ATTACHMENT E – MODELING WATER TEMPERATURE IN MCGREGOR CREEK

Modeling Water Temperature in McGregor Creek

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December 3, 2013

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Acronyms and Abbreviations

AME	absolute mean error
EPA	U.S. Environmental Protection Agency
DEQ	Montana Department of Environmental Quality
MRLC	Multi-Resolution Land Characteristics Consortium
NLCD	National Land Cover Dataset
QUAL2K	River and Stream Water Quality Model
REL	relative error
TMDL	total maximum daily load
USGS	U.S. Geological Survey (U.S. Department of the Interior)
WRCC	Western Regional Climate Center

Units of Measure

°C	degrees Celsius
°F	degrees Fahrenheit
cfs	cubic feet per second
cms	cubic meters per second
g/cm^3	grams per cubic centimeter
MSL	mean sea level
RM	river mile

Executive Summary

McGregor Creek was identified by the Montana Department of Environmental Quality (DEQ) as being impaired due to elevated water temperatures. The cause of the impairment was attributed to “impacts from hydrostructure flow regulation/modification (DEQ 2012). The U.S. Environmental Protection Agency contracted with Tetra Tech to develop a QUAL2K water quality model to investigate the relationship between flow, shade, and in-stream water temperature.

Field studies were carried out in 2011 to support water quality model development for the project. A QUAL2K water quality model was then developed for McGregor Creek to evaluate management practices suitable for meeting state temperature standards. The QUAL2K model was constructed, in part, using field collected data from the summer of 2011. Shadev3.0 models were also developed to assess shade conditions using previously collected field data to calibrate the shade model. The calibrated and validated QUAL2K model met previously designated acceptance criteria. Once developed, various water temperature responses were evaluated for a range of potential watershed management activities. Four scenarios were considered:

- **Scenario 1:** Critical existing condition (i.e., the calibrated model with critical weather conditions)
- **Scenario 2:** Critical existing conditions with a 15 percent reduction of water withdrawals
- **Scenario 3:** Critical existing condition with improved riparian vegetation in a 50-foot buffer
- **Scenario 4:** An improved flow and shade scenario that combines the potential benefits associated with a 15 percent reduction in water withdrawals with a 50-foot vegetated buffer.

In comparison to scenario 1, the results ranged from almost no change in water temperature (scenario 2) to considerable reductions (scenario 3). The improved flow and shade scenario that combined the potential benefits associated with a 15 percent reduction in water withdrawals (scenario 2) with a 50-foot vegetated buffer (scenario 3) to represent application of conservation practices was also simulated. This scenario resulted in overall reductions along the entire reach which ranged from 1.6 ° F to 7.3 ° F. Generally, small changes in shade or inflow had minimal effects on water temperature while large increases in shade had a considerable effect on water temperature.

1 Introduction

Tetra Tech, Inc. is under contract with the U.S. Environmental Protection Agency (EPA) to set up, calibrate, and conduct scenario analysis with a temperature model (QUAL2K) for McGregor Creek in support of future total maximum daily load (TMDL) development by the Montana Department of Environmental Quality (DEQ). Background information is provided in the following section (**Section 2**). A summary of model set up, calibration, and validation is provided in **Section 3** and a series of model scenarios and results are presented in **Section 4**.

2 Background

This section presents background information to support QUAL2K model development.

2.1 Problem Statement

McGregor Creek (MT76N005_030) is located in northwest Montana in the Northern Rockies ecoregion and is part of the Thompson River TMDL Planning Area. The impaired segment is 6.82 miles long and extends from McGregor Lake to the Thompson River (**Figure 1**).

McGregor Creek has a B-1 use class. It is not supporting its aquatic life designated use due to a number of reasons (DEQ 2012). Four potential causes of impairment are identified in the assessment record, including temperature (DEQ 2012). The potential source of the water temperature impairment was listed as “impacts from hydrostructure flow regulation/modification” (DEQ 2012). In an assessment in 2004, DEQ found that the stream temperature just below the lake was 16.26°C and was approximately 10.5°C near the mouth. According to the assessment record, the upstream temperature is potentially harmful to westslope cutthroat trout, which are present but rare in McGregor Creek (DEQ 2012, p.17).

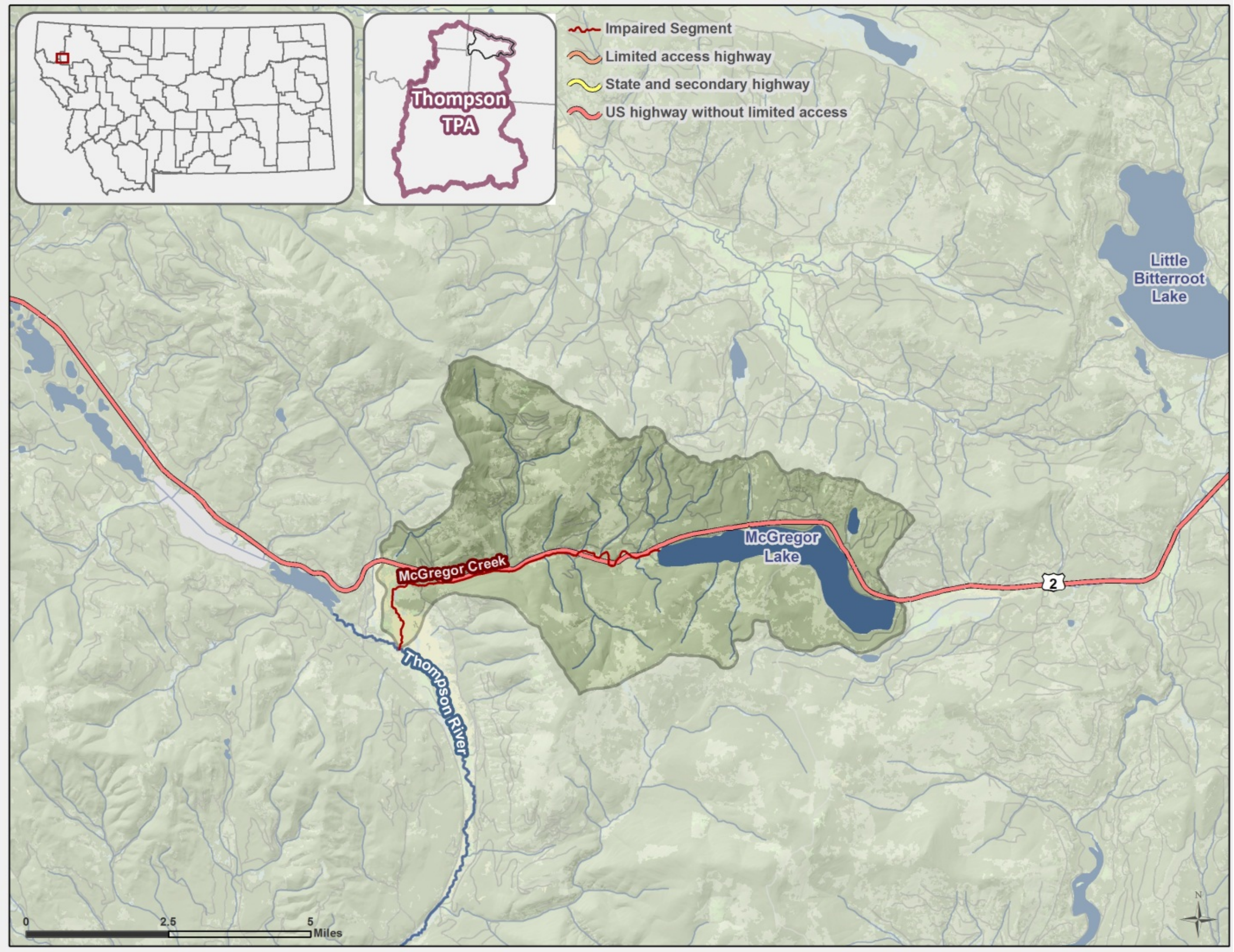

Figure 1. McGregor Creek watershed.

2.2 Montana Temperature Standard

For a waterbody with a use classification of B-1, the following temperature criteria apply:[1]

> A 1° F maximum increase above naturally occurring water temperature is allowed within the range of 32° F to 66° F; within the naturally occurring[2] range of 66° F to 66.5° F, no discharge is allowed [that] will cause the water temperature to exceed 67° F; and where the naturally occurring water temperature is 66.5° F or greater, the maximum allowable increase in water temperature is 0.5° F. A 2° F per-hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is above 55° F. A 2° F maximum decrease below naturally occurring water temperature is allowed within the range of 55° F to 32° F.

The model results will ultimately be compared to these criteria.

2.3 Project History

Tetra Tech was contracted by EPA in February 2011 to develop the QUAL2K temperature model. Temperature and flow data were collected in McGregor Creek in 2011 by Atkins (Helena, MT; under contract with Tetra Tech). A field team from Atkins collected data on July 14-15 and September 12-13, 2011 to characterize channel geometry, flow, and shade in support of the modeling effort.

2.4 Factors Potentially Influencing Stream Temperature

Stream temperature regimes are influenced by processes that are external to the stream as well as processes that occur within the stream and its associated riparian zone (Poole et al. 2001). Examples of factors external to the stream that can affect in-stream water temperatures include: topographic shade, land use/land cover (e.g., vegetation and the shading it provides, impervious surfaces), solar angle, meteorological conditions (e.g., precipitation, air temperature, cloud cover, relative humidity), groundwater exchange and temperature, and tributary inflow temperatures and volumes. The shape of the channel can also affect the temperature—wide shallow channels are more easily heated and cooled than deep, narrow channels. The amount of water in the stream is another factor influencing stream temperature regimes. Streams that carry large amounts of water resist heating and cooling, whereas temperature in small streams (or reduced flows) can be changed more easily.

McGregor Creek begins at the outlet of McGregor Lake at Palm Dam (**Figure 2**). Two water rights are associated with the dam. The senior water right is to supply water for flood irrigation approximately 6 miles downstream along McGregor Creek. Water temperatures in McGregor Lake, therefore, influence the water temperature of McGregor Creek. However, conditions resulting from the operation of dams constructed prior to 1971 are considered natural[3].

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[1] ARM 17.30.623(e).

[2] ARM 17.30.602(17): "Naturally occurring" means conditions or material present from runoff or percolation over which man has no control or from developed land where all reasonable land, soil and water conservation practices have been applied. Conditions resulting from the reasonable operation of dams in existence as of July 1, 1971, are natural.

[3] ARM 17.30.602(17): "Naturally occurring" means conditions or material present from runoff or percolation over which man has no control or from developed land where all reasonable land, soil and water conservation practices have been applied. *Conditions resulting from the reasonable operation of dams in existence as of July 1, 1971, are natural* [emphasis added].

Figure 2. The outlet of McGregor Lake at Palm Dam.

Additional factors that may have an influence on stream temperatures in McGregor Creek were evaluated prior to model development and are discussed in detail in **Appendix A**:

- Local/regional climate
- Land ownership
- Land use
- Riparian vegetation
- Shade
- Hydrology
- Point sources

2.5 Observed Stream Temperatures

EPA (and their consultants Tetra Tech and Atkins as described above) collected stream temperature data using in-stream loggers at multiple locations in the McGregor Creek watershed. The dataset is presented and discussed in the following sections.

2.5.1 Available Temperature Data

In 2011, EPA collected continuous temperature data at six locations in McGregor Creek (sites MGRC-T1, MGRC-T3, MGRC-T4, MGRC-T7, MGRC-T8, and MGRC-T9) and at two tributary locations (MGRC-T5 on an unnamed tributary and MGRC-T6 on Twin Creek) (**Figure 3)**. Data loggers recorded temperatures every one-half hour for approximately two months between July 14-15 and September 12-13. Instantaneous temperatures were also monitored by EPA and DEQ in 2004 and 2011 (refer to **Appendix A** for these data).

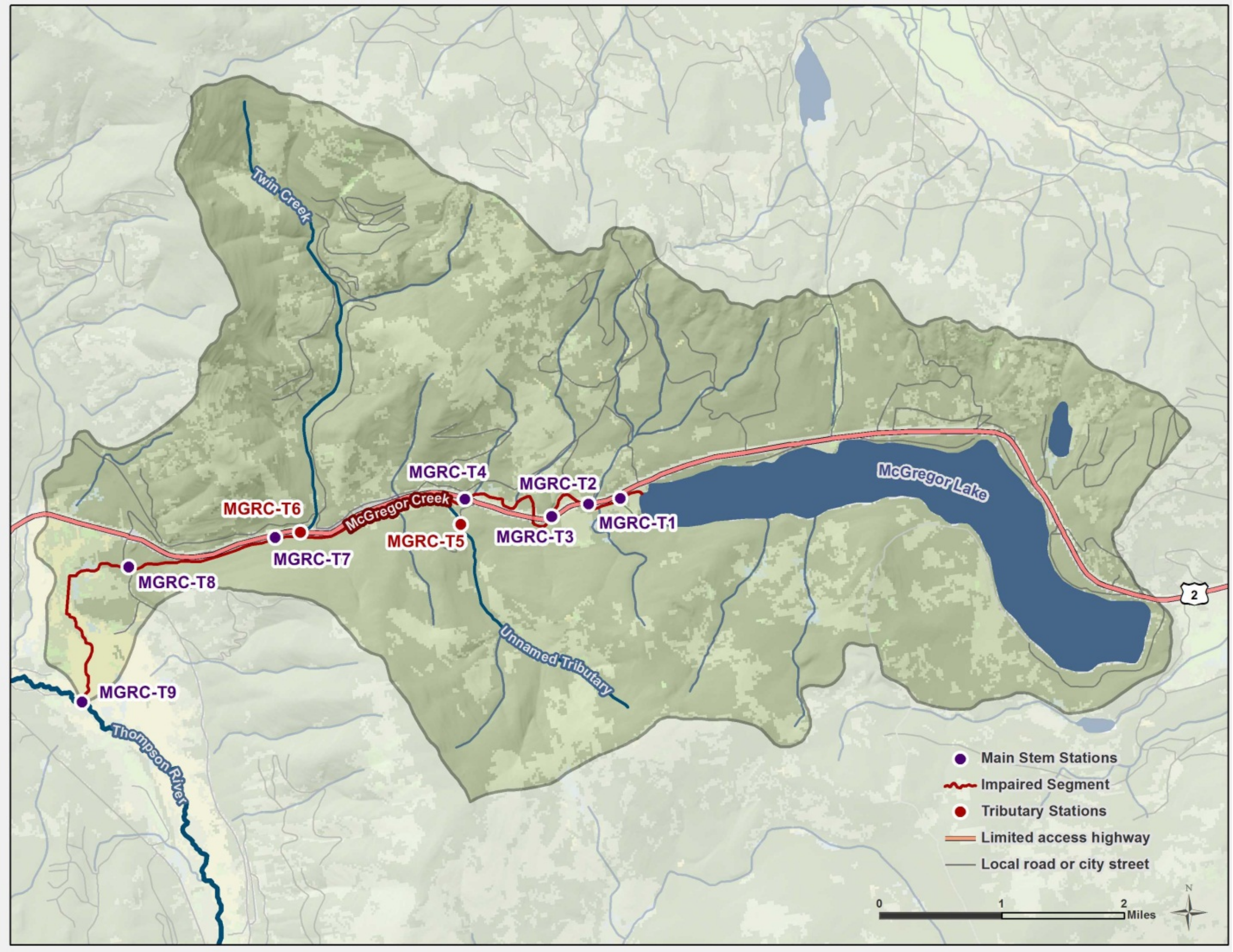

Figure 3. Temperature loggers in the McGregor Creek watershed.

2.5.2 Temperature Data Analysis

Stream temperatures in McGregor Creek generally decrease from its source at McGregor Lake downstream toward its mouth and then increase again in its lowest reaches (**Figure 4**). Twin Creek (MGRC-T6) and an unnamed tributary (MGRC-T5), tributaries to McGregor Creek, contributed considerably cooler temperatures while the highest temperatures were observed at the headwaters of McGregor Creek (MGRC-T1) just below the outlet from McGregor Lake. Another unnamed tributary to McGregor Creek (MGRC-T2) was dry each time the field team visited. Maximum temperatures (**Figure 5**) generally follow similar patterns with temperatures steadily decreasing from the warm discharges at the outlet of McGregor Lake downstream, with inputs of cooler water from an unnamed tributary (MGRC-T5) and Twin Creek (MGRC-T6), until its lowest reaches where temperatures increase again. As shown in **Figure 6**, the diurnal variation in McGregor Creek below McGregor Lake is larger than that of Twin Creek.

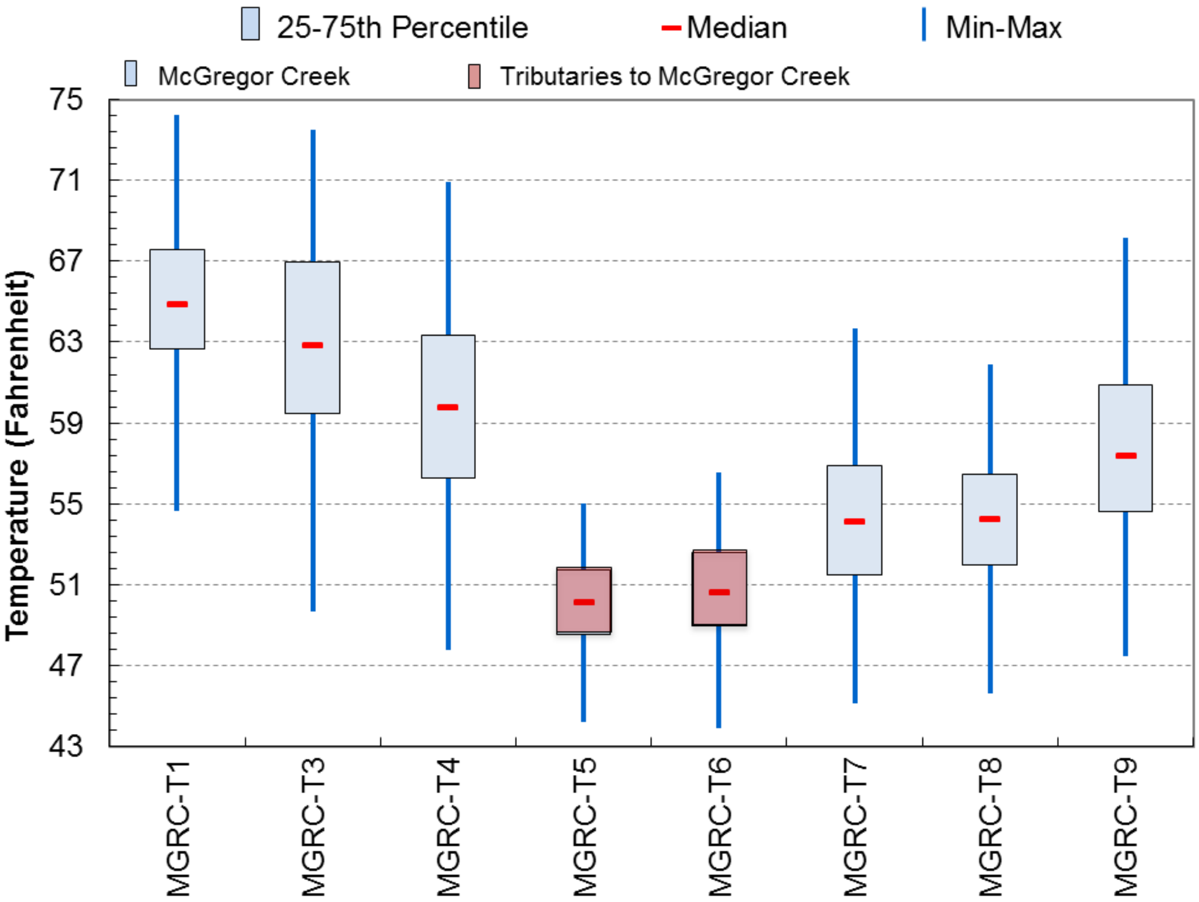

Figure 4. Box-and-whisker plots of temperature data, July 14-15, 2011 to September 12-13, 2011.

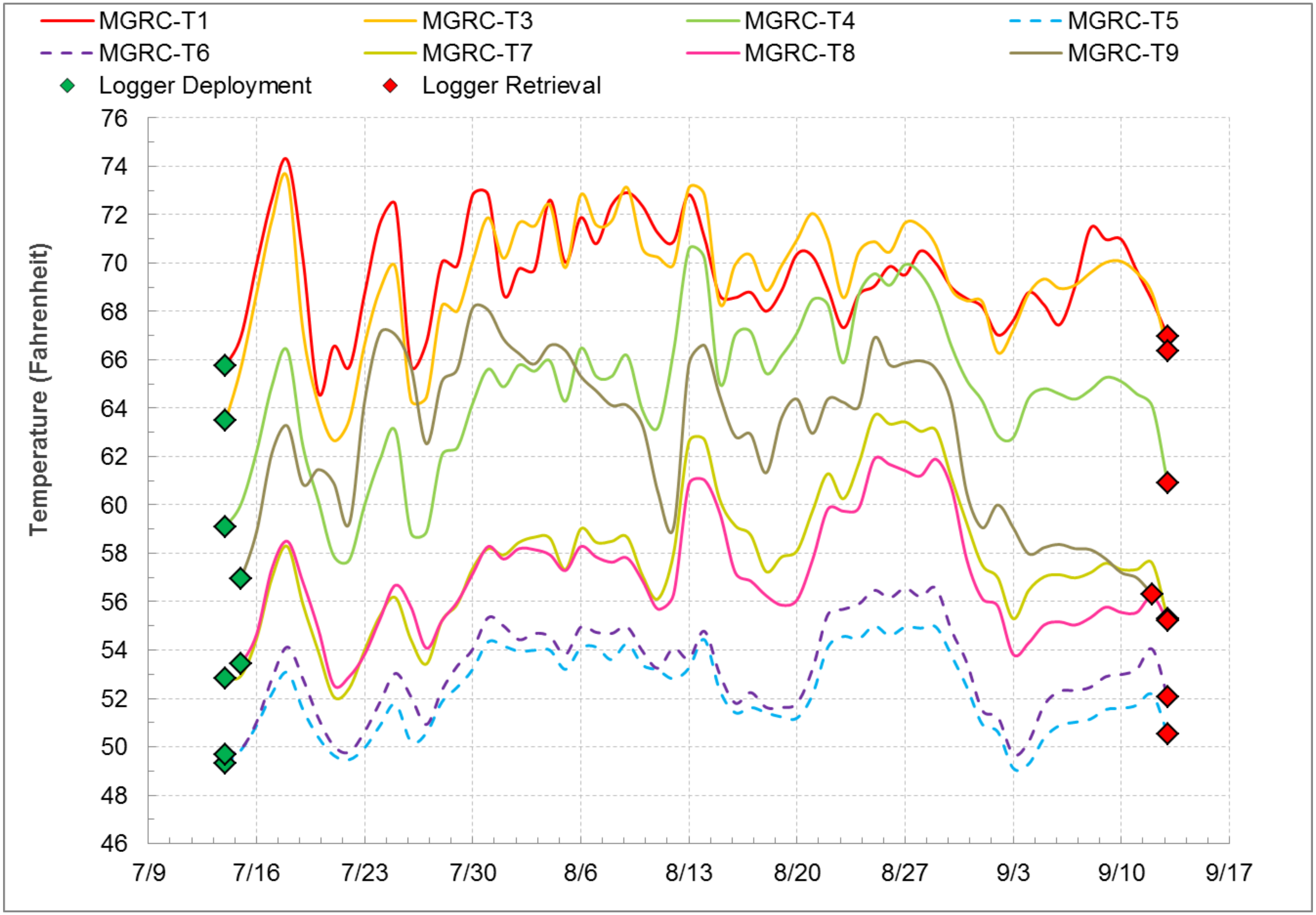

Figure 5. Daily maximum temperatures along McGregor Creek, upper half of the watershed, July 14-15, 2011 to September 12-13, 2011.

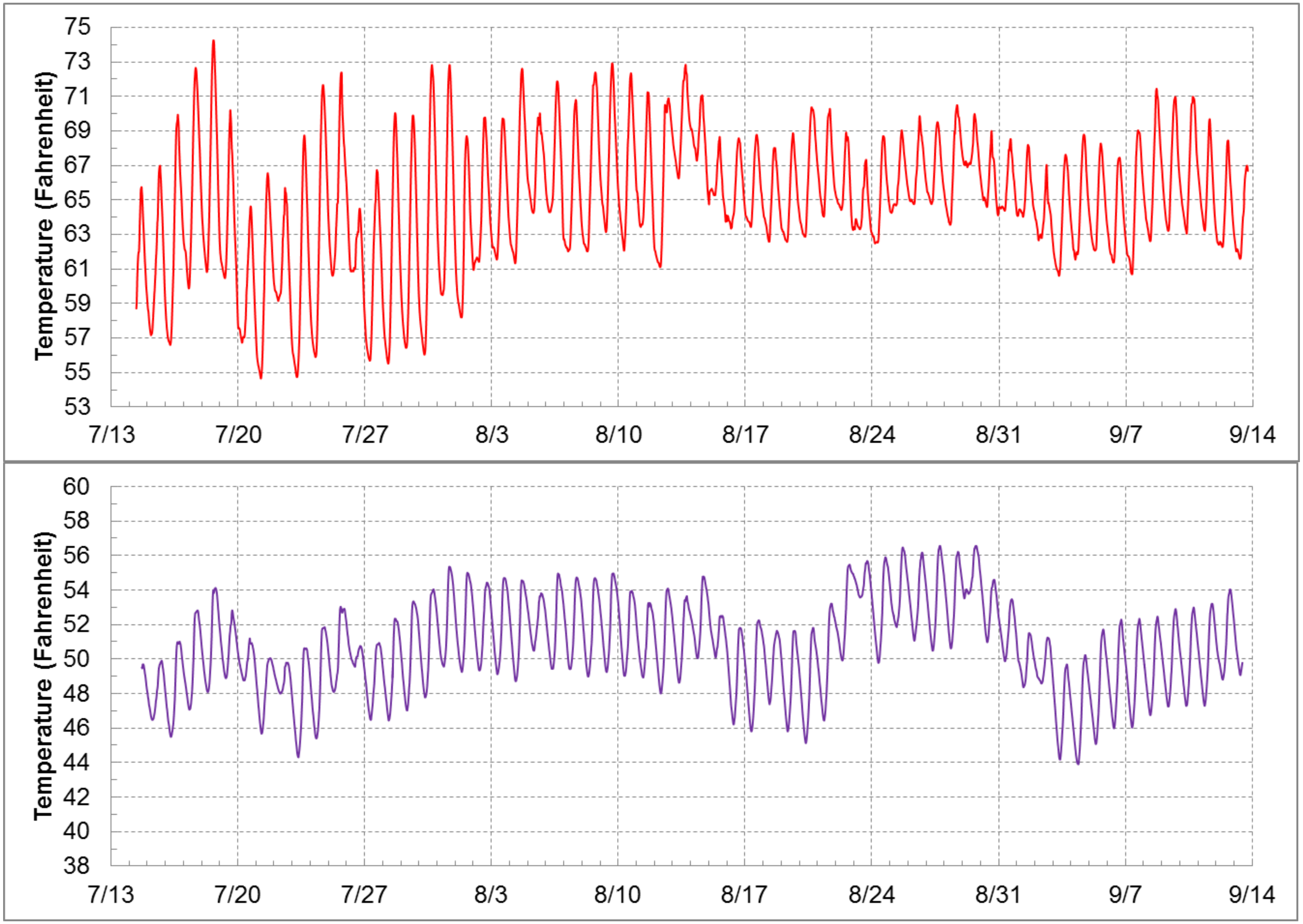

Figure 6. Continuous temperature in McGregor Creek (top; MGRC-T1) and Twin Creek (bottom, MTRC-T5), July 14 to September 13, 2011.

3 QUAL2K Model Development

EPA and DEQ selected the QUAL2K model to simulate temperatures in McGregor Creek. QUAL2K is supported by EPA and has been used extensively for TMDL development and point source permitting across the country. The QUAL2K model is suitable for simulating water temperatures in small rivers and creeks. It is a one-dimensional uniform flow model with the assumption of a completely mixed system for each computational cell. QUAL2K assumes that the major pollutant transport mechanisms, advection and dispersion, are significant only along the longitudinal direction of flow. The heat budget and temperature are simulated as a function of meteorology on a diel time scale. Heat and mass inputs through point and nonpoint sources are also simulated. The model allows for multiple waste discharges, water withdrawals, nonpoint source loading, tributary flows, and incremental inflows and outflows. QUAL2K simulates in-stream temperatures via a heat balance that accounts “for heat transfers from adjacent elements, loads, withdrawals, the atmosphere, and the sediments” (Chapra et al. 2008, p. 19).

The current release of QUAL2K is version 2.11b8 (January 2009). The model is publicly available at http://www.epa.gov/athens/wwqtsc/html/QUAL2K.html. Additional information regarding QUAL2K is presented in the *Quality Assurance Project Plan for Montana TMDL Support: Temperature Modeling* (Tetra Tech 2012).

The following sections describe the process that was used to setup, calibrate, and validate the QUAL2K models for McGregor Creek.

3.1 Model Framework

The QUAL2K model (Chapra et al. 2008) was selected for modeling McGregor Creek. The modeling domain included the stream just below McGregor Lake at MGRC-T1 (about 0.2 miles downstream of the lake outlet) down to the confluence with the Thompson River at MGRC-T9 (**Figure 7**).

Data were specifically collected to support the QUAL2K model for McGregor Creek. Flow, shade, and continuous temperature were acquired during July 14-15 and September 12-13, 2011. In addition flow and temperature data were also collected at two major tributaries to McGregor Creek.

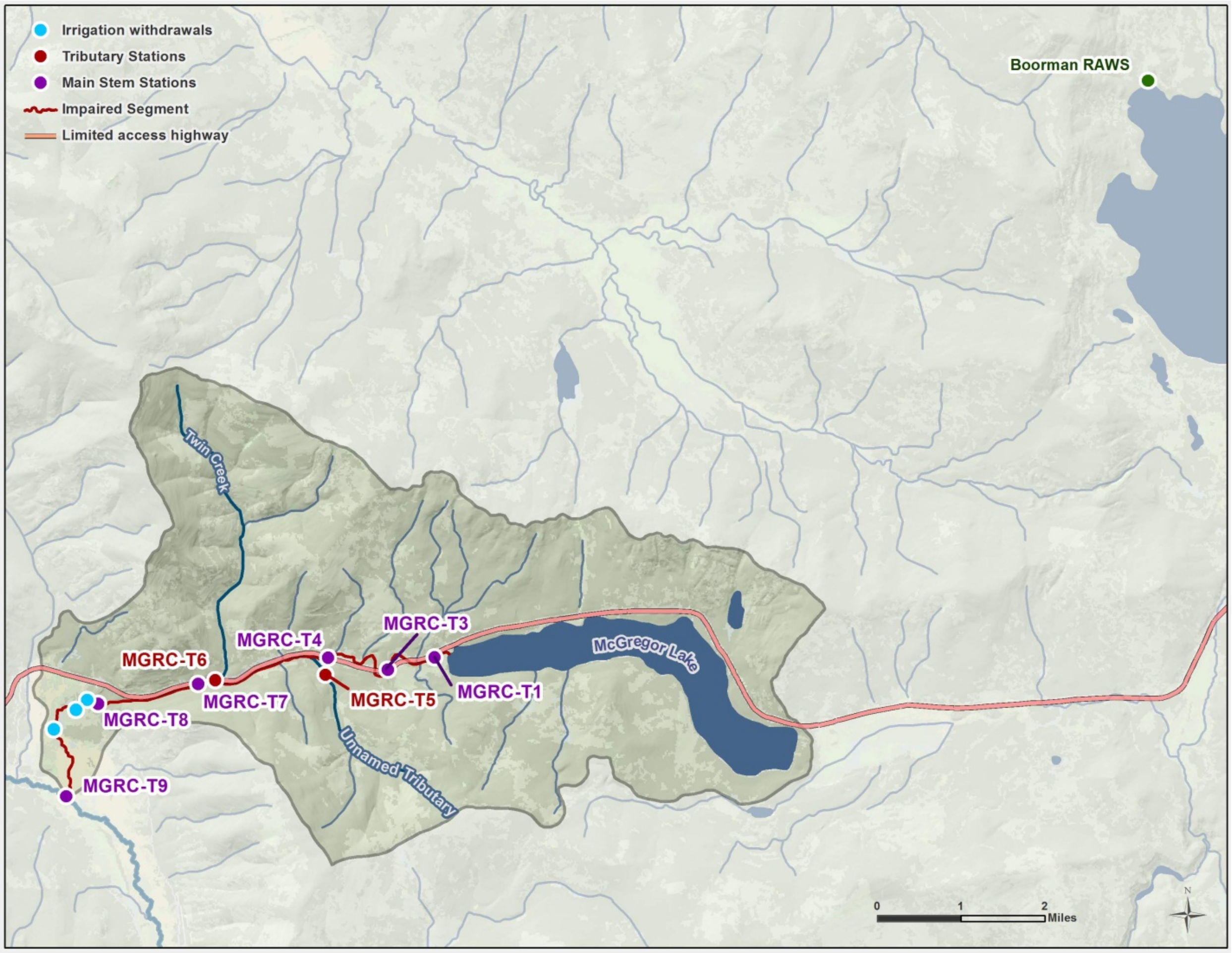

Figure 7. McGregor Creek modeling domain, logger locations, RAWS, and irrigation withdrawal.

3.2 *Model Configuration and Setup*

Model configuration involved setting up the model computational grid and setting initial conditions, boundary conditions, and hydraulic and light and heat parameters. All inputs were longitudinally referenced, allowing spatial and continuous inputs to apply to certain zones or specific stream segments. This section describes the configuration and key components of the model.

3.2.1 Modeling Time Period

The calibration and validation steady-state model periods were July 16, 2011 and September 11, 2011. These dates were selected since they had the most complete datasets that could be used for model setup and calibration. Flow and logger temperature data were available for most sites on both dates and weather data was also available for both dates. According to the Boorman RAWS, the daily average air temperature on September 11, 2011 was much warmer (by 4.7° F), with the late afternoon high 8° F warmer than on July 16, 2011 and the early morning low 6° F degrees warmer than on July, 16, 2011. However, despite the differences in daily temperatures, September 11, 2011 still allowed for validation of the model as sufficient data were available to evaluate the model's calibration.

Calibration Period: The calibration period was July 16, 2011, which was associated with logger deployment monitoring; flow was monitored July 14 or 15, 2011 at most EPA logger sites on McGregor Creek and its two major tributaries. Flow could not be monitored at the mouth (MGRC-T9) due to the depth. No logger was deployed at an unnamed tributary near the headwaters (MGRC-T2) since the tributary was dry during logger deployment. As loggers were deployed on July 14 and 15, 2011, the first date with a complete 24-hour temperature record at all loggers was July 16, 2011. Precipitation data were evaluated and no precipitation occurred during the calibration period or the preceding days; thus, hydrologic conditions on July 14 and 15, 2011 were assumed to be representative of flow conditions on July 16, 2011.

Validation: Period: The validation period was September 11, 2011, which is just before the retrieval of all the loggers on September 12 and 13, 2011. The last date before logger retrieval with full 24-hour data for all eight loggers was September 11, 2011. Flow data monitored on September 12 and 13, 2011 was assumed to be representative of flow conditions on September 11, 2011. Similar to logger deployment, flow could not be monitored at the mouth (MGRC-T9) due to the depth. The unnamed tributary near the headwaters (MGRC-T2) was also dry on September 13, 2011. Similar to the selection of the calibration period, precipitation data were evaluated and no precipitation occurred during the validation period or the preceding days; thus, hydrologic conditions on September 12 and 13, 2011 were assumed to be representative of flow conditions on September 11, 2011.

3.2.2 Segmentation

Segmentation refers to discretization of a waterbody into smaller computational units (e.g., reaches and elements). Reaches in QUAL2K have constant hydraulic characteristics (e.g. slope, bottom width) and each reach is further divided into elements that are the fundamental computational units. The McGregor Creek main stem was segmented into nine reaches with lengths ranging from 0.22 miles to 1.25 miles, and an element size of 850 feet within each reach. An element size of 850 feet was sufficient to incorporate any point inputs to the waterbody and to maintain current stability. Two major tributaries were represented through boundary condition designation (see **Section 3.2.4** for a discussion of boundary conditions and **Appendix A** for a discussion of the shade model). **Figure 8** shows the McGregor Creek mainstem and its tributaries.

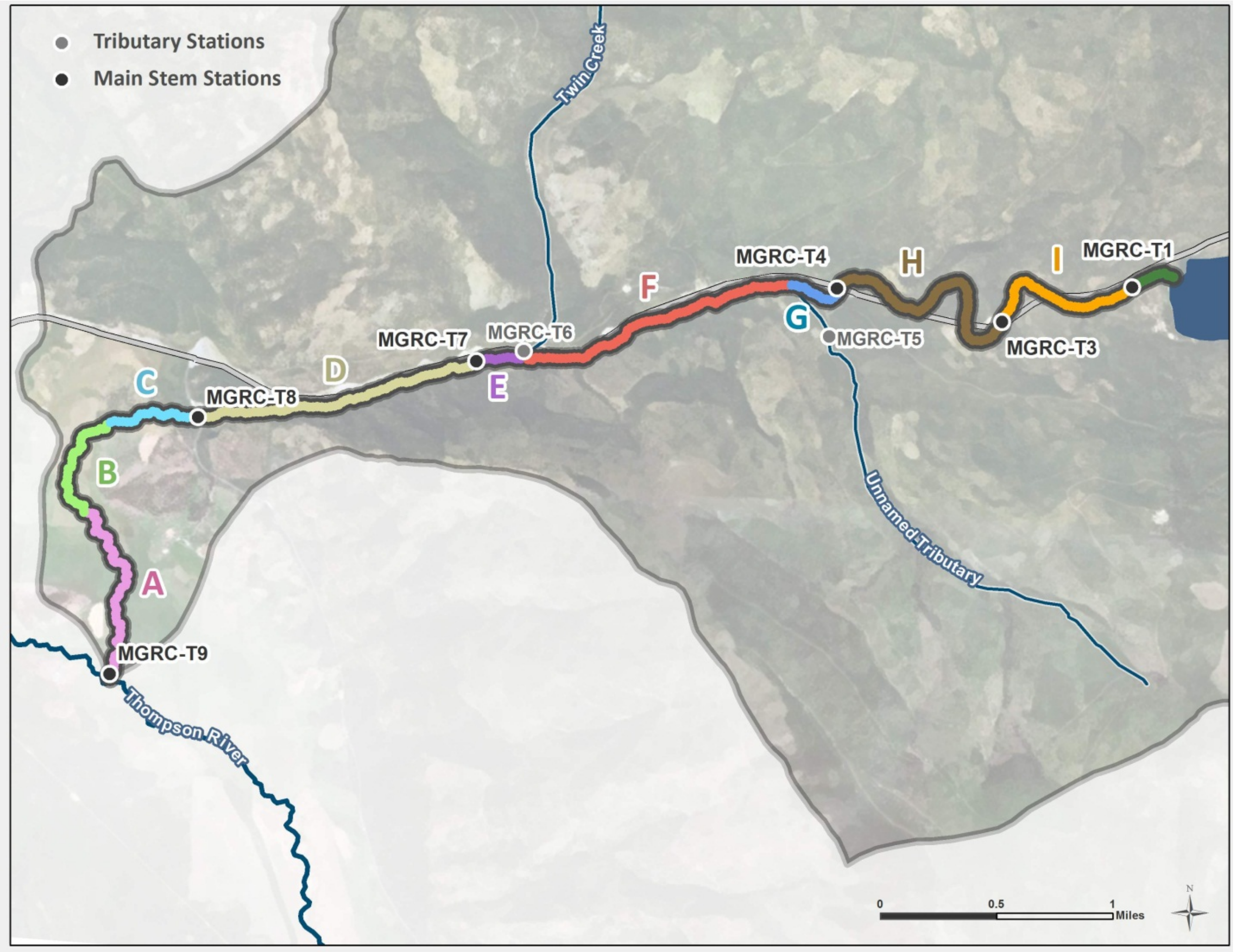

Figure 8. McGregor Creek model segments.

3.2.3 Streamflow and Hydraulics

The flow rates were estimated through instantaneous streamflow measurements and mass balance calculations at the loggers where flows were monitored. The rating curve method was used to relate the depth and the velocity to the flow rate in a reach. This method requires specification of empirical coefficients and exponents based on numerous measurements of depths, velocities, and flows. Due to the limited amount of field data, coefficients of the rating curve were treated to be the calibration parameters against the observed depths and velocities while typical exponent values (velocity = 0.43 and depth = 0.45) described in the QUAL2K manual (Chapra et al. 2008) were set for the rating curve exponents.

Figure 9 shows the channel elevations assigned in the QUAL2K model.

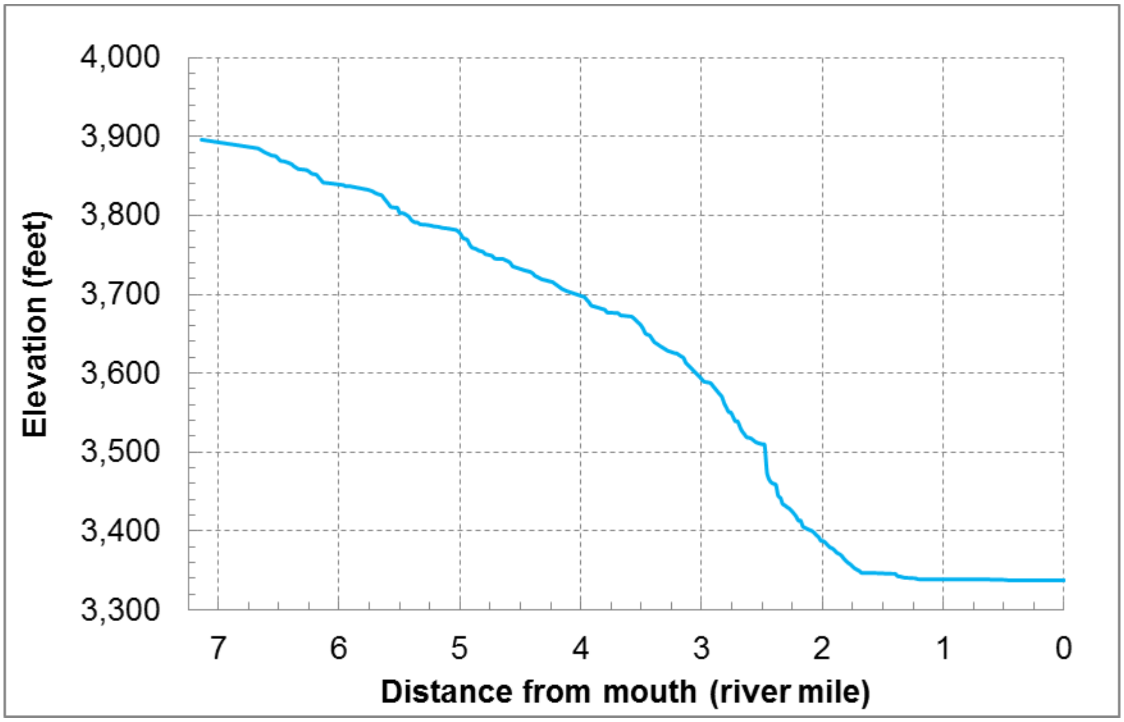

Figure 9. McGregor Creek channel elevation.

3.2.4 Boundary Conditions

Boundary conditions represent external contributions to the waterbody being modeled. A flow and temperature input file was configured for inputs to McGregor Creek. Boundary conditions were specified at the upstream terminus of McGregor Creek, for each of the two major tributaries' confluences with McGregor Creek, and for diffuse sources along the creek. These are further discussed in the following sections.

3.2.4.1 Headwater (Upstream) Boundary

QUAL2K requires specification of the headwater flow and temperature. Headwater flow (July 14, 2011) and diurnal temperature (July 16, 2011) at the upstream boundary were specified using observed data from the in-stream logger at site MGRC-T1 for the calibration period. A flow of 0.78 cubic feet per second (cfs) was specified for the calibration period. Note that flow for July 16, 2011 was not available and observed flow from July 14, 2011 was used.

Headwater flow (September 12, 2011) and diurnal temperature (September 11, 2011) at the upstream boundary were specified for the boundary conditions based on the data available at site MGRC-T1 for the validation period. A flow of 2.24 cfs was specified for the validation period. Note also that flow data for September 11, 2011 were not available and observed flow from September 12, 2011 was used as described in the previous section. **Figure 10** shows the headwater temperatures specified in the model.

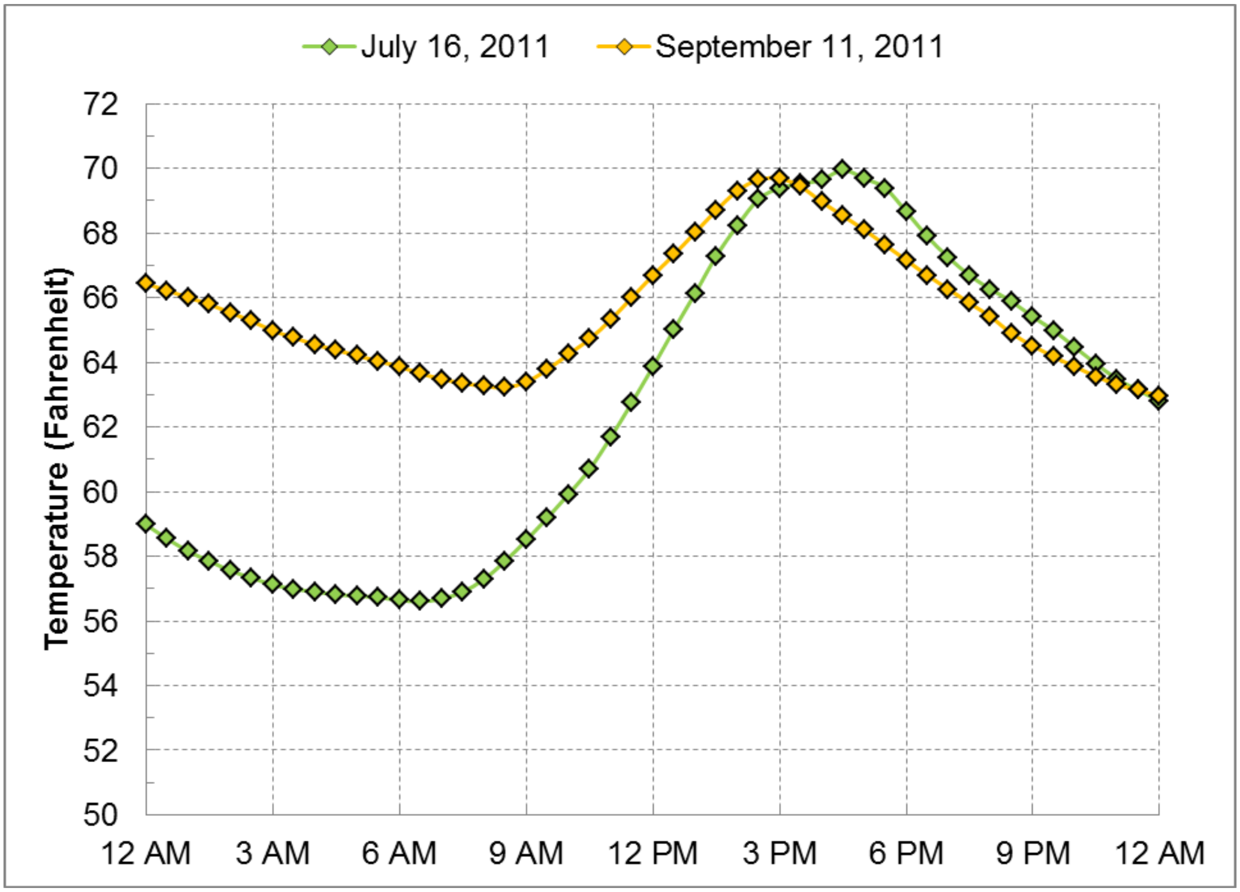

Figure 10. Diurnal temperature at the headwaters to McGregor Creek.

3.2.4.2 Tributary Inputs

There are many small tributaries in the watershed; however, monitoring data were available for only two major tributaries feeding into McGregor Creek – unnamed tributary (MGRC-T5) and Twin Creek (MGRC-T6) (**Figure 8**). Table 1 shows the flow and temperature assigned to the tributaries in the model. An unnamed tributary (MGRC-T2) was observed to be dry on July 14 and 15, 2011; it was assumed to be dry during the calibration and validation periods. Flows during the validation period were observed on September 12 and 13, 2011 and were used in conjunction with temperatures observed on September 11, 2011, which was the last day of full temperature data available.

In addition to tributary inputs, three irrigation withdrawals from McGregor Creek was also identified (see Appendix A for a discussion of these withdrawals) and assigned in the model; additional withdrawals in the watershed, mostly from McGregor Lake, were excluded from the model as they were outside of the model domain. Information on withdrawal rates or whether withdrawal is occurring during the calibration and validation dates was not readily available. Net irrigation requirements to irrigate the fields were queried from the Montana Natural Resource Information System for the month of July, which was 8.5 inches per month. A maximum daily flow rate was estimated using the net irrigation requirements and the maximum area irrigated (a total of 613 acres). It was calculated that up to 7.06 cfs may be withdrawn from McGregor Creek on a daily basis. These calculated withdrawals were used in the model (rows identified as *irrigation withdrawal* in **Table 1**). More information on the irrigation withdrawals can be found in **Appendix A**.

Table 1. QUAL2K model flow and temperature inputs to McGregor Creek - Tributaries and withdrawals

		Point sources [a]		Temperature [b]		
Description	Location (RM)	Abstraction (cfs)	Inflow (cfs)	Daily mean (°F)	½ daily range (°F)	Time of maximum (hour)
July 16, 2011						
unnamed tributary (MGRC-T5)	4.85	--	1.50	48.3	5.5	5:00 PM
Twin Creek (MGRC-T6)	3.58	--	3.50	48.3	5.5	6:00 PM
irrigation withdrawal	1.85	1.45	--	--	--	--
irrigation withdrawal	1.67	1.45	--	--	--	--
irrigation withdrawal	1.14	4.16	--	--	--	--
September 11, 2011						
unnamed tributary (MGRC-T5)	4.85	--	0.54	49.3	5.9	6:30 PM
Twin Creek (MGRC-T6)	3.58	--	0.97	50.3	5.9	6:00 PM
irrigation withdrawal	1.85	1.45	--	--	--	--
irrigation withdrawal	1.67	1.45	--	--	--	--
irrigation withdrawal	1.14	4.16	--	--	--	--

Notes

°F = degrees Fahrenheit; cfs = cubic feet per second; RM = rive mile.

a. Points sources represent abstractions (i.e., withdrawals) or inflows. Each point source can be an abstraction or an inflow.

b. The daily temperature, one-half of the range of temperatures across the model period, and time of the maximum hourly temperature are only applicable to point source inflows.

3.2.4.3 Diffuse Sources

Groundwater and other sources of water not accounted for in the tributaries can be specified along the length of the waterbody using the *Diffuse Sources* worksheet in the QUAL2K model. A flow balance was constructed using the observed flows along McGregor Creek and the observed tributary flows, and the amount of diffuse flow along McGregor Creek was calculated for the days when flow was available on July 14 and 15, 2011 and September 12 and 13, 2011. Diffuse flows for the QUAL2K reach from MGRC-T8 to MGRC-T9 and the mouth was estimated using the drainage area ratio method and flow measured at MGRC-T8. Note that flow was not collected at MGRC-T9 due to the depth and bottom substrate of McGregor Creek at that site. Since no irrigation withdrawals or tributaries were present along this model reach, the additional inflow (estimated as the difference between flow monitored at MGRC-T8 and flow estimated at MGRC-T9 using the drainage area ratio method) was assumed to be groundwater inflow.

Temperature assignment for the diffuse sources was estimated through: (1) the mean annual air temperature of July 16, 2010 through July 16, 2011 (39.9° F), and (2) a groundwater well temperature (46.9° F) available from the Groundwater Information Center. The initial diffuse flow temperature was selected to be the average of the two values (43.3° F), which was further refined during calibration and validation. The final diffuse source water temperature (45.5° F) was kept the same for the calibration and validation period, except for the most downstream three QUAL2K model reaches that were affected by irrigation return flow. The diffuse inflow temperatures selected for these reaches was warmer (49.1° F). The final flow and water temperature assignment are shown below in **Table 2**.

Table 2. QUAL2K model flow and temperature inputs to McGregor Creek - Diffuse sources

Segment description	Location [a] Upstream (RM)	Downstream (RM)	Diffuse Abstraction (cfs)	Diffuse Inflow Inflow (cfs)	Temp (°F)
July 16, 2011					
MGRC-T1 to MGRC-T3	6.95	6.23	--	0.19	45.5
MGRC-T3 to MGRC-T4	6.23	5.10	--	0.03	45.5
MGRC-T4 to unnamed tributary (MGRC-T5)	5.10	4.90	--	0.06	45.5
unnamed tributary (MGRC-T5) to Twin Creek (MGRC-T6)	4.90	3.60	--	2.36	45.5
Twin Creek (MGRC-T6) to MGRC-T7	3.60	3.37	--	0.19	45.5
MGRC-T7 to MGRC-T8	3.37	2.11	0.04	--	--
MGRC-T8 to MGRC-T9	2.11	1.68	--	1.80	49.1
	1.68	1.04	--	1.65	49.1
	1.04	0	--	4.40	49.1
September 11, 2011					
MGRC-T1 to MGRC-T3	6.95	6.23	--	0.03	45.5
MGRC-T3 to MGRC-T4	6.23	5.10	--	0.34	45.5
MGRC-T4 to unnamed tributary (MGRC-T5)	5.10	4.90	--	0.004	45.5
unnamed tributary (MGRC-T5) to Twin Creek (MGRC-T6)	4.90	3.60	--	0.14	45.5
Twin Creek (MGRC-T6) to MGRC-T7	3.60	3.37	--	0.01	45.5
MGRC-T7 to MGRC-T8	3.37	2.11	--	0.66	--
MGRC-T8 to MGRC-T9	2.11	1.68	--	1.65	49.1
	1.68	1.04	--	1.56	49.1
	1.04	0	--	0.43	49.1

Notes
°F = degrees Fahrenheit; cfs = cubic meters per second; RM = river mile.
a. Upstream and downstream termini of segment

3.2.5 Meteorological Data

Forcing functions for heat flux calculations are determined by the meteorological conditions in QUAL2K. The QUAL2K model requires hourly meteorological input for the following parameters: air temperature, dew point temperature, wind speed, and cloud cover. The Boorman RAWS is in closest proximity to McGregor Creek (**Figure 7**) and records hourly air temperature, dew point temperature, wind speed and solar radiation, whereas the Pleasant Valley weather station (246580 in **Appendix A**) only records hourly air temperature data. The Boorman RAWS hourly observed meteorological data were used to develop the QUAL2K model after appropriate unit conversions and adjustments (as discussed below).

Air temperature and dew point temperature data from the Boorman RAWS were adjusted using the moist air adiabatic lapse rate (-0.00656 degrees Celsius per meter) to account for the elevation difference between the RAWS and the individual model segments.

The wind speed measurements at the Boorman RAWS were measured at 20 feet (6.1 meters) above the ground. QUAL2K requires that the wind speed be at a height of 7.0 meters (23 feet). The wind speed measurements ($U_{w,z}$ in meter/second) taken at a height of 6.1 meters (z_w in meters) were converted to equivalent conditions at a height of z = 7.0 meters (the appropriate height for input to the evaporative heat loss equation), using the exponential wind law equation suggested in the QUAL2K user's manual:

$$U_w = U_{wz}\left(\frac{z}{z_w}\right)^{0.15}$$

3.2.6 Shade Data

The QUAL2K model allows for spatial and temporal specification of shade, which is the fraction of potential solar radiation that is blocked by topography and vegetation. A shade model was developed and calibrated for the McGregor Creek. The calibrated shade model was first run to simulate shade estimates for July 16, 2011 and September 11, 2011 to simulate hourly shade every 30 meters (the resolution of the shade model) along McGregor Creek. Reach-averaged integrated hourly effective shade results were then computed and were then input into each reach within the QUAL2K model. The overall average shade on September 11, 2011 (54 percent) was greater than that predicted on July 16, 2011 (46 percent). A more detailed discussion on the shade modeling can be found under **Appendix A**.

3.3 Model Evaluation Criteria

The goodness of fit for the simulated temperature using the QUAL2K model was summarized using the absolute mean error (AME) and relative error (REL) as a measure of the deviation of model-predicted temperatures (predicted, P) from the measured values (observed, O). These model performance measures were calculated as follows:

$$AME = \frac{1}{N}\sum_{n=1}^{n}|P_n - O_n|$$

$$\mathrm{REL} = \frac{\sum_{n=1}^{n}|P_n - O_n|}{\sum_{n=1}^{n}O_n}$$

These performance measures are detailed later in the section in evaluation of the model calibration and validation.

3.4 Model Calibration and Validation

The time periods selected for calibration and validation were July 16, 2011 and September 11, 2011, respectively. These dates were selected as they had the most comprehensive dataset available for modeling and corresponded to the synoptic study done for McGregor Creek, which included collecting flow, temperature, shade, and channel geometry information.

Flow, depth, velocity and temperature data were available at six locations along the main stem of McGregor Creek. **Table 3** shows the monitoring sites used for calibration and validation.

Table 3. Temperature calibration and validation locations

Site name	Distance (RM)	Available Data	Source
MGRC-T1	6.95	Flow, depth, velocity, and temperature	EPA
MGRC-T3	6.23	Flow, depth, velocity, and temperature	EPA
MGRC-T4	5.11	Flow, depth, velocity, and temperature	EPA
MGRC-T7	3.37	Flow, depth, velocity, and temperature	EPA
MGRC-T8	2.11	Flow, depth, velocity, and temperature	EPA
MGRC-T9	0.00	Temperature	EPA

Note: EPA = U.S. Environmental Protection Agency and its contractors; RM = river mile.

The first step for calibration was adjusting the flow balance and calibrating the system hydraulics. A flow balance was constructed for the calibration and validation dates. This involved accounting for all the flow in the system. Observed flows along McGregor Creek, tributary flows, and withdrawals were used to estimate the amount of diffuse flow along the system.

After the mass balance of the flow rates, the modeled velocity and depth were simulated using the previously described rating curve method. While the exponents were not varied during the model calibration, the rating curve coefficients were modified and evaluated against the observed data. After identifying the most suitable coefficients using the calibration data for July 16, 2011, the selected coefficients were evaluated with the validation data for September 11, 2011. The model results indicated a reasonable model representation (**Figure 11** and **Figure 12**)

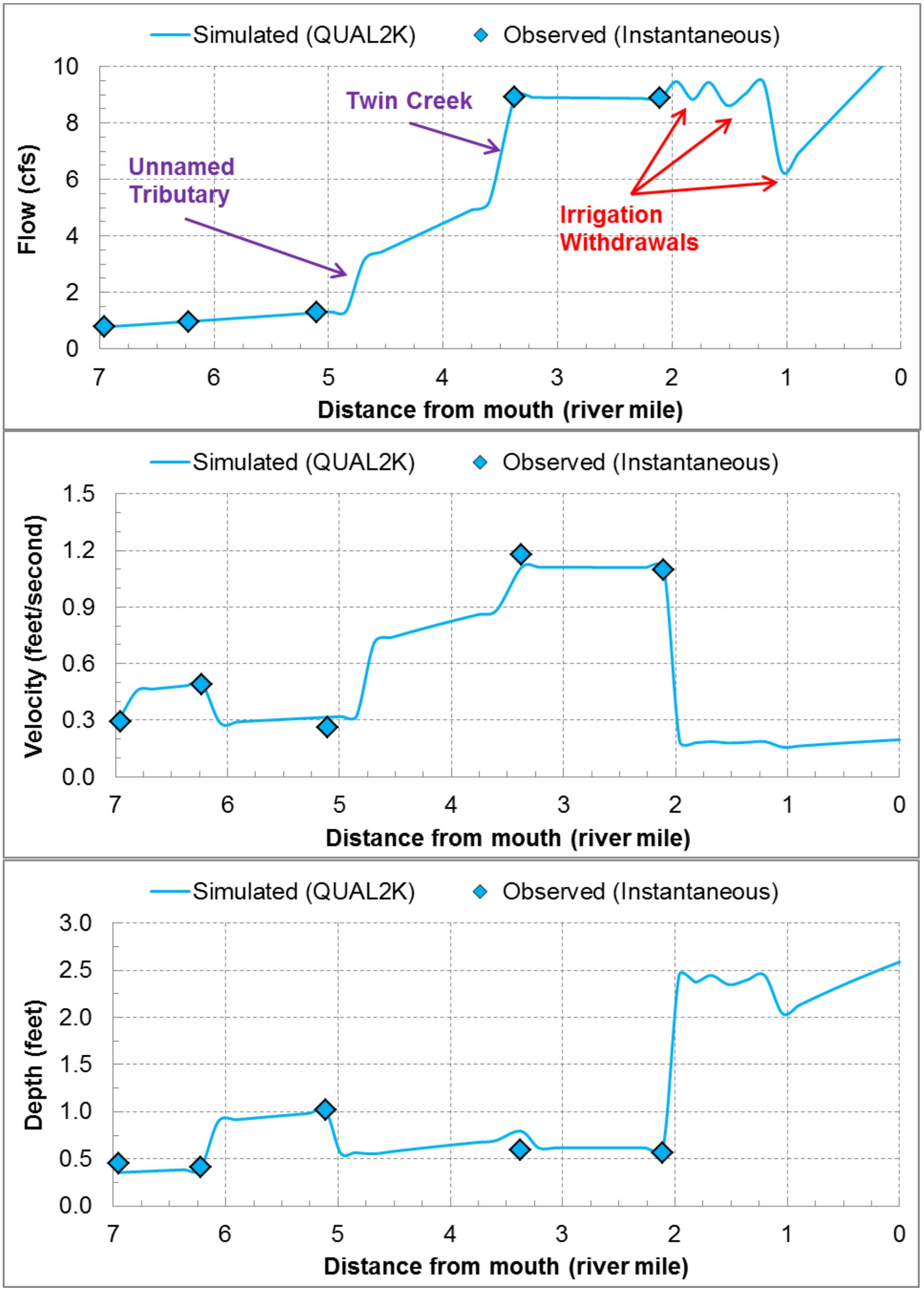

Figure 11. Observed and predicted flow, velocity, and depth on July 16, 2011 (calibration).

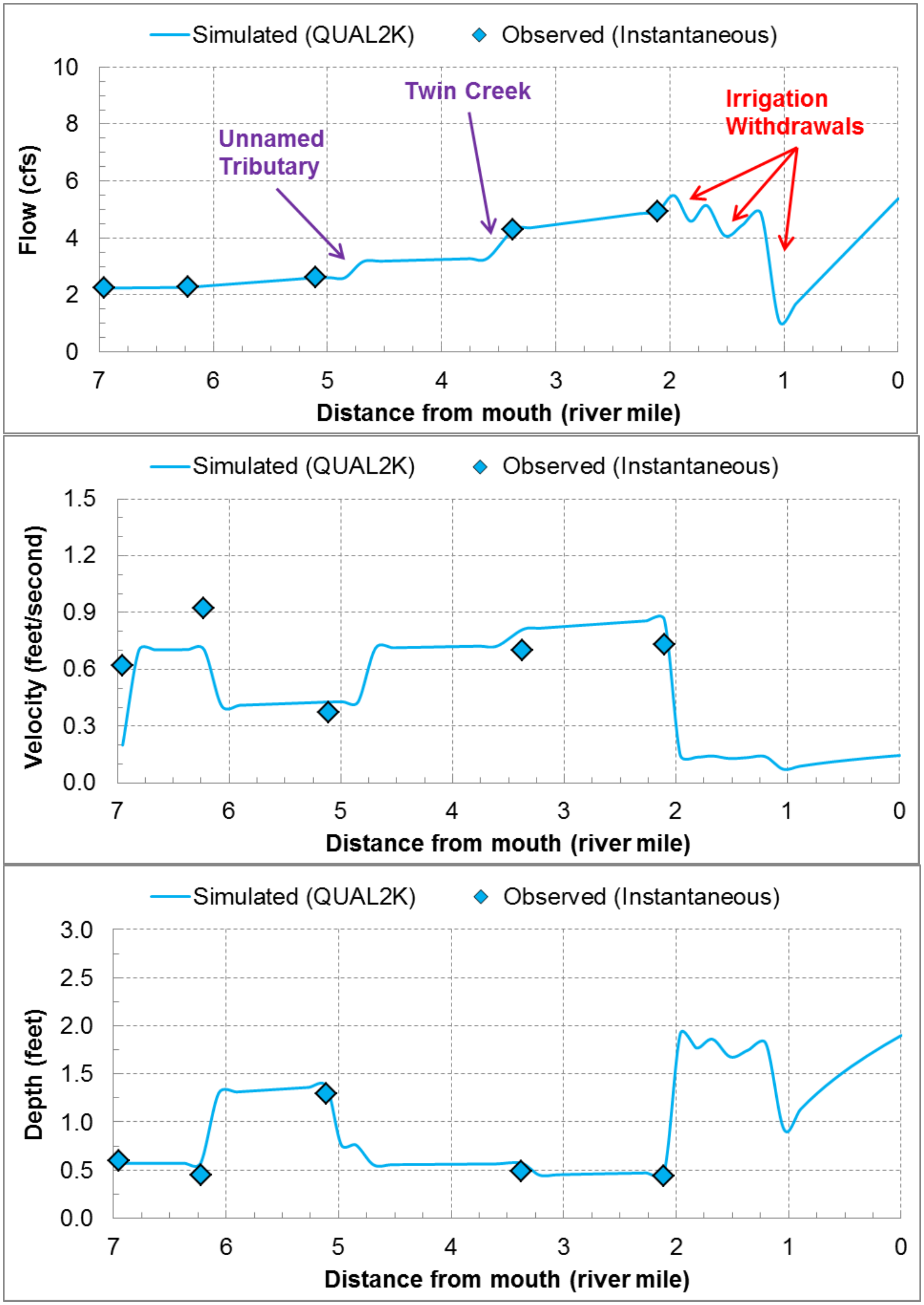

Figure 12. Observed and predicted flow, velocity, and depth on September 11, 2011 (validation).

Once the system hydraulics were established, the model was then calibrated for water temperature. Temperature calibration included calibrating the model by adjusting the light and heat parameters with available data. A discussion of the solar radiation model and calibration along with other heat related inputs that were selected is presented below.

Hourly solar radiation is an important factor that affects stream temperature. The QUAL2K model does not allow for input of solar radiation. Instead the model calculates short wave solar radiation using an atmospheric attenuation model. For McGregor Creek, the Ryan-Stolzenbach model was used to calculate the solar radiation. The calculated solar radiation values (without stream shade) for the calibration and validation were compared with observed solar radiation measurements at the Boorman RAWS. **Figure 13** shows the observed and predicted solar radiation for the calibration and validation periods. No cloud cover data were available and the observed solar radiation during calibration showed some influence due to cloud cover especially during hour 16. The cloud cover was adjusted to more closely mimic observed solar radiation during calibration on July 16, 2011. A cloud cover specification of 75 percent at hour 15 and a 40 percent cloud cover adjustment at all other times during the day was specified to match the observed solar radiation for the calibration period. No adjustment was required to be made to the cloud cover during the validation period on September 11, 2011. The Ryan-Stolzenbach atmospheric transmission coefficient was also adjusted to 0.85 (July 16, 2011) and 0.90 (September 11, 2011) to reflect the atmospheric conditions to minimize the deviation between the observed and modeled short wave solar radiation.

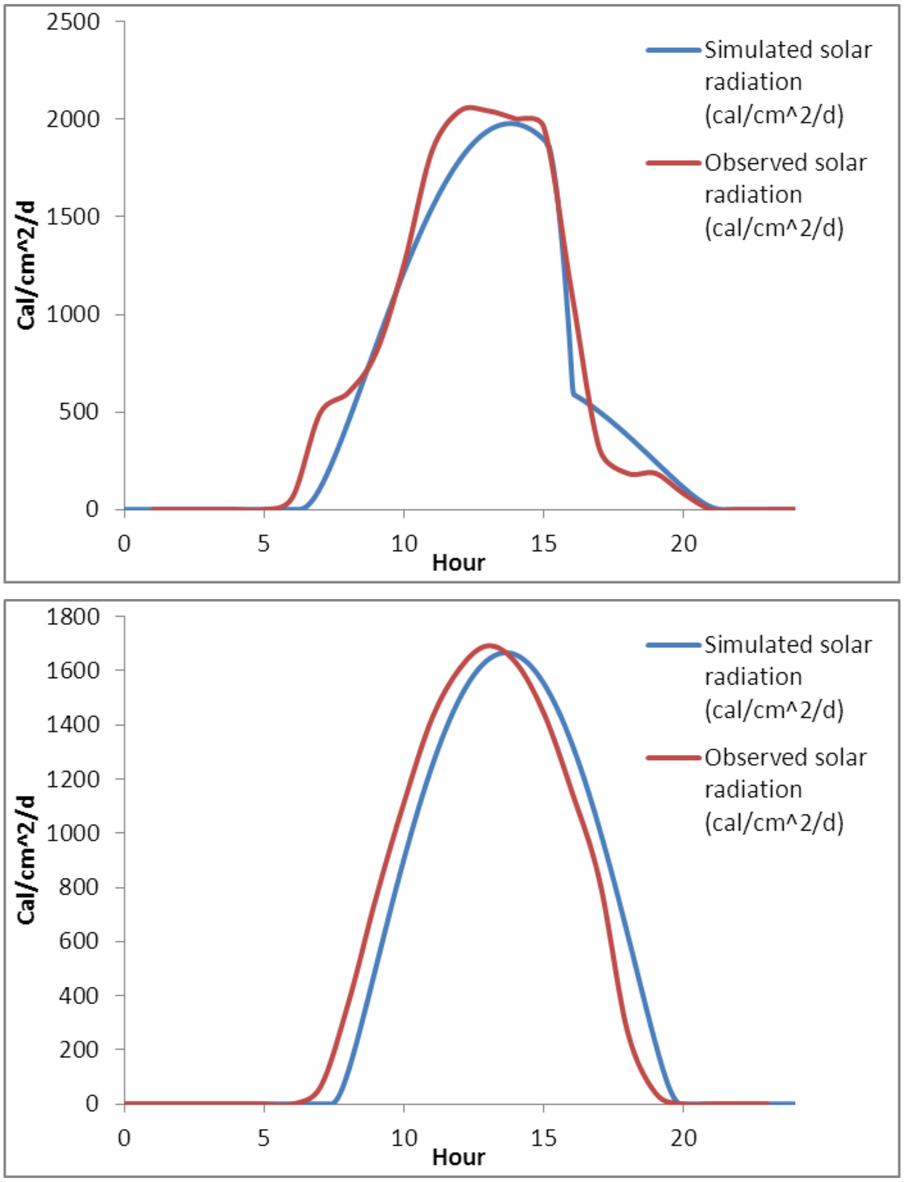

Figure 13. Observed and predicted solar radiation on July 16, 2011 and September 11, 2011 (calibration and validation).

The longwave solar radiation model and the evaporation and air conduction/convections models were kept at the default QUAL2K settings. The solar radiation settings are shown in **Table 4**.

Table 4. Solar radiation settings

Parameter	Value
Solar Shortwave Radiation Model	
Atmospheric attenuation model for solar	Ryan-Stolzenbach
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)	
Atmospheric transmission coefficient[a]	0.85 (calibration) 0.90 (validation)
Downwelling atmospheric longwave infrared radiation	
Atmospheric longwave emissivity model	Brunt
Evaporation and air convection/conduction	
Wind speed function for evaporation and air convection/conduction	Brady-Graves-Geyer

Note: a. The range of atmospheric transmission coefficients is 0.70 to 0.91 and the QUAL2K model default is 0.80 (Chapra et al. 2008).

The sediment heat parameters were also evaluated for calibration. In particular the sediment thermal thickness, sediment thermal diffusivity, and sediment density were adjusted during calibration. The sediment thermal thickness was slightly increased from the default value of 10 cm to 16 cm, and the sediment heat capacity of all component materials of the stream was set to 0.4 calories per gram °C, which is the QUAL2K default (Chapra et al. 2008). The sediment thermal diffusivity was set to a value of 0.0118 square centimeters per second (Chapra et al. 2008). This was consistent with the stream photos that indicated a predominantly rocky substrate along the main channel.

The sediment density was set to 2.24 grams per cubic centimeter (g/cm^3). A review of Soil Survey Geographic Database (SSURGO) data indicated that most of the soil proximal to the stream was sand and silt soil types. Geology data from Montana Bureau of Mines and Geology indicated that the type of rock geology within the watershed was mainly limestone and sandstone. Based on the field photographs, the surface layer of the stream substrate was estimated to be composed of 65 percent of sandstone and limestone rock and 35 percent of sand and silt with silt to be higher percentage based on SSURGO data. The following calculation was used to estimate sediment density:

$$\begin{aligned}\text{sediment density} &= (\text{ratio of rock} * \text{rock density}) + (\text{ratio of soil} * \text{soil density})\\ &= (0.65 * 2.65\ g/cm^3) + (0.35 * 1.49\ g/cm^3)\\ &= 2.24\ g/cm^3\end{aligned}$$

where 2.65 g/cm^3 is the average of the typical sandstone (2.6 g/cm^3) and limestone (2.7 g/cm^3) densities and 1.49 g/cm^3 is the typical clay and silt densities.

These adjustments helped in improving the minimum temperatures simulated.

Calibration was followed by validation. The validation provides a test of the calibrated model parameters under a different set of conditions. Only those variables that changed with time were changed during validation to confirm the hydraulic variables. This included headwater and tributary in-stream temperatures, air and dew point temperatures, wind speed, cloud cover, solar radiation, and shade. All other inputs were based on observed data in September 11, 2011. Groundwater temperatures, for which there were no direct observed data, were unchanged since they are not expected to vary greatly.

Figure 14 and **Figure 15** show the calibration and validation results along McGregor Creek. The temperature calibration and validation statistics of the average, maximum, and minimum temperatures are shown in **Table 5** and **Table 6**, respectively.

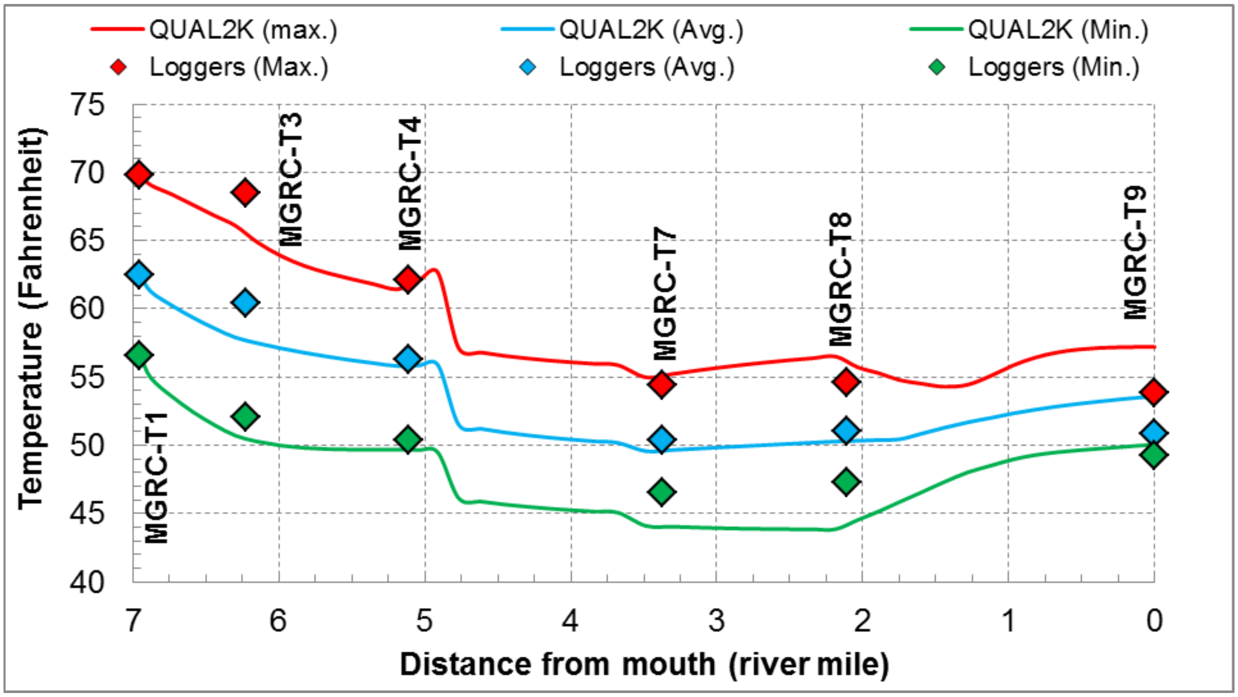

Figure 14. Longitudinal profile of the temperature calibration (July 16, 2011).

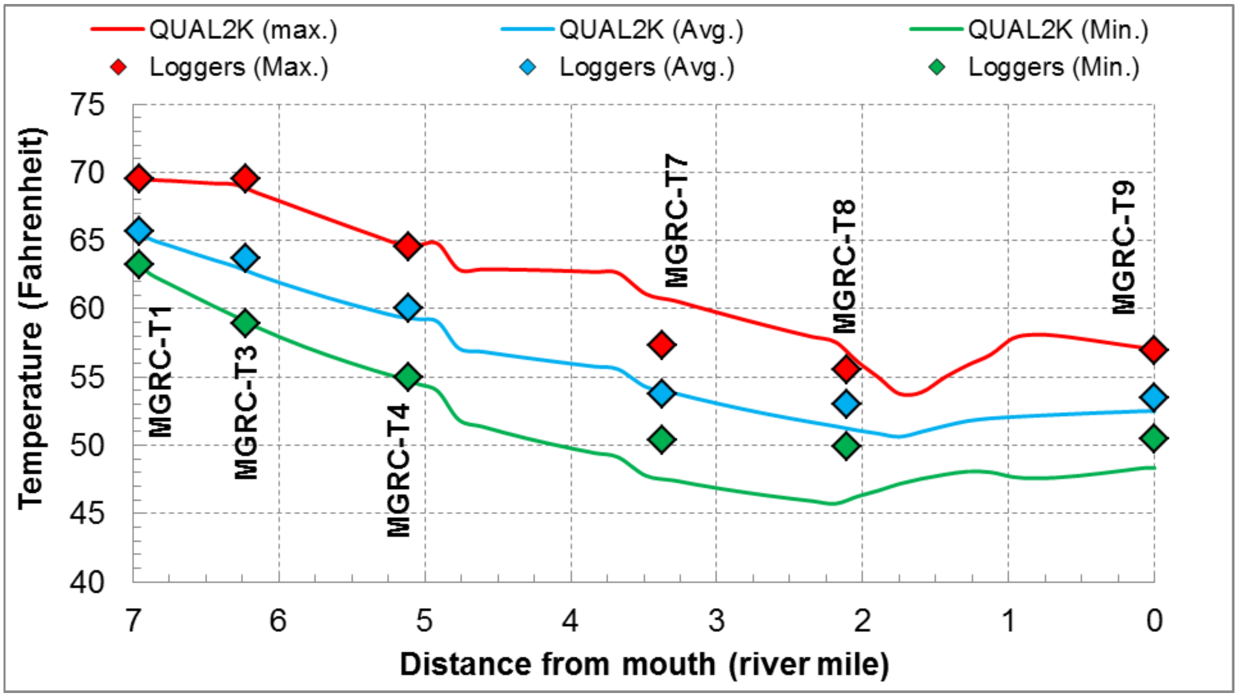

Figure 15. Longitudinal profile of the temperature validation (September 11, 2011).

Table 5. Calibration statistics of observed versus predicted water temperatures

Site name	RM	Average daily temperature		Maximum daily temperature		Minimum daily temperature	
		AME (°F)	REL (%)	AME (°F)	REL (%)	AME (°F)	REL (%)
MGRC-T1	6.95	--	--	--	--	--	--
MGRC-T3	6.23	2.48	4.1%	3.66	5.6%	1.79	3.4%
MGRC-T4	5.11	0.35	0.6%	0.67	1.1%	0.87	1.7%
MGRC-T7	3.37	0.66	1.3%	0.84	1.5%	2.52	5.4%
MGRC-T8	2.11	0.51	1.0%	1.89	3.3%	3.42	7.2%
MGRC-T9	0.00	3.08	6.1%	3.32	5.8%	0.76	1.5%
Overall Calibration		1.18	2.2%	1.73	2.9%	1.56	3.2%

Note: AME = absolute mean error; REL = relative error; RM = river mile.

Table 6. Validation statistics of observed versus predicted water temperatures

Site name	RM	Average daily temperature		Maximum daily temperature		Minimum daily temperature	
		AME (°F)	REL (%)	AME (°F)	REL (%)	AME (°F)	REL (%)
MGRC-T1	6.95	--	--	--	--	--	--
MGRC-T3	6.23	0.63	1.0%	0.37	0.5%	0	0.0%
MGRC-T4	5.11	0.79	1.3%	0	0.0%	0	0.0%
MGRC-T7	3.37	0	0.0%	3.33	5.8%	2.98	5.9%
MGRC-T8	2.11	1.59	3.0%	2.01	3.6%	3.67	7.4%
MGRC-T9	0.00	1.06	2.0%	0	0.0%	2.17	4.3%
Overall Validation		0.68	1.2%	0.95	1.7%	1.47	2.9%

Note: AME = absolute mean error; REL = relative error; RM = river mile.

In general, the model was able to capture the observed temperature range and longitudinal profile. All the simulated minimum, maximum, and mean temperatures were contained within relatively small errors. The overall calibration results showed an overall 2.9 percent relative error with an AME of 1.73° F for the maximum temperatures. The overall validation results for the maximum temperatures had an overall 1.7 percent relative error and an AME of 0.95° F.

The observed data and simulated temperatures indicate that the upstream boundary (MGRC-T1) had the warmest temperatures, which were assumed to reflect the outflow of McGregor Lake. The simulated longitudinal temperature results from MGRC-T1 to MGRC-T8 show a gradual cooling of the in-stream temperatures, followed by a slight warming between MGRC-T8 and MGRC-T9. Further examination of the model results reveals three significant inflows that reduce the temperature:

- Unnamed tributary inflow at McGregor Creek RM 4.8.
- Twin Creek inflow at McGregor Creek RM 3.6
- Estimated diffuse flow along the segment of McGregor Creek from RMs 2.1 to 1.7.

An evaluation of the temperature data available at MGRC-T9 indicate a narrower temperature range compared to the range at MGRC-T8. Although no channel geometry measurements were collected in the field at MGRC-T9, a few conclusions were drawn from the field notes that may explain why temperatures warmed slightly between MGRC-T8 and MGRC-T9.

- Stream depth was much deeper at MGRC-T9 than any other sampling location
- Stream velocity was very slow at MGRC-T9
- Minimum observed temperatures were warmer at MGRC-T9 as compared to MGRC-T8

Deeper stream depth at MGRC-T9 could dampen the effects of sunlight (i.e., solar radiation) upon McGregor Creek. During calibration, the simulated deeper depth and slower velocity at MGRC-T9 yielded a narrower temperature range and warmer minimum temperatures, as compared to MGRC-T8.

Warmer irrigation return flows may also explain the warming between MGRC-T8 and MGRC-T9. Various techniques were explored during calibration to simulate the in-stream warming observed at MGRC-T9 and such techniques included assigning warmer diffuse flows and varying the sediment thermal thickness and sediment thermal diffusivity. However, such techniques were excluded from the final calibration as they did not adequately replicate stream temperatures at MGRC-T9

Additionally, there was no significant shading (less than 10 percent) during the solar noon hours (i.e., the hour with the highest solar radiation energy). Thus, shade had minimal impact on McGregor Creek from MGRC-T8 to MGRC-T9 and shading could not explain the warmer observed temperatures at MGRC-T9.

Based on these sensitivity analyses, stream depth and velocity appeared to be critical factors along McGregor Creek from MGRC-T8 to MGRC-T9. Despite lacking channel geometry data at MGRC-T9, the constructed model reasonably simulated the convergence of the temperature at MGRC-T9.

4 Model Scenarios and Results

The McGregor Creek QUAL2K model was used to evaluate in-stream temperature response associated with multiple scenarios. **Table 7** summarizes the alterations to input parameters for each model scenario. The following sections present a discussion of the modifications to the QUAL2K models and the results for each scenario.

Table 7. QUAL2K model scenarios for McGregor Creek

Scenario [a]		Description	Rationale
Existing Condition Scenarios			
1	Critical Existing Condition [b]	Existing shade and irrigation practices under observed flows and critical summer weather conditions.	The baseline model simulation from which to construct the other scenarios and compare the results against.
Water Use Scenario			
2	15% reduction in withdrawals	Reduce existing withdrawals by 15 percent.	Represent application conservation practices for agricultural and domestic water use.
Shade Scenario			
3	50-foot buffer	Transform all vegetation communities, with the exception of hydrophytic shrubs, roads, and the 60-foot right-of-way adjacent to Highway 2 to **medium density trees** within 50 feet of the stream banks. Existing conditions vegetation to be retained beyond the 50-foot buffer.	Represent application of conservation practices for riparian vegetation.
Water Use and Shade Scenario			
4	Improved flow and shade	Existing conditions with critical flow (scenario 1), reduced withdrawals (scenario 2), and a 50-foot buffer (scenario 3).	Represent application of conservation practices for water withdrawals and riparian vegetation.

Notes

a. Scenarios were developed in accordance with electronic correspondence from the EPA task order manager Lisa Kusnierz to Tetra Tech's project manager Ron Steg on September 12, 2013.

b. The critical existing condition scenario was set to critical summer weather conditions and not to critical summer low-flow conditions (e.g., 25th percentile) due to dam operations and water rights in accordance with electronic correspondence from the EPA task order manager, Lisa Kusnierz, to Tetra Tech project manager, Ron Steg, on August 27, 2013.

4.1 Critical Existing Condition Scenario

The critical existing conditions model (scenario 1) serves as the baseline model simulation from which to construct the other scenarios and compare the results against. The critical existing condition scenario was run using the observed discharge in McGregor Creek (on the calibration date) and modified to represent critical meteorological conditions. Based on an analysis of a discharge records from a nearby USGS gage, flows in McGregor Creek during the calibration timeframe were likely above average (see **Appendix A, Section A-6**).

Meteorological conditions were established by calculating a critical meteorological condition using historical data from the Boorman RAWS. These changes included adjusting the air temperature; dew point temperatures, wind speed, and cloud cover to represent critical conditions. The Boorman RAWS has hourly data available for the period from January, 2004 through December 3012. Since the weather data extends only for a period of eight years, a nearby station with long-term meteorological data (Kalispell Glacier Park International Airport [1988-2012]) was queried to confirm if the period from 2004 to 2013 were not anomalously warm or cold years and were similar to the overall historical normal. The monthly median and maximum air temperatures for the period from 2004 to 2012 were estimated to be similar to the overall period from 1988 through 2012, indicating that the period from 2004 through 2012 were not anomalous years (**Figure 16**).

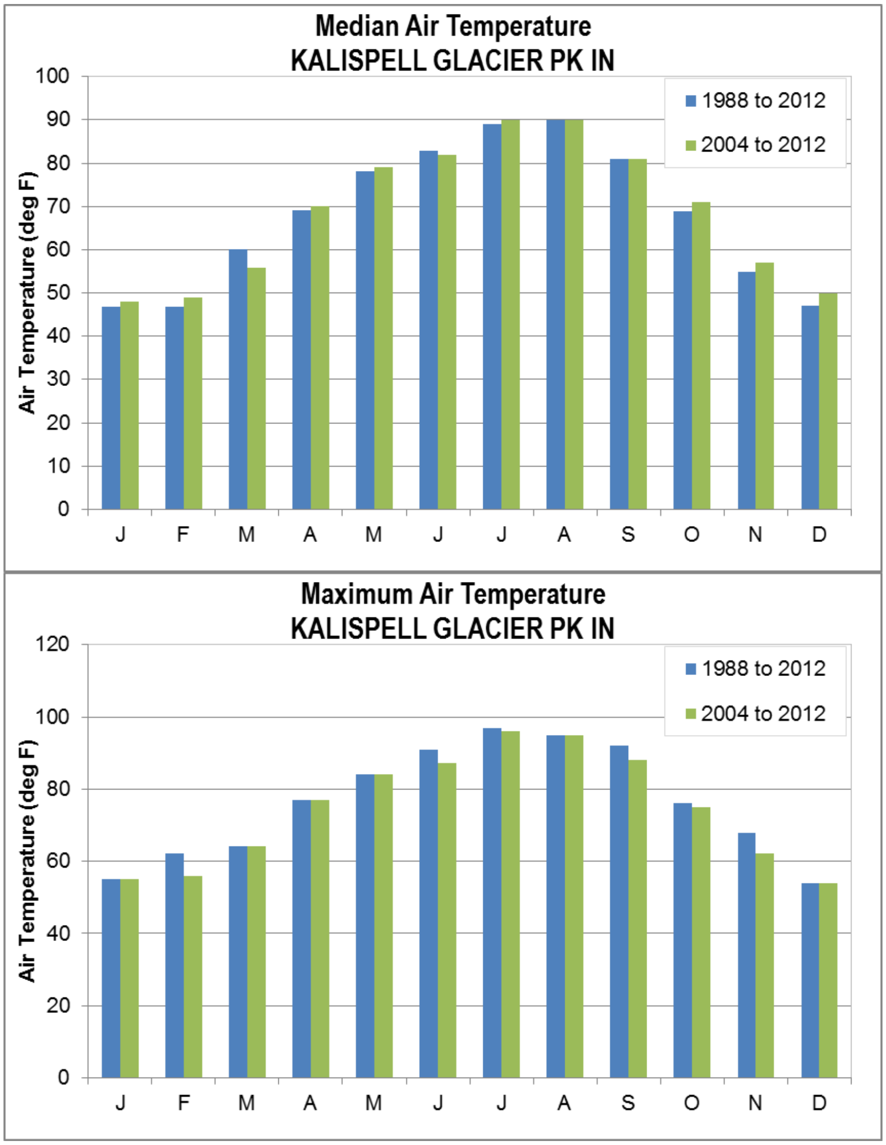

Figure 16. Monthly air temperature at Kalispell Glacier Park International Airport.

This Boorman RAWS data were then used to calculate the two day moving average of the daily maximum temperature. The 2-day duration for averaging was selected based on the travel time of the McGregor Creek QUAL2K model, which was 32 hours for the calibration. The maximum of the two day maximum air temperature for each year was then calculated for the month of July. Using this dataset the median air temperature was then calculated across the years, which defined the critical temperature period. Once the critical temperature period was identified, the hourly air temperature, dew point temperature and wind data represented by the critical two day period were averaged to create an hourly data set to represent the critical meteorological conditions in the model. The cloud cover in the model was set to zero to represent clear sky conditions. The modeled water temperature using the critical flow and meteorological data is shown below in **Figure 17**.

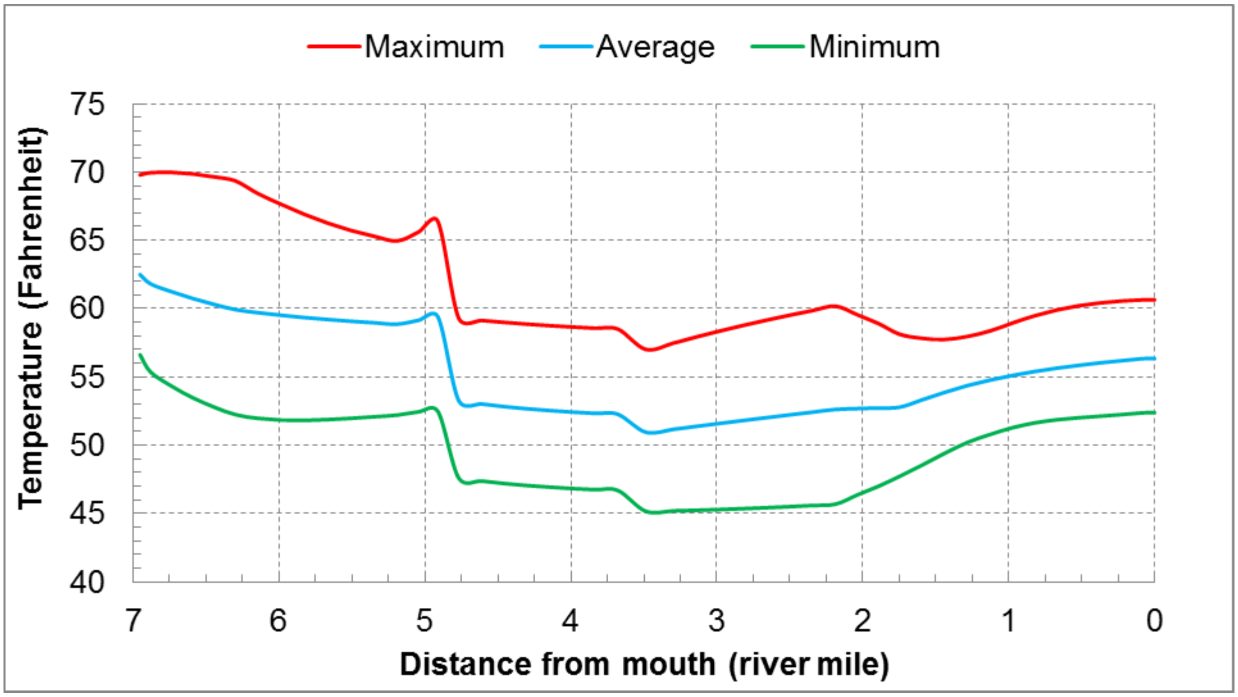

Figure 17. Simulated water temperature for existing critical condition.

4.2 Water Use Scenarios

Irrigation (or other water withdrawals) depletes the volume of water in the stream and reduces in-stream volumetric heat capacity. Theoretically the reduced stream water volume heats up more quickly, and to a higher temperature, given the same amount of thermal input. A single water use scenario was modeled to evaluate the potential benefits associated with application of water use best management practices (scenario 2).

In this scenario, the point source abstractions representing the withdrawals (see **Appendix A** for the withdrawals) in the QUAL2K model are reduced by 15 percent (NRCS 1997). The water previously withdrawn is now allowed to flow down McGregor Creek. This scenario is intended to represent application of water conservation practices for water withdrawals.

Water temperatures in McGregor Creek for this scenario generally decreased slightly in the lower reaches (**Figure 18**). A maximum change in the maximum daily water temperature of 0.4° F from the existing condition was observed in the segment from river mile 0.52, which can just barely be seen in **Figure 18**. The difference in water temperature was always less than 0.5° F, signifying minimal sensitivity and conditions that are similar to the critical existing condition.

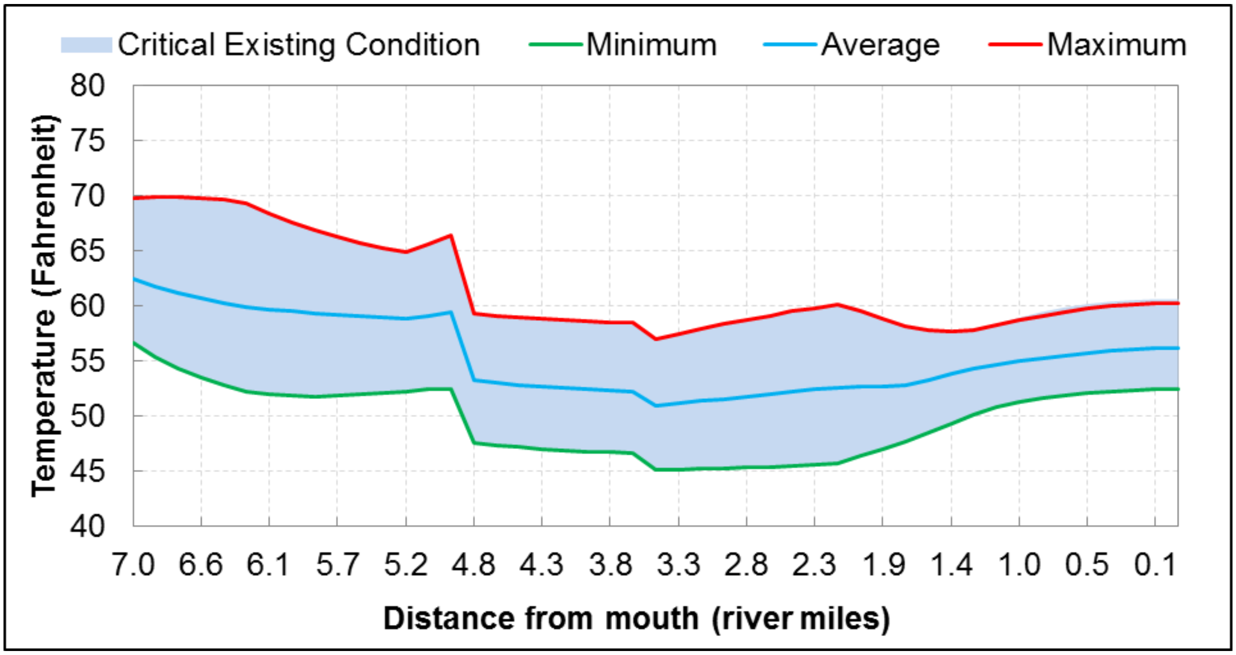

Figure 18. Simulated water temperatures for the critical existing condition (scenario 1) and 15-percent withdrawal reduction (scenario 2).

4.3 Shade Scenarios

The riparian plant community blocks incoming solar radiation, which directly reduces the heat load to the stream. A single shade scenario was modeled to evaluate the potential benefits associated with increased shade within a 50-foot buffer along McGregor Creek.

The 50-foot buffer scenario consists of the existing condition scenario with a 50-foot buffer along the stream channel where vegetation is allowed to grow naturally. All vegetation communities (with the exception of hydrophytic shrubs, roads, and a 60-foot right-of-way adjacent to Highway 2) are transformed to medium density trees within 50 feet of the stream banks. Beyond 50 feet, existing condition vegetation remains. The Shade Model was re-run using this vegetation configuration (**Figure 19**). The 50-foot buffer was selected to be generally consistent with Montana's Streamside Management Zone Law, which limits clear cutting within 50 feet of the ordinary high water mark in order to provide large woody debris, stream shading, water filtering effects, and to protect stream channels and banks. This scenario is intended to represent application of *all reasonable land, soil and water conservation practices* relative to shade. The technical basis for this scenario is provided in **Appendix A** in **Section A-4**.

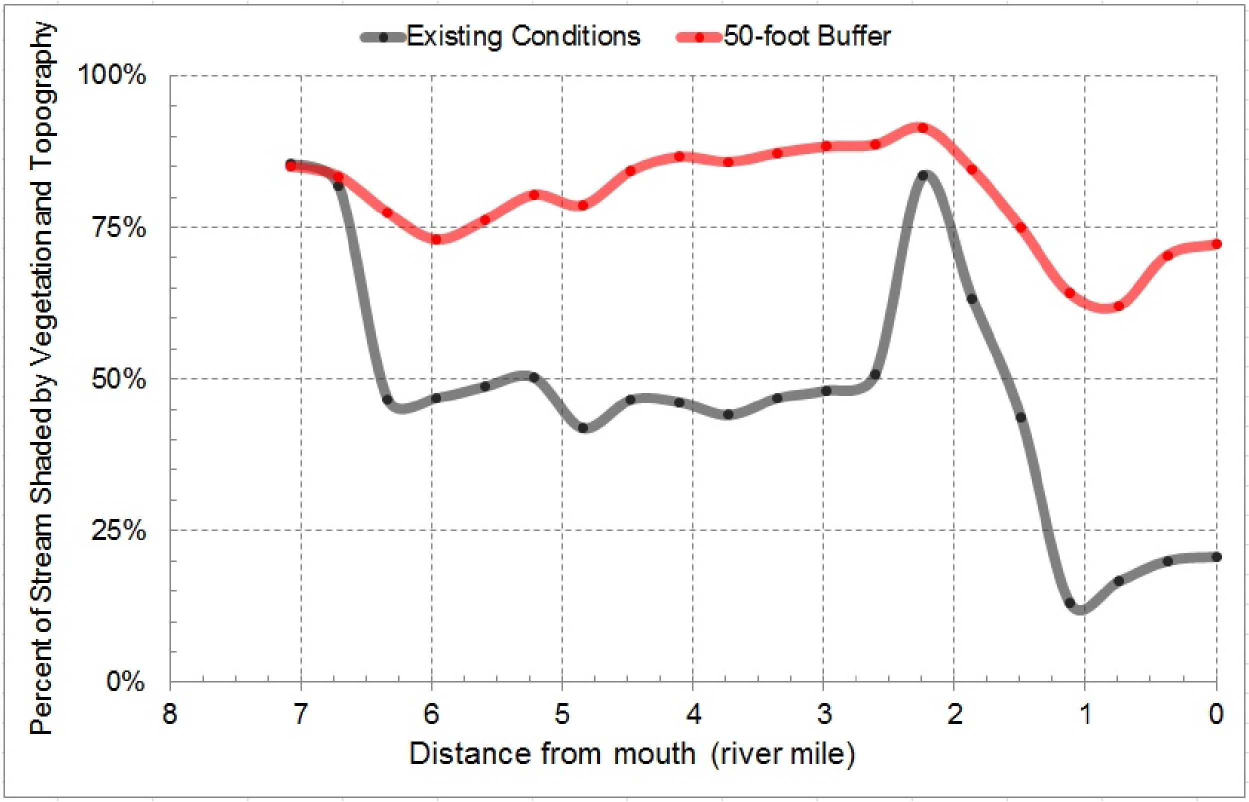

Figure 19. Effective shading along McGregor Creek for the critical existing condition and 50-foot buffer shade scenario.

The water temperatures for McGregor Creek in this scenario decrease throughout the system (**Figure 20**). A maximum change in the maximum daily water temperature of 7.3° F from the existing condition was observed at river mile 4.9. The difference in the daily maximum water temperature between the existing condition and maximum potential shade scenario was always greater than 0.5° F.

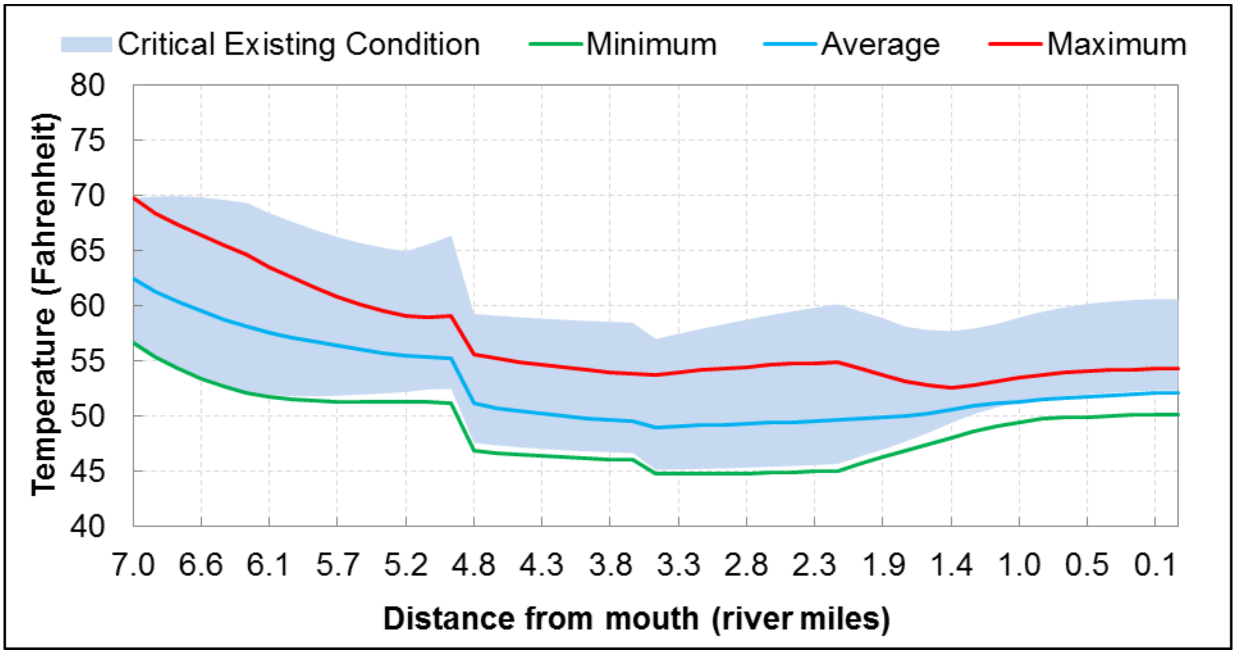

Figure 20. Simulated water temperatures for the critical existing condition (scenario 1) and shade with 50 feet buffer (scenario 3).

4.4 *Improved Flow and Shade Scenario*

The improved flow and shade scenario (scenario 4) combines the potential benefits associated with a 15 percent reduction in water withdrawals (scenario 2) with a 50-foot vegetated buffer (scenario 3). The headwater inputs below Palm Dam at the outlet of McGregor Lake were not altered as the dam was constructed prior to 1971 and is considered natural.

The water temperatures for McGregor Creek in this scenario decrease throughout the system (**Figure 21** and **Figure 22**). A maximum change in the maximum daily water temperature of 7.3° F from the critical existing condition was observed at river mile 4.9. The results are similar to scenario 3 since scenario 2 showed negligible sensitivity to a 15 percent reduction in the withdrawals. The difference in the daily maximum water temperature between the existing condition and maximum potential shade scenario was always greater than 0.5° F for this scenario.

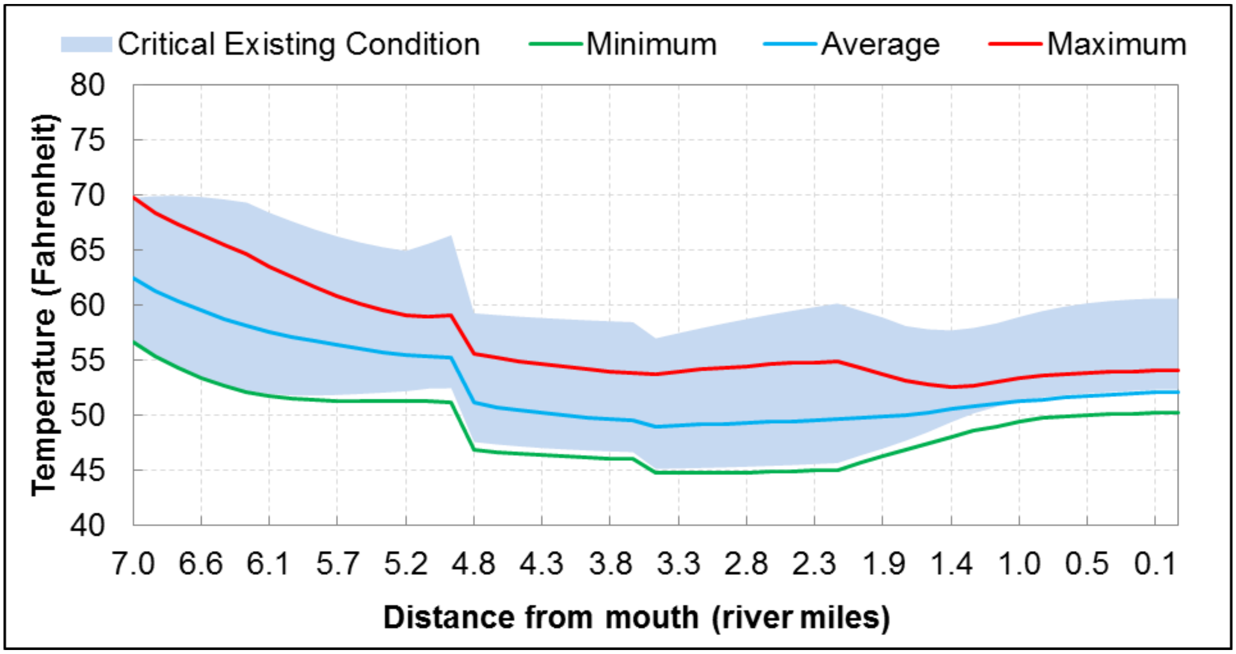

Figure 21. Simulated water temperature for the critical existing condition (scenario 1) and the improved flow and shade scenario (scenario 4).

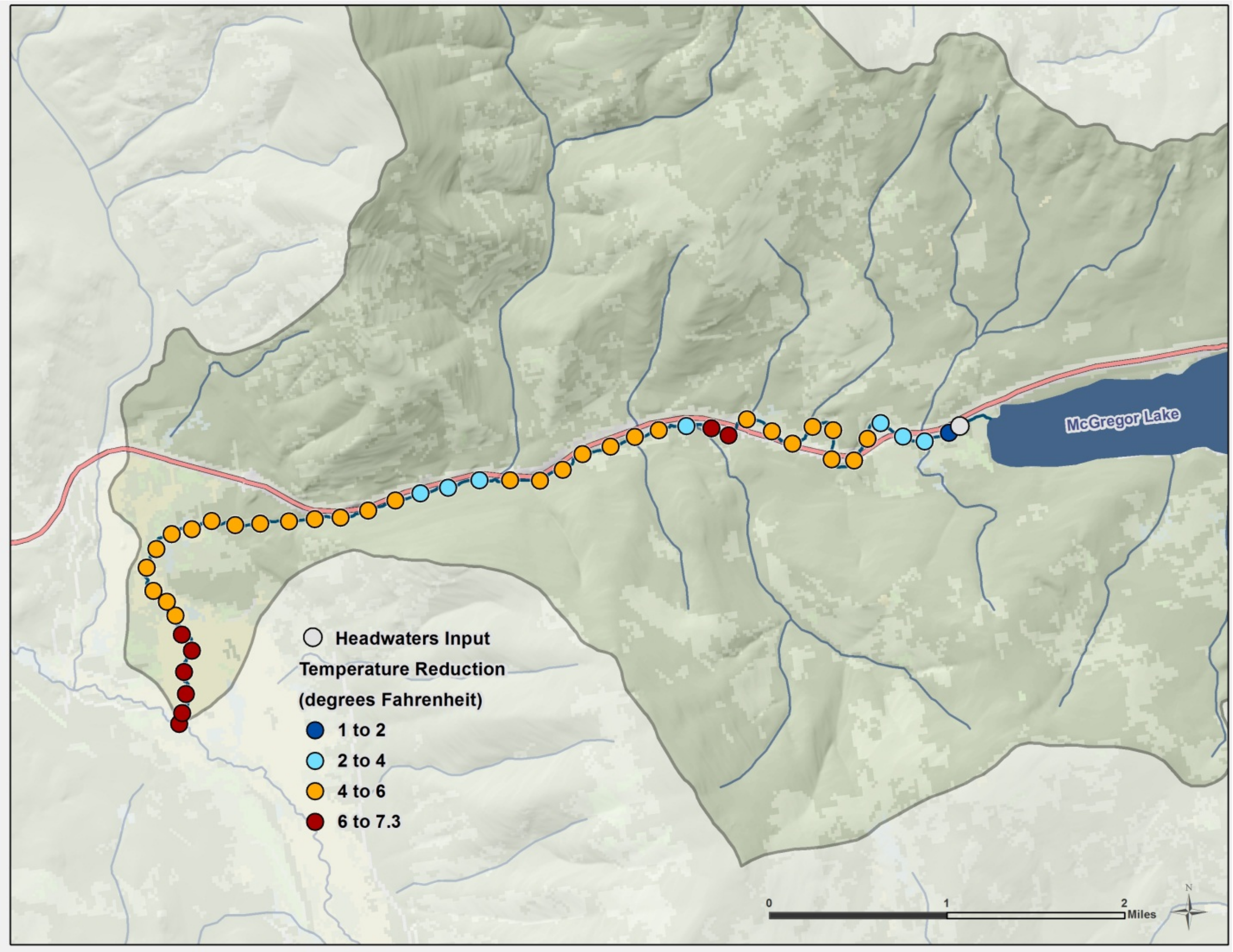

Figure 22. In-stream temperature difference from the critical existing condition (scenario 1) to the improved flow and shade scenario (scenario 4).

5 Assumptions and Uncertainty

As with any model, the QUAL2K model is subject to uncertainty. The major sources of model uncertainty include the mathematical formulation, input and boundary conditions data uncertainty, calibration data uncertainty, and parameter specification (Tetra Tech 2012). As discussed in the QAPP (Tetra Tech 2012), the QUAL2K model code has a long history of testing and application, so outright errors in the coding of the temperature model is unlikely. The Shade Model has also been widely used so a similar sentiment exists. A potentially significant amount of the overall prediction uncertainty is due to uncertainty in the observed data used for model setup, calibration, and validation.

The secondary data used during model setup included instantaneous flow, continuous temperature, channel geometry, hourly weather, and spatial data. Weather and spatial data were obtained from other government agencies, were found to be in reasonable ranges, and the data are therefore assumed to be accurate. Uncertainty was minimized for the use of other secondary data following procedures described in the QAPP (Tetra Tech 2012).

In addition to uncertainty associated with secondary datasets, assumptions regarding how the secondary data are used during model development contain uncertainty. The following key assumptions were used during model development:

- McGregor Creek can be divided into distinct segments, each considered homogeneous for shade, flow, and channel geometry characteristics. Monitoring sites at discrete locations were selected to be representative of segments of McGregor Creek.
- Spatial variability of velocity and depth (e.g. stream meander and hyporheic flow paths) are represented through exponents and coefficients of the selected rating curves for each segment.
- Weather conditions at the Boorman RAWS, which were elevation-corrected, are representative of local weather conditions along McGregor Creek.
- Shade Model results are representative of riparian shading along segments of McGregor Creek. Shade Model development relied upon the following three estimations of riparian vegetation characteristics:
    - Riparian vegetation communities were identified from visual interpretation of aerial imagery.
    - Tree height and percent overhang were estimated from other similar studies conducted outside of the McGregor Creek watershed.
    - Vegetation density was estimated using the NLCD and best professional judgment.

  Shade Model results were corroborated with field measured Solar Pathfinder^{TM} results and were found to be reasonable. The average absolute mean error is 8 percent. (i.e., the average error from the Shade Model output and Solar Pathfinder^{TM} measurements was 8 percent daily average shade).
- All of the cropland associated with water rights is fully irrigated. No field measurements of irrigation withdrawals or returns were available.
- Simulated diffuse flow rates are representative of groundwater inflow/outflow, irrigation diversion, irrigation return flow, and other sources of inflow and outflow not explicitly modeled. Diffuse flow rates were estimated using flow mass balance equations for each model reach.

- Shallow groundwater temperature is approximately 45.5° F and 49.1° F (as the model was calibrated and validated), which were derived, in part, from the average of mean daily air temperatures from the preceding year and from groundwater temperature measurements from nearby wells.

Sensitivity analysis is the most widely applied parameter uncertainty analysis approach for complex simulation models. Although sensitivity analysis is limited in its ability to evaluate nonlinear interactions among multiple parameters, model sensitivity was evaluated by making changes to shade and water use (i.e., the key thermal mechanisms [Tetra Tech 2012]) in separate model runs and evaluating the model response.

The increased shade scenario (scenario 3) assumes that the system potential vegetation for the riparian area within 50 feet of the stream bank is medium density trees (i.e., with the exception of areas currently dominated by hydrophytic shrubs or areas such as roads that no longer have the potential to support vegetation). The increased shade scenario (scenario 3) represents the maximum temperature benefit that could be achieved over a time period long enough to allow vegetation to mature (tens of years). Therefore, temperature improvements in the short term are likely to be less than those identified in the scenario 3 results. Natural events such as flood and fire may also alter the maximum potential for the riparian vegetation or shift the time needed to achieve the maximum potential. This condition may not be achievable for all areas due to the coarse scaled used to identify the current and potential shade conditions.

Model Sensitivity to Water Withdrawals and Shade

Model sensitivity to water withdrawal and shade was further evaluated by varying the amounts of water withdrawn and shade and re-running the model. To assess model sensitivity to water withdrawals, the point source abstractions representing the withdrawals (see ***Appendix A*** *for the withdrawals) were removed and the existing condition model was run to represent the maximum achievable change in water temperatures from changes in water use. To assess model sensitivity to shade, all vegetation was converted to high density trees (with the exception of roads, railroads, and hydrophytic shrubs) to represent the maximum potential shade. While not likely feasible, these conditions were run to assess model sensitivity. The results suggest that the model is not very sensitive to changes in water use but is sensitive to changes in shade.*

6 Model Use and Limitations

The model is only valid for summertime, low flow conditions and should not be used to evaluate high flow or other conditions. As described above, steps were taken to minimize uncertainty as much as possible. Despite the uncertainty, the model adequately addresses the primary questions:

1. What is the sensitivity of in-stream temperature to the following thermal mechanisms and stressors: shade, irrigation withdrawal and return?
2. What levels of reductions in controllable stressors are needed to achieve temperature standards?

The first principal study question can be answered using the calibrated and validated QUAL2K model for McGregor Creek. As previously discussed, McGregor Creek is sensitive to shade.

The second principal study questions can be answered using the calibrated QUAL2K model and the scenarios developed to assess shade. Increasing riparian shading will decrease in-stream temperatures; however, there is uncertainty in the magnitude of temperature reduction necessary to achieve the temperature standard caused by uncertainty in the Shade Model results and QUAL2K model results. While a “good” model calibration was achieved, the overall Absolute Mean Error (AME) for the maximum daily temperature was 1.7° F.

Montana’s temperature standard as applied to McGregor Creek is limited to an increase of 1° F. The model results, therefore, should be used with caution relative to the second primary question. However, in spite of the uncertainty, the magnitude of difference between the maximum daily temperatures under the scenarios 1 and 4 is greater than the AME for most of the length of McGregor Creek (**Figure 23**). This suggests that, on average[4], a reduction of 4.9°F (range: 1.6° F to 7.3° F) is necessary to achieve the temperature standard in McGregor Creek.

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[4] Spatial average of the QUAL2K output at each element along the entire length of McGregor Creek.

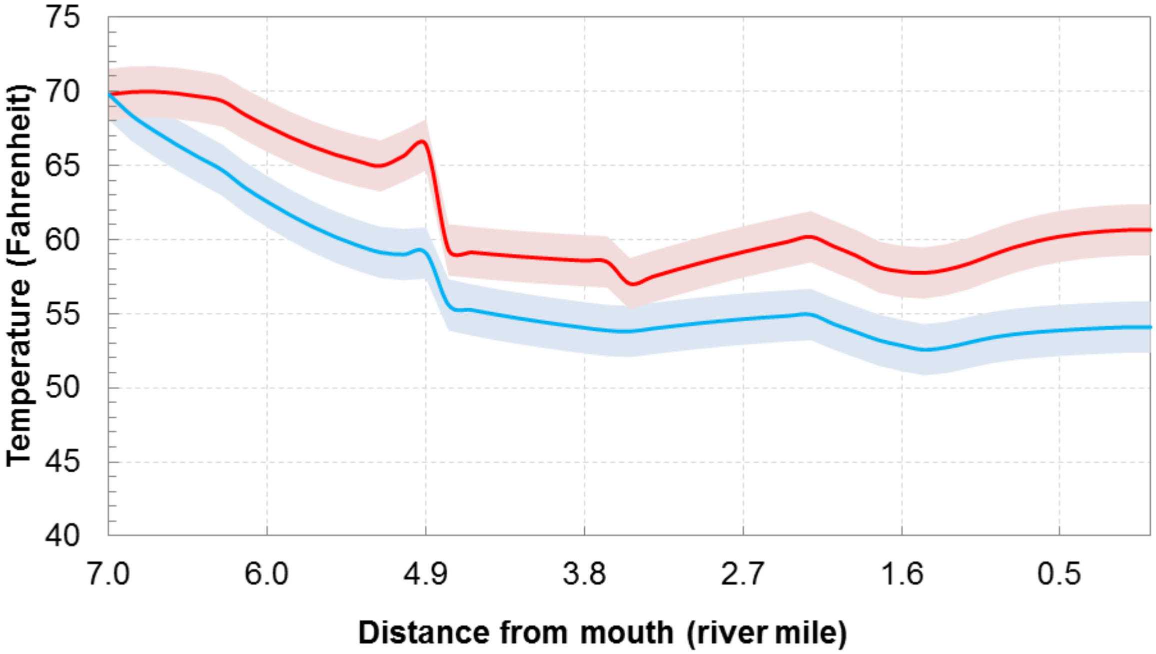


Figure 23. Simulated daily maximum water temperatures from the critical existing condition (red; scenario 1) and improved flow and shade scenario (blue; scenario 4).

7 Conclusions

The scenarios resulted in a range of no change in water temperatures to reductions as much as 7.3° F. Some of the reductions in water temperatures were localized and others affected nearly the entire reach.

A flow scenario representing irrigation efficiency was evaluated and the locations that showed the greatest potential for improvement were localized to areas just downstream of the existing withdrawals. The 15-percent reductions in water use did not result in any appreciable reduction to the temperature with a maximum change of 0.4° F.

The shade scenario showed the greatest extent and impact (reduction) to water temperatures along the entire reach. The 50-foot buffer scenario that represents a more realistic representation of potential shade improvements showed reductions in temperature ranging from 1.6 ° F to 7.3° F.

The improved flow and shade scenario that combined the potential benefits associated with a 15 percent reduction in water withdrawals (scenario 2) with a 50-foot vegetated buffer (scenario 3) to represent application of conservation practices was also simulated. This scenario resulted in overall reductions along the entire reach which ranged from 1.6 ° F to 7.3 ° F. The scenario shows that significant reductions in water temperatures are achievable throughout the reach (**Figure 22**). The areas with the greatest changes demonstrate the most sensitive areas. The greatest potential improvement (i.e., reduction) occurs near river mile 5 (about a 7° F improvement) with several other areas upstream and downstream along the system also showing sensitivity to shade (**Figure 25**). Hence efforts should largely be spent on re-vegetation in those areas most amenable to this type of restoration activity.

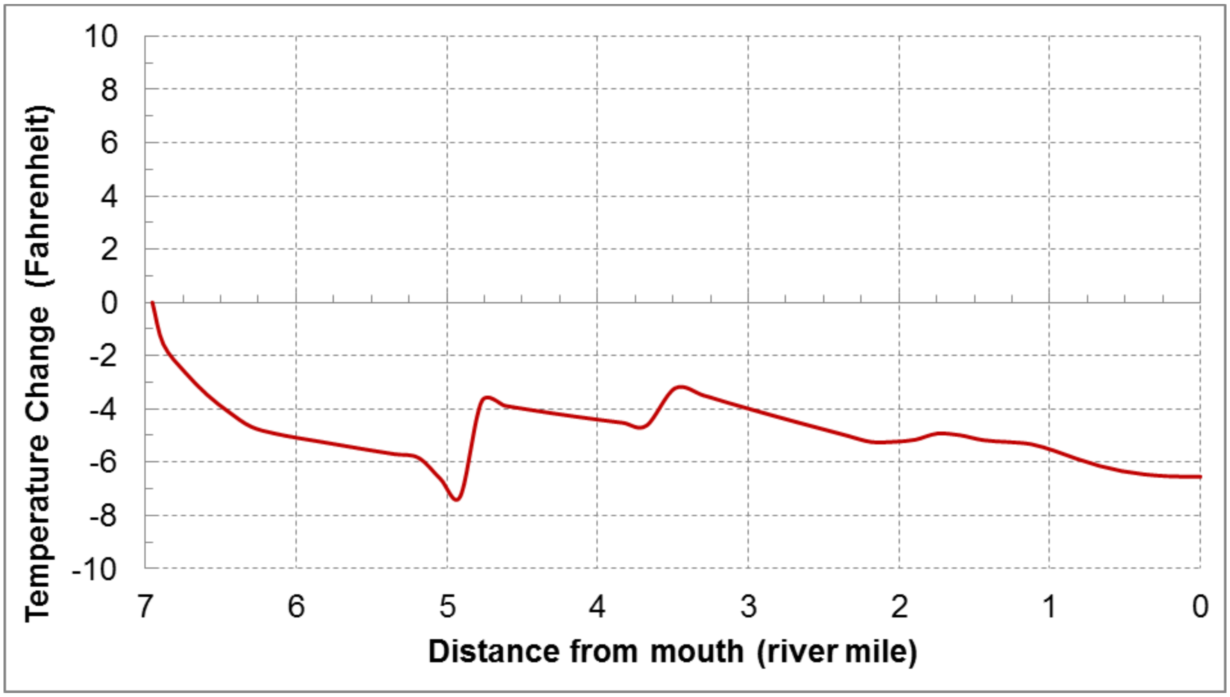


Figure 24. Simulated water temperature reduction from the critical existing condition (scenario 1) to the improved flow and shade scenario (scenario 4).

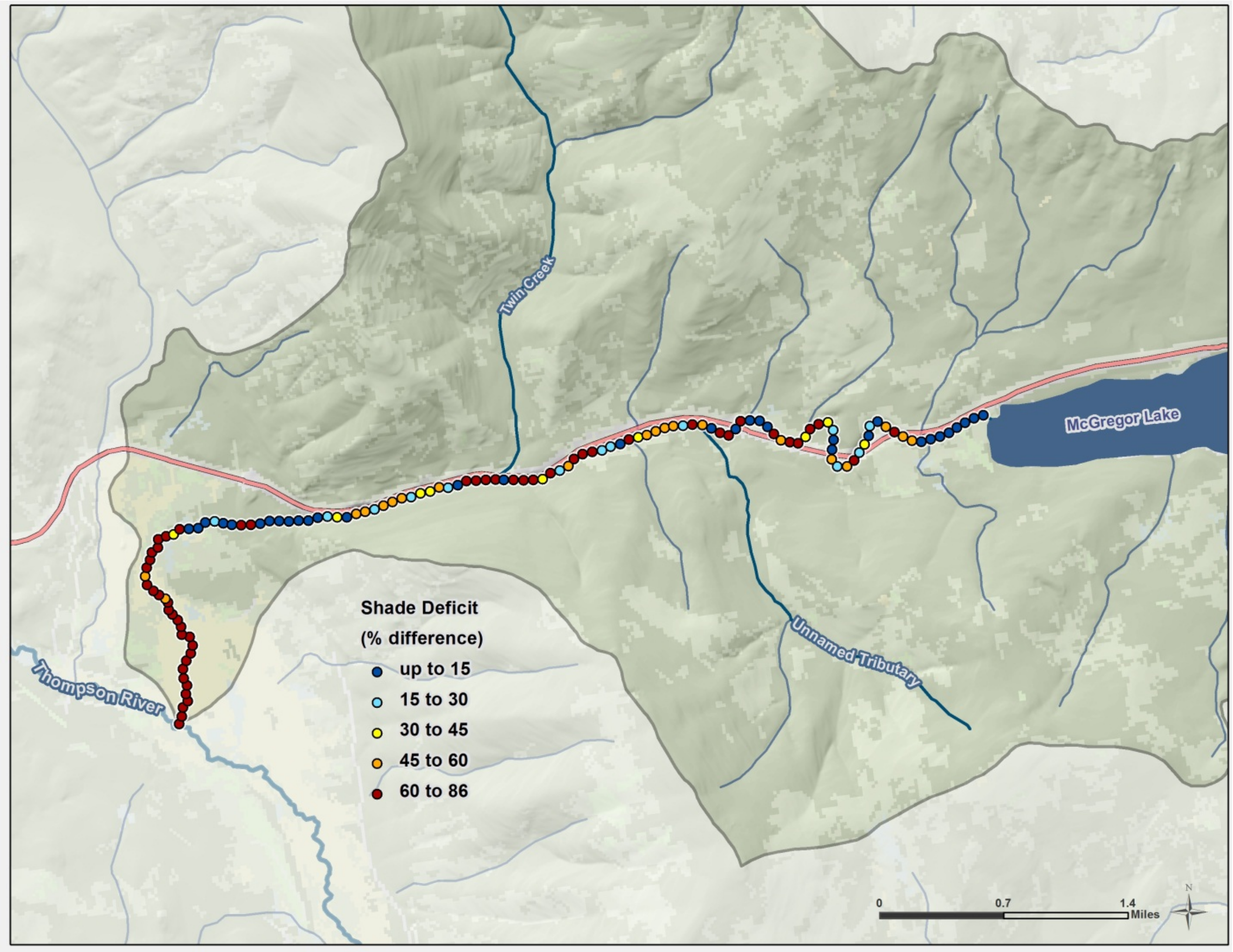


Figure 25. Shade deficit of the critical existing condition (scenario 1) from the improved flow and shade scenario (scenario 4).

8 References

Bartholow, J.M., 2000. Estimating cumulative effects of clear cutting on stream temperatures, Rivers, 7(4), 284-297.

Chapra, S.C., 1997. Surface water quality modeling. McGraw-Hill Companies, Inc.

Chapra, S., G. Pelletier, and H. Tao. 2008. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.11: Documentation and User's Manual. Tufts University, Civil and Environmental Engineering Department, Medford, MA.

Chow, V.T., D.R. Maidment, and L.W. Mays, 1988. Applied Hydrology. McGraw-Hill, New York. 592 pp.

Coffin, C., and S. Lee. June 2011. Green River Temperature Total Maximum Daily Load: Water Quality Improvement Report. Washington State Department of Ecology. Publication No. 11-10-046. (https://fortress.wa.gov/ecy/publications/publications/1110046.pdf).

CREM (Council for Regulatory Environmental Modeling). 2009. *Guidance on the Development, Evaluation, and Application of Environmental Models.* EPA/100/K-09/003. Office of the Science Advisor, Council for Regulatory Environmental Modeling, U.S. Environmental Protection Agency, Washington, DC.

DEQ (Montana Department of Environmental Quality). 2012. Water Quality Assessment Database. Montana Department of Environmental Quality, Clean Water Act Information Center. <http://cwaic.mt.gov/query.aspx>. Accessed March 16, 2012.

Marcus, A, K. Roberts, L. Harvey, and G. Tackman. 1992 An Evaluation of Methods for Estimating Manning's n in Small Mountain Streams. *Mountain Research and Development 12(3):* 227-239.

MRLC (Multi-Resolution Land Characteristics Consortium). 2006. *National Land Cover Dataset 2006*. <http://www.mrlc.gov/nlcd2006.php>. Accessed June 28, 2012.

NCDC (National Climatic Data Center). 2012. *Monthly Summaries GHCND.* <http://www.ncdc.noaa.gov/land-based-station-data/find-station>. Accessed December 6, 2012.

NRCS (Natural Resources Conservation Service). 1997. National Engineering Handbook Irrigation Guide, Part 652. United States Department of Agriculture, Natural Resources Conservation Service. Washington, D.C.

NRIS (Natural Resources Information System). 2012. *GIS Data List.* <http://nris.mt.gov/gis/gisdatalib/gisDataList.aspx>. Accessed June 28, 2012.

Oregon Department of Environmental Quality. 2001. TTools 3.0 Users Manual. Oregon Department of Environmental Quality.

Poole, G.C., Risley, J. and M. Hicks. 2001. Issue Paper 3 – Spatial and Temporal Patterns of Stream Temperature (Revised). United States Environmental Protection Agency. EPA-910-D-01-003.

Shumar, M. and J. de Varona. 2009. The Potential Natural Vegetation (PNV) Temperature Total Maximum Daily Load (TMDL) Procedures Manual. Idaho Department of Environmental Quality. State Technical Services Office. Boise, ID.

Stuart, T. 2012. Asotin Creek Temperature Straight-to-Implementation Vegetation Study. Washington State Department of Ecology. Eastern Regional Office. Spokane, WA

Tetra Tech. 2012. *Quality Assurance Project Plan for Montana TMDL Support: Temperature Modeling*. QAPP 303 Revision 1, June 29, 2012. Prepared for the U.S. Environmental Protection Agency, by Tetra Tech, Inc., Cleveland, OH.

Western Regional Climate Center. 2013. Boorman RAWS. http://www.raws.dri.edu/cgi-bin/rawMAIN.pl?inMBOO. Accessed June 19, 2013.

Appendix A.

Factors Potentially Influencing Stream Temperature in McGregor Creek

Contents

Tables

Figures

• Introduction

Stream temperature regimes are influenced by processes that are external to the stream as well as processes that occur within the stream and its associated riparian zone (Poole et. al., 2001). Examples of factors external to the stream that can affect in-stream water temperatures include: topographic shade, land use/land cover (e.g., vegetation and the shading it provides, impervious surfaces), solar angle, meteorological conditions (e.g., precipitation, air temperature, cloud cover, relative humidity), groundwater exchange and temperature, and tributary inflow temperatures and volumes. The shape of the channel can also affect the temperature—wide shallow channels are more easily heated and cooled than deep, narrow channels. The amount of water in the stream is another factor influencing stream temperature regimes. Streams that carry large amounts of water resist heating and cooling, whereas temperature in small streams (or reduced flows) can be changed more easily.

The following factors that may have an influence on stream temperatures in McGregor Creek are discussed below:

- Local/regional climate
- Land ownership
- Land use
- Riparian vegetation
- Shade
- Hydrology
- Point sources

- ## Climate

The nearest weather station to the McGregor Creek watershed is located four miles to the north in Pleasant Valley, Montana (Station 246580). Average annual precipitation is 13.2 inches with the greatest amounts falling in February and June (**Figure A-26**). Average maximum temperatures occur in July and August and are 81.4° F and 80.3°F, respectively (**Figure A-27**).

It should be noted the Pleasant Valley weather station is located at an elevation of 3,550 feet above mean sea level (MSL), compared to the impaired reach of McGregor Creek which ranges in elevation from approximately 3,900 to 3,340 feet above MSL.

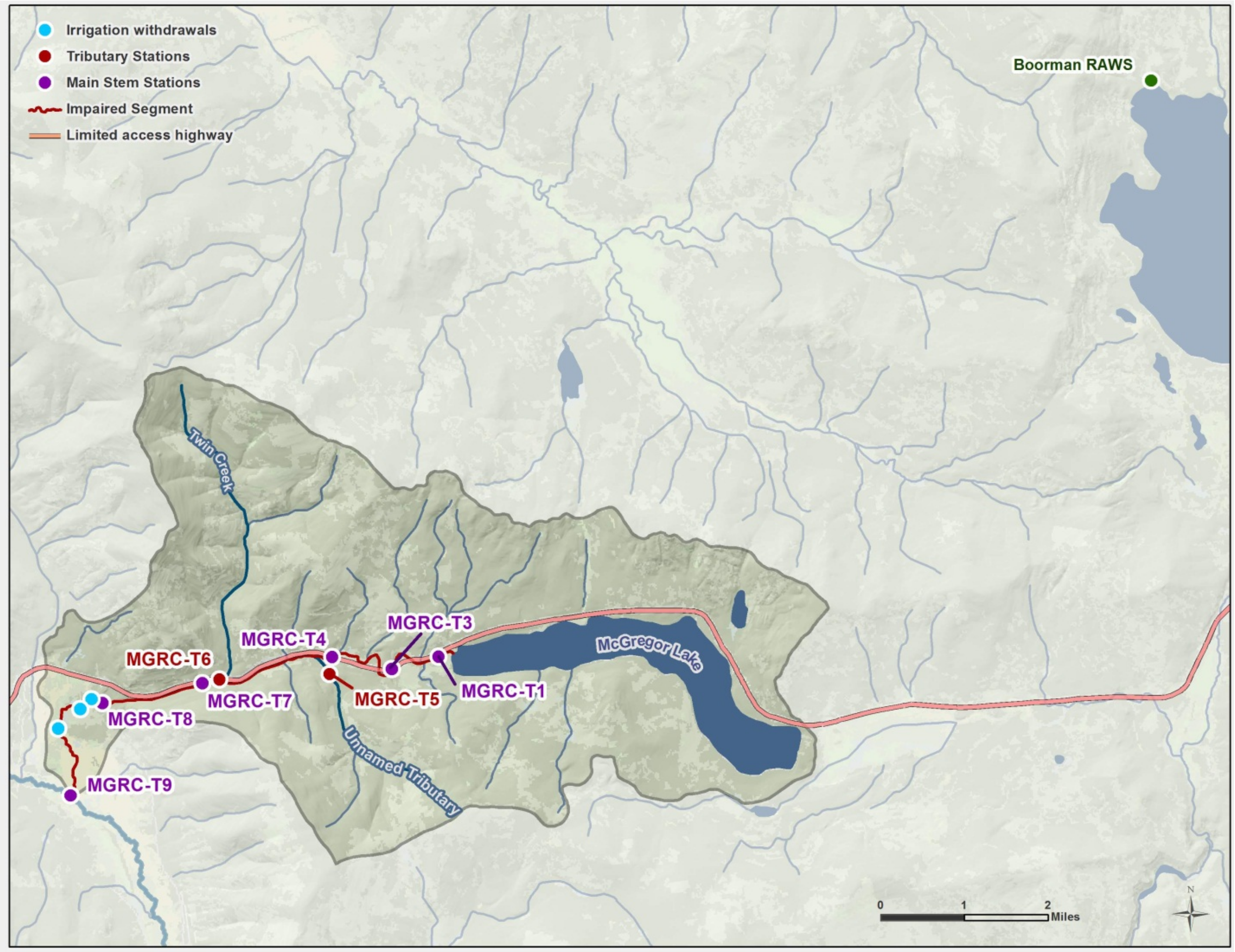
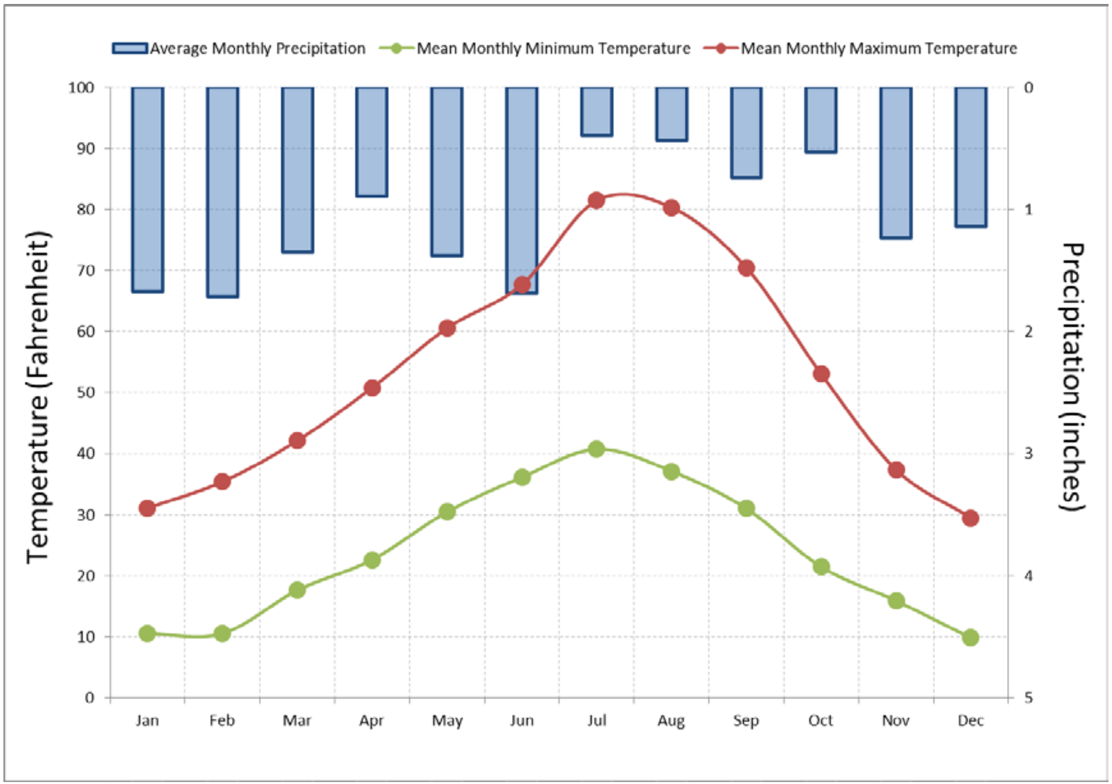


Figure A-26. McGregor Creek watershed.



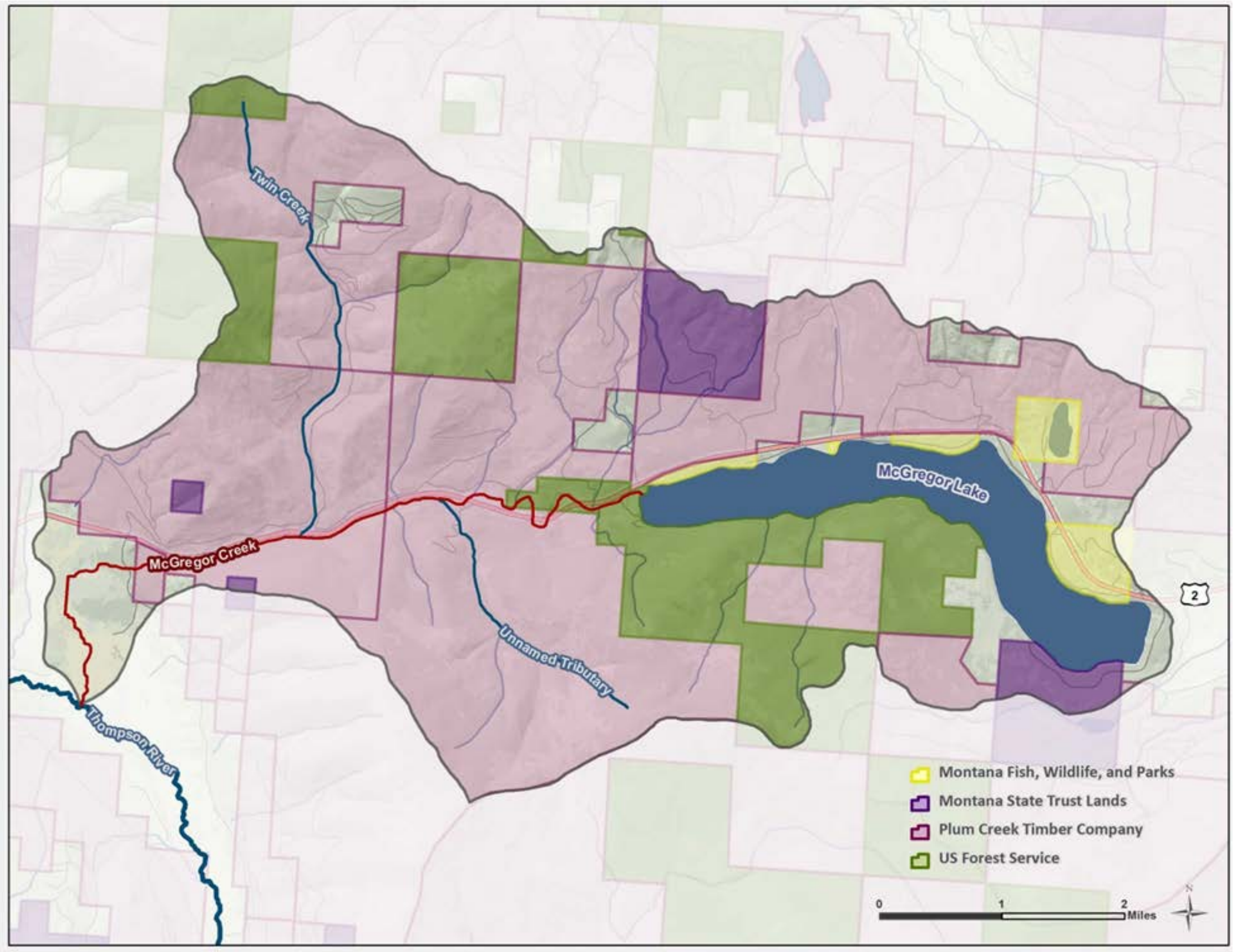
Source: GHCN-D Monthly Summaries from 2001 to 2012 at Station 246580 (NCDC)

Figure A-27. Monthly average temperatures and precipitation at Pleasant Valley, Montana.

As discussed in the main report, the Pleasant Valley station only has hourly air temperature data and does not have additional hourly datasets necessary for QUAL2K modeling. The Boorman RAWS records hourly air temperature, dew point temperature, wind speed and solar radiation and these data were used to develop the QUAL2K model.

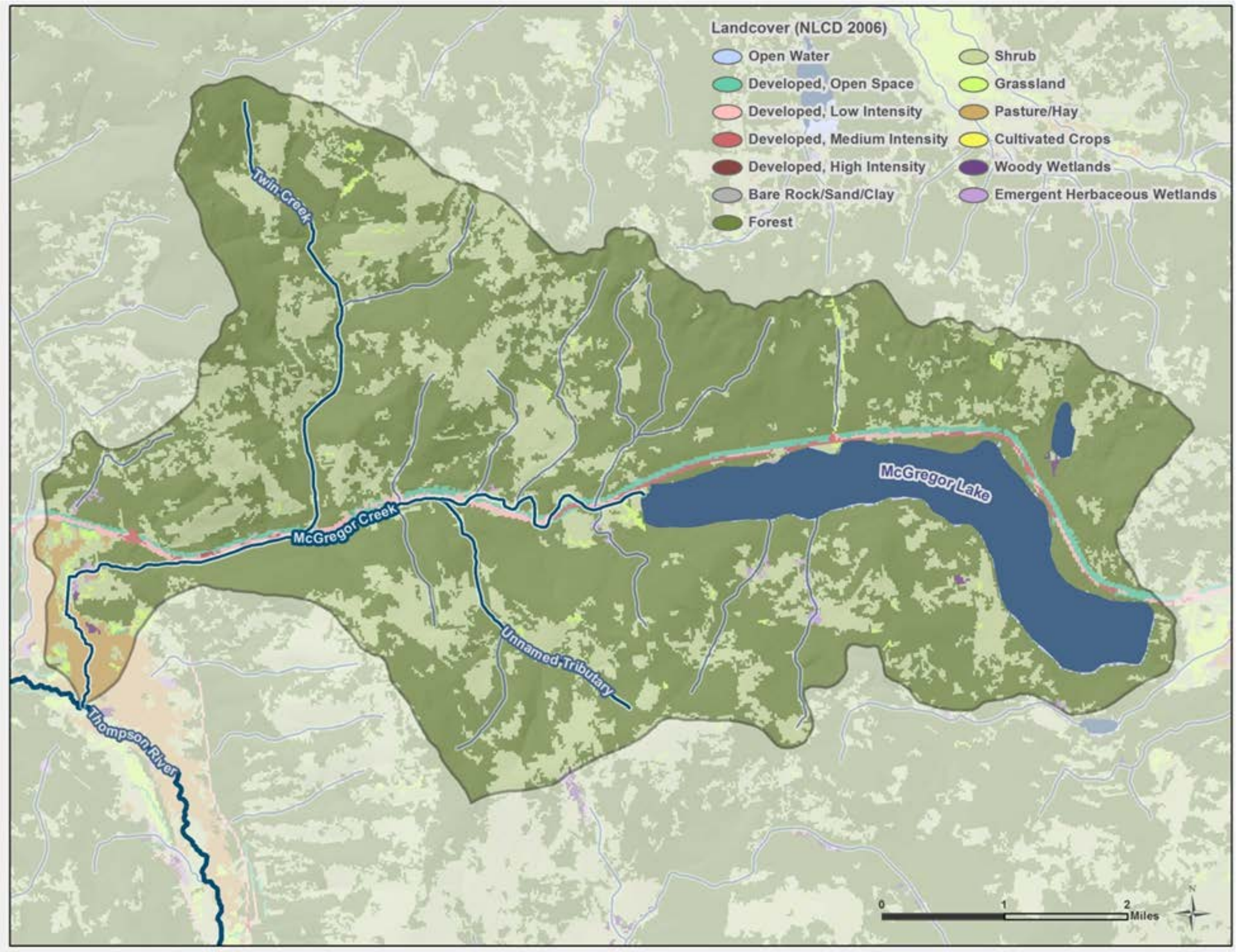
Land Ownership and Land Use

Most of the McGregor Creek watershed is owned by the Plum Creek Timber Company (**Figure A-28**). The landscape is typical of timber harvest conditions, with patches of mature forest interspersed with selective harvests and clearcuts at various stages of regrowth. The U.S. Forest Service owns a section of land bordering the southern edge of McGregor Lake, which is used for camping and recreation. The lower reaches of the watershed transition into a broad, flat privately owned pasture land (**Figure A-29** and **Figure A-30**). U.S. Highway 2 bisects the watershed, crossing McGregor Creek in several locations.



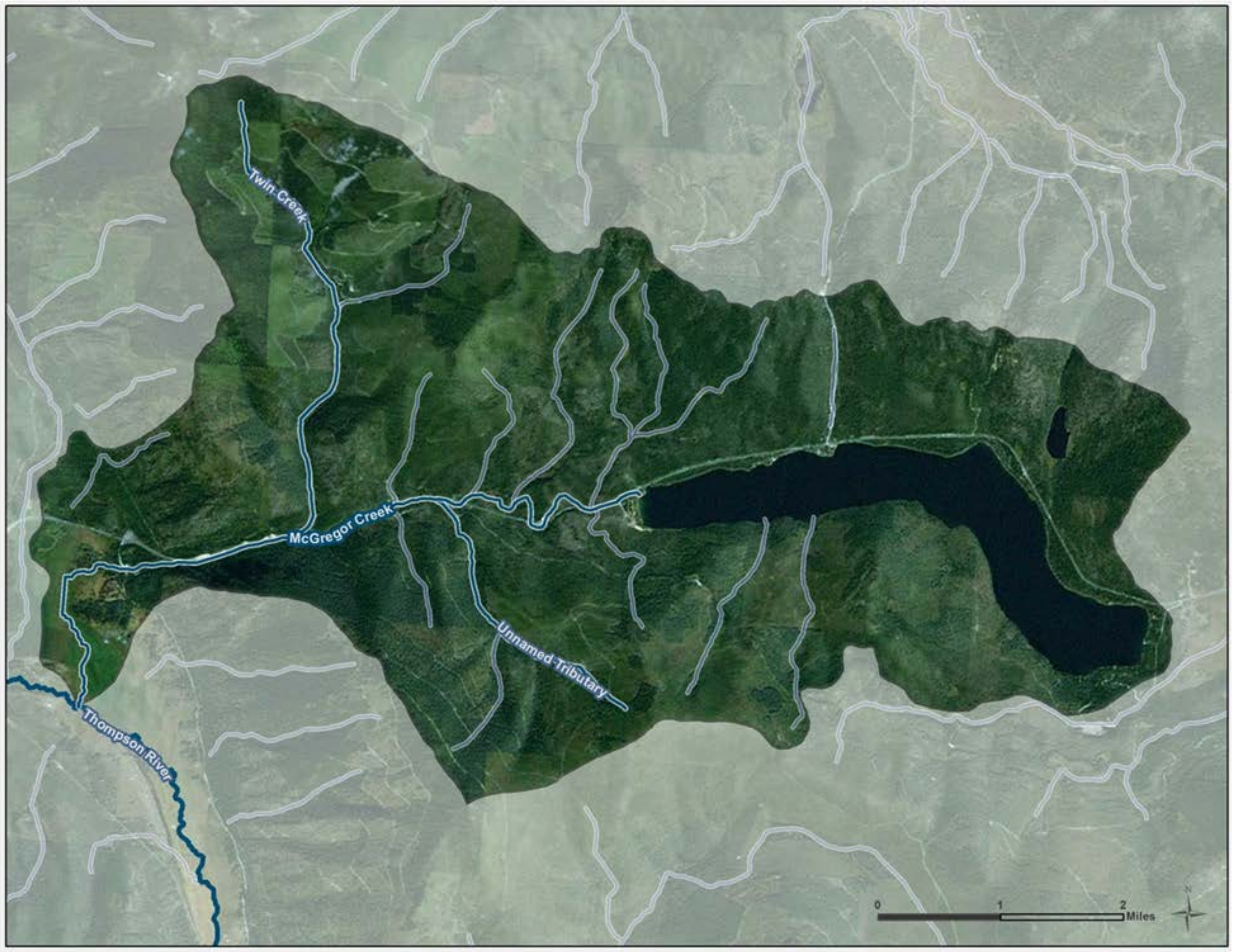
Source of land ownership: NRIS 2012.

Figure A-28. Land ownership in the McGregor Creek watershed.



Source of land cover: 2006 National Land Cover Dataset (Multi-Resolution Land Characteristics Consortium 2006).

Figure A-29. Land cover and land use in the Wolf Creek watershed.



Source of aerial Imagery: 2009 NAIP (NRIS 2012).

Figure A-30. Aerial imagery of the McGregor Creek watershed.

• Existing Riparian Vegetation

Vegetation communities between the shade monitoring sites were visually characterized based on aerial imagery (Google Earth 2012) with qualitative field verification conducted during July 14-15, 2011 shade monitoring. Observed vegetative communities within 150 feet of the stream centerline were classified as trees, shrubs, herbaceous. Areas without vegetation, such as bare earth or roads, were also identified. Trees were further divided into the following classes based on percent canopy cover derived from the 2001 NLCD (**Figure A-31**):

- High density (75 to 100 percent cover)
- Medium density (51 to 74 percent cover)
- Low density (25 to 50 percent cover)
- Sparse density (less than 24 percent cover)

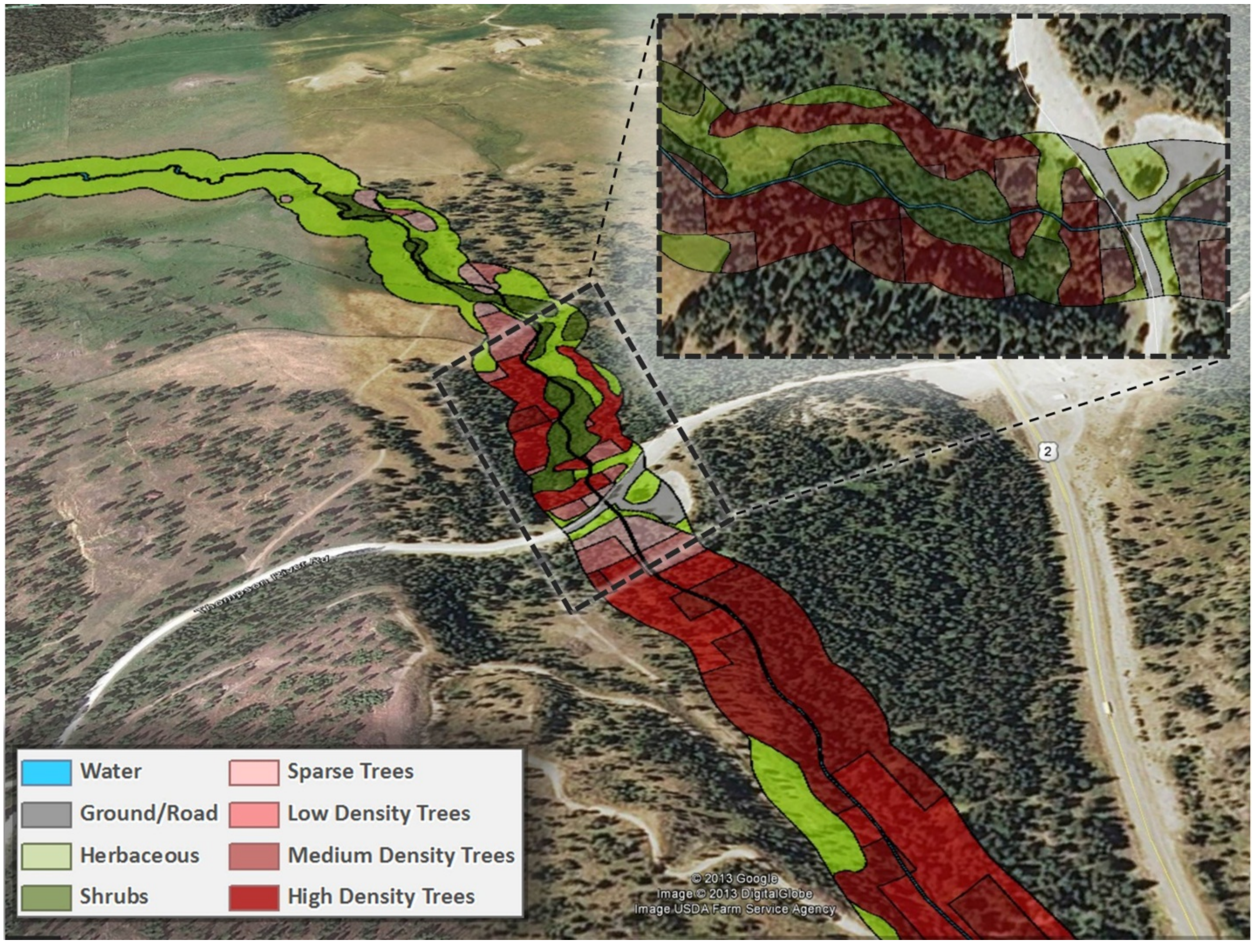


Figure A-31. Vegetation mapping example for McGregor Creek.

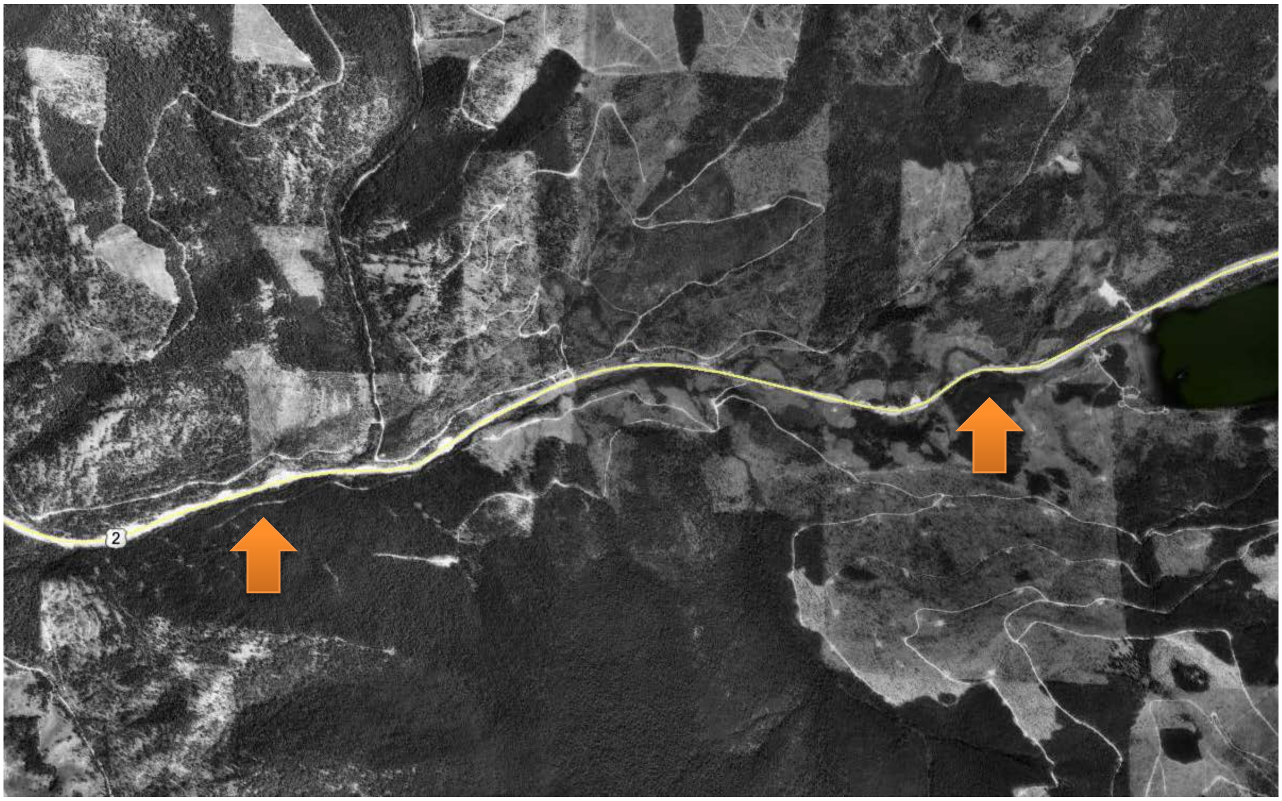
Herbaceous vegetation (44 percent) is the most common cover types along McGregor Creek, followed by sparse trees and shrubs (**Table A-8**).

Table A-8. Land cover types in the McGregor Creek riparian zone

Land cover type	Area (acres)	Relative area (percent)
Bare ground	1.0	0.4%
Herbaceous	115.2	44.3%
Roads	17.3	6.6%
Shrub	22.2	8.5%
Sparse trees	46.3	17.8%
Low density trees	17.8	6.9%
Medium density trees	16.0	6.1%
High density trees	18.3	7.0%

From McGregor Lake downstream to roughly the Thompson River Road, McGregor Creek flows along Highway 2 through a fairly narrow valley that is flanked by mountains that steeply rise over 1,000 feet on both sides of the creek. From Thompson River Road downstream to its confluence with the Thompson River, McGregor Creek flows through a broad, flat floodplain. Based on review of aerial photography, the vegetation communities upstream from Thompson River Road appear to be influenced by the presence of Highway 2 (i.e., including both the paved highway, shoulders, and an approximate 60 foot right-of-way), unpaved roads, and historic timber harvest. Extensive areas of timber harvest are visible on 1990 aerial imagery (**Figure A-32**). The 1990 aerial imagery also shows that areas not affected by timber harvest were dominated by fairly dense timber stands down to creek.

Downstream from Thompson River Road, McGregor Creek flows through irrigated hay fields with a buffer between the stream bank and actively hayed areas ranging in width from less than five feet to approximately 30 feet (**Figure A-33**). The vegetation in these lower reaches of McGregor Creek are not at potential.



Source of aerial imagery: GoogleEarth™ 2013 (obtained from U.S. Geological Survey, 7/18/1990).
Note: The arrows identify areas of dense trees that were not harvested for timber.

Figure A-32. 1990 aerial imagery of McGregor Creek showing timber harvests.

Source of aerial imagery: GoogleEarth^{TM} 2013 .

Figure A-33. 2001 aerial imagery of McGregor Creek showing the lower reaches.

• Shade

Shade is one of several factors that control in-stream water temperatures. Shade is defined as the fraction of potential solar radiation that is blocked by topography and vegetation.

o *Measured Shade*

EPA (i.e., Atkins) collected shade characterization data on July 14, 2011, at seven monitoring locations along McGregor Creek using a Solar Pathfinder^{TM} (**Figure A-34**). Hourly shade estimates based on the Solar Pathfinder^{TM} measurements are presented in **Attachment A**. The data are summarized in **Table A-9**.

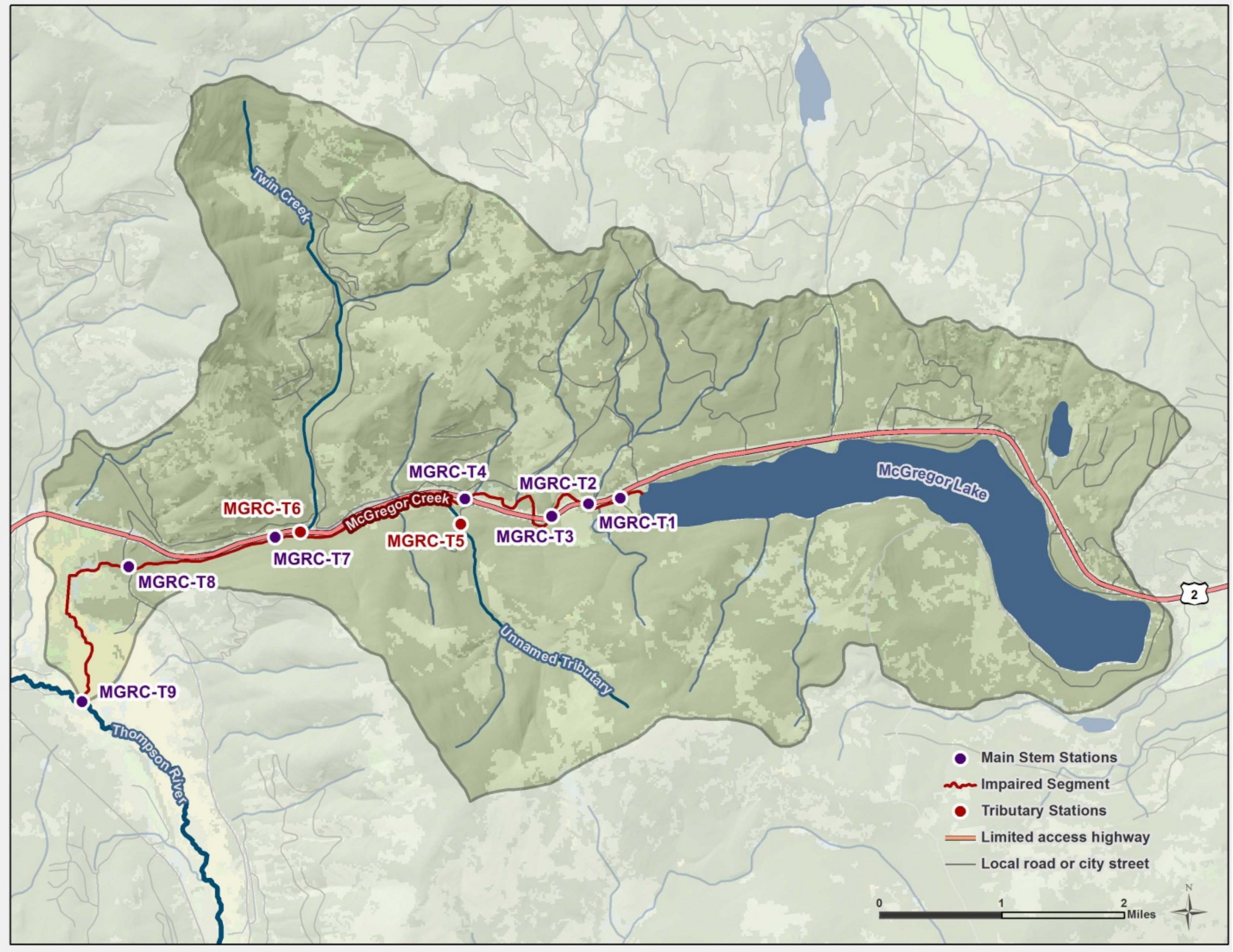


Figure A-34. EPA flow, shade, and continuous temperature monitoring locations.

Table A-9. Average shade per reach from Solar Pathfinder$^{\text{TM}}$ measurements

Site ID	Average daily shade (averaged across daylight hours)
MGRC-T1	56%
MGRC-T3	45%
MGCR-T4	68%
MGRC-T7	74%
MGRC-T8	75%
MGRC-T9	9%

Note: Sites are listed as headwaters to mouth from top to bottom.

o *Shade Modeling*

An analysis of aerial imagery and field reconnaissance showed that shading along Wolf Creek was highly variable. Therefore, shade was also evaluated using the spreadsheet Shadev3.0.xls. Shade version 3.0 is a riparian vegetation and topography model that computes the hourly effective shade for a single day (Washing State Department of Ecology 2008). Shade is an Excel/Visual Basic for Applications program.

The model uses the latitude and longitude, day of year, aspect and gradient (the direction and slope of the stream), solar path, buffer width, canopy cover, and vegetation height to compute hourly, dawn-to-dusk shade. The model input variables include channel orientation, wetted width, bankfull width, channel incision, topography, and canopy cover. Bankfull width in the shade calculations is defined as the near-stream disturbance zone (NSDZ), which is the distance between the edge of the first vegetation zone on the left and right bank.

- **Available Data**

The application of the Shade Model to McGregor Creek relied upon field data collected during a 2011 field study and the interpretation of these data (**Attachment B**). The results of the study included: tree/shrub height, overhang, wetted channel width, and bankfull width.

- **GIS Pre-Processing**

TTools version 3.0 is an ArcView extension to translate spatial data into Shade Model inputs (Oregon Department of Environmental Quality 2001). TTools was used to estimate the following values: elevation, aspect, gradient, distance from the stream center to the left bank, and topographic shade. Elevation was calculated using a 10 meter (33 feet) digital elevation model (DEM) and a stream centerline file digitized from aerial imagery in GoogleEarth^{TM}. Aspect was calculated to the nearest degree using TTools with the stream centerline file.

Although the field study report provided an estimate of the wetted width, an assessment along the entire stream was obtained by digitizing both the right and left banks from aerial imagery in GoogleEarth^{TM}. TTools then calculates wetted width based on the distance between the stream centerline and the left and right banks. Topographic shade was calculated using TTools with the stream centerline file and a DEM.

- **Riparian Input**

The Shade Model requires the description of riparian vegetation: a unique vegetation code, height, density, and overhang (OH). The results in the field study report and the above described vegetation mapping were used to develop a riparian description table (**Table A-10**). Vegetation descriptions used the average value for tree/shrub height and overhang from field observation.

Table A-10. Vegetation input values for the Shade Model

ribute	Value	Basis
es		
ght	feet	he absence of site-specific data, this value was based on work conducted in Wolf and Fortine creeks.
nsity	iable	6 NLCD.
erhang	feet	mated as 10% of height (Stuart 2012).
ubs		
ght	feet	he absence of site-specific data, this value was based on work conducted in Wolf and Fortine creeks.
nsity	%	ular estimate based on aerial imagery.
erhang	feet	imated as 25% of height (Shumar and de Varona 2009)
rbaceous		
ght	feet	imated average based on site reconnaissance (July 14, 2011).
nsity	%	
erhang	eet	

Shade Input

The Shade Model inputs are riparian zones, reach length, channel incision, elevation, aspect, wetted width, near-stream disturbance zone width, distance from the bank to the center of the stream, and topographic shade. Input for the riparian zone is presented in **Table A-10**. The Shade Model requires reach lengths be an equal interval. The reaches in the field study report were not at an equal interval and were very widely spaced. A uniform reach length interval of 98 feet was used. Channel incision was estimated from an examination of field photos. Incision is the vertical drop from the bankfull edge to the water surface, and was estimated at 1 foot. The remaining variables were computed as part of the GIS pre-processing described above.

Shade Model Results

The current longitudinal effective shade profile generated from the Shade Model and the Solar Pathfinder^{TM} measurements are presented in **Figure A-35**.

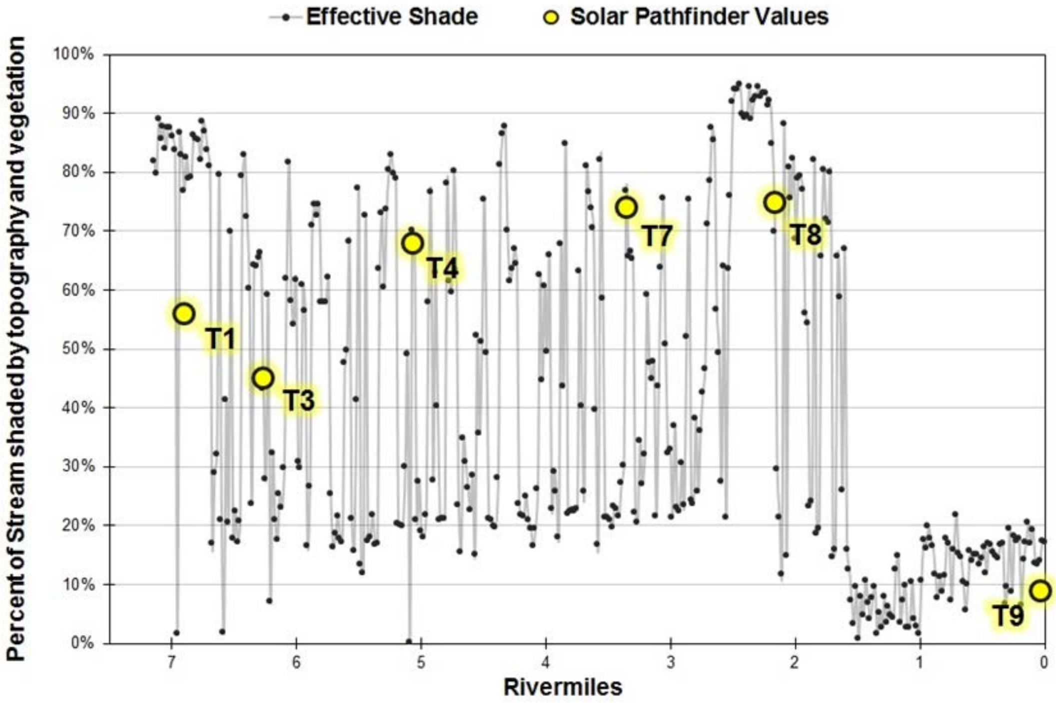


Figure A-35. Longitudinal estimates of observed and simulated effective shade along McGregor Creek.

The goodness of fit for the Shade Model was summarized using the mean error (ME), average absolute mean error (AME), and root mean square error (RMSE) as a measure of the deviation of model-predicted shade values from the measured values. These model performance measures were calculated as follows:

$$ME = \frac{1}{N}\sum_{n=1}^{n} P_n - O_n$$

$$AME = \frac{1}{N}\sum_{n=1}^{n} |P_n - O_n|$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{n} (P_n - O_n)^2}$$

where

P = model predicted values
O = observed values
n = number of samples

Model error statistics are provided in **Table A-11** and suggest a good fit between observed and predicted average effective shade values. The average absolute mean error is 8 percent. (i.e., the average error from the Shade Model output and Solar Pathfinder^{TM} measurements was 8 percent daily average shade; see **Table A-11**).

Table A-11. Shade model error statistics

Error Statistic	Formula	Result	Units
Mean Error (ME)	$(1/N)*\Sigma(P_n-O_n)$	7%	percent of percent shade
Average Absolute Mean Error (AME)	$(1/N)*\Sigma\|(P_n-O_n)\|$	8%	percent shade
Root Mean Square Error (RMSE)	$[(1/N)*\Sigma(P_n-O_n)^2]^{1/2}$	11%	percent of percent shade

• Stream Temperatures

In 2011, EPA collected continuous temperature data at six locations in McGregor Creek (sites MGRC-T1, MGRC-T3, MGRC-T4, MGRC-T7, MGRC-T8, and MGRC-T9) and at two tributary locations (MGRC-T5 on an unnamed tributary and MGRC-T6 on Twin Creek). Data loggers recorded temperatures every one-half hour for approximately two months between July 14-15 and September 12-13. Instantaneous temperatures were also monitored by EPA and DEQ in 2004 and 2011 (**Table A-12** and **Table A-13**).

Table A-12. EPA instantaneous water temperature measurements (ºF), summer 2011

Date	MGCA	MGCA-249	MGCA-251	MGCA-247
September 12, 2011	65.5	64.0	57.0	54.9

Notes

Temperatures were originally reported in degrees Celsius and were converted to degrees Fahrenheit as displayed in this table.

EPA Region 8 stations are co-located at DEQ stations. MGCA = MGRC-T1, MGCA-249 = MGRC-T4, MGCA-251 = MGRC-T7, and MGCA-247 = MGRC-T8.

Table A-13. DEQ instantaneous water temperature measurements (ºF)

Date	C13MCGRC10	C13MCGRC02	C13MCGRC03	C13MCGRC20
August 23, 2011	--	61.5	57.6	63.3
September 3, 2004	61.3	--	--	51.0

Note: Temperatures were originally reported in degrees Celsius and were converted to degrees Fahrenheit as displayed in this table.

• Hydrology

No active U.S. Geological Survey (USGS) continuously recording gages are located on McGregor Creek. Peak streamflow was historically monitored (water years 1972-1982) at USGS gage 12389150 (McGregor Creek trib near Marion, MT). EPA (i.e., Atkins) collected instantaneous flow measurements in 2011, during temperature data logger deployment and retrieval (**Table A-14**; **Attachment C**). An unnamed tributary (MGRC-T2) near McGregor Lake was observed to be dry on July 14 and September 13, 2011. DEQ monitored flow on September 3, 2004 at two sites on McGregor Creek: C13MCGRC10 (2.52 cfs) and C13MCGRC20 (1.4 cfs). Locations of the flow measurements are shown in **Figure A-36**.

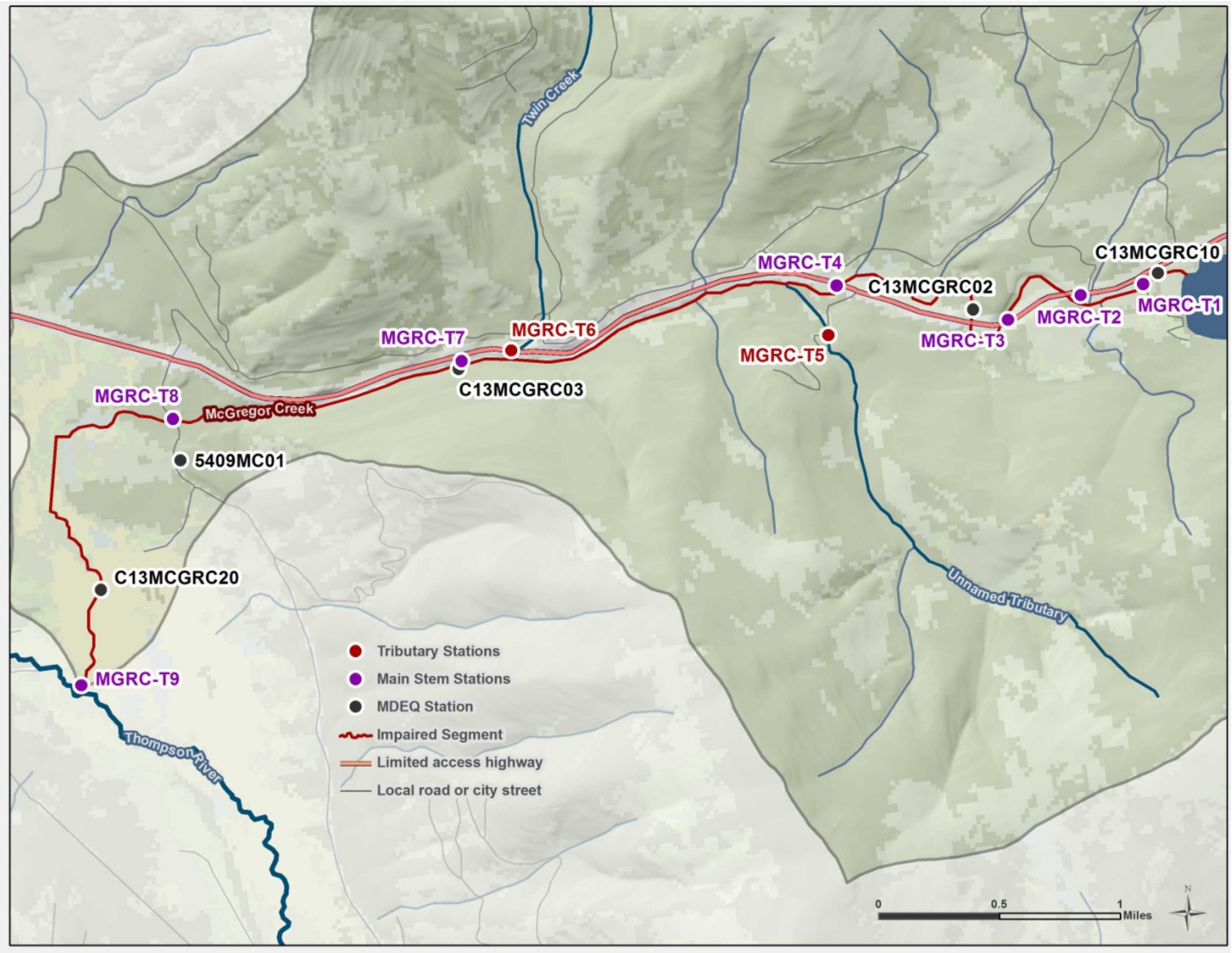
Table A-14: EPA instantaneous flow measurements (cfs) on McGrgor Creek in support of modeling

Date	MGRC-T1	MGRC-T3	MGRC –T4	MGRC –T5 [a]	MGRC –T6 [b]	MGRC –T7	MGRC –T8	MGRC-T9
July 14-15, 2011	0.78	0.98	1.28	1.51	3.50	8.97	8.87	--
September 12-13, 2011	2.24	2.27	2.61	0.54	0.97	4.28	4.94	--

Notes

a. Site is on an unnamed stream that is a tributary of McGregor Creek.

b. Site is on Twin Creek that is a tributary of McGregor Creek.

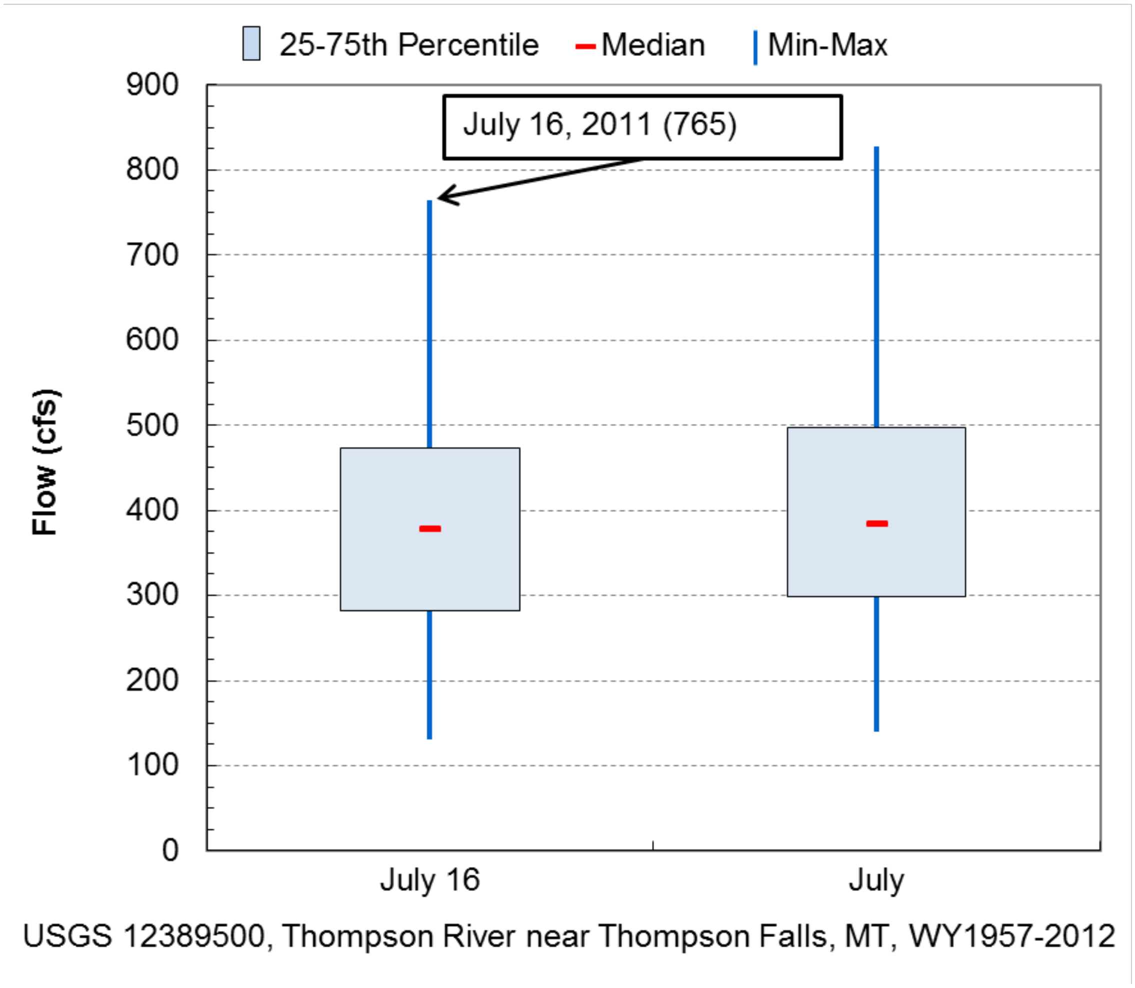


Note: 5409MC01 is located on McGregor Creek but erroneously plots south of the creek.

Figure A-36. Flow monitoring locations in the McGregor Creek watershed.

Continuous flow data monitored on the Thompson River at USGS gage 12389500 were evaluated with instantaneous discharge data from McGregor Creek to assess the hydrologic conditions of McGregor Creek during the summer of 2011. USGS gage 12389500 was used as a surrogate to represent regional hydrologic conditions. Statics were calculated for the average daily flows (per year) for the month of July and for July 16th from water years 1957 through 2012 at the gage (**Figure A-37**).

The flow at gage 12389500 on July 16, 2011 (the calibration date for the QUAL2K model) was 765 cfs, which is the maximum of flows on July 16th across the period of record. Additionally, August of 2011 was the wettest August across the period of record.

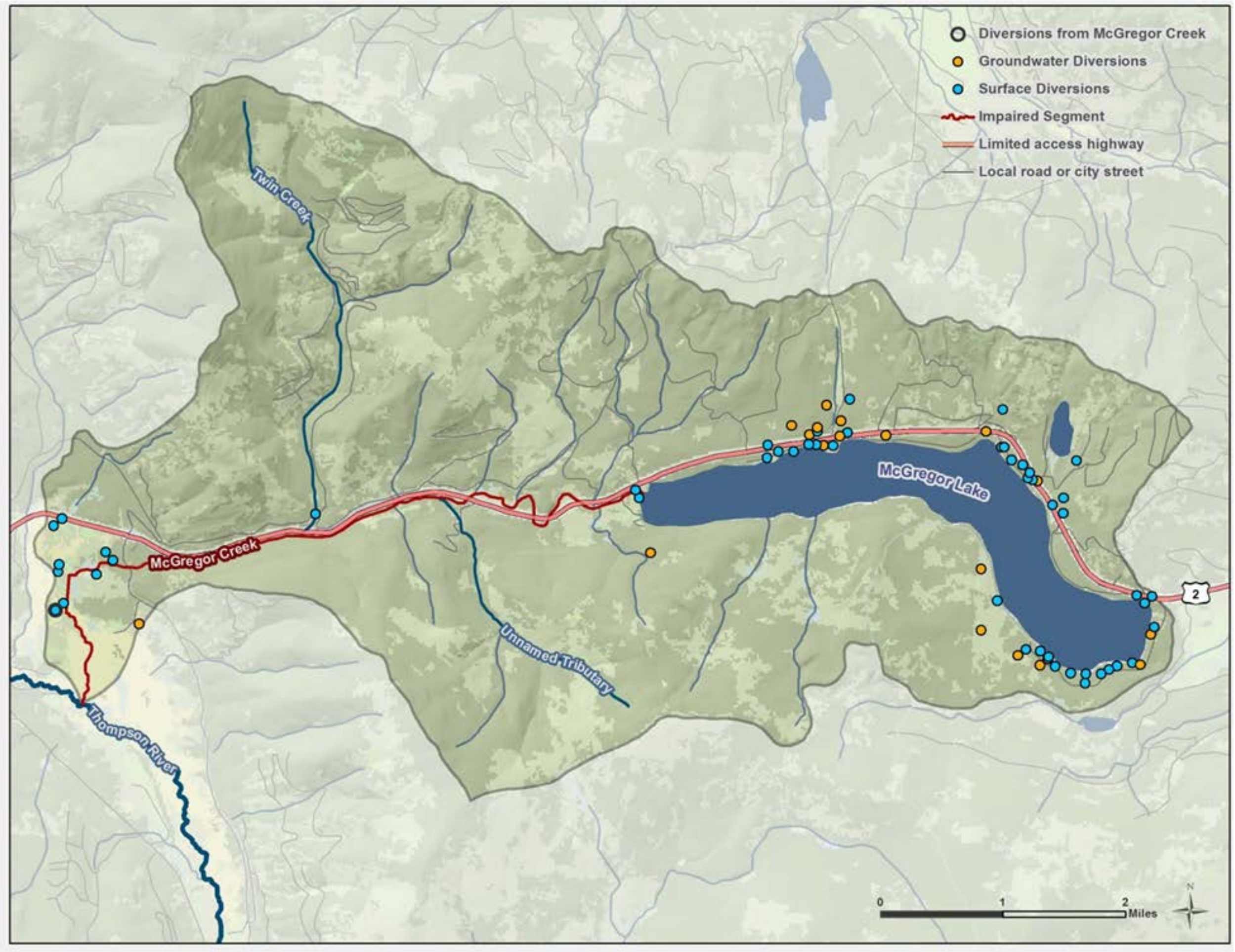


Note: "July" represents the daily average flow for the month of July per year (i.e., the average of 31 daily average flows)

Figure A-37. Flow analysis with USGS gage 12389500 (Thompson River near Thompson Falls, MT).

• Flow Modification

It is understood that McGregor Lake outflow is controlled by a head gate, but no further information is available at this time (http://cwaic.mt.gov/wqrep/2012/assmtrec/MT76N005_030.pdf). Based on review of aerial photographs and online water rights data (ftp://nris.mt.gov/dnrc), there are surface and groundwater diversions in the McGregor Creek watershed that support localized irrigation (**Figure A-38**). "Points of diversion" and "places of use" spatial data were obtained from the Montana Natural Resource Information System (NRIS 2012). Of the 135 diversions in the McGregor Creek watershed, 45 were directly from McGregor Creek. Six water rights (for a total of three diversions) are used for flood irrigation near the mouth (**Figure A-38** and **Table A-15**). Diversions from McGregor Lake, groundwater, or tributaries to McGregor Creek were not considered during QUAL2K modeling as QUAL2K simulated one-dimensional flow along the McGregor Creek mainstem.



Source of "points of diversion" data: NRIS 2012.

Figure A-38. Surface and groundwater diversions in the McGregor Creek watershed.

Table A-15. Points of diversion from McGregor Creek

WRNUMBER	Purpose	Irrigation type	Means of Diversion	Max Area (acres)	Max flow-rate (cfs)	Volume (acre-ft/yr)	Est. daily volume applied (ft^3)[a]	Est. daily flow rate (cfs)[b]
76N 133241 00	Stock		L	0	0	0.0	--	--
76N 133247 00	Stock		L	0	0	0.0	--	--
76N 133243 00	Irrigation	F	H	70	1.75	166.6	69,640	0.823
76N 133254 00	Irrigation	F	H	70	1.75	166.6	69,640	0.823
76N 133237 00	Irrigation	F	D	95	2.38	226.1	94,511	1.117
76N 133248 00	Irrigation	F	D	95	2.38	226.1	94,511	1.117
76N 39610 00	Irrigation	F	H	378	13.00	1,663.2	376,055	4.445
76N 39612 00	Irrigation	F	H	378	1.00	370.8	376,055	4.445
76N 114589 00	Domestic		P	0	0.02	1.5	--	0.016
76N 118313 00	Domestic		P	0	0.02	1.5	--	0.016
76N 123298 00	Domestic		P	0	0.02	1.5	--	0.022
76N 133256 00	Domestic		P	0	0.03	1.5	--	0.033
76N 133301 00	Domestic		P	0	0.02	2.0	--	0.022
76N 133345 00	Domestic		P	0	0.04	1.5	--	0.040
76N 133419 00	Domestic		P	0	0.03	1.5	--	0.027
76N 134511 00	Domestic		P	0	0.07	1.5	--	0.067
76N 23346 00	Domestic		P	0	0.04	1.5	--	0.045
76N 23368 00	Domestic		P	0	0.02	1.5	--	0.022
76N 23372 00	Domestic		P	0	0.02	1.5	--	0.022
76N 2846 00	Domestic		P	0	0.06	1.5	--	0.056
76N 35626 00	Domestic		P	0	0.03	1.5	--	0.033
76N 4705 00	Domestic		P	0	0.02	1.5	--	0.022
76N 6712 00	Domestic		P	0	0.03	1.5	--	0.033
76N 693 00	Domestic		P	0	0.00	1.5	--	0.004
76N 215081 00	Domestic		P	0.1	0.02	1.6	99	0.001
76N 103277 00	Domestic		P	0.25	0.03	1.5	249	0.003
76N 133297 00	Domestic		P	0.25	0.06	1.5	249	0.003
76N 133397 00	Domestic		P	0.25	0.02	1.5	249	0.003
76N 117936 00	Domestic		P	0.36	0.03	1.5	358	0.004
76N 11603 00	Domestic		P	0.39	0.03	1.5	388	0.005
76N 109461 00	Domestic		P	0.42	0.02	1.5	418	0.005
76N 116327 00	Domestic		P	0.5	0.03	2.0	497	0.006

76N 118308 00	Domestic		P	0.5	0.02	1.5	497	0.006
76N 133318 00	Domestic		P	0.5	0.04	1.5	497	0.006
76N 23371 00	Domestic		P	0.5	0.02	2.0	497	0.006
76N 819 00	Domestic		P	0.64	0.09	1.5	637	0.008
76N 34299 00	Domestic		P	0.72	0.03	1.5	716	0.008
76N 502 00	Domestic		P	1	0.03	1.5	995	0.012
76N 25299 00	Domestic		P	1.2	0.06	1.5	1,194	0.014
76N 407 00	Domestic		P	1.5	0.02	4.0	1,492	0.018
76N 9250 00	Domestic		P	2	0.02	5.0	1,990	0.024
76N 133300 00	Domestic		P	2.5	0.04	2.0	2,487	0.029
76N 133307 00	Commercial		P	0	0.06	23.5	--	0.065
76N 133308 00	Commercial		P	0	0.06	23.5	--	0.065
76N 133346 00	Commercial		P	0	0.12	5.0	--	0.123
Total Withdrawal				***1,099.6***				***13.66***

Source: NRIS 2012

Notes

F = flood; L = livestock; H = headgate; D = dam, P = pump.

a. The daily volume applied was estimated using the Irrigation Water Requirements (IWR) program developed by the USDA to estimate crop requirements. This method assumes application over the maximum acres reported.
http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/irrigation/?cid=stelprdb1044890

b. A constant flow rate across a 24 hour period was assumed. Shaded cells assume maximum reported flow rate.

• Point Sources

Any facility that discharges to McGregor Creek or its tributaries must be permitted through DEQ's Montana Pollution Discharge Elimination System. A search of U.S. EPA's Enforcement and Compliance Online database (http://www.epa-echo.gov/echo/index.html) identified two facilities in the McGregor Creek watershed and both facilities were upstream of McGregor Lake. McGregor Lakes RV was identified in ECHO but is not permitted through the MPDES program. The McGregor Lake Quarry, operated by Montana Rockworks Inc., MPDES permits for stormwater associated with mining and with oil and gas activities (MTR000517) and stormwater associated with industrial activity (MTR300265). As neither point source discharged to McGregor Creek (i.e., both point sources are outside of the model domain), they will not be further considered.

An evaluation of abandoned mines data from NRIS (2012) showed that no abandoned mines are in the McGregor Creek watershed.

• References

DEQ (Montana Department of Environmental Quality). 2012. Water Quality Assessment Database. Montana Department of Environmental Quality, Clean Water Act Information Center. <http://cwaic.mt.gov/query.aspx>. Accessed March 16, 2012.

GoogleEarth 2012. Aerial imagery of Wolf Creek and surrounding area. dated August 17, 2012 <http://www.google.com/earth/index.html>. Accessed December 12, 2012.

MRLC (Multi-Resolution Land Characteristics Consortium). 2006. *National Land Cover Dataset 2006*. http://www.mrlc.gov/nlcd2006.php. Accessed June 28, 2012.

NRIS (Natural Resources Information System). 2012. *GIS Data List.* http://nris.mt.gov/gis/gisdatalib/gisDataList.aspx. Accessed June 28, 2012.