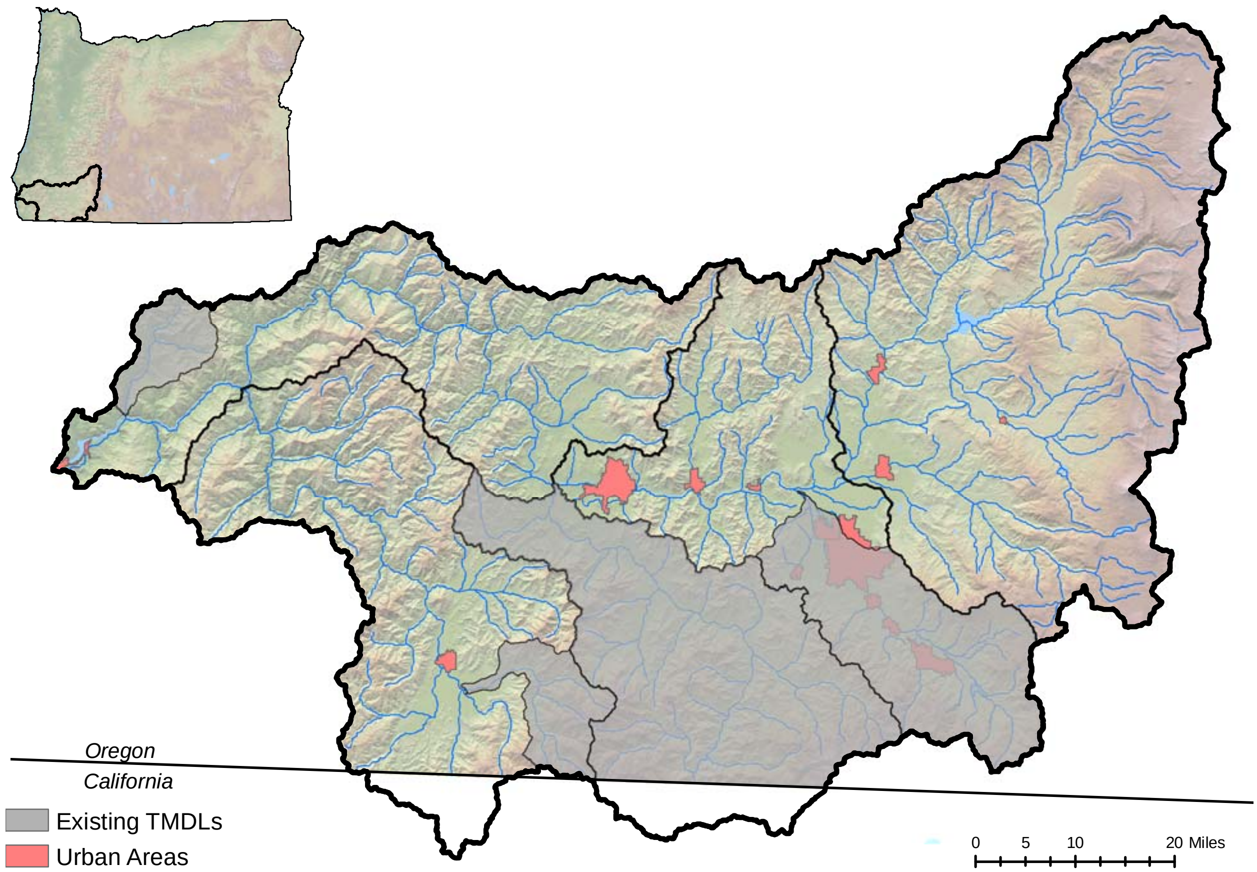
Appendix A:
Temperature Model Calibration Report



THIS DOCUMENT IS SUPPLEMENTAL TO THE ROGUE RIVER BASIN TEMPERATURE TMDL (CHAPTER 2)

DEQ

State of Oregon Department of Environmental Quality

Table of Contents

Tables

Figures

1. LIMITATIONS

It should be acknowledged that there are limitations to this effort:

- The scale of this effort is large with obvious challenges in capturing spatial variability in stream and landscape data. Available spatial data sets for vegetation and channel morphology are coarse, while derived data sets are limited to aerial photo resolution and human error.

- The hydraulics of the model is one dimensional, which necessitates lateral and depth averaging. Although appropriate for many of the reaches modeled, portions of the streams and river with impoundments, side channels, deep pools or a high degree of lateral variability may not be represented accurately.

- Data are insufficient to describe high-resolution instream flow conditions, making validation of derived mass balances difficult.

- The water quality issues are complex and interrelated. The state of the science is still evolving in the context of comprehensive landscape scaled water quality analysis. For example, quantification techniques for microclimates that occur in near stream areas are not developed and available to this effort. Regardless, recent studies indicate that forested microclimates play an important, yet variable, role in moderating air temperature, humidity fluctuations and wind speeds.

- Quantification techniques for estimating potential subsurface inflows/returns and behavior within substrate are not employed in this analysis. While analytical techniques exist for describing subsurface/stream interactions, it is beyond the scope of this effort with regard to data availability, technical rigor and resource allocations.

- Land use patterns vary through the drainage from heavily impacted areas to areas with little human impacts. However, it is extremely difficult to find large areas without some level of either current or past human impacts.

- The development of natural thermal potential stream temperatures is based on stated assumptions within this document. Limitations to stated assumptions are presented where appropriate. It should be acknowledged that as better information is developed these assumptions will be refined.

- Current analysis is focused on a defined critical condition. This usually occurs in late July or early August when stream flows are low, radiant heating rates are high and ambient conditions are warm. However, there are several other important time periods where data and analysis are less explicit. For example, spawning periods have not received such a robust consideration on streams other than the mainstem.

- Current analytical methods fail to capture some upland, atmospheric and hydrologic processes. At a landscape scale these exclusions can lead to errors in analytical outputs. For example, methods do not currently exist to simulate riparian microclimates at a landscape scale. In some cases, there is not scientific consensus related to riparian, channel morphology and hydrologic potential conditions. This is especially true when confronted with highly disturbed sites, meadows and marshes, potential hyporheic/subsurface flows, and sites that have been altered to a state where potential conditions produce an environment that is not beneficial to stream thermal conditions (such as a dike).

The following items affect model uncertainty:

- Riparian vegetation was mapped from aerial photographs and placed within general height categories. For example, trees identified as “Large Conifers” were assigned a single height of 125 feet throughout a single watershed, when in reality, “Large Conifer” heights may range between 110 and 140 feet. It is not possible to assign actual heights to each tree mapped using aerial photographs. These general height categories became Heat Source inputs and are one source of modeling imprecision.

- Riparian vegetation densities were estimated based on aerial photograph analysis. General categories of “dense”, “moderately dense”, and “sparse” were used to delineate vegetation stands. Potential vegetation used single density values for each ecoregion and vegetation type. In the real world, vegetation densities are variable and this variability is not accounted for in the simulations.

- The actual position of the sun within the sky can only be calculated with an uncertainty of 10-15%. The sun’s position is important when determining a stream’s effective shade. Solar position is another source of modeling imprecision.

- Heat Source always assumes that the wetted stream is flowing directly down the center of the active channel, and effective shade calculations are based upon that assumption. In reality, a stream migrates all over the active channel. This is another source of modeling imprecision.

- Microclimates often develop around streams. Humidity, air temperature, and wind depend on factors such as elevation, vegetation, terrain, etc. Stream temperatures are affected by microclimates which are another source of modeling imprecision.

- Groundwater exchanges and hyporheic flows are difficult to measure and may not always be accounted for within stream temperature modeling. In addition, natural stream conditions may have had more groundwater connection, wetland areas, and hyporheic interactions prior to anthropogenic disturbances. These conditions are not included in the Natural Thermal Potential (NTP) scenarios. Stream restoration may increase groundwater connectivity which could reduce the NTP temperatures.

- Increased channel complexity and more coarse woody debris are not accounted for in the NTP simulations. Including these factors may result in cooler NTP temperatures.

- Heat Source breaks the stream into 50-meter segments. Inputs (vegetation, channel morphology, etc.) are averaged for each 50-meter segment, which means that the simulation may not account for some of the real world variability. For example, isolated pools or riffles within a 50 meter reach will not be included as unique features.

- For the tributaries to the Rogue River, Heat Source simulations were performed for a two month period during a single summer, which was intended to represent a critical condition for aquatic life. Stream temperatures will react differently to effective shade under other flow regimes and climactic conditions.

- “Natural” flows were included in the NTP simulations. Estimates were used to create the existing flow mass balances, and withdrawals were estimated for the current condition, based on thermal infrared aerial data, the OWRD points of diversion database, and instream flow measurements. “Natural” flows are estimates based on removing the assumed anthropogenic impacts on the current flow regimes.

- To estimate natural thermal potential, some headwater and boundary condition stream temperature had to be estimated using professional judgment or the biologically based criterion as a guide.

- Stream velocities and depths were calculated by Heat Source for the “natural” flow conditions based on measured channel dimensions and substrate composition. These estimated velocities and depths for the “natural” flows may have some error associated with them since they have not been verified through field measurements.

- Stream elevations and gradients were sampled and calculated from 10-meter digital elevation models (DEMs). DEMs have a certain level of imprecision associated with them and may be a source of uncertainty in the simulation results.

- Existing air temperature and relative humidity were assigned to each simulation from various weather stations in the basin. Natural variations in air temperature and relative humidity along the stream may not be accounted for in the simulations. For example, temperatures may change as the landscape changes over short distances along the stream. These are similar to the microclimates created by vegetation cover.

In this TMDL process, there are a number of necessary decisions which are based on information with a certain amount of uncertainty: determination of impairment, model calibration acceptance, model scenario acceptance and allocations. For each of these four decision points, the uncertainty is handled differently.

The determination of impairment is based on a comparison of data with the water quality standard. The comparison of data with a numeric standard is relatively straight forward, however comparison of data to a ‘natural conditions’ based standard has more uncertainty because ‘natural condition’ cannot be observed and is based on estimates. DEQ accounts for this uncertainty by trying to minimize the likelihood of a Type II error (where the actual condition is impaired but analysis shows the system is not impaired).

The determination that a model is representing a system (i.e. acceptance of a calibrated model) is based on comparison of model results with observed data, using statistics and graphical comparison. The uncertainty related to model scenarios is evaluated using a sensitivity analysis. Lastly, the uncertainty related to allocations is accounted for in the Margin of Safety.

While these assumptions outline potential areas of weakness in the methodology used in the stream temperature analysis, the Oregon Department of Environmental Quality has undertaken a comprehensive approach. All important stream parameters that can be accurately quantified are included in the analysis. In the context of understanding stream temperature dynamics, these areas of limitations should be the focus for future studies.

2. AVAILABLE DATA

2.1 Ground Level Data

Overview

Several ground level data collection efforts have been completed in the Rogue River Basin. Specifically, this stream temperature analysis relied on the following data types: continuous temperature data, flow volume (gage data and instream measurements), vegetation surveys, channel morphology surveys, and effective shade measurements.

The following parties are credited for collecting the data used in the Rogue River Basin Temperature TMDL:

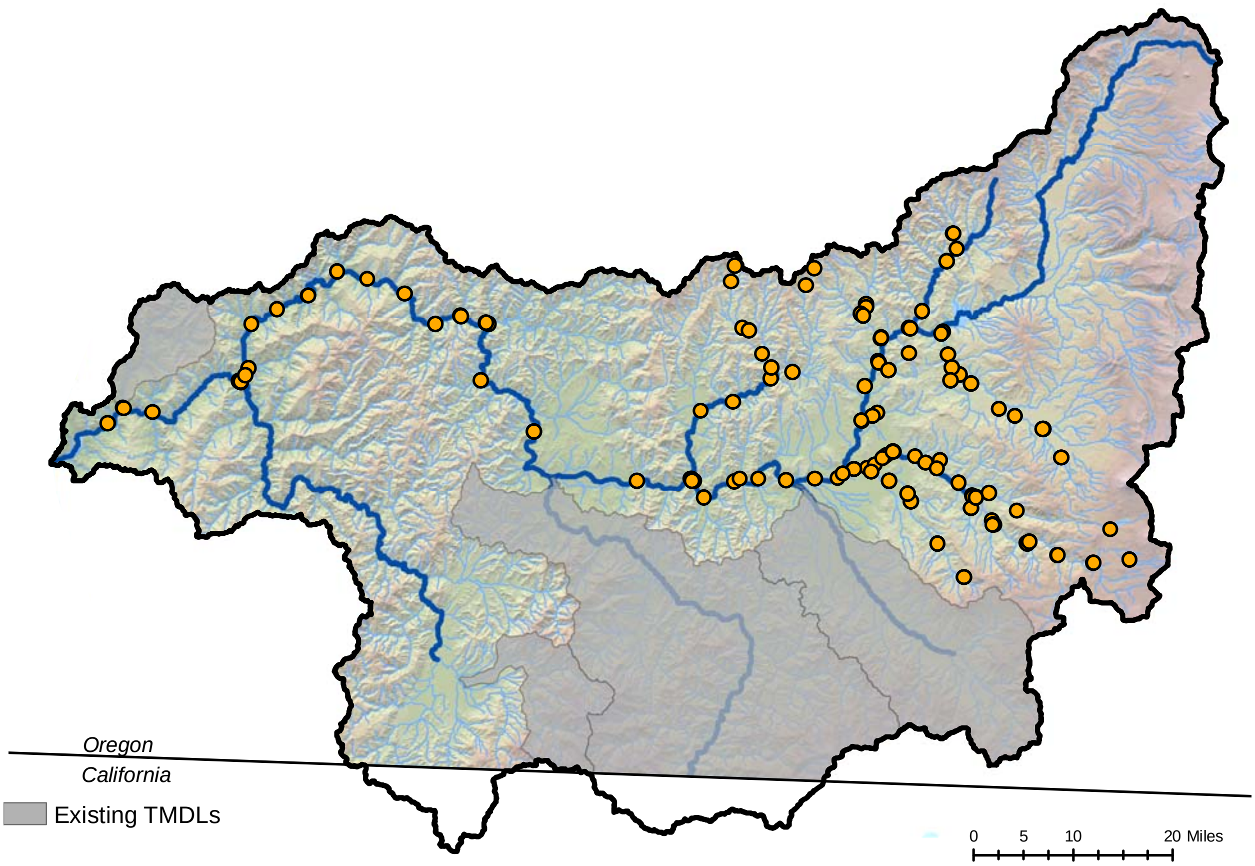
Little Butte Watershed Council
Medford Water Commission
Oregon Department of Environmental Quality
Oregon Department of Fish and Wildlife
Oregon Department of Forestry
Oregon Water Resources Department
United States Army Corp of Engineers
United States Bureau of Land Management
United States Bureau of Reclamation
United States Forest Service
United States Geological Survey
Watershed Sciences, Inc.
National Climatic Data Center

Continuous Temperature Data

Continuous temperature data were used in this analysis to:
- Calibrate stream emissivity for thermal infrared radiometry (TIR),
- Calculate temperature statistics and assess the temporal component of stream temperature,
- Calibrate temporal temperature simulations.

Continuous temperature data were collected at one location for a specified period of time, usually spanning several summertime months. Measurements were collected using thermistors[1], and data from these devices were routinely checked for accuracy. Continuous temperature data were collected throughout the basin during several years. **Figure A1** displays continuous temperature data monitoring locations for the years 2001, 2002, and 2003. (Actual stream temperature data are available from DEQ upon request.)

Figure A1. Continuous stream temperature measurement locations for 2001 - 2003

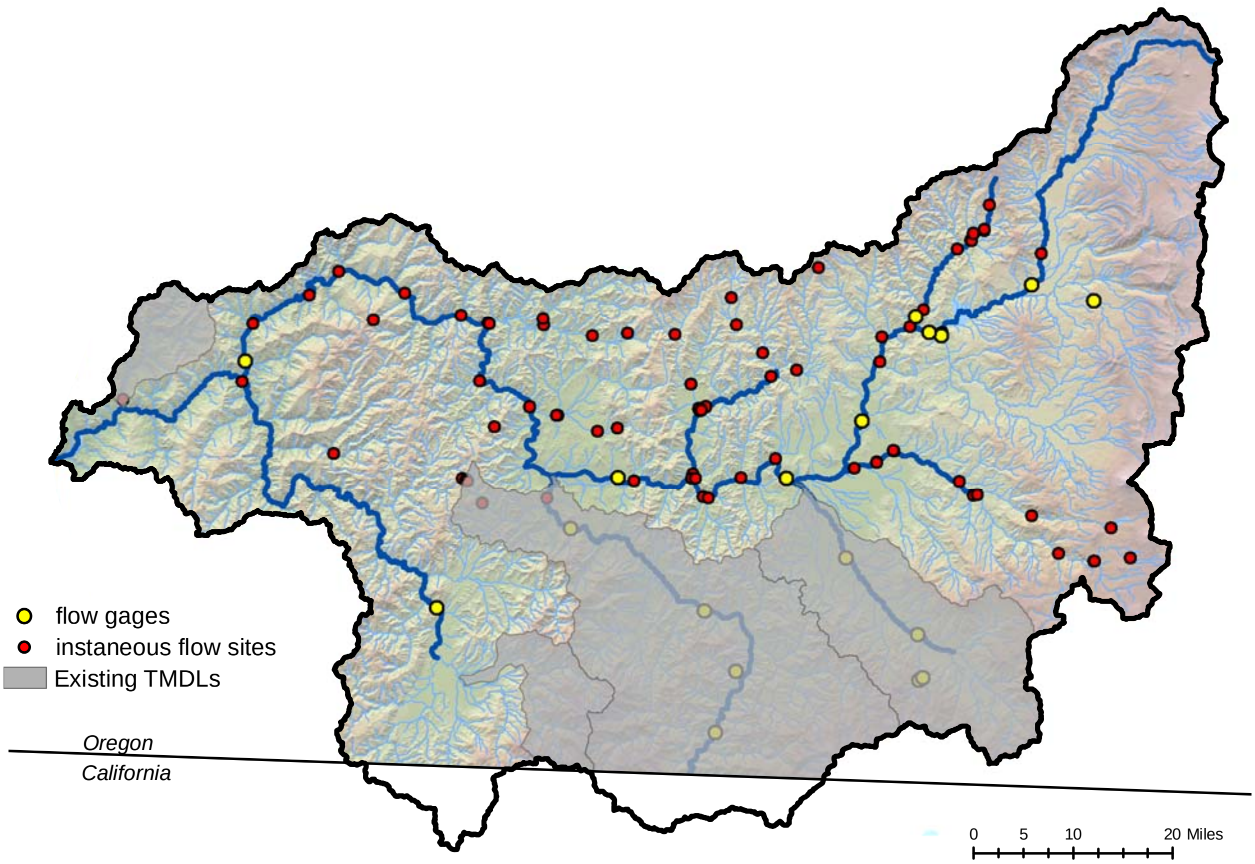


[1] Thermistors are small electronic devices that are used to record half-hourly or hourly stream temperature at one location for a specified period of time.

Flow Volume – Gage Data and Instream Measurements

Flow volume data were collected at several sites during the critical stream temperature period in 2001 and 2003 (**Figure A2**). These measurements were used to develop flow mass balances for the modeled streams. (Actual stream flow data is available upon request from DEQ.)

Figure A2. Instream flow measurement and gage locations (2001 and 2003)



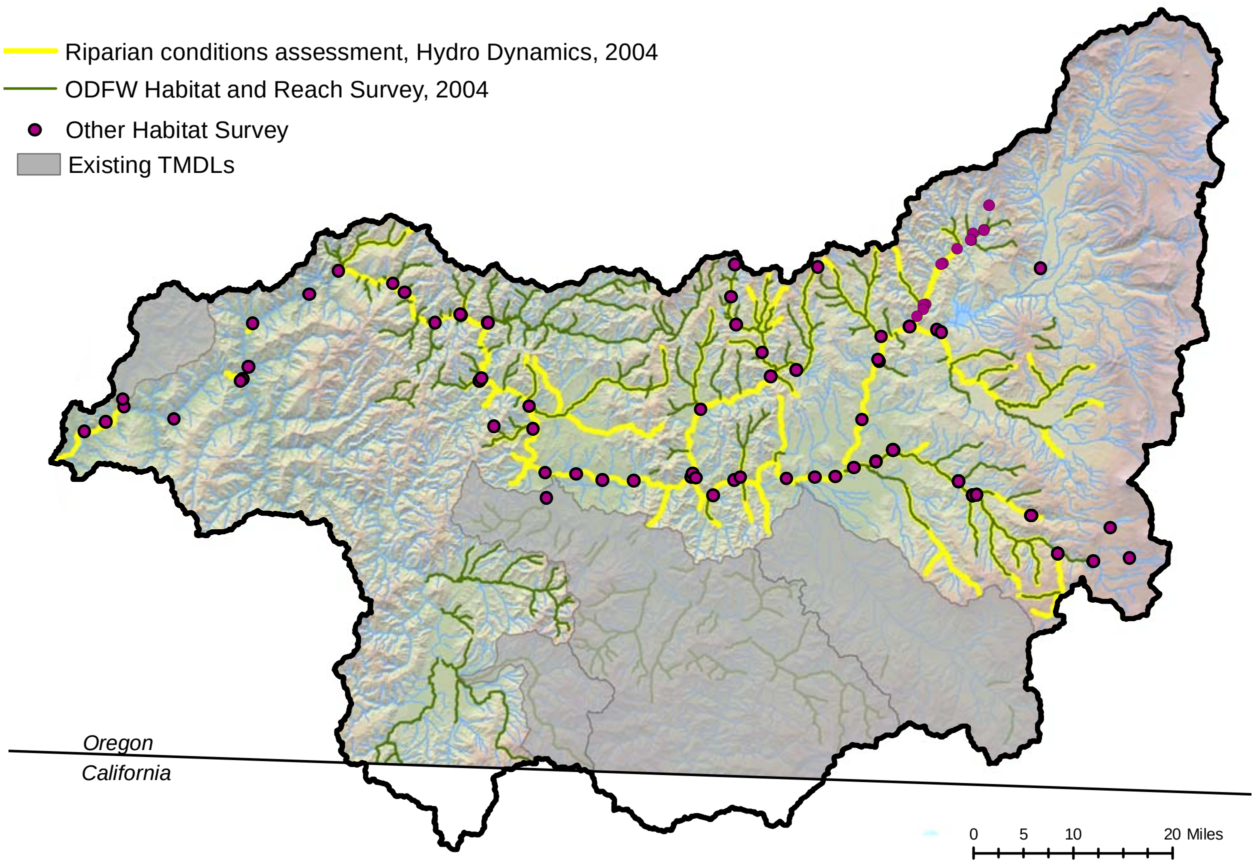
Stream Habitat Surveys

Ground-level habitat data were collected at several locations in the Rogue River Basin (**Figure A3**). Stream survey data (identified as “other habitat survey in **Figure A3**) focuses on vegetation classification and measurements, channel morphology measurements, and effective shade measurements.

ODFW has also collected stream habitat data (ODFW 1997). Their data sets also focus on channel morphology, vegetation, and stream shade measurements. The stream habitat coverages used were last updated by ODFW in February 2004.

Hydro Dynamics (2004), under contract from DEQ, conducted an analysis of aerial photographs to assess the current and potential riparian conditions.

Figure A3. Ground Level Channel Morphology Measurement Sites



2.2. GIS and Remotely Sensed Data

Overview

A wealth of spatial data have been developed for the Rogue River Basin. The stream temperature TMDL relies extensively on GIS and remotely sensed data. Water quality issues in the Rogue River Basin are interrelated, complex and spread over hundreds of square miles. The TMDL analysis strives to capture these complexities using the highest resolution spatial data available. Some of the GIS data used to develop the Rogue River Basin Temperature TMDL are listed in **Table A1** along with the application for which it was used.

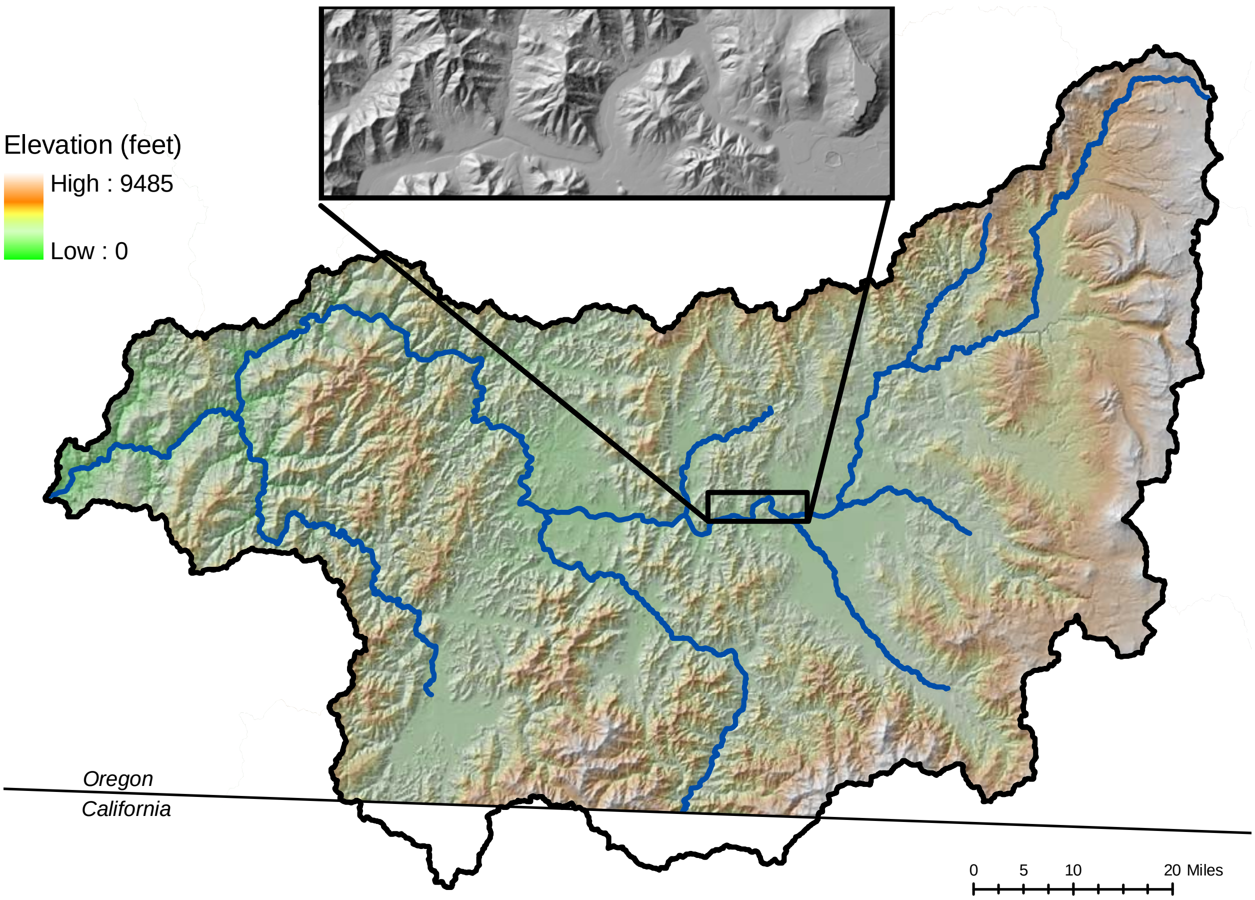
Table A1. Spatial Data and Application

Spatial Data	Application
10-Meter Digital Elevation Models (DEM)	Measure Stream Elevation and Gradient Measure Topographic Shade Angles
Aerial Imagery – Digital Orthophoto Quads	Map Vegetation Map Channel Morphology Map Roads, Development, Structures
Thermal Infrared Radiometry (TIR) Stream Temperature Data	Measure Surface Temperatures Develop Longitudinal Temperature Profiles Identify Subsurface Hydrology, Groundwater Inflow, Springs
Water Rights Information System (WRIS) and Points of Diversion (POD) Data	Map locations and estimate quantities of water withdrawals

10-Meter Digital Elevation Model (DEM)

A digital elevation model (DEM) consists of digital information that provides a uniform matrix of terrain elevation values (**Figure A4**). It provides basic quantitative data for deriving terrain elevation, stream elevation, stream slope, and topographic information. The 10-meter DEM contains a land surface elevation value for each 10-meter square. The U.S. Geological Survey, as part of the National Mapping Program, produces these digital cartographic/geographic data files. The DEMs were produced in 1999 and are available through the Oregon Geospatial Data Clearinghouse (OGDC).

Figure A4. The 10-meter DEM, hill-shaded for contrast (zoom of Rogue River)



Aerial Imagery – Digital Orthophoto Quads

Aerial imagery was used to:

- Map stream features such as stream position, channel edges and wetted channel edges,
- Map near stream vegetation,
- Map instream structures such as dams, weirs, unmapped diversions/withdrawals, etc.

A digital orthophoto quad (DOQ) is a digital image of an aerial photograph in which displacements caused by the camera angle and terrain have been removed. In addition, DOQs are projected in map coordinates combining the image characteristics of a photograph with the geometric qualities of a map. For this analysis, color DOQs were provided by Jackson County (images from 2001 – 2003) and Josephine County (images from 2002). Color DOQs are available for the entire Rogue River Basin and may be downloaded from http://www.oregonexplorer.info/imagery/.

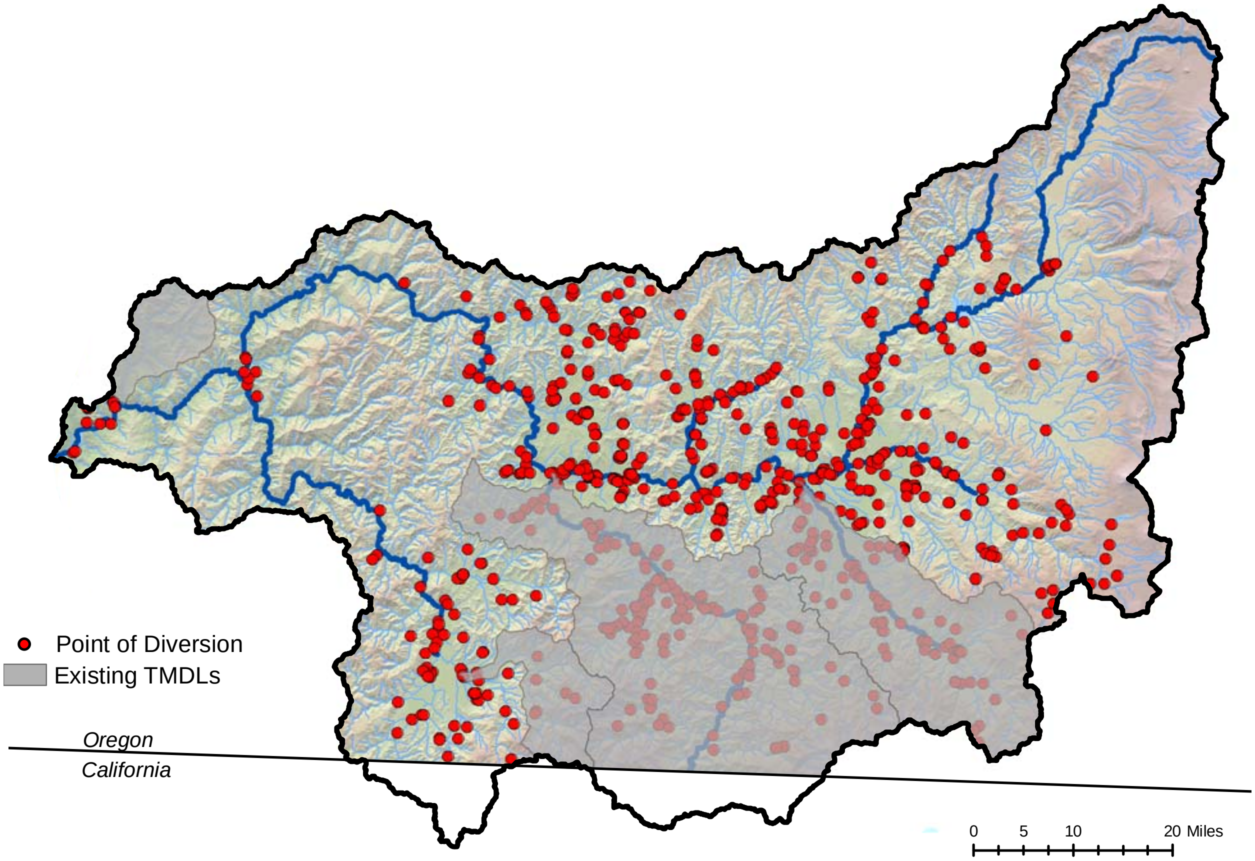
WRIS and POD Data – Water Withdrawal Mapping

WRIS and POD Data were used to:

- Map stream diversions/withdrawals,
- Associate an estimated flow rate to each diversion/withdrawal.

The Oregon Water Resources Department (OWRD) maintains the Water Rights Information System (WRIS). WRIS is a database used to monitor information related to water rights. A separate database tracks points of diversions (POD). These two databases were linked by DEQ to map the locations of diversions, rates of water use and types of water use in the Rogue River basin (**Figure A5**). Consumptive use was estimated using these data and incorporated in developing mass balance flow profiles for the simulated streams.

Figure A5. Mapped points of diversion in the Rogue River Basin derived from the WRIS and POD databases (Oregon Water Resources Department)



Thermal Infrared Radiometry (TIR) Temperature Data

TIR temperature data were used to:
- Develop continuous spatial temperature data sets,
- Calculate longitudinal heating profiles/gradients,
- Visually observe complex distributions of stream temperatures at a large landscape scale,
- Map/Identify significant thermal features,
- Develop flow mass balances,
- Validate simulated stream temperatures.

TIR imagery measures the temperature of the outermost portions of the bodies/objects in the image (i.e., ground, riparian vegetation, and stream). The bodies of interest are opaque to longer wavelengths and there is little, if any, penetration of the bodies.

TIR data was gathered through a sensor mounted on a helicopter that collected digital data directly to an on-board computer at a rate that insured the imagery maintained a continuous image overlap of at least 40%. The TIR detected emitted radiation at wavelengths from 8-12 microns (long-wave) and recorded the level of emitted radiation as a digital image across the full 12-bit dynamic range of the sensor. Each image pixel contained a measured value that was directly converted to a temperature. Each thermal image has a spatial resolution of less than one-half meter/pixel. Visible video sensor captured the same field-of-view as the TIR sensor. GPS time was encoded on the imagery.

Data collection was timed to capture maximum daily stream temperatures, which typically occur between 14:00 and 18:00 hours. The helicopter was flown longitudinally over the center of the stream channel with the sensors in a vertical (or near vertical) position. In general, the flight altitude was selected so that the stream channel occupied approximately 20-40% of the image frame. A minimum altitude of approximately 300 meters was used both for maneuverability and for safety reasons. If the stream split into two channels that could not be covered in the sensor’s field of view, the survey was conducted over the larger of the two channels.

In-stream temperature data loggers (Onset Stowaways or VEMCOs) were distributed in each subbasin prior to the survey to ground truth the radiant temperatures measured by the TIR. TIR data can be viewed as GIS point coverages or TIR imagery.

Direct observation of spatial temperature patterns and thermal gradients is a powerful application of TIR derived stream temperature data. Thermally significant areas can be identified in a longitudinal stream temperature profile and related directly to specific sources (i.e., water withdrawal, tributary confluence, vegetation patterns, etc.). Areas with stream water mixing with subsurface flows (i.e., hyporheic and inflows) are apparent and often dramatic in TIR data. Thermal changes captured with TIR data can be quantified as a specific change in stream temperature or a stream temperature gradient that results in a temperature change over a specified distance.

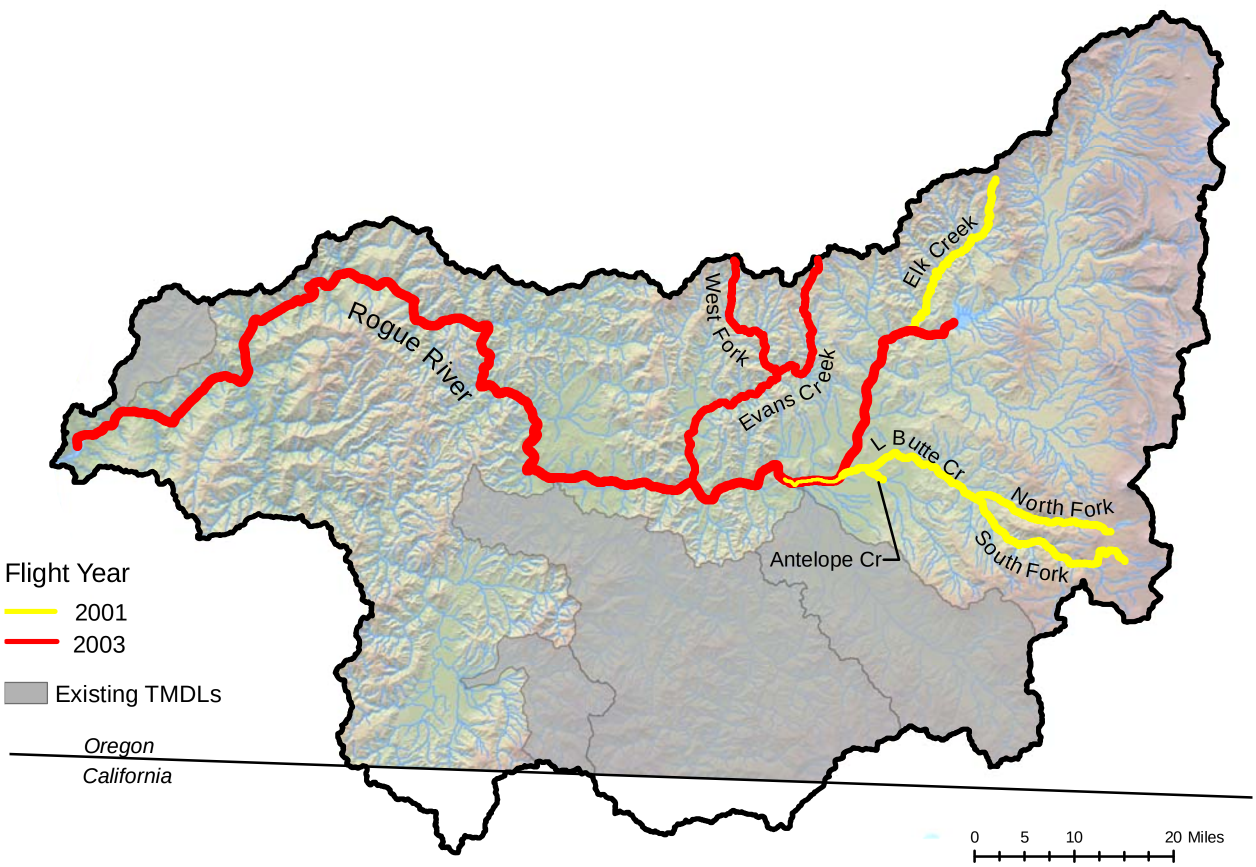
Rogue River Basin TIR Data

DEQ contracted with Watershed Sciences, Inc. to collect TIR data in the Rogue River Basin during 2001 and 2003 (**Figure A6**). TIR data also has been collected for Bear Creek and Applegate River (see applicable TMDLs). Longitudinal river temperatures were sampled using thermal infrared radiometry (TIR) in separate flights for each stream. Temperature data sampled from the TIR imagery revealed spatial patterns that are variable due to localized stream heating, tributary mixing, and groundwater influences.

Thermal stratification was identified in TIR imagery and by comparison with the instream temperatures loggers. For example, the imagery may reveal a sudden cooling at a riffle or downstream of an instream structure, where water was rather stagnant or deep just upstream.

TIR-derived longitudinal stream temperature profiles are presented in **Section 4**. Each year's Rogue River Basin TIR survey report is available for download at the Oregon DEQ website (Watershed Sciences, Inc. 2002 and 2004). The TIR survey reports contain detailed flight information, results discussions, sample imagery, and longitudinal temperature profiles. (Actual TIR data is available upon request from DEQ. Viewing the TIR data requires ArcView with Spatial Analyst.)

Figure A6. TIR flight paths in the Rogue Basin.



3. DERIVED DATA AND SAMPLED PARAMETERS

Several landscape scale GIS data sets were sampled to derive spatial stream data. Sampling density was user-defined and generally matched any GIS data resolution and accuracy. The sampled parameters used in the stream temperature analysis were:

- Stream Position and Aspect
- Stream Elevation and Gradient
- Maximum Topographic Shade Angles (East, South, West)
- Channel Width
- Mass balanceTIR Temperature Data Associations
- Vegetation

The following sub-sections detail the methodologies used for each derived data type. The results, resolution and accuracy for each derived data type are discussed in **Sections 4.1-4.6**.

3.1 Channel Morphology

Overview

Channel morphology is largely a function of high flow volume magnitude and frequency, stream gradient, sediment supply and transportation, stream bed and bank materials and stream bank stability (Rosgen 1996 and Leopold et al. 1964).

The predominant thermodynamic influence of channel morphology is quite simple. Wider channels result in the combined effect of increased solar radiation loading via decreased stream surface shade and increased stream surface area exposed to solar radiation loading. A wider stream has a larger surface exposed to surface thermal processes. Other thermal effects that relate to channel morphology include altered stream hydraulics caused by increased wetted perimeter and decreased stream depth. Disturbance of surface water and groundwater interactions may also result from channel morphology modifications and have the combined effects of lowering near stream groundwater tables, reducing the groundwater inflow, removing cool sources of groundwater that serve to reduce instream temperatures and modifying hyporheic flows. Substrate changes may decrease or impair hyporheic flows (i.e., flows that occur in the interstitial spaces in the bed substrate) that help buffer stream temperature change.

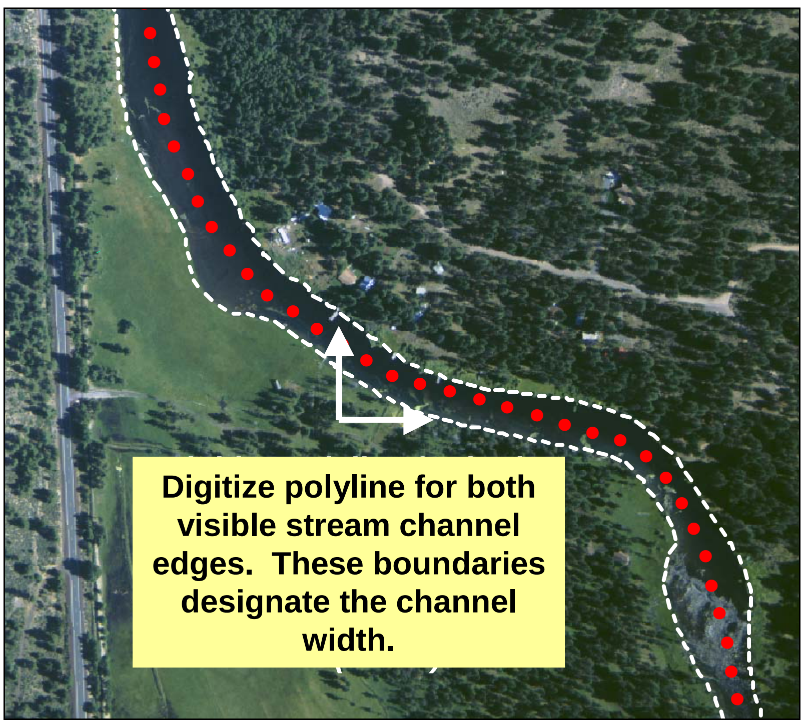
In places where channel morphology is anthropogenically disturbed, resulting in decreased effective shade levels, passive restoration could be a primary focus of temperature related restoration efforts in the Rogue River Basin. Passive restoration efforts could include removing sources of channel disturbance that are known to degrade and slow or prevent restoration. Vegetation is a primary component in shaping channel form and function and should be a significant emphasis in all restoration planning and activities. Active restoration could be considered where severe channel disturbances cannot be remedied via passive restoration techniques. Examples of areas where active restoration could be considered include severe vertical down cutting, diked channels and removal of instream structures that prevent progress towards the desired stream channel condition. Other instream structures can serve as beneficial components in channel restoration such as rock barbs, sediment catchments, etc.

Channel Width Assessment

Channel width is an important component in stream heat transfer and mass transfer processes. Effective shade, stream surface area, wetted perimeter, stream depth and stream hydraulics are all highly sensitive to channel width. Accurate measurement of channel width across the stream network, coupled with other derived data, allows a comprehensive analytical methodology for assessing channel morphology. The steps for conducting channel width assessment are listed below (**Figure A7**).

Step 1. Stream channel edges were digitized from DOQs at a 1:5,000 or less map scale. These channel boundaries establish the active channel width, which is defined for purposes of the TMDL, as the width between shade-producing near-stream vegetation. Where near-stream vegetation is absent, the near-stream boundary is used, defined as downcut stream banks or areas where the near-stream zone is unsuitable for vegetation growth due to external factors (i.e., roads, railways, buildings, etc.).
Step 2. Channel widths were sampled at every 50 meters using TTools[2]. The sampling algorithm measured the channel width in the transverse direction relative to the stream aspect.
Step 3. Compared sampled channel width and ground level measurements. TTools sampled channel widths were then compared to ground level measurements for verification purposes.
Step 4. The **bottom width** was derived by assuming a trapezoidal channel and parameterized side slopes and width-to-depth ratios.

Figure A7. Digitized channel centerline, right bank, and left bank



[2] A GIS tool developed by Oregon DEQ for automatically sampling spatial data sets and creating a Heat Source input database (Boyd and Kasper, 2003).

3.2 Vegetation

Overview

The role of vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in scientific literature (Beschta et al. 1987). Vegetation impacts the stream and the surrounding environment in the following ways:

- Vegetation plays an important role in regulating radiant heat in stream thermodynamic regimes.
- Channel morphology is often highly influenced by vegetation type and condition by affecting flood plain and instream roughness, contributing coarse woody debris, and influencing sedimentation, stream substrate compositions and stream bank stability.
- Vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity and lower wind speeds along stream corridors.
- Riparian and instream nutrient cycles are affected by vegetation.

Vegetation – Mapping, Classification and Sampling

With the recognition that vegetation is an important parameter in influencing water quality, DEQ made the development of vegetation data sets in the Rogue River Basin a high priority. Variable vegetation conditions in the Rogue River Basin require a higher resolution than currently available GIS data sources. To meet this need, DEQ mapped vegetation using Digital Orthophoto Quads (DOQs) at a 1:5,000 map scale. Existing vegetation was digitized and sampled for the streams with TIR Data (**Figure A8)** following the steps listed below. Vegetation features were mapped 300 feet in the transverse direction from channel edge. Vegetation data was developed by DEQ in successive steps.

Step 1. Vegetation polygons and stream polylines were digitized from DOQs. All digitized polygons were drawn to capture visually like vegetation features. All digitized line work was completed at a 1:5,000 map scale or less.

Step 2. Basic vegetation types were categorized and assigned to individual polygons. The vegetation categories used in this effort were aggregate vegetation groups, such as: conifers, hardwoods, shrubs, etc. Existing heights and densities were assigned according to aerial photograph analysis and ground level data collection.

Step 3. Automated sampling was conducted on classified vegetation spatial data sets in 2-dimensions using TTools. Every 50 meters along the stream (i.e., in the longitudinal direction), the vegetation was sampled radially every 15 meters; starting at the channel center, out to 60 meters. This sampling rate resulted in 928 measurements of vegetation per every mile of stream.

Step 4. Ground level vegetation data was statistically summarized and sorted by vegetation type. Median values for vegetation height and density were then used to describe DEQ vegetation classifications.

Figure A9 summarizes the steps followed for vegetation classification. More detailed information can be found in *Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0* (Boyd and Kasper 2003), which can be downloaded from the DEQ website. (http://www.heatsource.info/)

Figure A8. Streams where near stream vegetation and channel morphology were digitized from digital orthophoto quads.

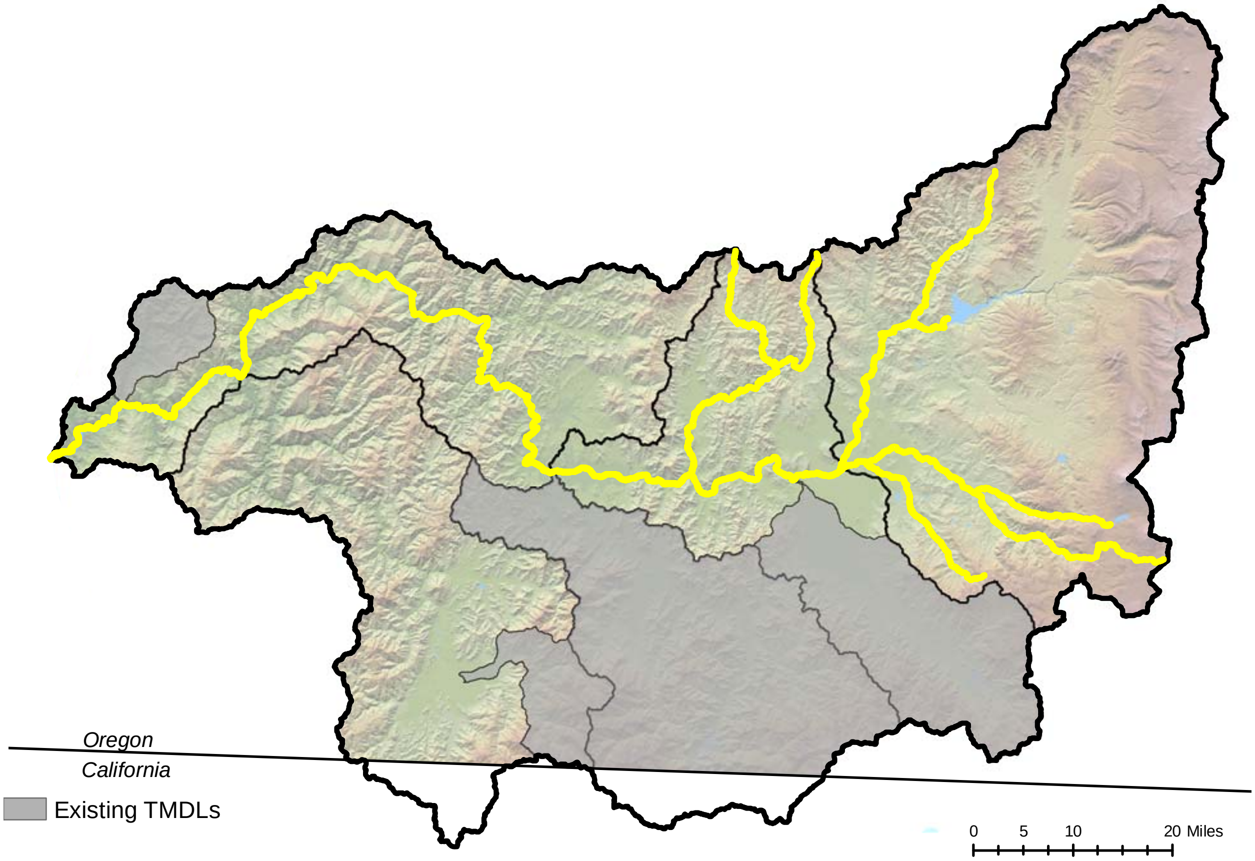
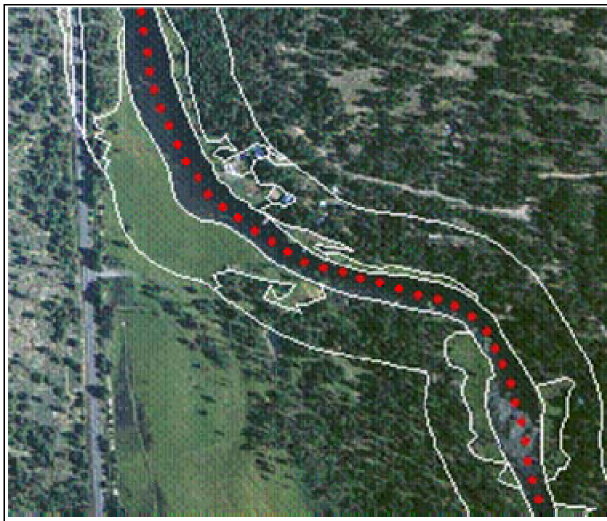
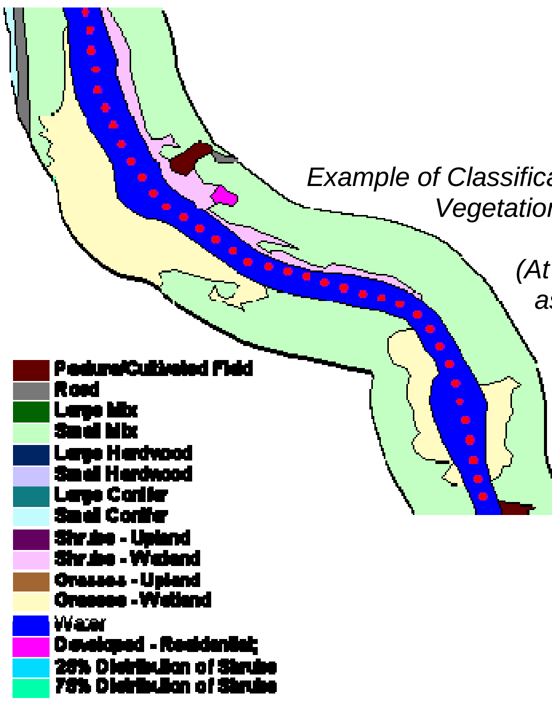


Figure A9. Steps for digitizing and classifying vegetation.



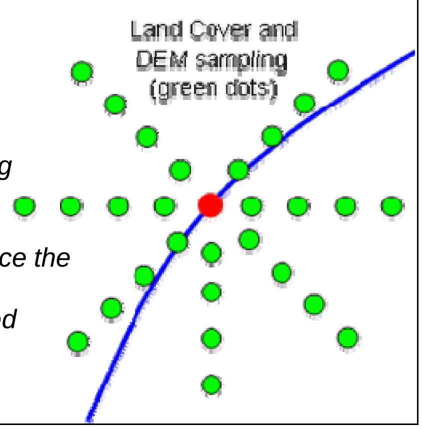
Example of Polygon Mapping of Vegetation from Aerial Color Imagery

(At this point only the line work is complete and no data is associated with the polygons.)



Example of Classification of the Vegetation Polygons Associating a Vegetation Type to Each of the Polygons

(At this point a vegetation type numeric code is associated with each polygon.)



TTools radial sampling pattern for vegetation (sampling interval is user defined). Sampling occurs for every stream data node at four user-defined intervals every 45 degrees from north (North is not sampled since the sun does not shine from that direction in the northern hemisphere). A database of vegetation type in created for each stream data node.

3.3 Hydrology

Mass Balance Development

TIR sampled stream temperature data was used to develop a flow mass balance which was verified with ground level flow measurements. Mass transfer areas (tributaries, springs, return flows, etc.) were identified for each stream. Several unmapped subsurface mass transfer areas were identified and the relative thermal and hydrologic impact to the stream system was quantified.

All stream temperature changes that result from mass transfer processes can be described mathematically using the following relationship:

$$T_{mix} = \frac{(Q_{up} \cdot T_{up}) + (Q_{in} \cdot T_{in})}{(Q_{mix})}$$

where,
Q_{up}: Stream flow rate upstream from mass transfer process
Q_{in}: Inflow volume or flow rate
Q_{mix}: Resulting volume or flow rate from mass transfer process ($Q_{up} + Q_{in}$)
T_{up}: Stream temperature directly upstream from mass transfer process
T_{in}: Temperature of inflow
T_{mix}: Resulting stream temperature from mass transfer process assuming complete mix

All water temperatures (i.e. T_{up}, T_{in} and T_{mix}) were provided by the TIR data. Provided that at least one instream flow rate is known the other flow rates can be calculated.

Following are assumptions and limitations of the flow mass balance methodology:

- **Small mass transfer processes were not accounted for.** Only mass transfer processes with measured flow rates or those that caused a quantifiable change in stream temperature in the receiving waters (identified by TIR data) could be included. *This assumption can lead to an under estimate of influent mass transfer processes.*
- **Ground level flow data was limited**. Errors in the calculations of mass transfer can become cumulative and propagate in the methodology since validation can only be performed at sites with known flow rates. *These mass balance profiles should be considered estimates of a steady state flow condition*.
- **Water withdrawals were not directly quantified**. Instead, water right data is obtained from the POD and WRIS OWRD databases. An assumption is made that these water rights are being used if water availability permits. *This assumption can lead to an over estimate of water withdrawals.*
- **Water withdrawals were assumed to occur only at OWRD mapped points of diversion sites.** There may have been additional diversions occurring throughout the stream network. *This assumption can lead to an underestimate of water withdrawals and an under estimate of potential flow rates.*

3.4 Effective Shade

Overview

Factors that influence stream surface effective shade are incorporated into the simulation methodology, and include the following:

Season/Time: Date/Time
Stream Morphology: Aspect, Channel Width, Incision
Geographic Position: Latitude, Longitude, Topography
Vegetation: Vegetation Height, Width, Density
Solar Position: Solar Altitude, Solar Azimuth

For detailed information, refer to “Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0” (Boyd and Kasper 2003).

Effective shade was simulated every 50 longitudinal meters along the stream. Simulation periods were for July and August. Effective shade simulations were performed for a total of 258.7 stream miles in the Rogue River Basin (see **Chapter 2**: *Rogue River Basin Temperature TMDL*).

Effective shade simulation validation was conducted by comparing simulated results with ground level measured shade values. Solar Pathfinder® data was used to collect all ground level data. These data were compared to the predicted shade simulated by the model.

Total Daily Solar Heat Load Analysis

The total daily solar heat load is the cumulative solar heat received by a stream over one day during the critical period (i.e. July/August period). For the purposes of this analytical effort, the total daily solar heat load is the sum of the products of the daily solar heat flux and surface area of exposure for each stream reach (i.e., for each stream data node every 50 meters).

$$H_{solar} = \sum\left(\Phi_{solar} \cdot A_y\right) = \sum\left(\Phi_{solar} \cdot W_{wetted} \cdot dx\right)$$

Background levels of solar heat estimate the portion of the total daily solar heat load that occurs when anthropogenic nonpoint sources of heat are minimized. The total daily solar load is calculated for both the current condition (H_{solar}) and the potential condition ($H_{solar}^{Background}$). The anthropogenic nonpoint source total daily solar load is the difference between the total daily solar load and the background total daily solar load.

$$H_{solar}^{NPS} = H_{solar} - H_{solar}^{Background}$$

where,

A_y:	Stream surface area unique to each stream segment
Dx:	Stream segment length and distance step in the methodology
Φ_{solar}:	Solar heat flux for unique to each stream segment
H_{solar}:	Total daily solar heat load delivered to the stream
H_{solar}^{NPS}:	Portion of the total daily solar heat load delivered to the stream that originates from anthropogenic nonpoint sources of pollution
$H_{solar}^{Background}$:	Portion of the total daily solar heat load delivered to the stream that originates from background sources of pollution that are not affected by human activities
W_{wetted}:	Wetted width unique to each stream segment

The Rogue River Basin Temperature TMDL displays the solar heat load contributions for each stream where temperature/hydrology was simulated. Longer and wider streams have the most solar heat load. In any case, anthropogenic nonpoint sources account for a fraction of the heat load in most streams simulated (i.e., much of the existing heat load is naturally occurring).

4. STREAM TEMPERATURE MODEL SETUP AND CALIBRATION

4.1 Overview

Heat Source version 8.0 was used to model stream temperatures in the Rogue River Basin. For detailed information regarding Heat Source and the methodologies used, refer to “Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0” (Boyd and Kasper, 2003). Specifics for each of the modeled streams follow.

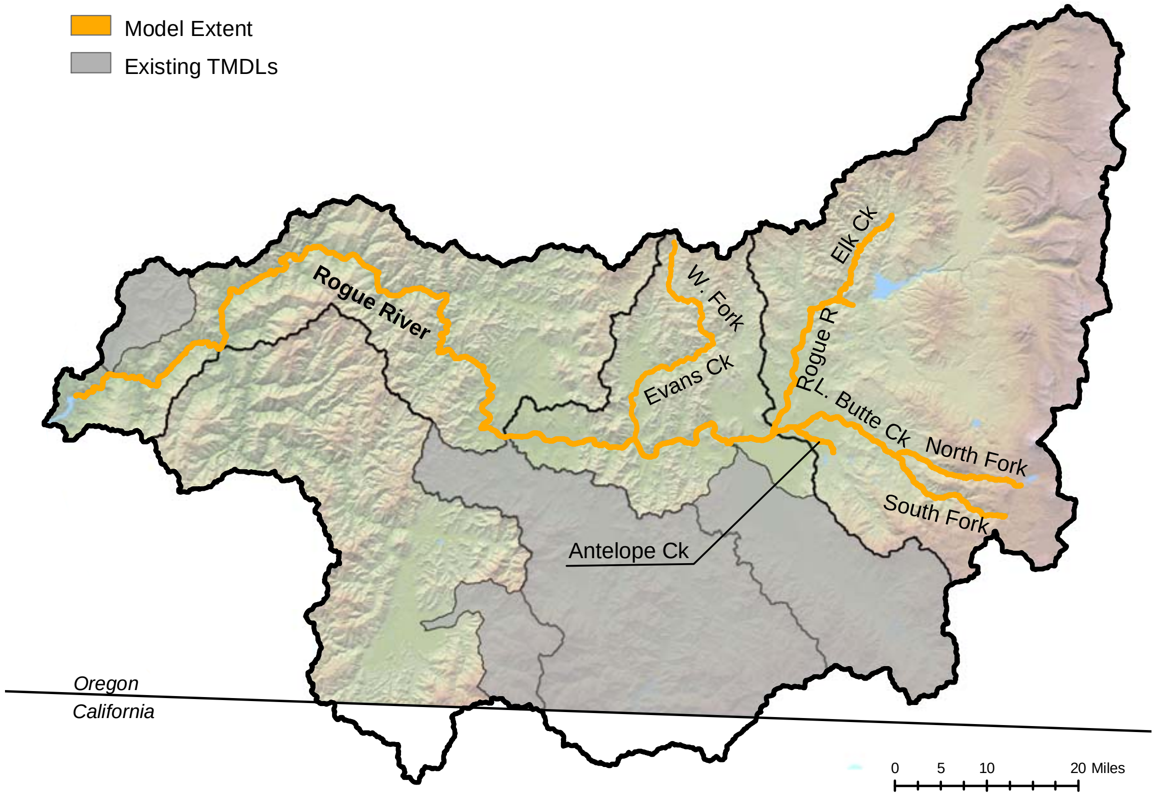
Spatial and Temporal Scale

The length of the defined finite difference and data input sampling rate was 50 meters. Prediction time steps and spatial scale were limited by stability considerations for the finite difference solution method. Simulations were performed for a total of 258.7 stream miles in the Rogue River Basin (**Table A2 and Figure A10**).

Table A2. Stream Temperature Simulation Periods and Extents

River/Stream	Simulation Period	Time Step (minutes)	Spatial Resolution (meters)	Model spin up (days)	Simulation Extent
Rogue River	3/1 to 10/31/2003	1	500	0	Lost Creek Reservoir to estuary: 239.6 km
Little Butte Creek and North Fork Little Butte Creek	7/1 to 8/31/2001	0.5	200	5	Fish Lake to mouth of Little Butte Creek: 54.1 km
South Fork Little Butte Creek	7/1 to 8/31/2001	0.5	100	5	Confluence with Beaver Dam Creek to mouth: 28.5 km
Antelope Creek	7/1 to 8/31/2001	1	100	2	Yankee Creek Road crossing to mouth: 10.1 km
Elk Creek	7/1 to 8/31/2001	1	100	5	Confluence with Bitter Lick Creek to mouth: 22.5 km
Evans Creek/West Evans Creek	7/1 to 8/31/2003	1	100	5	West Fork Evans Creek near headwaters: 59.7 km
					Total Simulation Extent: 414.5 kilometers

Figure A10. Extent of modeled rivers and streams.



Simulation Accuracy

Error statistics were calculated for each calibrated model. Below are the equations used for each type of error statistic.

Mean Error: $$ME = \frac{1}{n}\sum X_{sim} - X_{obs}$$

Mean Absolute Error: $$MAE = \frac{1}{n}\sum \left| X_{sim} - X_{obs} \right|$$

Root Mean Square Error: $$RMSE = \sqrt{\frac{1}{n}\sum \left(X_{sim} - X_{obs} \right)^2}$$

Nash-Sutcliffe efficiency coefficient: $$E = 1 - \frac{\sum (X_{sim} - X_{obs})^2}{\sum (X_{sim} - \overline{X_{obs}})^2}$$

where,

X_{sim} = the simulated temperature;

X_{obs} = the observed or measured temperature;

$\overline{X_{obs}}$ = the mean of the observed or measured temperatures;

n = the sample size.

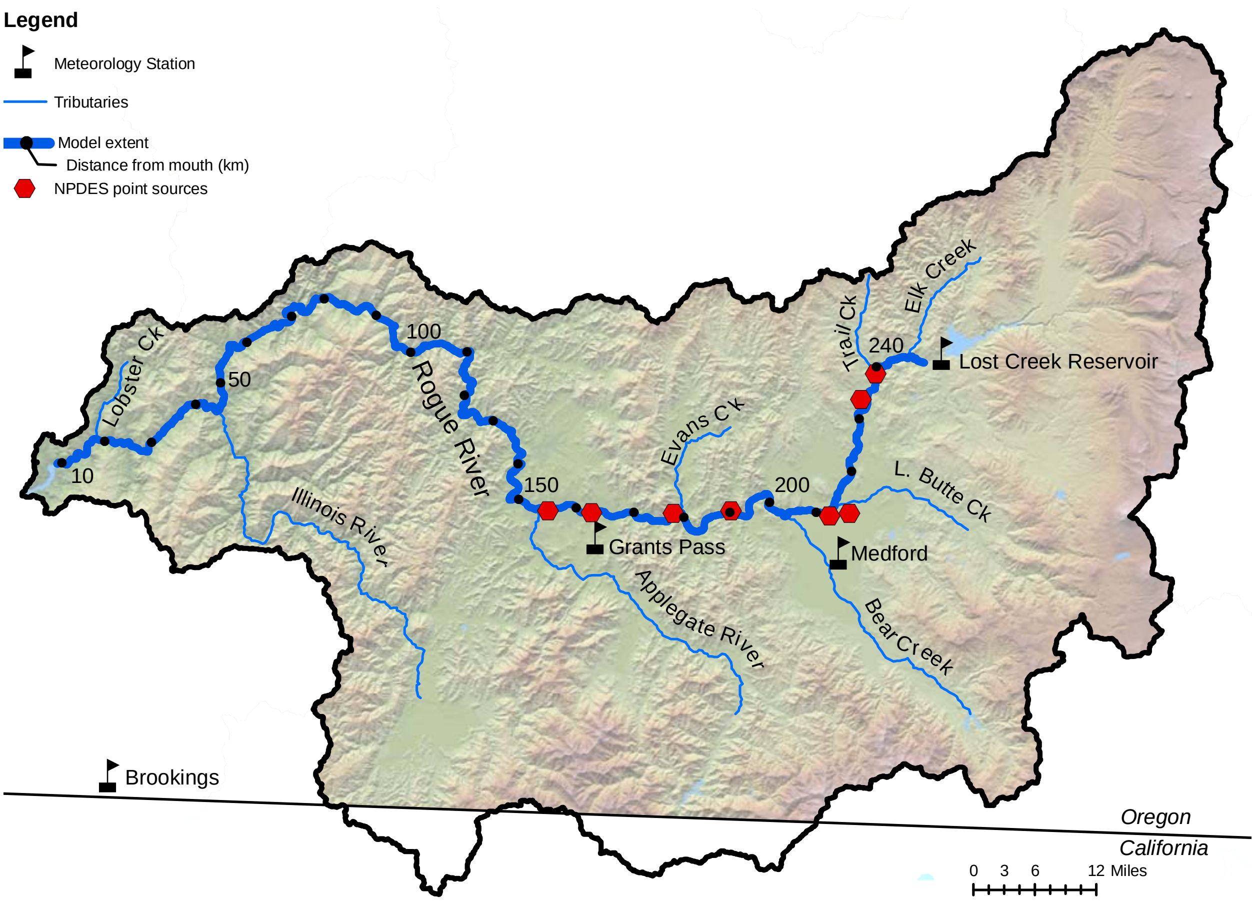
Error statistics were calculated for both the spatial (TIR) and temporal (hourly instream measurements) temperatures (specific stream discussions below follow).

4.2 Rogue River

Overview

Stream Name: Rogue River
Model: Heat Source version 8.0
Beginning date: 3/1/2003
Ending date: 10/31/2003
Time step: 1 minute
Distance step: 500 m
Extent: Upstream of estuary at river km 9.3 to downstream of Lost Creek Reservoir at river km 248.9 (**Figure A11**).

Figure A11. Rogue River model extent



The model year (2003) was chosen based on the availability of data, and the model period (March through October) was based on times when impairments are common. The model only represents a single year, and hence the flow regime and weather patterns of that year. Stream temperatures upstream of the Lost Creek Reservoir were generally warmer during the model year from May through October than the long term median temperatures (**Figure A12**). During the model period, flows were generally less than the long term median flows with some flows less than the 7Q10 (seven day average low flow period with a 10 year recurrence) (**Figure A13**). Using the 2003 model as a basis for scenarios will likely lead to a warmer prediction of NTP than if a year with more average conditions was used.

Figure A12. Comparison of observed river temperatures upstream of Lost Creek Reservoir

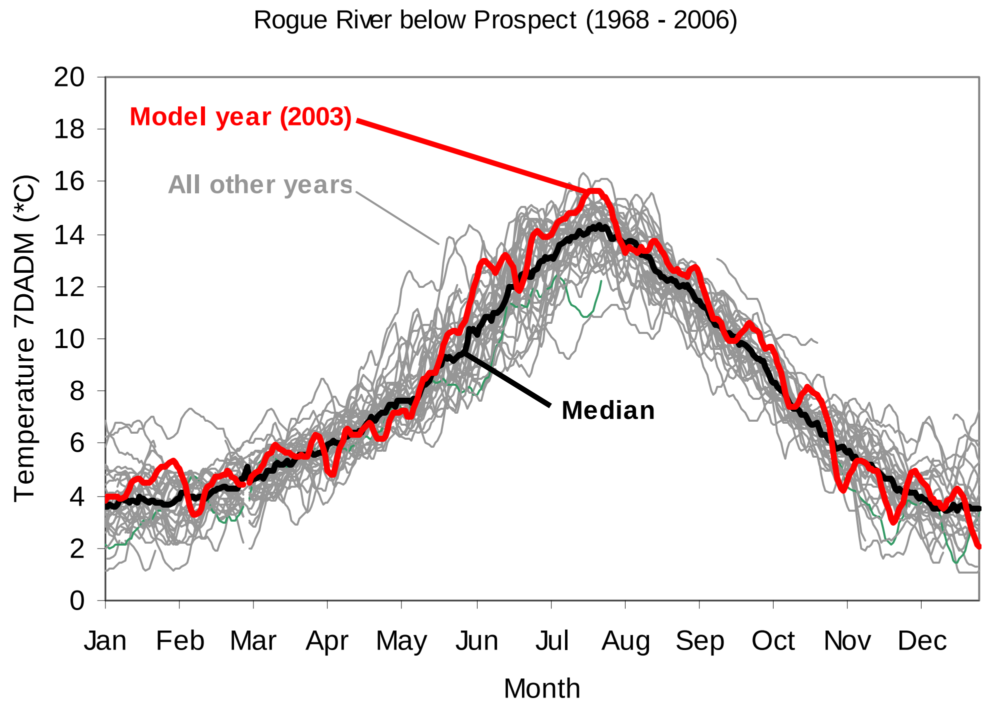
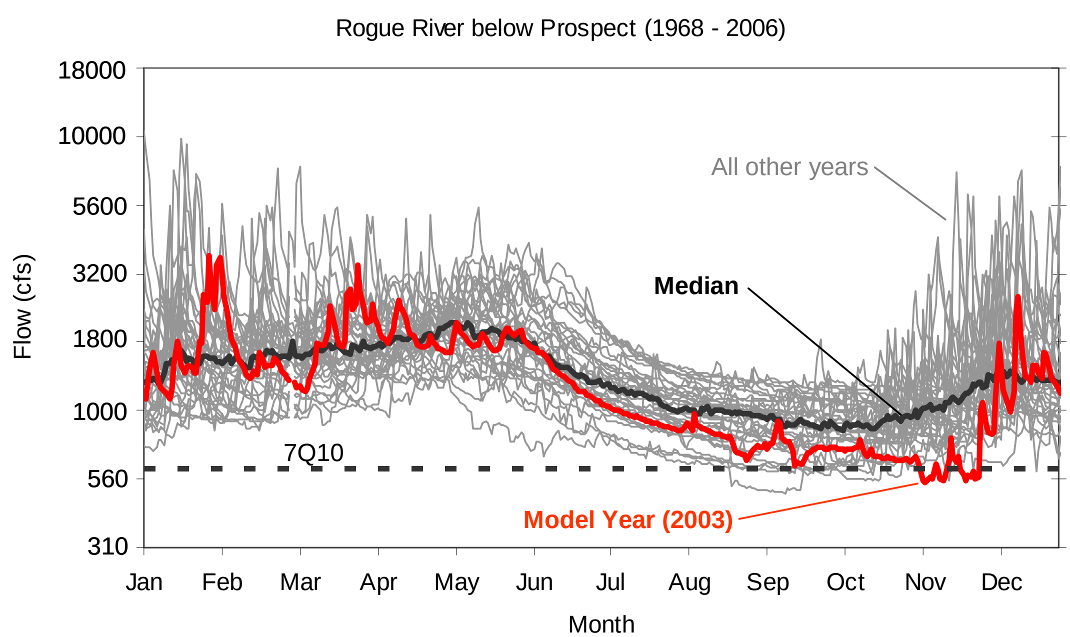


Figure A13. Comparison of observed river flow upstream of Lost Creek Reservoir



Model Inputs

Reach Properties

The channel properties were determined using the methodology documented previously in this report (see **Section 3**). **Figure A14** shows the elevation profile and reach gradient. The bottom width was derived using the active channel width measured from aerial photographs. Bottom width was estimated by assuming a trapezoidal channel with side slopes that are three times as long as they are high and also using a width-to-depth ratio of 100 (**Figure A15**). The width-to-depth ratio was based on measurements from the USGS gage sites. Non-spatially varying coefficients are presented in **Table A3**.

Manning's n was iteratively altered so that the model temperatures approximately reproduced measured temperatures. Since the model does not have the capability of representing dams, Manning's n was increased in the pooled area of each dam to represent a hydraulically equivalent reach (**Figure A16**). The temperature profile of Hellgate Canyon area was not initially represented using literature values for Manning's n. The morphology of the canyon is controlled by bedrock which forms deep pools. Again, Manning's n was increased to reproduce the observed temperature.

Topographic and riparian vegetation heights were determined through a GIS analysis (**Figure A17 -- Figure A19**). Shade measurements from the middle of the Rogue River were not available to corroborate the shade predicted using the channel and vegetation inputs.

Figure A14. Model setup channel elevation and gradient

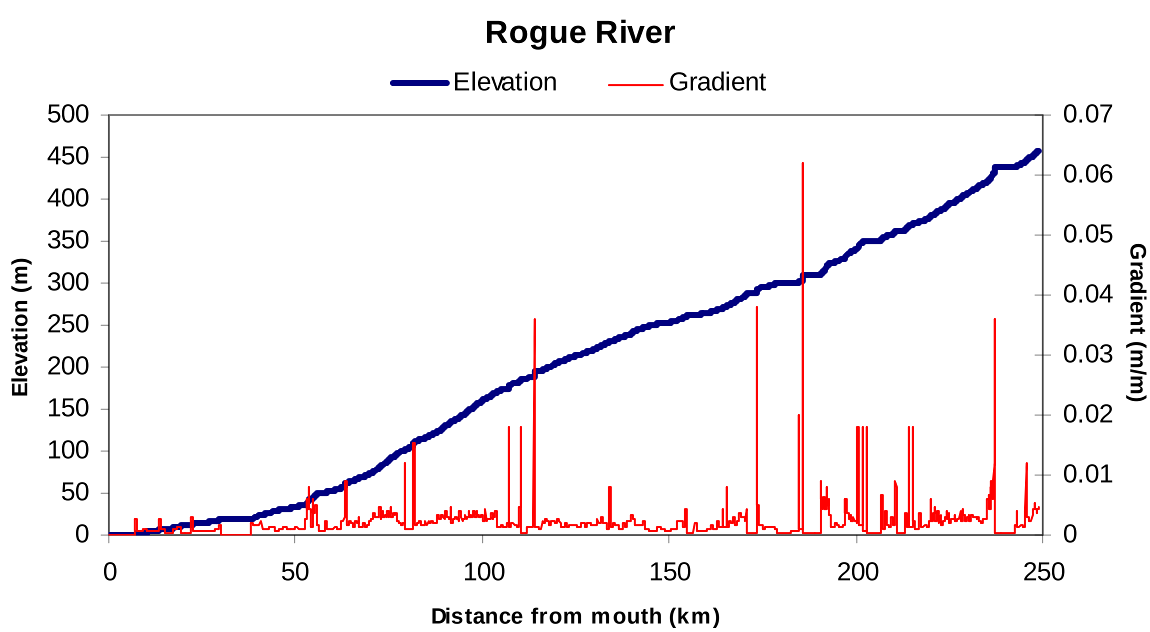


Figure A15. Model setup for channel bottom width

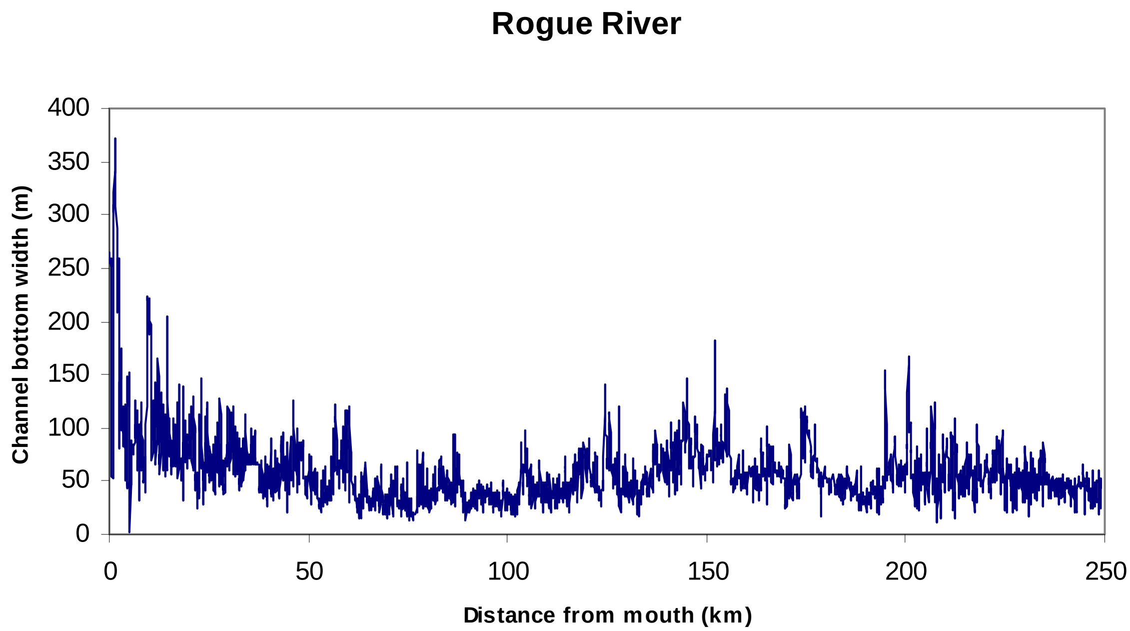


Table A3. Model coefficients for non-spatially varying parameters

Parameter name (units)	Value
Wind Function, coefficient a	1.51×10^{-9}
Wind Function, coefficient b	1.60×10^{-9}
Channel angle (ratio of transverse to vertical lengths)	3.0*
Sediment Thermal Conductivity (W/m/°C)	1.57
Sediment Thermal Diffusivity (cm^2/sec)	0.0064
Sediment / hyporheic zone thickness (m)	0.5
Percent Hyporheic Exchange	0%
Porosity	33%

* Except for the reach impact by Gold Ray dam in which channel angle = 6 to account for volume in side channels and back waters.

Figure A16. Model setup for roughness coefficient

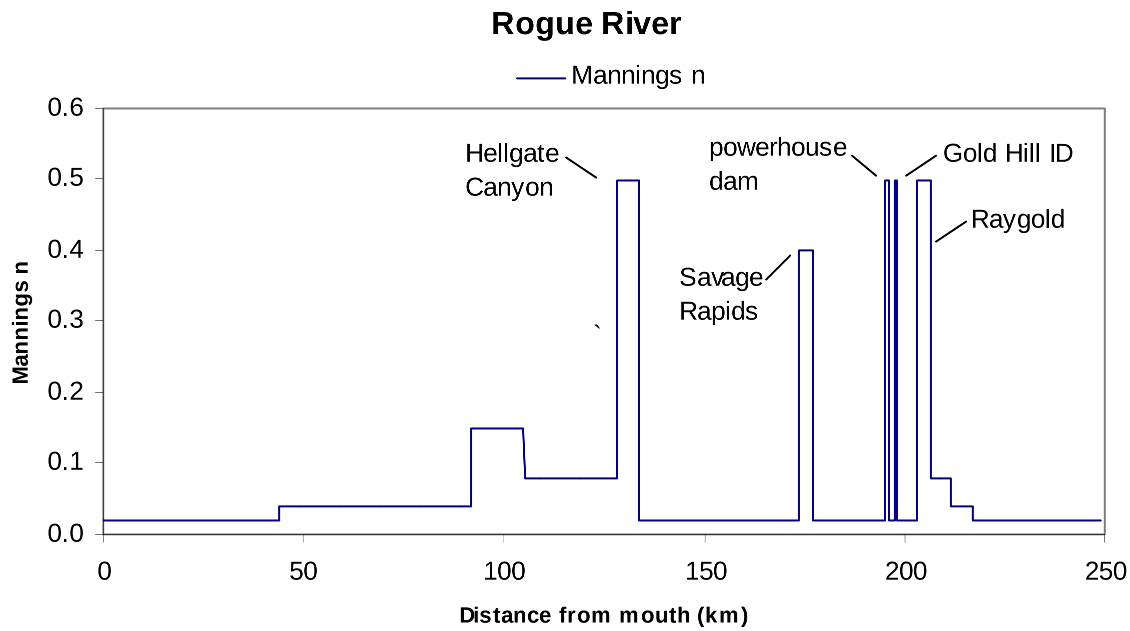


Figure A17. Model setup for topographic angle

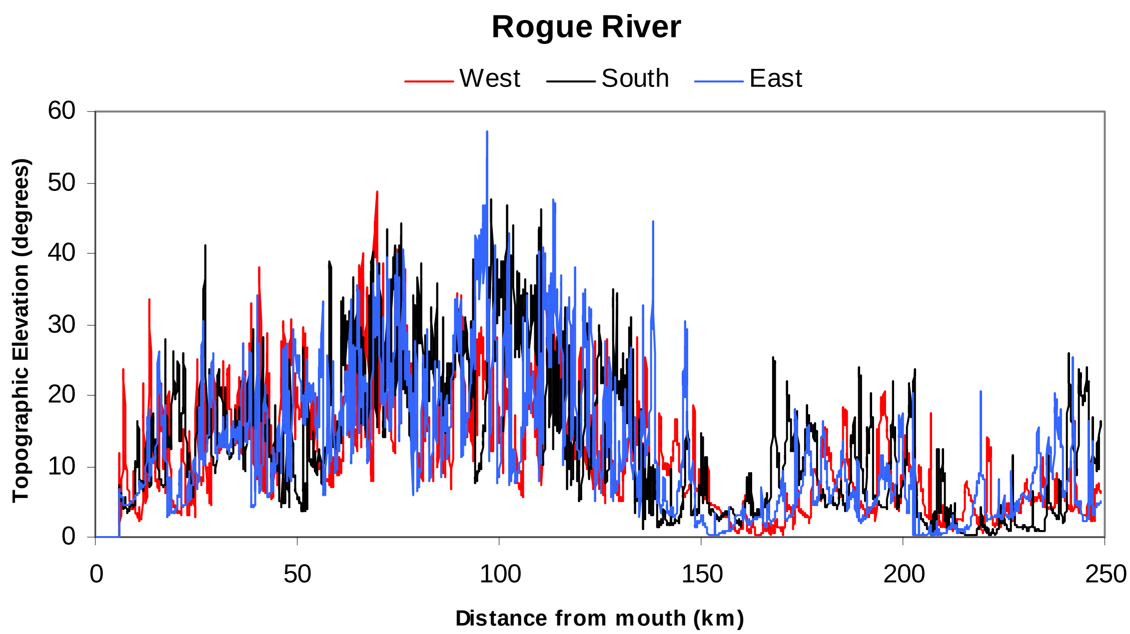


Figure A18. Model setup for height of streamside vegetation

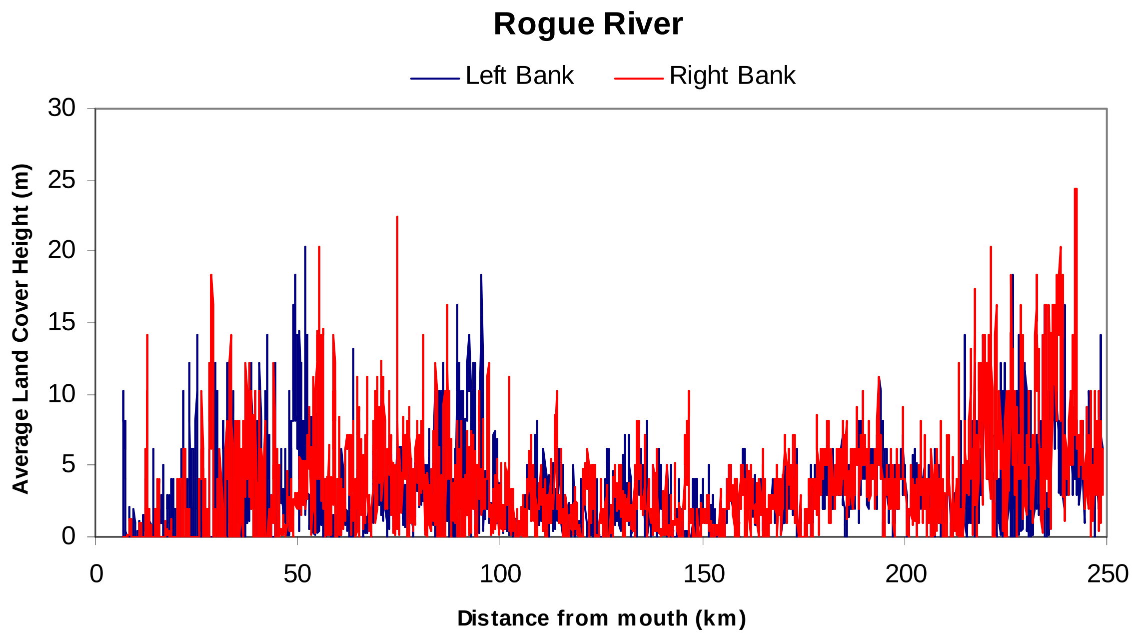
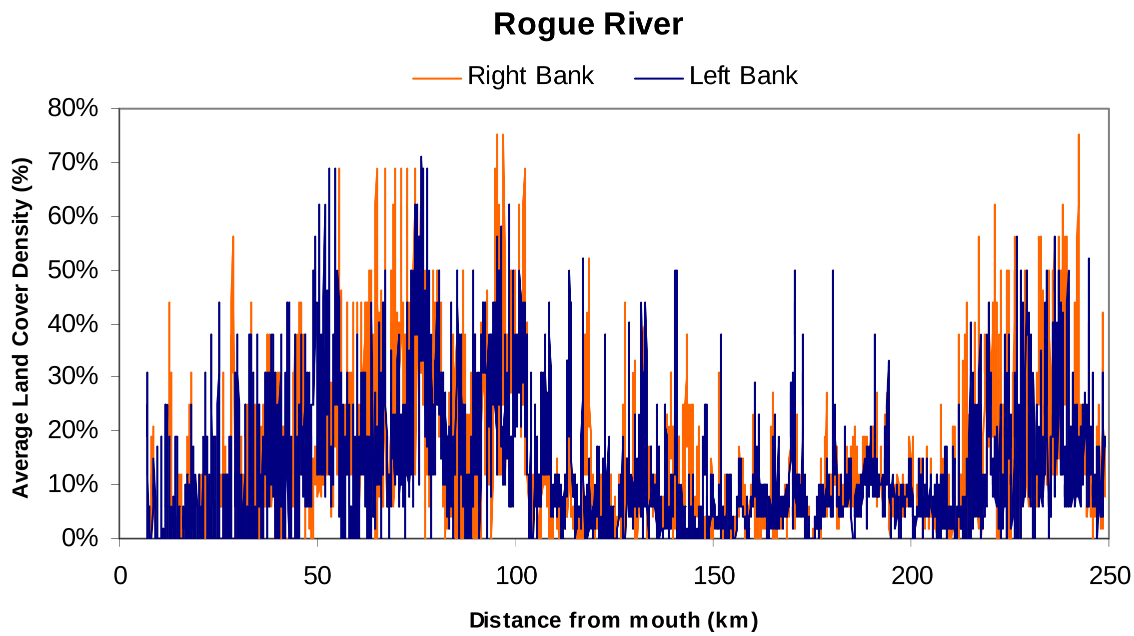


Figure A19. Model setup for density of streamside vegetation



Meteorology

The model used air temperature, relative humidity, wind speed and cloudiness from various sites (**Table A4 and Table A5**). The meteorological observations are presented in **Figure A20 - Figure A24**. A sine wave function was used to calculate hourly air temperatures for stations with only daily minimum and maximum air temperatures. At the Brookings station, cloudiness was calculated from solar radiation observations. The meteorological inputs varied by stream kilometer based on proximity to the weather station. A multiplicative wind sheltering coefficient was applied to the wind speed for calibration.

Table A4. Meteorological data sources

Site	Source	Meteorological Parameters
Medford Airport	NCDC	Cloudiness, wind speed, relative humidity, air temperature
Lost Creek Reservoir	US Army Corp of Engineers	Daily minimum and maximum temperature
Grants Pass	Oregon Climate Service	Daily minimum and maximum temperature
Brookings	Agrimet	Solar radiation, wind speed, relative humidity, air temperature

Table A5. Data inputs to Rogue River model by river km

Range (river km)	Cloudiness	Relative Humidity	Air Temperature	Wind Speed	Wind sheltering Coefficient
249 - 210	Medford	Medford	Lost Creek *	Medford	0.0
210 - 203	Medford	Medford	Medford	Medford	0.0
203 - 119	Medford	Medford	Grants Pass**	Medford	0.0
119 - 55	Medford	Medford	Grants Pass**	Medford	0.25
55 - 0	Brookings	Brookings	Brookings	Brookings	0.5

*missing data filled in with Medford data.
**missing data filled in with a regression with Medford
.

Figure A20. Cloudiness data used in model setup. The intervals are a residual from reported measurements at the Medford station.

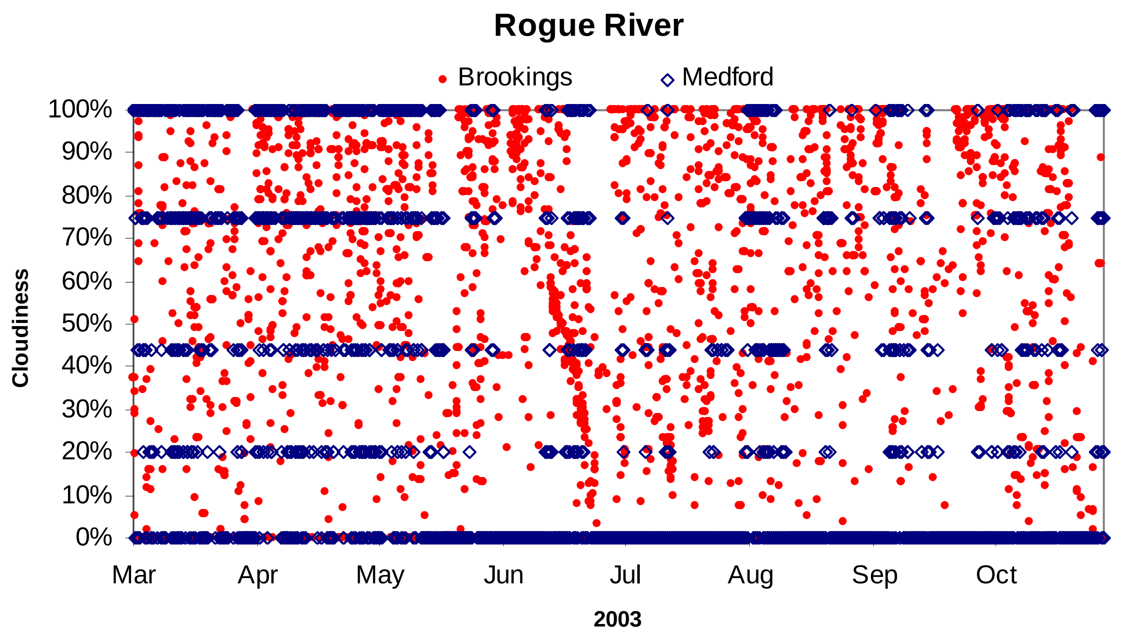


Figure A21. Wind speed data used in model setup

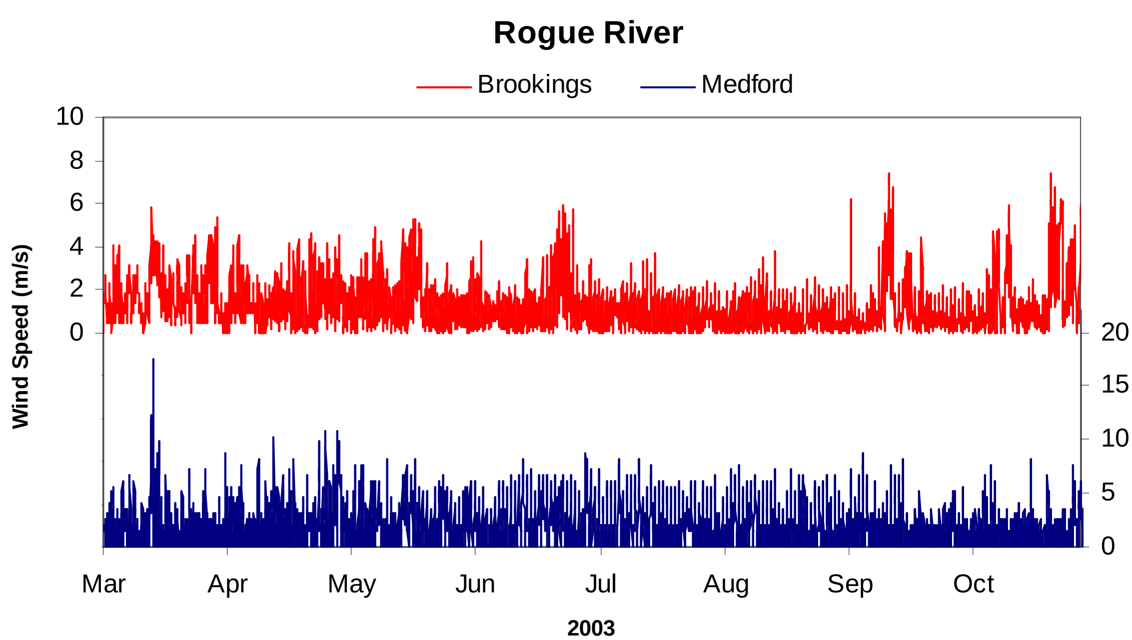


Figure A22. Relative humidity data used in model setup

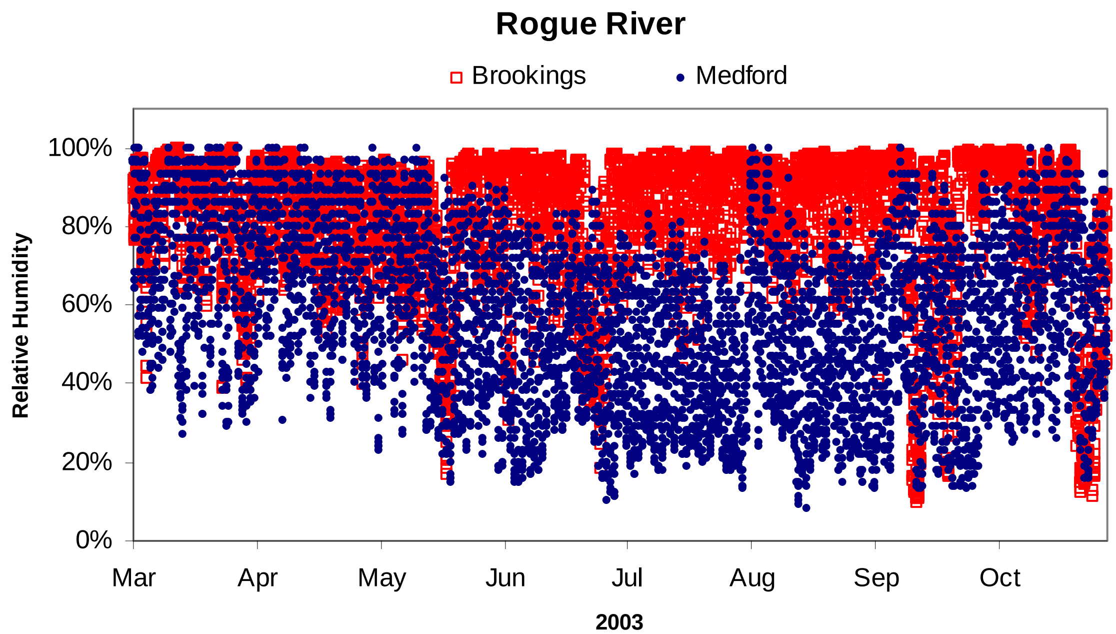


Figure A23. Air temperature used in model setup (1 of 2)

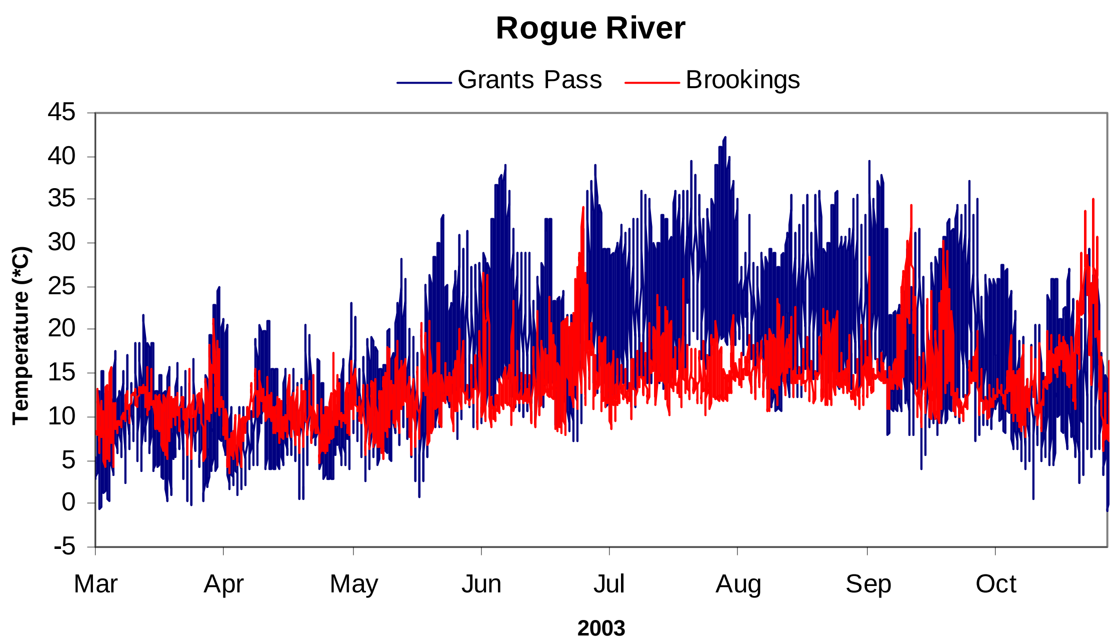
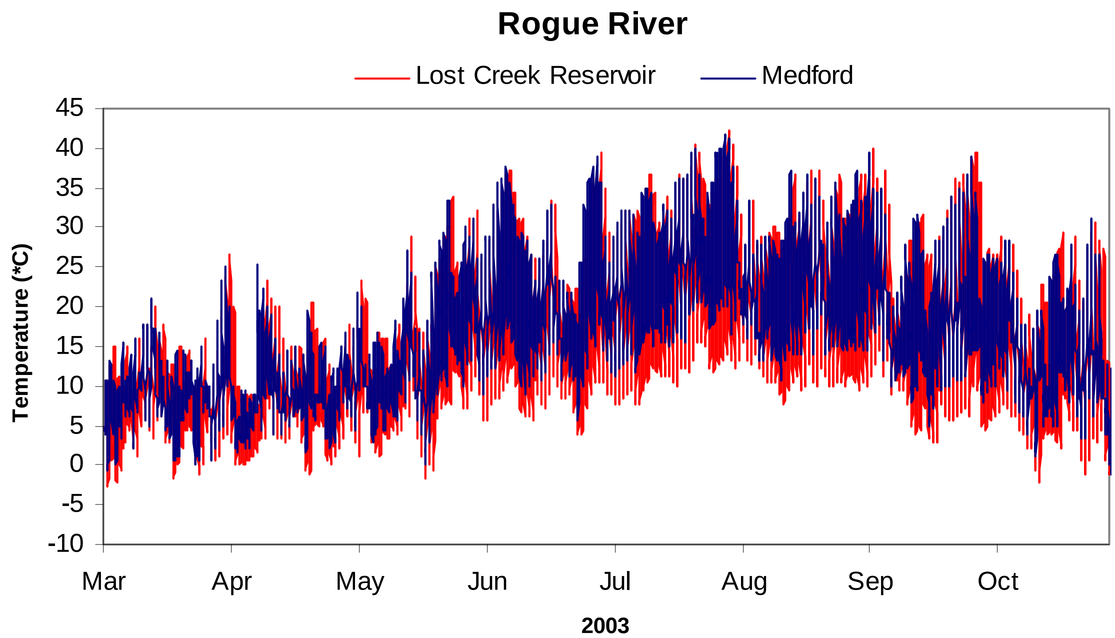


Figure A24. Air temperature used in model setup (2 of 2)



Flow

Discharge inputs at the model headwater (Rogue River near McLeod) and tributaries used field measurements when available and relationships with other gages were used otherwise (**Table A6** and **Figure A25**). At three locations, additional flow and / or withdrawal was necessary to reproduce observed flows (**Figure A26** and **Table A6**). The discharge rates of the eight NPDES point sources were based on discharge monitoring reports (**Figure A27 & Figure A28**). Maximum consumptive use is based on information provided by Oregon Water Resources Department (**Figure A29**). The temporal component of consumptive use was estimated based on the irrigation season. Using these flow inputs, the performance of the Rogue River model at several locations is shown in **Figure A30, a-e**.

Table A6. Source of flow information for the Rogue River model

Inflow	Stream km	Source
Headwater: Rogue River at McLeod	249	USGS gage
Elk Creek	245.1	USGS gage at river mile 0.5
Trail Creek	239.8	No gage, used ratio of drainage area with Elk Creek (0.442) to compute flow
Little Butte Creek	213.5	No current gage, used regression with Elk Creek 1945 - 1950, historic gage below Eagle Creek
Bear Creek	203.8	USGS gage at river mile 10.1
Derived flow (d/s of Bear Creek)	200	Added to reproduce observed flows at USGS gage near Grants Pass (rKM 164.8)
Derived flow (at Evans Creek)	178.8	No gage on Evans Creek, mass balance to derive using the Grants Pass gage (rKM 164.8)
Applegate River	153.3	USGS gage at RM 7.6 (near Wilderville)
Derived Flow (at Foster Creek)	55.1	No gage on Foster Creek, added to reproduce observed flows at USGS gage near Agness
Illinois River	44.5	Used regression between Illinois River near Kerby (rm 50) and Illinois R. near Agness (river mile 5) between 1961 and 1983
Lobster Creek	18.4	No gage, used ratio of drainage area with South Fork Coquille River at Powers (0.41) to compute flow

Figure A25. Tributary flow boundary conditions

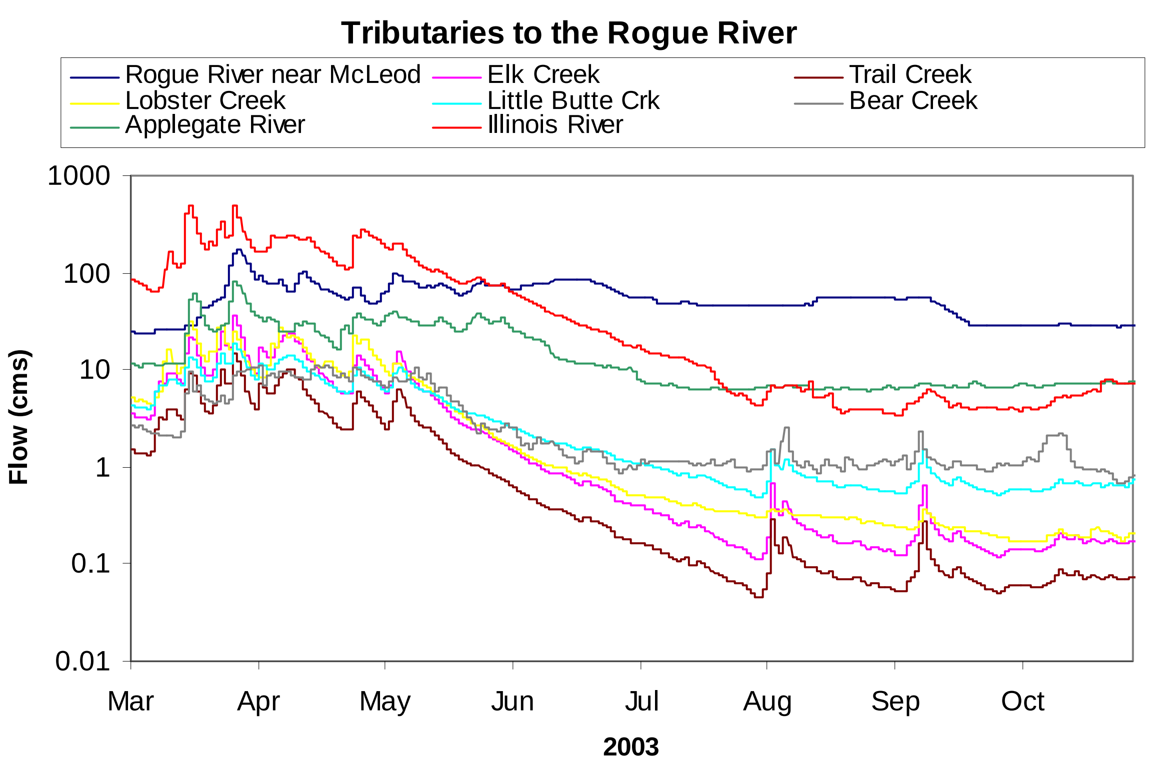


Figure A26. Derived tributary flow boundary conditions based on mass balance with mainstem gages

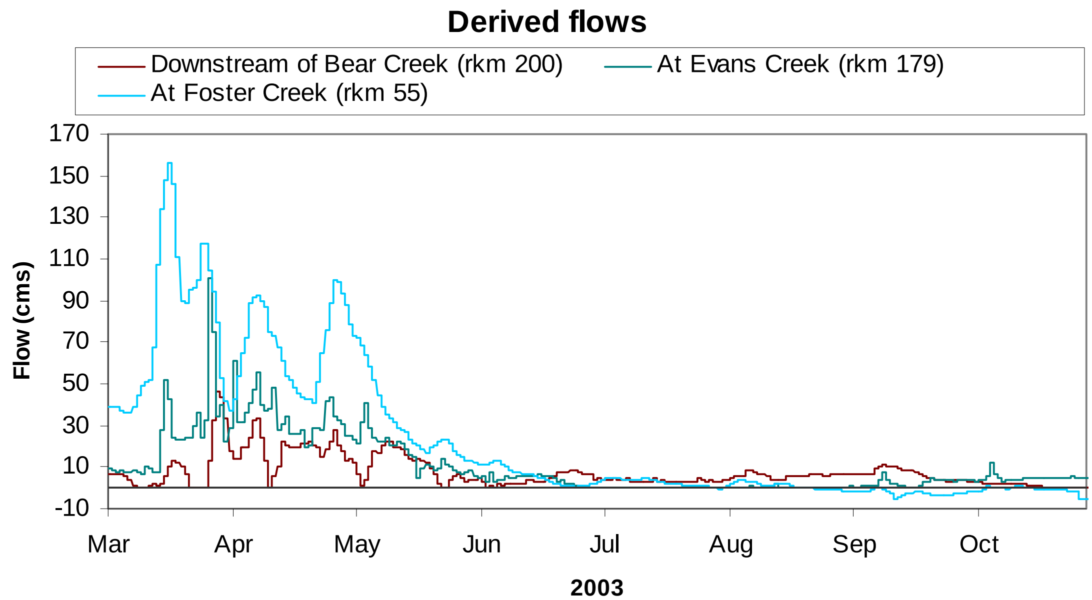


Figure A27. Point sources flow of the two larger sources

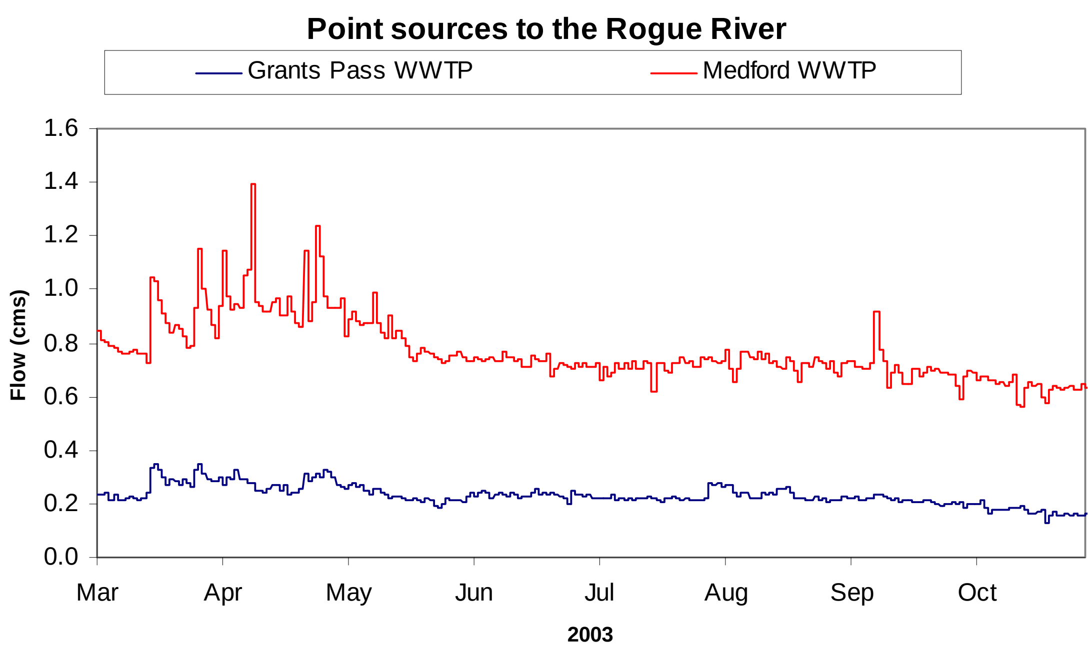


Figure A28. Point sources flow of the six smaller sources

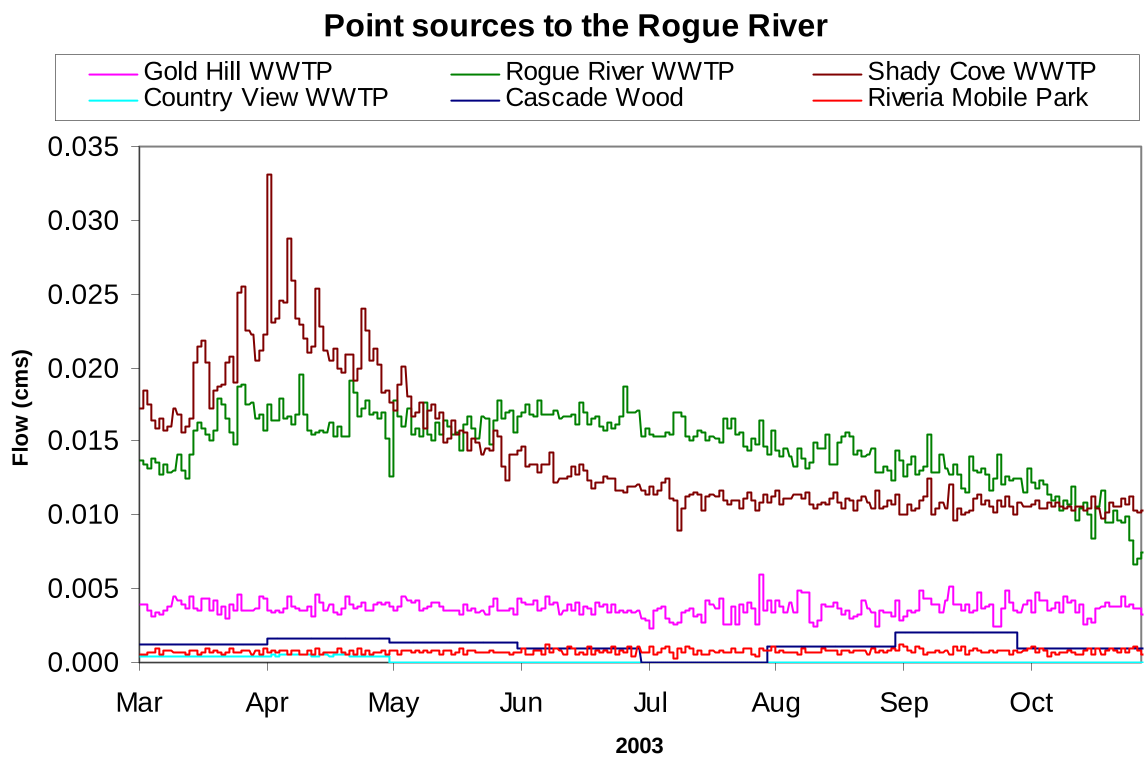


Figure A29. Water withdrawals from model reach and Big Butte Creek

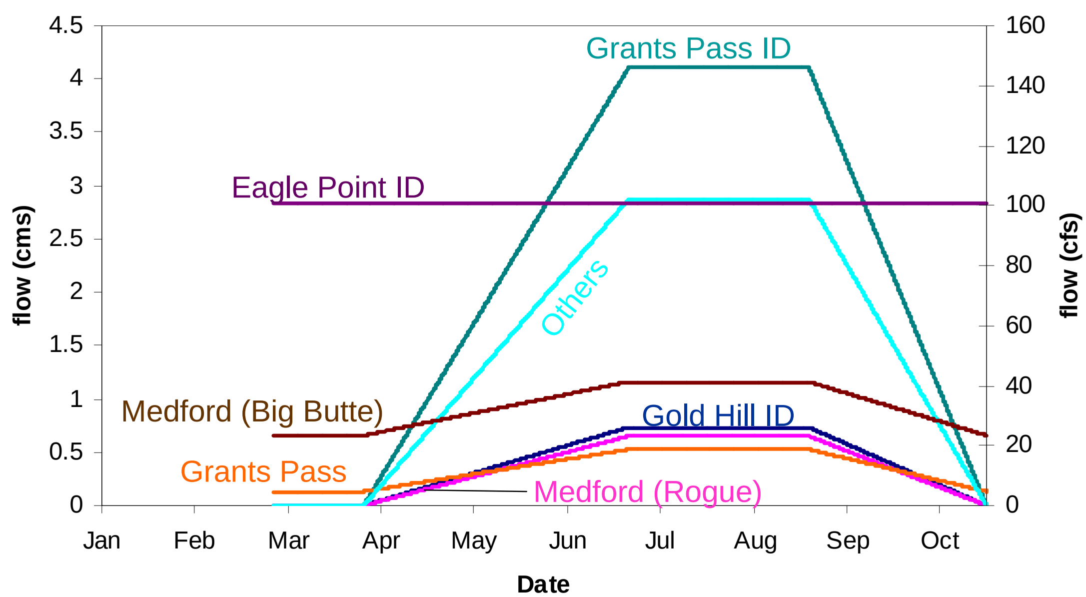


Figure A30, a-e. Flow Calibration

Figure A30-a

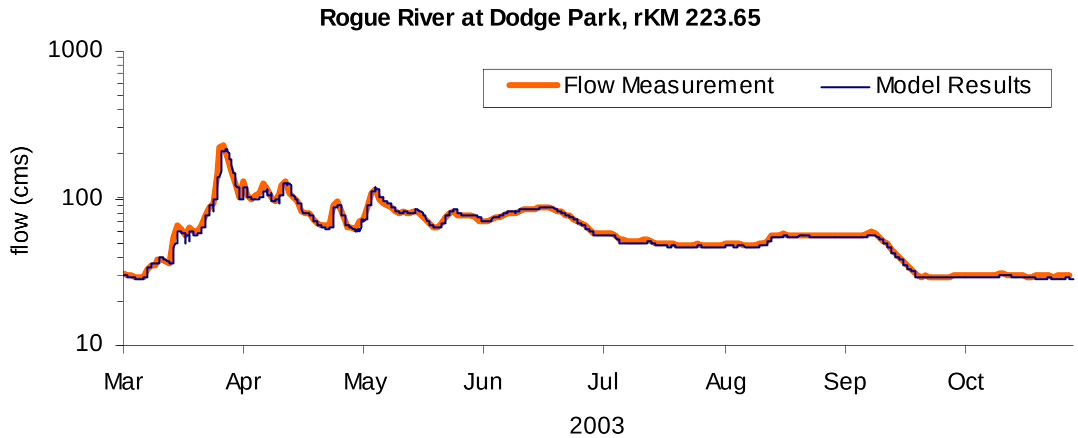


Figure A30-b

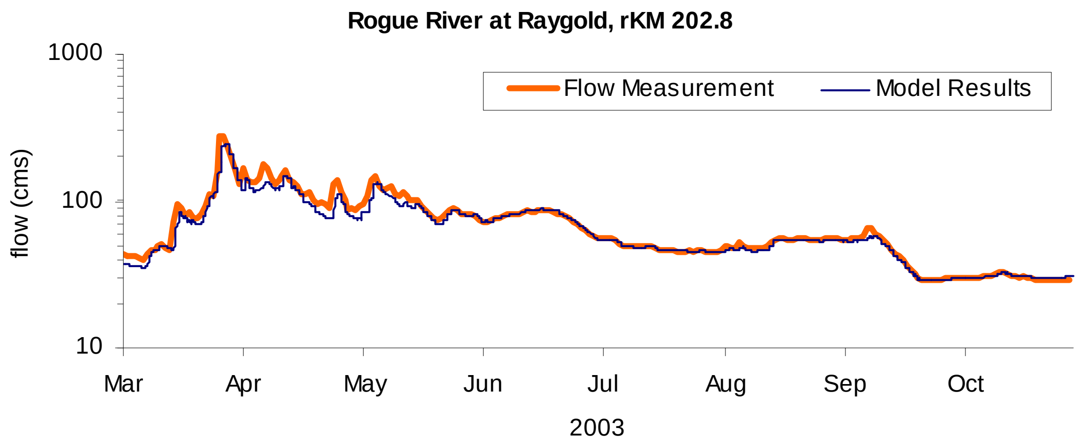


Figure A30-c

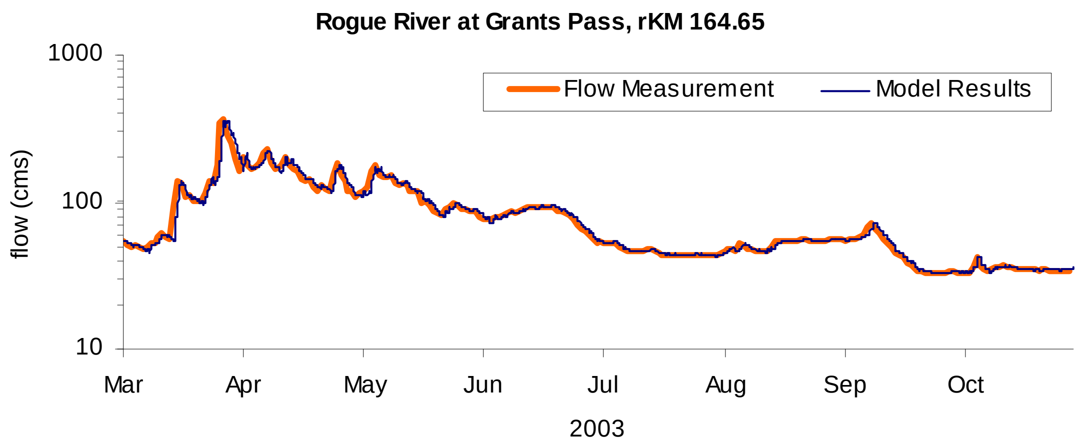


Figure A30-d

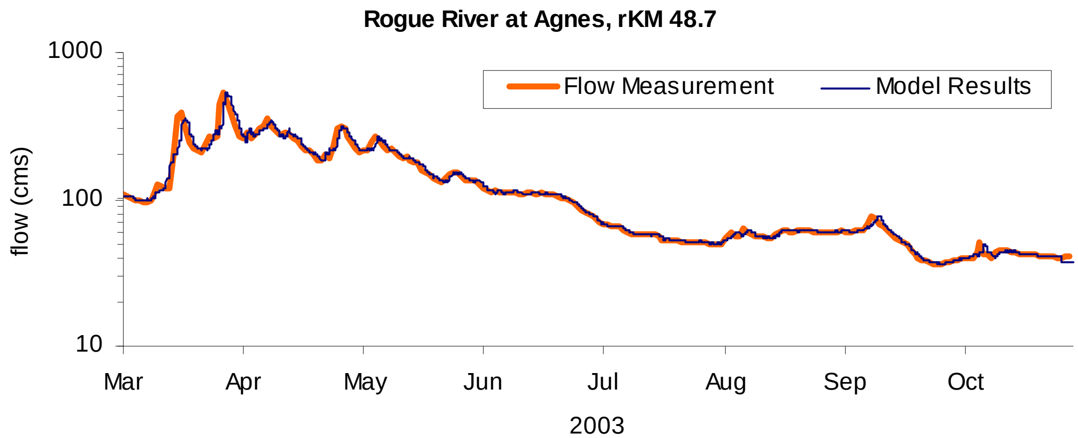
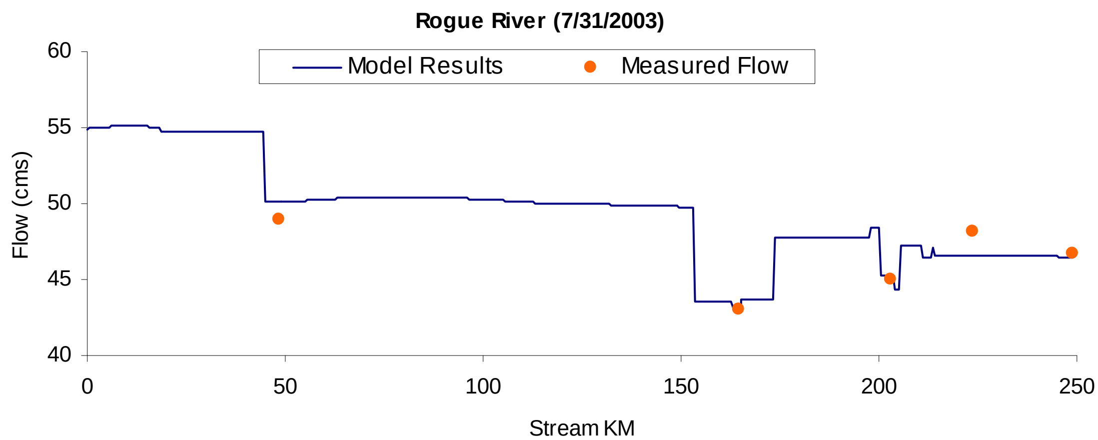


Figure A30-e



Temperature

Table A7 and **Table A8** and **Figure A31 & Figure A32** document the temperature inputs at the model headwaters (Rogue River near McLeod) and of the tributaries and the NPDES point sources in the model. Cascade Wood discharges into Military Slough. In the current condition model, Military Slough is represented with a 0.0283 cms flow and temperature the same as Little Butte mixed with the effluent from Cascade Wood.

Table A7. Source of tributary and boundary condition temperature inputs to Rogue River model.

Inflow Temperature	Stream km	Source
Headwater: Rogue River at McLeod	249	USGS data
Elk Creek	245.1	USGS data
Trail Creek	239.8	DEQ data at mouth (site # 24477) for 5/7 - 9/16, used linear regression Elk Creek for other times.
Little Butte Creek	213.5	DEQ data from 5/7 – 6/30 (site # 10602), Medford Water Commission data from 7/1 – 9/15, linear regression with Elk Creek otherwise.
Bear Creek	203.8	No data from 2003, used Little Butte Creek as surrogate.
Derived flow (downstream of Bear Creek)	200	Used data from Big Butte Creek (Medford Water Commission and regression with Elk Creek, with a minimum of 5 °C)
Derived flow (at Evans Creek)	178.8	DEQ data at mouth of Evans Creek (site # 11372) from 4/23 – 9/16, otherwise regression with Applegate.
Applegate River	153.3	USGS data
Derived Flow (at Foster Creek)	55.1	DEQ data at mouth of Foster Creek (site # 30369) from 7/11 – 9/24, otherwise used Evans Creek.
Illinois River	44.5	DEQ data at mouth from 7/17 – 10/13 (site # 10425), otherwise regression with Applegate.
Lobster Creek	18.4	DEQ data at mouth from 7/17 – 10/13 (site # 30194), otherwise same as Illinois River.

Table A8. Source of NPDES temperature inputs to Rogue River model

Inflow Temperature	Stream km	Source
Country View WWTP	238.6	No data, used Shady Cove as surrogate
Shade Cove WWTP	233.6	Daily grab temperature from DMR
Cascade Wood (Military Slough at RM 1.6)	213.3	Monthly grab data from DMR
Medford WWTP	210.6	Hourly data provided by source.
Gold Hill WWTP	190.2	Daily grab temperature from DMR
Rogue River WWTP	178.0	Daily grab temperature from DMR
Grants Pass WWTP	162.8	Daily grab temperature from DMR
Riveria Mobile Park	155.2	Daily grab temperature from DMR

Figure A31, a-b. Temperature inputs of tributaries to the Rogue River model

Figure A31-a

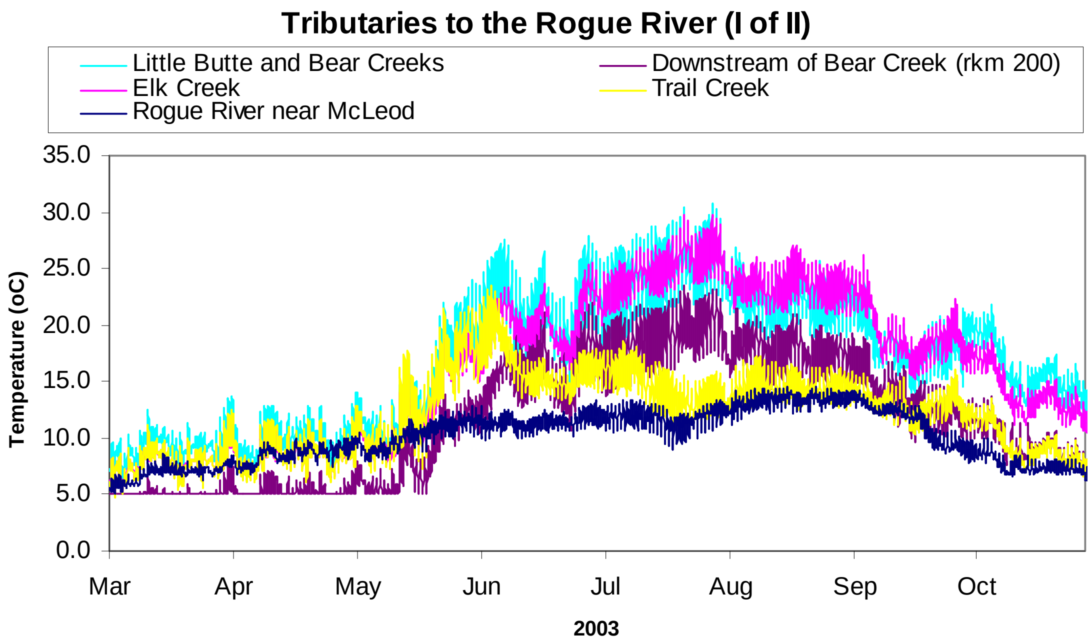


Figure A31-b

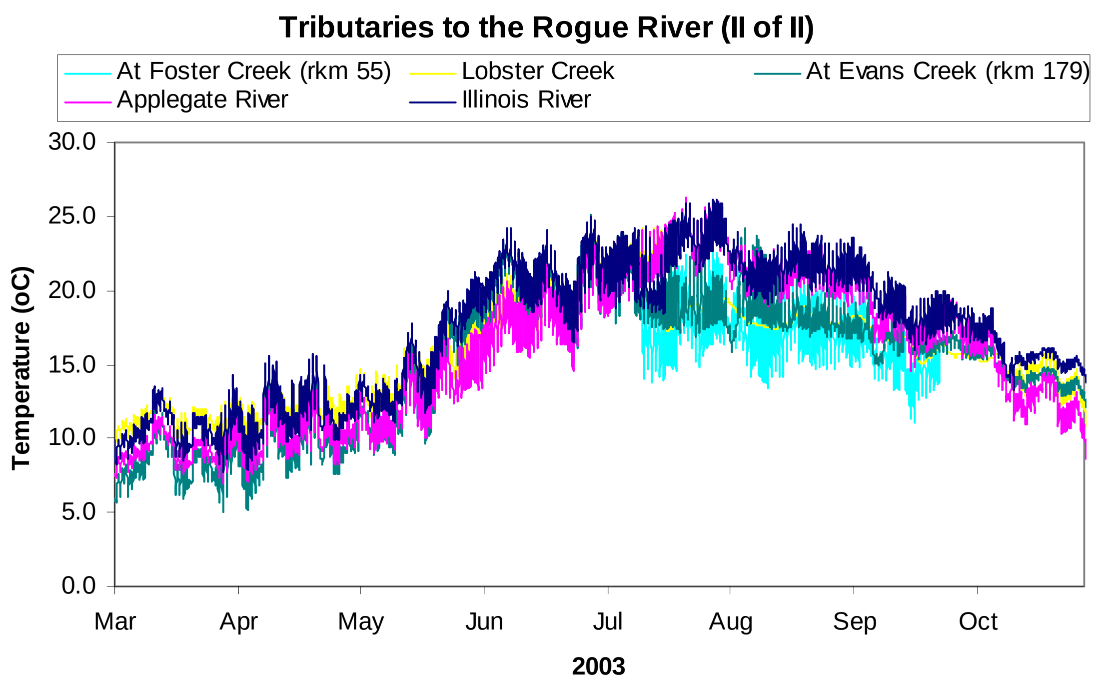
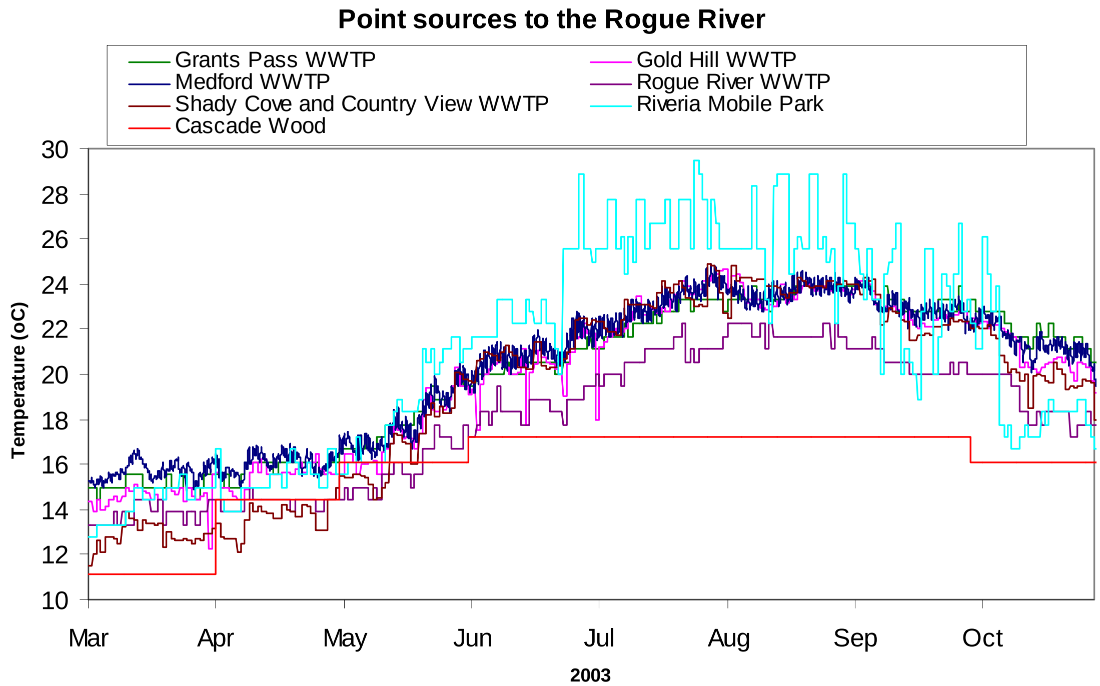


Figure A32. Temperature inputs of point sources to the Rogue River model



Temperature Calibration

The model outputs generally reproduced spatially and temporally varying temperature measurements (**Table A9 -- Table A11 and Figure A33 -- Figure A35**). See previous statistics discussion at the beginning of **Section 4** for definitions.

Table A9. Continuous monitoring error statistics. Headwaters not included in averaging.

Site Name	Source	Site #	rKM	n	Mean Error	Abs Mean Error	RMSE	Nash-Sutcliffe
Rogue River near McLeod (headwaters)	USGS	14337600	248.9	5874	0.00	0.00	0.00	1.00
Rogue River @ Shady Cove Park	DEQ	30517	235.6	3166	-0.02	0.25	0.32	0.96
Rogue River @ Dodge Bridge	USGS	14339000	223.9	5829	-0.16	0.55	0.70	0.95
Rogue River @ Dodge Park	DEQ	10423	223.8	3069	-0.24	0.60	0.75	0.88
Rogue River u/s Medford WWTP	Medford	na	211.0	4581	-0.45	0.76	0.96	0.91
Rogue River d/s of Medford WWTP	DEQ	30317	208.5	5879	-0.35	0.61	0.78	0.95
Rogue River @ Raygold	USGS	14359000	202.7	5830	-0.23	0.57	0.71	0.94
Rogue River @ d/s Gold Ray Dam	DEQ	30195	202.6	2122	-0.51	0.93	1.21	0.81
Rogue River @ Highway 234	DEQ	10421	189.2	3140	-0.26	0.83	1.02	0.82
Rogue River @ Valley of the Rogue	DEQ	10600	182.8	3266	-0.22	0.72	0.89	0.88
Rogue River @ Robertson Bridge	DEQ	10418	140.1	2531	-0.52	0.67	0.83	0.92
Rogue River d/s of Galice Creek	DEQ	30211	126.9	2458	-0.34	0.74	0.96	0.90
Rogue River d/s of Graves Creek	DEQ	10417	110.5	3352	-0.23	0.67	0.83	0.92
Rogue River d/s of Whiskey Creek	DEQ	30570	105.7	1822	0.44	0.65	0.85	0.82
Rogue River d/s of Meadow Creek	DEQ	30641	92.0	1823	0.17	0.60	0.77	0.86
Rogue River d/s of East Creek	DEQ	30647	68.2	1824	0.29	0.63	0.77	0.86
Rogue River d/s of Fall Creek	DEQ	30646	61.5	1822	0.14	0.53	0.67	0.90
Rogue River near Agness	USGS	14372300	48.7	5880	-0.08	0.58	0.72	0.98
Rogue River d/s Shasta Costa Creek	DEQ	30654	47.4	2111	0.29	0.57	0.73	0.92
Rogue River u/s of Illinois River	DEQ	10416	44.9	2111	0.07	0.53	0.68	0.94
Rogue River d/s of Illinois River	DEQ	10415	44.5	2111	-0.01	0.54	0.68	0.93
Rogue River u/s of Lobster Creek	DEQ	10414	18.7	2110	0.00	0.77	0.93	0.86
Rogue River @ Huntley Park	DEQ	10413	14.3	169	0.54	0.67	0.78	0.09
Average					-0.08	0.63	0.80	0.86

Table A10. Continuous monitoring error statistics for July and August.

		All data					Daily Maximums			
Site Name: Number	rKM	n	Mean Error	Abs Mean Error	RMSE	Nash-Sutcliffe	n	Mean Error	Abs Mean Error	RMSE
Rogue River near McLeod (headwaters)	248.9	1488	0.00	0.00	0.00	1.00	62	0.00	0.00	0.00
Rogue River @ Shady Cove Park	235.6	1488	-0.11	0.30	0.37	0.94	62	0.00	0.21	0.33
Rogue River @ Dodge Bridge	223.9	1475	-0.45	0.75	0.90	0.79	62	-0.38	0.55	0.70
Rogue River @ Dodge Park	223.8	1488	-0.36	0.76	0.91	0.79	62	-0.19	0.43	0.64
Rogue River u/s Medford WWTP	211.0	609	-0.90	1.15	1.35	0.43	26	-0.18	0.39	0.50
Rogue River d/s of Medford WWTP	208.5	1488	-0.75	0.88	1.07	0.68	62	-0.04	0.33	0.51
Rogue River @ Raygold	202.7	1488	-0.19	0.55	0.70	0.38	62	0.06	0.28	0.39
Rogue River @ d/s Gold Ray Dam	202.6	994	-0.79	1.26	1.54	-0.78	42	-1.31	1.31	1.38
Rogue River @ Highway 234	189.2	1370	-0.31	0.76	0.94	-0.88	58	0.37	0.44	0.56
Rogue River @ Valley of the Rogue	182.8	1275	-0.26	0.60	0.77	0.45	54	0.30	0.46	0.65
Rogue River @ Robertson Bridge	140.1	971	-0.46	0.65	0.84	0.75	41	-0.43	0.50	0.61
Rogue River d/s of Galice Creek	126.9	976	-0.39	0.61	0.77	0.56	41	-0.23	0.47	0.60
Rogue River d/s of Graves Creek	110.5	1488	-0.24	0.56	0.69	0.64	62	0.19	0.45	0.57
Rogue River d/s of Whiskey Creek	105.7	1281	0.29	0.55	0.71	0.61	54	0.84	0.86	0.98
Rogue River d/s of Meadow Creek	92.0	1260	0.00	0.53	0.66	0.71	53	0.44	0.46	0.60
Rogue River d/s of East Creek	68.2	1237	0.15	0.57	0.70	0.55	52	0.50	0.55	0.69
Rogue River d/s of Fall Creek	61.5	1234	-0.01	0.46	0.59	0.72	52	0.27	0.38	0.50
Rogue River near Agness	48.7	1488	-0.01	0.49	0.61	0.82	62	-0.58	0.69	0.77
Rogue River d/s Shasta Costa Creek	47.4	1094	0.28	0.53	0.67	0.75	46	-0.09	0.52	0.67
Rogue River u/s of Illinois River	44.9	1093	-0.01	0.46	0.59	0.83	46	-0.34	0.57	0.67
Rogue River d/s of Illinois River	44.5	1093	0.02	0.50	0.63	0.81	46	-0.23	0.57	0.70
Rogue River u/s of Lobster Creek	18.7	1091	0.15	0.78	0.94	0.31	46	0.61	0.83	0.99
Rogue River @ Huntley Park	14.3	169	0.54	0.67	0.78	0.09	8	0.72	0.72	0.90
Average			-0.17	0.65	0.81	0.50		0.01	0.55	0.68

Table A11. TIR error statistics

Error type	value
mean	-0.11
Absolute mean	0.50
Root mean square	0.63
Nash-Sutcliffe	0.97

Figure A33. Longitudinal profile of measured temperatures using Thermal Infrared Radiometry and model results

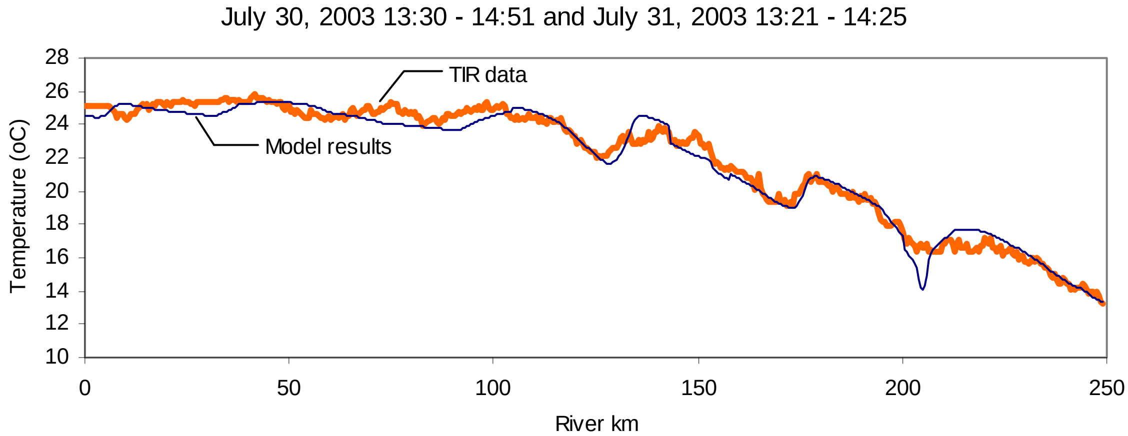


Figure A34, a-tt. Measurements versus model results for entire model period and between July and August for added detail during the critical season. Graphs are in order of upstream to downstream. The first set is the headwater boundary condition.

Figure A34-a

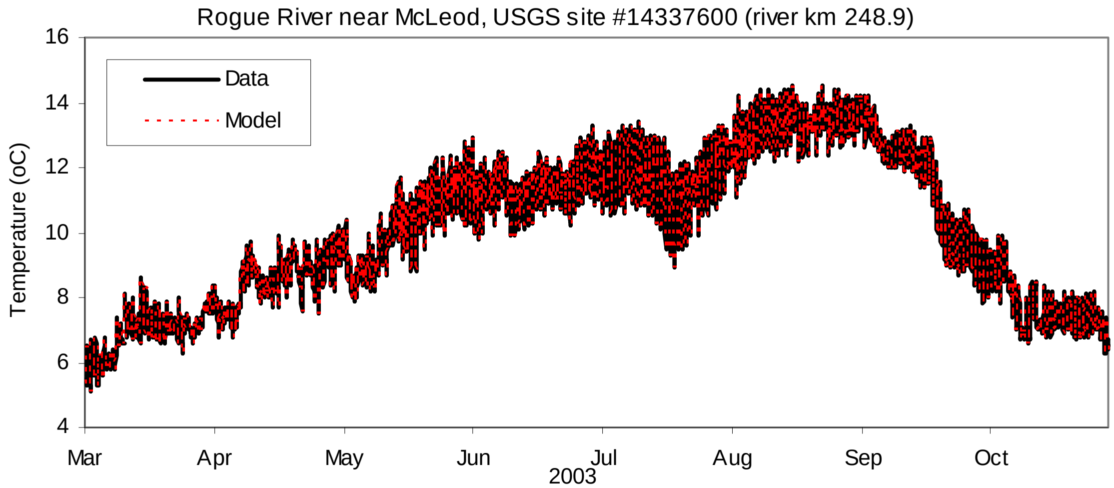


Figure A34-b

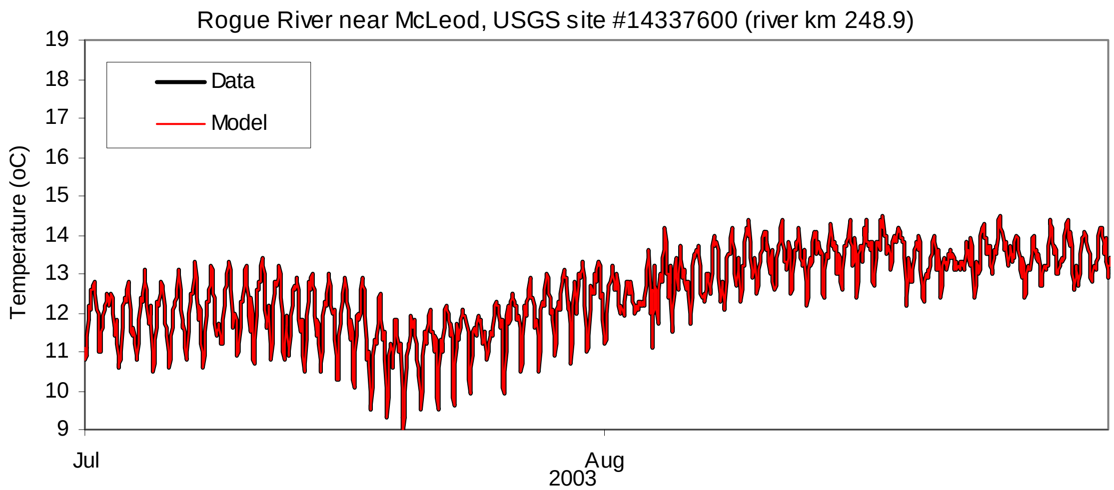


Figure A34-c

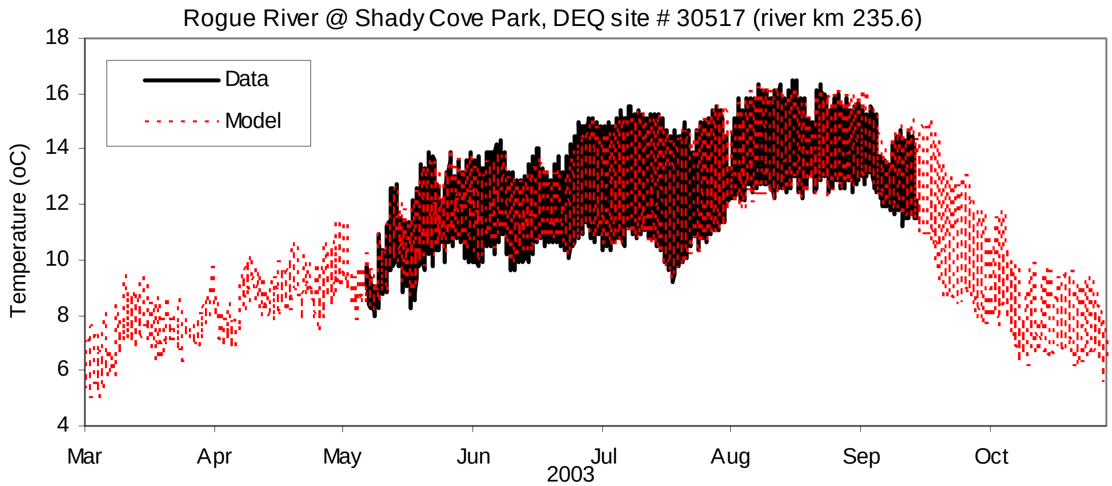


Figure A34-d

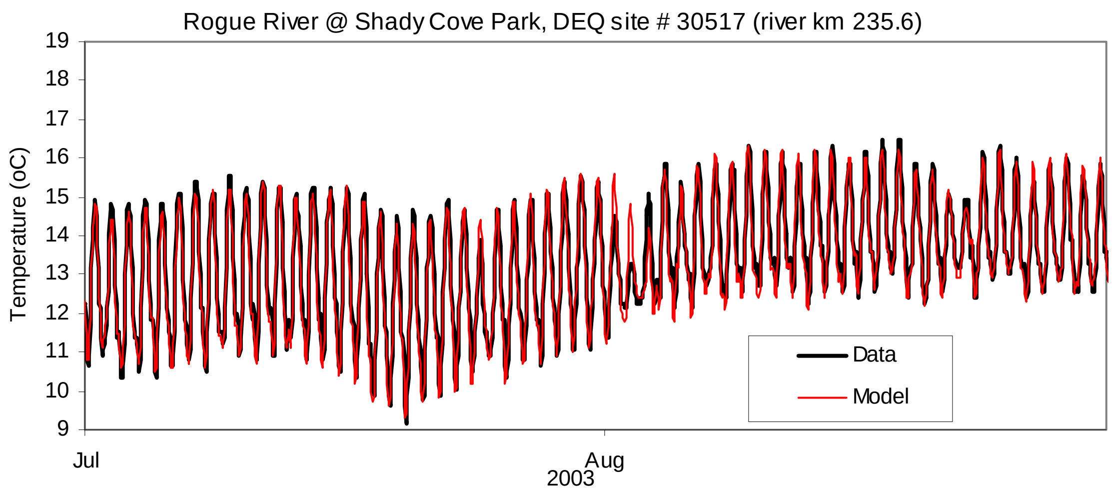


Figure A34-e

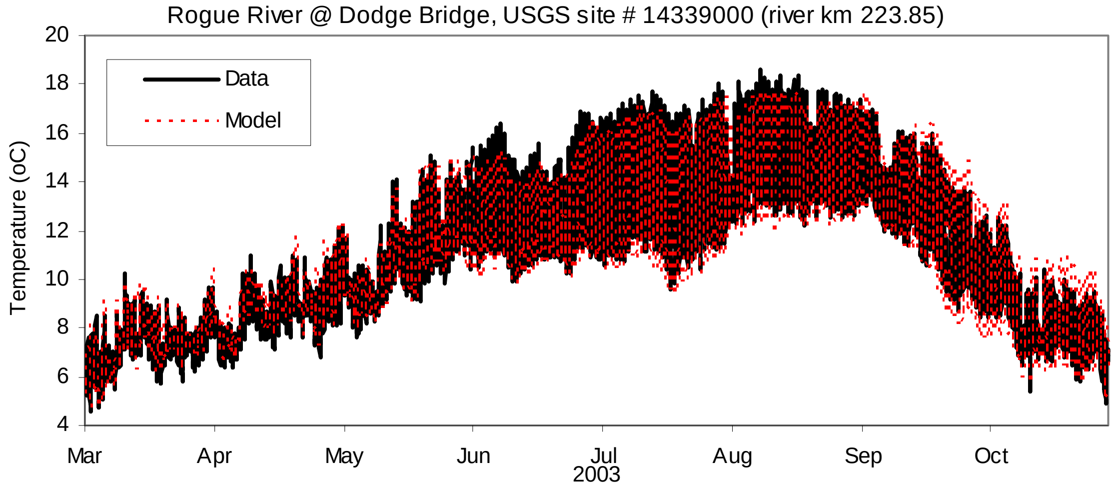


Figure A34-f

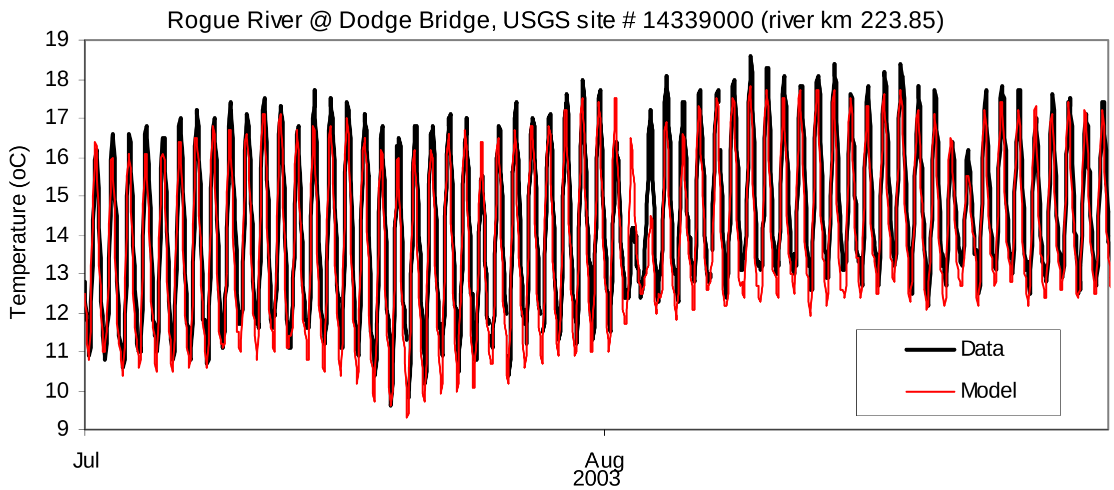


Figure A34-g

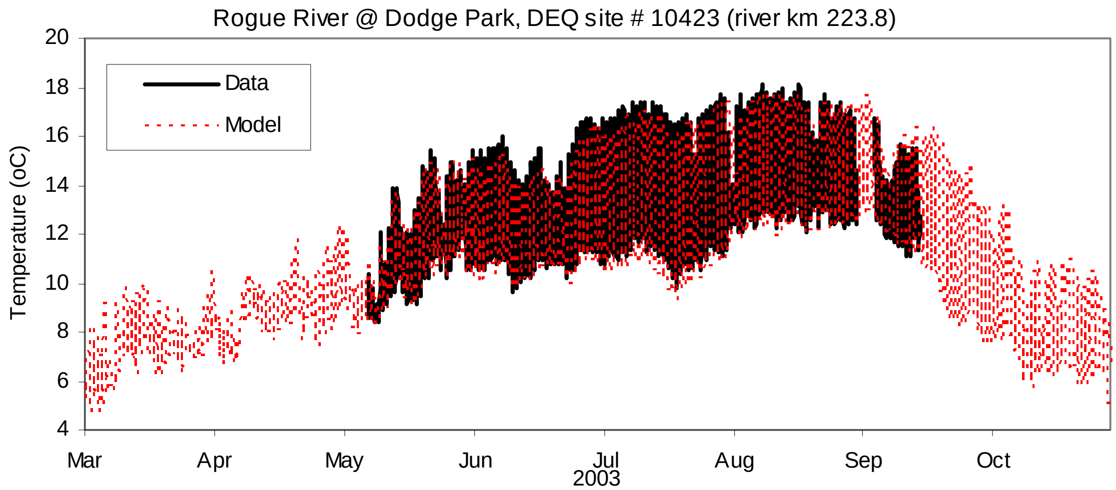


Figure A34-h

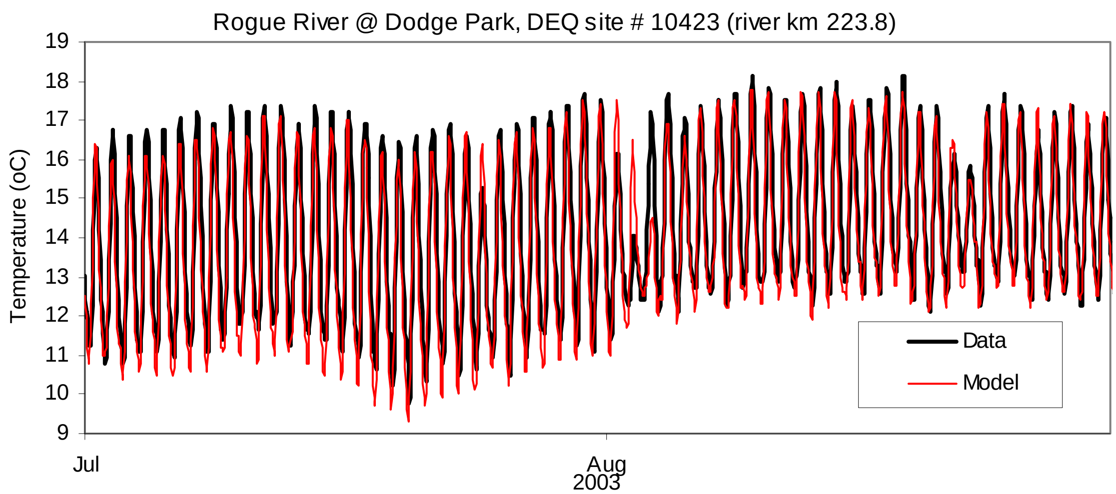


Figure A34-i

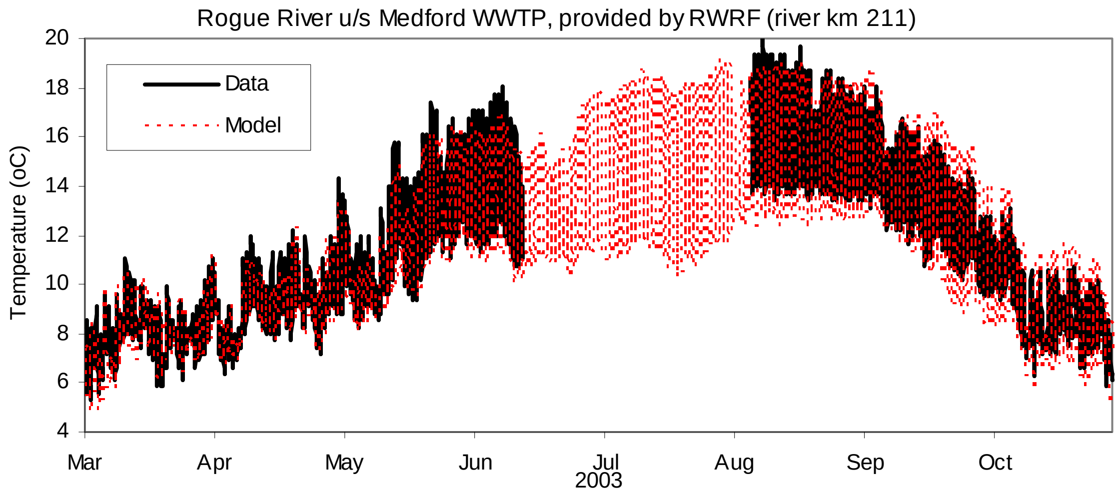


Figure A34-j

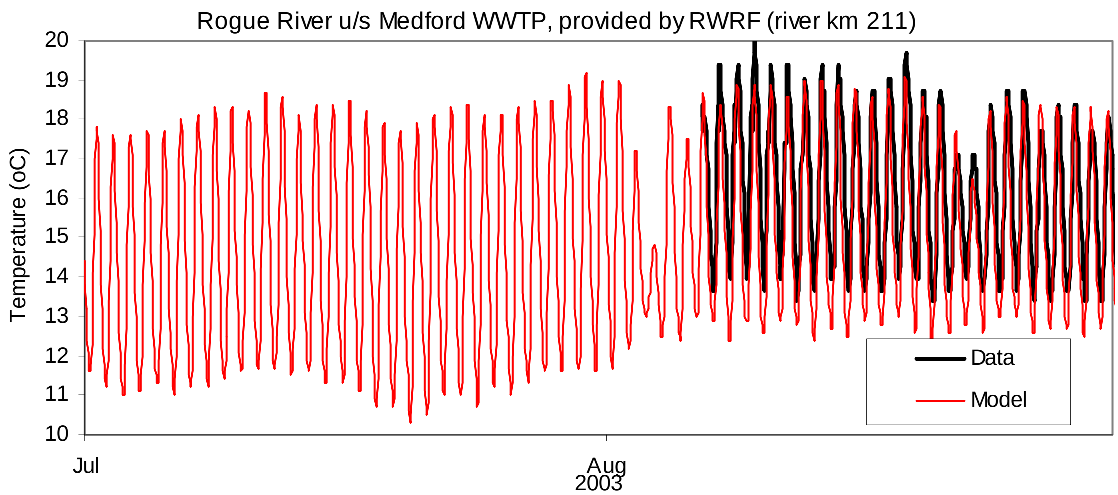


Figure A34-k

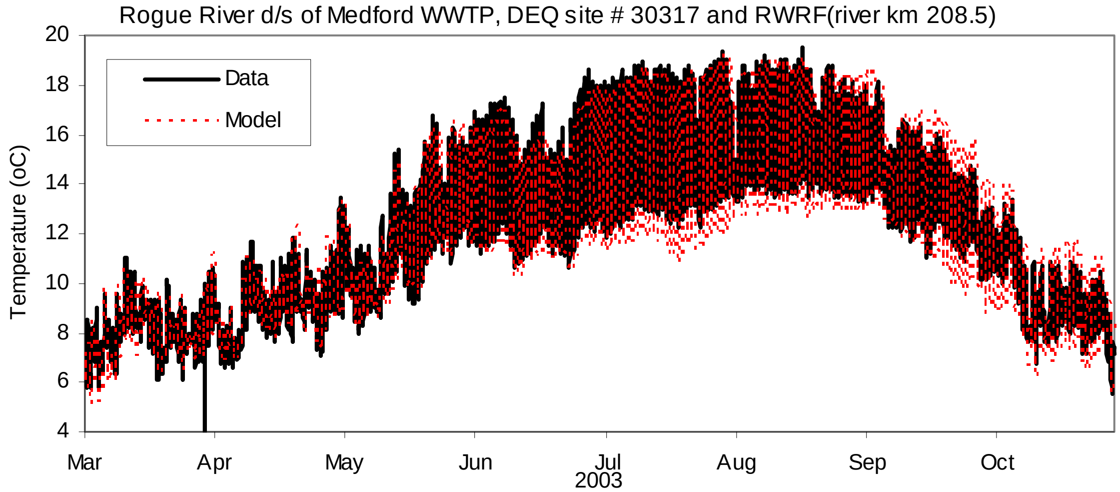


Figure A34-l

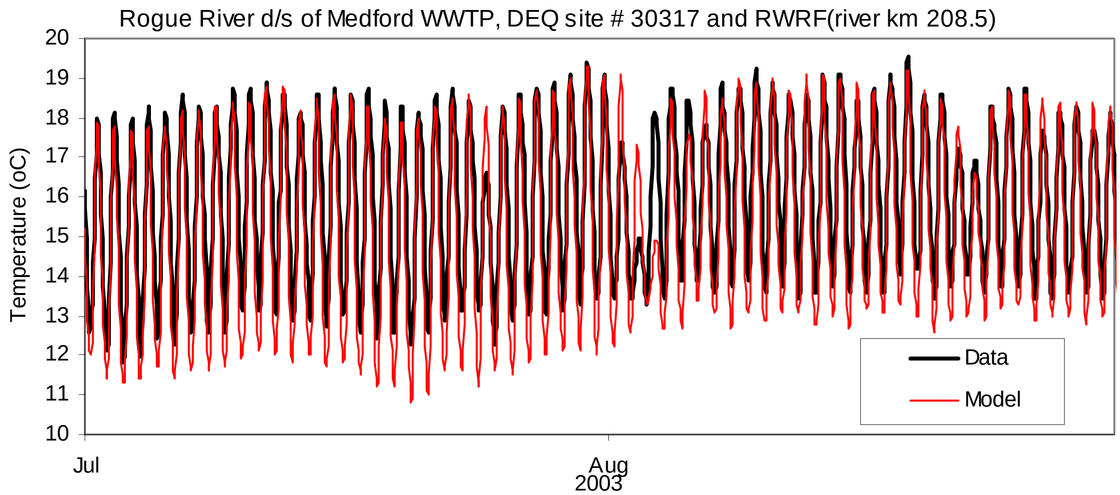


Figure A34-m

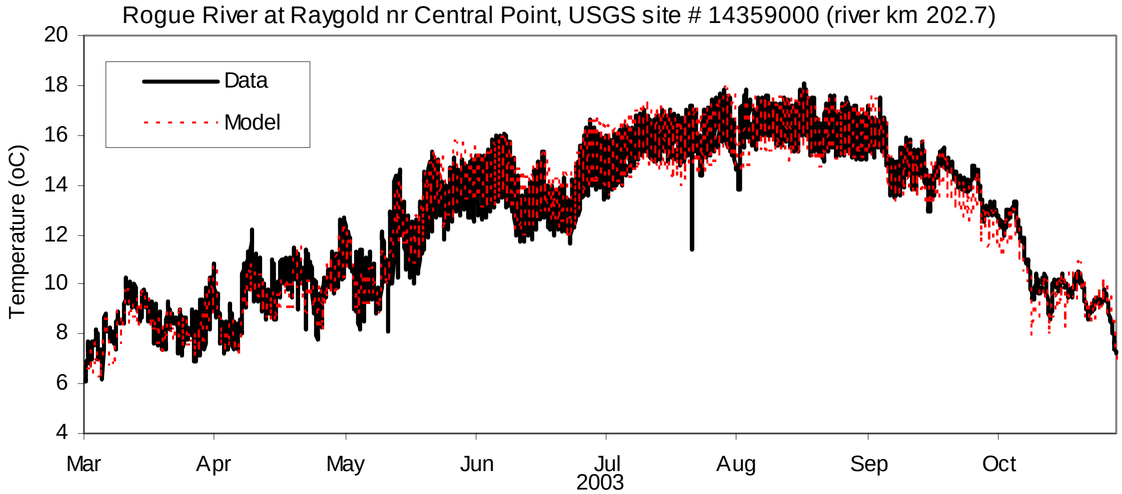


Figure A34-n

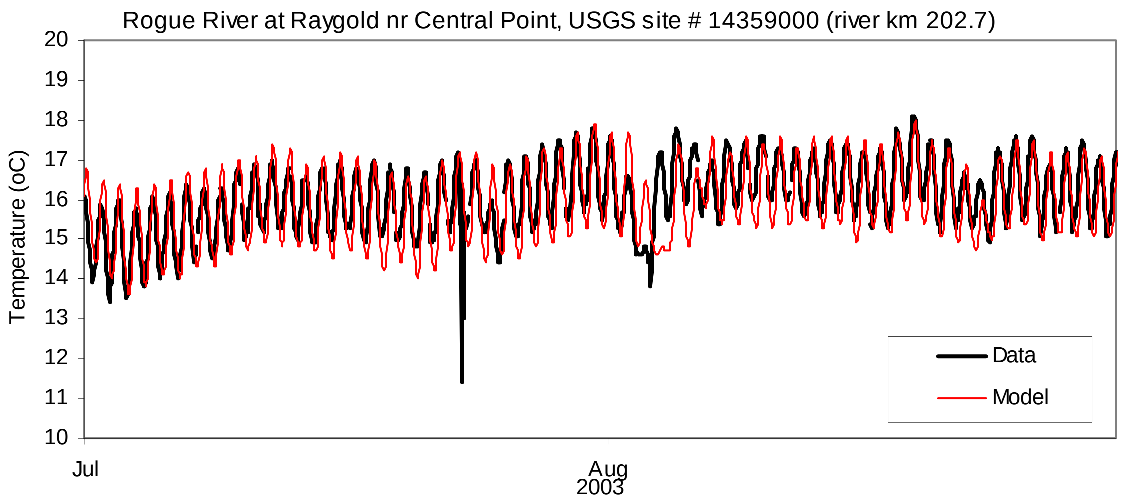


Figure A34-o

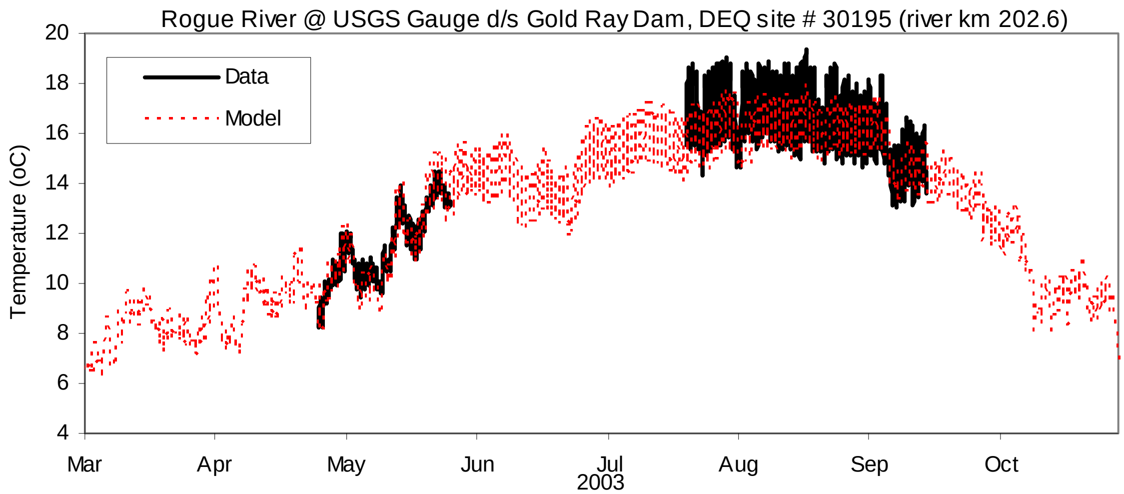


Figure A34-p

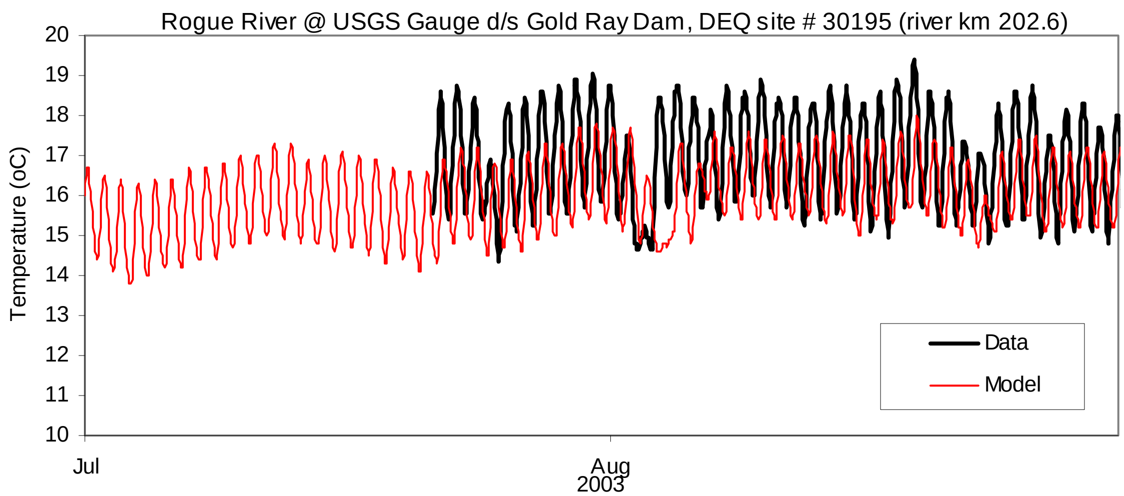


Figure A34-q

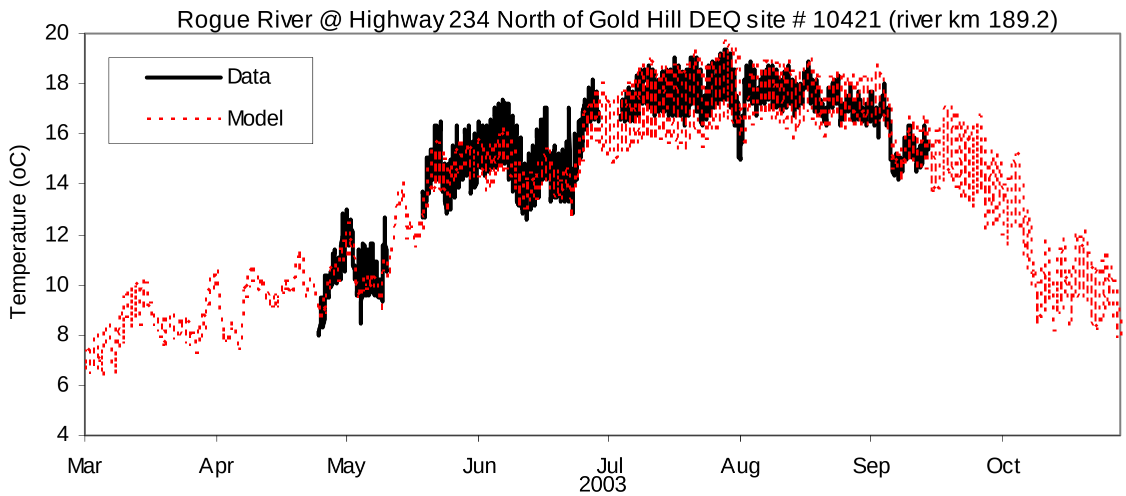


Figure A34-r

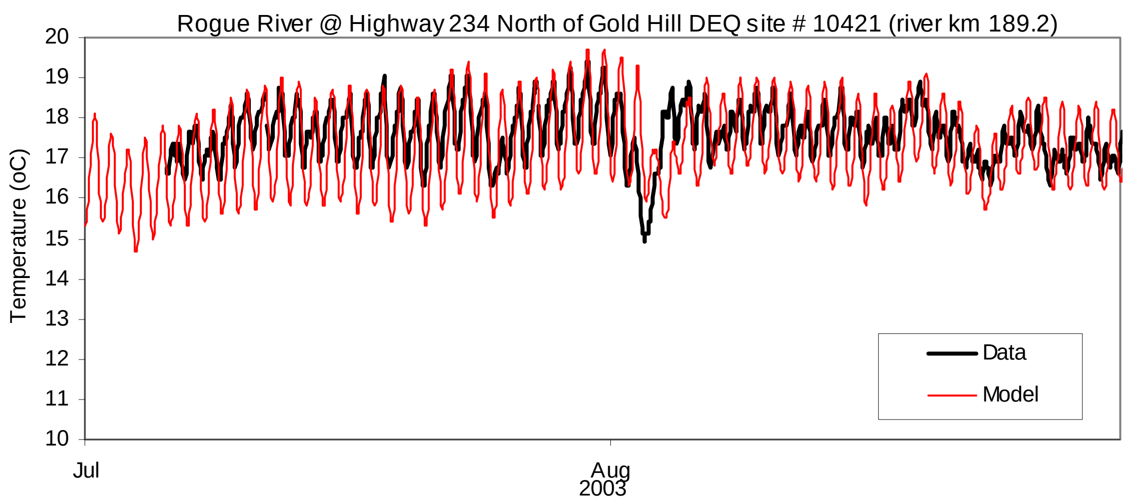


Figure A34-s

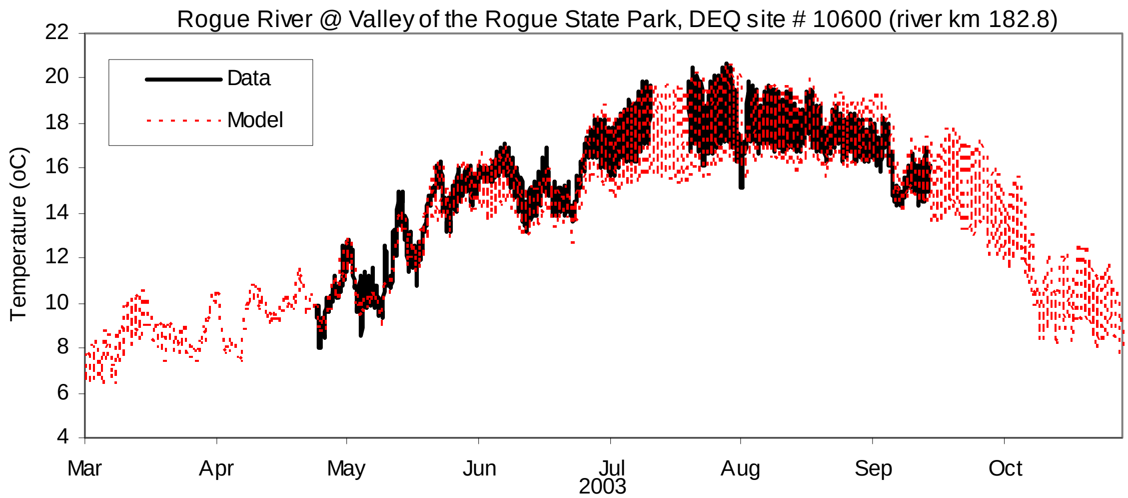


Figure A34-t

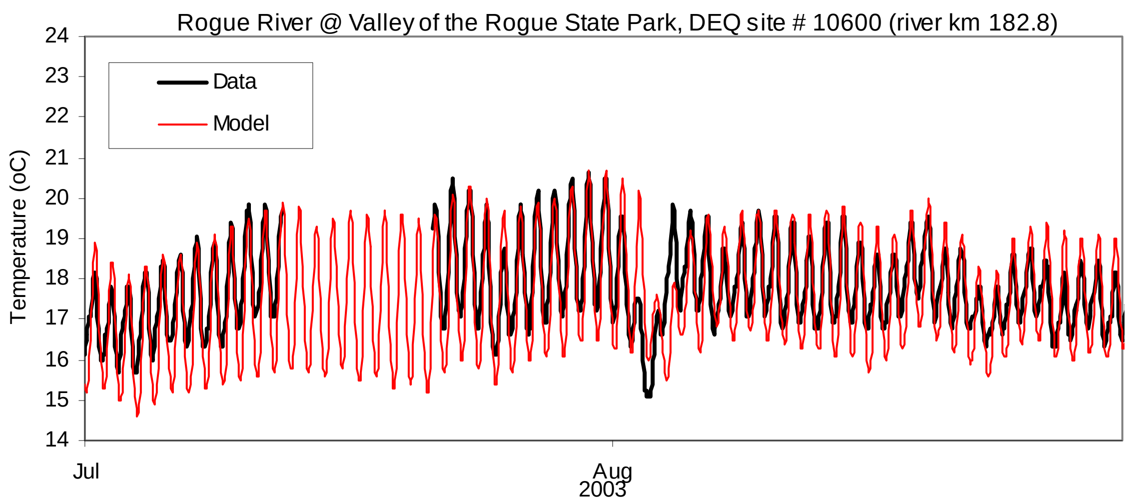


Figure A34-u

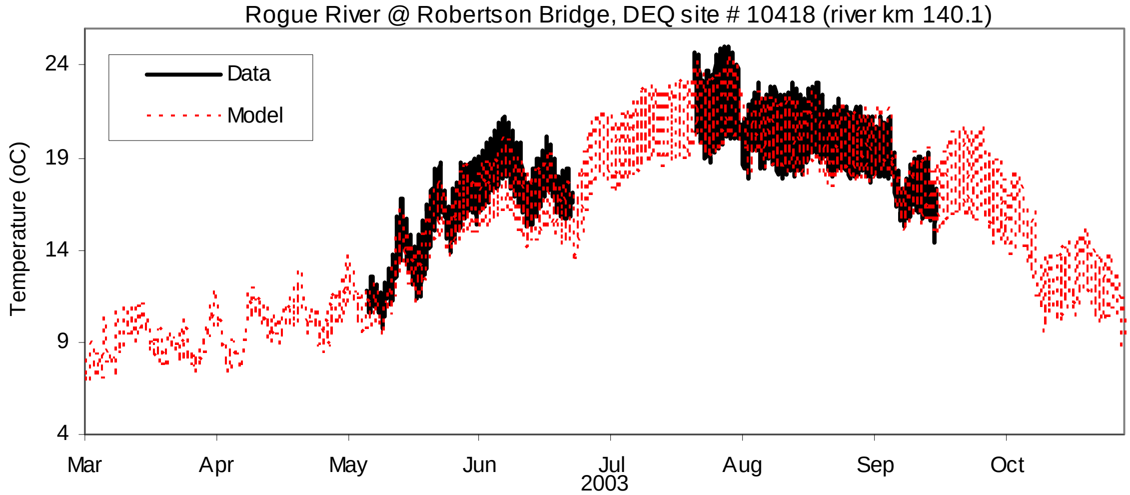


Figure A34-v

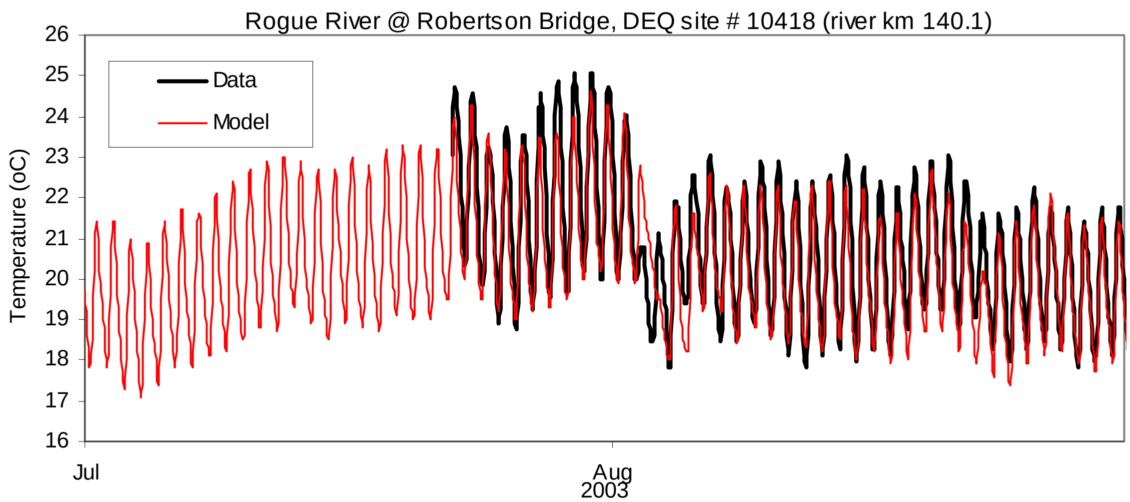


Figure A34-w

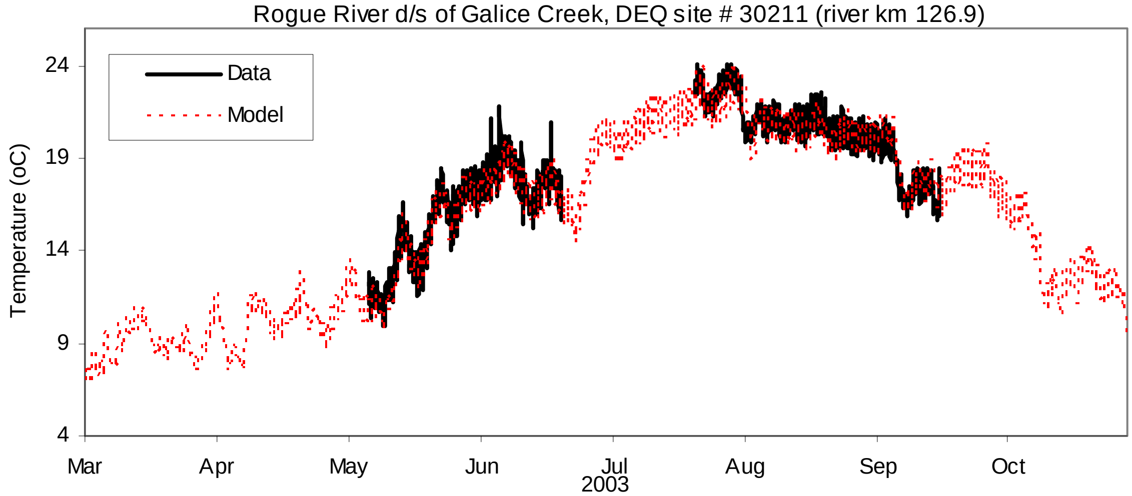


Figure A34-x

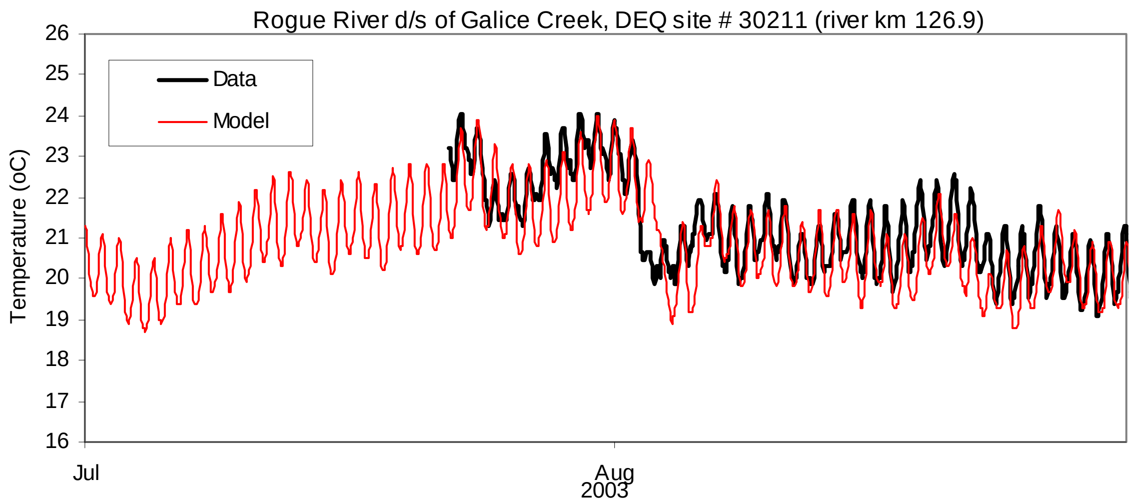


Figure A34-y

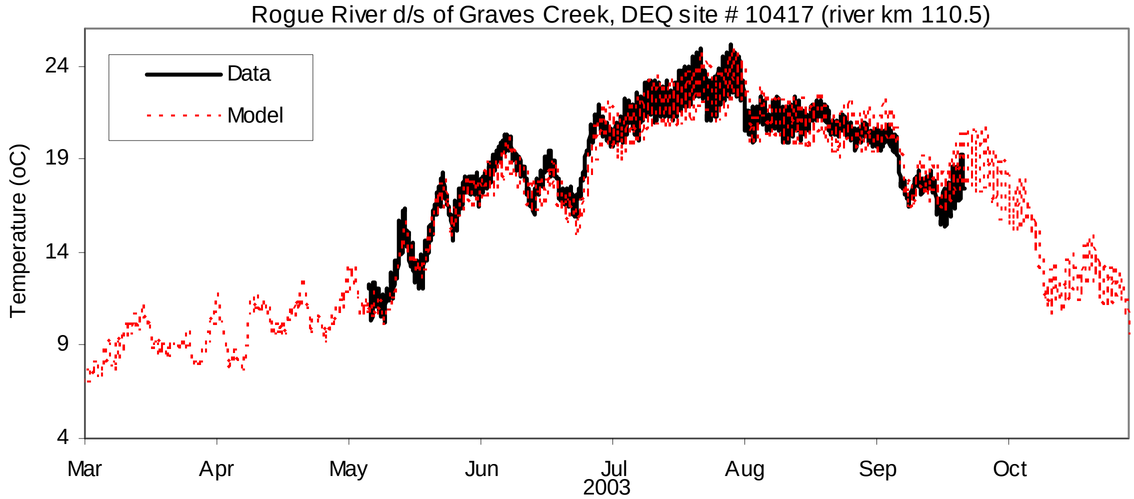


Figure A34-z

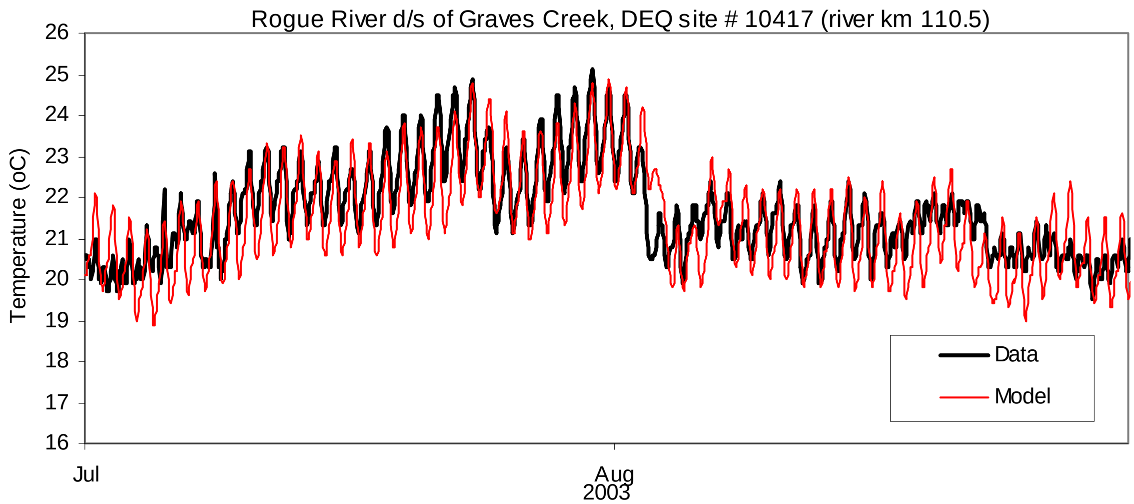


Figure A34-aa

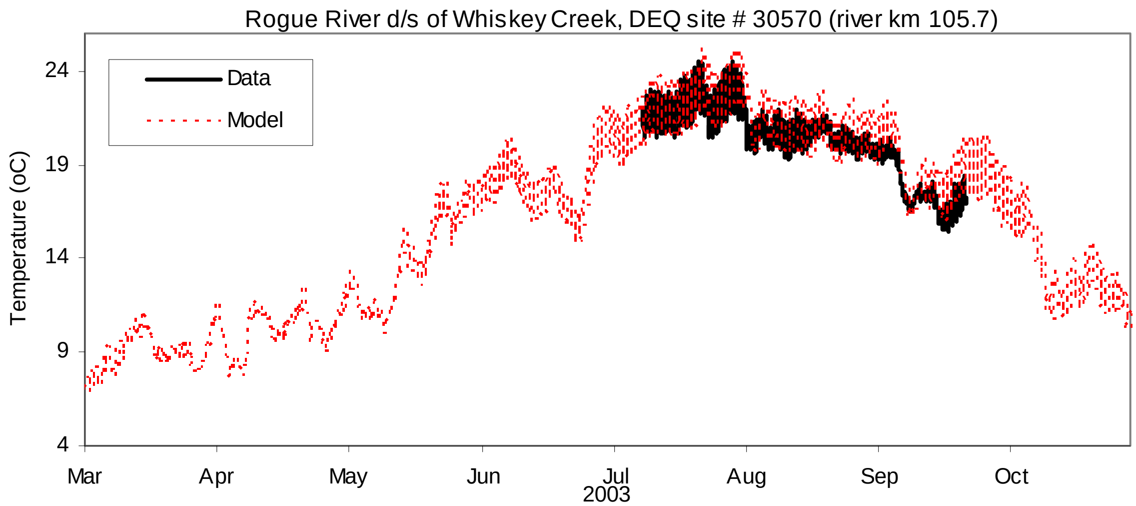


Figure A34-bb

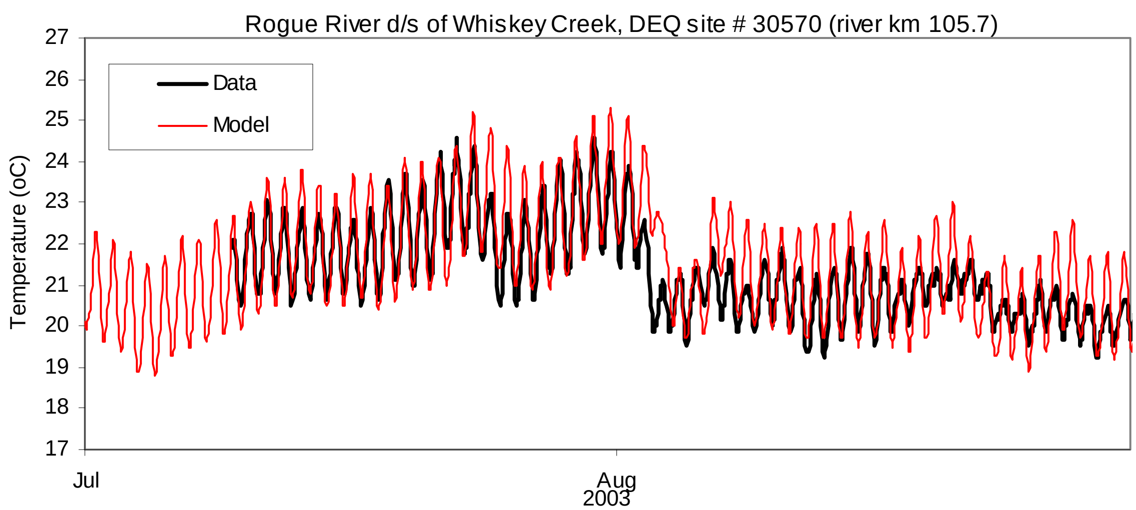


Figure A34-cc

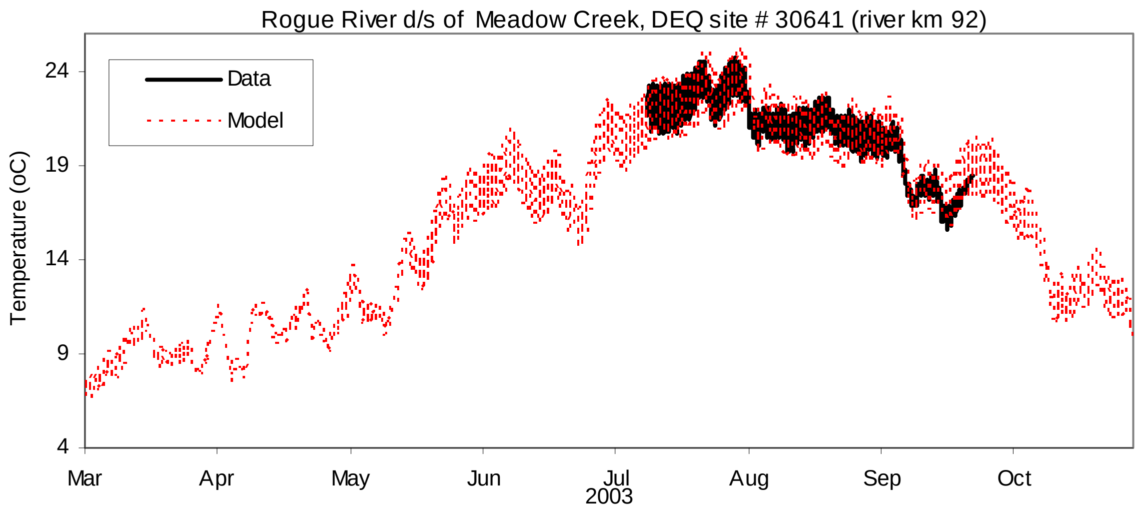


Figure A34-dd

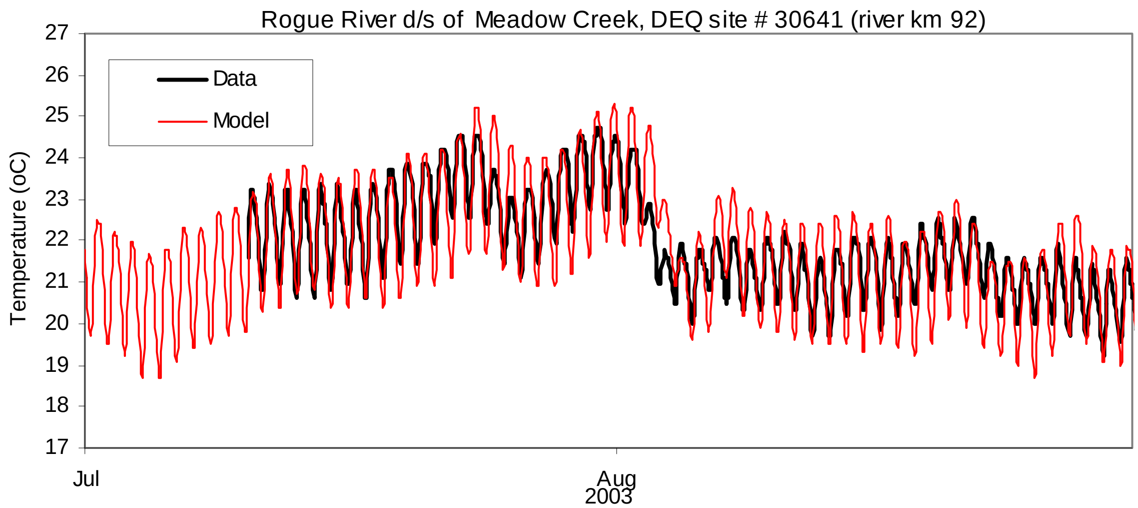


Figure A34-ee

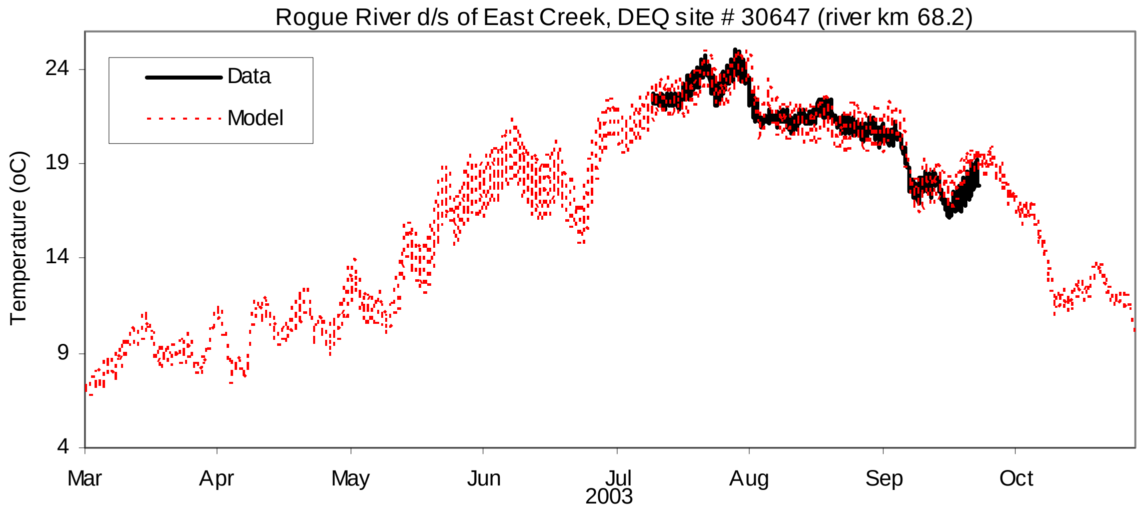


Figure A34-ff

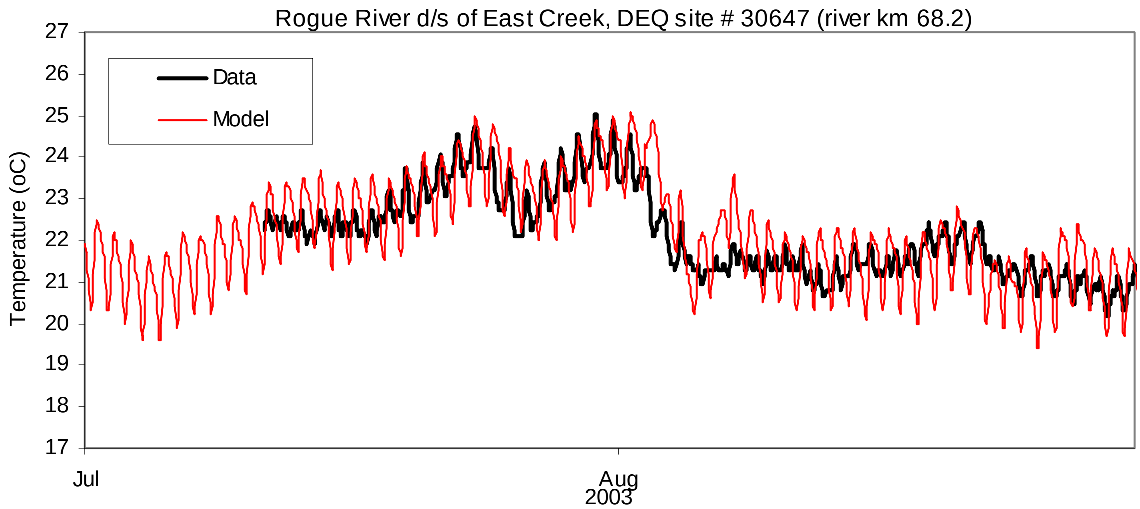


Figure A34-gg

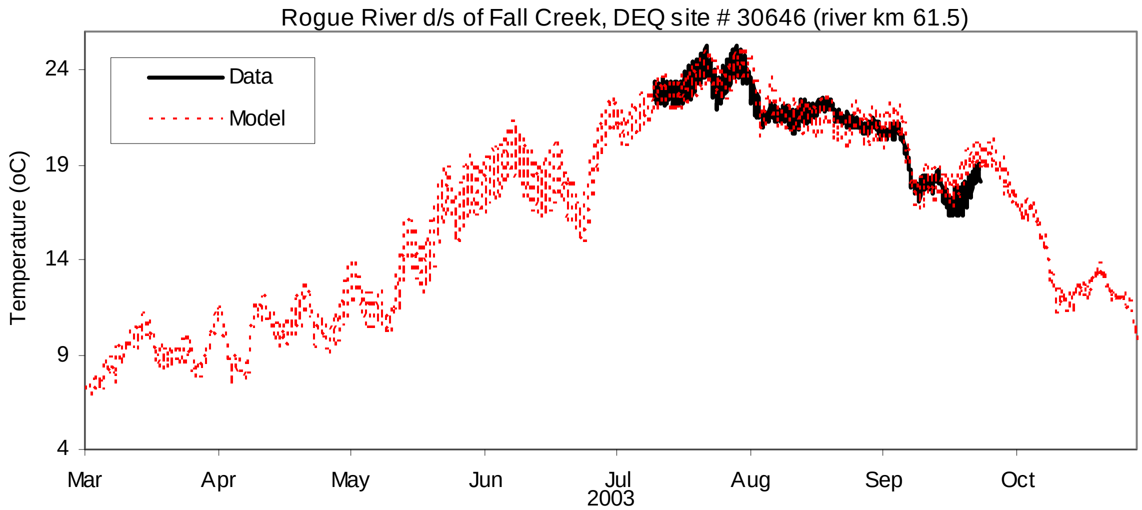


Figure A34-hh

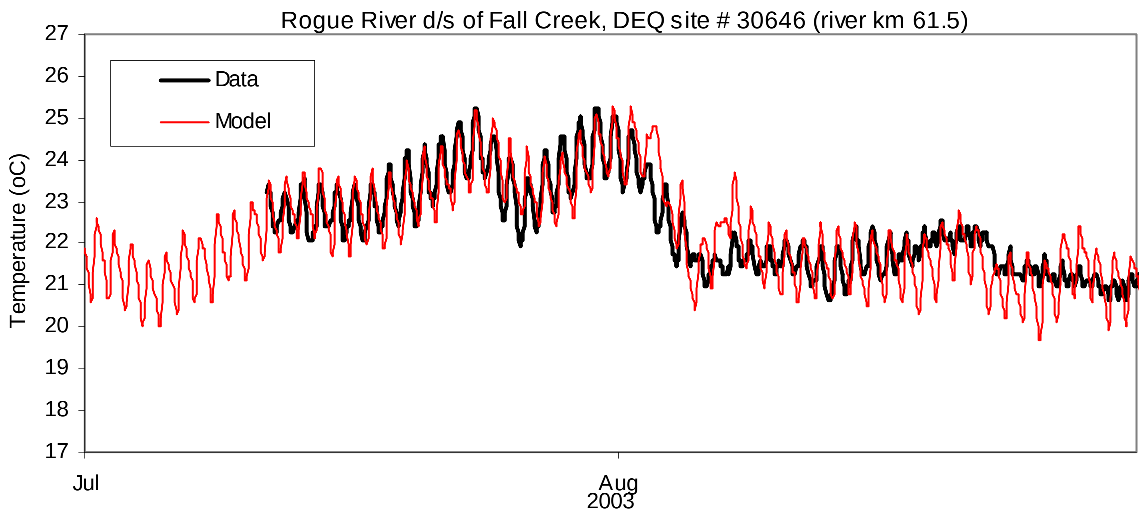


Figure A34-ii

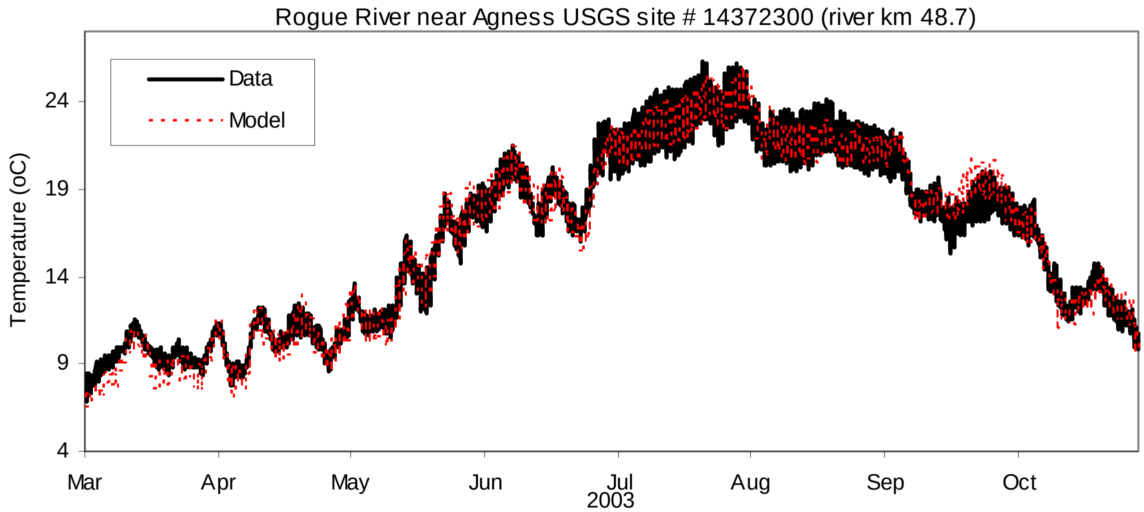


Figure A34-jj

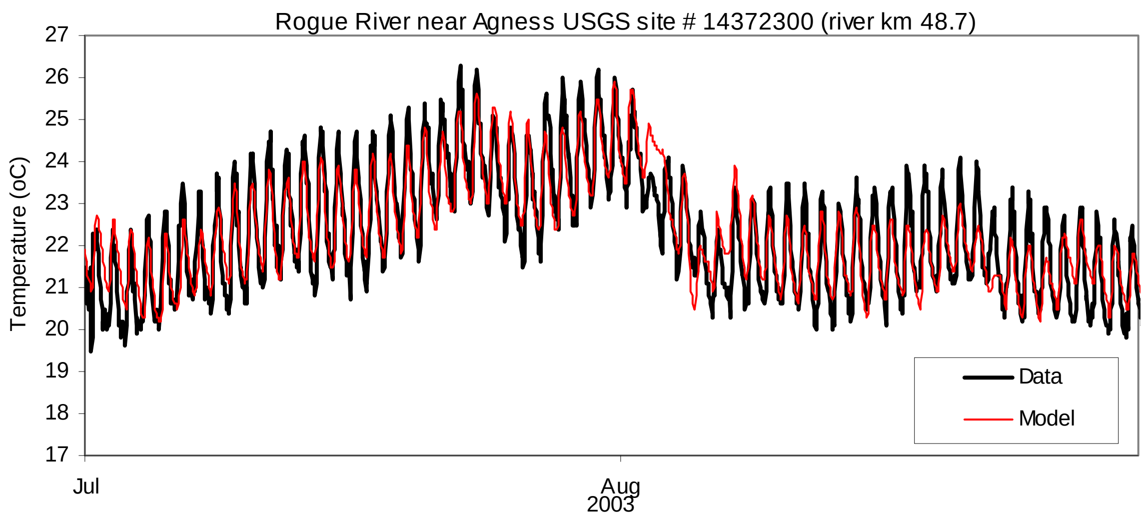


Figure A35-kk

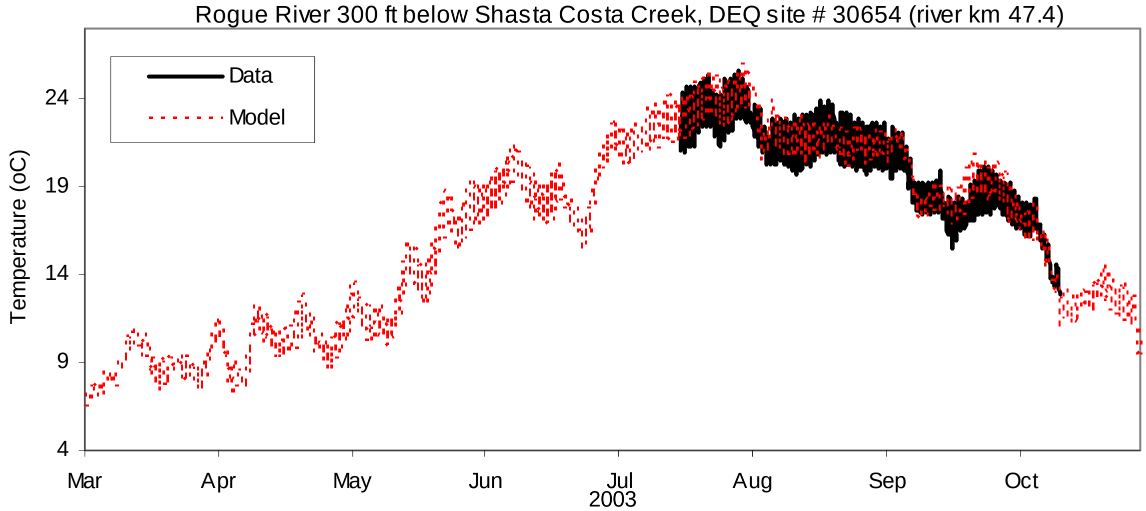


Figure A35-ll

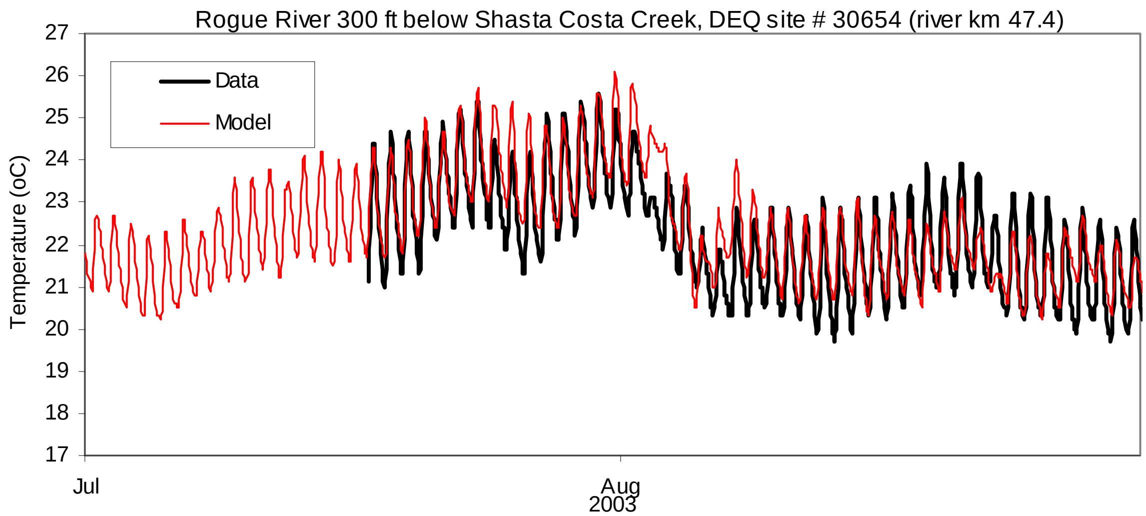


Figure A34-mm

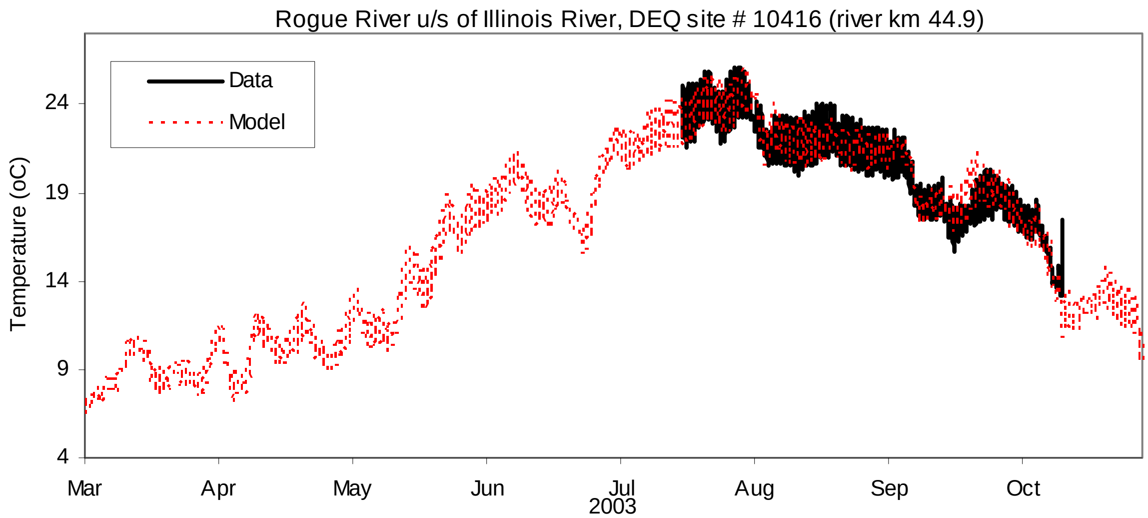


Figure A34-nn

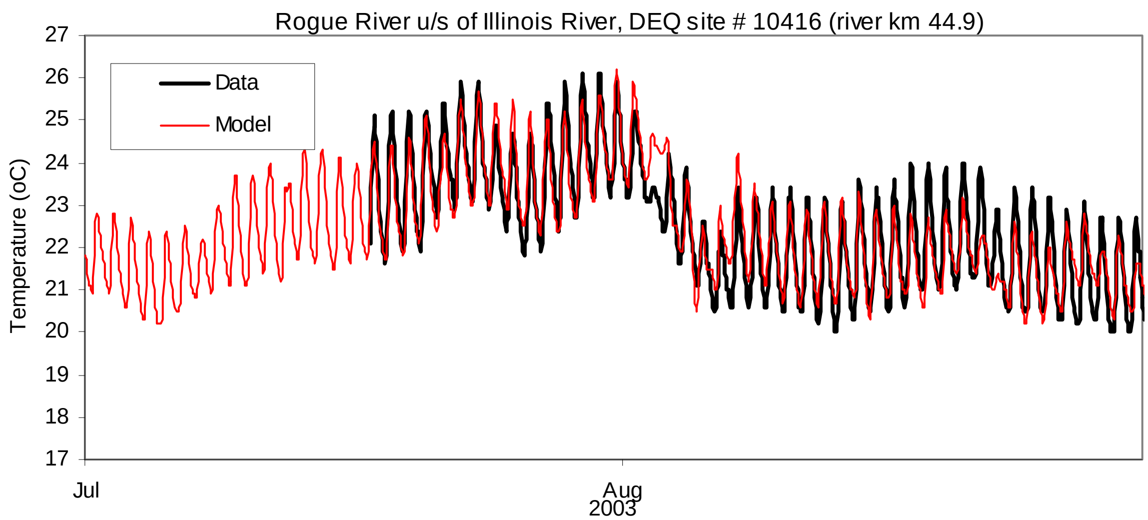


Figure A34-oo

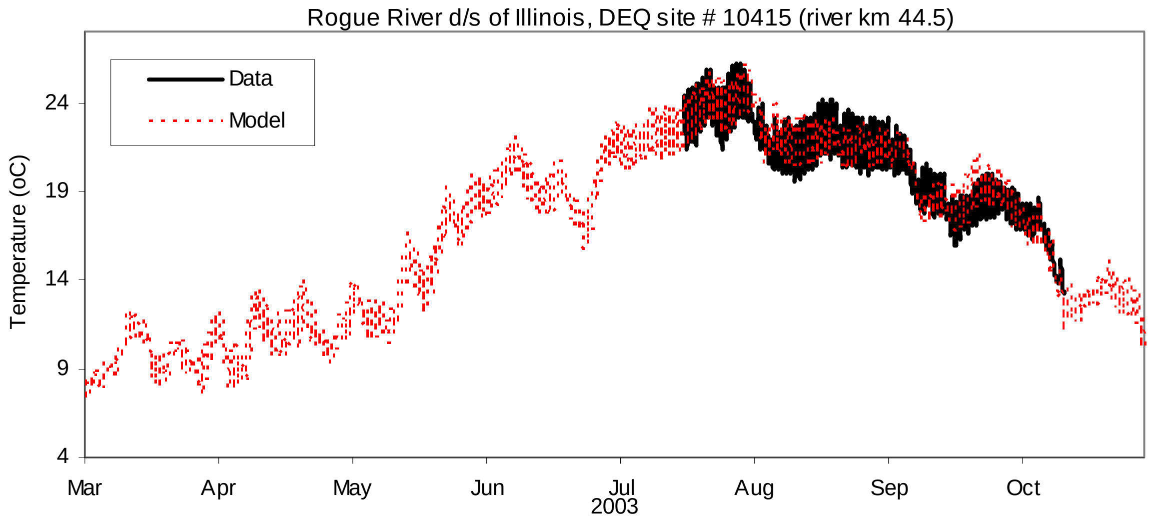


Figure A34-pp

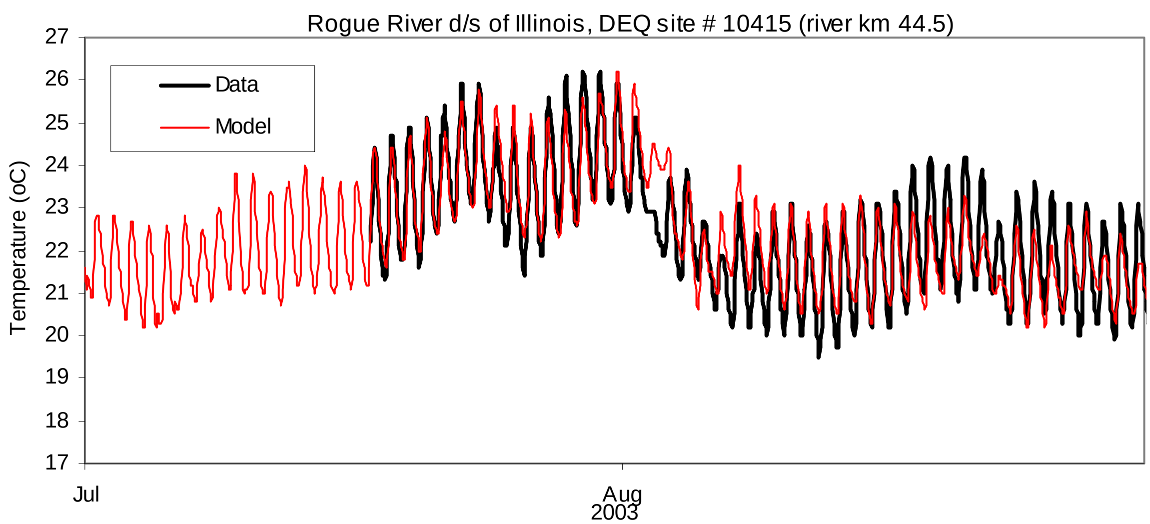


Figure A34-qq

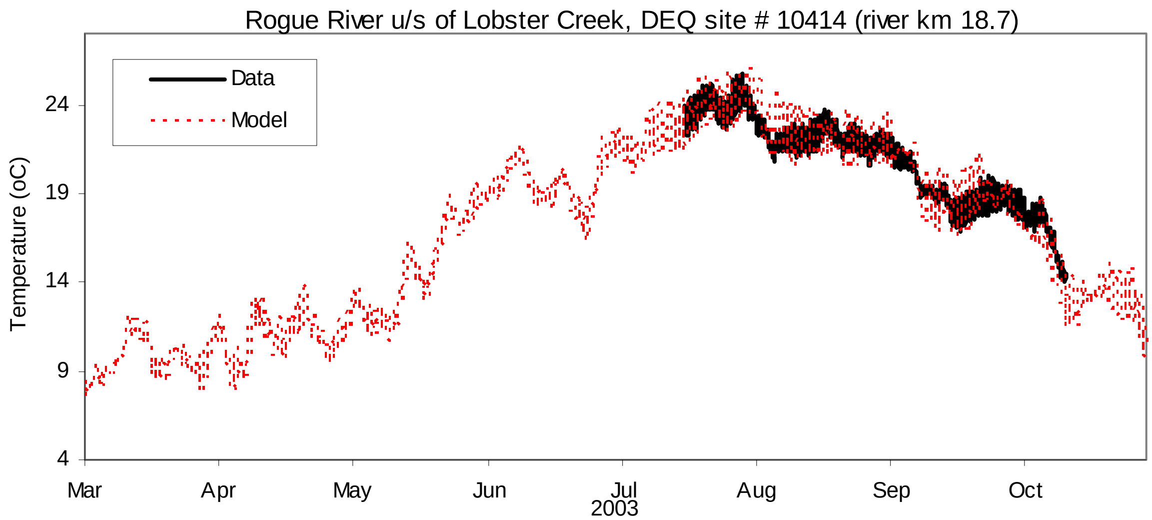


Figure A34-rr

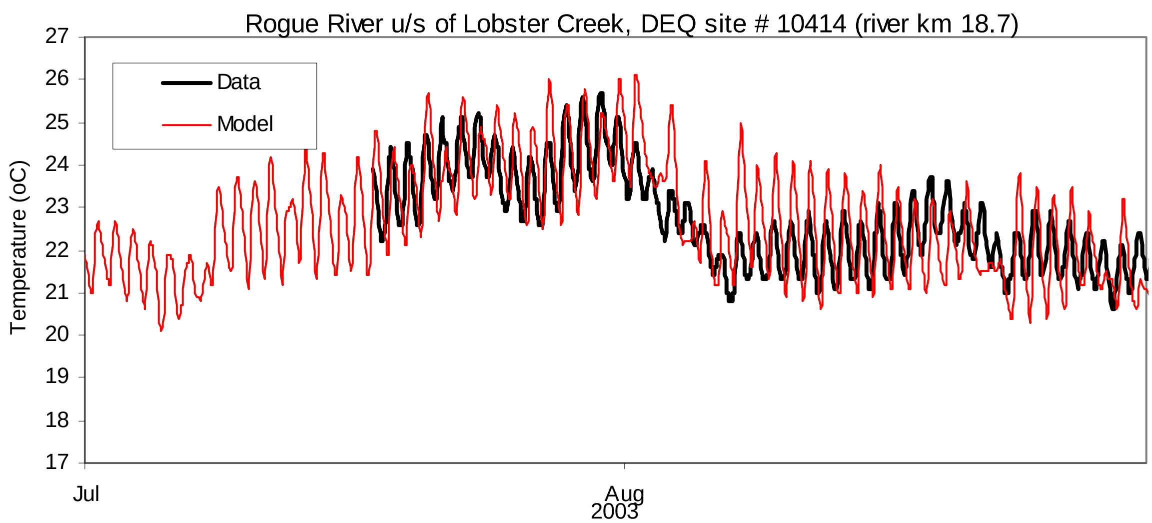


Figure A34-ss

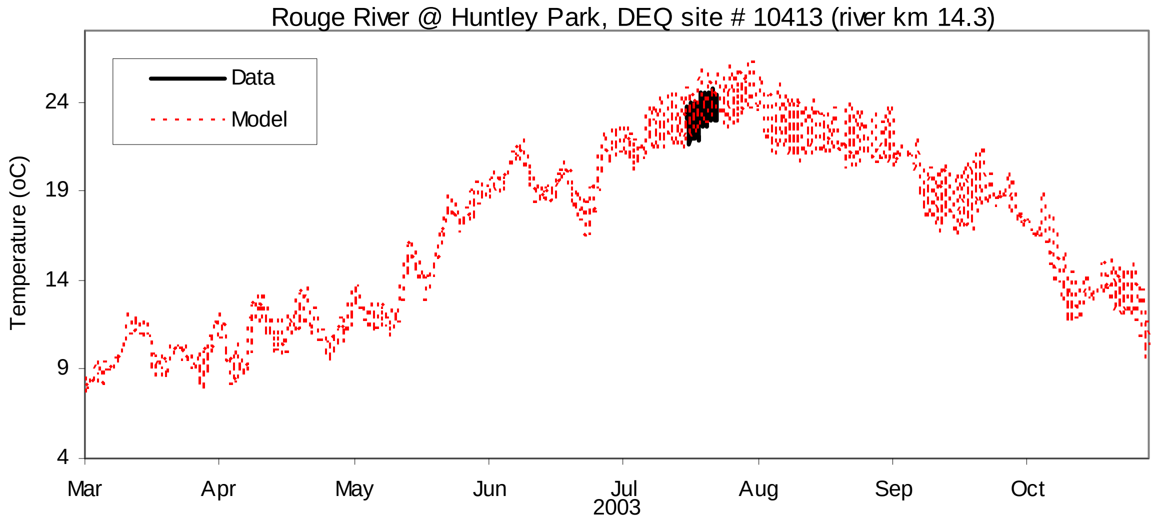


Figure A34-tt

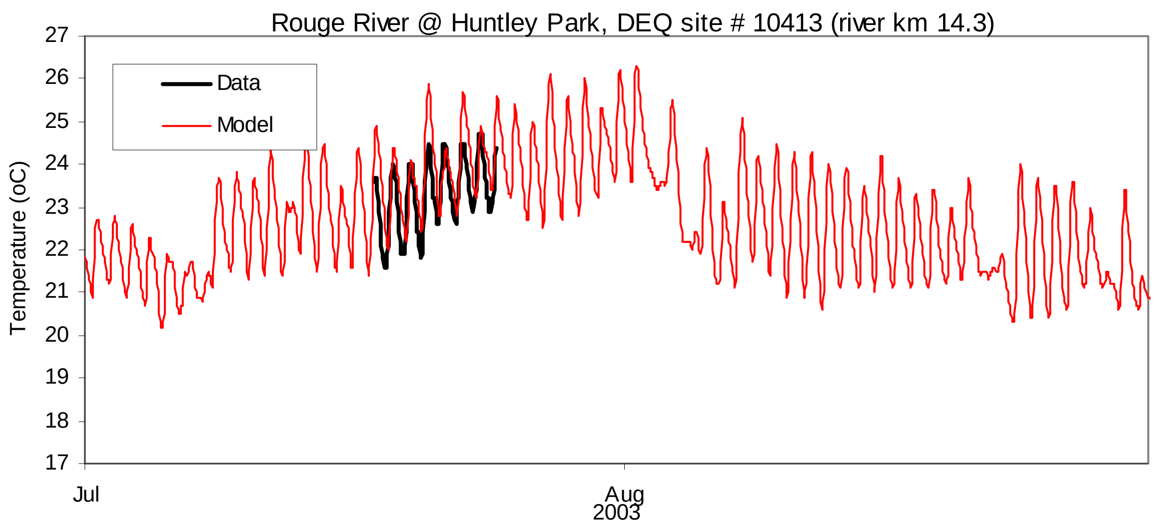
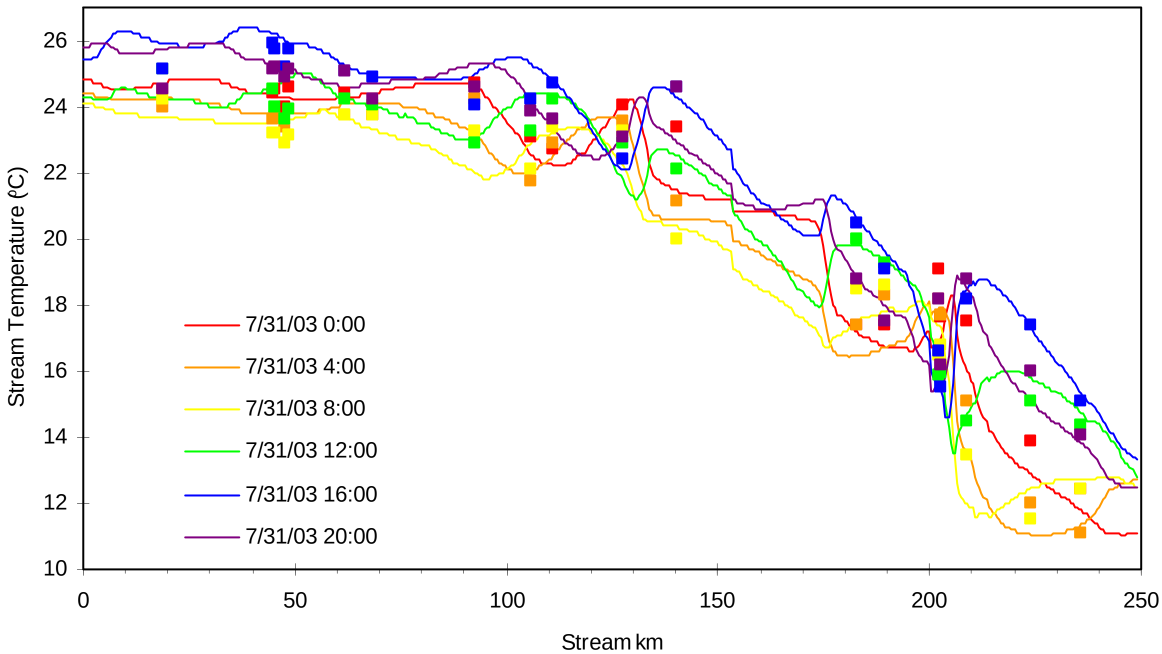


Figure A35. Longitudinal profile of temperature of model results (lines) and sampled measurements (points) for various hours on July 31, 2003. The graph shows the longitudinal and diel variation of measurements and model results.

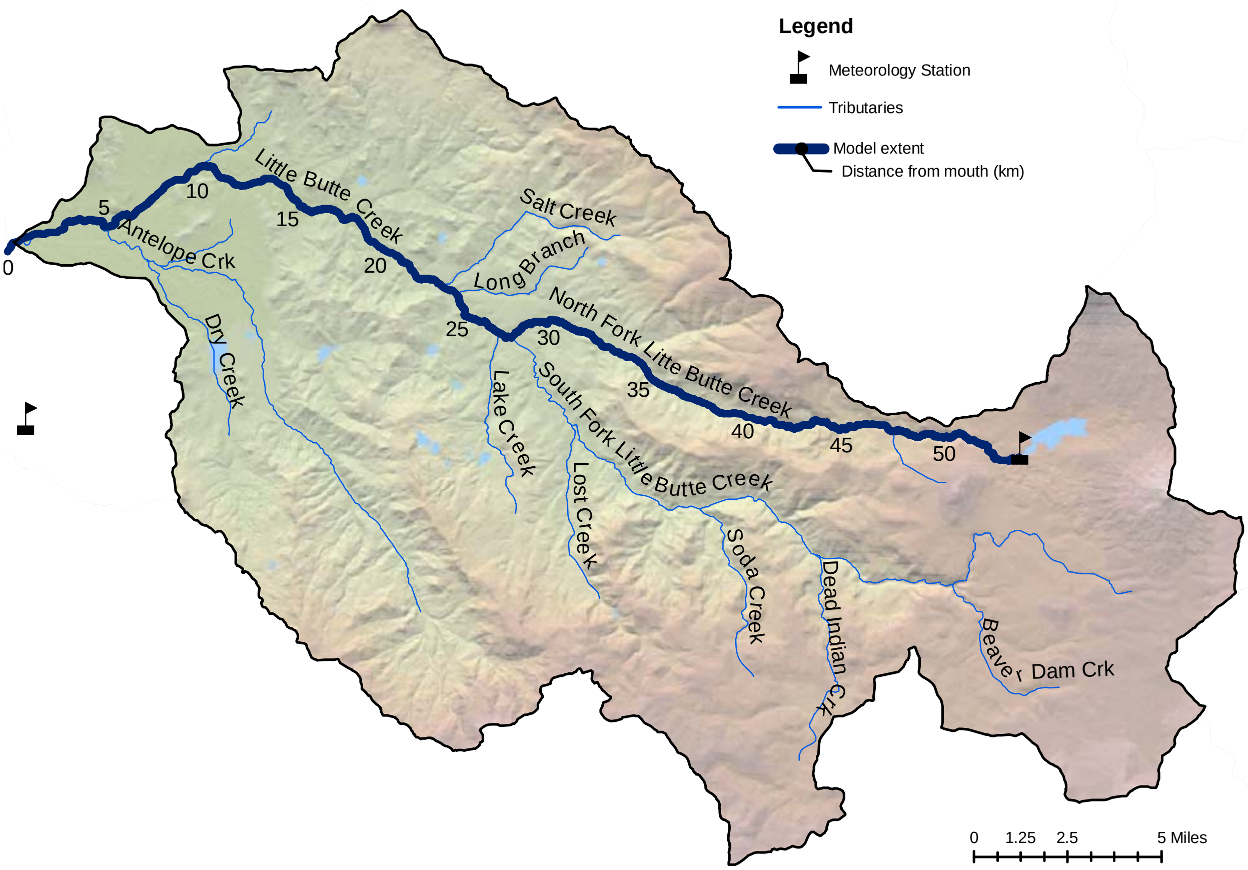


4.3 Little Butte and North Fork Little Butte Creek

Overview

Stream Name: Little Butte Creek and North Fork Little Butte Creek
Model: Heat Source version 8.0
Beginning date: 7/1/2001
Ending date: 8/31/2001
Time step: 0.5 minute
Distance step: 200 m
Extent: Confluence with Rogue River to Fish Lake at river km 54.1 (**Figure A36**).

Figure A36. Extent of the Little Butte and North Fork Little Butte temperature model.



Reach Properties

The channel properties were determined using the methodology documented previously in this report (see **Section 3**). **Figure A37** shows the elevation profile and reach gradient. The bottom width was derived using the active channel width measured from aerial photographs. Bottom width was estimated by assuming a trapezoidal channel with side slopes that are three times as long as they are high and also using a variable width-to-depth ratio determined through model calibration (**Figure A38**). The active channel width from creek kilometers 23.0-4.6 and percent hyporheic exchange values were modified based on information from project consultant TetraTech (see Appendix C). Non-spatially varying coefficients are presented in **Table A12**. Manning's n values were iteratively altered so that the model temperatures approximately reproduced measured temperatures (**Figure A39**). Topographic and riparian vegetation heights were determined through a GIS analysis (**Figure A40 -- Figure A42**). Using these channel and vegetation inputs, the performance of the Little Butte and North Fork Little Butte Creek model in predicting shade is shown in **Figure A43**.

Figure A37. Model setup channel elevation and gradient

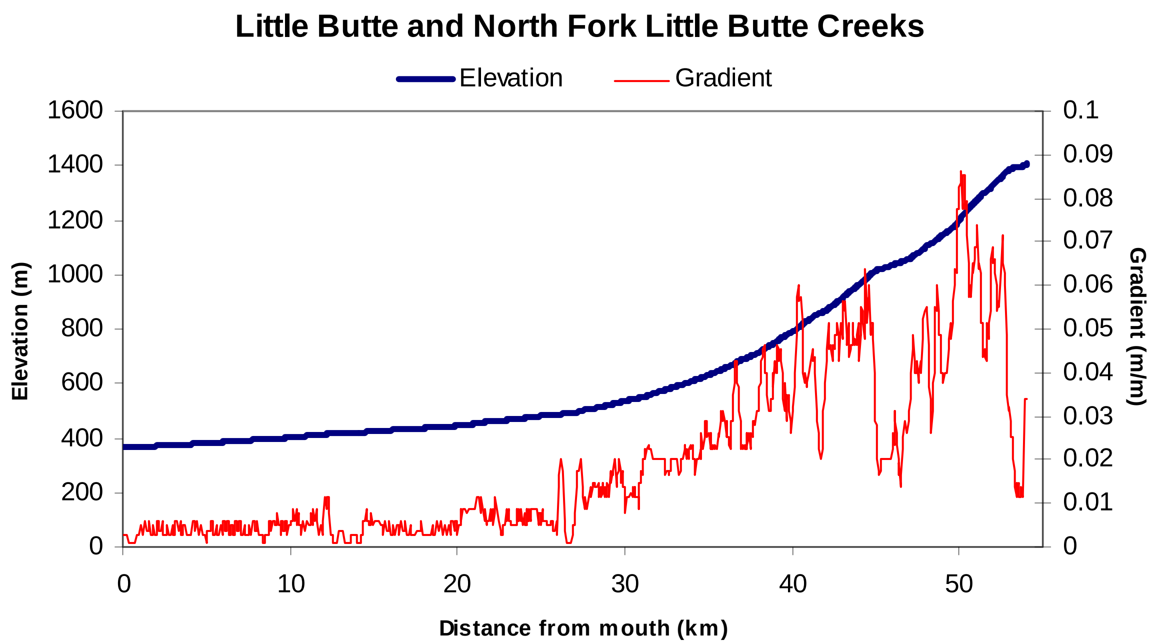


Figure A38. Model setup for channel bottom width and channel angle

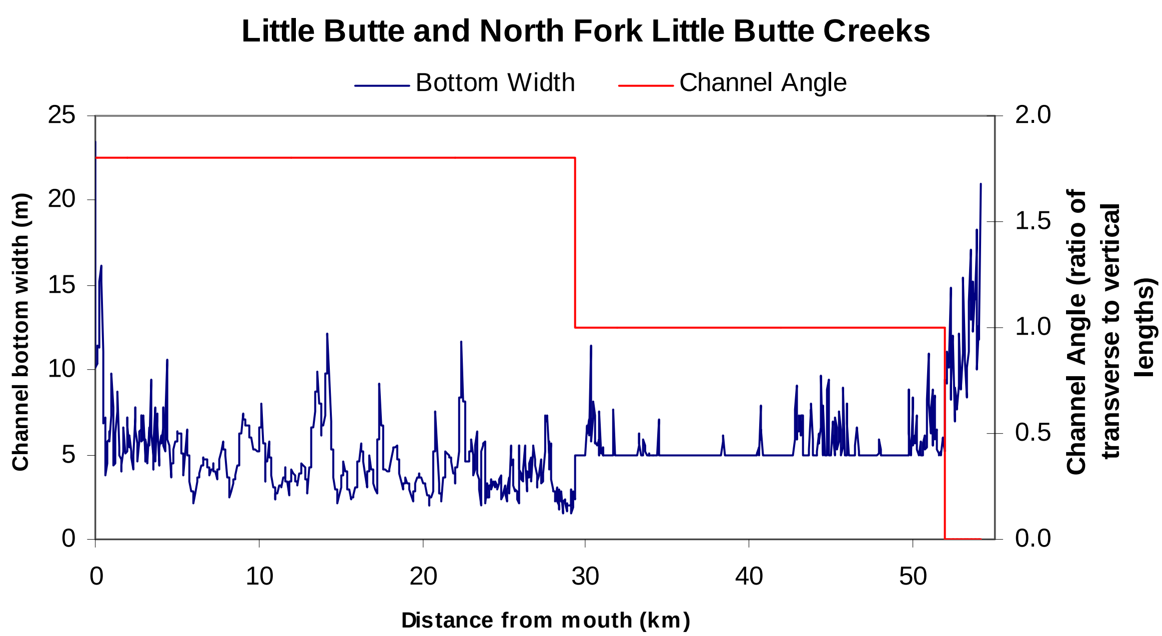


Table A12. Model coefficients for non-spatially varying parameters

Parameter name (units)	Value
Wind Function, coefficient a	1.51×10^{-9}
Wind Function, coefficient b	1.60×10^{-9}
Sediment Thermal Conductivity (W/m/°C)	1.57
Sediment Thermal Diffusivity (cm^2/sec)	0.0064
Sediment / hyporheic zone thickness (m)	0.5
Porosity	30%

Figure A39. Model setup for roughness coefficient

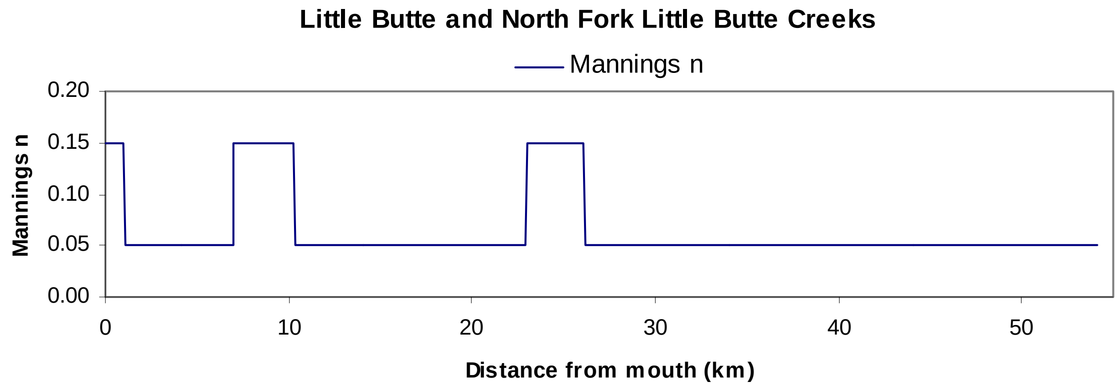


Figure A40. Model setup for topographic angle

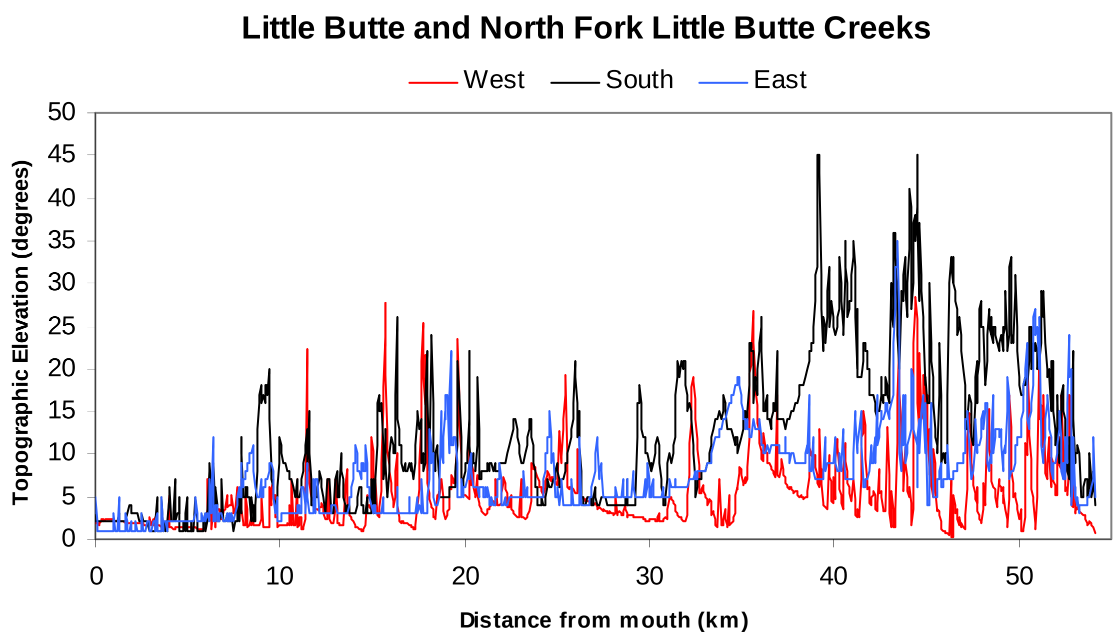


Figure A41. Model setup for height of streamside vegetation

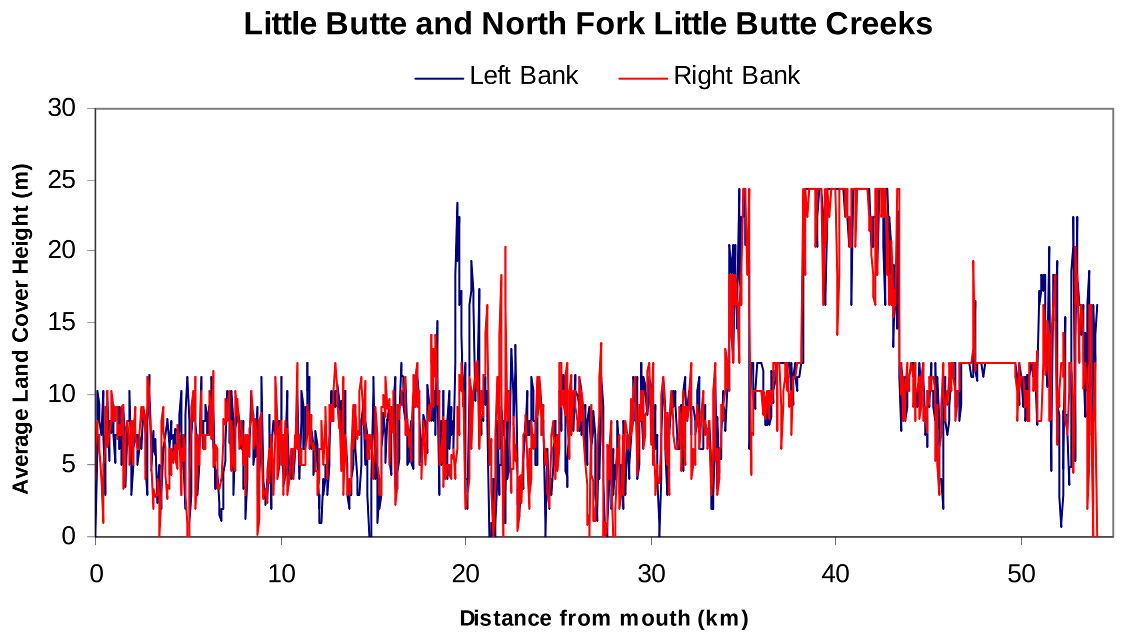


Figure A42. Model setup for density of streamside vegetation.

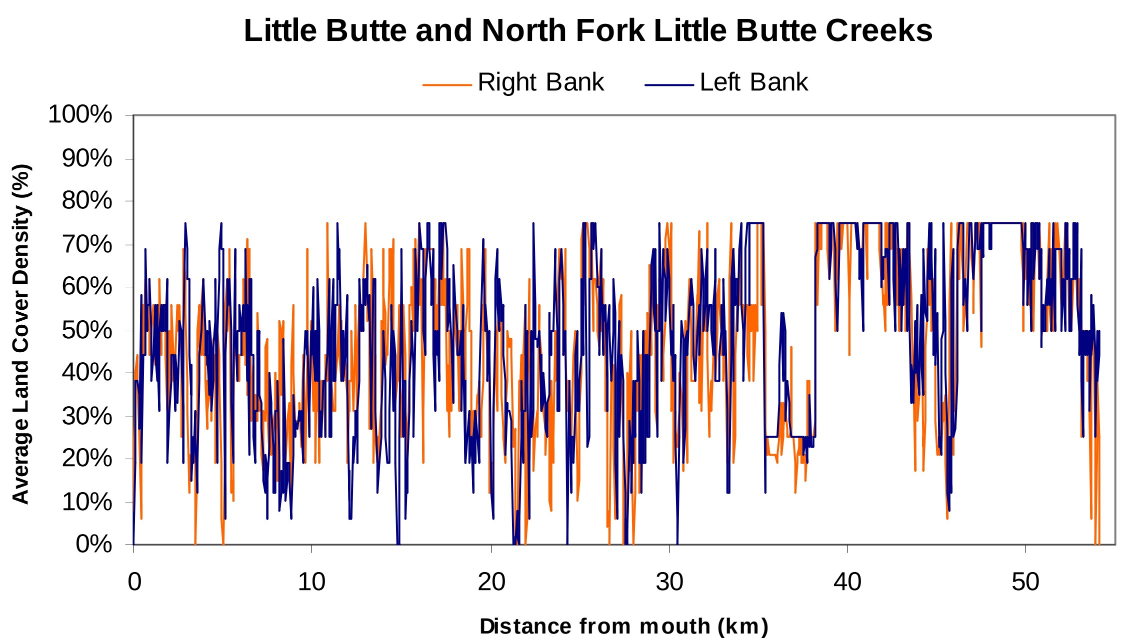
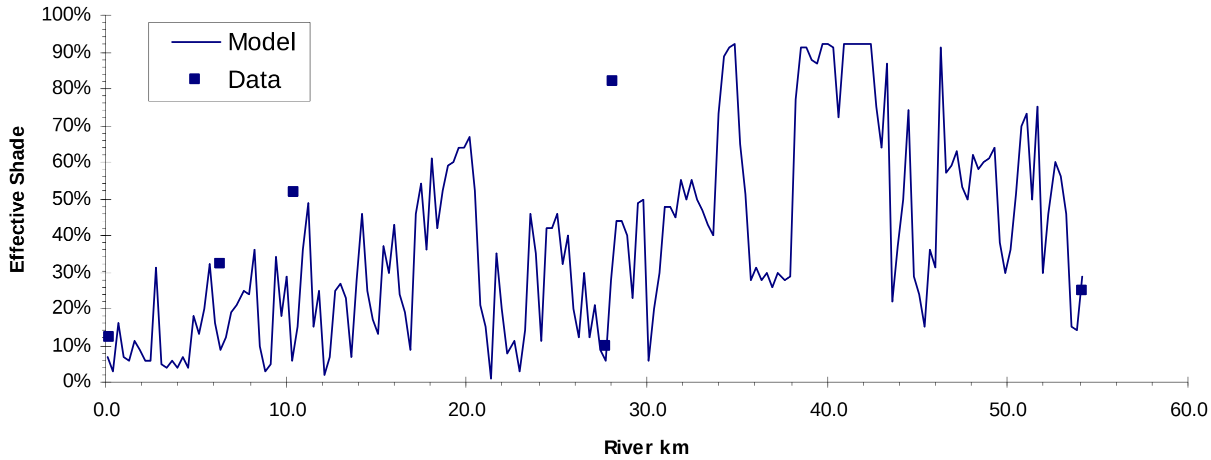


Figure A43. Predicted versus measured shade.



Meteorology

The model used air temperature measurements from Fish Lake (USBR 2008) and temperature, relative humidity, wind speed and cloudiness from the Medford airport. The 2 hour Fish Lake data was linearly interpolated hourly, and missing data were filled in using a regression with Medford. The meteorological inputs varied by stream kilometer based on proximity to the weather station (**Table A13**). A multiplicative wind sheltering coefficient was applied to the wind speed for calibration. The meteorological observations are presented in **Figure A44, a-d**.

Table A13. Source of meteorological inputs into model.

Range (river km)	Cloudiness	Relative Humidity	Air Temperature	Wind Speed	Wind sheltering Coefficient
54 - 45	Medford	Medford	Fish Lake	Medford	0.1
45 - 32	Medford	Medford	Average of Fish Lake and Medford	Medford	0.1
32 - 9	Medford	Medford	Medford	Medford	0.1
9 - 4	Medford	Medford	Medford	Medford	0.3
4 - 0	Medford	Medford	Medford	Medford	0.5

Figure A44, a-d. Meteorology inputs for model setup

Figure A44-a. The intervals area a residual from reported measurements.

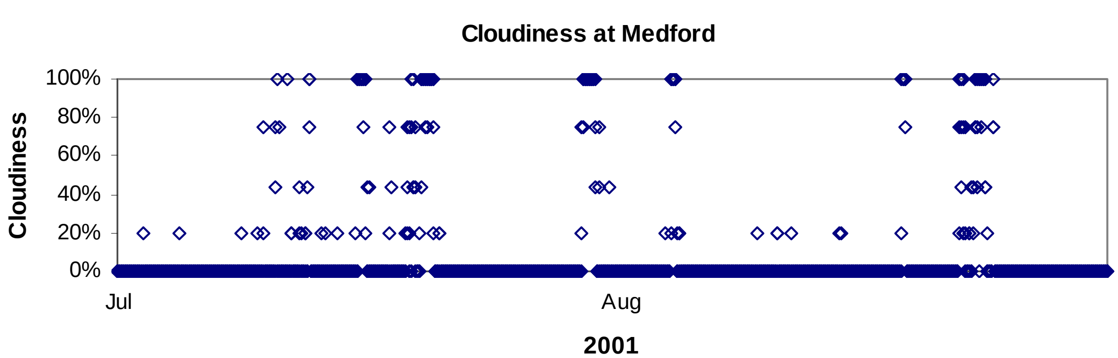


Figure A44-b

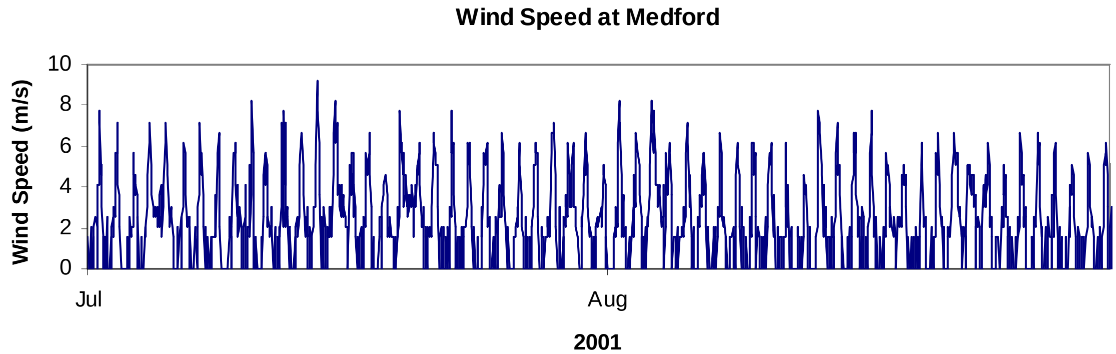


Figure A44-c

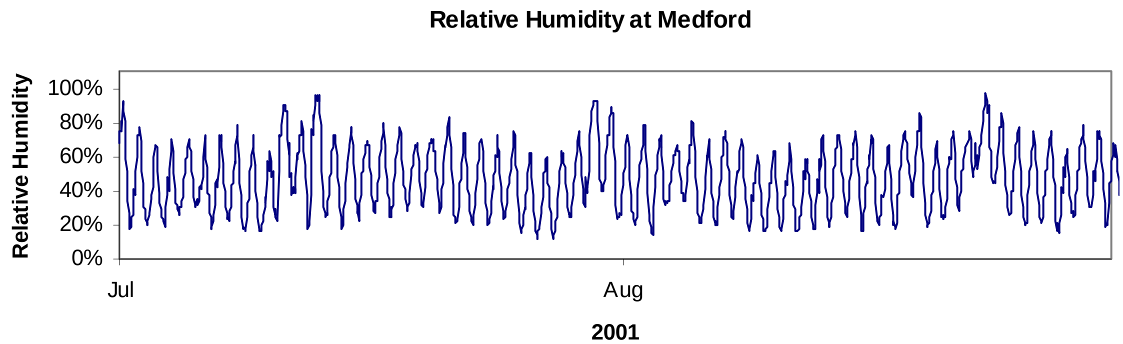
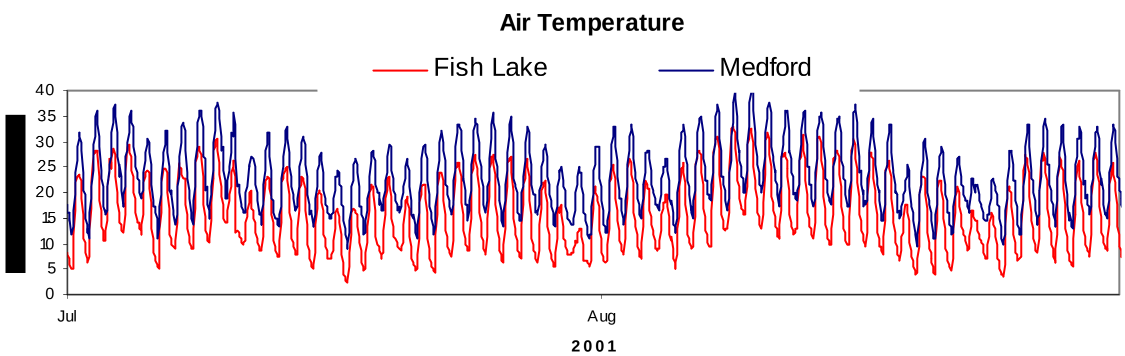


Figure A44-d



Flow

When available, flow measurements taken in the Little Butte Creek watershed were used to generate model input. Otherwise, relationships with other gages were used (**Table A14 and Figure A45**). Discharge inputs at the model headwater (Fish Lake) were acquired from USBR (2007). Data from one additional flow gage in 2001 were available for the model reach: Little Butte Creek at Lake Creek. Instantaneous flow measurements were collected at various places and time during the model period. Flow balance was derived through various methods including using the TIR temperatures and upstream flow. Maximum consumptive use is based on information provided by Oregon Water Resources Department (**Figure A46**). Withdrawals were based on the WRD points of diversion GIS layer described Section 2. In order to match observed flows, the maximum rate was used for withdrawals on the North Fork and half the maximum rate was used on Little Butte Creek. Using these flow inputs, the performance of the Little Butte Creek model at several times and locations is shown in **Figure A47 & Figure A48.**

Table A14. Source of flow information for the Little Butte Creek model. EPID refers to Eagle Point Irrigation District.

Inflow / Outflow	Stream km	Source
Fish Lake outlet	54.1	USBR gage
Springs	52 - 47	Flow balance
Diversion to Joint System Canal	29.3	Flow balance
SF Little Butte	27.9	Flow and temperature balance
Lake Creek	27.23	Average of 3 instantaneous flow measurements
Salt Creek	23.55	Average of 2 instantaneous flow measurements
Diversion to Crater Canal	13.3	Flow balance
Nichols Branch	10.3	Linear interpolation of 3 instantaneous measurements
Return flow from Buchanan Ditch	6.95	Average of 2 instantaneous flow measurements
Return flow from EPID Ditch	6.9	Average of 2 instantaneous flow measurements
Antelope Creek	4.5	Linear interpolation of 2 instantaneous measurements

Figure A45. Tributary flows and irrigaton system withdrawals. Lake Creek and Salt Creek are not shown (<0.008 cms).

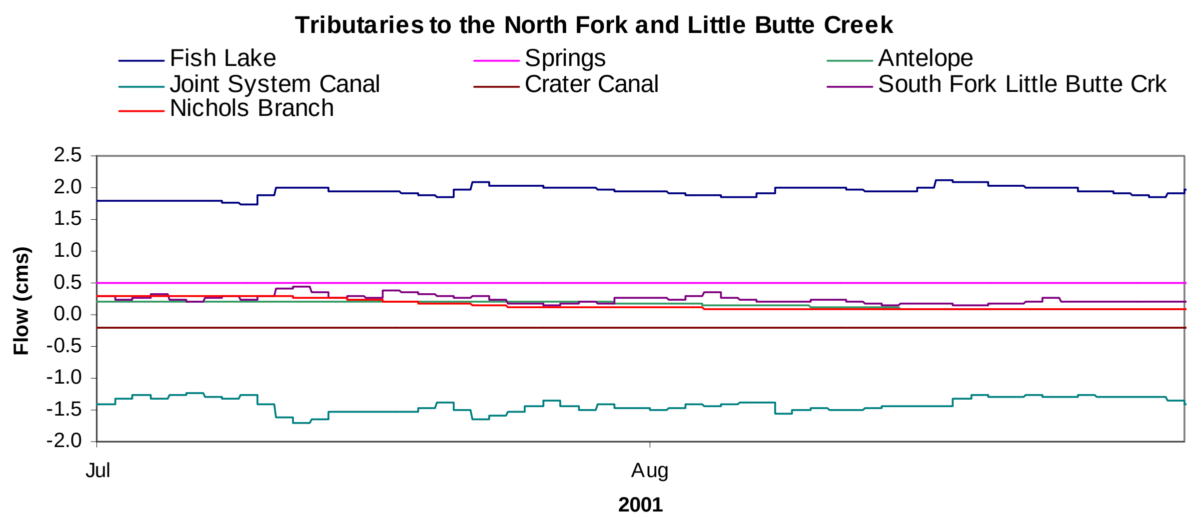


Figure A46. Sum of the withdrawals in the downstream direction not including the two diversions presented in Table A14 because they are dynamic.

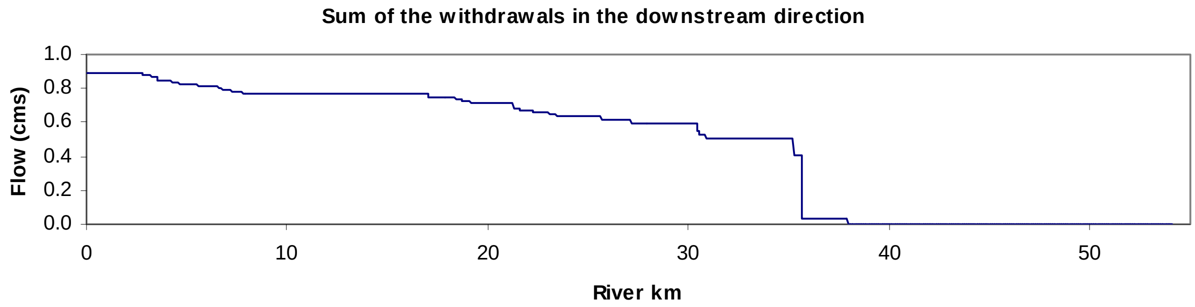


Figure A47. Time series of measured flow versus model results.

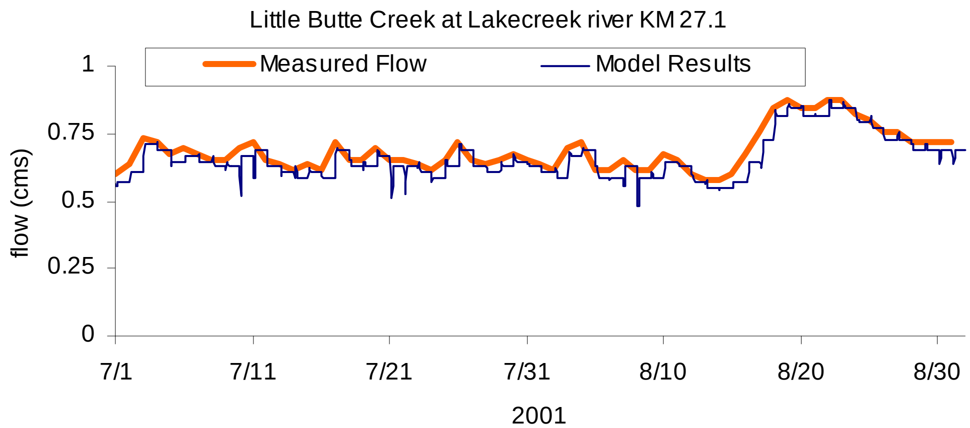
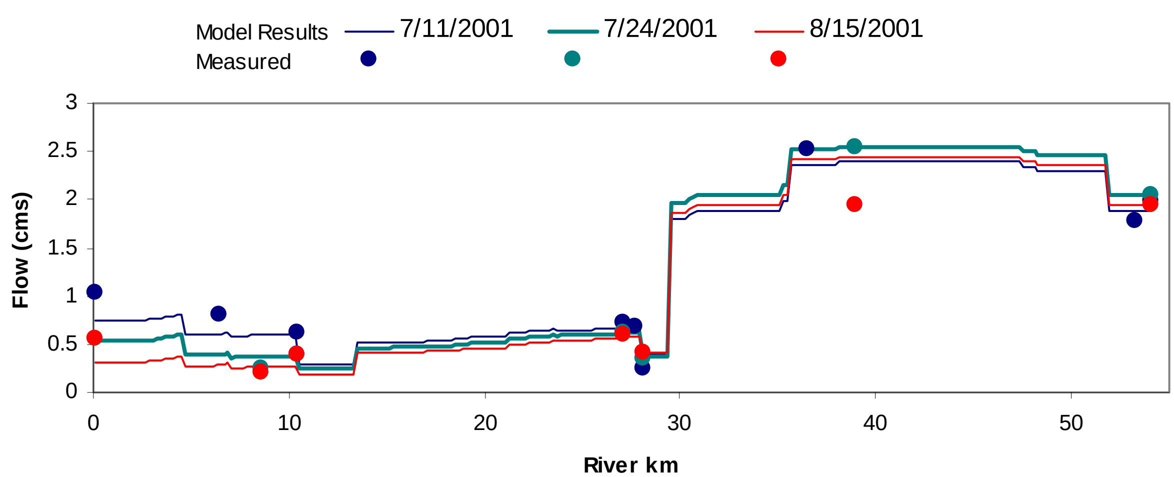


Figure A48. Longitudinal profile of measured flow versus model results. Model results are represent by lines while measurements by points. Each color represents a different day.



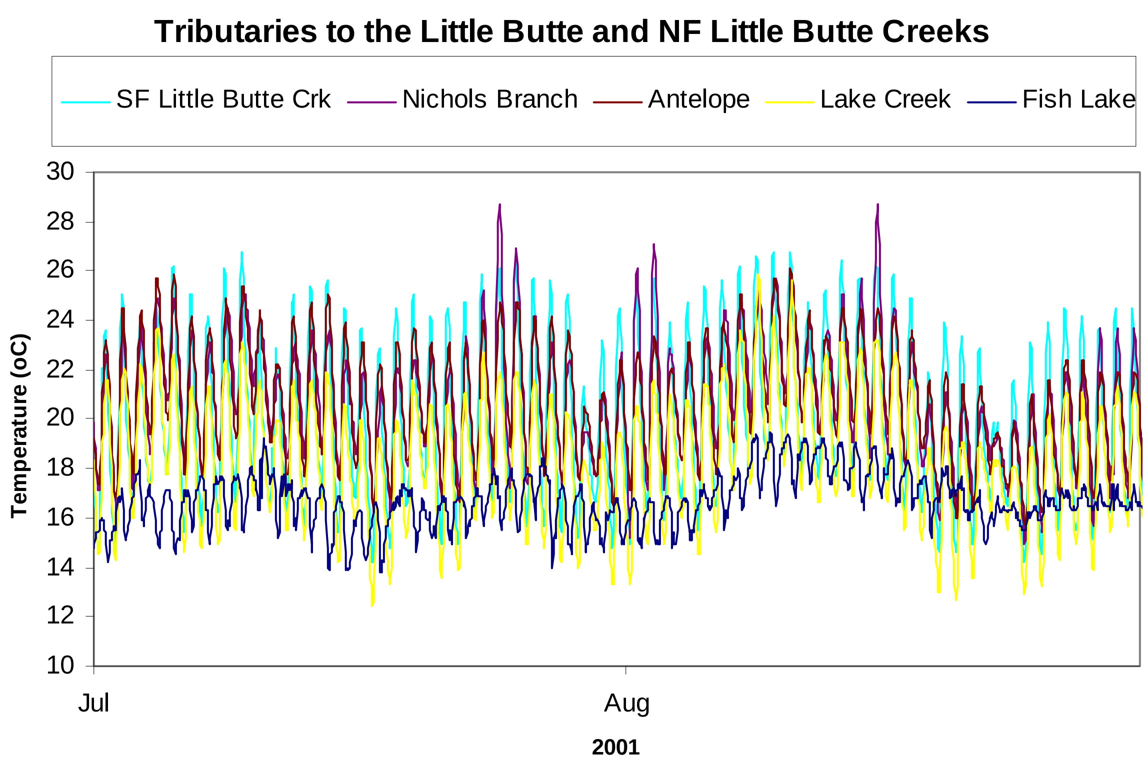
Temperature

Table A15 and **Figure A49** document the temperatures of the tributaries, springs and canal returns incorporated in the model.

Table A15. Source of tributary and boundary condition temperature inputs for Little Butte Creek model

Inflow	Stream km	Source of temperature data
Fish Lake outlet	54.1	DEQ data site #25598
Springs	52 - 47	Estimate based on average annual air temperature (8 °C)
SF Little Butte	27.9	DEQ data site #25595
Lake Creek	27.23	DEQ data site #25594
Salt Creek	23.55	Estimate
Nichols Branch	10.3	DEQ data site #25591
Return flow from Buchanan Ditch	6.95	Estimate (22 °C)
Return flow from EPID Ditch	6.9	Estimate (22 °C)
Antelope Creek	4.5	DEQ data site #25584

Figure A49. Temperature inputs of tributaries to the Little Butte Creek model.



Temperature Calibration

The model outputs generally reproduced spatially and temporally varying temperature measurements (**Table A16 and Table A17, and Figure A50 & Figure A51**). See previous statistics discussion at the beginning of **Section 4** for definitions.

Table A16. TIR error statistics

Error type	value
mean	-0.23
Absolute mean	0.78
Root mean square	1.41
Nash-Sutcliffe	0.85

Figure A50. Longitudinal profile of measured temperatures using Thermal Infrared Radiometry and model results. The disconnect in the model results around river km 42 is because the model output is hourly and changes from one hour to the next at this point for best comparison to the measurements.

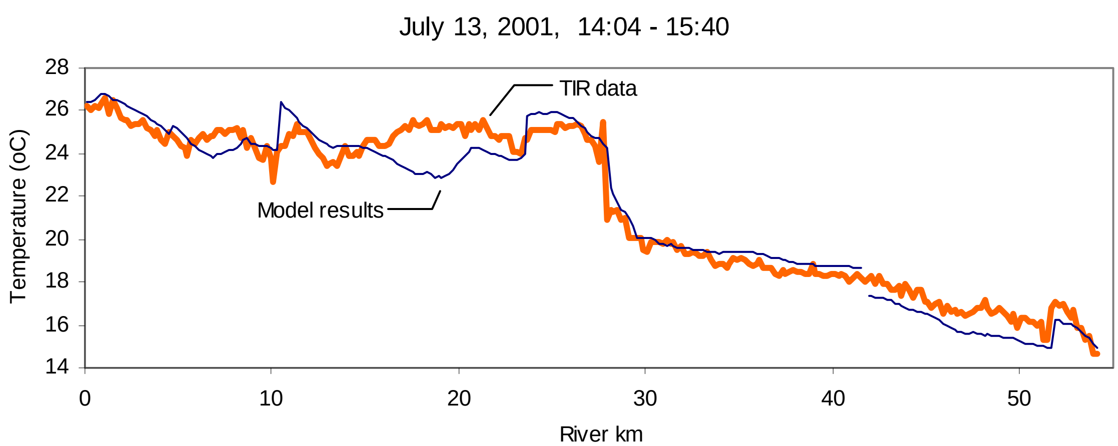
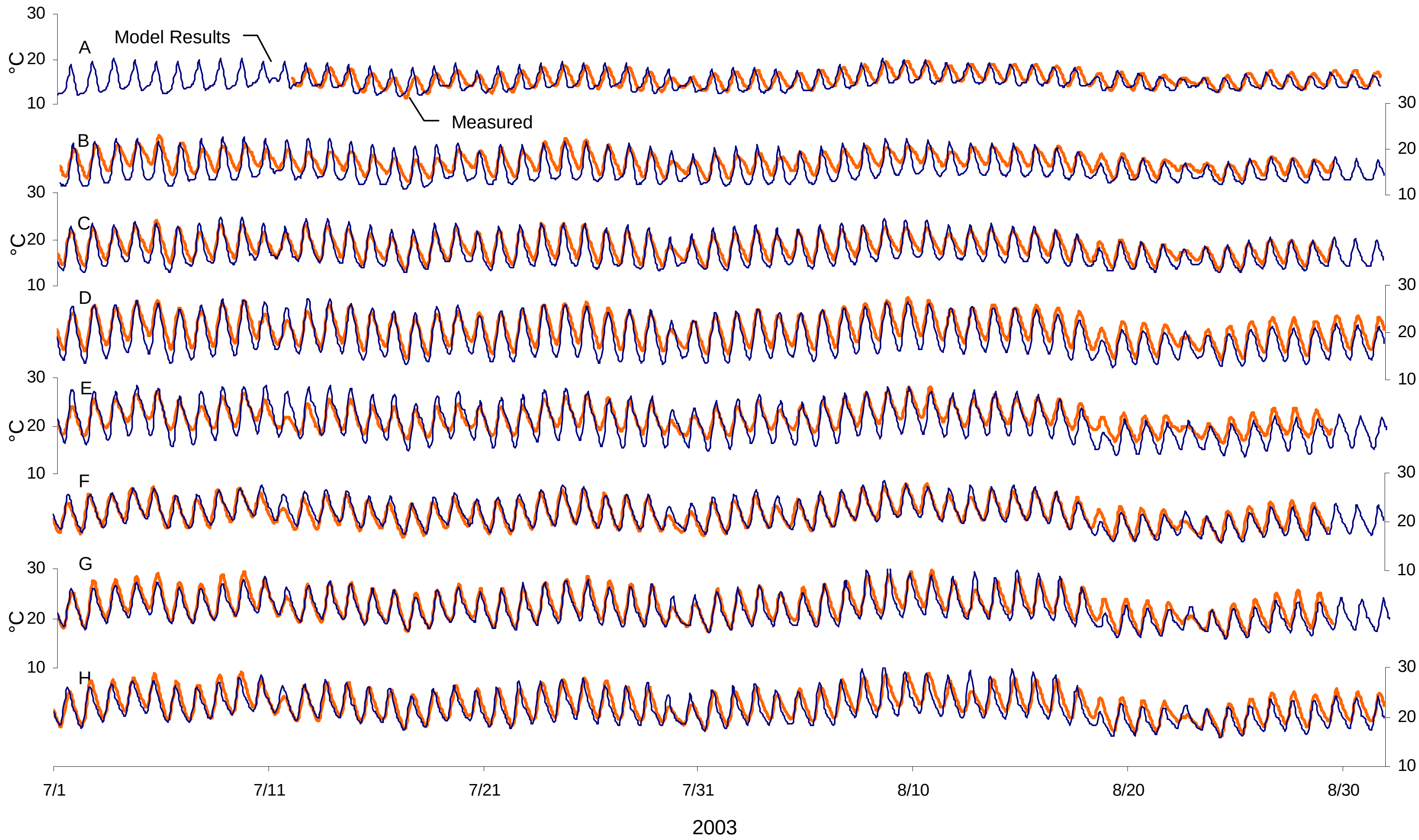


Table A17. Continuous monitoring error statistics

				All data					Daily Maximums			
Site Name	Site #*	Ref	rKM	n	Mean Error	Abs Mean Error	RMSE	Nash-Sutcliffe	n	Mean Error	Abs Mean Error	RMSE
N. Fork Little Butte Creek @ gage / Hwy 140	LB43	A	36.45	1224	-0.57	1.35	1.65	-0.06	52	0.48	0.81	1.00
N. Fork Little Butte Creek @ Little Butte RM 0.1	25596	B	28	1430	-1.58	1.92	2.24	-0.33	59	1.00	1.22	1.49
Little Butte Creek d/s forks' confluence RM 19.1	25789	C	27.78	1430	-0.97	1.22	1.42	0.62	59	0.91	0.98	1.12
Little Butte Creek @ R.M. 11.8	LB18	D	19.23	1488	-1.55	1.72	1.92	0.57	62	-0.09	1.00	1.21
Little Butte Creek u/s Nichols Branch	25592	E	10.48	1426	-0.83	1.58	1.94	0.34	59	1.01	1.57	1.82
Little Butte Creek u/s Hwy. 62 bridge @ gage	25585	F	6.58	1426	-0.06	0.87	1.08	0.81	59	0.48	0.87	1.05
Little Butte Creek @ Agate Rd	10602	G	2.3	1424	-0.76	0.97	1.17	0.83	59	-0.19	0.99	1.24
Little Butte Creek @ Agate Rd Bridge	LB33	H	2.2	1488	-0.70	1.32	1.55	0.66	62	0.13	0.98	1.23
Average					-0.88	1.37	1.62	0.43		0.46	1.05	1.27

* Sites labeled as LB were reported by Medford Water Commission. All other data was collected by DEQ.

Figure A51. Measured steam temperature versus model results

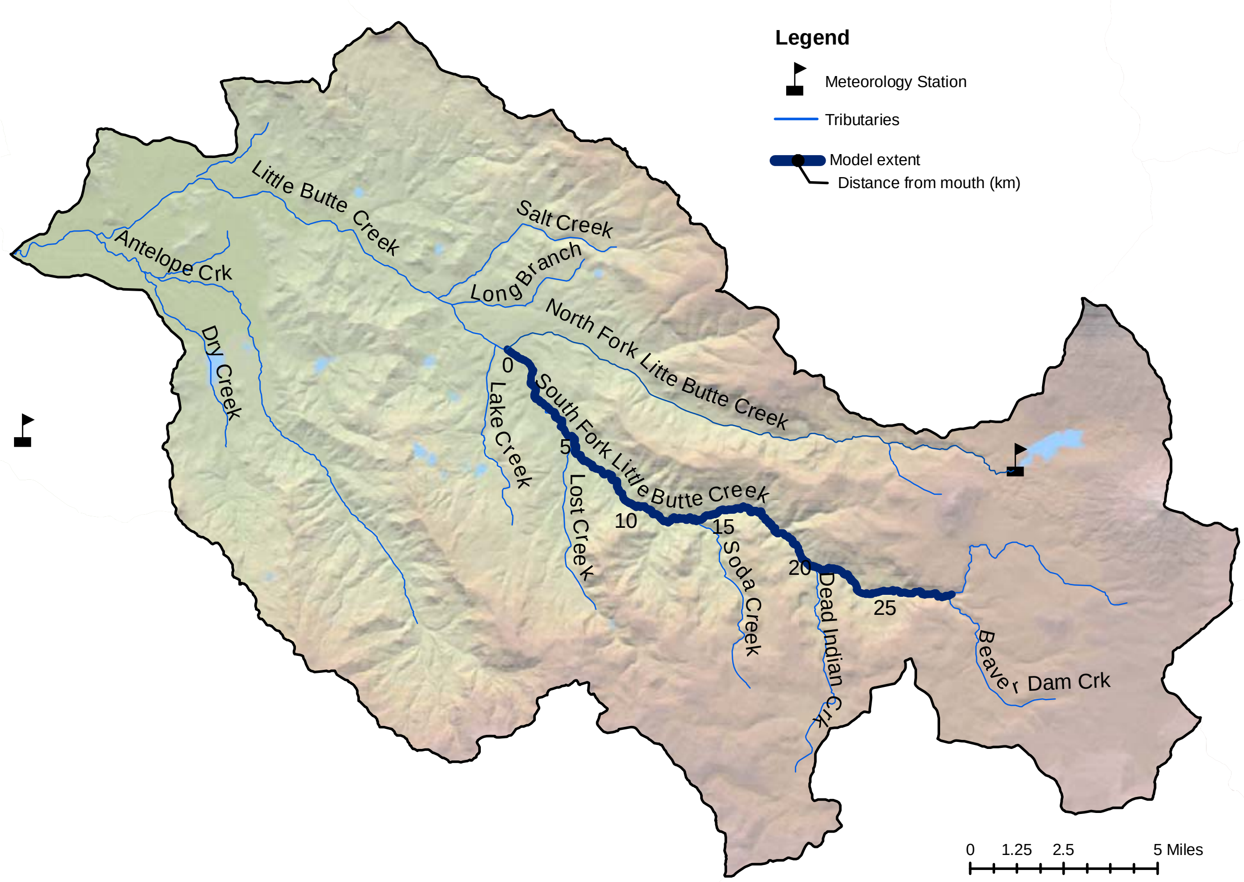


4.4 South Fork Little Butte Creek

Overview

Stream Name: South Fork Little Butte Creek
Model: Heat Source version 8.0
Beginning date: 7/1/2001
Ending date: 8/31/2001
Time step: 0.5 minute
Distance step: 100 m
Extent: Confluence with Little Butte Creek to just upstream of Beaver Dam Creek (river km 28.5) (**Figure A52**).

Figure A52. Extent of the South Fork Little Butte temperature model



Reach Properties

The channel properties were determined using the methodology documented previously in this report (see **Section 3**). **Figure A53** shows the elevation profile and reach gradient. The bottom width was derived using the active channel width measured from aerial photographs. Bottom width was estimated by assuming a trapezoidal channel with side slopes that are three times as long as they are high and also using a variable width-to-depth ratio determined through model calibration (**Figure A54**). Non-spatially varying coefficients are presented in **Table A18**. Manning's n was iteratively altered so that the model temperatures approximately reproduced measured temperatures (**Figure A55**). Percent hyporheic exchange values (**Figure A56**) were modified based on information from project consultant TetraTech (see **Appendix C**). Topographic and riparian vegetation heights were determined through a GIS analysis

(**Figure A57 -- Figure A59**). Using these channel and vegetation inputs, the performance of the South Fork Little Butte Creek model in predicting shade is shown in **Figure A60**.

Figure A53. Model setup channel elevation and gradient.

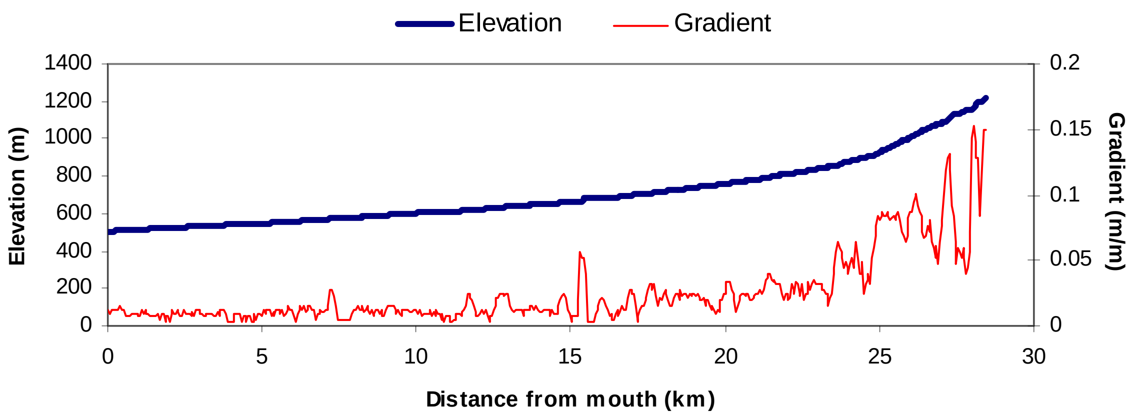


Figure A54, Model setup for channel bottom width and channel angle.

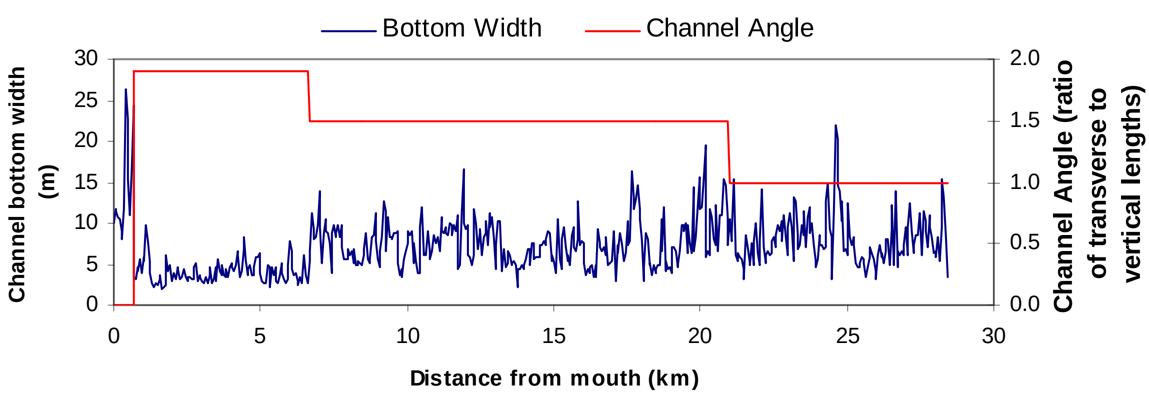


Table A18. Model coefficients for non-spatially varying parameters.

Parameter name (units)	Value
Wind Function, coefficient a	1.51×10^{-9}
Wind Function, coefficient b	1.60×10^{-9}
Sediment Thermal Conductivity (W/m/°C)	1.57
Sediment Thermal Diffusivity (cm^2/sec)	0.0064
Porosity	30%

Figure A55. Model setup for roughness coefficient

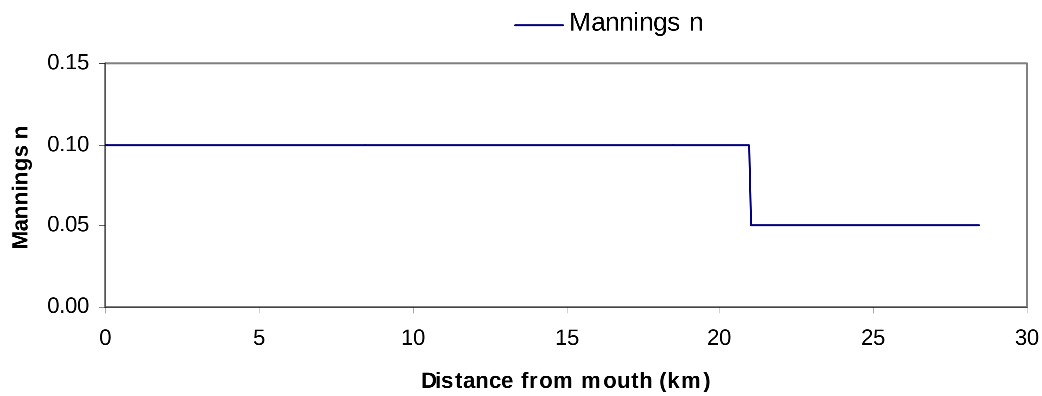


Figure A56. Model setup for substrate parameters. Hyporheic exchange is the percent of the stream flow which is transferred to and from the shallow groundwater per a 50 meter reach.

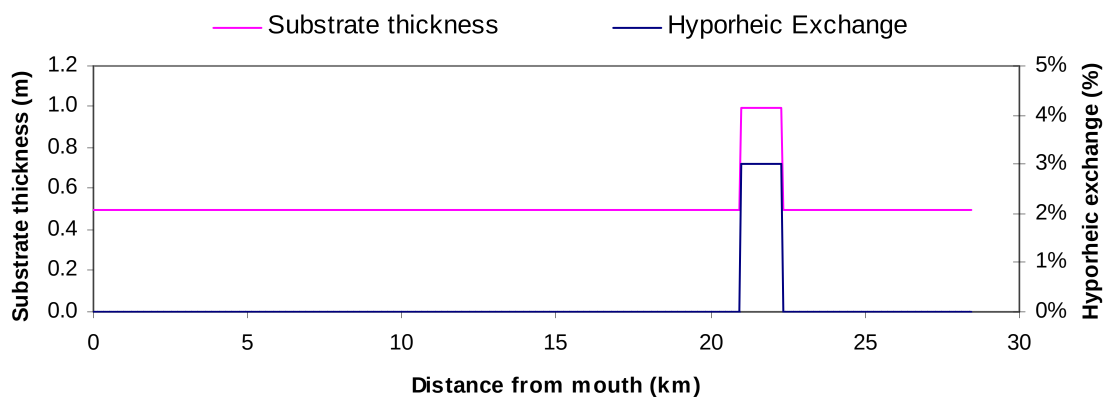


Figure A57. Model setup for topographic angle

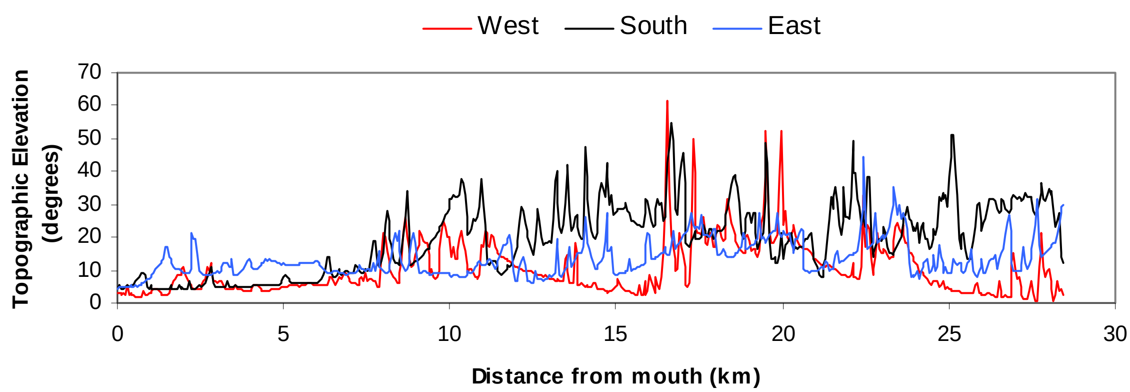


Figure A58. Model setup for height of streamside vegetation

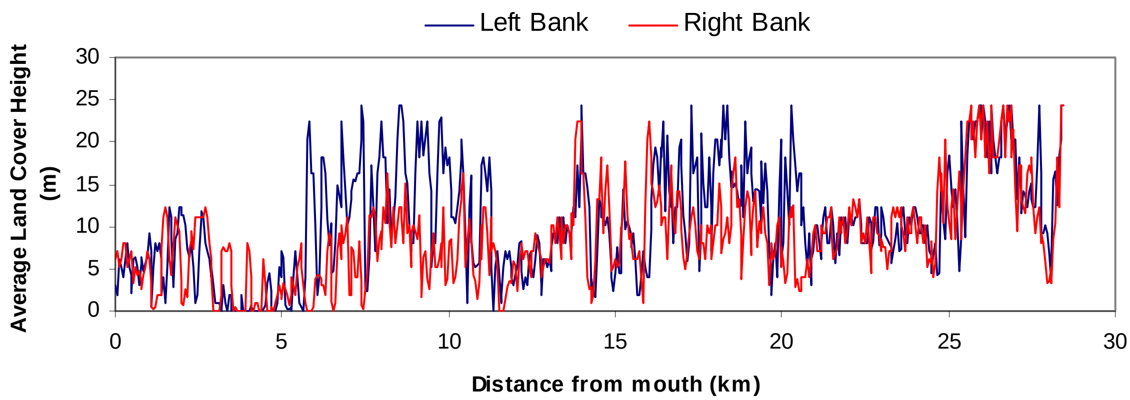


Figure A59. Model setup for density of streamside vegetation.

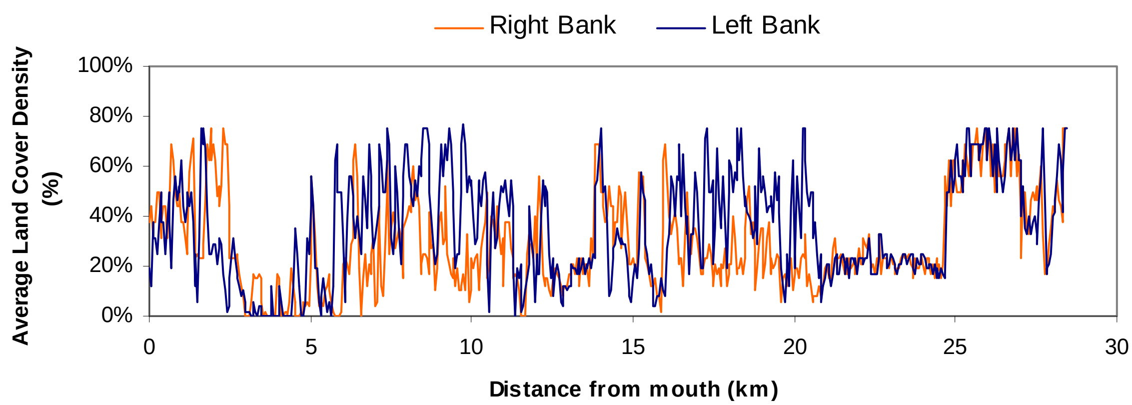
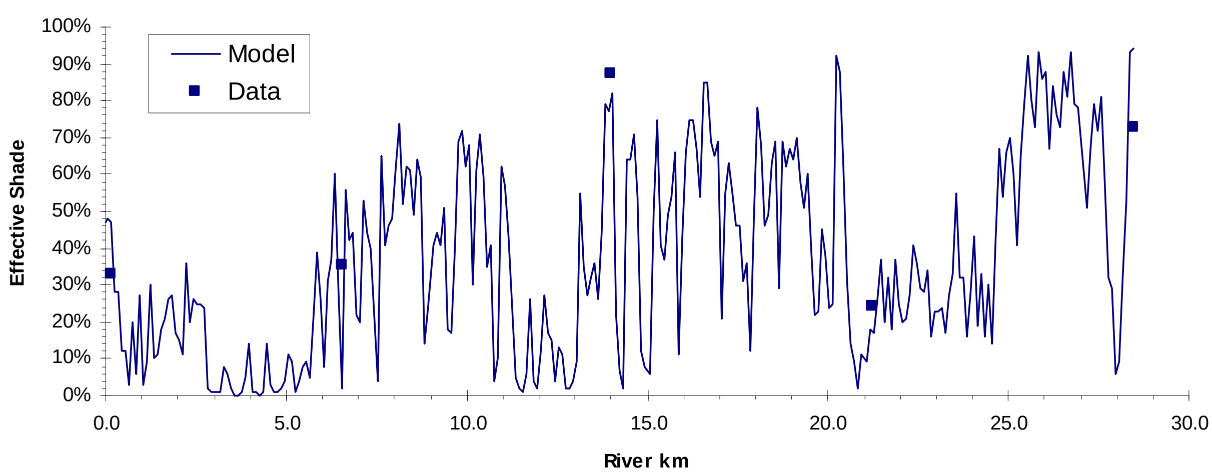


Figure A60. Predicted versus measured effective shade



Meteorology

The model used air temperature, relative humidity, wind speed and cloudiness data from the Medford airport. These data are presented in the Little Butte Creek and North Fork Little Butte Creek section of this Appendix. The meteorological inputs varied by stream kilometer based on proximity to the weather station (**Table A19**). A multiplicative wind sheltering coefficient was applied to the wind speed for calibration.

Table A19. Source of meteorological inputs into model. See Little Butte Creek model setup for data.

Range (river km)	Cloudiness	Relative Humidity	Air Temperature	Wind Speed	Wind sheltering Coefficient
28 -18	Medford	Medford	Medford	Medford	0.5
18 - 0	Medford	Medford	Medford	Medford	0.1

Flow

No continuous gage data for were available for 2001, so flows were based on instantaneous flow measurements and mass balance derived from temperature data (**Table A20 & Figure A61**). Flow balance was derived through various methods including using the TIR temperatures and upstream flow. In order to match instream measured flows, additional water loss was necessary between river km 21 and 25. There is only very limited reported withdrawals for agriculture in this reach. Therefore, it is likely that this is a losing reach and the decrease in flow is not anthropogenic. Water losses further downstream correspond with information provided by Oregon Water Resources Department on consumptive use (**Figure A62**). The temporal component of consumptive use was estimated based on the irrigation season. Using these flow inputs, the performance of the South Fork Little Butte Creek model at several locations is shown in **Figure A63**.

Table A20. Source of flow information for South Fork Little Butte Creek model.

Inflow/outflow	Stream km	Source
Headwaters	28.45	Instantaneous flow measurement
Beaver Dam Creek	28.3	Instantaneous flow measurement
Dead Indian Creek	20.9	Instantaneous flow measurement
Soda Creek	13.8	Instantaneous flow measurement
Diversion to Joint System Canal	1.75	Temperature and flow balance
Spill from canal	0.7	Temperature and flow balance

Figure A61. Tributary flows and irrigaton system withdrawals

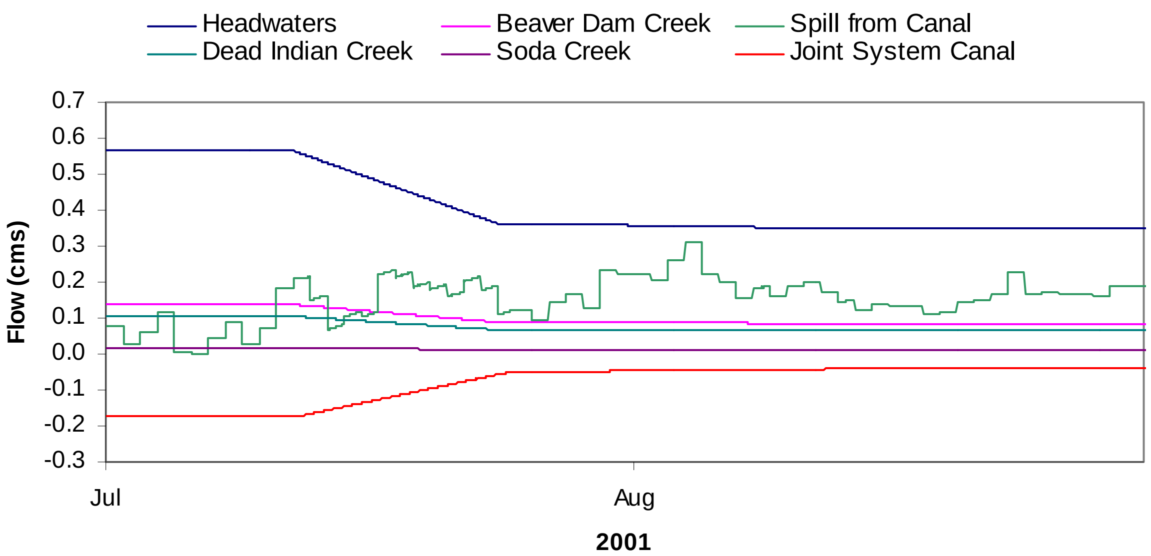


Figure A62. Sum of the withdrawals in the downstream direction not included above in Figure A61.

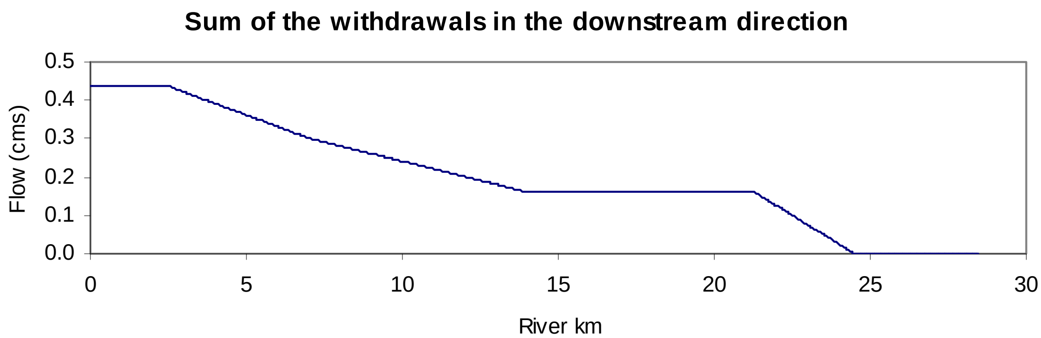
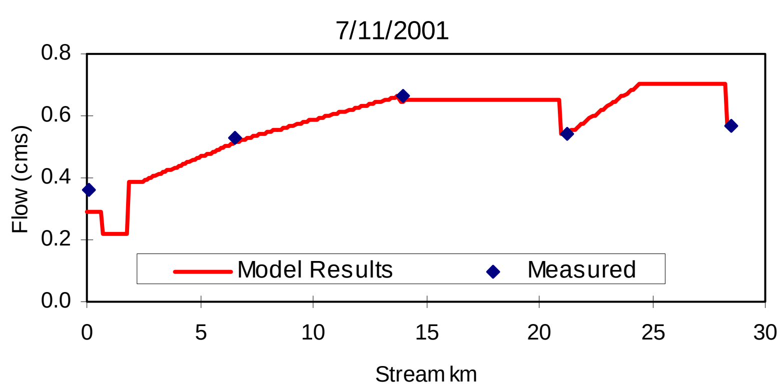


Figure A63. Longitudinal profile of measured flow versus model results.



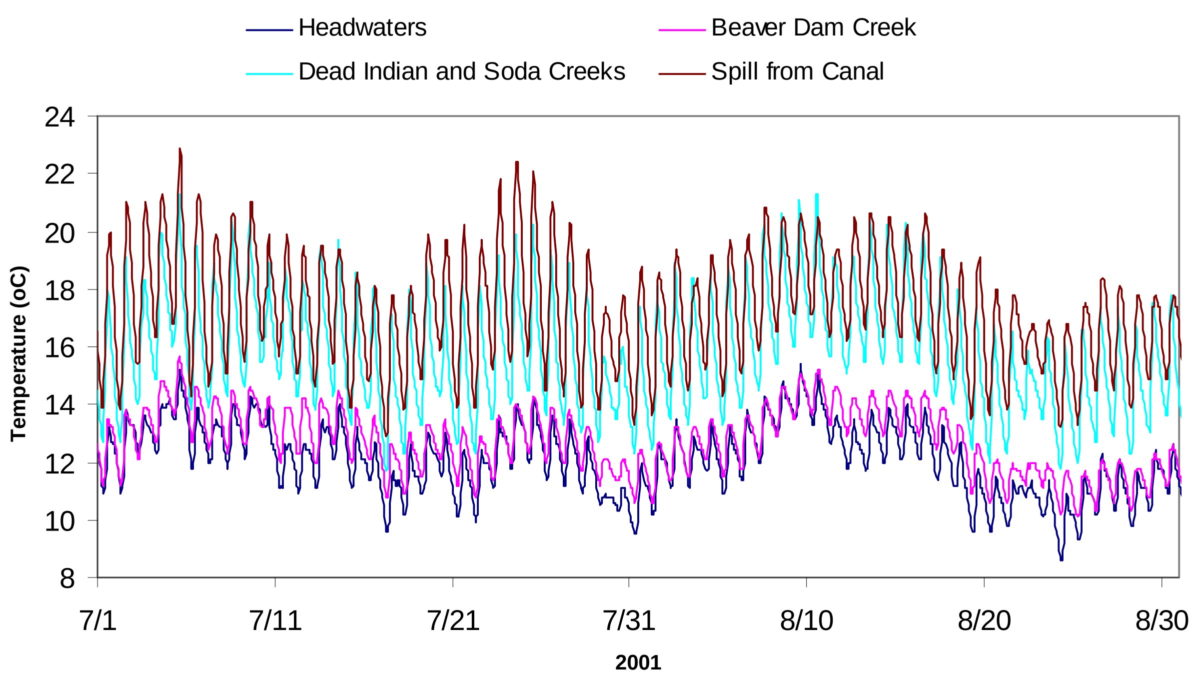
Temperature

Table A21 and **Figure A64** document the temperatures of the tributaries and canal spills incorporated in the model.

Table A21. Source of tributary and boundary condition temperature inputs for the South Fork Butte Creek model.

Inflow	Stream km	Source
Headwaters	28.45	DEQ site #25799
Beaver Dam Creek	28.3	DEQ site #25798
Dead Indian Creek	20.9	DEQ site #25797
Soda Creek	13.8	Used Dead Indian Creek as a surrogate
Spill from canal	0.7	North Fork Little Butte Creek at mouth measurements (water in the canal is originates in the north fork not far from this location)

Figure A64. Temperature inputs of tributaries to the South Fork Little Butte Creek model.



Temperature Calibration

The model outputs generally reproduced spatially and temporally varying temperature measurements (**Table A22 and Table A23 and Figure A65 & Figure A66**). See previous statistics discussion at the beginning of **Section 4** for definitions.

Table A22. TIR error statistics

Error type	value
mean	-0.29
Absolute mean	0.67
Root mean square	0.86
Nash-Sutcliffe	0.95

Figure A65. Longitudinal profile of measured temperatures using Thermal Infrared Radiometry and model results

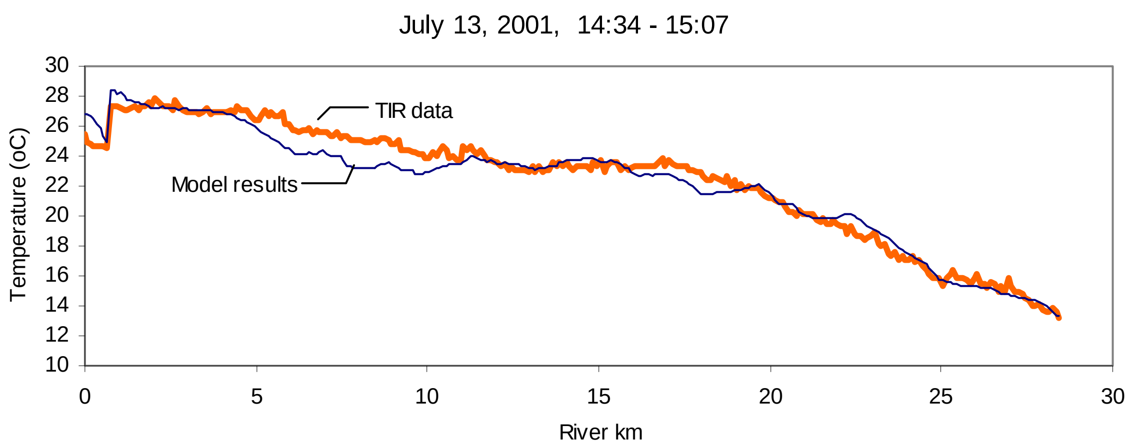
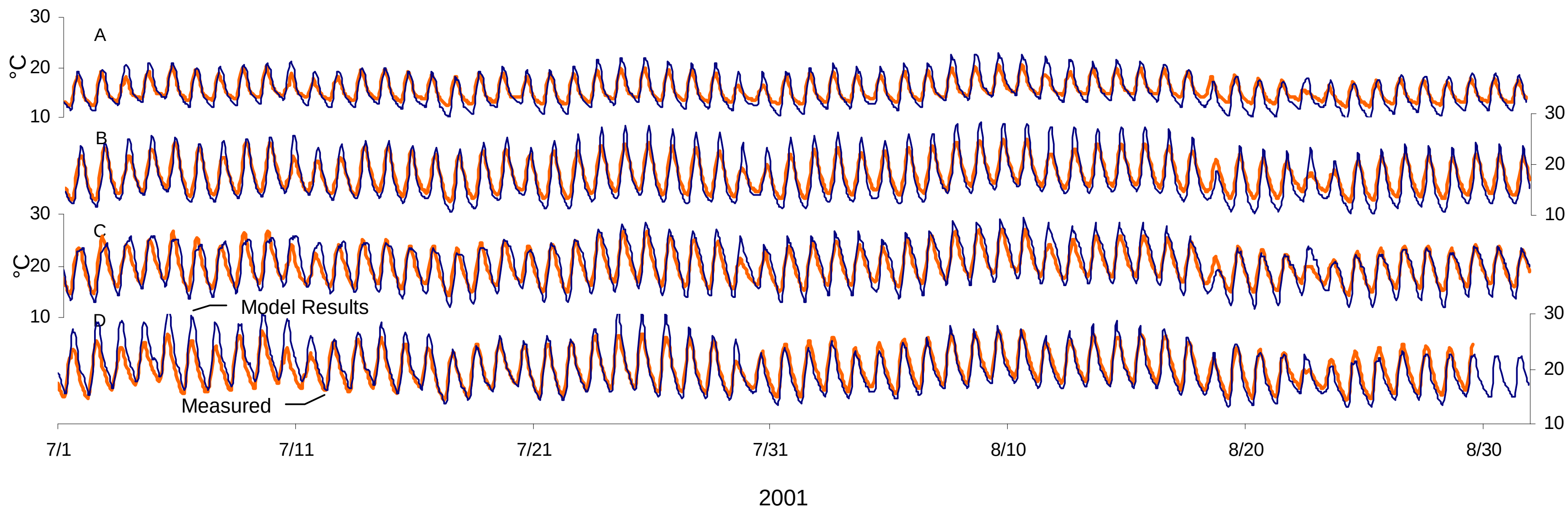


Table A23. Continuous monitoring error statistics

				All data					Daily Maximums			
Site Name	DEQ Site #	Ref	rKM	n	Mean Error	Abs Mean Error	RMSE	Nash-Sutcliffe	n	Mean Error	Abs Mean Error	RMSE
S. Fork Little Butte Creek u/s Dead Indian Cr.	25597	A	21.23	1488	-0.26	1.13	1.34	0.52	62	1.20	1.27	1.51
S. Fork Little Butte Creek u/s Soda Cr. RM 9.8	25795	B	13.98	1430	-0.67	1.57	1.81	0.64	62	2.50	2.58	2.80
S. Fork Little Butte Creek u/s Lost Cr. RM 4.5	25792	C	6.53	1488	0.15	1.54	1.84	0.62	59	1.39	1.90	2.38
S. Fork Little Butte Creek @ Little Butte Cr.	25595	D	0.13	1431	-0.06	1.35	1.66	0.71	62	2.01	2.56	4.64
Average					-0.21	1.40	1.66	0.62		1.21	1.28	1.53

Figure A66. Measured steam temperature versus model results

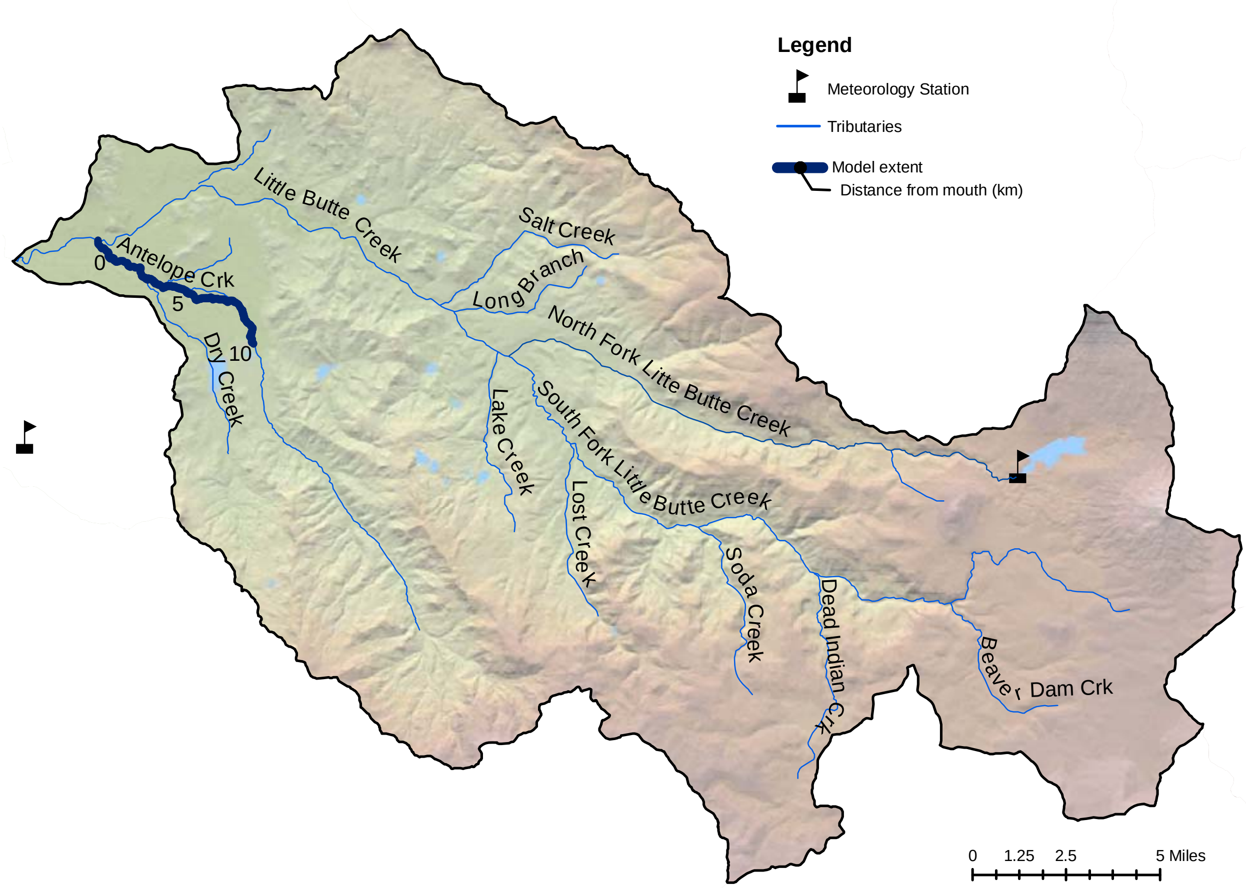


4.5 Antelope Creek

Overview

Stream Name: Antelope Creek
Model: Heat Source version 8.0
Beginning date: 7/1/2001
Ending date: 8/31/2001
Time step: 1 minute
Distance step: 100 m
Extent: Confluence with Little Butte Creek to just upstream of Yankee Creek (river km 10.1) (**Figure A67**).

Figure A67. Extent of the Antelope Creek temperature model.



Reach Properties

The channel properties were determined using the methodology documented previously in this report (see **Section 3**). **Figure A68** shows the elevation profile and reach gradient. The bottom width was derived using the active channel width measured from aerial photographs. Bottom width was estimated by assuming a trapezoidal channel with variable side slopes (**Figure A69**) and a constant width-to-depth ratio of 8 determined through model calibration. Non-spatially varying coefficients are presented in **Table A24**. Manning's n was iteratively altered so that the model temperatures approximately reproduced measured temperatures (**Figure A70)**. Topographic and riparian vegetation heights were determined through a GIS analysis (**Figure A71 -- Figure A73**). Unfortunately, there were no shade data available to corroborate the predicted effective shade.

Figure A68. Model setup channel elevation and gradient.

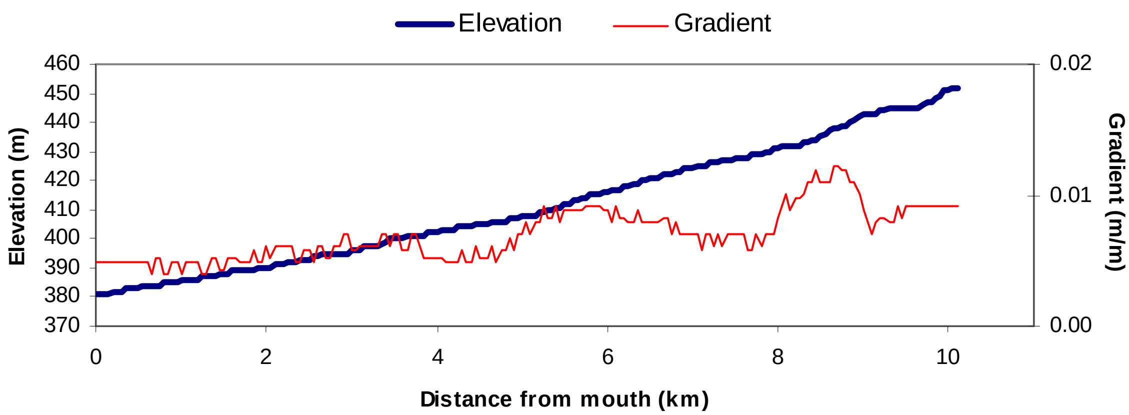


Figure A69. Model setup for channel bottom width and channel angle.

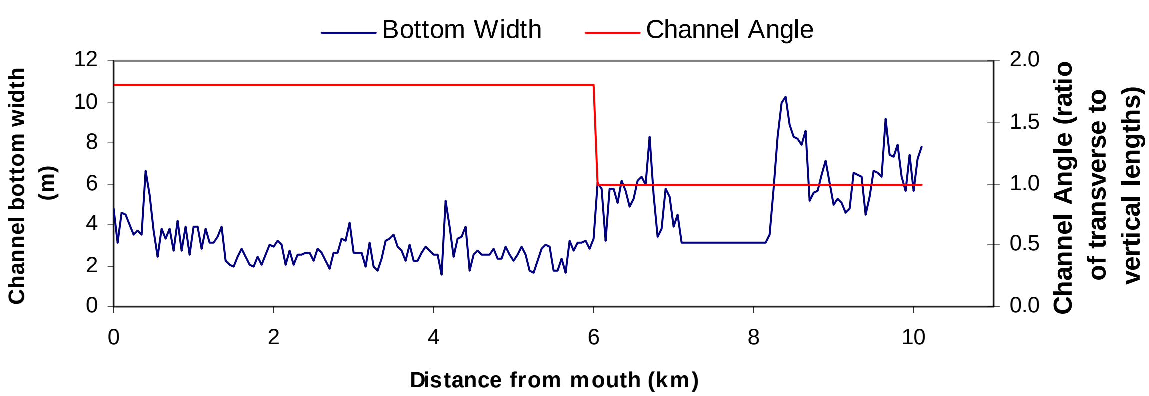


Table A24. Model coefficients for non-spatially varying parameters.

Parameter name (units)	Value
Wind Function, coefficient a	1.51×10^{-9}
Wind Function, coefficient b	1.60×10^{-9}
Sediment Thermal Conductivity (W/m/°C)	1.57
Sediment Thermal Diffusivity (cm^2/sec)	0.0064
Sediment / hyporheic zone thickness (m)	0.5
Percent Hyporheic Exchange	0%
Porosity	30%

Figure A70. Model setup for roughness coefficient.

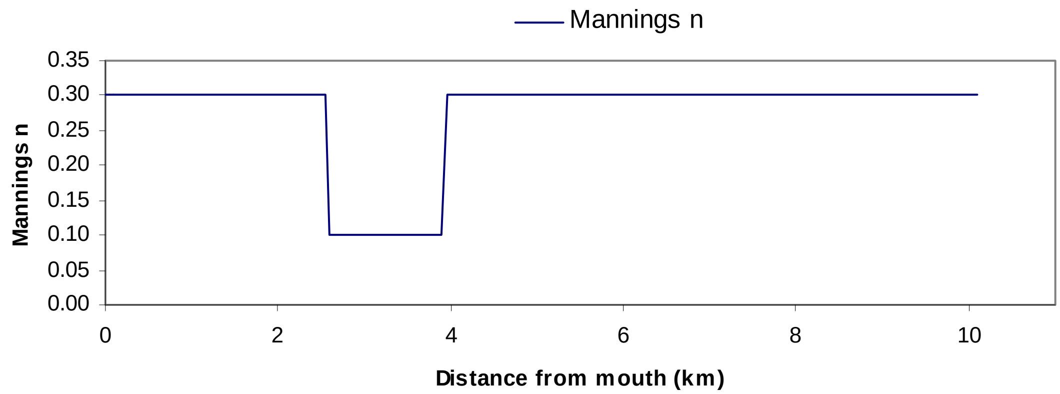


Figure A71. Model setup for topographic angle

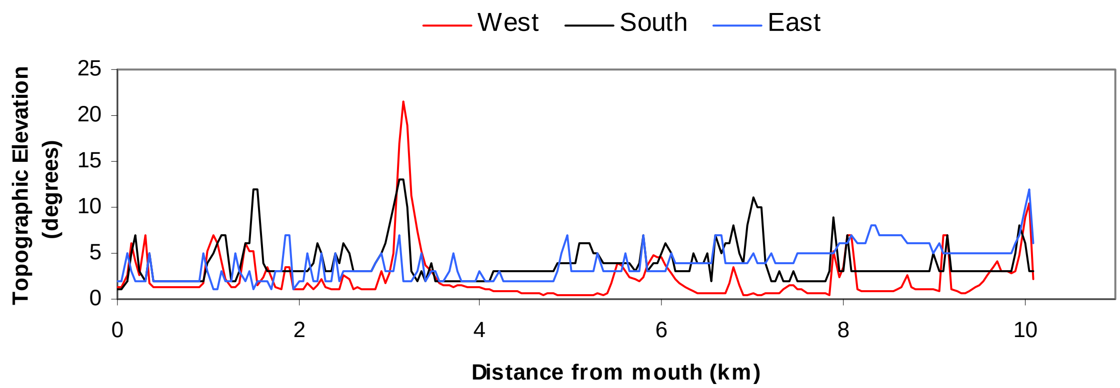


Figure A72. Model setup for height of streamside vegetation

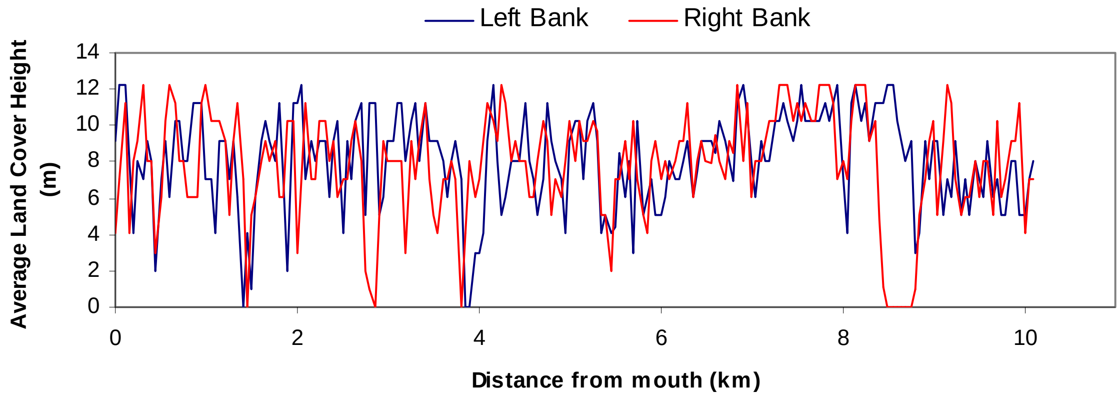
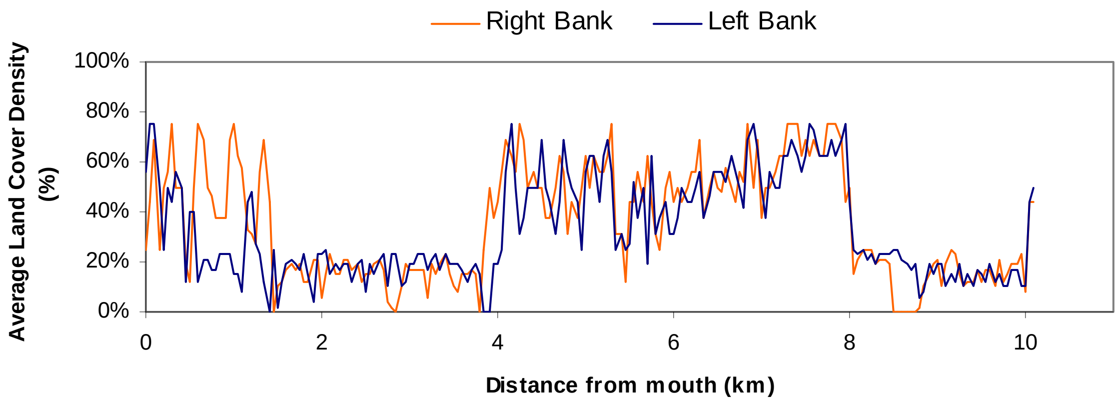


Figure A73. Model setup for density of streamside vegetation.



Meteorology

The model used air temperature, relative humidity, wind speed and cloudiness from the Medford airport. These data are presented in the Little Butte Creek and North Fork Little Butte Creek section of this Appendix. The meteorological inputs varied by stream kilometer based on proximity to the weather station (**Table A25**). A multiplicative wind sheltering coefficient was applied to the wind speed for calibration.

Table A25. Source of meteorology inputs (see graphs from Little Butte Creek model section).

Range (river km)	Cloudiness	Relative Humidity	Air Temperature	Wind Speed	Wind sheltering Coefficient
10.1 - 0	Medford	Medford	Medford	Medford	0.5

Flow and temperature

No continuous gage data were available for 2001 and only one instantaneous flow measurement was collected at the mouth. WRD reports 1.3 cfs withdrawal in the model reach, with 2.5 cfs total withdrawal on Antelope Creek. However, given the paucity of flow data, the withdrawals were not included in the calibrated model. Temporally variable flows were computed to match inflows into the Little Butte Creek model. The flow at the mouth was proportioned to the headwater, Quarter Branch (river km 4.05) and Dry Creek (river km 3.35) based on professional judgment (**Figure A74**).

The headwater temperature condition was based on continuous monitoring (site: Antelope Creek at Yankee Road Bridge) (**Figure A75**). The same temperature values were applied to Quarter Branch and Dry Creek, because no data were available. Using these flow inputs, the performance of the Antelope Creek model at several locations is shown in **Figure A76**.

Figure A74. Tributary flow boundary conditions

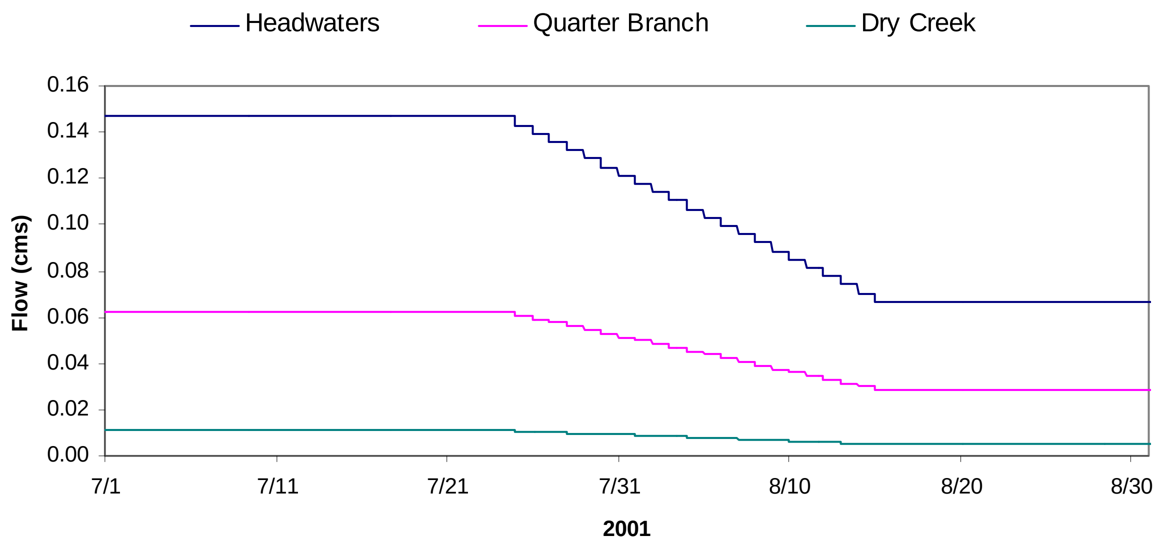


Figure A75. Temperature boundary conditions.

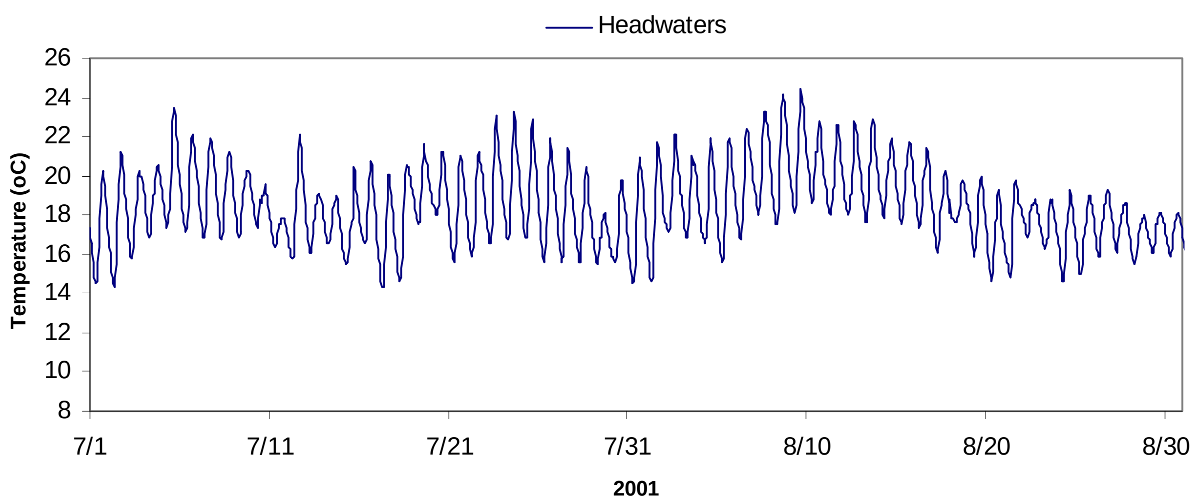
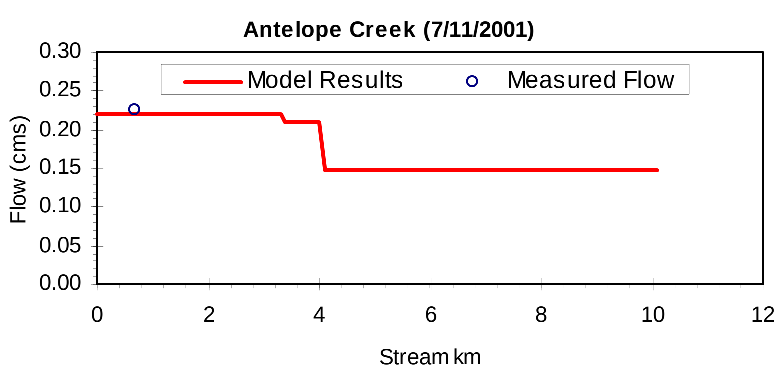


Figure A76. Longitudinal profile of measured flow versus model results.



Temperature Calibration

The model outputs generally reproduced spatially and temporally varying temperature measurements (**Table A26 and Table A27 and Figure A77 & Figure A78**). See previous statistics discussion at the beginning of **Section 4** for definitions.

Table A26. TIR error statistics

Error type	value
mean	-0.49
Absolute mean	0.50
Root mean square	0.63
Nash-Sutcliffe	-0.18

Figure A77. Longitudinal profile of measured temperatures using Thermal Infrared Radiometry and model results.

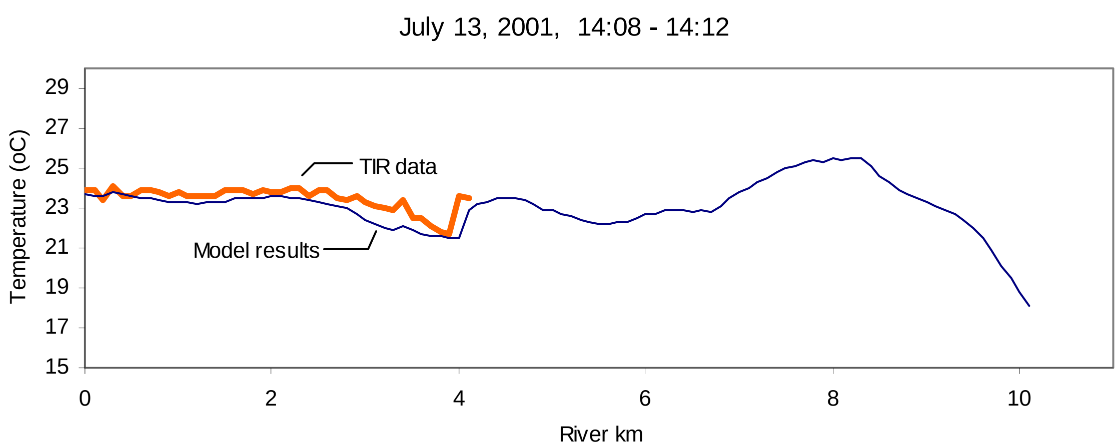
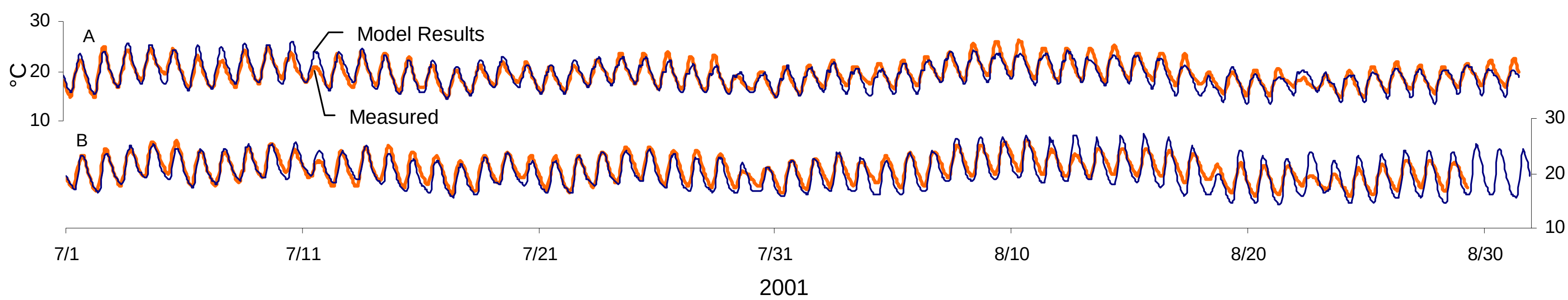


Table A27. Continuous monitoring error statistics

				All data					Daily Maximums			
Site Name	Site #*	Ref	rKM	n	Mean Error	Abs Mean Error	RMSE	Nash-Sutcliffe	n	Mean Error	Abs Mean Error	RMSE
Antelope Creek @ Riley Road	LB17	A	5.45	1488	-0.25	0.87	1.09	0.79	62	-0.27	1.09	1.29
Antelope Creek @ Little Butte RM 0.1	25584	B	0.30	1425	-0.58	1.11	1.33	0.66	59	0.62	1.12	1.45
Average					-0.41	0.99	1.21	0.73		0.17	1.10	1.37

* Site labeled as LB was collected by Medford Water Commission. Data at the other site was collected by DEQ.

Figure A78. Measured steam temperature versus model results.

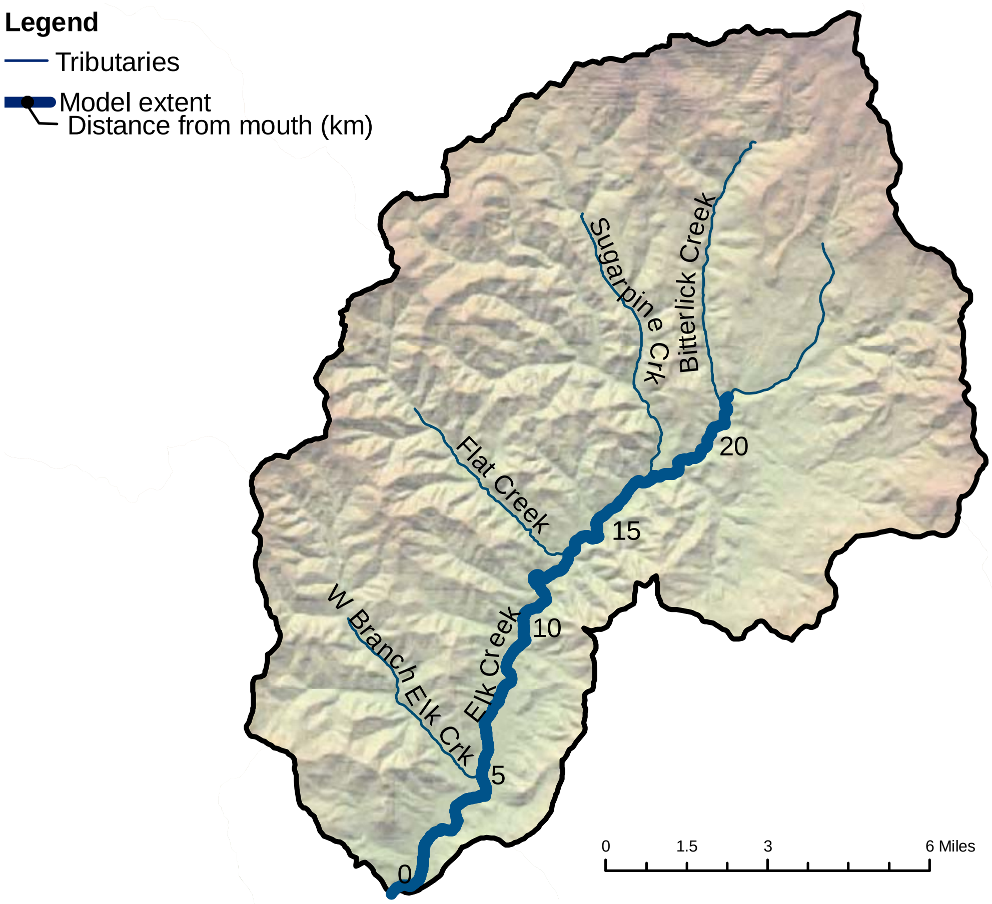


4.6 Elk Creek

Overview

Stream Name: Elk Creek
Model: Heat Source version 8.0
Beginning date: 7/1/2001
Ending date: 8/31/2001
Time step: 1 minute
Distance step: 100 m
Extent: Confluence with Rogue River to just upstream of Bitter Lick Creek at river km 22.5 (**Figure A79**).

Figure A79. Extent of the Elk Creek temperature model.



The model year (2001) was chosen based on the availability of data, and the model period (July and August) was based on times when impairments are typically most severe and nonpoint sources have the largest impact. The model only represents a single year, and hence the flow regime and weather patterns of that year. Stream temperatures near the mouth of Elk Creek during July and August, 2001 were generally warmer than the long term median temperatures (**Figure A80 & Figure A81**). During the model period, flows were less than the long term median flows, with some flows being the lowest recorded for a specific day. Using the 2001 model as the basis for scenarios will likely lead to a warmer prediction of NTP than if a year with more average conditions was used.

Figure A80. Comparison of observed river temperatures for Elk Creek near its mouth.

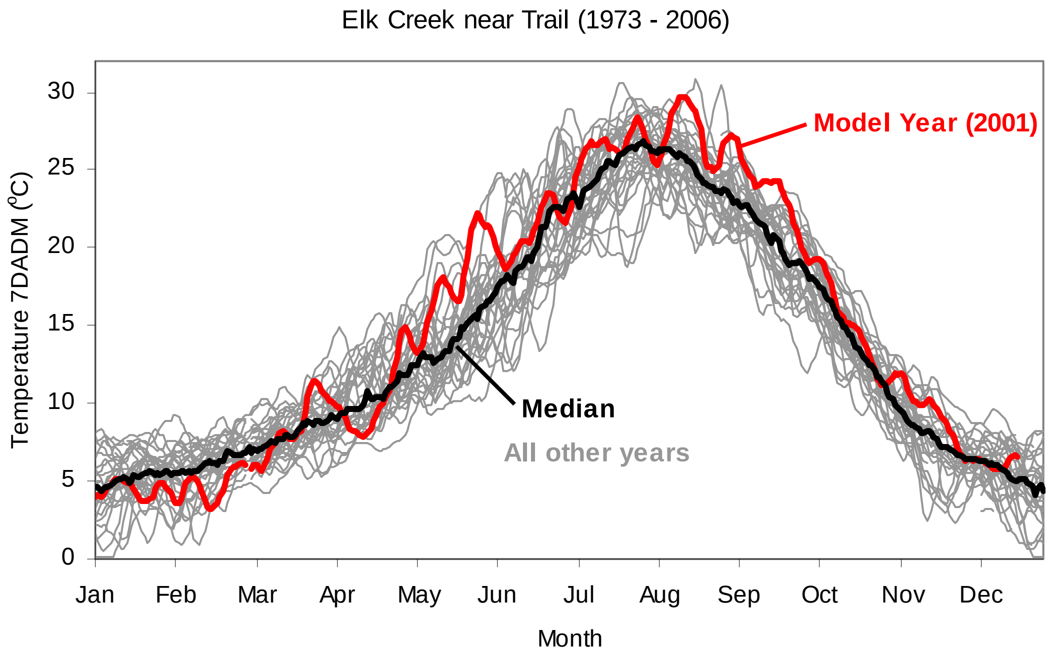
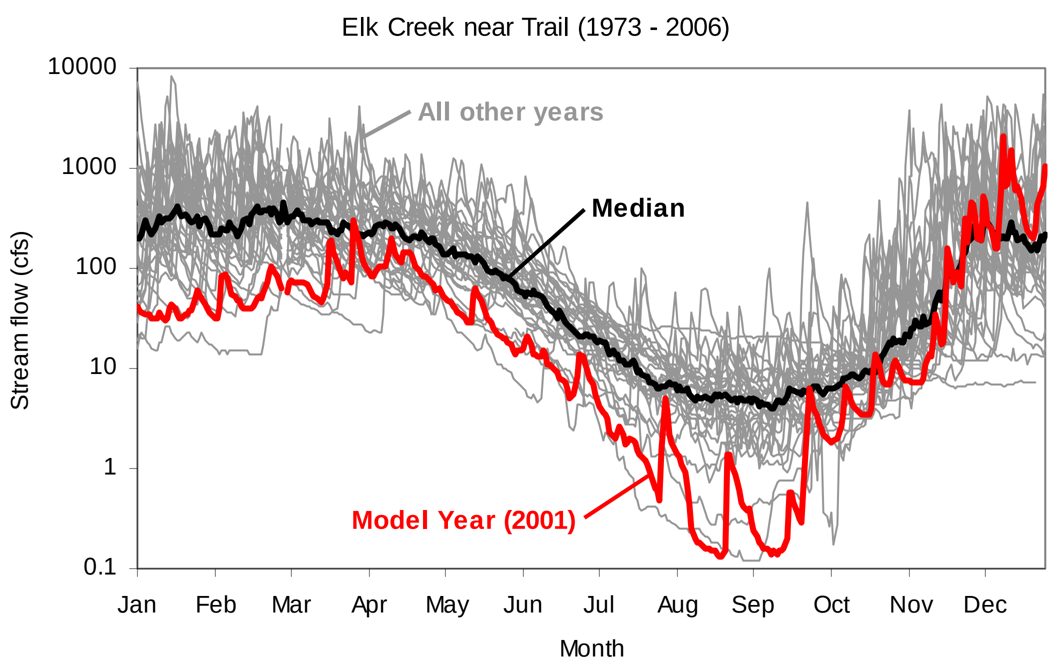


Figure A81. Comparison of observed river flow upstream for Elk Creek near its mouth.



Reach Properties

The channel properties were determined using the methodology documented previously in this report (see **Section 3**). The available digital elevation models (DEMs) represented a large reach of Elk Creek as the elevation of the pool behind the future dam, which was never completed (**Figure A82**). Therefore, an average slope was applied to this reach. The bottom width was derived using the active channel width measured from aerial photographs. Bottom width was estimated by assuming a trapezoidal channel with variable side slopes (**Figure A83**) and a constant width-to-depth ratio of 8 determined through model calibration. Non-spatially varying coefficients are presented in **Table A28**. Manning's n, substrate thickness and hyporheic exchange were iteratively altered so that the model temperatures approximately reproduced measured temperatures (**Figure A84 & Figure A85**). Topographic and riparian vegetation heights were determined through a GIS analysis (**Figure A86 -- Figure A88)**. Using these channel and vegetation inputs, the performance of the Elk Creek model in predicting shade is shown in **Figure A89**.

Figure A82. Model setup channel elevation and gradient.

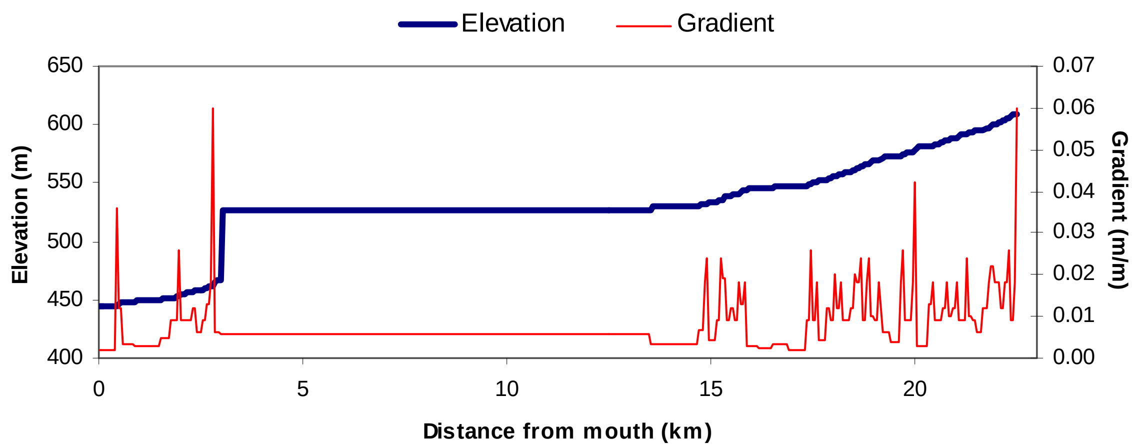


Figure A83. Model setup for channel bottom width and channel angle.

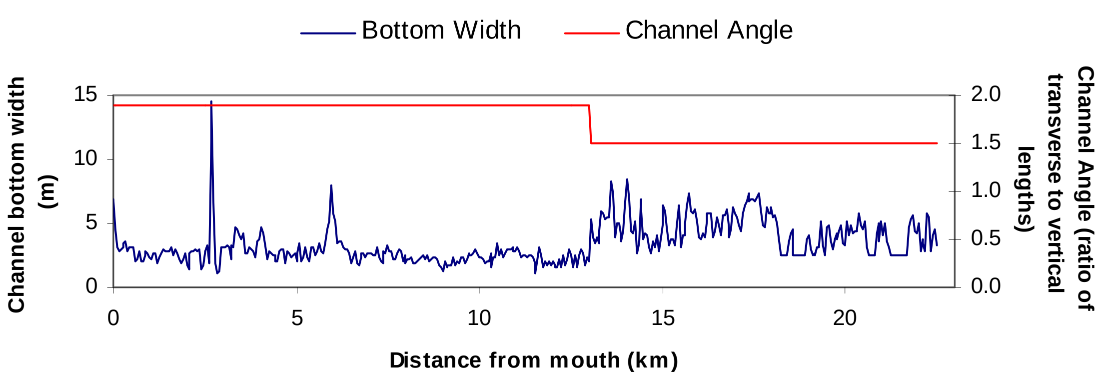


Table A28. Model coefficients for non-spatially varying parameters

Parameter name (units)	Value
Wind Function, coefficient a	1.51×10^{-9}
Wind Function, coefficient b	1.60×10^{-9}
Sediment Thermal Conductivity (W/m/°C)	1.57
Sediment Thermal Diffusivity (cm^2/sec)	0.0064
Porosity	33.0%

Figure A84. Model setup for roughness coefficient.

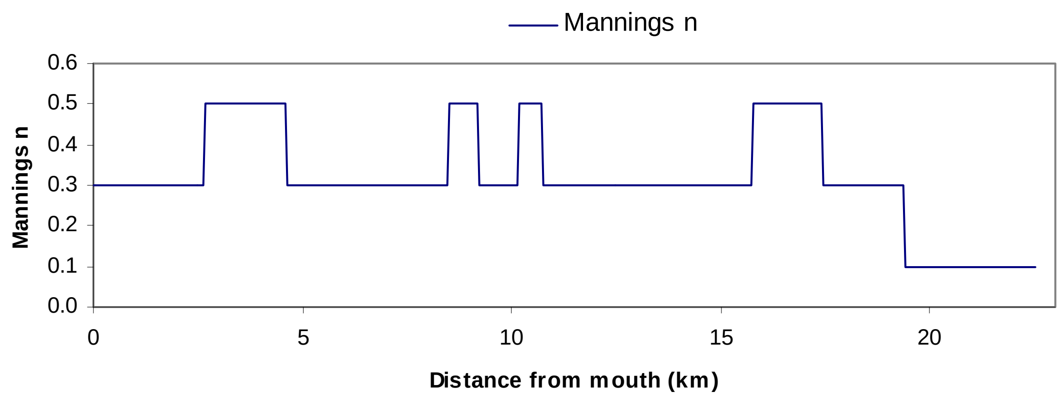


Figure A85. Model setup for substrate parameters. Hyporheic exchange is the percent of the stream flow which is transferred to and from the shallow groundwater per a 50 meter reach.

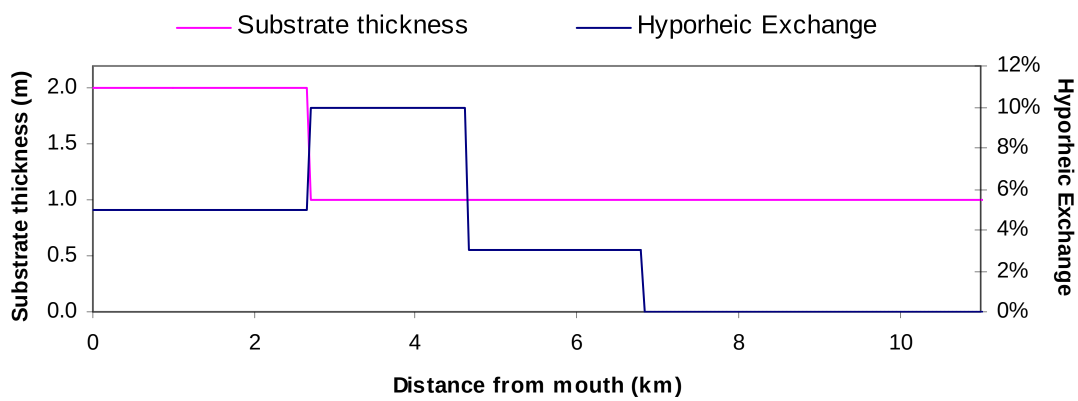


Figure A86. Model setup for topographic angle

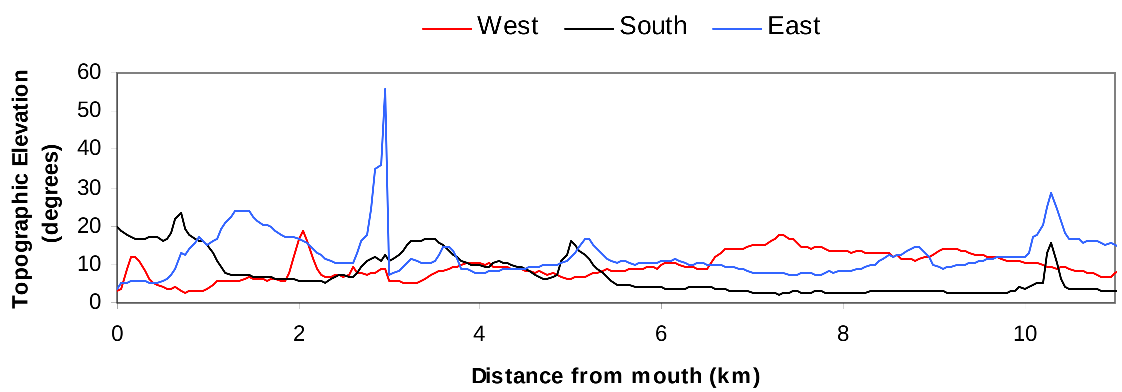


Figure A87. Model setup for height of streamside vegetation.

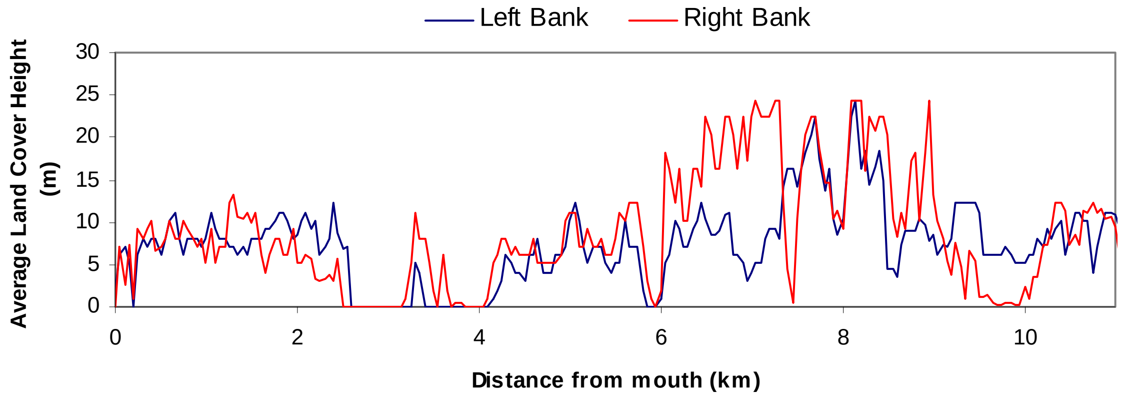


Figure A88. Model setup for density of streamside vegetation.

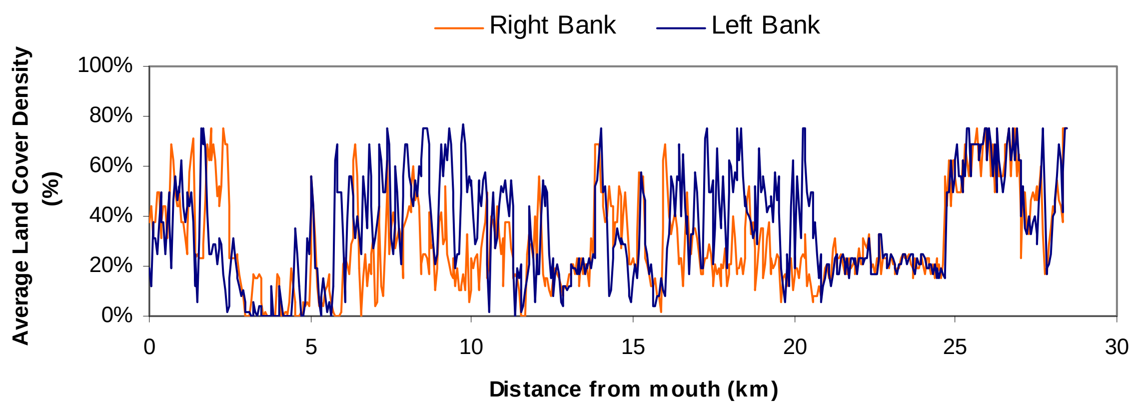
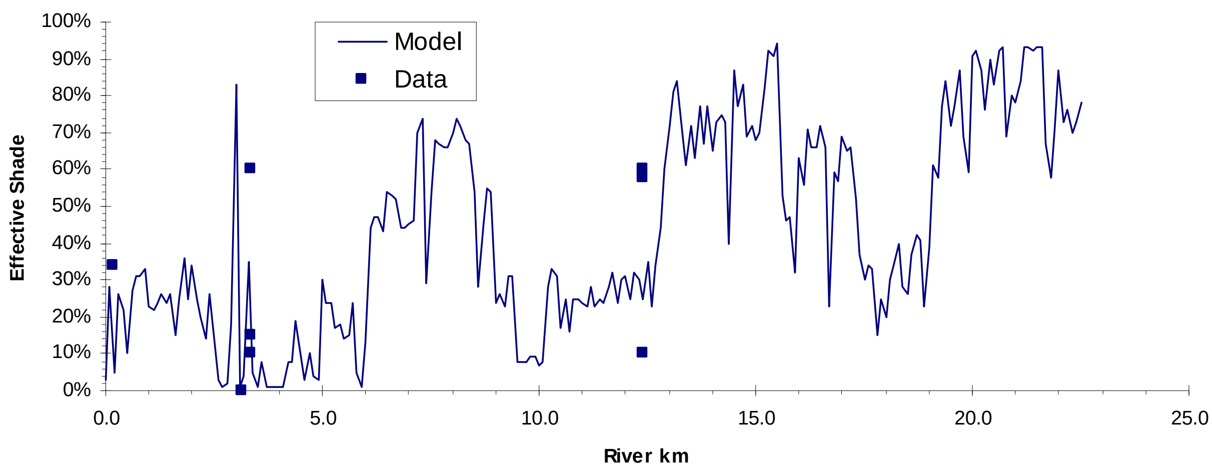


Figure A89. Predicted versus measured shade.



Meteorology

The model used air temperature, relative humidity, wind speed and cloudiness from the Medford airport. There data are presented in the Little Butte Creek and North Fork Little Butte Creek section of this

Appendix. A multiplicative wind sheltering coefficient was applied to the wind speed for calibration (**Table A29**). Additionally, the model originally over predicted the daily maximum temperatures for all continuous monitoring stations between 8/7 and 8/17. Satellite images showed smoke from forest fires during this period (NOAA 2001). Therefore, cloudiness was iteratively increased to 0.5 to match daily stream temperatures during this period.

Table A29. Wind sheltering coefficients by reach.

Range (river km)	Wind sheltering Coefficient
23 - 10	0
10 - 4	0.5
4 - 0	0.75

Flow

Discharge data from a continuous gage were available in 2001 on Elk Creek near Trail, OR (USGS 14338000) at river km 2.5. DEQ also collected instantaneous flow measurements from 7 sites within the model reach and from major tributaries (**Table A30** & **Figure A90**). In order to match instream flows, water loss was necessary between river km 5 and 19 which corresponds with information provided by Oregon Water Resources Department on consumptive use (**Figure A91**). Using these flow inputs, the performance of the Elk Creek model at several locations and times is shown in **Figure A92 & Figure A93**. The temporal shift between measured flow and model results is due to derivation of the dynamic boundary condition flow inputs that were based on a downstream gage. The derivation did not account for travel time between the locations.

Table A30. Source of flow information for Elk Creek model.

Inflow	Stream km	Source
Headwater	22.5	Instantaneous flow plus relationship with gage
Bitter Lick Creek	22.4	Instantaneous flow plus relationship with gage
Sugarpine Creek	17.85	Instantaneous flow plus relationship with gage
Flat Creek	14.3	Instantaneous flow plus relationship with gage
West Branch Elk Creek	5.65	Instantaneous flow plus relationship with gage

Figure A90. Tributary and headwater flow conditions.

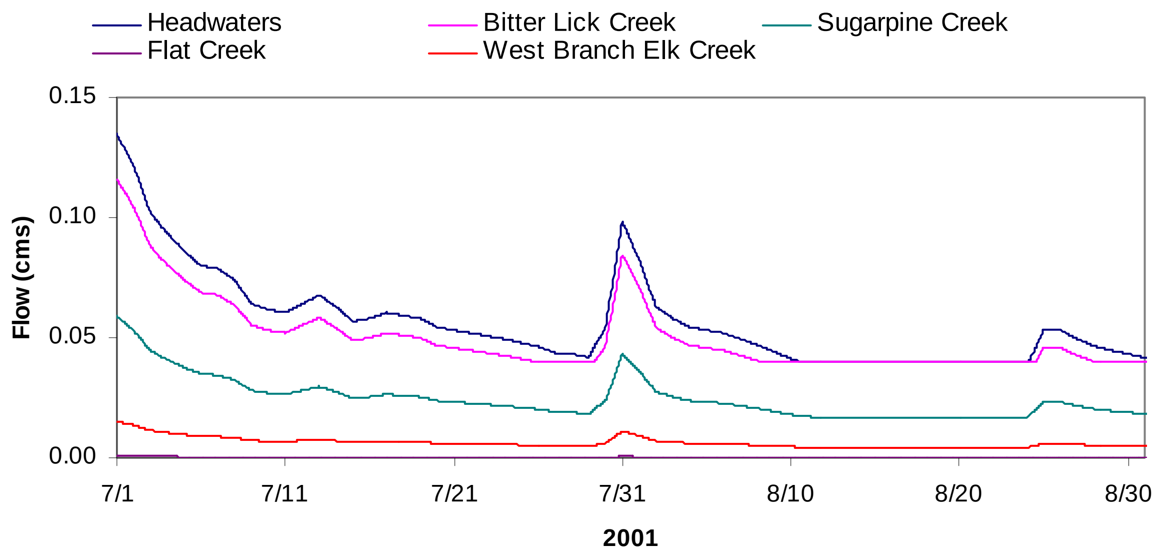


Figure A91. Sum of the withdrawals in the downstream direction

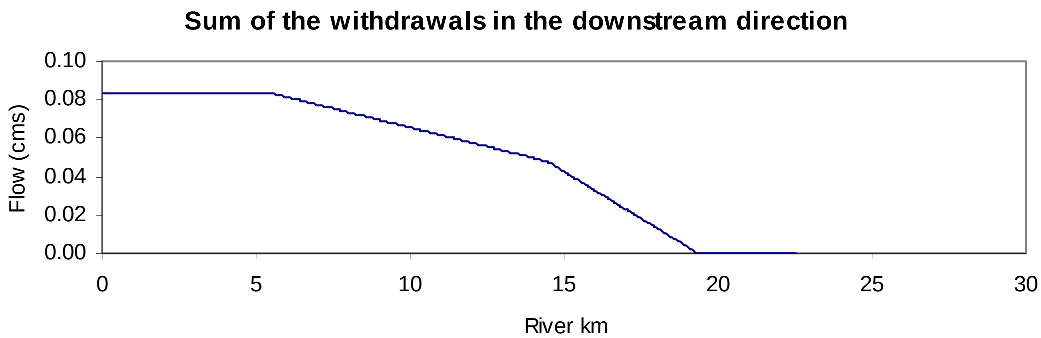


Figure A92. Longitudinal profile of measured flow versus model results.

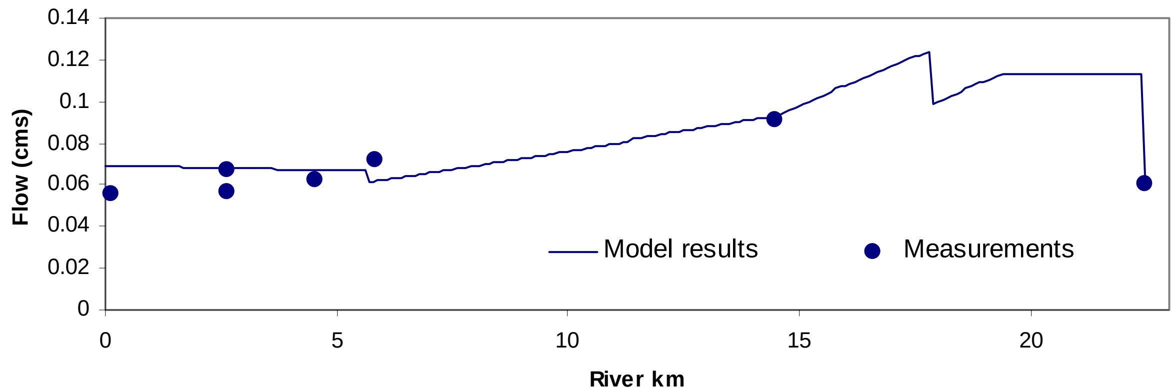
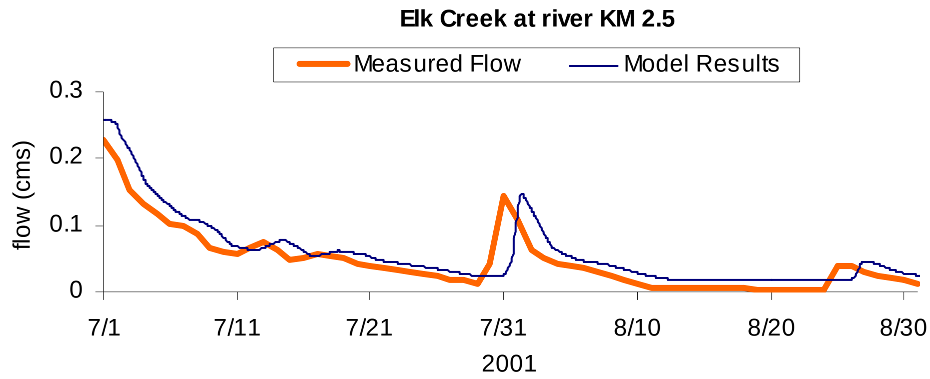


Figure A93. Time series of measured flow versus model results.



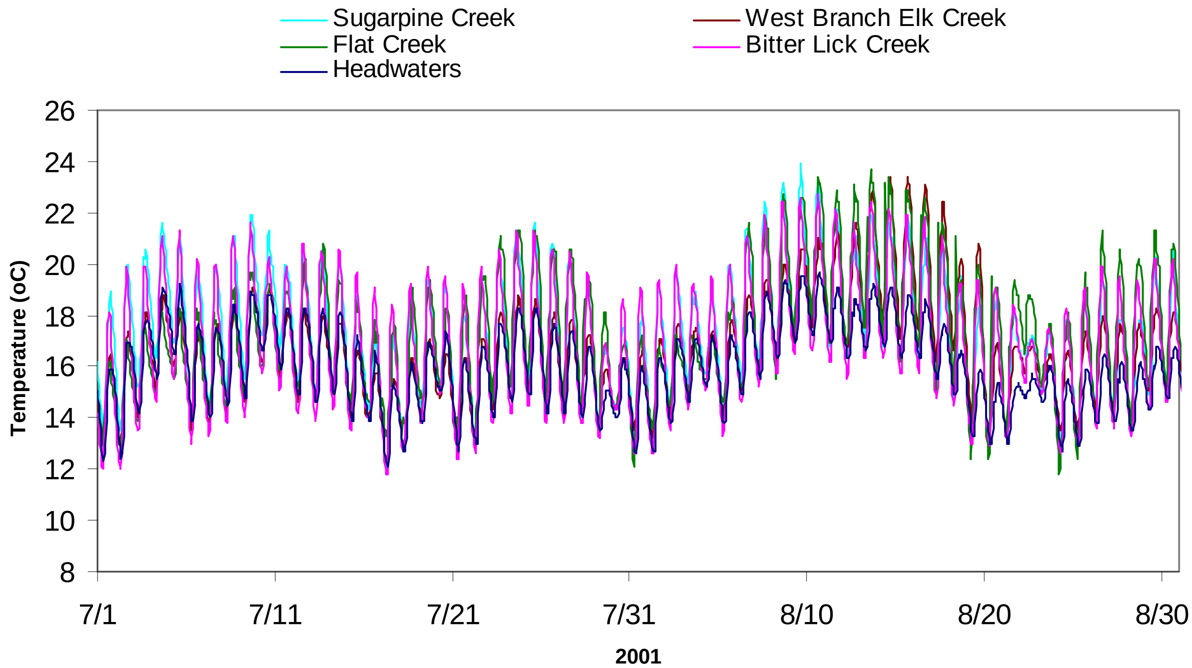
Temperature

Table A31 and Figure A94 document the temperatures of the headwaters and tributaries incorporated in the model.

Table A31. Source of tributary and boundary condition temperature inputs for the Elk Creek model.

Inflow	Stream km	Source of temperature data
Headwater	22.5	DEQ data site #25968
Bitter Lick Creek	22.4	DEQ data site #25967
Sugarpine Creek	17.85	DEQ data site #25966
Flat Creek	14.3	DEQ data site #25964
West Branch Elk Creek	5.65	DEQ data site #25804

Figure A94. Temperature inputs of tributaries to the Elk Creek model.



Temperature Calibration

The model outputs generally reproduced spatially and temporally varying temperature measurements (**Table A32 and Table A33 and Figure A95 & Figure A96**). However, there were some deviations between TIR data and model results. Part of this deviation was likely due to the assumed slopes between river km 3 and 14 due to the DEM representing elevations of a reservoir behind the dam which was never completed. Without an accurate representation of hydraulics, the temperature calibration suffered. See previous statistics discussion at the beginning of **Section 4** for definitions.

Table A32. TIR error statistics

Error type	value
Mean Error	-0.88
Abs Mean Error	1.45
RMSE	1.83
Nash-Sutcliffe	0.49

Figure A95. Longitudinal profile of measured temperatures using Thermal Infrared Radiometry and model results.

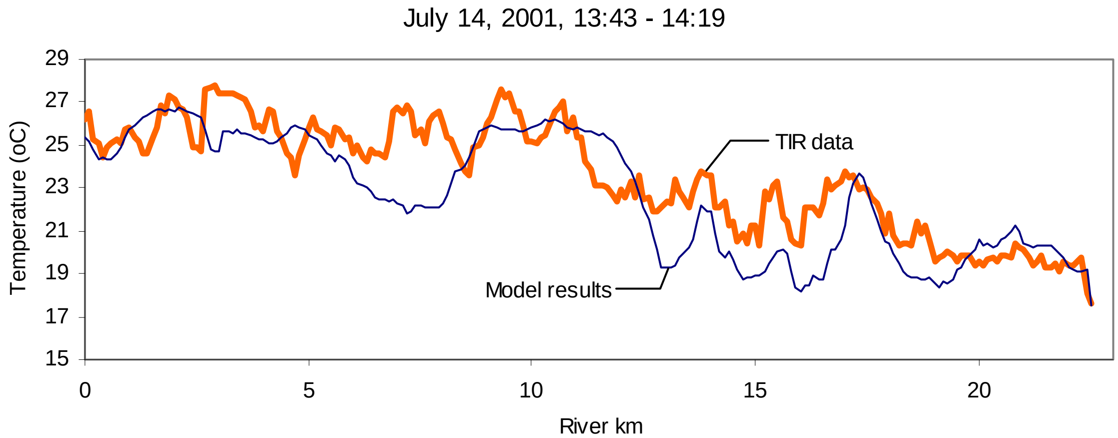
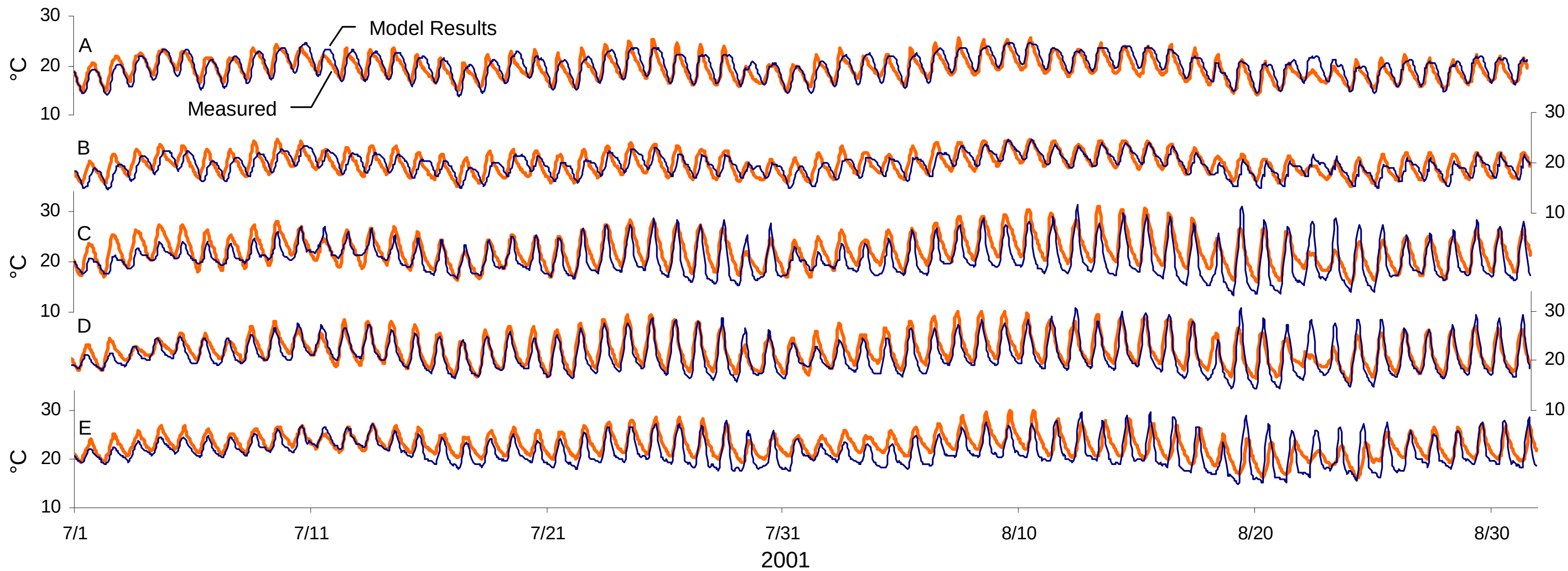


Table A33. Continuous measurement error statistics

Site Name	DEQ Site #	Ref	rKM	All data: n	All data: Mean Error	All data: Abs Mean Error	All data: RMSE	All data: Nash-Sutcliffe	Daily Maximums: n	Daily Maximums: Mean Error	Daily Maximums: Abs Mean Error	Daily Maximums: RMSE
Elk Creek @ S.M. 9.4	?	A	15.7	1488	0.43	1.23	1.50	0.56	62	-0.33	0.83	1.03
Elk Creek u/s Flat Creek	25965	B	14.5	1488	-0.27	1.51	1.84	0.24	62	-0.96	1.11	1.27
Elk Creek ~ 250' u/s West Branch	25805	C	5.85	1488	-1.61	2.02	2.42	0.38	62	-0.09	1.67	2.19
Elk Creek ~1000' u/s Elk Creek Dam	25803	D	4.55	1488	-0.98	1.48	1.81	0.64	62	0.03	1.66	2.05
Elk Creek d/s Elk Creek Dam (@ gage)	25802	E	2.65	1488	-1.43	1.98	2.31	0.04	62	-0.35	1.63	1.93
Average					-0.77	1.64	1.98	0.37		-0.34	1.38	1.70

Figure A96. Measured steam temperature versus model results.

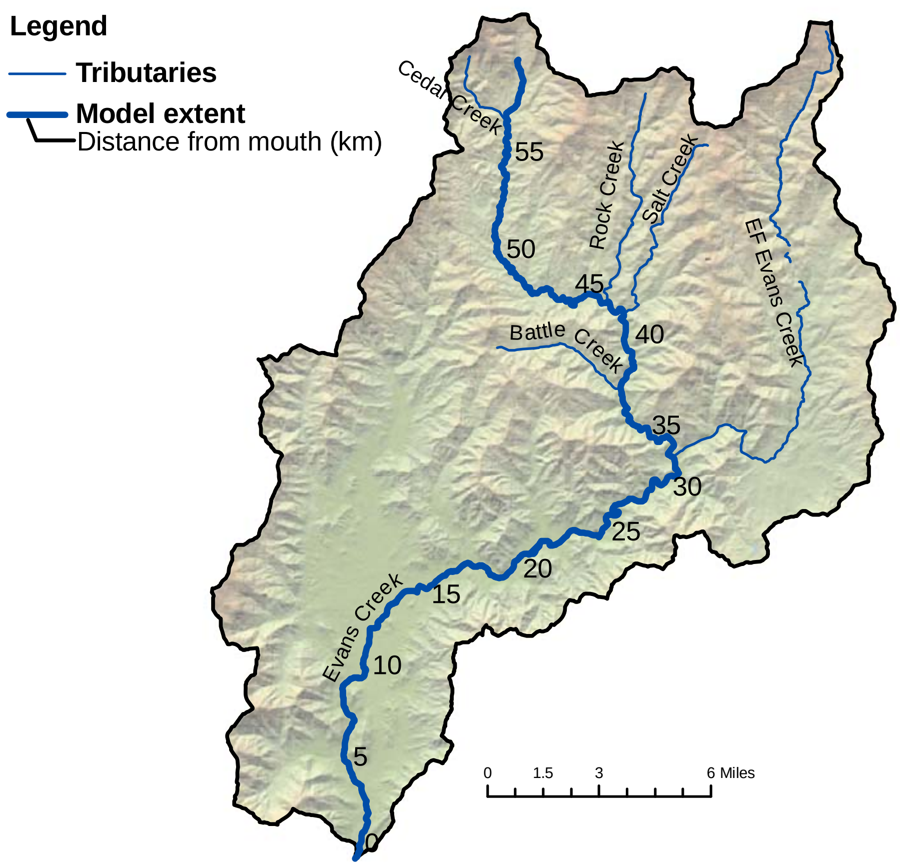


4.7 Evans Creek and West Fork Evans Creek

Overview

Stream Name: Evans Creek and West Fork Evans Creek
Model: Heat Source version 8.0
Beginning date: 7/1/2003
Ending date: 8/31/2003
Time step: 1.0 minute
Distance step: 100 m
Extent: West Fork Evans Creek near headwaters river km 59.7 (**Figure A97**).

Figure A97. Extent of the Evans Creek temperature model.



Reach Properties

The channel properties were determined using the methodology documented previously in this document (**see Section 3**). **Figure A98** shows the elevation and reach gradient profiles. The bottom width was derived using the active channel width measured from aerial photographs. Bottom width was estimated by assuming a trapezoidal channel with side slopes that are same long as they are high and also using a constant width-to-depth ratio of 8 determined through model calibration (**Figure A99**). Non-spatially varying coefficients are presented in **Table A34**. Manning's n, sediment thermal conductivity, and sediment thermal diffusivity were iteratively altered so that the model temperatures approximately reproduced measured temperatures (**Figure A100 & Figure A101**). Topographic and riparian vegetation heights were determined through GIS analysis (**Figure A102 & Figure A104**). Using these channel and vegetation inputs, the performance of the Evans Creek model in predicting shade is shown in **Figure A105**.

Figure A98. Model setup channel elevation and gradient

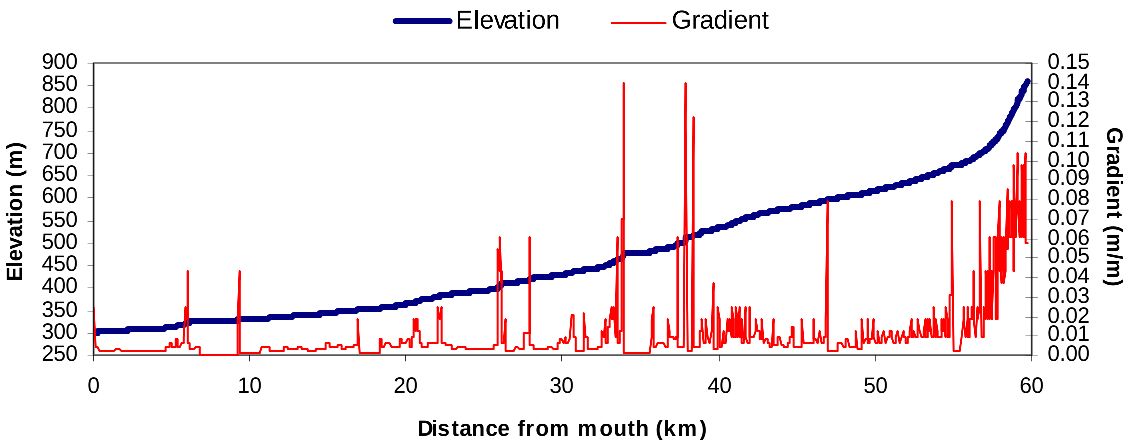


Figure A99. Model setup for channel bottom width.

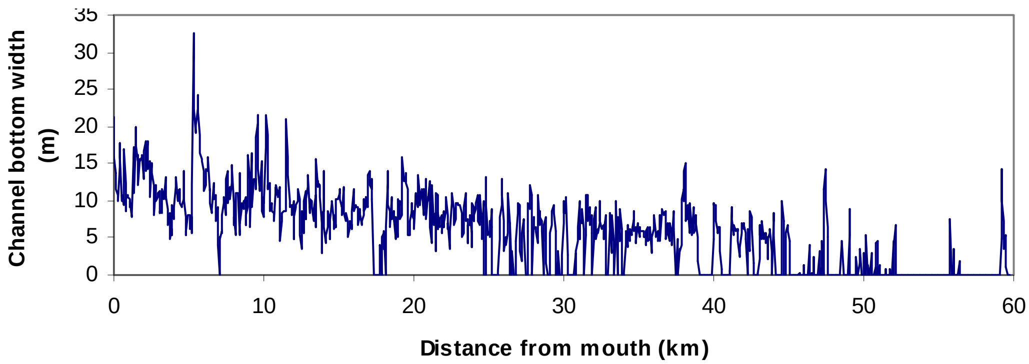


Table A34. Model coefficients for non-spatially varying parameters

Parameter name (units)	Value
Wind Function, coefficient a	1.51×10^{-9}
Wind Function, coefficient b	1.60×10^{-9}
Channel Angle	1.0
Sediment / hyporheic zone thickness (m)	0.5
Percent hyporheic exchange	0%
Porosity	30%

Figure A100. Model setup for roughness coefficient

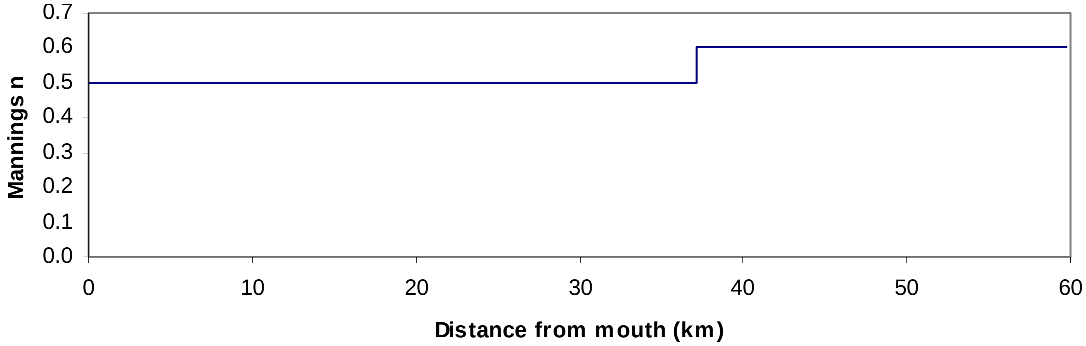


Figure A101. Model setup for substrate parameters

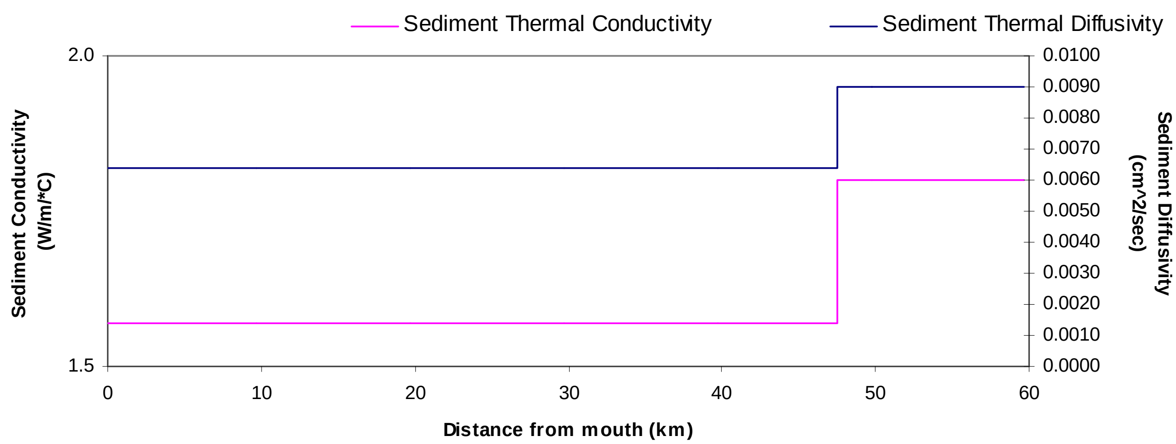


Figure A102. Model setup for topographic angle

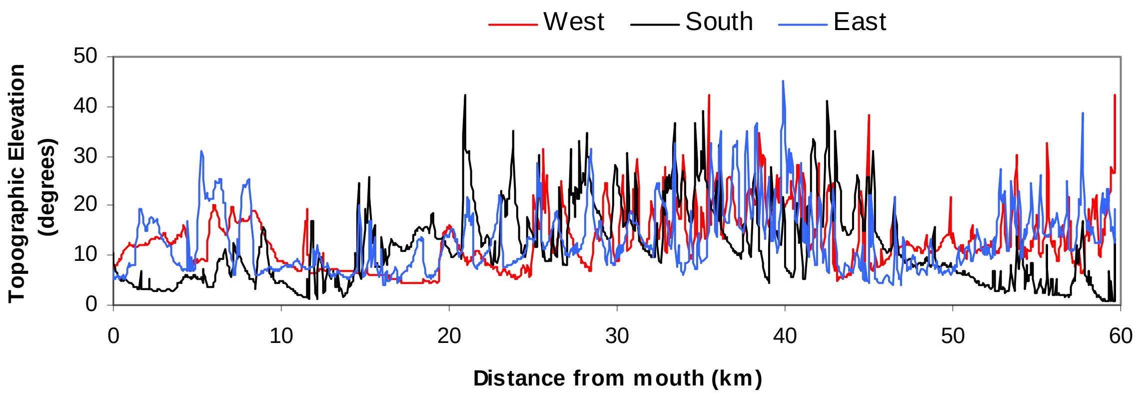


Figure A103. Model setup for height of streamside vegetation

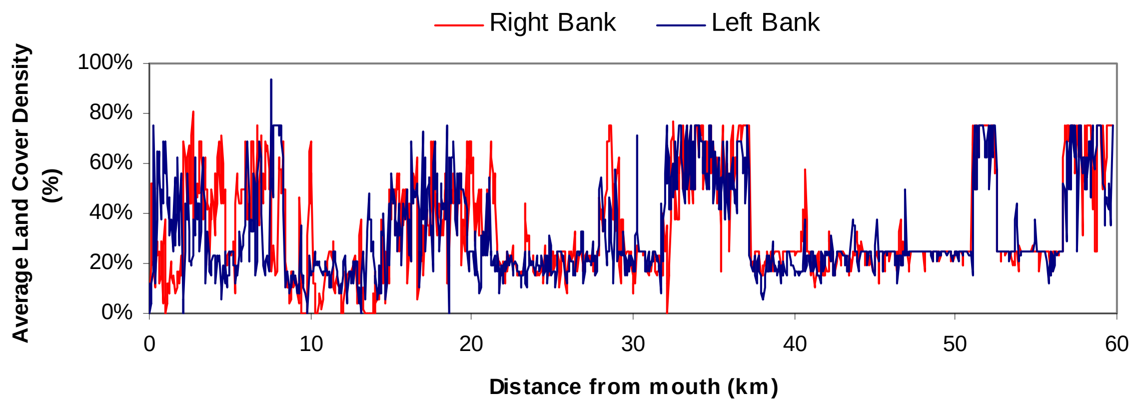


Figure A104. Model setup for density of streamside vegetation.

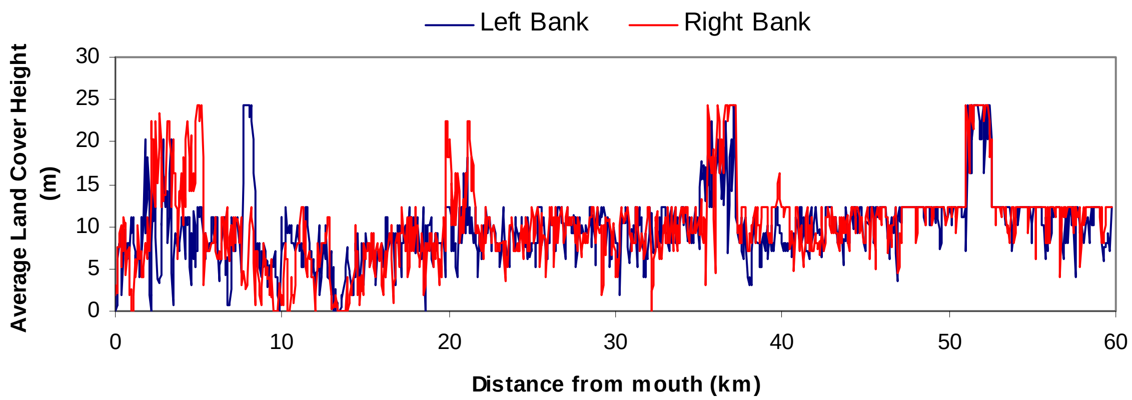
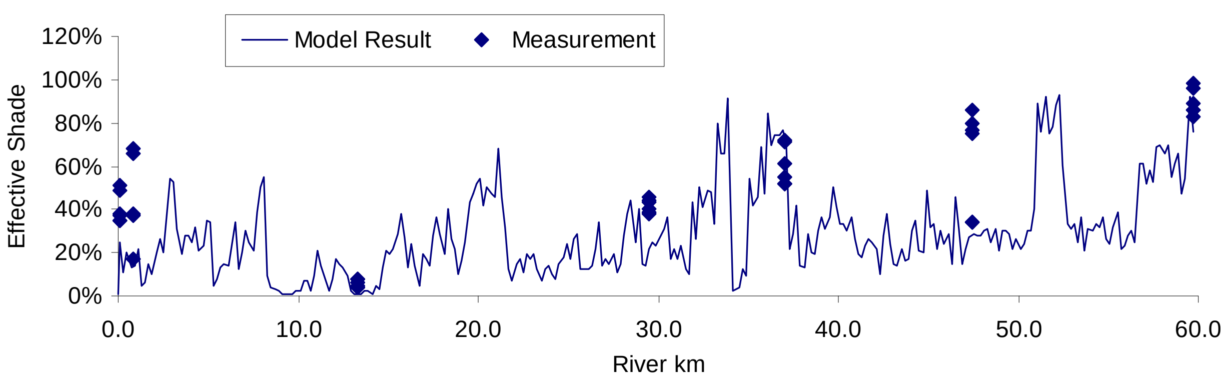


Figure A105. Predicted versus measured effective shade



Meteorology

The model used air temperature, relative humidity, wind speed and cloudiness data collected in Medford at the airport. These data are presented in the Little Butte Creek and North Fork Little Butte Creek section of this Appendix. A multiplicative wind sheltering coefficient was applied to the wind speed for calibration (**Table A35**).

Table A35. Applicable wind sheltering coefficients

Range (river km)	Wind sheltering Coefficient
59.7 - 25.2	1.0
25.2 - 6.5	0.5
6.5 - 0.0	1.0

Flow

No continuous gage data for Evans Creek were available for 2003, so flows were based on instantaneous flow measurements (**Table A36**). Tributary inflow rates were held constant over the modeling season (**Table A37**). Stream withdrawal rates assumed no water withdrawal upstream of river kilometer 37.1 and were held constant over reach segments to reproduce flow measurements (**Figure A106**). Using these flow inputs, the performance of the Evans Creek model at several locations is shown in **Figure A107.**

Table A36. Source of flow information for Evans Creek/West Evans Creek model.

Inflow	Stream km	Source of temperature data
Evans Creek at Swamp Cr Rd Bridge	53.35	Instantaneous flow measurement
West Fork Evans Creek d/s of Sand Creek	47.45	Instantaneous flow measurement
West Fork Evans Creek d/s of Battle Creek	37.05	Instantaneous flow measurement
Evans Creek @ Bridge 341	29.5	Instantaneous flow measurement
Evans Creek D/S Wimer Bridge	13.3	Instantaneous flow measurement
Evans Creek @ Palmerton Park	0.8	Instantaneous flow measurement
Evans Creek at Mouth	0.05	Instantaneous flow measurement

Table A37. Constant flow conditions based on instantaneous flow measurements during the model period

Model inflow	Stream km	Flow rate (cms)
Headwaters	59.7	0.075
Cedar Creek	56.75	0.055
Rock Creek and Salt Creek	45.0	0.050
Battle Creek	37.15	0.050
EF Evans Creek	31.65	0.015

Figure A106. Sum of the withdrawals in the downstream direction

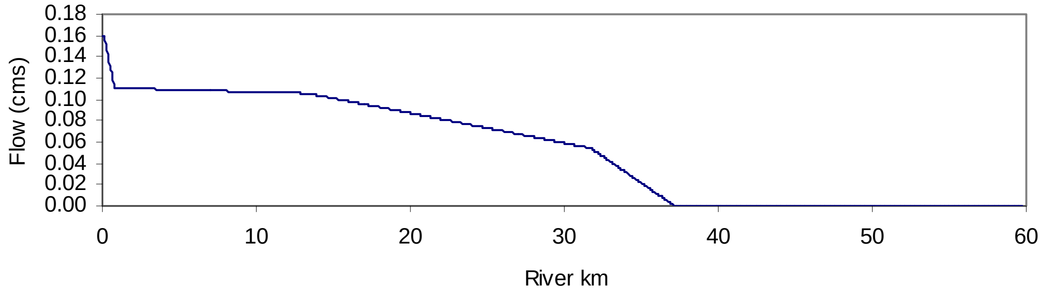
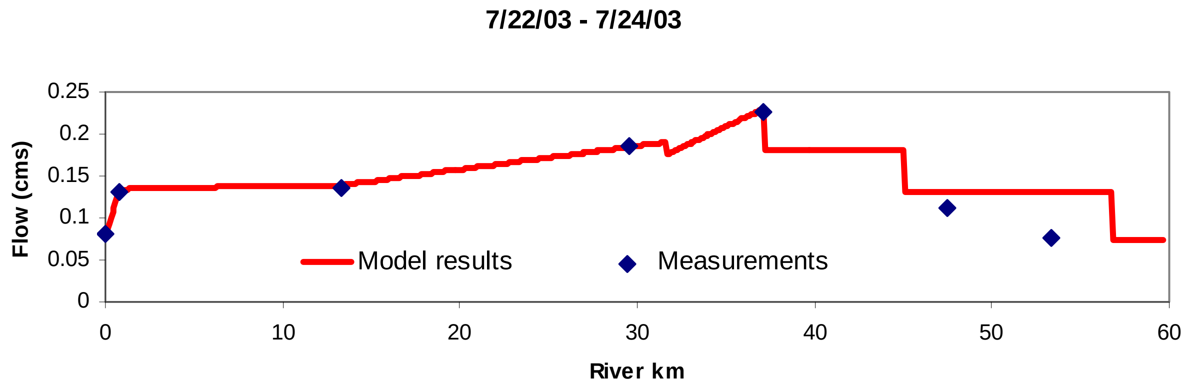


Figure A107. Longitudinal profile of measured flow versus model results.



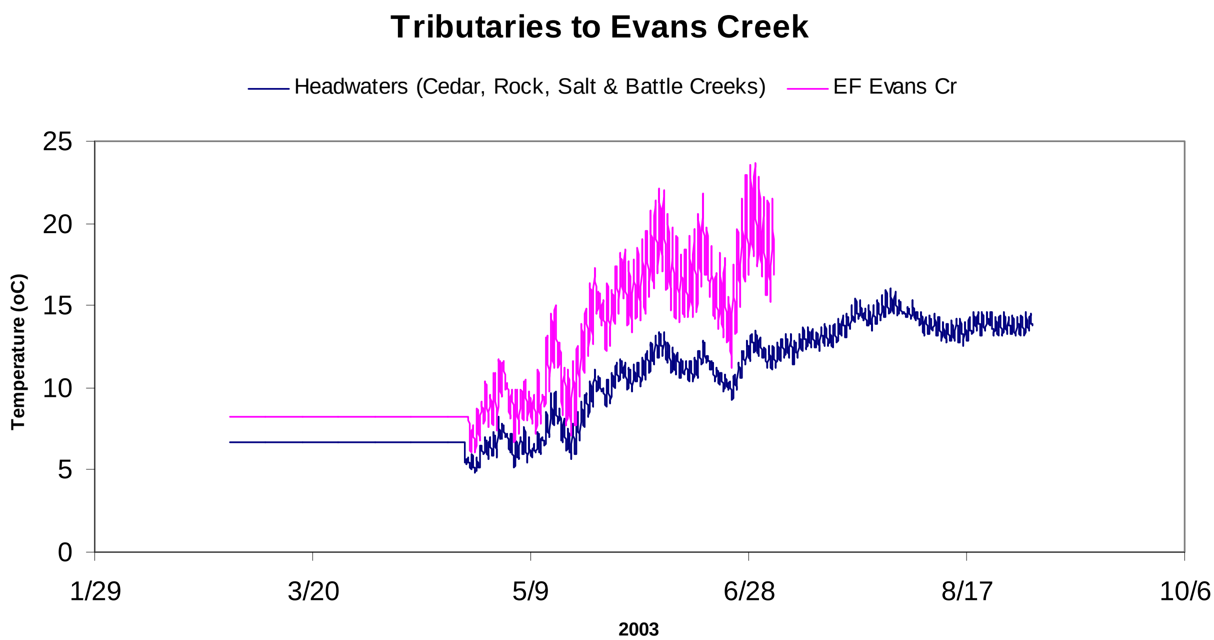
Temperature

Table A38 and **Figure A108** document the temperatures of the tributaries used in the model. There were no continuous temperature data for the tributaries to Evans Creek, so the West Fork Evans Creek headwater data (Vemco 2700) were applied.

Table A38. Source of tributary and boundary condition temperature inputs for the Evans Creek/West Fork Evans Creek model

Model inflow	Stream km	Temperature
W. Fork Evans Creek Headwaters	59.7	ODEQ Vemco 2700
Cedar Creek	56.75	ODEQ Vemco 2700
Rock Creek and Salt Creek	45.0	ODEQ Vemco 2700
Battle Creek	37.15	ODEQ Vemco 2700
E. Fork Evans Creek	31.65	ODEQ Vemco 2693

Figure A108. Boundary condition and tributary temperatures used in Evans Creek/West Evans Creek model



Temperature Calibration

The model outputs generally reproduced spatially and temporally varying temperature measurements between river kilometers 13.3 – 59.7 (**Table A39 and Table A40 and Figure A109 & Figure A110**). See previous statistics discussion at the beginning of **Section 4** for definitions. Between river kilometers 0.05 and 13.3, the model over predicts the maximum temperatures (**Figure A110**). This may be due to stratification of water at different temperatures or cold water influence from groundwater or the Rogue River. The TIR data, which represents the surface water temperatures, also recorded higher temperatures than the continuous data loggers, which represent subsurface water temperatures, in this reach (seen when comparing Figure A110F on August 1 and Figure A109 at the mouth). The temperatures measured in the Rogue River just upstream of Evans Creek compare closely with the temperatures at the mouth of Evans Creek (**Figure A111**). Evans Creek temperatures are slightly warmer and shifted temporally from the Rogue River temperatures .

Table A39. TIR error statistics

Error type	value
mean	0.35
Absolute mean	1.38
Root mean square	1.82
Nash-Sutcliffe	0.54

Figure A109. Longitudinal profile of measured temperatures using Thermal Infrared Radiometry and model results

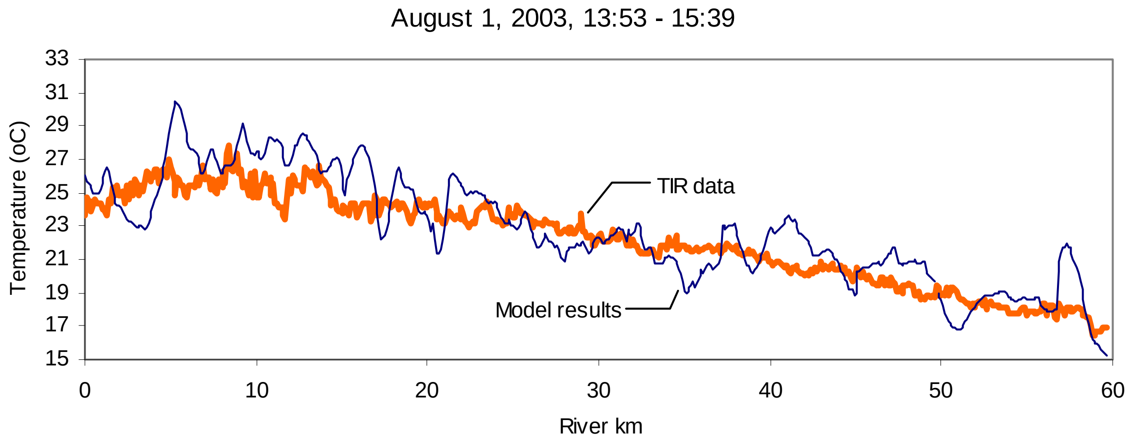


Table A40. Continuous measurement error statistics. The sites shaded in grey near the mouth were determined to be influenced by water from the Rogue River and were not used in the calibration process or in the average statistics.

				All data					Daily Maximums			
Site Name	Site #	Ref	rKM	n	Mean Error	Abs Mean Error	RMSE	Nash-Sutcliffe	n	Mean Error	Abs Mean Error	RMSE
W. Fork Evans Creek near headwaters	30188	A	59.70	1488	0.02	0.02	0.03	1.00	62	0.02	0.02	0.03
W. Fork Evans Creek d/s of Sand Creek	30189	B	47.45	1180	0.43	0.79	1.01	0.70	49	0.65	0.82	1.02
W. Fork Evans Creek d/s of Battle Creek	30190	C	37.05	923	-1.36	1.47	1.70	0.41	39	-1.93	1.93	2.05
Evans Creek downstream of Wimer	11373	D	13.30	1488	0.14	0.92	1.19	0.79	62	0.36	0.76	.99
Evans Creek at Mouth	11372	E	0.05	1488	0.99	2.61	3.32	-2.39	62	4.44	4.52	5.26
Evans Creek at Mouth, duplicate	11372	F	0.05	1488	1.69	2.64	3.45	-4.90	62	5.10	5.10	5.78
Average					-0.19	0.80	0.98	0.73		-0.22	0.88	1.02

Figure A110. Measured steam temperature versus model results.

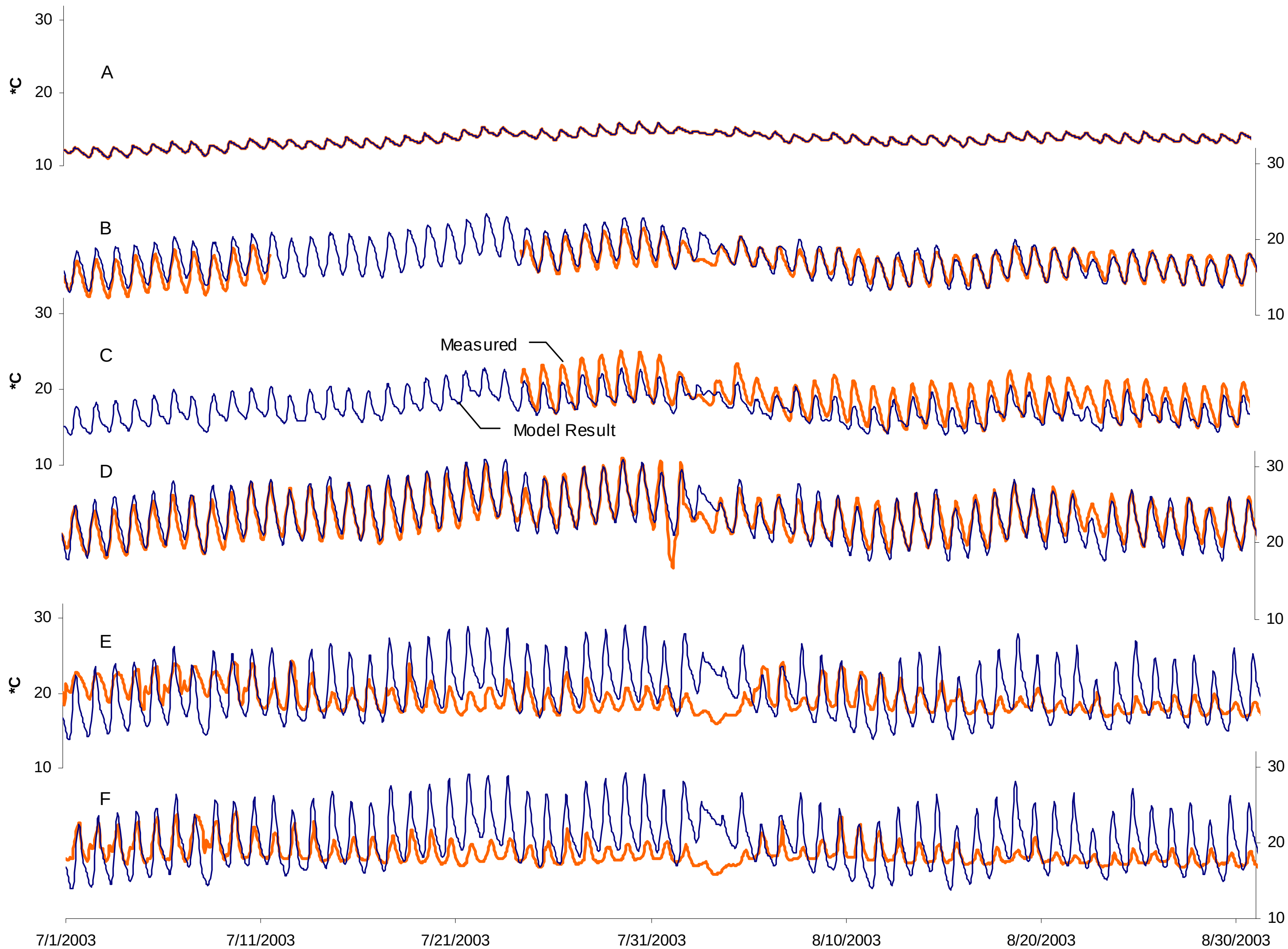
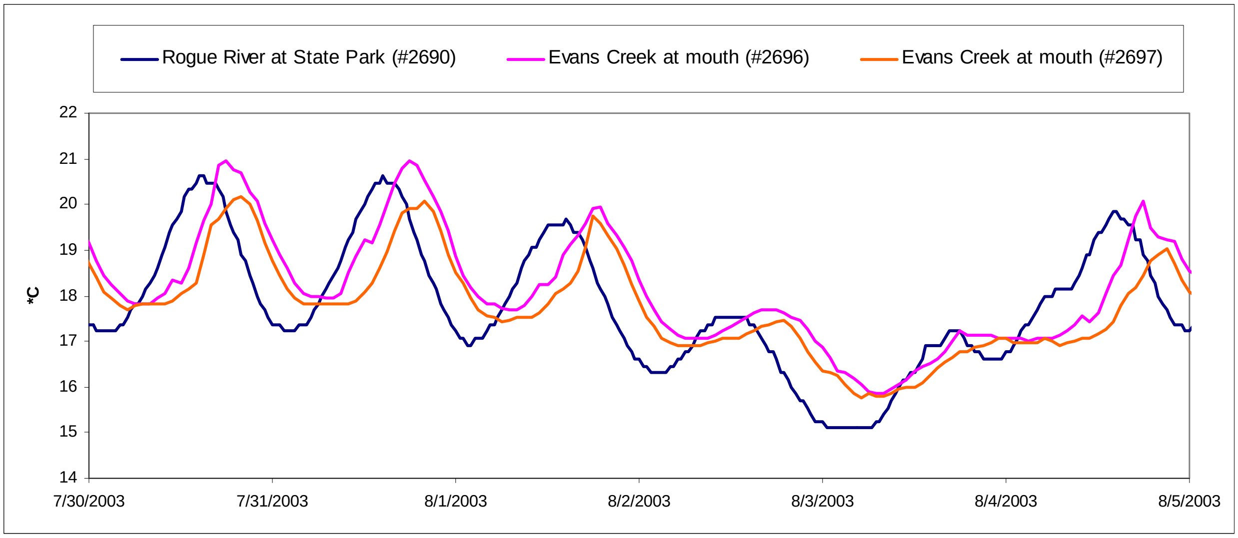


Figure A111. Comparison of temperature measurements from the mouth of Evans Creek and the mainstem of the Rogue River upstream of the confluence with Evans Creek.



5. REFERENCES

Boyd, M. & Kasper, B. (2003). Improvements in stream temperature assessment. *Hydrological Science and Technology*, 19(1-4), 149-169.

Beschta, R. L., Bilby, R. E., Brown, G. W., Holtby, L. B., and Hofstra, T. D. (1987). Stream temperature and aquatic habitat: Fisheries and forestry interactions. *Streamside Management: Forestry and Fishery Interactions*. University of Washington, Institute of Forest Resources, Seattle, USA. 191-232 [in E. O. Salo and T. W. Cundy, eds.]

Bryce, S.A., Comstock, J.A., Kagan, J., Lammers, D.A., Omernik, J.M., Pater, D.E., Thorson, T.D., and Woods, A.J. (2003). Ecoregions of Oregon (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,500,000). **http://www.epa.gov/wed/pages/ecoregions/or_eco.htm.**

Department of Environmental Quality (1999). *Water quality management plan*. Rogue River Basin Illinois River Sub Basin.

Department of Environmental Quality (2002a). *Total maximum daily load and water quality management plan. Lower Sucker Creek*, Illinois Subbasin.

Department of Environmental Quality (2002b). *Total maximum daily load and water quality management plan, Lobster Creek*. Lower Rogue Subbasin.

Department of Environmental Quality (2003). *Total maximum daily load*. Applegate Subbasin.

Department of Environmental Quality (2007). *Total maximum daily load.* Bear Creek Watershed.

Hydro Dynamics (2004). Rogue Basin Riparian Conditions Assessment, BLM and Private Managed Land, for Oregon Department of Environmental Quality.

Leopold, L. B., Miller, J. P., and Wolman, M. G. (1964). Fluvial Processes in Geomorphology. *Freeman*, San Francisco, California. 522 pp.

Oregon Department of Fish & Wildlife (1997). *Aquatic Inventories Project Stream Habitat Distribution Coverages, Natural Production Section*. Oregon Department of Fish & Wildlife, Corvallis.

Oregon Watershed Assessment Manual (1999). developed for the Governor's Watershed Enhancement Board, http://www.oregon.gov/OWEB/docs/pubs/OR_wsassess_manuals.shtml accessed 3/26/2008.

National Oceanic and Atmospheric Administration (2001). Operational Significant Event Imagery, FSMHSusOR227_N2.jpg, FSMHSusSOR228_N2.jpg, FSMHSusOR229_N2.jpg, http://www.osei.noaa.gov/Events/Fires/US_Northwest/2001/, accessed on April 14, 2008.

Rosgen, D. (1996). Applied River Morphology. *Wildland Hydrology.* Pagosa Springs, Colorado.

US Bureau of Reclamation (2007). Hydromet, http://www.usbr.gov/pn/hydromet/, accessed June 2007.

Watershed Sciences (2002). Aerial Surveys in the Rogue River Basin, Thermal Infrared and Color Videography, for Oregon Department of Environmental Quality.

Watershed Sciences (2004). Aerial Surveys in the Rogue River Basin, Thermal Infrared and Color Videography, for Oregon Department of Environmental Quality.