APPENDIX F – GRANT CREEK QUAL2K MODEL REPORT

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ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AME	Absolute Mean Error
DEM	Digital Elevation Model
DEQ	Department of Environmental Quality (Montana)
EPA	Environmental Protection Agency (U.S.)
FTS	Forest Technology Systems
GIS	Geographic Information System
HUC	Hydrologic Unit Code
ME	Mean Error
MPDES	Montana Pollutant Discharge Elimination System
MSL	Mean Sea Level
NLCD	National Land Cover Dataset
NSDZ	Near-Stream Disturbance Zone
OH	Overhang
QAPP	Quality Assurance Project Plan
RAWS	Remote Automated Weather Station
REL	Relative Error
RM	River Mile
SSURGO	Soil Survey Geographic Database
TMDL	Total Maximum Daily Load
USGS	Geological Survey (U.S.)

UNITS OF MEASURE

°F	degrees Fahrenheit
cfs	cubic feet per second
cm^2/s	square centimeter per second
g/cm^3	grams per cubic centimeter
MSL	mean sea level
RM	river mile

EXECUTIVE SUMMARY

Grant 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 loss of riparian habitat and flow alterations from water diversions (Montana Department of Environmental Quality, 2012). The U.S. Environmental Protection Agency (EPA) contracted with Tetra Tech to develop a QUAL2K water quality model to investigate the relationship between flow, shade, and instream 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 Grant 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. 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:** Baseline condition (i.e., existing condition that is the calibrated model)
- **Scenario 2:** Baseline with a 15% reduction of water withdrawals
- **Scenario 3:** Baseline with improved riparian vegetation in certain segments based upon reference segments
- **Scenario 4:** An improved flow and shade scenario that combines the potential benefits associated with a 15% reduction in water withdrawals with improved shading along certain segments.

In comparison to scenario 1, results ranged from minimal change in water temperature (scenario 2) to considerable reductions (scenarios 3 and 4). The improved flow and shade scenario (scenario 4), which combined the potential benefits associated with a 15% reduction in water withdrawals (scenario 2) with improved shading to certain segments based upon reference segments (scenario 3) to represent application of conservation practices, resulted in overall reductions along the entire reach that ranged from 0.1° F to 2.1° 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.

F1.0 Introduction

This appendix is based on a report by Tetra Tech, Inc. for a temperature model (QUAL2K) for Grant Creek. Background information is provided in the following section (**Section F2**). A summary of model set up and calibration, is provided in **Section F3** and a series of model scenarios and results are presented in **Section F4**.

F2.0 Background

This section presents background information to support QUAL2K model development.

F2.1 Problem Statement

Grant Creek is in the Rocky Mountains of western Montana and is part of the Middle Clark Fork Tributaries Total Maximum Daily Load (TMDL) Planning Area. The Grant Creek watershed is in the Middle Clark Fork 8-digit HUC (17010204). The impaired segment is 18.8 miles long and extends from the headwaters to the mouth (Montana Department of Environmental Quality, 2012) (**Figure F-1**).

Grant Creek has a B-1 use class. The entire 18.8 mile creek is not supporting its Aquatic Life and Primary Contact Recreation designated uses (Montana Department of Environmental Quality, 2012). Six potential causes of impairment are identified in the assessment record, including water temperature (Montana Department of Environmental Quality, 2012). The potential sources of the water temperature impairment are: loss of riparian habitat and flow alterations from water diversions (Montana Department of Environmental Quality, 2012).

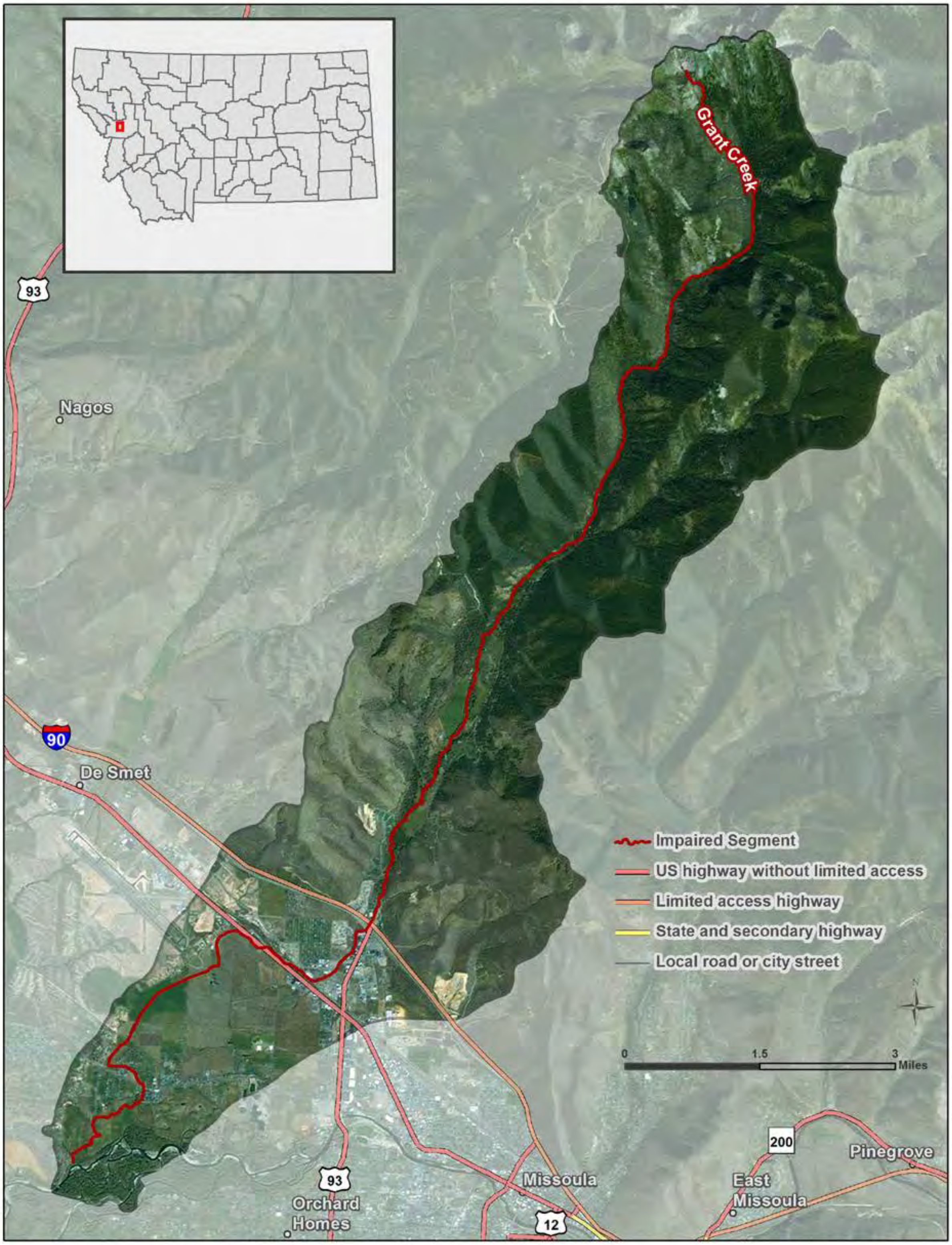


Figure F-1. Grant Creek watershed

F2.2 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.

F2.3 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 instream 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, irrigation return flows, 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 Grant Creek were evaluated prior to model development and are further discussed in **Attachment F1**:

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

F2.4 STREAM TEMPERATURE DATA

In 2011, Atkins collected continuous temperature data at eight sites along Grant Creek and at one tributary site (East Fork Grant Creek) in support of this modeling effort (**Figure F-2**). Data loggers recorded temperatures every one-half hour for two months between July 11 and September 20, 2011. DEQ also collected instantaneous temperatures from Grant Creek (**Attachment F1**). Temperatures varied spatially and temporally; generally, the warmest instantaneous temperatures were detected in August.

[1] ARM 17.30.623(e).
[2] "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.

Atkins and Tetra Tech identified periods of partial and full exposure to ambient air at the following three loggers: GRTC-T7, GRTC-T8, and GRTC-T9. Based upon Atkins field notes and photographs, the following general conclusions can be drawn:

- **GRTC-T7:** Atkins reported that logger GRTC-T7 was probably pooled or had minimal flow from August 1, 2011 to August 6, 2011, was probably dry until August 26, 2011, and then was definitely dry thru the remainder of the study. Thus, it is assumed that the logger was in an isolated pool and was then partially or fully exposed to ambient air during much of the summer season.
- **GRTC-T8:** Atkins reported that logger GRTC-T8 was probably exposed to ambient air from July 23, 2011 thru the remainder of the study. Thus, it is assumed that the logger was partially or fully exposed to ambient air during much of the summer season.
- **GRTC-T9**: Atkins reported that logger GRTC-T9 was probably exposed to ambient air from July 26, 2011 thru the remainder of the study. Thus, it is assumed that the logger was partially or fully exposed to ambient air during much of the summer season.

Continuous temperature data that was recorded when the loggers were, or were suspected to be, fully or partially exposed to ambient air were excluded from analyses and model development.

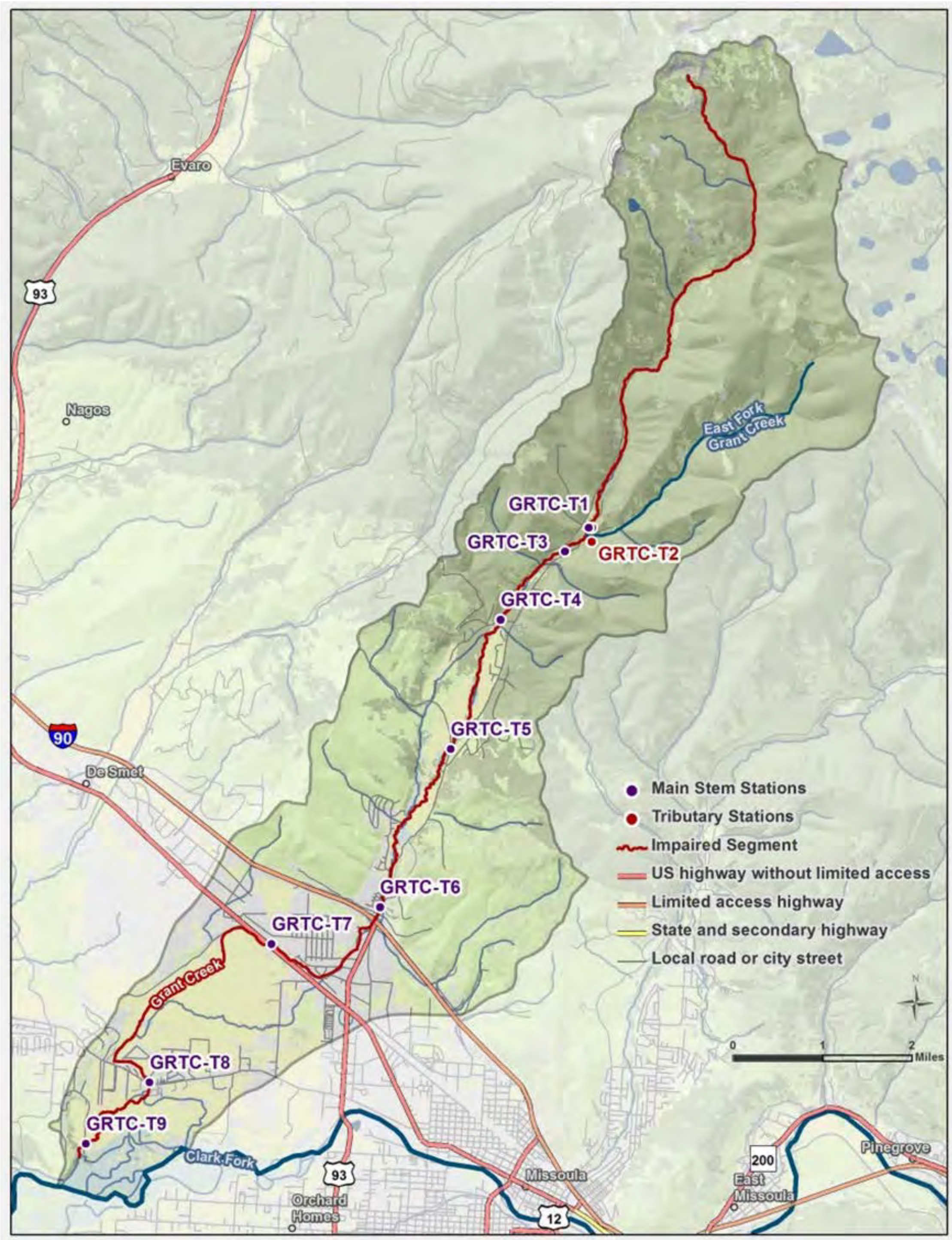
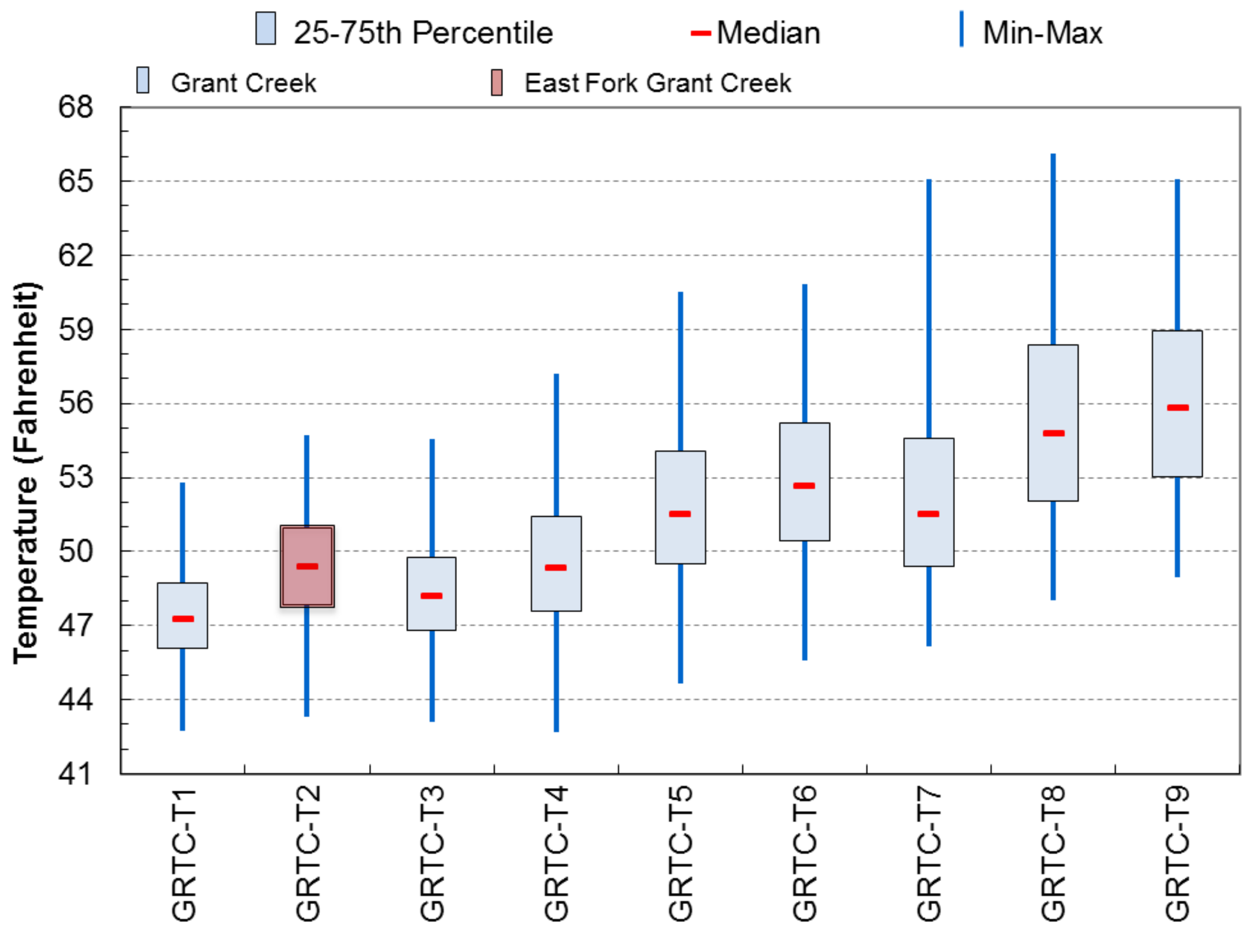


Figure F-2. Temperature loggers in the Grant Creek watershed

F2.5 Temperature Data Analysis

Temperatures within Grant Creek tend to gradually increase from headwaters to mouth (**Figure F-3).** Median temperatures in Grant Creek ranged from 47.2° F to approximately 55.8° F. East Fork Grant Creek is relatively warm compared to Grant Creek (median of 49.4° F).



Notes

- Data that were recorded during periods that were, or were suspected to be, exposed to ambient air were excluded from this figure.
- Atkins reported that logger GRTC-T7 was probably pooled or had minimal flow from August 1, 2011 to August 6, 2011, was probably dry until August 26, 2011, and then was definitely dry thru the remainder of the study. The data presented in this figure are limited to a subset of the monitored temperatures from July 11, 2011 through July 31, 2011.
- Atkins reported that logger GRTC-T8 was probably exposed to ambient air from July 23, 2011 thru the remainder of the study. The data presented in this figure are limited to a subset of the monitored temperatures from July 11, 2011 through July 22, 2011.
- Atkins reported that logger GRTC-T9 was probably exposed to ambient air from July 26, 2011 thru the remainder of the study. The data presented in this figure are limited to a subset of the monitored temperatures from July 11, 2011 through July 25, 2011.

Figure F-3. Box-and-whisker plots of summer 2011 EPA continuous temperature data

Maximum daily temperatures in Grant Creek ranged from 52.8° F to 66.1° F (**Table F-1**). The highest maximum daily temperature was recorded at GRTC-T8 on July 18, 2011. The highest maximum temperatures occurred on August 27, 2011 for all loggers except the three that were exposed to ambient air (GRTC-T7, GRTC-T8, and GRTC-T9). The warmest weeks were generally from August 22 through August 28, except for the three loggers that were exposed to ambient air during that time period. Daily maximum recorded temperatures in Grant Creek are summarized in **Table F-1** and shown in **Figure F-4**. As shown in **Figure F-5**, the diurnal variation in Grant Creek is smaller in the upper watershed (as shown with GRTC-T1) than the lower watershed (as shown with GRTC-T6).

Table F-1. Maximum and maximum weekly maximum temperatures in Grant Creek, 2011

Temperature logger site	Maximum temperatures [a]		Maximum weekly maximum temperature [b]	
	Temperature (°F)	Date	Temperature (°F)	Date
GRTC-T1	52.8	Aug 27	52.0	Aug 22 - 28
GRTC-T2[c]	54.7	Aug 27	54.0	Aug 24 – 30
GRTC-T3	54.6	Aug 27	53.7	Aug 22 - 28
GRTC-T4	57.2	Aug 27	56.1	Aug 22 - 28
GRTC-T5	60.5	Aug 27	59.2	Aug 22 - 28
GRTC-T6	60.8	Aug 27	59.8	Aug 22 - 28
GRTC-T7[d]	65.1	July 31	61.4	July 25 – 31
GRTC-T8[e]	66.1	July 18	61.5	July 15 – 21
GRTC-T9[f]	65.1	July 18	62.7	July 18 - 24

Notes: Data that were recorded during periods that were, or were suspected to be, exposed to ambient air were excluded from this table.

[a.] Maximum temperature is the maximum of recorded one-half hourly temperatures.

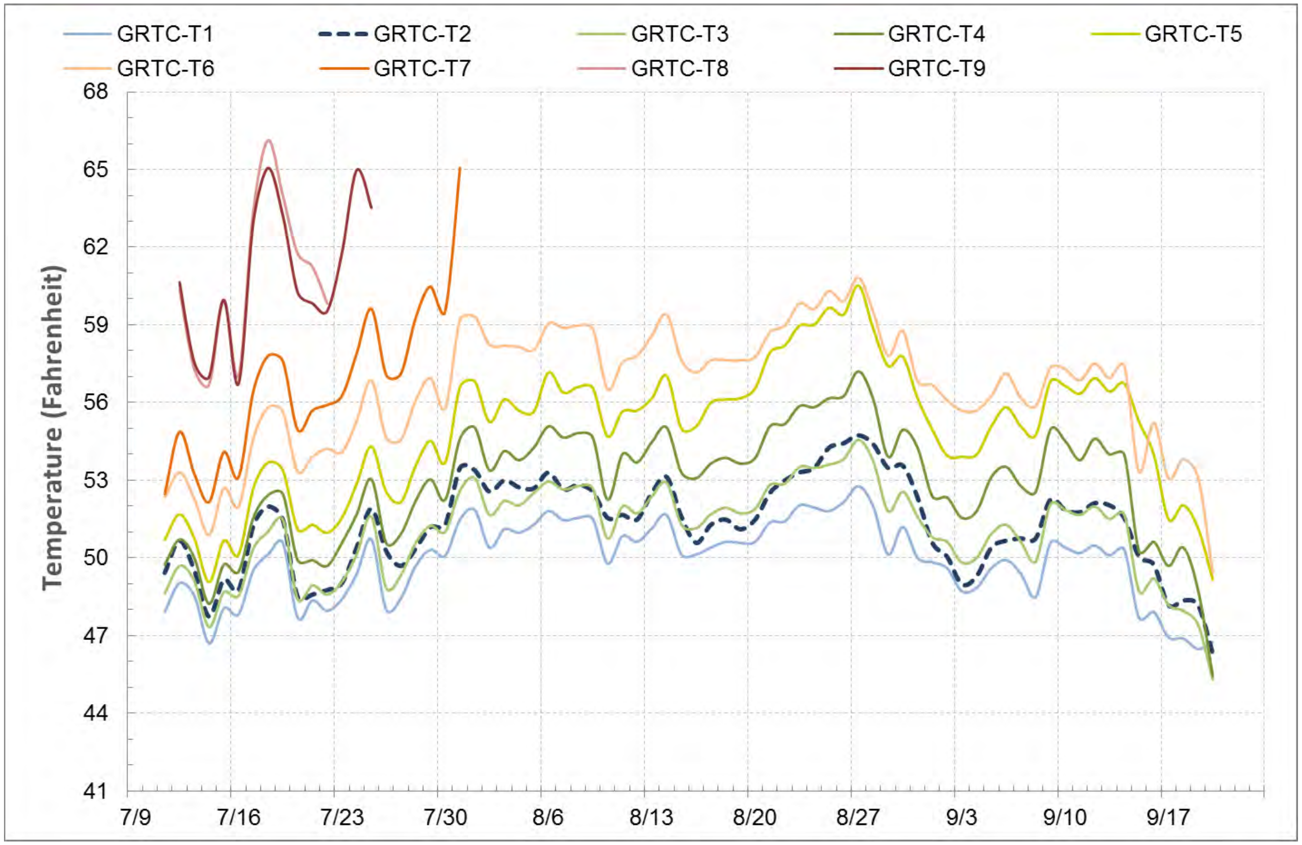
[b.] Maximum weekly maximum temperature is the mean of daily maximum water temperatures measured over the warmest consecutive seven-day period.

[c.] Site is located on East Fork Grant Creek, a tributary to Grant Creek.

[d.] Atkins reported that logger GRTC-T7 was probably pooled or had minimal flow from August 1, 2011 to August 6, 2011, was probably dry until August 26, 2011, and then was definitely dry thru the remainder of the study. The data presented in this table are limited to a subset of the monitored temperatures from July 11, 2011 through July 31, 2011.

[e.] Atkins reported that logger GRTC-T8 was probably exposed to ambient air from July 23, 2011 thru the remainder of the study. The data presented in this table are limited to a subset of the monitored temperatures from July 11, 2011 through July 22, 2011.

[f.] Atkins reported that logger GRTC-T9 was probably exposed to ambient air from July 26, 2011 thru the remainder of the study. The data presented in this table are limited to a subset of the monitored temperatures from July 11, 2011 through July 25, 2011.



Notes:

- Data that were recorded during periods that were, or were suspected to be, exposed to ambient air were excluded from this figure.
- Atkins reported that logger GRTC-T7 was probably pooled or had minimal flow from August 1, 2011 to August 6, 2011, was probably dry until August 26, 2011, and then was definitely dry thru the remainder of the study. The data presented in this figure are limited to a subset of the monitored temperatures from July 11, 2011 through July 31, 2011.
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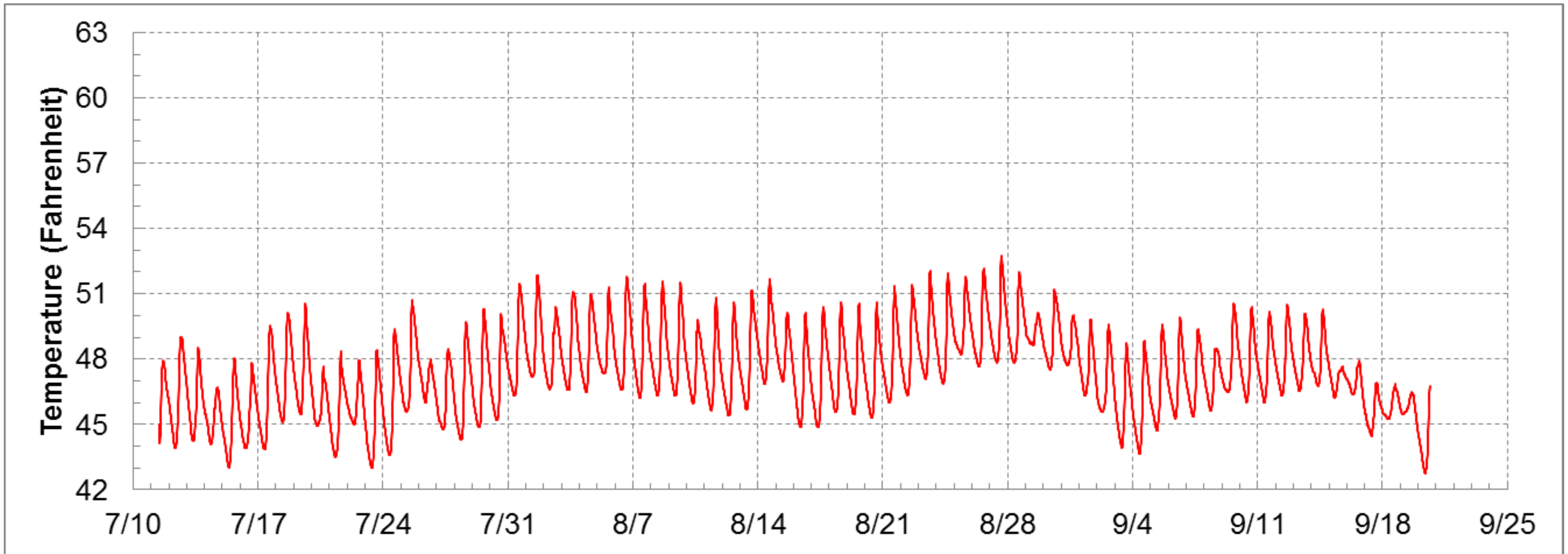
- Atkins reported that logger GRTC-T9 was probably exposed to ambient air from July 26, 2011 thru the remainder of the study. The data presented in this figure are limited to a subset of the monitored temperatures from July 11, 2011 through July 25, 2011.

Figure F-4. Daily maximum temperatures, Grant Creek and a tributary (dashed line), July 11/3 to September 14/15, 2011



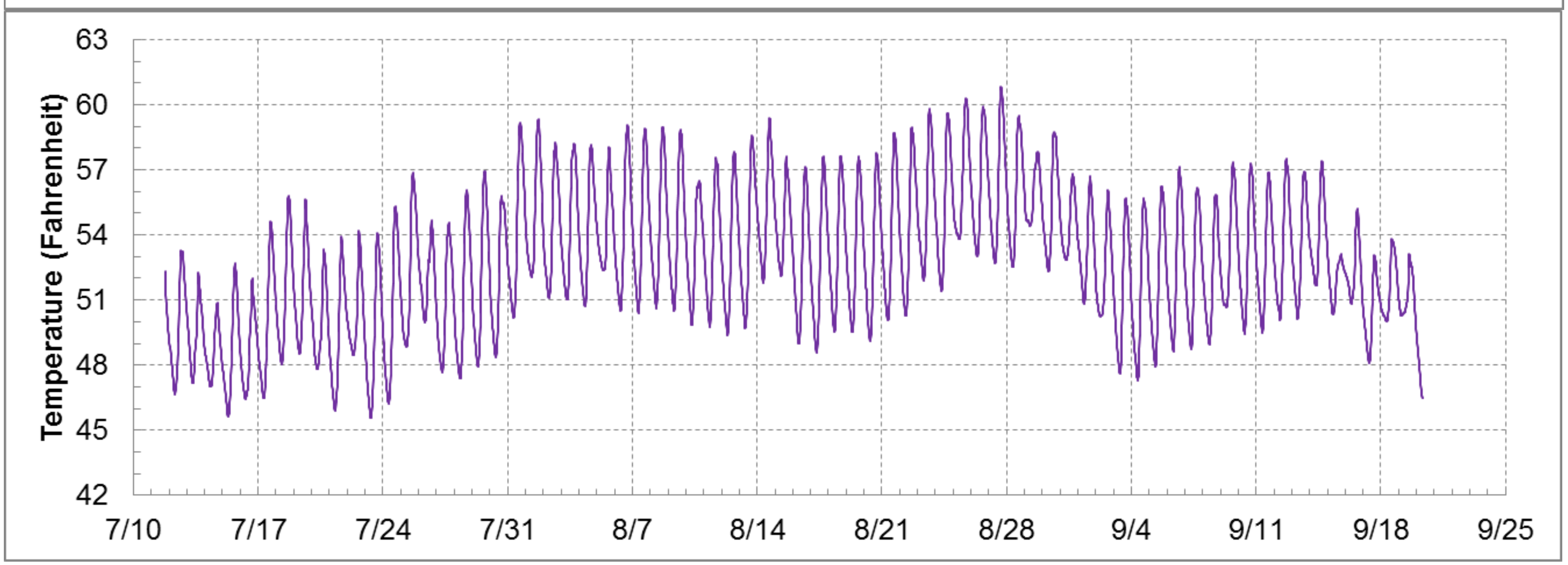


Figure F-5. Continuous temperature at logger GRTC-T1 (top) in upper Grant Creek and logger GRTC-T6 (bottom) in lower Grant Creek, July 11 to September 20, 2011

F3.0 QUAL2K MODEL DEVELOPMENT

EPA and DEQ selected the QUAL2K model to simulate temperatures in Grant 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 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 instream temperatures via a heat balance that accounts "for heat transfers from adjacent elements, loads, withdrawals, the atmosphere, and the sediments" (Chapra et al., 2007, 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, Inc., 2012).

The following describes the process that was used to setup, calibrate, and validate the QUAL2K models for Grant Creek.

F3.1 MODEL FRAMEWORK

The QUAL2K model (Chapra et al., 2007) was selected for modeling Grant Creek. The modeling domain included the entire 18.8 mile reach of Grant Creek (refer back to **Figure F-2** for a map of the Grant Creek watershed).

Data were specifically collected to support the QUAL2K model for the Grant Creek. Flow, shade, and continuous temperature were acquired during July and September 2011. In addition flow and temperature data were collected at a major tributary to Grant Creek.

F3.2 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.

F3.2.1 Modeling Time Period

The calibration steady-state model period was September 15, 2011. The date was selected since it 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 that date and weather data were also available for that date.

Flow data were not collected on July 11 and 12, 2011 at three loggers (GRTC-T3, GRTC-T4, and GRTC-T5) because Grant Creek was too deep and swift to wade. Additionally, the first full day of recorded temperatures was July 13, 2011. A 0.38 inch rainfall occurred on July 12, 2011 after logger deployment and flow monitoring but before a full day of continuous temperatures was recorded. As the rainfall had a cooling effect upon instream temperatures, it is not appropriate to couple the flows monitored before the rainfall with the temperatures recorded after the rainfall. Due to the lack of monitored flow data at three consecutive sites and the occurrence of a considerable rainfall between flow monitoring and continuous temperature recording, it was determined that insufficient flow data were available to develop a second model period for validation.

Calibration Period: The calibration period was September 15, 2011 and was selected due to the availability of flow and temperature data (**Attachment F1**). Flow was monitored at loggers GRTC-T2 through GRTC-T6 on September 20, 2011 and at loggers GRTC-T8 and GFTC-T9 on September 15, 2011. Flow was estimated at logger GRTC-T1, and Grant Creek was dry at logger GRTC-T7. As only 0.01 inch of rain occurred between September 15 and 20, 2011, it was assumed that flows on September 20, 2011 were representative of flows on September 15, 2011. Continuous temperature data were available at loggers GRTC-T1 through GRTC-T6 on September 15, 2011; loggers GRTC-T7 through GRTC-T9 were exposed to ambient air during this time (i.e., these three loggers cannot be used for calibration). In addition September 15, 2011 also represented critical hot summer period conditions.

Validation Period: Model validation was not performed. Insufficient flow data were available to develop a validation model for another period during the summer of 2011.

F3.2.2 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 in QUAL2K. The Grant Creek mainstem was segmented into reach lengths of 0.31 mile (500 meters), which were sufficient to incorporate any point inputs to the waterbody and to maintain stability. In addition since shading is applied at the reach level this allowed for better representation of the spatial variability observed in the Shade Model results along Grant Creek (see **Attachment F1** for shade modeling discussion). One major tributary, East Fork Grant Creek, was represented through boundary condition designation (see **Section F3.2.4** for a discussion of boundary conditions). Refer back to **Figure F-2** for a map that shows the Grant Creek mainstem and its tributaries.

F3.2.3 Streamflow and Hydraulics

The flow rates were estimated through flow mass balance (continuity) calculations at the loggers and other sites 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 the 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.

Typical exponents for velocity (0.43) and depth (0.45) are described in the QUAL2K manual (Chapra et al., 2007). Exponents were also calculated for two nearby U.S. Geological Survey (USGS) gages of similar size to Grant Creek, which is 35.5 square miles (**Table F-2)**. The exponents were set to the averages calculated from the three USGS gages: 0.55 for velocity and 0.37 for depth.

Table F-2. Calculated exponents for nearby USGS gages

Gage ID	Gage name	Drainage area (square miles)	Exponents	
			Velocity	Depth
12381400	South Fork Jocko River near Arlee, Montana	57.58	0.56	0.36
12387450	Valley Creek near Arlee, Montana	16.02	0.54	0.38

F3.2.4 Boundary Conditions

Boundary conditions represent external contributions to the waterbody being modeled. A flow and temperature input file was therefore configured for inputs to Grant Creek. Boundary conditions were specified at the upstream terminus of Grant Creek, for the East Fork Grant Creek confluence with Grant Creek, and for diffuse sources along the creek. These are further discussed in the following sections.

F3.2.4.1 Headwater (Upstream) Boundary

QUAL2K requires specification of the headwater flow and temperature. Diurnal temperatures (September 15, 2011) at the upstream boundary were specified using observed data from the instream logger at site GRTC-T1 for the calibration period. A flow of 8 cubic feet per second (cfs) was specified for the calibration period; note that flow for September 15, 2011 was not available and Atkins estimated the flow. **Figure F-6** shows the headwater temperatures specified in the model.

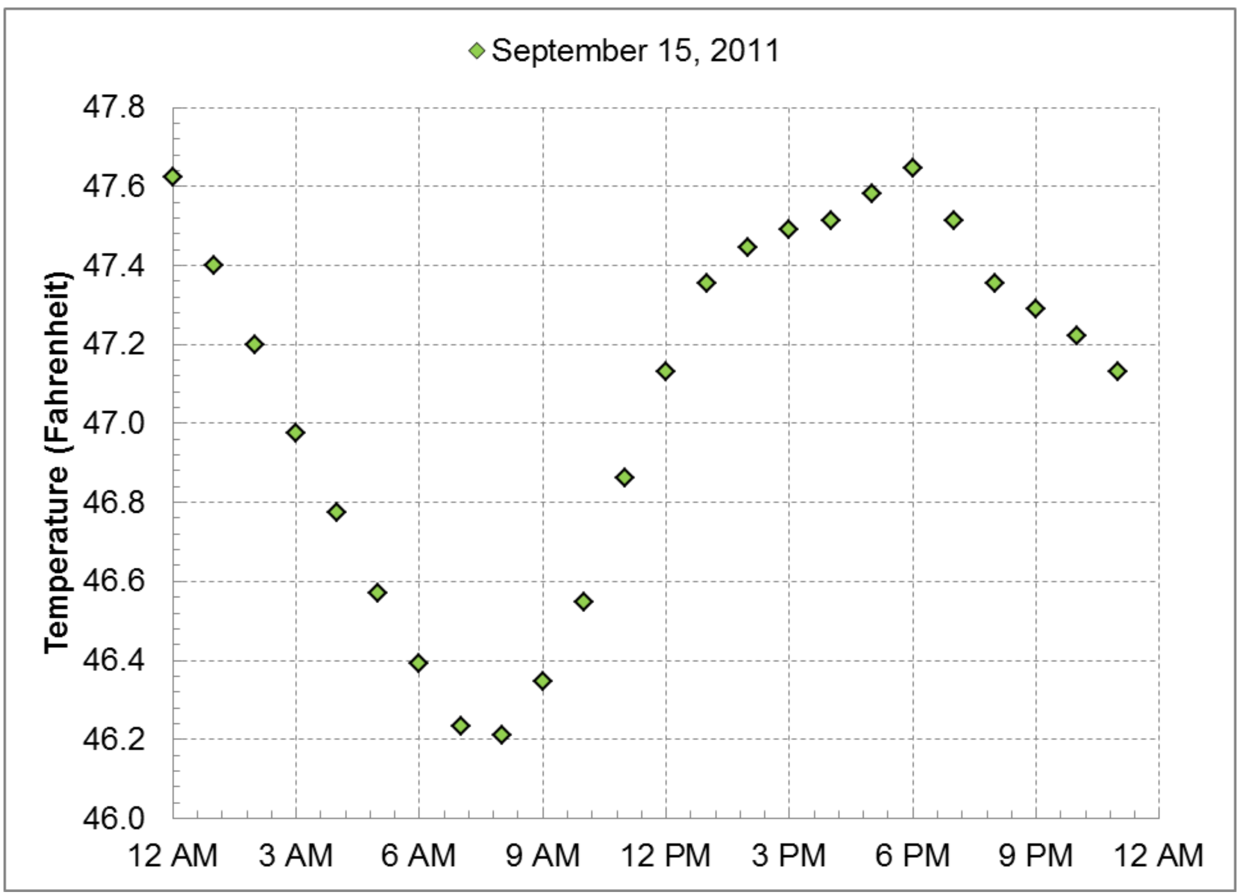


Figure F-6. Diurnal temperature at the headwaters to Grant Creek

F3.2.4.2 Permitted Point Source Inputs

DEQ issued a private minor Montana Pollutant Discharge Elimination System (MPDES) permit to Econolodge (MT0029840), in Missoula, that discharges non-contact cooling water from a heat exchanger. Additionally, DEQ issued 48 MPDES permits for construction stormwater, one MPDES permit for non-exposure from industrial stormwater, and three Section 318 exemptions (refer to **Attachment F1** for more information regarding permitted point sources).

The only continuous discharger is the Econolodge; therefore, a boundary condition was developed for this facility. EPA provided flow and temperature data from 1998 through 2013 that Econolodge is required to submit via its MPDES permit. A subset of these data was used to develop the boundary condition. The temperature input was estimated to be 54.1° F, which is the 75^{th} percentile of reported end-of-pipe temperatures from 2004 through 2013.

F3.2.4.3 Tributary and Irrigation Inputs

There are many small tributaries in the watershed; however, monitoring data were available for only one major tributary – East Fork Grant Creek (**Figure F-2**). **Table F-3** shows the flow and temperature assigned to East Fork Grant Creek. Flows during the validation period were observed on September 15, 2011.

In addition to tributary inputs, irrigation withdrawals from Grant Creek were also identified (see **Attachment F1** for a discussion of these withdrawals) and assigned in the model. Information on withdrawal rates or whether withdrawal is occurring during the calibration date was not readily available. Net irrigation requirements to irrigate the fields were queried from the Montana Natural Resource Information System for the month of September. A maximum daily flow rate was estimated using the net irrigation requirements and the maximum area irrigated (4,476 acres[3]). It was calculated that up to 24.6 cfs may be withdrawn from Grant Creek on a daily basis during September. These calculated withdrawals were used in the model (rows identified as *irrigation withdrawal* in **Table F-3**). More information on the irrigation withdrawal can be found in **Attachment F1**.

[3] The 4,476 acres of irrigated land was calculated using the “places of use” data associated with the “points of diversion” data available from the Natural Resources Information System (http://nris.mt.gov/gis/gisdatalib/gisDataList.aspx).

Table F-3. QUAL2K model flow and temperature inputs to Grant Creek - Tributary and irrigation withdrawals

Description	Location	Point sources [a]		Temperature [b]		
		Abstraction	Inflow	Daily mean	½ daily range	Time of maximum
	(RM)	(cfs)	(cfs)	(°F)	(°F)	(hour)
East Fork Grant Creek	12.61	--	2.16	49.3	0.87	6:00 PM
irrigation withdrawal	12.51	0.01	--	--	--	--
irrigation withdrawal	12.23	<0.01	--	--	--	--
irrigation withdrawal	11.33	<0.01	--	--	--	--
irrigation withdrawal	11.26	0.09	--	--	--	--
irrigation withdrawal	11.15	0.58	--	--	--	--
irrigation withdrawal	10.98	0.02	--	--	--	--
irrigation withdrawal	10.91	0.12	--	--	--	--
irrigation withdrawal	10.64	0.03	--	--	--	--
irrigation withdrawal	10.55	0.10	--	--	--	--
irrigation withdrawal	10.52	0.03	--	--	--	--
irrigation withdrawal	10.45	0.02	--	--	--	--
irrigation withdrawal	10.38	0.20	--	--	--	--
irrigation withdrawal	9.84	0.09	--	--	--	--
irrigation withdrawal	9.46	0.14	--	--	--	--
irrigation withdrawal	9.30	0.18	--	--	--	--
irrigation withdrawal	9.02	0.26	--	--	--	--
irrigation withdrawal	8.86	0.14	--	--	--	--
irrigation withdrawal	7.62	2.58	--	--	--	--
irrigation withdrawal	7.07	7.24	--	--	--	--
irrigation withdrawal	6.92	3.63	--	--	--	--
irrigation withdrawal	6.90	0.08	--	--	--	--
MT0029840	6.63	--	0.49	54.1	0	6:00 PM
irrigation withdrawal	6.24	1.62	--	--	--	--
irrigation withdrawal	6.13	0.08	--	--	--	--
irrigation withdrawal	6.11	<0.01	--	--	--	--
irrigation withdrawal	6.06	1.54	--	--	--	--
irrigation withdrawal	5.98	0.13	--	--	--	--
irrigation withdrawal	5.87	2.64	--	--	--	--
irrigation withdrawal	5.44	0.08	--	--	--	--
irrigation withdrawal	4.97	0.50	--	--	--	--
irrigation withdrawal	4.67	0.50	--	--	--	--
irrigation withdrawal	4.11	0.10	--	--	--	--
irrigation withdrawal	3.36	1.88	--	--	--	--

Notes: °F = degrees Fahrenheit; cfs = cubic feet per second; RM = river mile.
[a.] Points sources represent abstractions (i.e., withdrawals) or inflows. Each point source can be an abstraction or an inflow.
[b.] The daily mean temperature, one-half of the daily range of temperatures across the model period, and time of the maximum hourly temperature are only applicable to point source inflows.

F3.2.4.4 Diffuse Sources

Groundwater, irrigation return flows, 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 Grant Creek and its tributary. The amount of diffuse flow along Grant Creek was calculated for September 15, 2011.

The initial diffuse flow temperature was selected as the maximum reported groundwater temperature (range: 46.4° F to 54.1° F) from nearby wells, which was further evaluated during calibration. The initial diffuse source water temperature (54.4° F) was slightly increased during calibration (55.4° F), in part, to account for irrigation return flows, except from river miles (RMs) 7.48 to 8.11. This short segment is composed of a braided stream with multiple channels, which could indicate more interactions between surface and subsurface water. The final flow and water temperature assignment are shown below in **Table F-**.

Table F-4. QUAL2K model flow and temperature inputs to Grant Creek - Diffuse sources

Segment [a]	Location [b]		Diffuse Abstraction	Diffuse Inflow	
	Upstream	Downstream		Inflow	Temp
	(RM)	(RM)	(cfs)	(cfs)	(°F)
G1	12.69	12.30	--	0.02	55.4
F2	12.30	11.17	--	0.87	55.4
E3	11.17	10.86	--	1.09	55.4
E4	10.86	10.54	--	0.66	55.4
E5	10.54	10.23	1.35	--	55.4
E6	10.23	9.92	3.53	--	55.4
E7	9.92	9.61	3.53	--	55.4
E8	9.61	9.35	--	4.14	55.4
D9	9.35	9.04	--	0.18	55.4
D10	9.04	8.73	--	2.16	55.4
D11	8.73	8.42	0.02	--	55.4
D12	8.42	8.11	--	--	55.4
D13	8.11	7.80	--	2.12	50.0
D14	7.80	7.48	--	0.79	50.0
D15	7.48	7.17	<0.01	--	55.4
D16	7.17	7.00	0.01	--	55.4
C17	7.00	6.69	--	3.71	55.4
C18	6.69	6.38	1.58	--	55.4
C19	6.38	6.07	--	3.23	55.4
C20	6.07	5.76	--	2.76	55.4
C21	5.76	5.45	0.64	--	55.4
C22	5.45	5.15	--	0.60	55.4
B23	5.15	4.84	--	--	55.4
B24	4.84	4.53	--	0.97	55.4
B25	4.53	4.22	--	0.42	55.4
B26	4.22	3.91	--	0.10	55.4
B27	3.91	3.60	--	0.09	55.4
B28	3.60	3.29	--	1.89	55.4
B29	3.29	2.98	--	0.04	55.4
B30	2.98	2.67	--	0.54	55.4
B31	2.67	2.36	--	0.06	55.4
B32	2.36	2.05	--	0.21	55.4
B33	2.05	1.92	--	0.00	55.4
A34	1.92	1.61	--	0.14	55.4
A35	1.61	1.30	--	0.17	55.4
A36	1.30	0.99	--	0.09	55.4
A37	0.99	0.68	--	2.29	55.4
A38	0.68	0.23	--	0.98	55.4
X39	0.23	0.00	--	0.31	55.4

Notes: °F = degrees Fahrenheit; cfs = cubic feet per second; RM = river mile.
[a.] The numbers in the segment ID refer to the segments from headwaters to mouth as 1 to 39. The letter of the segment ID refers to channel geometry: segments with the same letter have identical depth and velocity exponents and coefficients.
[b.] Upstream and downstream termini of segments.

F3.2.5 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. One of the nearest weather stations in the vicinity of the Grant Creek watershed is the Missoula Forest Technology Systems (FTS) Remote Automated Weather Station (RAWS) (National Weather Service ID 241513), which is two miles south of Grant Creek at an elevation of 3,200 feet above mean sea level (MSL). The other nearby weather station is also in Missoula (National Weather Service ID 24153) at the airport; however, considerable data gaps were present in its hourly dataset. Since the Missoula FTS RAWS has a complete dataset, the RAWS was used to develop the QUAL2K model (refer to **Attachment F1** for more discussion of these two weather stations).

The Missoula FTS RAWS records hourly air temperature, dew point temperature, wind speed and solar radiation. The Missoula FTS RAWS hourly observed meteorological data were used to develop the QUAL2K model after appropriate unit conversions.

The wind speed measurements at the Missoula FTS RAWS were measured at 20 feet (6.10 meters) above the ground. QUAL2K requires that the wind speed be at a height of 7 meters. The wind speed measurements ($U_{w,z}$ in meters per second) taken at a height of 6.10 meters (z_w in meters) were converted to equivalent conditions at a height of z = 7 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 (Chapra et al., 2007):

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

F3.2.6 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 Grant Creek. The calibrated Shade Model was first run to simulate shade estimates for September 15, 2011 to simulate hourly shade every 49 feet (15 meters, the resolution of the Shade Model) along Grant Creek. Reach-averaged integrated hourly effective shade results were then computed at every 0.31 mile (500 meters; i.e., each reach). The reach-averaged results were then input into each reach within the QUAL2K model. A more detailed discussion on the shade modeling can be found under **Attachment F1**.

F3.3 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 temperature values from the measured values. 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.

F3.4 Model Calibration and Validation

The time period selected for calibration was September 15, 2011 and the travel time was two days. This date was selected as it had the most comprehensive dataset available for modeling and corresponded to the synoptic study done for Grant Creek, which included collecting flow, temperature, and shade. Validation was not completed due to a lack of available data.

Flow, depth, velocity and temperature data were available at six locations along the mainstem of Grant Creek. **Table F-5** shows the monitoring sites used for calibration.

Table F-5. Temperature calibration locations

Site name	Distance (RM)	Available Data	Source
GRTC-T1	12.69	Flow, depth, velocity, and temperature	EPA
GRTC-T3	12.30	Flow, depth, velocity and temperature	EPA
GRTC-T4	11.17	Flow, depth, velocity and temperature	EPA
GRTC-T5	9.35	Flow, depth, velocity, and temperature	EPA
GRTC-T6	7.00	Flow, depth, velocity, and temperature	EPA
GRTC-T8	1.92	Flow, depth, and velocity	EPA
GRTC-T9	0.23	Flow, depth, and velocity	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 date. This involved accounting for all the flow in the system. Observed flows along Grant Creek, East Fork Grant Creek, 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. To summarize, the exponents of the rating curve for the depth and the velocity were set to be 0.37 and 0.55 respectively. While the exponents were not varied during the model calibration, the rating curve coefficients were modified and evaluated against the observed data. The model results indicated a reasonable model representation. The calibrated coefficients were deemed appropriate since they were based upon observed data and yielded reasonable fits of velocity and depth, as shown in **Figure F-7**.

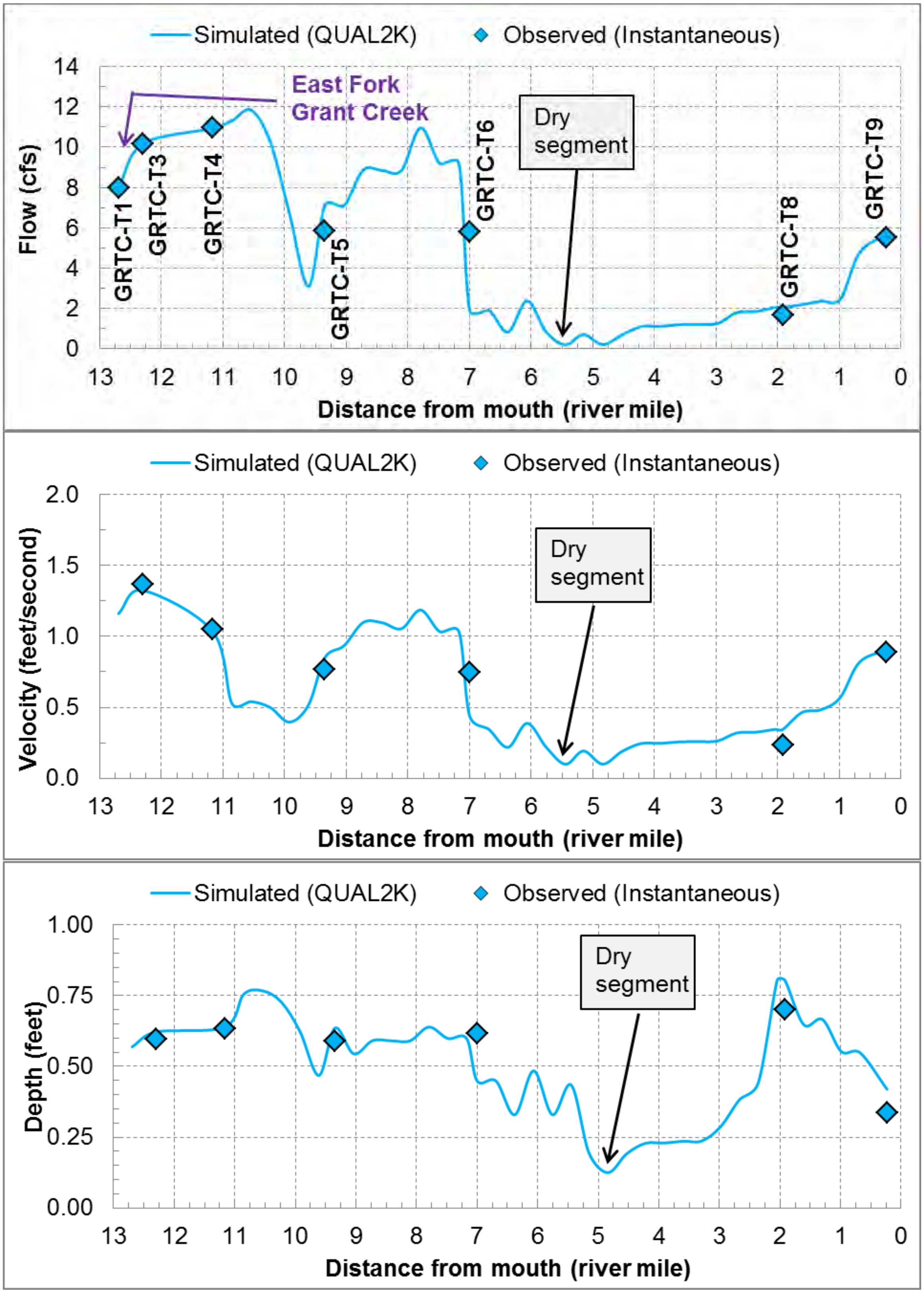


Figure F-7. Observed and predicted flow, velocity, and depth on September 15, 2011 (calibration)

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 Grant Creek, the Ryan-Stolzenbach model was used to calculate the solar radiation. The calculated solar radiation values (without stream shade) for the calibration were compared with observed solar radiation measurements at the Missoula FTS RAWS[4]. **Figure F-8** shows the observed and predicted solar radiation for the calibration. The Ryan-Stolzenbach atmospheric transmission coefficient was set at 0.70 for the calibration to reflect the atmospheric conditions (i.e., cloudy) to minimize the deviation between the observed and modeled short wave solar radiation.

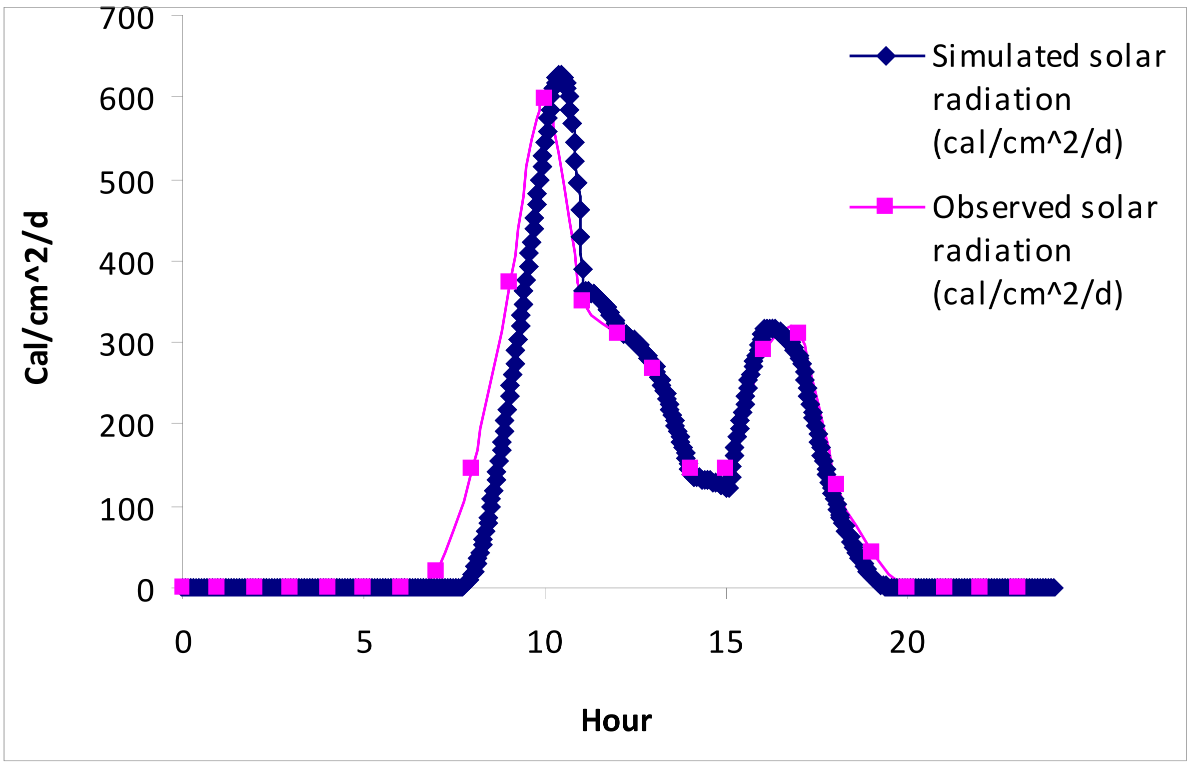


Figure F-8. Observed and predicted solar radiation on September 15, 2011 (calibration)

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 F-6**.

[4] Data from the Missoula airport (National Weather Service ID 241513) were also evaluated using both the Ryan Stolzenbach and Bras methods. In both cases, the values associate with heavily overcast skies (0.7 for Ryan-Stolzenbach and 5 for Bras) were input. However, QUAL2K could not accurately simulate the solar radiation using these methods with the Missoula airport data without increasing the cloud cover above 100%.

Table F-6. 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]	0.70
Downwelling atmospheric longwave infrared radiation	
Atmospheric longwave emissivity model	Brutsaert
Evaporation and air convection/conduction	
Wind speed function for evaporation and air convection/conduction	Adams 2

[a.] The range of atmospheric transmission coefficients is 0.70 to 0.91 and the QUAL2K model default is 0.80 (Chapra et al., 2007).

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 increased from the default value of 10 cm to 20 cm, and the sediment heat capacity of all component materials of the stream was set to 0.4 calories per gram per degree Celsius, which is the QUAL2K default (Chapra et al., 2007).

The sediment density was set to 1.98 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 silt soil types. Geology data from Montana Bureau of Mines and Geology indicated that the type of rock geology within the watershed was mainly argillite. Based on the field photographs, the surface layer of the stream substrate was estimated to be composed of 50% of argillite rock, 35% of silt, and 15% gravel. The following calculation was conducted:

$$
\begin{aligned}
\text{sediment density} &= (\text{ratio} * \text{density})_{\text{argillite}} + (\text{ratio} * \text{density})_{\text{silt}} + (\text{ratio} * \text{density})_{\text{gravel}} \\
&= (0.50 * 1.82\ g/cm^3) + (0.35 * 2.20\ g/cm^3) + (0.15 * 2.00\ g/cm^3) \\
&= 1.98\ g/cm^3
\end{aligned}
$$

where 1.82 g/cm^3 is the density of argillite, 2.20 g/cm^3 is typical of clay and silt densities, and the density of gravel is 2.00 g/cm^3.

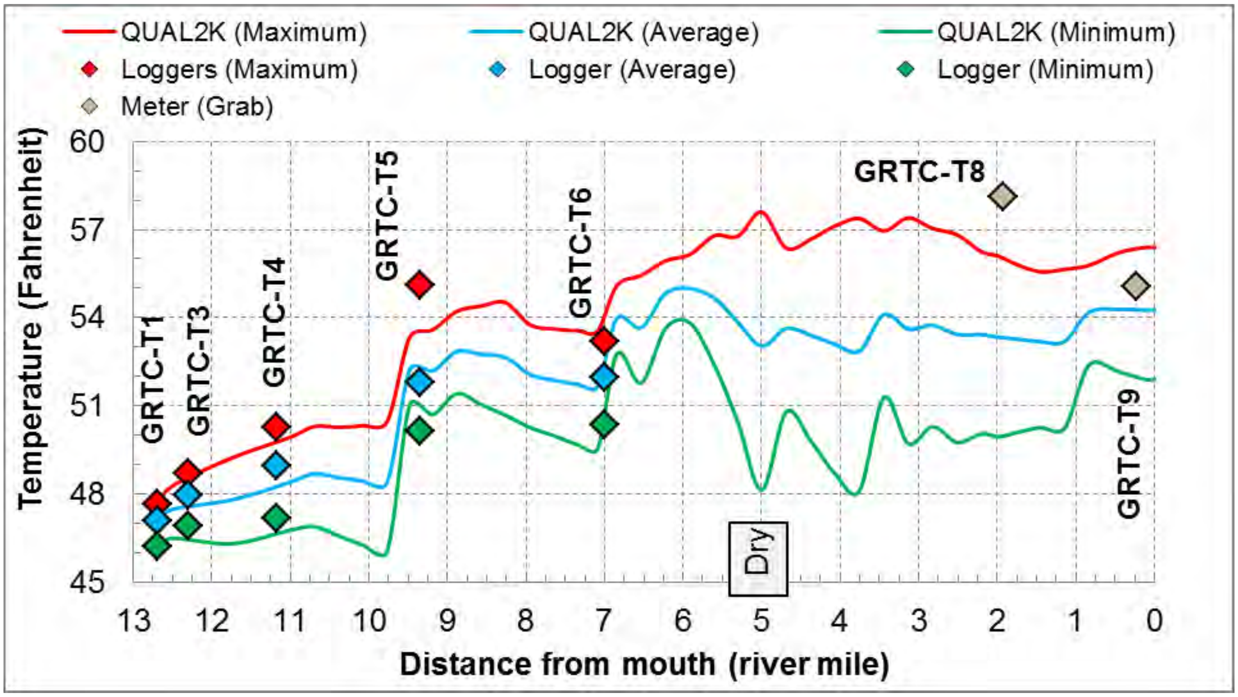
The sediment thermal diffusivity was set to a value of 0.0111 square centimeters per second (cm^2/s; Chapra et al., 2007). The following calculation was conducted:

$$
\begin{aligned}
\text{thermal diffusivity} &= (\text{ratio} * \text{thermal diffusivity})_{\text{argillite+gravel}} + (\text{ratio} * \text{thermal diffusivity})_{\text{silt}} \\
&= (0.65 * 0.118\ cm^2/s) + (0.35 + 0.0098\ cm^2/s) \\
&= 0.0111\ cm^2/s
\end{aligned}
$$

where 0.118 cm^2/s is the thermal diffusivity of rock and 0.0098 cm^2/s is the thermal diffusivity of clay, which is assumed to be representative of silt.

These adjustments helped in improving the minimum temperatures simulated.

While calibration is typically followed by validation, no validation was performed for the Grant Creek QUAL2K because there are insufficient flow data to develop a validation model. **Figure F-9** shows the calibration results along Grant Creek. As can be seen in the figure, the ranges of temperatures during calibration vary more in the lower reaches than in the upper reaches. The temperature calibration statistics of the average, maximum, and minimum temperatures are shown in **Table F-7**. Loggers GRTC-T7, GRTC-T8, and GRTC-T9 were exposed to ambient air on September 15, 2011; instantaneous meter results are presented for GRTC-T8 (12:40 pm) and GRTC-T9 (2:10 pm) in **Figure F-9**.



Note: Grant Creek ran dry in the short segment with logger GRTC-T7. As flow cannot be set to zero in QUAL2K, the segment was simulated with a tiny flow volume. All other hydraulic and meteorological parameters were set equivalent to the upstream, wet reach.

Figure F-9. Longitudinal profile of the temperature calibration (September 15, 2011)

Table F-7. 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 (%)
GRTC-T1	12.69	0	--	0	--	0	--
GRTC-T3	12.30	0.49	1.0%	0.42	0.9%	0.42	0.9%
GRTC-T4	11.17	0.55	1.1%	0.33	0.7%	0.42	0.9%
GRTC-T5	9.35	0.44	0.9%	1.77	3.2%	0.91	1.8%
GRTC-T6	7.00	0.31	0.6%	0.36	0.7%	0.81	1.6%
Overall Calibration		**0.45**	**0.9%**	**0.72**	**1.4%**	**0.65**	**1.3%**

Note: AME = absolute mean error; km = river kilometer; REL = relative error.

The model is able to simulate the flow, depth, and velocity and the minimum, mean, and maximum temperatures well. The model over-predicts the minimum, mean, and maximum temperature at logger GRTC-T6 and under-predicts the instantaneous temperature meter measurement at logger GRTC-T8, which was measured at the logger that was exposed to ambient air. The overall calibration results showed an overall 1.4% REL with an AME of 0.72° F for the maximum temperatures; thus, the model simulation is good.

Initially, the QUAL2K model considerably over-predicted minimum, mean, and maximum temperatures at logger GRTC-T6 (by 1.7° F, 1.9° F, and 2.2° F, respectively). The diffuse inflow temperature was reduced from 55.4° F to 50.0° F during calibration to account for the multiple active flow channels in this segment. As previously discussed, a braided stream channel may have more interaction with subsurface flow.

The model is not able to simulate the warmer temperature measured with a meter at logger GRTC-T8, where the logger went dry. There is increased uncertainty below logger GRTC-T7 at RM 5.2 because the segment immediately above logger GRTC-T7 ran dry. Since the measured instantaneous temperature at logger GRTC-T9, which was also exposed to ambient air, was within the range of simulated temperatures, the temperature differential at logger GRTC-T8 may be due to localized factors (e.g., an irrigation return flow).

F4.0 Model Scenarios and Results

The Grant Creek QUAL2K model was used to evaluate instream temperature response associated with multiple management scenarios. **Table F-8** summarizes the alterations for each model scenario. The following subsections present discussions of the modifications to the QUAL2K models and the results for each scenario.

Table F-8. QUAL2K model scenarios for Grant Creek

Scenario [a]		Description	Rationale
Baseline Scenario			
1	Existing Condition	Existing shade and irrigation practices under field-measured flows[b]	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%	Represent application of conservation practices for agricultural and domestic water use.
Shade Scenario			
3	Shade increased to reference levels	Increased shading along the segment from loggers GRTC-T4 to GRTC-T6 and from logger GRTC-T6 to the mouth to reference levels.	Represent application of conservation practices for riparian vegetation.
Improved Flow and Shade			
4	Improved flow and shade	Existing conditions with 15% reduction in withdrawals (scenario 2) and increase to reference levels (scenario 3).	Represent application of conservation practices for water withdrawals and riparian vegetation.

[a.] Scenarios were developed in accordance with electronic correspondence from the DEQ project manager Eric Sivers to Tetra Tech's project manager Ron Steg on February 20, 2014.
[b.] Based on an analysis of a discharge records from a nearby USGS gage, flows in Grant Creek during the calibration timeframe were likely above the median (83rd percentile) of flows recorded on September 15th.

F4.1 Baseline Scenario (Existing Condition)

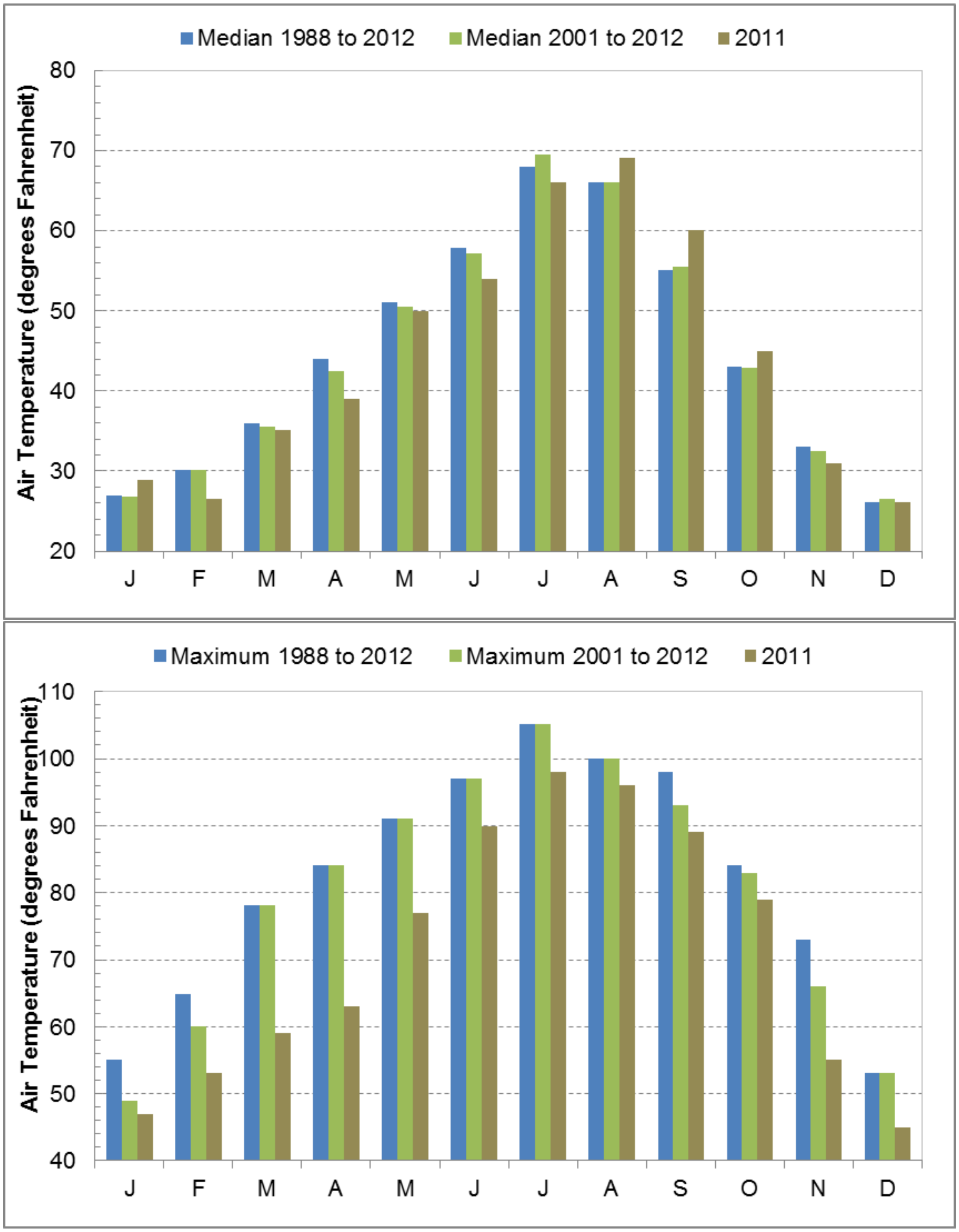
The baseline model (scenario 1) serves as the model simulation from which to construct the other scenarios and compare the results against. The baseline scenario was run using the existing flow and weather conditions on the calibration date (i.e., the calibration model).

The Missoula FTS RAWS has hourly data available for the period from March 2001 through March 2014. Since the weather data extends only for a period of thirteen years, a nearby station with long-term meteorological data (Missoula International Airport [1988-2012]) was queried to confirm if the years from 2001 to 2012 were (1) not anomalously warm or cold and (2) similar to the overall historical normal. Additionally, comparisons with the year 2011 (during which the QUAL2K model calibration period occurs) were made to ensure that 2011 was not an anomalous year. The long-term monthly median and maximum air temperatures for the period from 2001 to 2012 and for the year 2011 were estimated to be similar to the overall period from 1988 through 2012 (**Figure F-10**)[5]. While the monthly maximum air temperatures in the summer of 2011 were cooler than the monthly long-term maximum of monthly maximum air temperatures of the years 1988-2012, they were warmer in some months and cooler than other months as compared with the monthly long-term median of monthly maximum air temperatures of the years 1988-2012 (**Figure F-10**). Therefore, since neither the period from 2001 through 2012 nor the summer of 2011 was substantially anomalous, it is appropriate to use the Missoula FTS RAWS data for QUAL2K modeling.

Existing conditions weather (September 15, 2011) used for the calibration model was also used for the baseline model. While existing conditions were cloudy for part of the day on September 15, 2011, the heat and light parameters were not altered to create synthetic hourly solar radiation for a cloudless day. Instead, the heat and light parameters in the baseline model were left unchanged from the calibration model.

No continuous flow datasets are available in the Grant Creek watershed. The closest continuously recording USGS gage in a watershed of similar size is gage 12340000 (Black River near Bonner, Montana; water years 1940-2012). The daily average flow on September 15, 2011 at gage 12340000 was the 83rd percentile of recorded daily average flows of all September 15ths on record (see **Attachment F1** for evaluations of the gage).

[5] Hourly average air temperatures were obtained for the Missoula International Airport (KMSO). Monthly maximum air temperatures were calculated for each month from January 1988 through December 2012 using the hourly average air temperatures. Monthly long-term medians and maximums were calculated from the 25 years of monthly maximums of hourly average air temperatures.



Note: Hourly average air temperatures were obtained for the Missoula International Airport (KMSO). Monthly maximum air temperatures were calculated for each month from January 1988 through December 2012 using the hourly average air temperatures. Monthly long-term medians and maximums were calculated from the 25 years of monthly maximums of hourly average air temperatures.

Figure F-10. Long-term median (chart on top) and maximum (chart on bottom) of monthly air temperature at Missoula

The modeled water temperature using the existing condition flow and meteorological data is shown below in **Figure F-11**.

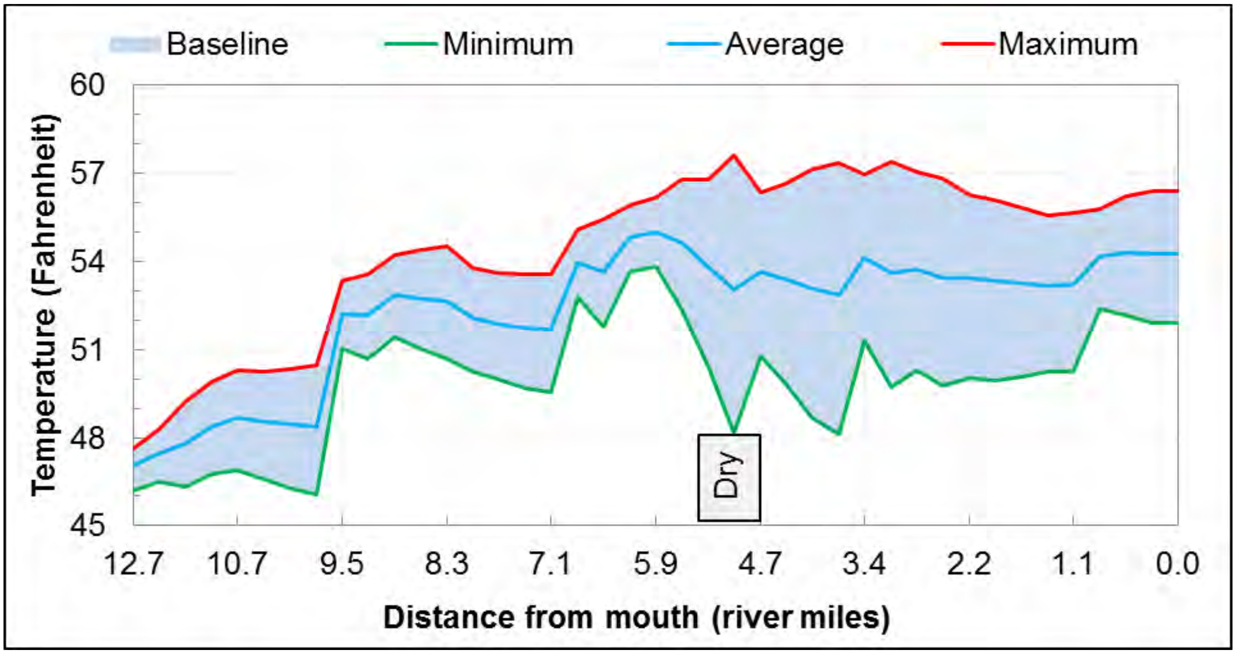


Figure F-11. Simulated water temperature for existing condition (September 15, 2011)

F4.2 Water Use Scenario

Irrigation (or other water withdrawals) deplete the volume of water in the stream and reduce instream volumetric heat capacity. Theoretically the reduced stream water volume heats up more quickly (and also cools more quickly), 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 sources abstractions representing the withdrawals (see **Attachment F1** and **Table F-3** for the withdrawals) in the QUAL2K model are reduced by 15% (Natural Resources Conservation Service, 1997). The water previously withdrawn is now allowed to flow down Grant Creek. This scenario is intended to represent application of conservation practices relative to water use.

The water temperatures under this scenario exhibited both increases and decreases along Grant Creek that reflect the locations of the irrigation withdrawals (**Figure F-12**). The maximum change in the maximum daily water temperature is representative of the worst case conditions. A maximum change in the maximum daily water temperature of 0.55° F from the existing condition was observed at RM 6.5. The temperature difference of the daily maximums never exceeds 0.56° F.

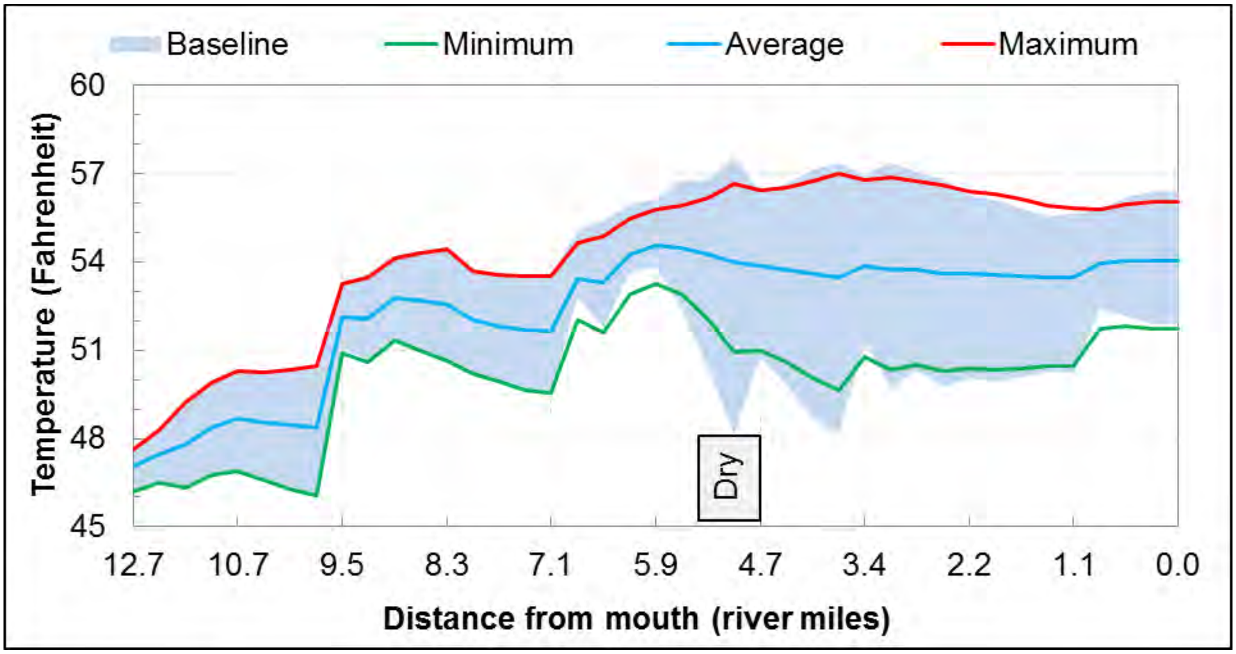


Figure F-12. Simulated water temperatures for the baseline (scenario 1) and 15% withdrawal reduction (scenario 2)

F4.3 Shade Scenario

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 along certain segments of Grant Creek.

An evaluation of shading using the Solar Pathinder™ measurements, Shade model results, GIS, and aerial imagery and incorporating DEQ's input resulted in the following conclusions:

1. Vegetation along Grant Creek above logger GRTC-T4 is likely at potential and there is very little opportunity to improve shade. Therefore, the segments upstream of logger GRTC-T4 will not be altered for the shade scenario.
2. Vegetation communities along Grant Creek downstream of logger GRTC-T4 and upstream of I-90 (i.e., near logger GRTC-T6) are impacted by encroachment from agriculture, residential subdivisions, and power line right-of-ways. There is opportunity to convert some of the herbaceous areas to shrubs or trees. Therefore, shade along this segment will be improved to a reference condition, which is conservatively defined as the segment immediately upstream of logger GRTC-T5 that is composed of a narrow band of trees on one side of the creek.
3. Downstream of I-90, Grant Creek flows through mixed residential, commercial, and agricultural lands. There is considerable opportunity to improve the vegetation communities in the agricultural areas. Therefore, shade along this segment will be improved to a reference condition, which is conservatively defined as the segment immediately downstream of logger GRTC-T8 that is composed of shrubs in a 25-foot buffer.

The Grant Creek QUAL2K model was re-run using the altered shade inputs, based upon the findings presented above (**Table F-9**). This scenario is intended to represent application of conservation practices relative to shade although it is important to note that even in natural forested conditions, there are still openings in the canopy and some areas without vegetation. Hence this is likely an upper limit to what plausibly could occur from vegetation management practices.

Table F-9. Average daily shade inputs per model segment

Segment	Existing condition (scenario 1)	Shade (scenario 3)
GRTC-T1 to GRTC-T3	69%	69%
GRTC-T3 to GRTC-T4	68%	68%
GRTC-T4 to GRTC-T5	61%	63%
GRTC-T5 to GRTC-T6	50%	70%
GRTC-T6 to GRTC-T7	35%	62%
GRTC-T7 to GRTC-T8	37%	60%
GRTC-T8 to GRTC-T9	35%	60%
GRTC-T9 to mouth	34%	59%

Note: For each segment, the effective shade per hour was averaged across 15 meter intervals for each hour from 5:00 am through 9:59 pm (yielding average effective shade per hour per model segment) and then averaged across daylight hours (yielding average effective shade per day per model segment.

Water temperatures in Grant Creek downstream of logger GRTC-T4 (about RM 11.2) decreased, with considerable decreases, below the dry segment at RM 4.7 (**Figure F-13**). The largest temperature decrease occurred in the lower reaches of Grant Creek, where considerable improvements can be made to the riparian corridor within agricultural lands. A maximum change in the maximum daily water temperature of 2.6° F from the baseline was observed at RM 3.8. The difference in the daily maximum water temperature between the baseline and shade scenario was greater than 0.5° F below the dry segment and between RMs 7.1 and 8.3. It is important to note the caveats previously stated: that this is likely the largest improvement that could be observed through vegetation management practices.

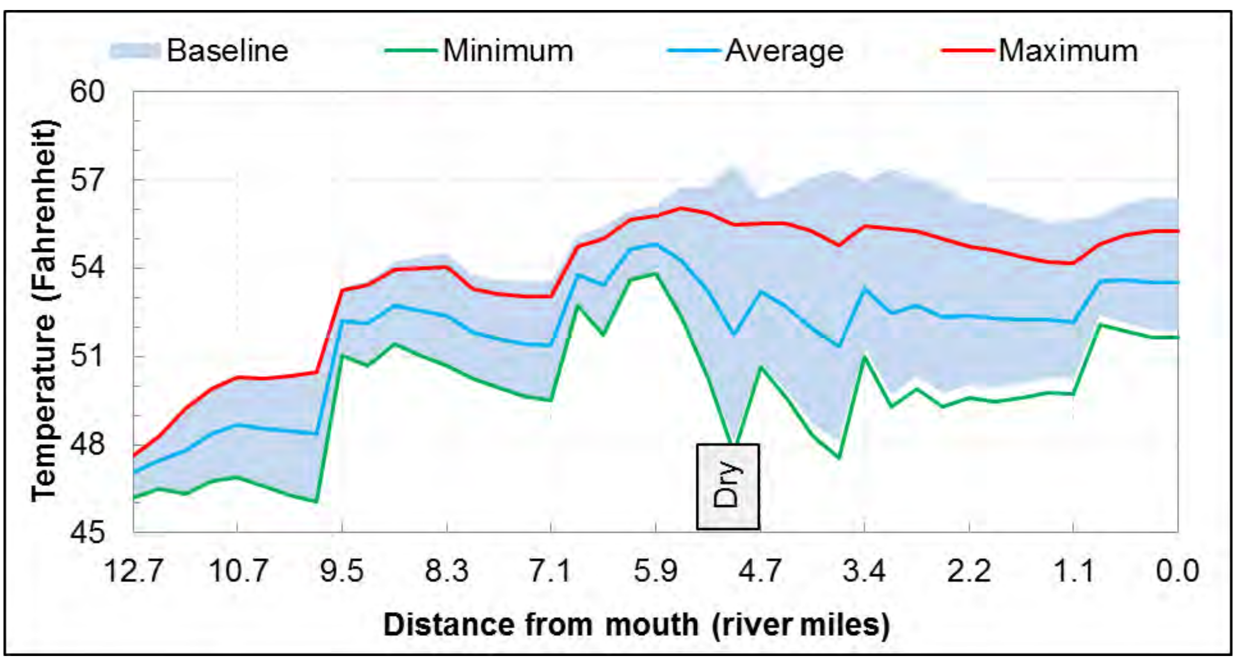


Figure F-13. Simulated water temperatures for the existing condition (scenario 1) and increased shade (scenario 3)

F4.4 IMPROVED FLOW AND SHADE SCENARIO

The improved flow and shade scenario (scenario 4) combines the potential benefits associated with a 15% reduction in water withdrawals (scenario 2) with increases shade to reference levels along certain segments (scenario 3).

In this scenario, water temperatures in Grant Creek decrease throughout the system (**Figure F-14** and **Figure F-15**). A maximum change in the maximum daily water temperature of 2.1° F from the baseline was observed at RM 3.1. The results are similar to scenario 3 since scenario 2 showed limited sensitivity to a 15% reduction in the withdrawals. The difference in the daily maximum water temperature between the baseline and the improved flow and shade scenario was greater than 0.5° F from RM 8.6 to the mouth and greater than 1.0° F from RM 4.4 to the mouth.

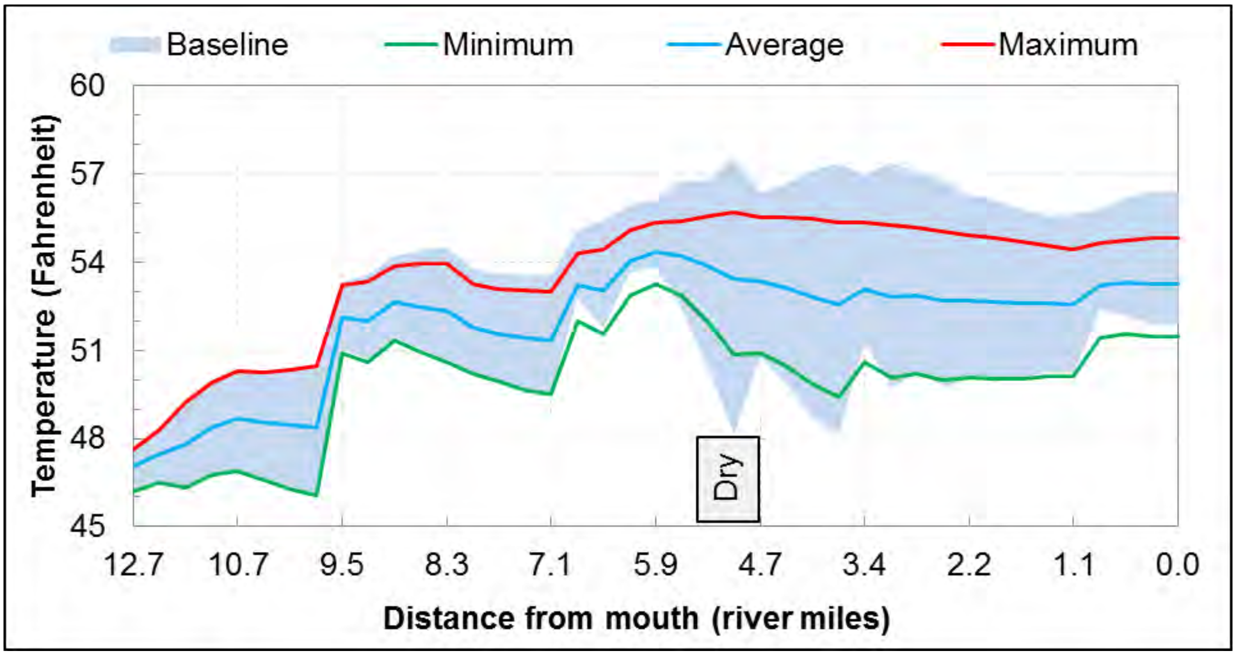


Figure F-14. Simulated water temperature for the existing condition (scenario 1) and the improved flow and shade scenario (scenario 4)

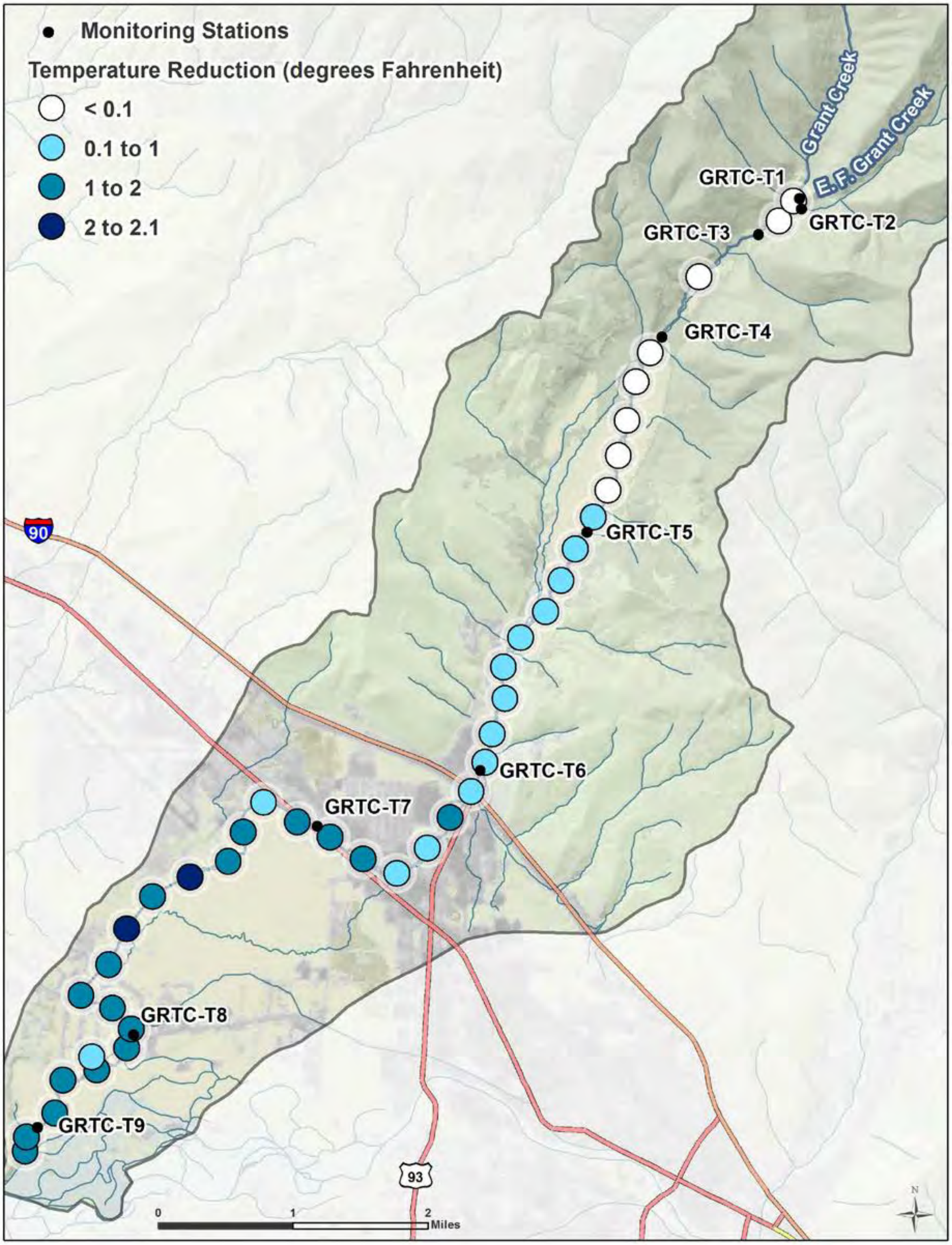


Figure F-15. Instream temperature difference from existing condition (scenario 1) to the improved flow and shade scenario (scenario 4)

F5.0 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, Inc., 2012). As discussed in the quality assurance project plan (Tetra Tech, Inc., 2012), the QUAL2K model code has a long history of testing and application, so outright errors in the coding of the temperature model are 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 and calibration, and assumptions used in the scenario analysis itself.

With respect to input data (including instantaneous flow, continuous temperature, channel geometry, hourly weather, spatial data or other secondary data), weather and spatial data were obtained from other government agencies and were found to be in reasonable ranges, and are therefore assumed to be accurate. Uncertainty was minimized for the use of other these data following procedures described in the quality assurance project plant (Tetra Tech, Inc., 2012).

In addition, assumptions regarding how these data are used during model development contain uncertainty. The following key assumptions were used during Grant Creek QUAL2K model development:

- Grant 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 Grant 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 Missoula FTS RAWS are representative of local weather conditions along Grant Creek.
- Shade Model results are representative of riparian shading along segments of Grant 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 (OH) were estimated from other similar studies conducted outside of the Grant Creek watershed.
    - Vegetation density was estimated using the National Land Cover Dataset (Multi-Resolution Land Characteristics Consortium, 2006) and best professional judgment.

  Shade Model results were corroborated with field measured Solar Pathfinder™ results and were found to be reasonable. The average AME is 8%. (i.e., the average error from the Shade Model output and Solar Pathfinder™ measurements was 8% 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.

The increased shade scenario (scenario 3) assumes that the shade from vegetation along the reference segment is achievable in the segments with anthropogenically diminished shade. The increased shade scenario (scenario 3) represents the feasible 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 and the fact that even natural systems tend to have spatial patchiness of tree canopy cover.

F6.0 Model Use and Limitations

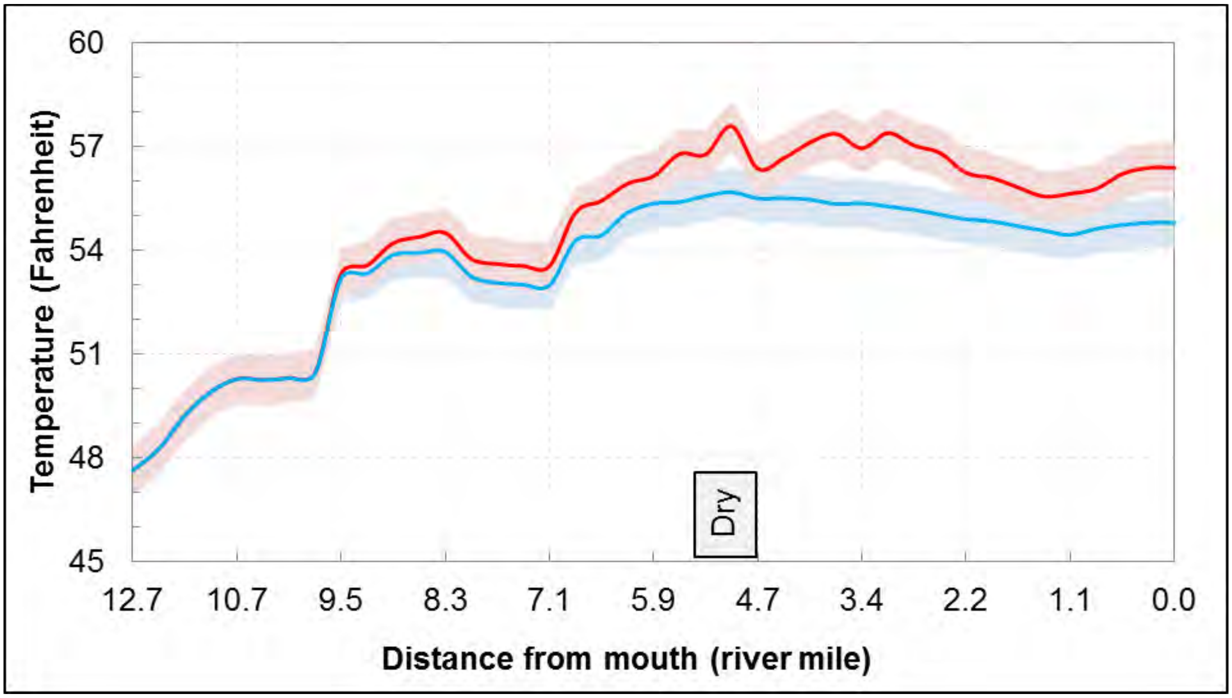
The model is only valid for summertime, warm-weather conditions and should not be used to evaluate high flow or other conditions. As described above, steps were taken to minimize uncertainty as much as possible. Despite the uncertainty, the model adequately addresses the primary questions:

1. What is the sensitivity of instream 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 question can be answered using the calibrated and validated QUAL2K model for Lynch Creek. As previously discussed, Lynch Creek is sensitive to shade but not flow.

The second question can be answered using the calibrated QUAL2K model and the scenarios developed to assess shade. In this instance, increasing riparian shading will decrease instream temperatures significantly (>2°F for maximum); however, there is uncertainty in the magnitude of temperature reduction as estimates are contingent on what was considered to be reference shade (>59% shading). While a “good” model calibration was achieved, the overall AME for the maximum daily temperature was 0.7° F with unknown uncertainty in the lowermost portions of the model without continuous logger day to compare simulated results with.

Figure F-16 graphically summarizes the comparison between the baseline condition and improved flow and shade scenario. Based on these results, and the fact that Montana’s temperature standard as applied to Grant Creek is limited to an increase of 1° F, it is clear that impacts are occurring to the stream and that the mechanism to address these temperature concerns will be the mitigation of stream shade through plantings or riparian enhancement. Continued monitoring should be done in conjunction with these activities to ensure that they are of benefit, in particular given that model results are uncertain as described previously.



Note: The baseline (scenario 1) is the red line and the improved flow and shade scenario (scenario 4) is the blue line. The shaded areas are plus or minus the average AME (0.7° F).

Figure F-16. Simulated daily maximum water temperatures from the baseline (red; scenario 1) and improved flow and shade scenario (blue; scenario 4)

F7.0 CONCLUSIONS

The scenarios resulted in a range of minimal change in water temperatures to reductions as much as nearly 2.6° F. Some of the reductions in water temperatures were localized and others affected nearly the entire stream.

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% reductions in water use did not result in any appreciable reduction to the temperature from the headwaters downstream to RM 7.1 and temperatures slightly increased from RMs 0.8 to 2.5. The largest reductions (range: 0.38° F to 0.55° F) occurred from RMs 5.9 to 7.1.

The shade scenario showed the greatest extent and impact (reduction) to water temperatures along much of the stream. Reductions of 0.5° F occurred from RMs 7.1 to 8.0 and reductions of 1.0° F to 2.6° F occurred from RM 4.7 to the mouth.

The improved flow and shade scenario that combined the potential benefits associated with a 15% reduction in water withdrawals (scenario 2) with increased shading based upon reference levels (scenario 3) to represent application of conservation practices relative to the temperature impairment was also simulated. This scenario resulted in overall reductions along the most of the stream, which ranged from 0.1° F to 2.1° F. The scenario shows that reductions in water temperatures are achievable throughout the stream, but reductions of 0.5° F are achievable from RM 8.6 to the mouth and reductions of 1.0° F are achievable from RM 4.4 to the mouth (refer back to Figure F-15 for a map of potential temperature reductions). The greatest potential improvement (i.e., reduction) occurs between RMs 2.5 and 4.1 (1.8° F to 2.1° F improvement) (**Figure F-18**). Above logger GRTC-T4 (about RM 11.2), the vegetation communities are at potential and no shade improvements were simulated. Efforts should be spent on re-vegetation in these areas most amenable to this type of restoration activity in the lower reaches of Grant Creek.

Table F-10. Instream temperature difference from the baseline scenario

Scenario ID	Scenario name	Daily maximum			Daily average		
		Range of change [a]	Average change [b]	Median change [c]	Range of change [a]	Average change [b]	Median change [c]
2	Water Use	-0.89to +0.37	-0.14	-0.08	-0.59 to +0.60	-0.03	-0.03
3	Shade	-2.61 to 0	-0.81	-0.50	-1.54 to 0	-0.49	-0.29
4	Improved Flow and Shade	-2.12 to 0	-0.88	-0.84	-1.01 to 0	-0.46	-0.32

Notes: Results are reported in degrees Fahrenheit. Negative values represent scenario results that were cooler than the Baseline scenario while positive values represent scenario results that were warmer than the baseline scenario.
[a.] The range of temperature changes along Grant Creek as compared with the baseline scenario.
[b.] The distance-weighted average temperature change along Grant Creek as compared with the baseline scenario.
[c.] The distance-weighted median temperature change along Grant Creek as compared with the baseline scenario.

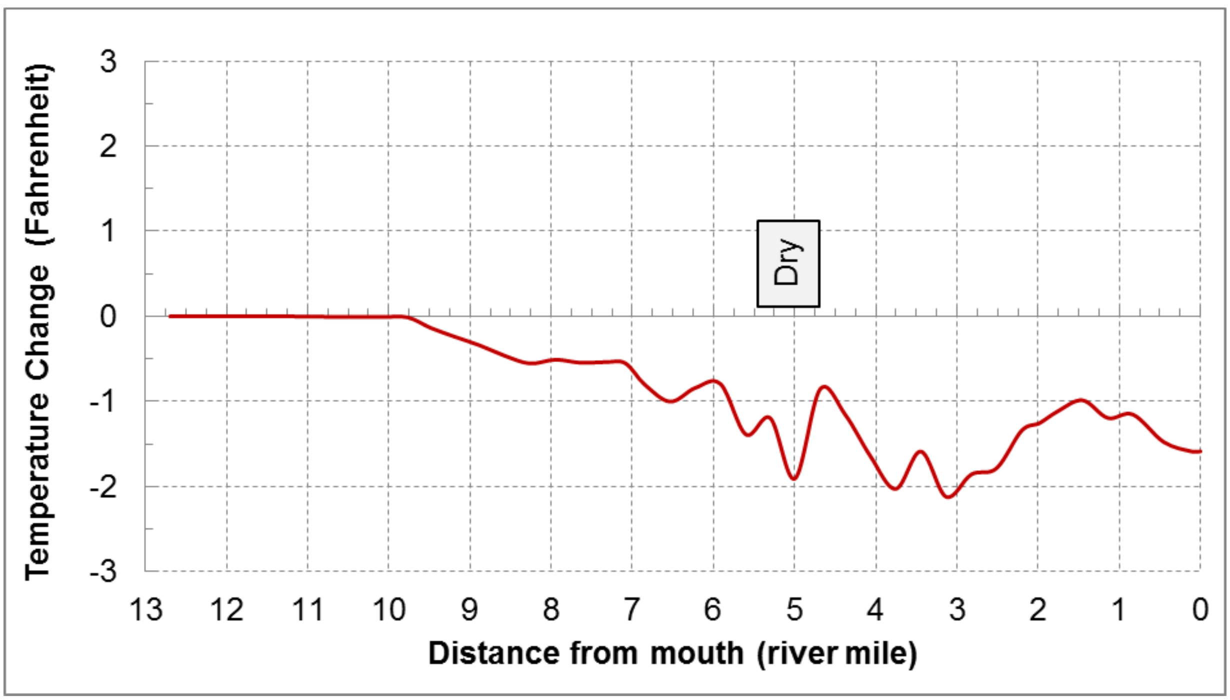


Figure F-17. Simulated water temperature reduction from the existing condition (scenario 1) to the improved flow and shade scenario (scenario 4)

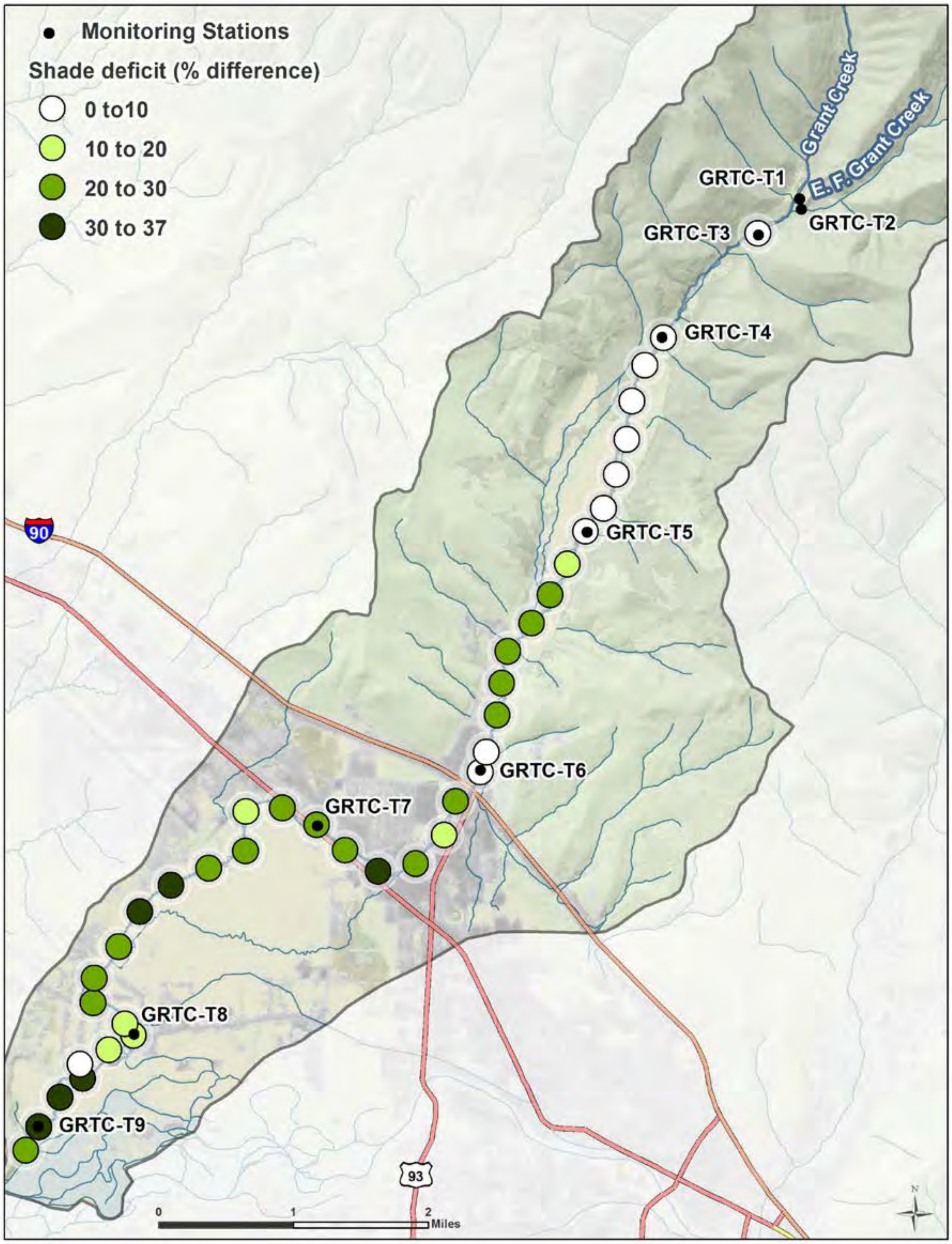


Figure F-18. Shade deficit of the existing condition (scenario 1) from the improved flow and shade scenario (scenario 4)

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ATTACHMENT F1 – FACTORS POTENTIALLY INFLUENCING STREAM TEMPERATURE IN GRANT CREEK

F1-1.0 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 instream 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 Grant Creek are discussed below:

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

F1-2.0 CLIMATE

The nearest weather station to the Grant Creek watershed is one half mile to the west in the city of Missoula, Montana (National Weather Service station 24153) at an elevation of 3,200 feet above MSL. A RAWS is 2 miles south in Missoula, Montana (National Weather Service station ID 241513, **Figure1-1**) at 3,200 feet above MSL. Grant Creek ranges in elevation from approximately 3,120 to 7,150 feet above MSL.

Average annual precipitation at station 24153 is 13.7 inches, with slightly higher amounts falling in the spring months (**Figure F1-1**). Average maximum temperatures occur in July and August and are 84.9° F and 83.0° F, respectively (**Figure F1-2**).

Average maximum temperatures at the Missoula FTS RAWS station occur in July and August and are 88.5° F and 85.5° F, respectively. The available data at Missoula FTS RAWS only date back to 2001, but the station records weather data hourly whereas station 24153 only records weather data daily. Thus, Missoula FTS RAWS hourly temperature data were used to develop the QUAL2K inputs. The Missoula FTS RAWS data are also summarized in **Figure F1-2.**

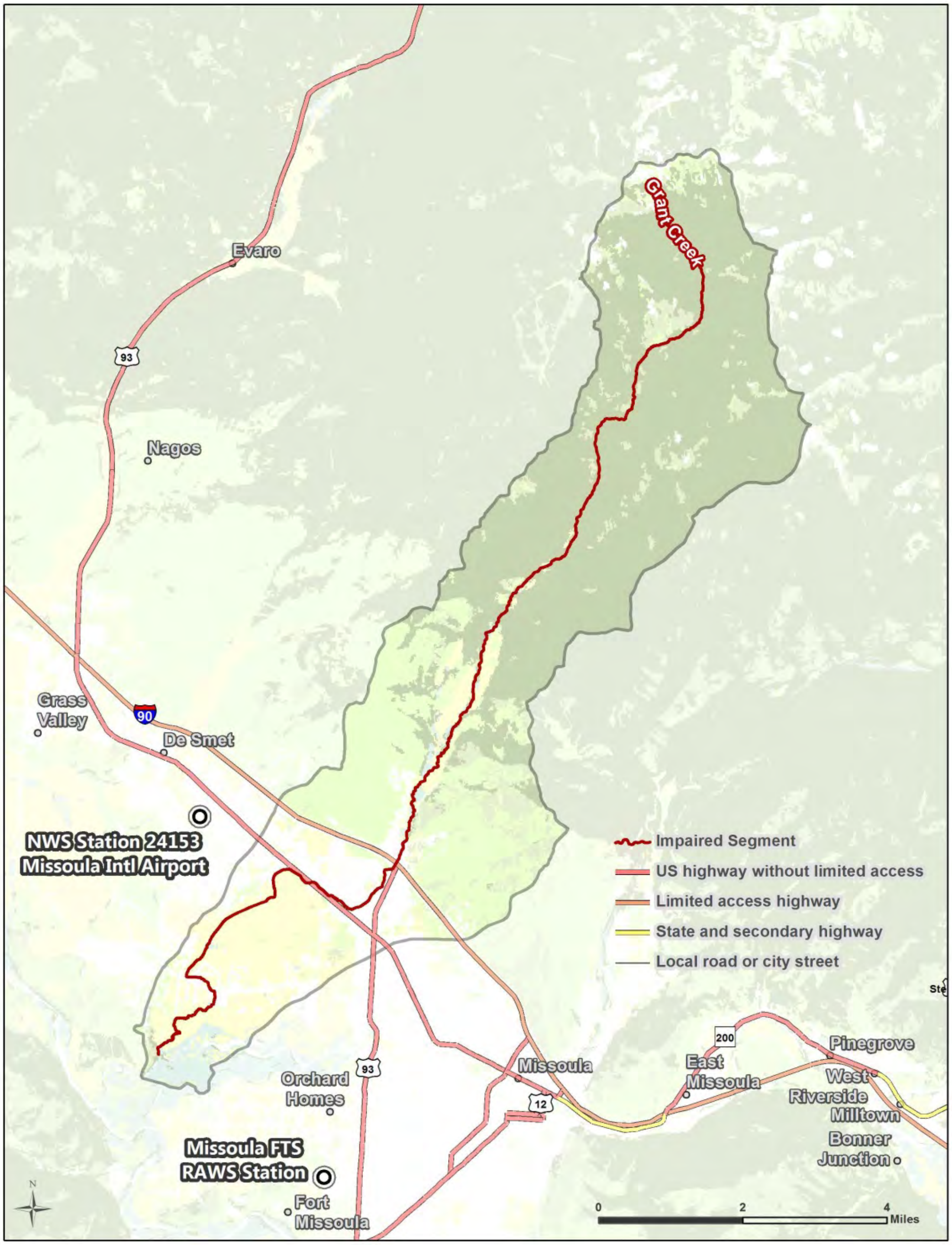
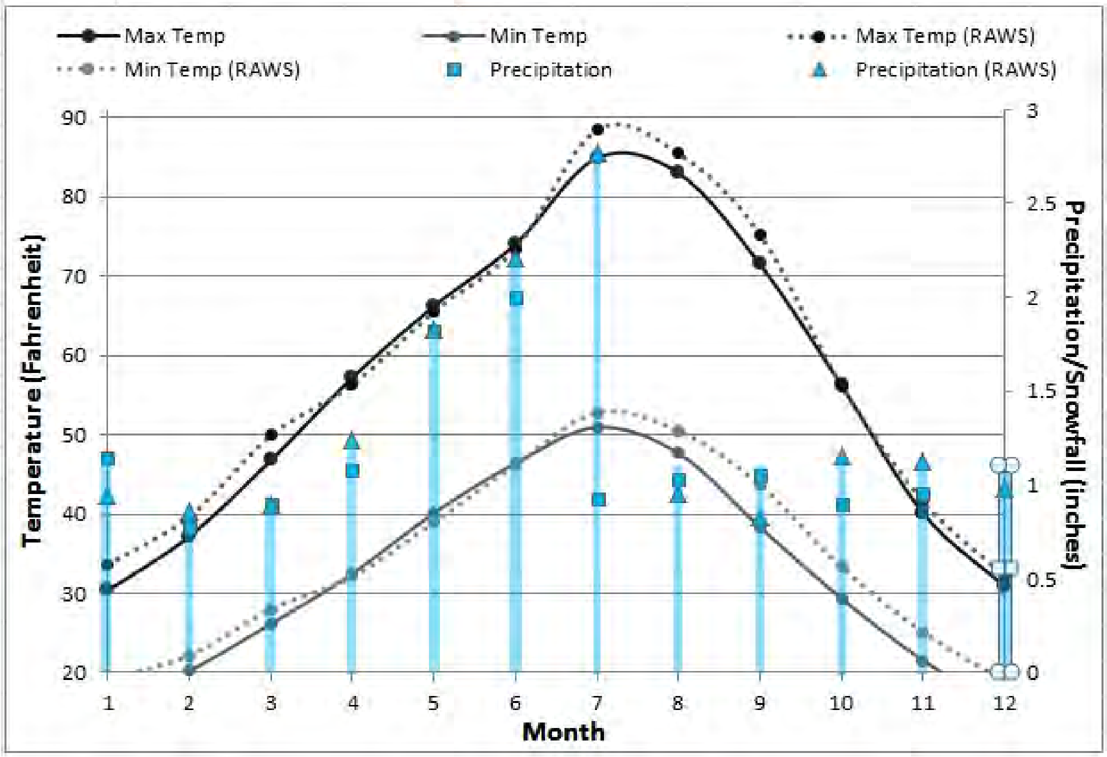


Figure F1-1. Grant Creek watershed and Missoula FTS RAWS



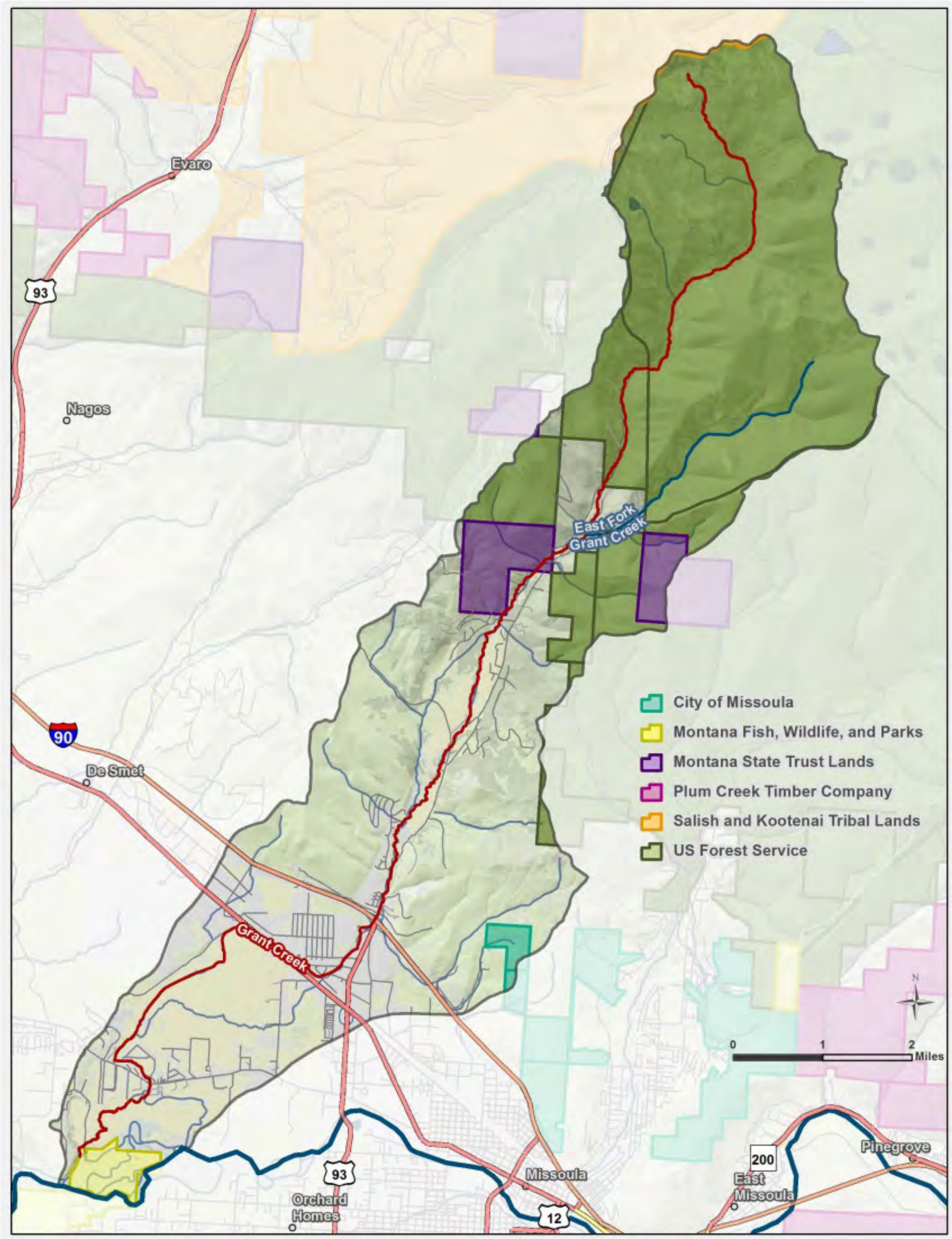
Source: GHCN-D Monthly Summaries from 1948 to 2013 at NWS station 24153 (National Climate Data Center, 2013) and from 2001 to 2013.at the Missoula FTS RAWS station (Western Regional Climate Center, 2013).
Figure F1-2. Monthly average temperatures and precipitation at Missoula, Montana

As previously discussed, the Missoula 24153 station only has hourly air temperature data and does not have additional hourly datasets necessary for QUAL2K modeling. The Missoula FTS RAWS records hourly air temperature, dew point temperature, wind speed and solar radiation and these data were used to develop the QUAL2K model.

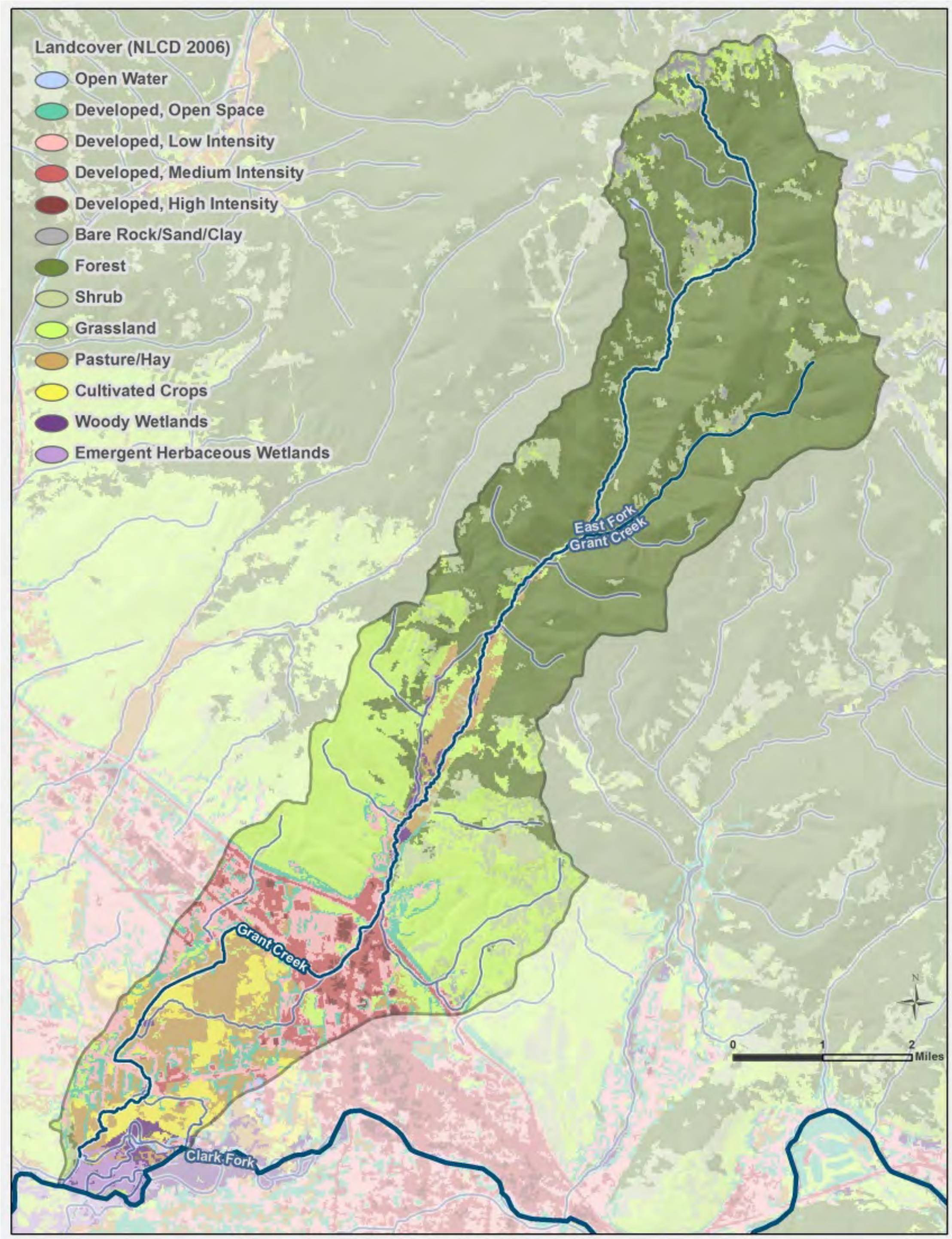
F1-3.0 LAND OWNERSHIP AND LAND USE

Grant Creek is in the Rocky Mountains of western Montana and is part of the Middle Clark Fork Tributaries TMDL Planning Area. The Grant Creek watershed is in the Middle Clark Fork subbasin (hydrologic unit code 17010204). The impaired segment is 18.8 miles long and extends from the headwaters to the mouth (Montana Department of Environmental Quality, Planning, Prevention and Assistance Division, Water Quality Planning Bureau, 2014).

Private ownership accounts for 54% of the land ownership in the Grant Creek watershed, primarily located in the southern, downstream half (**Figure F1-3**). The U.S. Forest Service manages 41% of the area, and the remaining 5% is split between the State of Montana, the City of Missoula, and the Montana Fish, Wildlife, and Parks service. The landscape in the upper half of the watershed is predominantly forested, with increasing development in the lower half (**Figure F1-4** and **Figure F1-5**). Starting approximately halfway along Grant Creek, grasses begin to dominate the hills, with residential development along the river. Once Grant Creek passes under Interstate 90, the landscape becomes heavily developed as it enters the City of Missoula. Once past U.S. Highway 93, it enters a long, straightened channel as it travels through agricultural lands, until passing through more suburban and rural development near the mouth.



Source of land ownership: Natural Resource Information System (2012)
Figure F1-3. Land ownership in the Grant Creek watershed



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

Figure F1-4. Land cover and land use in the Grant Creek watershed

Source of aerial imagery: 2011 National Agricultural Imagery Program (Natural Resource Information System, 2012)

Figure F1-5. Aerial imagery of the Grant Creek watershed

F1-4.0 EXISTING RIPARIAN VEGETATION

Vegetation communities between the shade monitoring sites were visually characterized based on aerial imagery (GoogleEarth, 2013) with qualitative field verification conducted during September 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 National Land Cover Dataset (NLCD) (**Figure F1-6**):

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

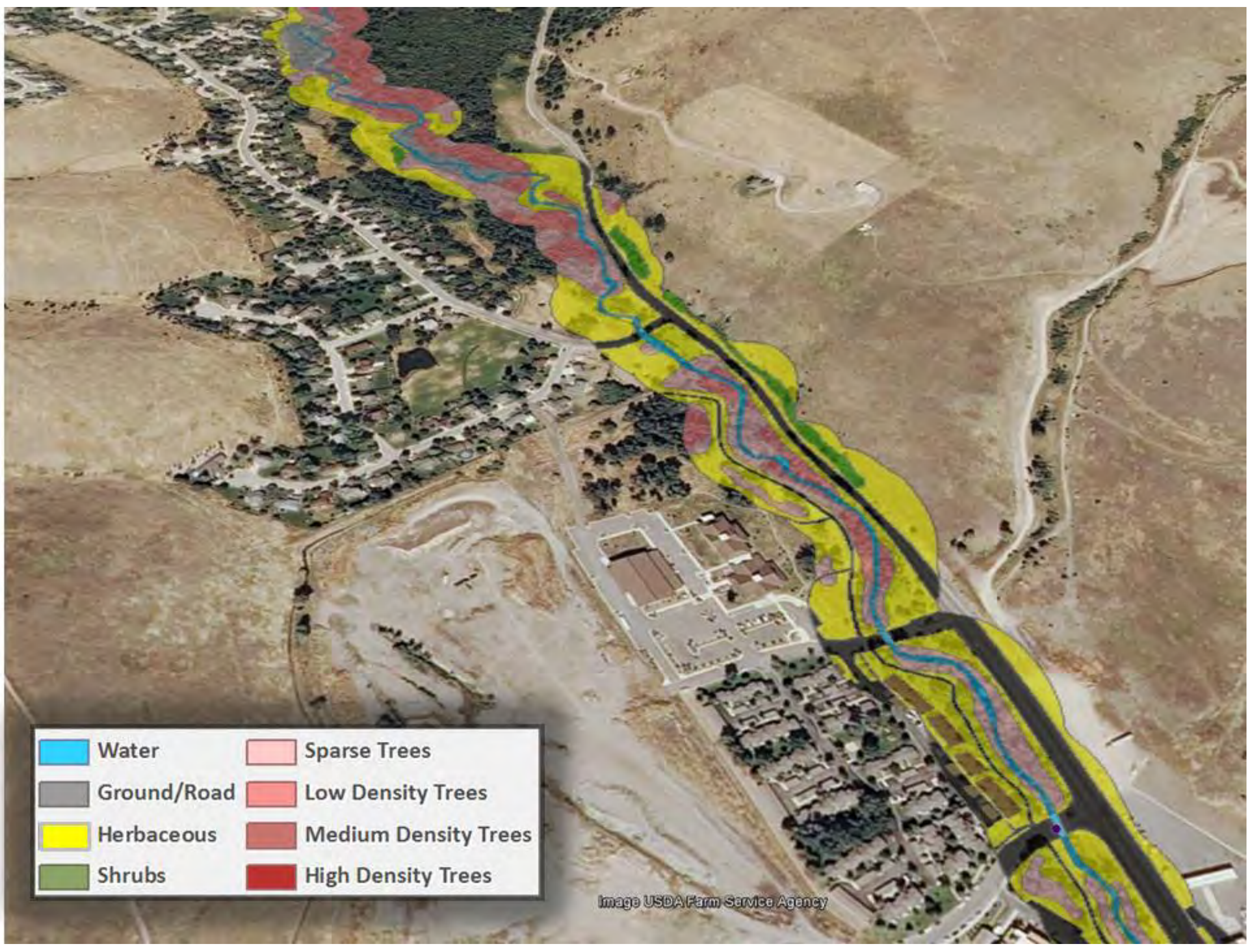


Figure F1-6. Vegetation mapping example for Grant Creek

Herbaceous vegetation and low density trees are the most common cover types along Grant Creek, followed by medium and high density trees (**Table F1-1**). Roads, shrubs, bare ground, and buildings compose only a small percentage of the riparian area.

Table F1-1. Land cover types in the Grant Creek riparian zone

Land cover type	Area (acres)	Relative area (percent)
Bare ground	8.1	1.2%
Buildings	6.4	0.9%
Herbaceous	287.6	41.5%
Roads	34.1	4.9%
Shrub	23.3	3.4%
Sparse trees	46.9	6.8%
Low density trees	122.7	17.7%
Medium density trees	81.8	13.0%
High density trees	73.7	10.6%

F1-5.0 SHADE

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

F1-5.1 MEASURED SHADE

EPA (i.e., Atkins) collected shade characterization data on September 15, 2011, at six monitoring locations along Grant Creek using a Solar Pathfinder™ (**Figure F1-7**). Hourly shade estimates based on the Solar Pathfinder™ measurements are summarized in **Table F1-2**.

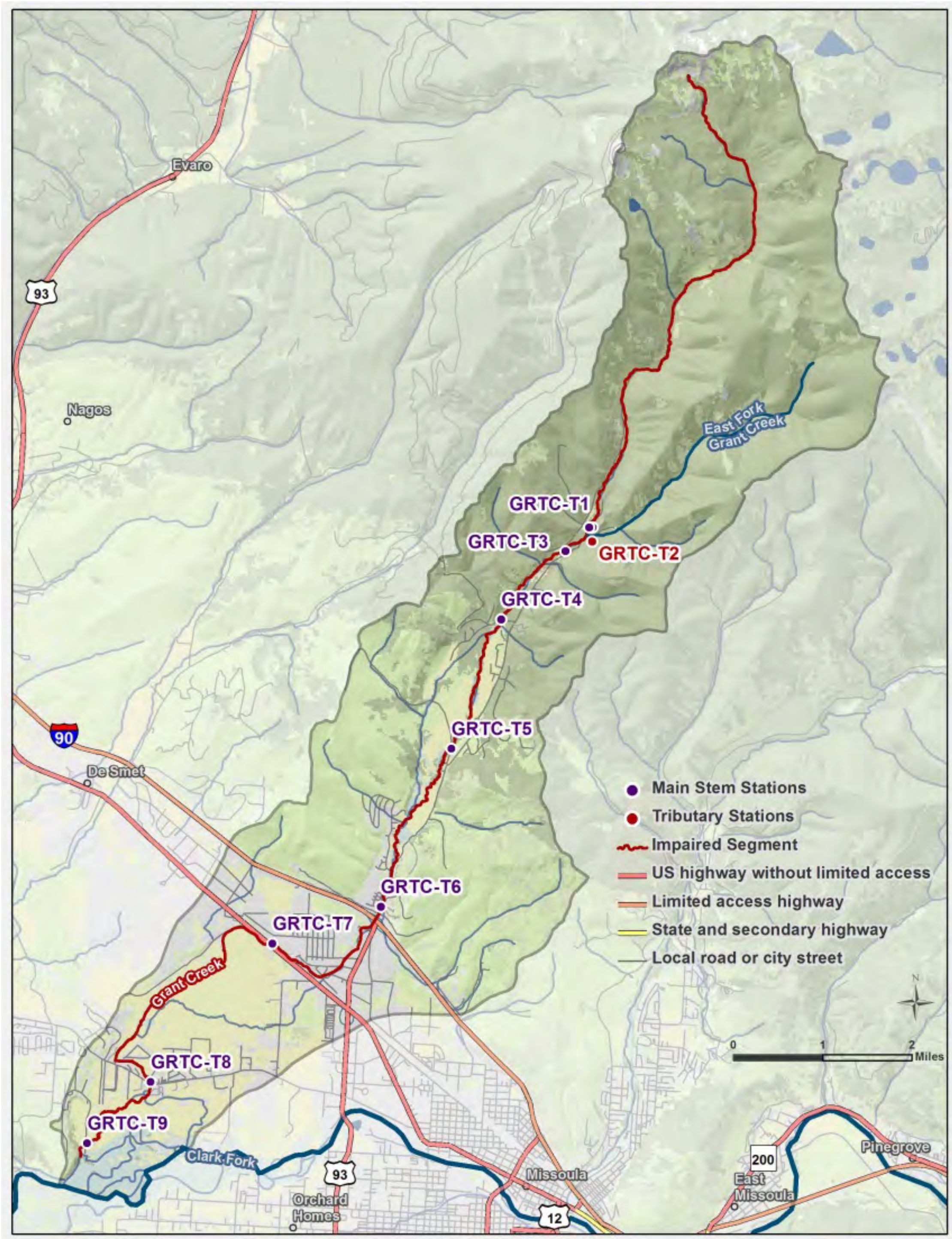


Figure F1-7. EPA flow, shade, and continuous temperature monitoring locations

Table F1-2. Average shade per reach from Solar PathfinderTM measurements

Site ID	Average daily shade (averaged across daylight hours)
GRNT-T3	69%
GRTC-T1	84%
GRTC-T4	74%
GRTC-T5	74%
GRTC-T6	78%
GRTC-T7	57%
GRTC-T8	45%
GRTC-T9	14%

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

F1-5.2 Shade Modeling

An analysis of aerial imagery and field reconnaissance showed that shading along Grant 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 (Washington 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.

F1-5.2.1 Available Data

The application of the Shade Model to Grant Creek relied upon field data collected during a 2011 field study and the interpretation of these data. The results of the study included: tree/shrub height, OH, wetted channel width, and bankfull width.

F1-5.2.2 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; Oregon Department of Environmental Quality, 2009). 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 foot) digital elevation model (DEM) and a stream centerline file digitized from aerial imagery in GoogleEarth™. 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™. 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.

F1-5.2.3 Riparian Input

The Shade Model requires the description of riparian vegetation: a unique vegetation code, height, density, and OH. The results in the field study report and the above described vegetation mapping were used to develop a riparian description table (**Table F1-3**). Vegetation descriptions used the average value for tree/shrub height and OH from field observation.

Table F1-3. Vegetation input values for the Shade Model

Attribute	Value	Basis
Trees		
Height	23 meters (75 feet)	In the absence of site-specific data, this value was based on work conducted in Wolf and Fortine creeks.
Density	Variable	2001 NLCD.
Overhang	2.3 meters (7.5 feet)	Estimated as 10% of height (Stuart, 2012).
Shrubs		
Height	4.0 meters (13 feet)	In the absence of site-specific data, this value was based on work conducted in Wolf and Fortine creeks.
Density	90%	Ocular estimate based on aerial imagery.
Overhang	1.0 meter (3.3 feet)	Estimated as 25% of height (Shumar and de Varona, 2009)
Herbaceous		
Height	1.5 meter (4.9 feet)	Estimated
Density	100%	Estimated
Overhang	0 meters	Estimated

F1-5.2.4 Shade Input

The Shade Model inputs are riparian zones, reach length, channel incision, elevation, aspect, wetted width, NSDZ width, distance from the bank to the center of the stream, and topographic shade. Input for the riparian zone is presented above in **Table F1-3**. 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 30 meters (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 0.3 meter (1 foot). The remaining variables were computed as part of the GIS pre-processing described above.

F1-5.3 Shade Model Results

The current longitudinal effective shade profile generated from the Shade Model and the Solar Pathfinder^{TM} measurements are presented in **Figure F1-8**.

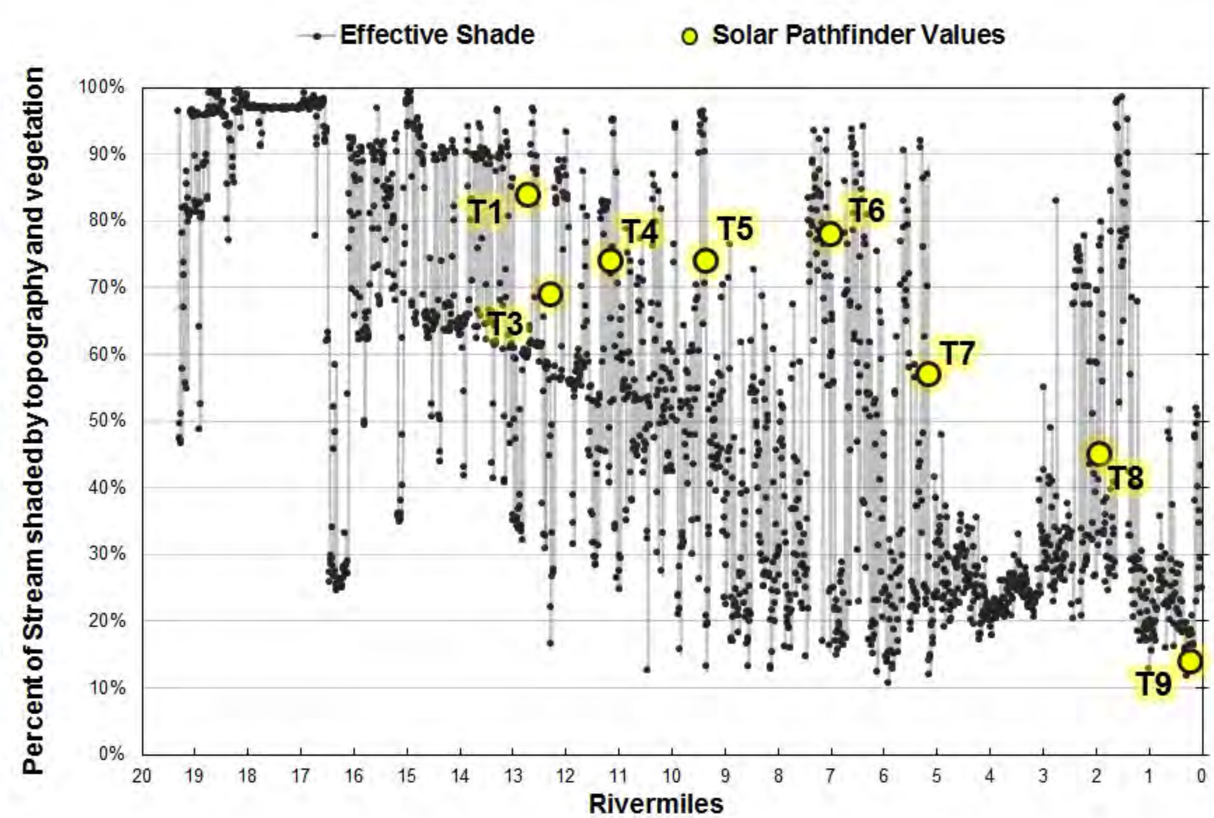


Figure F1-8. Longitudinal estimates of observed and simulated effective shade along Grant Creek

The goodness of fit for the Shade Model was summarized using the mean error (ME), average AME, and root mean square error 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 F1-4** and suggest a good fit between observed and predicted average effective shade values. The average AME is 8%. (i.e., the average error from the Shade Model output and Solar Pathfinder™ measurements was 8% daily average shade; see **Table F1-4**).

Table F1-4. Shade model error statistics

Error Statistic	Formula	Result	Units
Mean Error (ME)	$(1/N)*\Sigma(P_n-O_n)$	-1%	percent of percent shade
Average Absolute Mean Error (AME)	$(1/N)*\Sigma\|(P_n-O_n)\|$	4%	percent shade
Root Mean Square Error (RMSE)	$[(1/N)*\Sigma(P_n-O_n)^2]^{1/2}$	7%	percent of percent shade

F1-6.0 STREAM TEMPERATURES

In 2011, Atkins collected continuous temperature data at eight sites along Grant Creek and at one tributary site (East Fork Grant Creek) in support of this modeling effort. Data loggers recorded temperatures every one-half hour for two months between July 11 and September 20, 2011.

DEQ also collected instantaneous temperatures from Grant Creek in the summer of 2011 (**Table F1-5**). The warmest temperatures were detected in July and instream temperatures tended to increase downstream.

Table F1-5. DEQ instantaneous temperature measurements (F) in support of other water quality studies

Date	C04GRNTC01	C04GRNTC05	C04GRNTC02	C04GRNTC03	C04GRNTC07	C04GRNTC04
September 27, 2011	--	51.44	54.68	--	--	56.3
August 29-30, 2011	49.46	50.36	58.1	--	--	59.54
July 25, 2011	--	--	--	--	58.64	60.44
September 30, 2010	--	--	--	--	--	54.5
August 29, 2010	--	--	--	--	--	54.5
July 30, 2010	--	--	--	--	--	64.58
September 10-11, 2009	46.22	47.3	49.46	--	--	61.88
August 7-8, 2009	48.56	50.9	53.06	--	--	60.26
July 27-28, 2009		56.66	54.86	--	--	65.66
August 10-11, 2004	49.46	--	65.48	69.8	--	55.4

F1-7.0HYDROLOGY

No active USGS continuously recording gages are located on Grant Creek. Peak streamflow was historically monitored (water years 1930-2012) at USGS gage 12353000 (Clark Fork below Missoula, Montana) one mile away from Grant Creek. The closest continuously recording gage is gage 12340000, located 66 miles away on the Black River[6].

[6] USGS gage 12340000 on the Black River near Bonner, MT drains 2,290 square miles.

Atkins (under subcontract from Tetra Tech) collected instantaneous flow measurements in 2011, during temperature data logger deployment and retrieval (**Table F1-6**). Flow data were also collected by DEQ in support of other water quality studies in 2004, 2010, and 2011 (**Table F1-7**). Locations of the flow measurements are shown in Figure F1-9.

Table F1-6. EPA instantaneous flow measurements (cfs) on Grant Creek in support of modeling

Date	GRTC-T1	GRTC-T2[a]	GRTC-T3	GRTC-T4	GRTC-T5	GRTC-T6	GRTC-T7	GRTC-T8	GRTC-T9
July 11-12, 2011	78.18	20.68	--	--	--	100.58	72	77.40	83.42
September 15-20, 2011	--	2.16	10.17	10.95	5.85	5.81	--	1.67	5.50

[a.] Site is located on East Fork Grant Creek, a tributary to Grant Creek.

Table F1-7. DEQ instantaneous flow measurements (cfs) in support of other water quality studies

Date	C04GRNTC01	C04GRNTC05	C04GRNTC02	C04GRNTC03	C04GRNTC07	C04GRNTC04
September 27, 2011	--	8.02	5.72	--	--	7.4
August 29-30, 2011	8.69	12.9	8.17	--	0	9.06
July 25, 2011	--	--	--	--	15.15	19.58
September 30, 2010	--	--	--	--	--	2.53
August 29, 2010	--	--	--	--	--	3.12
July 30, 2010	--	--	--	--	--	3.25
August 10-11, 2004	10.72	--	3.65	0.1	--	2.5

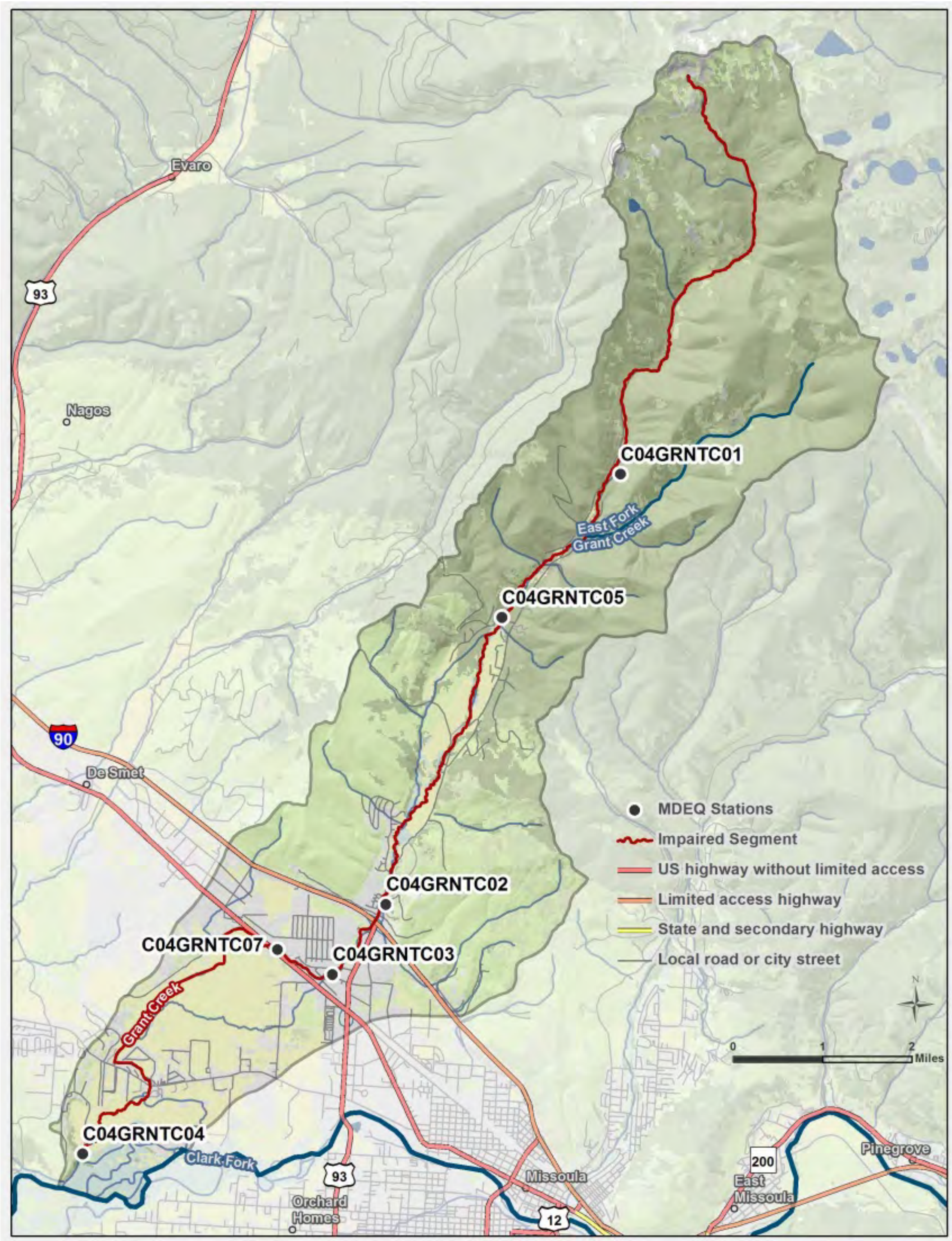
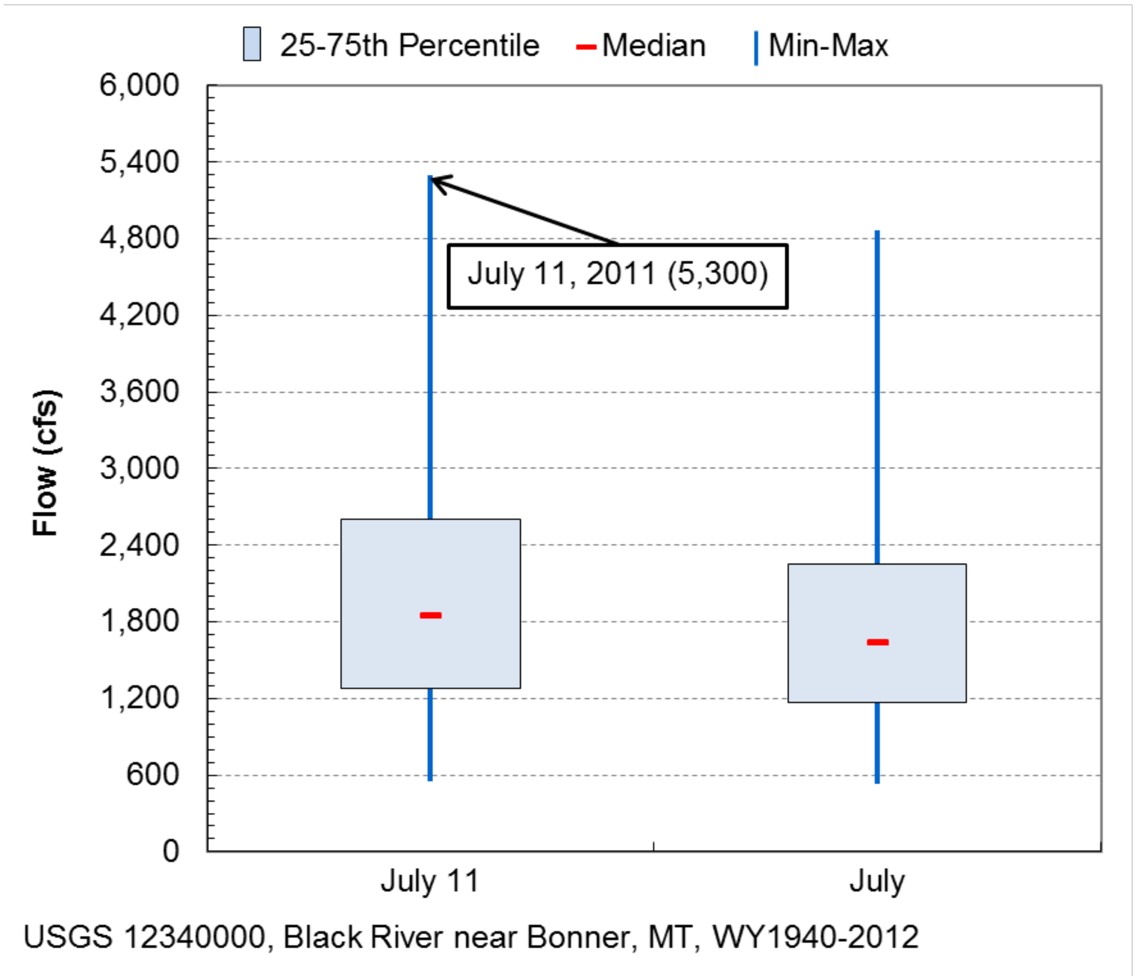


Figure F1-9. Instantaneous flows collected in the Grant Creek watershed

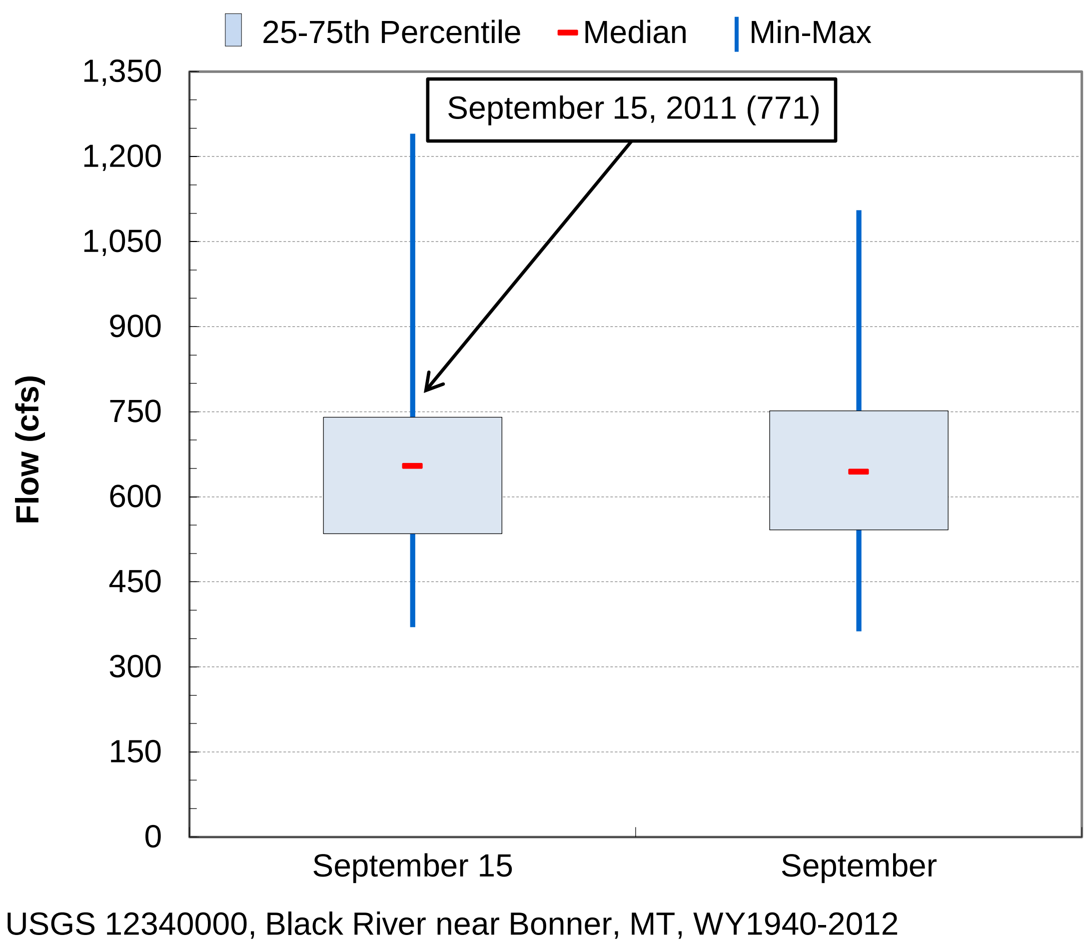
All available data were used to evaluate the water balance in Grant Creek and to develop a pre-modeling understanding of the hydrology. However, the 2011 data will be relied upon for model inputs and hydrologic calibration. It should be noted that, compared to the historic period of record at the nearest continuous recording USGS gage (i.e., USGS 12353000, Black River near Bonner, Montana), flows on July 11, 2011 were well above the average of 72 years of records while flows on September 15, 2011 were also above the median (at approximately the 83rd percentile).

Statics were calculated for the average daily flows (per year) for the month of July, for July 11th, for the month of September, and for September 15th from water years 1940 through 2012 at the gage (**Figure F1-10** and **Figure F1-11**, respectively). The flow at gage 12340000 on July 11, 2011 (during logger deployment) was 5,300 cfs, which is near the maximum of flows on July 11th across the period of record. Additionally, July of 2011 was the wettest July 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 F1-10. Flow analysis at USGS gage 12340000 (Black River near Bonner, Montana), July



Note: "September" represents the daily average flow for the month of September per year (i.e., the average of 30 daily average flows).

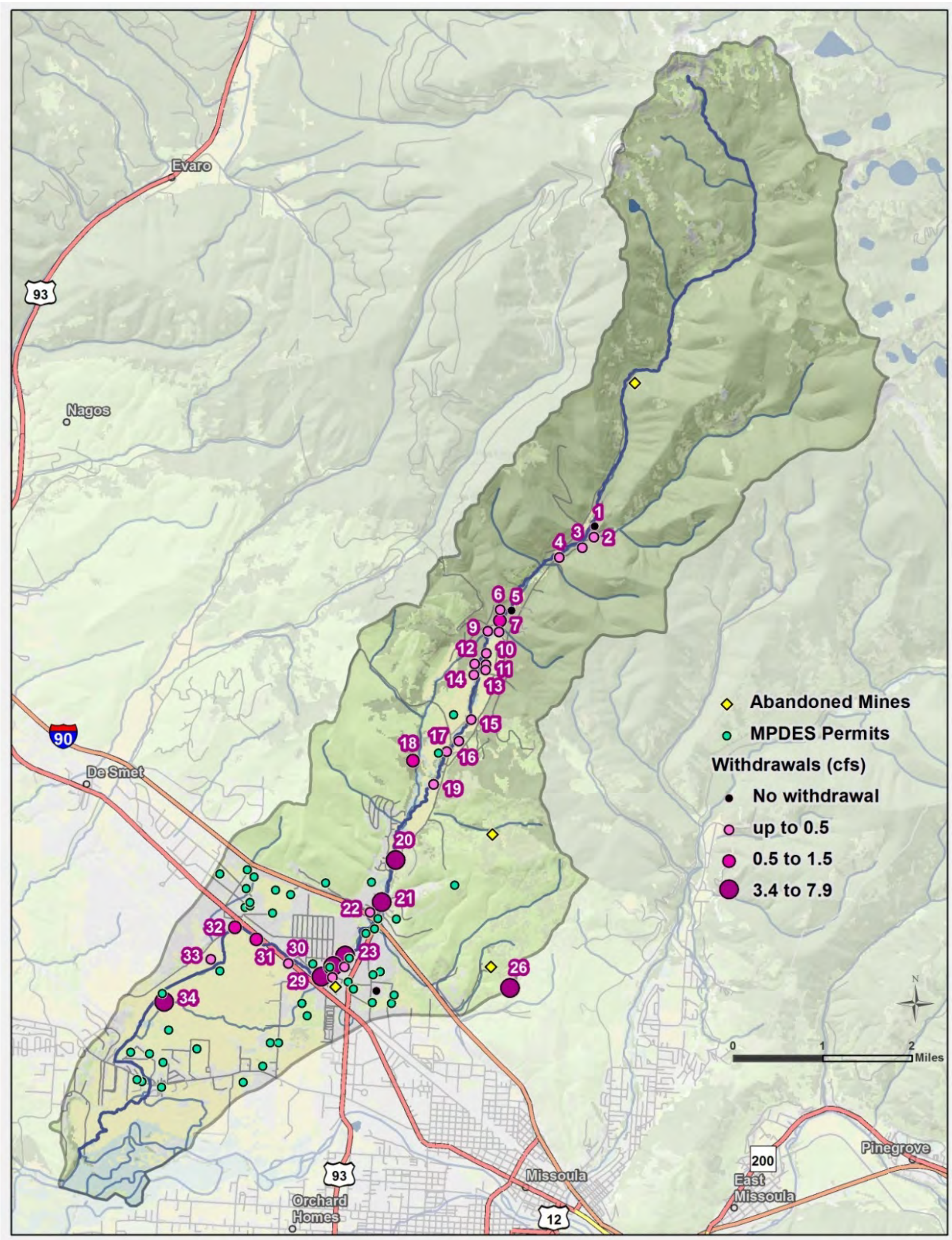
Figure F1-11. Flow analysis at USGS gage 12340000 (Black River near Bonner, Montana), September

F1-8.0 Flow Modification

Based on review of aerial photographs and online water rights data (ftp://nris.mt.gov/dnrc), there are surface and groundwater diversions in the Grant Creek watershed that support localized irrigation (**Figure F1-12**). "Points of diversion" and "places of use" spatial data were obtained from the Montana Natural Resource Information System (Natural Resource Information System, 2012). A total of 518 "places of use" were found, which represent individual water usage allotments, such as a total annual volume required for a specific acreage of land. These "places of use" corresponded to 163 "points of diversion", which represent individual water right permit numbers associated with the physical stream diversions. These "points of diversion" further correspond to 34 distinct locations along Grant Creek. Diversions from groundwater or tributaries to Grant Creek were not considered during QUAL2K modeling as QUAL2K simulated one-dimensional flow along the Grant Creek mainstem.

Where individual locations corresponded to multiple permits, the estimated withdrawal rates were summed. Where individual permits were associated with multiple locations, an equal distribution of the permitted rate was assumed across sites. The withdrawal volume applied was estimated using the

Irrigation Water Requirements program developed by the U.S. Department of Agriculture to estimate crop requirements (Natural Resources Conservation Service, 2003). This method assumes application over the maximum acres reported at a constant rate across a 24-hour period. It is estimated that a maximum of 42.35 cfs may be withdrawn from Grant Creek during the month of June and 24.63 cfs may be withdrawn during September (**Table F1-8**).



Source of "points of diversion" data: Natural Resource Information System (2012).

Figure F1-12. Surface diversions, MPDES permits, and abandoned mines in the Grant Creek watershed

Table F1-1. Points of diversion from Grant Creek

Map ID	Purpose[a]	Irrigation type	Means of withdrawal[b]	Estimated daily flow rate (cfs)	
				June	Sept
1	Power generation	--	Pipeline	0	0
2	Fishery, Irrigation	--	Pipeline, Pump	0.10	0.07
3	Irrigation	Sprinkler	Pump	0.01	0.01
4	Irrigation	Flood	Headgate	0.01	0.00
5	Stock	--	Headgate	0	0
6	Irrigation	Flood	Headgate	0.21	0.09
7	Ir, Rc, St	--	Pu/Hg w/Dt or Pl	1.31	0.58
8	Irrigation	Flood	Pump	0.04	0.02
9	Irrigation, Stock	--	Pu/Hg w/Dt or Pl	0.27	0.12
10	Fishery	--	Headgate	0.03	0.03
11	Irrigation, Stock	--	Pu/Hg w/Dt or Pl	0.24	0.10
12	Irrigation	Sprinkler/Flood	Pu/Hg w/Dt or Pl	0.06	0.03
13	Irrigation	Flood	Pump	0.04	0.02
14	Irrigation, Stock	--	Pu/Hg w/Dt or Pl	0.44	0.20
15	Dm, Ir, St	--	Fw, Pu/Hg W/Dt or Pl	0.21	0.09
16	Irrigation, Stock	--	Pu/Hg w/Dt or Pl	0.30	0.14
17	Ir, Rc, St	--	Pu/Hg w/Dt or Pl	0.40	0.18
18	Irrigation	Multiple	Headgate	0.59	0.26
19	Irrigation, Stock	--	Pu/Hg w/Dt or Pl	0.30	0.14
20	Irrigation, Stock	--	Headgate, Ditch	5.80	2.58
21	FP, In, Ir, MW	Flood	Hg w/Dt or Pl/Fl and Dk	7.85	7.24
22	Irrigation	Flood	Ditch	0.17	0.08
23	FP, Ir, St	--	Headgate, Ditch	3.63	1.62
24	Irrigation	Sprinkler/Flood	Headgate	0.17	0.08
25	FP, Ir, St	--	Headgate, Ditch	3.46	1.54
26	FP, In	--	Headgate	3.63	3.63
27	Stock	--	Ditch	0	0
28	Ir, MW	--	Headgate, Dike	0.29	0.13
29	Irrigation, Stock	Flood	Pu/Hg w/Dt or Pl	5.92	2.64
30	Irrigation	Sprinkler/Flood	Headgate	0.19	0.08
31	FP, Ir, St	--	Headgate, Ditch	1.12	0.50
32	FP, Ir, St	--	Headgate, Ditch	1.12	0.50
33	Irrigation	Sprinkler/Flood	Hg w/Dt or Pl/Fl and Dk	0.21	0.10
34	Irrigation	Sprinkler	Hg w/Dt or Pl/Fl and Dk	4.22	1.88
			Total Withdrawal	***42.35***	***24.63***

Source: Natural Resource Information System (2012)
[a.] Rc = Recreation, Dm = Domestic, FP = Fire Protection, MW = Mitigation Water, Ir = Irrigation, In = Industrial, LG = Lawn and Garden, St = Stock.
[b.] Hg = Headgate, Dk = Dike, Dt = Ditch, Pu = Pump, Pl = Pipeline, Fl and Dk = Flood and Dike, w/ = with.

F1-8.0 POINT SOURCES

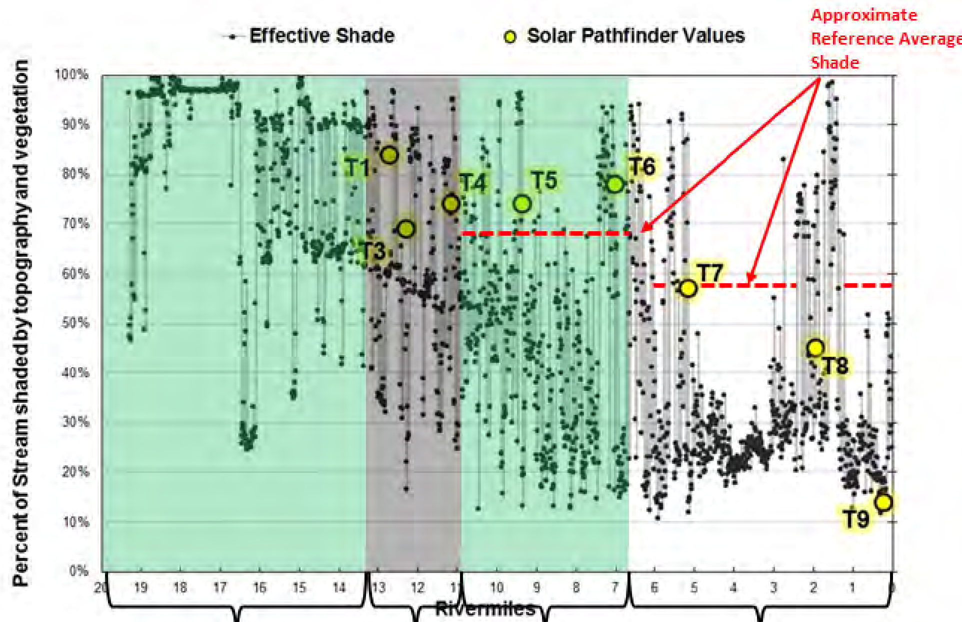
Any facility that discharges to Grant Creek or its tributaries must be permitted through DEQ's Montana Pollution Discharge Elimination System. A search of U.S. EPA's Enforcement and Compliance Online database (http://www.epa-echo.gov/echo/index.html) identified 48 facilities in the Grant Creek watershed. Thirty-four permits are for stormwater associated with construction sites and one permit is for stormwater associated with industrial activities that does not discharge off-site and thus results in no exposure to pollutants (MTRNE0002).

There are four abandoned mines within the Grant Creek watershed. Hellgate Coal Mine was an underground coal mine, Bonanza Lime Prospect was a gold and copper prospect mine, L.S. Jensen & Sons Inc. was a surface stone mine, and there was also one unnamed pumice mine.

Three facilities have short-term turbidity water quality standards for construction sites. Such short-term standards are authorized under section 318 of the Montana Water Quality Act. The exemptions are issued permits that begin with MTB but are not MPDES permits.

The Motel Partners I - Econolodge (MT0029840) is permitted to discharge non-contact cooling water from a heat exchanger to Grant Creek. The facility is required to monitor effluent flow volume and temperature and must also monitor upstream, instream temperature in Grant Creek. The facility reported data to U.S. EPA from January 1998 through September 2013. A comparison of end of pipe and upstream records from the past decade shows that the effluent is warmer and Grant Creek from November through June.

ATTACHMENT F2. VEGETATION AND SHADE ANALYSIS FOR SCENARIO DEVELOPMENT FOR GRANT CREEK



Summary of Existing Condition: From Hwy 200 downstream to the mouth, Grant Creek flows through the Clark Fork River valley in an area of mixed agricultural, residential, and commercial land uses. Based on air photo analysis, there appears to be significant opportunity to improve shade in the agricultural areas (i.e., introduce a vegetated buffer comprised of shrubs or trees where none currently exist).

Proposed Shade Scenario: Use the reach downstream from GRTC-T8 as a reference (shown to left) and apply reference shade (approximately 59% average daily) to this entire reach.

Note that the reference reach is comprised of a an approximate 25' buffer of shrubs.

Summary of Existing Condition: The riparian corridor and associated vegetation upstream from GRTC-T1 appears to be un-impacted by anthropogenic activities. This area is dominated by coniferous trees (of various densities) in mountainous terrain interspersed by natural openings. The vegetation in this area appears to be at potential.

Proposed Shade Scenario: This reach is above the model domain. No action.

Summary of Existing Condition: Although the terrain and vegetation in this approximate two mile reach is similar to the upstream reach, the vegetation has been impacted by Grant Creek Road, Bench Road, and numerous openings in the canopy resulting from low density residential development (i.e., lawns, driveways, etc.). However, there does not appear to be much opportunity to increase shade given the current development (i.e., most of the riparian area is currently mapped as trees of varying densities).

Proposed Shade Scenario: Given the limited opportunity to improve shade, no-action.

Summary of Existing Condition: From GRTC-T4 downstream to Hwy 90 (just downstream from GRTC-T6) Grant Creek flows through the foot hills down to the Clark Fork River valley bottom. Where the riparian corridor has been un-impacted by encroachment from agriculture, power lines, and subdivisions, it is comprised of predominantly moderate to low density mixed deciduous and coniferous trees. There appears to be some limited opportunity to improve shade in this reach by converting some (but not all) of the current herbaceous areas to shrubs or trees.

Proposed Shade Scenario: Use the reach just upstream from GRTC-T5 as a reference (shown below) and apply reference shade (approximately 69% average daily) to this entire reach.

Summary

Based on air photo analysis, it appears that:

1. Shade is at potential upstream from GRTC-T1.
2. Shade has been degraded slightly between GRTC-T1 and GRTC-T4. However, there is little that can be done to improve conditions given current development.
3. The "natural" condition for the riparian corridor between GRTC-T4 and GRTC-T6 is likely moderate to low density mixed deciduous/coniferous trees. There is some opportunity to improve shade in this reach, but only in discrete areas. Apply reference shade (approximately 69% average daily shade) to this reach for the shade scenario.
4. The riparian corridor downstream from Hwy 200 has been highly degraded and there is significant opportunity to improve shade. Apply reference shade (approximately 59% average daily shade) to this reach for the shade scenario.