APPENDIX B – BEAVERHEAD RIVER TEMPERATURE MODEL

ABSTRACT

The enhanced river water quality model QUAL2K was applied to the Beaverhead River in southwestern Montana by the Montana Department of Environmental Quality (DEQ) to evaluate stream temperature improvement scenarios for a 66 mile reach extending from Barretts to Twin Bridges, MT as part of the temperature Total Maximum Daily Load (TMDL) investigation for the river. Heat transfer principles were used to evaluate a number of scenarios and their effect on diurnal water temperature. A companion model, Shadev3.0.xls was used to evaluate shade. Existing data were used for model development including climatic information from the National Weather Service (NWS) and Bureau of Reclamation AgriMet program, streamflow and temperature data from Montana State University (collected for the Bureau of Reclamation), data from the U.S. Geological Survey, and associated field measurements made by DEQ during 2009. Models were calibrated relatively successfully with mean relative error of 0.01% and root mean squared error of 0.9°F. Following calibration we employed scenario analysis to determine feasible management strategies for the river. We evaluated the following: (1) the effect of riparian vegetation and shading improvement along the stream corridor, (2) morphological changes to the river's width depth ratio, (3) irrigation efficiency improvement and maintenance projects, and (4) natural and naturally occurring conditions. Based on our evaluation, we determined that the Beaverhead River is impaired for water temperature due to a number of reasons, most notably, the cumulative effect of irrigation dewatering and shade removal. Overall, the river is 3.7°F warmer than naturally occurring with the most significant effect being irrigation. Consequently, we recommend that irrigation efficiency be considered as the highest priority for any management plan to meet the state water temperature standard. Other best management practices that should be considered in conjunction with these activities include riparian enhancement (tree planting). The study was commissioned by DEQ as part of our statewide watershed planning work.

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ACRONYMS

Acronym	Definition
ARM	Administrative Rules of Montana
ASOS	Automated surface observing Station
BLM	Bureau of Land Management (federal)
BOR	Bureau of Reclamation
CC	Clark Canyon Dam
CCWC	Canyon Canal Water Company
DEQ	Department of Environmental Quality (Montana)
DNRC	Department of Natural Resources & Conservation
EBID	East Bench Irrigation District
EPA	Environmental Protection Agency (US)
FWP	Fish, Wildlife, and Parks
FWS	Fish & Wildlife Service (US)
GWIC	Groundwater Information Center
HUC	Hydrologic Unit Code
MBMG	Montana Bureau of Mines and Geology
MCA	Montana Codes Annotated
MPDES	Montana Pollutant Discharge Elimination System
MSU	Montana State University
NAIP	National Agriculture Imagery Program
NOAA	National Oceanic and Atmospheric Administration
NSDZ	Near Stream Disturbance Zone
NWS	National Weather Service
QA	Quality Assurance
RE	Relative Error
RMSE	Root Mean Squared Error
TMDL	Total Maximum Daily Load
TPA	TMDL Planning Area
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant

B1.0 BACKGROUND

The river water quality model QUAL2K was applied to the Beaverhead River in southwestern Montana to evaluate stream temperature improvement scenarios for a 66.3 mile reach between Barretts and Twin Bridges, MT. Models were constructed to ascertain the relationship between flow, riparian conditions, river management, and instream water temperature as part of the TMDL. Information on the project background, modeling results, and scenario analyses are contained within the rest of the document.

B1.1 PRIOR STUDIES

Prior investigations into water temperature on the Beaverhead River have suggested that it is impaired for a number of reasons. For example numerous times the river has been greater than 21.1°C (70°F), and twice it has exceeded 25°C (78 and 79°F) (CDM Federal Programs Corporation et al., 2003). Such values are near the upper limit for most salmonid species and are of concern. To compound the issue, the river is dewatered (Montana Department of Fish, Wildlife and Parks, Fisheries Division, 2003). Sections with problems include:

- The upper Beaverhead River, which is periodically dewatered from the Clark Canyon Dam to the West Side Canal (21 miles).
- The lower Beaverhead River, which is chronically dewatered from the West Side Canal to the Big Hole River (39 miles).

In addition to the previous assertions, vegetation losses from the riparian corridor and dam operation have all been speculated as other possible causes of impairment (CDM Federal Programs Corporation et al., 2003). None have ever been validated quantifiably however. As a result, modeling was commissioned by DEQ to identify whether feasible irrigation efficiency improvement or maintenance projects or riparian vegetation or channel morphology improvements as part of the TMDL would have a significant influence on water temperature. We subsequently will use that information to identify management practices, if any, are of merit in meeting the Montana stream temperature standard (ARM 17.30.623(2)(e), 2006).

B1.2 MONTANA'S TEMPERATURE STANDARD (ARM 17.30.623)

Water quality impairment in Montana is currently arbitrated according to the state water temperature standard (ARM 17.30.623(2)(e), 2006). For B-1 waters (which the Beaverhead River is) a maximum allowable increase of 1°F over "naturally occurring" is acceptable when natural temperatures are within the range of 32°F to 66°F. If temperatures are 66.5°F or greater, a 0.5°F increase is allowed (ARM 17.30.623(2)(e), 2006). Hence certain increases are allowed, but with limitations. The standard was originally developed to address point source discharges therefore it is difficult to interpret for nonpoint sources. To fully evaluate its requirements, DEQ must first characterize the departure from "naturally occurring" (which reflects the implementation of "all reasonable soil and water conservation practices") (per ARM 17.30.602) and then recommend best management practices (BMPs) to mitigate the impairment. Modeling is one of the most effective ways to make this determination. Consequently, this document and project were conceptualized to link water temperature with reasonable management conditions along the river corridor).

B1.3 THE EFFECTS OF MANAGEMENT ON WATER TEMPERATURE

It has been well established that river management has an effect on water temperature (LeBlanc et al., 1997; Meier et al., 2003; Poole and Berman, 2001; Rutherford et al., 1997). For example, healthy riparian areas absorb incoming solar shortwave radiation, reflect longwave radiation, and influence microclimate (i.e., air temperature, humidity, and wind speed). Added streamflow volume (i.e., flow rate) increases the temperature buffering capacity of a waterbody via thermal inertia or assimilative heat capacity. Channel morphology is critical for maintenance of hyporheic flow and minimizes solar gain.

These variables that are influenced by river management are important in assessing stream health and associated effects on fish and aquatic life. Critical limits and temperature tolerances for fluvial inhabitants are an effective way to characterize waterbody condition. Temperature tolerances for fish species present in the Beaverhead River are summarized in **Table 1-1.** Temperatures slightly over 70°F are lethal for 10 percent of the salmonid population (LC_{10}) in an exposure lasting 24 hours[1]. Optimum ranges are nearer 60°. Thus given our knowledge about the Beaverhead River, there are potentially impacts to most of the trout species.

Table B1-1. General trout temperature tolerances

From DEQ 2011 (R. McNeil, personal communication).

Species	Optimum Range (°F)	LC_{10} for 24 hours (°F)
Brown trout (adult)	57	75
Rainbow trout (adult)	57	80
Brook trout (adult)	60	77
Cutthroat trout (adult)	56	71

B1.4 RESERVOIR INFLUENCE

The Beaverhead River is also reservoir regulated therefore the operation of upstream storage facilities is a consideration. Clark Canyon Reservoir is at the uppermost end of the project reach and provides nearly all flow in the river. According to Smith (1973), this is a net benefit as the reservoir buffers diurnal temperatures and provides stable cool hypolimnetic water. It also provides flow beyond what may naturally be available. As a result, temperature downstream of the reservoir is significantly better (i.e., cooler and less diurnal flux) than a non-regulated system of similar size. A second consideration is Lima Reservoir (much further upstream) which also partially regulates flow in the Red Rock River, a tributary to Clark Canyon Reservoir. It is less important given its storage volume and proximity to the study area. Consequently, there are further considerations in regard to water temperature management in the Beaverhead River than those stated in previous sections.

B2.0 STUDY AREA DESCRIPTION

The Beaverhead River is located in Beaverhead and Madison counties in southwestern Montana (**Figure B2-1**). The river flows out of Clark Canyon Dam northeasterly for approximately 80 miles past the towns of Dillon and Twin Bridges, MT until ultimately confluencing with the Big Hole River near Twin Bridges.

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[1] It should be noted that coldwater fish species have varied temperature requirements that are dependent on life stage. **Table 1-1** should only be used as a rough guide.

The temperature impairment extends from Grasshopper Creek to the Big Hole River (segment ID MT41B001_020) and is 62.7 miles long (Montana Department of Environmental Quality, 2011). The entire area is part of United States Geological Survey (USGS) Hydrologic Unit Code (HUC) 10020002. **Note:** the 62.7 miles referenced above is a different length than used in model development (as detailed in later sections).

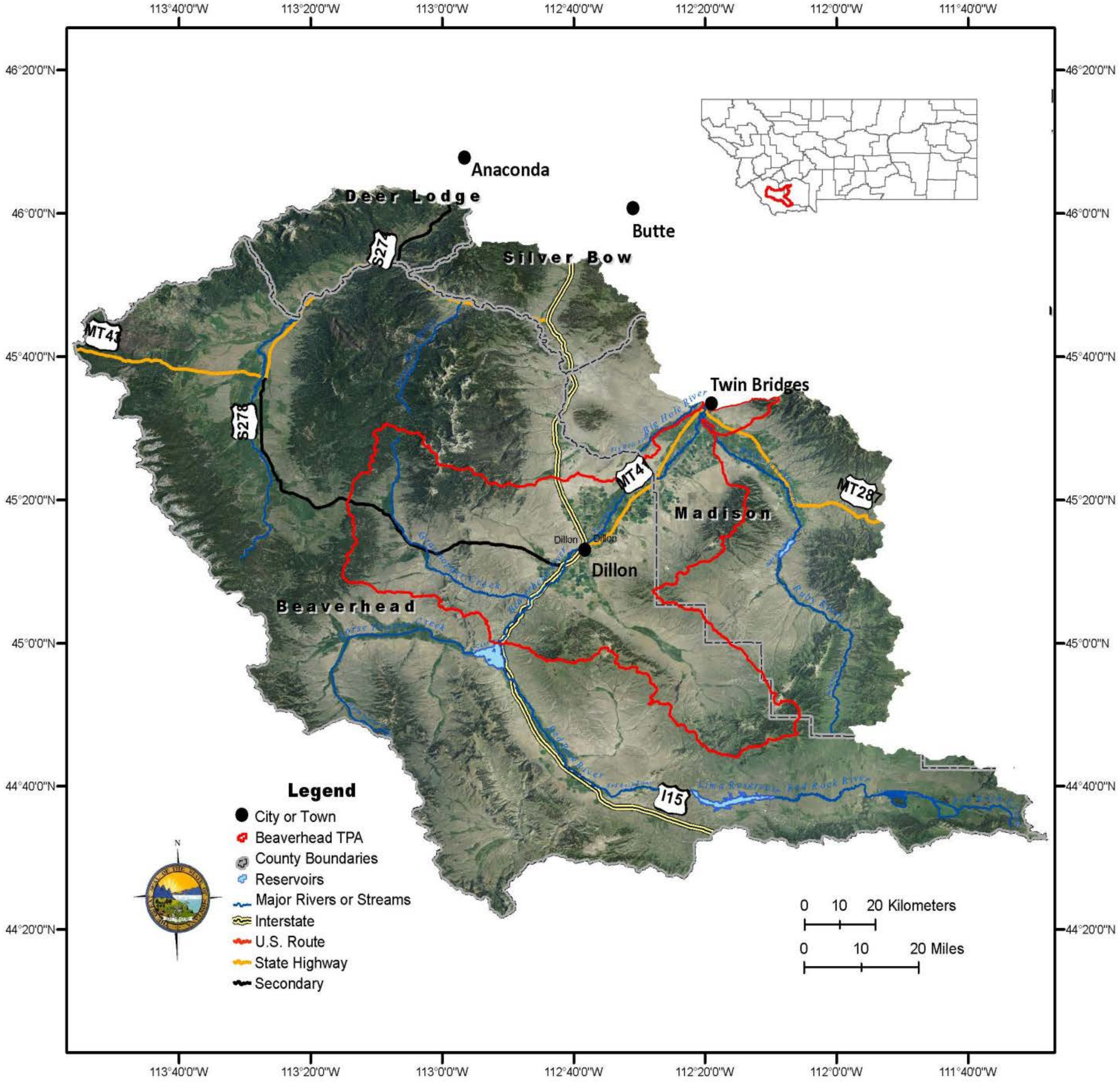

Figure B2-1. Beaverhead River vicinity map showing TPA boundary and associated features

The area being modeled extends from the USGS gage at Barretts (USGS 06016000) to the Highway 41 Bridge near Twin Bridges (Madison County Fairgrounds). This encompasses the available field data. The impairment actually extends slightly upstream to Grasshopper Creek. The study area is most easily accessed via Interstate-15 between Idaho Falls, ID and Dillon, MT, and on Montana Highway 41 between

Dillon and Twin Bridges (**Figure B2-2**). Monitoring sites and USGS gages are also shown and are referenced in future sections.

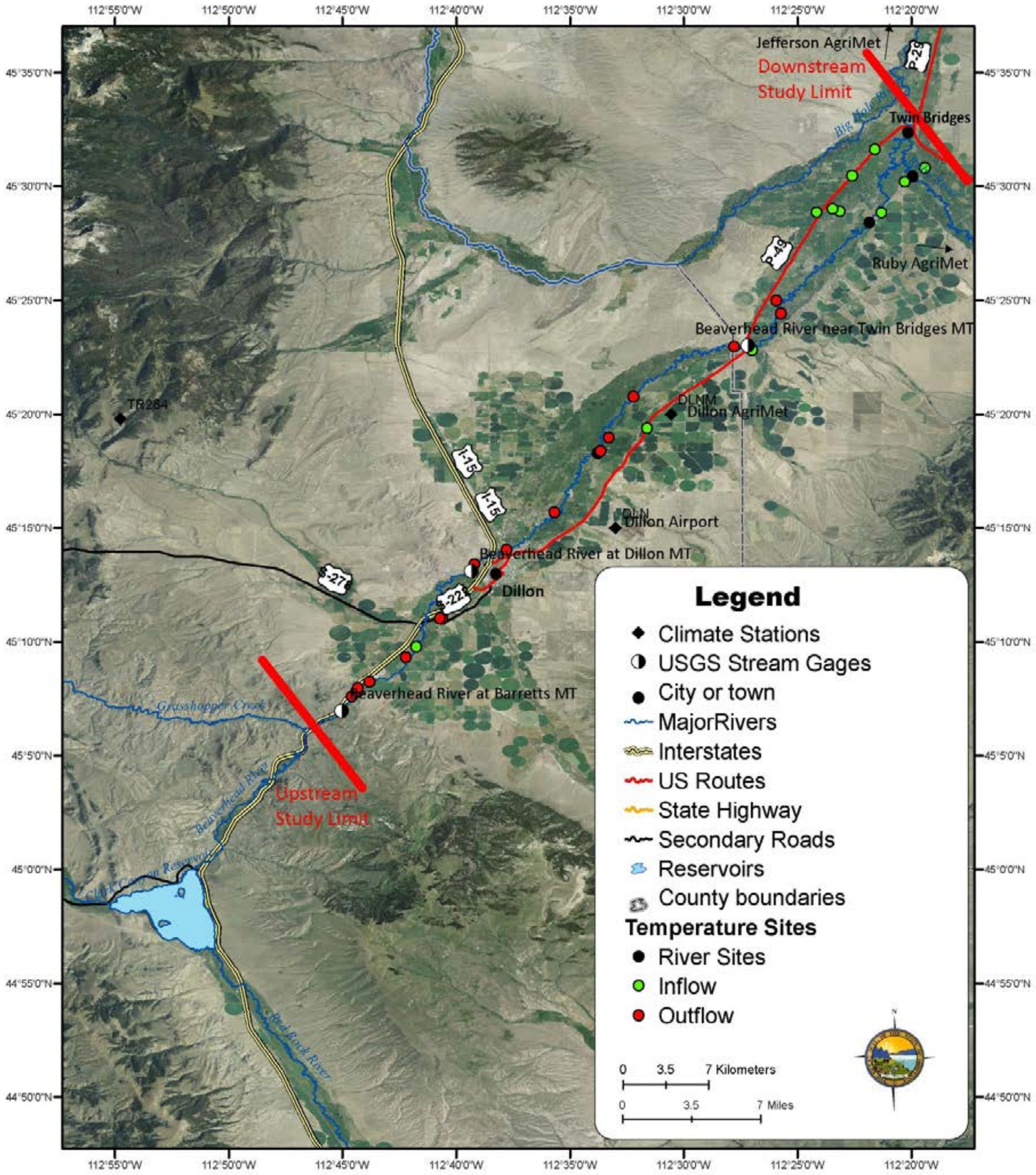

Figure B2-2. Beaverhead River detailed study reach

B2.1 CLIMATE

Climate of the Beaverhead River is inter-continental. Located on the eastern side of the continental divide, it is influenced by relatively dry cells pushed inland by prevailing westerly to northwesterly winds. Systems of low-pressure are most prevalent during the winter months and produce both rain and snow. Pacific highs influence the summer climate and cause long periods of warm and dry weather. Automated surface observing Station (ASOS) number 242404 is most proximal to the project reach and provides a suitable characterization of long-term climate (Dillon Airport, period of record of 1948-2005). According to site records (Western Regional Climate Center, 2006), July and early August are the most probable time-period when river impairment would occur. Air temperatures approach 80-85°F and coincide with a relatively dry period in the basin (**Figure B2-3**, left).

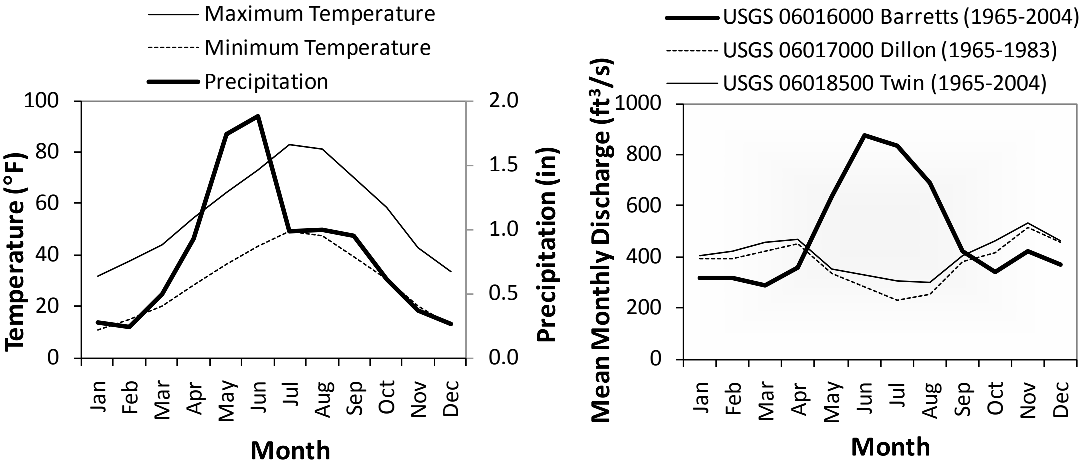

Figure B2-3. Beaverhead River climate and streamflow summary
(Left panel). Monthly temperature and precipitation for the Dillon airport. (Right panel) Mean monthly discharge for gages in the project site. Both climate station and gage locations are shown in **Figure B2-2**.

B2.2 STREAMFLOW

Streamflow in the watershed originates primarily from snowmelt out of the Tendoy and Centennial mountain ranges to the south and east and from the Beaverhead Mountains to west. Precipitation concentrates in these locations to form both major inflows to Clark Canyon Reservoir (Red Rock River and Horse Prairie Creek). Hydrology downstream of the reservoir is entirely regulated. From October to March, water is stored for the upcoming irrigation season. Conservation pool releases then occur from April through September to meet irrigation demands.

The U.S. Geological Survey (USGS) operates three gages on Beaverhead River (**Figure B2-3**, right panel). These include: (1) USGS 06016000 Beaverhead River at Barretts MT (upstream of all major diversions), (2) USGS 06017000 Beaverhead River at Dillon MT, and (3) USGS 06018500 Beaverhead River near Twin Bridges MT. The hydrograph at all locations is influenced by irrigation. Annual streamflow in the upper watershed has a pronounced yet shifted hydrograph peak of about 800 ft^3/s in July (during the irrigation season due to storage releases) whereas streamflow in the lower river shows an inverted hydrograph from cumulative diversions (flows between 200 and 500 ft^3/s). Minimum discharges usually occur during late summer months and often result in late-season shortages of irrigation water.

B2.3 GROUNDWATER

Groundwater is abundant in the project area and potentiometric surface maps indicate the flow path is generally from the uplands towards the floodplains, and then northeast along the Beaverhead River (Uthman and Beck, 1998). The uppermost tertiary aquifer is believed to have the most interaction with the river resulting in both gaining and losing reaches. Near Dillon, the river is thought to be gaining.

Groundwater accretion comprises a large part of this baseflow. The upper reaches are characterized as losing (Uthman and Beck, 1998).

Historical hydrogeologic data suggest groundwater resources in the basin are stable. The construction of Clark Canyon Dam (CC) caused the water table in the vicinity of the East Bench irrigation canal to rise as much as 100 feet [Botz 1967 as cited in Uthman and Beck (1998)], however, groundwater elevations are now seasonally stable. In some places, drain tiles have been installed to help route groundwater. Changes are related to artificial recharge from the dam and leakage through the canals, and further detail on the hydrogeology of the project site is found in Uthman and Beck (1998).

B2.4 IRRIGATION AND LAND USE

Land use in the Beaverhead River valley is primarily irrigated agriculture. Crops consist of alfalfa and grass hay (U.S. Department of Agriculture, 2011) and production consists of 2 or 3 cuttings per year which are then either sold as hay or are used to winter cattle. Water for irrigation is provided by two main companies; the East Bench Irrigation District (EBID) whose major diversion is located approximately three miles below Grasshopper Creek at Barretts (eleven miles below Clark Canyon Reservoir), and the Clark Canyon Water Supply Company which is on the west side of the river and consists of a number of smaller ditch companies or private irrigation shareholders. In total, each unit provides full irrigation service to 28,055 and 33,706 acres respectively (U.S. Department of the Interior, Bureau of Reclamation, 2006a).

About 46 percent of the watershed is under private ownership. Another 39 percent is under federal management, and 15 percent is stewarded by the state (including FWP managed lands and surface waters) (CDM Federal Programs Corporation et al., 2003). Most of the federal lands are in the higher elevations whereas the lower elevations are mostly private (with some BLM and State Trust Lands). The condition of these areas is highly variable. Riparian corridors vary from healthy native vegetation stands in some instances to severely impacted locations elsewhere. In most places, willow and aspen communities were historically present, but have been removed through human activity (BLM, 2003 as cited in CDM et al., (2003)).

B2.5 FISH AND AQUATIC LIFE

Despite being one of the better fisheries in the state, the Beaverhead River has declined over the years. The upper and mid-river has suffered from reductions in fish populations for nearly a decade as a result of persistent drought (R. Oswald, personal communication as cited in CDM et al., (2003)). Conditions have not improved much until recently. Limited releases from Clark Canyon Reservoir during the winters of 2002-2003 (<27 ft^3/s) were mostly to blame. These depressed trout populations through reductions in wetted stream perimeter, feeding habitat, macroinvertebrate prey food, spawning sites, and protective woody debris (R. Oswald, personal communication as cited in CDM et al., (2003)). The size, health, and vigor of the trout population in the Beaverhead River was cumulatively affected.

The lower river (Anderson Lane, Mule Shoe, and Twin Bridges sections, downstream of Dillon) has suffered from low fish densities for a long time (since the 1970s). This is believed to be related to a variety of habitat problems including altered flow regimes, heavy bedload transport, channel atrophy, excessively high summer temperatures, and bank instability from a lack of woody riparian vegetation (Oswald (2000) and Oswald and Brammer (1993) as cited in CDM et al., (2003)). The lower river is in poor condition subsequently, and will likely benefit from a temperature TMDL.

B3.0 DATA SUMMARY

A data summary has been prepared to overview some of the information collected by other agencies in support of the modeling. Most of the review is focused on the data collected by Montana State University (MSU) (Sessoms and Bauder, 2005) for Bureau of Reclamation (BOR) water contract renegotiations. These were the primary data used in the model development. Since some of this data happened to be an indirect measure (i.e., the dataloggers just happened to record temperature), a short section is provided here to ensure that the data is valid for TMDL planning purposes.

B3.1 OVERVIEW

Thirty-four discharge and temperature monitoring stations were established in 2005 as part of the Bureau of Reclamation (BOR) water balance effort (Sessoms and Bauder, 2005). Monitoring instrumentation was Tru-track WT-VO capacitance meters which are voltage output water height probes that log both water height and temperature. Stage is measured with a temperature corrected accuracy of ±1%, and water temperatures are measured within ±0.5°F. Thus the absolute accuracy of these instruments is 2% and 1.0°F respectively. Each logger was housed in a stilling well and logged at one-hour intervals.

Flow measurements were made with Marsh-McBirney Model 2000 Flo-Mate portable flow meters to rate the gaging sites. Discharges were correlated with Tru-track stage heights to establish site rating curves and were visited approximately once per month from April 4 to October 24. Standard operating procedures were used in the collection of the data as outlined in the “Water Measurement Manual” (U.S. Department of the Interior, Bureau of Reclamation, 2001) or USGS Water Supply Paper 2175 Measurement and Computation of Streamflow (Rantz, 1982)[2]. EBID uses flumes for their discharge measurements, which according to Sessoms and Bauder (2005) are sufficiently accurate for use as well.

The flow measurement and temperature monitoring locations used in this study are identified in **Table B3-1**. From **Figure B2-2** it is apparent that many sites are not located directly on the main river, but are on its periphery (i.e., the easiest locations to measure). From a water temperature perspective this is not ideal as the potential arises (however unlikely that it is) that changes could occur between the diversion point and the logger location. This concern is further compounded by the fact that there was no formal quality documentation for the work (personal communication, H. Sessoms, 2006). Hence a quality assurance (QA) assessment was completed to ensure this data met our requirements.

B3.2 QUALITY ASSESSMENT OF PREVIOUSLY COLLECTED DATA

The first phase of QA consisted of completing spot checks of temperature at several locations during the fall of 2005. A Horiba Water Quality Checker U-10 (accuracy ±0.5°F) was used. Field measured temperatures were correlated with the date and time of the datalogger recording for comparison. Results are shown in **Figure B3-1** (Left panel). As evidenced by the good correlation between field temperature and recorded temperature at the logger, the MSU data appears to have good accuracy and precision over the study reach. Sites that received field QA included: (1) Beaverhead River at Madison

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[2] These are the two primary sources for such flow measurement activities.

County Fairgrounds, (2) Jacobs Slough, (3) Ruby River, (4) Greenhouse Slough, (5) East Bench 41-2 Lateral Wasteaway, (6) Beaverhead River at Giem Bride, (7) Spring Creek, (8) California Slough, (9) Schoolhouse Slough, (10) Owsley Slough, (11) Coop Ditch, and (12) Beaverhead River at Anderson Lane Bridge.

Table B3-1. Overview of the monitoring locations on Beaverhead River in 2005.

Site Type	Agency	Locations
Mainstem River	USGS USGS MSU USGS MSU/BOR MSU	Beaverhead River at Barretts MT Beaverhead River at Dillon MT Beaverhead River at Anderson Lane Bridge Beaverhead River near Twin Bridges MT Beaverhead River at Giem (Silverbow Lane) Bridge Beaverhead River at Twin Bridges (Madison County Fairgrounds)
Tributaries	MSU MSU MSU MSU MSU MSU MSU MSU MSU MSU MSU MSU	Poindexter Slough Stone Creek near Highway 41 bridge Trout Creek near Point of Rocks California Slough near Silverbow Lane Spring Creek near Silverbow Lane East Bench 41-2 lateral waste way Baker Ditch waste way/Redfield Lane Ditch Schoolhouse Slough at Highway 41 crossing Owsley Slough at Highway 41 crossing Greenhouse Slough at East Bench Road Ruby River at East Bench Road bridge Jacob's Slough at East Bench Road
Diversions	EBID CCWC MSU MSU MSU MSU MSU MSU MSU MSU MSU MSU MSU MSU MSU MSU MSU	East Bench Canal Canyon Canal Smith-Rebich Canal below Barrett's gauging station Outlaw Ditch at Barrett's Diversion Dam Perkins Ditch at Barrett's Diversion Dam Horton Haines Ditch Van Camp Ditch Poindexter Slough Diversion Westside Canal Selway Slough/Ditch Horton Haines Ditch Bishop Ditch 1872 Ditch Brown Ditch Co-op Ditch near Point of Rocks Muleshoe Canal Baker Ditch

BOR = Bureau of Reclamation, CCWC = Canyon Canal Water Company, EBID = East Bench Irrigation District, MSU = Montana State University, USGS = U.S. Geological Survey

A similar correlation was made between the USGS temperature monitor on the mainstem river and the Co-op ditch Tru-track (very close proximity to the USGS gage) in order to verify that the logger temperature (even though some distance from the river) is similar to that of the mainstem river (**Figure B3-1**, Right panel). In this instance, there seems to be a potential issue due to a consistent positive bias.

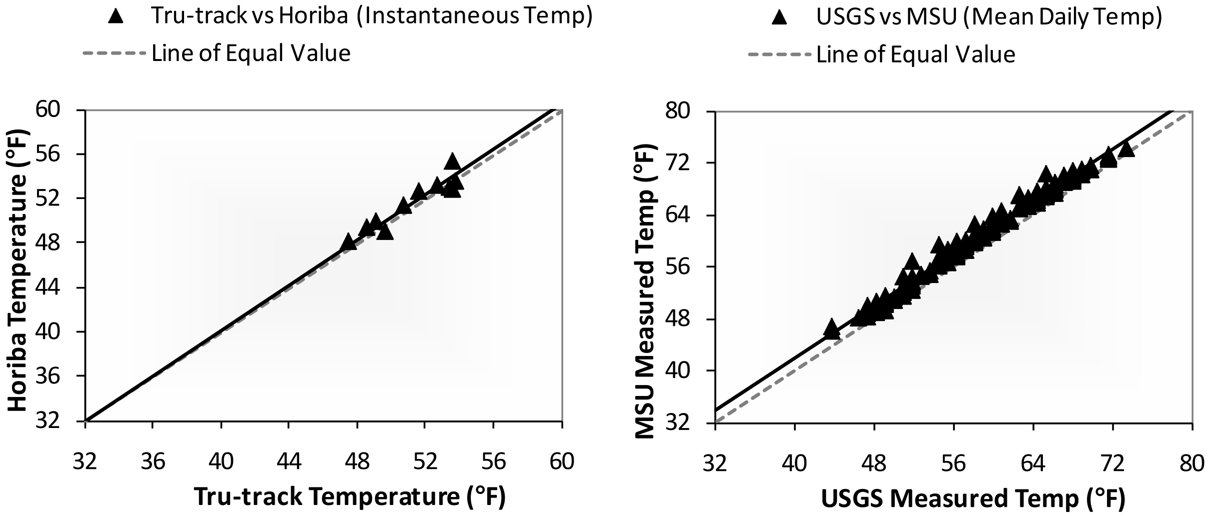

Figure B3-1. Temperature QA comparisons for the Beaverhead River
(Left panel). MSU Tru-track vs. DEQ Horiba at multiple sites. (Right panel) MSU Tru-track vs. USGS gage.

After further review of the data supporting **Figure B3-1** (Right panel), it was identified that the MSU comparison site (Co-op canal) had a hot spring in it (i.e., 80°F in October noted by field personnel). It therefore is a poor comparison site. Consequently we cannot verify our assumption whether outgoing ditch temperatures truly reflect the mainstem river. We will address this concern later through the use of the model. To correct the Co-op Tru-track site, we did a simple adjustment as shown in **Figure B3-2** which required a constant shift of -2°F.

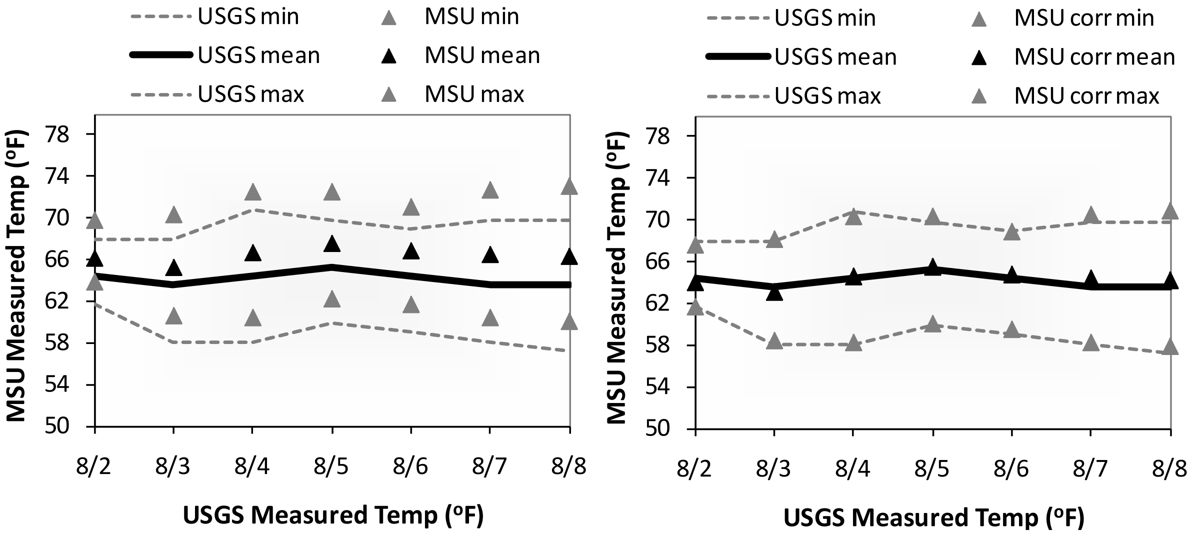

Figure B3-2. Correction of Co-op canal data for influence of hot spring
(Left panel). Uncorrected Co-op canal data. (Right panel). Corrected data.

QA of the flow data is shown in **Figure B3-3**. We compared daily USGS, BOR, and MSU flow measurements. Most discharge measurements appear to be reasonable according to the line of equal value as only minor deviations occur between USGS and BOR observations[3]. For example, residuals were not greater than 15% at any time which indicate a suitable fit (Sauer and Meyer, 1992). Deviation between the MSU and BOR data, however, is more concerning. MSU discharge estimates at Anderson Bridge are nearly 40% different than the BOR data[4]. Giem Bridge provided much better results (approximately 15% low) somewhat affirming the quality of the data.

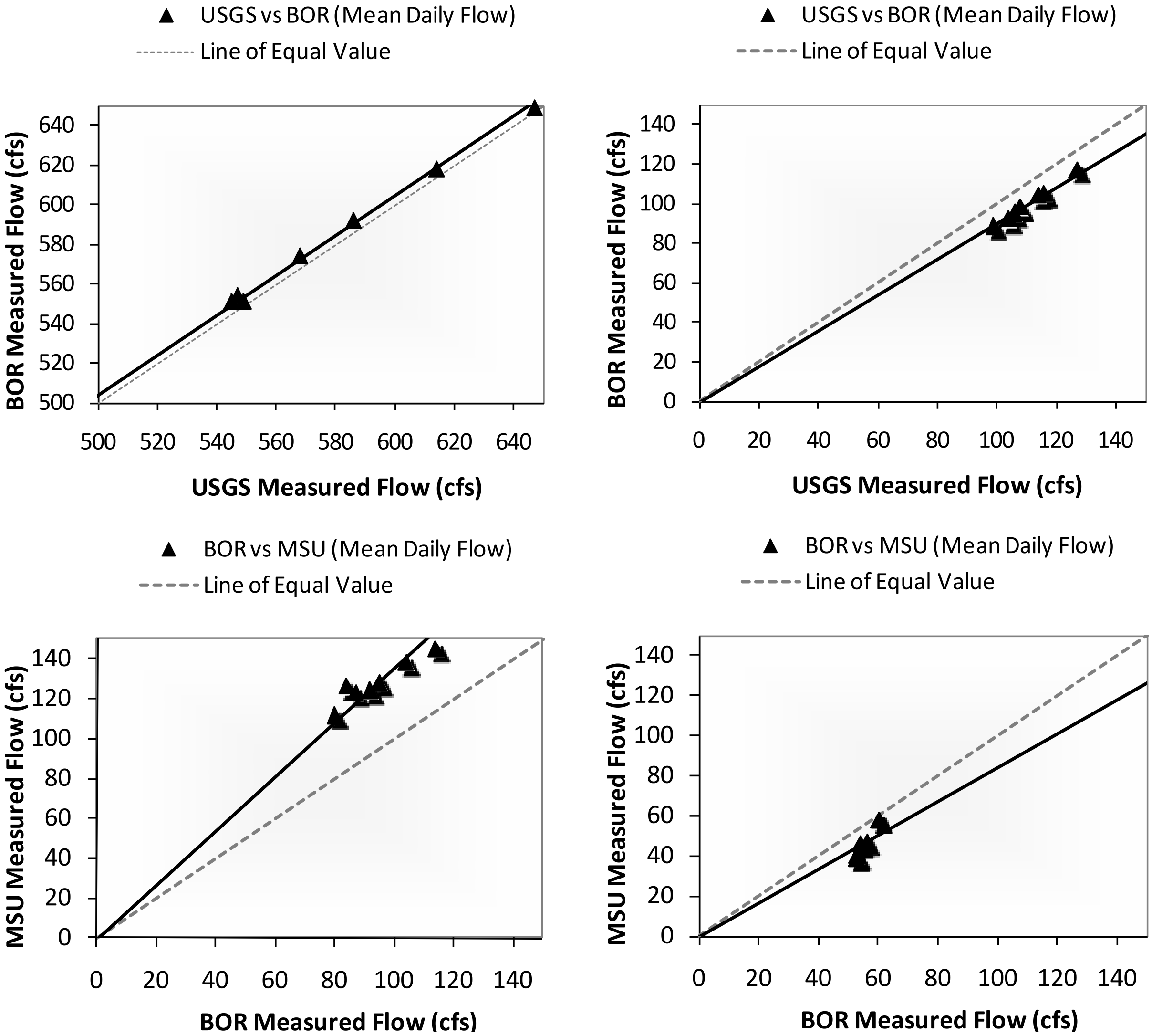

Figure B3-3. Quality assessments between USGS, BOR, and MSU discharge measurements
(Top left and right panels). Comparisons between Barretts and Twin Bridges for USGS and BOR sites. (Bottom left and right panels). Same but between MSU and BOR for Anderson and Giem Bridge.

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[3] Mean daily discharge for these locations were obtained electronically via the National Water Information System (NWIS) and BOR Hydromet websites (U.S. Geological Survey, 2006; U.S. Department of the Interior, Bureau of Reclamation, 2006b).

[4] This site had nuisance weeds/algae which apparently interfered with the flow measurement.

B3.3 SUMMARY

Based on the data in this section (in regard to both temperature and flow), DEQ feels comfortable in proceeding with the modeling assuming that the concerns and limitation of the data are adequately addressed in their use. As such, any questionable information will be scrutinized and validated prior to use. In cases of unexplainable or grossly erroneous data, these will be removed from the analysis entirely. Any data concerns from this point on will be noted in the text.

B4.0 MODELING APPROACH

DEQ selected a mechanistic modeling approach to evaluate the relationship between management activities and water temperature on the Beaverhead River. The enhanced river quality model QUAL2K (Q2K) was selected for analysis due to a number of reasons including its frequency in application for TMDL planning, fairly standardized heat flux algorithms, and endorsement by EPA (Rauch et al., 1998; Wool, 2009). Shadev3.0 was used as a companion model to identify hourly changes in shade from topographic and riparian shade. Each tool is briefly described in this section.

B4.1 QUAL2K DESCRIPTION

Q2K is a steady-state one-dimensional river model that simulates the movement of water and heat flux in completely mixed systems. It is applicable to rivers where the major transport mechanisms of advection and dispersion are significant along the longitudinal direction of flow, with the assumption that lateral and vertical water temperature gradients are negligible. By operating the model in a quasi-dynamic mode, the user has the ability to study the diurnal variation of temperature on an hourly or sub-hourly time scale. Q2K allows multiple waste discharges, withdrawals, tributary flows, and incremental inflow and outflow to be positioned anywhere along the channel, and includes sediment heat flux routines and reach variable meteorology. Consequently it is a significant improvement over the original QUAL2E model (Brown and Barnwell, Jr., 1987). Q2K is limited to periods where both streamflow and input heat loads are steady-state and input data requirements are shown in **Table B4-1**.

Table B4-1. QUAL2K input requirements

Data Type	Input Requirement[1]
Meteorology	1. Hourly air temperature 2. Hourly dew point temperature 3. Hourly wind speed 4. Hourly percent cloud cover 5. Atmospheric turbidity coefficient 6. Reach latitudes and longitudes
Hydrology	1. Discharge data for headwaters, and point and nonpoint sources 2. Temperature data for headwaters, and point and nonpoint sources
Hydraulics	1. Stream network configuration 2. Reach lengths and elevations 3. Transport function (rating curves, etc.)
Shade	1. Hourly percent shade for each reach

[1] Most of the input variables in **Table 4-1** can readily be acquired through existing field measurement programs. Their use in development of the model are described in **Section B5.0**.

B4.2 CONCEPTUAL REPRESENTATION

A river in Q2K is represented as a series of reaches and elements where point sources (e.g., tributaries) and nonpoint source inflows (e.g., groundwater) or withdrawals are present (**Figure B4-1**). Reaches are homogeneous stretches of river that have similar aspect, shading, or hydraulic characteristics, whereas the element is the fundamental computational unit of the model. Reach stationing determines the placement of the point and nonpoint source inflows. Additional information regarding Q2K can be found in Chapra, et al., (Chapra et al., 2008b).

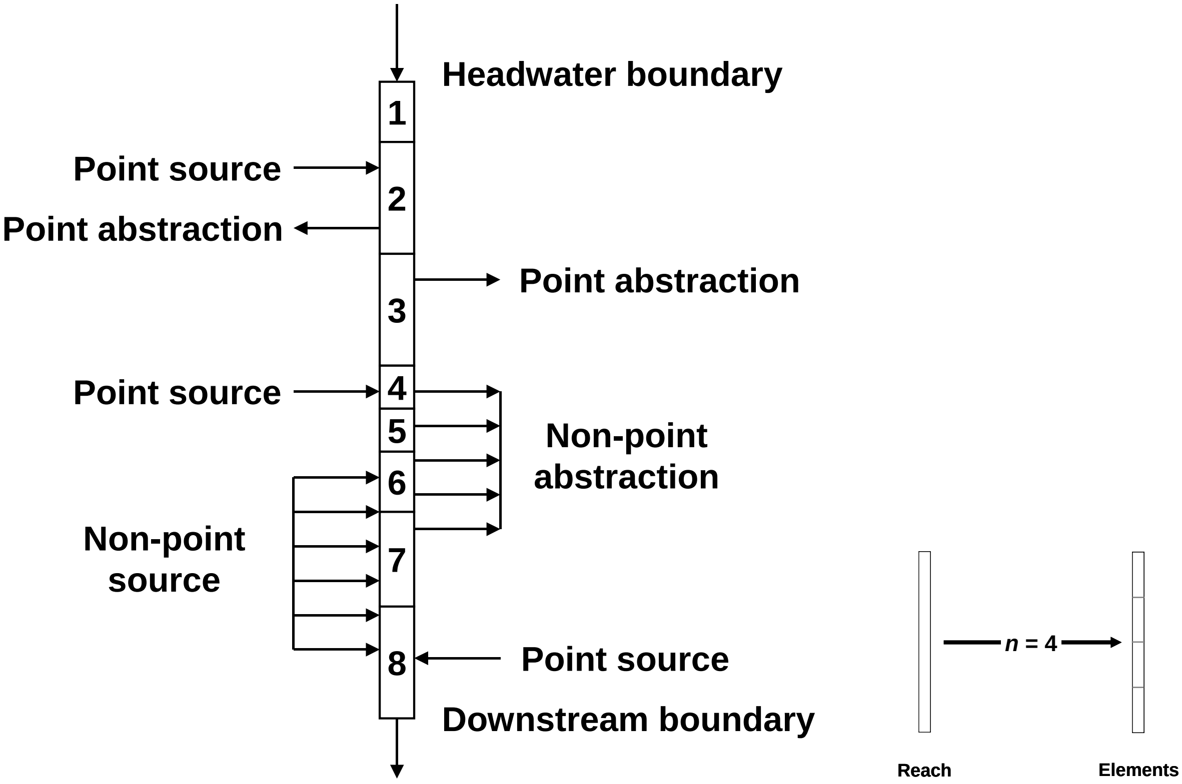

Figure B4-1. Conceptual representation of a river reach within QUAL2K

Taken from Chapra, et al., (2004). Please refer to the modeling documentation for further discussion.

B4.3 HEAT BALANCE

The heat balance in Q2K is written as **Equation B4-1**, where for each control volume i (an element) the change in temperature T_i [^{o}C] is computed according to t = time [d], E'_i = the bulk dispersion coefficient between reaches i and $i + 1$ [m^3/d], $W_{h,i}$ = the net heat load from point and nonpoint sources into reach i [cal/d], ρ_w = the density of water [g/cm^3], C_{pw} = the specific heat of water [cal/(g ^{o}C)], $J_{h,i}$ = the air-water heat flux [cal/(cm^2 d)], and $J_{s,i}$ = the sediment-water heat flux [cal/(cm^2 d)] (Chapra et al., 2008b). This is shown graphically in **Figure B4-2**.

(Equation B4-1)

$$\frac{dT_i}{dt} = \frac{Q_{i-1}}{V_i} T_{i-1} - \frac{Q_i}{V_i} T_i - \frac{Q_{ab,i}}{V_i} T_i + \frac{E'_{i-1}}{V_i}\left(T_{i-1} - T_i\right) + \frac{E'_i}{V_i}\left(T_{i+1} - T_i\right)$$
$$+ \frac{W_{h,i}}{\rho_w C_{pw} V_i}\left(\frac{\mathrm{m}^3}{10^6\ \mathrm{cm}^3}\right) + \frac{J_{h,i}}{\rho_w C_{pw} H_i}\left(\frac{\mathrm{m}}{100\ \mathrm{cm}}\right) + \frac{J_{s,i}}{\rho_w C_{pw} H_i}\left(\frac{\mathrm{m}}{100\ \mathrm{cm}}\right)$$

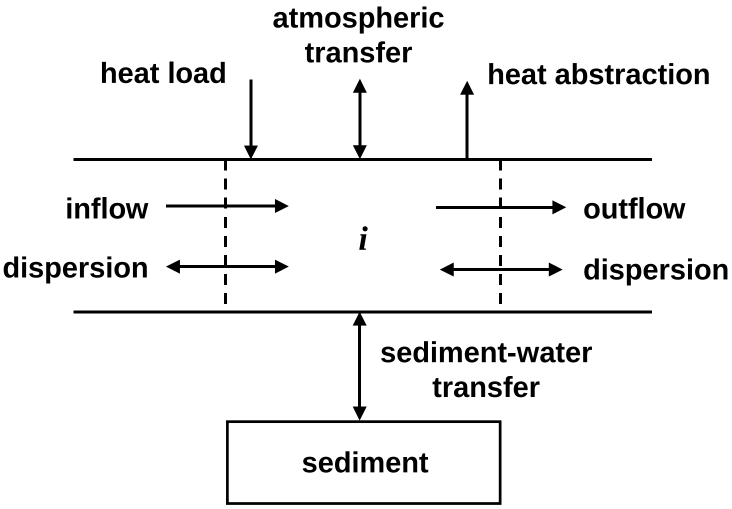

Figure B4-2. Graphical representation of the heat balance within a Q2K model element
Reproduced from Chapra, et al., (Chapra et al., 2008b).

The surface heat exchange is modeled as a combination of five processes including solar shortwave radiation, atmospheric longwave radiation, conduction from air and sediments, and advective heat input from water inflows. This is shown in **Equation B4-2**, where *I*(0) = net solar shortwave radiation at the water surface, J_{an} = net atmospheric longwave radiation, J_{br} = longwave back radiation from the water, J_c = conduction, and J_e = evaporation. All fluxes are expressed as cal/cm^2/d.

(Equation B4-2) [5]

$$J_h = I(0) + J_{an} - J_{br} - J_c - J_e$$

A graphical rendition of surface heat exchage is also shown in **Figure B4-3**. Heat losses include longwave radiation, conduction to air and bed sediments, and evaporation and outflow from the river. Heat gains include both radiation and non-radiation terms.

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[5] Shortwave radiation within the model is determined as a function of latitude and longitude of the modeled reach. It is attenuated by atmospheric transmission, cloud cover, reflection, and topographic and vegetative shading. Water and atmospheric longwave radiation are calculated according to the Stefan-Boltzmann law and conduction and evaporation are calculated using the Brady, Graves, and Geyer method and Dalton's Law (Chapra et al., 2008b). Air and water temperature, wind speed, and the saturation vapor pressure (relative humidity) are all required as well.

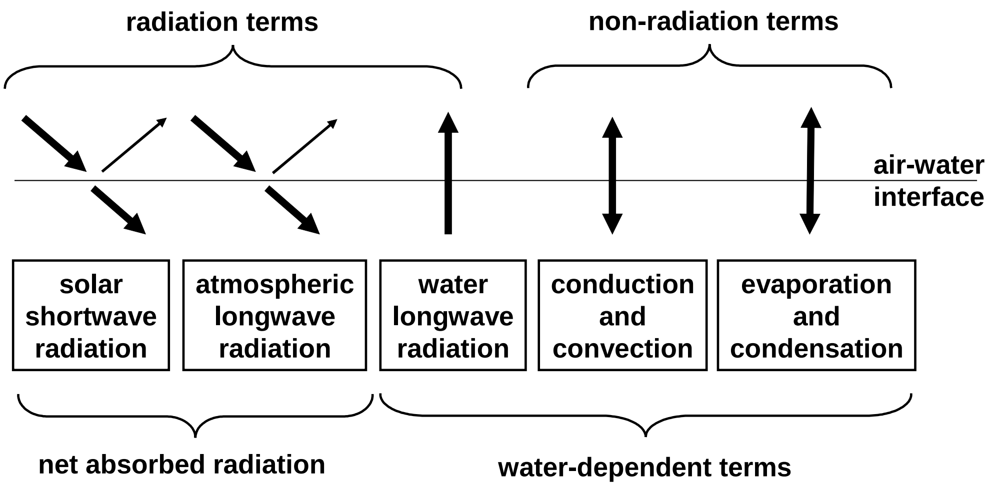

Figure B4-3. Surface heat exchange in Q2K model
Reproduced from Chapra, et al., (2008b)

B4.4 ASSUMPTIONS AND LIMITATIONS

Q2K has a number of assumptions and limitations. Those critical to temperature assessment such as in the Beaverhead River include the following:

- Negligible water temperature gradients (i.e., the channel is assumed to be well-mixed both vertically and laterally).
- Steady flow and heat load conditions (i.e., river hydrology, hydraulics, and boundary conditions are assumed to be steady state).
- Diurnally uniform meteorological forcings (i.e., climatic conditions are assumed uniform over the project reach both spatially and temporally).

A final assumption implicit in the model is that diversion water temperatures measured by MSU are representative of the temperature of the Beaverhead River (in order to calibrate the model). We were unable to prove this in **Section B3.2**. However the assumption is valid given the relative proximity of these sites to the diversion point from the river. We provide further justification in **Section B6.0**.

B4.5 SHADE MODEL (SHADEV3.0.XLS)

Shade for Q2K was simulated in Shadev3.0.xls. This software is a visual basic for applications package developed by the Oregon Department of Environmental Quality and adapted by Washington Ecology (Pelletier, 2007) to determine shade from both topography and vegetation using solar time and position, aspect, position, and vegetation characteristics of a channel (**Figure B4-4**). Required field data for the shading calculation include: (1) tree canopy height, (2) density, (3) overhang, (4) stream reach aspect, (5) wetted channel width, (6) near stream disturbance zone (NSDZ) width, (7) channel incision, and (8) topographic shading (**Table B4-2**). These values were collected by a DEQ contractor in 2009.

Similar to Q2K, Shadev3.0.xls has a number of assumptions. These include: (1) that vegetative parameters (tree height, density, and overhang) are considered uniform over the project reach for a particular species type and age class (2) that calculation of solar position (e.g. azimuth and altitude) is accurate for each Julian day at the respective modeling latitude and longitude, and (3) that topographic angle can accurately be estimated using ArcGIS viewshed. Further information regarding Shadev3.0.xls can be found in Boyd and Kasper (2003) and Pelletier (2007).

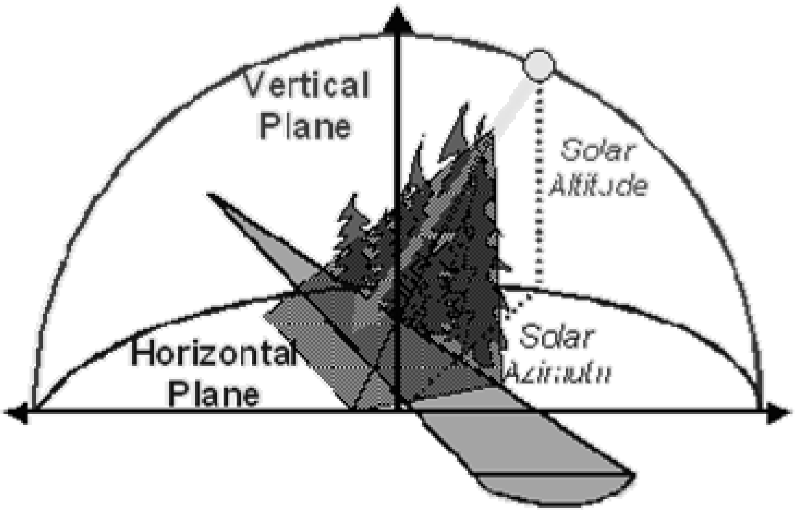

Figure B4-4. Conceptual representation of Shadev3.0.xls
Diagram taken from Boyd and Kasper (2003).

Table B4-2. ShadeV3.0.xls model input requirements.

Data Type	Specific Input Requirement
Solar Position	1. Latitude and longitude of reach 2. Date and time
Stream Morphology	1. Aspect 2. Channel width 3. Near stream disturbance zone (NSDZ) width 4. Incision
Vegetation	1. Canopy height 2. Canopy density 3. Overhang
Geographic	1. Topographic angle

B5.0 MODEL SETUP AND DEVELOPMENT

The Q2K model setup and development is described in this section. Included is a brief summary of the analysis period, details on the physical model construction, and other information related to model development.

B5.1 MODELING ANALYSIS PERIOD SELECTION

The analysis period was based on critical limiting conditions (i.e., the time of year when temperature impairment is most likely to occur). Review of 5 years of temperature data at USGS 06018500 Beaverhead River near Twin Bridges gage (2000-2004) suggests this period occurs somewhere between July and August (**Figure B5-1**, left panel). Temperature data collected during 2005 (the year the model will be developed) corroborate these findings (**Figure B5-1**, right panel). Accordingly, the period of

August 4-7, 2005 was used for Q2K development, at or when conditions are likely to impair water temperature.

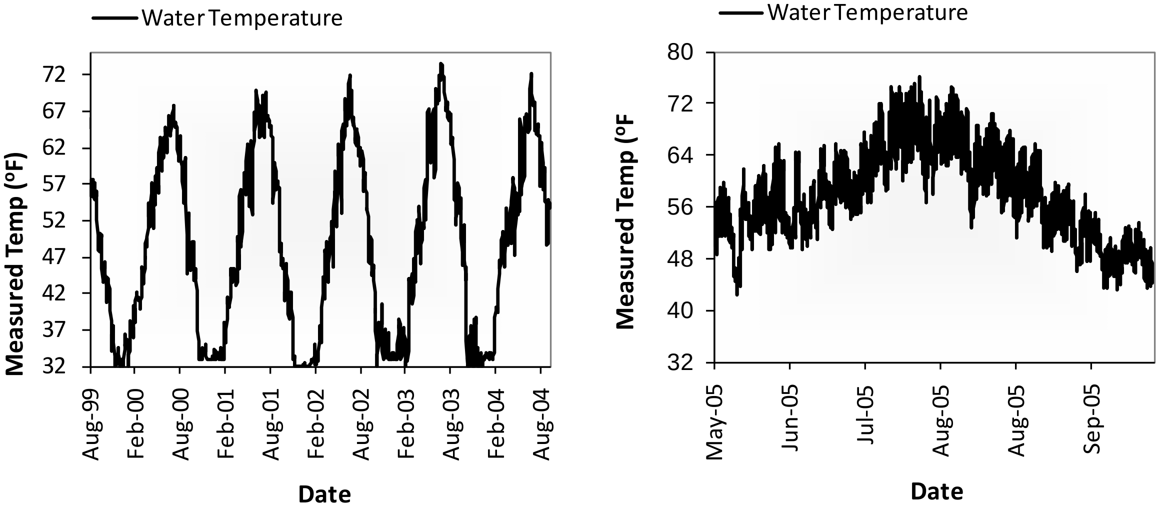

Figure B5-1. Water temperature data used to determine the model analysis period
(Left panel). USGS temperature data from 1999-2004. (Right panel) Data from 2005 at Anderson Bridge. The most critical limiting period occurs sometime in July or August.

Data were then compiled over the period of interest. MSU discharge data were readily available in MS Excel spreadsheets and required very little reduction. USGS, BOR, and NOAA data were downloaded from each agency's website and assembled into individual data files. All units were converted to standard international (S.I.) and were aggregated into a format for modeling (i.e., mean repeating day time-series which are consistent with the requirements of Q2K). In other words, input data were averaged over the study period into a single daily time-series of climate, discharge, and temperature.

B5.2 COMPARISON WITH HISTORICAL CONDITIONS

A comparison of the analysis period with historical conditions is shown in **Figure B5-2**. Both climate (as represented by mean daily air temperature and precipitation) and streamflow (as annual hydrograph) were evaluated. The meteorological conditions during August were very similar to that of the climatic normals (1970-2001) (National Oceanic and Atmospheric Administration, 2011) (**Figure B5-2**, left) and streamflow was below average, between the 5th and 25th percentile. Thus the conditions are very close to those that would be expected during critical low flow conditions.

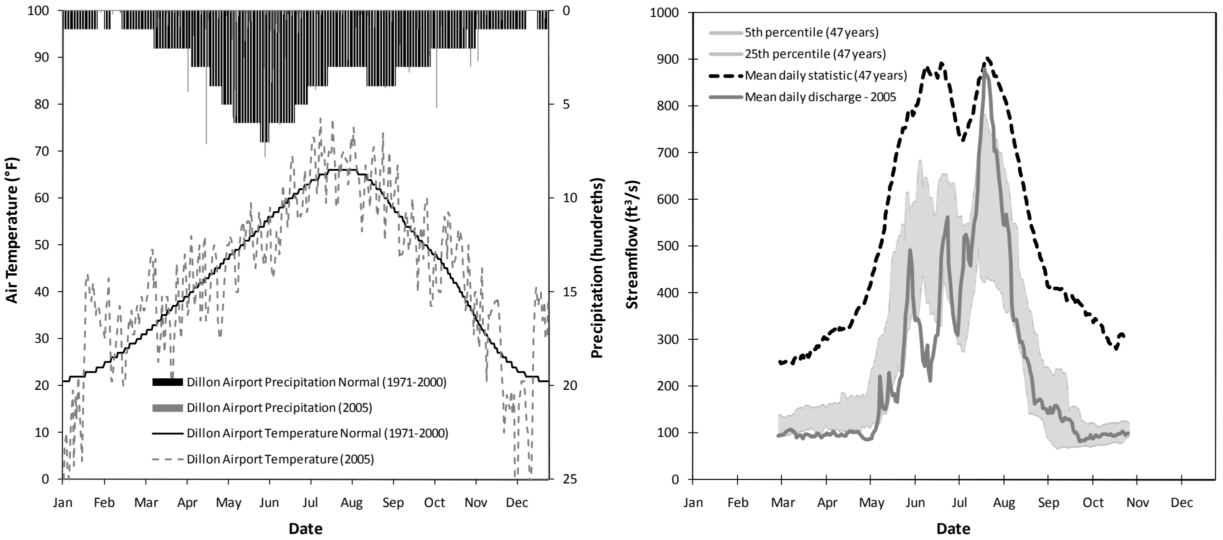

Figure B5-2. Conditions encountered during 2005 compared to historical data
(Left panel) Climatological data. (Right panel) Streamflow hydrology. For flow, only March through October is shown as the gage was not operated during the winter months for most of the period of record.

Water temperature data for this period is shown in **Figure B5-3**. Upon examination, a number of general interpretations can be made. First, temperatures are fairly similar in the mainstem river, but show a slight increase from approximately 65°F at Barretts to 68°F near Twin Bridges (mean daily temperatures are reported in the figure). On the whole, incoming tributaries tend to be cooler than the river, whereas the sloughs and Ruby River (in the lower watershed) are nearly the same temperature or perhaps slightly cooler. Probably the biggest difference in the figure is flow. Mean daily discharges ranges from over 550 ft^3/s in the upper river to nearly 50 ft^3/s in the lower reaches. From up- to down-stream, the profile is characteristic of heavy irrigation depletion followed by a number of irrigation returns. Slough inflow from Spring Creek, California Slough, Schoolhouse Slough, Charlton Slough, Greenhouse Slough, etc. (most of these are from the Big Hole River) and the Ruby River nearly quadruple the flow over a very short extent. This perhaps somewhat attenuates the temperature effect.

Additionally from **Figure B5-3** it should be apparent that ascertaining the relationship between river management and water temperature from simply looking at data is difficult. While a 3°F increase in water temperature does occur (in combination with flow depletion), we have no way of knowing whether the increase is natural or human-caused, or the extent thereof. Water quality models will therefore be used to: (1) better formalize the mechanistic relationship between variables such as flow, water temperature, and others, (2) determine whether this increase in temperature is natural or anthropogenic, (3) understand the cause-effect relationships of management activities and observed stream temperature, and (4) provide recommendations, if any, that can be implemented to meet the temperature standard in the river.

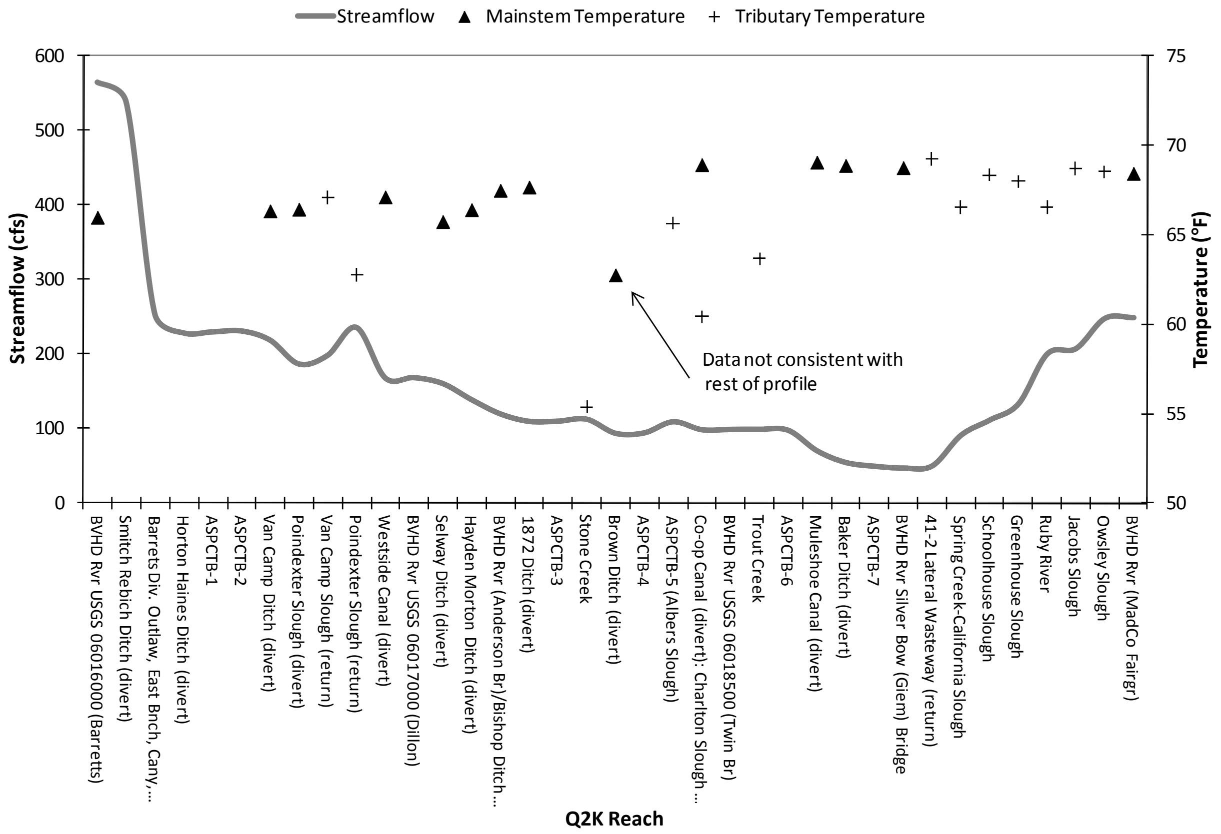

Figure B5-3. Longitudinal discharge and water temperature relationships for the Beaverhead River. Water temperature data are reflective of the mean daily temperature.

B5.3 MODEL PHYSICAL DESCRIPTION AND SEGMENTATION

The Beaverhead River Q2K model reflects the physical mechanics of advection and dispersive heat transport for the river. The model was segmented to describe: (1) major inflows and outflows identified by Sessoms and Bauder (2005), (2) the USGS and BOR gage sites, (3) aspect and vegetation breaks, and (4) other important features identified by DEQ. In total, 36 reaches were discretized with an average approximate reach length of three miles. These are shown in **Figure B5-4** (Left panel). They also coincide with the Q2K reaches shown in **Figure B5-3**.

Although 36 different reaches were identified (as indicated by the dark black lines on the river plan drawing) there was insufficient information to describe all of these hydraulically. The paucity of river width and depth data necessitated a much simpler hydraulic representation. As a result only 3 generalized hydraulic regions were used which correspond to the USGS gaging sites (also shown in **Figure B5-4**, Left panel). The stationing of tributaries, other inflows, and outflows is shown in **Figure B5-4** (Right panel). These are more directly addressed in **Section B5.5**. More information on the model hydraulics is contained within **Section B5.6**.

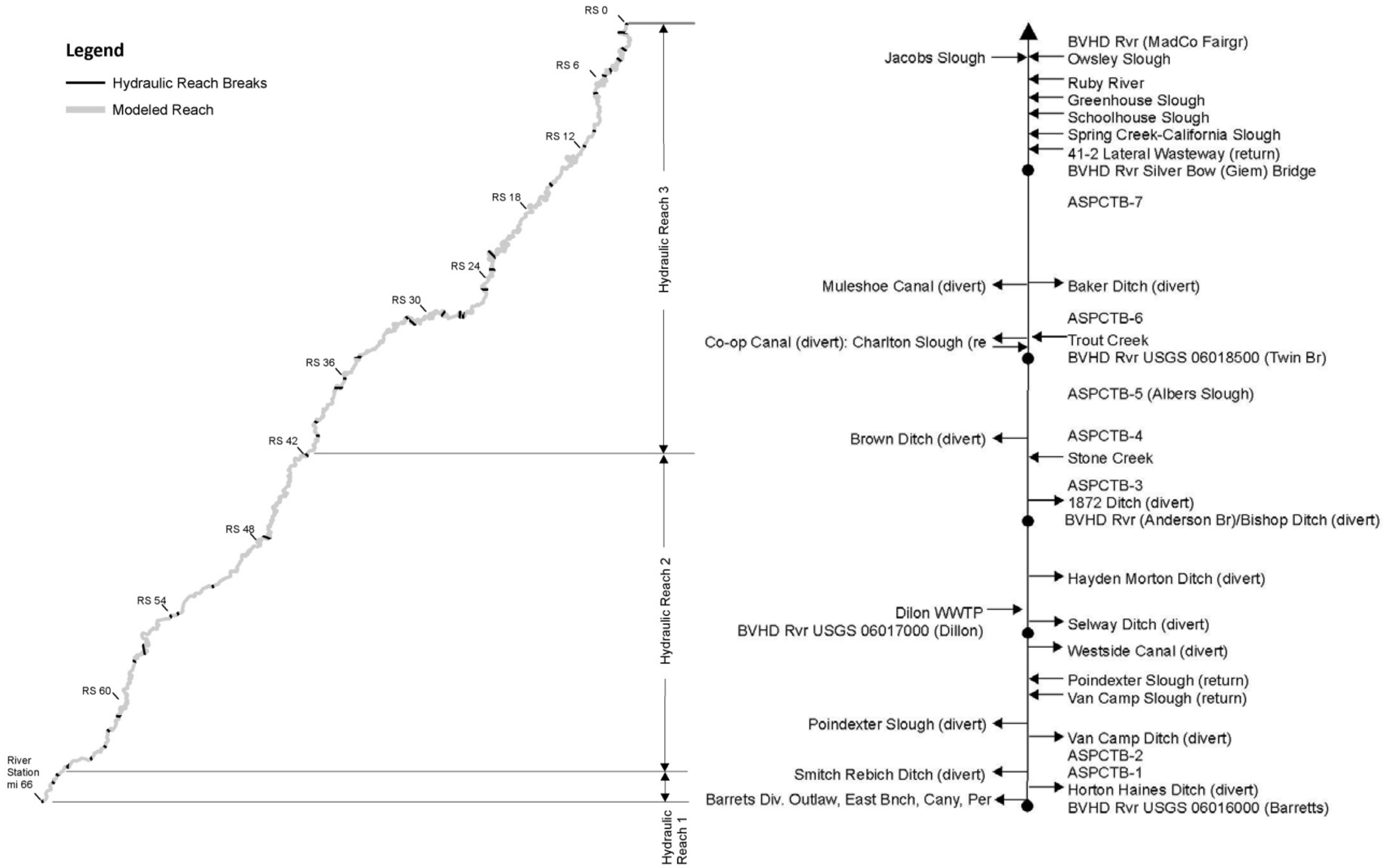

Figure B5-4. Q2K model segmentation and spatial inflow/outflow summary for Beaverhead River.

(Left panel) Model segmentation and hydraulic reach assignments for the Q2K model (based on USGS gages). (Right panel) Inflow outflow summary where inflows are denoted with an incoming arrow, outflow as outgoing arrows, and circles as mainstem river gage sites. The side in which the inflow or outflow originates on the figure (i.e., left/right) has no physical meaning.

B5.4 METEOROLOGICAL DATA

Q2K requires hourly meteorological data to calculate diurnal heat flux within the model. Four sites have requisite data. These are: (1) ASOS 242404 Dillon, MT, (2) Dillon Valley Agrimet, (3) Ruby Valley Agrimet, and (4) Jefferson Valley Agrimet. Hourly observations of temperature, wind speed, and dew point were available from each location and are shown in **Figure B5-5**. They were averaged[1] to provide mean repeating day input for Q2K (**Figure B5-6**).

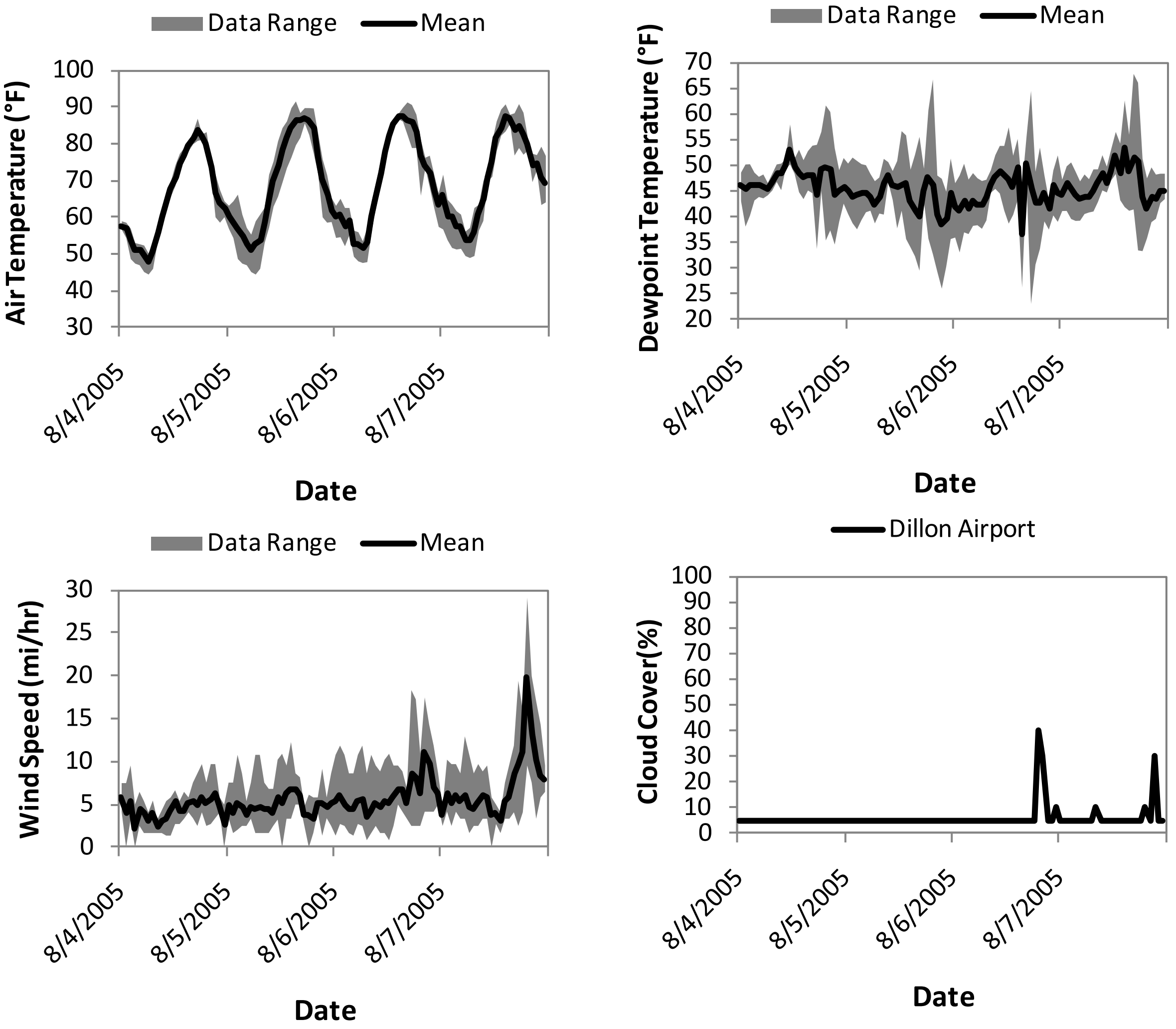

Figure B5-5. Hourly meteorological data summary for August 4-7th, 2005 summer period. (Top left/right panel). Air and dew point temperature [°F]. (Bottom left/right panel). Wind speed [mi/hr] and cloud cover [%]. It should be noted that the model actually requires input in SI units.

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[1] All sites were within close proximity to the watershed, therefore the average of the four sites were used. Only one site, (Dillon ASOS) had information regarding cloud cover.

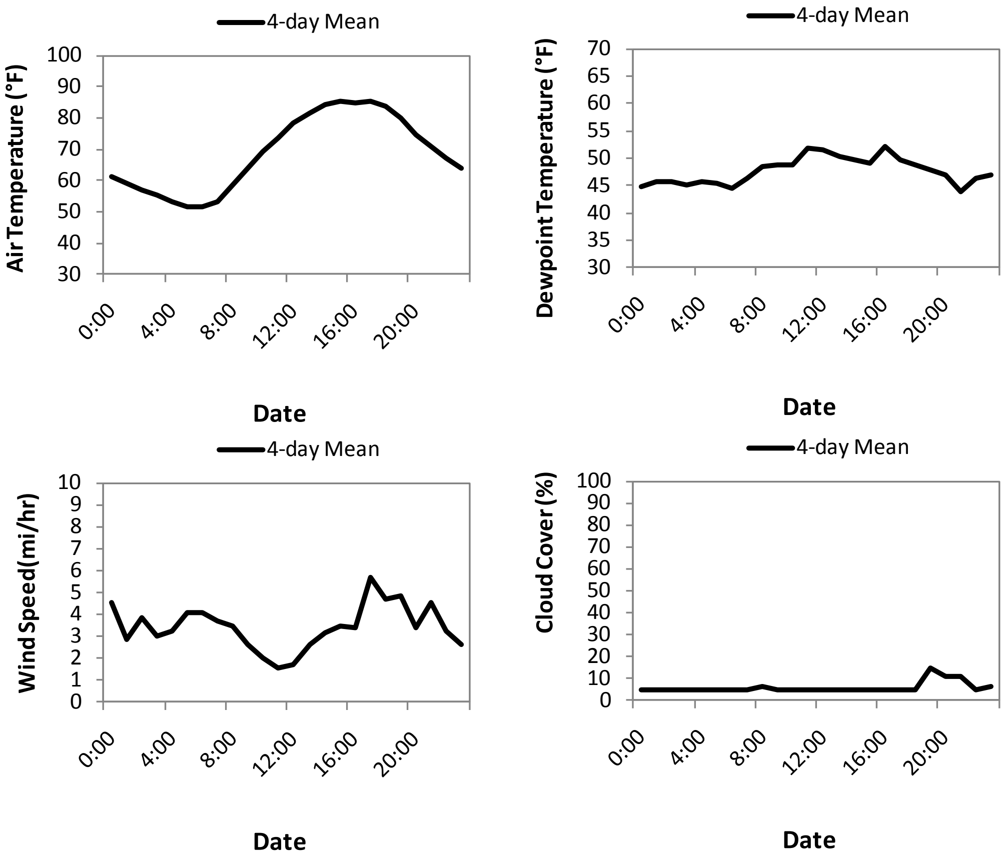

Figure B5-6. Mean repeating day meteorological data summary for August 4-7th, 2005 summer period. These data reflect the aggregation of the time-series in **Figure B5-5**. In other words, values at 6:00 a.m., 7:00 a.m., and so on were averaged to provide a single day's time-series.

Wind speed data were corrected to an appropriate height using the power-law profile (Linsley et al., 1982) (**Equation B5-1**), where: v = mean wind speed at conversion height, v_1= measured wind speed at some standard height, z = conversion height, z_1 = standard measurement height, and k = exponent.

$$\frac{v}{v_1} = \left(\frac{z}{z_1}\right)^k$$

(Equation B5-1)

The height of the anemometer at Dillon is 33 ft (10 m) (personnel communication, National Weather Service, Great Falls, 2006). Agrimet sensor heights are approximately 6.5 ft (2 m) (personal communication T. Grove, BOR, 2006). A value of k= 0.18 was used for the Dillon ASOS (airport) and 0.25 for the AgriMet sites (grass field) to make the adjustment to the 7 meter height required by Q2K.

B5.5 HYDROLOGY

A steady-state flow balance was used to define the hydrology in the model (**Equation B5-2**), where Q_i = outflow from reach i into reach i + 1 [m^3/d], Q_{i-1} = inflow from the upstream reach i – 1 [m^3/d], $Q_{in,j}$= total inflow into the reach from point and nonpoint sources [m^3/d], and $Q_{ab,i}$= total outflow from the reach due to point and nonpoint abstractions [m^3/d]. All major inflow and outflow components were field measured. A graphical version of this balance is shown in **Figure B5-7**.

(**Equation B5-2**)

$$Q_i = Q_{i-1} + Q_{in,i} - Q_{ab,i}$$

Inflow and outflow locations in the water balance were based on the channel centerline digitized by DEQ using aerial photography from 2005 National Agriculture Imagery Program (NAIP) while nonpoint sources and abstractions were modeled as line sources. A tabular version of the water balance for the model analysis period is shown in **Table B5-1**.

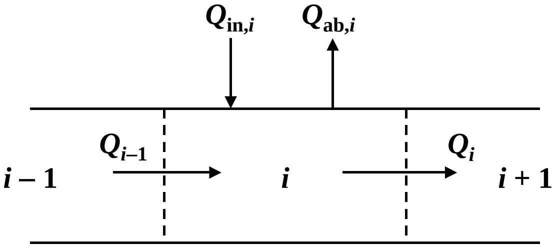

Figure B5-7. QUAL2K steady-state water balance for a given element.
Reproduced from Chapra, et al., (2008a).

Table B5-1. Beaverhead River steady-state water balance.
Data for the period of August 4-7th, 2005.

Location	Description	Surface Water (m^3/s)[1]	Groundwater (m^3/s)
BVHD00	Observed - BVHD Rvr USGS 06016000 (Barretts)	564.6	17.8
BVHD01	Smith Rebich Ditch (divert)	-27.7	
BVHD02	Barretts Diversions (divert)	-285.4	
BVHD03	Horton Haines Ditch (divert)	-25.7	
BVHD04	ASPCTB-1	0	
BVHD05	ASPCTB-2	0	
BVHD06	Van Camp Ditch (divert)	-13.2	
BVHD07	Poindexter Slough (divert)	-33.1	
BVHD08	Van Camp Slough (return)	6.9	
BVHD09	Poindexter Slough (return)	36.2	
BVHD10	Westside Canal (divert)	-72	
TOTAL		150.6	
BVHD11	Observed - BVHD Rvr USGS 06017000 (Dillon)	168.4	
*Includes Outlaw, East Bench, Canyon Canal, and Perkins Diversions			
BVHD12	Selway Ditch (divert)	-5.4	-15.7
BVHD13	Hayden Morton Ditch (divert)	-16.5	
++++++	Bishop Ditch (divert)	-11.1	
TOTAL		135.4	
BVHD14	Observed - BVHD Rvr (Anderson Br)	119.7	
*Bishop ditch diversion occurs directly upstream of Anderson Bridge			

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[1] Recall that all flow estimates were based on the MSU water balance during 2005 (Sessoms and Bauder, 2005).

Table B5-1. Beaverhead River steady-state water balance.
Data for the period of August 4-7th, 2005.

Location	Description	Surface Water (m^3/s)[1]	Groundwater (m^3/s)
BVHD15	1872 Ditch (divert)	-10.5	5.5
BVHD16	ASPCTB-3	0	
BVHD17	Stone Creek	1.7	
BVHD18	Brown Ditch (divert)	-19.1	
BVHD19	ASPCTB-4	0	
BVHD20	ASPCTB-5 (Albers Slough)	13.5	
BVHD21	Co-op Canal (divert)	-23.6	
++++++	Charlton Slough (return)	11.6	
TOTAL		93.4	
BVHD22	Observed - BVHD Rvr USGS 06018500 (Twin Br)	98.9	
*Charlton Slough Return occurs directly downstream of the Co-op Canal			
BVHD23	Spring-Trout Creek	0.4	-10.9
BVHD24	ASPCTB-6	0	
BVHD25	Muleshoe Canal (divert)	-26.5	
BVHD26	Baker Ditch (divert)	-14.8	
BVHD27	ASPCTB-7	0	
TOTAL		58.0	
BVHD28	Observed - BVHD Rvr Silver Bow (Giem) Bridge	47.0	
BVHD29	41-2 Lateral Wasteway (return)	1.5	18.2
BVHD30	Spring Creek-California Slough-Redfield Ditch	36.7	
BVHD31	Schoolhouse Slough	16.9	
BVHD32	Greenhouse Slough	20.5	
BVHD33	Ruby River	64.4	
BVHD34	Jacobs Slough	5.3	
BVHD35	Owsley Slough	38.2	
TOTAL		230.6	
BVHD36	Observed - BVHD Rvr (MadCo Fairgr)	248.9	

$BVHD_{ij}$ is the Beaverhead reach number in the Q2K model
ASPCTB denotes reach break due to aspect change

B5.6 HYDRAULICS

The movement of water through the model was represented using rating curves[1]. These relate mean velocity and depth to discharge in the form of a power equation (**Equation B5-3** and **Equation B5-4**), where H=depth [m] and U=velocity [m/s] are related to discharge (Q)[m/s] through the empirical coefficients and exponents a and b and α, and β [all unitless].

Equation B5-3. $U = aQ^b$

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[1] The rating curve approach was selected for the hydraulic parameterization due the paucity of hydraulic data (cross-sectional geometry, top width, etc.). We regressed discharge with mean channel velocity and width to come up with coefficient and exponent estimates for the river.

Equation B5-4. $H = \alpha Q^{\beta}$

Computed *U* and *H* are then used to determine the cross-sectional area (A_c) and average reach top width (*B*) which are the primary attributes of interest for temperature modeling (**Equation B5-5** and **Equation B5-6**) (Chapra, et al., (2008b)).

Equation B5-5. $A_c = \frac{Q}{U}$

Equation B5-6. $B = \frac{A_c}{H}$

Data to determine the coefficients and exponents described previously are available from the USGS gages (i.e., Barretts [upper], Dillon [middle], and Twin Bridge [lower]). The values *a* and *b* and α, and β were determined through least-square regression and were assigned the hydraulic regions identified previously in **Figure B5-4**. Estimates were found to be consistent with the literature (Barnwell, Jr. et al., 1989; Flynn and Suplee, 2010b; Leopold and Maddock, Jr., 1953) (**Table B5-2**) and the sum of b and β was less than or equal to 1.

Table B5-2. Beaverhead River rating curve coefficients and exponents.

Equation	Exponent	Typical value	Range[1]	Beaverhead Values
$U = aQ^b$	b	0.43	0.4-0.6	Upper=0.43, Middle=0.46, Lower=0.37
$H = \alpha Q^{\beta}$	β	0.45	0.3-0.5	Upper=0.43, Middle=0.35, Lower=0.41

[1]From the following: (Barnwell et al., 1989; Flynn and Suplee, 2010a; Leopold and Maddock, 1953).

We also measured bankfull width and wetted width properties during 2009 (4 sites) to benefit the model calibration. A summary of reach properties determined through this work are shown in **Table B5-3**. Rating curves for the sites are in **Figure B5-8**[1.]

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[1] It should be noted that additional data became available on the river after the initial modeling. This came in the form of a HEC-RAS model developed by the Bureau of Reclamation (BOR) for the purpose of sediment flushing flow analysis. The analysis extent was from Clark Canyon Dam to Barretts (Klumpp, 2010), however the model had insufficient cross-sectional geometry (only three surveyed sections) which were actually provided by DEQ. Since this did not provide any additional information beyond what DEQ had already obtained, we did not use the HEC-RAS information.

Table B5-3. Beaverhead River Q2K reach properties.

Reach ID	Reach Label	Reach Length (mi)	River Station (mi)	Latitude	Longitude	Upstream Elevation (ft)	Downstream Elevation (ft)	Rating Curve Info.			
								U coef	Exp	*H* coef	Exp
BVHD01	Smith Rebich Ditch	1.0	65.3	45.13	112.74	5269	5249	0.18	0.43	0.34	0.43
BVHD02	Barretts, East Bnch, Cany, etc.	0.0	64.9	45.13	112.74	5249	5246	0.18	0.43	0.34	0.43
BVHD03	Horton Haines Ditch	1.0	64.3	45.14	112.73	5246	5243	0.20	0.46	0.46	0.35
BVHD04	ASPCTB-1	1.0	63.3	45.14	112.71	5243	5220	0.20	0.46	0.46	0.35
BVHD05	ASPCTB-2	1.0	62.3	45.15	112.70	5220	5207	0.20	0.46	0.46	0.35
BVHD06	Van Camp Ditch	1.0	61.6	45.15	112.70	5207	5197	0.20	0.46	0.46	0.35
BVHD07	Poindexter Slough	1.0	60.8	45.16	112.70	5197	5184	0.20	0.46	0.46	0.35
BVHD08	Van Camp Slough	4.0	57.2	45.18	112.69	5184	5144	0.20	0.46	0.46	0.35
BVHD09	Poindexter Slough	1.0	56.3	45.20	112.68	5144	5141	0.20	0.46	0.46	0.35
BVHD10	Westside Canal	3.0	53.0	45.21	112.67	5141	5108	0.20	0.46	0.46	0.35
BVHD11	USGS 06017000 (Dillon)	0.0	52.7	45.22	112.66	5108	5098	0.20	0.46	0.46	0.35
BVHD12	Selway Ditch	2.0	50.7	45.50	112.35	5098	5069	0.20	0.46	0.46	0.35
BVHD13	Hayden Morton Ditch	4.0	46.6	45.25	112.61	5069	5020	0.20	0.46	0.46	0.35
BVHD14	Anderson Br/Bishop Ditch	6.0	40.2	45.30	112.58	5020	4954	0.20	0.46	0.46	0.35
BVHD15	1872 Ditch	1.0	39.0	45.31	112.56	4954	4941	0.19	0.37	0.37	0.41
BVHD16	ASPCTB-3	1.0	38.3	45.32	112.56	4941	4928	0.19	0.37	0.37	0.41
BVHD17	Stone Creek	2.0	35.9	45.33	112.55	4928	4905	0.19	0.37	0.37	0.41
BVHD18	Brown Ditch	0.0	35.5	45.34	112.54	4905	4902	0.19	0.37	0.37	0.41
BVHD19	ASPCTB-4	2.0	33.9	45.35	112.53	4902	4882	0.19	0.37	0.37	0.41
BVHD20	ASPCTB-5 (Albers Slough)	4.0	30.2	45.37	112.51	4882	4852	0.19	0.37	0.37	0.41
BVHD21	Co-op Canal: Charlton Slough	3.0	26.9	45.38	112.48	4852	4829	0.19	0.37	0.37	0.41
BVHD22	USGS 06018500 (Twin Br)	1.0	25.9	45.38	112.46	4829	4823	0.19	0.37	0.37	0.41
BVHD23	Trout Creek	0.0	25.5	45.38	112.45	4823	4821	0.19	0.37	0.37	0.41
BVHD24	ASPCTB-6	2.0	23.5	45.39	112.44	4821	4803	0.19	0.37	0.37	0.41
BVHD25	Muleshoe Canal	2.0	22.0	45.40	112.43	4803	4797	0.19	0.37	0.37	0.41
BVHD26	Baker Ditch	1.0	20.7	45.41	112.43	4797	4783	0.19	0.37	0.37	0.41
BVHD27	ASPCTB-7	7.0	13.2	45.44	112.41	4783	4724	0.19	0.37	0.37	0.41
BVHD28	Silver Bow (Giem) Bridge	4.0	9.6	45.46	112.38	4724	4708	0.19	0.37	0.37	0.41
BVHD29	41-2 Lateral Wasteway	1.0	8.9	45.48	112.36	4708	4706	0.19	0.37	0.37	0.41
BVHD30	Spring Creek-California Slough	2.0	6.6	45.49	112.35	4706	4678	0.19	0.37	0.37	0.41
BVHD31	Schoolhouse Slough	2.0	4.7	45.51	112.35	4678	4655	0.19	0.37	0.37	0.41
BVHD32	Greenhouse Slough	1.0	4.0	45.51	112.35	4655	4642	0.19	0.37	0.37	0.41

Table B5-3. Beaverhead River Q2K reach properties.

Reach ID	Reach Label	Reach Length (mi)	River Station (mi)	Latitude	Longitude	Upstream Elevation (ft)	Downstream Elevation (ft)	Rating Curve Info.			
								U coef	Exp	*H* coef	Exp
BVHD33	Ruby River	1.0	2.7	45.52	112.34	4642	4641	0.19	0.37	0.37	0.41
BVHD34	Jacobs Slough	1.0	1.7	45.52	112.34	4641	4639	0.19	0.37	0.37	0.41
BVHD35	Owsley Slough	1.0	0.5	45.53	112.33	4639	4637	0.19	0.37	0.37	0.41
BVHD36	BVHD Rvr (MadCo Fairgr)	1.0	0.0	45.54	112.34	4637	4636	0.19	0.37	0.37	0.41

Reach lengths based on digitized centerline 2005 NAIP Imagery

Up- and down-stream elevations taken from USGS DEM

U = Velocity *H* = Depth

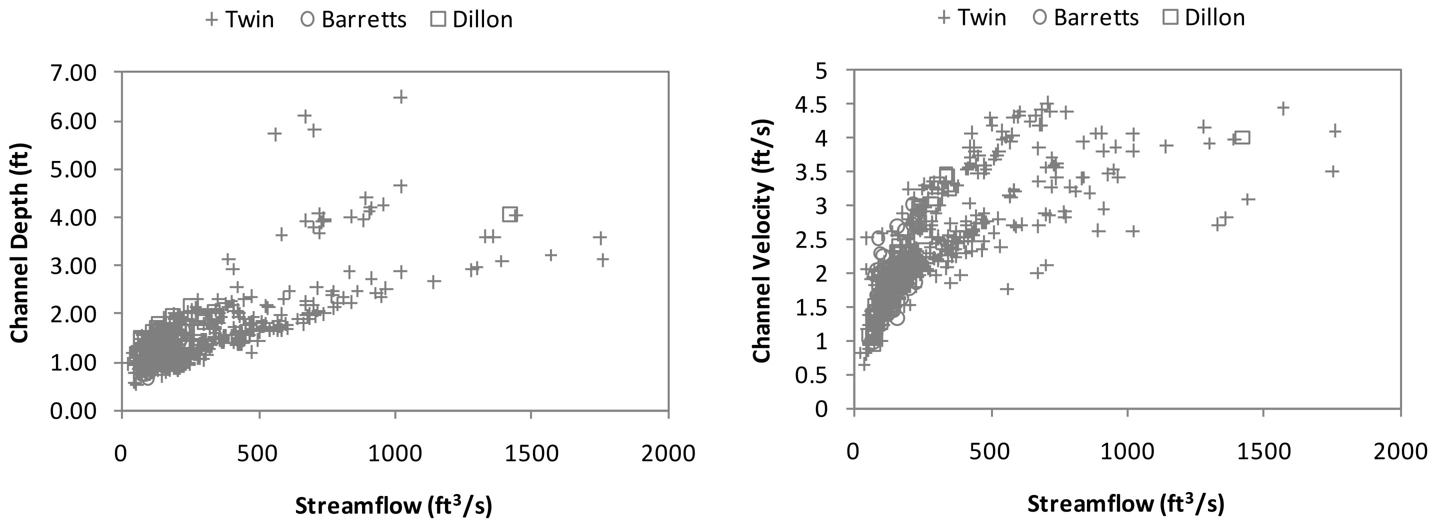

Figure B5-8. Rating curve compilation for gages on the Beaverhead River.

Data from USGS 06016000 Beaverhead River at Barretts MT, USGS 06017000 Beaverhead River at Dillon MT, and USGS 06018500 Beaverhead River near Twin Bridges MT.

B5.7 SHADE

Shade was estimated using Shadev3.0.xls. Segmentation identical to the Q2K model was used (i.e., 36 reaches) and average conditions for each species type, condition, and age class determined during 2009 (Water & Environmental Technologies, 2009) were used in the analysis (**Table B5-4**). Shade was also measured along with dominant vegetation type, height, offset/overhang, canopy density, and channel dimensions to validate the model.

Table B5-4. Shade and morphological data for the Beaverhead River.

Location	Dominant Veg. Type	Topo. + Veg. Shade (%)	Overhang (ft)	Veg. Height (ft)	Density (%)	Wetted Width (ft)
Upstream of Grasshopper Creek (BHS-6)	Willow	2.4	0	7	77	69
Barrett's campground (BHS-5)	Cottonwood	8.3	0	66	68	49
Anderson Lane (BHS-4)	Grass-sedge	0.9	0	3	18	42
Highway 41 (BHS-3)	Willow	0.3	0	13	12	43
Silverbow Lane (BHS-2)	Grass-sedge	0.6	0	3	53	64
DS confluence with Ruby (BHS-1)	Grass-sedge	0.1	0	2	65	75

Note: only the dominant vegetation at each site shown.

Values from **Table B5-4** were averaged to provide reach-wide estimates for the modeling (**Table B5-5**). Simulated shade results are shown in **Figure B5-9** (against observed data) and mean daily values are quite low, less than 10%. Subsequently shade is not of great importance to the heat balance on the Beaverhead River. This will be reiterated in later sections. **Table B5-6** identifies the input parameters used in the calculation.

Table B5-5. Beaverhead River riparian shade conditions from aerial assessment and 2009 field data.

Code	Source	Description	Height (m)	Density %	OH (m)
700	DEQ	willow complex - sparse	2.5	63	0.1
701	DEQ	willow complex - dense	2.7	73	0.4
702	DEQ	dmd (cottonwood) - medium, sparse	15.0	68	0.0
703	DEQ	grass/rush/sedge riparian	0.6	61	0.0
704	DEQ	50% willow 50%grass-sedge	1.6	62	0.0
705	DEQ	css - conifer, small, sparse	15.0	68	0.0

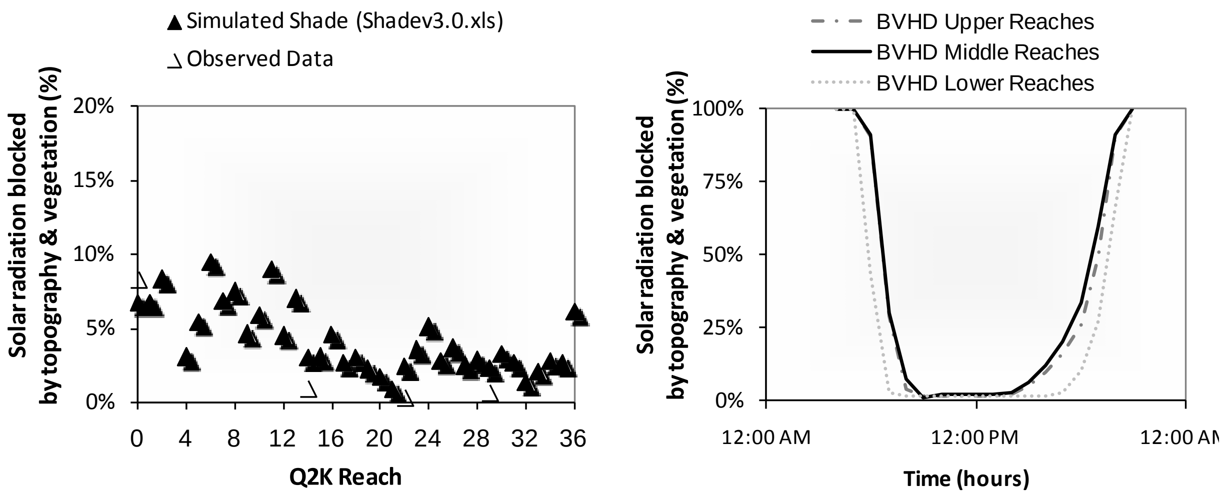

Figure B5-9. Simulated and observed longitudinal shade on the Beaverhead River.
(Left panel) Simulated and observed longitudinal shade from the Shadev3.0.xls model. Note that the simulated values pattern the field measurements well. (Right panel). Diurnal shade for one of the reaches. Shade from both vegetation and topography was considered.

Table B5-6. Shadev3.0.xls input parameters.

Reach	ID	Aspect from N	NSDZ (bfull)	B (est)	NSDZ	θ W	θ S	θ E	LB	RB
BVHD01	Smitch Rebich Ditch (divert)	25	25.0	19.0	3.0	10	6	6	701	701
BVHD02	Barretts, East Bnch, Cany, etc.	30	18.5	14.0	2.0	9	5	5	701	700
BVHD03	Horton Haines Ditch (divert)	40	16.5	12.0	2.0	10	2	5	700	702
BVHD04	ASPCTB-1	75	15.5	12.0	2.0	3	1	3	700	703
BVHD05	ASPCTB-2	50	15.0	11.0	2.0	2	2	4	700	703
BVHD06	Van Camp Ditch (divert)	10	16.5	12.0	2.0	2	2	3	700	700
BVHD07	Poindexter Slough (divert)	30	18.5	14.0	2.0	2	2	3	700	700
BVHD08	Van Camp Slough (return)	15	19.5	15.0	2.0	2	2	3	700	700
BVHD09	Poindexter Slough (return)	50	20.0	15.0	3.0	2	1	3	700	700
BVHD10	Westside Canal (divert)	40	18.5	14.0	2.0	4	2	3	700	700
BVHD11	USGS 06017000 (Dillon)	70	19.5	15.0	2.0	11	2	2	702	700
BVHD12	Selway Ditch (divert)	60	17.0	13.0	2.0	5	2	2	700	701
BVHD13	Hayden Morton Ditch (divert)	40	15.5	12.0	2.0	2	2	3	700	700
BVHD14	(Anderson Br)/Bishop Ditch	25	17.5	13.0	2.0	1	2	2	704	704
BVHD15	1872 Ditch (divert)	30	16.0	12.0	2.0	1	3	1	703	703
BVHD16	ASPCTB-3	350	15.0	11.0	2.0	2	1	1	703	703
BVHD17	Stone Creek	35	17.5	13.0	2.0	2	3	1	703	703
BVHD18	Brown Ditch (divert)	25	17.5	13.0	2.0	2	3	1	703	703
BVHD19	ASPCTB-4	35	20.5	15.0	3.0	2	2	2	703	703
BVHD20	ASPCTB-5 (Albers Slough)	50	21.0	16.0	3.0	2	2	2	703	703
BVHD21	Co-op Canal: Charlton Slough	80	22.0	17.0	3.0	2	2	2	703	703
BVHD22	USGS 06018500 (Twin Br)	90	21.0	16.0	3.0	2	2	2	700	700
BVHD23	Trout Creek	110	20.0	15.0	3.0	4	1	2	701	704
BVHD24	ASPCTB-6	40	19.5	15.0	2.0	2	1	2	700	704
BVHD25	Muleshoe Canal (divert)	30	17.5	13.0	2.0	1	1	1	703	703
BVHD26	Baker Ditch (divert)	355	20.5	15.0	3.0	2	1	1	703	704
BVHD27	ASPCTB-7	35	18.0	14.0	2.0	1	1	2	703	703

Table B5-6. Shadev3.0.xls input parameters.

Reach	ID	Aspect from N	NSDZ (bfull)	B (est)	NSDZ	θ W	θ S	θ E	LB	RB
BVHD28	Silver Bow (Giem) Bridge	30	17.0	13.0	2.0	3	1	2	703	703
BVHD29	41-2 Lateral Wasteway (return)	30	21.0	16.0	3.0	3	2	1	703	705
BVHD30	Spring Creek-California Slough	355	20.0	15.0	3.0	1	3	1	703	703
BVHD31	Schoolhouse Slough	30	18.0	14.0	2.0	2	3	1	703	703
BVHD32	Greenhouse Slough	65	19.5	15.0	2.0	3	2	1	703	703
BVHD33	Ruby River	40	20.5	15.0	3.0	2	3	1	703	703
BVHD34	Jacobs Slough	0	23.0	17.0	3.0	2	3	1	703	703
BVHD35	Owsley Slough	330	25.0	19.0	3.0	3	2	2	703	703
BVHD36	BVHD Rvr (MadCo Fairgr)	20	25.0	19.0	3.0	2	3	2	701	703

θ = Degrees, N = North, E = East, W = West
NSDZ = Near Stream Disturbance Zone

B5.8 BOUNDARY CONDITIONS

Surface water boundary conditions were specified for remaining tributary and point source inputs using field data. They were averaged over the analysis period similar to other data. Temperature at each location was varied as a sinusoid per the Q2K documentation (Chapra et al., 2008b) which necessitated specification of mean daily temperature, time of maximum, and range (**Figure B5-10**, left panel). A comparison of how the approximation correlated with measured data is shown in **Figure B5-10** (right panel). A summary of all tributary boundary conditions are shown in **Table B5-7**.

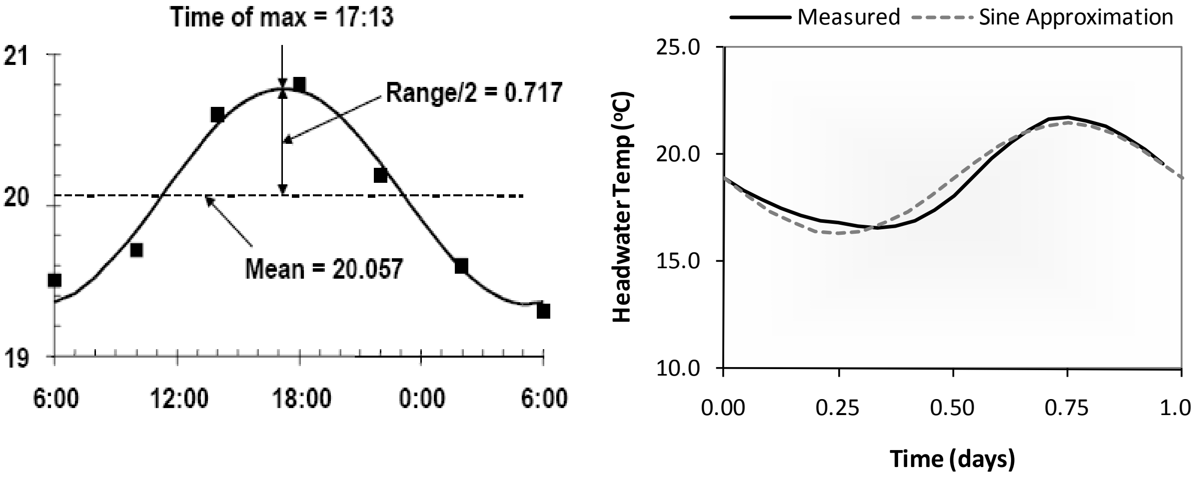

Figure B5-10. Comparison of diurnal sinusoid with respect to field data
(Left panel). Methodology used to approximate diurnal conditions. (Right panel) Sinusoid approximation at one location in the model network. Note that the estimates are very close to the observed diel cycle in the river.

Table B5-7. Beaverhead River boundary conditions.

Name	Location (mi)	Abstraction (ft^3/s)	Inflow (ft^3/s)	mean (°F)	range/2 (°F)	Time of max
USGS 06016000 (Barretts)	66.3	Headwater boundary condition				
Smith Rebich Diversion	65.3	27.7	n/a	n/a	n/a	n/a
Barretts Diversion Dam	64.9	285.4	n/a	n/a	n/a	n/a
Horton Haines Diversion	64.4	25.7	n/a	n/a	n/a	n/a

Table B5-7. Beaverhead River boundary conditions.

Name	Location (mi)	Abstraction (ft^3/s)	Inflow (ft^3/s)	mean (°F)	range/2 (°F)	Time of max
Van Camp Diversion	61.8	13.2	n/a	n/a	n/a	n/a
Poindexter Slough (divert)	60.8	33.1	n/a	n/a	n/a	n/a
Van Camp Slough (return)	57.2	n/a	6.9	67	36	5:30 PM
Poindexter Slough (return)	56.3	n/a	36.2	63	37	4:00 PM
Westside Canal Diversion	53.0	72	n/a	n/a	n/a	n/a
USGS 06017000 (Dillon)	52.7	0	n/a	n/a	n/a	n/a
Selway Ditch (divert)	50.6	5.4	n/a	n/a	n/a	n/a
Hayden Morton Ditch (divert)	46.6	16.5	n/a	n/a	n/a	n/a
BVHD Rvr Anderson/Bishop Ditch	40.2	11.1	n/a	n/a	n/a	n/a
1872 Ditch (divert)	39.0	10.5	n/a	n/a	n/a	n/a
Stone Creek	35.9	n/a	1.7	55	38	4:30 PM
Brown Ditch (divert)	35.5	19.1	n/a	n/a	n/a	n/a
ASPCTB-5 (Albers Slough)	30.2	n/a	13.5	66	40	5:30 PM
Co-op Canal (divert)	26.9	23.6	n/a	n/a	n/a	n/a
Charlton Slough (return)	26.9	n/a	11.6	60	41	5:00 PM
BVHD Rvr USGS 06018500 (Twin Br)	25.8	0	n/a	n/a	n/a	n/a
Trout Creek	25.5	n/a	0.4	64	41	5:00 PM
ASPCTB-6	23.5	0	n/a	n/a	n/a	n/a
Muleshoe Canal (divert)	21.9	26.5	n/a	n/a	n/a	n/a
Baker Ditch (divert)	20.7	14.8	n/a	n/a	n/a	n/a
ASPCTB-7	13.2	n/a	n/a	n/a	n/a	n/a
BVHD Rvr Silver Bow (Giem) Bridge	9.6	n/a	n/a	n/a	n/a	n/a
41-2 Lateral Wasteway (return)	8.9	n/a	1.5	69	36	5:00 PM
Spring Creek-California Slough	6.5	n/a	36.7	67	41	5:30 PM
Schoolhouse Slough	4.7	n/a	16.9	68	39	6:00 PM
Greenhouse Slough	3.9	n/a	20.5	68	38	5:30 PM
Ruby River	2.6	n/a	64.4	67	38	6:00 PM
Jacobs Slough	1.7	n/a	5.3	69	40	4:00 PM
Owsley Slough	0.5	n/a	38.2	69	38	6:00 PM
BVHD Rvr (MadCo Fairgr)	0.0	n/a	0	32	32	n/a

B5.9 GROUNDWATER TEMPERATURE

The last consideration in model development is groundwater temperature, which according to Smith and Lavis (1998) can account for large temperature changes in smaller streams (7-9° F). Uthman and Beck (1998) previously demonstrated localized areas of groundwater influx occur in the Beaverhead River and we wished to reflect these appropriately in the model. Therefore the groundwater temperature for the Beaverhead River was calculated using two approaches: (1) from mean annual air temperature as recommended by Theurer, et al., (1984) and (2) through evaluation of the Montana Ground Water Information Center (GWIC) database records. From the first method, mean annual temperature at Dillon ASOS 242404 was 43°F (6°C). The GWIC database indicates a slightly warmer estimate; 51°F based on examination of wells within one mile laterally of the river (**Table B5-8**). We use the GWIC data due to its applicability to the project site and similarity with other locations in the state.

Table B5-8. Groundwater data used in accretion flow determination.
Data from Montana Bureau of Mines and Geology (MBMG) GWIC database[10].

Sample	GWIC ID	Latitude	Longitude	Aquifer	Depth (ft)	Agency	Sample Date	Water Temp. (°F)
1996Q0408	151328	45.234	-112.599	110ALVM	41	MBMG	9/21/1995	46
1996Q0375	109401	45.232	-112.606	111ALVM	29	MBMG	9/14/1995	54
1996Q0379	109402	45.233	-112.617	111ALVM	30	MBMG	9/14/1995	52
1996Q0378	109436	45.228	-112.627	111ALVM	55	MBMG	9/14/1995	54
1994Q5009	145389	45.228	-112.634	110ALVM	0	DNRC	11/14/1993	45
1991Q5000	109444	45.219	-112.636	111ALVM	60	USGS	8/21/1991	48
1996Q0410	109444	45.219	-112.636	111ALVM	60	MBMG	9/21/1995	51
1996Q0409	151329	45.214	-112.673	110ALVM	84	MBMG	9/21/1995	51
1991Q5001	149185	45.214	-112.672	110ALVM	124	USGS	8/22/1991	49
1994Q0353	133400	45.208	-112.674	110ALVM	85	USGS	8/27/1993	50
1994Q0357	133402	45.208	-112.674	110ALVM	20	USGS	8/27/1993	50
1994Q0503	133403	45.218	-112.654	110ALVM	31	USGS	9/15/1993	53
2004Q0138	133390	45.191	-112.673	110ALVM	18	MBMG	9/17/2003	52
1994Q0505	133398	45.181	-112.702	110ALVM	92	USGS	9/14/1993	51
1994Q0522	133394	45.164	-112.686	110ALVM	49	USGS	9/2/1993	52
1994Q0355	133396	45.153	-112.704	110ALVM	51	USGS	8/28/1993	49
1994Q0515	133409	45.140	-112.714	110ALVM	53	USGS	9/1/1993	57
1994Q0502	133397	45.134	-112.730	110ALVM	51	USGS	9/14/1993	49
2004Q0176	133397	45.134	-112.730	110ALVM	51	MBMG	10/1/2003	51

B5.10 WASTEWATER TREATMENT FACILITY INFLUENT

The last input consideration was the Dillon, MT wastewater treatment plant (WWTP). Inflow was determined from MPDES permit records for the month of August 2005 and consisted of a flow rate of 450,000 gallons per day and a temperature of 67.3 °F. There was insufficient data to prescribe temperature from the Dillon WWTP in the model, so data from Darby, MT (a similar lagoon system) was used instead.

B6.0 MODEL CALIBRATION

The calibration involved adjustment of the model representation to reflect the observed data from Sessoms and Bauder (2005). Fourteen locations were used for the calibration. These were: (1) Barrets Diversion Dam, (2) Van Camp Ditch, (3) Poindexter Slough (diversion), (4) Westside Canal, (5) Selway Ditch, (6) Hayden Morton Ditch, (7) Beaverhead River at Anderson Bridge, (8) 1872 Ditch, (9) Brown Ditch, (10) Co-op Canal, (11) Muleshoe Canal, (12) Bishop Canal, (13) Silver Bow (Giem) Bridge, and (14) Madison County Fairgrounds. Model calibration procedures are described in detail elsewhere (American

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[10] A screening procedure was used to filter un-representative wells out of the GWIC database. This included the following:

1. Sorting on geologic code - keeping only ALVM
2. Sorting on date - removing data that is not +/- 2 months of study date
3. Removing data older than 20 years
4. Removing data with null temperature values (0.0 degrees)
5. Removing data greater than 2 standard deviations from the mean.

Society for Testing and Materials, 1984; Reckhow and Chapra, 1983; Thomann, 1982). Details specific to the Beaverhead River are described in the following sections.

B6.1 EVALUATION CRITERION

Two statistical methods were selected to evaluate the sufficiency of the Beaverhead River model. These were relative error (RE) and root mean squared error (RMSE). RE is a measure of the percent difference between observed and predicted ordinates. It was calculated as shown in **Equation B6-1**, where *RE* = relative simulation error, T_o = observed temperature, and T_s = simulated temperature. RE should be less than ±5.0% at all locations (or ±1°F respectively). Overall system RE should approach 0%.

(Equation B6-1)

$$RE = \frac{\left(T_s - T_o\right)}{T_o}$$

Root mean squared error (RMSE) was also used which is a common objective function for water quality model calibration (Chapra, 1997; Little and Williams, 1992). It compares the difference between the modeled and observed ordinates and uses the squared difference as the measure of fit. Thus a difference of 10 units between the predicted and observed values is one hundred times worse than a difference of 1 unit. Squaring the differences also treats both overestimates and underestimates by the model as undesirable. The root of the average difference is then taken. Calculation of RMSE is shown in **Equation B6-2** (Diskin and Simon, 1977), where *n*=the number of observations being evaluated.

(Equation B6-2)

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{i_n}[T_o(i) - T_s(i)]}^{\,2}$$

B6.2 RESULTS AND DISCUSSION

The results and discussion regarding the Beaverhead River Q2K model calibration are presented below.

B6.2.1 Hydrology

Simulated and observed hydrology are shown in **Figure B6-1**. There was no model error (RE and RMSE were 0% and 0°F) because we directly implemented the steady-state water balance outlined in **Section B5.0**. Features of significance were the diversion at Barretts which withdrew approximately half of the flow in the river and then numerous smaller diversions that incrementally deplete flow until it a minimum is reached near Silver Bow (Giem) Bridge. Gains occur thereafter from sloughs out of the Big Hole River and the Ruby River. The lowest flow was approximately 50 ft^3/s.

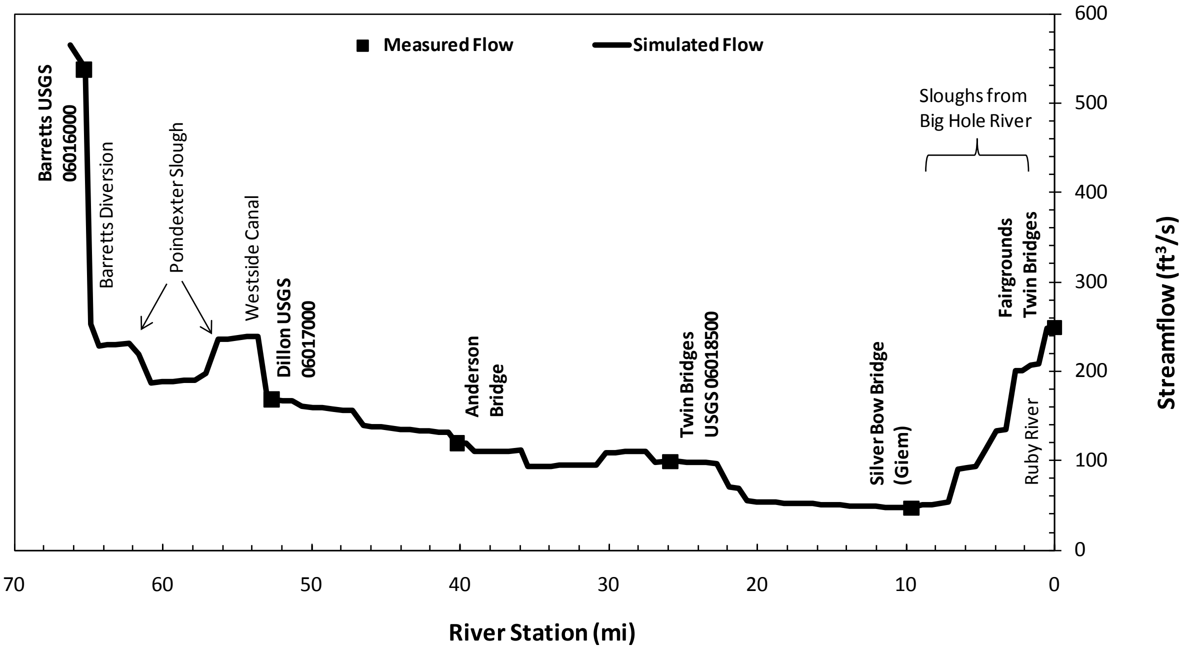

Figure B6-1. Streamflow calibration for the Beaverhead River.
Longitudinal plot of streamflow over the August 4-7, 2005 calibration period.

B6.2.2 Hydraulics

A plot of simulated channel wetted width is shown in **Figure B6-2**. RE and RMSE for the simulation were 4.5% and 12.7 ft respectively, which is adequate for our purposes. Hydraulic calibration involved adjustment of both depth and velocity coefficients until the observed and simulated indicators of (1) observed diel maximum and minimum peaks at each calibration node and (2) simulated wetted widths were in agreement. From examination of our results, it appears as if the model represents channel attributes reasonably. Observed values in the figure were taken from field data as well as analysis of rating curves for each of the USGS gage sites[11]. Only a very basic summary of hydraulics is presented here given the limited data in the watershed.

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[11] Channel wetted widths were determined from the rating curves described in **Section B5.5** which were then applied to the flow conditions during 2005 to estimate velocity, depth, and wetted width using a wide rectangular channel approximation.

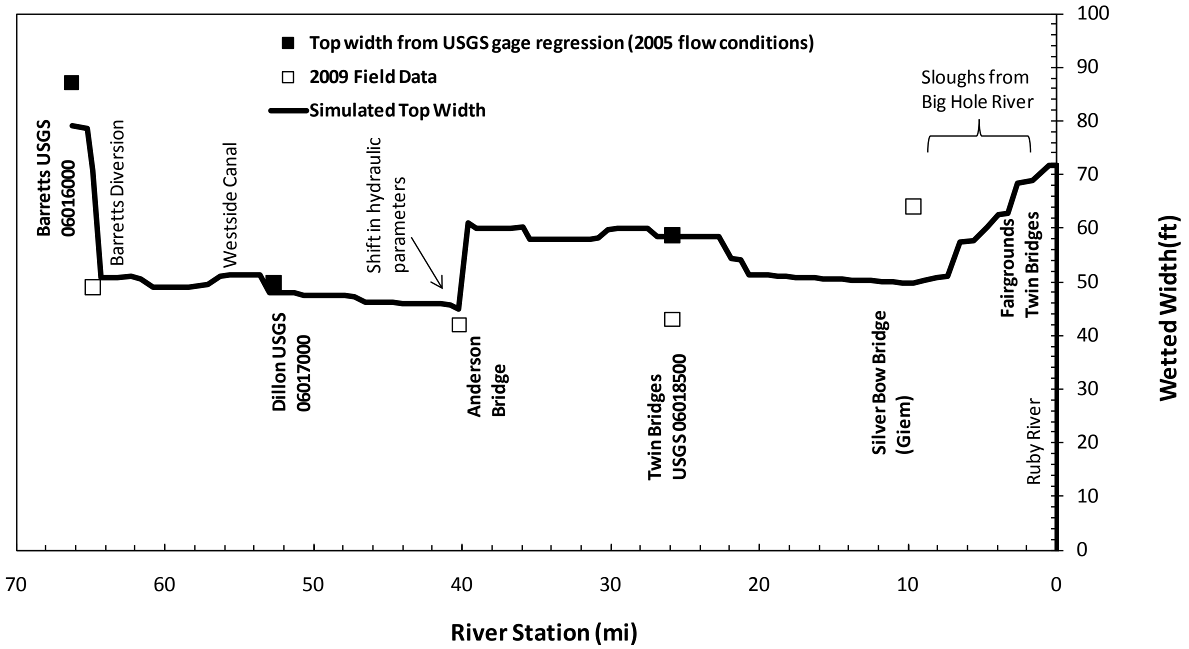

Figure B6-2. Simulated Beaverhead River hydraulics.
Longitudinal plot of over the August 4-7, 2005 calibration period.

B6.2.3 Water Temperature

Simulated minimum, mean, and maximum daily water temperatures are shown in **Figure B6-3**. RE and RMSE were quite good at 0.01% and 0.91°F, which included the exclusion of one data point which was clearly in error[12] (mile 46.6). Overall, the river generally increases in temperature (and diurnal flux) from the headwater boundary to mile 12, and then has a short region of cooling coincident with increased flow volume. The addition of the WWTP discharge was found to have a small effect in the middle river and actually caused a decrease in maximum temperatures of less than 0.05°F for several miles downstream (i.e., the WWTP effluent is cooler than the river).

In summary, very little calibration was needed to accurately simulate water temperature after physical constraints in the previous sections were addressed (i.e., hydrology and hydraulics). The calibration mainly involved adjustment of influent nonpoint source water temperature by attributing it to either groundwater (cold water) or unaccounted return flow (warm water). The procedure for ascribing the relative relationship was determined by modifying the percentage of each component until temperature simulations were within the desired criterion. Composite statistics for the temperature simulation are provided in **Table B6-1**.

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[12] According to several authors (Barnwell, Jr. et al., 1989; Theurer et al., 1984) temperature loggers are easily affected by local environmental conditions and model users should be skeptical of observed data when major unexplained differences between observed and simulated values occur. Selway ditch (mi 50.6) and Hayden Morton ditch (mi 46.6) and are two such examples.

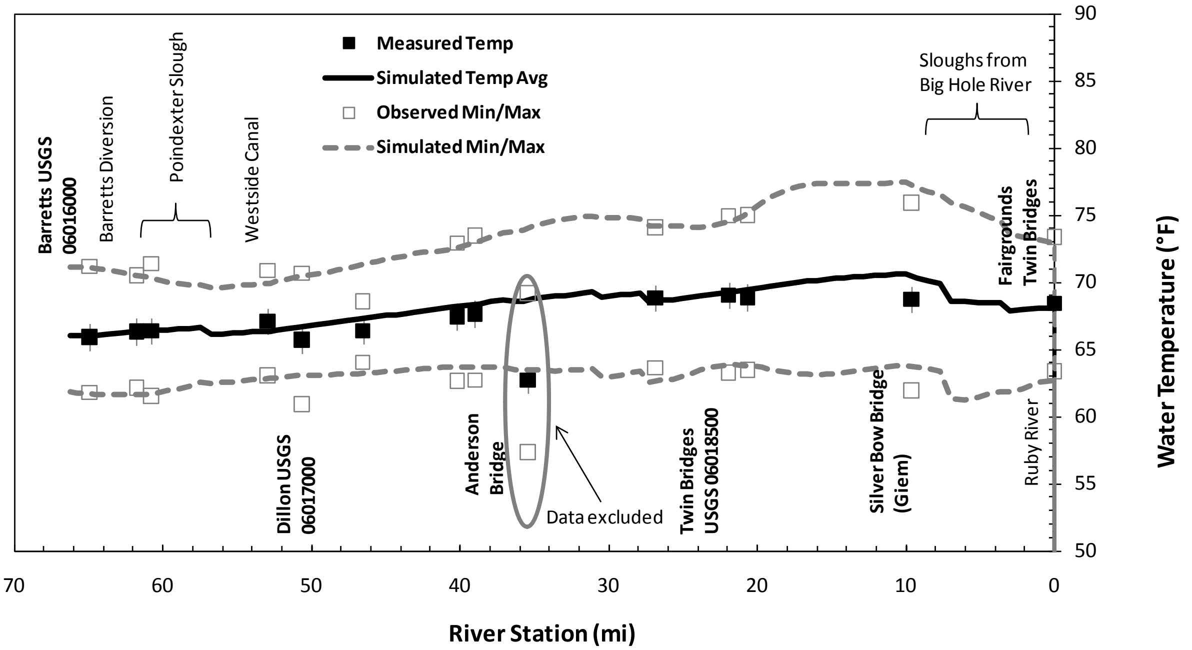

Figure B6-3. Simulated and observed water temperatures for the Beaverhead River during 2005.

Table B6-1. Calibration statistics for each calibration node

Calibration Node	Distance x(mi)	Mean Temp (°F)	Min Temp (°F)	Max Temp (°F)	RE			Error		
					Mean	Min	Max	Max	Min	Max
Barretts	64.9	66.1	61.7	71.0	0.00	0.00	0.00	0.02	0.02	0.02
Van Camp	61.8	66.3	61.7	70.4	0.00	-0.01	0.00	0.00	0.27	0.03
Poindexter	60.8	66.4	61.8	70.2	0.00	0.00	-0.02	0.00	0.05	1.41
Westside Canal	53.0	66.4	62.8	69.9	-0.01	0.00	-0.01	0.50	0.07	0.97
Selway Ditch	50.6	66.8	63.0	70.5	0.02	0.03	0.00	1.17	4.49	0.03
Hayden Morton	46.6	67.3	63.3	71.4	0.01	-0.01	0.04	0.87	0.62	8.03
Anderson Bridge	40.2	68.3	63.7	72.8	0.01	0.02	0.00	0.72	1.08	0.01
1872 ditch	39.0	68.4	63.7	73.0	0.01	0.02	-0.01	0.56	0.92	0.21
Brown ditch	35.5	68.7	63.4	74.2	Data excluded from analysis					
Co-op canal	26.9	68.6	62.8	74.2	0.00	-0.01	0.00	0.05	0.76	0.01
Muleshoe canal	21.9	69.3	63.9	74.6	0.00	0.01	-0.01	0.06	0.39	0.16
Baker Ditch	20.7	69.5	63.8	75.4	0.01	0.00	0.01	0.42	0.10	0.15
Giem Bridge	9.6	70.4	63.7	77.1	0.02	0.03	0.01	2.63	3.23	1.20
Madison Co. Fair.	0.0	68.1	62.6	73.0	0.00	-0.01	-0.01	0.09	0.61	0.20
				Averages	**RE = 0.01**			**RMSE = 0.91**		

B7.0 WATERSHED MANAGEMENT SCENARIOS

The calibrated Q2K model was subsequently used to determine the impact of potential watershed management alternatives on the flow and temperature regime of the Beaverhead River. Six different management scenarios were evaluated: (1) baseline conditions; (2) two improved riparian habitat scenarios, (3) an increased flow scenario, (4) a naturally occurring condition scenario, and (5) an unmodified hydrology scenario. Results of the model simulations are described below and will be used to determine the amount of stream temperature impairment, and the relative effectiveness of management changes on the warm weather temperatures in the river.

B7.1 BASELINE

The baseline scenario describes existing conditions in the watershed and is merely a reflection of the calibration. In review, baseline modeling was completed during drought and in low flow conditions. The simulation results have been documented in prior sections and indicate reasonable good water temperature calibration based on performance statistics of RE and RMSE. Water temperature was shown to increase from the upstream boundary near Barretts until Silver Bow (Giem) Bridge and then decrease thereafter. Simulated values from the baseline form the basis for which all other scenarios will be compared.

B7.2 IMPROVED RIPARIAN HABITAT SCENARIO

Enhanced riparian conditions were simulated on the Beaverhead River to evaluate the influence of shade along the river corridor. Previous work suggests shade could be a possible contributor to river impairment and could potentially be improved. Consequently, two different shade conditions were evaluated: (1) where reference willow canopy was present along the entire reach (which is likely the best possible condition under reservoir hydrology) and (2) where vigorous cottonwood stands were present due to natural conditions (i.e. no human impacts or native hydrology).

Simulations were implemented by simply changing riparian cover conditions in the model. For example in the first scenario, shade was changed to “dense willow complex” which effectively provided more shade for the river. The second scenario was done identically, but with cottonwoods. The results of these scenarios are shown in **Figure B7-1**. Relative to baseline conditions, the temperature effect of both scenarios decreases the maximum and minimum temperatures over the entire modeling reach. The cottonwood shade scenario resulted in a significant decrease of river temperatures of 5.2 ^{o}F compared to the willow shade scenario which decreased temperatures less than 1^{o}F. This shows that under the current reservoir regulated hydrology, riparian enhancements will provide limited temperature improvement to the river if implemented (unless continuous tree-planting programs are instated). Tabular results for this scenario (and all others) are shown in **Table B7-1** at the end of this section.

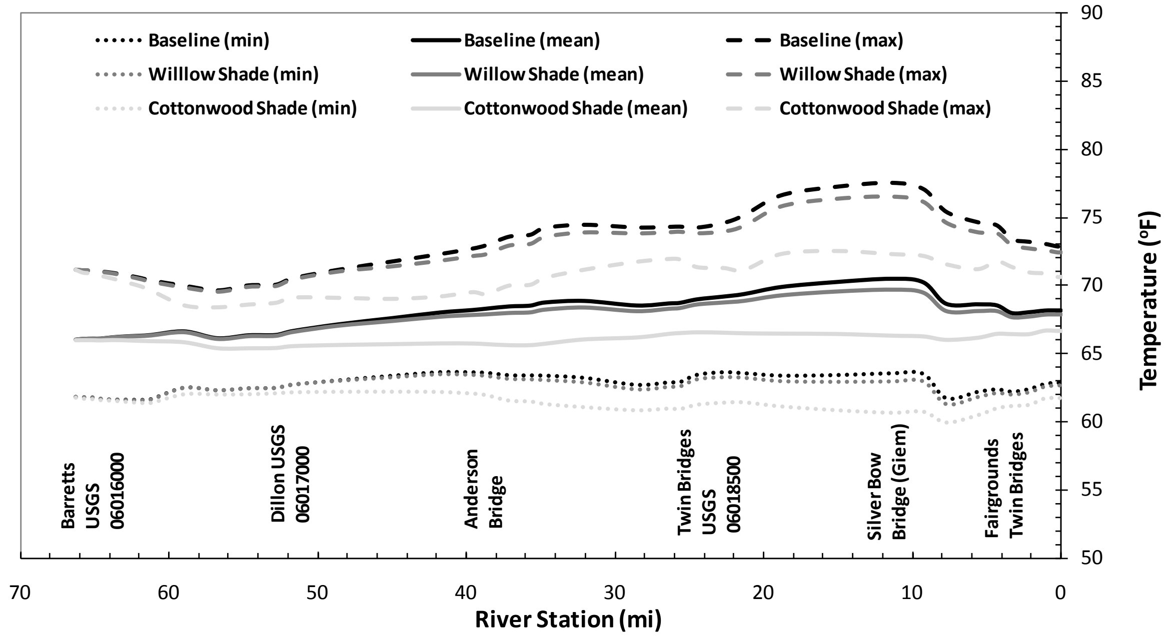

Figure B7-1. Simulated reference shade conditions for the Beaverhead River.

B7.3 INCREASED FLOW SCENARIO

The effect of water use on instream flow and water temperature was considered. Although Montana standards do not necessarily apply to existing water rights, it is important to assess the cumulative effect of these practices on the overall thermal regime of the river. The simple relationship presented by Brown (1969) suggests that large volume streams are less responsive to temperature changes than low flow streams and will also exhibit smaller diel fluctuations. The scenario consisted of keeping the 20% water savings gained through improved irrigation delivery and allowing that water savings to flow down the lower Beaverhead River (any voluntary water savings and subsequent instream flow augmentation must be done in a way that protects water rights).

The 20% water savings was based on three grant proposals submitted to the state of Montana by the East Bench Irrigation District (EBID). Two of the grants were for lining 2,000 (Montana Department of Natural Resources and Conservation, 2007) and 1,175 (Montana Department of Natural Resources and Conservation, 2009) feet of main canal respectively which were estimated by EBID to reduce annual leakage by 3,600 and 2,585 acre-feet. The third grant was to replace slide gates at three existing check structures (Montana Department of Natural Resources and Conservation, 2011) which was expected to conserve another 7,855 acre-feet. Hence the total annual water savings by the three proposals was 14,040 acre-feet or 20.8% of the 67,260 acre-feet diverted annually between 1996 and 2005 (except for 2004 when no water was diverted) was. This value was rounded to 20% for the scenario and reflects the potential improvement through implementing reasonable BMPs. Additional reductions may be feasible through other canal improvements or improvement in irrigation delivery and efficiency in other areas of the watershed, but it is unknown whether these are reasonable or feasible at this time.

Results of the increased flow scenario are shown in **Figure B7-2**. Based on model simulations, the 20% savings would result in an additional 117 ft^3/s of water in the river and would lead to maximum reductions of 3°F between miles 10 and 20. Minimum temperatures actually increased nearly the same

(2.6°F) due to added thermal inertia. This scenario indicates that reasonable irrigation delivery improvements can have a significant effect on the overall temperature regime in the river.

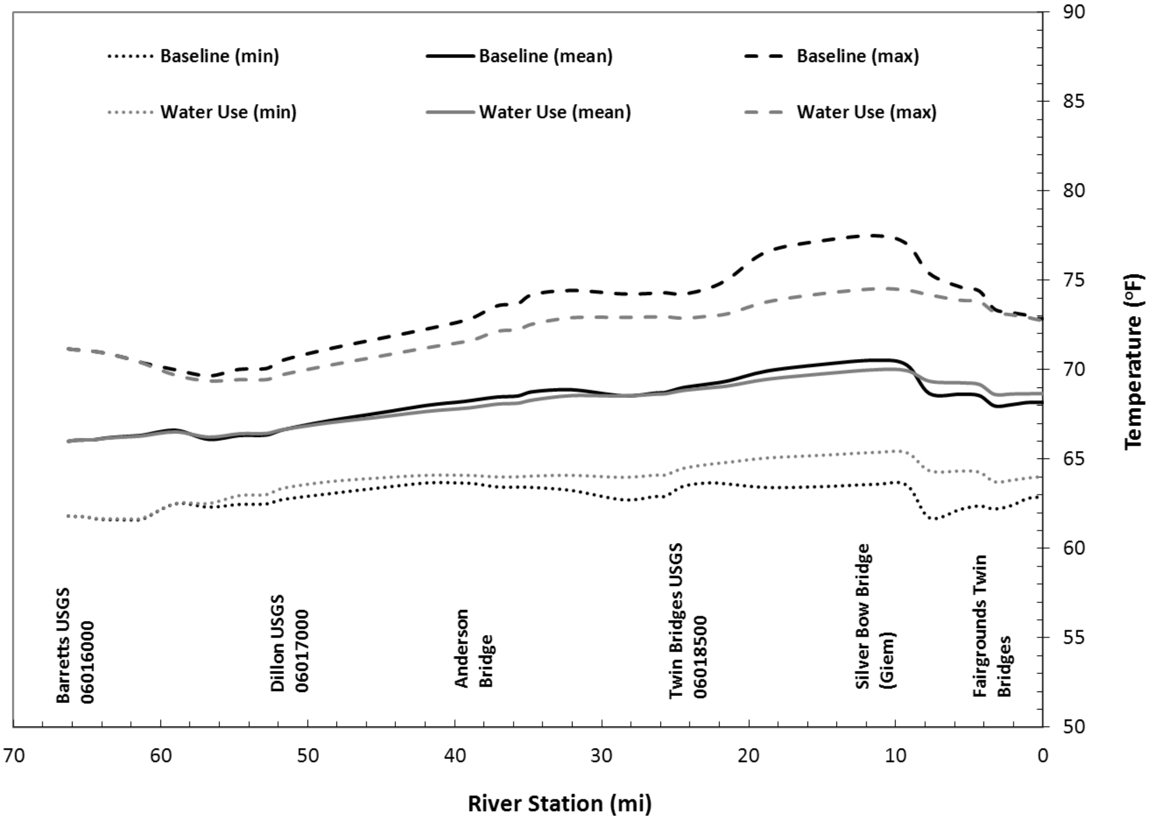

Figure B7-2. Increased flow (water use) scenario on the lower Beaverhead River

B7.4 NATURALLY OCCURRING CONDITION SCENARIO

The naturally occurring scenario represents lower Beaverhead River water temperatures when all reasonable land, soil, and water conservation practices are implemented (**ARM 17.30.602**). Pursuant to 75-5-306, Montana Code Annotated (MCA) "Conditions resulting from the reasonable operation of dams at July 1, 1971" are also considered natural. Thus, this scenario establishes the bar for which the allowable 0.5°F temperature increase is compared (refer to **Section B1.2**). Assumptions used in the development of the naturally occurring scenario include the following: (1) shade conditions as described in the shade scenario (willow complex) and (2) a 20% reduction in the rate of diverted flow as described in the water use scenario.

Results of the naturally occurring scenario are shown in **Figure B7-3**. The scenario indicates the river is impaired extending from approximately mile 56 downstream to the confluence with the Big Hole River (mile 0). The largest temperature increase over baseline condition is 3.7°F at mile 11.4. The impairment is believed to be primarily related to irrigation based on evaluation of the previous scenarios.

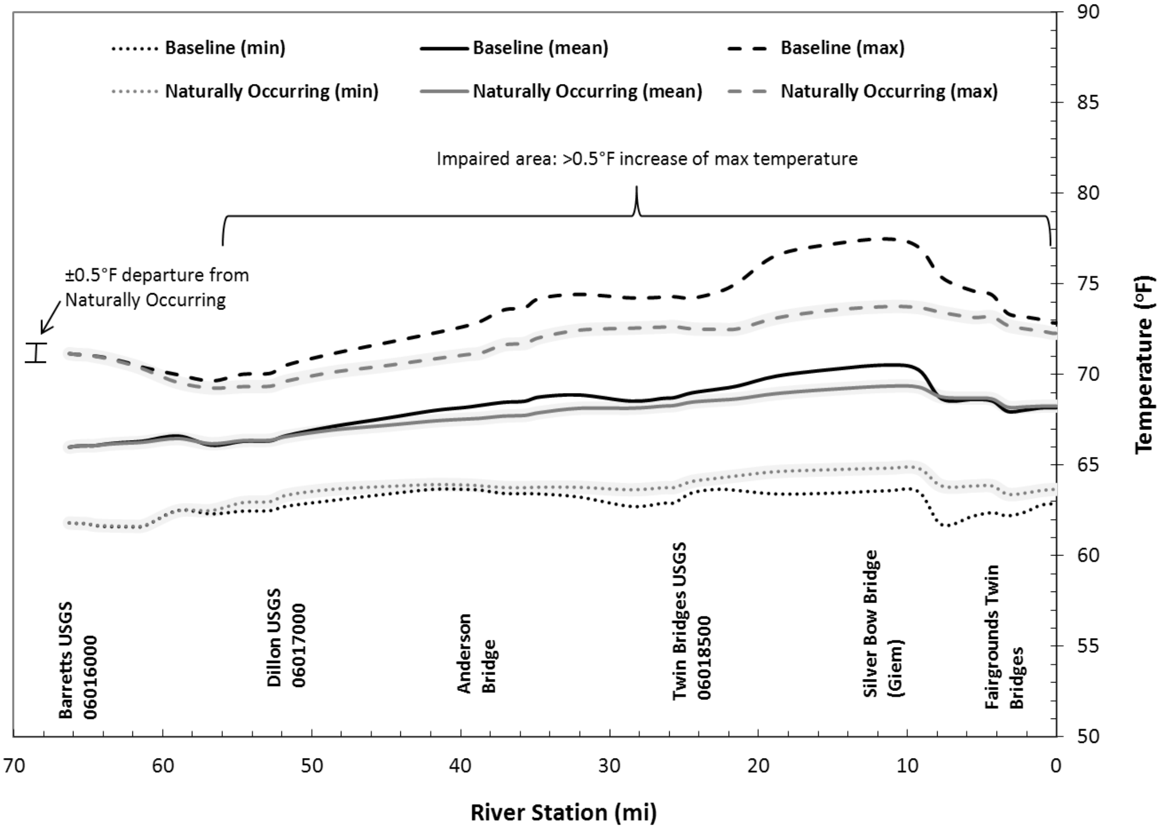

Figure B7-3. The maximum naturally occurring temperature relative to the existing condition (baseline scenario) and the allowed temperature

B7.5 UNMODIFIED HYDROLOGY SCENARIO

The unmodified hydrology scenario reflects the temperature regime that would be expected absent of the influence of humans. While this scenario is clearly not realistic from a socio-economic implementation standpoint, it does allow us to characterize the extent of departure from original hydrologic conditions and evaluate the maximum potential improvement in the watershed. It also may be helpful in future resource conservation efforts. For the purpose of this study, unmodified hydrology was defined as the removal of all human influences that affect the river. Unmodified hydrology scenario assumptions included the following: (1) reference shade conditions by incorporating 50% willows and 50% cottonwoods along the river, (2) decreased width to depth ratios (3) no irrigation or consumptive water use, (4) removal of CC and Lima dam, and (5) removal of the Dillon WWTP discharge.

Evaluation of unmodified hydrology first required estimation of original flows within the river. The CC dam began altering the flow regime in the study area in 1964. Prior to 1964 the river was still modified to a lesser extent by the Lima dam upstream. The annual median hydrograph from the USGS Beaverhead at Barretts gage (#06016000) both pre- and post-construction of the CC dam is shown in **Figure B7-4**. Several other unregulated streams/rivers in the project vicinity are also shown (Grasshopper Creek, USGS 06015500 and the Big Hole River near Melrose, USGS 06025500) for comparative purposes[13]. The dam extends the period of high flow into the latter parts of the summer months to supply irrigation water which subsequently provides additional flow that would otherwise not be present. To estimate this increase, the influence of storage in the Lima Reservoir[14] (which was constructed in 1902) was removed from the pre-Clark Canyon dam hydrograph at Barrets. The result was that the original flow during the modeling period (August 5th) is likely around 180 ft^3/s, or about 32% of the existing flow (564.4 cfs).

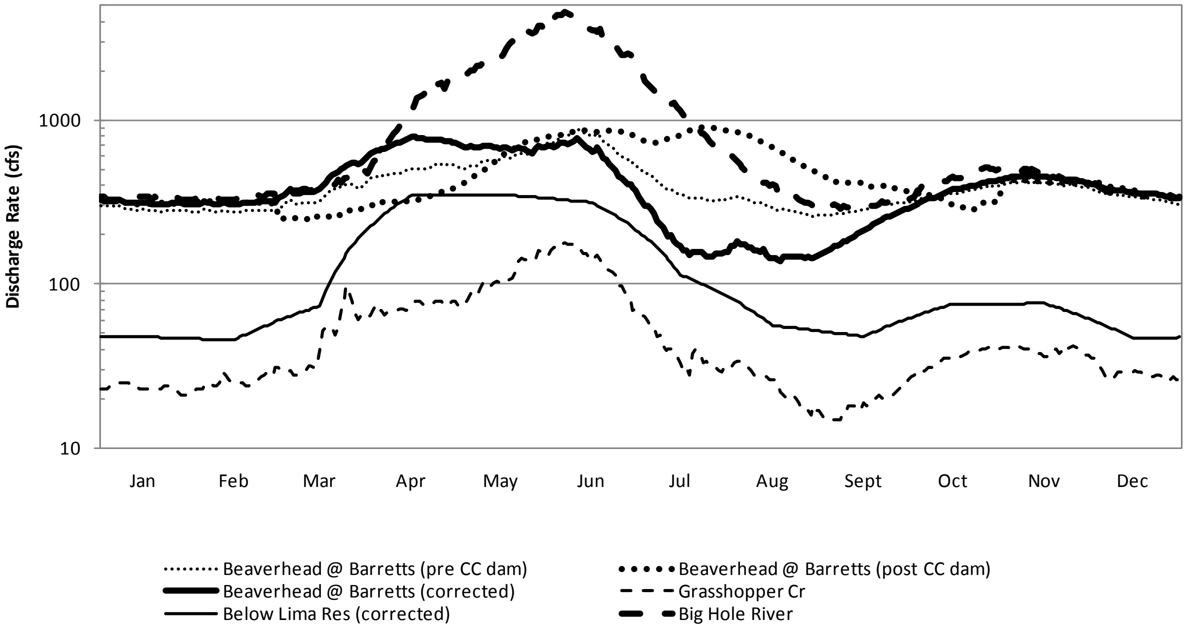

Figure B7-4. Median discharge rates corrected for dam influences.

Results of the unmodified hydrology scenario are shown in **Figure B7-5**. Clearly the river's thermal regime has been significantly altered and the cumulative effect is very apparent. The results show a significant improvement (decrease) of the maximum temperatures throughout most of the modeling reach, with a maximum temperature decrease of 6.4°F at mile 11.4. If the unmodified hydrology scenario only accounted for dam removal, the results would show temperature increases as compared to baseline.

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[13] Each gage station has irrigation diversions above them, so the hydrographs are not considered unaltered, but are applicable to comparison to the Beaverhead River.

[14] The Lima reservoir storage was based on monthly average values of inflow versus outflow from 1989-2011 as recorded by the BOR. The BOR records are only monthly averages and these were interpolated linearly to provide an estimated daily corrections for storage in this analysis.

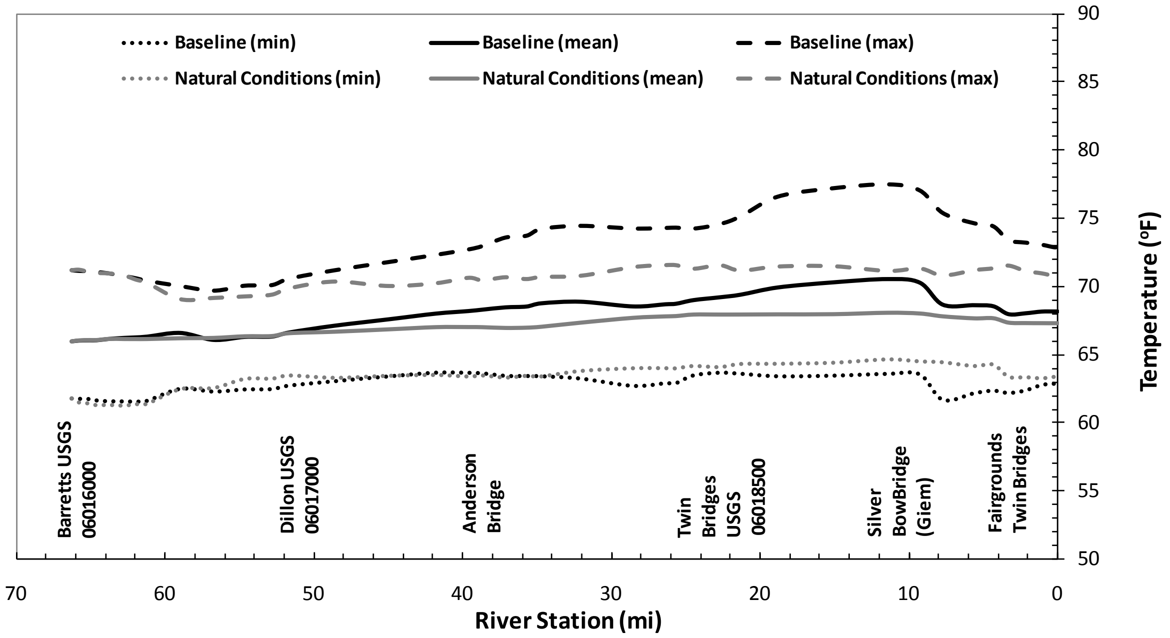

Figure B7-5. Simulated unmodified hydrology conditions on the Beaverhead River.

B7.6 SCENARIO SUMMARY

All of the scenarios detailed in this section are summarized below (**Figure B7-6**). In every situation, water temperature improvements were gained, the most significant being those related to the water volume (i.e., flow). Future conservation efforts should therefore focus on prioritizing restoration efforts with these in mind. A tabular summary of the findings are shown in **Table B7-1**.

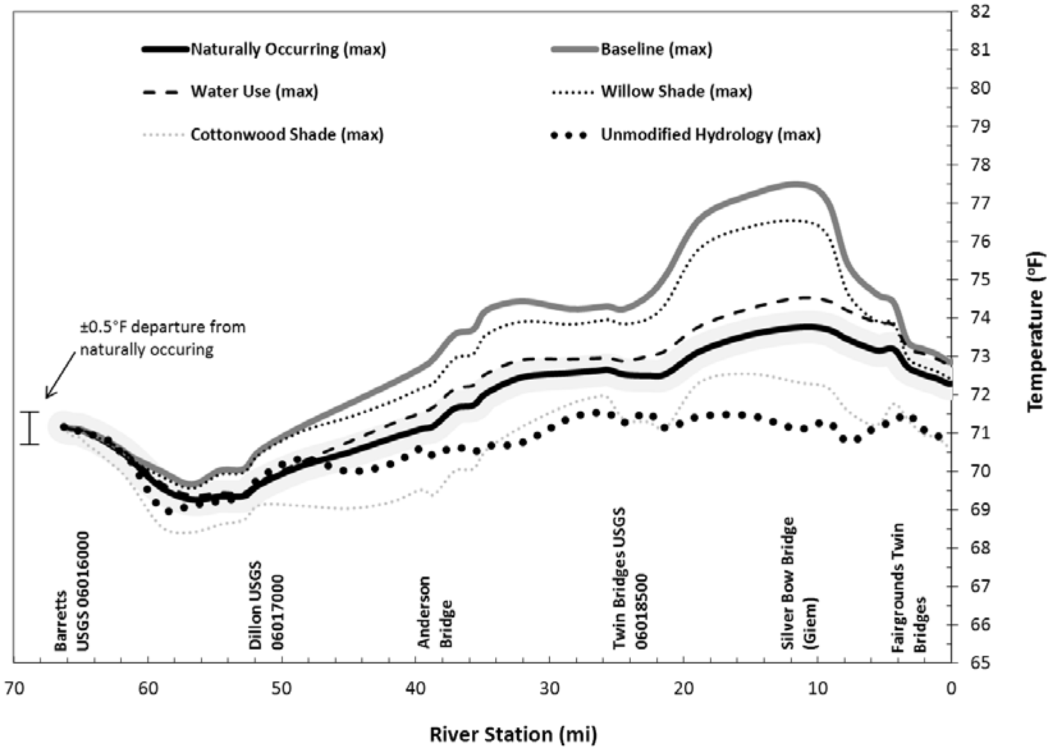

Figure B7-6. Comparison of management scenarios on the Beaverhead River.

Table B7-1. Summary of the management scenario analysis for the Beaverhead River.

Scenario	Mean Temp (°F)	Min Temp (°F)	Max Temp (°F)	Mean ΔT decrease (°F)	Min ΔT decrease (°F)[1]	Max ΔT decrease (°F)
Baseline	67.9	61.6	77.5	NA	NA	NA
Willow Shade	67.6	61.3	76.5	0.4	0	1.0
Cottonwood Shade	66.1	60.0	72.5	2.4	0	5.2
Increased Flow (Water Use)	67.9	61.6	74.5	0.9	0	3.0
Naturally Occurring	67.6	61.6	73.8	1.3	0	3.7
Unmodified Hydrology	67.1	61.3	71.5	2.2	-0.1	6.4

[1] Negative values indicate an increase of temperature compared to baseline.

B8.0 CONCLUSION

Water temperature modeling was completed on the lower Beaverhead River such that the mechanistic relationship between instream water temperature, riparian conditions, and water management practices could be established for the summer critical low-flow period. Through scenario analysis, it was shown that flow alteration was the most crucial management component influencing water temperature in the basin. Existing water temperatures are up to 3.7°F warmer than naturally occurring conditions, and are up to 6.4°F higher than the unmodified hydrological condition. Thus the key management recommendation originating from this study is to protect and reestablish instream flows to the extent possible. Other management scenarios were evaluated to identify the most effective means of the improving water temperature in the river. Decreasing irrigation diversions through better delivery efficiency appears to be the most effective method available. However, riparian improvement could also be used in conjunction with improved irrigation delivery and efficiency to a greater benefit. If riparian improvements were realized, it would reduce the amount of water savings needed from irrigation delivery and efficiency to fully mitigate the current temperature impairment.

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