Little River
Stream Temperature Model

DEQ Western Region

December, 2001

DEQ

State of Oregon
Department of Environmental Quality

Survey Purpose

Field measured data (collected on 9/14/95) was used to calibrate a stream temperature model, *Heat Source 6.0*. Current monitoring data sets strive to collect data during the time of maximum solar loading (plus or minus two weeks from August 1st). The Little River data set was collected several years before Heat Source 6.0 was available, and had been optimized to collect data during the summer's lowest stream flows. Two simulations, one using the peak solar loading of August 1st and another using mid-September solar loading, showed essentially no difference in the resulting stream temperature profile. Therefore, calibrating to the mid-September time frame should introduce little, if any, additional error to the analysis.

The model uses field measurements and model-derived parameters as inputs to simulate how stream temperatures respond to unique conditions within the watershed. Once the model parameters have been balanced so that the simulation accurately describes the conditions measured in the field (the calibration step), reasonable and obtainable "future conditions" are entered into the model. The model recalculates the amount of energy reaching the stream and estimates stream temperatures based on those future condition(s) simulated. Equilibrium conditions are calculated for each of the 432 segments that make up the Little River model (segments are 100 meters long).

Two additional reaches, a short section of Jim Creek and the lower 12 miles of Cavitt Creek, were also instrumented. See Map 1 for the extent of the Little River watershed that was modeled. Both reaches wound up with only one upstream one downstream temperature logger data set (some instruments were stolen during the summer). Because of the lack of middle data sets to aid calibration, these simulations will not be presented in detail. However, the simulated stream temperatures at the downstream location (the tributary mouth) **were** used as inputs for the Little River future condition simulations (See Figures 19a and 19b).

Two future conditions for Little River were modeled: the "System Potential" condition and the "Current Management Potential" condition, described below.

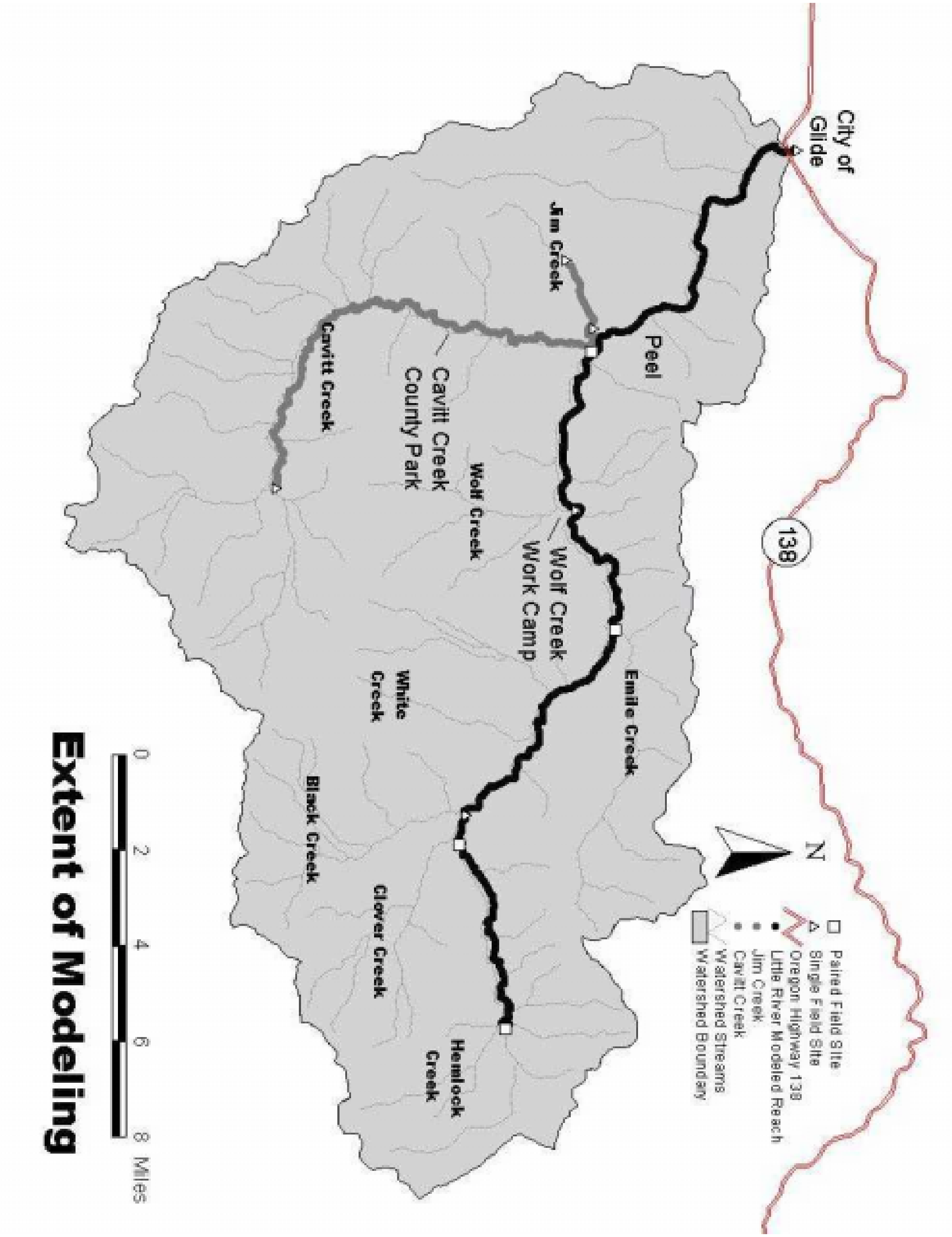
System Potential

This condition assumes a watershed where all shade producing vegetation has grown to its maximum height and density for these soils, rainfall and ecoregion (simulation assumes 140' trees and 76% shade density). The width of the shade buffer is wider than that required to achieve maximum shade values. System potential does not assume any changes in vegetation due to human activities. This "System Potential" simulation also assumes that all channel parameters and flow profiles were unchanged from the calibration condition.

Current Management Potential

Simulation of this scenario is an attempt to understand how our present management options will affect temperature if implemented. This simulation assumes that trees will grow just as high and dense as in the shade potential simulation, but that any shade buffer width is constrained by present zoning setbacks and special management zones (Oregon Forest Practices Act, Northwest Forest Plan). The actual widths used in the simulation are outlined in the Shade Width section. Channel parameters and flow profiles were also unchanged from those used in the calibration process.

Data used in the modeling were of high quality, and the model calibrated easily with the data, so there is confidence in the model simulation results. But, like any model that attempts to "look into the future," there is likely to be a disparity between what is predicted and what will actually come to pass. Our understanding of the processes that determine stream temperature are imperfect, and any predictions using them are similarly imperfect. Any resulting simulation of the future is less a blueprint with survey point accuracy than a roadmap that identifies only the most obvious landmarks. Roadmaps, however, are useful for planning a journey and navigating to a destination. While only the broadest suggestions of possible management strategies are suggested by the model, they should point us in the right direction.


City of Glide
Jim Creek
Peel
Cavitt Creek County Park
Cavitt Creek
Wolf Creek
Wolf Creek Work Camp
138
Emile Creek
White Creek
Black Creek
Clover Creek
Hemlock Creek
N
Paired Field Site
Single Field Site
Oregon Highway 138
Little River Modeled Reach
Jim Creek
Cavitt Creek
Watershed Streams
Watershed Boundary
0 2 4 6 8 Miles
Extent of Modeling

Map 1

Methods for Field Data Collection

Temperature Sets

Hourly instantaneous stream temperatures were taken throughout the summer at six locations within the Little River mainstem and six tributary locations (see Map 1 for locations) using calibrated and audited logging devices. The term “paired site” means that there was a logger placed both in the mainstem upstream of the tributary and near the tributary mouth Each logger data set was reviewed, and it was determined that the data from 9/14/95 was most suitable to a basin-wide Heat Source simulation. Each data set, if required, was thinned to 24 hourly observations for the day.

Stream Discharge Measurements

Flow measurements were taken at all 12 mainstem and tributary sites within two days of September 14th. Measurements were via hand-held current meters. Measurement transects were chosen in areas with wadeable cross-sections and good stream velocities. Each transect consisted of a minimum of 10 individual measurements.

Stream/Shade Conditions

Riparian characteristics relating to shade quality and quantity were measured from aerial photography, digital imagery and on site field measurements. The shading values so calculated were: shade height, shade belt width, shade density and shade overhang. Values assumed for the two “future condition” simulations were based on forest characteristics appropriate to this ecoregion, soil class, species composition and expected tree density. Channel wetted width was also measured via field observations.

Model Inputs

Elevation/Gradient

Elevations were obtained from digital elevation information (Digital Elevation Model - DEM - type data). The elevation of the upstream and downstream point of each reach segments was derived. These elevations were related to the elapsed reach lengths so that elevation and gradient profiles could be calculated. See Figures 1 & 2.

Figure 1

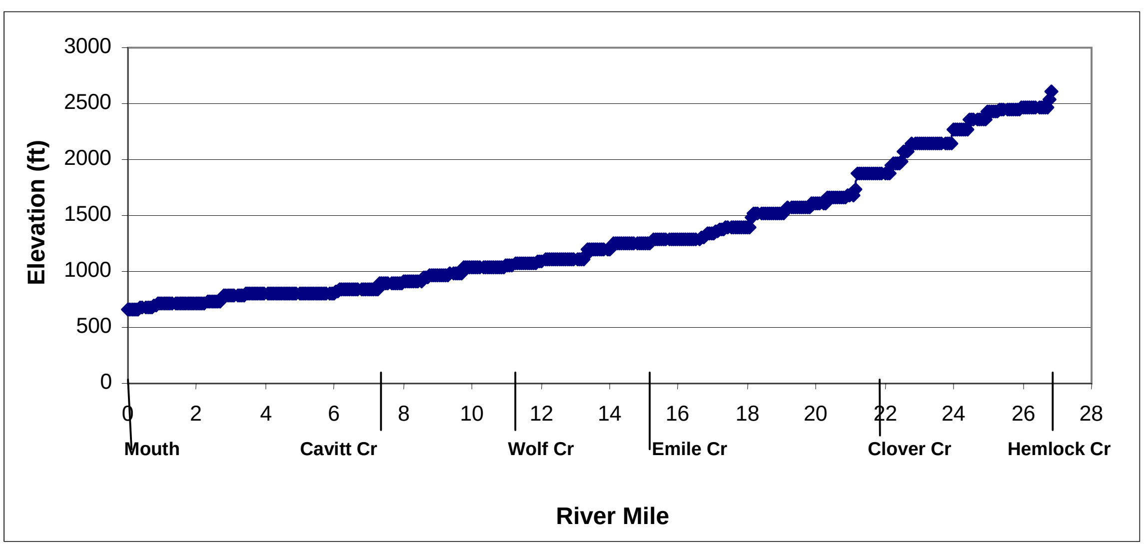
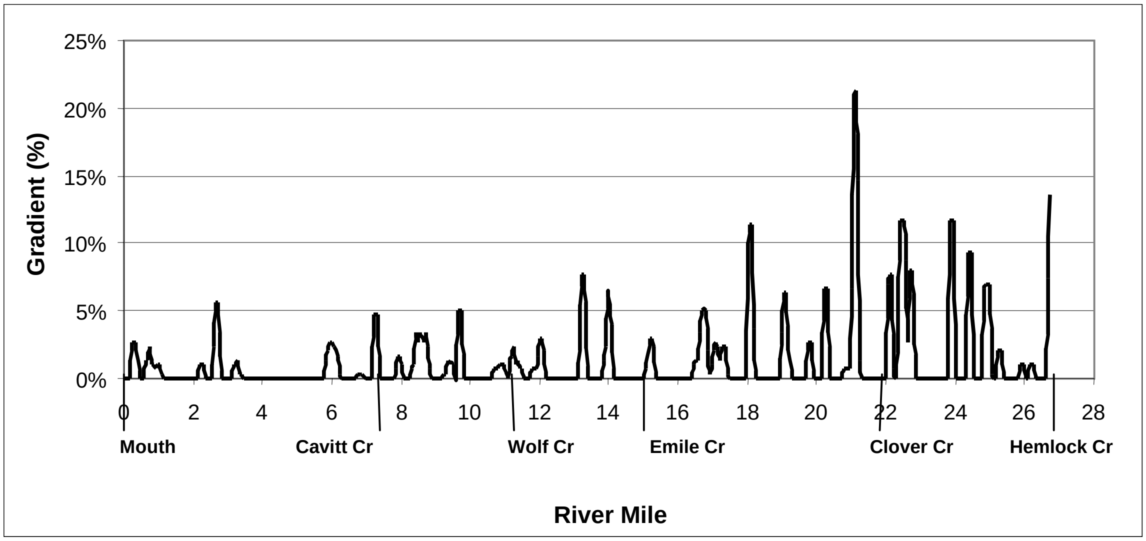


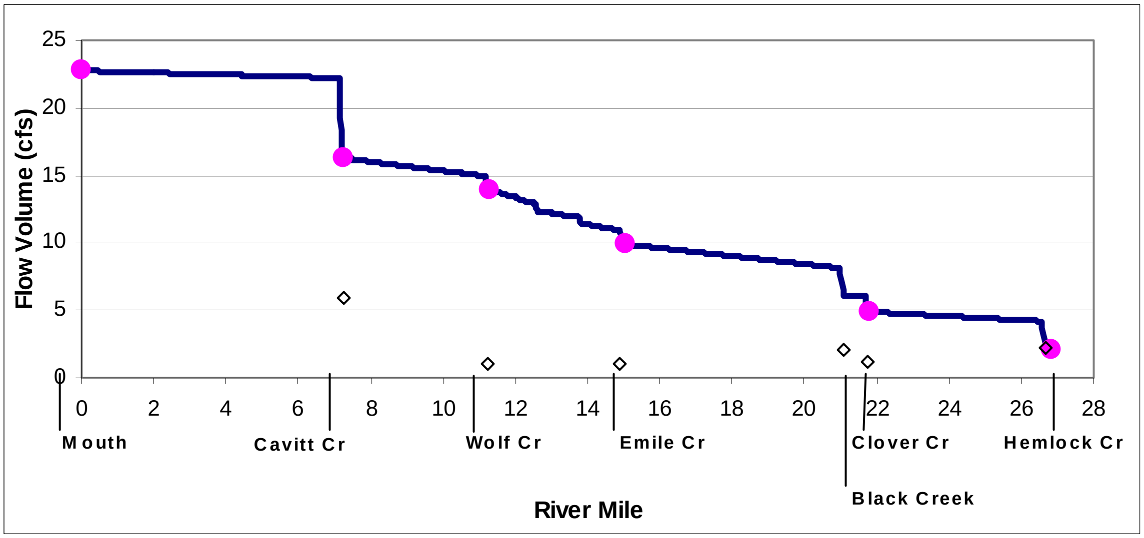
Figure 2



Flow Volume

Flow was measured on the mainstem at the sites shown in Figure 3 as solid dots. Flow measured at tributary mouths is shown as open diamonds. Flows downstream of each tributary are calculated by adding the mainstem flow to the tributary flow. Intervening flow was extrapolated so that a complete flow profile could be constructed.

Figure 3



Significant flow in the Little River Watershed is allocated for irrigation and domestic use. The modeled section of the main stem of Little River currently has legal water diversions of up to 9.5 cfs in flow. The tributaries along this reach potentially divert an additional 18.5 cfs. Not all of these points withdraw their full allocation all the time. These points of diversion along the modeled reach are identified in the map shown below. No attempt was made to identify which diversions were active during the week that flows in Little River were measured. Figure 4 shows how much flow is potentially diverted between each mile of river. This gives an idea as to which sections of the modeled reach might be most prone to fluctuations in flow during the calibration phase and in the future condition predictions.

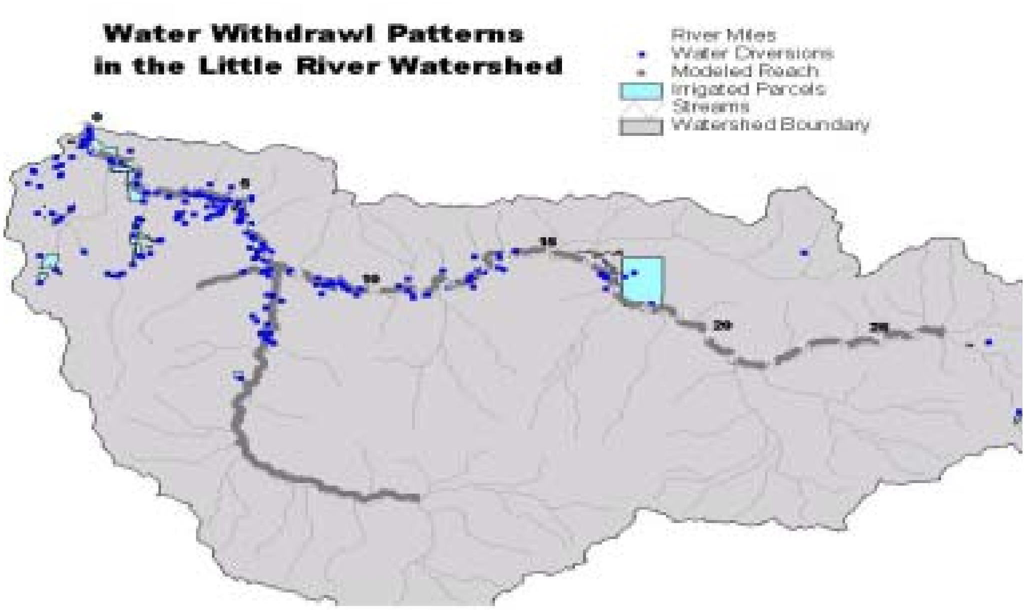
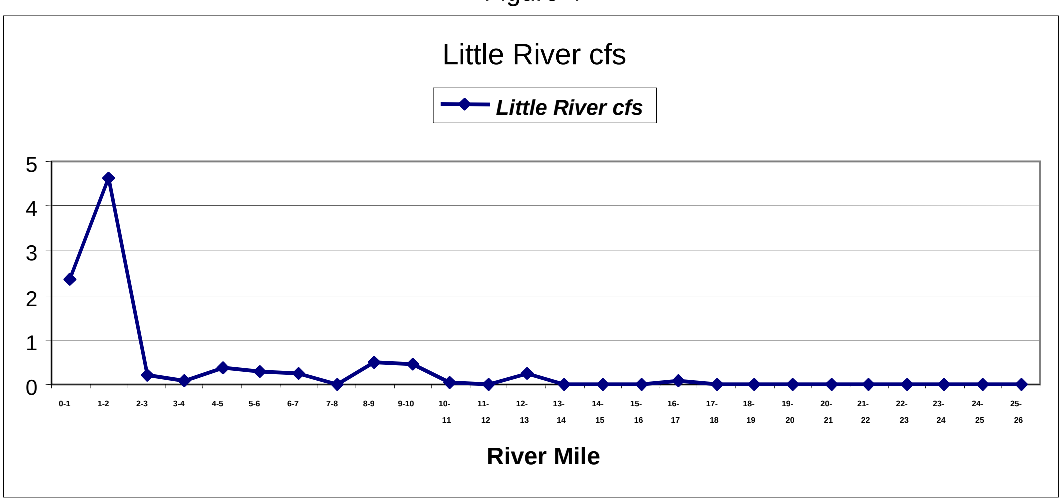


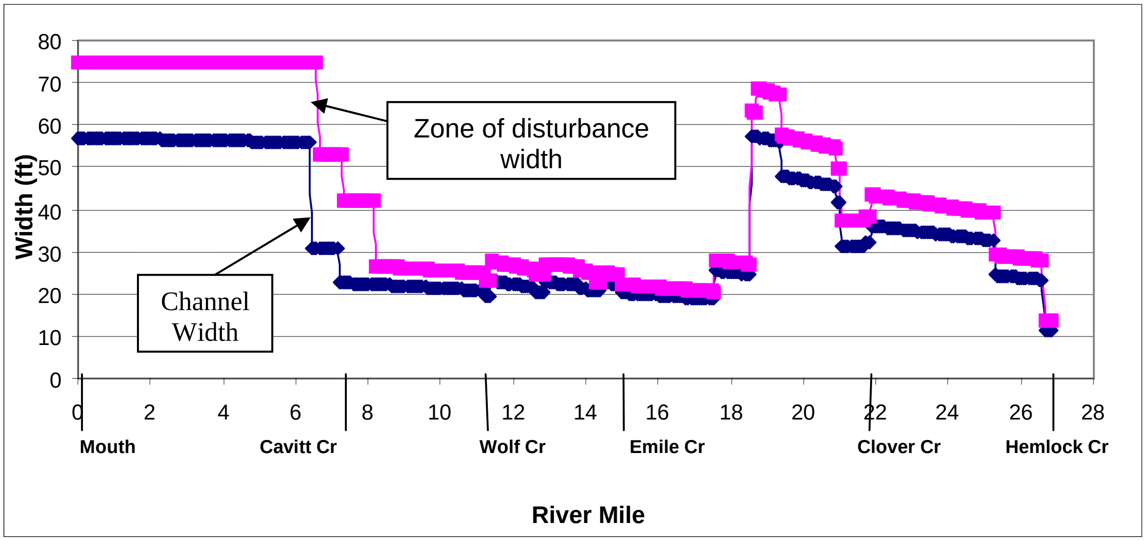
Figure 4



Channel Wetted Width / Zone of Disturbance Width

Channel width (upper line) was measured in the field or scaled off of conventional or digital photos. The zone of disturbance width (lower line) was scaled from aerial photos. The zone of disturbance is defined as the distance between the shade-producing areas on either bank. Figure 5 shows the width profiles used in the model.

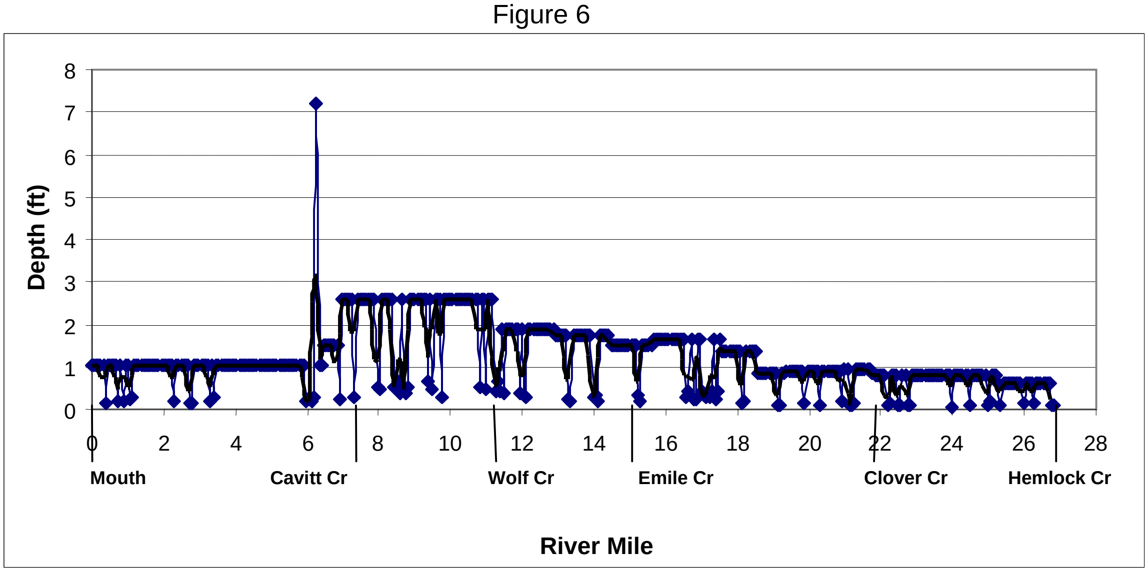
Figure 5



Average Depth

Average depth for each segment was calculated from the flow volume and wetted width values used for that segment. Figure 6 shows the average depth profile used in the model. The spike seen near river mile 6 corresponds to a mainstem impoundment at Peel.

Figure 6



Flow Velocity

Average velocity for each segment was calculated from the channel geometry, segment slope and Manning's "n" used for that segment. The velocity profile is shown in Figure 7. Figure 8 shows the assumed time of travel along the modeled reach using the flow velocities seen in Figure 7.

Figure 7

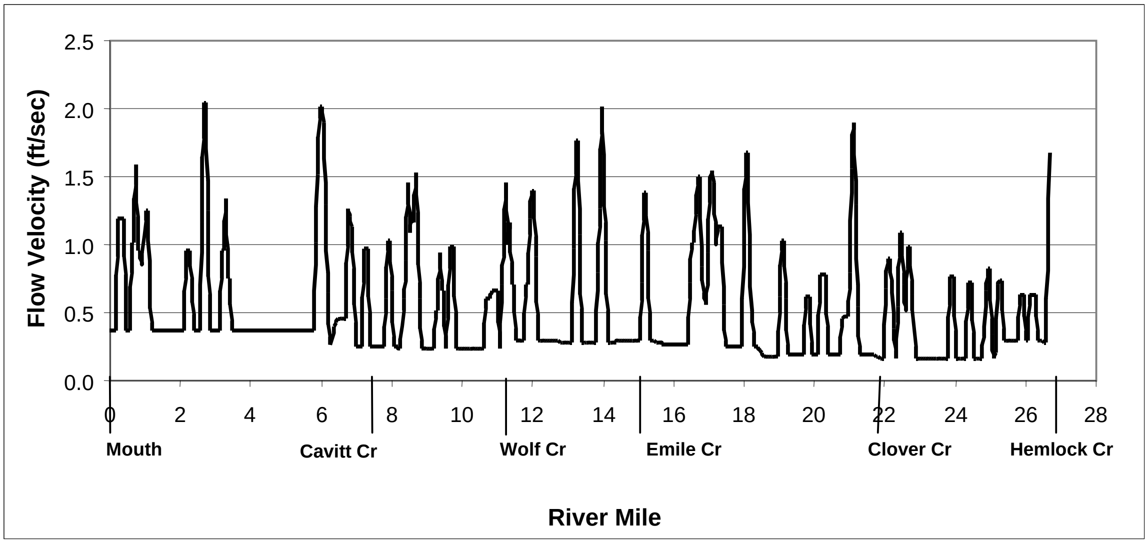
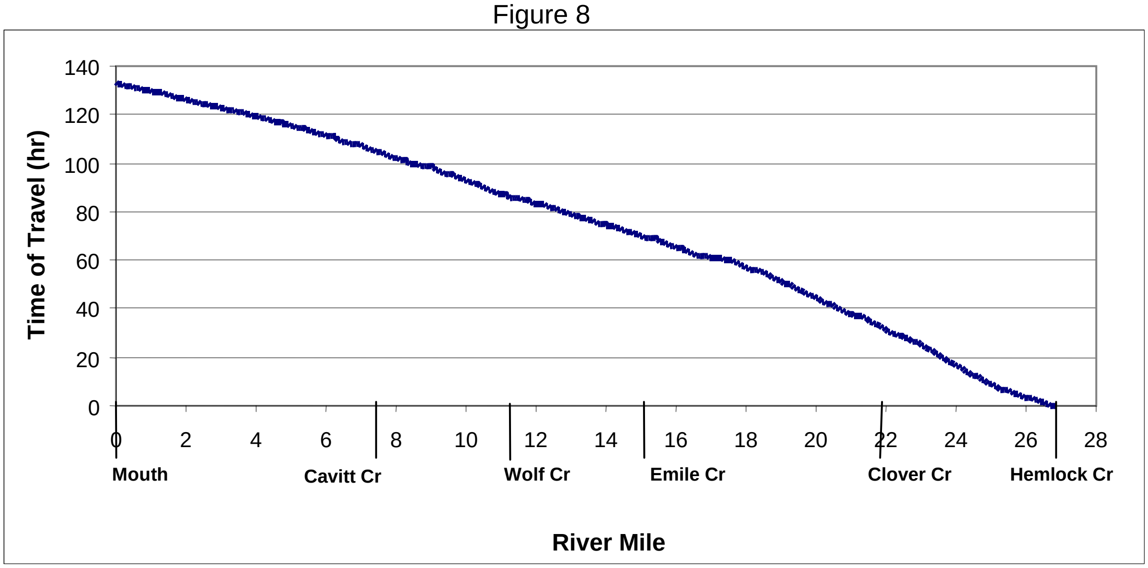


Figure 8



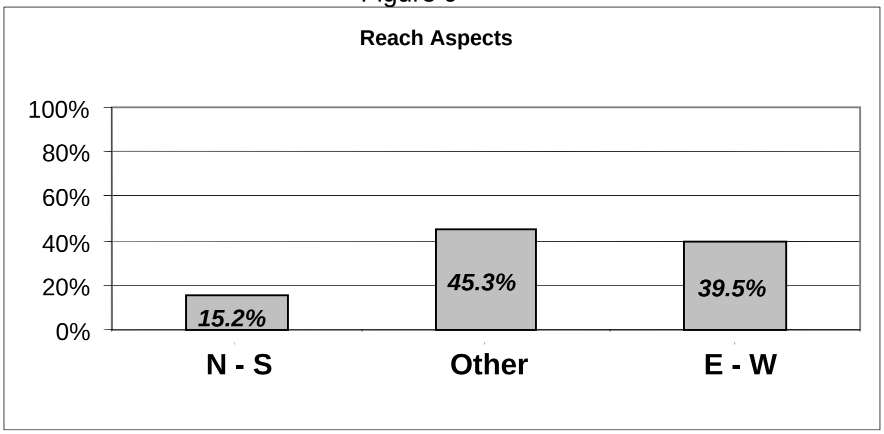
Channel Substrate

Channel substrate larger that cobble size can absorb solar energy and release it during the night. The Little River mainstem channel above Wolf Creek was assumed to have a 10% cobble or larger composition. Little River below Wolf Creek was assumed to have 50% cobble or larger composition.

Stream Aspect

Figure 9 shows the relative amount of the Little River main stem study reach headed in these general directions. Aspect is important because North – South streams are less influenced by riparian shading as a means of temperature control while East – West streams are greatly affected by riparian shade. Almost 85% of the stream miles along the Little River should have an average or better than average response to riparian shade for temperature control.

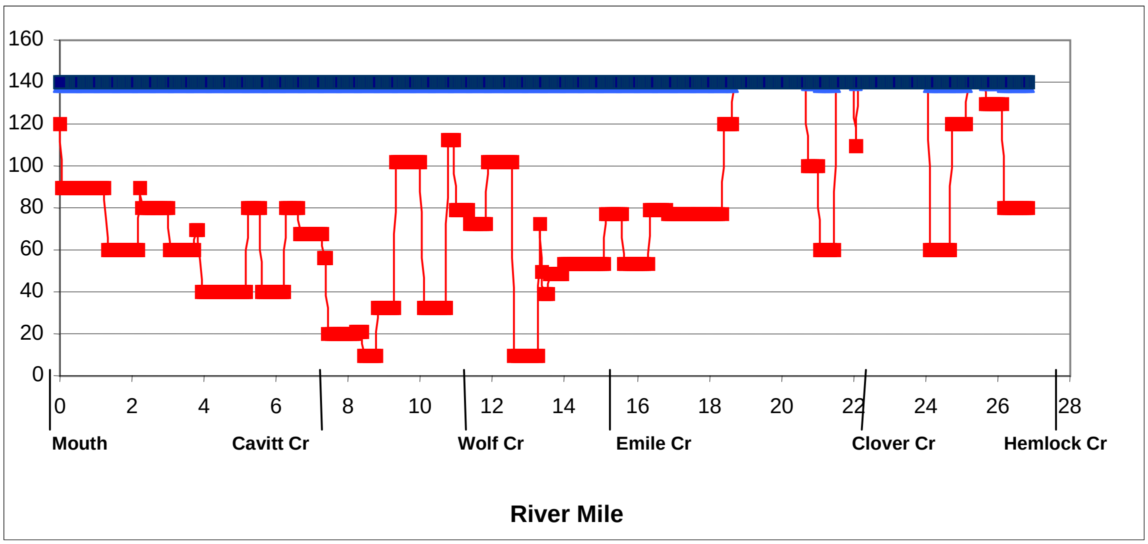
Figure 9



Shade Height

Shade height is one of three shade parameters that is assumed to change for the future condition simulations. The calibration condition for shade height, based on field measurements, is shown in Figure 10 as the lower (red) line. The assumed future condition for system potential is shown as the upper (blue) line. The shade height used for the current management potential condition (black) is essentially the same as for the system potential case.

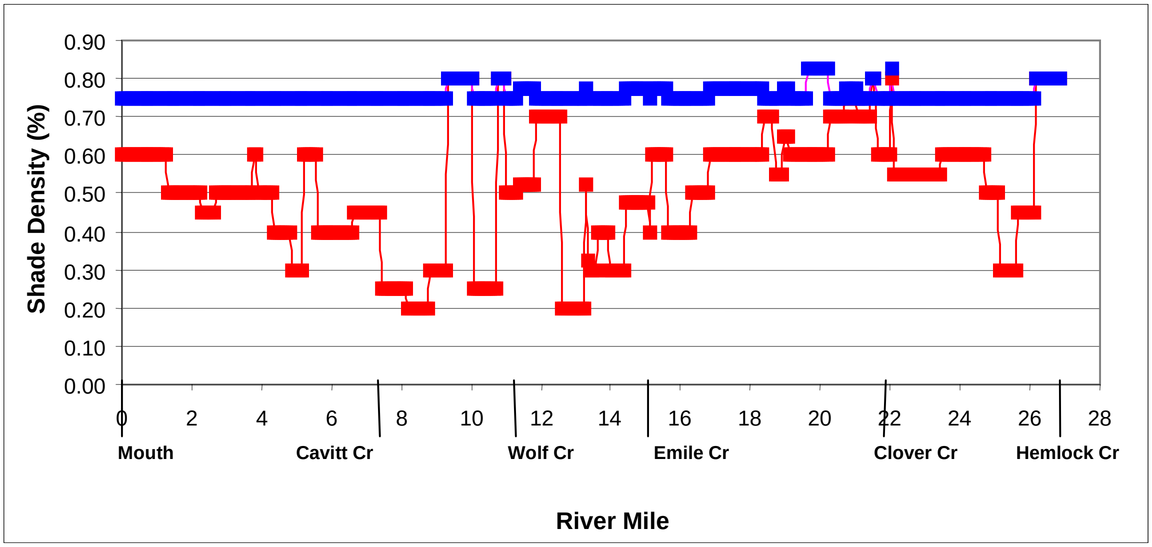
Figure 10



Shade Density

Shade density is also assumed to change in the future. The lower (red) line in figure 11 is field measured shade density as it exists today. The future shade densities, used in both the system potential and current management potential simulations are assumed to be uniform (top line in figure 11, centered at the 75% value). In some cases, the existing shade density is already greater than 75%. In these cases, the present value is used for both future simulations. Many future shade densities will likely be higher than 75%, so choosing this value will add a margin of safety to the future condition projections.

Figure 11



Shade Width

The current width of the shade producing zone was measured form aerial photographs. This average width is shown as the lower (red) line in figure 12. The assumed width for the current management potential condition is shown in figure 12 as the middle (blue) line. These widths were derived from the expected setbacks called for in present zoning classifications and special management areas. See Tables 1-3 for a tabulation of the widths used. Map 2 shows where these designations applied. The shade width used for the system potential simulation (top black line in figure 12) was 300'. This width was chosen because it is beyond the width needed to provide full shading. The actual width needed to provide full shade in any particular segment will depend on local conditions.

Figure 12

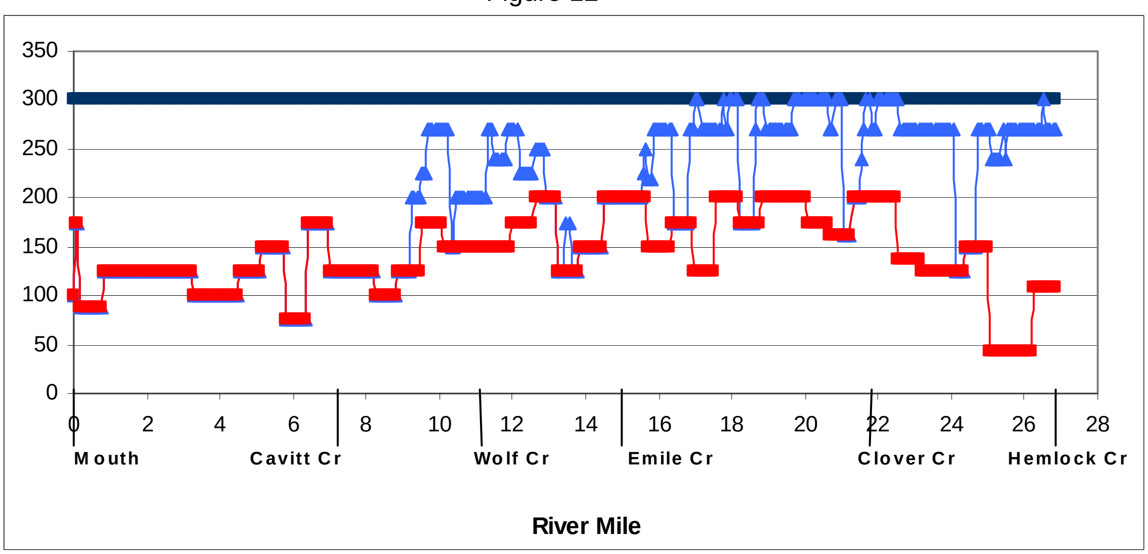


Table 1

Expected Future Shade Belt Widths Used in the Little River Model

Management Designation	Jim Creek	Cavitt Creek	Little River
Farm Forest	-	-	50'
Farm Grazing	-	-	50'
Forest Practices Act	70'	100'	100'
Northwest Forest Plan	-	300'	300'
Recreation Areas	-	250'	250'
Rural Residential	50'	50'	50'
City of Glide	-	-	25'

Notes:
Land Use classification derived from Douglas County and State of Oregon zoning maps.
All shade widths were reduced by 60' when a road was within 300' of the stream.
The present shaded width was used if greater than the expected future width.

Table 2

Total Stream Miles in each Land Use Designation

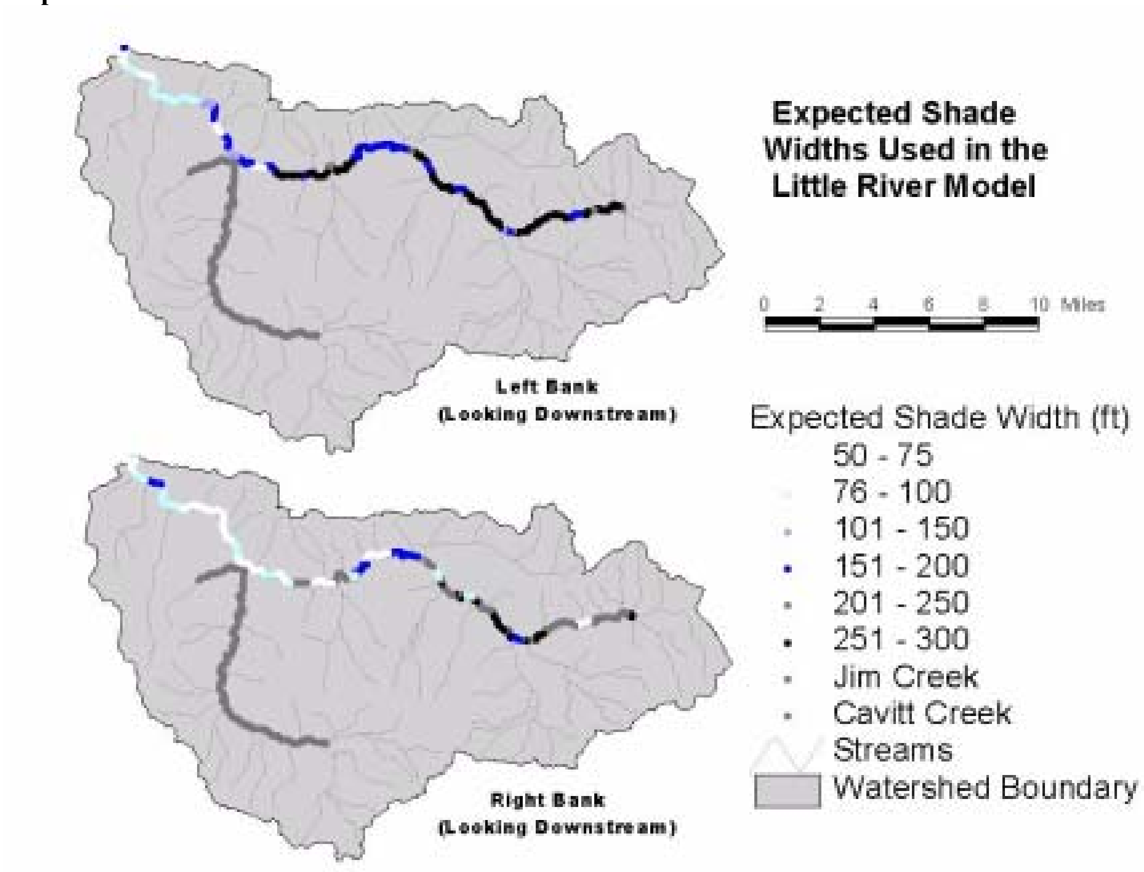
Management Designation	Jim Creek	Cavitt Creek	Little River
Farm Forest	-	-	0.9
Farm Grazing	-	-	3.2
Forest Practices Act	1.7	7.2	3.4
Northwest Forest Plan	-	1.1	12.1
Recreation Areas	-	0.7	0.2
Rural Residential	0.2	3.1	7.0
City of Glide	-	-	0.2
Total Miles Modeled	1.9	12.1	27.0

Table 3

Total Stream Miles Affected by Roads

Jim Creek	Cavitt Creek	Little River
0.0	2.2	16.6

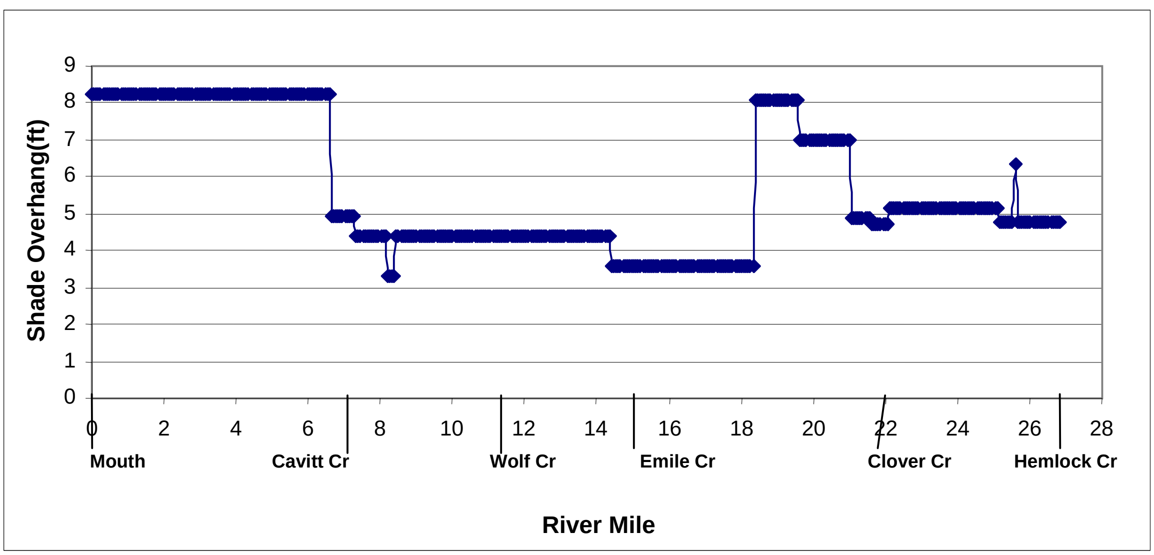
Map 2



Shade Overhang

The shade overhang profile used in the calibration conditions was used unchanged in both of the future condition simulations. Expected increases in shade overhang that are not used in the simulation result in an additional margin of safety in the analysis.

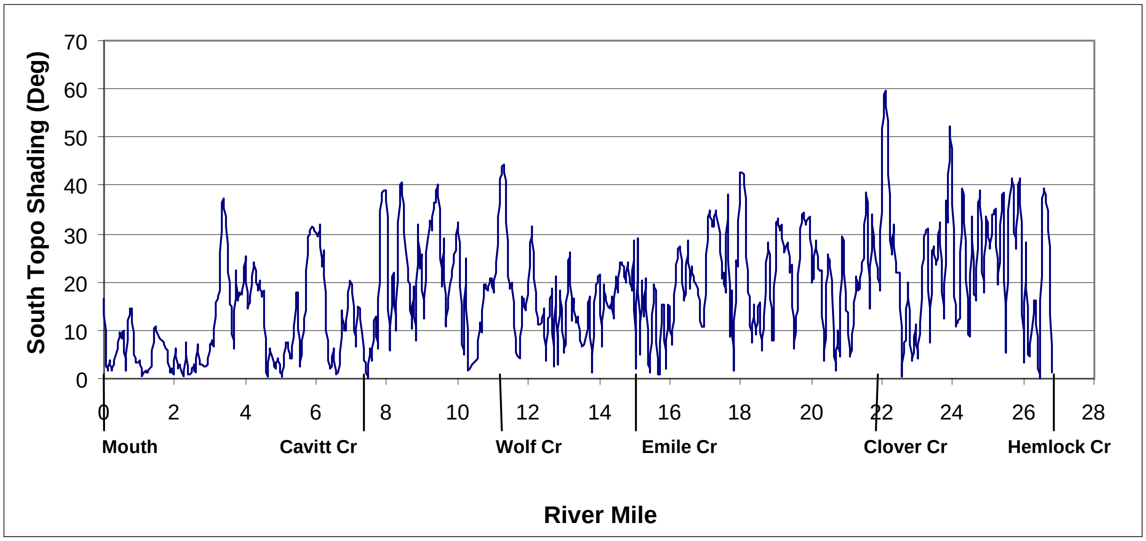
Figure 13



Topographic Shading

Topographic shading is defined as the shading provided to the stream by ridgelines or hills. It is extremely localized and unique for each system. Southern shading can result in an appreciable lowering of solar energy during the day. East/West shading effectively shortens the amount of daylight hours by delaying local sunrise or hastening local sunset. Figure 14 shows that many parts of Little River get a generous amount of topographic shading to the south.

Figure 14



Model Input Data Summary

Below is a summary of the model parameters used, how they were derived, and if that parameter was changed between the calibration and the future condition simulations. Parameters in italic type are those used for model calibration.

Data Class	Parameter	Method (measured/calculated)	Source	Future Condition Different from Calibration
Stream	Elevation	Measured	DEM Data	No
	Gradient	Calculated	GIS Utility	No
	Topographic Shade	Calculated	GIS Utility	No
	Stream Reach Aspect	Calculated	GIS Utility	No
Flow	Volume	Measured	Field Measurement	No
	Velocity	Measured/Calculated	*Model calculated To field data*	No
	Depth	Measured/Calculated	*Model calculated To field data*	No
Channel	Zone-of-Disturbance Width	Measured	Digital Photos	No
	Wetted Width	Measured/Calculated	Model calculated To field data	No
	Channel Substrate	Measured	Field Measurement	No

Shade	Height	Measured	Field Measurement	**Yes**
	Width	Measured	Field Measurement	Yes
	Density	Measured	Field Measurement	**Yes**
	Overhang	Measured	Field Measurement	No
Stream Temperature	Main Stem	Measured	Field Measurement	---
	Tributaries	Measured	Field Measurement	Yes
Weather	Humidity	Measured	Field Measurement	No
	Wind Speed	Measured	Field Measurement	No
	Air Temperature	Measured	Field Measurement	No

Model Calibration

All models require some calibration to make the computer simulation match the observed data. For this series of Heat Source simulations, the only parameters that changed during the calibration process were Manning's "n", average channel width and average channel depth. The average width/depth values, although not measured in each of the 432 segments, were compared to a handful of actual measurements (usually taken during flow volume measurements). Care was taken so that model-calculated values did not divert significantly from the field-observed values.

Any data obtained from field measurements or scaled from photos were used as recorded. Adjustments to the three calibration parameters ceased when the simulation output matched the observed field data. None of the calibration parameters were changed during the simulation of future conditions.

Most models are calibrated to one set of conditions. A unique feature of the Heat Source model is that it allows calibration simulations to be compared directly to observed stream temperature logged during an entire 24 hour day. This allows calibration to not only daily minimum and maximum values, but also the ability to fit modeled heating and cooling rates to observed data. For this study, the main-stem of Little River had six data loggers where simulated vs. observed data sets could be compared. A summary of how well the modeled set matched the field measured set is shown below. Each logger summary is based on 24 data pairs (one pair for each hour throughout the day).

Logger Location	Approximate River Mile	"r Squared" Value	Standard Deviation (Deg)	Standard Error (Deg)	
Upstream Hemlock	26.8	1.000	0.07	0.08	
Upstream Clover	21.8	0.844	4.62	0.33	
Upstream Emile	25.7	0.752	1.62	0.65	
Upstream Wolf	11.3	0.876	0.95	0.27	
Upstream Cavitt	7.3	0.842	1.51	0.45	
Mouth	0.0	0.758	1.00	0.72	
	Avg	0.845	1.628		Deg C
	Avg		2.931	0.750	Deg F

Reach-specific difficulty was experienced in the early stages of model calibration. Predicted temperatures were warmer than the instream logger observations, especially in the stretch between Emile and Wolf Creeks. In order to cool the predicted temperatures down, groundwater inputs to Little River were assumed within this section. Field investigation during the summer of 2000 found numerous groundwater sources entering Little River throughout this reach, supporting the assumption.

Model Output

Solar Flux

Figure 15 shows the total daily solar flux loading by river mile. The upper (black) line shows the total amount of solar energy available to the Little River system. The dips in available energy near river miles 22 and 24 are due to local topographic shading. The next line down (thick red) is the daily solar flux available for stream heating under current conditions. The next two lines down are projected loading expected for the two future condition simulations. The lowest line (thick dark blue) corresponds to the system potential condition. The thin line (light blue) between the system potential and current conditions is the projected solar loading for the current management potential condition. Figure 16 uses the same symbols and colors as figure 15, however the total solar flux data is excluded. This allows an expansion of scale for closer examination of the current/expected solar flux simulations.

Figure 15

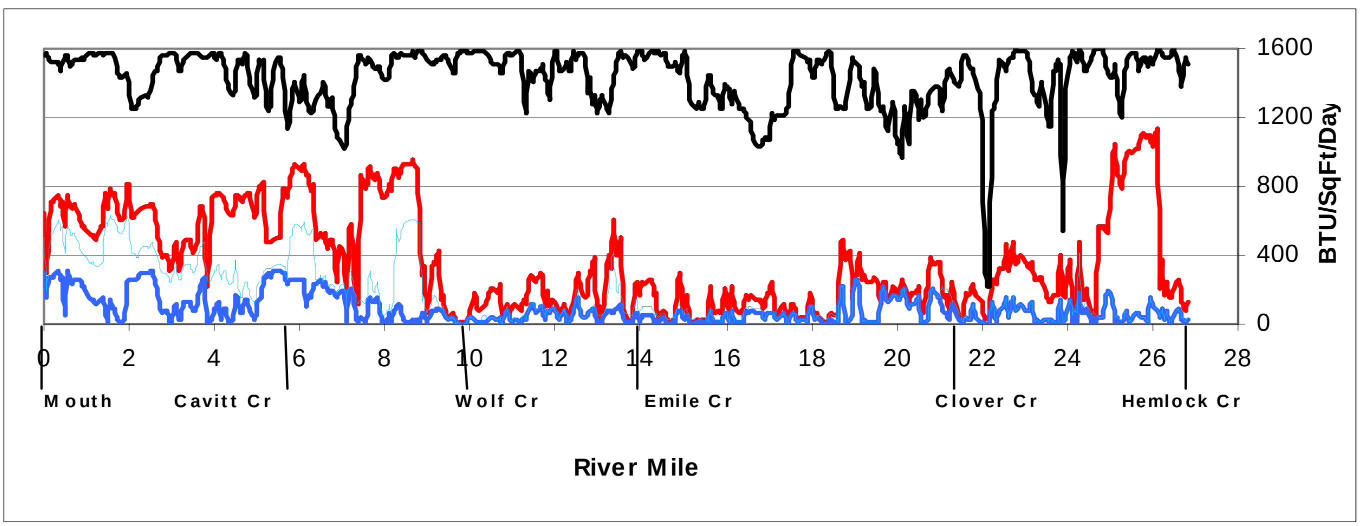


Figure 16

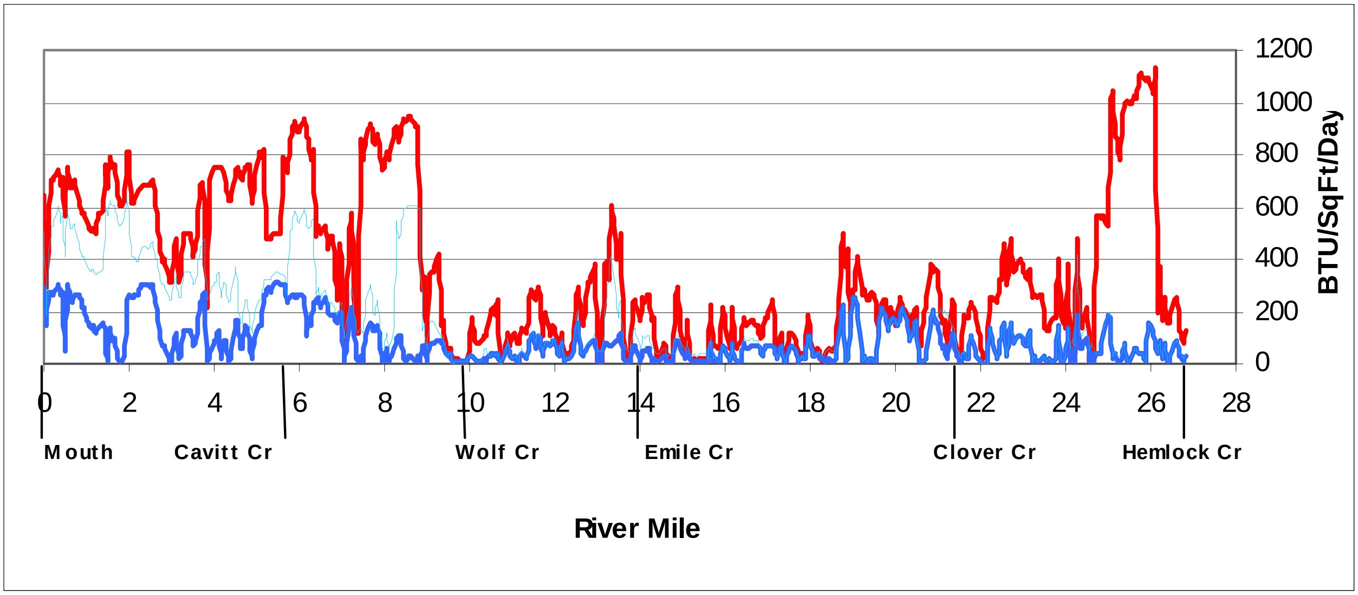


Figure 17a and 17b show the solar flux information displayed as percentile plots. The colors are the same as in figures 15 and 16.

Figure 17a

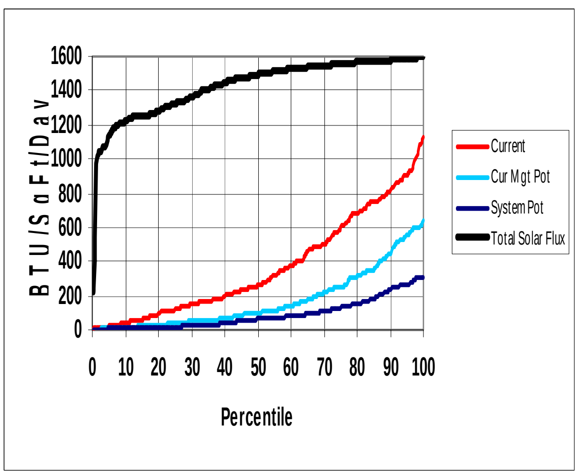
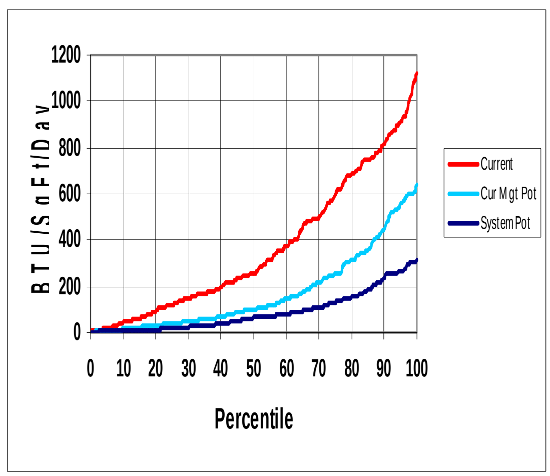


Figure 17b



Effective Shading in the Riparian Zone

Effective shading is defined as the amount of available solar flux intercepted before reaching the stream. A situation which allows 200 BTU/SqFt/Day to enter the stream when the available solar flux is 1500 BTU/SqFt/Day would be calculated as (all units are BTU/SqFt/Day):

Total Available Energy	1500
Energy Blocked	1500-200 =1300
Effective Shade Percentage	(1300/1500)*100 = 86.7%

Figure 18 and Map 3 shows the amount of effective shading provided to the stream by riparian vegetation in the present and two future conditions. Present conditions provide a distance-weighted average of 74.5% shade to the main stem (lower thick red line), while future conditions should provide 88% shade in the current management potential condition (middle dashed line) and almost 94% in the system potential condition (upper thick blue line). Figure 19 is the percentile plot of the % Effective shading data.

Figure 18

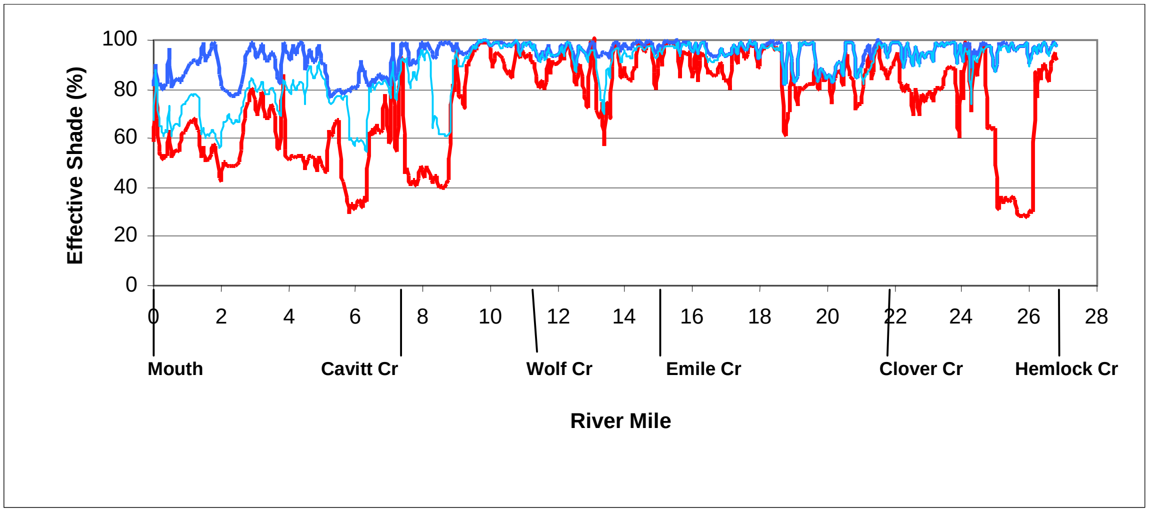
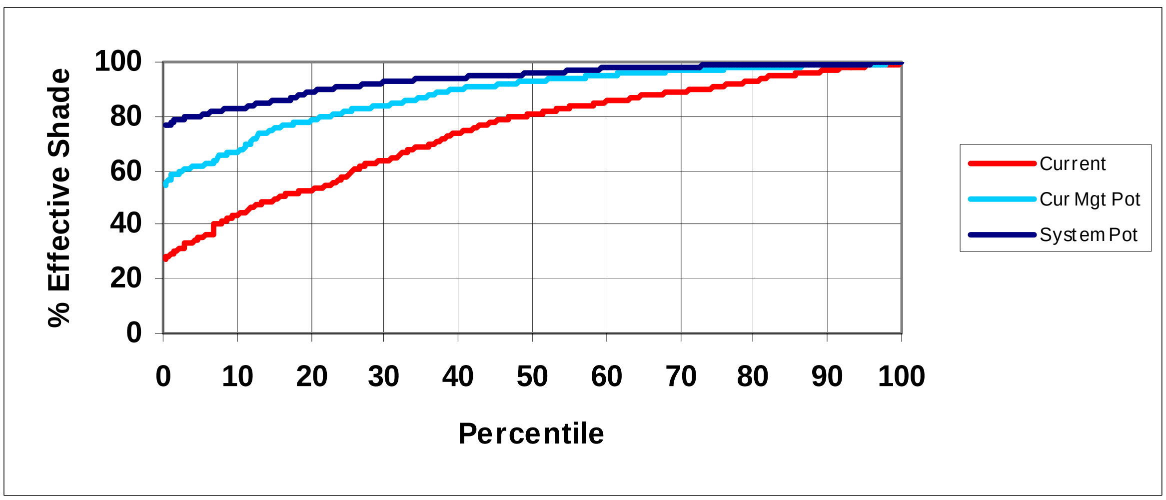


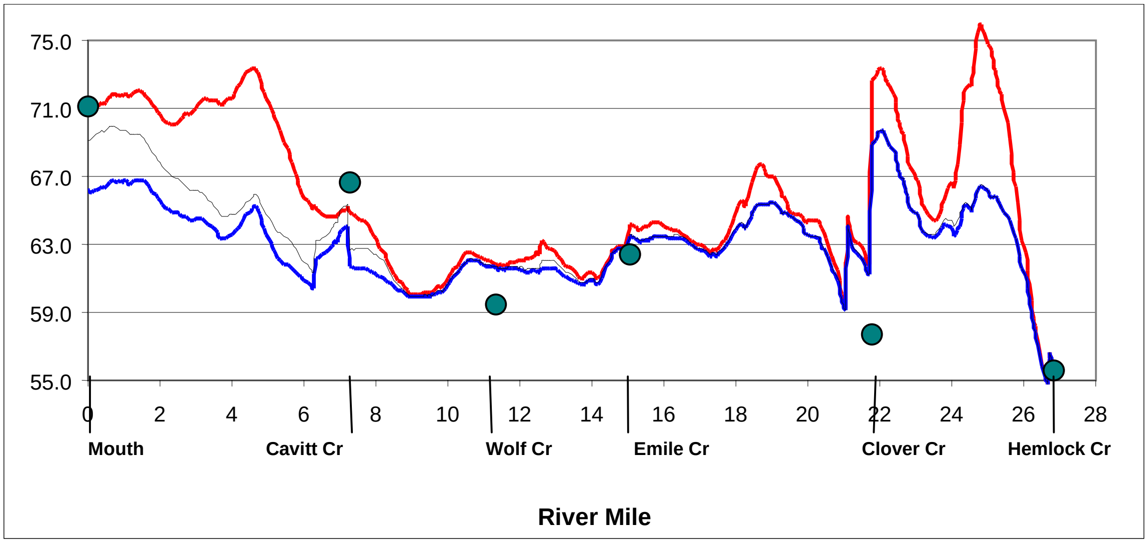
Figure 19



Stream Temperature

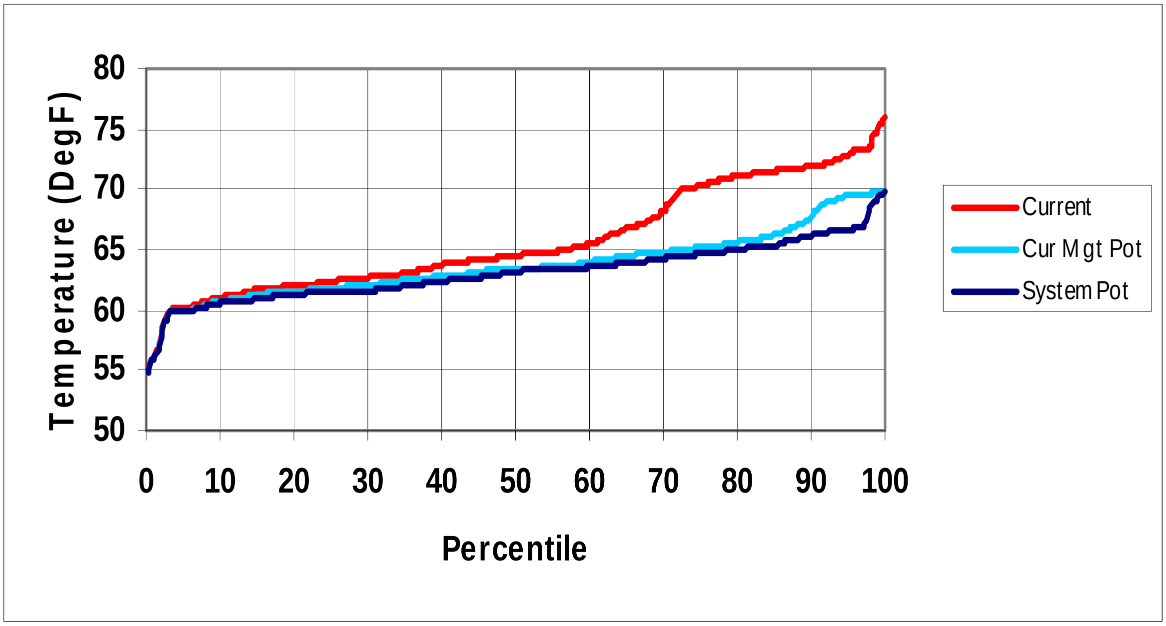
Figure 20 and Map 4 shows current stream temperature conditions and two projected stream temperature profiles. The open circles in Figure 19 are the corresponding same-day 4:00 PM temperatures recorded by the six data loggers deployed in the main stem. The r-squared value of actual vs. simulated temperatures for these six locations (4:00 PM temperatures only, n = 6) was 0.797. The two expected future stream temperature profiles are based on the assumed future conditions. All temperature profiles show stream temperatures **at 4:00 PM in the afternoon in mid-September** The difference between the lines shows potential reduction in stream temperature if the assumed future conditions are achieved.

Figure 20



In Figure 20, the top thick (red) line shows the present temperature profile, the bottom thick (blue) line shows the system potential temperature and the middle think (black) line shows the current management potential temperature profile. The model simulation for each future condition did not assume any additional cooling to any tributary other than Jim and Cavitt Creek. **Any additional cooling at the mouth of any of the tributary sub-watersheds would result in additional cooling in the main stem of Little River.** The percentile plot of temperature data is shown in Figure 21.

Figure 21



The next two graphs (Figures 22a and 22b) show the temperature data broken into 5 different temperature–range intervals. These intervals are roughly comparable to probable success of salmonid survival/reproduction. At the extremes, temperatures below 55 degrees F. are optimal for reproduction, temperatures above 72 degrees are lethal to immature fish. These graphs show the same information, only displayed in different formats. Again, these temperatures would be expected **at 4:00 PM in mid-September.**

Figure 22a

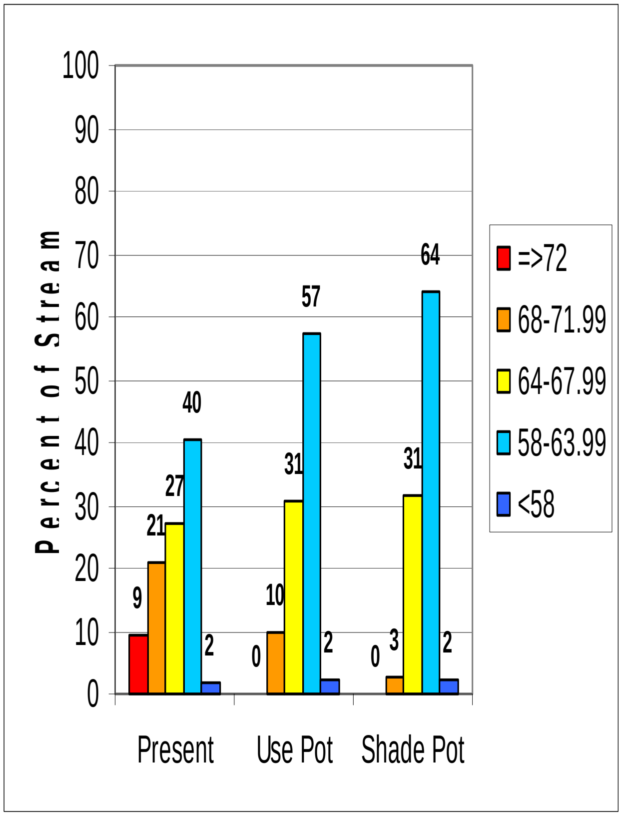
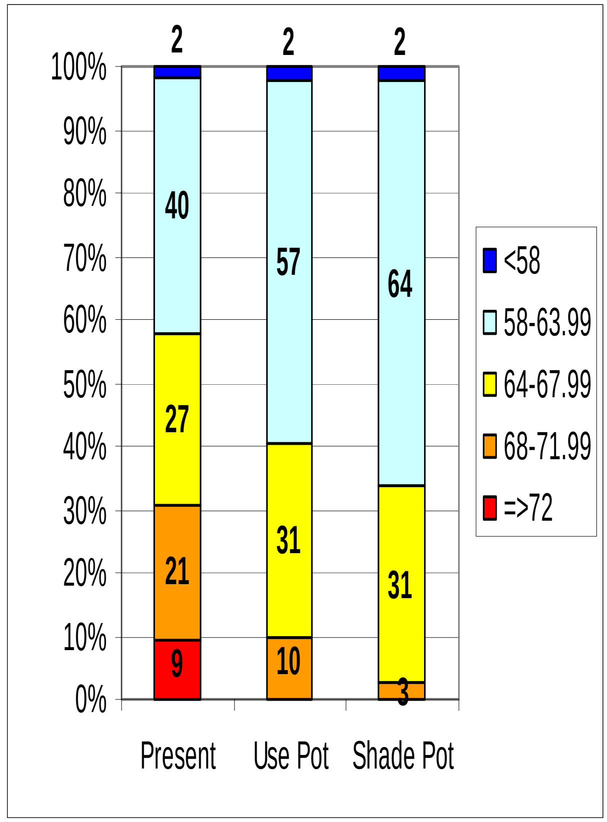
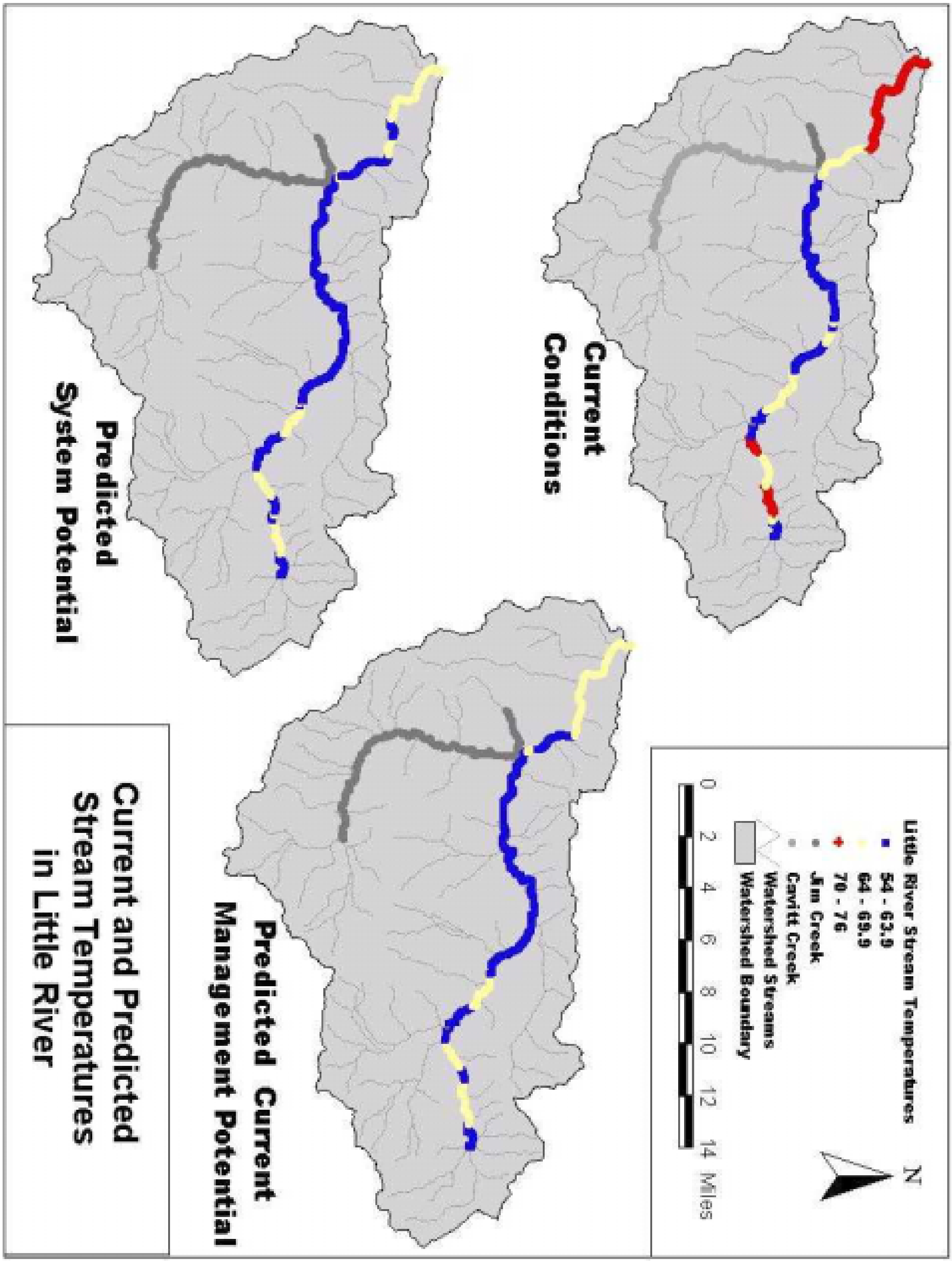


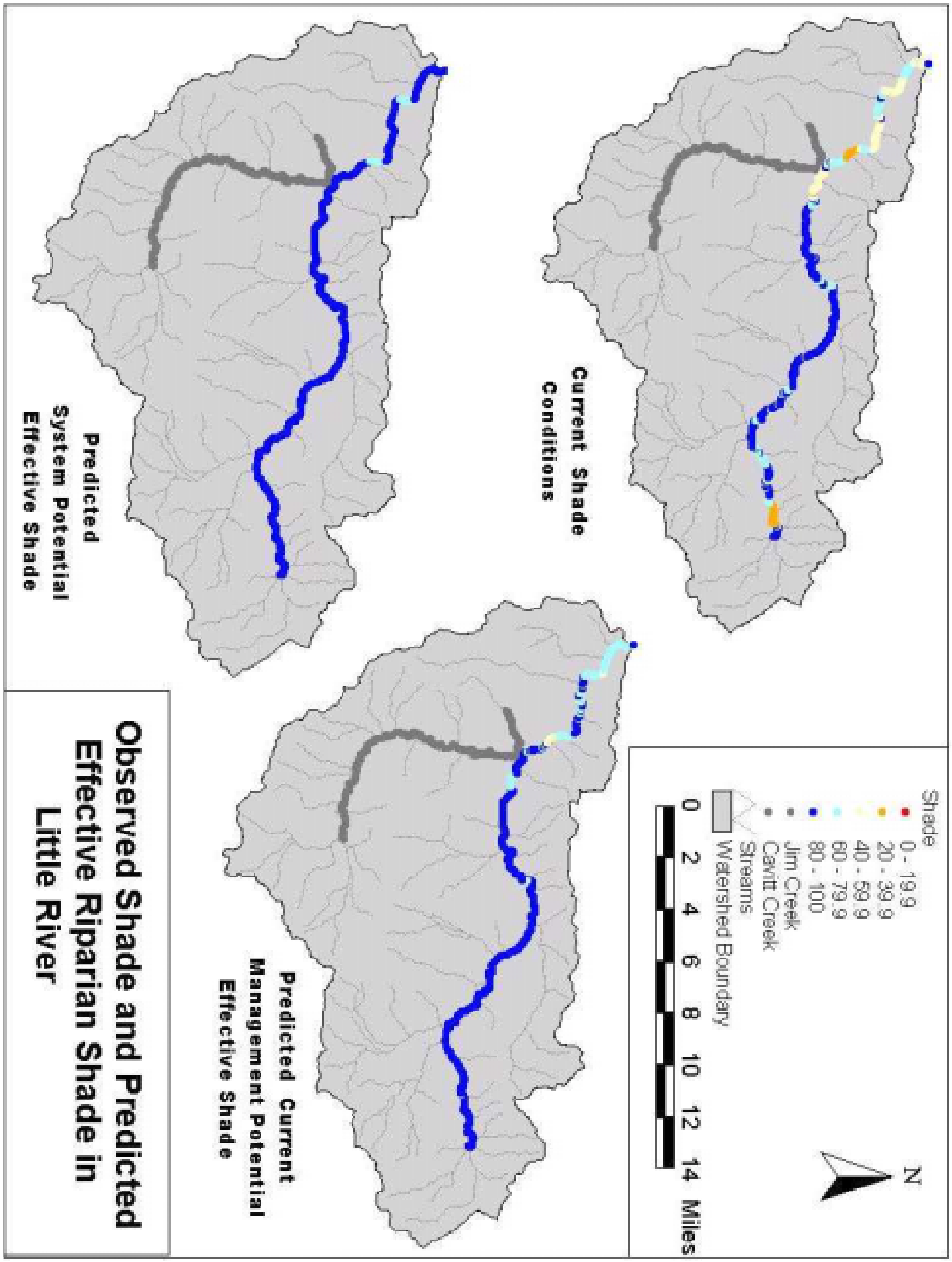
Figure 22b



Map 3


Current Conditions
Predicted System Potential
Predicted Current Management Potential
Little River Stream Temperatures
54 - 63.9
64 - 69.9
70 - 76
Jim Creek
Cavitt Creek
Watershed Streams
Watershed Boundary
0 2 4 6 8 10 12 14 Miles
N
Current and Predicted Stream Temperatures in Little River

Map 4


Observed Shade and Predicted Effective Riparian Shade in Little River
Current Shade Conditions
Predicted System Potential Effective Shade
Predicted Current Management Potential Effective Shade
Shade
0 - 19.9
20 - 39.9
40 - 59.9
60 - 79.9
80 - 100
Jim Creek
Cavitt Creek
Streams
Watershed Boundary
0 2 4 6 8 10 12 14 Miles
N

The Cumulative Effects of Tributary Cooling

It is not possible to calibrate and project future conditions in the bulk of tributaries within Little River. The field data and modeling time required is prohibitive. It was possible to put instruments into Jim and Cavitt Creeks so that future conditions could be simulated. These expected future temperatures were used as inputs for the mainstem model so that the cumulative effects of tributary cooling on the mainstem could be examined. These projected temperatures are shown in Figures 23a and 23b.

Figure 23a

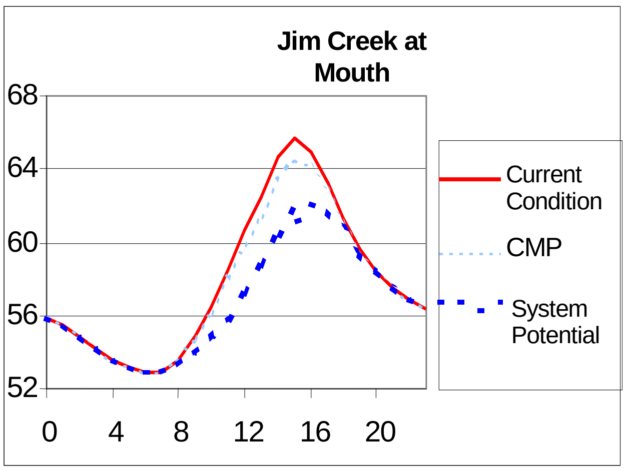
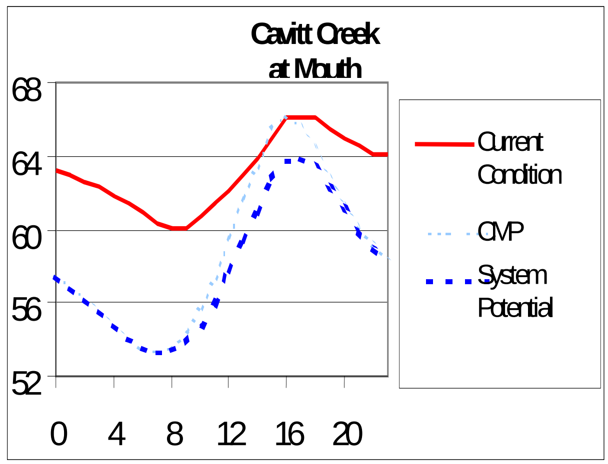
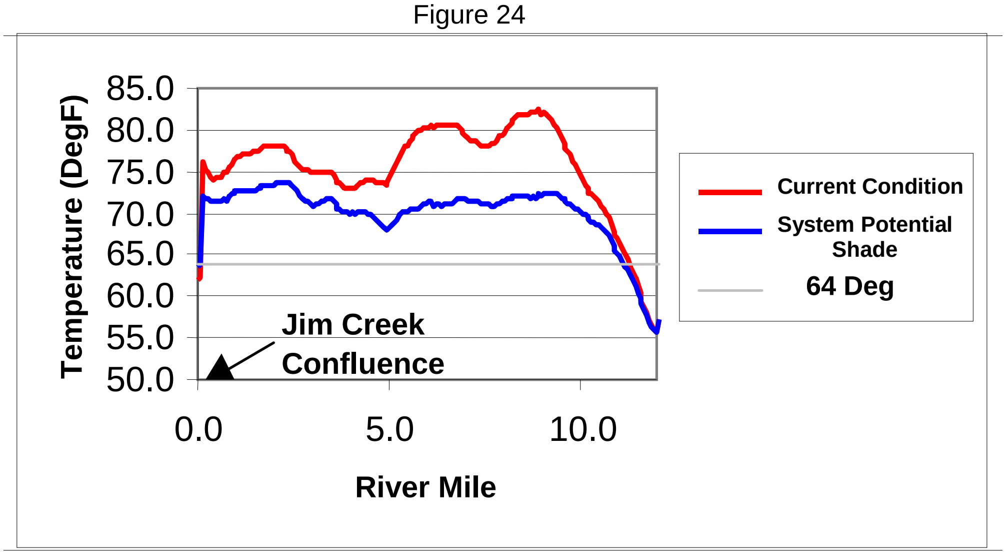


Figure 23b



Cavitt Creek provides examples of two important principles. Figure 24 shows the temperature profiles for current conditions and at system potential. While increased shading does reduce temperatures, it is a minimal improvement. Cavitt Creek runs predominately North-South. Even with increased riparian shading, the southern horizon is never fully obscured from solar energy inputs. Projected temperatures are never below the desired 64 degree F benchmark.

Figure 24



The second important principle here is the effect of Jim Creek on Cavitt Creek temperature. Projected cooling in Jim Creek is enough to cool Cavitt at the mouth to about halfway to the 64 degree F criterion. If each of the other tributaries to Cavitt Creek were cooled to the same degree as Jim Creek, the temperature profile of Cavitt Creek would be significantly lower. Indeed, the only likelihood of reducing temperatures significantly in Cavitt Creek is via tributary cooling.