ATTACHMENT 3 – STREAM TEMPERATURE ASSESSMENT FOR THE BOULDER RIVER – BOULDER-ELKHORN TMDL PLANNING AREA

ADDITION TO ATTACHMENT 3 - DISCUSSION OF BLDR-T21

INTRODUCTION

Figure 2-2 in the Stream Temperature Assessment for the Boulder River (**Attachment 3**) shows a significant drop in temperature at station BLDR-T21. Text in the report does not explain this anomaly in the temperature profile and so this discussion is included to review the temperature data at BLDR-T21, and any potential implications that site may have to analysis.

DISCUSSION

Figure 2-2 presents the maximum, average, and minimum water temperatures of the recorded field data from July 24-26, 2010. The data points were taken from 15 locations along the Boulder River, and represent a longitudinal profile of temperature trends over those three days. The profile shows relatively consistent water temperatures from between data points until around BLDR-T14, when temperatures start increasing. These higher temperatures persist through the remaining sites except at BLDR-T21, where temperatures plummet about 6 degrees C, only to jump right back up at BLDR-T22 to temperatures similar to those observed at BLDR-T20. This very distinctive drop raises questions about why the location at BLDR-T21 is so unique in comparison to the overall temperature profile. Apart from water use, geology plays a role in water availability in the Boulder River valley. Communication with the Montana Bureau of Mines & Geology describes the general trend of surface water/groundwater interaction in that area:

> "We are seeing a shift from generally losing to generally gaining in that area. It appears that there is converging groundwater flow from the East Ridge and Doughty Mtn. in Negro Hollow. There is little if any surface water flow; however all of the southern/northern groundwater flow from these areas must flow to the Boulder River alluvium (or to the east). This combined with the bedrock canyon to the south (essentially a dam forcing groundwater to the river) makes it likely that groundwater is entering the Boulder River in this area. Since there is very little surface water flow in the summer, a small contribution of groundwater would cause more of a change in temperature."

Figure X-1 below further illustrates the location of BLDR-T21 in the context of geologic maps of the area. **Figure X-2** provides an aerial view of the corridor with data logger locations for BLDR-T21, T22, and T23. Finally, **Figure X-3** is a close up aerial view of BLDR-T21. Of note is the irrigated field immediately adjacent to BLDR-T21 on river right.

Figure 2-3 in **Attachment 3** illustrates the streamflow data profile which follows the general narrative provided by MBMG. From upstream to downstream, flows gradually increase until about BLDR-T12, after which flows steadily decrease until BLDR-T19, where flows again increase.

A review of the actual continuous temperature data also shows the range in diurnal temperature fluctuations at BLDR-T21 to be less than the diurnal temperature fluctuations at BLDR-T20 upstream and BLDR-T22 downstream. For some of the dates reviewed, the difference between maximum and minimum daily temperatures at the BLDR-T21 location is at times as little as 5 degrees F, whereas the temperature ranges at the other two sites were greater than 10 degrees F. This suggests that there may be the influence of coldwater upwelling at BLDR-T21. However, examination of the bihourly data also showed an interesting shift during the time period reviewed. On August 5, at 21:30, the temperature recorded at BLDR-T21 jumped over 8 degrees F. All temperature recordings before and after this point in time never showed a temperature change greater than 1.5 degrees in a 30 minute period. The data logger itself however was in proper working order throughout its deployment and therefore it is unlikely that there were any technical malfunctions. In addition, temperature ranges at BLDR-T21 after that moment followed the trends of the upstream and downstream locations. In other words, the temperatures at BLDR-T21 suddenly became consistent with the temperature observations at the upstream and downstream data collection sites.

While this situation is somewhat perplexing, given what we know of the site and the data logger, there are a few reasonable possibilities. It is possible that data logger BLDR-T21 was coincidentally located directly on top of a coldwater upwelling, and at 21:30 on August 5, it was moved somehow out of the influence of that source, without being removed from the site. The significant jump in temperature could also be the result of a sudden change in irrigation withdrawal or return – whether that was a local or immediate influence from management of the adjacent field, or the delayed effect of water use elsewhere in the valley observed through groundwater flow.

CONCLUSION

The data recording device and the data collected appear sound, and although the temperature profile is unique, there are reasonable explanations that could account for the anomaly at BLDR-T21. In addition, the modeling that was used to analyze temperature trends in the Boulder River is not affected by this anomaly. All temperature data loggers undergo a quality control check before and after deployment, and the loggers used in this study were found to be functioning properly. The dip in the temperature profile at BLDR-T21 does not invalidate the data recorded at all other locations, and model analysis shows that much of the lower Boulder River exceeds the temperature standard. If the anomaly at BLDR-T21 is taken as is, it shows that groundwater likely influences the temperature for a short distance around BLDR-T21 to levels that would be acceptable under the temperature standard. On the other hand, if it is assumed that the data at BLDR-T21 misrepresents the water temperature conditions through this location because it was coincidentally located within the immediate influence of a source of coldwater, then based on data reviewed post 21:30 on August 5, it can be presumed that the temperature profile at BLDR-T21 would be similar to the upstream and downstream data sites. Under this assumption, the result would indicate that temperature levels are elevated above the limits of the standard throughout this stretch of the river. Therefore, the profile would not contain a noticeable drop in temperature, but rather the line through BLDR-T21 would roughly follow the course of the upstream and downstream data points.

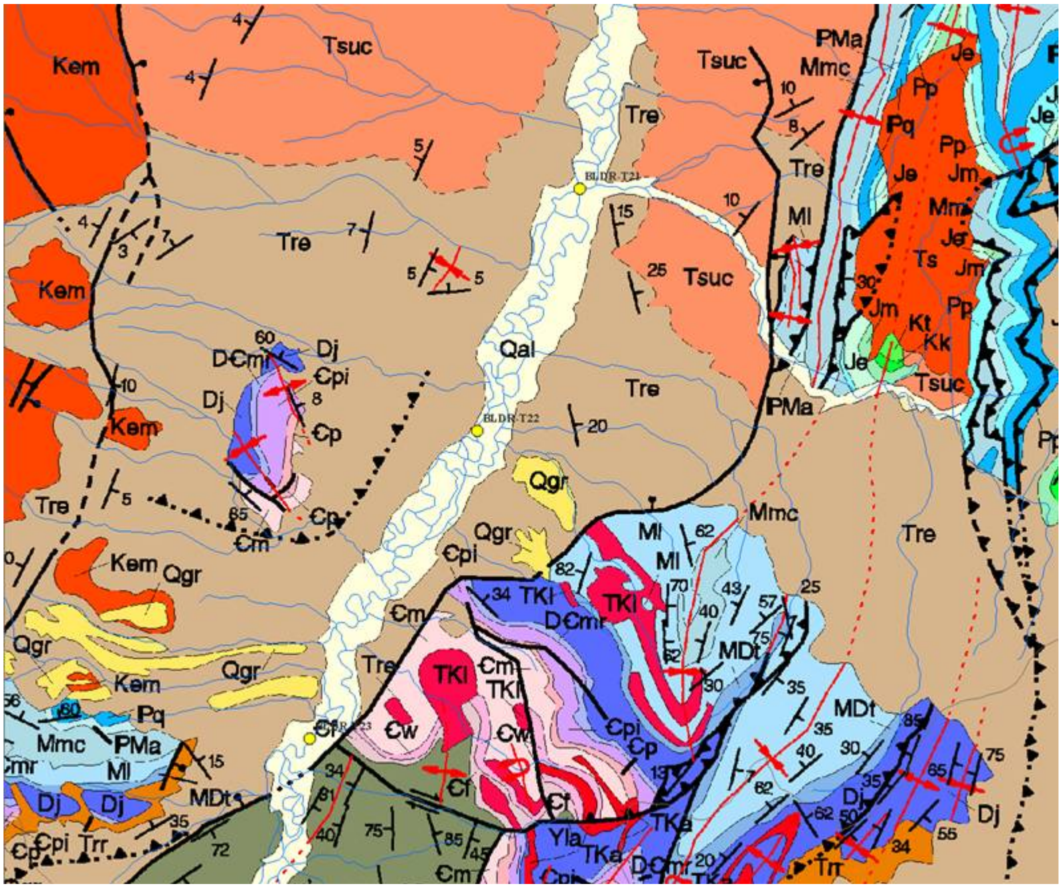

Figure X-1. Geologic Map of the Boulder River valley near BLDR T-20, T-21, and T-22.
(Taken from Geologic map of the Bozeman 30' X 60' quadrangle, southwestern Montana, Montana Bureau of Mines and Geology: Open-File Report 469, 39 p., 1 sheet, 1:100,000)

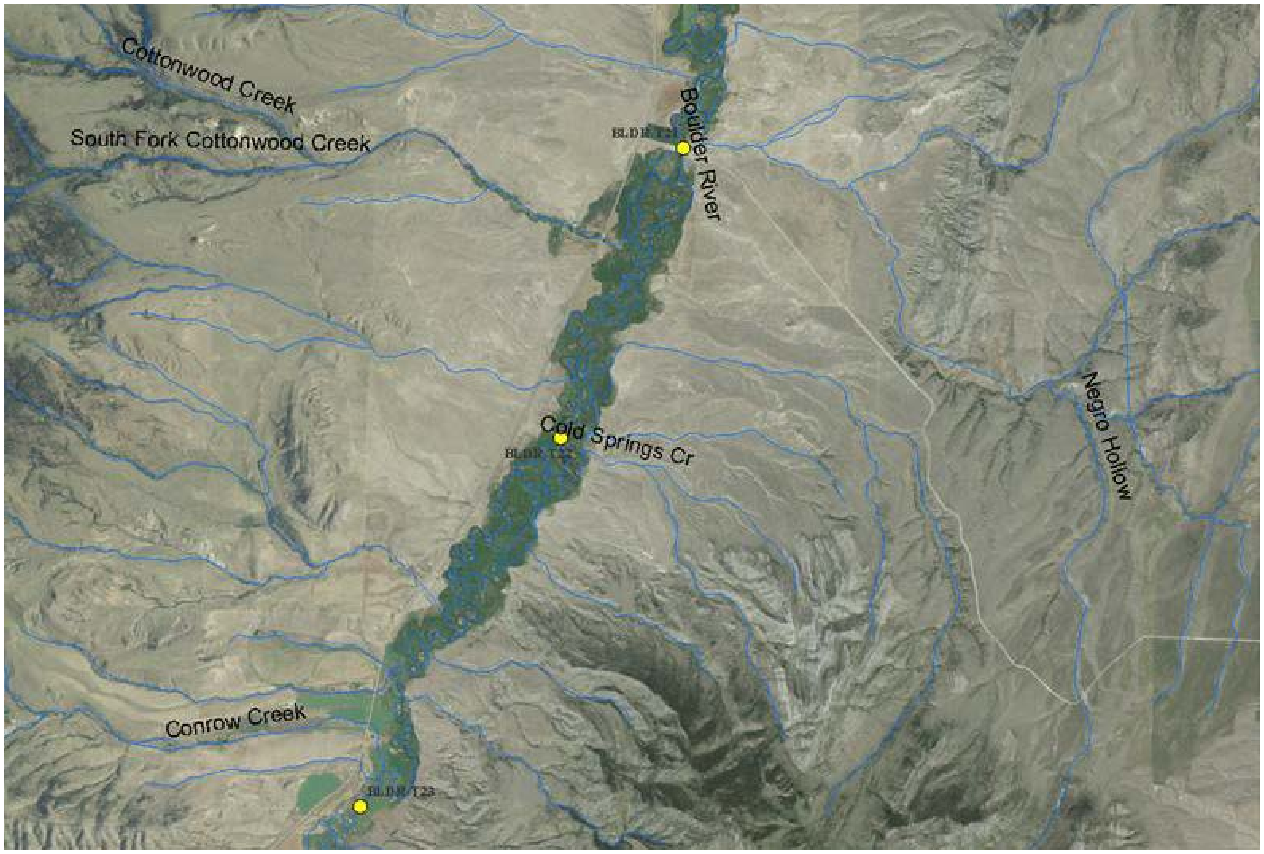

Figure X-2. Aerial view of Boulder River valley near BLDR-T20, T-21, and T-22.

Figure X-3. Aerial view of BLDR T-21.

STREAM TEMPERATURE ASSESSMENT FOR THE BOULDER RIVER

Boulder-Elkhorn TMDL Planning Area

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February 2011

Project No. 100015300

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1.0 Introduction

Temperature impairments were assessed within the Boulder River using a combination of in-stream temperature measurements, riparian shading assessments, mid-summer streamflow measurements, and modeling. The Boulder River temperature assessment was conducted to aid in the development of Total Maximum Daily Loads (TMDLs) for temperature impaired stream segments in the Boulder-Elkhorn TMDL Planning Area (TPA) (**Table 1-1**). Data collected during this assessment were used in the QUAL2K model to assess the influence of riparian shading and streamflow on stream temperatures in the Boulder River. The results of this assessment were compared to Montana's water quality standards for temperature to evaluate beneficial use support and potential restoration strategies.

Table 1-1. Temperature Impaired Segments of the Boulder River.

Waterbody ID	Length (Miles)	Use Class	Location	Probable Sources
MT41E001_022	32.9	B-1	Town of Boulder to Cottonwood Creek	Habitat Modification - other than Hydromodification Impacts from Abandoned Mine Lands (Inactive) Impacts from Hydrostructure Flow Regulation/modification Irrigated Crop Production Loss of Riparian Habitat
MT41E001_030	12.7	B-1	Cottonwood Creek to the mouth (Jefferson River)	Impacts from Abandoned Mine Lands (Inactive) Impacts from Hydrostructure Flow Regulation/modification Irrigated Crop Production

1.1 Montana Water Quality Standards

Montana's water quality standard for temperature addresses a maximum allowable increase above the "naturally occurring" temperature to protect the existing thermal regime for fish and aquatic life. Among other uses, the Boulder River is to be maintained suitable for the growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers. For waters classified as B-1, the associated standard specific to temperature is as follows: "A 1ºF maximum increase above naturally occurring water temperature is allowed within the range of 32ºF to 66ºF; within the naturally occurring range of 66ºF to 66.5ºF, no discharge is allowed which will cause the water temperature to exceed 67ºF; and where the naturally occurring water temperature is 66.5ºF or greater, the maximum allowable increase in water temperature is 0.5ºF. A 2ºF per-hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is above 55ºF. A 2ºF maximum decrease below naturally occurring water temperature is allowed within the range of 55ºF to 32ºF." [ARM 17.30.623(2e), ARM 17.30.624(2e) and ARM 17.30.627(2e)]. Temperature monitoring and modeling indicated that naturally occurring stream temperatures in the Boulder River are likely greater than 66.5°F during portions of the summer months (**Table 1-2, Attachment A**). Thus, the maximum allowable increase due to unmitigated human causes in the Boulder River is 0.5°F (0.23°C).

Table 1-2. Measured and Modeled Maximum Temperatures in the Boulder River, 2010.

Site	Measured Seasonal Maximum Temperature		Modeled Naturally Occurring Maximum Temperature	
	Date	Temperature (°F)	Date*	Temperature (°F)
BLDR-T02	08/05/10	71.1	7/24-7/26	68.1
BLDR-T04	07/25/10	71.1	7/24-7/26	66.5
BLDR-T05	07/25/10	71.1	7/24-7/26	66.1
BLDR-T08	07/25/10	71.5	7/24-7/26	65.4
BLDR-T09	07/25/10	71.6	7/24-7/26	65.4
BLDR-T10	07/25/10	71.3	7/24-7/26	66.2
BLDR-T11	07/25/10	71.4	7/24-7/26	66.7
BLDR-T13	07/25/10	71.4	7/24-7/26	66.9
BLDR-T14	07/25/10	71.4	7/24-7/26	68.0
BLDR-T15	07/25/10	73.2	7/24-7/26	71.2
BLDR-T19	07/25/10	76.4	7/24-7/26	71.2
BLDR-T20	07/25/10	75.9	7/24-7/26	70.7
BLDR-T22	07/25/10	76.2	7/24-7/26	73.9
BLDR-T24	07/25/10	74.3	7/24-7/26	69.1

*Modeled maximum temperatures based on average maximum temperature over a three day timeframe from July 24th-26th, 2010.

1.2 Temperature Thresholds

Special temperature considerations are warranted for the westslope cutthroat trout, which are present in the Boulder River watershed and listed by the State of Montana as a species of concern (Carlson 2001). Westslope cutthroat trout are currently found in several Boulder River tributaries, all of which enter the Boulder River upstream of the temperature impaired segments that are the focus of this assessment (R. Spoon, Montana FWP, personal communication, 2/14/11). Recently conducted research by Bear et al. (2005) found that the upper incipient lethal temperature (UILT) for westslope cutthroat trout was 67ºF (19.7ºC), while the UILT for rainbow trout was 76ºF (24.2ºC). The UILT is the temperature that is considered to be survivable indefinitely by 50 percent of the population (Lohr et al. 1996). Although these temperature thresholds are used as a reference that likely causes impact to fish, they are not targeted temperatures for the Boulder River and are not directly related to Montana's water quality standards.

2.0 Temperature Assessment

The Boulder River temperature assessment was performed in order to identify existing conditions and to determine if human caused disturbances have led to increased stream water temperatures. This assessment utilized field data and computer modeling to assess stream temperatures in relation to Montana's water quality standards.

2.1 Field Data Collection

Field data used in this assessment were collected during the 2010 summer field season and included temperature measurements, streamflow measurements, and an assessment of riparian shading along the Boulder River and selected tributary streams. Field methods are described in *Boulder-Elkhorn TMDL Planning Area Temperature and Instantaneous Flow Monitoring for the Boulder River* (DEQ 2010).

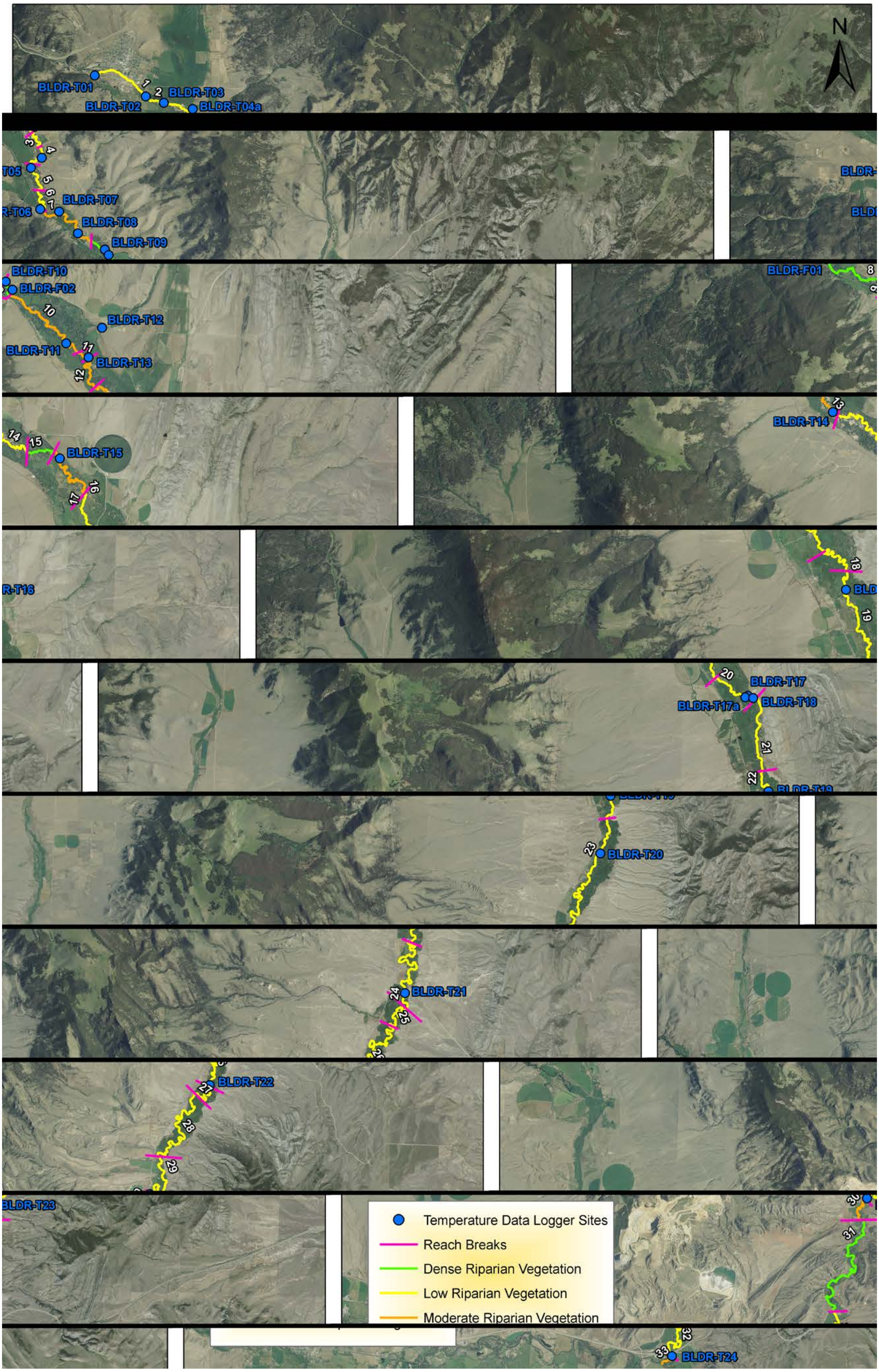
2.1.1 Temperature Measurements

Temperature monitoring was conducted in the Boulder River between late-June and late-September in 2010. The study timeframe examined stream temperatures during the period when streamflows tend to be lowest, water temperatures are warmest, and negative effects to the cold water fishery and aquatic life beneficial uses are likely most pronounced. Temperature monitoring consisted of placing temperature data logging devices at 22 sites in the Boulder River mainstem (**Figure 2-1**). In addition, temperature data logging devices were placed on three tributary streams (Muskrat Creek, Elkhorn Creek, and the Little Boulder River) and at three sites within ditches. Temperature monitoring sites were selected to bracket stream reaches with similar hydrology, riparian vegetation type, valley type, stream aspect, and channel width so that the temperature data collected during this assessment could be utilized in the QUAL2K model. A summary of temperature data is presented in **Attachment A**.

2.1.2 Streamflow Measurements

In 2010, streamflow was measured at five sites in the Boulder River watershed in late-June, at 27 sites in early-August, and at 24 sites in late-September. Streamflow data collected during the early-August timeframe were used in the QUAL2K model to help determine if in-stream temperatures exceed Montana standards.

Figure 2-1. Boulder River Temperature Monitoring Sites and Riparian Vegetation Reaches.



2.1.3 Riparian Shading Assessment

Riparian shading was assessed at 14 sites along the Boulder River using a Solar Pathfinder which measures the amount of shade at a site in one-hour intervals between 6 a.m. and 6 p.m. The Solar Pathfinder was utilized to assess riparian shading using the August template for the path of the sun. Shade was measured at three locations over a 200-foot reach at each site. In addition to the Solar Pathfinder readings, the following measurements were performed at each site in which riparian shading was assessed:

- Stream azimuth
- Bankfull width
- Wetted width
- Dominant tree species

Riparian shading data were used to assess existing and potential riparian shading conditions relative to the level of anthropogenic disturbance at a site. Measurements obtained with the Solar Pathfinder were utilized in the QUAL2K model to help determine if in-stream temperatures exceed Montana standards. Solar Pathfinder hourly shade measurements are presented in **Attachment B** and supplemental field data are presented in **Attachment C.**

2.2 QUAL2K Model

The QUAL2K model was used to determine if human caused disturbances within the Boulder River watershed have increased the water temperature above the “naturally occurring” level and, if so, to what degree. QUAL2K is a one dimensional river and stream water quality model that assumes the channel is well-mixed vertically and laterally. The QUAL2K model utilizes steady state hydraulics that simulate non-uniform steady flow. Within the model, water temperatures are estimated based on climatic data, riparian shading, and channel conditions. For this assessment, the QUAL2K model was used to evaluate maximum summer water temperatures in the Boulder River. The QUAL2K model is available at:
http://www.epa.gov/ATHENS/wwqtsc/html/qual2k.html.

Stream temperature, riparian shading and streamflow data collected in the summer of 2010 were used to calibrate the QUAL2K model for existing conditions. The potential to reduce stream temperatures was then modeled based on seven scenarios, including:

- Baseline scenario (existing conditions)
- Increased shade scenario 1 (reference shade)
- Increased shade scenario 2
- Decreased water consumptive use scenario
- Natural condition scenario (no anthropogenic impacts)
- Naturally occurring scenario (full application of BMPs to present uses)
- Increased shade scenario 1 (reference shade) and increased irrigation efficiency (as applied in the naturally occurring scenario)

The QUAL2K model inputs and outputs are based on the metric system and the plotted results are presented in °C. For comparison, a conversion between °C and °F is included in **Table 2-1**.

Table 2-1. Conversion Table °C to °F.

°C	°F	°C	°F	°C	°F
1	33.8	11	51.8	21	69.8
2	35.6	12	53.6	22	71.6
3	37.4	13	55.4	23	73.4
4	39.2	14	57.2	24	75.2
5	41.0	15	59.0	25	77.0
6	42.8	16	60.8	26	78.8
7	44.6	17	62.6	27	80.6
8	46.4	18	64.4	28	82.4
9	48.2	19	66.2	29	84.2
10	50.0	20	68.0	30	86.0

2.2.1 Data Sources and Model Assumptions

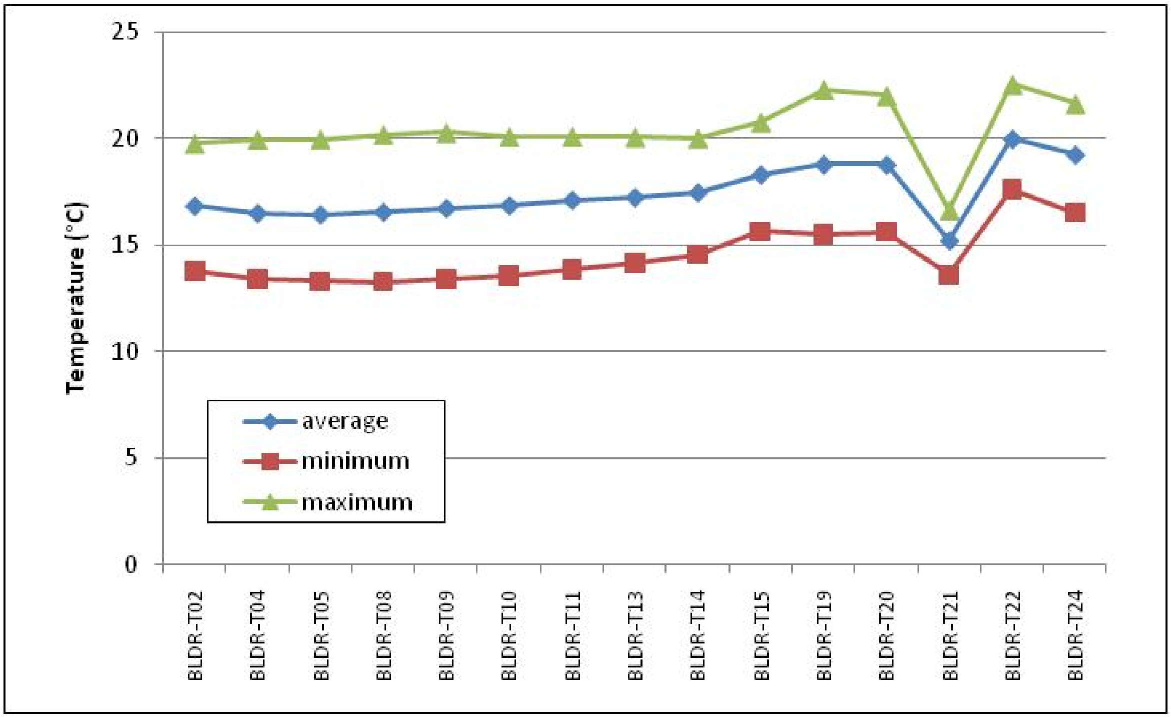
Data sources and model assumptions made during this assessment are described within the following sections. A more detailed discussion of specific model inputs for each data entry tab of the QUAL2K model is presented in **Attachment D**.

2.2.1.1 Temperature Data

Temperature data collected in the Boulder River during the summer of 2010 were applied in the QUAL2K model. Data loggers were deployed between June 27th and 28th and retrieved between September 27th and 30th. Out of the 22 temperature monitoring sites established on the mainstem of the Boulder River in 2010, temperature data loggers were retrieved from 21 sites, while the temperature data logger from site BLDR-T07 was not recovered. Out of the 21 sites on the Boulder River mainstem with temperature data, four sites (BLDR-T01, BLDR-T03, BLDR-T16, and BLDR-T18) have incomplete datasets due to low flows resulting in the data loggers being out of the water for a portion of the monitoring period during the late-July and early-August timeframe. In addition, the data logger at BLDR-T23 was found missing and subsequently replaced in August and one data logger (BLDR-T17a) was added for additional data collection in August. Both of these data loggers also lack data in the late-July and early-August timeframe. Overall, 15 sites have complete temperature datasets for the Boulder River mainstem. Out of these 15 sites, the daily maximum temperature for the period of record was recorded on July 25th, 2010 at 13 sites, while the remaining two sites recorded daily maximum temperatures during August 5th (BLDR-T02) and August 6th (BLDR-T21) (**Attachment A**).

The 7-day average maximum temperature occurred between July 22nd and August 18th at the 15 Boulder River mainstem sites with complete datasets. The 7-day average maximum temperature was reported at five sites on July 22nd, five sites on July 31st, two sites on August 2nd, two sites on August 4th, and one site on August 18th (**Attachment A**). Thus, temperature data recorded in 2010 indicates that the warmest temperatures in the mainstem of the Boulder River occurred between July 22nd and August 18th, with the majority of the high temperatures occurring within the July 22nd to August 6th timeframe. Since nearly all of the daily maximum temperatures occurred on July 25th and this date occurs within the period of greatest 7-day average temperatures, this day was selected for modeling temperature for the Boulder River. In the Boulder River, a three day travel time (the time it takes for water to flow through the study reach) is estimated. Temperature data from July 24th, 25th and 26th were averaged for input into the QUAL2K model, which was run for the July 24th through 26th timeframe (**Figure 2-2**).

Figure 2-2. Boulder River Temperature Data, July 24th-26th, 2010.

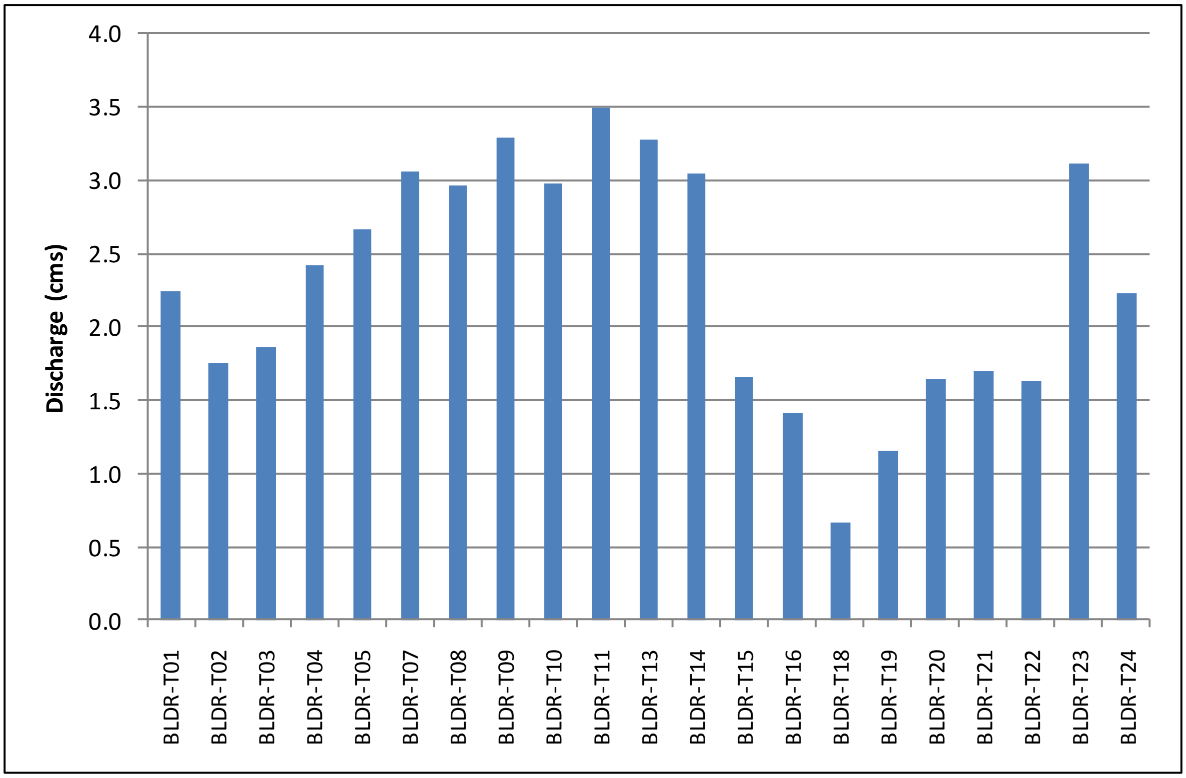


In addition to temperature data collected in the Boulder River, UGSG gaging station data from the Jefferson River near Three Forks (06036650) recorded a maximum temperature of 24.2°C on July 25th, with the 14 days with the highest maximum temperatures occurring between July 21st and August 7th. This information further justifies the use of the July 24th through 26th timeframe to represent the warmest temperature conditions in the Boulder River in 2010.

2.2.1.2 Streamflow Data

Streamflow data collected in the Boulder River during August of 2010 were applied in the QUAL2K model. Streamflow measurements were performed at 21 sites on the mainstem of the Boulder River between August 4th and 6th, 2010 (**Figure 2-3**). Streamflow in three ditches was also measured during this timeframe. Streamflow measurements were performed on the Little Boulder River on August 4th and on Muskrat Creek on August 12th. Elkhorn Creek was dry during the August monitoring event.

Figure 2-3. Boulder River Streamflow Data, August 4th-6th, 2010.



2.2.1.3 Streamside Shading

Streamside shading data collected in the Boulder River during the summer of 2010 were applied in the QUAL2K model. Prior to field data collection, the Boulder River was divided into 33 distinct reaches covering 81.6 kilometers (50.7 miles) using the 1:24:000 NHD stream layer (**Figure 2-1**). Reaches were delineated based on observed riparian conditions using NAIP color aerial imagery from 2009. Reaches were categorized as “dense”, “moderate”, or “low” riparian vegetation density, with 13% of the study reach classified as dense, 18% classified as moderate, and 69% classified as low riparian vegetation density. The predominant riparian vegetation for each reach was evaluated using aerial imagery and the vegetation type was assigned using best professional judgment. Dense riparian vegetation areas had a mix of deciduous trees and shrubs, while moderate riparian vegetation areas contained fewer deciduous trees and generally had an understory comprised of deciduous shrubs and herbaceous vegetation. Areas with low riparian vegetation densities generally lacked overstory vegetation and were comprised of herbaceous vegetation with sparse deciduous shrubs in the understory.

Fourteen shade assessment sites were selected for field data collection, with three sites in the dense riparian category, three sites in the moderate riparian category, and eight sites in the low riparian category. In the QUAL2K model, solar pathfinder hourly data was applied directly to the reaches in which a field monitoring site was located. When no field monitoring site was located within a reach, the average value for the given riparian vegetation category (low, moderate, or dense) at the reach scale was applied. Field data was evaluated based on the following criteria: dense (>30%), moderate (10-30%) and low (<10%) (**Table 2-2**). The complete riparian shading dataset is presented in **Attachment B** and supplemental information for each assessed reach is presented in **Attachment C**. Existing riparian vegetation reach types as determined through GIS analysis of aerial imagery are presented in **Attachment E**.

Table 2-2. Boulder River Riparian Vegetation Reach Type Average Hourly Shade Conditions.

Riparian Vegetation Reach Type	Morning (AM)						Afternoon (PM)						Average Daily Shade
	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	
Dense Riparian	88%	64%	30%	11%	5%	7%	12%	17%	30%	43%	64%	78%	37%
Moderate Riparian	59%	31%	23%	12%	4%	1%	2%	4%	6%	16%	41%	62%	22%
Low Riparian	10%	2%	2%	3%	2%	1%	2%	0%	0%	2%	5%	15%	4%

2.2.1.4 Climatic Data

Climatic data inputs for the QUAL2K model were obtained from the Western Regional Climate Center (http://www.raws.dri.edu/wraws/nidwmtF.html) station in Whitehall, Montana and included air temperature, dew point temperature and wind speed. The dew point temperature was adjusted by increasing the relative humidity by 15% based on local conditions within the stream corridor as measured in a similar assessment in the Big Hole River watershed (Flynn et al. 2008).

2.2.1.5 Hydrologic Balance

To evaluate tributary inflows, waste water treatment plant discharges, and irrigation water withdrawals along the Boulder River, a hydrologic balance was created. Basic assumptions applied when developing the hydrologic balance include:

- Streamflows were balanced between each data logger where streamflow measurements were performed.
- Streamflow measurements from three tributaries (Muskrat Creek, Little Boulder River, Elkhorn Creek) were utilized in the QUAL2K model. Elkhorn Creek was dry during the August monitoring event and all other tributaries besides Muskrat Creek and the Little Boulder River were also assumed to be dry for modeling purposes.
- Wastewater treatment plant discharges were estimated based on August 2010 measurement data obtained from the Montana DEQ Water Protection Bureau.
- Streamflow measurements from two irrigation diversions were utilized in the QUAL2K model. Other irrigation withdrawals were modeled based on the hydrologic balance. If a loss in streamflow was identified between streamflow measurement sites, then it was assumed that all of the lost flow was diverted for irrigation purposes. If multiple diversions were present between streamflow measurement sites and a loss in streamflow was identified, then the flow was divided evenly amongst the diversions.

A detailed hydrologic balance for the Boulder River is presented in **Attachment F**.

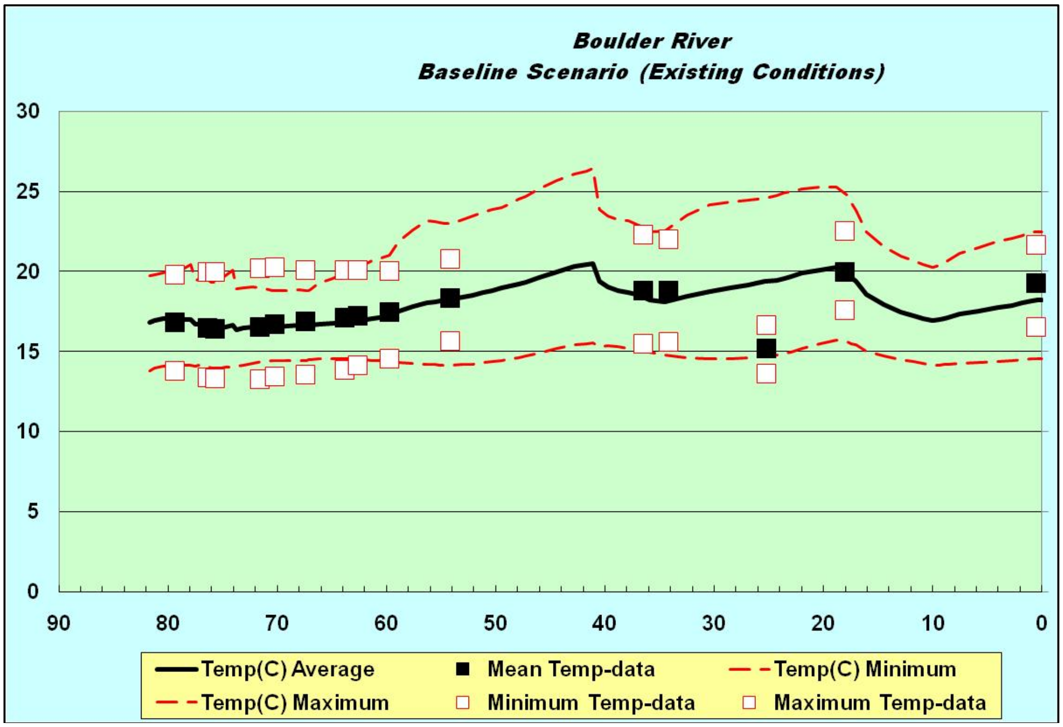
2.2.2 Boulder River Model Scenarios

Several model scenarios were examined for the Boulder River, including the baseline (existing conditions) scenario, two shade scenarios, a water consumptive use scenario, a natural condition scenario, a naturally occurring scenario, and a scenario examining reference shade conditions in combination with increased irrigation efficiency.

2.2.2.1 Baseline Scenario (Existing Conditions)

Once the above calibration steps were performed, the QUAL2K model was run for the baseline scenario, which is intended to represent the existing conditions within the Boulder River. This model run utilized measured field data, with the assumptions described in **Section 2.2.1** and **Attachment D**. Hydraulic output in the model accurately reflected measured conditions, indicating that water routing and channel morphology were adequately calibrated. Subsequent model scenarios were compared to the existing conditions results of the baseline model and not to the field measured values to assure consistency when evaluating the potential to reduce stream temperatures (**Figure 2-4)**.

Figure 2-4. Boulder River QUAL2K Baseline (Existing Conditions) Scenario.



2.2.2.2 Shade Scenario 1 (Reference Shade)

For shade scenario 1, all reaches were assigned the average value for dense riparian vegetation to evaluate reference conditions along the Boulder River. The reference shade scenario assumes the entire length of the Boulder River between the town of Boulder and the confluence with the Jefferson River is capable of supporting a riparian area comprised of large cottonwood trees in the overstory and shrubs in the understory. There is a relatively broad floodplain along the majority of the study reach and the meandering channel is not entrenched, allowing for natural gravel bar formation and the establishment of new cottonwood stands. In this scenario, riparian shade density was increased along a total of 44.1 miles of the Boulder River (**Table 2-3**). Reference shade values for dense riparian vegetation were developed based on riparian vegetation reach type average hourly shade values (see **Table 2-2**). An evaluation of existing shade and potential shade as assigned in shade scenario 1 is presented for each reach in **Attachment F**. The results of shade scenario 1 indicate that an increase in streamside shading along the Boulder River would lead to a decrease in stream water temperature (**Figure 2-5, Table 2-4**).

Table 2-3. Boulder River Existing Conditions and Shade Scenarios for Riparian Vegetation Reach Types.

Riparian Vegetation Reach Type	Baseline (Existing Conditions) Scenario			Shade Scenario 1 (Reference Shade)*			Shade Scenario 2**		
	Number of Reaches	Length (Miles)	Percent	Number of Reaches	Length (Miles)	Percent	Number of Reaches	Length (Miles)	Percent
Dense Riparian	4	6.6	13%	33	50.7	100%	12	15.6	31%
Moderate Riparian	8	9.0	18%	0	0.0	0%	21	35.1	69%
Low Riparian	21	35.1	69%	0	0.0	0%	0	0.0	0%

* Also applied in the Natural Condition Scenario.

** Also applied in the Naturally Occurring Scenario.

Figure 2-5. Boulder River QUAL2K Shade Scenario 1 (Reference Shade).

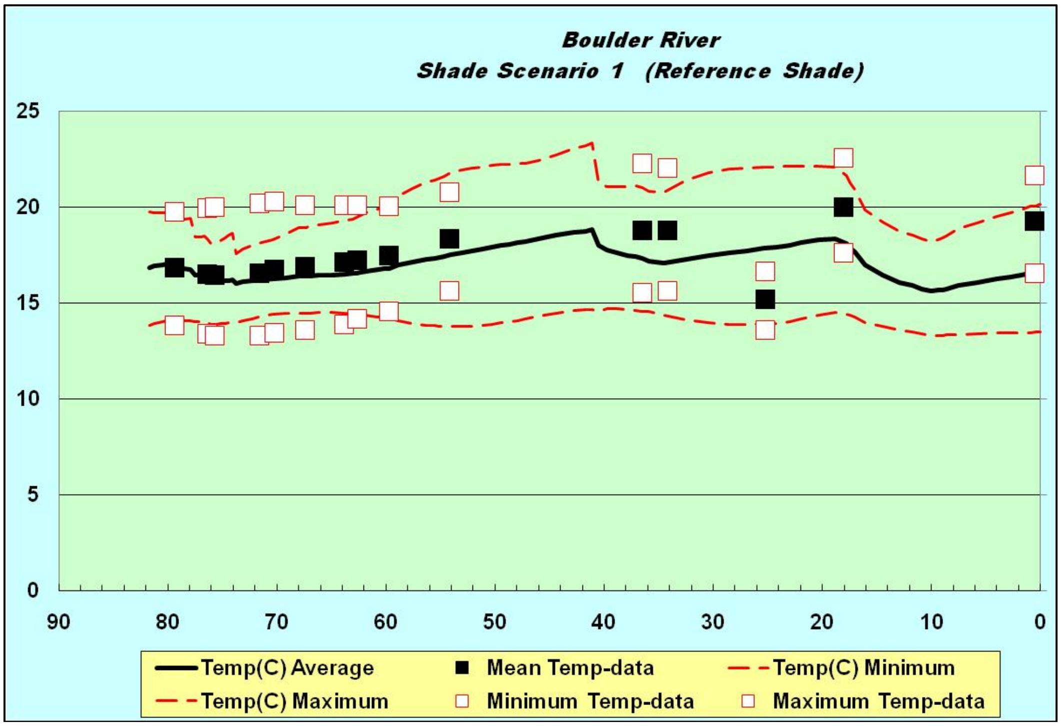


Table 2-4. Boulder River QUAL2K Shade Scenario 1 (Reference Shade).

Data Logger Site	Q2K Existing Conditions			Q2K Shade Scenario 1			Departure from Existing Conditions Model (°C)	Departure from Existing Conditions Model (°F)
	Distance (km)	Maximum Temperature (°C)	Maximum Temperature (°F)	Distance (km)	Maximum Temperature (°C)	Maximum Temperature (°F)		
BLDR-T02	79.1	20.1	68.1	79.1	19.4	66.9	-0.6	-1.1
BLDR-T04	76.3	19.5	67.1	76.3	18.3	65.0	-1.2	-2.2
BLDR-T05	75.6	19.4	66.8	75.6	18.1	64.6	-1.3	-2.3
BLDR-T08	71.4	19.0	66.2	71.4	18.1	64.6	-0.8	-1.5
BLDR-T09	70.4	18.8	65.9	70.4	18.3	64.9	-0.5	-1.0
BLDR-T10	67.4	18.8	65.9	67.4	18.9	66.1	0.1	0.2
BLDR-T11	63.7	20.0	67.9	63.7	19.3	66.8	-0.6	-1.1
BLDR-T13	62.7	20.1	68.3	62.7	19.4	67.0	-0.7	-1.3
BLDR-T14	59.8	21.0	69.9	59.8	20.1	68.2	-0.9	-1.7
BLDR-T15	54.1	23.0	73.4	54.1	21.8	71.2	-1.2	-2.2
BLDR-T19	36.5	22.8	73.0	36.5	21.0	69.8	-1.7	-3.1
BLDR-T20	34.5	22.5	72.6	34.5	20.8	69.4	-1.8	-3.2
BLDR-T22	18.8	25.3	77.5	18.8	22.1	71.7	-3.2	-5.8
BLDR-T24	1.0	22.5	72.5	1.0	20.0	68.0	-2.5	-4.4
Grey highlighted values indicate that the model scenario predicts a potential decrease in temperature greater than 0.5°F.								

2.2.2.3 Shade Scenario 2

For shade scenario 2, reaches categorized as low riparian vegetation (35.1 miles) were assigned the average value for reaches with moderate riparian vegetation, while reaches with moderate riparian vegetation (9.0 miles) were assigned the average value for reaches with dense riparian vegetation. Reaches currently exhibiting dense riparian vegetation were assigned the average value for dense riparian vegetation based on field collected data. This scenario is based on the premise that land-use practices within the watershed have altered the composition of the riparian vegetation along the Boulder River. While the re-establishment of dense cottonwood stands along the entire stream corridor may not be possible, an improvement in riparian vegetation density through the application of Best Management Practices is reasonable. In this scenario, a total of 15.6 miles of stream (31%) were modeled with dense riparian vegetation, while 35.1 miles of stream (69%) were modeled with moderate riparian vegetation (**Table 2-3**). An evaluation of existing shade and potential shade as assigned in shade scenario 2 is presented for each reach in **Attachment F**. The results of shade scenario 2 indicate that an increase in streamside shading along the Boulder River would lead to a decrease in stream water temperature (**Figure 2-6, Table 2-5**).

Figure 2-6. Boulder River QUAL2K Shade Scenario 2.

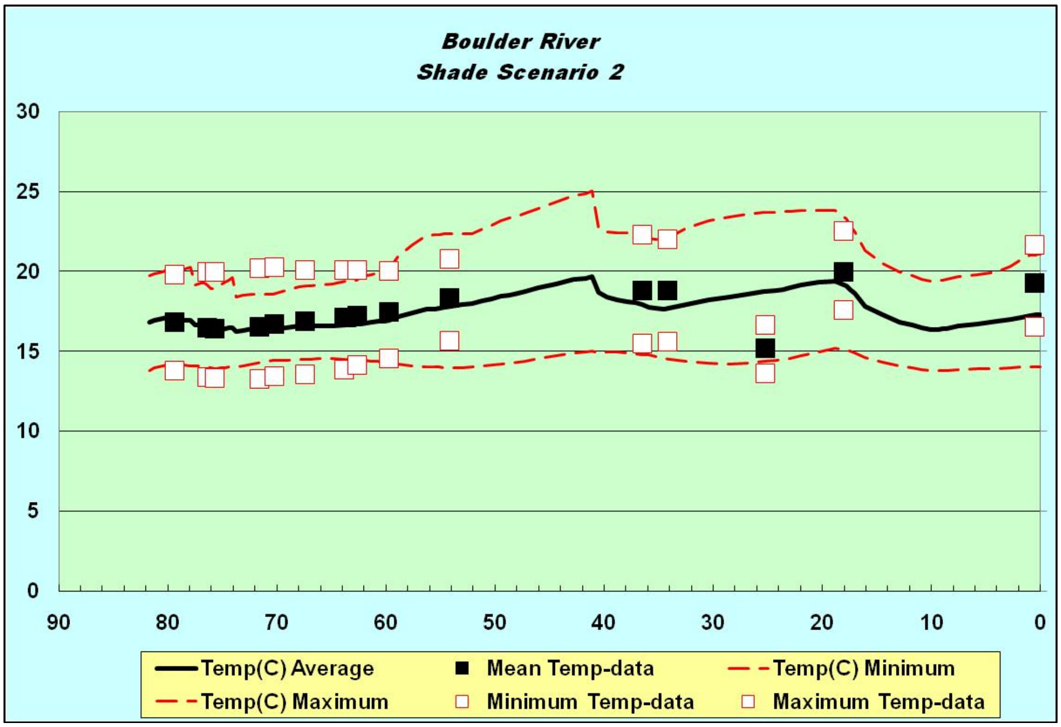


Table 2-5. Boulder River QUAL2K Shade Scenario 2.

Data Logger Site	Q2K Existing Conditions			Q2K Shade Scenario 2			Departure from Existing Conditions Model (°C)	Departure from Existing Conditions Model (°F)
	Distance (km)	Maximum Temperature (°C)	Maximum Temperature (°F)	Distance (km)	Maximum Temperature (°C)	Maximum Temperature (°F)		
BLDR-T02	79.1	20.1	68.1	79.1	20.1	68.1	0.0	0.0
BLDR-T04	76.3	19.5	67.1	76.3	19.1	66.5	-0.4	-0.7
BLDR-T05	75.6	19.4	66.8	75.6	18.9	66.1	-0.4	-0.7
BLDR-T08	71.4	19.0	66.2	71.4	18.5	65.4	-0.4	-0.8
BLDR-T09	70.4	18.8	65.9	70.4	18.6	65.4	-0.3	-0.5
BLDR-T10	67.4	18.8	65.9	67.4	19.1	66.3	0.3	0.5
BLDR-T11	63.7	20.0	67.9	63.7	19.4	66.8	-0.6	-1.1
BLDR-T13	62.7	20.1	68.3	62.7	19.5	67.0	-0.7	-1.2
BLDR-T14	59.8	21.0	69.9	59.8	20.1	68.2	-0.9	-1.6
BLDR-T15	54.1	23.0	73.4	54.1	22.4	72.2	-0.7	-1.2
BLDR-T19	36.5	22.8	73.0	36.5	22.3	72.1	-0.5	-0.8
BLDR-T20	34.5	22.5	72.6	34.5	22.0	71.5	-0.6	-1.1
BLDR-T22	18.8	25.3	77.5	18.8	23.8	74.8	-1.5	-2.7
BLDR-T24	1.0	22.5	72.5	1.0	21.0	69.8	-1.5	-2.6

Grey highlighted values indicate that the model scenario predicts a potential decrease in temperature greater than 0.5°F.

2.2.2.4 Water Consumptive Use Scenario

The water consumptive use scenario describes the thermal effect of irrigation and domestic water uses on water temperatures in the Boulder River. This scenario was modeled by removing existing water diversions from the study reach as identified in the hydrologic balance (**Attachment F**). This scenario indicated that increased streamflows would lead to a decrease in water temperatures in the Boulder River (**Figure 2-7, Table 2-6**). Due to a lack of measurements of irrigation withdrawals throughout the system, the results of the water consumptive use scenario should be interpreted with caution. If more detailed flow data for the irrigation network becomes available, this scenario may need to be reevaluated.

Figure 2-7. Boulder River QUAL2K Water Consumptive Use Scenario.

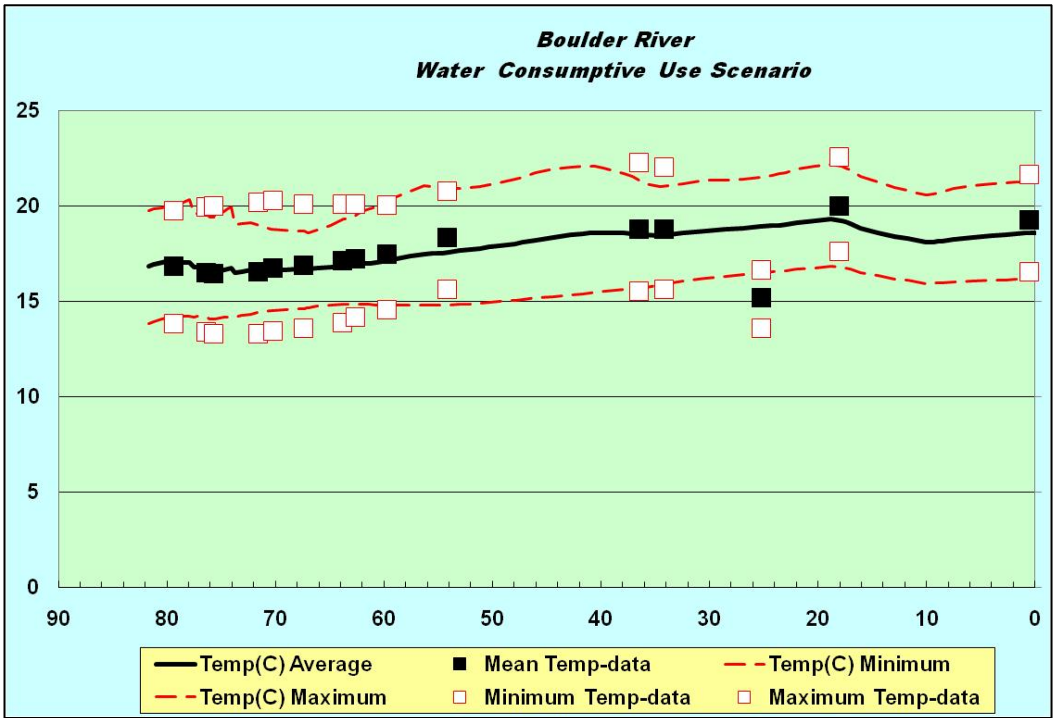


Table 2-6. Boulder River QUAL2K Water Consumptive Use Scenario.

Data Logger Site	Q2K Existing Conditions			Q2K Water Consumptive Use Scenario			Departure from Existing Conditions Model (°C)	Departure from Existing Conditions Model (°F)
	Distance (km)	Maximum Temperature (°C)	Maximum Temperature (°F)	Distance (km)	Maximum Temperature (°C)	Maximum Temperature (°F)		
BLDR-T02	79.1	20.1	68.1	79.1	20.0	68.1	0.0	0.0
BLDR-T04	76.3	19.5	67.1	76.3	19.6	67.3	0.1	0.1
BLDR-T05	75.6	19.4	66.8	75.6	19.4	66.9	0.1	0.1
BLDR-T08	71.4	19.0	66.2	71.4	19.0	66.2	0.0	0.0
BLDR-T09	70.4	18.8	65.9	70.4	18.8	65.8	0.0	0.0
BLDR-T10	67.4	18.8	65.9	67.4	18.7	65.6	-0.1	-0.3
BLDR-T11	63.7	20.0	67.9	63.7	19.3	66.8	-0.6	-1.2
BLDR-T13	62.7	20.1	68.3	62.7	19.5	67.0	-0.7	-1.2
BLDR-T14	59.8	21.0	69.9	59.8	20.1	68.2	-0.9	-1.6
BLDR-T15	54.1	23.0	73.4	54.1	20.9	69.6	-2.1	-3.8
BLDR-T19	36.5	22.8	73.0	36.5	21.3	70.4	-1.4	-2.5
BLDR-T20	34.5	22.5	72.6	34.5	21.0	69.8	-1.6	-2.8
BLDR-T22	18.8	25.3	77.5	18.8	22.2	71.9	-3.1	-5.6
BLDR-T24	1.0	22.5	72.5	1.0	21.3	70.3	-1.2	-2.2

Grey highlighted values indicate that the model scenario predicts a potential decrease in temperature greater than 0.5°F.

2.2.2.5 Natural Condition Scenario

The natural condition scenario reflects the temperature regime that would be expected in the absence of human influence. This allows for the characterization of the extent of the departure from the natural condition. Factors applied in shade scenario 1 (reference shade) and the water consumptive use scenario (no irrigation withdrawals) were applied to run this scenario. The waste water treatment plant input was also removed from the model. All other parameters from the baseline scenario were retained. The results of the natural condition scenario indicate stream temperatures would naturally be lower than the existing condition along much of the Boulder River (**Figure 2-8, Table 2-7**).

Figure 2-8. Boulder River QUAL2K Natural Condition Scenario.

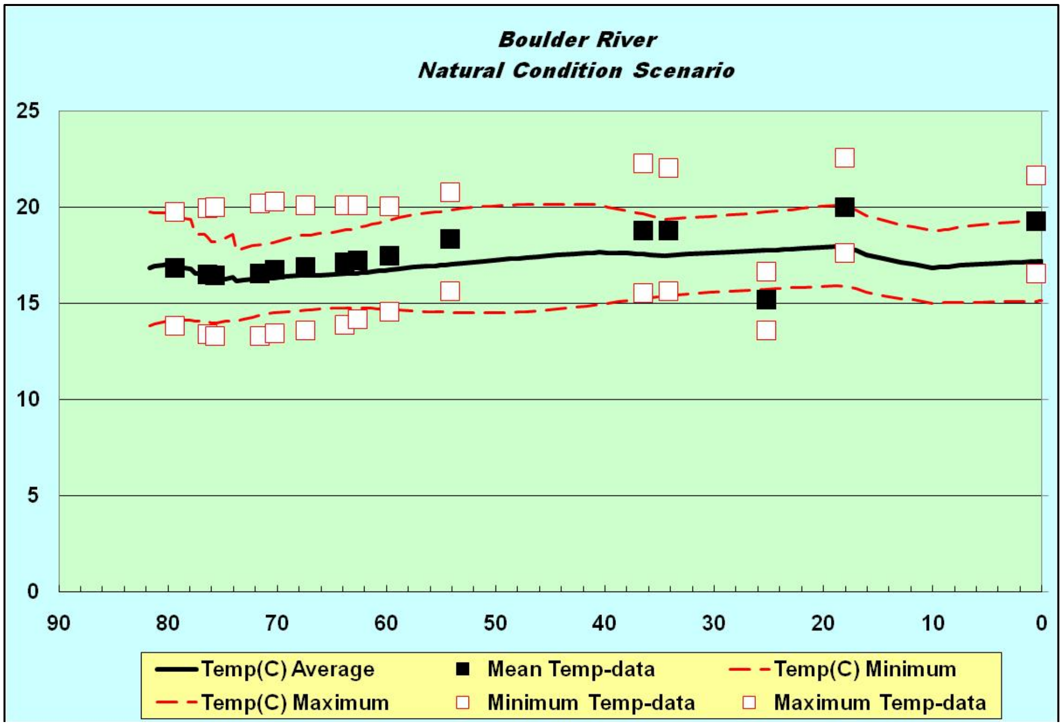


Table 2-7. Boulder River QUAL2K Natural Condition Scenario.

Data Logger Site	Q2K Existing Conditions			Q2K Natural Condition Scenario			Departure from Existing Conditions Model (°C)	Departure from Existing Conditions Model (°F)
	Distance (km)	Maximum Temperature (°C)	Maximum Temperature (°F)	Distance (km)	Maximum Temperature (°C)	Maximum Temperature (°F)		
BLDR-T02	79.1	20.1	68.1	79.1	19.4	67.0	-0.6	-1.1
BLDR-T04	76.3	19.5	67.1	76.3	18.4	65.2	-1.1	-2.0
BLDR-T05	75.6	19.4	66.8	75.6	18.2	64.8	-1.2	-2.1
BLDR-T08	71.4	19.0	66.2	71.4	18.1	64.5	-0.9	-1.7
BLDR-T09	70.4	18.8	65.9	70.4	18.1	64.6	-0.7	-1.2
BLDR-T10	67.4	18.8	65.9	67.4	18.5	65.3	-0.3	-0.5
BLDR-T11	63.7	20.0	67.9	63.7	18.8	65.8	-1.2	-2.1
BLDR-T13	62.7	20.1	68.3	62.7	18.9	66.0	-1.3	-2.3
BLDR-T14	59.8	21.0	69.9	59.8	19.3	66.8	-1.7	-3.1
BLDR-T15	54.1	23.0	73.4	54.1	19.9	67.7	-3.2	-5.7
BLDR-T19	36.5	22.8	73.0	36.5	19.6	67.3	-3.1	-5.6
BLDR-T20	34.5	22.5	72.6	34.5	19.4	66.9	-3.2	-5.7
BLDR-T22	18.8	25.3	77.5	18.8	20.1	68.2	-5.2	-9.3
BLDR-T24	1.0	22.5	72.5	1.0	19.3	66.7	-3.2	-5.7

Grey highlighted values indicate that the model scenario predicts a potential decrease in temperature greater than 0.5°F.

2.2.2.6 Naturally Occurring Scenario (ARM 17.30.602)

The naturally occurring scenario defines water temperature conditions resulting from the implementation of all reasonable land, soil and water conservation practices as outlined in ARM 17.30.602. This scenario identifies the “naturally occurring” temperature in water bodies of interest and establishes the temperatures to which a 0.5°F (0.23°C) temperature increase is allowable. This, in turn, can be used to identify the impairment status of a water body. The naturally occurring scenario included shade scenario 2 (see **Section 2.2.2.3**) along with a 15% increase in irrigation and domestic water use efficiency. This was estimated by reducing identified irrigation withdrawals by 15%, which is the efficiency improvement estimated by Montana DEQ and Montana DNRC when irrigation best management practices are implemented (Flynn et al. 2008). Based on the results of the naturally occurring scenario, it appears there is the potential for a reduction in in-stream temperatures relative to the existing condition as identified in the baseline scenario (**Figure 2-9, Table 2-8**).

Figure 2-9. Boulder River QUAL2K Naturally Occurring Scenario.

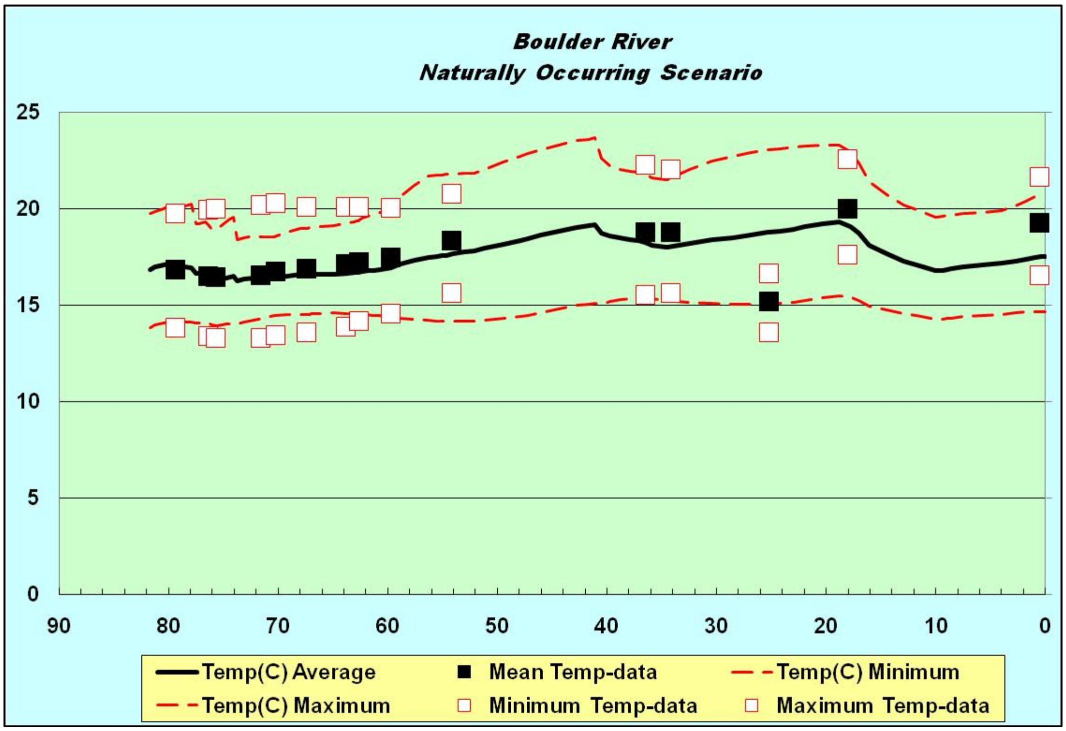


Table 2-8. Boulder River QUAL2K Naturally Occurring Scenario.

Data Logger Site	Q2K Existing Conditions			Q2K Naturally Occurring Scenario			Departure from Existing Conditions	Departure from Existing Conditions
	Distance (km)	Maximum Temperature (ºC)	Maximum Temperature (ºF)	Distance (km)	Maximum Temperature (ºC)	Maximum Temperature (ºF)		
BLDR-T02	79.1	20.1	68.1	79.1	20.1	68.1	0.0	0.0
BLDR-T04	76.3	19.5	67.1	76.3	19.2	66.5	-0.4	-0.7
BLDR-T05	75.6	19.4	66.8	75.6	19.0	66.1	-0.4	-0.7
BLDR-T08	71.4	19.0	66.2	71.4	18.6	65.4	-0.4	-0.8
BLDR-T09	70.4	18.8	65.9	70.4	18.5	65.4	-0.3	-0.5
BLDR-T10	67.4	18.8	65.9	67.4	19.0	66.2	0.2	0.3
BLDR-T11	63.7	20.0	67.9	63.7	19.3	66.7	-0.7	-1.2
BLDR-T13	62.7	20.1	68.3	62.7	19.4	66.9	-0.8	-1.4
BLDR-T14	59.8	21.0	69.9	59.8	20.0	68.0	-1.1	-1.9
BLDR-T15	54.1	23.0	73.4	54.1	21.8	71.2	-1.2	-2.2
BLDR-T19	36.5	22.8	73.0	36.5	21.8	71.2	-1.0	-1.8
BLDR-T20	34.5	22.5	72.6	34.5	21.5	70.7	-1.0	-1.9
BLDR-T22	18.8	25.3	77.5	18.8	23.3	73.9	-2.0	-3.6
BLDR-T24	1.0	22.5	72.5	1.0	20.6	69.1	-1.8	-3.3

Grey highlighted values indicate that the model scenario predicts a potential decrease in temperature greater than 0.5°F.

2.2.2.7 Shade Scenario 1 (Reference Shade) and Increased Irrigation Efficiency

The final scenario assessed combines shade scenario 1 (reference shade) with the potential for increased irrigation efficiency as presented in the naturally occurring scenario. The reference shade scenario assumes the entire length of the Boulder River between the town of Boulder and the confluence with the Jefferson River is capable of supporting a riparian area comprised of large cottonwood trees in the overstory with shrubs in the understory (see **Section 2.2.2.2**). For this scenario, a 15% increase in irrigation and domestic water use efficiency is also applied (see **Section 2.2.2.6)**. Based on the results of this scenario, it appears there is the potential for a reduction in in-stream temperatures relative to the existing condition as identified in the baseline scenario (**Figure 2-10, Table 2-9**).

Figure 2-10. Boulder River QUAL2K Shade Scenario 1 (Reference Shade) and Increased Irrigation Efficiency.

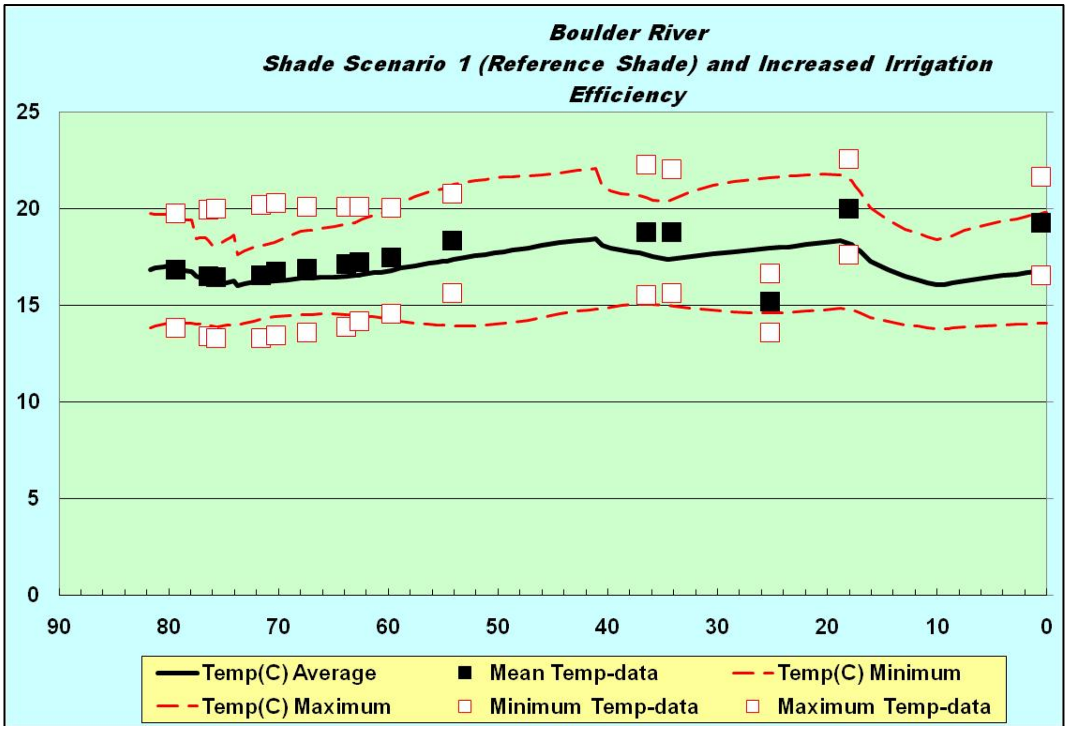


Table 2-9. Boulder River QUAL2K Shade Scenario 1 (Reference Shade) and Increased Irrigation Efficiency.

Data Logger Site	Q2K Existing Conditions			Q2K Shade Scenario 1 (Reference Shade) and Increased Irrigation Efficiency			Departure from Existing Conditions Model (°C)	Departure from Existing Conditions Model (°F)
	Distance (km)	Maximum Temperature (°C)	Maximum Temperature (°F)	Distance (km)	Maximum Temperature (°C)	Maximum Temperature (°F)		
BLDR-T02	79.1	20.1	68.1	79.1	19.4	67.0	-0.6	-1.1
BLDR-T04	76.3	19.5	67.1	76.3	18.3	65.0	-1.2	-2.1
BLDR-T05	75.6	19.4	66.8	75.6	18.1	64.6	-1.2	-2.2
BLDR-T08	71.4	19.0	66.2	71.4	18.1	64.6	-0.9	-1.5
BLDR-T09	70.4	18.8	65.9	70.4	18.3	64.9	-0.6	-1.0
BLDR-T10	67.4	18.8	65.9	67.4	18.9	65.9	0.0	0.1
BLDR-T11	63.7	20.0	67.9	63.7	19.2	66.6	-0.7	-1.3
BLDR-T13	62.7	20.1	68.3	62.7	19.3	66.8	-0.8	-1.5
BLDR-T14	59.8	21.0	69.9	59.8	20.0	67.9	-1.1	-1.9
BLDR-T15	54.1	23.0	73.4	54.1	21.2	70.2	-1.8	-3.2
BLDR-T19	36.5	22.8	73.0	36.5	20.6	69.0	-2.2	-3.9
BLDR-T20	34.5	22.5	72.6	34.5	20.4	68.7	-2.1	-3.9
BLDR-T22	18.8	25.3	77.5	18.8	21.7	71.1	-3.5	-6.4
BLDR-T24	1.0	22.5	72.5	1.0	19.7	67.5	-2.8	-5.0

Grey highlighted values indicate that the model scenario predicts a potential decrease in temperature greater than 0.5°F.

2.3 Modeled Temperatures Relative to Montana Standards

The naturally occurring scenario for the Boulder River indicated that water temperatures greater than 66.5°F can be expected (see **Table 1-2**). Thus, the maximum allowable increase in temperature due to unmitigated human causes is 0.5°F (0.23°C) (see **Section 1.1**). Along the Boulder River in 2010, this standard was exceeded at 11 out of 14 temperature monitoring sites evaluated using the QUAL2K model (**Table 2-10**). Model scenarios indicate that both an increase in shade and an increase in streamflow would help reduce water temperatures in the Boulder River.

Table 2-10. Boulder River Temperatures Relative to Montana's Water Quality Standards.

Data Logger Site	Distance (km)	Field Measured Data	QUAL2K Existing Conditions	Departure from Field Data (°F)	Naturally Occurring Scenario	Departure from Existing Conditions Model (°F)
		Maximum Temperature (°F)	Maximum Temperature (°F)		Maximum Temperature (°F)	
BLDR-T02	79.1	67.6	68.1	0.5	68.1	0.0
BLDR-T04	76.3	67.9	67.1	-0.8	66.5	-0.7
BLDR-T05	75.6	67.9	66.8	-1.1	66.1	-0.7
BLDR-T08	71.4	68.3	66.2	-2.2	65.4	-0.8
BLDR-T09	70.4	68.5	65.9	-2.6	65.4	-0.5
BLDR-T10	67.4	68.2	65.9	-2.3	66.2	0.3
BLDR-T11	63.7	68.2	67.9	-0.3	66.7	-1.2
BLDR-T13	62.7	68.1	68.3	0.1	66.9	-1.4
BLDR-T14	59.8	68.0	69.9	1.8	68.0	-1.9
BLDR-T15	54.1	69.4	73.4	4.1	71.2	-2.2
BLDR-T19	36.5	72.1	73.0	0.8	71.2	-1.8
BLDR-T20	34.5	71.6	72.6	0.9	70.7	-1.9
BLDR-T22	18.8	72.6	77.5	4.9	73.9	-3.6
BLDR-T24	1.0	70.9	72.5	1.5	69.1	-3.3

Grey highlighted values indicate that the model scenario predicts a potential decrease in temperature greater than 0.5°F.

3.0 Conclusions

Major findings and restoration recommendations include:

- Temperature data collected in 2010 and the results of this QUAL2K modeling effort suggest that the Boulder River between the town of Boulder and the confluence with the Jefferson River fails to meet Montana's standard for temperature during low flow periods in the middle of summer.

- Modeling indicated that increased shading along 44.1 miles of the Boulder River would lead to a decrease in in-stream temperatures. Improved riparian shading in combination with improved irrigation water management efficiency would lead to additional decreases in water temperatures.

Limitations of this study include a lack of detailed flow measurements for tributary streams and the irrigation network, as well as the reliance on a simplified hydrologic balance based on limited data points. Thus, the results of this assessment may need to be reevaluated as additional information becomes available.

4.0 References

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Attachment A

2010 TEMPERATURE DATA SUMMARY

Boulder-Elkhorn TMDL Planning Area

Summary Data for Montana Rainbow Trout (deg F)

Site Name	Lat	Long	Start Date	Stop date	Seasonal Maximum		Seasonal Minimum		Seasonal Max ΔT		7-Day averages				Days >	Days >	Days >	Hours >	Hours >	Hours >	Warmest day of 7-day max			Agency
					Date	Value	Date	Value	Date	Value	Date	Maximum	Minimum	Δ T	66 F	75 F	78 F	66 F	75 F	78 F	Date	Maximum	Minimum	
2376167 (BLDR-T12, Elkhorn Creek)	46.1656	111.9907	06/29/10	07/13/10	07/09/10	81.1	07/07/10	47.2	07/08/10	30.6	07/10/10	77.3	50.7	26.6	13	6	2	71.0	16.0	5.5	07/09/10	81.1	51.0	DEQ
2376168 (BLDR-T22, Boulder River)	45.9487	111.9036	06/30/10	09/28/10	07/25/10	76.2	09/23/10	48.9	08/25/10	13.7	08/02/10	75.1	64.3	10.8	50	5	0	591.5	11.0	0.0	07/30/10	75.9	65.1	DEQ
2376170 (BLDR-T06, Little Boulder River)	46.1976	112.0869	06/29/10	09/26/10	07/25/10	67.6	09/07/10	43.3	07/25/10	13.1	08/02/10	65.0	55.4	9.6	3	0	0	6.5	0.0	0.0	07/30/10	66.3	54.9	DEQ
2376171 (BLDR-T08, Boulder River)	46.1908	112.0703	06/29/10	09/27/10	07/25/10	71.5	09/11/10	43.9	08/25/10	15.5	07/22/10	68.6	55.3	13.3	29	0	0	139.5	0.0	0.0	07/25/10	71.5	56.2	DEQ
2376172 (BLDR-T10, Boulder River)	46.1785	112.0328	06/29/10	09/27/10	07/25/10	71.3	09/11/10	44.4	07/24/10	14.9	08/04/10	68.9	56.8	12.1	31	0	0	179.0	0.0	0.0	08/05/10	70.6	56.3	DEQ
2376176 (BLDR-T19, Boulder River)	46.0333	111.8708	06/30/10	09/28/10	07/25/10	76.4	09/23/10	48.3	08/24/10	16.0	07/31/10	72.7	60.1	12.6	48	1	0	408.0	3.5	0.0	07/28/10	73.9	58.8	DEQ
2376177 (BLDR-F02, Boulder Ditch)	46.1761	112.0298	06/29/10	09/19/10	07/25/10	71.3	09/11/10	44.4	07/24/10	14.9	08/04/10	68.8	56.9	11.9	31	0	0	175.5	0.0	0.0	08/05/10	70.5	56.3	DEQ
2376178 (BLDR-T15, Boulder River)	46.1289	111.9392	06/30/10	09/28/10	07/25/10	73.2	09/11/10	46.3	08/25/10	13.3	07/31/10	70.6	60.1	10.6	40	0	0	296.0	0.0	0.0	07/30/10	72.4	60.4	DEQ
2376181 (BLDR-T17, Boulder Ditch)	46.0617	111.8808	06/29/10	09/28/10	08/08/10	72.3	09/11/10	23.3	08/21/10	33.4	08/24/10	67.9	47.8	20.1	10	0	0	51.5	0.0	0.0	08/25/10	69.8	36.8	DEQ
2376182 (BLDR-T13, Boulder River)	46.1566	111.9961	06/29/10	09/27/10	07/25/10	71.4	09/11/10	45.2	07/24/10	13.7	07/22/10	68.6	56.7	11.9	33	0	0	192.0	0.0	0.0	07/25/10	71.4	57.9	DEQ
2376183 (BLDR-T02, Boulder River)	46.2255	112.1108	06/29/10	09/26/10	08/05/10	71.1	09/11/10	43.4	08/25/10	14.6	08/02/10	68.2	57.6	10.6	29	0	0	132.0	0.0	0.0	08/05/10	71.1	57.3	DEQ
2449494 (BLDR-T04, Boulder River)	46.213	112.087	06/29/10	09/29/10	07/25/10	71.1	09/11/10	43.8	08/25/10	15.6	07/22/10	68.5	55.6	13.0	29	0	0	128.0	0.0	0.0	07/25/10	71.1	56.5	DEQ
2449496 (BLDR-T11, Boulder River)	46.1606	112.0059	06/30/10	09/29/10	07/25/10	71.4	09/24/10	45.8	07/24/10	14.5	07/31/10	68.7	57.5	11.2	33	0	0	190.5	0.0	0.0	07/29/10	70.5	58.0	DEQ
2449499 (BLDR-T20, Boulder River)	46.016	111.8744	06/30/10	09/28/10	07/25/10	75.9	09/23/10	48.5	07/28/10	15.4	07/31/10	74.1	60.4	13.7	47	2	0	386.0	4.5	0.0	07/29/10	75.1	60.4	DEQ
2449500 (BLDR-F01, Boulder Ditch)	46.1846	112.0568	06/30/10	09/27/10	07/25/10	71.6	09/07/10	44.2	07/24/10	15.4	08/04/10	68.8	56.6	12.3	31	0	0	162.0	0.0	0.0	08/05/10	70.5	56.0	DEQ
2449501 (BLDR-T14, Boulder River)	46.1418	111.9838	06/30/10	09/27/10	07/25/10	71.4	09/11/10	45.5	07/14/10	13.3	07/22/10	68.9	57.2	11.7	31	0	0	186.5	0.0	0.0	07/25/10	71.4	58.5	DEQ
2449503 (BLDR-T09, Boulder River)	46.1862	112.0585	06/29/10	09/27/10	07/25/10	71.6	09/11/10	44.2	08/25/10	15.6	08/04/10	69.0	56.6	12.5	30	0	0	160.5	0.0	0.0	08/05/10	70.9	56.0	DEQ
2449504 (BLDR-T21, Boulder River)	45.9752	111.8887	06/30/10	09/28/10	08/06/10	73.0	09/25/10	48.5	08/05/10	13.3	08/18/10	70.1	59.9	10.2	26	0	0	193.5	0.0	0.0	08/17/10	71.4	61.2	DEQ
2449505 (BLDR-T24, Boulder River)	45.8693	111.9417	06/30/10	09/28/10	07/25/10	74.3	09/23/10	49.3	07/24/10	12.7	07/31/10	72.4	62.2	10.3	46	0	0	479.5	0.0	0.0	07/29/10	73.7	62.3	DEQ
9760509 (BLDR-T05, Boulder River)	46.2099	112.0915	06/29/10	09/26/10	07/25/10	71.1	09/11/10	43.8	08/25/10	15.6	07/22/10	68.5	55.4	13.1	29	0	0	126.5	0.0	0.0	07/25/10	71.1	56.3	DEQ
9760520 (BLDR-T17a, Boulder River)	46.06121	111.882	08/13/10	09/28/10	08/17/10	71.5	09/23/10	48.0	08/16/10	13.8	08/18/10	69.6	57.3	12.3	11	0	0	65.0	0.0	0.0	08/17/10	71.5	58.1	DEQ
9760522 (BLDR-T23, Boulder River)	45.9155	111.9278	08/07/10	09/28/10	08/18/10	71.1	09/23/10	49.2	08/24/10	13.5	08/18/10	69.2	58.3	10.8	16	0	0	106.0	0.0	0.0	08/18/10	71.1	59.9	DEQ
9774611 (BLDR-T04a, Muskrat Creek)	46.2222	112.0904	08/13/10	09/26/10	08/25/10	64.6	09/07/10	42.4	08/25/10	16.8	08/18/10	63.4	49.4	14.0	0	0	0	0.0	0.0	0.0	08/20/10	64.5	48.2	DEQ
2376173 (BLDR-T18, Boulder River) 6/29/2010-7/15/2010	46.0611	111.8786	06/29/10	07/15/10	07/15/10	78.9	07/07/10	51.5	07/15/10	24.9	07/12/10	69.3	57.1	12.2	8	1	1	46.0	3.0	1.5	07/15/10	78.9	54.0	DEQ
2376173 (BLDR-T18, Boulder River) 8/6/2010-9/28/2010	46.0611	111.8786	08/06/10	09/28/10	08/06/10	74.9	09/23/10	48.0	08/06/10	15.4	08/18/10	71.1	57.6	13.5	20	0	0	121.0	0.0	0.0	08/17/10	72.7	58.3	DEQ
2376174 (BLDR-T16, Boulder River) 7/2/2010-7/14/2010	46.0916	111.9079	07/02/10	07/14/10	07/09/10	68.6	07/07/10	51.0	07/14/10	12.9	07/11/10	66.8	56.8	10.0	6	0	0	23.0	0.0	0.0	07/09/10	68.6	56.8	DEQ
2376174 (BLDR-T16, Boulder River) 8/7/2010-9/28/2010	46.0916	111.9079	08/07/10	09/28/10	08/18/10	72.2	09/11/10	47.4	08/16/10	12.4	08/19/10	70.1	59.4	10.7	17	0	0	123.0	0.0	0.0	08/18/10	72.2	60.5	DEQ
2376175 (BLDR-T01, Boulder River) 6/29/2010-7/23/2010	46.2313	112.1331	06/29/10	07/23/10	07/20/10	71.0	07/07/10	46.6	07/20/10	18.9	07/18/10	67.9	54.3	13.6	7	0	0	15.5	0.0	0.0	07/20/10	71.0	52.1	DEQ
2376175 (BLDR-T01, Boulder River) 8/5/2010-9/27/2010	46.2313	112.1331	08/05/10	09/27/10	08/05/10	70.0	09/11/10	43.2	08/25/10	13.1	08/19/10	65.7	55.1	10.7	6	0	0	17.0	0.0	0.0	08/17/10	67.1	55.1	DEQ
2376184 (BLDR-T03, Boulder River, Duplicate) 6/29/2010-7/24/2010	46.2238	112.1029	06/29/10	07/24/10	07/24/10	69.5	07/07/10	47.1	07/24/10	13.9	07/21/10	67.7	56.1	11.6	9	0	0	39.5	0.0	0.0	07/24/10	69.5	55.6	DEQ
2376184 (BLDR-T03, Boulder River, Duplicate) 8/5/2010-9/26/2010	46.2238	112.1029	08/05/10	09/26/10	08/05/10	71.1	09/11/10	43.4	08/25/10	14.7	08/19/10	66.6	55.3	11.3	12	0	0	45.0	0.0	0.0	08/17/10	68.2	55.4	DEQ
2449498 (BLDR-T03, Boulder River) 6/29/2010-7/24/2010	46.2238	112.1029	06/29/10	07/24/10	07/24/10	69.5	07/07/10	47.2	07/24/10	14.0	07/21/10	67.8	56.1	11.8	9	0	0	41.5	0.0	0.0	07/24/10	69.5	55.6	DEQ
2449498 (BLDR-T03, Boulder River) 8/5/2010-9/26/2010	46.2238	112.1029	08/05/10	09/26/10	08/05/10	71.3	09/11/10	43.6	08/25/10	14.6	08/19/10	66.6	55.4	11.2	12	0	0	45.5	0.0	0.0	08/17/10	68.2	55.5	DEQ
2449495 (BLDR-T16, Boulder River, Duplicate) 7/2/2010-7/14/2010	46.0916	111.9079	07/02/10	07/14/10	07/09/10	68.9	07/07/10	51.2	07/14/10	13.2	07/11/10	67.2	57.1	10.2	6	0	0	29.5	0.0	0.0	07/09/10	68.9	57.0	DEQ
2449495 (BLDR-T16, Boulder River, Duplicate) 8/7/2010-9/28/2010	46.0916	111.9079	08/07/10	09/28/10	08/18/10	72.4	09/11/10	47.5	08/16/10	12.4	08/19/10	70.3	59.6	10.7	17	0	0	127.0	0.0	0.0	08/18/10	72.4	60.6	DEQ

Attachment B

SOLAR PATHFINDER HOURLY SHADE MEASUREMENTS

Boulder-Elkhorn TMDL Planning Area

	Section	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	TOTAL
Reach	Potential	3	5	8	10	12	12	12	12	10	8	5	3	
SP-2-1	Transect 1-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-2-1	Transect 1-left	2	1	0	0	0	0	0	0	0	0	0	0	
SP-2-1	Transect 1-right	0	0	0	0	0	0	0	0	0	0	0	0	
SP-2-1	Transect 1 Average	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
SP-2-2	Transect 2-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-2-2	Transect 2-left	3	0	0	0	0	0	0	0	0	0	0	0	
SP-2-2	Transect 2-right	0	0	0	0	0	0	0	0	0	0	0	0	
SP-2-2	Transect 2 Average	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
SP-2-3	Transect 3-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-2-3	Transect 3-left	2	0	0	0	0	0	0	0	0	0	0	0	
SP-2-3	Transect 3-right	0	0	0	0	0	0	0	0	0	0	0	0	
SP-2-3	Transect 3 Average	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
SP-2	**Average %**	**26%**	**2%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**2%**
SP-1-1	Transect 1-center	0	0	0	0	0	0	0	0	0	0	0	1	
SP-1-1	Transect 1-left	3	5	5	0	0	0	0	0	0	0	0	0	
SP-1-1	Transect 1-right	1	0	0	0	0	0	0	0	0	0	0	1	
SP-1-1	Transect 1 Average	1.3	1.7	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	5.3
SP-1-2	Transect 2-center	3	4	0	0	0	0	0	0	0	0	1	3	
SP-1-2	Transect 2-left	3	5	8	1	0	0	0	0	0	0	0	0	
SP-1-2	Transect 2-right	3	1	0	0	0	0	1	9	10	8	5	3	
SP-1-2	Transect 2 Average	3.0	3.3	2.7	0.3	0.0	0.0	0.3	3.0	3.3	2.7	2.0	2.0	22.7
SP-1-3	Transect 3-center	0	0	0	0	0	0	0	0	0	0	5	3	
SP-1-3	Transect 3-left	0	0	0	0	0	0	0	0	0	0	5	3	
SP-1-3	Transect 3-right	0	2	1	2	4	4	6	10	10	7	4	3	
SP-1-3	Transect 3 Average	0.0	0.7	0.3	0.7	1.3	1.3	2.0	3.3	3.3	2.3	4.7	3.0	23.0
SP-1	**Average %**	**48%**	**38%**	**19%**	**3%**	**4%**	**4%**	**6%**	**18%**	**22%**	**21%**	**44%**	**63%**	**24%**
SP-4-1	Transect 1-center	3	5	8	5	0	0	0	0	0	7	3	2	
SP-4-1	Transect 1-left	3	5	8	9	6	1	0	0	0	0	0	1	
SP-4-1	Transect 1-right	3	5	7	0	0	0	0	0	8	3	4	3	
SP-4-1	Transect 1 Average	3.0	5.0	7.7	4.7	2.0	0.3	0.0	0.0	2.7	3.3	2.3	2.0	33.0
SP-4-2	Transect 2-center	3	5	1	0	0	0	0	0	0	0	1	3	
SP-4-2	Transect 2-left	3	5	7	0	0	0	0	0	0	0	1	3	
SP-4-2	Transect 2-right	3	4	0	0	0	0	0	0	7	8	5	3	
SP-4-2	Transect 2 Average	3.0	4.7	2.7	0.0	0.0	0.0	0.0	0.0	2.3	2.7	2.3	3.0	20.7
SP-4-3	Transect 3-center	3	5	1	0	0	1	0	8	10	7	5	3	
SP-4-3	Transect 3-left	3	5	1	0	0	0	0	1	9	8	5	2	
SP-4-3	Transect 3-right	2	2	0	7	10	9	6	12	7	7	5	3	
SP-4-3	Transect 3 Average	2.7	4.0	0.7	2.3	3.3	3.3	2.0	7.0	8.7	7.3	5.0	2.7	49.0
SP-4	**Average %**	**96%**	**91%**	**46%**	**23%**	**15%**	**10%**	**6%**	**19%**	**46%**	**56%**	**64%**	**85%**	**46%**
SP-3-1	Transect 1-center	3	5	1	0	0	0	0	0	0	0	0	3	
SP-3-1	Transect 1-left	3	5	8	4	0	0	0	0	0	0	0	1	
SP-3-1	Transect 1-right	3	4	1	0	0	0	0	0	0	0	1	2	
SP-3-1	Transect 1 Average	3.0	4.7	3.3	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.0	14.7
SP-3-2	Transect 2-center	3	0	0	0	0	0	0	0	0	0	3	2	
SP-3-2	Transect 2-left	3	3	0	0	0	0	0	0	0	0	3	3	
SP-3-2	Transect 2-right	2	0	0	0	0	0	0	0	0	0	3	2	
SP-3-2	Transect 2 Average	2.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	2.3	9.0
SP-3-3	Transect 3-center	2	0	0	0	0	3	11	11	10	6	4	1	
SP-3-3	Transect 3-left	2	0	0	0	0	0	4	11	8	6	3	2	
SP-3-3	Transect 3-right	1	0	0	0	0	9	10	9	8	6	5	1	
SP-3-3	Transect 3 Average	1.7	0.0	0.0	0.0	0.0	4.0	8.3	10.3	8.7	6.0	4.0	1.3	44.3
SP-3	**Average %**	**81%**	**38%**	**14%**	**4%**	**0%**	**11%**	**23%**	**29%**	**29%**	**25%**	**49%**	**63%**	**31%**
SP-5-1	Transect 1-center	3	5	7	0	0	0	0	0	1	2	4	3	
SP-5-1	Transect 1-left	3	5	8	4	0	0	0	0	1	3	3	3	
SP-5-1	Transect 1-right	2	4	5	0	0	0	0	1	4	5	5	3	
SP-5-1	Transect 1 Average	2.7	4.7	6.7	1.3	0.0	0.0	0.0	0.3	2.0	3.3	4.0	3.0	28.0
SP-5-2	Transect 2-center	3	5	0	0	0	0	0	0	2	3	3	3	
SP-5-2	Transect 2-left	3	5	2	0	0	0	0	0	0	3	3	2	
SP-5-2	Transect 2-right	3	4	0	0	0	0	7	2	5	7	4	2	
SP-5-2	Transect 2 Average	3.0	4.7	0.7	0.0	0.0	0.0	2.3	0.7	2.3	4.3	3.3	2.3	23.7
SP-5-3	Transect 3-center	2	0	0	0	0	0	0	0	0	4	4	3	
SP-5-3	Transect 3-left	2	0	0	0	0	0	0	0	0	2	5	1	
SP-5-3	Transect 3-right	2	0	0	0	0	0	0	0	0	6	5	3	
SP-5-3	Transect 3 Average	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.7	2.3	13.0
SP-5	**Average %**	**85%**	**62%**	**31%**	**4%**	**0%**	**0%**	**6%**	**3%**	**14%**	**49%**	**80%**	**85%**	**35%**
SP-6-1	Transect 1-center	0	0	0	0	0	0	0	0	0	0	1	2	
SP-6-1	Transect 1-left	0	0	0	0	0	0	0	0	0	0	0	1	
SP-6-1	Transect 1-right	0	0	0	0	0	0	0	0	0	4	4	2	
SP-6-1	Transect 1 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.7	1.7	4.7
SP-6-2	Transect 2-center	0	0	0	0	0	0	0	0	0	3	4	1	
SP-6-2	Transect 2-left	1	0	0	0	0	0	0	0	0	2	2	2	
SP-6-2	Transect 2-right	0	0	0	0	0	0	0	0	0	7	5	1	
SP-6-2	Transect 2 Average	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	3.7	1.3	9.3
SP-6-3	Transect 3-center	2	0	1	1	0	0	0	0	0	0	0	0	
SP-6-3	Transect 3-left	3	0	0	0	0	0	0	0	0	0	0	0	
SP-6-3	Transect 3-right	2	0	3	6	0	0	0	0	0	0	0	0	
SP-6-3	Transect 3 Average	2.3	0.0	1.3	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
SP-6	**Average %**	**30%**	**0%**	**6%**	**8%**	**0%**	**0%**	**0%**	**0%**	**0%**	**22%**	**36%**	**33%**	**11%**
SP-7-1	Transect 1-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-7-1	Transect 1-left	0	0	3	8	6	2	0	0	0	0	0	0	
SP-7-1	Transect 1-right	0	0	0	0	0	0	0	0	0	0	0	0	
SP-7-1	Transect 1 Average	0.0	0.0	1.0	2.7	2.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	6.3
SP-7-2	Transect 2-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-7-2	Transect 2-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-7-2	Transect 2-right	0	0	0	0	0	0	0	0	0	0	0	0	
SP-7-2	Transect 2 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SP-7-3	Transect 3-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-7-3	Transect 3-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-7-3	Transect 3-right	0	0	0	0	0	0	0	0	0	0	1	3	
SP-7-3	Transect 3 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	1.3
SP-7	**Average %**	**0%**	**0%**	**4%**	**9%**	**6%**	**2%**	**0%**	**0%**	**0%**	**0%**	**2%**	**11%**	**3%**

	Section	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	TOTAL
Reach	**Potential**	**3**	**5**	**8**	**10**	**12**	**12**	**12**	**12**	**10**	**8**	**5**	**3**	
SP-8-1	Transect 1-center	1	0	0	0	0	0	0	0	0	0	0	2	
SP-8-1	Transect 1-left	2	0	0	0	0	0	0	0	0	0	0	0	
SP-8-1	Transect 1-right	1	0	0	0	0	0	0	0	0	0	0	2	
SP-8-1	Transect 1 Average	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.7
SP-8-2	Transect 2-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-8-2	Transect 2-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-8-2	Transect 2-right	0	0	0	0	0	0	0	0	0	0	0	0	
SP-8-2	Transect 2 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SP-8-3	Transect 3-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-8-3	Transect 3-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-8-3	Transect 3-right	0	0	0	0	0	0	0	0	0	0	0	1	
SP-8-3	Transect 3 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
SP-8	**Average %**	**15%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**19%**	**3%**
SP-X-1	Transect 1-center	3	2	8	5	0	0	0	0	0	0	4	3	
SP-X-1	Transect 1-left	3	2	3	10	5	0	0	0	0	0	4	3	
SP-X-1	Transect 1-right	3	3	6	0	0	0	0	0	0	1	5	3	
SP-X-1	Transect 1 Average	3.0	2.3	5.7	5.0	1.7	0.0	0.0	0.0	0.0	0.3	4.3	3.0	25.3
SP-X-2	Transect 2-center	3	5	8	7	0	0	0	0	0	0	0	3	
SP-X-2	Transect 2-left	3	5	6	9	8	0	0	0	0	0	0	3	
SP-X-2	Transect 2-right	3	4	8	2	0	0	0	0	0	0	0	1	
SP-X-2	Transect 2 Average	3.0	4.7	7.3	6.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	2.3	26.0
SP-X-3	Transect 3-center	0	0	0	0	0	0	0	0	0	0	2	3	
SP-X-3	Transect 3-left	1	0	0	0	0	0	0	0	0	0	0	2	
SP-X-3	Transect 3-right	0	0	0	0	0	0	0	0	0	6	5	3	
SP-X-3	Transect 3 Average	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.3	2.7	7.3
SP-X	**Average %**	**70%**	**47%**	**54%**	**37%**	**12%**	**0%**	**0%**	**0%**	**0%**	**10%**	**44%**	**89%**	**30%**
SP-9-1	Transect 1-center	3	5	2	0	0	0	0	0	0	2	5	3	
SP-9-1	Transect 1-left	3	5	6	0	0	0	0	0	0	0	2	3	
SP-9-1	Transect 1-right	3	4	0	0	0	0	0	0	0	7	5	3	
SP-9-1	Transect 1 Average	3.0	4.7	2.7	0.0	0.0	0.0	0.0	0.0	0.0	3.0	4.0	3.0	20.3
SP-9-2	Transect 2-center	3	1	0	0	0	0	0	0	0	0	0	1	
SP-9-2	Transect 2-left	3	1	1	1	0	0	0	0	0	0	0	0	
SP-9-2	Transect 2-right	3	1	0	0	0	0	0	0	0	0	1	3	
SP-9-2	Transect 2 Average	3.0	1.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.3	6.3
SP-9-3	Transect 3-center	0	0	0	0	0	0	0	0	0	0	0	2	
SP-9-3	Transect 3-left	3	1	0	0	0	0	0	0	0	0	0	1	
SP-9-3	Transect 3-right	3	0	0	0	0	0	0	0	0	0	4	1	
SP-9-3	Transect 3 Average	2.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.3	5.0
SP-9	**Average %**	**89%**	**40%**	**13%**	**1%**	**0%**	**0%**	**0%**	**0%**	**0%**	**13%**	**38%**	**63%**	**21%**
SP-10-1	Transect 1-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-10-1	Transect 1-left	1	0	0	0	0	0	0	0	0	0	0	0	
SP-10-1	Transect 1-right	0	0	0	0	0	0	0	0	0	0	0	0	
SP-10-1	Transect 1 Average	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
SP-10-2	Transect 2-center	0	0	0	0	0	0	0	0	0	0	0	3	
SP-10-2	Transect 2-left	0	0	0	0	0	0	0	0	0	0	0	1	
SP-10-2	Transect 2-right	0	0	0	0	0	0	0	0	0	0	5	3	
SP-10-2	Transect 2 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	2.3	4.0
SP-10-3	Transect 3-center	0	0	0	0	0	0	0	0	0	0	0	2	
SP-10-3	Transect 3-left	0	0	0	0	0	0	0	0	0	0	0	1	
SP-10-3	Transect 3-right	0	0	0	0	0	0	0	0	0	0	5	3	
SP-10-3	Transect 3 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	2.0	3.7
SP-10	**Average %**	**4%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**22%**	**48%**	**6%**
SP-11-1	Transect 1-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-11-1	Transect 1-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-11-1	Transect 1-right	0	0	0	0	0	0	0	0	0	0	0	0	
SP-11-1	Transect 1 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SP-11-2	Transect 2-center	0	0	0	0	0	0	0	0	0	0	0	1	
SP-11-2	Transect 2-left	1	0	0	0	0	0	0	0	0	0	0	1	
SP-11-2	Transect 2-right	0	0	0	0	0	0	0	0	0	0	0	2	
SP-11-2	Transect 2 Average	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.7
SP-11-3	Transect 3-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-11-3	Transect 3-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-11-3	Transect 3-right	0	0	0	0	0	0	0	0	0	0	0	1	
SP-11-3	Transect 3 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
SP-11	**Average %**	**4%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**19%**	**2%**
SP-12-1	Transect 1-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-12-1	Transect 1-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-12-1	Transect 1-right	0	0	0	0	0	0	0	0	0	0	0	0	
SP-12-1	Transect 1 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SP-12-2	Transect 2-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-12-2	Transect 2-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-12-2	Transect 2-right	0	0	0	0	0	0	0	0	0	0	0	0	
SP-12-2	Transect 2 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SP-12-3	Transect 3-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-12-3	Transect 3-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-12-3	Transect 3-right	0	0	0	0	0	0	0	0	0	0	0	3	
SP-12-3	Transect 3 Average	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
SP-12	**Average %**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**11%**	**1%**
SP-13-1	Transect 1-center	0	0	0	0	0	0	0	0	0	0	0	0	
SP-13-1	Transect 1-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-13-1	Transect 1-right	0	0	1	0	0	0	0	0	0	0	0	0	
SP-13-1	Transect 1 Average	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
SP-13-2	Transect 2-center	0	0	0	0	0	2	6	0	0	0	0	0	
SP-13-2	Transect 2-left	0	0	0	0	0	0	0	0	0	0	0	0	
SP-13-2	Transect 2-right	0	0	0	7	12	0	8	0	0	0	0	0	
SP-13-2	Transect 2 Average	0.0	0.0	0.0	2.3	4.0	0.7	4.7	0.0	0.0	0.0	0.0	0.0	11.7
SP-13-3	Transect 3-center	1	0	0	0	0	0	0	0	0	2	2	0	
SP-13-3	Transect 3-left	3	5	8	6	0	0	0	0	0	0	0	0	
SP-13-3	Transect 3-right	1	0	0	0	0	0	0	0	2	8	2	0	
SP-13-3	Transect 3 Average	1.7	1.7	2.7	2.0	0.0	0.0	0.0	0.0	0.7	3.3	1.3	0.0	13.3
SP-13	**Average %**	**19%**	**11%**	**13%**	**14%**	**11%**	**2%**	**13%**	**0%**	**2%**	**14%**	**9%**	**0%**	**9%**

Attachment C

SOLAR PATHFINDER SUPPLEMENTAL FIELD DATA

Boulder-Elkhorn TMDL Planning Area

Solar Pathfinder Site	Reach	GIS Riparian Vegetation Reach Type	Site Description	Average Daily Shade (%)	GIS Reach Scale Aspect	Azimuth			Bankfull Width (Feet)			Average Bankfull Width (Feet)	Wetted Width (Feet)			Average Wetted Width (Feet)	Potential Riparian Conditions
						1	2	3	1	2	3		1	2	3		
SP-1	BLDR-01	low	Young cottonwoods and willows along channel margin, with urban/industrial clearing on floodplain along both sides of channel. Gravel berms limit lateral channel migration.	24	-45	-45	-45	90	93	102	115	103	40	62	41	48	cottonwoods
SP-2	BLDR-04	low	Sparse willows with grassy streambanks. Riparian clearing along river right for agriculture.	2	45	0	0	0	66	66	75	69	47	51	53	50	cottonwoods
SP-3	BLDR-07	moderate	Willows and cottonwoods. Mature cottonwood stands lack understory shrubs. Cottonwood regeneration occurring on point bars.	31	0	0	0	-45	82	78	80	80	44	39	37	40	cottonwoods
SP-4	BLDR-08	high	Mature cottonwoods and aspen with shrubs in understory. Site at potential conditions.	46	0	0	0	-45	81	72	75	76	45	54	40	46	cottonwoods
SP-5	BLDR-10	high	Mature cottonwoods. Site approaching potential conditions.	35	0	0	0		80	88	115	94	52	45	39	45	cottonwoods
SP-X	BLDR-16	moderate	Mature cottonwoods with herbacous understory and sparse willows.	30	0	0	0	-45	90	80	78	83	56	49	29	45	cottonwoods
SP-6	BLDR-17	low	Sparse willows with grassy streambanks, some decadent cottonwoods.	11	0	0	-45	90	95	108	82	95	40	50	39	43	cottonwoods
SP-7	BLDR-19	low	Sparse willows with grassy streambanks. Riparian clearing along river right for agriculture.	3	90	90	90	45	70	64	85	73	65	55	66	62	cottonwoods
SP-8	BLDR-20	low	Grassy streambanks with a few young willows.	3	-45	90	90	90	55	43	69	56	51	38	51	47	cottonwoods
SP-9	BLDR-22	low	Mature cottonwoods and willows.	21	0	0	0	0	62	64	81	69	57	40	48	48	cottonwoods
SP-10	BLDR-24	low	Willows, wetland vegetation and grass.	6	0	0	0	0	97	66	84	82	47	53	57	52	cottonwoods
SP-11	BLDR-26	low	Willows lining both banks with sparse cottonwoods on the floodplain.	2	45	0	45	0	58	56	55	56	54	38	37	43	cottonwoods
SP-12	BLDR-30	moderate	Willows lining both banks. Channel somewhat incised at site limiting floodplain access.	1	90	45	45	45	52	56	56	55	45	52	52	50	cottonwoods
SP-13	BLDR-31	high	Cottonwoods, junipers, and willows. Powerlines along river left bank.	9	90	90	90	90	53	66	51	57	44	62	45	50	cottonwoods

Attachment D

QUAL2K MODEL CALIBRATION INPUTS

Boulder-Elkhorn TMDL Planning Area

1. **QUAL2K**
    a. Model timeframe covers 3 days: July 24, 25, 26

2. **Headwater**
    a. Flow rate taken from BLDR-T01
    b. Temperature data taken from BLDR-T02
    c. Elevation based on the top of the impaired segment just upstream of Boulder
    d. Rating curve coefficients calculated using mean velocity and mean depth from August streamflow measurements at 21 sites and exponents based on typical values as presented in the QUAL2K guidance manual

3. **Downstream**
    a. No prescribed downstream boundary

4. **Reach**
    a. 33 reaches based on vegetation and aspect derived from GIS analysis of aerial imagery from 2009
    b. Reach stationing developed from the 1:24,000 NHD layer, with station 81.632km at the upper end of the study area and station 0.000km at the mouth
    c. Rating curve coefficients calculated using mean velocity and mean depth from August streamflow measurements at 21 sites and exponents based on typical values as presented in the QUAL2K guidance manual

5. **Reach Rates**
    a. N/A

6. **Air Temperature**
    a. Western Regional Climate Center, Whitehall, MT, averaged over 3 days (July 24-26)

7. **Due Point Temperature**
    a. Averaged over 3 days (July 24-26)
    b. Increased relative humidity data by 15% based on Big Hole assessment

8. **Wind Speed**
    a. Averaged over 3 days (July 24-26)

9. **Cloud Cover**
    a. Assumed to be 0%

10. **Shade**
    a. Solar pathfinder measurements were assigned to the reach in which they were located
    b. Riparian vegetation reach type average solar pathfinder values were assigned to reaches in which no measurement was performed
    c. Riparian vegetation reach types assessed in GIS using 2009 NAIP color aerial imagery (dense, moderate, and low riparian categories)
    d. Riparian vegetation reach type averages derived from field data based on the following criteria: dense (>30%), moderate (10-30%), and low (<10%)
    e. For shade scenario 1, all reaches assigned the average value for dense riparian vegetation (also applied in the natural conditions scenario)
    f. For shade scenario 2, low riparian reaches were assigned the average value for moderate riparian vegetation, while moderate riparian and dense riparian reaches were assigned the average value for dense riparian vegetation (also applied in the naturally occurring scenario)

11. **Rates**
    a. No adjustment to standard model assumptions

12. **Light and Heat**
    a. Utilized sediment thermal thickness of 10 cm and sediment thermal diffusivity of 0.005 cm^2/s

13. Diffuse Sources

a. Hydrologic balance performed between each streamflow measurement site
b. Irrigation loss assumed in five reaches, though actual diversions not observed in aerial imagery
c. Gains in streamflow documented in 10 reaches, with six assumed to be due to groundwater upwelling and spring flows, while the remaining four reaches were assumed to be surface water inputs
d. Groundwater inputs modeled at 11°C
e. Surface water inputs modeled at 15.19°C based on the temperature measured at BLDR-T06 (Little Boulder River)
f. Based on communication with MFWP Fisheries Biologist Ron Spoon (2/14/11), inflows in reaches BLDR27 through BLDR29 were primarily attributed to contributions from "Cold Springs" within reach BLDR27 and were modeled at 11°C
g. For the water consumptive use scenario and the natural condition scenario, diffuse abstractions were assumed to be zero
h. For the naturally occurring scenario, diffuse abstractions were reduced by 15%

14. Point Sources

a. 13 identified tributaries based on 1:100,000 NHD layer
b. two tributary streamflow measurements (Muskrat Creek/BLDR-T04a, Little Boulder River/BLDR-T06)
c. Elkhorn Creek (BLDR-T12) dry during August monitoring
d. all other tributaries assumed to be dry or intercepted by ditches
e. Temperature data from BLDR-T06 on the Little Boulder River applied to Muskrat Creek since the Muskrat Creek data logger lacked data from the July 24-26 timeframe
f. WWTP discharge based on flow/temperature data for August 2010
g. Inflow from point source with data logger BLDR-T17 modeled at temperature measured at BLDR-T06 since the BLDR-T17 data logger indicated groundwater influences
h. 20 identified diversions based on review of 2009 NAIP color aerial imagery
i. Measured abstractions from two diversions (BLDR-F01, BLDR-F02)
j. Hydrologic balance performed between each streamflow measurement site
k. If a loss in streamflow was identified in the hydrologic balance, then it was assumed that all of the lost flow was diverted for irrigation
l. If multiple diversions were present between streamflow measurement sites and a loss in streamflow was identified in the hydrologic balance, then the flow was divided evenly amongst the diversions
m. Modeled abstractions from 10 diversions based the on hydrologic balance
n. Irrigation withdrawals for the remaining diversions were modeled to be zero since no loss in streamflow was identified based on the hydrologic balance
o. For the water consumptive use scenario and the natural condition scenario, abstractions were assumed to be zero
p. For the water consumptive use scenario and the natural condition scenario, the inflow at station 40.355km was assumed to be zero since this is a potential irrigation return flow (BLDR-T17)
q. For the natural condition scenario, the WWTP input was removed
r. For the naturally occurring scenario, point source abstractions were reduced by 15%

15. Hydraulics Data

a. 21 streamflow measurements recorded between August 4-6
b. discarded flow measurement from BLDR-T17a since recorded on August 12

16. Temperature Data

a. 15 temperature measurements, averaged over 3 days (July 24-26)
b. Model not calibrated to BLDR-T21, appears site measures groundwater upwelling
c. BLDR-T21 was not included when evaluating model scenarios

Attachment E

RIPARIAN VEGETATION REACH TYPES

Boulder-Elkhorn TMDL Planning Area

Reach	Length (Kilometers)	Length (Miles)	Existing Shade	Shade Scenario 1	Shade Scenario 2
BLDR-01	2.2	1.4	low	dense	moderate
BLDR-02	1.8	1.1	low	dense	moderate
BLDR-03	0.8	0.5	low	dense	moderate
BLDR-04	0.9	0.6	low	dense	moderate
BLDR-05	1.3	0.8	low	dense	moderate
BLDR-06	1.0	0.6	low	dense	moderate
BLDR-07	2.6	1.6	moderate	dense	dense
BLDR-08	3.5	2.2	dense	dense	dense
BLDR-09	0.6	0.4	dense	dense	dense
BLDR-10	3.7	2.3	moderate	dense	dense
BLDR-11	0.5	0.3	moderate	dense	dense
BLDR-12	1.6	1.0	moderate	dense	dense
BLDR-13	1.5	1.0	moderate	dense	dense
BLDR-14	3.8	2.4	low	dense	moderate
BLDR-15	1.2	0.7	dense	dense	dense
BLDR-16	2.9	1.8	moderate	dense	dense
BLDR-17	2.6	1.6	low	dense	moderate
BLDR-18	2.1	1.3	low	dense	moderate
BLDR-19	4.9	3.0	low	dense	moderate
BLDR-20	1.8	1.1	low	dense	moderate
BLDR-21	2.8	1.7	low	dense	moderate
BLDR-22	1.9	1.2	low	dense	moderate
BLDR-23	6.2	3.8	low	dense	moderate
BLDR-24	4.8	3.0	low	dense	moderate
BLDR-25	1.8	1.1	low	dense	moderate
BLDR-26	4.7	2.9	low	dense	moderate
BLDR-27	1.2	0.7	low	dense	moderate
BLDR-28	4.7	2.9	low	dense	moderate
BLDR-29	2.5	1.6	low	dense	moderate
BLDR-30	1.2	0.7	moderate	dense	dense
BLDR-31	5.2	3.3	dense	dense	dense
BLDR-32	2.7	1.6	low	dense	moderate
BLDR-33	0.5	0.3	moderate	dense	dense

Attachment F

HYDROLOGIC BALANCE

Boulder-Elkhorn TMDL Planning Area

Reach	Temperature Data Logger Site	Measurement Date	Measured Discharge (cfs)	Modeled Discharge (cms)	Modeled Discharge (cfs)	Notes
1	BLDR-T01	8/4/2010	79.2	2.242	79.2	BLDR-T01
				0.491	17.3	Diversion 1 - irrigation loss (both sides of channel)
				1.751	61.8	flow at outlet of 1
2	BLDR-T02	8/4/2010	61.8	1.751	61.8	BLDR-T02
				0.004	0.1	WWTP discharge - gain
				0.105	3.7	gain
						Diversion 2 - irrigation loss
	BLDR-T03	8/4/2010	65.7	1.860	65.7	BLDR-T03
				1.860	65.7	flow at outlet of 2
				0.405	14.3	trib 1 - Muskrat Creek (BLDR-T04a on 8/12/10)
3				2.265	80.0	flow at outlet of 3
				0.156	5.5	gain
4	BLDR-T04	8/4/2010	85.5	2.421	85.5	BLDR-T04
				2.421	85.5	flow at outlet of 4
				0.238	8.4	gain
5	BLDR-T05	8/4/2010	93.9	2.659	93.9	BLDR-T05
				2.659	93.9	flow at outlet of 5
6				2.659	93.9	flow at outlet of 6
				0.742	26.2	trib 2 - Little Boulder River (BLDR-T06)
				0.347	12.3	loss
7	BLDR-T07	8/5/2010	107.8	3.053	107.8	BLDR-T07
						trib 3 - Farnham Creek
				0.097	3.4	loss
	BLDR-T08	8/5/2010	104.4	2.957	104.4	BLDR-T08
				2.957	104.4	flow at outlet of 7
						Diversion 3 - irrigation loss
				0.327	11.5	gain
8	BLDR-T09	8/5/2010	116.0	3.284	116.0	BLDR-T09
				0.357	12.6	Diversion 4 - irrigation loss (BLDR-F01)
				2.927	103.4	flow at outlet of 8
				0.048	1.7	gain
9	BLDR-T10	8/5/2010	105.1	2.975	105.1	BLDR-T10
				0.100	3.5	Diversion 5 (BLDR-F02)
				2.875	101.5	flow at outlet of 9
						Diversion 6 - irrigation loss
						Diversion 7 - irrigation loss
				0.613	21.6	gain
10	BLDR-T11	8/6/2010	123.2	3.488	123.2	BLDR-T11
				3.488	123.2	flow at outlet of 10
				0.000	0.0	trib 4 - Elkhorn Creek (BLDR-T12)
				0.213	7.5	loss
11	BLDR-T13	8/6/2010	115.6	3.274	115.6	BLDR-T13
				3.274	115.6	flow at outlet of 11
12				3.274	115.6	flow at outlet of 12
				0.224	7.9	loss
13	BLDR-T14	8/6/2010	107.7	3.050	107.7	BLDR-T14
				1.387	49.0	Diversion 8 - irrigation loss
				1.663	58.7	flow at outlet of 13
						trib 5 - Jack Creek
14				1.663	58.7	flow at outlet of 14
15				1.663	58.7	flow at outlet of 15
16	BLDR-T15	8/5/2010	58.7	1.663	58.7	BLDR-T15
				0.081	2.9	Diversion 9 - irrigation loss
						trib 6 - Dry Creek
						trib 7 - Quinn Creek
				1.582	55.9	flow at outlet of 16
				0.081	2.9	Diversion 10 - irrigation loss
17				1.501	53.0	flow at outlet of 17
				0.081	2.9	Diversion 11 - irrigation loss
18				1.419	50.1	flow at outlet of 18
19	BLDR-T16	8/6/2010	50.1	1.419	50.1	BLDR-T16
				0.460	16.2	Diversion 12 - irrigation loss
						trib 8 - Brady Creek
				0.960	33.9	flow at outlet of 19
				0.460	16.2	Diversion 13 - irrigation loss
				0.500	17.6	flow downstream of Diversion 13
	BLDR-T17a	8/12/2010	66.4	1.880	66.4	BLDR-T17a
				0.164	5.8	gain (BLDR-T17)
20	BLDR-T18	8/5/2010	23.4	0.664	23.4	BLDR-T18
				0.664	23.4	flow at outlet of 20
						Diversion 14 - irrigation loss
						trib 9 - Dunn Creek
21				0.664	23.4	flow at outlet of 21
						Diversion 15 - irrigation loss
				0.494	17.4	gain
22	BLDR-T19	8/5/2010	40.9	1.157	40.9	BLDR-T19
						Diversion 16 - irrigation loss
						Diversion 17 - irrigation loss
						trib 10 - Dry Cottonwood Creek
				1.157	40.9	flow at outlet of 22
				0.482	17.0	gain
23	BLDR-T20	8/6/2010	57.9	1.639	57.9	BLDR-T20
						trib 11 - McKanna Spring Creek
				1.639	57.9	flow at outlet of 23
				0.055	1.9	gain
24	BLDR-T21	8/6/2010	59.8	1.694	59.8	BLDR-T21
				1.694	59.8	flow at outlet of 24
						trib 12 - Cottonwood Creek
25				1.694	59.8	flow at outlet of 25
				0.061	2.2	loss
26	BLDR-T22	8/6/2010	57.7	1.633	57.7	BLDR-T22
				1.633	57.7	flow at outlet of 26
27				1.633	57.7	flow at outlet of 27
28				1.633	57.7	flow at outlet of 28
						trib 13 - Conrow Creek
				1.475	52.1	gain
29	BLDR-T23	8/6/2010	109.8	3.108	109.8	BLDR-T23
				3.108	109.8	flow at outlet of 29
30				3.108	109.8	flow at outlet of 30
				0.291	10.3	Diversion 18 - irrigation loss
				0.291	10.3	Diversion 19 - irrigation loss
				0.291	10.3	Diversion 20 - irrigation loss
31				2.234	78.9	flow at outlet of 31
32	BLDR-T24	8/5/2010	78.9	2.234	78.9	BLDR-T24
32				2.234	78.9	flow at outlet of 32
33				2.234	78.9	flow at outlet of 32