Technical Appendix: Development and Application of the Q2ESHADE Temperature Modeling System to the Upper Main Eel River

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A.1 Background

The Upper Main Eel River (UME) is located in northwest California. Its basin stretches across Lake, Glenn and Mendocino counties. The UME has been identified as an important habitat for cold-water fish populations such as the salmonid species. One of the major water quality concerns for these fish species is increased water temperature, which can severely impair their survival and reproduction. Increased temperatures caused the UME to be placed on California's Clean Water Act Section 303(d) list of impaired waterbodies.

A major factor contributing to elevated stream temperatures is the reduction in stream shading caused by the removal of riparian vegetation. To predict temperatures throughout the UME system and to assess relationships with riparian vegetation characteristics and topography, a QUAL2E-SHADE temperature modeling system was developed. This modeling system is comprised of a Geographical Information System (GIS) - based SHADE model linked to a modified QUAL2E receiving water model (Q2ESHADE). The components of the modeling system are summarized in Figure A-1.

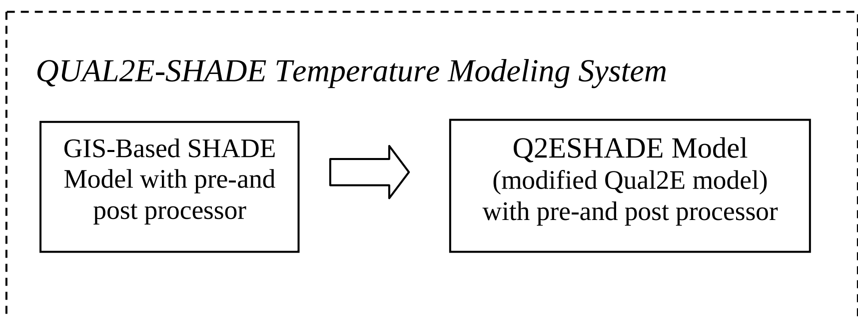

Figure A-1. QUAL2E-SHADE temperature modeling system

QUAL2E is a USEPA-supported, public-domain receiving water model. It has undergone extensive peer review over the past several decades and has been widely used numerous watersheds throughout the world. The SHADE model linked to QUAL2E is a simplified version of the model developed by Chen et al. (1998a) and applied to the Upper Grande Ronde watershed (Chen et al., 1998b).

The modeling system has been modularized such that the user can run the SHADE model alone or in conjunction with Q2ESHADE. Independently, the SHADE model can provide a screening level view of the influence of shade on in-stream temperatures. Coupled with the QUAL2E model, it provides the ability to simulate all or selected reaches within a particular watershed. This allows more flexibility during modeling and supports the exclusion of reaches that are not considered hydrologically important (i.e., no flow during the summer).

When operated in tandem, the Q2ESHADE modeling system calculates hourly shade-attenuated solar radiation at various locations based on riparian vegetation characteristics, topographic relief, and initial flow conditions and subsequently predicts in-stream temperatures throughout a stream network. The maximum weekly average stream temperatures (MWAT) are then calculated from the model output. The effects of riparian-zone vegetation management strategies on stream temperatures during low-flow/critical conditions can also be evaluated. To further understand the factors contributing to stream temperature in the watershed, Q2ESHADE can predict the impact of headwater flow conditions by varying the flow rate and initial temperature value.

For the UME, the integrated modeling system was applied to watersheds corresponding to Tomki Creek (referred to as the Tomki Creek watershed throughout the remainder of this document) and the main stem of the Upper Eel river beginning near Cape Horn Dam and terminating at the confluence of Outlet Creek (referred to as the main stem watershed throughout the remainder of this document). These watersheds are illustrated in Figure A-2. The model was calibrated using observed temperature monitoring data provided by the Humboldt County Resource Conservation District (RCD) and the North Coast Regional Water Quality Control Board (NCRWQCB). The United States Environmental Protection Agency (USEPA) provided additional temperature data in the UME watershed. A series of scenarios based on various riparian vegetation and headwater flow conditions downstream of Cape Horn Dam were then simulated to support TMDL development.

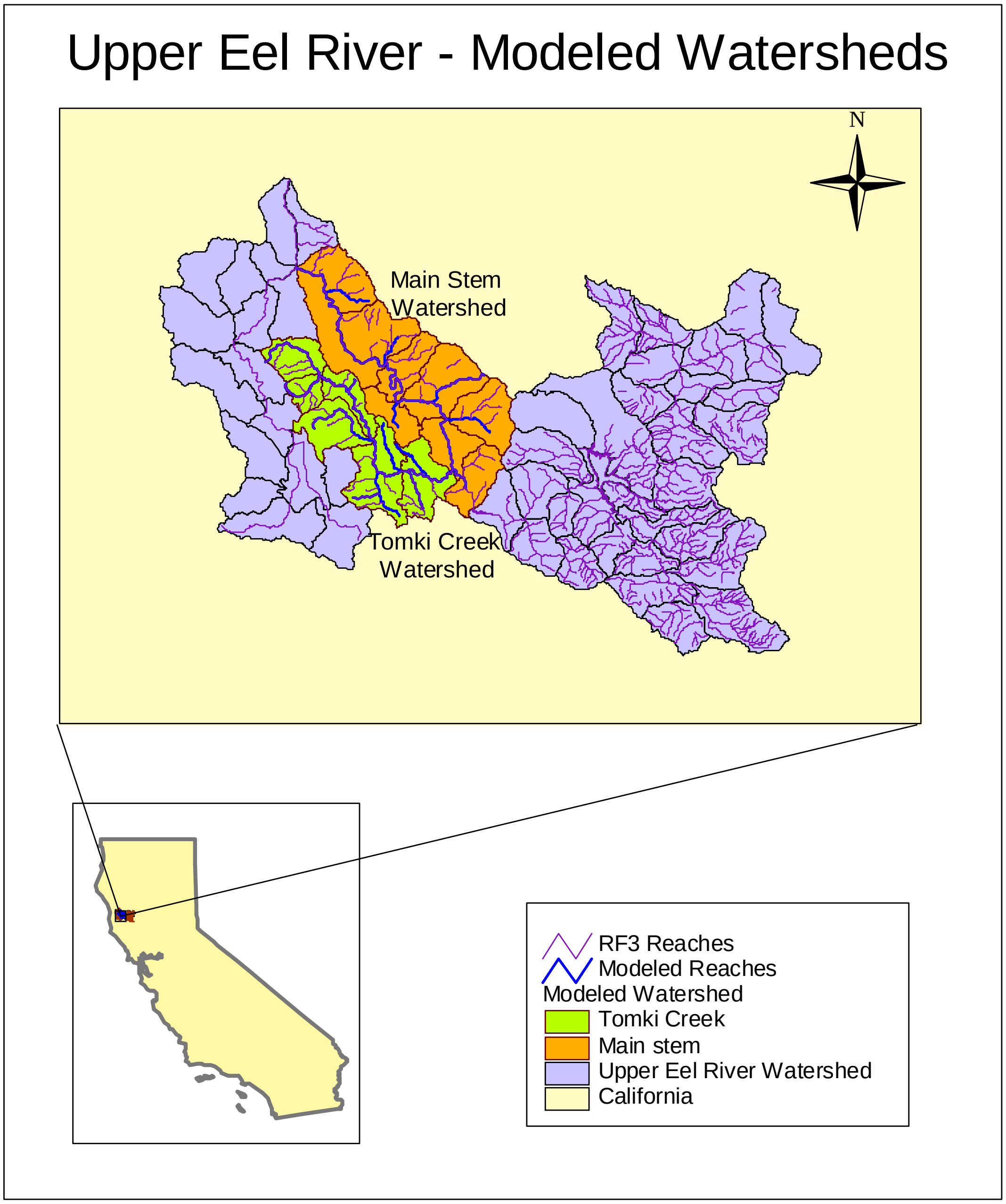

Figure A-2. Upper Main Eel River Watershed

A.2 GIS-Based SHADE Model

The GIS-Based SHADE model consists of two major components: the underlying SHADE model algorithms and a GIS-based preprocessor for the SHADE model. The methodology and data used to parameterize and run the SHADE preprocessor and model are presented in the next two sections and illustrated in Figure A-3.

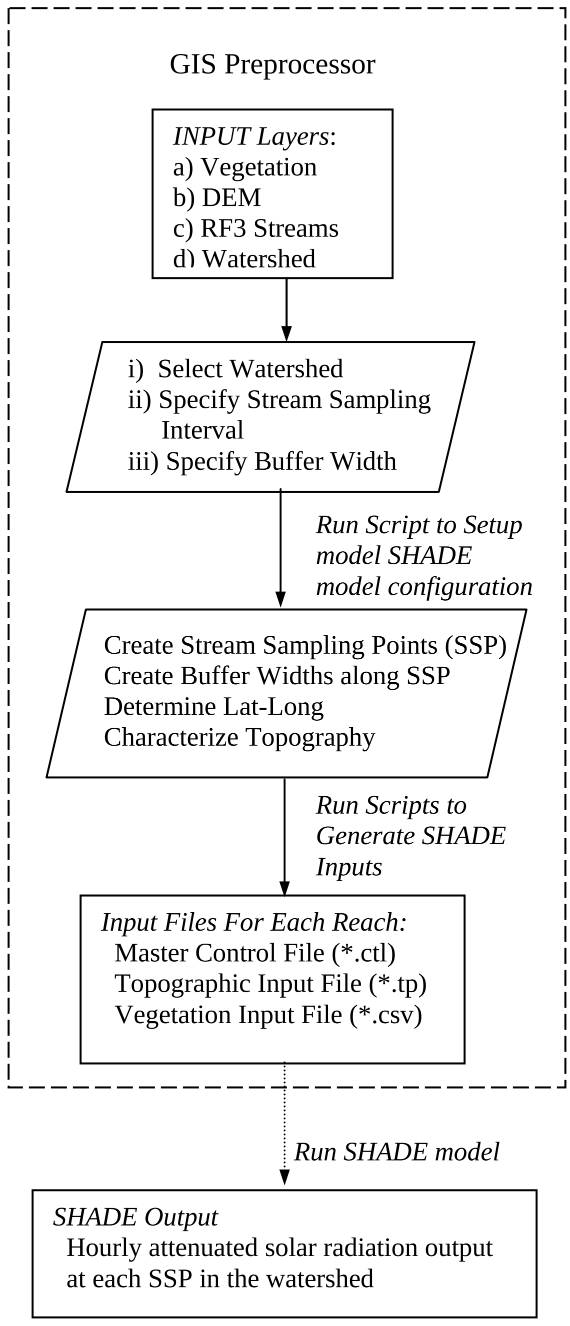

Figure A-3. SHADE GIS Preprocessor

A.2.1 SHADE GIS Preprocessor

A preprocessor was developed using a GIS platform to generate three input files required by the SHADE model. User-supplied input data include digital elevation model (DEM) data, site-specific vegetation data, streams (USEPA Reach File, Version 3 [RF3]), time zones, and watershed boundaries. The site-specific data used to represent the UME watersheds and the preprocessing steps are described below and presented in Figure A-3.

A.2.1.1 Data Requirements and Sources

Digital Elevation Model (DEM)
Elevation values were obtained from the 30-meter DEM data distributed by the United States Geological Survey (USGS). These data were used in determining the topographic shading.

Vegetation Data
The California Vegetation theme (CALVEG) from the United States Forest Service (USFS) was used to determine the vegetation related parameters. This data set was chosen due to its completeness and because it contained the required information to parameterize the SHADE model. The wildlife habitat relationships (WHR) classification system incorporated in the vegetation data provides information on general tree habitat classes (Table A-1), diameter-at-breast height (DBH), and canopy closure classes (Table A-2). The CALVEG vegetation layer was used to derive the tree height and density data layers, which are necessary inputs to the SHADE model to predict solar radiation.

Table A-1. Tree Size Classes

Size Class	DBH Range (inches)	DBH Range (centimeters)
0	0 – 0.9	0 – 2.4
1	1 – 4.9	2.5 – 12.6
2	5 – 11.9	12.7 – 30.4
3	12 – 23.9	30.5 – 60.9
4	24 – 39.9	61 – 101.5
5	≥ 40	≥ 101.6

Table A-2. Canopy Closure Classes

Closure Class	Canopy Closure (%)	Closure Class	Canopy Closure (%)
0	0-9	6	60-69
1	10-19	7	70-79
2	20-29	8	80-89
3	30-39	9	90-100
4	40-49	10	Not Determined
5	50-59		

Watershed Boundary

The CALWTR 2.2 watershed boundaries available from the State of California were used to represent the watershed boundaries. The watershed boundary is used to define the geographic extent of the study area, the Tomki Creek and main stem watersheds. All streams within the selected watersheds can be simulated or specific streams can be selected during preprocessing.

Stream Network

The RF3 provided by USEPA was used to represent the stream network. This shapefile provides detailed stream connectivity and lengths, which are necessary to ensure that the stream numbering scheme is generated properly for use by both SHADE and Q2ESHADE. The stream layers were amended to include the stream-wetted width at the start and end of each reach. Stream width information for each reach is necessary to calculate the surface area for individual reaches and account for the total solar radiation received at the stream surface. Measured widths were available for some reaches along the main stem of the UME from the Humboldt County RCD temperature monitoring data. For additional reaches along the main stem, linear extrapolation between sampling points was used to assign widths to unmeasured reaches. Only one Humboldt County RCD monitoring station was available for the Tomki Creek watershed. Observed low flow widths were available for Tomki Creek from the California Department of Fish and Game (CDFG). CDFG prepared a Stream Inventory Report for Tomki Creek, which included measured wetted widths at several survey locations described in Table A-3 (CDFG, 1997).

Table A-3. CDFG Survey Locations

Stream Name	Stream Survey Locations (distance from confluence with the Main Stem)	Sample Dates
Tomki Creek, Reach 1	11,906 feet (3,629 meters)	07/03/97 – 07/29/97
Tomki Creek, Reach 2	19,435 feet (5,924 meters)	07/03/97 – 07/29/97
Tomki Creek, Reach 3	29,808 feet (9,085 meters)	07/03/97 – 07/29/97
Tomki Creek, Reach 4	68,306 feet (20,820 meters)	07/03/97 – 07/29/97

To assign values to small or unmeasured tributaries, average widths were calculated from the Humboldt County RCD data for smaller streams across the watershed and applied to the Tomki Creek and main stem tributaries. The RF3 layer was also used to select the specific streams simulated in the Tomki Creek and main stem watersheds (Figure A-2).

Time Zone

The USGS time zone GIS layer was incorporated into the SHADE model to determine the standard time zone meridian (longitude) of the UME watershed.

A.2.1.2 Preprocessor Methodology

To generate the SHADE model files, the preprocessor creates user-specific stream sampling points (SSP) and buffers for each SSP. The distance between SSPs and the buffer widths are user-specified values, which depend on the spatial variability and level of detail required. The SSP distance for Tomki Creek and the main stem was 500 meters (1,640 feet), while buffer widths were 300 meters (984 feet). The SSP and buffer configuration for the main stem and Tomki Creek are shown in Figures A-4 and A-5.

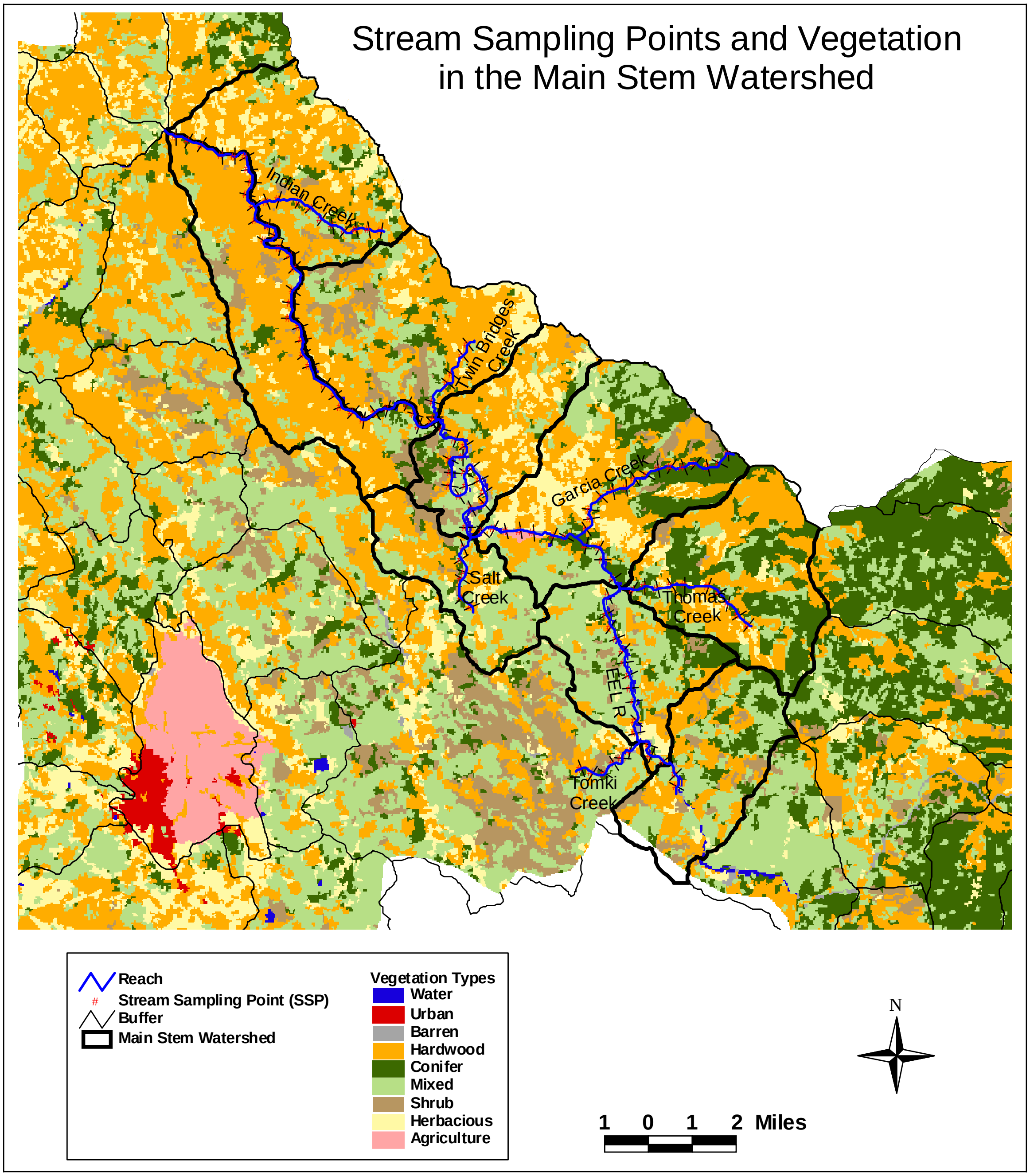

Figure A-4. Stream sampling points and vegetation for the Main Stem of the Upper Eel River

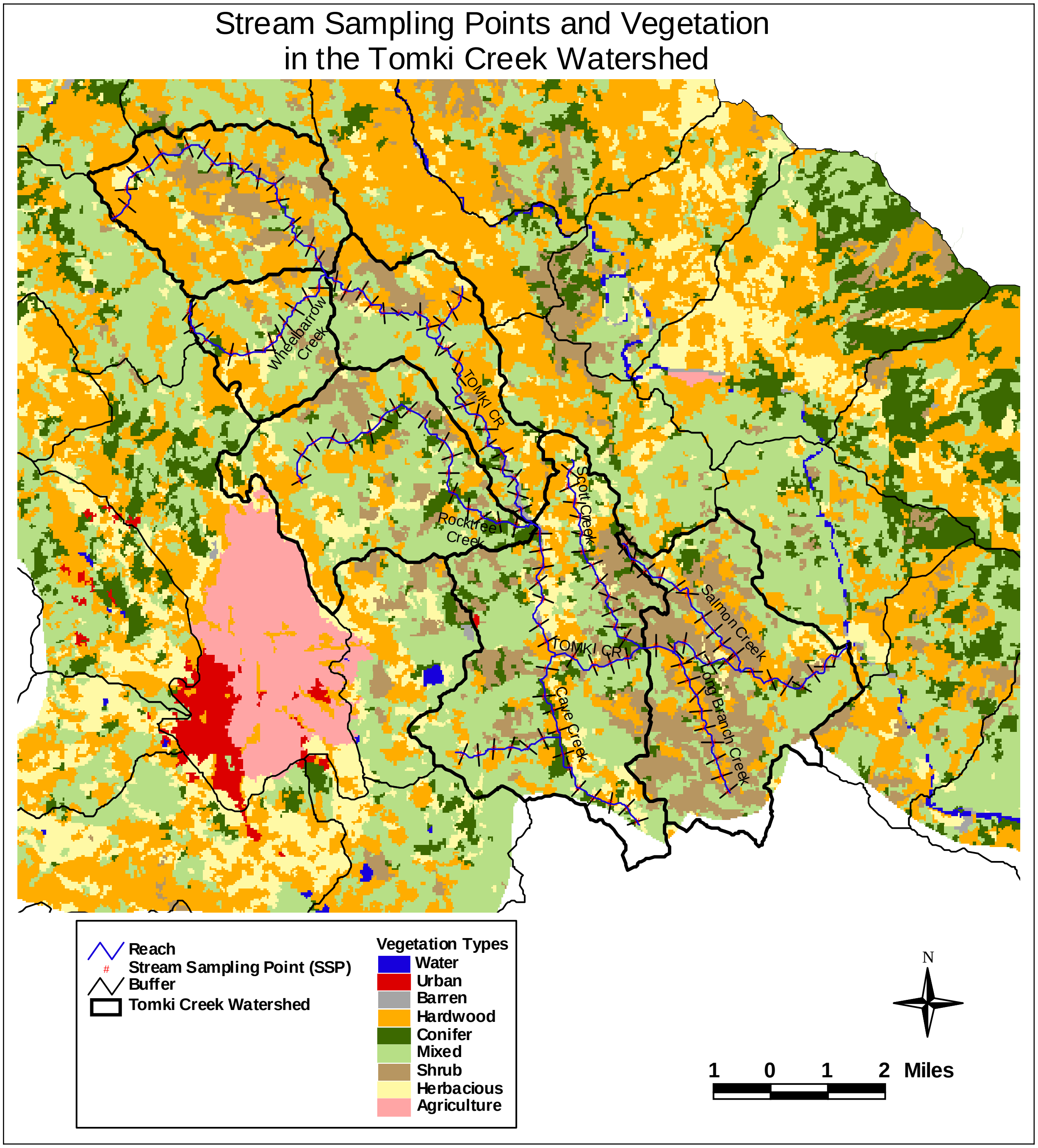

Figure A-5. Stream sampling points and vegetation for Tomki Creek

SSPs are automatically identified using an upstream to downstream numbering scheme, which is compatible with SHADE and the computational elements used by the Q2ESHADE model. After extracting the latitude and longitude and numbering each SSP, the preprocessor was used to characterize the topography and generate vegetation height and density layers required by the SHADE model.

Tree heights were derived using the asymptotic height-diameter regression equations available for 24 tree species in Oregon (Garman et al, 1995). For each of the different tree species identified in the California vegetation data layer, tree heights were determined using the DBH and local site-specific information about tree height and DBH values. The DBH range for each size class was provided in Table A-1.

The various tree species were then simplified into two distinct categories, conifers and hardwoods, and generalized DBH versus tree height relationships were developed for each. The general form of the asymptotic height-diameter equation is presented in Equation 1:

$$Height\ (m) = 1.37 + (b_0[1 - \exp(b_1 \cdot \mathrm{DBH})]^{b_2}) \qquad (1)$$

where, b_0, b_1, and b_2 are regression coefficients, which are dependent on the type of tree species and site class. The parameter b_0 is the asymptote or maximum height coefficient, b_1 is the steepness parameter coefficient, and b_2 is the coefficient for the curvature parameter.

The vegetation data was then summarized to identify the dominant coniferous and hardwood tree species in the Tomki Creek and main stem watersheds. In both areas, the most dominant conifer was determined to be the Douglas Fir and the most dominant hardwood tree species was the Oregon White Oak. Height-diameter regression coefficients developed for a model of the Middle Fork Eel River were selected as initial values and used to compute rating curves of tree height versus DBH using equation 1. The rating curves for Douglas Fir and White Oaks are presented in Figures A-6 and A-7.

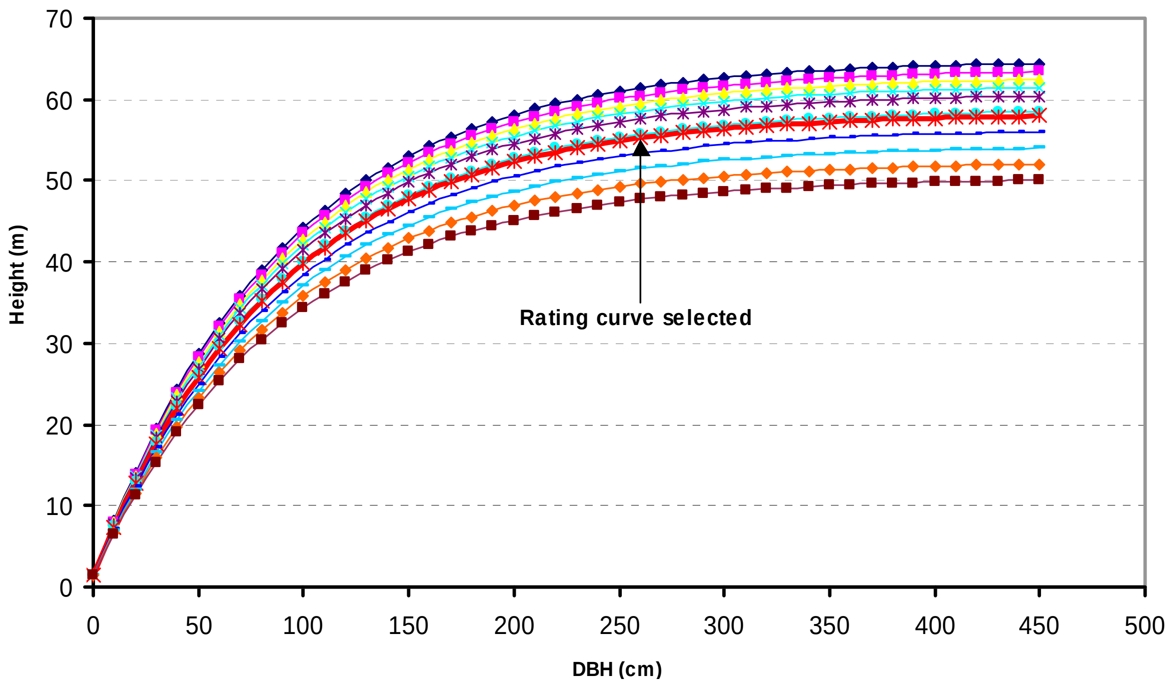

Figure A-6. Tree height-diameter for various site classes for Douglas Fir.

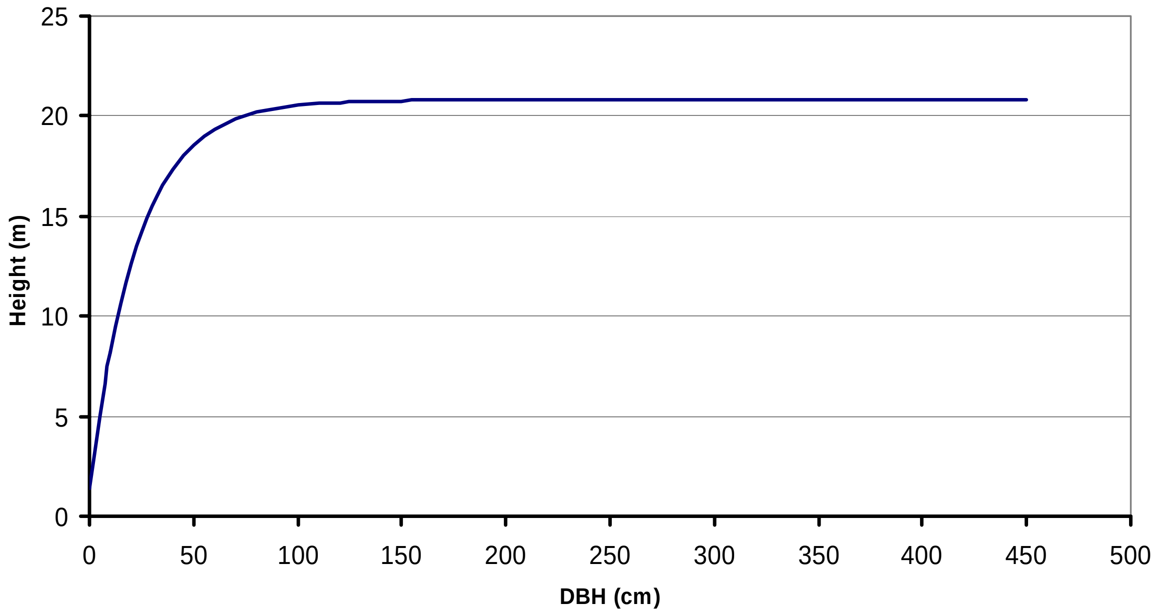

Figure A-7. Tree height-diameter for all site classes for White Oaks.

For conifers, the coefficients were varied to create a series of rating curves (Figure A-6). The rating curves were compared with observed conifer tree plot data for the Upper Eel River watershed provided by the USFS. The rating curve that most closely matched the Douglas Fir tree plot data was selected. The rating curve resulted in a maximum tree height of 40.1 meters (131.6 feet) for a DBH of 101.6 cm (40 inches). At the same DBH, an observed Douglas Fir was found to be 38.1 meters (125 feet) tall. The coefficients associated with this rating curve are identified in Table A-4 and a comparison between tree plot data and the selected rating curve is presented in Figure A-8.

Table A-4. Height-Diameter Coefficients

Vegetation Type	**b_0**	**b_1**	**b_2**
Conifers	56.96814	-0.01229	0.913189
Hardwoods	19.42621	-0.045116	0.958897

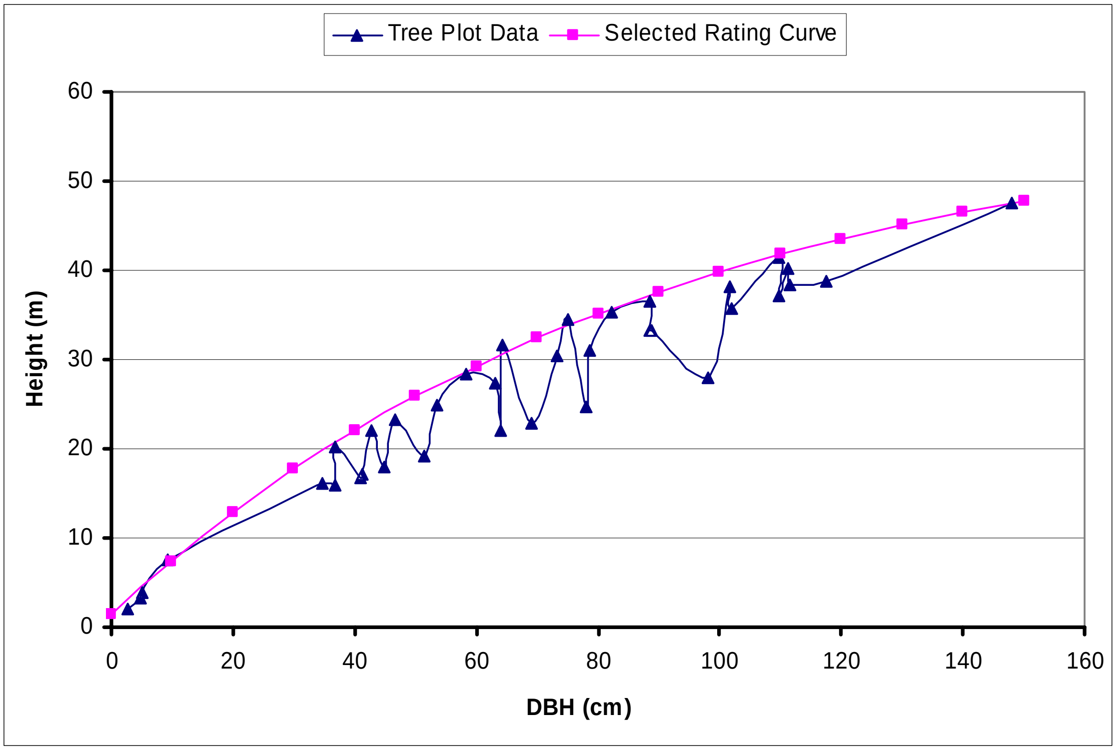

Figure A-8. Douglas Fir tree plot data and rating curve.

No observed data were available for hardwood tree species; therefore, the coefficients used in the Middle Fork Eel River model were applied to this watershed (Table A-4). Using these coefficients, the maximum computed tree height for hardwood trees was 21 meters (68.9 feet) for a DBH of 101.6 cm (40 inches). To address other vegetation types, a constant minimum height of 0.5 meter (1.6 feet) was assigned to herbaceous plants and 1 meter (3.3 feet) to other deciduous species.

Vegetation density is an additional parameter required by the SHADE model. The tree density was determined by assigning the appropriate average density based on the canopy closure ranges (Table A-2) for each closure class in the vegetation layer. The vegetation layer was also used to determine the two-character vegetation cover code required for the vegetation shade input file (*.csv). This code is generated automatically based on the cover type in the vegetation layer.

The result of the above processing is the generation of three required input files that supply the SHADE model with information on each reach (Figure A-3). These files include master input files (*.inp), topographic input files (*.tp), and vegetation input files (*.csv).

A.2.2 SHADE Model

Chen et al. (1998a, 1998b) have incorporated a series of computational procedures identifying the geometric relationships among sun position, stream location, and orientation, riparian shading characteristics into a computer program called SHADE. This model has the capability of predicting shade–attenuated solar radiation on a watershed scale.

A.1.1.0 SHADE Model Inputs

The output files from the SHADE GIS preprocessor are incorporated directly into the SHADE model. In addition to this information, SHADE also requires daily solar radiation data. Hourly solar radiation data for 2003 were available from the California Department of Water Resources at the Alder Springs weather station (approximately 28 miles east of the center of the watershed) (CDEC, 2004). A daily time series containing cloud attenuated solar radiation for the modeling period was generated, as per SHADE model requirements. All SHADE model inputs are summarized in Table A-5.

Table A-5. SHADE Model Inputs

Input Parameter	Description
Watershed location	• Watershed latitude • Watershed longitude • Time zone standard meridian where the watershed is located
Stream width	Wetted stream width at the start and end of each reach
SSP coordinates	Universal Transverse Mercator (UTM) coordinates of all stream sampling points (topographic and vegetation shading characteristics will be defined at each of these locations)
Topographic shading characteristics	Topographic shade angles (degrees) measured from the stream surface to up to the topographic features that obstruct the sunbeam (Input in 12 standard azimuth directions at each SSP)
Vegetation shading characteristics	Includes vegetation characteristics at each SSP: • Distance from the edge of the stream to riparian buffer (m) • Average absolute height of vegetation canopy (m) • Average height of vegetation canopy with respect to the stream surface (m) • Average canopy density (%)
Global solar radiation	Time series of daily global solar radiation at watershed location (Langleys) for entire simulation period

A.2.2.2 SHADE Model Methodology

SHADE computes a time-series of the effective solar radiation reaching the stream surface after accounting for the effects of riparian vegetation and topography. A detailed description of the SHADE model can be found in the paper *Streams Temperature Simulation of Forested Riparian Areas*: I. Watershed-Scale Model Development (Chen et.al.,1998a). The methodology employed in SHADE is summarized below:

0. A watershed's location is determined by latitude and longitude. The latitude is used to compute the solar path (the sun's position over the day defined by two angles: the solar altitude and the solar zenith) and half-day length at a location. The longitude and standard meridian where the watershed time zone is centered is used to convert standard time to local time in the watershed.

0. The daily global radiation is disaggregated into hourly direct-beam and diffuse radiation based on the watershed latitude using a number of theoretical considerations and empirical relationships.

0. Using an hourly time step, the topographic and vegetation shading effects on direct-beam radiation are computed from sunrise to sunset by relating the solar path geometry to shade angles provided by the topography and vegetation. Computations are performed at every SSP. The final direct-beam radiation with shading effects is calculated as a function of the stream width.

0. Shading effects on diffuse radiation are assumed to be controlled by sky openness (the fraction of the sky not blocked by riparian vegetation or topography), which is considered constant over time and estimated at each SSP from topographic and vegetation shade angles.

0. Direct-beam and diffuse radiation are further reduced by the albedo (reflectivity) of the moving water surface. The albedo of direct-beam radiation is assumed to be a function of the solar zenith angle, while a constant value is assumed for diffuse radiation albedo.

0. Direct-beam and diffuse radiation are summed to obtain the effective solar radiation absorbed by the stream water at each SSP. The solar radiation factor (effective radiation for heating divided by the incoming radiation) is also computed at each SSP.

Using this methodology, the SHADE model can be used to evaluate various riparian management scenarios, such as logging and fire management.

A.2.2.3 SHADE Model Output and Post-Processing

SHADE calculates adjusted global solar radiation and a solar radiation factor, which are used by the Q2ESHADE model. These output parameters are described in Table A-6.

Table A-6. SHADE Model Output

Output Parameter	Description
Adjusted global solar radiation	Time series of hourly (and daily) global solar radiation (Langleys) reaching the stream surface and available for elevating the stream temperature
Solar radiation factor	Ratio (dimensionless) of effective radiation for stream heating divided by the incoming radiation on the top of the channel valley

To evaluate data at each SSP, a post-processing tool was developed to generate a statistical summary of the maximum, minimum, and average shade attenuated solar radiation for the simulation period at each SSP. These values were then used to estimate the amount of effective shade at each SSP (i.e. the percent reduction in solar radiation after being attenuated by the topography and vegetation). Post-processing tools also calculated an average heat load for the entire watershed (Langley/day).

A.3 Q2ESHADE Model

A customized SHADE version of USEPAs QUAL2E (Brown, et. al., 1987) in-stream model was developed (Q2ESHADE). The Q2ESHADE model uses all the underlying algorithms of QUAL2E and can be easily linked with the SHADE model. The Q2ESHADE enhancements provide interpretation of hourly solar radiation time series data from the SHADE GIS model output, as well as heat balance calculations. A preprocessor was developed to reformat SHADE hourly solar radiation data into a format that can be read by Q2ESHADE. The Q2ESHADE model along with its post-processing features and required data files are discussed below and illustrated in Figure A-9.

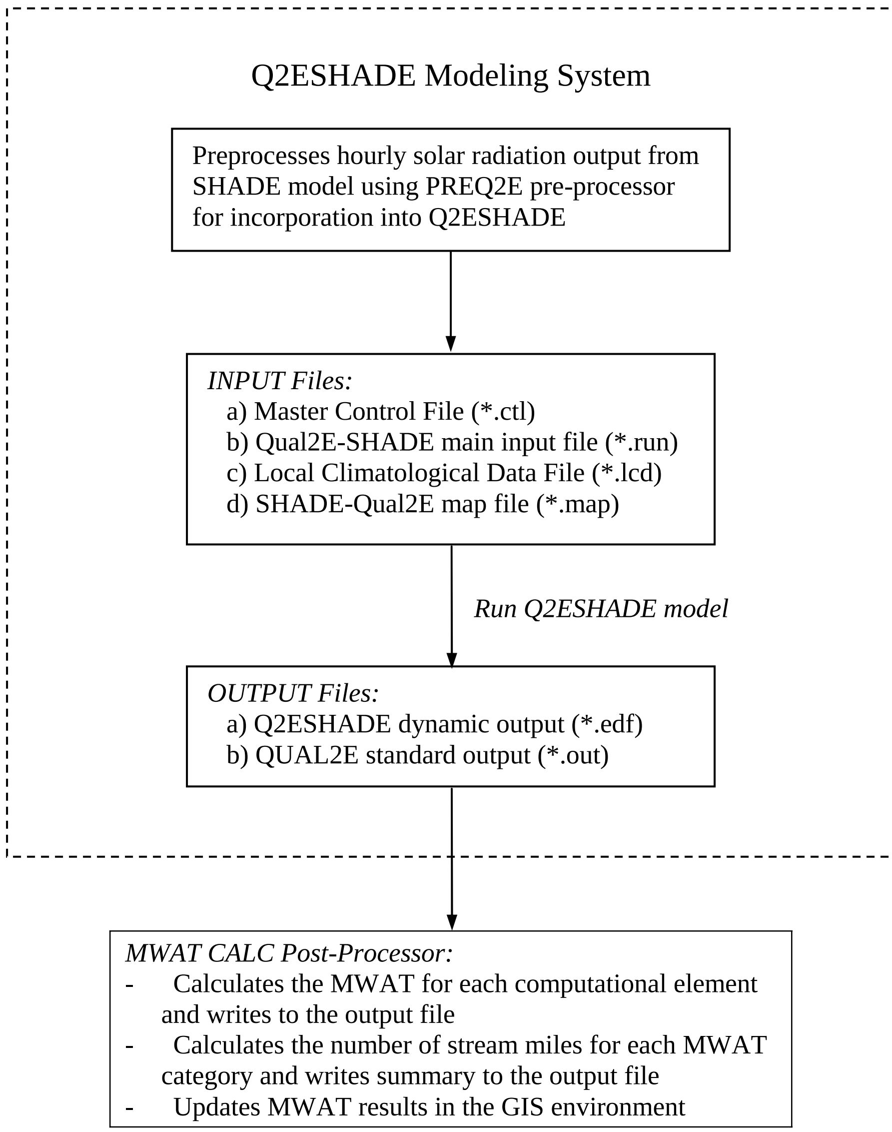

Figure A-9. Q2ESHADE Model Functionality

A.3.1 Q2ESHADE Data Requirements

Q2ESHADE utilizes SHADE model output with channel hydraulics and climatological data during its simulation process. These new data sources are described below.

Channel Hydraulics

Since Q2ESHADE is a steady-state model, it requires a constant stream flow and water temperature at the headwaters (from both major tributaries and Cape Horn Dam). The Cape Horn Dam headwater flow used for the main stem was estimated using the average critical condition (July 15 through August 14) flow at the USGS gage near Cape Horn Dam (USGS gage #11471500) for 1993-2002. The average critical condition flow for this 10-year period was ~7 cubic feet per second (cfs). Additional tributary headwater flows along the main stem were calculated using an area-weighted average based on flow measurements at the USGS gage. All headwater temperatures were calculated based on the closest or most representative 2003 temperature monitoring station (Humboldt County RCD or NCRWQCB). The baseline temperature at Cape Horn Dam was 20.9^{o}C.

The tributary headwater flows throughout the Tomki Creek watershed were calculated using an area-weighted average based on the summer flow value reported in the CDFG report. Similar to the main stem watershed, the temperatures were assigned using the closest or most representative temperature monitoring station from the Humboldt County RCD.

To describe the hydraulic characteristics of the system, the functional representation option within Q2ESHADE was used. This involved calculating the velocity and depth for the system using power equations. The power equations are in the form of $v = aQ^b$ and $d = cQ^d$; where:

> v = velocity,
> d = depth,
> Q = flow,
> a and c = coefficients, and
> b and d = exponents.

Based on the flow and depth measurements provided in the CDFG reports, coefficients a, c and exponents b, d were derived for the Tomki Creek watersheds. Coefficients and exponents were determined for the main stem watersheds using velocity and depth values provided in IFIM model output from Pacific Gas & Electric. Rating curves were established using these coefficients and exponents, which were adjusted during model calibration, to ensure that the range of summer base flow conditions would be covered for both modeled watersheds.

Climatological Data

The Q2ESHADE model requires time-series climatological data including atmospheric pressure, dry bulb temperature, wet bulb temperature, wind speed, and cloud cover data for simulating the diurnal variation in the temperature. The CDEC station at Alder Springs did not have all of the required weather parameters to prepare the weather file for the Q2ESHADE model. A complete dataset with hourly time-series data by month was available for the Ukiah, California station, which is located approximately 22 miles (35.4 kilometers [km]) south of the center of the UME watershed. Climatological data for the Ukiah station was downloaded for the summer of 2003 from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA).

The Q2ESHADE model allows for the clear-sky solar radiation to be adjusted by the observed cloud cover. However, since solar radiation used in the SHADE model was cloud cover attenuated (and not clear sky), this option was disabled.

A.3.2 Q2ESHADE Development and Methodology

The Q2ESHADE model was used to predict in-stream temperatures at different segments throughout the stream network. The model is applicable to dendritic streams that are well mixed and assume a constant stream flow at the headwaters. Q2ESHADE is a one-dimensional model in which the main transport mechanisms are significant only in the major direction of flow. Because the highest temperature conditions are typically observed during low-flow periods, the model is suitable for critical condition temperature modeling.

In Q2ESHADE, the stream is conceptualized as a series of computational elements (completely mixed batch reactors) that have the same hydrogeometric properties within a reach. Flow is routed via transport and dispersion mechanisms and mass balance is performed for the constituent of concern. A link is made with the SHADE model by keeping the computational element spacing identical to the SHADE SSP spacing.

Although the in-stream model algorithms are used to represent a single flow condition, the model can be operated quasi-dynamically to simulate temperature fluctuations. Based on available hourly local climatological data, the model can update the source/sink term for the heat balance over time. Therefore, the diurnal response of the steady-state hydraulic system to changing temperature conditions can be simulated.

The model can also be parameterized to simulate the impact of different headwater conditions by modifying the flow rate and initial temperature values. Model simulations can then be performed to determine the in-stream water temperature under various background conditions. These simulations can be performed in conjunction with different vegetation scenarios to further characterize past, present, and future conditions in the watershed.

For constant headwater inflows, the model can currently simulate temperature dynamically for a period of 31 days (744 hours). This limitation was stipulated because the model stores hourly solar radiation in memory for each computational element, and the array size grows very large as the length of time modeled increases. One month was determined to be reasonable since the model is not dynamic with respect to flow. This time period appropriately represents the critical period (July 15, 2003 through August 14, 2003) with regard to temperature (constant low flow conditions).

A.3.3 Q2ESHADE Model Output and Post-Processing

The Q2ESHADE model creates two important output files: the Q2ESHADE dynamic output file (*.edf) and the QUAL2E standard model output (*.out). The files contain an enormous amount of data that need to be processed for analysis. To evaluate the time series Q2ESHADE model output at each SSP, post-processors were developed to quantify and summarize the time series data for TMDL analysis (Figure A-9).

The post-processors read the output data and then generate the MWAT during the critical period at each SSP. In addition to producing MWAT values, the stream mileage associated with different stream temperature categories is calculated. These categories include: Good <15^{o}C, Fair 15^{o}C – 16.99^{o}C, Marginal 17^{o}C – 18.99^{o}C, Stressful 19^{o}C – 23.99^{o}C, and Lethal Conditions >24^{o}C.

A.4 Model Calibration and Results

Once the required datasets were collected, the SHADE and Q2ESHADE models were parameterized for the Tomki Creek watershed and the main stem watershed. The SHADE-GIS system was used to generate input files for the SHADE model simulation, based on the specified SSP interval and buffer width. Height-diameter coefficients were used to compute the tree heights for the baseline condition and the resulting shade attenuated solar radiation time-series were then routed through the in-stream Q2ESHADE model to simulate the stream MWATs.

The 2003 temperature monitoring data from the Humboldt County RCD and the NCRWQCB were used for calibration. One station was available in the Tomki Creek watershed and six stations along the main stem reaches were used for calibration. There were three other Humboldt County RCD stations located along the main stem; however, these stations were not used for calibration because the temperature monitors were located in deep pools that are known to stratify. MWATs were calculated for the temperature monitoring data for July 15, 2003 through August 14, 2003 and were compared with the MWATs predicted by the model for the same time period. Results are presented for Tomki Creek in Table A-7 and the main stem in Table A-8. The average percent error was 0.32% for Tomki Creek and –0.07% for the main stem (percent error ranged from –1.6% to 0.83%). Additional results are incorporated into the TMDL report. These MWAT stations used for calibration are illustrated in Figure A-10.

Table A-7. Model Calibration Results for Tomki Creek

Source	Station ID	Location	Observed Temperature MWAT (deg C)	Predicted Temperature MWAT (deg C)
Humboldt County RCD	1648	Tomki Creek (near the confluence with the main stem)	24.85	24.93

Table A-8. Model Calibration Results for the Main Stem Upper Eel River

Source	Station ID	Location	Observed Temperature MWAT (deg C)	Predicted Temperature MWAT (deg C)
Humboldt County RCD	8009	Upper Eel River (upstream of Tomki Creek)	25.04	24.64
Humboldt County RCD	8008	Upper Eel River (downstream of Tomki Creek)	25.62	25.45
NCRWQCB	626439	Upper Eel River at Hearst	27.63	27.86
Humboldt County RCD	8005	Upper Eel River (Emandel)	27.77	28.00
Humboldt County RCD	1452	Upper Eel River (upstream of Outlet Creek)	27.97	27.94
NCRWQCB	626442	Upper Eel River (upstream of Outlet Creek)	27.86	27.94

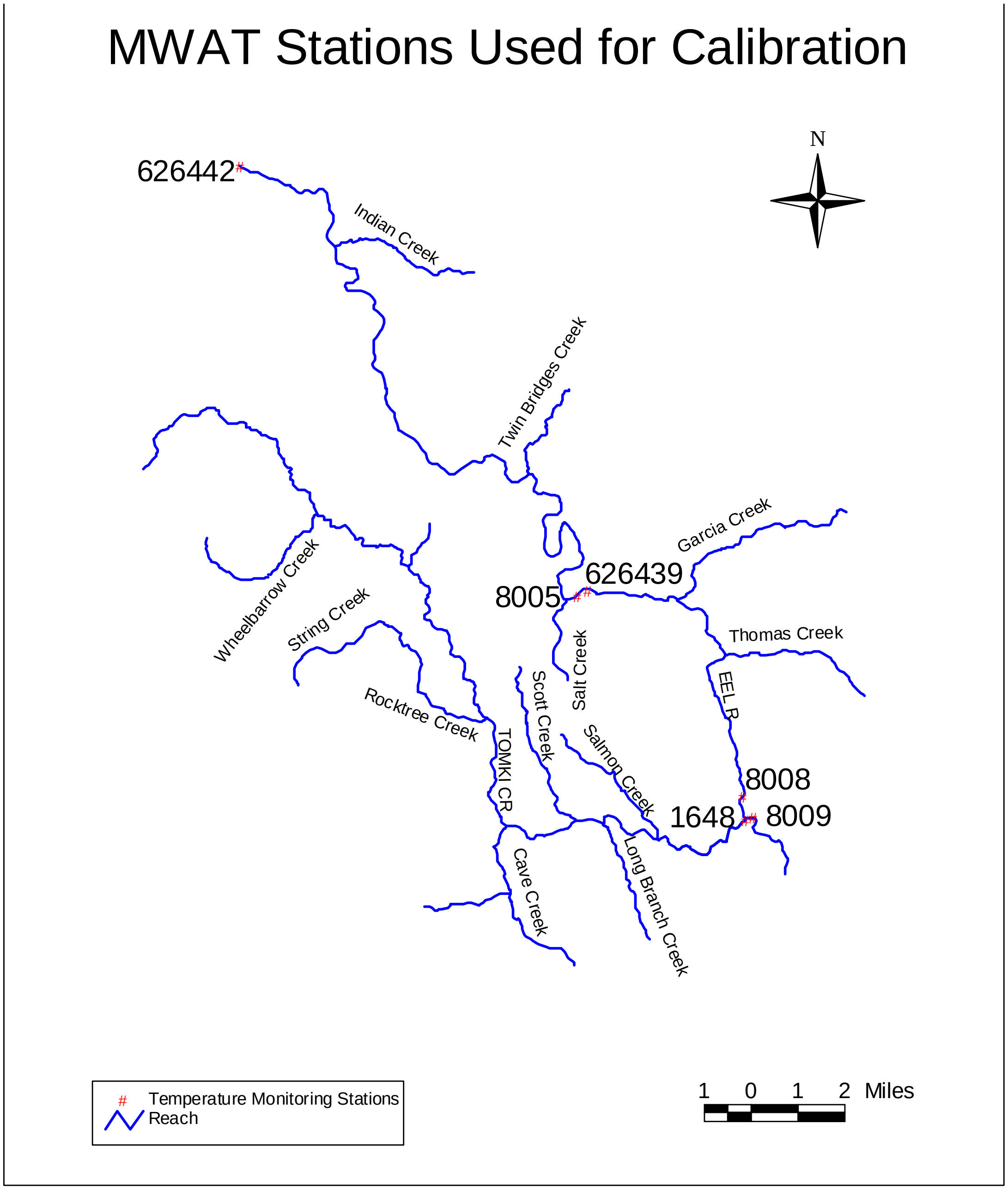

Figure A-10. Monitoring station locations used for calibration

Table A-9 presents the model results associated with the baseline conditions described in Sections A.2 through A.4 for Tomki Creek and the Main Stem. The model results are presented as the number of stream miles associated with different MWAT categories, the solar radiation, and the average percent shade. In addition, Figures A-11 and A-12 illustrate the average percent shading using baseline conditions.

Table A-9. Baseline (1975-2003 Operating Conditions, 7 cfs at 20.9°C) Model Results for Tomki Creek and the Main Stem Upper Eel River

Temperature Category	Tomki Creek		Main Stem Upper Eel River	
	Stream Miles	% of Total	Stream Miles	% of Total
Good (MWAT < 15° C)	0.0	0%	0.0	0%
Fair (15° C < MWAT < 17° C)	0.9	2%	0.0	0%
Marginal (17° C < MWAT < 19° C)	3.7	8%	0.0	0%
Stressful (19.1° C < MWAT < 20° C)	2.8	6%	0.6	1%
Stressful (20.1° C < MWAT < 21° C)	2.8	6%	0.9	2%
Stressful (21.1° C < MWAT < 22° C)	2.5	5%	2.5	6%
Stressful (22.1° C < MWAT < 23° C)	2.2	4%	1.9	4%
Stressful (23.1° C < MWAT < 24° C)	4.0	8%	3.1	7%
Lethal (MWAT > 24° C)	30.4	62%	35.4	80%
TOTAL	49.3	100%	44.4	100%
Solar Radiation (Langley/day)	295.0		315.3	
% Shade	49.2%		46.3%	

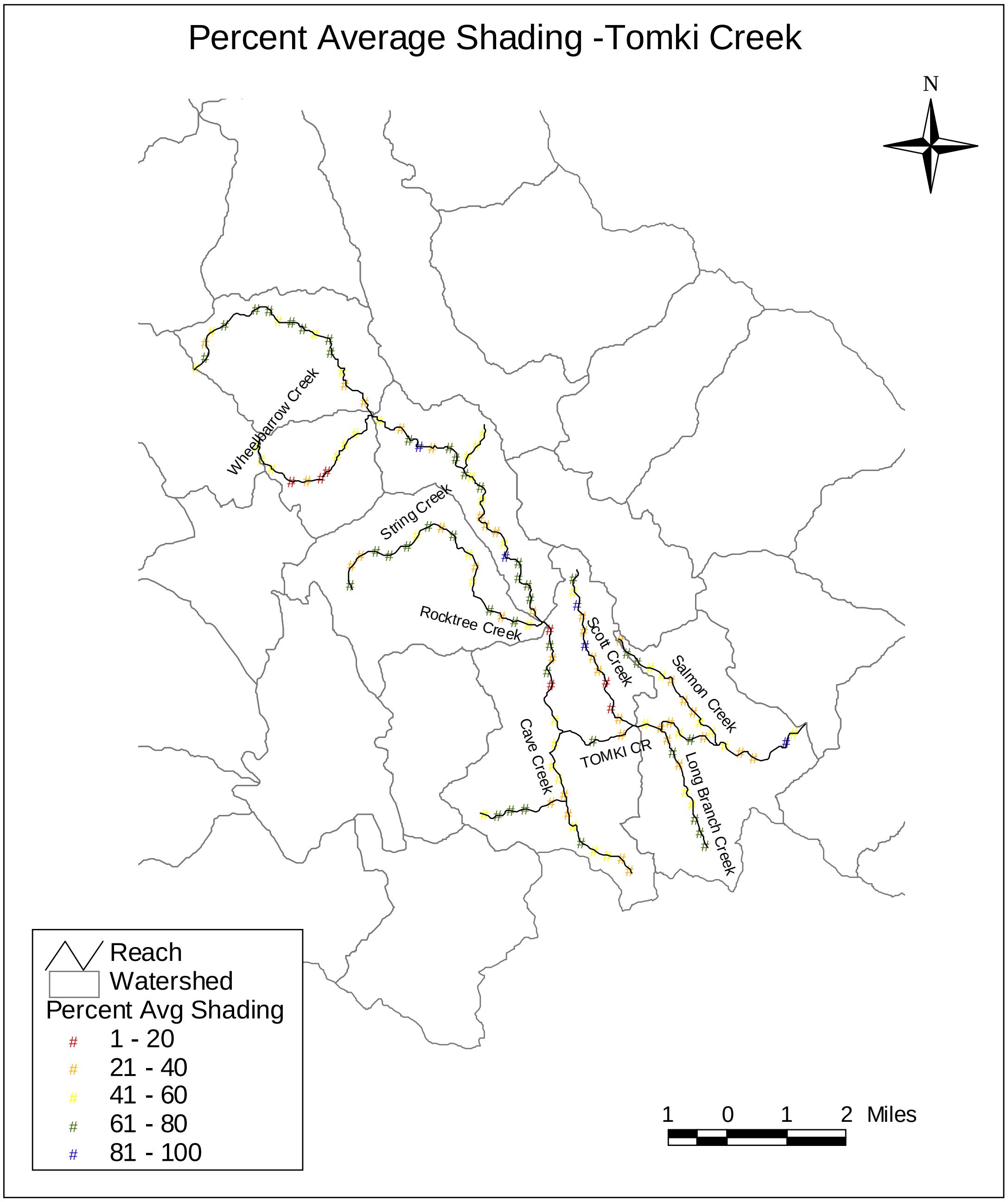

Figure A-11. Percent average shading for baseline conditions at Tomki Creek

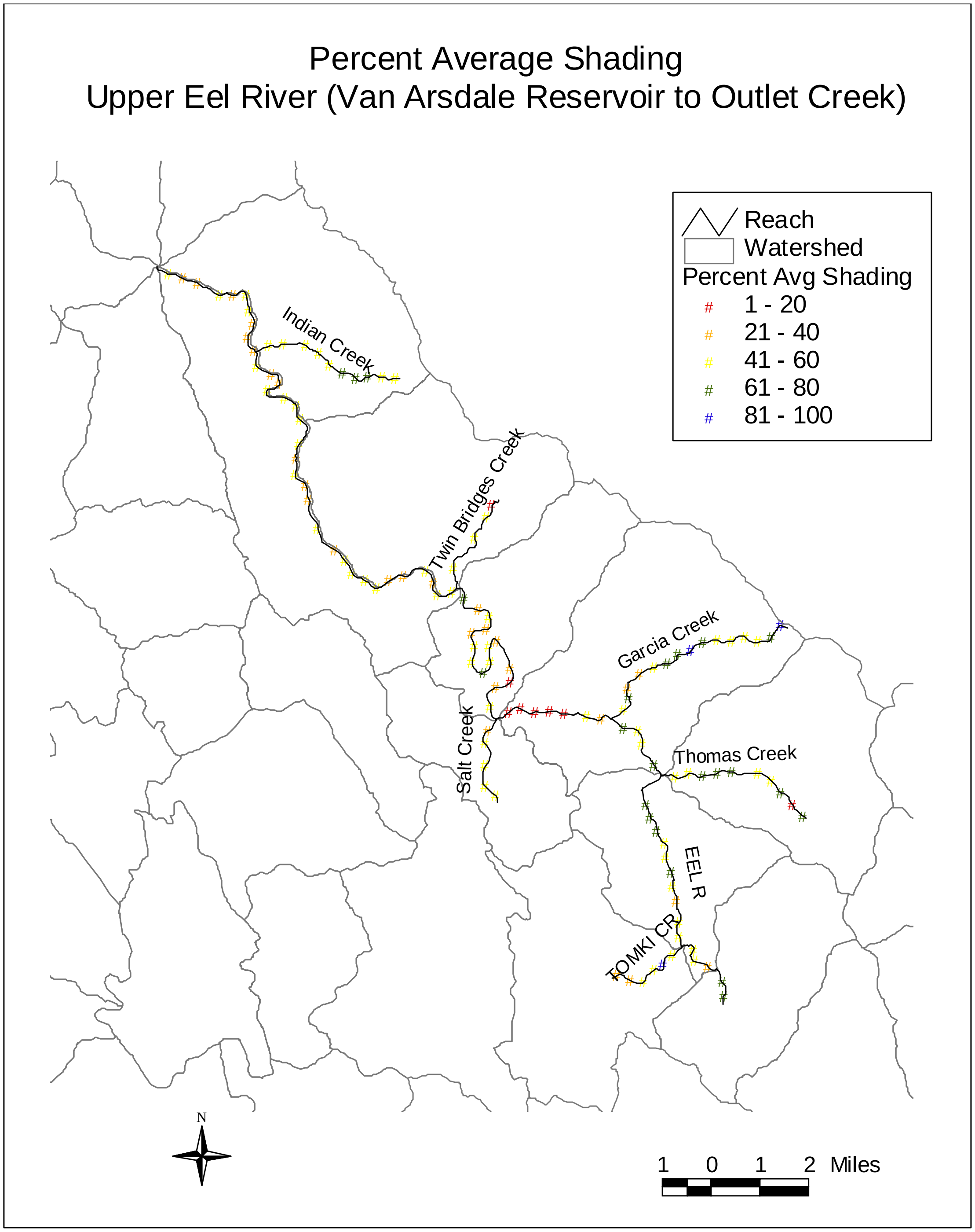

Figure A-12. Percent average shading for baseline conditions at the Main Stem Upper Eel River

To further support the calibration along the main stem, both graphical and statistical model-data time-series comparisons were made for five main stem monitoring stations for (1) hourly temperatures, (2) daily average temperatures, and (3) weekly average temperatures. The graphical comparisons are useful tools to visually determine the status of the model calibration, while the quantitative statistical summaries provide a different perspective on model-data comparison. These comparisons numerically quantify the state of model calibration/verification (sometimes referred to as model "skill assessment").

A.4.1 Statistical Methods Used to Assess Calibration Results on the Main Stem

Although numerous methods exist for analyzing and summarizing model performance, there is not a consensus in the modeling community on a standard analytical suite. A set of basic statistical methods were used to compare model predictions and sampling observations which included the mean error statistic, the absolute mean error, the root-mean-square error, and the relative error. These statistical methods are described below.

<u>Mean Error Statistic</u>
The mean error between model predictions and observations is defined in Equation 2. A mean error of zero is ideal. A non-zero value is an indication that the model may be biased toward either over- or under-prediction. A positive mean error indicates that on average the model predictions are less than the observations. A negative mean error indicates that on average the model predictions are greater than the observed data. The mean error statistic may give a false ideal value of zero (or near zero) if the average of the positive deviations between predictions and observations is about equal to the average of the negative deviations in a data set. Because of this possibility, it is never a good idea to rely solely on the mean error statistic as a measure performance. Instead, it should be used in conjunction with the other statistical measures that are described below.

$$E = \frac{\sum (O - P)}{n} \qquad (2)$$

where:

E = mean error
O = observation, aggregated by month and over water-column
P = model prediction, aggregated by month and over vertical layers
n = number of observed-predicted pairs

<u>Absolute Mean Error Statistic</u>
The absolute mean error (E_{abs}) between model predictions and observations is defined in Equation 3. An absolute mean error of zero is ideal. The magnitude of the absolute mean error indicates the average deviation between model predictions and observed data. Unlike the mean error, the absolute mean error cannot give a false zero.

$$Eabs = \frac{\sum\left|(O-P)\right|}{n} \qquad (3)$$

where:

E_{abs} = absolute mean error
O = observation, aggregated by month and over water-column
P = model prediction, aggregated by month and over vertical layers
n = number of observed-predicted pairs

Root-Mean-Square Error Statistic

The root-mean-square error (E_{rms}) is defined in Equation 4. A root-mean-square error of zero is ideal. The root-mean-square error is an indicator of the deviation between model predictions and observations. The E_{rms} statistic is an alternative to (and is usually larger than) the absolute mean error.

$$E_{rms} = \sqrt{\frac{\sum (O-P)^2}{n}} \qquad (4)$$

where:

E_{rms} = root-mean-square error
O = observation, aggregated by month and over water-column
P = model prediction, aggregated by month and over vertical layers
n = number of observed-predicted pairs

Relative Error Statistic

The relative error (E_{rel}) between model predictions and observations is defined in Equation 5. A relative error of zero is ideal. The relative error is the ratio of the absolute mean error to the mean of the observations and is expressed as a percent.

$$E_{rel} = \frac{\sum\left|O-P\right|}{\sum O} \qquad (5)$$

where:

E_{rel} = relative error
O = observation, aggregated by month and over water-column
P = model prediction, aggregated by month and over vertical layers

A.4.2 Detailed Calibration Results on the Main Stem

The observations and model predictions along the main stem were tabulated over the 30-day simulation period beginning July 15, 2003 (Julian Day 196) and ending August 14, 2003 (Julian Day 226). The five main-stem monitoring stations used in the analyses (listed in order from upstream to downstream location) were stations 8009, 8008, 626439, 8005, and 1452. The hourly temperature summary statistics for each main stem monitoring location are shown in Table A-10, while Figures A-13 through A-17 present the results graphically. The daily average temperature statistics are presented in Table A-11 and illustrated in Figures A-18 through A-22. The weekly average temperature statistics are shown in Table A-12, while Figures A-23 through A-27 present the results graphically. When reviewing model performance at all three temporal scales, the statistical and graphical results show that the model follows the observed data closely and is a good predictor of stream temperatures.

Table A-10. Hourly Temperature Summary Statistics.

Station	Q2Eshade Element	Mean Error (°C)	Absolute Mean Error (°C)	Root-Mean-Square Error (°C)	Relative Error (°C)	n
8009	5	0.022	1.271	1.635	5.36%	719
8008	13	-0.002	1.155	1.458	4.77%	719
626439	60	-0.045	1.126	1.430	4.34%	719
8005	61	0.028	1.262	1.559	4.83%	719
1452	143	0.092	1.285	1.670	4.91%	719

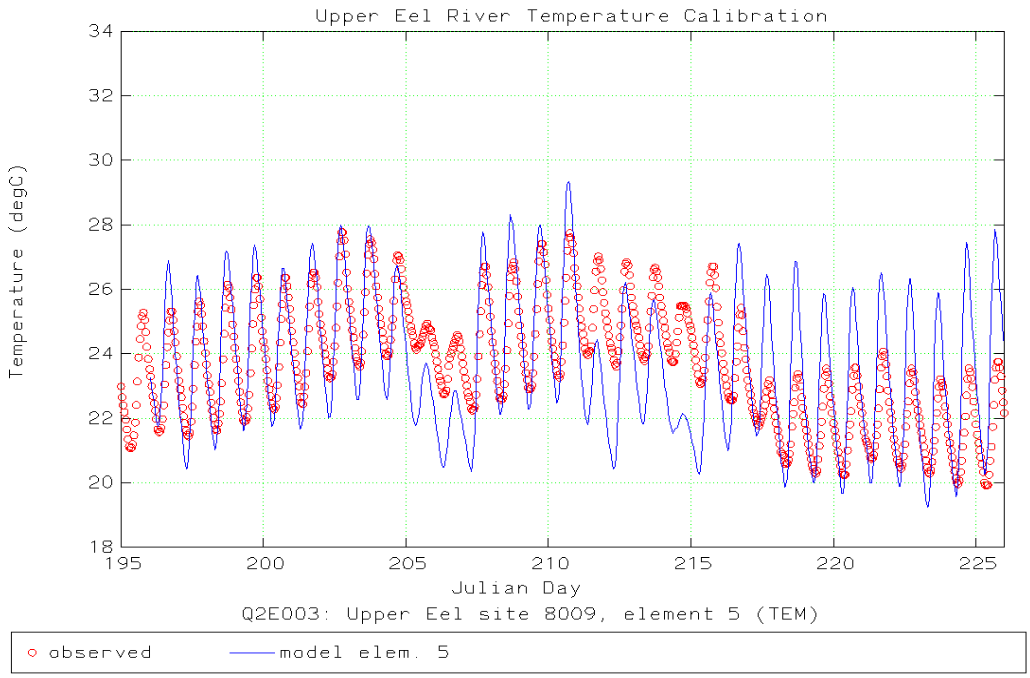

Figure A-13. Hourly temperature comparison at monitoring station 8009

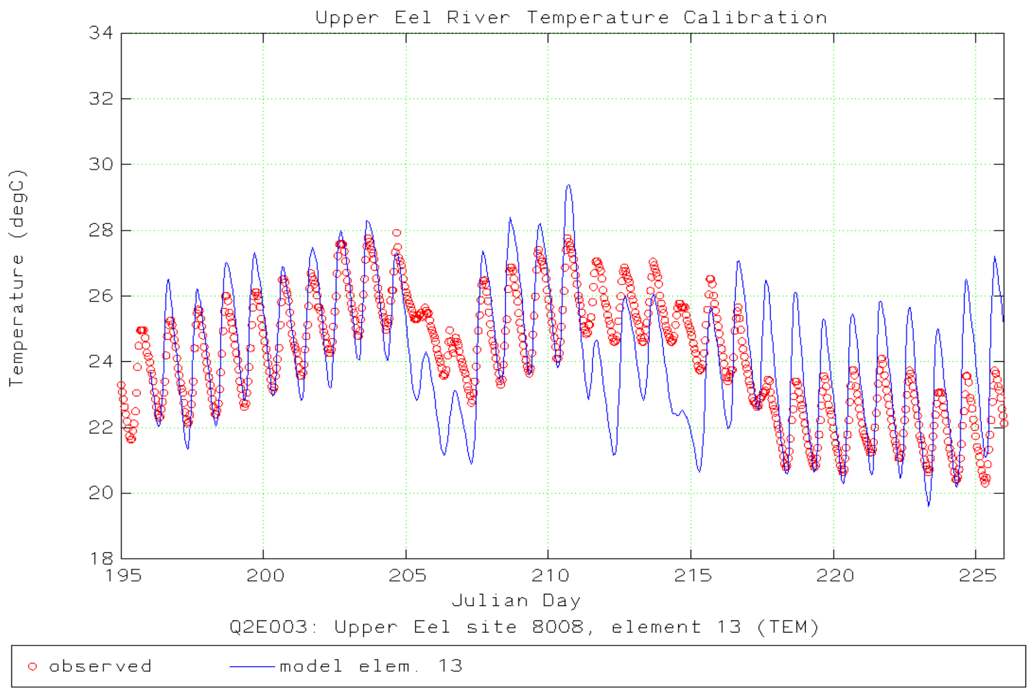

Figure A-14. Hourly temperature comparison at monitoring station 8008

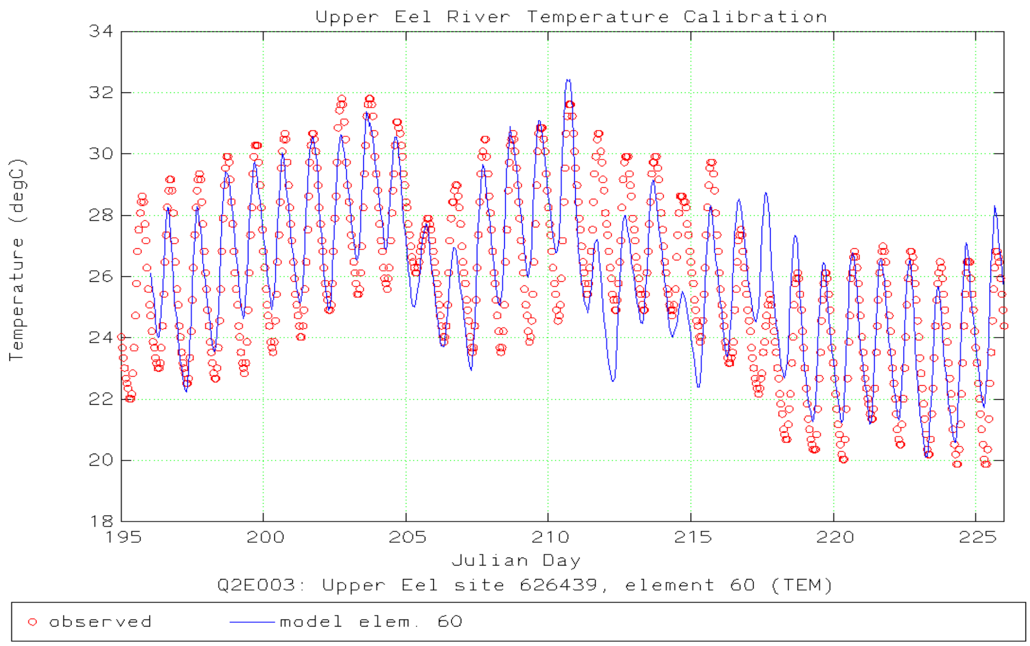

Figure A-15. Hourly temperature comparison at monitoring station 626439

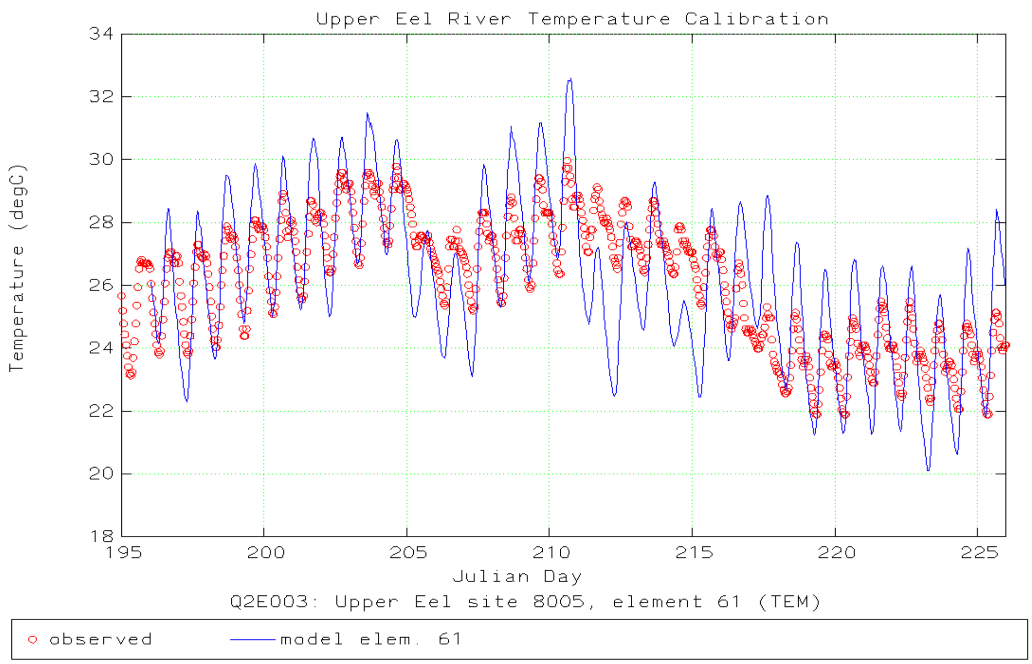

Figure A-16. Hourly temperature comparison at monitoring station 8005

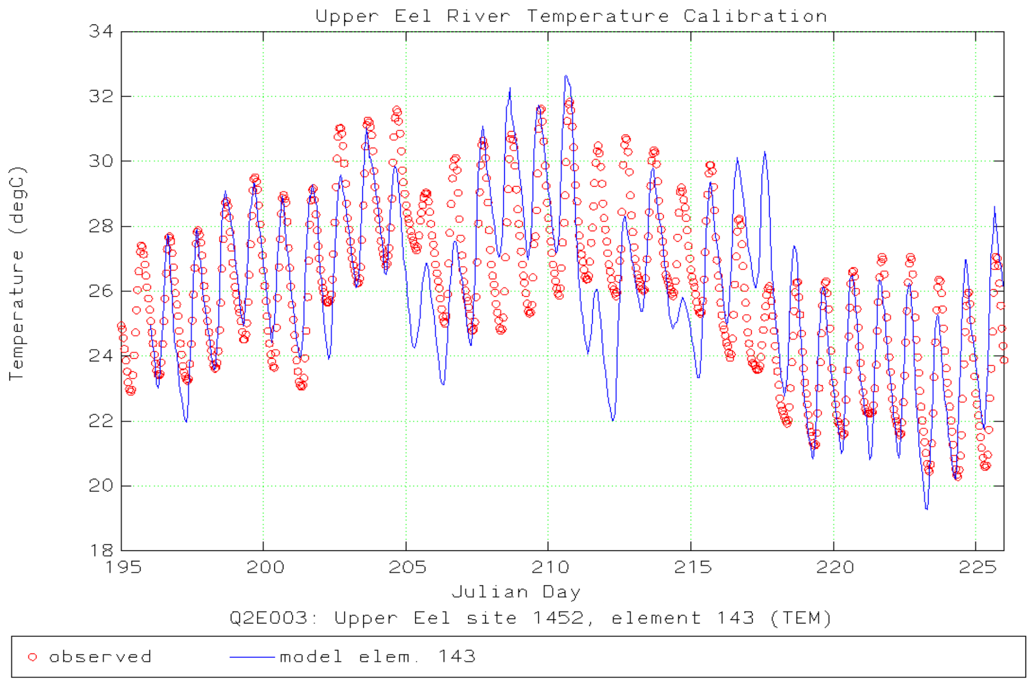

Figure A-17. Hourly temperature comparison at monitoring station 1452

Table A-11. Daily Average Temperature Summary Statistics

Station	Q2Eshade Element	Mean Error (°C)	Absolute Mean Error (°C)	Root-Mean-Square Error (°C)	Relative Error (°C)	n
8009	5	0.078	0.958	1.204	4.04%	696
8008	13	0.044	0.945	1.188	3.90%	696
626439	60	-0.008	0.853	1.083	3.28%	696
8005	61	0.072	0.870	1.101	3.32%	696
1452	143	0.121	1.084	1.406	4.14%	696

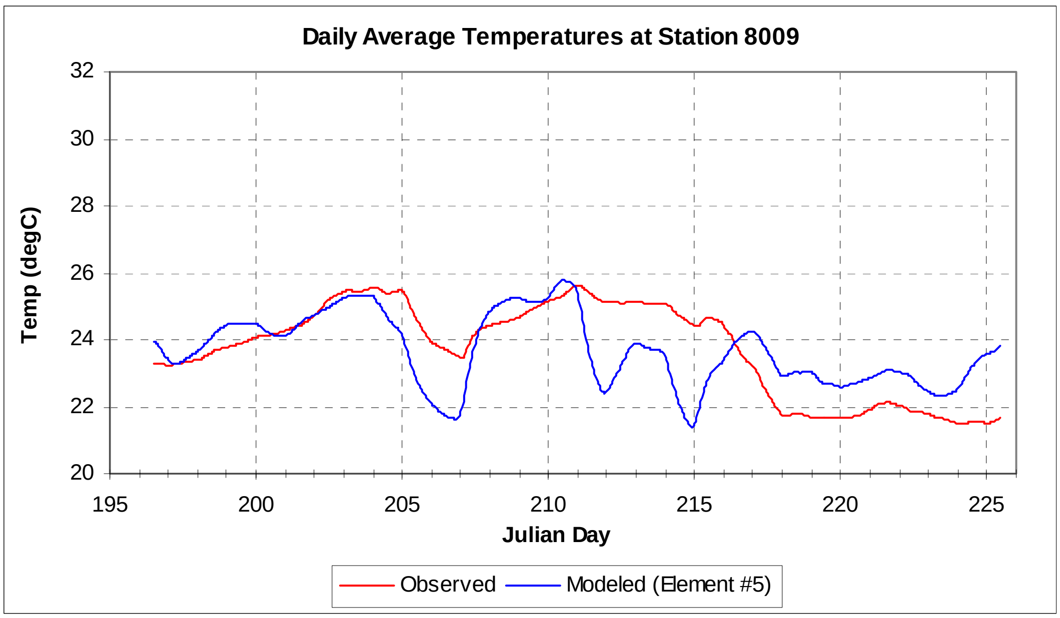

Figure A-18. Daily average temperature comparison at monitoring station 8009

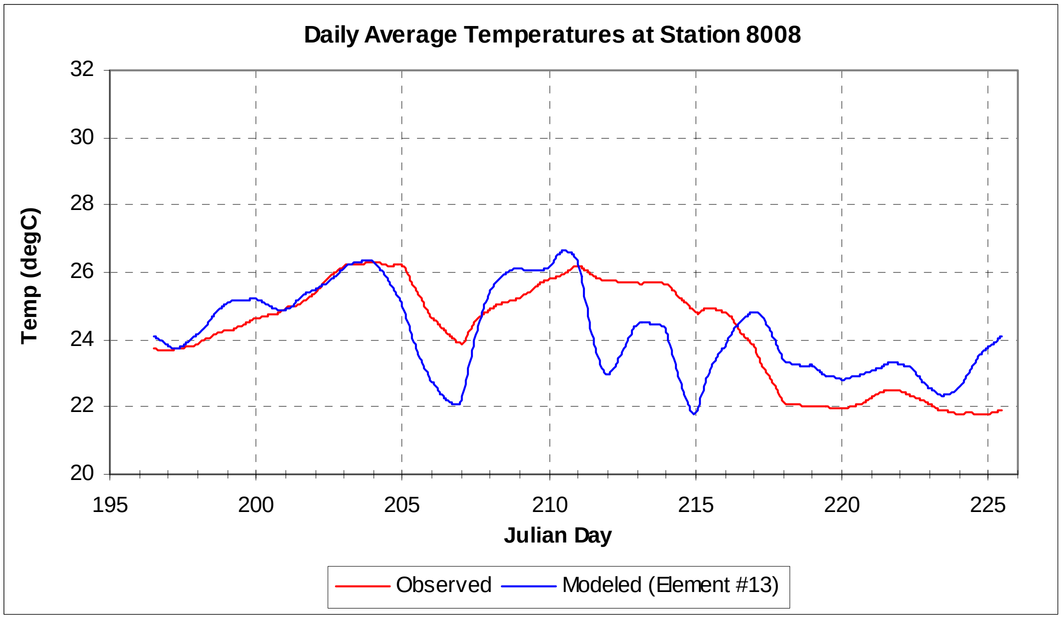

Figure A-19. Daily average temperature comparison at monitoring station 8008

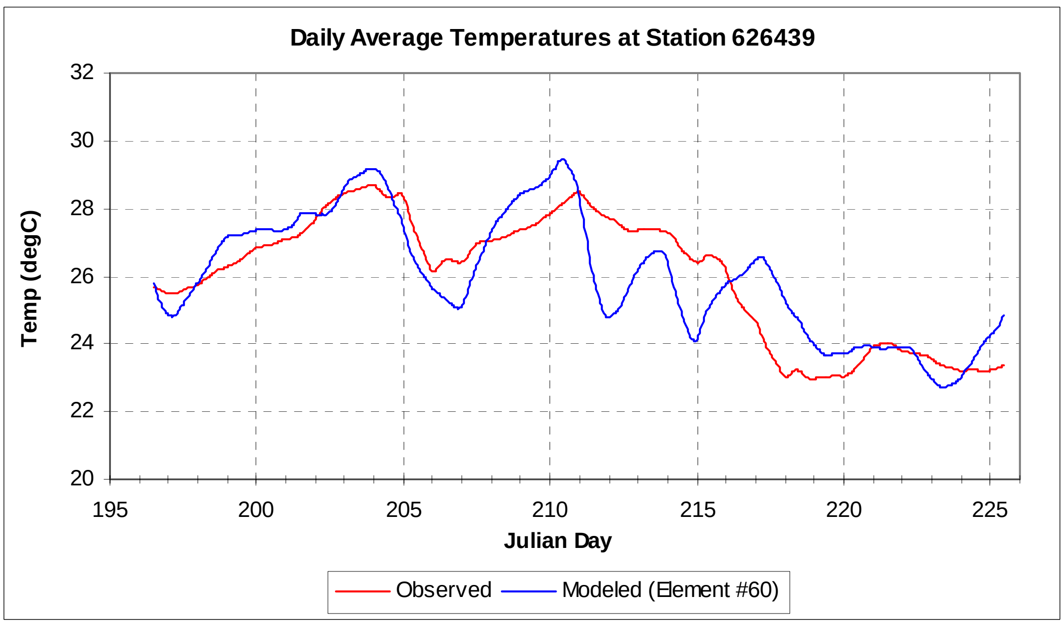

Figure A-20. Daily average temperature comparison at monitoring station 626439

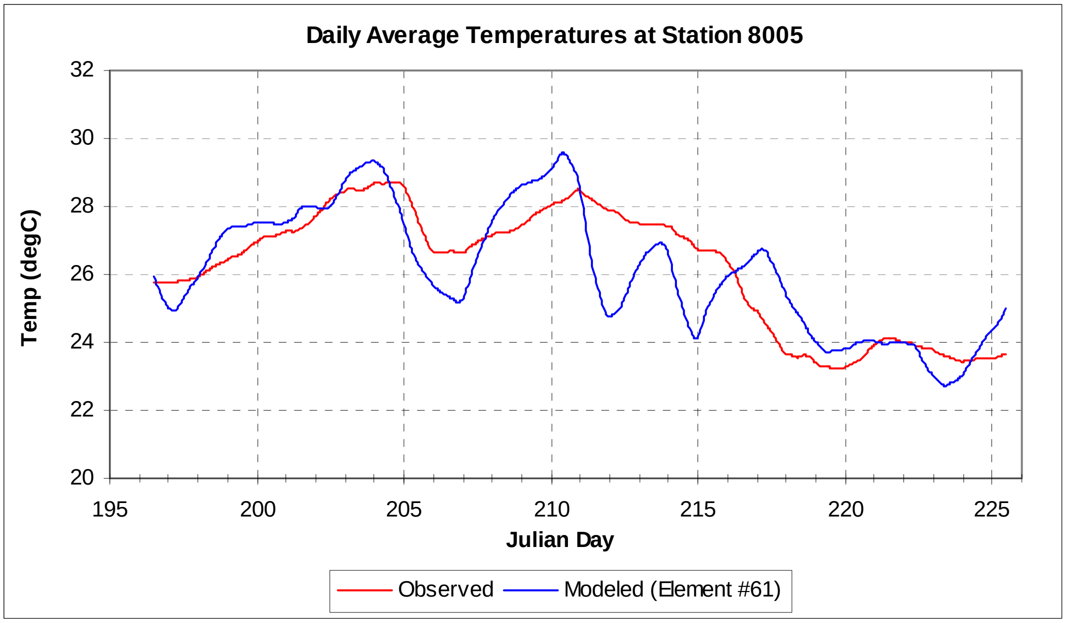

Figure A-21. Daily average temperature comparison at monitoring station 8005

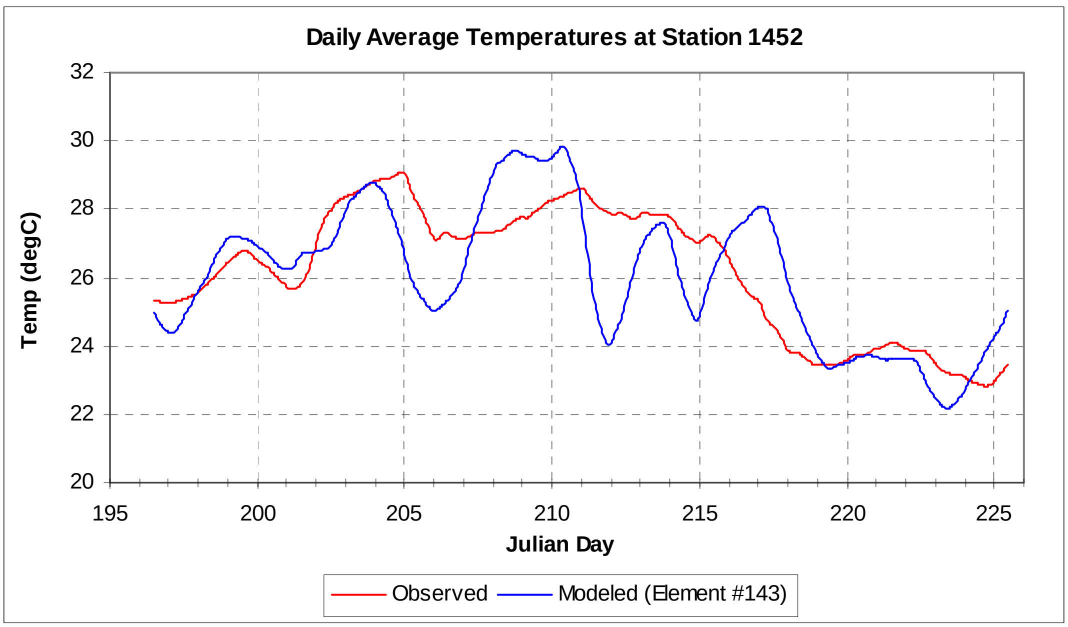

Figure A-22. Daily average temperature comparison at monitoring station 1452

Table A-12. Average Weekly Temperature Summary Statistics.

Station	Q2Eshade Element	Mean Error (°C)	Absolute Mean Error (°C)	Root-Mean-Square Error (°C)	Relative Error (°C)	n
8009	5	0.298	0.683	0.776	2.84%	552
8008	13	0.241	0.611	0.697	2.49%	552
626439	60	0.032	0.386	0.465	1.46%	552
8005	61	0.112	0.366	0.454	1.38%	552
1452	143	0.155	0.375	0.460	1.41%	552

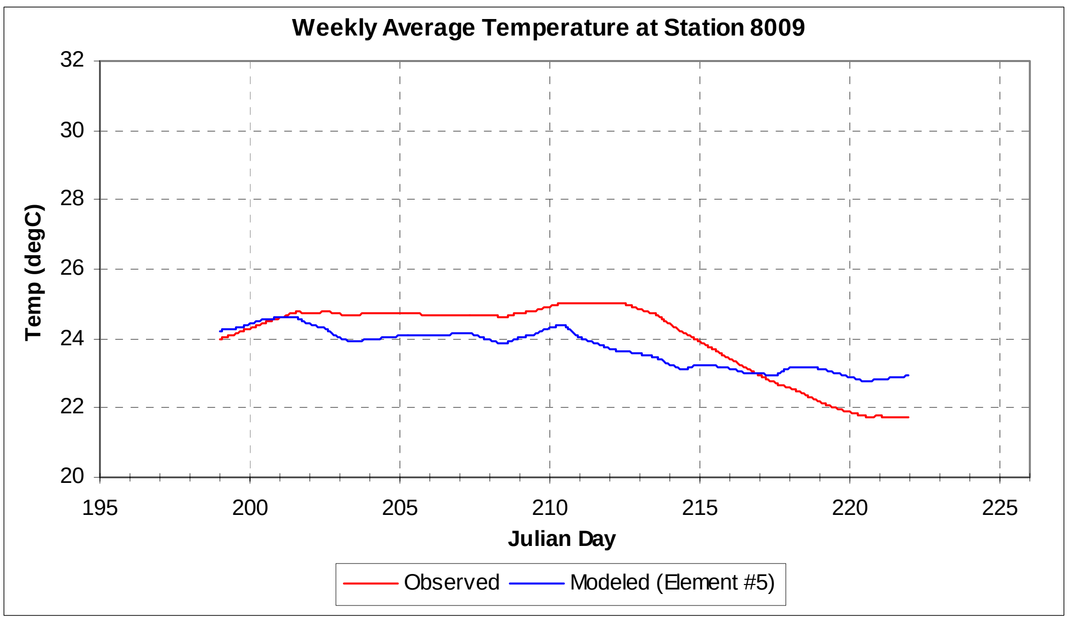

Figure A-23. Weekly average temperature comparison at monitoring station 8009

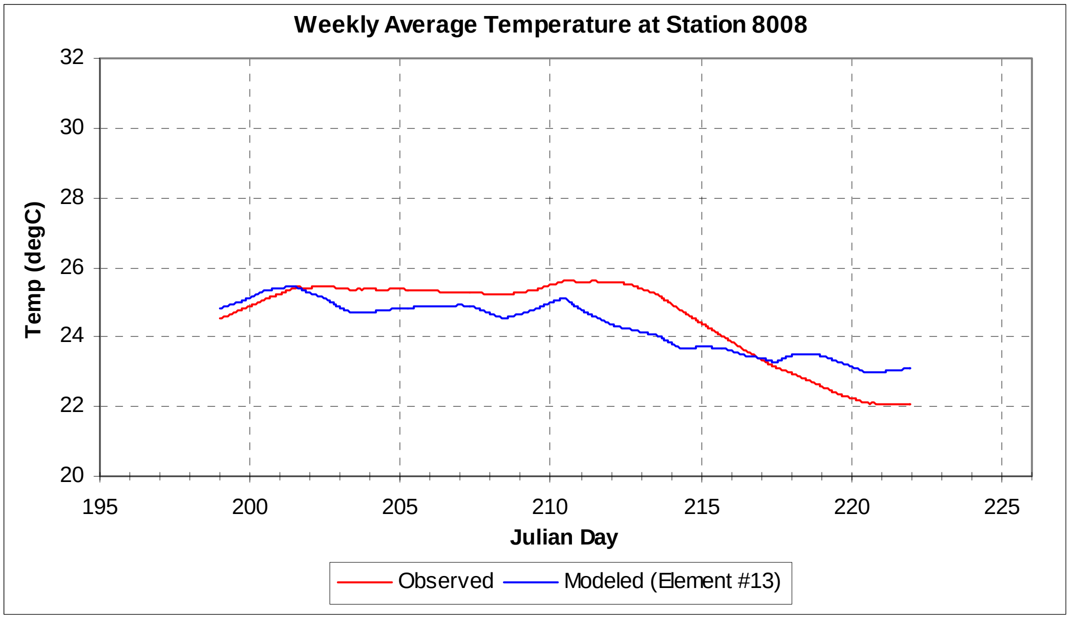

Figure A-24. Weekly average temperature comparison at monitoring station 8008

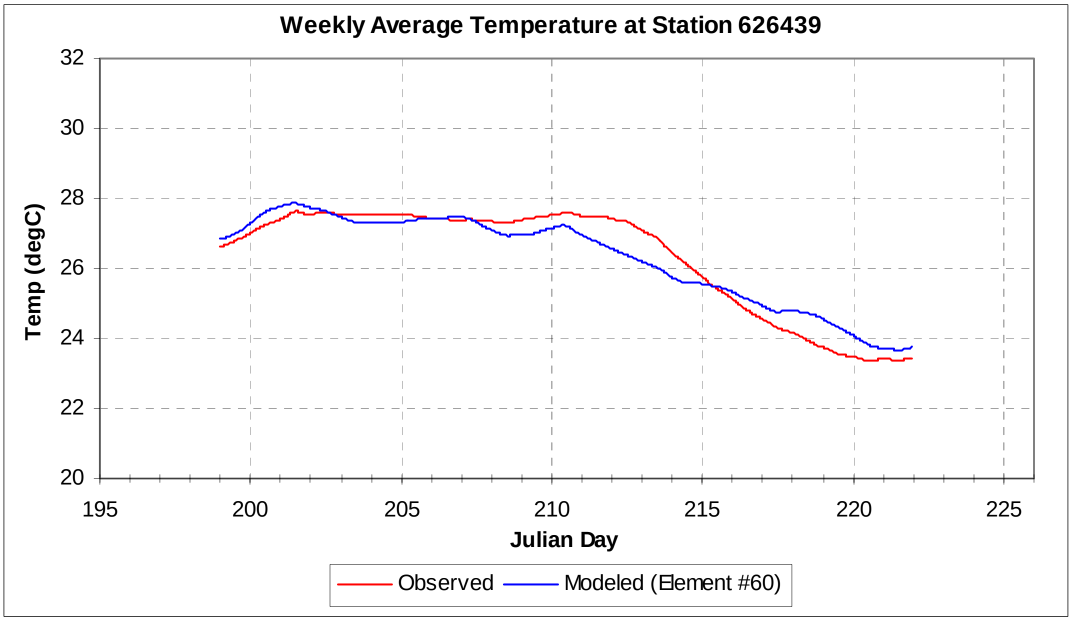

Figure A-25. Weekly average temperature comparison at monitoring station 626439

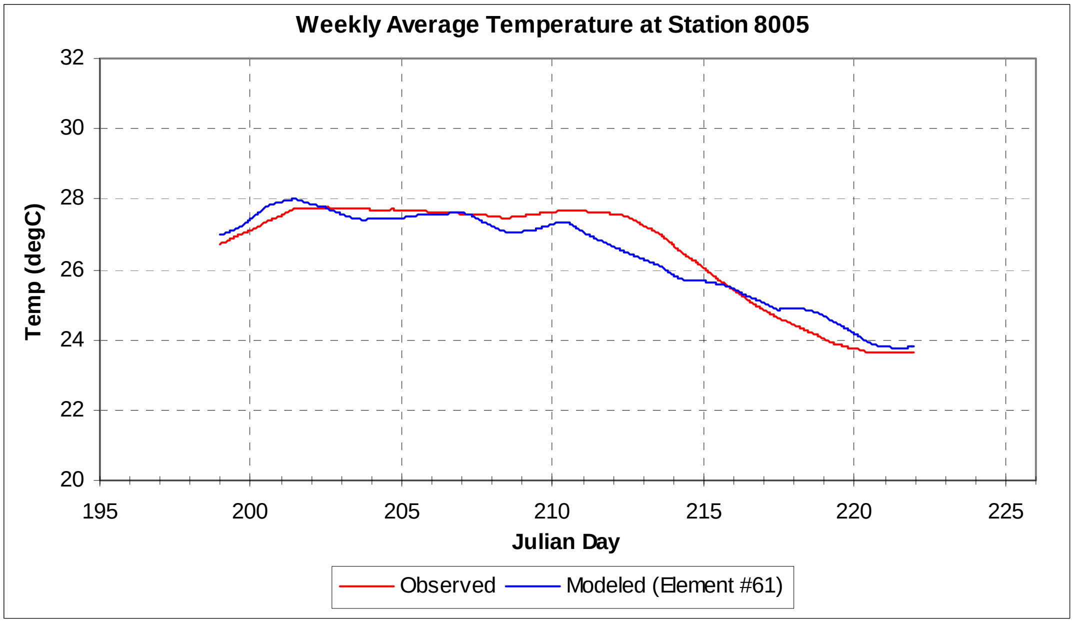

Figure A-26. Weekly average temperature comparison at monitoring station 8005

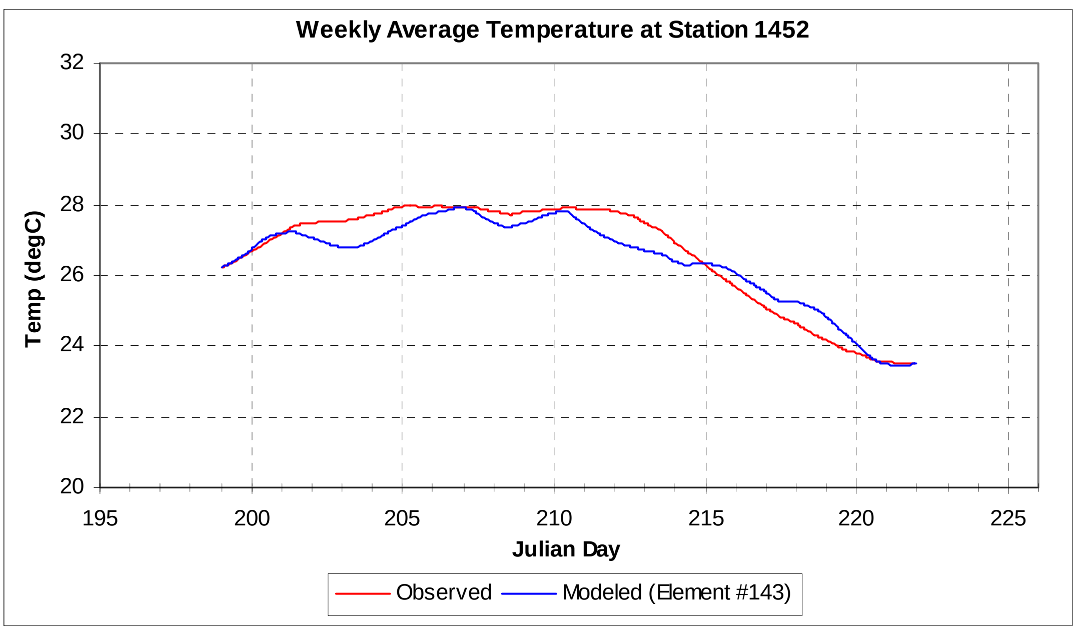

Figure A-27. Weekly average temperature comparison at monitoring station 1452

In addition to reviewing how the model responded at different temporal scales, the model was evaluated to determine its sensitivity to initial temperature conditions and how quickly it reached equilibrium. Three sensitivity runs were made to investigate the impact of initial temperatures on the model results. The model was run with initial temperatures of 17°C, 30°C, and the initial temperature values from calibrated model (which were based on observed data). The sensitivity results indicate the model reaches equilibrium within 1 day in the upstream portion of the watershed and within 4 days at the downstream portion. Model results at each monitoring station are presented graphically in Figures A-28 through A-32, beginning with the most upstream station.

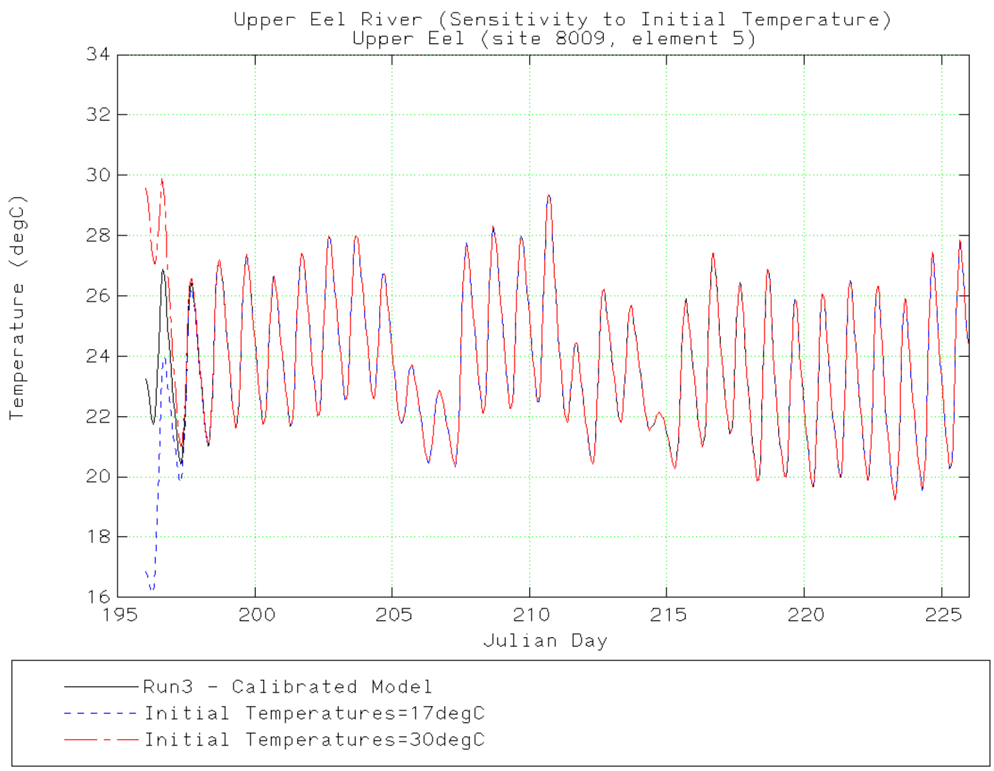

Figure A-28. Sensitivity to varying initial conditions at monitoring station 8009

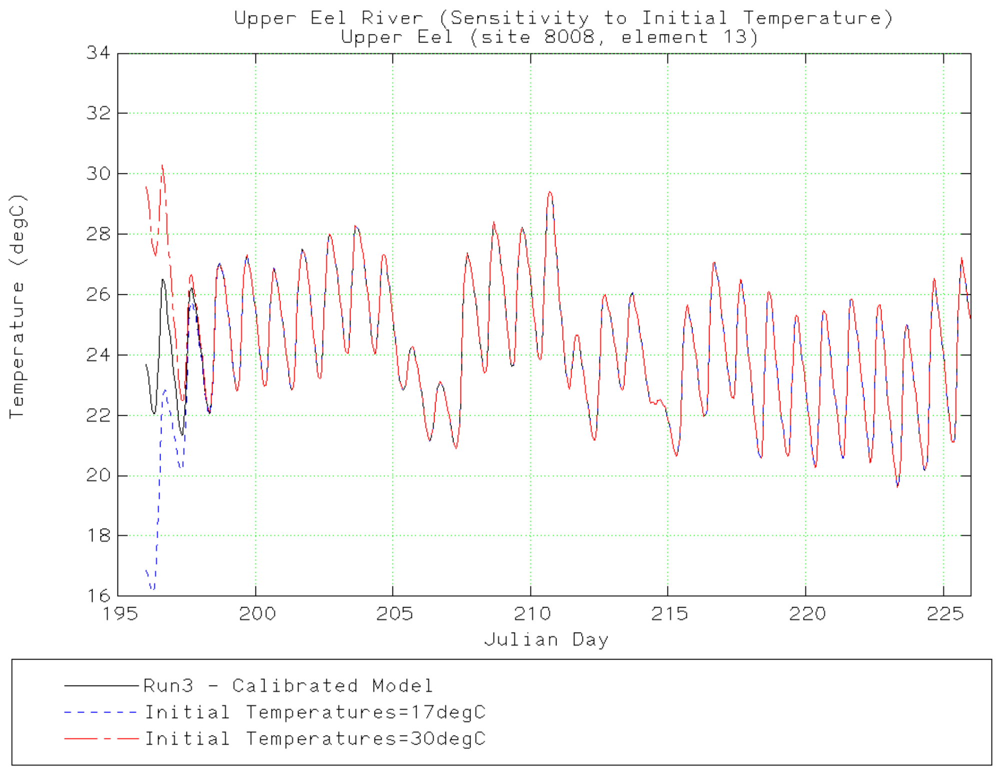

Figure A-29. Sensitivity to varying initial conditions at monitoring station 8008

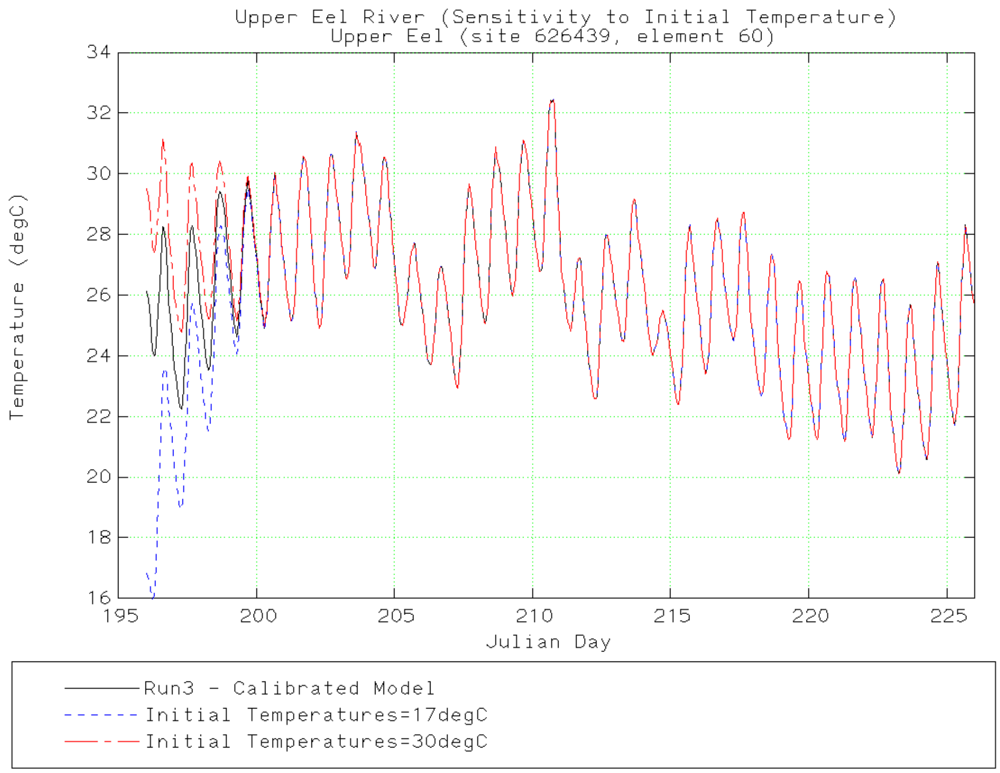

Figure A-30. Sensitivity to varying initial conditions at monitoring station 626439

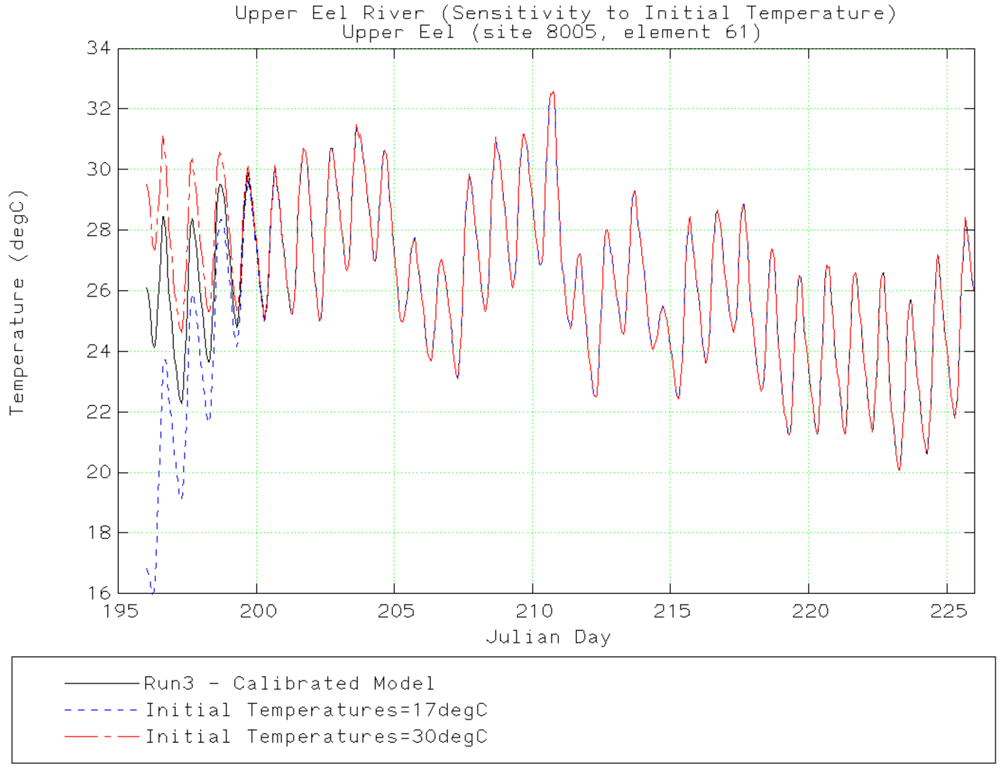

Figure A-31. Sensitivity to varying initial conditions at monitoring station 8005

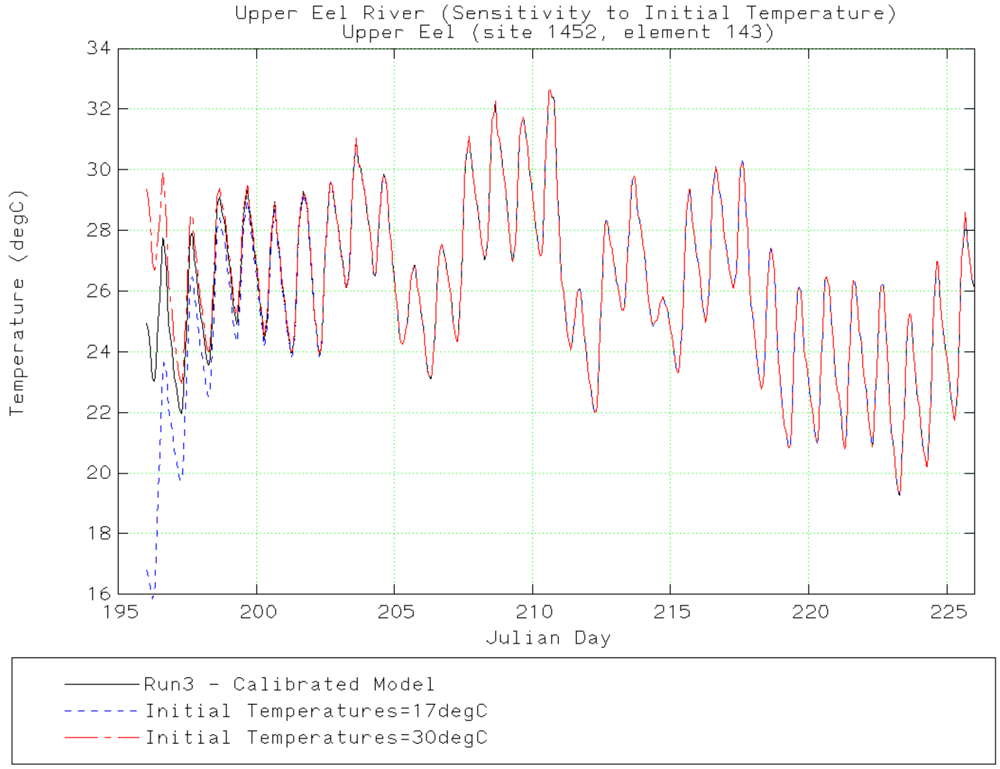

Figure A-32. Sensitivity to varying initial conditions at monitoring station 1452

One additional method was used to assess model performance in the main stem watershed. Specifically, results along each modeling transect were reviewed to determine if they fell within expected ranges. The seven modeled streams were:

1. Upper Eel River main stem
2. Tomki Creek
3. Thomas Creek
4. Garcia Creek (Bear Pen Creek)
5. Salt Creek
6. Twin Bridges Creek
7. Indian Creek

Figures A-33 through A-39 are transect plots of average, minimum, and maximum temperatures for each stream modeled in the main stem watershed averaged over the entire modeling period. Overall, the results indicate that the model predicts stream temperatures within the expected ranges for the area. The maximum temperature values in the downstream portion of Salt Creek were fairly high; however, temperatures in the main stem just downstream of Salt Creek (model kilometer 35) were not significantly impacted. Figure A-33 shows the 25th and 75th percentile values in addition to the average, maximum and minimum values along the mainstem. In general the model predicts the average values very well, with the maximum values being slightly overestimated and minimum slightly underestimated at the downstream end.

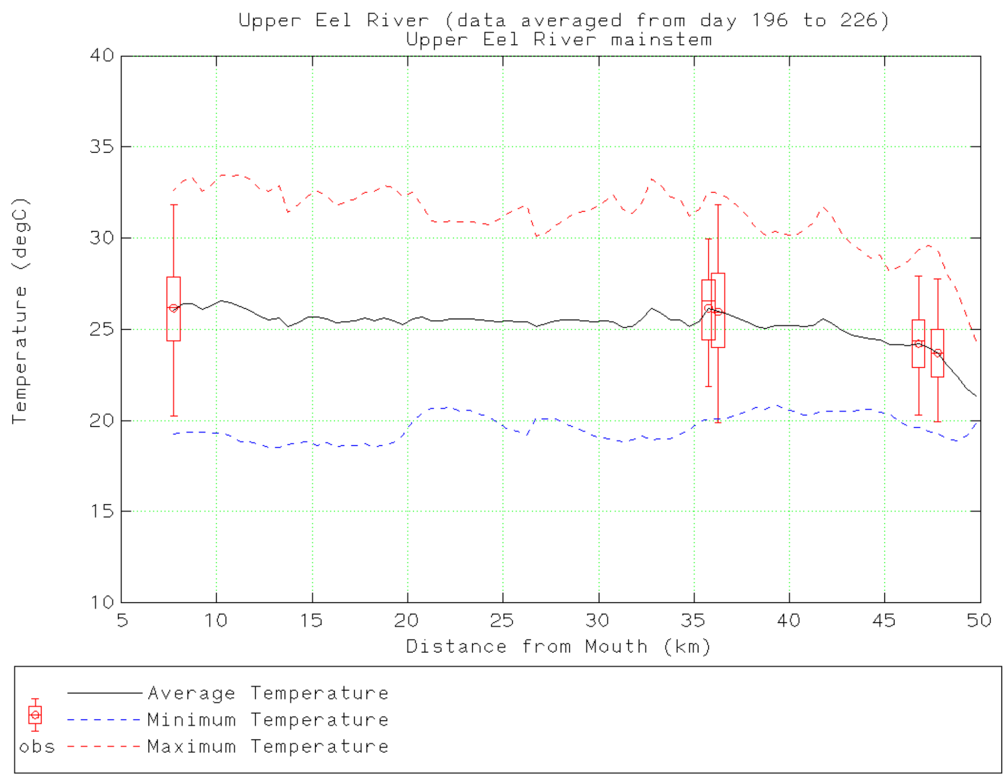

Figure A-33. Average, minimum, and maximum temperatures for the main stem of the Upper Eel River

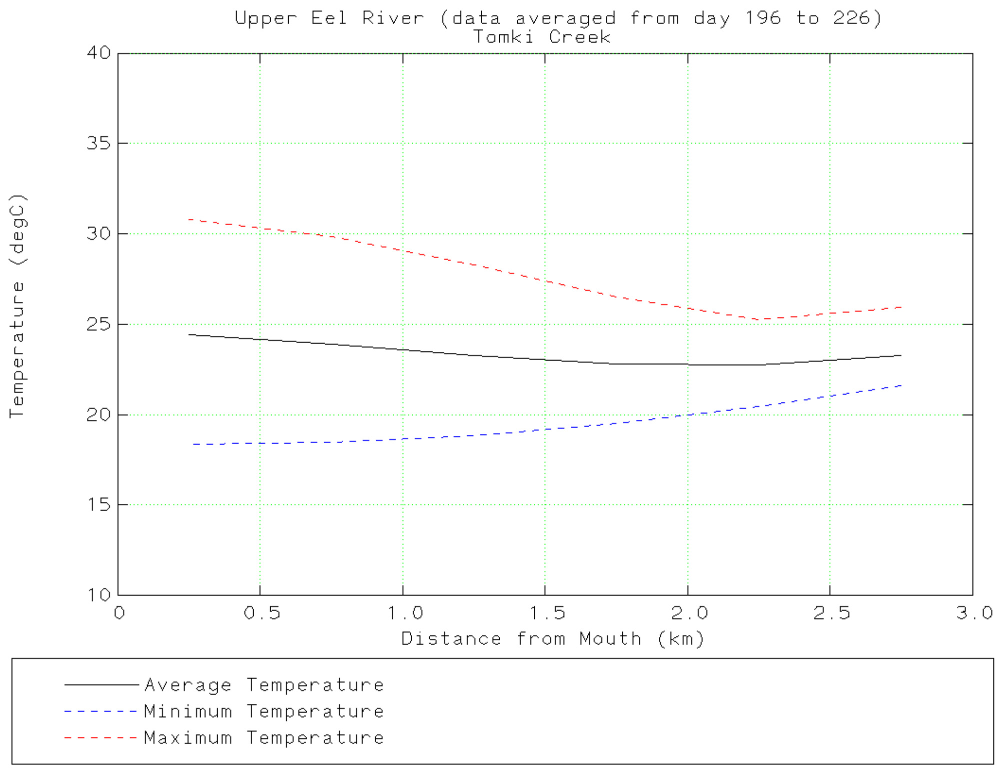

Figure A-34. Average, minimum, and maximum temperatures for a portion of Tomki Creek

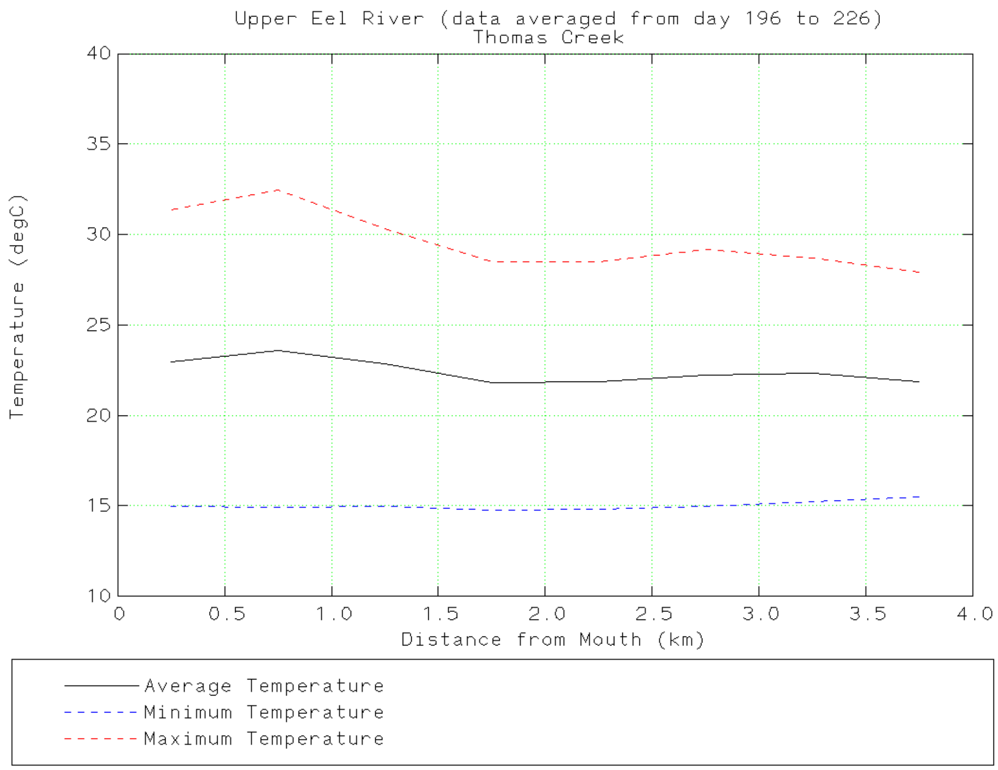

Figure A-35. Average, minimum, and maximum temperatures for Thomas Creek

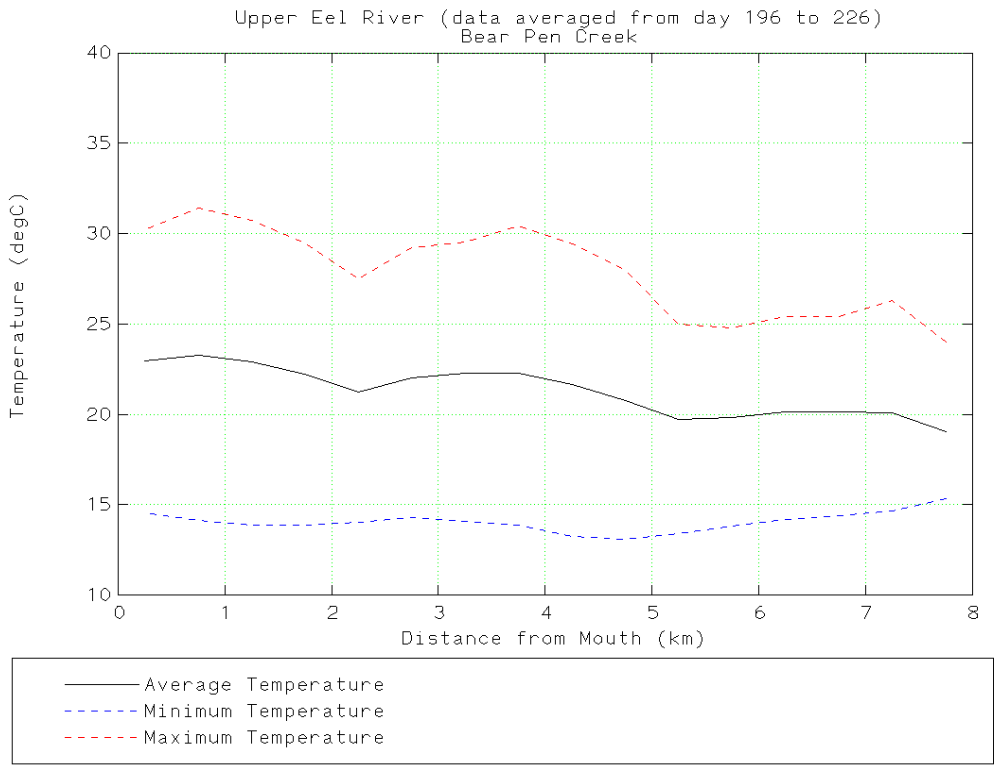

Figure A-36. Average, minimum, and maximum temperatures for Garcia Creek (Bear Pen Creek)

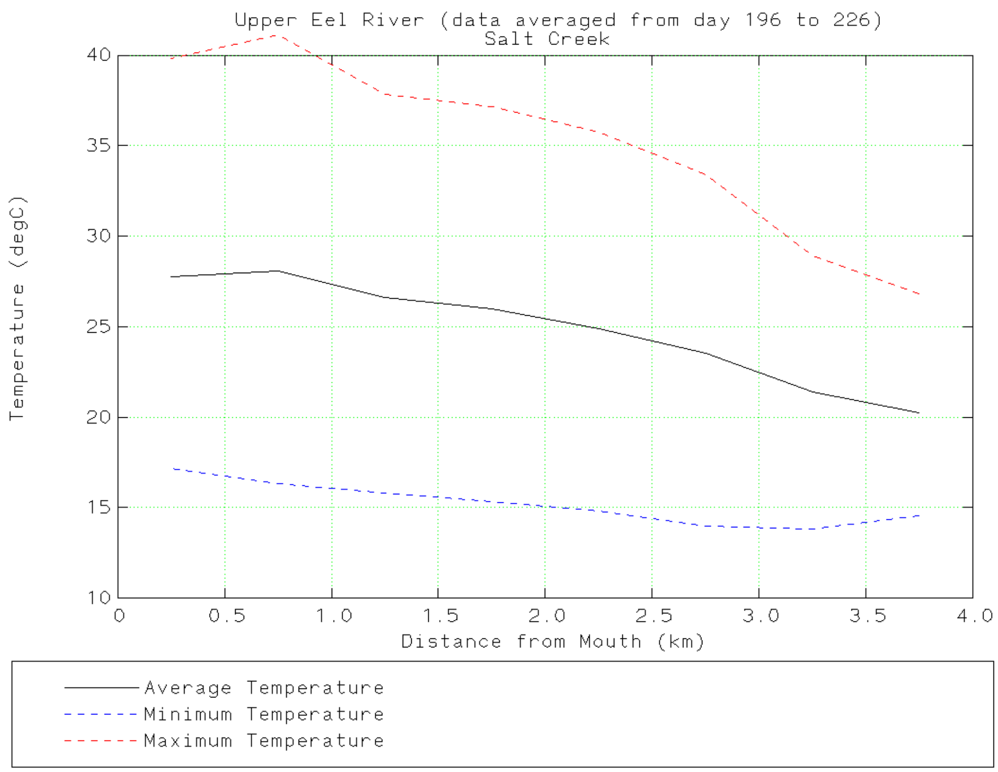

Figure A-37. Average, minimum, and maximum temperatures for Salt Creek

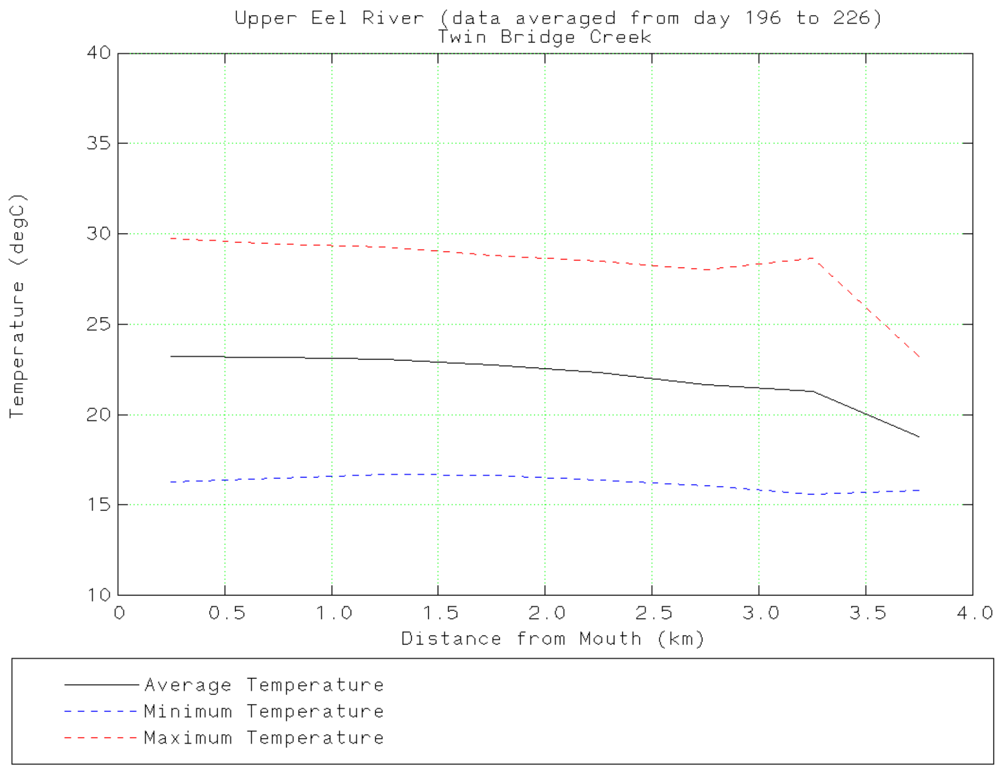

Figure A-38. Average, minimum, and maximum temperatures for Twin Bridges Creek

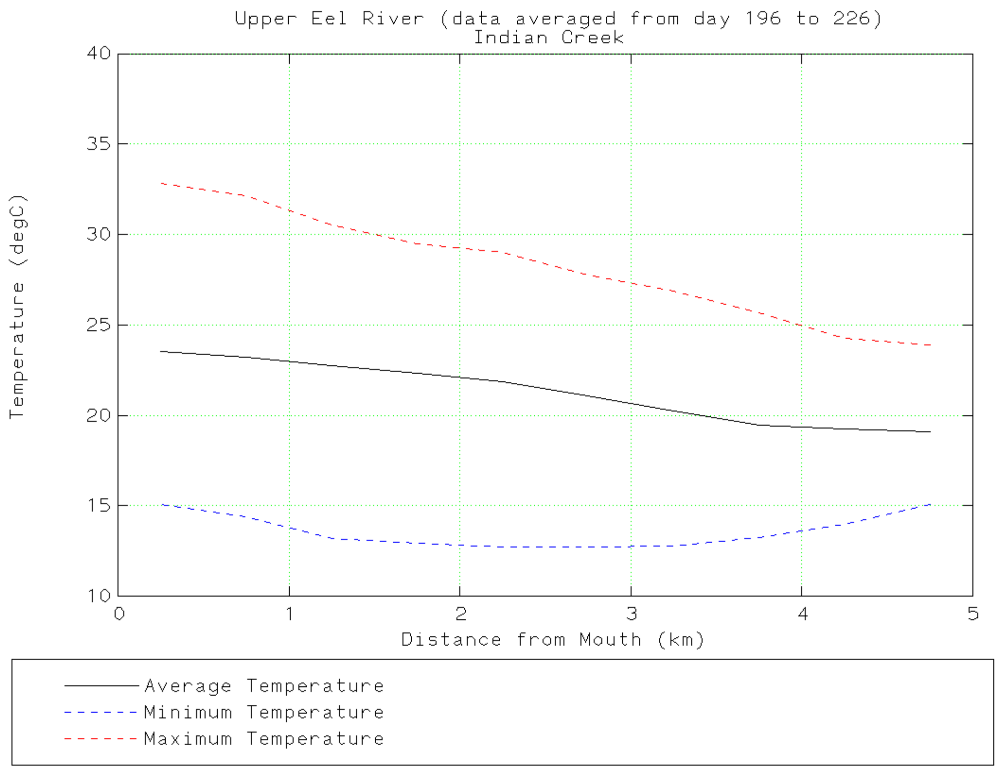

Figure A-39. Average, minimum, and maximum temperatures for Indian Creek

A.5 Scenarios

Both SHADE and Q2ESHADE can be used to simulate scenarios to determine the resulting change to in-stream temperature. SHADE parameters are modified to simulate vegetation-specific scenarios, while Q2ESHADE is used directly to model flow-related scenarios. The vegetation and flow scenarios simulated are described below and their results are presented in the TMDL document.

A.5.1 Vegetation Scenarios

The SHADE-GIS model allows the user to simulate scenarios based on the regression equation (Equation 1), a constant height, or a percentage change in the tree height based on a particular reference vegetation height layer. Scenarios varying the DBH or tree height conditions were simulated for TMDL development. It was assumed that the tree density remained the same as the baseline conditions for all scenarios. The five vegetation scenarios are described below.

1. Topographic Shading Only – This scenario involved simulating the shading effects due to topography only (i.e. no vegetation). All trees were assigned a zero height.

2. Private Land Management with 18 inch (45.7 cm) DBH – A maximum DBH of 18 inches was assigned to conifers for this simulation. The corresponding tree height for a 18" DBH was computed using Equation 1 and the coefficients presented in Table A-4 for conifers. This resulted in a maximum tree height of 24.2 meters (79.4 feet) for conifers. Hardwoods were assigned a maximum height of 21 meters (68.9 feet), which was the maximum height based on equation 1 and the hardwood coefficients presented in Table A-4. Hence, for this scenario, all conifers were assigned a height of 24.2 meters and all hardwoods were assigned a height of 21 meters, regardless of seral stage in the watershed.

3. Private Land Management with 24 inch (61 cm) DBH – A maximum DBH of 24 inches was assigned to conifers for this simulation. The corresponding tree height for a 24" DBH was computed using Equation 1 and the coefficients presented in Table A-4 for conifers. This resulted in a maximum tree height of 29.6 meters (97.1 feet) for conifers. Hardwoods were assigned a maximum height of 21 meters (68.9 feet), which was the maximum height based on equation 1 and the hardwood coefficients presented in Table A-4. Hence, for this scenario, all conifers were assigned a height of 29.6 meters and all hardwoods were assigned a height of 21 meters, regardless of seral stage in the watershed.

4. Natural Vegetation (48 inch [101.6 cm] DBH) – A maximum DBH of 48 inches was assigned to conifers for this simulation. The corresponding tree height for a 48" DBH was computed using Equation 1 and the coefficients presented in Table A-4 for conifers. This resulted in a maximum tree height of 43.8 meters (143.8 feet) for conifers. Hardwoods were assigned a maximum height of 21 meters (68.9 feet), which was the maximum height based on equation 1 and the hardwood coefficients presented in Table A-4. Hence,

for this scenario, all conifers were assigned a height of 43.8 meters and all hardwoods were assigned a height of 21 meters, regardless of seral stage in the watershed.

5. Historical Riparian Vegetation (30 foot [9.15 meters] riparian vegetation) – All shrub and herbaceous vegetation were assigned a constant height of 30 feet (9.15 meters) throughout the Tomki Watershed only. In addition, a maximum DBH of 48 inches was assigned to conifers and the corresponding tree height for a 48” DBH was computed using Equation 1 and the coefficients presented in Table A-4. This resulted in a maximum tree height of 43.8 meters (143.8 feet) for conifers. Hardwoods were assigned a maximum height of 21 meters (68.9 feet), which was the maximum height based on equation 1 and the hardwood coefficients presented in Table A-4. Hence, for this scenario, all conifers were assigned a height of 43.8 meters, all hardwoods were assigned a height of 21 meters, and all shrub and herbaceous vegetation were assigned a height of 9.15 meters, regardless of seral stage in the watershed.

Tables A-13 and A-14 present model results for the vegetation scenarios at Tomki Creek, as compared to the baseline conditions. Table A-13 includes the stream miles associated with different MWAT categories, the solar radiation, and average percent shading, while Table A-14 identifies the specific MWAT value associated with each SSP along Tomki Creek (see Figure A-40 for an illustration of the SSPs along Tomki Creek). Figure A-41 graphically compares the baseline conditions with the vegetation scenarios presented in Table A-14. Figures A-42 through A-46 illustrate the average percent shading at each SSP for the Tomki Creek watershed.

Table A-13. Model Results for Vegetation Scenarios at Tomki Creek

Temperature Category	Baseline (1975-2003 Operations)		Topographic Shading	18 Inch DBH	24 Inch DBH	48 Inch DBH		Historical Riparian Veg.
	Stream Miles	% of Total	Stream Miles	Stream Miles	Stream Miles	Stream Miles	% of Total	Stream Miles
Good (MWAT < 15° C)	0.0	0%	0.0	0.0	0.0	0.0	0%	0.0
Fair (15° C < MWAT < 17° C)	0.9	2%	0.3	0.6	0.9	0.9	2%	0.9
Marginal (17° C < MWAT < 19° C)	3.7	8%	1.6	3.1	3.1	3.7	7%	3.7
Stressful (19.1° C < MWAT < 20° C)	2.8	6%	2.5	3.1	2.8	2.8	6%	2.8
Stressful (20.1° C < MWAT < 21° C)	2.8	6%	0.6	2.2	2.5	3.1	6%	3.1
Stressful (21.1° C < MWAT < 22° C)	2.5	5%	1.6	2.5	2.5	2.8	6%	2.8
Stressful (22.1° C < MWAT < 23° C)	2.2	4%	2.5	3.4	3.1	1.9	4%	1.9
Stressful (23.1° C < MWAT < 24° C)	4.0	8%	0.9	3.1	3.1	4.7	10%	5.0
Lethal (MWAT > 24° C)	30.4	62%	39.5	31.4	31.4	29.5	60%	29.2
TOTAL	49.3	100%	49.5	49.4	49.4	49.4	100%	49.4
Solar Radiation (Langley/day)	295.0		458.4	316.4	316.6	290.2		288.8
% Shade	49.2%		21.6%	45.6%	45.6%	50.1%		50.3%

Table A-14. MWAT Values for Vegetation Scenarios at Each SSP Along Tomki Creek

SSP Identification Number	1975-2003 Operations	Topographic Shading	18 inch DBH	24 inch DBH	48 inch DBH	Historical Riparian Vegetation
1	16.66	16.85	16.67	16.67	16.67	16.67
2	16.89	17.54	16.90	16.89	16.90	16.9
3	17.43	18.27	17.43	17.43	17.44	17.44
4	17.77	18.91	17.80	17.81	17.75	17.75
5	18.10	19.58	18.36	18.27	18.07	18.07
6	18.48	20.28	18.78	18.69	18.43	18.43
7	18.73	20.91	19.02	18.94	18.68	18.68
8	18.94	21.48	19.23	19.15	18.89	18.89
9	19.31	22.05	19.62	19.54	19.26	19.26
10	19.63	22.65	19.94	19.86	19.57	19.57
11	19.86	23.17	20.18	20.10	19.80	19.8
12	20.22	23.74	20.53	20.44	20.16	20.16
13	20.44	24.29	20.85	20.78	20.37	20.36
14	20.60	24.68	21.02	20.94	20.52	20.52
15	20.95	25.15	21.35	21.28	20.86	20.86
16	21.73	26.08	22.11	22.06	21.63	21.62
17	21.97	26.52	22.35	22.29	21.85	21.84
18	22.45	26.85	22.84	22.77	22.33	22.24
31 (Wheelbarrow Creek)	24.85	29.52	25.31	25.28	24.68	24.67
32	25.18	29.72	25.63	25.60	25.00	24.93
33	25.37	29.80	25.80	25.77	25.19	25.11
34	25.47	29.96	25.89	25.86	25.27	25.19
35	25.66	30.17	26.15	26.04	25.47	25.39
36	25.56	30.31	26.03	25.93	25.35	25.28
37	25.54	30.45	25.99	25.89	25.34	25.27
38	25.53	30.55	25.95	25.85	25.32	25.25
42	24.49	28.37	24.80	24.79	24.36	24.31
43	24.59	28.63	24.89	24.88	24.46	24.41
44	24.59	28.78	24.89	24.88	24.47	24.42
45	24.73	28.95	25.03	25.03	24.62	24.58
46	24.96	29.16	25.27	25.26	24.86	24.81
47	25.00	29.31	25.29	25.28	24.90	24.85
48	25.03	29.45	25.40	25.38	24.98	24.94
49	25.05	29.61	25.48	25.47	25.07	25.03
51	24.99	29.92	25.59	25.59	25.07	25.03
52	25.12	30.06	25.59	25.59	25.21	25.17
53	25.37	30.23	25.72	25.73	25.45	25.41
54	25.57	30.38	25.98	25.97	25.65	25.61
55	25.79	30.49	26.19	26.18	25.86	25.82
74 (Rocktree Creek)	26.19	31.46	26.40	26.39	26.11	26.2
75	26.20	31.54	26.92	26.93	26.11	26.2
76	26.33	31.65	26.92	26.93	26.24	26.33
77	26.28	31.69	27.05	27.05	26.19	26.28
78	26.48	31.80	26.99	26.99	26.39	26.47
79	26.54	31.87	27.17	27.17	26.45	26.53
80	26.51	31.86	27.22	27.22	26.42	26.5
98 (Cave Creek)	27.27	32.81	27.18	27.18	27.04	27.08
99	27.43	32.91	27.88	27.91	27.20	27.24
100	27.43	32.93	28.03	28.05	27.19	27.23
101	27.36	32.87	28.05	28.06	27.12	27.16
114 (Scott Creek)	26.38	31.15	27.98	27.99	26.64	26.52
124	23.24	25.28	27.53	27.52	23.09	23.07
125 (Long Branch Creek)	23.29	25.62	23.63	23.63	23.13	23.11
126	23.47	25.94	23.79	23.79	23.30	23.28
127	23.71	26.23	24.02	24.02	23.54	23.52
128	24.07	26.55	24.37	24.37	23.89	23.87

SSP Identification Number	1975-2003 Operations	Topographic Shading	18 inch DBH	24 inch DBH	48 inch DBH	Historical Riparian Vegetation
139 (Salmon Creek)	24.08	26.78	24.15	24.17	23.82	23.67
140	24.44	27.40	24.57	24.58	24.18	24.04
141	24.39	27.61	24.56	24.57	24.14	24
142	24.50	27.88	24.71	24.72	24.25	24.12
143	24.74	28.14	25.02	25.02	24.49	24.3
144	25.03	28.41	25.37	25.37	24.79	24.6
145	24.93	28.28	25.33	25.32	24.70	24.51

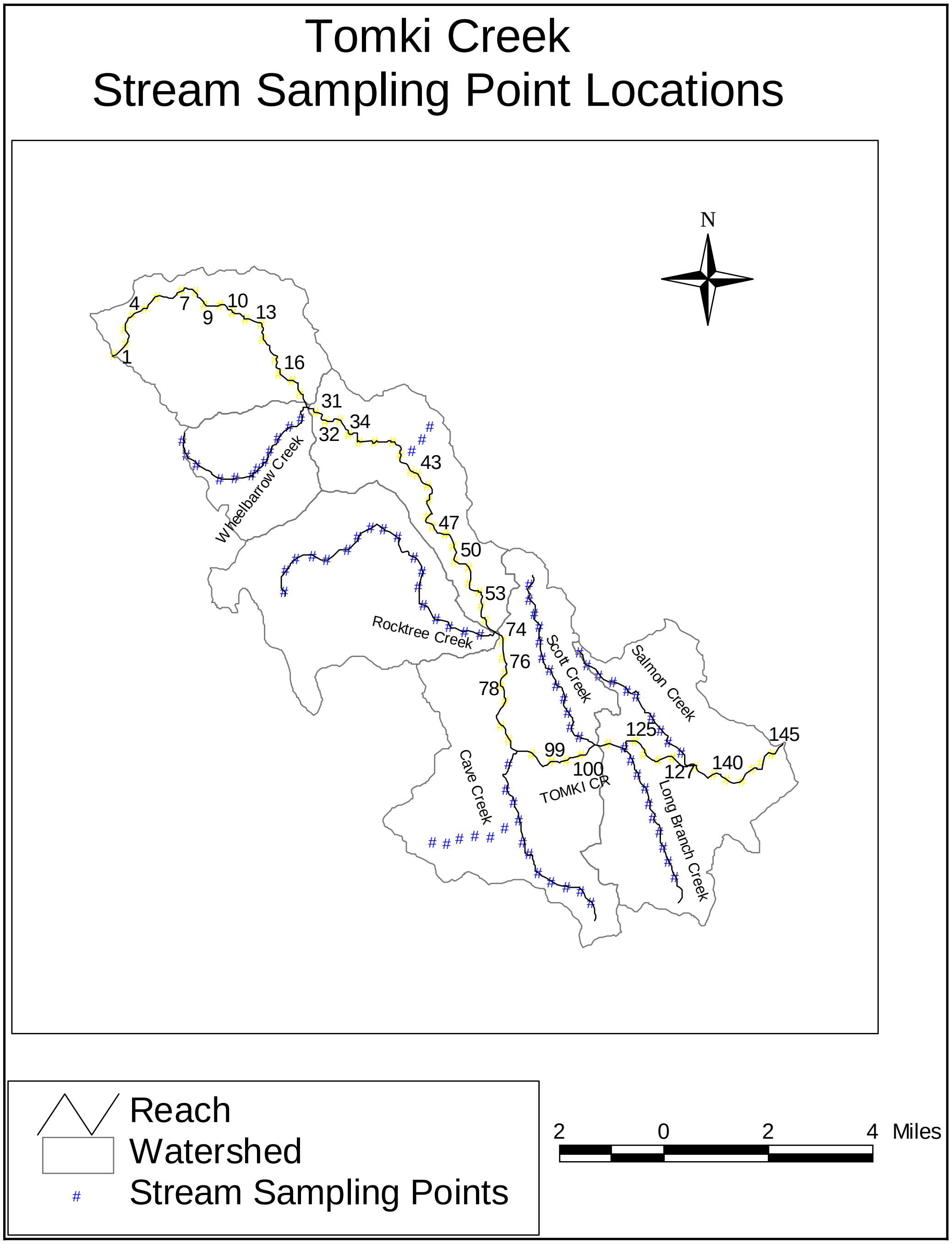

Figure A-40.   SSP locations and identification numbers for Tomki Creek

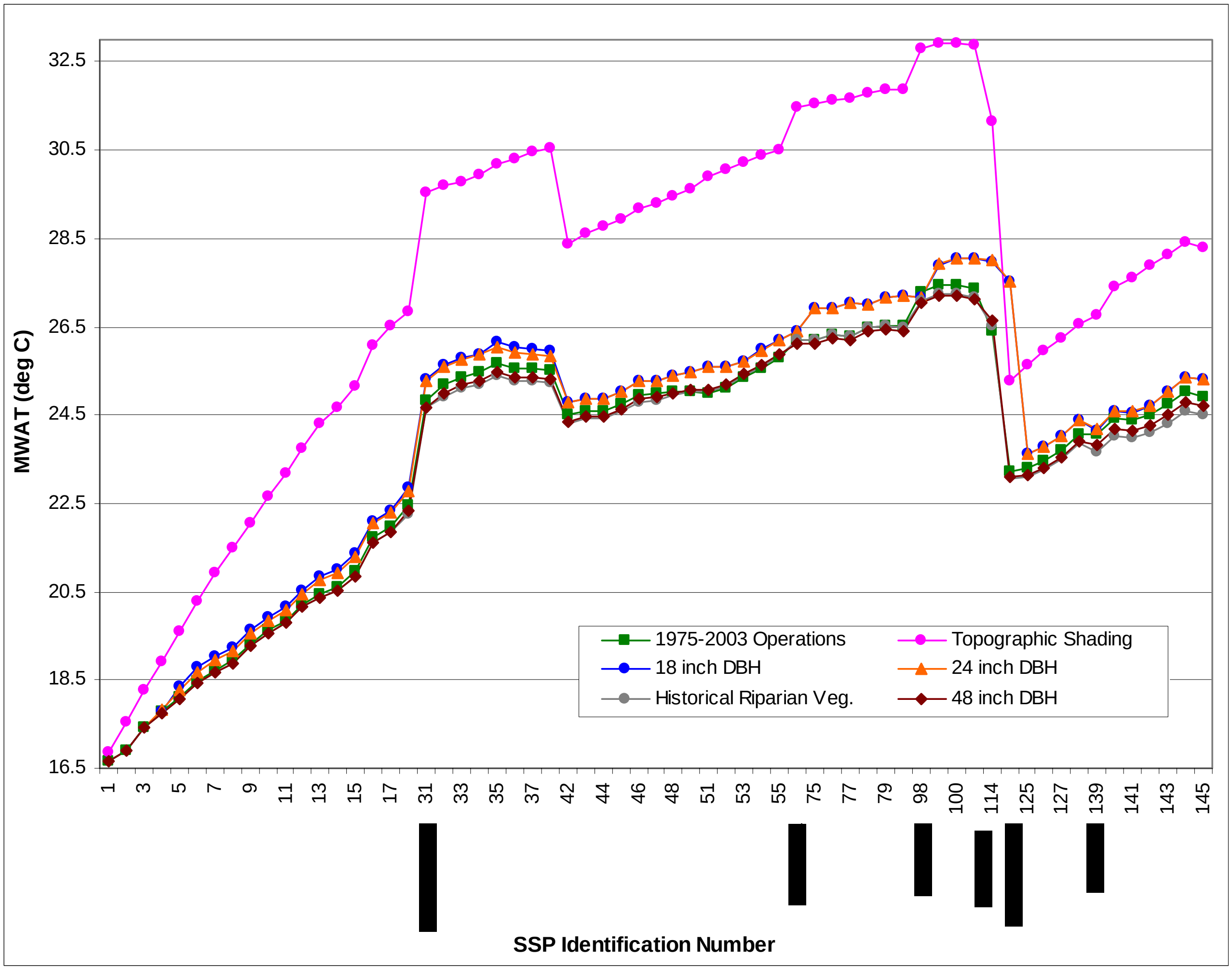

Figure A-41. MWAT values for vegetation scenarios at each SSP on Tomki Creek

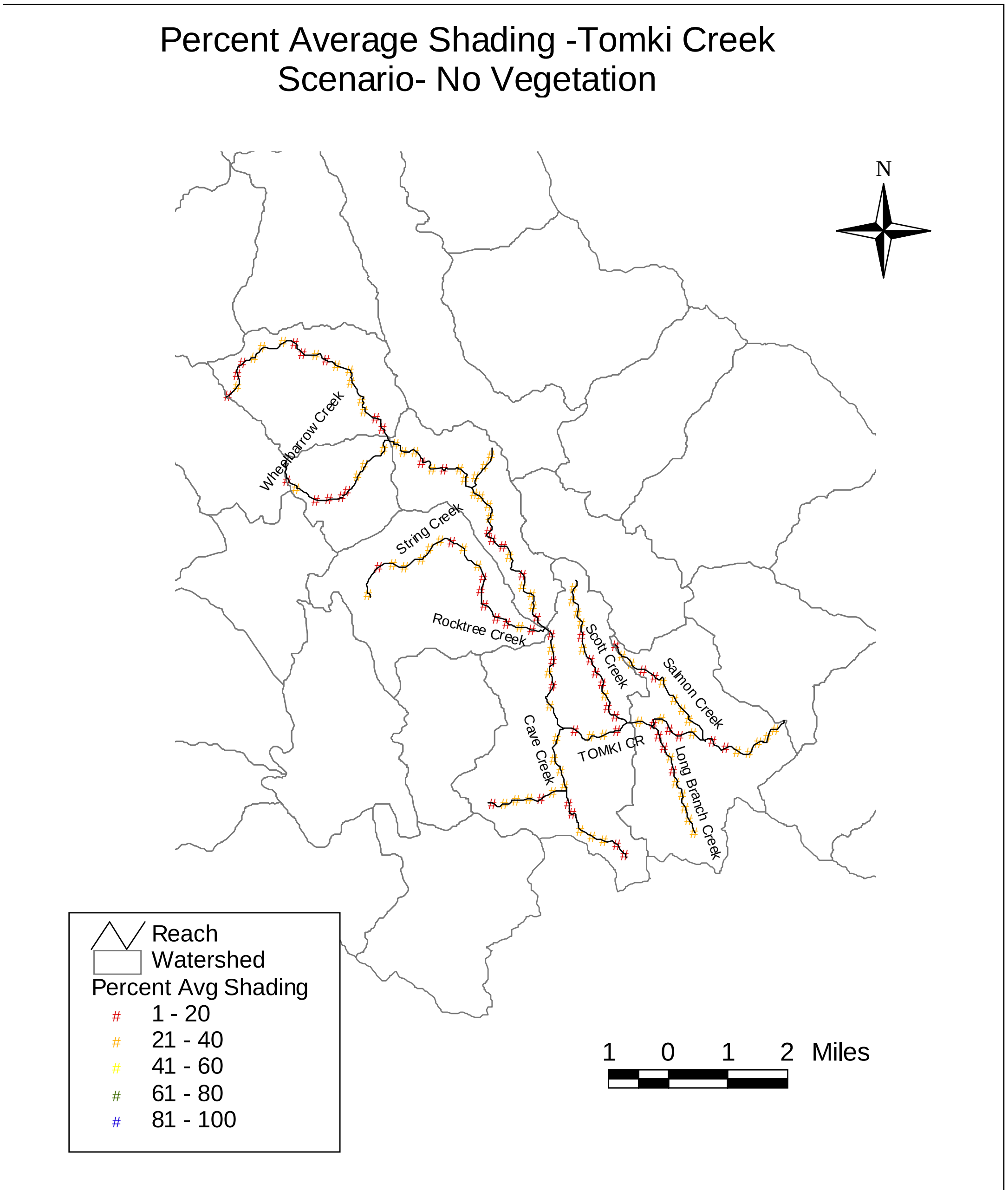

Figure A-42. Percent average shading for the topographic shading scenario at Tomki Creek

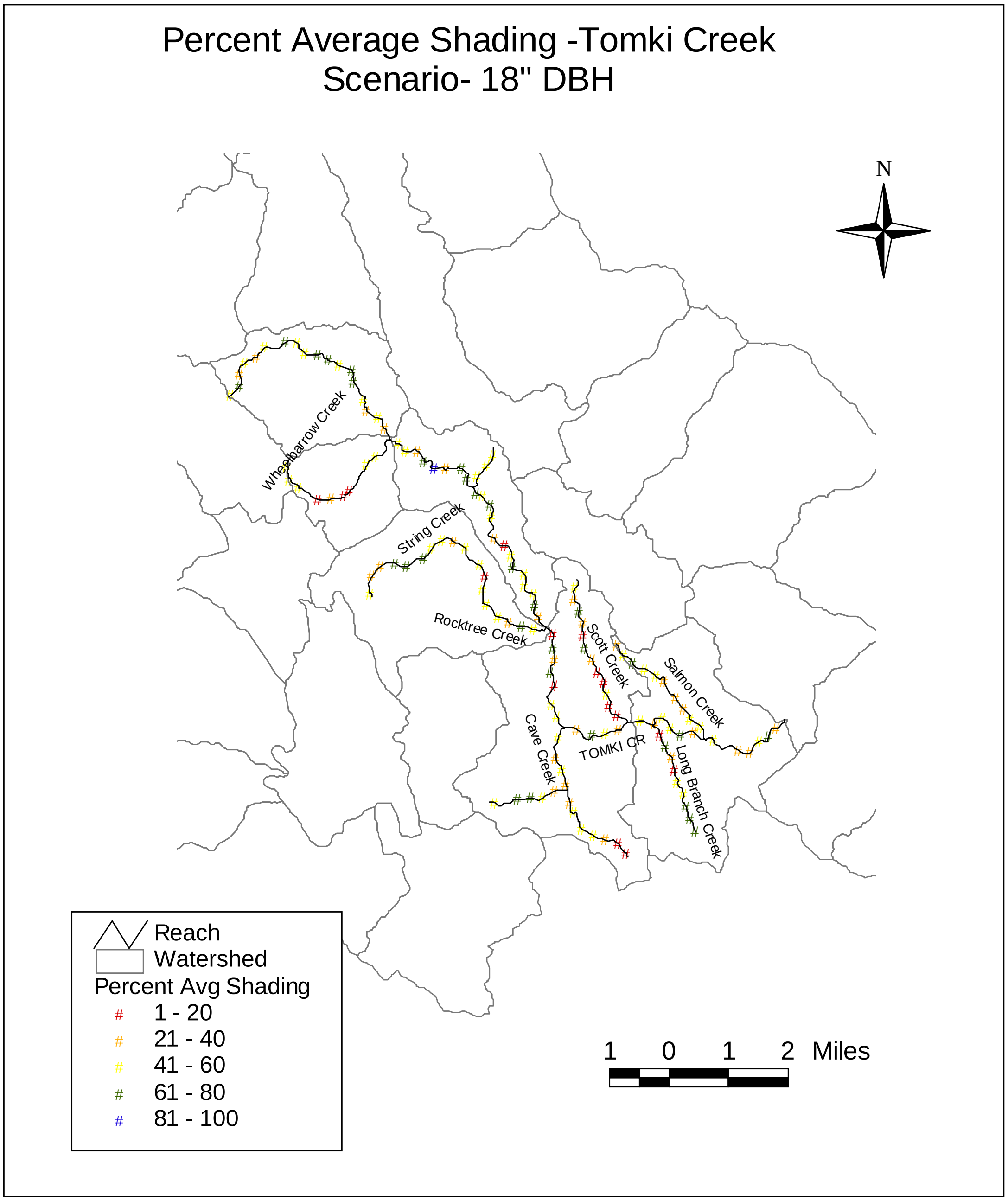

Figure A-43. Percent average shading for the 18 inch DBH vegetation scenario at Tomki Creek

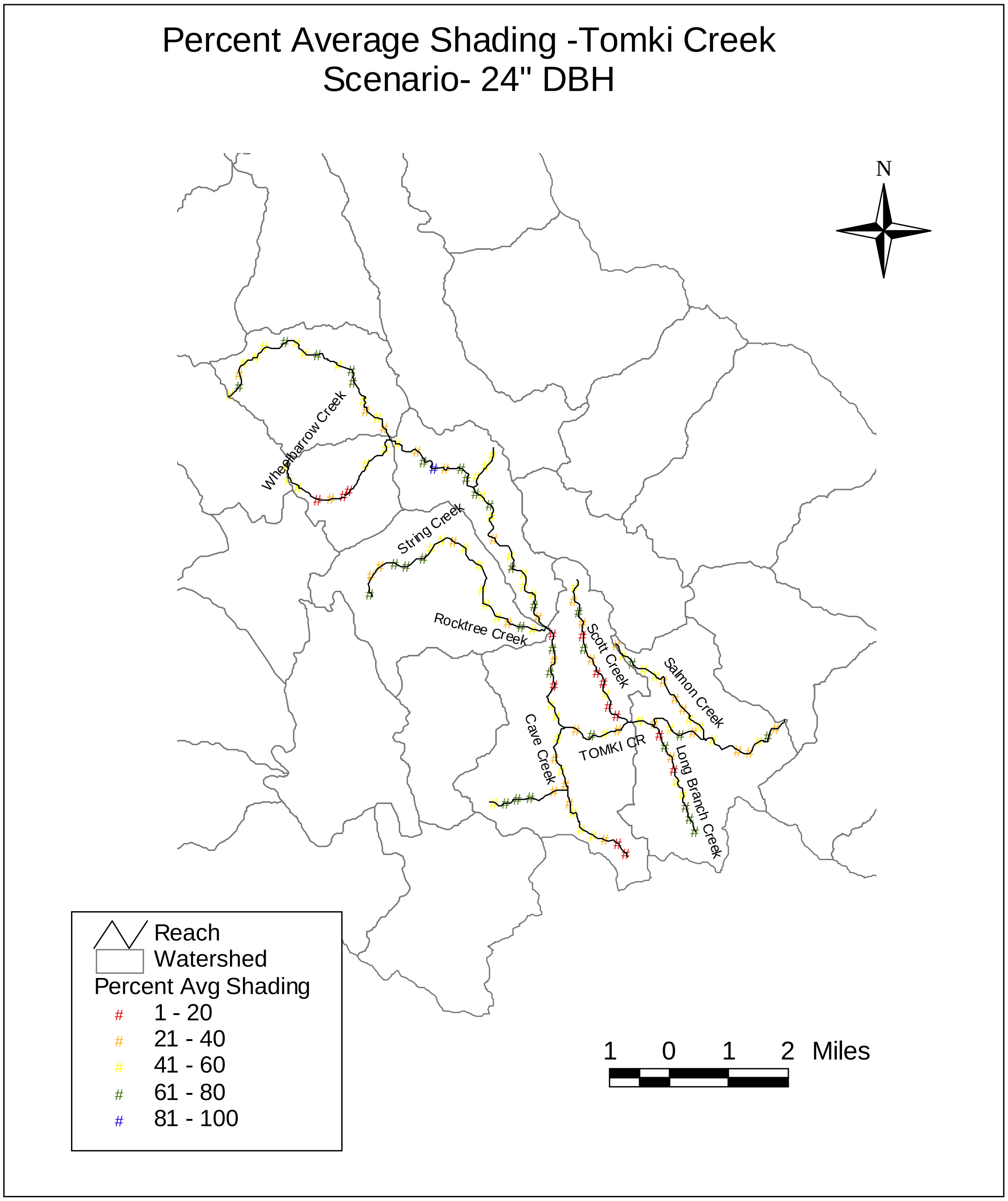

Figure A-44. Percent average shading for the 24 inch DBH vegetation scenario at Tomki Creek

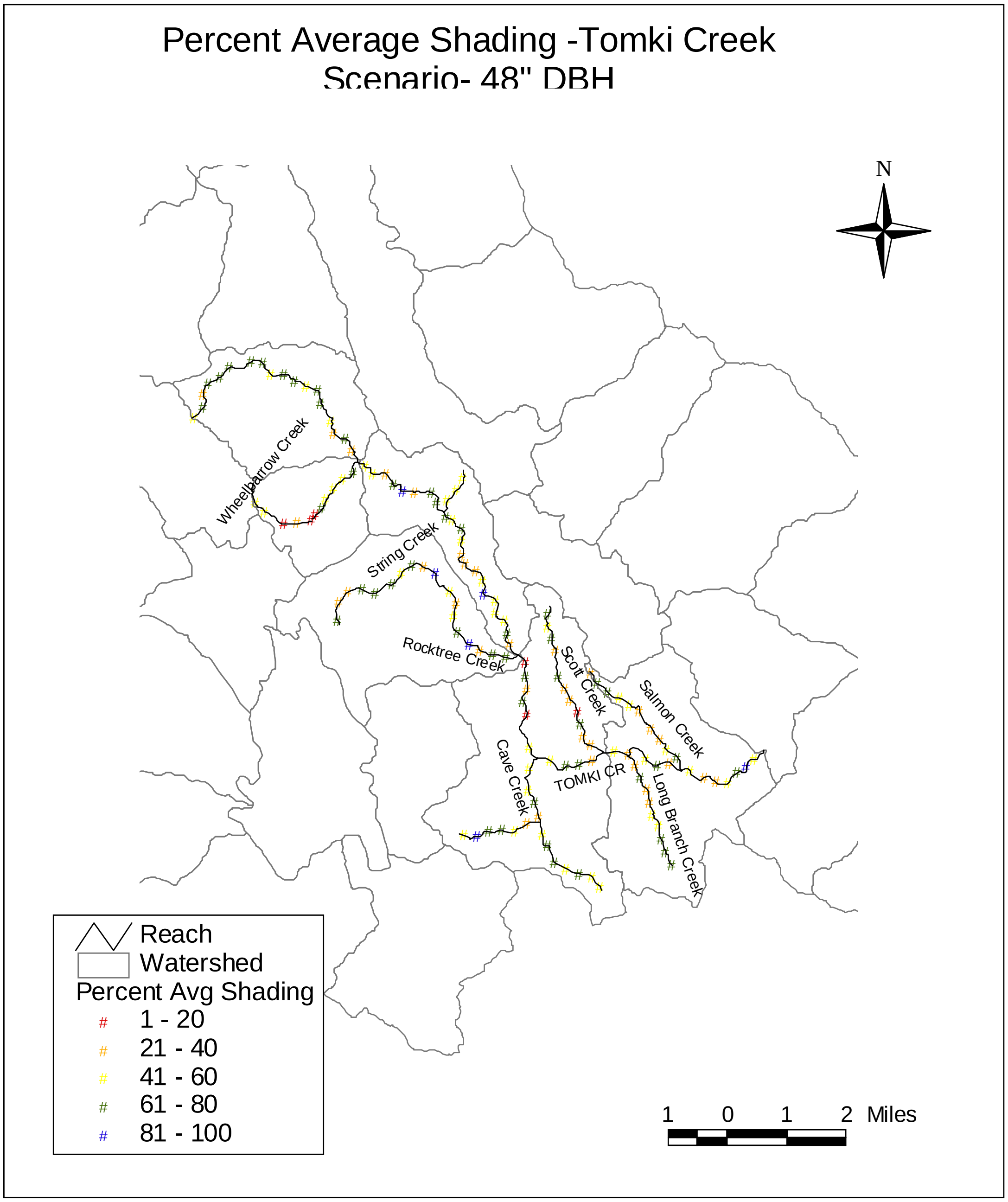

Figure A-45. Percent average shading for the 48 inch DBH vegetation scenario at Tomki Creek

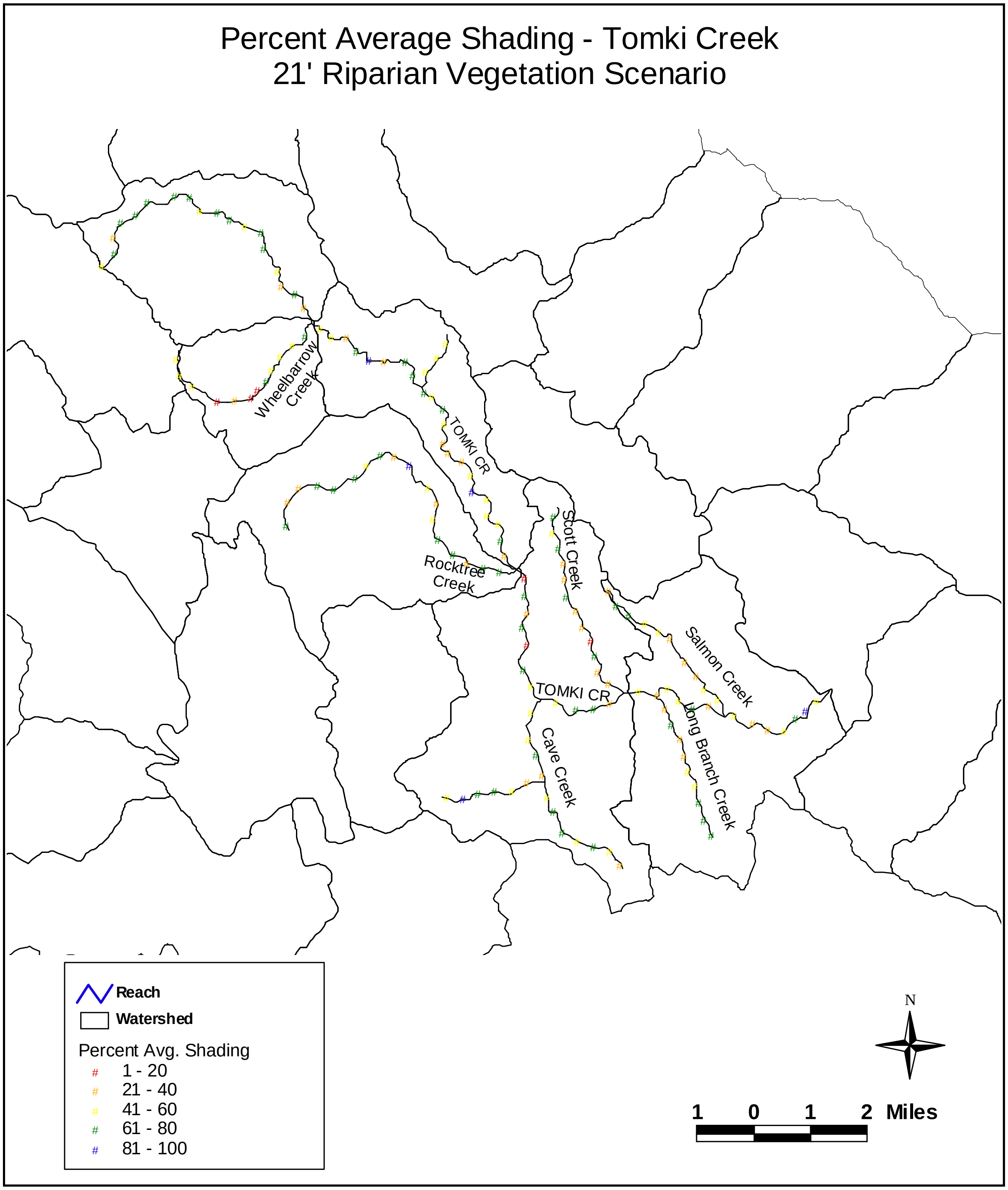

Figure A-46. Percent average shading for the historical riparian vegetation scenario at Tomki Creek

Similar to the Tomki Creek results, Tables A-15 and A-16 present the model results for the vegetation scenarios compared to baseline conditions at the main stem. Table A-15 includes the stream miles associated with different MWAT categories, the solar radiation, and average percent shading, while Table A-16 identifies the specific MWAT value associated with each SSP along the main stem (see Figure A-47 for an illustration of the SSPs along the main stem). Figure A-48 graphically compares the baseline conditions with the vegetation scenarios presented in Table A-16. Figures A-49 through A-52 illustrate the average percent shading at each SSP for the main stem watershed.

Table A-15. Model Results for Vegetation Scenarios at the Main Stem Upper Eel River

Temperature Category	Baseline (1975-2003 Operations)		Topographic Shading	18 Inch DBH	24 Inch DBH	48 Inch DBH	
	Stream Miles	% of Total	Stream Miles	Stream Miles	Stream Miles	Stream Miles	% of Total
Good (MWAT < 15° C)	0.0	0%	0.0	0.0	0.0	0.0	0%
Fair (15° C < MWAT < 17° C)	0.0	0%	0.0	0.0	0.0	0.0	0%
Marginal (17° C < MWAT < 19° C)	0.0	0%	0.0	0.0	0.0	0.0	0%
Stressful (19.1° C < MWAT < 20° C)	0.6	1%	0.3	0.6	0.6	0.6	1%
Stressful (20.1° C < MWAT < 21° C)	0.9	2%	0.3	0.3	0.3	1.2	3%
Stressful (21.1° C < MWAT < 22° C)	2.5	6%	1.2	1.6	1.6	2.2	5%
Stressful (22.1° C < MWAT < 23° C)	1.9	4%	0.9	2.8	2.8	2.8	6%
Stressful (23.1° C < MWAT < 24° C)	3.1	7%	0.9	1.9	1.9	4.0	9%
Lethal (MWAT > 24° C)	35.4	80%	40.7	37.3	37.3	33.6	76%
TOTAL	44.4	100%	44.3	44.5	44.5	44.4	100%
Solar Radiation (Langley/day)	315.3		435.2	332.9	330.6	310.4	
% Shade	46.3%		25.6%	43.2%	43.6%	47.0%	

Table A-16. MWAT Values for Vegetation Scenarios at Each SSP Along the Main Stem Upper Eel River

SSP Identification Number	1975-2003 Operations	Topographic Shading	18 inch DBH	24 inch DBH	48 inch DBH
1 (Van Arsdale)	21.5	22.42	21.56	21.53	21.48
2	22.15	23.75	22.29	22.24	22.11
3	23.06	25.12	23.3	23.22	23.01
4	23.82	26.34	24.47	24.36	24.02
5	24.64	27.23	25.55	25.44	25.1
12 (Tomki Cr)	25.07	27.91	25.95	25.85	25.45
13	25.45	28.67	26.32	26.18	25.78
14	25.48	29.06	26.38	26.21	25.77
15	25.56	29.41	26.51	26.33	25.84
16	25.63	29.63	26.59	26.38	25.88
17	25.93	29.93	26.9	26.68	26.15
18	26.04	29.95	26.98	26.77	26.25
19	26.15	30.19	27.11	26.88	26.34
20	26.31	30.32	27.27	27.04	26.49
21	26.61	30.52	27.55	27.32	26.77
22	27.01	30.78	27.92	27.69	27.15
33 (Thomas Cr)	26.95	30.86	27.89	27.65	27.08
34	26.95	30.95	27.92	27.67	27.07
35	26.98	31.09	27.94	27.69	27.08
36	26.94	30.97	27.86	27.62	27.02
52 (Garcia Cr)	26.81	30.88	27.88	27.64	26.92
53	26.93	30.83	27.96	27.73	27.03
54	27.2	30.84	28.15	27.94	27.29
55	27.42	30.82	28.3	28.1	27.49
56	27.65	30.83	28.47	28.28	27.72
57	27.86	30.83	28.64	28.46	27.92
58	28	30.78	28.71	28.54	28.02

SSP Identification Number	1975-2003 Operations	Topographic Shading	18 inch DBH	24 inch DBH	48 inch DBH
65 (Salt Cr)	27.24	30.59	28.06	27.87	27.31
66	27.32	30.19	28.05	27.81	27.35
67	27.27	30.03	27.91	27.7	27.29
68	27.68	30.05	28.22	28.05	27.7
69	27.97	29.98	28.43	28.28	27.99
70	27.33	29.76	28.16	28	27.65
71	26.96	29.5	27.75	27.59	27.23
72	26.84	29.14	27.53	27.39	27.07
73	27.18	29.16	27.78	27.66	27.4
74	27.25	29.18	27.8	27.68	27.43
75	27.21	29.14	27.81	27.69	27.38
76	27.26	29.18	27.88	27.75	27.42
77	27.27	29.1	27.86	27.75	27.42
78	27.3	29.13	27.86	27.75	27.44
79	27.28	29.12	27.84	27.73	27.41
80	27.1	29.03	27.66	27.54	27.22
87 (Twin Br. Cr)	27.19	29.09	27.7	27.61	27.36
88	27.19	29.1	27.69	27.6	27.36
89	27.22	29.1	27.71	27.63	27.38
90	27.22	29.1	27.72	27.63	27.37
91	27.25	29.08	27.73	27.64	27.39
92	27.3	29.1	27.77	27.68	27.43
93	27.32	29.09	27.77	27.68	27.44
94	27.3	29.11	27.74	27.66	27.42
95	27.3	29.12	27.71	27.63	27.41
96	27.2	29.1	27.6	27.53	27.31
97	27.19	29.08	27.58	27.5	27.29
98	27.38	29.15	27.73	27.66	27.47
99	27.3	29.16	27.59	27.53	27.37
100	27.01	28.81	27.25	27.2	27.06
101	27.31	29	27.51	27.47	27.35
102	27.4	28.96	27.57	27.53	27.43
103	27.3	29.11	27.44	27.41	27.32
104	27.41	29.32	27.53	27.51	27.43
105	27.27	29.22	27.36	27.34	27.28
106	27.19	29.19	27.27	27.26	27.2
107	27.16	28.94	27.23	27.21	27.16
108	27.29	29.14	27.34	27.33	27.29
109	27.38	29.26	27.43	27.42	27.37
110	27.39	29.14	27.43	27.41	27.38
111	27.16	29.1	27.18	27.17	27.14
122 (Indian Cr)	27.4	29.23	27.54	27.5	27.41
123	27.34	29.04	27.45	27.42	27.34
124	27.47	29.28	27.56	27.53	27.47
125	27.84	29.5	27.91	27.89	27.83
126	28.07	29.56	28.12	28.1	28.05
127	28.32	29.75	28.34	28.33	28.29
128	28.19	29.59	28.32	28.19	28.16
129	28.22	29.49	28.41	28.21	28.17
130	28.3	29.56	28.46	28.28	28.24
131	27.94	29.08	28.07	27.91	27.87

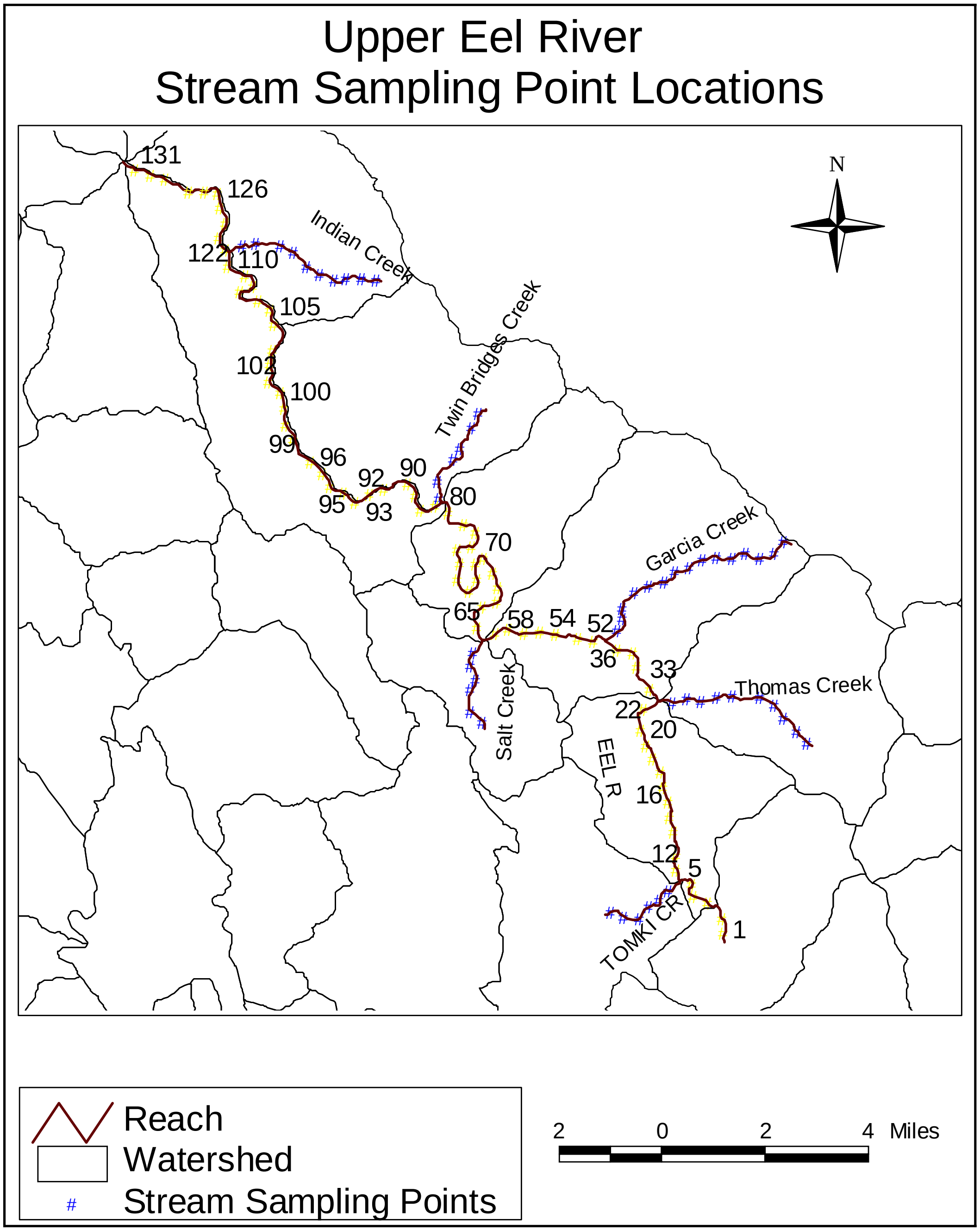

Figure A-47. SSP locations and identification numbers for the main stem

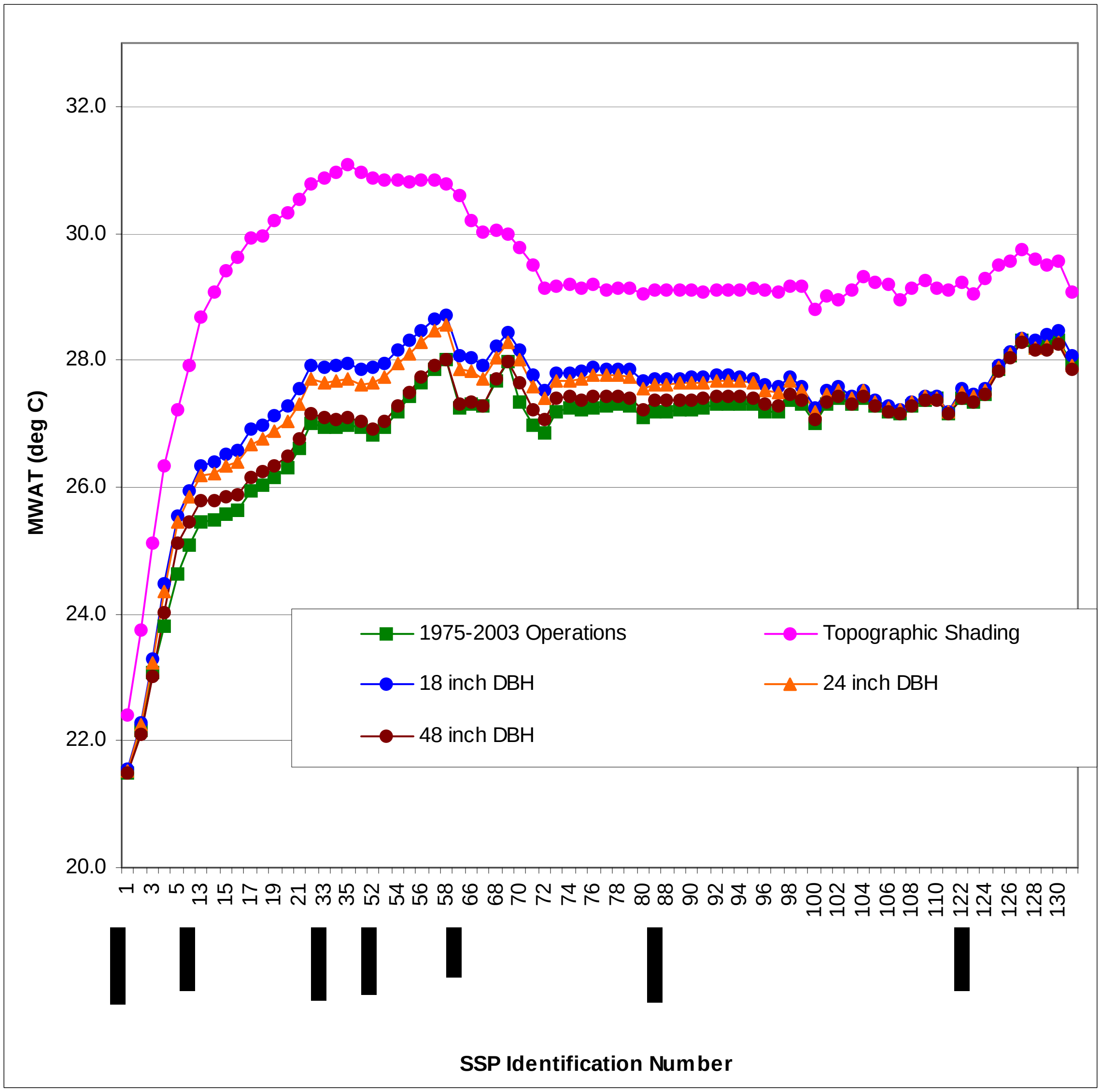

Figure A-48. MWAT values for vegetation scenarios at each SSP on the main stem

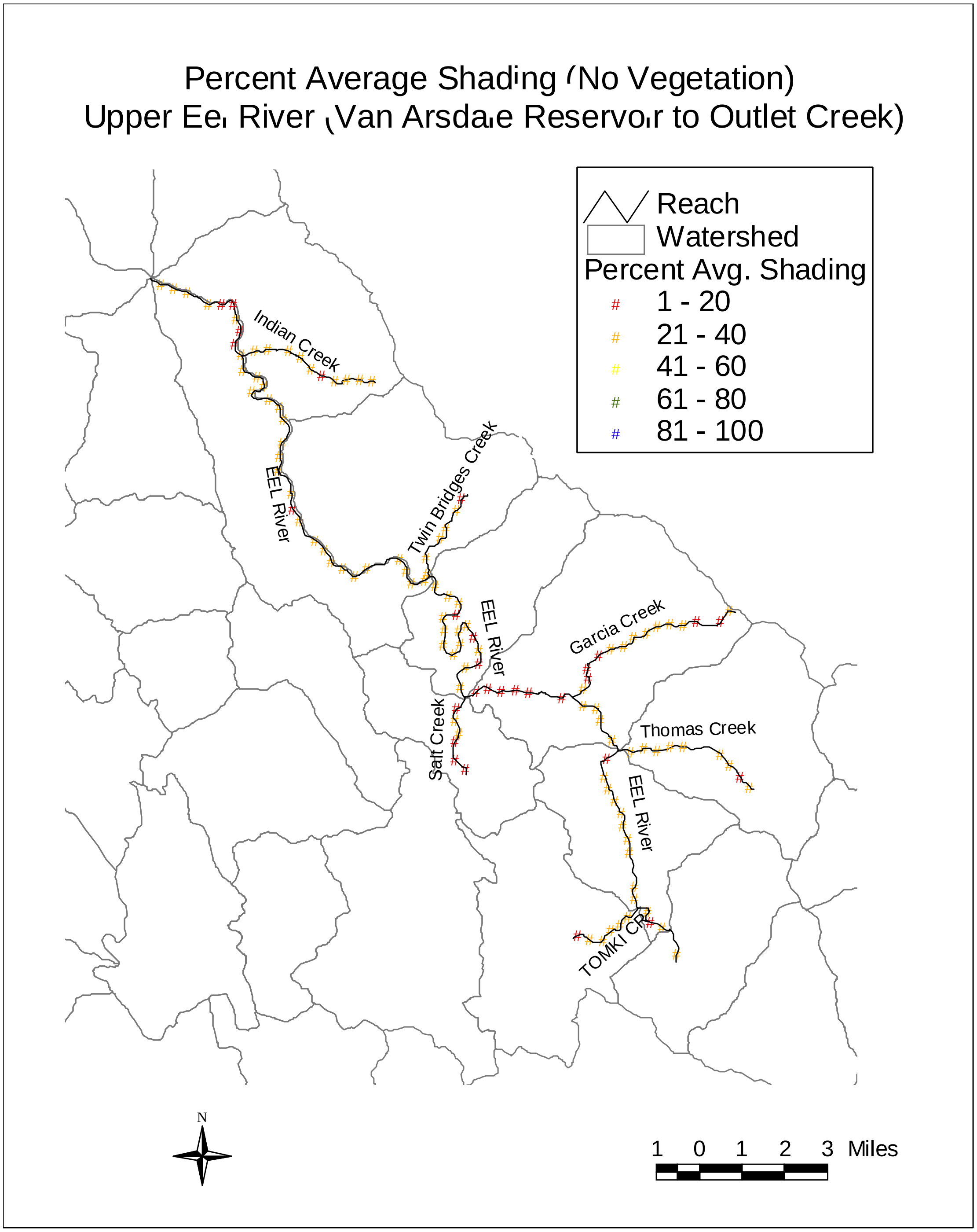

Figure A-49. Percent average shading for the topographic shading scenario at the main stem

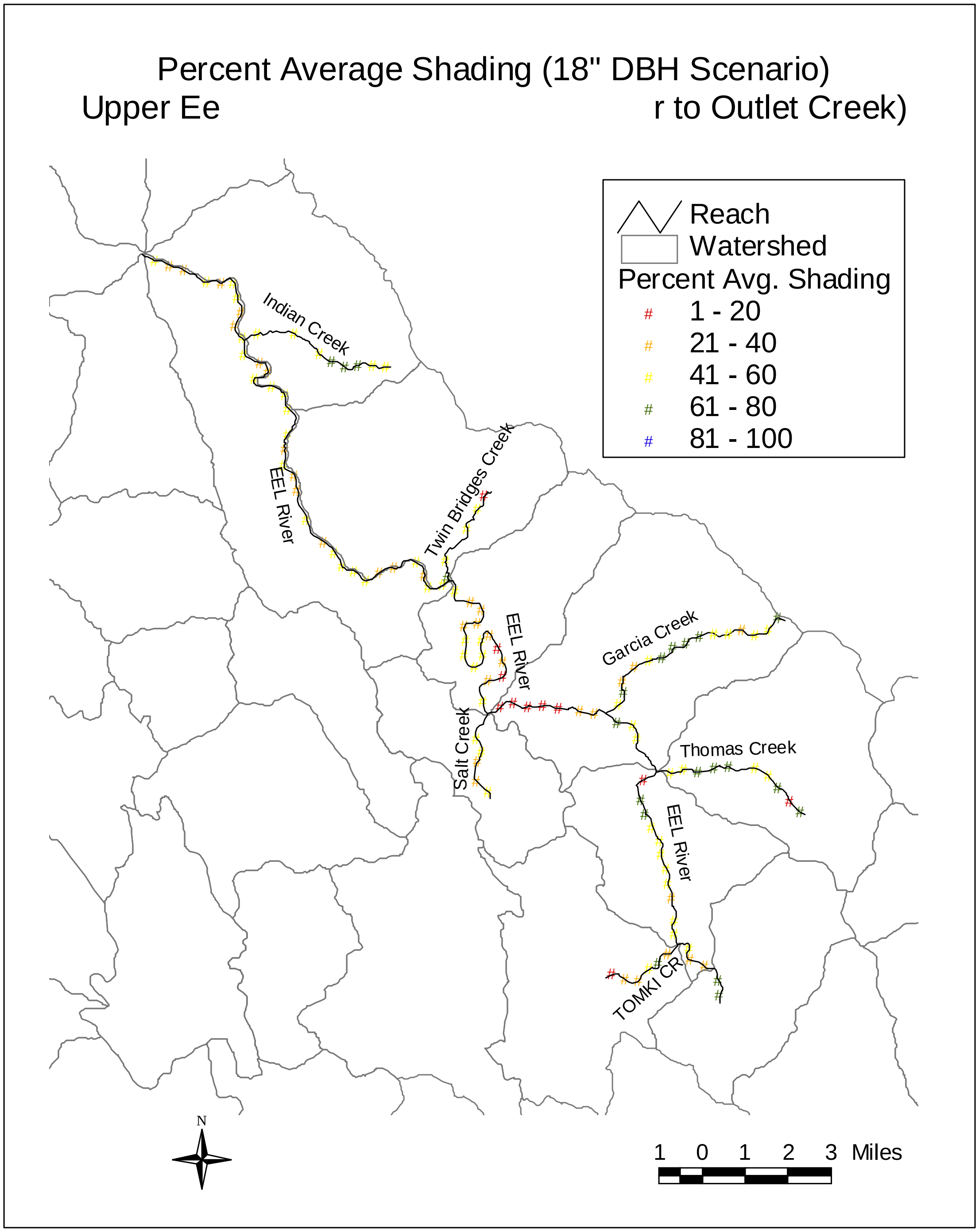

Figure A-50. Percent average shading for the 18 inch DBH vegetation scenario at the main stem

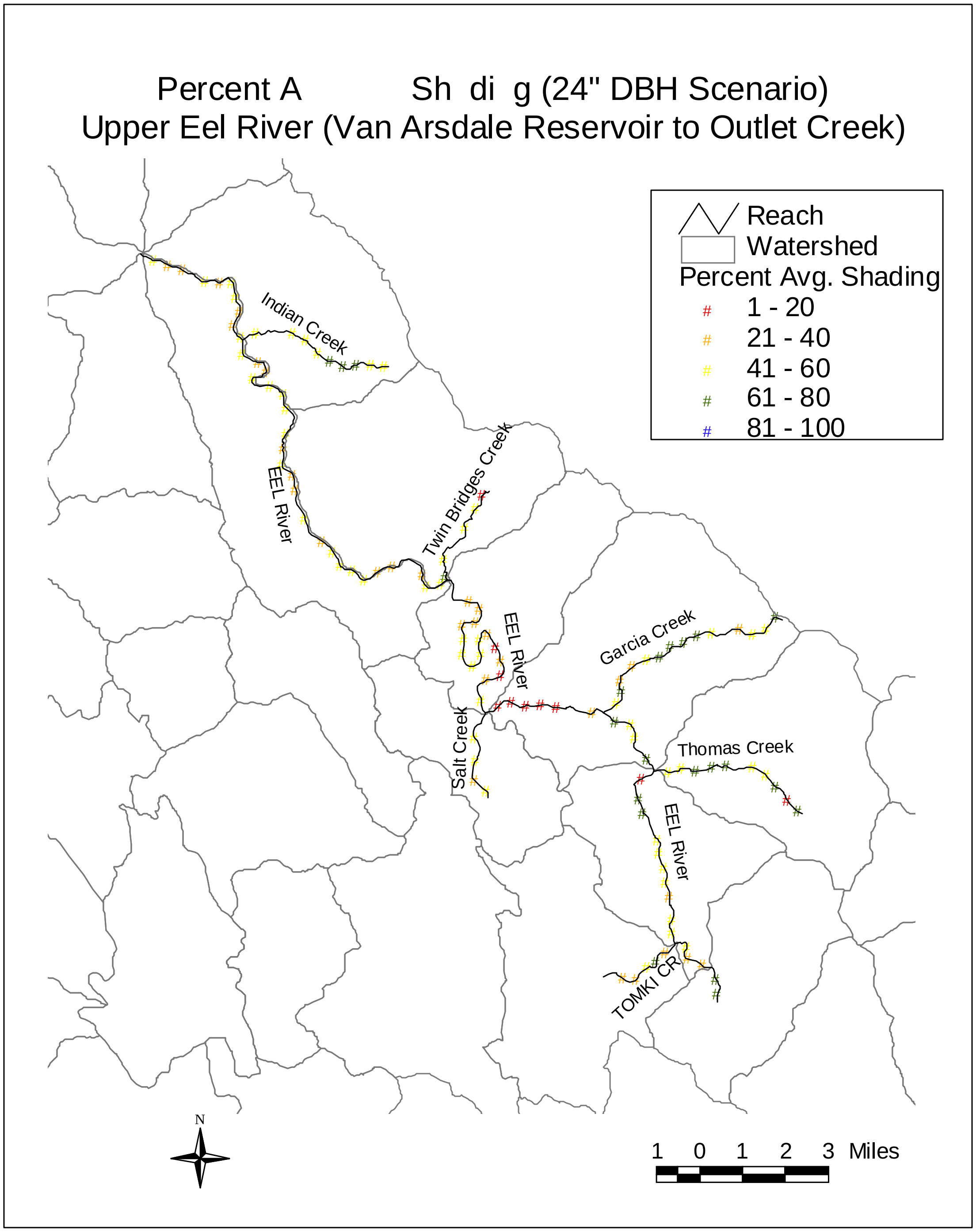

Figure A-51. Percent average shading for the 24 inch DBH vegetation scenario at the main stem

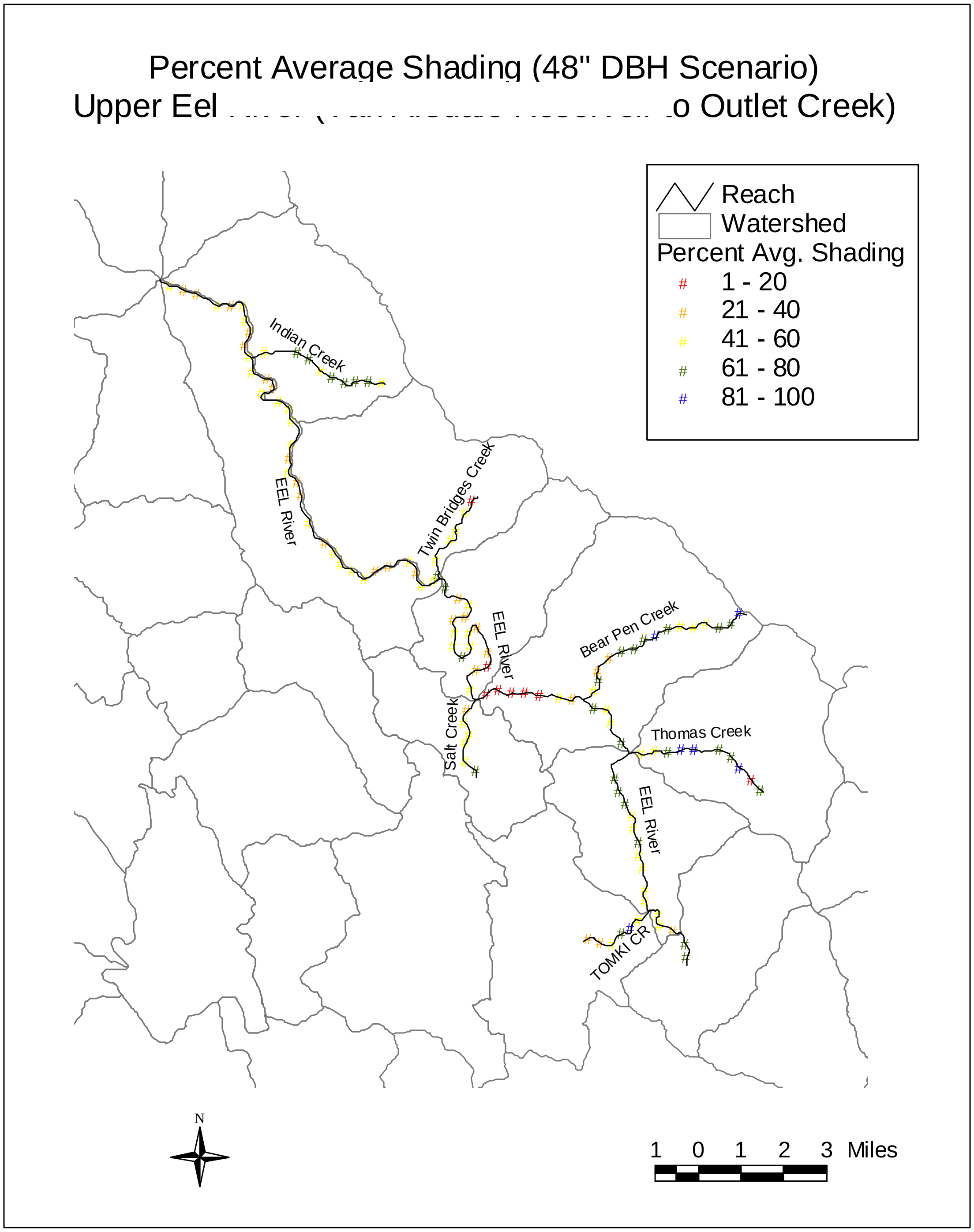

Figure A-52. Percent average shading for the 48 inch DBH vegetation scenario at the main stem

A.5.2 Flow Scenarios

Modifying the Q2ESHADE *.run allows the user to simulate scenarios based on different flow and temperature conditions. Scenarios varying the flow released from Cape Horn Dam were simulated for TMDL development. It was assumed that the vegetation conditions described for the baseline simulations remained the same for all flow scenarios. The ten flow and temperature scenarios are described below.

1. FERC/NMFS Dry Condition (9 cfs at 20.9°C) – Q2ESHADE was parameterized to determine the impact to stream temperature associated with adding 9 cfs of flow at 20.9°C from Cape Horn Dam. To complete this scenario, the headwater conditions associated with the most upstream reach of the main stem watershed (from Cape Horn Dam) was assigned a flow rate of 9 cfs and a temperature of 20.9°C.

2. FERC/NMFS Wet Condition (15 cfs at 20.9°C) – Q2ESHADE was parameterized to determine the impact to stream temperature associated with adding 15 cfs of flow at 20.9°C from Cape Horn Dam. To complete this scenario, the headwater conditions associated with the most upstream reach of the main stem watershed (from Cape Horn Dam) was assigned a flow rate of 15 cfs and a temperature of 20.9°C.

3. FERC/NMFS Very Wet Condition (30 cfs at 20.9°C) – Q2ESHADE was parameterized to determine the impact to stream temperature associated with adding 30 cfs of flow at 20.9°C from Cape Horn Dam. To complete this scenario, the headwater conditions associated with the most upstream reach of the main stem watershed (from Cape Horn Dam) was assigned a flow rate of 30 cfs and a temperature of 20.9°C.

4. Natural Dry Conditions – Lower (10 cfs at 22.5°C) – Q2ESHADE was parameterized to determine the impact to stream temperature associated with adding 10 cfs of flow at 22.5°C from Cape Horn Dam. To complete this scenario, the headwater conditions associated with the most upstream reach of the main stem watershed (from Cape Horn Dam) was assigned a flow rate of 10 cfs and a temperature of 22.5°C.

5. Natural Wet Conditions – Lower (20 cfs at 22.5°C) – Q2ESHADE was parameterized to determine the impact to stream temperature associated with adding 20 cfs of flow at 22.5°C from Cape Horn Dam. To complete this scenario, the headwater conditions associated with the most upstream reach of the main stem watershed (from Cape Horn Dam) was assigned a flow rate of 20 cfs and a temperature of 22.5°C.

6. Natural Very Wet Conditions – Lower (50 cfs at 22.5°C) – Q2ESHADE was parameterized to determine the impact to stream temperature associated with adding 50 cfs of flow at 22.5°C from Cape Horn Dam. To complete this scenario, the headwater conditions associated with the most upstream reach of the main stem watershed (from Cape Horn Dam) was assigned a flow rate of 50 cfs and a temperature of 22.5°C.

7. Natural Very Wet Conditions – Lower (60 cfs at 22.5°C) – Q2ESHADE was parameterized to determine the impact to stream temperature associated with adding 60 cfs of flow at 22.5°C from Cape Horn Dam. To complete this scenario, the headwater conditions associated with the most upstream reach of the main stem watershed (from Cape Horn Dam) was assigned a flow rate of 60 cfs and a temperature of 22.5°C.

8. Natural Dry Conditions – Upper (10 cfs at 25°C) – Q2ESHADE was parameterized to determine the impact to stream temperature associated with adding 10 cfs of flow at 25°C

from Cape Horn Dam. To complete this scenario, the headwater conditions associated with the most upstream reach of the main stem watershed (from Cape Horn Dam) was assigned a flow rate of 10 cfs and a temperature of 25°C.

9. Natural Wet Conditions – Upper (20 cfs at 24.3°C) – Q2ESHADE was parameterized to determine the impact to stream temperature associated with adding 20 cfs of flow at 24.3°C from Cape Horn Dam. To complete this scenario, the headwater conditions associated with the most upstream reach of the main stem watershed (from Cape Horn Dam) was assigned a flow rate of 20 cfs and a temperature of 24.3°C.

10. Natural Very Wet Conditions – Upper (50 cfs at 23.5°C) – Q2ESHADE was parameterized to determine the impact to stream temperature associated with adding 50 cfs of flow at 23.5°C from Cape Horn Dam. To complete this scenario, the headwater conditions associated with the most upstream reach of the main stem watershed (from Cape Horn Dam) was assigned a flow rate of 50 cfs and a temperature of 23.5°C.

Tables A-17 through A-22 present the model results for the flow scenarios compared to baseline conditions (1975-2003 condition) at the main stem. Tables A-17 through A-19 include the stream miles associated with different MWAT categories, while Tables A-20 through A-22 identify the specific MWAT value associated with each SSP along the main stem (see Figure A-47 for an illustration of the SSPs along the main stem). Figures A-53 through A-55 graphically compare the baseline conditions with the flow scenarios presented in Tables A-20 through A-22.

Table A-17. Model Results for Dry Year Flow Scenarios at the Main Stem Upper Eel River

Temperature Category	1975-2003 (7cfs at 20.9C)		NMFS/FERC (9cfs at 20.9C)		Natural-Lower (10cfs at 22.5C)		Natural-Upper (10cfs at 25C)	
	Stream Miles	% of Total	Stream Miles	% of Total	Stream Miles	% of Total	Stream Miles	% of Total
Good (MWAT < 15° C)	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Fair (15° C < MWAT < 17° C)	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Marginal (17° C < MWAT < 19° C)	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Stressful (19.1° C < MWAT < 20° C)	0.6	1%	0.6	1%	0.6	1%	0.6	1%
Stressful (20.1° C < MWAT < 21° C)	0.9	2%	0.9	2%	0.9	2%	0.9	2%
Stressful (21.1° C < MWAT < 22° C)	2.5	6%	2.8	6%	2.2	5%	2.2	5%
Stressful (22.1° C < MWAT < 23° C)	1.9	4%	1.9	4%	1.9	4%	1.6	4%
Stressful (23.1° C < MWAT < 24° C)	3.1	7%	2.8	6%	3.1	7%	2.5	6%
Lethal (MWAT > 24° C)	35.4	80%	35.4	80%	35.7	80%	36.7	82%
TOTAL	44.4	100%	44.4	100%	44.4	100%	44.5	100%

Table A-18. Model Results for Wet Year Flow Scenarios at the Main Stem Upper Eel River

Temperature Category	1975-2003 (7cfs at 20.9C)		NMFS/FERC (15cfs at 20.9C)		Natural-Lower (20cfs at 22.5C)		Natural-Upper (20cfs at 24.3C)	
	Stream Miles	% of Total	Stream Miles	% of Total	Stream Miles	% of Total	Stream Miles	% of Total
Good (MWAT < 15° C)	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Fair (15° C < MWAT < 17° C)	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Marginal (17° C < MWAT < 19° C)	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Stressful (19.1° C < MWAT < 20° C)	0.6	1%	0.6	1%	0.6	1%	0.6	1%
Stressful (20.1° C < MWAT < 21° C)	0.9	2%	0.9	2%	0.9	2%	0.9	2%
Stressful (21.1° C < MWAT < 22° C)	2.5	6%	2.8	6%	2.2	5%	2.2	5%
Stressful (22.1° C < MWAT < 23° C)	1.9	4%	2.2	5%	2.2	5%	1.6	4%
Stressful (23.1° C < MWAT < 24° C)	3.1	7%	3.4	8%	3.1	7%	2.5	6%
Lethal (MWAT > 24° C)	35.4	80%	34.5	78%	35.4	80%	36.7	82%
TOTAL	44.4	100%	44.4	100%	44.4	100%	44.5	100%

Table A-19. Model Results for Very Wet Year Flow Scenarios at the Main Stem Upper Eel River

Temperature Category	1975-2003 (7cfs at 20.9C)		NMFS/FERC (30cfs at 20.9C)		Natural-Lower (50cfs at 22.5C)	
	Stream Miles	% of Total	Stream Miles	% of Total	Stream Miles	% of Total
Good (MWAT < 15° C)	0.0	0%	0.0	0%	0.0	0%
Fair (15° C < MWAT < 17° C)	0.0	0%	0.0	0%	0.0	0%
Marginal (17° C < MWAT < 19° C)	0.0	0%	0.0	0%	0.0	0%
Stressful (19.1° C < MWAT < 20° C)	0.6	1%	0.6	1%	0.6	1%
Stressful (20.1° C < MWAT < 21° C)	0.9	2%	0.9	2%	0.9	2%
Stressful (21.1° C < MWAT < 22° C)	2.5	6%	3.1	7%	2.2	5%
Stressful (22.1° C < MWAT < 23° C)	1.9	4%	3.1	7%	2.5	6%
Stressful (23.1° C < MWAT < 24° C)	3.1	7%	7.5	17%	5.6	13%
Lethal (MWAT > 24° C)	35.4	80%	29.2	66%	32.6	73%
TOTAL	44.4	100%	44.4	100%	44.4	100%

Temperature Category	Natural-Upper (50cfs at 23.5C)		Natural-Lower (60cfs at 22.5C)	
	Stream Miles	% of Total	Stream Miles	% of Total
Good (MWAT < 15° C)	0.0	0%	0.0	0%
Fair (15° C < MWAT < 17° C)	0.0	0%	0.0	0%
Marginal (17° C < MWAT < 19° C)	0.0	0%	0.0	0%
Stressful (19.1° C < MWAT < 20° C)	0.6	1%	0.6	1%
Stressful (20.1° C < MWAT < 21° C)	0.9	2%	0.9	2%
Stressful (21.1° C < MWAT < 22° C)	2.2	5%	2.2	5%
Stressful (22.1° C < MWAT < 23° C)	1.6	4%	2.5	6%
Stressful (23.1° C < MWAT < 24° C)	3.4	8%	6.5	15%
Lethal (MWAT > 24° C)	35.7	80%	31.7	71%
TOTAL	44.4	100%	44.4	100%

Table A-20. MWAT Values for Dry Year Flow Scenarios at SSPs Along the Main Stem Upper Eel River

SSP Identification Number	1975-2003 Operations (7 cfs at 20.9C)	FERC/NMFS Dry Year (9 cfs at 20.9C)	Natural Dry Year - Lower (10 cfs at 22.5C)	Natural Dry Year - Upper (10 cfs at 25C)
1 (Van Arsdale)	21.5	21.41	22.87	25.19
2	22.15	21.97	23.29	25.45
3	23.06	22.75	23.93	25.94
4	23.82	23.41	24.46	26.33
5	24.64	24.14	25.07	26.8
12 (Tomki Cr)	25.07	24.55	25.37	26.96
13	25.45	24.92	25.66	27.14
14	25.48	24.97	25.67	27.07
15	25.56	25.06	25.73	27.09
16	25.63	25.13	25.78	27.09
17	25.93	25.4	26	27.27
18	26.04	25.51	26.09	27.32
19	26.15	25.62	26.17	27.36
20	26.31	25.78	26.3	27.44
21	26.61	26.04	26.52	27.63
22	27.01	26.39	26.82	27.89
33 (Thomas Cr)	26.95	26.36	26.79	27.82
34	26.95	26.41	26.8	27.76
35	26.98	26.46	26.83	27.76
36	26.94	26.43	26.79	27.67
52 (Garcia Cr)	26.81	26.33	26.71	27.62
53	26.93	26.46	26.81	27.67
54	27.2	26.71	27.02	27.83
55	27.42	26.92	27.19	27.96
56	27.65	27.14	27.38	28.1
57	27.86	27.34	27.55	28.23
58	28	27.47	27.65	28.28
65 (Salt Cr)	27.24	26.81	27.08	27.79
66	27.32	26.97	27.16	27.71
67	27.27	26.97	27.14	27.63
68	27.68	27.34	27.45	27.88
69	27.97	27.62	27.69	28.06
70	27.33	27.14	27.24	27.57
71	26.96	26.87	26.98	27.27
72	26.84	26.79	26.89	27.15
73	27.18	27.03	27.11	27.38
74	27.25	27.1	27.17	27.42
75	27.21	27.07	27.14	27.38
76	27.26	27.12	27.18	27.42
77	27.27	27.13	27.19	27.42
78	27.3	27.15	27.21	27.43
79	27.28	27.14	27.2	27.41
80	27.1	26.98	27.04	27.25
87 (Twin Br. Cr)	27.19	27.06	27.13	27.37
88	27.19	27.06	27.13	27.37
89	27.22	27.09	27.16	27.38
90	27.22	27.1	27.16	27.38
91	27.25	27.12	27.18	27.4
92	27.3	27.17	27.22	27.43
93	27.32	27.19	27.23	27.44
94	27.3	27.18	27.23	27.42
95	27.3	27.18	27.22	27.41
96	27.2	27.1	27.16	27.34
97	27.19	27.1	27.15	27.33
98	27.38	27.26	27.29	27.46
99	27.3	27.22	27.25	27.4
100	27.01	26.99	27.05	27.18
101	27.31	27.24	27.27	27.39
102	27.4	27.33	27.35	27.45
103	27.3	27.26	27.28	27.38
104	27.41	27.36	27.37	27.45
105	27.27	27.25	27.27	27.34

SSP Identification Number	1975-2003 Operations (7 cfs at 20.9C)	FERC/NMFS Dry Year (9 cfs at 20.9C)	Natural Dry Year - Lower (10 cfs at 22.5C)	Natural Dry Year - Upper (10 cfs at 25C)
106	27.19	27.19	27.22	27.29
107	27.16	27.17	27.19	27.25
108	27.29	27.28	27.29	27.34
109	27.38	27.35	27.36	27.41
110	27.39	27.37	27.37	27.41
111	27.16	27.17	27.18	27.22
122 (Indian Cr)	27.4	27.34	27.35	27.45
123	27.34	27.3	27.32	27.4
124	27.47	27.41	27.42	27.5
125	27.84	27.72	27.7	27.77
126	28.07	27.92	27.89	27.95
127	28.32	28.14	28.09	28.14
128	28.19	28.09	28.05	28.1
129	28.22	28.13	28.1	28.14
130	28.3	28.21	28.18	28.21
131	27.94	27.84	27.8	27.83

Table A-21. MWAT Values for Wet Year Flow Scenarios at SSPs Along the Main Stem Upper Eel River

SSP Identification Number	1975-2003 Operations (7 cfs at 20.9C)	FERC/NMFS Wet Year (15 cfs at 20.9C)	Natural Wet Year - Lower (20 cfs at 22.5C)	Natural Wet Year - Upper (20 cfs at 24.3C)
1 (Van Arsdale)	21.5	21.26	22.73	24.45
2	22.15	21.66	23	24.65
3	23.06	22.23	23.41	24.99
4	23.82	22.73	23.77	25.28
5	24.64	23.28	24.17	25.62
12 (Tomki Cr)	25.07	23.63	24.42	25.78
13	25.45	23.94	24.64	25.95
14	25.48	24.01	24.68	25.95
15	25.56	24.1	24.73	25.98
16	25.63	24.16	24.78	26
17	25.93	24.36	24.92	26.13
18	26.04	24.46	24.99	26.18
19	26.15	24.56	25.06	26.23
20	26.31	24.69	25.16	26.3
21	26.61	24.9	25.31	26.44
22	27.01	25.15	25.51	26.61
33 (Thomas Cr)	26.95	25.17	25.52	26.6
34	26.95	25.26	25.58	26.62
35	26.98	25.32	25.62	26.65
36	26.94	25.31	25.59	26.59
52 (Garcia Cr)	26.81	25.24	25.56	26.57
53	26.93	25.37	25.65	26.64
54	27.2	25.58	25.81	26.77
55	27.42	25.76	25.95	26.88
56	27.65	25.96	26.09	27
57	27.86	26.14	26.24	27.11
58	28	26.25	26.3	27.14
65 (Salt Cr)	27.24	25.75	25.93	26.83
66	27.32	26	26.1	26.9
67	27.27	26.08	26.15	26.91
68	27.68	26.37	26.37	27.08

SSP Identification Number	1975-2003 Operations (7 cfs at 20.9C)	FERC/NMFS Wet Year (15 cfs at 20.9C)	Natural Wet Year - Lower (20 cfs at 22.5C)	Natural Wet Year - Upper (20 cfs at 24.3C)
69	27.97	26.62	26.55	27.23
70	27.33	26.39	26.39	27.02
71	26.96	26.28	26.3	26.9
72	26.84	26.28	26.29	26.85
73	27.18	26.46	26.43	26.96
74	27.25	26.53	26.48	26.99
75	27.21	26.52	26.47	26.97
76	27.26	26.56	26.51	26.99
77	27.27	26.58	26.52	27
78	27.3	26.61	26.54	27.01
79	27.28	26.61	26.55	27.01
80	27.1	26.48	26.42	26.86
87 (Twin Br. Cr)	27.19	26.51	26.47	26.97
88	27.19	26.53	26.48	26.97
89	27.22	26.56	26.51	26.98
90	27.22	26.57	26.51	26.98
91	27.25	26.6	26.54	26.99
92	27.3	26.64	26.57	27.02
93	27.32	26.66	26.59	27.02
94	27.3	26.67	26.59	27.02
95	27.3	26.68	26.6	27.02
96	27.2	26.63	26.56	26.98
97	27.19	26.64	26.57	26.97
98	27.38	26.76	26.67	27.05
99	27.3	26.75	26.67	27.03
100	27.01	26.63	26.56	26.95
101	27.31	26.81	26.71	27.07
102	27.4	26.9	26.78	27.12
103	27.3	26.89	26.78	27.1
104	27.41	26.98	26.85	27.16
105	27.27	26.94	26.83	27.12
106	27.19	26.93	26.83	27.1
107	27.16	26.93	26.84	27.1
108	27.29	27.02	26.91	27.16
109	27.38	27.09	26.97	27.2
110	27.39	27.12	27	27.22
111	27.16	26.98	26.88	27.08
122 (Indian Cr)	27.4	26.93	26.81	27.14
123	27.34	26.94	26.82	27.13
124	27.47	27.04	26.91	27.2
125	27.84	27.26	27.08	27.36
126	28.07	27.43	27.22	27.48
127	28.32	27.6	27.36	27.61
128	28.19	27.65	27.42	27.64
129	28.22	27.74	27.51	27.71
130	28.3	27.82	27.58	27.77
131	27.94	27.42	27.16	27.33

Table A-22. MWAT Values for Very Wet Year Flow Scenarios at SSPs Along the Main Stem Upper Eel River

SSP Identification Number	1975-2003 Operations (7 cfs at 20.9C)	FERC/NMFS Very Wet Year (30 cfs at 20.9C)	Natural Very Wet Year - Lower (50 cfs at 22.5C)	Natural Very Wet Year - Upper (50 cfs at 23.5C)	Natural Very Wet Year - Lower (60 cfs at 22.5C)
1 (Van Arsdale)	21.5	21.12	22.62	23.6	22.61
2	22.15	21.38	22.77	23.72	22.74
3	23.06	21.74	22.99	23.92	22.93
4	23.82	22.06	23.19	24.1	23.11
5	24.64	22.42	23.41	24.31	23.31
12 (Tomki Cr)	25.07	22.67	23.56	24.43	23.44
13	25.45	22.9	23.7	24.55	23.56
14	25.48	22.96	23.73	24.57	23.59
15	25.56	23.02	23.76	24.6	23.62
16	25.63	23.07	23.79	24.62	23.65
17	25.93	23.2	23.87	24.69	23.71
18	26.04	23.27	23.91	24.72	23.75
19	26.15	23.34	23.95	24.76	23.78
20	26.31	23.43	24	24.8	23.83
21	26.61	23.56	24.08	24.88	23.9
22	27.01	23.72	24.18	24.97	23.99
33 (Thomas Cr)	26.95	23.75	24.2	24.98	24
34	26.95	23.84	24.26	25.02	24.05
35	26.98	23.89	24.29	25.05	24.08
36	26.94	23.89	24.26	25	24.05
52 (Garcia Cr)	26.81	23.86	24.27	25.03	24.06
53	26.93	23.96	24.33	25.08	24.12
54	27.2	24.11	24.42	25.16	24.2
55	27.42	24.25	24.51	25.24	24.28
56	27.65	24.38	24.6	25.32	24.36
57	27.86	24.52	24.68	25.4	24.44
58	28	24.59	24.7	25.39	24.44
65 (Salt Cr)	27.24	24.28	24.53	25.25	24.3
66	27.32	24.5	24.65	25.34	24.41
67	27.27	24.59	24.7	25.38	24.46
68	27.68	24.79	24.82	25.49	24.56
69	27.97	24.97	24.93	25.58	24.65
70	27.33	24.91	24.89	25.53	24.63
71	26.96	24.91	24.89	25.52	24.63
72	26.84	24.95	24.92	25.53	24.66
73	27.18	25.09	25	25.6	24.73
74	27.25	25.16	25.04	25.64	24.77
75	27.21	25.17	25.05	25.64	24.78
76	27.26	25.21	25.08	25.66	24.8
77	27.27	25.24	25.1	25.68	24.82
78	27.3	25.27	25.12	25.7	24.84
79	27.28	25.29	25.13	25.7	24.85
80	27.1	25.2	25.03	25.59	24.76
87 (Twin Br. Cr)	27.19	25.17	25.05	25.64	24.78
88	27.19	25.2	25.07	25.65	24.8
89	27.22	25.23	25.09	25.67	24.82
90	27.22	25.25	25.11	25.68	24.83
91	27.25	25.28	25.13	25.7	24.85
92	27.3	25.32	25.15	25.72	24.88
93	27.32	25.35	25.17	25.74	24.9
94	27.3	25.37	25.19	25.75	24.91
95	27.3	25.4	25.2	25.76	24.93
96	27.2	25.39	25.2	25.75	24.92
97	27.19	25.41	25.21	25.76	24.94
98	27.38	25.5	25.27	25.81	24.99
99	27.3	25.55	25.31	25.84	25.03
100	27.01	25.51	25.29	25.8	25.01
101	27.31	25.62	25.35	25.86	25.08
102	27.4	25.67	25.39	25.89	25.11
103	27.3	25.7	25.4	25.89	25.13
104	27.41	25.79	25.44	25.91	25.16

SSP Identification Number	1975-2003 Operations (7 cfs at 20.9C)	FERC/NMFS Very Wet Year (30 cfs at 20.9C)	Natural Very Wet Year - Lower (50 cfs at 22.5C)	Natural Very Wet Year - Upper (50 cfs at 23.5C)	Natural Very Wet Year - Lower (60 cfs at 22.5C)
105	27.27	25.81	25.45	25.92	25.17
106	27.19	25.85	25.48	25.94	25.18
107	27.16	25.89	25.51	25.96	25.21
108	27.29	25.97	25.57	26.01	25.26
109	27.38	26.05	25.63	26.06	25.31
110	27.39	26.1	25.67	26.09	25.35
111	27.16	26.03	25.59	26	25.28
122 (Indian Cr)	27.4	25.72	25.42	25.9	25.14
123	27.34	25.77	25.43	25.91	25.16
124	27.47	25.86	25.48	25.95	25.2
125	27.84	26.02	25.58	26.04	25.27
126	28.07	26.15	25.67	26.12	25.34
127	28.32	26.28	25.76	26.2	25.42
128	28.19	26.4	25.85	26.28	25.51
129	28.22	26.53	25.96	26.36	25.61
130	28.3	26.61	26.01	26.41	25.66
131	27.94	26.15	25.44	25.83	25.05

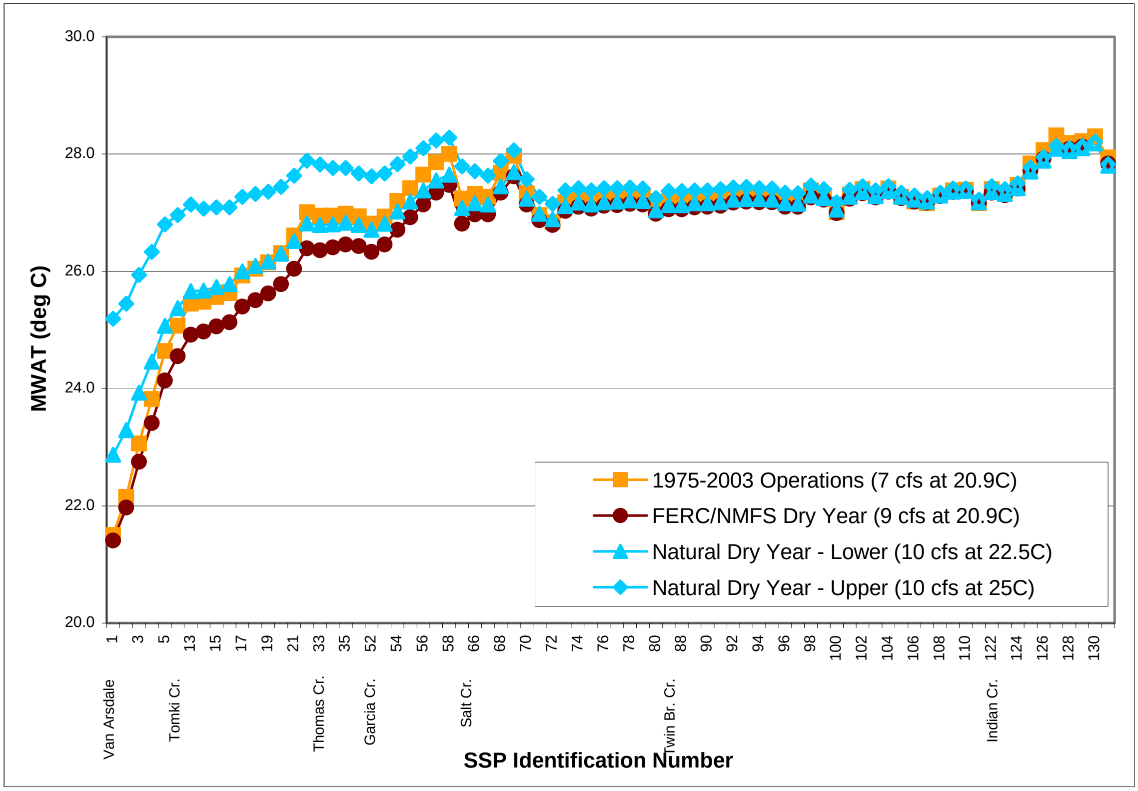

Figure A-53. MWAT values for dry year flow scenarios at each SSP on the main stem

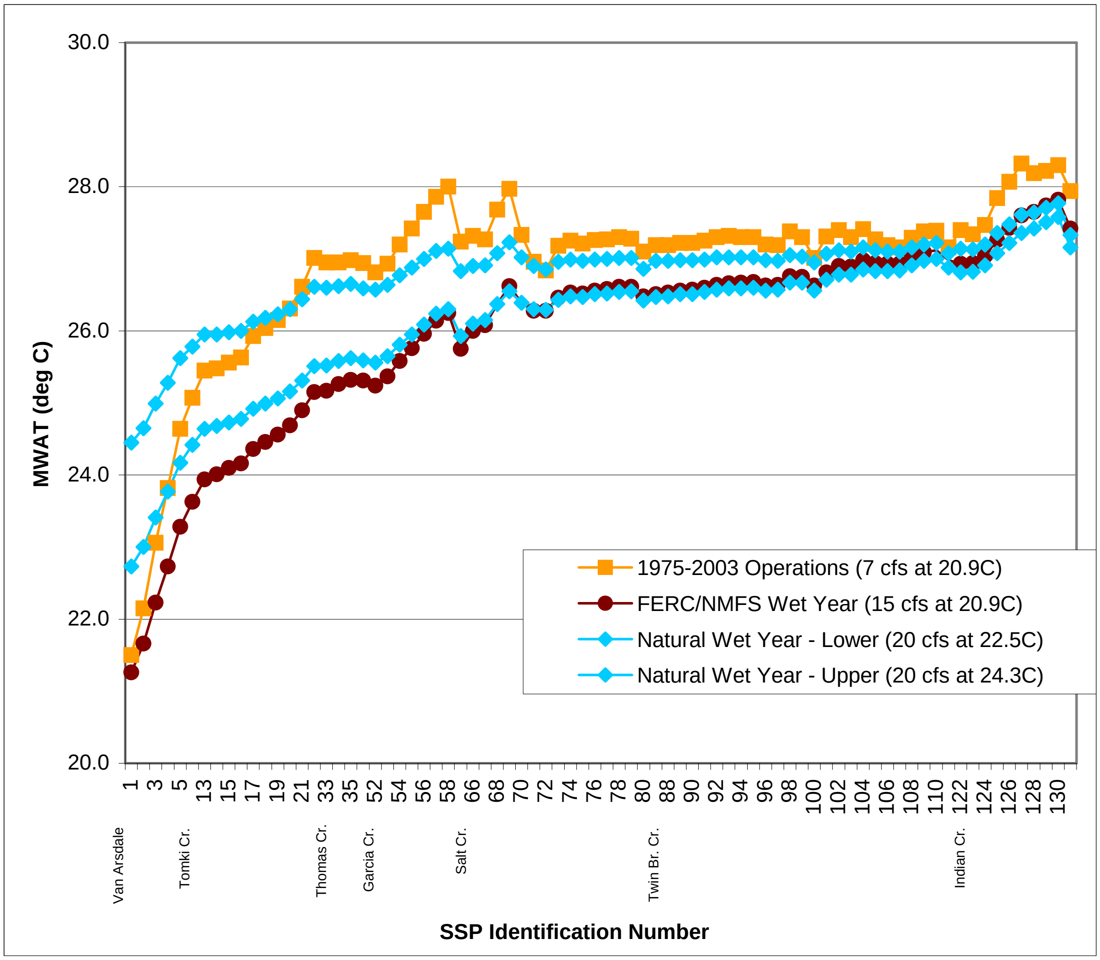

Figure A-54. MWAT values for wet year flow scenarios at each SSP on the main stem

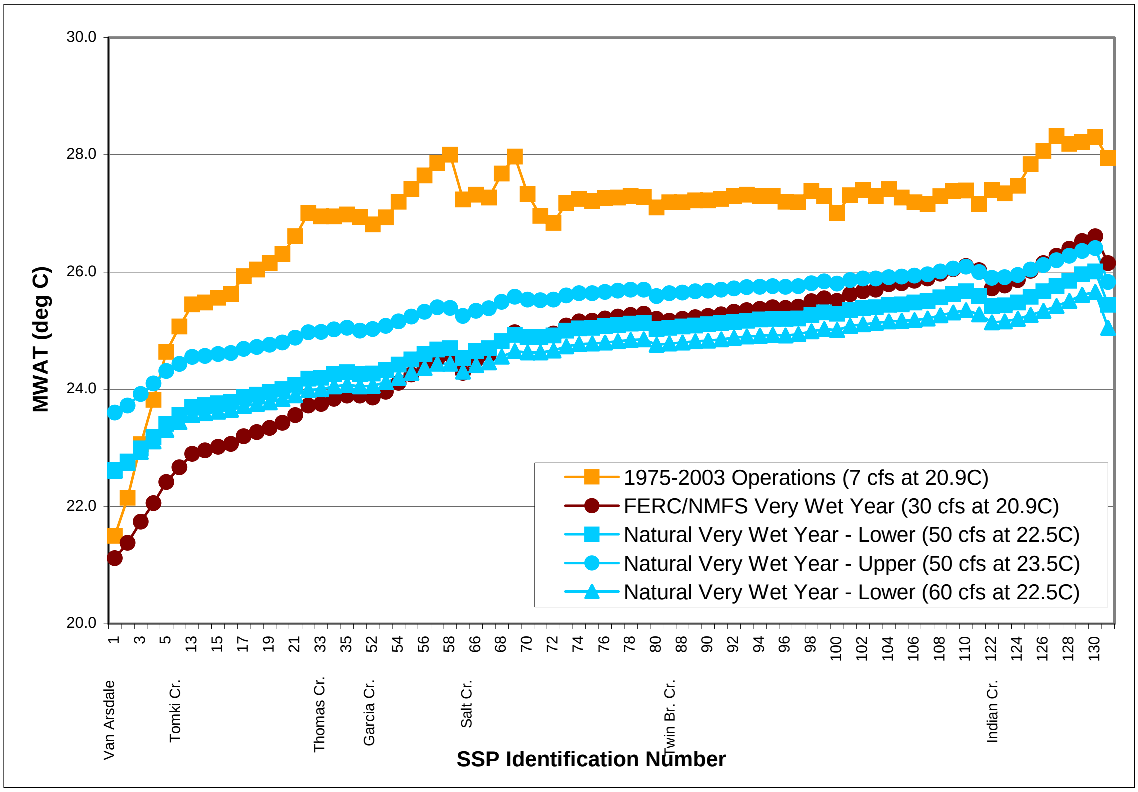

Figure A-55. MWAT values for very wet year flow scenarios at each SSP on the main stem

A.6 References

Brown, L. C., and Barnwell, Jr.,T. O. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and Users Manual. EPA-600/3-87/007

California Data Exchange Center (CDEC). 2004. California Department of Water Resources. <http://cdec.water.ca.gov>

Chen, Y. D, Carsel, R. F., McCutcheon, S. C., and Nutter, W. L. 1998a. Stream Temperature Simulation of Forested Riparian Areas: I. Watershed-Scale Model Development. Journal of Environmental Engineering 124(4): 304-315.

Chen, Y. D, McCutcheon, S. C., Norton, D. J., and Nutter, W. L. 1998b. Stream Temperature Simulation of Forested Riparian Areas: II. Model Application. Journal of Environmental Engineering 124(4): 316-328.

California Department of Fish and Game Reports 1997. Stream Inventory Report; Tomki Creek, Mainstem Eel River. Salmon and Steelhead Restoration and Enhancement Program. North Coast Basin Planning Project.

Garman, S. L., Acker, S. A., Ohmann, J. L., and Spies, T. A. 1995. Asymptotic Height-Diameter Equations for Twenty-Four Tree Species in Western Oregon. College of Forestry – Forest Research Laboratory, Oregon State University.