APPENDIX C

TEMPERATURE MODEL AND DATA ANALYSIS OF THE LOWER RUBY RIVER AND MILL CREEK

TEMPERATURE MODEL AND ANALYSIS

OF THE LOWER RUBY RIVER AND MILL CREEK

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1. INTRODUCTION

1.1 Background

The lower Ruby River and its tributary, Mill Creek, in southwestern Montana are currently listed on the State of Montana’s 303(d) List of Impaired Waterbodies for water temperature impairments. Under the Clean Water Act, a Total Maximum Daily Load (TMDL) Water Quality Clean-up Plan is required for both waterbodies. To assist in developing the TMDLs, a modeling study was needed to review the effects of watershed management options for improving temperature conditions on the Ruby River and Mill Creek. This SNTEMP model analysis was conducted to determine water temperature at various locations on the Ruby River and Mill Creek under different shading and flow conditions.

Objectives of the modeling were to:

1. Support a compliance assessment of Montana's temperature water quality standards. A very general interpretation of the applicable temperature standard for conditions in the Ruby River Watershed can be described as a 1 ^{o}F increase in water temperature due to human influences that are not addressed with reasonable

land, soil, and water conservation practices. More details are provided in Montana's administrative rules [ARM17.30.624 (1) (e)].

2. Support a source assessment that will provide enough information for TMDL allocations. Other information from field sampling, aerial photo assessment, and Forward Looking Infrared (FLIR) assessment will be used to complement the SNTEMP modeling results for use in TMDL allocation.

3. Estimate the potential impact on water temperature though implementation of various management scenarios, including re-vegetation of the river banks (i.e. change in shading) and reduction of diverted water through improved irrigation practice (i.e. change in flow condition).

Two steps are required in this modeling study. First, the chosen water temperature model, SNTEMP, must be calibrated under known conditions. Upon calibration, the model is employed to estimate water temperature in the Ruby River and Mill Creek for four scenarios: 1) a baseline used as benchmark to compare predictions under other scenarios; 2) a shading scenario based on higher canopy effects; 3) a flow scenario based on a reduction of diverted water from the Ruby River and Mill Creek due to improved irrigation practice; and 4) a scenario that combines the shading and flow scenarios. All of the four scenarios are modeled for critical climatic conditions with meteorological inputs representing one of the hottest years within the Ruby River watershed.

This report first presents the selected water temperature simulation model, SNTEMP. The calibration process employed for the model is then presented, including the description of the inputs and the assumptions used to ensure a good fit between observed and predicted water temperature. Calibration results are then followed by implementation of temperature management scenarios, including the procedure, results and analysis of model predictions. The conclusion finally highlights the relevant findings of this study.

2. SNTEMP Model and Calibration

2.1 Description of the Temperature Model

The Stream Network Temperature Model (SNTEMP, Theurer *et al.*, 1984, Bartholow, 2000a and b) is a mechanistic, steady state one-dimensional heat transport model that predicts water temperatures. The energy budget performed by the model includes the following components: heat from long-wave atmospheric radiation; direct short-wave solar radiation; convection; conduction; evaporation; streamside shading; streambed fluid friction; back radiation from water and advective heat energy due to water inflows and outflows.

The model requires a stream to be represented in a hydrologic network composed of homogeneous stream segments. Each segment is described by length, surface water width, slope, channel roughness (Manning's n) or travel time, and shading characteristics, and assigned a streamflow. A schematic view of the modeled Ruby River and Mill Creek hydrologic network is provided in Figure A1. A depiction of the energy balance used in the SNTEMP model is provided in Figure A2.

The key meteorological data for the model are air temperature, relative humidity, wind speed, percent possible sunshine, and ground-level solar radiation. Flow source from surface water input (e.g. a creek) or groundwater inflow must be defined by a flow rate and the corresponding water temperature. The complete list of data requirements can be found in Theurer et al. (1984) and Bartholow (2000a).

The analytic components of the model have been validated (Theurer and Voos, 1982; Theurer, 1985; Mattax and Quigley, 1989; Bartholow, 1991), and its performance compares well with other water temperature models (Sullivan *et al.*, 1990; Tu et al., 1992). The SNTEMP model has been shown to simulate mean daily stream temperatures with a high degree of accuracy, typically $< 0.5^{o}C$ (Bartholow, 1991). However, the accuracy of the model depends of the quality of input data used for the calibration. The model is regularly used (ENTRIX, 2002; HDR, 2002), notably to predict the effect of shading on stream temperature.

2.2 Calibration Inputs

The goal of the calibration is to ensure that the SNTEMP model is suitable for predicting water temperature of the Ruby River and Mill Creek. This model requires seven data files to represent the stream system and its thermal balance. The major features of these data files include the river network (i.e., reaches, diversion, sources), the meteorological inputs, the flow and water temperature conditions associated with the river network, and the characteristics of the reaches (manning coefficient, width, shading).

Important information for the model calibration process is summarized in Table 1 and Figure A1 and Table A1 in Attachment A. Figure A1 shows the stream network, including the modeled segments, flow input and output points and shading factors. Table A1 provides the details of the measured flow and water temperature conditions. The 3-day averaged water temperature, flow and meteorological data were used, where available. The 3-day average data is required since travel time for water from the top to the bottom of the modeled stream system is approximately 3 days. Table A1 also lists one of the characteristics of the reaches, shade condition. Table A2 completes the characteristics of the reaches (i.e. Manning coefficient and stream width), while Table A3 provides the groundwater temperature employed in the model. All the data were collected from August 3 – 6, 2004 by Watershed Consulting, LLC, except groundwater temperatures, which were taken in the fall of 2002 in a separate study completed by Kirk Environmental. Groundwater temperatures were taken directly from this study and were used as inputs for groundwater temperatures in the model.

Meteorological inputs (Table 1) are based on data collected at local meteorological stations (Alder and Ennis, MT) from August 3 – 6, 2004. Air temperature was collected from the meteorological station at Alder, MT. Wind speed, humidity, and sunshine were collected from the meteorological station at Ennis, MT. Solar radiation is an average of three stations located near the Ruby River Watershed.

TABLE 1

Meteorological Inputs for the Calibration.

Meteorological parameter	Value
Mean air temperature for the period (ºC)	18.8
Mean wind speed for the period (m/s)	2.8
Humidity (decimal)	0.54
Sunshine (decimal)	0.78
Solar radiation (W/m2)	224

2.3 General Assumptions

In order to ensure a good fit between observed and modeled water temperatures, some assumptions were necessary. These assumptions are summarized below:

- Undocumented inflow (1.3 m^3/s) of groundwater occurs into the Ruby River near Alder Creek.
- 75% of measured increase in flow (0.8 m3/s) within RBYLR08 is from groundwater and the remaining 25% is from surface water.
- Undocumented groundwater inflow (0.4 m3/s) occurs between KM 62.6 and KM 57.2.
- There is some undocumented flow increase of 0.15 m3/s for RBYLR015 due to groundwater.
- Undocumented inflows occur into the upper reaches of Mill Creek. These flows are primarily groundwater. In the lower reaches the inflows are 80% surface water and 20% groundwater. More specifically in reach M06, the proportions are 90% surface water and 10% groundwater.

Detailed assumptions for model calibration by stream segment are presented in Table A1. These assumptions are necessary because undocumented inflows and outflows of surface and groundwater occur within the modeled reaches. Actual field measurements were only taken at the upstream and downstream ends of each reach and unmeasured surface/groundwater exchanges occur throughout the reach. The assumptions described above of undocumented inflows of groundwater is in agreement with observational information provided by field visits from Watershed Consulting and FLIR information collected in 2004.

2.4 Calibration Results

The calibration was based on observed data from August 3 – 6, 2004 and data collected at meteorological stations located near the Ruby River basin. The performance criterion for acceptable calibration was based on a maximum temperature difference of 0.5 ºC between observed and modeled data. This calibration performance criterion is standard for the SNTEMP model (Bartholow, 1991 and 200b). Figures 1 and 2 show the calibration results. The results are also shown in Table A1.

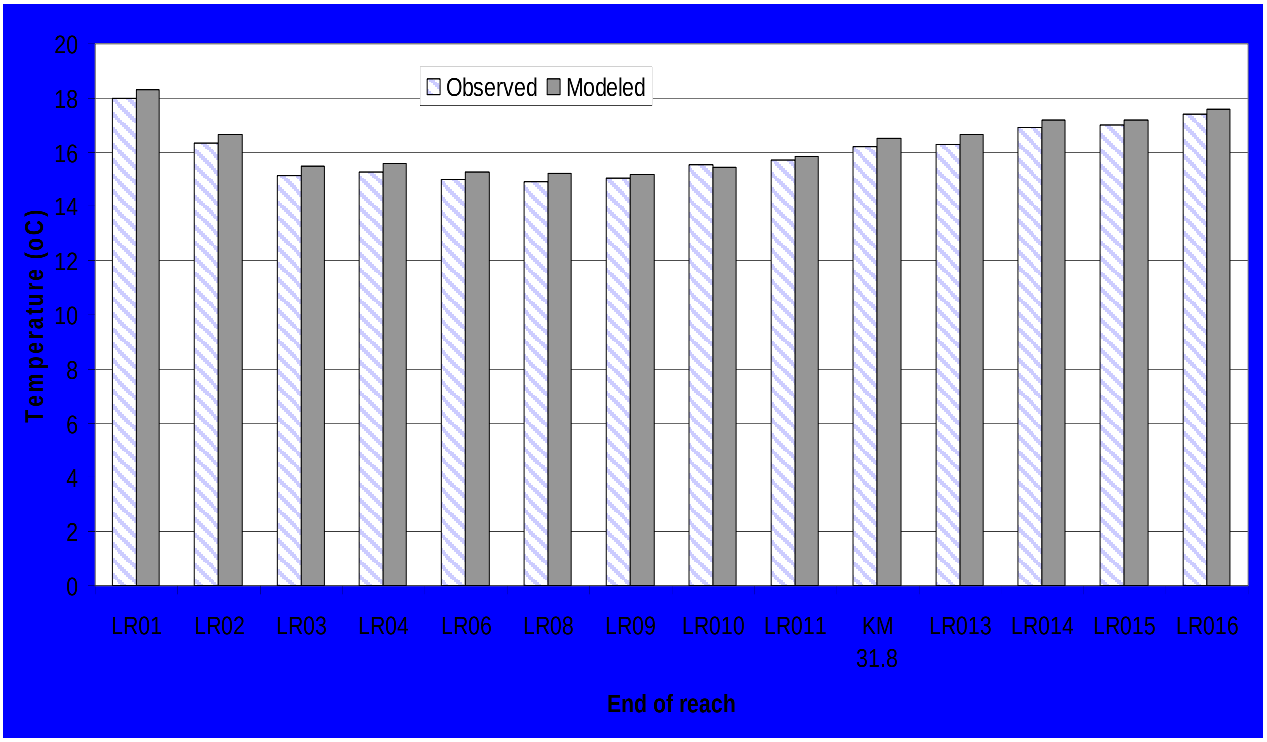

Figure 1. Observed versus modeled water temperatures on the Ruby River for the calibration process

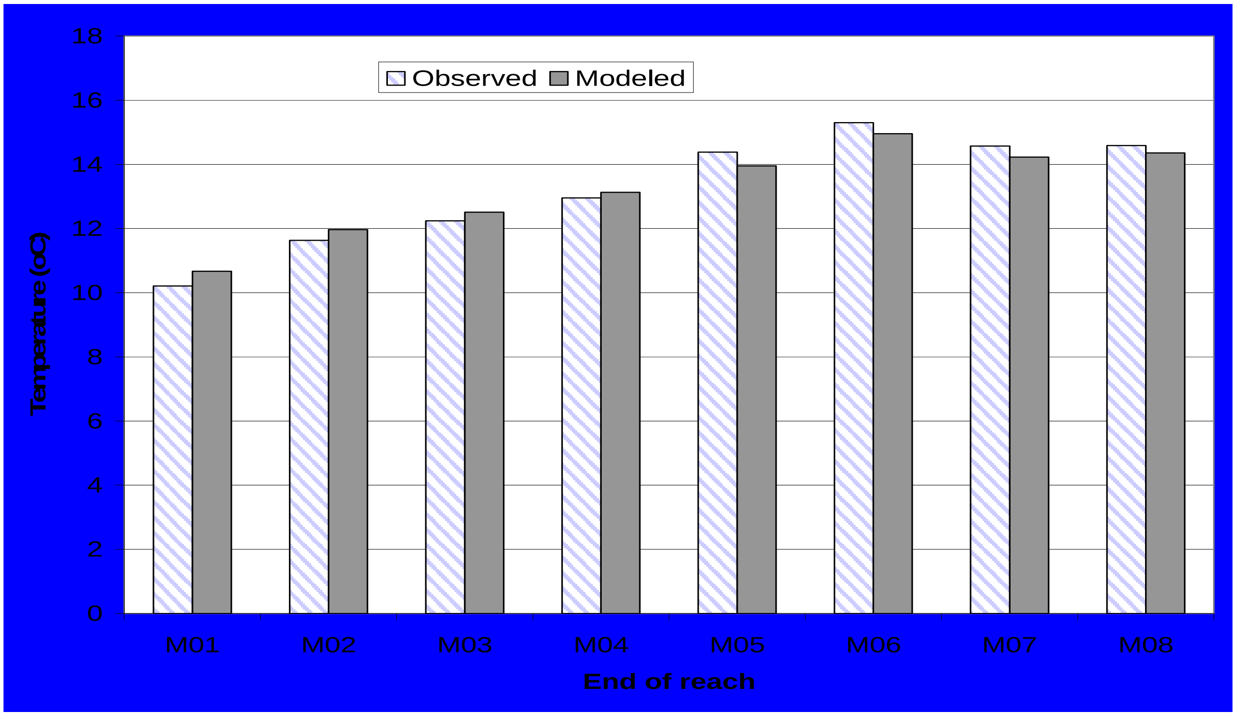

Figure 2. Observed versus modeled water temperatures on the Mill Creek for the calibration process

Figures 1 and 2 show that differences between observed and modeled water temperature are below 0.5 ºC or 0.9 ºF in all stream reaches. General review of the model indicates a tendency to overestimate temperatures on the Ruby River and show a variable pattern on Mill Creek, though all modeled temperatures are within a generally acceptable 0.5 ºC deviation from measured temperature. A greater number of observed temperatures would be preferable for a more reliable estimation of the possible presence of a trend in modeled temperature.

3. TEMPERATURE MANAGEMENT SCENARIOS

3.1 Description of the Scenarios

The calibrated model was used to investigate four scenarios for temperature management, namely:

- Baseline scenario (S0): This scenario establishes the reference to which all the other scenarios are compared. It differs from the calibration settings by the meteorological inputs. For this scenario and for all the other, the meteorological inputs represents the hottest 3-day period of the year;

- Shading effect scenario (S1): This scenario differs from the baseline by the shading parameters in the model;

- Flow change scenario (S2): This scenario differs from the baseline by the water balance imposed on the model. The scenario has a reduction of water diverted from the river with a consequent reduction in groundwater input to the river;

- Shading effect and flow change scenario (S3): This scenario is the combination of S1 and S2, with a change in the shading effect and the water balance compared with the baseline.

A detailed description of the scenarios and their rationale is presented in Attachment B. Scenarios were analyzed for both the Ruby River and its tributary Mill Creek together at the same time.

The impacts of temperature management scenarios was desired for critical periods. The critical period was determined to be the hot period of the meteorological record (July 19-22, 2003). As a result, meteorological inputs for the calibrated model were changed to run the baseline and scenarios for the critical period. Meteorological inputs for the scenarios are based on data collected for a hot period on the record (July 19 – 22, 2003). The critical period meteorological data are summarized in Table 2.

TABLE 2

Meteorological Inputs for the Scenarios

Meteorological parameter	**Value**
Mean air temperature for the period (ºC)	26.1
Mean wind speed for the period (m/s)	2.4
Humidity (decimal)	0.26
Sunshine (decimal)	0.78
Solar radiation (W/m2)	306

In reviewing the results of baseline condition and scenarios under the critical meteorological period described above, it is important to note that groundwater and surface water inputs are those available from measurement period (August 2004) used in the calibration. It is unlikely that groundwater temperature are significantly affected by the change in the meteorological factors, however surface temperatures are more affected by meteorological factors.

As a result water temperature inputs from surface water flows for the critical meteorological period are likely to be cooler than would be expected to occur for those meteorological conditions. The end result is that the baseline and scenario predictions under the critical meteorological period may slightly underestimate actual temperatures.

Baseline scenario was determined based on actual vegetation cover collected in the field. This was measured at three locations (left bank, center, and right bank) of each transect and monitored in the field using a densiometer. The average densiometer value for each transect was obtained as input into the model. The canopy density may be considered as equivalent to effective shade for the model, on the assumption that topography has no significant effect on shading for the simulated conditions (e.g., sun high in the sky) (Bartolow 1989). Field confirmation indicated that topography was not a significant shade contributor. Reference conditions were developed for scenarios S1 and S3 that were equivalent to the most functioning vegetation condition observed on the ground. Development and rationale for the shade scenarios is described in detail in Attachment B. Scenarios S1 and S3 involve increasing shading values from actual to reference condition for all reaches. As stated above, the increase in shade is based on local reference conditions. Table 3 shows the new shading parameters applied to scenarios S1 and S3.

TABLE 3

Shading Values for Scenarios S1 and S3

Reach	Shading value (%)
M01 – M03	55
M04 – M06	71
M07 – M09	35
LR1 – LR17	30

Scenarios S2 and S3 involve a reduction in the amount of diverted water from the Ruby River and Mill Creek. On the Ruby River, at the main diversion just below the dam, it is assumed that a reduction of 37% (2.925 m^3/s) in diverted water occurs. As well, a 43% reduction of diverted water also occurs on the Mill Creek in reaches M04, M05, M06 and M07. The reduction corresponds to 0.105, 0.042, 0.040 and 0.200 m^3/s for M04, M05, M06 and M07. The rationale for quantities used in the model scenarios are provided in detail in Attachment B.

The reduction in diverted water was assumed to result in a similar reduction of groundwater inputs to the streams. The groundwater inputs to the streams are not known from the available observed data. Therefore, reduction of groundwater inputs was assumed to be a function of net groundwater flux, which can be determined from the water balance performed by the model.

For any segment on the Ruby River, from Reach LR02 down to the mouth of the river, groundwater input is reduced by 37% of the net groundwater flux determined for that segment. The groundwater is reduced by 43% for the segments of the Mill Creek, from Reach M4 down to the confluence with the Ruby River. The water balance is modified to account for the reduction in diverted water from the streams and groundwater inputs.

The resulting flows used for Scenarios S2 and S3 are given in Table 4.

TABLE 4

Flows (m^3/s) on the Ruby River and Mill Creek for All Scenarios

Ruby River			**Mill Creek**		
Reach	**S0 and S1**	**S2 and S3**	**Reach**	**S0 and S1**	**S2 and S3**
RBYLR01	9.628	9.628	RBYM01	0.134	0.134
RBYLR02	1.722	4.647	RBYM02	0.413	0.413
RBYLR03	1.399	4.001	RBYM03	0.243	0.243
RBYLR04	1.422	3.829	RBYM04	0.201	0.213
RBYLR05	1.331	3.511	RBYM05	0.108	0.203
KM 62.6*	1.946	4.078	RBYM06	0.032	0.190
RBYLR06	1.951	4.037	RBYM07	0.066	0.234
RBYLR07	1.617	3.509	RBYM08	0.289	0.437
RBYLR08	1.84	3.732	RBYM09	0.580	0.603
RBYLR09	2.639	4.310	Mouth	0.116	0.338
RBYLR010	3.115	4.773			
RBYLR011	3.058	4.686			
RBYLR012	2.353	3.720			
KM 31.8*	2.647	4.014			
RBYLR013	2.197	3.397			
RBYLR014	2.359	3.556			
RBYLR015	1.481	2.678			
RBYLR016	1.512	2.900			
RBYLR017	1.121	2.365			

*intermediary reach breaks created as a result of model set-up

3.2 Scenario Results

Figures 3 and 4 illustrate the water temperature results obtained for all scenarios. The results are also available in tabular format in Table A4. Table 5 presents statistics of the temperature differences between Scenarios S1, S2 and S3 versus Scenario S0. In Table 5, a negative difference implies a temperature decrease for the given scenario compared to Scenario S0. The locations of the occurrence of maximum and minimum differences are also given in Table 5.

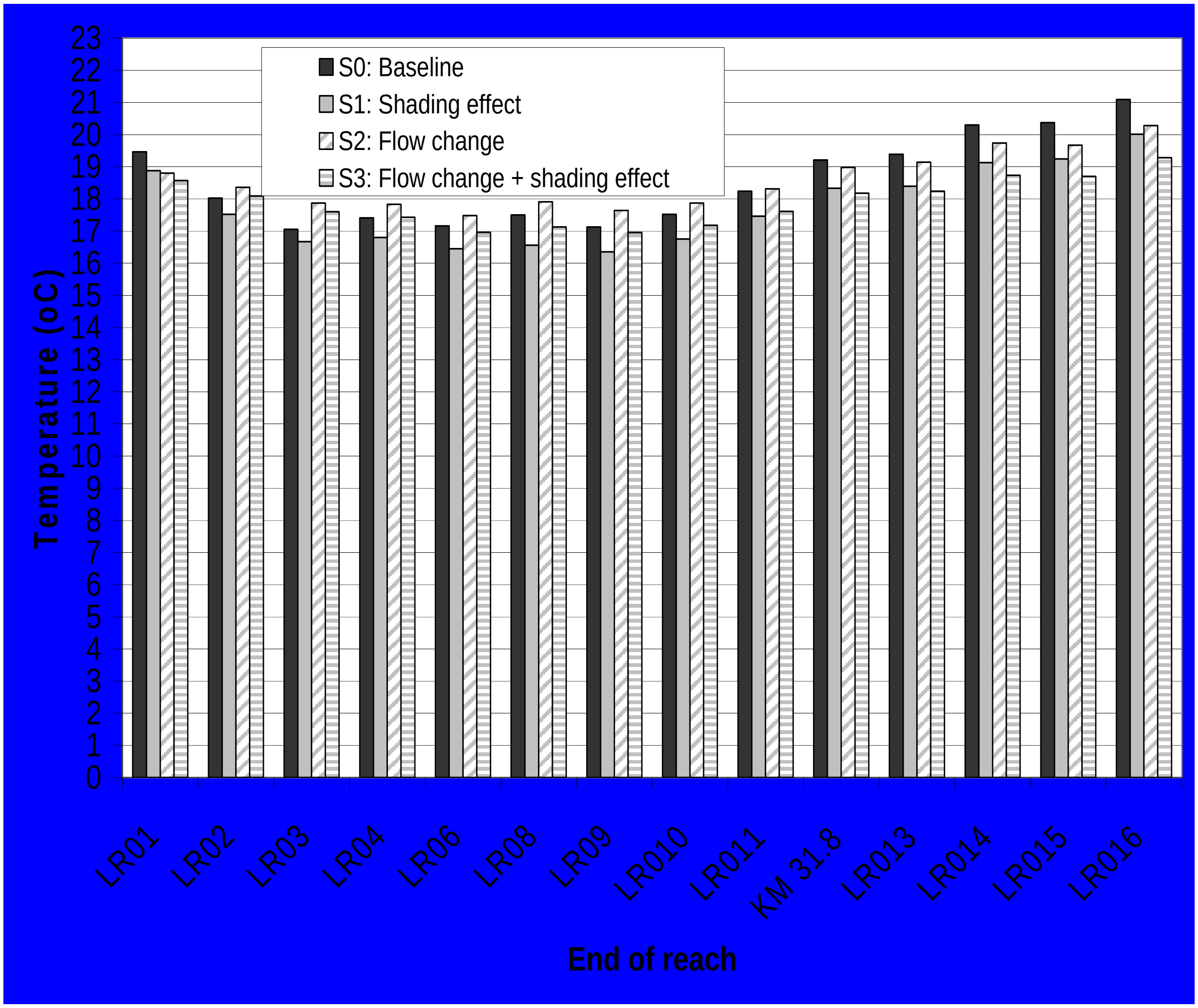

Figure 3. Modeled water temperatures on the Ruby River for all scenarios

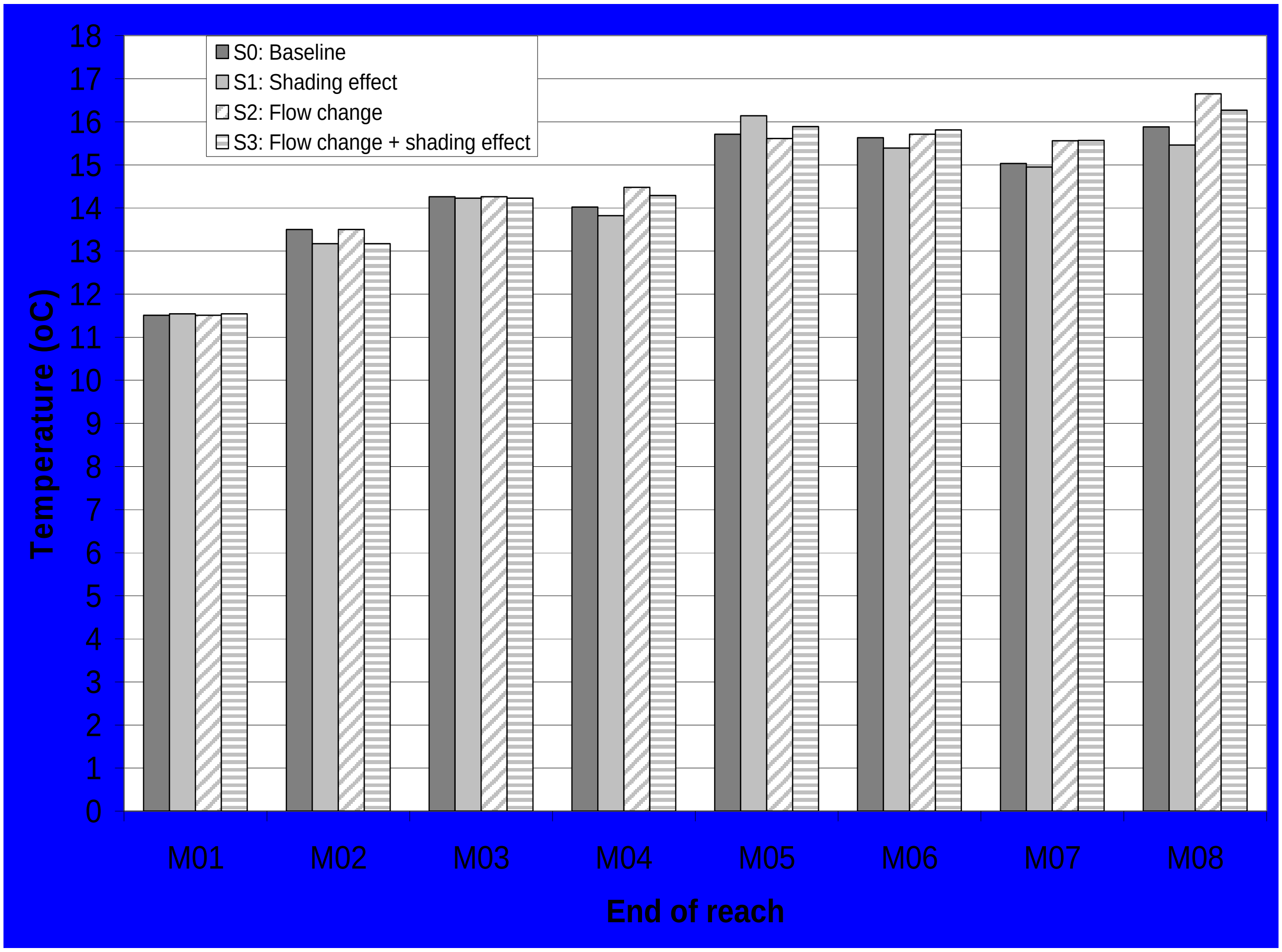

Figure 4. Modeled water temperatures on the Mill Creek for all scenarios

TABLE 5

Temperature differences (°C) from Scenarios S1, S2 and S3 versus Scenario S0

Stream	Scenario	Average	Max	Location of max (end of reach)	Min	Location of min (end of reach)
Ruby River	S1	-0.81	-0.38	LR03	-1.17	LR14
	S2	0.00	0.82	LR03	-0.81	LR16
	S3	-0.66	0.55	LR03	-1.81	LR16
Mill Creek	S1	-0.11	0.43	M05	-0.42	M08
	S2	0.22	0.77	M08	-0.10	M05
	S3	0.15	0.54	M07	-0.33	M02

3.3 Discussion

The shading effect (Scenario S1) is appreciable on the Ruby River. The average decrease on the Ruby River due to shading improvements is 0.81 ºC, with a maximum decrease of 1.17 ºC occurring at the end of Reach LR14 and a minimum decrease of 0.38 ºC at end of Reach LR03. The shading effect is also notable on the Mill Creek (average decrease of 0.11 ºC and maximum decrease of 0.42 ºC at end of Reach M08), even though there is an increase in temperature at end of Reach M05. This increase in temperature at end of Reach M05 is however expected, because the shading used in Scenario S1 is slightly lower than the observed shading in Scenario S0 for Reach M05.

Changing the flow regime through reduction of diverted flow (scenario S2) also has an effect on water temperature. For the Ruby River, there are two processes at work. The temperature in the flow scenario is warmer compared with the baseline at the upper reaches of the Ruby River (LR02 to LR11) because of the increased inflow of surface water and decreased inflow of groundwater. However, larger volumes of surface flows under Scenarios S2 are not warmed up by solar radiation as rapidly compared to flows under the baseline conditions. Consequently water temperatures predicted in the lower part of the river (KM 31.8 to LR16) in the flow scenario (S2) are lower than those predicted in the baseline (S0)

For Mill Creek, higher temperatures under the flow scenario (S2) compared with the baseline occur downstream from Reach M04, while temperatures for the baseline and flow scenario are similar in the upper reaches. The higher temperature at the downstream reaches is due to increased surface water and reduced groundwater inflow. The proportion of surface water versus groundwater is higher in the flow scenario (S2) than in the baseline, and consequently water temperature in the creek increases.

Scenario S3 presents the combined effects of Scenarios S1 and S2. The shading effect contributes to lower water temperature while the change in flow results in increasing predicted values in all cases except the lower portion of the Ruby River. For the Ruby River, the highest temperature difference occurs at end of Reach LR16, with a decrease of 1.81 ºC between scenarios S0 and S3.

For Mill Creek, at the end of Reach M06, temperature in Scenario S3 is slightly higher (by 0.1 ºC) than that of Scenario S2. This slightly higher temperature can be attributed to the combined effect of more surface flow and lower shading effect at node M05. As discussed previously, Scenario S1 is based on a lower shading factor at M05 than what is observed, leading to higher water temperature. The increase in water temperature under Scenario S3 persists up to the end of Reach M06 and beyond due the mass of water involved.

4. CONCLUSIONS

The SNTEMP model is suitable for modeling water temperature in the Ruby River and Mill Creek. All differences between observed and modeled water temperatures are lower than 0.5 ºC in the calibration process.

Further analysis involved investigating several scenarios under the hottest 3-day period of the year (critical period). A baseline scenario was compared with scenarios that included an overall increase in the shading, a change in the flow regime due to reduction in diverted water, and a combination of change in shading and flow. In general, the increase in shading has the effect of lowering water temperatures, while the change in the flow regime would have the effect of increasing water temperature due to the corresponding decrease in groundwater returns. The exception to this occurs in the downstream part of the Ruby River, where the increased flow warms less and results in an overall lower water temperature. This effect of increase in water temperature due to increasing surface water is most pronounced on Mill Creek.

Compared with Scenario S0, the average temperature differences for Scenarios S1, S2 and S3 are -0.81, 0.00, and -0.66 ºC in the Ruby River, and -0.11, 0.22 and 0.15 ºC in the Mill Creek. Average water temperatures decrease the most under the shading scenario (S1) compared with the baseline (S0), with a decrease of -0.81 ºC in the Ruby River and -0.11 ºC in Mill Creek. Overall, however, the highest temperature difference occurs at the downstream end of the Ruby River (LR16), with a decrease of 1.81 ºC as result of increasing flows and shading between scenarios S0 and S3.

The modeling indicates that restoration approaches that increase shading will have a complete spatial effect on reducing temperatures. The modeling indicates that Mill Creek and the upper two-thirds of the Ruby River below the dam will be warmed by increasing surface flows from irrigation water savings while the lower third of the Ruby will be cooled. Combining the two restoration approaches has an additive effect and varies in results according to location.

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Attachment A

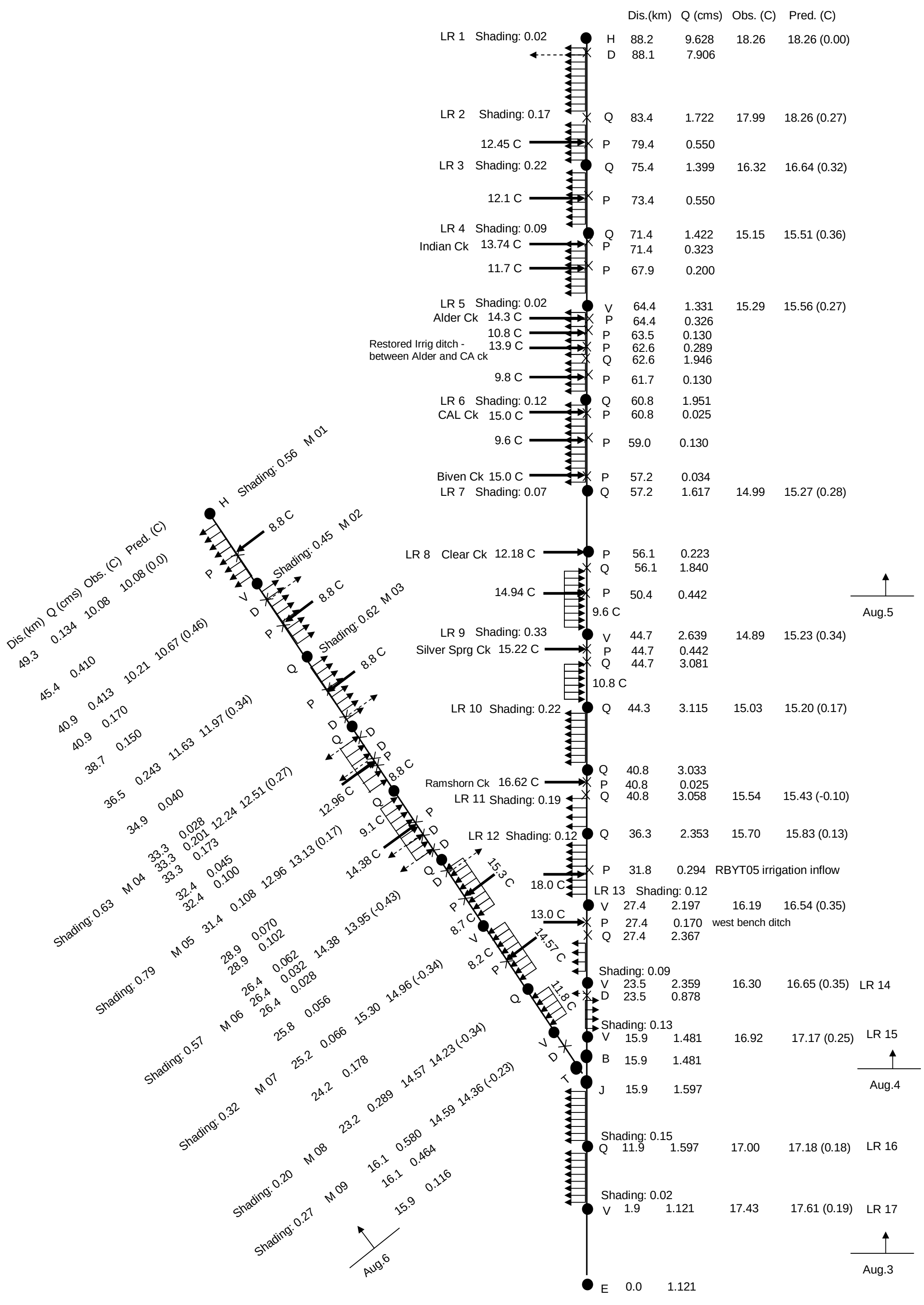

Figure A1. Schematics of the Ruby River systems as represented in SNTEMP*

***Schematic and associated symbols as presented by SNTEMP model and described in Bartholow (2000a)**

Table A1. Inputs and results of the calibration process

Reach	Distance of Top of Reach from Mouth of Ruby River	Upstream Flow	Additional Inflow			Shading	Water Temperature at End of Reach		Comments/Assumptions for Calibration
	(km)	(m^3/s)	Type	Rate (m^3/s)	Temp (^oC)	Measured	Measured (^oC)	Calculated (^oC)	
Top of Model							18.26	18.26	
RBYLR01	88.2	9.628	Point	-7.906		2	17.99	18.29	
RBYLR02	83.4	1.722	Point and non-point	-0.873 (non-point), 0.55 (point)	12.45 (point)	17	16.32	16.64	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that an inflow of 0.55 cms goes into the reach with a temperature equivalent to that of groundwater, while a lateral flow of 0.873 cms goes from the river to the ground to establish the balance. The inflow is simulated as a point source occurring midway into the reach.
RBYLR03	75.4	1.399	Point and non-point	-0.527 (non-point), 0.55 (point)	12.1 (point)	22	15.15	15.51	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that an inflow of 0.55 cms goes into the reach with a temperature equivalent to that of groundwater, while a lateral flow of 0.527 cms goes from the river to the ground to establish the balance. The inflow is simulated as a point source occurring midway into the reach.
RBYLR04	71.4	1.422	Point and non-point	0.323 (Indian Ck), -0.614 (non-point), 0.2 (point)	13.74 (Indian Ck), 11.7 (point)	9	15.29	15.56	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that an inflow of 0.2 cms goes into the reach with a temperature equivalent to that of groundwater, while a lateral flow of 0.614 cms goes from the river to the ground to establish the balance. The inflow is simulated as a point source occurring midway into the reach.
RBYLR05	64.4	1.331	Point and non-point	0.326 (Alder Ck), 0.289 (Res. Irr. Ditch), -0.130 (non-point), 0.130 (point)	14.3 (Alder Ck), 13.9 (Res. Irr. Ditch), 10.8 (point)	2			Adjustment required on the surface/GW flow balance in order to match the observed temperature at end of Reach LR06. It is assumed that an inflow of 0.130 goes into the reach with a temperature equivalent to that of groundwater, while a lateral flow of 0.130 cms goes from the river to the ground to establish the balance. The inflow is simulated as a point source occurring midway into the reach.

Reach	Distance of Top of Reach from Mouth of Ruby River	Upstream Flow	Additional Inflow			Shading	Water Temperature at End of Reach		Comments/Assumptions for Calibration
	(km)	(m^3/s)	Type	Rate (m^3/s)	Temp (°C)	Measured	Measured (°C)	Calculated (°C)	
	62.6	1.946	Point and non-point	-0.125 (non-point), 0.130 (point)	9.8 (point)				Adjustment required on the surface/GW flow balance in order to match the observed temperature at end of Reach LR06. It is assumed that an inflow of 0.130 cms goes into the reach with a temperature equivalent to that of groundwater, while a lateral flow of 0.125 cms goes from the river to the ground to establish the balance. The inflow is simulated as a point source occurring midway into the reach.
RBYLR06	60.8	1.951	Point and non-point	0.025 (Cal Ck), 0.034 (Bivens Ck), -0.523 (non-point), 0.130 (point)	15 (Cal Ck), 15 (Bivens Ck), 9.6 (point)	12	14.99	15.27	Adjustment required on the surface/GW flow balance in order to match the observed temperature at end of Reach LR06. It is assumed that an inflow of 0.130 cms goes into the reach with a temperature equivalent to that of groundwater, while a lateral flow of 0.523 cms goes from the river to the ground to establish the balance. The inflow is simulated as a point source occurring midway into the reach.
RBYLR07	57.2	1.617	Point	0.223 (Clear Ck)	12.18 (Clear Ck)	7			
RBYLR08	56.1	1.84	Point and non-point	0.599 (non-point), 0.2 (point)	9.6 (non-point), 14.94 (point)		14.89	15.23	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that 25% (0.2 cms) of the inflow is surface flow with a temperature equivalent to that of surface flow. The remaining 75% (0.599 cms) of the inflow is assumed to be groundwater flow with a temperature equivalent to that of groundwater flow. The surface inflow is simulated as a point source occurring midway into the reach.
RBYLR09	44.7	2.639	Point and non-point	0.442 (Silver Sp Ck), 0.034 (non-point)	15.22 (Silver Sp Ck), 10.8 (non-point)	33	15.03	15.2	Temperature equivalent to that of groundwater is assigned to the non-point source.

Reach	Distance of Top of Reach from Mouth of Ruby River	Upstream Flow	Additional Inflow			Shading	Water Temperature at End of Reach		Comments/Assumptions for Calibration
	(km)	(m^3/s)	Type	Rate (m^3/s)	Temp (^oC)	Measured	Measured (^oC)	Calculated (^oC)	
RBYLR010	44.3	3.115	Point and non-point	0.025 (Ramshorn Ck), -0.082 (non-point)	16.62	22	15.54	15.43	
RBYLR011	40.8	3.058	Non-point	-0.705		19	15.7	15.83	
RBYLR012	36.3	2.353	Point	0.294 (RBYT05 irr inflow)	18	12			
	31.8	2.647	Non-point	-0.45			16.19	16.54	
RBYLR013	27.4	2.197	Point and non-point	0.170 (West bench ditch), -0.008 (non-point)	13.0 (West bench ditch)	2	16.3	16.65	
RBYLR014	23.5	2.359	Point	-0.878		9	16.92	17.17	
RBYLR015	15.9	1.481	Point and non-point	0.116 (Mill Ck), -0.085 (non-point)		13	17	17.18	
RBYLR016	11.9	1.512	Non-point	-0.391		15	17.43	17.61	
RBYLR017	1.9	1.121				2			
RBYM01	49.3	0.134	Point and non-point	-0.131 (non-point), 0.41 (point)	8.8 (point)	56	10.21	10.67	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that an inflow of 0.41 cms goes into the reach with a temperature equivalent to that of groundwater, while a lateral flow of 0.131 cms goes from the river to the ground to establish the balance. The inflow is simulated as a point source occurring midway into the reach. The difference between groundwater surface water temperatures is small, therefore proportioning of the inflow to surface and sub-surface components is not critical for the calibration.

Reach	Distance of Top of Reach from Mouth of Ruby River	Upstream Flow	Additional Inflow			Shading	Water Temperature at End of Reach		Comments/Assumptions for Calibration
	(km)	(m^3/s)	Type	Rate (m^3/s)	Temp (^oC)	Measured	Measured (^oC)	Calculated (^oC)	
RBYM02	40.9	0.413	Point and non-point	-0.17 (first diversion), -0.15 (non-point), 0.15 (point)	8.8 (point)	45	11.63	11.97	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that an inflow of 0.15 cms goes into the reach with a temperature equivalent to that of groundwater, while a lateral flow of 0.15 cms goes from the river to the ground to establish the balance. The new inflow is simulated as a point source occurring midway into the reach. The difference between groundwater surface water temperatures is small, therefore proportioning of the inflow to surface and sub-surface components is not critical for the calibration.
RBYM03	36.5	0.243	Point and non-point	-0.028 (2nd diversion), -0.054 (non-point), 0.04 (point)	8.8 (point)	62	12.24	12.51	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that an inflow of 0.15 cms goes into the reach with a temperature equivalent to that of groundwater, while a lateral flow of 0.15 cms goes from the river to the ground to establish the balance. The new inflow is simulated as a point source occurring midway into the reach. The difference between groundwater surface water temperatures is small, therefore proportioning of the inflow to surface and sub-surface components is not critical for the calibration.
RBYM04	33.3	0.201	Point and non-point	-0.218 (3rd and 4th diversion), 0.025 (non-point), 0.1 (point)	8.8 (non-point), 12.96 (point)	63	12.96	13.13	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that 80% (0.1 cms) of the inflow is surface flow with a temperature equivalent to that of surface flow. The remaining 20% (0.025 cms) of the inflow is assumed to be groundwater flow with a temperature equivalent to that of groundwater flow. The surface inflow is simulated as a point source occurring midway into the reach.

Reach	Distance of Top of Reach from Mouth of Ruby River	Upstream Flow	Additional Inflow			Shading	Water Temperature at End of Reach		Comments/Assumptions for Calibration
	(km)	(m^3/s)	Type	Rate (m^3/s)	Temp (°C)	Measured	Measured (°C)	Calculated (°C)	
RBYM05	31.4	0.108	Point and non-point	-0.164 (5th and 6th diversion), 0.018 (non-point), 0.07 (point)	9.1 (non-point), 14.38 (point)	79	14.38	13.95	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that 80% (0.07 cms) of the inflow is surface flow with a temperature equivalent to that of surface flow. The remaining 20% (0.018 cms) of the inflow is assumed to be groundwater flow with a temperature equivalent to that of groundwater flow. The surface inflow is simulated as a point source occurring midway into the reach.
RBYM06	26.4	0.032	Point and non-point	-0.028 (7th diversion), 0.006 (non-point), 0.056 (point)	8.7 (non-point), 15.3 (point)	57	15.3	14.96	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that 90% (0.056 cms) of the inflow is surface flow with a temperature equivalent to that of surface flow. The remaining 10% (0.006 cms) of the inflow is assumed to be groundwater flow with a temperature equivalent to that of groundwater flow. The surface inflow is simulated as a point source occurring midway into the reach.
RBYM07	25.2	0.066	Point and non-point	0.045 (non-point), 0.178 (point)	8.2 (non-point), 14.57 (point)	32	14.57	14.23	Adjustment required on the surface/GW flow balance in order to match the observed temperature. It is assumed that 80% (0.178 cms) of the inflow is surface flow with a temperature equivalent to that of surface flow. The remaining 20% (0.045 cms) of the inflow is assumed to be groundwater flow with a temperature equivalent to that of groundwater flow. The surface inflow is simulated as a point source occurring midway into the reach.
RBYM08	23.2	0.289	Non-point	0.291	11.8	20	14.59	14.36	
RBYM09	16.1	0.580	Point	-0.464		27			

Table A2

Manning coefficient and stream width employed with SNTEMP

Reach	Elevation (m)	Manning coefficient	Stream width (m)
LR01	1631	0.037	17.678
LR02	1594	0.019	7.437
LR03	1561	0.019	16.886
LR04	1551	0.019	10.455
LR05	1536	0.019	14.417
LR06	1527	0.019	17.739
LR07	1522	0.019	15.270
LR09	1497	0.019	11.247
LR10	1497	0.019	12.741
LR11	1490	0.019	17.587
LR12	1481	0.019	16.002
LR13	1475	0.037	14.905
LR14	1460	0.019	10.820
LR15	1448	0.019	11.765
LR16	1445	0.032	12.558
LR17	1420	0.019	18.623
M01	2444	0.037	4.054
M02	1951	0.049	6.218
M03	1762	0.019	4.420
M04	1640	0.049	6.035
M05	1582	0.037	6.218
M06	1487	0.031	2.621
M07	1475	0.037	4.633
M08	1463	0.044	4.755
M09	1448	0.02	6.279

Table A3

Groundwater Temperatures Employed with SNTEMP

Ruby River		Mill Creek and others	
Reach	**Temperature (ºC)**	**Reach**	**Temperature (ºC)**
LR01	12.7	M04	8.4
LR02	12.8	M04 and M05	9.1
LR03	12.3	M06	9.2
LR03	11.9	M06 and M07	8.2
LR05	11.7	M8	12.4
LR06	9.8	M8	11.1
LR07	9.4	Ramshorn Creek	10.3
LR08	9.6	Ramshorn Creek	11.4
LR11	10.8	Silver Spring	13.7
LR12	12.2		
LR12	11.4		
LR13	9.9		
LR14	10		
LR14	11.2		
LR15	10.6		
LR16	12.2		
LR17	9.2		

TABLE A4

Modeling Results for All Scenarios

Reach	Temperature (ºC) at end of reach for scenario			
	S0 (Baseline)	S1 (Shading effect)	S2 (Flow change)	S3 (S1 + S2)
Ruby River				
LR01	19.46	18.88	18.8	18.57
LR02	18.02	17.52	18.36	18.09
LR03	17.05	16.67	17.87	17.6
LR04	17.41	16.8	17.83	17.43
LR06	17.16	16.45	17.48	16.96
LR08	17.5	16.56	17.91	17.13
LR09	17.13	16.35	17.64	16.95
LR010	17.52	16.75	17.87	17.18
LR011	18.24	17.46	18.31	17.61
KM 31.8	19.21	18.33	18.98	18.18
LR013	19.39	18.39	19.14	18.24
LR014	20.3	19.13	19.74	18.73
LR015	20.37	19.24	19.67	18.7
LR016	21.09	20.01	20.28	19.28
Mill Creek				
M01	11.51	11.54	11.51	11.54
M02	13.5	13.17	13.5	13.17
M03	14.26	14.23	14.26	14.23
M04	14.02	13.82	14.48	14.29
M05	15.71	16.14	15.61	15.89
M06	15.63	15.39	15.71	15.81
M07	15.03	14.95	15.56	15.57
M08	15.88	15.46	16.65	16.27

Attachment B
Ruby Watershed SNTEMP Modeling Scenarios

Prepared by Watershed Consulting, LLC

Potential Shade Scenario

The shade scenario is related to canopy density as measured using a concave spherical densiometer held at waist height. Canopy density was used as an input for SNTEMP temperature modeling for the Ruby River. Canopy density is an accepted input used by the model as a surrogate for shade.

Measurements of canopy density in 2004 provide the basis for canopy density values to be used for the potential shade scenario. Canopy density was measured for the 1200 feet upstream of every temperature logger on the lower Ruby River and many reaches on Mill Creek. On the narrower and steeper, higher elevation stream reaches, canopy density was measured for 1000 upstream of loggers. In some cases property boundaries necessitated shorter reaches as well. The average canopy density for each temperature logger site was used as a model input to calibrate the SNTEMP model. The scenario for potential shade is based on the highest canopy densities observed for Mill Creek and the Ruby River below Ruby Dam.

The Mill Creek assessment reaches span a range of conditions, from steep, forested conditions to low-gradient, willow-dominated areas. The canopy density targets for use in the shade scenario therefore are different for each landscape. The highest canopy density for the steeper, forested reaches of Mill Creek was 56% in a reach considered to be close to its potential condition. The potential canopy density value for the shade scenario based on this measurement is 55% for all areas above site M3, which assumes some reaches in this area have higher or lower shade potential but on average could have a 55% canopy density. The target canopy density for reaches in the foothills and outwash fan landscapes (reaches M4-M6) is 71%, based on the value measured in the reach of the best condition in that area. The lower reaches in the low-gradient alluvial plain landscape of Mill Creek are willow-dominated and do not have as high potential for shading as the upper reaches. The target value for modeling potential shade for reaches M7-M9 is 35%, which is slightly higher than any measured value but assumes some improvement in overall riparian condition over current conditions.

Table 1. Measured Canopy Density by Landscape on Mill Creek and Lower Ruby River.

Water Body	Stream Reaches	Avg. Canopy Density	Range in values
Mill Creek	M1-M3	54%	45-62%
Mill Creek	M4-M6	66%	56-79%
Mill Creek	M7-M9	27%	20-33%
Ruby River	LR1-LR17	13%	2-33%

The canopy density value for modeling potential shade is 30% for all reaches on the Ruby River below Ruby dam. This value is based on the measured value of 33% in the reach in best available conditions. The 30% value is used with the assumption that most areas on the lower Ruby River will remain willow-dominated, that recovery of woody riparian vegetation is needed on most reaches, and that some areas do not have the potential for willows lining 100% of both streambanks.

Uncertainty

It should be noted that collection of canopy density measurements in 2004 followed standard protocols that differed from protocols assumed for the model. The measurements were taken with the densiometer at waist height, while the model input calls for measurements taken with the densitometer held 1 ft above water level. In most areas this discrepancy should make little difference in the values measured, but shading may actually be higher in some cases. The protocols should remain consistent with the 2004 methods in effectiveness monitoring for the sake of consistency. All values should be considered plus or minus 3% in effectiveness monitoring, based on duplicate measurements taken for quality control.

Irrigation Improvement Modeling Scenario and Justification

The SNTEMP model will be run with two scenarios related to irrigation. The scenarios will be based on two different percent increases in in-stream flow to determine if and how much stream temperature would be lowered with each change in in-stream flow.

In-stream flow scenario for the lower Ruby is based on information presented in the Lower Ruby Valley Groundwater Management Plan (Payne, 2004). This report concluded that an estimated 10,000 to 30,000 acre-feet per year (during the irrigation season) could be added to in-stream flows with increased irrigation efficiency, barring added irrigation development. The irrigation season spans approximately 6 months. The irrigation season water yield measured in 2002-2003 at Seyler Lane at the downstream end of the watershed was 55,000 ac-ft/yr. Comparing the estimated increase in water yield due to improved irrigation to the water yield at Seyler Lane results in an estimated 18-73% savings during this timeframe. This estimated increase in flow will be modeled by increasing flows throughout the basin by somewhere below the midpoint of this range, or by 37%. This is a conservative assumption because the water savings could be used only during the hot summer timeframe instead of an average of the six month irrigation period.

There is not enough information for outflows occurring along either of the water bodies to determine the relative change in flow for separate reaches, therefore it is necessary to assume a uniform percent increase in flow for all reaches. The first irrigation scenario will entail increasing the flow at site LR2 below the main irrigation diversions, and subsequently at all reaches downstream, by 45%. If this scenario results in a change in temperature, the second scenario will be to increase the surface water flow by 18%. If no change in temperature results, the second scenario will be to increase surface flow by 73%. An equivalent percent decrease in groundwater accretion will be modeled to account for lowered groundwater recharge from inefficient irrigation practices.

The estimates of potential water savings are not applicable to Mill Creek, therefore the flow scenario for Mill Creek could not be derived from these same data.

The degree to which irrigation is the cause of dewatering on Mill Creek is unknown, but is most likely significant. Flows monitored on August 6, 2004 are represented from upstream to downstream (right to left) in Figure 1. Flow increases from the headwaters site (RBYM01) to RBYM02, but then decreases significantly below RBYM02 until RBYM07. There is a large diversion just below RBYM02, and several other diversions downstream.

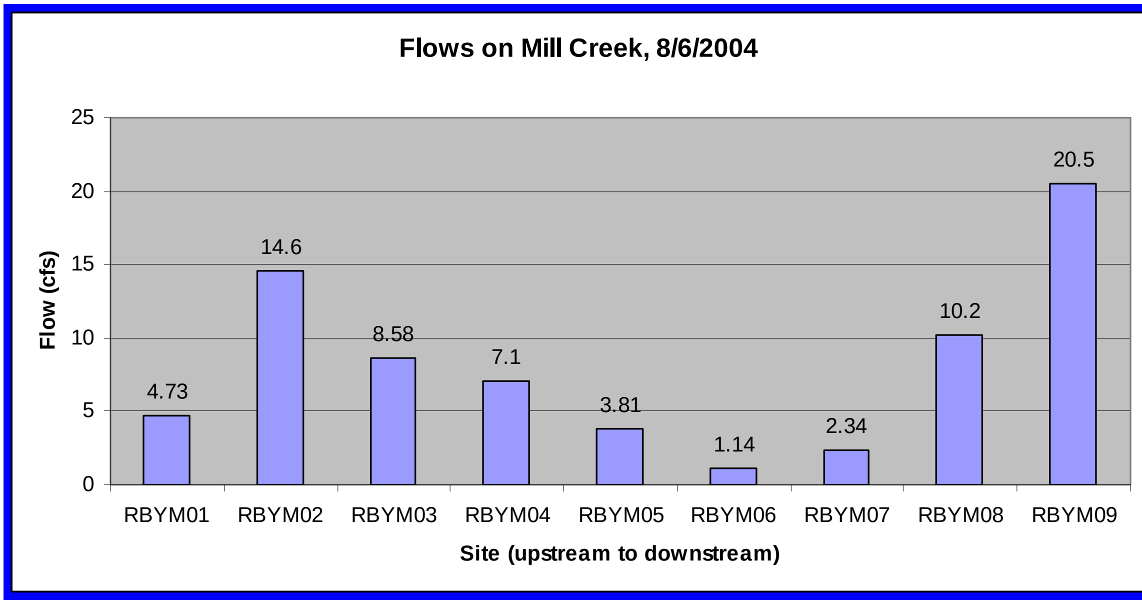

Figure 1. Trends in Streamflow on Mill Creek on August 6, 2004. Sites are Listed Left to Right from Upstream to Downstream.

The location and magnitude of irrigation diversions on August 6, 2004 are summarized in Table 2 (Hamler, pers comm.).

Table 2. Irrigation Withdrawals for Mill Creek Above Irrigation Water Inputs.

Reach	Location	Miners Inches	Flow in cfs
Bbottom M3	Above Shackletons	50	1
TopM4	At Shackletons	265	5.3
TopM4	Below Shackleton	40	0.8
M4	Triple Ck Ranch	30	0.6
M4	Funk/Triple Creek Ranch	50	1
M5	Pearce at Browns	70	1.4
M5	At Indian Ck Rd	10	0.2
M5	Swans above Sheridan	85	1.7
M5	Right above Sheridan	15	0.3
Bottom M5	Melhoffs	109	2.18
Top M6	At ballpark	50	1

Improved irrigation efficiency may be achieved by a change in irrigation methods, such as a shift from flood irrigation to pivot, or from reducing conveyance losses through ditch lining. Payne (2004) estimated 21 to 46% canal and ditch water loss. According to this same document, lined canals often keep water loss below 10%, resulting in an 11 to 36% savings. According to Payne (2004) the average increase in irrigation efficiency for changing from flood irrigation to more efficient sprinkler irrigation is approximately 20%. Adding the two sources of irrigation water savings, the potential increase in surface water flow from reduced irrigation withdrawals ranges from 31 to 56%. It is unlikely all of the potential water savings will be achieved, and that savings due to increased irrigation efficiency will actually result in a corresponding increase in surface water. The irrigation scenario for Mill Creek will model increasing instream flows by 43%, the mid point of the potential water savings. The second scenario will be based on the results of the first run, specifically its effect on simulated stream temperature. A corresponding decrease in groundwater flow will be modeled to account for reduced groundwater inputs from irrigation ditches and inefficient irrigation practices.

The streamflow added to each reach should be based on the distribution of irrigation withdrawals on Mill Creek. Not all Table 3 provides a summary of flow taken out per reach and the flow to be added to each reach based on irrigation efficiency improvements. Withdrawals at the bottom of a reach are applied to the next reach downstream, where the effects of the diversion are seen. Flows added to each reach should be applied to reaches further downstream as well.

Table 3. Summary of Flows Diverted for Each Reach on Aug 6, 2004.

Reach	Total Flow Diverted	Flow to Return to Reach for Flow Scenario
M4	8.7	3.7
M5	3.6	1.5
M6	3.2	1.4
M9	16.4	7.1

The flows diverted in reaches M3-M6 amount to greater than 100% of the flow coming into Mill Creek above the glacial outwash fan, which indicates all inflows are not considered. In addition, sites RBYM03 through RBYM06 are located on a glacial outwash fan, and surface water naturally infiltrates from the channel to ground water on that landscape (Payne, 2004). According to the Mill Creek ditch walker (Hamler, pers comm.), most to all of the water in Mill Creek is taken out for irrigation, and the channel is often dry just below Sheridan. During irrigation season, most of the streamflow in the lower reaches (below M6) on Mill Creek is due to irrigation return flow from ditches or groundwater (Payne, 2004). Accretion temperature for inputs to lower Mill Creek may need to be adjusted to reflect the surface water returns. Unfortunately, there is not enough information to determine exactly how much is returned to Mill Creek via surface water instead of ground water.

Flows measured in 2004 in the lower reaches of Mill Creek reflect large increases in flow due to irrigation returns. Water is diverted into Mill Creek from the Ruby River above M9, but this much water is removed again through a diversion just above M9.There is a large diversion at the base of Mill Creek that takes much of the flow again. This diversion is between M9 and the mouth, and takes an estimated 80% of the flow measured at M9. The exact amount diverted is unknown. The estimated amount diverted is in Table 3 for reach M9. The total amount diverted is equal to 80% of the flow measured at M9. There is no commissioner for diversions below Middle road on Mill Creek.

Diverted flows should be considered for each reach when applying the modeled increase in flow for Mill Creek. There is not enough information for outflows from the lower Ruby River to determine the relative change in flow for separate reaches, therefore it is necessary to model a uniform percent increase in flow for all reaches.

For both water bodies the second flow increase scenario will be determined based on the results of the first scenario. If the first scenario results in no change in temperature, the second scenario will be to increase the surface water flow. If a change in temperature results, the second scenario will be to decrease surface flow from the first modeled increase. The specific percent increases to model will be decided cooperatively based on the results of the first flow scenario. An equivalent percent decrease in ground water accretion will be modeled to account for lowered ground water recharge from inefficient irrigation practices.

References

Hamler, Ralph. 2005. Mill Creek Ditch Walker. Personal Communication February 2005.

Kirk Environmental. 2004. Lower Ruby Valley Groundwater Management Plan. Report to the Ruby Valley Conservation District and Ruby Watershed Council, Sheridan, Montana.