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A Water Temperature Model of the Trinity River

By

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CONVERSION TABLE

Metric	to	U.S. Customary
Meters (m)	* 3.28	Feet
Kilometers (km)	* 0.6214	Miles
Hectares (ha)	* 2.471	Acres
Cubic Meters / Second (cms)	* 35.31	Cubic Feet / Second (cfs)
Celsius Degrees (°C)	1.8 (°C) + 32	Fahrenheit degrees (°F)

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INTRODUCTION

The Trinity River of northern California became a regulated river in the early 1960s when construction of the Trinity River Division (TRD) of the Central Valley Project was completed. Due to this construction, which includes both Clair Engle and Lewiston Reservoirs, nearly 175 kilometers of anadromous fish habitat was lost upstream of the dam sites and many physical changes to the stream channel below the dam also occurred. Recognized physical changes include: a channelized stream bed morphology, increased riparian encroachment, reduced flow magnitude and volume, and an altered water temperature regime. In addition, factors such as poor land management practices in watersheds below the dams, oceanic and drought conditions, and over harvest, have been suspected for decreasing numbers of returning adult salmon and steelhead.

In January of 1981, the Secretary of the Interior authorized increased flows to the Trinity River for fisheries purposes. In addition to the increase in flow to the river, the United States Fish and Wildlife Service (Service) was to conduct a study to evaluate the effects of the increased flows and to ascertain what future flows would be needed to help restore in-river habitats for the fishery. This study began in October of 1984 and is scheduled for completion by September of 1996. A major component of the study was to develop a water temperature model for the Trinity River that could be used as a predictive tool for management of river temperature and flow for the anadromous fish. This modeling effort began in 1991 and the results are described in this report.

BACKGROUND INFORMATION

The Trinity River is located in northern California and is the largest tributary to the Klamath River (Figure 1). Its basin is nearly 7,770 square kilometers in area of which approximately one-quarter is located above Lewiston dam. Below Lewiston dam, the Trinity mainstem flows for 180 km before entering the Klamath River at Weitchpec. From Weitchpec, the Klamath River flows for another 70 km before flowing into the Pacific Ocean.

Several species of salmonids and other native fish use the Trinity River for all or part of their life-cycle. Anadromous salmonids include the chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead (*O. mykiss*); resident salmonids include the rainbow trout (*O. mykiss*) and the introduced brown trout (*Salmo trutta*). Other anadromous species include the Pacific lamprey (*Lampetra tridentata*) and the green sturgeon (*Acipenser medirostris*). The Trinity also supports populations of speckled dace (*Rhinichthys osculus*) and the Klamath smallscale sucker (*Catostomus rimiculus*).

The TRD of the Central Valley Project, which includes Clair Engle Reservoir Lewiston Reservoir, the Clear Creek Tunnel, Whiskeytown Reservoir, and the Spring Creek Tunnel linking it to the Sacramento River (see Figure 1), has a large influence on water temperatures of the Trinity River. Since Clair Engle Reservoir has a capacity of 2.48 million acre-feet

Figure 1. Trinity River

and Trinity Dam has two different outlet works, selective withdrawal can be accomplished to provide cold water for the Trinity and Sacramento rivers and the Trinity River Hatchery during the summer and early fall. In the summer when diversions to Whiskeytown Reservoir are large (up to 3,600 cfs), Lewiston Reservoir essentially becomes a slow-moving river and remains cold. Conversely, when diversions are low and retention time is high, Lewiston Reservoir temperatures begin to warm during the summer months or they may cool during the winter.

Since 1991, flows from Lewiston Dam have ranged from 8.5 cms (300 cfs) to about 195 cms (6900 cfs), and annual volumes released from Lewiston Dam have ranged from 230,000 AF in 1991 to about 720,000 AF in 1995; the high volume in 1995 was due to the wet and full reservoir conditions. Although the Trinity River is a regulated river, flows downstream become more variable with distance from the dam. For example, the average daily flow at Burnt Ranch (104 km below Lewiston Dam) can exceed 708 cms (25,000 cfs) as they did in January of 1995 (U.S. Geological Survey [USGS] data) when the discharge from Lewiston Dam was about 8.5 cms (300 cfs).

In October 1991 the North Coast Regional Water Quality Control Board established water temperature objectives to assure that a temperature refugia existed for the adult salmon in the Trinity. The Basin Plan Objectives that went into effect the following year are that the daily average temperatures should not exceed 15.6 °C at Douglas City bridge from July 1 to September 15 and 13.3 °C from September 15 to October 1; and 13.3°C at the Trinity's confluence with the North Fork Trinity River from October 1 through December 31.

THE SNTEMP MODEL

The SNTEMP model was developed by Theurer et al. (1984) and is intended to be a generalized water temperature model that can be applied to any size watershed or river basin of any complexity. Since development, this model has been used to evaluate the effects that reservoir releases, both flow and water temperature, have on downstream water temperatures, the effects of removing riparian vegetation (Zedonis 1994), and the effects of diverting and returning water from a stream (Bartholow 1989). Development of the SNTEMP models of the Trinity River began in 1991. The model evaluates the effects of Lewiston Dam release water temperature and discharge for the entire Trinity River.

The model's main components include:

(1) A heat transport model that predicts the average mean weekly temperature as a function of stream distance;

(2) A heat flux model that predicts the energy balance between the water and its surrounding environment;

(3) A solar model that predicts the solar radiation that penetrates the water as function of latitude, time of year, and meteorological conditions;

(4) Meteorological corrections that predict changes in air temperature, relative humidity, and atmospheric pressure, as functions of a change in elevation; and

(5) Regression aids that smooth and/or fill in missing water temperature data at headwater and internal validation/calibration locations.

You are referred to Instream Flow Information Paper number 16 (Theurer et al. 1984) for more detailed information regarding each component of the SNTEMP model.

DATA REQUIREMENTS AND SOURCES

Time Step

The time step chosen for the water temperature model was seven days. This time step represents a compromise in resolution between monthly and daily time steps. In addition, model results become more reliable when the time step is equal to or greater than the travel time for the water released at the dam (Theurer et al. 1984); this criterion was met when the discharge from Lewiston Dam is 8.5 cms (300 cfs) or greater (Limerinos 1967). This time step also coincided with the time step being used by the National Ecology Research Center, to develop a population response model (SALMOD) for the Trinity River for quantifying pre-smolt production from flow-dependent physical habitat and water temperature (Williamson et al. 1992).

The SNTEMP model of the Trinity is an annual model composed of 52 time periods and begins October 1. Except in leap years and the week of September 23, which are comprised of eight-day weeks, all other time periods were represented by seven-day weeks.

Stream System Network

For organizational purposes, the Trinity River is composed of a series of nodes, which are used to describe different attributes of locations in the stream network. A schematic of the stream network used for the water temperature model is illustrated in Figure 2. Descriptions of each node type are provided in Table 1.

Because the Trinity River Hatchery is located at Lewiston Dam, and uses water directly from Lewiston Reservoir, which is discharged into the river several hundred meters below the dam, the start point was not at the dam. Rather, the start point was located at the CDEC (California Data Exchange Center) station (United States Geological Survey Station Number 11525500), which is about 800 meters below the effluent point. The start point (Rkm 178.47), was selected to assure that the effluent from the hatchery and flows from the dam were thoroughly mixed providing a simplified modeling situation.

Figure 2. Schematic of the stream network used in the Trinity River SNTEMP model (not drawn to scale)

Table 1. Descriptions of nodes used in the SNTEMP model of the Trinity River.

NODE TYPE	DEFINITION
H (Headwater)	Upstream boundaries of tributaries and mainstem.
B (Branch)	Point on the mainstem upstream of a tributary confluence.
T (Terminal)	The last point of a Tributary before entering the mainstem.
J (Junction)	The point on the mainstem just below a tributary confluence.
S (Structure)	A point at which there is a discontinuity of discharge or water temperature.
E (End)	The network end point.
V (Validation)	A node where the water temperature is known and can be compared to predicted temperatures.

Stream Geometry

Required channel geometry included: 1) elevations and upstream distances of each node; and 2) the average stream width, hydraulic retardence (Manning's n) and generalized shading parameters associated with the reach below each node. For each geometry node measures of latitude, stream distance, and elevations were obtained from USGS 7.5 minute series topographic maps. A Manning's n-value of 0.50 was used; adjusting this value only alters the maximum temperature (Barthowlow 1989). Mainstem width-flow relationships were empirically derived from transect sites already established as part of the Physical Habitat Simulation System (PHABSIM) portion of the Trinity River Flow Evaluation Study.

Meteorology

The SNTEMP model of the Trinity River required four basic meteorological input parameters in the form of a 7-day average daily and they included: 1) air temperature, 2) relative humidity, 3) wind speed, and 4) percent possible sunshine. Interpolation was used to generate missing data for the calibration years.

Local air temperature data were obtained from Trinity River Hatchery (TRH). Data from this source was in the form of daily maximum and minimum values which were averaged for each day. Data were available from 1965 to 1994.

Similar to air temperature, average weekly relative humidity values were derived from average daily data. This data, however, came from the Redding and Red Bluff Municipal Airports. The period of record for the Redding Airport consisted of data from August of 1986 to October 1994, while the record from Red Bluff was from July 1948 to December 1965 and from January 1985 to August of 1986.

Wind speed values were also obtained from the TRH. The period of record for wind speed data was from 1974 to 1994.

Percent possible sunshine was obtained from Redding and Red Bluff Municipal Airports. The period of record for the Redding Airport consisted of data from August of 1986 to 1994, while the Red Bluff Airport record consisted of data from January 1965 to November 1966, from January 1969 to September 1982, and January of 1985 to August of 1986.

For gaming purposes and "what if " questions, hypothetical years were developed. Hypothetical years were constructed with weekly exceedance criteria rather than being based on an entire year. Meteorological data from 1965 to 1992 were used to determine exceedance values. Exceedance values are presented in tabular form in Appendix A**.** This method of determining a year type can be thought of as extreme in that one would not expect to find a year containing 52 weeks of hot-dry, median, or cold-wet conditions. Thus, modeling results for the hypothetical years are not useful for analyzing an entire year, but are useful for investigating the effects during independent weeks of a year.

The procedure taken to develop hypothetical year types was to summarize historic meteorology and hydrology (see next section) data into weekly exceedance charts. Hypothetical year types were determined from historic weekly data and included: (1) a cold-wet year, represented by 90 percent exceedance for air temperature and percent possible sunshine, 50 percent for wind speed, and 10 percent for relative humidity; (2) a hot-dry year, represented by 10 percent exceedance for air and percent possible sunshine, 50 percent for wind speed, and 90 percent for relative humidity; and (3) a median year, represented by 50 percent exceedance for all parameters. Weekly exceedance values were then smoothed using a five-week running average (see Figure 3); this was completed to make sure that a distinct trend of increasing or decreasing values occurred for different exceedance levels, and to create a synthetic data set that would be a maximum likelyhood estimator or future conditions. Exceedance values for each meteorological variable are also tabulated in Appendixes A to D. Combined with exceedance data for the hydrology (described in the following section), these data were used to develop the input files for hypothetical year simulations.

Hydrology

The hydrologic data required to run the model consisted of flow data for all specified nodes throughout the stream network. In this case, several tributaries were included for which no gaging stations existed. SNTEMP offers the option to synthesize tributary water temperatures given they are put in the model as zero flow headwater tributaries (they start at zero flow) and flows at the terminus of the tributary are known. This option was used in all tributaries that were included in the model and tributary flows were synthesized. Three gaging stations on the Trinity River were used to synthesize flow data: 1) Lewiston (U.S.G.S Station # 11525500), the upstream end of the network; 2) Burnt Ranch (Approx. 108 river kilometers downstream; U.S.G.S. # 11527000); and 3) Hoopa (Approx. 160 km downstream; U.S.G.S. # 11530000). The difference in discharge between two successsive gauges was determined to be the accretion of water or "water gain" in the mainstem between these two points. For this report, the areas between Lewiston and Burnt Ranch and Burnt Ranch and Hoopa gauges will be called Zone 1 and

Figure 3. Exceedance probabilities for meteorological data used in SNTEMP for hypothetical year simulations.

Zone 2, respectively. Tributary inflow was derived by apportioning this "water gain" based on the proportion of the tributaries drainage area to the combined drainage area of tributaries in the gage basin area. Tributaries less than approximately 6,000 ha in area were not considered in deriving tributary drainage area proportions nor where they included in the model. For simplicity, Mill Creek was included into Zone 2 although it lies just below. Synthesized tributary flow data were then placed into the appropriate input files. Table 2 contains the names of tributaries included in the model, as well as the proportion of the total accretion allocated to each.

Table 2. Tributaries used in the SNTEMP model and the proportion of accretion between Lewiston, Burnt Ranch, and Hoopa gaging stations on the Trinity River.

SITE	TRIBUTARY NAME	PROPORTION OF TOTAL ACCRETION
Zone 1 (Lewiston to Burnt Ranch)	Rush Creek	0.046
	Grass Valley Creek	0.074
	Indian Creek	0.068
	Weaver Creek	0.099
	Reading Creek	0.062
	Browns Creek	0.144
	Canyon Creek	0.126
	North Fork Trinity River	0.304
	Big French Creek	0.078
	Total	**1.000**
Zone 2 (Burnt Ranch to Hoopa)	New River	0.169
	South Fork Trinity River	0.694
	Willow Creek	0.032
	Horse Linto Creek	0.048
	Tish Tang Creek	0.022
	Mill Creek	0.036
	Total	**1.000**

Similar to the meteorological data, exceedance values for tributary inflow were determined for each week, then smoothed using a five-week centered running average, and used in development of hypothetical year types. The period of record used in developing these exceedance values were from water years 1931 to 1939 and from 1956 to 1992. Exceedance levels of 10, 50, and 90 percent corresponded to wet, median, and dry years, respectively. Exceedance values for the flow accretion for Zone 1 are illustrated in Figure 4, and are represented in tabular form in Appendix E.

Exceedance values for tributaries of Zone 2 were completed using a simple ratio method. Because the zone basin areas and the area above the Lewiston gage were known (Lewiston = 719 square miles , Zone 1 = 1439, Zone 2 = 2853), the actual drainage area between zones was easily calculated (Zone 1 = 720, Zone 2 = 1414). From this calculation, it was determined that the ratio between zones was 1:2. Correspondingly, although not presented in figures or tables, values provided in Figure 4 and Appendix E were multiplied by two to obtain total accretion in Zone 2 for synthesizing tributary flow patterns. Although flow accretion values from Zone 1 were based on data that were derived from the historic record for that region, flow accretion of Zone 2 accretion were not. Because of this, a sensitivity analysis was conducted and results showed that the error associated with the ratio method to be insignificant (Appendix E.2).

Figure 4. Exceedance probabilities for hydrologic data used in SNTEMP for hypothetical year simulations.

Water temperature data is also required in the hydrology data file at the start of the network (below Lewiston Dam) and at all validation nodes. Water temperature data were collected with continuous recorders at several sites along the Trinity River. Recording devices included portable submersible recorders, as well as permanent recorders maintained by the California Data Exchange Center (CDEC), the latter of which was retrieved electronically. Recording devices were, in general, set to record at one or two hour intervals. Data were subsequently downloaded onto a computer and summarized into daily then 7-day average values. At times recorders were lost during floods, vandalized, or failed leading to lost data. When recorders were placed in or pulled out, the temperature last recorded was usually compared to an ASTM (American Society of Testing Materials) thermometer to assure that the recorders were operating properly.

Six mainstem validation nodes and one structure node (Lewiston Dam; RK 178) were included in this model for which some water temperature data were available for the water years of 1991 to 1994. For the Structure-node, a complete set of water temperature data were used and is illustrated in Figure 5. From upstream to downstream, the locations of the validation nodes were Steelhead Bridge (RK 158.5), Douglas City Bridge (RK 150.8), Trinity Canyon Lodge (formerly the Elkhorn Lodge, RK 118.8), Burnt Ranch Transfer Station (RK 77), near the Town of Willow Creek (RK 37), and at Weitchpec Falls (RK 1.1). Most sites had a large set of data, but some sites were missing large blocks of data in different years (Table 3). Time periods that water temperature data was missing were filled with water temperature data generated from a subprogram of SNTEMP that performs regressions based on local meteorology, hydrology, and stream geometry. The high correlation coefficients (0.96 to 0.98, excluding the S-node) indicate that the predicted temperatures for which there is observed temperature data are in close agreement (Table 4). In addition, the absolute maximum error ranged from -2.1 to 3.6 °C, probable error ranged from 0.5 to 0.75 °C, and bias error ranged from 0.04 to 0.06.

Some water temperatures at the Trinity Canyon Lodge validation node (RK 118.84) were filled in with temperatures from Idaho Bar (RK 118.26) and were assumed to be the same at the Trinity Canyon Lodge; no corrections of these temperatures were made. Months that were filled with these data included October, November, and December of water year 1991. Most temperature data were collected by the Lewiston Office except for the data collected at the site near the town of Willow Creek and New River, which were supplied by the Coastal California Fish and Wildlife Office (CCFWO) in Arcata, and at Horse Linto Creek, which was supplied by the U.S. Forest Service (Six Rivers National Forest).

Select tributaries, for which there were water temperature data, were also modeled. They included: Rush Creek, Indian Creek, Canyon Creek, North Fork Trinity River, Big French Creek, New River, South Fork Trinity River, and Horse Linto Creek. Among these tributaries, however, only New River had extensive water temperature data. Most other tributaries were only monitored for temperature in the last year of the data collection efforts. The number of weeks that temperature data were available for any one of these sites is given in Table 3.

Figure 5. Lewiston Dam release water temperatures (7-day average daily) for water years 1991 to 1994.

Table 3. Quantity of water temperature data used in the Trinity River temperature model calibration.

Temperature Site	Number of Weeks of Data in Water Year				Total	Percentage of Total (208) Possible
	91	92	93	94		
Mainstem						
Steelhead Bridge	8	52	52	52	164	78.85%
Douglas City Bridge	52	40	52	52	196	94.23%
Trinity Canyon Lodge	25	52	52	52	181	87.02%
Burnt Ranch Transfer Station	14	48	51	50	163	78.37%
Near Town of Willow Creek	31	40	34	42	147	70.67%
Weitchpec Falls	10	52	52	52	166	79.81%
Tributary						
Rush Creek	0	0	0	35	35	16.83%
Indian Creek	0	0	0	35	35	16.83%
Canyon Creek	11	0	0	35	46	22.12%
North Fork Trinity River	0	0	0	29	29	13.94%
Big French Creek	0	0	0	11	11	5.29%
New River	52	52	26	49	179	86.06%
South Fork Trinity River	0	0	0	11	11	5.29%
Horse Linto Creek	0	0	13	39	52	25.00%

Table 4. Water temperature regression statistics used for filling in missing observed data.

Other Variables

Other nonsensitive variables that are required by the model included the dust coefficients and ground reflectivity. Dust coefficients were estimated from Table II.1 of Instream Flow Information Paper: No. 16 (Theurer et al. 1984). Ground reflectivity values were estimated from Table 5 of Instream Flow Information Paper: No. 13 (Bartholow 1989).

CALIBRATION

The SNTEMP model can be thought of as calibrated when the predicted values closely match the observed values with some specified or reasonable error. This is often accomplished by adjusting those input parameters which are thought to be least accurate. Calibration of the SNTEMP model refers to calibration of the regression model as well as the heat transport model. The statistics used to calibrate the regression model were to achieve the highest multiple correlation coefficient (R) and the smallest probable difference (also called probable error). These statistics are presented in Table 4. The statistics used to calibrate the heat transport model were to eliminate bias (mean error) and to minimize probable differences. While error associated with the regression model is primarily from measurement error, which includes water temperature recorder error (± 0.3°C) and CDEC station recorder error (± 0.2 °C), the error associated with the physical process model is associated with both the regression error and errors in the model itself. General statistics generated from the models are described below and include:

1) The coefficient of determination (effect if bias removed);
2) The sample correlation coefficient (effect if bias removed and probable error reduced);
3) The mean error (bias);
4) The probable error of prediction about the mean error (50% confidence limits);
5) The maximum error (range);
6) The probable error of estimate for the bias (50% confidence limits); and
7) The number of error terms.

Calibration of the model was completed using a two step process that included: 1) calibration of the tributaries, for which there was real water temperature data available; and 2) calibration of the mainstem validation nodes.

Calibration of the tributaries was accomplished through an iterative process of modifying several input variables. Stream geometry and hydrology data file input variables were modified until predicted temperatures were in close agreement with observed values. Initial steps were to modify the stream geometry variables (stream width, shading, and H-node elevations) and compare regression results to observed data. Some of these modifications helped calibration, but addition of lateral flow temperatures to the H-nodes of the hydrology file had a greater effect;

lateral flow temperatures were derived from historical TRH air temperature data. Average weekly air temperature data were averaged for the period of record and were modified until "reasonable calibration" occurred. In this case, "reasonable calibration" referred to minimizing the regression and heat transport model error for the one tributary that had extensive data - New River. When the lateral flow temperature pattern (also referred to as groundwater temperature) that resulted in "reasonable calibration" was defined, it was applied to all the other modeled tributaries including those that had no water temperature data (i.e., the derived lateral flow temperature pattern was subsequently used in all monitored and unmonitored tributaries [e.g., Reading and Browns Creeks]).

Calibration of the mainstem validation nodes was completed by iteratively modifying meteorological variables (air temperature, wind speed, relative humidity, and percent possible sunshine) in the JOB CONTROL file to meet the previously described objectives. In this case, the summary statistics (combined statistics of individual validation nodes) provided in the readable output file KVRSTAT were used as a way of judging the performance of the models. After many adjustments to the meteorologic variable coefficients and several model runs, it was determined that only an adjustment to the air temperature variable by a factor of 0.95 was necessary for reasonable calibration.

Results

Calibration statistics (VSTATS output file) for the mainstem validation nodes for each time period are provided in Appendixes F - K. Specifically, statistics for Steelbridge, Douglas City, and Trinity Canyon Lodge, are provided in Appendixes F to H, and statistics for Burnt Ranch, Willow Creek, and Weitchpec are provided in Appendixes I to K. Summary statistics are provided in Appendix L. Graphical display of mean, probable, and maximum error terms are provided in Appendix M. Graphic illustrations of predicted temperatures and observed temperatures for mainstem nodes for each calibration year are provided in Appendix N, while those for tributaries are provided in Appendix O.

Steelbridge

Calibration statistics at the Steelbridge site indicate that the mean and probable error was always less than 1.8°C and 1.0°C, respectively, for any time period (Appendix F). On the average, maximum error was less than 2.0°C with the exception of a few time periods during late winter and spring. Comparison of observed and predicted temperatures indicate that the model is performing quite well at this node, especially during 1994 (See Appendix N)

Douglas City

Calibration statistics for this site essentially mimicked those of Steelbridge. Mean error and probable error terms were on average -0.58 and 0.57°C, respectively (Appendix G). Maximum error was 2.71°C and was greatest during the early winter and spring. Comparison of observed and predicted temperatures indicated that the model was consistently tracking real temperature data (Appendix N). Again, this trend is most evident in 1994.

Trinity Canyon Lodge

Calibration statistics indicate that on average the mean and probable error was -0.59 and 0.58°C, respectively, and maximum error was always less than 2.82°C. Similar to the previous two nodes, the maximum error was greatest during the winter and spring months (Appendix H). Comparisons of observed and predicted temperatures indicate that the model is closely tracking real temperature data for all calibration years (Appendix N)

Burnt Ranch

Calibration statistics indicate that on average the mean error and probable error were -0.11 and 0.63°C, respectively, and the maximum error was 3.16°C (Appendix I). Dissimilar to the previous nodes, the maximum error occurred sporadically throughout the year. Similar to the preceding nodes, however, the comparisons of the observed and predicted temperatures are favorable (Appendix N).

Willow Creek

Calibration statistics indicate that the mean error and probable error were -0.15 and 0.94°C and maximum error was 5.8°C; although maximum error was, in general, greatest during the winter months. Inspection of the input data for this site indicates that there was a lack of wintertime water temperature data for the regression model to use resulting in high maximum error. Although large maximum error occurred at this site, it is evident, from the comparisons of observed and predicted temperatures, that the model is still performing relatively well.

Weitchpec Falls

Calibration results indicate that the model is still performing quite well even though the distance from Lewiston Dam is approximately 177 kilometers. Mean and probable error terms were -0.21 and 0.72°C, and maximum error was 3.48°C (Appendix K). These statistics, in addition to the comparisons of observed and predicted temperatures, indicate that the model is tracking observed water temperature data closely (Appendix N)

Summary Statistics

Results of calibration indicate that the model is performing relatively well at all mainstem validation nodes. The statistics indicate that overall the mean error is -0.37°C, probable error is 0.69°C, and maximum error is 5.77°C (Appendix L).

Tributaries

Comparisons of observed and predicted water temperatures in tributaries indicate that the model is tracking observed temperature patterns, but the degree of accuracy varies with tributary (Appendix O). Of all tributaries modeled, only New River had a substantial amount of observed data from which to compare (see Table 3). Similar to the mainstem validation nodes, the model appears to track water temperatures of this tributary relatively well. However, it also appears that the model's ability to predict temperatures was most limited during the winter months. Of the other tributaries modeled, Rush Creek and the North Fork Trinity River were two tributaries in which observed and predicted temperatures were in close agreement, while over prediction generally occurred at Big French Creek, South Fork Trinity River, and Horse Linto Creek. Under prediction occurred at Indian Creek and Canyon Creek. Trends of predicted water temperatures for time periods for which there was no real temperature data, however, do appear to be within a reasonable range of what one might expect for any time of the year (see Appendix O).

VALIDATION

To ascertain the reliability or credibility of the Trinity River SNTEMP model, a validation study was conducted using data independent of the calibration years. The criteria used to measure the success or failure of this effort was: 1) do the predicted temperatures track (follow the pattern) with observed values; and 2) do predicted temperatures fall within the calibration error, in this case, maximum error. For this study, the years 1988 and 1990 were used; these two years represented years for which there was some water temperature data available at specific validation nodes from which to compare model results. In 1988, the two sites that were used included the Steelbridge and the Trinity Canyon Lodge sites. In 1990, three sites were used and they included the Douglas City, Trinity Canyon Lodge, and Burnt Ranch Transfer Station sites. Data from these years were not included in the calibration data set.

Results

Results of the validation study indicate that at certain nodes and in different years or times of the year, the model's ability to predict temperatures varied (Appendix P). In 1988, the model's predictions of water temperatures at the Steelbridge node indicated that the model was tracking the observed data relatively well, but that there were five time periods in the spring in which the predicted temperatures were greater than +/- 3.52°C (maximum error) of the observed temperatures. Overall about 73 and 44% of the predictions were within 2.0°C and 1.0°C of the observed values, respectively.

Comparisons of predicted and observed water temperatures at the Trinity Canyon Lodge for 1988 showed a similar trend to the Steelbridge site. At this node, however, there were three time periods in which water temperature predictions were greater than +/- 2.82°C (maximum error). These time periods included late fall and spring and one time period during the summer. Overall, approximately 50% and 25% of predicted values fell within 2.0°C and 1.0°C of observed values, respectively.

Comparisons of observed and predicted temperatures in 1990 showed that the model was able to predict temperatures much more accurately than in 1988 and that predicted temperatures tracked relatively well with observed values. Although there were only 20 weeks of data from which to compare observed and predicted values, water temperatures at the Douglas City site were almost always less than 1.5°C, well within the maximum error (2.71°C). In addition, 65% of the predicted values were within 1.0°C of observed values. At the next lower node, Trinity Canyon Lodge, predictions were also always within the maximum error (2.82°C) and 64 and 51% of the weeks were within 2.0°C and 1.0°C of observed values, respectively. Similar to the other sites, the water temperature predictions at Burnt Ranch were always within the maximum error (3.16°C). Again, although there was little observed data from which to compare predictions, 86% and 43% of predicted temperatures at Burnt Ranch were within 2.0°C and 1.0°C of observed values, respectively.

SIMULATION RESULTS

Release volume and temperature, in addition to hydro meteorological conditions, play an important role in the longitudinal temperature profile of the Trinity River. To illustrate these influences and system behavior, four similar time periods were chosen from each hypothetical year. The time periods used included: October 1, which corresponds to a time of salmon spawning and a time that the water temperature objectives are in effect (see the Background Information section of this report for dates and criteria); December 31, which represents winter and a time of salmon egg incubation; May 20, which represents spring and the time of salmon smolt emigration; and July 1, which represents summer and also a time in which the temperatures objectives go into effect. For each of these time periods, model simulations were run for two different release water temperatures at Lewiston Dam. The range of release water temperatures (maximum and minimum average weekly) was dictated by the range of temperatures observed for that time period for the water years 1987 to 1994. Simulations were also performed for six discharges ranging from 4.2 to 169.8 cms (150 to 6000 cfs). The results of these simulations for hot-dry, median, and cold-wet year types are illustrated in Appendixes Q, R, and S, respectively. In addition, a summary of the results for the two time periods for which the Basin Plan water temperature objectives are in effect is provided in Table 5.

Hot-dry Year Type

<u>October 1</u>

The simulations for this time period for two different release temperatures indicate several points. First, when release water temperatures are about 8.0°C, the amount of water required to meet the temperature objective of 13.3°C at the North Fork Trinity River (~ 60 km downstream of Lewiston Dam) was greater than 8.5 cms (300 cfs), but less than 17.0 cms (600 cfs). Since the temperature objectives went into effect in the summer of 1992, experience has shown that a flow of about 12.8 cms (450 cfs) has been sufficient to meet these objectives under most meteorological conditions. With a Lewiston Dam release of 4.2 and 169.8 cms, the water temperatures at Weitchpec would reach 17°C and 11°C, respectively.

Table 5. The interrelation of flow and release temperature to meet the water temperature objectives of the Basin Plan under the three hypothetical year types.

Date	Release Temperature (°C)	Compliance Location (Km from dam)	Temperature Objective (°C)	Lewiston Dam Release (cms) to meet Objectives		
				Year Type		
				Hot-dry	Median	Cold-wet
July 1	10.0	Douglas City (~ 30 km)	15.6	8.5 to 17.0	4.2 to 8.5	< 4.2
"	13.4	"	15.6	17.0 to 28.3	8.5 to 17.0	< 4.2
October 1	8.1	North Fork Trinity River (~ 60 km)	13.3	8.5 to 17.0	4.2 to 8.5	< 4.2
"	10.6	"	13.3	8.5 to 17.0	8.5	< 4.2

When the release water temperature from Lewiston Dam was 10.6°C, the amount of flow required to meet the temperature objectives would be between 8.5 cms (300 cfs) and 17.0 cms (600 cfs). Similar to the previous scenario, high volume releases (169.8 cms [6000 cfs]) tend to keep temperatures cold at Weitchpec (< 13°C).

December 31

Simulations for this time period indicated that low release temperatures (4.1°C) resulted in a trend of warming under all flow conditions, but more pronounced warming occurred with lower flow.

Simulations with warmer releases (7.1°C), indicated that the spatial pattern of warming was variable with flow conditions. With a large Lewiston Dam release (169.8 cms [6,000 cfs]), only a slight warming from Lewiston to Weitchpec Falls occurred, while at lower flows a trend of decreasing temperatures followed by increasing temperatures occurred. Because the water temperatures of the entire Trinity River were always predicted to be less than 8.0°C, the Basin Plan Objectives would be met under all discharge conditions.

May 20

Simulations for this time period indicated that a release temperature of 9°C resulted in increased downstream temperatures regardless of flow magnitude. At low flow conditions (4.2 cms [150cfs]) water temperatures at Weitchpec Falls warmed to more than 18°C, while at high flows (169.8 cms [6,000 cfs]), temperatures warmed to about 13.0°C.

Simulations under a warmer release temperature (13.1°C) indicate that the downstream effects can be spatially variable. At low flows, temperatures decrease from the dam down to about 40 kilometers and was probable related to snowmelt conditions of tributaries. Beyond 40 kilometers, all flow scenarios showed a trend of increasing temperature. Similar to the low temperature simulation presented above, flows of 4.2 cms from Lewiston Dam resulted in temperatures to more than 18°C at Weitchpec Falls, while higher flows (169.8 cms [6,000 cfs]) resulted in temperatures to 16°C.

<u>July 1</u>

Similar to the October 1 scenario, the simulations for this time period also indicated that release temperature and flow conditions could have a great effect on downstream temperatures. Comparison of high and low flow conditions, when releases are 10.0°C, indicate that water temperatures could possibly be maintained as cold as 14.0°C at Weitchpec Falls with a discharge of 169.8 cms (6,000 cfs), while at a lower discharges (4.2 cms [150 cfs]), the water temperature may get as high as 23°C. Under this scenario, the temperature criteria of 15.6°C as specified in the Basin Plan for Douglas City (~ 30 km below Lewiston Dam) could be met if releases were between 8.5 cms (300 cfs) and 17.0 cms (600 cfs). Again, experience has shown that a flow of about 12.8 cms (450 cfs) from Lewiston Dam is adequate to meet the Basin Plan Objectives under most meteorological conditions.

At a high release water temperature (13.4°C), the water temperature at Weitchpec approached 23°C with flows from Lewiston Dam at 4.2 cms (150 cfs). At a higher discharge (169.8 cms [6,000 cfs]) with the same release water temperature, the water temperature at Weitchpec would be about 16°C. To meet the Basin Plan Objective with the warmer release water temperature, a flow in excess of 17.0 cms would be required (600 cfs).

Median Year Type

<u>October 1</u>

Similar to the simulations of the previous section, simulations for this time period also indicated that flow and release temperature have an effect on downstream temperatures. With a low discharge from Lewiston Dam (4.2 cms) and a release water temperature of 8.0°C, the water temperature at Weitchpec Falls may reach 16°C, while at a higher discharge (169.8 cms [6,000 cfs]), the water temperature may only reach 11°C. Under this scenario, it would require a flow between 4.2 cms (150 cfs) and 8.5 cms (300 cfs) to meet the Basin Plan Objective of 13.3°C at the confluence with the North Fork Trinity River (see summary in Table 5).

With a warmer release (10.6°C) and a low discharge (4.2 CMS [150 cfs]), the water temperature at Weitchpec Falls reached 16.0°C and a higher discharge (169.8 CMS [6,000 cfs]) resulted in cooler water temperatures (12.5°C). To meet the temperature under this scenario, it would require a flow of about 8.5 CMS (300 cfs).

<u>December 31</u>

Simulations for the December 31 time period indicate that a low release water temperature (4.1°C) results in a narrow range of temperatures down river under all simulated discharges; water temperatures fall between 3 and 5°C.

With warmer releases (7.1°C) and a dam discharge less than 169.8 CMS (6,000 cfs), down river water temperatures generally decreased for the first 40 km then increased or remained the same. At a higher discharge (169.8 CMS [6,000 cfs]), water temperatures essentially remained the same for the entire length of the Trinity River. Similar to the Hot-dry scenario, the Basin Plan Objectives would be met under the range of discharges and release temperatures used in this modeling effort.

May 20

Simulations for this time period indicated that a release of about 9°C would result in a trend of increasing temperatures with distance from Lewiston Dam. With a discharge of 4.2 CMS (150 cfs), the water temperature warmed to more than 15.5°C at Weitchpec Falls, while a higher discharge (169.8 CMS (6,000 cfs) resulted in a temperature less than 13°C.

With a dam release water temperature (13.1°C), the effect downstream varied spatially with magnitude of discharge released from Lewiston Dam. Simulations for the lower of the range of discharges, indicated that water temperatures decrease from the dam down to about 40 kilometers (probably related to snowmelt conditions in tributaries), and then, in general, increase. With a discharge of 4.2 CMS (150 cfs), the temperature at Weitchpec Falls could just exceed 15.5°C, while a discharge of 169.8 cms (6,000 cfs) would only result in a moderate water temperature reduction (~0.5°C).

July 1

Simulations for this time period showed that the effects of a 10°C release on downstream temperatures is dependent on discharge magnitude. With a low discharge of 4.2 cms (150 cfs), the water temperature reached about 21°C at Weitchpec Falls, while a discharge of 169.8 cms (6,000 cfs) resulted in substantially cooler water temperatures (~14°C). To meet the Basin Plan requirements, a discharge between 4.2 cms (150 cfs) and 8.5 cms (300 cfs) would be required.

With a warmer release water temperature (13.4°C), water temperatures at Weitchpec Falls reached ~21°C at 4.2 cms (150 cfs) and about 16°C at 169.8 cms (6,000 cfs). To meet Basin Plan requirements with this warm release, a discharge between 8.5 and 17.0 cms (300 to 600 cfs) would be required.

Cold-wet Year Type

October 1

Simulations for this time period for two different release water temperatures indicated that downstream temperatures are moderated by meteorological conditions. When release water temperatures are 8.1°C, temperatures at Weitchpec Falls may reach about 12.5°C under a low discharge (4.2 cms [150 cfs]) and about 10°C under a high discharge (169.8 cms [6,000 cfs]).

With a warmer discharge (10.6°C), low and high discharges result in similar temperature conditions to about 60 km downstream of Lewiston Dam. Beyond 60 km, however, higher discharges began to have a cooling effect. Under these conditions, the temperature objectives of the Basin Plan would be met with a discharge less than 4.2 cms (150 cfs)(see the summary in Table 5).

<u>December 31</u>

Simulations under cold water temperature releases (4°C) from Lewiston Dam indicate that downstream water temperatures were moderated by high discharges in contrast to lower discharges. At a discharge of 169.8 cms (6,000 cfs), temperatures remained close to 4.0°C for the first 60 km then slowly increased to 5.0°C at Weitchpec Falls. At lower discharges, water temperatures were more variable in the first 60 km below the dam, although temperatures remained within 2.0°C of the Lewiston Dam release temperature throughout the network.

Simulations with warmer release water temperatures (7.1°C) also indicate that water temperature is moderated by a discharge of 169.8 cms (6,000 cfs), but in this case, there was a slight cooling effect with distance from the dam. At lower discharges (< 169.8 cms [6,000 cfs]), water temperatures decreased for about the first 40 km before slowly increasing and reaching 5.0°C at the end of the network.

<u>May 20</u>

Simulations indicate that a cold release water temperature (9.2 °C) results in water temperatures below 13°C at Weitchpec Falls regardless of discharge magnitude. When release water temperatures are warmer (13.1°C), however, the effect downstream is variable and depends on the discharge. At a discharge up to 56.6 cms (2,000 cfs), water temperatures decrease for about 40 km downstream before increasing. At a higher discharge (169.8 cms [6,000 cfs]), the water temperature is moderated and remains near 13°C for the entire length of the Trinity.

<u>July 1</u>

Similar to the Hot-dry and Median year types, simulation results indicate that water temperatures continue to warm with distance from the dam. With a release of 10.0°C, water temperatures at Weitchpec Falls reach more than 18°C with a discharge of 4.2 cms (150 cfs) and 14°C at 169.8 cms (6,000 cfs).

With warmer releases (13.4°C), water temperatures may reach more than 18°C with a discharge of 4.2 cms (150 cfs) and 16°C at 169.8 cms (6,000 cfs). At both release temperatures, however, it would only require a discharge of 4.2 cms (150 cfs) to meet the Basin Plan Objectives at Douglas City (Table 5).

DISCUSSION

A SNTEMP water temperature model, calibrated with four years of data, was developed for the entire Trinity River basin that predicts the average weekly (7-day average of daily averages) water temperature for any time of the year or location. The statistics generated from calibration of the SNTEMP model for the Trinity River indicate that the model is capable of predicting temperatures at any mainstem location in the network to within 1.06°C fifty percent of the time and almost always within 3.5°C (if the Willow Creek validation node was excluded). As previously stated, the Willow Creek validation node was lacking water temperature data during the winter months for all calibration years. Because of this lack of data, the regression model didn't have any data points from which to fill in temperatures accurately, which led to the observed high maximum error.

Calibration statistics for tributaries, where available, indicated that the model was predicting water temperature reasonably well. For example, although not presented in this report, the New River calibration indicated that the model was tracking observed data and was capable of predicting temperatures to within 1.7°C most of the time and 5.3°C all of the time. Because of the lack of water temperature data for most of the other tributaries, the statistics generated by the model were not presented in this report. The ranges of predicted water temperatures for time periods for which there was no real temperature data, however, do appear to fall within a reasonable range of what one might expect for any time of the year.

Validation of the model indicated that the heat transport model and regression models were capable of performing relatively well under most conditions independent of those used in calibration. Comparisons of observed and predicted temperatures for water year 1988 indicated that the model's ability to predict temperatures was most limited during the winter and early spring when error exceeded the calibration error. A possible explanation for this excessive error could be that the meteorologic and hydrologic conditions differed from conditions in the calibration years. At all of the other locations and time periods in 1990, the model appeared to track the observed data quite well and predicted temperatures were always within the range of error (maximum error) that was associated with model calibration.

Although the current model calibration tends to slightly underpredict water temperatures (-0.37°C), the results in this report have indicated that the current calibration is adequate for testing managment strategies and addressing "what if " type questions. This is especially true for simulations in which the modeler wishes to determine flow and temperature relations at lower river locations. For more accurate simulations in the upper river, however, the model would probably need to be recalibrated with only these sites in mind, and not for the entire river as was done for this report. It may be that the closer proximity of the lower basin to the Pacific Ocean creates meteorological conditions different from the upper basin; in deed the spatial coverage of the model (178 km) is a long way for site specific meteorological data of the upper basin to apply to the lower basin. It may also be that the adiabatic lapse rate values (adjustments to the air temperature based on elevation change) supplied by the model are incorrect for the Trinity River below the North Fork Trinity River where many kilometers of gorge type topography exist.

Although these hypothetical years were developed with real data, the combination of different variables at a certain exceedance level may have represented unrealistic conditions. Comparisons of the meteorological data that was used in the hypothetical years, however, revealed that the hypothetical year data sets were relatively similar to the real data used in the calibration data sets. Thus, the hypothetical years developed probably represent a degree of reality. As stated earlier, however, these hypothetical years are only useful for evaluating independent weeks rather than a year as a whole. As with any model, however, simulation output should be evaluated objectively, especially when input data or model output requests are outside the range of conditions for which the model was calibrated. Continued model calibration with new water temperature data represented by variable hydrometeorological conditions would result in a more accurate water temperature model.

This modeling exercise has shown the interrelationship that both release temperature and discharge have on downstream water temperatures depending on the year type and the time of year. Generally, high discharge conditions resulted in moderated temperature regimes throughout the year and low discharge conditions usually resulted in downstream water temperatures that were approaching ambient meteorologic conditions.

Collaborative information from this modeling exercise and empirical evidence which indicates that temperatures can be influenced throughout the mainstem Trinity River system (nearly 180 km). Supporting evidence that there can be “control” over water temperatures in the lower Trinity River is shown in Appendix N, where in 1992 an experimental discharge of 169 cms (6,000 cfs) at 9.3°C was released from Lewiston Dam in mid-June. The effects of this high flow on observed water temperatures at Weitchpec were significant (e.g., 7-day average daily water temperatures only reached a little over 15°C, whereas the previous weeks temperatures were as warm as 21°C). Extensive shading, both topographic and vegetative, the small increase of channel width to increased flows (stage-discharge relationship), and typically small accretions along the network are probable reasons for reduced heat gain at higher discharges.

The use of the hypothetical years in the management of the Trinity River should consider the results of these simulations and others to achieve a water temperature objective. In addition, it is apparent that the way the Trinity River flow schedule is set, establishment of a flow schedule for the future with uncertain hydro meteorological conditions, that near worst case conditions should be utilized to achieve more certainty that a temperature objective is met. While currently the water temperature objectives of the Basin Plan are limited to July 1 to December 31, it may be that this model could also be used to help establish a temperature objective during the spring time, a time of salmon and steelhead smolt emigration.

REFERENCES

Bartholow, J.M. 1989. Stream temperature investigations: field and analytical methods. Instream Flow Information Paper No. 13. U.S. Fish and Wildlife Service. Biol. Rep. 89(17). 139 pp.

Limerinos, J. T. 1967. Time-of-travel study of Trinity River, California. U.S. Geological Survey, Water Resource Division. Open-file report. Menlo Park, California. 24 pp.

North Coast Regional Water Quality Control Board. 1991. Water Quality Control Plan for the North Coast Region, Amendments from September 26, 1991.

Theurer, F.D., K. A. Voos, and W. J. Miller. 1984. Instream water temperature model. Instream Flow Information Paper 16. U. S. Fish and Wildlife Service. FWS/OBS-84/15. v.p.

Williamson, S.C., J.M. Bartholow, and C.B. Stalnaker. 1992. Conceptual model for quantifying pre-smolt production from flow-dependent physical habitat and water temperature. Regulated Rivers: Research and Management, Vol. 7, 000-000.

Zedonis, P. 1994. Estimated influences of feather edge and side-channel projects on water temperatures of the upper Trinity River. U.S. Fish and Wildlife Service Report. Sacramento, California. 19 pp.

APPENDIXES

A. Exceedance Probabilities for air temperature (°C) data measured at Trinity River Hatchery, Trinity County, CA.

AVERAGE WEEKLY AIR TEMPERATURE (°C)						
EXCEED LEVEL	10	25	50	75	90	95
01-Oct	18.6	17.2	15.8	13.8	11.4	10.6
08-Oct	17.5	16.0	14.7	12.9	10.2	9.1
15-Oct	16.1	14.7	13.1	11.6	9.2	8.0
22-Oct	14.1	13.1	11.6	10.1	7.9	6.9
29-Oct	12.7	11.5	9.9	8.6	6.6	5.5
05-Nov	11.2	10.0	8.5	7.3	5.6	4.6
12-Nov	9.4	8.4	7.1	5.9	4.3	3.7
19-Nov	8.4	7.2	6.1	4.8	3.1	2.5
26-Nov	7.5	6.2	5.1	3.8	1.9	0.9
03-Dec	6.7	5.4	4.3	3.0	1.0	-0.0
10-Dec	6.3	5.0	3.7	2.3	0.4	-0.5
17-Dec	6.2	4.6	3.1	1.7	-0.2	-1.1
24-Dec	6.0	4.5	2.8	1.4	-0.4	-1.2
31-Dec	6.2	4.7	2.7	1.4	-0.1	-0.6
07-Jan	6.2	4.9	3.0	1.6	0.2	-0.3
14-Jan	6.4	5.2	3.4	1.9	0.2	-0.5
21-Jan	6.7	5.8	3.8	2.5	0.8	-0.1
28-Jan	7.3	6.0	4.3	3.0	1.3	0.4
04-Feb	7.8	6.5	4.9	3.4	1.8	0.6
11-Feb	8.8	7.2	5.2	4.0	2.2	0.9
18-Feb	9.5	7.8	5.9	4.8	3.0	1.8
25-Feb	10.1	8.2	6.4	5.1	3.2	2.1
04-Mar	10.5	8.8	6.9	5.6	3.6	2.7
11-Mar	11.2	9.1	7.2	5.9	3.8	3.1
18-Mar	12.0	9.7	7.9	6.2	4.3	3.7
25-Mar	13.0	10.3	8.4	6.4	4.8	4.0
01-Apr	13.8	11.0	9.1	6.9	5.4	4.7
08-Apr	14.5	11.8	9.6	7.6	5.9	5.1
15-Apr	15.1	12.8	10.6	8.6	6.9	6.0
22-Apr	16.0	13.5	11.3	9.4	7.8	6.9
29-Apr	16.8	14.4	12.3	10.7	9.2	8.3
06-May	17.9	15.6	13.4	11.8	10.1	9.3
13-May	19.1	16.8	14.6	12.9	11.1	10.3
20-May	20.3	18.0	15.8	13.6	11.9	11.0
27-May	20.8	18.9	16.7	14.6	13.0	12.2
03-Jun	21.6	20.0	17.7	15.6	13.9	13.2
10-Jun	22.5	20.8	18.5	16.4	14.7	14.0
17-Jun	23.4	21.5	19.2	17.2	16.0	15.3
24-Jun	23.7	22.1	19.8	18.4	17.0	16.5
01-Jul	24.5	23.1	20.9	19.4	18.1	17.5
08-Jul	25.0	23.6	21.6	20.1	18.7	18.1
15-Jul	25.4	24.1	22.5	21.0	19.9	19.3
22-Jul	25.7	24.4	23.0	21.6	20.5	19.9
29-Jul	25.9	24.6	23.1	21.5	20.4	19.7
05-Aug	25.5	24.0	22.6	21.1	20.0	19.2
12-Aug	25.1	23.3	21.9	20.4	19.3	18.6
19-Aug	24.4	22.8	21.2	19.8	18.5	17.7
26-Aug	23.5	22.0	20.4	19.0	17.2	16.5
02-Sep	22.6	21.2	19.3	18.0	16.3	15.7
09-Sep	21.8	20.4	18.8	17.2	15.2	14.7
16-Sep	21.0	19.7	18.1	16.4	14.2	13.6
23-Sep	19.8	18.6	17.0	15.2	12.7	12.2

B. Exceedance probabilities for relative humidity from Redding and Red Bluff Municipal Airports.

AVERAGE WEEKLY RELATIVE HUMIDITY (FRACTIONS)						
EXCEED LEVEL	10	25	50	75	90	95
01-Oct	0.64	0.53	0.44	0.37	0.32	0.30
08-Oct	0.66	0.56	0.45	0.40	0.35	0.32
15-Oct	0.68	0.59	0.48	0.42	0.36	0.32
22-Oct	0.71	0.63	0.52	0.45	0.37	0.33
29-Oct	0.73	0.66	0.56	0.49	0.40	0.35
05-Nov	0.76	0.70	0.61	0.53	0.43	0.37
12-Nov	0.78	0.72	0.64	0.54	0.44	0.39
19-Nov	0.80	0.75	0.67	0.57	0.47	0.42
26-Nov	0.83	0.78	0.68	0.59	0.50	0.46
03-Dec	0.84	0.80	0.70	0.61	0.53	0.49
10-Dec	0.85	0.81	0.72	0.62	0.53	0.51
17-Dec	0.85	0.81	0.72	0.63	0.56	0.53
24-Dec	0.86	0.83	0.74	0.65	0.56	0.52
31-Dec	0.86	0.83	0.75	0.66	0.55	0.51
07-Jan	0.86	0.82	0.74	0.65	0.54	0.49
14-Jan	0.86	0.82	0.72	0.63	0.55	0.50
21-Jan	0.86	0.82	0.72	0.62	0.53	0.49
28-Jan	0.85	0.79	0.68	0.60	0.53	0.49
04-Feb	0.84	0.78	0.67	0.56	0.51	0.47
11-Feb	0.82	0.75	0.64	0.54	0.48	0.45
18-Feb	0.81	0.74	0.64	0.53	0.47	0.44
25-Feb	0.79	0.72	0.63	0.52	0.45	0.42
04-Mar	0.78	0.72	0.62	0.51	0.45	0.41
11-Mar	0.75	0.70	0.62	0.52	0.45	0.41
18-Mar	0.74	0.69	0.60	0.51	0.44	0.41
25-Mar	0.71	0.66	0.57	0.49	0.43	0.40
01-Apr	0.70	0.65	0.56	0.48	0.43	0.39
08-Apr	0.68	0.63	0.55	0.46	0.41	0.38
15-Apr	0.67	0.62	0.54	0.46	0.41	0.39
22-Apr	0.66	0.61	0.54	0.46	0.40	0.38
29-Apr	0.65	0.60	0.53	0.45	0.40	0.38
06-May	0.63	0.58	0.51	0.45	0.38	0.37
13-May	0.62	0.56	0.49	0.43	0.35	0.33
20-May	0.62	0.55	0.47	0.40	0.33	0.31
27-May	0.59	0.53	0.45	0.38	0.31	0.29
03-Jun	0.57	0.52	0.43	0.36	0.30	0.27
10-Jun	0.56	0.49	0.41	0.34	0.29	0.26
17-Jun	0.52	0.46	0.39	0.33	0.29	0.26
24-Jun	0.49	0.43	0.37	0.32	0.29	0.26
01-Jul	0.48	0.41	0.36	0.32	0.28	0.26
08-Jul	0.48	0.40	0.35	0.32	0.28	0.27
15-Jul	0.45	0.39	0.35	0.32	0.29	0.27
22-Jul	0.45	0.39	0.35	0.32	0.29	0.28
29-Jul	0.46	0.40	0.36	0.32	0.29	0.27
05-Aug	0.46	0.41	0.37	0.32	0.29	0.28
12-Aug	0.48	0.43	0.38	0.33	0.29	0.27
19-Aug	0.49	0.43	0.39	0.33	0.28	0.27
26-Aug	0.51	0.44	0.40	0.34	0.28	0.26
02-Sep	0.54	0.46	0.41	0.35	0.29	0.27
09-Sep	0.58	0.47	0.41	0.35	0.29	0.27
16-Sep	0.58	0.48	0.42	0.35	0.30	0.28
23-Sep	0.62	0.51	0.44	0.36	0.31	0.29

C. Exceedance probabilities for wind speed (m/s) measured at Trinity River Hatchery.

AVERAGE WEEKLY WIND SPEED (M/S)						
EXCEED LEVEL	10	25	50	75	90	95
01-Oct	0.51	0.42	0.36	0.31	0.25	0.22
08-Oct	0.50	0.40	0.33	0.28	0.23	0.19
15-Oct	0.48	0.39	0.29	0.25	0.20	0.16
22-Oct	0.46	0.38	0.29	0.23	0.18	0.14
29-Oct	0.45	0.39	0.29	0.22	0.16	0.13
05-Nov	0.47	0.40	0.29	0.22	0.16	0.13
12-Nov	0.46	0.40	0.30	0.22	0.15	0.14
19-Nov	0.48	0.40	0.32	0.23	0.16	0.13
26-Nov	0.49	0.40	0.32	0.24	0.17	0.14
03-Dec	0.49	0.39	0.32	0.25	0.16	0.14
10-Dec	0.49	0.39	0.32	0.24	0.15	0.12
17-Dec	0.48	0.39	0.31	0.23	0.16	0.12
24-Dec	0.47	0.39	0.31	0.21	0.14	0.12
31-Dec	0.45	0.39	0.30	0.20	0.14	0.12
07-Jan	0.45	0.40	0.31	0.18	0.13	0.11
14-Jan	0.48	0.40	0.32	0.19	0.15	0.13
21-Jan	0.52	0.41	0.32	0.20	0.15	0.13
28-Jan	0.54	0.41	0.35	0.22	0.16	0.14
04-Feb	0.56	0.43	0.36	0.24	0.18	0.16
11-Feb	0.58	0.44	0.37	0.27	0.21	0.18
18-Feb	0.58	0.46	0.39	0.29	0.23	0.19
25-Feb	0.58	0.49	0.42	0.32	0.25	0.21
04-Mar	0.63	0.52	0.44	0.34	0.28	0.23
11-Mar	0.70	0.56	0.48	0.37	0.29	0.24
18-Mar	0.76	0.60	0.51	0.39	0.32	0.27
25-Mar	0.81	0.62	0.53	0.41	0.33	0.29
01-Apr	0.83	0.64	0.56	0.44	0.36	0.32
08-Apr	0.84	0.67	0.58	0.47	0.38	0.35
15-Apr	0.85	0.67	0.59	0.49	0.41	0.38
22-Apr	0.85	0.68	0.59	0.52	0.43	0.38
29-Apr	0.82	0.69	0.59	0.54	0.46	0.42
06-May	0.82	0.70	0.59	0.53	0.47	0.42
13-May	0.81	0.71	0.58	0.52	0.46	0.42
20-May	0.78	0.70	0.56	0.51	0.45	0.42
27-May	0.80	0.68	0.57	0.50	0.43	0.41
03-Jun	0.79	0.67	0.57	0.49	0.42	0.39
10-Jun	0.78	0.66	0.58	0.49	0.41	0.38
17-Jun	0.77	0.65	0.57	0.48	0.42	0.38
24-Jun	0.75	0.64	0.57	0.48	0.42	0.38
01-Jul	0.70	0.62	0.55	0.47	0.43	0.39
08-Jul	0.68	0.60	0.54	0.46	0.41	0.39
15-Jul	0.67	0.59	0.52	0.46	0.42	0.39
22-Jul	0.66	0.58	0.51	0.46	0.41	0.39
29-Jul	0.67	0.58	0.51	0.45	0.42	0.40
05-Aug	0.65	0.59	0.52	0.46	0.41	0.39
12-Aug	0.66	0.60	0.51	0.46	0.41	0.39
19-Aug	0.65	0.59	0.51	0.45	0.39	0.36
26-Aug	0.64	0.59	0.50	0.44	0.38	0.35
02-Sep	0.62	0.57	0.48	0.43	0.35	0.31
09-Sep	0.59	0.54	0.46	0.40	0.33	0.30
16-Sep	0.56	0.50	0.43	0.37	0.31	0.27
23-Sep	0.55	0.46	0.39	0.35	0.29	0.25

D. Exceedance probabilities for possible sunshine from Redding and Red Bluff Municipal Airports.

AVERAGE WEEKLY POSSIBLE SUNSHINE (fractions)						
EXCEED LEVEL	10	25	50	75	90	95
01-Oct	0.99	0.97	0.92	0.83	0.73	0.68
08-Oct	0.98	0.96	0.89	0.81	0.72	0.68
15-Oct	0.98	0.95	0.88	0.78	0.71	0.67
22-Oct	0.97	0.93	0.83	0.70	0.63	0.56
29-Oct	0.96	0.90	0.79	0.65	0.54	0.46
05-Nov	0.94	0.87	0.74	0.59	0.47	0.39
12-Nov	0.95	0.86	0.73	0.54	0.38	0.30
19-Nov	0.94	0.86	0.69	0.48	0.31	0.21
26-Nov	0.94	0.87	0.69	0.46	0.28	0.19
03-Dec	0.93	0.86	0.67	0.45	0.29	0.21
10-Dec	0.93	0.85	0.68	0.43	0.27	0.20
17-Dec	0.91	0.82	0.65	0.42	0.28	0.21
24-Dec	0.89	0.76	0.62	0.41	0.25	0.21
31-Dec	0.88	0.75	0.59	0.40	0.24	0.21
07-Jan	0.90	0.77	0.61	0.40	0.25	0.21
14-Jan	0.91	0.78	0.62	0.43	0.26	0.21
21-Jan	0.91	0.79	0.66	0.48	0.29	0.22
28-Jan	0.93	0.85	0.70	0.50	0.31	0.25
04-Feb	0.94	0.86	0.75	0.56	0.36	0.32
11-Feb	0.91	0.85	0.75	0.58	0.38	0.34
18-Feb	0.92	0.87	0.76	0.58	0.41	0.38
25-Feb	0.91	0.88	0.75	0.59	0.46	0.44
04-Mar	0.92	0.89	0.77	0.64	0.52	0.49
11-Mar	0.93	0.89	0.79	0.67	0.55	0.51
18-Mar	0.95	0.91	0.82	0.68	0.60	0.53
25-Mar	0.96	0.93	0.85	0.73	0.64	0.56
01-Apr	0.98	0.94	0.89	0.77	0.66	0.58
08-Apr	0.98	0.94	0.89	0.79	0.70	0.62
15-Apr	0.99	0.94	0.90	0.82	0.74	0.65
22-Apr	0.99	0.95	0.91	0.85	0.75	0.69
29-Apr	0.99	0.95	0.92	0.87	0.79	0.73
06-May	0.99	0.96	0.92	0.88	0.81	0.77
13-May	0.99	0.97	0.94	0.89	0.80	0.75
20-May	0.99	0.97	0.93	0.88	0.79	0.75
27-May	0.99	0.98	0.94	0.88	0.81	0.77
03-Jun	0.99	0.97	0.93	0.88	0.82	0.76
10-Jun	0.99	0.98	0.94	0.89	0.82	0.76
17-Jun	0.99	0.98	0.94	0.90	0.85	0.79
24-Jun	1.00	0.98	0.95	0.92	0.88	0.84
01-Jul	1.00	0.99	0.96	0.93	0.89	0.84
08-Jul	1.00	1.00	0.97	0.94	0.90	0.87
15-Jul	1.00	1.00	0.98	0.94	0.92	0.88
22-Jul	1.00	1.00	0.98	0.95	0.92	0.88
29-Jul	1.00	1.00	0.98	0.94	0.89	0.84
05-Aug	1.00	0.99	0.97	0.94	0.90	0.84
12-Aug	1.00	0.99	0.97	0.93	0.88	0.83
19-Aug	1.00	0.99	0.97	0.93	0.88	0.82
26-Aug	1.00	0.99	0.97	0.92	0.85	0.80
02-Sep	1.00	0.99	0.97	0.90	0.83	0.78
09-Sep	1.00	0.99	0.96	0.89	0.80	0.75
16-Sep	1.00	0.99	0.96	0.89	0.79	0.74
23-Sep	1.00	0.98	0.95	0.86	0.75	0.70

E. Exceedance probabilities for flow accretion between Lewiston and Burnt Ranch Gauge Stations for determination of tributary flow.

AVERAGE WEEKLY ACCRETION (CMS)						
EXCEED LEVEL	10	25	50	75	90	95
01-Oct	8.20	4.76	3.07	2.05	1.25	1.08
08-Oct	11.46	5.71	3.61	2.30	1.39	1.18
15-Oct	13.97	7.45	4.21	2.63	1.67	1.35
22-Oct	21.50	9.72	5.09	2.97	1.91	1.56
29-Oct	44.13	14.55	6.57	3.42	2.17	1.85
05-Nov	59.02	22.27	8.12	4.16	2.58	2.10
12-Nov	70.38	29.83	10.29	4.78	2.95	2.37
19-Nov	85.13	37.32	13.18	5.53	3.48	2.70
26-Nov	97.37	47.51	15.38	6.75	4.12	3.05
03-Dec	104.22	54.50	17.52	7.64	4.66	3.30
10-Dec	109.95	54.05	19.76	8.76	5.29	3.62
17-Dec	111.34	55.95	20.53	10.30	5.57	3.84
24-Dec	118.07	60.22	23.29	11.92	6.66	4.45
31-Dec	147.99	67.82	27.56	13.17	7.55	5.29
07-Jan	155.07	71.41	31.29	14.17	8.13	5.79
14-Jan	168.98	79.81	35.62	15.75	9.21	6.76
21-Jan	184.60	84.24	42.29	17.36	10.14	7.42
28-Jan	195.48	92.89	47.71	20.86	11.53	8.90
04-Feb	194.54	88.12	49.64	24.53	13.59	10.61
11-Feb	193.99	91.12	51.64	28.33	17.25	13.13
18-Feb	193.98	94.21	54.84	31.58	20.57	16.26
25-Feb	189.46	99.09	56.94	35.21	24.18	18.81
04-Mar	183.25	94.90	55.55	36.26	25.98	20.06
11-Mar	165.46	93.46	56.72	37.37	27.12	21.35
18-Mar	154.35	89.56	57.57	38.93	27.41	22.57
25-Mar	140.15	85.24	55.31	38.37	26.93	22.26
01-Apr	136.44	83.18	51.95	36.69	26.29	22.08
08-Apr	125.39	80.66	48.94	35.57	25.67	22.19
15-Apr	109.92	77.49	45.64	33.77	25.26	22.30
22-Apr	99.24	73.86	42.52	31.42	23.92	21.45
29-Apr	92.51	70.36	40.10	30.25	22.51	20.36
06-May	83.70	62.52	37.56	28.77	21.49	19.81
13-May	79.68	57.06	36.62	26.72	20.12	18.35
20-May	75.26	53.71	34.33	24.16	18.13	16.28
27-May	69.62	48.30	31.23	21.34	15.90	14.00
03-Jun	61.16	42.62	28.13	18.74	13.59	11.81
10-Jun	51.88	37.09	24.58	15.96	11.05	9.76
17-Jun	41.57	30.09	20.23	13.07	8.85	7.97
24-Jun	32.84	24.80	16.70	10.89	7.07	6.13
01-Jul	26.00	20.63	13.72	9.06	5.64	4.82
08-Jul	21.53	16.18	10.65	7.04	4.65	3.98
15-Jul	17.19	12.69	8.24	5.66	3.69	3.11
22-Jul	14.39	10.01	6.50	4.58	2.90	2.47
29-Jul	12.16	7.92	5.28	3.61	2.11	1.89
05-Aug	10.09	6.41	4.22	2.84	1.70	1.47
12-Aug	8.26	5.22	3.50	2.44	1.47	1.34
19-Aug	7.17	4.44	3.09	2.08	1.31	1.18
26-Aug	5.93	3.95	2.76	1.84	1.18	1.12
02-Sep	5.87	3.77	2.64	1.74	1.17	1.11
09-Sep	6.23	3.70	2.60	1.75	1.19	1.18
16-Sep	6.53	3.90	2.61	1.76	1.13	1.05
23-Sep	6.92	4.22	2.72	1.90	1.21	1.08

E2. Sensitivity Analysis of Increased tributary flow in Zone 2 on water temperatures of the Trinity River at Weitchpec.

As part of the SNTEMP model development for the Trinity River, three hypothetical years (hot-dry, median, cold-wet) were developed with the idea that these years, represented by independent weeks, would serve as a way of characterizing a wide range of past hydrometeorological conditions. These conditions could subsequently be used for predicting possible future outcomes Hydrologically, these years are represented by 90, 50 and 10 % probabilities of exceedance for independent weeks, respectively. This was only done for Zone 1 (Lewiston to Burnt Ranch) and the synthesized year types in this zone are reflective of flow conditions in this zone. However, tributary flows in the lower segment (Zone 2) were determined in a different fashion. These flows were derived by a basic ratio. Because the basin size of Zone 1 was approximately 0.5 that Zone 2, I simply multiplied Zone 1 values by 2 to obtain the tributary accretion of the each week for each respective year type. However, because it is know that run-off, and consequently tributary flow patterns, can vary within and between watersheds, a sensitivity test was performed to see how increased accretion in Zone 2 would affect water temperatures at Weitchpec.

Methods

A median year was selected for comparison purposes. Baseline conditions represented by given flow accretions based on the 2 x method were compared with altered flow conditions represented by an increase of 50% in tributary flows in Zone 2 for four time periods (Dec 31, Apr 1, Jul 1, and Oct 1) for median year conditions. A 50% increase in flows was selected to provide an exaggerated level of potential error in the 2X method. Flow alterations were accomplished using the utility program tdeltaq.exe which cascades changes made to flows at selected nodes throughout the stream network. Model output was requested with dam releases that ranged from 300 to 6,000 cfs.

Results.

Results showed low sensitivity to increased accretion in Zone 2, and thus utilization of the method used to provide tributary flow values in Zone 2 are adequate. Results of the test (Table 1) showed that even a 50% increase in lateral accretion in Zone 2 did not significantly affect water temperature model results (always less than 0.4 C), and generally within the range of error associated with water temperature recording devices. Therefore, the simple ratio method appears to be satisfactory for the intended purposes of use of hypothetical years.

Table 1. Comparison of predicted water temperatures of the Trinity River at Weitchpec using

baseline conditions and 50% increase in tributary flows in Zone 2.

Sensitivity Analysis									
Lewiston Dam Release		Water Temperature (C) at Weitchpec, Trinity River							
		December 31		April 1		July 1		October 1	
Cubic Meters per Sec	Cubic Feet per Sec.	Base Line	50% Increase	Base Line	50% Increase	Base Line	50% Increase	Base Line	50% Increase
8.5	300	5.3	5.4	10.2	9.9	20.6	20.2	15.7	15.6
28.3	1000	5.7	5.7	10.3	10.1	19.5	19.4	14.4	14.5
56.6	2000	6.1	6.1	10.5	10.3	18.4	18.5	13.5	13.6
169.8	6000	7.1	7	11.1	10.8	16.6	16.8	12.5	12.6

F. Validation Statistics - Steelbridge Site.

G. Validation Statistics - Douglas City.

H. Validation Statistics - Trinity Canyon Lodge

I. Validation Statistics - Burnt Ranch.

J. Validation Statistics - Willow Creek.

K. Validation Statistics - Weitchpec Falls.

L. Validation Statistics - Summary of all V- nodes.

M. Graphic Illustration of Validation Statistics for all Sites.
(Begin page 43 and end page 49)

N.   Comparisons of Observed and Predicted Water Temperatures - Mainstem Validation Nodes. (Begin page 51 and end page 56)

O. Comparisons of Observed and Predicted Water Temperatures - Tributary Validation Nodes. (Begin page 58 and end page 65)

P. Validation Study Results for 1988 and 1990.
(Begin page 67 end page 71)

Q. Hot-dry Year Type Simulation Results.

(Begin page 73 and end page 80)

R. Median Year Type Simulation Results.
(Begin page 82 and end page 89)

S. Cold-wet Year Type Simulation Results.
(Begin page 91 and end page 98)