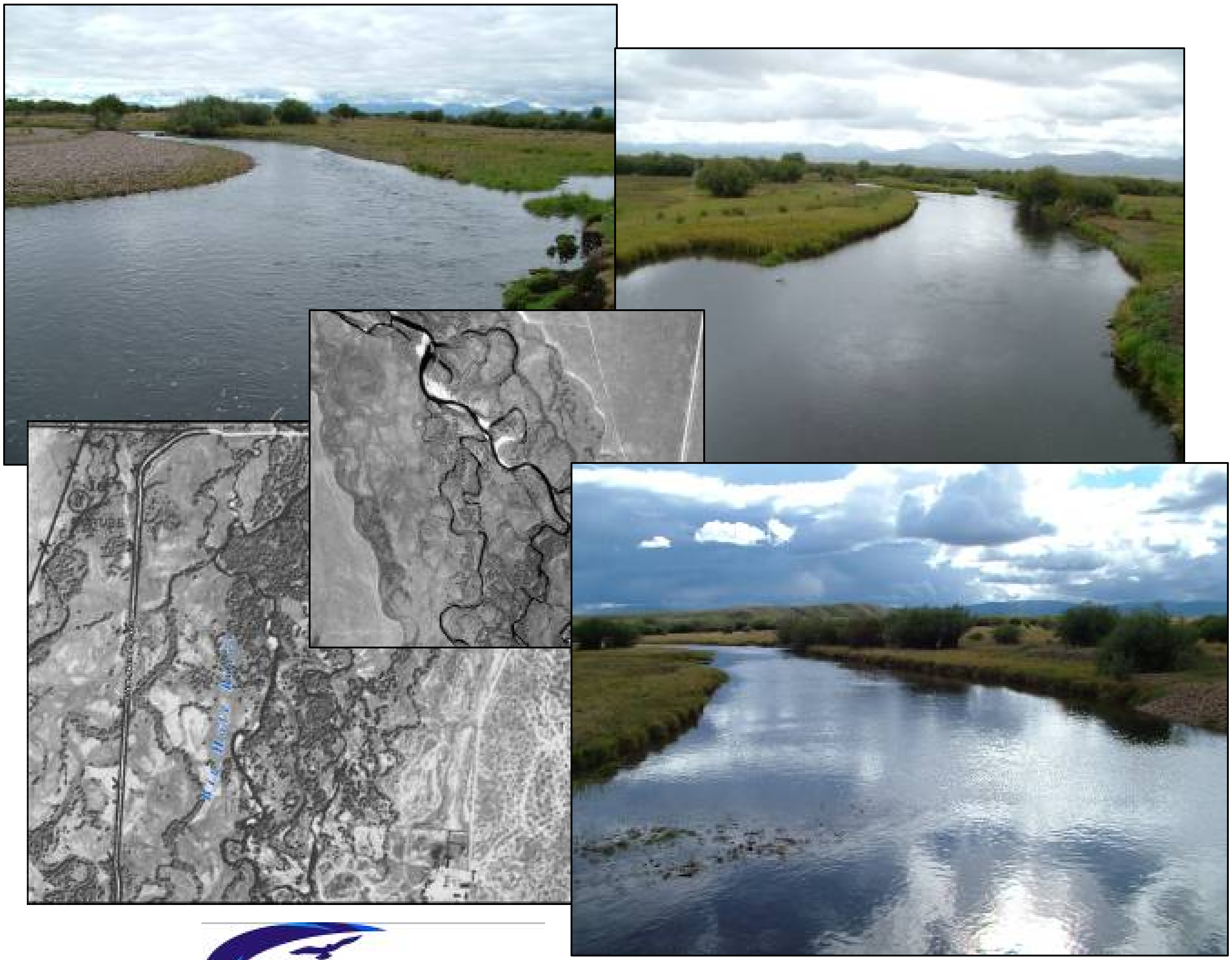
APPENDIX B
MODELING STREAM TEMPERATURES IN THE UPPER BIG HOLE RIVER - 2003



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Upper Big Hole River photos

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SECTION 1.0
BACKGROUND

Non-point source thermal loading presents a scenario that differs from most pollutants, in that the “sources” are not sources of heat in the true sense. Rather, alterations to riparian vegetation, channel geometry, and flow volumes influence insolation of the stream surface and decreased thermal inertia that alters temperatures. These alterations are pronounced along much of the Big Hole River. This investigation identifies how these factors influence temperatures along the upper Big Hole River above Pintlar Creek. This was completed via water temperature, stream flow, riparian vegetation, and stream channel measures and their use within a modeling framework called the Stream Segment Temperature Model (SSTEMP).

Initially, an aerial photo analysis, combined with field investigations, identified reaches where modifications to riparian vegetation and channel geometry possibly contributed to thermal loading. Also in the aerial assessment, reference areas were discovered and subsequently monitored to determine reasonable restoration conditions.

Other potential sources include irrigation return flows of three types. First are ditch returns where ditches re-intercept streams. Ditches in the Big Hole River probably vary in terms of their potential to accrue temperature; however, field observations in 2005 indicated many ditches had sparse shading and long residence times, factors that may promote warming (Confluence, unpublished data). Discrete, but intermittent, inputs of overland flow across fields present another potential source of thermal loading. Field observers noted several instances of overland flow entering streams at discernable locations. These were likely the result of years of flood irrigation waters cutting distinct channels through irrigated pastures. The third type of irrigation return flows were diffuse returns via overland flow. Presumably, groundwater return flows would be relatively cool, although residence time and associated factors make this difficult to predict. Given the unpredictable and potentially ephemeral locations of these features, determination of their influence on stream temperature was not possible during this project. These sources will be addressed through long-term monitoring and the adaptive management approach.

Riparian vegetation attributes, channel geometry, stream flow, and water temperature monitoring supported a thermal modeling approach to source assessment and provided the basis to allocate thermal pollution among influential factors in the Big Hole. The influential factors investigated to determine their role in attenuating thermal loading included riparian vegetation, channel geometry, and flow volume. Human caused shifts to these physical factors have resulted in elevated water temperatures in the Big Hole River that have commonly reached levels known to be harmful to fluvial Arctic grayling, the most sensitive fish species present.

Following review of a variety of options, the SSTEMP model emerged as the preferred method for allocating thermal pollution among the influential factors in the project area. SSTEMP had the most useful features and produced the most meaningful output given a relatively small budget for input data collection. In addition, this model addressed specific concerns in the upper Big Hole River planning area; specifically, the roles of channel widening, canopy removal, and irrigation withdrawals on thermal loading.

SECTION 2.0
MODEL CONSIDERATIONS

The Stream Segment Temperature Model or SSTEMP (Bartholow, 2002) applied to the Big Hole River conditions evaluates the thermal effects of proposed restoration strategies on individual stream segments. SSTEMP is a Windows based, simplified version of the Stream Network Temperature Model (SNTEMP) designed to develop temperature models for large stream systems or networks (Bartholow, 2002). SSTEMP is a physically based model that operates on basic energy balance principles. Data inputs include hydrology, meteorology, stream channel geometry, time of year, and shading (topographic and vegetative). SSTEMP includes a sensitivity and uncertainty analysis feature, which allows the modeler to see which input parameters have the greatest effect on the predicted output. The model gives predictions of mean daily and maximum water temperatures at the downstream end of the modeled reach.

SSTEMP evaluates the effects of proposed management strategies on temperature in individual stream segments, making it an excellent choice to allocate thermal pollution to the three influential factors in thermal data collection reaches. Nevertheless, limitations exist in any model. In the case of SSTEMP, several of the assumptions were inapplicable to the existing physical conditions in the upper Big Hole River planning area. Specifically, SSTEMP applies to single thread channels and the Big Hole River in this planning area is a naturally, highly braided system, which complicated both data collection and modeling efforts. Water management activities in the basin also confound attempts to model temperature. Irrigation activities increase the complexity of the system as irrigation ditches crossed multiple channels or mixed water by inter-basin transfers. In several instances, irrigation return flows reentering the Big Hole via overland flow were observable. Many small surface inputs are difficult to simulate with SSTEMP, which assumes that any gain in flow within a reach comes directly from groundwater. Because overland return flow sources are not visible on maps or aerial photos, it was difficult to account for these features in site selection.

Another challenge in applying the SSTEMP in valley portions of the upper Big Hole River planning area is its inherent bias in terms of model inputs designed for forested watersheds. The model computes shading of the stream based on a series of input parameters that describe the extent of vegetation along the stream corridor. The input parameters include vegetation height, offset, crown diameter, and density, parameters developed for trees with limited applicability to shrubs, which are the primary vegetative form providing streamside shading (**Figure B-1**). As a result, model inputs designed for trees with single trunks and a defined canopy, needed modification to apply to multi-stem shrubs lacking a defined canopy.

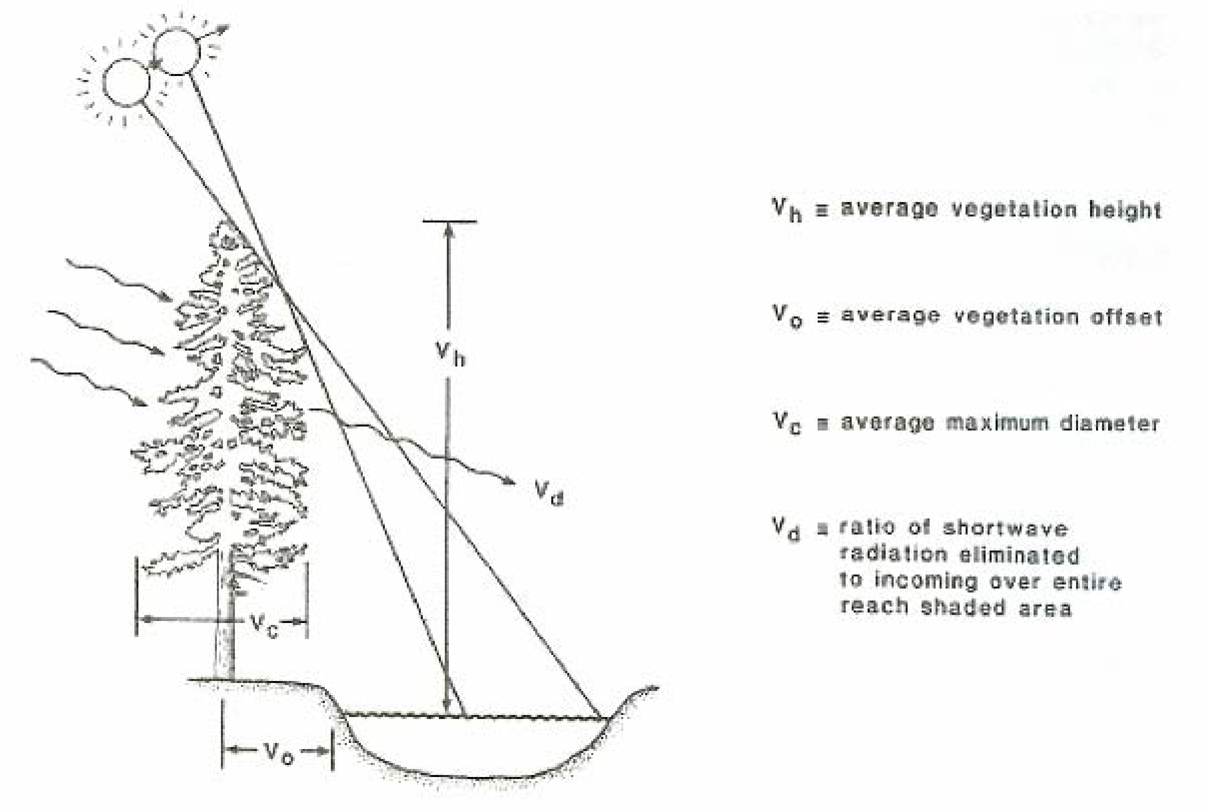

Figure B-1: SSTEMP vegetation shading variables (from Bartholow 2002).

Meteorological data from the National Oceanic and Atmospheric Administration's (NOAA) local climatological data reports was used for model input (Bartholow, 2002). These data are available for weather stations at Wisdom, MT and Jackson, MT in the Big Hole River valley, but only includes temperature and precipitation data and lacks other weather inputs such as wind speed, relative humidity, and solar radiation.

Preferably, application of the SSTEMP model results in development of a calibrated model to aid in the allocation of thermal loading among sources. Weather impeded these efforts with an unseasonable cold spell occurring during field efforts to collect key model inputs, including stream flow and temperature. As a result, data were not representative of conditions likely to result in elevated temperatures, limiting the ability to develop a calibrated model that described temperatures likely to exceed water quality standards. Therefore, the model was calibrated to these conditions and then hot summer weather conditions were applied to simulate the most sensitive timeframe when Montana's temperature standards are likely exceeded.

This assortment of limitations and confounding factors precluded the ability to produce a fully calibrated model for the upper Big Hole River planning area. The alternative was development of a demonstrative model using flow, temperature, and meteorological data available from the summer of 2004. This alternative was feasible given the relatively small data collection budget. Because it has not been fully calibrated, the drawback of a demonstrative model is that it cannot be used to predict actual, resultant temperatures over a wide range of hydrologic and meteorological conditions. Nevertheless, a demonstrative model, based on worst-case scenario conditions, provides a means to compare the *relative significance* of altered flow rate, riparian vegetation, and channel geometry on thermal loading and reach outflow temperatures.

SECTION 3.0
METHODS

Five reaches on the Big Hole River, and a single reach on Pintlar Creek, were the subjects of thermal modeling efforts (**Table B-1**). These reaches represented both least impacted or reference reaches, and impacted reaches, and all lie within the valley portions with a dominant shrub understory. Reference reaches provided the "potential" or least impacted channel dimensions and riparian shading characteristics for use in developing allocations. Thermal models were developed for four of the seven monitored reaches. BH09 and BH19 were excluded from modeling because extensive braiding confounded thermograph placement. Confounding monitoring and environmental factors precluded modeling PC04 at this time.

Table B-1: Reaches included in thermal monitoring efforts for the upper Big Hole River planning area.

Stream	*Reach*	*Reference or Impacted*
Big Hole River	BH09	Reference
Big Hole River	BH18	Reference
Big Hole River	BH19	Impacted
Big Hole River	BH22	Impacted
Big Hole River	BH26	Impacted
Big Hole River	BH28	Reference
Pintlar Creek	PC04	Impacted

Field data collection to support thermal modeling included stream flow measurement, temperature monitoring, and measures of riparian vegetation. Segment inflow and outflow were measured in the field using a Swoffer horizontal axis propeller flow meter. Estimation of average velocities followed the six-tenths depth method. None of the four reaches modeled had evidence of significant groundwater inflow or mid reach irrigation withdrawal at the time of sampling. Differences between reach inflow and outflow fell into the range that could be the result of the inherent error associated with flow measurement in open channels (+/-10 percent). Reaches were considered neither gaining nor losing flow in the demonstrative models.

Remote data loggers placed at the ends of each reach recorded inflow and outflow temperatures at 30-minute increments from July through September 2004. These data provided the input parameters for the demonstrative model that reflected field conditions. Accretion temperature, which is generally the same as groundwater temperature, was approximated by the mean annual air temperature recorded for Montana for the period of record from 1931 to 2000 (NOAA, 2002). This may differ in the upper Big Hole River planning area because the shallow groundwater, augmented by flood irrigation practices, may not be the standard temperature. Although at the time of monitoring these reaches appeared to not be gaining groundwater, but localized interactions between surface and groundwater may occur.

Modifications of prescribed field measures of riparian vegetation corrected the SSTEMP's bias towards forested, as opposed to shrub dominated riparian areas, the latter of which dominate the upper Big Hole River mainstem. These modifications account for differences in life form and canopy dimensions between trees and shrubs. As a single main trunk rarely exists in willow thickets, vegetation offset was the distance from the waters edge to the center of the first clump of willows. Measures of the vegetation crown provided information on the general width of the willows. Where willows were overhanging the waters edge the vegetation offset was set at 0 ft and the vegetation crown was given a value of two times the distance that vegetation was overhanging the waters edge. Median values for the shading parameters were applied to all reaches except BH26, for which the parameters that were measured at transect C were used because this transect better represented the whole reach than the median value when comparing to aerial photos of the reach.

Vegetation density was calculated by first determining the length of bank within a reach that was covered by either thick vegetation (healthy, mature willows), thin vegetation (unhealthy or sparse willows and tall grass), or non-shade producing vegetation (short grasses or bare ground). Analysis of the available aerial photos for each reach with ArcView 9.0 GIS/mapping software provided the basis for these classifications. Thick vegetation was assumed to filter approximately 85 percent of light, and thin vegetation was assumed to filter approximately 65 percent of light. All other areas were assumed to filter zero percent of light. A length-weighted average of vegetation density was determined and applied in the model. These estimates are based upon field measures and comparison to measured vegetation types with values provided by Bartholow in SSTEMP modeling guidance.

Mean reach latitude, reach length, upstream elevation, and downstream elevation were determined using GIS/mapping techniques in ArcView Version 9.0. Width's A term was determined by methods described by Bartholow (2002) assuming that the width's B term was a constant value of 0.2. Manning's n was estimated based on **Equation 1**, (Sturm, 2001) which relates Manning's n to the mean sediment diameter determined from pebble counts performed in the field.

Equation 1: $n = 0.04 d_{50}{}^{1/6}$ *d_{50} given in ft*

Results were validated by comparison with channel photos showing typical conditions and associated Manning's n values (Sturm, 2001).

The demonstrative SSTEMP models were developed based on meteorological conditions that could be expected on a hot summer day in the upper Big Hole River valley (**Table B-2**). Mean air temperature was selected based on the mean temperature for July in Montana and ground temperature was based on average annual air temperature for Montana (NOAA 2002). Because the upper Big Hole River planning area is cooler than most of Montana, this is probably an overestimate of average monthly temperatures, but represents some of the warmest days in July in this study area. A thermal gradient of 1.65 j/m²/s/C is the recommended default value (Bartholow, 2002). Selected sun and dust coefficient values represented a clear, cloudless day. Ground reflectivity followed values developed by the Tennessee Valley Authority (TVA) (Bartholow 2002) for a region made up mostly of meadows and fields. All of the reach models were run using the same meteorological input parameters.

Table B-2: Meteorological parameters used in the demonstrative SSTEMP models.

Input Parameters	Value
Mean Air Temperature	67.0 °F
Max Air Temperature	85.0 °F
Relative Humidity	15 %
Wind Speed	5.0 mph
Ground Temperature	42.4 °F
Thermal Gradient	1.65 j/m²/s/C
Possible Sun	100 %
Dust Coefficient	3.5
Ground Reflectivity	14.0 %

SSTEMP models of the four selected reaches were run with input parameters describing the existing conditions in each reach. Model outputs included predicted mean daily and maximum temperatures at the outlet of each reach. Initial results were compared with actual water temperature data from July 15, 2004 to determine the model's validity. Meteorological conditions and stream flow data from that date closely matched the inputs used in the demonstrative models. Model results matched measured stream temperatures closely, though the model generally predicted higher outflow temperature than were observed in the field (**Table B-3**).

Table B-3: Reach model validation.

Reach	**Predicted Mean Temperature (°F)**	**Measured Mean Temperature (°F)**	**Predicted Maximum Temperature (°F)**	**Measured Maximum Temperature (°F)**
BH18	66.32	64.49	77.95	73.75
BH22	67.56	66.47	80.30	73.44
BH26	66.97	66.75	79.89	76.44
BH28	66.27	N/A	78.10	N/A

Model validation included a sensitivity analysis, which allows identification of the most influential parameter on thermal regime. Results of the sensitivity analysis showed that model outputs were highly dependent on accuracy of data describing stream flow, air temperature, relative humidity, wind speed, and possible sun. Site specific stream flow data for July 15, 2004 were unavailable and had to be estimated based on USGS stream gage data from Wisdom, MT. The lack of highly accurate, site-specific meteorological and stream flow data was likely the cause of the discrepancies between model outputs and actual temperatures measured in the field. Temperature data were unavailable for the downstream end of reach BH28 for the dates modeled (data loggers could not be located during retrieval), but the results from the other three reaches show that models give acceptable results given the level of uncertainty in the input data.

A paired reach approach allowed evaluation of the relative influence of riparian vegetation and channel geometry on stream temperature. Following the initial model runs evaluating existing conditions on the four reaches, four additional alternatives for each of the impaired reaches (BH22 and BH26) allowed estimation of the relative importance of riparian vegetation, channel geometry, and stream flow on temperature (**Table B-4**). In additional scenario runs, input parameters allowed demonstration of the relative effect of restoring riparian vegetation, channel geometry, or both riparian vegetation and channel geometry to reference conditions on water temperature. Because SSTEMP cannot compute cumulative effects of changing a single physical characteristic of the stream system (Bartholow 2002), reduced vegetation and altered channel geometry were changed simultaneously to reference conditions in an attempt to estimate the possible cumulative effect of a more complete stream restoration. BH18 was the reference for vegetation characteristics for both BH22 and BH26, as its riparian community represented "least impaired" with implementation of reasonable soil and water conservation practices. BH18 was also the reference for channel geometry for BH22. In contrast, BH28 was the channel geometry reference reach for BH26 to more closely approximate channel geometry changes that occur naturally moving downstream along the river continuum.

Table B-4: Modeled scenarios for reaches BH22 and BH26 to evaluate the relative importance of riparian vegetation, channel geometry, and stream flow on temperature.

Number	Modeled Scenarios
1	Existing vegetation and channel geometry over a range of flow rates;
2	Existing channel geometry with vegetation changed to reference conditions over a range of low rates;
3	Existing vegetation with channel geometry changed to reference conditions over a range of low rates; and
4	Vegetation and channel geometry changed to reference conditions over a range of low rates.

No records of stream flow exist for the Big Hole River prior to the inception of agricultural development and irrigation practices that affect minimum flows in the basin (Confluence et al. 2003). As a result, quantification of potential low flow conditions for the Big Hole is unfeasible. Instead of selecting a specific value for minimum flow reference conditions, reaches were modeled over a range of flows. Outflow temperatures (daily mean and daily maximum) were predicted at increments of 10 cfs from 10 cfs to 100 cfs for all riparian vegetation and channel geometry conditions (reference and impaired).

SECTION 4.0
RESULTS & DISCUSSION

Application of the SSTEMP model to the upper Big Hole River indicates substantial decreases in both maximum and mean daily temperatures are possible with increased flow, narrower channels, and increased riparian shading. Nevertheless, an important consideration in interpreting these results is that the models developed for this study are demonstrative rather than predictive and have not been calibrated over a wide range of meteorological and hydrologic conditions. Modeled outflow temperatures were slightly higher than actual temperatures in most cases due to lack of high quality, site-specific meteorological input data. As the model has not been fully calibrated, using the model to predict actual outflow temperatures is inappropriate. However, comparison of the results is an appropriate and effective way to determine relative importance of riparian vegetation, channel geometry, and stream flow on water temperatures in the upper Big Hole and can be used for TMDL allocation.

Reach BH18 provided a reference for least impaired riparian vegetation and channel geometry. Because it was a riparian and channel condition reference reach, only existing conditions were modeled over a range of flow rates. Model results show that increasing flow has a minimal effect on mean daily outflow temperatures when vegetation and channel geometry are in a least impaired condition (**Figure B-2**). On the other hand, increasing stream flows has a significant inverse relationship with maximum daily outflow temperatures (**Figure B-3**). The greater the stream flow, the lower the predicted maximum temperature.

BH28 was also a reference reach, but only for channel geometry as the vegetation in BH28 was reduced considerably compared to BH18. Model results again show that increasing flow rate has minimal effect on lowering mean outflow temperatures but a significant effect on lowering maximum outflow temperatures (**Figures B-4 and B-5**). Model runs simulating improved vegetation predict decreases in both mean and max outflow temperatures.

Generally, the results show that improving vegetation and channel geometry and increasing flow rate results in lower mean and maximum outflow temperatures (**Figures B-6 through B-9**). The most marked decreases in predicted outflow temperatures occur when all the influential factors (vegetation, channel geometry, and flow) approximated reference conditions. In addition to these findings, closer analysis of the results provided a platform on which to base relative ranking of the three impairment categories based on their ability to attenuate thermal loading.

The relative roles of riparian vegetation and channel geometry differed in terms of influence on mean versus maximum daily temperatures. Changing riparian vegetation from impaired to reference conditions resulted in lower *mean* outflow temperatures when compared to the results of changing channel geometry from impaired to reference conditions (**Figures B-6 and B-8**). This was true for all modeled flow rates. Conversely, at all but the lowest flow rates, ($Q \leq 20$ cfs for BH22, and $Q \leq 10$ cfs for BH26), changing channel geometry from impaired to reference conditions resulted in lower *maximum* outflow temperatures when compared to the results of changing riparian vegetation from impaired to reference conditions (**Figures B-7 and B-9**). These results suggest that riparian vegetation has more effect on mean daily temperature than channel geometry, and that channel geometry has more effect on maximum daily temperature than riparian vegetation.

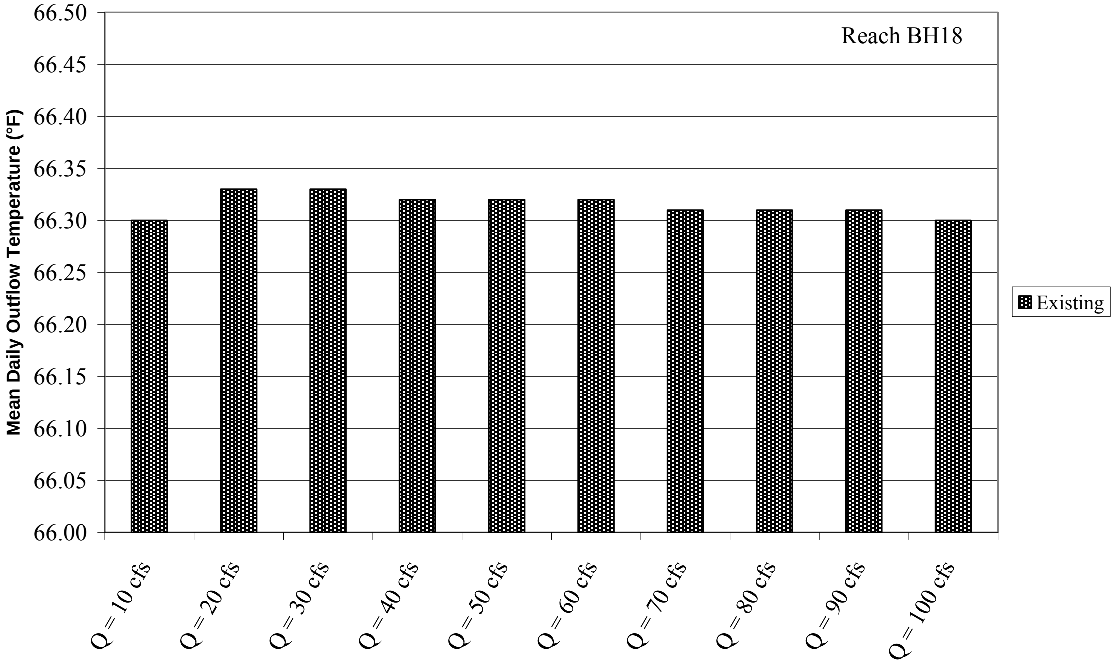

Figure B-2: Thermal modeling results*. Predicted mean daily outflow temperatures for reach BH18.

* Note on figures B-3 through B-9:

Existing - denotes a model run with input data describing existing riparian vegetation and channel geometry conditions

Veg. - denotes a model run with input data describing riparian vegetation in a least impaired (reference) condition

Geom. - denotes a model run with input data describing channel geometry in a least impaired (reference) condition

Both - denotes a model run with input data describing channel geometry and vegetation in a least impaired (reference) condition

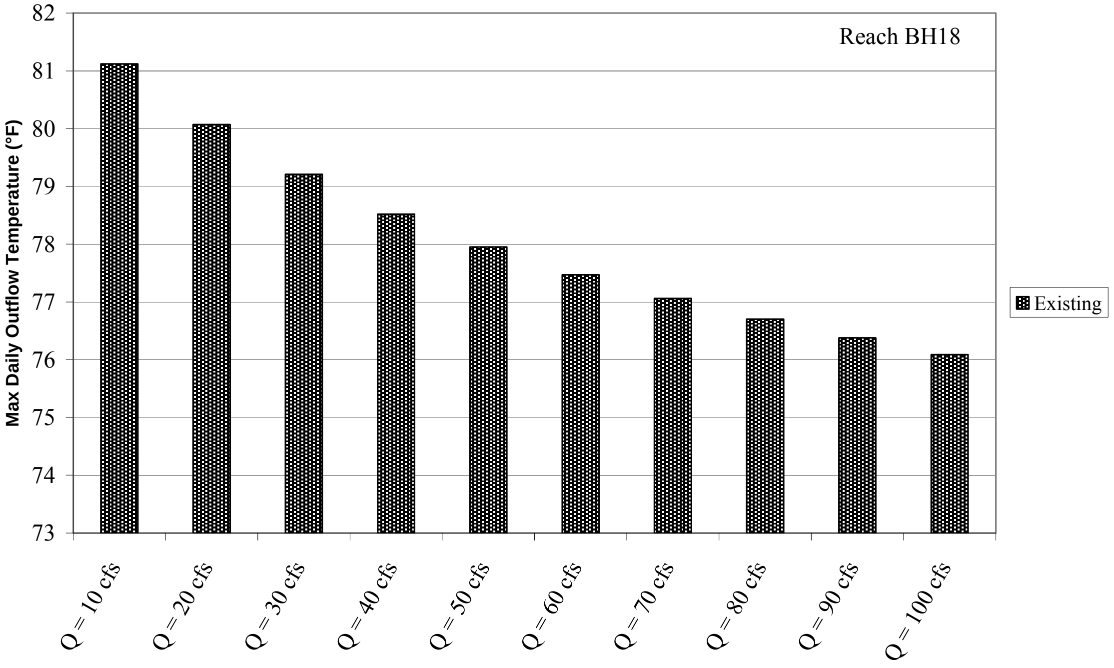

Figure B-3: Thermal modeling results*. Predicted max daily outflow temperatures for reach BH18.

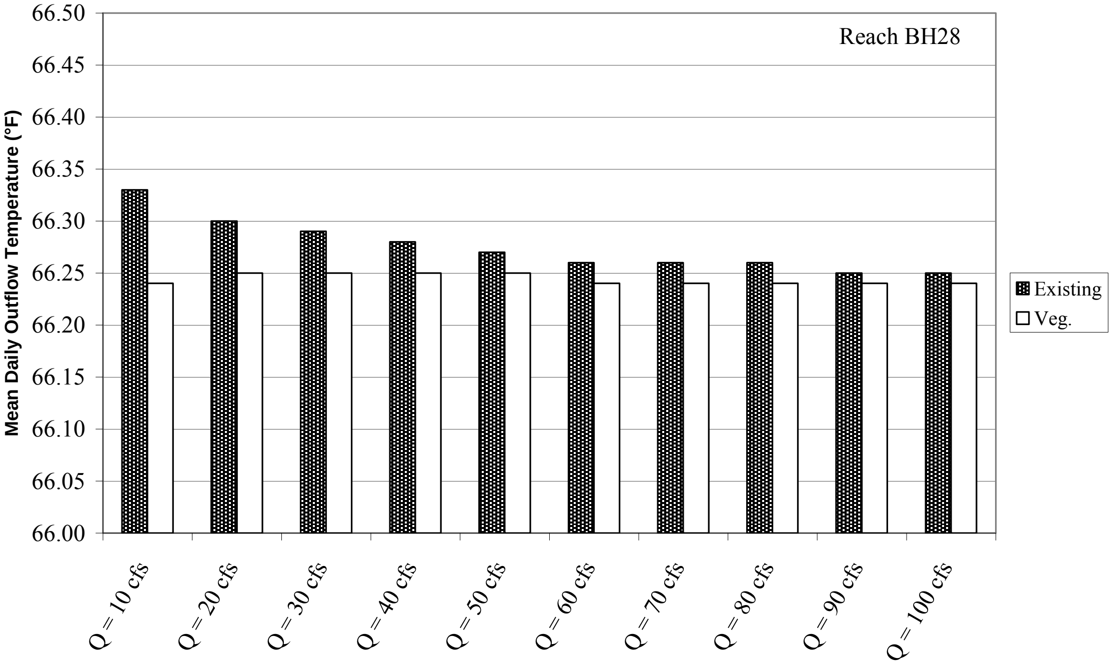

Figure B-4: Thermal modeling results*. Predicted mean daily outflow temperatures for reach BH28.

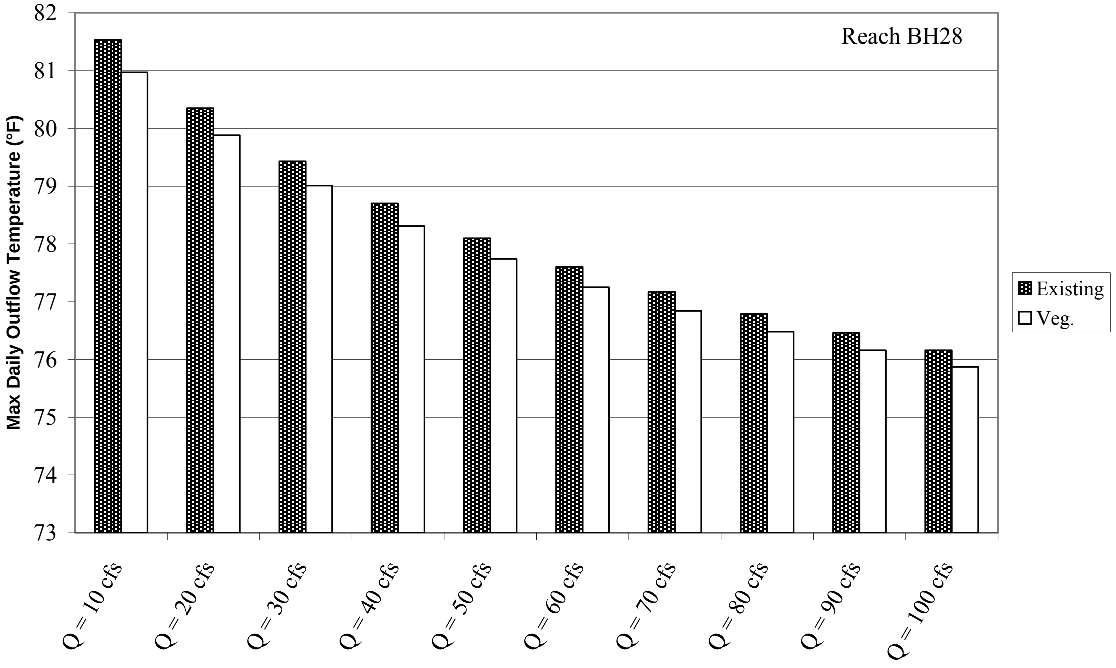

Figure B-5: Thermal modeling results*. Predicted max daily outflow temperatures for reach BH28.

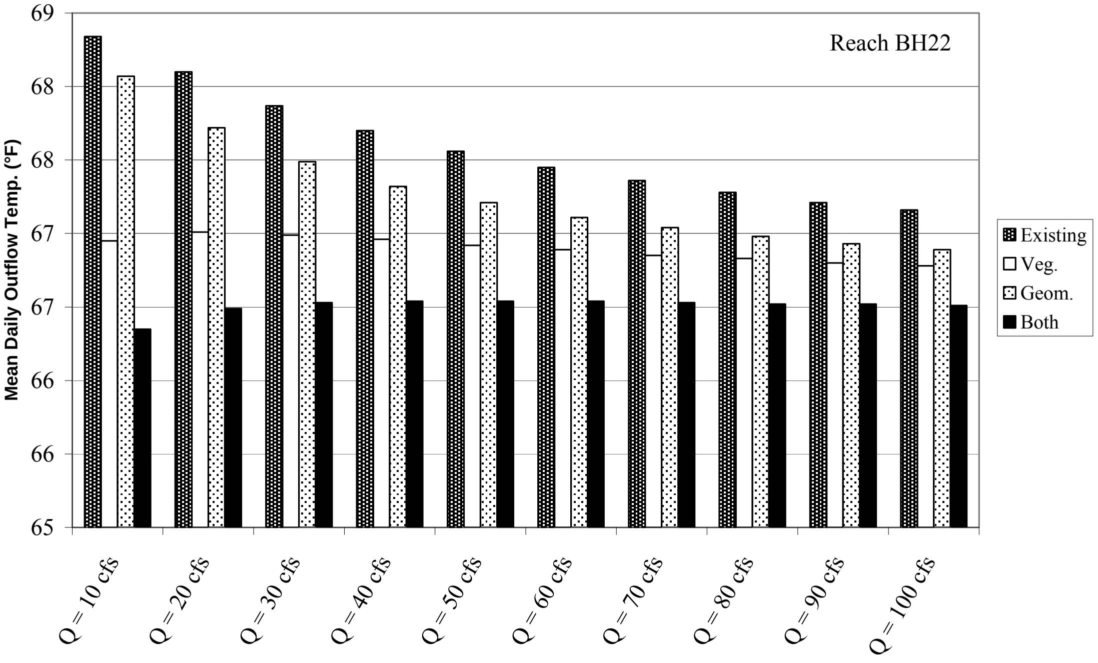

Figure B-6: Thermal modeling results*. Predicted mean daily outflow temperatures for reach BH22.

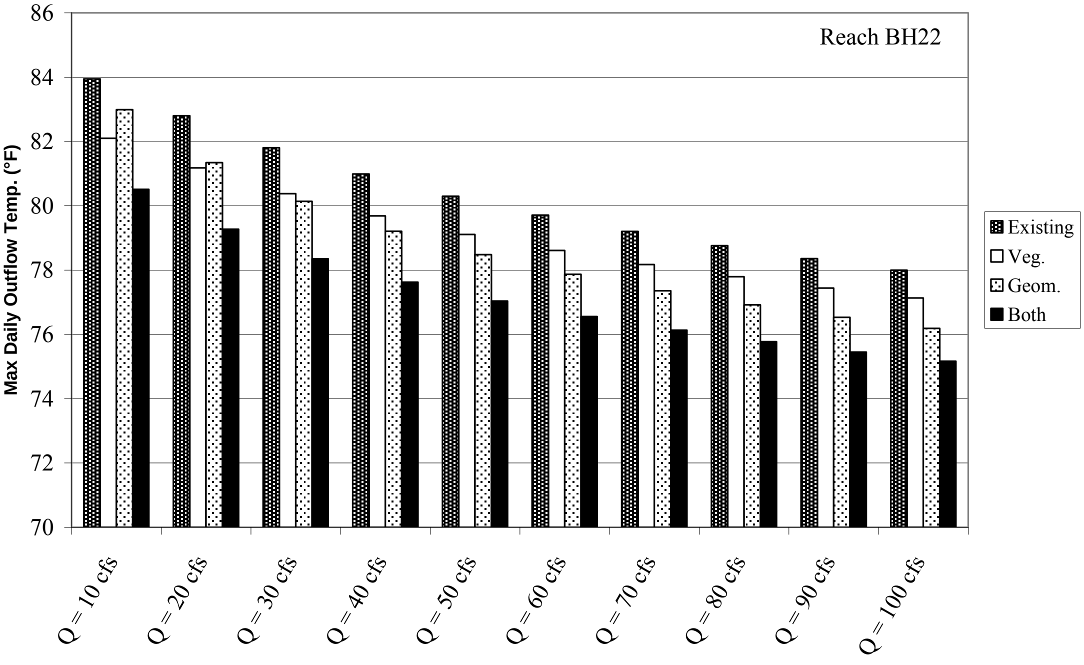

Figure B-7: Thermal modeling results*. Predicted max daily outflow temperatures for reach BH22.

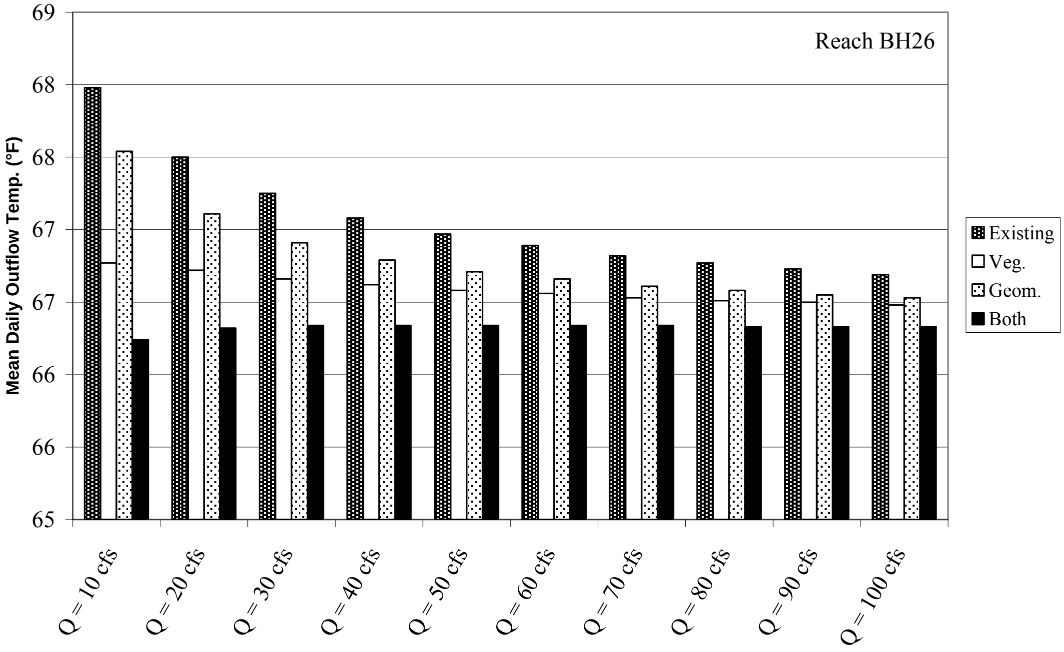

Figure B-8: Thermal modeling results*. Predicted mean daily outflow temperatures for reach BH26.

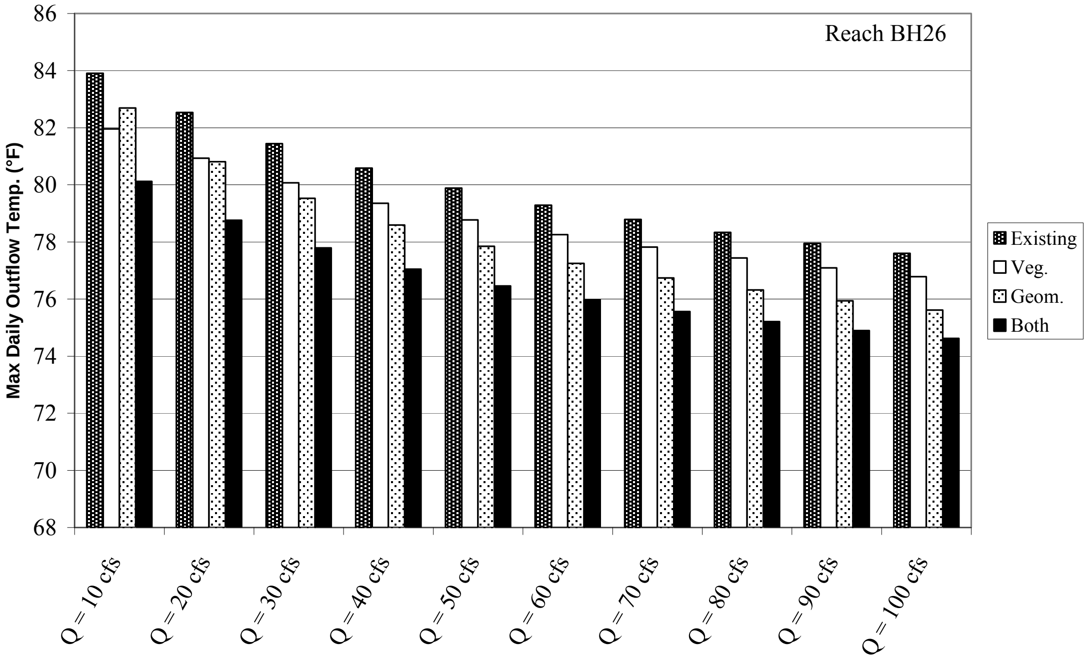

Figure B-9: Thermal modeling results*. Predicted max daily outflow temperatures for reach BH26.

These seemingly confounding results can be explained when the interaction between the components of the stream system are considered from a heat transfer perspective. When vegetative shading approaches reference conditions, a shift in the diel (24-hour) temperature regime occurs. Increased shade from the additional vegetation keeps sun off the water, which decreases maximum daily temperatures to some extent. At the same time, channel width remains in the impaired, overly wide state resulting in the maximum amount of cooling from the large exposed water surface during the night and in turn low minimum temperatures. Lower maximum daily temperatures combined with lower minimum daily temperatures result is a significant decrease in mean daily temperatures. When channel geometry mimics reference conditions, a buffering effect on temperatures occurs. Because less water surface is available as a heat transfer interface (heating by day and cooling by night), the result is lower maximum daily temperatures and higher minimum daily temperatures. The mean temperature changes little, while daily maximum temperatures decrease by a large amount. Of course, changing both riparian vegetation and channel geometry to reference conditions combines the effects described above; resulting in significantly lower mean and maximum daily reach outflow temperatures. These results emphasize the need to consider both maximum daily and mean daily temperatures in establishing thermal targets for the Big Hole River.

Modeling predicts that maximum outflow temperatures decrease significantly with increased flow rates for all modeled reaches, as larger volumes of water require a greater thermal energy input to experience equal gains in temperature. In addition, travel time (the time required for a piece of water to travel the length of a reach) generally decreases with increased flow because flow velocities increase. Water spends less time in a given reach and has less time to collect thermal pollution. Modeling results for reaches BH22 and BH26 suggest that mean outflow temperatures also decrease with increased flow rates when the model inputs describe existing impaired conditions, riparian vegetation returned to a least impaired state, or channel geometry returned to a least impaired state. When both riparian vegetation and channel geometry are modeled in a least impaired state, or when reference reaches are modeled in their existing state, increased flow rate has a minimal affect on mean daily temperatures. In fact, at lower flow rates (10 – 40 cfs) model results suggest that mean daily outflow temperatures actually increase very slightly (less than ½ of one °F) as flow rate increases. As flow rate increases above 40 cfs the predicted mean daily outflow temperatures begin to decrease slightly again.

Again, the interactions between components of the stream system from a heat transfer perspective explain the failure of increases in flow to have significant effect on mean daily temperatures. As flow rate increases from 10 cfs to 40 cfs, the open water surface area increases resulting in greater cooling effect at night. During the day, dense vegetation that lines the channel shades only a portion of the heating surface so more heat is lost at night than is gained during the day. The result is a lower minimum daily temperature and a near constant maximum daily temperature. The nighttime heat loss is the dominant factor in this case. As flow rates increase above 40 cfs, travel time decreases enough to become the dominant factor and cause large enough decreases in maximum temperature that the mean temperature begins to decrease again. Reaches BH22 and BH26 were 6 and 2.6 miles long respectively indicating BH22 has greater potential to lose heat at night compared to BH26.

Modeled flows include proposed targets for Arctic grayling conservation and other flows used in conservation planning. The CCAA plan for the Big Hole River calls for variable minimum flows in this portion of the Big Hole River depending on season and reach designation (MFWP in press). The prescribed minimum flow for reaches BH22 and BH26 are 60 and 100 cfs, respectively during summer months. A minimum survival flow of 20 cfs has been used as a trigger in the Big Hole River drought management plan and is used here to evaluate the sufficiency of these flows in maintaining a thermal regime favorable to Arctic grayling.

A break down of the modeling results shows the relative effects of improving flow volume, riparian vegetation, and channel geometry on mean daily temperatures (**Table B-5**) which provides the basis for allocating thermal loading among the three primary sources. Examining the change in predicted mean daily outflow temperatures when impacts are changed from impacted to reference conditions suggests that riparian vegetation is the most significant single factor influencing temperature. Stream flow rate and channel geometry follow in order of decreasing significance. In contrast, when considering maximum daily temperatures, stream flow rate was the most significant factor influencing water temperatures (**Table B-6**). Channel geometry and riparian vegetation follow in order of decreasing significance.

Table B-5: Predicted mean daily outflow temperature deviation from predicted temperatures for existing, impaired conditions.

Reach ➔		***BH22***			***BH26***		
Code * ➔		***Existing***	***Veg.***	***Geom.***	***Existing***	***Veg.***	***Geom.***
Predicted Daily Mean Outflow Temperature, T (°F)	Q = 20 cfs	0.00	-1.09	-0.38	0.00	-0.78	-0.39
	Q = 30 cfs	-0.23	-0.88	-0.38	-0.25	-0.59	-0.34
	Q = 40 cfs	-0.40	-0.74	-0.38	-0.42	-0.46	-0.29
	Q = 50 cfs	-0.54	-0.64	-0.35	-0.53	-0.39	-0.26
	Q = 60 cfs	-0.65	-0.56	-0.34	-0.61	-0.33	-0.23
	Q = 100 cfs	-0.94	-0.38	-0.27	-0.81	-0.21	-0.16
	-0.55	-0.72	-0.35	-0.52	-0.46	-0.28	-0.30

* Existing - denotes a model run with input data describing existing riparian vegetation and channel geometry conditions
Veg. - denotes a model run with input data describing riparian vegetation in a least impaired (reference) condition
Geom. - denotes a model run with input data describing channel geometry in a least impaired (reference) condition

Table B-6: Predicted maximum daily outflow temperature deviation from predicted temperatures for existing, impaired conditions.

Reach ➔		***BH22***			***BH26***		
Code * ➔		***Existing***	***Veg.***	***Geom.***	***Existing***	***Veg.***	***Geom.***
Predicted Daily Maximum Outflow Temperature, T (°F)	Q = 20 cfs	0.00	-1.62	-1.46	0.00	-1.60	-1.73
	Q = 30 cfs	-0.99	-1.43	-1.67	-1.09	-1.38	-1.92
	Q = 40 cfs	-1.81	-1.30	-1.78	-1.95	-1.23	-2.00
	Q = 50 cfs	-2.50	-1.19	-1.82	-2.65	-1.12	-2.04
	Q = 60 cfs	-3.09	-1.10	-1.84	-3.25	-1.03	-2.04
	Q = 100 cfs	-4.80	-0.87	-1.81	-4.94	-0.81	-1.99
	Average	-2.64	-1.25	-1.73	-2.78	-1.20	-1.95

* Existing - denotes a model run with input data describing existing riparian vegetation and channel geometry conditions
Veg. - denotes a model run with input data describing riparian vegetation in a least impaired (reference) condition
Geom. - denotes a model run with input data describing channel geometry in a least impaired (reference) condition

Modeling results indicate thermal regime in the upper Big Hole River relates to the three major influential factors, riparian shading, stream flow, and channel geometry, in different ways. Based on analysis of mean daily outflow results of the SSTEMP models, the most significant factor influencing thermal pollution to the upper Big Hole is impaired riparian vegetation, followed by impaired stream flow, and channel geometry (in decreasing order of significance). Based on analysis of maximum daily outflow results of the SSTEMP models, the most significant source of thermal pollution to the upper Big Hole River is reduced stream flow, followed closely by impaired riparian vegetation and channel geometry. The modeling effort identifies that the state water quality temperature standards are likely exceeded and that all three factors significantly affect instream water temperatures.

Although not included in this modeling and allocation effort, it is likely that overland irrigation return flows and ditch returns are potential sources of thermal pollution and may have significant effects on temperatures in the upper Big Hole River (**Figure B-10**). During the TMDL development effort, the impact from this source is not well known. Recent fish-sampling efforts in some ditches were frequently ceased by early afternoon because temperatures exceeded MFWP's guidelines of 59 °F (Confluence, unpublished data). Efforts have been initiated through fisheries restoration efforts that will identify ditches that are contributing to the thermal loading. Relatively long residence time combined with low shrub cover likely contribute to warming in ditches. Similarly, overland flow entering streams at discrete locations presents another potential source of warm water (**Figure B-11**). Due to their unpredictable locations and ephemeral nature, estimation of their influence on temperature is unfeasible with the available resources. A color infrared imaging (CIR) flight calibrated to stream temperature was completed during the summer of 2008 via fishery restoration efforts but results are not available at this time. The results of the CIR imaging will be useful to identify warm water irrigation impacts.

Figure B-10: Example of a larger irrigation ditch in the upper Big Hole River planning area.

In conclusion, modeling thermal inputs and temperature regime in the Big Hole River is challenging given a variety of factors. Extensive channel braiding, a complicated irrigation infrastructure with approximately 1000 diversions in the basin, and unidentified inputs from ditch returns and discrete surface returns, all thwart attempts to identify magnitudes and relative contributions among sources during this modeling effort. Application of the SNTEMP model, which examines a stream network, is Unfeasible in the upper Big Hole River planning area. This approach would require potentially hundreds of thermographs and flow measurements to capture the influence of irrigation withdrawals and returns and the extensive braiding. Nevertheless, these SSTEMP model results provide information to prioritize among actions to meet water quality standards both over the long and short-term and also provide a basis for initial allocations. An adaptive management approach will be identified in the TMDL to further the understanding about irrigation water return flow impacts.

Figure B-11: Example of a discrete source of overland return of irrigation water to the Big Hole River.

SECTION 5.0

CONSIDERATIONS FOR BUILDING ALLOCATIONS FOR SOURCES OF THERMAL LOADING

Results of the SSTEMP modeling (0 Results and Discussion) provide the technical basis to allocate temperature loading among the influential factors (flow volume, channel geometry, and riparian shading.) As discussed, calculation of estimated load allocations or an explicit loading margin of safety is not useful for restoration efforts. Therefore, development of surrogate allocations following EPA guidance (EPA 1999) is appropriate in the main TMDL document.

Probable sources of impairment are another consideration in development of allocations. Agricultural activities, including cattle grazing, hay production, and willow removal, are the human influences responsible for alterations of three factors across the basin. Other human influences, such as transportation corridors, presumably have a negligible influence on thermal loading, and therefore have no performance-based allocation.

A brief review of the links among human activities, the measured perturbations, and water quality supports these allocations. The links between flow withdrawals, flow volumes, and water temperature are straightforward. Modeling results indicate that instream flows are a significant influence on water temperatures (**Table B-7**). Nevertheless, difficulties arise in determining the feasibility of achieving flow targets and the associated allocations given the complexity of the irrigation system and associated diversions and ditch networks above Wisdom. Recent efforts to identify and map diversions and ditches will assist in this effort. However, in the interim, it is not possible to determine the amount of irrigation water savings that can be realized from irrigation water management practices such as ditch lining, field leveling, installing gated pipes, or installing other practical water saving BMPs. Such an effort should have a high priority for future funding because it will be useful for prioritizing locations of the irrigation water management restoration activities.

The links among human activities to channel morphology, riparian shading, and temperature are also clear. Livestock grazing and mechanical removal of willows has reduced shading and bank resilience to high flows. These denuded banks are more susceptible to sheer stress resulting in lateral migration and the overly wide channel geomorphology. Combined, these factors have an adverse effect on water temperature, an assumption supported by data and thermal modeling.

A final consideration in adoption of this temperature allocation strategy is consideration of Montana's water law, which prohibits the taking or imperilment of any existing water right in order to attain water quality standards. Therefore, locally coordinated approach to restoring instream flow is essential for achieving the goal of the performance based allocation process that relates to instream flows. Local watershed groups, MFWP, and landowners, are currently working together to increase instream flow during drought and in CCAA efforts.

5.1 Margin of Safety and Seasonal Considerations

Margin of safety considerations for the thermal modeling assessment involve an implicit approach based on conservative assumptions. Modeling incorporated temperatures typical of Montana as a whole, which tends to be warmer overall than the upper Big Hole River planning area. Allocations to riparian shading incorporate data from a least impaired reach on the Big Hole River that had exemplary riparian conditions in conjunction with well-managed livestock grazing. Similarly, desired channel geometry follows a conservative approach based on three reference reaches showing stable channel geomorphology and width-to-depth ratios considerably lower than impaired reaches. A margin of safety is provided in assessing not only the factors that affect thermal loads, but also addressing instream flows that affect the streams capacity to adsorb heat without increasing temperature.

Seasonal considerations are considerable for temperature. Obviously, with high temperatures being a primary limiting factor for Arctic grayling in the Big Hole River, summer temperatures are a paramount concern. Therefore, focusing on summer thermal regime is the appropriate approach. Nevertheless, the types of perturbations in the upper Big Hole River planning area may also limit overwintering habitat. Removal of canopy cover increases formation of anchor ice, which may physically limit habitat for fish (Winegar 1977). This may be especially pronounced in overly wide sections where conditions for anchor ice formation are favorable. Therefore, although the allocations and restoration plans were developed chiefly with summer temperatures in mind, the aquatic community will also benefit during winter months because restoration scenarios used in the modeling will moderate cold ice forming conditions during the winter also.

SECTION 6.0
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Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River

Info		Date	Geometry						
Model Reach	Model Description	Month/ day	Latitude	Segment Length	Upstream Elevation	Downstream Elevation	Width's A Term	Width's B Term	Manning's n
(--)	(--)		(degrees)	(mi)	(ft)	(ft)	(s/ft2)	(--)	(--)
BH18	existing conditions modeled	15-Jul	45.399	1.305	6400.89	6361.52	17.603	0.2	0.045
BH22	existing conditions modeled	15-Jul	45.502	6.089	6259.82	6171.24	26.561	0.2	0.041
BH22	vegetation changed to reference conditions	15-Jul	45.502	6.089	6259.82	6171.24	26.561	0.2	0.041
BH22	channel geometry changed to reference conditions	15-Jul	45.502	6.089	6259.82	6171.24	17.45	0.2	0.041
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	45.502	6.089	6259.82	6171.24	17.45	0.2	0.041
BH26	existing conditions modeled	15-Jul	45.639	2.61	6040	6003.91	27.049	0.2	0.042
BH26	vegetation changed to reference conditions	15-Jul	45.639	2.61	6040	6003.91	27.049	0.2	0.042
BH26	channel geometry changed to reference conditions	15-Jul	45.639	2.61	6040	6003.91	16.56	0.2	0.042
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	45.639	2.61	6040	6003.91	16.56	0.2	0.042
BH28	existing conditions modeled	15-Jul	45.662	0.534	5974.39	5961.26	17.625	0.2	0.039
BH28	vegetation changed to reference conditions	15-Jul	45.662	0.534	5974.39	5961.26	17.625	0.2	0.039

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Hydrology**			
Model Reach	**Model Description**	**month / day**	**Segment Inflow**	**Inflow Temp.**	**Segment Outflow**	**Accretion Temp.**
(--)	**(--)**	**(--)**	**(cfs)**	**(*F)**	**(cfs)**	**(*F)**
BH18	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH22	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH22	vegetation changed to reference conditions	15-Jul	20	66.2	20	42.4
BH22	channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH26	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH26	vegetation changed to reference conditions	15-Jul	20	66.2	20	42.4
BH26	channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	20	66.2	20	42.4
BH28	existing conditions modeled	15-Jul	20	66.2	20	42.4
BH28	vegetation changed to reference conditions	15-Jul	20	66.2	20	42.4

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Meteorology**									
Model Reach	**Model Description**	**Month / Day**	**Air Temp.**	**Max. Air Temp**	**Relative Humidity**	**Wind Speed**	**Ground Temp**	**Thermal Gradient**	**Possible Sun**	**Dust Coeff.**	**Ground Reflectivity**
(--)	**(--)**	**(…)**	**(*F)**	**(*F)**	**(%)**	**(mph)**	**(*F)**	**(j/m2/s/C)**	**(%)**	**(--)**	**(%)**
BH18	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	vegetation changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH26	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH26	vegetation changed to reference	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Meteorology**								
Model Reach	**Model Description**	**Month / Day**	**Air Temp.**	**Max. Air Temp**	**Relative Humidity**	**Wind Speed**	**Ground Temp**	**Thermal Gradient**	**Possible Sun**	**Dust Coeff.**	**Ground Reflectivity**
(--)	**(--)**	**(…)**	**(*F)**	**(*F)**	**(%)**	**(mph)**	**(*F)**	**(j/m2/s/C)**	**(%)**	**(--)**	**(%)**
	conditions										
BH26	channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH28	existing conditions modeled	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14
BH28	vegetation changed to reference conditions	15-Jul	67	85	15	5	42.4	1.65	100	3.5	14

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Optional Shading Variables**										
Model Reach	**Model Description**	**Month/ Day**	**Segment Azimuth**	**Topo. Altitude (E)**	**Vegetation Height (E)**	**Vegetation Crown (E)**	**Vegetation Offset (E)**	**Vegetation Density (E)**	**Topo. Altitude (W)**	**Vegetation Height (W)**	**Vegetation Crown (W)**	**Vegetation Offset (W)**	**Vegetation Density (W)**
(--)	**(--)**	**(--)**	**(degrees)**	**(degrees)**	**(ft)**	**(ft)**	**(ft)**	**(%)**	**(degrees)**	**(ft)**	**(ft)**	**(ft)**	**(%)**
BH18	existing conditions modeled	15-Jul	-6.6	3	12	6	8	46.22%	3	13	6	12	73.12 %
BH22	existing conditions modeled	15-Jul	-0.8	3	9	4	10	26.99%	3	4	2	1	4.39%
BH22	vegetation changed to reference conditions	15-Jul	-0.8	3	12	6	8	46.22%	3	13	6	12	73.12 %
BH22	channel geometry changed to reference conditions	15-Jul	-0.8	3	9	4	10	26.99%	3	4	2	1	4.39%
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	-0.8	3	12	6	8	46.22%	3	13	6	12	73.12 %
BH26	existing conditions modeled	15-Jul	5.2	1.5	6	2	20	7.80%	4	3	2	1	6.33%

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Optional Shading Variables										
Model Reach	Model Description	Month/ Day	Segment Azimuth	Topo. Altitude (E)	Vegetation Height (E)	Vegetation Crown (E)	Vegetation Offset (E)	Vegetation Density (E)	Topo. Altitude (W)	Vegetation Height (W)	Vegetation Crown (W)	Vegetation Offset (W)	Vegetation Density (W)
(--)	(--)	(--)	(degrees)	(degrees)	(ft)	(ft)	(ft)	(%)	(degrees)	(ft)	(ft)	(ft)	(%)
BH26	vegetation changed to reference conditions	15-Jul	5.2	1.5	12	6	8	46.22%	4	13	6	12	73.12 %
BH26	channel geometry changed to reference conditions	15-Jul	5.2	1.5	6	2	20	7.80%	4	3	2	1	6.33%
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	5.2	1.5	12	6	8	46.22%	4	13	6	12	73.12 %
BH28	existing conditions modeled	15-Jul	11.6	2	2.5	1	0	45.10%	5	8	2	2	60.85 %
BH28	vegetation changed to reference conditions	15-Jul	11.6	2	12	6	8	46.22%	5	13	6	12	73.12 %

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results - Outflow Temperature**					
Model Reach	**Model Description**	**Month/ Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut - Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**	**(*F)**	**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 10 cfs					
BH18	existing conditions modeled	15-Jul	66.30	0.10	0.08	81.12	14.82	11.36
BH22	existing conditions modeled	15-Jul	68.34	2.14	0.35	83.95	15.61	2.56
BH22	vegetation changed to reference conditions	15-Jul	66.95	0.75	0.12	82.10	15.15	2.49
BH22	channel geometry changed to reference conditions	15-Jul	68.07	1.87	0.31	82.99	14.92	2.45
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.35	0.15	0.02	80.51	14.16	2.33
BH26	existing conditions modeled	15-Jul	67.98	1.78	0.68	83.91	15.93	6.10
BH26	vegetation changed to reference conditions	15-Jul	66.77	0.57	0.22	81.96	15.19	5.82
BH26	channel geometry changed to reference conditions	15-Jul	67.54	1.34	0.51	82.69	15.15	5.80
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.24	0.04	0.02	80.12	13.88	5.32
BH28	existing conditions modeled	15-Jul	66.33	0.13	0.24	81.53	15.20	28.46
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	80.97	14.73	27.58

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month/ Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**	**(*F)**	**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 20 cfs					
BH18	existing conditions modeled	15-Jul	66.33	0.13	0.10	80.07	13.74	10.53
BH22	existing conditions modeled	15-Jul	68.10	1.90	0.31	82.80	14.70	2.41
BH22	vegetation changed to reference conditions	15-Jul	67.01	0.81	0.13	81.18	14.17	2.33
BH22	channel geometry changed to reference conditions	15-Jul	67.72	1.52	0.25	81.34	13.62	2.24
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.49	0.29	0.05	79.27	12.78	2.10
BH26	existing conditions modeled	15-Jul	67.50	1.30	0.50	82.54	15.04	5.76
BH26	vegetation changed to reference conditions	15-Jul	66.72	0.52	0.20	80.94	14.22	5.45
BH26	channel geometry changed to reference conditions	15-Jul	67.11	0.91	0.35	80.81	13.70	5.25
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.32	0.12	0.05	78.76	12.44	4.77
BH28	existing conditions modeled	15-Jul	66.30	0.10	0.19	80.35	14.05	26.31
BH28	vegetation changed to reference conditions	15-Jul	66.25	0.05	0.09	79.88	13.63	25.52

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month /Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**	**(*F)**	**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 30 cfs					
BH18	existing conditions modeled	15-Jul	66.33	0.13	0.10	79.21	12.88	9.87
BH22	existing conditions modeled	15-Jul	67.87	1.67	0.27	81.81	13.94	2.29
BH22	vegetation changed to reference conditions	15-Jul	66.99	0.79	0.13	80.38	13.39	2.20
BH22	channel geometry changed to reference conditions	15-Jul	67.49	1.29	0.21	80.14	12.65	2.08
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.53	0.33	0.05	78.35	11.82	1.94
BH26	existing conditions modeled	15-Jul	67.25	1.05	0.40	81.45	14.20	5.44
BH26	vegetation changed to reference conditions	15-Jul	66.66	0.46	0.18	80.07	13.41	5.14
BH26	channel geometry changed to reference conditions	15-Jul	66.91	0.71	0.27	79.53	12.62	4.84
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	77.79	11.45	4.39
BH28	existing conditions modeled	15-Jul	66.29	0.09	0.17	79.43	13.14	24.61
BH28	vegetation changed to reference conditions	15-Jul	66.25	0.05	0.09	79.01	12.76	23.90

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**		**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 40 cfs					
BH18	existing conditions modeled		66.32	0.12	0.09	78.52	12.20	9.35
BH22	existing conditions modeled		67.70	1.50	0.25	80.99	13.29	2.18
BH22	vegetation changed to reference conditions		66.96	0.76	0.12	79.69	12.73	2.09
BH22	channel geometry changed to reference conditions		67.32	1.12	0.18	79.21	11.89	1.95
BH22	vegetation & channel geometry changed to reference conditions		66.54	0.34	0.06	77.62	11.08	1.82
BH26	existing conditions modeled		67.08	0.88	0.34	80.59	13.51	5.18
BH26	vegetation changed to reference conditions		66.62	0.42	0.16	79.36	12.74	4.88
BH26	channel geometry changed to reference conditions		66.79	0.59	0.23	78.59	11.80	4.52
BH26	vegetation & channel geometry changed to reference conditions		66.34	0.14	0.05	77.05	10.71	4.10
BH28	existing conditions modeled		66.28	0.08	0.15	78.70	12.42	23.26
BH28	vegetation changed to reference conditions		66.25	0.05	0.09	78.31	12.06	22.58

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month/Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 50 cfs					
BH18	existing conditions modeled	15-Jul	66.32	0.12	0.09	77.95	11.63	8.91
BH22	existing conditions modeled	15-Jul	67.56	1.36	0.22	80.30	12.74	2.09
BH22	vegetation changed to reference conditions	15-Jul	66.92	0.72	0.12	79.11	12.19	2.00
BH22	channel geometry changed to reference conditions	15-Jul	67.21	1.01	0.17	78.48	11.27	1.85
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.54	0.34	0.06	77.04	10.50	1.72
BH26	existing conditions modeled	15-Jul	66.97	0.77	0.30	79.89	12.92	4.95
BH26	vegetation changed to reference conditions	15-Jul	66.58	0.38	0.15	78.77	12.19	4.67
BH26	channel geometry changed to reference conditions	15-Jul	66.71	0.51	0.20	77.85	11.14	4.27
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	76.46	10.12	3.88
BH28	existing conditions modeled	15-Jul	66.27	0.07	0.13	78.10	11.83	22.15
BH28	vegetation changed to reference conditions	15-Jul	66.25	0.05	0.09	77.74	11.49	21.52

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		Date	Model Results-Outflow Temperature					
Model Reach	**Model Description**	**Month/ Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut - Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 60 cfs					
BH18	existing conditions modeled	15-Jul	66.32	0.12	0.09	77.47	11.15	8.54
BH22	existing conditions modeled	15-Jul	67.45	1.25	0.21	79.71	12.26	2.01
BH22	vegetation changed to reference conditions	15-Jul	66.89	0.69	0.11	78.61	11.72	1.92
BH22	channel geometry changed to reference conditions	15-Jul	67.11	0.91	0.15	77.87	10.76	1.77
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.54	0.34	0.06	76.55	10.01	1.64
BH26	existing conditions modeled	15-Jul	66.89	0.69	0.26	79.29	12.40	4.75
BH26	vegetation changed to reference conditions	15-Jul	66.56	0.36	0.14	78.26	11.70	4.48
BH26	channel geometry changed to reference conditions	15-Jul	66.66	0.46	0.18	77.25	10.59	4.06
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	75.98	9.64	3.69
BH28	existing conditions modeled	15-Jul	66.26	0.06	0.11	77.60	11.34	21.24
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	77.25	11.01	20.62

Attachment B-1. Modeling Stream Temperatures in the Upper Big Hole River Attachment 1

Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month/Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 70 cfs					
BH18	existing conditions modeled	15-Jul	66.31	0.11	0.08	77.06	10.75	8.24
BH22	existing conditions modeled	15-Jul	67.36	1.16	0.19	79.20	11.84	1.94
BH22	vegetation changed to reference conditions	15-Jul	66.85	0.65	0.11	78.17	11.32	1.86
BH22	channel geometry changed to reference conditions	15-Jul	67.04	0.84	0.14	77.36	10.32	1.69
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.53	0.33	0.05	76.13	9.60	1.58
BH26	existing conditions modeled	15-Jul	66.82	0.62	0.24	78.79	11.97	4.59
BH26	vegetation changed to reference conditions	15-Jul	66.53	0.33	0.13	77.82	11.29	4.33
BH26	channel geometry changed to reference conditions	15-Jul	66.61	0.41	0.16	76.74	10.13	3.88
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.34	0.14	0.05	75.56	9.22	3.53
BH28	existing conditions modeled	15-Jul	66.26	0.06	0.11	77.17	10.91	20.43
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	76.84	10.60	19.85

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Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month/Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 80 cfs					
BH18	existing conditions modeled	15-Jul	66.31	0.11	0.08	76.70	10.39	7.96
BH22	existing conditions modeled	15-Jul	67.28	1.08	0.18	78.76	11.48	1.89
BH22	vegetation changed to reference conditions	15-Jul	66.83	0.63	0.10	77.79	10.96	1.80
BH22	channel geometry changed to reference conditions	15-Jul	66.98	0.78	0.13	76.92	9.94	1.63
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.52	0.32	0.05	75.77	9.25	1.52
BH26	existing conditions modeled	15-Jul	66.77	0.57	0.22	78.34	11.57	4.43
BH26	vegetation changed to reference conditions	15-Jul	66.51	0.31	0.12	77.44	10.93	4.19
BH26	channel geometry changed to reference conditions	15-Jul	66.58	0.38	0.15	76.32	9.74	3.73
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.33	0.13	0.05	75.21	8.88	3.40
BH28	existing conditions modeled	15-Jul	66.26	0.06	0.11	76.79	10.53	19.72
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	76.48	10.24	19.18

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Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month /Day**	**Predicted Mean**	**Mean TOut -Mean TIn**	**Length Normalized Mean TOut -Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 90 cfs					
BH18	existing conditions modeled	15-Jul	66.31	0.11	0.08	76.38	10.07	7.72
BH22	existing conditions modeled	15-Jul	67.21	1.01	0.17	78.36	11.15	1.83
BH22	vegetation changed to reference conditions	15-Jul	66.80	0.60	0.10	77.44	10.64	1.75
BH22	channel geometry changed to reference conditions	15-Jul	66.93	0.73	0.12	76.53	9.60	1.58
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.52	0.32	0.05	75.45	8.93	1.47
BH26	existing conditions modeled	15-Jul	66.73	0.53	0.20	77.95	11.22	4.30
BH26	vegetation changed to reference conditions	15-Jul	66.50	0.30	0.11	77.09	10.59	4.06
BH26	channel geometry changed to reference conditions	15-Jul	66.55	0.35	0.13	75.94	9.39	3.60
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.33	0.13	0.05	74.90	8.57	3.28
BH28	existing conditions modeled	15-Jul	66.25	0.05	0.09	76.46	10.21	19.12
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	76.16	9.92	18.58

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Info		**Date**	**Model Results-Outflow Temperature**					
Model Reach	**Model Description**	**Month /Day**	**Predicted Mean**	**Mean TOut - Mean TIn**	**Length Normalized Mean TOut - Mean TIn**	**Estimated Maximum**	**Tmax - Mean Tout**	**Length Normalized Tmax - Mean TIn**
(--)	**(--)**		**(*F)**		**(*F / mile)**	**(*F)**	**(*F)**	**(*F / mile)**
			Q = 100 cfs					
BH18	existing conditions modeled	15-Jul	66.30	0.10	0.08	76.09	9.79	7.50
BH22	existing conditions modeled	15-Jul	67.16	0.96	0.16	78.00	10.84	1.78
BH22	vegetation changed to reference conditions	15-Jul	66.78	0.58	0.10	77.13	10.35	1.70
BH22	channel geometry changed to reference conditions	15-Jul	66.89	0.69	0.11	76.19	9.30	1.53
BH22	vegetation & channel geometry changed to reference conditions	15-Jul	66.51	0.31	0.05	75.17	8.66	1.42
BH26	existing conditions modeled	15-Jul	66.69	0.49	0.19	77.60	10.91	4.18
BH26	vegetation changed to reference conditions	15-Jul	66.48	0.28	0.11	76.79	10.31	3.95
BH26	channel geometry changed to reference conditions	15-Jul	66.53	0.33	0.13	75.61	9.08	3.48
BH26	vegetation & channel geometry changed to reference conditions	15-Jul	66.33	0.13	0.05	74.62	8.29	3.18
BH28	existing conditions modeled	15-Jul	66.25	0.05	0.09	76.16	9.91	18.56
BH28	vegetation changed to reference conditions	15-Jul	66.24	0.04	0.07	75.87	9.63	18.03