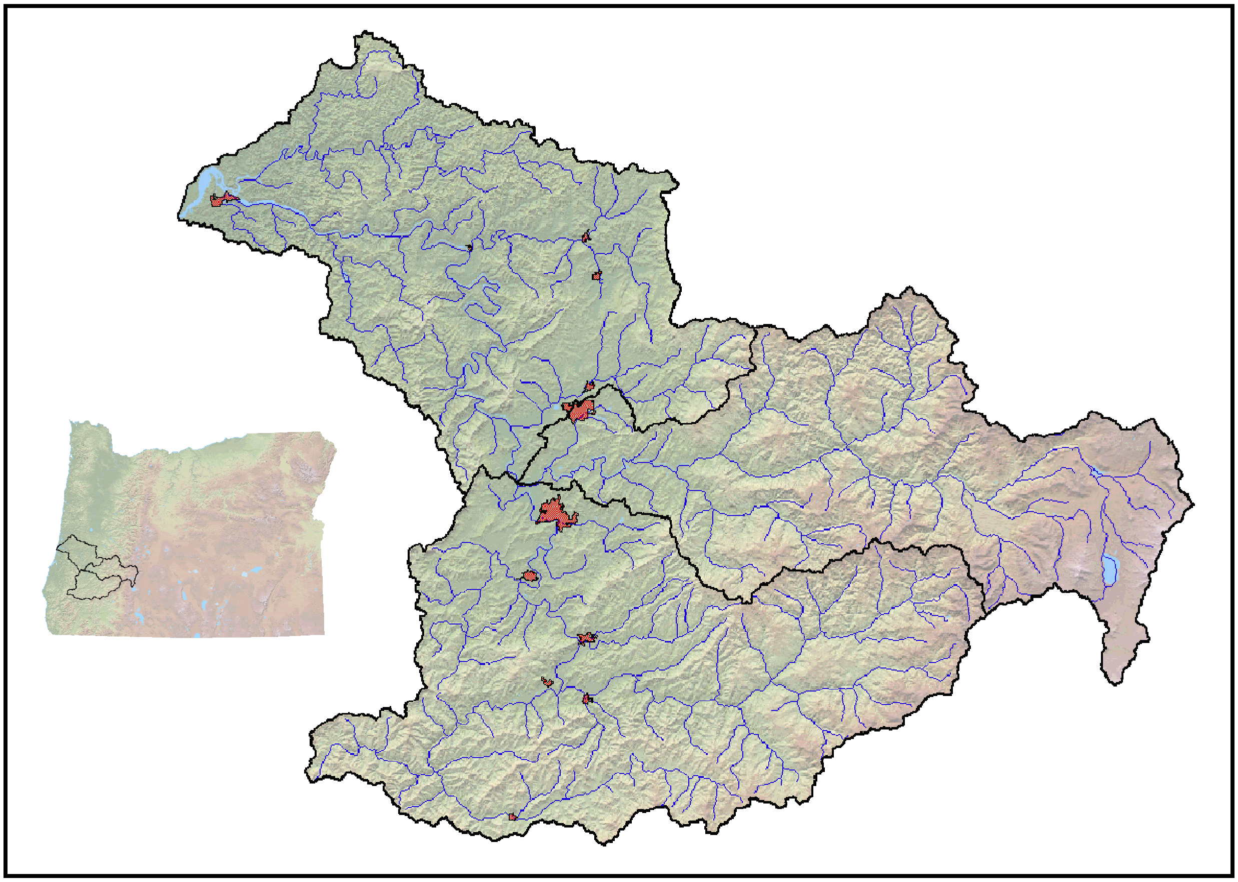
Appendix 2: Umpqua Basin
Stream Temperature TMDL Supplemental Information



THIS DOCUMENT IS SUPPLEMENTAL TO THE UMPQUA BASIN TEMPERATURE TMDL (CHAPTER 3)

DEQ

State of Oregon
Department of
Environmental
Quality

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SECTION 1. INTRODUCTION

SCALE

The Umpqua River basin contains 4,688 square miles in southwestern Oregon (**Figure 1**). It includes three 4th field hydrologic unit subbasins: the Umpqua River Subbasin (Hydrologic Unit Code 17100303), the North Umpqua Subbasin (Hydrologic Unit Code 17100301), and the South Umpqua Subbasin (Hydrologic Unit Code 17100302). While the stream temperature TMDL is developed for all surface waters within the Umpqua River Basin, this analysis focuses on the largest water bodies and those that are most thermally impaired. The waterbodies within the Smith River watershed are discussed separately in Section 6.

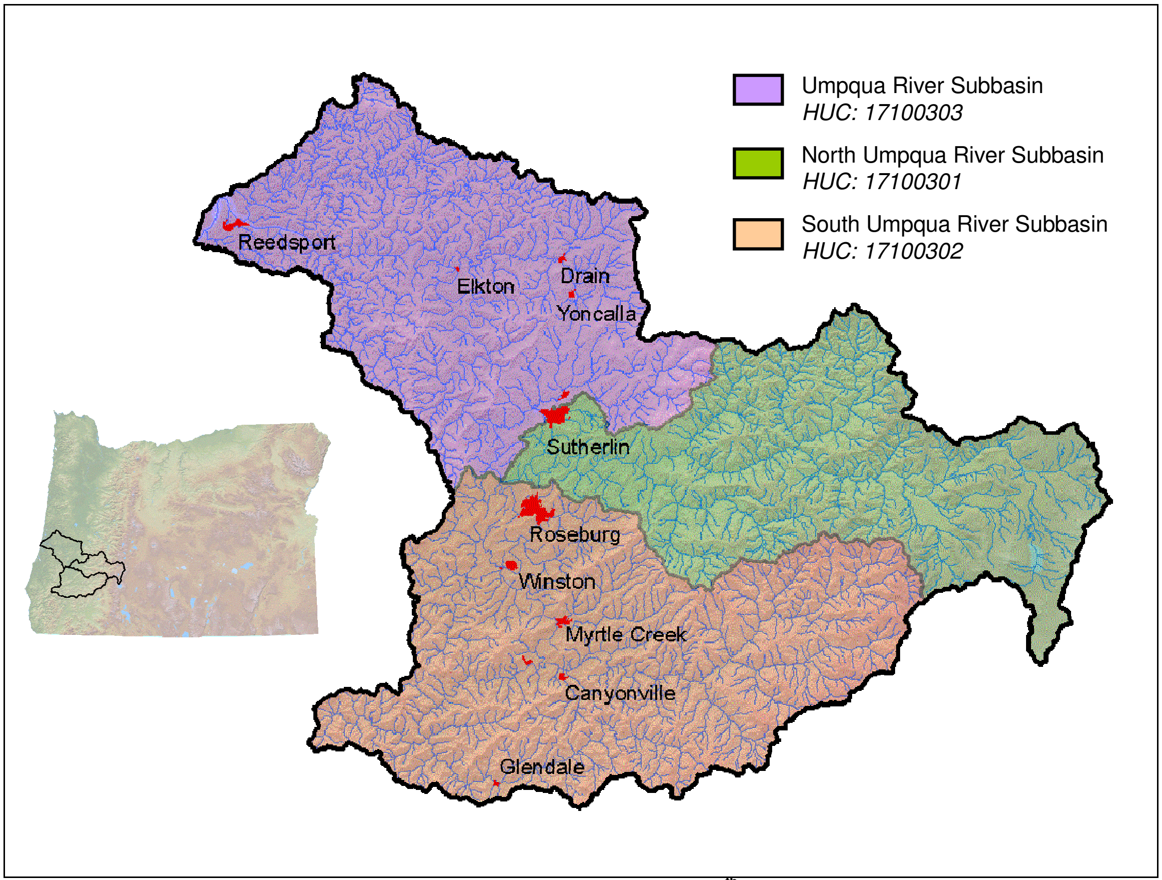

Figure 1. The Umpqua River Basin includes three subbasins (4th field hydrologic units).

SCOPE

Parameters that affect stream temperature can be categorized as vegetation, channel morphology, and hydrology (**Figure 2**). Many of these stream parameters are interrelated (i.e., the condition of one may impact one or more of the other parameters). These parameters affect stream **heat transfer processes** and stream **mass transfer processes** to varying degrees. The analytical techniques employed to develop this temperature TMDL are designed to include all of the parameters that affect stream temperature given that available data and methodologies allow accurate quantification.

Stream temperature dynamics are further complicated when these parameters are evaluated on a watershed or subbasin scale. Many parameters exhibit considerable spatial variability. For example, channel width measurements can vary greatly over short distances. Some parameters can have a diurnal and seasonal temporal component as well as spatial variability. The current analytical approaches developed for stream temperature assessment consider all of these parameters and rely on ground level and remotely sensed spatial data. To understand temperature on a landscape scale is a difficult and often resource intensive task. General analytical techniques employed in this effort are statistical and deterministic modeling of hydrologic and thermal processes.

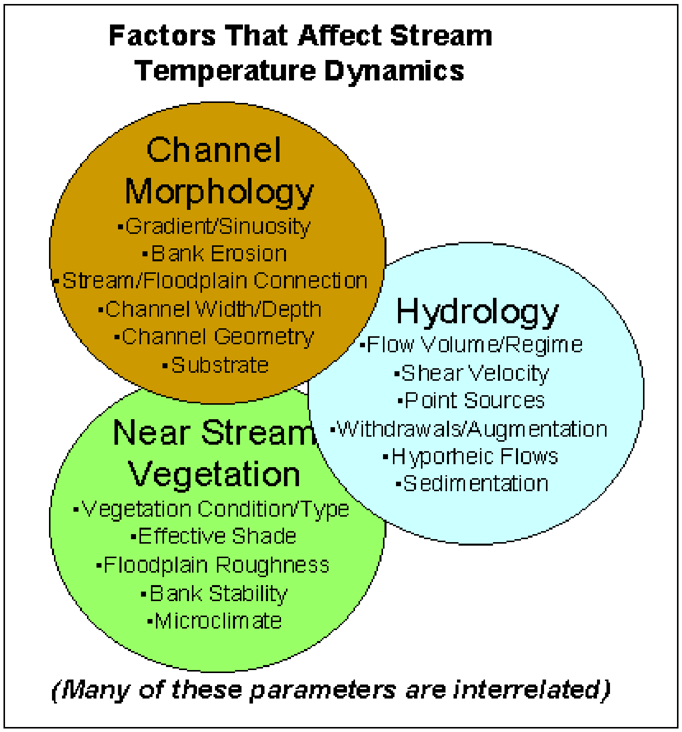

Figure 2. Factors that affect stream temperature.

Stated Purpose:
The overriding intent of this analytical effort is to improve the understanding of Umpqua Basin stream temperature dynamics in both spatial and temporal scales.

Acknowledged Limitations

It should be acknowledged that there are limitations to this effort:
The scale of this effort is large with obvious challenges in capturing spatial variability in stream and landscape data. Available spatial data sets for vegetation and channel morphology are coarse, while derived data sets are limited to aerial photo resolution and human error.
Data are insufficient to describe high-resolution instream flow conditions making validation of derived mass balances difficult.

The water quality issues are complex and interrelated. The state of the science is still evolving in the context of comprehensive landscape scaled water quality analysis. For example, quantification techniques for microclimates that occur in near stream areas are not developed and available to this effort. Regardless, recent studies indicate that forested microclimates play an important, yet variable, role in moderating air temperature, humidity fluctuations and wind speeds.
Quantification techniques for estimating potential subsurface inflows/returns and behavior within substrate are not employed in this analysis. While analytical techniques exist for describing subsurface/stream interactions, it is beyond the scope of this effort with regard to data availability, technical rigor and resource allocations.

Land use patterns vary through the drainage from heavily impacted areas to areas with little human impacts. However, it is extremely difficult to find large areas without some level of either current or past human impacts. The development of natural thermal potential stream temperatures is based on stated assumptions within this document. Limitations to stated assumptions are presented where appropriate. It should be acknowledged that as better information is developed these assumptions will be refined. Current analysis is focused on a defined critical condition. This usually occurs in late July or early August when stream flows are low, radiant heating rates are high and ambient conditions are warm. However, there are several other important time periods where data and analysis are less explicit. For example, spawning periods have not received such a robust consideration.

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

Riparian vegetation was mapped from aerial photographs and placed within general height categories. For example, trees identified as “Large Conifers” were assigned a single height of 125 feet throughout a single watershed, when in reality, “Large Conifer” heights may range between 110 and 140 feet. It is impossible to assign actual heights to each tree mapped using aerial photographs. These general height categories became Heat Source inputs and are one source of modeling imprecision.

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

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

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

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

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

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

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

Heat Source simulations were performed for a single 3-week period during a single summer, which was intended to represent a critical condition for aquatic life. Stream temperatures will react differently to effective shade under other flow regimes and climactic conditions.

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

Stream velocities and depths were calculated by Heat Source for the “natural” flow conditions based on measured channel dimensions and substrate composition. These estimated velocities and depths for the “natural” flows may have some error associated with them since they have not been verified through field measurements. In particular, the North Umpqua hydroelectric bypass reaches had around 30 cfs during the current condition and near 600 cfs during the NTP condition. Such a large difference in flow volume adds uncertainty to the NTP simulation results.

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

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

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

SECTION 2. AVAILABLE DATA

GROUND LEVEL DATA

Overview

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

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

Douglas County
InSight Consultants
Oregon Department of Environmental Quality
Oregon Department of Fish and Wildlife
Oregon Department of Forestry
Oregon Water Resources Department
Pacificorp
Umpqua Basin Watershed Council
United States Bureau of Land Management
United States Forest Service
United States Geological Survey
Watershed Sciences, Inc.

Continuous Temperature Data

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

Continuous temperature data was collected at one location for a specified period of time, usually spanning several summertime months. Measurements were collected using thermistors[1] and data from these devices were routinely checked for accuracy. Continuous temperature data were collected throughout the basin during several years. **Figure 3** displays continuous temperature data monitoring locations for the years 2000, 2001, and 2002. (Actual stream temperature data is available from DEQ upon request.)

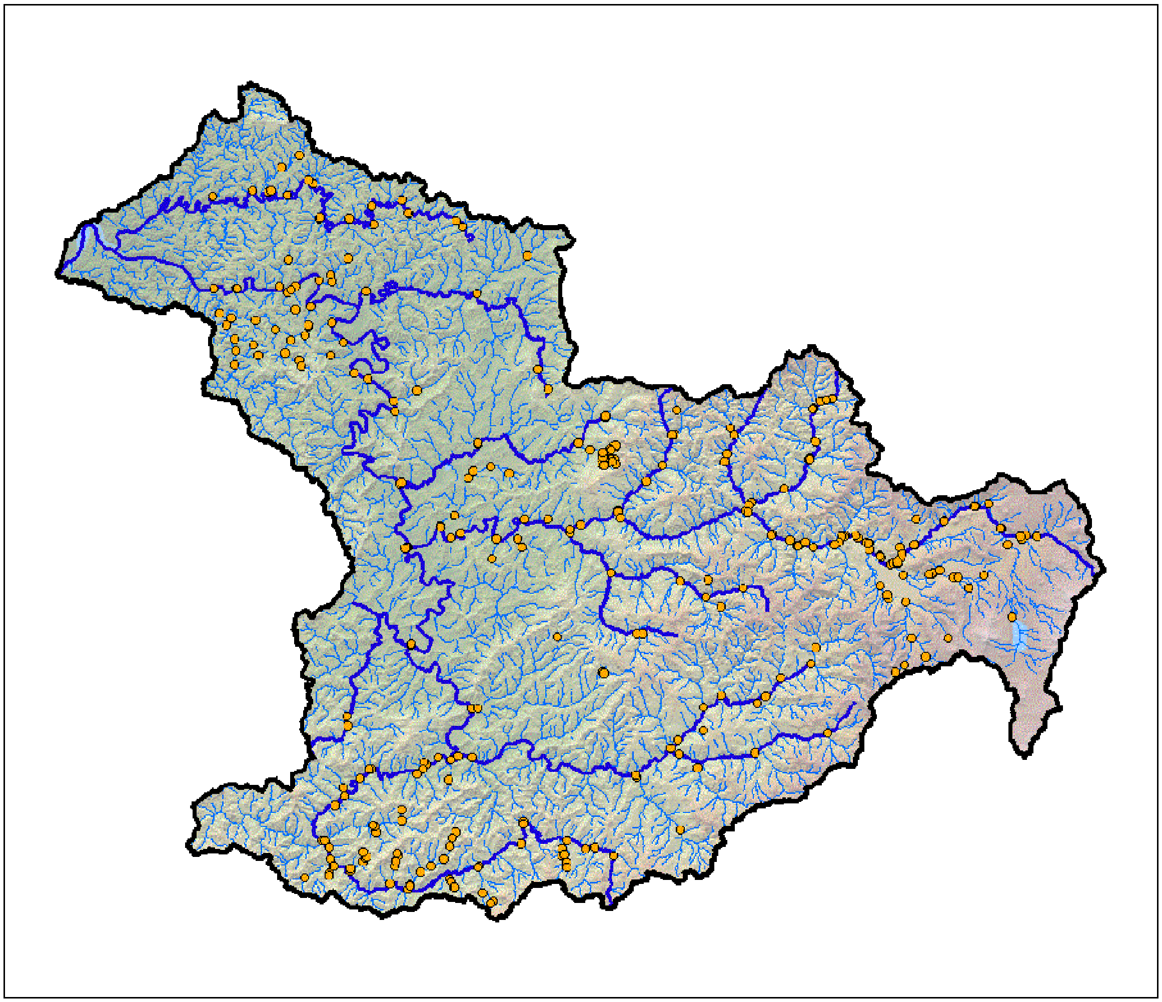

Figure 3. Continuous stream temperature measurement locations for 2000-2002.

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

Flow Volume – Gage Data and Instream Measurements

Flow volume data was collected at several sites during the critical stream temperature period in 2000, 2001, and 2002 (**Figure 4**). These measurements were used to develop flow mass balances for the streams that were modeled for temperature. (Actual stream flow data is available upon request from DEQ.)

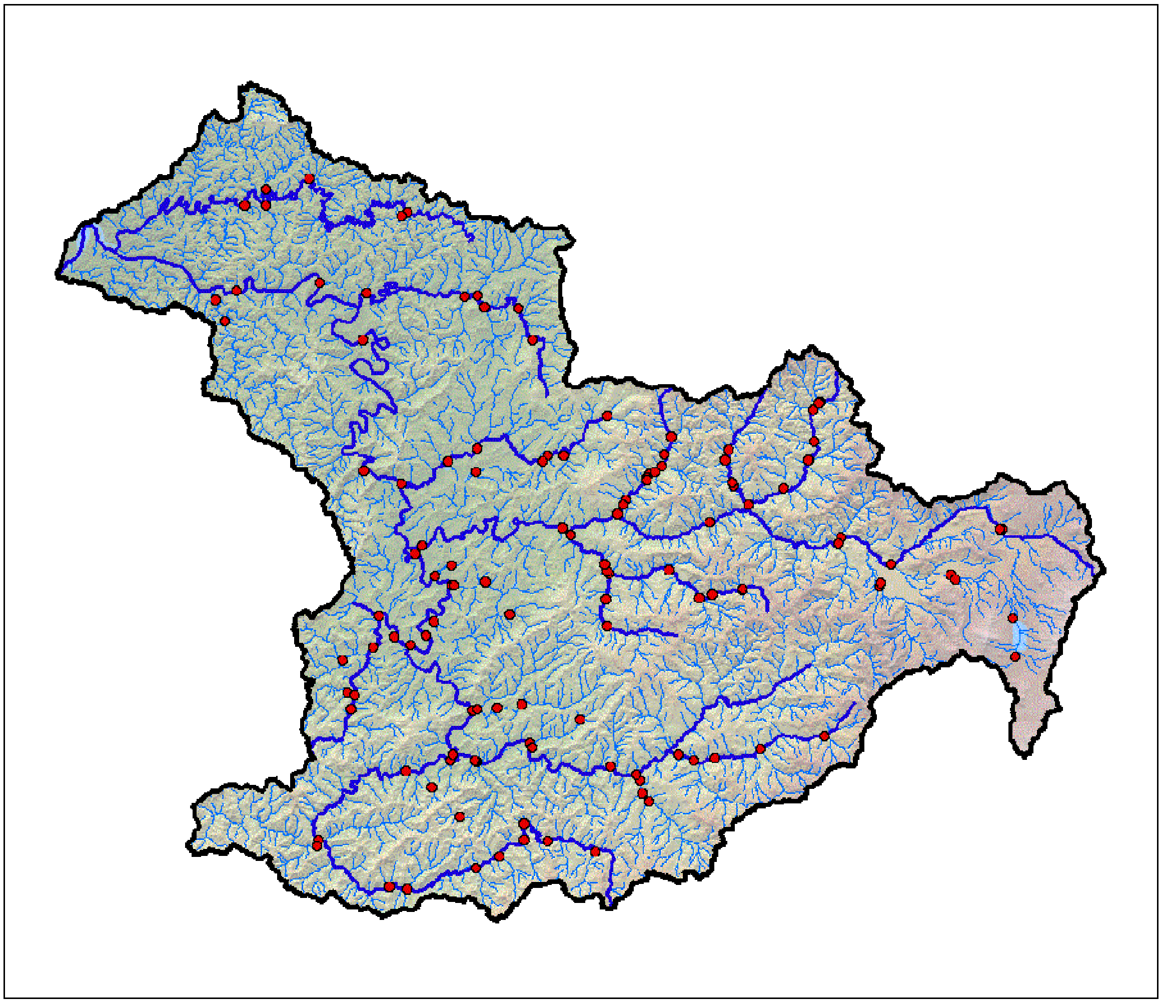

Figure 4. Instream flow measurement and gage locations (2000, 2001, 2002).

Stream Habitat Surveys

Ground-level habitat data was collected at several locations in the Umpqua Basin. Stream survey data focuses on vegetation classification and measurements, channel morphology measurements, and effective shade measurements.

ODFW has also collected stream habitat data (ODFW, 1997). Their data sets also focus on channel morphology, vegetation, and stream shade measurements. **Figure 5** displays the ODFW and other stream survey locations. (The stream habitat coverages used were last updated by ODFW in February 2004.)

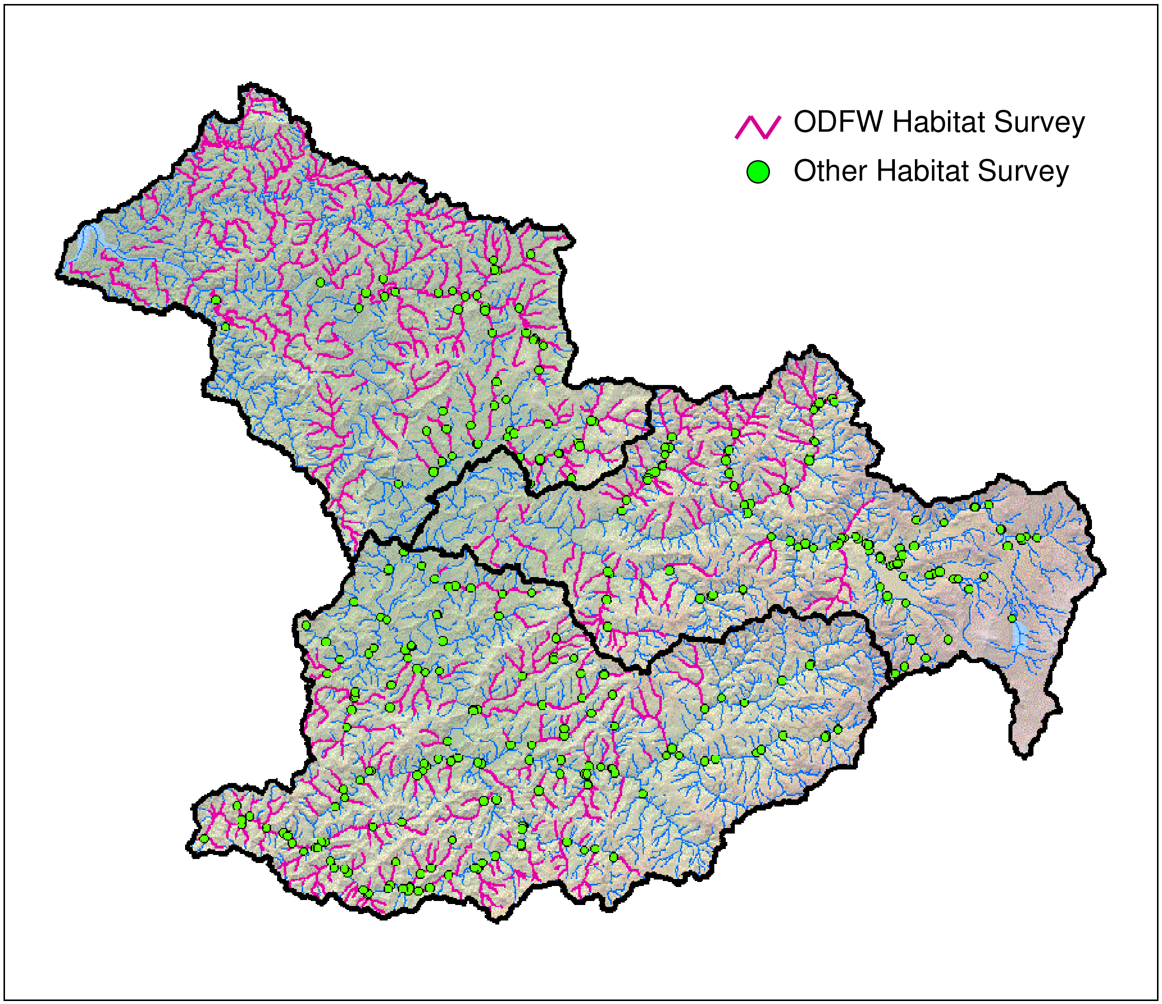

Figure 5. Ground Level Channel Morphology Measurement Sites

GIS AND REMOTELY SENSED DATA

Overview

A wealth of spatial data has been developed for the Umpqua Basin. The stream temperature TMDL relies extensively on GIS and remotely sensed data. Water quality issues in the Umpqua Basin are interrelated, complex and spread over hundreds of square miles. The TMDL analysis strives to capture these complexities using the highest resolution spatial data available. Some of the GIS data used to develop the Umpqua Basin Temperature TMDL are listed in **Table 1** along with the application for which it was used.

Table 1. Spatial Data and Application

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

10-Meter Digital Elevation Model (DEM)

A digital elevation model (DEM) consists of digital information that provides a uniform matrix of terrain elevation values (**Figure 6**). It provides basic quantitative data for deriving terrain elevation, slope, and topographic information. The 10-meter DEM contains a land surface elevation value for each 10-meter square. The U.S. Geological Survey, as part of the National Mapping Program, produces these digital cartographic/geographic data files. The DEMs were produced in 1999 and are available through the Oregon Geospatial Data Clearinghouse (OGDC).

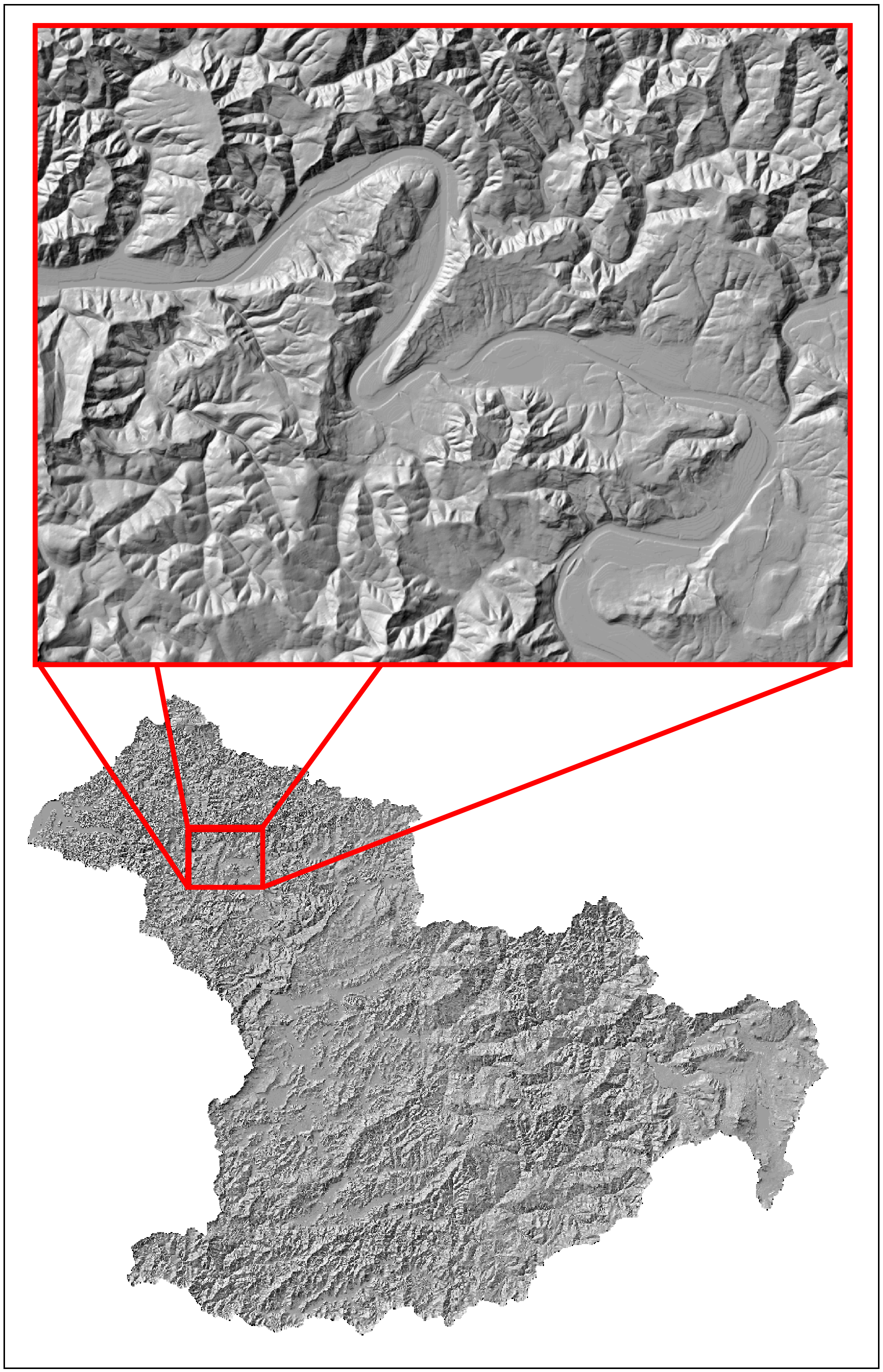

Figure 6. **The 10-meter DEM, hill-shaded for contrast (Zoom of Umpqua River with Elk Creek confluence at the right).**

Aerial Imagery – Digital Orthophoto Quads

Aerial imagery was used to:
Map stream features such as stream position, channel edges and wetted channel edges,
Map near stream vegetation,
Map instream structures such as dams, weirs, unmapped diversions/withdrawals, etc.

A digital orthophoto quad (DOQ) is a digital image of an aerial photograph in which displacements caused by the camera angle and terrain have been removed. In addition, DOQs are projected in map coordinates combining the image characteristics of a photograph with the geometric qualities of a map. The standard USGS digital orthophoto is black-and-white with one-meter pixels covering a USGS quadrangle. Black-and-white DOQs are available for the entire basin and may be downloaded from the Oregon Geospatial Data Clearinghouse (OGDC). Color DOQs are also available for portions of the Umpqua River Basin (**Figure 7**) and may be downloaded from the Douglas County Surveyor's Office.

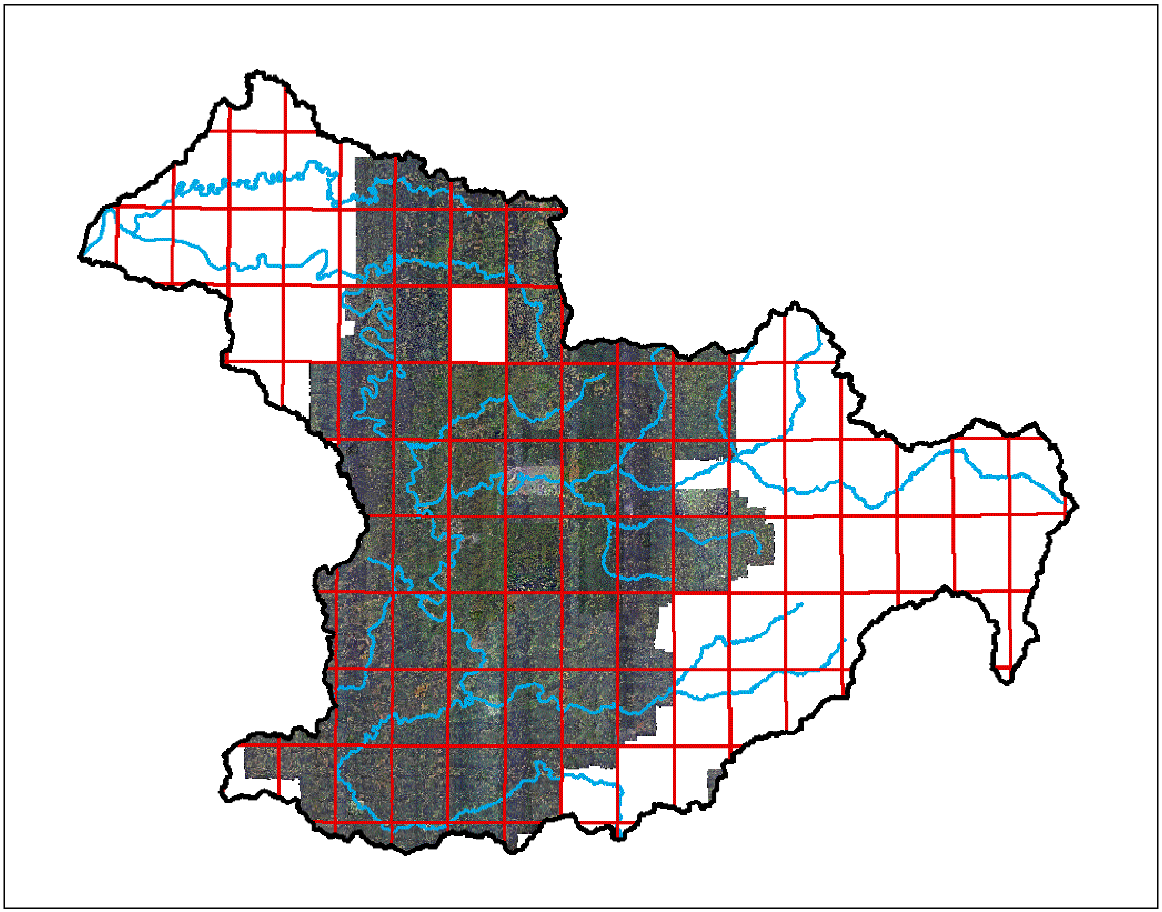

Figure 7. **Color DOQ coverage. Black-and-white DOQs are available for entire basin. Red lines indicate USGS quadrangle boundaries.**

WRIS and POD Data – Water Withdrawal Mapping

WRIS and POD Data were used to:
Map stream diversions/withdrawals,
Associate an estimated flow rate to each diversion/withdrawal.

The Oregon Water Resources Department (OWRD) maintains the Water Rights Information System (WRIS). WRIS is a database used to monitor information related to water rights. A separate database tracks points of diversions (POD). These two databases were linked by DEQ to map the locations of diversions, rates of water use and types of water use in the Umpqua River basin (**Figure 8**). Consumptive use was estimated using these data and incorporated in developing mass balance flow profiles for the simulated streams.

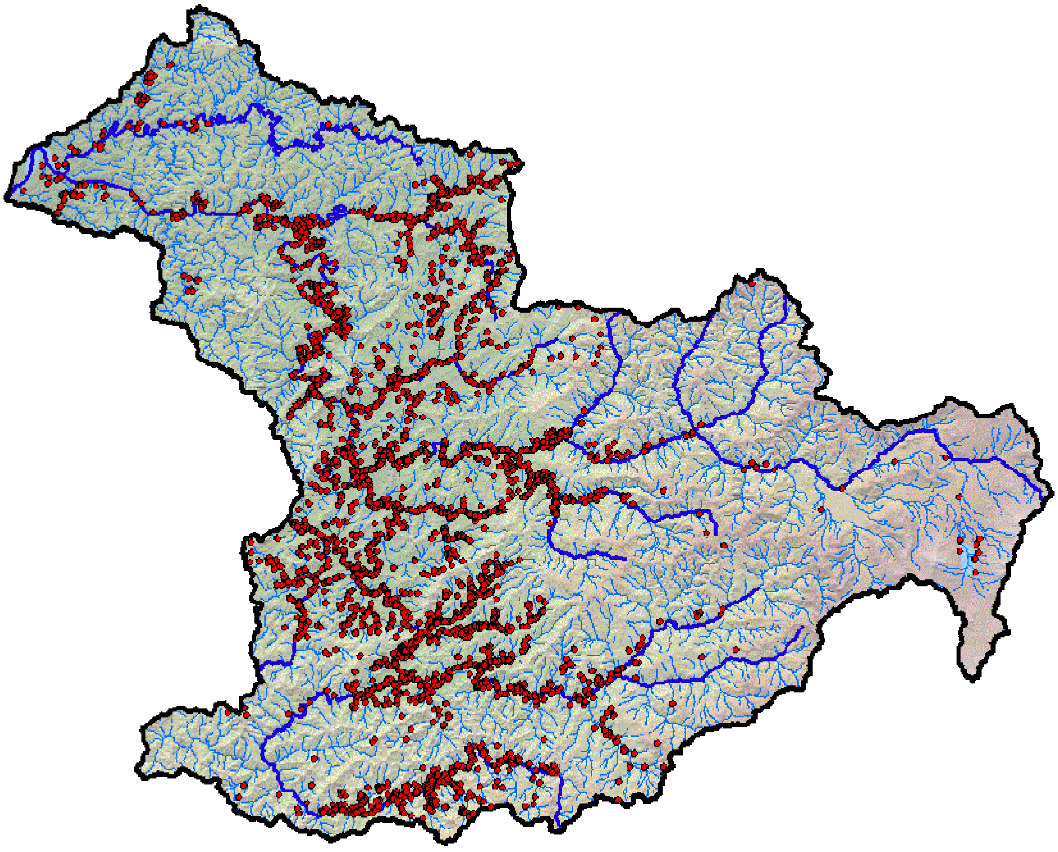

Figure 8. **Mapped points of diversion in the Umpqua River Basin derived from the WRIS and POD databases (Oregon Water Resources Department).**

Thermal Infrared Radiometry (TIR) Temperature Data

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

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

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

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

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

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

Umpqua River Basin TIR Data

DEQ contracted with Watershed Sciences, Inc. to collect TIR data in the Umpqua River Basin during 2000, 2001, and 2002 (**Figure 9**). Longitudinal river temperatures were sampled using thermal infrared radiometry (TIR) in separate flights for each stream. Temperature data sampled from the TIR imagery revealed spatial patterns that are variable due to localized stream heating, tributary mixing, and groundwater influences.

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

TIR-derived longitudinal stream temperature profiles are presented in **Section 4**. Each year's Umpqua Basin TIR survey report is available for download at the Oregon DEQ website (**Watershed Sciences, Inc., 2000, 2001, and 2002**). The TIR survey reports contain detailed flight information, results discussions, sample imagery, and longitudinal temperature profiles. (Actual TIR data is available upon request from DEQ. The TIR data is 17 Gigabytes and requires ArcView with Spatial Analyst.)

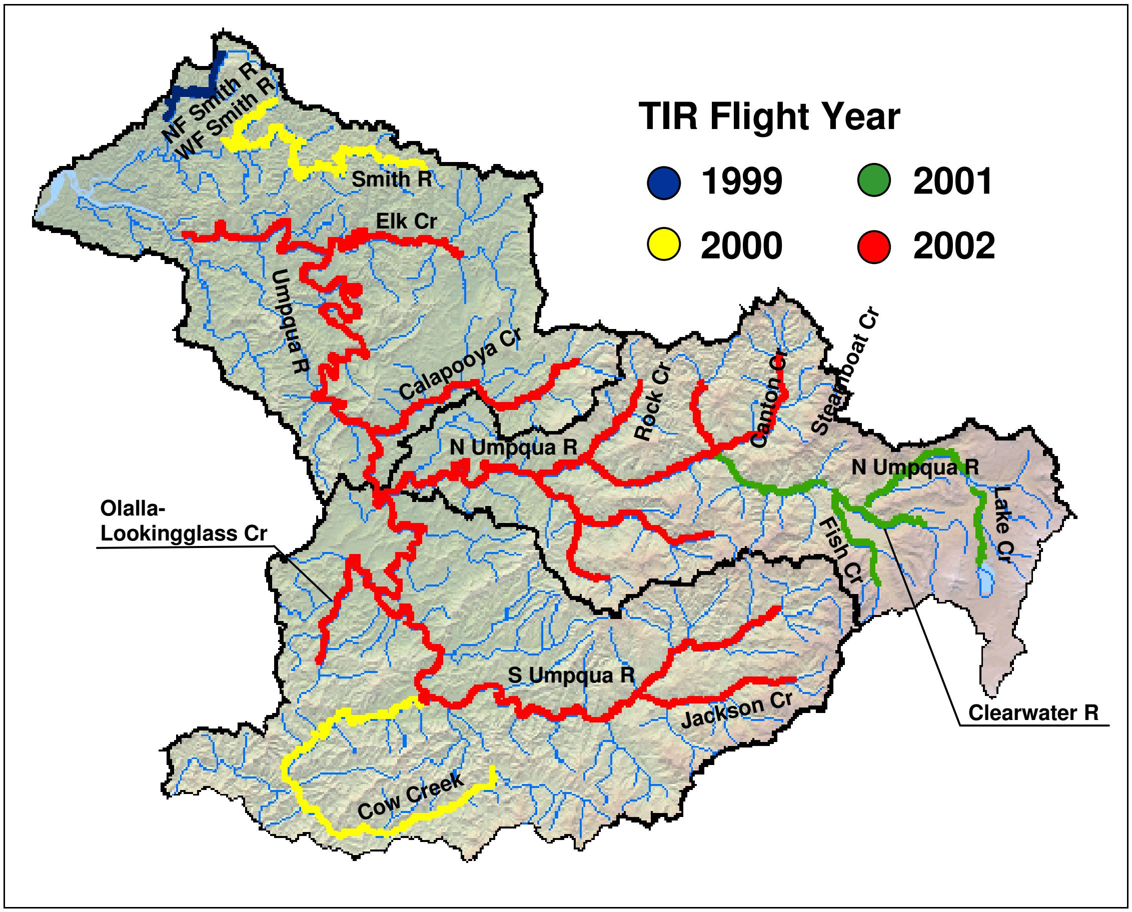

Figure 9. TIR flight paths in the Umpqua Basin.

SECTION 3. DERIVED DATA AND SAMPLED PARAMETERS

Several landscape scale GIS data sets were sampled to derive spatial stream data. Sampling density was user-defined and generally matched any GIS data resolution and accuracy. The sampled parameters used in the stream temperature analysis were:
Stream Position and Aspect
Stream Elevation and Gradient
Maximum Topographic Shade Angles (East, South, West)
Channel Width
TIR Temperature Data Associations
Vegetation

The following sections of this section detail the methodologies, results, resolution and accuracy for each derived data type.

CHANNEL MORPHOLOGY

Overview

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

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

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

Channel Width Assessment

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

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

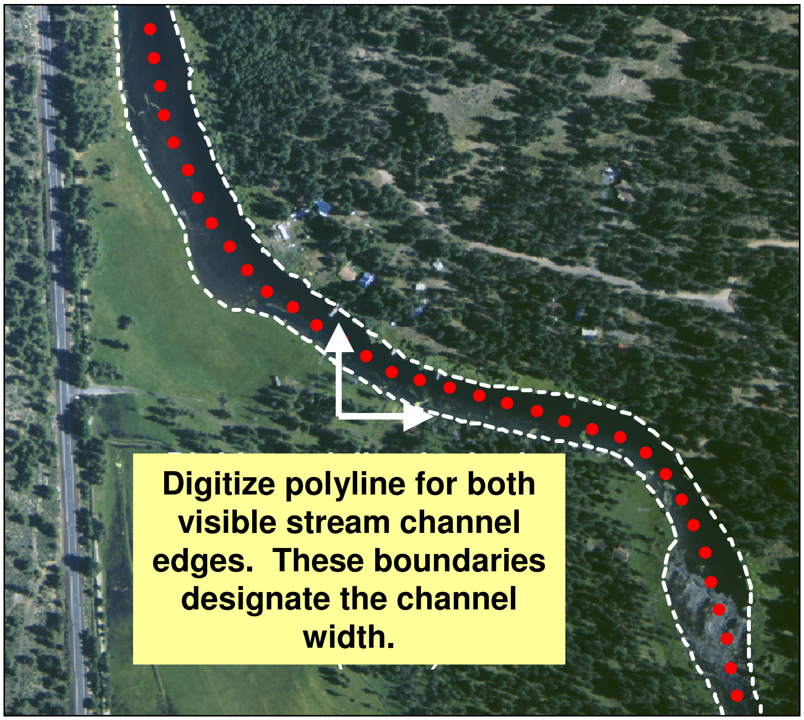

Figure 10. Digitized channel centerline, right bank, and left bank.

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

VEGETATION

Overview

Existing vegetation was digitized and sampled for the all of the streams shown in **Figure 11** by DEQ and Insight Consultants. TTools was used to sample the vegetation coverage and derive Heat Source inputs. Existing heights and densities were assigned according to aerial photograph analysis and ground level data collection.

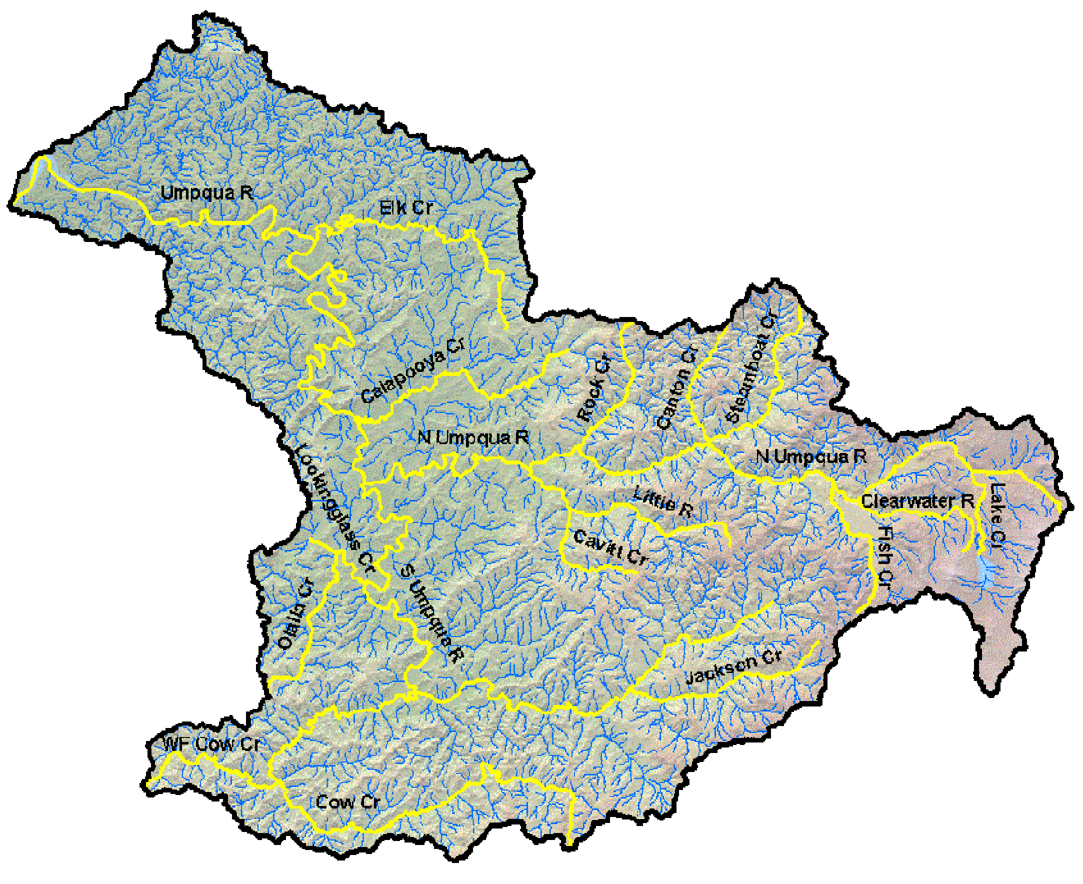


Figure 11. Streams where near stream vegetation and channel morphology were digitized from digital orthophoto quads.

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

Vegetation plays an important role in regulating radiant heat in stream thermodynamic regimes.

Channel morphology is often highly influenced by vegetation type and condition by affecting flood plain and instream roughness, contributing coarse woody debris, and influencing sedimentation, stream substrate compositions and stream bank stability.

Vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity and lower wind speeds along stream corridors.

Riparian and instream nutrient cycles are affected by vegetation.

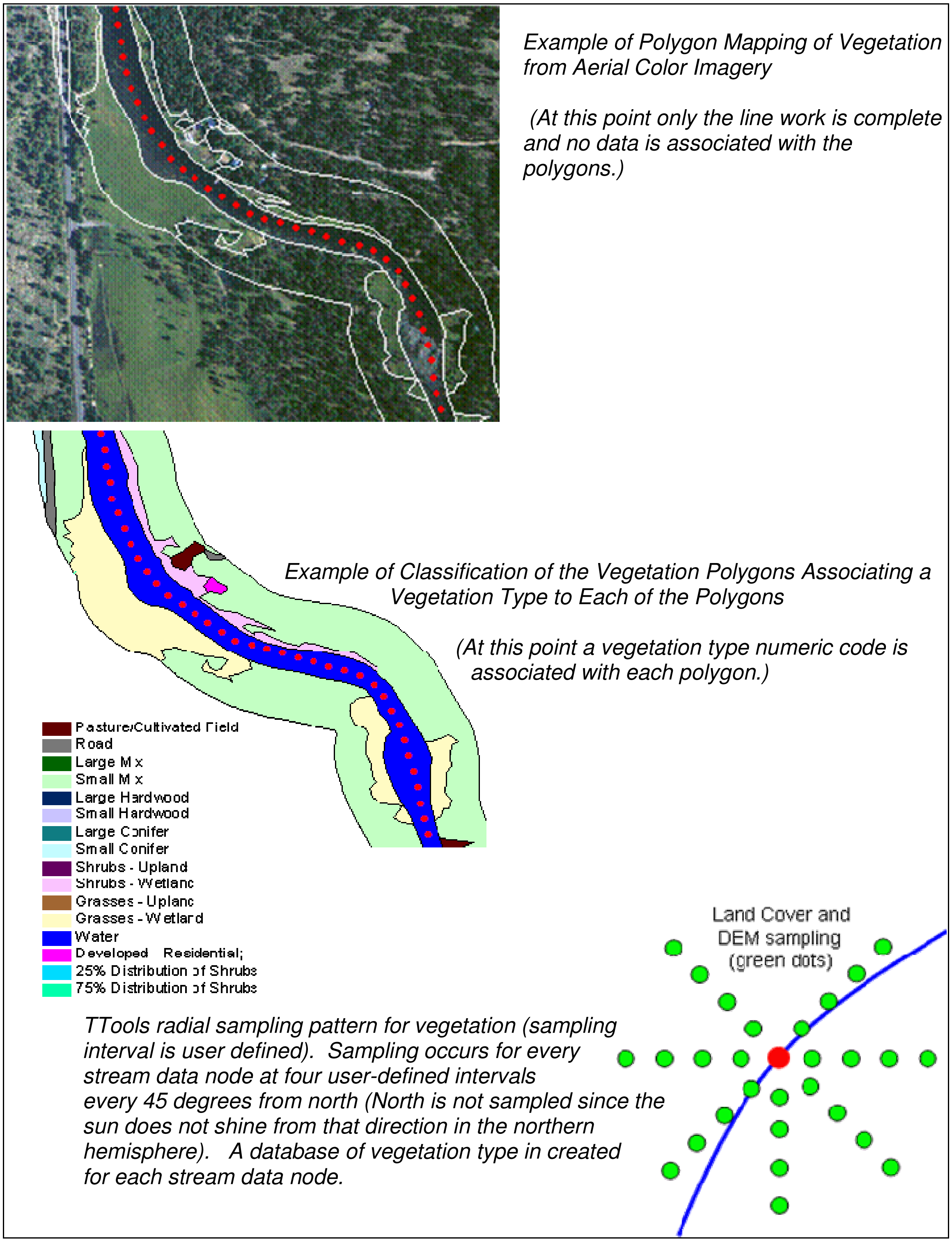
Vegetation – Mapping, Classification and Sampling

With the recognition that vegetation is an important parameter in influencing water quality, DEQ made the development of vegetation data sets in the Umpqua River Basin a high priority. Variable vegetation conditions in the Umpqua River Basin require a higher resolution than currently available GIS data sources. To meet this need, DEQ has mapped vegetation using Digital Orthophoto Quads (DOQs) at a 1:5,000 map scale. Vegetation features were mapped 300 feet in the transverse direction from channel edge. Vegetation data is developed by DEQ in successive steps.

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

Step 2. Basic vegetation types were categorized and assigned to individual polygons. The vegetation categories used in this effort were aggregate vegetation groups, such as: conifers, hardwoods, shrubs, etc.
Step 3. Automated sampling was conducted on classified vegetation spatial data sets in 2-dimensions using TTools. Every 50 meters along the stream (i.e., in the longitudinal direction), the vegetation was sampled radially every 15 meters; starting at the channel center, out to 60 meters. This sampling rate resulted in 928 measurements of vegetation per every mile of stream.
Step 4. Ground level vegetation data was statistically summarized and sorted by vegetation type. Median values for vegetation height and density were then used to describe DEQ vegetation classifications.

Figure 12 summarizes the steps followed for vegetation classification. More detailed information can be found in *Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0* (Boyd, Kasper, 2003), which can be downloaded from the DEQ website. (http://www.heatsource.info/)



Example of Polygon Mapping of Vegetation from Aerial Color Imagery

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

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

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

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

Figure 12. Steps for digitizing and classifying vegetation.

Potential Vegetation

On March 30, 2004 DEQ held a meeting with members of the Umpqua Basin TMDL Advisory Committee to determine potential vegetation. Potential vegetation is essentially the mature species composition, height, and density of vegetation that would occur in the absence of human disturbances. These conditions were used in stream temperature modeling scenarios to quantify the impacts of nonpoint source solar radiation loads, and ultimately to develop nonpoint source load allocations for the TMDL.

The Umpqua River Basin is large and consists of a variety of unique ecosystems, each capable of supporting different types of vegetation. The committee agreed that EPA Level IV Ecoregions[3] are appropriate geographic divisions to be used when determining potential vegetation (**Figure 13**). Ecoregions are classified based on multiple parameters, including elevation, climate, soils, vegetative communities, geology, physiography, hydrology, land use, etc.

The committee agreed that each Level IV ecoregion has unique vegetation species, heights, and densities for the following three categories:

Conifer
Hardwood
Mixed Conifer & Hardwood

Table 2 summarizes the potential vegetation species compositions, heights, and densities that the committee suggested for each Level IV Ecoregion.

The methodology for applying potential vegetation in the temperature models was based on the following general rules:

Existing stands of trees were assigned their potential heights and densities. Existing mature trees were left as-is, while immature tree stands were assigned the appropriate potential (mature) heights.

Non-vegetated areas which are capable of supporting vegetation (i.e., clear cuts, fields, recently disturbed areas) were assigned the nearest neighbor vegetation type on the same side of the stream.

Areas that are naturally incapable of supporting vegetation were left as-is (i.e., barren steep rocky slopes, bedrock outcrops, etc.)

Serpentine soils were left as-is since those areas are poor sites for vegetation.

Developed areas (i.e., roads, buildings, rail, dams, etc.) were assigned the nearest neighbor vegetation.

Natural disturbance was randomly applied for temperature modeling (**see Section 5**).

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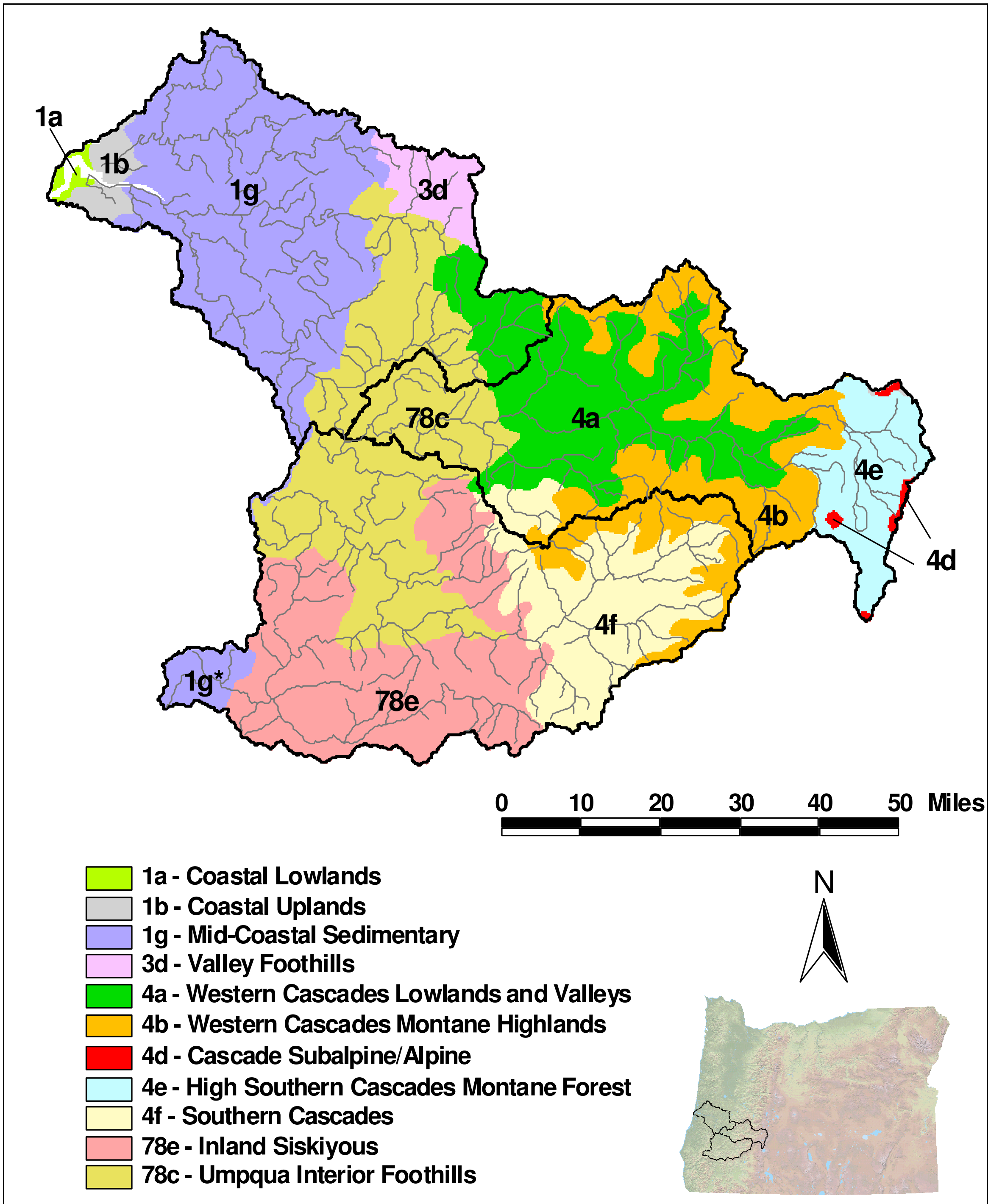
[3] **Citation:** Thorson, T.D., Bryce, S.A., Lammers, D.A., Woods, A.J., Omernik, J.M., Kagan, J., Pater, D.E., and Comstock, J.A., 2003. Ecoregions of Oregon (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,500,000).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



*Umpqua Basin Technical Advisory Committee recommended that Ecoregion 1g surrounding West Fork Cow Creek actually be considered as Ecoregion 78e. Therefore, Ecoregion 1g in the southwest corner of the basin, surrounding West Fork Cow Creek will be assigned the same system potential land cover as Ecoregion 78e.

Figure 13. EPA Level IV Ecoregions in the Umpqua River Basin

Table 2. Potential Vegetation by Ecoregion

Level IV Ecoregion	Vegetation Type	Average Potential Height (feet)	Average Potential Density
4a	Conifer (Douglas Fir)	170	80%
	Hardwood (ash, oak, maple, white alder, black cottonwood)	80	60%
	Mixed Conifer and Hardwood	100	65%
4b	Conifer (Douglas Fir)	170	80%
	Hardwood (ash, oak, maple, white alder, black cottonwood)	80	60%
	Mixed Conifer and Hardwood	100	65%
4f	Conifer (Douglas Fir and various conifer mix)	140	80%
	Conifer (Douglas Fir)	170	70%
	Hardwood (ash, oak, maple, white alder, black cottonwood)	80	60%
	Mixed Conifer and Hardwood	100	65%
4e	True Fir	140	70%
	meadow remains as meadow (i.e., Lake Creek)		
78e	Conifer (Douglas Fir)	130	70%
	Hardwoods (alder, ash, maple, live oak)	75	60%
	Mixed Conifer and Hardwood	100	65%
78c	Conifer (Douglas Fir)	125	60%
	Hardwood (ash, oak, white alder)	70	60%
	Mixed Conifer and Hardwood	95	60%
1g	Conifer (Douglas Fir dominant with Grand Fir, Alder, Hemlock)	170	80%
	Hardwood (alder, red cedar, big leaf maple)	90	70%
	Mixed Conifer and Hardwood	110	70%
1b	Conifer (Spruce, Hemlock)	135	80%
	Hardwood - (alder dominant with maple)	90	70%
	Mixed Conifer and Hardwood	100	75%
3d	Conifer (Douglas Fir dominant with Hemlock)	150	80%
	Hardwood (Ash, Maple, Alder)	40	65%
	Mixed Conifer and Hardwood	80	70%
1a	Not forested	-	-

Fire suppression and re-planting after timber harvest may result in more trees per acre than might occur in the absence of human impact. However, if such trees are immature they may not be shading the stream to their maximum potential. Tree height is one major determining factor of effective shade. Determining the potential effective shade must account for all aspects of vegetation geometry (height, density, and overhang), as opposed to just the number of trees in a given area.

HYDROLOGY

Mass Balance Development

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

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

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

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

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

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

Figure 14 displays the longitudinal flow mass balances derived from measured flows, OWRD points of diversion data and TIR temperature data. The “natural” flow shown on each chart assumes that there are no withdrawals, diversions, returns, or reservoirs. The “401 Flows” represent the minimum bypass reach flows described in Pacificorp’s 401 Certification.

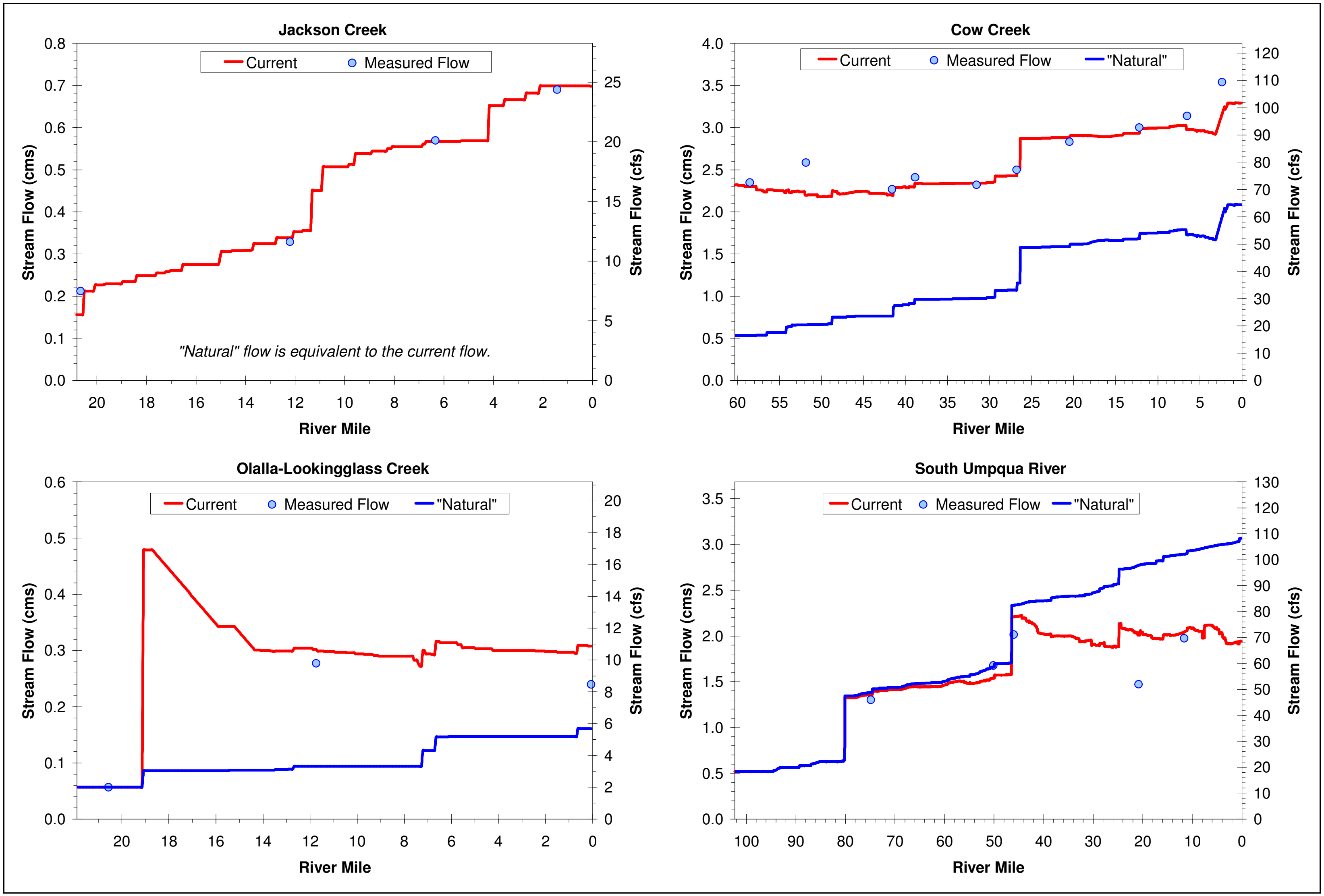


Figure 14. **Derived Flow Mass Balances**

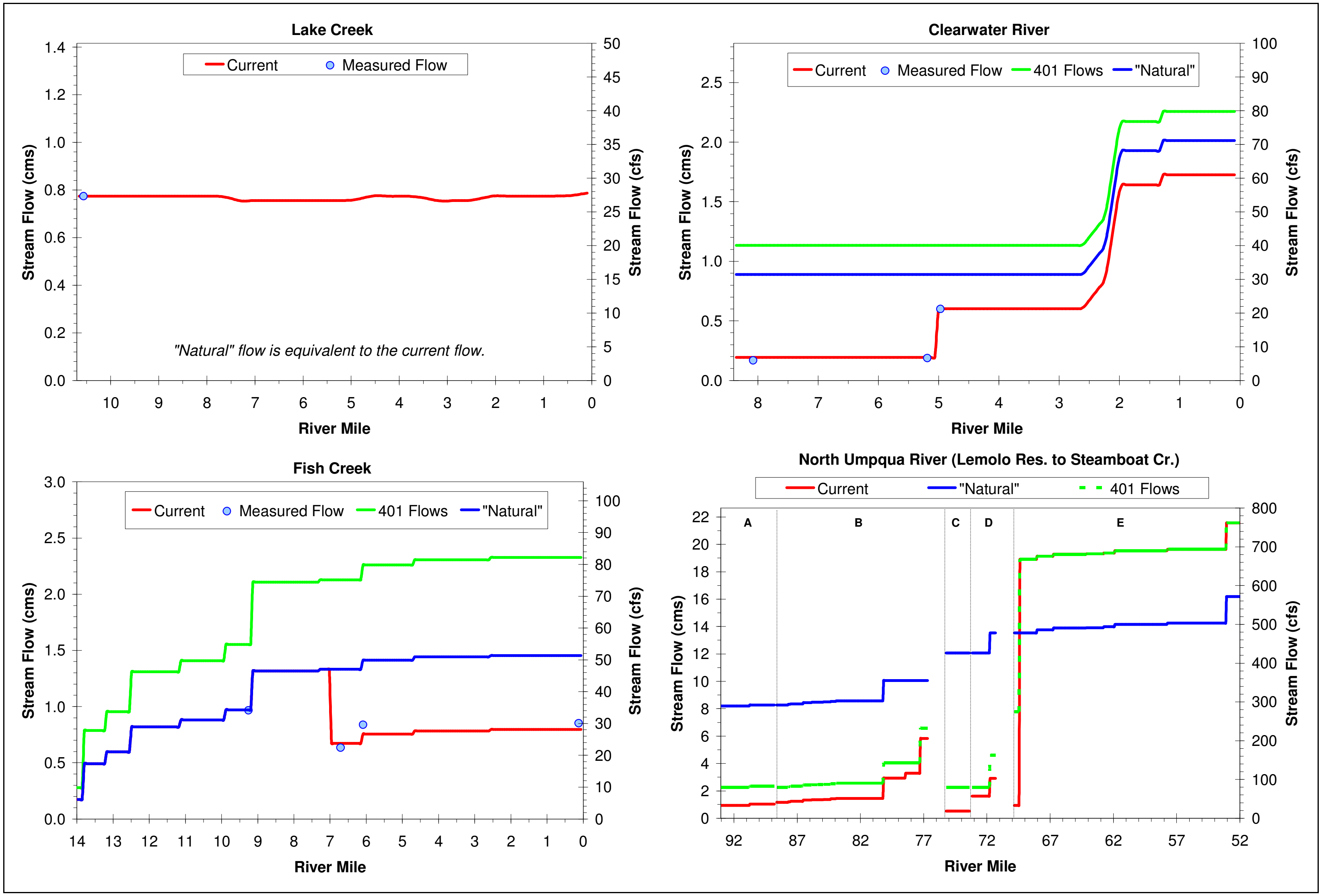


Figure 14 (continued). Derived Flow Mass Balances

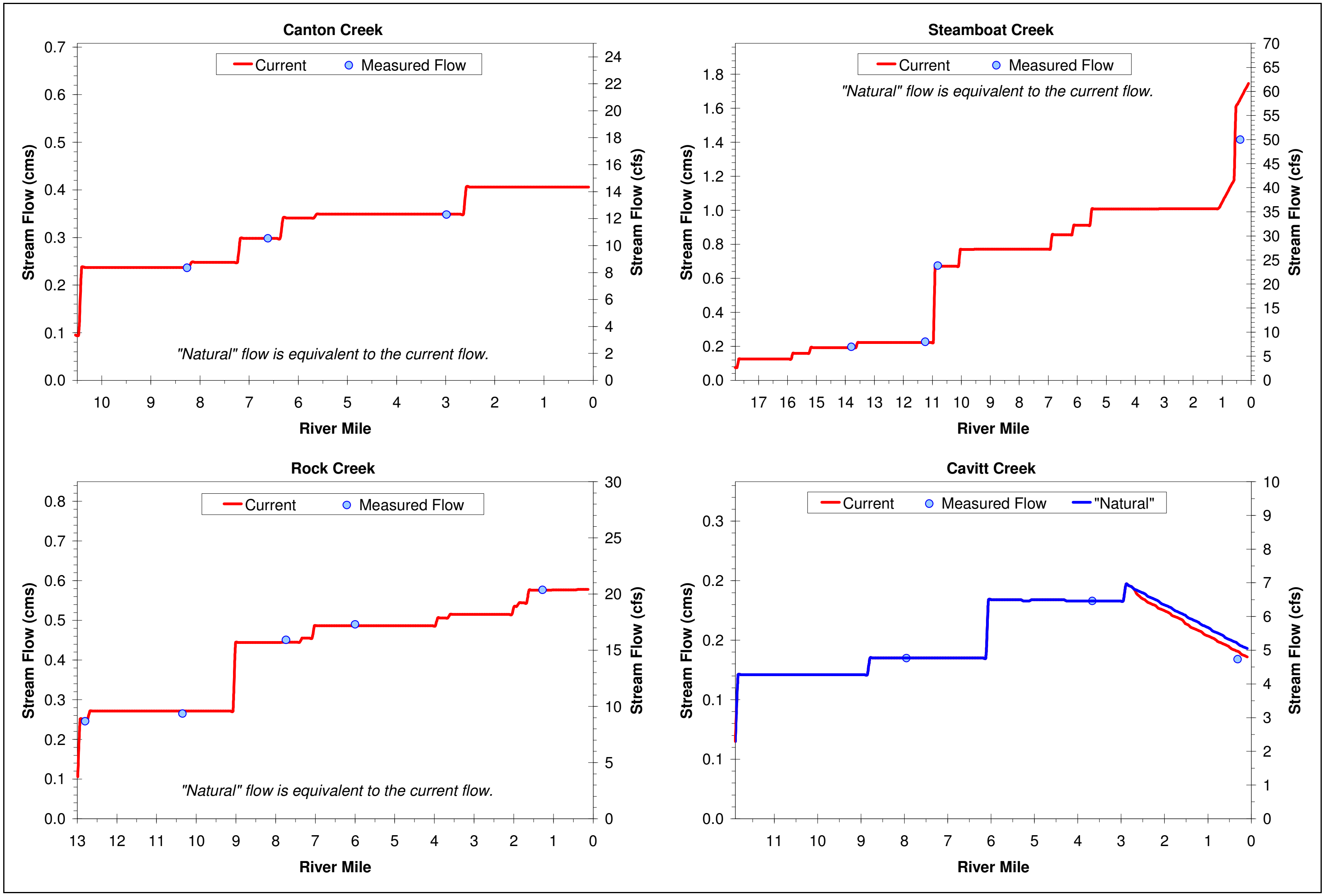


Figure 14 (continued). Derived Flow Mass Balances

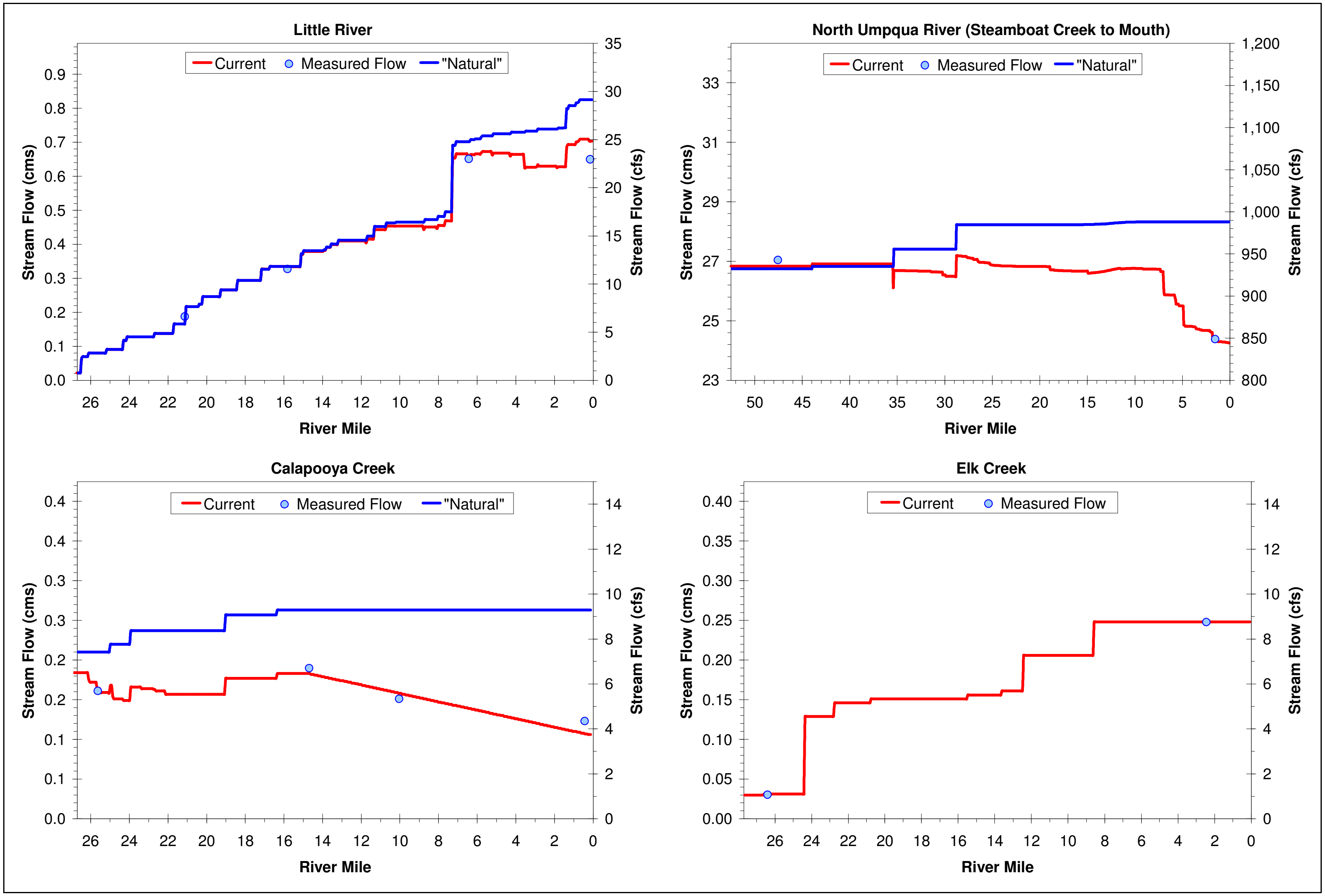


Figure 14 (continued). Derived Flow Mass Balances

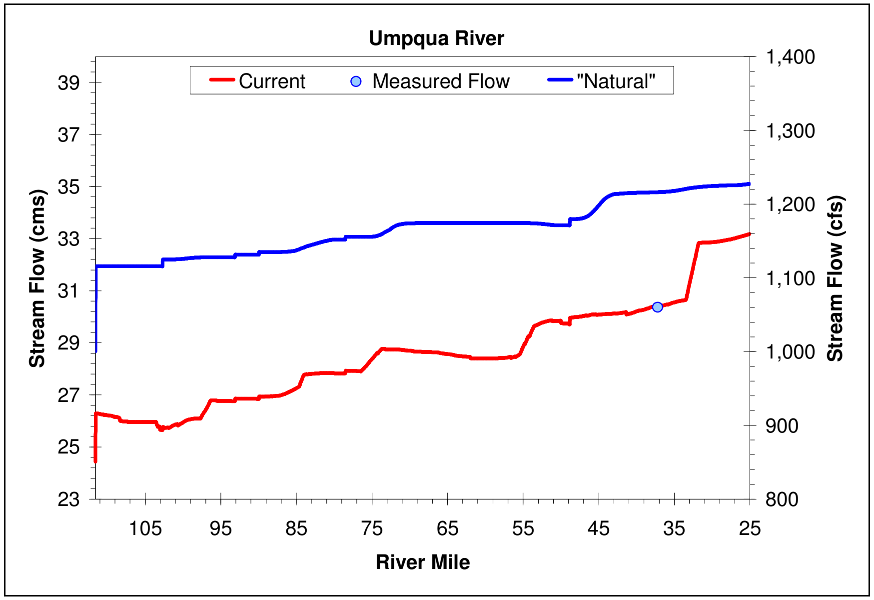


Figure 14 (continued). Derived Flow Mass Balances

SECTION 4. SIMULATIONS

EFFECTIVE SHADE

Overview

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

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

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

Effective shade was simulated every 50 longitudinal meters along the stream. Simulation periods were for late July and early August. Effective shade simulations were performed for a total of 563 stream miles in the Umpqua River Basin (see Chapter 5: *The Umpqua River Basin Temperature TMDL*).

Effective shade simulation validation was conducted by comparing simulated results with ground level measured shade values. Solar Pathfinder® data was used to collect all ground level data. Shade simulations have a standard error of 7.6% when compared to these values. The correlation coefficient between measured and simulated values is 0.84. The statistical significance of model output is roughly 8% effective shade.

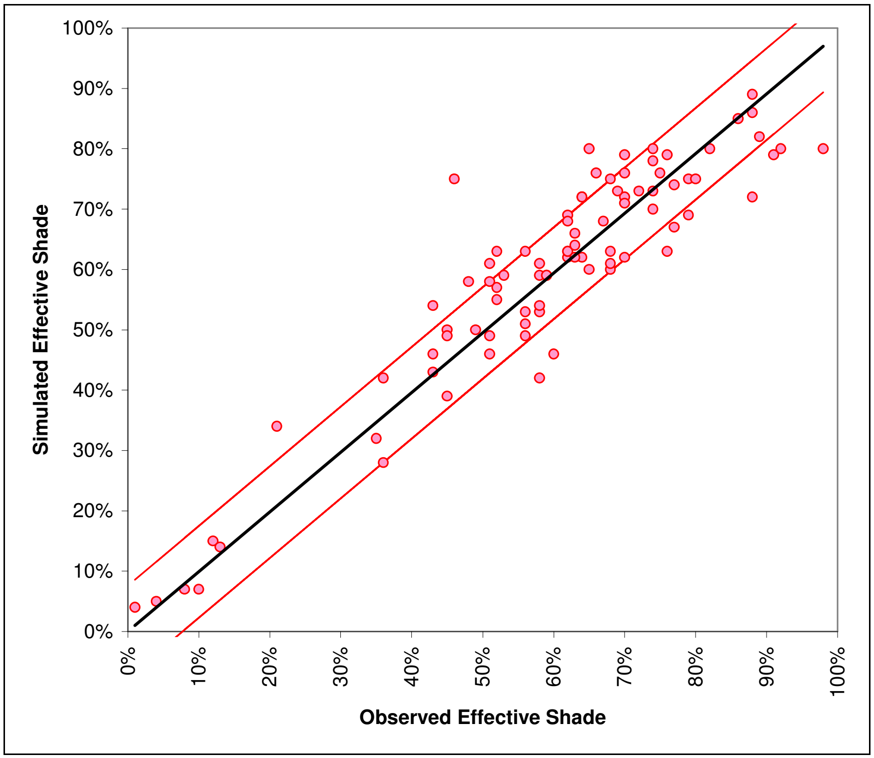


Figure 15. Effective Shade Simulation Validation

Total Daily Solar Heat Load Analysis

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

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

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

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

where,

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

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

STREAM TEMPERATURE SIMULATIONS

Overview

Heat Source version 7.0 was used to model stream temperatures in the Umpqua River Basin. For detailed information regarding Heat Source and the methodologies used, refer to "Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0" (Boyd, Kasper, 2003).

Spatial and Temporal Scale

The length of the defined finite difference and data input sampling rate was 50 meters. Output was generated for every 100 meters. The temperature model was calibrated to analyze and predict stream temperature for 20 days on most streams. However, data availability limited the simulation period for some North Umpqua Subbasin streams to 4 days. Prediction time steps were limited by stability considerations for the finite difference solution method. Simulation periods represent the critical summertime period. Simulations were performed for a total of 563 stream miles in the Umpqua River Basin. **Table 3** lists the spatial extent and simulation period by stream.

Table 3. Stream Temperature Simulation Periods and Extents

River/Stream	Simulation Period	Simulation Extent
Jackson Creek	July 12-31, 2002	Falcon Creek to Mouth
Cow Creek	July 12-31, 2000	Galesville Reservoir to Mouth
Olalla-Lookingglass Creek	July 12-31, 2002	Berry Creek to Mouth
South Umpqua River	July 12-31, 2002	Castle/Black Rock Forks to Mouth
Lake Creek	July 8-11, 2001	Diamond Lake to Mouth
Clearwater River	July 8-11, 2001	Stump Lake to Mouth
Fish Creek	July 8-11, 2001	Clear Creek to Mouth
North Umpqua River (upper)	July 8-11, 2001	Lemolo Reservoir to Steamboat Creek
Canton Creek	July 12-31, 2002	Pass Creek to Mouth
Steamboat Creek	July 12-31, 2002	Little Rock Creek to Mouth
Rock Creek	July 12-31, 2002	Northeast Rock Creek to Mouth
Cavitt Creek	July 12-31, 2002	Cultus Creek to Mouth
Little River	July 12-31, 2002	Hemlock Creek to Mouth
North Umpqua River (lower)	July 12-31, 2002	Steamboat Creek to Mouth
Calapooya Creek	July 12-31, 2002	North Fork Calapooya River to Mouth
Elk Creek	July 12-31, 2002	Wise Creek to Mouth
Umpqua River	July 12-31, 2002	Forks to Tidewater

Total Simulation Extent:
563 stream miles

Simulation Accuracy

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

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

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

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

where,

X_{sim} = the simulated temperature;
X_{obs} = the observed or measured temperature;
n = the sample size.

Error statistics were calculated for both the spatial (TIR) and temporal (hourly instream measurements) temperatures. **Table 4** contains the error statistics for each stream simulated.

Table 4. Stream Temperature Simulation Accuracy

	TIR (Spatial)				Hourly Measurements (Temporal)			
Stream	**n**	**ME**	**MAE**	**RMSE**	**n**	**ME**	**MAE**	**RMSE**
Jackson Creek	336	-0.13	0.35	0.43	720	-0.37	0.70	0.88
Cow Creek	971	0.08	0.32	0.39	1,692	-0.61	0.88	1.19
Olalla-Lookingglass Creek	308	-0.02	0.71	0.88	480	-0.61	1.56	2.09
South Umpqua River	1,459	-0.14	0.52	0.66	1,473	-1.04	1.36	1.64
Lake Creek	172	0.00	0.20	0.25	48	0.52	0.83	0.98
Clearwater River	135	-0.07	0.40	0.68	192	-0.70	1.02	1.32
Fish Creek	226	-0.01	0.24	0.31	192	-1.30	1.44	1.76
Upper North Umpqua River	571	-0.18	0.32	0.42	336	-0.39	0.83	1.05
Canton Creek	170	-0.31	0.45	0.57	480	-0.96	1.06	1.42
Steamboat Creek	287	-0.11	0.40	0.54	480	-1.78	1.78	1.93
Rock Creek	209	-0.08	0.37	0.46	274	0.00	0.87	1.04
Cavitt Creek	192	0.06	0.39	0.50	72	-0.93	1.24	1.54
Little River	431	-0.10	0.37	0.46	480	-1.55	1.80	2.26
Lower North Umpqua River	846	0.04	0.19	0.23	771	-0.42	0.75	0.95
Calapooya Creek	596	-0.01	0.58	0.73	1,195	-0.74	1.11	1.56
Elk Creek	446	-0.26	0.83	1.01	261	-1.00	1.24	1.45
Umpqua River	1,395	-0.07	0.33	0.42	392	0.87	1.16	1.43
	Total n	*Average ME*	*Average MAE*	*Average RMSE*	*Total n*	*Average ME*	*Average MAE*	*Average RMSE*
	8,750	*-0.08*	*0.41*	*0.53*	*9,538*	*-0.65*	*1.15*	*1.44*

Figure 16 shows the measured TIR temperatures versus the simulated temperatures. Individual figures for the temporal data are not included in this appendix. (The models are available upon request from DEQ.)

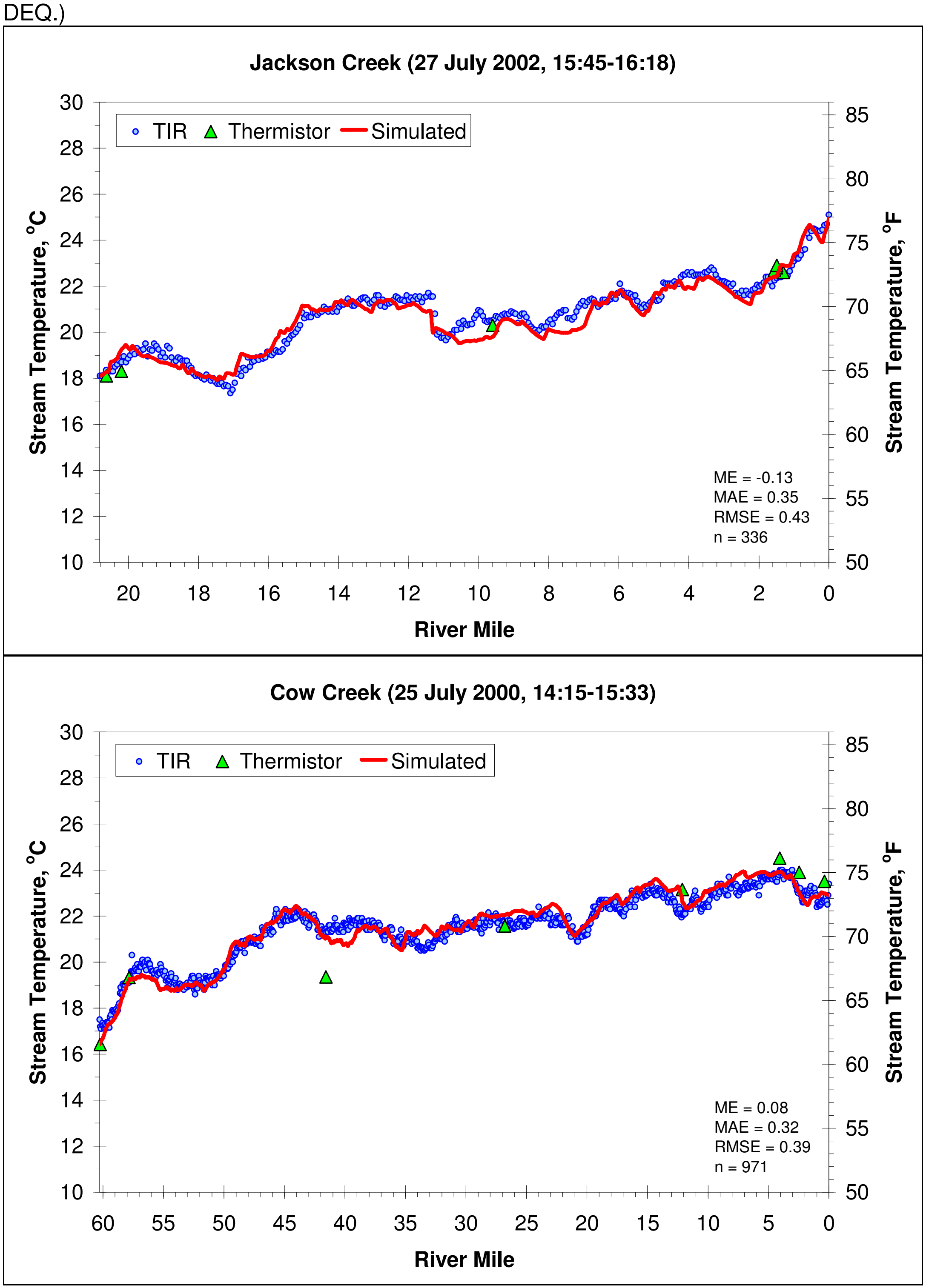
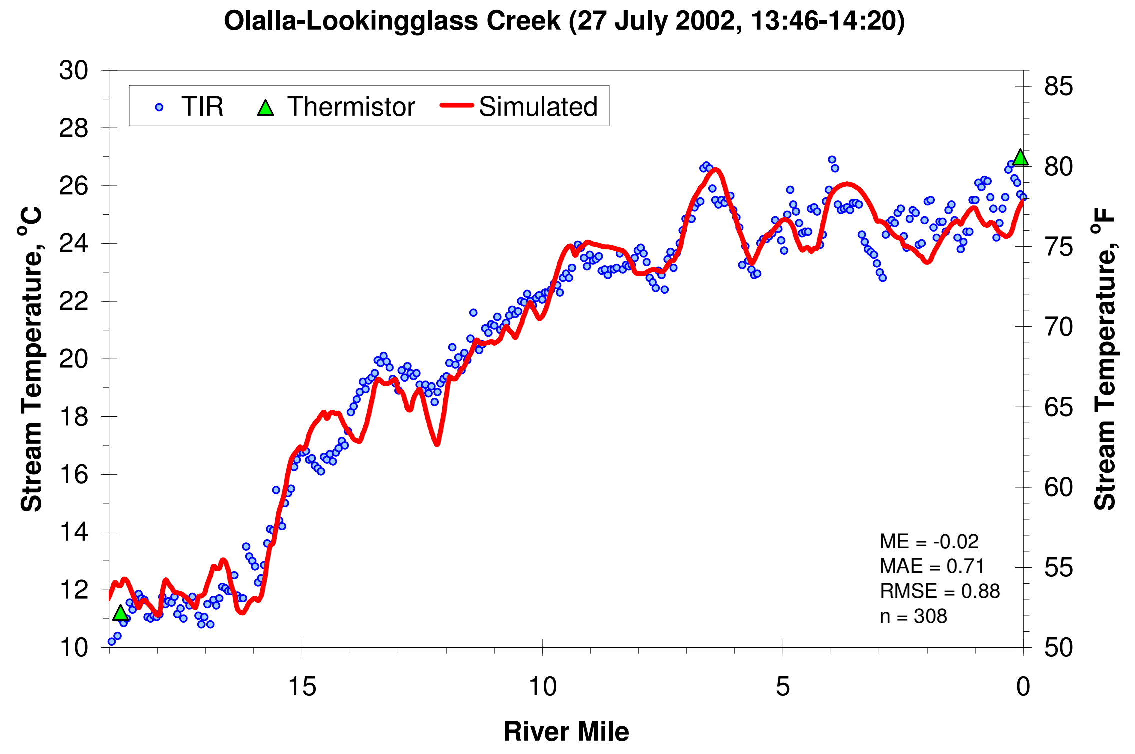
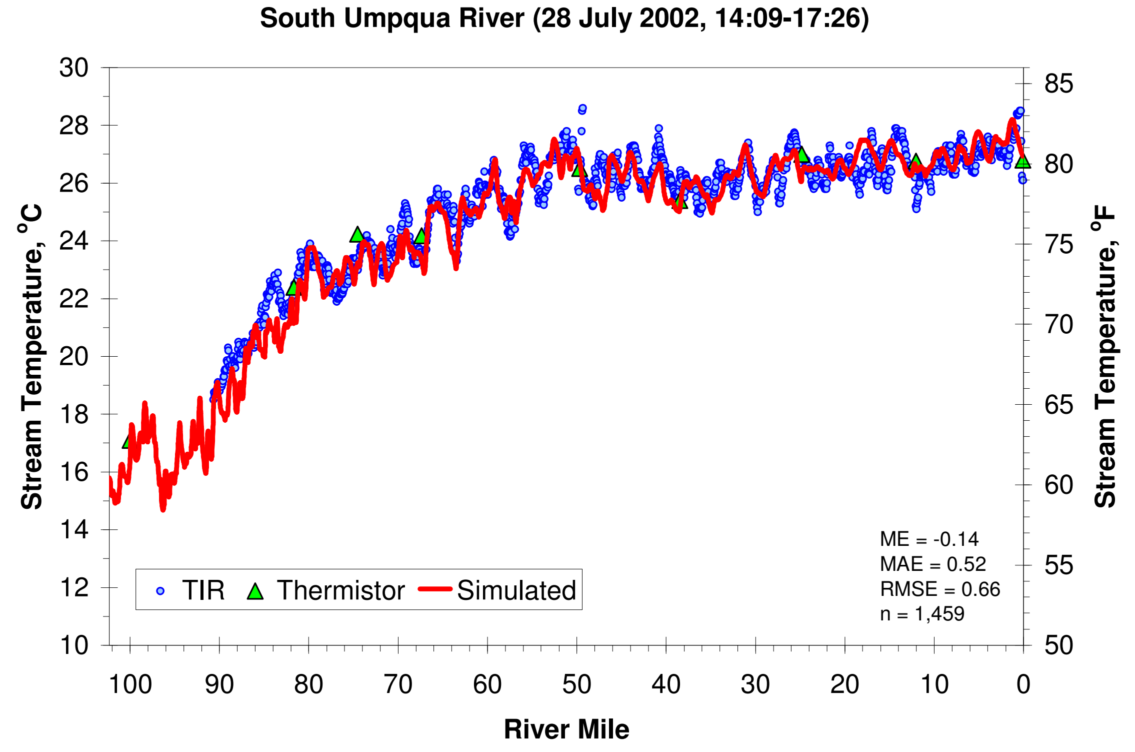


Figure 16. Current Condition Stream Temperature Simulation Calibration Results



Olalla-Lookingglass Creek (27 July 2002, 13:46-14:20)



South Umpqua River (28 July 2002, 14:09-17:26)

Figure 16 (continued). Current Condition Stream Temperature Simulation Calibration Results

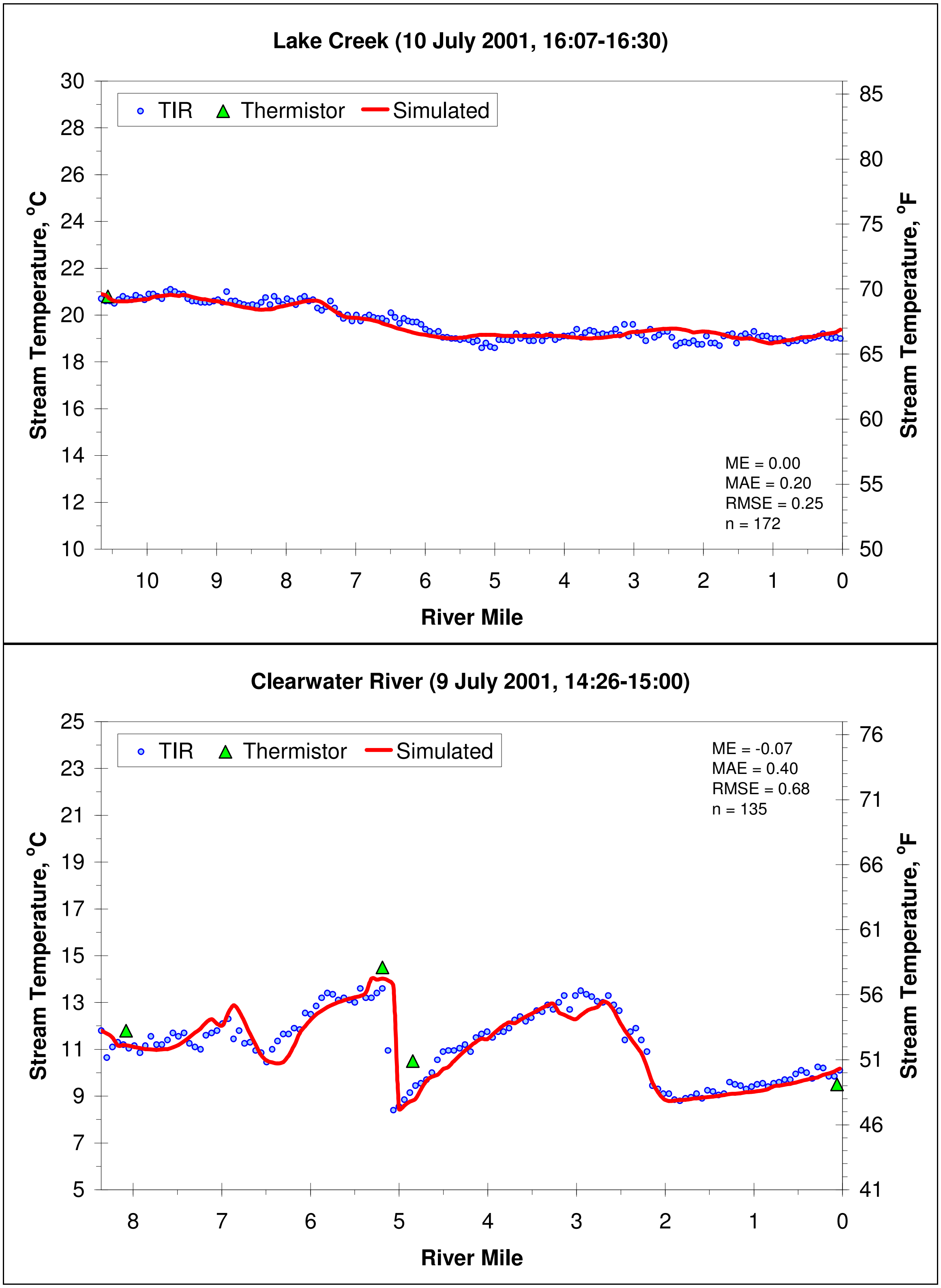


Figure 16 (continued). Current Condition Stream Temperature Simulation Calibration Results

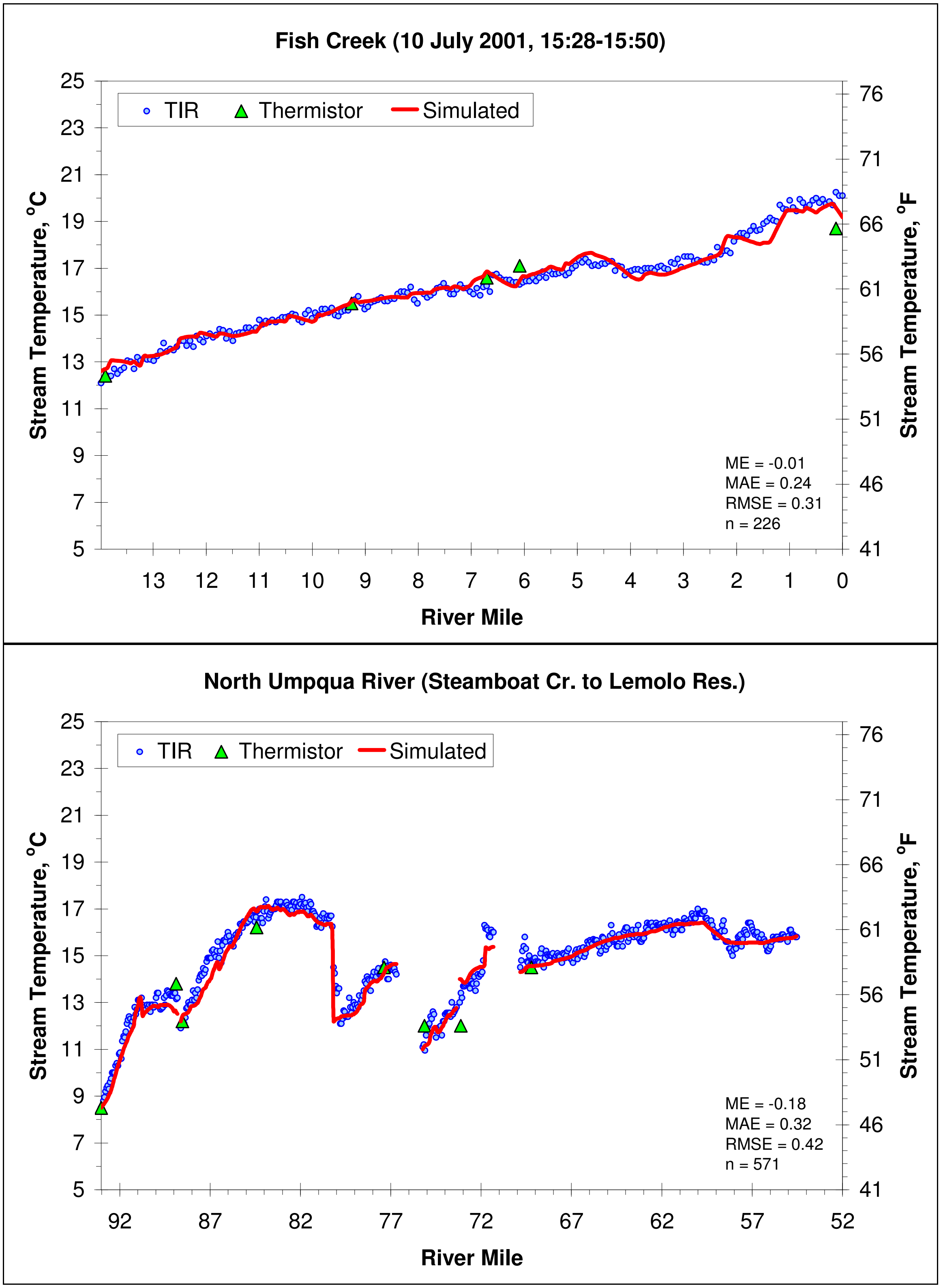
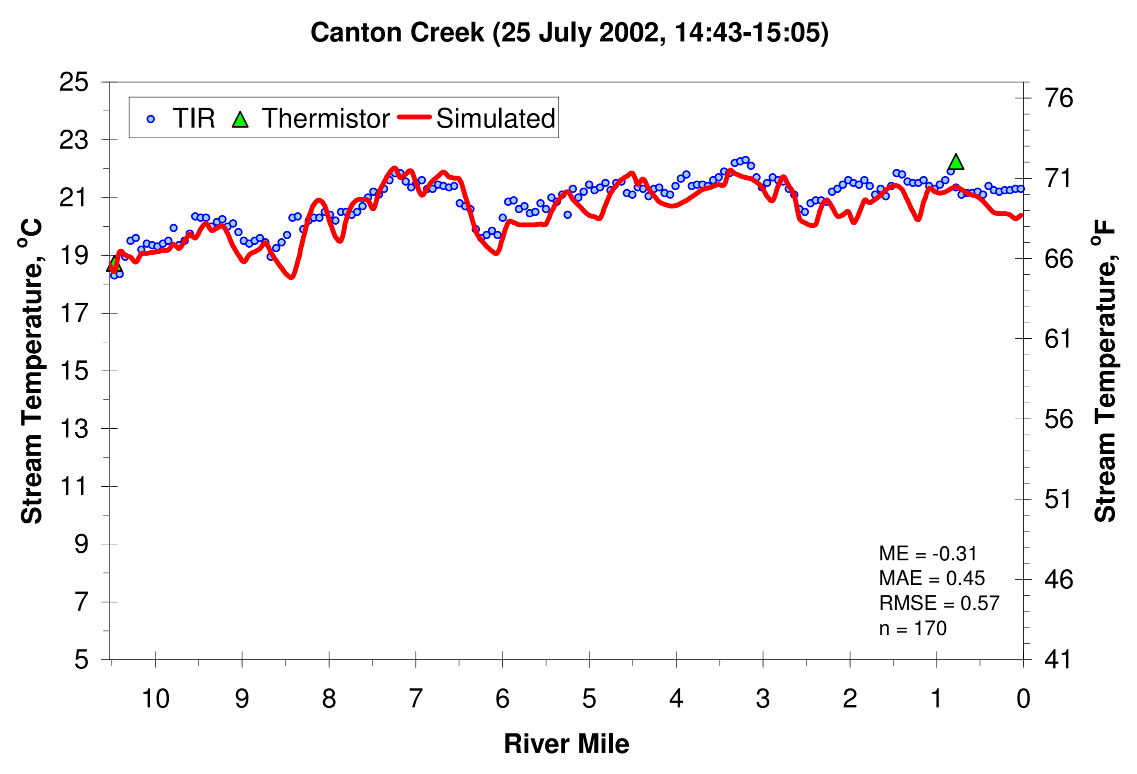


Figure 16 (continued). Current Condition Stream Temperature Simulation Calibration Results


Canton Creek (25 July 2002, 14:43-15:05)

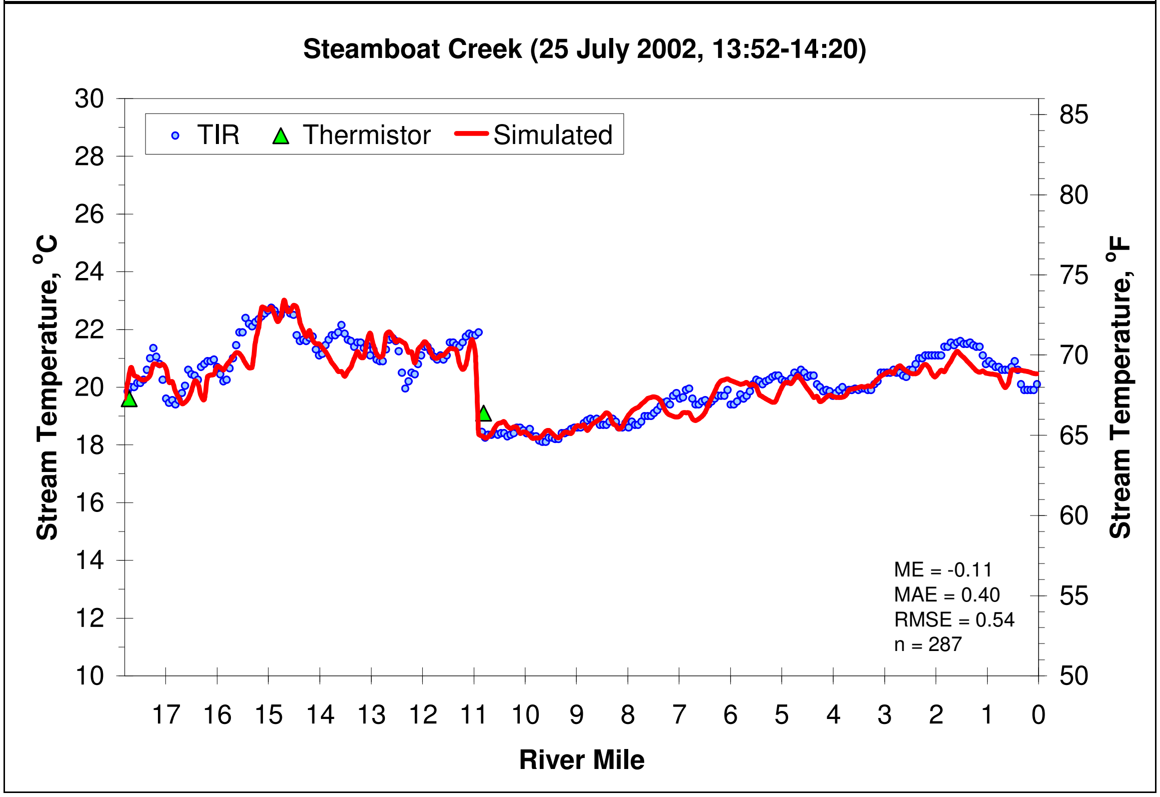

Steamboat Creek (25 July 2002, 13:52-14:20)

Figure 16 (continued). Current Condition Stream Temperature Simulation Calibration Results

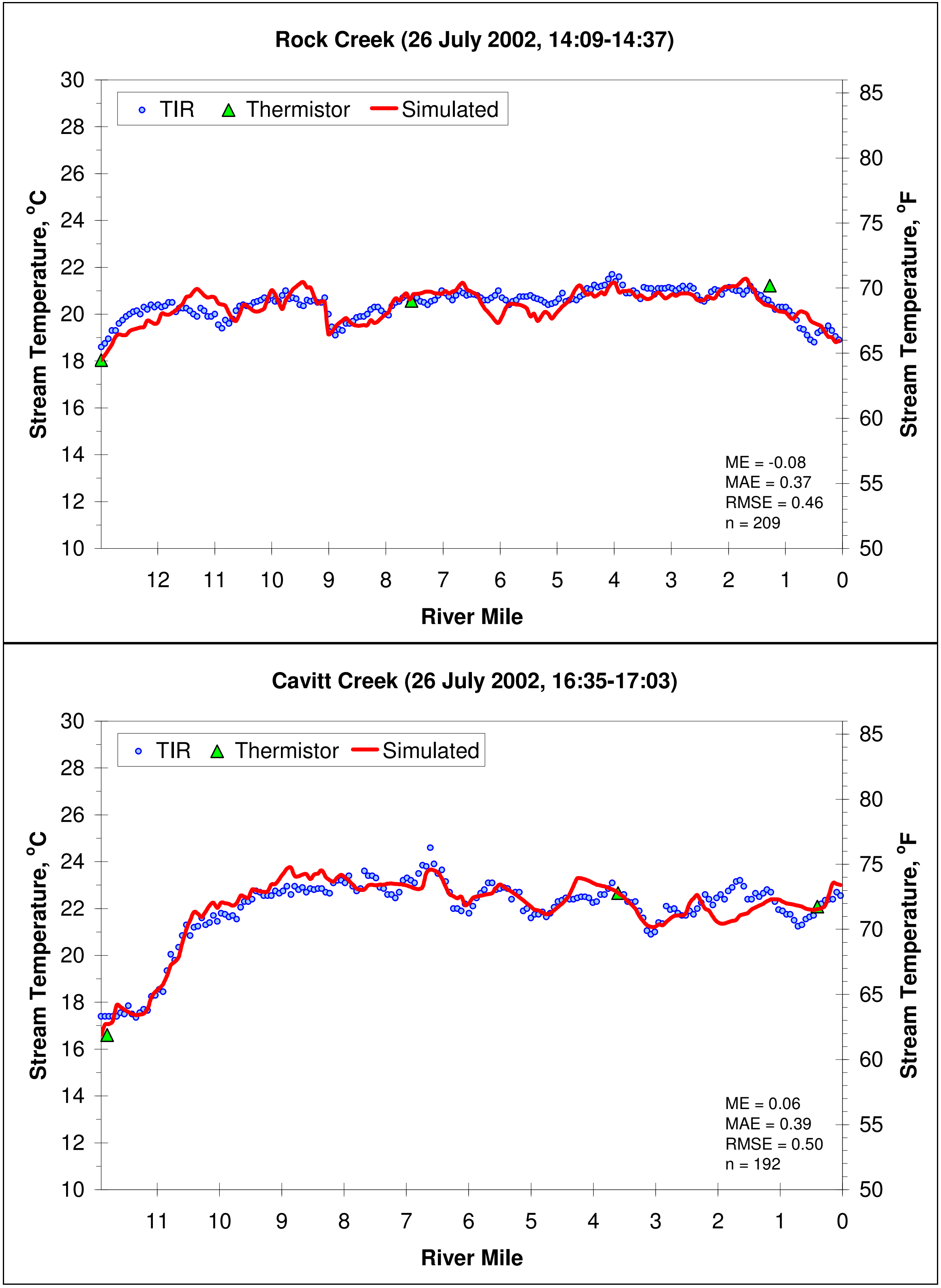
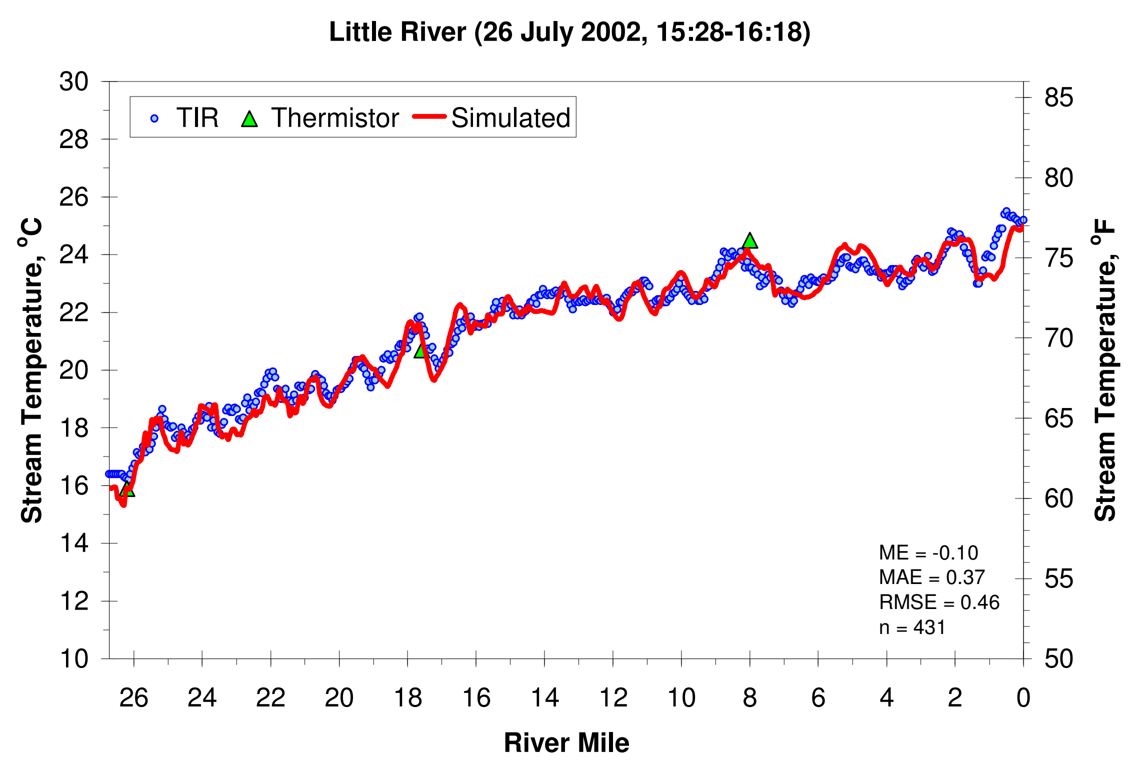
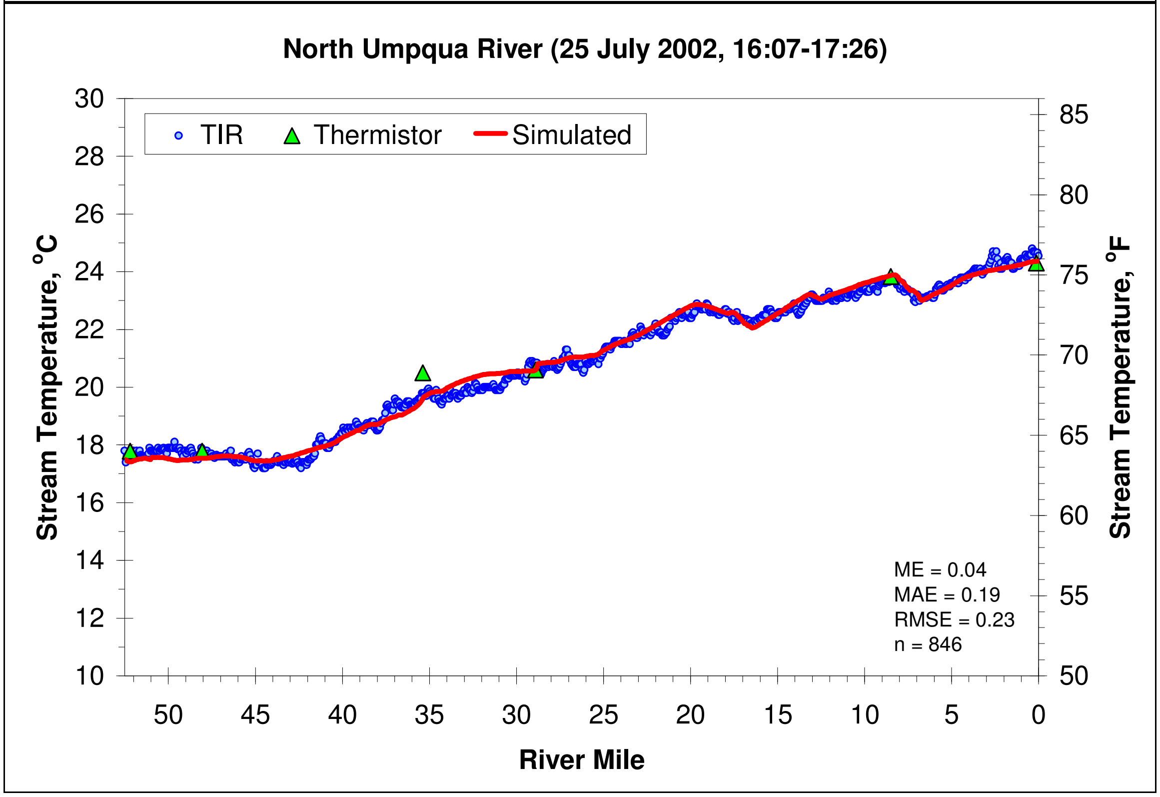


Figure 16 (continued). Current Condition Stream Temperature Simulation Calibration Results



Little River (26 July 2002, 15:28-16:18)



North Umpqua River (25 July 2002, 16:07-17:26)

Figure 16 (continued). Current Condition Stream Temperature Simulation Calibration Results

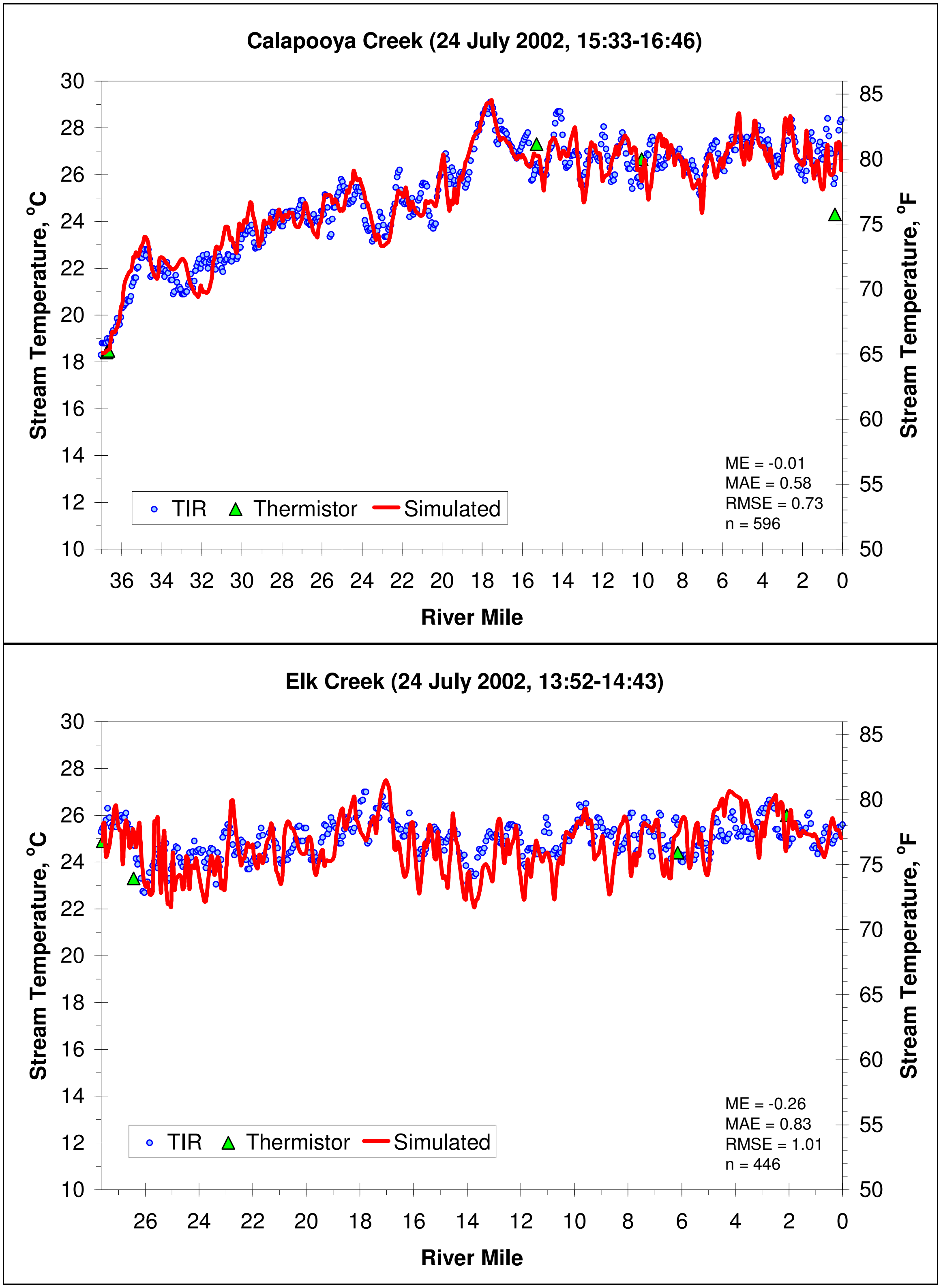


Figure 16 (continued). Current Condition Stream Temperature Simulation Calibration Results

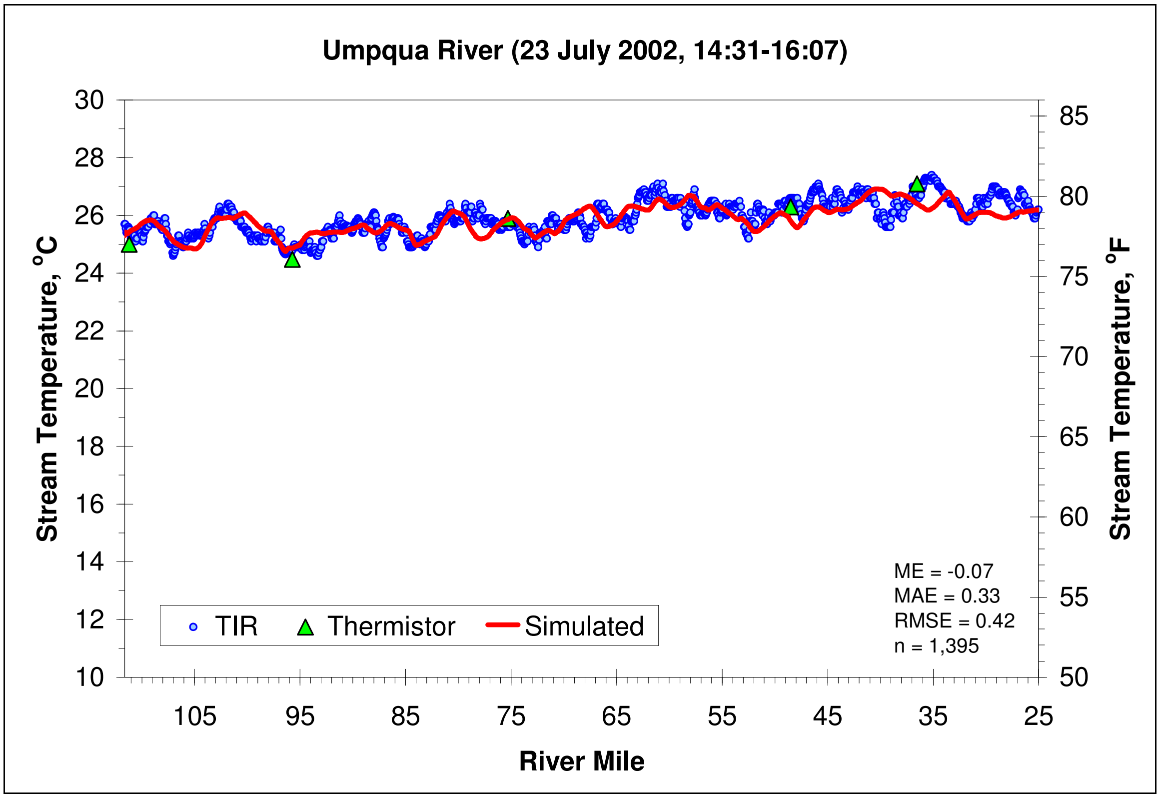


Figure 16 (continued). Current Condition Stream Temperature Simulation Calibration Results

Simulated Scenarios

Once stream temperature models were calibrated, several scenarios were simulated by changing one or more input parameters. The simulated scenarios focused largely on defined potential vegetation and derived flow mass balances.

Table 5 describes the different simulation scenarios presented in **Figures 17 through 33**.

Table 5. Simulated Scenario Definitions

"Current"	Current Condition
"Veg"	Potential Vegetation
"Flow"	Potential Flow (no dams, withdrawals, diversions, or point sources)
"Veg/Flow"	Potential Vegetation and Potential Flow
"NTP"	Natural Thermal Potential: Potential Vegetation incorporating natural disturbance, Potential Flow, Reduced Tributary Temperatures[4], Potential Channel Width[5]
"401 Cert."	Same as the NTP, except instead of Potential Flow, the 401 certification[6] minimum bypass reach flows were used.

The following pages include the simulation results and discussions for each stream.

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[4] Where applicable, very warm tributaries were set to approximate the temperature of other cooler tributaries in the same watershed.

[5] A small reach on Cow Creek is the only stream where channel widths were changed from their existing condition.

[6] The 401 certification documents for the North Umpqua Hydroelectric Project (FERC Project No. 1927) are available for download at the Oregon Department of Environmental Quality website.

Jackson Creek Simulation Scenarios

Jackson Creek flow is relatively unaffected by the few water rights it has. Therefore, the “flow” scenario results in the same temperature as the current condition (**Figure 17**). Likewise, the “veg/flow” scenario results in the same temperature as the “veg” scenario. The difference between the “veg” scenario and the “NTP” scenarios is that some tributary temperatures have been reduced in the NTP scenario.

The simulation scenarios reveal that the stream temperatures are primarily impacted by effective shade reductions, and secondarily impacted by tributary influences. The upper 6 miles of Jackson Creek flows through some old growth forest where the current effective shade is at its potential.

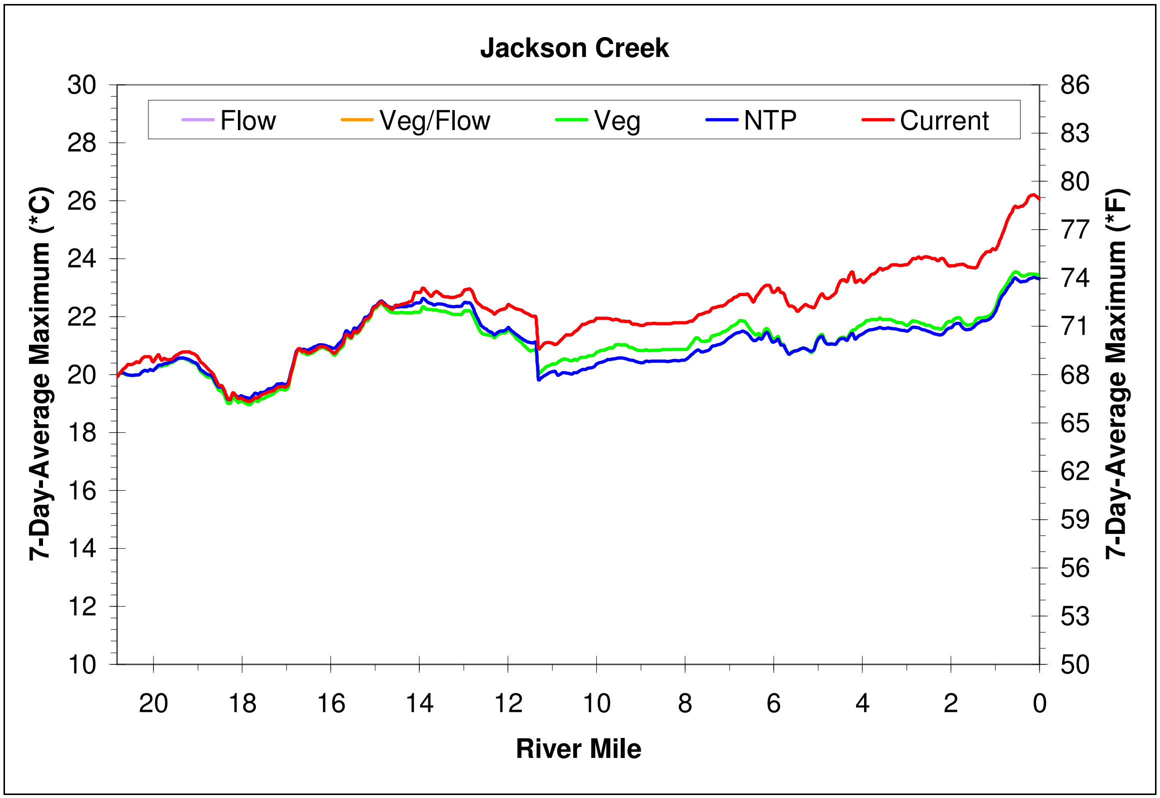


Figure 17. **Jackson Creek Simulation Scenario Results**

Cow Creek Simulation Scenarios

Galesville Reservoir currently augments Cow Creek's summer flow volumes and moderates temperatures.

The "veg" scenario included potential vegetation types, heights, and densities, while leaving all other parameters at their current condition. **Figure 18** shows that reduced vegetation (or effective shade) is partially responsible for the current condition temperatures.

The "flow" scenario used the natural river flow, as if Galesville Reservoir did not exist and no anthropogenic point sources or withdrawals were present. Data from upstream of the reservoir was used to represent the model boundary conditions in this simulation. Nearly the entire stream is warmer in the "flow" scenario than its current condition. This is solely a result of lower flows. Lower flow volumes are more sensitive to solar heating. The "flow" scenario results also display more variability over shorter distances.

The "veg/flow" scenario used the natural river flow and potential vegetation. In the upper and middle reaches, these results are the same as the Natural Thermal Potential (NTP). Generally, increased effective shade from potential vegetation helps moderate stream temperatures.

The "NTP" scenario incorporates natural flow, potential vegetation with natural disturbance, reduced tributary temperatures, and some channel width reductions (river mile 50-45). The natural thermal potential is warmer than the current condition in many reaches, largely due to the difference between the current and natural flow volumes.

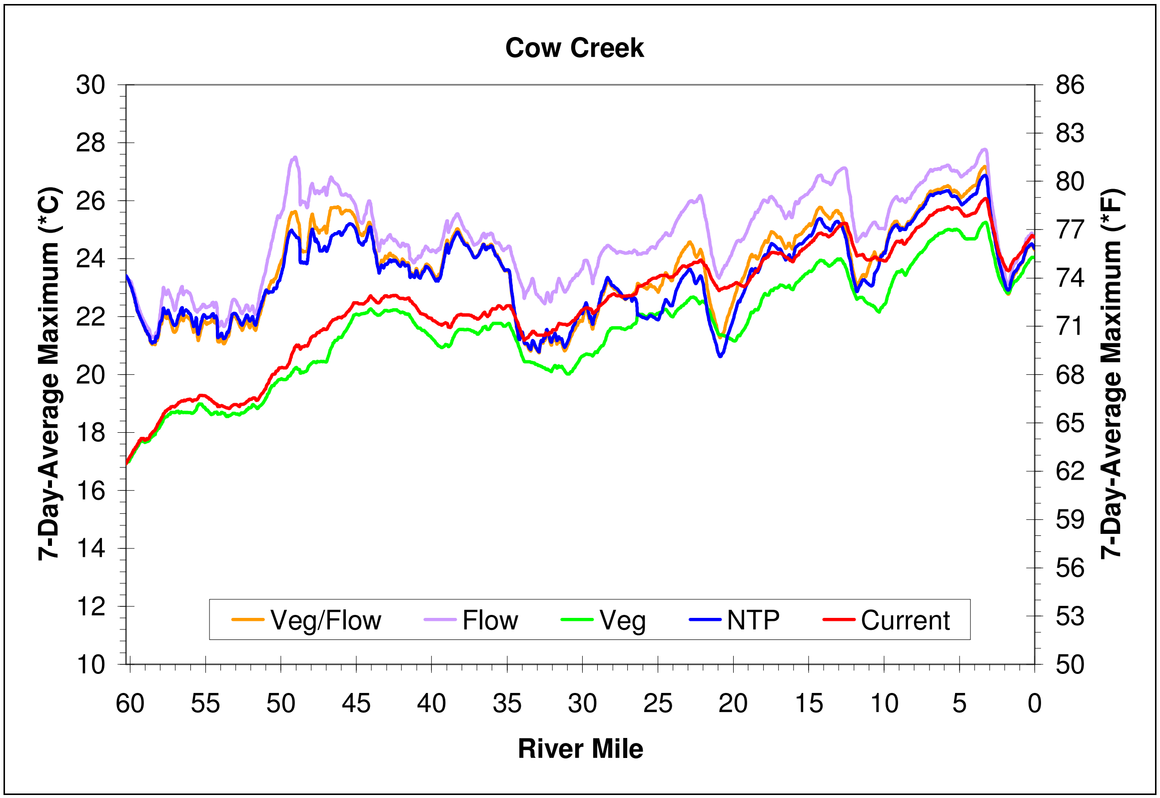


Figure 18. **Cow Creek Simulation Scenario Results**

Olalla-Lookingglass Creek Simulation Scenarios

Olalla-Lookingglass Creek temperatures are currently influenced by Berry Creek reservoir. Reservoir releases add significant volumes of cool water to Olalla-Lookingglass Creek just above river mile 19.

The "veg" scenario includes potential vegetation, while all other parameters were left at their current condition. **Figure 19** shows that just changing the inputs to the potential vegetation has a relatively small impact on the current stream temperatures. Much of the stream is already close to its potential effective shade.

The "flow" scenario includes the natural stream flow, which means no reservoir and no anthropogenic point sources or withdrawals. The upper reaches of Olalla-Lookingglass Creek are much warmer in this scenario, simply because there is no cool water flow augmentation from the reservoir. Berry Creek is assumed to be entering Olalla-Lookingglass Creek at its natural flow volume and temperature. This results in less flow within Olalla-Lookingglass Creek and more variability and warmer stream temperatures. The lower 8 miles are similar to the current temperatures in the "flow" scenario.

The "veg/flow" scenario includes the natural stream flow and potential vegetation, while all other parameters are left at their current condition. In the chart below, the "veg/flow" results (orange line) lie directly beneath the "NTP" line in most reaches.

The "NTP" scenario includes the natural stream flow, potential vegetation with natural disturbance, and reduced tributary temperatures. It is cooler than the "flow" scenario results because effective shade levels are higher and some tributary temperatures are reduced.

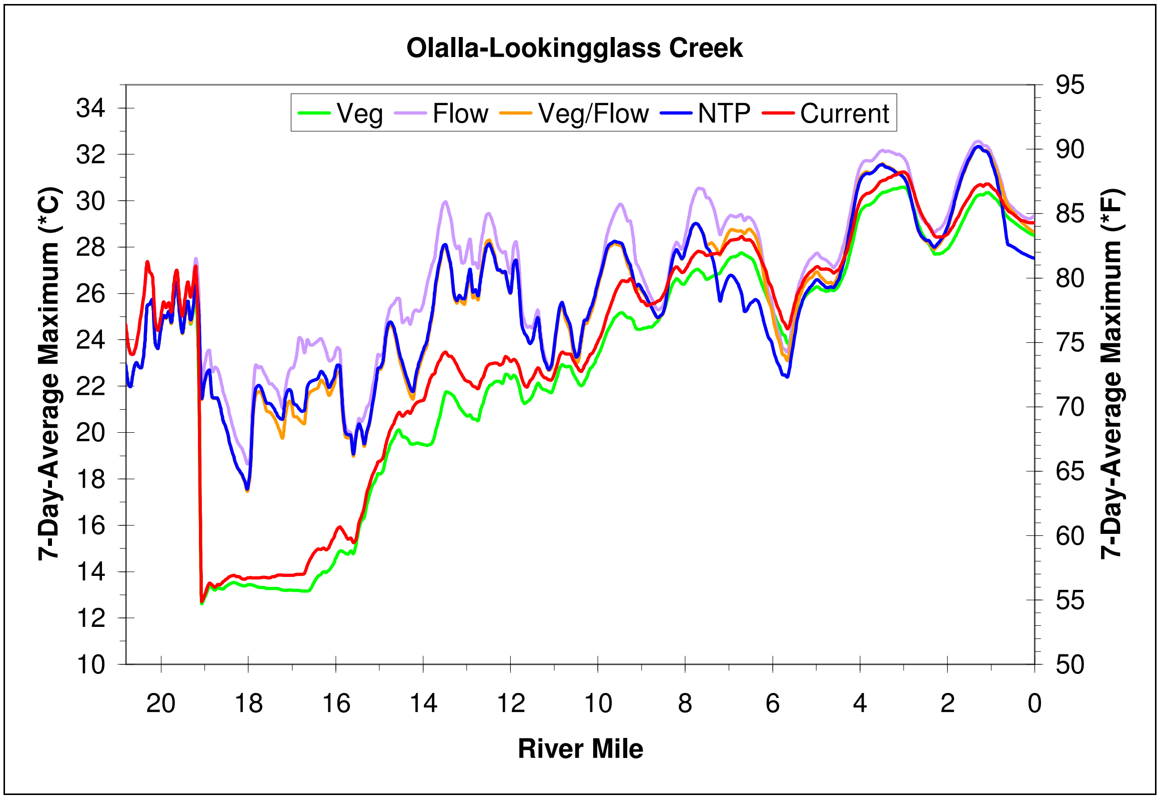


Figure 19. **Olalla-Lookingglass Creek Simulation Scenario Results**

South Umpqua River Simulation Scenarios

The various scenario results do not differ greatly from the current condition temperatures. The South Umpqua River is fairly well-vegetated in most reaches, while other reaches are too wide to be significantly shaded by riparian vegetation.

The “flow” scenario resulted in temperatures virtually identical to the current condition (**Figure 20**). Withdrawals and anthropogenic point sources have relatively little impact on the current stream temperatures.

The “veg” and “veg/flow” and “NTP” scenarios resulted in similar temperatures (see blue line in the chart below). Ultimately, the simulated natural thermal potential temperatures are very close to the current conditions. The South Umpqua River is currently well vegetated and/or are too wide to be significantly shaded by riparian vegetation.

Stream temperature simulations do not account for the historical anthropogenic impacts on channel morphology and floodplain connectivity. Data is insufficient for such modeling scenarios. For example, it is not possible to quantify what the channel dimensions were or how much groundwater interactions there were prior to settlement. Land use activities such as development, agriculture, forestry, diking, and road development often disconnect the river from its natural floodplain which decreases cool groundwater inputs. The historical temperature of the South Umpqua River may have been cooler when the channel and floodplain were undisturbed by human activities. The “NTP” results were simulated using the best available technology and scientific information.

Studies show long term increases in low-flow channel widths have occurred in the South Umpqua Subbasin since 1937 (Dose and Roper, 1994). However, the period of record and amount of data is insufficient to accurately model narrower channel widths within the NTP scenario.

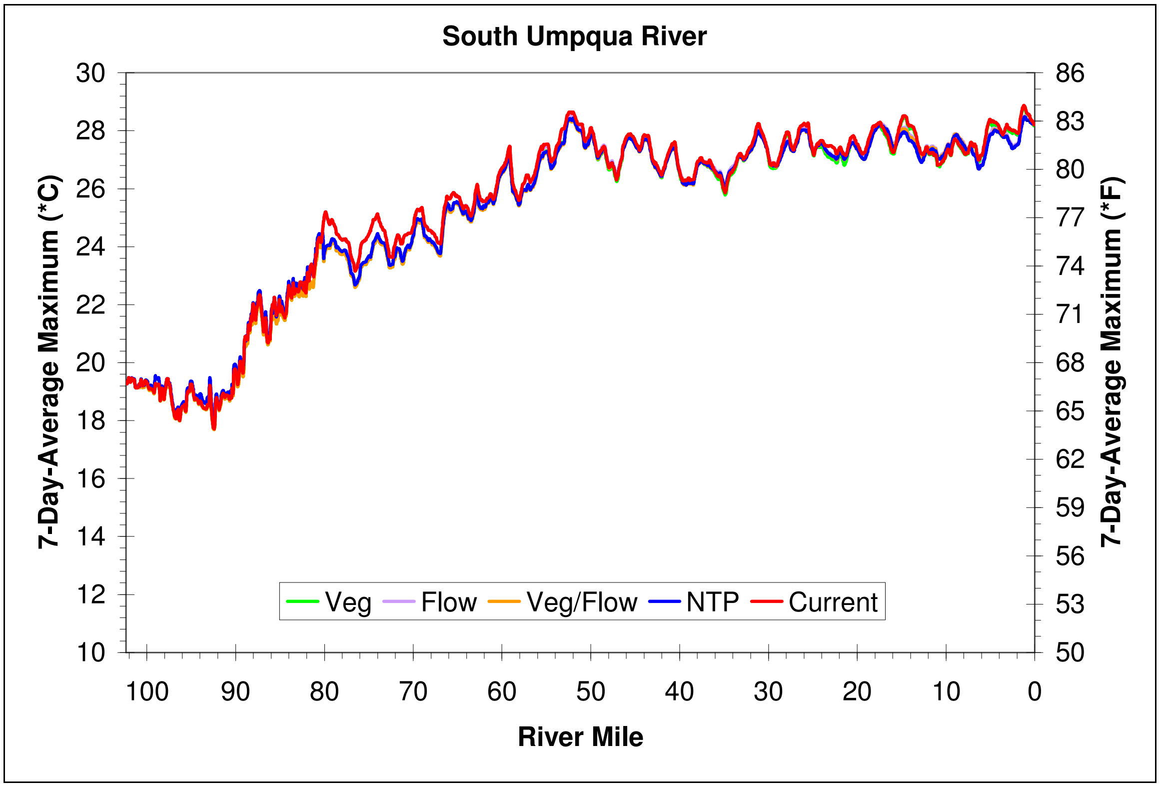


Figure 20. **South Umpqua River Simulation Scenario Results**

Lake Creek Simulation Scenarios

There are no known withdrawals on Lake Creek. No tributaries were included in the Lake Creek model. Lake Creek is cooler under potential vegetation conditions, due to increased effective shade levels. The "NTP" scenario is the nearly the same as the "veg" scenario results (**Figure 21**).

It should be noted that tree stands along Lake Creek appeared to be shorter and less dense than other locations in the upper North Umpqua River watershed. This could be a naturally occurring aspect of the Lake Creek watershed. At the time of TMDL development, DEQ was unable to verify if the trees surrounding Lake Creek have been naturally or anthropogenically disturbed. Potential vegetation conditions defined for the ecoregion were applied within the simulations.

In any case, there is no assimilative capacity available for Lake Creek because its current and simulated NTP temperatures exceed the applicable numeric criterion (18°C). If it is determined that Lake Creek vegetation is currently at its potential, the NTP temperature would be more similar to the current temperature.

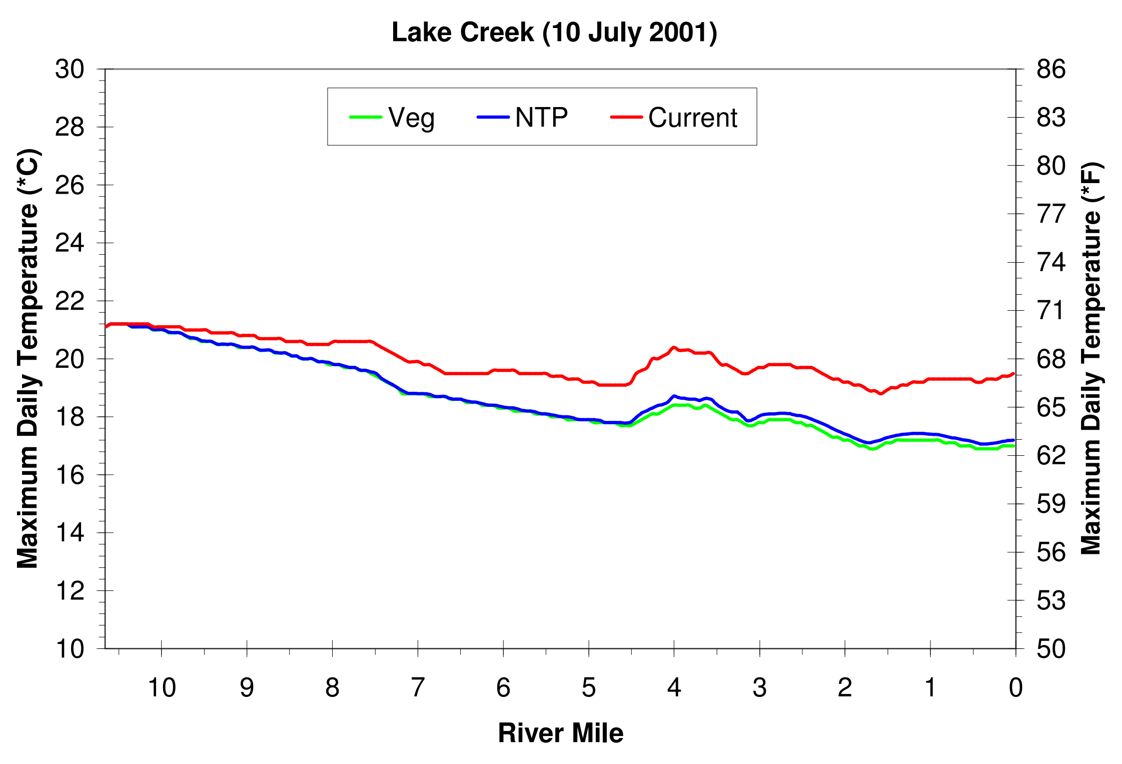


Figure 21. **Lake Creek Simulation Scenario Results**

Clearwater River Simulation Scenarios

Timber harvests along the Clearwater River have reduced effective shade levels and increased stream temperatures. The hydroelectric project modifies flow volumes, which also impacts stream temperatures.

The "veg" scenario includes potential vegetation, while all other parameters are at their current condition. There are some improvements in stream temperature over the current condition (**Figure 22**).

The "flow" scenario includes the natural stream flow, with no diversions, withdrawals, or dams. This means that the reaches simulated have more flow volume, which acts to moderate stream temperature variability. Since the water is naturally flowing and there is no return water at the powerhouse near river mile 5, the resultant stream temperatures are slightly warmer than the current condition in the lower reaches.

The "veg/flow" scenario includes the natural stream flow and potential vegetation. Compared to the "flow" scenario results, stream temperatures are cooler.

The "NTP" scenario results are slightly below the "veg/flow" scenario results in some reaches because of cooler tributary temperatures.

The "401 Cert." scenario includes the potential vegetation and the flow specified in the re-licensing agreement for the North Umpqua Hydro Project (**Figure 14**).

The natural thermal potential is warmer than the current condition in some reaches, while it is cooler than the current condition in other reaches. In general the natural thermal potential temperature profile is less variable than the current condition because the stream is assumed to be flowing naturally.

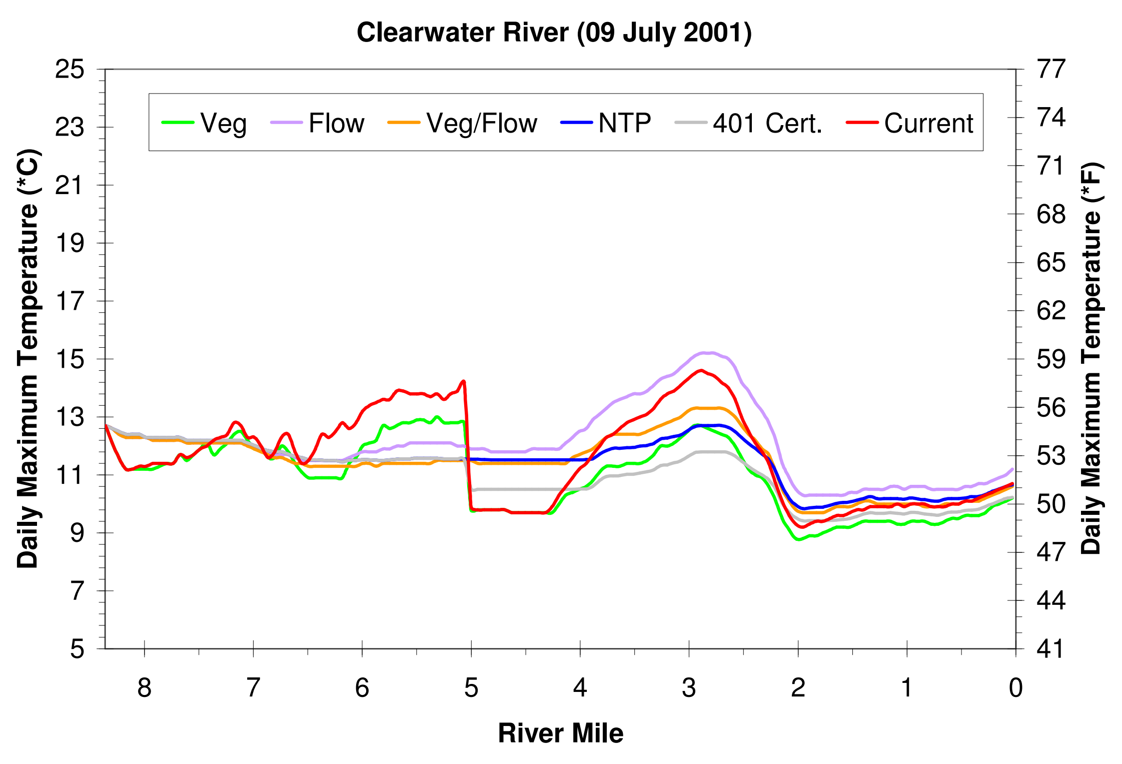


Figure 22. **Clearwater River Simulation Scenario Results**

Fish Creek Simulation Scenarios

Fish Creek has some nearby timber harvest activities which have reduced effective shade. In addition, the hydroelectric project reduces stream flow and impacts stream temperatures (**Figure 23**).

The "veg" scenario includes potential vegetation, while all other parameters are left unchanged from the current condition. Within the upper 7 miles, the "veg" scenario temperatures are nearly the same as the current condition. The lower 7 miles show more divergence from the current temperatures.

The "flow" scenario includes the natural stream flow, without dams, diversions, or withdrawals. The upper 7 miles are naturally flowing stream. Near river mile 7, there is a hydroelectric project diversion that reduces stream flow. As a result, there is a measurable difference between the current stream temperature and the "flow" scenario stream temperature. In other words, the diversion is causing the lower 7 river miles to heat.

The "veg/flow" scenario includes the potential vegetation and the natural flow. Cooler stream temperatures are especially noticeable within the lower 7 river miles.

The "NTP" scenario includes potential vegetation, natural flow, and some reduced tributary temperatures. Generally, the natural thermal potential temperature is close to the current condition above river mile 7, and well beneath the current condition in the lower 7 miles.

The "401 Cert." scenario includes the potential vegetation and the flow specified in the re-licensing agreement for the North Umpqua Hydro Project (**Figure 14**).

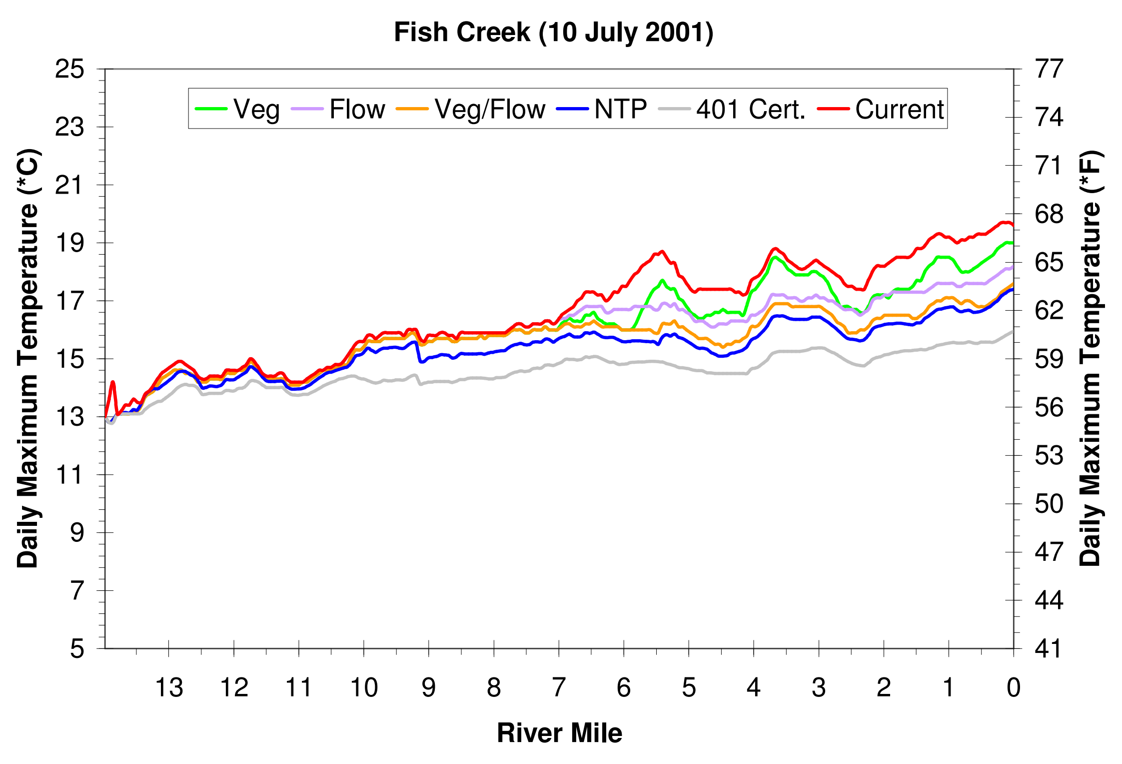


Figure 23. Fish Creek Simulation Scenario Results

North Umpqua River (Lemolo Reservoir to Steamboat Creek) Simulation Scenarios

The hydroelectric project diverts most of the stream flow between Lemolo Reservoir and Soda Springs, resulting in significantly increased stream temperatures (**Figure 24**).

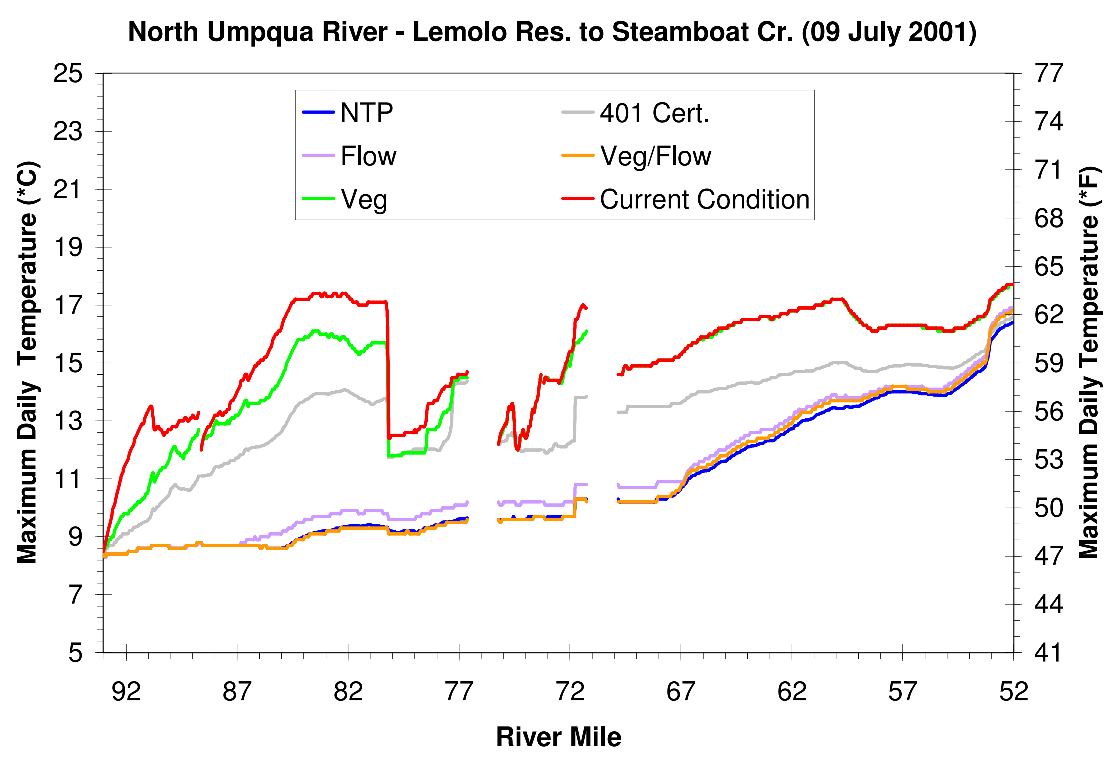
The “veg” scenario includes potential vegetation, while all other parameters remain at their current condition. Between Lemolo Reservoir and river mile 77 (Toketee Lake), there are some observed reductions in stream temperature in the “veg” scenario. Due to hydroelectric diversions, the flow within the bypass reaches (Lemolo #1and Lemolo #2) is approximately 5% of it natural flow. As a result, the stream temperatures are more sensitive to effective shade fluctuations and tributary inputs. Below river mile 77, the stream is wider and less sensitive to the added effective shade from potential vegetation, so the stream temperatures are nearly identical to the current stream temperatures.

The “flow” scenario includes the natural flow, where dams, withdrawals, diversions, and powerhouses are removed from the model. Since much of the natural flow originates from cool springs in the vicinity of Lemolo Reservoir (i.e., Spring River), the boundary condition temperatures are very cool (8-9^{o}C). Current flow in most reaches is around 30 cfs, while the natural flow is around 600 cfs. This large volume of cold water in the natural flow scenario is relatively insensitive to tributary inputs and effective shade fluctuations. Cool temperatures are carried many miles downstream.

The “veg/flow” scenario includes the potential vegetation and the natural flow. The results (orange line) are virtually identical to the “NTP” scenario results (blue line).

The “NTP” scenario includes the potential vegetation, natural flow, and potential tributary temperatures. The significant natural flow volume dominates the thermal profile.

The “401 Cert. Proposal” scenario is the same as the “NTP” scenario with one major difference; the hydroelectric project is operating and implementing its proposed 401 settlement agreement minimum bypass reach flows. The proposed minimum bypass reach flows are significantly smaller than the natural flow, but somewhat greater than the current flows. As a result, the simulated temperatures are between the current condition and the natural thermal potential.



River Mile 88.6 = Lemolo Powerhouse #1
River Mile 75.2 = Lemolo Powerhouse #2
River Mile 73.3 = Toketee Powerhouse
River Mile 71.2 = Slide Powerhouse
River Mile 69.8 = Soda Springs Dam

Figure 24. North Umpqua River (Lemolo Res. To Steamboat Cr.) Simulation Scenario Results

Canton Creek Simulation Scenarios

Canton Creek has no known flow withdrawals. Timber harvest activities have reduced effective shade and increased stream temperatures. Several tributaries drain lands where the forest has been impacted by human activities, and are likely to have elevated stream temperatures.

The “veg” scenario includes potential vegetation, while all other parameters were left at their current condition. Resultant temperatures are below the current temperatures as a result of increased effective shade levels (**Figure 25**).

The “NTP” scenario includes potential vegetation and reduced tributary temperatures. Since there are no known withdrawals, flows are the same as the current condition. The effect of reducing tributary temperatures further decreases the simulated temperatures.

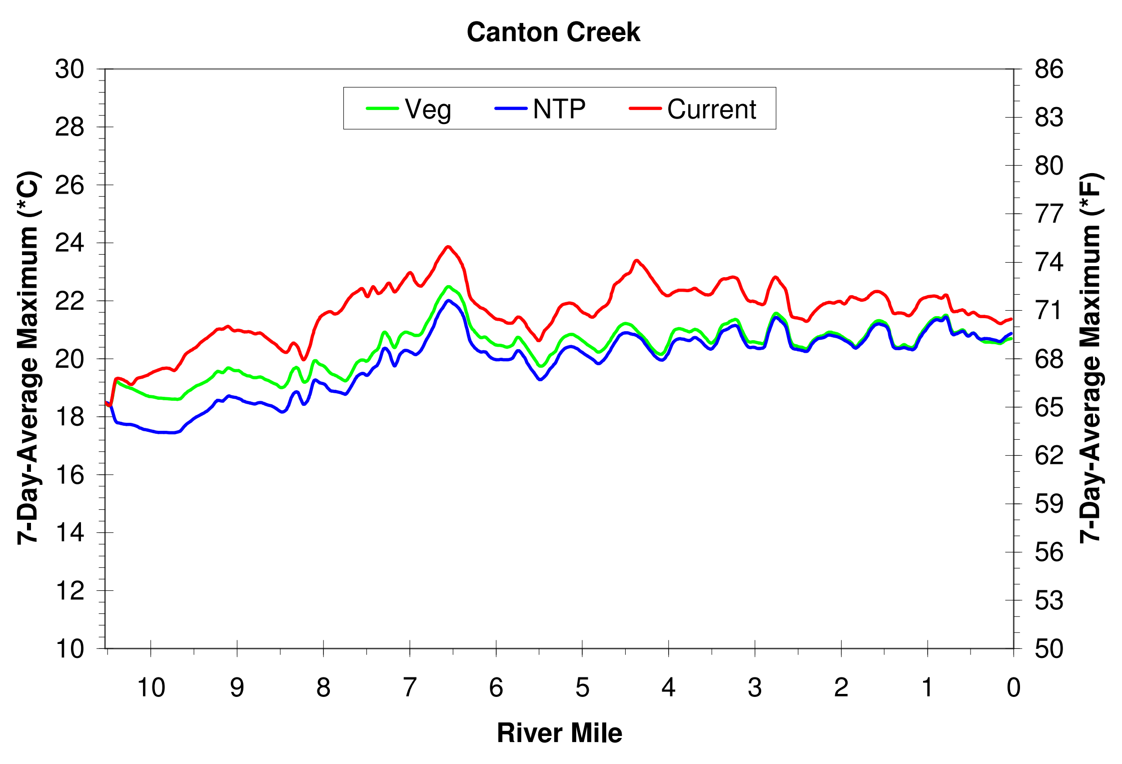


Figure 25. **Canton Creek Simulation Scenario Results**

Steamboat Creek Simulation Scenarios

Steamboat Creek has no known flow withdrawals. Timber harvest activities have reduced effective shade and increased stream temperatures. Several tributaries drain lands where the forest has been impacted by human activities, and are likely to have elevated stream temperatures.

The “veg” scenario includes potential vegetation, while all other parameters were left at their current condition. Upstream of river mile 7, the resultant temperatures are similar to the current condition (**Figure 26**). Effective shade levels are near their potential in that reach. From river mile 7 to the mouth, the resultant temperatures are noticeably cooler than the current conditions.

The “NTP” scenario includes potential vegetation and reduced tributary temperatures. Since there are no known withdrawals, flows are the same as the current condition. The effect of reducing tributary temperatures further decreases the simulated temperatures. Notably, the upper reaches have a cooler simulated stream temperature when some warm tributary temperatures are reduced.

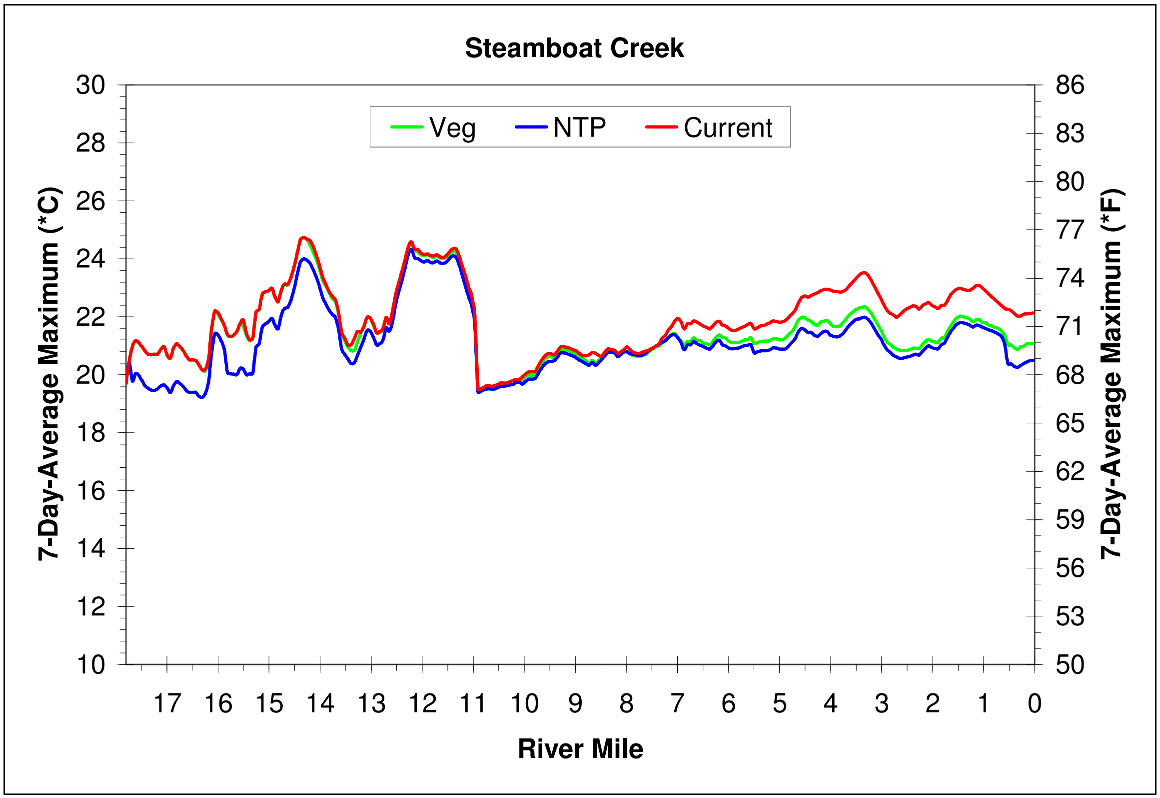


Figure 26. **Steamboat Creek Simulation Scenario Results**

Rock Creek Simulation Scenarios

There are no known water withdrawals on Rock Creek, other than a small water right near the mouth, used by the fish hatchery.

The "veg" scenario includes potential vegetation, while all other parameters were left at their current condition. For the most part, the "veg" scenario results are the same as the "NTP" scenario results (**Figure 27**).

The "NTP" scenario includes potential vegetation and reduced tributary temperatures. Since most tributaries are not significantly hot, they have relatively little impact in this scenario.

Effective shade reductions due to timber harvest and road construction are primarily responsible for the differences between the natural thermal potential and the current temperatures.

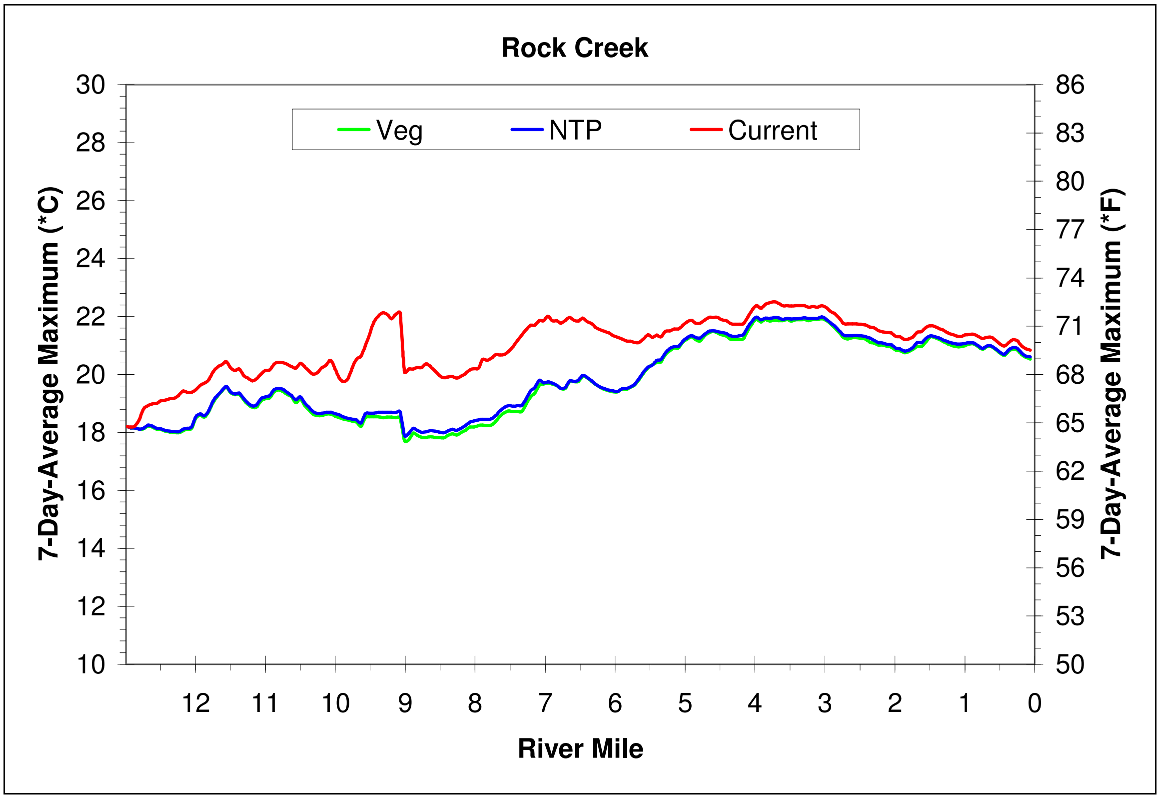


Figure 27. Rock Creek Simulation Scenario Results

Cavitt Creek Simulation Scenarios

Cavitt Creek has experienced timber harvest across much of its watershed. Stream temperatures are currently elevated as a result of lowered effective shade levels. Withdrawals are relatively insignificant on Cavitt Creek.

The "veg" scenario includes potential vegetation, while all other parameters were left at their current condition. In **Figure 28**, the "veg" scenario simulated temperatures (green line) are similar to the "NTP" scenario temperatures (blue line).

The "flow" scenario includes the natural stream flow, in which the few withdrawals are removed from the simulation, while all other parameters remain at their current condition. The results (lavender line) are the same as the current stream temperatures (red line).

The "veg/flow" scenario includes the potential vegetation and the natural flow. Since withdrawals are insignificant, the resultant temperatures are the same as the "veg" scenarios.

The "NTP" scenario includes potential vegetation with natural disturbance, natural flow, and reduced tributary temperatures. Most tributaries are very small and/or not very hot and do not measurably impact the temperature results.

Effective shade reductions are the primary reason that the current stream temperatures exceed the natural thermal potential.

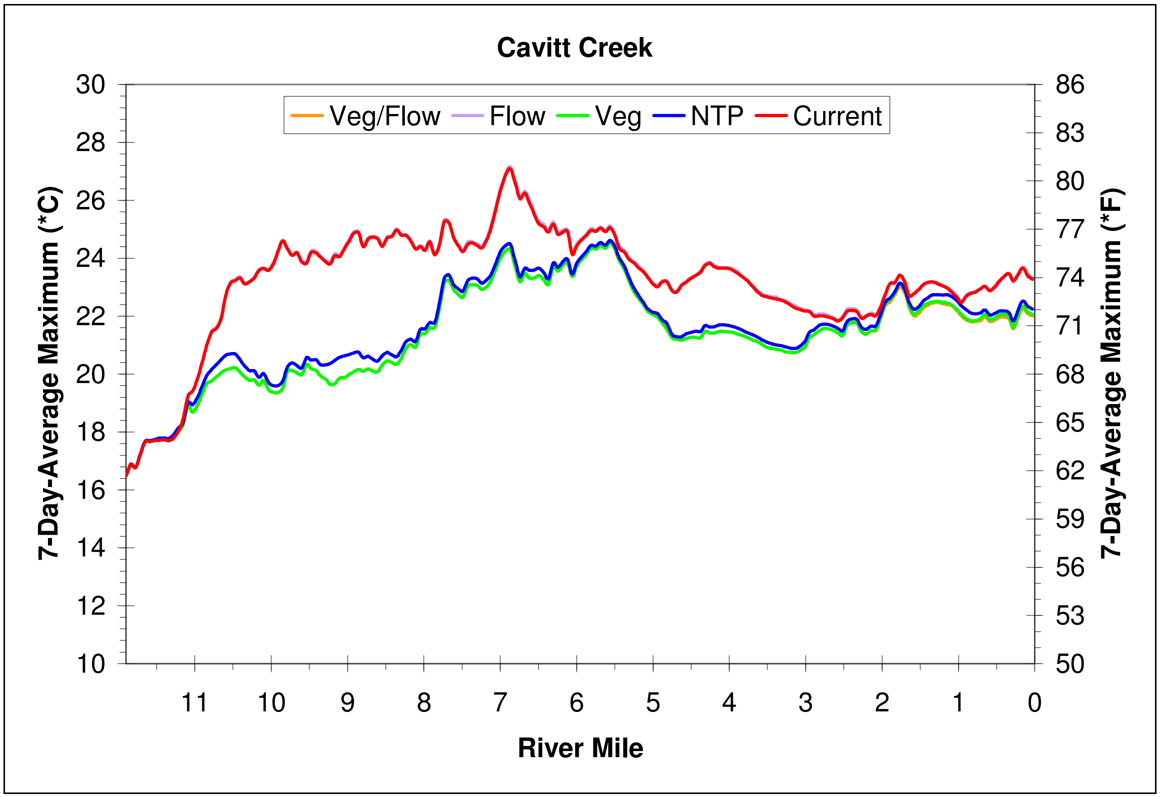


Figure 28. **Cavitt Creek Simulation Scenario Results**

Little River Simulation Scenarios

Timber harvest activities have reduced effective shade levels along much of Little River. Water withdrawals along Little River are relatively insignificant.

The “flow” scenario includes natural stream flow, while all other parameters remain at their current condition. The “flow” scenario results are virtually identical to the current stream temperatures (**Figure 29**).

The “veg” scenario includes potential vegetation, while all other parameters remain at their current condition. The “veg” scenario results are the same as the “veg/flow” and similar to the “NTP” scenario results.

The “NTP” scenario includes potential vegetation, natural flow, and reduced tributary temperatures. Current tributary conditions have no measurable impact on the natural thermal potential.

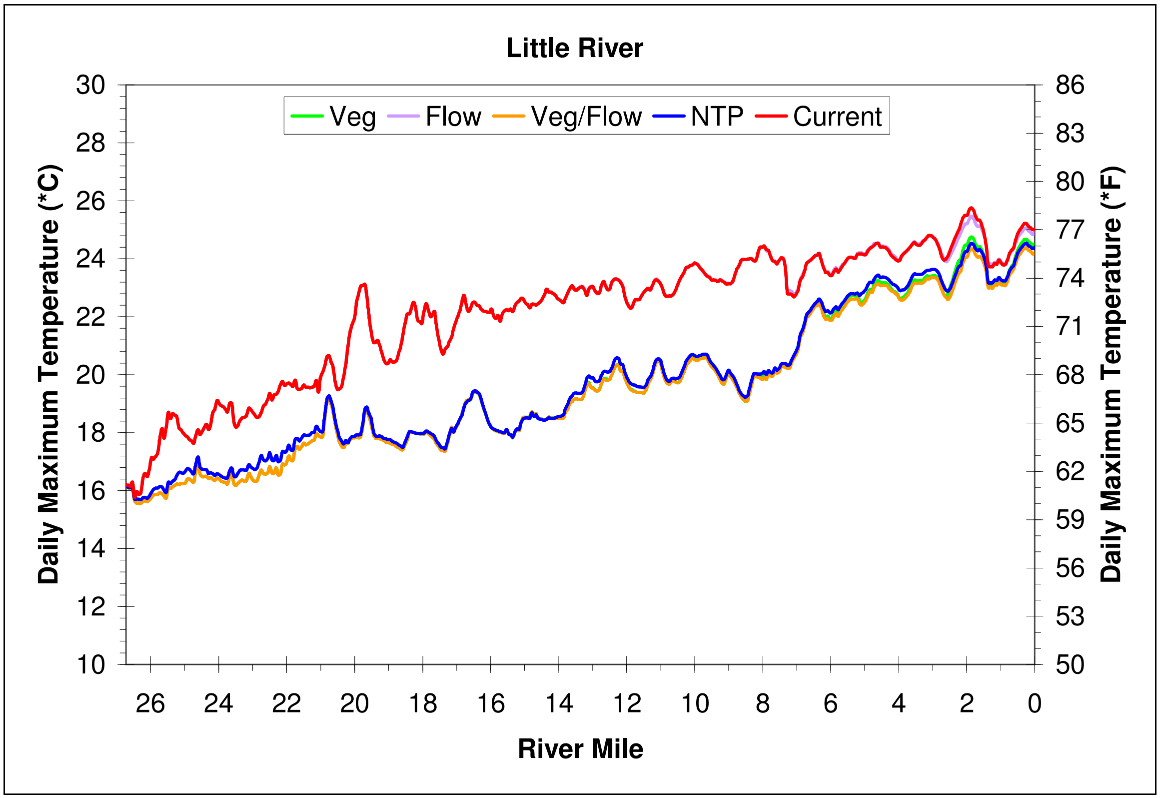


Figure 29. **Little River Simulation Scenario Results**

North Umpqua River (Steamboat Creek to Mouth) Simulation Scenarios

The North Umpqua River downstream of Steamboat Creek contains a significant amount of water during the summer months (around 600 cubic feet per second during late July). As a result, this portion of the river is less sensitive to effective shade reductions. Also, the river is currently well-vegetated in many reaches.

The “veg” scenario (green line) results in only slightly cooler than current stream temperatures (**Figure 30**). The “veg” scenario results are similar to the “veg/flow” and the “NTP” scenario results.

Stream temperature simulation results from the upper North Umpqua River are incorporated into these simulations. The “flow” scenario includes natural flows and includes the temperature reductions simulated between Lemolo Reservoir and Steamboat Creek. The resultant temperatures (lavender line) are nearly identical to the “NTP” scenario results (blue line).

The “NTP” scenario includes potential vegetation, natural flows, reduced tributary temperatures, and inputs from upstream and tributary models.

The hydroelectric project is increasing the upstream temperatures, and those elevated temperatures are being carried throughout the length of the North Umpqua River. Since the North Umpqua River below Soda Springs has such significant flow, heat is retained within the river over long distances. The increased temperatures from the hydroelectric project are also seen in the mainstem Umpqua River.

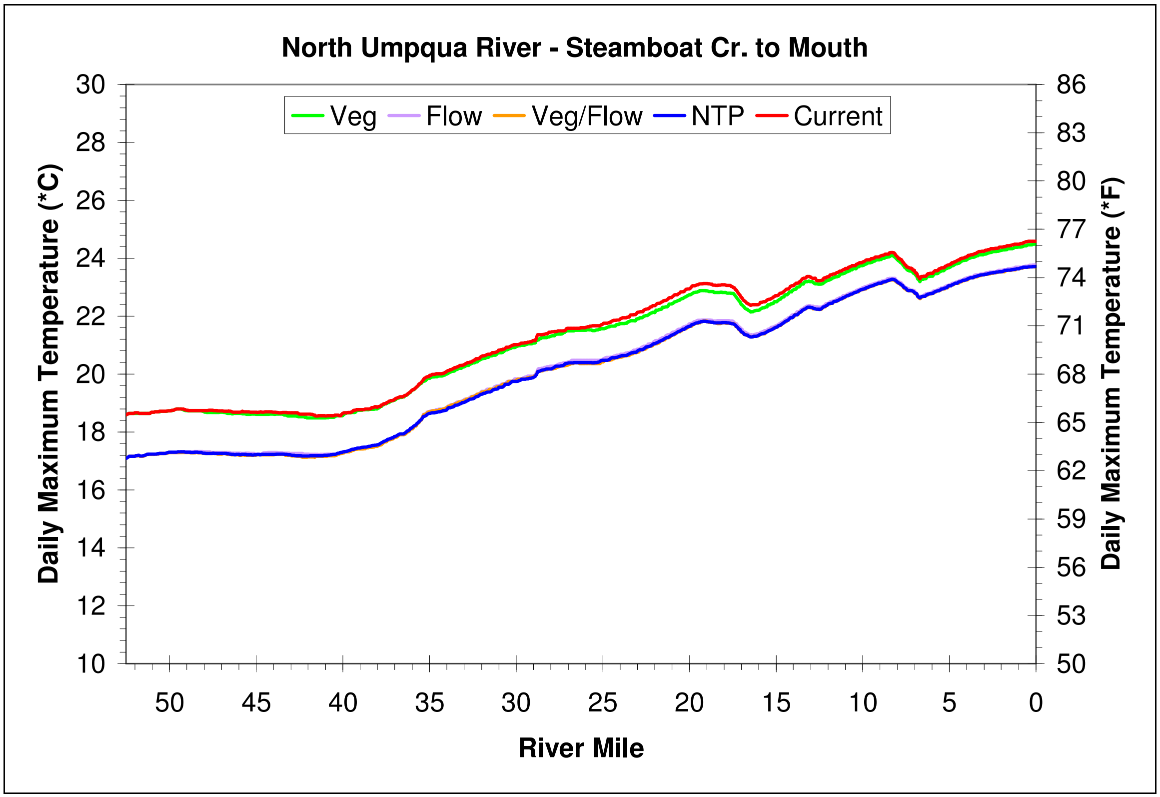


Figure 30. **North Umpqua River (Steamboat Cr. to Mouth) Simulation Scenario Results**

Calapooya Creek Simulation Scenarios

The section of Calapooya Creek simulated below is flows through low-gradient agricultural lands, **Figure 31**.

The “veg” scenario includes potential vegetation, while all other parameters were left at their current condition. Wherever not visible in the chart below, the “veg” scenario results (green line) is the same as the “NTP” scenario results (blue line).

The “flow” scenario includes natural stream flow, without withdrawals, diversions, or anthropogenic point sources. In the upper reaches, the resultant temperatures are the same s the current condition. There are some cooler temperatures in some downstream reaches as a result of natural flow volumes.

The “veg/flow” scenario includes potential vegetation and natural flow, while all other parameters remain at their current condition. The resultant temperatures (orange line) are similar to the “NTP” scenario temperatures (blue line).

This low-gradient system does not display much temperature improvement from the current condition to the natural thermal potential over most of its length.

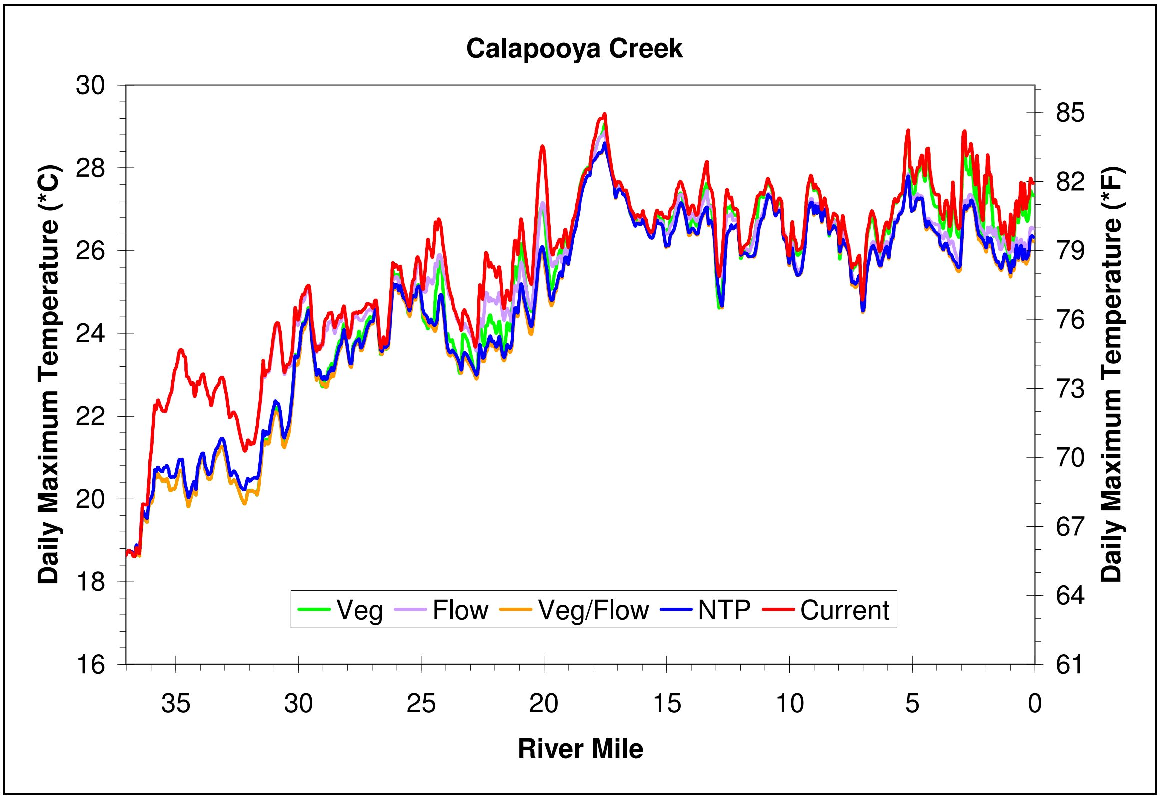


Figure 31. **Calapooya Creek Simulation Scenario Results**

Elk Creek Simulation Scenarios

The reaches of Elk Creek simulated are low-gradient and flow through primarily agricultural lands. The low velocities and small flow volume allow the stream to heat and cool rapidly over short distances, resulting in a highly variable stream temperature profile. Localized hyporheic activity (although not measured in the field) could potentially be responsible for some of the quick drops in stream temperatures.

The "veg" scenario includes potential vegetation, while all other parameters were left at their current condition. The simulated temperatures for the "veg" scenario (green line) are almost identical to those for the "NTP" scenario (blue line) (**Figure 32**).

No flow scenario was simulated because the quantity of permitted water rights far exceeded the current condition available flow. As a result, it was impossible to estimate the amount of withdrawals occurring in the current condition model and a conservative assumption of zero was made.

The "NTP" scenario includes potential vegetation and some reduced tributary temperatures. Little difference was observed between the "veg" scenario and the "NTP" scenario as a result of reduced tributary temperatures.

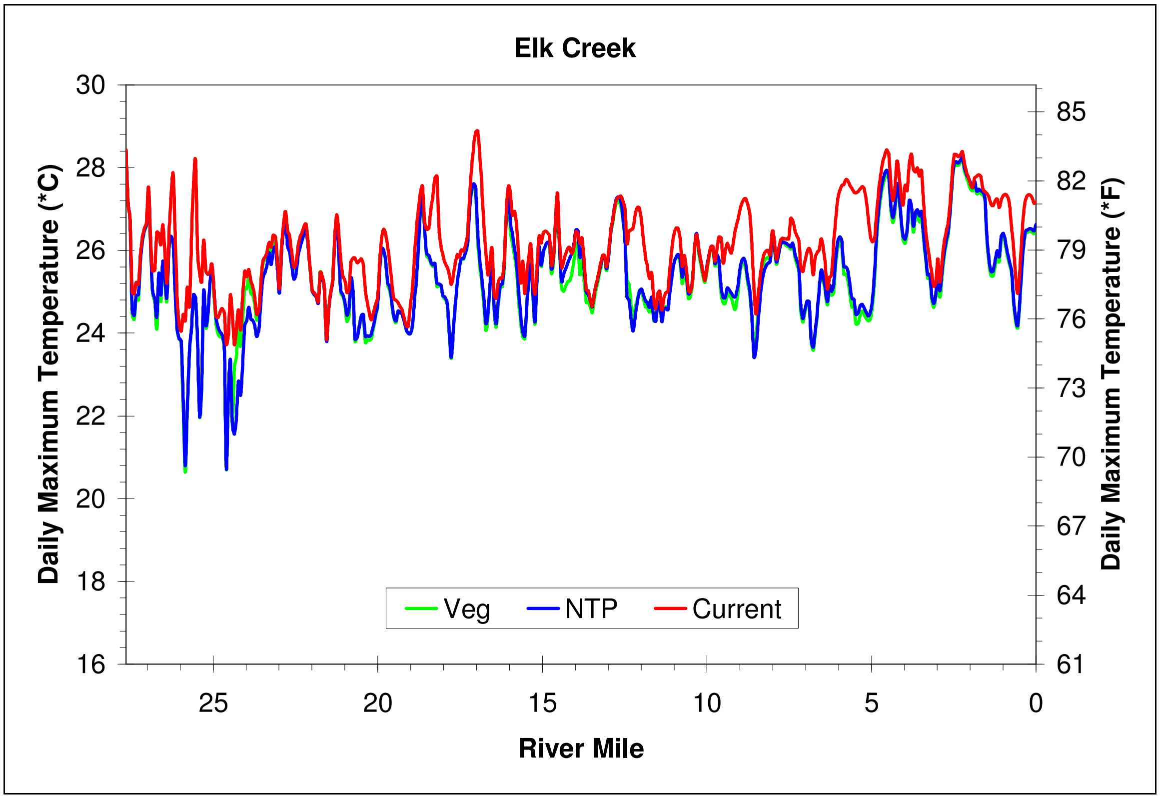


Figure 32. Elk Creek Simulation Scenario Results

Umpqua River Simulation Scenarios

The hydroelectric project on the North Umpqua River causes elevated stream temperatures that are carried all the way through the Umpqua River. The Umpqua River is very wide, and riparian vegetation naturally provides very little effective shade. The primary difference in stream temperature of the Umpqua River is caused by influences from the North Umpqua River. Although warmer than the North Umpqua River, NTP of the South Umpqua River is similar to current condition at the mouth.

The "veg" scenario includes potential vegetation, while all other parameters were left at their current condition. Due to the naturally wide channels and large flow volume, there is little added effective shade and the simulated "veg" scenario temperatures are the same as the current condition (**Figure 33**).

The "flow" scenario includes natural flow, including the effects from all upstream modeled rivers. The "flow" scenario temperatures (lavender line) are the same as the "NTP" scenario temperatures (blue line).

The "veg/flow" scenario temperatures include natural flow and potential vegetation. The resultant temperatures (orange line) are the same as the "NTP" and "veg/flow" scenario temperatures.

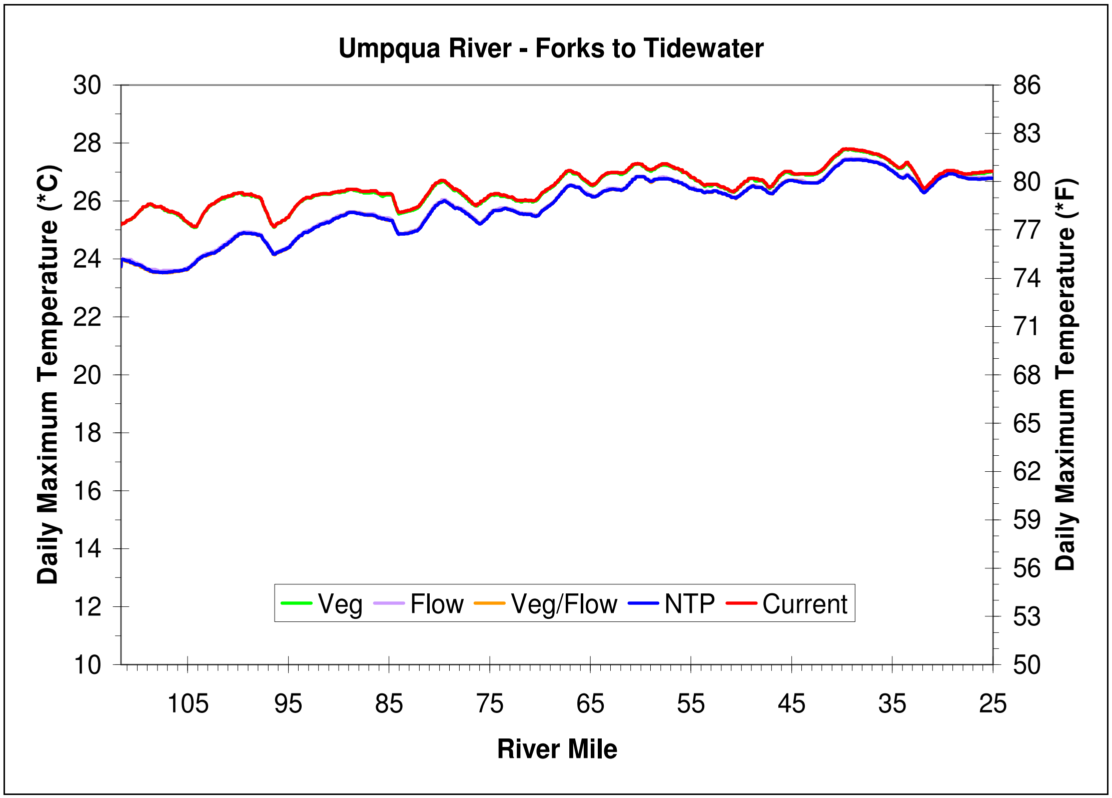


Figure 33. **Umpqua River (Forks to Tidewater) Simulation Scenario Results**

SECTION 5. NATURAL DISTURBANCE

This section discusses natural disturbance relative to the *Umpqua Basin Temperature TMDL*.

OVERVIEW

Natural disturbance includes fire, landslide, flood, disease, storm, insect damage, or any non-human induced change to near stream vegetation resulting in the reduction of effective shade. It is difficult to quantify the difference between historical and current natural disturbance rates for any given system. Human activities such as timber harvest, fire suppression, development, flood control, and other land use activities impact the amount and severity of natural disturbance. The timing, location, extent, and severity of natural disturbance events are unpredictable. Therefore, this analysis examines the impacts from a number of different disturbance scenarios.

Since, natural disturbance is a non-anthropogenic cause of increased solar radiation flux, any heat load contributed to the stream due to natural disturbance is considered part of the background load. In other words, effective shade reductions that occur after a natural disturbance are not considered a violation of the TMDL.

In most streams analyzed, the difference between current condition and natural thermal potential was greater than the variability predicted to be caused by a range of natural disturbance scenarios. The predicted natural thermal potential incorporates the average effective shade of 10 natural disturbance scenarios. The average increase in the 7-day average of the daily maximums caused by incorporating natural disturbance in natural thermal potential stream temperatures is 0.09° C with a standard deviation of 0.09° C. In 99.8% of the modeled reaches, the difference between predicted natural thermal potential with and without natural disturbance was less than the uncertainty of the model (0.5° Celsius).

Natural Disturbance and Stream Temperature

Natural disturbance in the riparian area may reduce effective shade which increases the solar radiation received by the stream.

Factors such as stream width, flow, and orientation determine the response that stream temperatures have to natural disturbance. Smaller streams are more sensitive to increased solar radiation and often exhibit more drastic temperature changes.

Large streams that naturally receive little shade from riparian vegetation (i.e., the Umpqua River mainstem) are less sensitive to natural disturbance. For example, the Umpqua River potential effective shade is often around 10%, so the solar heat load is naturally large. Natural disturbances might reduce the effective shade from 10% to 5%, but this additional heat load has little measurable impact on stream temperatures because of the large stream size and already large heat load.

NATURAL DISTURBANCE AND THE UMPQUA BASIN TEMPERATURE TMDL

Conservative estimates of natural disturbance frequency and severity were incorporated into the TMDL analysis. Specifically, a range of 0.25-2.0% per year (400- to 50-year return frequency) mixed severity natural disturbance per year was used in the simulations.

Fire Return Interval Examples

Table 6 is from *Fire Ecology of the Pacific Northwest* (Agee, 1993). The dominant conifer in the Umpqua River Basin is Douglas-fir.

Table 6. Fire-Return Intervals for Oregon over the Past Few Centuries (Agee, 1993).

Forest Type	Area in Type (1,000 ha)	Fire Cycle (yr)	Area Burned per Year (1,000 ha)	Percent Area Burned Per Year
Cedar/spruce/hemlock	292	400	0.7	0.2%
Douglas-fir	4,444	150	29.6	0.7%
Mixed conifer	399	30	13.3	3.3%
Lodgepole pine	757	80	9.4	1.2%
Woodland	1,001	25	40.0	4.0%
Subalpine	1,075	800	1.3	0.1%
Ponderosa pine	3,142	15	209.4	6.7%
Other	2,397	133	18.0	0.8%
Total/Average	13,507	42	321.7	2.1%

There are site conditions more prone to natural disturbances then others. Non-anthropogenic factors that influence natural disturbance patterns include climate, slope, geology, soils, vegetation, and elevation. DEQ did not attempt to model or predict events at such a fine scale because of the tremendous amount data and technical modeling required for such a detailed analysis. DEQ's intent is to capture the broader natural disturbance trends at the watershed and basin scale and model its effect on the Natural Thermal Potential.

"Disturbance" is a natural process in ecosystems which initiates "succession". A variety of biotic and abiotic processes which vary in frequency, magnitude, intensity, and timing constitute natural disturbance. "Chronic disturbance" relates more to the frequency, or return interval, of a disturbance event which alters the existing physical environment and community of organisms at a particular site. "Chronically disturbed ecosystems" exist in a narrow window of time. Longer return intervals allow a succession of identifiable "seral communities" to appear on a given site. Shorter return intervals result in "natural selection" for species resistant to the disturbance, and a single relatively stable community persists on a given site. Chronically disturbed ecosystems are generally dominated by species with "r-selected life histories", and exhibit a high degree of variability following each disturbance event.

Figure 34 on the following page shows fire regimes for the Umpqua River Basin (Hardy et al, 2001 and Schmidt et al, 2002).

Figure 34. Fire Regimes by Hardy et al. (2001) and Schmidt et al. (2002).

Method of Incorporating Natural Disturbance into Heat Source

The NTP models were run 10 times for each stream with 0.25-2.0% mixed severity natural disturbance per year frequency. Average results were presented as the simulated NTP temperature.

Step One: "Grow" riparian vegetation to its maximum potential heights and densities (refer back to **Table 2**).

Step Two: Run a Visual Basic macro that randomly applies natural disturbance to the riparian vegetation over a 100-year period. Disturbed vegetation then re-grows during subsequent years according to regional tree growth curves. The result is riparian vegetation that varies in height and density, mimicking a "natural" riparian landscape. This is repeated 10 times, generating 10 separate randomly disturbed vegetation input data sets for each stream.

Example: 2.0% of the riparian area is disturbed per year. The macro repeats this 100 times, to represent one century of natural disturbance events. During the 100 repetitions, previously disturbed vegetation is growing according to regional tree growth curves. Some locations may be disturbed more than once during the 100-year period.

"Mixed severity" includes the following five options which are also randomly selected by the Visual Basic macro:

Step Three: Put each of the 10 naturally disturbed vegetation data sets into 10 separate Heat Source models and run them to simulate the NTP.

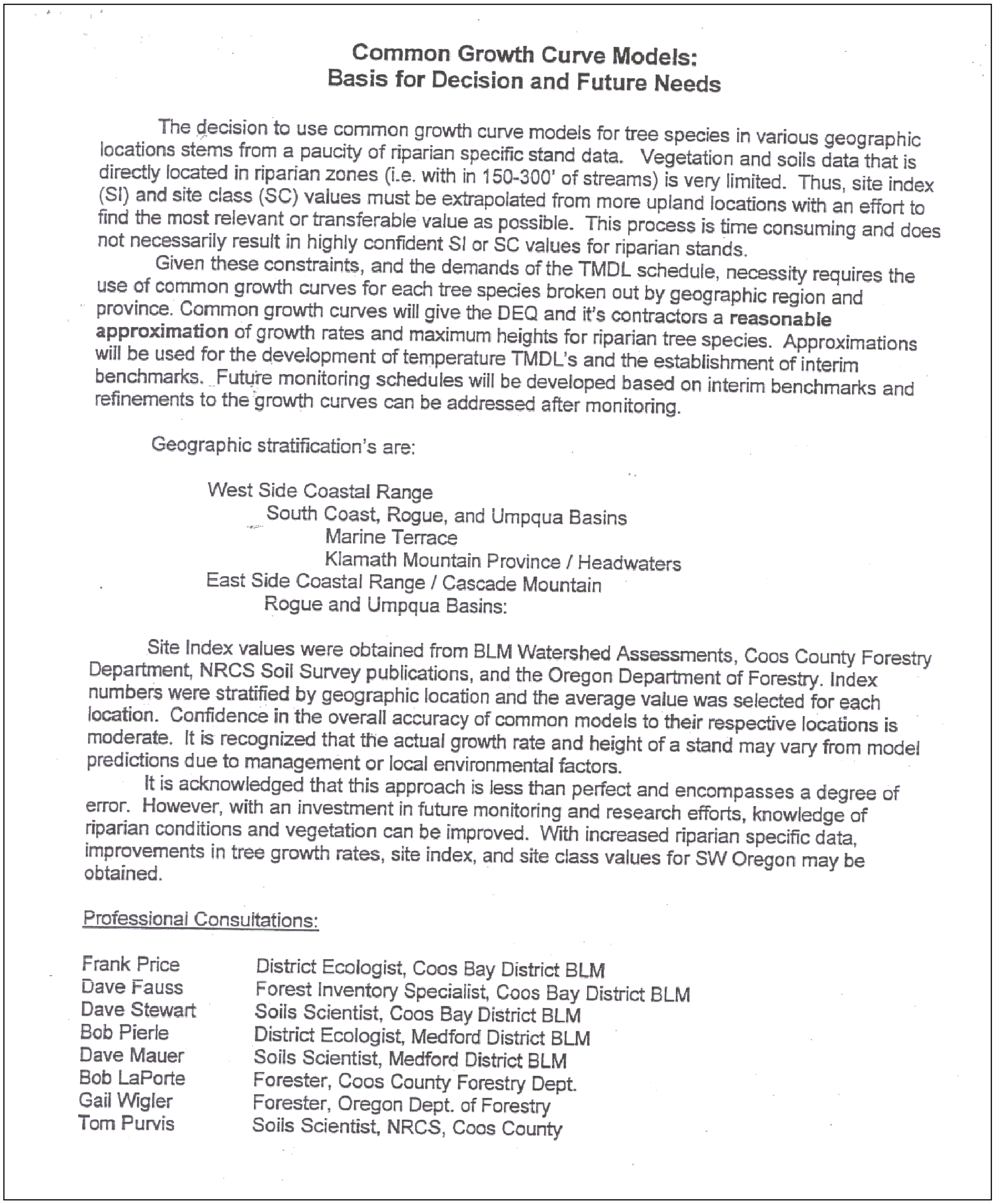
Step Four: Retrieve the NTP temperatures from each of the 10 separate simulations and calculate the average. This value represents the average NTP temperature for 0.25-20% mixed severity natural disturbance per year.

Randomization was based on the output of a pseudo-random number algorithm developed by B.A. Wichman and I.D. Hill (Wichman, Hill 1982, 1987). Pseudo-random numbers are those in a very long sequence that will eventually repeat itself. The Wichman-Hill algorithm generates ten trillion numbers before a sequence is repeated. This is within an acceptable range for DEQ purposes. The Wichman-Hill algorithm has been shown to pass a series of random number generator tests such as, the DIEHARD tests and those administered by the National Institute of Standards (Rotz et al, 2001).

Random numbers produced from the Wichman-Hill algorithm were used to choose where natural disturbance occurred along the riparian corridor and the disturbance type that occurred at that location.

After a disturbance event, the resulting heights, densities, and overhang values of the vegetation depend on the severity and the vegetation that is being disturbed. The model does not try to predict the kind of disturbance (i.e., fire, wind, flood, etc.), but rather that some sort of natural disturbance happened. After a disturbance event occurs, the vegetation begins to recover and grow for however many years are left in the cycle. For example, if an event happened on year 25 (out of 100), then the vegetation had 75 years of growth and recovery before the cycle stopped. In many cases, the vegetation that was disturbed in the early part of the cycle was mostly grown back by the time the cycle stopped. The heights, densities and overhang values throughout the growing cycle were based on local growth curves.

Figure 35 is a scanned document containing growth curve models determined by local experts.



Common Growth Curve Models:
Basis for Decision and Future Needs

The decision to use common growth curve models for tree species in various geographic locations stems from a paucity of riparian specific stand data. Vegetation and soils data that is directly located in riparian zones (i.e. with in 150-300' of streams) is very limited. Thus, site index (SI) and site class (SC) values must be extrapolated from more upland locations with an effort to find the most relevant or transferable value as possible. This process is time consuming and does not necessarily result in highly confident SI or SC values for riparian stands.

Given these constraints, and the demands of the TMDL schedule, necessity requires the use of common growth curves for each tree species broken out by geographic region and province. Common growth curves will give the DEQ and it's contractors a **reasonable approximation** of growth rates and maximum heights for riparian tree species. Approximations will be used for the development of temperature TMDL's and the establishment of interim benchmarks. Future monitoring schedules will be developed based on interim benchmarks and refinements to the growth curves can be addressed after monitoring.

Geographic stratification's are:

- West Side Coastal Range
  - South Coast, Rogue, and Umpqua Basins
    - Marine Terrace
    - Klamath Mountain Province / Headwaters
- East Side Coastal Range / Cascade Mountain
  - Rogue and Umpqua Basins:

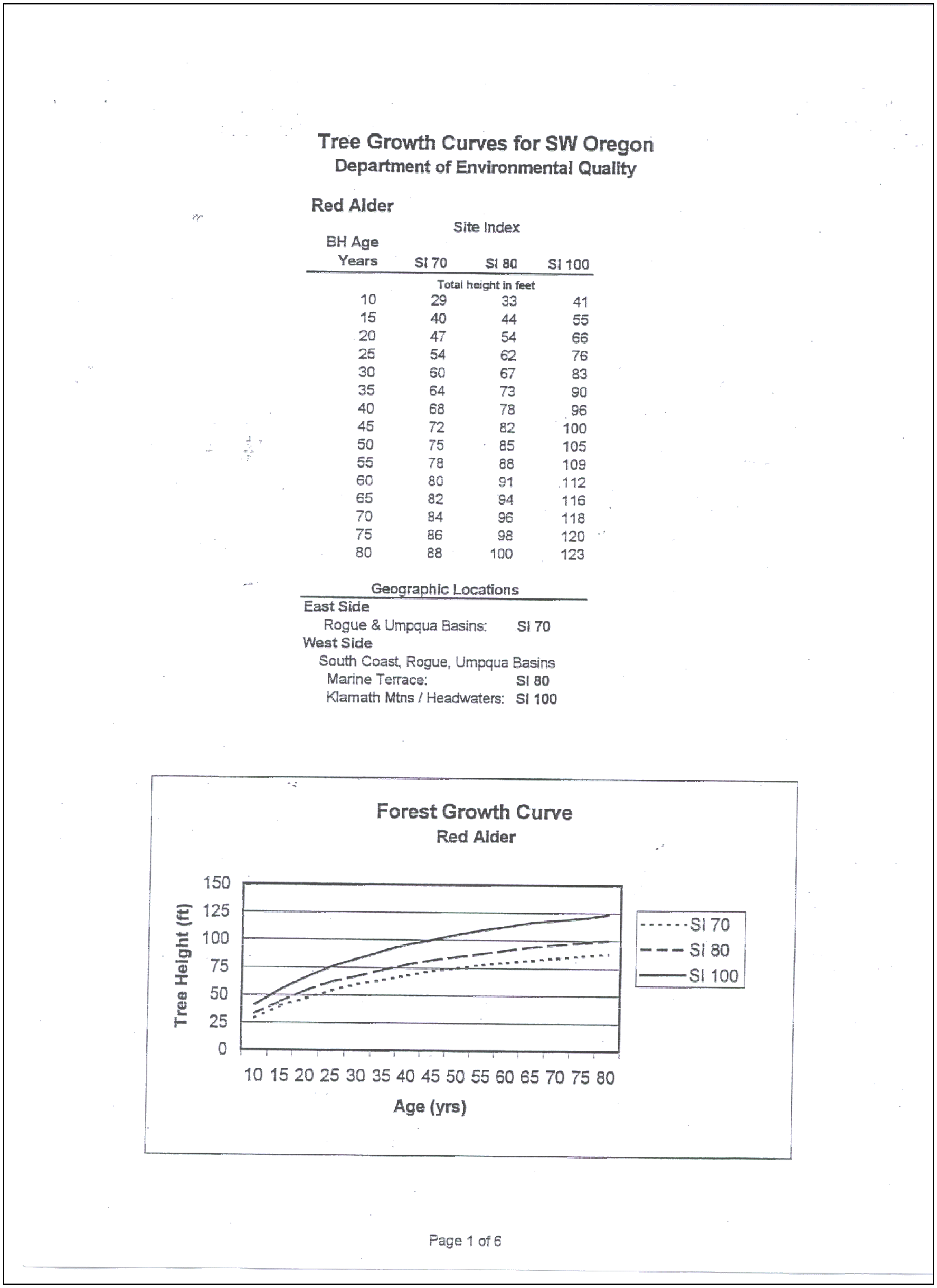
Site Index values were obtained from BLM Watershed Assessments, Coos County Forestry Department, NRCS Soil Survey publications, and the Oregon Department of Forestry. Index numbers were stratified by geographic location and the average value was selected for each location. Confidence in the overall accuracy of common models to their respective locations is moderate. It is recognized that the actual growth rate and height of a stand may vary from model predictions due to management or local environmental factors.

It is acknowledged that this approach is less than perfect and encompasses a degree of error. However, with an investment in future monitoring and research efforts, knowledge of riparian conditions and vegetation can be improved. With increased riparian specific data, improvements in tree growth rates, site index, and site class values for SW Oregon may be obtained.

Professional Consultations:

Frank Price	District Ecologist, Coos Bay District BLM
Dave Fauss	Forest Inventory Specialist, Coos Bay District BLM
Dave Stewart	Soils Scientist, Coos Bay District BLM
Bob Pierle	District Ecologist, Medford District BLM
Dave Mauer	Soils Scientist, Medford District BLM
Bob LaPorte	Forester, Coos County Forestry Dept.
Gail Wigler	Forester, Oregon Dept. of Forestry
Tom Purvis	Soils Scientist, NRCS, Coos County

Figure 35. Common Growth Curve Models



Tree Growth Curves for SW Oregon

Department of Environmental Quality

Red Alder

BH Age Years	Site Index SI 70	SI 80	SI 100
	Total height in feet		
10	29	33	41
15	40	44	55
20	47	54	66
25	54	62	76
30	60	67	83
35	64	73	90
40	68	78	96
45	72	82	100
50	75	85	105
55	78	88	109
60	80	91	112
65	82	94	116
70	84	96	118
75	86	98	120
80	88	100	123

Geographic Locations

East Side

Rogue & Umpqua Basins: **SI 70**

West Side

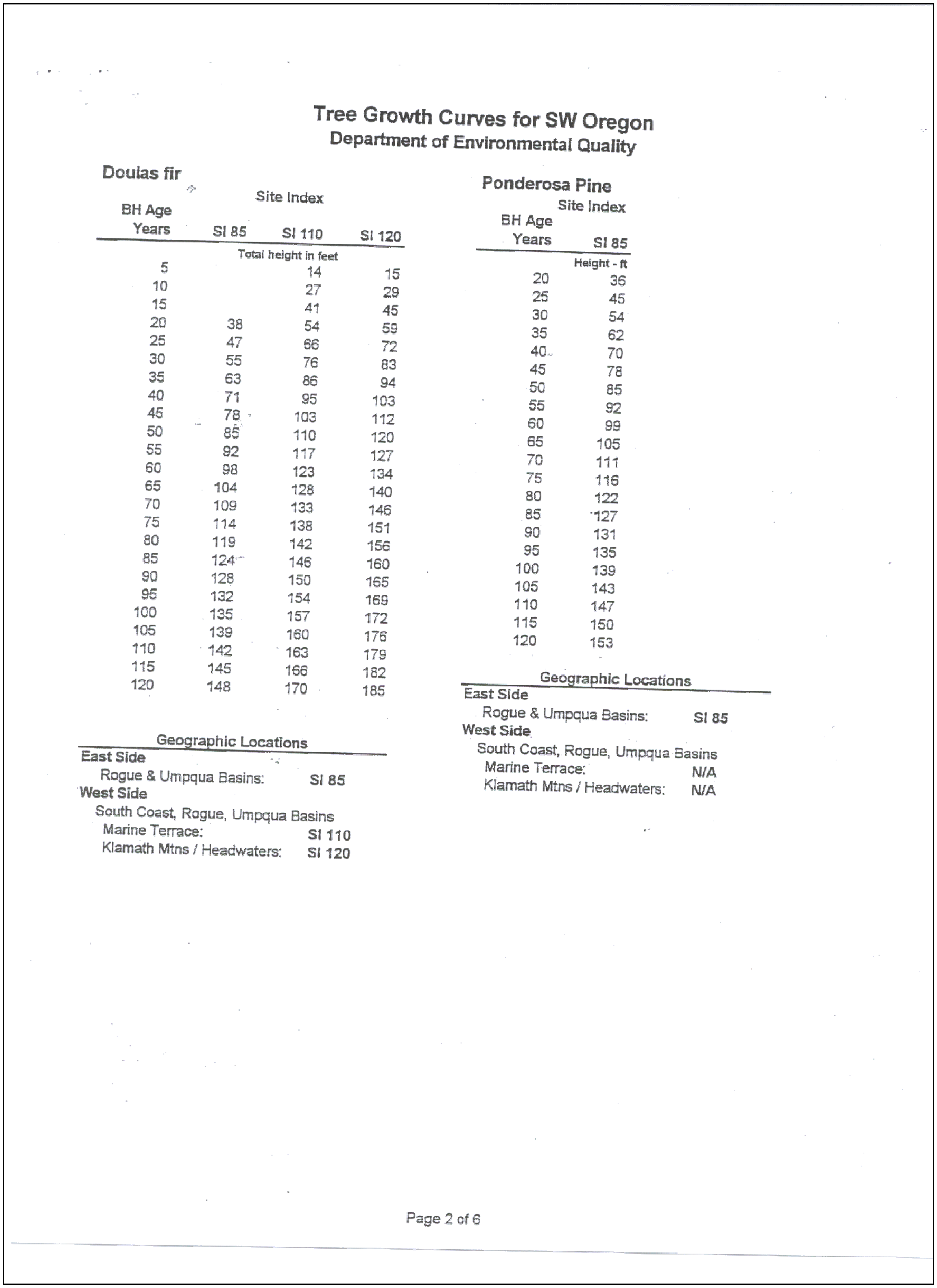
South Coast, Rogue, Umpqua Basins

Marine Terrace: **SI 80**

Klamath Mtns / Headwaters: **SI 100**

Page 1 of 6

Figure 35 (continued). Common Growth Curve Models



Tree Growth Curves for SW Oregon

Department of Environmental Quality

Doulas fir

BH Age Years	SI 85	SI 110	SI 120
	Total height in feet		
5		14	15
10		27	29
15		41	45
20	38	54	59
25	47	66	72
30	55	76	83
35	63	86	94
40	71	95	103
45	78	103	112
50	85	110	120
55	92	117	127
60	98	123	134
65	104	128	140
70	109	133	146
75	114	138	151
80	119	142	156
85	124	146	160
90	128	150	165
95	132	154	169
100	135	157	172
105	139	160	176
110	142	163	179
115	145	166	182
120	148	170	185

Site Index

Geographic Locations

East Side

Rogue & Umpqua Basins:	**SI 85**

West Side

South Coast, Rogue, Umpqua Basins

Marine Terrace:	**SI 110**
Klamath Mtns / Headwaters:	**SI 120**

Ponderosa Pine

BH Age Years	SI 85
	Height - ft
20	36
25	45
30	54
35	62
40	70
45	78
50	85
55	92
60	99
65	105
70	111
75	116
80	122
85	127
90	131
95	135
100	139
105	143
110	147
115	150
120	153

Site Index

Geographic Locations

East Side

Rogue & Umpqua Basins:	**SI 85**

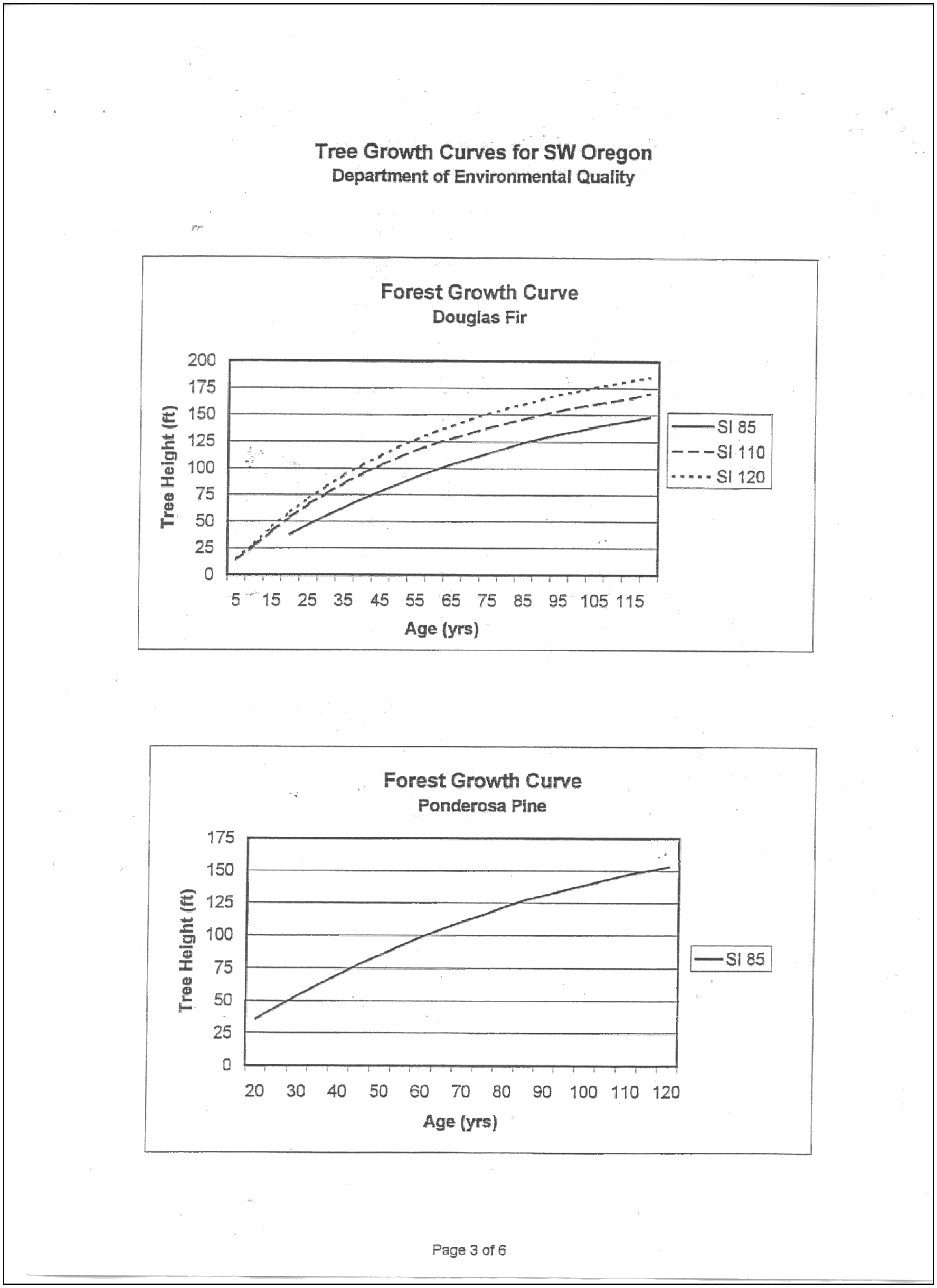
West Side

South Coast, Rogue, Umpqua Basins

Marine Terrace:	**N/A**
Klamath Mtns / Headwaters:	**N/A**

Page 2 of 6

Figure 35 (continued). Common Growth Curve Models



Tree Growth Curves for SW Oregon

Department of Environmental Quality

Forest Growth Curve

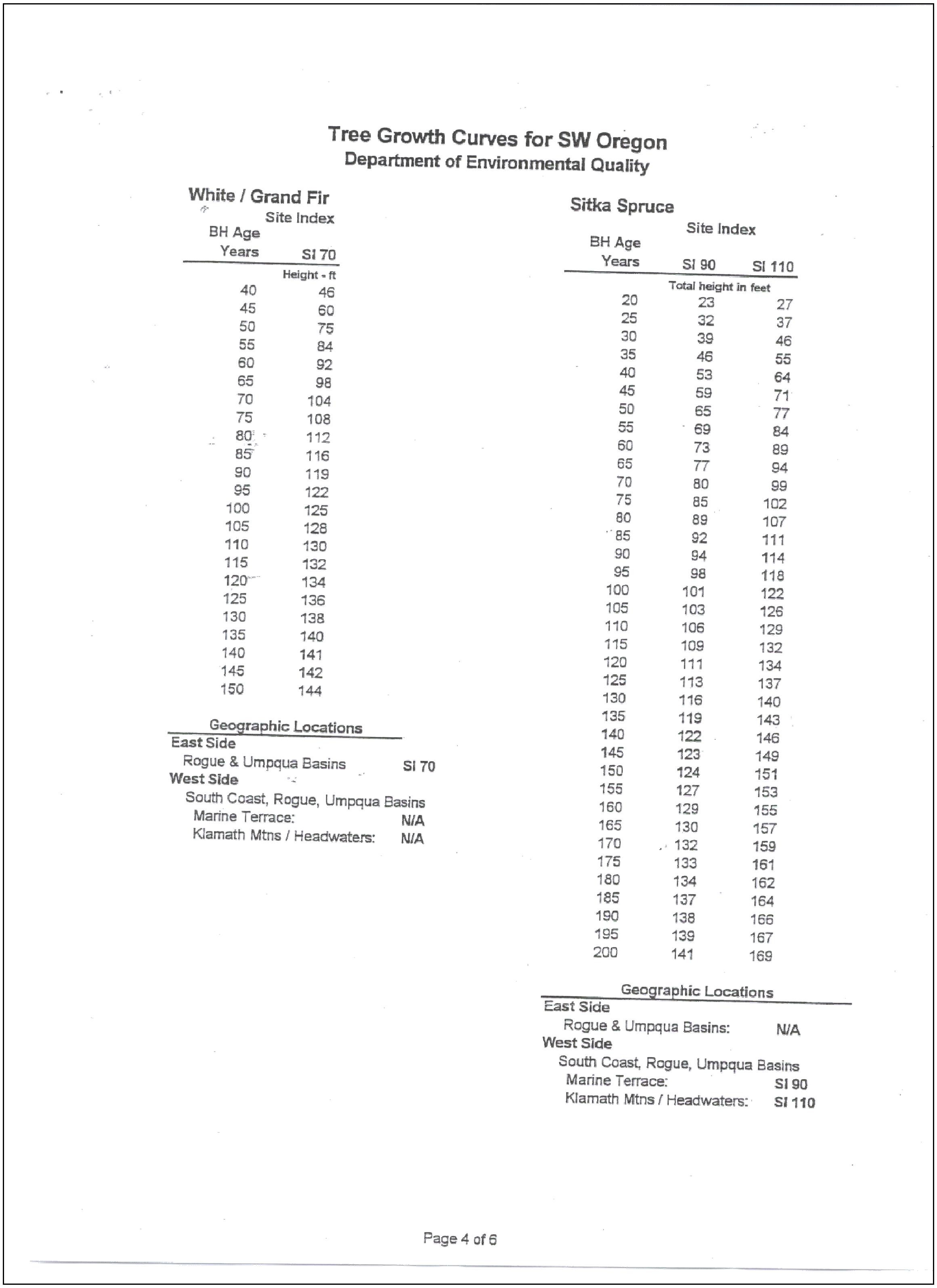
Douglas Fir

Forest Growth Curve

Ponderosa Pine

Page 3 of 6

Figure 35 (continued). Common Growth Curve Models



Tree Growth Curves for SW Oregon
Department of Environmental Quality

White / Grand Fir

BH Age Years	Site Index SI 70 Height - ft
40	46
45	60
50	75
55	84
60	92
65	98
70	104
75	108
80	112
85	116
90	119
95	122
100	125
105	128
110	130
115	132
120	134
125	136
130	138
135	140
140	141
145	142
150	144

Geographic Locations

East Side

Rogue & Umpqua Basins SI 70

West Side

South Coast, Rogue, Umpqua Basins

Marine Terrace: N/A

Klamath Mtns / Headwaters: N/A

Sitka Spruce

BH Age Years	Site Index SI 90	SI 110
	Total height in feet	
20	23	27
25	32	37
30	39	46
35	46	55
40	53	64
45	59	71
50	65	77
55	69	84
60	73	89
65	77	94
70	80	99
75	85	102
80	89	107
85	92	111
90	94	114
95	98	118
100	101	122
105	103	126
110	106	129
115	109	132
120	111	134
125	113	137
130	116	140
135	119	143
140	122	146
145	123	149
150	124	151
155	127	153
160	129	155
165	130	157
170	132	159
175	133	161
180	134	162
185	137	164
190	138	166
195	139	167
200	141	169

Geographic Locations

East Side

Rogue & Umpqua Basins: N/A

West Side

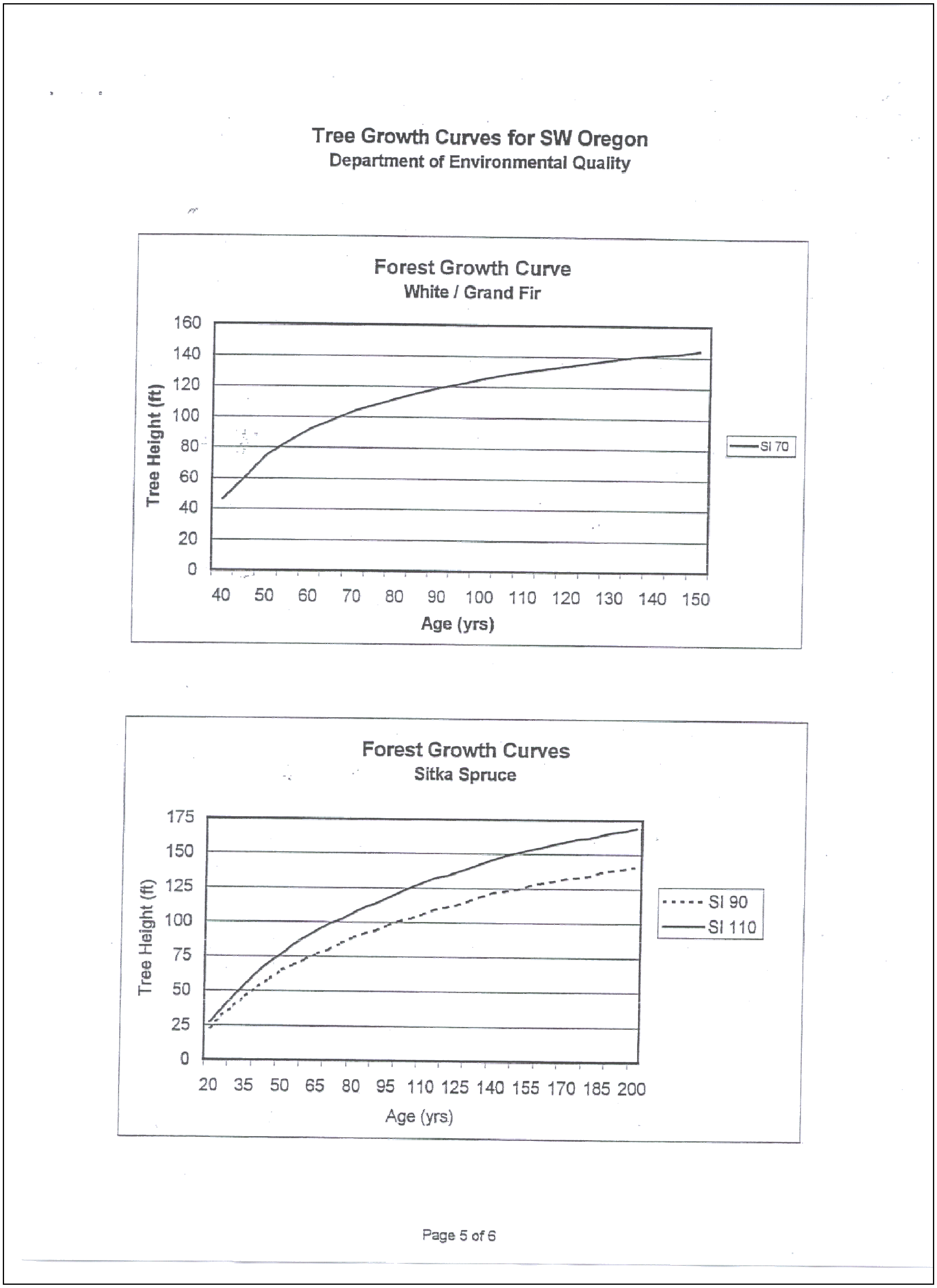
South Coast, Rogue, Umpqua Basins

Marine Terrace: SI 90

Klamath Mtns / Headwaters: SI 110

Page 4 of 6

Figure 35 (continued). Common Growth Curve Models



Tree Growth Curves for SW Oregon

Department of Environmental Quality

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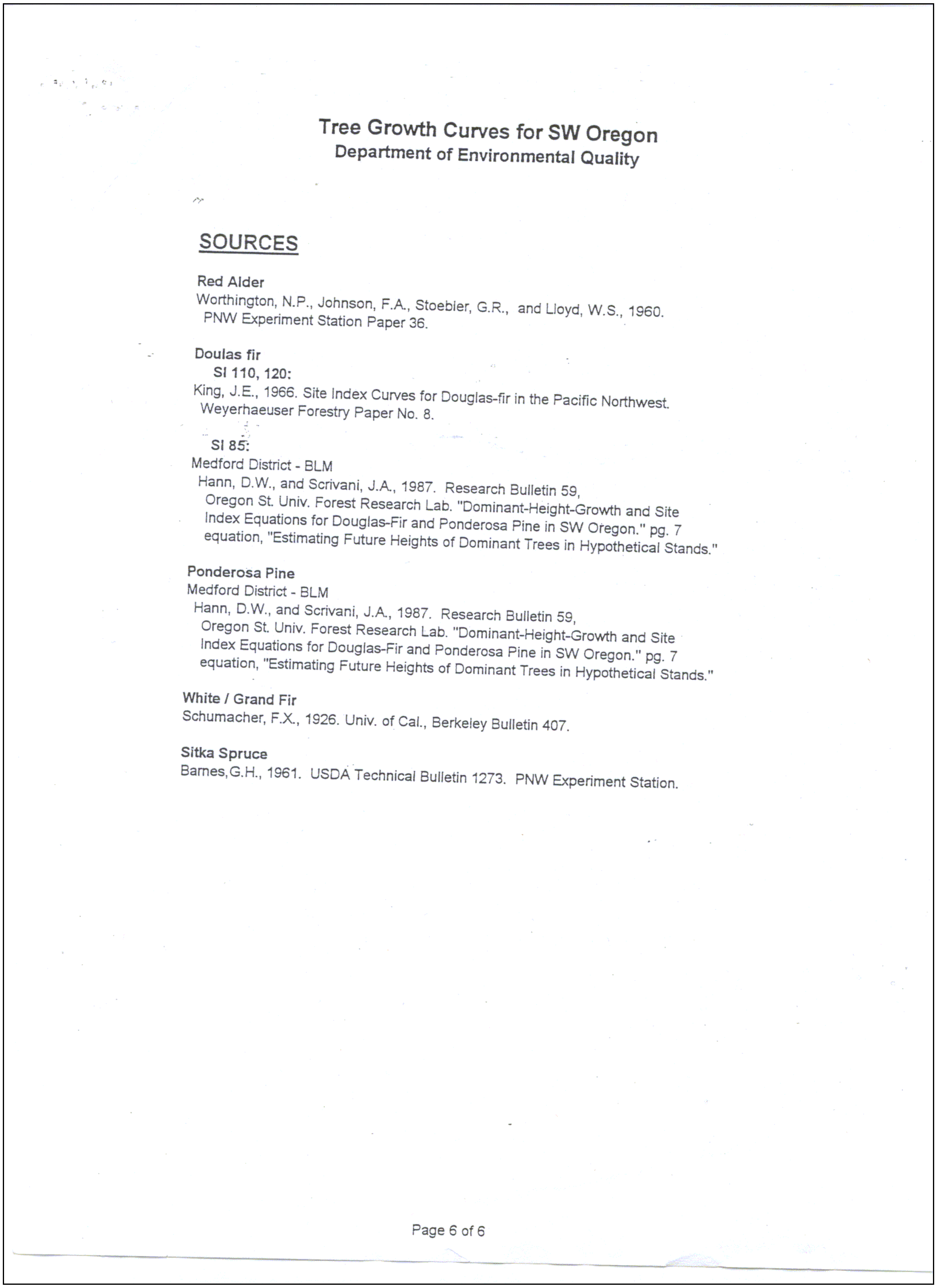
Figure 35 (continued). Common Growth Curve Models



Tree Growth Curves for SW Oregon
Department of Environmental Quality

SOURCES

Red Alder
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Doulas fir
SI 110, 120:
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SI 85:
Medford District - BLM
Hann, D.W., and Scrivani, J.A., 1987. Research Bulletin 59, Oregon St. Univ. Forest Research Lab. "Dominant-Height-Growth and Site Index Equations for Douglas-Fir and Ponderosa Pine in SW Oregon." pg. 7 equation, "Estimating Future Heights of Dominant Trees in Hypothetical Stands."

Ponderosa Pine
Medford District - BLM
Hann, D.W., and Scrivani, J.A., 1987. Research Bulletin 59, Oregon St. Univ. Forest Research Lab. "Dominant-Height-Growth and Site Index Equations for Douglas-Fir and Ponderosa Pine in SW Oregon." pg. 7 equation, "Estimating Future Heights of Dominant Trees in Hypothetical Stands."

White / Grand Fir
Schumacher, F.X., 1926. Univ. of Cal., Berkeley Bulletin 407.

Sitka Spruce
Barnes, G.H., 1961. USDA Technical Bulletin 1273. PNW Experiment Station.

Page 6 of 6

Figure 35 (continued). Common Growth Curve Models

Mixed Severity Natural Disturbance Related to Solar Radiation

While mixed severity is being applied to a vegetation data set, one of five severity options is randomly selected. The amount of increased solar radiation was quantified for each of the severity options for a north-south running stream surrounded by 100-foot tall forest at 80% density. **Table 7** summarizes the results, averaged for a stream between 2 and 20 meters wide.

Table 7. Mixed Severity Natural Disturbance Translated into Solar Radiation Increase.

Severity Option	Height Reduction	Density Reduction	Solar Radiation Increase/Effective Shade Decrease
1	0%	75%	64%
2	25%	25%	28%
3	50%	50%	54%
4	75%	25%	49%
5	100%	100%	100%

On average, mixed severity natural disturbance increases solar radiation (reduces effective shade) by 59%. (Applicable to streams 2-20 meters wide, running north south, containing 100-foot tall, 80% density vegetation before natural disturbance.)

Figure 36 shows the effective shade which results from each natural disturbance severity option for a variety of channel widths on a north-south running stream. The mature, undisturbed forest is assumed to be 100 feet tall and have 80% density.

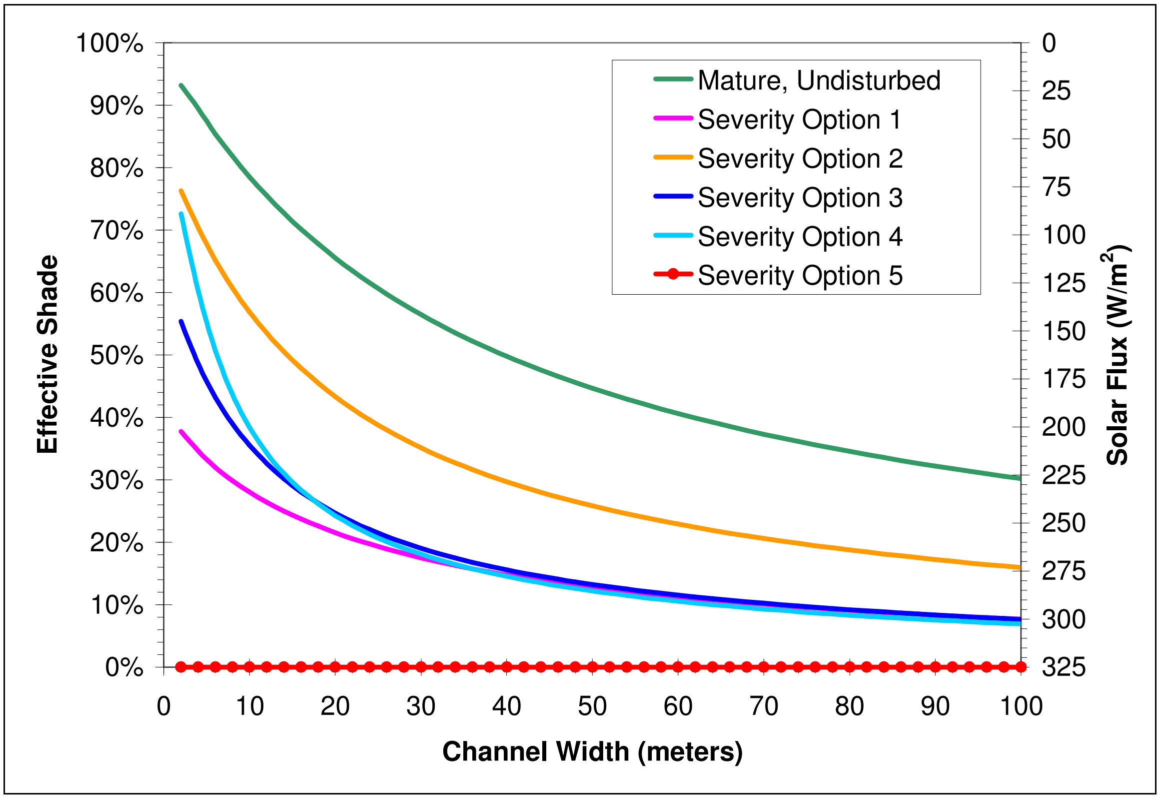


Figure 36. **Effective Shade and Solar Radiation Results for each Natural Disturbance Severity Option on a North-South Running Stream.**

Natural Disturbance and Load Allocations

Including natural disturbance in the NTP simulations usually has no effect on nonpoint source load allocations.

Streams with no assimilative capacity (i.e., those that exceed the numeric criteria) are assigned an anthropogenic nonpoint source heat load allocation of zero. Since natural disturbance would increase the simulated NTP temperatures, the stream would still have no assimilative capacity.

Streams with assimilative capacity receive an anthropogenic nonpoint source heat load allocation designed to allow human activities to add heat to the stream, without exceeding the water quality standards. This is based on the simulated NTP temperatures. Including natural disturbance in the temperature simulations actually increases the NTP for many streams. The more natural disturbance included, the higher the simulated NTP temperatures. This translates into less assimilative capacity and smaller anthropogenic nonpoint source heat load allocations.

In some cases, increasing the amount of natural disturbance in the NTP temperature simulation might mean the difference between having assimilative capacity or not. For example, assume a stream is slightly below the numeric criterion when a 100-year natural disturbance return interval is included in the NTP simulation. It will have some assimilative capacity and heat load will be allocated to anthropogenic nonpoint sources. Now assume the same stream is simulated with a 50-year natural disturbance return interval and the NTP temperature then exceeds the numeric criterion because of the lower effective shade levels. In this case, there is no assimilative capacity and the anthropogenic nonpoint source heat load is zero.

Hypothetical Natural Disturbance Scenarios and the Impact on TMDLs

If a stream's NTP is below the applicable criterion, there will be assimilative capacity and heat load available for anthropogenic nonpoint source allocations. If the NTP is above the applicable criterion, there is no assimilative capacity and zero anthropogenic nonpoint source allocation. In other words, anthropogenic nonpoint sources are not allowed to heat the stream when its NTP exceeds the applicable criterion.

Higher natural disturbance rates and severities will result in warmer NTP temperatures. Higher NTP temperatures are more likely to exceed the applicable criterion and the chance of having no assimilative capacity is greater.

Figure 37 contains hypothetical NTP simulation results for a variety of natural disturbance rates/severities. The current temperature exceeds the numeric criterion (18^{o}C).

NTP 3 represents the most conservative (lowest) natural disturbance rate/severity. The temperatures are well below the numeric criterion. There is assimilative capacity and anthropogenic nonpoint sources can be allocated heat load (as long as there are no downstream violations).

NTP 2 represents less conservative (higher) natural disturbance rate/severity. The temperatures are still below the numeric criterion, but there is less assimilative capacity. The anthropogenic nonpoint source allocation will be less than the NTP 1 scenario.

NTP 1 represents the least conservative (highest) natural disturbance rate/severity. The temperatures exceed the numeric criterion. There is no assimilative capacity and the anthropogenic nonpoint source allocation will be zero.

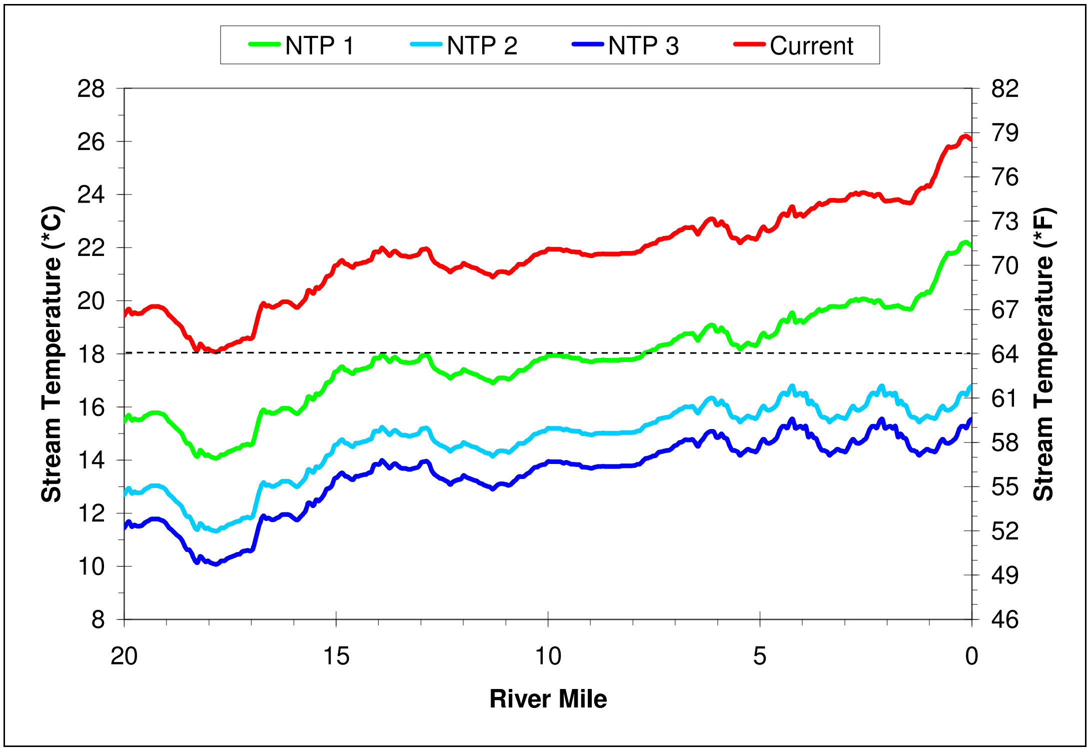


Figure 37. **Hypothetical Natural Thermal Potential (NTP) Simulation Results**

Natural Disturbance Impacts on Effective Shade

Including natural disturbance in the Umpqua Basin temperature TMDL's NTP simulations resulted in a mosaic of effective shade levels along the stream. Some reaches have effective shade below the maximum potential. In many cases, natural disturbance resulted in effective shade levels **below the current condition**. For example, the lower reaches of Rock Creek are surrounded by mature conifer forest and effective shade levels are currently at their maximum potential. Adding natural disturbance within the NTP simulation reduced the tree heights/densities along lower Rock Creek and decreased effective shade levels. These lower effective shade values were used in the Rock Creek NTP simulations.

Figure 38 is an example from one of the 10 NTP simulations on Rock Creek. The red bars indicate the percentage that effective shade was *below* its maximum potential, due to natural disturbance. For example, the simulated NTP effective shade between river miles 2 and 3 was approximately 30% below the maximum potential level due to natural disturbance. In other words, if natural disturbance never occurred between river miles 2 and 3, and the trees were fully mature, there would be 30% more effective shade.

This chart is typical of all NTP simulations performed in The Umpqua River Basin Temperature TMDL.

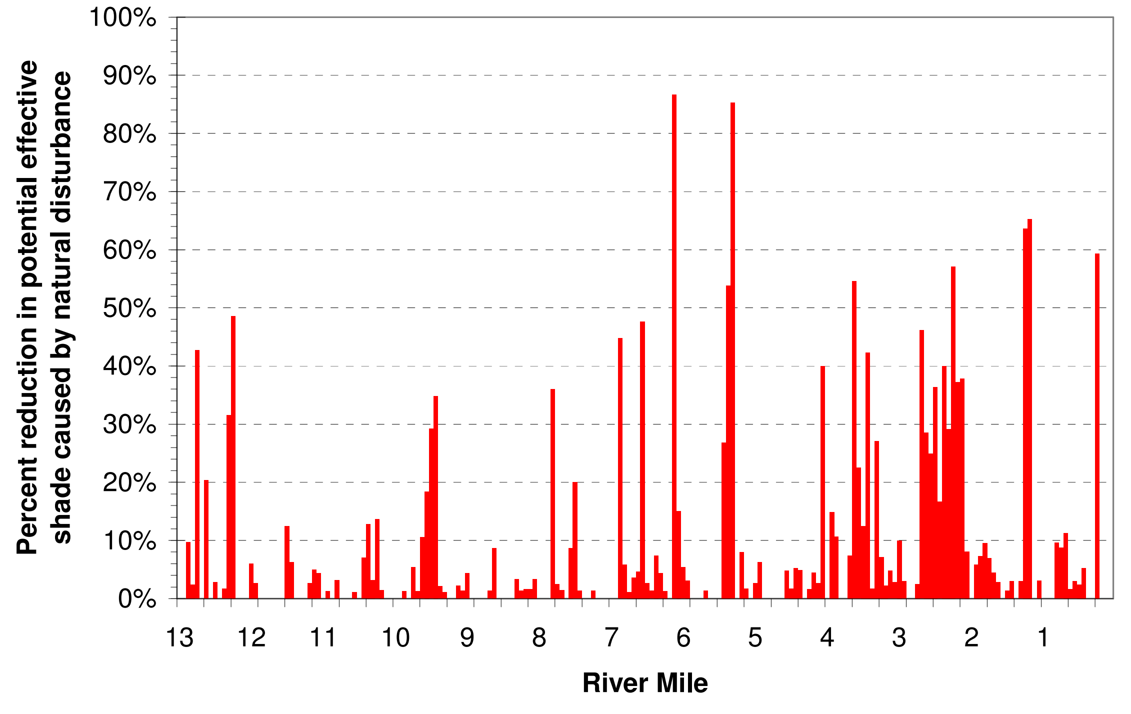


Figure 38. **Percentage below Potential Effective Shade Caused by Natural Disturbance on One Rock Creek NTP Simulation.**

Natural Disturbance Impacts on NTP Stream Temperatures

The largest streams simulated (i.e., South Umpqua River, North Umpqua River, Umpqua River) showed no measurable NTP temperature increase when natural disturbance was included. They have larger flow volumes and naturally low effective shade levels. Smaller streams simulated (i.e., Rock Creek, Canton Creek) displayed some sensitivity to natural disturbance. The NTP temperatures with natural disturbance were slightly warmer than the NTP temperatures without natural disturbance.

In most streams analyzed, the difference between current condition and natural thermal potential was greater than the variability predicted to be caused by a range of natural disturbance scenarios. The predicted natural thermal potential incorporates the average effective shade of 10 natural disturbance scenarios. The average increase in the 7-day average of the daily maximums caused by incorporating natural disturbance in natural thermal potential stream temperatures is 0.09° C with a standard deviation of 0.09° C. In 99.8% of the modeled reaches, the difference between predicted natural thermal potential with and without natural disturbance was less than the uncertainty of the model (0.5° Celsius).

Figure 39 displays the results from all 10 NTP simulations with natural disturbance and the NTP simulation without natural disturbance for comparison. The blue lines represent the range of results from the NTP simulations. The lowest of the blue lines represents the simulated NTP without natural disturbance. The *Umpqua River Basin Temperature TMDL* presents the NTP temperatures as the average of the 10 simulations. Some streams had statistically insignificant temperature increases when natural disturbance was included in the NTP simulation.

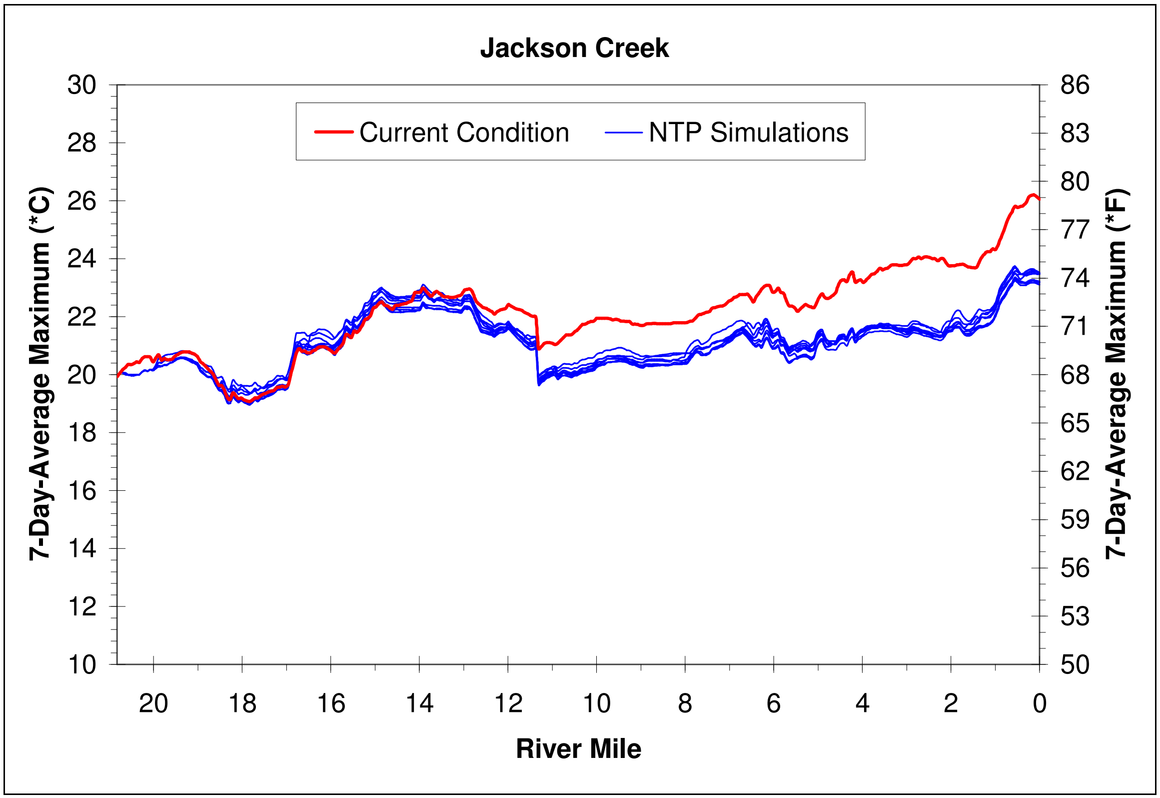
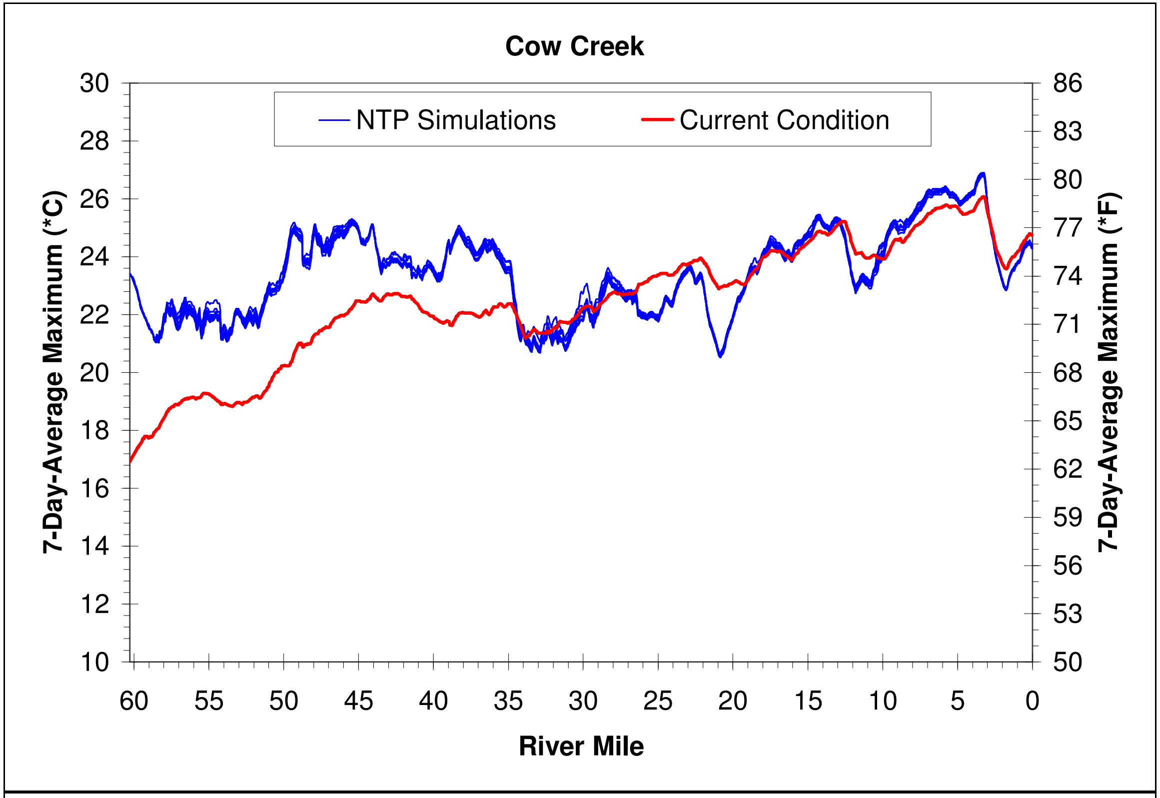


Figure 39. NTP Temperatures Representing the Natural Disturbance Ranges Simulated



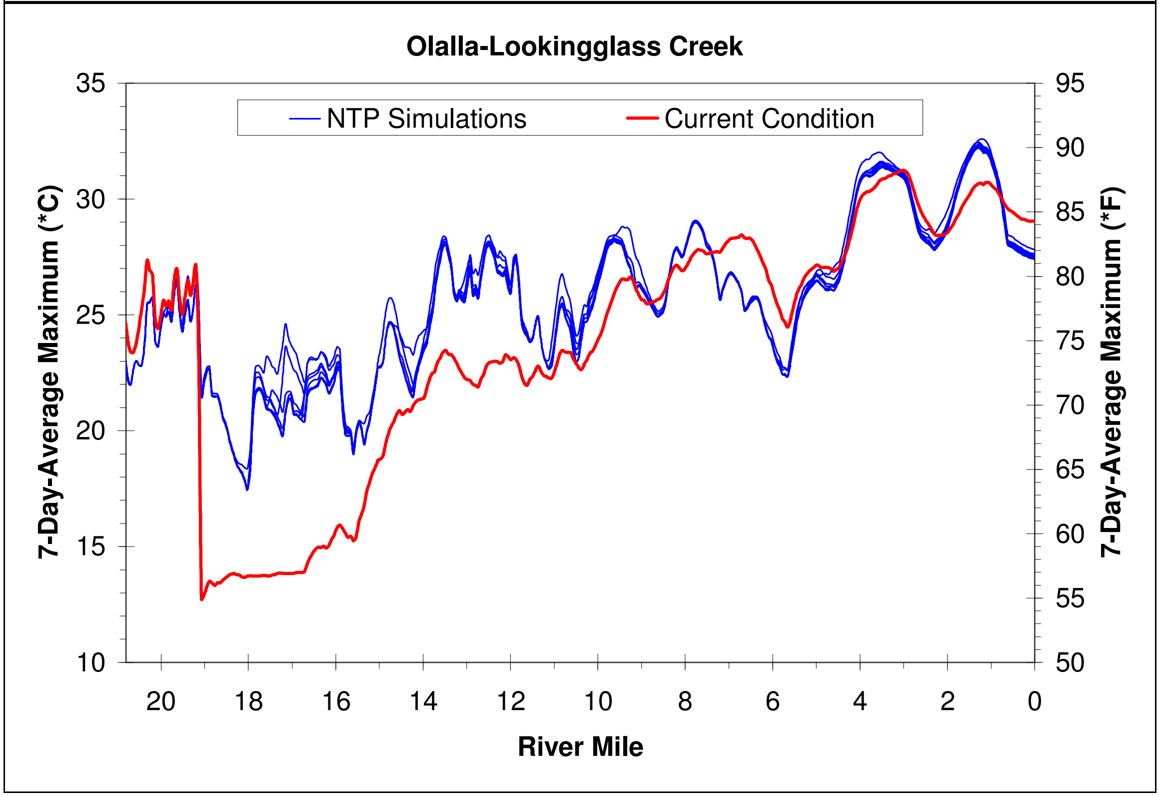
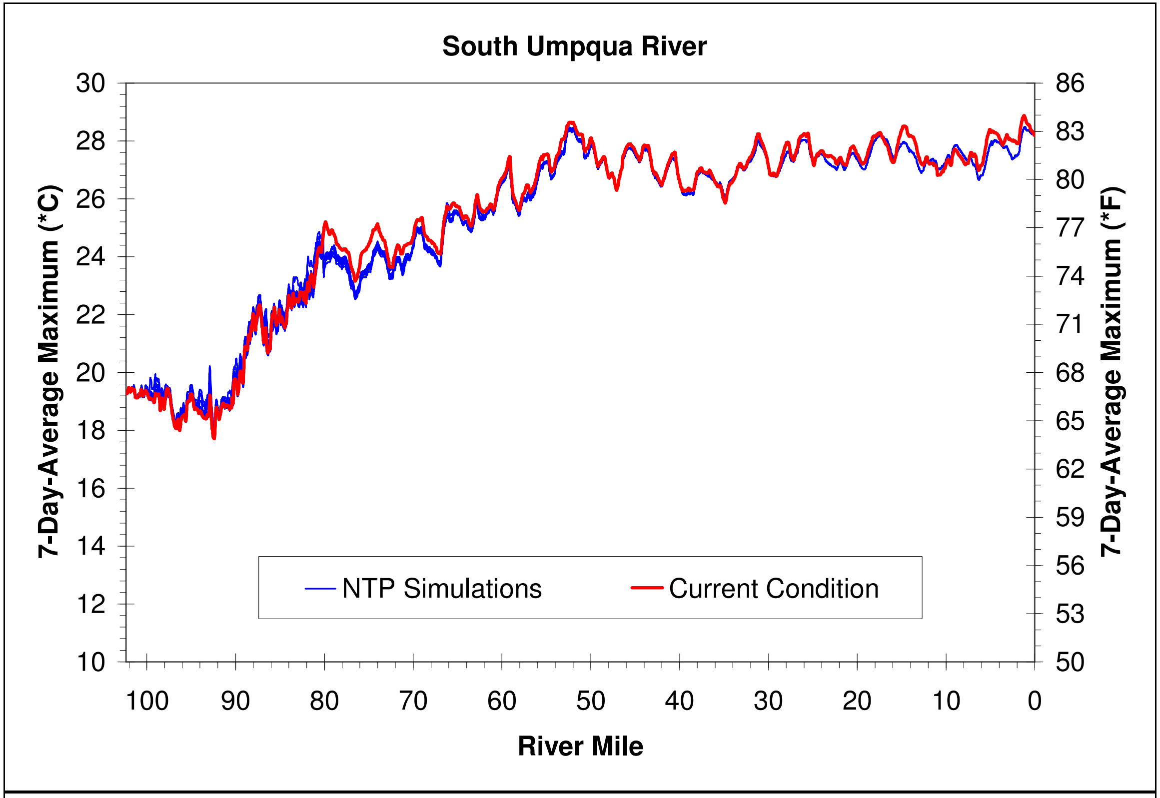


Figure 39 (continued). NTP Temperatures Representing the Natural Disturbance Ranges Simulated



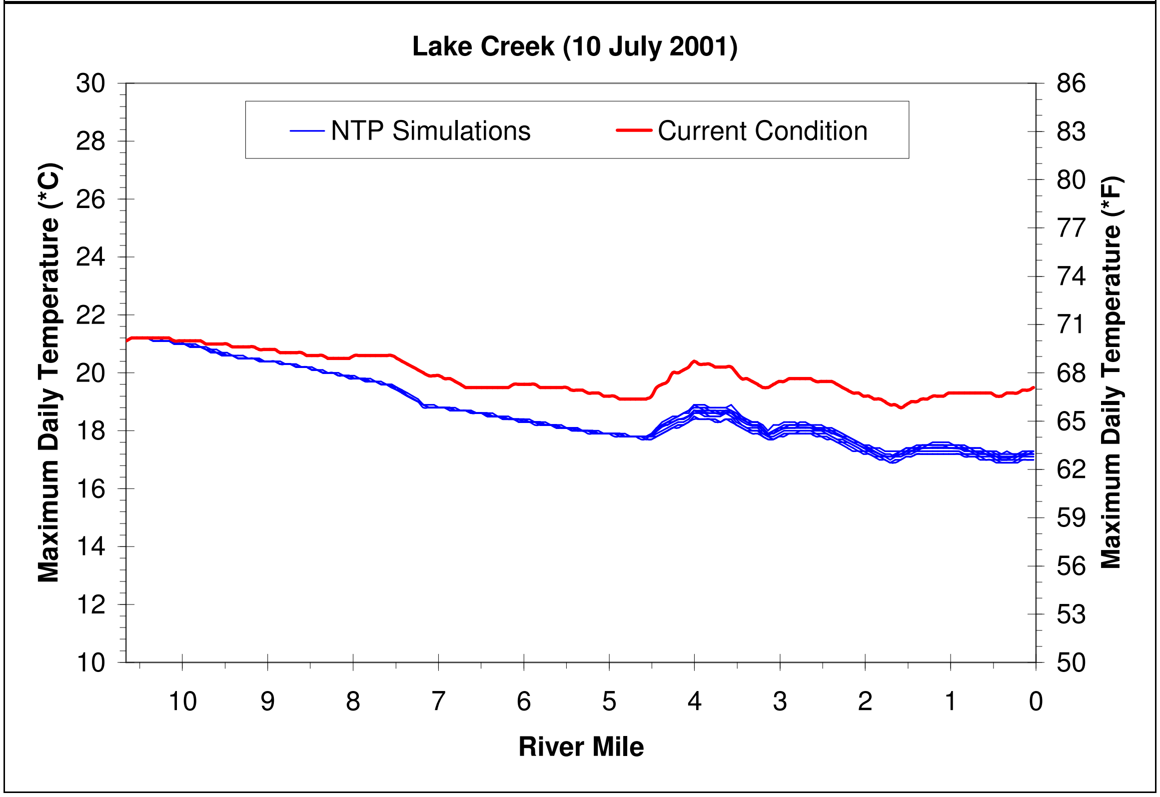
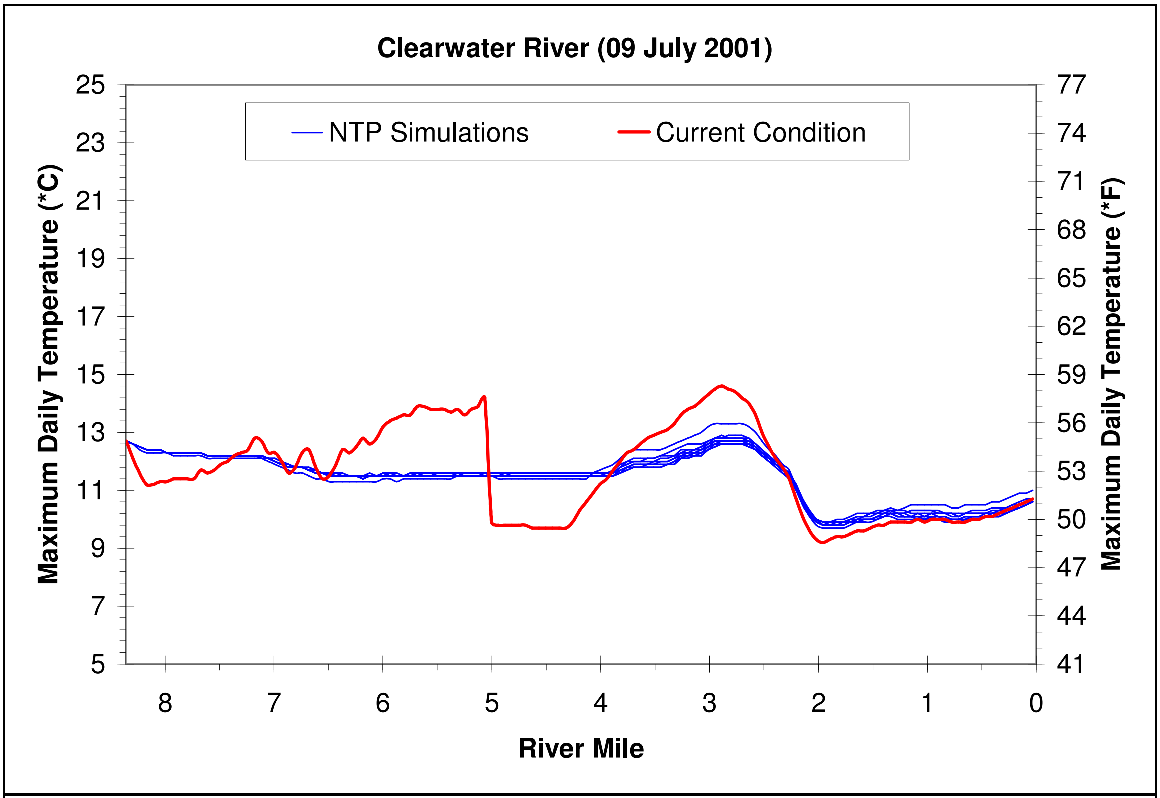


Figure 39 (continued). NTP Temperatures Representing the Natural Disturbance Ranges Simulated



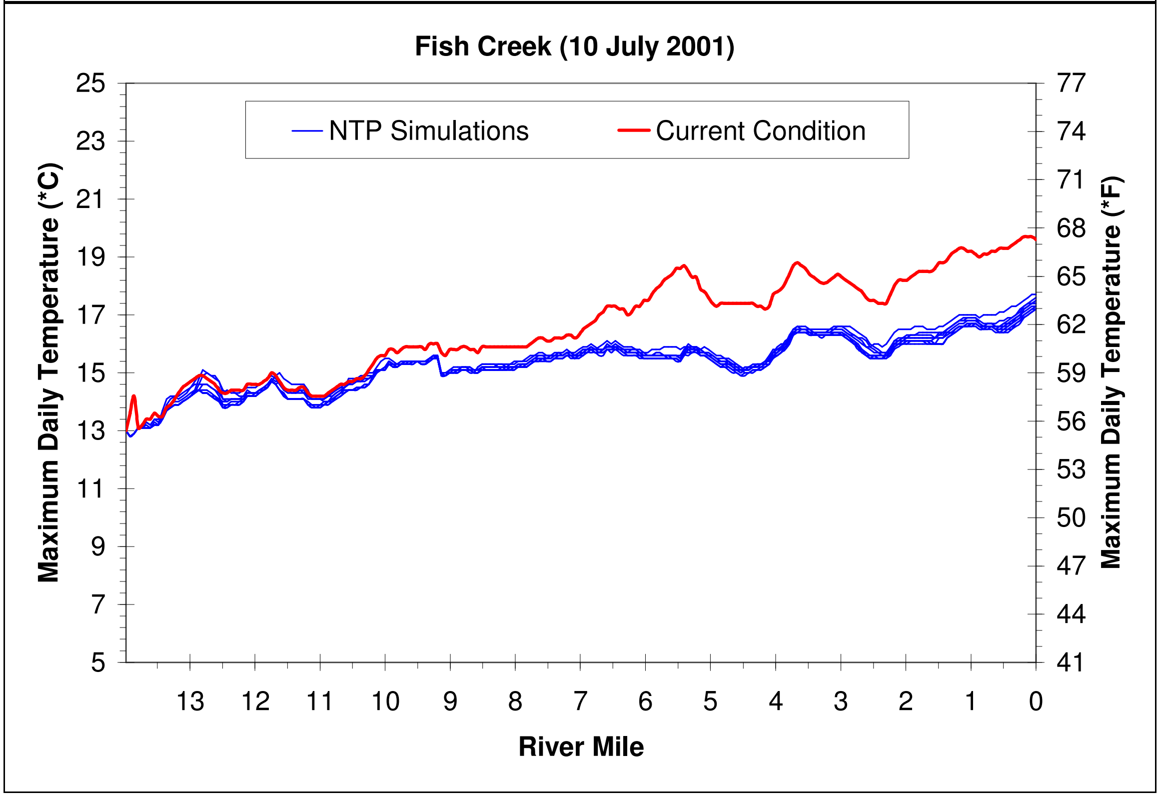


Figure 39 (continued). NTP Temperatures Representing the Natural Disturbance Ranges Simulated

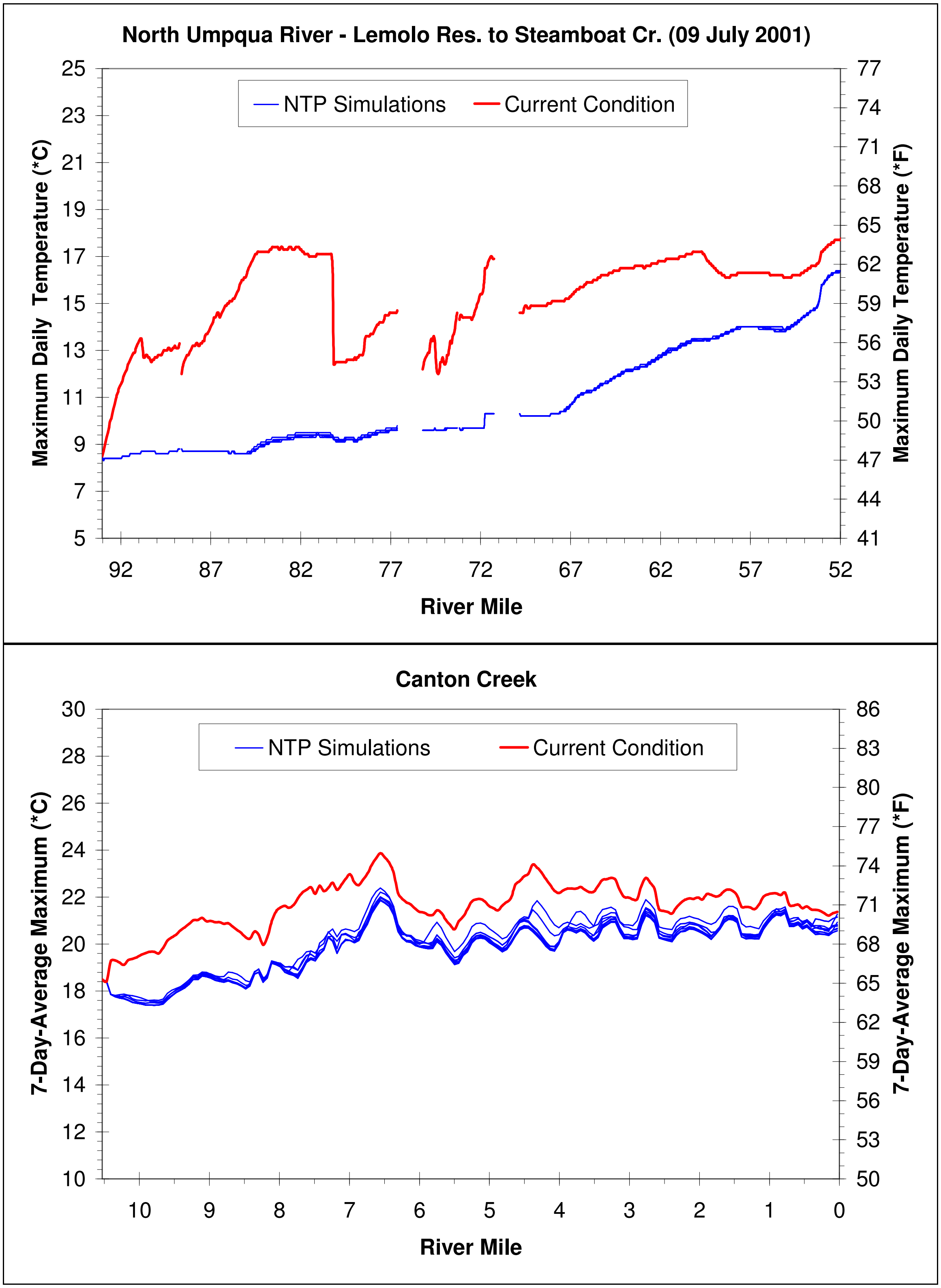


Figure 39 (continued). NTP Temperatures Representing the Natural Disturbance Ranges Simulated

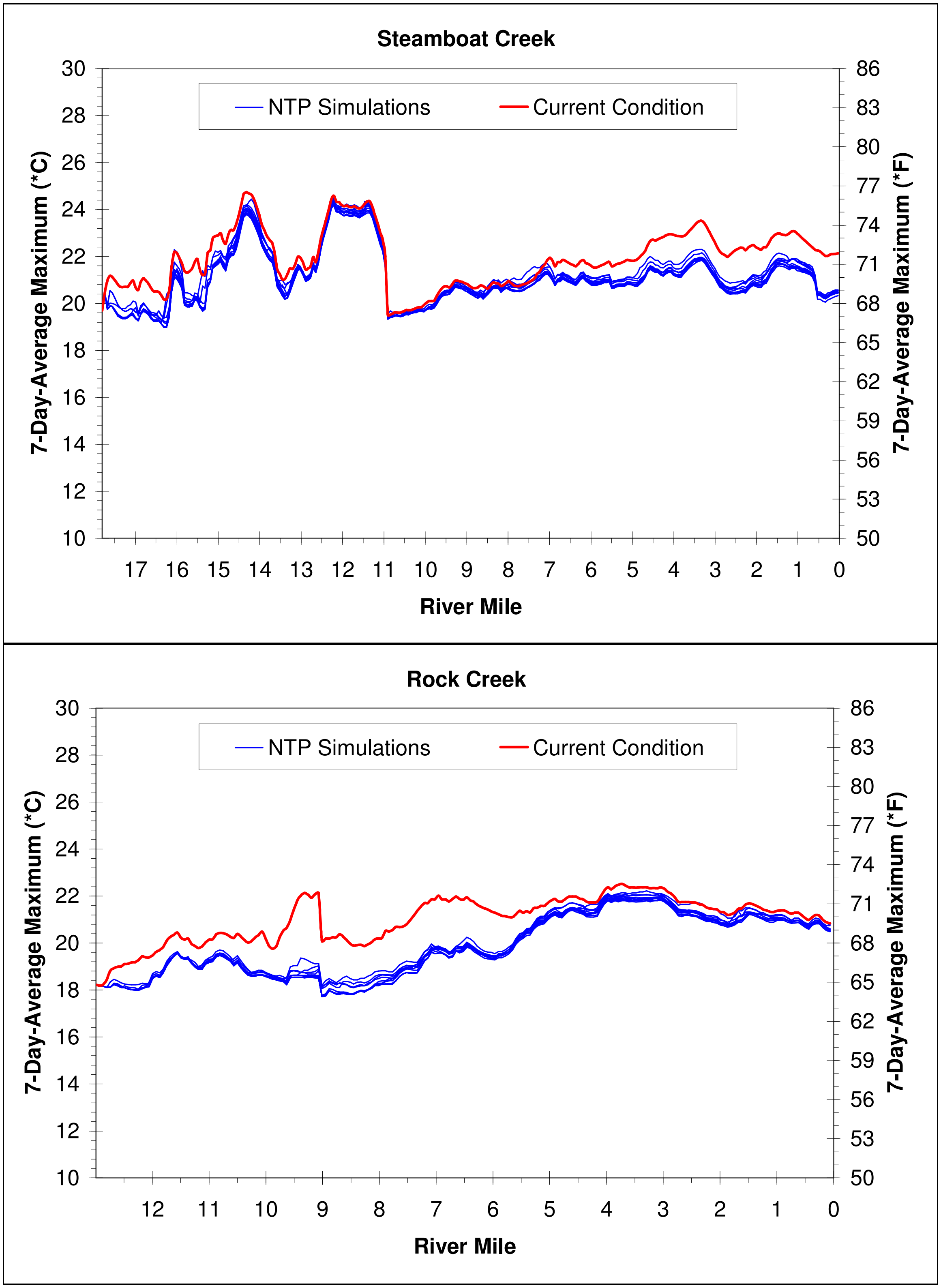


Figure 39 (continued). NTP Temperatures Representing the Natural Disturbance Ranges Simulated

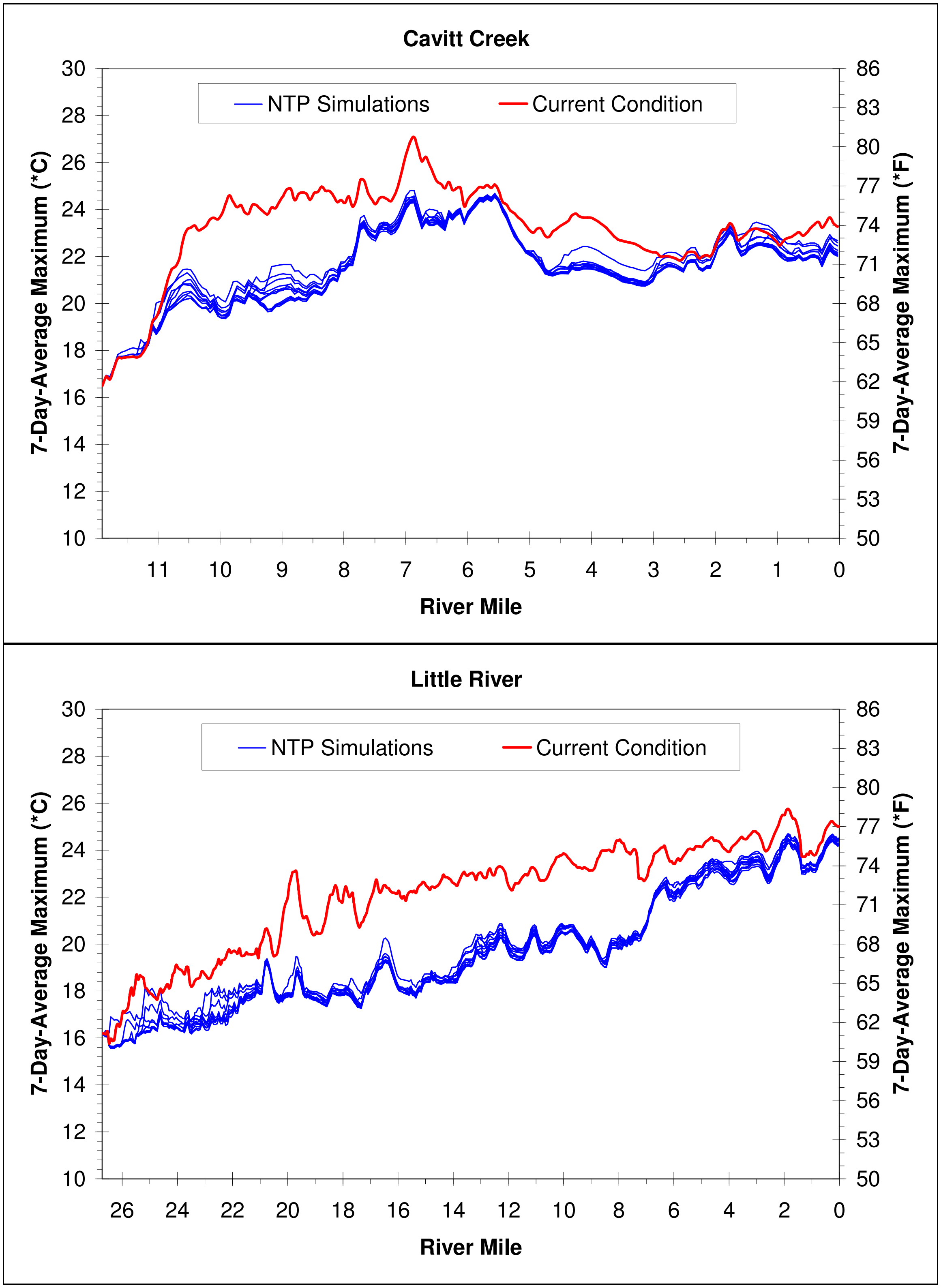


Figure 39 (continued). NTP Temperatures Representing the Natural Disturbance Ranges Simulated

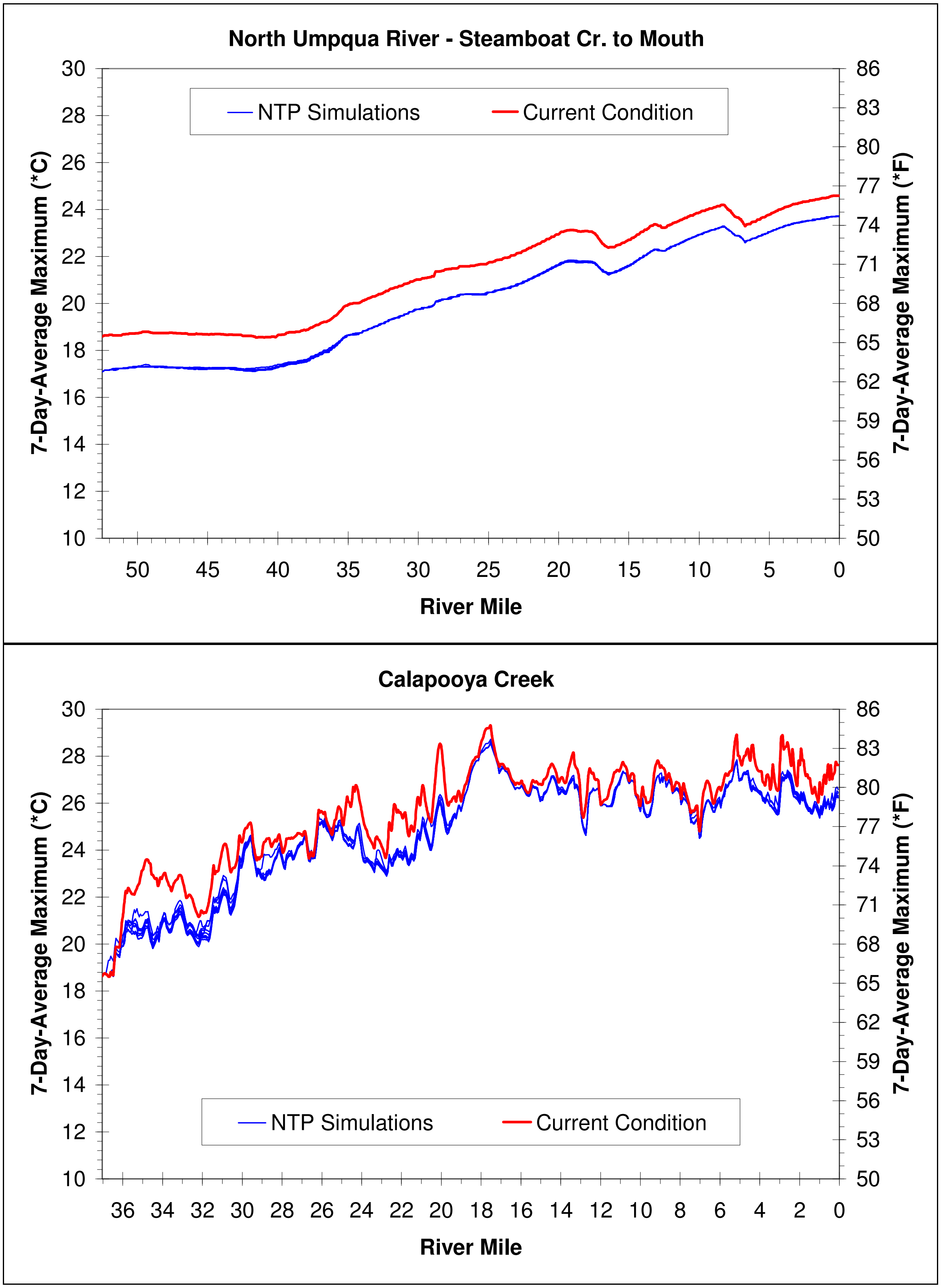
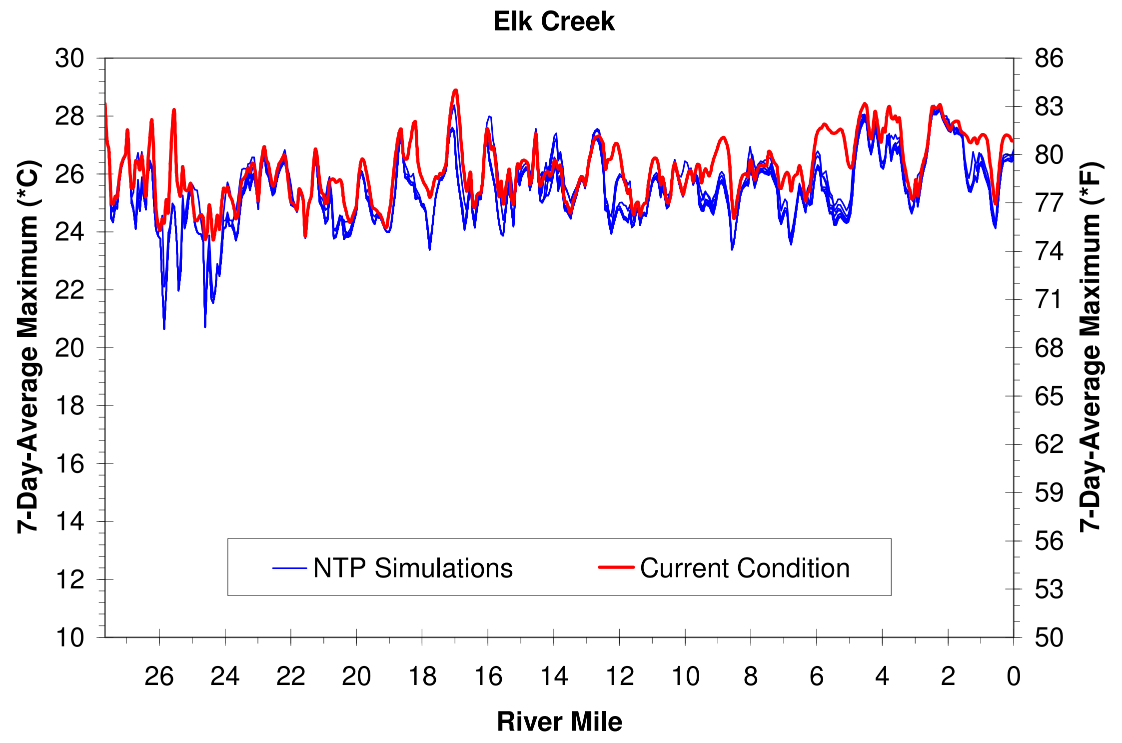


Figure 39 (continued). NTP Temperatures Representing the Natural Disturbance Ranges Simulated



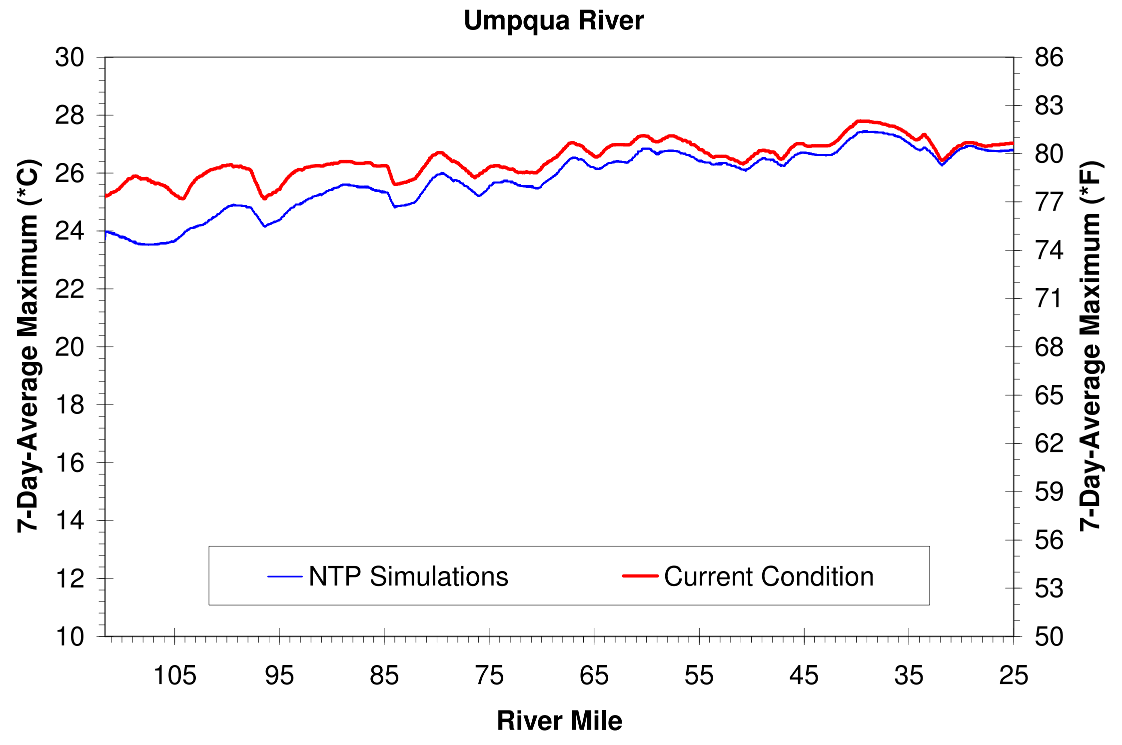


Figure 39 (continued). NTP Temperatures Representing the Natural Disturbance Ranges Simulated

SENSITIVITY ANALYSIS

Two streams were chosen to assess the difference between simulating mixed severity natural disturbance and completely de-vegetative natural disturbance. The results are presented in this section.

Figure 40 shows the NTP temperatures with mixed severity and with completely-devegetative natural disturbance. The blue line shows the NTP temperatures that have been simulated for the Umpqua River Basin TMDL. This includes 0.25-2.0% mixed severity natural disturbance per year over 100 years. The green line shows the NTP temperatures for a sensitivity analysis scenario which included 0.25-2.0% completely de-vegetative natural disturbance per year over 100 years.

In both NTP scenarios, the current condition temperatures are elevated in upper Rock Creek. These elevated temperatures are a result of anthropogenic activities which have altered stream side vegetation and reduced effective shade levels below their potential. Current stream temperatures within lower Rock Creek are very similar to the NTP because these reaches are currently well-vegetated.

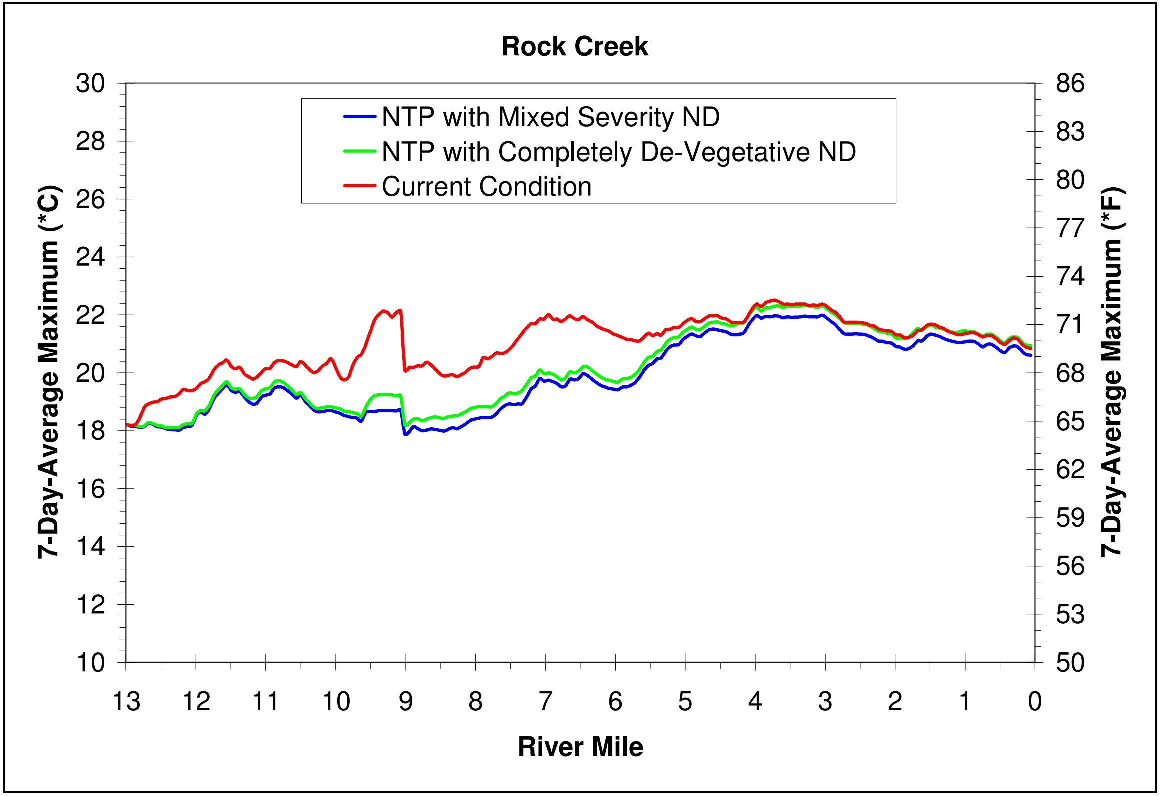


Figure 40. **Rock Creek Natural Disturbance Sensitivity Scenarios**

Figure 41 shows the natural thermal potential temperatures that result under the different natural disturbance scenarios for Cavitt Creek.

The blue line shows the NTP temperatures that have been simulated for the Umpqua River Basin TMDL. This includes 0.25-2.0% mixed severity natural disturbance per year over 100 years. The green line shows the NTP temperatures for a sensitivity analysis scenario which included 0.25-2.0% completely de-vegetative natural disturbance per year over 100 years.

Current condition temperatures are warmer in most stream reaches because timber harvest has occurred within the watershed and a mature forest has not yet been re-established.

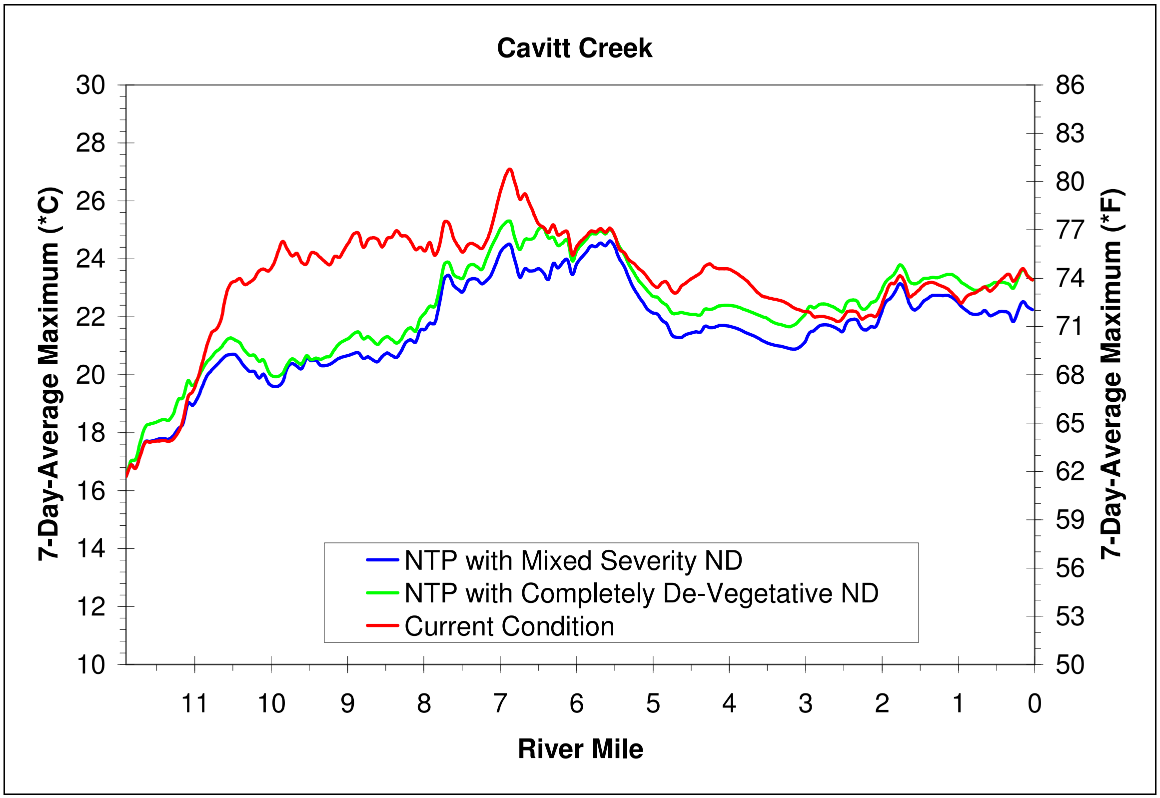


Figure 41. **Cavitt Creek Natural Disturbance Sensitivity Scenarios**

It is important to note that smaller streams with less flow (i.e., first order forested streams) are more sensitive to natural disturbance. This TMDL analysis focuses on medium and large streams which contain more flow than typical first order streams. Larger flow volumes heat less readily when solar jradiation is increased.

CONCLUSION

Very few streams in the Umpqua River Basin are free from human-induced warming. Flow, channel, and vegetation modifications have increased stream temperatures above their natural thermal potential. Anthropogenic impacts outweigh any reductions in natural disturbance (i.e., though fire suppression and flood control). Therefore the natural thermal potential, even when it includes natural disturbance, is typically cooler than the current condition for many streams simulated in the Umpqua River Basin.

Following is an example where anthropogenic impacts have reduced effective shade and caused increased stream temperatures, regardless of fire suppression.

Reduced effective shade levels in upper Rock Creek result in elevated stream temperatures. An aerial photograph of upper Rock Creek (approximately river mile 10) shows why effective shade is currently below its potential (**Figure 42**). (Red dots indicate the location of Rock Creek.) Much of upper Rock Creek has experienced recent timber harvest and very few mature trees remain near the stream. A stand of mature trees on O & C land is visible in the upper left of the photograph. In comparison, trees on private lands around the stream are much shorter. A road is also visible alongside the stream. The lower reaches of Rock Creek (downstream of reaches in this photo) are surrounded by more mature trees and no roads, thus effective shade levels in those reaches are closer to potential.

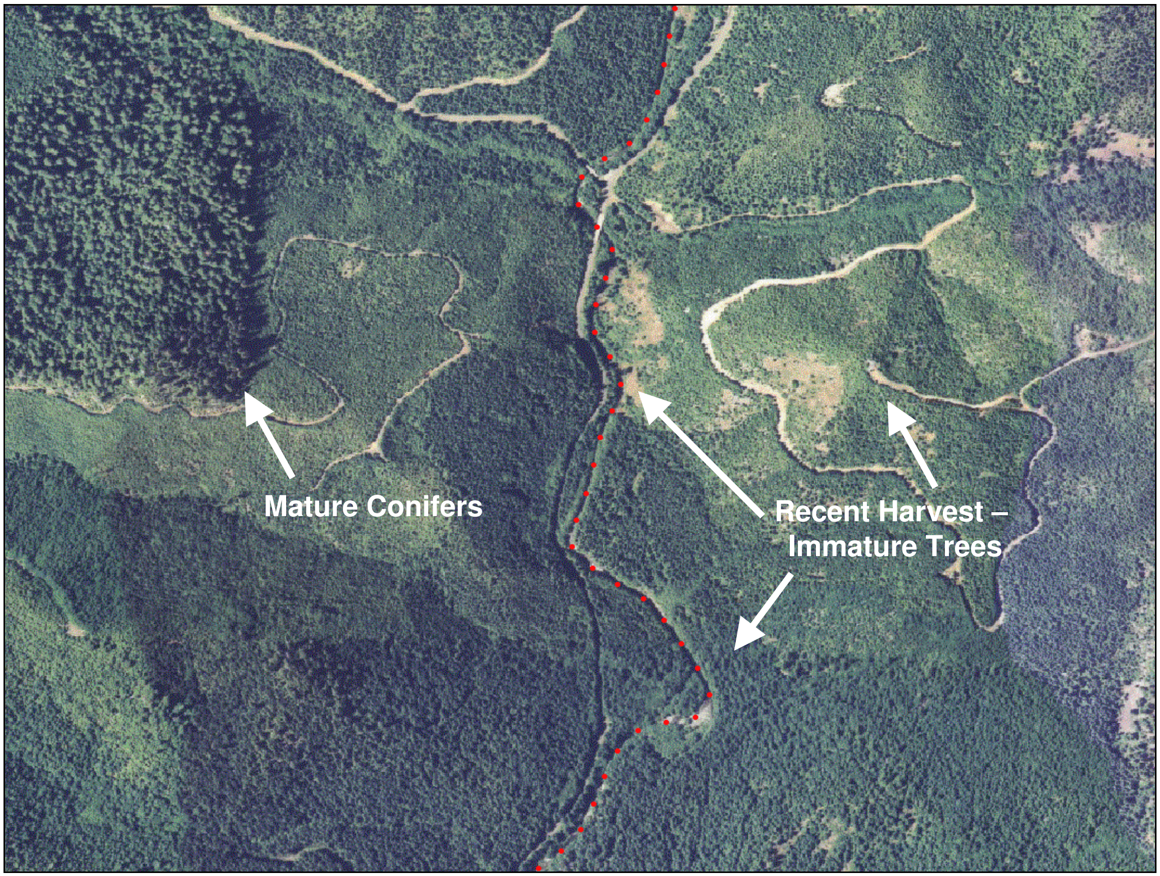
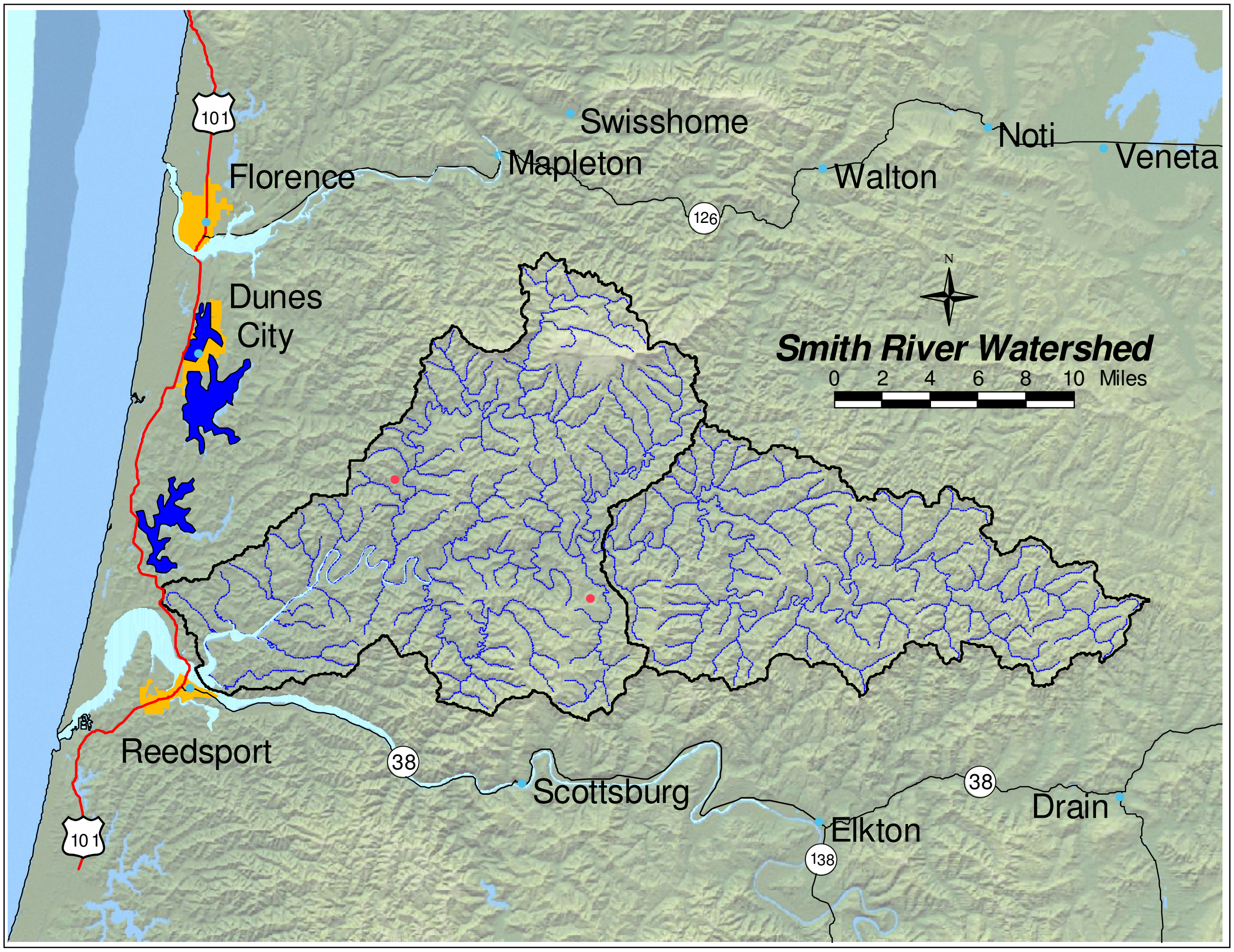


Figure 42. Upper Rock Creek near River Mile 10.

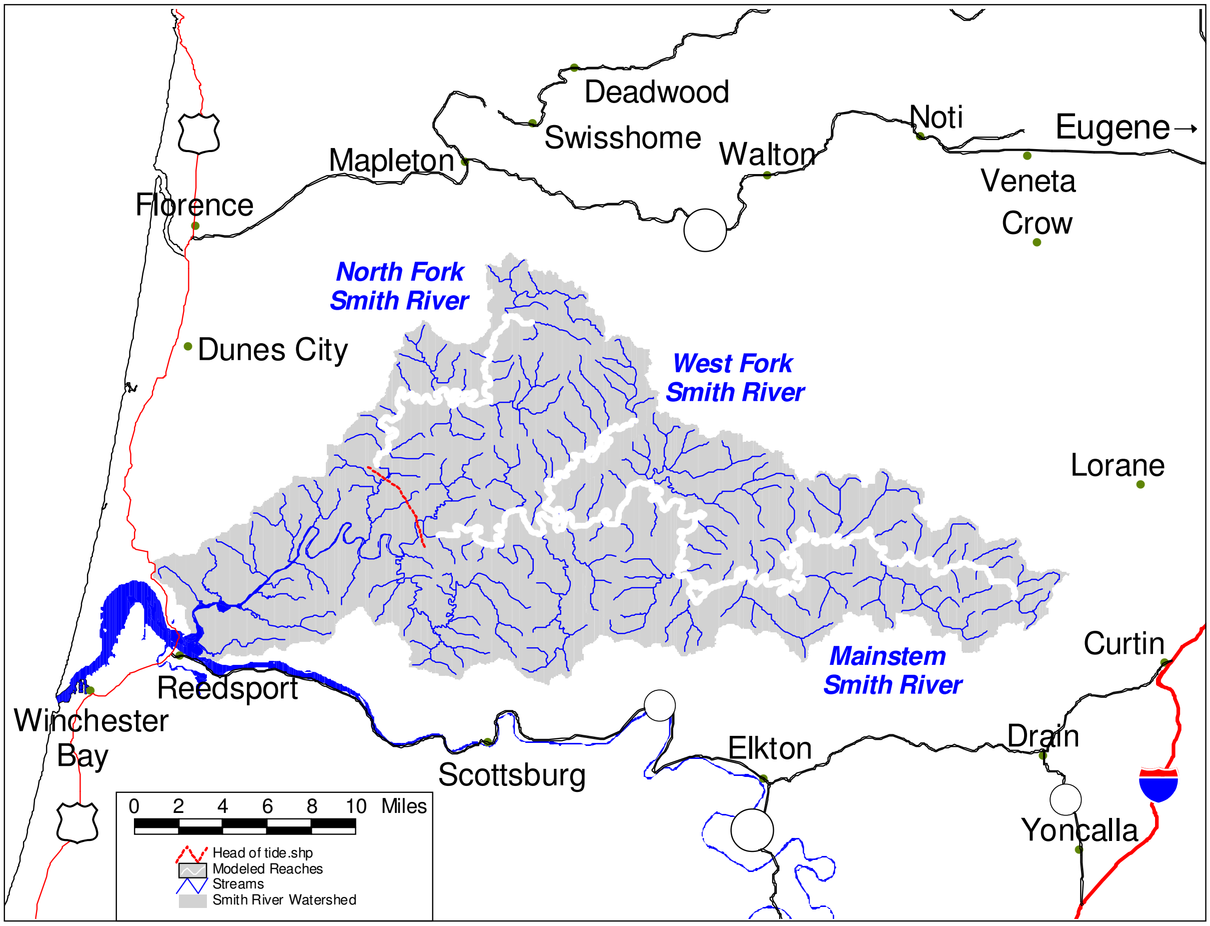
SECTION 6. SMITH RIVER TEMPERATURE ANALYSIS



OVERVIEW

Originally, DEQ planned to release the Smith River Temperature TMDLs earlier than remaining Umpqua TMDLs, as a separate document. DEQ made the decision to combine the TMDLs into one document to gain efficiencies. The Smith River temperature analysis was completed using an earlier version of Heat Source and targets were developed in conjunction with a different set of stake holders. Therefore, the Smith River Temperature TMDLs are presented in a separate section. Field-measured data was used to calibrate a stream temperature model, Heat Source 6.5.1. Data was collected in July and August so that the conditions used to calibrate the models were as close to a seasonal worst case condition for temperature as possible. The mainstem Smith, the West Fork Smith and parts of the North Fork Smith River were modeled. See Map 1.

Map 1. Smith River Watershed



The model uses field measurements and model-derived parameters as inputs to simulate how stream temperatures respond to unique conditions within the watershed. Once the model parameters have been adjusted, so that the simulation accurately describes the conditions measured in the field (the calibration step), "future conditions" are entered into the model. The model summates the amount of energy reaching the stream and re-calculates stream temperatures based on those future condition(s) that are assumed. Equilibrium conditions are calculated for each of the 913 segments that make up the Smith River model, the 187 segments that make up the West Fork model and the 350 segments that make up the North Fork model (segments are 328 feet (100 meters long)).

Heat Source 6.5.1 does not handle tidal conditions, so the mainstem Smith model and North Fork model end where tidal influences begin. Because of the limited stream access in the upper North Fork watershed, the uppermost monitoring site for the North Fork model was actually on Kentucky Creek (about 1.4 miles upstream from the Kentucky/North Fork confluence). Therefore this model predicts temperatures in the lower 1.4 miles of Kentucky Creek as well as in the North Fork from the confluence with Kentucky Creek down to approximately river mile 5.2.

Like any model that attempts to "look into the future," there is a disparity between what is predicted and what will actually come to pass. Our understanding of the processes that determine stream temperature are imperfect, and any predictions using them are similarly imperfect. While only the broadest suggestions of possible management strategies are shown by the model, they should point us in the right direction.

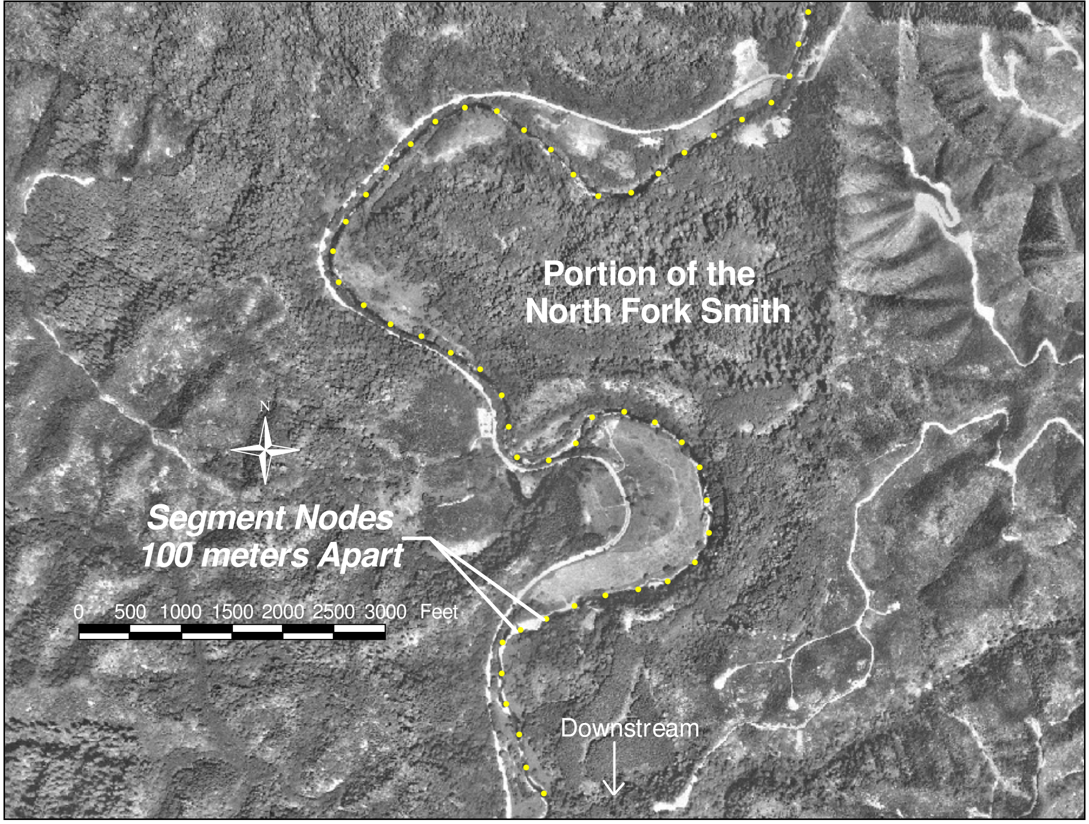
INPUT PARAMETERS FOR HEAT SOURCE MODELING

Field data was collected in the North Fork Smith during early August of 1999, and August 8, 1999 was the date modeled. Field data for the West Fork Smith and along the mainstem was collected during July of 2000, and July 16, 2000 was the date modeled.

Geographic Information System (GIS) Parameters

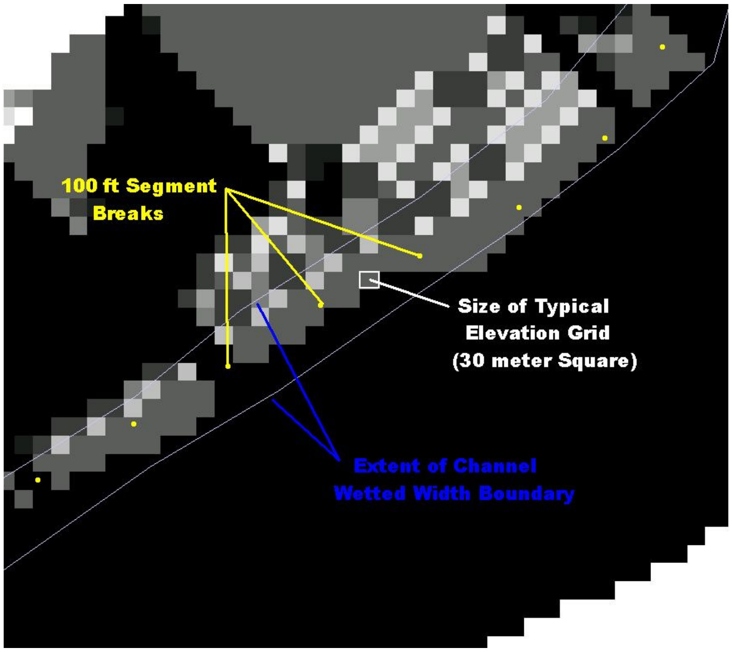
Longitudinal Flow-Path: Defines the reaches to which spatial input parameters are referenced. Model reaches are 328 feet (100 meters) long and are derived from geo-referenced DOQ (Digital Orthophoto Quad) aerial images. See Figure 43. The river flow path was digitized from these photos and then broken up into the proper segment lengths using a GIS utility.

Figure 43. Digital Ortho-Quad Image Showing Segment Breaks



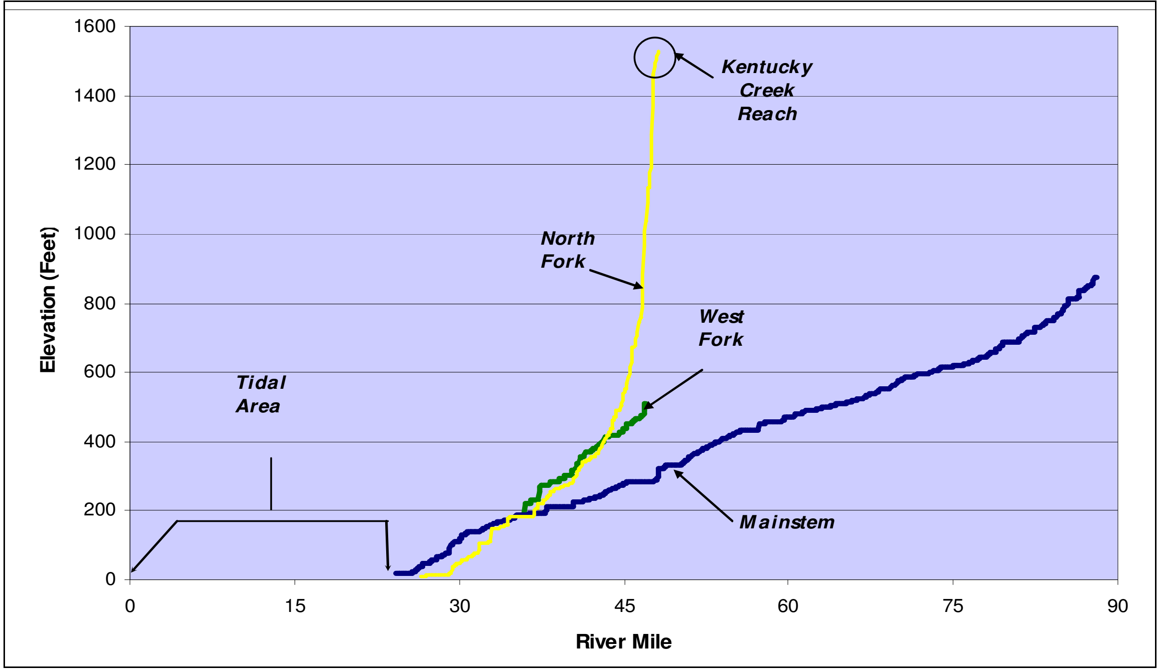
Segment Break Elevation: Elevation was sampled at each 100 meter segment break using the USGS 1:24,000 Digital Elevation Model (DEM) data. This data is in the form of 30 meter grids with an elevation value associated with each grid. See Figure 44.

Figure 44. **USGS DEM Grid-Data Set Showing Channel Outline and Segment Breaks**



When the elevation of each segment is shown associated with its distance from the mouth of the river, a longitudinal elevation profile can be constructed. See Figure 45.

Figure 45. **Elevation Profiles of the Smith River Modeled Reaches**



Segment Gradient: The gradient for each segment is the difference between the upstream and downstream elevations divided by the reach length. Figures 46 a, b, and c show the gradient profiles of the Smith systems. Blue dots are individual segment gradient data, the black line is a 5-reach moving average of gradient values.

Figure 46. a: Gradient Profile of the 57-mile Modeled Segment of the mainstem Smith River

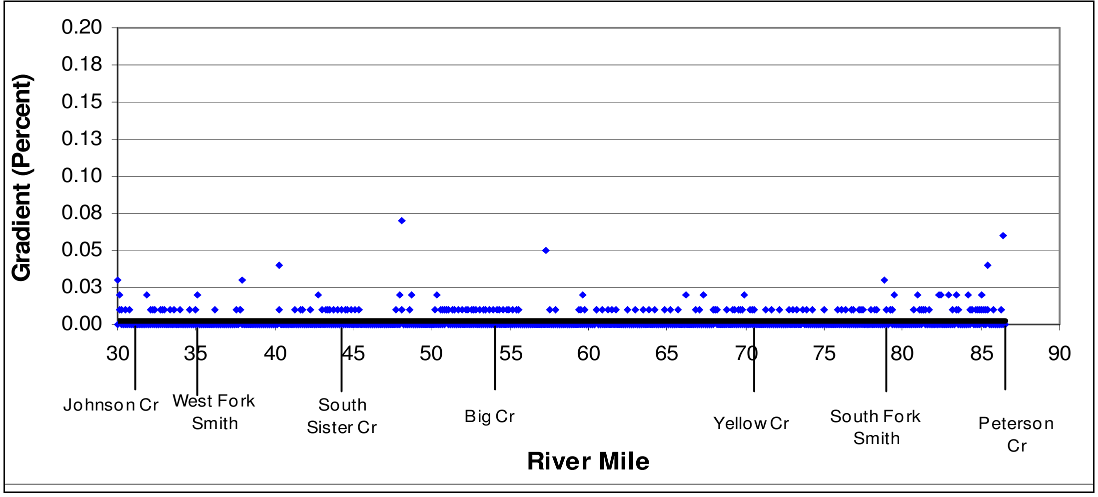


Figure 46. b: Gradient Profile of the 12-mile Modeled Segment of the West Fork Smith River

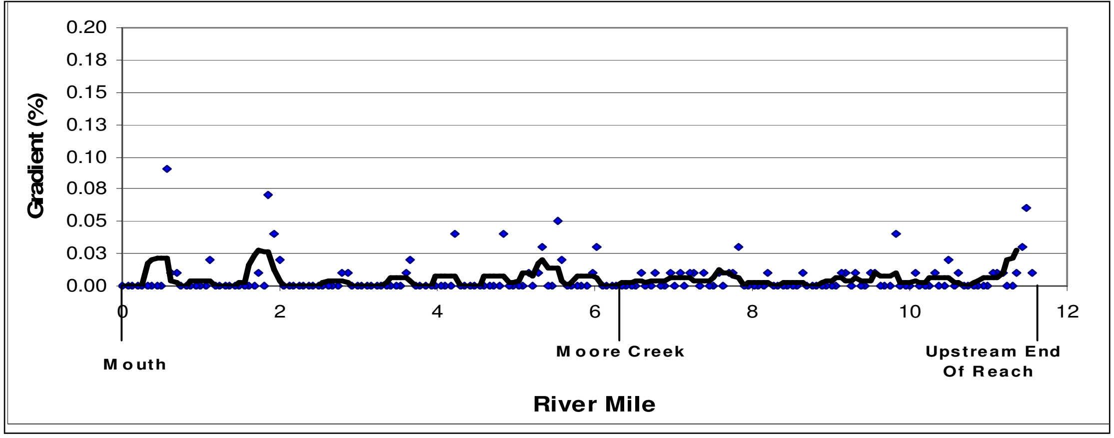
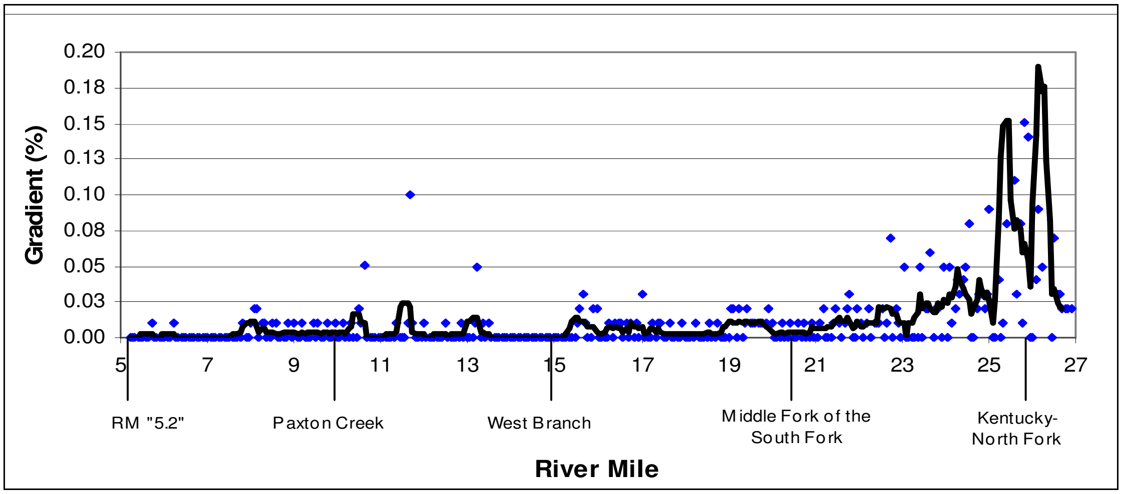
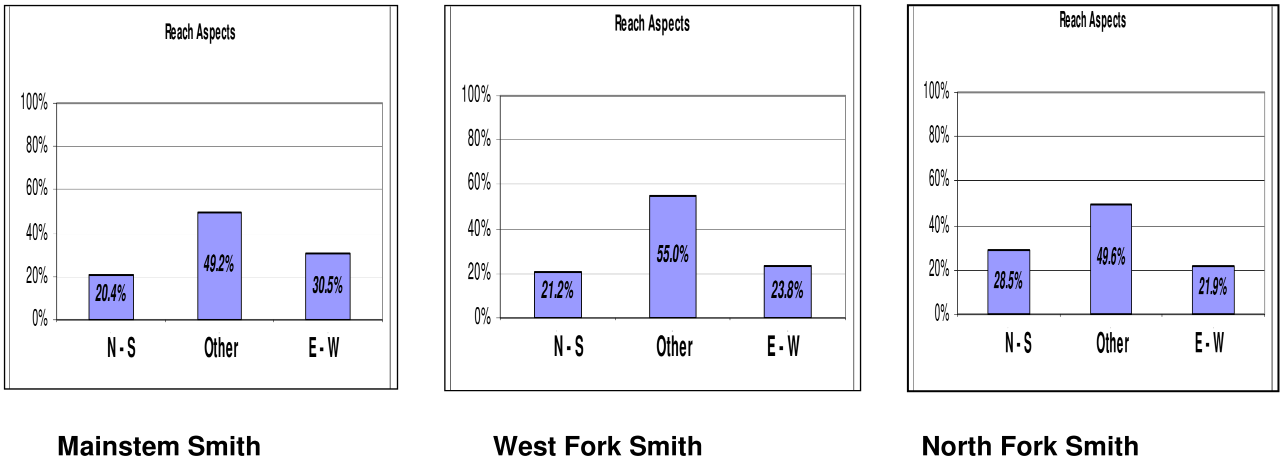


Figure 46. c: Gradient Profile of the 22-mile Modeled Segment of the North Fork Smith River



Segment Aspect: Calculated at each 100 meter segment break, the aspect is the compass heading that the river travels along this reach. Aspect is important because with the sun always being on the southern horizon, shading is more effective in controlling temperature along reaches with an East-West Aspect than a North-South Aspect. Figure 47 shows the percentage of the reaches that are orientated in three aspect groupings.

Figure 47. **Distribution of Reach Aspects in the Smith River Models**



Topographic Shade Angle: The angle made between the stream surface and the highest topographic features to the west, east and south as calculated from DEM data at each reach break. Features which provide shade to the stream include distant mountain ranges, canyon walls or other near stream-relief. Topographic shading to the south blocks solar flux throughout the day. Topographic shading to the east delays sunrise, while shading to the west hastens sunset. Topographic shading is extremely localized and unique for each system. Figure 48 shows a typical topographic shading data set, this example being the south shading of the Smith River mainstem. East and West shading, as well as shading data for the North and West Forks of the Smith, are not shown.

Figure 48. **Southern Topographic Shading (in Degrees Above the Horizon) for the mainstem Smith River**

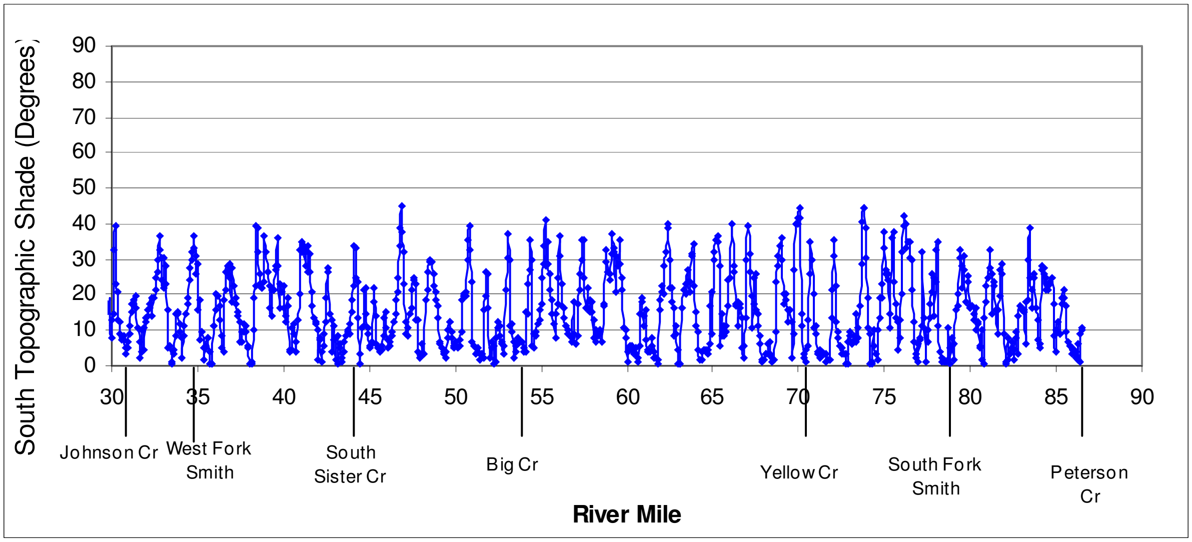
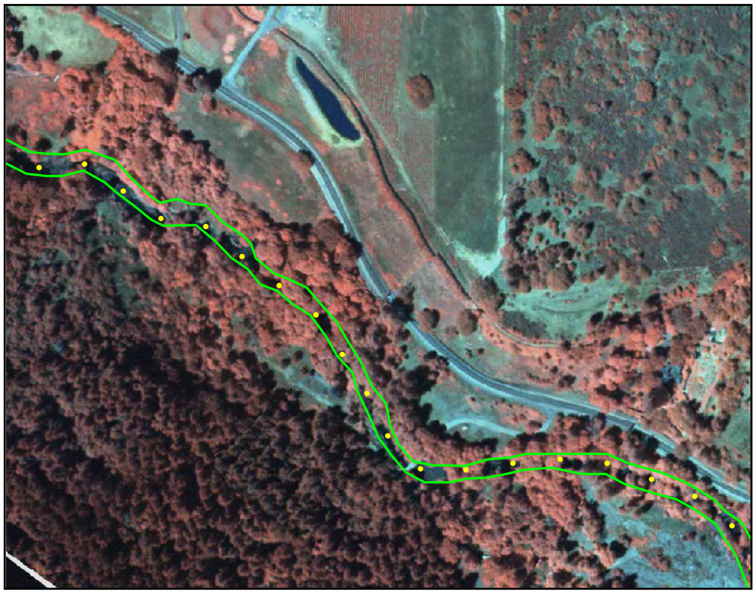


Figure 49. **Near Stream Disturbance Zone Drawn on Photo (from another watershed). A GIS utility is then used to measure this distance at each segment break.**



Stream Wetted Width: The wetted width of the stream is scaled directly from aerial photos, Figure 49. Near-Stream Disturbance Zone Width (NSDZ): Defined as the distance from the vegetation line of one bank to the vegetation line of the opposite bank, or the "hole" in the vegetative cover that the stream occupies, the near-stream disturbance zone is often referred to as the "active channel area." This zone of disturbance allows solar energy to reach the river. The distance is digitized from photos.

Figure 50 shows the longitudinal profiles of wetted widths (blue line) and NSDZ widths (patterned gray line) measured for each of the models.

Figure 50. **a: Wetted Width/NSDZ Width for the Smith River mainstem**

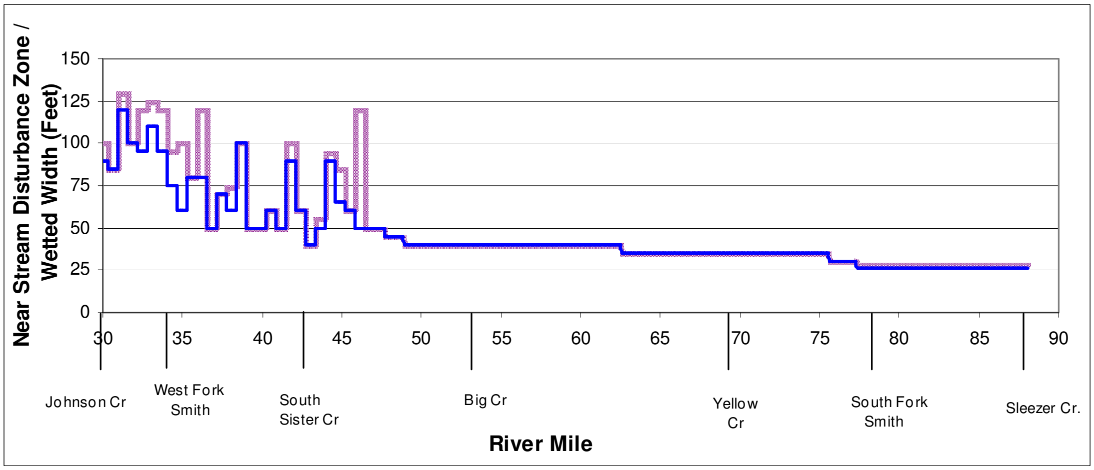


Figure 50. **b: Wetted Width/NSDZ Width for the West Fork Smith River**

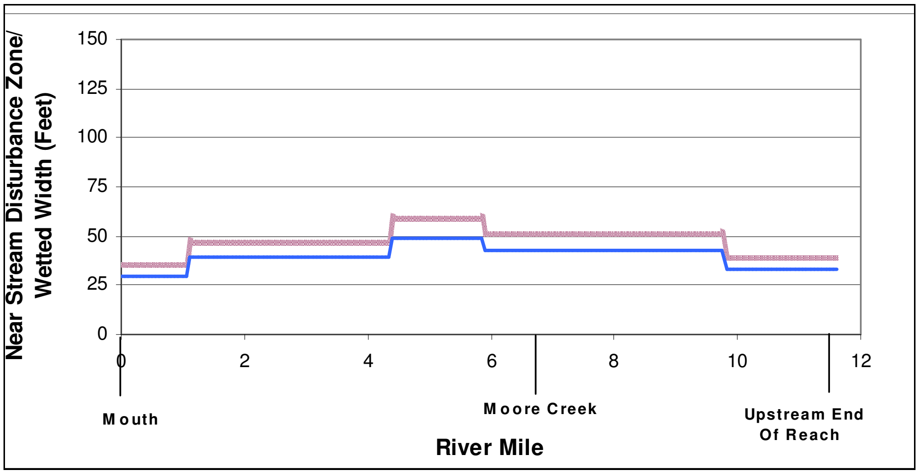
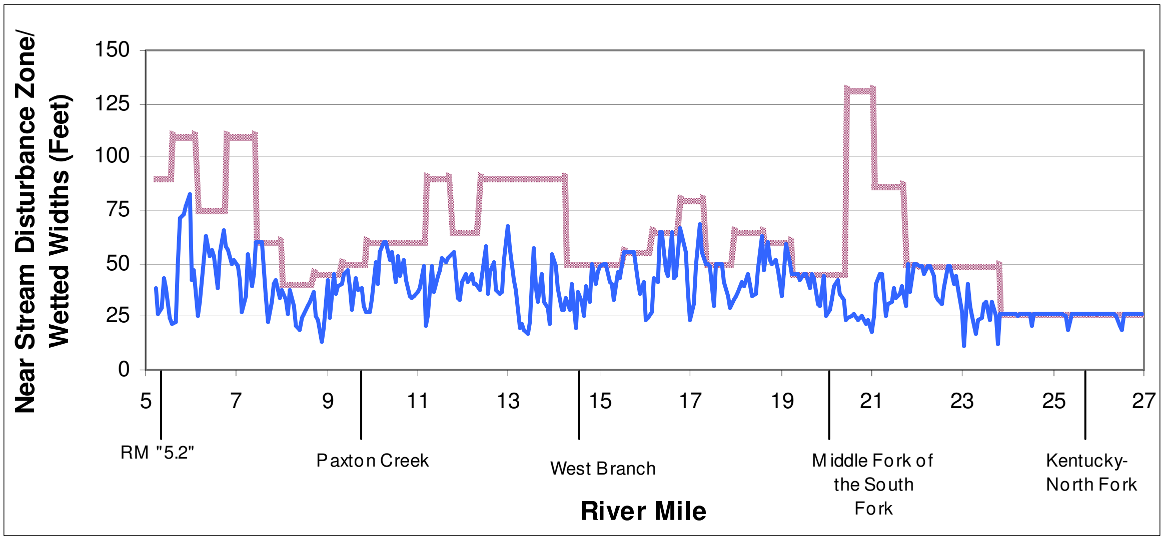


Figure 50. **c: Wetted Width/NSDZ Width for the North Fork Smith River**



Hydraulic Parameters

Flow Volume: Flow volume (discharge) is measured in the field (see Map.2 for measurement locations) using standard USGS protocols. Figures 51 a, b, and c show the flow profiles constructed for the mainstem, West Fork and North Fork model reaches. White circles show actual data measurements along the modeled reaches, and the blue line connecting them is extrapolated flow between the points of known discharges. The blue “x’s” are flow volume measurements taken near the mouths of major tributaries.

Map 2. **Flow Measurement Locations**

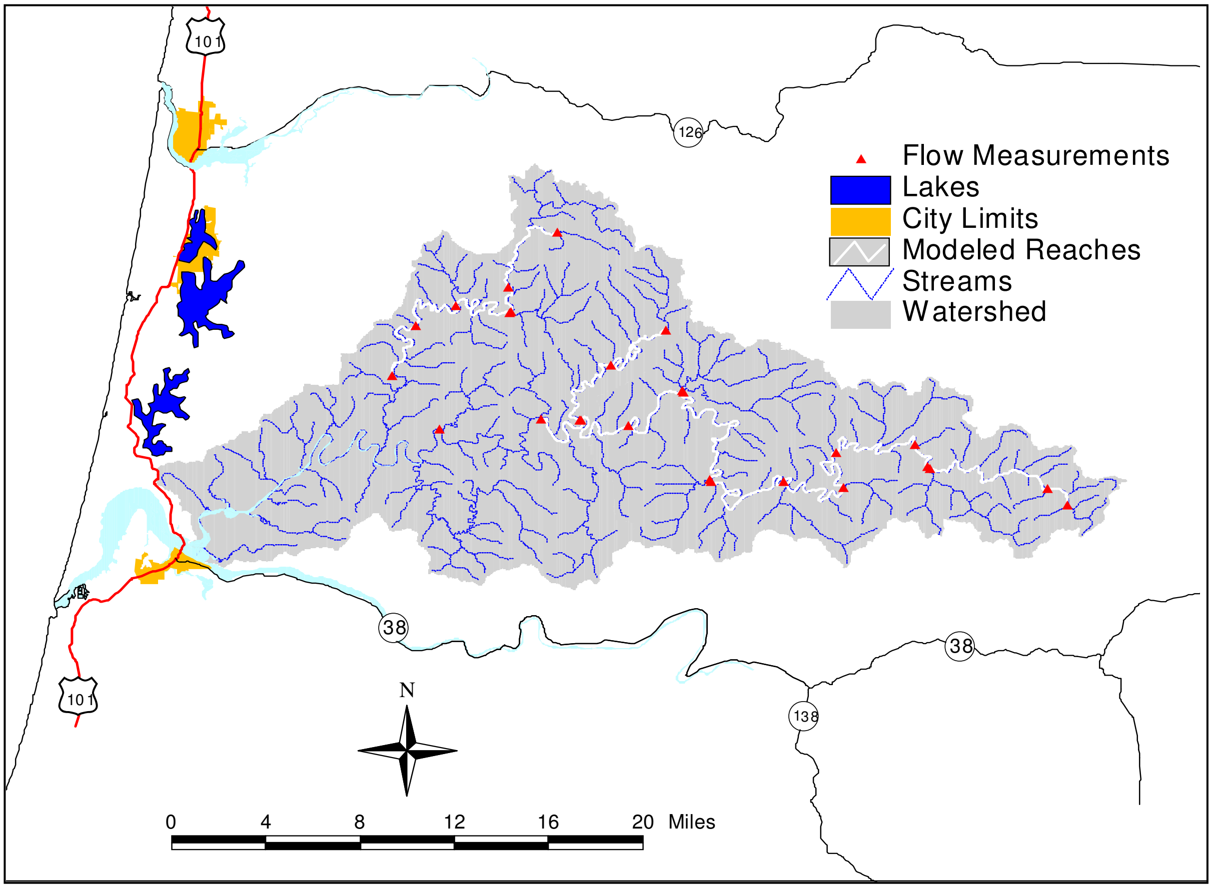


Figure 51. a: Flow Profile of the mainstem Smith River

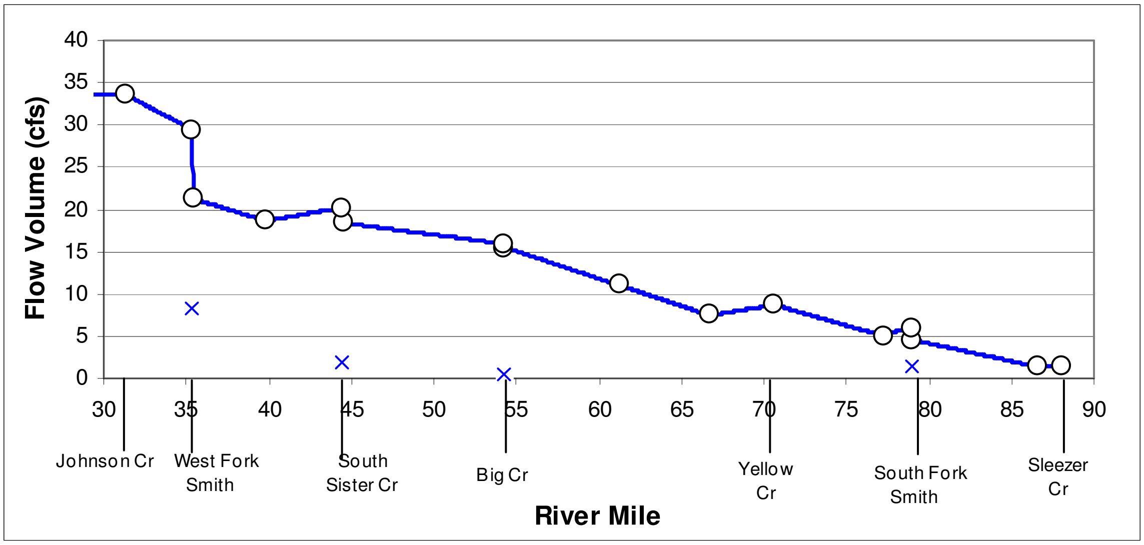


Figure 51. b: Flow Profile of the West Fork Smith

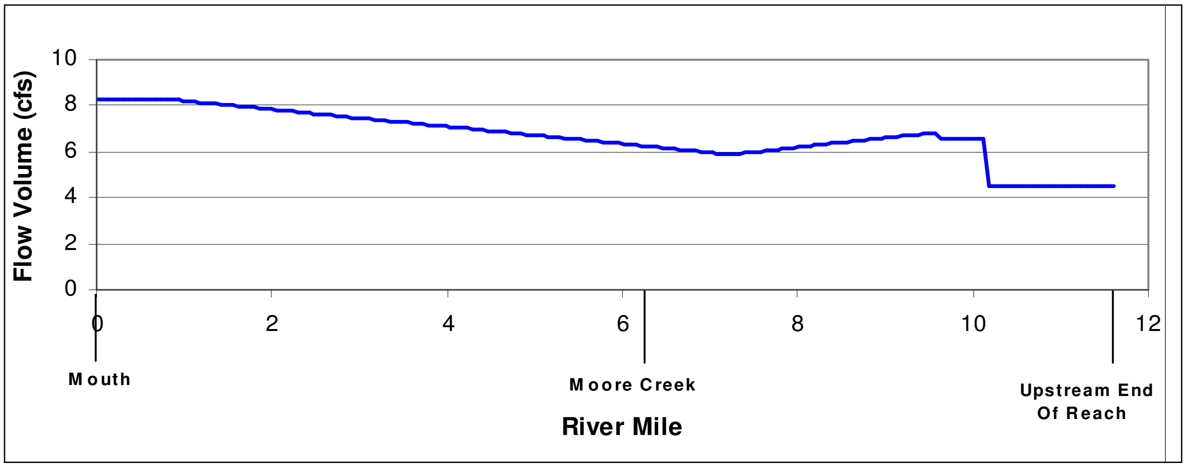
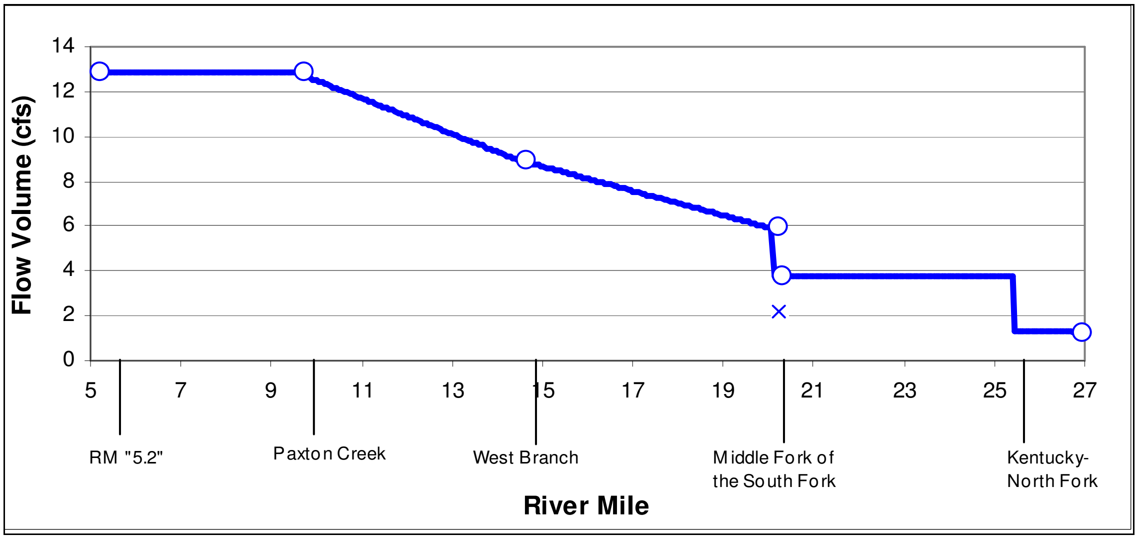
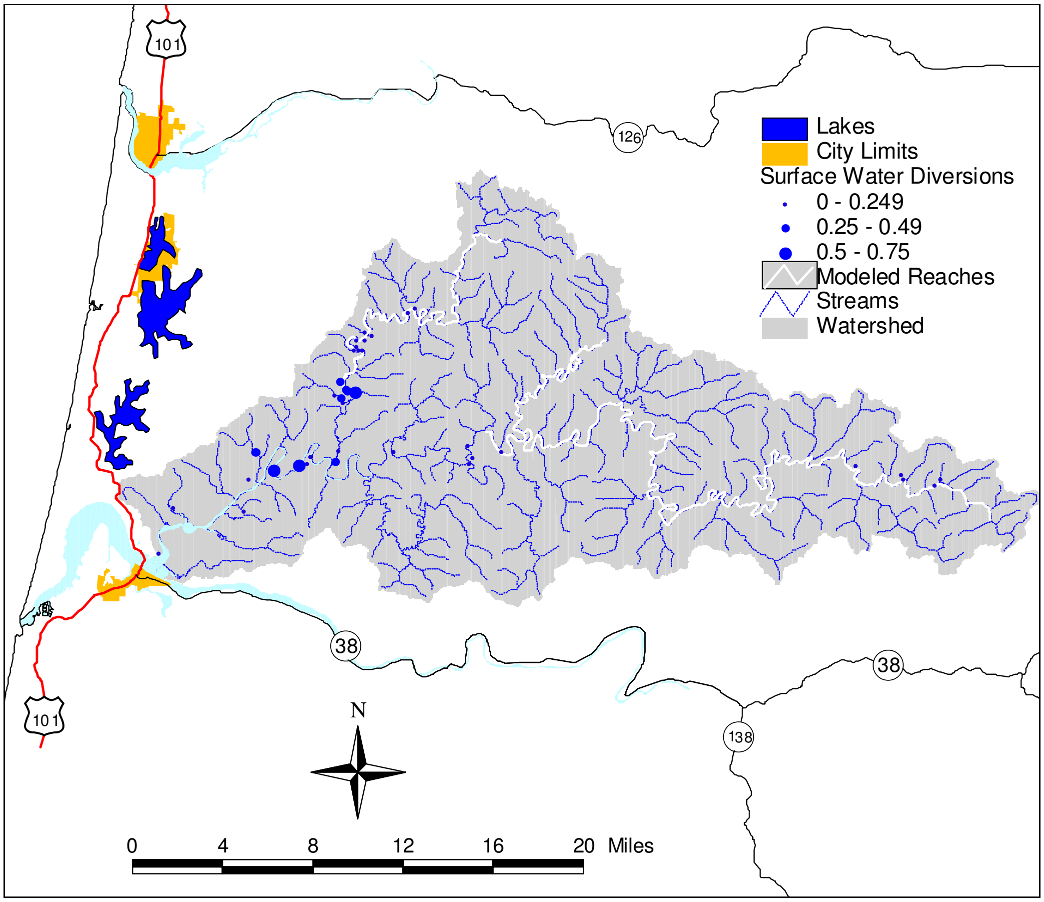


Figure 51. c: Flow Profile of the North Fork Smith River



Map.3 shows the points of stream diversion in the Smith River system. Few diversions are located along the modeled reaches, and very little flow is allocated. Unlike most other basins, water withdrawals would be expected to have only a minimal effect on flows.

Map 3. Water Diversion Points in the Smith



Flow Velocity: Flow velocity is derived from segment gradient and flow volume. Manning's equation was adjusted so that velocities fit actual field measurements of velocity. Figures 52 a, b, and c show the flow velocity data used by the models. Blue dots are individual segment velocity data, and the red line is a 5-reach moving average of velocity data.

Figure 52. a: Assumed Flow Velocities for the Smith River Mainstem Model

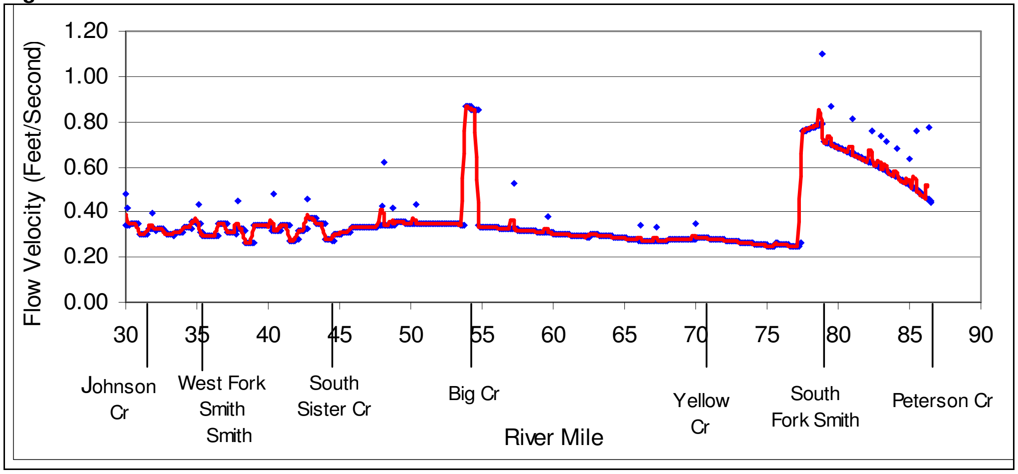


Figure 52. **b: Assumed Flow Velocities for the West Fork Smith Model**

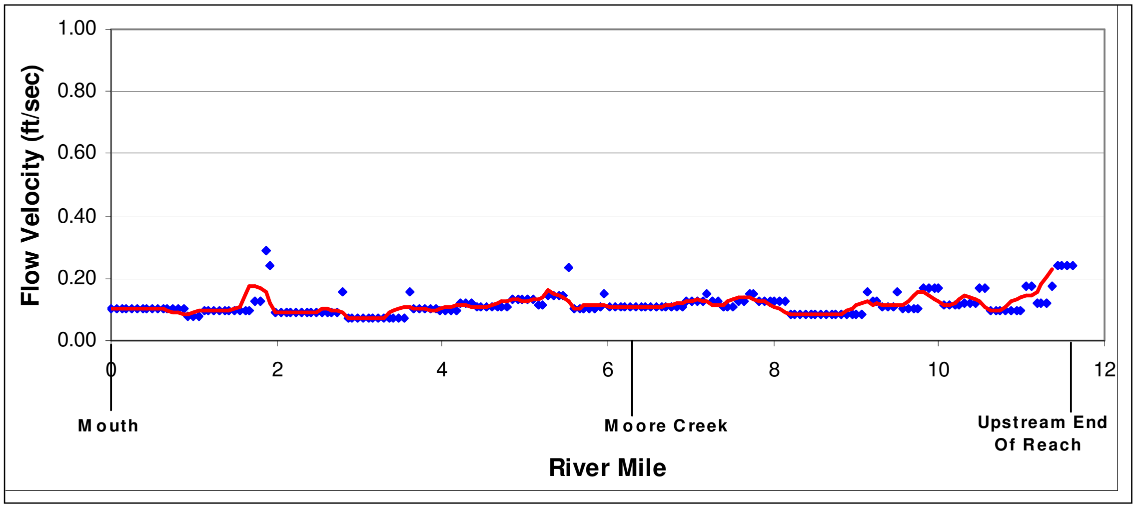


Figure 52. **c: Assumed Flow Velocities for the North Fork Smith Model**

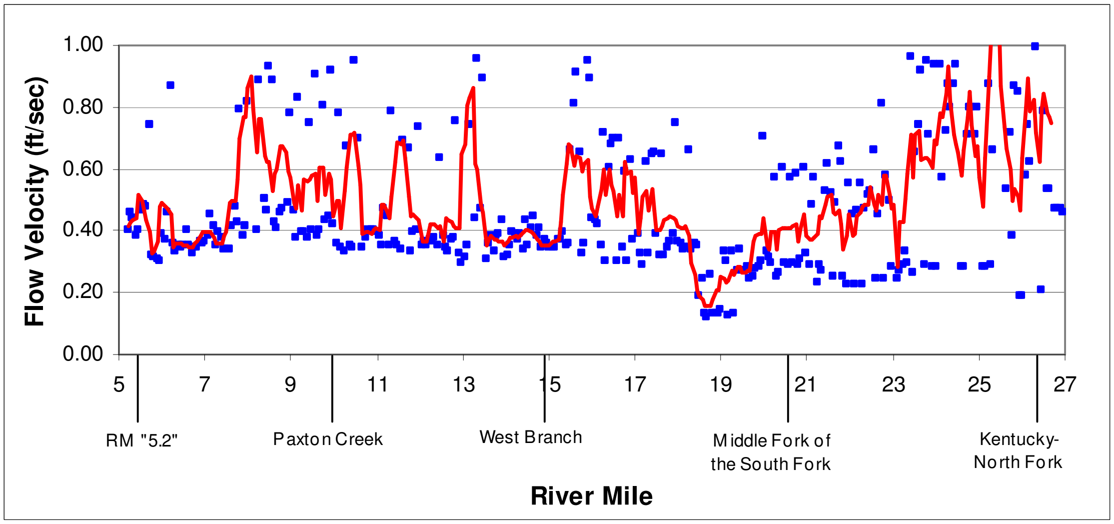
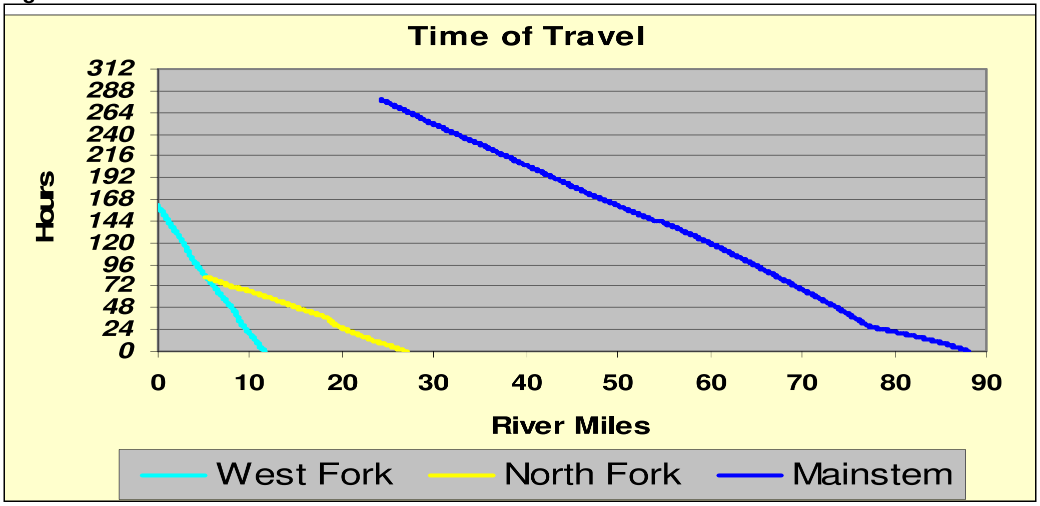


Figure 53 shows the velocity data converted into time-of-travel information.

Figure 53. **Assumed Time-of-Travel in the Smith River Models**



Average Depth: Average depth is derived from wetted width measurements and flow volume. Manning's equation was adjusted to bring depths to values actually measured in the field. The calculated values are based on the assumption of rectangular channel cross sections. See Figure 54. The blue dots are individual segment data and the red line is a 5-reach moving average of channel depth data.

Figure 54. **a: Assumed Channel Depths in the Smith River**

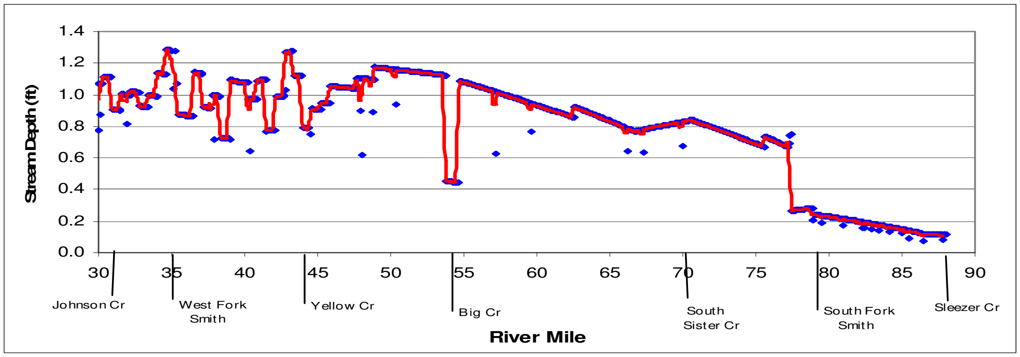


Figure 54. **b: Assumed Channel Depths in the West Fork Smith River**

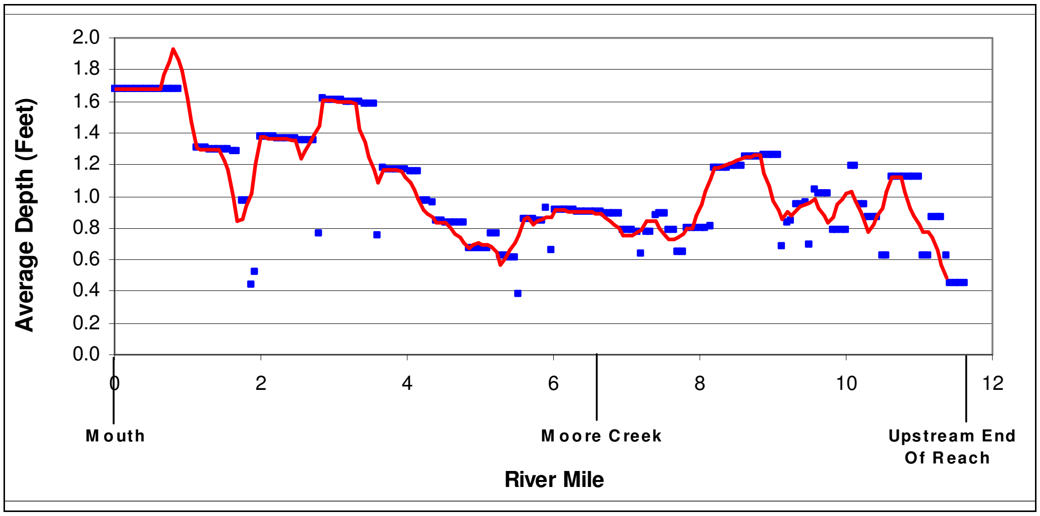
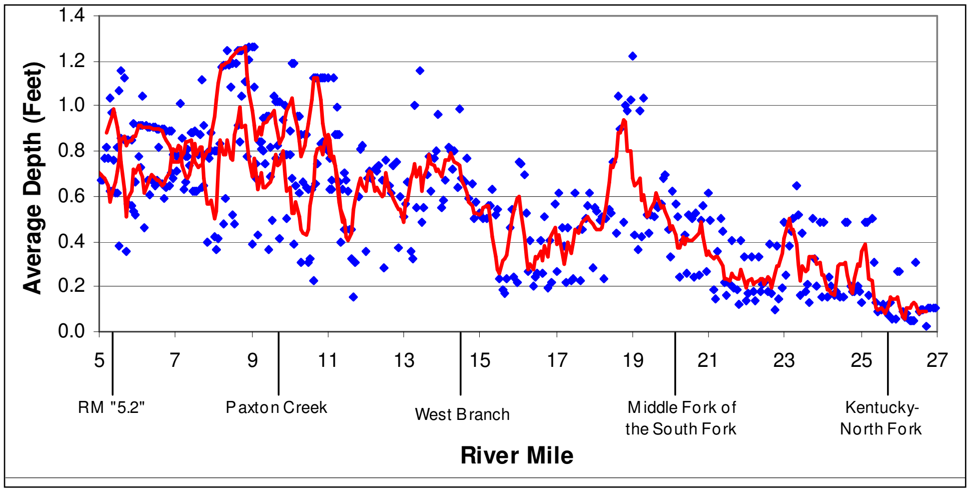


Figure 54. **c: Assumed Channel Depths in the North Fork Smith River**



Percent Channel Bedrock: This parameter is the percentage of streambed material that has a diameter of 25 cm or greater. Values are derived from stream survey data (from DEQ and Siuslaw National Forest data) or best available data.

Continuous Data Parameters

Weather parameters (hourly values for Wind Speed, Relative Humidity and Air Temperature) were obtained from the Remote Automated Weather Station (RAWS) at Goodwin Peak, which is located at Latitude 43.9281, Longitude -123.8903 and elevation 1,801 feet. The station is part of a network of nearly 1,500 interagency stations located strategically throughout the United States, mostly in the Western States. See http://www.fs.fed.us/raws/ for more information.

Wind Speed: Hourly values of wind speed are measured at the Goodwin Peak RAWS weather station (USFS).
Relative Humidity: Hourly values measured at the Goodwin Peak RAWS weather station (USFS)
Air Temperature: Hourly values measured at the Goodwin Peak RAWS weather station (USFS)
Tributary Temperature: Half-hourly values measured by ODEQ using instream data loggers.*
Stream Temperature: Half-hourly values measured by ODEQ using instream data loggers.*

* Stream temperature data from 8/9/1999 was used to calibrate the North Fork Smith model; stream temperature data from 7/16/2000 was used to calibrate both the West Fork and mainstem Smith models.

Riparian Shade Parameters

Riparian shade parameters were measured from a mix of aerial photograph and satellite data. The interpretation of these products into model parameters was done by the Siuslaw National Forest (North Fork, West Fork and mainstem up to Blackwell Creek – approximate river mile 37.25) and the Coos Bay office of the Bureau of Land Management (mainstem from approximate river mile 37.25 to river mile 88). The existing shade values used for calibration are detailed in the charts shown in the "system potential" section.

MODEL CALIBRATION

A measure of how well the model works is to compare what stream temperature the model predicts at the same stream locations where in-stream temperature devices were deployed. The mainstem model had 12 locations where this was possible. At each comparison point, hourly temperature values were compared. The "r squared" value suggests how close this comparison was. A value of 1.000 would be perfect agreement for all 24 hourly values. "r Squared" values above .900 and above are considered good; values above .950 are considered excellent.

Logger Location	**Approximate River Mile**	**"r Squared" Value**	**Standard Error (Deg)**	**Average Deviation (Deg)**	
MS U/S Peterson Creek	86.6	0.999	0.00	0.00	
MS U/S South Fork Smith	79.0	0.275	0.70	1.20	
MS D/S Salmonberry	77.3	0.766	0.50	1.40	
MS U/S Yellow Creek	70.6	0.856	0.50	2.60	
MS U/S Cleghorn	66.7	0.823	0.70	3.80	
MS U/S Halfway Creek	61.2	0.940	0.50	2.40	
MS U/S Big Creek	54.3	0.948	0.50	2.40	
MS U/S South Sister Creek	44.5	0.961	0.40	1.20	
MS U/S Carpenter Creek	39.8	0.944	0.50	2.40	
MS U/S West Fork Smith	35.4	0.903	0.40	3.30	
MS U/S Johnson Creek	31.3	0.970	0.20	1.60	
	Avg	0.853	0.445	2.027	Deg C
	Avg	0.853	0.802	3.649	Deg F

The West Fork model had only three locations where comparisons could be made:

Logger Location	**Approximate River Mile**	**"r Squared" Value**	**Standard Deviation (Deg)**	**Standard Error (Deg)**	
U/S End of Reach	11.6	1.000	0.00	0.00	
U/S Moore Creek	6.2	0.942	1.50	0.40	
Mouth	0.0	0.900	0.40	0.50	
	Avg	0.947	0.633	0.300	Deg C
	Avg	0.947	1.900	0.900	Deg F

The North Fork model had six points of comparison:

Logger Location	**Approximate River Mile**	**"r Squared" Value**	**Standard Deviation (Deg)**	**Standard Error (Deg)**	
Kentucky Creek	27.0	0.994	0.00	0.10	
1.5 Mi U/S NF Trail	21.9	0.833	1.80	0.80	
U/S Middle Fork of N Fork	20.3	0.976	1.60	0.40	
D/S West Branch	14.7	0.883	1.20	0.70	
D/S Paxton Cr	9.7	0.932	0.60	0.50	
Approx RM 5.2	5.2	0.837	1.40	0.80	
	Avg	0.909	1.100		Deg C
	Avg		1.650		Deg F

Based on the r-squared values, model predictions, on the whole, are good to excellent. The upper parts of the mainstem are less well accounted for with the model.

SYSTEM POTENTIAL ANALYSIS

A myriad of conditions could be changed within the model to try to reflect future conditions in the Smith River Watershed. This is in fact is why the calibrated model is such a useful tool in planning watershed restoration and recovery projects, since many future conditions can be envisioned and run through the model to see how much effect they are likely to have. To determine a formal system potential, which will help to determine TMDL load allocations, it is important to expressly state which assumptions about the future the model has used. Only the conditions listed here were changed to do the System Potential modeling. All other parameters were kept the same as in the calibration model.

Three shade parameters were changed: Shade Height, Shade Width and Shade Density. These were changed in all three models. The “future” shade conditions were calculated for mature stands of conifers that would occur in these soils, in this climate and at this latitude. The current condition/system potential conditions used in the simulations are shown in Figures 55, 56 and 57. All current conditions are shown as the red (lower) line, system potential conditions are shown as the blue (higher) line. The values shown are averages of the left bank and right bank values. Because water withdrawals are minimal and believed to have little influence on flows and there are no major reservoirs in the watershed, natural flows are best estimated by using the current flows.

Stream temperature at the mouth of the West Fork: The West Fork model at system potential conditions predicted a maximum stream temperature of just over 53 degrees Fahrenheit (compared to just under 70 degrees F at current conditions). This was used as the input temperature for the mainstem model at system potential conditions.

Figure 55. **a – Shade Height used in the mainstem Smith model**

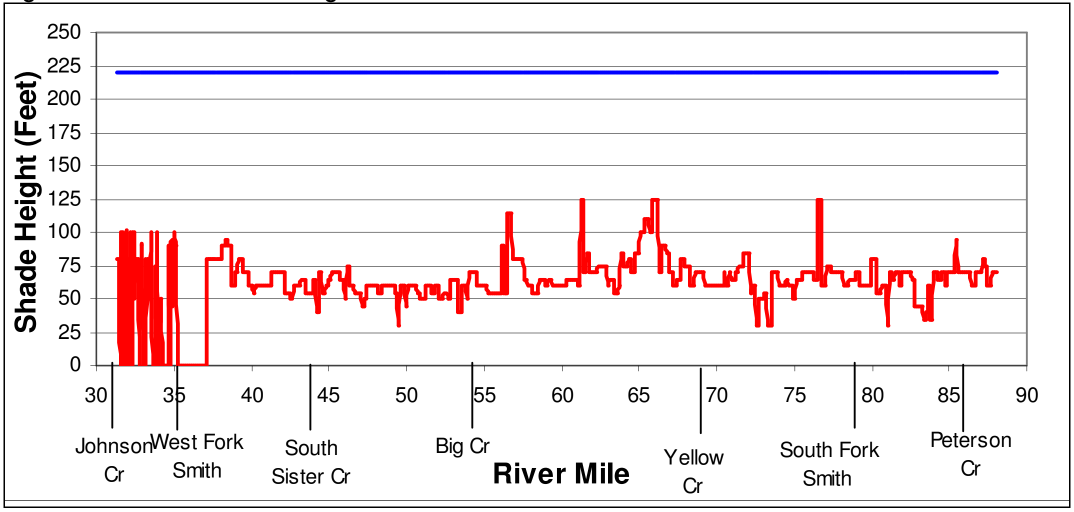


Figure 55. **b – Shade Height used in the West Fork Smith model**

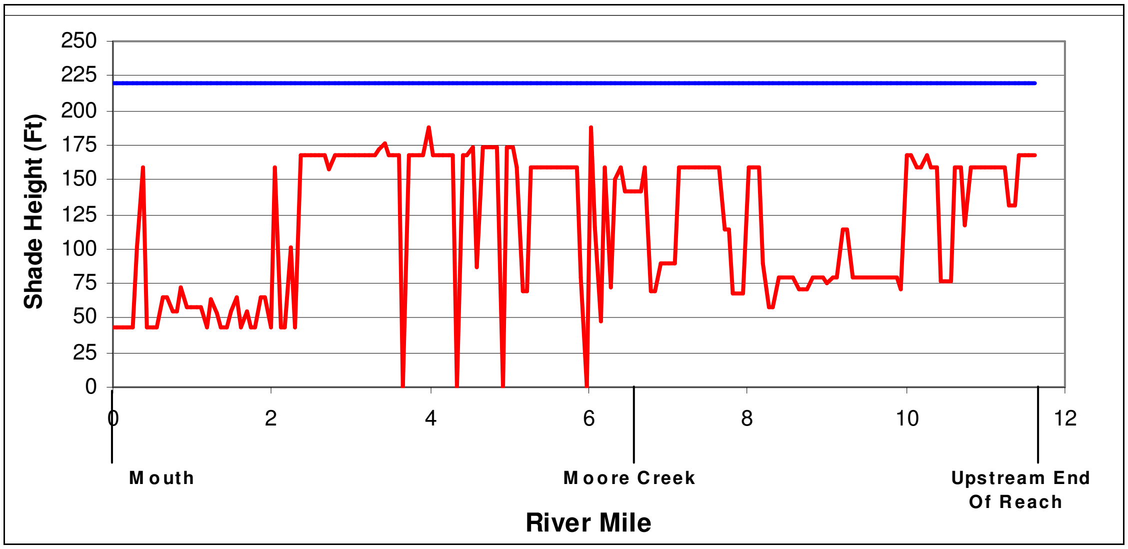


Figure 55. **c – Shade Height used in the North Fork Smith model**

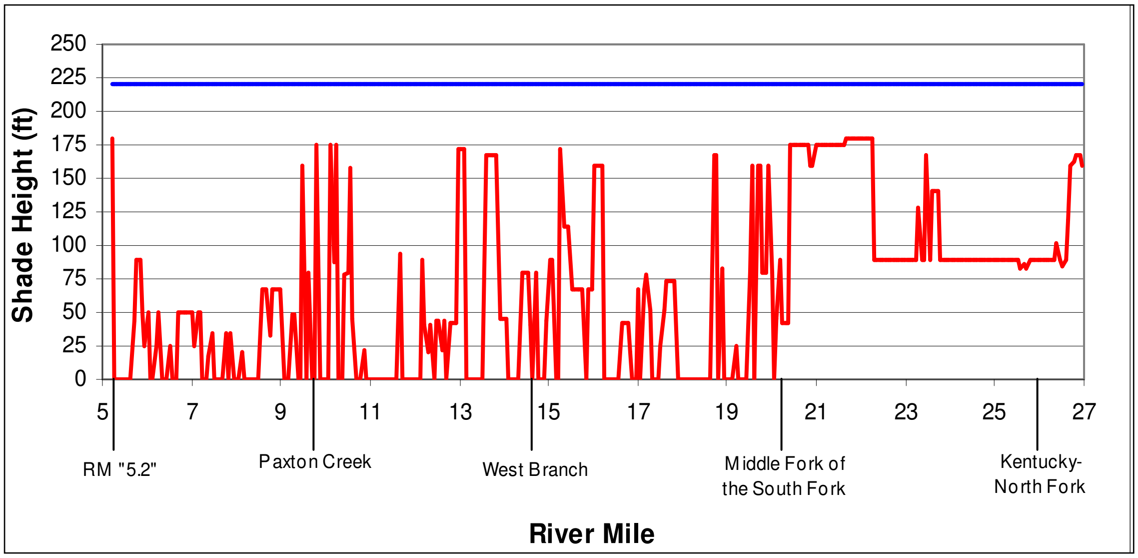


Figure 56. **a: Shade Width used in the mainstem Smith model**

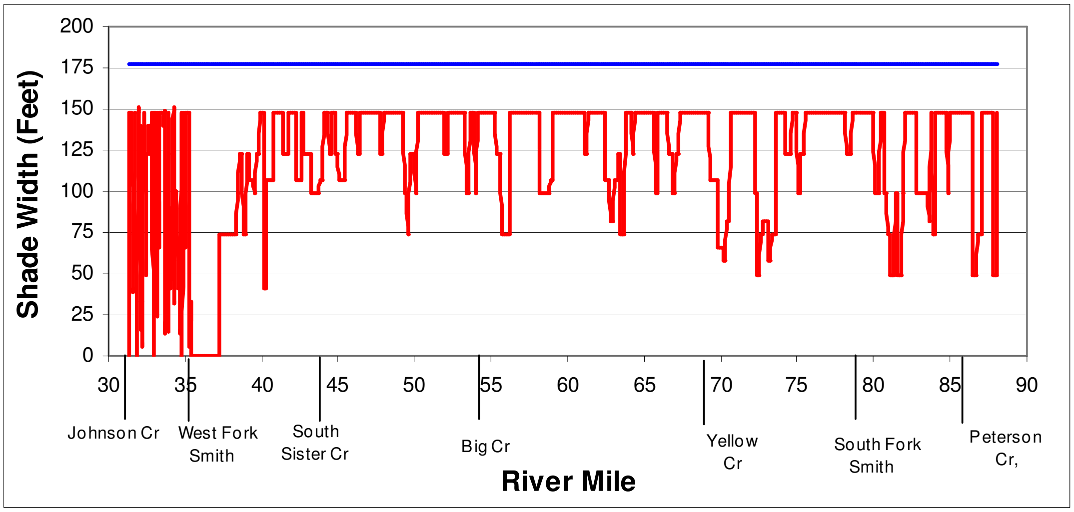


Figure 56. **b – Shade Width used in the West Fork Smith model**

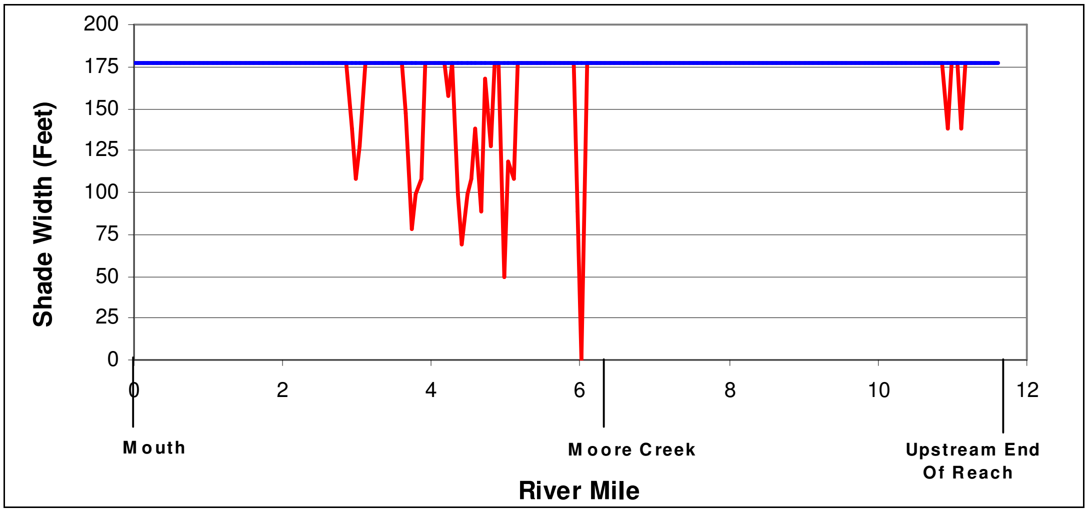


Figure 56. **c – Shade Width used in the North Fork Smith model**

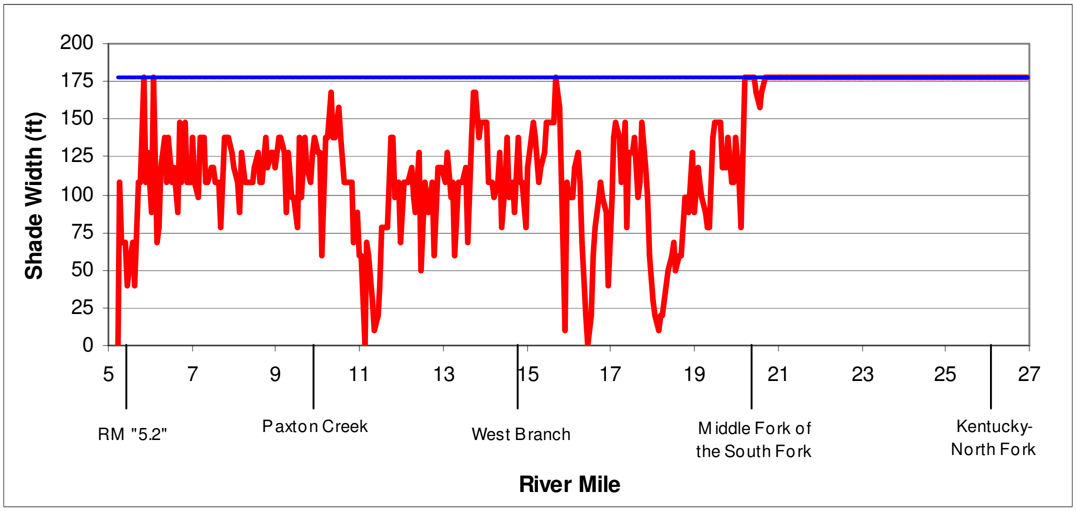


Figure 57. a – Shade Density used in the mainstem Smith River Model

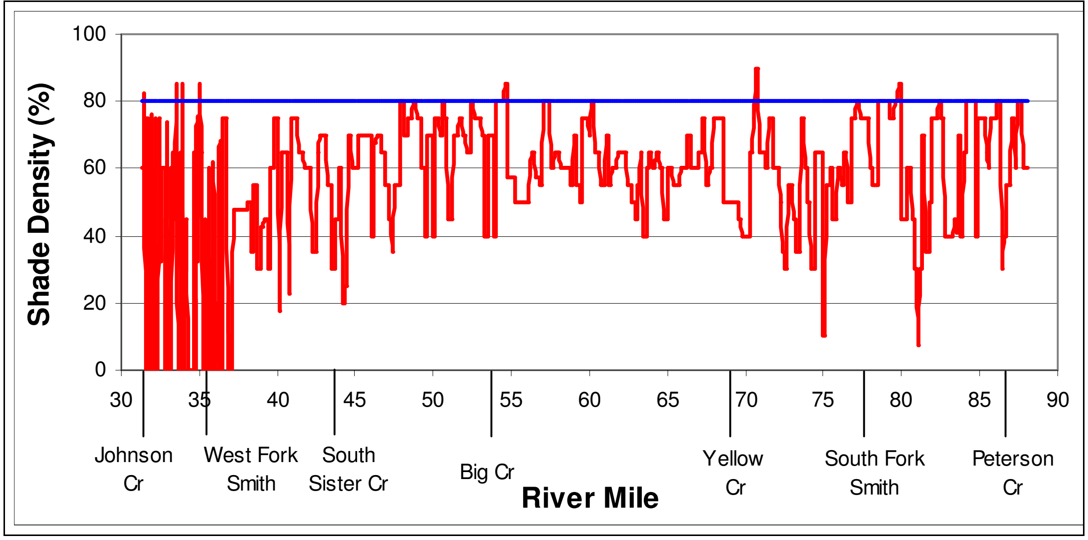


Figure 57. b – Shade Density used in the West Fork Smith River Model

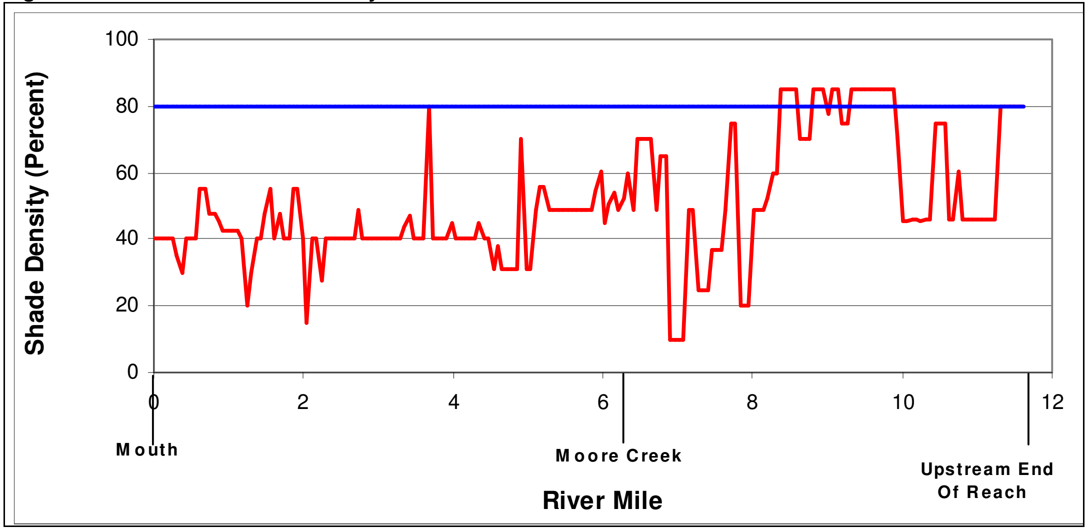
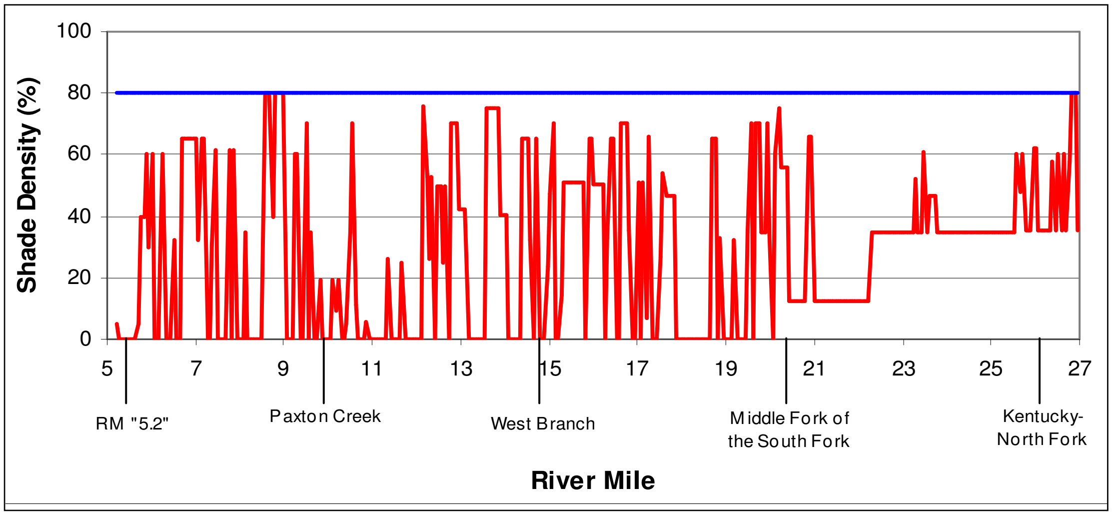


Figure 57. c – Shade Density used in the North Fork Smith River Model



MODEL OUTPUT

Solar Flux

Solar flux is a measurement of the intensity of solar radio emissions from the sun, essentially a measure of the sun's energy. Figure 58 shows the longitudinal solar flux profiles for the Smith. In each graph, the black line is the ambient solar load that reaches the top of the streamside vegetation. The slight non-uniformity in this value is due to topographic shading of the solar energy by surrounding topography. The red (upper) line is the solar energy that currently reaches the stream through the riparian vegetation. The blue line (lower) is the amount of solar energy expected to reach the stream surface at system potential conditions.

Figure 58. a -Solar Flux Along the mainstem Smith River

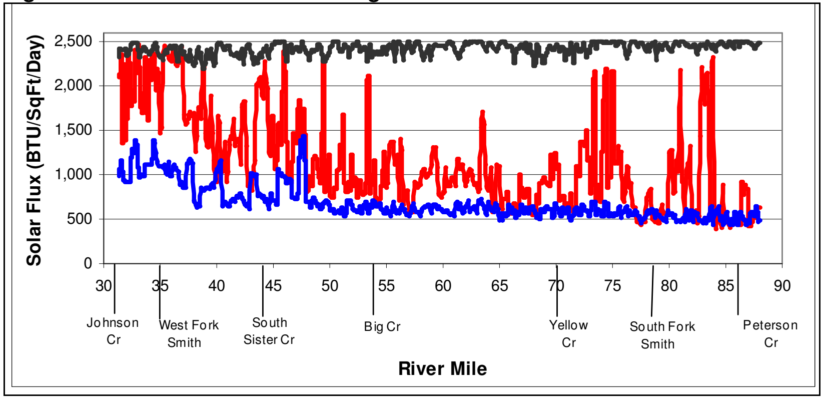


Figure 58. b -Solar Flux Along the West Fork Smith River

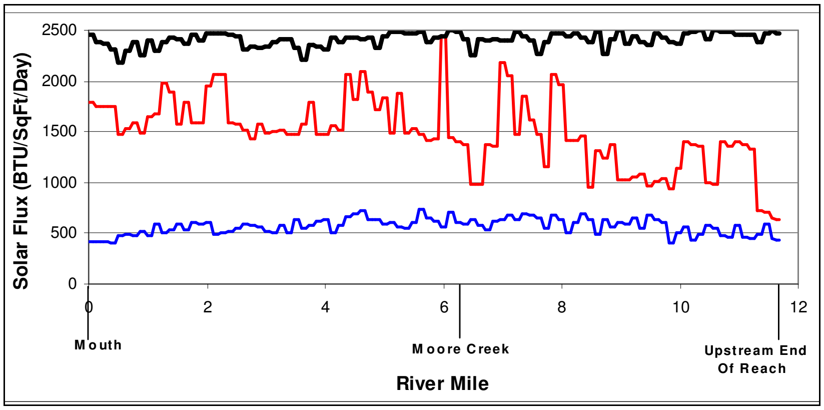


Figure 58. c -Solar Flux Along the North Fork Smith River

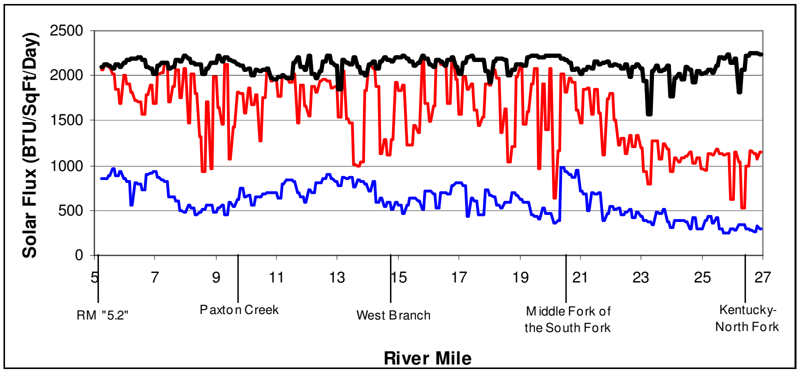
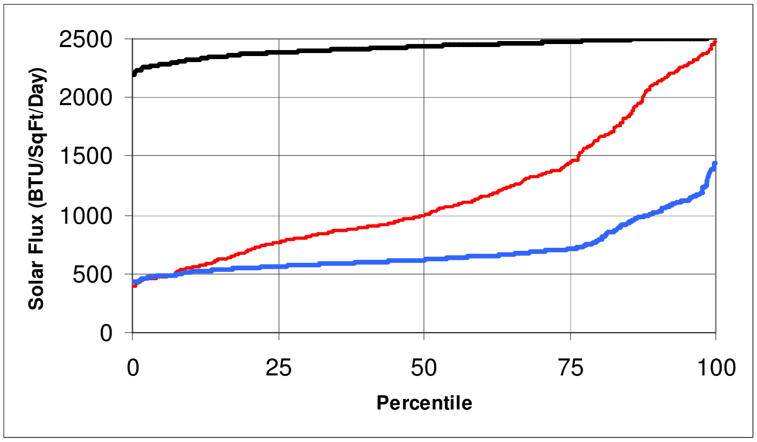
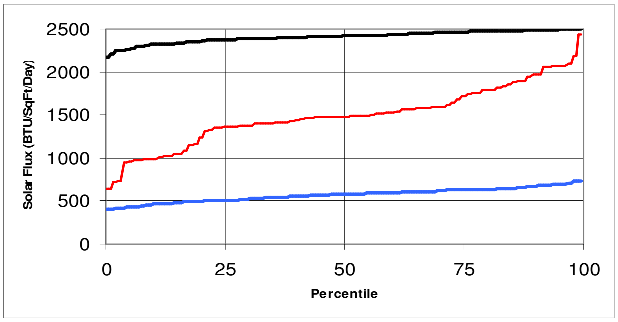


Figure 59 shows this same solar flux data but in cumulative frequency plots. This gives a better idea of the relative solar flux values experienced and expected in each system.

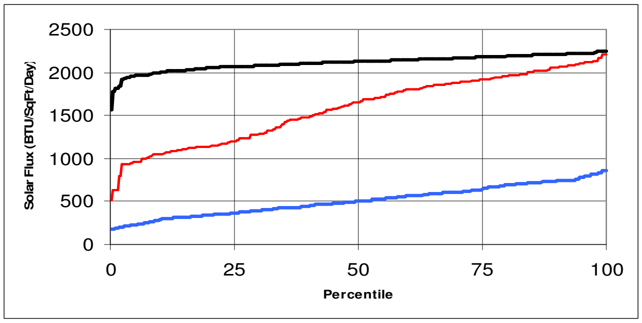
Figure 59. **Cumulative Frequency Plots of Solar Fluxes**
(Black-Ambient, Red-Current conditions, Blue-system potential conditions).



Mainstem Smith



West Fork Smith



North Fork Smith

Percent Effective Shade

Reducing the amount of solar flux available to the stream is the basic physical process involved in lowering stream temperatures. This is a scientifically well-understood principle, but can be somewhat hard to envision. Another measure, percent effective shade, has been developed to aid in showing what kind of reductions in solar energy are available when corrected for current vegetation and local topographic shading. Percent effective shade is the percent of available solar energy that is blocked by topographic features or stream side vegetation. Figure 60 shows the % effective shade profiles, Figure 61 shows the Cumulative frequency plots for percent effective shade and Map 3.4 shows the percent difference in effective shade that can be gained in moving from current conditions to system potential conditions. Figures 60 and 61 use red (lower line) for current conditions and blue (upper line) for system potential conditions. Map 4 color codes are explained in the map legend.

Figure 60. a – Percent Effective Shade Along the mainstem Smith River

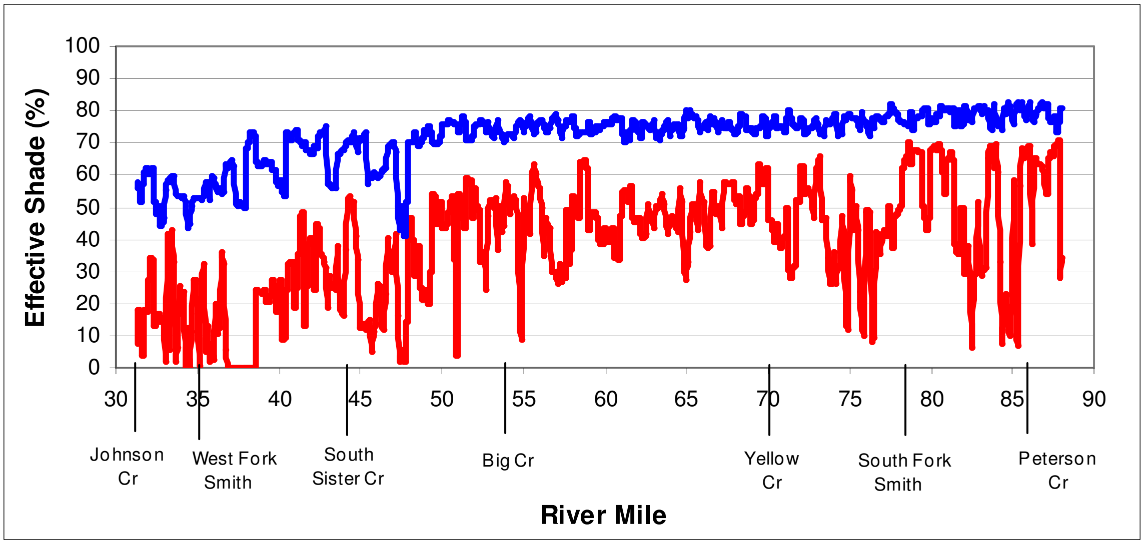


Figure 60. b – Percent Effective Shade Along the West Fork Smith

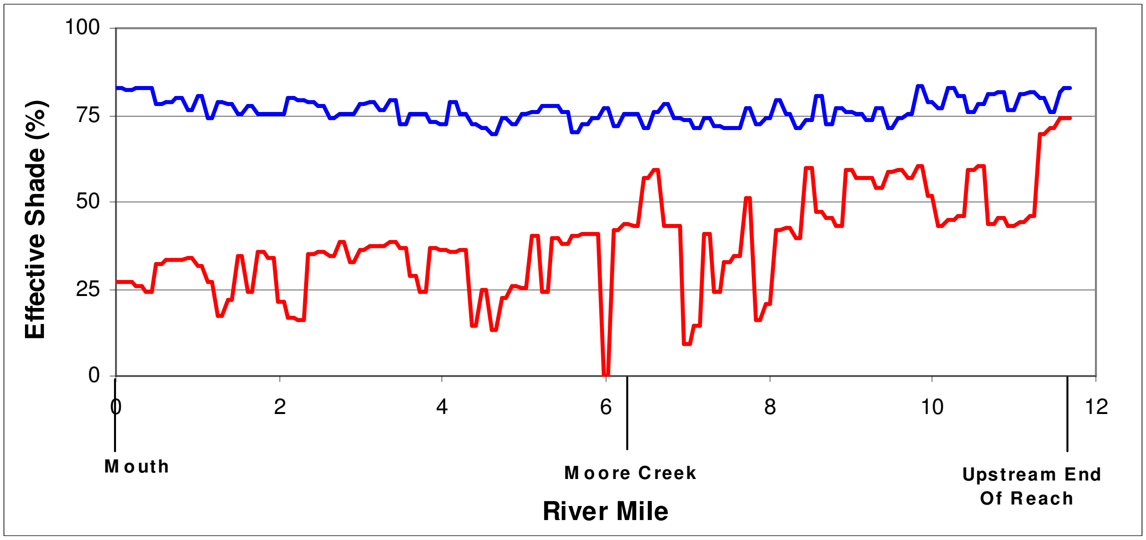


Figure 60. c – Percent Effective Shade Along the North Fork Smith

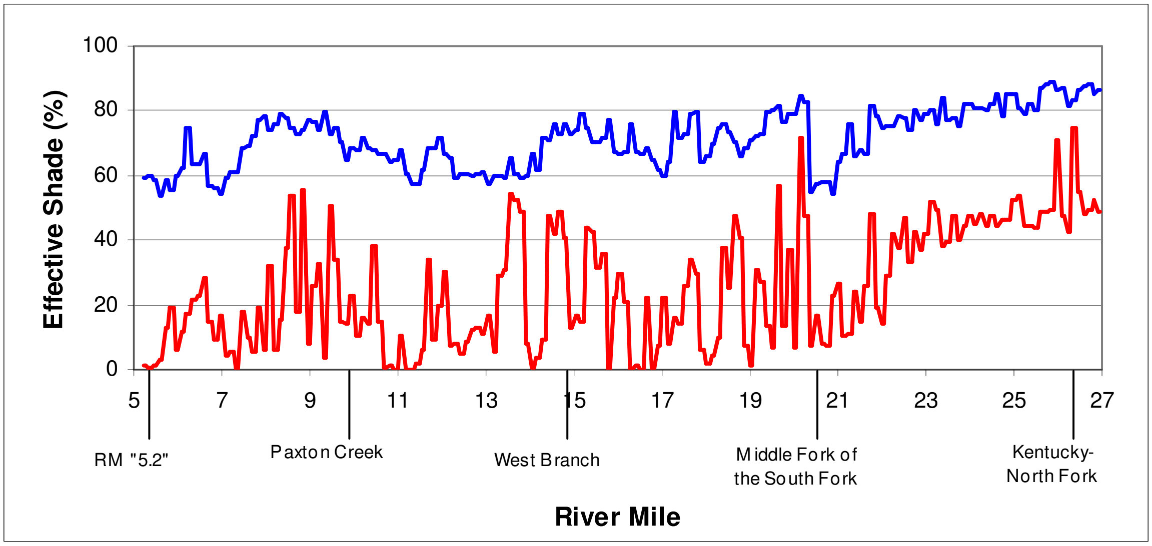
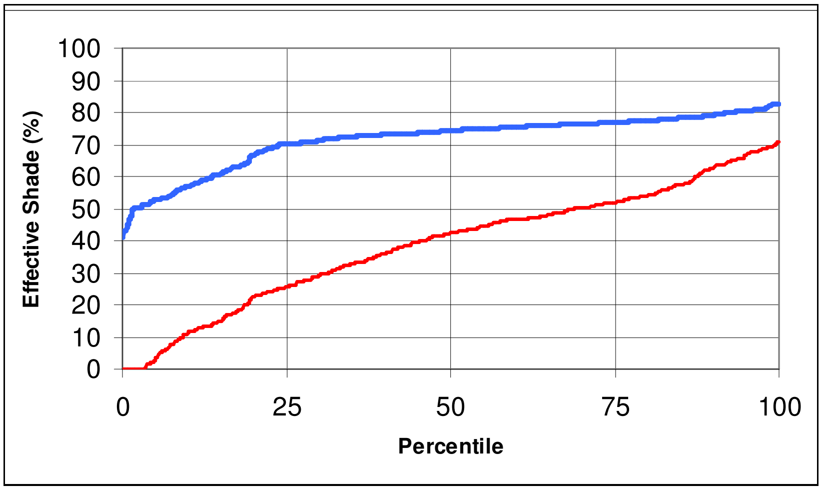
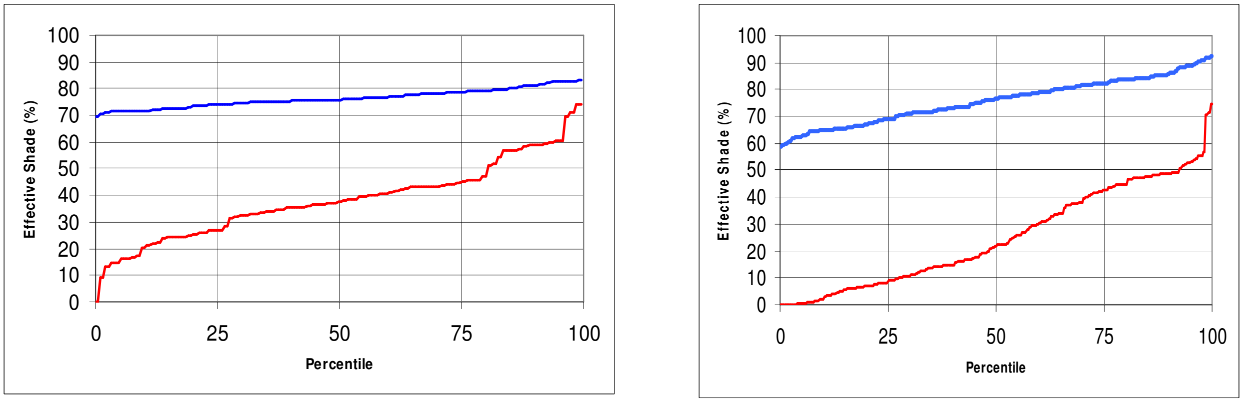


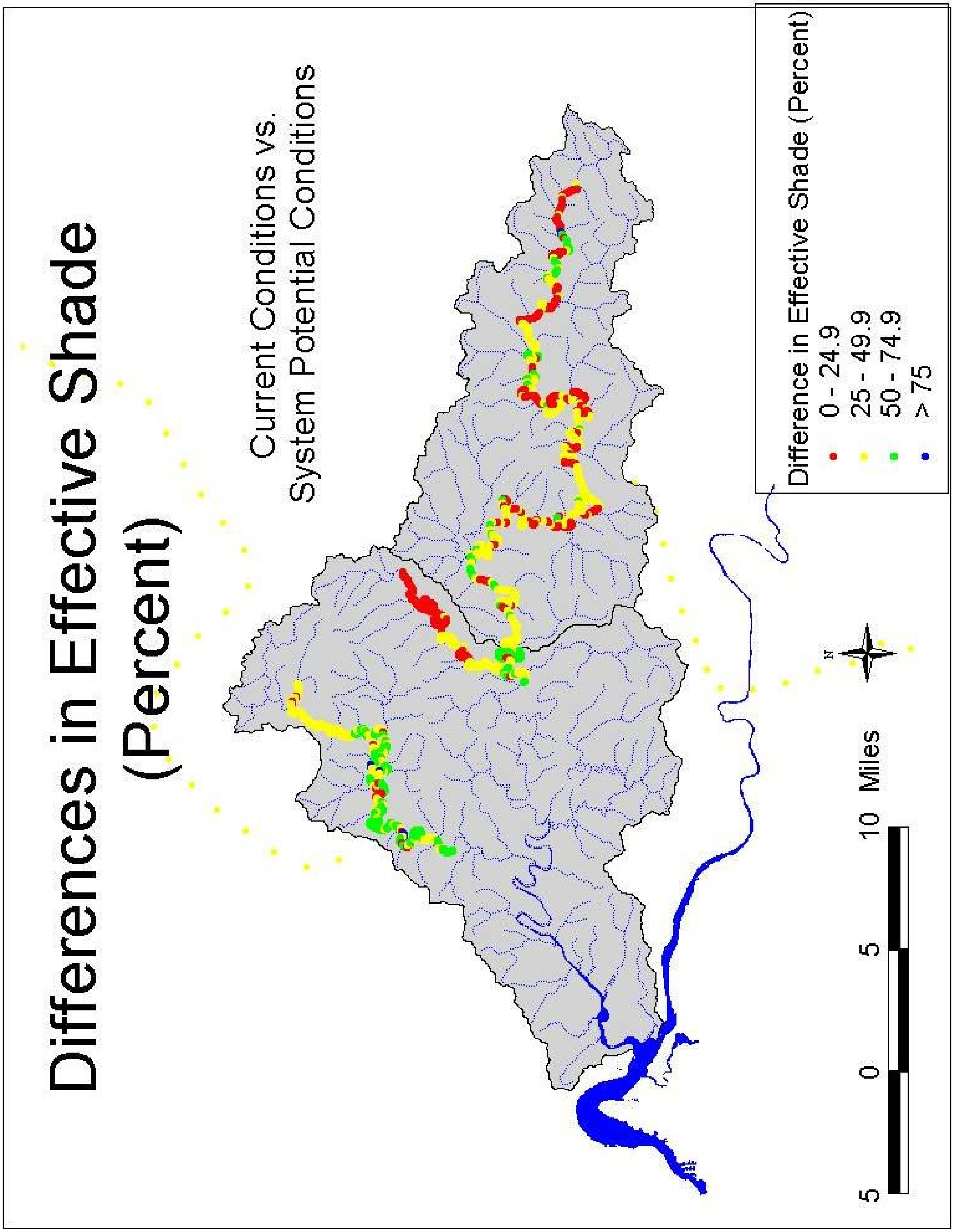
Figure 61. Cumulative Frequencies of Percent Effective Shade


Smith River Mainstem


West Fork

North Fork

Map 4. The percent difference in effective shade that can be gained in moving from current conditions to system potential.



The following table is a summary of 50th percentile (median) solar flux energies reaching the water (over a 24 hour day) and the % Effective Shade values based on simulations of current conditions and system potential conditions for the Smith mainstem, the West Fork Smith and the North Fork.

Unblocked Solar Flux and % Effective Shade – Flux Units are BTU/SqFt/Day

	Current Solar Flux (% Effective Shade)	**System Potential Solar Flux (% Effective Shade)**
Mainstem Smith	**998 (42.3%)**	**618 (74.3%)**
West Fork Smith	**1480 (37.5%)**	**680 (71.1%)**
North Fork Smith	**1659 (22.0%)**	**597 (71.1%)**

STREAM TEMPERATURE

Figures 62 and 63 show stream temperatures for the mainstem Smith, West Fork and North Fork. Color choices are the same, red (upper line) for current temperature, blue (lower line) for system potential temperature. The models simulate temperatures at 4:00 pm. The mainstem Smith and West Fork simulate 4:00 p.m. temperatures during a mid-July afternoon. The model for the North Fork simulates temperatures at 4:00 pm in mid-August.

Figure 62. a – Longitudinal Temperature Profile for the mainstem Smith River

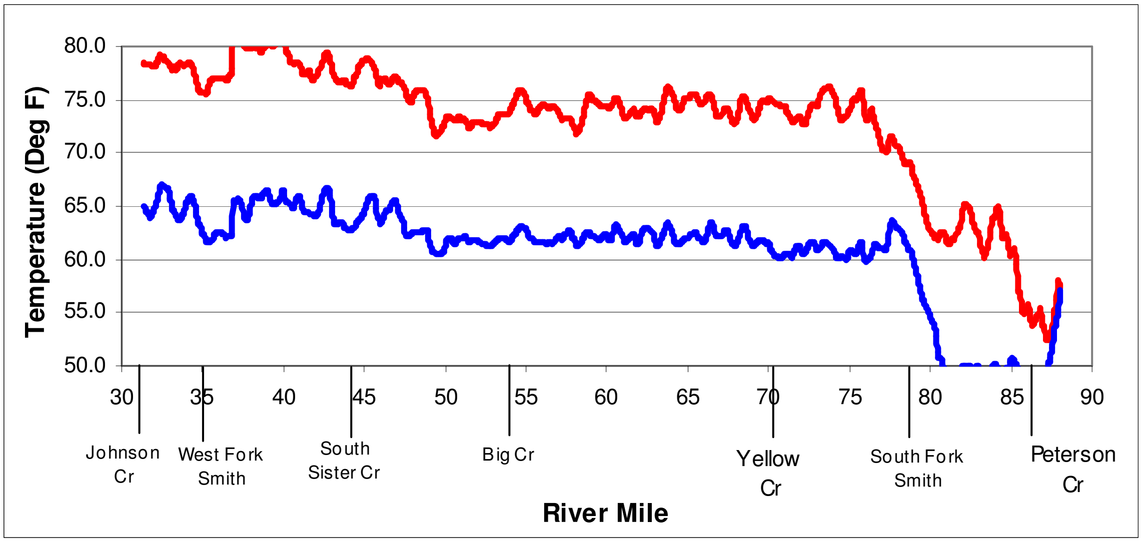


Figure 62. b – Longitudinal Temperature Profile for the West Fork Smith

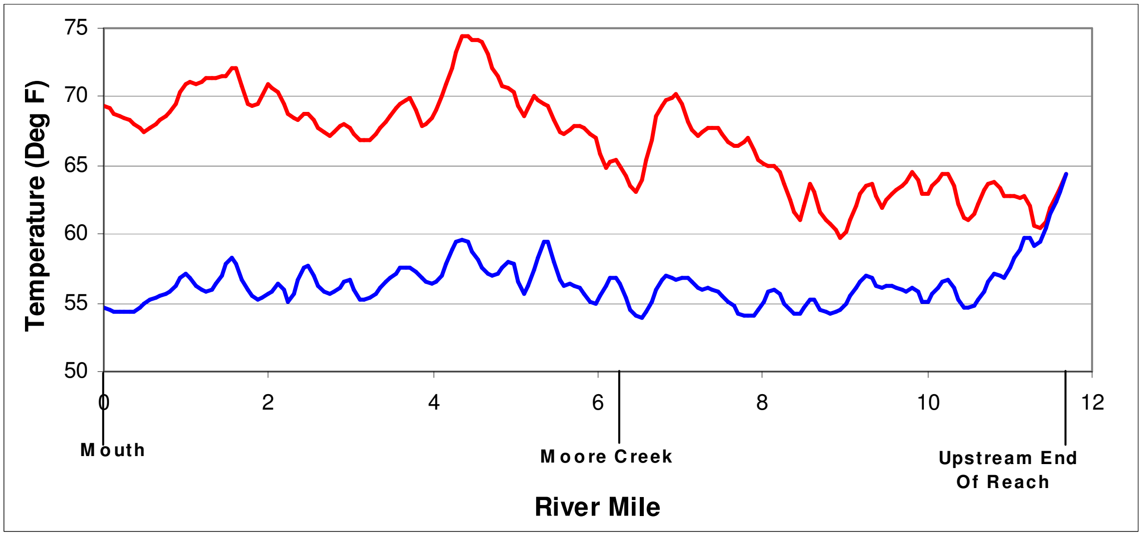


Figure 62. c – Longitudinal Temperature Profile for the North Fork Smith

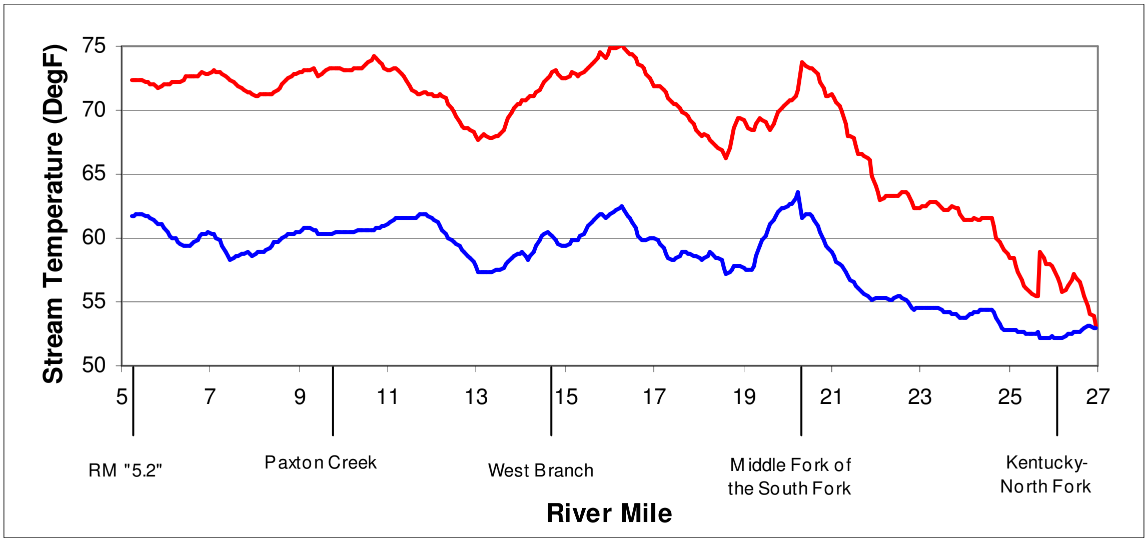
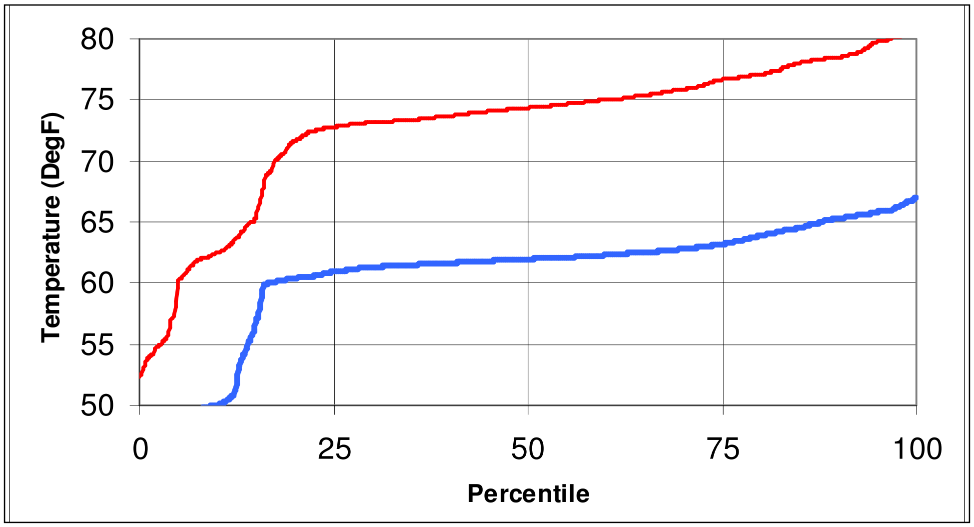


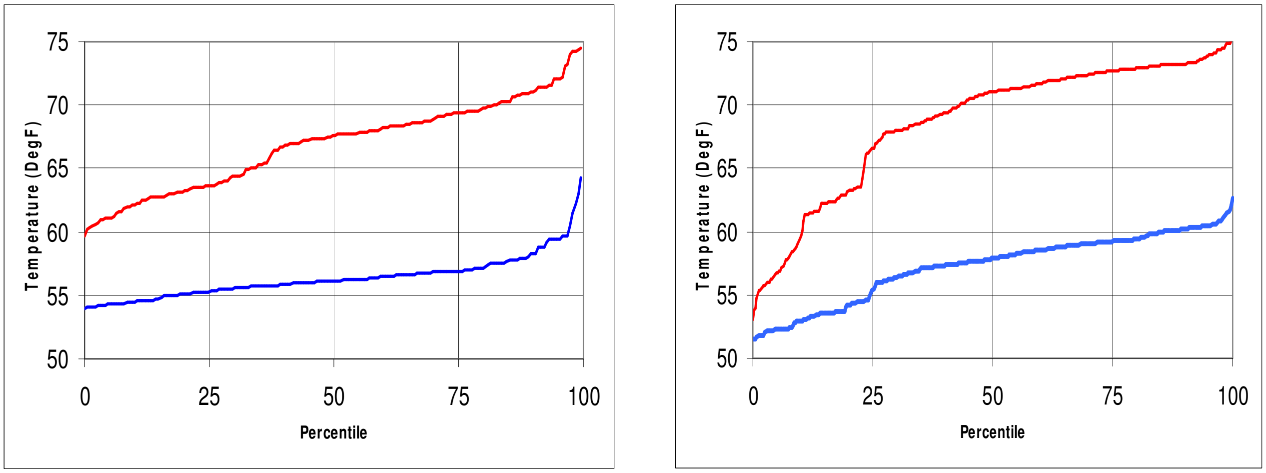
Figure 63. **Cumulative Frequency Plot for Temperatures**

Smith River Mainstem



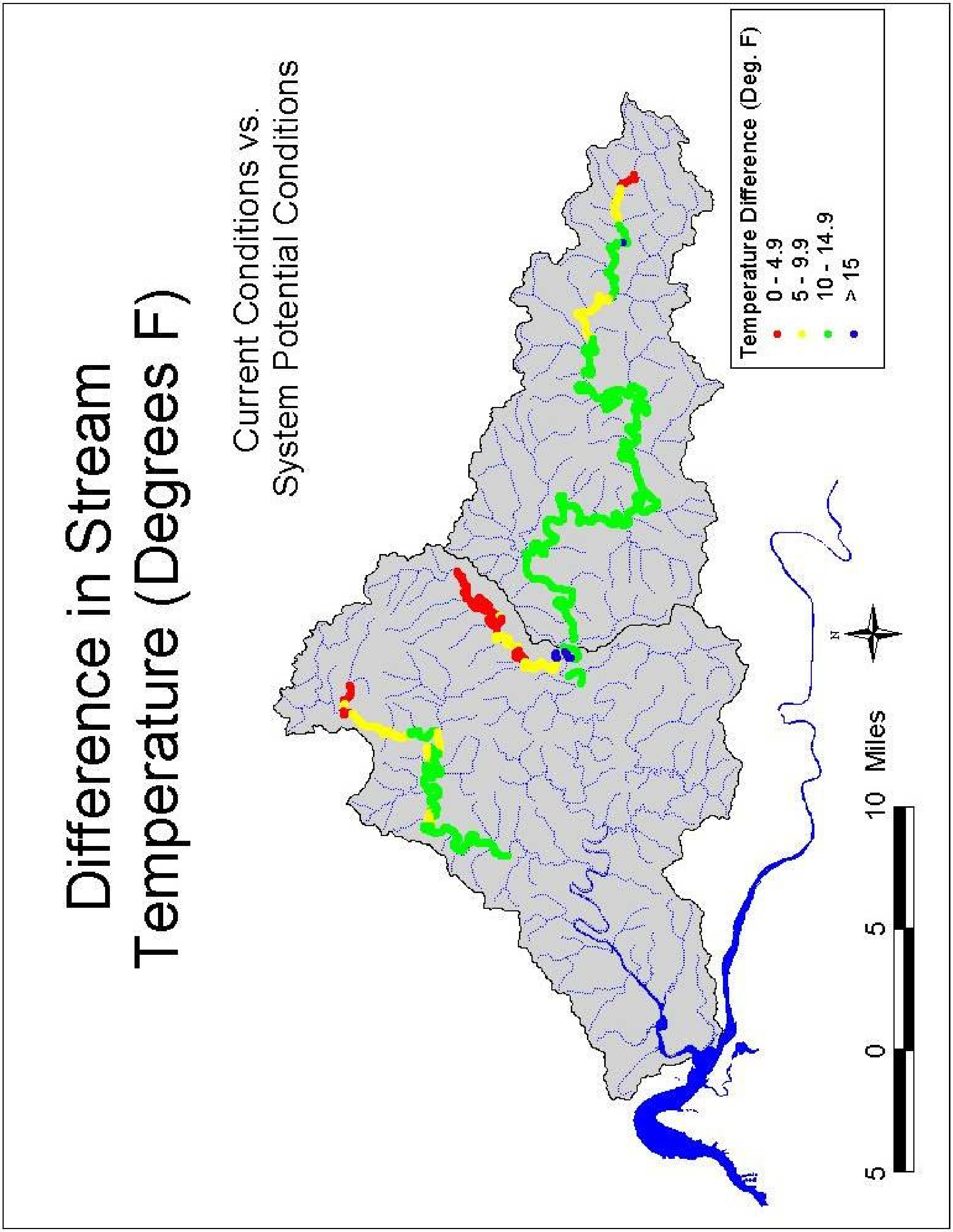
North Fork

West Fork



Map 5 shows the change in stream temperature achievable by moving from current condition to system potential conditions.

Map 5. Current condition vs. system potential temperatures

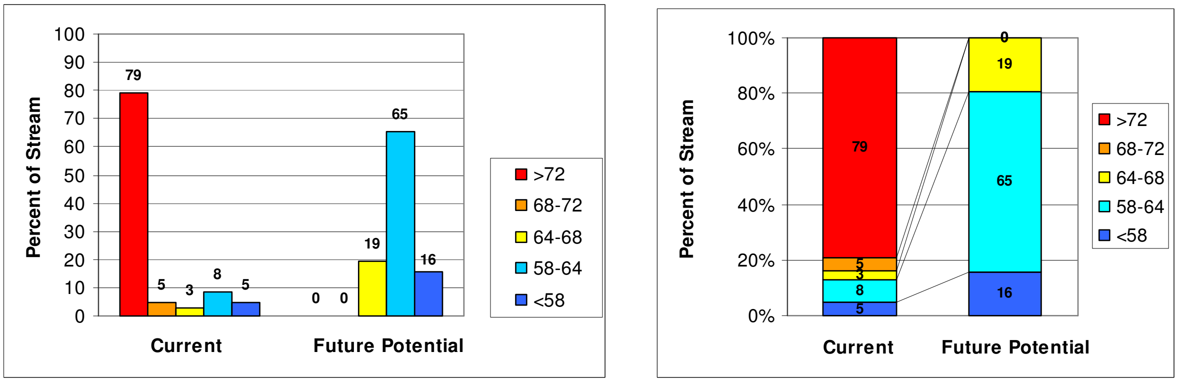


Temperature Distributions

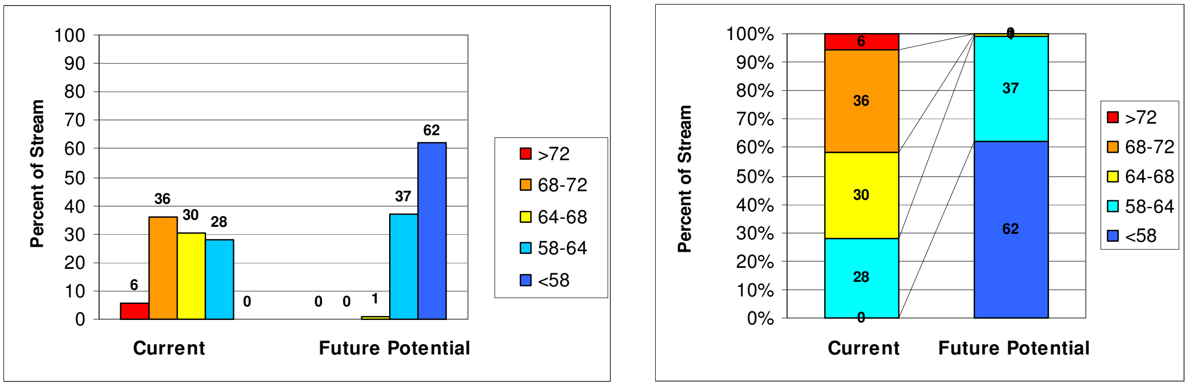
Figure 64 shows how many model segments in each system are in, or are expected to be in several temperature classes. These temperature intervals are generally consistent with temperatures needed at several of the life-stages for salmonids. Each graph-pair show the same information in two different formats.

Figure 64. **Modeled Temperature Distributions in Smith River Watershed**

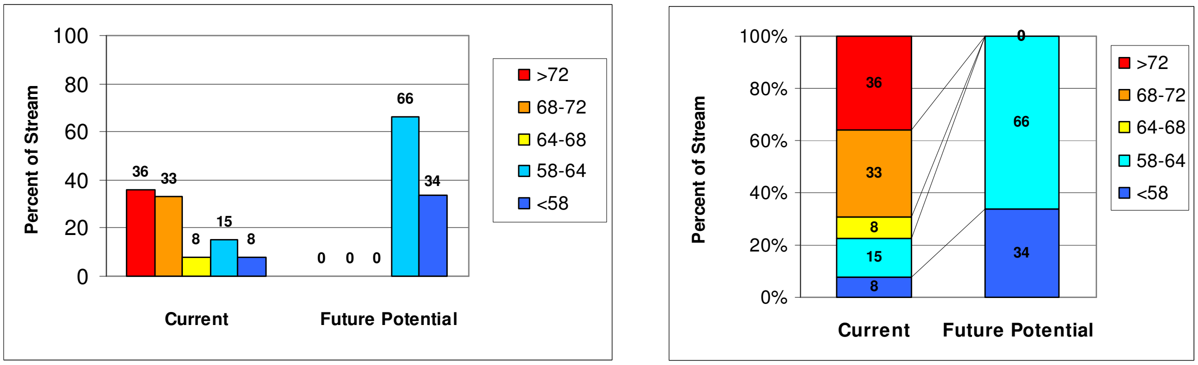
Mainstem Smith River



West Fork Smith



North Fork Smith



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