State of Idaho
Department of Environmental Quality
Contract # C046

Final Report

# Water Temperature of The Lochsa River and Selected Tributaries

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July 23, 2002

Mr. Don Essig
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Subject: Water Temperature Model for the Lochsa River and Selected Tributaries (QRP00023) – Final Report

Dear Mr. Essig:

Enclosed is the Water Temperature Model for the Lochsa River and Selected Tributaries Report. It was a pleasure to work with you on this project. We believe the results of the modeling effort and subsequent analysis contribute much to the understanding of the Lochsa River watershed.

We sincerely appreciate your input and support during all phases of this project. We look forward to working with you again in the near future. Please feel free to call us if you have any questions at (208) 342-3779.

Sincerely,

HDR Engineering, Inc.

Jason Kent

Jason Kent, PE
Project Manager

Enclosures

Cc: David L. Clark, HDR Engineering, Inc.

# Lochsa River Temperature Model

Prepared for

**Idaho Department of Environmental Quality**

Prepared by

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July 23, 2002

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Cover Photo: J. Fellos, HDR Engineering - 2000. Lochsa River.

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# Executive Summary

The Lochsa River is located in the Clearwater National Forest in north central Idaho. It is formed by the confluence of the Crooked Fork and White Sand Creek. The river flows east-northeast to west-southwest through approximately 70 river miles of forested mountain and canyon terrain. Water temperatures at the mouth of the Lochsa River (near its confluence with the Selway River) at times exceeds Idaho cold water biota (CWB) maximum daily temperature criteria of 19°C average and 22°C instantaneous, or maximum daily high. For this reason, the Lochsa River was placed on Idaho's 303(d) list of water quality-impaired waters.

An assessment of water quality in the Lochsa watershed by Idaho Department of Environmental Quality (IDEQ) (Bugosh 1999) concluded that current summer temperatures in the Lochsa were not different from historic temperatures observed in the late 1950's prior to substantial anthropogenic, or human-caused, disturbance. Thus, the above-criteria temperatures were deemed a "natural condition" and not an impairment of water quality. This led DEQ to propose the removal of the Lochsa River from the 303(d) list. This conclusion was not accepted by the U.S. Environmental Protection Agency (EPA) in their oversight role. It is for this reason that a water temperature modeling study was initiated on the Lochsa River.

The objectives of the Lochsa River Modeling Project were as follows:

- Develop a model that simulates historic daily average and maximum water temperatures in the Lochsa River and select tributaries during the summer months based on measured data.
- Apply the model to simulate the system under a range of scenarios for the purpose of understanding heat loading in the Lochsa River.

Water temperatures were to be modeled for the summer months of July and August for 1994, 1997, and 1998. These years were selected because of their range in hydrologic conditions: 1997 registered the second highest flow on record, while 1994 registered the sixth lowest flow on record. The year 1998 was an average flow year. The year 1998 was also selected because copious water temperature and flow data were collected during the summer months.

Model simulated temperature output was sought throughout the length of the Lochsa River, but specifically at Lowell, Idaho, Split Creek Packbridge, Wilderness Gateway, Eagle Mountain Packbridge, Mocus Point Packbridge, Jerry Johnson Packbridge, and Powell Ranger Station. In addition, temperature output was requested at the mouths of the modeled tributaries: Crooked Fork, White Sand Creek, Deadman Creek, and Canyon Creek.

Existing peer-reviewed temperature and water quality modeling programs were evaluated for their application to the Lochsa River Temperature Modeling Project. The candidate models were evaluated considering capabilities, limitations, input data requirements, minimum and maximum temperature predictions, applicability to the modeling project, and acceptance in the modeling community. Based on the characteristics of the candidate models and the selection criteria, the SNTEMP program was selected.

Two system models were developed: a model for 1997-1998 (high flow and average flow, respectively) and one for 1994 (low flow). The model was first calibrated to mean daily water temperatures, and then calibrated to maximum daily water temperatures through adjustment of appropriate process variables.

After the temperature models were calibrated and validated, a single-parameter sensitivity analysis (Chapra 1997) was performed to identify key input variables in the model. It was found that air temperature, inflow temperature, and incoming solar radiation, respectively, were the three variables to which the average temperature model was most

sensitive. Incoming solar radiation, air temperature, and inflow temperature were the three variables that most influenced maximum temperature, respectively. In the SNTEMP model, inflow temperature and air temperature can be directly changed by the user, while solar radiation is an internal parameter affected by several input variables.

Several model runs were performed to simulate alternate scenarios. As a result of these simulations, it was found that water temperatures did not meet Idaho CWB temperature criteria throughout the Lochsa River on the 90$^{th}$ percentile air temperature day. Increasing riparian vegetative shading to full potential would decrease Lochsa River daily average water temperature by as much as 1.35°C, not enough to meet Idaho CWB temperature criteria at Lowell, near the mouth of the river. Alternately, the water temperature of all tributaries to the Lochsa River would have to be reduced by more than 8°C to meet Idaho CWB temperature criteria. This scenario is not particularly reasonable, as many of the tributaries to the Lochsa River drain wilderness areas or unmanaged watersheds, and an 8°C decrease in water temperature is likely not physically possible in these areas.

Since the Lochsa River is an unregulated stream with little disturbance other than State Highway 12 and modest timber harvest over the past 45 years, the reduction in shade provided by riparian canopy cover is the primary disturbance likely to increase water temperature. Thus, the question to be answered was "what fraction of the departure between current canopy conditions and full potential canopy in the riparian zone is due to natural disturbances, and what fraction is due to human disturbances?" The question was investigated by quantifying the difference in riparian canopy conditions for stands of trees that are undisturbed or have natural changes and those that have human-caused changes. The SNTEMP model was used to determine the difference in stream temperatures that may then be attributed to human activity.

It was found that between 75% and 97% of the difference in water temperature between the existing and full potential canopy cover conditions in the Lochsa River basin is due to natural disturbances. While human-caused disturbances increase water temperatures in the basin, natural disturbances are a more dominant factor in the difference between existing condition and full potential canopy cover water temperatures.

# Introduction

The Lochsa River is located in the Clearwater National Forest in north central Idaho (Figure 1). It is formed by the confluence of the Crooked Fork and White Sand Creek (aka Colt Killed Creek). The river flows east-northeast to west-southwest through approximately 70 river miles of forested mountain and canyon terrain (Figure 2). Several small tributaries flow into the Lochsa River, including Canyon Creek and Deadman Creek. At the River's mouth near the town of Lowell, Idaho, the Lochsa River merges with the Selway River to create the Middle Fork of the Clearwater River.

Data collected by federal and state resource agencies and private companies were used to build a historical temperature model for the Lochsa River. The data used include meteorological data, stream geometry, stream and watershed hydrology, local topography, and vegetation data. The model was built to predict average and maximum daily water temperature throughout the Lochsa River and four tributaries, Crooked Fork, White Sand Creek, Deadman Creek, and Canyon Creek, for the mid-summer months of July and August of 1994, 1997, and 1998.

The years to be modeled were selected because of their range in hydrologic extremes: 1997 registered the second highest flow on record, while 1994 registered the sixth lowest flow on record. 1998 was considered an average flow year. 1998 was also selected because copious water temperature and flow data were collected during the summer months.

# Model Selection

**Evaluation of Existing Programs**

Existing peer-reviewed temperature and water quality models were evaluated for their application to the Lochsa River Temperature Modeling Project. Each model's capabilities and limitations, along with an assessment of each, are shown in Table 1.

The candidate models were evaluated considering capabilities, limitations, input data requirements, minimum and maximum temperature predictions, applicability to the modeling project, and acceptance in the modeling community. A brief description of each of the candidate models follows.

***SNTEMP***

SNTEMP and its companion program, SSTEMP, model temperatures in a stream as a function of hydrologic conditions, riparian and topographic shading, and meteorological conditions. The one-dimensional model assumes steady flow, complete mixing, and requires daily means for input variables. SNTEMP is a stream network model with a spatial grid as fine as 100 meters, while SSTEMP is a simplistic version of SNTEMP that can assess conditions for a single stream reach in a single time period. Both models call upon output from companion programs, SSSOLAR and SSSHADE, to provide data on short-wave radiation and shading percentages. Both SNTEMP and SSTEMP have text interfaces and are public domain models.

SNTEMP and its associated models were developed by the U. S. Fish and Wildlife Service's Instream Flow Group. This group subsequently became the U.S. Geological Survey—Mid-Continent Ecological Science Center (USGS-MESC). The USGS-MESC website (www.mesc.usgs.gov) provides the models for free download and also provides technical support.

***Heat Source***

Heat Source was developed as part of a Masters thesis at Oregon State University, and is currently supported by the Oregon Department of Environmental Quality (ODEQ). It is an energy-based finite difference temperature model with heavy reliance on geographic information system (GIS)-based input. Heat Source has fine internal spatial and temporal scales (100 ft, 1 minute) and is suitable for a reach scale of analysis. The model involves a wide variety of atmospheric, solar, and stream reach parameters. It has a spreadsheet-based user interface and is public domain, available on CD from ODEQ.

**Figure 1. Project Vicinity Map**

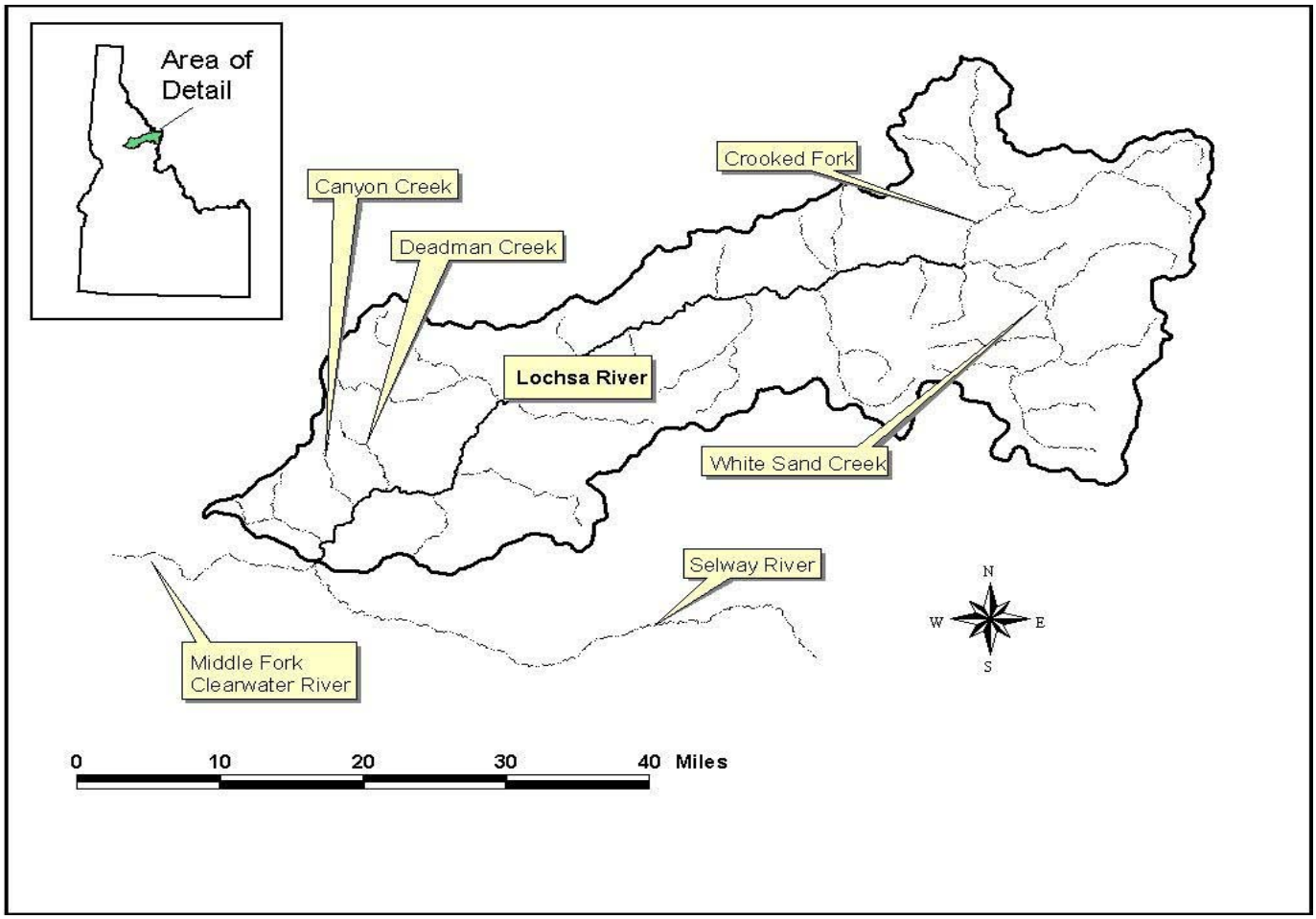



**Figure 2. Photograph of Lochsa River**

| Model | Strengths | Weaknesses | Timestep | Applicability to Lochsa River Project | Criteria | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Process-Based Temperature Models** | | | | | Mean/Max T | Network capability | Input parameters | Shading | Ease of use | Accepted |
| SNTEMP | Stream network model. Considers latitude and time of year, predicts topographic and riparian shading, and corrects climate data as function of elevation. | Uses algorithm to predict daily max. temps based on daily average temps. Cannot handle rapidly varying flows | daily | Applicable to project. Model known to Idaho DEQ and EPA,<br><br>Public domain model. Good support network in place. | Only mean is directly calculated | Yes | Data-driven | Yes | Users manual, self-directed study, technical support | Peer-reviewed, widely used |
| Heat Source | Flexible time step model. Relies on Arc View for topographic input. Very fine temporal and spatial scale. | Not suited for a stream network application. Data-intensive model. Limitations in groundwater mixing and canopy density. Limited model support. | flexible | New technology, generally getting good reviews. Model familiar to Oregon DEQ but has limited project application outside of Oregon. Possibly applicable to project. Decribed by developer as a very data-intensive model.<br><br>Public domain. | Calculates instantaneous temperatures for timestep | No | Heavily data-driven | Yes | Requires large amounts of data, little support | Minimally peer-reviewed, not used outside of Oregon |
| BasinTemp | Steady state, 1-D, GIS-linked model. Requires little collected data. | Assumes no cloud cover and does not use relative humidity data. Assumes linear relationship between mean and max. temps. Not suited for stream networks. Simplest model. | daily | New technology with limited feedback on use. May be too simplistic for this project due to its non-reliance on collected data.<br><br>Proprietary model, work must be done by vendor (with associated cost). | Only mean is directly calculated | Yes | GIS-driven, requires minimum of field data | Yes | Model must be operated by Stillwater Sciences | Not peer-reviewed, new technology |
| **Hybrid Combination Model Approaches** | | | | | | | | | | |
| SNTEMP / Heat Source | Advantages of modeling mean temperatures for July/August, and investigating maximum temperatures and diurnal changes during a period of interest. | Each node to describe multiplies the effort for setting up the Heat Source model. Requires that two distinct models be developed. | daily / flexible | Advantages of mean daily averages in the stream network, as well as maximum temps and diurnal changes in chosen segments. | See above | See above | See above | Yes | See above | See above |
| SNTEMP / SSTEMP | Can re-calculate maximum water temperature in a segment of interest using maximum values for air temperature | Does not directly calculate maximum temperature and cannot describe diurnal fluctuations. | daily | Each model can be calibrated to better represent maximum daily temperatures by adjustment of 3 or 4 empirical coefficients. | See above | See above | See above | Yes | See above | See above |
| 2 calibrated SNTEMP models | Same as SNTEMP, with added value of a model calibrated to observed daily maximum temperatures. | While it is both feasible and acceptable, calibrating to maximum temperatures is not a typical operating procedure. | daily | Having two calibrated models increases the level of accuracy of the analysis. How well the maximum temperature model will calibrate is an unknown factor at this point. This option satisfies all project criteria. | See above | See above | See above | Yes | See above | See above |
| **Multi-Constituent Water Quality Models** | | | | | | | | | | |
| CE-QUAL-W2 | Flexible time step, 2-dimensional model that includes water quality parameters. | Simple shading function included in model. Extensive data requirements. | flexible | Powerful water quality model. Version 3.0 applicable to river systems. May be too sophisticated for economical application to project.<br><br>Public domain model. | Calculates instantaneous temperatures for timestep | Yes | Data-driven | Simple short-wave solar radiation algorithm | Complicated model, little support | Peer-reviewed, widely used |
| CE-QUAL-RIV1 | Flexible time step, 1-dimensional, steady and unsteady flow model with water quality parameters. | Hydrodynamics not linked with temperature. | flexible | May be applicable to project.<br><br>Public domain model. | Calculates instantaneous temperatures for timestep | Yes | Data-driven | No | Complicated model, little support | Peer-reviewed |
| RMA-11 | Inclusion of water quality parameters, 1-, 2- and 3-dimensional simulation, steady or unsteady flow, short timesteps | No shading included in model. Extensive data requirements. A 30-minute timestep is considered "relatively long". | flexible | Complex hydrodynamic and water quality model, may be too sophisticated for project.<br><br>Proprietary model with prohibitative cost. | Calculates instantaneous temperatures for timestep | Yes | Data-driven | No | Complicated model, little support | Peer-reviewed |
| MIKE-11 | Flexible time step, option of simplified or complete heat calculations, GIS-capable, stream network capable | Extensive data requirements. | flexible | Powerful hydrodynamic and water quality model. May be too sophisticated for economical application to project.<br><br>Proprietary model with prohibitative cost. | Calculates instantaneous temperatures for timestep | Yes | Data-driven | Yes | Complicated model, e-mail support | Peer-reviewed |

**Table 1. Lochsa River Temperature Model Selection Matrix**

***BasinTemp***

BasinTemp, developed by Stillwater Sciences, is a simple, one-dimensional, steady-state, network scale mechanistic temperature model, whose strength lies in its non-reliance on field-based data. As such, it is heavily reliant on GIS-based input data. It utilizes daily average input data to produce estimates of daily average water temperature and uses linear relationships to estimate daily maximum temperatures. It requires a minimum of atmospheric, flow, and water temperature data. It has a variable spatial network scale, allowing a network as fine as 30 meters. BasinTemp is a proprietary model that is not available to the general public at this time. All input data must be sent to Stillwater Sciences for model operation.

***CE-QUAL-W2***

CE-QUAL-W2 is a two-dimensional, laterally-averaged, hydrodynamic and water quality model that has been used to model over 200 waterbodies, including rivers, lakes, reservoirs, and estuaries. The model simulates temperature, dissolved oxygen (DO), the nitrogen, phosphorus, and organic carbon cycles, and up to three types of algae. It predicts instantaneous temperatures in a variable spatial scale within a user-defined temporal scale, which must be converted to average and maximum temperatures using post-modeling analysis techniques. CE-QUAL-W2 is modular in nature, such that water temperature can be modeled with or without the interactions of other constituents. CE-QUAL-W2, developed by the U.S. Army Corps of Engineers—Waterways Experiment Station (USACE—WES), is a network-scale, public domain program and has both text and Windows input user interfaces. Output is currently text files with a Windows interface scheduled for release later this year.

***CE-QUAL-RIV1***

The Hydrodynamic and Water Quality Model for Streams (CE-QUAL-RIV1) is a one-dimensional, network-scale, unsteady flow model capable of dynamic simulations. CE-QUAL-RIV1 was developed by USACE—WES to simulate transient water quality conditions associated with highly unsteady flow conditions that occur in regulated rivers. CE-QUAL-RIV1 allows simulation of rivers with multiple hydraulic control structures, such as run-of-the-river dams, waterway locks and dams, and regulation dams. The hydraulic model component requires that river geometry and boundary conditions are defined in order to perform hydraulic computations. CE-QUAL-RIV1 can simulate temperature, salinity, biological oxygen demand (BOD)-DO, the nitrogen and phosphorus cycles, phytoplankton in the water column, benthic algae, macrophytes, and bacteria. It predicts instantaneous temperatures in a variable spatial scale within a user-defined temporal scale, which must be converted to average and maximum temperatures using post-modeling analysis techniques. CE-QUAL-RIV1 has a text user interface and is a public domain program.

***RMA-11***

RMA-11, developed by Resource Management Associates, is a stream network scale finite element model for the one-, two-, or three-dimensional simulation of water quality in rivers, estuaries, and groundwater systems. This proprietary software was originally developed as the public domain model RMA-4 for the USACE. Its constituents include temperature, DO, the nitrogen and phosphorus cycles, algal growth and decay, and suspended sediments. RMA-11 is modular in nature, such that water temperature can be modeled with or without the interactions of other constituents. The user interface is DOS-based, and incorporates ASCII text files for data input. RMA-11 is a sophisticated proprietary model that is relatively expensive compared to the public domain models.

***MIKE-11***

The MIKE-11 model is proprietary software commercially available from DHI, Inc., formerly known as the Danish Hydraulic Institute. MIKE-11 allows dynamic water quality simulations and has a Windows user interface. It is a one-dimensional stream

network model capable of simulating water temperature and the nitrogen and phosphorus cycles, and is modular in nature, such that water temperature can be modeled with or without the interactions of other constituents. It predicts instantaneous temperatures in a variable spatial scale within a user-defined temporal scale, which must be converted to average and maximum temperatures using post-modeling analysis techniques. This is also a sophisticated model that is relatively expensive compared to the public domain models.

***Hybrid Model Combinations***

The use of combined models was considered in order to meet multiple project objectives. These objectives include analysis of both average and peak water temperatures. Also desired was the ability to model a stream network, as well as individual reaches. Evaluation of the candidate models indicated that no single model was capable of meeting all of these objectives. The use of two models provided the potential to combine the strengths of two tools to provide the capabilities required.

Three hybrid combination model options are summarized in Table 1. Combining SNTEMP with other models was considered, since SNTEMP appears to best meet most project objectives, including simulation of average temperatures in a stream network model, direct simulation of the effect of shade on water temperature, being peer-reviewed and in the public domain, utilizing field data-driven input parameters, and having good documentation and technical support. Combining Heat Source with SNTEMP adds an ability to simulate diurnal variations in temperature. The drawback to this approach is the added complexity involved in developing two distinct models, both Heat Source and SNTEMP. Combining SSTEMP with SNTEMP links two companion models with similar input data. The stream segment model SSTEMP provides the ability to simulate maximum temperatures in a given stream reach but not diurnal variations. Alternately, a pair of SNTEMP network models calibrated first to average water temperatures, and then to maximum temperatures, may provide a better approach. The potential drawback to this approach is that calibration of maximum daily water temperatures is empirical and its suitability is unknown.

**Summary of Model Features Required for Lochsa River Modeling Project**

The candidate models were assessed for the Lochsa River Modeling Project based on the following criteria:

- Prediction of mean and maximum water temperatures
- River network capability
- Availability and requirements of input parameters
- Ease of use
- Peer reviewed and utilized within the scientific community

Each of these criteria is described in the following paragraphs.

***Prediction of Mean and Maximum Water Temperatures***

The selected model should simulate mean and maximum water temperatures at a minimum of a daily temporal scale, with a diurnal range, if possible. The selected model should simulate temperatures at several locations in the stream network.

***River Network Capability***

The selected model should simulate the entire Lochsa River from its headwaters to its mouth on a network scale. The stream network includes several tributaries that must be modeled as well, and the output from those tributaries is to be modeled as input to the Lochsa River at the same temporal scale.

***Availability and Requirements of Input Parameters***

Idaho Department of Environmental Quality (IDEQ) and the U.S. Forest Service (USFS) have collected data for several input parameters for use in the selected water

temperature model. The selected model should take advantage of these data, as one of the purposes of the project is to utilize a peer-reviewed model to produce a calibrated process-based water temperature model based on collected data from the Lochsa River basin.

***Ease of Use***

The selected model should be suitable for operation by HDR Engineering, Inc. and IDEQ and should not require an inordinate amount of time for data collection or data entry. The output from the model should be exportable to a spreadsheet or database program for easy processing and reporting. In addition, documentation for the selected model should be easy to follow and technical support should be reasonably accessible.

***Peer Review and Utilization of Model Within the Scientific Community***

The selected model should be peer-reviewed and utilized within the scientific community.

**Model Selection and Recommendation**
Based on the characteristics of the candidate models and the selection criteria described above, the HDR-IDEQ team selected SNTEMP for the Lochsa River Modeling Project. The SNTEMP model was calibrated to mean daily water temperatures, and then calibrated to maximum daily water temperatures through adjustment of appropriate process variables. Based on calibration and validation performance, two models were developed: one for 1997-1998 and one for 1994. This is discussed in greater depth in the Calibration and Validation section of this report.

SNTEMP was selected based on several characteristics, including its technical capabilities, applicability to the project, the stream network component of the program, existing support network, and availability as a public domain program. SNTEMP's main shortcoming is its use of an algorithm to determine maximum water temperatures instead of calculating them directly. The equation used in SNTEMP to determine maximum water temperatures is as follows:

$$T_{\max} = T_e - \left[\left(T_e - T_{avg}\right)^{\left[-(k_x t_x)/(\rho c_p d)\right]}\right]$$

Where:

$T_{max}$ = Average maximum daytime water temperature (at sunset) at point of interest

$T_e$ = equilibrium water temperature for average daytime conditions

$T_{avg}$ = average daily water temperature at travel time distance upstream from point of interest

$k_x$ = first order thermal exchange coefficient for daytime conditions

$t_x$ = travel time from noon to sunset

$\rho$ = density of water

$c_p$ = specific heat of water

d = average flow depth

Other algorithms are used to determine equilibrium water temperature, average daily water temperature, travel time, and average depth. The maximum daily temperature model was calibrated to better predict the estimated maximum water temperature by re-estimation of appropriate empirical coefficients.

# Model Structure

The SNTEMP model utilizes six input files that include measured data and two system control files, as described below:

**Study File**
The study file includes the locations and types of nodes that define the stream network system, as well as locations in the network where output is required.

**Geometry File**
The geometry file provides a network definition of the modeled streams, the site location and the stream geometry (e.g. channel width, depth, and gradient).

**Shade File**
The shade file includes data for parameters that contribute to the shading of the stream due to topographic and vegetative conditions.

**Time Period Data File**
This file is primarily used by SNTEMP as a system file but includes two parameters that are used in the determination of incoming solar radiation: the dust coefficient and ground reflectivity.

**Meteorology Data File**
The meteorology data file includes all remaining meteorological data for the study reach for each day in the study period.

**Hydrology Data File**
The hydrology data file provides the mean daily stream flows and temperatures for the modeled streams and all tributaries to the stream network for each day in the study period.

**Hydrology Node File**
The hydrology node file contains information needed by the program on where hydrology data are required. No input data are included in this file.

**Job Control File**
The job control file contains information required by the program that defines the size of the network, the extent of output desired, years of data simulated, node counts, calibration factors, and file names. No input data are included in this file.

# Input Data

The sources of the data that were acquired vary. Much of the measured data were furnished by the Clearwater National Forest. Most of these data came in electronic formats. Additional data used in the model were obtained from IDEQ, the USGS, Clearwater BioStudies, Inc., and the Tennessee Valley Authority (TVA).

The acquisition of the required measured data is described in Table 2. In addition, data reduction for collected data of key parameters are described in more detail in the sections that follow.

**Study File—Segmentation**
The SNTEMP model requires segmentation of the river network based on the following features and requirements:

- Required temperature output locations
- Confluences with certain tributaries with measured temperature data
- Locations of measured temperature data in the mainstem of the River
- Major changes in gradient
- Major changes in stream orientation
- Major changes in stream width

The Lochsa River temperature model segmentation is shown in Figure 3.

***Shade File—Vegetation Parameters***

***East/West Crown Measurement***

Used for determining vegetative shading, this parameter is defined as the average maximum diameter of the shade-producing strata of vegetation along the stream.

A crown diameter of 10 meters was assumed for all segments in the SNTEMP model. No data are available that are specific to the study area.

***East/West Vegetation Height***

Used for determining vegetative shading, this parameter is the average height of the shade-producing strata of vegetation, measured from the water surface. Average height of trees data were taken from a GIS database provided by Clearwater National Forest. The GIS data recorded average values of stand height and stand crown closure, a measure of density, for each distinct stand in the Clearwater National Forest. Data for the stands that were directly adjacent to the streams of interest were collected, along with a weighting factor based on the relative length the stream. An average

**Table 2. Data Collection Sources**

| Data File | Parameter | Data Source | Adjusted in calibration? |
|---|---|---|---|
| Study File | Segmentation | GIS software and USGS 7.5-minute maps—see text | No |
| Geometry File | Latitude, Elevation, Azimuth | GIS software and USGS 7.5-minute maps | No |
| | Manning's n | Clearwater BioStudies reports (Rosgen 1994) | No |
| | Width | Clearwater BioStudies reports | Yes |
| | Ground temperature | System default to mean annual air temperature | No |
| | Streambed thermal gradient | System default | No |
| Shade File | Latitude, Azimuth | See above | No |
| | Width | See above | Yes |
| | East/west topographic altitude | GIS software | No |
| | East/west crown measurement | Data not available specific to study area—see text | No |
| | East/west vegetation height | Clearwater National Forest's Timber Stand Management Record System—see text | No |
| | East/west vegetation offset | Aerial photography and digital aerial infrared imagery—see text | No |
| | East/west vegetation density | Clearwater National Forest's Timber Stand Management Record System—see text | No |
| Time Period File | Dust coefficient | Suggested values in User's Manual (Theurer et al. 1984)—TVA (1972) | No |
| | Ground reflectivity | Suggested values in User's Manual (Theurer et al. 1984)—TVA (1972) | No |
| Meteorology File | Meteorology station latitude and elevation | Remote Automated Weather Stations (RAWS) located at Powell and Lowell—see text | No |
| | Annual air temperature | Meteorological station located at Fenn Ranger Station | No |
| | Time period mean air temperature | RAWS located at Powell and Lowell | Yes |
| | Time period mean wind speed | RAWS located at Powell and Lowell | Yes |
| | Time period relative humidity | RAWS located at Powell and Lowell | Yes |
| | Time period percent sunshine | Meteorological station located at Missoula, Montana airport | No |
| | Observed ground level solar radiation | Not used | N/A |
| Hydrology Data File | Time period discharge and water temperature | USGS gage data, USFS gages and temperature monitors. See text | Yes |
| | Lateral inflow water temperature | System default to mean annual air temperature | Yes |
| | Reservoir inflow temperature | Not used | N/A |
| Hydrology Node File | None | N/A | N/A |
| Job Control File | None | N/A | N/A |

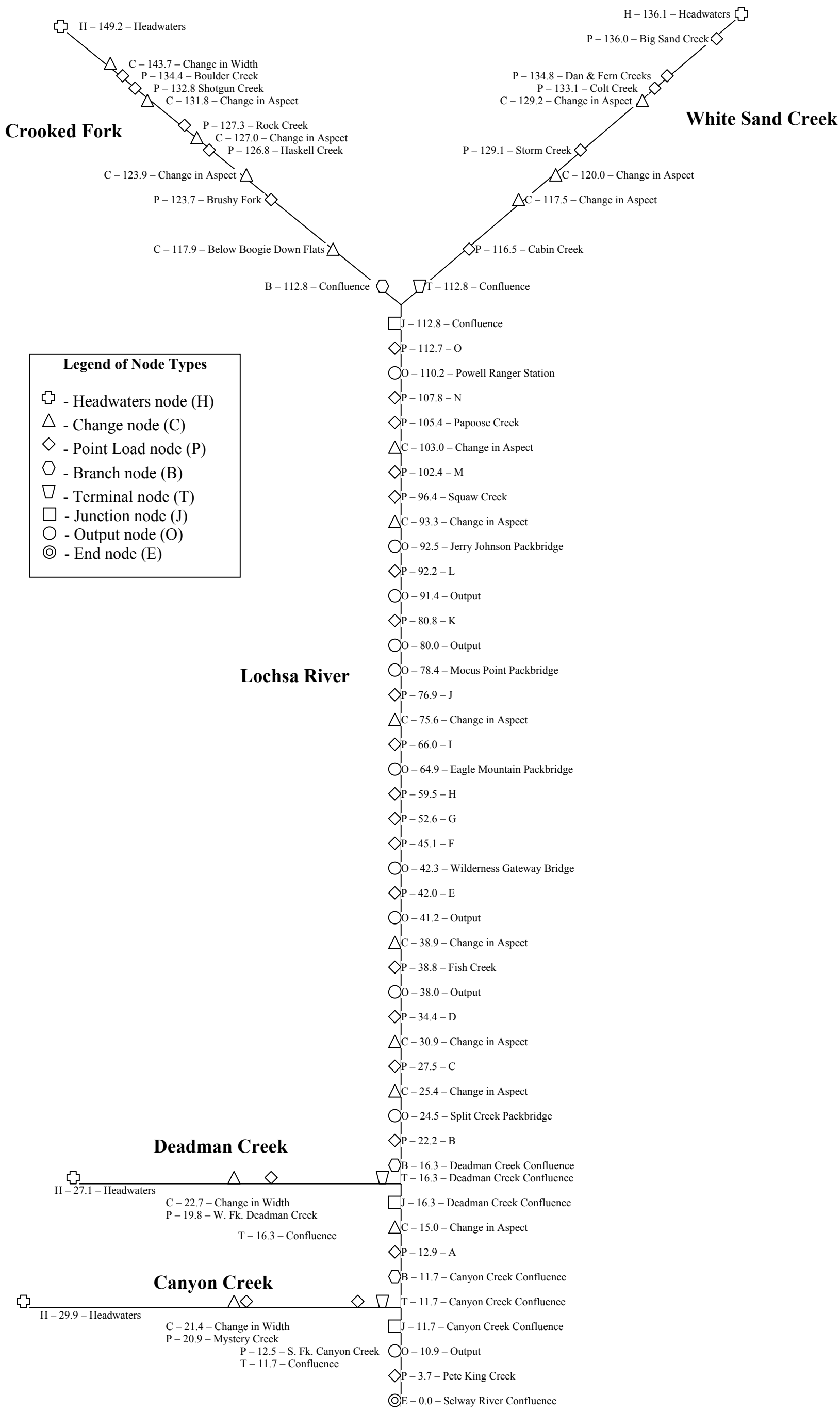



**Figure 3. Schematic of Model Segmentation.**

tree height was developed for each stream segment using the weighting factor for each of the stands.

***East/West Vegetation Offset***

This parameter is the average offset of the trunks of the shade-producing strata of vegetation from the edge of the stream.

Offset of the trunks of the riparian trees to the edge of stream was determined using aerial photography. For the Lochsa River, digital color infrared imagery was examined. An example of this imagery, photographed by IRZ Consulting (2001), is shown in Figure 4. For the four tributaries, black and white aerial photography stereo pairs were examined. The offsets used for each segment in SNTEMP reflect an average offset for the corresponding reaches.

**Figure 4. Color Infrared (CIR) Imagery of Lochsa-Selway Confluence**

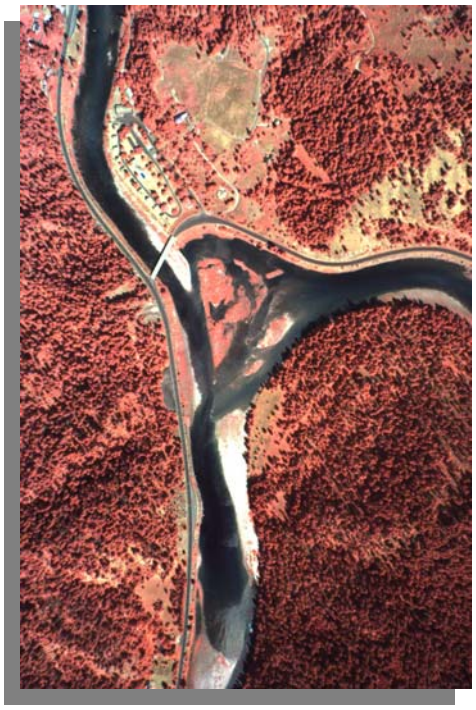


Photo: IRZ Consulting, 2001

***East/West Vegetation Density***

This parameter is the average screening factor, on a 0 to100 percent scale, of the shade-producing strata of vegetation along the stream.

Vegetation density data were taken from the crown closure data for each stand from the Clearwater National Forest database, as described above. The vegetation densities used for reach segment in SNTEMP reflect an average density for the corresponding examined reaches.

***Meteorology Data File—Meteorology Station Latitude and Elevation***

These data represent the location at which meteorology input data represent measured conditions. Because SNTEMP only accommodates one set of meteorology data, only one set of station information can be entered into the model. SNTEMP automatically applies adiabatic correction factors to air temperatures based on elevation and adjusts incoming solar radiation based on latitude.

SNTEMP requires a set of meteorology data be provided from only one station. Ideally, this station would be located at the mid-point of the river network being studied. Most meteorology data for this project were collected from Remote Automated Weather Stations (RAWS) located near the river at two separate locations: 1) near Lowell, the downstream end of the Lochsa River, at about River Kilometer (RKM) 0.0, and 2) near Powell, Idaho, the upstream end of the Lochsa River, at about RKM 112.8. The air temperature, wind speed, and relative humidity data used in the SNTEMP meteorology data file are weighted average values of the data from the Lowell and Powell RAWS. The weighted average corresponds with a meteorology station located at approximately RKM 101.5.

**Hydrology Data File—Time Period Discharge and Water Temperature**

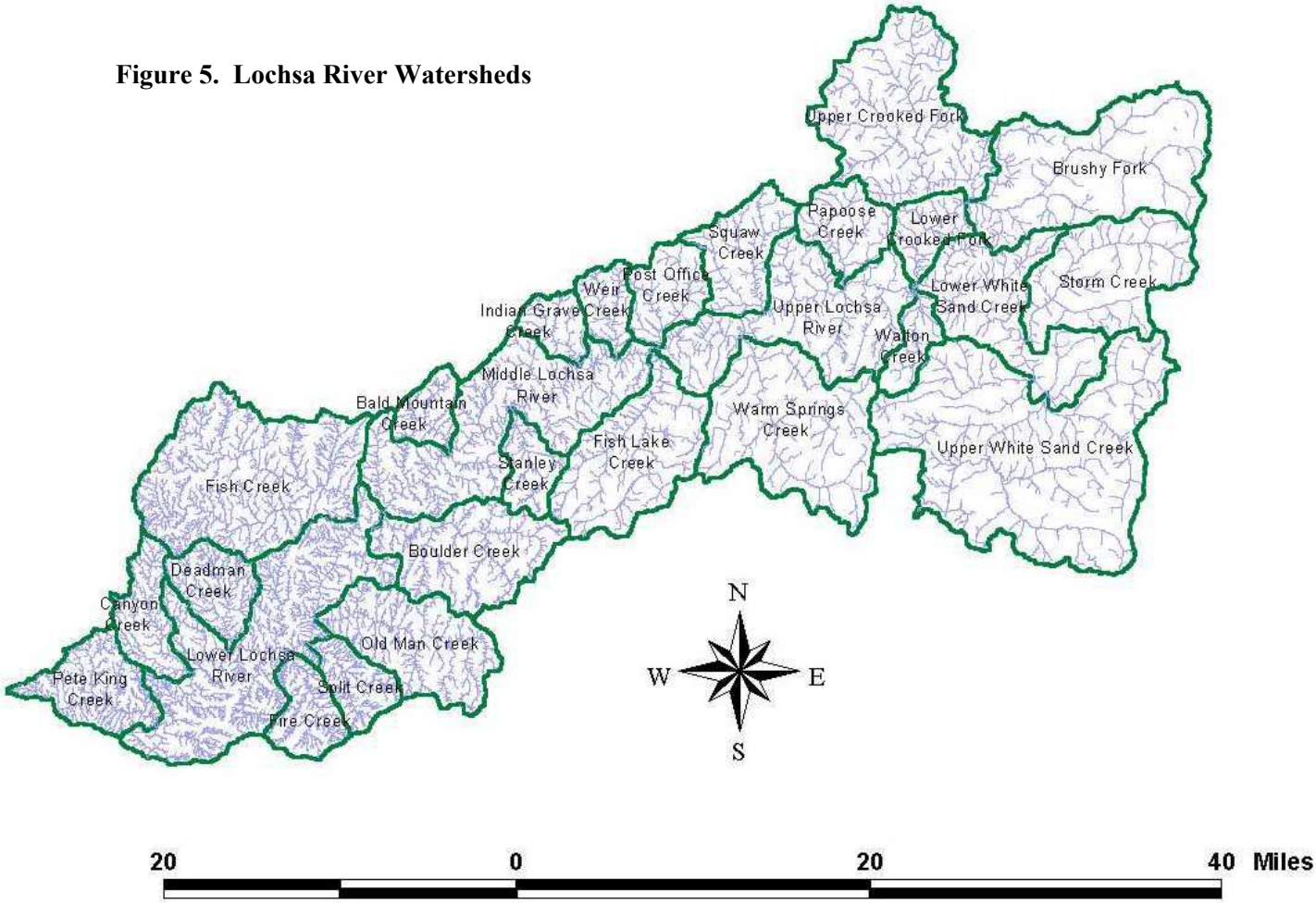
These parameters describe the mean daily flow and mean daily water temperature for each day in the modeling period for each point of inflow into the system. Known discharges and water temperatures in the modeled streams, if available, are included in this data file.

Discharge data were provided for all study years for the downstream end of the Lochsa River at the USGS Lowell gage. In addition, Clearwater National Forest staff collected discharge data for Pete King Creek, Canyon Creek, Deadman Creek, Fish Creek, Squaw Creek, Papoose Creek, Crooked Fork, and White Sand Creek for a portion of the study years. In some cases, discharge data were missing for large portions of the study period. These missing data were too large to be reproduced using the methods provided in the SNTEMP model for synthesizing data. Therefore, linear interpolation was used to produce input to substitute for the missing data. In the few cases where extrapolation was necessary, the last known discharge was used to fill in the missing points.

Many of the tributary streams that were to be modeled in SNTEMP as point source discharges had measured water temperature data but no associated flow rate. Estimated discharges were created using a normalization to area method that determined the discharge of a stream based on the area of the tributary subbasin in relation to a discharge and subbasin area of a similar gaged stream. This method was also used to create discharges on the gaged streams for years in which field data were not collected. Subbasin areas were determined from the watershed delineation map developed by Don Essig of IDEQ, shown in Figure 5.

This normalization to area method did not result in a total discharge equal to the observed Lochsa River discharge at Lowell. There are a number of potential explanations for this discrepancy. Two of the most important explanations are that minor laterals and groundwater recharge were not considered. The remainder of the unaccounted for flow was redistributed geographically throughout the system by adjusting the flows of each of the streams by an equivalent percentage, such that the total estimated flow at Lowell matched the observed flows.

**Figure 5. Lochsa River Watersheds**



After the redistribution of the remaining discharge, the stream discharges were grouped and summed based on the model segmentation and converted to metric units for entry into SNTEMP.

Measured temperature data were not collected in all streams for all study years. Therefore, measured data for each stream were used when they were available. When measured data were not available, measured temperature data for the most similar stream were used. Stream temperatures were then grouped and averaged based on the model segmentation for entry into SNTEMP.

Data were not available for approximately the first two weeks of July 1998 for many upstream tributaries (the upstream-most stream with measured water temperatures for the first two weeks of July was Skookum Creek, which enters Lochsa River at RKM 63.1). For these streams without measured temperatures, the water temperature on July 1, 1997, was used as a surrogate, and water temperatures were linearly interpolated between the July 1 value and the first measured value. The 1997 (high flow) data were used instead of the 1994 (low flow) data because the hydrology in 1997 was more similar to 1998 than was 1994 hydrology.

# Model Calibration and Validation

### Average Temperature

#### *Calibration*

The model was calibrated by adjusting input parameters for the modeled tributaries and global calibration coefficients for July 1 to August 31 in 1994, 1997, and 1998. Headwater flows, headwater temperatures, and groundwater temperatures were adjusted in calibration of the tributaries. In addition, stream widths were adjusted in Crooked Fork, Canyon Creek, and Deadman Creek during model calibration. Table 3 shows the default, starting, and final calibration values for the 1997-1998 and 1994 models

Daily mean water temperatures in the Lochsa River were calibrated to measured temperatures by adjusting the global calibration coefficients for daily average air temperature, daily average wind speed, and daily average relative humidity. For entry into the model, these measured meteorological values were averaged between the Lowell and Powell meteorological stations. Adjusting these values using the global coefficients returns the meteorological parameters to values that better describe daily mean water temperatures. Daily average relative humidity values were increased by 20 percent to account for the increased humidity at the air-water interface. This practice is recommended in Bartholow (1989).

All four modeled tributaries were calibrated based on measured water temperature at the mouths of each stream. None of the four tributaries were gaged at or near the headwaters; thus, headwaters flows were used for tributary calibration in the model. Similarly, headwater temperatures were not known, so headwater temperatures were also used for calibration of tributaries. Groundwater temperatures were not measured at any point in the stream network; therefore, the groundwater temperature parameter was used for calibration of tributaries. Mean annual air temperature was used as the default groundwater temperature and as a starting point for calibration. Finally, for Canyon Creek, Deadman Creek, and Crooked Fork, stream widths were adjusted to calibrate the water temperature of modeled tributaries to the measured water temperature at the mouth of each stream.

Table 4 shows the results of the model calibration for 1998 (average flow). Absolute Mean Error (AME), median error (median), and percentage of error, or percent of difference from the measured value, (%) were calculated for each calibration node. All AME values were below 1°C, and the overall error was held below 5 percent.

The criterion for model validation was that the AME value for average temperatures each year was to be below 1°C. This criterion was

**Table 3. Default, Starting, and Final Values for Calibration Parameters**

| | | | Default Values | 1997-1998 Model Values | 1994 Model Values |
|---|---|---|---|---|---|
| **Global Calibration Coefficients** | | | | | |
| | | Air temperature | 1 | 0.9 | 0.9 |
| | | Wind speed | 1 | 1.1 | 1.1 |
| | | Relative humidity | 1 | 1.2 | 1.2 |
| | | % sunshine | 1 | 1 | 1 |
| | | Solar radiation | 1 | 1 | 1 |
| **Groundwater Temperature** | | | | | |
| **River** | **Description** | **River KM** | | | |
| Crooked Fork | Headwaters to Boulder Creek | 149.2 to 134.4 | 10.03 | 4.0 | 4.0 |
| | Boulder Creek to Shotgun Creek | 134.4 to 132.8 | 10.03 | 5.5 | 5.5 |
| | Shotgun Creek to Mouth | 132.8 to 112.8 | 10.03 | 7.0 | 7.0 |
| White Sand Creek | Wilderness Boundary to Dan & Fern Creeks | 136.1 to 134.8 | 10.03 | 5.5 | 5.5 |
| | Dan & Fern Creeks to Mouth | 134.8 to 112.8 | 10.03 | 7.0 | 7.0 |
| Deadman Creek | Headwaters to Mouth | 27.1 to 16.3 | 10.03 | 12.0 | 3.0 |
| Canyon Creek | Headwaters to Mystery Creek | 29.9 to 20.9 | 10.03 | 6.9 | 2.0 |
| | Mystery Creek to Mouth | 20.9 to 11.9 | 10.03 | 6.9 | 6.9 |
| **Stream Width** | | | | | |
| Crooked Fork | Headwaters to Hopeful Creek | 149.2 to 143.7 | 3.4 | 1.7 | 1.7 |
| | Hopeful Creek to Haskell Creek | 143.7 to 131.8 | 9.6 | 4.8 | 4.8 |
| | Haskell Creek to Brushy Fork | 131.8 to 127.0 | 16.6 | 8.3 | 8.3 |
| | Brushy Fork to change in aspect | 127.0 to 123.9 | 20.8 | 10.4 | 10.4 |
| | Change in aspect to change in aspect | 123.9 to 117.9 | 26.4 | 13.2 | 13.2 |
| | Change in aspect to mouth | 117.9 to 112.8 | 26.3 | 13.1 | 13.1 |
| White Sand Creek | Big Sand Creek to Storm Creek | 136.1 to 129.2 | 21 | 21.0 | 21.0 |
| | Storm Creek to change in aspect | 129.2 to 120.0 | 19.3 | 19.3 | 19.3 |
| | change in aspect to change in aspect | 120.0 to 117.5 | 26.7 | 26.7 | 26.7 |
| | change in aspect to mouth | 117.5 to 112.8 | 30 | 30.0 | 30.0 |
| Lochsa River | Confluence to change in aspect | 112.8 to 103.0 | 50.2 | 50.2 | 50.2 |
| | Change in aspect to change in aspect | 103.0 to 93.3 | 38.1 | 38.1 | 38.1 |
| | Change in aspect to change in aspect | 93.3 to 75.6 | 29.1 | 29.1 | 29.1 |
| | Change in aspect to Fish Creek | 75.6 to 38.8 | 35.1 | 35.1 | 35.1 |
| | Fish Creek to change in aspect | 38.8 to 30.9 | 37.1 | 37.1 | 37.1 |
| | Change in aspect to change in aspect | 30.9 to 25.4 | 44.3 | 44.3 | 44.3 |
| | Change in aspect to Deadman Creek | 25.4 to 16.3 | 48.7 | 48.7 | 48.7 |

**Table 3. Default, Starting, and Final Values for Calibration Parameters (continued)**

| | | | Default Values | 1997-1998 Model Values | 1994 Model Values |
|---|---|---|---|---|---|
| **Stream Width** | | | | | |
| **River** | **Description** | **River KM** | | | |
| Lochsa River (continued) | Deadman Creek to change in aspect | 16.3 to 15.0 | 36.9 | 36.9 | 36.9 |
| | Change in aspect to Canyon Creek | 15.0 to 11.7 | 32.1 | 32.1 | 32.1 |
| | Canyon Creek to mouth | 11.7 to 0.0 | 41.7 | 41.7 | 41.7 |
| Deadman Creek | Headwaters to West Fork Deadman Creek | 27.1 to 22.7 | 5 | 3.2 | 3.2 |
| | West Fork Deadman Creek to mouth | 22.7 to 16.3 | 6.7 | 4.2 | 4.2 |
| Canyon Creek | Headwaters to Mystery Creek | 29.9 to 21.4 | 4.1 | 1.6 | 1.6 |
| | Mystery Creek to mouth | 21.4 to 11.7 | 6.2 | 2.5 | 2.5 |

**Table 4. 1998 (Average Flow) Average Temperature Model Calibration Results**

| River | River KM | AME (°C) | Median Error (°C) | Range (°C) | |
|---|---|---|---|---|---|
| | | | | Min | Max |
| Lochsa River | 0.0 | 0.84 | 0.14 | -4.00 | 1.40 |
| Deadman Creek | 16.3 | 0.81 | 0.09 | -2.77 | 1.77 |
| Lochsa River | 42.3 | 0.70 | -0.30 | -2.73 | 1.05 |
| Lochsa River | 64.9 | 0.79 | -0.63 | -2.86 | 0.97 |
| Lochsa River | 78.4 | 0.69 | -0.47 | -2.08 | 1.13 |
| Crooked Fork | 112.8 | 0.81 | 0.24 | -1.69 | 3.25 |
| White Sand | 117.9 | 0.76 | 0.36 | -1.48 | 3.43 |
| | | | | | |
| Average AME<br>% Difference from Measured | | | 0.77<br>4.69% | | |

met for 1998 (average flow) and 1997 (high flow), but 1994 (low flow) validation statistics indicated that re-calibration for 1994 was necessary. As a result, 1994 was separated from the model and was calibrated as a separate model using similar parameters as the original model: headwater discharge, head-water temperature, groundwater temperature, and global calibration coefficients. Stream widths were not changed in the 1994 model calibration. In addition, Canyon Creek was not calibrated in the 1994 model because it was already calibrated to 1994 measured data in the original model due to the lack of 1998 measured data. Results of 1994 average temperature model calibration are shown in Table 5.

**Table 5. 1994 (Low Flow) Average Temperature Model Calibration Results**

| River | River KM | AME (°C) | Median Error (°C) | Range (°C) | |
|---|---|---|---|---|---|
| | | | | Min | Max |
| Lochsa River | 0.0 | 0.54 | 0.04 | -1.52 | 1.78 |
| Canyon Creek | 11.7 | 0.49 | -0.32 | -1.41 | 0.84 |
| Deadman Creek | 16.3 | 1.11 | 0.21 | -3.00 | 3.49 |
| | | | | | |
| Average AME<br>% Difference from Measured | | | 0.71<br>4.55% | | |

### *Validation*

Table 6 shows the results of average temperature model validation for 1997 (high flow). The AME for each node was below 0.9°C, and overall difference from measured temperatures was slightly above 4 percent.

**Table 6. 1997 (High Flow) Average Temperature Model Validation Results**

| River | River KM | AME (°C) | Median Error (°C) | Range (°C) | |
|---|---|---|---|---|---|
| | | | | Min | Max |
| Lochsa River | 0.0 | 0.54 | -0.09 | -2.02 | 0.87 |
| Canyon Creek | 11.7 | 0.50 | -0.04 | -1.64 | 1.06 |
| Deadman Creek | 16.3 | 0.53 | 0.35 | -0.82 | 1.36 |
| Lochsa River | 42.0 | 0.59 | -0.34 | -1.99 | 1.30 |
| White Sand | 117.9 | 0.86 | 0.29 | -1.03 | 2.61 |
| | | | | | |
| Average AME<br>% Difference from Measured | | | 0.60<br>4.08% | | |

## Maximum Temperature

### *Calibration*

Maximum water temperature calibration was accomplished by adjustment of four regression coefficients in the job control file (Theurer et al. 1984). The regression coefficients relate measured average daily air temperature to estimated maximum daily air temperature using the following model:

$$T_{ax} = T_a + \left[a_o + a_1 H_{sg} + a_2 R_h + a_3 \left(S / S_o\right)\right]$$

Where:

$T_{ax}$ = maximum daytime air temperature (° C)

$T_a$ = average daily air temperature (° C)

$H_{sg}$ = ground level solar radiation ($J/m^2/sec$)

$R_h$ = relative humidity (decimal)

$S/S_o$ = percent possible sunshine (decimal)

$a_0$, $a_1$, $a_2$, $a_3$ = regression coefficients

The maximum daily air temperature is used by SNTEMP to find the maximum daily water temperature for a given day at all model nodes. This maximum air temperature regression model is the only method SNTEMP uses to calculate maximum water temperatures.

Maximum temperatures calculated using the above equation are not reported in SNTEMP output. Thus, a hand calculation was performed to compare the result of the equation, maximum air temperature, to the measured maximum air temperature on a random day – July 28, 1998. Final calibration regression coefficients and measured values were entered into the equation. The solar radiation value was obtained by entering the complete set of input parameters into the SSTEMP model. Values of the coefficients and variables were as follows:

$T_a$ = 20.87°C
$H_{sg}$ = 216.13 $J/m^2/s$
$R_h$ = 80.2%
$S/S_o$ = 67.3%
$a_0$ = -9.89
$a_1$ = 0.0082
$a_2$ = 2.79
$a_3$ = 0.5

The result of the equation was a maximum air temperature of 15.33°C, several degrees below the measured maximum air temperature of 23.48°C. While the difference between the two values is substantial, this is not surprising, as maximum air temperature is not treated as a state variable, rather as the only means of calibrating the SNTEMP daily average temperature model to maximum temperatures.

The maximum air temperature regression coefficients were modified from the program default values and values given in Theurer et al. (1984) using trial and error. The coefficients for the 1997-1998 (high flow-average flow) model were different than those used in the 1994 (low flow) model. Tables 7 and 8 show maximum temperature model calibration results for 1998 and 1994, respectively.

**Table 7. 1998 (Average Flow) Maximum Temperature Model Calibration Results**

| River | River KM | AME (°C) | Median Error (°C) | Range (°C) | |
|---|---|---|---|---|---|
| | | | | Min | Max |
| Lochsa River | 0.0 | 1.14 | -1.01 | -3.07 | 0.97 |
| Deadman Creek | 16.3 | 0.97 | 0.25 | -3.89 | 2.53 |
| Lochsa River | 42.3 | 1.93 | -1.97 | -3.47 | 0.43 |
| Lochsa River | 64.9 | 0.86 | -0.16 | -2.81 | 2.59 |
| Lochsa River | 78.4 | 1.03 | -0.42 | -2.59 | 1.53 |
| Crooked Fork | 112.8 | 2.76 | -2.93 | -5.23 | 1.23 |
| White Sand | 117.9 | 1.40 | 1.36 | -1.14 | 6.18 |
| | | | | | |
| Average AME<br>% Difference from Measured | | | 1.40<br>7.17% | | |

**Table 8. 1994 (Low Flow) Maximum Temperature Model Calibration Results**

| River | River KM | AME (°C) | Median Error (°C) | Range (°C) | |
|---|---|---|---|---|---|
| | | | | Min | Max |
| Lochsa River | 0.0 | 0.81 | -0.60 | -2.74 | 1.19 |
| Canyon Creek | 11.7 | 0.46 | 0.17 | -1.48 | 1.17 |
| Deadman Creek | 16.3 | 1.47 | 0.97 | -3.09 | 3.99 |
| | | | | | |
| Average AME<br>% Difference from Measured | | | 0.91<br>5.05% | | |

### *Validation*

Table 9 shows the results of maximum temperature model validation for 1997 (high flow). The AME for the validation nodes averaged 1.31°C, with overall difference from measured values below 8 percent. The errors for the maximum temperature models are higher than those for the average temperature models and can be attributed to SNTEMP's lack of a robust maximum temperature model.

The results of the maximum temperature model validation illustrate a key limitation of the SNTEMP model, that which constrains the ability to develop a more elaborate calibration to maximum daily temperatures. An alternative model selection would be necessary to expand the analysis of maximum daily temperatures.

**Table 9. 1997 (High Flow) Maximum Temperature Model Validation Results**

| River | River KM | AME (°C) | Median Error (°C) | Range (°C) | |
|---|---|---|---|---|---|
| | | | | Min | Max |
| Lochsa River | 0.0 | 0.72 | -0.22 | -2.69 | 1.62 |
| Canyon Creek | 11.7 | 1.26 | 0.86 | -2.52 | 5.14 |
| Deadman Creek | 16.3 | 1.15 | 1.01 | -0.49 | 3.18 |
| Lochsa River | 42.0 | 1.63 | 0.50 | -0.79 | 2.56 |
| White Sand | 117.9 | 1.76 | 0.63 | -3.11 | 5.67 |
| | | | | | |
| Average AME<br>% Difference from Measured | | | 1.15<br>7.05% | | |

# Model Simulations

Following model calibration and validation, the models were used to simulate scenarios to answer the following six questions posed by IDEQ:

1. What are predicted water temperatures under current canopy conditions?
2. What are predicted water temperatures with full potential canopy cover?
3. What input variable most explains predicted water temperatures?
4. How much decrease in thermal load would be necessary to meet Idaho's CWB criteria on a day that air temperature reaches the 90$^{th}$ percentile of the annual peaks in seven-day average of daily maximum air temperature?
5. How much of this decrease in thermal load could be provided by increased stream shading?
6. How much cooling in tributary inflow temperatures would be needed for the Lochsa River to meet CWB criteria at Lowell on the 90$^{th}$ percentile air temperature day?

**Simulation 1—What are predicted water temperatures under current canopy conditions?**

An "existing conditions" water temperature model was calibrated and validated (see

previous section) to current canopy conditions. The current canopy conditions are summarized in Table 10. Modeled temperature values under existing canopy conditions are summarized as the Baseline Condition in Table 11.

**Simulation 2—What are predicted water temperatures with full potential canopy cover?**

"Full potential canopy cover" was simulated by changing the vegetative shade parameters of crown width, crown height, offset, and percent (%) density for each segment of the modeled system. The changes were attained by assuming a "passive restoration" strategy, where the dominant species and habitat type would be allowed to grow to its full potential with no anthropogenic changes, nor changes due to fire or disease. The full potential was determined by observing the 80$^{th}$ percentile value for the tree height and canopy density variables from nearby stands with similar habitat types. Table 10 shows the habitat type groups for each of the stream segments, and the canopy densities for the existing and full potential canopy scenarios.

The theoretical maximum potential for a wilderness, unmanaged, untouched stand of trees is the 50$^{th}$ percentile of that stand; average values of the stand that are already at maximum potential. However, stands in the Lochsa River basin are subject to human management. Even under wilderness conditions, these stands are susceptible to fire and disease. Based on discussion with Clearwater National Forest silviculturist Bill Wulf (2001), the 80$^{th}$ percentile of the tree height and canopy density parameters was used for this simulation. The 80$^{th}$ percentile of these variables represent the natural disturbances that are an integral part of the forest landscape.

Two full potential canopy cover scenario were simulated: Scenario 1 reflects passive restoration strategy for all tributaries and the south/east bank of the Lochsa River only, and Scenario 2 reflects passive restoration strategy for all tributaries and both banks of the Lochsa River. Scenario 1 was simulated to acknowledge the continued presence of U.S. Route 12. In this scenario, the south/east bank of the Lochsa River was modeled with full potential canopy cover, while the north/west bank of the Lochsa River exhibited existing canopy cover. Scenario 2 simulates the abandonment of U.S. Route 12 to allow full potential canopy cover to generate on both banks as a result of passive restoration.

The average changes in temperature for the July-August modeling period are shown in Table 11 for the full canopy simulations. The daily average and daily maximum water temperatures under full potential canopy conditions, averaged over the modeling period, are compared to baseline conditions throughout the Lochsa River in Figures 6 and 7, respectively.

Under full potential canopy conditions, daily average water temperatures of the Lochsa River at the USGS gage would be approximately 1.0 to 1.5°C cooler than under existing canopy conditions in the modeled years. Maximum water temperatures would be decreased approximately 1.4 to 2.1°C for the same period. These changes in water temperature are not enough to meet either Idaho CWB daily average or daily maximum temperature criteria.

An additional model was run using tree height and canopy density values based on the 98$^{th}$ percentile of nearby stands. Average decreases in temperature were 1.3° and 2.0°C greater than those seen in the 80$^{th}$ percentile simulation, respectively. Water temperatures would be reduced sufficiently to meet the Idaho CWB criterion of 22.0°C for maximum temperature; however, daily average stream temperatures in the Lochsa River still would not meet Idaho CWB average temperature criterion of 19.0°C under this scenario. An average stand of trees growing to sizes

| | | | | Existing conditions | | | | | Potential full canopy - 80th percentile, Scenario 1 | | | | | Potential full canopy - 80th percentile, Scenario 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River | Reach | River KM | Habitat type group (Clearwater NF TSMRS) | Crown width (m) | Height (m) | East Offset (m) | West Offset (m) | Density (%) | Crown width (m) | Height (m) | East Offset (m) | West Offset (m) | Density (%) | Crown width (m) | Height (m) | East Offset (m) | West Offset (m) | Density (%) |
| Crooked Fork | Headwaters to Hopeful Creek | 149.2 to 143.7 | Moist - S/SAF/MH | 10 | 22.6 | 2 | 2 | 37.1 | 18 | 23.3 | 1 | 1 | 63 | 18 | 23.3 | 1 | 1 | 63 |
| | Hopeful Creek to Haskell Creek | 143.7 to 131.8 | Moist - S/SAF/MH | 10 | 22.6 | 2 | 2 | 37.1 | 18 | 23.3 | 1 | 1 | 63 | 18 | 23.3 | 1 | 1 | 63 |
| | Haskell Creek to Brushy Fork | 131.8 to 127.0 | Moist - S/SAF/MH | 10 | 26.1 | 2 | 2 | 32.3 | 18 | 23.3 | 1 | 1 | 63 | 18 | 23.3 | 1 | 1 | 63 |
| | Brushy Fork to change in aspect | 127.0 to 123.9 | Moist - S/SAF/MH | 10 | 24.7 | 2 | 2 | 32.1 | 18 | 27.3 | 1 | 1 | 54 | 18 | 27.3 | 1 | 1 | 54 |
| | Change in aspect to change in aspect | 123.9 to 117.9 | Wet - WRC | 10 | 30 | 2 | 2 | 11.2 | 18 | 32.9 | 1 | 1 | 74 | 18 | 32.9 | 1 | 1 | 74 |
| | Change in aspect to mouth | 117.9 to 112.8 | Wet - WRC | 10 | 30.7 | 4 | 4 | 15.8 | 18 | 32.9 | 1 | 1 | 74 | 18 | 32.9 | 1 | 1 | 74 |
| White Sand Creek | Big Sand Creek to Storm Creek | 136.1 to 129.2 | Moist - S/SAF/MH | 10 | 26.9 | 2 | 2 | 37.2 | 18 | 29.3 | 1 | 1 | 71 | 18 | 29.3 | 1 | 1 | 71 |
| | Storm Creek to change in aspect | 129.2 to 120.0 | Moist - WRC/WH | 10 | 26.3 | 2 | 2 | 41.4 | 18 | 26.9 | 1 | 1 | 55 | 18 | 26.9 | 1 | 1 | 55 |
| | change in aspect to change in aspect | 120.0 to 117.5 | Moist - WRC/WH | 10 | 27.8 | 2 | 2 | 47.9 | 18 | 28.1 | 1 | 1 | 54 | 18 | 28.1 | 1 | 1 | 54 |
| | change in aspect to mouth | 117.5 to 112.8 | Moist - WRC/WH | 10 | 29.9 | 4 | 4 | 47.8 | 18 | 28.1 | 1 | 1 | 54 | 18 | 28.1 | 1 | 1 | 54 |
| Lochsa River | Confluence to change in aspect | 112.8 to 103.0 | Moist - WRC/WH | 10 | 27.8 | 9 | 20.9 | 45.6 | 18 | 30.7 | 8.6 | 20.9 | 75 | 18 | 30.7 | 8.6 | 8.6 | 75 |
| | Change in aspect to change in aspect | 103.0 to 93.3 | Moist - WRC/WH | 10 | 29.4 | 7 | 40.9 | 51.8 | 18 | 30.7 | 8.6 | 40.9 | 75 | 18 | 30.7 | 8.6 | 8.6 | 75 |
| | Change in aspect to change in aspect | 93.3 to 75.6 | Moist - WRC/WH | 10 | 25.3 | 9.6 | 30.6 | 49.1 | 18 | 30.7 | 8.6 | 30.6 | 75 | 18 | 30.7 | 8.6 | 8.6 | 75 |
| | Change in aspect to Fish Creek | 75.6 to 38.8 | Moist - WRC/WH | 10 | 23.2 | 9.3 | 22.4 | 33.4 | 18 | 27 | 8.6 | 22.4 | 67 | 18 | 27 | 8.6 | 8.6 | 67 |
| | Fish Creek to change in aspect | 38.8 to 30.9 | Moist - WRC/WH | 10 | 20.7 | 12.9 | 27.3 | 32.1 | 18 | 27 | 8.6 | 27.3 | 67 | 18 | 27 | 8.6 | 8.6 | 67 |
| | Change in aspect to change in aspect | 30.9 to 25.4 | Moist - WRC/WH | 10 | 19.7 | 6.5 | 16.1 | 28.4 | 18 | 27 | 8.6 | 16.1 | 67 | 18 | 27 | 8.6 | 8.6 | 67 |
| | Change in aspect to Deadman Creek | 25.4 to 16.3 | Moist - WRC/WH | 10 | 22.8 | 10.9 | 44.2 | 28.2 | 18 | 27 | 8.6 | 44.2 | 67 | 18 | 27 | 8.6 | 8.6 | 67 |
| | Deadman Creek to change in aspect | 16.3 to 15.0 | Moist - WRC/WH | 10 | 25.1 | 14.9 | 59.8 | 35.5 | 18 | 26.8 | 8.6 | 59.8 | 67 | 18 | 26.8 | 8.6 | 8.6 | 67 |
| | Change in aspect to Canyon Creek | 15.0 to 11.7 | Moist - WRC/WH | 10 | 24.7 | 11.4 | 13.8 | 42.1 | 18 | 26.8 | 8.6 | 13.8 | 67 | 18 | 26.8 | 8.6 | 8.6 | 67 |
| | Canyon Creek to mouth | 11.7 to 0.0 | Moist - WRC/WH | 10 | 27.6 | 16.5 | 25.6 | 32.0 | 18 | 26.8 | 8.6 | 25.6 | 67 | 18 | 26.8 | 8.6 | 8.6 | 67 |
| Deadman Creek | Headwaters to West Fork Deadman Creek | 27.1 to 22.7 | Moist - WRC/WH | 10 | 25.4 | 2 | 2 | 35.3 | 18 | 31 | 2 | 2 | 68 | 18 | 31 | 2 | 2 | 68 |
| | West Fork Deadman Creek to mouth | 22.7 to 16.3 | Moist - WRC/WH | 10 | 27.2 | 2 | 2 | 37.4 | 18 | 31 | 2 | 2 | 68 | 18 | 31 | 2 | 2 | 68 |
| Canyon Creek | Headwaters to Mystery Creek | 29.9 to 21.4 | Moist - WRC/WH | 10 | 25.5 | 2 | 2 | 39.3 | 18 | 31 | 2 | 2 | 68 | 18 | 31 | 2 | 2 | 68 |
| | Mystery Creek to mouth | 21.4 to 11.7 | Moist - WRC/WH | 10 | 31.7 | 2 | 2 | 47.0 | 18 | 31 | 2 | 2 | 68 | 18 | 31 | 2 | 2 | 68 |

Note: Baseline—Existing canopy conditions
Scenario 1—Full potential canopy cover assuming the continued presence of U.S. Route 12
Scenario 2—Full potential canopy cover assuming passive restoration in place of U.S. Route 12

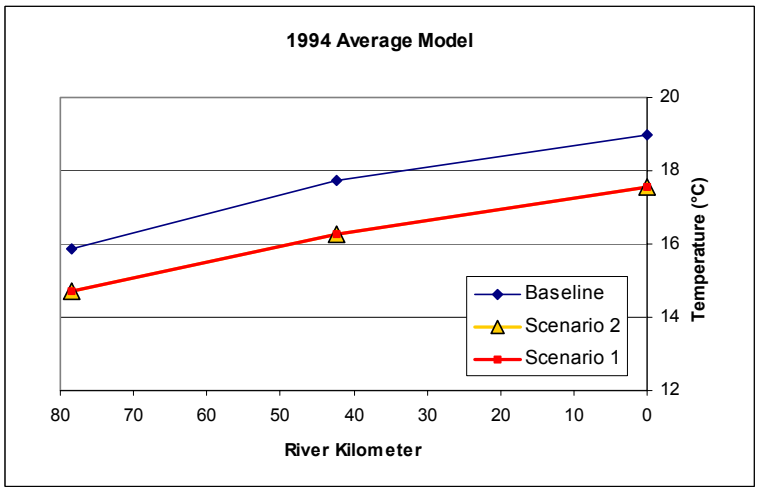
**Table 10. Current and Full Potential Canopy Cover Conditions**

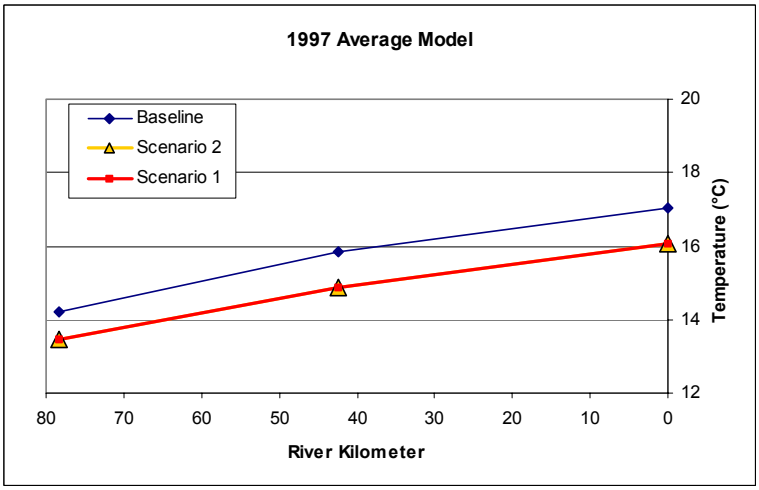
**Table 11. Output from Full Potential Canopy Cover Models, Average for Modeling Period**

| RKM | Average Temperature Model | | | Maximum Temperature Model | | |
|---|---|---|---|---|---|---|
| | Baseline | Δ Temp Scenario 1 | Δ Temp Scenario 2 | Baseline | Δ Temp Scenario 1 | Δ Temp Scenario 2 |
| **1994 (low flow)** | | | | | | |
| 0.0 | 18.99 | -1.42 | -1.45 | 20.87 | -2.05 | -2.08 |
| 42.3 | 17.73 | -1.49 | -1.49 | 20.23 | -2.31 | -2.31 |
| 78.4 | 15.88 | -1.18 | -1.18 | 18.15 | -2.12 | -2.12 |
| **1997 (high flow)** | | | | | | |
| 0.0 | 17.02 | -0.94 | -0.95 | 18.51 | -1.39 | -1.41 |
| 42.3 | 15.86 | -0.98 | -0.98 | 17.96 | -1.63 | -1.63 |
| 78.4 | 14.21 | -0.76 | -0.76 | 16.15 | -1.51 | -1.51 |
| **1998 (average flow)** | | | | | | |
| 0.0 | 19.38 | -1.08 | -1.09 | 21.07 | -1.59 | -1.60 |
| 42.3 | 18.28 | -1.15 | -1.15 | 20.59 | -1.85 | -1.85 |
| 78.4 | 16.39 | -0.91 | -0.91 | 18.54 | -1.73 | -1.73 |

Note: Baseline—Existing canopy conditions
Scenario 1—Full potential canopy cover assuming the continued presence of U.S. Route 12
Scenario 2—Full potential canopy cover assuming passive restoration in place of U.S. Route 12

**Figure 6. Full Potential Canopy Cover Models vs. Baseline Model: Average Temperature, Averaged Over Modeling Period**



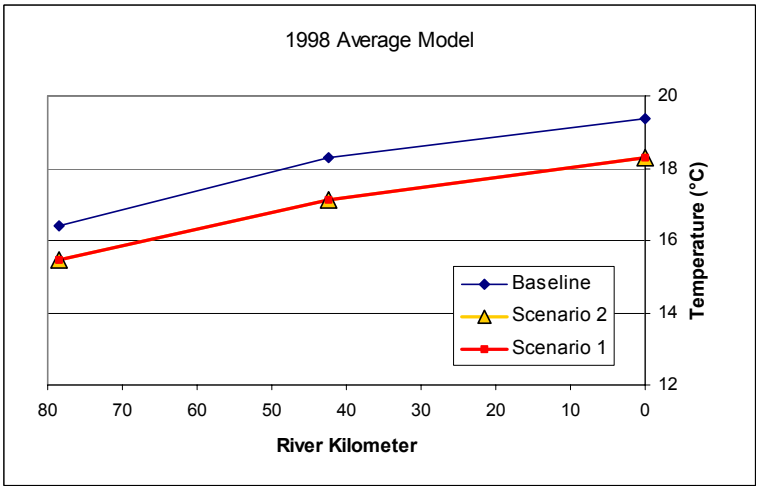
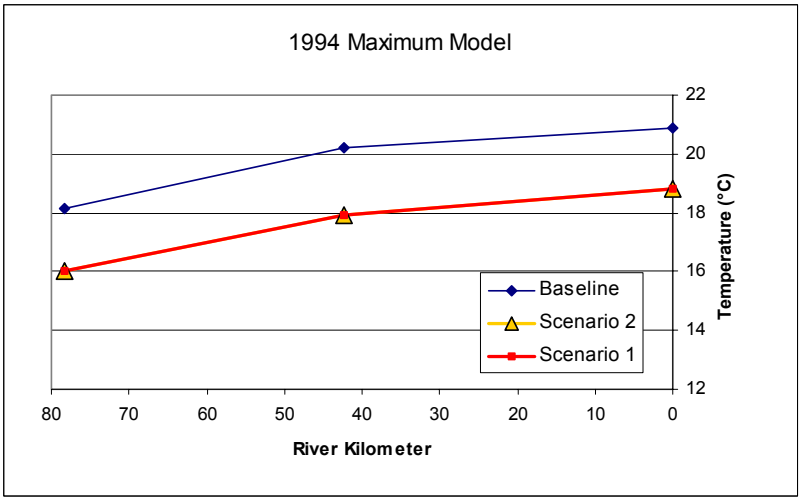
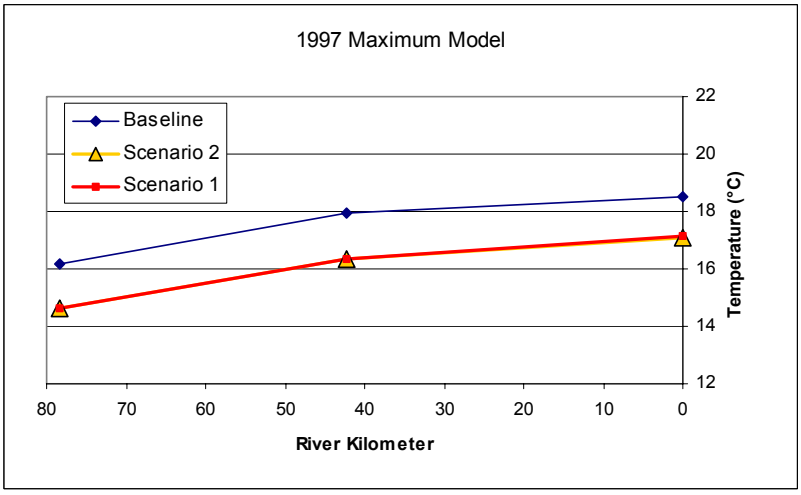
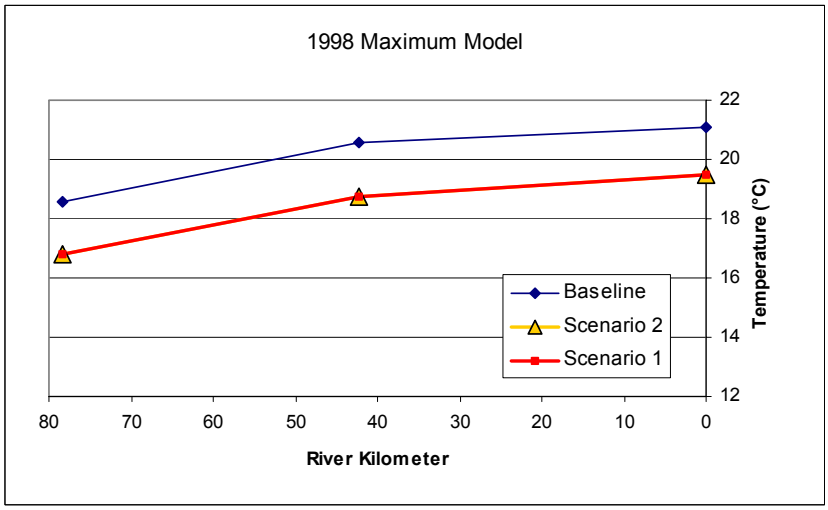



**Figure 7. Full Potential Canopy Cover Models vs. Baseline Model: Maximum Temperature, Averaged Over Modeling Period**



indicated by the 98th percentile for these two variables is not considered attainable in the Lochsa River basin, even with a full passive restoration effort (Wulf 2001). Therefore, the 80th percentile for the variables was used to attain a more plausible simulation.

**Simulation 3—What input variable most explains predicted stream temperatures?** This question can easily and accurately be answered, in the context of the SNTEMP models, using a sensitivity analysis. A sensitivity analysis is a method of identifying the important parameters and understanding the general behavior of a model by systematically changing the value of one or more input parameters (Chapra 1997). A sensitivity analysis is useful because of its role in model validation and evaluating model results when input has been changed. Other features of a sensitivity analysis include: 1) It assists in identifying the input parameters that contribute only marginally to the functional relationships of the model; 2) It quantitatively measures the change in output due to variations in the input; and 3) It describes the degree to which input parameter values can be altered without significantly affecting the model output (Hendrickson 1984).

The sensitivity of SNTEMP to various input parameters was tested by parameter perturbation of one baseline parameter per analysis (Chapra 1997). The percentage of the change of each parameter was based on what can realistically be seen in the physical system.

A parameter perturbation sensitivity analysis is performed by varying each of the model parameters while holding the other terms constant (Chapra 1997). One method of varying the parameters is raising and lowering the value of the parameter being tested a fixed percent. This is how the sensitivity analysis was performed in this study.

Sensitivity analyses involving perturbation of 12 parameters were performed and compared to quantify the sensitivity of the output to the input. The 1998 (average flow) model of the Lochsa River was selected as the model to be tested. The 62-day time series for a single parameter was increased by 10 percent from the baseline, and the model was run with the modification to the single parameter. This model was then run with a reduction of 10 percent from the baseline. This process was repeated for all 12 parameters. For each treatment, the change in output water temperature at the downstream-most node was compared to the baseline. The value that each treatment differed from the baseline was plotted in Figures 8 and 9 for average temperature and maximum temperature models, respectively. The total °C each parameter varied from the baseline is given in Table 12.

As shown in Figures 8 and 9, the parameters that the 1998 (average flow) model were most sensitive to were air temperature, inflow temperature, solar radiation, stream width, relative humidity, and stream flow. Five of these six parameters were also recognized as the top six most sensitive parameters in a sensitivity analysis described in Bartholow (1989). Note that the relative "importance" of an input parameter to ultimate downstream water temperature predictions varies between the average and maximum water temperature models, as shown in Table 12.

Figure 10 plots the full range of values for each of the input parameters. Comparing the full range of input to the change in output based on parameter perturbation, given in Figures 8 and 9, gives a good indication of the sensitivity of the system to each parameter. For example, in Figure 8, 10 percent increases and decreases of the relative humidity and stream flow input parameters result in an approximately equal change in output temperature. However, values of stream flow vary more in the 1998 data set than do values of relative humidity, as shown in Figure 10. Because of the great range of stream flows over the course of the two month data set, the stream flow variable can be considered more important than relative humidity in explaining stream temperatures.

**Figure 8. Sensitivity of the Output Water Temperature Predictions of the 1998 Average Temperature Model to the 10% Increase and Decrease of Selected Input Parameters**

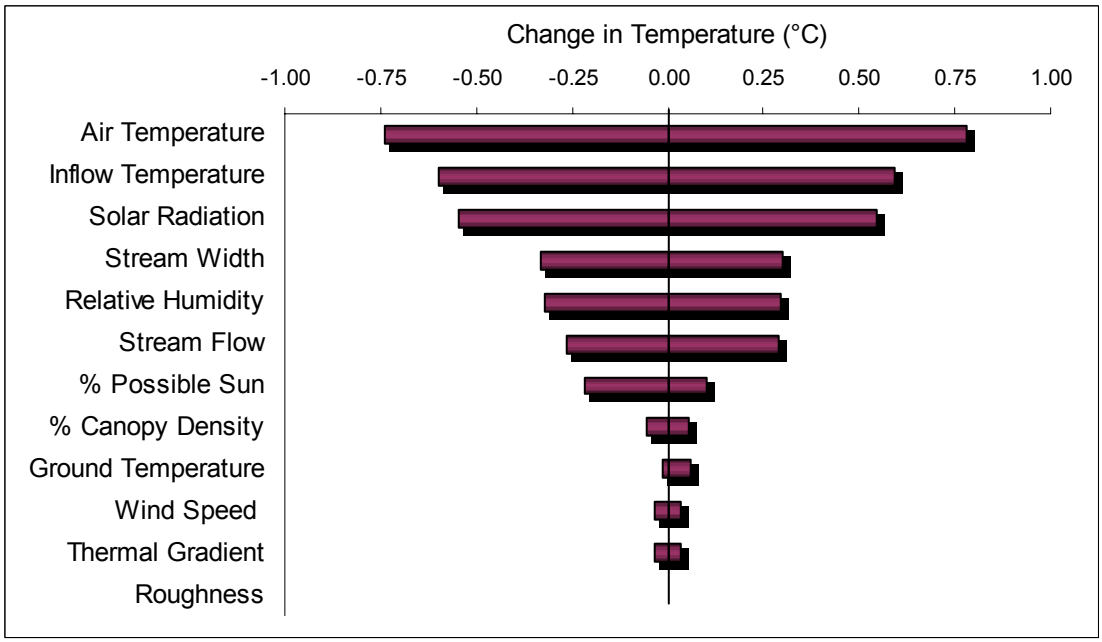



**Figure 9. Sensitivity of the Output Water Temperature Predictions of the 1998 Maximum Temperature Model to the 10% Increase and Decrease of Selected Input Parameters**

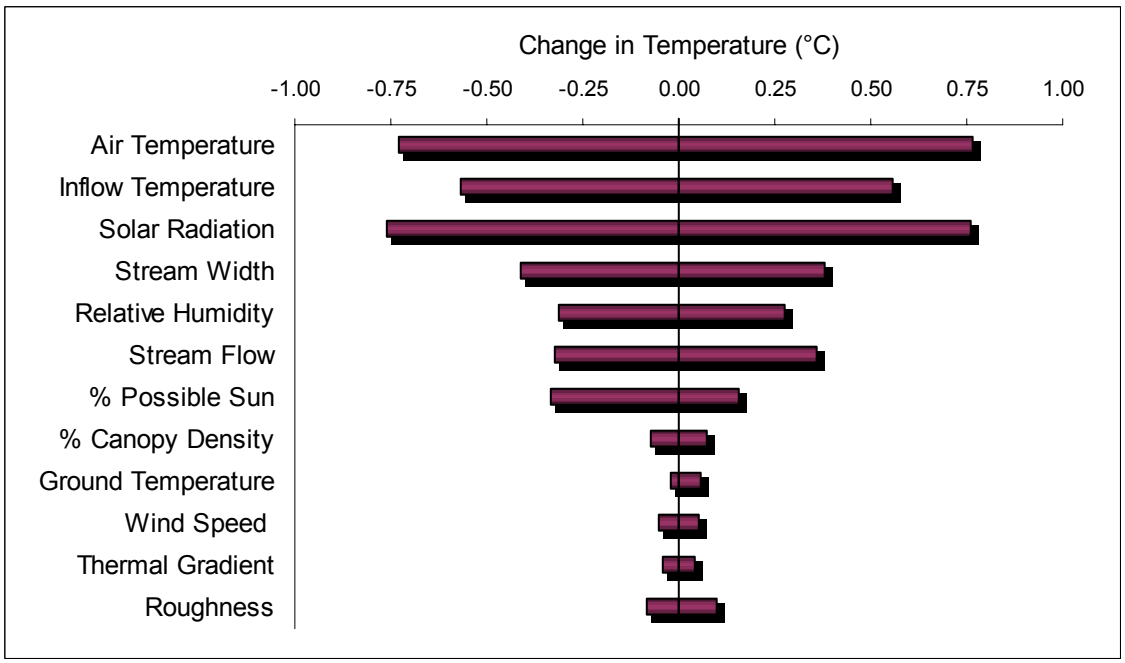


**Figure 10. Temporal Range of Input Parameters at Lochsa River RM 42.3, 1998 Model**

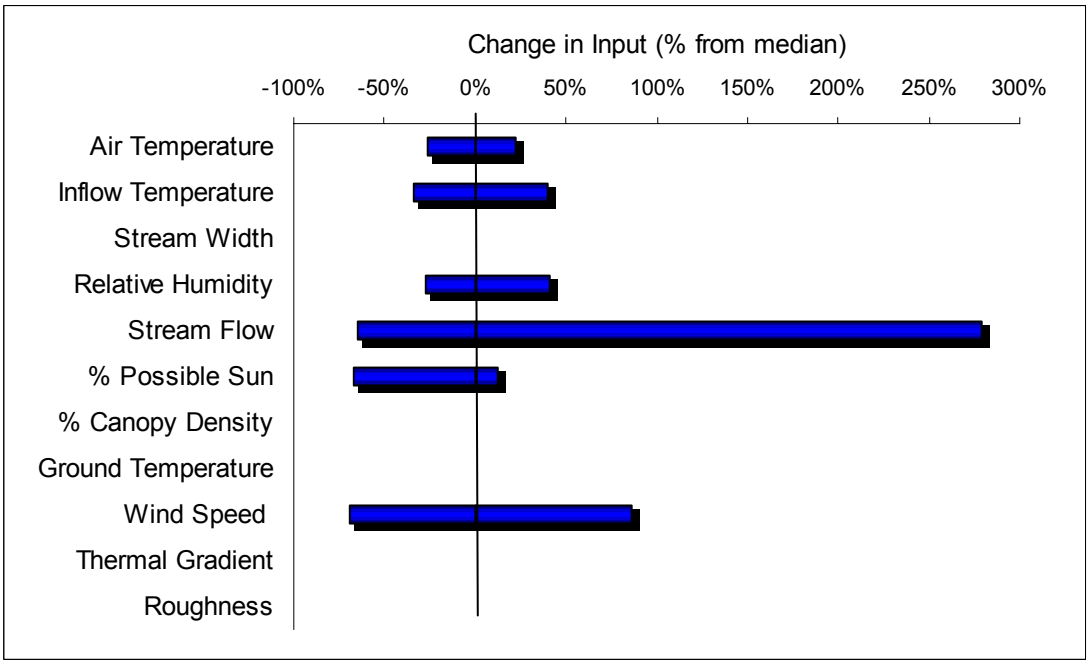



**Table 12. Sensitivity of the Temporal Scale Input Parameter Values and Output Water Temperature Predictions of the 1998 Models Based on ±10% Parameter Perturbation[1]**

| Parameter | Scale | Input Range Min % | Input Range Max % | Average T Model (°C) | Maximum T Model (°C) |
|---|---|---|---|---|---|
| Air Temperature | Temporal | -26.3% | 21.9% | 1.52 | 1.50 |
| Inflow Temperature | Temporal & Spatial | -33.9% | 40.3% | 1.19 | 1.12 |
| Solar Radiation | Temporal | [2] | [2] | 1.09 | 1.52 |
| Stream Width | Spatial | -- | -- | 0.63 | 0.79 |
| Relative Humidity | Temporal | -27.0% | 41.0% | 0.62 | 0.59 |
| Stream Flow | Temporal & Spatial | -64.5% | 278.9% | 0.55 | 0.68 |
| % Possible Sun | Temporal | -66.9% | 11.9% | 0.32 | 0.49 |
| % Canopy Density | Spatial | -- | -- | 0.11 | 0.15 |
| Ground Temperature | Spatial | -- | -- | 0.07 | 0.08 |
| Wind Speed | Temporal | -69.6% | 86.6% | 0.07 | 0.10 |
| Thermal Gradient | Constant | -- | -- | 0.07 | 0.08 |
| Roughness | Spatial | -- | -- | 0.00 | 0.18 |

[1] – Input ranges are measured in percentage difference from the median, and output ranges are measured in total °C change from baseline temperature.

[2] – Ranges of incoming solar radiation cannot be obtained easily from SNTEMP output. See text for further explanation.

(Note: A sensitivity analysis was performed on the solar radiation parameter by adjusting the global calibration coefficient for solar radiation in the job control file. The range of solar radiation in the input set is determined internally by the model and is not recorded in the model output. Therefore, the range of input values could not be determined. However, the results of the sensitivity analysis for solar radiation are included in Figures 8 and 9 and Table 12.)

Based on the above analysis, it can be inferred that air temperature is the input variable that most explains stream temperatures in the Lochsa River. Inflow water temperature is another important input variable. However, the great variability of the stream flow input underscores its significance to Lochsa River water temperatures, as the Lochsa River is not flow regulated.

**Simulation 4—How much decrease in thermal load would be necessary to meet Idaho's CWB criteria on a day that air temperature reaches the 90$^{th}$ percentile of the annual peaks in seven-day average of daily maximum air temperature?**

The Lochsa River falls within National Climatic Data Center—Idaho Climate Division 4, in which there are three official weather stations. The study site lies closest to the McCall, Idaho, weather station (Coop Station ID # 105708). Analysis of maximum temperature data recorded at the McCall station indicates that 7-day average maximum air temperature exceeded the 90$^{th}$ percentile (32.78°C) during the period of July 23 through August 1, 1994. The 90$^{th}$ percentile was not exceeded in 1997 (high flow) or 1998 (average flow).

Of the July 23 through August 1, 1994, period, the 7-day average maximum temperature on August 1 most closely matched the 90$^{th}$ percentile (32.94°C). The 1994 (low flow) maximum temperature model was run for August 1 (Julian Day 213) to answer this question.

The average flow at the Lochsa River gage near Lowell on August 1, 1994, was 18.21 $m^3/s$. Measured temperatures indicate the average daily water temperature on this date was 22.3°C; 3.3°C above the average daily temperature criterion. The maximum measured water temperature on this date was 25.2° C; 3.2°C above the instantaneous temperature criterion.

For the water temperature at this section of the Lochsa River to decrease to the instantaneous criterion on this date, approximately $2.432 \times 10^8$ joules (J) ($2.305 \times 10^5$ BTU, $5.813 \times 10^4$ C) would have to be removed from the river.

The average temperature of 22.3°C reflects an average value of water temperature throughout a 24-hour period. A daily thermal load contributes to this temperature. To decrease the water temperature at this location to the average water temperature criterion, a thermal load of approximately $2.167 \times 10^{13}$ J/day ($2.054 \times 10^{10}$ BTU/day, $5.179 \times 10^9$ C/day) would have to be removed from the river.

**Simulation 5—How much of this decrease in thermal load could be provided by increased stream shading?**

Energy, in units of joules (J), British Thermal Units (BTU), or kilocalories (C), cannot be extracted from the SNTEMP model output without significant changes to the source code. However, increasing vegetative shade in the reach can simulate a reduction of thermal load. The increased shading prevents energy, in the form of solar radiation, from entering the river. The decreased temperature as a result of increased vegetative shading reflects the reduction in thermal load input to the Lochsa River.

The full potential canopy cover simulation, as described above, simulates reduced thermal conditions due to increased stream shading. Table 13 compares output from the two full potential canopy cover scenarios with the baseline simulation on the 90$^{th}$ percentile air temperature day, August 1, 1994.

As shown in Table 13, full potential canopy cover can decrease the average stream temperature on August 1, 1994, at RKM 0.0 by as much as 1.35°C. However, since the target decrease is 2.76°C, increasing stream shading to full potential canopy cover will not decrease water temperatures below the average temperature criterion. Maximum temperatures at the same location can be reduced by as much as 1.88°C under the 80$^{th}$ percentile full potential canopy cover scenario. The target reduction in maximum water temperature to meet the instantaneous criterion is 1.32°C. Thus, on the 90$^{th}$ percentile air temperature day represented by August 1, 1994, the maximum water temperature criterion can be met if stream shading is increased to full potential canopy cover conditions.

**Simulation 6—How much cooling in tributary inflow temperatures would be needed for the Lochsa River to meet CWB criteria at Lowell on 90$^{th}$ percentile air temperature day?**

Model inflow water temperatures on August 1, 1994, were adjusted to answer this question. The inflow temperatures were reduced using a trial-and-error process until the Idaho CWB temperature criteria were met for both daily average temperature (19.0°C) and maximum temperature (22.0°C). A total tributary reduction of 8.53°C would be needed to meet Idaho CWB temperature criteria at Lowell on August 1, 1994. The average temperature criterion is the limiting factor, as the maximum temperature criterion is met with an approximately 4.6°C reduction in inflow temperature. This conclusion is consistent with the results of Simulations 2 and 5, in which a change in vegetative shading resulted in a greater decrease in maximum water temperature than average water temperature.

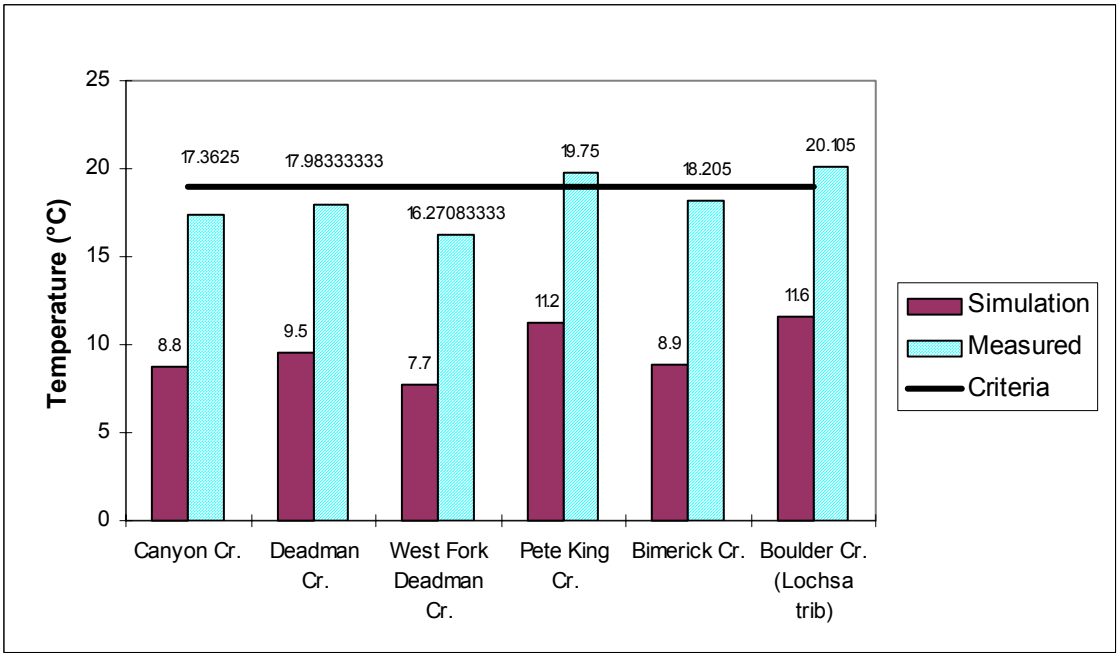
Decreasing all tributaries by an average of 8.53°C in the mid-summer is not a physically attainable goal. Figure 11 compares the measured average water temperature for August 1, 1994 with the simulated water temperature an the same date and the CWB criterion. Many of these tributaries are in unmanaged (i.e. Bimerick Creek) or wilderness (i.e. Boulder Creek) areas, and riparian cover is at or near maximum potential throughout the creeks. The simulated temperatures are represented at the mouths of each of the creeks, implying that temperatures would be even colder upstream. Two of the tributaries, Boulder Creek and Pete King Creek, have average measured water temperatures at the mouths of the creeks higher than the 19°C CWB criterion on August 1, 1994. As stated earlier, Boulder Creek drains a mostly un-managed area. Inducing a reduction of approximately 8.5°C on this day is very unlikely.

**Table 13. Full Potential Canopy Cover Simulation Results for August 1, 1994**

| | Average Temperature Model | | | Maximum Temperature Model | | |
|---|---|---|---|---|---|---|
| RKM | Baseline (°C) | Δ Temp Scenario 1 (°C) | Δ Temp Scenario 2 (°C) | Baseline (°C) | Δ Temp Scenario 1 (°C) | Δ Temp Scenario 2 (°C) |
| 0.0 | 21.76 | -1.33 | -1.35 | 23.32 | -1.86 | -1.88 |
| Target Δ Temp (°C) | | 2.76 | | | 1.32 | |

Note: Baseline—Existing canopy conditions
Scenario 1—Full potential canopy cover assuming the continued presence of U.S. Route 12
Scenario 2—Full potential canopy cover assuming passive restoration in place of U.S. Route 12

**Figure 11. 1994 July-August Simulated vs. Measured Tributary Water Temperatures, Simulation 6**



# Discussion

Results of the model simulations indicate the following:

- Water temperatures in the Lochsa River exceed Idaho CWB temperature criteria on a 90$^{th}$ percentile air temperature day.
- The reduction in thermal load to meet Idaho CWB temperature criteria on a 90$^{th}$ percentile air temperature day would be approximately $2.167 \times 10^{13}$ J/day ($2.054 \times 10^{10}$ BTU/day, $5.179 \times 10^{9}$ C/day).
- Allowing passive restoration strategies to generate full potential canopy cover in riparian areas throughout the watershed would decrease average and maximum water temperatures but not enough to satisfy Idaho CWB temperature criteria.
- To satisfy Idaho daily average temperature criteria on a 90$^{th}$ percentile air temperature day without adjusting canopy cover, inflow temperatures for all tributaries in the Lochsa River watershed would have to be reduced by more than 8°C. This is unrealistic as the water temperatures at the mouths of many tributaries would be as low as 7.7° C or lower in the months of July and August.
- Air temperature, inflow temperature, and stream flow are the input variables that are most important in determining water temperature in the Lochsa River.

# Conclusions

A water temperature model of the Lochsa River and four of its tributaries, Crooked Fork, White Sand Creek, Deadman Creek, and Canyon Creek, was developed based on measured meteorological and hydrologic data in 1994, 1997, and 1998. Other measured data used in the model included stream geometry, stream and watershed hydrology, local topography, and vegetation data. After a comprehensive evaluation process of several temperature models and hybrid model combinations, the model selected to simulate water temperatures was SNTEMP, developed by the U.S. Fish and Wildlife Service (Theurer et al. 1984).

Two models were developed: a 1994 model and a 1997-1998 model. These years were selected due to their range in hydrologic extremes: 1997 registered the second highest flow on record, while 1994 registered the sixth lowest flow on record. The year 1998 was considered an average flow year. The year 1998 was also selected because copious water temperature and flow data were collected during the summer months.

The models predicted average daily water temperatures throughout the modeled system with an average calibration error of less than 0.8°C and a validation error of 0.6°C. Maximum temperatures were also predicted using the maximum air temperature regression method within SNTEMP.

After the temperature models were calibrated and validated, a single-parameter sensitivity analysis (Chapra 1997) was performed to identify key input variables in the model. It was found that air temperature, inflow temperature, and incoming solar radiation, respectively, were the three variables to which the average temperature model was most sensitive. Incoming solar radiation, air temperature, and inflow temperature were the three variables that most influenced maximum temperature, respectively.

Several model runs were performed to simulate alternate scenarios. As a result of these simulations, it was found that water temperatures exceeded Idaho CWB temperature criteria throughout the Lochsa River on the 90$^{th}$ percentile air temperature day. Increasing riparian vegetative shading to full potential would decrease Lochsa River water temperature but not enough to meet Idaho CWB temperature criteria. Alternately, the water temperature of all tributaries to the Lochsa River would have to be reduced by more than 8°C in order for the Lochsa River to meet Idaho CWB temperature criteria. This latter step does not seem feasible, as it would require unrealistically low temperatures (e.g. 7.7°C or lower) in some tributaries during the hottest months of the year.

# Canopy Cover Refinement

## Introduction

Water temperature modeling of the Lochsa River and its tributaries Crooked Fork, White Sand Creek, Canyon Creek, and Deadman Creek, explored the effects of riparian canopy on water temperature (see discussion in the previous sections of this report). The original modeling study indicated that water temperatures in the Lochsa River exceeded the Idaho maximum daily temperature criteria for cold water biota (CWB) under existing canopy conditions. In addition, modeling of full potential canopy cover conditions (defined as the 80$^{th}$ percentile of tree height and crown closure for a large sample of measured stands in the vicinity of the study reach) showed that increased canopy cover would reduce stream temperatures, but that the Idaho CWB temperature criteria would still be exceeded.

The analysis showed the departure between existing and full potential canopy conditions for riparian canopy cover and the associated change in water temperature. However, this analysis did not distinguish between the differences in cover and resulting water temperature due to natural disturbances, such as lightning-caused fires, disease, and wind, and those due to human-caused disturbances, such as timber harvest and human-caused fires.

Since the Lochsa River is an unregulated stream with little disturbance other than State Highway 12 and modest timber harvest over the past 45 years, the reduction in shade provided by riparian canopy cover is the primary disturbance likely to increase water temperature. Thus, the question to be answered is "what fraction of the departure between current canopy conditions and full potential canopy in the riparian zone is due to natural disturbances, and what fraction is due to human disturbances?" This question is investigated in the present study by quantifying the difference in riparian canopy conditions for stands of trees that are undisturbed or have natural changes and those that have human-caused changes for the same modeling period as the previous study (July and August of 1994, 1997, and 1998). The SNTEMP model was used to determine the difference in stream temperatures that may then be attributed to human activity. Thus, the objective of this study is to assess the difference in water temperatures in the Lochsa River and four tributaries based on changes in riparian vegetation. Differences between natural and human-caused disturbances in vegetation are evaluated.

## Methods

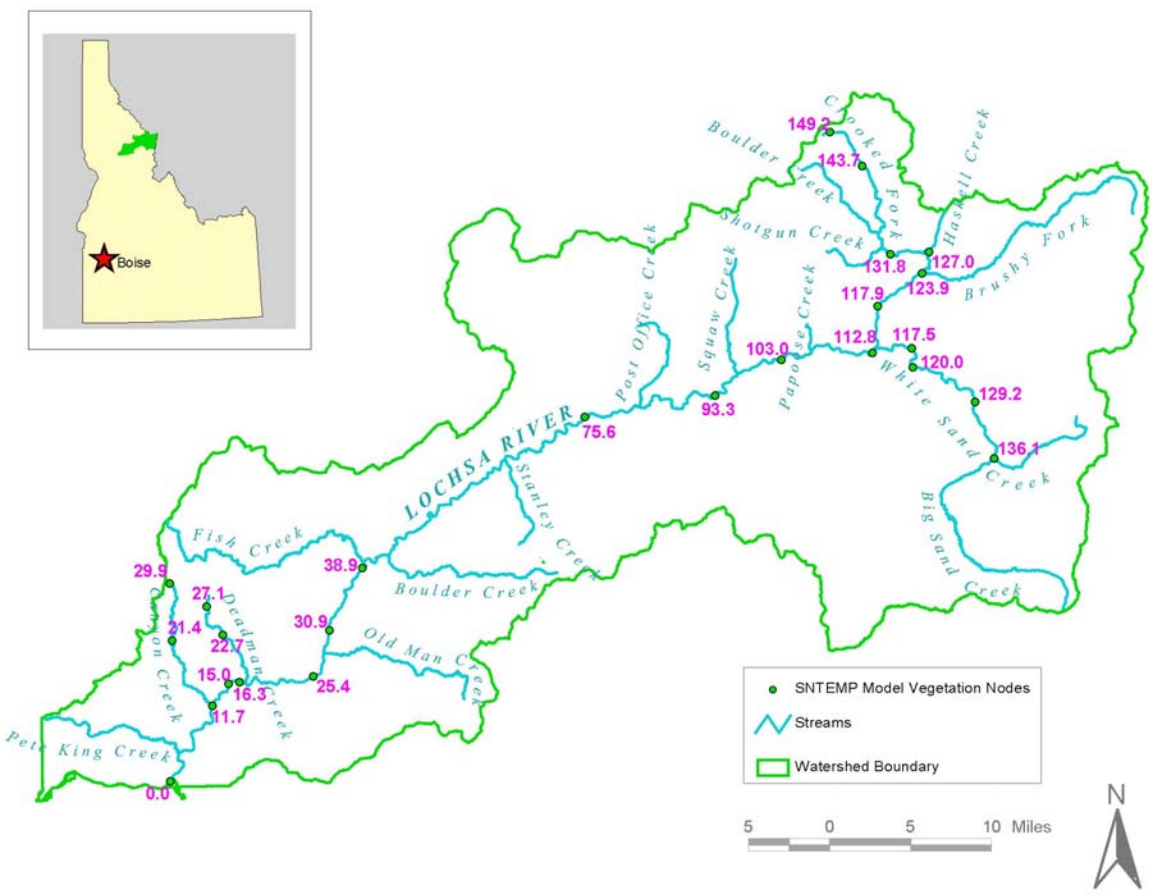
Clearwater National Forest 2001 Forest Inventory Vegetation Data, known as the "cstands database," were used for this study. The data were stratified based on location, defined in Table 10, and change activities, defined as natural or human-caused disturbances that affect the trees in a stand. Change activities were recorded in the cstands database by USFS personnel during on-site field visits. The stands were identified as having human-caused disturbances, natural disturbances, or no disturbances by using codes that identified the cause of the disturbance. The codes were linked to the change activities (either having human-caused, natural, or no disturbances) as shown in Table 14. Codes that begin with the numbers "49" are typically burning activities that follow a harvest. However, the cstands database does not indicate when the harvest was or to what extent the stand was harvested. In these cases, the change activities were considered to be fire-caused.

The stands were then organized into the riparian vegetation reaches defined in the shade file of the original SNTEMP model (Figure 12).

**Table 14. Clearwater National Forest Vegetation Change Codes**

| Field Code | Description | Was Cause Of Disturbance Fire, Harvest, Or Natural? | Change Activity |
|---|---|---|---|
| 4113 | Human Caused | Harvest | Stand |
| 4230 | Human Caused | Harvest | Sanitation/Salvage |
| 4250 | Natural | Natural | Natural Changes |
| 4260 | Human Caused | Fire | Man Caused Fire Damage |
| 4270 | Human Caused | Harvest | Permanent Land Clearing |
| 4471 | Human Caused | Fire | Burning |
| 4976 | Human Caused | Fire | Burn Hand Piles |
| 4978 | Human Caused | Fire | Broadcast Burn |
| 4985 | Human Caused | Fire | Wildlife Burn |
| 4986 | Human Caused | Fire | Hand Piling |
| 4987 | Human Caused | Fire | Fireline Construction |
| 4994 | Human Caused | Fire | Fuelbreak |
| 4996 | Human Caused | Fire | Natural Abatement |
| 4997 | Human Caused | Fire | Burn Landings |

**Figure 12. Map of Lochsa River Basin and Locations of Vegetation Reaches**



As was done for the full potential canopy cover simulation, only the crown closure and tree height parameters from the database were used in the study. The crown diameter and distance from bank parameters were not changed because new information for these parameters was not available. Average crown closure and tree height were calculated for each activity grouping of stands in each vegetation reach. The activity grouping of stands were "human-caused disturbances," "no human-caused disturbances," and "existing conditions." These are not the same as the vegetation codes. Stands that were identified as possessing human-caused disturbances were considered in the "human-caused disturbances" grouping. Stands that were identified as possessing natural disturbances were considered in the "no human-caused disturbances" grouping along with those stands that were not identified as possessing any disturbances. The "existing conditions" grouping included all measured stands.

Also as in the original study, the crown closure parameter in the cstands database was used to represent the canopy density parameter in the SNTEMP shade input file. From this point forward, the crown closure parameter shall be referred to as canopy density. See the Input Data section of this report for details on the data reduction procedure for the canopy density and tree height parameters.

The new canopy density and tree height data were entered into a new set of shade files in the SNTEMP model for the existing conditions and no human-caused disturbances scenarios. Model output of the two scenarios were tabulated and graphed with the full potential canopy cover scenario from the original study.

Three model scenarios were run. The existing conditions scenario represented the existing condition of the riparian canopy at the time of data collection, 2001 in this case, and used the "existing conditions" shade file. The no human-caused disturbances scenario represented the riparian canopy if human-caused disturbances had not occurred, and used the "no human-caused disturbances" shade file. The full potential canopy cover scenario was the 80$^{th}$ percentile of tree height and canopy cover for the dominant habitat type of a large local sample of stands. This scenario was unchanged from the original study.

The new shade files were run with the input files of the original models (1994 and 1997-1998) to predict water temperatures. The predicted water temperatures for the existing conditions and no human-caused disturbances scenarios were tabulated and graphed with the water temperatures of the full potential canopy cover scenario.

# Results

**Vegetation Data**

Based on two single factor ANOVAS, the full potential canopy cover grouping had significantly higher values of average canopy density and average height ($\alpha = 0.05$, $P<0.0001$) than the no human-caused disturbances and existing conditions groupings (Table 15). The existing conditions grouping, representing the existing conditions of the riparian canopy at the time of data collection had lower values of average height and significantly lower values of average canopy density ($\alpha = 0.05$, $P<0.0007$) than the no human-caused disturbances grouping. However, there were instances where average canopy density and height values were higher than those for the no human-caused disturbances grouping when the stands with human-caused disturbances possessed average parameter values greater than those of the existing conditions grouping (the vegetation reach average). This situation was rare, but happened with one reach in the Crooked Fork subbasin for average canopy density, two reaches in the Lochsa River basin for average canopy density, and one reach in the Lochsa River basin for both average canopy density and average tree height (Table 15).

## Table 15. Lochsa River Basin Measured Vegetation Values

| Reach | Average Canopy Density (%) | | | | | Average Tree Height (m) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Existing conditions | Human-caused fire damage stands only | Harvested stands only | Stands with no disturbances | Full potential canopy cover | Existing conditions | Human-caused fire damage stands only | Harvested stands only | Stands with no disturbances | Full potential canopy cover |
| **Crooked Fork** | | | | | | | | | | |
| 149.2 to 143.7 | 50.5 (n=20) | -- | -- | 50.5 (n=20) | 63 | 24.2 (n=20) | -- | -- | 24.2 (n=20) | 23.3 |
| 143.7 to 131.8 | 58.8 (40) | -- | -- | 58.8 (40) | 63 | 24.7 (40) | -- | -- | 24.7 (40) | 23.3 |
| 131.8 to 127.0* | 45.0 (2) | -- | -- | -- | 63 | 29.0 (2) | -- | -- | -- | 23.3 |
| 127.0 to 123.9 | 45.4 (11) | 0.0 (n=1) | 47.6 (n=7) | 55.3 (3) | 54 | 21.9 (11) | 0.0 (1) | 22.3 (7) | 28.5 (3) | 27.3 |
| 123.9 to 117.9 | 58.6 (24) | -- | 50.2 (6) | 61.3 (18) | 74 | 28.7 (24) | -- | 26.5 (6) | 29.4 (18) | 32.9 |
| 117.9 to 112.8 | 61.2 (9) | -- | 66.5 (2) | 59.7 (7) | 74 | 32.0 (9) | -- | 27.6 (2) | 33.3 (7) | 32.9 |
| **White Sand Creek** | | | | | | | | | | |
| 136.1 to 129.2 | 49.9 (33) | -- | -- | 49.9 (33) | 71 | 24.5 (33) | -- | -- | 24.5 (33) | 29.3 |
| 129.2 to 120.0 | 46.6 (21) | -- | -- | 46.6 (21) | 55 | 20.8 (21) | -- | -- | 20.8 (21) | 26.9 |
| 120.0 to 117.5 | 59.2 (19) | -- | -- | 59.2 (19) | 54 | 22.6 (19) | -- | -- | 22.6 (19) | 28.1 |
| 117.5 to 112.8 | 75.5 (4) | -- | 73.0 (1) | 76.3 (3) | 54 | 28.7 (4) | -- | 21.9 (1) | 30.9 (3) | 28.1 |
| **Lochsa River** | | | | | | | | | | |
| 112.8 to 103.0 | 65.4 (21) | -- | 43.5 (5) | 72.0 (16) | 75 | 27.4 (21) | -- | 23.3 (5) | 28.7 (16) | 30.7 |
| 103.0 to 93.3 | 49.9 (72) | 52.8 (4) | 51.9 (5) | 49.5 (63) | 75 | 23.0 (71) | 31.6 (4) | 19.6 (5) | 22.8 (63) | 30.7 |
| 93.3 to 75.6 | 55.3 (73) | 66.0 (2) | 29.8 (3) | 57.9 (66) | 75 | 22.0 (73) | 29.3 (2) | 13.9 (3) | 22.8 (66) | 30.7 |
| 75.6 to 38.8 | 49.1 (193) | 29.4 (18) | -- | 48.2 (175) | 67 | 20.5 (193) | 15.7 (18) | -- | 21.1 (175) | 27.0 |
| 38.8 to 30.9 | 39.8 (53) | 0.0 (1) | -- | 42.1 (50) | 67 | 18.2 (53) | 0.0 (1) | -- | 19.2 (50) | 27.0 |
| 30.9 to 25.4 | 37.2 (41) | 12.0 (1) | -- | 41.4 (36) | 67 | 17.2 (41) | 6.7 (1) | -- | 19.2 (36) | 27.0 |
| 25.4 to 16.3 | 40.0 (52) | 17.7 (5) | -- | 39.8 (42) | 67 | 19.0 (52) | 15.4 (5) | -- | 21.5 (42) | 27.0 |
| 16.3 to 15.0 | 33.8 (4) | 0.0 (1) | -- | 45.0 (3) | 67 | 17.9 (4) | 0.0 (1) | -- | 23.8 (3) | 26.8 |
| 11.7 to 15.0 | 47.8 (18) | 13.7 (2) | -- | 53.8 (16) | 67 | 24.2 (18) | 12.3 (2) | -- | 26.3 (16) | 26.8 |
| 0.0 to 11.7 | 44.1 (45) | -- | -- | 44.1 (45) | 67 | 21.9 (45) | -- | -- | 21.9 (45) | 26.8 |
| **Deadman Creek** | | | | | | | | | | |
| 27.1 to 22.7 | 43.7 (17) | -- | 29.0 (7) | 51.5 (10) | 68 | 22.1 (17) | -- | 5.3 (7) | 31.1 (10) | 31.0 |
| 22.7 to 16.3 | 47.7 (32) | 38.7 (3) | 0.0 (1) | 51.2 (28) | 68 | 25.6 (32) | 27.9 (3) | 0.0 (1) | 26.8 (28) | 31.0 |
| **Canyon Creek** | | | | | | | | | | |
| 29.9 to 21.4 | 53.5 (34) | 36.0 (1) | 48.6 (14) | 59.1 (17) | 68 | 22.2 (34) | 5.6 (1) | 11.1 (14) | 31.4 (17) | 31.0 |
| 21.4 to 11.7 | 57.2 (38) | 24.0 (1) | 28.7 (3) | 59.2 (35) | 68 | 32.6 (38) | 2.0 (1) | 10.5 (3) | 34.4 (35) | 31.0 |

* - This stand was burned in the 2000 Crooked Fire. Vegetation data collected prior to 2000 were used for this analysis.

In addition, the no human-caused disturbances grouping was broken down to "human-caused fire disturbances" and "harvest activities." Some vegetation reaches contained both fire and harvest disturbances, several reaches had only one of the two human-caused disturbances, and some reaches had no human-caused disturbances. For example, of the four vegetation reaches that represent White Sand Creek, the three upstream reaches did not possess human-caused disturbances. For these vegetation reaches, the existing conditions data were equal to the no human-caused disturbances data.

**Model Output**

Generally, average water temperatures in the Lochsa River and its tributaries were lowest in the full potential canopy cover scenario and highest in the existing conditions scenario. For White Sand Creek, the existing conditions and no human-caused disturbances output were close to identical, as were the input data for the two scenarios (see discussion above). The output data are given in Table 16 and displayed in Figures 13, 14, and 15.

# Discussion

**Vegetation Data**

The purpose of this study was to assess water temperature differences due to naturally occurring and human-caused disturbances of the riparian vegetation of the Lochsa River and four of its tributaries. The key to the study is the accuracy and level of detail of the collected vegetation data. These data were collected by the Clearwater National Forest and entered into the Forest Inventory database.

Historically, large fires have consumed much of the Lochsa River basin. Fires prior to 1910 are not well documented, and only the largest fires in the 20$^{th}$ Century are delineated by their boundaries (Figure 16). Pre- and post-fire stand data are not available for these fires. As such, there is no way of knowing which stands within the fire boundaries were burned, and at what intensity (Wulf 2002). Therefore, current parameters describing forest stands that have not been disturbed by humans are categorized as "having no historical disturbances or natural disturbances only." This assumes, as is generally believed, that the largest fires in the 20$^{th}$ Century were started by lightning strikes and not by human activities (Wulf 2002).

A paired t-test of the new vegetation data (Table 15) with the vegetation data from the previous study (Table 10) shows that the average canopy density parameter has significantly increased since the original data were collected ($\alpha = 0.05$, $P<0.0001$). This is ostensibly due to tree growth. However, data collection and data management may play a part in the changes in average values for an entire stand.

A sizeable fire occurred in the Crooked Fork basin in the summer of 2000, known as the Crooked Fire. The fire engulfed portions of the Haskell Creek, Rock Creek, and Crooked Fork drainages (Figure 17) and completely burned nearly every stand within its boundaries. On the Crooked Fork, the fire was contained entirely within one vegetation reach, RKM 131.8-127.0. For this reach, the vegetation data for the previous study was used for the existing conditions scenario because the previous vegetation data better describes the forest conditions for this reach during the modeling periods, July and August of 1994, 1997 and 1998. The no human-caused disturbances scenario was not run for the affected reach.

Figure 18 shows typical vegetation data, used as input for the shade files, in this case for the downstream vegetation reach of Canyon Creek, RKM 21.4 to 11.7. In this reach, the average canopy density is less than that of the full potential canopy cover and stands that have no human-caused disturbances. The average value is decreased by the low canopy density values in the harvested stands and the stands disturbed by human-caused fires. This is also the case for average tree height, except that the value for the no human-caused disturbances average is higher than that of the full potential. There are several possible explanations for this. First, the "full potential" value is actually the 80$^{th}$ percentile for the

## Table 16. Predicted Water Temperatures at Selected Locations in Lochsa River Basin

| Model | Stream | River KM | Average Temperature Model (°C) | | | Maximum Temperature Model (°C) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Existing Conditions | No Human-Caused Disturbances | Full potential canopy cover | Existing Conditions | No Human-Caused Disturbances | Full potential canopy cover |
| **1994 (low flow)** | Crooked Fork | 117.9 | 10.99 | 10.91 | 10.44 | 12.42 | 12.20 | 10.88 |
| | White Sand Creek | 112.8 | 14.04 | 14.00 | 13.66 | 16.37 | 16.16 | 15.95 |
| | Deadman Creek | 16.3 | 14.38 | 14.06 | 12.84 | 16.83 | 16.26 | 13.75 |
| | Canyon Creek | 11.7 | 13.57 | 13.42 | 12.98 | 14.80 | 14.55 | 13.62 |
| | Lochsa River | 78.4 | 15.70 | 15.64 | 14.70 | 18.06 | 17.94 | 16.03 |
| | Lochsa River | 42.3 | 17.53 | 17.49 | 16.25 | 19.96 | 19.90 | 17.92 |
| | Lochsa River | 0.0 | 18.88 | 18.83 | 17.54 | 20.81 | 20.75 | 18.79 |
| **1997 (high flow)** | Crooked Fork | 112.8 | 10.46 | 10.43 | 10.25 | 11.79 | 11.66 | 10.87 |
| | White Sand Creek | 112.8 | 13.10 | 13.08 | 12.88 | 15.33 | 15.17 | 15.09 |
| | Deadman Creek | 16.3 | 14.35 | 14.19 | 13.64 | 16.72 | 16.36 | 14.86 |
| | Canyon Creek | 11.7 | 13.09 | 12.98 | 12.67 | 14.63 | 14.43 | 13.70 |
| | Lochsa River | 78.4 | 14.07 | 14.03 | 13.45 | 16.05 | 15.97 | 14.64 |
| | Lochsa River | 42.3 | 15.71 | 15.67 | 14.88 | 17.73 | 17.69 | 16.33 |
| | Lochsa River | 0.0 | 16.92 | 16.88 | 16.07 | 18.43 | 18.39 | 17.11 |
| **1998 (average flow)** | Crooked Fork | 112.8 | 11.78 | 11.74 | 11.51 | 13.22 | 13.07 | 12.18 |
| | White Sand Creek | 112.8 | 14.91 | 14.88 | 14.58 | 17.53 | 17.33 | 17.17 |
| | Deadman Creek | 16.3 | 15.04 | 14.86 | 14.24 | 17.39 | 17.01 | 15.43 |
| | Canyon Creek | 11.7 | 13.59 | 13.51 | 13.28 | 14.85 | 14.69 | 14.11 |
| | Lochsa River | 78.4 | 16.24 | 16.19 | 15.48 | 18.44 | 18.35 | 16.82 |
| | Lochsa River | 42.3 | 18.12 | 18.08 | 17.13 | 20.34 | 20.30 | 18.74 |
| | Lochsa River | 0.0 | 19.28 | 19.24 | 18.28 | 20.99 | 20.95 | 19.47 |

**Figure 13. 1994 Average Predicted Water Temperatures in the Lochsa River**

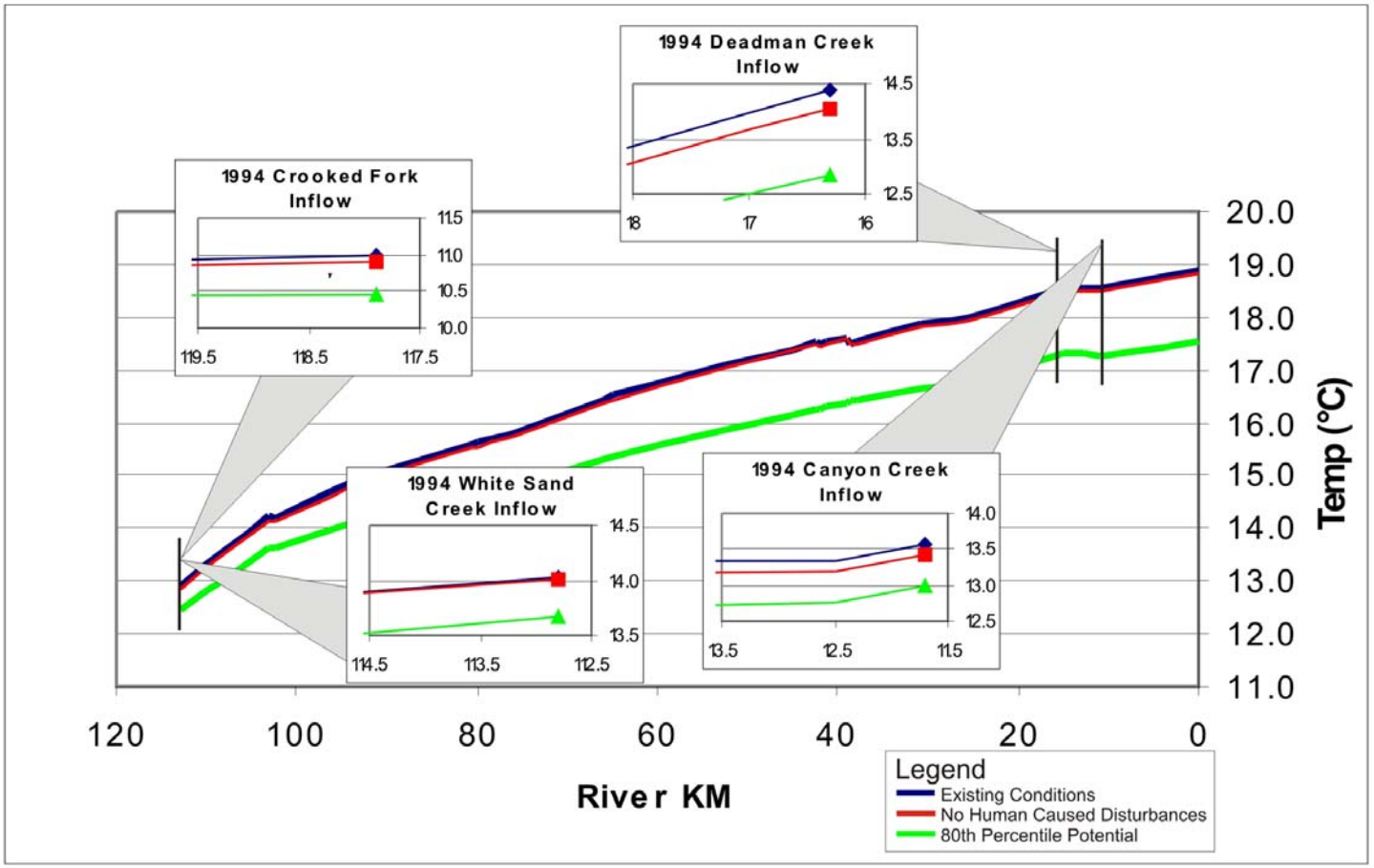


**Figure 14. 1997 Average Predicted Water Temperatures in the Lochsa River**

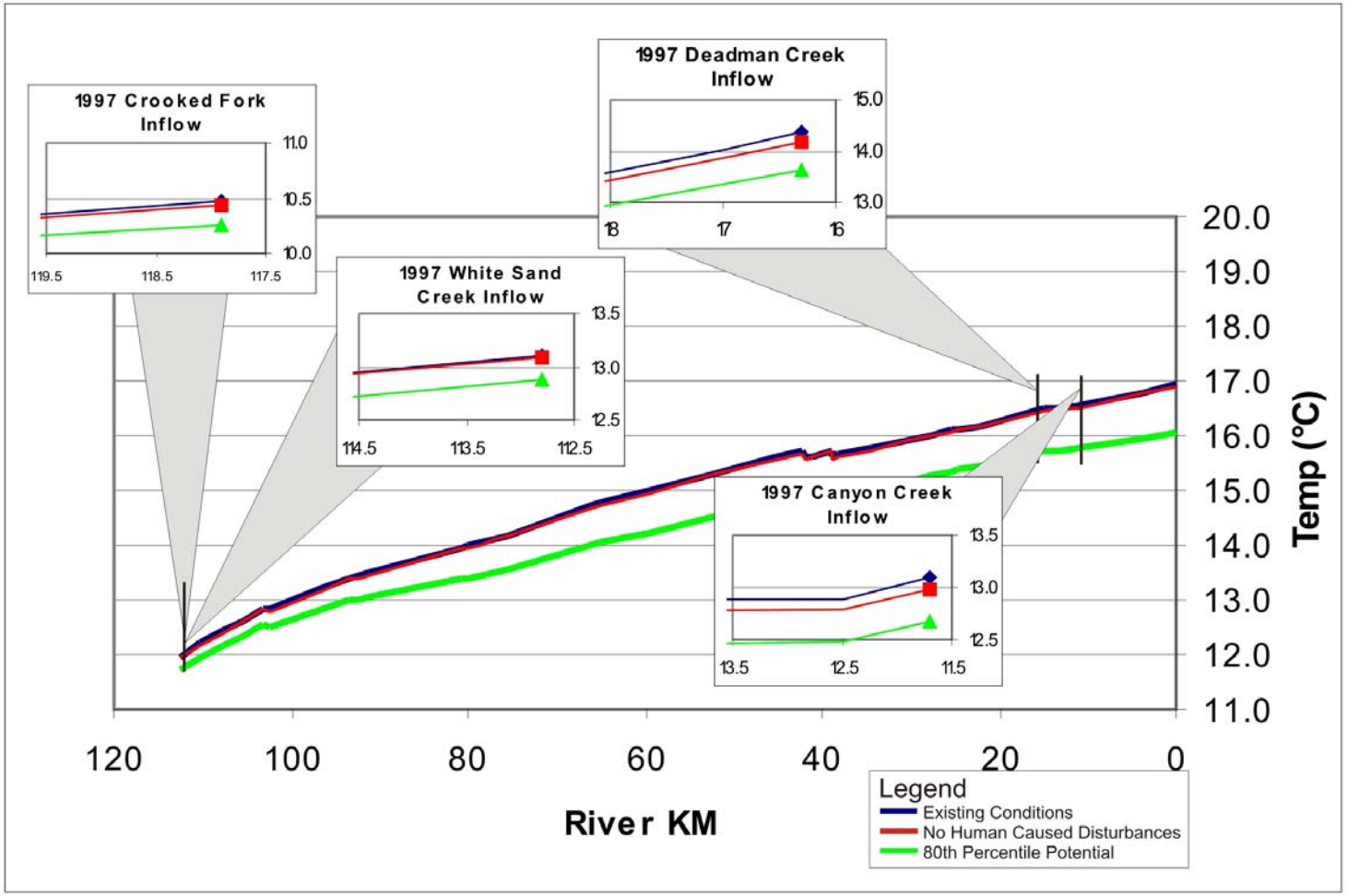


**Figure 15. 1998 Average Predicted Water Temperatures in the Lochsa River**

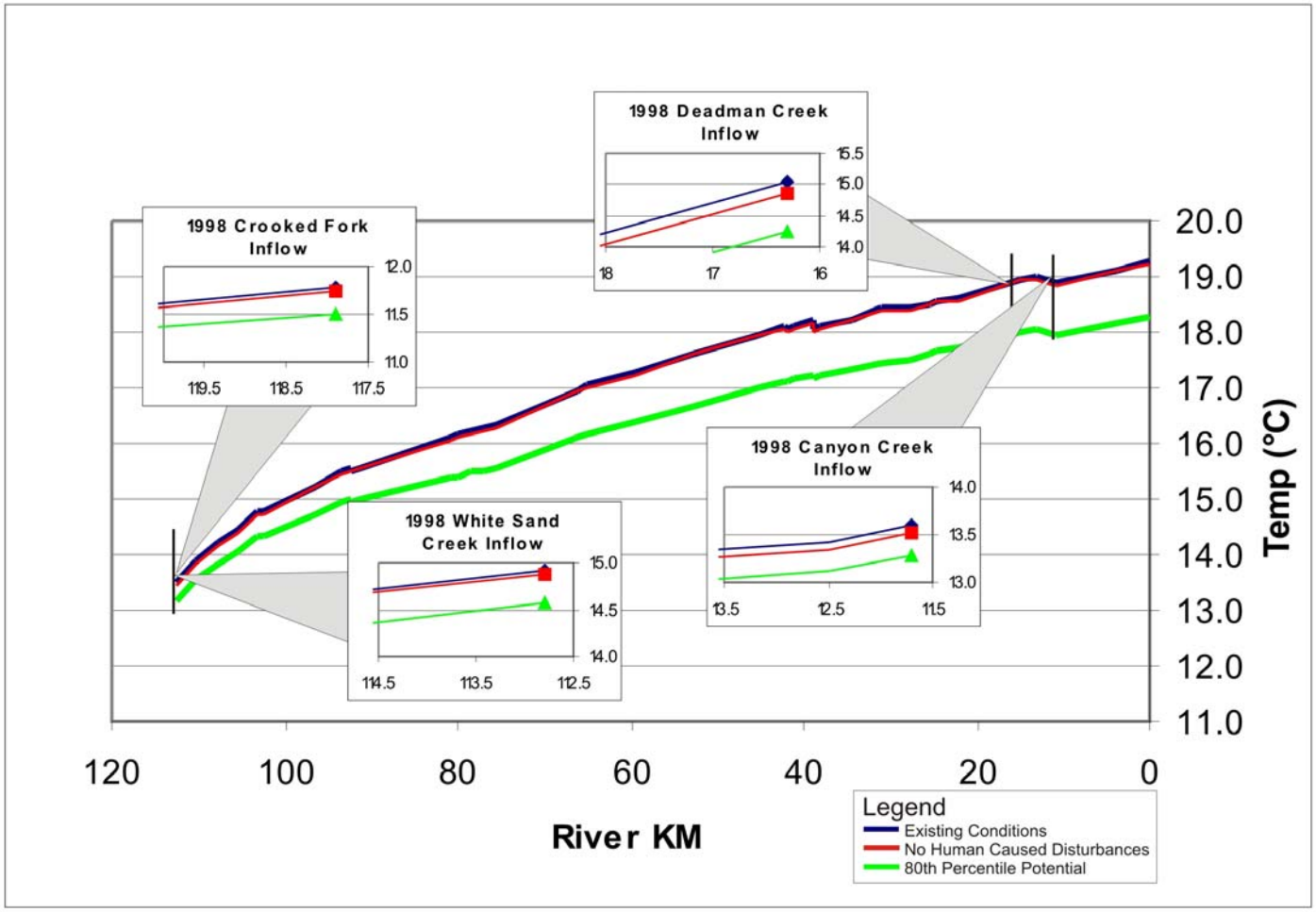


**Figure 16. Boundaries of Historical Fires in the Lochsa River Basin**

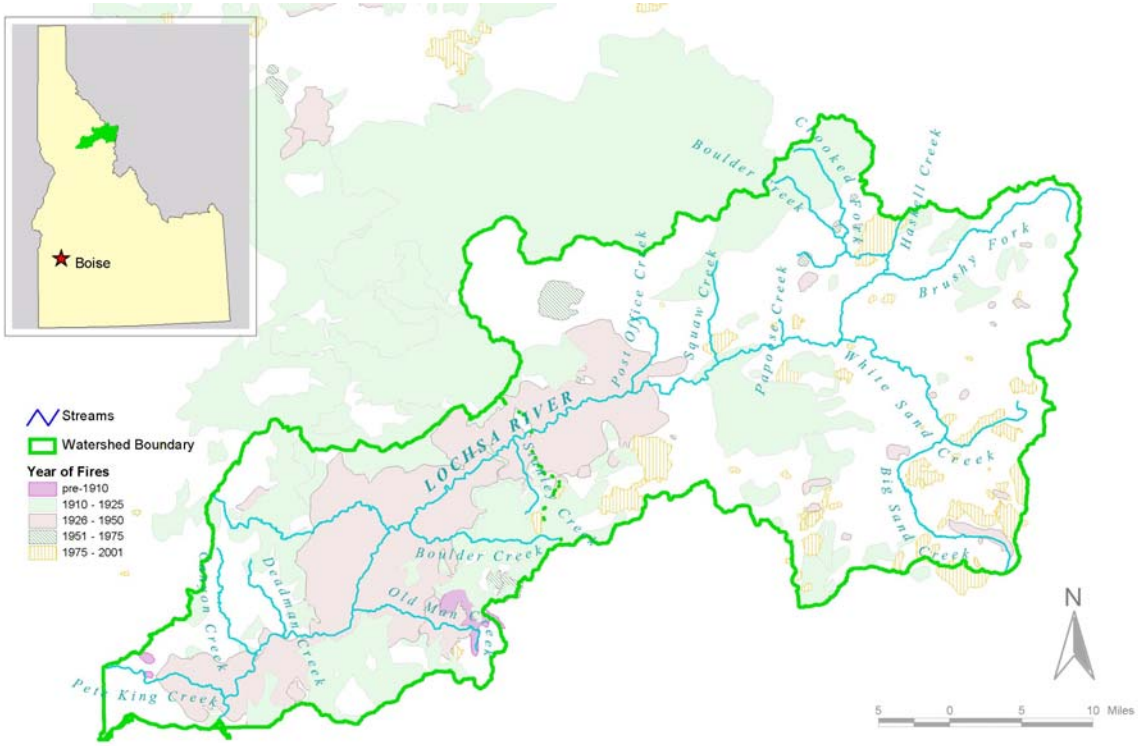
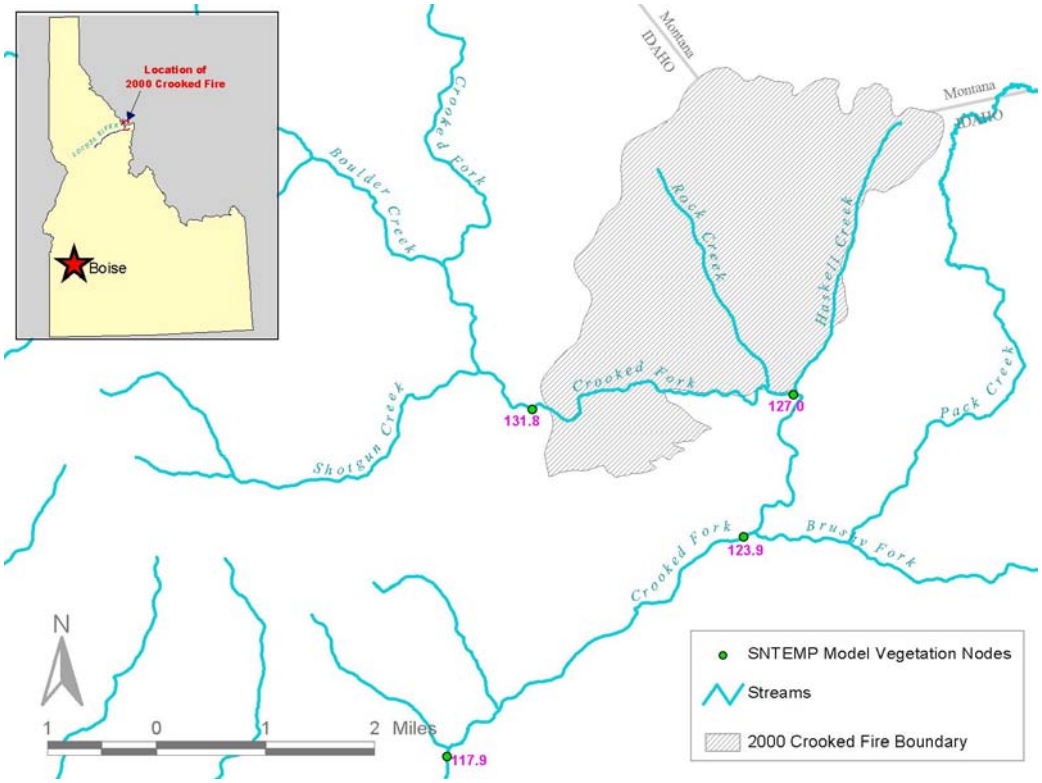



**Figure 17. Boundaries of the 2000 Crooked Fire**



dominant habitat type of a large local sample of stands. The tree heights in this vegetation reach may exist in the 85th percentile, for example, of the same sample. Another explanation could be that the full potential value represents the dominant habitat type (and the corresponding range of species) for that area, while the reach values include all habitat types. The different habitat types present in the reach can increase or decrease the average reach values of canopy density and tree height relative to the full potential values of the dominant habitat type.

Undisturbed stands generally possessed much higher values of canopy density and tree height than stands with human-caused disturbances (Figure 19). However, the difference in average canopy density and average tree height between undisturbed stands and the existing condition was much less distinct for most vegetation segments. For the Lochsa River, differences in these parameters varied significantly from upstream to downstream based on t-tests ($\alpha = 0.05$, $P < 0.03$ for both parameters). There were a few segments with existing conditions values slightly greater than those with no human-caused disturbances for average canopy density (Figure 19, three of 10 reaches) and average tree height (Figure 20, one of 10 reaches). The values of these parameters for both scenarios never reached those of the full potential canopy cover scenario for the Lochsa River. Average values for both parameters generally decreased in the downstream direction, then trended upwards again near the vicinity of the confluence with Deadman Creek.

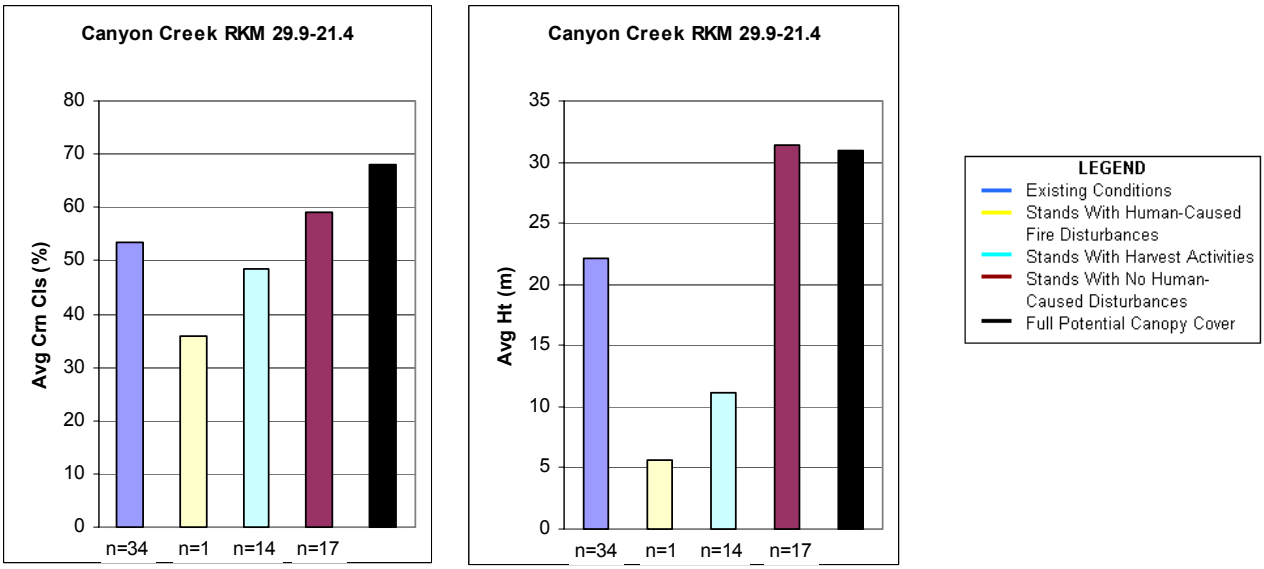
**Model Output**

Riparian canopy conditions play a major role in water temperatures in the Lochsa River basin, as shown in the original study. In most vegetation reaches, full potential canopy cover possessed higher values of average density and average tree height than both the existing conditions and the conditions with no human-caused disturbances. There were a few exceptions to this, located in the uppermost reaches of Crooked Fork and White Sand Creek and the lower reach of Canyon Creek, but none on the Lochsa mainstem. The result was that water temperatures throughout the Lochsa River basin were lower for the full potential canopy cover model than for the existing conditions and the no human-caused disturbances models. The departure was greater at the mouth of the Lochsa River, where there was an average temperature difference of 1.34°C between the existing conditions and the full potential canopy cover models in July and August of the low flow year of 1994, than upstream in the system, where average temperature differences were 1.00°C, 0.55°C, and 0.37°C at the Mocus Point Packbridge on the Lochsa River, the mouth of Crooked Fork, and the mouth of White Sand Creek, respectively, for the same modeling period (Table 16 and Figure 21).

The difference in water temperatures between the existing conditions and no human-caused disturbances models was much less than between the existing conditions and full potential canopy cover models. The temperature difference was almost zero at the mouth of White Sand Creek because there are very few human-caused disturbances in the White Sand Creek subbasin. There were more disturbances elsewhere in the Lochsa River basin, and predicted temperature differences were more apparent in these locations. In July and August of the low flow year of 1994, for example, the average temperature differences were 0.32°C, 0.08°C, and 0.06°C at the mouth of Deadman Creek, the mouth of Crooked Fork, and at both the Mocus Point Packbridge and the mouth of the Lochsa River, respectively (Table 16 and Figure 21).

Based on the above analysis, natural disturbances accounted for 96.3%, 95.3%, and 96.0% of the departure of existing water temperatures from the full potential canopy cover at the mouth of the Lochsa River, and human-caused disturbances accounted for the remainder during the low flow year of 1994, the high flow year of 1997, and the average flow year of 1998, respectively (Table 17). The percentages of maximum temperature

**Figure 18. Measured Vegetation Parameters in Canyon Creek, RKM 29.9-21.4**




departure due to human-caused disturbances for White Sand Creek are relatively high because the maximum temperature difference between the existing conditions and the full potential conditions for White Sand Creek are relatively small. As such, the small departure in temperature as a result of the few human-caused disturbances in the basin calculate as a large percentage.

Based on t-tests of the 1994, 1997, and 1998 models, human-caused disturbances factored more upstream in the system and in the modeled tributaries ($\alpha = 0.05$, $P<0.010$, $P<0.021$, $P<0.017$). Under existing conditions, the mouth of White Sand Creek exhibits maximum water temperatures near that of the full potential canopy cover scenario (Table 16). Although maximum water temperatures as a result of human-caused disturbances contributes a relatively large percentage of the deviation from full potential canopy cover temperature conditions, the overall deviation in water temperature is small, ranging from 0.16°C to 0.21°C.

A reason that the water temperatures of the existing conditions of the Lochsa subbasin were so much greater than those of the full potential canopy cover scenario, and relatively close to those of the no human-caused disturbances scenario, is that there are relatively few stands in riparian zone of the Lochsa River (and its tributaries) that have been disturbed by human causes. Of the 876 riparian stands used in this analysis, 94 were disturbed by human causes. The remaining 782 stands were subject to natural conditions. Only three of these 782 stands exhibited obvious disturbances due to natural causes. However, this does not take into account possibility that the undisturbed riparian stands were subject to unseen natural stresses that were not apparent in the collected data.

While the water temperatures of the existing condition and no human-caused disturbance models differ greatly than those of the full potential canopy cover model, there is little difference in water temperatures between the existing condition and the no human-caused disturbance models. However, the mechanism for the differences is exactly the same. Increased canopy cover, in the form of

**Figure 19. Average Canopy Density in Riparian Vegetation Reaches of Lochsa River**

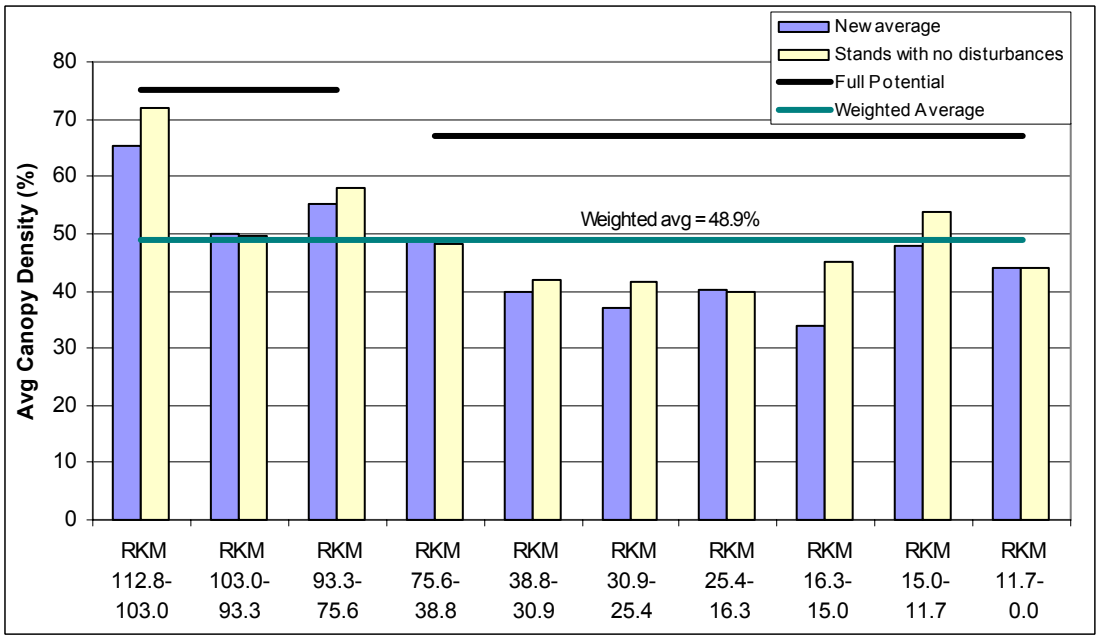



**Figure 20. Average Tree Height in Vegetation Reaches of Lochsa River**

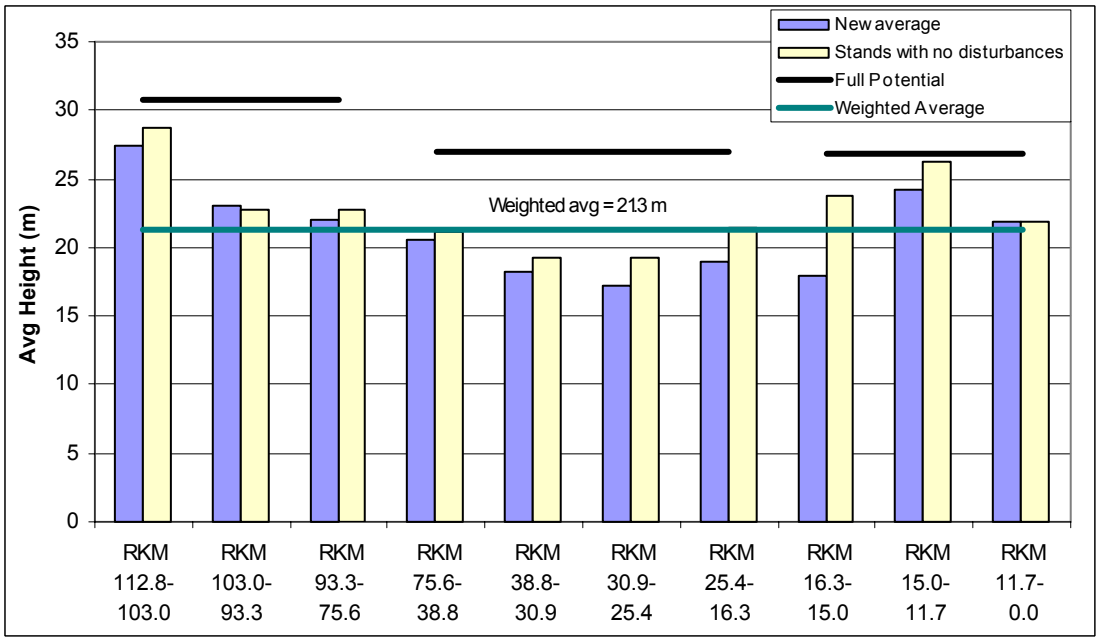


**Figure 21. Predicted Water Temperatures at Selected Locations in Lochsa River Basin**

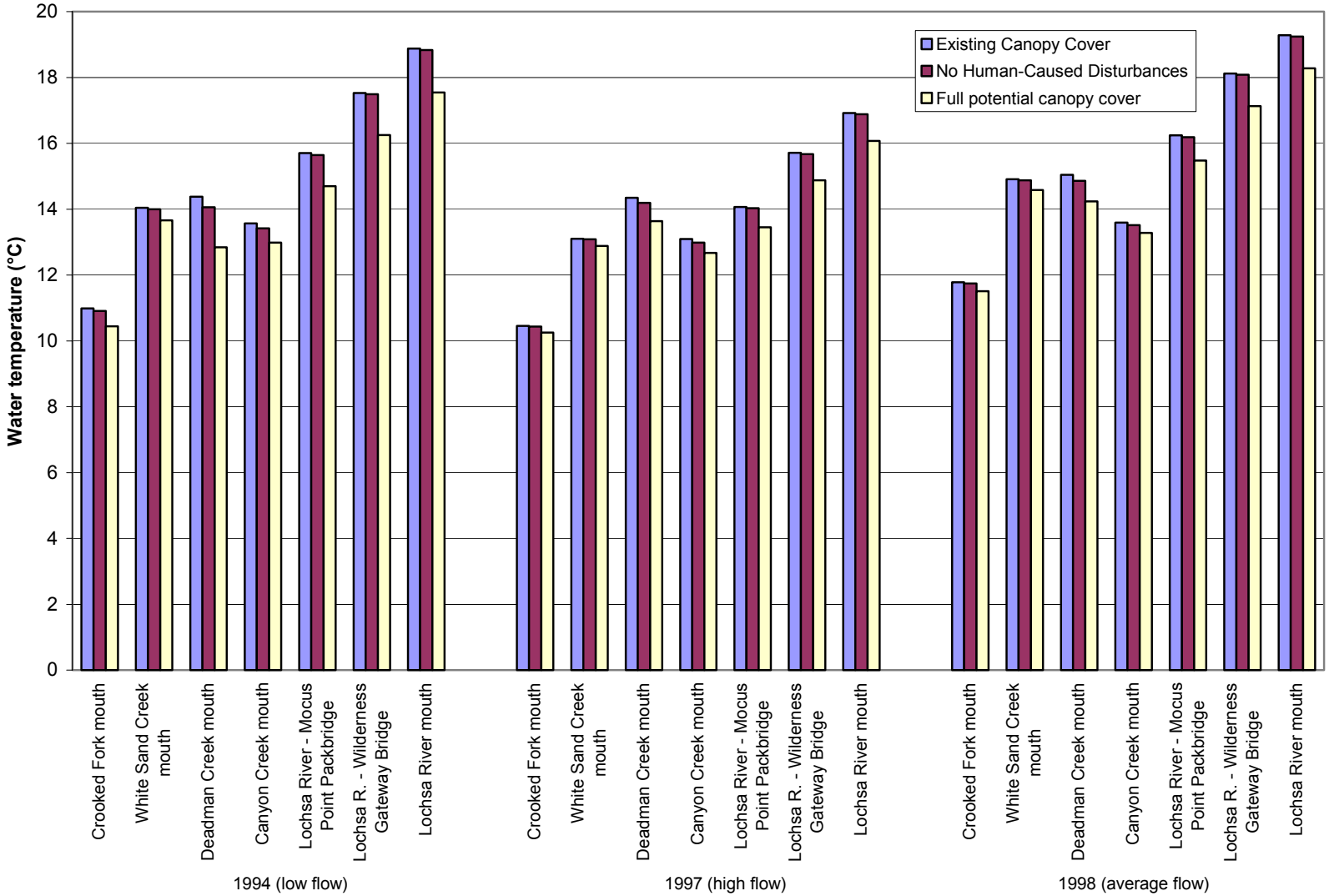


**Table 17. Fraction of Temperature Departure From Full Potential Canopy Cover Model Due To Natural or Human-Caused Disturbances**

| Model | Stream | River KM | Average Temperature Model (°C) | | Maximum Temperature Model (°C) | |
|---|---|---|---|---|---|---|
| | | | Due to natural disturbances | Due to human-caused disturbances | Due to natural disturbances | Due to human-caused disturbances |
| **1994 (low flow)** | Crooked Fork | 117.9 | 85.5% | 14.5% | 85.7% | 14.3% |
| | White Sand Creek | 112.8 | 89.5% | 10.5% | 50.0% | 50.0% |
| | Deadman Creek | 16.3 | 79.2% | 20.8% | 81.5% | 18.5% |
| | Canyon Creek | 11.7 | 74.6% | 25.4% | 78.8% | 21.2% |
| | Lochsa River | 78.4 | 94.0% | 6.0% | 94.1% | 5.9% |
| | Lochsa River | 42.3 | 96.9% | 3.1% | 97.1% | 2.9% |
| | Lochsa River | 0.0 | 96.3% | 3.7% | 97.0% | 3.0% |
| **1997 (high flow)** | Crooked Fork | 112.8 | 85.7% | 14.3% | 85.9% | 14.1% |
| | White Sand Creek | 112.8 | 90.9% | 9.1% | 33.3% | 66.7% |
| | Deadman Creek | 16.3 | 77.5% | 22.5% | 80.6% | 19.4% |
| | Canyon Creek | 11.7 | 73.8% | 26.2% | 78.5% | 21.5% |
| | Lochsa River | 78.4 | 93.5% | 6.5% | 94.3% | 5.7% |
| | Lochsa River | 42.3 | 95.2% | 4.8% | 97.1% | 2.9% |
| | Lochsa River | 0.0 | 95.3% | 4.7% | 97.0% | 3.0% |
| **1998 (average flow)** | Crooked Fork | 112.8 | 85.2% | 14.8% | 85.6% | 14.4% |
| | White Sand Creek | 112.8 | 90.9% | 9.1% | 44.4% | 55.6% |
| | Deadman Creek | 16.3 | 77.5% | 22.5% | 80.6% | 19.4% |
| | Canyon Creek | 11.7 | 74.2% | 25.8% | 78.4% | 21.6% |
| | Lochsa River | 78.4 | 93.4% | 6.6% | 94.4% | 5.6% |
| | Lochsa River | 42.3 | 96.0% | 4.0% | 97.5% | 2.5% |
| | Lochsa River | 0.0 | 96.0% | 4.0% | 97.4% | 2.6% |

increased tree height and canopy density, blocks a fraction of incoming solar radiation to the water surface that would otherwise convert its energy to heat and contribute to increased water temperatures. Predicted maximum temperatures responded similarly to predicted average temperatures. Maximum water temperature model output is given in Table 16.

One aspect of this study that may have contributed to possible inaccuracies is that 2001 vegetation data was used with 1994, 1997 and 1998 meteorological and water temperature data in the models. While the stands remained relatively unchanged between 1994 and 2001, save for the vegetation reach burned in the 2000 Crooked Fire, undoubtedly some growth was measured as increases in average tree height and average canopy density (crown closure) between the old and new data. This growth may account for slightly lower predicted water temperatures in the modeled streams. The new models were not recalibrated to account for the new vegetation data. As tree growth is likely to be relatively uniform throughout the Lochsa River basin, the growth would not affect the conclusions of the study.

# Conclusion

This goal of this study was to find what fraction of the departure between current canopy conditions and full potential canopy cover in the riparian zone was due to natural disturbances, and what fraction was due to human disturbances. It was found that between 75% and 97% of the difference in water temperature between the existing and full potential canopy cover conditions in the Lochsa River basin is due to natural disturbances. While human-caused disturbances increase water temperatures in the basin, natural disturbances are a more dominant factor in the difference between existing condition and full potential canopy cover water temperatures.

The influence of human-caused disturbances on average temperatures is most apparent in Deadman and Canyon Creeks, and least apparent in the mainstem Lochsa River. In White Sand Creek, existing condition average and maximum water temperatures were close to those for the full potential condition because there were few stands with observed human-caused disturbances and no stands with observed natural disturbances.

The disparity in the departures of water temperature values between the existing conditions and the maximum potential canopy cover scenarios, and the existing conditions and the no human-caused disturbances scenarios, provides a glimpse into the mechanism of the riparian zone in the Lochsa River basin. While human-caused disturbances decrease the average canopy densities and tree heights of the stands they affect, and thereby increase the water temperature of the stream they are adjacent to, only 10.7% of the stands in the Lochsa basin had been subject to human-caused disturbances. In contrast, all of the stands were subject to naturally occurring physical and biological processes, including snow, wind, rain, fire, disease, insects, extreme heat and cold, temperature fluctuations, over- and under-exposure to sunlight. These natural factors, as well as undocumented fires prior to 1910 and the poorly documented fires in the early 20$^{th}$ Century, have served to keep average stand values of canopy density and tree height below the maximum potential values. These factors, in turn, led to the majority of the departures in water temperature between existing conditions and the full potential canopy cover scenario. While the departure in average water temperature due to human-caused disturbances is discernable in all but the White Sand Creek subbasin, the reduction in canopy cover due to natural factors is apparently the driving force in higher water temperatures in the Lochsa River basin.

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