ATTACHMENT B – MODELING STREAMFLOW AND WATER TEMPERATURE IN THE BITTERROOT RIVER, MONTANA

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IN THE BITTERROOT RIVER, MONTANA

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EXECUTIVE SUMMARY

The Bitterroot River and several of its tributaries have been identified by the Montana Department of Environmental Quality (DEQ) as being impaired due to elevated water temperatures. The cause of the impairment has been attributed to 1) moderately impacted stream banks and riparian habitat, and 2) chronic dewatering, both of which lead to summertime temperatures at/near the high end of optimal conditions for mixed salmonid populations. As such DEQ has commissioned a water temperature study to investigate the mechanistic relationship between stream flow, shade from vegetation, and in-stream water temperature.

Field studies were carried out in 2004 and 2006 to support water quality model development for the project. QUAL2K water quality models were developed for the Bitterroot River and its three listed tributaries, Miller, Sleeping Child, and Willow creeks to evaluate management practices suitable for meeting state temperature standards. For, the Bitterroot River, a previously developed QUAL2E model (converted to QUAL2K) was used for the analysis. New QUAL2K models were constructed for the tributaries. Shadev3.0 models were also developed to assess shade conditions using previously collected field data. Overall the models show reasonable agreement with forward-looking infrared (FLIR) data based on a root mean squared error (RMSE) of 1.4^{o}F for the minimum water temperatures and 0.9^{o}F for the maximum water temperatures. Once developed, various water temperature responses were evaluated for a range of potential watershed management activities. Seven scenarios were considered including.

1. A shade scenario which uses reference conditions for all reaches where the existing vegetation density, unless impacted by fire, is less than in the existing conditions model.
2. A headwater and tributary influence scenario where the tributary mean water temperature values were reduced by 1^{o}F based on expected feasible reductions from the Headwater Bitterroot TMDL (DEQ, 2005b).
3. A set of flow scenarios to evaluate the effect of water use diversions on temperature.
4. A set of wastewater treatment plant/facility (WWTP) scenarios where the amount of discharge from each plant was varied.
5. A natural condition scenario where the changes in the shade, headwater and tributary, flow, and WWTP scenarios were integrated.
6. A naturally occurring scenario which combines the changes included in the shade, headwater and tributary, and flow 20 percent decrease scenarios based on DEQ’s interpretation of all reasonable land, soil, and water conservation measures.

Simulation results ranged from almost no change in water temperatures to reductions as much as nearly 8^{o}F. Changes in shade were found to be most significant for the tributaries. Conversely, changes in flow were the most significant restoration strategy for reducing temperatures in the Bitterroot River. Overall, a range of viable outcomes were evaluated and are being considered as part of the upcoming TMDL.

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1.0 BACKGROUND

The Montana Department of Environmental Quality (DEQ) has commissioned a water temperature study to investigate the mechanistic relationship between stream flow, shade from vegetation, and in-stream water temperature in the Bitterroot River and three tributaries. The one-dimensional dynamic stream water quality model QUAL2K v2.11 (Chapra, Pelletier, and Tao, 2007) was applied to a 82.3-mile reach of the Bitterroot River extending from the United States Geological Survey (USGS) gage near Darby to the confluence with the Clark Fork River near Missoula, and on Miller Creek, Sleeping Child Creek, and Willow Creek. The riparian vegetation model Shade v3.0 (Ecology, 2008) was applied to the same reaches. The models were used to assess scenario responses to alternative riparian and water management conditions. The results will be used to support DEQ's Total Maximum Daily Load (TMDL) program.

1.1 Montana Temperature Standard (ARM 17.30.623)

Montana's in-stream temperature standard is narrative. It is more difficult to interpret for non-point sources compared to point sources. This is especially true when attempting to characterize the departure from "naturally-occurring conditions," which reflect the implementation of "all reasonable land, soil and water conservation practices" (ARM 17.30.602). B-1 (ARM 17.30.607) is the predominant water use classification adopted for the Clark Fork River watershed of the Columbia River drainage, which includes the Bitterroot River watershed. As currently written, a maximum allowable increase of 1^{o}F over "naturally occurring conditions" is acceptable for B-1 waters when natural temperatures are within the range of 32^{o}F to 66^{o}F. For temperatures 66^{o}F or greater, a 0.5^{o}F increase is allowed (ARM 17.30.623 (2) (e)). Based on monitoring data from the Bitterroot River and its tributaries, the 0.5^{o}F standard applies, except on the Bitterroot River above Skalkaho Creek near Grantsdale (60-mi) where the 1^{o}F standard applies.

1.2 Problem Statement

DEQ has divided the Bitterroot River into three segments for scientific and administrative purposes: 24.3-miles (East and West Forks of the Bitterroot River to Skalkaho Creek), 36.5-miles (Skalkaho Creek to Eightmile Creek) and 23.4-miles (Eightmile Creek to Clark Fork River). DEQ assessed the data from each of these segments in accordance with Montana's 303(d) assessment process. The assessment records indicate that the river is moderately impaired (CWAIC, 2009) and DEQ's beneficial use support assessments indicate that aquatic life and cold water fishery uses are partially supported in all three reaches. On Montana's 2008 303(d) list of impaired waters, only the middle segment of the Bitterroot River (Skalkaho Creek to Eightmile Creek) is indicated as likely impaired by thermal conditions (CWAIC, 2009). The causes of the impairment may include: 1) summertime temperatures at/near the high end of optimal conditions for mixed salmonid populations; 2) moderately impacted stream banks and riparian habitat; and 3) chronic dewatering. Models were developed and various potential scenarios that influence water temperature performed to support assessment of water temperature conditions.

2.0 STUDY AREA

The Bitterroot River study area drains approximately 2,800-square miles (mi^2) of high- and mid-elevation mountainous topography in western Montana. The East Fork Bitterroot River originates from the continental divide while the West Fork Bitterroot River originates from the Idaho-Montana border. The forks merge near Darby and the river flows south past the towns of Grantsdale, Hamilton, Woodside, Corvallis, Victor, Stevensville, Florence, and Lolo before reaching its endpoint at the Clark Fork River. The entire watershed is part of the USGS 4th Hydrologic Unit Code (HUC) 17010205.

The East and West Forks of the Bitterroot Rivers (headwaters) are part of the Bitterroot Headwaters TMDL planning area (TPA), while the lower Bitterroot River (Darby downstream to the Clark Fork River) is part of the Bitterroot TPA. This study focuses on the lower Bitterroot River. Access to the study area site is from US-93, which parallels much of this reach of the river (**Figure 2-1**).

2.1 Climate

Climate in the Bitterroot River watershed is intermontane continental, with marked seasonality (**Figure 2-2**). The cooperative observation station at Hamilton (COOP ID 243885) is located near the middle of the Bitterroot TPA and provides representative climatic information regarding the project site. The Cooperative Network has been recognized as the most definitive source of information on U.S. climate trends for temperature and precipitation and follows established data standards (NOAA, 2009). Records from Hamilton indicate that average air temperatures from 1895 to 2008 range from about 85°F in the summer to about 15°F in the winter (WRCC, 2009). This range in air temperatures is similar to those recorded at eight other cooperative observation stations in the watershed (Darby, Lolo Hot Springs 2NE, Missoula 2NE, Missoula 2WNW, Missoula WSO AP, Stevensville, Sula 3ENE, and the Western Agricultural Research Center). Average annual precipitation is approximately 12 inches with a fairly uniform distribution of about 1 inch per month. The driest months are usually February and March with about 0.8 inch of precipitation, and the wettest months are May and June with about 1.6 inches of precipitation. The eight other cooperative observation stations in the valley recorded similar precipitation. Cooperative observation stations at higher elevations recorded about double the amount of annual precipitation, with most of the additional precipitation falling as snow during the winter months.

2.2 Surface Water

In general, Bitterroot River watershed hydrology is predominantly snowmelt-driven, as demonstrated in the mean monthly hydrographs (**Figure 2-3**). Within the study area, there are six USGS stream flow stations on the Bitterroot River. The gages, with the drainage area in parentheses include: (1) USGS 12344000 Bitterroot River near Darby (1049-mi^2); (2) USGS 12346000 Bitterroot River near Grantsdale (1,414-mi^2); (3) USGS 12348200 Bitterroot River near Corvallis (1,711-mi^2); (4) USGS 12350250 Bitterroot River at Bell Crossing near Victor (1,963-mi^2); (5) USGS 12351200 Bitterroot River near Florence (2,354-mi^2); and (6) USGS 12352500 Bitterroot River near Missoula (2,814-mi^2). Typically, spring snowmelt begins in midto late-March, peaks in June, and then rapidly declines in July and August back to base flow. Tributary inflow to the Bitterroot River is variable, and depends on the aspect, basin elevation, drainage area and mountain range, water use and the presence of irrigation diversions. Many of the larger tributaries are similar in drainage area and flow. These tributaries include: Rock Creek, Lick Creek, Lost Horse Creek, Sleeping Child Creek, Skalkaho Creek, Blodgett Creek, Fred Burr Creek, Sweathouse Creek, North Fork Burnt Creek, and Lolo Creek.

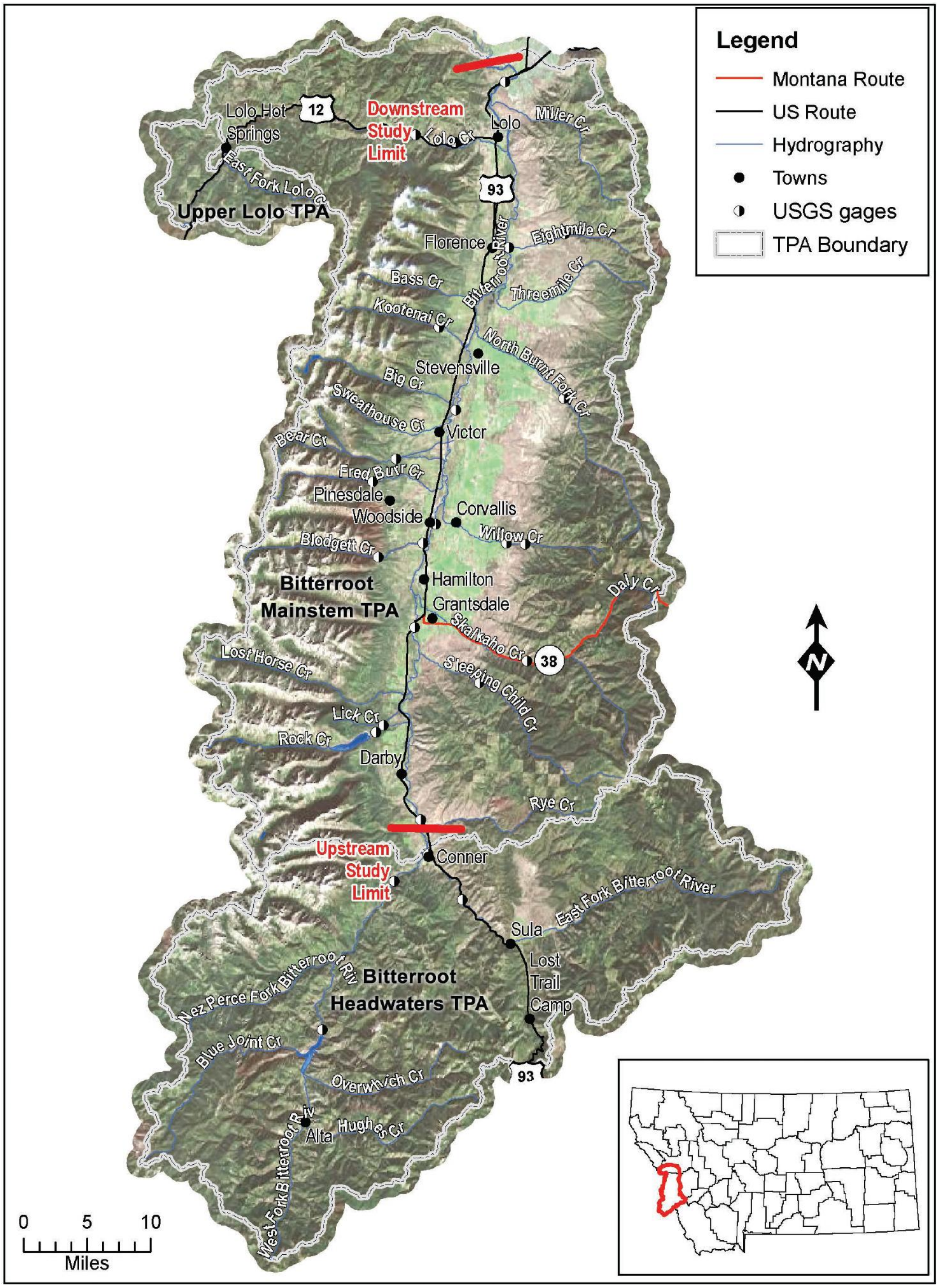

Figure 2-1. Bitterroot River watershed, hydrography, and stream flow stations

The modeling reach in **Figure 2-1** extends from approximately Darby to the confluence with the Clark Fork River near Missoula. The limits of the study area reach are delineated by a red line and are labeled.

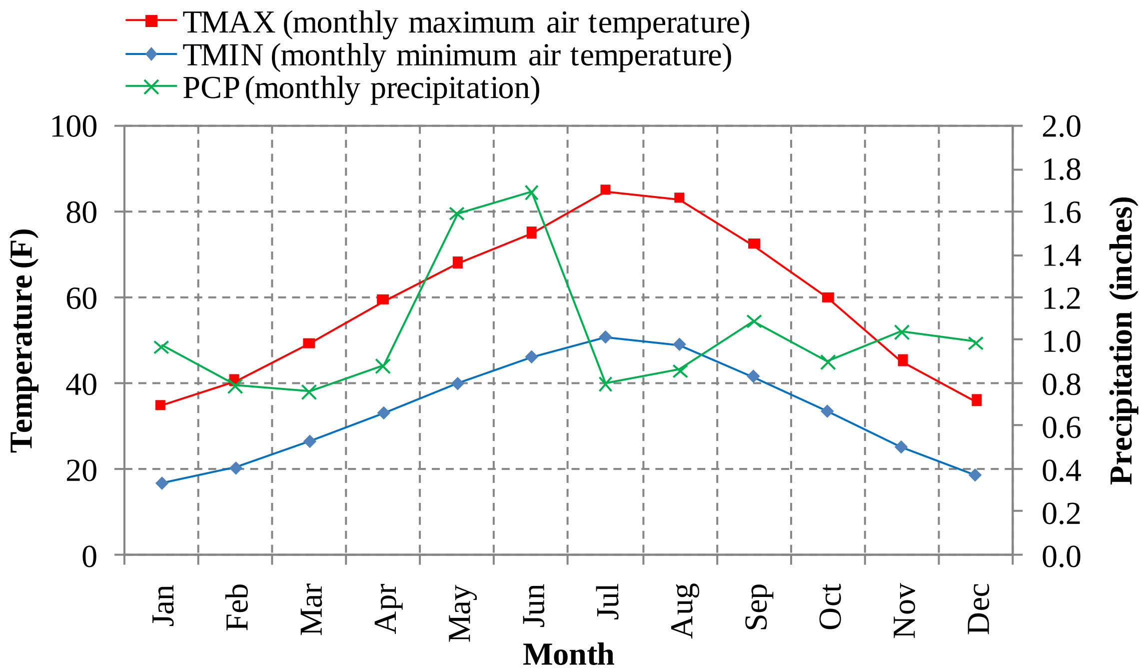

Figure 2-2. Bitterroot River climate at Hamilton, MT

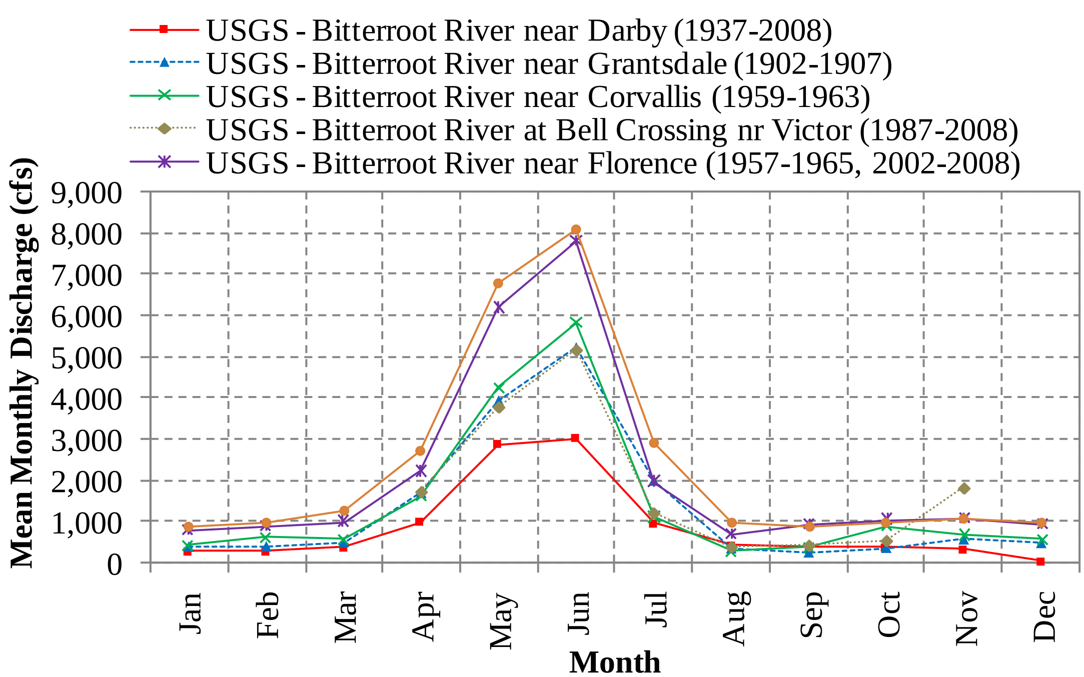

Figure 2-3. Bitterroot River USGS hydrographs

2.3 Groundwater

The Bitterroot Valley is underlain by unconsolidated to semi-consolidated tertiary sediments and groundwater flow under the valley is characterized by a complex seasonal interaction with recharge from streams and irrigation (McMurtrey, et.al., 1959). The permeable soils and extensive agricultural activities that occur in the valley generally prevent surface runoff, except during storms of high intensity or during snowmelt when the ground is frozen (Briar and Dutton, 2000). Groundwater levels tend to gradually decline through the winter and early spring, and then rise in late spring and summer due to recharge from precipitation and irrigation (McMurtrey, et.al., 1972). A result of this interaction is a systematic correlation that is suggestive of a direct relationship between snow pack, recharge, aquifer level, and stream flow. It is estimated that the shallow aquifer along the valley floor alone holds 628 billion gallons with the annual recharge averaging about 180 billion gallons per year (LaFave, 2008). (If this volume were added to the annual average volume of flow for the Bitterroot River at Missoula, it would be an increase of about 30 percent.)

3.0 METHODS AND MATERIALS

Data for this study came from various agencies, including: flow from the USGS, climatic data from the National Oceanic and Atmospheric Administration (NOAA), and water temperature and shade data from DEQ. The data are described as part of the Model Development sections.

4.0 SHADE MODEL DEVELOPMENT

4.1 Model Description

Shade v3.0 is a riparian vegetation and topography model that computes the hourly effective shade for a single day (Ecology, 2008). Effective shade is the reduction in solar radiation caused by both land forms (hills, mountains, etc.) and plants that block the path of solar rays. Shade is an Excel/Visual Basic for Applications program. The model uses the latitude/longitude, day of year, aspect and gradient (the direction and slope of the stream), solar path, buffer width, canopy cover, and vegetation height to compute hourly, dawn-to-dusk shade. The model input variables include channel orientation, wetted width, bankfull width, channel incision, topography, buffer width and height, and canopy cover. Bankfull width in the shade calculations is defined as the near-stream disturbance zone (NSDZ), which is the distance between the edge of the first vegetation zone on the left and right bank.

4.2 Available Data

The application of the Shade model to the Bitterroot River relied upon field data collected during a 2006 field study and the interpretation of these data (DEQ, 2005a and DEQ, 2007). The results of the study included: tree height, crown diameter, tree-to-channel distance, buffer width, overhang, shade density, active channel width, terrain slope, and percent of reach. Aspect was estimated and provided in the shade report; however, it was reported as Aspect Class with the bearing grouped into categories of either 60 or 120 degrees. The Aspect Class provided only a gross approximation of the bearing. No values were provided for the stream disturbance zone and the distance from the stream center to the left or right bank.

4.3 GIS Pre-Processing

TTools v3.0 is an ArcView extension to translate spatial data into Shade model inputs (ODEQ, 2001). TTools was used to estimate the values that were not provided in the field study report: (1) elevation; (2) aspect; (3) near stream disturbance zone (NSDZ) width, the distance from the stream center to the left bank; and (4) topographic shade. (1) Elevation was calculated using a 30-m (98-ft) digital elevation model (DEM) and the stream centerline file included with the field study report as provided by DEQ. (2) Aspect was calculated to the nearest degree using TTools with the stream centerline file. (3) The field study report only provided an estimate of the active channel or "the width of the channel at bankfull." The active channel and wetted width were assumed conservatively to be the equivalent. However, the NSDZ was always estimated as more than the wetted width, averaging 1.8 times greater. TTools calculates these values based on the stream centerline and left and right bank NSDZ. Left and right banks were delineated in GIS based on the aerial photographs from the Montana Natural Resource Information System, Natural-Color Aerial Photos of Montana, (2005) and U.S. Farm Services Agency National Agricultural Imagery Program (NAIP). Performing the delineation required some interpretation of the location of the stream centerline in the meandering and braided reaches of the Bitterroot River. This provided a method to estimate the widths required by the Shade model. Again the NSDZ was based on the available aerial photography from 2005. (4) Topographic shade was calculated using TTools with the stream centerline file and a DEM.

4.4 Riparian Input

The Shade model requires the description of riparian vegetation. The description includes: vegetation code, description, height, density, and overhang (OH). The results in the field study report were used to develop a riparian description table (**Table 4-1**). Vegetation descriptions used the average value for tree height and shade density when multiple field observations were recorded. The overhang reported in the field study report spreadsheet was zero for all vegetation types. While there may be some slight overhang along small portions of the Bitterroot River, the river is wide and using a value of zero provides a conservative estimate.

Table 4-1. Riparian land cover types and associated attributes used in the Bitterroot River Shade model

Land Cover	Height (ft)	Density (%)
Brush/saplings	41.0	60
Coniferous/deciduous	74.1	80
Deciduous	61.4	42
Deciduous/brush	65.9	70
Deciduous/brush/herbaceous	74.5	78
Deciduous/coniferous	73.8	73
Deciduous/coniferous/brush	70.2	79
Deciduous/coniferous./brush/herbaceous	77.8	66
Deciduous/coniferous/herbaceous	76.4	65
Deciduous/coniferous/herbaceous/wetland	107.9	90
Deciduous/coniferous/shrubs	72.5	75
Deciduous/coniferous/shrubs/herbaceous	80.4	66
Deciduous/herbaceous	71.5	59
Deciduous/herbaceous/wetland	87.6	83
Deciduous/shrubs	44.9	20
Deciduous/shrubs/herbaceous	65.9	58
Shrubs	7.9	80

4.5 Shade Input

The Shade model inputs include: (1) riparian zones, (2) reach length, (3) channel incision, and (4) elevation, aspect, wetted width, near-stream disturbance zone width, distance from the bank to the center of the stream, and topographic shade. (1) The riparian zones for the left and right bank were based on the existing vegetation composition as provided in the field study, and were assigned values based on the riparian vegetation descriptions (**Table 4-1**). (2) The Shade model requires reach lengths be an equal interval. The reaches in the field study report were not at an equal interval and were subdivided while maintaining the same reach characteristics. A uniform reach length interval of 660-ft was used. (3) Channel incision was estimated based on the bank stability provided in the field study report. Incision is the vertical drop from the bankfull edge to the water surface. Where the bank was stable, incision was set at zero (no steep eroding cutbank); otherwise the incision was estimated as 6.5 feet based on the database comment field of vertical or near vertical stream banks. (4) The remaining variables were computed as part of the GIS pre-processing.

4.6 Model Evaluation

The Shade model results generally indicate between 10 and 30 percent effective shade along the Bitterroot River (**Figure 4-1**). Effective shade is the reduction in solar reflection due to light reflection and shading from both vegetation and topography. The field study report included ground truth results (field measurements) (DEQ, 2007). These values are similar to the estimated shade.

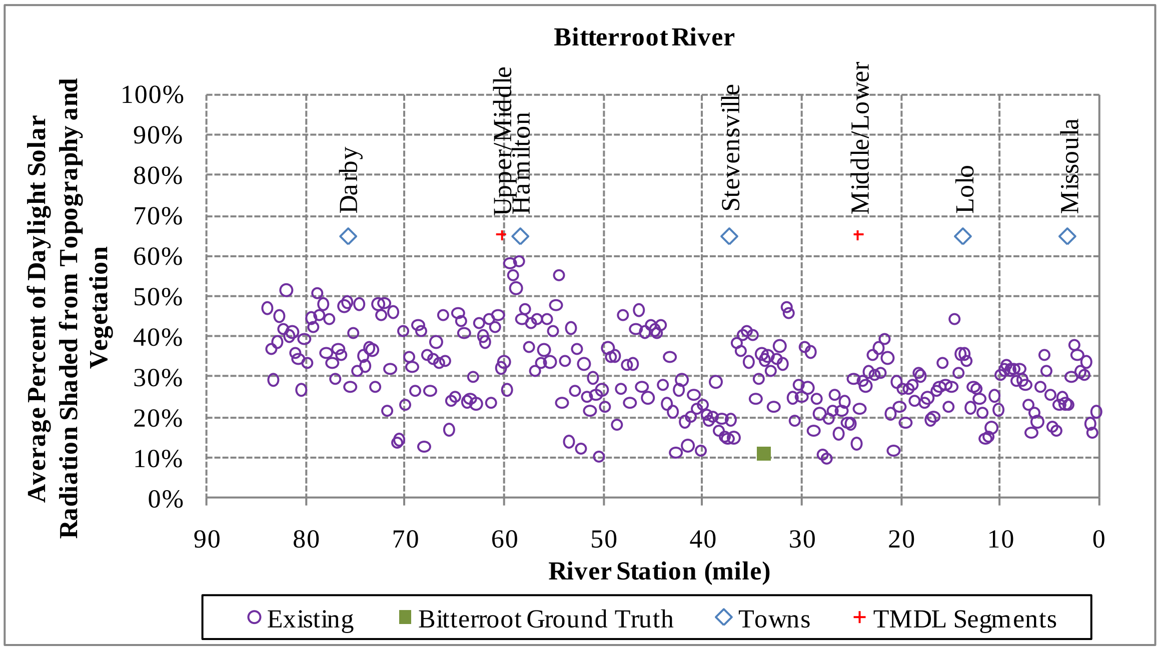

Figure 4-1. Shade model Bitterroot River longitudinal effective shade profile

5.0 QUAL2K MODEL DEVELOPMENT

5.1 Model Description

QUAL2K v2.11 is a river and stream water quality model that is intended to represent a modernized version of the QUAL2E model (Chapra, Pelletier, Tao, 2007). QUAL2E is a one-dimensional water quality model that was developed in the late 1980s/early 1990s and was previously supported by the U.S. Environmental Protection Agency (EPA). QUAL2K was recently developed by the EPA, Tufts University, and the Washington Department of Ecology.

The QUAL2K model is a one-dimensional, steady-state hydraulics model. In other words, flow in the stream channel is assumed to be well-mixed vertically and laterally, and that non-uniform, steady flow is simulated. The heat budget and temperature are simulated as a function of meteorology for a diel (24-hr) time scale. The model permits subdividing the river into reaches of unique length that can have multiple inflow loads and withdrawals.

5.2 Available Data

The application of the QUAL2K model for this study relied upon the conversion of previously developed QUAL2E model of the Bitterroot River (HDR, 2005). The model report includes data reviews and model inputs that were useful in the model conversion and upgrades.

5.3 Simulation Period and Model Coefficients

Models were developed for six simulation periods: June 15th, July 15th and August 15th for 1992 and 1999. These dates were selected based on data availability, representation of growing season conditions, and the capabilities of the model for single-day, steady-state conditions. For the water temperature simulations, the August 1992 date was selected as the period of critical low flows and high water temperatures.

5.4 Flow Input

The flow inputs in the QUAL2K model include: headwater (the most upstream reach of the model near Darby), diffuse sources (e.g., groundwater recharge and losses, shallow irrigation infiltration/return flows, bankflows, etc.) and point sources (tributaries, irrigation withdrawals, and municipal discharges). Flow accounting in the Bitterroot River watershed is challenging due to the interaction between surface water and groundwater, agricultural water use, and many small, un-gaged tributaries. Taking these factors into consideration, the following approach was used to assess the hydrology and develop flow inputs for the model.

5.4.1 Flow Approach

Accuracy in the water balance is important for heat transfer calculations in water temperature model simulations. The original water balance used in the QUAL2E model was reviewed by comparing historical USGS gage data and associated regressions to estimate tributary inflow to the river. Additionally, new information for the QUAL2K update was acquired regarding water use and irrigation diversions from Al Pernichele of the Bitterroot Water User's Association. USGS flow records for the mainstem Bitterroot River and tributaries were downloaded from the USGS National Water Information System Web Interface (USGS, 2009). The tributaries were organized by the east-side and the west-side of the watershed due to hydrologic differences in both annual average precipitation and water yield. The drainage area and flow records were then used as part of a flow-regression analysis.

5.4.2 Flow-Regression Analysis

The flow-regression analysis was completed to estimate flows for un-gaged basins as part of the water balance. The analysis included comparing mean monthly discharge with the basin drainage area. Linear, exponential, and power regressions were evaluated. Overall, the linear regression model resulted in the best coefficient of determination (e.g. r-squared value). A linear relationship also matches low-flow conditions conceptually; e.g. as the drainage area increases, the discharge from a basin typically increases proportionately under low-flow conditions. The regressions were also examined using data for the full period of record, versus using aligned datasets for common periods. Both the relationships and the r-squared values were similar for the period of record and the common period analyses.

Relationships developed for the mainstem, east-side, and west-side are shown in **Table 5-1** and **Figure 5-1**. Data from some of the west-side gages were not included in the analysis due to large differences in the drainage area (e.g. Lolo Creek), the impact of canal and reservoir operations and lack of definitive watershed area (e.g. Rock Creek), and inconsistent records and the appearance of stream depletion by water use, diversions and/or other seasonal influences (e.g. Blodgett Creek).

Table 5-1. Mean of monthly discharge to drainage area linear regressions		
Bitterroot River	**Equation**	**R^2**
June	Q=2.7369DA+693.3	0.8679
July	Q=0.8778DA+35.991	0.5651
August	Q=0.3414DA-133.32	0.6710
Stations used: Bitterroot River near Missoula, near Florence, at Bell Crossing near Victor, near Corvallis, near Grantsdale, near Darby		
East-side tributaries	**Equation**	**R^2**
June	Q=4.7664DA-71.37	0.9210
July	Q=1.6855DA-27.101	0.8830
August	Q=0.7096DA-10.757	0.8662
Stations used: Eightmile Creek near Florence, Willow Creek near Corvallis, Willow Creek at Anfinson Reach near Corvallis, Sleeping Child Creek near Hamilton, Burnt Fork Bitterroot River near Stevensville, Skalkaho Creek near Hamilton, Skalkaho Creek at Brennan's Ranch near Hamilton		
West-side tributaries	**Equation**	**R^2**
June	Q=7.1152DA+72.656	0.9871
July	Q=7.6574DA-95.92	0.9901
August	Q=8.4193DA-186.09	0.9210
Stations used: Fred Burr Creek near Victor, Blodgett Creek near Corvallis, Bear Creek near Victor, Kootenai Creek near Stevensville, Rock Creek near Darby **Stations not used:** Lolo Creek near Lolo, Lolo Creek above Sleeman near Lolo, Rock Creek Canal near Darby, Blodgett Creek near Hamilton		
Q = flow (cfs), DA = drainage area (square miles)		

Monthly flow produced by the regression analysis was adjusted by the ratio of the monthly mean flow to the mean of monthly discharge at the Bitterroot River at Missoula (the long-term average flow of the month to the 1992 or 1999 average flow for the month) for the final adjustment. When a long-term record was available without data for 1992 or 1999, this adjustment provided a more specific estimation of flows for that year.

In some instances, the estimated tributary flow based on the regression analysis may have over-predicted the actual flow reaching the Bitterroot River. Comments from TMDL meetings suggest much of the tributary flow does not reach the Bitterroot River in August because the flows are diverted for agricultural use. Additionally, the diversion flows may under-predict the total diverted flows for irrigation because only the main canals are explicitly identified in the water balance. The diversion flow for June, July, and August is approximately 27 percent of the total estimated irrigation surface water withdrawals in the watershed (USGS, 2004). Therefore the following two adjustments to the regression flows were made. West side tributaries from Darby to Corvallis were reduced to a minimal in-stream flow of 10-cfs in August to achieve the water balance. Flows in Willow Creek were set to zero based on the comment that the flows go into a wetland refuge.

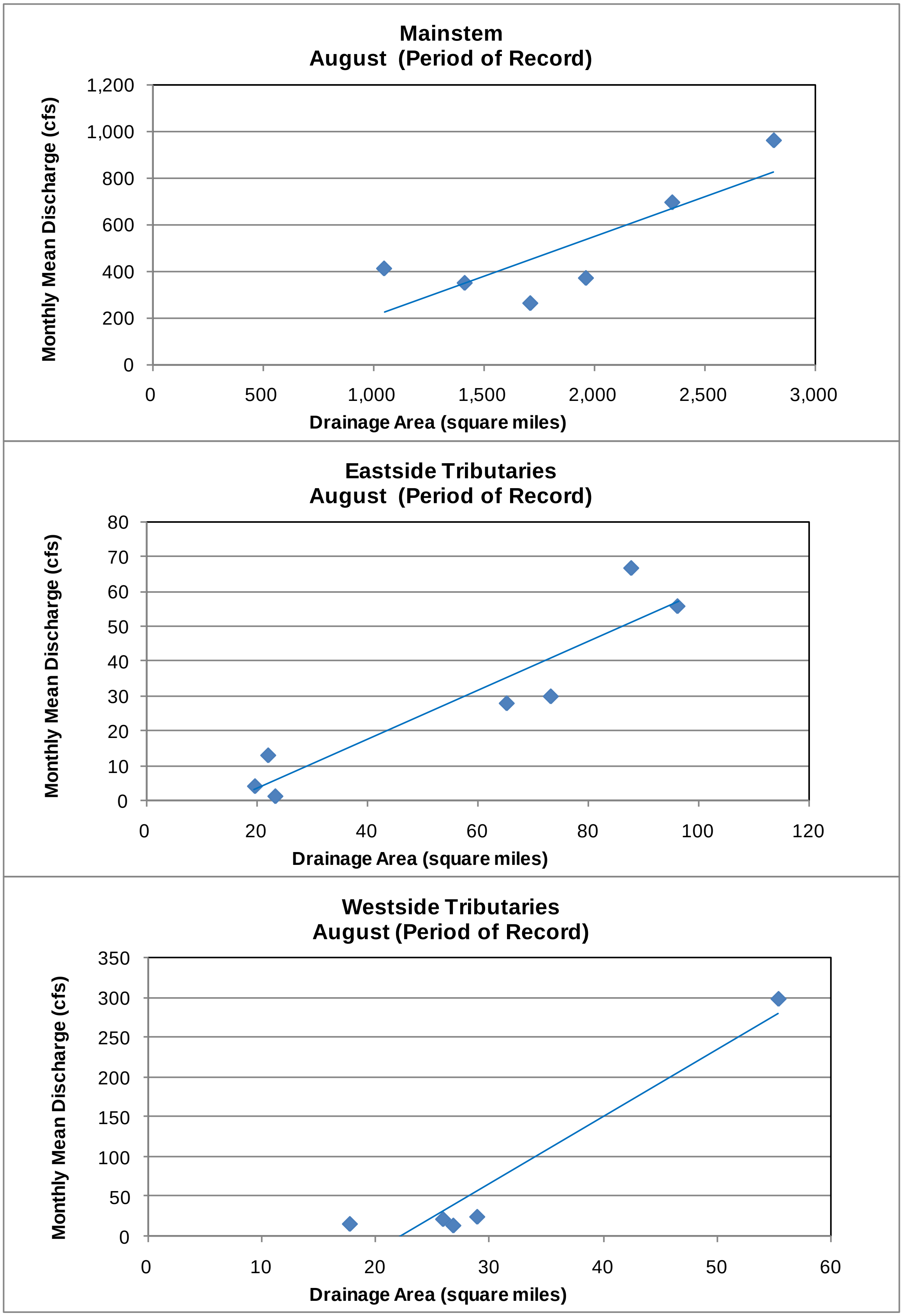

Figure 5-1. Flow-regression relationships

5.4.3 Model Flows

The flow for the upstream model boundary condition was set as the gaged monthly mean flow (June, July, or August for 1992 or 1999) from the Bitterroot River near Darby, MT. Gaged mean monthly flows were used for gages operating in the watershed during 1992 and 1999. For those gages that have operated historically in the watershed, but were not recording during 1992 and 1999, regression relationships were reviewed. The regressions for mainstem flow do not have high r-squared values during the summer because flow decreases through the middle reach of the Bitterroot River due to irrigation withdrawals. For this reason, the regressions were not used to compute the comparison of mainstem flow values. Instead, these values were estimated to be the ratio of the monthly mean flow to the mean of monthly discharge at the Bitterroot River at Missoula gage (the long-term average flow of the month to the 1992 or 1999 average flow for the month), multiplied by the mean of monthly discharge at the intermediate mainstem gage.

Diversions to main canals were set based on information regarding irrigation diversions provided by Al Pernichele from the Bitterroot Water User's Association. The municipal discharges in the model are a small percentage of the total flow (0.7 percent of the mean August 1992 flow at Missoula and 1 percent of the seven-day consecutive low flow with a 10-year return frequency (7Q10) flow at Missoula) and were based on "previous studies and the Environmental Protection Agency's (EPA) National Pollutant Discharge Elimination System (NPDES) database" (HDR, 2005). These were not adjusted as part of the 2009 water balance update.

An unmeasured, or accretion flow, term was developed for each reach to match the sums of the headwater, point-source, tributary, and diversion flows to the mainstem flows. The accretion flows are meant to include the combination of groundwater inflows and losses, and other unaccounted flows. Information on groundwater reach gain/losses was researched but no specific data were found. Groundwater is highly variable and interconnected with the storage of high stream flow and irrigation in the Bitterroot River valley (Sandals, 1947). This interconnectivity can result in variations of 30 feet or more in the groundwater table (McMurtrey, et.al., 1959). Comments from the technical advisory committee suggested groundwater recharge of 200-cfs for the Darby to Grantsdale reach. The results of the water balance were generally lower than 200-cfs, ranging from a loss of about 260-cfs to a gain of about 120-cfs in this reach.

No return flows are included in the water balance. It is assumed that all diverted flows are either consumptively used or lost to groundwater, and accounted for the accretion flow, given the agricultural water demand in the valley. These assumptions are based on firsthand discussions with agricultural water users about the actual water management practices that occur in the valley. Previous studies indicate that approximately half of the diverted flow has the potential to become groundwater (McMurtrey, et.al., 1959). The irrigation based groundwater flow is part of the total groundwater flow for the overall water balance and associated inflow boundary conditions for the model.

5.5 Water Temperature Input

Each of the flow inputs in the QUAL2K model has an associated water temperature. The following approach was used to develop water temperature inputs for the model.

5.5.1 Water Temperature Approach

The original estimates in the QUAL2E model were based on all available data from June, July, and August for 1971 through 2001 (HDR, 2005). The following approach was used to update these estimates. Relationships between flow and water temperature were examined using regression analysis for each tributary individually and grouped as east-side and west-side tributaries. The results of the regression analysis were used to update the water temperatures in the model for the updated flows from the water balance.

5.5.2 Water Temperature Regression Analysis

The goal of the water temperature regression analysis was to improve the estimates of tributary water temperatures for the modeled flow conditions. Since limited data were available a variety of regressions and groupings of data were evaluated. The exponential and power regressions did not provide a significantly different coefficient of determination (e.g. r-squared value) than the linear regression. The grouping of east-side and west-side Bitterroot River watershed tributaries did not provide stronger correlations than the individual regressions for each tributary. While all of the evaluated relationships indicated that water temperatures decrease as flows increase, the linear regression of summer data by tributary was selected as the best estimation of water temperature to flow. The linear regression relationships and r-squared values developed for each tributary using data from all three summer months, June, July, and August are in **Table 5-2**.

Table 5-2. Flow to water temperature linear regressions for inflows

Inflow	Equation	R^2
Bitterroot near Darby	T=-0.0041Q+14.872	0.4958
Lick Creek	T=-0.5161Q+12.019	0.6700
Lost Horse Creek	T=-0.0205Q+17.222	0.8013
Sleeping Child Creek	T=-0.058Q+16.802	0.7631
Skalkaho Creek	T=-0.0176Q+12.255	0.5995
Blodgett Creek	T=-0.0094Q+8.2635	0.3024
Willow Creek	T=-0.0293Q+5.5533	0.1117
Big Creek	T=-0.011Q+9.6422	0.4416
Kootenai Creek	T=-0.0045Q+8.0681	0.0426
North Fork Burnt Creek	T=-0.0108Q+6.7344	0.1655
Bass Creek	T=-0.0283Q+8.3962	0.1808
Threemile Creek	T=-0.0779Q+16.049	0.3650
Eightmile Creek	T=-0.0712Q+6.2432	0.4053
Lolo Creek	T=-0.0067Q+16.33	0.8343
T = water temperature (^oF), Q = flow (cfs)		

5.5.3 Model Water Temperatures

For the tributaries with data, linear regression equations were used to compute water temperatures for the model inputs. Water temperatures for the four creeks without sufficient data for regressions were estimated. Rock Creek was estimated based on two historical field measurements. Sweathouse Creek was estimated based on field aquarod measurements collected by DEQ from August of 2005 and 2006. Bear Creek was estimated to be the same as Sweathouse Creek. Miller Creek was estimated as the average of the other six east side creeks.

For the accretion flows, the average of the August aquarod measurements from Big Creek and Sweathouse Creek was used. The aquarod measurements were used to estimate the diurnal range (between 3.6 and 5.9^{o}F) and time of the maximum (between 6 and 10pm) for the east and west side tributaries.

The water temperatures for the tributaries were less than the mean monthly August air temperature of 64^{o}F, which was calculated as the average of the mean monthly air temperature from nine weather stations in the watershed. The data are from the historical summaries maintained by the Western Regional Climate Center (WRCC, 2009).

Five general types of wastewater treatment facilities exist throughout the watershed: on-site septic systems, infiltration systems (Corvallis), land application systems (Victor), lagoons (Darby and Stevensville), and mechanical treatment plants (Hamilton and Lolo). Data from lagoons in Twin Bridges and Whitehall were used to estimate the mean water temperature, range of 4.0^{o}F, and time of the maximum at 9pm for Darby and Stevensville. Data from the treatment plant in Missoula were used to estimate the mean water temperature, range of 5.9^{o}F, and time of the maximum at 8pm for Hamilton and Lolo.

For the diffuse flow, the mean of the average air temperature of the preceding months (May, June, July, and August) was used to estimate the water temperature at 60^{o}F. The temperature of groundwater generally varies around the mean annual air temperature above the land surface which is 45^{o}F for the valley (NGWA, 2009). Diffuse flows in the model include more than groundwater and thus were estimated at a higher water temperature.

5.6 Climate Input

The climate inputs in the QUAL2K model include air temperature, dew point temperature, wind speed, and cloud cover. Data from the Missoula 2NE station were used for the entire watershed (HDR, 2005). This station collected all the input parameters for the day modeled.

5.7 Shade Input

The Shade model results were incorporated into the QUAL2K August 1992 model. Since the reach lengths in QUAL2K were set the same as in the Shade model, the Shade model results (see the calculation of effective shade under the heading Shade Model Development and specifically the subheading Model Evaluation) were directly input into the QUAL2K model. The shade data are hourly percentages of the solar radiation that is blocked because of shade from topography and vegetation. Hourly values are applied as integrated values for each hour, e.g. the value at 12:00 AM is applied from 12:00 to 1:00 AM.

5.8 Model Evaluation and Calibration

The lowest flows tend to occur in the reach between the USGS gages near Corvallis and Victor. The USGS records for both gages have low mean monthly flows of about 120-cfs. The lowest daily average flows in the record are 114-cfs near Corvallis and 63-cfs near Victor. The flow regressions and water balance appear to be appropriately representing low flow conditions.

A quasi-calibration/validation of the 1992 model was performed using FLIR data that were collected in 2004 by using a forward-looking infrared (FLIR) device which senses infrared radiation. The QUAL2K predicted water temperatures were compared against the FLIR data. The day and night FLIR values were averaged for each tenth of a mile interval of the Bitterroot River. For locations with only a day or a night water temperature value, the missing values were interpolated. The data were averaged for each mile and resulted in 82 points, which were then compared to the QUAL2K results.

Improvements to the QUAL2K model prediction, compared to the FLIR data, were achieved with the following modifications. The water temperature at Darby, the headwater condition, along with the air temperature and dew point temperatures were modified from a single value to varying for each hour of the day to better represent the diurnal cycle minimum and maximum temperatures. Air and dew point temperatures were previously single daily averages.

The reach data include hydraulic rating curves for which velocity and depth of flow are specified as a function of discharge, and for which top width and mass transport formulations are subsequently calculated. Discharge measurement data sheets from the USGS were used to develop the coefficient and exponent values for depth and velocity to discharge relationships (HDR, 2005). However, the data poorly represent low flow conditions such as August 1992. The depth coefficient and exponent was adjusted to improve the representation at low flows (The coefficient and exponent used for each reach corresponding to the gages from upstream to downstream were: Darby 0.35 and 0.3, Grantsdale 0.33 and 0.31, Corvallis 0.31 and 0.32, Victor 0.29 and 0.33, and Florence 0.25 and 0.395).

No weather data were collected as part of the 2004 FLIR study. Daily maximum and minimum air temperatures, dew point temperature, wind speed, and sky conditions were acquired from the Missoula 2NE station, for August 1992 and 2004. Maximum and minimum air temperatures were relatively similar between the two years in August. Dew points varied the most, with 2004 near 50^{o}F and 1992 near 40^{o}F. Wind speeds were similar between about 3 and 5 mph. Cloud cover averaged about 50% during August for both 1992 and 2004. The mean monthly percent possible sunshine for Missoula is 77 percent in August (WRCC, 2009). This was translated to an average cloud cover of 23 percent.

By setting cloud cover to 23 percent and the atmospheric longwave emissivity model to Brutsaert, the model results are similar to the FLIR data (**Figure 5-2**). The root mean squared error (RMSE) (of the FLIR data to the model results) is 1.4^{o}F for the minimum water temperatures and 0.9^{o}F for the maximum water temperatures (the FLIR dataset did not include the mean daily water temperature).

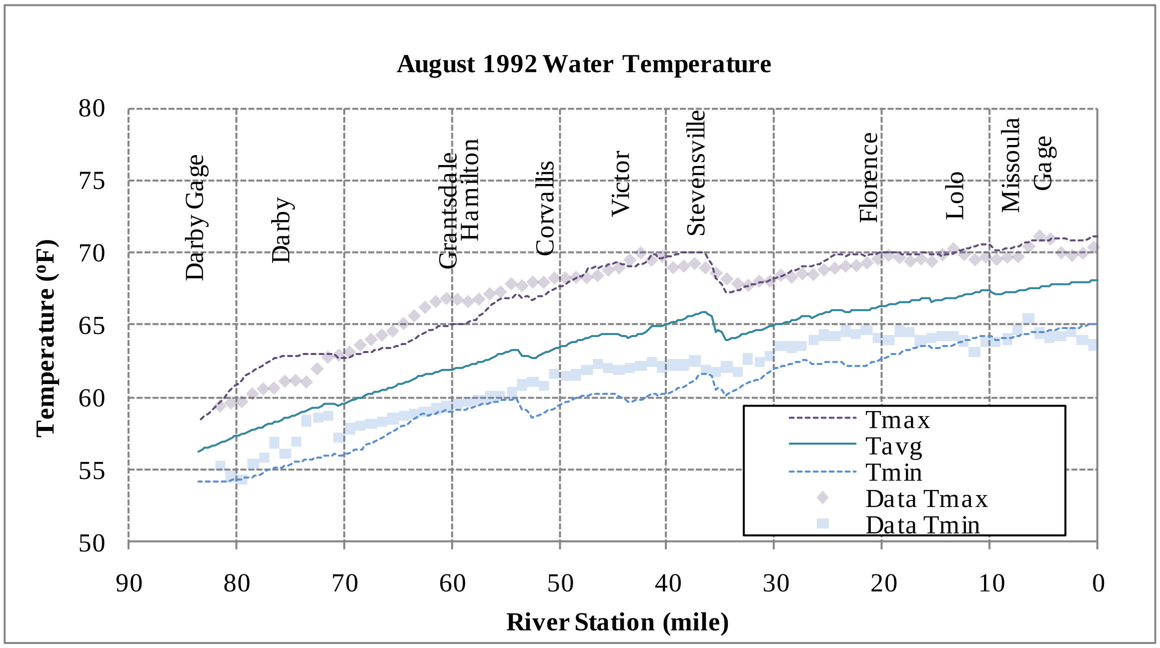

Figure 5-2. Bitterroot River simulated water temperature (lines) for August 1992 and 2004 FLIR data (squares)

6.0 RESULTS AND DISCUSSION

6.1 Flow

Simulated stream flows in the Bitterroot River generally increase downstream in June, with withdrawals starting to impact the increase in flows along the middle reach (**Figures 6-1** and **6-2**). The stream flows in July and August show the Bitterroot River has significantly lower flows due to withdrawals and reduced inflows in the middle reach. While limited data were used in the development of the water balance, results do match the USGS measured flows at the end of each of the reaches (the USGS reaches are defined under the heading Surface Water, DEQ's segments are defined under the heading Problem Statement).

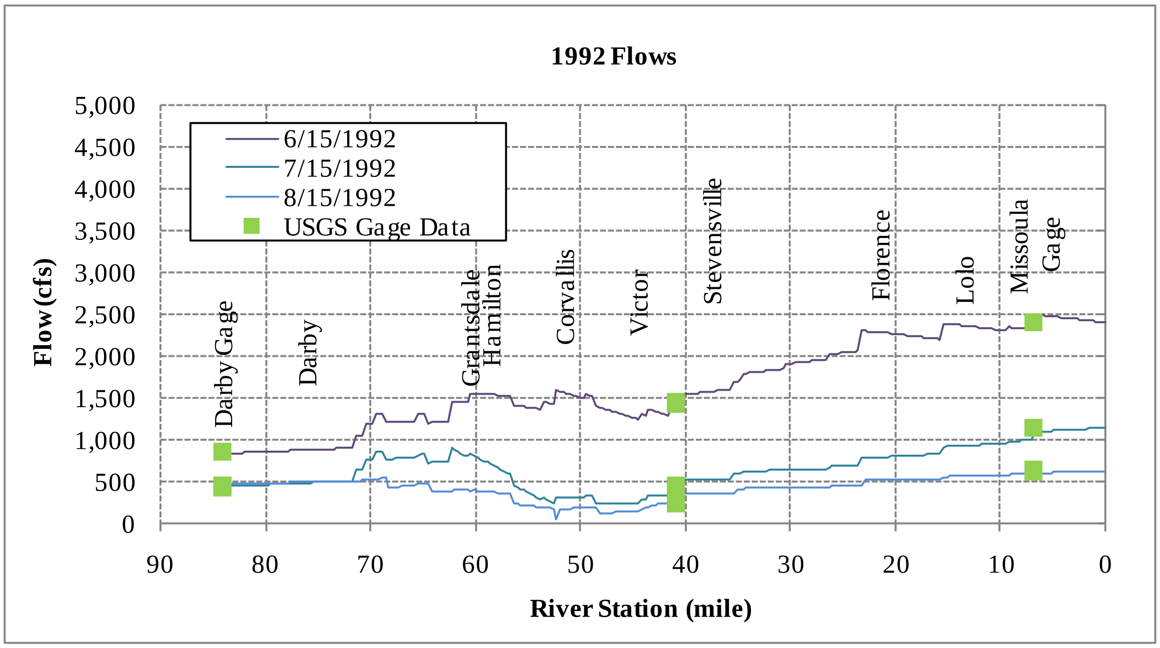

Figure 6-1. Bitterroot River simulated flow (lines) for June, July and August for 1992. River station zero is the confluence with the Clark Fork River

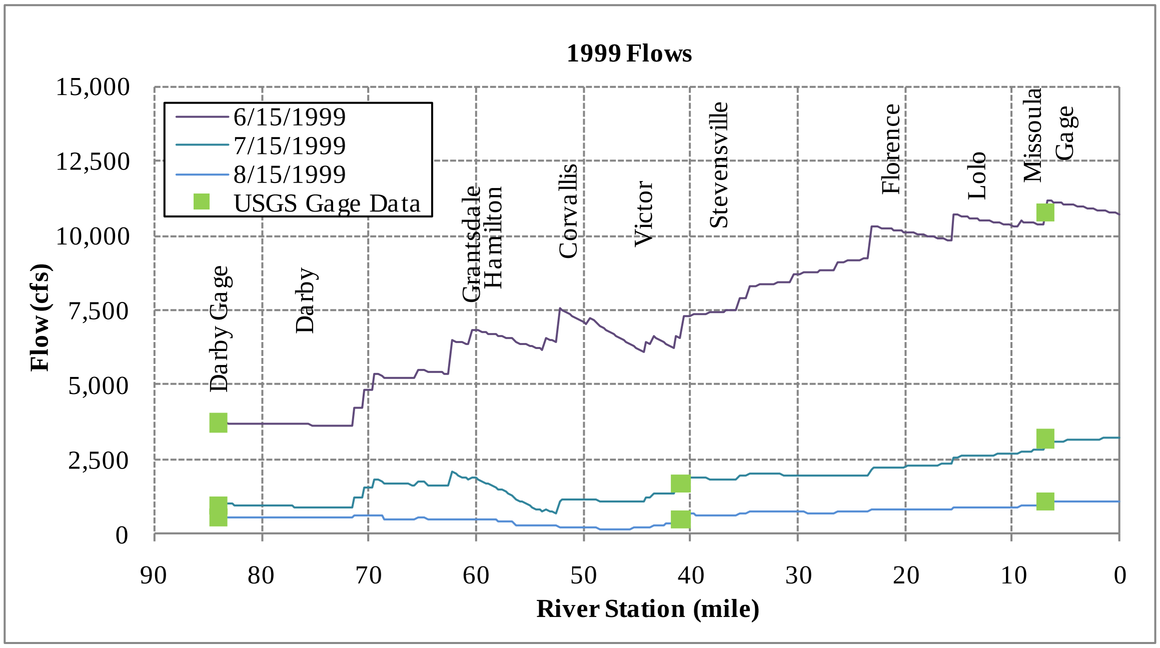

Figure 6-2. Bitterroot River simulated flow (lines) for June, July and August for 1999. River station zero is the confluence with the Clark Fork River

6.2 Water Temperature

Simulated water temperatures in the Bitterroot River generally increase downstream in August. Although limited data were available for the water temperature inputs; data from a 2004 FLIR study were available for comparison.

For comparative purposes, the headwater flow was changed to the August 2004 flow since the FLIR data are from 2004. The root mean squared error (RMSE) is 1.4^{o}F for the minimum water temperatures and 1.0^{o}F for the maximum water temperatures. The simulated water temperatures in the Bitterroot River are similar with some small changes in the minimum and maximum water temperatures. Maximum water temperatures continue to be slightly underestimated by the QUAL2K model near Hamilton.

7.0 TRIBUTARY SHADE MODEL DEVELOPMENT

The Shade model was applied to Miller Creek and Sleeping Child Creek, which are tributaries to the Bitterroot River. The Shade models of the tributaries were based on field data collected during a 2006 field study and the interpretation of these data (DEQ, 2007). The tributary shade data were collected as part of the same study as the Bitterroot River shade data. TTools was again used for the GIS pre-processing and in assisting with the development of the Shade models.

7.1 Riparian Input

The Shade model requires the description of riparian vegetation. The description includes: vegetation code, description, height, density, and overhang (OH). The results in the field study report, based on the aerial photograph interpretation, were used to develop the description table (**Table 7-1**). The existing vegetation composition was used to develop the codes for the model. The tree height, shade density, and overhang were averaged for each vegetation type.

7.2 Shade Input

The Shade model inputs include: (1) riparian zones, (2) reach length, (3) channel incision, and (4) elevation, aspect, wetted and near stream disturbance zone width, distance from the bank to the center of the stream, and topographic shade. (1) The left and right bank riparian codes for all zones were based on the existing vegetation composition as provided in the field study. (2) The reach length must be an equal interval. The reaches in the field study report were not at an equal interval and were subdivided while maintaining the same reach characteristics. A uniform reach length interval of 660-ft was used. (3) Channel incision was estimated based on the bank stability provided in the field study report. Where the bank was stable, incision was set at zero; otherwise the incision was estimated as 1.5-ft based on the database comment field of vertical or near-vertical stream banks. (4) The remaining parameters where computed using TTools and the process as described for the Bitterroot River under section 4.3 GIS Pre-processing.

Table 7-1. Riparian land cover types and associated attributes used in the tributary Shade models

Land Cover	Height (ft)	Density (%)	Overhang (ft)
Miller Creek			
Brush	21.3	10	2.3
Coniferous	57.4	73	12.8
Coniferous/brush	65.9	48	7.2
Coniferous/brush/herbaceous	74.1	60	16.1
Coniferous/deciduous	69.9	53	10.8
Coniferous/deciduous/herbaceous	57.1	10	2.3
Coniferous/herbaceous	38.1	0	1.6
Deciduous/brush	46.9	18	1.6
Deciduous/coniferous	67.6	25	2.3
Deciduous/coniferous/brush	45.9	90	20.7
Deciduous/coniferous/herbaceous	49.9	10	2.3
Sleeping Child Creek			
Brush	15.1	20	4.6
Coniferous	66.9	100	11.8
Coniferous/brush	45.9	86	4.9
Coniferous/deciduous/brush	53.1	100	23.0
Coniferous/snags	77.1	78	4.6
Coniferous/wet meadow	42.0	83	8.2
Deciduous	77.1	43	3.0
Deciduous/brush	69.9	70	16.1
Deciduous/coniferous	67.9	90	20.7
Deciduous/coniferous/brush	43.0	90	7.5
Snags	69.9	95	3.0

7.3 Model Evaluation

The Shade model results range from zero to ninety-eight percent effective shade along these two tributaries (**Figures 7-1** and **7-2**). The highest shade values are generally near the headwaters, where the stream width is small, the vegetation is tall and extensive, and the topography is steep. In general, the shade then decreases to its lowest value nearest the tributary confluence with the Bitterroot River.

Ground truth points (field measurements) were available for Miller Creek and Sleeping Child Creek. Willow Creek was does not have ground truth points because it did not meet the criteria of the ground truthing study. Both the Miller Creek and Sleeping Child Creek ground truth points plot within the model results and appear to confirm the model predictions. The results for Miller Creek appear to indicate some clustering with various areas of more or less shade. The field assessment has data coverage on the different vegetation type, height, and density for the length of the creek, but only one or two field measurements of the effective shade. The upper most reach has taller and high density vegetation and thus greater shade. The areas with less shade have shrubs and grasses and occasionally trees with a low density.

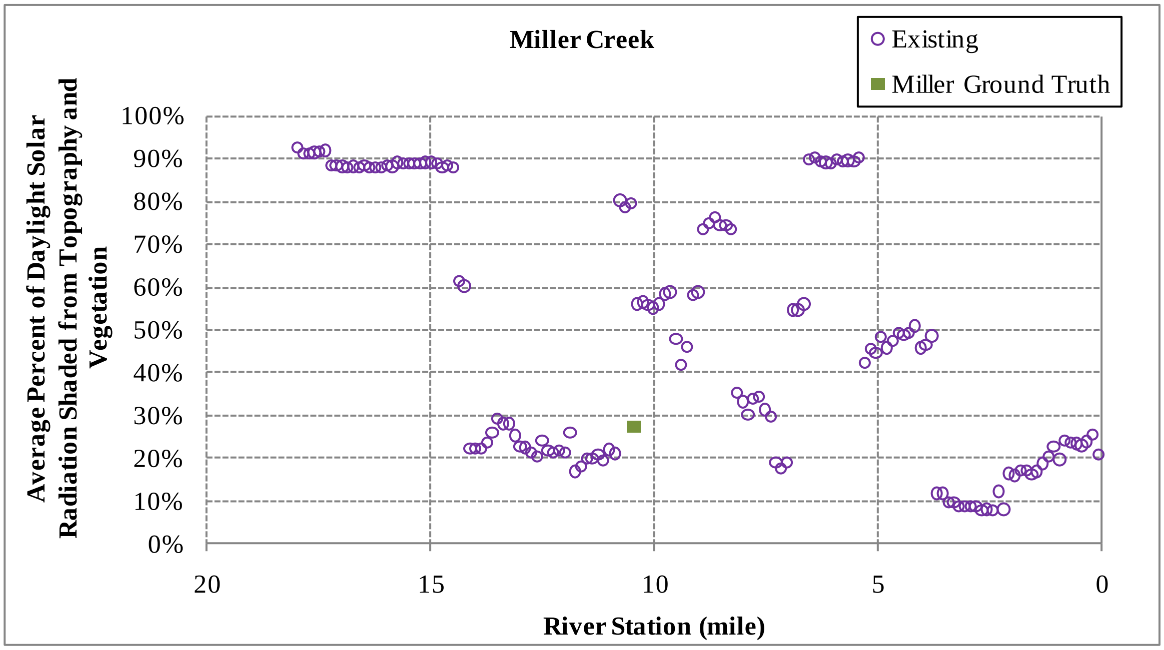

Figure 7-1. Shade model Miller Creek longitudinal effective shade profile

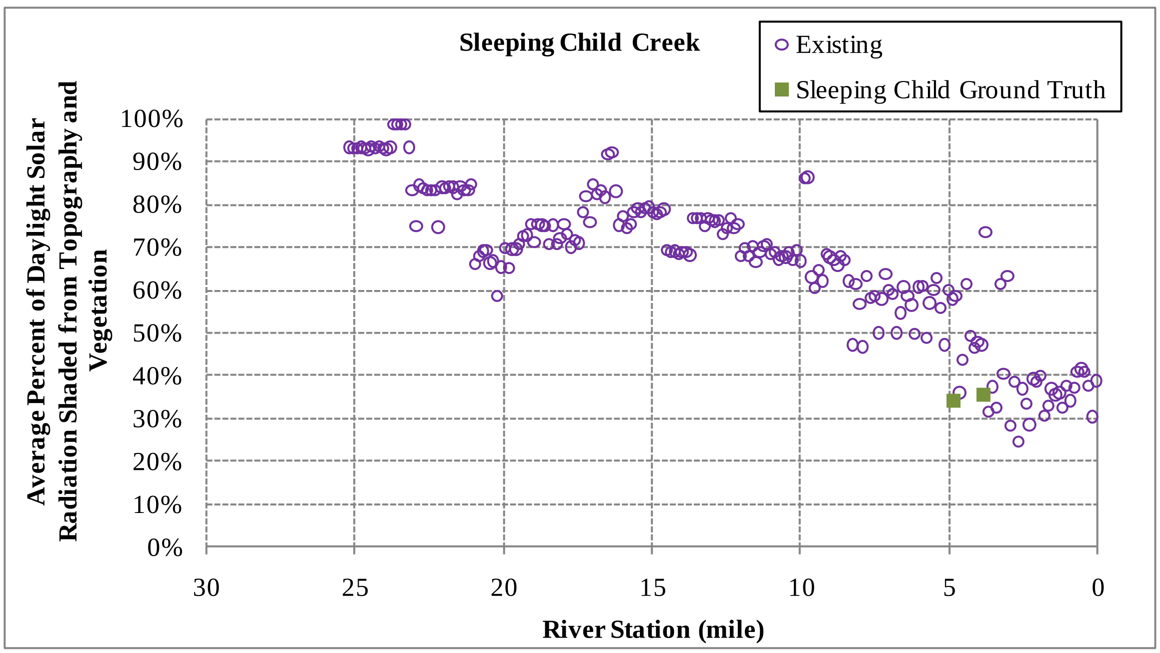

Figure 7-2. Shade model Sleeping Child Creek longitudinal effective shade profile

8.0 TRIBUTARY QUAL2K MODEL DEVELOPMENT

QUAL2K models were developed for Miller Creek, Sleeping Child Creek, and Willow Creek for August of 1992.

8.1 Available Data

The construction of the QUAL2K models for the tributaries relied heavily on existing data as documented and used in the Bitterroot River QUAL2E and QUAL2K models (HDR, 2005).

8.2 Simulation Period and Model Coefficients

Models were developed for one simulation period: August 15th for 1992. This is same date selected for the Bitterroot River water temperature simulations; the August 1992 date was considered as the period of critical low flows and high water temperatures. The water column rate coefficients (coefficients that relate physical, chemical, and biological parameters), as well as the light and heat values, were set at the same values as in the Bitterroot River model (Chapra, Pelletier, and Tao, 2007). No point sources are included.

8.3 Flow and Water Temperature Inputs

DEQ conducted a field study in the summer of 2007. Flow and water temperature data were collected by DEQ using a flow meter and an onset stowaway data logger at selected sites along the three tributaries. Flows were measured at the start and end of the study. The temperature loggers were installed at the start of the study, July 12, 2007, and retrieved at the end of the study, October 10, 2007. The headwater and diffuse flows were set similar to these flows. There are three points along Willow Creek that intermix with the Oilwell, Republic, and Corvallis canals. Field observations indicate that the water temperatures immediately upstream and downstream of these locations are different. QUAL2K is unable to add and remove diffuse flow in the same segment. In order to mimic this intermixing of flows, the two segments, upstream and downstream of the canal location, were used with equal addition and subtraction of flows and water temperatures from the monitoring dataset.

The headwater elevation was based on the TTools results. No hydraulic rating curves for flow relationships or other data to develop flow relationships were readily available. Instead of using hydraulic rating curves as used in the Bitterroot River model, the Manning Formula was used. The channel slope was calculated based on the reach length and elevations from TTools. The width was based on the Shade Study data, and Manning's n (0.040) and side slopes were based on the channel characteristics. The headwater water temperatures were set based on the field monitoring data.

The reaches used in the QUAL2K model are the same as the reaches developed from TTools, which were used in the Shade models. The reach length used was 660-ft, which subdivided the creeks into between 139 and 203 reaches depending upon the stream. The air temperature, dew point temperature, wind speed, and cloud cover data are the same as in the Bitterroot River model because data from the Missoula International Airport were used to represent the entire valley.

8.4 Shade Input

The shade inputs for Miller Creek and Sleeping Child Creek used the results of their respective Shade models. Willow Creek was not included in 2006 field study so there was insufficient information to use TTools and develop a Shade model for this creek. Averages of the shade values for Miller Creek and Sleeping Child Creek, mountain and valley reaches, were used for Willow Creek, mountain and valley reaches.

8.5 Model Evaluation and Calibration

Water temperatures for the three tributaries warm from the headwaters to the confluence with the Bitterroot River. The flows matched those from the 2007 field study. These flows and the model input values selected resulted in water temperatures being well represented when comparing to monitoring results.

9.0 TRIBUTARY RESULTS AND DISCUSSION

9.1 Flow

The July 2007 field data flows were used to develop the QUAL2K models. Simulated stream flows in the Miller Creek generally increase downstream with some loss near the confluence with the Bitterroot River (**Figure 9-1**). For Sleeping Child Creek, simulated stream flows also generally increase downstream (**Figure 9-2**). Simulated stream flows in Willow Creek vary along the creek, a result of the interaction with the crossing canals (**Figure 9-3**). The October 2007 field data flows are much lower than the July flows but were used as a reference point for the general magnitude of flows in the creek.

9.2 Water Temperature

The model results of water temperature for the tributaries were similar to the August 2007 field data (used for comparison, not calibration since the modeled date is August 15, 1992). The field data included: hourly minimum, average, and maximum values. The model averages are similar to the field data. The model range for minimum and maximum temperatures for Miller Creek is within a few degrees of the field data (**Figure 9-4**). The model range for minimum and maximum temperatures for Sleeping Child Creek is greater than the field data by a few degrees (**Figure 9-5**). The model range for minimum and maximum temperatures for Willow Creek is similar to the field data (**Figure 9-6**). The minimum, average, and maximum values from the hourly data for the monitoring season, (July through November) are shown for reference.

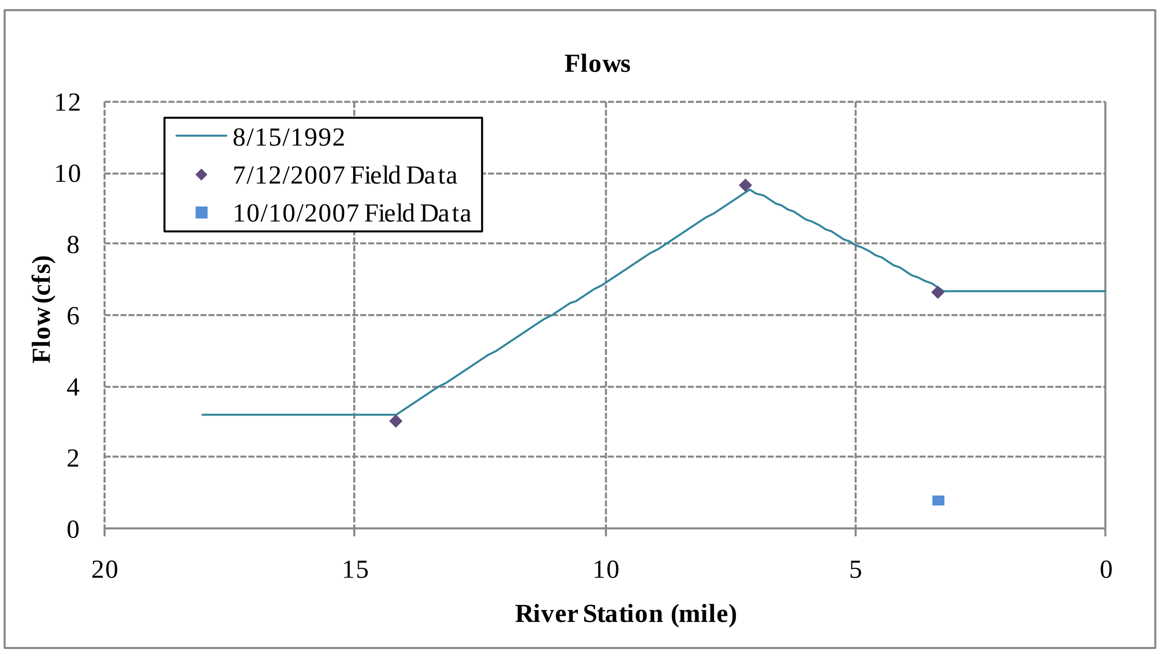

Figure 9-1. Miller Creek simulated flow (lines) and data (diamonds and squares)

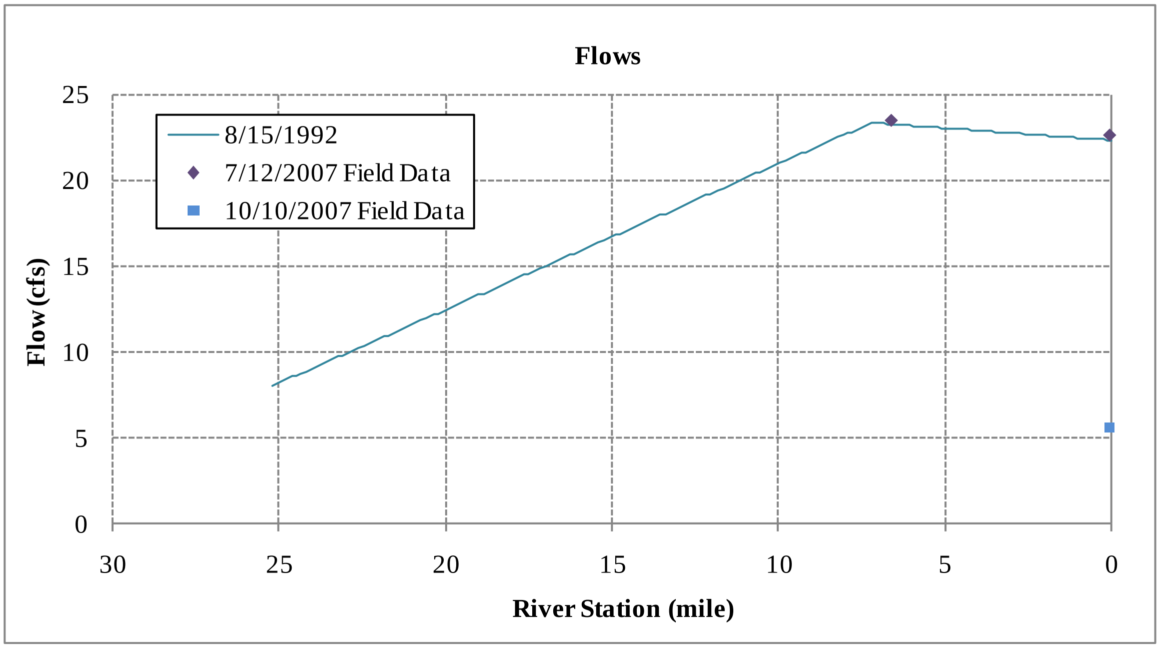

Figure 9-2. Sleeping Child Creek simulated flow (lines) and data (diamonds and squares)

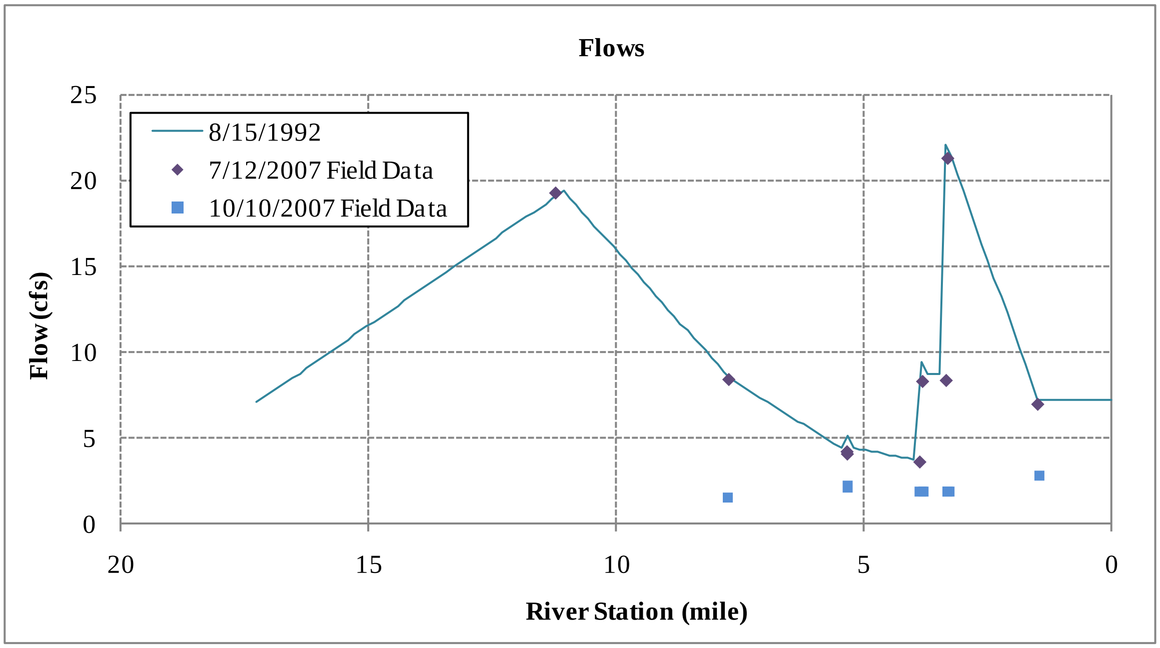

Figure 9-3. Willow Creek simulated flow (lines) and data (diamonds and squares)

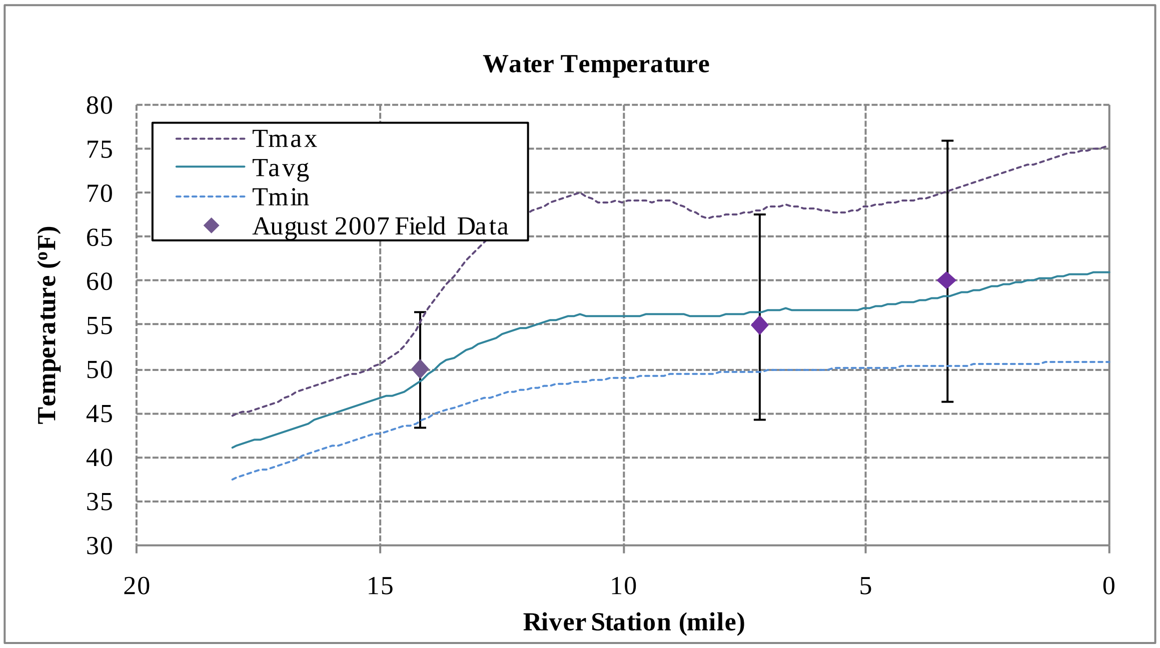

Figure 9-4. Miller Creek simulated water temperatures (lines) and data (diamonds and squares)

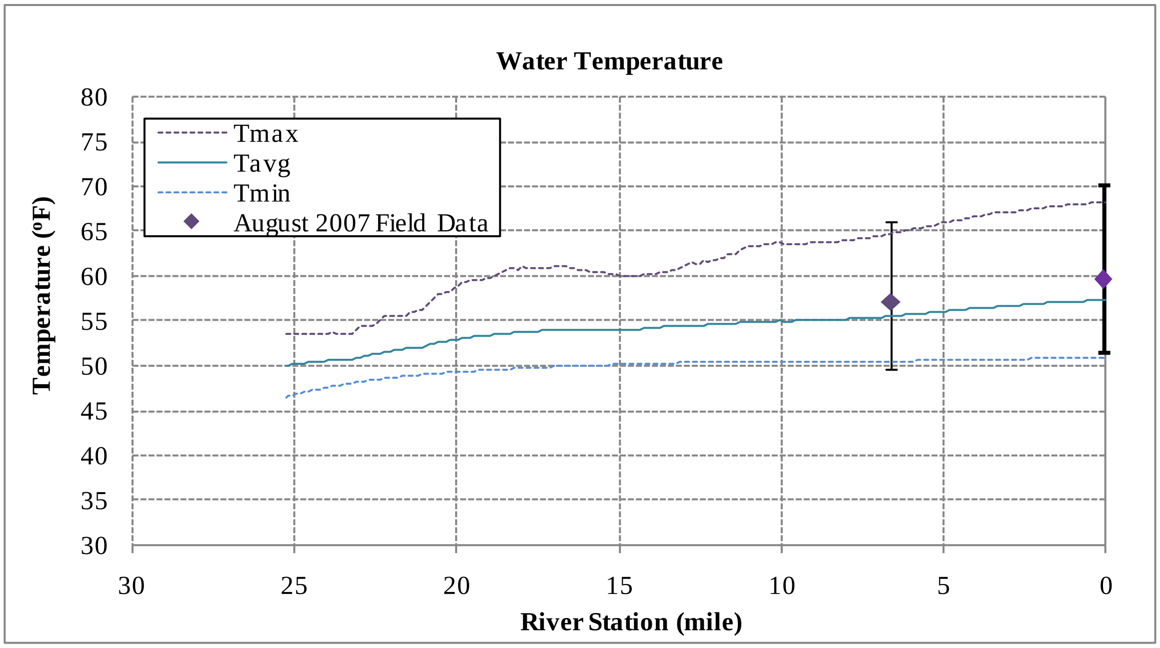

Figure 9-5. Sleeping Child Creek simulated water temperatures (lines) and data (diamonds and squares)

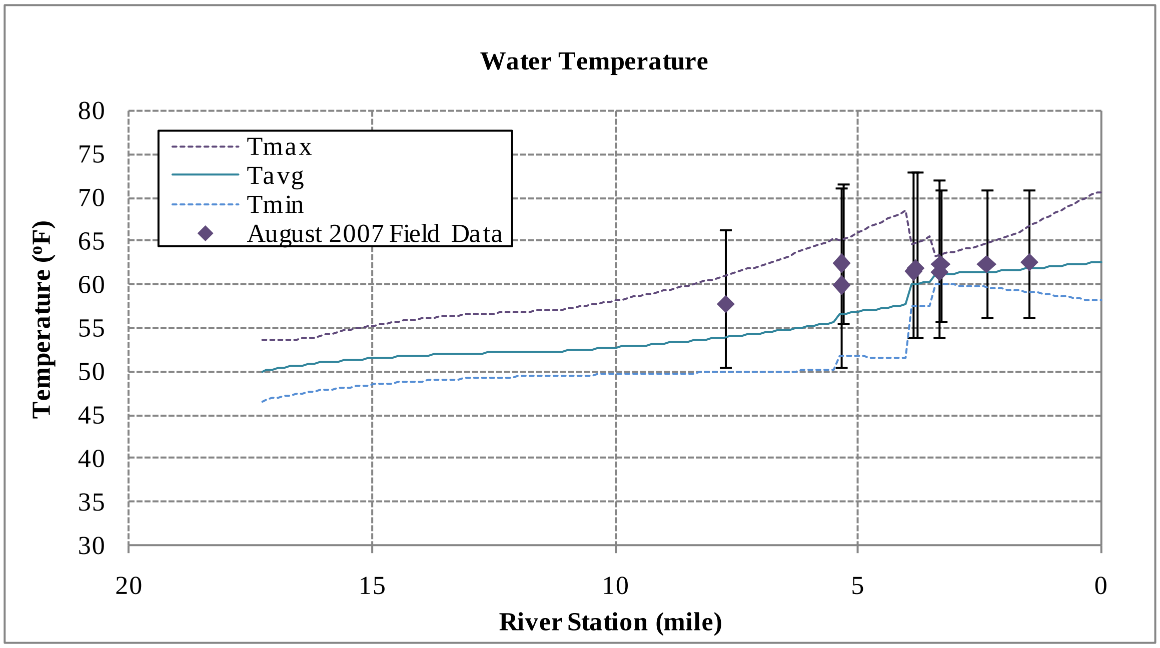

Figure 9-6. Willow Creek simulated water temperatures (lines) and data (diamonds and squares)

In **Figures 9-4** through **9-6**, DEQ's 2007 field monitoring data are shown for reference. The markers are the average of the hourly August 2007 data, with the minimum and maximum values for August 2007 shown as error bars. The expected water temperature should be similar since flows were low in August for both 1992 and 2007. (For comparison, the Bitterroot River at Missoula gage mean monthly flow for August 1992 was 623 cfs and for August 2007 was 498cfs. The mean annual flow for 1992 was 1,366 cfs and for 2007 was 1,934 cfs.)

10.0 SCENARIO ANALYSIS

Various scenarios were developed to evaluate the water temperature response of the Bitterroot River and three tributaries. These scenarios provide watershed managers information for recommendations for meeting water quality criteria in the river. The different scenarios were simulated to represent a range of potential watershed management activities. Various human influenced factors that can affect the water temperature include vegetation loss from the riparian corridor, alteration of channel morphometry, and irrigation withdrawals.

Scenarios may be simulated to assess the potential for improving water temperature conditions in the study area. Increased shading from vegetation could be accomplished with projects that improve the riparian vegetation in reaches currently with little or sparse vegetation. Changes in consumptive water use could include both increases and decreases in water demands. Increases in water demands could occur with continued development in the valley. Decreases in water demand could be accomplished through increased water use efficiency or the purchase or leasing of water rights.

Changes in channel geomorphology have the potential to influence water temperatures, but were not considered. Bitterroot River width to depth ratios are likely near their potential for such a braided river channel. The risk and cost of trying to reduce width to depth ratios for the Bitterroot River outweighs the potential for reducing temperatures. Based on the findings in Headwater Bitterroot TMDL that localized site specific streambank instability due to alterations is the main impact, channel geomorphology was not explicitly modeled for the tributaries (DEQ, 2005b and USFS, 2009).

Seven scenarios are considered to evaluate potential water temperature changes in the Bitterroot River (**Table 10-1**). Similar scenarios were developed for evaluating potential water temperatures in Miller Creek, Sleeping Child Creek, and Willow Creek.

1. The shade scenario uses reference conditions for all reaches where the existing vegetation density, unless impacted by fire, is less than in the existing conditions model. The reference condition is based on existing reaches with high quality riparian vegetation where reasonable land, soil and water conservation practices are in place.
2. The headwater and tributary influence scenario uses the existing conditions model with the headwater and all the tributary mean water temperature values reduced by 1^{o}F for the Bitterroot River. (The temperature range was unchanged. The headwater was not changed for the tributary models.) A reduction of 1^{o}F is based on expected feasible reductions and modeling results in the Headwater Bitterroot TMDL (DEQ, 2005b).
3. The flow scenarios vary the water use diversion flows by decreasing diverted flows by 15, 20, 25, and 100-percent over existing conditions. (The 100-percent decrease scenario sets all diversions to zero.) Decreased water use is based on the premise that reasonable irrigation water savings practices can achieve a certain reduction in water use. This results in four sub-scenarios for flow.
4. The wastewater treatment plant/facility (WWTP) scenarios vary the amount of flow discharged. The flow from each of the four individual dischargers (Darby, Hamilton,

Stevensville, and Lolo) is set to zero. Additionally the flow from all the dischargers is set to zero and doubled. This results in six sub-scenarios for WWTPs.

5. The stream channel dimensions scenario was not simulated given the challenges in trying to change river channel morphology, as well as the appropriateness of an overall restoration approach, as previously discussed.
6. The natural condition scenario combines the changes included in the shade, headwater and tributary, flow, and WWTP scenarios. Water use and WWTP flows were set to zero. Although this scenario is not economically viable, the natural condition scenario provides an indication of current departure from pristine conditions.
7. The naturally occurring scenario combines the changes included in the, shade, headwater and tributary, and flow 20 percent decrease scenarios. A flow decrease of 20-percent was deemed reasonable and achievable and as wells as protective of water temperatures based on the flow scenarios. The existing WWTP flows were used due to the low flow rates and localized influences based on the WWTP scenarios. DEQ's interpretation of all reasonable land, soil, and water conservation measures resulted in this selection of inputs for the naturally occurring scenario.

Since the upstream watershed conditions are relatively undisturbed and the reservoir operations are accepted by DEQ (thus DEQ has categorized the reservoirs as part of the natural condition), the upstream boundary conditions were not modified except for the water temperature in the headwater and tributary, natural condition, and naturally occurring scenarios based on the material presented in the Headwater Bitterroot TMDL (DEQ, 2005b).

The Shade and Qual2K models were modified to represent scenarios for comparison to the existing conditions. While the model provides the ability to report temperatures to the hundredth decimal, there is inherent uncertainty in the data used to construct the model, the model itself, and the ability to measure temperatures in the field to such accuracy. The model results provide the relative magnitude of potential management options.

For the Bitterroot River, the results were segmented into the three TMDL reaches. These three reaches include:

- Upper Reach - From confluence of East and West Forks near Conner, MT to Skalkaho Creek near Grantsdale, MT
- Middle Reach - From Skalkaho Creek near Grantsdale, MT to Eightmile Creek near Florence, MT
- Lower Reach - From Eightmile Creek near Florence, MT to the mouth with the Clark Fork River near Missoula, MT

For the tributaries, Miller Creek, Sleeping Child Creek, and Willow Creek, the results were not segmented and were examined for the entire reach modeled.

Table 10-1. Model scenarios and summary of inputs	
Location/Scenario	**Inputs**
Bitterroot River	
Calibration/Existing Conditions	Field data, as previously discussed
Shade	Change riparian values to reference values unless existing conditions value is greater
Headwater and Tributary (1°F reduction)	Reduce the water temperature of the headwater and all tributaries by 1°F
Flow (four sub-scenarios)	Decrease water use withdrawals by 15, 20, 25, and 100 percent (i.e., set all use to zero)
WWTP (six sub-scenarios)	Set the four individual dischargers to zero, set all dischargers to zero, double the flow from all dischargers
Stream Channel Dimensions	Not simulated.
Natural Condition	Combine Shade, Headwater and Tributary, Flow (zero use), and WWTP (zero discharge)
Naturally Occurring	Combine Shade, Headwater and Tributary, and Flow (20 percent)
Miller Creek	
Existing Conditions	Field data, as previously discussed
Shade	Change riparian values to reference values unless existing conditions value is greater
Sleeping Child Creek	
Existing Conditions	Field data, as previously discussed
Shade	Change riparian values to reference values unless existing conditions value is greater or fire conditions exist
Willow Creek	
Existing Conditions	Use non-reference conditions
Shade	Change riparian values to reference values unless existing conditions value is greater
Natural Condition	Combine Shade, Headwater and Tributary and Flow

10.1 Existing Conditions

The calibration/existing conditions models serve as the baseline model simulation for which to construct the other scenarios and compare the results against (**Table 10-1**). This model represents low flow conditions with average August cloud cover and is based on available data (**Figure 5-2**). The construction and inputs to the model have been discussed previously.

The changes to the calibration/existing conditions model for each of the scenarios is summarized in **Table 10-1** and discussed for each of the scenarios. This process isolates individual factors for evaluation of its relative impact on water temperatures.

10.2 Shade Scenario

The shade scenario uses the existing conditions models of the Bitterroot River, Miller Creek, Sleeping Child Creek, and Willow Creek with increase shading. For the shade scenario, the riparian shade parameters, (e.g. vegetation height, density, and overhang), were changed to reference values. In other words, for existing conditions parameters less than the reference condition, the parameters were changed to the reference condition. The reference parameters (vegetation height, density, and overhang) were developed for mountain and valley reaches. The 2006 field data were summarized by reference and non-reference reaches (**Table 10-2**). The classification was based on a visual assessment of the aerial photos including an examination of the riparian area, land use impacts, and stream meanders, along with the 2006 field data. Additionally, on-the-ground knowledge about the study streams along with best professional judgment was used for the final reference or non-reference categorization.

Table 10-2. Riparian land cover types and associated attributes for reference and non-reference conditions

Location	Height (m)	Density (%)	Overhang (m)
Bitterroot River Valley Non-Reference Shade	21.1	0.3	0.0
Bitterroot River Valley Reference Shade	22.6	0.4	0.0
Miller Creek Valley Non-Reference Shade	13.6	0.0	0.1
Miller Creek Valley Reference Shade	13.7	0.5	0.1
Miller Creek Mountain Non-Reference Shade	14.1	0.2	0.2
Miller Creek Mountain Reference Shade	20.4	0.6	0.5
Sleeping Child Creek Valley Non-Reference Shade	23.5	0.3	0.0
Sleeping Child Creek Valley Reference Shade	23.8	0.5	0.1
Sleeping Child Creek Mountain Non-Reference Shade	Insufficient data, 1 non-reference reach		
Sleeping Child Creek Mountain Reference Shade	15.0	0.4	0.2
Sleeping Child Creek Mountain Fire Reference Shade	22.5	0.2	0.1
Willow Creek Valley Non-Reference Shade	13.4	0.0	0.1
Willow Creek Valley Reference Shade	23.8	0.5	0.1
Willow Creek Mountain Non-Reference Shade	15.0	0.4	0.2
Willow Creek Mountain Reference Shade	15.0	0.4	0.2

For the Bitterroot River, there are only valley reaches. Approximately 70 percent of the reach is at or above the reference condition. The reference shade results in an increase of about 1.5 percent to the average percent of daylight solar radiation shaded from topography and vegetation (**Figure 10-1**). For the Bitterroot River, water temperatures for the shade scenario are essentially the same as the existing conditions due to combination of the size of the river and the relatively intact shade producing vegetation (**Figure 10-2**).

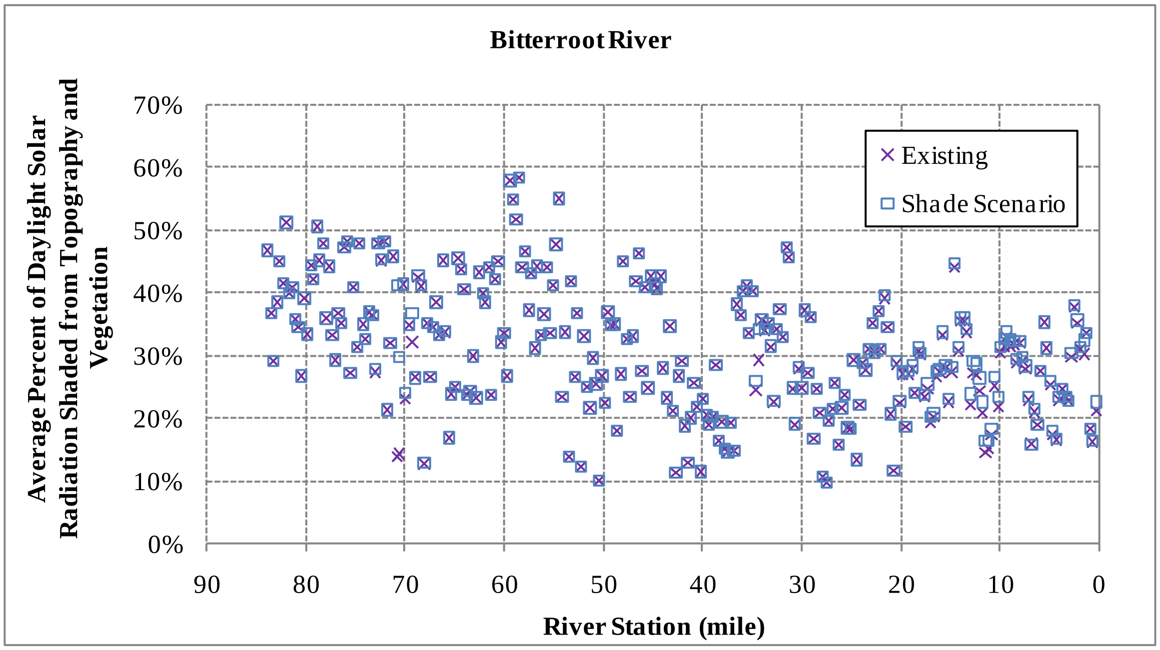

Figure 10-1. Bitterroot River existing conditions and shade scenario effective shade

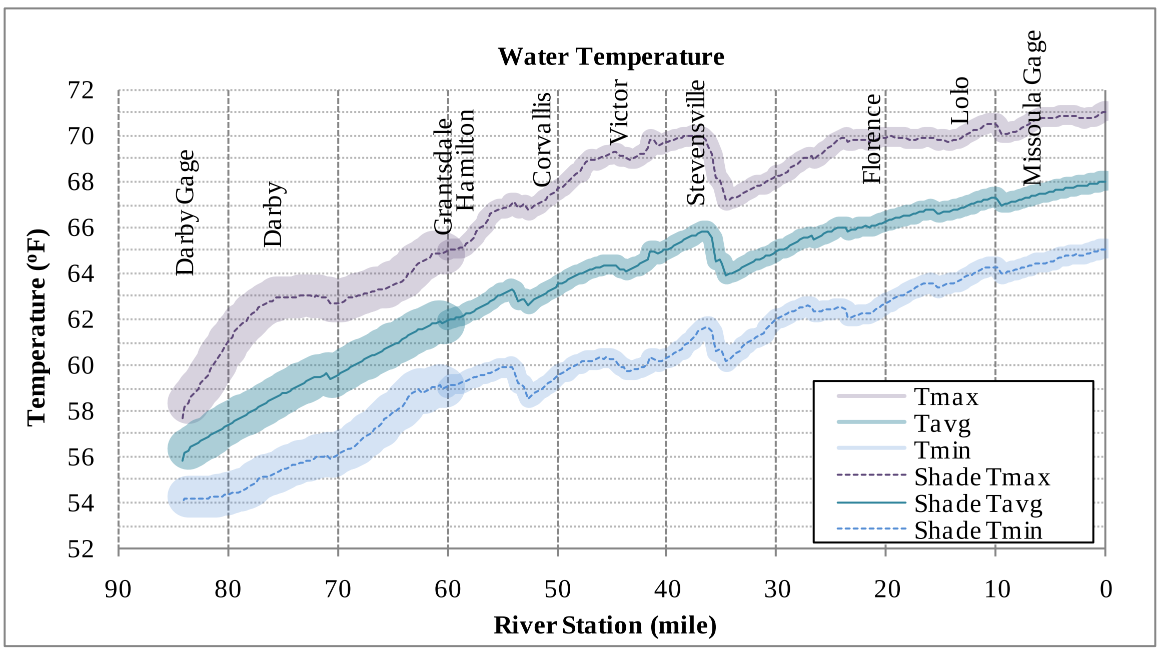

Figure 10-2. Bitterroot River simulated water temperatures for existing conditions and shade scenario

For Miller Creek, there are mountain and valley reaches. The valley portion of this stream runs from the confluence with the Bitterroot River to river mile 6.5 and mountain conditions are to the headwaters. There was insufficient data to develop a reference valley reach for Miller Creek, so the reference valley data from Sleeping Child Creek are used. Approximately 72 percent of the reach is below the reference conditions. The reference shade results in an increase of about 22.5 percent to the average percent of daylight solar radiation shaded from topography and vegetation

(**Figure 10-3**). For the Miller Creek, water temperatures for the shade scenario are 2°F to 6°F cooler than the existing conditions (**Figure 10-4**).

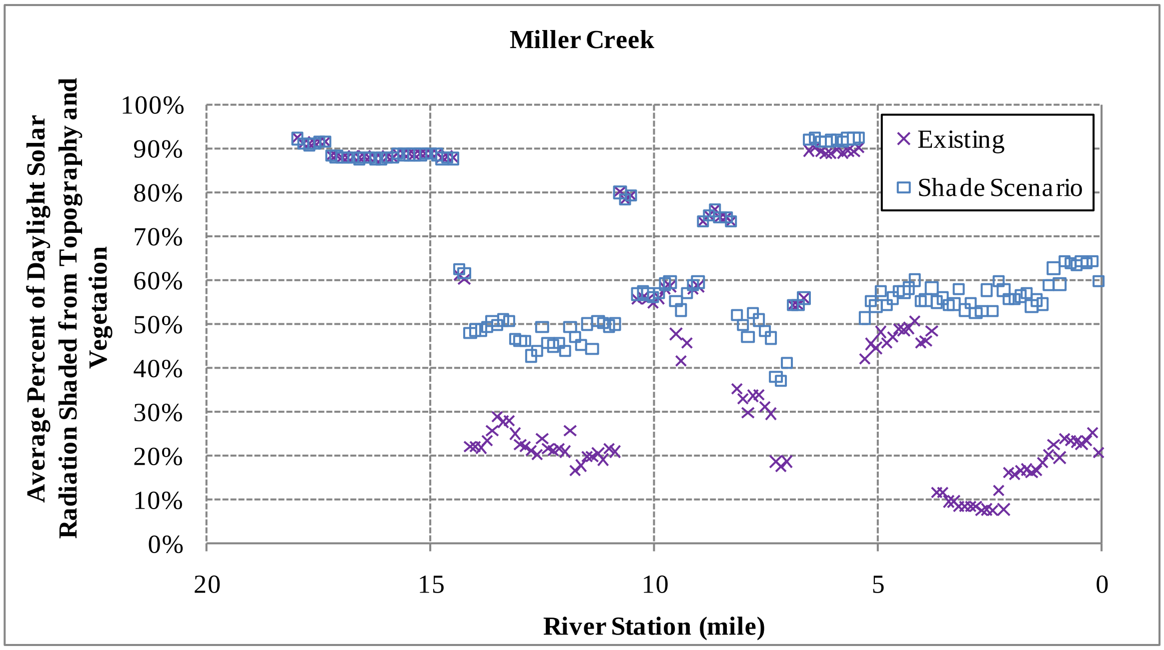

Figure 10-3. Miller Creek existing conditions and shade scenario effective shade

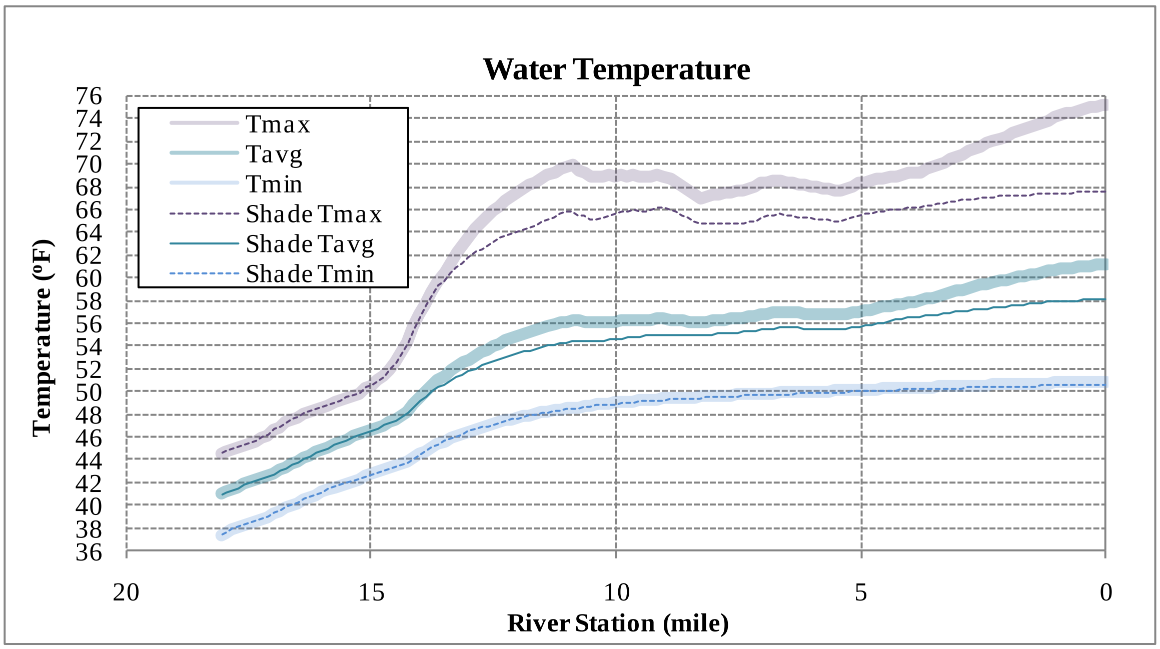

Figure 10-4. Miller Creek simulated water temperatures for existing conditions and shade scenario

For Sleeping Child Creek, there are mountain and valley reaches. Additionally, there is a mountain fire disturbed reach. The valley is from the confluence with the Bitterroot River to river mile 3.2, the mountain conditions extend to river mile 9.6, the fire conditions extend to river mile 19.4, and mountain conditions extend to the headwaters. Approximately 73 percent of the reach is below the reference conditions. Approximately 54 percent of the reach is below the reference condition when excluding the area with fire conditions. The fire conditions were treated as a natural occurrence and the vegetation was not changed to reference shade conditions. The reference shade results in an increase of about 2.6 percent to the average percent of daylight solar radiation shaded from topography and vegetation (**Figure 10-5**). For the Sleeping Child Creek, water temperatures for the shade scenario are about 0.5°F cooler than the existing conditions (**Figure 10-6**).

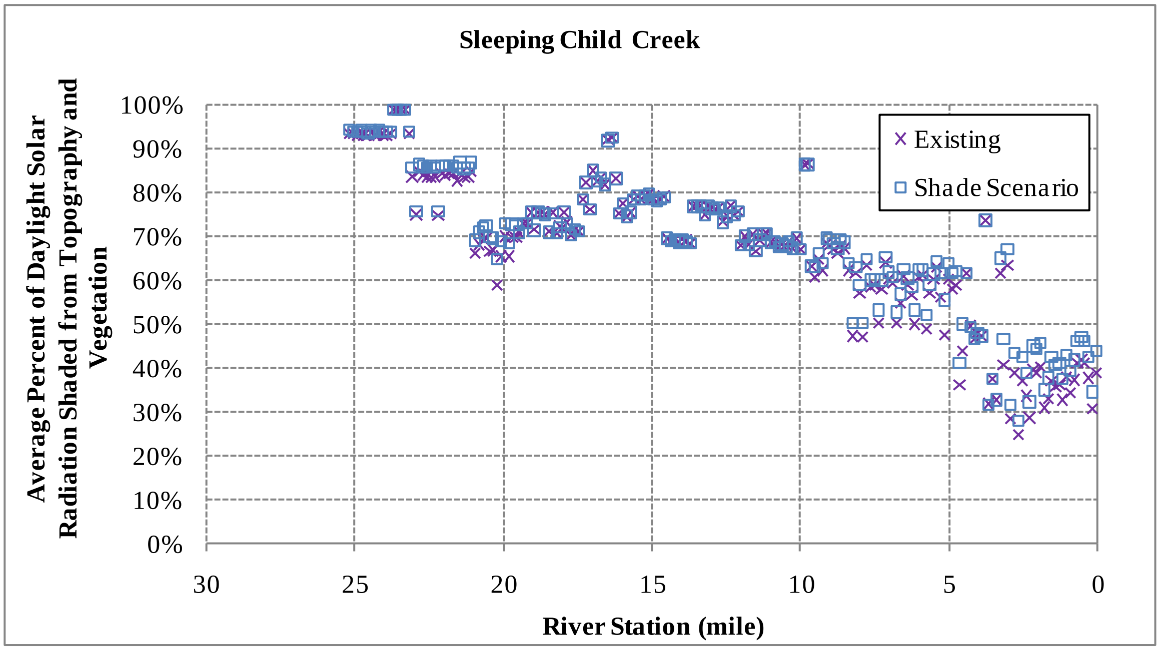

Figure 10-5. Sleeping Child Creek existing conditions and shade scenario effective shade

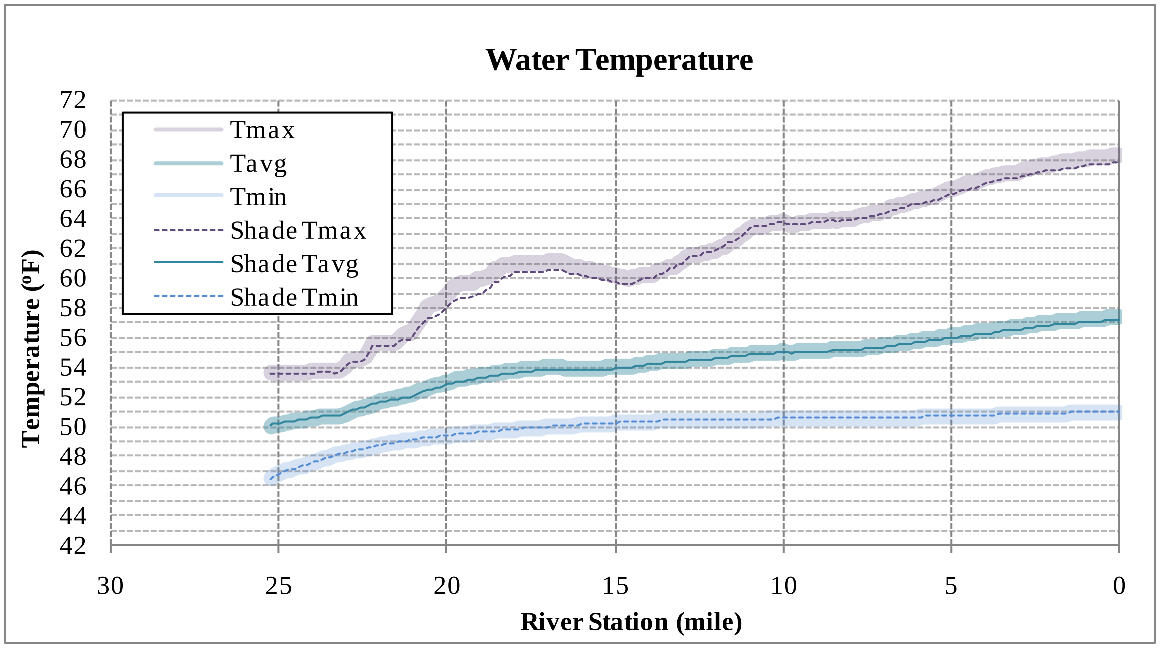

Figure 10-6. Sleeping Child Creek simulated water temperatures for existing conditions and shade scenario

For Willow Creek, there are mountain and valley reaches. The valley is from the confluence with the Bitterroot River to river mile 4.0 and mountain conditions extend to the headwaters. However, no field data were collected for this tributary. Without data, the average reference shade for the mountain and valley reaches from Miller Creek and Sleeping Child Creek were used for Willow Creek, mountain and valley reaches. The reference shade results in an increase of about 8.9 percent to the average percent of daylight solar radiation shaded from topography and vegetation (**Figure 10-7**). For the Willow Creek, water temperatures for the shade scenario are about 1^{o}F cooler than the existing conditions (**Figure 10-8**).

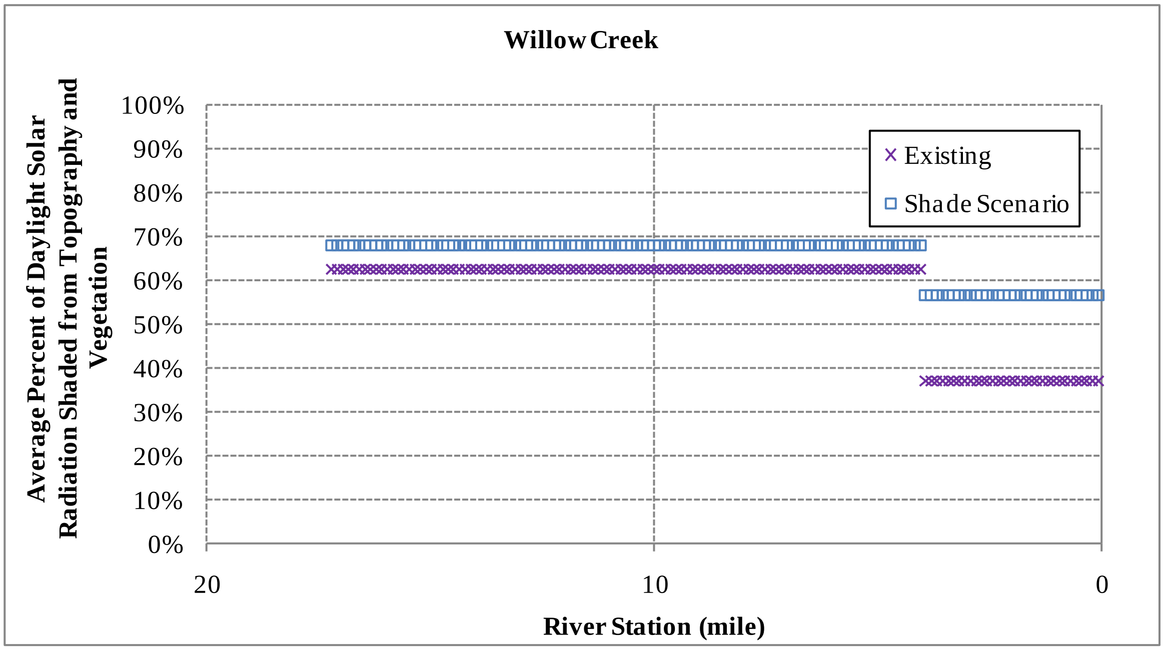

Figure 10-7. Willow Creek existing conditions and shade scenario effective shade

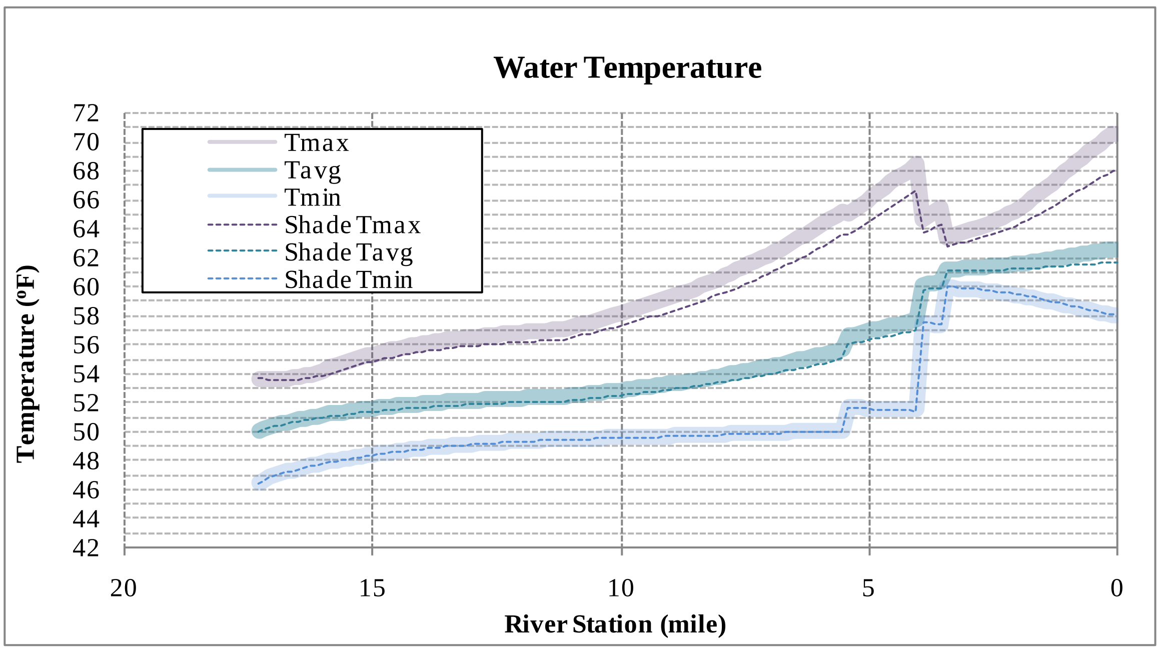

Figure 10-8. Willow Creek simulated water temperatures for existing conditions and shade scenario

The maximum change in the maximum daily water temperature is representative of the worst case conditions (**Table 10-3**). The locations where the difference in water temperature is greater than 0.5°F between the existing conditions and shade scenario are summarized (**Table 10-4**). The results are also shown by reach on the map of the streams (**Figure 10-9**).

Table 10-3. Tabular results of differences in water temperatures for existing conditions and shade scenario

River/Creek	Maximum Change in Maximum Daily Water Temperature (^oF)	Location River Station (mile)
Bitterroot River Upper Reach	-0.11	63 to 67
Bitterroot River Middle Reach	-0.03	28 to 33
Bitterroot River Lower Reach	-0.07	7 to 12
Miller Creek	-7.58	0 to 0.5
Sleeping Child Creek	-1.03	18.5 to 20
Willow Creek	-2.45	0 to 1

Table 10-4. Water temperature (daily maximum and mean) comparison, existing conditions and shade scenario

Maximum Daily Water Temperature		
River/Creek	**Difference > 0.5^oF**	**Location River Station (mile)**
Bitterroot River Upper Reach	No	n/a
Bitterroot River Middle Reach	No	n/a
Bitterroot River Lower Reach	No	n/a
Miller Creek	Yes	0 to 13.5
Sleeping Child Creek	Yes	0 to 3 and 15.5 to 21
Willow Creek	Yes	0 to 15
Mean Daily Water Temperature		
River/Creek	**Difference > 0.5^oF**	**Location River Station (mile)**
Bitterroot River Upper Reach	No	n/a
Bitterroot River Middle Reach	No	n/a
Bitterroot River Lower Reach	No	n/a
Miller Creek	Yes	0 to 13.5
Sleeping Child Creek	No	n/a
Willow Creek	Yes	0 to 1.5 and 4 to 7

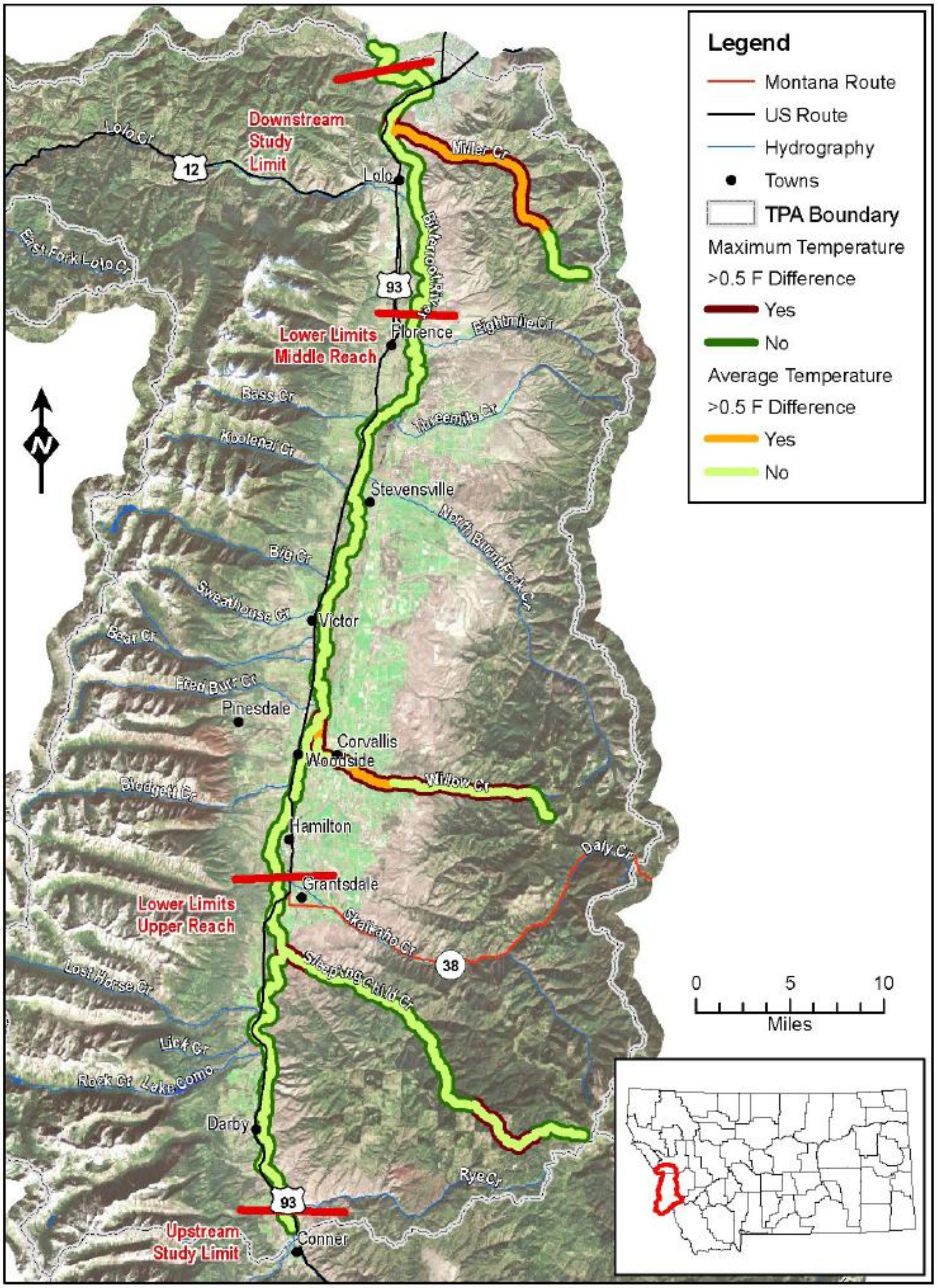

Figure 10-9. Water temperature (maximum and mean) comparison, existing conditions and shade scenario

10.3 Headwater and Tributary Water Temperature Reduction Scenario

The headwater and tributary water temperatures were reduced by 1°F in the existing conditions model of the Bitterroot River. The water temperature range was unchanged. A reduction of 1°F is based on expected feasible reductions and modeling results in the Headwater Bitterroot TMDL (DEQ, 2005b). This scenario was not performed for Miller Creek, Sleeping Child Creek, and Willow Creek since there is no basis for reducing the headwater and there are no tributaries in these models.

For the Bitterroot River, water temperatures for the headwater and tributary water temperature reduction scenario are about 0.5°F lower than the existing conditions (**Figure 10-10**). The maximum change in the maximum daily water temperature is representative of the worst case conditions (**Table 10-5**). The locations where the difference in water temperature is greater than 0.5°F between the existing conditions and headwater and tributary water temperature reduction scenario are summarized (**Table 10-6**). The results of the comparison are also shown by reach on the map of the streams (**Figure 10-14**).

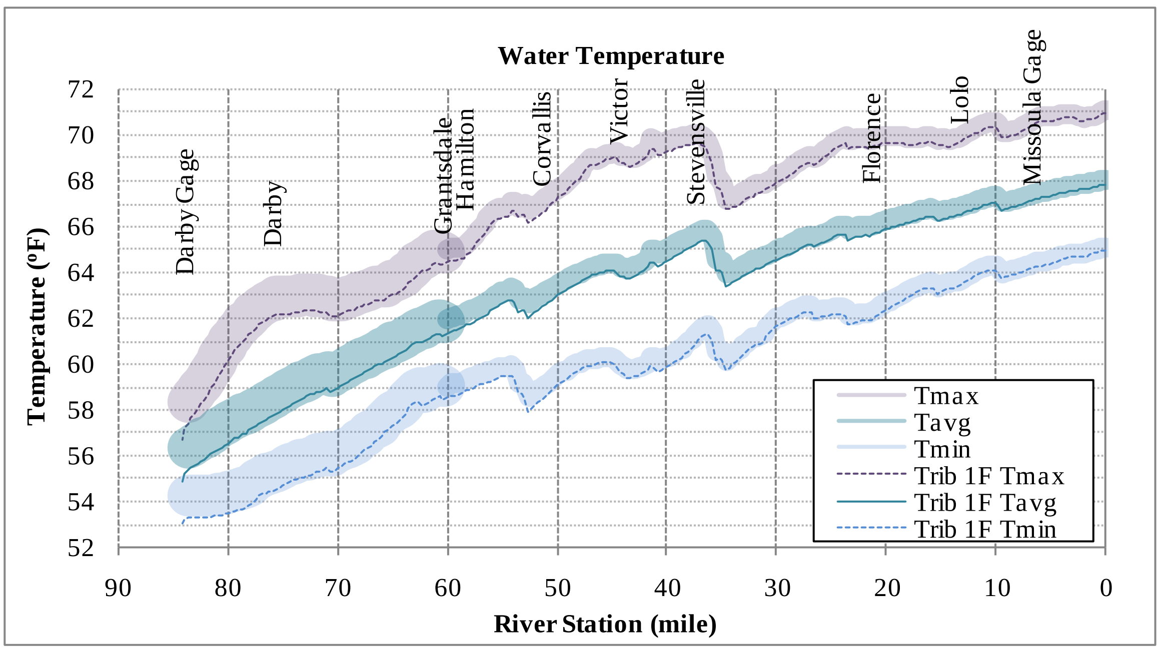

Figure 10-10. Bitterroot River simulated water temperatures for existing conditions and headwater and tributary water temperature reduction scenario

Table 10-5. Tabular results of differences in water temperatures for existing conditions and headwater and tributary water temperature reduction scenario

River/Creek	Maximum Change in Maximum Daily Water Temperature (°F)	Location River Station (mile)
Bitterroot River Upper Reach	-1.00	82 to 84
Bitterroot River Middle Reach	-0.67	51.5 to 53
Bitterroot River Lower Reach	-0.39	18 to 21.5

Table 10-6. Water temperature (daily maximum and mean) comparison, existing conditions and headwater and tributary water temperature reduction scenario

Maximum Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	Yes	60.5 to 84
Bitterroot River Middle Reach	Yes	39.5 to 41 and 50 to 60.5
Bitterroot River Lower Reach	No	n/a
Mean Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	Yes	60.5 to 84
Bitterroot River Middle Reach	Yes	39.5 to 41 and 50 to 60.5
Bitterroot River Lower Reach	No	n/a

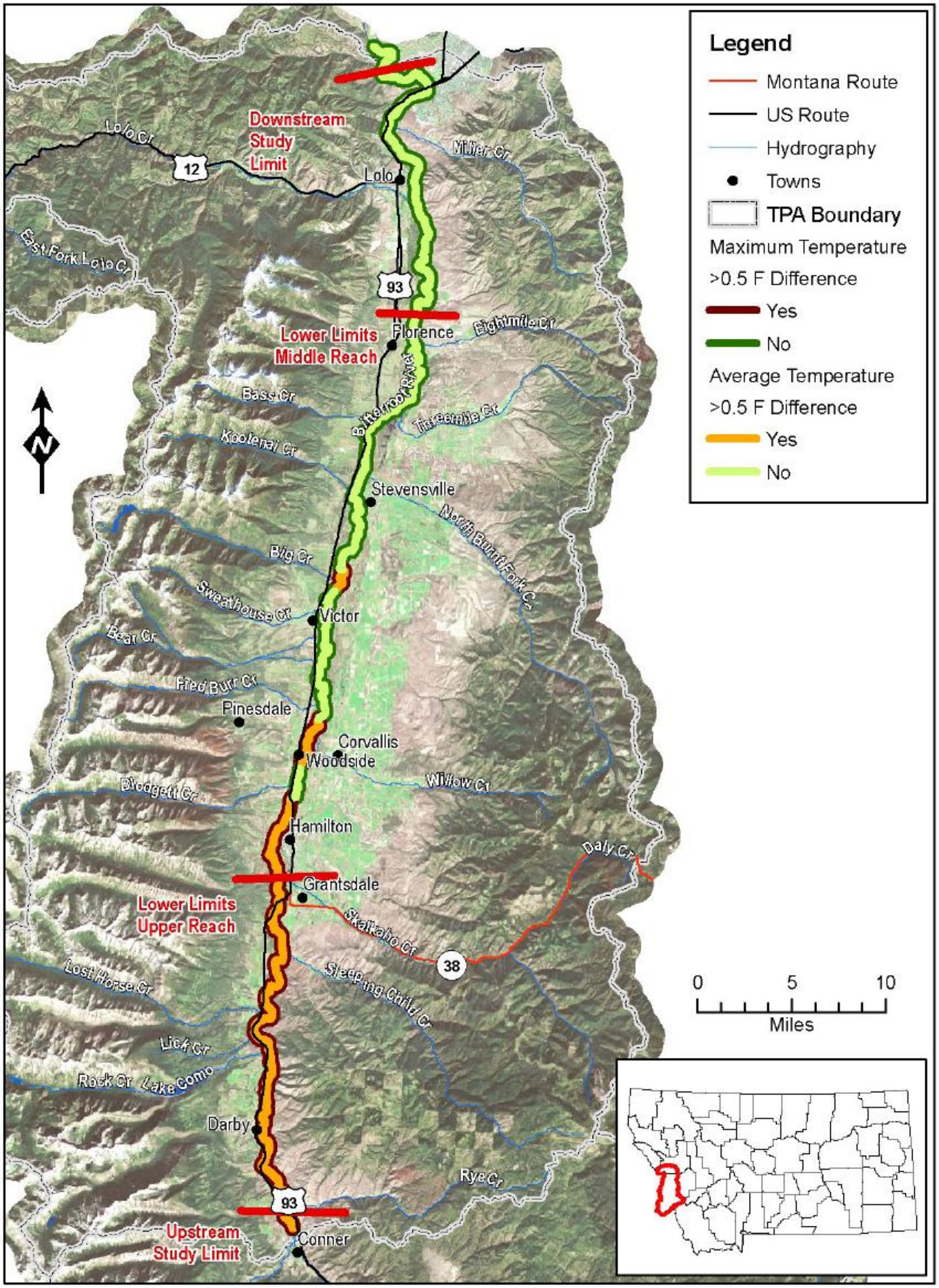

Figure 10-11. Water temperature (maximum and mean) comparison, existing conditions and headwater and tributary water temperature reduction scenario

10.4 Flow Scenarios

The flow scenarios consist of multiple simulations with decreases in water use in the existing conditions model of the Bitterroot River. The Miller Creek, Sleeping Child Creek, and Willow Creek existing conditions models do not have any water use included that reduces the streamflow and do not have separate scenario simulations. The simulations consist of decreasing water use by 15, 20, 25, and 100 percent from the Bitterroot River (**Figure 10-12**). While not feasible due to water rights and other issues, the 100 percent decrease scenario indicates the maximum possible achievable change in water temperatures from changes in water use. Decreases in water use of 15 to 25 percent may be feasible with changes in irrigation practices.

For the Bitterroot River, water temperatures for the flow scenarios result in incremental decreases in water temperature, especially in the middle reach (**Figure 10-13**, **Figure 10-14**, **Figure 10-15**, and **Figure 10-16**). The maximum change in the maximum daily water temperature is representative of the worst case conditions (**Table 10-7**). The locations where the difference in water temperature is greater than 0.5^{o}F between the existing conditions and flow scenarios are summarized for each of the four scenarios (**Table 10-8**, **Table 10-9**, **Table 10-10**, and **Table 10-11**). The results of the comparison are also shown by reach on the map of the streams (**Figure 10-17** and **Figure 10-18**).

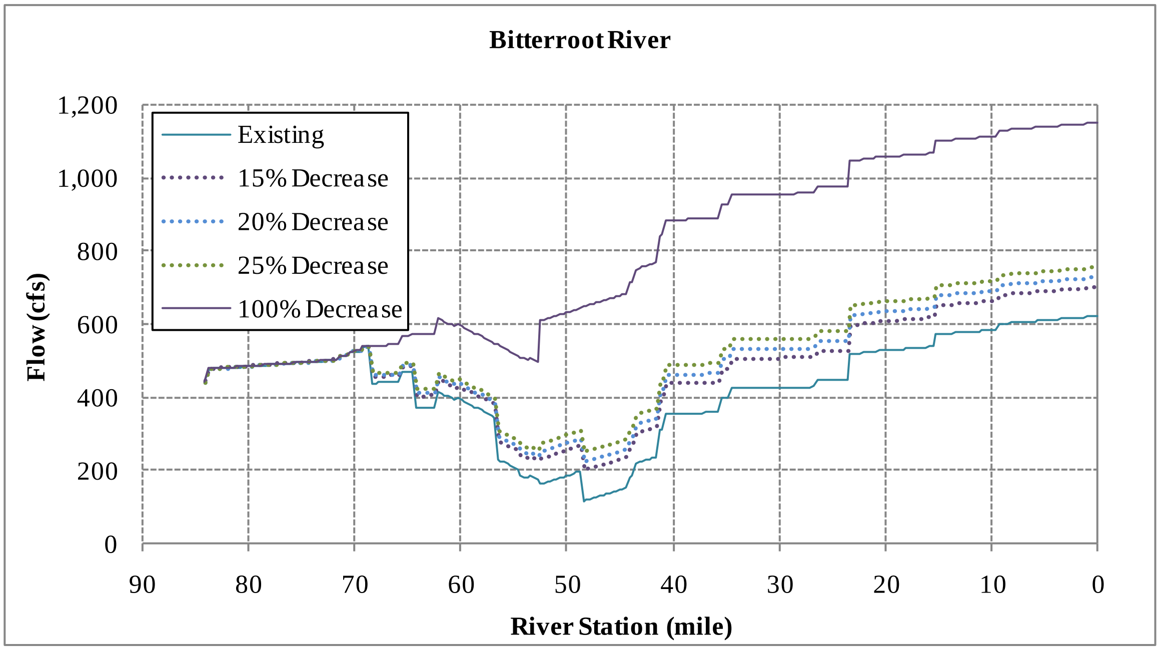

Figure 10-12. Bitterroot River flows for flow scenarios, 15, 20, 25 and 1000 decreases in water use

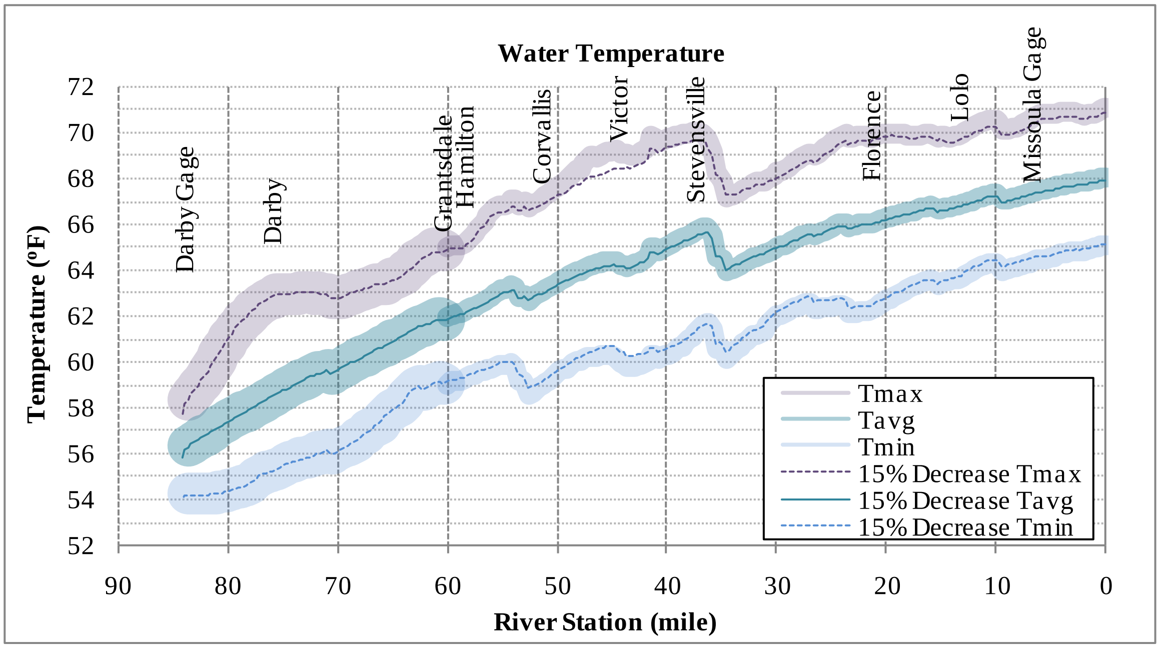

Figure 10-13. Bitterroot River simulated water temperatures for existing conditions and flow scenarios, 15 percent decrease in water use

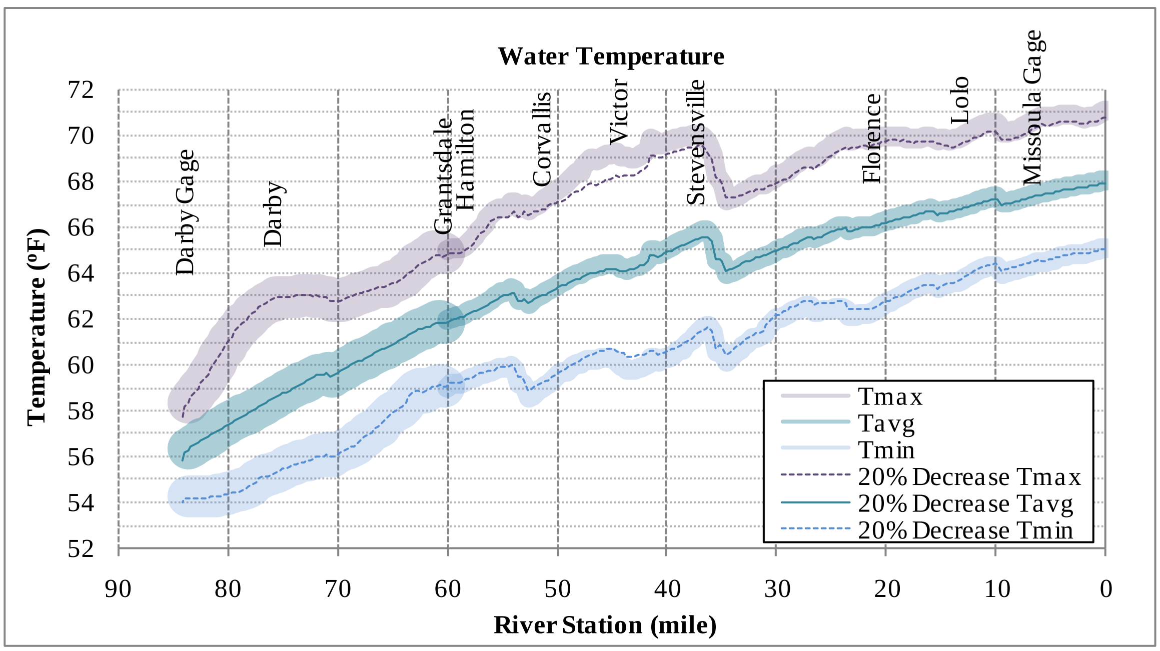

Figure 10-14. Bitterroot River simulated water temperatures for existing conditions and flow scenarios, 20 percent decrease in water use

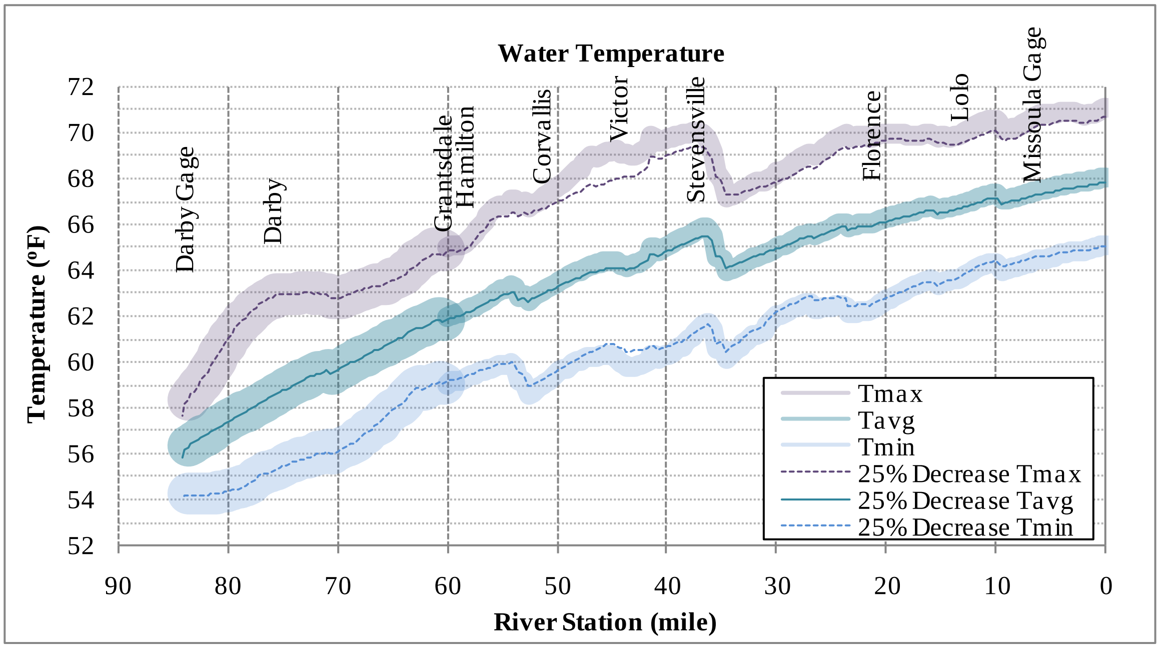

Figure 10-15. Bitterroot River simulated water temperatures for existing conditions and flow scenarios, 25 percent decrease in water use

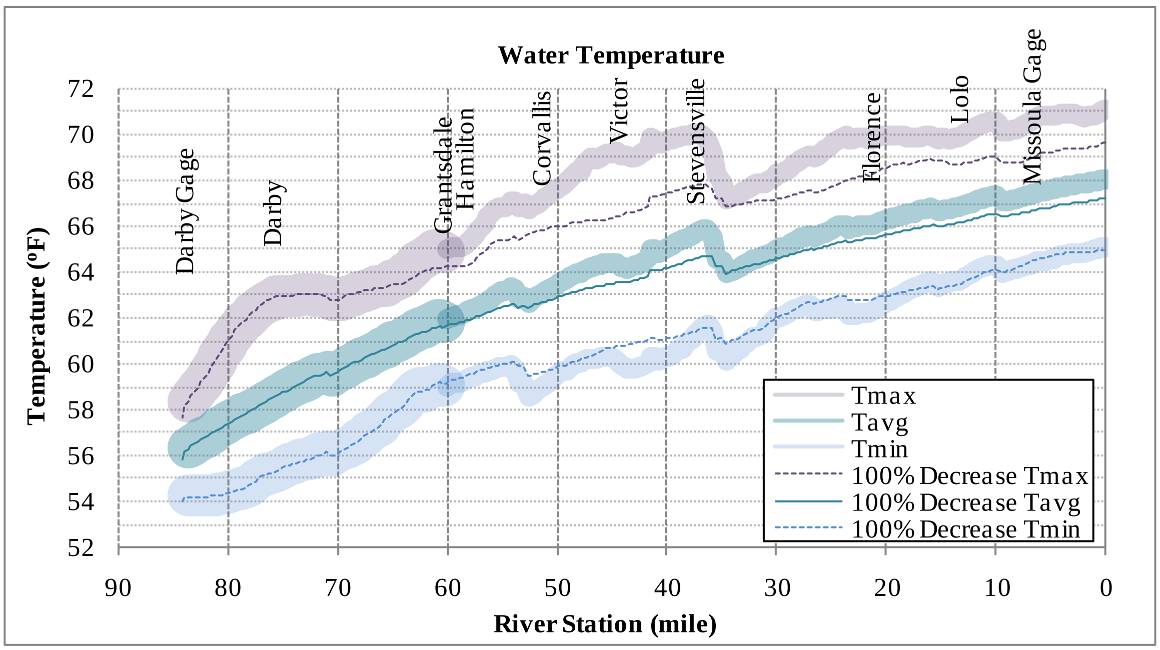

Figure 10-16. Bitterroot River simulated water temperatures for existing conditions and flow scenarios, 100 percent decrease in water use

Table 10-7. Tabular results of differences in water temperatures for existing conditions and flow scenarios		
River/Creek	**Maximum Change in Maximum Daily Water Temperature (^{o}F)**	**Location River Station (mile)**
Scenario: Flow 15 percent decrease in water use		
Bitterroot River Upper Reach	-0.15	60 to 61
Bitterroot River Middle Reach	-0.91	44.5 to 47.5
Bitterroot River Lower Reach	-0.35	10 to 12
Scenario: Flow 20 percent decrease in water use		
Bitterroot River Upper Reach	-0.19	60 to 62
Bitterroot River Middle Reach	-1.14	45 to 46
Bitterroot River Lower Reach	-0.46	10 to 12
Scenario: Flow 25 percent decrease in water use		
Bitterroot River Upper Reach	-0.24	60 to 61
Bitterroot River Middle Reach	-1.35	45 to 46
Bitterroot River Lower Reach	-0.56	10 to 11.5
Scenario: Flow 100 percent decrease in water use		
Bitterroot River Upper Reach	-0.77	60 to 61
Bitterroot River Middle Reach	-2.96	44.5 to 46
Bitterroot River Lower Reach	-1.73	5 to 7

Table 10-8. Water temperature (daily maximum and mean) comparison, existing conditions and flow scenarios, 15 percent decrease in water use		
Maximum Daily Water Temperature		
River/Creek	**Difference > 0.5^{o}F**	**Location River Station (mile)**
Bitterroot River Upper Reach	No	n/a
Bitterroot River Middle Reach	Yes	41 to 49.5
Bitterroot River Lower Reach	No	n/a
Mean Daily Water Temperature		
River/Creek	**Difference > 0.5^{o}F**	**Location River Station (mile)**
Bitterroot River Upper Reach	No	n/a
Bitterroot River Middle Reach	No	n/a
Bitterroot River Lower Reach	No	n/a

Table 10-9. Water temperature (daily maximum and mean) comparison, existing conditions and flow scenarios, 20 percent decrease in water use

Maximum Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	No	n/a
Bitterroot River Middle Reach	Yes	37 to 50.5
Bitterroot River Lower Reach	No	n/a
Mean Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	No	n/a
Bitterroot River Middle Reach	No	n/a
Bitterroot River Lower Reach	No	n/a

Table 10-10. Water temperature (daily maximum and mean) comparison, existing conditions and flow scenarios, 25 percent decrease in water use

Maximum Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	Yes	9.5 to 10.5
Bitterroot River Middle Reach	Yes	23.5 to 28.5 and 36.5 to 54.5
Bitterroot River Lower Reach	No	n/a
Mean Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	No	n/a
Bitterroot River Middle Reach	No	n/a
Bitterroot River Lower Reach	No	n/a

Table 10-11. Water temperature (daily maximum and mean) comparison, existing conditions and flow scenarios, 100 percent decrease in water use

Maximum Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	Yes	60 to 63
Bitterroot River Middle Reach	Yes	21.5 to 60
Bitterroot River Lower Reach	Yes	0 to 21.5
Mean Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	No	n/a
Bitterroot River Middle Reach	Yes	21.5 to 28.5 and 35.5 to 56.5
Bitterroot River Lower Reach	Yes	0 to 21.5

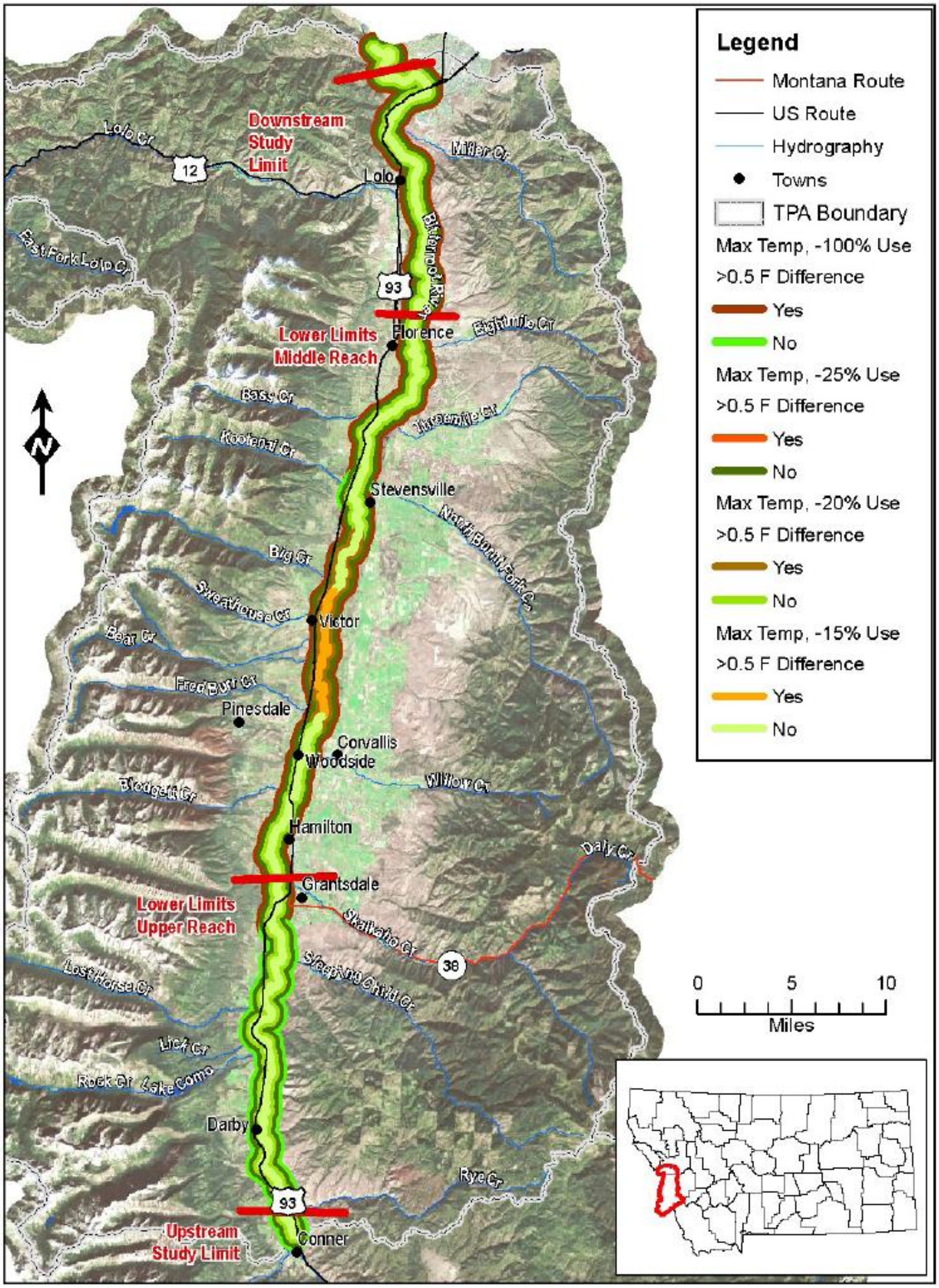

Figure 10-17. Water temperature (maximum) comparison, existing conditions and flow scenarios

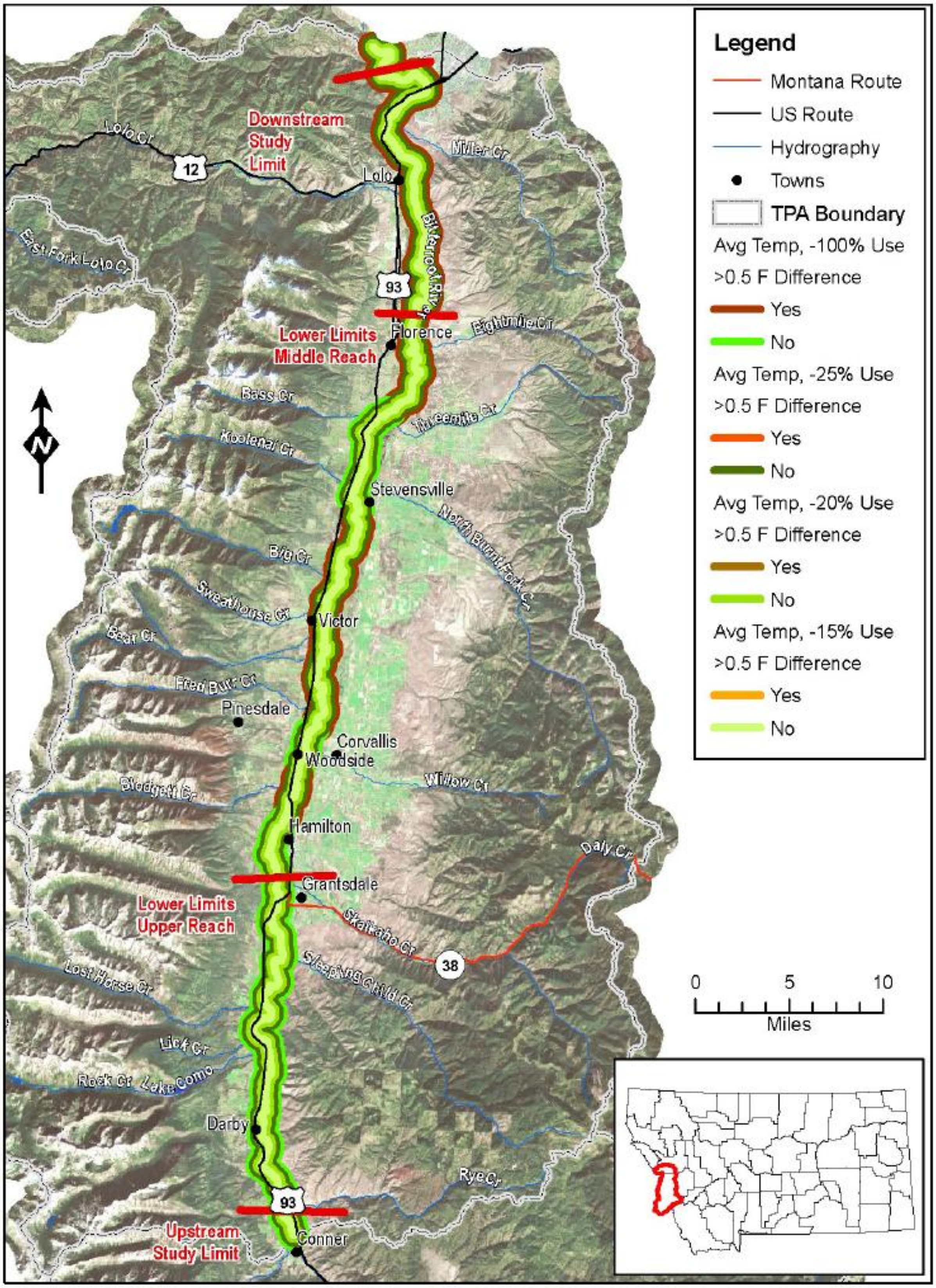

Figure 10-18. Water temperature (mean) comparison, existing conditions and flow scenarios

10.5 Wastewater Treatment Plant/Facility Scenarios

The WWTP scenarios consist of multiple simulations with changes in the discharge rates from the wastewater treatment facilities in the existing conditions model of the Bitterroot River. The Miller Creek, Sleeping Child Creek, and Willow Creek existing conditions models do not have any WWTPs and do not have separate scenario simulations. The simulations consist of setting the four individual dischargers to zero (Darby, Hamilton, Stevensville, and Lolo), setting all dischargers to zero, and doubling the flow from all the dischargers to the Bitterroot River.

For the Bitterroot River, water temperatures for the WWTP scenarios are essentially the same as the existing conditions (**Figure 10-19**, **Figure 10-20**, **Figure 10-21**, **Figure 10-22**, **Figure 10-23**, and **Figure 10-24**). The impacts are small from all facilities, with Hamilton being the greatest, since it has the greatest flow of the four. The maximum change in the maximum daily water temperature is representative of the worst case conditions (**Table 10-12**). The locations where the difference in water temperature is greater than 0.5°F between the existing conditions and WWTP scenarios are summarized (**Table 10-13**).

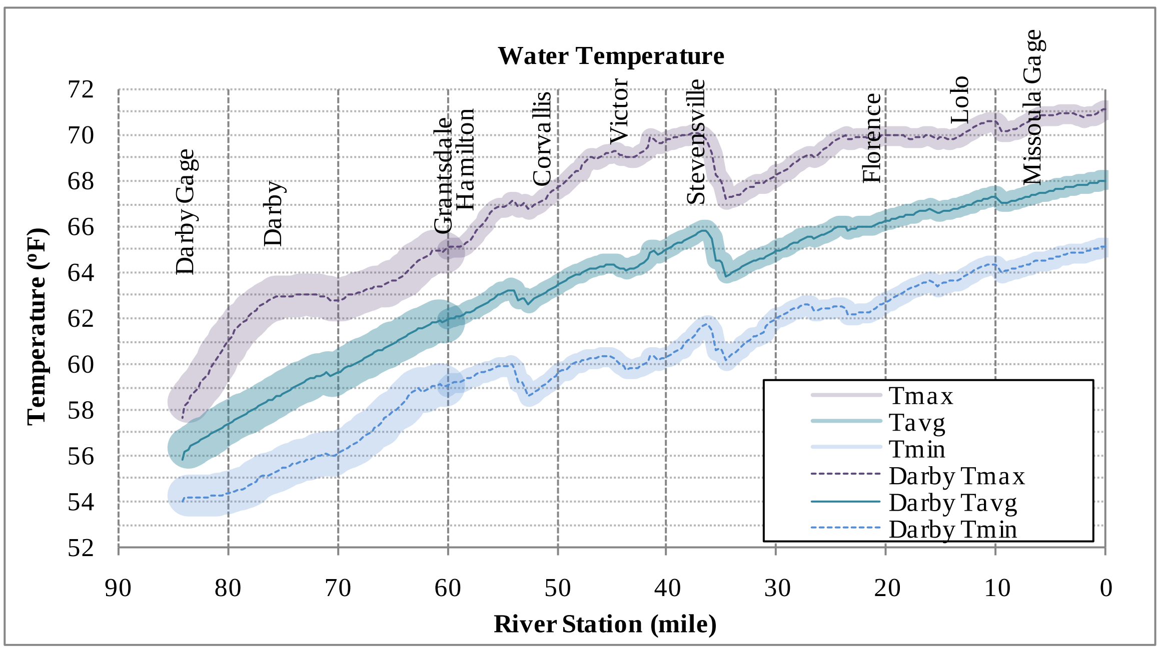

Figure 10-19. Bitterroot River simulated water temperatures for existing conditions and WWTP scenarios, Darby flow set to zero

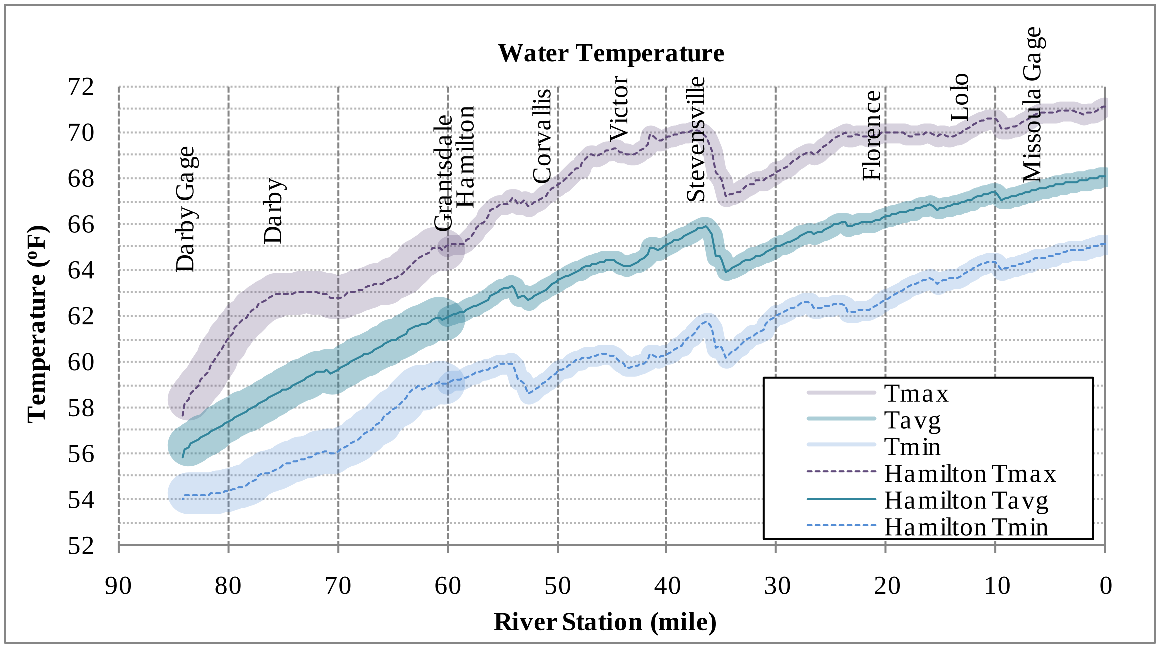

Figure 10-20. Bitterroot River simulated water temperatures for existing conditions and WWTP scenarios, Hamilton flow set to zero

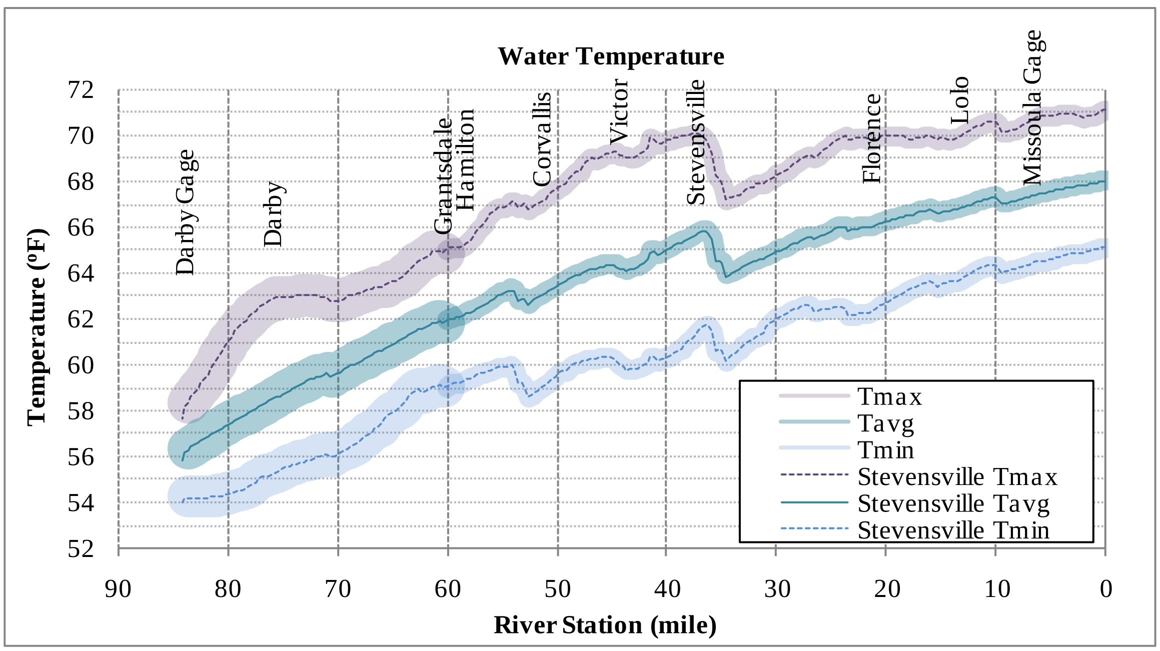

Figure 10-21. Bitterroot River simulated water temperatures for existing conditions and WWTP scenarios, Stevensville flow set to zero

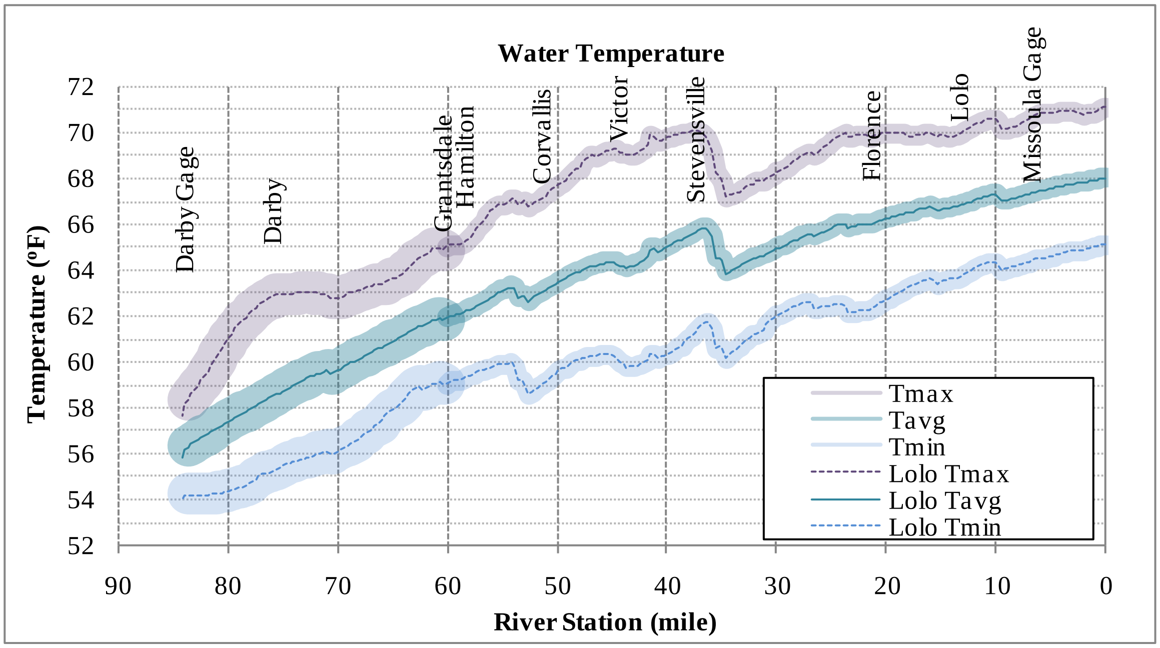

Figure 10-22. Bitterroot River simulated water temperatures for existing conditions and WWTP scenarios, Lolo flow set to zero

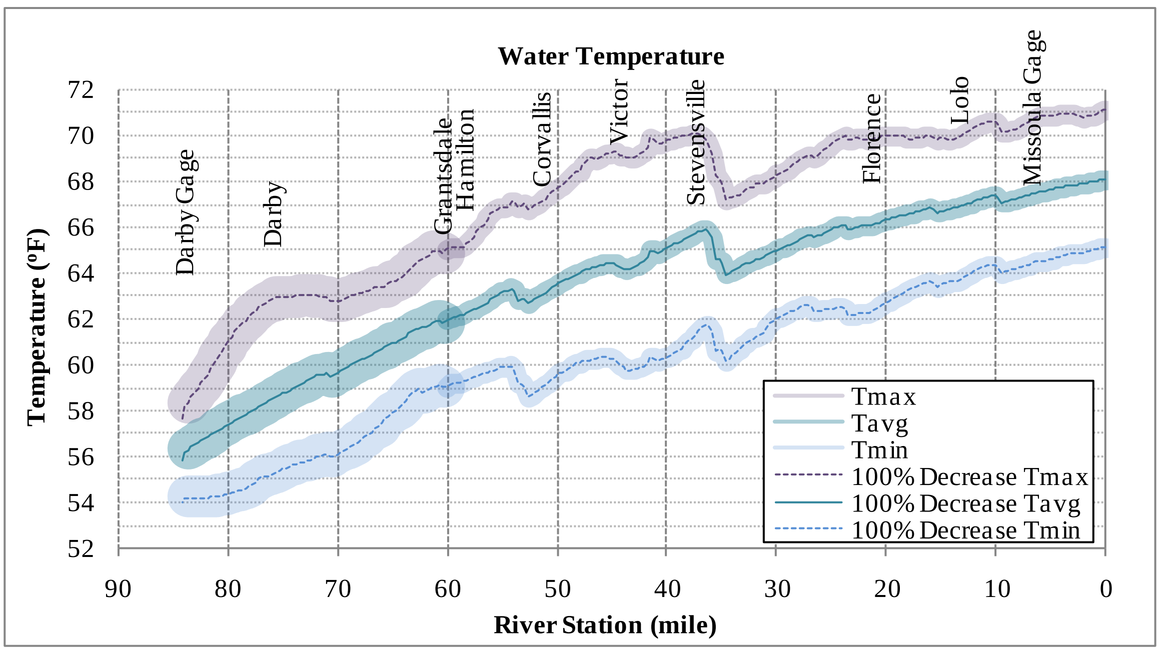

Figure 10-23. Bitterroot River simulated water temperatures for existing conditions and WWTP scenarios, all WWTP flow set to zero

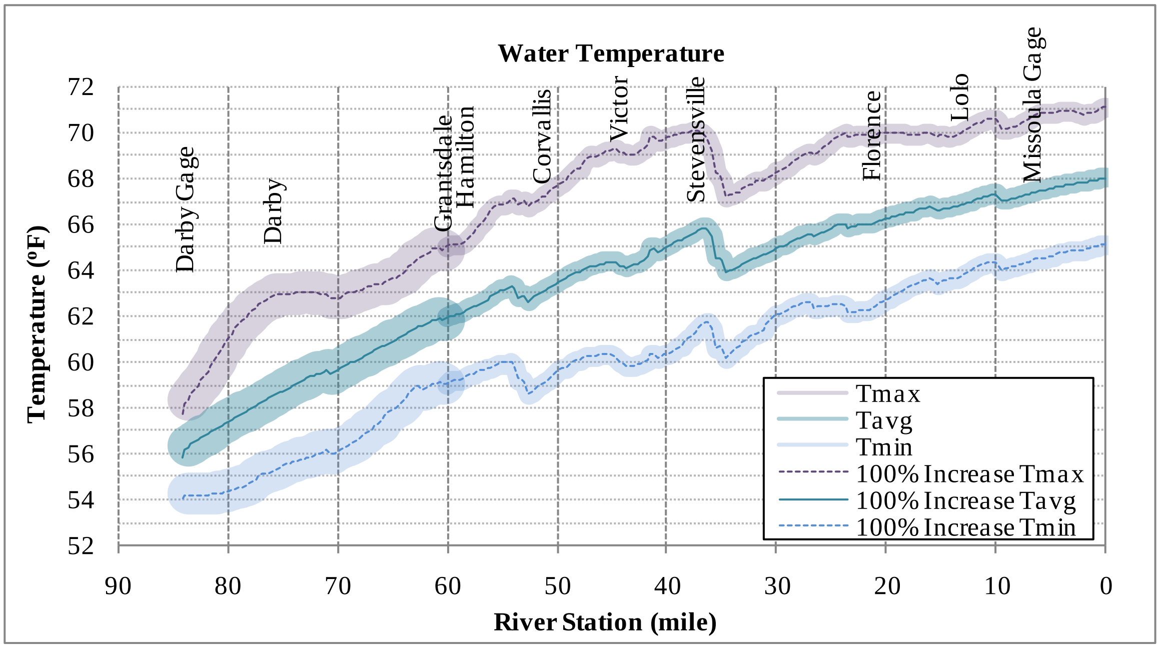

Figure 10-24. Bitterroot River simulated water temperatures for existing conditions and WWTP scenarios, all WWTP flow doubled

Table 10-12. Tabular results of differences in water temperatures for existing conditions and WWTP scenarios		
River/Creek	**Maximum Change in Maximum Daily Water Temperature (°F)**	**Location River Station (mile)**
Darby flow set to zero		
Bitterroot River Upper Reach	0	n/a
Bitterroot River Middle Reach	0	n/a
Bitterroot River Lower Reach	0	n/a
Hamilton flow set to zero		
Bitterroot River Upper Reach	0	n/a
Bitterroot River Middle Reach	-0.02	56.5 to 58.5
Bitterroot River Lower Reach	0	0 to 16
Stevensville flow set to zero		
Bitterroot River Upper Reach	0	n/a
Bitterroot River Middle Reach	0	n/a
Bitterroot River Lower Reach	0	n/a
Lolo flow set to zero		
Bitterroot River Upper Reach	0	n/a
Bitterroot River Middle Reach	0	n/a
Bitterroot River Lower Reach	0	n/a
All WWTP flow set to zero		
Bitterroot River Upper Reach	0	n/a
Bitterroot River Middle Reach	-0.02	56.5 to 58.5
Bitterroot River Lower Reach	0	0 to 16
All WWTP flow doubled		
Bitterroot River Upper Reach	0	n/a
Bitterroot River Middle Reach	+0.02	56.5 to 58.5
Bitterroot River Lower Reach	0	0 to 16

Table 10-13. Water temperature (daily maximum and mean) comparison, existing conditions and WWTP scenarios, all six WWTP flow scenarios		
Maximum Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	No	n/a
Bitterroot River Middle Reach	No	n/a
Bitterroot River Lower Reach	No	n/a
Mean Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	No	n/a
Bitterroot River Middle Reach	No	n/a
Bitterroot River Lower Reach	No	n/a

10.6 Stream Channel Dimensions Scenario

Changes in stream channel dimensions were not deemed an appropriate restoration approach on the Bitterroot River and were not simulated.

10.7 Natural Condition Scenario

The natural condition scenario combines many of the individual scenarios (discussed in earlier sections) and represents conditions without anthropogenic influence. Those specific to the Bitterroot River include: (1) shade improvement, (2) headwater and tributary water temperature reductions of 1°F, (3) flow reduction of 100 percent for water consumptive use, and (4) WWTPs discharge set to zero for all four wastewater facilities. The tributary natural condition scenario is the same as the shade scenario for Miller Creek and Sleeping Child Creek since there are no tributaries or WWTPs. For Willow Creek, the tributary natural condition includes the shade scenario and the removal of intermixing of Willow Creek stream water with canal water.

Results suggest that for the Bitterroot River, natural water temperatures would be about 0.1°F to 3.5°F cooler than the existing conditions, with the upper reach being the least affected and the middle reach the most (**Figure 10-25**). For Willow Creek, water temperatures average about 1°F to7.5°F cooler than the existing conditions (**Figure 10-26**).

The maximum change in the maximum daily water temperature is representative of the worst case conditions (**Table 10-14**). The locations where the difference in water temperature is greater than 0.5°F between the existing conditions and the natural condition scenario are summarized (**Table 10-15**), indicating potential impairment. The results of the comparison are also shown by reach on the map of the streams (**Figure 10-27**).

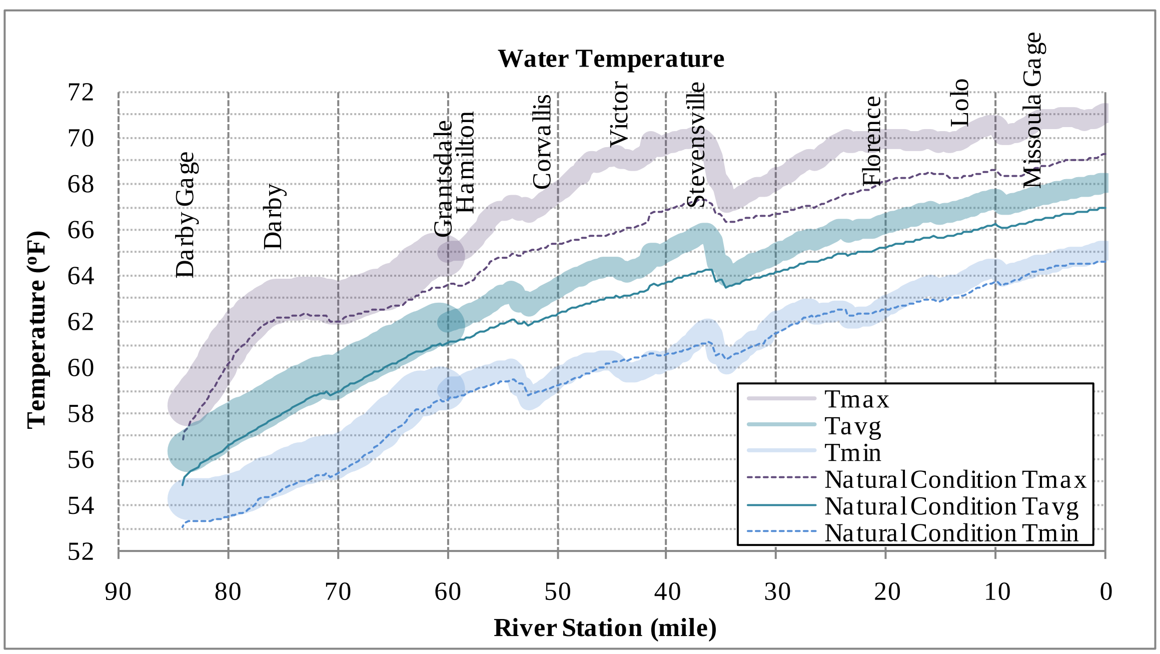

Figure 10-25. Bitterroot River simulated water temperatures for existing conditions and natural condition scenario

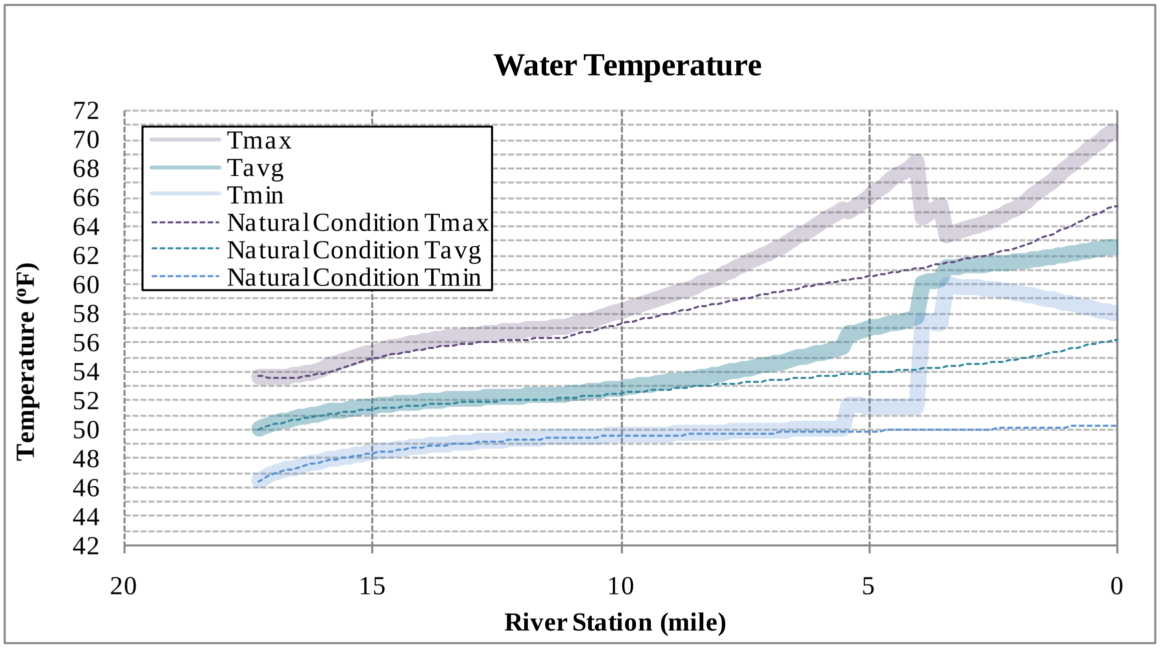

Figure 10-26. Willow Creek simulated water temperatures for existing conditions and natural condition scenario

Table 10-14. Tabular results of differences in water temperatures for existing conditions and natural condition scenario

River/Creek	Maximum Change in Maximum Daily Water Temperature (°F)	Location River Station (mile)
Bitterroot River Upper Reach	-1.45	60.5 to 63.5
Bitterroot River Middle Reach	-3.45	44.5 to 47.5
Bitterroot River Lower Reach	-2.08	5.5 to 7
Willow Creek	-7.34	4 to 4.5

Table 10-15. Water temperature (daily maximum and mean) comparison, existing conditions and natural condition scenario

Maximum Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	Yes	60.5 to 84
Bitterroot River Middle Reach	Yes	21.5 to 60.5
Bitterroot River Lower Reach	Yes	0 to 21.5
Willow Creek	Yes	0 to 15
Mean Daily Water Temperature		
River/Creek	**Difference > 0.5°F**	**Location River Station (mile)**
Bitterroot River Upper Reach	Yes	60.5 to 84
Bitterroot River Middle Reach	Yes	21.5 to 60.5
Bitterroot River Lower Reach	Yes	0 to 21.5
Willow Creek	Yes	0 to 9

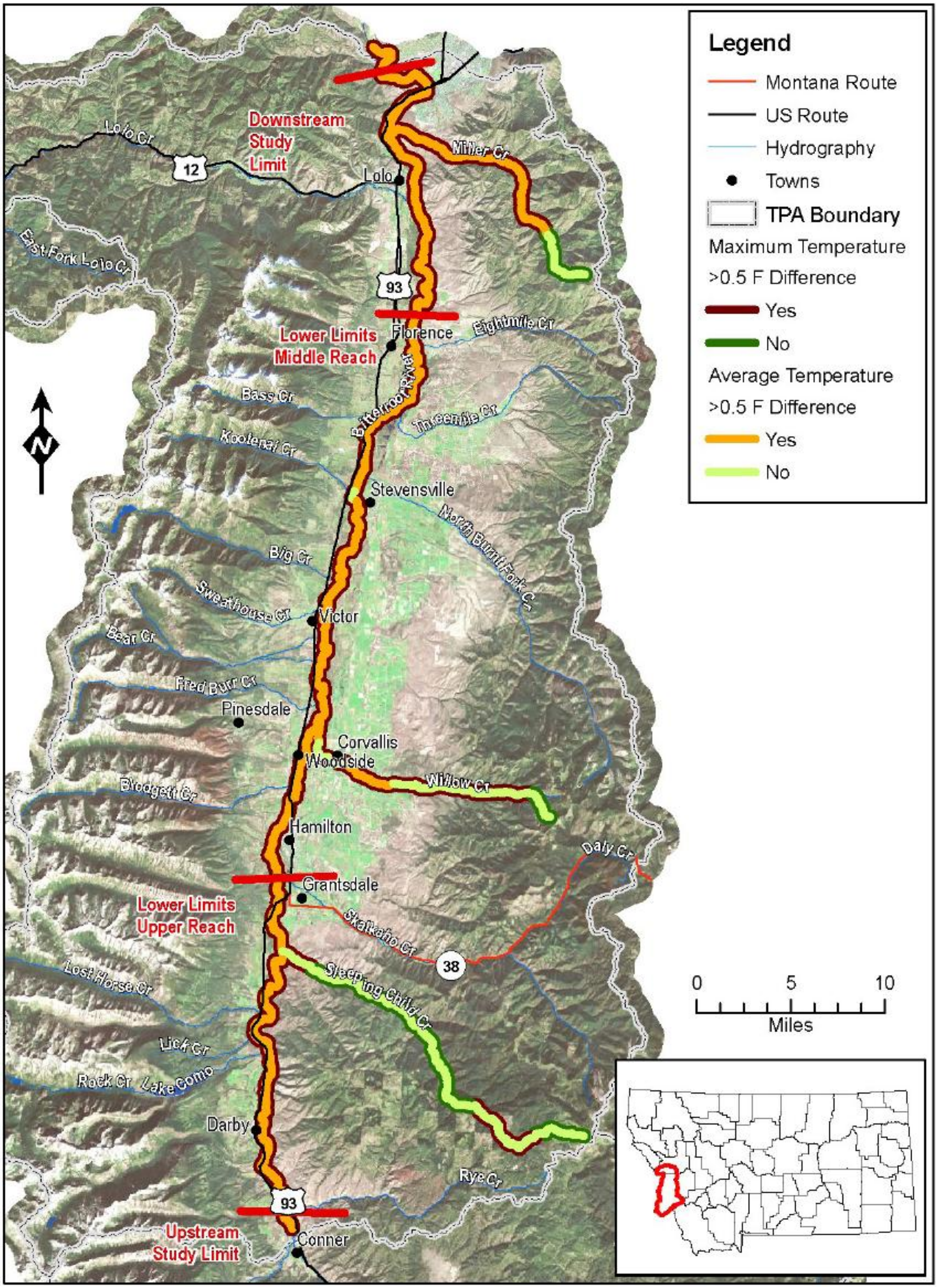

Figure 10-27. Water temperature (maximum and mean) comparison, existing conditions and natural condition scenario

10.8 Naturally Occurring Scenario

The naturally occurring scenario combines many of the individual scenario changes and represents the implementation of all reasonable land and soil water conservation practices in the watersheds. Specifically this includes: (1) shade improvement, (2) headwater and tributary water temperature reduction of 1^{o}F, and (3) flow reduction of 20 percent for water use. In Miller, Sleeping Child, and Willow creeks, naturally occurring scenarios are defined as the same as the natural condition scenarios, and therefore are not repeated. The differences between the naturally occurring and natural condition scenarios are flow and WWTPs and these are not present in the three tributary models.

For the Bitterroot River naturally occurring scenario, water temperatures would be about 0.1^{o}F to 1.5^{o}F cooler than the existing conditions. The upper reach exhibited the least variability from the baseline condition, with the middle reach showing the most (**Figure 10-28**). The maximum change in the maximum daily water temperature is representative of the worst case conditions and is indicative of impairment (**Table 10-16**). Locations where the difference in water temperature is greater than 0.5^{o}F between the existing conditions and the naturally occurring scenario are summarized in (**Table 10-17**). The results of the comparison are also shown by reach on the map of the streams (**Figure 10-29**).

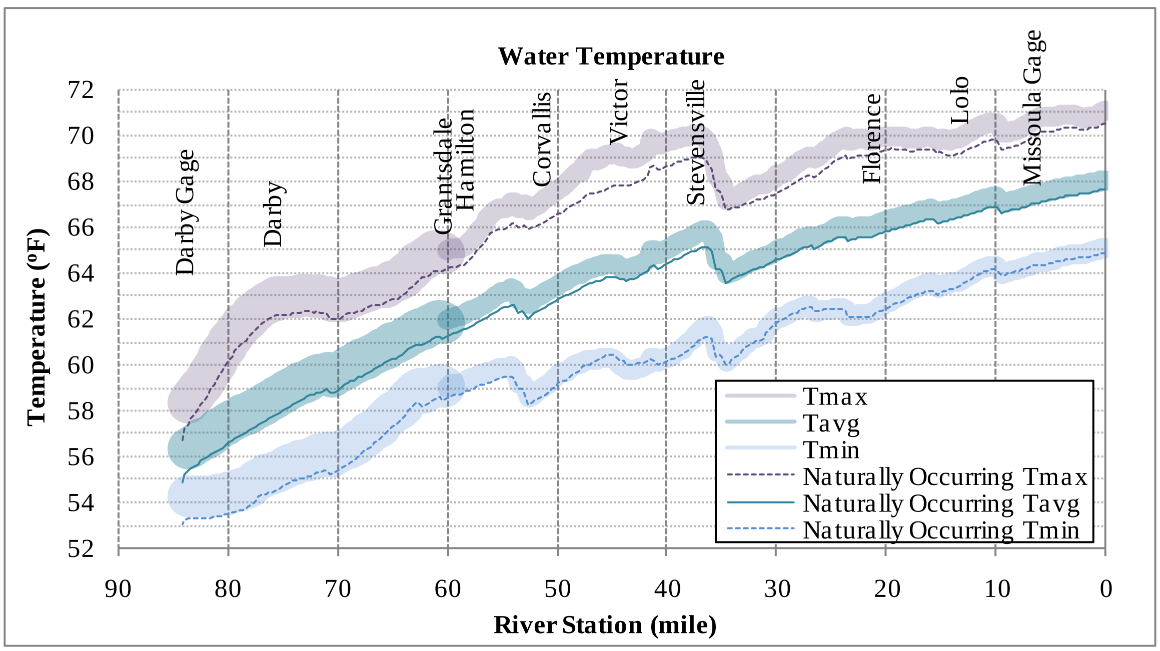

Figure 10-28. Bitterroot River simulated water temperatures for existing conditions and naturally occurring scenario

Table 10-16. Tabular results of differences in water temperatures for existing conditions and naturally occurring scenario

River/Creek	Maximum Change in Maximum Daily Water Temperature (^{o}F)	Location River Station (mile)
Bitterroot River Upper Reach	-1.00	80 to 84
Bitterroot River Middle Reach	-1.53	44.5 to 47.5
Bitterroot River Lower Reach	-0.82	10 to 12

Table 10-17. Water temperature (daily maximum and mean) comparison, existing conditions and naturally occurring scenario

Maximum Daily Water Temperature		
River/Creek	**Difference > 0.5^{o}F**	**Location River Station (mile)**
Bitterroot River Upper Reach	Yes	60.5 to 84
Bitterroot River Middle Reach	Yes	21.5 to 60.5
Bitterroot River Lower Reach	Yes	0 to 21.5
Mean Daily Water Temperature		
River/Creek	**Difference > 0.5^{o}F**	**Location River Station (mile)**
Bitterroot River Upper Reach	Yes	60.5 to 84
Bitterroot River Middle Reach	Yes	36 to 60.5
Bitterroot River Lower Reach	No	n/a

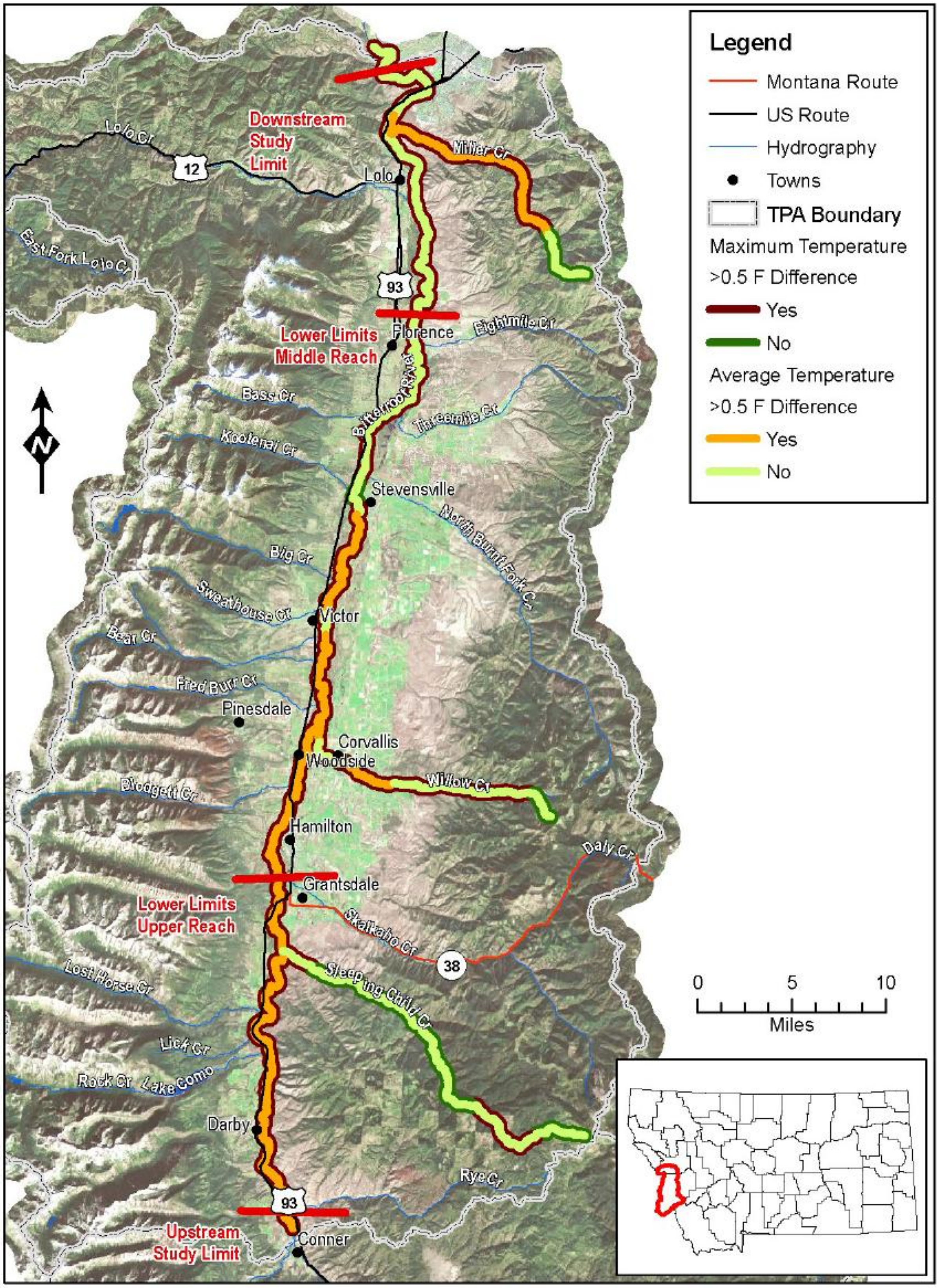

Figure 10-29. Water temperature (maximum and mean) comparison, existing conditions and naturally occurring scenario

11.0 SCENARIO RESULTS AND DISCUSSION

A difference of more than 0.5^{o}F between existing conditions and scenario was determined to be significant, and indicative of impairment based on the existing state temperature standard. The scenarios resulted in anywhere from almost no change in water temperatures to reductions as much as nearly 8^{o}F. Some of the reductions in water temperatures were localized and others affected nearly the entire reach.

For the shade scenario, there is no significant change in water temperature in the Bitterroot River. Sleeping Child Creek there is short reach with impacted water temperatures due to reduced shade. Miller Creek and Willow Creek show the greatest extent and impact to water temperatures due to shade reductions.

The headwater and tributary water temperature reduction scenario provided some reduction in water temperatures primarily in the middle reach of the Bitterroot River. This reduction in water temperature was attenuated by the downstream end of the Bitterroot River to less than 0.2^{o}F.

Flow scenarios representing irrigation efficiency changes were performed on the Bitterroot River. Again the middle reach showed the greatest potential for improvement. The 15, 20, and 25 percent reductions in water use resulted in a water temperature decrease of around 1^{o}F in the middle reach, while the 100 percent reduction resulted in a 1^{o}F to 3^{o}F reduction throughout the river.

Multiple WWTP scenarios were also performed on the Bitterroot River. All the combinations of zero to doubled flow from one to all of the WWTPs resulted in almost no change to water temperatures. The greatest change was 0.02^{o}F at Hamilton, the WWTP with the largest flow.

The natural condition scenario resulted in the greatest decrease in water temperatures as this scenario combined the effects of the individual scenarios. The Bitterroot River showed significant decreases in water temperatures generally throughout the entire reach.

For the naturally occurring scenario, the maximum decrease in water temperatures is about half of the natural condition scenario. The scenario still shows significant reductions in water temperatures are achievable throughout the reach. The areas with the greatest changes demonstrate the most sensitive areas. For the Bitterroot River the greatest change is 1.5^{o}F in the middle reach near Victor, river mile 44.5 to 47.5. The last 0.5 miles of Miller Creek near the confluence with Bitterroot River has the greatest change of 7.6^{o}F. For Sleeping Child Creek about 5 miles below the headwaters, river mile 18.5 to 20, has the greatest change of 1.0^{o}F. About 4 to 4.5 miles above the confluence of Willow Creek with the Bitterroot River near existing canals has the greatest change of 7.3^{o}F. This demonstrates the scenario may be feasible and beneficial to meeting water temperature standards for the Bitterroot River.

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