6.0 TEMPERATURE

Monitoring for temperature was conducted by SWQB in 2003. Based on available data, several exceedences of the New Mexico WQS for temperature were noted throughout the watershed (Figure 6.1). Thermographs were set to record once every hour for several months during the warmest time of the year (generally May through September). Thermograph data are assessed using Appendix C of the *State of New Mexico Procedures for Assessing Standards Attainment for the Integrated §303(d)/§305(b) Water Quality Monitoring and Assessment Report* (NMED/SWQB 2004b). Based on 2003 data, the temperature listing on the 2002-2004 CWA §303(d) for Rio Ruidoso (US Highway 70 to Mescalero Apache boundary) was confirmed. Temperature data from 2003 were used to develop TMDLs.

6.1 Target Loading Capacity

Target values for these temperature TMDLs will be determined based on 1) the presence of numeric criteria, 2) the degree of experience in applying the indicator, and 3) the ability to easily monitor and produce quantifiable and reproducible results. For this TMDL document, target values for temperature are based on the reduction in solar radiation necessary to achieve numeric criteria as predicted by a temperature model. This TMDL is also consistent with New Mexico's antidegradation policy.

The State of New Mexico has developed and adopted numeric water quality criteria for temperature to protect the designated use of high quality coldwater fishery (HQCWF) (20.6.4.900.C NMAC). These WQS have been set at a level to protect cold-water aquatic life such as trout. The HQCWF use designation requires that a stream reach must have water quality, streambed characteristics, and other attributes of habitat sufficient to protect and maintain a propagating coldwater fishery (i.e., a population of reproducing salmonids). The primary standard leading to an assessment of use impairment is the numeric criterion for temperature of 20 °C (68°F). Table 6.1 and Figure 6.1 highlight the 2003 thermograph deployments. The following TMDL addresses a reach where temperatures exceeded the criterion (**Appendix G** of this document provides a graphical representation of thermograph data):

> *Rio Ruidoso (US Highway 70 to Mescalero Apache boundary):* Three thermographs were deployed on this reach in 2003. One thermograph was deployed at Rio Ruidoso at Hollywood USGS gage (site 8), recorded temperatures from May 20 (17:00) through September 15 (14:00) exceeded the HQCWF criterion 185 of 2,830 times (6.5%) with a maximum temperature of 23.71°C on July 8. A second thermograph was deployed at Rio Ruidoso at Hwy 70 above the WWTP (site 9), recorded temperatures from May 20 (17:00) through September 16 (12:00) exceeded the HQCWF criterion 362 of 2,852 times (13%) with a maximum temperature of 23.74°C on August 10. The third thermograph was deployed at Rio Ruidoso at Mescalero boundary (site 10), recorded temperatures from May 20 (17:00) through September 16 (14:00) exceeded the HQCWF criterion 289 of 2,854 times (10%) with a maximum temperature of 25.07°C on July 9.

Table 6.1 Rio Hondo Watershed Thermograph Sites

Site Number	Site Name	2003 Deployment Dates
1	Carrizo Creek at Two Rivers Park	5/20-9/15
2	Rio Bonito at Hwy 48 at Angus Canyon [1]	5/19-8/18 [a]
3	Rio Bonito at BLM Apple Orchard [1]	5/19-9/15
4	Rio Bonito above Bonito Lake at FR 107	5/19-9/17
5	Rio Hondo at Riverside [1]	5/19-9/16
6	Rio Hondo below Ruidoso-Bonito confluence [1]	5/19-9/16
7	Rio Ruidoso at Glencoe	5/20-9/15
8	Rio Ruidoso at Hollywood USGS gage	5/20-9/15
9	Rio Ruidoso at Hwy 70 above WWTP [1]	5/20-9/16
10	Rio Ruidoso at Mescalero boundary [1]	5/20-9/16
11	Rio Ruidoso above Rio Bonito	5/20-9/15

Note: [1] air thermograph simultaneously deployed
[a] air thermograph deployed through 9/17/2003

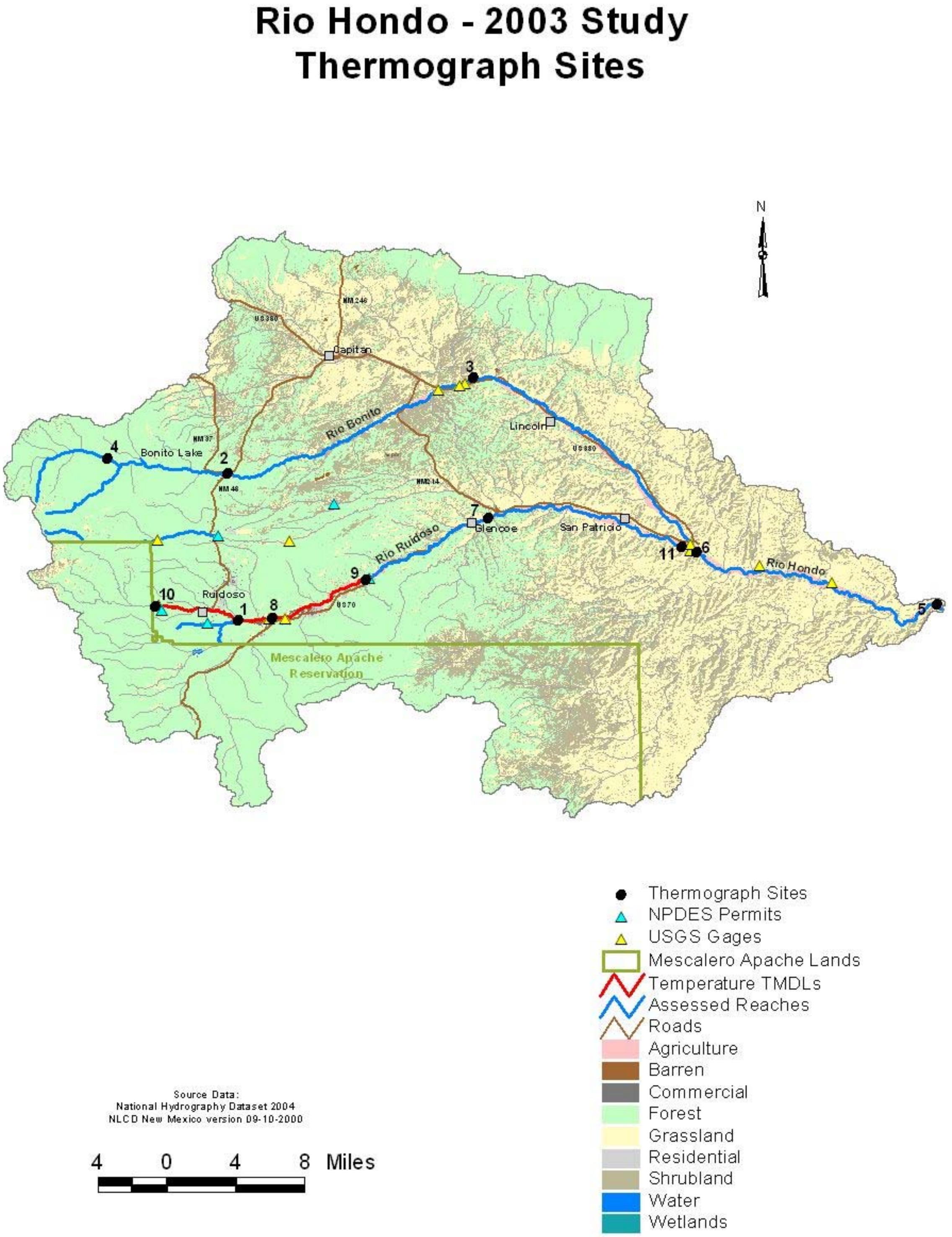

Figure 6.1 Rio Hondo Thermograph sites

6.2 Calculations

The Stream Segment Temperature (SSTEMP) Model, Version 2.0 (Bartholow 2002) was used to predict stream temperatures based on watershed geometry, hydrology, and meteorology. This model was developed by the USGS Biological Resource Division (Bartholow 2002). The model predicts mean, minimum, and maximum daily water temperatures throughout a stream reach by estimating the heat gained or lost from a parcel of water as it passes through a stream segment (Bartholow 2002). The predicted temperature values are compared to actual thermograph readings measured in the field in order to calibrate the model. The SSTEMP model identifies current stream and/or watershed characteristics that control stream temperatures. The model also quantifies the maximum loading capacity of the stream to meet water quality criteria for temperature. This model is important for estimating the effect of changing controls or factors (such as riparian grazing, stream channel alteration, and reduced streamflow) on stream temperature. The model can also be used to help identify possible implementation activities to improve stream temperature by targeting those factors causing impairment to the stream.

6.3 Waste Load Allocations and Load Allocations

6.3.1 Waste Load Allocation

There are no active point source contributions associated with these TMDLs. The WLA is zero.

6.3.2 Load Allocation

Water temperature can be expressed as heat energy per unit volume. SSTEMP provides an estimate of heat energy expressed in joules per square meter per second ($j/m^2/s$) and Langley's per day. The following information relevant to the model runs used to determine temperature TMDLs is taken from the SSTEMP documentation (Bartholow 2002). Please refer to the SSTEMP User's Manual for complete text. Various notes have been added below in brackets to clarify local sources of input data.

> **Description of Logic**:
> In general terms, SSTEMP calculates the heat gained or lost from a parcel of water as it passes through a stream segment. This is accomplished by simulating the various heat flux processes that determine that temperature change. . . These physical processes include convection, conduction, evaporation, as well as heat to or from the air (long wave radiation), direct solar radiation (short wave), and radiation back from the water. SSTEMP first calculates the solar radiation and how much is intercepted by (optional) shading. This is followed by calculations of the remaining heat flux components for the stream segment. The details are just that: To calculate solar radiation, SSTEMP computes the radiation at the outer edge of the earth's atmosphere. This radiation is passed through the attenuating effects of the atmosphere and finally reflects off the water's surface depending on the angle of the sun. For shading, SSTEMP computes the day length for the level plain case, i.e., as if there were no local topographic influence. Next, sunrise and sunset times are computed by factoring in local east and west-side topography. Thus, the local topography results in a percentage decrease in the level plain daylight hours. From this local sunrise/sunset, the program computes the percentage of light that is filtered out by the riparian vegetation. This filtering is the result of the size, position and density of the shadow-casting vegetation on both sides of the stream. . .

HYDROLOGY VARIABLES

. . . 1. Segment Inflow (cfs or cms [cubic meters per second]) -- Enter the mean daily flow at the top of the stream segment. If the segment begins at an effective headwater, the flow may be entered as zero so that all accumulated flow will accrue from accretions, both surface water and groundwater. If the segment begins at a reservoir, the flow will be the outflow from that reservoir. Remember that this model assumes steady-state flow conditions.

If the inflow to the segment is the result of mixing two streams, you may use the mixing equation to compute the combined temperature:

$$T_j = \frac{(Q_1 \times T_1) + (Q_2 \times T_2)}{Q_1 + Q_2}$$

where

T_j = Temperature below the junction
Q_n = Discharge of source n
T_n = Temperature of source n

2. Inflow Temperature (°F or °C) -- Enter the mean daily water temperature at the top of the segment. If the segment begins at a true headwater, you may enter any water temperature, because zero flow has zero heat. If there is a reservoir at the inflow, use the reservoir release temperature. Otherwise, use the outflow from the next upstream segment.

3. Segment Outflow (cfs or cms) -- The program calculates the lateral discharge accretion rate by knowing the flow at the head and tail of the segment, subtracting to obtain the net difference, and dividing by segment length. The program assumes that lateral inflow (or outflow) is uniformly apportioned through the length of the segment. If any "major" tributaries enter the segment, you should divide the segment into two or more subsections. "Major" is defined as any stream contributing greater than 10% of the mainstem flow, particularly if there are major discontinuities in stream temperature.

[NOTE: To be conservative, 4Q3 low flow values were used as the segment outflow. These critical low flows were used to decrease assimilative capacity of the stream to adsorb and disperse solar energy. See **Appendix H** for calculations.]

4. Accretion Temperature (°F or °C) -- The temperature of the lateral inflow, barring tributaries, generally should be the same as groundwater temperature. In turn, groundwater temperature may be approximated by the mean annual air temperature. You can verify this by checking United States Geological Survey (USGS) well log temperatures. Exceptions may arise in areas of geothermal activity. If irrigation return flow makes up most of the lateral flow, it may be warmer than mean annual air temperature. Return flow may be approximated by equilibrium temperatures.

GEOMETRY VARIABLES

. . . 1. Latitude (decimal degrees or radians) -- Latitude refers to the position of the stream segment on the earth's surface. It may be read off of any standard topographic map.

[NOTE: Latitude is generally determined in the field with a global positioning system (GPS) unit.]

2. Dam at Head of Segment (checked or unchecked) -- If there is a dam at the upstream end of the segment with a constant, or nearly constant diel release temperature, check the box, otherwise

leave it unchecked . . . Maximum daily water temperature is calculated by following a water parcel from solar noon to the end of the segment, allowing it to heat towards the maximum equilibrium temperature. If there is an upstream dam within a half-day's travel time from the end of the segment, a parcel of water should only be allowed to heat for a shorter time/distance. By telling SSTEMP that there is a dam at the top, it will know to heat the water only from the dam downstream. . . Just to confuse the issue, be aware that if there is no dam SSTEMP will assume that the stream segment's meterology and geometry also apply upstream from that point a half-day's travel time from the end of the segment. If conditions are vastly different upstream, this is one reason that the maximum temperature estimate can be inaccurate.

3. Segment Length (miles or kilometers) -- Enter the length of the segment for which you want to predict the outflowing temperature. Remember that all variables will be assumed to remain constant for the entire segment. Length may be estimated from a topographic map, but a true measurement is best.

[NOTE: Segment length is determined with National Hydrographic Dataset Reach Indexing Geographic Information System (GIS) tool.]

4. Upstream Elevation (feet or meters) -- Enter elevation as taken from a 7 ½ minute quadrangle map.

[NOTE: Upstream elevation is generally determined in the field with a GPS unit or GIS tool.]

5. Downstream Elevation (feet or meters) -- Enter elevation as taken from a 7 ½ minute quadrangle map. Do not enter a downstream elevation that is higher than the upstream elevation. . .

[NOTE: Downstream elevation is generally determined in the field with a GPS unit or GIS tool.]

6. Width's A Term (seconds/foot^2 or seconds/meter^2) -- This parameter may be derived by calculating the wetted width-discharge relationship. . . To conceptualize this, plot the width of the segment on the Y-axis and discharge on the X-axis of log-log paper. . . The relationship should approximate a straight line, the slope of which is the B term (the next variable). Theoretically, the A term is the untransformed Y-intercept. However, the width vs. discharge relationship tends to break down at very low flows. Thus, it is best to calculate B as the slope and then solve for A in the equation:

$$W = A * Q^B$$

where Q is a known discharge
W is a known width
B is the power relationship

Regression analysis also may be used to develop this relationship. First transform the flow to natural log (flow) and width to natural log (width). Log (width) will be the dependent variable. The resulting X coefficient will be the B term and the (non-zero) constant will be the A term when exponentiated. That is:

A = e^constant from regression

where ^ represents exponentiation

As you can see from the width equation, width equals A if B is zero. Thus, substitution of the stream's actual wetted width for the A term will result if the B term is equal to zero. This is satisfactory if you will not be varying the flow, and thus the stream width, very much in your simulations. If, however, you will be changing the flow by a factor of 10 or so, you should go to the trouble of calculating the A and B terms more precisely. Width can be a sensitive factor under many circumstances.

[NOTE: After Width's B Term is determined (see note below), Width's A Term is calculated as displayed above.]

7. Width's B Term (essentially dimensionless) -- From the above discussion, you can see how to calculate the B term from the log-log plot. This plot may be in either English or international units. The B term is calculated by linear measurements from this plot. Leopold et al. (1964, p.244) report a variety of B values from around the world. A good default in the absence of anything better is 0.20; you may then calculate A if you know the width at a particular flow.

[NOTE: Width's B Term is calculated at the slope of the regression of the natural log of width and the natural log of flow. Width vs. flow data sets are determined by entering cross-section field data into WINXSPRO (USDA 1998). See **Appendix H** for details.]

8. Manning's n or Travel Time (seconds/mile or seconds/kilometer) -- Manning's n is an empirical measure of the segment's "roughness. . ." A generally acceptable default value is 0.035. This parameter is necessary only if you are interested in predicting the minimum and maximum daily fluctuation in temperatures. It is not used in the prediction of the mean daily water temperature.

[NOTE: Rosgen stream type is also taken into account when estimating Manning's n (Rosgen 1996).]

TIME OF YEAR

Month/Day (mm/dd) -- Enter the number of the month and day to be modeled. January is month 1, etc. This program's output is for a single day. To compute an average value for a longer period (up to one month), simply use the middle day of that period, e.g., July 15. The error encountered in so doing will usually be minimal. Note that any month in SSTEMP can contain 31 days.

METEOROLOGICAL PARAMETERS

1. Air Temperature (°F or °C) -- Enter the mean daily air temperature. This information may of course be measured (in the shade), and should be for truly accurate results; however, this and the other (following) meteorological parameters may come from the Local Climatological Data (LCD) reports which can be obtained from the National Oceanic and Atmospheric Administration for a weather station near your site. The LCD Annual Summary contains monthly values, whereas the Monthly Summary contains daily values. The Internet is another obvious source of data today. If only scooping-level analyses are required, you may refer to sources of general meterology for the United States, such as USDA (1941) or USDC (1968).

Use the adiabatic lapse rate to correct for elevational differences from the met station:

$$Ta = To + Ct * (Z - Zo)$$

where Ta = air temperature at elevation E (°C)
To = air temperature at elevation Eo (°C)
Z = mean elevation of segment (m)
Zo = elevation of station (m)
Ct = moist-air adiabatic lapse rate (-0.00656 °C/m)

NOTE: Air temperature will usually be the single most important factor in determining mean daily water temperature. . .

[NOTE: Mean daily air temperature data were determined from air thermographs deployed in the shade near the instream thermograph locations or found at the New Mexico Climate Center web site (http://weather.nmsu.edu/data/data.htm). Regardless of the source, air temperatures are corrected for elevation using the above equation.]

2. Maximum Air Temperature (°F or °C) -- The maximum air temperature is a special case. Unlike the other variables where simply typing a value influences which variables "take effect", the maximum daily air temperature overrides only if the check box is checked. If the box is not checked, the program continues to estimate the maximum daily air temperature from a set of empirical coefficients (Theurer et al., 1984) and will print the result in the grayed data entry box. You cannot enter a value in that box unless the box is checked.

3. Relative Humidity (percent) -- Obtain the mean daily relative humidity for your area by measurement or from LCD reports by averaging the four daily values given in the report. Correct for elevational differences by:

$$Rh = Ro \times [1.0640**(To - Ta)] \times \left(\frac{Ta + 273.16}{To + 273.16} \right)$$

where Rh = relative humidity for temperature Ta (decimal)
Ro = relative humidity at station (decimal)
Ta = air temperature at segment (°C)
To = air temperature at station (°C)
** = exponentation
0 <= Rh <= 1.0

[NOTE: Relative humidity data are found at the New Mexico Climate Center web site (http://weather.nmsu.edu/data/data.htm). Regardless of the source, relative humidity data are corrected for elevation and temperature using the above equation.]

4. Wind Speed (miles per hour or meters/second) -- Obtainable from the LCD. Wind speed also may be useful in calibrating the program to known outflow temperatures by varying it within some reasonable range. In the best of all worlds, wind speed should be measured right above the water's surface.

[NOTE: Wind speed data are found at the New Mexico Climate Center web site (http://weather.nmsu.edu/data/data.htm).]

5. Ground Temperature (°F or °C) – In the absence of measured data, use mean annual air temperature from the LCD.

[NOTE: Mean annual air temperature is found at the New Mexico Climate Center web site (http://weather.nmsu.edu/data/data.htm).]

6. Thermal Gradient (Joules/Meter^2/Second/°C) -- This elusive quantity is a measure of rate of thermal input (or outgo) from the streambed to the water. It is not a particularly sensitive parameter within a narrow range. This variable may prove useful in calibration, particularly for the maximum temperature of small, shallow streams where it may be expected that surface waters interact with either the streambed or subsurface flows. In the absence of anything better, simply use the 1.65 default. **Note** that this parameter is measured in the same units regardless of the system of measurement used.

7. Possible Sun (percent) -- This parameter is an indirect and inverse measure of cloud cover. Measure with a pyrometer or use the LCD for historical data. Unfortunately, cloud cover is no longer routinely measured by NOAA weather stations. That means that one must "back calculate" this value or use it as a calibration parameter.

[NOTE: Percent possible sun is found at the New Mexico Climate Center web site (http://weather.nmsu.edu/data/data.htm).]

8. Dust Coefficient (dimensionless) -- This value represents the amount of dust in the air. If you enter a value for the dust coefficient, SSTEMP will calculate the solar radiation.

Representative values look like the following (TVA 1972):

Winter	6 to 13
Spring	5 to 13
Summer	3 to 10
Fall	4 to 11

If all other parameters are well known for a given event, the dust coefficient may be calibrated by using known ground-level solar radiation data.

9. Ground Reflectivity (percent) -- The ground reflectivity is a measure of the amount of short-wave radiation reflected back from the earth into the atmosphere. If you enter a value for the ground reflectivity, SSTEMP will calculate the solar radiation.

Representative values look like the following (TVA, 1972, and Gray, 1970):

Meadows and fields	14
Leaf and needle forest	5 to 20
Dark, extended mixed forest	4 to 5
Heath	10
Flat ground, grass covered	15 to 33
Flat ground, rock	12 to 15
Flat ground, tilled soil	15 to 30
Sand	10 to 20
Vegetation, early summer	19
Vegetation, late summer	29
Fresh snow	80 to 90
Old snow	60 to 80
Melting snow	40 to 60
Ice	40 to 50
Water	5 to 15

10. Solar Radiation (Langley's/day or Joules/meter^2/second) -- Measure with a pyrometer, or refer to Cinquemani et al. (1978) for reported values of solar radiation. If you do not calculate solar radiation within SSTEMP, but instead rely on an external source of ground level radiation, you should assume that about 90% of the ground-level solar radiation actually enters the water. Thus, multiply the recorded solar measurements by 0.90 to get the number to be entered. If you enter a value for solar radiation, SSTEMP will ignore the dust coefficient and ground reflectivity and "override' the internal calculation of solar radiation, graying out the unused input boxes.

[NOTE: Solar radiation data are found at the New Mexico Climate Center web site (http://weather.nmsu.edu/data/data.htm).]

SHADE PARAMETER

Total Shade (percent) -- This parameter refers to how much of the segment is shaded by vegetation, cliffs, etc. If 10% of the water surface is shaded through the day, enter 10. As a shortcut, you may think of the shade factor as being the percent of water surface shaded at noon on a sunny day. In actuality however, shade represents the percent of the incoming solar radiation that does not reach the water. If you enter a value for total shade, the optional shading parameters will be grayed out and ignored. You may find it to your advantage to use the Optional Shading Variables to more accurately calculate stream shading. . .

[NOTE: In a 2002 study, Optional Shading Parameters and concurrent densiometer readings were measured at seventeen stations in order to compare modeling results from the use of these more extensive data sets to modeling results using densiometer readings as an estimate of Total Shade. The estimated value for Total Shade was within 15% of the calculated value in all cases. Estimated values for Maximum Temperatures differed by less than 0.5% in all cases. The Optional Shading Parameters are dependent on the exact vegetation at each cross section, thus requiring multiple cross sections to determine an accurate estimate for vegetation at a reach scale. Densiometer readings are less variable and less inclined to measurement error in the field. Aerial photos are examined and considered whenever available.]

OUTPUT

The program will predict the minimum, mean, and maximum daily water temperature for the set of variables you provide. . . The theoretical basis for the model is strongest for the mean daily temperature. The maximum is largely an estimate and likely to vary widely with the maximum daily air temperature. The minimum is computed by subtracting the difference between maximum and mean from the mean; but the minimum is always positive. The mean daily equilibrium temperature is that temperature that the daily mean water temperature will approach, but never reach, if all conditions remain the same (forever) as you go downstream. (Of course, all conditions cannot remain the same, e.g., the elevation changes immediately.) The maximum daily equilibrium temperature is that temperature that the daily maximum water temperature will approach. . . Other output includes the intermediate parameters average width, and average depth and slope (all calculated from the input variables), and the mean daily heat flux components.

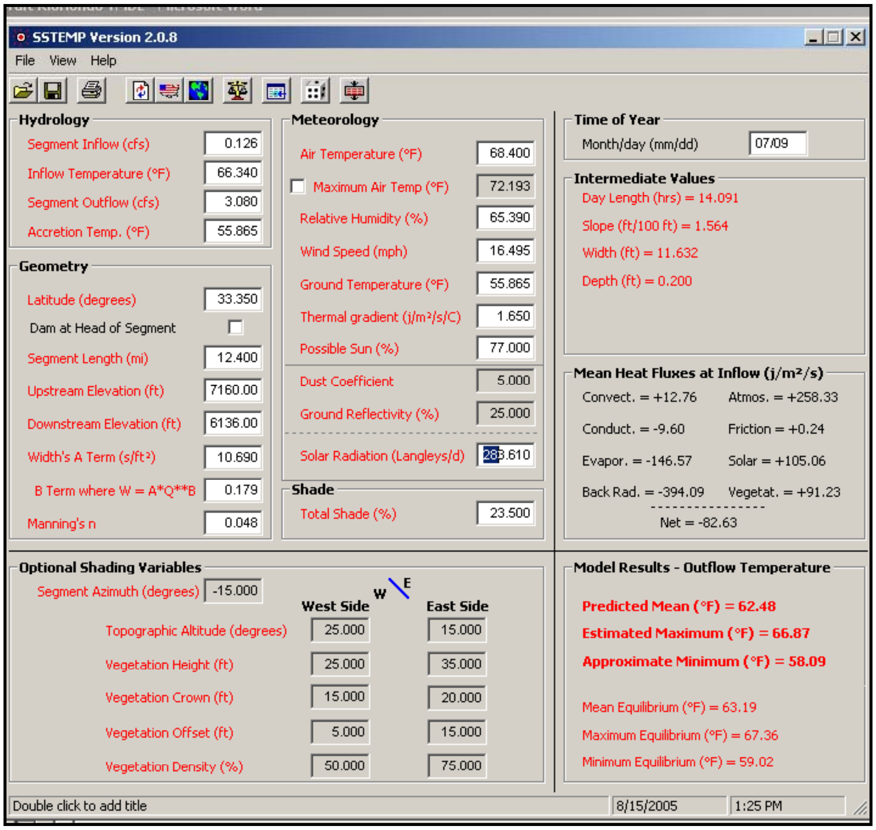

Figure 6.2 Example of SSTEMP input and output for Rio Ruidoso

. . . The mean heat flux components are abbreviated as follows:

Convect. = convection component
Conduct. = conduction component
Evapor. = evaporation component
Back Rad. = water's back radiation component
Atmos. = atmospheric radiation component
Friction = friction component
Solar = solar radiation component
Vegetat. = vegetative and topographic radiation component
Net = sum of all the above flux values

The sign of these flux components indicates whether or not heat is entering (+) or exiting (-) the water. The units are in joules/meter^2/second. In essence, these flux components are the best indicator of the relative importance of the driving forces in heating and cooling the water from inflow to outflow. SSTEMP produces two sets of values, one based on the inflow to the segment and one based on the outflow. You may toggle from one to the other by double clicking on the frame containing the values. In doing so, you will find that the first four flux values change as a function of water temperature which varies along the segment. In contrast, the last four flux values do not change because they are not a function of water temperature but of constant air temperature and channel attributes. For a more complete discussion of heat flux, please refer to Theurer et al. (1984). . .

The program will predict the total segment shading for the set of variables you provide. The program will also display how much of the total shade is a result of topography and how much is a result of vegetation. The topographic shade and vegetative shade are merely added to get the total shade. Use the knowledge that the two shade components are additive to improve your understanding about how SSTEMP deals with shade in toto.

SENSITIVITY ANALYSIS

SSTEMP may be used to compute a one-at-a-time sensitivity of a set of input values. Use **View|Sensitivity Analysis** or the scale toolbar button to initiate the computation. This simply increases and decreases most active input (i.e., non-grayed out values) by 10% and displays a screen for changes to mean and maximum temperatures. The schematic graph that accompanies the display. . . gives an indication of which variables most strongly influence the results. This version does not compute any interactions between input values.

FLOW/DISTANCE MATRIX

The **View|Flow/DistanceMatrix** option allows you to look at a variety of flow and distance combinations from your stream segment. You may enter up to five flows and five distances for further examination. The program will supply a default set of each, with flows ranging from 33% to 166% of that given on the main screen, and distances regularly spaced along the segment. After making any changes you may need, you may choose to view the results in simple graphs either as a function of distance (X) or discharge (Q). The units for discharge, distance and temperature used on the matrix and the graph are a function of those from the main form. The graph is discrete, i.e., does not attempt to smooth between points, and does not currently scale the X-axis realistically.

Note that changing the flow only changes the flow through the segment. That is, the accretion rate per unit distance will remain the same. Flow does impact shading (if active) and all other dependent calculations. . .

Note that you may enter distances beyond your segment length, but if you do so you are assuming that everything remains homogeneous farther downstream, just as you have assumed for the segment itself. *If you try to look at distances very close to the top of the segment, you may get mathematical instability*. . .

UNCERTAINTY ANALYSIS

SNTEMP and previous versions of SSTEMP were deterministic; you supplied the “most likely” estimate of input variables and the model predicted the “most likely” thermal response. This approach was comforting and easy to understand. But choosing this “most likely” approach is like putting on blinders. We know there is variability in the natural system and inherent inaccuracy in the model. The previous model did not reflect variance in measured or estimated input variables (e.g., air temperature, streamflow, stream width) or parameter values (e.g., Bowen ratio, specific gravity of water); therefore they could not be used to estimate the uncertainty in the predicted temperatures. This version (2.0) adds an uncertainty feature that may be useful in estimating uncertainty in the water temperature estimates, given certain caveats.

The built-in uncertainty routine uses Monte Carlo analysis, a technique that gets its name from the seventeenth century study of the casino games of chance. The basic idea behind Monte Carlo analysis is that model input values are randomly selected from a distribution that describes the set of values composing the input. That is, instead of choosing one value for mean daily air temperature, the model is repeatedly run with several randomly selected estimates for air temperature in combination with random selections for all other relevant input values. The distribution of input values may be thought of as representing the variability in measurement and extrapolation error, estimation error, and a degree of spatial and temporal variability throughout the landscape. In other words, we may measure a single value for an input variable, but we know that our instruments are inaccurate to a degree. . . and we also know that the values we measure might have been different if we had measured in a different location along or across the stream, or on a different day. . .

SSTEMP is fairly crude in its method of creating a distribution for each input variable. There are two approaches in this software: a percentage deviation and an absolute deviation. The percentage deviation is useful for variables commonly considered to be reliable only within a percentage difference. For example, USGS commonly describes stream flow as being accurate plus or minus 10%. The absolute deviation, as the name implies, allows entry of deviation values in the same units as the variable (*and always in international units*). A common example would be water temperature where we estimate our ability to measure temperature plus or minus maybe 0.2 degrees. Do not be fooled with input variables whose units are themselves percent, like shade. In this case, if you are in the percentage mode and shade is 50% as an example, entering a value of 5% would impose a deviation of ±2.5 percent (47.5-52.5%), but if you were in the absolute mode, the same 5% value would impose a deviation of ±5 percent (45-55%). Ultimately, SSTEMP converts all of the deviation values you enter to the percent representation before it computes a sample value in the range. No attempt is made to allow for deviations of the date, but all others are fair game, with three exceptions. First, the deviation on stream width is applied only to the A-value, not the B-term. If you want to be thorough, set the width to a constant by setting the B-term to zero. Second, if after sampling, the upstream elevation is lower than the downstream elevation, the upstream elevation is adjusted to be slightly above the downstream elevation. Third, you may enter deviations only for the values being used on the main screen.

The sampled value is chosen from either 1) a uniform (rectangular) distribution plus or minus the percent deviation, or 2) a normal (bell-shaped) distribution with its mean equal to the original value and its standard deviation equal to 1.96 times the deviation so that it represents 95% of the samples drawn from that distribution. If in the process of sampling from either of these two distributions, a value is drawn that is either above or below the "legal" limits set in SSTEMP, a new value is drawn from the distribution. For example, lets assume that you had a relative humidity of 99% and a deviation of 5 percent. If you were using a uniform distribution, the sample range would be 94.05 to 103.95; but you cannot have a relative humidity greater than 100%. Rather than prune the distribution at 100%, SSTEMP resamples to avoid over-specifying 100% values. No attempt has been made to account for correlation among variables, even though we know there is some. I have found little difference in using the uniform versus normal distributions, except that the normal method produces somewhat tighter confidence intervals.

SSTEMP's random sampling is used to estimate the average temperature response, both for mean daily and maximum daily temperature, and to estimate the entire dispersion in predicted temperatures. You tell the program how many trials to run (minimum of 11) and how many samples per trial (minimum of two). Although it would be satisfactory to simply run many individual samples, the advantage to this trial-sample method is twofold. First, by computing the average of the trial means, it allows a better, tighter estimate of that mean value. This is analogous to performing numerous "experiments" each with the same number of data points used for calibration. Each "experiment" produces an estimate of the mean. Second, one can gain insight as to the narrowness of the confidence interval around the mean depending on how many samples there are per trial. This is analogous to knowing how many data points you have to calibrate the model with and the influence of that. For example, if you have only a few days' worth of measurements, your confidence interval will be far broader than if you had several months' worth of daily values. But this technique does little to reduce the overall spread of the resulting predicted temperatures. . .

ASSUMPTIONS

a. Water in the system is instantaneously and thoroughly mixed at all times. Thus there is no lateral temperature distribution across the stream channel, nor is there any vertical gradient in pools.

b. All stream geometry (e.g., slope, shade, friction coefficient) is characterized by mean conditions. This applies to the full travel distance upstream to solar noon, unless there is a dam at the upstream end.

c. Distribution of lateral inflow is uniformly apportioned throughout the segment length.

d. Solar radiation and the other meteorological and hydrological parameters are 24-hour means. You may lean away from them for an extreme case analysis, but you risk violating some of the principles involved. For example, you may alter the relative humidity to be more representative of the early morning hours. If you do, the mean water temperature may better approximate the early morning temperature, but the maximum and minimum temperatures would be meaningless.

e. Each variable has certain built-in upper and lower bounds to prevent outlandish input errors. These limits are not unreasonable; however, the user should look to see that what he or she types actually shows up on the screen. The screen image will always contain the values that the program is using.

f. This model does not allow either Manning's n or travel time to vary as a function of flow.

g. The program should be considered valid only for the Northern Hemisphere below the Arctic Circle. One could theoretically "fast forward" six months for the Southern Hemisphere's shade calculations, but this has not been tested. The solar radiation calculations would likely be invalid due to the asymmetrical elliptical nature of the earth's orbit around the sun.

h. The representative time period must be long enough for water to flow the full length of the segment. . . Remember that SSTEMP, like SNTEMP, is a model that simulates the mean (and maximum) water temperature for some period of days. (One day is the minimum time period, and theoretically, there is no maximum, although a month is likely the upper pragmatic limit.) SSTEMP looks at the world as if all the inputs represent an average day for the time period. For this reason, SSTEMP also assumes that a parcel of water entering the top of the study segment will have the opportunity to be exposed to a full day's worth of heat flux by the time it exits the downstream end. If this is not true, the time period must be lengthened.

. . . suppose your stream has an average velocity of 0.5 meters per second and you want to simulate a 10 km segment. With 86,400 seconds in a day, that water would travel 43 km in a day's time. As this far exceeds your 10 km segment length, you can simulate a single day if you wish. But if your stream's velocity were only 0.05 mps, the water would only travel 4.3 km, so the averaging period for your simulation must be at least 3 days to allow that water to be fully influenced by the average conditions over that period. If, however, most conditions (flow, meteorology) are really relatively stable over the 3 days, you can get by with simulating a single day. Just be aware of the theoretical limitation.

i. Remember that SSTEMP does not and cannot deal with cumulative effects. For example, suppose you are gaming with the riparian vegetation shade's effect on stream temperature. Mathematically adding or deleting vegetation is not the same as doing so in real life, where such vegetation may have subtle or not so subtle effects on channel width or length, air temperature, relative humidity, wind speed, and so on. . .

6.3.2.1 Temperature Allocations as Determined by % Total Shade and Width-to-Depth Ratios

Table 6.2 details model run outputs for segments on the Rio Ruidoso. SSTEMP was first calibrated against thermograph data to determine the standard error of the model. Initial conditions were determined. As the percent total shade was increased and the Width's A term was decreased, the maximum 24-hour temperature decreased until the segment-specific standard of 20ºC was achieved. The calculated 24-hour solar radiation component is the maximum solar load that can occur in order to meet the WQS (i.e., the target capacity). In order to calculate the actual LA, the WLA and MOS were subtracted from the target capacity (TMDL) following **Equation 2**.

$$WLA + LA + MOS = TMDL \qquad \text{(Eq. 2)}$$

The allocations for each assessment unit requiring a temperature TMDL are provided in the following tables.

Temperature Load Allocation for Rio Ruidoso (US Highway 70 to Mescalero boundary)

The two densitometer readings for this assessment unit varied widely and there has been noted urbanization and development in this watershed after the aerial photographs were taken, so the starting "% shade" value was estimated on the low end of the scale. For Rio Ruidoso (US Highway 70 to Mescalero boundary), the WQS for temperature is achieved when the percent total shade is increased to 15%. According to the SSTEMP model, the actual LA of 72.86 j/m^2/s is achieved when the shade is further increased to 23.5% (Table 6.2).

Table 6.2 SSTEMP Model Results for Rio Ruidoso (US Highway 70 to Mescalero boundary)

<table>
<tr><th>Rosgen Channel Type</th><th>WQS (HQCWF)</th><th>Model Run Dates</th><th>Segment Length (miles)</th><th>Solar Radiation Component per 24-Hours (+/-)</th><th>% Total Shade</th><th>Width's A Term</th><th>Modeled Temperature °C (24 hour)</th></tr>
<tr><td>C5/B4C/ B3</td><td>20°C (68°F)</td><td>8/9/03</td><td>12.4</td><td>Current Field Condition
+127.72
joules/m^2/s</td><td>7</td><td>10.69</td><td>Minimum: 15.04
Mean: 17.64
Maximum: 20.24</td></tr>
<tr><td colspan="4" rowspan="3">TEMPERATURE ALLOCATIONS FOR (US Highway 70 to Mescalero boundary)

$^{(a)}$ 24-HOUR ACHIEVEMENT OF SURFACE WQS FOR TEMPERATURE

$^{(b)}$ 24-HOUR LOAD ALLOCATION (LA) NEEDED TO ACHIEVE SURFACE WQS WITH A 10% MARGIN OF SAFETY

Actual reduction in solar radiation necessary to meet surface WQS for temperature:

Current Condition – Load Allocation =

127.72 joules/m^2/s – 105.07 joules/m^2/s

=22.65 joules/m^2/s</td><td>Run 1
+123.60
joules/m^2/s</td><td>10</td><td>10.69</td><td>Minimum: 15.04
Mean: 17.58
Maximum: 20.13</td></tr>
<tr><td>Run 2
+116.74 $^{(a)}$
joules/m^2/s</td><td>15</td><td>10.69</td><td>Minimum: 15.03
Mean: 17.49
Maximum: 19.96</td></tr>
<tr><td>Actual LA
105.07 $^{(b)}$
joules/m^2/s</td><td>23.5</td><td>10.69</td><td>Minimum: 15.01
Mean: 17.33
Maximum: 19.64</td></tr>
</table>

According to the Sensitivity Analysis feature of the model runs, mean daily air temperature had the greatest influence on the predicted outflow temperatures and total shade values have the greatest influence on temperature reduction. However, reducing Width's A term had an insignificant effect on the predicted maximum temperature. The relationship between air and water temperature can be seen in Figures 6.4 and 6.5. The figures display the air and water thermograph readings on the day with the highest recorded water temperature (as well as the day before and the day after) at sites in both an impaired (Figure 6.4) and unimpaired assessment unit (Figure 6.5). The impaired reach experienced diurnal swings of 10ºC while the unimpaired reach reach only experienced a diurnal swing of 5ºC and both reaches experienced essentially the same air temperature.

The estimate of total shade used in the model calibration was based on densiometer readings and examination of aerial photographs (see **Appendix H**). Target loads as determined by the modeling runs are summarized in Tables 6.2 and 6.3. The MOS is estimated to be 10% of the target load calculated by the modeling runs. Results are summarized in Table 6.4. Additional details on the MOS chosen are presented in Section 6.7 below.

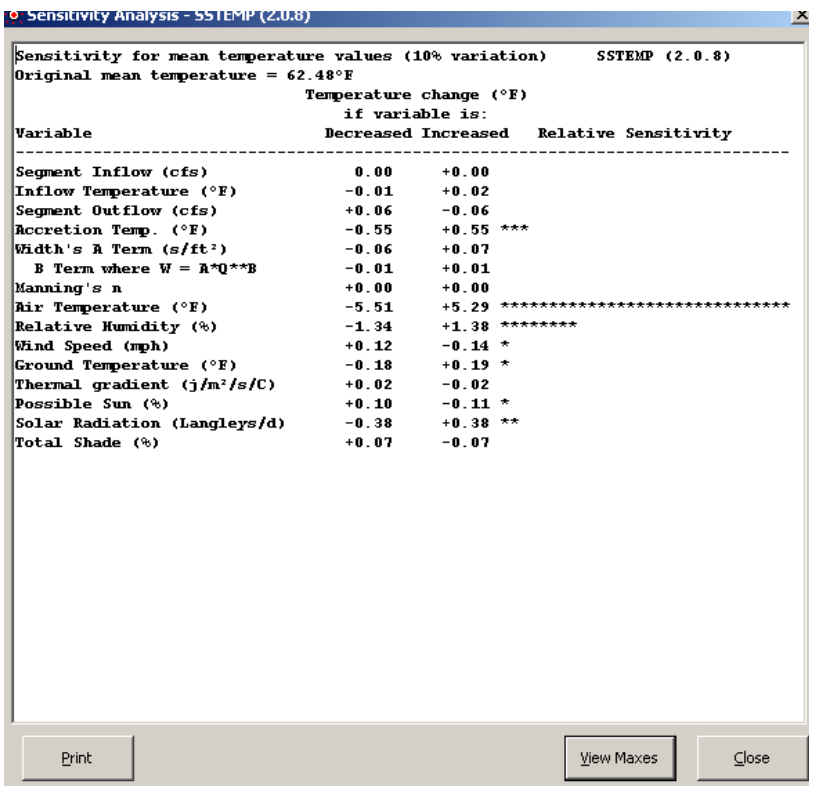

Figure 6.3 Example of SSTEMP sensitivity analysis for Rio Ruidoso

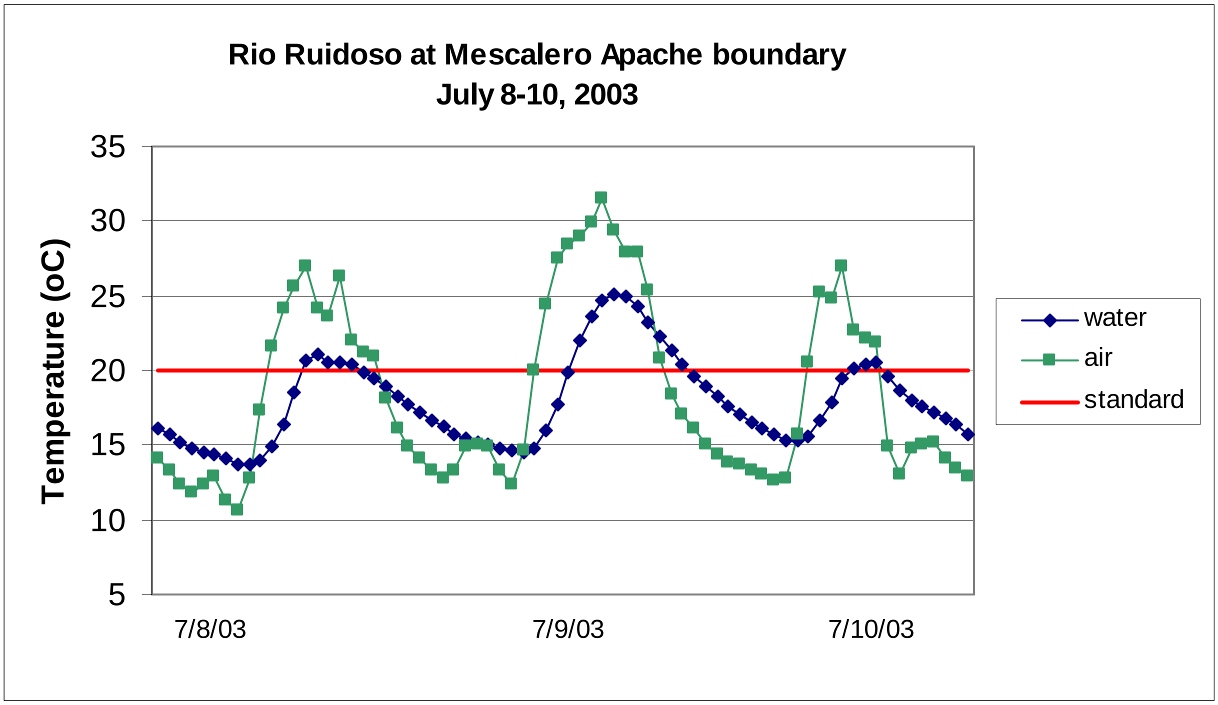

Figure 6.4 Air and water thermograph data for Rio Ruidoso

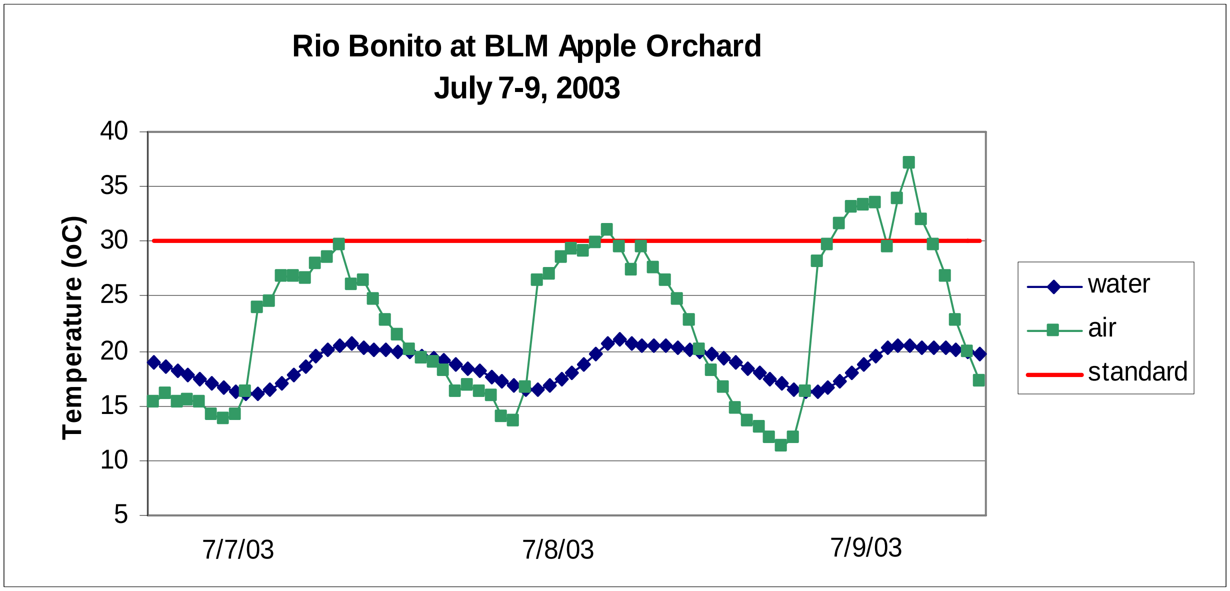

Figure 6.5 Air and water thermograph data for Rio Bonito

Table 6.3 Calculation of TMDLs for Temperature

Assessment Unit	WLA ($j/m^2/s$)	LA ($j/m^2/s$)	MOS (10%)[(a)] ($j/m^2/s$)	TMDL ($j/m^2/s$)
Rio Ruidoso (US Highway 70 to Mescalero Apache boundary)	0	105*	11.7*	117*

Notes:
[(a)] Actual MOS values may be slightly greater than 10% because the final MOS is back calculated after the Total Shade value is increased enough to reduce the modeled solar radiation component to a value less than the target load minus 10%.
* Values rounded to three significant figures.

The load reductions that would be necessary to meet the target loads were calculated to be the difference between the calculated target load and the measured load (i.e., current field condition in Tables 6.2 and 6.3), and are shown in Table 6.4.

Table 6.4 Calculation of Load Reduction for Temperature

Location	Target Load[(a)] ($j/m^2/s$)	Measured Load ($j/m^2/s$)	Load Reduction ($j/m^2/s$)	Percent Reduction[(b)]
Rio Ruidoso (US Highway 70 to Mescalero Apache boundary)	105*	128*	22.7*	18.0

Note: The MOS is not included in the load reduction calculations because it is a set aside value which accounts for any uncertainty or variability in TMDL calculations and therefore should not be subtracted from the measured load.
(a) Target Load = LA + WLA
(b) Percent reduction is the percent the existing measured load must be reduced to achieve the target load, and is calculated as follows: (Measured Load – Target Load) / Measured Load x 100.
* Values rounded to three significant figures.

6.4 Identification and Description of pollutant source(s)

Pollutant sources that could contribute to each segment are listed in Table 6.5.

Table 6.5 Pollutant source summary for Temperature

Pollutant Sources	Magnitude[(a)]	Location	Potential Sources[(b)] (% from each)
Point:			
None	0	--------	0%
Nonpoint:			
	128	Rio Ruidoso	100% Loss of riparian habitat Municipal Point Source Discharges On-site treatment systems (septic systems and similar decentralized systems) Rangeland grazing Site clearance (land development and redevelopment) Streambank modifications/destabilization Agriculture pastureland, animal holding areas, channelization, flow regulation (fieldnotes)

Notes:

[(a)] Measured Load as $j/m^2/s$
[(b)] From the 2004-2006 Integrated CWA §303(d)/305(b) list unless otherwise noted.
[(c)] Expressed as solar radiation.

6.5 Linkage of Water Quality and Pollutant Sources

Water temperature influences the metabolism, behavior, and mortality of fish and other aquatic organisms. Natural temperatures of a waterbody fluctuate daily and seasonally. These natural fluctuations do not eliminate indigenous populations, but may affect existing community structure and geographical distribution of species. In fact, such temperature cycles are often necessary to induce reproductive cycles and may regulate other aspects of life history (Mount 1969). Behnke and Zarn (1976) in a discussion of temperature requirements for endangered western native trout recognized that populations cannot persist in waters where maximum temperatures consistently exceed 21-22°C, but they may survive brief daily periods of higher temperatures (25.5-26.7°C). Anthropogenic impacts can lead to modifications of these natural temperature cycles, often leading to deleterious impacts on the fishery. Such modifications may contribute to changes in geographical distribution of species and their ability to persist in the presence of introduced species. Of all the environmental factors affecting aquatic organisms in a waterbody, many either present or not present, temperature is always a factor. Heat, which is a quantitative measure of energy of molecular motion that is dependent on the mass of an object or body of water is fundamentally different than temperature, which is a measure (unrelated to mass) of energy intensity. Organisms respond to temperature, not heat.

Temperature increases, as observed in SWQB thermograph data, show temperatures that exceed the State Standards for the protection of aquatic habitat, namely the HQCWF designed uses. Through monitoring, and pollutant source documentation, it has been observed that the most probable cause for these temperature exceedences are due to the alteration of the stream's hydrograph, removal of riparian vegetation, livestock grazing, and natural causes. Alterations can be historical or current in nature.

A variety of factors impact stream temperature (Figure 6.4). Decreased effective shade levels result from reduction of riparian vegetation. When canopy densities are compromised, thermal loading increases in response to the increase in incident solar radiation. Likewise, it is well documented that many past hydromodification activities have lead to channel widening. Wider stream channels also increase the stream surface area exposed to sunlight and heat transfer. Riparian area and channel morphology disturbances are attributed to past and to some extent current rangeland grazing practices that have resulted in reduction of riparian vegetation and streambank destabilization. These nonpoint sources of pollution primarily affect the water temperature through increased solar loading by: (1) increasing stream surface solar radiation and (2) increasing stream surface area exposed to solar radiation.

Riparian vegetation, stream morphology, hydrology, climate, geographic location, and aspect influence stream temperature. Although climate, geographic location, and aspect are outside of human control, the condition of the riparian area, channel morphology and hydrology can be affected by land use activities. Specifically, the elevated summertime stream temperatures attributable to anthropogenic causes in the Rio Hondo watershed result from the following conditions:

1. Channel widening (i.e., increased width to depth ratios) that has increased the stream surface area exposed to incident solar radiation,
2. Riparian vegetation disturbance that has reduced stream surface shading, riparian vegetation height and density, and
3. Reduced summertime base flows that result from instream withdrawals and/or inadequate riparian vegetation. Base flows are maintained with a functioning riparian system so that loss of a functioning riparian system may lower and sometimes eliminate baseflows. Although removal of upland vegetation has been shown to increase water yield, studies show that removal of riparian vegetation along the stream channel subjects the water surface and adjacent soil surfaces to wind and solar radiation, partially offsetting the reduction in transpiration with evaporation. In losing stream reaches, increased temperatures can result in increased streambed infiltration which can result in lower base flow (Constantz et al. 1994).

Analyses presented in these TMDLs demonstrate that defined loading capacities will ensure attainment of New Mexico WQS. Specifically, the relationship between shade, channel dimensions, solar radiation, and water quality attainment was demonstrated. Vegetation density increases will provide necessary shading, as well as encourage bank-building processes in severe hydrologic events.

Where available data are incomplete or where the level of uncertainty in the characterization of sources is large, the recommended approach to TMDL assignments requires the development of allocations based on estimates utilizing the best available information.

SWQB fieldwork includes a determination of the potential sources of impairment (NMED/SWQB 1999). The completed Pollutant Source(s) Documentation Protocol forms in **Appendix C** provide documentation of a visual analysis of probable sources along an impaired reach. Although this procedure is subjective, SWQB feels that it provides the best available information for the identification of potential sources of impairment in this watershed. Table 7.6 identifies and quantifies potential sources of nonpoint source impairments along each reach as determined by field reconnaissance and assessment. It is important to consider not only the land directly adjacent to the stream, but also to consider upland and upstream areas in a more holistic watershed approach to implementing this TMDL.

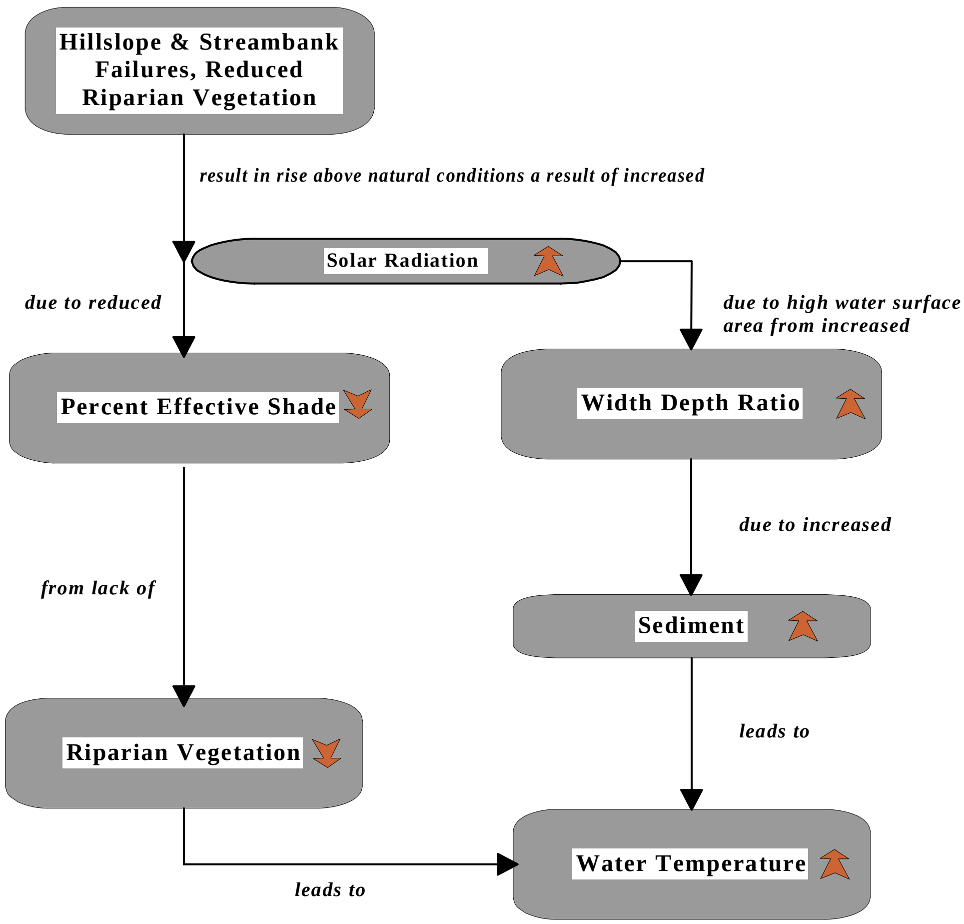

Figure 6.6 Factors That Impact Water Temperature

6.6 Margin of Safety (MOS)

The Federal CWA requires that each TMDL be calculated with a MOS. This statutory requirement that TMDLs incorporate a MOS is intended to account for uncertainty in available data or in the actual effect controls will have on loading reductions and receiving water quality. A MOS may be expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL (e.g., derivation of numeric targets, modeling assumptions or effectiveness of proposed management actions). The MOS may be implicit, utilizing conservative assumptions for calculation of the loading capacity, WLAs and LAs. The MOS may also be explicitly stated as an added separate quantity in the TMDL calculation.

For this TMDL, there were no MOS adjustments for point sources since there are none.

In order to develop this temperature TMDL, the following conservative assumptions were used to parameterize the model:

- Data from the warmest time of the year were used in order to capture the seasonality of temperature exceedences.
- Critical upstream and downstream low flows were used because assimilative capacity of the stream to absorb and disperse solar heat is decreased during these flow conditions.
- Low flow was modeled using formulas developed by the USGS. One formula (Thomas et al. 1997) is recommended when the ratio between the gaged watershed area and the ungaged watershed area is between 0.5 and 1.5. When the ratio is outside of this range, a different regression formula is used (Waltemeyer 2002). See **Appendix H** for details.

As detailed in **Appendix H,** a variety of high quality hydrologic, geomorphologic, and meteorological data were used to parameterize the SSTEMP model. Because of the high quality of data and information that was put into this model and the continuous field monitoring data used to verify these model outputs, an explicit MOS of 10% is assigned to this TMDL.

6.7 Consideration of seasonal variation

Section 303(d)(1) of the CWA requires TMDLs to be "established at a level necessary to implement the applicable WQS with seasonal variation." Both stream temperature and flow vary seasonally and from year to year. Water temperatures are coolest in winter and early spring months.

Thermograph records show that temperatures exceed State of New Mexico WQS in summer and early fall. Warmest stream temperatures corresponded to prolonged solar radiation exposure, warmer air temperature, and low flow conditions. These conditions occur during late summer and early fall and promote the warmest seasonal instream temperatures. It is assumed that if critical conditions are met, coverage of any potential seasonal variation will also be met.

6.8 Future Growth

Growth estimates by county are available from the New Mexico Bureau of Business and Economic Research. These estimates project growth to the year 2030. Growth estimates for Lincoln County project a 52% growth rate through 2030. Since future projections indicate that Nonpoint sources will more than likely increase as the region continues to grow and develop, it is imperative that BMPs continue to be utilized and improved upon in this watershed while continuing to improve road conditions and grazing allotments and adhering to SWPPP requirements related to activities convered under general permits.