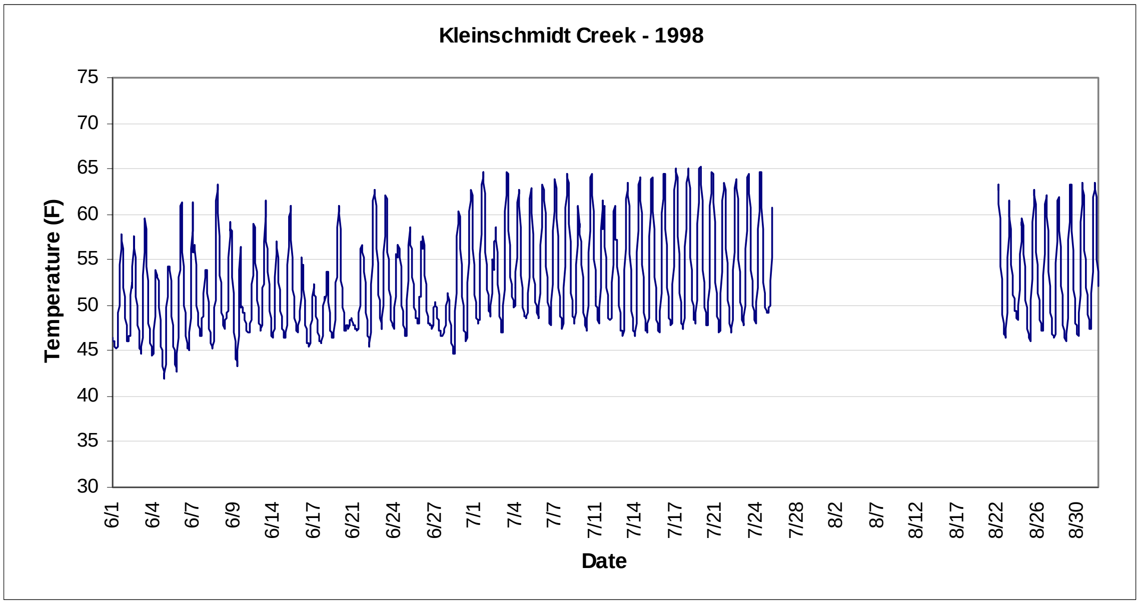


Figure A-8. Continuous water temperature, Kleinschmidt Creek, June 1 – August 31, 1998.

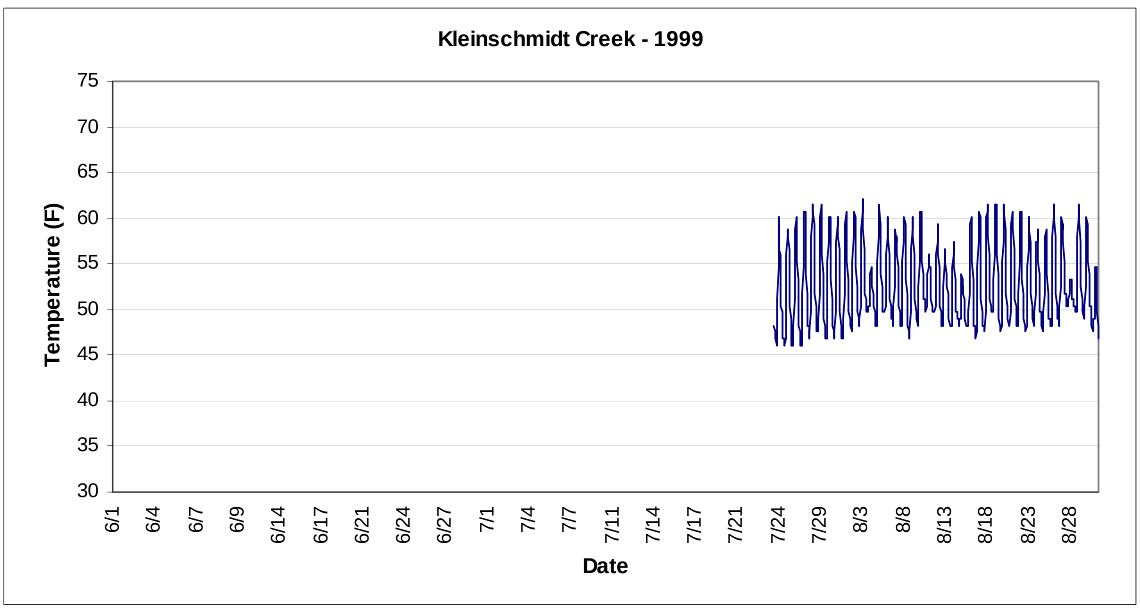


Figure A-9. Continuous water temperature, Kleinschmidt Creek, June 1 – August 31, 1999.

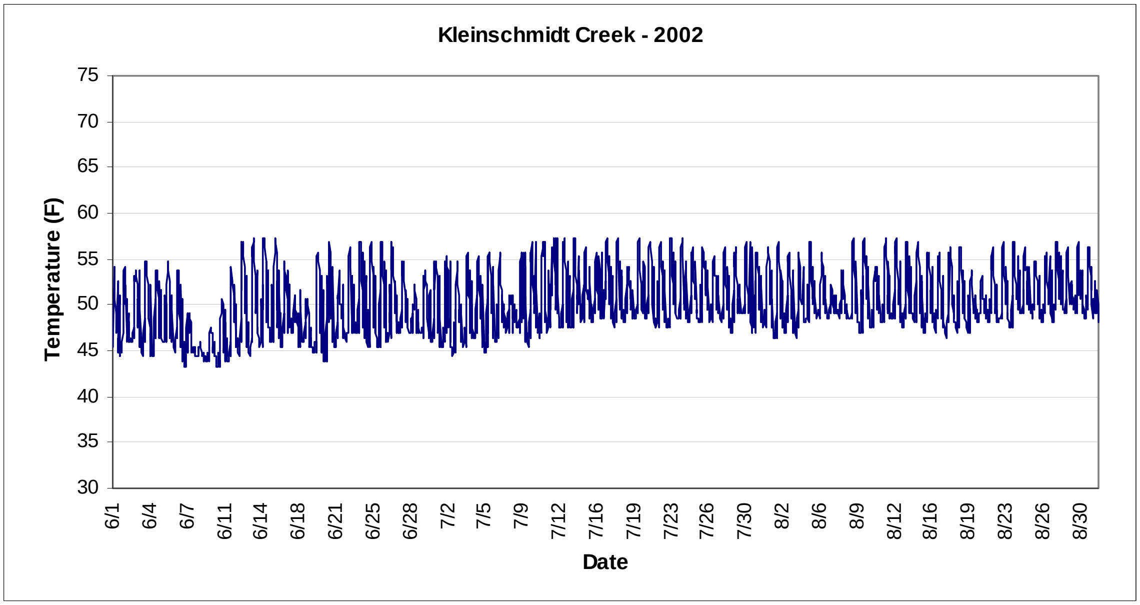


Figure A-10. Continuous water temperature, Kleinschmidt Creek, June 1 – August 31, 2002.

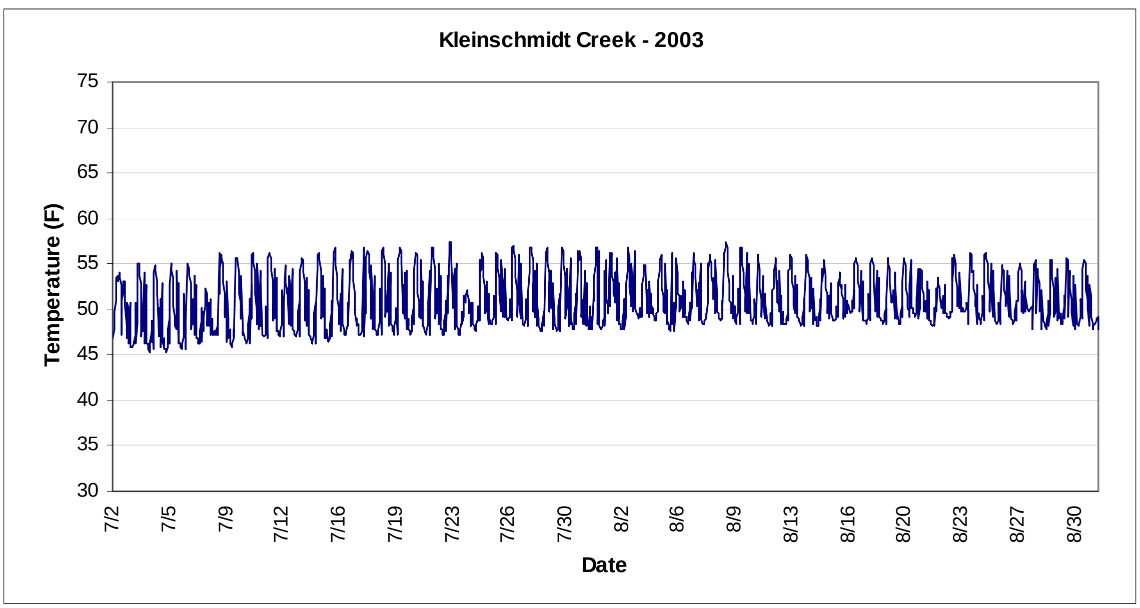


Figure A-11. Continuous water temperature, Kleinschmidt Creek, June 1 – August 31, 2003.

Union Creek – 2001

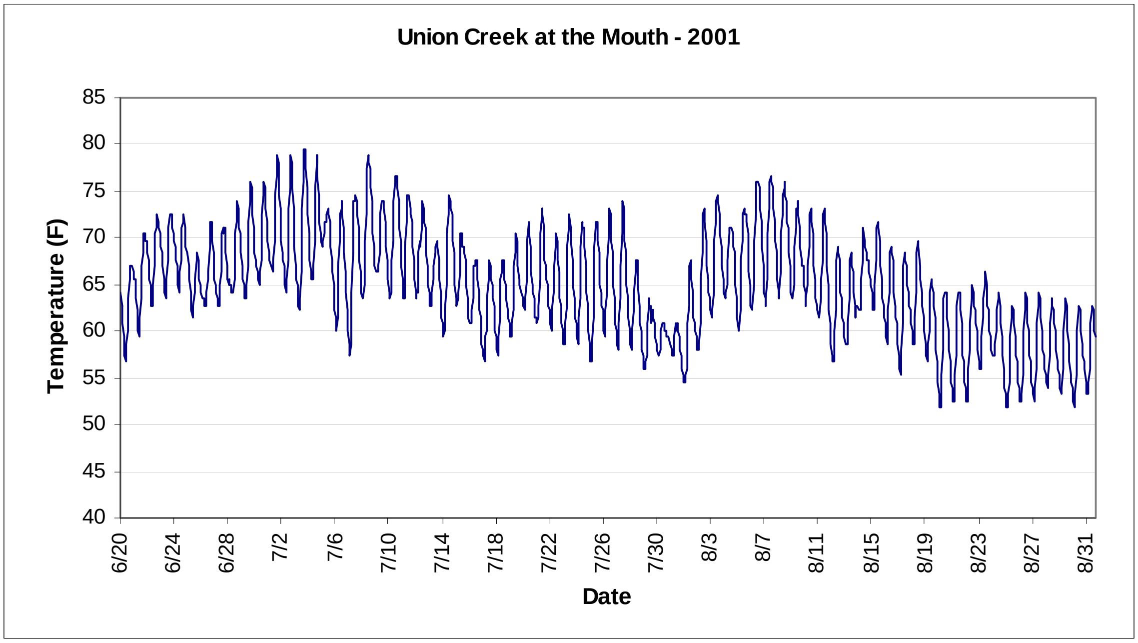


Figure A-12. Continuous water temperature, Union Creek at the mouth, June 20 – August 31, 2001.

Elk Creek – 2003

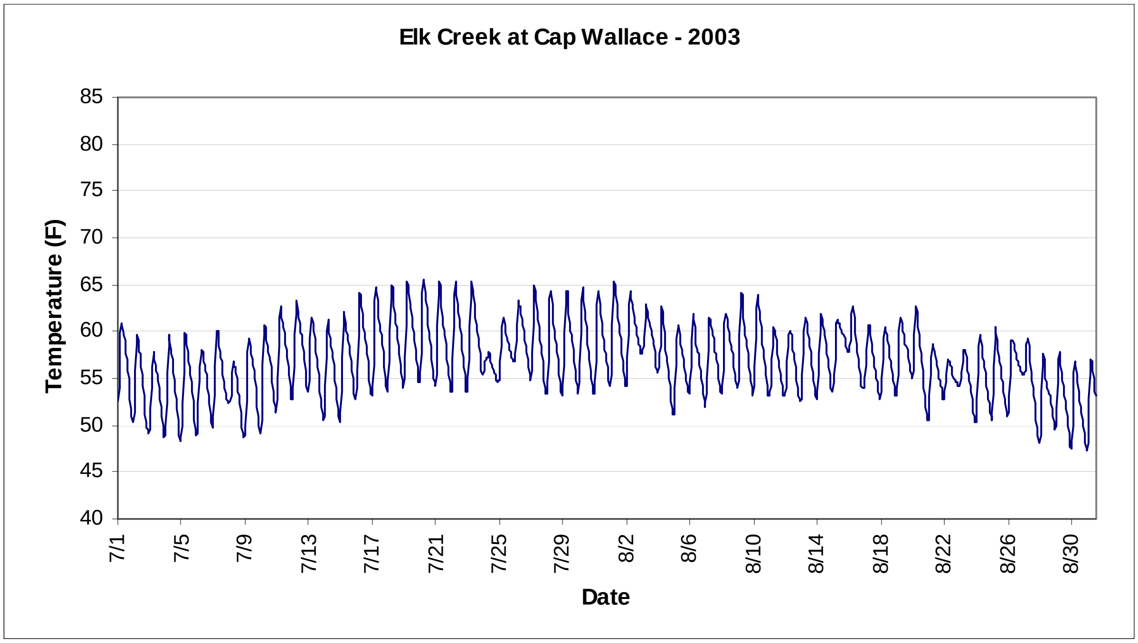


Figure A-13. Continuous water temperature for Elk Creek at Cap Wallace, July 1 – August 31, 2003.

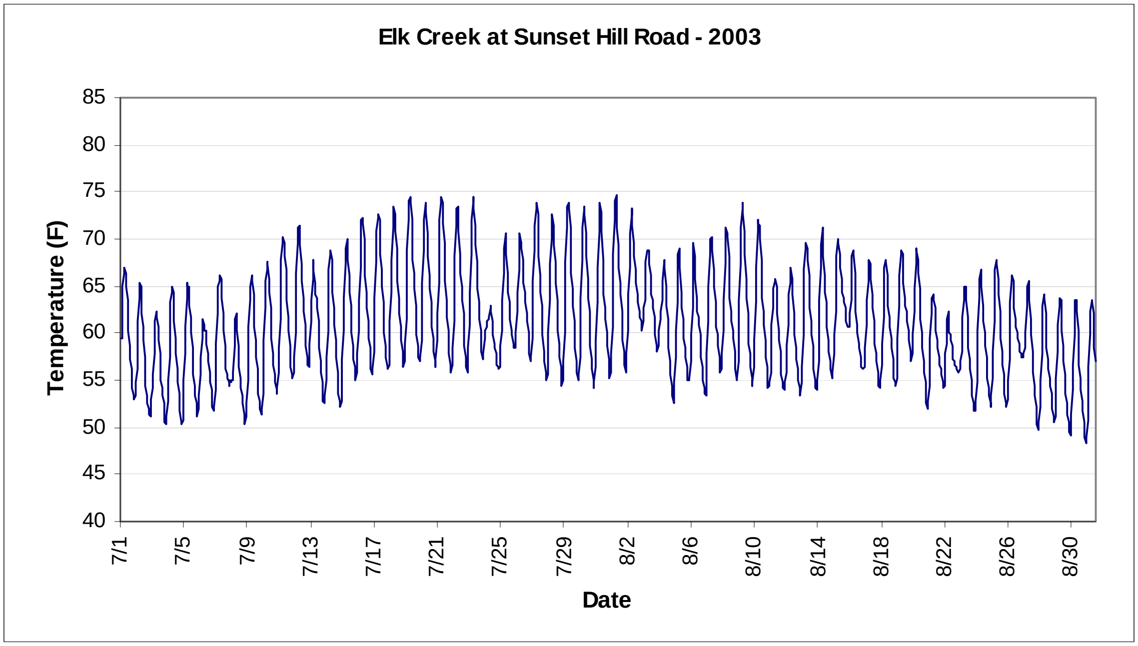


Figure A-14. Continuous water temperature for Elk Creek at Sunset Hill Road, July 1 – August 31, 2003.

Elk Creek – 2000

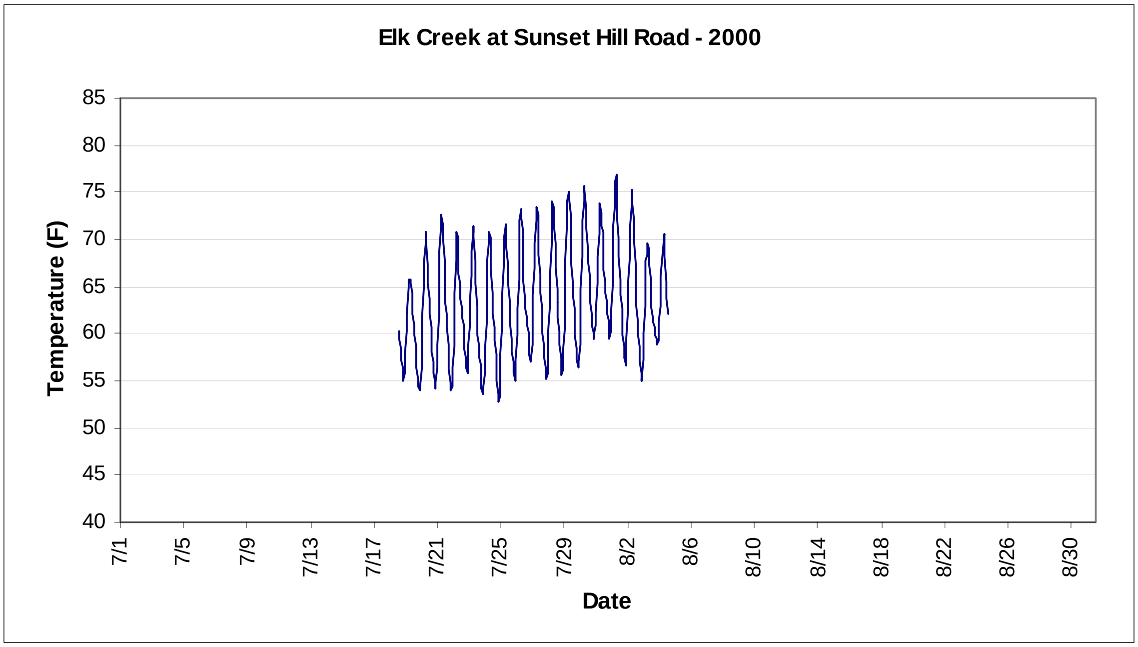


Figure A-15. Continuous water temperature for Elk Creek at Sunset Hill Road, July 1 – August 31, 2000.

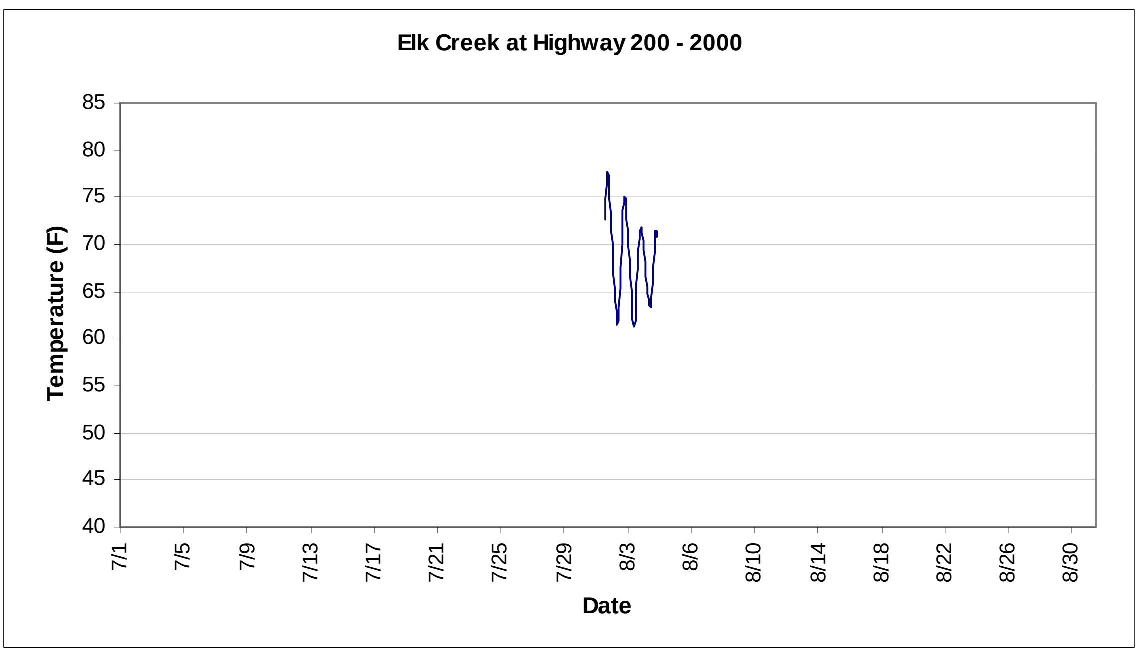


Figure A-16. Continuous water temperature for Elk Creek at Highway 200, July 1 – August 31, 2000.

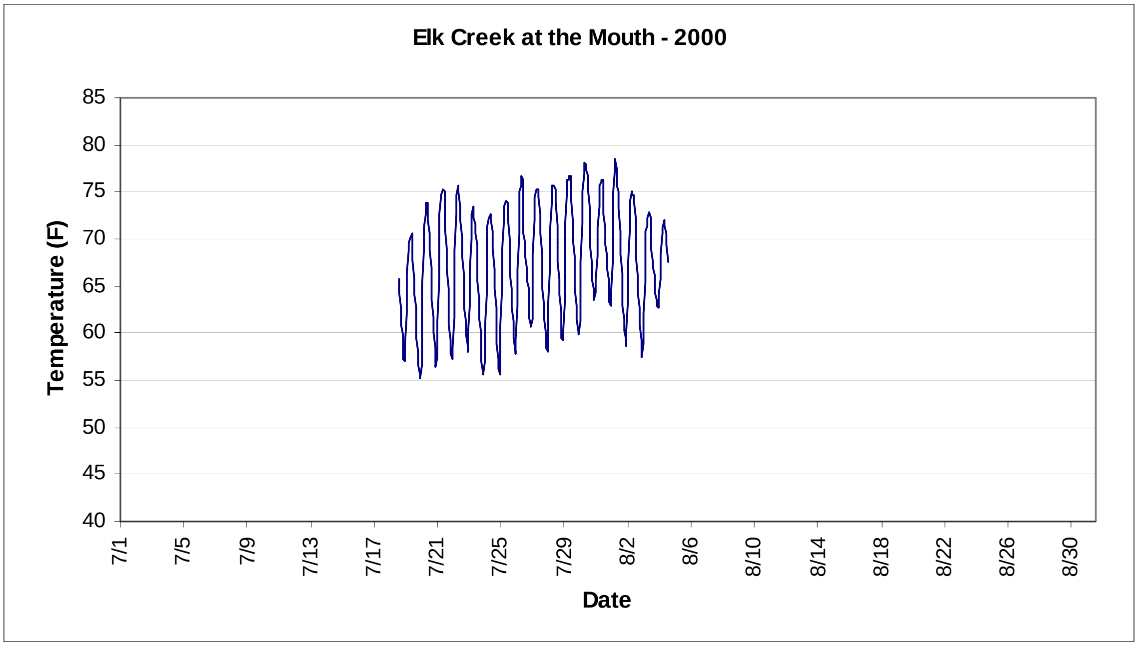


Figure A-17. Continuous water temperature for Elk Creek at the mouth, July 1 – August 31, 200

Blackfoot River – 2003

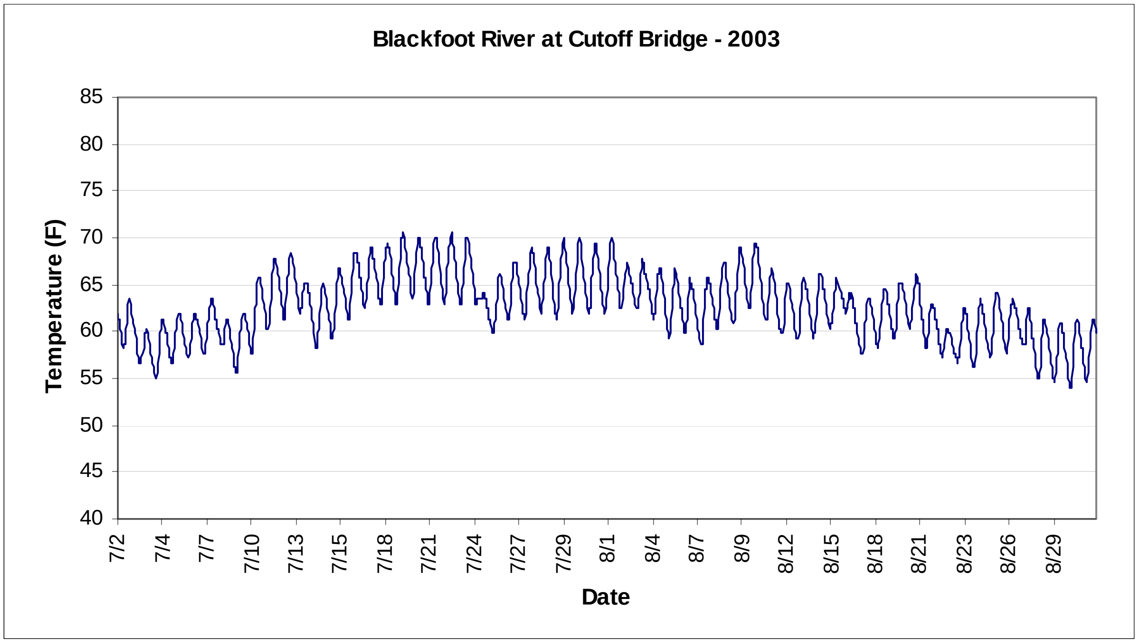


Figure A-18. Continuous water temperature for the Blackfoot River at Cutoff Bridge, July 2 – August 31, 2003.

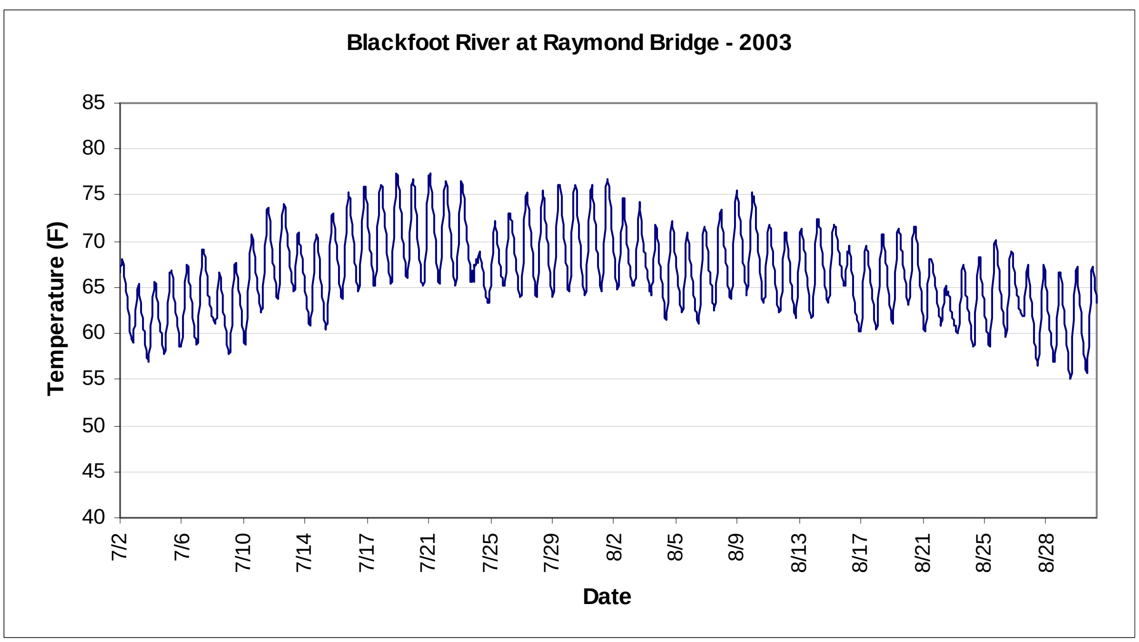


Figure A-19. Continuous water temperature for the Blackfoot River at Raymond Bridge, July 2 – August 31, 2003.

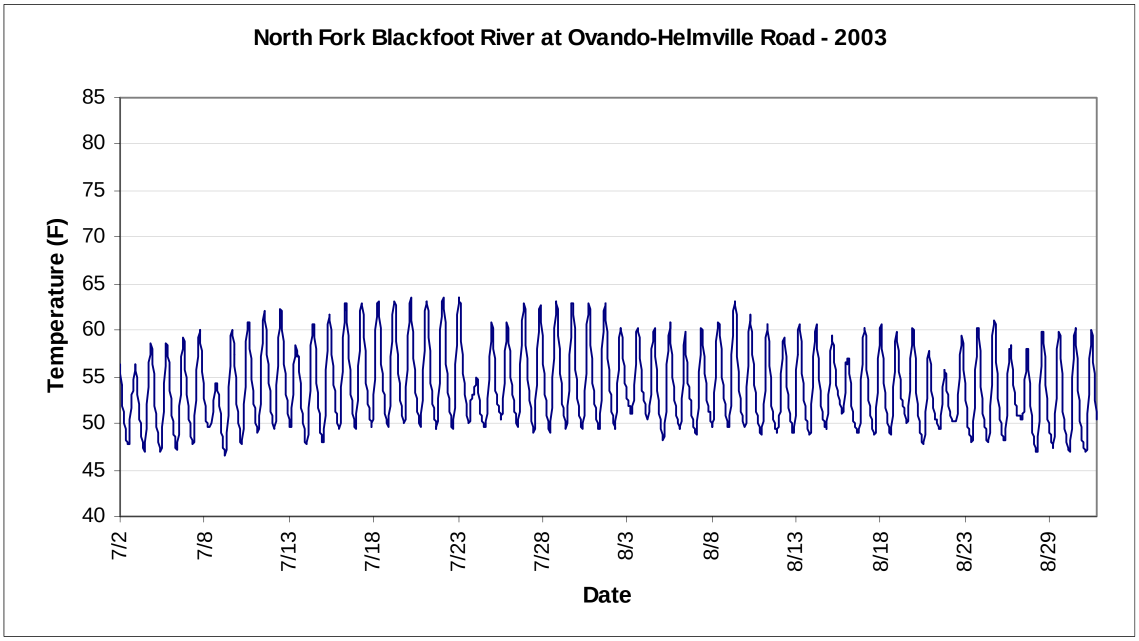


Figure A-20. Continuous water temperature for the North Fork Blackfoot River at Ovando Helmville Road, July 2 – August 31, 2003.

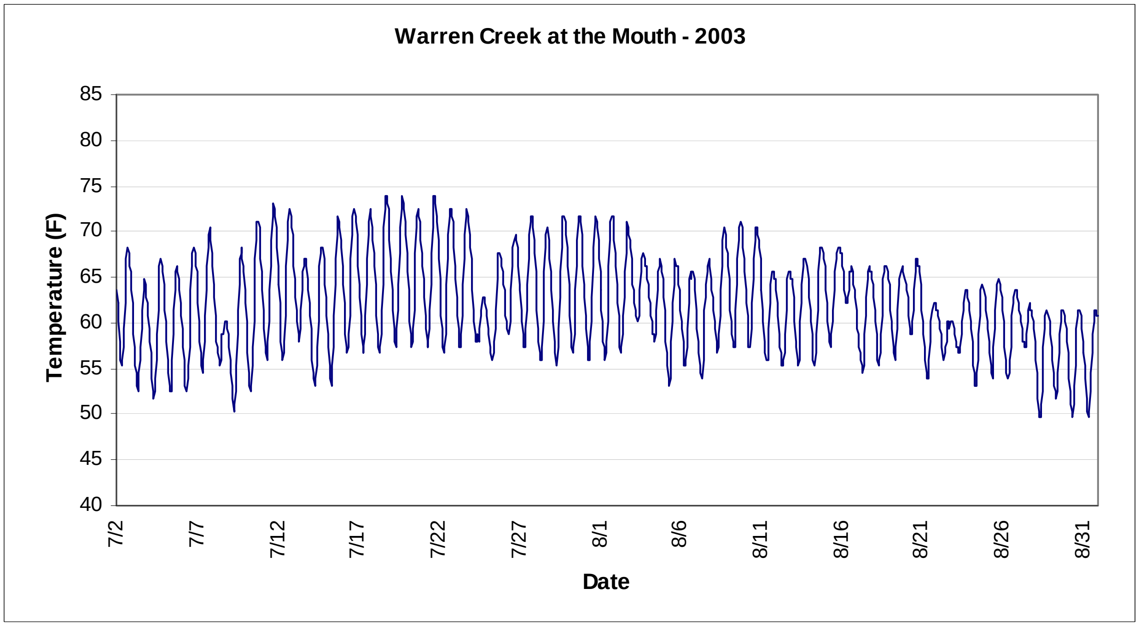


Figure A-21. Continuous water temperature for Warren Creek at the mouth, July 2 – August 31, 2003.

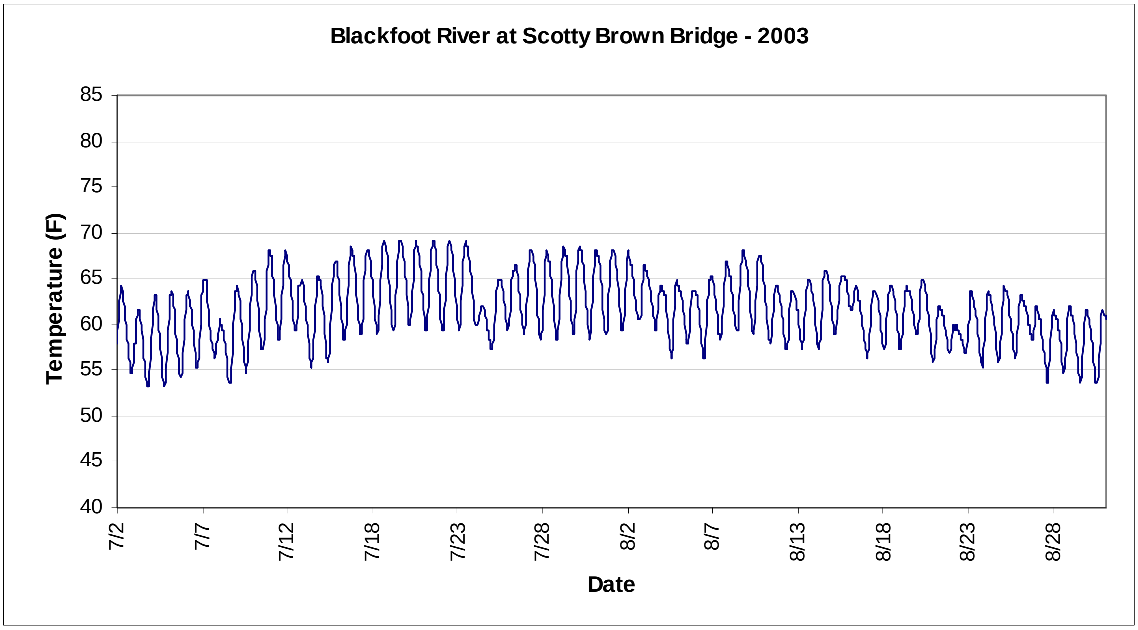


Figure A-22. Continuous water temperature for the Blackfoot River at Scotty Brown Bridge, July 2 – August 31, 2003.

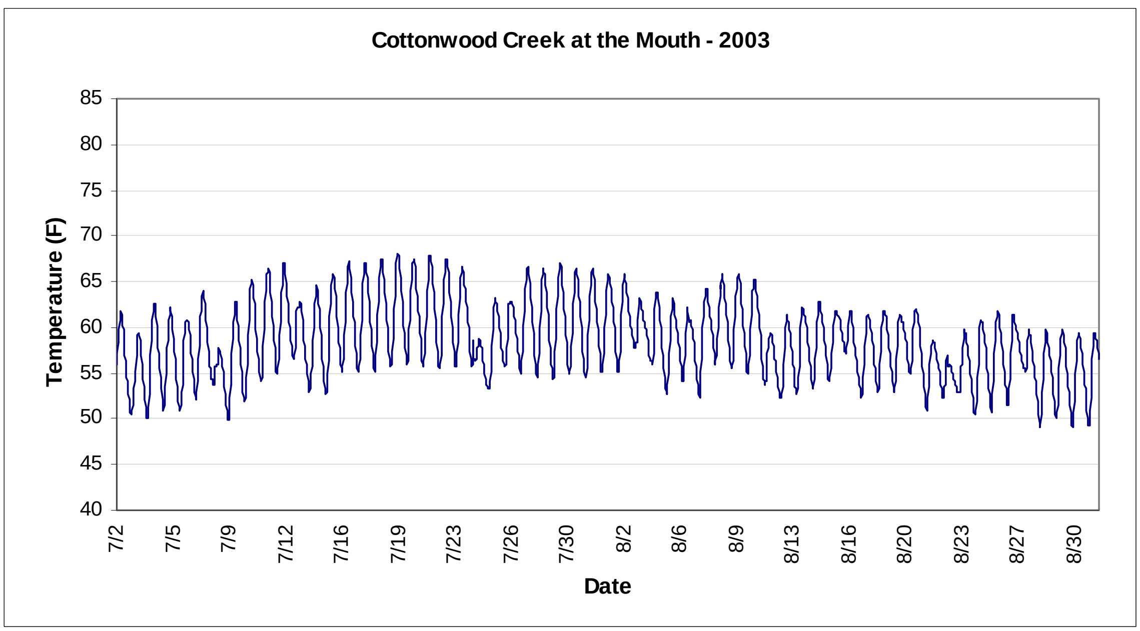


Figure A-23. Continuous water temperature for Cottonwood Creek, July 2 – August 31, 2003.

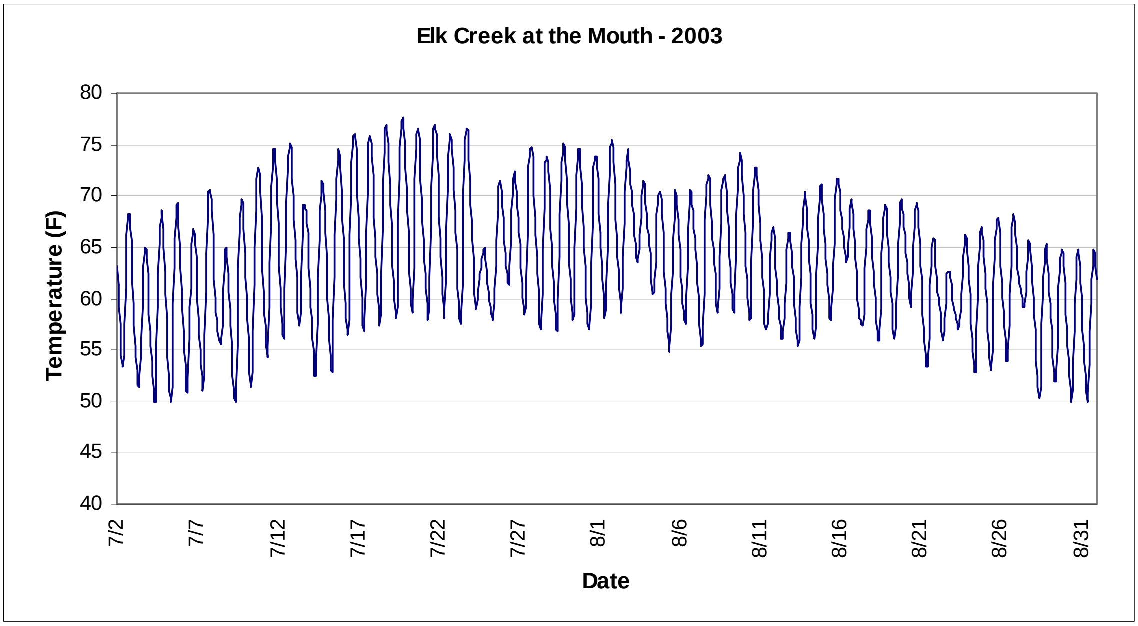


Figure A-24. Continuous water temperature for Elk Creek at the mouth, July 2 – August 31, 2003.

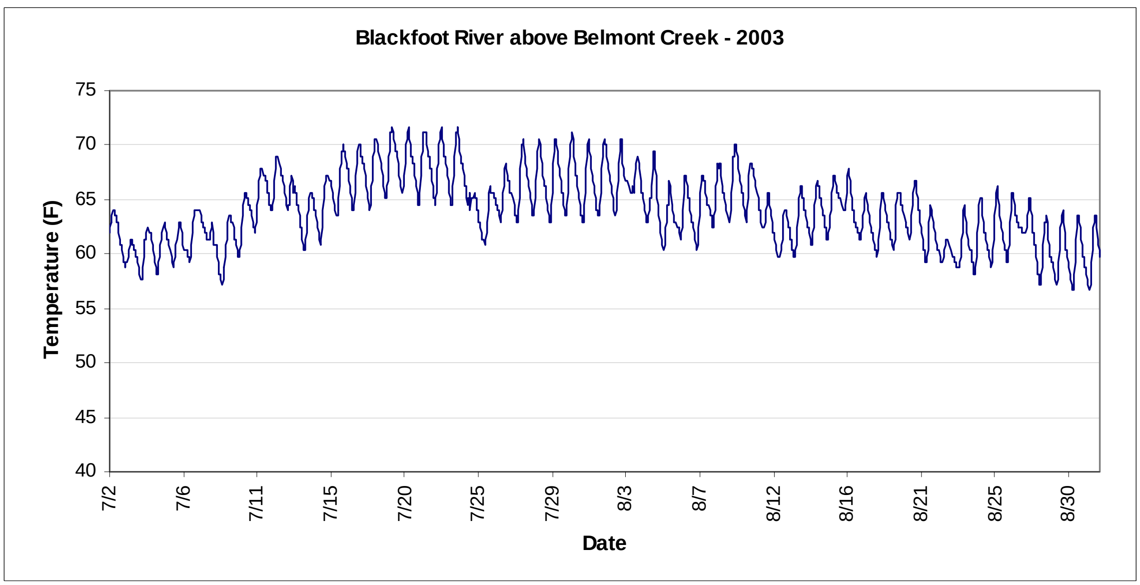


Figure A-25. Continuous water temperature for the Blackfoot River above Belmont Creek, July 2 – August 31, 2003.

B. Appendix B: Maximum Water Temperature Graphs

Lower Nevada Creek – 2004

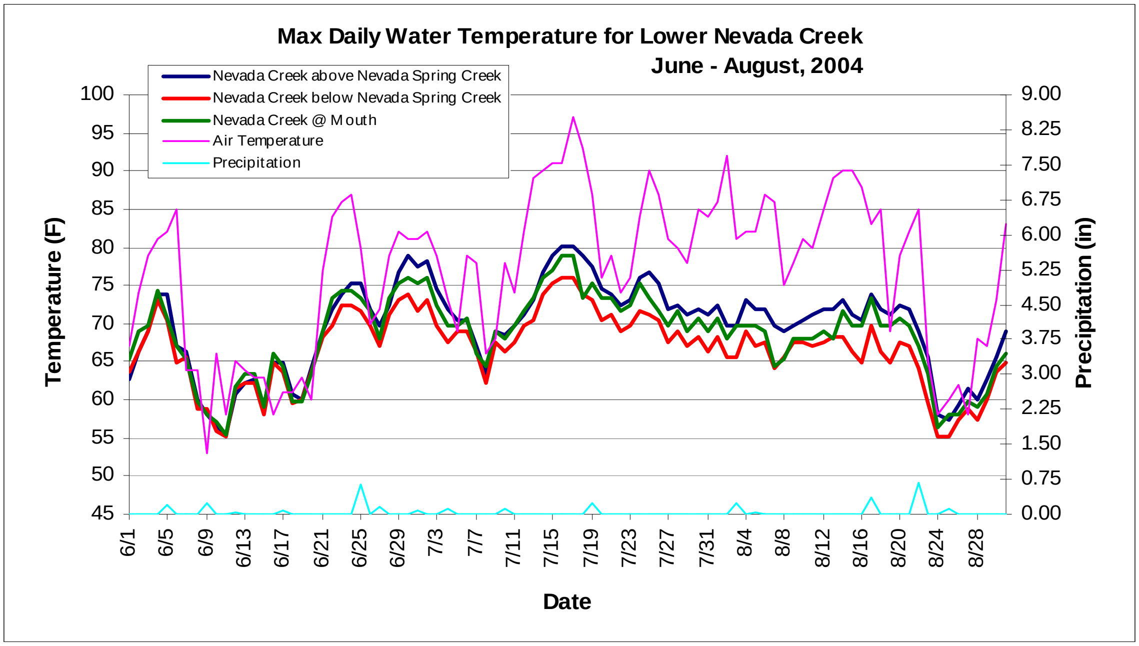


Figure B-1. Maximum daily water temperature, air temperature, and precipitation, lower Nevada Creek, 2004.

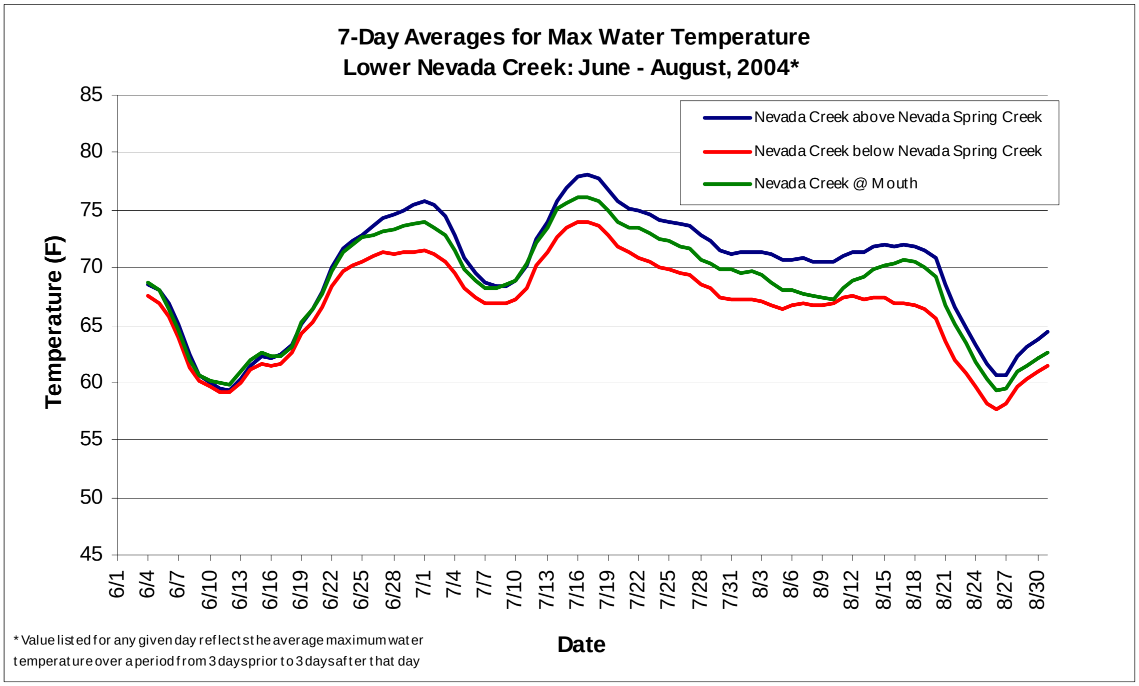


Figure B-2. 7-day average maximum daily temperatures, lower Nevada Creek, 2004.

Blackfoot River – 2003

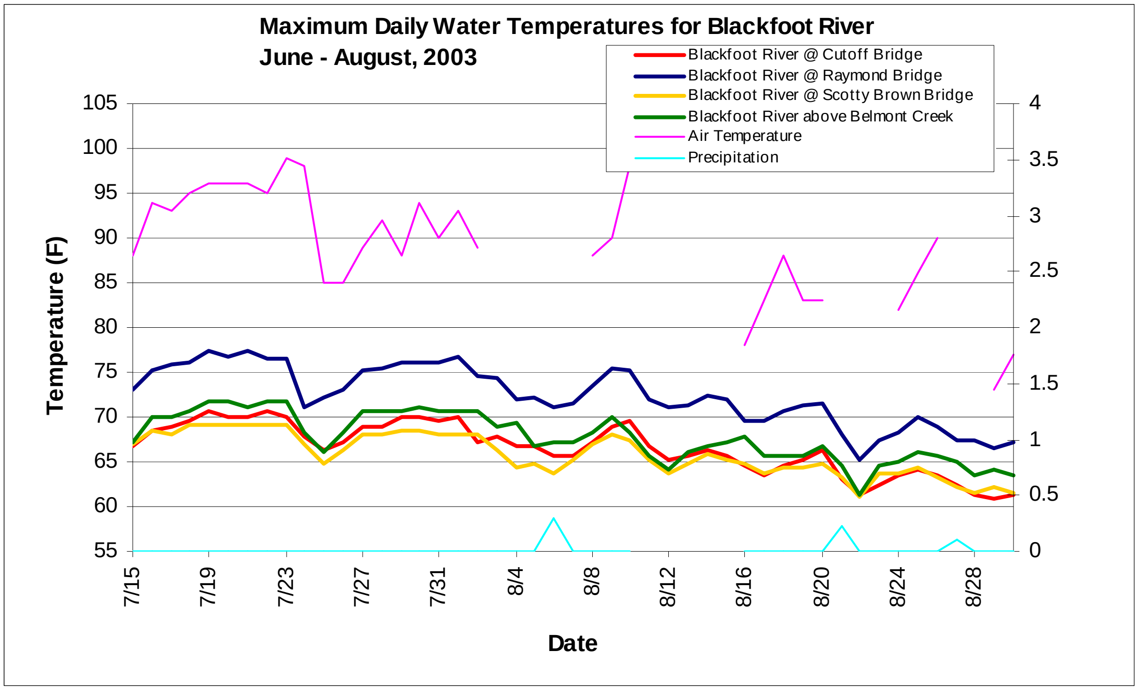


Figure B-3. Maximum daily water temperature, air temperature, and precipitation, Blackfoot River, 2003.

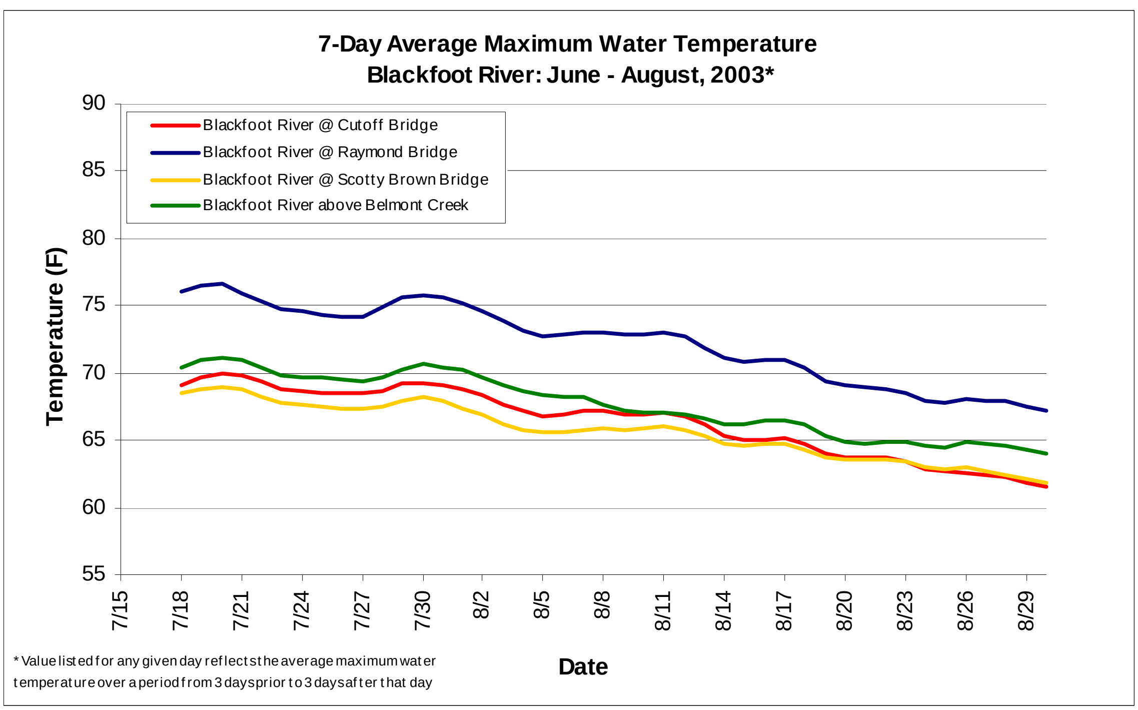


Figure B-4. 7-day average maximum daily temperatures, Blackfoot River, 2003.

Kleinschmidt Creek

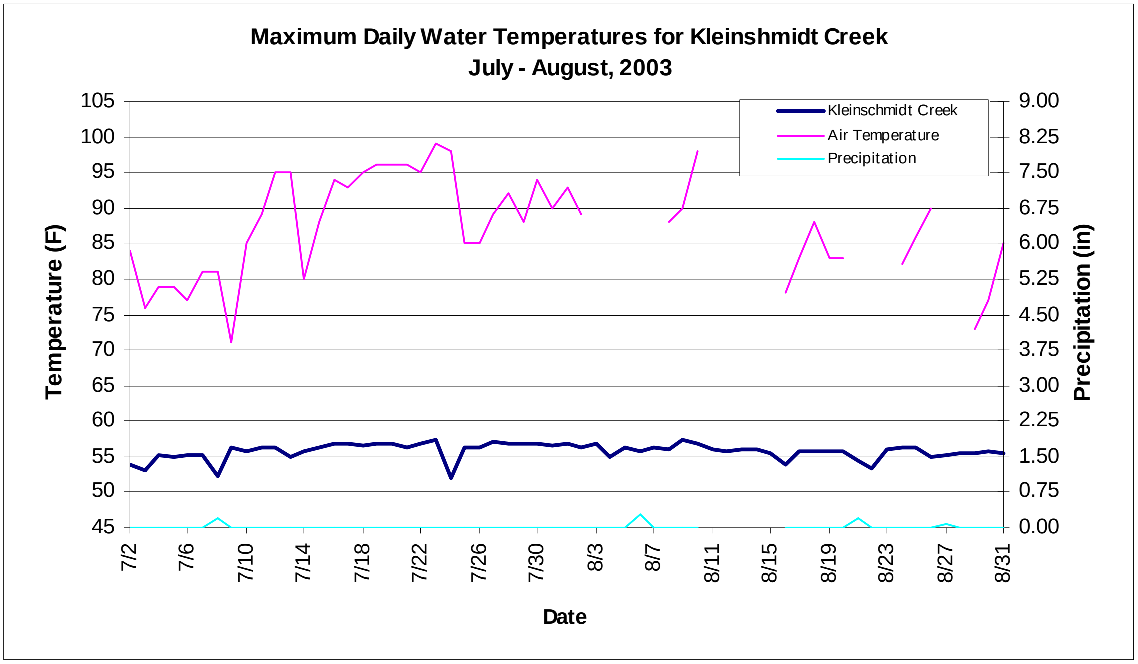


Figure B-5. Maximum daily water temperature, air temperature, and precipitation, Kleinschmidt Creek, 2003.

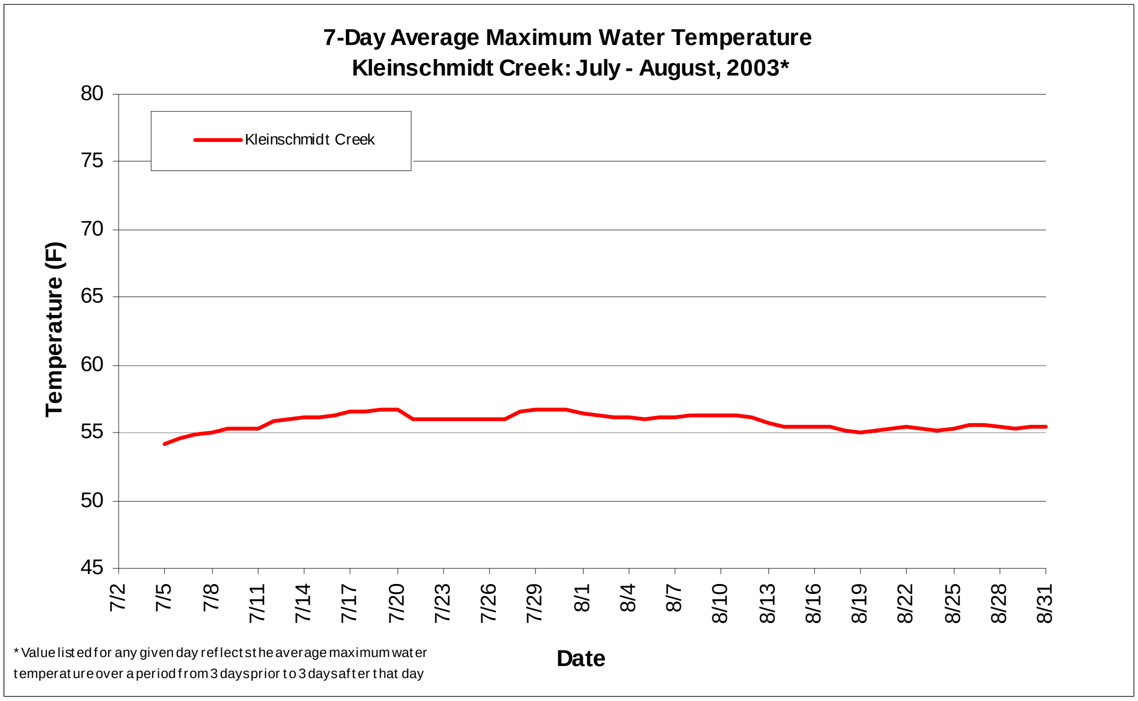
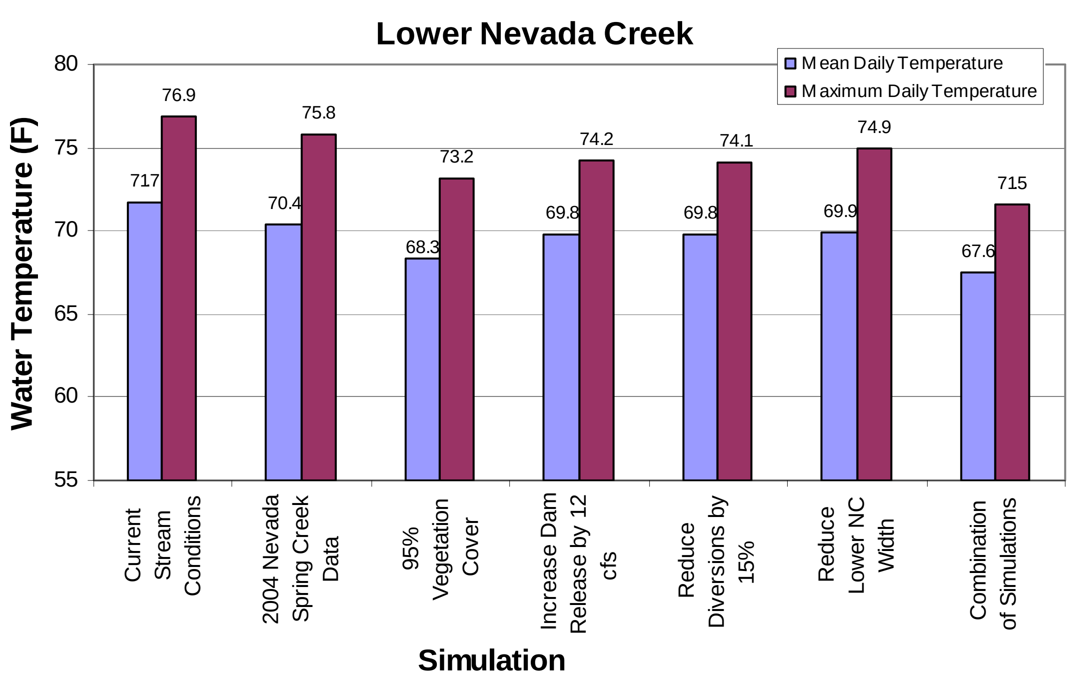


Figure B-6. 7-day average maximum daily temperatures, Kleinschmidt Creek, 2003.

C. Appendix C: Preliminary Simulations

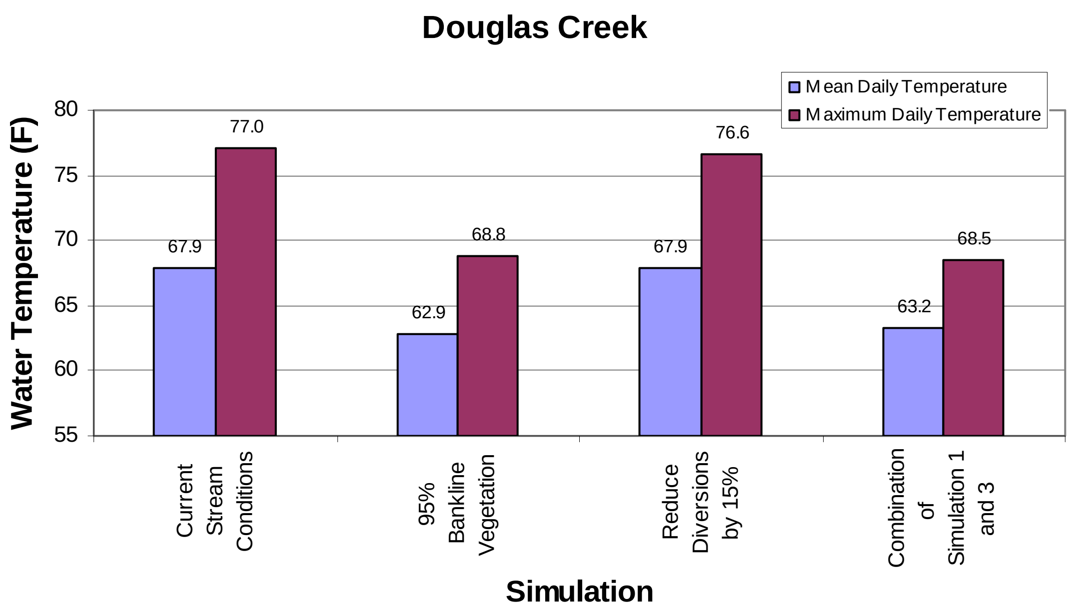
Preliminary simulation results for Lower Nevada Creek

Model Run	*Temperature (F)*		*Difference from Updated Calibration*		*Comments*
	Mean	*Max*	*Mean*	*Max*	
Observed Temperature	71.91	76.40	NA	NA	Current stream conditions and 2004 Nevada Spring Creek temperature data
Calibrated Temperature	71.71	76.89	1.30	1.13	Simulated temperature with current stream conditions
Updated Calibration	70.41	75.76	None	None	Current stream conditions and 2004 Nevada Spring Creek temperature data
Simulation 1	68.29	73.20	-2.12	-2.56	95% of bank with vegetation cover
Simulation 2	69.82	74.25	-0.59	-1.51	Increase flow 12 cfs through dam release
Simulation 3	69.78	74.14	-0.63	-1.62	Reduce diversions by 15% - increase overall flow by 12 cfs
Simulation 4	69.94	74.89	-0.47	-0.86	Reduce width in Nevada Creek lower segment from 39 to 32 feet
Simulation 5	67.55	71.53	-2.86	-4.23	95% bankline veg cover; reduce diversion by 15%; Change initial temperature for Douglas Creek



Preliminary simulation results for Douglas Creek

Model Run	***Temperature (F)***		***Difference from Calibration (F)***		***Comments***
	Mean	***Max***	***Mean***	***Max***	
Calibration	67.93	77.02	NA	NA	Simulated temperature with current stream conditions
Simulation 1	62.85	68.83	-5.08	-8.19	95% of bank with vegetation cover
Simulation 3	67.89	76.62	-0.04	-0.40	Reduce diversions by 15% - increase overall flow by 12 cfs
Simulation 5	63.23	68.54	-4.70	-8.48	95% bankline veg cover; reduce diversion by 15%; Change inital temperature for Douglas Creek



Preliminary simulation results for Cottonwood Creek

Model Run	***Temperature (F)***		***Difference from Calibration (F)***		***Comments***
	Mean	***Max***	***Mean***	***Max***	
Calibration	69.55	77.14	NA	NA	Simulated temperature with current stream conditions
Simulation 1	62.67	67.03	-6.88	-10.11	95% of bank with vegetation cover
Simulation 3	69.08	75.85	-0.47	-1.29	Reduce diversions by 15% - increase overall flow by 12 cfs
Simulation 5	62.47	66.27	-7.08	-10.87	95% bankline veg cover; reduce diversion by 15%; Change inital temperature for Douglas Creek