APPENDIX C – UPPER JEFFERSON RIVER TEMPERATURE MODEL

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C1.0 INTRODUCTION

This report details a temperature monitoring and modeling project completed on the Upper Jefferson River mainstem. The Jefferson River (waterbody # MT41G001_010, 83.6 miles from the headwaters to the mouth) is listed as impaired due to temperature on the 2014 303(d) List. This river is listed as a B-1 use class, which is regulated by the Administrative Rules of Montana (ARM 17.30.623 (2) (e)) to meet the following temperature conditions:

(1) A maximum allowable increase of 1 °F above naturally occurring temperatures within the range of 32° to 66° F;
(2) No discharge is allowed which will cause the water temperature to exceed 67ºF within the naturally occurring range of 66ºF to 66.5ºF; and
(3) Where the naturally occurring water temperature is 66.5ºF or greater, the maximum allowable increase in water temperature is 0.5ºF.

A temperature model calibrated with July 2009 field data was used to document existing temperature conditions and typical low flow conditions, and to simulate scenarios using various land and water management practices which would reduce temperature in the Upper Jefferson River to meet B-1 classification requirements.

Listed tributaries for temperature impairments, Big Pipestone Creek (waterbody MT41G002_010, 24.4 miles), and the Boulder River (waterbody MT41E001_030, MT41E001_22, 45.6 miles, which discharge into the Jefferson River within the study area, were not explicitly modeled as a part of this study. Big Pipestone Creek discharges to Whitetail Creek, and the combined flow discharges to the Jefferson Slough. The Boulder River discharges into the Jefferson Slough prior to its confluence with the Jefferson River.

C2.0 PROJECT STUDY AREA

The Jefferson River originates from three headwaters: Ruby River, Beaverhead River and the Big Hole River which drain approximately 7,632 mi^2 of high and mid-elevation topography. The Ruby River and Beaverhead River originate from the Ruby River Reservoir and the Clark Canyon Dam, respectively. The Big Hole River is free of any mainstem water impoundments. The entire watershed is part of United States Geological Survey (USGS) Hydrologic Unit Code (HUC) 10020005 and consists of predominantly of wide alluvial valleys that are constrained at a number of locations by narrowing geological outcrops. Currently, all 83.6 miles of the Jefferson River are listed as impaired for thermal modification (Montana Department of Environmental Quality, 2014). However, given the size of the watershed, the study area has been broken into two distinct planning segments: (1) the upper TMDL planning area (TPA) which extends from the headwaters to the Boulder River/Jefferson Slough, and (2) the lower TPA which extends from Boulder River to the confluence with the Missouri River.

This study is focused on the Upper Jefferson River TPA extending from the headwaters to downstream of the confluence with the Boulder River/Jefferson Slough. The Upper Jefferson River within the study area flows approximately 42 miles past the towns of Silver Star, Waterloo, Whitehall, and Cardwell. The project site is most easily accessed via MT-41 and MT-55 between Whitehall and Twin Bridges and via Point of Rocks Road between Waterloo and Whitehall **Exhibit C1**.

C2.1 CLIMATE

The Upper Jefferson River encompasses a geographic area of approximately 734 mi^2. The average annual rainfall in the Jefferson River Valley (as opposed to the mountainous portions of the watershed) is 9.65 inches and the average annual snowfall is 11 inches (Water & Environmental Technologies, 2006). The 1956 Jefferson County Water Resource Survey (WRS) notes that July and August are sunny, clear, and warm with occasional showers and thunderstorms. The WRS study noted that winds can be strong in the Jefferson River Valley. Cooperative observation station Whitehall, Montana (COOP ID 248910) indicates that from the 1961 – 1990 time period, July and August received 19% of the total precipitation with the heaviest precipitation in May and June (37% of total 10.52 inches). Average minimum and maximum air temperatures during 1961-1990 range from 47.1 ºF to 84.2ºF in July and August (Western Regional Climate Center, 2009).

C2.2 SURFACE WATER

Watershed hydrology is predominately snowmelt-driven and there are two operational USGS gauging stations in the study area. These include: (1) USGS 06026500 *Jefferson River below Twin Bridges, MT*, and (2) USGS 06027600 *Jefferson River at Parsons Bridge near Silver Star, MT*. Typically, spring snowmelt begins in early April, peaks in June, and then rapidly declines in July and August toward baseflow. Tributary inflow to the Upper Jefferson River is dependent on snowmelt and precipitation. The watershed includes two spring fed tributaries: Parsons Slough and Willow Springs. Important tributaries in the study reach include Hell's Canyon Creek, Fish Creek and the Boulder River/Jefferson Slough.

C2.3 GROUNDWATER

A recent groundwater study conducted in a subset of the TPA area was the Groundwater Study of the Waterloo Area (Water & Environmental Technologies, 2006) commissioned by Trout Unlimited for the area near Parsons Slough and Willow Springs, east of the Jefferson River channel. The study showed that the Jefferson River benefited from spring fed tributaries and groundwater inflow in the Waterloo area. Heavy irrigation withdrawals from major ditches at times exceeded surface flows at Twin Bridges, and groundwater and tributary inflow was a primary factor in maintaining streamflow through the middle reaches of the Jefferson.

For this study area, the principal water-bearing formation was unconsolidated alluvium. The alluvial deposits include valley fill, alluvial fan gravels and glacial deposits resulting from outwash derived from either a glacier or glacier dammed lakes. The full alluvium thickness is not well known as wells drilled in the area are generally completed when sufficient water is encountered, well above the alluvial bottom. Information reviewed from driller logs show a coarsening downward sequence consisting of silty clay, sand and coarse gravels.

The water bearing material is characterized as an unconfined aquifer with the water table depth varying throughout the valley. The greatest water table depth within the study area is on the Parrot Bench and ranges from 80 to 180 feet below ground surface (bgs), shallowing westward toward the valley center to depths of 1 to 10 feet bgs. In the Waterloo study area, groundwater flows to the north at an average gradient of 11.7 feet per mile (0.002%).

The Jefferson River Watershed Council (JRWC) has requested that the Upper Jefferson River Watershed be included as a basin study area as part of the MBMG Groundwater Investigation Program approved during the 2009 legislative session. There are several long-term wells in the project study area that are sampled by the MBMG as part of its statewide monitoring network.

C2.4 Irrigation and Domestic Water Use

Land ownership in the Upper Jefferson River watershed is 57% private, 28% Forest Service, and 15% Bureau of Land Management and State land combined. The primary land use is rangeland and forested areas, with 15% classified as agricultural use. The majority of agricultural production in the valley is irrigated land (Jefferson River Watershed Council, 2011). The Jefferson River Basin is a closed basin due to over-appropriation of water rights. The Jefferson River Watershed Council has enacted a voluntary drought management program with a critical low water level at Parson's Bridge of 50 cfs.

The majority of agricultural lands within the project study area are irrigated through shares from three major canals: the Parrot, Fish Creek, and Creeklyn. A small percentage of lands are irrigated by smaller diversions along the Jefferson River or through groundwater irrigation wells. The Parrot ditch is the largest delivery canal on the Jefferson River, flowing along the Parrot Bench, at the eastern edge of the study area. The Parrot Ditch is 26 miles long, serves approximately 9,000 irrigated acres, and carries over 200 cfs during the irrigation season. Combined diversions from these three canals often exceed 300 cfs.

Past irrigation practices were primarily flood irrigation, but over time a large percentage of land has been converted to sprinkler methods in an attempt to increase production and efficiency, and to reduce water usage and labor. Over 70% of the irrigated lands in the Jefferson Valley are now irrigated with sprinkler or center pivot systems. Where flood irrigation systems rarely applied water with greater than 50% efficiency, the application efficiency for center pivot systems is commonly 70 to 75% (Van Mullem, 2006). There are a number of smaller ditches throughout the project area that still provide flood irrigation to pasture and hay ground. These ditches generally flow from smaller diversions on the Jefferson River downstream of the Parrot Ditch, or from lateral ditches off the Parrot. There are also several old river channels or slough channels along the river bottom, some of which are used for irrigation or serve as return flow conduits.

C3.0 Field Methods and Materials

A multi-disciplinary field team from WET, DEQ, Trout Unlimited and MFWP deployed instream temperature loggers from 7/27/2009 through 7/31/2009, and collected field measurements from 8/16/2009 through 8/21/2009 to characterize continuous water temperature, meteorological data (e.g. air temperature, dew point, wind speed, and cloud cover.), and the associated water balance in support of the modeling effort. The intensive one-week synoptic flow monitoring program was supplemented with information from temperature loggers deployed in tributaries, return flows, headwater and mainstem channel water columns, and from a project-specific HOBO weather station. Additional information was obtained from the USGS National Water Information Program, Remote Automated Weather Station (RAWS) program, and Bureau of Reclamation AGRIMET network to provide comprehensive data regarding the project reach.

C3.1 Site Selection

Sites for discharge, temperature monitoring and shade characterization were identified by assessment of aerial images and USGS topographical maps to capture areas where stream temperature may be influenced by changes in land cover/land use and streamflow (via irrigation ditches, tributaries, and return flows). In addition, a riparian inventory of the Jefferson River was completed in 2002, which characterized the channel, riverbanks, and vegetation, and was used to assist with sample site selection. Irrigation diversions were identified through aerial images, Montana Water Resource Surveys (WRS) for Jefferson County (1956), Silver Bow County (1955) and Madison County (1965), the WET Ground Water Report (2006) and the Van Mullem Report (2006).

In total, 19 mainstem locations, 26 tributaries and irrigation return flows, and 18 irrigation withdrawals were monitored in the field. Twenty-four (24) sites were assessed for vegetative shade and 12 of these sites were also monitored with a Solar Pathfinder ™. Approximately 56% of the flow measurement sites and approximately 90% of the shade sites were accessed by watercraft, while the remainder were accessed by land.

C3.2 Temperature Data

Continuous temperature dataloggers were used to record diurnal variations in water temperature. Temperature loggers used in the Upper Jefferson River modeling study were Optic StowAway® model number WTA32-05+37. The StowAway® is a completely sealed underwater temperature logger with capability to record continuous readings from 0.5 seconds to 9 hours. Temperature measurements were collected at 15-minute increments, and were read on the hour for model input/calibration purposes. Logger calibration checks were completed by DEQ both pre- and post deployment, and were deemed acceptable. Loggers have a NIST traceable temperature accuracy of ±0.2°C, therefore the absolute accuracy is 0.4ºC. Loggers were in the field for approximately three months (late July through early October 2009).

Forty-nine (49) temperature loggers were deployed in the field; this included 20 mainstem locations, 26 tributaries and irrigation return flows, and three headwater rivers. Of the total deployed, 48 dataloggers were retrieved. The duplicate logger to the USGS gage downstream of Parsons Bridge could not be located (JEF-M-21.8). The logger JEF-M-20.7 (Joe Adams' boat launch) was found to be out of the water for a significant portion of the field week. The datalogger JEF-M-21 (railroad bridge overpass accessed from Loomont Road), is in close proximity to JEF-M-20.7 and was used to describe the mainstem temperature for this reach.

C3.3 Discharge Data

Instantaneous flow was measured at 63 locations (19 mainstem locations, 26 tributaries and irrigation return flows, and 18 irrigation withdrawals). Due to higher than anticipated streamflows during the field effort, it was necessary to adjust pre-selected locations to wadable sections of the river. Stream discharge was measured with a *Marsh McBirney Flo-Mate 2000™* current velocity meter and standard USGS area-velocity method at all sites. Four *Marsh McBirney Flo-Mate 2000™* current velocity meters were used in the field. Velocity output for the meters was verified to be within ±10% on the first day of the field effort. Results were ±6.4% (1.40, 1.44, 1.47, and 1.49 ft/sec).

The streamflow measurements were within 5% of the USGS measurements with the exception of JEF-M-38.3 (11%). There is a note on the field form at site JEF-M-38.3 that the tape measure was strung at a slight angle to the channel, which may explain the difference (**Table C1**).

Table C1. Accuracy Results for Field Collected Data – Stream Discharge

Date and Time	Location	Field (CFS)	Established Equipment Result	Relative Percent Difference
8/18/09, 13:00	BGH-H-F	437.76	USGS, 446 CFS	2%
8/18/09, 11:54	RUB-H-F	133.41	USGS, 140 CFS	5%
8/18/09, 11:00	BHD-H-F	418.63	USGS, 439 CFS	5%
8/20/09, 09:50	JEF-M-38.3	732.83	USGS, 818 CFS	11%
8/19/09, 16:00	JEF-M-21.8	579.32	USGS, 554 CFS	4%

C3.4 Morphological and Shade Data

River morphology and riparian vegetation data were assessed in the field to characterize direct solar radiation losses from topography and vegetative shade. The following measurements were collected to support the modeling efforts: (1) bankfull and wetted channel width, (2) vegetation/canopy height, (3) canopy density, (4) channel overhang, and (5) percent shade at specified transects. A fiberglass-tape, range-finder, clinometer, canopy densitometer, and Solar Pathfinder™ were used to acquire these attributes.

C3.5 Climate Data

Climate was field-monitored so that measurements in the river corridor could be correlated with that of surrounding RAWS, AGRIMET, and HOBO weather stations. Air temperature and wet bulb depression were measured with a U.S. Weather Bureau type sling phsychrometer having accuracy of ±0.5 °C. Wind speed was measured with a Dwyer hand-held wind meter (±0.2 m/s for low scales and ±1.3 m/s for high scales). Observations of cloud cover were also recorded. All measurements were collected four times daily.

C4.0 Model Development

C4.1 Model Description

QUAL2K v2_11b8 (Q2K) is a one-dimensional (channel is well-mixed vertically and laterally), steady state temperature model (Chapra et al., 2008). Q2K v2.11b8 utilizes a Microsoft Excel graphical interface and is programmed with Visual Basic for Applications (VBA). The components of the heat balance are simulated on a diel time scale. Calculations include solar shortwave radiation, downwelling atmospheric longwave IR radiation, evaporation and air convection/conduction, and sediment heat exchange.

Input parameters required to simulate the heat flux across the air-water interface include air temperature, wind speed, dew point temperature, and cloud cover. These parameters interact with shade, river morphology, and adjacent tributaries to provide a comprehensive description of mass/heat transfer and advection/dispersion throughout the simulated system. Springs, tributaries, and return flows are assumed to be mixed instantaneously, and reach-specific rating curves are used to estimate flow velocity and depth and associated hydraulics for a given discharge. Groundwater infiltration or depletion is input on a reach-specific basis.

C4.2 Shade Input and GIS Preprocessing

Shade.xls utilizes a Microsoft Excel graphical interface and is programmed with Visual Basic for Applications (VBA) that calculates the topographic and vegetative shade for equidistant nodes specified by the user. The interface is designed to conform to Q2K formatting. Forcing functions required to simulate the effective shade at each node include: type of vegetation, vegetation density, angle of topographical shade from water surface, aspect of water flow, wetted width, and bankfull width. A spatially explicit ArcView3.2 GIS pre-processor called TTools for efficient calculation of morphologic and shading attributes at river scales (Boyd and Kasper, 2003) was utilized to determine the type of vegetation at each node and the angle of topographical shade from the water surface. Fundamental input data required for implementation of TTools includes: (1) site topography in the form of a digital elevation model (DEM), (2) digitized channel morphology (e.g. bankfull width and centerline), (3) digitized riparian vegetation shapefile, and (4) user-defined vegetation characteristics. The 10-m USGS National Elevation Dataset (NED) was used for calculation of topographic characteristics. Channel centerline, bankfull width, and riparian vegetation classification were all digitized by using 2004 National Agricultural Imagery Program (NAIP) photography at a scale of 1:5,000. Project coordinate system and datum were Montana State-Plane NAD83 and NAVD88.

TTools includes a longitudinal and radial sampling algorithm that calculates site-specific morphologic and shading characteristics such as channel width and slope, topographic shade, and vegetative shade at user defined nodes (*i* and *i*+1) along the channel centerline. A node distance of 1000-m was used in the case of the Upper Jefferson.

The height, density, and overhang were determined by averaging all field entries for each specific vegetation type and calibrated with Shade.xls results to Solar Pathfinder™ effective shade results. The following vegetation classifications and shade input parameters are shown in **Table C2**. An example of the vegetation classification layer developed by TTools is shown in **Figure C1**. Blank vegetation description is used to populate unused columns within the Shade.xls excel program for each node. Three field teams characterized shade parameters; differences in best professional judgment of sparse or dense cottonwoods may account for similar vegetation densities.

Table C2. Shade.xls Input Parameters for Vegetation Type

Vegetation Description	Height	Density	Overhang
	(m)	(%)	(m)
Upland Native Grass	1.3	14%	0.1
Irrigated Wetland Grass	0.5	24%	0.2
Mixed High Level	12.6	48%	0.8
Mixed Low Level	3.0	36%	0.2
Cottonwood Dense	16.3	54%	0.0
Cottonwood Sparse	13.9	52%	0.0
Willow Dense	4.2	62%	0.1
Willow Sparse	2.6	46%	0.1
Bare	0.0	0%	0.0
Blank	0.0	0%	0.0

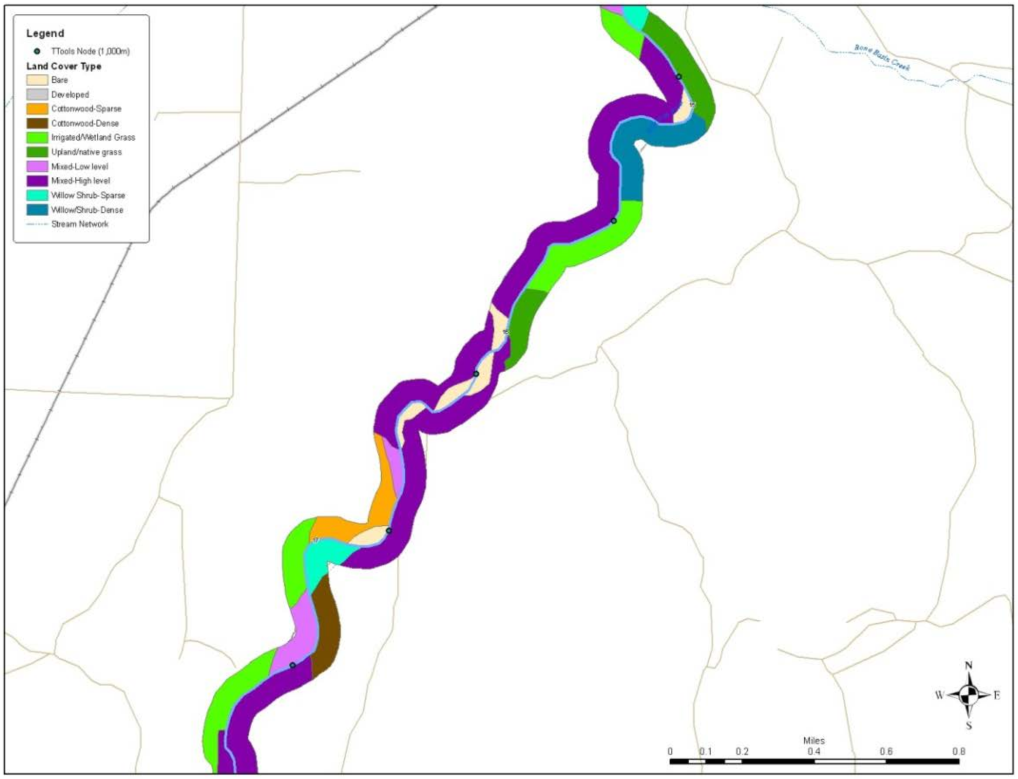

Figure C1. TTools Vegetation Classification

C4.3 Simulation Period and Global Control Specifications

The ideal model simulation period would occur with the critical limiting period, i.e., where standards are most likely to be exceeded and under steady-state climatic and hydrologic conditions. Based on a review of water temperature data at USGS 06026500 *Jefferson River below Twin Bridges, MT*, this period most frequently occurs in late July, when air temperatures are the highest, when the photoperiod is sufficiently long, and when the hydrograph has sufficiently recessed. The field data collection was pre-scheduled to this time when the photoperiod is long and the river levels reach baseflow.

A review of the seasonal maximum and seven day maximum of temperature logger results between 7/29/2009 and 9/30/2009 are summarized in **Table C3**. Seasonal maximum temperatures occurred in early or late August, depending on river location. The seasonal maximum temperature dates appear to be affected by the location in the upper half or lower half of the river, whereas the 7-day average occurred in late July for almost all temperature logger locations. After evaluating the logger data, a three day average temperature from August 20-22, 2009 was used in the model. This date overlapped with a majority of seasonal maximum temperature results and the loggers with the most days over 70°F, as well as two days of field measurements.

Control information specified during initial modeling efforts was: (1) number of days (2) calculation time steps, and (3) integration solution method. It was determined that the model ran adequately with a run time of three days, calculation step of 0.08 hours, and the Euler Method (default). The time of travel for the existing conditions was approximately one day whereas the time of travel in a 7-day 10-year low flow event is approximately two days; thus this time step exceeds the time of travel in all scenarios.

Table C3. Upper Jefferson River - Mainstem 2009 Temperature Data Summary: Data period 7/29/2009 – 9/30/2009

Site ID	Start	Stop	Seasonal Max.		7-Day Averages (ºF)				Days> 70F
			Date	Value	Date	Max	Min	ΔT	
RUB-H-T	7/28/09	9/30/09	8/1/09	69.8	7/30/09	67.7	60.7	7.0	0
BGH-H-T	7/28/09	9/30/09	8/3/09	73.1	8/21/09	70.5	61.8	8.7	16
BHD-H-T	7/28/09	9/30/09	8/3/09	72.5	7/29/09	70.5	61.3	9.1	8
JEF-M-41.2-T	7/29/09	9/30/09	8/3/09 & 8/4/09	72.7	7/29/09	70.3	61.8	8.5	7
JEF-M-39.5-T	7/29/09	9/30/09	8/4/09	73.8	7/29/09	70.7	62.0	8.7	13
JEF-M-38.3-T	7/29/09	9/30/09	8/4/09	73.7	7/29/09	70.6	62.3	8.3	9
JEF-M-35.2-T	7/29/09	9/30/09	8/4/09	73.1	7/30/09	70.5	62.9	7.6	10
JEF-M-35.2-T	Duplicate				8/1/09	70.5	63.0	7.4	Duplicate
JEF-M-32.4-T	7/29/09	9/30/09	7/31/09 & 8/4/09	73.1	7/30/09	70.6	63.3	7.3	13
JEF-M-27.1-T	7/29/09	9/30/09	8/4/09	73.1	7/29/09	70.5	62.9	7.6	9
JEF-M-24.5-T	7/29/09	9/30/09	8/22/09	73.1	7/29/09	70.6	63.4	7.3	14
JEF-M-21-T	7/29/09	9/30/09	8/22/09	72.5	7/29/09	70.1	63.2	6.9	7
JEF-M-19.2-T	7/29/09	10/1/09	8/4/09 & 8/21/09 & 8/22/09	72.5	8/21/09	69.9	61.0	8.9	12
JEF-M-15.9-T	7/29/09	10/1/09	8/4/09 & 8/21/09 & 8/22/09	72.9	7/30/09	70.2	62.9	7.3	9
JEF-M-15.9-T	Duplicate				8/21/09	70.2	61.7	8.5	Duplicate
JEF-M-12.1-T	7/29/09	10/1/09	8/22/09	72.8	7/30/09	70.2	63.2	7.0	11
JEF-M-9.5-T	7/29/09	9/29/09	8/22/09	72.8	7/29/09	70.5	62.9	7.6	11
JEF-M-9.5-T	Duplicate				7/30/09	70.5	63.3	7.1	Duplicate
JEF-M-7.2-T	7/29/09	9/29/09	8/22/09	73.1	7/29/09	70.6	63.0	7.6	13
JEF-M-7-T	7/29/09	9/29/09	8/22/09	73.2	7/29/09	70.7	62.9	7.8	16
JEF-M-3.9-T	7/28/09	9/29/09	8/22/09	73.7	7/29/09	71.3	63.5	7.8	20
JEF-M-3.9-T	Duplicate				8/1/09	71.3	64.1	7.2	Duplicate
JEF-M-1.4-T	7/29/09	9/30/09	8/4/09 & 8/22/09	73.4	7/29/09	71.1	63.6	7.5	19
JEF-M-0-T	7/29/09	9/30/09	8/4/09 & 8/22/09	73.7	7/29/09	71.1	63.4	7.7	20

C4.4 Hydrology and Mass Transfer Input

Hydrology and mass transfer data from the 2009 field effort were used to define the overall water balance and associated boundary conditions in the model. As shown in **Figure C2**, mean daily discharge at the USGS gage near Twin Bridges (06026500) for August 16 - 22, 2009 was approximately 789 cfs. This flow was calculated as the 7Q1.6 (63% probability of non-exceedance) based on the available years of record (1958-1972 and 1994-2009, Thomann and Mueller).

Temperature records were not available for the 2009 year at the USGS gage site near Twin Bridges. However, the temperature results from the USGS gage near Parson's Bridge (06027600) were available and are shown on **Figure C3.** The translucent yellow box on **Figures C2** and **C3** indicates the selected 3-day model period. The 2009 model period shows a warmer mean daily temperature than the mean value from 2006 – 2009 as shown in **Figure C3**.

The model application was developed for the 3-day period of August 20-22, 2009. The translucent yellow box on **Figures C2** and **C3** indicates the 3-day model period. Locations of all hydrology/mass transfer monitoring sites are shown in **Exhibit C1**.

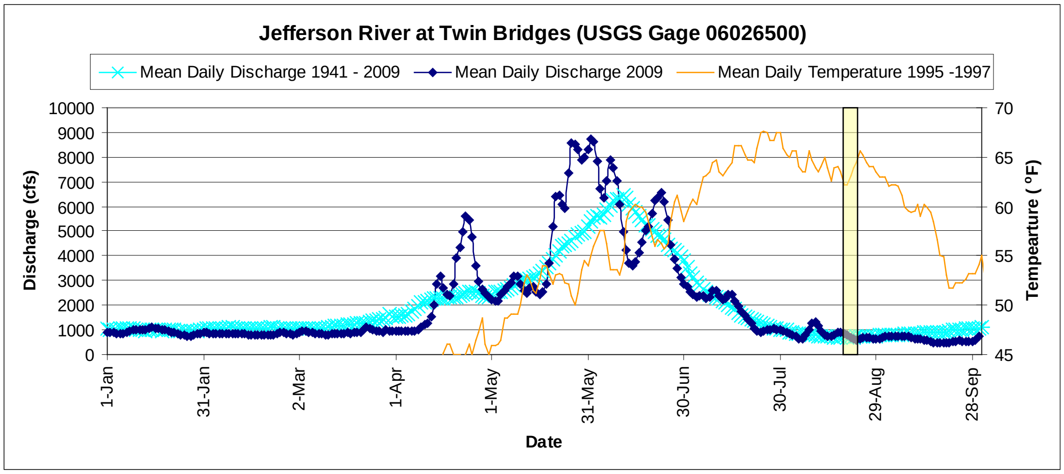

Figure C2. Summary of mean daily discharge, temperature, and associated statistics for the USGS gage near Twin Bridges, MT (USGS 06026500)

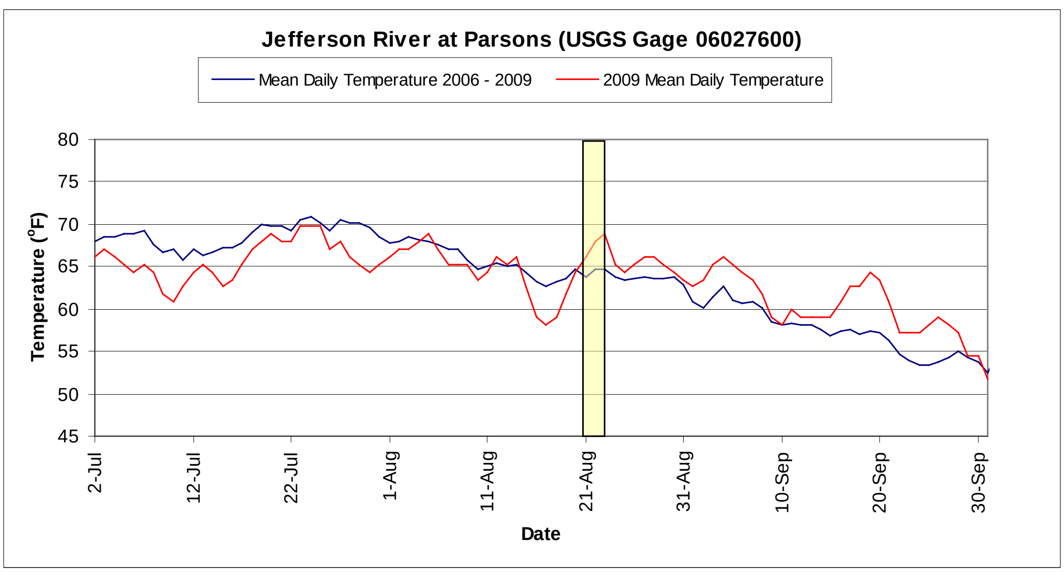

Figure C3. Summary of mean daily water temperature, and temperature statistics for the USGS gage at Parsons Bridge, MT (USGS 06026500).

A steady state upstream flow boundary condition was assumed for the use of Q2K to model temperature conditions. All tributary and irrigation exchanges were also considered steady-state. The average hourly temperature across the 3-day modeling period was entered into the model at the upstream boundary. All tributary and return flow temperature inputs consisted of the mean, range/2, and time of max for the average hourly value over the 3-day modeling period. Groundwater temperature was adjusted within published groundwater temperatures in order to best fit observed and simulated water column temperatures. Further discussion is included in **Section 5.4**.

Significant areas of split flow (greater than one mile) were not entered into the Q2K model. The split flow at mile 7 showed similar temperature trends in both channels, as shown on **Figure C4**, sites M-7 and M-7.2.

Box and whisker plots from all Jefferson River mainstem sites, incoming tributaries, and irrigation return flows are shown in **Figure C4**. The location of each temperature logger site is included in **Exhibit C2**. While minimums and maximums vary throughout the watershed, it is recognized that irrigation return flows (encapsulated in yellow translucent boxes) often have a much larger temperature range and associated quartiles, compared to that of natural tributary flow (encapsulated with blue translucent boxes). Specific to the model period, the increased temperature range was not entirely a function of flow volume in each return flow. The travel time and distance are mostly likely the other contributing parameters.

The temperature datalogger for the mainstem JEF-M-20.7 was out of the water for the first portion of the week. Thus, this specific box plot is not for the full seven day time period.

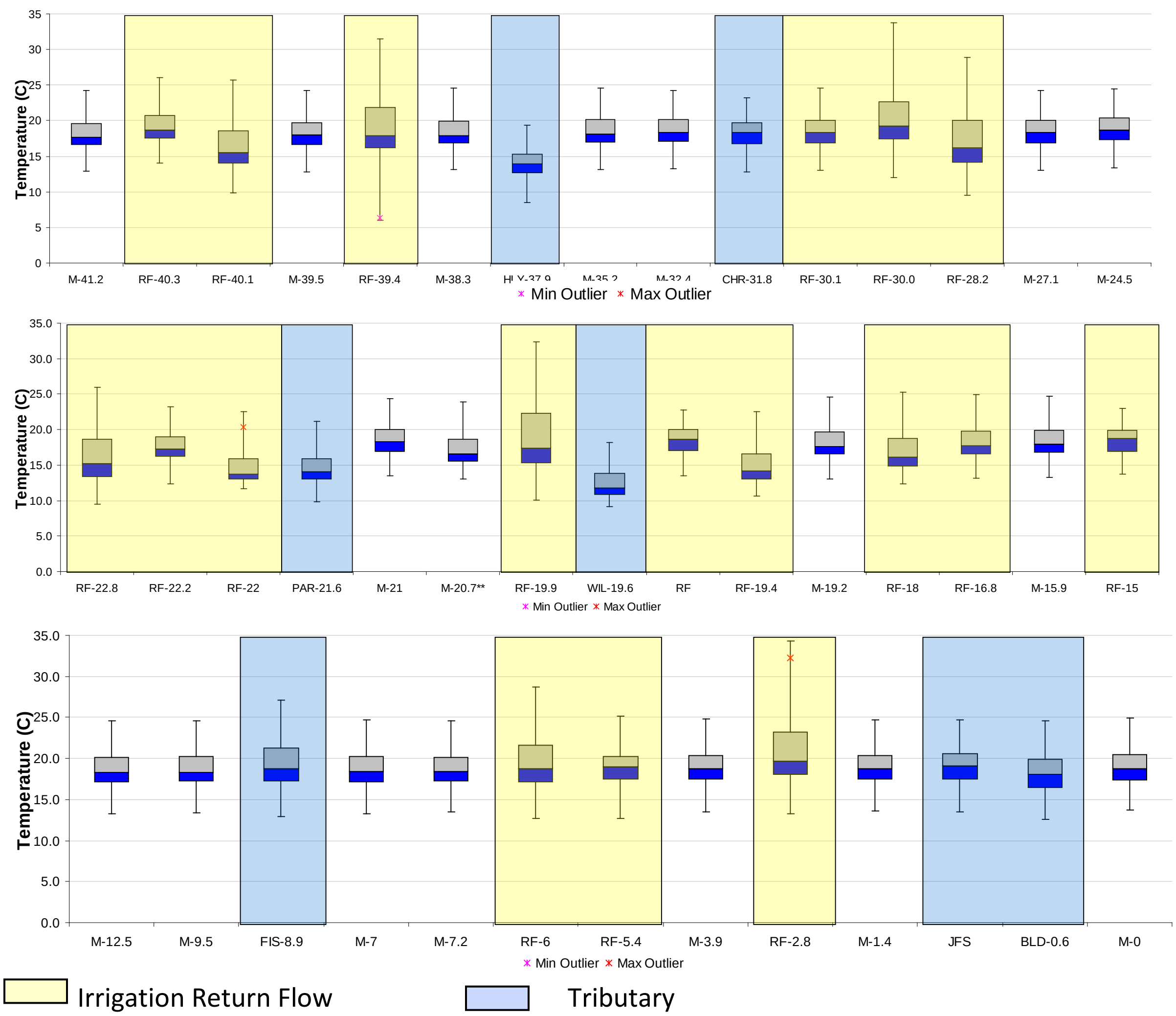

Figure C4. Box and Whisker Plots for 8/18/2009 through 8/24/2009

Flow measurements throughout the watershed were collected from 8/16/2009 through 8/21/2009. A water balance was created between each mainstem flow measurement to determine the groundwater influence. The water balance included seventeen mainstem reaches along the Upper Jefferson River and incorporated all known irrigation withdrawals and return flows, as well as tributary inflows. The model is divided into ten reaches as discussed in **Section C4.5, Figures C5** and **C6**); as a result, groundwater abstraction or inflow was combined at the reach breaks for model input data. Groundwater gain/loss was validated for the study reach within the WET 2006 report. The WET report included mainstem Jefferson River flow monitoring from above the Parrot Canal to below the Willow Spring confluence. Based on these data collected in 2005, a course level water balance was developed. The 2005 water balance identified similar gaining and losing reach locations as determined in this 2009 study; however it should be noted that flow conditions and monitoring reaches were different for each study. The 8/20/2009 water balance is shown in **Table C4.**

Table C4. Water Balance - Upper Jefferson River updated to 8/20/2009

UPPER JEFFERSON RIVER WATER BALANCE 8/18 - 8/21/09 Corrected to 8/20/2009			
		m3/s	**GWH20 EST**
JEF-M-41.2		**830.029**	
JEF-RF-40.3		4.319	
JEF-RF-40.1		22.140	**-19.597**
	TOTAL	**856.488**	**LOSING**
JEF-M-39.5		**836.890**	
JEF-RF-39.4		0.635	
JEF-D-38.8		-2.472	
JEF-D-38.6		-5.984	**-27.641**
	TOTAL	**831.541**	**LOSING**
JEF-M-38.3	**USGS gage 06026500**	**803.903**	
HCY-37.9	Hells Canyon	7.005	
JEF-D-37		-13.125	
JEF-D-36.3	Creeklyn Ditch	-45.180	**-60.015**
	TOTAL	**752.600**	**LOSING**
JEF-M-35.2		**757.685**	
JEF-D-35	Parrot Ditch	-169.075	
JEF-D-34.2		0.000	**84.446**
	TOTAL	**523.510**	**GAINING**
JEF-M-32.4		**607.956**	
CHR-31.8	Cherry Ck.	0.170	
JEF-D-30.5		-68.086	
JEF-RF-30.1		71.202	
JEF-RF-30.0		0.499	
JEF-RF-28.2		5.803	
JEF-2-28.1		-10.000	**39.790**
	TOTAL	**607.544**	**GAINING**
JEF-M-27.1		**647.334**	
JEF-D-26.7		-0.780	
JEF-D-25.1		-15.865	**-2.413**
	TOTAL	**630.689**	**LOSING**
JEF-M-24.5		**628.276**	
JEF-RF-23.8	(Redirected to 22.8)	0.000	
JEF-RF-22.8	Hirschy	11.686	
JEF-RF-22.2		1.027	
JEF-RF-22		3.000	
JEF-D-21.9	Fish Ck. Ditch	-87.717	**-29.372**
	TOTAL	**556.272**	**LOSING**
JEF-M-21.8	**USGS gage 06027600**	**526.900**	
PAR-T-21.6		1.249	**20.997**
	TOTAL	**528.149**	**GAINING**

UPPER JEFFERSON RIVER WATER BALANCE 8/18 - 8/21/09 Corrected to 8/20/2009			
		m3/s	**GWH20 EST**
JEF-M-21		**N/A**	
JEF-M-20.7		**549.146**	
JEF-RF-19.9		2.758	
WIL-T-19.6	Willow	20.913	
JEF-RF		4.993	
JEF-RF-19.4		2.132	**79.844**
	TOTAL	**579.942**	**GAINING**
JEF-M-19.2		**659.786**	
JEF-RF-18		3.240	
JEF-D-18		-42.781	
JEF-RF-16.8		39.435	**-55.073**
	TOTAL	**659.680**	**LOSING**
JEF-M-15.9		**604.607**	
JEF-RF-15		22.143	
JEF-D-14.6	Temple Ranch	-1.961	
JEF-D-14.6	Fish Creek	-37.640	
JEF-D-14.6	Slaughterhouse Slough	-33.120	**21.197**
	TOTAL	**554.029**	**GAINING**
JEF-M-12.5	**After Renova**	**575.226**	
JEF-D-12.1	(dry)	0.000	**-36.784**
	TOTAL	**575.226**	**LOSING**
JEF-M-9.5	**Koontz Bridge**	**538.442**	
FIS-T-8.9		76.777	
JEF-D-7.6		-8.201	**96.038**
	TOTAL	**607.018**	**GAINING**
JEF-M-7 SPLIT		**322.886**	
JEF-M-7.2 SPLIT		**380.170**	
JEF-RF-6	near Mayflower Bridge	0.137	
JEF-RF-5.4		23.148	**-23.359**
	TOTAL	**726.341**	**LOSING**
JEF-M-3.9		**702.982**	
JEF-D-3.5	pump, 0 flow 8/18	0.000	
JEF-RF-2.8		0.324	**100.175**
	TOTAL	**703.306**	**GAINING**
JEF-M-1.4	**near Jefferson Island**	**803.481**	
JFS-F		39.113	
Bld culvert		1.478	
BLD - 0.6		157.668	**-117.142**
	TOTAL	**1001.740**	**LOSING**
JEF-M-0	**near Lahood**	**844.007**	

Ideal model conditions would have a steady state flow condition (less than 10%) throughout the field and model simulation time periods. In order to best represent steady state conditions, each mainstem flow was corrected to a single date: 8/20/2009. This correction was performed based on the two USGS sites with continuous monitoring data for all four dates, and one mainstem site that was measured for flow on two consecutive days. The corrected values to 8/20/2009 enabled a better determination of the influence of groundwater between each reach.

The groundwater gain or loss between each mainstem measurement is shown on **Figure C5**. Groundwater gain or loss is described in the model based on user-defined Q2K reaches (further described in **Section C4.5**); the reaches with groundwater inflow are shown with translucent yellow boxes on **Figure C5.**

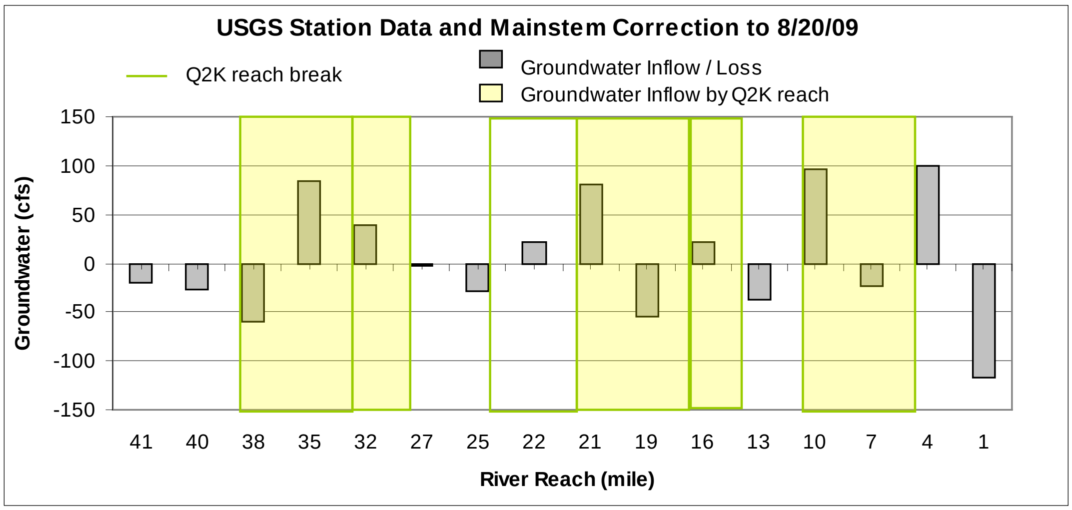

Figure C5. Groundwater Gain and Loss in the Q2K model

The Jefferson Slough was monitored for flow and temperature both upstream (station JFS) and downstream of the confluence with the Boulder River (station BLD-0.6). The Jefferson Slough shows a similar temperature range to the nearby Jefferson mainstem measurement (JEF-M-1.4) for the 2009 water year. Flow measurements are included in **Table C4**, however, only the combined Boulder and Jefferson Slough datum (BLD-0.6) were utilized in the model and for groundwater quantity calculations.

Temperature loggers were deployed at the effluent locations for the Twin Bridges and Whitehall wastewater lagoons. Neither effluent discharged directly to the Jefferson River; as a result, they were not included in the model.

C4.5 Reach Breaks and Hydraulic Input

Reach Breaks

Hydraulic data (depth and velocity) are calculated from reach-specific rating curves. Reach breaks were defined based on major channel elevation breaks and aspect changes from the 10-m DEM, as well as tributaries and major ditch locations (**Figure C6**). Each entry (blue diamond) is the intersection of the Jefferson River with a contour line. Several locations have the same elevation due to river meanders through the same contour line. This highlights the imprecision of using the 10-meter DEM.

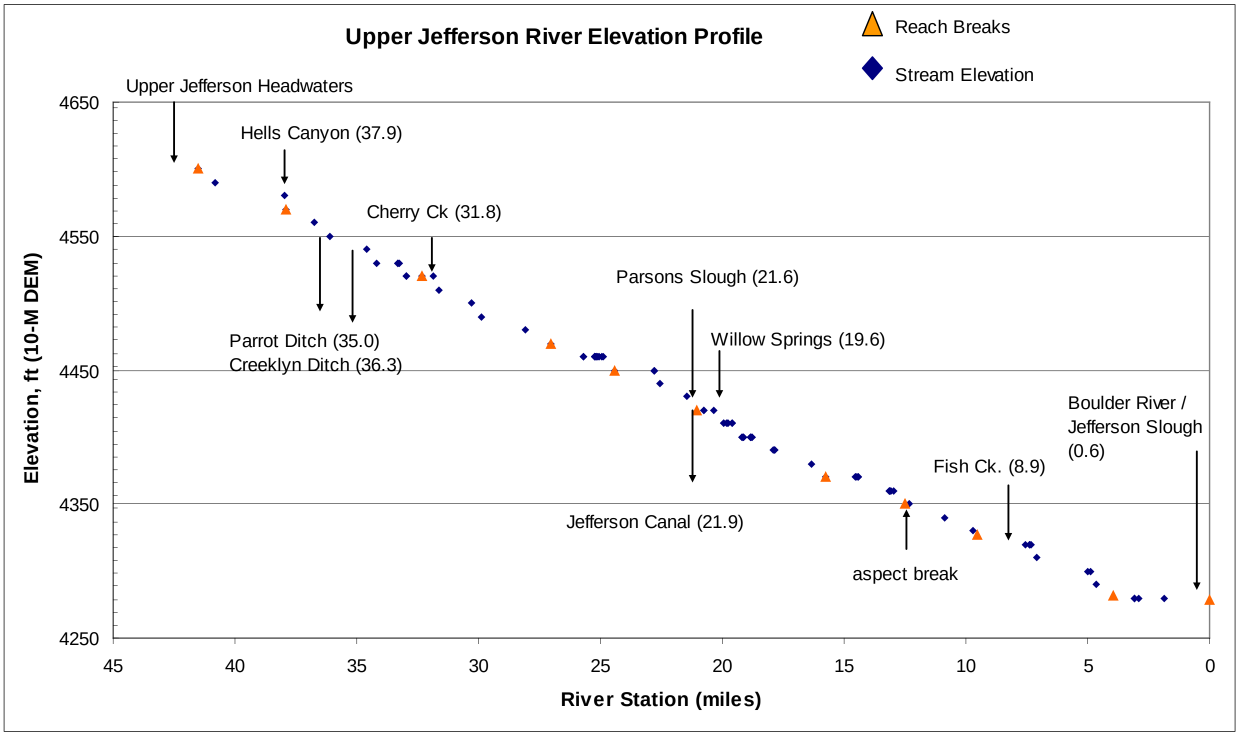

Figure C6. Upper Jefferson River Profile and Q2K Model Reach Breaks

The Q2K model was divided into ten reaches as shown above. Each reach was divided into ten elements in order to interpolate results at the same station as field measured locations and to compare output to the baseline model with a larger dataset. Thus there are 100 elements in the model. Elements are smaller river sections of uniform length within an existing reach break. Elements are utilized within the Q2K program to decrease the distance between output variables (width, depth, velocity, flow, and temperature).

Hydraulic Input

The Q2K model allows the user to utilize rating curves to describe the velocity and depth at each reach based on weir geometry, rating curves or Manning's Equation. This model utilized rating curves; exponent values were calculated based on the available velocity, discharge, and a wide river approximation from USGS gage 06026500 Jefferson River below Twin Bridges, MT. Two USGS gages are located within the project reach; however the USGS 06027600 (Jefferson River at Parsons Bridge nr Silver Star), MT had only four years of discharge data as compared to sixteen years of field measurements at the Twin Bridges site (06027500). As a result, the exponent values from USGS gage 06026500 were used for all Q2K reaches in the model.

Depth for each field measurement was calculated as the cross-sectional area divided by wetted width (Leopold and Maddock, Jr., 1953). The resulting rating curves (based on metric units) have the following power equations and r-squared values:

Velocity:	$U = 0.1918Q^{0.4000}$	$R^2 = 0.7177$
Depth:	$H = 0.1570Q^{0.4537}$	$R^2 = 0.8526$

A reach-specific coefficient was determined based on field-measured wetted width, velocity, flow, and depth for each mainstem flow measurement. The average velocity was calculated as the flow divided by area; the average depth was determined from area divided by wetted width. Field data was not adjusted for the hydraulic calculations; field collected discharge was corrected to a single day in order to calculate a water balance as discussed in **Section C4.4**. The Microsoft Excel add-in SOLVER was used to solve for the depth and velocity rating curve coefficients based on set values for the rating curve exponents, wetted width, average velocity, discharge, and average depth. Results are shown in **Table C5**.

Table C5. Reach Specific Rating Curves

Mainstem Site	Wetted Width, WW (ft)	Average Depth H=A/WW (ft)	Average Velocity U=Q/A (ft/sec)	Discharge, Q (ft^3/sec)	Velocity Rating Curve Coefficient (metric)	Depth Rating Curve Coefficient (metric)
JEF-M-41.2	176.0	1.59	3.18	889.8	0.2665	0.1122
JEF-M-39.5	169.0	1.70	3.12	897.2	0.2604	0.1197
JEF-M-38.3	153.0	2.05	2.34	732.8	0.2120	0.1576
Q2K Model input values (Twin Bridges Rating Curve)					**0.1918**	**0.1570**
JEF-M-35.2	218.0	1.09	2.93	692.6	0.2715	0.0857
JEF-M-32.4	166.2	1.61	2.43	650.1	0.2312	0.1308
Q2K Model input values (Twin Bridges Rating Curve)					**0.1918**	**0.1570**
JEF-M-27.1	150.0	1.46	2.96	647.3	0.2815	0.1189
Q2K Model input values (Twin Bridges Rating Curve)					**0.1918**	**0.1570**
JEF-M-24.5	154.0	1.67	2.44	628.3	0.2356	0.1378
Q2K Model input values (Twin Bridges Rating Curve)					**0.1918**	**0.1570**
JEF-M-21	160.0	1.34	2.70	579.3	0.2689	0.1148
JEF-M-20.7	133.0	1.65	2.50	549.1	0.2538	0.1452
Q2K Model input values (Twin Bridges Rating Curve)					**0.1918**	**0.1570**
JEF-M-19.2	160.0	1.30	3.19	663.4	0.3004	0.1049
JEF-M-15.9	128.5	1.82	2.59	604.6	0.2529	0.1530
Q2K Model input values (Twin Bridges Rating Curve)					**0.1918**	**0.1570**
JEF-M-12.1	171.0	2.08	1.41	500.4	0.1485	0.1904
Q2K Model input values (average of JEF-M-12.1 and JEF-M-9.5)					**0.2341**	**0.1763**
JEF-M-9.5	96.0	1.94	3.28	612.4	0.3197	0.1622
Q2K Model input values (average of JEF-M-12.1 and JEF-M-9.5)					**0.2341**	**0.1763**
JEF-M-7	105.0	1.73	2.67	485.3	Split flow	Split flow
JEF-M-7.2	134.5	2.98	1.04	416.1	Split flow	Split flow
JEF-M-3.9	148.5	2.01	2.68	799.4	0.2343	0.1488
Q2K Model input values (results from JEF-M-3.9)					**0.2343**	**0.1488**
JEF-M-1.4	179.0	1.50	2.60	699.0	0.2397	0.1183
JEF-M-0	192.0	2.25	2.09	904.9	0.1743	0.1575
Q2K Model input values (average of JEF-M-1.4 and JEF-M-0)					**0.2070**	**0.1379**

Use of the Twin Bridges rating curve coefficient versus a best fit coefficient constrained by field data was calibrated by comparison of the model output to field collected temperature, wetted width, depth and velocity. These comparisons are further discussed in the results section.

C4.6 Climate Input

Project specific meteorological data from the HOBO Weather Station was utilized within the model. The hourly air temperature (°C), wind speed (m/s), and dew point (°C) data is compared to the AGRIMET and

RAWS stations located in Whitehall, MT in **Figures C7 – C9** for the model input data (average of hourly results from 8/20/09 – 8/22/09). Field measurements taken from within the river corridor are also shown on the charts where available.

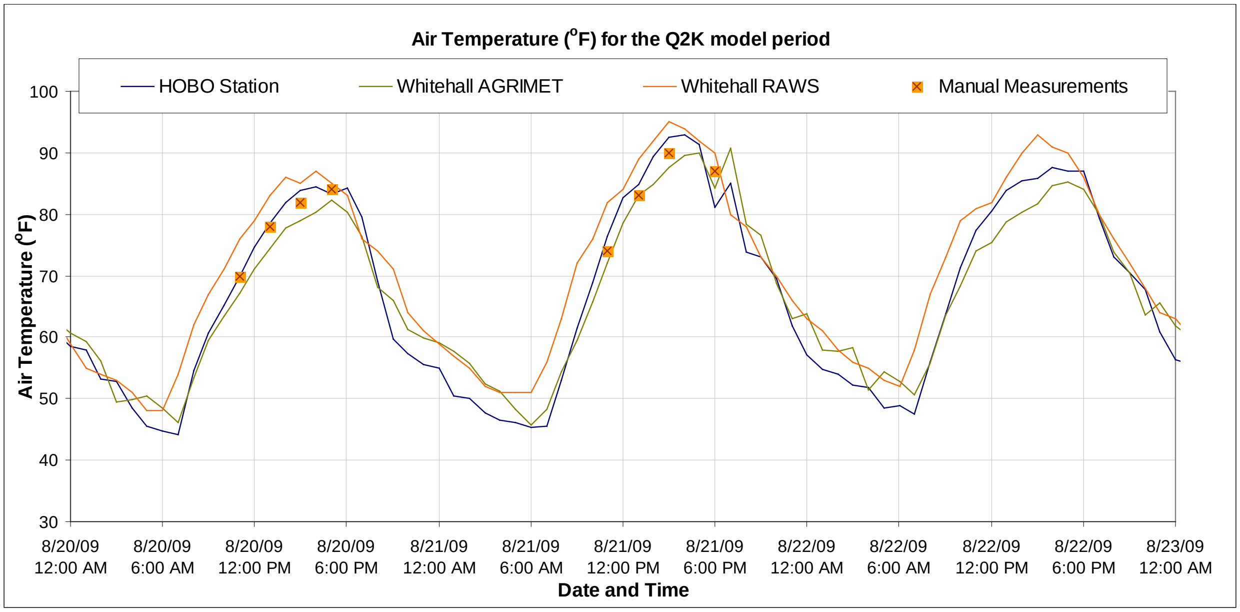

Figure C7. Weather Stations and Field Data Results: Air Temperature

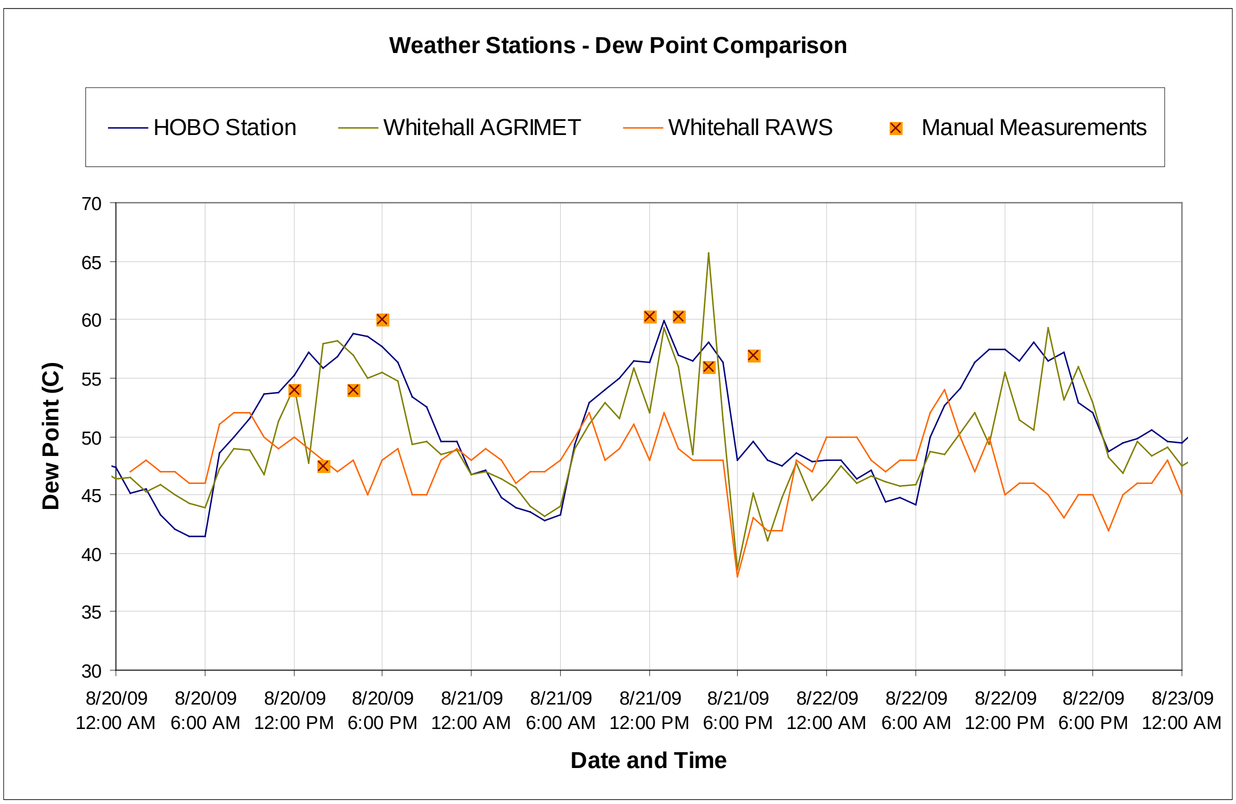

Figure C8. Weather Stations and Field Data Results: Dew Point

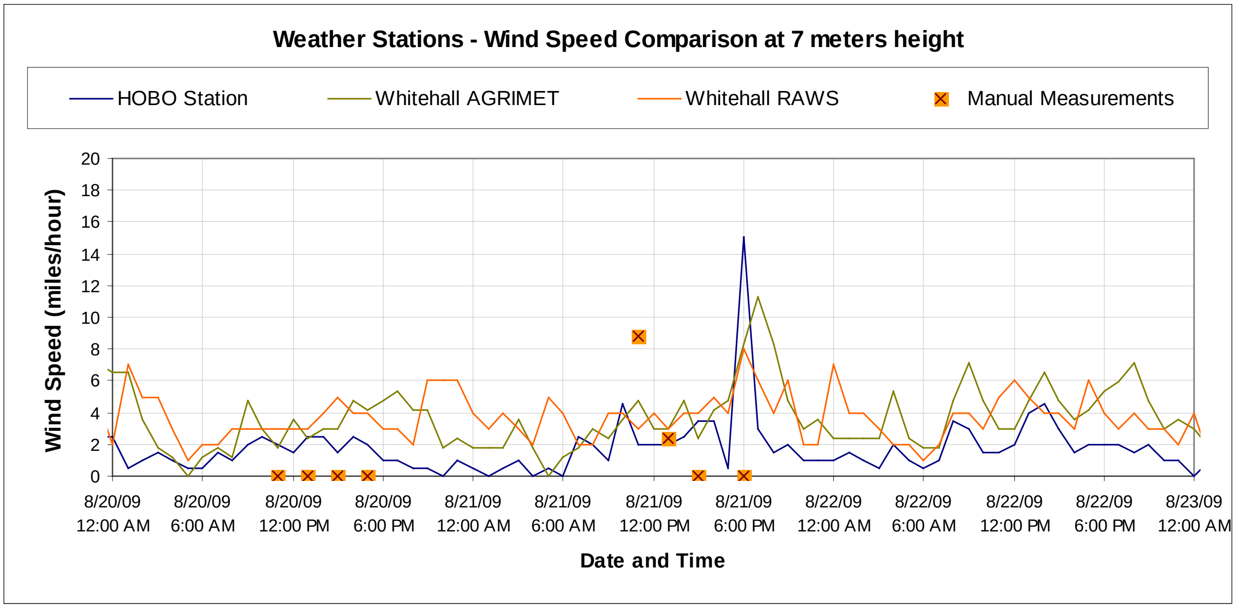

Figure C9. Weather Stations and Field Data Results: Wind Speed

Of all inputs (temperature, wind speed, and dew point temperature), wind speed was found to vary the most between locations. With the exception of the brief thunderstorm on the evening of 8/21/09, the wind speed was lowest at the HOBO station. Due to the proximity of the HOBO weather station to the river channel, it most likely best represents the actual conditions in the study area. The wind speed was corrected to seven meters for the HOBO and AGRIMET stations in **Figure C9**. This correction was generated based on Q2K input requirements.

Cloud cover was estimated from the Solar Radiation (W/m^2) that was blocked during the model period. Solar radiation (W/m^2) was collected hourly at the HOBO weather station. Cloud cover was calculated as follows:

$$\text{Cloud Cover} = \frac{S_{\max(8/18/19-8/22/09)} - \overline{S_{average(8/20/09-8/22/09)}}}{S_{\max(8/18/19-8/22/09)}} \quad (1)$$

where:

S = solar radiation (W/m^2)

An alternative cloud cover calculation was entered into the model to diminish the effect of the storm on the evening of 8/21/2009. The effect on the model output was indiscernible.

C4.7 Model Evaluation Criteria

Following model input development, performance statistics were selected to assess minimum, maximum and average temperature predictions from Q2K v2.11b8. The first criterion was percent bias (PBIAS), which is a measure of the average tendency of the simulated temperatures to be larger or smaller than an observed value. Optimal PBIAS is 0.0 while a positive value indicates a model bias toward overestimation. A negative value indicates bias toward underestimation. PBIAS is calculated as follows:

$$PBIAS = \frac{\sum_{i=1}^{n}(T_{isim} - T_{iobs})}{\sum_{i=1}^{n}(T_{iobs})} \times 100 \quad (2)$$

where:

PBIAS = deviation of temperature in percent
T_{iobs} = observed temperature (ºC)
T_{isim} = simulated temperature (ºC)

DEQ has defined acceptable model bias (PBIAS) as less than or equal to ±5%.

The second evaluation criterion used in the Upper Jefferson River modeling is the sum of squared residuals (SSR), which is a commonly used objective function for hydrologic model calibration, and standard error (SE). Sum of square residuals (SSR) compares the difference between the modeled and observed ordinates, and uses the squared differences as the measure of fit. As an example, a difference of 2°C between the predicted and observed temperature value is four times worse than a difference of 1°C. Squaring the differences also treats both overestimates and underestimates by the model as undesirable. The equation for calculation of SSR is shown below (Diskin and Simon, 1977).

$$SSR = \sum_{i=1}^{n}(T_{iobs} - T_{isim})^2 \quad (3)$$

where:

SSR = sum of squared residuals

The standard error is described as the standard deviation of the residual error. The residual is defined as the difference between the observed and simulated value.

C4.8 Sensitivity Analysis and Model Uncertainty

Model uncertainty was assessed using a simple one-at-a-time (OAT) sensitivity analysis with parameter perturbations of ±10% and ±30%. The OAT methodology ensures that changes in output can unambiguously be attributed to the changes in model input. Parameter sensitivity is typically expressed as a normalized sensitivity coefficient (NSC) as shown below (Brown and Barnwell, Jr., 1987).

$$\text{NSC} = \left| \frac{\Delta Y_o / Y_o}{\Delta X_I / X_I} \right| \quad (4)$$

where:

NSC = normalized sensitivity coefficient
ΔY_o = change in the output variable Y_o
ΔX_i = change in the input variable X_i

NSCs for model parameters in Q2K v2_11b8 are shown in **Table C6**. NSCs are taken as the average results of the four sensitivity runs (±10% and ±30% perturbations) for minimum, average, and maximum temperatures for two locations on the Jefferson: mile 0.0 and mile 21.9.

Table C6. Summary of parameter sensitivity for the Upper Jefferson River Q2K v2.11b8 model

Parameter	Rank	NSC
Headwater T (°C)	1	0.32
Tributary and Irrigation Return Mean T (°C)	2	0.26
Tributary and Irrigation Return Time of Max T (time)	3	0.26
Tributary Mean T (°C)	4	0.14
Rating Curves – coefficient	5	0.13
Air T (°C)	6	0.13
Dew Point T (°C)	7	0.08
Headwater Q (cms)	8	0.06
Groundwater T (°C)	9	0.06
Groundwater Q (cms)	10	0.03
Tributary and Irrigation Return Q (cms)	11	0.02
Tributary and Irrigation Return T Range/2 (°C)	12	0.01
Hourly Effective Shade (%)	13	0.01
Vegetation Density (%, shade.xls)	14	0.00
Cloud Cover (%)	15	0.00

Results indicate that inputs directly related to mass transfer (headwater, tributary and irrigation return flow temperatures) are highly sensitive in the Upper Jefferson River watershed. Tributary and irrigation return mean temperature was highly sensitive, yet the flow and temperature range adjustments were less sensitive. This is likely a result of the high water year and higher discrepancy between mainstem and tributary / irrigation return inflows. Parameters related to flow routing (rating curves) and meteorological forcing data were also sensitive to the model output. With the exception of rating curves, the eight highest ranking parameters are well known (directly measured in the field). This model was qualified as a moderately-certain project for the existing conditions.

C4.9 Model Calibration Procedure

The Upper Jefferson River Q2K model was calibrated based on the evaluation criteria identified previously. Meteorological input data were first assessed for reasonable representation based on DEQ's experience on other rivers (Beaverhead and Big Hole). Meteorological input data was then evaluated with field measurements and the Whitehall AGRIMET and RAWS stations. Unaltered results from the HOBO weather station were deemed adequate for all reaches in the Upper Jefferson River for the model period. Model calibration features as provided within Q2K were best fit between simulated temperature output and observed temperatures: solar shortwave radiation model (Bras, atmospheric turbidity coefficient of 2.0), downwelling atmospheric longwave IR radiation (Brutsaert) and evaporation and air convection/conduction model (Brady-Grave-Geyer). The following sediment heat parameters were adjusted for a cobble bed: sediment thermal thickness (10 cm), sediment thermal diffusivity (0.0127 cm^2/s), sediment density (1.6 g/cm^2) and sediment heat capacity (0.5 cal/g ºC).

Groundwater temperatures were best fit between simulated temperature output and observed temperatures for groundwater temperature values ranging between 9ºC to 15 ºC (further discussed in **Section C5.4**). The rating curves were the model input data with the most impact on the temperature profile. All data were adjusted within a reasonable range so that agreement between observed and simulated values occurred. Final calibrated reach parameters are shown in **Attachment C**. Subsequent PBIAS and SSR values for the temperature calibration are described in the Results and Discussion section.

C4.10 Model Validation / Confirmation

After calibration, a model should be validated or confirmed against an independent dataset. This effectively demonstrates that the model performs adequately over a range of conditions beyond that which it was calibrated to (Bartholow, 1989; Reckhow and Chapra, 1983; Chapra, 1997). For the Jefferson River, independent data outside of the 2009 field effort do not exist for validation purposes largely due to the dynamic conditions encountered in the watershed. As a result, auxiliary lines of evidence were evaluated in a “low-level” confirmation exercise. This included: an assessment of appropriate instream water temperature responses to varying climatic and headwater conditions.

C5.0 Results & Discussion

C5.1 Hydrology

Simulated streamflow for the August 20-22, 2009 modeling period is shown in **Figure C10**. Inspection of the observed and predicted flow shows good agreement. Hydrology is within ±7.3% at all monitoring nodes (not including JEF-M-19.2 (30.8 km), JEF-M-3.9 (6.3 km), and split flow at JEF-M-7 and JEF-M-7.2 (11 km)). The two non-braided sites, JEF-M-19.2 and JEF-M-3.9, likely under-predict the observed flow due to linear addition of groundwater influx or depletion across long reaches built into this particular Q2K model. Mean prediction PBIAS and standard error were -0.13% and 1.06 cms respectively (comparing daily simulated flow values with instantaneous field-measurements). Surface water hydrology is clearly a function of the combined influence of tributary inflow, irrigation withdrawal and return flow, split channel flow (e.g. braiding), and localized groundwater inflow. Major surface water inflows occur at Hells Canyon, Waterloo (Willow/Parsons), Fish Creek and the Boulder River/Jefferson Slough areas. River reaches with groundwater inflow are shown with translucent yellow rectangles on **Figure C10**.

The results in **Figure C10** and model evaluation statistics were computed from corrected data to a single date of 8/20/09 as described in **Section C4.4.** A few trends are noticed in **Figure C10** for unnamed irrigation control that should be further explained. Q2K applies groundwater linearly over the entire reach whereas tributaries, and irrigation diversions and return flows cause immediate changes to the mainstem flow. A sharp dip is shown near 30 miles (50 km): this is due to a diversion (JEF-D-30.5, 68.1 cfs) followed by a return flow (JEF-M-30.1, 71.2 cfs) within 0.4 miles. The second un-named but significant diversion occurs at kilometer 28.87 (JEF-D-18, 42.8 cfs) near Temple Ranch and the Renova Structure.

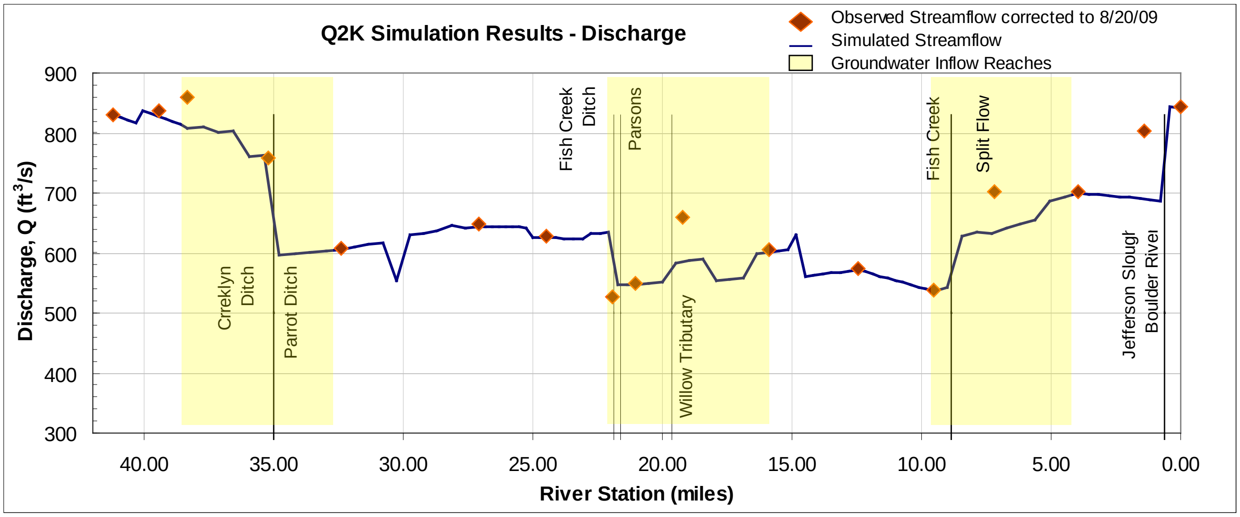

Figure C10. Observed versus Simulated Discharge

C5.2 Hydraulics

Correct simulation of river hydraulics ensures that the air-water interface and associated water column are exposed to an accurate duration and area of meteorological inputs within the model. For confirmation purposes, a comparison of model hydraulics against measured field data is shown in **Figures C11 - C12**. Relatively good agreement is seen between observed and simulated wetted widths. Differences between velocity and depth have a higher PBIAS, which is likely due to the high flow conditions experienced in 2009. Wadeable sites selected for streamflow measurements were often not representative of the channel across the entire reach. Mean PBIAS for computed channel velocities, wetted widths, and associated depths were -18.5%, 0.06%, and 35.7%, respectively. Standard errors were 0.56 ft/s, and 24.11 and 0.32 feet, respectively. These values are adequate given the field conditions in a high water year, as well as the simplified hydraulic portion of the Q2K model as compared to more detailed hydraulic models.

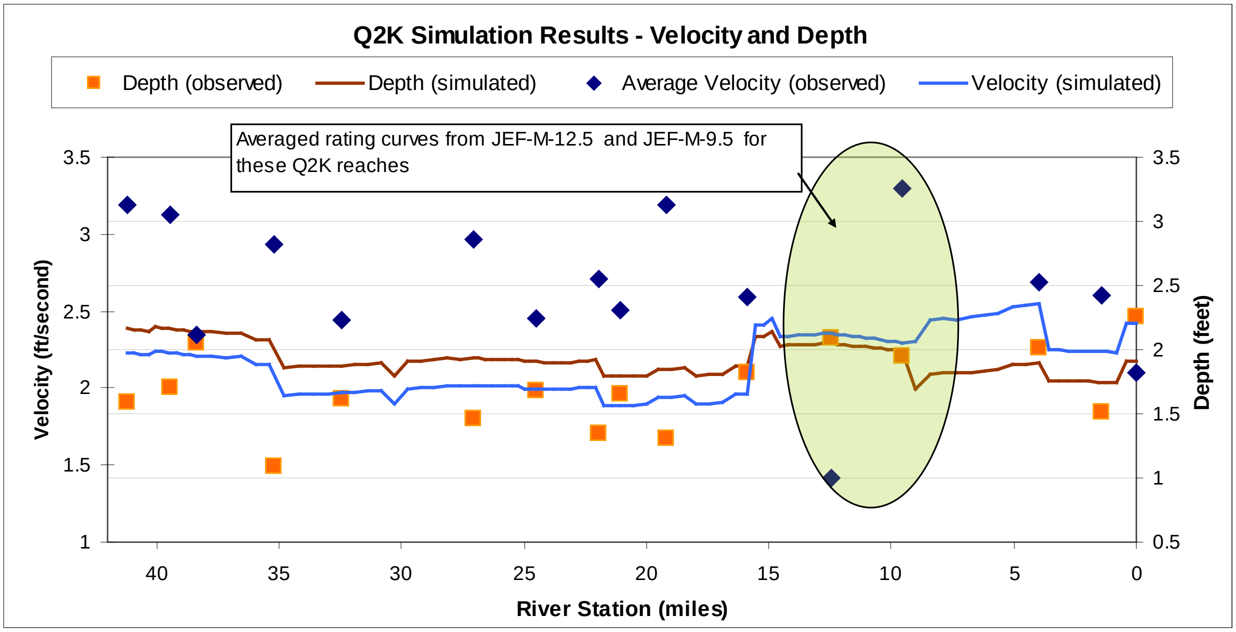

Figure C11. Observed versus Simulated Velocity and Depth

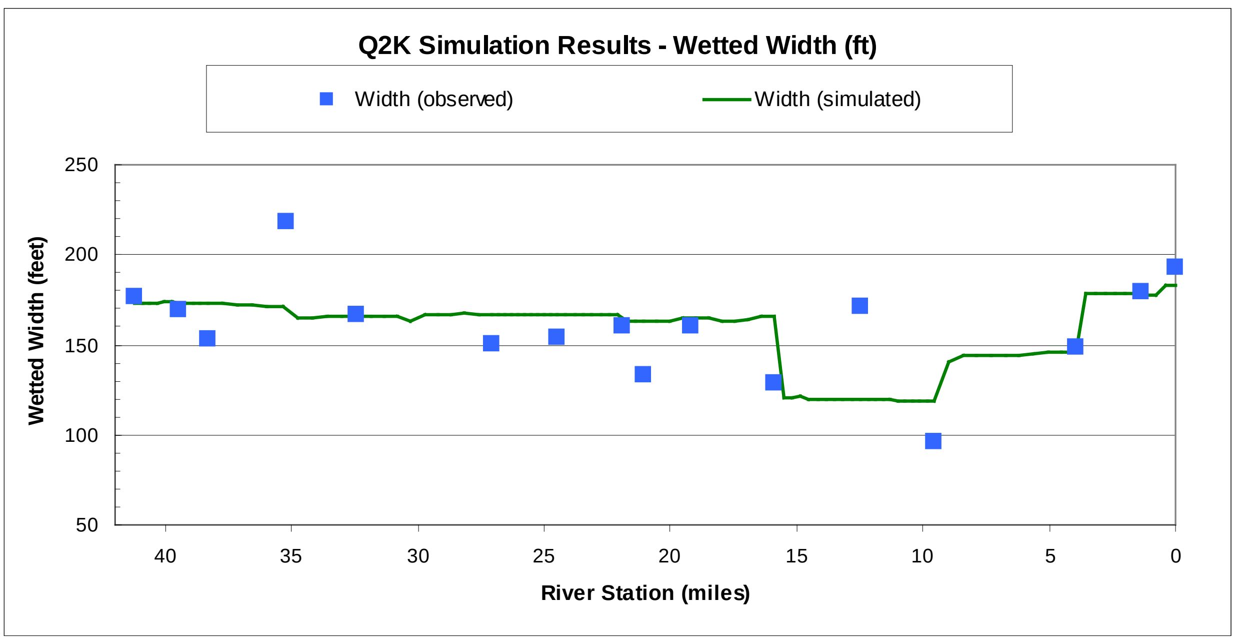

Figure C12. Observed versus Simulated Wetted Width

C5.3 Shade

Simulated stream shade includes shading from both topography and vegetation and integrates the effects of channel aspect, offset, and width at a particular model node. Shade.xls outputs hourly effective shade and daily effective shade. Daily effective shade predictions ranged from 0% to 13.2% as compared to 0% to 13% at field-measured individual stations. Overall simulation PBIAS was 29% with a standard error (in % shade) of 2.4%. While these numbers are not within ideal model ranges, when compared to site-specific observations taken with a solar pathfinder, model simulation values are within reason (**Figure C13**). Discrepancies between simulated and observed values exemplify the difference between measured point values and averages over the 1,000-m distance step. There are three Solar Pathfinder results at each field-measured site. These are the averages from 25%, 50% and 75% of the wetted width from the right bank at each of three transects. The uncorrected shade results utilize vegetation density as averaged from all field data. The corrected shade results utilize vegetation density that is decreased to increase fit with field data. The solid line shows average effective shade across all nodes within each Q2K reach. The use of shade data on a reach basis in Q2K indicates why one-at-a-time sensitivity analysis for vegetation density and shade input parameters were low-ranking.

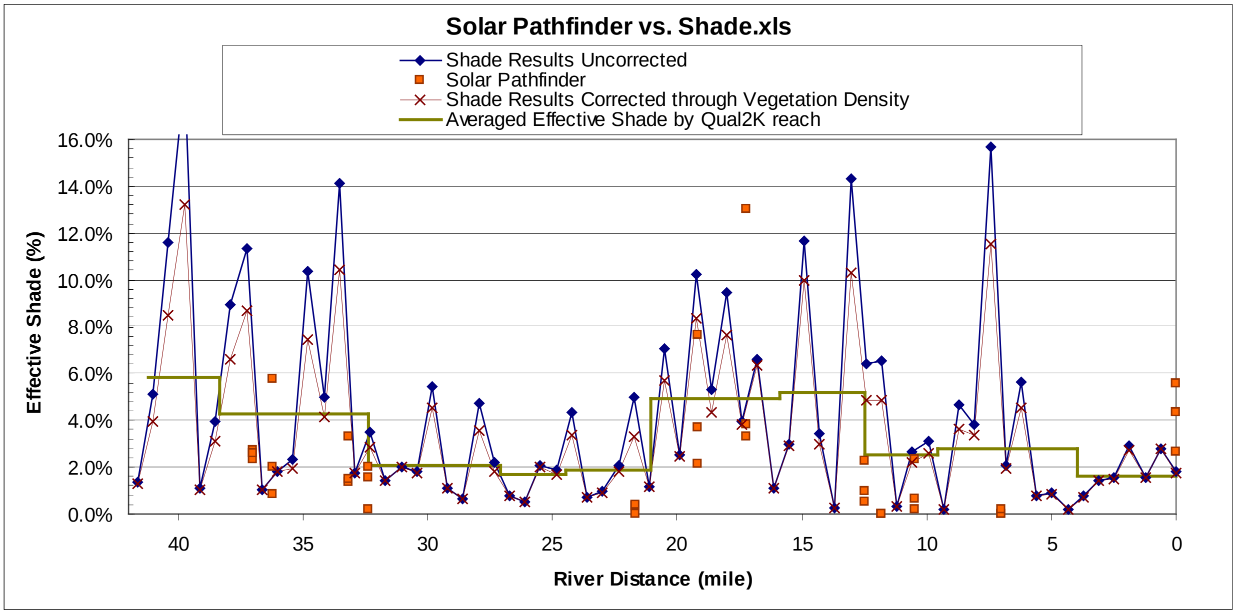

Figure C13. Shade Results versus Solar Pathfinder Measurements

C5.4 Water Temperature

Computed and observed minimum, mean, and maximum water temperatures for the August 20-22, 2009 modeling period are shown in **Figure C14**.

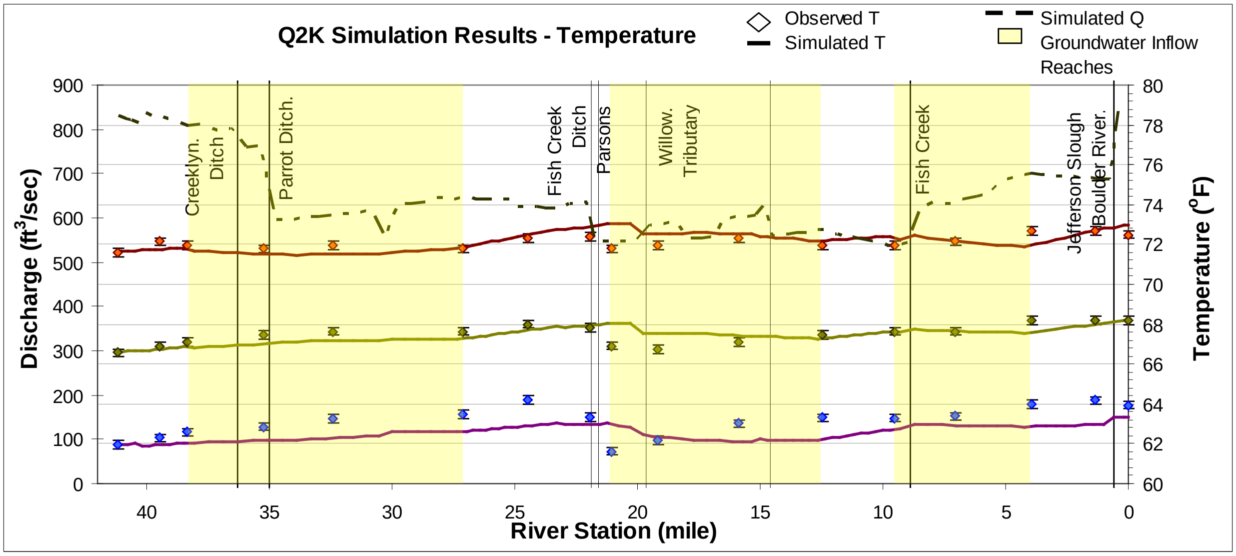

Figure C14. Modeled vs. Observed Water Temperature

Overall, there is very good agreement between the simulated and observed values for minimum, maximum, and mean temperatures. Diurnal plots are included in **Figure C15** for mainstem locations approximately every ten miles. The simulated values are provided for a single 24 hour day in the Q2K model. These simulated results are repeated across the three day model period for the charts below.

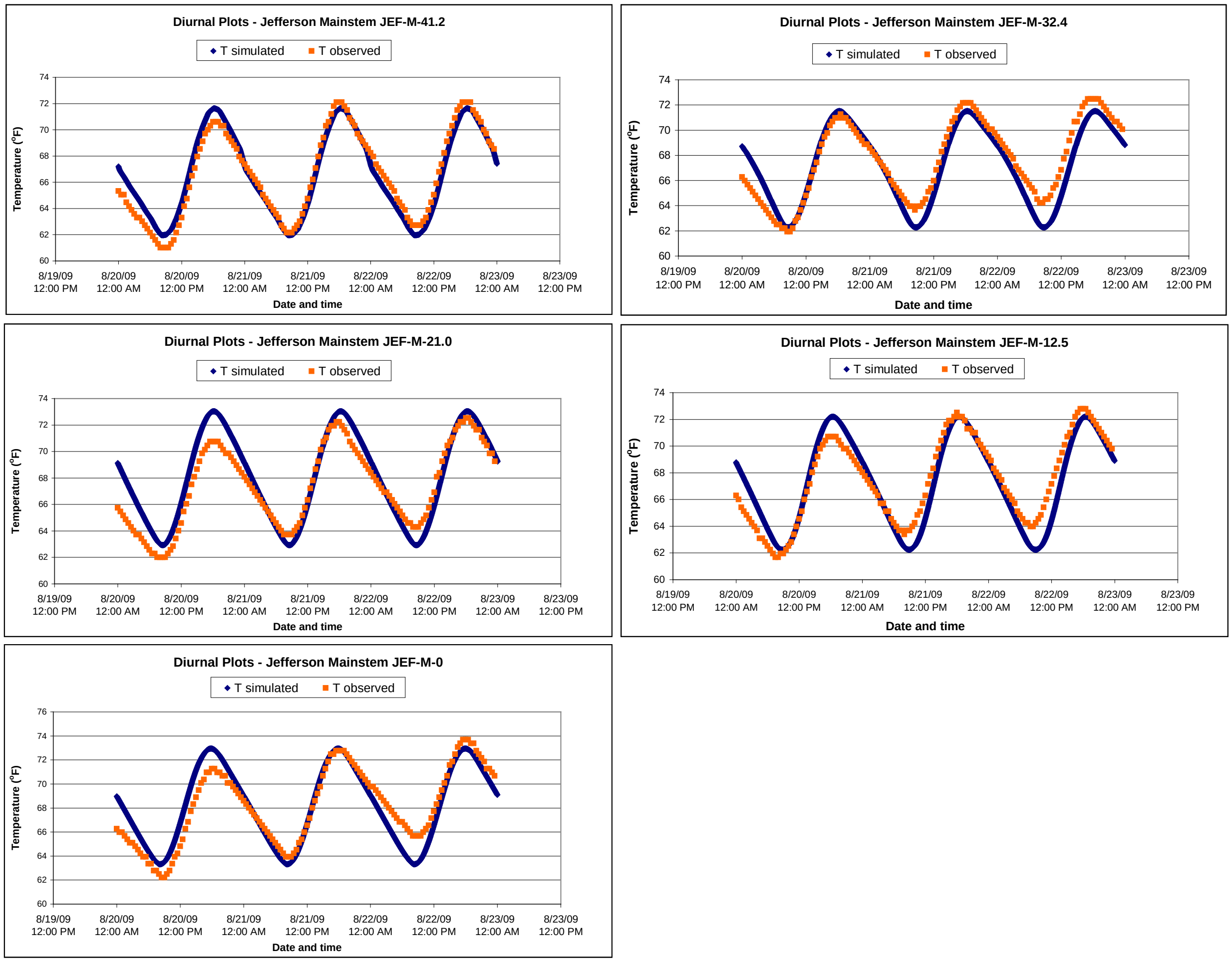

Figure C15. Diurnal Temperature Plots for 3-Day Model Period on Jefferson Mainstem

Calibration statistics were determined by combining the mean, minimum and maximum simulated and observed values for each mainstem location. Results are as follows: PBIAS was largely negligible (-0.53%), SSR = 1.92 and standard error = 0.53°F. Individual calibration statistics for average, minimum and maximum temperatures are shown in **Table C7**.

Table C7. Individual Station Calibration Statistics

Statistics	Average Temperature	Minimum Temperature	Maximum Temperature	Average Result
Percent Bias (%)	-0.08	-1.81	0.29	-0.53
SSR	0.96	3.66	1.13	1.92
Standard Error (ºF)	0.43	0.63	0.47	0.52

Examination of the longitudinal temperature profile of the Upper Jefferson River provides important information regarding instream water temperatures and associated river dynamics. Beginning at the upstream boundary (mile 41.2), temperature remains relatively constant until reaching river mile 27, where an increasing trend is noted. This area shows significant off-stream agricultural development on both sides of the river. This area is also a losing stretch of the river. Maximum temperatures reach 73.0°F in this section. The warming trend continues as additional irrigation withdrawals occur and flows decrease until reaching the Willow Springs confluence near mile 19.6. The spring fed tributaries and groundwater inflow through this reach lower the average, maximum and minimum temperatures. Also, the Point of Rocks geologic outcrop provides topographic shade through this reach which may also affect river temperatures. Temperatures remain relatively constant for approximately the next 15 miles, but a second increasing trend is noted near the end of the study area, starting at mile 3.9.

The maximum simulated river temperature occurs at mile 21.2 (73°F) where there is significant agricultural development and a losing stretch of the river. A second temperature maximum is at mile 0.0 (73°F) where there is significant agricultural development, as well as several backwater sloughs and oxbow channels. The river enters the LaHood Canyon just downstream of the end of the study area. Overall, the model shows a very consistent temperature profile. This constant profile is a function of the high water year.

In calibration of the longitudinal profile of surface water temperature, groundwater inflow temperature was found to vary depending on nearby springs or geothermal activity. Data collected for the WET report (2006) included groundwater temperatures near Willow Springs and Parson's Bridge. For the same model period (Aug 20 – Aug 22), groundwater temperatures were stable within 0.5°F and water temperatures were as follows: monitoring wells Willow-8 (53°F), Willow-10 (55.5°C) and Parsons-1 (51.7°C). Known hot springs are located near Silver Star (mile 31.7) and along Point of Rocks Road (mile 15.9). In areas where large alluvial groundwater systems converged (reaches 38.3 – 27.1 miles), a temperature of 53.6°F was used. In reaches downgradient of Willow Springs, temperatures of 48.2°F (reach 21.1 – 15.8 miles), and 51.8°F (reach 15.8 – 12.5 miles) were used. A temperature of 59.0°F was used where both regional groundwater flow and hot springs occur, throughout reach 9.6 – 3.9 miles. These groundwater temperatures are within ranges queried from the Groundwater Information Center (GWIC) database. The GWIC database showed a range of 45.7 to 64.8°C in nearby wells. Groundwater inflow temperatures were adjusted to available field data in those reaches where previous studies have been conducted.

Overall, a good surface water temperature calibration was achieved based on model statistical efficiency. The primary drawback to model calibration activities was the high flows in which the study was conducted, which resulted in some hydraulic calibration variations. Once sufficient calibration of the existing condition model was achieved, scenarios for TMDL planning and analysis were developed. The flows used for model calibration represented a relatively high flow condition compared to those experienced over the past decade; as a result, a scenario was created to include the 7Q10 flow event, with a limited validation.

C6.0 SCENARIO ANALYSIS

A number of scenarios were developed as part of this study so that watershed managers can provide reasonable recommendations for meeting water quality criteria in the river. Vegetation losses along the riparian corridor, irrigated crop production, and hydrostructures (dams and diversions) have all been cited as causes for elevated water temperature in the Jefferson River (Montana Department of Environmental Quality, 2008). In addition to these identified causes, impacts from tributaries and other inflows to the river are potential causes for impairment.

Although it is known that human activities are impacting the Upper Jefferson River, little has been done to associate management activities in the river corridor with instream temperatures. As a result, this report developed modeling scenarios to address the following: (1) 7Q10 low flow or "baseline" conditions, (2) a naturally occurring scenario in which all reasonable land, soil, and water conservation practices are applied (ARM 17.30.602 (3) a shade scenario in which reference condition shade is applied across the study area, and (4) improved irrigation water practices. A detailed description of assumptions for each scenario is included in each subsection. The 7Q10 scenario, and therefore all subsequent scenarios because the 7Q10 is the baseline scenario, were updated in 2014 to incorporate climate data from 2013, which was very near to a 7Q10 year (370 cfs for a period of time during August, 2013).

C6.1 Scenario 1: 7Q10 Water Year – Baseline Scenario

The goal of this modeling study was to collect data and model the typical summer time low flow or baseline condition of the Upper Jefferson River. The 2009 water year experienced significantly higher flows during the model period than in the past several years. As a result, it was necessary to develop a baseline scenario that simulated conditions during a 7-day 10-yr low flow condition (e.g. statistically a condition that would happen every ten years).

It was determined that the 7Q10 flow was an appropriate representation of low flow conditions. The 7Q10 flow is the lowest 7-day average flow that occurs (on average) once every ten years. The 7Q10 flow for the July – October time period (as stated in the USGS Statistical Summaries of Streamflow for gage 06026500 Jefferson River near Twin Bridges, MT) is 387 cfs. The 2009 existing conditions model (830 cfs) was altered by changing the following parameters:

- Headwater flow was decreased to 387 cfs (53% reduction). All tributary inputs (Point Sources worksheet) were decreased by 50% including Hells Canyon Creek, Cherry Creek, Fish Creek and the Boulder River/Jefferson Slough. Willow Springs and Parsons Slough are influenced by springs; as a result, flows were not adjusted.

- Headwater average temperature was increased to 68.7ºF, based on available temperature data from recent 7Q10 flow conditions. Hourly temperature inputs were based on the same diurnal pattern as exhibited in the 2009 existing conditions model.

- Groundwater gaining reaches (Diffuse Sources worksheet) were decreased by 25% and groundwater losing reaches were decreased by 50%.

- Climate data averaged from August 17-19, 2013 were used from the Jefferson AgriMet site, where wind was adjusted down x0.32 (Flynn and Suplee, 2013).

- The minimum, maximum, and average verification temperatures for the baseline 7q10 condition were calculated based on three days of record (August 17-19, 2013) at USGS gaging stations 06026500 (Jefferson River near Twin Bridges MT) and at 06027600 (Jefferson River at Parsons Bdg nr Silver Star, MT). These dates were selected to evaluate the 7Q10 scenario with post-hoc data because 2013 approximated a 7Q10 flow, and no test of the model had been made under those conditions.

Maximum temperatures above 80ºF occur between miles 10.9 to9.7. The Q2K model output results are shown are shown in **Table C8**. The Scenario 1 - Baseline 7Q10 water year is utilized as the baseline model for the remaining scenarios, as this flow condition better displays the impact of management scenarios on temperature.

Table C8. Temperature Changes – Scenario 1: Baseline 7Q10 Condition

Condition	**Location**	**(Q, cfs)**	**T_{min}**	**T_{avg}**	**T_{max}**
Scenario 1: Baseline 7Q10	Parson's Bridge (mi. 21.9)	52.2	60.61	68.88	76.94
2009 Existing Conditions		547.2	62.99	67.96	72.92
*Scenario Change (ºF)			**-2.38**	**0.92**	**4.02**
Scenario 1: Baseline 7Q10	Outlet – (mile 0.0)	178.3	60.74	68.44	76.14
2009 Existing Conditions		841.5	63.32	68.20	72.95
*Scenario Change (ºF)			**-2.58**	**0.24**	**3.19**
Average deviation of all model nodes			**-3.15**	**-0.02**	**3.81**
Greatest temperature increase (and location) from 2009 condition			**1.80** (headwaters)	**2.07** (headwaters)	**10.22** (mile 9.7)

*A negative number indicates that the baseline condition is cooler than the existing condition, and a positive number indicates the baseline condition is warmer than the existing condition.

C6.2 Scenario 2: Naturally Occurring Condition Scenario

The naturally occurring condition scenario defines water temperature conditions resulting from the implementation of all reasonable land, soil, and water conservation practices (LSWCP), e.g. where best management practices are implemented as outlined in ARM 17.30.602. Essentially, "naturally occurring" establishes the bar for which the allowable 0.5°F temperature increase is compared to, and effectively determines if a waterbody is meeting or exceeding a temperature standard. The following changes were made to the 7Q10 baseline model in the naturally occurring scenario:

- Decrease headwater temperature. Determine headwater temperature from a mixing calculation using naturally occurring maximum temperature from three headwaters streams (**Table C9**, Results: T_{min} =62.71, T_{avg} = 67.44, T_{max} =72.59°F).
- Increase all open/grassed sites, barren areas, and any other area with diminished shading vegetation to a reference shade condition (averaged shade from Scenarios 3a and 3b).
- Incorporate a 15% irrigation efficiency improvement for all diversions and return flows (Scenario 4).

Table C9. Parameters used in Headwater Mixing Calculations – Naturally Occurring

River Name	(Q, cfs)	Source data for Q	Tavg °F	Source data for Tavg	Tmax °F	Source data for Tmax
Ruby River	94	*	N/A	Tavg not provided	66.70**	DEQ model, naturally occurring
Beaverhead River	89	*	68.41	DEQ model, naturally occurring scenario	72.14***	DEQ model, naturally occurring
Big Hole River	135	*	71.67	DEQ model, naturally occurring scenario	77.00**	DEQ model, naturally occurring
Jefferson Headwater					**72.60**	**Mixing Calculation**

*Headwater flows were determined as a contributing ratio to the Jefferson River USGS gage at Twin Bridges. Available data for all four USGS gage sites when the Jefferson River was below 600 cfs were from 8/3/2008 through 8/31/2008.
USGS gages:
- 06023000 Ruby River near Twin Bridges, MT
- 06018500 Beaverhead River near Twin bridges, MT
- 06026420 Big Hole R blw Hamilton Ditch nr Twin Bridges, MT
- 06026500 Jefferson River near Twin Bridges MT

Combined flows for the three rivers add up to be less than the 7Q10, but is acceptable for calculating mixing equations.
**Naturally occurring temperatures for the Ruby and Big Hole Rivers were calculated using models for TMDL development of those rivers (completed in 2006 and 2009 respectively)
***Naturally occurring temperature for the Beaverhead River used in the Jefferson River temperature model was calculated before the completion of the Beaverhead River temperature model. The resulting maximum naturally occurring temperature at the mouth from the Beaverhead River temperature model is 0.15°F above the maximum naturally occurring temperature used in the Jefferson model, which means that the temperature used in the mixing equation results in a slightly more conservative estimate of the naturally occurring temperature of the Jefferson River.

The mixing calculation is as follows:

$$T_{JeffersonHeadwater} = \frac{(Q_{Beaverhead} * T_{Beaverhead}) + (Q_{Ruby} * T_{Ruby}) + (Q_{BigHole} * T_{BigHole})}{Q_{Beaverhead} + Q_{Ruby} + Q_{BigHole}}$$

Baseline (7Q10) and naturally occurring scenario results, along with associated water temperatures near Parson's Bridge (21.9 miles) and at the downstream boundary of the study area (0.0 miles) are shown in **Table C10**.

Table C10. Temperature Changes – Scenario 2: Naturally Occurring

Condition	Location	T_{min}	T_{avg}	T_{max}
Naturally Occurring Scenario	Parson's Bridge (mi. 21.9)	60.97	68.34	75.62
Baseline		60.61	68.88	76.94
*Scenario 2 Change (ºF)		**0.36**	**-0.54**	**-1.32**
Naturally Occurring Scenario	Outlet – (mile 0.0)	61.09	67.94	74.97
Baseline		60.74	68.44	76.14
*Scenario 2 Change (ºF)		**0.35**	**-0.50**	**-1.17**
Average deviation of all model nodes		**1.04**	**-0.29**	**-1.93**
Greatest temperature reduction (and location) from 7Q10 baseline		**-1.06** (headwaters)	**-1.79** (mile 13.4)	**-7.91** (mile 9.7)

*A negative number indicates that the scenario temperature is cooler than the baseline temperature, and a positive number indicates the scenario temperature is warmer than the baseline

Results of the naturally occurring scenario suggest that maximum temperatures could be reduced by an average of 1.93°F. Of the 102 output locations within the model, only 1 location met the state of the Montana temperature standard during the baseline (7Q10) scenario (e.g. within the 0.5°F allowable increase). Areas with the greatest potential for improvement occur in several locations: 1) the upper reach as a result of implementation of all reasonable land, soil, and water conservation practices in the Ruby, Beaverhead, and Big Hole rivers (41.2 - 35.08 miles); and 2) various lower reaches largely as a result of water management practices (miles 27-20, 18-15.4, and 14.3-0), with the greatest temperature reduction of 7.91°F at mile 9.7.

C6.3 Scenario 3: Shade/Vegetation Improvement

During the field reconnaissance, the riparian corridor varies between being in relatively good condition and having eroding banks, grazing impacts, and riparian clearing to accommodate irrigated agriculture. A hypothetical shading scenario was run to characterize the maximum possible influence of shade on instream temperature. The following assumptions were made in the shade scenario: (1) all open/grassed sites, barren areas, and any other area with diminished shading vegetation were increased to a reference shade condition, and (2) all other conditions were held constant.

Two reference shade conditions were evaluated. The first reference condition was defined as improvement to a mixed low level vegetation type. The second reference condition was defined as a mixed high level (inclusion of cottonwoods) in which grass/bare areas as well as willow areas and mixed low level areas were increased. The potential temperature reduction due to naturally occurring increased shade is somewhere between these two shade conditions with a potential for low level shrubs/willows in some areas and cottonwoods in other areas throughout the upper segment of the river. Thus an arithmetic average of the shade from the two reference conditions was used in the model.

As stated in Section 5.3, shade parameters were input into Shade.xls at every kilometer and then all nodes within each model reach were averaged into a single average hourly value for the entire reach. The Upper Jefferson River TPA has varied vegetation conditions, and aerial photography and field reconnaissance did not show significant vegetation breaks. Thus the averaging method is appropriate; however, the long reaches within this Q2K model do not allow for assessment of localized conditions.

Simulations were implemented by simply changing riparian cover conditions in the model. The shade scenario used the averaged shade values (from the two evaluated conditions) to reflect a mix of high and low level vegetation (cottonwoods and shrubs/willows). Existing cottonwoods or mixed high level conditions were not adjusted. Scenario results, along with associated instream water temperatures near Parson's Bridge (mile 21.9), and at the downstream boundary of the study area (mile 0.0) are shown in **Table C11**.

Table C11. Temperature Changes – Scenario 3: Shade/Vegetation Improvement

Condition	Location	T_{min}	T_{avg}	T_{max}
Shade Scenario	Parson's Bridge (mi. 21.9)	60.49	68.62	76.65
Baseline		60.61	68.88	76.94
*Scenario 3 Change (ºF)		**-0.12**	**-0.26**	**-0.29**
Shade Scenario	Outlet – (mile 0.0)	60.68	68.22	75.81
Baseline		60.74	68.44	76.14
*Scenario 3 Change (ºF)		**-0.06**	**-0.22**	**-0.33**

Table C11. Temperature Changes – Scenario 3: Shade/Vegetation Improvement

Condition	Location	T_{min}	T_{avg}	T_{max}
Average deviation of all model nodes		**-0.08**	**-0.20**	**-0.30**
Greatest temperature reduction (and location) from 7Q10 baseline		**-0.26** (mile 9.7)	**-0.51** (mile 9.7)	**-0.71** (mile 9.7)

*A negative number indicates that the scenario temperature is cooler than the baseline temperature, and a positive number indicates the scenario temperature is warmer than the baseline

The upgrade from bare, native grass and irrigated grass to a mixed high and low level vegetation shows that the greatest temperature reduction (0.71°F) would occur at mile 9.7. Results show that shade is not a major temperature influencing factor unless it is of significant height, due to the wide river channel. However, it should be noted that shade is an important part of a healthy river system, as healthy riparian vegetation not only provides thermal protection but also improves bank stability and fish habitat.

C6.4 Scenario 4: Improved Water Management Practices

The water management practices scenario describes the thermal effect of improved irrigation management on the Upper Jefferson River. Although Montana standards do not necessarily apply to consumptive water use, it is important to assess the cumulative effect of these practices on the overall thermal regime of the river. The following changes were made to the 7Q10 baseline model in the improved water management practices scenario:

- Irrigation diversions and return flows in the Upper Jefferson were decreased 15% to account for private land owners' voluntary water restrictions during the 7Q10 flow.

Naturally occurring and improved water management scenario results, along with associated instream water temperatures near Parson's Bridge (35.25 km) and at the downstream boundary of the study area (0 km) are shown in **Table C12**.

Table C12. Temperature Changes – Scenario 4: Improved Water Management

Condition	Location	T_{min}	T_{avg}	T_{max}
Water Use Scenario	Parson's Bridge (mi. 21.9)	61.35	68.84	76.17
Baseline		60.61	68.88	76.94
*Scenario 4 Change (ºF)		**0.74**	**-0.04**	**-0.77**
Water Use Scenario	Outlet – (mile 0.0)	61.21	68.19	75.30
Baseline		60.74	68.44	76.14
*Scenario 4 Change (ºF)		**0.47**	**-0.25**	**-0.84**
Average deviation of all model nodes		**1.49**	**0.27**	**-1.29**
Greatest temperature reduction (and location) from 7Q10 baseline		**0.00** (headwaters to mile 36.9)	**-1.38** (mile 9.7)	**-7.42** (mile 9.7)

*A negative number indicates that the scenario temperature is cooler than the baseline temperature, and a positive number indicates the scenario temperature is warmer than the baseline

A 15% increase in streamflow shows that the greatest temperature reduction (7.42°F) would occur at mile 9.7. The increased flow scenario shows that reducing the amount of water diverted during low flow is a significant contributing factor to maximum temperature reductions, however it does raise minimum temperatures throughout the segment. Based on model results, irrigation water savings are an important means to achieve state temperature regulations. However, compliance would be on a voluntary basis by landowners. In addition to these results, water temperatures in the Upper Jefferson River would also be beneficially affected by similar improvements in the Ruby, Beaverhead, and Big Hole Rivers.

C7.0 Conclusion

Water temperature monitoring was conducted on the Upper Jefferson River during the 2009 field season and temperature modeling activities were completed using Q2K and Shade.xls. The calibrated 2009 existing conditions model showed daytime peak temperatures exceeded 70ºF during a flow event of 830 cfs. This report also developed a 7Q10 baseline flow event from the calibrated 2009 existing conditions model (post-audited and updated with 2013 data), in order to simulate multiple low flow conditions experienced over that past decade. Several scenarios were developed to define the impact of specific watershed management changes on Jefferson mainstem temperatures; also, a naturally occurring scenario was developed that simulates temperature conditions with the implementation of all reasonable land, soil, and water conservation practices. Each management change scenario is compared to a 7Q10 baseline scenario in **Table C13.**

Table C13. Summary of Scenario Results: Average Temperature Change across all Q2K Elements from 7Q10 Baseline

Scenario	Average Temperature (ºF) Difference from 7Q10 Baseline Model across all Q2K elements		
	Minimum	Average	Maximum
Scenario 2: Naturally Occurring	1.04	-0.29	-1.93
Scenario 3: Shade/Vegetation Improvement – Mixed Low and High Level averaged	-0.08	-0.20	-0.30
Scenario 4: Improved Water Management	1.49	0.27	-1.29

*A negative number indicates that the scenario temperature is cooler than the baseline temperature, and a positive number indicates the scenario temperature is warmer than the baseline

The scenario analysis shows that the establishment of a reference shade condition consisting of mixed low and high level vegetation would reduce the maximum instream temperatures by an average of 0.3ºF and up to 0.71ºF at river station 9.7 miles.

The water management scenarios (Scenario 4) shows significant reductions in maximum river temperature. A 15% water conservation scenario (Scenario 4) would reduce the maximum temperature by 1.29 ºF on average throughout the reach and up to 7.42ºF at river station 9.7 miles (near Koontz Bridge), and efforts should be focused on achieving this target.

Areas with the greatest improvement between the 7Q10 baseline simulation results and the naturally occurring scenario occur in several locations:

1. The upper reach (41.2 - 35.08 miles) as a result of the implementation of all reasonable land, soil, and water conservation practices in the Ruby, Beaverhead and Big Hole Rivers, and
2. Various lower reaches (miles 27-20, 18-15.4, and 14.3-0) largely as a result of water management practices.

Watershed management activities should be prioritized to address these most impacted sections first, with activities on other sections of the river completed at a later time. It is important to point out that for water temperature, the location of the impacted section may not necessarily coincide with the location where the critical management action needs to be undertaken. In this regard, additional modeling of proposed management practices should be completed to prioritize which results in the most improvement for the least cost.

Q2K modeling results of Scenarios 1-4, along with the Shade.xls file, and 2009 field data can be found in the WQPB library at the DEQ.

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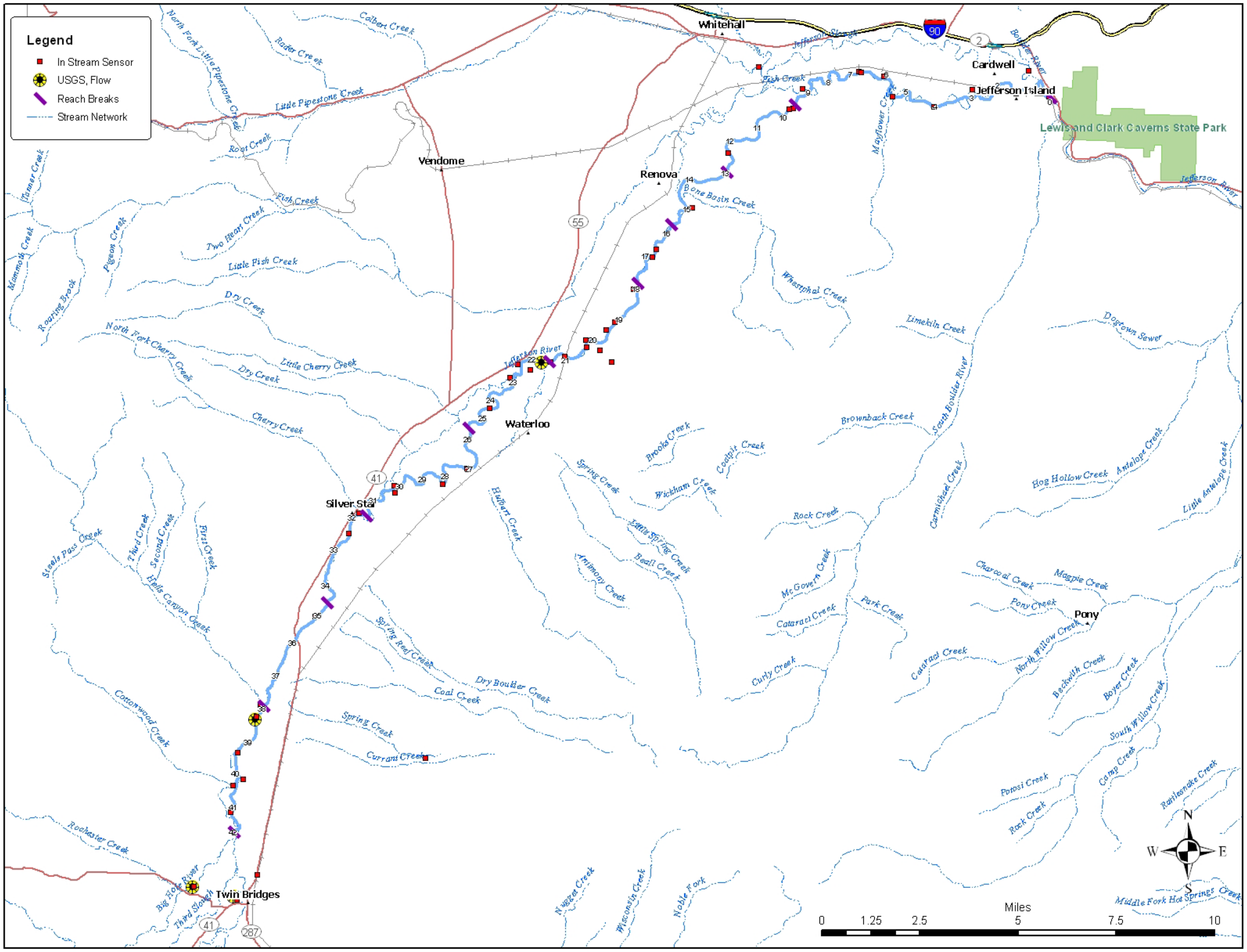
Exhibit C1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In Stream Sensor
USGS, Flow
Reach Breaks
Stream Network
Whitehall
Cardwell
Jefferson Island
Lewis and Clark Caverns State Park
Vendome
Renova
Waterloo
Silver Star
Pony
Twin Bridges
Jefferson River
Miles
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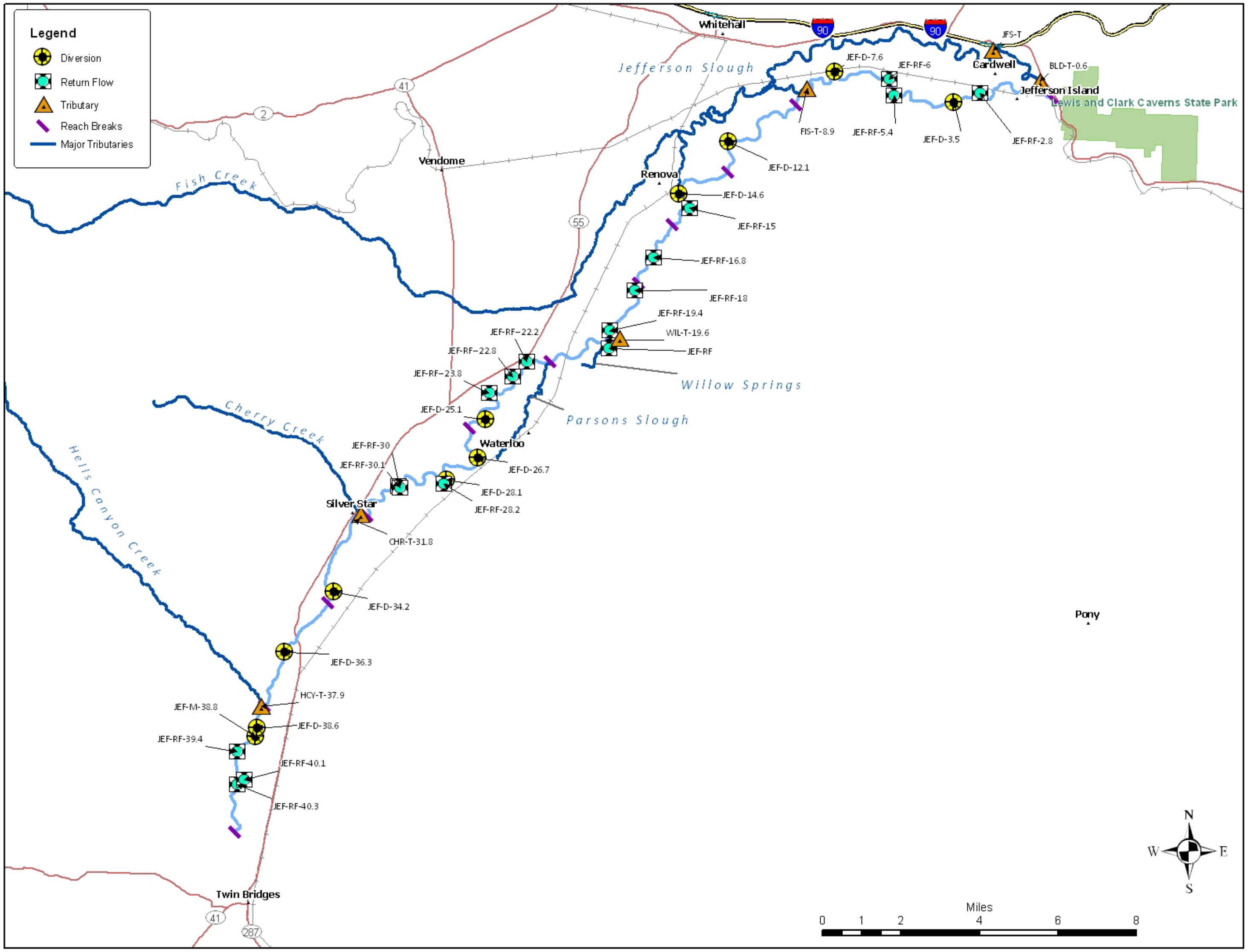
EXHIBIT C2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Diversion
Return Flow
Tributary
Reach Breaks
Major Tributaries
Whitehall
Cardwell
Jefferson Island
Lewis and Clark Caverns State Park
Vendome
Renova
Waterloo
Silver Star
Twin Bridges
Pony
Jefferson Slough
Fish Creek
Willow Springs
Parsons Slough
Cherry Creek
Hells Canyon Creek
JFS-T
BLD-T-0.6
JEF-D-7.6
JEF-RF-6
FIS-T-8.9
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JEF-RF-18
JEF-RF-19.4
WIL-T-19.6
JEF-RF
JEF-RF-22.2
JEF-RF-22.8
JEF-RF-23.8
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Miles
0 1 2 4 6 8
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