APPENDIX J
MODELING STREAMFLOW AND WATER TEMPERATURE IN THE BIG HOLE RIVER, MONTANA – 2006
ADDENDUM-1; DIVIDE CREEK

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TMDL Technical Report DMS-2008-03

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March 2008

Suggested Citation:

Flynn, K., Kron, D., Granger, M. 2008. Modeling Streamflow and Water Temperature in the Big Hole River, Montana – 2006. Addendum-1; Divide Creek. TMDL Technical Report DMS-2008-03. Montana Department of Environmental Quality.

ADDENDUM SUMMARY

The purpose to this addendum is to document temperature modeling activities completed on Divide Creek, as part of the Big Hole River temperature TMDL. Previously, a comprehensive modeling assessment was completed on 152.5 kilometers of the mainstem Big Hole River using Heatsourcev7.0. A similar approach was applied to 27.75 km of Divide Creek, albeit greatly simplified in scope. Identical methods and material to that of the mainstem study were used, thus these are not detailed as part of this addendum. The addendum does include discussions specific to Divide Creek, including the study area, model inputs, results and discussion, and scenario analyses. Overall, it was found that shade was main contributor to observed temperature exceedances in the watershed, and that maximum predicted water temperatures would be reduced up to 0.25°C (0.45°F) with the improvement of riparian cover. Because of this, riparian improvement projects are the primary recommendation to mitigate temperature impairments in the Divide Creek watershed. In-stream flow was also found to be significant, albeit, in an unusual way. Return flow from the Big Hole River via the Divide Canal was shown to moderate temperatures by 2.80°C (5.04°F). Finally, irrigation within Divide Creek itself was also assessed, and is believed to a possible source of temperature impairment in the watershed. Uncertainty in field data made this conclusion largely speculative and further study is warranted to make concrete conclusions about the impact.

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STUDY AREA

Divide Creek is a relatively small tributary to the Big Hole River that drains approximately 245-km2 (153-mi2) of low-elevation topography in the north-central portion of the watershed (**Figure J-1**). It is part of the Lower Big Hole River TMDL Planning Area (TPA), and extends south from the continental divide near Butte, MT to the town of Divide, MT. The North and East Forks form the headwaters, and flow approximately 24.9-km (15.5-mi) prior to reaching the Big Hole River. In the last 4-km of the project reach, the stream splits into two separate channels (east and west branches), appropriately near the town of Divide

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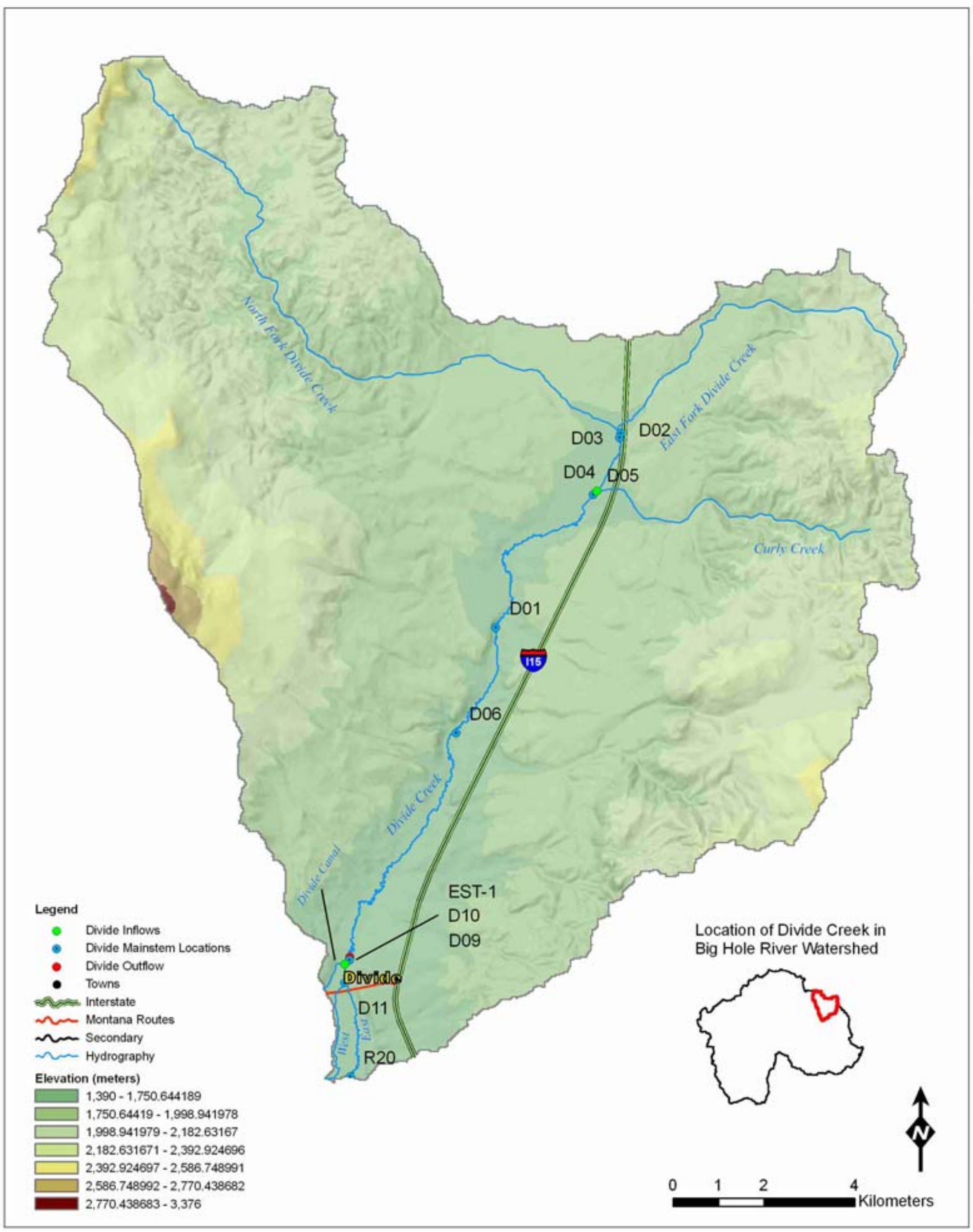
Figure J-1. Divide Creek study area showing terrain, hydrography, and monitoring locations.



MODEL DEVELOPMENT

GIS Pre-processing

TTools was used for the initial setup of the Divide Creek model. The 30-m USGS National Elevation Dataset (NED) was used for calculation of topographic characteristics including elevation and gradient using digitized channel centerline and bankfull geometry. Riparian vegetation classification was completed by MDEQ using the 2004 National Agricultural Imagery Program (NAIP) photography at a scale of 1:5,000. Raster input files at a 1-m grid resolution were then developed for model pre-processing. Project coordinate system and datum were State-Plane NAD83 and NAVD88. A node distance of 50-m was for longitudinal sampling, and 1-m increments were used to determine landcover and shading attributes.

Simulation Period and Global Control Specifications

To maintain consistency with the mainstem modeling effort, the same simulation period of July 25 through 31, 2006 was used in the Divide Creek analysis. Additionally, a scaled down distance, and time-step of that of the mainstem model was used, 250-m and 5 minutes respectively.

Hydrology/Mass Transfer Input

Hydrology and mass transfer data from the 2006 field effort were used to define the overall water balance for the simulation reach (**Table J-1**). Due to the fact that the stream splits into two channels in the last 4-km, only the east channel was modeled as part of the analyses. This is because it appears to be the main natural conveyance for surface water, and that groundwater and unmeasured irrigation return flow appear to be the dominant influences on the western channel. Diurnal temperatures of dataloggers deployed in Divide Creek during the study are shown in **Figure J-2**.

Hydraulic Input

Hydraulic input for the Divide Creek model was developed using the Heatsourcev7.0 TTools extension. Manning's roughness coefficient was estimated from the mainstem modeling effort, and the three reaches were identified for unique parameterization of hydraulics based on channel gradient (**Table J-2** and **Figure J-3**).

Climate Input

The Bert-Mooney Federal Aviation Agency (FAA) station in Butte, MT was used for the Divide Creek modeling effort to be consistent with station assignments used in the mainstem modeling effort. Information regarding observations during the study period are included in the text of the mainstem modeling report.

Table J-1. Water balance for Divide Creek during the July 25-31, 2006 modeling period. All data are in cubic meters per second (m3/s).

DIVIDE CREEK WATER BALANCE 7/25-31/06		m^3/s	GWH_20 EST
D03 -NORTH FORK DIVIDE CREEK		**0.000**	↑
D02 - EAST FORK DIVIDE CREEK		0.010	-0.003
D04 - CURLY CREEK		0.002	↓
	TOTAL	**0.012**	**LOSING**
D05 - DIVIDE CREEK MAINSTEM (23.38 KM)		**0.009**	**0.009**
			↑
			-0.004
	TOTAL	**0.009**	**LOSING**
D01 - DIVIDE CREEK MAINSTEM (17.07 KM)		**0.005**	**0.005**
			↑
			0.012
	TOTAL	**0.005**	**GAINING**
D06 - DIVIDE CREEK MAINSTEM (13.30 KM)		**0.017**	**0.017**
EST1 - WEST BRANCH DIVIDE CR DVT		-0.016	0.000
	TOTAL	**0.001**	**BALANCED**
D10 - DIVIDE CREEK MAINSTEM (4.30 KM)		**0.001**	**0.001**
D09 - DIVIDE CANAL RTN		0.312	↑
			-0.048
	TOTAL	**0.313**	**LOSING**
D11 - DIVIDE CREEK MAINSTEM (3.65 KM)		**0.265**	**0.265**
			↑
			-0.180
	TOTAL	**0.265**	**LOSING**
R20 - DIVIDE CREEK OUTLET (0.00 KM)		**0.085**	**0.085**

Notes:
(1) D01, D02, R20, etc. – field ID (not necessarily in alphanumeric order)
(2) DVT = diversion
(3) RTN = return flow

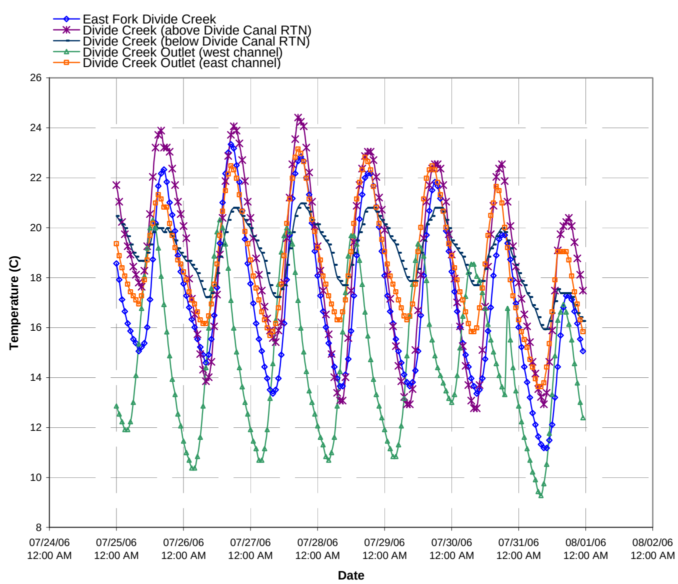


Figure J-2. Representative plots of water temperature in Divide Creek during the modeling period of July 25-31, 2006.

Shade Input

Eight riparian landcover types were identified through air photo interpretation, and ground-truth to parameterize typical reach shading attributes in the model (**Table J-3**). Verified model parameters were then assigned to corresponding land classes to complete the radial shading calculations in Heatsource v7.0.

Table J-2. Hydraulic parameters used in the Divide Creek Heatsource v7.0 model.

River Reaches	Gradient (%)	Width- Depth Ratio	Mannings "n"
Reach 1	2.4%	10	0.12
Reach 2	1.0%	10	0.12
Reach 3	0.1%	15	0.12

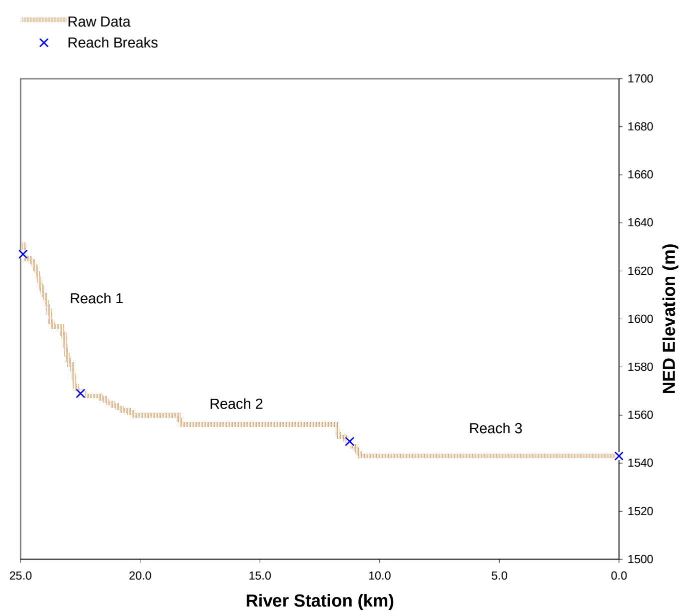


Figure J-3. Unique reaches defined for model parameterization of hydraulics. Elevation data taken from USGS National Elevation Dataset (NED) 30-m grid.

Table J-3. Riparian landcover types and associated attributes used in Heatsource v7.0 shading calculations.

Land Cover	Height (m)	Density (%)	Over-hang (m)
Bare	0.0	0%	0.0
Deciduous (sparse)	17.2	40%	3.0
Developed	0.0	0%	0.0
Grass/sedge	0.4	50%	0.0
NSDZ/water	0.0	0%	0.0
Pasture/field	0.5	90%	0.1
Transportation	0.0	0%	0.0
Willow (sparse)	4.9	40%	1.0
Willow (dense)	5.7	75%	1.5

RESULTS & DISCUSSION

Hydrology

Flow conditions in Divide Creek were difficult to reproduce in Heatsourcev7.0 due the extremely low flows (<0.01 cms), and the number of significant figures carried in the model calculations. As a result, hydrology had a poor statistical calibration as evidenced by an average PBIAS of 281.6 percent (e.g. comparing daily simulated flow values with instantaneous field-measurements). However, given that the standard error is quite low (e.g. 0.005 cms or 0.2 cfs), it is apparent that the model is performing satisfactorily. Observed and predicted results for July 28th of the July 25-31, 2006 modeling period confirm this observation, and are shown in **Figure J-4.**

Hydraulics

A comparison of model hydraulics against measured field data is also shown in **Figure J-4**. In general, acceptable agreement is seen between observed and simulated velocities, and wetted widths. Mean PBIAS for computed channel velocities, and wetted widths were 264.9 percent and -93.5 percent, respectively. Standard errors were 0.05 m/s and 0.1 meters. Again, this illustrates the propensity for relatively small simulation errors to manifest as large errors in PBIAS.

Shade

Simulated stream shade is shown in **Figure J-5**. Predictions ranged from approximately 10 to 90 percent, and averaged 22.2 percent for the study reach. A majority of the shade was observed in the upper 5-km due to extensive willow canopy, and a very narrow channel. Modeled shade appears to track adequately with observed measurements, and overall simulation PBIAS was 57.5 percent with a standard error (in percent shade) of 4.3 percent.

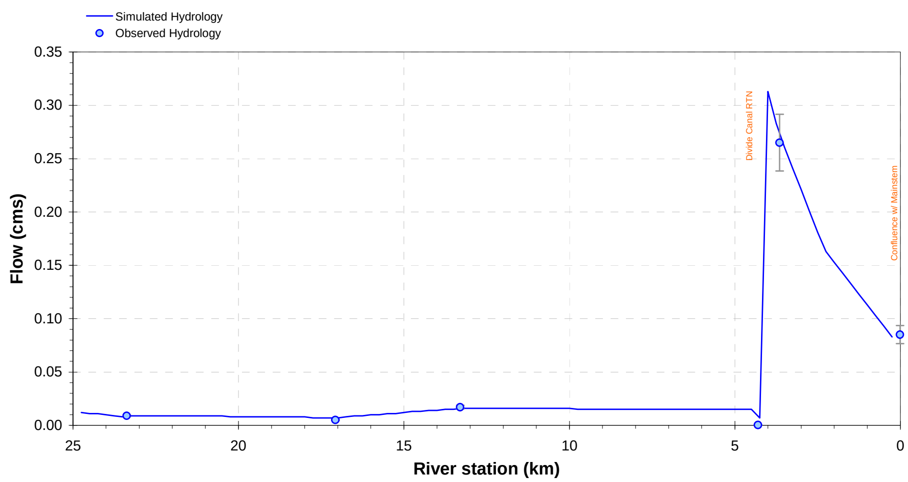
Water Temperature

Hourly diurnal temperature plots for the simulation period are shown in **Figure 6**. The longitudinal temperature profile is shown in **Figure 7**. Clearly the model performs best in the lower two reaches, which contain the highest flow volume. In review of the temperature calibration, average PBIAS was 2.0 percent, NSE was 0.33, SSQR = 493.2, and standard error = 1.7°C. Individual calibration statistics for model calibration nodes are shown in Table J-4. Overall, there appears to be acceptable agreement between observed and predicted water temperatures. This demonstrates the utility of the model for TMDL planning.

Table J-4. Hourly water temperature calibration statistics for July 25-31, 2006 modeling period.

Site ID	PBIAS	NSE	SSR	SE
River km – 23.38 (D05)	6.5%	0.49	162.9	0.6
River km – 17.07 (D01)	3.4%	<0	1,072.1	3.1
River km – 13.30 (D06)	-1.5%	<0	737.7	1.7
River km – 04.30 (D10)	1.6%	0.00	898.2	2.9
River km – 03.65 (D11)	-0.2%	0.92	11.0	0.3
River km – 00.01 (R20)	1.9%	0.59	77.0	1.4
AVG	2.0%	0.33	493.2	1.7

a)



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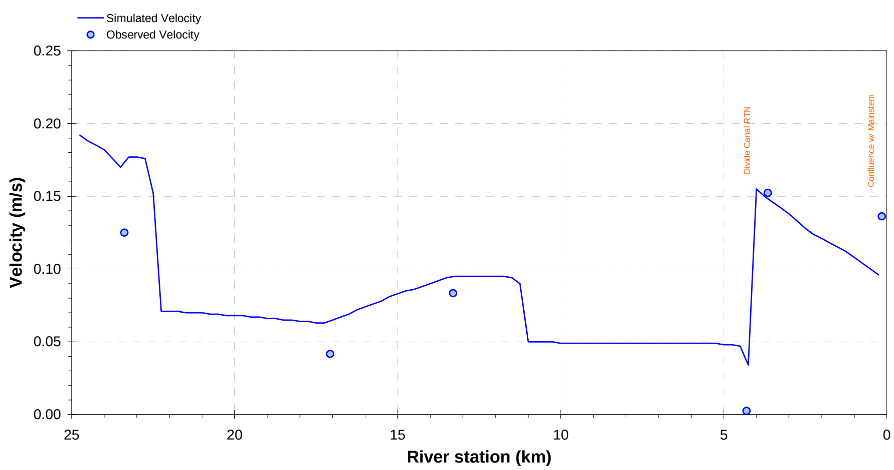

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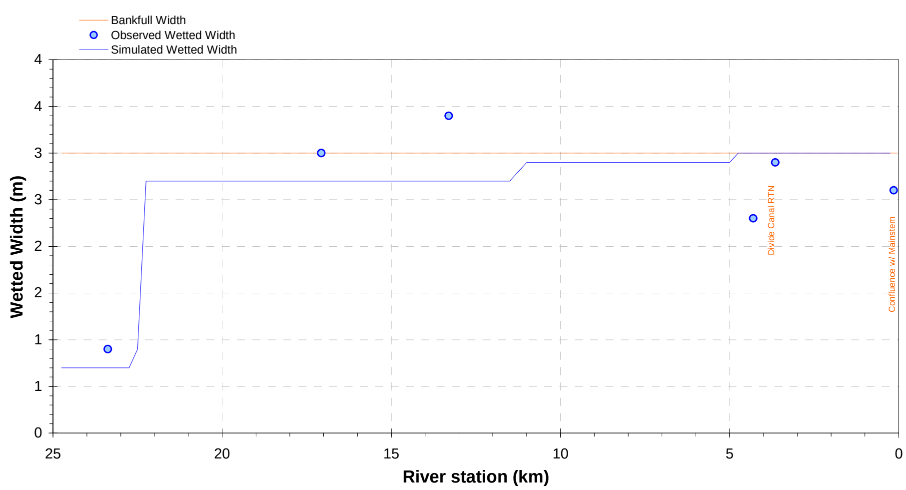


Figure J-4. Simulated and observed hydrology and hydraulics for Divide Creek: a) hydrology, b) mean channel velocity, and c) mean wetted width for July 28th of the July 25-31, 2006 modeling period. Observed measurements were taken instantaneously over the study period and may not necessarily reflect conditions that day.

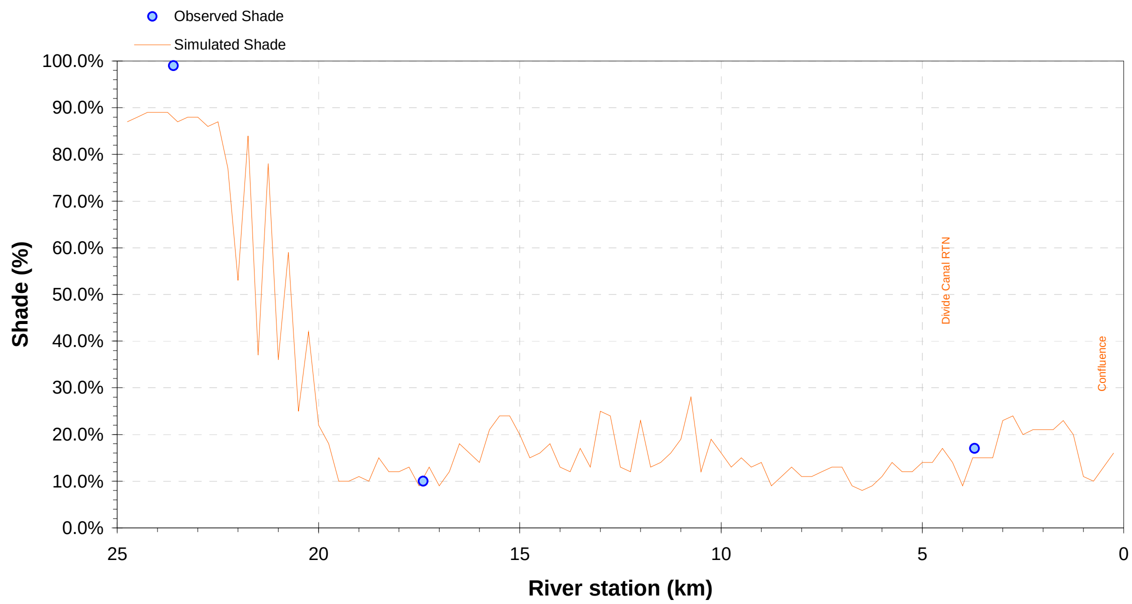


Figure J-5. Simulated stream shade for the July 28th of the July 25-31, 2006 modeling period.

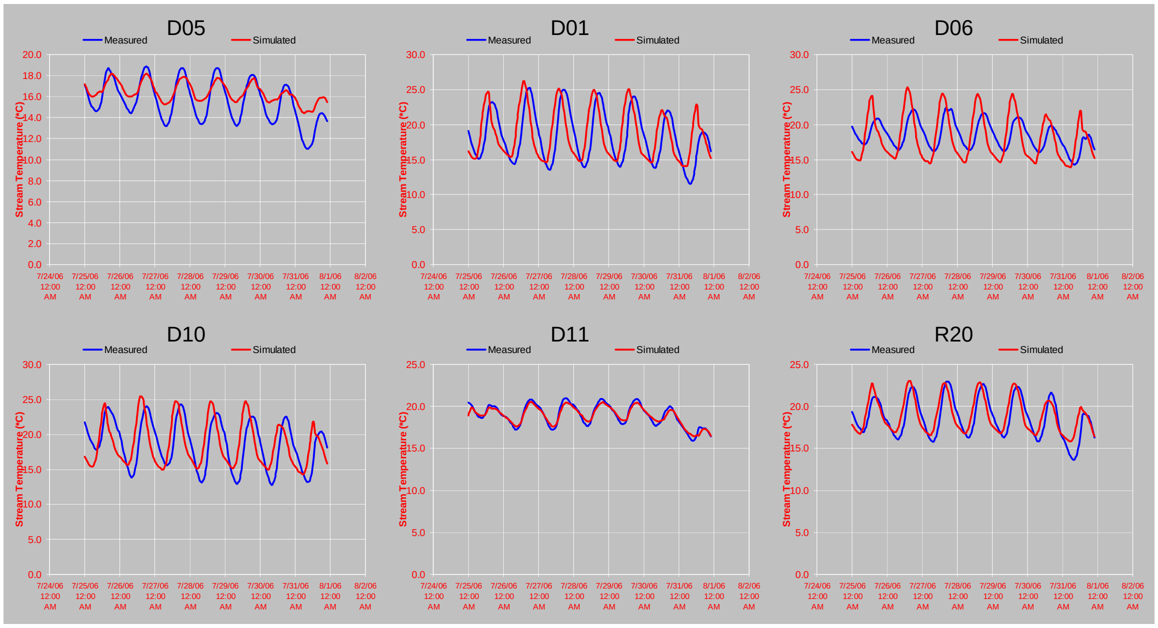


Figure J-6. Diurnal plots of observed and simulated temperature on Divide Creek during the July 25-31, 2006 modeling period. Nodes are order from up to downstream going from left to right and top to bottom.

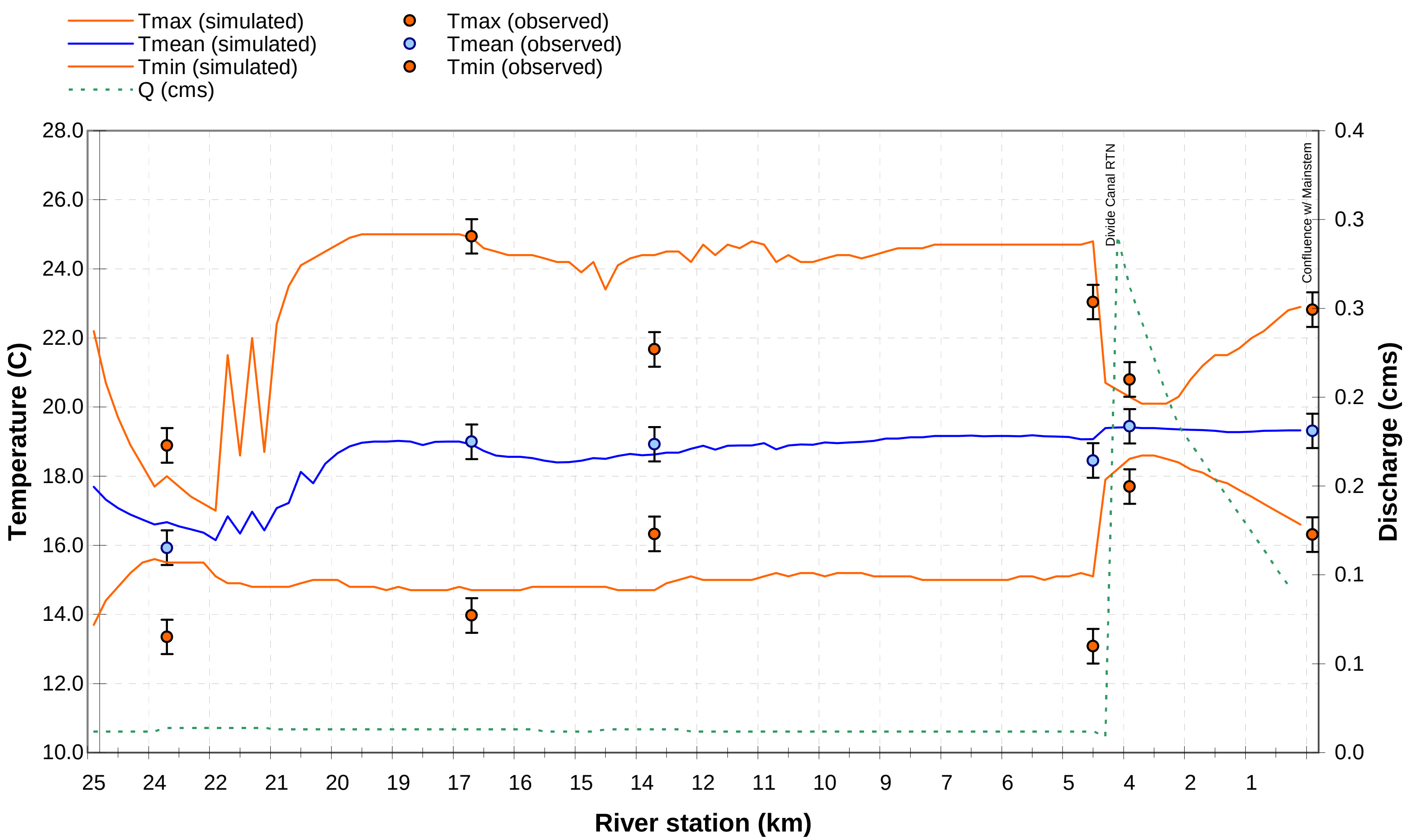


Figure J-7. Longitudinal temperature profile of Divide Creek displaying Tmin, Tmax, Tavg, and discharge for July 28th of the July 25-31, 2006 modeling period. Error bounds of measured data (±0.2 ºC datalogger accuracy) are shown along with major inflows and outflows.

SCENARIO ANALYSIS

Following model development, a number of scenarios were formulated so that watershed managers can provide reasonable recommendations for meeting water quality criteria in the river. Specifically, modeling scenarios addressed the following: (1) baseline conditions, (2) a shade scenario in which reference shade was applied across the project reach, (3) water consumptive use scenario where effects of irrigation, and domestic withdrawls were assessed, (4) a second flow scenario where the effects of irrigation return flow from the Big Hole River were addressed, (5) a natural condition scenario with no anthropogenic influence, and (6) naturally occurring scenario in which all reasonable land, soil, and water conservation practices were applied (ARM 17.30.602).

Baseline Scenario

The baseline scenario describes existing conditions, and is merely a reflection of the calibration. The simulation results have been documented in prior sections and indicate a marginal water temperature calibration based on performance statistics of NSE, PBIAS, and SSR. Simulated values from the baseline scenario form the basis for which all other scenarios will be compared. For the rest of the document, temperature comparisons are reported as the 7-day minimum (7Dmin), 7-day average (7Davg), and 7-day maximum (7Dmax) temperature.

Shade Scenario

Shade was assessed to identify its potential influence on water temperature in Divide Creek. A shading scenario was run to characterize the maximum possible influence of stream shade on in-stream temperature based on the following assumptions: (1) all open/grassed sites, barren areas, and any other area with diminished shading vegetation was assumed to be converted to reference shade condition and (2) all other conditions were held constant. Reference shade was defined as the combination of 80 percent willow and 20 percent grass, which is identical to the assumptions made in the mainstem study. Results indicate that average shade would be increased from 22.2 percent to 27.2 percent (e.g. 5 percent) which translates to an average 7Dmax decrease of 0.25°C (0.45°F) at the watershed outlet. The decrease in temperature averaged 0.19 (0.34°F) across all modeling nodes. From review of the shade scenario, minor standard violations were observed at a number of locations in the study reach (e.g. change of >0.23°C; mostly in 7Dmax). Because of this, riparian improvement activities are recommended from stream kilometer 22.0-12.0 and 7.5-4.0 km, to mitigate these impacts. Baseline and simulated shade, along with associated in-stream water temperatures are shown in **Table J-5** and **Figure J-8**.

Table J-5. Temperature changes resulting from modification of shade on Divide Creek.

Condition	% Shade	Tmin	Tavg	Tmax
Baseline	22.2%	16.44	18.88	22.19
Shade Scenario	27.2%	16.51	18.77	21.94
Δ TEMP-Outlet		+0.07	-0.11	-0.25
Δ TEMP – all (1)		+0.08	-0.07	-0.19

(1)Average deviation of all model nodes, not just watershed outlet

Water Consumptive Use Scenario (Flow-1)

The water consumptive use scenario describes the thermal effect of irrigation, and domestic water use directly from Divide Creek. For the purpose of this scenario, natural stream hydrology was simulated including the removal of irrigation withdrawals, or associated return flows from Divide Creek (including any known inter-basin transfer to or from the drainage). Because of this, the baseline model run was first reformatted to exclude the Divide Canal return flow which was significantly altering temperatures in the lower 4-km of the study reach. In completion of the scenario, it was apparent that very little water was actually available for diversion in Divide Creek. An estimated 0.008 cms (0.28 cfs) was transferred to the west fork of Divide Creek near stream km-4.35. This withdrawl was inferred to be for irrigation, however, since no direct field observations were made regarding the water use, the assumption was characterized as highly uncertain. If irrigation was the reason for removal, modeling results show that standard violations would occur downstream of the diversion, and 7Dmax and 7Dmin temperatures would be 0.57 and 2.47°C cooler (1.03 and 4.5°F) without it (**Table J-6** and **Figure J-8**). However, the uncertainty regarding assumptions in this scenario should strongly be considered by managers and used with caution in interpretation of results.

Table J-6. Temperature changes resulting from water consumptive use in Divide Creek.

Condition	**Q (cms)**	**Tmin**	**Tavg**	**Tmax**
Baseline(1)	0.011	17.50	20.55	24.51
Flow-1 Scenario	0.019	15.03	18.69	23.94
Δ TEMP-Outlet		-2.47	-1.86	-0.57
Δ TEMP – all (2)		-0.26	-0.19	-0.11

(1) Baseline taken at 0.50-km; channel dry at 0.25-km
(2) Average deviation of all model nodes, not just watershed outlet

Irrigation Return Flow Scenario (Flow-2)

The Divide Canal return flow from the Big Hole River was identified in the previous section as having a significant influence on water temperature in Divide Creek. Therefore a second irrigation return flow scenario was developed to ascertain how the removal of this water would affect in-stream temperature in Divide Creek. Assumptions of this scenario included those already made in the first irrigation scenario, with the focus specifically being the effect of the Divide Canal. In review of the results, return flow from the canal is actually a benefit to Divide Creek, buffering temperatures, and adding to instream flow. 7Dmax and 7Dmin would be 2.80 and 0.63°C warmer without it (5.04 and 1.13°F) (**Table J-7** and **Figure J-8**). When compared to the previous irrigation scenario, it is apparent that the effects of the canal far outweigh those occurring from irrigation within Divide Creek, thus it is the opinion of DEQ that the return flow is of benefit to Divide Creek

Table J-7. Temperature changes from Divide Canal Irrigation return flow.

Condition		Tmin	Tavg	Tmax
Baseline(1)		17.50	20.55	24.51
Flow-2 Scenario		16.87	18.88	21.71
Δ TEMP-Outlet		-0.63	-1.67	-2.80
Δ TEMP – all (2)		+0.13	-0.14	-0.58

(1) Baseline taken at 0.50-km; channel dry at 0.25-km

(2) Average deviation of all model nodes, not just watershed outlet

Natural Condition Scenario

The natural condition scenario reflects the temperature regime that would be expected absent of the influence of man. While this type of scenario is clearly not realistic from a socio-economic standpoint, it does afford the ability to characterize the extent of departure from natural conditions, and subsequently, the maximum potential improvement in the watershed. For the purpose of the study, natural conditions were defined as the removal of all human influences that affect heat or mass transfer. Natural condition scenario assumptions include the following: (1) reference shade conditions were applied as described in the shade scenario, (2) the same irrigation and consumptive use conditions as in the water consumptive use scenario were applied (e.g. natural system hydrology), and (3) no other associated changes. Results of the natural condition scenario parallel that of the flow scenarios, and indicate that maximum temperatures in Divide Creek would actually be warmer if returned to natural conditions (e.g. no return flows from the Big Hole River). 7Dmax would increase by 0.90 (1.62°F), while 7Dmean and 7Dmin would decrease (**Table J-8** and **Figure J-8**). It appears overall, that natural conditions are less desirable to aquatic life than that of existing condition.

Table J-8. Temperature changes resulting from natural conditions in Divide Creek.

Condition		Tmin	Tavg	Tmax
Baseline		16.44	18.88	22.19
Natural Scenario		15.19	18.50	23.09
Δ TEMP-Outlet		-1.25	-0.38	+0.90
Δ TEMP – all (1)		-0.14	-0.32	+0.28

(1)Average deviation of all model nodes, not just watershed outlet

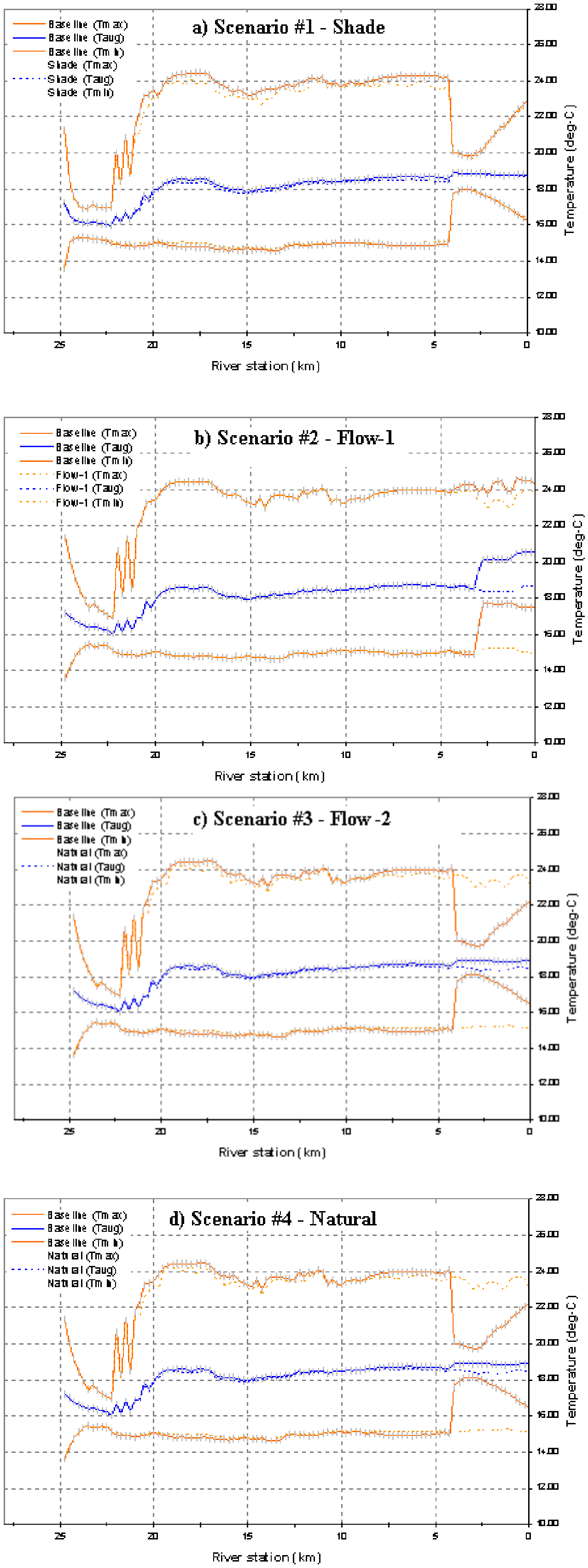
Naturally Occurring Scenario (ARM 17.30.602)

The naturally occurring scenario defines water temperature conditions resulting from the implementation of all reasonable land, soil, and water conservation practices (LSWCP) as outlined in ARM 17.30.602. Essentially, “naturally occurring” establishes the bar for which the allowable 0.23°C (0.5°F) temperature increase is compared to. Assumptions used in the development of the naturally occurring scenario include the following: (1) identical shade conditions to those described in the shade scenario, (2) a 15 percent reduction in the assumed 0.008 cms irrigation withdrawl to the west fork channel, and (3) a reduction of 15 percent in the return flow from the Divide Canal and associated withdrawls (per the assumptions in the mainstem modeling effort). Results of the scenario very much parallel the shade scenario, suggesting that under naturally occurring conditions (as defined by state law) shade would be the primary TMDL necessity to decrease water temperatures in Divide Creek. Standard violations still occur at stream kilometer 22.0-12.0 and 7.5-4.0 km (**Table J-9** and **Figure J-8**), and 7Dmax and 7Dmin would be 0.09 and 0.11°C cooler than current (0.16 and 0.20ºF). Therefore, the primary management recommendation coming from this study is to prioritize and address reaches for shade improvement as part of the upcoming TMDL effort.

Table J-9. Temperature changes resulting from naturally occurring conditions in Divide Creek.

Condition		**Tmin**	**Tavg**	**Tmax**
Baseline		16.44	18.88	22.19
Naturally Scenario		16.33	18.75	22.10
Δ TEMP-Outlet		-0.11	-0.13	-0.09
Δ TEMP – all (1)		+0.05	-0.07	-0.17

(1)Average deviation of all model nodes, not just watershed outlet



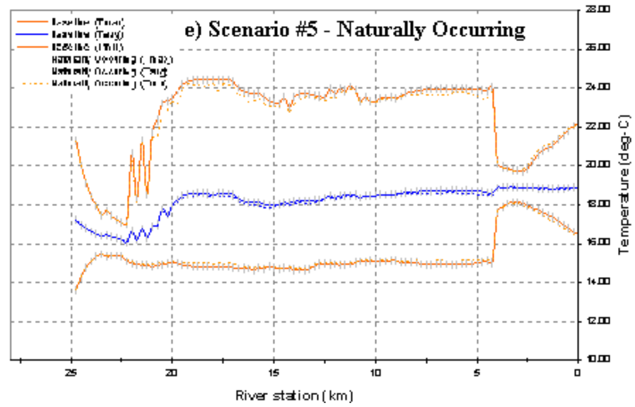


Figure J-8. Longitudinal temperature effects of management scenarios on Divide Creek. The grey shaded area represents ±0.23ºC degree variation from that of baseline conditions. Scenarios that deviate outside the 0.23ºC boundary indicate potential impairment.

CONCLUSION

Modeling was completed on Divide Creek using Heatsource v7.0 to better understand the relationship between instream water temperature, riparian conditions, and water management practices for the summer critical low-flow period. Through scenario analysis, it was shown that shade, and riparian corridor enhancement were the primary mechanisms for achieving "naturally occurring conditions" in the watershed. Thus the key management recommendation originating from this study is to protect and reestablish effective riparian areas to the extent possible. In-stream flow was also shown to be important to stream thermodynamics, and return flow from the Big Hole River (e.g. Divide Canal) was found to buffer maximum and minimum water temperatures in the lower reaches of Divide Creek. Finally, irrigation from within Divide Creek itself was also assessed, and was found to be a potential source of impairment in the watershed. This conclusion was constrained by uncertainty in field data and further study is warranted to make concrete determinations about associated impacts, if any.

REFERENCES

Please refer to main document