UPPER KLAMATH AND LOST RIVER SUBBASINS TMDL

APPENDIX A: TRIBUTARIES TO THE UPPER KLAMATH AND LOST RIVERS TEMPERATURE MODELS

Final
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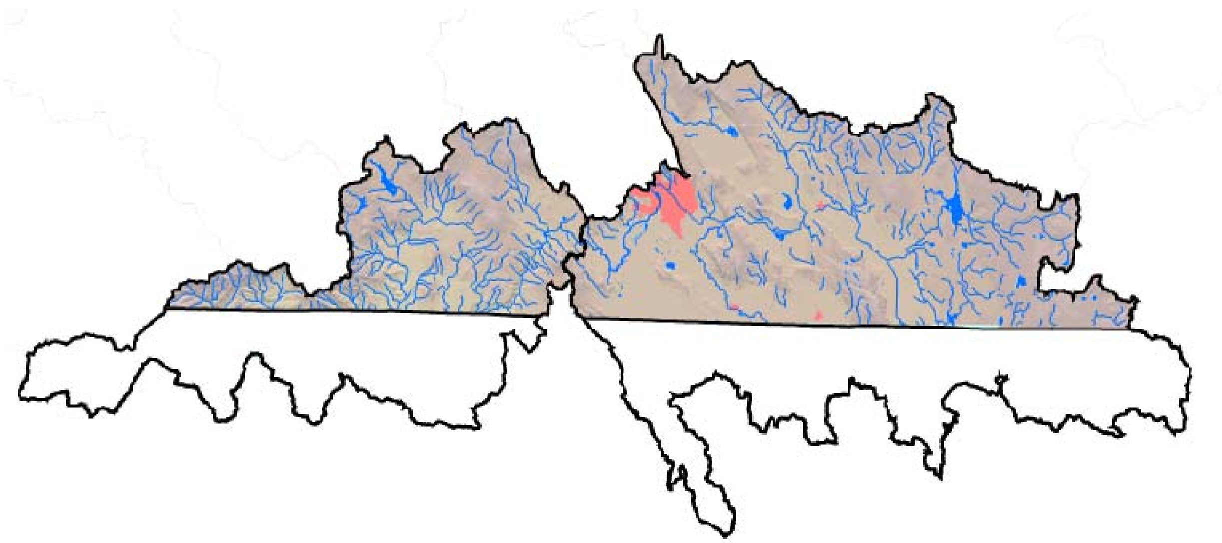

THIS DOCUMENT IS SUPPLEMENTAL TO THE KLAMATH RIVER TMDL

DEQ

State of Oregon
Department of Environmental Quality

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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 base 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, system potential 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 Klamath and Lost Rivers, Heat Source simulations were performed for at most 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.

- “System potential” 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. “System potential” 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 “system potential” flow conditions based on measured channel dimensions and substrate composition. These estimated velocities and depths for the “system potential” 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 system (i.e., acceptance of a calibrated model) is based on comparison of model results with observed data. Statistics and graphical comparison are utilized. While 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 (see margin of safety discussion in Chapter 4.4.10).

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 of 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 Upper Klamath River and Lost River Subbasins. 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 Upper Klamath River and Lost River Tributaries Temperature TMDL:

Oregon Department of Environmental Quality
US Bureau of Land Management
US Bureau of Reclamation
US Forest Service
Watershed Sciences, Inc.
Jackson County
Oregon Water Resources Department
US Geological Survey
National Climatic Data Clearinghouse

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 was 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 (Actual stream temperature data is available from DEQ upon request).

Flow Volume – Gage Data and Instream Measurements

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

2.2. GIS and Remotely Sensed Data

Overview

A wealth of spatial data has been developed for the Klamath River Basin. The stream temperature TMDL relies extensively on GIS and remotely sensed data. Water quality issues in the Upper Klamath and Lost River Subbasins 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.

[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.

10-Meter Digital Elevation Model (DEM)

A digital elevation model (DEM) consists of digital information that provides a uniform matrix of terrain elevation values. 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 US Geological Survey, US Forest Service, and Bureau of Land Management produce these digital cartographic/geographic data files and are distributed through the Oregon Geospatial Data Clearinghouse (OGDC).

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). The BLM provided false color near infrared photographs for some riparian areas of the Lost River tributaries and for Spencer Creek (images from 2000). Black and white DOQs provided by USGS were used when no other aerial images were available (images from 1994). Color DOQs are now available for the entire state and may be downloaded from http://www.oregonexplorer.info/imagery/.

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 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.

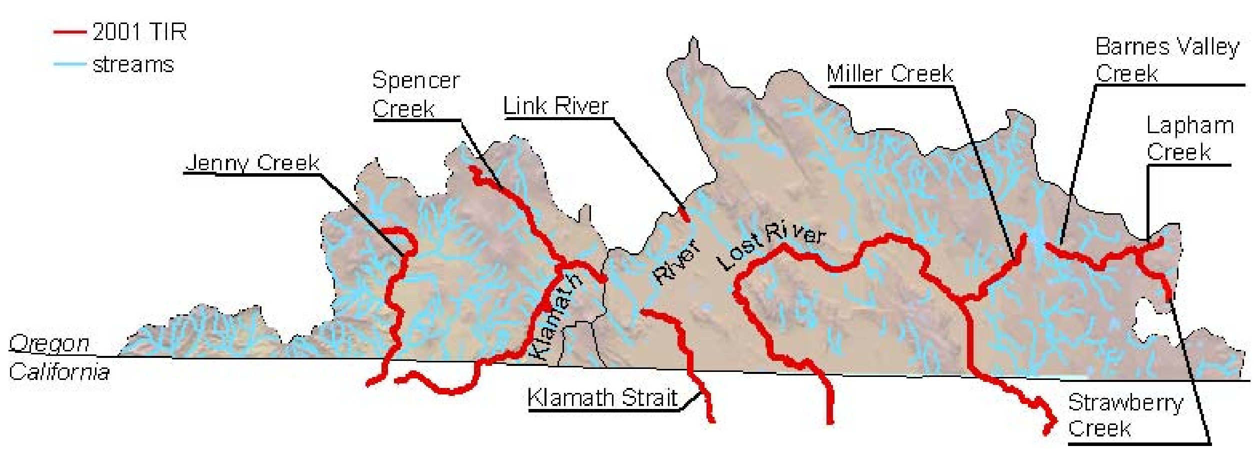
Klamath River Basin TIR Data

DEQ contracted with Watershed Sciences, Inc. to collect TIR data in the Upper Klamath and Lost River Subbasins during 2001 (**Figure A1**). 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**. The Klamath Basin TIR survey report is available for download at the Oregon DEQ website (Watershed Sciences, Inc. 2002). 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 A1. TIR flight paths in the Klamath River 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 4.1-4.10**.

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. 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

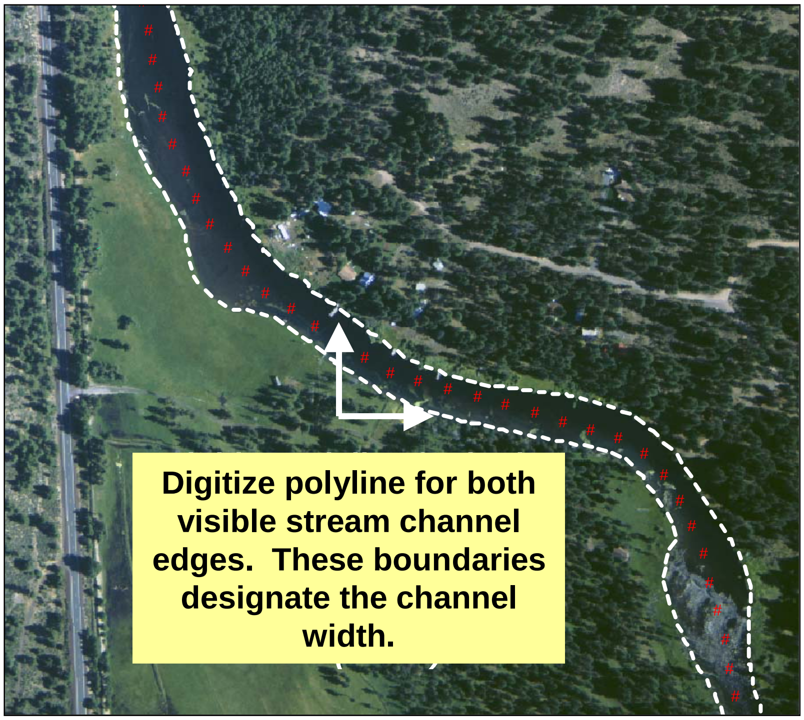
Channel width is an important component in stream heat transfer and mass transfer processes. Effective shade, stream surface area, wetted perimeter, stream depth and stream hydraulics are all highly sensitive to channel width. Accurate measurement of channel width across the stream network, coupled with other derived data, allows a comprehensive analytical methodology for assessing channel morphology. The steps for conducting channel width assessment are listed below (**Figure A2**).

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.

[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).

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 A2. Digitized channel centerline, right bank, and left bank



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 Klamath River Basin a high priority. Variable vegetation conditions in the Klamath River Basin require a higher resolution than currently available GIS data sources. To meet this need, DEQ has 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 A3**) 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.

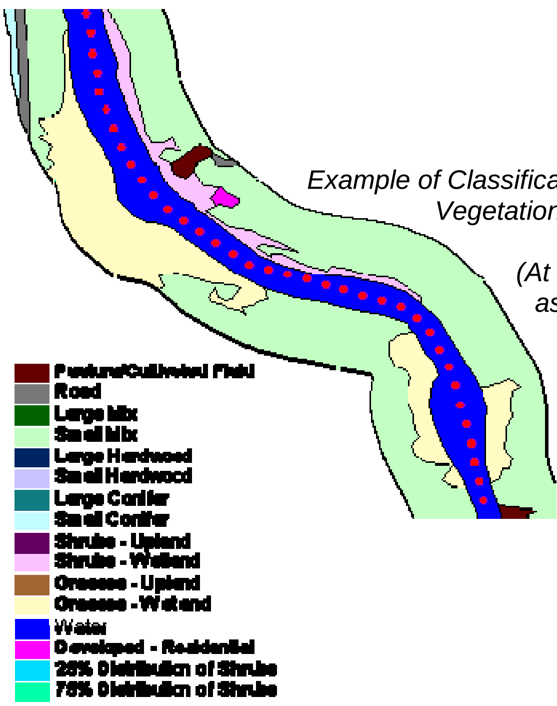
Step 4. Ground level vegetation data was statistically summarized and sorted by vegetation type. Median values for vegetation height and density were then used to describe DEQ vegetation classifications.

Figure A3 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 A3. Steps for digitizing and classifying vegetation.

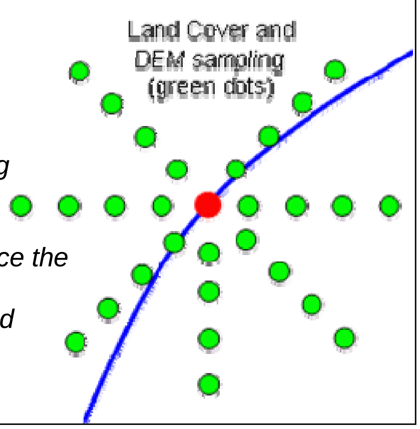
Example of Polygon Mapping of Vegetation from Aerial Color Imagery

(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:

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

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 114 stream kilometers in the Upper Klamath River and Lost River Subbasins.

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 Upper Klamath River and Lost River Subbasin Tributary 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).

3.5 Simulated Scenarios

Once stream temperature models were calibrated, several scenarios were simulated by changing one or more input parameters for each of the calibrated models. The simulated scenarios focused largely on defined system potential vegetation and derived flow mass balances. A summary of the difference between current conditions and Natural Thermal Potential (NTP) results are presented in **Table A1**. In addition, it is noted that the location of the POMI may change seasonally and with changes in human impacts.

Table A1. Maximum predicted difference between current conditions and NTP and the location of the maximum difference (point of maximum impact).

Waterbody	Maximum difference between current and NTP (Max 7-DADM, °C)	Point of Maximum Impact (river km)
Jenny Creek	6.5	17.4
Spencer Creek	8.8	1.8
Miller Creek	5.4	4.57

4. STREAM TEMPERATURE MODEL SETUP, CALIBRATION AND SCENARIOS

4.1 Overview

Heat Source was used to model stream temperatures in the Klamath 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.

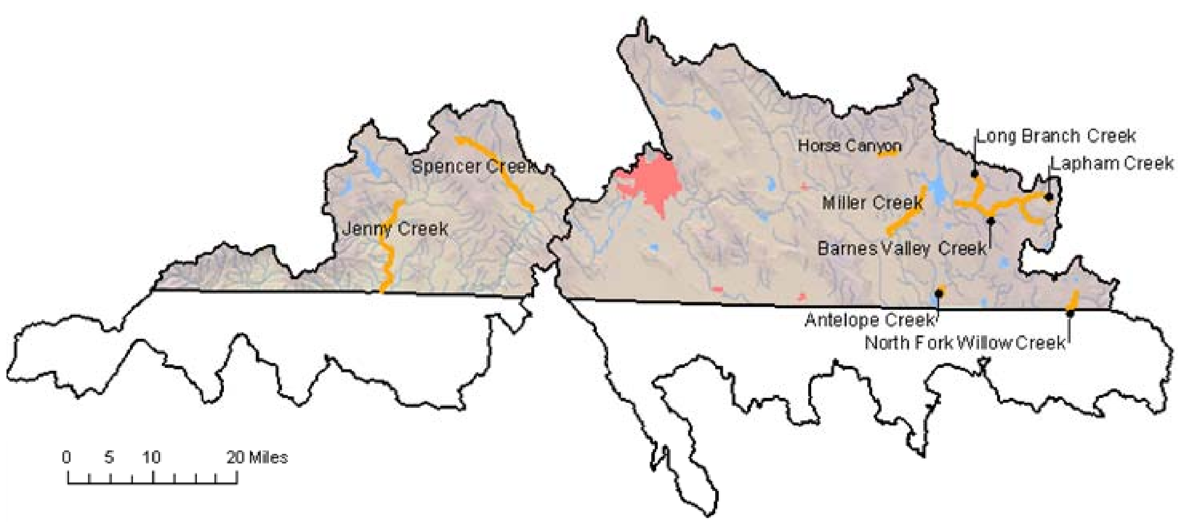
Spatial and Temporal Scale

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 113.93 stream kilometers in the Klamath River Basin (**Table A2 Figure A4).**

Table A2. Stream Temperature Simulation Periods and Extents

River/Stream	Simulation Period	Time Step (minutes)	Spatial Resolution (meters)	Model spin up (days)	Simulation Extent	HS version
Jenny Creek	7/4 to 7/23/2001	1	100	5	Confluence with Johnson Cr to OR/CA border: 23.7 km	7.0
Spencer Creek	7/2 to 7/21/2001	1	100	5	Headwaters to mouth: 25.2 km	8.0.2
Miller Creek	7/17 to 8/5/2001	1	100	5	Gerber Reservoir to mouth: 14.57 km	7.0
River/Stream	**Simulation Period**	**Time Step (minutes)**	**Spatial Resolution (meters)**	**Buffer Width from center point (m)**	**Simulation Extent (km)**	**HS version**
Antelope	7/15/2005	10	100	12	1.77	7.0
Barnes Valley	7/15/2005	10	100	20	23.9	7.0
Horse Canyon	7/15/2005	10	100	16	3.81	7.0
Lapham	7/15/2005	10	100	12	7.44	7.0
Long Branch	7/15/2005	10	100	12	8.11	7.0
North Fork Willow	7/15/2005	10	100	8	5.43	7.0
				Total Simulation Extent:	113.93	

Figure A4. 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.

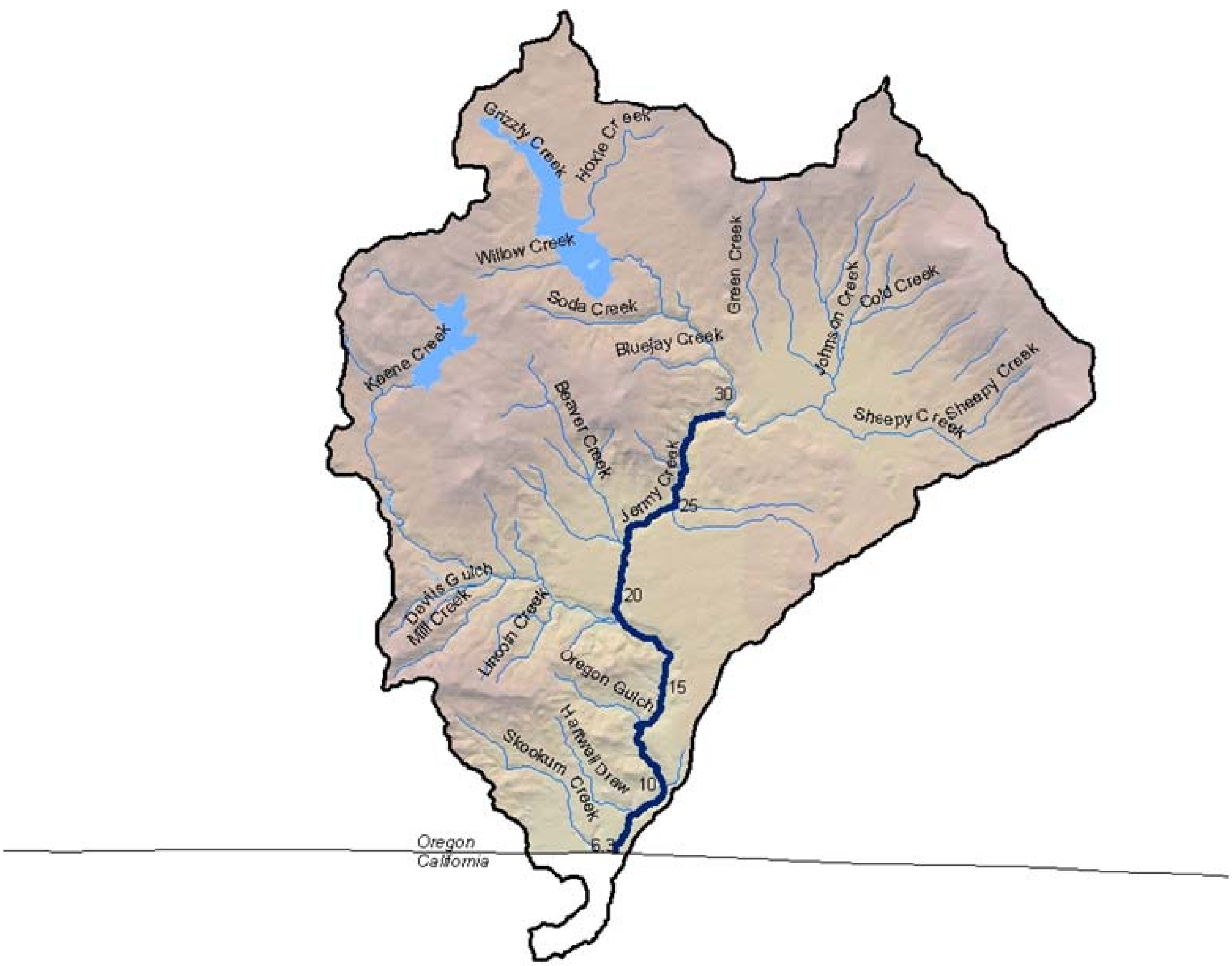
Error statistics were calculated for both the spatial (TIR) and temporal (hourly instream measurements) temperatures (see specific stream discussions below).

4.2 Jenny Creek

Overview

Stream Name: Jenny Creek
Model: Heat Source version 7.0
Beginning date: 7/4/2001
Ending date: 7/23/2001
Time step: 1 minute
Distance step: 100 m
Extent: Confluence with Johnson Creek to Oregon/California border at river km 6.3 (23.7km) (**Figure A5**).

Figure A5. Extent of the Jenny Creek temperature model.



Reach Properties

The channel properties were determined using the methodology documented previously in this report (see **Section 3**). **Figure A6** 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 sloping side slopes and a variable width-to-depth ratio determined through model calibration (**Figure A7 and Figure A8**). Non-spatially varying coefficients are presented in **Table A3**. Manning's n values were iteratively altered so that the model temperatures approximately reproduced measured temperatures (**Figure A8**). Topographic and riparian vegetation heights were determined through a GIS analysis (**Table A4**, **Figure A9 through Figure A11**). Using these channel and vegetation inputs, the Jenny Creek model predicted shade is shown in **Figure A12**.

Figure A6. Model setup channel elevation and gradient

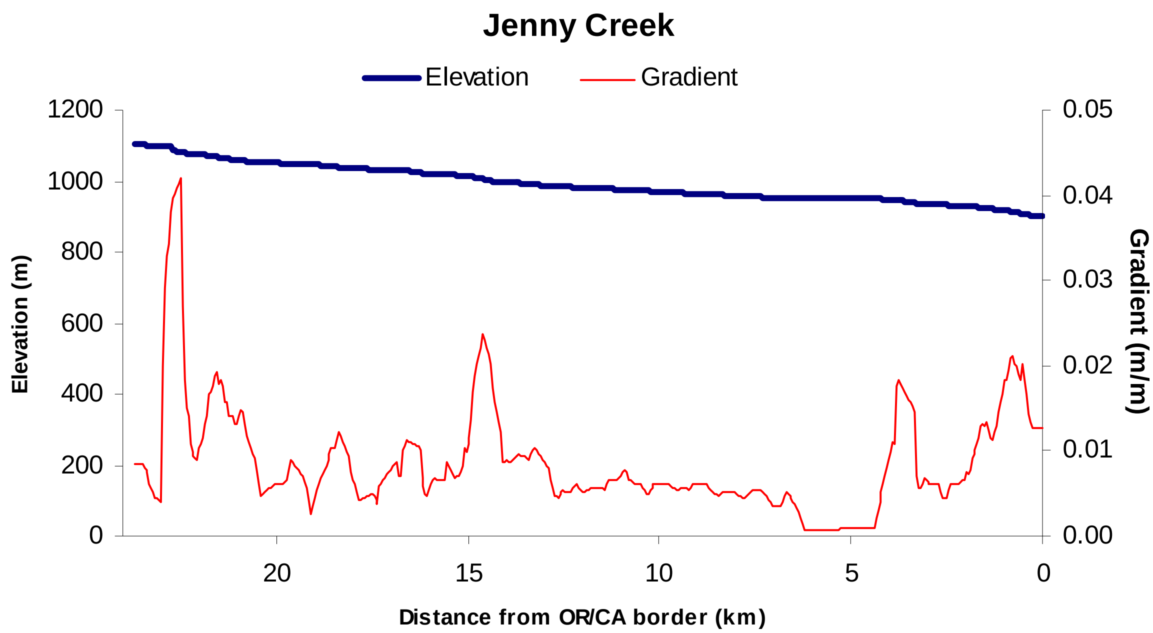


Figure A7. Model setup for bankfull width and channel angle

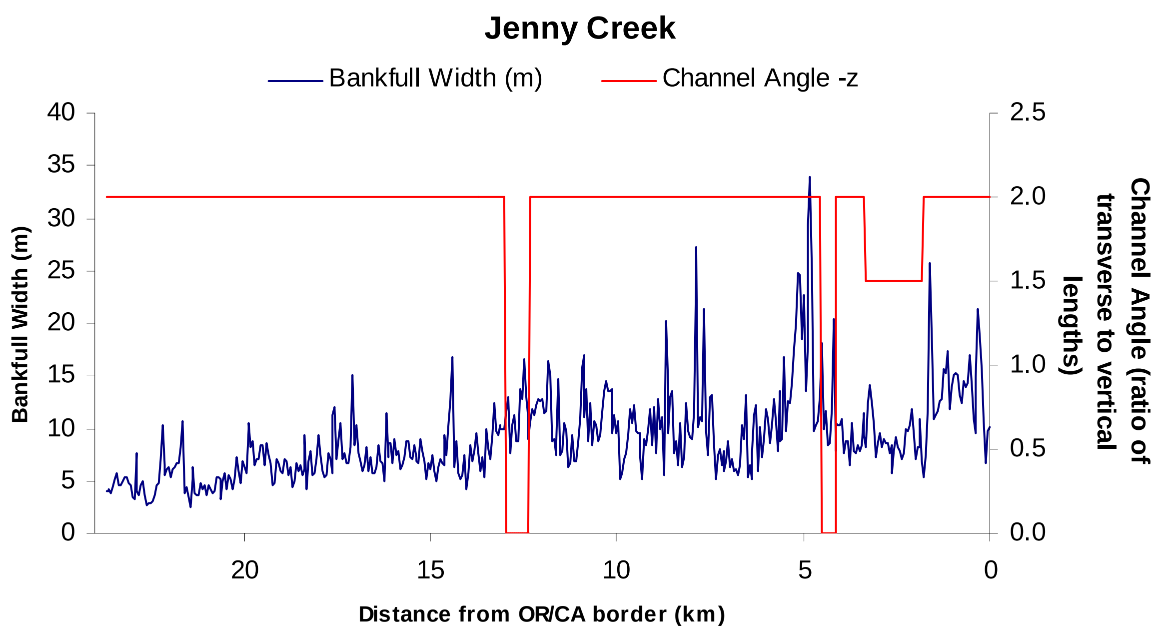


Figure A8. Model setup for roughness coefficient and width to depth ratio

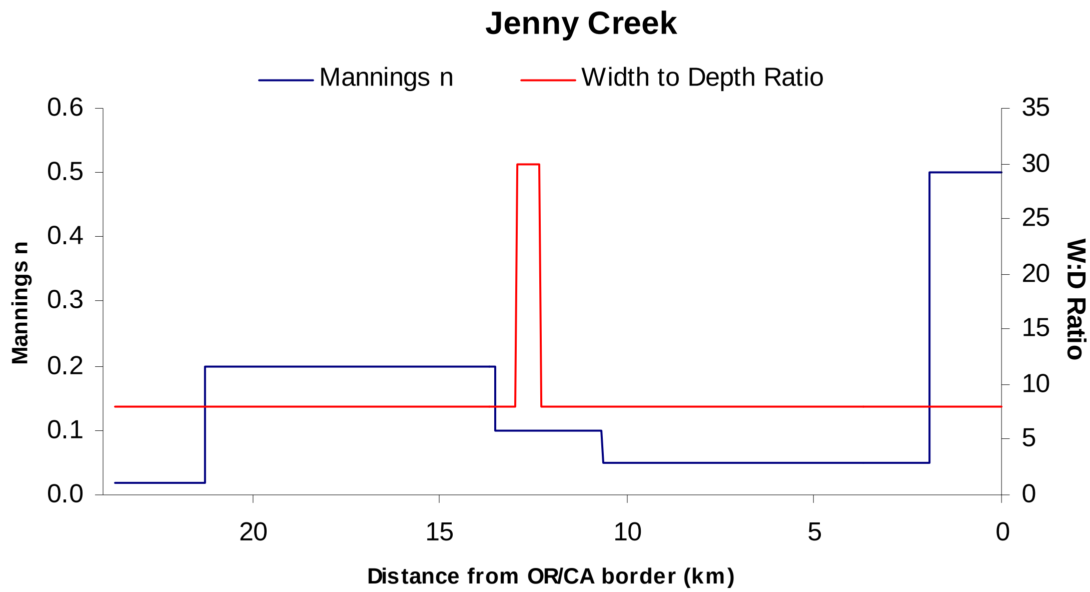


Table A3. Model coefficients for non-spatially varying parameters

Parameter name (units)	Value
Wind Function, coefficient a	1.0×10^{-9}
Wind Function, coefficient b	1.0×10^{-9}
Horizontal Bed Conductivity (mm/s)	20.0
Bed Particle Size (mm)	2
Embeddedness	0.3

Figure A9. Model setup for topographic angle

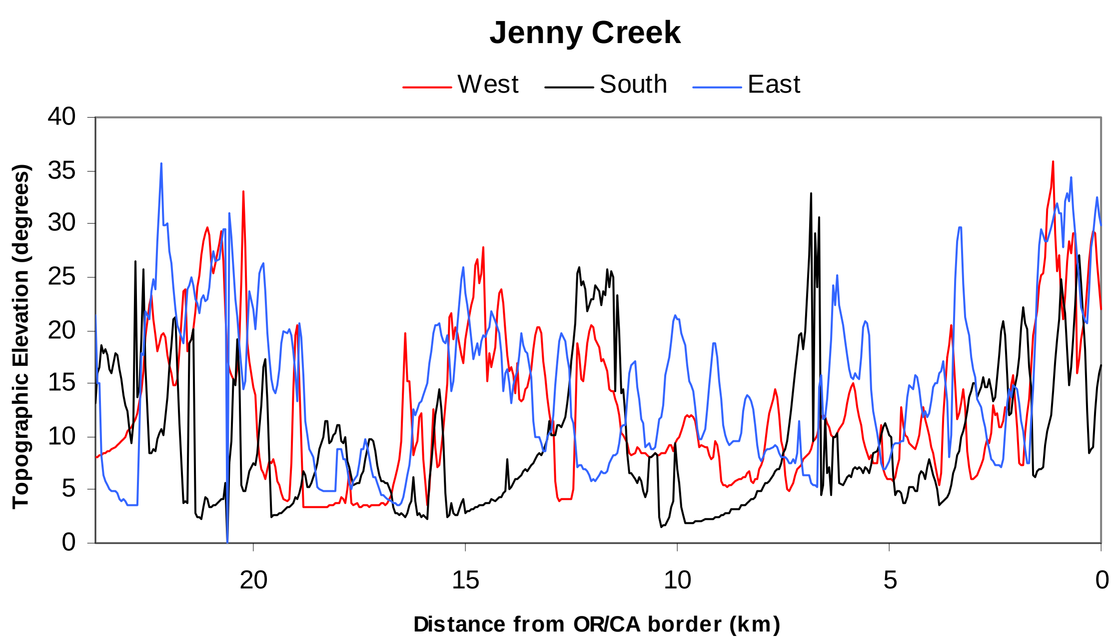


Figure A10. Model setup for height of streamside vegetation

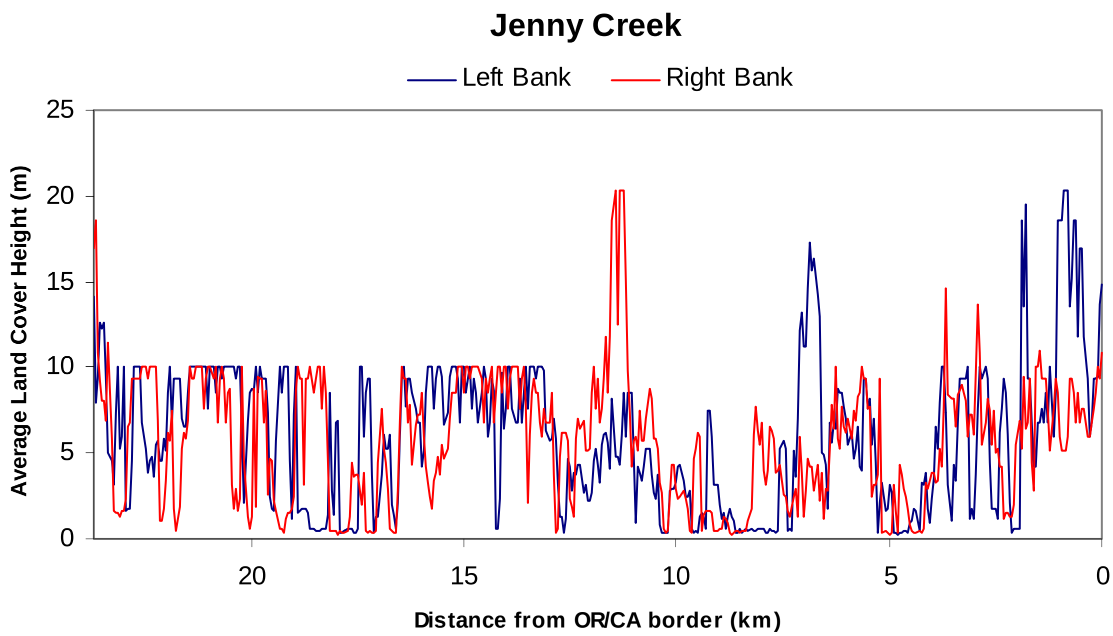


Figure A11. Model setup for density of streamside vegetation.

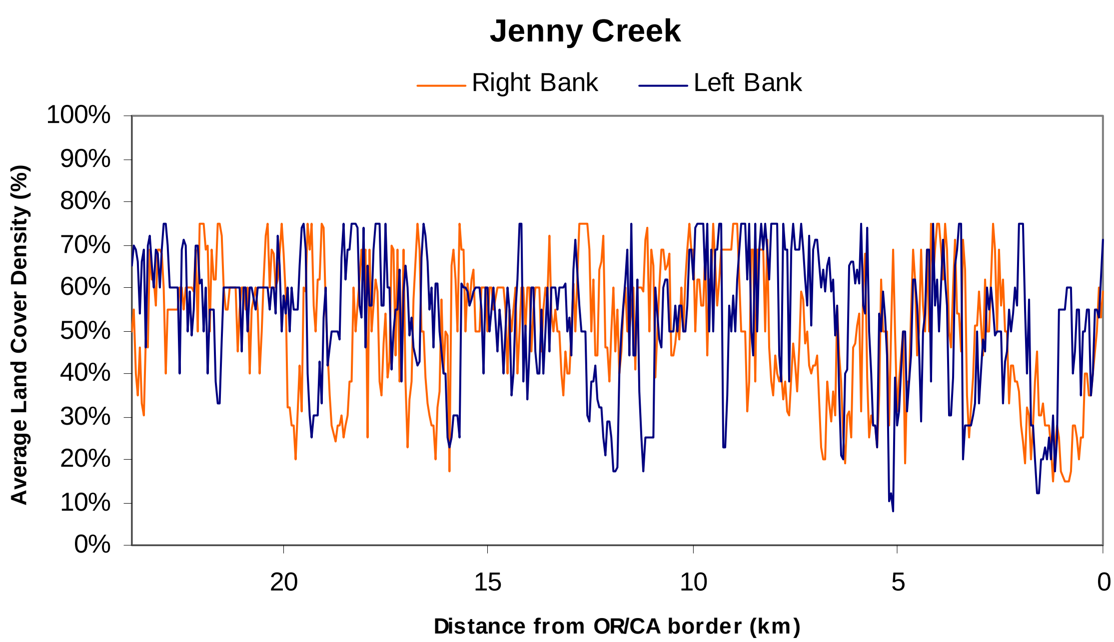


Figure A12. Predicted shade on Jenny Creek.

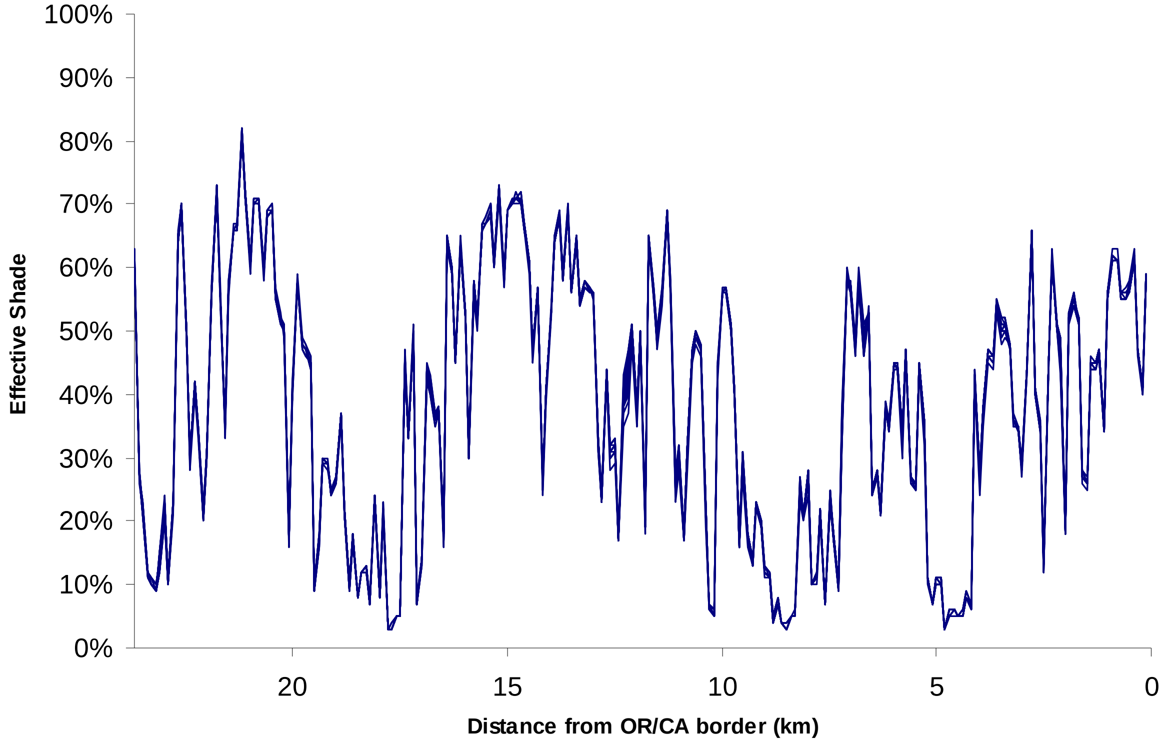


Table A4. Spatial Data and Application: GIS data source and the application used in Jenny Creek watershed

Spatial Data	Data Source	Application
10-Meter Digital Elevation Models (DEM)	Oregon Geospatial Data Clearinghouse	Measure Stream Elevation and Gradient Measure Topographic Shade Angles
Aerial Imagery – Digital Orthophoto Quads	Jackson County	Map Vegetation Map Channel Morphology Map Roads, Development, Structures
Thermal Infrared Radiometry (TIR) Stream Temperature Data	Watershed Sciences 2002, Collected on 7/14/2001	Measure Surface Temperatures Develop Longitudinal Temperature Profiles Identify Subsurface Hydrology, Groundwater Inflow, Springs

Meteorology

The Jenny Creek model uses air temperature, relative humidity, wind speed and solar radiation measurements from a BLM monitoring station at Buckhorn Springs (downloaded from RAWS on 1/30/2006). Cloudiness was determined by calculating the deviation of actual solar radiation from expected sunny solar radiation. The wind speed was used without adjustment. The meteorological observations are presented in **Figure A13, a-d**.

Figure A13, a-d. Meteorology inputs for model setup

Figure A13-a.

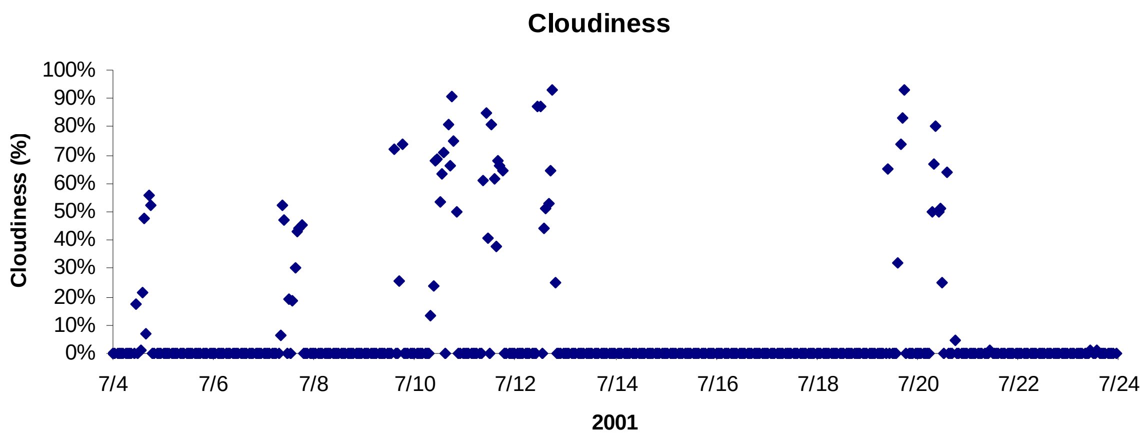


Figure A13-b

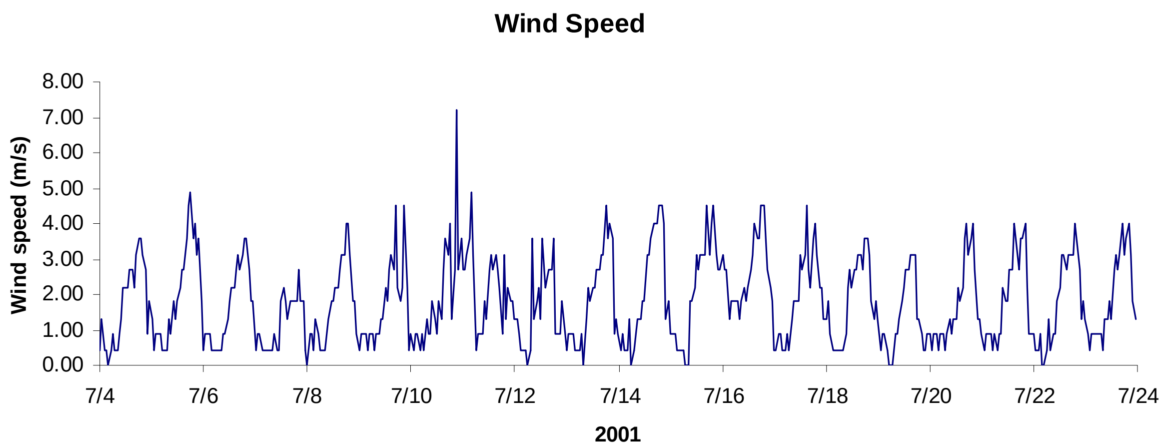


Figure A13-c

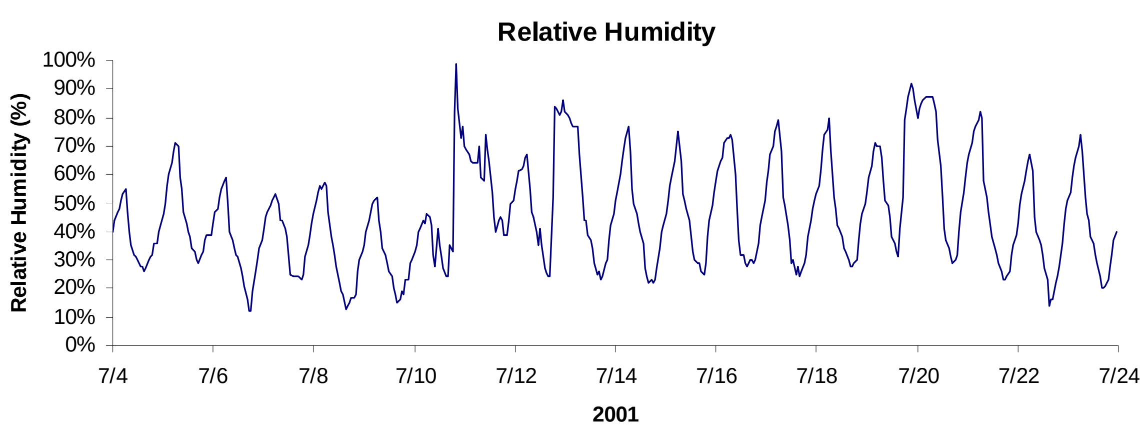
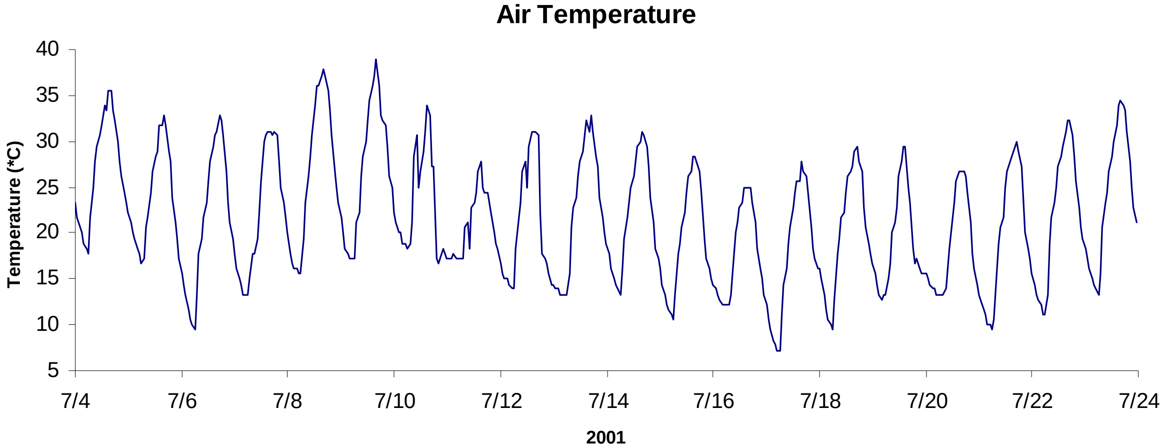


Figure A13-d



Flow

When available, flow measurements taken in the Jenny Creek watershed were used to generate model input (**Table A5**). Instantaneous flow and velocity measurements were collected by BLM at various places and times during the model period. Flow balance was derived through various methods including using the TIR temperatures and upstream flow. The Jenny Creek model assumed there were no significant water withdrawals from the system. Using these flow inputs, the performance of the Jenny Creek model at several times and locations is shown in **Figure A14** and **Figure A15.**

Table A5. Flow inputs and rates for the Jenny Creek model.

Location name	Stream km	Flow rate (cms)	Source
Boundary condition	23.7	0.036	Flow balance
spring (from TIR)	17.35	0.04	Flow balance
Beaver Creek	15.95	0.04	Flow balance
Keene Creek	12.75	0.07	BLM instantaneous flow measurement 7/18/2001
spring (from TIR)	3.9	0.06	Flow balance
Spring Creek	3.35	0.18	Flow balance

Figure A14. Longitudinal profile of model results with measured flow. Model results are represented by lines and measurements by points.

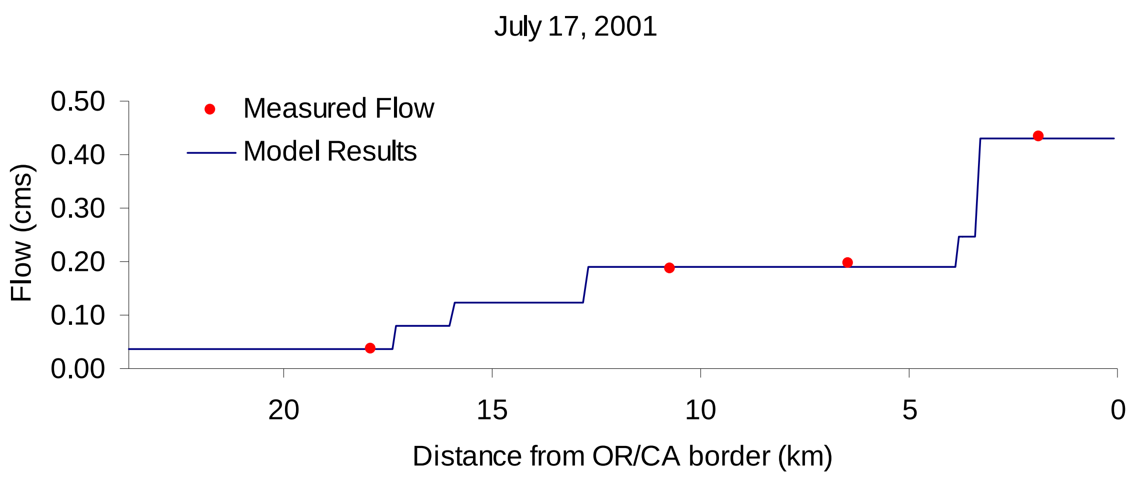
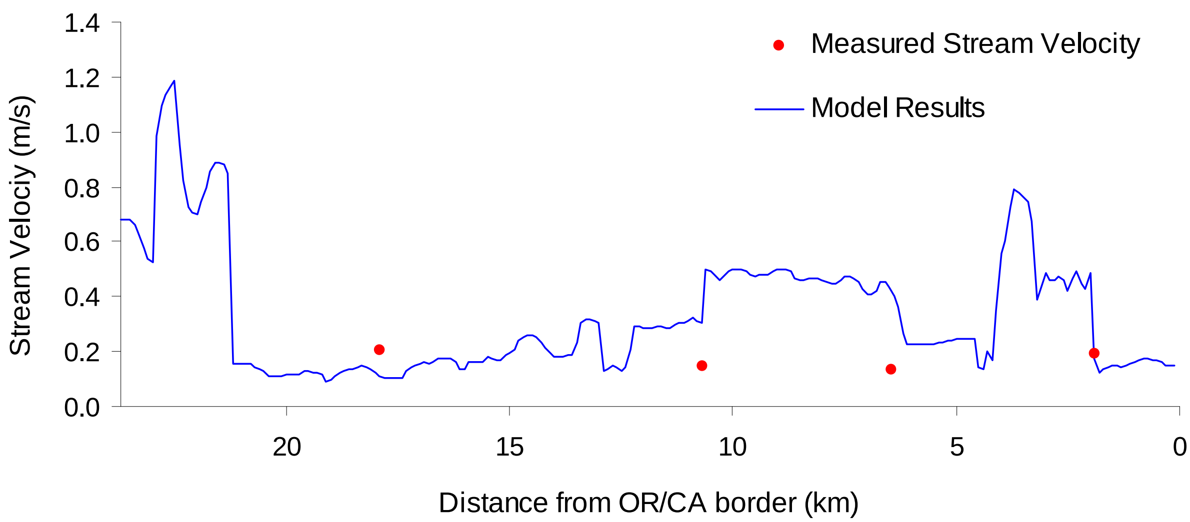


Figure A15. Longitudinal profile of model results with measured stream velocities. Model results are represented by lines and measurements by points.



Temperature

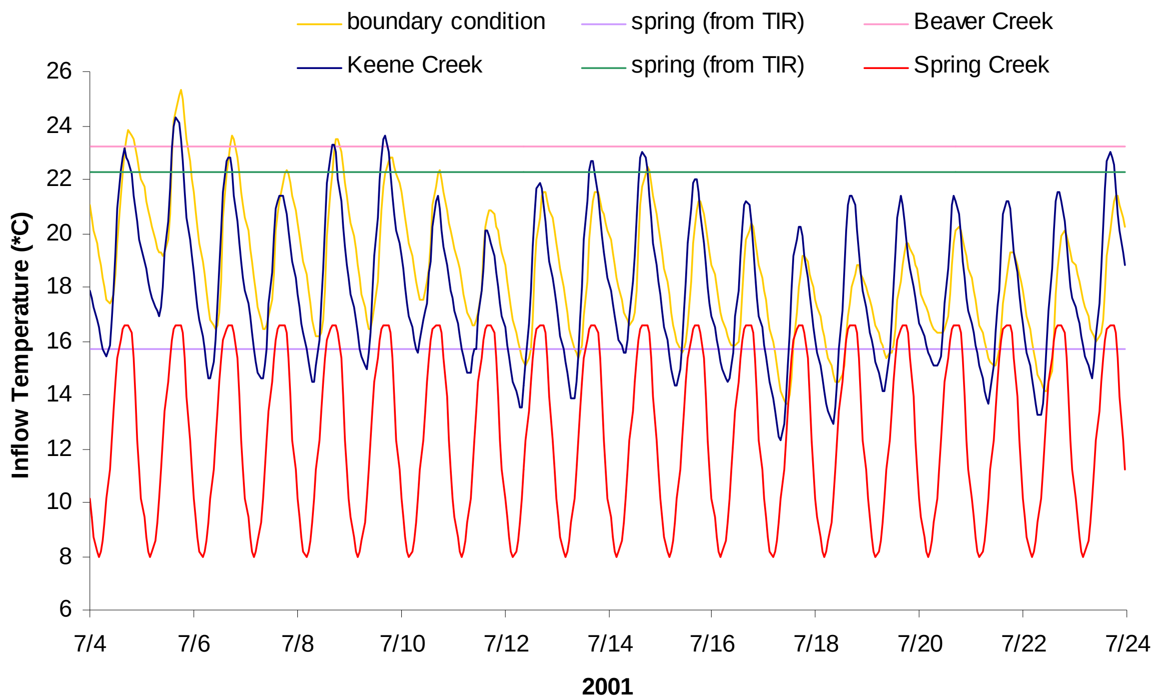
Table A6 and **Figure A16** document the temperatures of the tributaries and springs incorporated in the model.

Table A6. Source of tributary and boundary condition temperature inputs for Jenny Creek model

Inflow	Stream km	Source of temperature data
Boundary Condition	23.7	Derived from BLM continuous gage Jenny Creek above Johnson Creek (JNYU)
spring (from TIR)	17.35	TIR temperature

Beaver Creek	15.95	TIR temperature
Keene Creek	12.75	Derived from BLM continuous gage Keene Creek below Lincoln Creek (BXDW)
spring (from TIR)	3.9	TIR temperature
Spring Creek	3.35	Derived diel from assumed minimum temperature and assumed maximum TIR temperature

Figure A16. Temperature of inflows to the Jenny Creek model.



Temperature Calibration

The model generally reproduces spatially and temporal varying temperature measurements (**Table A7 and Table A8,** and **Figure A17 and Figure A18**). The Medford BLM office provided continuous instream temperature data. See previous statistics discussion at the beginning of **Section 4** for definitions.

Table A7. TIR error statistics

Error type	value
Mean	-0.28
Absolute mean	0.66
Root mean square	0.70

Figure A17. Longitudinal profile of measured temperatures using Thermal Infrared Radiometry and model results.

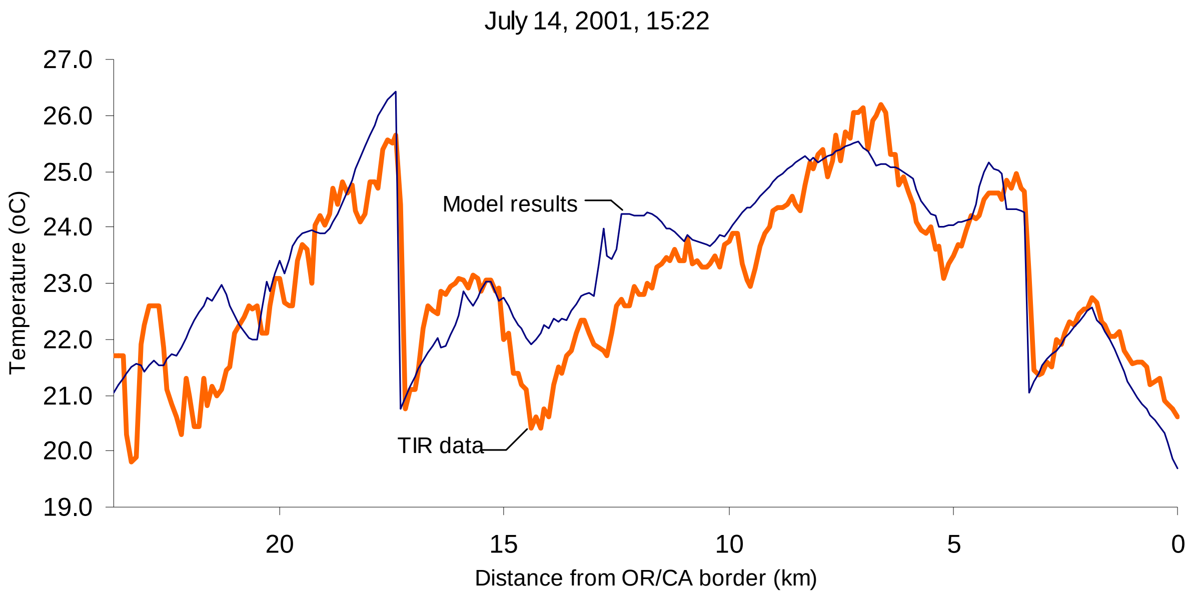
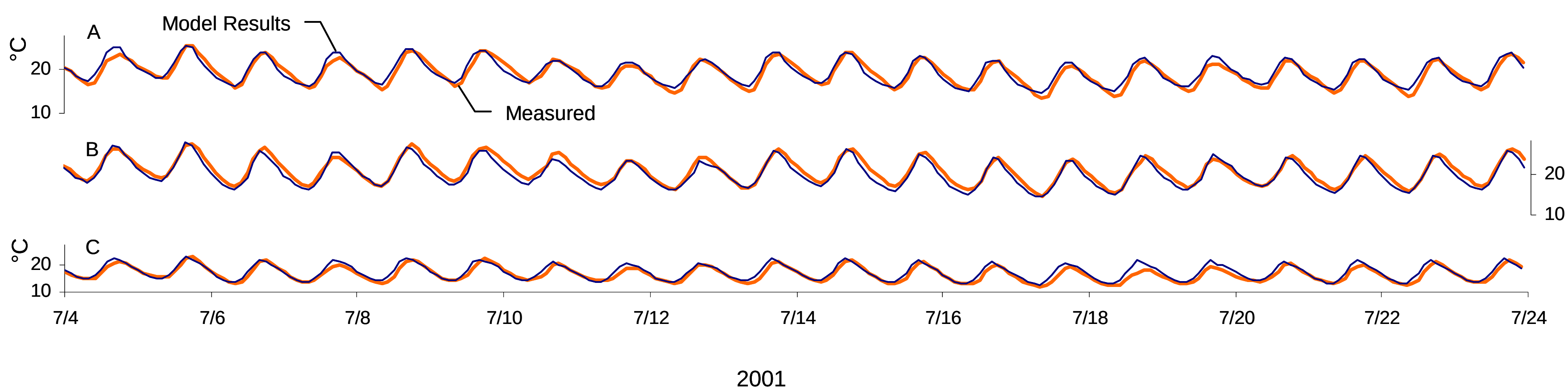


Table A8. Continuous monitoring error statistics

Site Name	Site #	Ref	rKM	All data n	Mean Error	Abs Mean Error	RMSE	Nash-Sutcliffe
Jenny Creek below Keene Creek, @ Box O Ranch north boundary	BXON	A	10.7	240	-0.28	0.81	0.97	0.88
Jenny Creek below Oregon Gulch, @ Box O Ranch south boundary	BXOS	B	6.45	240	0.71	0.88	1.03	0.88
Jenny Creek below Spring Creek, @ Road 41-2E-10.1	LWRX	C	1.9	240	-0.68	0.91	1.21	0.80
Average					-0.08	0.87	1.07	0.85

Figure A18. Measured steam temperature versus model results



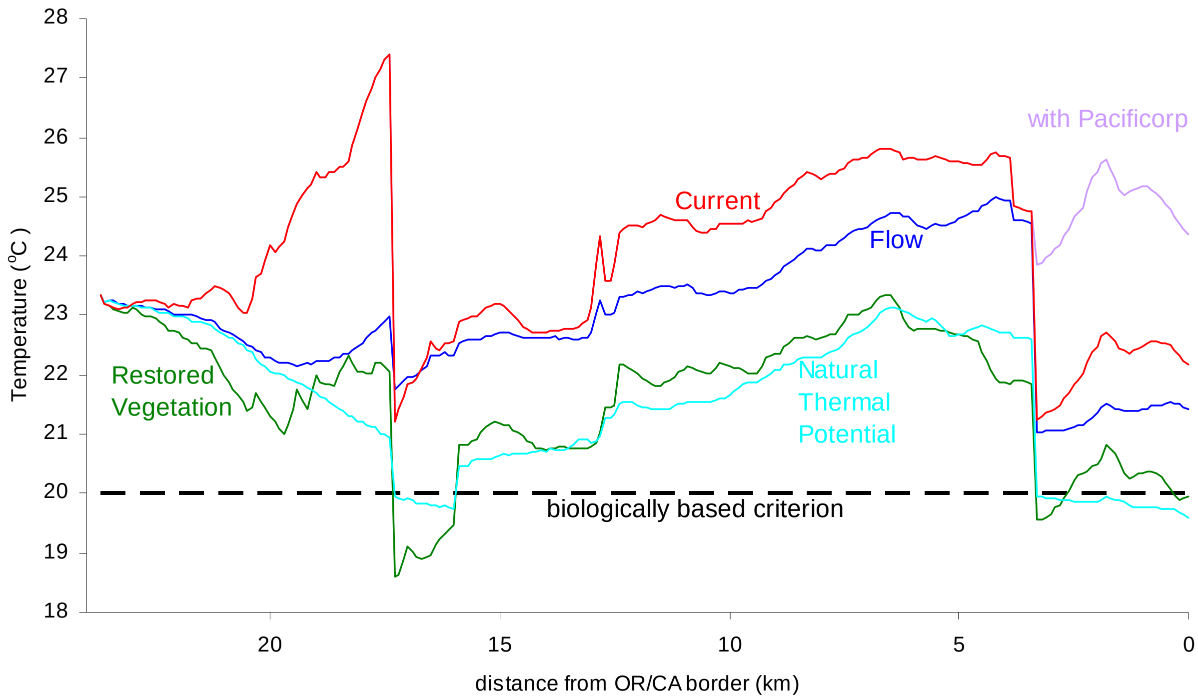
Scenario Results

The Heat Source model was used to predict the influence of various factors on stream temperature by modifying the Current Calibrated Condition as specified in **Table A9**. As seen in **Figure A19**, because the NTP temperatures are greater than the biologically based criterion of 20ºC along most of the modeled reach, the NTP temperature is the applicable criteria at those nodes. Segments where the NTP temperatures are less than 20ºC, the biologically based criterion is applied.

Table A9. Simulated Scenario Definitions

"Current" "CCC"	Current Calibrated Condition
"Restored Vegetation"	Potential Vegetation (see effective shade figure, potential vegetation table and summary of results in the main text of this document, Chapter 2).
"Flow"	No points of diversion and boundary condition flow adjusted (see main text, Chapter 2 for a summary of the results)
"PacCorp withdrawals"	Flow removed from the tributary Spring Creek to reflect Pacificorp's current impacts
"NTP"	Natural Thermal Potential: combining the inputs of system potential vegetation and system potential flow. No other adjustments were made to tributary inputs.

Figure A19. Predictions for Jenny Creek scenarios based on the maximum 7-DADM, July 4-23, 2001.



System Potential Vegetation

System potential vegetation is essentially the mature species composition, height, density, and overhang width of vegetation that would occur in the absence of human disturbances. System potential vegetation conditions were used in stream temperature modeling scenarios to quantify the impacts of nonpoint source solar radiation loads, and ultimately to develop nonpoint source load allocations for the TMDL.

System potential vegetation values were estimated for the Jenny Creek watershed by examining multiple references. To determine habitat potentials, physical parameters including elevation, gradient, climate, soils, vegetative communities, geology, physiography, hydrology, land use, etc. were assessed. Jenny Creek travels between three EPA Level IV Ecoregions (Thorson et al. 2003), so the habitats were more distinguished by a change in elevation at river kilometer 12.5. To determine potential plant species, narrative reports, especially vegetation descriptions from the Oregon Watershed Assessment Manual (1999), were consulted. Estimates of plant community height, density and overhang width were compiled and averaged by best professional judgment from site indices, tree growth curves, and plant guide books **Table A10**. Generally, vegetation is expected to increase or remain the same in average height, density, and overhang distance. The largest Mixed Conifers are also expected to decrease in height, on average, as the species composition changes. Finally, the current land cover vegetation types were assigned a potential (mature) vegetation type, which are also described in **Table A10**.

Table A10. Summary of the current vegetation type heights, densities, and overhang widths and assigned system potential vegetation type.

Vegetation Type	Height (m)	Density (%)	Overhang (m)	Prevalence in model (%)	Potential Vegetation Type	Height (m)	Density (%)	Overhang (m)
Water	0.0	0	0.0	19.3	Water	0.0	0	0.0
Pastures/Cultivated Field/lawn	0.5	75	0.3	15.5	Riparian mixed hardwoods	12.2	75	2.0
Barren - Rock	0.0	0	0.0	0.0	N/A			
Barren - Embankment	0.0	0	0.0	0.0	N/A			
Barren - Clearcut	0.0	0	0.0	0.0	N/A			
Barren - Soil	0.0	0	0.0	0.0	N/A			
Barren - Road	0.0	0	0.0	0.2	Mixed conifers & hardwood	25.0	50	2.0
Barren - Forest Road	0.0	0	0.0	0.0	N/A			
L. Mixed Con/Hard (50-100% CC)	16.4	75	2.1	0.4	Riparian hardwoods	16.4	75	2.1
S. Mixed Con/Hard (50-100% CC)	8.2	75	1.0	2.7	Riparian hardwoods	16.4	75	2.1
L. Mixed Con/Hard (<50% CC)	16.4	25	2.1	0.0	N/A			
S. Mixed Con/Hard (<50% CC)	8.2	25	1.0	0.6	Riparian hardwoods	16.4	75	2.1
L. Mixed Con/Hard (10% CC)	16.4	10	2.1	0.0	N/A			
Large Hardwood	12.5	75	1.9	0.0	N/A			
Small Hardwood	6.2	75	0.9	9.4	Riparian mixed hardwoods	12.2	75	2.0
Large Hardwood - Low Density	12.5	10	1.9	0.0	N/A			
Small Hardwood - Low Density	6.2	30	0.9	2.3	Riparian mixed hardwoods	12.2	75	2.0
Large Conifer	35.0	60	2.0	24.5	Mixed conifers	30.0	60	2.0
Medium Conifer – Upper watershed	20.3	60	2.0	3.6	Mixed conifers	30.0	60	2.0
Medium Conifer – Lower watershed	20.3	60	2.0	3.6	Mixed conifers & hardwood	25.0	50	2.0
Small Conifer	10.2	60	1.0	0.0	N/A			
Large Conifer - Low Density	35.0	30	2.0	0.0	N/A			

Vegetation Type	Height (m)	Density (%)	Overhang (m)	Prevalence in model (%)	Potential Vegetation Type	Height (m)	Density (%)	Overhang (m)
Medium Conifer - Low Density	20.3	30	2.0	10.5	Mixed conifers & hardwood	25.0	50	2.0
Small Conifer - Low Density	10.2	30	1.0	0.0	N/A			
Western Juniper	5.4	10	0.5	0.0	N/A			
Upland shrubs	1.8	50	0.3	3.0	Mixed conifers & hardwood	25.0	50	2.0
Shrubs on wet floodplain	1.8	75	0.3	5.8	Shrubs on wet floodplain	2.3	75	0.3
Grasses - upland	0.5	75	0.3	2.0	Mixed conifers & hardwood	25.0	50	2.0
Active Channel Bottom	0.0	0	0.0	0.0	N/A			
Development - Residential	6.1	100	0.0	0.0	Mixed conifers & hardwood	25.0	50	2.0
Development - Industrial	9.1	100	0.0	0.0	N/A			
Dam/Wier	0.0	0	0.0	0.0	N/A			
Canal	0.0	0	0.0	0.0	N/A			
Dike	0.0	0	0.0	0.0	N/A			

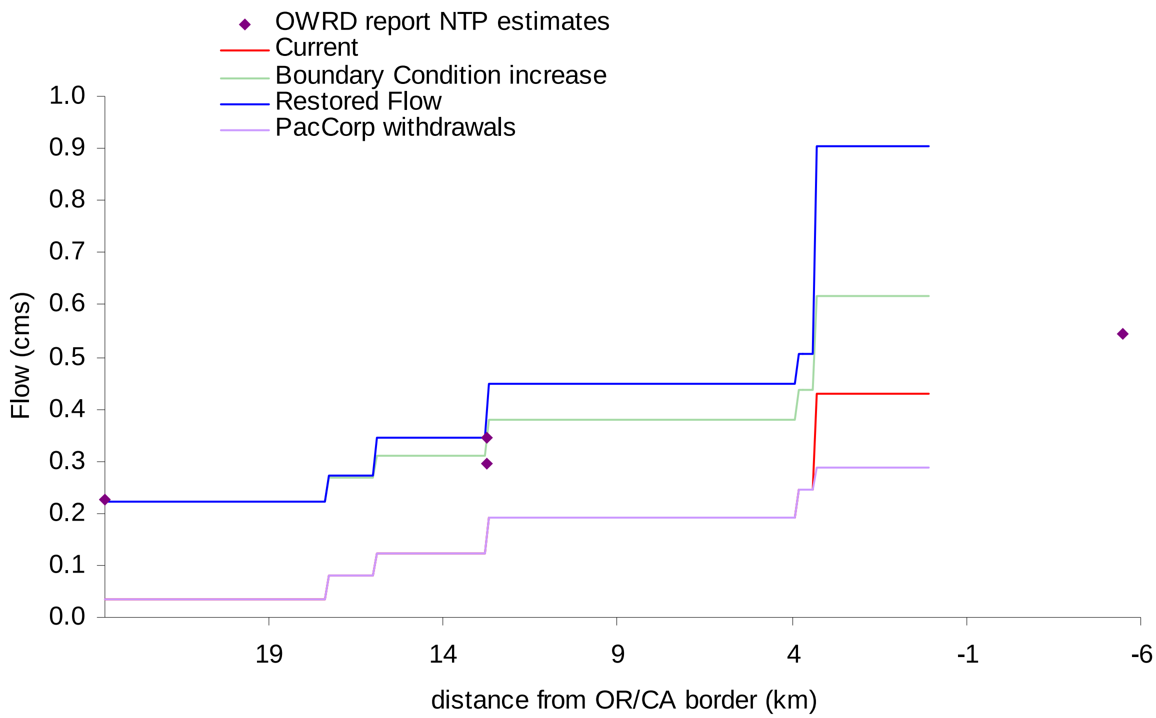
System Potential Flow

System potential flow is the volumetric flow of water estimated to be in the modeled reach if there were no anthropogenic influences. In the Jenny Creek watershed, OWRD provided estimates of the 50th percentile natural flow at several points (OWRD 2002). The OWRD estimate was incorporated in to the model only at the boundary condition (**Table A11 and Figure A20**). According to the Current Calibrated model, the increase in flow at the boundary increases the flow downstream to greater than flows estimated by OWRD. Instead, in the "Restored Flow" model, flow was added to tributaries to reflect the water that is currently withdrawn from the mainstem Jenny Creek and Spring Creek according to the OWRD points-of-diversion database. This flow was added to the closest tributary node. The "Restored Flow" scenario represents a greater volumetric flow at the mouth than was estimated by the OWRD report. During the model year, 2001, a significant water withdrawal from Spring Creek was not used. The scenario "PacCorp withdrawals" incorporates the current estimated consumptive water use from Spring Creek and is a reflection of the current water flow in Jenny Creek.

Table A11. Flow inputs and rates for the Jenny Creek flow modified model.

Location name	Stream km	Current flow rate (cms)	Restored flow rate (cms)	Source
Boundary condition	23.7	0.036	0.224	OWRD report
spring (from TIR)	17.35	0.04	0.049	OWRD POD consumptive use
Beaver Creek	15.95	0.04	0.072	OWRD POD consumptive use
Keene Creek	12.75	0.07	0.104	OWRD POD consumptive use
spring (from TIR)	3.9	0.06	0.06	
Spring Creek	3.35	0.18	0.396	OWRD POD consumptive use

Figure A20. Longitudinal profiles of predicted flows for scenarios which considered flow alterations on Jenny Creek, July 24, 2001.

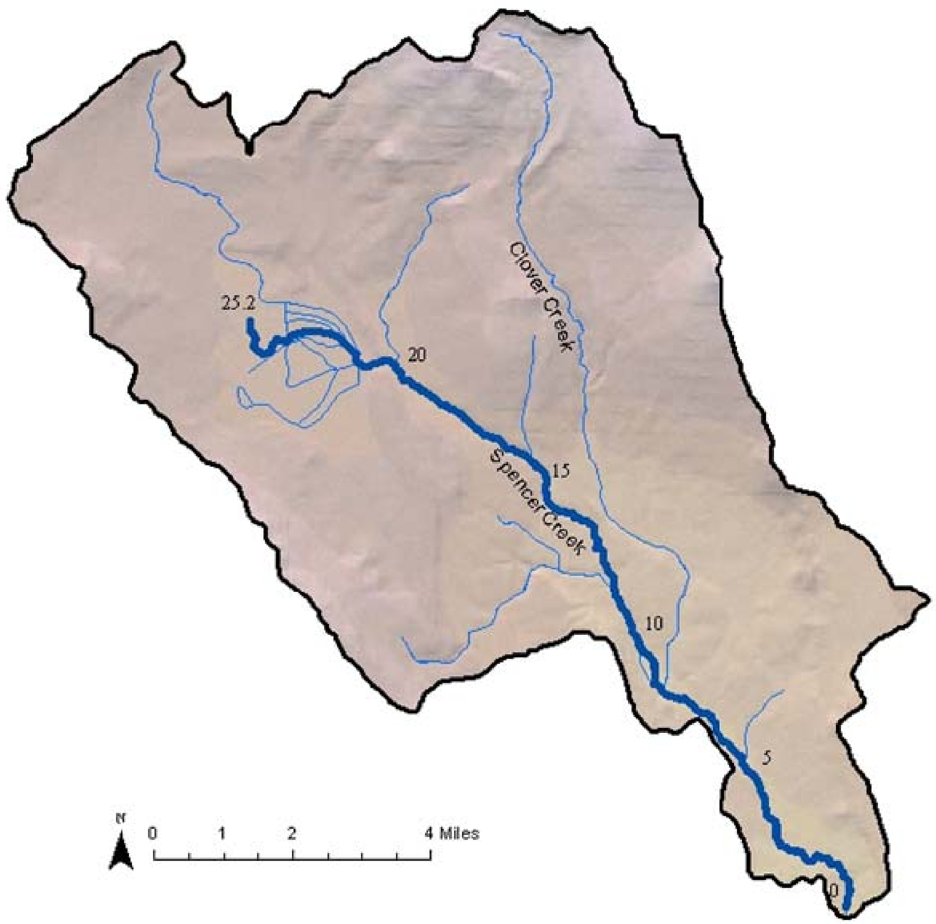


4.3 Spencer Creek

Overview

Stream Name: Spencer Creek
Model: Heat Source version 8.0.2
Beginning date: 7/2/2001
Ending date: 7/21/2001
Time step: 1 minute
Distance step: 100 m
Extent: Headwaters (25.2 km) to mouth (**Figure A21**).

Figure A21. Extent of the Spencer Creek temperature model



Reach Properties

The channel properties were determined using the methodology documented previously in this report (see **Section 3**). **Figure A22** 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 sloping side slopes and a variable width-to-depth ratio determined through model calibration (**Figure A23**). Non-spatially varying coefficients are presented in **Table A12**. Manning's n was iteratively altered so that the model temperatures approximately reproduced measured temperatures (**Table A12**). Topographic and riparian vegetation heights were determined through a GIS analysis (**Table A13**, **Figure A25 through Figure A27**). Using these channel and vegetation inputs, the performance of the Spencer Creek model in predicting shade is shown in **Figure A28**.

Figure A22. Model setup channel elevation and gradient.

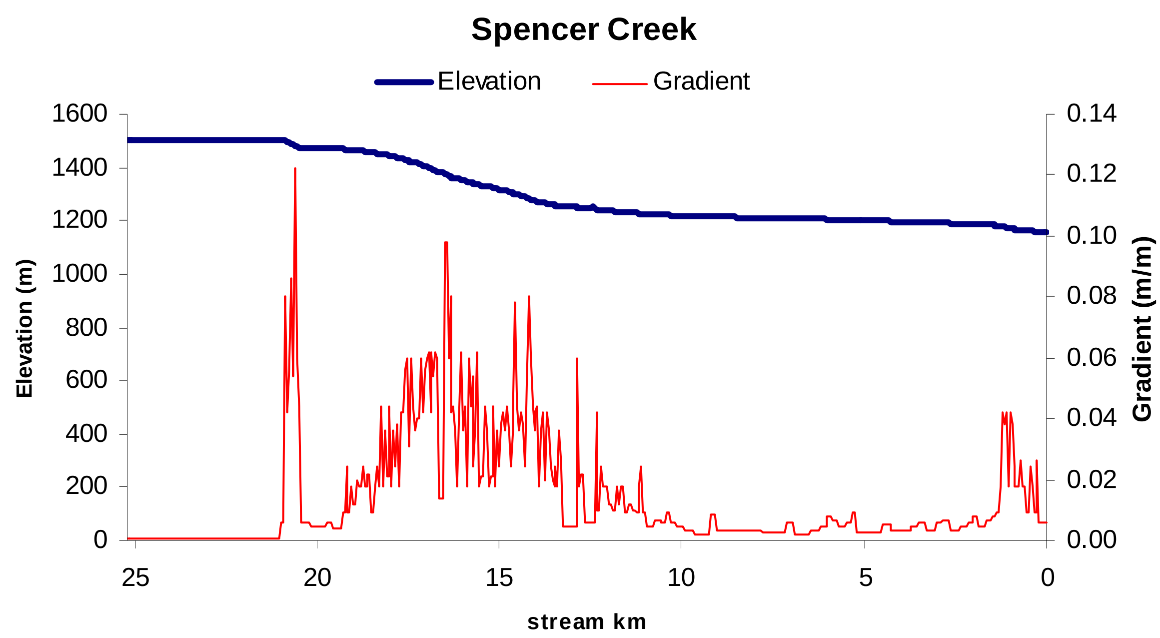


Figure A23 Model setup for channel bottom width and channel angle.

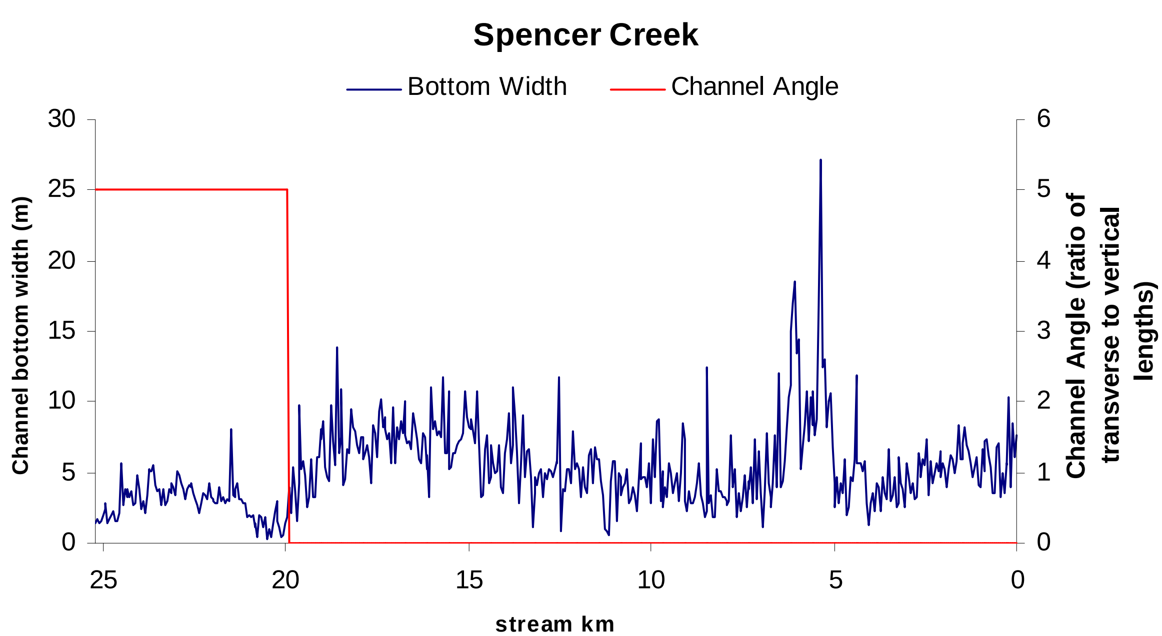


Table A12. Model coefficients for non-spatially varying parameters.

Parameter name (units)	Value
Wind Function, coefficient a	1.51×10^{-9}
Wind Function, coefficient b	1.60×10^{-9}
Width:Depth Ratio	26.0
Sediment Thermal Conductivity (W/m/°C)	1.57
Sediment Thermal Diffusivity (cm^2/sec)	0.0064
Sediment/hyporheic zone thickness (m)	0.20
Percent Hyporheic Exchange	0%
Porosity	33%

Figure A24. Model setup for roughness coefficient

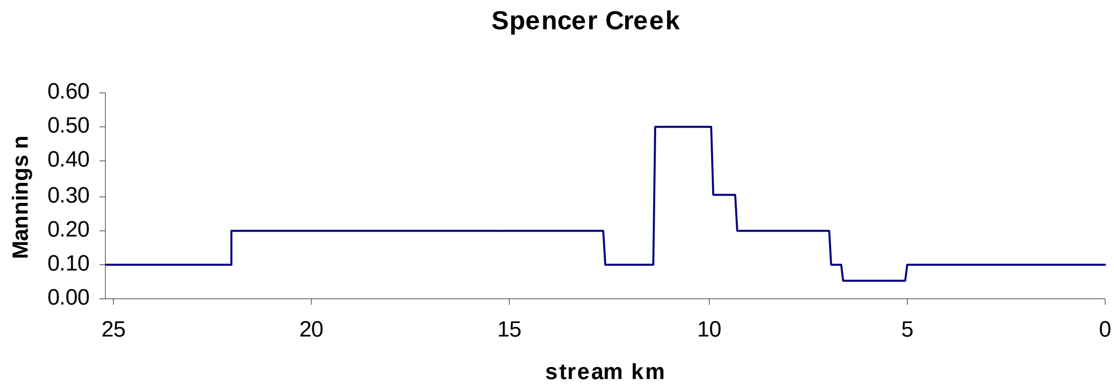


Table A13. Spatial Data and Application: GIS data source and the application used in Spencer Creek watershed

Spatial Data	Data Source	Application
10-Meter Digital Elevation Models (DEM)	Oregon Geospatial Data Clearinghouse	Measure Stream Elevation and Gradient Measure Topographic Shade Angles
Aerial Imagery – Digital Orthophoto Quads	BLM	Map Vegetation Map Channel Morphology Map Roads, Development, Structures
Thermal Infrared Radiometry (TIR) Stream Temperature Data	Watershed Sciences 2002, collected on 7/15/2001	Measure Surface Temperatures Develop Longitudinal Temperature Profiles Identify Subsurface Hydrology, Groundwater Inflow, Springs

Figure A25. Model setup for topographic angle

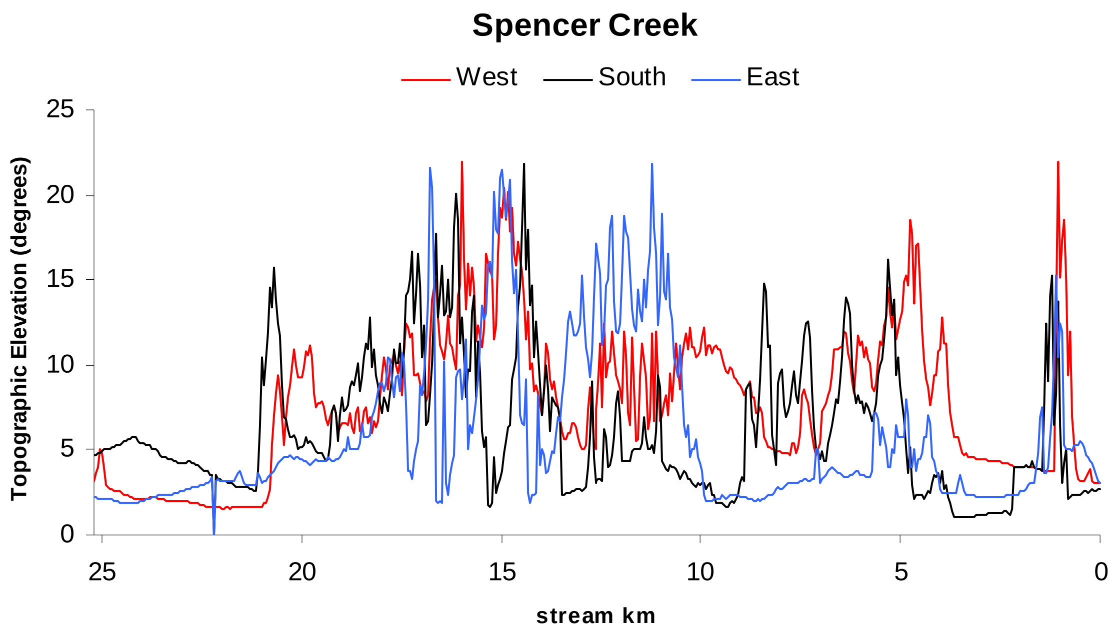


Figure A26. Model setup for height of streamside vegetation

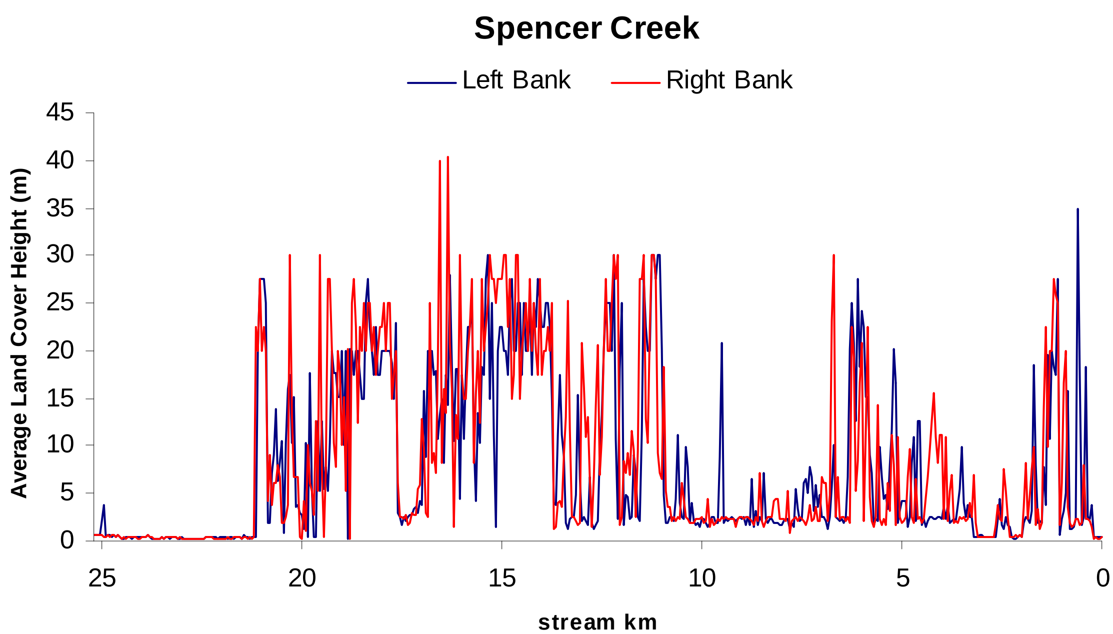


Figure A27. Model setup for density of streamside vegetation.

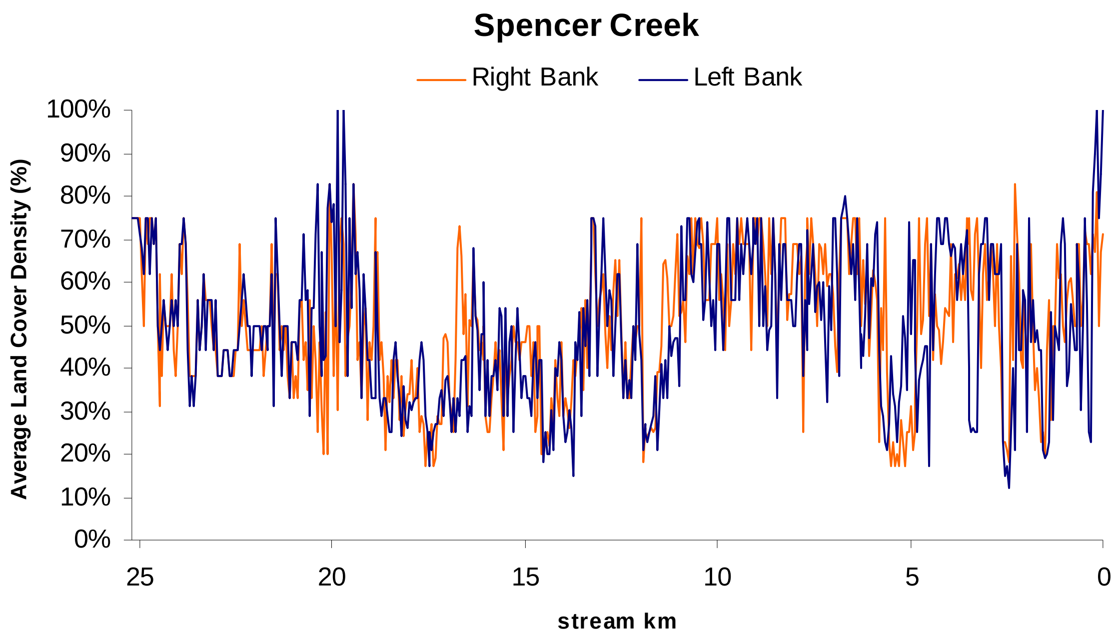
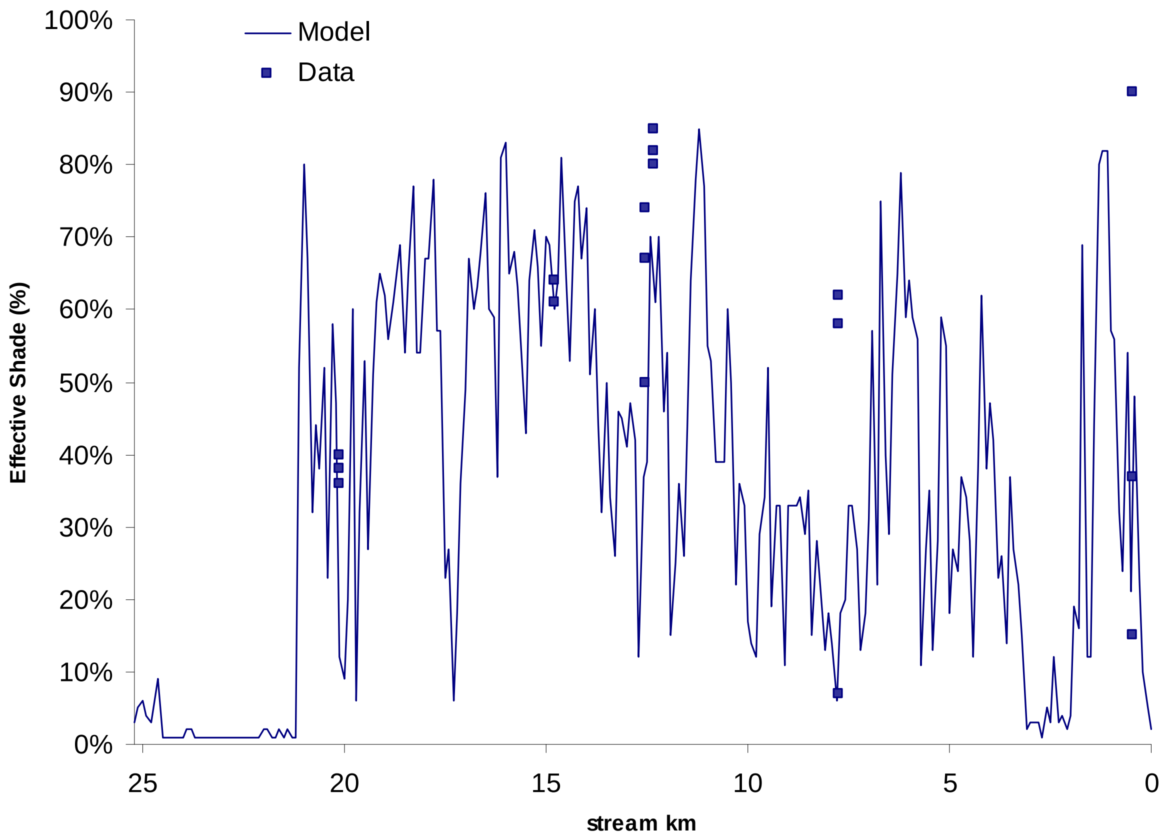


Figure A28. Predicted versus measured effective shade



Meteorology

The Spencer Creek model uses air temperature, relative humidity, and wind speed data from a BLM meteorology station in the Spencer Creek watershed (US BLM 2004). Solar radiation data was obtained from the Medford airport meteorology site (NOAA 2001a) and used to derive cloudiness. The meteorological observations are presented in **Figure A29, a-d**.

Figure A29, a-d. Meteorology inputs for model setup

Figure A29-a.

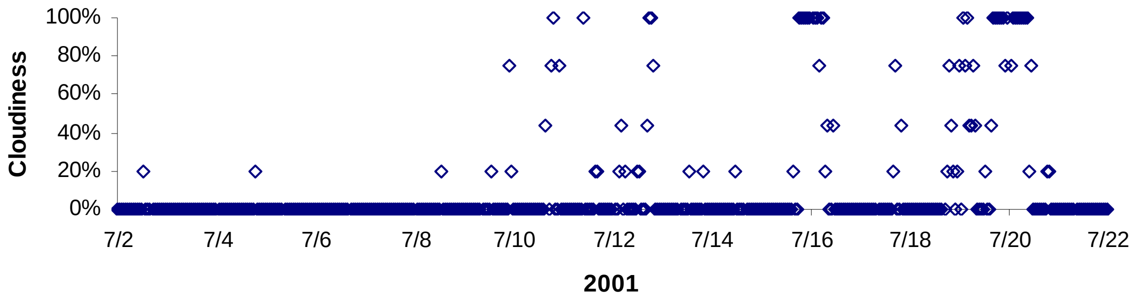


Figure A29-b

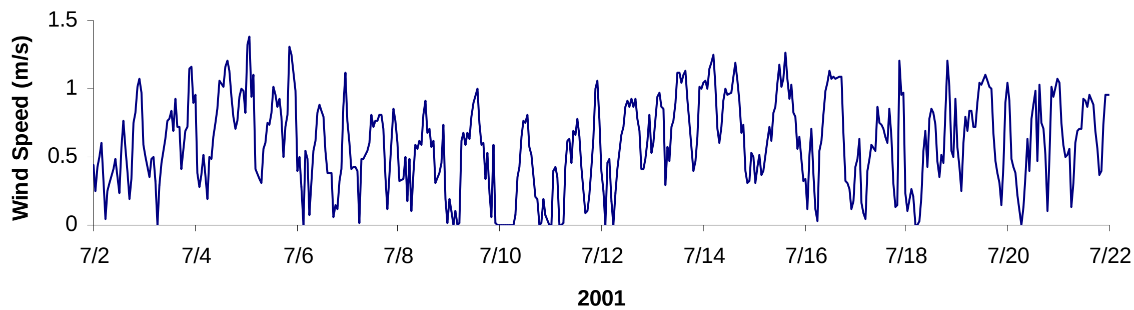


Figure A29-c

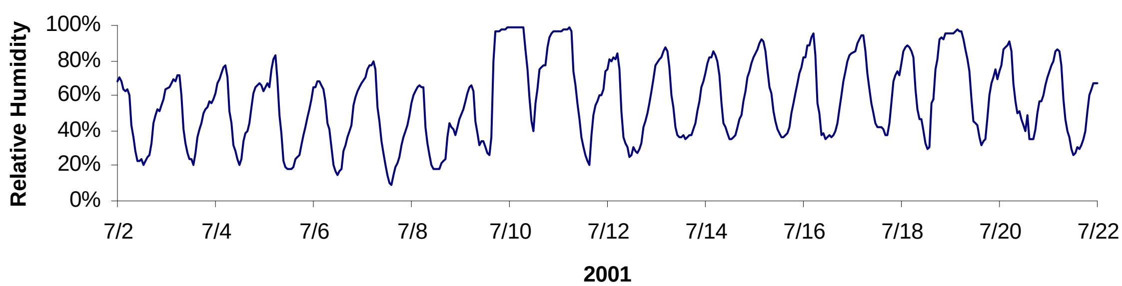
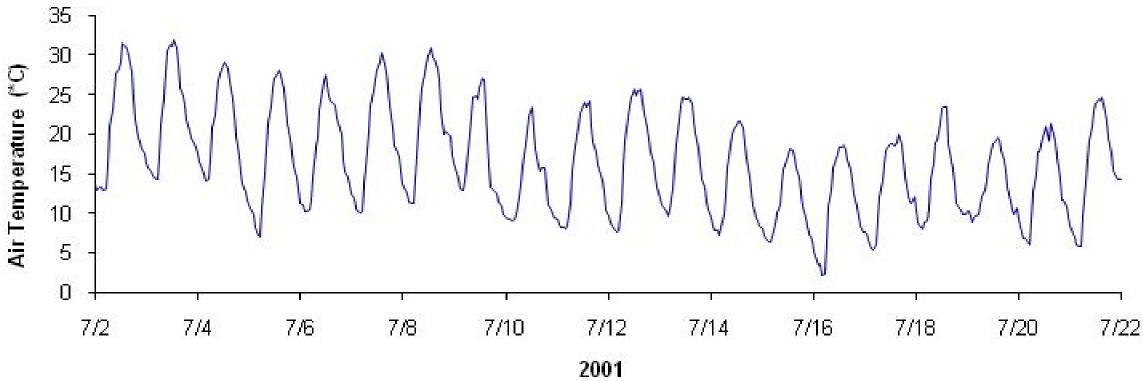


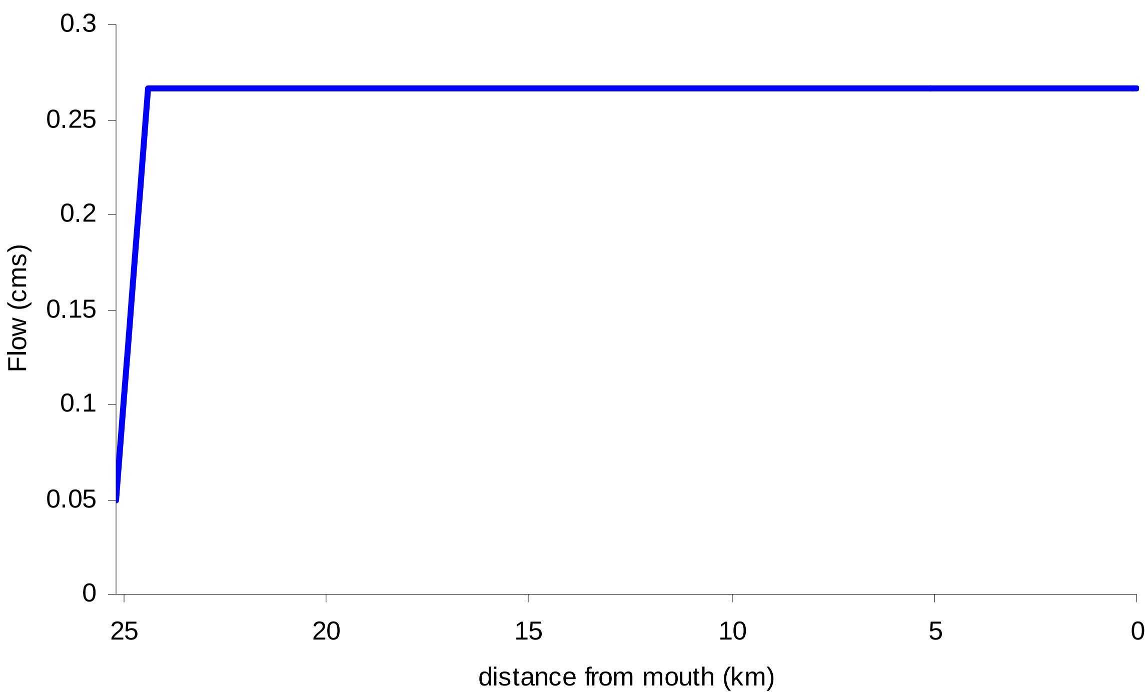
Figure A29-d



Flow and Temperature

No continuous gage or instantaneous flow data for were available in the Spencer Creek watershed for 2001, so flows were assumed based on best professional judgment and field transects provided by BLM (Elizabeth Berger, personal communication, 2001). In order to match TIR temperatures, supplemental water was added for calibration between river km 24.4 and 25.2 at a rate of 0.0135 cms every 0.05 km. The supplemental water was assumed to be groundwater inflow at 12ºC. There were no other tributaries added to the model. The model assumed a constant inflow at the headwaters (25.2km) of 0.05 cms. Using these flow inputs, the Spencer Creek model predicted flow is shown in **Figure A30**.

Figure A30. Longitudinal profile of measured flow.



Temperature Calibration

The model generally reproduces spatially and temporal varying temperature measurements (**Table A14 and Table A15** and **Figure A31 and Figure A32**). See previous statistics discussion at the beginning of **Section 4** for definitions.

Table A14. TIR error statistics

Error type	value
mean	-0.46
Absolute mean	1.04
Root mean square	1.29
Nash-Sutcliffe	0.41

Figure A31. Longitudinal profile of measured temperatures using Thermal Infrared Radiometry and model results

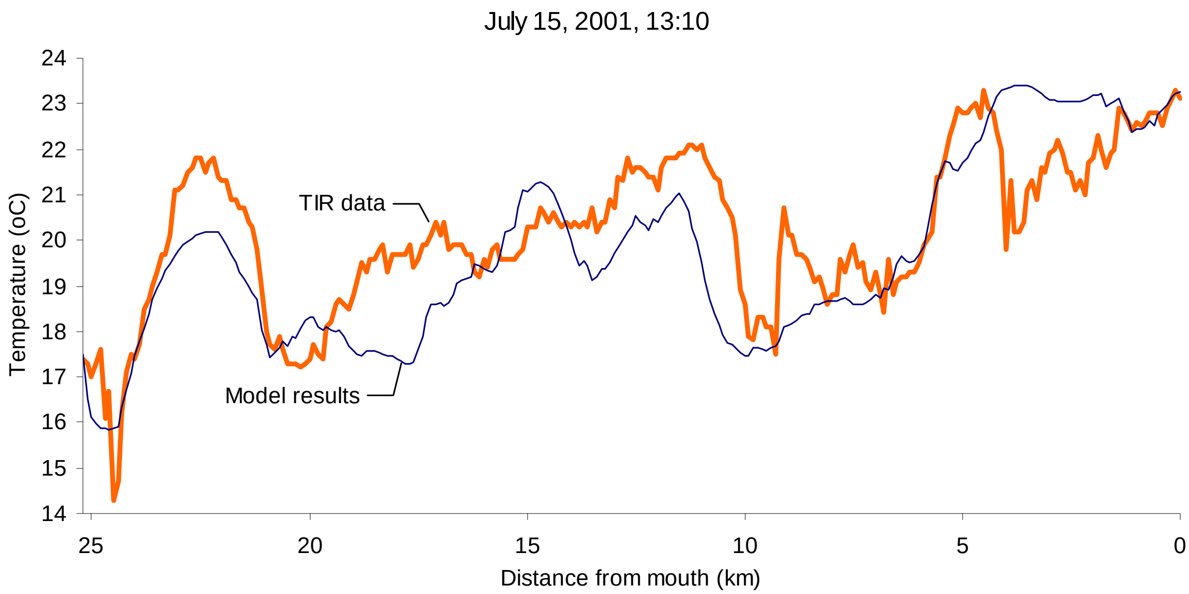
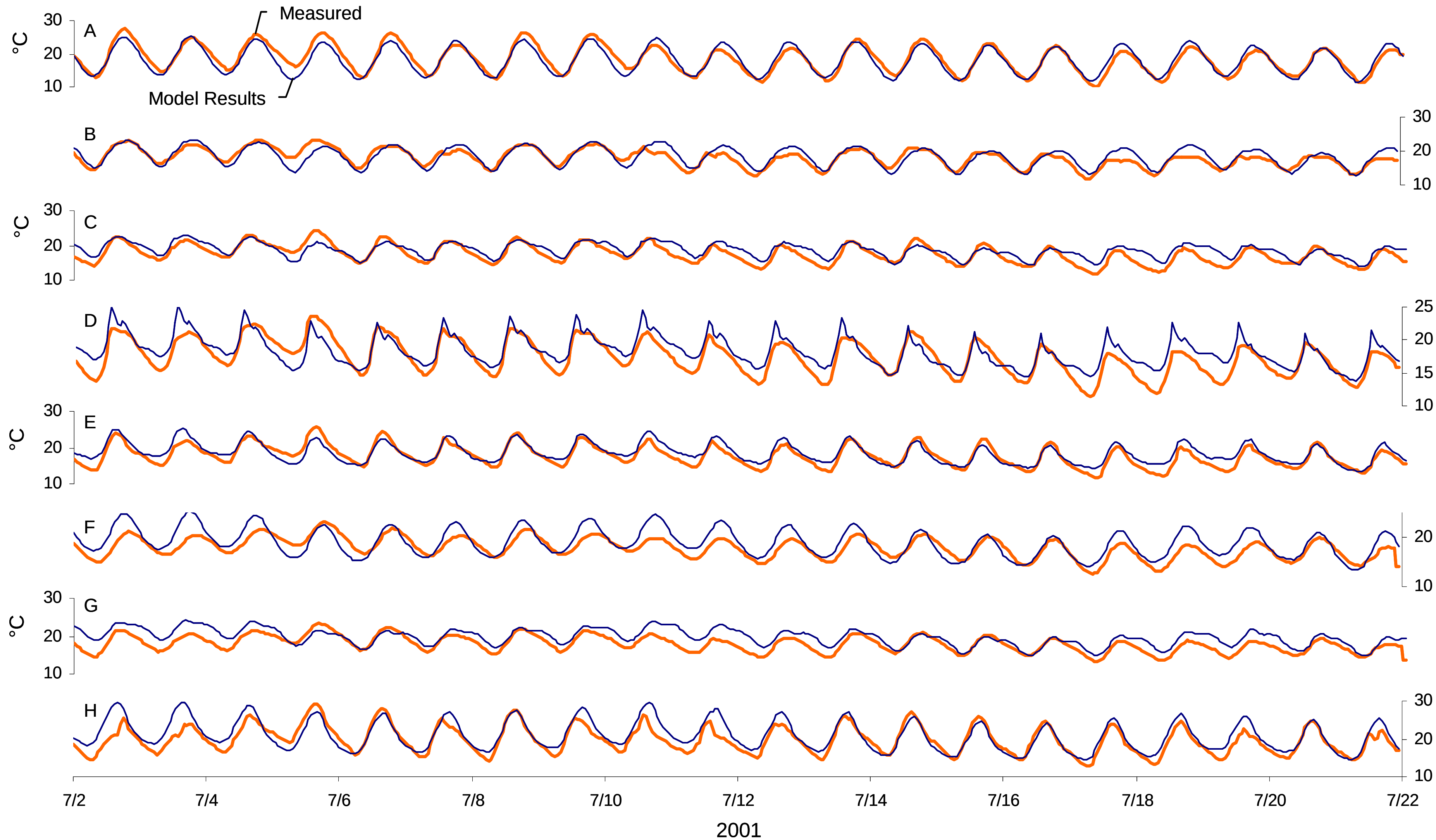


Table A15. Continuous monitoring error statistics

				All data				
Site Name	Site #	Ref	rKM	n	Mean Error	Abs Mean Error	RMSE	Nash-Sutcliffe
Spencer Cr. at outlet of Buck Lake	4920	A	21.1	480	-0.37	1.32	1.63	0.84
Spencer Cr. (section 17)	4800	B	18.8	480	0.38	1.26	1.62	0.60
Spencer Cr. (section 21)	4600	C	16.95	480	1.09	1.52	1.85	0.50
Spencer Cr. (section 28)	4300	D	14.7	480	0.89	1.41	1.71	0.57
Spencer Cr. upstream from Hook-Up Road (section 34)	4100	E	12.7	480	0.75	1.33	1.60	0.70
Spencer Cr. at upstream end of meadow (Broken Bridge)	4000	F	9.95	480	1.06	1.67	2.04	0.06
Spencer Cr. at downstream end of meadow	3985	G	7.4	480	1.78	1.95	2.32	-0.20
Spencer Cr. at mouth	3800	H	0.5	480	1.14	1.77	2.32	0.57
Average					0.84	1.53	1.88	0.46

Figure A32. Measured steam temperature versus model results



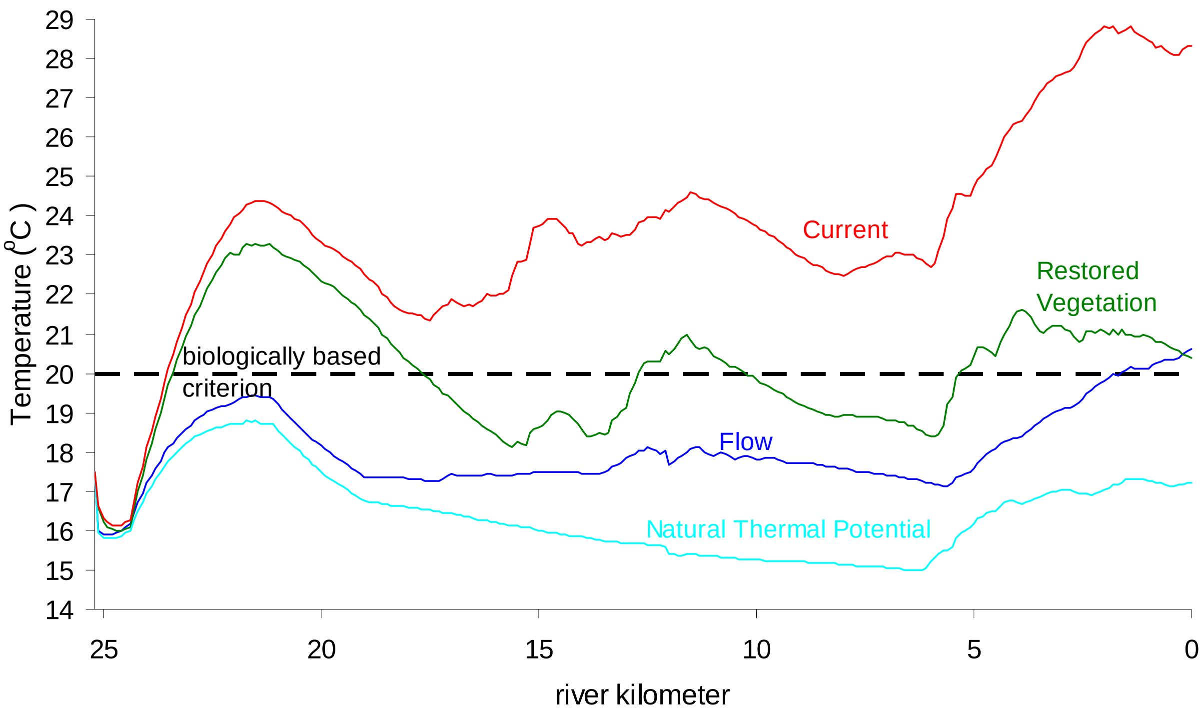
Scenario Results

The Heat Source model was used to predict the influence of various factors on stream temperature (**Table A16**). As seen in **Figure A33**, because the biologically based criterion of 20ºC is greater than NTP temperatures along the whole modeled length of stream, 20ºC is the applicable criterion.

Table A16. Simulated Scenario Definitions

“Current” “CCC”	Current Calibrated Condition
“Restored Vegetation”	Potential Vegetation (see effective shade figure, potential vegetation table and summary of results in the main text of this document, Chapter 2).
“Flow”	No points of diversion (see main text, Chapter 2 for a summary of the results)
“NTP”	Natural Thermal Potential: combining the inputs of system potential vegetation and system potential flow. No other adjustments were made to tributary inputs.

Figure A33. Predictions for Spencer Creek scenarios based on the maximum 7-DADM, July 2-21, 2001.



System Potential Vegetation

System potential vegetation is essentially the mature species composition, height, density, and overhang width of vegetation that would occur in the absence of human disturbances. System potential vegetation conditions were used in stream temperature modeling scenarios to quantify the impacts of nonpoint source solar radiation loads, and ultimately to develop nonpoint source load allocations for the TMDL.

System potential vegetation values were estimated for the Spencer Creek watershed by examining multiple references. To determine habitat potentials, physical parameters including elevation, gradient, climate, soils, vegetative communities, geology, physiography, hydrology, land use, etc. were assessed. Habitats were distinguished by changes in elevation at river kilometers 20.0 and 11.0. The habitats were called “Buck Lake”, “Upper watershed”, & “Lower watershed” in order of average elevation. The potential habitat scenario assumes the watershed has been morphologically restored. Buck Lake is assumed to be returned to a more natural hydrological state of a wetland meadow. The water in the current chanel will be filled with emergent vegetation. The HeatSource program has an "emergent vegetation" function that was used to calculate the potential temperature impacts due to this shading. To determine potential plant species, narrative reports, especially vegetation descriptions from the Oregon Watershed Assessment Manual (1999), were consulted. Estimates of plant community height, density and overhang width were compiled and averaged by best professional judgment from site indices, tree growth curves, and plant guide books (**Table A17**). Generally, vegetation is expected to increase or remain the same in average height, density, and overhang distance. The potential height of the largest Ponderosa Pines is expected to decrease in height, on average. The current height of the largest Ponderosa Pines is 5 meters taller than the estimated potential height (30 meters). The current height is likely an over-estimate of actual conditions. The system potential height for Ponderosa Pine is based on local site indeces and field data (Oliver and Powers 1978, Seeds 2007, Sokol 2007). The largest Mixed Conifers are also expected to decrease in height, on average, as the species composition changes. Finally, the current land cover vegetation types were assigned a potential (mature) vegetation type, which are described in **Table A17**.

Table A17. Summary of the current vegetation type heights, densities, and overhang widths and assigned system potential vegetation type.

Vegetation Type	Height (m)	Density (%)	Overhang (m)	Prevalence in model (%)	Potential Vegetation Type	Potential Height (m)	Potential Density (%)	Potential Overhang (m)
Water (Buck Lake)	0.0	0	0.0	6	Emergent Vegetation - Buck Lake	0.5	50	0.0
Water	0.0	0	0.0	18	Water	0.0	0	0.0
Pastures/Cultivated Field/lawn (Buck Lake)	0.5	75	0.3	11	Wetland Complex - Buck Lake	2.3	75	0.3
Pastures/Cultivated Field/lawn (Upper watershed)	0.5	75	0.3	0	Mixed Conifer - Large	55.6	80	2.0
Pastures/Cultivated Field/lawn (Lower watershed)	0.5	7	0.3	3	Ponderosa Pine - Large	30.0	60	2.0
Barren - Rock	0.0	0	0.0	0	Barren - Rock	0.0	0	0.0
Barren - Embankment	0.0	0	0.0	0	Barren - Embankment	0.0	0	0.0
Barren - Clearcut / recent re-plant	0.0	0	0.0	0	Ponderosa Pine - Large	30.0	60	2.0
Barren - Soil	0.0	0	0.0	0	Ponderosa Pine - Large	30.0	60	2.0
Dead Stand	15.0	5	0.0	0	Ponderosa Pine - Large	30.0	60	2.0
Barren - Road (Buck Lake)	0.0	0	0.0	0	Wetland Complex - Buck Lake	2.3	75	0.3
Barren - Road (Upper watershed)	0.0	0	0.0	0	Mixed Conifer - Large	55.6	80	2.0
Barren - Road (Lower watershed)	0.0	0	0.0	0	Ponderosa Pine - Large	30.0	60	2.0
Aspen	5.0	50	0.3	0	Aspen	15.0	50	1.0
Ponderosa Pine - Large	35.0	60	2.0	0	Ponderosa Pine - Large	30.0	60	2.0
Ponderosa Pine - Medium	20.0	60	2.0	1	Ponderosa Pine – Large	30.0	60	2.0

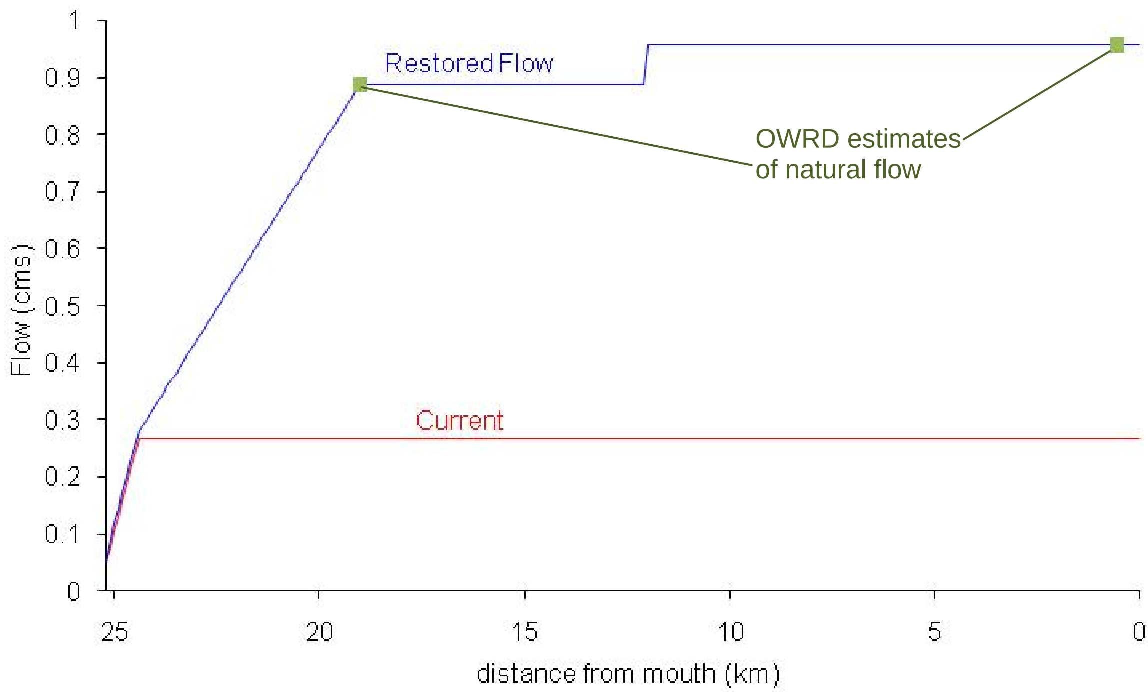
Vegetation Type	Height (m)	Density (%)	Overhang (m)	Prevalence in model (%)	Potential Vegetation Type	Potential Height (m)	Potential Density (%)	Potential Overhang (m)
Ponderosa Pine - Small	10.0	60	1.0	0	Ponderosa Pine - Large	30.0	60	2.0
Ponderosa Pine - Large - Low Density	35.0	30	2.0	0	Ponderosa Pine - Large	30.0	60	2.0
Ponderosa Pine - Medium - Low Density	20.0	30	2.0	1	Ponderosa Pine - Large	30.0	60	2.0
Ponderosa Pine - Small - Low Density	10.0	30	1.0	0	Ponderosa Pine - Large	30.0	60	2.0
Mixed Conifer - Large	60.0	80	2.0	0	Mixed Conifer - Large	55.6	80	2.0
Mixed Conifer - Medium	30.0	50	0.0	16	Mixed Conifer - Large	55.6	80	2.0
Mixed Conifer - Small	10.0	80	0.0	0	Mixed Conifer - Large	55.6	80	2.0
Mixed Conifer - Smaller (recent replant)	5.0	50	0.5	1	Mixed Conifer - Large	55.6	80	2.0
Mixed Conifer - Medium - Low Density	30.0	30	2.0	2	Mixed Conifer - Large	55.6	80	2.0
Mixed Conifer - Small - Low Density	10.0	30	2.0	0	Mixed Conifer - Large	55.6	80	2.0
Upland shrubs	1.8	50	0.3	0	Ponderosa Pine - Large	30.0	60	2.0
Upland shrubs	1.8	20	0.3	0	Ponderosa Pine - Large	30.0	60	2.0
Shrubs and grasses floodplain / riparian (Buck Lake)	2.5	75	1.0	1	Wetland Complex - Buck Lake	2.3	75	0.3
Shrubs and grasses floodplain / riparian (Upper watershed)	2.5	75	1.0	4	Riparian shrubs- Upper watershed	3.6	75	1.0
Shrubs and grasses floodplain / riparian (Lower watershed)	2.5	75	1.0	20	Riparian shrubs- Lower watershed	12.2	75	2.0
Shrubs and grasses floodplain / riparian (Buck Lake)	2.5	25	1.0	0	Wetland Complex - Buck Lake	2.3	75	0.3

Vegetation Type	Height (m)	Density (%)	Overhang (m)	Prevalence in model (%)	Potential Vegetation Type	Potential Height (m)	Potential Density (%)	Potential Overhang (m)
Shrubs and grasses floodplain / riparian (Upper watershed)	2.5	25	1.0	2	Riparian shrubs-Upper watershed	3.6	75	1.0
Shrubs and grasses floodplain / riparian (Lower watershed)	2.5	25	1.0	4	Riparian shrubs-Lower watershed	12.2	75	2.0
Grasses - upland	0.5	75	0.3	0	Ponderosa Pine - Large	30.0	60	2.0
Grasses - wetland (Buck Lake)	0.5	100	0.0	1	Wetland Complex - Buck Lake	2.3	75	0.3
Grasses - wetland (Upper watershed)	0.5	100	0.0	2	Riparian shrubs-Upper watershed	3.6	75	1.0
Grasses - wetland (Lower watershed)	0.5	100	0.0	1	Riparian shrubs-Lower watershed	12.2	75	2.0
Active Channel Bottom	0.0	0	0.0	0	Active Channel Bottom	0.0	0	0.0
Pine plantation	10.0	75	1.0	0	Ponderosa Pine - Large	30.0	60	2.0
Dense pine on floodplain	30.0	75	1.0	2	Ponderosa Pine - Large	30.0	60	2.0

System Potential Flow

System potential flow is the volumetric flow of water estimated to be in the modeled reach if there were no anthropogenic influences. On the Spencer Creek mainstem, OWRD provided estimates of the 50th percentile natural flow at two points (OWRD 2002). In the Spencer Creek model, accretion flow was added to approximate the OWRD estimate at the National Forest boundary and represents spring inflow around Buck Lake. However, OWRD notes that there was very little accretion flow downstream of the National Forest boundary (Jonathon LaMarche, personal communication, 2008). The OWRD estimate of flow at the mouth of Spencer Creek necessitated adding a tributary representing Miners Creek to balance the increase in flow. These estimates were incorporated into the model as “Restored Flow” (**Figure A34**).

Figure A34. Longitudinal profiles of predicted flows for scenarios which considered flow alterations on Spencer Creek, July 21, 2001.

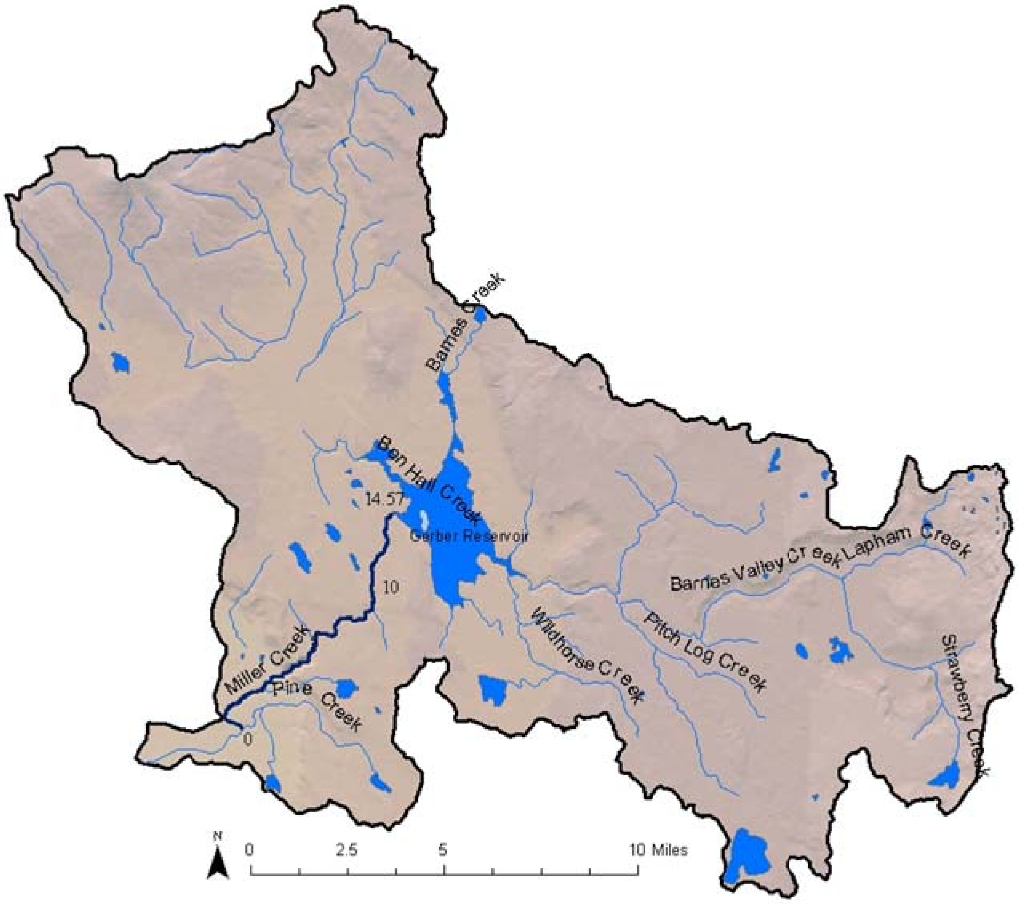


4.4 Miller Creek

Overview

Stream Name: Miller Creek
Model: Heat Source version 7.0
Beginning date: 7/17/2001
Ending date: 8/5/2001
Time step: 1 minute
Distance step: 100 m
Extent: Gerber Reservoir to confluence with Pine Creek (river km 14.57) (**Figure A35**).

Figure A35. Extent of the Miller Creek temperature model.



Reach Properties

The channel properties were determined using the methodology documented previously in this report (see **Section 3**). **Figure A36** shows the elevation profile and reach gradient. The bankfull width was derived using the active channel width measured from aerial photographs relatively low resolution black and white aerial photographs (all that was available when the model was developed). The active channel width appeared to be underestimated in a number of reaches. Therefore, if the estimated stream width was less than 12m, it was corrected using the formula: $width_{adj} = width + \frac{12 - width}{2}$

Bottom width was estimated by assuming a rectangular channel with perpendicular side slopes (**Figure A37**) and a constant width-to-depth ratio of 4 determined through model calibration. 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 A38.** Topographic and riparian vegetation heights were determined through a GIS analysis (**Figure A39 through Figure A41, and Table A19**). Unfortunately, there are no shade data available to corroborate the predicted effective shade (**Figure A42**). Due to diversions of water from Miller Creek, there was too little flow in the below the confluence with Pine Creek to calibrate the model.

Figure A36. Model setup channel elevation and gradient.

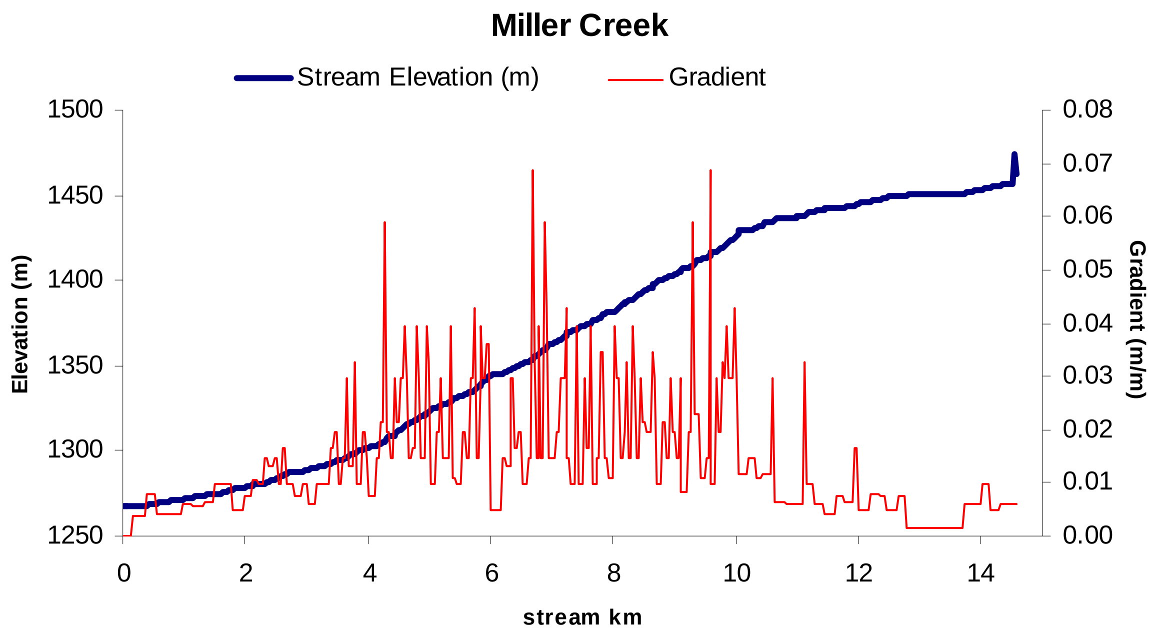


Figure A37. Model setup for bankfull width.

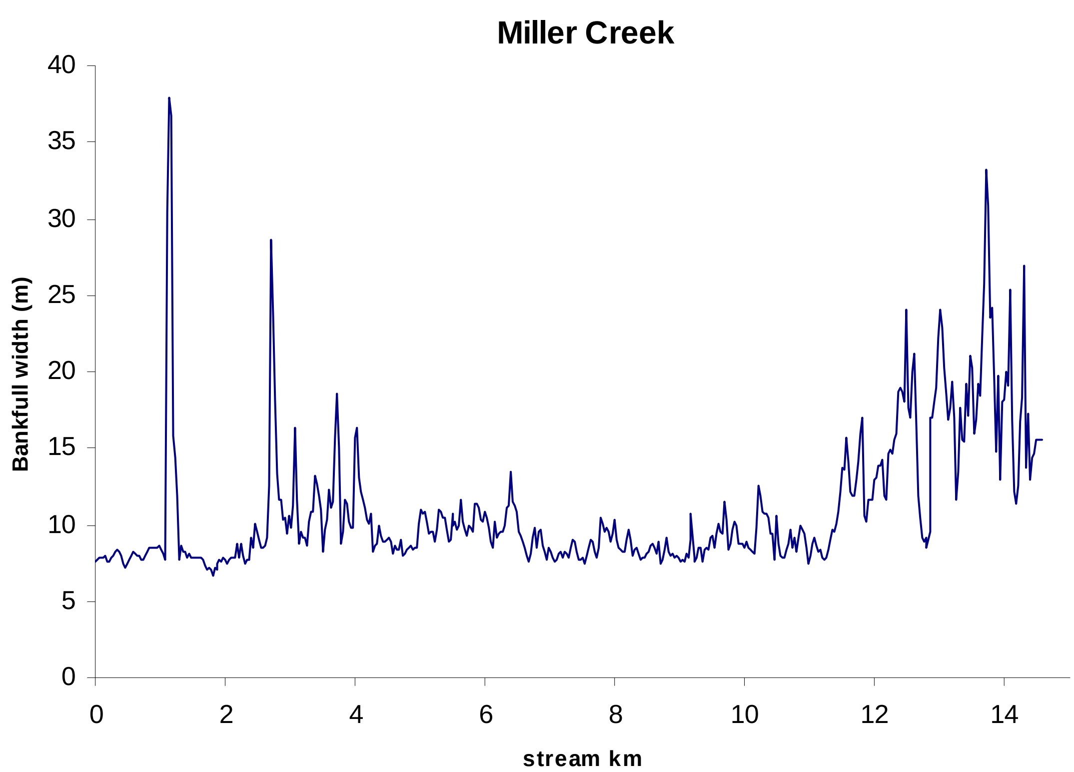


Table A18. Model coefficients for non-spatially varying parameters.

Parameter name (units)	Value
Wind Function, coefficient a	0.5×10^{-9}
Wind Function, coefficient b	0.5×10^{-9}
Channel Angle –z	0
Width to Depth Ratio	4.00
Horizontal Bed Conductivity (mm/s)	2.00
Bed Particle (mm)	1
Embedded-ness	0.5

Figure A38. Model setup for roughness coefficient.

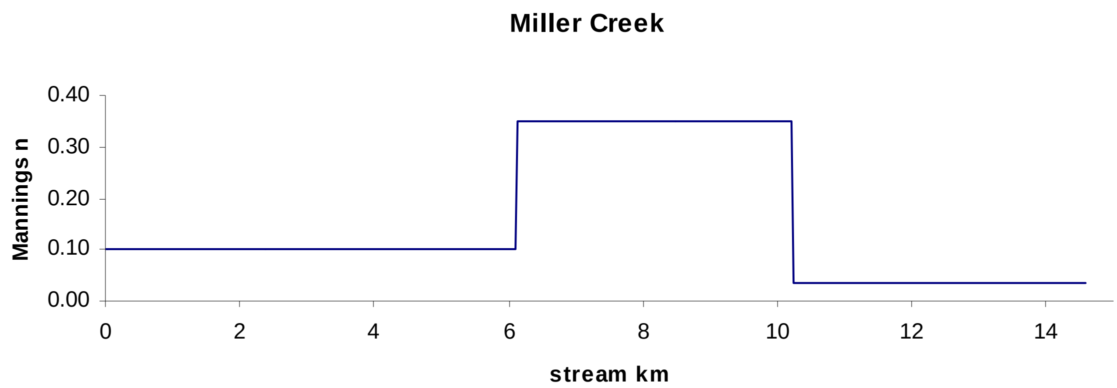


Figure A39. Model setup for topographic angle

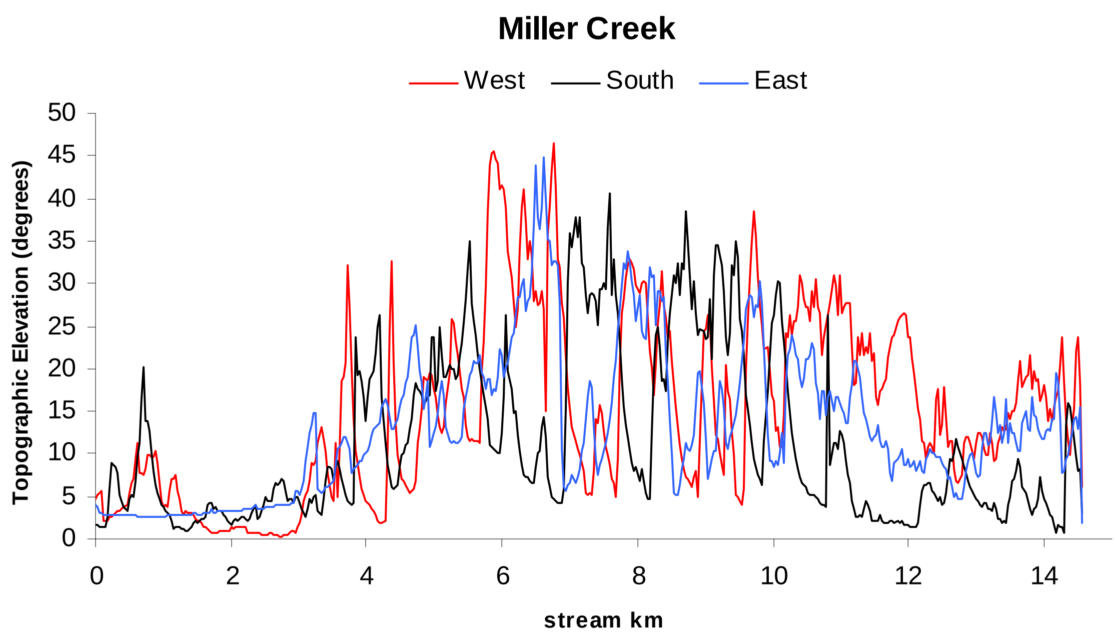


Figure A40. Model setup for height of streamside vegetation

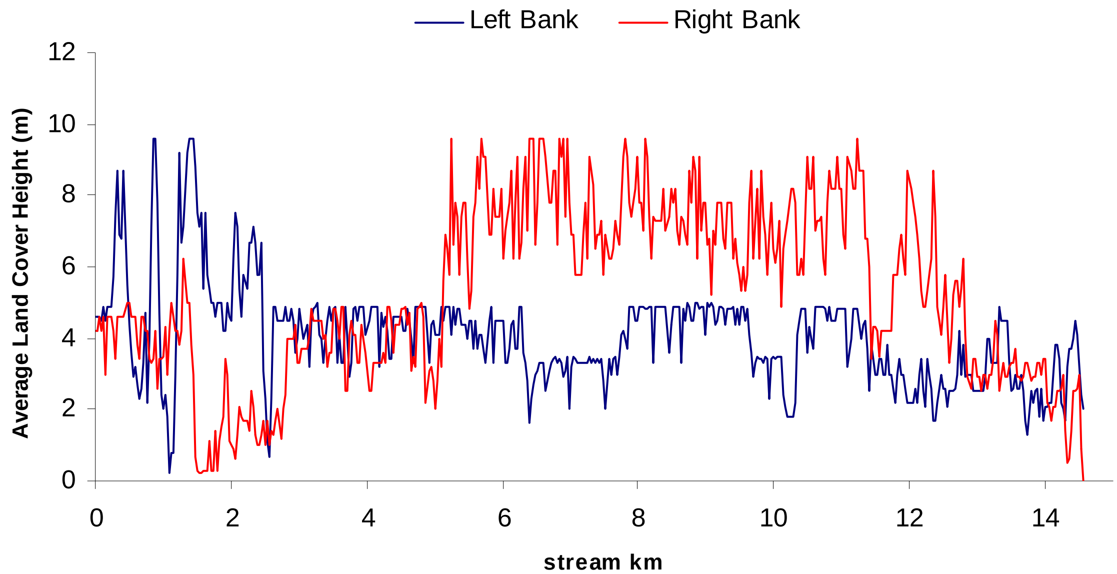


Figure A41. Model setup for density of streamside vegetation.

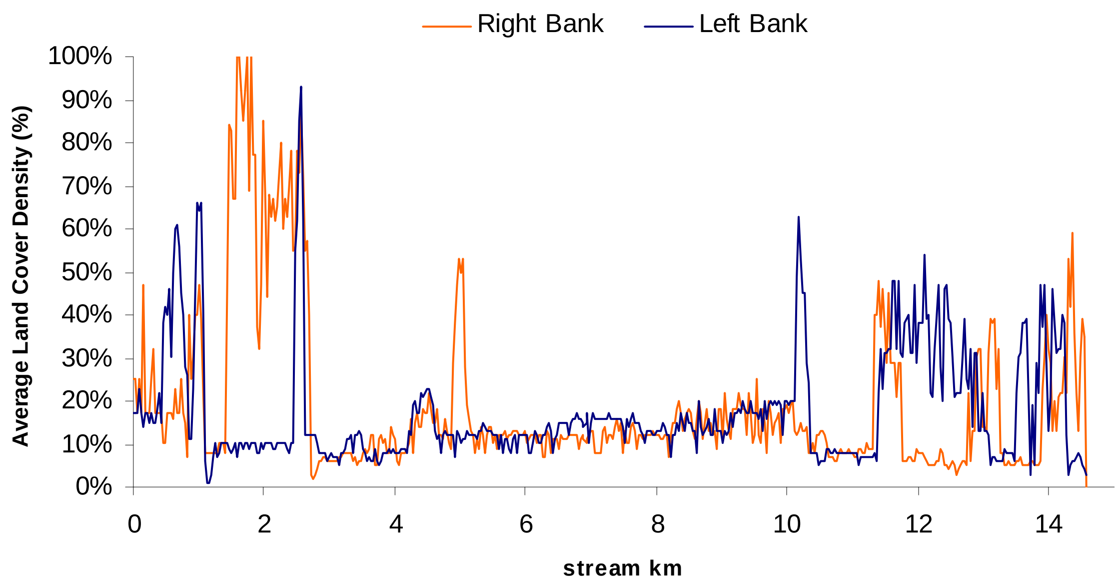
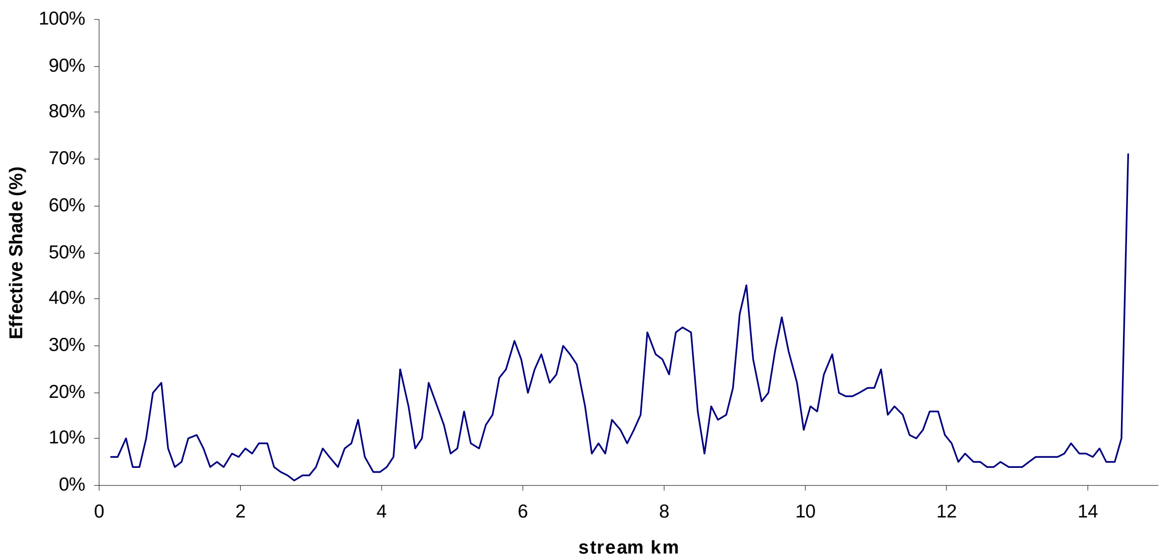


Table A19. Spatial Data and Application: GIS Data Source and the application used in Miller Creek Watershed

Spatial Data	Data Source	Application
10-Meter Digital Elevation Models (DEM)	Oregon Geospatial Data Clearinghouse	Measure Stream Elevation and Gradient Measure Topographic Shade Angles
Aerial Imagery – Digital Orthophoto Quads	US Geological Survey	Map Vegetation Map Channel Morphology Map Roads, Development, Structures
Thermal Infrared Radiometry (TIR) Stream Temperature Data	Watershed Science 2002, Collected on 7/17/2001	Measure Surface Temperatures Develop Longitudinal Temperature Profiles Identify Subsurface Hydrology, Groundwater Inflow, Springs

Figure A42. Predicted effective shade. The effective shade near the headwaters of the model was influenced by the dam.



Meteorology

The model uses hourly air temperature, relative humidity, and wind speed from the Agrimet station at Loralla, Oregon. Cloudiness was assumed to be zero during the summer period. The meteorological observations are presented in **Figure A43, a-c**.

Figure A43, a-d. Meteorology inputs for model setup

Figure A43-a.

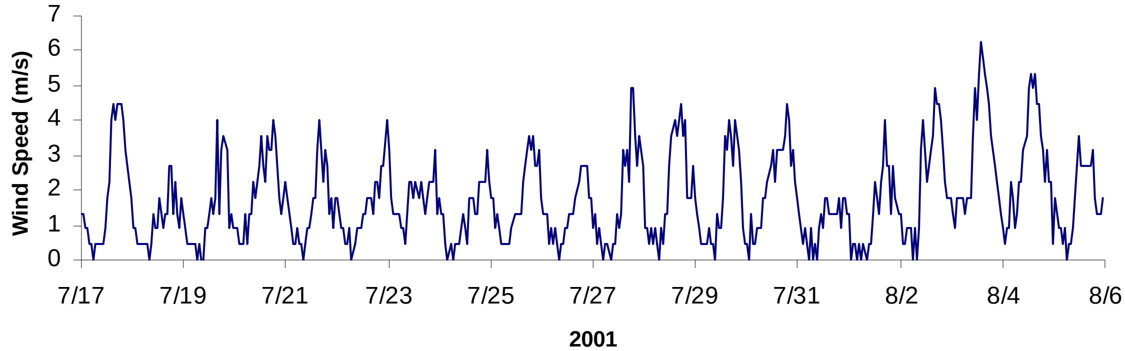


Figure A43-b

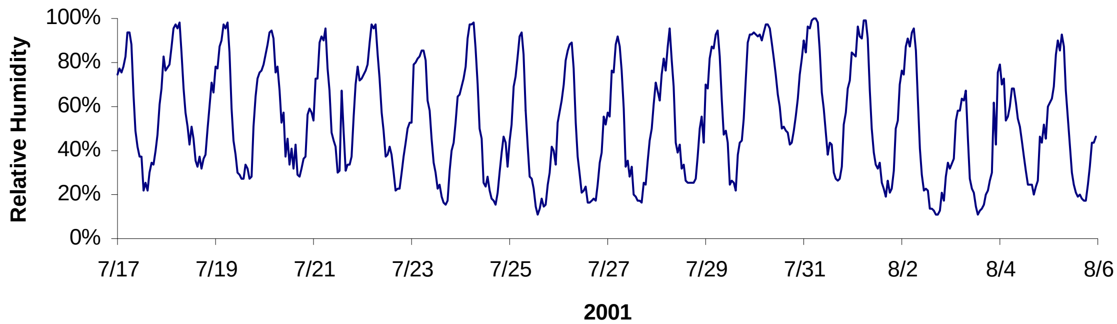
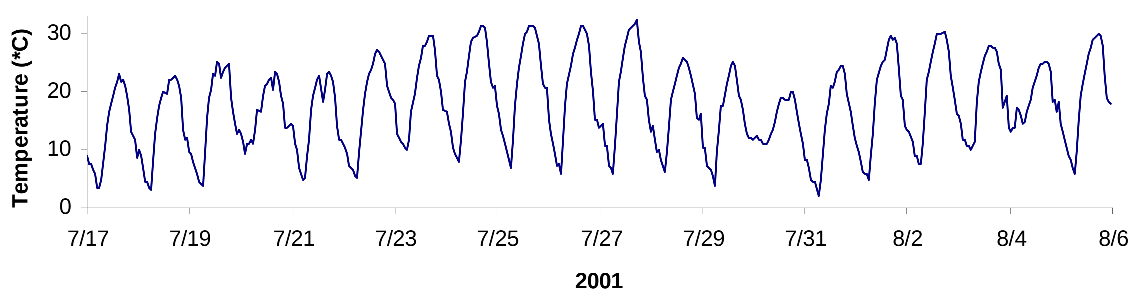


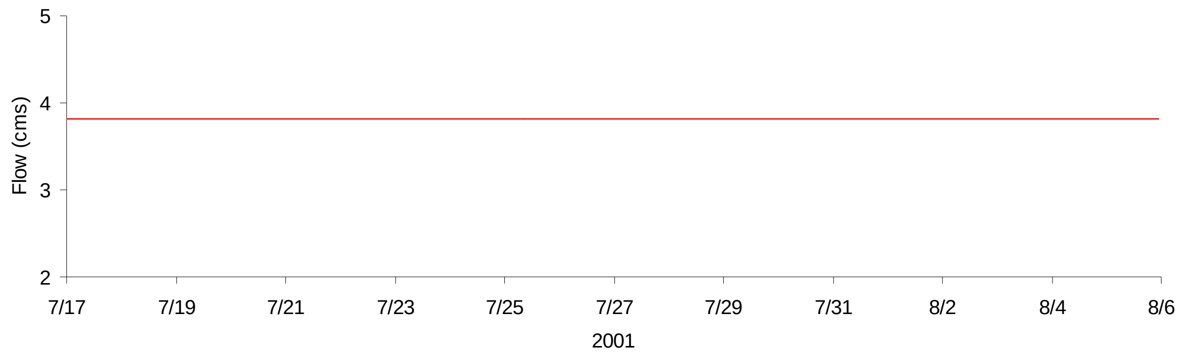
Figure A43-c



Flow

Estimates of the flow out of Gerber Reservoir were provided by USBOR and used as the boundary input to the model (John Hicks, personal communication, 2005). The reported flow varied greatly from day to day and caused model instabilities. Therefore, the data was averaged over the model period. These were the only flow inputs to the model (**Figure A44**).

Figure A44. Inflow boundary condition (14.57 km)



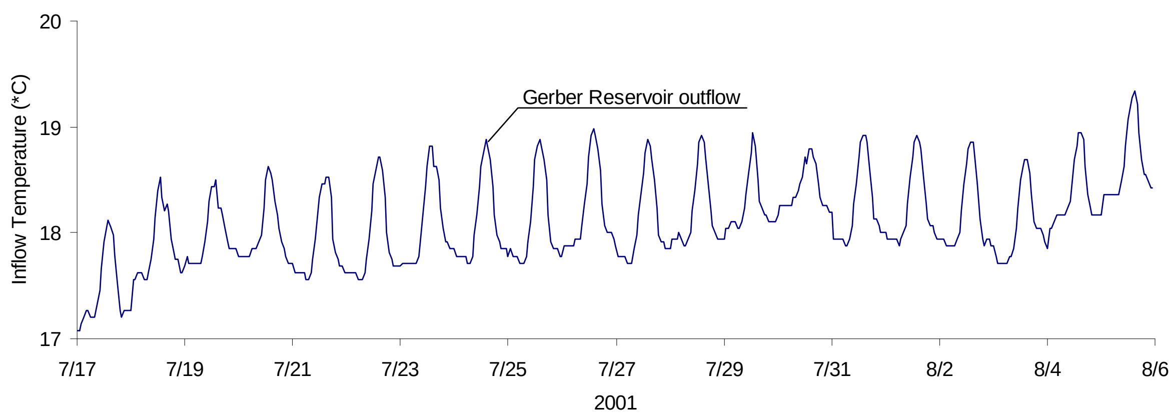
Temperature

The headwater temperature data were provided by BLM (A Hamilton, personal communication, 2005) (**Table A20** and **Figure A45)**.

Table A20. Source of inflow temperature inputs for Miller Creek model

Site	Stream km	Source of temperature data
Boundary Condition	14.57	BLM

Figure A45. Temperature of inflows to the Miller Creek model.



Temperature Calibration

The model generally reproduces spatially and temporally varying temperature measurements (**Table A21 and Table A22** and **Figure A46 and Figure A47**) See previous statistics discussion at the beginning of **Section 4** for definitions.

Table A21. TIR error statistics

Error type	value
mean	-0.37
Absolute mean	0.49
Root mean square	0.70
Nash-Sutcliffe	0.79

Table A22. Continuous monitoring error statistics

Site Name	Site #*	Ref	rKM	n	Mean Error	Abs Mean Error	RMSE	Nash-Sutcliffe
Miller Creek at Bridge	MR4760	A	12.59	240	0.13	0.32	0.37	0.83

Figure A46. Longitudinal profile of measured temperatures using Thermal Infrared Radiometry and model results.

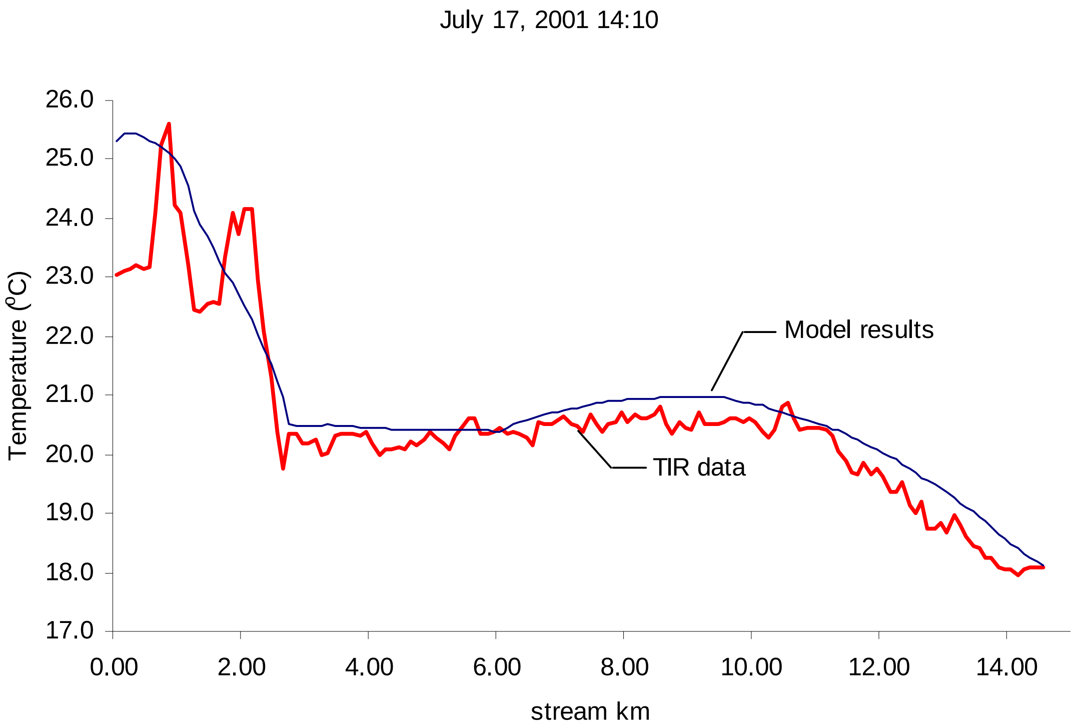
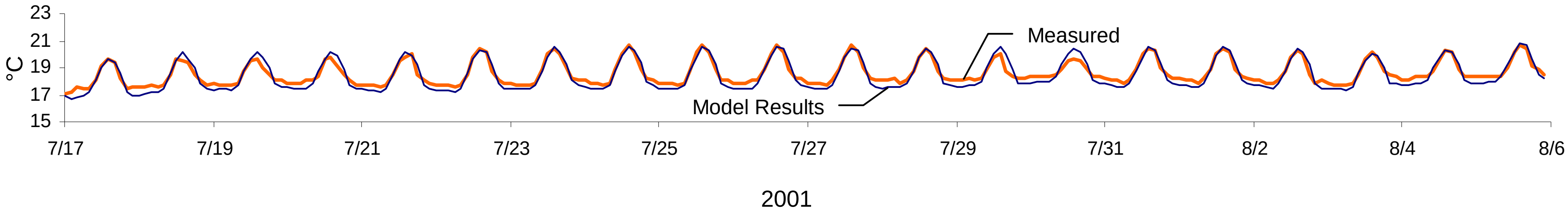


Figure A47. Measured steam temperature versus model results.



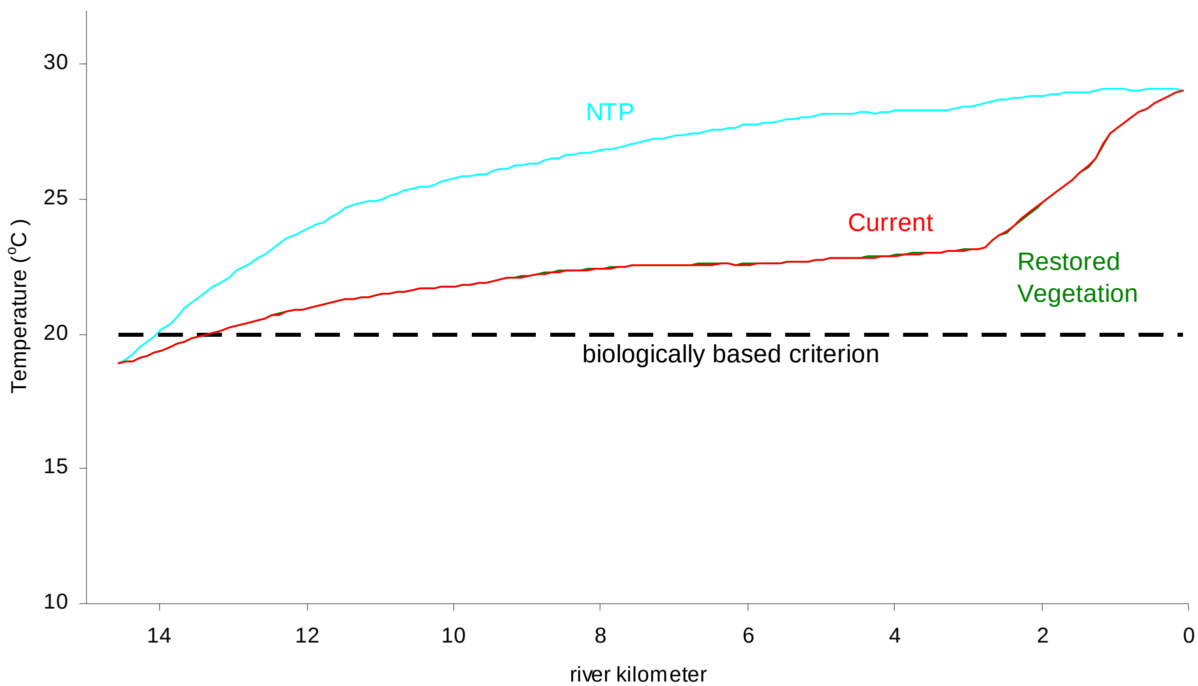
Scenario Results

The Heat Source model was used to predict the influence of flow and vegetation on stream temperature (**Table A23**). The predicted NTP is warmer than the biologically based criterion for most of the stream and therefore, NTP is the applicable criteria (**Figure A47**).

Table A23. Simulated Scenario Definitions

"Current"	Current Calibrated Condition
"Restored Vegetation"	System Potential Vegetation (see effective shade figure and summary of results in the main text of the TMDL document, **Chapter 4**).
"NTP"	"Restored Vegetation" with an estimate of system potential flow based on professional judgment. System potential flows are much less than current because of the storage reservoir and irrigation conveyance in the creek during irrigation season. Channel morphology was modified to accommodate the dramatic decrease in flow: Manning's n = 0.07, channel angle = 0.95 and vegetation up to the wetted width.

Figure A48. Predictions of Miller Creek scenarios based on the maximum 7-DADM, 7/17 to 8/5/2001.



System Potential Vegetation

The following tributaries in the Lost River subbasin were analyzed only for shade: Miller, Antelope, Barnes Valley, Horse Canyon, Lapham, Long Branch, & North Fork Willow Creeks. Unlike temperature modeling, this shade analysis does not predict the stream temperatures resulting from restoration. Rather, this analysis attempts to document current riparian conditions and compare to system potential riparian conditions. The current vegetation was digitized using the methodology described in **Section 3.2.** The system potential vegetation on private lands was determined using methodology similar to Jenny and Spencer Creeks. The system potential vegetation communities on public land were determined and delineated on false color, infrared aerial imagery and expertise from BLM and USFS

(Elizabeth Berger and Karen Zamudio, respectively, personal communication, 2005). This information was digitized and sampled by TTools. **Table A24** shows the relative prevalence of vegetation types used in the current condition and potential vegetation model scenarios. The Miller Creek model does not predict much influence of restoring riparian vegetation on stream temperatures (at current flow rates).

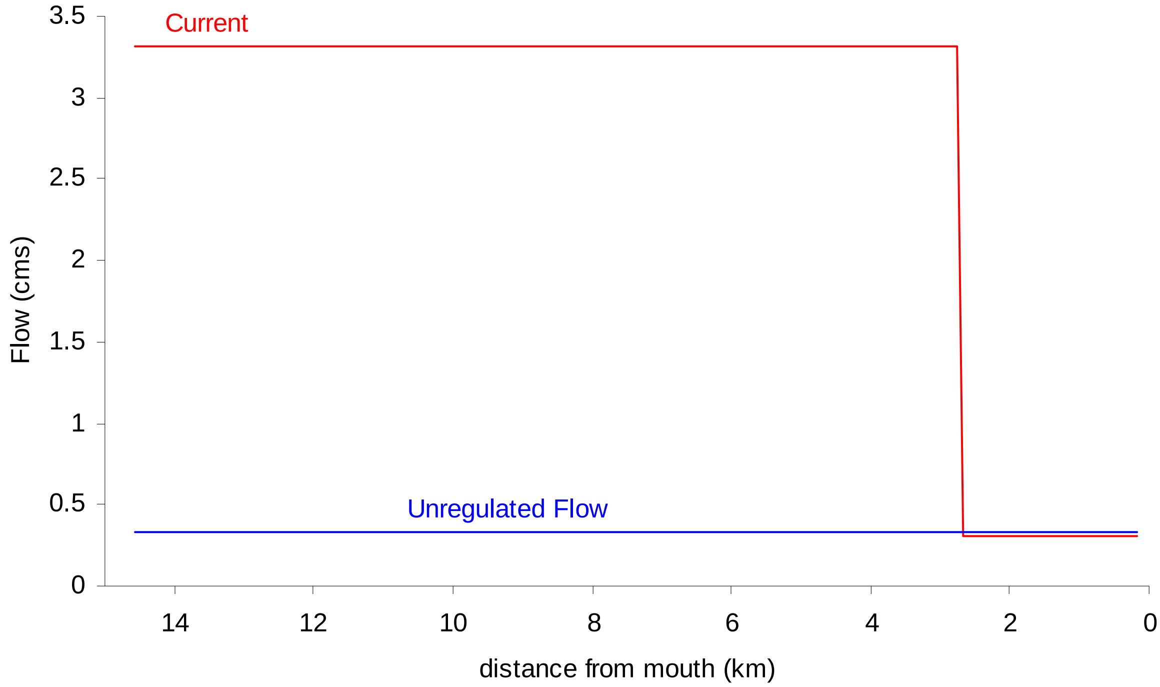
Table A24. Miller Creek riparian area vegetation

Land Cover Name	Height (m)	Density (%)	Overhang (m)	Prevalence in Scenario (%) Current Condition	Prevalence in Scenario (%) Potential Vegetation
Barren-Road	0	0%	0	0%	0%
Western Juniper	5.0	10%	0	38%	35%
Juniper and some pine	10.0	10%	0	20%	20%
Mainly shrub with scattered pine and juniper	3.0	15%	0	5%	7%
Upland Shrubs	2	0.75	0	1%	1%
Water Sedge	0.3	1	0	3%	4%
Wetland Shrubs	4.6	0.3	0	6%	7%
Wetland grasses	0.3	1	0	4%	4%
Dryland Grasses	0.3	1	0	3%	3%
Wetland grasses/shrubs mix (majority grasses/minority shrubs)	4.6	0.05	0	7%	3%
Wetland grasses/shrubs mix (50/50)	4.6	0.15	0	0%	0%
Wetland shrubs/grasses mix (majority shrubs/minority grasses)	4.6	0.2	0	12%	16%
Dam/Weir	0	0	0	0%	0%

System Potential Flow

Current conditions flow is dominated by release of stored water in Gerber Reservoir for irrigation. The stream is used as a conveyance for the water and therefore current much greater flows than without the storage reservoir (**Figure A49**). Because of the high volume of water in the creek, stream temperatures are currently cooler than predicted NTP and therefore the stream is meeting the temperature standard.

Figure A49. Longitudinal profiles of predicted flows for scenarios which considered flow alterations on Miller Creek for 7/17/2001.



4.5. Antelope Creek

The following figures and tables document the shade analysis on Antelope Creek. The reach that was examined is completely within BLM managed lands (**Figure A50**). Shade due to system potential vegetation is less than current shade (**Figure A51(d)**). This effect is because the predicted potential vegetation for near stream juniper and pine is less dense than the current stands due to fire suppression. **Table A25** shows the relative prevalence of vegetation types used in the current condition and potential vegetation model scenarios.

Figure A50. Antelope Creek analysis extent with ownership and distance upstream from Willow Valley Reservoir (km).

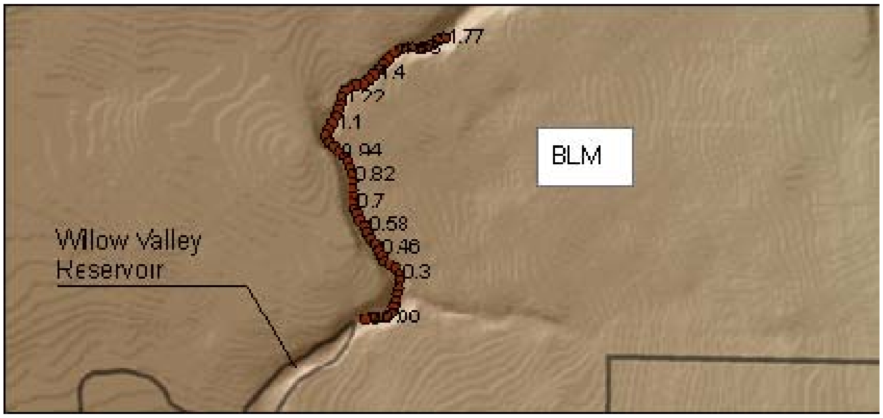


Figure A51. Antelope Creek existing conditions (a – c) and shade analysis results (d).

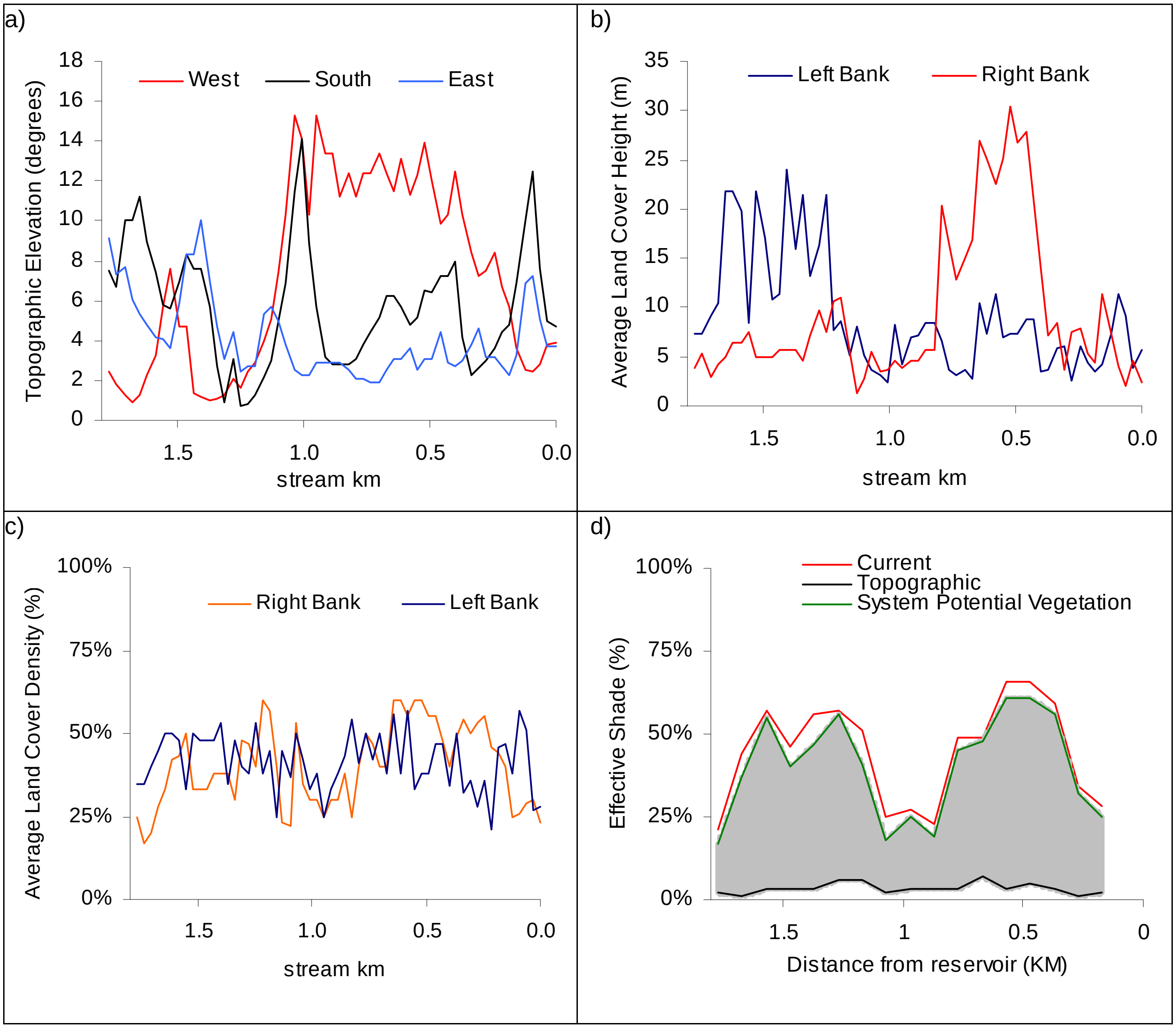


Table A25. Antelope Creek riparian area vegetation

Land Cover Name	Height (m)	Density (%)	Overhang (m)	Prevalence in Scenario (%) Current Condition	Potential Vegetation
Wetland grasses/shrubs mix	3.7	50%	0.3	26%	26%
Wetland Shrubs	4.6	30%	0.3	20%	20%
Large Conifer	30.5	60%	2.1	17%	17%
Western Juniper/Pine Mix	15.2	30%	0.9	1%	16%
Non-Riparian Juniper	9.1	30%	0.5	2%	13%
Warm Willow	4.6	30%	0.9	4%	4%
Wetland grasses	0.9	30%	0.3	2%	2%
Western Juniper/Pine Mix	15.2	60%	0.9	16%	1%
Non-Riparian Juniper	9.1	60%	0.5	11%	0%

4.6. Barnes Valley Creek

The following figures and tables document the shade analysis on Barnes Valley Creek. The reach that was examined flows through private, USFS and BLM lands (**Figure A52**). Most of the increases in shade are predicted to occur on private land due to the predicted increase in wetland shrubs (**Figure A53(d)**). In addition, an average 4% increase in effective shade is predicted through the most downstream 9 km. **Table A26** shows the relative prevalence of vegetation types used in the current condition and potential vegetation model scenarios.

Figure A52. Barnes Valley Creek analysis extent with ownership and distance upstream from Gerber Reservoir (km).

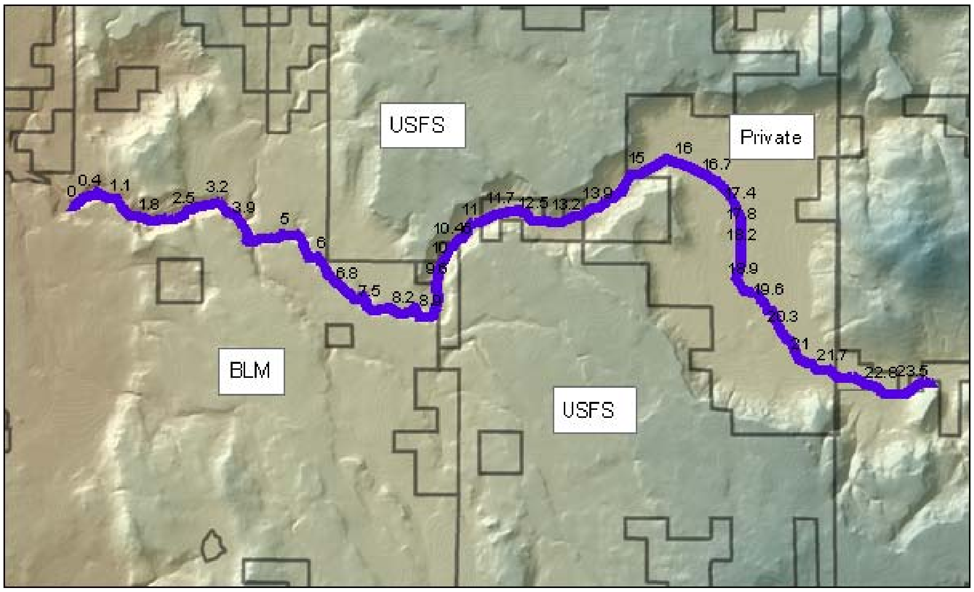


Figure A53. Barnes Valley Creek existing conditions (a – c) and shade analysis results (d).

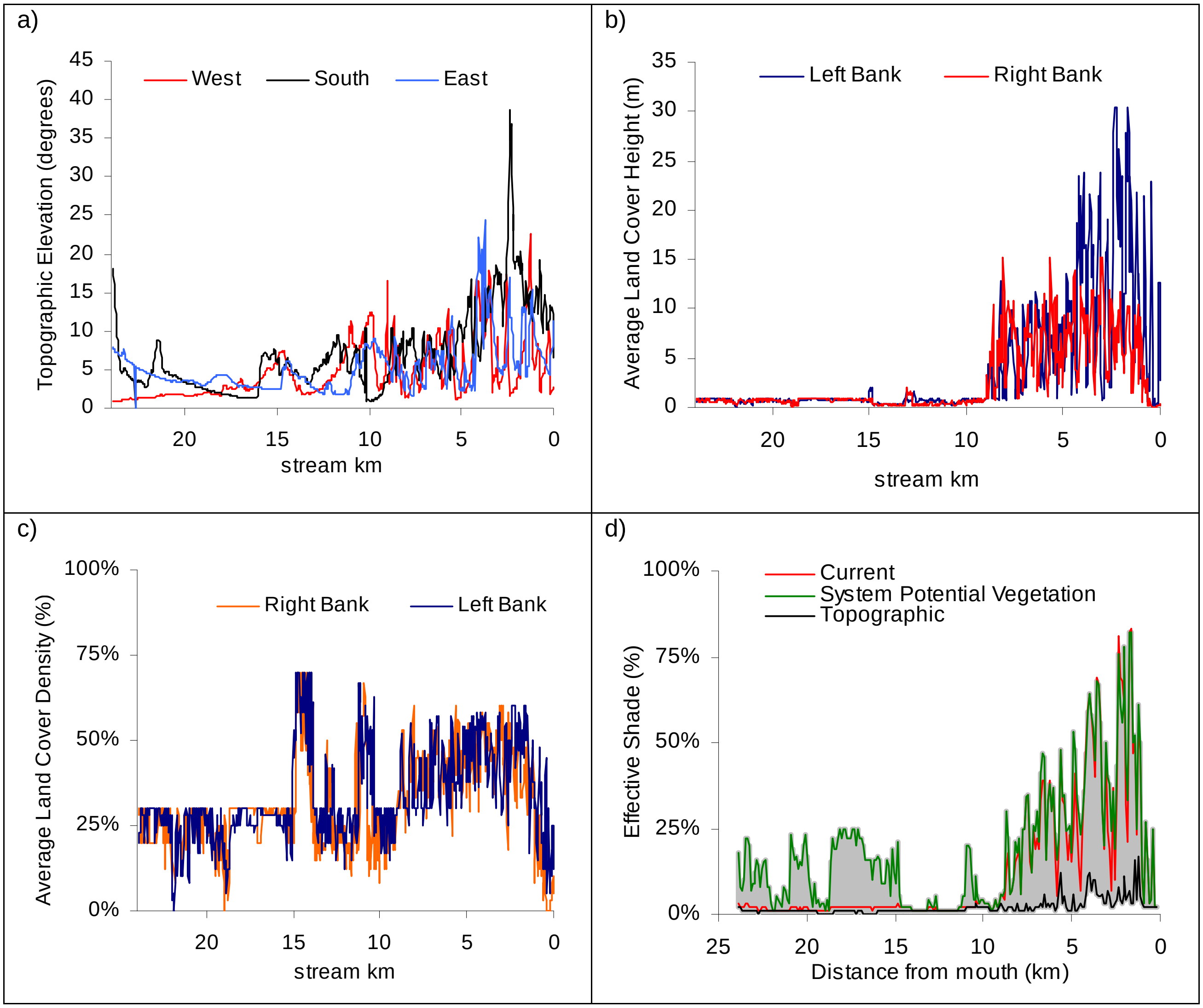


Table A26. Barnes Valley Creek riparian area vegetation.

				Prevalence in Scenario (%)	
Land Cover Name	**Height (m)**	**Density (%)**	**Overhang (m)**	**Current Condition**	**Potential Vegetation**
Wetland grasses/shrubs mix	3.7	50%	0.3	4%	38%
Warm Willow	4.6	30%	0.9	5%	18%
Wetland grasses	0.9	30%	0.3	16%	16%
Western Juniper/Pine Mix	15.2	60%	0.9	8%	8%
Dry Meadow	0.3	30%	0.3	5%	5%
Meadow	0.3	70%	0.3	7%	4%
Wetland Grasses	0.9	30%	0.3	40%	4%
Large Conifer	30.5	60%	2.1	4%	4%
Large Deciduous	9.1	40%	1.8	1%	1%
Non-Riparian Ponderosa Pine	30.5	30%	1.2	0%	1%
Wetland Shrubs 2	2.0	50%	0.3	7%	0%
Wetland Shrubs	4.6	30%	0.3	1%	0%
Dryland Grasses	0.9	30%	0.3	1%	0%

4.7. Horse Canyon

The following figures and tables document the shade analysis for Horse Canyon. The reach that was examined is within USFS and private lands (**Figure A54**). Shade due to system potential vegetation is less than current shade for the middle portion of the reach (**Figure A55(d)**). This effect is because the predicted potential vegetation for near conifers is less dense the current stands due to fire suppression and encroachment on meadows. **Table A27** shows the relative prevalence of vegetation types used in the current condition and potential vegetation model scenarios.

Figure A54. Horse Canyon analysis extent with ownership and distance upstream from mouth (km).

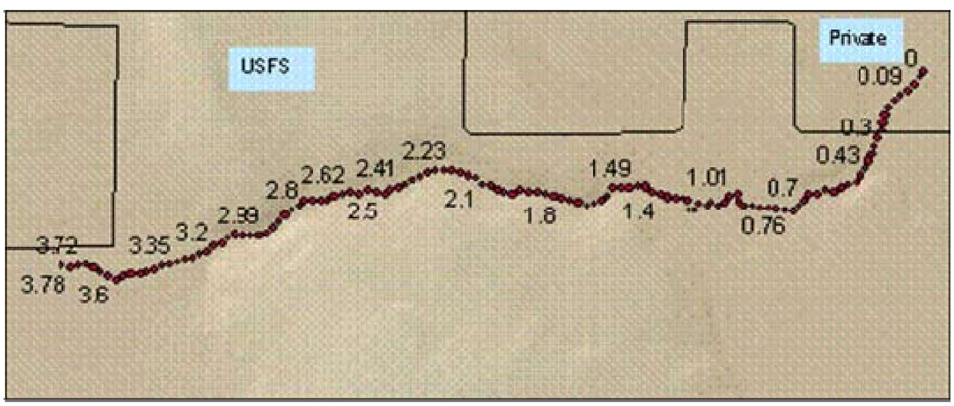


Figure A55. Horse Canyon existing conditions (a – c) and shade analysis results (d).

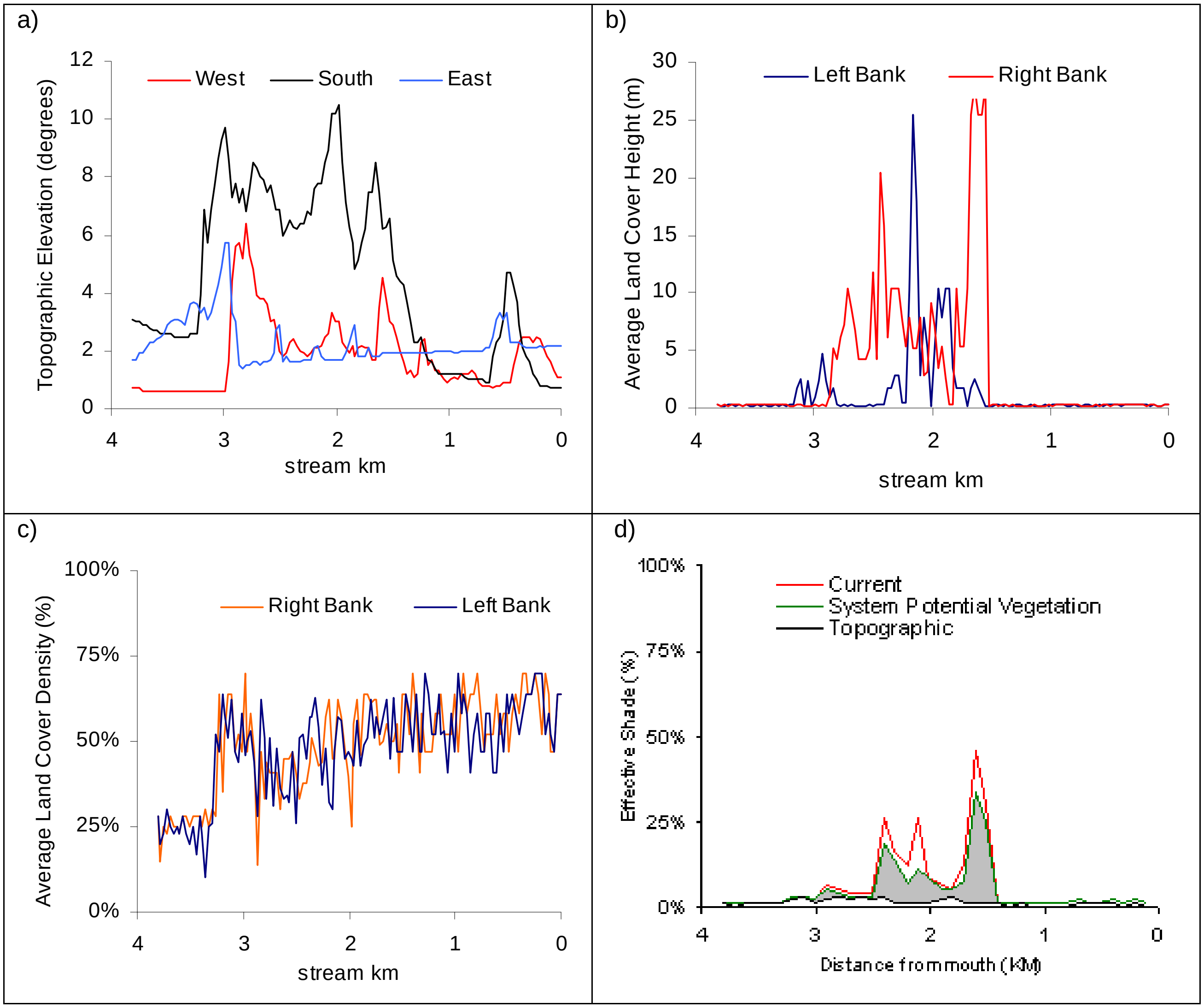


Table A27. Horse Canyon riparian area vegetation.

				Prevalence in Scenario (%)	
Land Cover Name	**Height (m)**	**Density (%)**	**Overhang (m)**	**Current Condition**	**Potential Vegetation**
Dry Meadow	0.3	70%	0.3	39%	39%
Meadow	0.3	70%	0.3	32%	34%
Dry Meadow	0.3	30%	0.3	17%	15%
Large Conifer	30.5	30%	2.1	1%	5%
Silver Sagebrush/Wetland Grasses	0.9	30%	0.3	0%	3%
Non-Riparian Juniper	9.1	30%	0.5	0%	2%
Large Conifer	30.5	60%	2.1	5%	1%
Large Deciduous	9.1	40%	1.8	1%	1%
Barren- Forest Road	0.0	0%	0.0	0%	0%
Small Conifer	12.2	30%	1.1	3%	0%
Non-Riparian Juniper	9.1	60%	0.5	2%	0%

4.8. Lapham Creek

The following figures and tables document the shade analysis on Lapham Creek. The reach that was examined flows through private and USFS (**Figure A56**). Most of the increases in shade are predicted to occur on private land in the lower portion due to the predicted increase in wetland shrubs (**Figure A57(d)**). **Table A28** shows the relative prevalence of vegetation types used in the current condition and potential vegetation model scenarios.

Figure A56. Lapham Creek analysis extent with ownership and distance upstream from mouth (km).

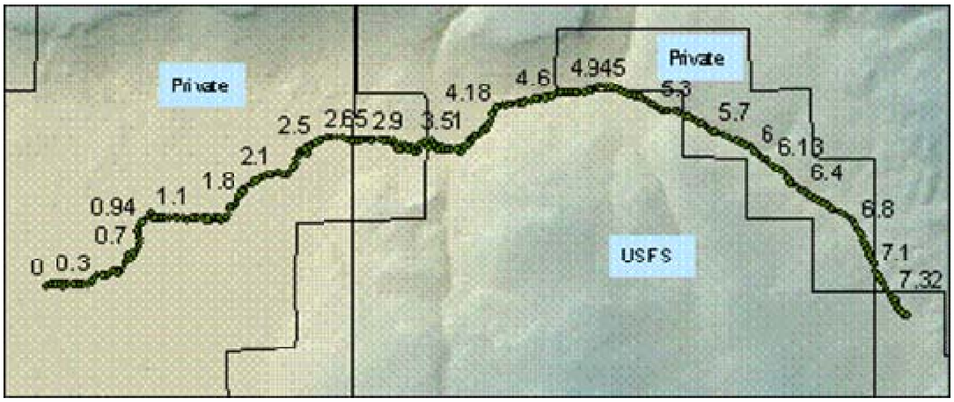
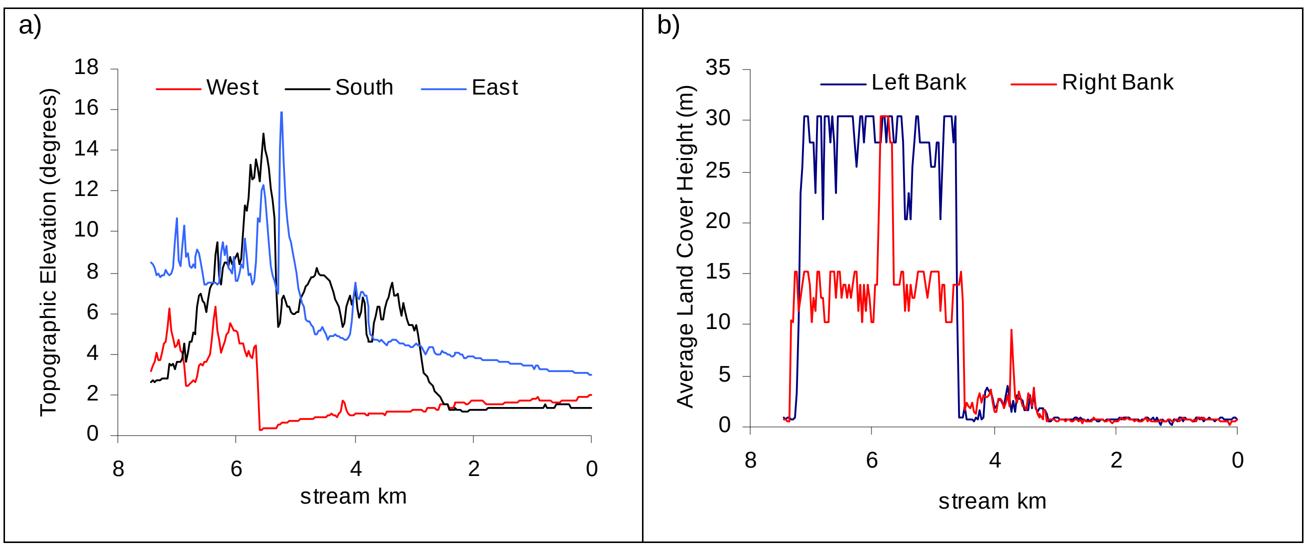


Figure A57. Lapham Creek existing conditions (a – c) and shade analysis results (d).



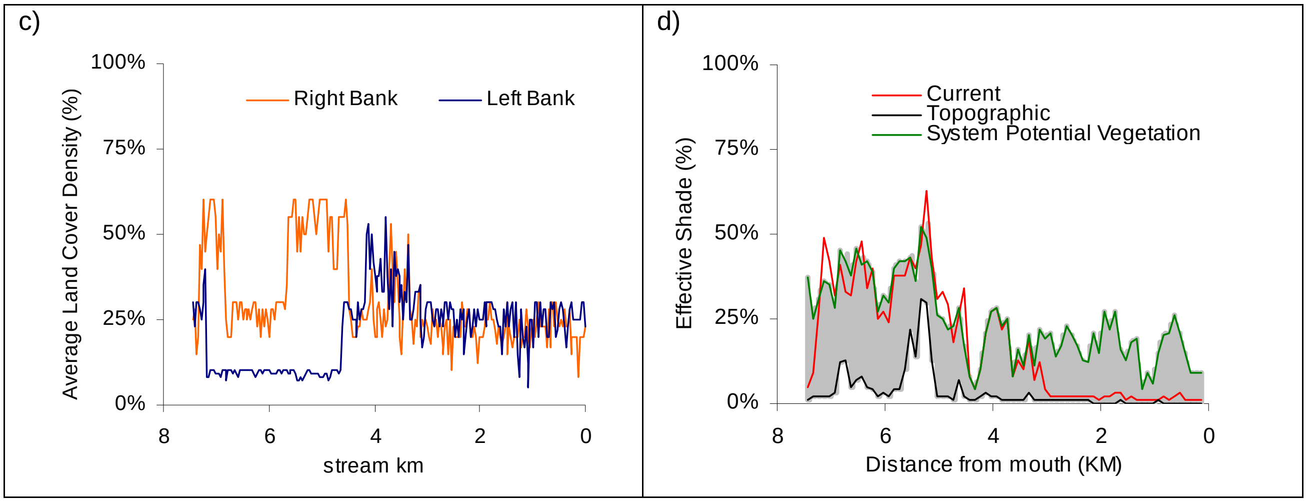


Table A28. Lapham Creek riparian area vegetation.

Land Cover Name	Height (m)	Density (%)	Overhang (m)	Prevalence in Model (%) Current Condition	Prevalence in Model (%) Potential Vegetation
Wetland grasses/shrubs mix	3.7	50%	0.3	0%	68%
Western Juniper/Pine Mix	15.2	30%	0.9	6%	17%
Wetland Shrubs 1	4.6	60%	0.3	6%	6%
Silver Sagebrush/Wetland Grasses	0.9	30%	0.3	9%	4%
Wetland Shrubs	4.6	30%	0.3	3%	3%
Large Conifer	30.5	30%	2.1	2%	2%
Wetland grasses	0.9	30%	0.3	41%	0%
Shrubs with Ponderosa Pine mix	30.5	10%	0.9	21%	0%
Western Juniper/Pine Mix	15.2	60%	0.9	11%	0%
Dryland Grasses	0.9	30%	0.3	1%	0%

4.9. Long Branch Creek

The following figures and tables document the shade analysis on Long Branch Creek. The reach that was examined flows through private, USFS and BLM lands (**Figure A58**). Most of the increases in shade are predicted to occur on private land due to the predicted increase in wetland shrubs (**Figure A59(d)**). **Table A29** shows the relative prevalence of vegetation types used in the current condition and potential vegetation model scenarios.

Figure A58. Long Branch Creek analysis extent with ownership and distance upstream from mouth (km).

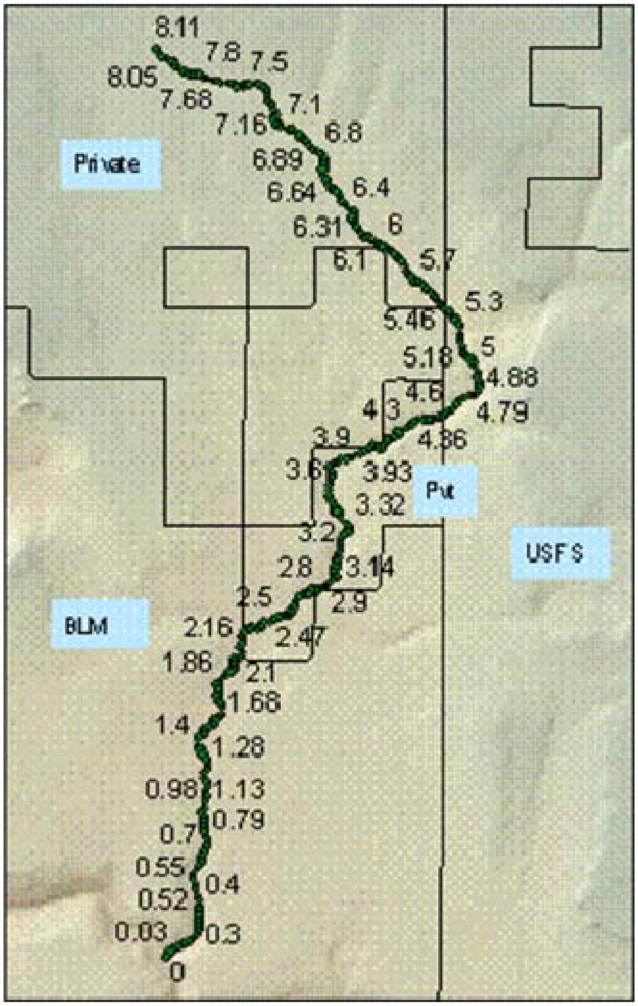


Figure A59. Long Branch Creek existing conditions (a – c) and shade analysis results (d).

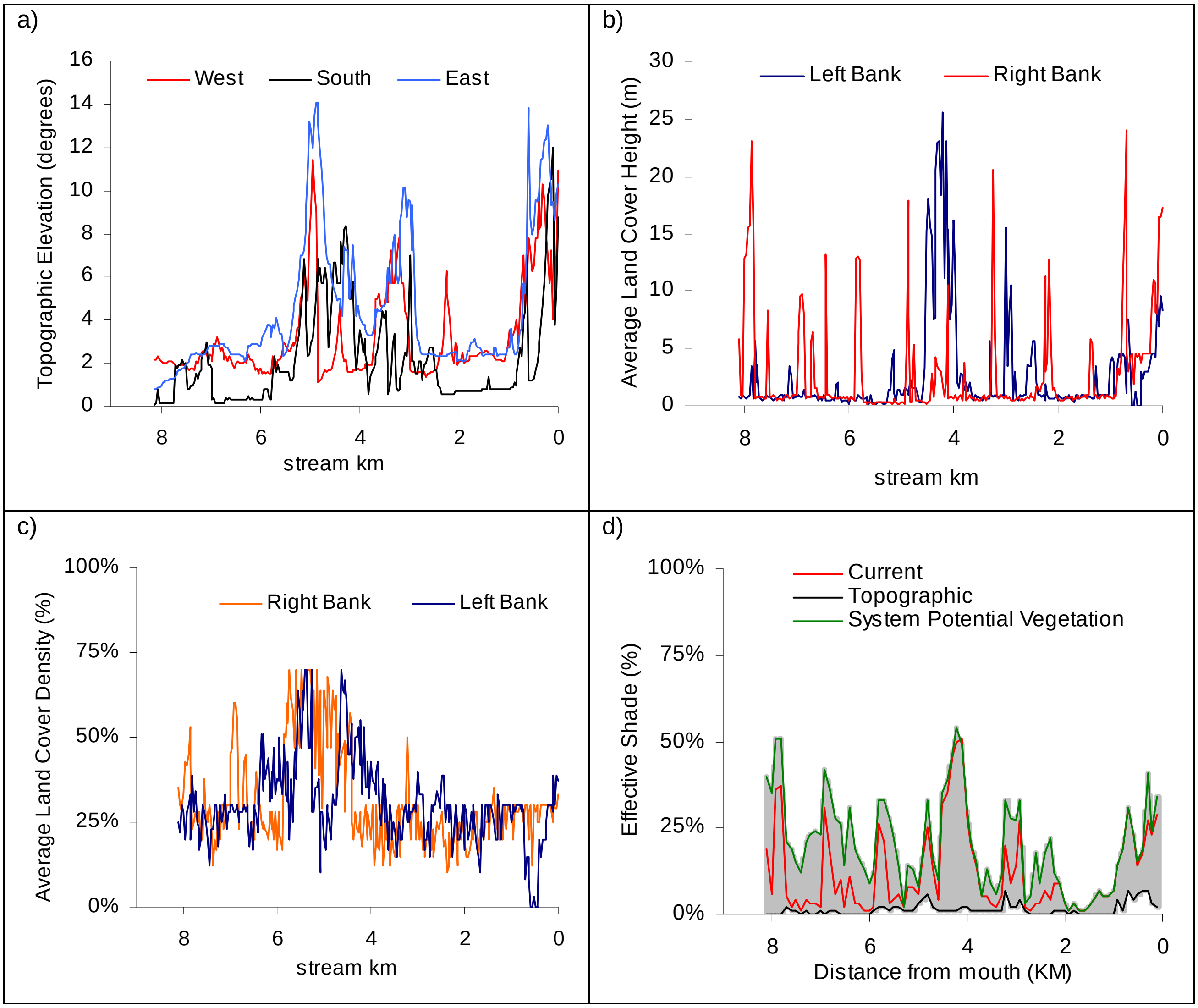


Table A29. Long Branch Creek riparian area vegetation.

Land Cover Name	Height (m)	Density (%)	Overhang (m)	Prevalence in Model (%) Current Condition	Prevalence in Model (%) Potential Vegetation
Wetland grasses/shrubs mix	3.7	50%	0.3	2%	36%
Silver Sagebrush/Wetland Grasses	0.9	30%	0.3	22%	19%
Wetland grasses	0.9	30%	0.3	35%	10%
Warm Willow	4.6	30%	0.9	0%	9%
Meadow	0.3	70%	0.3	12%	8%
Wetland Shrubs	4.6	30%	0.3	10%	4%
Large Conifer	30.5	60%	2.1	4%	4%
Upland Shrubs/sagebrush	0.9	30%	0.3	3%	3%
barren-rubbleland	0.0	0%	0.0	2%	2%
Large Conifer	30.5	30%	2.1	1%	2%
Large Deciduous	9.1	40%	1.8	1%	1%
Small Conifer	12.2	60%	1.1	1%	1%
Upland shrub/tree mix	9.1	50%	0.0	1%	1%
Warm Willow	1.5	30%	0.9	3%	0%

4.10. North Fork Willow Creek

The following figures and tables document the shade analysis on North Fork Willow Creek. The reach that was examined flows through private and USFS lands (**Figure A60**). Most of the increases in shade are predicted to occur on private land due to the predicted increase in wetland shrubs (**Figure A61(d)** and **Table A30**). Shade due to system potential vegetation is less than current shade around river km 1. This effect is because the predicted potential vegetation for conifers is less dense the current stands due to fire suppression. **Table A30** shows the relative prevalence of vegetation types used in the current condition and potential vegetation model scenarios.

Figure A60. North Fork Willow Creek analysis extent with ownership and distance upstream from mouth (km).

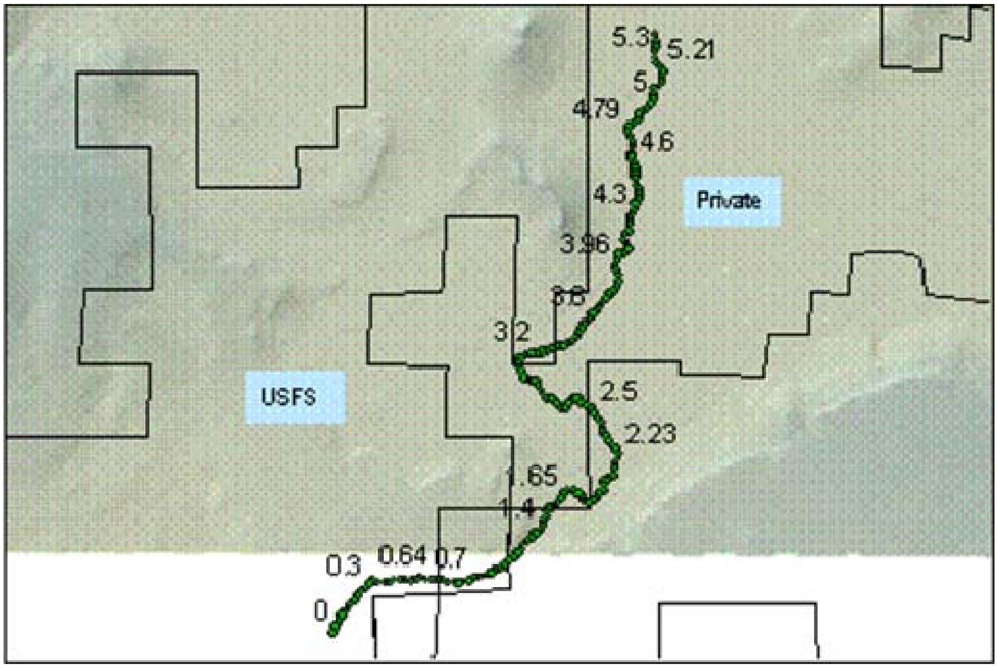


Figure A61. North Fork Willow Creek existing conditions (a – c) and shade analysis results (d).

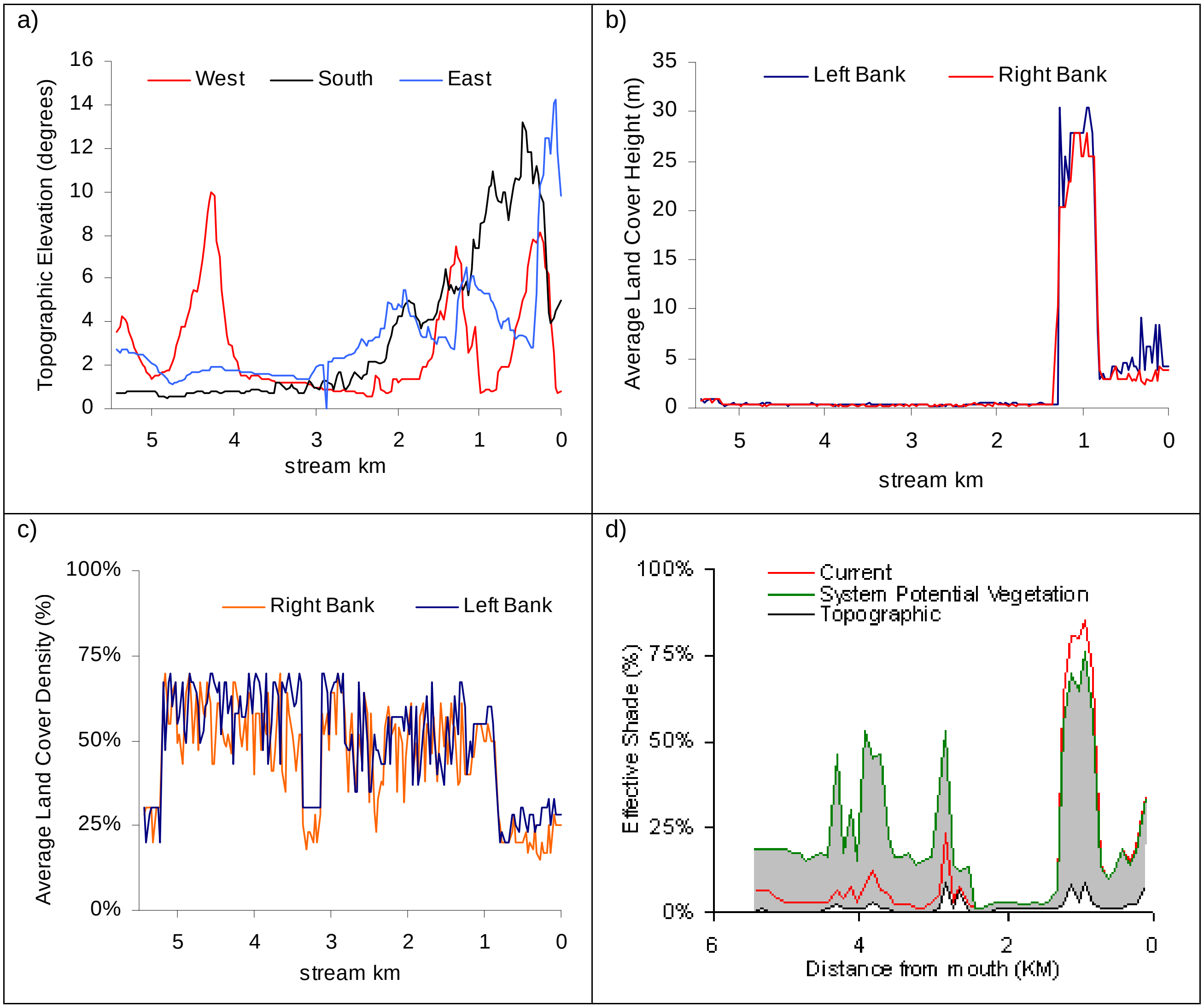


Table A30. North Fork Willow Creek riparian area vegetation.

Land Cover Name	Height (m)	Density (%)	Overhang (m)	Prevalence in Model (%) Current Condition	Prevalence in Model (%) Potential Vegetation
Warm Willow	4.6	30%	0.9	14%	66%
Meadow	0.3	70%	0.3	61%	18%
Large Conifer	30.5	30%	2.1	0%	9%
Upland Shrubs/sagebrush	0.9	30%	0.3	12%	7%
Dry Meadow	0.3	30%	0.3	5%	0%
Large Conifer	30.5	60%	2.1	9%	0%

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