The Effect of Riparian Vegetation on Stream Temperature in the Shasta River

by,

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1.0 BACKGROUND

1.1 STATEMENT OF PROBLEM

The California Department of Fish and Game (DFG) has determined that the Shasta River (Figure 1.1) is the most important spawning nursery area for chinook salmon in the Upper Klamath basin (DWR, 2001). Historically the Shasta supported fall and spring-run chinook salmon, coho salmon and steelhead trout. According to annual spawning counts at the Shasta River weir, the 1931 fall run of over 80,000 chinook salmon had dropped to 553 fish in 1990 (DFG, 1991). The Department of Water Resources (DWR) has identified physical barriers (dams, weirs), flow alterations due to water management practices, and water quality issues such as temperature and contaminant concentration as potential problems associated with the ability of salmon to spawn in this area. The DFG and the United States Fish and Wildlife Service (USFWS) have determined that flow and temperature are the critical water quality parameters for restoration of this system (DWR, 2001).

Concern for fish habitat, water temperature and flow has prompted a number of studies in the Shasta River basin. The California Department of Fish and Game (DFG, 1995; DFG, 1996) and the United States Fish and Wildlife Service (USFWS, 1992) have carried out studies to assess the current fish habitat and associated needs. Flow and water temperature studies have been performed by the California Department of Water Resources (DWR, 1964; DWR, 1985). The Department of Civil and Environmental Engineering Modeling Group at the University of California, Davis (CEEMG) conducted a data inventory in 1997. In addition, Deas et al. (1996) conducted a woody riparian vegetation inventory. Preliminary modeling of flow and temperature was explored by the
CEEMG (1998). These studies provide a basis for continuing work in the Shasta River basin.

Figure 1.1 Location of the Shasta River

Water temperatures in sections of the 32-mile study reach of the Shasta River, which extends from four miles below Dwinnell Reservoir to the confluence with the Klamath River, are documented to occasionally exceed temperatures lethal to the three species of cold-water fish present in the basin (USFWS, 1992; Piper et al., 1983). The Shasta River basin is 800 square miles with a mean annual unimpaired runoff of approximately 162,300 acre-feet. The Shasta River receives numerous accretions from tributaries, springs, and agricultural return flows while losing water to several dams and irrigation diversions. For small streams, such as the Shasta River, riparian shading can play an important role in water temperature response through the direct reduction of incoming
solar radiation. Thus, riparian restoration is a potentially powerful tool to control stream temperature. The factors that make small streams sensitive to riparian shading include shallow depths, low flows, and the ability of the tree canopy to shade significant portions of the stream. Riparian revegetation is not the only viable alternative to reduce stream temperature. Flow also plays a vital role in the heating capacity of the system. Thus, two main options available to lower stream temperatures in the Shasta River are (a) to increase flow and (b) increase riparian vegetation. The focus of this study is to compare the effect of current riparian vegetation on stream temperature with the effect of riparian vegetation under various restoration scenarios.

1.2 Temperature and Fisheries

Temperature is a critical parameter for fish survival because it controls the rates of many biological, physical, and chemical processes including active heart rate, metabolic rate, growth rate, swimming speed, feeding rate and efficiency of food conversion (Brett, 1971; Elliot, 1981). Temperatures adequate for fish survival vary with species and life stage. Temperature response for various life stages of chinook salmon, coho salmon, and steelhead trout are briefly outlined herein.

Chinook salmon eggs can survive temperatures between 1.7 and 16.7°C, with highest survival rates between 4 and 12°C. Juvenile chinook salmon grow at temperatures from 8-24°C, under otherwise optimal conditions. Maximum growth rates occur between 13.2 and 20°C. Although chinook salmon exhibit high growth rates at temperatures approaching 19°C, lower temperatures are required to adapt to life in saltwater. Those salmon which smolt at temperatures above 16°C display reduced saltwater survival. Water temperature generally becomes lethal to Central Valley chinook salmon at chronic
temperatures of approximately 25°C, although temperatures as high as 29°C can be tolerated for short periods of time. It is important to note that chinook begin to experience serious chronic effects at temperatures below their lethal limits. In addition, at higher temperatures salmon have increased risk of predations and are more sensitive to other water quality parameters and pathogens. (Myrick et al., 2001)

Preferred temperatures for coho salmon eggs are between 4.4 and 13.4°C. Juvenile coho salmon prefer temperatures between 11.8 and 14.6°C. However, coho can survive temperatures up to approximately 25°C (Hassler, 1987). Temperatures ranging from 7.2 to 16.7°C are required for coho out migration. The upper lethal limit for out migration of coho is also approximately 25°C (Birk, 1996).

Steelhead trout eggs can survive temperatures between 2 and 15°C, with highest survival rates between 7 and 10°C. Juvenile steelhead experience significant mortality at chronic temperatures of greater than 25°C, although temperatures as high as 29.6°C can be tolerated for short periods of time. Juvenile steelhead grow at temperatures from =6.9°C to at least 22.5°C, under otherwise optimal conditions. The highest growth rates reported for Central Valley steelhead occur at 19°C, however higher temperatures have not been tested. As with chinook salmon lower temperatures are required to become adapted to life in salt water. Steelhead smolt at temperatures between 6.5 and 11.3°C. (Myrick et al., 2001)

In summary, chinook and coho salmon and steelhead trout survival rates exhibit a temperature dependence that varies with life stage. Eggs for these species show the highest survival rates at temperatures between approximately 4 and 13°C. Juveniles show maximum growth rates at warmer temperatures between 15 and 19°C for chinook
and steelhead, and cooler water temperatures of about 11.8 to 14.6°C for coho. All three species require cooler temperatures for transition into salt water (10-17°C for chinook, 7-17°C for coho, and 6-10°C for steelhead). All three species experience high mortality rates at chronic temperatures above 25°C. (Myrick et al. 2001; Hassler, 1987; Birk, 1996)

1.3 Functions of Riparian Vegetation

Riparian vegetation is important geomorphically, biologically, and plays a potentially significant role in water quality. Riparian vegetation acts as a cohesive agent to resist erosion from both precipitation and the stream itself. Biologically, vegetation provides habitat for various species, including insects that in turn provide food for juveniles. Trees are specifically vital to fish survival because they supply woody debris to the river that accumulate in log jams used as hiding places from predators in addition to providing a range of velocities acceptable to juveniles. A well-developed riparian zone can also assist in controlling water temperatures.

Riparian vegetation can affect stream temperature by altering the heat flux in several ways. Vegetation can affect the heat flux by reducing wind speed, altering the microclimate above the water surface (i.e. air temperature and relative humidity), and reflecting long-wave radiation (CEEMG, 2001). If the forest canopy covers a significant portion of the stream, perhaps its greatest effects are absorbing, filtering and reflecting solar radiation. Brown (1970) noted that incoming solar radiation may account for close to 95% of the heat input during midday in the summer. Under non-shaded conditions solar radiation has more of an influence on water temperature than air temperature, thus being the dominant source of heat input into the stream. In addition, Bartholow (1989)
described two other (less effective) ways through which riparian vegetation affects stream temperature. First, vegetation reduces the amount of the water’s back radiation at night, tending to moderate the minimum stream temperatures. Second, the vegetation produces its own long wave (thermal) radiation, which also tends to raise minimum temperatures at night.

For this study it is estimated that the largest impact riparian vegetation has on stream temperature of the Shasta River is through the filtering of incoming solar radiation. This research focuses on that primary role.

1.4  **Previous Temperature Studies Involving Riparian Shading**

Interest in modeling riparian vegetation as it affects stream temperature surfaced in 1972 when the United States Government amended the Federal Water Pollution Control Act (Public Law 92-500). In this amendment, increases in stream temperature as caused by silvicultural practices were designated as non-point source pollution. As a result, each state was advised to develop “best management practices” to control temperature increases (Patton 1973; Rishel *et al.* 1982). This piece of legislation spurred interest in researching the effects of vegetation on stream temperature. The early (1970’s and 1980’s) literature on modeling is dominated by foresters concerned with quantifying the effects of clear-cutting practices on stream temperature. Today a large portion of modeling is motivated by concern for the preservation or restoration of riparian and stream habitat for threatened or endangered species, including cold-water fish.

Modeling of riparian vegetation typically focuses on representing the attenuation of solar radiation as it passes from the upper atmosphere to the water surface. The following
section is a summary of some important approaches and advances in modeling riparian shading as it applies to stream temperature.

1.4.1 Temp-84
Temp-84 was developed by Bestcha and Weatherred (1984) to assess forest management practices near streams. Solar radiation is assumed to pass through the atmosphere to a plane surface immediately above the forest canopy. Then, the available solar radiation is attenuated through the forest canopy. The attenuation of radiation through the canopy is calculated as a function of a canopy cover coefficient and the path length of the radiation through the canopy. After passing through the canopy the radiation is further reduced to account for brush and logs that may shade the stream.

Longwave radiation is also passed though the forest canopy and added to longwave radiation produced by the canopy. The attenuation of the sum or net longwave radiation is then determined for the brush and logs just above the stream surface.

The shading data used in this modeling approach includes average angles of topographic and forest shading, average hillslope and forest shading angles, canopy cover coefficient, vegetation height, buffer strip width, and the percent of stream section shaded by overhanging brush and logs.

1.4.2 US Fish and Wildlife Service, SNTEMP
The US Fish and Wildlife Service supports a Stream Network Temperature Model (SNTEMP) that includes a parameter to account for stream shading. SNTEMP is a one-dimensional uniform flow model. The heat transport component predicts the daily mean water temperatures and computes maximum temperatures from a regression equation. The solar radiation component of the heat flux equation is altered to take into account
streamside vegetation. The energy budget also accounts for back radiation from the water surface. The heat transport model is based on the dynamic temperature steady-flow equation and assumes that all input data, including meteorological and hydrological variables, can be represented by 24-hour averages. This model was originally developed to assist aquatic biologists and engineers in predicting the consequences of stream management scenarios on water temperatures (USGS, 2001).

The model calculates the stream temperature as modified by local topographic shading and vegetation. First, the model computes the position of the sun with respect to the location of the stream segment on the earth’s surface. Next, day length is computed as if there were no local topographic influence. After which, the local topography is factored in by recomputing the sunrise and sunset times based local topographic angles. This decreases the effective daylight hours by a certain percentage. From this local sunrise/sunset the program computes the percentage of light that is filtered by the vegetation. The filtering is calculated from input of the size, position, and density of the shadow-casting vegetation on both sides of the stream. The topographic shade and vegetative shade are merely added to get the total shade.

In a general sensitivity test it was found that the model is moderately sensitive to shading when stream flow is low, width-to-depth ratio is high, wind speed is low and solar radiation is high.

1.4.3 La Marche, et al., STRTEMP

La Marche, et al. (1997) used a model called STRTEMP in conjunction with a GIS database to quantify the topographic and vegetative shading on two reaches within the Deschutes River catchment in southwestern Washington. STRTEMP consists of a short-wave radiation scheme, which accounts for topography and shading due to near-
stream vegetation, and a stream energy balance scheme, which predicts stream
temperature along a 1-D reach. The shading component is calculated using Beer’s Law
with input of radiation that has already been filtered by the topography, a coefficient of
attenuation, and the leaf area index. The model can run at sub-daily intervals.

Through their simulations, La Marche et al. (1997) concluded that the impacts of stream
orientation and buffer widths are important determinants in the dominant energy factor
affecting stream temperature, short-wave solar radiation. They learned that the stream
received maximum solar radiation when oriented east/west, due to sunlight entering the
stream without attenuation by vegetation early in the morning and late in the day. They
suggest that a buffer width greater than 10 -15 m is generally sufficient to maintain
shading comparable to uncut riparian vegetation. Their results, however, may be
influenced by the fact that they had relatively short canopy heights. They propose that
streams shaded by larger trees may be likely to have fewer branches on the lower trunks
and therefore may require a wider buffer zone. According to their simulations, removing
the riparian corridor along their study reach would lead to a daily peak temperature
increase of as much as 3°C.

1.4.4 Chen, et al., HSPF (Hydrologic Simulation Program in Fortran)
Chen et al. (1997) applied a modified version of The Hydrologic Simulation Program in
Fortran (HSPF), an EPA and USGS watershed-modeling tool, to the Upper Grande
Ronde watershed in northeast Oregon. The original version of HSPF did not have a
shading component. Enhancements were made to the existing model’s applicability and
accuracy for forested catchments. This modified version was used with a recently-
developed stand-alone program called SHADE. SHADE calculates the riparian shading
based on the sun’s position, location and orientation of a reach, hillslope topography,
and quantifications of the riparian vegetation buffers. Over an hourly time interval,
SHADE computes the riparian shading and thus adjusts the incoming global solar radiation to the amount of radiation that is effective for stream heating. SHADE requires stream sample points located at 100-meter intervals throughout a reach. Using these sample points the average solar radiation for that reach is then estimated. Vegetation parameters include: location of shading; nature (forest/shrub or gap) and dimensions of each vegetation polygon mapped as homogeneous stands; and the distance from the edge of the stream’s wetted perimeter.

Chen et al. (1997) found that the application of the enhanced HSPF modeling system with the new SHADE model to the Upper Grande Ronde watershed accurately simulated the hydrology and stream temperatures. With the use of the model they simulated impacts of hydroclimatic shifts and hypothetical riparian vegetation buffers. They determined that natural weather cycles in air temperature, solar radiation, and precipitation could not sufficiently decrease the stream temperature for the survival of salmon. Rather, they determined that riparian vegetation was the only critical factor that could be managed to significantly decrease the lethal and sub-lethal stream temperatures. The model, which is accurate to ± 2.6 - 3°C, can now be used to evaluate various restoration scenarios for revegetation in Oregon.

1.4.5 Lowney, RMA 10
Lowney (CEEMG, 2000) used a modified version of RMA 10, a hydrodynamic and water temperature finite-element model, to assess the effects of riparian vegetation on the Sacramento River, California. Modifications to account for riparian vegetation included incorporation of a “transmittance” term. “The canopy transmittance is an instantaneous value representing the percentage of solar radiation that is neither absorbed nor reflected by the forest canopy at any particular point in time.” Transmittance is defined to be a function of the vegetation type, structure, and density of the canopy as it changes
with time of day and year. Using the above information, the model outputs water temperature at all nodal locations within the system at predetermined time increments over a specific time period.

Lowney used this model to examine several effects of riparian vegetation in addition to shading. These include the vegetative effect on vapor pressure, air temperature, and wind speed. She found that riparian shading is more effective than any other riparian effect (e.g. vapor pressure, air temperature, or wind speed) in reducing heat flux at the air-water interface. Through her simulations of the Sacramento River she concluded that the effects of riparian vegetation on the temperature of such a large system were minimal. Her suggestion is that the most promising possibilities for riparian vegetation as a means of decreasing water temperature are found in smaller tributaries and side-channels, which are typically close to equilibrium temperature and are less wide than the Sacramento River.

Lowney’s ‘transmittance’ was determined from field measurements of solar radiation in shaded \( A_s \) and unshaded \( A \) areas.

Transmittance is defined as:

\[
\tau_r = \frac{\Delta t_s \sum_{t=0}^{n} A_s}{\Delta t \sum_{t=0}^{m} A}
\]

where \( \tau_r \) = transmittance (%)  
\( \Delta t_s \) = sampling rate at the shaded station  
\( \Delta t \) = sampling rate at the unshaded station  
\( A_s \) = measured solar radiation at the shaded site \( \text{(Wm}^{-2}\text{)} \)  
\( A \) = measured solar radiation at the unshaded site \( \text{(Wm}^{-2}\text{)} \)  
\( n \) = the number of samples per day at the shaded station  
\( m \) = the number of samples at the unshaded station
Riparian transmittance was estimated to be between 5 and 13% in a large riparian forest and 15-25% in a riparian band of trees (CEEMG 2001).

1.4.6 Summary of Vegetation Effects on Water Temperature

These researchers and others have helped to provide a basis for understanding the effects of riparian vegetation on stream temperature through modification of existing temperature models to account for riparian vegetation. The USFWS adapted SNTEMP to include shading. Their modeling shows that streams are sensitive to shading when flows are low, the width-to-depth ratio is large, wind speed is low, and solar radiation is high. La Marche, et al. altered STRTEMP to model vegetative effects on two reaches of the Dechutes River. They discovered that stream orientation and the width of a strip of buffer vegetation were key to maximizing shading effects. Chen, et al. modified HSPF to incorporate shading. In modeling of the Upper Grande Ronde watershed they determined that riparian vegetation was the only critical factor that could be managed to reduce stream temperature. Lowney adapted RMA 10 to model several vegetative effects on the temperature of the Sacramento River. She found that the largest effect of vegetation was shading. She also concluded that riparian shading had a negligible effect on rivers the size of the Sacramento. Based on the above findings, the Shasta River appears to present the ideal conditions for maximum use of vegetation to control river temperature. The Shasta River is a small system that experiences low flows during the summer that typically exhibit very high solar radiation fluxes and low wind speeds.

1.5 Study Area

The Shasta River, located in central Siskiyou County, Northern California, originates in the Eddy Mountains and flows northeastward for roughly seventy miles before discharging into the Klamath River. The Shasta River flow is fed by glacial melting and
mountain precipitation from Mount Shasta that is delivered to the river by underground flows and springs. The river is impounded by Dwinnell Dam at river mile 36.4. Due to minimal flows (J. Whelan, pers. comm.) and difficulty in gaining access to the upper river, the study area extends from approximately river mile 32 to the confluence with the Klamath River. Figure 1.2 depicts the Shasta River as derived from the National Hydrography Dataset. The upstream end of the study reach is referred to as Shasta above Parks (SRP). The Shasta River flowing downstream from SRP is joined by several small tributaries including Parks Creek, Willow Creek, Little Shasta River, and Yreka Creek and a large tributary, Big Springs, that is spring fed. Many of the system’s smaller tributaries are dry in the summer. During the irrigation season from April to October there are several agricultural diversions along the river, the most substantial being those of the Grenada Irrigation District (GID) and the Shasta Water Users Association (SWA). Agricultural return flow varies along the system and enters the river in a variety of forms: as flow in defined channels, diffuse overland flow, and subsurface flow. The Shasta River is steep in the headwaters with an average slope from Dwinnell Reservoir (RM 36.4) to SRP (RM 31.8) of 0.008, or about 40 feet per mile. Between SRP and where Interstate 5 crosses the river (RM 8.3) the average slope is shallower at 0.002, or about 10 feet per mile. This allows the river to develop a complex set of meanders. For the last eight miles the river runs through a canyon with a steeper slope of 0.01, or about 50 feet per mile. Figure 1.3 illustrates the profile of the river with elevations taken from 1:24,000-scale United States Geological Survey (USGS) maps.
Figure 1.2 Shasta River as derived from the National Hydrography Dataset

Figure 1.3 Shasta River longitudinal profile
2.0 MODELING APPROACH

To quantify the influence of riparian vegetation on the Shasta River it was necessary to simulate both flow and temperature. This chapter addresses the choice of an appropriate model, the mathematical formulations in the model, the theoretical considerations in modeling temperature and a discussion of modifications made to the model for this particular application.

2.1 MODEL CHOICE

After a review of the models available in the public domain, the Tennessee Valley Authority’s (TVA) River Modeling System (RMS), a one-dimensional hydrodynamic and water quality model, was chosen to model the Shasta River. This model was chosen because it is readily available, contains basic shading logic, allows for modeling at an hourly time step, and is supported by TVA. RMS has two components, the hydrodynamic model, ADYN, and the water quality model, RQUAL. These components may be used independently or in sequence by a change in the control codes. This section includes a discussion of the formulations of each model component. Information discussed below about model formulation was found in the RMS User’s Manual (Hauser, 1995).

2.1.1 The Hydrodynamic Component: ADYN

ADYN solves the one-dimensional unsteady flow equations for conservation of mass and momentum using either a four-point implicit finite difference scheme with weighted spatial derivatives or a McCormack explicit scheme. The four-point implicit finite difference scheme was chosen for this application because the irregularity of the channel geometry rendered the explicit scheme inadequate. ADYN can model
interactions with dynamic tributaries at channel junctions, multiple tributary systems with multiple internal boundary conditions along each system, and the effects of distributed or point lateral inflows. For this application the Shasta River will be modeled as one reach with several distributed dynamic lateral inflows but no dynamic tributaries at channel junctions or internal boundary conditions.

2.1.2 The Water Quality Component: RQUAL

RQUAL uses the geometry, velocities and depths from the hydrodynamic model in the calculation of the water quality parameters. RQUAL can be used to study several water quality parameters. However, this application will employ only the temperature modeling capability. RQUAL offers three options of numerical schemes used to solve the one-dimensional transport equation: a four-point-implicit finite difference scheme with weighted spatial derivatives, a McCormack explicit scheme, or a Holly-Preissman scheme. Preliminary model testing found negligible difference in results between the four-point-implicit and Holly-Preissman schemes when applied to the Shasta River. The four-point implicit scheme was chosen for use in this application. In the coding of RQUAL, dispersion is neglected presumably due to the application in highly dynamic systems (rivers) where transport is the dominant factor. The numerical dispersion of the model is not quantified and is considered to be large enough to account for the neglected dispersion term (Hauser, pers. comm.).

The heat budget (outlined in Section 2.2) used in RQUAL includes logic for bed heat exchange and riparian shading. After reviewing the bed conduction logic, it was determined that it did not represent a process being modeled based on measured parameters, but rather a tool used for calibration. Due to the lack of physical basis for this logic, it was turned off and not used in the modeling. The shading logic was not
entirely sufficient to represent the dynamics of the Shasta River. Section 2.3 addresses the modifications made to RQUAL. In addition, a piece of the shading logic that lowers the dry bulb temperature in the shade was disabled in RQUAL. After inquiring of the authors it was determined that this too was a calibration parameter and was not necessary in simulating the Shasta River.

It should be noted that RQUAL does not model topographic shading. If topographic shading is considered to have a significant effect on water temperature, then modifications need to be made to the model to account for it. For the Shasta River the only significant topographic shading in the system occurs between RM 7 and the Mouth, where the Shasta enters the canyon below Anderson Grade. For this modeling effort the effect of topographic shading was considered to be negligible.

2.2 Heat Budget

Temperature models fall into two general classes: empirical relationships based on observations of stream temperature and stream properties (such as discharge, channel geometry, and streamside vegetation characteristics) and models that represent the physical processes of the system by means of the energy (or heat) budget. Although convenient to use, empirical methods cannot provide detailed information about the effects of certain factors on stream temperature. These factors include variations in discharge, geometry of the vegetative cover, cumulative effects of upstream disturbances in riparian areas, and stream orientation effects on incoming solar radiation (La Marche, et al., 1997). Brown (1969) noted that one of the most effective process-based techniques for predicting river temperatures and temperature changes is the heat budget approach. The water quality component of the TVA model (RQUAL) uses the
heat budget approach that quantifies pertinent factors by formulations based on physical processes.

The heat budget approach quantifies the net exchange of heat at the air-water interface. TVA has extended the approach to also include heat exchange at the water-bed interface. This net change may be expressed as the sum of the major sources and sinks of thermal energy or the sum of the heat fluxes.

TVA Heat Budget Formulation

\[
Q_n = \frac{Q_{ns} + Q_{na} + Q_{bed} - Q_b - Q_e - Q_c}{D}
\]

where:
- \( Q_n \) = the net heat flux (representing the rate of heat released from or added to storage in a particular volume) (kcal/m³s)
- \( Q_{ns} \) = net solar (short-wave) radiation flux adjusted for shade (kcal/m²s)
- \( Q_{na} \) = net atmospheric (long-wave) radiation flux (kcal/m²s)
- \( Q_{bed} \) = net flux of heat at the water-channel bed interface (kcal/m²s)
- \( Q_b \) = net flux of back (long-wave) radiation from water surface (kcal/m²s)
- \( Q_e \) = evaporative (latent or convective) heat flux (kcal/m²s)
- \( Q_c \) = conductive (sensible) heat flux (kcal/m²s)
- \( D \) = mean depth (m)

2.2.1 Net Solar (Short-wave) Radiation Flux

The net short-wave radiation flux (\( Q_{en} \)) is that portion of the total short-wave solar radiation that reaches the water surface. This term represents that portion of the short-wave radiation that is not scattered, intercepted, or reflected by the atmosphere, clouds or vegetation on its way to the water surface. Hence, this term largely depends on the local altitude of the sun, cloud cover, vegetation cover, and an atmospheric turbidity factor. Some models calculate this value based on a theoretical value of solar radiation
and the above-mentioned parameters. RMS has incoming solar radiation ($Q_s$) as an input in the meteorology input file that is then adjusted in the model to account for the vegetation cover by shading factor ($R_s$).

$$Q_{ns} = Q_s \cdot R_s.$$  

where:  
$Q_s$ = incoming solar radiation (an input parameter for the model)  
$R_s$ = shade factor, a portion (0-1) of solar radiation that reaches the water surface

### 2.2.1.1 Computation of the Shade Factor ($R_s$)

The shade factor, $R_s$, depends on size and proximity of trees and banks, solar azimuth, river aspect, and the percent of solar radiation that penetrates the vegetation canopy (here referred to as vegetative transmittance, SHSOL).

There are three steps that must be taken before directly computing $R_s$:

1) Calculate the solar altitude ($S_a$)

2) Calculate the length of the shadow parallel to the azimuth of the sun (AZS)

3) Calculate the length of the shadow normal to the bank of the river

Solar altitude, $S_a$, is the angle between the sun and the observer’s horizon (see Figure 2.1). $S_a$ is a function of the latitude of the river, the declination of the sun, and the time of day (hour angle of the sun). $S_a$ is calculated by the following equation (TVA 1972):

$$S_a = Sin^{-1}(Sin\phi Sin\delta + Cos\phi Cos\delta Cos\tau)$$

where:  
$S_a$ = solar altitude (radians)  
$\phi$ = latitude of the river (radians)  
$\delta$ = declination of the sun (radians)  
$\tau$ = local hour angle of the sun (radians)
The declination of the sun is the angle between the earth’s equator and the sun. It is dependent upon the time of year represented as Julian days. The declination is calculated by the following equation (TVA, 1972) where JD is the Julian day (1-365):

$$
\delta = 23.45 \left( \frac{2\pi}{360} \right) \cos \left( 2\pi \left( \frac{172 - JD}{365} \right) \right)
$$

The hour angle is the time of day, expressed in radians. The local hour angle, or the fraction of $2\pi$ that the earth has turned after local solar noon (CEEMG 2001), is calculated in RQUAL by the following equation. (Note: This formulation is appropriate for western longitudes.)

$$
\tau = \left( 180 + l - t_m \right) - \left( 360 \cdot \frac{hr}{24} \right) \left( \frac{2\pi}{360} \right)
$$

where:
- $l$ = longitude of the river (degrees)
- $t_m$ = local time zone meridian (degrees)
- $hr$ = hour of the day
Next the azimuth of the sun AZS (radians) must be found to calculate the direction of the shadow cast by the vegetation. AZS is a function of declination, solar altitude, and the latitude of the river. This is done by the following equation which yields a value for AZ that varies from 0° to 180°. (Note: The azimuth of the sun is measured clockwise from north when the sun is east of the local meridian, and counter-clockwise from north when the sun is west of the local meridian.)

\[
AZS = \cos^{-1} \left( \frac{\sin \delta - \sin S_a \sin \phi}{\cos S_a \cos \phi} \right)
\]

where:
AZS = solar azimuth
S_a = solar altitude (radians)
f = latitude of the river (radians)
d = declination of the sun (radians)

The length of the shadow (X) cast by the effective barrier (vegetation or bank) that is parallel to the azimuth of the sun (AZS) can be found by geometry as shown in Figure 2.2.

Figure 2.2 Diagram depicting the variables for calculating X, the length of the shadow parallel to the azimuth of the sun
\[ X = \frac{EBH}{\tan(S_a)} \]

where:
EBH = effective bank height (meters)
\( X \) = length of shadow parallel to the azimuth of the sun (meters)

Using geometry \( X_n \), the length of the shadow normal to the stream aspect, can be calculated as shown in Figure 2.3.

\[ X_n = X(\sin(AZS-AZ)) \]

where:
\( X_n \) = length of the shadow normal to the stream aspect
\( X \) = length of the shadow cast by the effective barrier
AZS = azimuth of the sun
AZ = stream aspect

Figure 2.3 Diagram depicting the variables for calculating \( X_n \)

There are fundamentally three possible shading scenarios: shade free, partially shaded, and fully shaded. Once the length of the shadow normal to the stream bank is
determined, $R_s$ can be calculated by the following equations according to the appropriate scenario:

**No Shade**

$(X_n = B$ or $\cos \beta = 0.01)$: 

$$R_s = R_{sm}$$

**Partial Shade**

$(W+B < X_n = B)$: 

$$R_s = R_{sm} \left(\frac{W+B-X_n}{W} + SHSOL(X_n-B)/W\right)$$

**Full Shade**

$(X_n > W+B$ or $S_a = 1.5$ or hr $< TFOG)$: 

$$R_s = SHSOL$$

where:

- $R_{sm}$ = the shade free absorption coefficient
- $X_n$ = shadow length normal to stream bank (m)
- $SHSOL$ = vegetative transmittance ($0=SHSOL=1$, $0 = no$ shading)
- $\beta$ = angle between the sun and normal to the stream axis (radians)
- $S_a$ = solar altitude (radians)
- $TFOG$ = time of fog lift (hours)
- $B$ = bank width or vegetative setback (m)
- $W$ = channel width (m)

The shade free absorption coefficient ($R_{sm}$) is a factor that accounts for the reflectivity of the water surface given no shading by streamside vegetation or banks. $R_{sm}$ represents the fraction of solar radiation not reflected by the shade-free water surface. The formulation of this factor as found in RQUAL is taken from Anderson (1954):

$$R_{sm} = \frac{(1-a)}{\left(\frac{180}{\pi} S_a\right)^b}$$

<table>
<thead>
<tr>
<th>C</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.05</td>
<td>1.18</td>
<td>0.77</td>
</tr>
<tr>
<td>0.05-0.5</td>
<td>2.20</td>
<td>0.97</td>
</tr>
<tr>
<td>0.5-0.95</td>
<td>0.95</td>
<td>0.75</td>
</tr>
<tr>
<td>&gt;0.95</td>
<td>0.35</td>
<td>0.45</td>
</tr>
</tbody>
</table>

where:

- $R_{sm}$ = shade free absorption coefficient
- $a$, $b$ = coefficients depending on cloud cover
- $S_a$ = solar altitude
- $C$ = cloud cover
2.2.2 Net Atmospheric Radiation

The net atmospheric long-wave radiation flux \( Q_{na} \) originates from the atmosphere when it re-radiates some of the short-wave radiation that it intercepted from the sun. This term depends on air temperature and cloud cover. The equation used to calculate \( Q_{na} \) is in a form derived from Swinbank (1963) with a value of 0.03 for the reflectivity of the water surface \( R_L \).

\[
Q_{na} = 1.23 \times 10^{-16} (T_a + 273)^6 \left( 1 + 0.17 C^2 \right)
\]

where:
- \( Q_{na} = \) net atmospheric radiation (kcal/m²s)
- \( C = \) cloud cover
- \( T_a = \) dry bulb air temp (°C)

2.2.3 Net Back Radiation from the Water Surface

The net water surface long-wave radiation flux \( Q_b \) is the radiation reflected by the water surface. This term is mainly dependent on water temperature and is calculated using the Stefan-Boltzmann equation:

\[
Q_b = \varepsilon \sigma (T + 273)^4
\]

\[
= 0.736 + 0.00117 T
\]

where:
- \( Q_b = \) net back radiation (kcal/m²s)
- \( \sigma = \) Stefan-Boltzmann constant
- \( T = \) water temperature (°C)
- \( \varepsilon = \) emissivity = 0.97 the commonly assumed value for objects on the earth’s surface.

2.2.4 Net Evaporative Heat Flux

The evaporative (latent or convective) heat flux \( Q_e \) occurs at the stream surface. It is the transfer of heat through the state change of surface water to vapor, or water vapor to liquid water. Hence, the important factors in convection are the latent heat of
vaporization, wind speed, the temperature gradient between air and water (usually expressed in the form of vapor pressures at the surface and in the atmosphere). In the RMS formulation if the saturation vapor pressure in the water is less than the pressure in the air, then the net evaporative heat loss is assumed to be zero. Hence, in RMS this term cannot be used to model condensation in addition to evaporation.

If \( e_s > e_a \)

\[
Q_e = \rho L (a_1 + b_1 W) (e_s - e_a)
\]

where:
\( \rho = \) density of water (kg/m\(^3\))
\( L = \) latent heat of vaporization (kcal/kg) = 597-0.57 \( T \)
\( T = \) water temperature (°C)
\( a_1 = \) empirical wind coefficient (mb\(^{-1}\)m/s)
\( b_1 = \) empirical wind coefficient (mb\(^{-1}\))
\( W = \) wind speed (m/s)
\( e_a = \) saturation vapor pressure at air temp (mb)
\( e_s = \) saturation vapor pressure at water temp (mb)

Saturation vapor pressure at water temperature and air temperature are defined as:

\[
e_a = 2.171 \times 10^8 \exp \left( \frac{-4157}{T_d 239.09} \right)
\]

\[
e_s = \alpha j + \beta j T
\]

where:
\( T_d = \) dewpoint temperature (°C).

\subsection{2.2.5 Net Conductive Heat Flux}

The sensible or conductive heat flux, \( Q_c \), is heat flux through molecular or turbulent transfer between the air and water surface. The amount of heat gained or lost through sensible heat flux depends on the gradient of temperature in the vertical direction. The RMS formulation of this equation is derived using Bowen’s Ratio.
\[ Q_c = \rho L \left( a_i + b_i W \right) \left( C_B \times 10^{-3} P \right) \left( T - T_a \right) \]

\( Q_c \) = net conductive heat transfer (kcal/m² s)
\( ?, L, T, a_i, b_i, W, T_a \) = as defined above
\( C_B \) = Bowen’s Ratio (0.61 °C⁻¹)

### 2.2.6 Net Bed Heat Flux

The bed heat flux or bed conduction, \( Q_{bed} \), is the net transfer of heat from the channel bed to the water. This heat flux depends on the temperature gradient between the water and the bed. (Note: This term was turned off in the calculation of the heat budget for the Shasta River simulations. See Section 2.1.2.) The RMS formulation of this process is:

\[ Q_{bed} = - \left( Q_{nsr} + Q_{bc} \right) \]

where:
\( Q_{bed} \) = net bed heat flux (kcal/m² s)
\( Q_{nsr} \) = net solar radiation available for warming the channel bed (kcal/m² s)
\( Q_{bc} \) = heat conducted from water to bed due to temperature differential (kcal/m² s)

\[ Q_{nsr} = \left( 1 - A_\beta \right) \left( 1 - \beta \right) \exp(-\eta(D - 0.6)) Q_{ns} \]

where:
\( Q_{nsr} \) = net solar radiation available for warming the channel bed (kcal/m² s)
\( A_\beta \) = albedo of bed material
\( \beta \) = fraction of solar radiation absorbed in surface 0.6m of water
\( \eta \) = extinction coefficient in water (1/m)
\( D \) = mean depth of water (m)
\( Q_{ns} \) = net short-wave solar radiation corrected for shading (kcal/m² s)

\[ Q_{bc} = \frac{10C_v K \left( T - T_{bed} \right) / 0.5L}{3600} \]

where:
\( Q_{bc} \) = heat conducted from water to bed due to temperature differential (kcal/m² s)
\( C_v \) = heat storage capacity of bed material (cal/cm³ °C)
\( K \) = thermal diffusivity of bed material (cm²/hr)
\( T \) = water temperature (°C)
\( T_{bed} \) = average temperature of the bed (°C)
\( L \) = effective bed thickness (cm).
2.3 MODEL MODIFICATIONS

As originally constituted in RQUAL, the formulations for calculating $R_s$, the shade factor, are coded with the following limitations:

1) The user may enter only one value for vegetative transmittance (SHSOL) for an entire system.

2) The user may enter only one value for effective bank height (EBH) per node.

These limitations were designed for a river system in which there is little variability of effective bank height and continuity of vegetation. The Shasta River is fundamentally different from the rivers typically studied by the Tennessee Valley Authority (TVA), for which this model was designed. Whereas the rivers within the TVA study region run through thick forests, the Shasta River runs through reaches of sparse vegetation, where vegetation may only occur on one bank or the other. In addition, the purpose of the Shasta River modeling project is to assess the effect of riparian vegetation on stream temperature and to provide quantitative analysis of possible revegetation scenarios. In order to have the flexibility required to accurately represent the current streamside vegetation and to run various revegetation scenarios, the model required expansion of the current ability to represent the transmittance and effective bank height. In order to accomplish this the representation of SHSOL was expanded to allow for input of two values at each node, one for each bank. EBH was also expanded to allow for input of vegetation height on the right and left bank at each node.

2.3.1 Altered Shading Logic

Several modifications were made to the model to implement the required changes:
1) Four solar output files were added to allow access to key variables in time series at each of four nodes. The key variables include EBH, SHSOL, SWS (incoming solar radiation), QNS (adjusted solar radiation), and T2 (water temperature).

2) Modifications were made to the main program and to subroutine CRS to allow the input of right and left bank parameters for EBH and SHSOL.

3) Shading logic was added in the subroutine CRS to correctly process the new right and left bank parameters.

The solar output files currently are programmed to output information at specific nodes. This can be altered in the code by changing the node in the write statements to files 28-31 found in the main program beginning at line 940.

In order to make the code flexible, a flag (IRS) was added to the first line of the water quality coefficient input file that can turn on/off the new shading logic. If IRS = 1, the new shading logic is used. (See APPENDIX A for input file modifications.) The modifications made to the subroutine CRS in order to correctly process the new right and left bank parameters are outlined below.

In order to determine which bank information to use the model must first determine which bank provides shade to the stream at sunrise. After the first bank is labeled the model switches bank information when the sun crosses the river. This is determined by comparing the aspect of the river and the azimuth of the sun. When the aspect of the river is equal to the azimuth of the sun then the sun is directly over the river and no shading occurs. To illustrate, if the stream was flowing north the aspect would be 0° (recall that stream aspect is measured clockwise from north ranging from 0°-360°), the right bank would be on the east side of the stream and the left bank would be on the
west. At sunrise the east (right bank) will be shading the stream. When the sun’s azimuth reaches 180° it is directly over the stream, and once the azimuth of the sun crosses the stream the west bank (or left bank) provides the shade, as shown in Figure 2.4.

Figure 2.4 Diagram of sample stream, with aspect = 0.0

Figure 2.5 illustrates the situation if this same stream were flowing south instead of north. The aspect of the stream would be 180° and the first bank to provide shade would be the left bank.

Figure 2.5 Diagram of sample stream, with aspect = 180.0
Determining which is the first bank to provide shade and then switching to use information from the opposite bank when the sun crosses the stream is accomplished by the logic described in Figure 2.6. Figure 2.6 is a flowchart of the two-bank shading logic added to RQUAL. The full listing of the modified program code can be found in Appendix B.
Figure 2.6 Flowchart of two-bank shading logic
Depicted in Figure 2.7 are the three scenarios to consider when assigning the first bank that provides shade to the river. Scenario One occurs when the stream aspect is less than the azimuth of the sun. Scenario Two occurs when the stream aspect is greater than the azimuth of the sun and less than the azimuth of the sun plus 180°. Scenario Three occurs when the stream aspect is greater than the azimuth of the sun and greater than the azimuth of the sun plus 180°.

![Diagram](image)

**Figure 2.7 Diagram depicting three aspect scenarios of the two bank shading logic**

In Scenario One the first bank to provide shade is the right bank. In Scenario Two, the first bank to provide shade is the left bank. In Scenario Three the first bank to provide shade is the right bank. After the first bank is assigned, the logic switches bank information as the sun’s azimuth passes over the stream azimuth.

Before sunrise and after sunset the amount of solar radiation compared to peak daily values is negligible. Whatever solar radiation does exist at dawn and dusk is diffuse. For modeling purposes SHSOL and EBH during these times is set to an average of right and left bank values. This is partially a relict of the original coding which requires a value for SHSOL and EBH during the nighttime hours. Since there is no appreciable
solar radiation before sunrise or after sunset this logic does not affect simulated temperatures.

2.3.2 Testing of Modifications

The modified shading logic was tested using seven test cases. The test cases were run using a rectangular channel 2 feet deep and 100,000 feet long with flow of 100 cfs. Meteorological data from August 28, 2001 was used. Transmittance factors for all left bank nodes were set to 0.15 and all right bank nodes were set to 0.0. Effective bank height (EBH) was set to 10 feet (3.048 m) for the left bank and 40 feet (12.192 m) for the right bank. Figure 2.8 depicts the stream aspects and compass direction for each test case, they were: 0(north), 45(northeast), 90(east), 135 (southeast), 180(south), 225 (southwest), 270 (west). Each test case was assigned a different stream aspect to test the ability of the model to use the appropriate bank information for each time step throughout a 24-hour period. It was expected that as the sun passed from one side of the stream to the other the value of SHSOL and EBH would change according to the values for the left and right bank. The model accurately assigned both variables for each time of day for each test case as shown in Tables 2.1 and 2.2.
To illustrate, at 1pm (or hour 13) for the north flowing stream the transmittance switched from the right bank value of 0.0 to the left bank value of 0.15. In addition, the effective bank height also changed from the right bank height of 12.192 m to the left bank height of 3.048 m. Note that before sunrise and after sunset the value for SHSOL and EBH is an average of the values for right and left bank (explanation included in Section 2.3.1).
Table 2.1: Transmittance factors during the course of one day for seven test cases

<table>
<thead>
<tr>
<th>SimHR</th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
<th>SW</th>
<th>W</th>
</tr>
</thead>
<tbody>
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<td>0.075</td>
<td>0.075</td>
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<td>0.075</td>
<td>0.075</td>
</tr>
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<td>0.075</td>
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<td>0.075</td>
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<td>0.075</td>
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</tr>
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<td>0.075</td>
<td>0.075</td>
</tr>
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<td>0.15</td>
<td>0</td>
<td>0</td>
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<tr>
<td>7</td>
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</tr>
<tr>
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<td>9</td>
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<td>10</td>
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<tr>
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<td>0.15</td>
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</tr>
<tr>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>13</td>
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<td>0</td>
<td>0</td>
<td>0.15</td>
</tr>
<tr>
<td>14</td>
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<td>0.15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.15</td>
</tr>
<tr>
<td>15</td>
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<td>0</td>
<td>0</td>
<td>0.15</td>
</tr>
<tr>
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<td>0</td>
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</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0.15</td>
</tr>
<tr>
<td>19</td>
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<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
</tr>
<tr>
<td>20</td>
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<td>0.075</td>
<td>0.075</td>
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<td>0.075</td>
<td>0.075</td>
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<tr>
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<td>0.075</td>
<td>0.075</td>
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<tr>
<td>23</td>
<td>0.075</td>
<td>0.075</td>
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<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
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<tr>
<td>24</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
</tr>
</tbody>
</table>

Table 2.2: Effective bank height during the course of one day for seven test cases

<table>
<thead>
<tr>
<th>SimHR</th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
<th>SW</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>3.048</td>
<td>3.048</td>
<td>3.048</td>
<td>3.048</td>
<td>3.048</td>
<td>12.192</td>
<td>3.048</td>
</tr>
</tbody>
</table>
2.3.3 Limitations of the Shading Logic

There are limitations to the correct application of the shading logic in RQUAL. The two-bank shading logic should be applied to systems using an hourly or finer time step. Time steps greater than one hour could result in misapplication of bank information. There is a possibility that with large time steps the model would not be able to detect the first bank accurately. In addition, the formulation of the hour angle equation limits the use of this model to the western hemisphere.
3.0 FIELDWORK

Required data for modeling flow and temperature include geometric descriptions of locations and cross-sections, flow and water temperature data, riparian vegetation data, and climatic data. Fieldwork was conducted from May to October of 2001 to supplement the existing data base with more detailed and robust data for flow, temperature, cross-section geometry and riparian vegetation. The field team was staffed by the DFG, Watercourse Engineering, Inc. and Great Northern Corporation. Several temperature and flow devices were placed in the field and downloaded on an average of two-three week intervals. Two four-day field sessions were devoted to riparian vegetation and geometric data during July and August 2001.

3.1 RIVER MILE INDEX

In order to effectively describe the location of various data collection sites on the river a river mile index was developed. The National Hydrography Dataset (NHD) was used to produce a digital base map of the Shasta River. XY coordinates in latitude and longitude for line segments along the Shasta River were extracted from the NHD and densified by Cindy Moore at the Information Center for the Environment, University of California, Davis.

The NHD is a seamless set of digital spatial data maintained by the United States Geological Survey (USGS). The NHD is based on the USGS 1:100,000-scale Digital Line Graph (DLG) hydrography data and integrated with reach-related information from the EPA Reach File Version 3 (RF3). Thus, while NHD was initially based on 1:100,000-scale data, it is designed to incorporate higher-resolution data. The NHD came online in the spring of 2001. The USGS has built tools in ArcView to allow users to update the NHD with 1:24,000 datasets. The USGS is working with several state
partners and the Forest Service to create the higher resolution data. As the work is verified and comes online it is classified as “high resolution” data. The data used for this study is classified as “medium” resolution data. The USGS is also working to link topographic, flow, and velocity data to the spatial data.

In processing the dataset nine duplicate points were identified and removed. One digitizing error was located. This point was also removed. No other changes were made to the NHD dataset.

To compute river miles the geographic coordinates in decimal degrees were converted to radians by multiplying the number of degrees by $\pi/180 = 0.017453293$ radians/degree. Assuming a spherical earth with radius, $R$, river mile distance was calculated using the Haversine Formula (Sinnott, 1984):

\[
\begin{align*}
dlon &= \text{lon2}-\text{lon1} \\
dlat &= \text{lat2}-\text{lat1} \\
a &= (\sin(dlat/2))^2 + \cos(lat1)*\cos(lat2)*(\sin(dlon/2))^2 \\
c &= 2*\arcsin(\min(1,\sqrt{a})) \\
d &= R*c
\end{align*}
\]

where:

- two points in spherical coordinates (longitude and latitude) are lon1, lat1 and lon2, lat2
- dlon = difference in longitude (radians)
- dlat = difference in latitude (radians)
- $c$ = the great circle distance (radians)
- $R$ = radius of the earth = 3956 miles (min = 3937, max = 3976)
- $D$ = the great circle distance in the same units as $R$

Using the Haversine formula distances were calculated between NHD coordinates. Major features on the Shasta were located in the NHD coordinate system and the River Mile Index (RMI) was calculated (Table 3.1). The sites listed in Table 3.1 can be located on the map in Figure 3.1.
Table 3.1 River mile index

<table>
<thead>
<tr>
<th>Location</th>
<th>River Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth</td>
<td>0.0</td>
</tr>
<tr>
<td>USGS Gage</td>
<td>0.5</td>
</tr>
<tr>
<td>HWY 263</td>
<td>7.1</td>
</tr>
<tr>
<td>Yreka Creek</td>
<td>7.6</td>
</tr>
<tr>
<td>Anderson Grade</td>
<td>7.9</td>
</tr>
<tr>
<td>Interstate 5</td>
<td>8.3</td>
</tr>
<tr>
<td>Yreka-Ager Road</td>
<td>10.3</td>
</tr>
<tr>
<td>Oregon Slough (R bank)</td>
<td>11.2</td>
</tr>
<tr>
<td>HWY 3</td>
<td>12.3</td>
</tr>
<tr>
<td>Monteque-Grenada Road (DWR Weir)</td>
<td>14.7</td>
</tr>
<tr>
<td>Little Shasta River</td>
<td>15.5</td>
</tr>
<tr>
<td>SWU Association</td>
<td>16.8</td>
</tr>
<tr>
<td>HWY A-12</td>
<td>21.9</td>
</tr>
<tr>
<td>Willow Creek</td>
<td>22.6</td>
</tr>
<tr>
<td>Grenada Irrigation District Pumps</td>
<td>26.9</td>
</tr>
<tr>
<td>Big Springs Creek</td>
<td>29.9</td>
</tr>
<tr>
<td>Louie Road</td>
<td>30.1</td>
</tr>
<tr>
<td>Parks Creek</td>
<td>31.0</td>
</tr>
<tr>
<td>Shasta above Parks</td>
<td>31.8</td>
</tr>
<tr>
<td>Riverside Drive</td>
<td>35.6</td>
</tr>
<tr>
<td>Dwinnell Reservoir</td>
<td>36.4</td>
</tr>
</tbody>
</table>

The study reach from river mile (RM) 31.8 to the Mouth was broken into five study segments in order to quickly reference and discuss each part of the system. Table 3.2 is a table of statistics for each reach including the number of NHD coordinates, length, and number of coordinates per mile. Note that there are more coordinates per mile in the meandering portions of the river, study segments 3 and 4. This is necessary to accurately represent the small-scale meanders in the system.
Figure 3.1 Shasta River site locations in geographic coordinates

Table 3.2 River segments statistics for Shasta River RMI

<table>
<thead>
<tr>
<th>Study Segments</th>
<th>No. of NHD Coordinates</th>
<th>Segment Length (mi)</th>
<th>No. of Cords. Per Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mouth to Anderson Grade</td>
<td>269</td>
<td>7.9</td>
<td>34</td>
</tr>
<tr>
<td>2 Anderson Grade to DWR Weir</td>
<td>253</td>
<td>6.9</td>
<td>37</td>
</tr>
<tr>
<td>3 DWR Weir to A12</td>
<td>333</td>
<td>7.2</td>
<td>46</td>
</tr>
<tr>
<td>4 A12 to GID</td>
<td>267</td>
<td>5.0</td>
<td>53</td>
</tr>
<tr>
<td>5 GID to Shasta above Parks</td>
<td>188</td>
<td>4.8</td>
<td>39</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1310</td>
<td>31.8</td>
<td></td>
</tr>
</tbody>
</table>


3.2 **CROSS-SECTIONAL DATA**

In order to properly represent the geometric features of the stream it was necessary to gather information about the cross-sectional shape of the Shasta River at various locations. Ten equally-spaced sample locations were chosen in each of the five reaches. Access was not available for 7 of the 50 sites. Of the remaining 43, only 25 sites were visited and measured due to time constraints and difficult access. At each site key selected parameters associated with the shape of the cross-section including bankfull width, water surface width, water depth, and bank height were measured. Bankfull width was defined as the width of the stream when it is about to inundate the active floodplain. The required equipment included a staff and a 100 ft tape measure. In addition, pictures were taken of each site. The sites accessed and their associated river miles are listed in Table 3.3.

**Table 3.3 Cross-section sampling sites**

<table>
<thead>
<tr>
<th>Reach No.</th>
<th>River Mile</th>
<th>Property Owner</th>
<th>PT Logger Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>2.36</td>
<td>BLM</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>3.14</td>
<td>Stewart Higgs</td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>3.93</td>
<td>BLM</td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>5.50</td>
<td>BLM</td>
<td></td>
</tr>
<tr>
<td>1.9</td>
<td>6.28</td>
<td>Dewey Smith</td>
<td></td>
</tr>
<tr>
<td>1.10</td>
<td>7.07</td>
<td>Dewey Smith</td>
<td>Hwy 263</td>
</tr>
<tr>
<td>2.1</td>
<td>7.85</td>
<td>Siskiyou County</td>
<td>Anderson Grade Rd.</td>
</tr>
<tr>
<td>2.2</td>
<td>8.54</td>
<td>Eric Peters</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>9.22</td>
<td>Eric Peters</td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>9.91</td>
<td>Bruce &amp; Boyd Fiock</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>10.60</td>
<td>Bruce &amp; Boyd Fiock</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>14.72</td>
<td>Don Meambers</td>
<td>DWR Weir</td>
</tr>
<tr>
<td>3.2</td>
<td>15.44</td>
<td>Dale, Greg, &amp; Richard Kuck</td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>16.17</td>
<td>Dale, Greg, &amp; Richard Kuck</td>
<td></td>
</tr>
<tr>
<td>3.4</td>
<td>16.89</td>
<td>Joe Rice</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>17.61</td>
<td>Joe Rice</td>
<td></td>
</tr>
<tr>
<td>3.6</td>
<td>18.33</td>
<td>Willard Freeman</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>21.95</td>
<td>Jim Rice</td>
<td>Hwy A-12</td>
</tr>
<tr>
<td>4.2</td>
<td>22.45</td>
<td>Jim Rice</td>
<td></td>
</tr>
<tr>
<td>4.7</td>
<td>24.97</td>
<td>Richard Peters</td>
<td></td>
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<tr>
<td>4.9</td>
<td>25.98</td>
<td>Richard Peters</td>
<td></td>
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<td>4.10</td>
<td>26.48</td>
<td>Richard Peters</td>
<td></td>
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<tr>
<td>5.1</td>
<td>26.98</td>
<td>Richard Peters</td>
<td>GID</td>
</tr>
<tr>
<td>5.3</td>
<td>27.95</td>
<td>Richard Peters</td>
<td></td>
</tr>
<tr>
<td>5.10</td>
<td>31.38</td>
<td>Emerson Investments</td>
<td>Shasta Above Parks</td>
</tr>
</tbody>
</table>
The analysis of the cross-section data is found in Table 3.4. Depth is defined as depth from the top of the bank to the lowest measured point of the cross-section. Cross-sectional data for individual sites can be found in Appendix C. Protocols for gathering geometric information can be found in Appendix D.

### Table 3.4 Cross-section statistics

<table>
<thead>
<tr>
<th>Reach No.</th>
<th>River Mile</th>
<th>No. Cross-Sections per Reach</th>
<th>Avg. Depth (ft)</th>
<th>Avg. Top Width (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0-7.85</td>
<td>6</td>
<td>4.4</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>7.85-14.72</td>
<td>5</td>
<td>4.8</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>14.72-21.95</td>
<td>5</td>
<td>5.4</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>21.95-26.98</td>
<td>5</td>
<td>5.5</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>26.98-31.83</td>
<td>3</td>
<td>5.2</td>
<td>31</td>
</tr>
</tbody>
</table>

### 3.3 Flow Study

There are two full-time flow gages on the Shasta River, the USGS gage (RM 0.5) and the DWR gage at the water master weir (RM 14.7). To supplement these data, six sites were selected to further monitor the flow by measuring the water level and determining a rating curve at each site. The locations of flow monitoring sites are found in Table 3.5.

### Table 3.5 Locations of pressure transducers

<table>
<thead>
<tr>
<th>Location</th>
<th>River Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anderson-Grade Road</td>
<td>7.9</td>
</tr>
<tr>
<td>DWR Weir</td>
<td>14.7</td>
</tr>
<tr>
<td>A12</td>
<td>21.9</td>
</tr>
<tr>
<td>Grenada (GID)</td>
<td>26.9</td>
</tr>
<tr>
<td>Parks Creek</td>
<td>31.0</td>
</tr>
<tr>
<td>Shasta above Parks Creek</td>
<td>31.8</td>
</tr>
</tbody>
</table>

Global Water Instrumentation, Inc. water level loggers (WL15) were deployed at each site. The WL15’s have a range of 0-3 feet. This pressure transducer/data logger system has an accuracy of 0.2% of the full scale over a temperature range, or 0.1% of full scale at a constant temperature. Each pressure transducer was placed in a temporary stilling well secured to the bank by a small concrete footing. Due to complications with two of the pressure transducers, on July 20th, 2001, the WL15’s at the DWR weir and GID were replaced with WL15’s of the weir-stick-type sensor. The weir sticks were deployed in
PVC casings, which were attached to T-posts driven into the riverbed. The weir stick units fit into the casing snugly, with the rim of the unit resting on the rim of the PVC case. Both types of sensors were perpendicular to the river surface at all times. Values were logged every 15 minutes and downloaded every two to three weeks. Each time the loggers were downloaded the section was rated using a Flo-Mate Portable Flowmeter Model 2000 from Marsh-McBirney, Inc. The portable flow meter measures stream velocity at an accuracy of ± 2% of the reading. It can measure within a range from −0.5 to +20 ft/s (-0.15 to 6 m/s). To rate each section the width of the river was divided into sections with each section being no more than 10% of the total width. The flow meter, mounted to a staff, was used to take velocity measurements in the middle of each section. The velocities were averaged over 30 second intervals and then applied to the whole section. The flows in each section were added to achieve a flow for the site. Full field protocol for monitoring flow in the Shasta River can be found in Appendix D.

Table 3.6 contains the rating curves that were developed for each site to relate water level to flow. This table also contains the number of data points used to create the curves, the $R^2$ value associated with each curve, and the difference in elevation between the pressure transducer and staff gage. Since the staff gage and the pressure transducer were at different elevations, the change in elevation between them was needed to adjust the pressure transducer data so that it could be used with the rating curve that was related to heights measured from the staff gage. The value found in Table 2.6 was added to the measured pressure transducer value before using the rating curve to calculate flow. There is more than one value at the DWR weir because the pressure transducer at this site was removed for repairs and not replaced at the same elevation, thus the relationship between pressure transducer height and staff gage was altered. After the 15-minute interval pressure transducer heights were converted to
flows using the rating curves, the data was averaged up to an hourly flow dataset.

Appendix C contains monthly graphs of hourly-averaged flow for each site.

Table 3.6 Pressure transducer site rating curves

<table>
<thead>
<tr>
<th>Location</th>
<th>Rating Curve</th>
<th>R² value</th>
<th>Number of Points</th>
<th>Change in Elevation (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anderson-Grade Road</td>
<td>y=97.075x^{1.7377}</td>
<td>0.9956</td>
<td>7</td>
<td>-0.737</td>
</tr>
<tr>
<td>DWR Weir</td>
<td>y=49.661x^{1.6241}</td>
<td>0.9424</td>
<td>9</td>
<td>0.345, 0.235, -0.478</td>
</tr>
<tr>
<td>A12</td>
<td>y=99.978x^{1.3848}</td>
<td>0.9261</td>
<td>8</td>
<td>-1.117</td>
</tr>
<tr>
<td>Grenada (GID)</td>
<td>y=23.447x^{1.609}</td>
<td>0.9681</td>
<td>4</td>
<td>1.065</td>
</tr>
<tr>
<td>Parks Creek</td>
<td>y=20.371x^{1.4061}</td>
<td>0.924</td>
<td>9</td>
<td>-0.153</td>
</tr>
<tr>
<td>Shasta above Parks</td>
<td>y=11.635x^{1.7377}</td>
<td>0.6703</td>
<td>6</td>
<td>0.233</td>
</tr>
</tbody>
</table>

Wide spatial and temporal variation was found in analysis of the flow data from the Shasta River. Table 3.7 contains monthly flow statistics including the mean, minimum and maximum hourly flows (cfs) during the months of study. It was found that Parks Creek was a sizable contribution, typically doubling the flow. The major gaining reach is from Shasta above Parks to the Grenada Irrigation District Pumps with flows increasing about 45 cfs on average, approximately a five-fold increase over flows below Parks Creek. There was no discernable trend in flow from A12 to GID. This reach fluctuated between gaining and losing a flow less than 10 cfs. Flows generally decreased between A12 and DWR weir about 35 cfs, with no discernable trend between DWR weir and Anderson Grade. A study of the flow statistics also yields a trend of lower flows during the months of June, July, and August and increasing flows in September and October for all sites except Shasta above Parks.
The only site where temporarily flow measurements were duplicated with a permanent station was at the DWR weir. Data was available from two sources at this site, the DWR Weir and the pressure transducer. Figure 3.2 is a comparison between the two types of flow measurements at the DWR weir. The data for the two sites are remarkably close, verifying the reliability of the temporary flow measurement method.

![Figure 3.2 Comparison of flow measurement methods at DWR Weir](image-url)
3.4 Water Temperature Study

Onset Hobo and Stowaway loggers were placed at eleven sites along the Shasta River. The Onset loggers measure temperatures within a range of -5°C to +37°C, with an accuracy of ± 0.2°C (± 0.36°F). The temperature devices logged hourly data and were downloaded approximately every two to three weeks during the summer months.

It was found at the end of the field season that there was no established protocol for deployment and downloading of the temperature devices. It was also discovered that two devices were deployed at several of the sites. Analysis of the temperature data yielded discrepancies of up to 4°C between several of the duplicate loggers, and up to 7°C at one logger site. Preliminary water temperature data was obtained from the DWR 2001 monitoring program and used to discern the properly functioning units. A comparison of the two data sets for these sites found that several of the duplicate temperature devices did not yield reliable data due to either the device itself, or the deployment method. Fortunately reliable data was available for all sites except Hwy 263 and Yreka-Ager Road. Table 3.8 contains a list of the temperature logger sites, associated river mile, and serial number of the reliable logger. In cases where the data from both loggers were reliable, an average was taken. This implies that the difference in readings between the two loggers was within the error of the instrument.

<table>
<thead>
<tr>
<th>Location</th>
<th>RM</th>
<th>Serial Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth of Shasta</td>
<td>0.0</td>
<td>331932</td>
</tr>
<tr>
<td>Hwy 263</td>
<td>7.1</td>
<td>Not used</td>
</tr>
<tr>
<td>Anderson Grade</td>
<td>7.9</td>
<td>155044</td>
</tr>
<tr>
<td>Yreka-Ager Rd</td>
<td>10.3</td>
<td>Not used</td>
</tr>
<tr>
<td>Hwy A-3</td>
<td>12.3</td>
<td>103555</td>
</tr>
<tr>
<td>DWR Weir</td>
<td>14.7</td>
<td>155048</td>
</tr>
<tr>
<td>Hwy A-12</td>
<td>21.9</td>
<td>877</td>
</tr>
<tr>
<td>GID</td>
<td>26.9</td>
<td>331942</td>
</tr>
<tr>
<td>Louie Rd</td>
<td>30.1</td>
<td>155050</td>
</tr>
<tr>
<td>Parks Creek</td>
<td>31.0</td>
<td>Average of 331936 and 103557</td>
</tr>
<tr>
<td>Shasta above Parks Creek</td>
<td>31.8</td>
<td>Average of 332048 and 126375</td>
</tr>
</tbody>
</table>
An analysis of monthly temperatures for each site can provide initial insight into the spatial and temporal variability in the system. Statistics of monthly temperature data including mean, minimum, and maximum monthly temperatures are given in Table 3.9. All temperatures listed are in degrees Celsius. Generally, water temperatures increase moving downstream, with the exception of temperatures at GID. Presumably, GID has lower temperatures due to the influx of cooler water at Big Springs. On average the river gains (from SRP to the Mouth) $3^\circ$C in May, $3.5^\circ$C in June, $5.0^\circ$C in July, $6^\circ$C in August, $4^\circ$C in September and $1^\circ$C in October. Summer water temperature highs range from $19^\circ$C at SRP to $30^\circ$C at the Mouth. Monthly plots of hourly temperature data for each site can be found in Appendix C.

### Table 3.9 Monthly water temperature statistics ($^\circ$C)

<table>
<thead>
<tr>
<th>Location</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mouth</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>19.3</td>
<td>20.4</td>
<td>23.4</td>
<td>23.4</td>
<td>18.8</td>
<td>13.2</td>
</tr>
<tr>
<td>min</td>
<td>10.7</td>
<td>14.8</td>
<td>18.7</td>
<td>18.0</td>
<td>13.4</td>
<td>8.4</td>
</tr>
<tr>
<td>max</td>
<td>27.6</td>
<td>27.9</td>
<td>29.8</td>
<td>30.4</td>
<td>26.1</td>
<td>19.0</td>
</tr>
<tr>
<td><strong>Anderson-Grade Road</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>18.9</td>
<td>19.9</td>
<td>22.7</td>
<td>22.5</td>
<td>18.1</td>
<td>12.8</td>
</tr>
<tr>
<td>min</td>
<td>11.6</td>
<td>14.3</td>
<td>18.1</td>
<td>18.6</td>
<td>13.0</td>
<td>8.6</td>
</tr>
<tr>
<td>max</td>
<td>25.4</td>
<td>25.2</td>
<td>27.3</td>
<td>28.6</td>
<td>23.1</td>
<td>18.1</td>
</tr>
<tr>
<td><strong>Hwy 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>mean</td>
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<td>20.6</td>
<td>21.9</td>
<td>21.6</td>
<td>17.6</td>
<td>12.8</td>
</tr>
<tr>
<td>min</td>
<td></td>
<td>17.2</td>
<td>17.4</td>
<td>17.4</td>
<td>13.4</td>
<td>8.8</td>
</tr>
<tr>
<td>max</td>
<td></td>
<td>23.8</td>
<td>26.1</td>
<td>26.4</td>
<td>23.6</td>
<td>16.9</td>
</tr>
<tr>
<td><strong>DWR Weir</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
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<td>21.7</td>
<td>21.2</td>
<td>17.3</td>
<td>12.7</td>
</tr>
<tr>
<td>min</td>
<td>13.0</td>
<td>14.1</td>
<td>15.6</td>
<td>16.4</td>
<td>12.8</td>
<td>7.9</td>
</tr>
<tr>
<td>max</td>
<td>25.5</td>
<td>26.6</td>
<td>27.4</td>
<td>27.6</td>
<td>23.1</td>
<td>17.4</td>
</tr>
<tr>
<td><strong>A12</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>mean</td>
<td>17.3</td>
<td>17.9</td>
<td>19.7</td>
<td>19.1</td>
<td>15.9</td>
<td>12.3</td>
</tr>
<tr>
<td>min</td>
<td>11.9</td>
<td>13.1</td>
<td>16.1</td>
<td>14.7</td>
<td>12.2</td>
<td>8.9</td>
</tr>
<tr>
<td>max</td>
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<td>24.1</td>
<td>24.5</td>
<td>21.4</td>
<td>17.2</td>
</tr>
<tr>
<td><strong>Louie Road</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>17.2</td>
<td>17.4</td>
<td>19.0</td>
<td>18.4</td>
<td>16.1</td>
<td></td>
</tr>
<tr>
<td>min</td>
<td>9.4</td>
<td>11.5</td>
<td>14.0</td>
<td>13.9</td>
<td>11.9</td>
<td>No data</td>
</tr>
<tr>
<td>max</td>
<td>25.3</td>
<td>23.9</td>
<td>25.3</td>
<td>24.6</td>
<td>21.9</td>
<td></td>
</tr>
<tr>
<td><strong>Grenada (GID)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>17.3</td>
<td>16.4</td>
<td>17.6</td>
<td>17.1</td>
<td>14.8</td>
<td>12.1</td>
</tr>
<tr>
<td>min</td>
<td>11.6</td>
<td>10.5</td>
<td>13.0</td>
<td>13.4</td>
<td>11.3</td>
<td>8.7</td>
</tr>
<tr>
<td>max</td>
<td>22.9</td>
<td>22.2</td>
<td>22.2</td>
<td>21.1</td>
<td>18.3</td>
<td>15.9</td>
</tr>
<tr>
<td><strong>Parks Creek</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>17.9</td>
<td>18.4</td>
<td>21.2</td>
<td>20.1</td>
<td>17.4</td>
<td>14.6</td>
</tr>
<tr>
<td>min</td>
<td>9.7</td>
<td>10.9</td>
<td>13.6</td>
<td>13.4</td>
<td>11.0</td>
<td>9.7</td>
</tr>
<tr>
<td>max</td>
<td>27.6</td>
<td>30.3</td>
<td>31.8</td>
<td>29.0</td>
<td>27.4</td>
<td>20.3</td>
</tr>
<tr>
<td><strong>Shasta above</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>16.1</td>
<td>17.0</td>
<td>18.7</td>
<td>17.6</td>
<td>15.0</td>
<td>12.4</td>
</tr>
<tr>
<td>min</td>
<td>10.9</td>
<td>13.8</td>
<td>15.2</td>
<td>14.6</td>
<td>11.6</td>
<td>8.8</td>
</tr>
<tr>
<td>max</td>
<td>23.0</td>
<td>23.2</td>
<td>22.0</td>
<td>22.1</td>
<td>19.0</td>
<td>16.4</td>
</tr>
</tbody>
</table>
3.5 Riparian Vegetation Study

Field measurements were carried out to quantify vegetation height and transmittance, the key factors in characterizing the effect of riparian vegetation on stream temperature.

3.5.1 Vegetation Height

Vegetation height was measured at 25 sites along the Shasta River. At each site species, height, and location (right or left bank) were recorded for trees and bulrush present. If the height of the trees/bulrush was under 25 feet then a staff (25 ft in length) was used to directly measure the height. When this was not possible, a Brunton compass and 100-ft tape was used to calculate the vegetation height. The Brunton measures vertical angles to accuracies better than 1 degree. To calculate the tree height using a Brunton:

1. Measure the distance between the observer and the tree.
2. Site the top of the tree and measure the vertical angle with the Brunton. (The angle can be read as a percent or in degrees.)
3. \[ \text{height} = (\text{distance to tree}) \times \left(\frac{\% \text{ grade}}{100} \text{ or tangent of the angle}\right) \]

A full protocol for gathering vegetation data can be found in Appendix D. Table 3.10 includes a list of riparian tree species native to the Shasta Valley.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Other Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Alder</td>
<td>Alnus rhombifolia</td>
<td>Sierra Alder, Western Alder,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>California Alder</td>
</tr>
<tr>
<td>Oregon Ash</td>
<td>Fraxinus latifolia</td>
<td>Water Ash, Black Ash</td>
</tr>
<tr>
<td>Black Cottonwood</td>
<td>Populus trichocarpa</td>
<td>Western Balsam Poplar, California</td>
</tr>
<tr>
<td>Water Birch</td>
<td>Betula fontanalis</td>
<td>Red Birch</td>
</tr>
<tr>
<td>Oregon White Oak</td>
<td>Quercus garryana</td>
<td></td>
</tr>
<tr>
<td>Red Willow</td>
<td>Salix laevigata</td>
<td>Smooth Willow, Polished Willow</td>
</tr>
<tr>
<td>Arroyo Willow</td>
<td>Salix lasiolepsis var.</td>
<td>White Willow</td>
</tr>
<tr>
<td></td>
<td>bracelinea</td>
<td></td>
</tr>
<tr>
<td>Pacific Willow</td>
<td>Salix lasiandra</td>
<td>Wester Black Willow, Yellow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Willow, Waxy Willow</td>
</tr>
<tr>
<td>Sandbar Willow</td>
<td>Salix hindsiana</td>
<td>Hind’s Willow, Valley Willow</td>
</tr>
</tbody>
</table>
In this report the trees will be referred to by the common name given in Table 3.10. During the surveying all willows not identified as Sandbar Willows were classified as Arroyo Willow due to the difficulty in distinguishing between the Red, Arroyo and Pacific Willows. Trees under ten feet in height were considered saplings, and not included in the statistical analysis of tree heights found in Table 3.11. This eliminated four trees from the sampling dataset. Water Birch and Sandbar Willow were found to have similar height ranges and averages. Thirty-four of the sixty-eight trees measured were either Sandbar Willow or Water Birch, with an average height of twenty-two feet. Twenty-three out of sixty-eight were Arroyo Willow, with an average height of thirty-eight feet. The remaining eleven trees were White Alder, Oregon Ash, Oregon White Oak, and Black Cottonwood. Bulrush (Scirpus) was found throughout the system where the stream was protected from grazing. Bulrush ranged in height from 7-10 feet, the average being 9 feet.

**Table 3.11 Vegetation height statistics**

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Species</th>
<th>Range of Height (ft)</th>
<th>Average Height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>White Alder</td>
<td>21-35</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>Oregon Ash</td>
<td>17-37</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>Black Cottonwood</td>
<td>32-45</td>
<td>39</td>
</tr>
<tr>
<td>7</td>
<td>Water Birch</td>
<td>16-36</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>Oregon White oak</td>
<td>55-73</td>
<td>64</td>
</tr>
<tr>
<td>23</td>
<td>Arroyo Willow</td>
<td>20-54</td>
<td>38</td>
</tr>
<tr>
<td>27</td>
<td>Sandbar Willow</td>
<td>13-35</td>
<td>22</td>
</tr>
</tbody>
</table>

**3.5.2 Vegetative Transmittance**

The vegetative transmittance (Tr) is the percent of solar radiation passing through a particular type of barrier along the stream. Possible barriers include trees, stream banks, or other shade-rendering vegetation including bulrush. If \( Tr = 0.2 \) then 20% of the solar radiation is passing through the effective barrier. Transmittance will vary throughout a year for a particular type of barrier. For example, in the summer when the trees are in full bloom, the percent of solar radiation that penetrates the canopy is much
less than in the winter when the trees are without leaves. This modeling project is concerned with summer temperatures of the Shasta River; therefore transmittance measurements were taken during the summer months.

\[ T_r = \frac{Q_v}{Q_s} \]

where:
- \( T_r \): transmittance
- \( Q_v \): Solar radiation under the tree canopy or effective barrier (W/m\(^2\))
- \( Q_s \): Unimpeded solar radiation (W/m\(^2\))

**Instrumentation:** To determine the transmittance it is necessary to measure direct solar radiation and solar radiation underneath the effective barrier. Two devices were used to make these measurements. The LI200 was used to measure direct (unimpeded) solar radiation. SOLRAD was used to measure solar radiation underneath the tree canopy or other effective barrier.

SOLRAD is the Solar Radiation Measurement System produced by Kipp & Zonen, Inc. It consists of two main components, the CM 3 thermopile-type pyranometer and the CC 20 hand-held data logger. The pyranometer can be used in temperatures ranging from -40 to 80 °C. It measures within the spectral range from 305 to 2800 nm. The sensitivity is 10-35 µV/Wm\(^2\). The accuracy under normal conditions is ± 10%. The data logger runs on a DC-standard 9 volt battery. The logger allows the user to choose actual or integrated values, set the sensor type, set the integration method, read stored totals, set the calibration type, and set the internal clock. (Kipp & Zonen Manual, 1992)

Whereas SOLRAD was designed to measure unobstructed or shaded conditions, the LI200 pyranometer was designed to measure only unobstructed solar
radiation. The LI200, a product of LI-COR, Inc., has a maximum absolute error under natural daylight conditions of ± 5%. Since the sensitivity of the LI200 is 80 micro-amps per 1000 W/m2, an adapter was needed to amplify the signal to the HOBO logger, a product of Onset. The amplifier used was a UTA 200 made by EME Systems. It is specifically designed to be an interface between the LI200 and the HOBO loggers. See Table 3.12 for more detailed specifications of SOLRAD and the LI200.

**Table 3.12 Specifications of the solar radiation measurement devices**

<table>
<thead>
<tr>
<th>Specifications</th>
<th>SOLRAD</th>
<th>LI200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Time</td>
<td>(95%) 18 s</td>
<td>10µs</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>10-35µV/Wm²</td>
<td>90µA/1000 Wm²</td>
</tr>
<tr>
<td>Linearity</td>
<td>± 2.5% (&lt;1000 W/m²)</td>
<td>± 1% (&lt;3000 W/m²)</td>
</tr>
<tr>
<td>Stability</td>
<td>&lt;± 1% change/year</td>
<td>&lt;± 2% change/year</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-40 to +80 °C</td>
<td>-40 to +60°C</td>
</tr>
<tr>
<td>Tilt Response</td>
<td>&lt;± 2%</td>
<td>No error.</td>
</tr>
<tr>
<td>Temperature Dependence</td>
<td>6% (-10 to 40°C)</td>
<td>0.15% per °C max.</td>
</tr>
</tbody>
</table>

SOLRAD and the LI200 were tested and calibrated so that they could be used together in the establishment of a transmittance value. For calibration purposes the instruments were each deployed in full sunlight for a 7.5-hour period. The two solar curves were compared and a calibration factor assigned. See Figure 3.3 for the solar curves before and after calibration. Note that the solar curves show a constant relationship after about 11:45am. There was some morning fog until about 10am, which may have been the cause of the varied relationship between the two curves in the morning hours. The data after 10am was compiled and averaged to yield a calibration factor for the LI200 of 0.9 (i.e. the data from the LI200 is multiplied by 0.9 to compare it to data from SOLRAD).
Figure 3.3 Calibration of LI200 and SOLRAD (a) before (b) after calibration

Field Procedure and Data: Transmittance measurements were made at two locations along the Shasta River. Measurements were taken downstream of the DWR Weir at Mr. Meamber’s property (RM 14.7) and on Mr. Fioc’s property at RM 10.6. At each location the LI200 was deployed in direct sunlight and SOLRAD was moved between three tripods located under various effective barriers including trees, cut banks, and bulrush. The LI200 logged solar radiation continuously at 1-minute intervals. Three
values were recorded with SOLRAD: the starting value, the ending value, and an integrated value over the five-minute monitoring period at each station. With a five-minute integrating period each station was visited once every 20 minutes. The deployments varied in time from half of a day to a full day depending on the weather. If through the course of the day the SOLRAD station became exposed to full sunlight, then the tripod was moved to a new site and the transfer noted. A copy of the protocols for use of each device is included in Appendix B. Figure 3.4 is a sample graph of the solar radiation data on the Shasta River at the Fiock’s property. Direct solar radiation as measured by the LI200 and calibrated for use with the SOLRAD data is the continuous line. The interruptions are due to the formation of clouds at various times of day. The squares are SOLRAD measurements taken under an Arroyo Willow and the triangles are SOLRAD measurements taken under a Sandbar Willow. Note that the relationship between unimpeded solar radiation and solar radiation under the canopy is not a direct relationship throughout the day. However, for the purposes of this study a single number was used to represent transmittance for a particular barrier. In the graph in Figure 3.4 the average transmittance is 0.1, or 10%.
Table 3.13 contains the averaged transmittance data for all deployments and stations. Each type of barrier was given a grade of good, fair or bad. “Good” meant full foliage, “bad” was poor cover, and “fair” was in between. Good foliage had values of transmittance that ranged from 6 to 14%. Fair foliage had values that ranged from 19 to 38%. The lower 2/3 of bulrush had values akin to good foliage, whereas the top 1/3 had values akin to fair foliage.

Table 3.13 Average transmittance values for various barriers

<table>
<thead>
<tr>
<th>Type of Barrier</th>
<th>Grade (good/medium/bad)</th>
<th>Average Transmittance for deployment period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut bank</td>
<td>Good</td>
<td>11</td>
</tr>
<tr>
<td>Arroyo Willow</td>
<td>Good</td>
<td>6</td>
</tr>
<tr>
<td>Sandbar Willow</td>
<td>Good</td>
<td>10</td>
</tr>
<tr>
<td>Arroyo Willow</td>
<td>Fair</td>
<td>21</td>
</tr>
<tr>
<td>Arroyo Willow</td>
<td>Fair-Good</td>
<td>19</td>
</tr>
<tr>
<td>Arroyo &amp; Sandbar Willow</td>
<td>Fair</td>
<td>38</td>
</tr>
<tr>
<td>Arroyo &amp; Sandbar Willow</td>
<td>Good</td>
<td>14</td>
</tr>
<tr>
<td>Birch</td>
<td>Good</td>
<td>7</td>
</tr>
<tr>
<td>Bulrush Top 1/3 of plant</td>
<td>Good</td>
<td>30</td>
</tr>
<tr>
<td>Bulrush Lower 2/3 of plant</td>
<td>Top 1/3 of plant</td>
<td>4</td>
</tr>
<tr>
<td>Bulrush Lower 2/3 of plant</td>
<td>Top 2/3 of plant</td>
<td>8</td>
</tr>
<tr>
<td>Bulrush Lower 2/3 of plant</td>
<td>Lower 2/3 of plant</td>
<td>7</td>
</tr>
</tbody>
</table>
4.0 MODEL IMPLEMENTATION AND SENSITIVITY TESTING

Model implementation is the process of gathering and formatting all necessary data for model application. In order to efficiently transfer the geometric, flow and water quality data from an EXCEL spreadsheet to a format read by the model it was determined that a computer program, called a preprocessor, was needed to expedite the formatting process. A preprocessor was written for the hydrodynamic model, ADYN, and a separate preprocessor was written for the water quality model, RQUAL. A code listing for each preprocessor can be found in Appendix E. After the input files for the model were completed it was necessary to test the model to insure that it functioned properly. This period of testing also provided insight into system response, the sensitivity and relationships between various modeling parameters. This section addresses sources for the modeling data and the results of model testing prior to model application.

4.1 MODELING DATA

To implement the hydrodynamic and water quality models a significant amount of data was required for several aspects of the system. Since temperature was the parameter of interest and the highest temperatures occur in July and August, it was preferential to choose modeling periods during these months. Based on the continuity of available data two six-day modeling periods were selected, July 21-27 and August 17-23 of 2001. Geometric, meteorological, flow, temperature, and vegetation data were assembled for each modeling period. The following sections describe the data sources, and estimations or approximations used when data was unavailable.
4.1.1 Geometry

To characterize the geometry of the Shasta River three types of data were required: nodes with associated river aspects, bed elevations, and cross-sectional shape.

4.1.1.1 River Grid

In order to model the river, formation of a grid was required. The Tennessee Valley Authority's River Modeling System (RMS) had a limit of 500 nodes in the grid. The edited NHD dataset provided 1310 points describing the river. In order to form the grid every third point was captured, including the first and last points, for a total of 438 nodes. The minimum node spacing was 110 feet, with maximum node spacing of 853 feet.

The concern with using just under 500 points to represent the river was that sections of the Shasta River had meanders that are of finer resolution than the grid. This had two effects. First, the grid length was shorter than the length of the full dataset because of the inherent straightening of the river through skipping data points. This is important because it affects the travel time of the water in the system. The grid length of the entire river (not just the study section) was 35.03 miles, whereas the NHD dataset was 36.38 miles. In certain models x-y coordinates are entered into the model as part of the geometry, and scale factors can be used to match the true river length. RMS does not require the input of the x-y coordinates. RMS bases the analysis on river miles entered with each cross-section. At no time does the model independently calculate the distance between nodes. Due to this method, the Shasta River model grid was composed of every third node with the associated river mile as calculated from the full NHD dataset. This preserved the true length of the river for accurate representation.
Capturing every third point also affects the river by changing the aspect of each element (segment between two nodes). As this modeling project was concerned with calculating the incoming solar radiation as reduced by vegetation, the aspect at each node was vital. The two sets of coordinates, NHD and the grid, were run through Make River, a Fortran preprocessor for the RMA models, to calculate the aspect at each node. The aspect associated with each NHD data point was compared with the new aspect calculated using the grid dataset. In a visual analysis of the grid it was determined that the representation was adequate for the purposes of this model. Twenty-five deviations (i.e. where a part of a meander was cut off) occurred in the grid. However, the majority of the aspects of the river segments were preserved. A plot of the two representations was not included in this report because it would show no detectable differences between the grid and the NHD data set at the full river scale.

4.1.1.2 River Slope
The model determines the river slope from the bed elevations input with the cross-sectional data. Bed elevations were read off USGS 1:24K topographical maps. For those nodes located between the intersections of topographic contours and the river, bed elevations were linearly extrapolated between known values.

4.1.1.3 Cross Sections
Cross-sectional data were compiled from the 2001 field studies. Cross-sections for the modeling were assembled for each of the 24 nodes corresponding to a measured cross-section and then linearly interpolated at the intermediate nodes. (NOTE: Measured data at River Mile 17.61 was not used due to an extremely wide measurement of 101 feet. This was not considered representative.) A modified trapezoidal cross-section was calculated assuming 1:1 side slopes, the maximum measured depth was assumed to occur in the middle of the section, the bottom width was approximated by the measured
water surface on the day of field measurements. Bank heights were extended five feet
to account for modeling of larger flows. The maximum depth at each node was assigned
the corresponding bed elevation from the 1:24K USGS maps. A sample cross-section
is found in Figure 4.1.

![Sample cross section used for modeling river mile 3.94](image)

**Figure 4.1 Sample cross section used for modeling river mile 3.94**

### 4.1.2 Meteorological data

Meteorological data required to run the temperature model includes cloud cover,
barometric pressure (mb), dry bulb temperature (°C), wind speed (m/s), short wave solar
radiation (Kcal/m2/hr), and dewpoint temperature (°C). Cloud cover was assumed to be
0.0 (no cloud cover) for the simulation period, to simulate the warmest conditions and
because cloud cover data was not available. Barometric pressure (P) was assumed
constant and calculated according to the elevation (EL) of the Shasta Valley with the
following equation (University of California. Converting humidity expressions with
computers and calculators, Leaflet 21372. Cooperative Extension):

\[
P = 1013 - 3.436 \left( \frac{EL}{100} \right) - 0.0029 \left( \frac{EL}{100} \right)^2 + 0.0001 \left( \frac{EL}{100} \right)^3
\]
Hourly meteorological data was acquired from the USGS gauging site at Brazie Ranch (BRZ) located to the west of the study area. The Brazie Ranch Handbar weather station is operated by US Department of Forestry. The data used from the BZR station were dry bulb air temperature (F), wind speed (mph), solar radiation (W/m²), and relative humidity (%). The Brazie Ranch hourly data were corrected for daylight savings time by lagging the data one hour. (On the California Data Exchange Center website where the Brazie Ranch data is posted the solar radiation is listed with units of cal/cm. These units are incorrect and should be listed as W/m². This misprint was confirmed with Pete Gilbert, the director of the Remote Automatic Weather Station program, RAWS.)

The dewpoint temperature was calculated using the relative humidity and dry bulb temperature from BZR by first converting the temperature to degrees Celsius.

\[
T_c = \frac{5.0}{9.0} (T_f - 32.0)
\]

Then the saturation vapor pressure (E_s) was computed.

\[
E_s = 6.11 \times 10^{-6} \left( \frac{17.27T_c}{237.3T_c} \right)
\]

The vapor pressure (E) is then computed by multiplying the relative humidity by the saturation vapor pressure. Finally dewpoint temperature (D) is computed using the vapor pressure (E).
\[ D = \frac{(-430.22 + 237.7 + \ln[E])}{(-\ln[E] + 19.08)} \]

Meteorological data for modeling periods 1 and 2 can be found in Figure 4.2 and 4.3 respectively.

Figure 4.2 Meteorological data for July 21\textsuperscript{st} to July 27\textsuperscript{th}: (a) solar radiation (b) wind speed (c) dry bulb temperature
Figure 4.3 Meteorological data for Aug. 17th to Aug. 23rd: (a) solar radiation (b) wind speed (c) dry bulb temperature

4.1.3 Flow

Hourly measured flows for the six pressure transducer sites, and the USGS gage (RM 0.5) were combined to determine model flows. The hourly hydrograph at Shasta above Parks was used as the upstream boundary condition for the hydrodynamic model. Diversions were estimated from irrigation district records, where available. Partial
records were available from the Grenada Irrigation District and the Shasta Water Users Association. Parks Creek inflow was derived from the measured data. All of the above-mentioned data were used to determine the ungaged accretions (inflows) and depletions (outflows) in the system for each of the five study segments using a water balance approach.

4.1.3.1 Water Balance

To determine lateral inflows/outflows a water balance approach was taken for each of the five study segments, moving from upstream to downstream. The water balance consisted of tracking the inflows and outflows of the system starting at Shasta above Parks and proceeding downstream segment-by-segment. Although the Shasta River has many ungaged diversions, spring flows, return flows and tributaries, these quantities are simplified for modeling into two categories: accretions and depletions. Since a particular reach can experience an accretion in one time period and a depletion during a subsequent time period the accretions and depletions are in some reaches lumped into one "net a/d" value.

Table 4.1 Location and method of determination for system flows

<table>
<thead>
<tr>
<th>Reach</th>
<th>Location</th>
<th>River Mile</th>
<th>Measured/Estimated/Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream BC</td>
<td>Shasta above Parks</td>
<td>31.8</td>
<td>measured</td>
</tr>
<tr>
<td></td>
<td>Parks Creek</td>
<td>31.0</td>
<td>measured</td>
</tr>
<tr>
<td>5</td>
<td>Accretion: Big Springs Creek</td>
<td>29.9</td>
<td>calculated by water balance</td>
</tr>
<tr>
<td></td>
<td>Diversion: GID</td>
<td>26.9</td>
<td>estimated from records</td>
</tr>
<tr>
<td>4</td>
<td>Net A/D: A12</td>
<td>21.9</td>
<td>calculated by water balance</td>
</tr>
<tr>
<td>3</td>
<td>Diversion: SWUA</td>
<td>16.8</td>
<td>estimated from records</td>
</tr>
<tr>
<td></td>
<td>Net A/D: DWR</td>
<td>14.72–21.89</td>
<td>calculated by water balance</td>
</tr>
<tr>
<td>2</td>
<td>Net A/D: Anderson Grade</td>
<td>7.9</td>
<td>calculated by water balance</td>
</tr>
</tbody>
</table>

The locations of the accretions/depletions (a/d) were assigned based on the best information available. The location of Parks Creek is known and properly located. The major accretion in Reach 5 was assigned to Big Springs Creek. It is evident from aerial photographs of the channel that this accretion is quite sizeable, however, the exact magnitude is unknown. Hence, this accretion was based on a water balance between
the accretion at Parks Creek and the measured flow at GID, taking into account the GID diversion. The diversion at the Grenada Irrigation District pumps was estimated from the irrigation records. Since the difference in flow between GID and A12 was small, and since little is known about this reach, the net a/d was applied just above A12. Between A12 and DWR the major depletion is assigned to the Shasta Water Users Association with the magnitude based on DWR water master records. This reach gains water all along the reach, likely due to various return flows (e.g. Huseman ditch). Therefore, the net a/d was distributed throughout the entire reach. A water balance between A12 and DWR Weir, taking into account the SWA depletion, was used to determine the magnitude of the net a/d of Reach 3. Little is known about Reach 2, so the net a/d depletion was assigned just above Anderson Grade. No accretion/depletion was calculated for Reach 1. The values of these net accretions/depletions are different for each modeling period, and vary by hour. The average magnitudes of the accretions/depletions for each modeling period are located in Table 4.2.

### Table 4.2 Average, minimum, and maximum values of lateral inflows

<table>
<thead>
<tr>
<th>Location</th>
<th>7-21 to 7-27 (avg, min, max) in cfs</th>
<th>8-17 to 8-23 (avg, min, max) in cfs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parks Creek</td>
<td>5 4 8</td>
<td>2 2 3</td>
</tr>
<tr>
<td>Accretion: Big Springs Creek</td>
<td>66 61 72</td>
<td>59 55 63</td>
</tr>
<tr>
<td>Diversion: GID</td>
<td>-20 -20 -20</td>
<td>-10 -10 -10</td>
</tr>
<tr>
<td>Net A/D: A12</td>
<td>1 -4 7</td>
<td>-3 -7 2</td>
</tr>
<tr>
<td>Net A/D: DWR</td>
<td>9 1 15</td>
<td>11 4 54</td>
</tr>
<tr>
<td>Net A/D: Anderson Grade</td>
<td>-3 -16 7</td>
<td>0 -13 14</td>
</tr>
</tbody>
</table>

#### 4.1.4 Water Temperature

Hourly water temperature data from the 2001 field study were used for boundary conditions and calibration/validation data. Measured water temperature for Shasta above Parks was applied as the upstream boundary condition. Measured data at Parks
Creek was applied to the accretion at Parks Creek. Water temperatures for the Big Springs accretion were approximated by the water temperatures at GID. All other water temperatures for the accretions and depletions were assumed to be at the temperature of the Shasta River.

4.1.5 Riparian Vegetation Representation

The data required to characterize riparian vegetation in the model were setback (bank width), effective bank height, and the net transmittance at each node (SHSOL). Due to the close proximity of the vegetation (where present) to the stream, setback was assumed to be zero along the entire system. Due to lack of data for each tree in the system, effective bank height was estimated to be homogeneous throughout the basin. Effective bank height was modeled using results from the 2001 fieldwork. The tree height in the basin was estimated to be 22 feet, the average height of the majority of trees measured. Model runs were made to test the sensitivity of this parameter (see Section 4.2). SHSOL, the net transmittance at each node, is a function of the continuity of vegetation at that node and the transmittance of the vegetation type. Due to the complicated nature of this system, the portion of the river represented by each node is not homogeneous in continuity of vegetation, so a system of weighted averages was used to obtain a single value for the transmittance at each node.

To obtain a value for the net transmittance at a node it was necessary to quantify the density of vegetation at that node. Location and density of riparian vegetation was quantified using fieldwork completed in 1996 as cited in Shasta River Woody Riparian Vegetation (Deas, et al. 1996). Each node was assigned a value, called a continuity factor (CF), based on the classification system listed below.
Density Classification:

0 = No vegetation
1 = Scattered or in patches
2 = Continuous

where:
0 = no trees
1 = less than 2 trees per 100 feet
2 = greater than 2 trees per 100 feet

Figure 4.4 (a) depicts the continuity factors for right and left banks along the entire system. The right bank is indicated by positive numbers on the top, while the left bank is indicated by negative numbers on the bottom. Figures 4.4 (b) through (f) depict the continuity factors for each reach, ordered from the Mouth moving upstream.

Figure 4.4 Vegetative continuity factors of the Shasta River (a) Mouth to Dwinnell Reservoir (b) Mouth to Anderson Grade
Figure 4.4 cont. Vegetative continuity factors of the Shasta River (c) Anderson Grade to DWR Weir (d) DWR Weir to Highway A12 (e) Highway A12 to GiD (f) GiD to Shasta Above Parks
Each continuity factor has an associated transmittance value. Where the CF=0 (i.e. no vegetation present) the transmittance = 100%. In other words, incoming solar radiation is not reduced. Where the CF=2 the vegetation is continuous and the transmittance is 10%, or the solar radiation is reduced by 90%. The transmittance value of 10% is an average value of “good” shading taken from the 2001 fieldwork (see Section 3.5.2). Where the CF=1, there are less than two trees per 100 feet. It was assumed that the average width of the crown of a tree was 2/3 the height of the tree, or about 15 feet. Hence, the amount of shading over 100 feet would be 15%. This would lead to a transmittance of 85% for a continuity factor of 1. Table 4.3 is a summary of the transmittance values associated with each continuity factor.

Table 4.3 Transmittance classification system

<table>
<thead>
<tr>
<th>Continuity Factor</th>
<th>Transmittance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>1</td>
<td>85%</td>
</tr>
<tr>
<td>2</td>
<td>10%</td>
</tr>
</tbody>
</table>

As stated above, a node may encompass sections of river that are classified by more than one type of continuity factor. Where this occurs a weighted average was used to determine the net transmittance value (SHSOL) for the model.

4.1.6 Model Parameters

There are certain parameters in each of the RMS components that were set before calibration and used throughout the modeling process. For both components the four-point implicit scheme with an hourly time step was employed. The section lists other parameters specific to each RMS component.
The flow model, ADYN, required selection of Manning’s n, contraction/expansion coefficients, and numerical controls. Manning’s n was set to 0.045 for each node. This value of Manning’s n was chosen based on previous flow and temperature modeling of the Shasta River (CEEMG, 1998). The transition between each node was considered to be gradual so that the contraction coefficient = 0.1 and the expansion coefficient = 0.3. (Transition loss in the model is computed as the product of this coefficient and the difference in velocity head between the nodes (Hauser, 1995).) The flow model required tolerances for convergence of the Newton-Raphson iterations. The tolerance for flow = 0.005 cfs, tolerance for elevation = 0.005 feet. The weighting factor on spatial derivatives in ADYN was set to 0.55.

The water quality component, RQUAL, required specification of river latitude/longitude, time of fog lift, wind coefficients, and numerical controls. River latitude was set to 41.875, longitude = 122.630. Since fog was not found to be a factor on the Shasta River, time of fog lift was set to 6am. The wind coefficients were initially set at: AA = 3.0E-09, BB = 1.4E-09. These coefficients were later used for calibration. The weighting factor on spatial derivatives in RQUAL was set to 0.5.

4.2 Sensitivity Testing

Sensitivity testing involved making several trial simulations while varying certain parameters to ensure that the model was working properly and to assess the system response to each parameter.

4.2.1 ADYN Sensitivity Testing

Trial simulations made using the hydrodynamic model were helpful in debugging the geometry file and in computing system transit times at the following steady-state flows:
2 cfs, 5 cfs, 10 cfs, 50 cfs, 100 cfs, 150 cfs, and 200 cfs. Manning’s roughness for all runs was 0.045 (this value was chosen based on previous work see CEEMG, 1998). Average velocities were captured at each node for each flow and averaged by study segment to compute travel times through each study segment. Table 4.4 contains the computed transit times. (Recall that reaches are numbered from downstream to upstream, see Table 3.2.)

Table 4.4 Comparison of Shasta River transit times in hours for each study segment

<table>
<thead>
<tr>
<th>Reach</th>
<th>Length (mi)</th>
<th>2 cfs</th>
<th>5 cfs</th>
<th>10 cfs</th>
<th>50 cfs</th>
<th>100 cfs</th>
<th>150 cfs</th>
<th>200 cfs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.9</td>
<td>10.8</td>
<td>8.6</td>
<td>7.4</td>
<td>4.9</td>
<td>3.9</td>
<td>3.4</td>
<td>3.1</td>
</tr>
<tr>
<td>2</td>
<td>6.9</td>
<td>14.0</td>
<td>11.2</td>
<td>9.5</td>
<td>6.3</td>
<td>5.1</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td>3</td>
<td>7.2</td>
<td>18.1</td>
<td>14.6</td>
<td>12.4</td>
<td>8.3</td>
<td>6.7</td>
<td>5.8</td>
<td>5.2</td>
</tr>
<tr>
<td>4</td>
<td>5.0</td>
<td>13.1</td>
<td>10.5</td>
<td>8.8</td>
<td>5.8</td>
<td>4.5</td>
<td>3.9</td>
<td>3.6</td>
</tr>
<tr>
<td>5</td>
<td>4.8</td>
<td>10.4</td>
<td>8.5</td>
<td>7.1</td>
<td>4.6</td>
<td>3.7</td>
<td>3.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Total Time (hrs)</td>
<td>66.4</td>
<td>53.3</td>
<td>45.2</td>
<td>29.8</td>
<td>23.9</td>
<td>20.8</td>
<td>18.8</td>
<td></td>
</tr>
<tr>
<td>Total Time (days)</td>
<td>2.8</td>
<td>2.2</td>
<td>1.9</td>
<td>1.2</td>
<td>1.0</td>
<td>0.9</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

In addition, during the steady-state test runs the water surface elevation was captured and used to calculate the maximum water depth at each node in the system. Figure 4.5 depicts the maximum water depth at 10 cfs, 50 cfs, and 100 cfs. When the flow was increased from 10 to 50 cfs the maximum water depth increased on average by 0.98 feet. When the flow was increased from 50 to 100 cfs, the maximum water depth increased an average by 0.63 feet.

Figure 4.5 Steady-state test cases: maximum water depth
4.2.2 RQUAL Sensitivity Testing

Using the water quality model and the Shasta River geometry file simulations were made to test the sensitivity of the temperature response to three parameters: flow, tree height, and transmittance. For these runs the flow was steady-state with no accretions or depletions, the upstream boundary had a constant temperature of 15°C, and meteorological data from August 28, 2001 was used.

4.2.2.1 Sensitivity to Flow

Sensitivity to flow was tested using 10 cfs, 50 cfs, and 100 cfs. The simulations made for flow contained no shading. Figure 4.6 contains a plot of the daily average temperature of each node over this range of flows.

![Figure 4.6 Longitudinal profile of average daily temperature for August 28, 2001 meteorological conditions for 10, 50, 100 cfs](image)

Notice that the flow-temperature relationship is not linear. The river warms approximately 0.7°C at the Mouth (RM 0.0) when the flow is reduced by 50% (100 cfs to 50 cfs). However, when the flow is reduced again by 80%, the river warms a maximum of 1.5°C in upper reaches and there is no net effect at the Mouth. The lack of a net effect at the Mouth is likely due to the water temperatures approaching an equilibrium with the meteorological conditions. Table 4.4 contains the average maximum and minimum daily temperatures for each of the three flow cases. This non-linear relationship illustrates that as flow increases, water temperature decreases at a slower rate. Whereas increasing flow from 10 to 50 cfs reduces the average maximum daily
temperature by 5°C, adding another 50 cfs only reduces the average maximum daily
temperature by approximately 1.5°C.

**Table 4.5 Average, maximum, and minimum temperatures for 10cfs, 50cfs, 100cfs test cases**

<table>
<thead>
<tr>
<th>Flow (cfs)</th>
<th>Average Minimum Daily Temperature (°C)</th>
<th>Average Maximum Daily Temperature (°C)</th>
<th>Avg Max – Avg Min (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>11.1</td>
<td>24.6</td>
<td>13.5</td>
</tr>
<tr>
<td>50</td>
<td>12.8</td>
<td>21.3</td>
<td>8.5</td>
</tr>
<tr>
<td>100</td>
<td>13.4</td>
<td>19.7</td>
<td>6.3</td>
</tr>
</tbody>
</table>

### 4.2.2.2 Sensitivity to Transmittance

To test the temperature response to transmittance, simulations were made over a range of flows (10 cfs, 50 cfs, 100 cfs) and transmittance factors (10%, 50%, 85%, 100%). For these simulations it was assumed that the river was fully shaded and that the trees were 22 feet in height. Effects the 50 cfs case are presented in Figure 4.7. Recall that a transmittance factor of 10% translates to only 10% of the solar radiation being available for heating the river, whereas a transmittance factor of 100% represents no shading.

**Figure 4.7 Longitudinal profile of average daily temperature for August 28, 2001 meteorological conditions for 50 cfs test case with varying transmittance (10%, 50%, 85%, 100%)**

As seen in Figure 4.7 if there is no shading the average daily temperature at the Mouth (RM 0.0) is 19.2°C. If the solar radiation is reduced 15%, this translates to an average cooling of the system at the Mouth of about 1.5°C. If the solar radiation is reduced by
50%, the average daily temperature is reduced by approximately 3.0°C. Finally, if the solar radiation is reduced by 90% the average daily temperature is reduced by approximately 4.0°C. This last scenario implies that if the river were fully shaded, with a transmittance factor of 10%, then there would be no net heating of the river through the study reach. The fieldwork supports an average transmittance factor of 10%. However, recall that this simulation requires that the river be flowing through a “tunnel” of trees. Notice that this relationship is also non-linear (i.e. tripling the reduction in solar radiation resulted in a doubling of the reduction in average daily temperature at the Mouth).

### 4.2.2.3 Sensitivity to Tree Height

Sensitivity to tree height was tested using the 50cfs test case and the average values of tree height found during the field season. Two tree heights were tested, the average tree height for Sandbar Willow (22 feet), and the average tree height for Arroyo Willow (38 feet). Figure 4.8 illustrates tree height sensitivity with two scenarios: (a) with a transmittance of 50% and (b) with a transmittance of 85%. The average daily temperature at the Mouth in case (a) is reduced by 0.7°C when the tree height is increased to 38 feet. However, if the transmittance is increased to 85% then there is approximately no difference in the average daily temperatures along the river due to tree height. It appears that the model is not as sensitive to variance in tree height as it is to flow and transmittance.
4.2.2.4 Sensitivity of Flow vs. Transmittance

Recall that the two main identified options available to lower temperature on the Shasta River are to (a) increase the flow and/or (b) increase the riparian vegetation. It is worthwhile, therefore, to compare the effect of increased flow on temperature. Since summer flows in the Shasta are closest to the 50 cfs test case, and the majority of trees measured in the Shasta averaged 22 feet these two parameters will be used as the base case. In addition, there is currently minimal shading on the Shasta River; hence 85% transmittance will be used as the base case. This test case compares the impact of increasing flow 100%, and increasing the vegetation so that there is 50% transmittance along the entire river. Figure 4.9 (a) shows that an increase in flow yields approximately 0.6°C at the Mouth, whereas Figure 4.9 (b) shows that an increase in vegetation yields approximately 1.4°C at the Mouth. The increase in vegetation has over twice the effect of the increase in flow. Hence, the preliminary testing indicates that increasing vegetation may have more of an effect than increasing flow in the Shasta River.
Figure 4.9 Longitudinal profile of average daily temperature for August 28, 2001 meteorological conditions flow vs. transmittance sensitivity (a) flow increased from 50cfs to 100cfs (b) transmittance decreased from 85% to 50%
5.0 MODEL APPLICATION

Following model testing, calibration/validation and model application were completed. The model was calibrated using the field observations of flow and temperature and meteorological data from August 17th to August 23rd, 2001. Following this calibration the model was validated using the field observations and meteorological data from July 21st to July 27th, 2001. After model calibration and validation several vegetation scenarios were applied to the system. This section addresses the processes of calibration and validation, quantifying the errors of those processes, and using the model results to provide insight into vegetation management scenarios.

5.1 BOUNDARY AND INITIAL CONDITIONS

Model application required specification of boundary and initial conditions for both flow and temperature. The upstream boundary condition for flow was represented by the hourly hydrograph of Shasta above Parks. There was no downstream boundary condition, as the model calculated flow at the downstream node. Nine initial conditions were assigned along the system after each lateral inflow/outflow and at the Mouth using a flow and an elevation. There were seven lateral inflows/outflows as shown in Table 4.1. The upstream boundary condition for temperature was represented by the hourly temperatures measured at Shasta above Parks. The nine initial condition temperatures were specified according to the temperatures of the closest field location where observed data was available.
5.2 Flow Verification

This project included a hydrodynamic representation of the river to effectively model water temperature. The hydrodynamic representation was achieved by a system water balance as described in section 4.1.3. This section contains the results of the flow simulation for the calibration and validation periods. The figures contain graphs of simulated versus measured flow for all measured sites ordered upstream to downstream.

5.2.1 Calibration Period

Figures 5.1 to 5.5 contain graphs of simulated versus measured flow for the calibration period, August 17\textsuperscript{th} to August 23\textsuperscript{rd}. All flow simulations were within 3 cfs of measured flows with two exceptions. The first exception was the short duration event observed in the DWR Weir hydrograph on August 18\textsuperscript{th}. This event was apparently due to the Shasta River Water Users shutting down for a period of time. It was difficult to simulate this peak because the accretion in this reach was assumed to be distributed over the entire reach. The second exception was at the Mouth. No correction was made for flow between Anderson Grade and the Mouth due to the limited information available about this reach. More data will be needed to properly simulate this section.

![Figure 5.1 Measured vs. simulated flow for GID, Aug 17-Aug 23, 2001](image-url)
Figure 5.2 Measured vs. simulated flow for A12, Aug 17-Aug 23, 2001

Figure 5.3 Measured vs. simulated flow for DWR Weir, Aug 17-Aug 23, 2001

Figure 5.4 Measured vs. simulated flow for Anderson Grade, Aug 17-Aug 23, 2001
5.2.2 Validation Period

Figure 5.6 – 5.10 contain graphs of simulated versus measured flow for the validation period, July 21st to July 27th. All flows are within 3cfs of the measured value with the exception of the flows at the Mouth. As with the calibration period, no correction was made for flows at the Mouth due to lack of data in that reach.
Figure 5.8 Measured vs. simulated flow for DWR Weir, July 21-July 27, 2001

Figure 5.9 Measured vs. simulated flow for Anderson Grade, July 21-July 27, 2001

Figure 5.10 Measured vs. simulated flow for Mouth, July 21-July 27, 2001

5.3 TEMPERATURE CALIBRATION

After verification of the flows was completed an initial temperature simulation was made with no temperatures assigned to the lateral inflows. It was evident from this first run
that a diurnal temperature cycle needed to be applied to Parks Creek and the Big Springs accretion. The measured temperatures at Parks Creek were applied to the Parks Creek lateral inflow, and because measured temperatures were unavailable at Big Springs, the measured temperatures at GID were applied to the Big Springs accretion. Calibration continued by adjusting the evaporation coefficients AA and BB, refining the placement of accretions/depletions, and adjusting boundary condition temperatures. The final coefficients were AA = 0.1E-09 and BB = 1.4E-09. These are consistent with the range of default values given in the RMS User’s Manual (Hauser, 1995). Simulated versus measured temperatures can be found in Figures 5.11-5.16.

![Figure 5.11 Measured vs. simulated temperature for Louie Rd., Aug 17-23, 2001](image)

![Figure 5.12 Measured vs. simulated temperature for GID, Aug 17-23, 2001](image)
The water temperature regime of small rivers can be highly sensitive to meteorological conditions. The Shasta River, with highly variable flows, but generally small volumes, exhibits such behavior. This was evident during the final day of simulation, August 22nd,
at Louie Road, DWR, Anderson Grade, and the Mouth. On this day at approximately 2:00 p.m. there was a disturbance in the solar radiation curve (Figure 4.3) that caused a drop in mid-day solar radiation of approximately 400 W/m$^2$. This was likely due to transient cloud cover. This disturbance was reflected in the temperature plots by a drop in simulated temperature at approximately the same time (see Figures 5.11-5.16). This illustrated the model’s sensitivity to meteorological conditions at low flows. However, when flows were greater, such as at GID or A12, the model performed better, and was less sensitive to meteorological data.

Table 5.1 contains the error analysis of this temperature calibration. At Louie Road (Figure 5.11) the mean absolute error (MAE) was 1.2°C. The simulated values consistently over-predict the measured values. This error was likely due to the sensitivity at low flows, and uncertain placement and quantity of the reach a/d. In addition, refinement of the geometry is necessary.

<table>
<thead>
<tr>
<th>Location</th>
<th>Average Bias</th>
<th>Maximum Bias</th>
<th>Minimum Bias</th>
<th>Mean Absolute Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louie Road</td>
<td>-0.3</td>
<td>1.7</td>
<td>-3.8</td>
<td>1.2</td>
</tr>
<tr>
<td>GID</td>
<td>-0.8</td>
<td>1.4</td>
<td>-3.0</td>
<td>1.0</td>
</tr>
<tr>
<td>A12</td>
<td>0.1</td>
<td>1.5</td>
<td>-1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>DWR Weir</td>
<td>1.0</td>
<td>5.0</td>
<td>-3.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Anderson Grade</td>
<td>1.2</td>
<td>4.8</td>
<td>-2.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Mouth</td>
<td>1.1</td>
<td>5.5</td>
<td>-2.7</td>
<td>1.9</td>
</tr>
</tbody>
</table>

GID (Figure 5.12) had a MAE of about 1°C. The simulated temperature signal was out of phase with the measured signal by about 2 hours. This is most likely due to approximating Big Springs inflow temperatures with water temperatures from GID. A further confounding factor may be the accretion location and quantity. It is possible that more flow was coming into the system downstream or upstream of Big Springs, and that
the Big Springs accretion was actually smaller. The best results occurred at A12 (Figure 5.13), with a MAE of less than 0.5°C. This reach generally experienced high flows and relatively modest lateral inflows. The peaks were well positioned at DWR weir (Figure 5.14), however a there was a craggy temperature trace. Just above DWR Weir vegetation becomes more frequent. Several simulations with and without vegetation were completed to identify the source of the cragginess. It appears that the signal was due to the shading logic, or the riparian vegetation representation. The exact component, or interaction of components, was not identified.

The MAE at DWR Weir was approximately 1.7°C. This was likely due to placement and quantity of the a/d in this reach. To better understand this reach it would be necessary to have a gage upstream and downstream of the SWA pumps. The variation of the temperature signal at DWR was likely perpetuated downstream and affected the temperature trace at Anderson Grade (Figure 5.15). The simulated signal at Anderson Grade, however, did recreate the flat peaks that distinguished the measured signal. The low troughs may be partially due to coarse geometry, an under estimation of the flow. Further characterization of the flow between DWR Weir and Anderson Grade, particularly below Yreka Creek, is necessary to improve simulations in this reach. The signal at the Mouth (Figure 5.16) had the highest mean absolute error of 1.9°C. This was expected considering that a water balance was not computed between Anderson Grade and the Mouth (see Figure 5.5). Additionally, refinement of the canyon geometry would assist in a better simulation of water temperature.
5.4 **TEMPERATURE VALIDATION**

Validation is the process of applying the parameters set during calibration to an independent time period. Figures 5.17 through 5.22 show the validated versus measured temperatures for each site. Similar trends appeared in the validation that were present in the calibration. Statistical analysis of validation can be found in Table 5.2.

**Table 5.2 Error analysis of the temperature validation (°C)**

<table>
<thead>
<tr>
<th>Location</th>
<th>Average Bias</th>
<th>Maximum Bias</th>
<th>Minimum Bias</th>
<th>Mean Absolute Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louie Road</td>
<td>-1.0</td>
<td>0.6</td>
<td>-4.6</td>
<td>1.1</td>
</tr>
<tr>
<td>GID</td>
<td>-1.1</td>
<td>0.5</td>
<td>-3.3</td>
<td>1.1</td>
</tr>
<tr>
<td>A12</td>
<td>-0.2</td>
<td>1.9</td>
<td>-1.6</td>
<td>0.7</td>
</tr>
<tr>
<td>DWR Weir</td>
<td>-0.1</td>
<td>4.7</td>
<td>-5.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Anderson Grade</td>
<td>-0.9</td>
<td>4.0</td>
<td>-6.5</td>
<td>1.9</td>
</tr>
<tr>
<td>Mouth</td>
<td>3.8</td>
<td>6.4</td>
<td>0.1</td>
<td>3.8</td>
</tr>
</tbody>
</table>

At Louie Road (Figure 5.17) the model systematically over-predicted the peaks, with a MAE only 0.1°C lower, at approximately 1.1°C. The temperature signal at GID (Figure 5.18) was only about 1 hour out of phase with the measured data. This was an hour less than the calibration simulation. The MAE at GID was 1.1°C, only 0.1°C more than in calibration. A12 (Figure 5.19) was the site with the lowest MAE. However, the MAE in validation was 0.7°C, 0.2°C greater than in August.

![Figure 5.17 Measured vs. simulated temperature for Louie Road, July 21-27, 2001](image-url)
Figure 5.18 Measured vs. simulated temperature for GID, July 21-27, 2001

Figure 5.19 Measured vs. simulated temperature for A12, July 21-27, 2001

Figure 5.20 Measured vs. simulated temperature for DWR Weir, July 21-27, 2001

Figure 5.21 Measured vs. simulated temperature for Anderson Gr, July 21-27, 2001
DWR Weir did not appear as craggy as in calibration, but persisted in over-predicting the peaks and under-predicting the troughs with a MAE of 1.9, 0.2°C greater than calibration. Anderson Grade was particularly sensitive to the meteorological data on July 25\textsuperscript{th}, and significantly under-predicted the troughs. The MAE was the same as DWR Weir. Again, the Mouth was the site of most deviation. However, whereas all of the previous errors were of amplitude, the error at the Mouth in Figure 5.22 was in the mean temperature, and represented a heat loss not present in the real system.

It was evident that the conditions that existed in calibration persisted in validation, suggesting that the model performed consistently.

5.5 Model Application: Riparian Vegetation Management

In order to determine the effect of various vegetation scenarios on the Shasta River the data of the August 17\textsuperscript{th} to August 23\textsuperscript{rd}, 2001 period was used. Figure 5.23 is a plot of the 6-day average, minimum, and maximum simulated temperatures at each node. From SRP to the Mouth there was an average temperature gain of approximately 4.4°C, with a six-day average temperature at the Mouth of approximately 21.4°C, and a maximum temperature of about 31.2°C. If the river exhibited a uniform-steady flow regime, a steady increase in temperature from headwaters to the Mouth would be expected.
However, the simulations of the Shasta River water temperature exhibit the complicated relationship between flow and temperature along the varied system. The sharp decrease in temperature range at about RM 30 was likely due to the increase in flow and water depths at Big Springs. The abrupt increase in temperature range at approximately RM 17, was probably due to the decrease in flow and depths at the SWA diversion.

![Temperature vs Distance Upstream](image)

**Figure 5.23** Simulated average, minimum, and maximum temperature at each node, Aug 17-Aug 23, 2001

Recall from section 1.2 that if the preferred temperatures for juvenile salmonid and steelhead range from 12 to 19°C, with temperatures becoming lethal at about 25°C, this simulation suggests temperatures in a large portion of the Shasta River would be too extreme for the majority of salmonids and steelhead to survive.

Three scenarios were simulated to characterize possible temperature benefits that revegetation might provide to the system. If the entire river were fenced, in the first few years bulrush would likely grow rapidly. Thus the effective bank height (EBH) would be raised to about 10 feet in the places where there is currently no vegetation. However, it was found in the fieldwork that only 2/3 of the height of the bulrush is effective at shading. Figure 5.24 shows the effect on temperature if an EBH of 7 feet was assumed to replace all areas where the current vegetation is zero.
Figure 5.24 Simulated average, minimum, and maximum temperature at each node: bulrush scenario

Figure 5.24 shows that the six-day average temperature at the Mouth is decreased by approximately 1°C to 20.2°C. The maximum temperature at the Mouth is decreased from 30.2°C to 29.4°C, slightly less than a degree. If vegetation were allowed to grow all along the river it would likely be 10 to 20 years before the trees were grown to full height and foliage. Figure 5.25 depicts the possible six-day average temperatures if this were allowed to occur. The mean temperature at the Mouth drops to approximately 17.1°C, with the maximum daily temperature at about 24.2°C. This assumes that the trees are 22 feet high and continuous along the bank.

Figure 5.25 Simulated average, minimum, and maximum temperature at each node: fully shaded scenario

It is likely that revegetation efforts would begin in phases. Figures 5.26 and 5.27 illustrate the need to focus revegetation efforts on the downstream reaches. Above SWA the flow is approximately 50 cfs, about twice as large as the flow below SWA. Recall from the sensitivity testing that shading has a smaller effect on larger flows. The
first run in Figure 5.26 assumed that the lower half of the river (below the SWA at RM 16.8) was left with the current vegetation, and that the upper half of the river was completely revegetated. The average temperature at the Mouth was reduced only 0.6°C, with the maximum temperature decreasing 1°C to 30.2°C.

Figure 5.26 Simulated average, minimum, and maximum temperature at each node: upstream of SWA (RM 16.8) shaded

Figure 5.27 is the opposite scenario with the upstream conditions remaining as original vegetation and downstream of SWA being completely revegetated. The average temperature at the Mouth decreased from 21.4°C to 19.7°C, approximately 1.5°C. What was more impressive was that the maximum temperature at the Mouth dropped from 30.2°C to 28.3°C, almost 2°C. Table 5.3 compares the results of all revegetation scenarios to the baseline simulation.

Figure 5.27 Simulated average, minimum, and maximum temperature at each node: downstream of SWA (RM 16.8) shaded
Table 5.3 Comparison of revegetation scenarios to baseline (°C)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Six-day Average Water Temperature at the Mouth</th>
<th>Six-day Maximum Water Temperature at the Mouth</th>
<th>Six-day Average Temperature Gain from SRP to Mouth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline (Original vegetation)</td>
<td>21.4</td>
<td>31.2</td>
<td>4.4</td>
</tr>
<tr>
<td>Bulrush Scenario</td>
<td>20.2</td>
<td>29.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Full Shade Scenario</td>
<td>17.1</td>
<td>24.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Upper River Shaded</td>
<td>20.8</td>
<td>30.2</td>
<td>3.8</td>
</tr>
<tr>
<td>Lower River Shaded</td>
<td>19.7</td>
<td>28.3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

5.6 CONCLUSIONS

This research provided great insight into the flow and temperature relationships in the Shasta River. A fundamental knowledge of the river was developed through successful flow, temperature, vegetation, and geometric field studies and through subsequent analysis of the measured data. Characterization of the system by calculating statistics of key parameters supplies a knowledge base that can provide needed understanding to decision-makers in the basin.

TVA’s River Modeling System was modified to accommodate for two-bank shading on small, variable streams such as the Shasta River. Model sensitivity testing provided insight into reach travel times, and relationships between flow, temperature, tree height and transmittance. The model calibration and validation was good based on the available data and inherent limitations. The model also exposed areas of the river that require further field characterization of temperature, flow and geometry (see Recommendations for Future Research, Chapter 6).

It is important to remember that a model in no way is expected to predict exact behavior, but rather can be used to discern trends of possible scenarios and couplings among interdependent processes. The various scenarios examined in this research suggest
that revegetation efforts should be focused on areas of shallow flows. They also suggest that the maximum vegetation effect on average daily temperatures would be approximately 4°C, if the entire river corridor were vegetated. Additionally, model results indicate that maximum daily temperatures can be reduced as much as 6°C. These preliminary scenarios have only taken into account the influence of 22-foot trees. Larger, denser trees (e.g. 40 feet in height) would likely increase the shading effect by about one more degree. Also, scenarios explored in this research also only accounted for vegetation changes. They did not simulate the effects of changes in flow. Combining changes due to both vegetation and flow could potentially have a greater effect on the river’s thermal regime.

In conclusion, the topic of this research has stimulated interest in further exploration of the effects of vegetation shading on the thermal regime of small streams like the Shasta River.
6.0 RECOMMENDATIONS FOR FUTURE RESEARCH

Whereas this project has provided much useful information, there are many areas that could greatly benefit from further research. Among the most promising areas are the following:

1) There is insufficient flow data to fully quantify this highly diverse system. Specifically, if access is available, pressure transducers should be deployed at Louie Road (RM 30.1), below the Shasta Water Users pumps (RM 16.8), and below Yreka Creek (RM 7.6).

2) In Reach 1, from the Mouth to Anderson Grade, it seems that there is a substantial loss in the system, however there are no major water users in this reach. Due to the bedrock geology it is not likely that there is a substantial loss to the ground water system. It is possible, however, that evaporation plays a major role. It would be advisable to quantify the evaporation-transpiration losses in this reach.

3) If access can be obtained, a temperature logger should be deployed above and below Big Springs to provide a more continuous record of water temperatures along the watercourse, and to better quantify the Big Springs inflow temperatures.

4) It is likely that a large part of the deviance in the temperature signal is due to uncertainties in the geometry grid. Further refinement of grid cross-sections
throughout the system is necessary, especially above Louie Road and below DWR Weir.

5) In the coding of TVA’s River Modeling System dispersion is neglected, presumably due to the application in highly dynamic systems (rivers) where advective transport is the dominant factor. Numerical dispersion in the model is not quantified and is considered to be large enough to account for the neglected dispersion term (G. Hauser, pers. comm.). It is recommended that dispersion be quantified.

6) Since RMS does contain bed conduction logic, it would be beneficial to do a thorough review of bed conduction phenomena. Brown (1969) noted that conduction might also occur through the bottom of small clear streams because thermal energy reaching the stream surface is not strongly attenuated by shallow water. Conduction may occur between the overlying water and the streambed. Brown computed bed conduction as the product of the thermal conductivity and the measured temperature gradient in the bottom material. Brown found that for a small stream, a bedrock streambed acted as an energy sink during the midday hours and as an energy source later in the day, whereas a gravel bed appeared to be an insignificant energy sink. In most calculations this type of conduction is neglected. However, when modeling a small stream, attention should be paid to the type of streambed in order to determine if it is plausible to neglect bed conduction in the energy budget. A review of bed conduction phenomena would help to better quantify this parameter in the Shasta River. Perhaps a more physical parameter (as opposed to a mere calibration tool) could be incorporated into the model. (Bed conduction was not included in this application.)
7) It would be beneficial to explore topographic shading in the canyon. It is not currently known whether topography in the canyon has an appreciable effect on the thermal regime of the Shasta River. If it is found to be appreciable, this could be modeled in one of two ways. There is no current shading logic in RMS, so either logic would have to be developed or the times of local sunrise and sunset would have to be adjusted in the meteorological data.
7.0 REFERENCES


California Department of Fish and Game (DFG). 1996. A Biological Needs Assessment for Anadromous Fish in the Shasta River, Siskiyou County, California - DRAFT. Northern Management Area (Area 2), Yreka, CA 96097. June.

California Department of Fish and Game (DFG). 1995. Habitat Study; A-12 to Anderson Grade Road, and Below Dwinnell Reservoir – Field notes (DRAFT).


La Marche, J. L., Dubin, A. & Lettenmair, D.P. A two-layer energy balance model for the prediction of stream temperature. Fall AGU. December 1997.


**PERSONAL COMMUNICATIONS**

Jim Whelan  California Department of Fish and Game, Yreka

Gary Hauser  Tennessee Valley Authority
APPENDIX A: MODIFIED INPUT FILES

One input file was modified and one input file was added to allow for the new shading logic. This appendix contains the modifications and the format for the new file.

A.1 Water Quality Coefficients (name.ric)

The first line (record) of the water quality coefficient input file was modified.

Original Input File (record number 1)

PRT,IPLT,THET,TSI,I02R,PLT,ROUTE,TDC,PDCX
(F8.0,I5,2F8.0,I5,F8.0,4X,A1,2F8.0)

Modified Input File (record number 1)

PRT,IPLT,THET,TSI,I02R,PLT,ROUTE,TDC,PDCX,IRS
(F8.0,I5,2F8.0,I5,F8.0,4X,A1,2F8.0,I5)

If IRS=0, RQUAL will run as originally constituted. If IRS=1, a shade data (shade.ris) input file is required. In addition, EBH and SHSOL should be left out of the .ric file.

A.2 Shade Data (shade.ris)

The shade data input file (shade.ris) must be named ‘shade.ris’ and be located in the same directory as RQUAL. The format of ‘shade.ris’ is (8X,4F8.0) where the first column may be used as an identifier with the node or river mile. The following four columns contain left effective bank height, right effective bank height, left bank transmittance factor, and right bank transmittance factor respectively.

Sample Input File (shade.ris)

<table>
<thead>
<tr>
<th>Head</th>
<th>10.0</th>
<th>40.00</th>
<th>0.15</th>
<th>0.0</th>
<th>EBHL, EBHR, SHSOLL, SHSOLR</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>10.0</td>
<td>40.00</td>
<td>0.15</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10.0</td>
<td>40.00</td>
<td>0.15</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10.0</td>
<td>40.00</td>
<td>0.15</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>10.0</td>
<td>40.00</td>
<td>0.15</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B: MODIFIED PROGRAM CODE

Modifications were made in the main program, the subroutine CRS, in the commonblock RA which exists in the MAIN program and in subroutines CRS, BEDFLX, BEDFL2, INTEGR, TEMPD, BODDK, NODDK, OXYDK, MROUTE, H-P, and in the commonblock CR which exists in the main program and in subroutine CRS. The original program code is in normal print, the modifications made for this application are in bold print. The dashed lines indicate that parts of the code have been deleted that were not of interest in these changes.

$debug
PROGRAM RQUAL
C Modified version agpa 09/10/01
------------------------------------------------------------------------
REAL N1,N2,NOD1,NOD2,NMD1,NMD2,NFL1,NFL2,NINIT,NK20,NODR,K1,K2
CHARACTER*1 ROUTE
C
  c agpa 9/17/01 modified EBH to accommodate both banks
  c COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG
  c    COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG,EBHL(500),
  c     XEBHR(500),IEBH
  c agpa 9/18/01 take out IEBH, no longer needed
  c only one control variable will be used to turn on new shading logic
  c if IRS=1 then the user inputs EBHL,EBHR and SHSOLL,SHSOLR
     COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG,EBHL(500),
     XEBHL(500)
   COMMON/HYD/DX(499),Q1(500),Q2(500),H1(500),H2(500),
    X A1(500),A2(500),E1(500),E2(500),W1(500),W2(500),
    X K1(500),K2(500),DT,THET,TSI,
    X QL1(499),QL2(499),QLAT1(44),QLAT2(44)
COMMON/HYDNC/NC(500),ICONST,WFAC,WLEN,pdc,pdcx
  c agpa 9/13/01 added IRS COMMON/RA/EXCO, HMAC, AA, BB, NXSEC, THR, THB, BK20, THS, SK20 (500),
  c XTHN, NK20, THPR, IK2EQ, BS20, BETW, XL, XL2, DIF, CV, BEDALB, SHSOL, SHDBT
     COMMON/RA/EXCO, HMAC, AA, BB, NXSEC, THR, THB, BK20, THS, SK20 (500),
     XTHN, NK20, THPR, IK2EQ, BS20, BETW, XL, XL2, DIF, CV, BEDALB, SHSOL, SHDBT,
     XIRS, SHSOLL(500), SHSOLR(500), SHSOLA(500), IDAY, JOLD
 COMMON/PHOT/PMAX(500), RESP(500), O2RM
 C
  COMMON/PROCES/PHOTO(500), RESPR(500), REAR(500), NODR(500), BODR(500),
  XSODR(500), RETYP(500), TQS(500), TRS(500), TQA(500), TQB(500), TQE(500)
 COMMON/PROCS2/TBC(500), TBC2(500), TQ(500), IPROC
  COMMON/WQ/O1(500), O2(500), Ti(500), T2(500), B1(500), B2(500),
  XOM(500), QM(500), N1(500), N2(500)
 COMMON/UWEIR/NEVQ, EVQ(20,2)
 COMMON/BDFX/TBED(500), TBED2(500)
 COMMON/LAT/NL,NLW,NLS(44,2), LSEC(11), INDS(11)
 C
  COMMON/JUK/ RM(500), CHB(500), RML(11), RMIND(11),
  X RSI(500), RS2(500), ALPHX(500), IC(500), ICCH(500),
  X TDK1(500), TDK2(500), TP1(500), TP2(500),
COMMON/JUK1/RDBT1(500),RDBT2(500),
COMMON/JUK2/ ODK1(500),ODK2(500),OP1(500),OP2(500),
X
NORMAL/JUK3/ WLT1(11),WLT2(11),WLO1(11),WLO2(11),
X          WLB1(11),WLB2(11),WT1(499),WT2(499),
X          WB1(499),WB2(499),WO1(499),WO2(499),
X          WLN1(11),WLN2(11),WN1(499),WN2(499)
COMMON/JUK4/ WTL2(11),WBL2(11),WOL2(11),WNL2(11)

C agpa 09/10/01 QNSO(I) added to output solar radiation in main program
C
DIMENSION JFIRST(4),NX(4),MCJ(3),NQLH(4),IDTSAVE(4)
DIMENSION JFIRST(4),NX(4),MCJ(3),NQLH(4),IDTSAVE(4),QNSO(500)
DATA IDTSAVE/4*0/,ipr/0/
------------------------------------------------------------------------
C agpa 09/10/01 Added an output files for solar radiation and shade factor
C Four outfiles, one for each of four nodes. Output is a time series
C OPEN SOLAR RADIATION OUTPUT FILE Solar.out
OPEN(28,FILE='Solar1.out ',STATUS='unknown')
WRITE(28,')') ' ***********************************************'
WRITE(28,')') ' *  Solar Radiation Output for RQUAL           *'
WRITE(28,')') ' * SIM Hr = simulation hour,RMI = River Mile   *'
WRITE(28,')') ' * SHSOL = shade reduction factor,            *'
WRITE(28,')') ' * EBH = effective bank height,             *'
WRITE(28,')') ' * RS = shade reduction, QNS = reduced solar *
WRITE(28,')') ' * SWS = incoming solar (kcal/m2-s)         *'
WRITE(28,')') ' ***********************************************'
WRITE(28,')') 'hr','mi','','m','','kcal/m2-s','kcal/m2-s','C'
OPEN(29,FILE='Solar3.out ',STATUS='unknown')
WRITE(29,')') ' ***********************************************'
WRITE(29,')') ' *  Solar Radiation Output for RQUAL           *'
WRITE(29,')') ' * SIM Hr = simulation hour,RMI = River Mile   *'
WRITE(29,')') ' * SHSOL = shade reduction factor,            *'
WRITE(29,')') ' * EBH = effective bank height,             *'
WRITE(29,')') ' * RS = shade reduction, QNS = reduced solar *
WRITE(29,')') ' * SWS = incoming solar (kcal/m2-s)         *'
WRITE(29,')') ' ***********************************************'
WRITE(29,')') 'hr','mi','','m','','kcal/m2-s','kcal/m2-s','C'
OPEN(30,FILE='Solar5.out ',STATUS='unknown')
WRITE(30,')') ' ***********************************************'
WRITE(30,')') ' *  Solar Radiation Output for RQUAL           *'
WRITE(30,')') ' * SIM Hr = simulation hour,RMI = River Mile   *'
WRITE(30,')') ' * SHSOL = shade reduction factor,            *'
WRITE(30,')') ' * EBH = effective bank height,             *'
WRITE(30,')') ' * RS = shade reduction, QNS = reduced solar *
WRITE(30,')') ' * SWS = incoming solar (kcal/m2-s)         *'
WRITE(30,')') ' ***********************************************'
WRITE(30,')') 'hr','mi','','m','','kcal/m2-s','kcal/m2-s','C'
OPEN(31,FILE='Solar11.out ',STATUS='unknown')
WRITE(31,')') ' ***********************************************'
WRITE(31,')') ' *  Solar Radiation Output for RQUAL           *'
WRITE(31,')') ' * SIM Hr = simulation hour,RMI = River Mile   *'
WRITE(31,')') ' * SHSOL = shade reduction factor,            *'
WRITE(31,')') ' * EBH = effective bank height,             *'
WRITE(31,')') ' * RS = shade reduction, QNS = reduced solar *
WRITE(31,')') ' * SWS = incoming solar (kcal/m2-s)         *'
WRITE(31,')') ' ***********************************************'
WRITE(31,')') 'hr','mi','','m','','kcal/m2-s','kcal/m2-s','C'
799 FORMAT(8A10)
------------------------------------------------------------------------
c agpa 9/13/01 added new variable IRS to added SHSOL on both banks
c READ(5,1011)PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE,pdc,pdcx
c WRITE(31,')') ' PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE='
c WRITE(60,1013)PRT,IPLT,THET,TSI,IPROC,PLT,ROUTE=
C agpa 9/17/01 added new variable IEBH as flag to turn on ability to enter l/r bank ebh
c agpa 9/18/01 went back to one control variable (IRS)
READ(5,1011)PRT, IPLT, THET, TSI, IPROC, PLT, ROUTE, pdc, pdcx, IRS
WRITE(60,'(A)') ' PRT, IPLT, THET, TSI, IPROC, PLT, ROUTE, IRS='
WRITE(60,1013)PRT, IPLT, THET, TSI, IPROC, PLT, ROUTE, IRS

s agpa 9/18/01 took out IEBH, and reverted back to one control variable for new logic (IRS)
c
READ(5,1011)PRT, IPLT, THET, TSI, IPROC, PLT, ROUTE, pdc, pdcx, IRS, IEBH
c
WRITE(60,'(A)') ' PRT, IPLT, THET, TSI, IPROC, PLT, ROUTE, IRS, IEBH='
WRITE(60,1013)PRT, IPLT, THET, TSI, IPROC, PLT, ROUTE, IRS, IEBH

IF(PLT.EQ.0.0)PLT=PRT
C
IF(PRT.GE.DTHR)GO TO 3
WRITE(60,'(A)') ' PRT, DTHR='
WRITE(60,3232)PRT,DTHR
3232 FORMAT(/' ERROR...PRT<DT  PRT=',F6.3,' DT=',F6.3)
GO TO 9999
3 CONTINUE
IF(PLT.GE.DTHR)GO TO 4
WRITE(60,'(A)') ' PRT, DTHR='
WRITE(60,3332)PLT,DTHR
3332 FORMAT(/' ERROR...PLT<DT  PLT=',F6.3,' DT=',F6.3)
GO TO 9999
4 CONTINUE
C
C
IF(THET.EQ.0.0)THET=0.5
IF(TSI.EQ.0.0)TSI=1.0
C
READ(5,1001)(ALPHX(J),J=1,NXSEC)
WRITE(60,7211)NXSEC,(ALPHX(J),J=1,5)
7211 FORMAT(I5,5F8.2)
C
READ SHADING FACTOR DATA
C PHILATITUDE, DECIMAL DEG
C ALON—LONGITUDE, DECIMAL DEG
C TZM—TIME ZONE MERIDIAN, DEG (TZM CHANGES EVERY 15 DEGREES
C WEST OF 0 DEGREES AT GREENWICH. WE ARE IN TIME ZONE
C MERIDIAN AREA 75, WHICH APPLIES TO AREA BETWEEN
C LONGITUDES 75 AND 90
READ(5,1001) PHIL, ALON, TZM, TFOG
IF(TFOG.EQ.0.0) TFOG=10.
C
C COMPUTE TIME ZONE MERIDIAN FROM LONGITUDE (I.E., IGNORE INPUT TZM)
MTZ=IFIX(ALON)/15
TZM=15.*FLOAT(MTZ)
WRITE(60,'(A)') ' PHIL, ALON, TZM, TFOG='
WRITE(60,2011) PHIL, ALON, TZM, TFOG
READ(5,1001) (AZ(I),I=1,NXSEC)
WRITE(60,2011) (AZ(I),I=1,NXSEC)
READ(5,1001) (BW(I),I=1,NXSEC)
WRITE(60,2011) (BW(I),I=1,NXSEC)
c
READ(5,1001) (EBH(I),I=1,NXSEC)
WRITE(60,2011) (EBH(I),I=1,NXSEC)
c
READ(5,1001) (EBHL(I),I=1,NXSEC)
WRITE(60,2011) (EBHL(I),I=1,NXSEC)
c
READ(5,1001) (EBHR(I),I=1,NXSEC)
WRITE(60,2011) (EBHR(I),I=1,NXSEC)
c
agpa 9/17/01 flag turns on logic to read in EBH for l/r banks
C
IF (IEBH.eq.0) THEN
READ(5,1001) (EBH(I),I=1,NXSEC)
WRITE(60,1011) (EBH(I),I=1,NXSEC)
ELSE IF (IEBH.eq.1) THEN
READ(5,1001) (EBHL(I),I=1,NXSEC)
WRITE(60,1011) (EBHL(I),I=1,NXSEC)
READ(5,1001) (EBHR(I),I=1,NXSEC)
WRITE(60,1011) (EBHR(I),I=1,NXSEC)
c  ENDIF

c agpa 9/13/01 READ SHSOL FOR LEFT AND RIGHT BANK IF IRS=1, ELSE CONTINUE
c IF (IRS .EQ. 1) THEN
  c READ(5,1001) (SHSOLL(I),I=1,NXSEC)
  c WRITE(60, (A)) 'SHSOLL = '
  c WRITE(60,(1001)) (SHSOLL(I),I=1,NXSEC)
  c READ(5,1001) (SHSOLR(I),I=1,NXSEC)
  c WRITE(60, (A)) 'SHSOLR = '
  c WRITE(60,(1001)) (SHSOLR(I),I=1,NXSEC)
ENDIF

C agpa 9/18/01 new input format for two bank shading input
C flag, IRS now opens a separate input file Unit=4
IF (IRS.eq.0) THEN
  READ(5,1001) (EBH(I),I=1,NXSEC)
  WRITE(60,1012) (EBH(I),I=1,NXSEC)
ELSE IF (IRS.eq.1) THEN
  OPEN(4,FILE='shade.ris',STATUS='OLD')
  WRITE (60,'(5A8)') 'RMI','EBHL','EBHR','SHSOLL','SHSOLR'
  WRITE (60,'(5A8)') '','ft','ft','',''
  DO J=1,NXSEC
    READ(4,'(8X,9F8.0)') EBHL(J),EBHR(J),SHSOLL(J),SHSOLR(J)
    WRITE(60,'(5F8.2)') RMI(J),EBHL(J),EBHR(J),SHSOLL(J),SHSOLR(J)
  ENDDO
ENDIF

C CHANGE BW,EBH UNITS FROM FT TO METERS
DO 12 J=1,NXSEC
  BW(J)=0.3048*BW(J)
  EBH(J)=0.3048*EBH(J)
C agpa 9/18/01 if IRS = 1 need to convert l/r bank
DO 12 J=1,NXSEC
  IF (IRS.eq.1) THEN
    BW(J)=0.3048*BW(J)
    EBHL(J)=0.3048*EBHL(J)
    EBHR(J)=0.3048*EBHR(J)
  ELSE IF (IRS.eq.0) THEN
    BW(J)=0.3048*BW(J)
    EBH(J)=0.3048*EBH(J)
  ENDIF
12 CONTINUE

C 1012 FORMAT(/(5F12.0))
C
C READ WIND COEFFICIENTS AND THERMAL PROPERTIES OF CHANNEL BED
C EVAP=(AA+BB*WIND)*(ES-EA)
C WHERE AA=M/(S MB)
C           BB=1/MB
C           ES,EA = MB
C XL = THICKNESS OF UPPER BED (CM)
C XL2 = THICKNESS OF LOWER BED (CM)
C DIF = THERMAL DIFFUSIVITY OF BED (SQ CM/HR)
C CV = HEAT STORAGE CAPACITY OF BED (CAL/ CU CM DEG C)
C agpa 9/13/01 commented out to add l/r bank shade logic
C READ(5,1001)AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHSOL,SHDBT
C SET DEFAULTS
C WRITE(60, (A)) ' AA, BB, XL, XL2, DIF, CV, BETW, BEDALB, SHSOL, SHDBT='
C WRITE(60,(1001)) AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHSOL,SHDBT
C IF((SHSOL.EQ.0.0)) SHSOL=0.2
C IF((SHDBT.GT.1.0)) SHDBT=1.0
C agpa 9/13/01 added to include IRS=1 for l/r bank shading
IF (IRS.EQ.0) THEN
  READ(5,1001)AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHSOL,SHDBT
C SET DEFAULTS
  WRITE(60, (A)) ' AA, BB, XL, XL2, DIF, CV, BETW, BEDALB, SHSOL, SHDBT='
  WRITE(60,(1001)) AA,BB,XL,XL2,DIF,CV,BETW,BEDALB,SHSOL,SHDBT
IF(SHSOL.EQ.0.0) SHSOL=0.2
ELSE IF (IRS.EQ.1) THEN
READ (5, 1001) AA, BB, XL, XL2, DIF, CV, BETW, BEDALB, SHDBT
WRITE (60, ' (A) ') ' AA, BB, XL, XL2, DIF, CV, BETW, BEDALB, SHDBT='
WRITE (60, 1111) AA, BB, XL, XL2, DIF, CV, BETW, BEDALB, SHDBT
ENDIF

--------------------------------------------------------------------------------
C
C  COMPUTE INITIAL SHADING FACTORS
C
C  IDAY=0 sets the flag for first time through the new shading logic
C  JOLD = julian date of previous time step, initialized at 999
C
IDAY=0
JOLD=999
CALL CRS(HOURJ,W1,RS1,RDBT1,CLD1)
C
C  INITIALIZE HEAT SOURCE, SINK TERMS
C
WRITE (60, 3335)
C3335 FORMAT(' CALLING TEMPDK')
CALL TEMPDK(A1,W1,CLD1,DBT1,DPT1,APR1,WND1,SWS1,RS1,RDBT1,
XT1,TDK1,T1)
CALL BEDC(IDT,T1)
CALL BEDFL2(T1,A1,W1,DTHR)
--------------------------------------------------------------------------------
C  BIG TIME LOOP FOR EACH DT
C
SIMHR=0.0
5 IDT=IDT+1
HOURJ=HOURJ+DT/3600.
C SIMHR=HOURJ-BHOURJ
SIMHR=SIMHR+DT/3600.
C WRITE(*,2789) SIMHR
C2789 FORMAT(' BEGINNING SIMULATION HOUR',F8.3)
--------------------------------------------------------------------------------
C COMPUTE SHADING FACTORS
C
WRITE (60, 3335)
C3335 FORMAT(' CALLING TEMPDK')
CALL TEMPDK(A2,W2,CL2,DB2,DP2,AP2,WI2,SW2,RS2,
RDBT2,T1,TDK2,TP2)
CALL BEDC(IDT,T1)
C
C COMPUTE TEMPERATURES FOR NEW DT (INTEGRATE)
C
WRITE (60, 3339)
C3339 FORMAT(' CALLING TEMP')
c agpa 09/11/01 added temperature to solar output file
WRITE(28,899) SIMHR, RMI(1), SHSOLA(1), EBH(1), RS2(1), QNSO(1),
  2SW2/3600., T2(1)
WRITE(29,899) SIMHR, RMI(3), SHSOLA(3), EBH(3), RS2(3), QNSO(3),
  2SW2/3600., T2(3)
WRITE(30,899) SIMHR, RMI(5), SHSOLA(5), EBH(5), RS2(5), QNSO(5),
  2SW2/3600., T2(5)
WRITE(31,899) SIMHR, RMI(11), SHSOLA(11), EBH(11), RS2(11), QNSO(11),
  2SW2/3600., T2(11)
899 FORMAT (8F10.3)
------------------------------------------------------------------
C**************************************************************************
C SUBROUTINE CRS(HOURJ,W,RS,RDBT,CLD)
C**************************************************************************
C SUBROUTINE FOR COMPUTING ABSORPTION COEFFICIENTS ON A RIVER
C VARIABLE DEFINITIONS
C RS(I)=ABSORPTION COEFFICIENT FOR NODE I
C RDBT(I)=DRYBULB TEMPERATURE REDUCTION FRACTION FOR NODE I
C SHSOL=FRACTION OF SOLAR ABSORBED BY WATER IN THE SHADE (FORMERLY 0.2)
C SHDBT=FRACTION OF DBT-DPT BY WHICH DBT IS REDUCED IN THE SHADE
C EBH(I)=TREE HEIGHT ON EFFECTIVE BARRIER HEIGHT FOR EACH SUBREACH,M
C AZ(I)=AZIMUTH OF RIVER SUBREACH,DEGREES
C AZS=AZIMUTH OF SUN,DEGREES
C BW(I)=BANK WIDTH,DISTANCE FROM TREES TO WATERS EDGE, METERS
C THE= ANGLE BETWEEN SUN AND STREAM AXIS, DEGREES
C BET= ANGLE BETWEEN SUN AND NORMAL TO THE STREAM AXIS, DEGREES
C ELEV=ELEVATION OF THE SUN, DEGREES
C XN= NORMAL DISTANCE FROM TREES TO EDGE OF SHADOW, METERS
C X= DISTANCE FROM TREES TO SHADOW ALONG A BEAM OF LIGHT, METERS
C DEL=DECLINATION OF THE SUN, DEGREES
C HA= HOUR ANGLE FROM ZENITH TO SUN, DEGREES
C HAD= HOUR ANGLE AT MIDNIGHT, DEGREES
C PHI= LATITUDE OF RIVER, DEGREES
C ALON= LONGITUDE OF RIVER, DEGREES
C TZM= TIME ZONE MERIDIAN
C JDAT= JULIAN DATE FOR WHICH SHADING COMPUTATIONS ARE MADE
C DR= DEGREE TO RADIAN CONVERSION
C
C agpa 09/13/01 four parameters added to add shading from either/both banks
C SHSOLL(I)=transmittance factor for left bank
C SHSOLR(I)=transmittance factor for right bank
C SHSOLA(I)=transmittance factor input if there is just one number for a whole system
C IDAY = flag indicating the first time through new shading logic each day
C iday=0 first time through, iday=1 not first time through
C JOLD = julian date of previous time step, initialized as 999 in main program
C FB = first bank to be shaded that day, RB=right, LB=left
C IZ = flag, 1=Az<AZS, 0=AZ>AZS at first timestep after ELEV>1.5
C IRS = flag to turn on logic for both banks (irs=1)
REAL NK20
DIMENSION A(4),B(4),RS(500),RDBT(500),W(500)
C agpa 9/17/01 modified ebh to accomodate both banks
C COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG
C COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG,EBHL(500),
C XEBHR(500), IEBH
C agpa 9/18/01 IEBH removed
C COMMON/CR/ EBH(500),AZ(500),BW(500),PHI,ALON,TZM,TFOG,EBHL(500),
C XEBHR(500)
C agpa 9/13/01 added IRS
C COMMON/RA/EXCO, HMAC, AA, BB, NXSEC, THR, THB, BK20, THS, SK20(500),
C XTHN, XK20, THPR, I2K2EQ, BS20, BETW, XL, XL2, DIF, CV, BEDALB, SHSOL, SHDBT
C COMMON/RA/EXCO, HMAC, AA, BB, NXSEC, THR, THB, BK20, THS, SK20(500),
C XTHN, XK20, THPR, I2K2EQ, BS20, BETW, XL, XL2, DIF, CV, BEDALB, SHSOL, SHDBT,
C XIRS, SHSOLL(500), SHSOLR(500), SHSOLA(500), IDAY, JOLD
C agpa 9/14/01 new local variables for both bank shading logic
INTEGER::IZ
CHARACTER::FB*2

DATA A/1.18,2.20,0.95,0.35/
DATA B/0.77,0.97,0.75,0.45/
DR=3.14159/180.0
HOURD=AMOD(HOURJ,24.)
DHA=DR*(HOURD*360./24.)
PHI=PHI*DR
JDAT=IFIX(HOURJ)/24+1
DEL=DR*23.45*COS(6.2832*(172.0-FLOAT(JDAT))/365.0)
HAD=(180.0+ALON-TZM)*DR
SDSP=SIN(DEL)*SIN(PHI)
CDCP=COS(DEL)*COS(PHI)
HA=HAD-DHA
S=SDSP+CDCP*COS(HA)
ELEV=ASIN(S)/DR
AZS=0.0
IFCLUD.LT.0.05)N=1
IFCLUD.GE.0.05.ANDCLUD.LT.0.5)N=2
IFCLUD.GE.0.5.ANDCLUD.LT.0.95)N=3
IFCLUD.GE.0.95)N=4
IF(ELEV.GT.1.5)RSM=1.0-A(N)*(1.0/ELEV**B(N))
IF(ELEV.GT.1.5)AZS=ACOS((SIN(DEL)-SIN(ELEV*DR)*SIN(PHI))/(COSX(ELEV*DR)*COS(PHI)))
IF(HA.LT.0.0)AZS=360.0*DR-AZS
WRITE(60,3001) HA,S,ELEV,RSM,AZS,DEL,HAD,SDSP,CDCP
C3001 FORMAT(4H STEP,9E12.4)
C
DO 12 I=1,NXSEC
  C agpa 9/14/01 setup SHSOLA array with either SHSOL, or l/r bank information
  IF(IRS.eq.0) SHSOLA(I)=SHSOL
  ELSE IF(IRS.eq.1) SHSOLA(I)=SHSOLL(I)
  ELSE IF(JDAT.ne.JOLD) IDAY=0
  IF(ELEV.gt.1.5) !Set first bank
     IF(IDAY.eq.0) IF(AZ(I).gt.AZS/DR) IF(AZ(I).gt.(AZS/DR+180.0)) THEN
        FB='RB'
        IZ=0
     ELSE
        FB='LB'
     ENDIF
     ELSE
        FB='RB'
        IZ=1
     ENDIF
     IDAY=1
  ENDIF
  !Fill SHSOLA(I) array with appropriate bank transmittance factor
  C agpa 9/18/01 added EBHL/EBHR to the new shading logic
  IF(IDAY.eq.1) THEN IF(FB.eq.'LB') THEN
     IF(AZ(I).gt.AZS/DR) THEN
        SHSOLA(I)=SHSOLR(I)
        EBH(I)=EBHR(I)
     ELSE
        SHSOLA(I)=SHSOLL(I)
        EBH(I)=EBHL(I)
     ENDIF
  ELSE IF(FB.eq.'RB') THEN
     IF(IZ.eq.0) THEN
        IF(AZ(I)-180.0.gt.AZS/DR) THEN
           SHSOLA(I)=SHSOLR(I)
           EBH(I)=EBHR(I)
        ELSE
           SHSOLA(I)=SHSOLL(I)
           EBH(I)=EBHL(I)
        ENDIF
     ELSE
        IF(IZ.eq.0) THEN
           IF(AZ(I)-180.0.gt.AZS/DR) THEN
              SHSOLA(I)=SHSOLR(I)
              EBH(I)=EBHR(I)
ENDIF
ELSE IF (IZ.eq.1) THEN
IF (AZ(I)+180.0.gt.AZS/DR) THEN
SHSOLA(I)=SHSOLR(I)
EBH(I)=EBHR(I)
ELSE
SHSOLA(I)=SHSOLL(I)
EBH(I)=EBHL(I)
ENDIF
ENDIF
ENDIF
ENDIF
ELSE
!River is fully shaded before sunrise, i.e. transmittance = 0.0
!agpa 9/17/01 make shsola() before sunrise the average of shsoll/shsolr
to represent shading influence on diffusive solar radiation
SHSOLA(I)=0.2
SHSOLA(I)=(SHSOLL(I)+SHSOLR(I))/2.
!agpa 9/18/01 make EBH(I) before sunrise the average of ebhl/ebhr
EBH(I)=(EBHL(I)+EBHR(I))/2.
ENDIF
ENDIF
WI=W(I)*0.3048
IF(ELEV.GT.1.5) GO TO 1
C     RS(I)=0.2
C  MAKE FRAC OF SOLAR ABSORBED IN SHARED AREA AN INPUT VARIABLE
C  RS(I)=SHSOL
C agpa 9/14/01 make frac of solar absorbed/transmittance an array
RS(I)=SHSOLA(I)
C  FRAC OF DBT-DPT TO REDUCE DBT BY IN SHARED AREA (INPUT VARIABLE)
RDBT(I)=SHDBT
GO TO 10
1 THE=ABS(AZS-AZ(I)*DR)
THE=THE-180.*DR
BET=ABS(THE-90.0*DR)
X=EBH(I)/TAN(ELEV*DR)
IF(COS(BET).GT.0.01) GO TO 2
RS(I)=RSM
RDBT(I)=0.0
GO TO 10
2 XN=X*COS(BET)
IF(XN.GE.BW(I)) GO TO 3
RS(I)=RSM
RDBT(I)=0.0
GO TO 10
3 IF(XN.LE.(BW(I)+WI)) GO TO 4
C     RS(I)=0.2
C  agpa 9/14/01 RS(I)=SHSOL
RS(I)=SHSOLA(I)
RDBT(I)=SHDBT
GO TO 10
C   4 RS(I)=RSM*(WI+BW(I)-XN)/WI+0.2*(XN-BW(I))/WI
C  agpa 9/14/01  4 RS(I)=RSM*(WI+BW(I)-XN)/WI+SHSOL*(XN-BW(I))/WI
4 RS(I)=RSM*(WI+BW(I)-XN)/WI+SHSOLA(I)*(XN-BW(I))/WI
RDBT(I)=0.0*(WI+BW(I)-XN)/WI+SHDBT*(XN-BW(I))/WI
C WRITE(60,3002)I,THE,BET,X,XN,W(I),RS(I)
C3002 FORMAT(5H GRID,I5,9E13.2)
C  10 IF(HOURD.LT.TFOG) RS(I)=0.2
C NOTE: If ELEV<=1.5 then SHSOLA(I) is an average of left and right bank,
C       IF ELEV>1.5 then SHSOLA(I) is assigned as left or right bank
10 IF(HOURD.LT.TFOG) RS(I)=SHSOLA(I)
IF(HOURD.LT.TFOG) RDBT(I)=SHDBT
IF(I.EQ.35)WRITE(60,3001)HOURD,HA,ELEV,RSM,AZS,THE,BET,X,XN,RS(I)
C3001 FORMAT(10F8.3)
12 CONTINUE
C WRITE(60,5050)JDAT,TZM,PHI,ALON
C5050 FORMAT(1H0,39X,'ABSORPTION COEFFICIENTS FOR SOLAR RADIATION',38X,
C X //,53X,'JULIAN DAY ','13,2X','TIME ZONE ','1F4.1,' DEGREES',29X,/,
C    X       'LATITUDE=',1F5.1,' LONGITUDE=',F5.1,' DEGREES',27X,,/
C    X       ' GRID   EBH   BW   AZIMUTH  ***************************************************',
C    X       '****HOUR******************************************************',/
C    X       8X,'METER  METER  DEGREE',4X,'5',5X,'6',5X,'7',5X,'8',5X,'9',4X,
C    X       '10',4X,'11',4X,'12',4X,'13',4X,'14',4X,'15',4X,'16',4X,'17
C    X       '18',4X,'19',3X)
C     DO 11 I=1,NXSEC
C       WRITE(60,3000)I,EBH(I),BW(I),AZ(I),RS(I)
C3000 FORMAT(' ',I4,F9.1,F7.1,F8.1,1X,15F6.3)
11 CONTINUE
C agpa 9/14/01 save previous time step julian date for next pass
JOLD=JDAT

RETURN
C    DEBUG UNIT(98),SUBTRACE
END
APPENDIX C: DATA

C.1 CHANNEL GEOMETRY

Table A.2.1 contains geometry data gathered for each of 25 sites along the Shasta River. Fifty sites were initially chosen at even intervals, ten sites in each of the five sub-reaches. Due to time constraints and lack of access, data were obtained at only 25 of those sites. Data collected includes top width, maximum depth of the cross-section, angle of the right and left side slopes, height from the water surface to the top of the bank on the right and left sides. Protocol for collecting these data can be found in Appendix B.

Table C.1 Channel geometry data for 25 sampling sites

<table>
<thead>
<tr>
<th>ID</th>
<th>River Mile</th>
<th>Top Width (ft)</th>
<th>Max Depth (ft)</th>
<th>R SS</th>
<th>L SS</th>
<th>Right Bank (ft)</th>
<th>Left Bank (ft)</th>
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</table>
**C.2 Flow Data**

This appendix contains monthly flow plots of hourly-averaged data for each of the six pressure transducer sites. They are ordered downstream to upstream. Note that there is a different scale for each site.

![Graph of flow data for Shasta River at Anderson Grade Road: June-Oct. 2001](image)

**Figure C.1** Hourly flow data for Shasta River at Anderson Grade Road: June-Oct. 2001 (a) June-October (b) June (c) July
Figure C.1 cont. Hourly flow data for Shasta River at Anderson Grade Road: June-Oct. 2001 (d) August (e) September (f) October
Figure C.2 Hourly flow data for Shasta River at Montaque-Grenada Road (DWR Weir): June-Oct. 2001 (a) June-October (b) June (c) July
Figure C.2 cont. Hourly flow data for Shasta River at Montaque-Grenada Road (DWR Weir): June-Oct. 2001 (d) August (e) September (f) October
Figure C.3 Hourly flow data for Shasta River at Highway A-12: June-Oct. 2001 (a) June-October (b) June (c) July
Figure C.3 cont. Hourly flow data for Shasta River at Highway A-12: June-Oct. 2001 (d) August (e) September (f) October
Figure C.4 Hourly flow data for Shasta River below the Grenada Irrigation District Pumps: July-Oct. 2001  (a) July-October (b) July (c) August

Note that the pressure transducer was not deployed until July.
Figure C.4 cont. Hourly flow data for Shasta River below the Grenada Irrigation District Pumps: July-Oct. 2001 (d) September (e) October
Figure C.5 Hourly flow data for Parks Creek above the confluence with the Shasta River: June-Oct. 2001 (a) June-October (b) June (c) July
Figure C.5 cont. Hourly flow data for Parks Creek above the confluence with the Shasta River: June-Oct. 2001 (d) August (e) September (f) October
Figure C.6 Hourly flow data for Shasta River above Parks Creek: June-Sept. 2001
(a) June-October (b) June (c) July

Note that there is no data for October.
Figure C.6 cont. Hourly flow data for Shasta River above Parks Creek: June-Sept. 2001 (d) August (e) September
C.3 W ATER T EMPERATURE D ATA

This appendix contains monthly temperature plots of hourly data for each of the nine temperature logger sites. They are ordered downstream to upstream.

Figure C.7 Shasta River at the Mouth: hourly water temperature with a daily averaged trendline. Plot (a) spans the entire study period from May 1, 2001 to October 31, 2001, plots (b) through (g) are monthly.
Figure C.7 cont. Shasta River at the Mouth: hourly water temperature with a daily averaged trendline.
Figure C.8 Shasta River at Anderson Grade Road: hourly water temperature with a daily averaged trendline. Plot (a) spans the entire study period from May 1, 2001 to October 31, 2001, plots (b) through (g) are monthly.
Figure C.8 cont. Shasta River at Anderson Grade Road: hourly water temperature with a daily averaged trendline.
Figure C.9 Shasta River at Highway 3: hourly water temperature with a daily averaged trendline. Plot (a) spans the entire study period from May 1, 2001 to October 31, 2001, plots (b) through (e) are monthly.

There are no monthly plots for May or June due to lack of data.
Figure C.9 cont. Shasta River at Highway 3: hourly water temperature with a daily averaged trendline.
Figure C.10 Shasta River at Montague-Grenada Road (DWR Weir): hourly water temperature with a daily averaged trendline. Plot (a) spans the entire study period from May 1, 2001 to October 31, 2001, plots (b) through (g) are monthly.
Figure C.10 cont. Shasta River at Montague-Grenada Road (DWR Weir): hourly water temperature with a daily averaged trendline.
Figure C.11 Shasta River at Highway A-12: hourly water temperature with a daily averaged trendline. Plot (a) spans the entire study period from May 1, 2001 to October 31, 2001, plots (b) through (g) are monthly.
Figure C.11 cont. Shasta River at Highway A-12: hourly water temperature with a daily averaged trendline.
Figure C.12 Shasta River below the Grenada Irrigation District Pumps: hourly water temperature with a daily averaged trendline. Plot (a) spans the entire study period from May 1, 2001 to October 31, 2001, plots (b) through (g) are monthly.
Figure C.12 cont. Shasta River below the Grenada Irrigation District Pumps: hourly water temperature with a daily averaged trendline.
Figure C.13 Shasta River at Louie Road: hourly water temperature with a daily averaged trendline. Plot (a) spans the entire study period from May 1, 2001 to October 31, 2001, plots (b) through (f) are monthly. There is no Louie Road data for October due to equipment failure.
Figure C.13 cont. Shasta River at Louie Road: hourly water temperature with a daily averaged trendline.
Figure C.14 Parks Creek: hourly water temperature with a daily averaged trendline. Plot (a) spans the entire study period from May 1, 2001 to October 31, 2001, plots (b) through (g) are monthly.
Figure C.14 cont. Parks Creek: hourly water temperature with a daily averaged trendline.
Figure C.15 Shasta River above Parks Creek: hourly water temperature with a daily averaged trendline. Plot (a) spans the entire study period from May 1, 2001 to October 31, 2001, plots (b) through (g) are monthly.
Figure C.15 cont. Shasta River above Parks Creek: hourly water temperature with a daily averaged trendline.
APPENDIX D: PROTOCOLS FOR FIELDWORK

This section contains field protocols used to gather geometric, vegetation, flow, and temperature data.

D.1 SHASTA RIVER PROTOCOL FOR GEOMETRIC AND VEGETATION DATA COLLECTION

Objective

Determine the general shape of the cross-section and tree height at sampling sites along the Shasta River. Important parameters associated with the shape of the cross-section include bankfull width, top width, and bank height.

Method

Locate ten equally spaced sites in each of the five study reaches. Attempt to visit each site to quantify the cross-sectional shape of the river and tree height. There may be difficulties with access to the sites, but all attempts should be made to get to the proposed site.

Equipment

The equipment required to measure tree height and characterize the cross-section included a Brunton Compass or another device to measure angle to top of tree, measuring tape, 25-foot staff, clipboard, data collection sheets, permanent ink pens, digital camera, gloves, watch, maps, binoculars, and two stakes.

The following PROTOCOL should take no longer than 20 minutes per site. Note that this work requires two field staff.

Site Characterization Protocol

Arrive at designated site. By looking at the site choose a cross-section that looks to have geometry representative of the reach. Person A crosses the stream with the tape
and staff while Person B fills out the data sheet with the date, time, weather, reach number, river mile, location description, and property owner. Persons A and B determine bankfull height on each bank (refer description below). While Person A is tying the tape at bankfull height, Person B sketches a cross-section of the river on the data sheet. Be sure to label right and left bank. Person A reads to Person B bank height, x-distance to water surface edge, x-distance to the top of bank, and 3 depths and respective distances in the channel. Estimate the bank slope (i.e. vertical, about 50-60, 45, 30, <10). Be sure to record numbers in the table and to include them on the sketch. While Person A is untying the tape, Person B takes pictures up and downstream. Estimate or measure tree height for a few trees on each bank (see below). Record the species, angle, distance or height, the bank and method. If there are no trees or bulrush exactly at the cross-section, but there is vegetation just up or downstream, measure that vegetation. Circle the species present in the table and estimate the percent of each species. Fill in the vegetation description below the cross-section. Write at the bottom of sheet the presence of bulrush (Is it continuous on both sides? What is the height? Can it significantly shade the river?) Make final notes on the vegetation that can be seen from the site up and downstream (“mostly SBW with only one or two Arroyos on both banks” or “right bank is all SBW and the left bank is lined with bulrush but no trees all the way to the next meander”). These types of observations can also be marked on the map of sites.

**Definitions**

**Bankfull width**

Bankfull width is the width of the stream when it is about to inundate the active floodplain (the floodplain used every couple of years). Clues used to identify this width are: change in slope and vegetation on bank. Bankfull width is used to denote the carved out
geometry of the river. It will be an upper limit for the geometry. Hence, if there is uncertainty between two heights, record the higher one.

**Bank height**

Bank height is the distance from the water surface to the top of the bank. This is measured using the staff.

**Top width**

The width of the water surface the day of observation.

**Vegetation Height Protocol**

If the height of the trees/bulrush is under 25 feet then Person A can take the staff, fully extend it standing next to the tree and Person B can use the binoculars to read off the height. When this is not possible, a Brunton or another angle measuring device should be used.

The Brunton measures vertical angles to accuracies better than 1 degree.

1. Measure the distance between the observer and the tree.
2. Site the top of the tree and measure the vertical angle with the Brunton. (You can read the angle in percent or degrees.)
3. Height = (distance to tree) x (% grade/100 or tangent of the angle)

Make sure to note the height of the person taking the angle. The angle needs to be <45 degrees.
D.2 Shasta River Flow Study Protocol

Objective

Define synoptic flow regimes of the Shasta River throughout the summer and fall season to determine hydrologic characteristics of the river in response to diversions and, as feasible, return flows.

Method

To collect continuous 15 minute flow data, remote logging pressure transducers are deployed at 6 locations in the Shasta River. Flow measurements are made at semi-monthly intervals to rate each section such that continuous records and a range of flows are obtained. These protocols outline the methods for deployment of pressure transducers and scheduled flow measurements throughout the field season.

Equipment

Equipment used for flow measurement includes remote logging pressure transducers, associated hardware and software, staff gages, a flow meter consisting of a velocity measuring device and staff, a tape measure, and field log sheets and notebook. Field logs are used to record observations, field conditions, and any other items of note. Flow data sheets are used to record velocity measurements for flow calculations.

The pressure transducers used are water level loggers (WL15) produced by Global Water Instrumentation, Inc. The WL15 has a range of 0-3 feet. This pressure transducer/data logger system has an accuracy of 0.2% of the full scale over a temperature range, or 0.1% of full scale at a constant temperature. The flow meter used is a Flo-Mate Portable Flowmeter Model 2000 from Marsh-McBirney, Inc. The portable flow meter measures stream velocity at an accuracy of ±2% of the reading. It can measure a range from -0.5 to +20 ft/s (-0.15 to 6 m/s).
Locations (as listed in Table 3.5)

Pressure Transducer Deployment Protocol

Two configurations are possible for the deployment of the transducers. If the pressure transducer is of the weir stick configuration the unit is mounted on a vertical, non-flexile cable inserted directly into PVC pipe, attached to metal T-post, and driven into the riverbed. Pressure transducer units with 25’ cable are deployed in 2” PVC pipe, secured in a temporary stilling well. All sensors are placed perpendicular to the flow, on bottom of river channel. Logger operation is verified by connecting to a laptop computer in the field. All existing data files are deleted. Real-time data is set to log for approximately 3 minutes to test depth readings. Data range of test data is recorded in logbook. If unit operates satisfactorily, unit is set to log data at 15-minute intervals.

Data Download and Flow Measurement Protocol

Data download and flow measurement protocol includes download of pressure transducer data, selection of cross-sections, flow measurement, and record keeping in the field. To provide a balance of useful data with time and budget constraints semi-monthly monitoring from June through October was determined adequate. These bi-weekly flows will be used to construct a stage-discharge curve for each location that will be employed to convert the data from the water level loggers to flows. Flow rating will coincide with downloading the pressure transducer data.

Data Download

Upon arrival at each site note field conditions (e.g. time, weather, observations). Make appropriate sketches of river as necessary. Take photos of site, upstream and downstream of rating section. Record date, time, and staff gage height. Download data
from logger. Record time of download. Save data to pre-established folders on disk, labeled RAW DATA – LOGGER. Make sure the data was downloaded correctly by opening the file. Inspect the logger for sign of bio-fouling, wear, etc. Use a toothbrush to gently clean the mesh screen on the sensor, using clean water (distilled, deionized in squeeze bottle); scrub mesh gently. Inspect the stilling well PVC. At least once per month (every other download period), or as determined by field conditions, replace the PVC in the river with clean length. Record date in field book when the pipe is replaced. Scrub the river pipe with river water and brush. Rinse. Take replaced pipe back to CDFG office; leave in sunlight to dry completely. Rinse with potable (e.g. city) water prior to redeployment in river. Obtain flow using flow measurement protocol below.

**Selection of Flow Monitoring Cross-Sections**

Selection of flow monitoring cross-sections requires inspection of the stream morphology under current and potential flow conditions. Cross-sections should be selected in areas of uniform flow, away from sharp bends and changes in slope, and without large boulders or other intrusions. The cross-section should be reduced to cells with widths less than 10 percent of the total cross-section. Cell velocities should be taken at depths consistent with that required of the equipment. Velocities should be averaged over a full period of 30 seconds. After determination of flow meter placement at cell, a full cycle of averaging should occur on the instrument.

Installation of staff gages should be done with care. The gage should be placed where it will be useful over a range of flows. Vandalism may be a concern with staff gages at certain locations. In such cases, more discrete measures may be used (e.g. can measure water surface from a defined benchmark on a bridge pier). Ideally, staff gages should be placed so they can be read from nearby shorelines such that wading is not necessary to determine flows.
Flow measurements should be made at all locations whether a staff gage is in place or not. A sufficient number of points are required to construct a rating curve. Limited flow measurements may compromise the usefulness of the staff gages.

**Flow Measurement**

Rate the same or a similar section of river each rating period. Set flow meter to average over a 30 second interval, note in field records if alternate setting is used. Establish cell unit size for flow measurement, either using 1.0’ increments as standard, or calculate the effective channel width and divide by 20, as per flow meter open channeling profile manual. No more than 10% of flow should pass through any single cell. At each cell, zero the display to reset the velocity calculating function. Record the average velocity of cell flow (ft/s), the depth of the flow meter (ft), the distance from the bank (ft), and cell width (ft).

**Record Keeping**

Data sheets should be completed prior to fieldwork. Information typically gathered for flow monitoring includes location, data, time, velocity and depth readings, velocity averaging period, sketch of the site (include aspect of river), a description of cross-section, and names of people involved in the data collection. If a staff gage is employed, the date it was installed and the gage reading should be included on the data sheet.
D.3 Shasta River Solar Radiation Measurement Protocol

Objective
Determine percent of incoming solar radiation that penetrates various types of vegetation along the Shasta River.

Method
Two devices are used to measure solar radiation. The LI200 (SOLBUD) is used to measure direct (unimpeded) solar radiation. SOLRAD is used to measure solar radiation underneath the tree canopy or other obstructions. The ratio of the two measurements will provide the percent of radiation penetrating the canopy. This is a key factor in determining the vegetative transmittance, a model input parameter.

Equipment
Equipment used for solar radiation measurements includes the LI200 solar pyranometer with adapter and HOBO logger, SOLRAD (CM3 pyranometer and CC20 logger) and carrying case, laptop computer (to launch the logger), four tripods, four nuts, four plates (three of the plates should have washers glued on them), duck tape, waiters, clipboard, data sheets, and campstool.

Locations
Locations for solar radiation measurements are chosen to maximize the variety and quality of vegetation at a site. Sites used in this study include the Shasta River at Montague-Grenada Road and the Shasta River downstream of Yreka-Ager Road.

Field Protocol at each Sampling Site
At each sampling site solar radiation will be measured under specified grades of shading, and direct solar radiation (no shading). The goal is to obtain radiation measurements every 20 minutes from 8 or 8:30am to 5 or 5:30pm to create a curve that will be compared to direct solar radiation. Three tripods will be used to form grade
curves, and the fourth tripod will be used to form the direct curve. Each value will be integrated over 5 minutes. Three to four “rounds” will be completed every hour. A round consists of measuring once at each grade for five minutes. Each round should take no more than 20 minutes.

After arriving at the site, first establish a location for the LI200 that will be in direct sunlight all day. Set up the LI200 following the protocol below. Locate three more sites that will be in shade for the entire day. If it is not possible to find a location that will be shaded all day then be prepared to move the station as the sun’s angle changes. If you need to move the tripod at any time note that in the margin or in the “notes” section. Be sure to describe the new location. Follow the SOLRAD protocol below for taking solar measurements underneath the canopy throughout the day.

**LI200 (SOLBUD) Protocol**

Set up a tripod in full sunlight. Launch the HOBO logger (with both channels active to log for one-minute intervals). Attach the plate without washers to the tripod with a nut. Place the sensor on top of the plate and tape the cord to the plate. Extend the cord placing the adapter and logger on the ground. Take the red cap off of the sensor. Note what time the logger way deployed and what time you take it down.

NOTE: If the sensor is dirty DO NOT clean sensor with a wipe containing ALCOHOL.

**SOLRAD (CM 3/ CC 20) Protocol**

The SOLRAD system consists of a CM3 pyranometer, a CC20 radiation indicator, and a leveling device. Three washers were glued to a metal socket plate in order to form a stable platform that could be secured to a tripod on which SOLRAD could be placed to measure solar radiation from a location in the stream.
Unpack SOLRAD and clean the pyranometer with a lens wipe or tissue. Attach SOLRAD to the leveling device with the two long screws provided. Attach the cable to the data logger. Attach the platforms to the tripods by placing the tripod screw through the hole in the corner of the socket plate and tightening it down with a nut. Identify the placement for the tripods. Set up the tripods. Set the leveling device on top of the platform, lining up the screws with the three washers in the platform. Level SOLRAD by turning the screws until the bubble is in the center of the black circle. You need only approximate the level. Sensitivity testing showed that if SOLRAD varied under 10 watts when the level was slightly off center. Turn on the logger. Choose the pyranometer as the measuring device. Set the logger to “integrate” the values with a “manual” reset. The logger will automatically begin measuring solar radiation. No time for calibration is needed. Stand at a distance of about 6 feet from the CM 3. Reset the logger manually by pressing the ‘+’ and ‘-’ buttons simultaneously for two seconds. Measure solar radiation for five minutes. At the end of five minutes reset the logger again. This will save the value in the memory. The memory will hold up to thirty values. Record in the field book the start time, stop time, the exact logging time to the second, integrated value (Whr/m2), the beginning W/m2 and ending W/m2 for that interval. Record any observations that might effect solar radiation (i.e. a cloud passing over the sun, the sun shining through a gap in the trees). Move to the next tripod and begin logging by resetting the logger. Repeat the logging steps listed above.

NOTE: The CC20 and HOBO loggers are not waterproof.

**Record Keeping**

Data sheets should be completed prior to fieldwork. Information gathered for solar radiation measurements includes location, date, time, a description of the site and placement of each tripod, names of people involved in the data collection, start/stop
times of each measurement, average solar radiation in Whr/m², and instantaneous solar radiation in W/m².

**Data Management**

The data acquired should be entered into spreadsheets and analyzed to determine if further field measurements are needed.

Data backups to diskette and/or hardcopy should be made to guard against data loss.
APPENDIX E: PREPROCESSOR CODE LISTINGS

Two preprocessors were written to expeditiously transfer the needed data from EXCEL spreadsheets to the necessary model input formats.

E.1 PREPROCESSOR FOR ADYN

! 10/30/01
!
! Program RMSPP: A preprocessor for the ADYN input file (.aii) for RMS by TVA.
!
! By Alida Abbott
!
! This program reads a text files created in EXCEL and saved as .prn. and merges the data input by the user to form a complete ADYN input file. NOTE: This file is designed for the Shasta River Project and modifications may need to be made to apply it to other uses of RMS.
!
! This preprocessor is for 1 reach and no dynamic junctions.
! This preprocessor does not prepare for node interpolation by ADYN.
!
~File Numbers~ ~Hardwired Values~
! 1 Geometry Text File ICG = 1
! 2 Flow Text File XUNIT = 0
! 3 Lateral Inflow Text File NJUNC = 0
! 5 ADYN input file (.aii) DGE = 50
! iMASS = 1
! PHIDEG = 0.0
! iQUAL = 1
! FNMX = 0.0
! IVRCH, IVEL = 0
! RFC = 0.0
!
! DDIST1, DDIST2 = 0
! PLT=DT=QUALDT
! IUSBC,IDSBC = 1
! NC(J) = 0
! QTTOL = 0.02
! QTOL = 0.005
! HTOL = 0.005
!
! Boundary Conditions:
! The upstream boundary is set to be a discharge hydrograph (CFS)
! The downstream boundary is set for the model to calculate using manning eq.
! The geometry text file has the following format:
! Line 1: Title
! Line 2: Identifiers
! Line 3: nxsec, iseco, ixsec
program RMS_PP
implicit none

character (80)                      geoname, ubcname, outname, yesno*1, title1, identifiers,
2 name, latname, isolv*1
integer no, i, nns, iog, iroute, idmpqh, iplt, nxsec, iseco, ixsec,
2 date, nord, ifmt, isopt, nqlh, j
real rmi, frn, kce1, kce2, rmiog1, rmiog2, rmiog3, dt, prt, hi,
2 rmlat1, rmlat2, rmic, qic, elic, theta
real, dimension (5) :: x, elev
real, dimension (5000) :: w, qlat

! Get file names of input files and open files

! Ask user for file name
100 WRITE (*, *) "Enter geometry input file name:"
    READ(*, *) geoname
WRITE(*, *) "Enter upstream boundary input file name:"
    READ(*, *) ubcname

! Try to open files
    name = geoname
    OPEN (1, file=geoname, status='OLD', ERR=110)
name = ubcname
OPEN (2, file=ubcname, status='OLD', ERR=110)
GOTO 120

! Error handler
110 WRITE (*,*) "Error, could not open file:", name
WRITE (*,*) "Try again? (y/n)"
READ (*,*) yesno
IF (yesno == "y".or. yesno == "Y") THEN
  GOTO 100
ELSE
  WRITE (*,*) "RMS PreProcessor aborting."
ENDIF

! Got the files, ok to proceed
120 Continue

! Get output file name and open file
WRITE (*,*) "Enter output file name"
READ (*,*) outname
WRITE (*,*) "Output file name:", outname
OPEN (5, file=outname, STATUS='unknown')

! Read input file title
READ(1, "(A80)") title1
WRITE(5,'(A)') title1
READ(1,*) identifiers

! Get information from user and write line 1 for .aii
WRITE (*,*) "Output geometry to DYNOUT?(0=no, 2=yes)"
READ (*,*) iog
WRITE (*,*) "Use ADYN to route (1) or just build geometry (0)?"
READ (*,*) iroute
WRITE (*,*) "Dump Q,H? (0=no dump, 1=dump)"
READ (*,*) idmpqh
WRITE (*,*) "Build plot file? (0=no, 1=yes)"
READ (*,*) iplt
WRITE(5,'(16I5)') 1,iog,0,iroute,1,idmpqh,iplt,1

! Get information from geo file and write line 2 for .aii
READ(1,*) nxsec,iseco,ixsec
WRITE (5,'(16I5)') nxsec,iseco,ixsec,0
READ(1,*) identifiers

! Get information from user and write line 3 for .aii
WRITE (*,*) "Enter 3 mileages for which geom table is desired:"
READ (*,*) rmiog1, rmiog2, rmiog3
WRITE (5,'(10F8.2)') 50.0,0.0, rmiog1,rmiog2,rmiog3,0.0,0.0

! Read information from Geo file write lines 4-10 for each cross-section
DO
READ(1, "(I2,6F6.2,5F8.2,I2,3F6.3)") no, rmi,
1 (x(I),I=1,no), (elev(I),I=1,no), nns, frn, kce1,kce2
WRITE (5, "(I5,F8.2)") no, rmi
WRITE (5, "(10F8.2)") (elev(I), I=1,no)
WRITE (5, "(10F8.2)") (x(I), I=1,no)
WRITE (5, "(I5)") nns
WRITE (5, "(10F8.3)") frn
IF (kce1 .lt. 0 .and. kce2 .lt. 0) THEN
  !End of Cross-sections do not write kce1 and kce2
GOTO 130
ELSE
  WRITE (5, "(10F8.2") kce1,kce2
ENDIF
ENDDO

130 CONTINUE

!Get boundary conditions and write line 12 of .aii
WRITE (*, *) "Enter beginning date of simulation (YYMMDD)."
WRITE (*, *) "The clock will start on hour 24 of that day."
READ (*, *) date
WRITE (*, *) "Enter time step and print interval (hours):"
READ (*, *) dt, prt
WRITE (5, '(I6,5F8.2,A40)') date, 24.00, dt, prt, dt, dt,
  2"begd/begt/dt/prt/plt/qdt"

!Get upstream boundary conditions from input file and print.
!Assumed upstream boundary is a discharge hydrograph, model calculates downstream
!Write lines 13-16 of .aii
WRITE (5,'(2I5,A40)') 1,1,"Main Channel Boundary Conditions"
READ (2,*) hi,nord,ifmt,isopt
WRITE (5,'(F8.2)') hi
WRITE (5,'(3I5)') nord,ifmt,isopt
READ (2,'(A)') identifiers
DO i=1,nord
  READ (2,'(12X,F10.0)') w(i)
ENDDO
WRITE (5,'(8F10.0)') (w(i),i=1,nord)

!Get downstream boundary conditions. (For IDSBC = 1 meaning the model calculates,
! no downstream conditions are needed. If this is changed the logic may be added here.)
!IDSBC = 1, records 17-21 omitted.

!Get internal boundary conditions for special nodes. This code is setup with NC(J) = 0,
! meaning there are no internal boundary conditions. If this is changed, logic can be
! added here.
!NC(J) = 0, records 22-26 omitted

!Get lateral inflows.
!Write record 27 (.aii)
WRITE(*,*) "Enter the number of lateral inflows:"
READ(*,*) nqlh
WRITE(5,('(I5)')) nqlh
IF (nqlh .gt.0) THEN
   WRITE(*,*) "Enter the lateral inflow input file name:"
   READ(*,*) latname
   OPEN (3, file=latname, status='OLD', ERR=210)
   GOTO 220
ELSE
   WRITE (*,*) "Error, could not open file:”, latname
   WRITE (*,*) "Try again? (y/n)"
   READ (*,*) yesno
   IF (yesno == "y",or. yesno == "Y") THEN
      GOTO 200
   ELSE
      WRITE (*,*) "RMS PreProcessor aborting."
      ENDIF
   !Got the file, ok to proceed
220    Continue
   READ (3,*) hi,nord,ifmt,isopt
   READ (3,*) identifiers
   !Write records 27-29 (.aii)
   WRITE(5,('(F8.2)')) hi
   WRITE(5,('(3I5)')) nord,ifmt,isopt
   !Read lateral inflow hydrographs from lateral inflow text file
   !Write records 30-31 (.aii)
   DO i=1,nqlh
      READ(3,*) rmlat1,rmlat2
      DO j=1,nord
         READ (3,('(14X,F10.0)')) qlat(j)
      ENDDO
      WRITE (5,('(2F8.2)')) rmlat1,rmlat2
      WRITE (5,('(8F10.0)')) (qlat(j),j=1,nord)
   ENDDO
   ELSE
      CONTINUE
      ENDIF
   !Get initial conditions: assumed initial conditions entered only at downstream end
   !Write records 32-34 (.aii)
   WRITE(*,*) "Enter initial condition at end node (RM,Q,Elev):"
   READ(*,*) rmic,qic,elic
   WRITE(5,('(I5)')) 0
   WRITE(5,('(3F8.2)')) rmic,qic,elic
   WRITE(5,('(F8.0)')) -100.
   !Get numerical solution control information
   !Write record 35 (.aii)
   WRITE(*,*) "What type of numerical scheme? (I/E)"
E.2 PREPROCESSOR FOR RQUAL

! 12/17/01
!
! Program RMSPP2: A preprocessor for the RQUAL Water Quality Coefficients input
! file (.ric) for RMS by TVA for simulation of water temperature only in conjunction
! with two bank shading parameters.
!
! By Alida Abbott
!
! This program reads text files created in EXCEL and saved as .prn and merges
! them data input by the user to form a complete WQC input file.
!
! The function of this program is to format the river aspect at each node and fill
! in zeros for the water quality parameters other than temperature.
!
! INPUT FILE: The river aspect file should be in two columns, the first 15 spaces
! can be used as an identifier with river mile and node number, the second column should
! contain the river aspect.
!
! The only user inputs are the river aspects, and the initial conditions
! the following values are hardwired into this program:
!
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRT</td>
<td>Print interval in hours for output</td>
<td>1 hour</td>
</tr>
<tr>
<td>IPLT</td>
<td>Plot output flag (0= no plot, 1=plot)</td>
<td>1</td>
</tr>
<tr>
<td>THET</td>
<td>Spatial derivative weighting factor</td>
<td>0.5</td>
</tr>
<tr>
<td>TSI</td>
<td>model testing coeff. (dummy variable)</td>
<td>1.0</td>
</tr>
<tr>
<td>I02R</td>
<td>flag to capture T and DO process rate</td>
<td>1.0</td>
</tr>
<tr>
<td>PLT</td>
<td>Plot file interval in hours</td>
<td>1.0</td>
</tr>
<tr>
<td>ROUTE</td>
<td>Numerical scheme (I, E, H)</td>
<td>I</td>
</tr>
<tr>
<td>PDC</td>
<td>Limits for H-P scheme</td>
<td>0.0</td>
</tr>
<tr>
<td>PDCS</td>
<td>limits for H-P scheme</td>
<td>0.0</td>
</tr>
<tr>
<td>IRS</td>
<td>Flag to use new shading logic</td>
<td>1</td>
</tr>
<tr>
<td>alphx(i)</td>
<td>not used in current model</td>
<td>0.0</td>
</tr>
<tr>
<td>PHI</td>
<td>latitude of river</td>
<td>41.875</td>
</tr>
<tr>
<td>ALON</td>
<td>longitude of river</td>
<td>122.63</td>
</tr>
<tr>
<td>TZM</td>
<td>no longer an input, model calculations</td>
<td>blank</td>
</tr>
<tr>
<td>TFOG</td>
<td>time of fog lift</td>
<td>6:00 am</td>
</tr>
<tr>
<td>BW(i)</td>
<td>bank width</td>
<td>0.0</td>
</tr>
<tr>
<td>AA</td>
<td>windspeed coefficient</td>
<td>3.0E-09</td>
</tr>
<tr>
<td>BB</td>
<td>bank width</td>
<td>1.4E-09</td>
</tr>
<tr>
<td>XL,XL2</td>
<td>channel bed thickness (upper,lower)</td>
<td>10 cm, 50 cm</td>
</tr>
<tr>
<td>DIF</td>
<td>thermal diffusivity of bed (=0 turns of bed logic)</td>
<td>0</td>
</tr>
</tbody>
</table>
program RMS_PP2
implicit none

character (80) aname,yesno*1,title1,outname
integer numnodes,i,no
real rmic,tinit,binit,ninit
real, dimension (500) :: alphx, aspect,bw,sfac,pfac,rfac

! Get file names of input files and open files

!Ask user for file name
WRITE ('*','(A)') 'Enter aspect input file name:'
READ(*,*) aname

!Try to open file
OPEN (1, file=aname, status='OLD', ERR=110)
GOTO 120

!Error handler
WRITE (*,'(A,1X,A)') 'Error, could not open file:', aname
WRITE (*,'(A,1X,A)') 'Try again? (y/n)'
READ(*,*) yesno
IF (yesno == 'y'.or. yesno == 'Y') THEN
  GOTO 100
ELSE
  WRITE ('*','(A)') 'RMS PreProcessor2 aborting.'
ENDIF
! Got the files, ok to proceed

120  Continue

! Get output file name and open file
  WRITE (*,*) "Enter output file name"
  READ (*,*) outname
  WRITE (*,*) "Output file name:", outname
  OPEN (5, file=outname, STATUS='unknown')

! Read input file title
  READ(1,*(A80)) title1

! Write record 1 for .ric (PRT,IPLT,THET,TSI,JO2R,PLT,ROUTE,PDC,PDCS,IRS)
  WRITE(5,'(F8.1,I5,2F8.1,I5,F8.1,4X,A1,2F8.1,I5)') 1.0,1,0.5,1.0,1,
  21.0,'I',0.0,0.0,1

! Write record 2 for .ric
  WRITE (*,*) "Enter the number of nodes:"
  READ (*,*) numnodes
  DO I=1,numnodes
    alphx(i)=0.0
  ENDDO
  WRITE (5,*(10F8.2)) (alphx(I), I=1,numnodes)

! Write record 3 for .ric PHI,ALON,TZM,TFOG (phi=lat of river, alon=lon of river)
  WRITE (5,*(2F8.3,8X,F8.2)) 41.875,122.63,6.0

! Read information from aspect file write record 4 for .ric
  DO i=1,numnodes
    READ(1,*(15X,F8.2)) aspect(i)
  ENDDO
  WRITE (5,*(10F8.2)) (aspect(I), I=1,numnodes)

! Write record 5 of .ric (Bank Width is considered 0.0 for the Shasta River)
  DO i=1,numnodes
    BW(i)=0.0
  ENDDO
  WRITE (5,*(10F8.2)) (bw(l), l=1,numnodes)

! Skip EBH (record 6) due to new shading logic input file.

! Write record 7 to .ric Leave out SHSOL due to new shading logic input file
! AA,BB,XL, XL2,DIF,CV,BETW,BEDALB,SHDBT where AA,BB are windspeed
! coefficients
! This line turns off the bed conduction term by setting DIV = 0.0
  WRITE(5,*(2A8,8F8.2))'3.0E-09','1.4E-09',10.,50.,0.,0.68,0.4,1.0,
  21.0

! Write record 8 (.ric)
These are the rate coefficients for water quality parameters, they must be entered even when only modeling temperature.

```
WRITE (5,'(9F8.2,I5)') 99.0,99.0,0.0,99.0,0.0,99.0,0.0,0.0,99.0,0
```

Write record 9 (.ric)

```
BS20,WFAC
WRITE(5,'(3F8.0)') 0.0, 0.0
```

Write record 10 (.ric) SFAC = 0.0

```
DO i=1,numnodes
   SFAC(i)=0.0
ENDDO
WRITE (5,'(F8.1)') 0.0
WRITE (5,'(10F8.2)') 0.0,(sfac(i), i=1,numnodes)
```

Write record 11 (.ric) PFAC = 0.0

```
DO i=1,numnodes
   PFAC(i)=0.0
ENDDO
WRITE (5,'(F8.1)') 0.0
WRITE (5,'(10F8.2)') 0.0,(pfac(i), i=1,numnodes)
```

Write record 12 (.ric) RFAC = 0.0

```
DO i=1,numnodes
   RFAC(i)=0.0
ENDDO
WRITE (5,'(F8.1)') 0.0
WRITE (5,'(10F8.2)') 0.0,(rfac(i), i=1,numnodes)
```

Write record 13 (.ric) The initial conditions. Need to be entered at at least two nodes.

```
!RMIC= river mile of IC, TINIT=ini temp, BINIT= ini BOD, NINIT = ini NOD
WRITE (*,*) "Enter number of initial conditions (at least two):"
READ (*,*) no
DO i=1, no
   WRITE(*,*) "Enter river mile of initial condition:"
   READ (*,*) rmic
   WRITE(*,*) "Enter initial temperature in degrees c:"
   READ (*,*) tinit
   WRITE(*,*) "Enter initial BOD concentration in mg/l:"
   READ (*,*) binit
   WRITE(*,*) "Enter initial NOD concentration in mg/l:"
   READ (*,*) ninit
   WRITE (5,'(10F8.2)') rmic,tinit,binit,ninit
ENDDO
WRITE(5,'(F8.1)') -100.0

WRITE (*,*) "RMSPP2 done."
```

END
**APPENDIX F: ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADYN</td>
<td>Hydrodynamic component of RMS</td>
</tr>
<tr>
<td>BZR</td>
<td>Brazie Ranch Weather Station</td>
</tr>
<tr>
<td>CF</td>
<td>Vegetative Continuity Factor</td>
</tr>
<tr>
<td>CFS</td>
<td>Cubic Feet per Second</td>
</tr>
<tr>
<td>CRS</td>
<td>Shading subroutine in RMS</td>
</tr>
<tr>
<td>DFG</td>
<td>California Department of Fish and Game</td>
</tr>
<tr>
<td>DLG</td>
<td>Digital Line Graph</td>
</tr>
<tr>
<td>DWR</td>
<td>California Department of Water Resources</td>
</tr>
<tr>
<td>EBH</td>
<td>Effective Bank Height</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>GID</td>
<td>Grenada Irrigation District Pumps</td>
</tr>
<tr>
<td>ICE</td>
<td>Information Center for the Environment</td>
</tr>
<tr>
<td>MAE</td>
<td>Mean Absolute Error</td>
</tr>
<tr>
<td>NHD</td>
<td>National Hydrography Dataset</td>
</tr>
<tr>
<td>PT</td>
<td>Pressure Transducer</td>
</tr>
<tr>
<td>RM</td>
<td>River Mile</td>
</tr>
<tr>
<td>RMS</td>
<td>River Modeling System</td>
</tr>
<tr>
<td>RQUAL</td>
<td>Water Quality component of RMS</td>
</tr>
<tr>
<td>SHSOL</td>
<td>Shade modeling parameter</td>
</tr>
<tr>
<td>SRP</td>
<td>Shasta Above Parks Creek</td>
</tr>
<tr>
<td>SWA</td>
<td>Shasta Water Users Association</td>
</tr>
<tr>
<td>Tr</td>
<td>Transmittance</td>
</tr>
<tr>
<td>TVA</td>
<td>Tennessee Valley Authority</td>
</tr>
<tr>
<td>USFWS</td>
<td>United States Fish and Wildlife Service</td>
</tr>
<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
</tbody>
</table>