Appendix B: Temperature Analysis

This appendix describes site selection, data inputs, and results of temperature analysis done using SSTEMP on selected reaches of the Salmon River.

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B.1 Sources of Increased Stream Temperatures

The water bodies in the Salmon River watershed are included on the 303(d) list as impaired for temperature. Increased surface water temperatures can result from point and non-point sources. Because there are no known point sources of heat input to the streams of the Salmon River watershed, temperature loads from point sources are not considered further in this document.

B.1.1 Temperature Sources: Stream Heating Processes

water temperature is a measure of the total heat energy contained in a volume of water. Stream temperature is the product of a complex interaction of heat exchange processes. These processes include heat gain from direct solar (short–wave) radiation; both gain and loss of heat through long-wave radiation, convection, conduction, and advection; and heat loss from evaporation (Brown 1980; Beschta et al. 1987; Sinokrot and Stefan 1993; Theurer et al., 1984).

- Net direct solar radiation reaching a stream surface is the difference between incoming radiation and reflected radiation, reduced by the fraction of radiation that is blocked by topography and stream bank vegetation (Sinokrot and Stefan, 1993). At a given location, incoming solar radiation is a function of the suns position, which in turn is determined by latitude, day of the year, and time of day. During the summer months, when solar radiation levels are highest and streamflows are low, shade from streamside forests and vegetation can be a significant control on direct solar radiation reaching streams (Beschta et al., 1987).

- Long-wave radiation emitted from the water surface can cool streams. Heat exchange via long-wave radiation at a stream surface is a function of the difference between air temperature and water surface temperature (Sinokrot and Stefan, 1993; ODEQ, 2000). During the course of a 24-hour period, heat leaving and heat entering a stream via long-wave radiation generally balance (Beschta, 1997; ODEQ, 2000).

- Evaporative heat losses are a function of the vapor pressure gradient above the stream surface and wind conditions (Sinokrot and Stefan, 1993). Evaporation tends to dissipate energy from water and thus tends to lower temperatures. The rate of evaporation increases with increasing stream temperature. Air movement (wind) and low vapor pressures (dry air) increase the rate of evaporation and accelerate stream cooling (ODEQ, 2000).

- Convection describes heat transferred between the air and water via molecular and turbulent motion. Heat is transferred from areas of warmer temperature to areas of cooler temperature. The amount of heat transferred by this mechanism is generally considered low (Brown 1980; Sinokrot and Stefan, 1993).

- Conduction is the means of heat transfer between the stream and its bed. In shallow streams, solar radiation may be able to warm the streambed (Brown, 1980). Bedrock or cobbles on the streambed may store heat and conduct heat back to the water if the bed is warmer than the water (ODEQ, 2000). Likewise, water can lose or gain heat as it passes through subsurface sediments during intra-gravel flow through gravel bars and meanders. Bed conduction is a function of the thermal conductivity of the bed and the temperature gradient within the bed (Sinokrot and Stefan, 1993). A streambed that has absorbed radiant energy during the day will conduct that energy back to the stream at night.
- Advection is heat transfer through the lateral movement of water as stream flow or groundwater. Advection accounts for heat added to a stream by tributaries or groundwater. This process may warm or cool a stream depending on whether a tributary or groundwater entering the stream is warmer or cooler than the stream.

Each of the heat fluxes discussed above can be represented by mathematical equations. By adding the values of the fluxes for a particular location, the net of the heat fluxes associated with all of these processes can be calculated (Theurer et al., 1984). The net heat flux represents the change in the water body's heat storage. The net change in storage may be positive, leading to higher stream temperatures, negative, leading to lower stream temperatures, or zero such that stream temperature does not change.

B.2 Analytical Methods

The modeling objective was to evaluate effects of management and land use factors, such as fire, timber harvest, roads, and landslides, on stream temperature.

The approach taken to develop this technical TMDL for stream temperature in the Salmon River watershed involved the use of a computer simulation model to investigate stream heating processes. The USGS SSTEMP model was used to evaluate the relative importance of the various factors that combine to produce the observed stream temperatures, and to evaluate what impact changes in stream shade, channel geometry, and flow may have on the stream temperature regime. The SSTEMP model is intended for application to a segment or reach of a stream or river (Bartholow, 2002). Figure B-1 depicts the basic input parameters required. In this figure, Q refers to flow, and T refers to stream temperature.

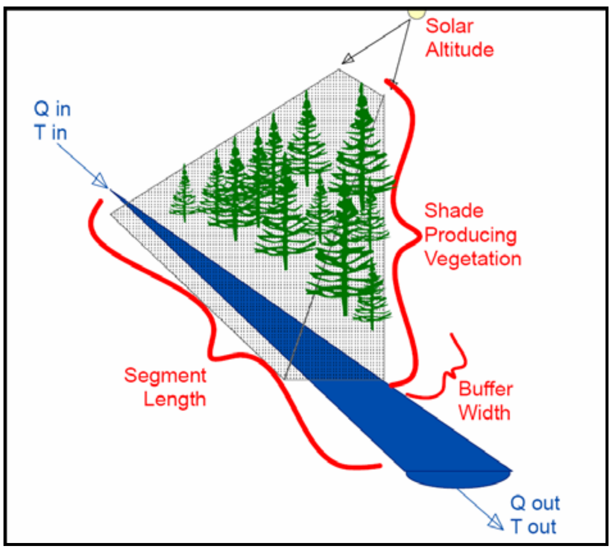


Figure B-1 Stream Reach Characteristics

Available data on the spatial and temporal distribution of stream and air temperature were assembled for the Salmon River watershed. Data on other parameters, including the wetted widths of streams, and flow rates necessary for stream temperature modeling were measured monthly. Active channel widths were measured at each site. Segments were chosen to address the modeling objectives. SSTEMP requires upstream flow and temperature as model inputs. Calibration of the model requires downstream temperature data. Selected segments had temperature data available both upstream and downstream, and a flow measurement for at least one location on the segment. The dates chosen for the simulations included both days of flow measurements as well as the MWAT date for 2002. Refer to Figure B-2 for locations of each segment.

The following sections describe the data requirements of the model, how the data was developed, and the results of the modeling exercise.

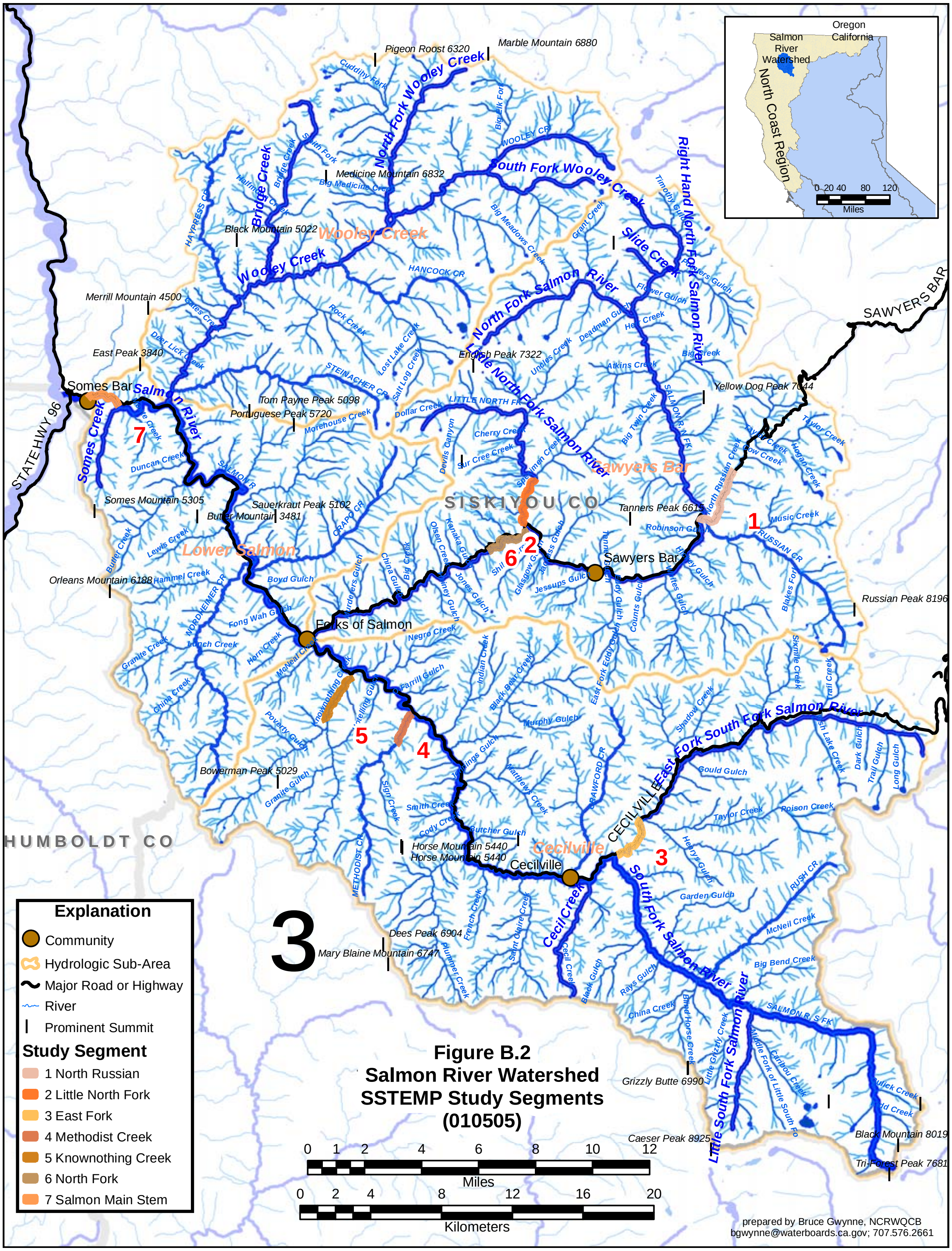


Figure B.2 Salmon River Watershed SSTEMP Study Segments

The parameters required for the SSTEMP model and sources for these data are summarized in Table B-1.

Table B-1 SSTEMP Variable Input Requirements

Table B-1 SSTEMP Variable Input Requirements		
Variable	**Data Source**	**Comments**
Hydrologic Data		
Segment Inflow*	Calculated	Drainage area / flow relationship
Inflow Temperature*	Measured	Continuously logged 6/02 thru 11/02
Segment Outflow*	Measured	Measured during 2002 summer months
Accretion (Groundwater) Temperature*	Weather station data	Average annual air temperature
Geometric Data		
Latitude (°)	USGS 7.5 minute quad. map	
Segment Length	USGS 7.5 minute quad. map	
Upstream Elevation	USGS 7.5 minute quad. map	
Downstream Elevation	USGS 7.5 minute quad. map	
Width's B Term*	Calculated	USGS Salmon River (RM1) gage data
Width's A Term*	Calculated	USGS Salmon River (RM1) gage data
Manning's n*	Default	Value verified: (Barnes, 1967)
Meteorologic Data		
Air Temperature*	Measured	Segments 1 thru 5: data loggers deployed; Segments 6 & 7: weather station data.
Relative Humidity*	Local weather station data	Corrected to each segments air temperature
Wind Speed*	Local weather station data	
Ground Temperature*	Calculated	Corrected to each segment's elevation
Thermal Gradient (j/m^2/s/C)*	Default	SSTEMP suggested value
Possible Sun (%)*	Local weather station data	
Solar Radiation*	Local weather station data	90% of recorded value
Shade Data		
Total Shade(%)*	Measured directly and calculated	Measured: Solar Pathfinder measurements Calculated: see vegetation and geometric input data sources
Vegetation Height	Model estimate	Simulated by UCDavis - ICE
Offset	Measured and calculated	Measured: Vegetation survey and solar pathfinder data Calculated: Bankfull and wetted width relationship
Crown Diameter	Estimated in field	Field picture logs
Density	Estimated in field	Similar watershed vegetation studies
Azimuth	USGS 7.5 minute quad. map	
Topographic Altitude	USGS 7.5 minute quad. map	
Time of Year		
Month/Day		Date of available data and the MWAT date
* Input parameter that was varied as part of the sensitivity analysis.		

B.2.1 Meteorologic Data

The Klamath National Forest Service maintains two weather stations within the watershed. One is located in the area of Somes Bar near the mouth of the Salmon River. The other weather station in the watershed is at Sawyers Bar near the center of the watershed. These weather stations provided data on a variety of meteorological parameters. Mean annual air temperature was used to approximate ground and groundwater (accretion) temperature. Observed mean annual air temperatures were corrected for elevational differences between the weather station and each segment using the adiabatic lapse rate. The weather stations also provided mean daily values for wind speed, solar radiation and relative humidity. For solar radiation values, SSTEMP suggests using 90% of the ground-level solar radiation data, with the reduction representing the amount of heat lost before actually entering the water. Relative humidity data were corrected for temperature differences between the weather station and each modeled segment. Air temperature data loggers set to record hourly were deployed at each segment. Air temperature data for each segment was utilized for relative humidity corrections as well as for calculating mean daily values for input into SSTEMP. The remaining two meteorological parameters, possible sun and thermal gradient, used SSTEMP model suggested values.

B.2.2 Hydrologic and Geometric Data

Data was collected for the hydrologic and geometric parameters required for input into the SSTEMP model. These parameters include: flow, water temperature, and stream widths. For Manning's n, the suggested value given by SSTEMP was used. This Manning's n value was verified by referring to the following USGS web site; Surface Water Techniques: Verified Roughness Characteristics of Natural Channels (Barnes, 1967).

B.2.2.1 Stream Flow Estimation

Stream flow was measured at least once a month from June through September 2002, on the Salmon River at Somes Bar, North Fork at Sawyers Bar, and South Fork at Cecilville. Flow was measured during the months of July, August, and September on: the North Russian at the log bridge; the North Fork below Little North Fork; and the mouths of the Little North Fork, Methodist Creek, and Knownothing Creek. The East Fork was measured in the month of July. The USGS gaging station, 11522500 SALMON R at SOMES BAR CA, located at River Mile 1, is continuously logging throughout the year and was included as well.

Table B-2 contains location names and coordinates of locations where flow measurements were taken or used for this analysis. Where flow measurements were not available, a relationship between stream flow and drainage area was developed from the above compiled data and associated drainage areas. This relationship allowed estimation of stream flow at locations and times without measurements. Figure B-3 shows the stream flow-drainage area relationship that was developed. This stream flow-drainage area relationship provides an adequate basis for estimating stream flow in a stream-temperature-modeling context.

Table B-2 SSTEMP Flow Measurement Data Collection Sites

SSTEMP Segment	**Downstream Location**	**Latitude (north)**	**Longitude (west)**	**Elevation (meters)**
North Russian	Log Bridge	41.32642	123.05563	806.8
Little North Fork	Mouth	41.32108	123.17909	603.5
East Fork	East Fork C.G.	41.15343	123.10901	729.4
Methodist Creek	Mouth	41.22183	123.25009	454.5
Knownothing Creek	Mouth	41.24287	123.29234	400.5
North Fork	At Boulder Gulch	41.30658	123.20286	569.1
Salmon Mainstem	River Mile One	41.37698	123.47721	147.2

B.2.2.2 Stream Temperatures

Stream temperatures were measured continuously every hour at the upstream and downstream boundaries of each segment modeled from June through September 2002. These data were used for model calibration, as well as characterization of current stream temperatures as discussed in chapter 3 of the TMDL report.

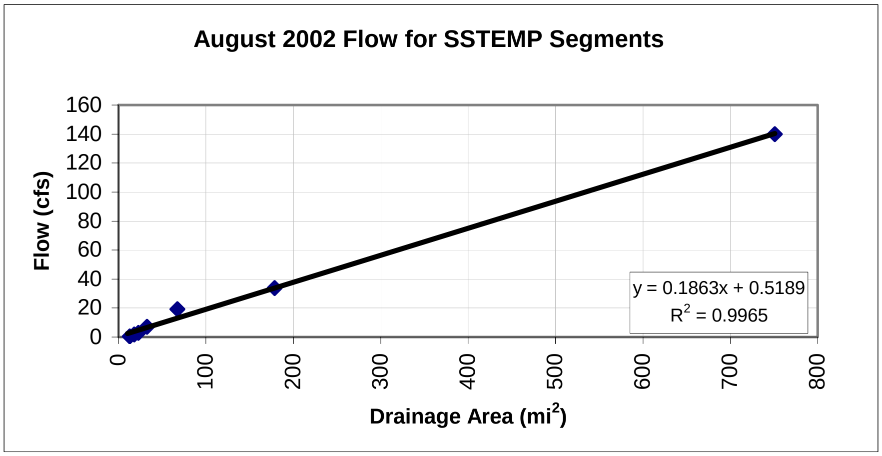


Figure B-3 Salmon River Flow vs. Drainage Area Relationship

B.2.2.3 Width-Discharge Relationship
SSTEMP (Bartholow, 2002) requires an estimate of mean stream width as a function of discharge: $W = A*Q^b$. The width's A and B terms are determined by plotting wetted width vs. discharge on a log-log plot. This relationship approximates a straight line, the slope of which is the B term. This value was determined from flow measurement records from the USGS gage located at Somes Bar (Figure B-4), and was applied to all segments.

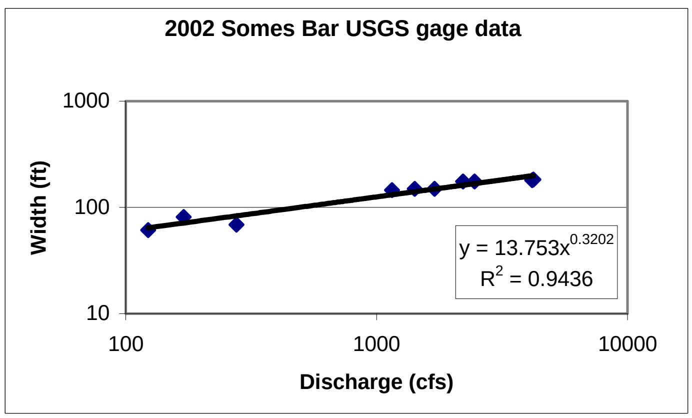
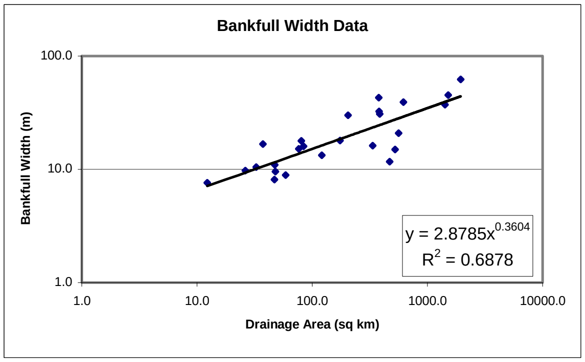


Figure B-4 Salmon River Width-Discharge Relationship

B.2.2.4 Bankfull Width Estimates
Bankfull width is a characteristic of all stream channels and corresponds to the top width of a stream flowing under bankfull conditions. In the simplest of channels, bankfull flow is the greatest flow the channel can accommodate before flooding occurs. Bankfull water levels correspond to the gage height of incipient flooding, submerged point bars, changes in bank slope, differences in substrate, and often differences in vegetation (Leopold, 1994). In this analysis, bankfull widths are based on current conditions as observed in the field and were used to approximate the width of the un-vegetated channel, or the first occurrence of shade producing vegetation.

Bankfull width values for each segment were assigned using a relationship for the Salmon River watershed (Figure B-5) developed for this project. The relationship used bankfull width estimates made by North Coast Regional Water Quality Control Board (NCRWQCB) and the Information Center for the Environment (ICE) at UC Davis staff at both upstream and downstream ends of each segment, together with each segment's associated drainage area. The equation derived from the line best fitting this data was applied to all segments. These values were then applied to both current and potential simulations. No attempt was made to quantify the potential for channel narrowing.

B.2.2.5 Wetted Width Estimates
The same procedure used to develop the bankfull width and drainage area relationship was also used in developing wetted width estimates (Figure B-6). The wetted width relationship was used with the bankfull width relationship to estimate the offset of shade producing vegetation from the stream channel. This offset is required input for calculating effective shade.



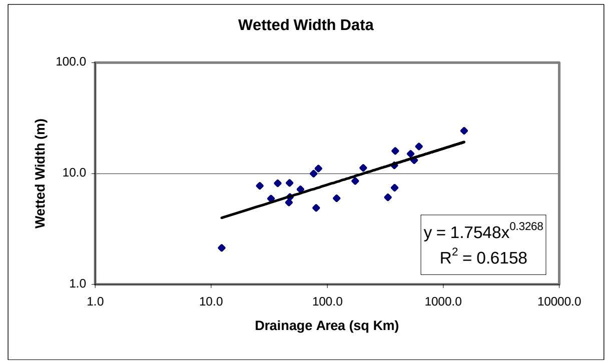


Figure B-5 and B-6 Salmon River Measured Bankfull Widths with Associated Drainage Areas and Salmon River Measured Wetted Widths with Associated Drainage Areas.

B.2.3 Vegetation Data
Stream shade is an important factor in the temperature dynamics of streams, therefore information describing current and natural stream shade conditions is important in evaluating the influence of management on stream temperatures. Stream shade is a function of topography, orientation, atmospheric conditions, time of year, and the effective shade produced by the riparian vegetation (i.e. size, position, and density). The Regional Water Board contracted with the ICE at UC Davis to provide riparian tree height estimates, which ICE developed, as explained in the vegetation height and characteristics section.

B.2.3.1 Vegetation Height and Characteristics
SSTEMP requires either a specified shade value or input on near stream geometry with respect to shade, including vegetation height and extent. Vegetation information was developed by Regional Water Board staff in cooperation with ICE at UC Davis, through vegetation surveys within each of the modeled segments and subsequent calculations.

The California Existing Vegetation GIS dataset was the primary source of distributed (watershed-scale) vegetation information. Particularly useful database fields included the vegetation classification by Wildlife Habitat Relationships (WHR) type and tree size classes (classified into diameter at breast height [dbh] ranges). In the GIS dataset, WHR types were identified on a polygon basis. A polygon is a closed shape defining an area of similar characteristics. This dataset contains a 10 meter grid size, which is also the smallest WHR polygon possible. To describe potential vegetation height conditions, the mature tree heights for hardwoods and conifers by vegetation class (WHR type) were combined with derived percent conifer and percent hardwood values to calculated polygon-specific potential vegetation heights. Site potential was assumed to be uniform for all sites. For current vegetation conditions, an additional step was performed. Each polygon in the GIS coverage has an associated dbh class. Using the conversions in Table B-3 along with field survey measurements, dbh information was converted to estimated current vegetation heights for each polygon.

A summary containing tree species occurring in the Salmon River watershed was compiled by ICE from published reports and field observations. For each species, reported heights of mature trees were compiled from a variety of sources (Burns and Honkala, 1990; Hickman, 1993; Munz and Keck, 1968; Sudworth, 1908; Whitney, 1998). For each tree species, a mature tree height considered to be representative of tree heights in riparian areas of this region of California was selected from the compiled values (Table B-3). In addition, estimated tree heights associated with dbh classes were developed (Burns and Honkala, 1990) for later use in characterizing current vegetation height conditions. Next, key tree species associated with the Klamath Region Vegetation Mapping Project habitat database vegetation types were identified.

B.2.3.2 Vegetation Coverage

In order for SSTEMP to accurately position the riparian vegetation along the stream, the distance from the waters edge to the edge of the bankfull or active channel must be determined.

The underlying stream network was developed from USGS topographic data by ICE. The un-vegetated active channel was defined using bankfull width, centered on the centerline of the stream channel. This combined with wetted-widths allowed for reasonable estimates of the un-vegetated active channel widths. Bankfull widths and wetted widths for each segment were assigned using relationships for the Salmon watershed developed for this project (Section B.2.2).

B.2.4 Effective Shade Estimates

Effective shade calculations require information on both stream geometry and vegetation. Effective shade predictions were calculated by two separate shade calculators: the shade calculator within SSTEMP, and the shade calculator from the February 18, 1998 version of Heat Source, a computer model that simulates stream temperatures. Table B-4 contains all input parameters and values required in each calculator and scenario. Shade was calculated with both models. Vegetation heights for current and potential shade were developed from ICE results.

SSTEMP and Heat Source handle topographic inputs slightly differently. Topographic altitude in SSTEMP requires a value of average incline to the horizon from the middle of the stream looking perpendicular to the direction of flow. In Heat Source, topographic shade is measured in 90^{o} intervals for each compass direction (i.e. west, south, and east).

Other differences between inputs are in name only. In the Heat Source shade simulator, aspect is the same as SSTEMP azimuth. Heat Source NSDZ width is set equal to bankfull width. NSDZ and wetted widths are used to calculate vegetation offset. In SSTEMP, vegetation offsets are set equal to one-half the difference between bankfull width and wetted width for the segment. Thus, these two sets of inputs are equivalent for these calculations.

Table B-5 shows solar pathfinder values developed from field measurements taken in situ during the summer of 2002. Field collection was limited to upstream and downstream ends of each segment. Shade was measured at 100 meter intervals. For each segment a reach average value was developed from all measurements made upstream and downstream. This average value for each segment was developed to compare with calculated values. Table B-5 values were developed to match dates of flow measurement which were in late August for all reaches except the East Fork, which was late July.

Table B-3 Summary of Tree Species and Mature Height Estimates for Near-Stream Vegetation Characteristics

Tree Names			Mature Height											Selected Value	
			Sudworth		Whitney	Burns and Honkala		Munz and Keck		Jepson Manual		Preston			
Common	**Generic**	**Specific**	**Typical (ft)**	**Extreme (ft)**	**(ft)**	**(ft)**	**(m)**	**(ft)Calc.**	**(m)**	**(ft)Calc.**	**(m)**	**(ft)**	**(m)Calc.**	**(ft)**	**(m)**
Conifers															
Douglas Fir	Psudotsuga	menziesii	180-190	200	80-200	250	76	<230	<70	<220	<67	<300	<92	190	58
Ponderosa Pine	Pinus	ponderosa	125-140	150-200		130	40	50-230	15-70	<225	<68	150-180	46-55	130	40
Sugar Pine	Pinus	lambertiana	160-180			175-250	53-76	66-246	20-75	<230	<70	175-200	53-61	175	
Incense-Cedar	Calocedrus	decurrens	75-90	100-110		60-150	18-46	66-115	20-35(-50)	66-164	20-50	80-120	25-37	90	
Pacific Yew	Taxus	brevifolia	20-50	60-75		50-60	15-18	16-80	5-25	<60	<18	20-50	6-15	50	
White Fir	Abies	Concolor	140-180	200		130-180	40-55	50-230	15-70	<200	<61	120-150	37-46	150	
Shasta Red Fir	Abies	magnifica var. shastensis	125-175	200				66-197	20-60	<187	<57	150-180	46-55	150	
Mountain Hemlock	Tsuga	mertensiana	25-60-80	100-125		50-150	15-46	66-148	20-45	<115	<35	75-100	23-31	75	
Western White Pine	Pinus	monticola	90-100			200	60	50-164	15-50	<240	<73	90-180	28-55	100	
Lodgepole Pine	Pinus	contorta	20-100			50-100		10-33	3-10(-16)	7-112	2-34	70-80	22-25	75	
Brewer's Spruce	Picea	breweriana	50-75	100		160	49	100	30	<174	<53			75	
Hardwoods															
Canyon Live Oak	Quercus	chrysolepis	30-40			60-100	18-30	20-65	6-20	<65	<20	60-80	18-25	40	
Black Oak	Quercus	kelloggii	50-75	80-85		80-130	25-40	33-80	10-25(>25)	<82	<25	60-90	18-28	70	
Pacific Madrone	Arbutus	menziesii	60-80		20-80	110	34	16-130	5-40	<130	<40	20-100	6-31	110	34
Bigleaf Maple	Acer	macrophyllum	60-80		30-70	50-100	15-30	15-100	5-30	15-100	5-30	80-100	25-31	70	21
California Bay	Umbellularia	californica	30-40	60-80	40-80	100	30	100-150	30-45	<150	<45	20-80	6-25	110	34
White Alder	Alnus	rhombifolia	50-75		70			35-115	10-35	<115	<35			70	21
Red Alder	Alnus	rubra	60-90		40-100	100-130	30-40	50-80	15-25	<80	<25	80-100	25-31	80	24
Mountain Alder	Alnus	icana spp. tenuifolia	20-25					3-10(-23)	1-3(-7)	<33	<10	30	9	25	
Sitka Alder	Alnus	viridis spp. sinuata	20-30					5-10	1.5-3	<26	<8	40	12	30	
Tanoak	Lithocarpus	densiflorus	50-75	80-85	50-80	150	46	65-150	20-45	<100	<30	70-90	22-28	90	27
Mackenzie's Willow	Salix	prolixa	15-18					20	<6	<16	<5			15	
Scouler's Willow	Salix	scouleriana						3-33	1-10	<33	<10			30	
Sitka Willow	Salix	sitchensis	20-25					6-23	2-7	<23	<7			20	

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Table B-4 Salmon River Watershed Optional Shading Parameters and Associated Values

SSTEMP Shade Calculator Input Data

Segment ID number	Segment Azimuth (deg)	Topographic Altitude (deg)		Vegetation Height (m)				Crown Diameter (m)		Vegetation Offset (m)		Vegetation Density %	
				Current		Adjusted Potential		Current		Current		Current	
		West side	East side	West side	East side	West side	East side	West side	East side	West side	East side	West side	East side
1	25	21	22	24.3	24.3	48.4	48.4	7.9	7.9	2.6	2.6	80.0	80.0
2	10	24	23	25.8	25.8	48.8	48.8	7.8	7.8	3.3	3.3	80.0	80.0
3	32	21	21	19.1	19.1	42.8	42.8	8.7	8.7	4.5	4.5	80.0	80.0
4	29	16	30	19.3	19.3	42.5	42.5	8.4	8.4	2.3	2.3	80.0	80.0
5	28	23	24	21.7	21.7	48.3	48.3	7.5	7.5	2.5	2.5	80.0	80.0
6	54	23	22	24.0	24.0	47.6	47.6	10.7	10.7	6.6	6.6	80.0	80.0
7	- 80	24	24	15.0	15.0	38.8	38.8	5.3	5.3	11.6	11.6	80.0	80.0

Heat Source Shade Simulator Input Data

Segment Number	Latitude (deg N)	Longitude (deg W)	Elevation (m)	Aspect (deg)	Wetted Width (m)	NSDZ Width (m)	Riparian Inputs				Topographic Shade		
							Height (m)	Width (m)	Density (%)	Overhang (m)	West (deg)	South (deg)	East (deg)
1	41.341	123.044	879.2	25	6.0	11.1	24.3 / 48.4	90	80	0.0	29	17	27
2	41.334	123.179	653.5	10	7.4	14.0	25.8 / 48.8	90	80	0.0	25	3	30
3	41.159	123.097	750.3	32	9.4	18.4	19.1 / 42.8	90	80	0.0	20	20	18
4	41.216	123.255	499.3	29	5.4	9.9	19.3 / 42.5	90	80	0.0	16	15	27
5	41.229	123.302	455.7	28	5.9	10.9	21.7 / 48.3	90	80	0.0	23	22	23
6	41.313	123.193	585.4	54	13.1	26.4	24.0 / 47.6	90	80	0.0	20	23	14
7	41.371	123.447	150.9	-80	20.8	43.9	15.0 / 38.8	90	80	0.0	24	31	12

Table B-5 Solar Pathfinder Values for Modeled Reaches

Station	Segment	% Vegetative	% Topographic	Total % Shade	Averages
N. Russia at 23 mp	**1 u/s**	52.2	20	72.2	
		32.2	20	52.2	
		42	18.5	60.5	**61.6**
N. Russian at Logbridge	**1 d/s**	66	7	73	
		65.7	9	74.7	
		52.2	7	59.2	**69.0**
Little N. Fork below Specimen Creek	**2u/s**	42.7	16	58.7	
		17.7	21	38.7	
		21.5	10	31.5	**43.0**
Little North Fork @ Hobo	**2 d/s**	25.3	17	42.3	
		32.3	24	56.3	
		59	7.5	66.5	
		44.8	30	74.8	**60.0**
E. Fork above Taylor Creek	**3 u/s**	16.8	17	33.8	
		0	39	39	
		0	44.5	44.5	**39.1**
E. Fork above S. Fork	**3 d/s**	92	0	92	
		62	0	62	
		51	0	51	
		88	0	88	**73.3**
Methodist Creek - upper site	**4 u/s**	33.6	20	53.6	
		35	30	65	**59.3**
Methodist Creek - Lower site @ mouth	**4 d/s**	51.1	3	54.1	
		41.7	5.5	47.2	
		40.6	7	47.6	**49.6**
Knownothing below Forks	**5 u/s**	37.4	22	59.4	
		45.5	32.5	78	
		51.8	18	69.8	**69.1**
Knownothing Creek ~6m u/s Hobo	**5 d/s**	45.2	3.5	48.7	
		49.8	10	59.8	
		71.6	3	74.6	
		68.5	10	78.5	**65.4**
N. Fork ~35m blw con w/ Little N. Fork	**6 u/s**	0	35	35	
		3.6	11	14.6	
		0	17	17	**22.2**
N. Fork ab Boulder Gulch	**6 d/s**	0	19.8	19.8	
		0	23	23	
		0	38.5	38.5	**27.1**
MS u/s Wooley Creek 15m ab bridge	**7 u/s**	0	23.5	23.5	
		0	25	25	
		0	23	23	**23.8**
MS 112m u/s USGS Gauge	**7 d/s**	0	18	18	
		0	3.5	3.5	
		0	4	4	**8.5**

Table B-6 shows predicted values for current conditions from each calculator, as well as solar pathfinder values from field measurements made by Regional Water Board staff. The Heat Source calculator was chosen because its predicted values fall closer to the field measurements. In addition it has robust input variables and can be used to easily run specific scenarios. For the mainstem location, field shade measurements (16.2%) were used in place of the simulated value of zero. Because the SSTEMP sensitivity analysis varies input values by +/- 10%, a zero value would predetermine the results. To enable the significance of shade to be evaluated, the measured (non-zero) value was used.

Table B-6 Total Percent Shade Comparisons of Current Conditions for Flow Measurement Dates

Segment	Solar Pathfinder Measurements (% Shade)	Heat Source Shade Simulator (% Shade)	SSTEMP's Shade Calculator (% Shade)
North Russian Creek	65.3	74.6	78.5
Little North Fork	51.5	71.4	67.9
East Fork	56.2	51.3	61.2
Methodist Creek	54.5	73.6	81.5
Knownothing Creek	67.2	73.8	78.0
North Fork	24.6	51.4	61.3
Salmon Mainstem	16.2	0.0	4.1

B.3 Stream Temperature Simulations and Results

The dynamics of stream heating processes are complex and non-linear. The degree to which a change in one factor will affect stream temperature depends on the values of other factors. Regional Board staff used the SSTEMP models capability for a sensitivity analysis of input value to give an indication of which parameters most strongly influence stream temperatures. Stream temperature modeling is a well-developed area of investigation and has been used extensively throughout the world to understand stream heating processes. The model was used to identify which factors affect stream temperatures the most and to evaluate the potential change in stream temperatures that could be expected as a result of changes to variables that can be affected by management. The hydrologic, meteorologic, and geometric parameters with associated values for each scenario that go into the SSTEMP model are presented in Table B-7.

B.3.1 Sensitivity Analysis and Results

Sensitivity analysis is a technique that can be used to understand the influences that various stream geometry, meteorological, and hydrological conditions have on stream temperature (Bartholow, 2002). The primary uses for sensitivity analysis in this report are to rank parameters and their interactions according to effects on predicted stream temperatures, and to identify the most important management-related parameters.

B.3.1.1 Approach

The sensitivity analysis approach used in this analysis is based on varying the value of one parameter while holding others constant. The approach uses the SSTEMP model to estimate the magnitude of effects that meteorological and stream conditions have on stream temperatures by using reasonable values of these parameters under different scenarios. This approach investigates the effect an individual parameter has on stream temperatures in reaches of both small (drainage area = 58.8 km^2 [22.7mi^2]) and large (drainage area = 1944.6 km^2 [750.8mi^2]) drainages. Lower Knownothing Creek was chosen to represent low order streams in the Salmon River watershed, while the Salmon River mainstem from just below Wooley Creek to the USGS gage was chosen to represent mainstem habitats.

Table B-7 Input Data for SSTEMP Analysis for Flow Measurement Dates

Meteorologic, Hydrologic and Geometric Parameters with Associated Values for Salmon River Water Temperature Sensitivity/Uncertainty Analysis

<u>Values used in all scenarios for all segments:</u>
Possible Sun: 90%
Manning's N: 0.035
Thermal Gradient: 1.65 J/m^2/s/C
Ground Temperature: same as accretion (groundwater) temperature
Width's B term: 0.3202
Width's A term: 13.753 s/m^2

Scenario	Inflow (cms)	Inflow Temp (^{o}C)	Outflow (cms)	Segment Length (km)	U/S Elev (m)	D/S Elev (m)	Air Temp (^{o}C)	Vege Height	Total Shade %	Date	U/S Latitude (radians)	Groundwater Temp (^{o}C)	Solar Rad. (Langleys)	Relative Humidity (%)	Wind Speed(m/s)
North Russian Creek, Current	0.0322	14.36	0.0515	4.01	951.6	806.8	20.77	24.28	74.6	8-28-02	0.72178	11.42	554.3	40.8	1.21
North Russian Creek, Potential	0.0322	14.36	0.0515	4.01	951.6	806.8	20.77	48.43	87.3	8-28-02	0.72178	11.42	554.3	40.8	1.21
Little North Fork, Current	0.1856	15.55	0.2013	3.32	703.5	603.5	19.87	25.81	71.4	8-28-02	0.72159	12.90	554.3	43.0	1.21
Little North Fork, Potential	0.1856	15.55	0.2013	3.32	703.5	603.5	19.87	48.76	81.4	8-28-02	0.72159	12.90	554.3	43.0	1.21
East Fork, Current	0.5390	17.24	0.5468	2.91	771.1	729.4	19.45	19.11	51.3	7-23-02	0.71857	12.27	596.5	65.8	1.30
East Fork, Potential	0.5390	17.24	0.5468	2.91	771.1	729.4	19.45	42.77	74.8	7-23-02	0.71857	12.27	596.5	65.8	1.30
Methodist Creek, Current	0.0065	15.97	0.0153	2.01	544.1	454.5	21.26	19.26	73.6	8-28-02	0.71921	13.91	554.3	39.6	1.21
Methodist Creek, Potential	0.0065	15.97	0.0153	2.01	544.1	454.5	21.26	42.47	88.1	8-28-02	0.71921	13.91	554.3	39.6	1.21
Knownothing Creek, Current	0.0128	14.72	0.0793	4.02	510.8	400.5	21.83	21.71	73.8	8-28-02	0.71934	14.20	554.3	38.3	1.21
Knownothing Creek, Potential	0.0128	14.72	0.0793	4.02	510.8	400.5	21.83	48.33	88	8-28-02	0.71934	14.20	554.3	38.3	1.21
North Fork, Current	0.9574	18.08	0.9747	3.19	601.7	569.1	22.5	23.95	51.4	8-27-02	0.72114	13.35	504.5	28.9	1.75
North Fork, Potential	0.9574	18.08	0.9747	3.19	601.7	569.1	22.5	47.55	76.6	8-27-02	0.72114	13.35	504.5	28.9	1.75
Mainstem, Current	3.8794	21.41	3.9644	5.63	154.5	147.2	27.32	14.99	16.2	8-28-02	0.72211	14.66	554.3	51.4	0.73
Mainstem, Potential	3.8794	21.41	3.9644	5.63	154.5	147.2	27.32	38.83	50.6	8-28-02	0.72211	14.66	554.3	51.4	0.73

The input parameters used for the sensitivity analysis of individual parameters are marked with an asterisk in Table B-1. The values of the parameters were varied individually +/- 10% from the initial conditions. Initial conditions and ranges of variation for the sensitivity analysis are presented below in Table B-8.

Table B-8 Summary of Parameters and Initial Values Used for SSTEMP Sensitivity Analysis

Parameter	Units	Reference Value		
		Knownothing Creek	Mainstem Salmon	Dependence
Air Temperature	°C (°F)	21.8 (55.0)	27.32(81.2)	+
Total Shade	%	73.8	16.2	-
Relative Humidity	%	38.3	51.4	+
Width's A Term	s/m^2	13.753	13.753	+
Width's B Term	Dimensionless	0.3202	0.3202	-
Segment Outflow	cms (cfs)	0.079 (2.79)	3.96 (140)	-
Possible Sun	%	90	90	+
Ground Temperature	°C (°F)	14.20 (57.56)	14.66 (58.39)	+
Manning's n	Dimensionless	0.035	0.035	-
Wind Speed	m/s	1.21	0.73	-
Thermal Gradient	Joules/m^2/sec/°C	1.65	1.65	-
Segment Inflow	cms (cfs)	0.0128 (0.45)	3.87 (137)	+
Inflow Temperature	°C (°F)	14.72 (58.50)	19.63 (67.33)	+
Note: Sensitivity analysis performed using SSTEMP sensitivity analysis function. Parameters were varied +/- 10% from the initial value.				
Note: Dependence column indicates temperature is directly dependent (+) or inversely dependent (-) on the parameter.				

B.3.1.2 Results

Results of the sensitivity analysis are presented in Figures B-7 and B-8. The results indicate that the sensitivity of daily mean stream temperature to changes in factors influencing stream temperatures depends on the size of the stream being analyzed.

Of the factors that determine stream temperatures, shade, flow, and channel geometry can be directly affected by management activities. Air temperature, relative humidity, wind speed, ground temperature, width-to-depth ratio, Manning’s n, and ground reflectivity can be indirectly affected by management activities. Shade, air temperature, wind speed and relative humidity interact with one another to create microclimates associated with riparian corridors, and thus have a direct effect on stream temperatures. In the Salmon River watershed, while these factors may be important, data are not sufficient to quantify the effect management has had or can have on microclimates.

Mainstem Salmon River. In the mainstem reach just below Wooley Creek, mean stream temperature was most sensitive to the segment inflow temperature. Mean stream temperature was also sensitive to air temperature, segment outflow (in this case a measure of groundwater contribution), segment inflow, solar radiation relative humidity, and widths A Term. Mean stream temperature is insensitive to the other parameters tested, including ground temperature, total shade, wind speed, thermal gradient, accretion temperature, Manning’s n, ground temperature, wetted channel widths B Term and possible sun. Sensitivities of maximum daily stream temperatures to changes in parameters in the mainstem reach are similar to the sensitivities of daily mean stream temperatures described above.

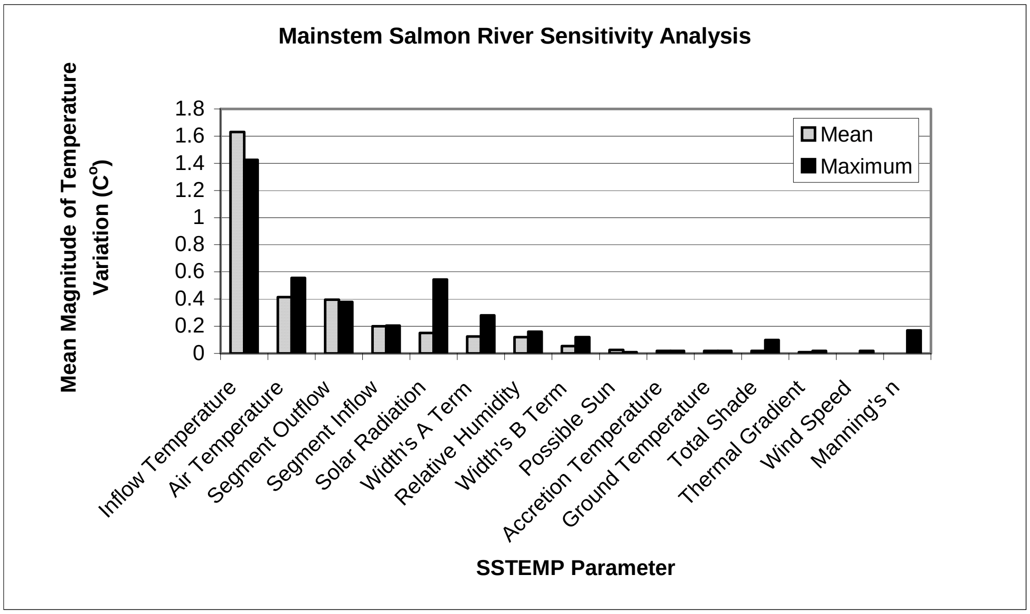

Figure B-7 Sensitivity Analysis of SSTEMP to +/- 10% Variation of Each Parameter, Salmon River Mainstem from below Wooley Creek to the USGS Stream Gage Segment Simulation, Sorted by the Effect on Mean Temperature.

Salmon River Tributary. In the smaller streams examined, mean stream temperature is most sensitive to air temperature, and is also sensitive to accretion temperature, total shade, relative humidity and solar radiation. Mean stream temperature is somewhat sensitive to segment outflow, ground temperature, and segment inflow. Mean stream temperature is not sensitive to the other parameters tested, including possible sun, thermal gradient, Manning's n, and wind speed. When the results are ranked by effect on the maximum stream temperature estimated by the model, total shade is the most important parameter; air temperature and solar radiation are also important. Maximum temperature is somewhat sensitive to accretion temperature and relative humidity, and is relatively insensitive to the remaining parameters including wind speed, wetted channel width and flow, ground temperature, thermal gradient, possible sun (a measure of cloud cover), Manning's n, and inflow temperature.

Discussion. Given the results of the sensitivity analysis, a logical question to ask is, "Why are smaller streams more sensitive to changes in effective shade than larger streams?" Stream geometry holds many of the answers. The ability of vegetation to provide shade to a watercourse is a function of the width and orientation of the stream. As streams become wider, taller trees are required to shade it. In smaller streams like Knownothing Creek, vegetation is able to consistently provide more shade than it can provide in larger, wider streams. In larger streams, if the wetted channel runs along the bank in an area of tall trees, there is likely to be substantial shade provided by those trees. However, given the fact that low-flow wetted channels shift or braid within the confines of their active channel, it is unlikely that substantial shade will be provided throughout a lengthy reach.

Total shade reflects circumstances of topography, vegetation, stream orientation, sun angle, and stream conditions in and near streams. The presence, type, height, and density of vegetation near streams all affect the nature and quantity of streamside shade.

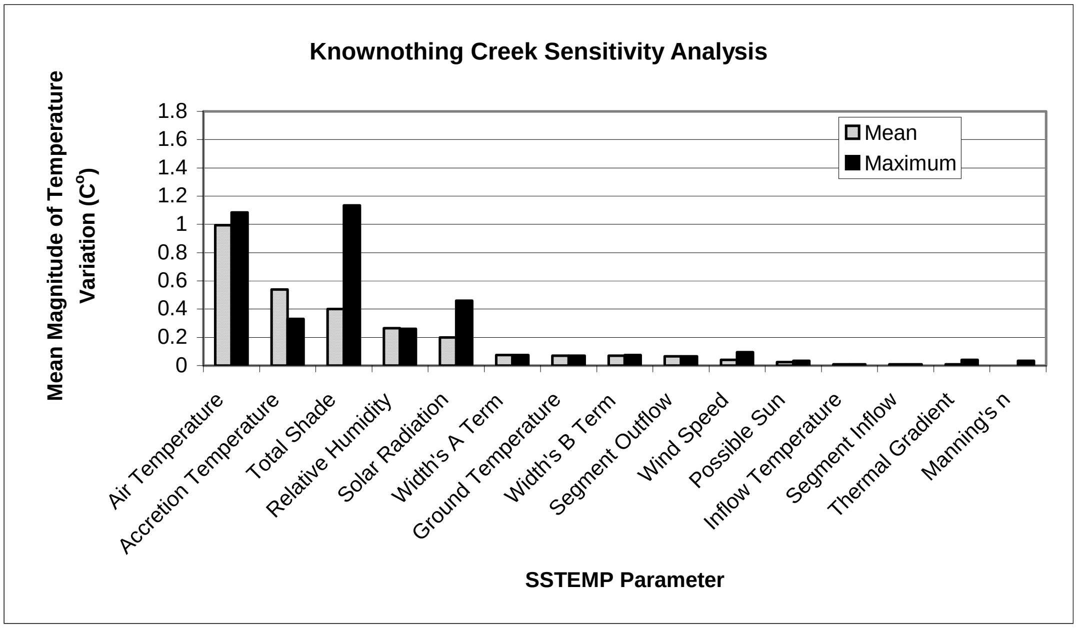

Figure B-8 Sensitivity Analysis of SSTEMP to +/- 10% Variation of Each Parameter, Knownothing Creek from below the Forks to the Mouth Simulation, Sorted by the Effect on Mean Temperature.

While air temperature, wind speed, relative humidity, and ground temperature would not be subject to management measures on a regional basis, values of these parameters may reflect local conditions near streams. In particular, these parameters can indirectly reflect or be affected by changes in riparian vegetation conditions. These parameters would vary together and balance one another to a certain extent. For example, a shaded streamside area generally has lower air temperatures, lower wind speeds and higher relative humidity than an open area. The net of these changes is lower water temperatures in more shaded areas.

B.3.2 Reach Level Simulations of Stream Temperatures

Further simulations were run with SSTEMP representing altered stream characteristics. These simulations were then evaluated for the change to stream temperature. These simulations were run with SSTEMP by adjusting specific parameters to simulate the upper end of reach-level increases in shade-producing vegetation, active and wetted channel widths, and flow, all of which can be affected by management. Simulations were run for the dates of flow measurement for tree height, channel geometry, and flow, and for the MWAT date of each segment to look at changes in shade associated with tree heights only.

B.3.2.1 Increased Streamside Vegetation

The impact of changes in effective shade on stream temperatures was evaluated for seven reaches of streams in the Salmon River watershed using the SSTEMP model. The reaches are listed in Table B-9. Stream temperature monitoring sites that could be simulated as a single reach were chosen for evaluation. Stream temperatures were simulated for current shade conditions, as well as mature riparian conditions. Mature riparian shade conditions were approximated by using potential tree height values for the tree species present. To account for natural events such as fire, landslides, and wind-throw that would reduce effective shade under ideal conditions, potential shade conditions were approximated as a 10% reduction from ideal conditions. In cases where a reduction of 10 percent from full potential shade conditions resulted in shade estimates less than the estimated current shade, the potential shade value was set equal to the estimated current shade. The resulting shade conditions are referred to as adjusted potential effective shade.

Table B-9 Measured and Modeled Daily Average Stream Temperatures of Modeled Segments for Flow Measurement Dates

Reach	Current Effective Shade (%)	Adjusted Potential Effective Shade (%)	Measured Temperature (°C) (°F)	Simulated Current Temperature (°C) (°F)	Simulated Potential Temperature (°C) (°F)
North Russian	74.6	87.3	15.5 59.9	15.6 60.1	14.7 58.4
Little North Fork	71.4	81.4	15.5 60.0	16.0 60.7	15.5 59.9
East Fork	51.3	74.8	17.8 64.1	18.1 64.6	17.5 63.5
Methodist Creek	73.6	88.1	16.3 61.4	16.4 61.5	15.4 59.7
Knownothing Creek	73.8	88.0	15.9 60.7	16.1 60.9	15.3 59.6
North Fork	51.4	76.6	18.3 65.0	17.9 64.3	17.6 63.6
Salmon Mainstem	16.2	50.6	20.7 69.3	20.9 69.7	20.4 68.7

Temperatures predicted by the model for current conditions for all locations are within 0.5°C of the measured temperatures.

The results of the stream temperature simulations demonstrate the impact that changes in shade conditions have on stream temperatures. The simulations show that an increase in effective shade from current to adjusted potential shade condition results in a decrease in stream temperatures. Temperature reductions for the segments simulated ranged from 0.3 to 1.0°C. Separating the seven segments into mainstem and tributary groups, reductions in stream temperature range from 0.3 to 0.6 °C for the three mainstem segments, while tributary segments show reductions from 0.5 to 1.0 °C. These results show that increased shade has a greater effect on stream temperatures of tributary segments than of mainstem segments. This analysis used 0.25°C as a threshold of significance, drawing on conclusions presented in USEPA (2003).

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Table B-10 Input Data for SSTEMP Analysis for the MWAT Date of Each Segment

Meteorologic, Hydrologic and Geometric Parameters and Associated Values for Salmon River Water Temperature Sensitivity/Uncertainty Analysis

Values used in all scenarios for all segments:
Possible Sun: 90%
Manning's N: 0.035
Thermal Gradient: 1.65 J/m^2/s/C
Ground Temperature: same as accretion (groundwater) temperature
Width's B term: 0.3202
Width's A term: 13.753 s/m^2

Scenario	Inflow (cms)	Inflow Temp (°C)	Outflow (cms)	Segment Length (km)	U/S Elev (m)	D/S Elev (m)	Air Temp (°C)	Vege Height (m)	Total Shade	Date	U/S Latitude (radians)	Groundwater Temp (°C)	Solar Rad. (Langleys)	Relative Humidity (%)
North Russian Creek, Current	0.08883	15.005	0.10817	4.01	951.6	806.8	23.1125	24.28	73.0	7-27-02	0.72178	11.42	629.340	42.63
North Russian Creek, Potential	0.08883	15.005	0.10817	4.01	951.6	806.8	23.1125	48.43	84.7	7-27-02	0.72178	11.42	629.340	42.63
Little North Fork, Current	0.69526	16.819	0.71104	3.32	703.5	603.5	22.6088	25.81	70.2	7-11-02	0.72159	12.90	643.697	45.32
Little North Fork, Potential	0.69526	16.819	0.71104	3.32	703.5	603.5	22.6088	48.76	82.2	7-11-02	0.72159	12.90	643.697	45.32
East Fork, Current	0.44474	17.179	0.45250	2.91	771.1	729.4	21.775	19.11	51.6	7-26-02	0.71857	12.27	584.830	50.49
East Fork, Potential	0.44474	17.179	0.45250	2.91	771.1	729.4	21.775	42.77	75.0	7-26-02	0.71857	12.27	584.830	50.49
Methodist Creek, Current	0.01472	18.271	0.02350	2.01	544.1	454.5	23.129	19.26	71.1	7-27-02	0.71921	13.91	629.340	42.59
Methodist Creek, Potential	0.01472	18.271	0.02350	2.01	544.1	454.5	23.129	42.47	85.9	7-27-02	0.71921	13.91	629.340	42.59
Knownothing Creek, Current	0.11672	16.166	0.18321	4.02	510.8	400.5	23.375	21.71	71.5	7-26-02	0.71934	14.20	584.830	45.97
Knownothing Creek, Potential	0.11672	16.166	0.18321	4.02	510.8	400.5	23.375	48.33	85.9	7-26-02	0.71934	14.20	584.830	45.97
North Fork, Current	2.69803	20.198	2.71520	3.19	601.7	569.1	31.12	23.95	36.4	7-11-02	0.72114	13.35	643.697	27.50
North Fork, Potential	2.69803	20.198	2.71520	3.19	601.7	569.1	31.12	47.55	66.0	7-11-02	0.72114	13.35	643.697	27.50
Mainstem, Current	11.07190	21.420	11.15680	6.44	154.5	147.2	28.98	14.99	1.1	7-11-02	0.72211	14.66	690.800	62.04
Mainstem, Potential	11.07190	21.420	11.15680	6.44	154.5	147.2	28.98	38.83	8.3	7-11-02	0.72211	14.66	690.800	62.04

Changes in the rate of heating from current conditions to the model's adjusted potential shade conditions also were investigated. Results in Figure B-9 show that increasing riparian trees to adjusted potential heights can produce a reduction in the rate of stream heating of 0.12 ^{o}C to 0.51^{o}C per stream kilometer, and in some cases can change a warming segment into a cooling segment.

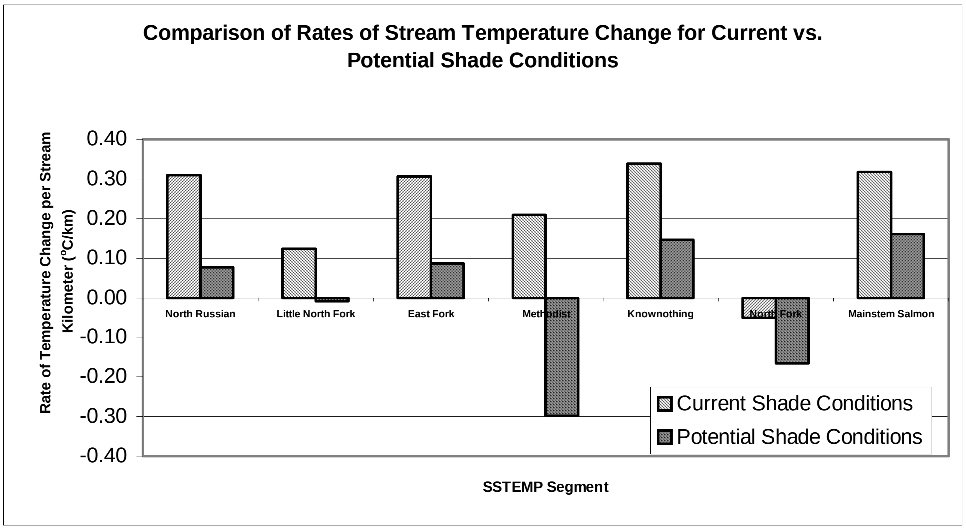


Figure B-9 Comparison of Rates of Stream Temperature Change for Current vs. Potential Shade Conditions.

Further SSTEMP analysis was performed for the MWAT date of each segment. Table B-10 shows the input data and associated values for all meteorologic, hydrologic and geometric variables used for analysis.

These simulations performed for the MWAT date show similar results (Table B-11) as the August simulations. Temperature reductions for the segments simulated ranged from 0.1 to 1.0^{o}C. Separating the seven segments into mainstem and tributary groups, reductions in stream temperature range from 0.1 to 0.8 ^{o}C for the three mainstem segments, while tributary segments show reductions from 0.3 to 1.0 ^{o}C.

According to the United States Forest Service mapping coverage approximately 1472.55 kilometers of watercourses are within the Salmon River watershed. This analysis was performed for seven SSTEMP segments only, and is intended to represent a range of conditions in the watershed, and thus be representative of the potential for change on other segments.

The results of the modeling exercise are consistent with the conclusions reached by Regional Board staff in their analysis of the Navarro and Mattole River watersheds (NCRWQCB, 2000 and 2002), as well as conclusions reached by Stillwater Sciences (USEPA, 1999) in their analysis of streams in the South Fork Eel River. Stillwater's modeling analysis demonstrated that streamside shade significantly affects stream temperatures in the sub basins that were modeled. Their analysis further showed that maintaining shade in class II streams (non-fish-bearing streams with aquatic habitat), in particular, is important for maintaining natural temperatures of class I (fish-bearing) streams.

Table B-11 Measured and Modeled Daily Average Stream Temperatures of Modeled Segments for the MWAT Date of Each Segment

Reach	Current Effective Shade (%)	Adjusted Potential Effective Shade (%)	Measured Temperature (°C) (°F)	Simulated Current Temperature (°C) (°F)	Simulated Potential Temperature (°C) (°F)
North Russian	73.0	84.7	16.4 61.5	17.1 62.8	16.4 61.5
Little North Fork	70.2	82.2	17.2 63.0	17.4 63.3	17.1 62.8
East Fork	51.6	75.0	17.8 64.0	17.9 64.2	17.2 63.0
Methodist Creek	71.1	85.9	18.4 65.1	17.7 63.9	16.7 62.1
Knownothing Creek	71.5	85.9	17.6 63.7	17.4 63.3	16.7 62.1
North Fork	36.4	66.0	20.6 69.1	20.9 69.6	20.5 68.9
Salmon Mainstem	1.1	8.3	22.3 72.1	22.7 72.9	22.6 72.7

Although stream canopy and effective shade are different measures of riparian characteristics, effective shade is dependent on stream canopy, thus large reductions of stream canopy result in large reductions in effective shade in most cases. The Basin Plan's water quality objective for temperature states that temperatures of intrastate waters shall not be altered unless it can be shown that such an alteration does not impact beneficial uses. Our analysis in the Salmon River watershed shows that increased streamside shade can lead to reduced stream temperatures, and suggests the corollary, that reduced stream shade can cause increases in stream temperature.

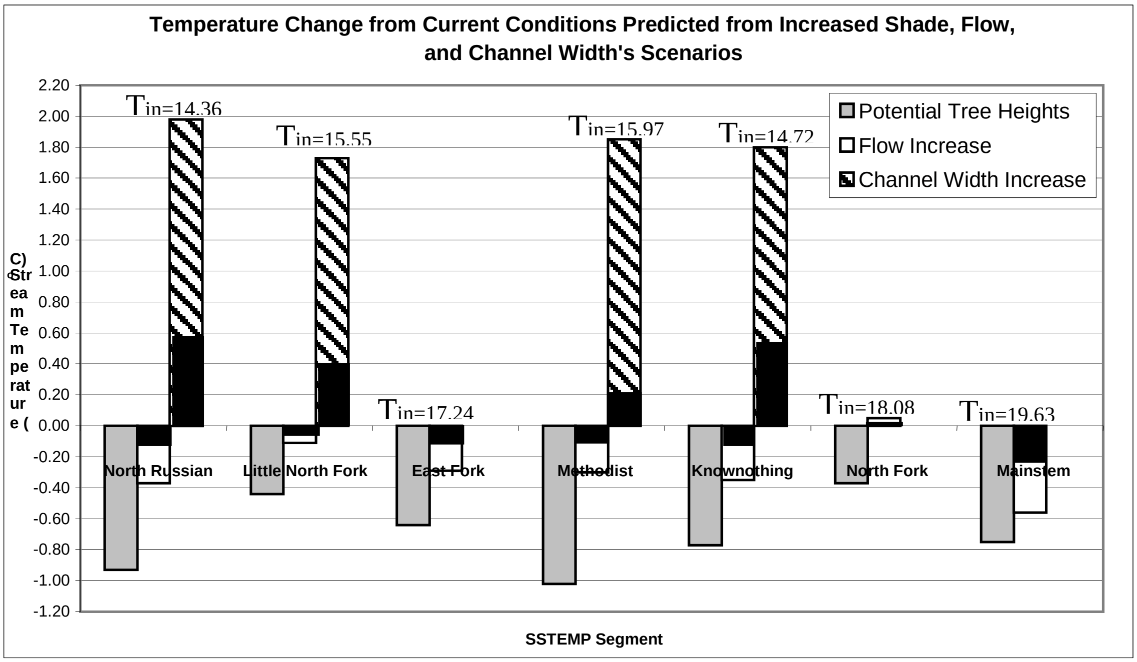
B.3.2.2 Increased Stream Width

SSTEMP was used to simulate an aggradation event (e.g., debris torrent). These simulations were run for tributary stream segments where a debris torrent could produce significant scouring that could significantly widen the active channel and wetted widths, as happened in areas near the Salmon River watershed during the 1997 flood events. For the aggradation event, this was accomplished by adjusting the model's input data for riparian vegetation placement, and wetted width geometry. In order to simulate a debris torrent, vegetation was placed further from the stream, producing a hypothetical reduction in effective shade. The distance of the vegetation from the water's edge, or active channel width, was increased incrementally up to double that of current conditions. The Heat Source calculator was utilized to predict the change in effective shade for the extended distance to the riparian vegetation. Wetted width was also increased to simulate the effects of a debris torrent. The SSTEMP model's A Term provided the ability to input alternate values of wetted widths to represent a wider, more shallow wetted stream. The A Term was stepped up incrementally to double that of current conditions. SSTEMP was then used to provide predicted stream temperatures for the combination of increased wetted widths and reduced effective shade (resulting from increases made to active channel widths).

B.3.2.3 Increased Flow

An additional scenario represents stream characteristics following a reduction of upland vegetation (e.g., as a result of fire, timber harvest, or vegetation management). These simulations were run for all SSTEMP segments. To represent the effects of fire, timber harvest, or changes in management at a landscape scale, the model's flow values were increased incrementally to double that used for the current condition scenarios. Increases in flow following a fire or logging event have been well documented in similar watersheds (Keppeler, 1998; Jones, 2000). Keppeler shows a reduction in upland vegetation results in increased flows in summer when flows are lowest. Increases in stream flow have been shown to be proportional to the amount of cover removed (Hibbert, 1967). Reduced cover could be associated with harvest, fire, or vegetation management (thinning, brush removal) to reduce the risk of fire.

Model results for current conditions, and for changes in shade, channel geometry, and flow are presented in Figure B-10.



Note: For flow and channel width columns, solid portion represents the temperature change from a 25% increase, while the full column length represents the change in temperature from a 100% increase. Tin is inflow temperature in ^{o}C.

Figure B-10 Temperature Change from Current Conditions Predicted for Increased Shade, Flow, and Channel Widths Scenarios.

B.4 Conclusions

The sensitivity analysis results indicate that air temperature, accretion temperature and total shade are the three most important parameters influencing mean daily stream temperatures in tributary reaches of the Salmon River. In the mainstem reaches of the Salmon River, the water temperature entering the segment is the most important factor influencing stream temperature, while air temperature and flow conditions also influence mainstem water temperature.

The results of the stream temperature modeling analysis show that changes in channel geometry, riparian vegetation conditions, and stream flow characteristics can change stream temperatures. Specifically, for vegetation and channel changes, increased solar radiation inputs to streams result in elevated stream temperatures. For flow, increases over current conditions generally result in modest decreases in predicted stream temperatures. For this variable, slight increases in solar radiation input are more than balanced by the increased resistance of higher flows to temperature change.

Shade is of greatest concern for this TMDL because management can affect it by changing the vegetative component, and changes in shade can alter stream temperatures from natural levels. Total shade can be directly related to solar radiation inputs that affect stream temperatures.

Stream temperatures also are sensitive to air temperature, and in some circumstances relative humidity and wind speed, which in turn are subject to change as a result of management of streamside vegetation. Changes in microclimate associated with removal of riparian vegetation and changes to these factors can also lead to increased stream temperatures. However, the degree of microclimate alteration due to reduction of riparian vegetation is not readily predictable, although the phenomenon has been well documented.

The stream temperature modeling analysis demonstrates that changes in solar radiation inputs from vegetation growth or channel geometry can lead to significant changes in stream temperatures, especially in small streams. Furthermore, the modeling analysis demonstrates that an increase in stream shade from current conditions to those that could be expected for mature vegetation conditions will lead to improved stream temperatures. Such changes can be expected to occur on a landscape scale. Changes to current channel geometry from large inputs of sediment are predicted to increase stream temperatures. Such large changes are often observed in some reaches of a watershed in response to extreme events (such as the 1997 flood), while minimally affecting other reaches in the same watershed.

In summary, this analysis demonstrates that vegetation effects on stream shade are influential on stream temperatures. Other effects of management activities, such as changes in stream geometry and flow, can also impact stream temperatures.

From a management standpoint, the analysis leads to three conclusions:

1. Where loss of riparian vegetation, or vegetation that provides shade to a stream, has caused stream temperatures to be elevated from natural receiving water temperatures, the Basin Plan's water quality objective for temperature is not being achieved.
2. The recovery of riparian vegetation from past disturbances is expected to be the most important factor at a landscape scale in lowering stream temperatures toward natural levels where they would meet Basin Plan objectives.
3. Increased sediment delivery resulting from upslope disturbances that lead to changes in channel geometry can increase stream temperatures. Where this situation is occurring or is threatened to occur, the Basin Plan objective for temperature may not be met.

B.5 Appendix B - References

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