APPENDIX B – FORTINE CREEK QUAL2K MODEL REPORT

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ACRONYMS AND ABBREVIATIONS

EPA	U.S. Environmental Protection Agency
DEQ	Montana Department of Environmental Quality
MRLC	Multi-Resolution Land Characteristics Consortium
NLCD	National Land Cover Dataset
QUAL2K	River and Stream Water Quality Model
RM	river mile
TMDL	total maximum daily load
TPA	TMDL Planning Area
USFS	U.S. Forest Service (U.S. Department of Agriculture)
USGS	U.S. Geological Survey (U.S. Department of the Interior)
WRCC	Western Regional Climate Center

UNITS OF MEASURE

°C	degrees Celsius
°F	degrees Fahrenheit
cfs	cubic feet per second
MSL	mean sea level

EXECUTIVE SUMMARY

Fortine Creek is on the 2012 303(d) List as impaired because of elevated water temperatures. Data were collected in 2012 and a QUAL2K water quality model was then developed for Fortine Creek to evaluate the impairment status and the effect that human sources are having on stream temperatures. Eight scenarios (described below) were developed to evaluate model sensitivity and a range of potential watershed management activities. Scenarios 2 through 6 were based on existing conditions (Scenario 1). Scenario 8 was based on existing conditions during a low flow year (Scenario 7). Generally, small changes in shade or inflow had minimal effects on water temperatures while large increases in shade and large increases or decreases of inflows had considerable effects on water temperatures.

- Scenario 1 - Baseline: Existing condition (i.e., the calibrated model). This served as the baseline scenario from which to compare all other scenarios except 7 and 8.
- Scenario 2 – No withdrawals: Existing condition without water withdrawals. This scenario was performed to test the sensitivity of the model to water withdrawals and is not intended for management purposes.
- Scenario 3 – Maximum Shade: Existing condition with riparian vegetation in a 150-foot buffer at its maximum potential shade. This scenario was performed to test the sensitivity of the model to shade and is not intended for management purposes.
- Scenario 4 – Improved Shade: Existing condition scenario with riparian vegetation in a 50-foot buffer improved to the maximum extent practicable. This is to simulate standards attainment regarding soil and land conservation practices.
- Scenario 5 – Improved Water Management: Existing condition scenario with a 15 percent reduction of water withdrawals. This is to simulate standards attainment regarding water conservation practices.
- Scenario 6 – Naturally Occurring: Existing condition scenario with improved riparian vegetation in a 50-foot buffer and a 15 percent reduction of water withdrawals. This is to simulate full standards attainment via the use of all reasonable land, soil, and water conservation practices.
- Scenario 7 – Low Flow Baseline: A baseline low flow scenario with a 56 percent reduction of flow relative to Scenario 1. This is an altered existing condition scenario in which the baseline flow is reduced. This scenario is to simulate the existing condition on a drier year than that used to calibrate the model under Scenario 1. Besides flow, all inputs were identical to Scenario 1. This served as a low flow baseline scenario from which to compare Scenario 8.
- Scenario 8 – Low Flow Naturally Occurring: A low flow scenario with a 56 percent reduction of flow, improved vegetation in a 50-foot buffer to the maximum extent practicable, and a 15 percent reduction of water withdrawals. This is to simulate full standards attainment via the use of all reasonable land, soil, and water conservation practices on a drier year than that used for Scenario 6.

B1.0 INTRODUCTION

This appendix is based on a model report completed by Tetra Tech (Tetra Tech 2013) for a temperature model (QUAL2K) that was used to support TMDL development for Fortine Creek. Background information is provided in the following section (**Section B2.0**). A summary of model set up, calibration, and validation is provided in **Section B3.0** and a series of model scenarios and results are presented in **Section B4.0**.

B2.0 BACKGROUND

This section presents background information to support QUAL2K model development.

B2.1 STUDY AREA

Fortine Creek (MT76D004_020) is identified on the 2012 303(d) List as impaired by temperature. Fortine Creek is located in northwest Montana (**Figure B-1**) in the Northern Rockies ecoregion and the impaired segment flows for approximately 33.46 miles from its headwaters to its confluence with Grave Creek, forming the headwaters of the Tobacco River.

Most of the Fortine Creek watershed is managed by the U.S. Forest Service (USFS) as part of the Kootenai National Forest (**Figure B-1**). However, significant portions of the valley bottom along Fortine Creek are privately owned. The landscape is predominantly forested, with patches of mature forest interspersed with selective harvests and clearcuts at various stages of regrowth (**Figure B-2**). U.S. Route 93 bisects the watershed, running along Dickey Lake and Murphy Lake and through the town of Fortine.

B2.2 MONTANA TEMPERATURE STANDARD

The model results will be used to verify Fortine Creek is not meeting the temperature standard. For a waterbody with a use classification of B-1, such as Fortine Creek, 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.

[1] Administrative Rules of the state of Montana 17.30.623(e).

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

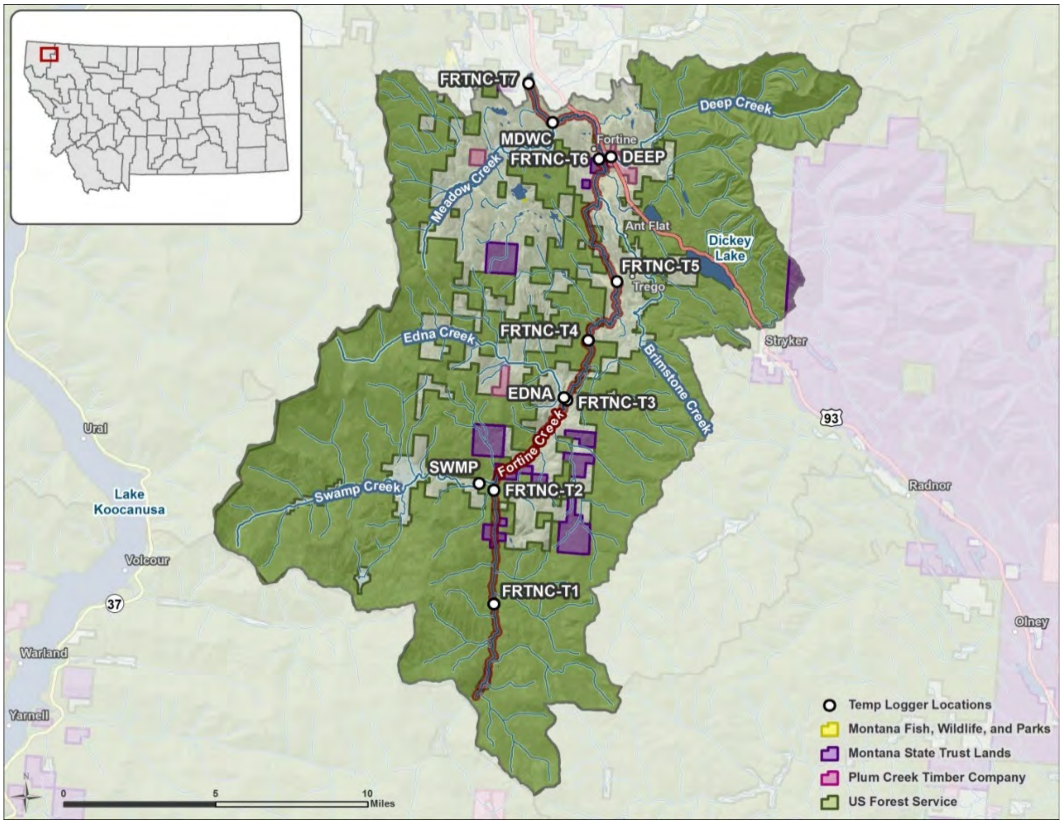


Figure B-1. Land ownership in the Fortine Creek watershed (NRIS, 2012)

Figure B-2. 2009 Aerial Imagery of Fortine Creek watershed (2009 NAIP; NRIS 2012)

B2.3 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, 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 the temperature in small streams (or those with reduced flows) can be changed more easily.

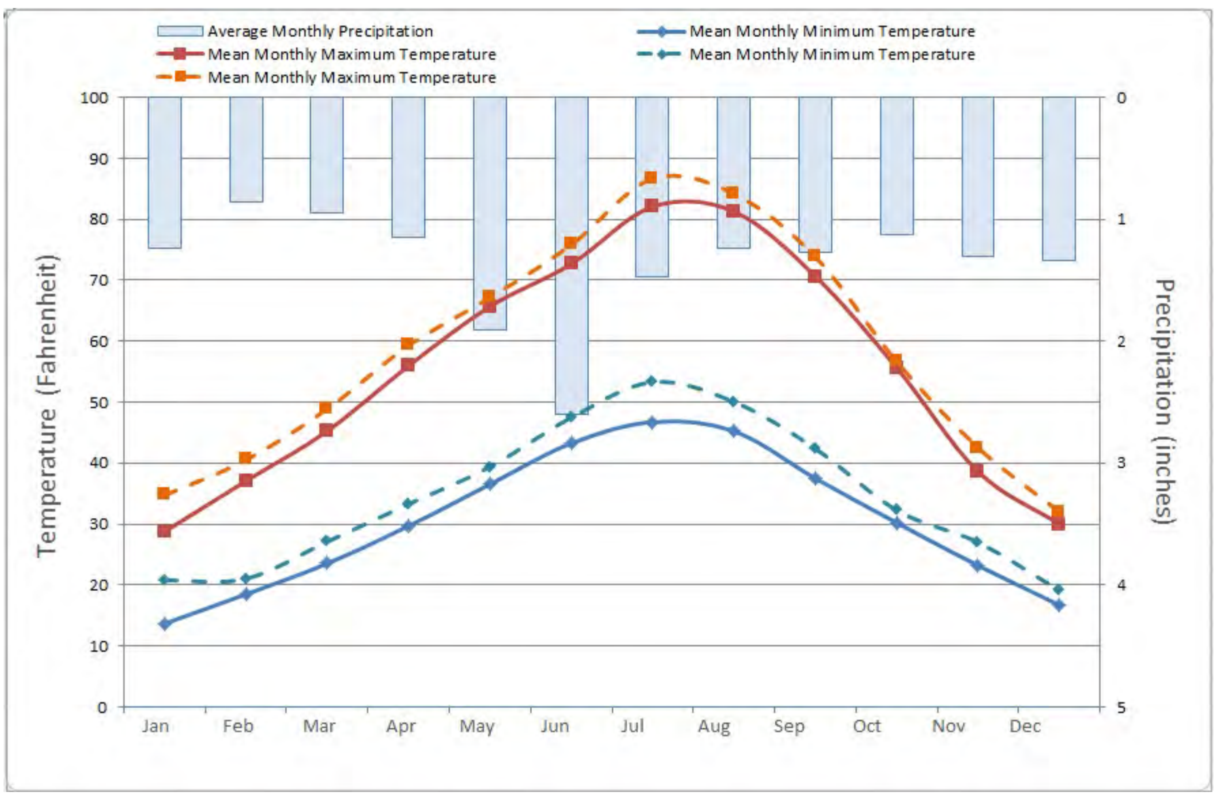
This section provides a summary of the available data pertaining to factors that could influence stream temperature in Fortine Creek and are necessary for model development: climate, shade, stream morphology, and hydrology. Point sources also have the potential to influence stream temperature but there are currently no permitted point sources to Fortine Creek (as of January 14, 2014).

B2.3.1 Climate

The nearest weather stations to the Fortine Creek watershed are located in Fortine, Montana (National Weather Service stations 243139 and 243142) at an elevation of 3,040 feet above mean seal level (MSL). These two stations represent one continuous, non-overlapping dataset, with station 243142 replacing station 243139 in October 2009. Average annual precipitation is 16.5 inches, with the greatest amounts falling in May and June (**Figure B-3**; Western Regional Climate Center 2012). Average maximum temperatures occur in July and August and are 82.1 °F and 81.3°F, respectively.

A Remote Automatic Weather Station (RAWS) is located in Eureka, Montana (National Weather Service station ID 240110) at 2,800 feet above MSL. This station records weather data hourly, which is preferable for QUAL2K model development, whereas stations 243139 and 243142 record data daily. Thus, Eureka hourly temperature data were used to develop the QUAL2K inputs. The Eureka RAWS data are also summarized in **Figure B-3**.

It should be noted the Eureka weather station is at an elevation of 2,800 above MSL, and Fortine Creek ranges in elevation from approximately 2,800 to 3,940 feet above MSL. Since elevation along Fortine Creek varies over a large range, temperature data were corrected for elevation differences between model segments and the Eureka RAWS (as described in **Section B3.5**).



Source: Monthly Summaries from 1950 to 2012 at Stations 243139 and 243142 as solid lines, and from 2001 to 2012 at the Eureka RAWS as dashed lines (precipitation not available) (NCDC 2012).

Figure B-3. Monthly average air temperatures and precipitation at weather stations near Fortine Creek

B2.3.2 Shade

Effective shade (which is referred to as shade hereafter) is defined as the fraction of solar radiation that is blocked by topography and vegetation. Shade measurements were collected on September 12 and 13, 2012, at eight monitoring locations along Fortine Creek using a Solar Pathfinder™ (**Figure B-4**). The data are summarized in **Table B-1** and accompanying field notes are in **Attachment B-3**. Hourly shade estimates based on the Solar Pathfinder™ measurements are available by request from DEQ or EPA but are not attached to this document due to file size.

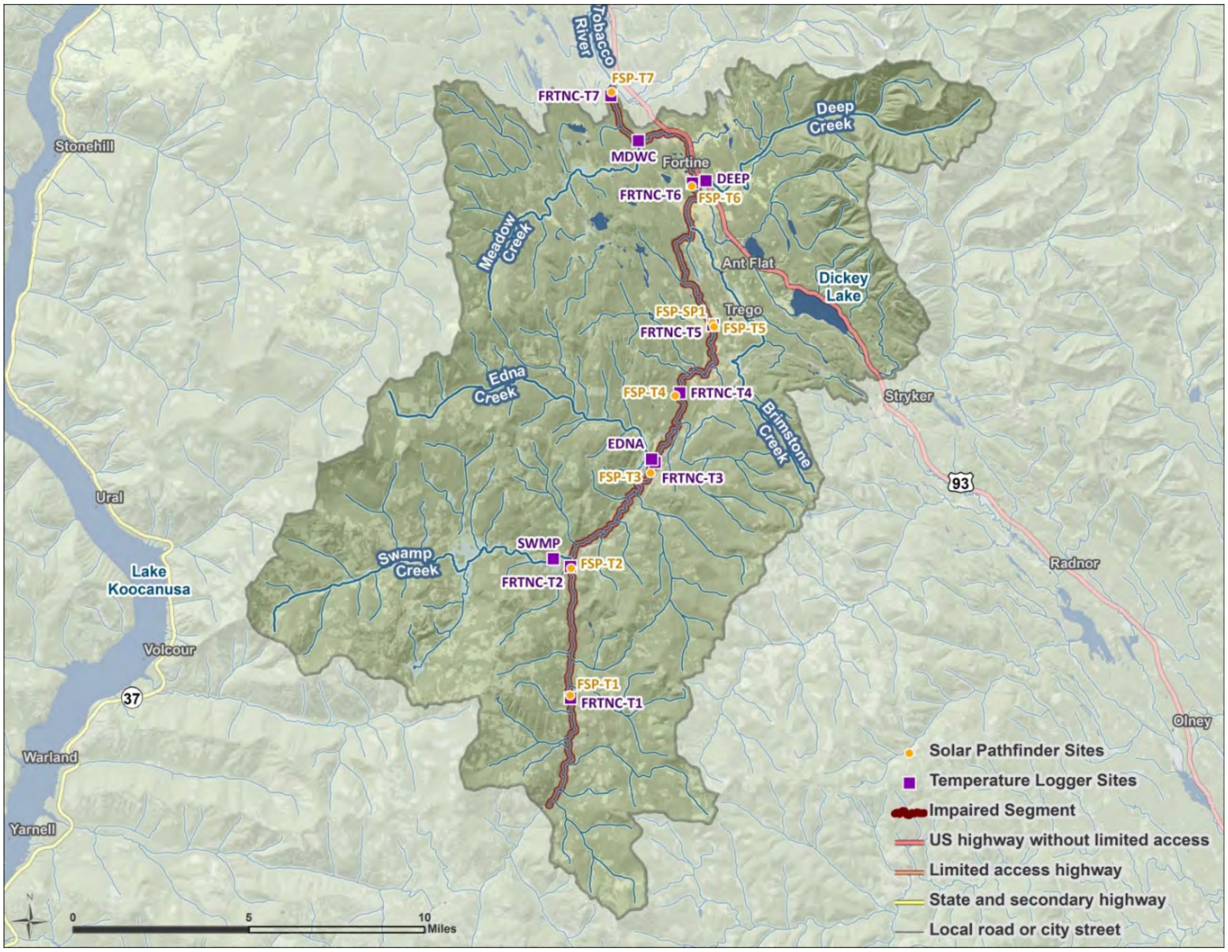


Figure B-4. 2012 EPA flow, shade, and continuous temperature monitoring sites

Table B-1. Average shade per site from Solar Pathfinder™ measurements

Site ID	Average daily shade (averaged across daylight hours)
FRTNC-T1	78%
FRTNC-T2	90%
FRTNC-T3	42%
FRTNC-T4	63%
FRTNC-T5	28%
FRTNC-T6	32%
FRTNC-T7	57%
FRTNC-SP1	10%

B2.3.3.1 Shade Modeling

An analysis of aerial imagery and field reconnaissance showed that shading along Fortine Creek was highly variable. Therefore, shade was also evaluated using the spreadsheet model Shadev3.0.xls. Shade version 3.0 is a riparian vegetation and topography model that computes the hourly shade for a single day (Washing State Department of Ecology 2008). Shade is an Excel/Visual Basic for Applications program. The model uses the latitude and longitude, day of year, aspect and gradient (the direction and slope of the stream), solar path, buffer width, canopy cover, and vegetation height to compute hourly, dawn-to-dusk shade. The model input variables include channel orientation, wetted width, bankfull width, channel incision, topography, and canopy cover. Bankfull width in the shade calculations is defined as the near-stream disturbance zone, which is the distance between the edge of the first vegetation zone on the left and right bank.

Available Data

The application of the Shade Model to Fortine Creek relied upon field data collected in 2012 and the interpretation of these data. Based on the field data, several model inputs were obtained: tree/shrub height, overhang, wetted channel width, and bankfull width.

Riparian and Shade Inputs

To characterize shade along a stream, it is important to know the composition of the riparian vegetation because different forms of vegetation have varying degrees of potential to provide shade. To supplement the field data collected at the sites shown in **Figure B-4** and provide a longitudinally continuous data set of vegetation characteristics along Fortine Creek, vegetation communities between the shade monitoring sites were visually characterized based on aerial imagery (dated August 17, 2012; GoogleEarth 2012). Using GIS, vegetative communities observed in the aerial imagery that were within a 150 foot buffer of the stream centerline were classified as trees, shrubs, or herbaceous. Bare ground and roads were also identified during GIS analyses. Trees were further divided into the following classes based on percent canopy cover derived from the 2006 NLCD (**Figure B-5**):

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

Based on the classification procedure described above, high density trees, medium density trees, shrubs, and herbaceous are all dominant cover types along Fortine Creek (**Table B-2**). Sparse trees, roads, and bare ground comprise only a small percentage of the riparian area.

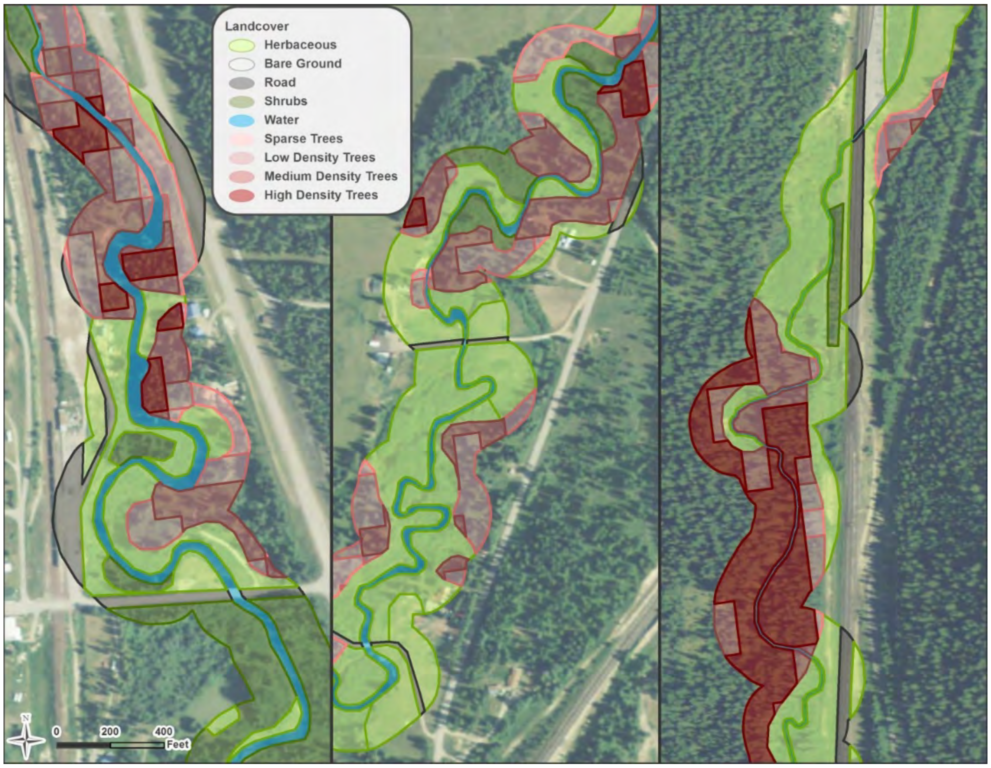


Figure B-5. Vegetation mapping examples for Fortine Creek

Table B-2. Land cover types in the Fortine Creek riparian zone

Land cover type	Area within 150ft Buffer (acres)	Relative Area within 150ft Buffer (percent)	Relative Area within 50ft Buffer (percent)
Bare ground	9.2	0.8%	0.4%
Herbaceous	225.8	18.6%	21.3%
Roads	32.5	2.7%	1.0%
Shrub	236.1	19.5%	25.1%
Sparse trees	50.1	4.1%	3.0%
Low density trees	105.4	8.7%	8.3%
Medium density trees	247.9	20.5%	20.6%
High density trees	304.6	25.1%	20.2%

The 2012 field notes and the above described vegetation mapping were used to develop a riparian description table with inputs needed for the Shade Model (**Table B-3**). Vegetation descriptions used the average value for tree/shrub height and overhang from field observation. Besides the riparian vegetation information summarized in **Table B-3**, other necessary inputs for the Shade Model are reach length, channel incision, elevation, aspect, wetted width, near-stream disturbance zone width, distance from the bank to the center of the stream, and topographic shade. Reach lengths within the model must be of equal intervals but the reaches in the field study were not at equal intervals and were very widely spaced. A uniform reach length interval of 30 meters (98 feet) was used as a model input. 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 below.

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

Attribute	Value	Basis
Trees		
Height	23 meters (75 feet)	Average of field values across all Solar Pathfinder™ sites.
Density	Variable	2006 NLCD.
Overhang	2.3 meters (7.5 feet)	Estimated as 10% of height (Stuart 2012).
Shrubs		
Height	4 meters (13 feet)	Average of field values across all Solar PathfinderTM sites.
Density	90%	Ocular estimate based on aerial imagery.
Overhang	1 meter (3.3 feet)	Estimated as 25% of height (Shumar and de Varona 2009)
Herbaceous		
Height	1 meter (3.3 feet)	Estimated average based on site reconnaissance (September 2012).
Density	100%	Estimated average based on site reconnaissance (September 2012).
Overhang	0 meters	Estimated based on site reconnaissance (September 2012).

GIS Pre-Processing

TTools version 3.0 is an ArcView extension to translate spatial data into Shade Model inputs (Oregon Department of Environmental Quality 2001). TTools was used to estimate the following values: elevation, aspect, gradient, distance from the stream center to the streambanks, 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 work 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.

B2.3.3.2 Shade Model Results

The current longitudinal effective shade profile generated from the Shade Model and the Solar Pathfinder™ measurements are presented in **Figure B-6.**

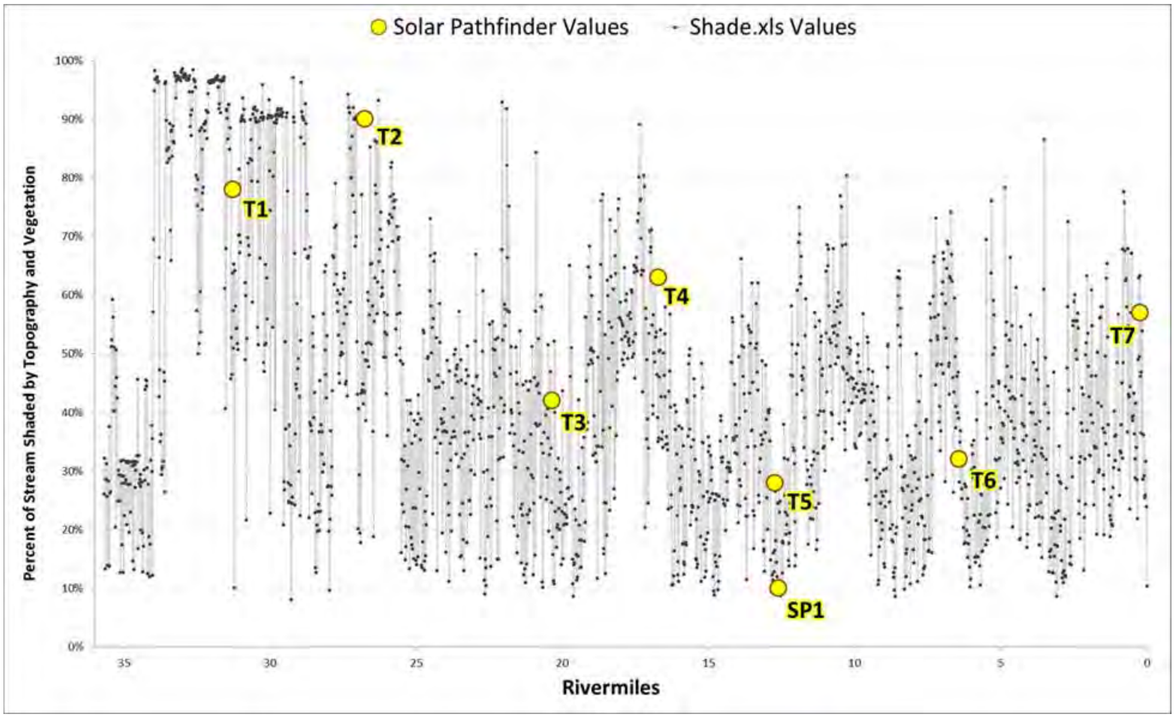


Figure B-6. Longitudinal estimates of observed and simulated effective shade along Fortine Creek

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

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

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

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

where

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

Shade model error statistics are provided in **Table B-4** and suggest a good fit between observed and predicted average effective shade values. The average absolute mean error is 7%. (i.e., the average error from the Shade Model output and Solar Pathfinder[TM] measurements was 7% daily average shade).

Table B-4. Fortine Creek Shade Model error statistics

Error Statistic	Formula	Result	Units
Mean Error (ME)	(1/N)*Σ(Pn-On)	6%	percent of percent shade
Average Absolute Mean Error (AME)	(1/N)*Σ|(Pn-On)|	7%	percent shade
Root Mean Square Error (RMSE)	[(1/N)*Σ(Pn-On)2]1/2	9%	percent of percent shade

B2.3.3 Stream Morphology

Stream morphology (channel pattern and geometry) departure from natural conditions might influence stream temperatures. Deteriorating stream channel morphology could reduce hyporheic flow, which is beneath and along the streambed where surface water and shallow groundwater mix, and can act as an effective stream temperature buffer. Additionally, channels that have been overwidened are less easily shaded and have a greater surface area, which can lead to an increased heat load to the stream (Poole and Berman 2001). Decreased stream depths from channel overwidening can also accelerate temperature increases.

Channel morphology measurements were taken in 2008 at three cross-sections each at five sites on Fortine Creek in support of sediment TMDL development (DEQ 2011). Additionally, bankfull and wetted width measurements were collected on September 12 and 13, 2012 at the locations evaluated for shade with Solar Pathfinder™ measurements (**Figure B-4**).

B2.3.4 Hydrology

No active U.S. Geological Survey (USGS) continuously recording gages are located on Fortine Creek. The closest such gage is 12301300, located downstream of Fortine Creek on the Tobacco River near Eureka, MT. EPA collected instantaneous flow measurements in 2012, during temperature data logger deployment and retrieval and during mid-season (**Table B-5**). Flow data were also collected by DEQ in support of other water quality studies in 2003, 2007, 2008, and 2012, and by the USFS for Deep Creek in 2011 and Edna and Fortine creeks in 2012 (**Tables B1-1** through **B1-4** in **Attachment B-1**). Locations of the flow measurements are shown in **Figure B-7**.

All available data were used to evaluate the water balance in Fortine Creek and to develop a pre-modeling understanding of the hydrology. However, only the 2012 data (primarily the August data) were 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 12301300, Tobacco River near Eureka MT), flows on August 10, 2012 were well above average and corresponded to the 87th percentile flow (**Figure B-8**).

Table B-5. 2012 EPA instantaneous flow measurements (cfs)

Date	FRTNC-T1	FRTNC-T2	SWMP [a]	FRTNC-T3	FRTNC-T4	FRTNC-T5	FRTNC-T6	DEEP b	FRTNC-T7
June 25, 2012	81.8	111.0	87.7	--	--	--	--	--	--
July 12, 2012	--	--	--	56.2	80.8	74.5	94.1	53.5	148.4
August 10, 2012	3.7	8.2	3.6	19.6	31.0	28.6	34.9	16.8	59.3
September 18, 2012	1.6	4.2	1.4	11.0	16.6	14.3	17.1	7.9	23.2

[a.] Site is located on Swamp Creek, a tributary to Fortine Creek.
[b.] Site is located on Deep Creek, a tributary to Fortine Creek.

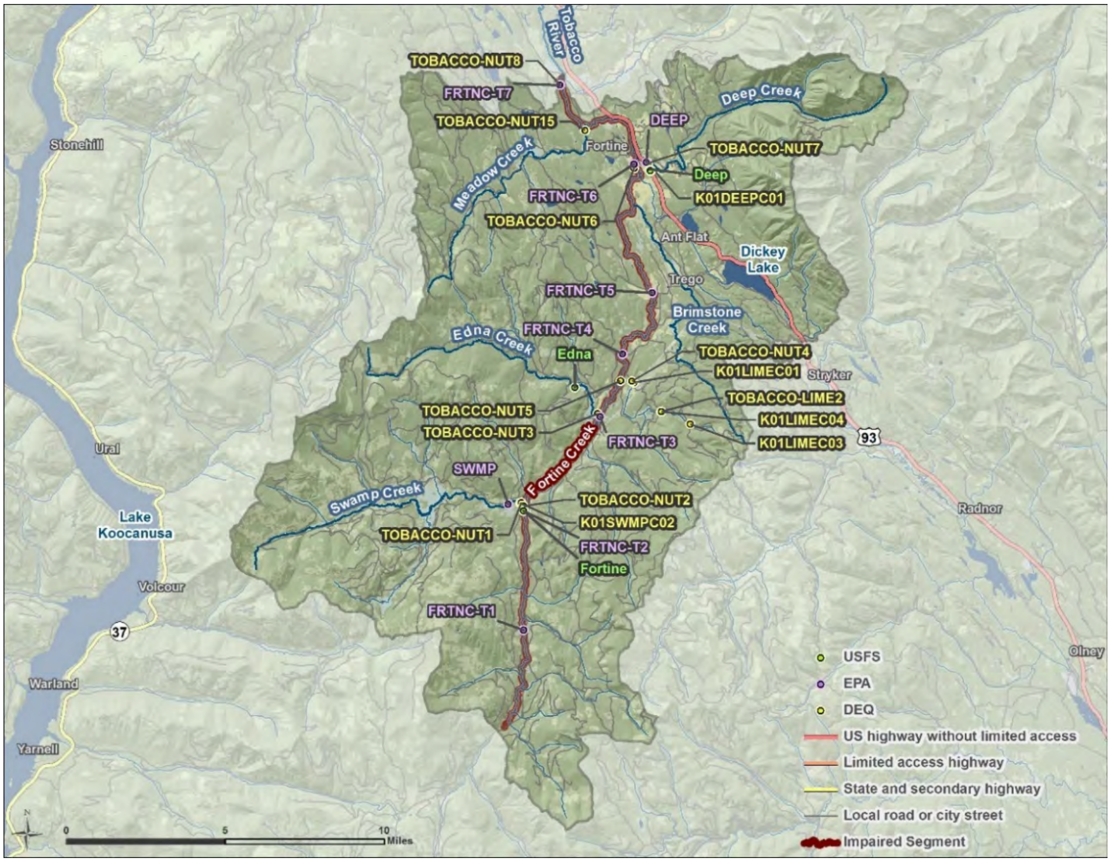


Figure B-7. All monitoring sites with recent instantaneous flow measurements

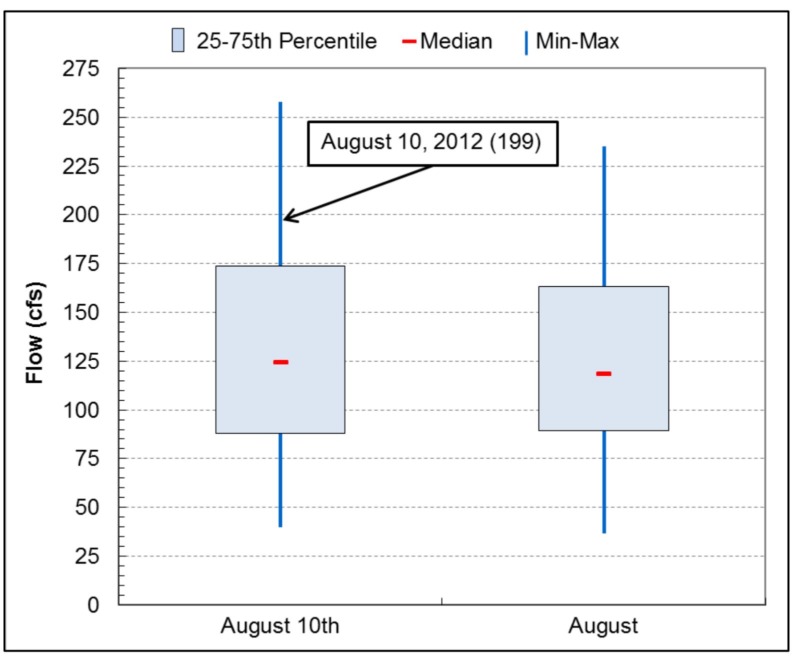
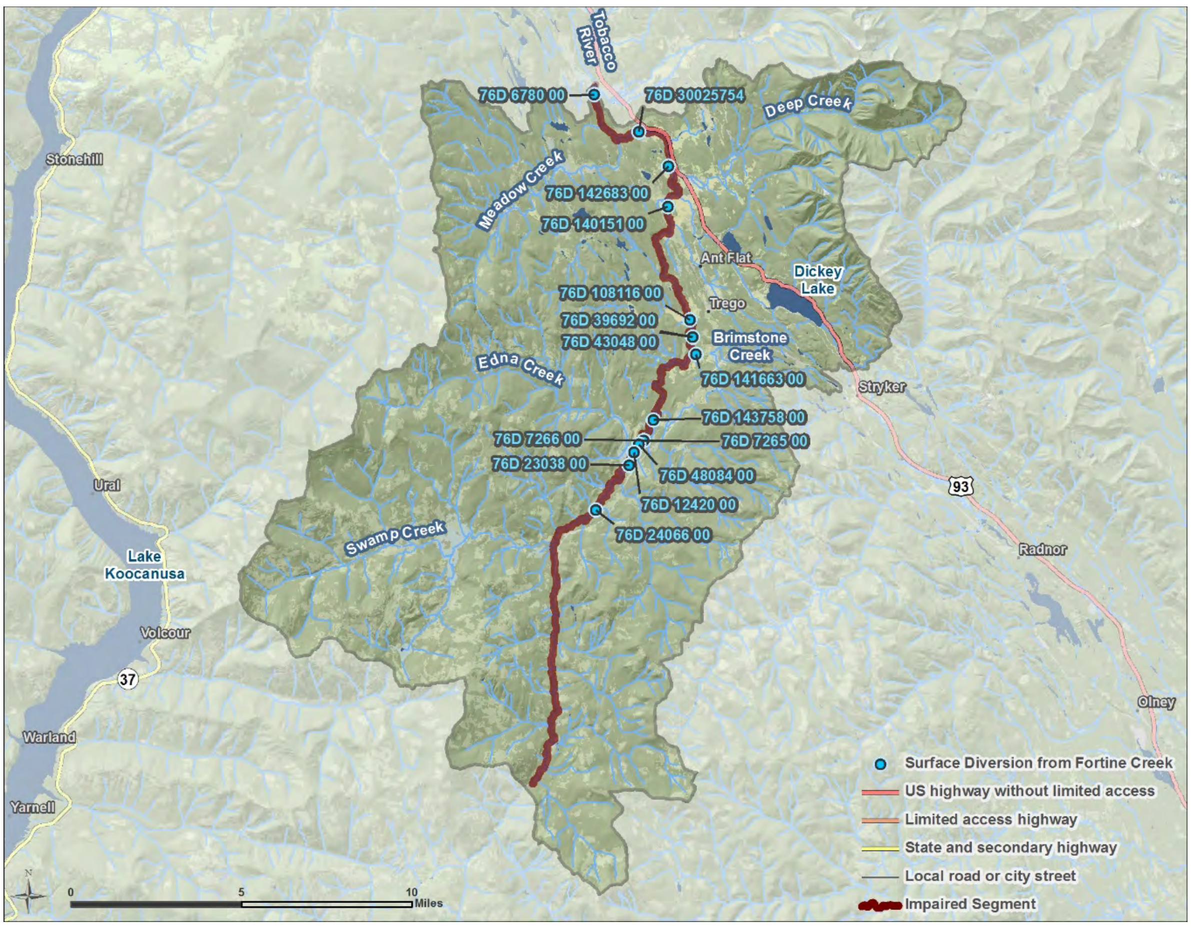


Figure B-8. Average discharge (cfs) at nearby USGS gage 12301300 (WY 1959 – 2012)

B2.3.4.1 Hydrologic Modification

Based on review of aerial photographs and online water rights data (ftp://nris.mt.gov/dnrc), there are 697 surface and groundwater diversions in the Fortine Creek watershed that support a variety of uses. “Points of diversion” and “places of use” spatial data were obtained from the Montana Natural Resource Information System (NRIS 2012). Of the 697 diversions in the Fortine Creek watershed, 31 were directly from Fortine Creek. Of those, only 15 appear to constitute potentially significant withdrawals (**Figure B-9** and **Table B-6**) because the remainder are for direct livestock access to Fortine Creek. Withdrawals were not field-verified.

It is estimated that up to 6.24 cfs may be withdrawn from Fortine Creek on a daily basis during July and August (**Table B-6**). This amount was estimated using the Irrigation Water Requirements program developed by the U.S. Department of Agriculture for estimating crop irrigation requirements (Dalton 2003). Most daily withdrawals are close to or less than 0.5 cfs but one just downstream of Brimstone Creek is estimated to be 3 cfs (76D 140151 00). This method assumes that the entire crop area associated with the withdrawal is irrigated.



Source of “points of diversion” data: NRIS 2012.

Figure B-9. Potentially significant surface and groundwater diversions along Fortine Creek and point sources in the Fortine Creek watershed

Table B-6. Potentially significant points of diversion from Fortine Creek (NRIS 2012)

WRNUMBER	Purpose	Irrigation type	Means of withdrawal	Max area (acres)	Max flow rate (cfs)	Volume (acre-ft/yr)	Est. daily volume applied a (cf)	Est. daily flow rate b (cfs)
76D 7266 00	Domestic	--	Pu	0	0.04	1.5	--	0.04
76D 143758 00	Domestic	--	Pu	0	0.04	1.5	--	0.04
76D 48084 00	Domestic	--	Pu	0.5	0.02	1.5	497	0.01
76D 43048 00	F&W	--	Pu	18	0.44	5.15	17,907	0.21
76D 30025754	F&W	--	IG	0	0.03	24.2	--	0.03
76D 142683 00	Industrial	--	Pi	0	0.60	217.73	--	0.60
76D 6780 00	Irrigation	F	H	39	1.48	162.5	38,799	0.46
76D 108116 00	Irrigation	S	Pu	44	0.49	95.5	43,774	0.52
76D 7265 00	Irrigation	S	Pu	7	0.12	15.75	6,964	0.08
76D 140151 00	Irrigation	S	Pu	263	3.34	900	261,647	3.09
76D 141663 00	Irrigation	S	Pu	2	0.01	2	1,990	0.02
76D 12420 00	Irrigation	F	H	49	1.86	215.6	48,748	0.58
76D 23038 00	Irrigation	S	Pu	4.5	0.17	6	4,477	0.05
76D 24066 00	Irrigation	S	Pu	4	0.15	17.6	3,979	0.05
76D 39692 00	Irrigation	S	Pu	38	0.64	86	37,804	0.45
Total Withdrawal				**469**				**6.24**

Notes: F = flood; F&W = fish and wildlife; H = headgate; IG= infiltration gallery; PI = pipeline; Pu = pump; S = sprinkler.

[a.] The daily volume applied was estimated using the USDA Irrigation Water Requirements program.

[b.] Non-shaded cells assume that the estimated daily volume is applied at a constant flow rate across a 24 hour period. Shaded cells assume maximum reported flow rate.

B2.4 Stream Temperature Data

Continuous temperature data is necessary for QUAL2K model development. Continuous temperature data have been collected in the Fortine Creek watershed by EPA, USFS, and the Montana Department of Fish, Wildlife and Parks (FWP). EPA collected continuous temperature data at seven sites along Fortine Creek and at two tributary sites (the mouth of Swamp and Deep creeks) in support of this modeling effort (**Figure B-10**). Monitoring sites were also proposed for Edna and Meadow creeks, but access could not be obtained near the mouth of Edna Creek and the mouth of Meadow Creek had insufficient flow. Data loggers recorded temperatures every one-half hour for two months between June 25 or July 12, 2012[3] and September 18, 2012. The USFS also collected continuous temperature data in 2012; loggers were deployed at one site in Fortine Creek (located in close proximity to EPA site FRTNC-T4) and Deep and Edna creeks[4] (**Figure B-10**) from June 15 to September 10. Additionally, FWP coordinated with DEQ to collect continuous temperature data at four locations in Fortine Creek in 2004 and 2005. The FWP logger sites extended from near Trego (and EPA site FRTNC-T5) to the mouth (**Figure B-10**).

[3] Temperature loggers were deployed on July 12, 2012 at the following sites because instream flow was too high to deploy loggers on June 25, 2012: FRTNC-T3, FRTNC-T4, FRTNC-T5, FRTNC-T6, DEEP, and FRTNC-T7.

[4] USFS's Deep and Edna creeks' loggers recorded extremely elevated temperatures prior to June 14, 2012 and after September 10, 2012. USFS Fortine Creek logger recorded extremely elevated temperatures prior to August 1, 2012 and after September 10, 2012. The high temperatures indicate the loggers were likely exposed to ambient air.

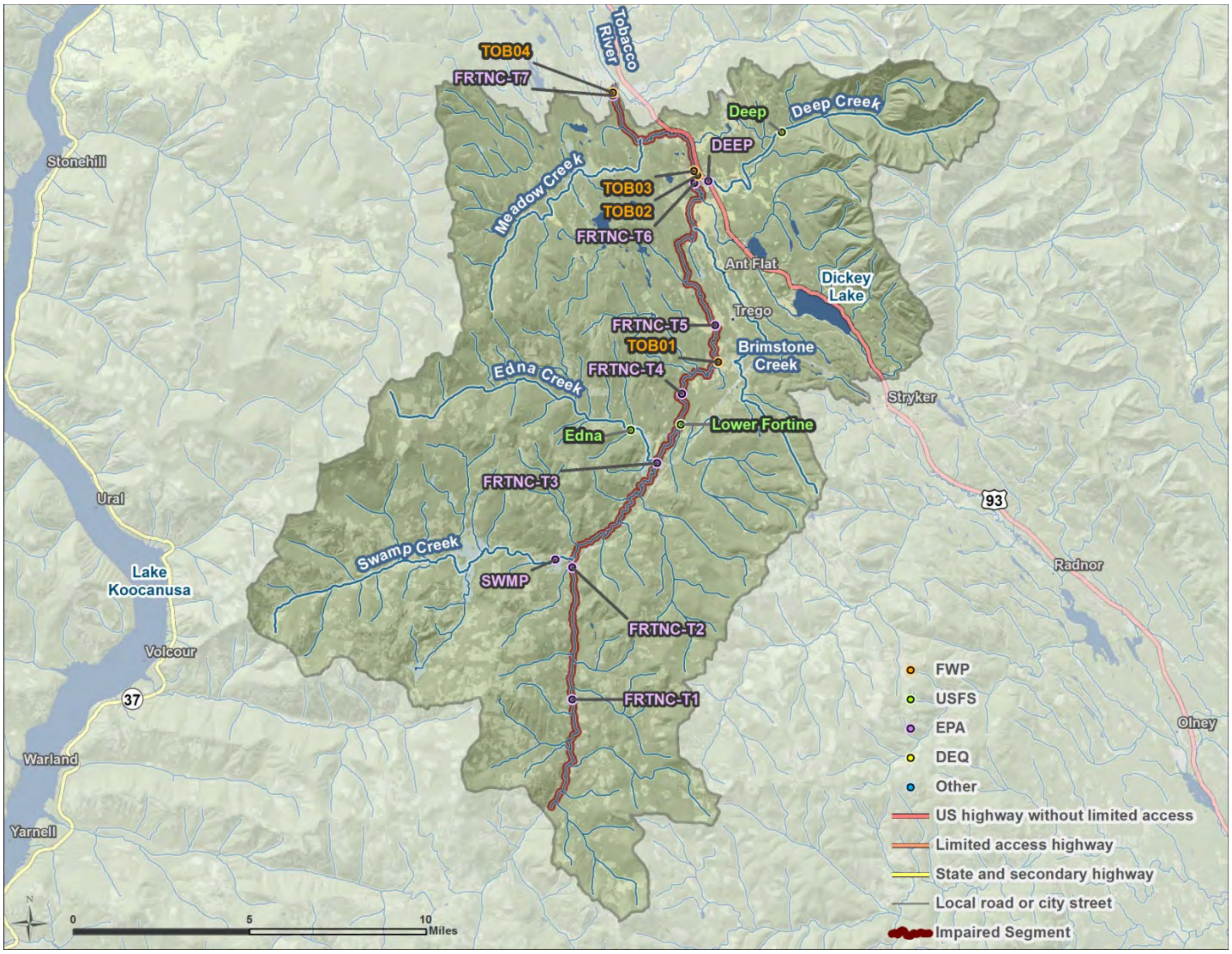


Figure B-10. Temperature loggers in the Fortine Creek watershed

A summary of the continuous temperature data collected by EPA and the USFS in 2012 is provided in **Figure B-11**. Median temperatures in Fortine Creek ranged from approximately 53°F to approximately 63°F with a general increasing trend from the headwaters to the mouth. The exception to this trend is site FRTNC-T6 where the highest median temperature was recorded. Maximum daily temperatures in Fortine Creek ranged from approximately 62°F to approximately 75°F (**Table B-7**). Unlike the median temperatures, a general trend of increasing maximum temperatures in a downstream direction does not hold true (**Figure B-12**). The highest maximum temperatures were recorded at FRTNC-T6. It appears that Swamp Creek (SWMP) have a warming influence on Fortine Creek, Edna Creek has no negligible influence, and Deep Creek has a cooling influence. In 2012, the warmest temperatures were detected on July 13 and August 7 and the warmest weeks were the second week of July and the first and second weeks of August (**Table B-7**).

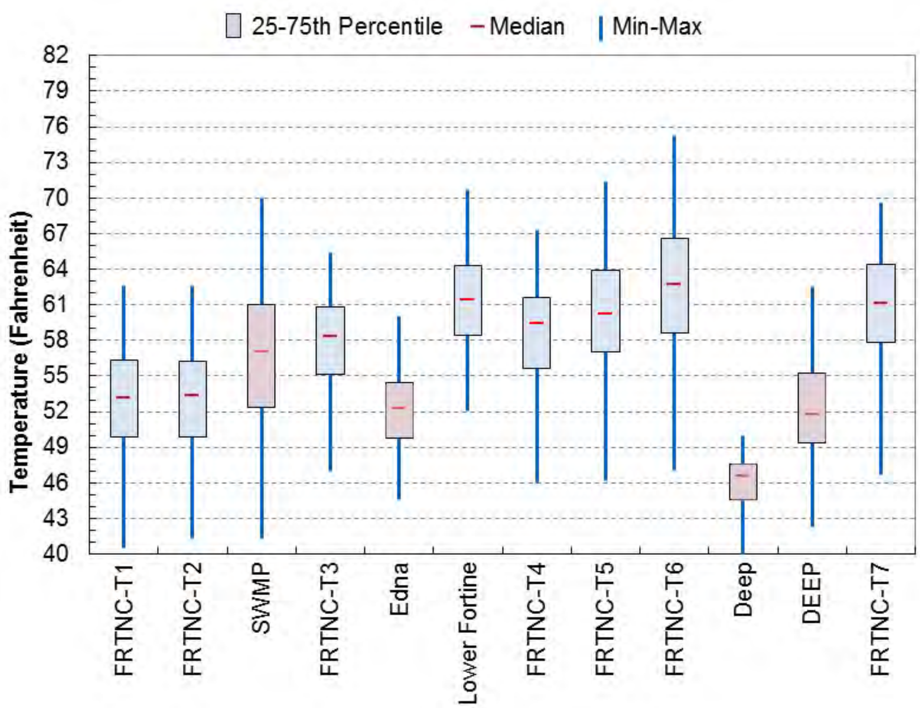


Figure B-11. Box-and-whisker plots of summer 2012 EPA and USFS continuous temperature data[5]

Table B-7. Maximum and maximum weekly maximum temperatures in Fortine Creek, 2012

Temperature logger site	Maximum temperatures a		Maximum weekly maximum temperature b	
	Temperature (°F)	Date	Temperature (°F)	Date
FRTNC-T1	62.6	August 7	61.0	August 5-11
FRTNC-T2 c	62.6	July 13	60.5	August 11-17
FRTNC-T3	65.4	July 13	63.4	July 12-18
Lower Fortine [d]	70.7	August 7	68.9	August 7-13
FRTNC-T4	67.3	August 7	65.8	August 7-13
FRTNC-T5	71.4	August 7	69.2	August 5-11
FRTNC-T6	75.3	July 13	72.4	July 25-31
FRTNC-T7	69.6	August 7	68.0	August 6-12

[a.] Maximum of recorded one-half hourly temperatures.
[b.] Mean of daily maximum water temperatures measured over the warmest consecutive seven-day period.
[c.] Logger FRNTC-T2 was probably exposed to ambient air from July 24, 2012 to mid-day August 10, 2012 when the logger was re-positioned. The data presented in this table are limited to a subset of the monitored temperatures from June 25, 2012 through July 23, 2012 and August 11, 2012 through September 18, 2012.
[d.] USFS's Fortine Creek logger recorded extremely elevated temperatures prior to August 1, 2012 and after September 10, 2012. The logger was likely exposed to ambient air. The data presented in this table are limited to a subset of the monitored temperatures from August 1 through September 10, 2012.

[5] Due to possible logger exposure to ambient air, the data presented in Figure B-11 are limited to a subset of the monitored temperatures from June 15 through September10, 2012 for the loggers in Deep and Edna creeks and from August 1 through September 10, 2012 for Fortine Creek. Also, EPA logger FRNTC-T2 was possibly out of water from July 24 through mid-day August 10, 2012; these data are excluded from Figure B-11.

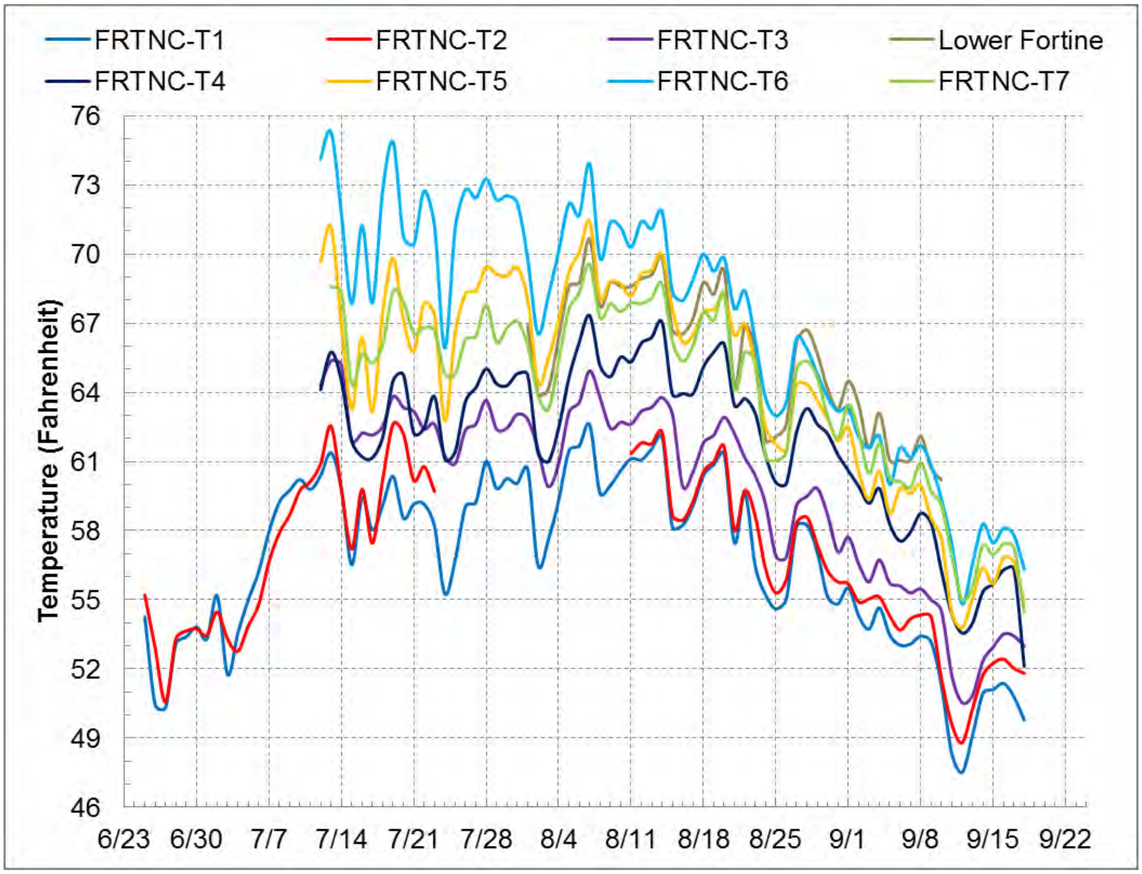


Figure B-12. Daily maximum temperatures, Fortine Creek and tributaries, June 25 or July 12 to September 18, 2012 (EPA sites) and August 1 to September 10, 2012 (USFS site)

The FWP data are discussed and presented separately from the EPA and USFS temperature data because they were collected during a different time period (i.e., 2004 and 2005). Although climatic and flow conditions were likely different in 2004/2005 as compared to 2012, the FWP logger data show a similar downstream trend as the 2012 data collected within the same portion of Fortine Creek (i.e., near Trego to the mouth): temperatures increased slightly until Deep Creek, which is between TOB02 and TOB03, which appears to have a cooling effect on temperatures in Fortine Creek (**Figures B-13** and **B-14)**. Comparing **Figure B-12** to **Figure B-13**, maximum temperatures measured in 2004/2005 were in the mid to upper 70s at several sites and higher than in 2012.

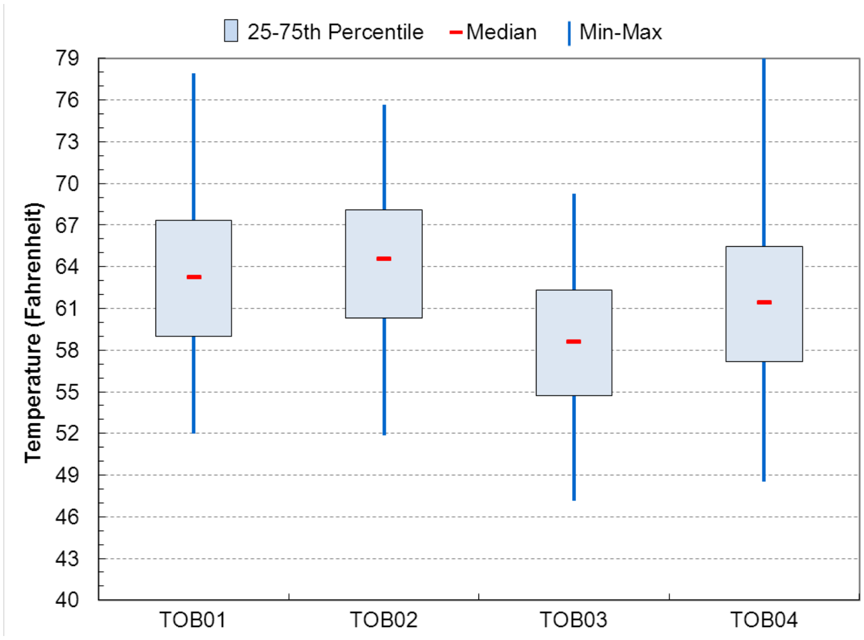


Figure B-13. Box-and-whiskers plots of FWP temperature data, 2004-2006[6]

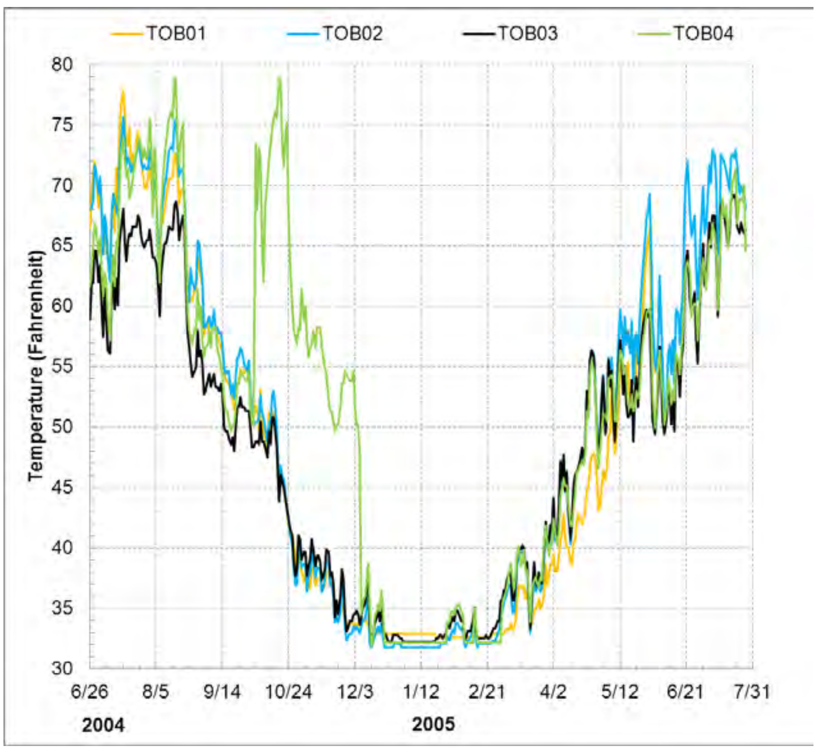


Figure B-14. Daily maximum temperatures along Fortine Creek, June 26, 2004 to July 27, 2005

[6] The FWP data shown in this figure are from roughly the same days per year as the EPA/USFS data shown in Figure B-12. TOB01 data are from July 5 to September 18, 2004. TOB02 and TOB04 data are from June 26 to September 18, 2004 and June 25 to July 27, 2005. TOB03 data are from June 26 to September 18, 2004 and June 25 to September 18, 2005.

B3.0 Model Setup

A QUAL2K model was used to simulate temperatures in Fortine Creek. QUAL2K is supported by EPA and has been used extensively for TMDL development and point source permitting across the country. The QUAL2K model is suitable for simulating hydraulics and water quality conditions of small rivers and creeks. It is a one-dimensional uniform flow model with the assumption of a completely mixed system for each computational element. QUAL2K assumes that the major pollutant transport mechanisms, advection and dispersion, are significant only along the longitudinal direction of flow. 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. 2008).

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

The following subsections describe the process that was used to setup the QUAL2K model for Fortine Creek.

B3.1 Channel Flow-Path

The QUAL2K model for Fortine Creek was developed for the 31.7-miles of the stream from the confluence with the Tobacco River upstream to site FRTNC-T1, which is near the headwaters (**Figure B-1**). This segment was delineated using the National Hydrography Dataset, which includes multiple named tributaries to Fortine Creek that were explicitly modeled as point sources: Deep Creek (river mile [RM] 6.0), Edna Creek (RM 19.6), and Swamp Creek (RM 26.4). All other tributaries were implicitly modeled as part of the net diffuse flow.

B3.2 Stream Segmentation

Segmentation refers to discretization of a waterbody into smaller computational units (e.g., reaches and elements). Segmentation into reaches allows for representation of stretches of the river that have constant hydraulic characteristics (e.g. slope, bottom width). Each reach is further divided into elements that are the fundamental computational units in QUAL2K. The number of elements is determined on the basis of the estimated velocity/computational time step to ensure the containment of the heat load calculation within each element per time step.

Fortine Creek was divided into nine linked reaches from the mouth to the headwaters (**Figure B-15**) identified as A, B, C, D, E, F, G, H, and I. The segmentation locations were selected on the basis of available diurnal temperature and flow data (available at the EPA and USFS sample sites), changes in vegetation, and changes in effective shade. Each of the nine linked reaches was further subdivided into elements. The element length was selected to be short enough to increase the spatial resolution and long enough to support model stability; the average element length was 0.34 miles (550 meters).

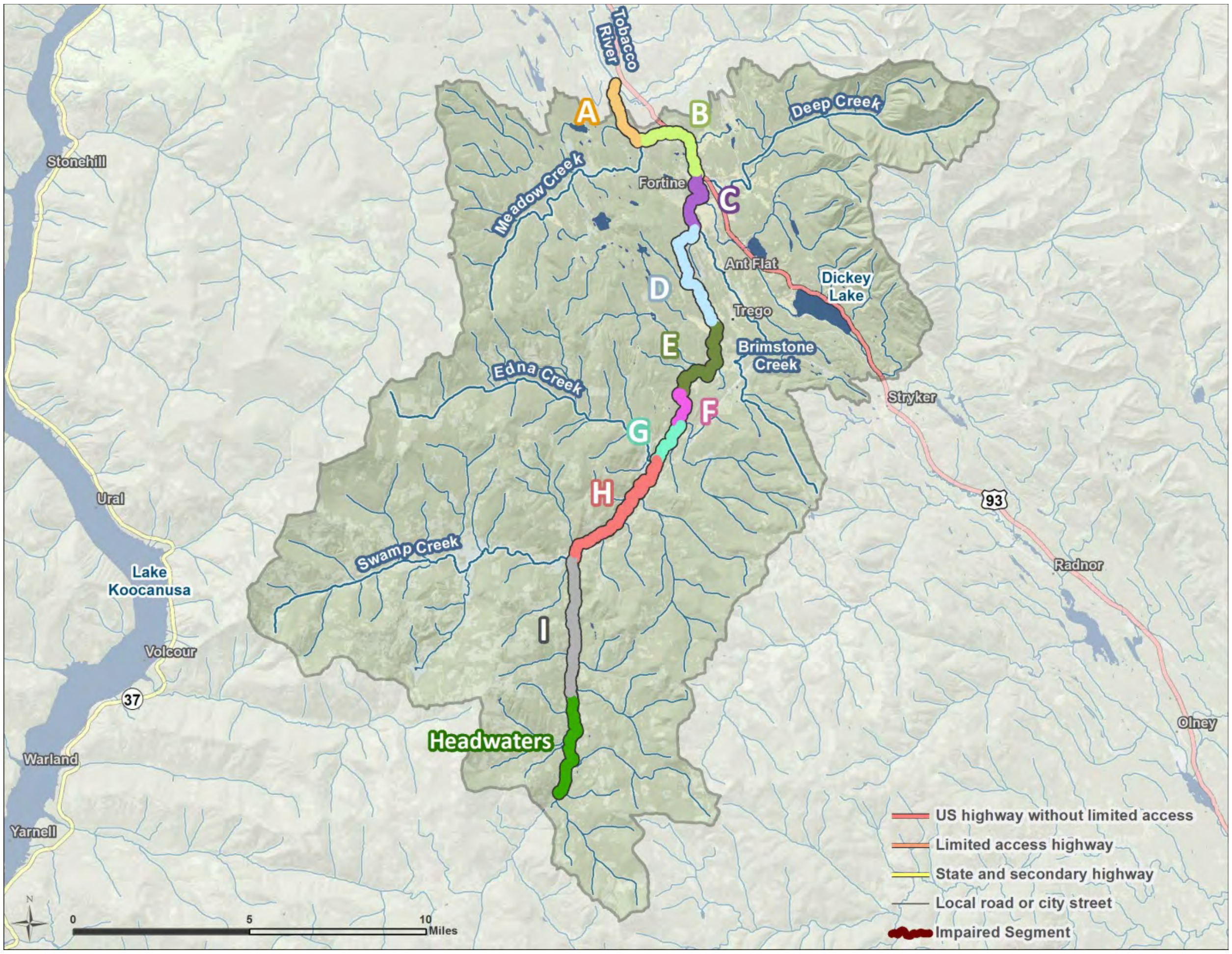


Figure B-15. Model segmentation along Fortine Creek

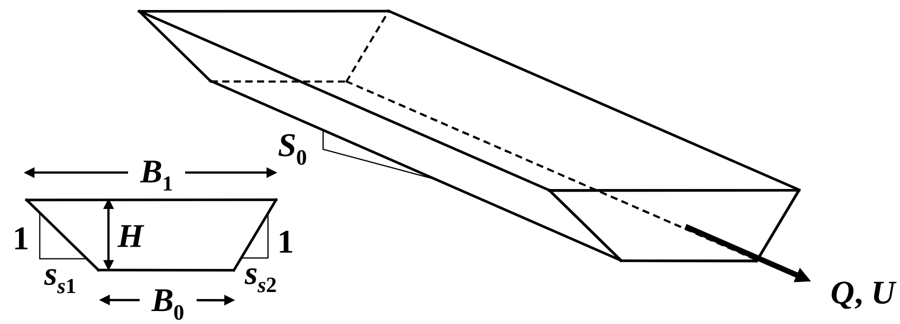
B3.3 Channel Geometry

The channel geometry data that was input into QUAL2K was derived from EPA field work. The model inputs and assumptions are presented in **Attachment B-2** (and the original field data are available upon request). Manning's n was calculated for each segment using site photographs and equations[7] presented in Marcus et al. (1992). Channel slopes were calculated for each model reach as the geometric mean of slopes calculated at each node of the Shade Model (i.e., every 98 feet [30 meters] along Fortine Creek). Stream bottom width and the sides of the trapezoidal cross-section assumed for modeling (**Figure B-16**) were estimated using widths measured in the field on September 12 and 13, 2012 and by assuming the sides were at a 1:1 ratio. The channel bottom widths were assumed to be slightly shorter than the wetted widths (using the assumed trapezoidal cross-section) measured at the eight Solar Pathfinder™ sites on September 12 and 13, 2012 since the stream depths were shallow on those dates. The assignments of the bottom widths to each model reach were based on availability of data within each reach and linear interpolation with the closest field measurement.

The Manning's n for the headwaters boundary condition was set equal to the Manning's n calculated for segment I. Channel slope was estimated for the headwaters boundary condition using slope data at the

[7] The equations were from Cowan (1956) and Chow (1959) and published in Marcus et al. (1992).

upstream terminus of segment I. The sides of the hypothetical trapezoidal cross-section were assumed to be at a 1:1 ratio and the field-measured wetted width at FRTNC-T1 was assumed for the bottom width of the headwaters boundary condition.



Source: Chapra et al. 2008.
Note: B_0 is stream bottom width, S_{s1} and S_{s2} are side lengths relative to one, and S_0 is channel slope.
Figure B-16. Idealized trapezoidal channel assumed in QUAL2K

B3.4 Hydrologic Simulation

Although QUAL2K can reasonably simulate flow and related parameters (i.e., velocity and depth), it does have limitations. The model does not allow for the explicit simulation of any natural flow retardation processes; such processes occur in pools, riffles, deep holes, side channels, or hyporheic zone flow exchanges. These processes could have a pronounced effect on stream hydrology and temperature condition of the river.

The observed data collected in 2012 by EPA and USFS along the mainstem were used to derive the flow inputs required to run the QUAL2K model for the calibration day of August 10, 2012 (**Attachment B-2**, **Table B2-6**). EPA measured flow at the mouths of Deep Creek and Swamp Creek on August 10, 2012, and the flows (16.8 cfs and 3.6 cfs, respectively) were input into QUAL2K. The flow for Edna Creek, which was not monitored, was estimated by subtracting the flows measured on Fortine Creek above and below the confluence with Edna Creek (7.8 cfs). The headwaters boundary condition inflow was defined as the flow monitored at site FRTNC-T1 (3.7 cfs).

A water balance was used to estimate diffuse flow, with the difference between each observation assumed to be diffuse flow. Diffuse flow in reaches I through F and reaches D through A was positive (i.e., inflow or net accretion), whereas diffuse flow from reach E was negative (i.e., outflow). Irrigation diversions are along the entire creek and 15 outflows were explicitly modeled as abstractions (**Attachment B-2**, **Table B2-7**).

B3.5 Weather

Weather inputs were compiled from the closest station recording the necessary hourly data, which was Eureka RAWS since the weather stations in the Fortine Creek watershed only report daily data (**Attachment B-2**, **Tables B2-10** and **B2-11**). These data were used as model input for the August 10, 2012 date for calibration. Air temperature and dew point temperature data from the Eureka RAWS were corrected using the moist air adiabatic lapse rate (-0.00656 C/m) to account for the elevation difference between the RAWS and the individual model segments. Wind speed was corrected (Chapra et al. 2008,

p. 27, equation 48) for the height differences of the sensor at Eureka RAWS (reported as 20 feet) and the required QUAL2K height of 23 feet (7 meters).

Cloud cover was estimated on the basis of available hourly data at the Kalispell Glacier Park International Airport (elevation 2,972 feet above MSL) weather station that is operated by the National Weather Service, which is the closest weather station that measures cloud cover. Zero percent cloud cover was observed at the Glacier Park International Airport on August 10, 2012; therefore, zero percent was input for all 24 hours in the QUAL2K model. Precipitation data collected at the Eureka RAWS were evaluated to verify that no precipitation occurred on August 10, 2012 as the occurrence of precipitation would indicate the presence of cloud cover.

B3.6 SHADE

Shade is a key input to the QUAL2K model. As recommended in the QUAL2K model documentation, estimates of shading are developed separately using the spreadsheet Shadev3.0.xls. For additional details on the Shade Model and how riparian shade was estimated, see **Section B3.2.3**. Hourly medians of the Shade model results were calculated for each of the nine model segments and entered into QUAL2K (**Attachment B-2**, **Table B2-12**). **Figure B-17** provides a stacked bar graph showing the existing riparian land cover within the 150 ft buffer and median percent shade for each of the model reaches. Note, the wet shrubs component indicated in purple (and present in segments I and H) are also referred to as hydrophytic shrubs within this appendix. Hydrophytic/wet shrubs represent stands of willow/alder that are at or near their potential and not anticipated to attain great height at maturity. They were identified based on a combination of aerial photographs and field work.

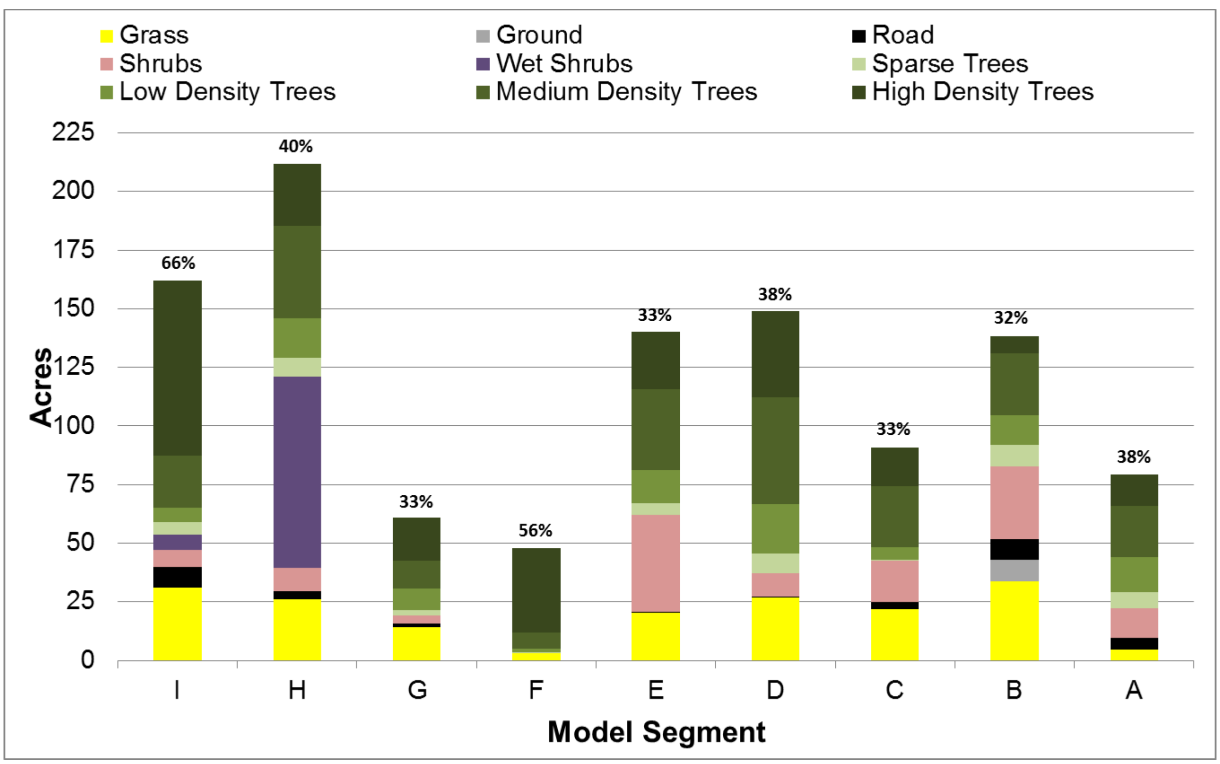


Figure B-17. Riparian vegetation within 150 feet of Fortine Creek and median percent shade (shown above each bar) under existing conditions going from the headwaters (I) to the mouth (A)

B3.7 HEAT

QUAL2K users can select various heat transfer model input parameters. For this project, default values recommended by Chapra et al. (2008) were used for some heat and light parameters; other heat and light parameters were used as calibration parameters. Calibrated heat and light parameters were within typical ranges reported in Chapra et al. (2008); the inputs are presented in **Table B2-13** in **Attachment B-2**.

B4.0 CALIBRATION AND VALIDATION

Environmental simulation models are simplified mathematical representations of complex, real-world systems. Models cannot accurately depict the multitude of processes occurring at all physical and temporal scales. Models can, however, make use of known interrelationships among variables to predict how a given quantity or variable would change in response to a change in an interdependent variable or forcing function. In this way, models can be useful frameworks for investigating how a system would likely respond to a perturbation from its current state. To provide a credible basis for predicting and evaluating mitigation options, the ability of the model to represent real-world conditions should be demonstrated through a process of model calibration and validation (CREM 2009). Discussions of calibration and validation are in the Quality Assurance Project Plan for Montana TMDL Support: Temperature Modeling (Tetra Tech 2012).

B4.1 ERROR ANALYSIS

Water quality models are often evaluated through visual comparisons, in which the simulated results are plotted against the observed data for the same location and time and are visually evaluated to determine if the model is able to mimic the trend and overall magnitude of the observed conditions. This method works well when data are limited in quantity and contain significant uncertainty. The limitation of this method is that it relies on the subjective judgment of modelers and lacks quantitative measures to differentiate among sets of calibration result. Because of this, both a visual comparison and quantitative measures were used during the Fortine Creek calibration and validation.

The two methods used to compare model predictions and observations are the deviation between model predictions and observations (i.e., absolute error) and deviation between model predictions and observations relative to the observation (i.e., relative error). The absolute error is calculated as the simulated value minus the observed value. A negative absolute error means that the model simulated cooler temperatures than were observed; a positive value means that the model simulated warmer temperatures than were observed. In this case, the relative error is simply the percentage of deviation between the model prediction and observation, with a statistic of zero being ideal.

According to the QAPP (Tetra Tech 2012), the acceptance criteria will be determined for each model on the basis of the available data. If sufficient data are available, per the QAPP, the proposed acceptable temperature differences between modeled and observed daily minima, means, and maxima are 2 degrees Celsius (°C) or a relative error of less than 10 percent for higher temperatures. These criteria were applied in this project.

B4.2 Calibration and Validation Periods

The dates for calibration and validation of the QUAL2K model were selected on the basis of the available data and the period of record during which the highest instream temperatures were observed (**Figure B-12**). The available flow and stream geometry data suggest that travel time in Fortine Creek, from headwaters to the mouth, is more than one day. Average velocities were calculated from depth-velocity interval data recorded when flow was monitored on 3 occasions across eight sites along Fortine Creek. Average velocities on August 10, 2012 ranged from 0.52 feet per second to 1.76 feet per second, with an average of 1.13 feet per second, and average velocities on September 18, 2012 ranged from 0.26 feet per second to 1.41 feet per second, with an average of 0.78 feet per second. Such velocities yield travel times of 1 day 2 hours to 3 days 15 hours on August 10, 2012 (average of 1 day 16 hours) and 1 day 8 hours to 7 days 5 hours on September 18, 2012 (average of 2 days 10 hours).

QUAL2K model input parameters were developed based upon a single day for the calibration (August 10, 2012) and validation (September 18, 2012). The dates selected to develop model input parameters consisted of warm days without precipitation on that day or preceding days during summer low-flows, which allows for calibration to conditions when temperatures are likely the highest. For both the calibration and validation, the simulation period was longer than the travel time in Fortine Creek to ensure that the model configuration achieved steady-state conditions for the Fortine creek watershed. Because QUAL2K is a steady-state model, respective input parameters were maintained throughout the entire calibration and validation periods. The calibration simulation was 4 days and the validation simulation period was 5 days, based in part upon instream velocities.

B4.3 Calibration Results

Temperature calibration for the Fortine Creek QUAL2K model relied on a comparison of model predictions to observations at the temperature loggers (**Figure B-18**). The model is able to simulate the mean and maximum temperatures fairly well but does have some difficulty consistently simulating the minimum temperatures at several locations (i.e., loggers –T2, -T4, and –T6). However, the absolute mean error (AME) for all the modeled minimum, mean and maximum temperatures for the model calibration are within 3.6°F (2° C) of the corresponding observed values (**Table B-8**), which meets the criteria set in the QAPP (Tetra Tech 2012). The calibration AME for the maximum daily temperature is 1.3°F and the relative error is 2.0%.

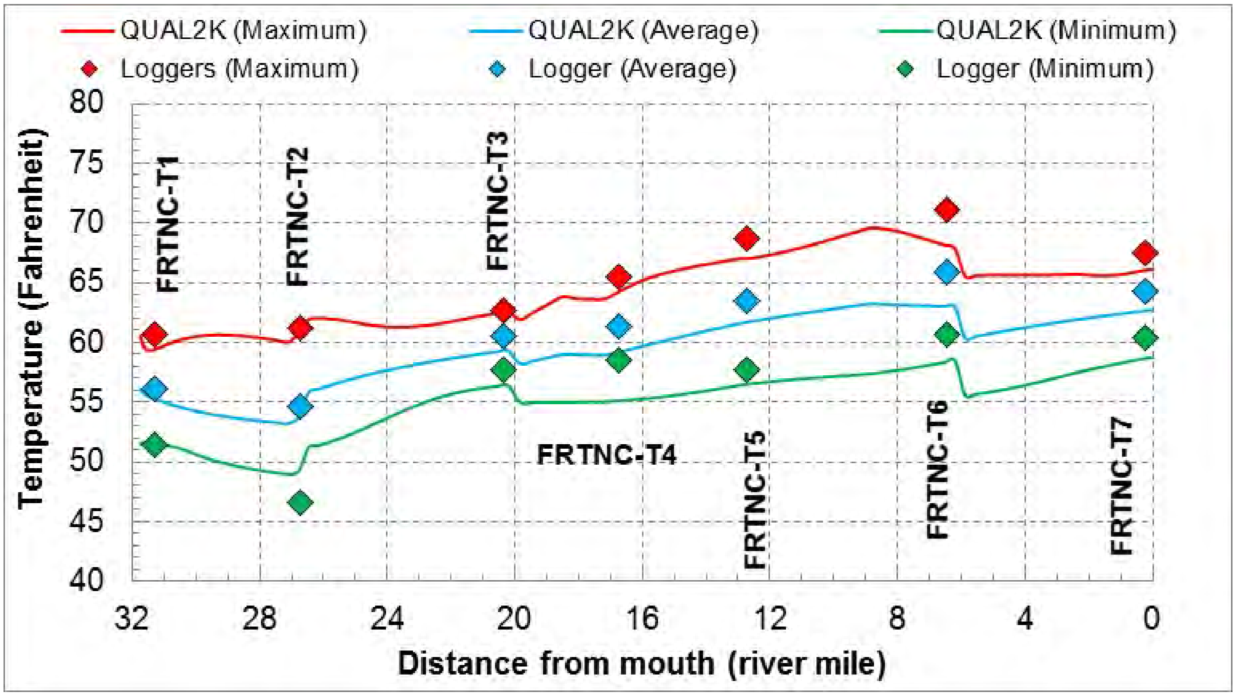


Figure B-18. Observed and modeled temperatures for the calibration (August 10, 2012)

Table B-8. Model calibration results for August 10, 2012 in Fahrenheit

Site name	RM	Average daily temperature		Maximum daily temperature		Minimum daily temperature	
		AME (°F)	REL (%)	AME (°F)	REL (%)	AME (°F)	REL (%)
FRTNC-T1	31.28	0.8	1.5%	1.2	1.9%	0.0	0.1%
FRTNC-T2	26.75	0.9	1.7%	0.4	0.7%	2.7	5.5%
FRTNC-T3	20.36	1.2	2.1%	0.2	0.4%	1.4	2.5%
FRTNC-T4	16.72	2.2	3.7%	1.4	2.2%	3.4	6.2%
FRTNC-T5	12.73	1.7	2.8%	1.7	2.5%	1.3	2.2%
FRTNC-T6	6.43	2.9	4.6%	3.0	4.4%	2.3	4.0%
FRTNC-T7	0.24	1.7	2.7%	1.4	2.1%	1.7	2.9%
Overall calibration		**1.6**	**2.7%**	**1.3**	**2.0%**	**1.8**	**3.3%**

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

B4.4 Validation Results

Model validation was determined by a second model run that was conducted under different hydrological and weather conditions (September 17, 2012). EPA temperature data (September 17, 2012) and flow data (September 18-19, 2012) were used to validate. During calibration, the model did have more difficulty consistently predicting temperatures near logger FRTNC-T6. However, similar to the calibration results, all the modeled minimum, mean, and maximum temperatures are within 3.6°F (2° C) of the corresponding observed values (**Table B-9**, **Figure B-19**), which meets the criteria set in the QAPP (Tetra Tech 2012). The validation AME for the maximum daily temperature is slightly higher than for the calibration at 2.2°F and also for the relative error, which is 3.7%.

Table B-9. Model validation results for September 17, 2012 in Fahrenheit

Site name	RM	Average daily temperature		Maximum daily temperature		Minimum daily temperature	
		AME (°F)	REL (%)	AME (°F)	REL (%)	AME (°F)	REL (%)
FRTNC-T1	31.28	1.3	2.8%	1.0	1.9%	0.0	0.1%
FRTNC-T2	26.75	1.2	2.5%	1.0	1.9%	1.4	3.1%
FRTNC-T3	20.36	0.5	0.9%	1.8	3.2%	0.4	0.8%
FRTNC-T4	16.72	1.1	2.1%	1.1	1.8%	0.7	1.4%
FRTNC-T5	12.73	1.1	2.0%	3.4	5.7%	0.2	0.4%
FRTNC-T6	6.43	2.3	4.0%	3.3	5.5%	1.5	3.0%
FRTNC-T7	0.24	2.5	4.5%	3.6	6.0%	2.6	5.1%
Overall validation		**1.4**	**2.7%**	**2.2**	**3.7%**	**1.0**	**2.0%**

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

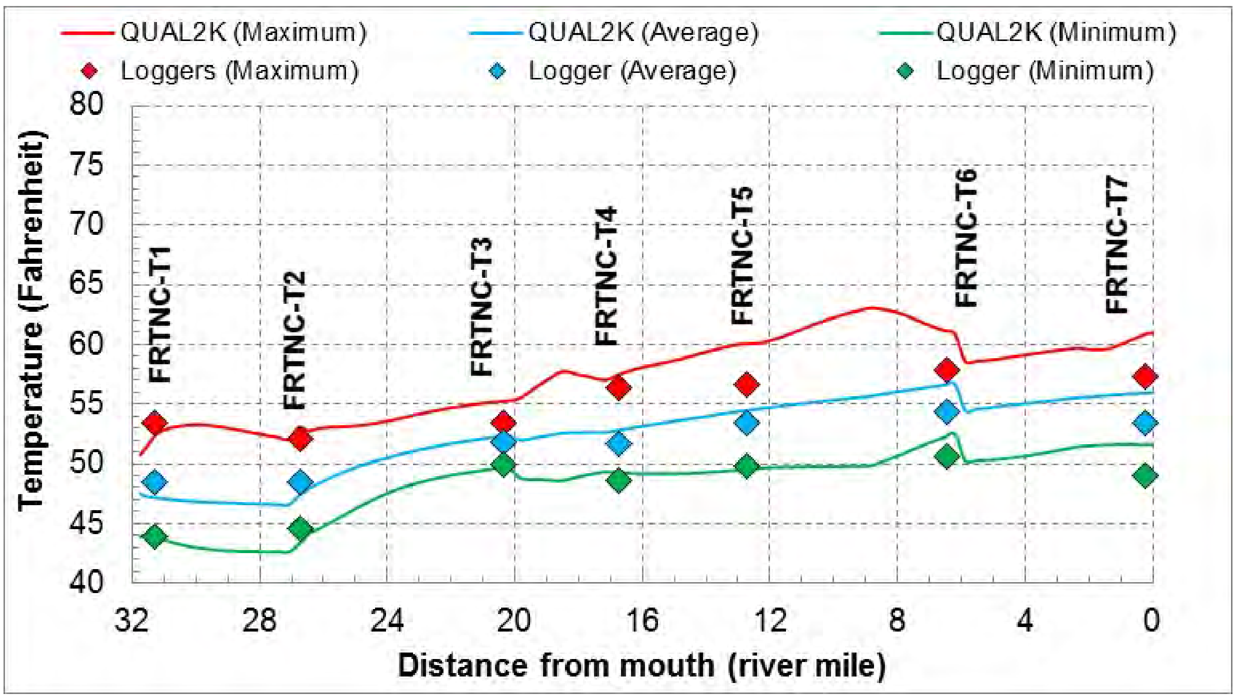


Figure B-19. Observed and modeled temperatures for the validation (September 17, 2012)

B5.0 Model Scenarios

The Fortine Creek QUAL2K model was used to evaluate instream temperature response associated with multiple scenarios. **Table B-10** summarizes the alterations to input parameters for each model scenario. The following sections discuss the modifications to the QUAL2K model and the results for each scenario. For each scenario, the simulated temperature range and degree of change relative to the existing condition scenario is summarized for all model elements, which essentially represents all of Fortine Creek. This information is then presented in a graph and for each logger location in a table.

Table B-10. Fortine Creek QUAL2K model scenarios and summary of inputs

Scenario	Summary
1 – Existing Condition (calibration)	Existing condition scenario from which to test model sensitivity and management induced changes to streamflow and riparian shade. Based on current streamflow, climate, and shade conditions.
2 – No withdrawals (sensitivity analysis)	Existing condition without water withdrawals. To test the sensitivity of the model to water withdrawals and not intended for management purposes.
3 - Maximum Shade (sensitivity analysis)	Existing condition with all vegetation communities within the 150 foot buffer along each side of the stream transformed to "high density trees" with the exception of roads, railroads, and areas dominated by hydrophytic shrubs[1]. To test the sensitivity of the model to shade and not intended for management purposes.
4 – Improved Shade	Existing condition with all vegetation communities, with the exception of hydrophytic shrubs[1], roads, and railroads transformed to medium density trees within 50 feet of the streambanks. Existing medium density and high density trees were retained and existing conditions vegetation was retained beyond the 50-foot buffer. To simulate achievement of all reasonable land and soil conservation practices.
5 – Improved Water Management	Existing condition with withdrawals reduced by 15%. To simulate achievement of all reasonable water conservation practices.
6 – Naturally Occurring	Existing condition scenario with improved riparian vegetation in a 50-foot buffer and a 15 percent reduction of water withdrawals. This is to simulate full standards attainment via the use of all reasonable land, soil, and water conservation practices.
7 – Low Flow Existing Condition	Low flow existing condition scenario. To simulate stream temperatures on a drier year than the existing baseline (Scenario 1).
8 – Low Flow Naturally Occurring	Existing condition scenario with improved riparian vegetation in a 50-foot buffer and a 15 percent reduction of water withdrawals. To simulate full standards attainment via the use of all reasonable land, soil, and water conservation practices relative to the Low Flow Baseline (Scenario 7).

[1]Hydrophytic shrubs represent stands of willow/alder that are at or near their potential and not anticipated to attain great height at maturity. They were identified based on a combination of aerial photographs and field work.

B5.1 Scenario 1: Existing Condition (Baseline)

The calibration model serves as the existing condition scenario (i.e., baseline). This scenario represents dry conditions during August when instream temperatures were at or near their maximum in 2012. The construction of the model and its inputs are discussed in **Section B3.0**. As shown in **Figure B-20**, maximum daily temperatures under this scenario range from 59.4°F to 69.6°F.

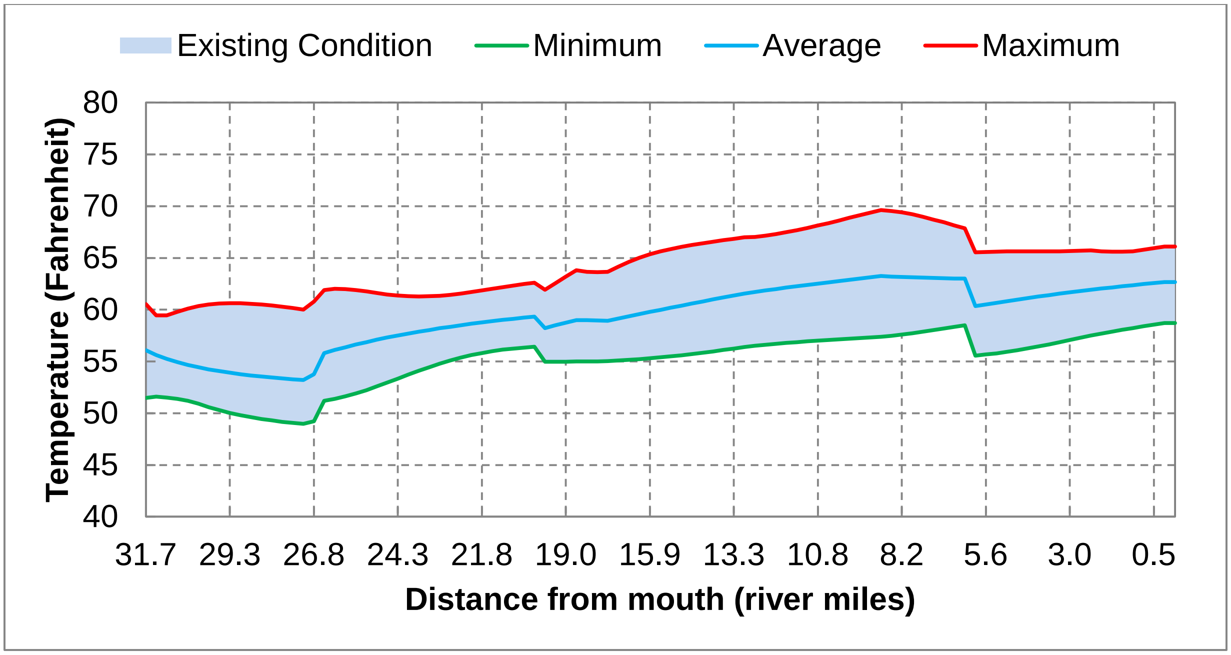


Figure B-20. Simulated water temperatures for the existing condition (August 10, 2012)

B5.2 Scenarios 2 and 3: Sensitivity Scenarios

Scenarios 2 and 3 were run entirely for the purpose of testing model sensitivity to shade and water usage. Neither is intended to reflect a reasonable management scenario.

B5.2.1 Scenario 2: No Water Withdrawals

In this scenario, the point source abstractions representing the withdrawals (see **Table B-6** for the withdrawals) in the QUAL2K model are removed. This scenario represents a lack of withdrawals for irrigation, domestic use, and other uses in the Fortine Creek watershed. The 6.24 cfs of water previously withdrawn is now allowed to flow down Fortine Creek. While not feasible due to water rights and other issues, the 100 percent decrease scenario indicates the maximum possible achievable change in water temperatures from changes in water use. To put this amount of water into context, in the existing condition scenario (i.e., Scenario 1) streamflow increases from 3.7 cfs near the headwaters to 59.3 cfs at the mouth and tributary inputs total 28.2 cfs.

No Water Withdrawal Scenario Results

The no withdrawal scenario results in little change along most of the stream, indicating the model is not very sensitive to changes in streamflow related to withdrawals. This is likely because the withdrawals are dispersed among roughly 25 miles and streamflow increases quite a bit along the stream. Under this scenario, the daily maximum temperatures range from 59.4°F to 69.2°F. Daily mean temperatures change along Fortine Creek, as compared to the existing condition scenario, from a 0.13°F decrease to a 0.20°F increase (river mile-weight average decrease of 0.01°F) [8]. The daily maximum temperatures vary between a 0.38°F decrease and a 0.09°F increase (river mile-weighted average decrease of 0.1°F) and the daily minimum temperatures vary between a 0.01°F decrease to a 0.34°F increase (river mile-weighted average increase of 0.06°F). Decreases in the maximum temperature do not start until close to river mile 23, which is midway between loggers FRTNC-T2 and FRTNC-T3. The maximum decrease occurs

[8] The river mile-weighted average is calculated with the temperature change per element and length per element.

in the lower watershed near Brimstone Creek, which is close to river mile 9 and between loggers FRTNC-T5 and FRTNC-T6, and where the largest withdrawal is located. **Table B-11** presents the results at the temperature logger sites and **Figure B-21** presents the continuous results along Fortine Creek.

Table B-11. Comparison of model results between baseline (1) and no water withdrawals (2)

Daily temperature	Source	FRTNC-*						
		*T1	*T2	*T3	*T4	*T5	*T6	*T7
Maximum	Existing	59.5	60.8	62.5	64.1	67.0	68.2	66.1
	Scenario	59.5	60.8	62.5	64.1	66.9	68.0	65.8
	Difference	**0**	**0**	**-0.010**	**-0.1**	**-0.1**	**-0.2**	**-0.3**
Mean	Existing	55.3	53.8	59.2	59.2	61.7	63.0	62.7
	Scenario	55.3	53.8	59.2	59.2	61.6	63.0	62.7
	Difference	**0**	**0**	**0.0**	**0.0**	**-0.1**	**-0.1**	**-0.01**
Minimum	Existing	51.5	49.2	59.2	55.1	56.5	58.3	58.7
	Scenario	51.5	49.2	59.3	55.2	56.5	58.3	58.9
	Difference	**0**	**0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.2**

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The difference (bolded) is calculated as the existing subtracted from the scenario. Negative results indicate that the scenario yields cooler instream temperatures as compared to the existing condition and positive results indicate the scenario yields warmer instream temperatures as compared to the existing condition.

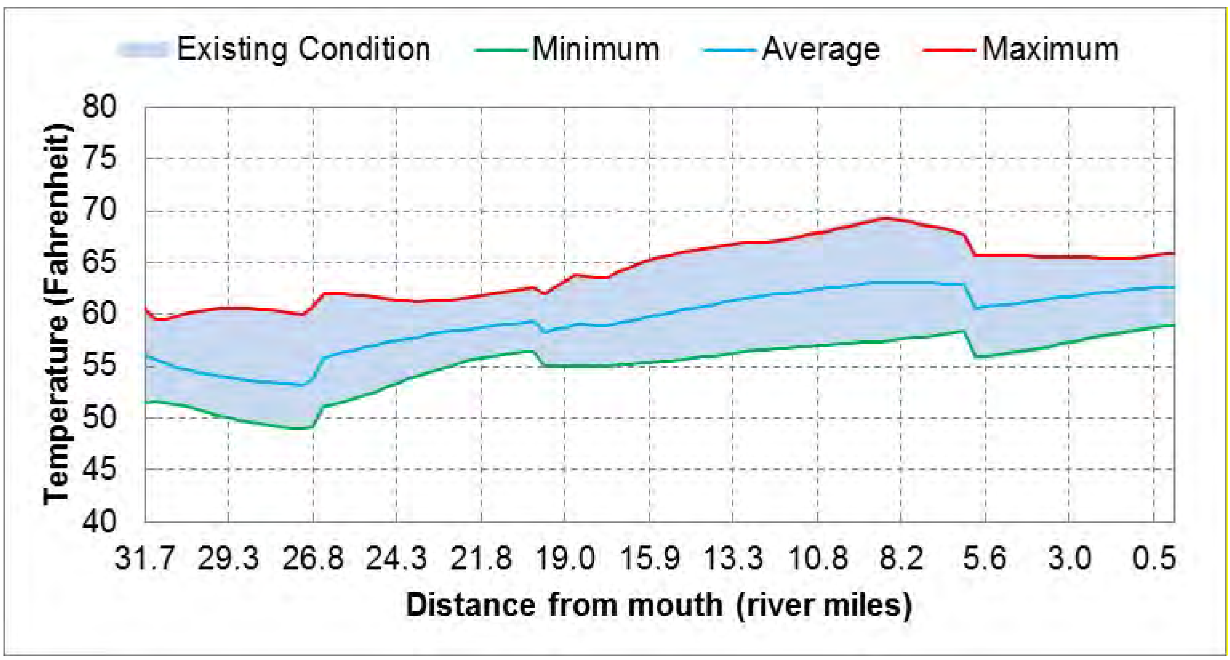


Figure B-21. Comparison of existing model results to Scenario 2: No water withdrawals

B5.2.2 Scenario 3: Maximum Shade

The maximum shade scenario uses the existing condition model and increases shading along Fortine Creek. Except for water, roads, railroads, and hydrophytic shrubs, all land covers were transformed to high density forest, and the Shade Model was re-run using this vegetation configuration (see **Figure B-22** and **Table B-12** for a comparison of the effective shade under the maximum shade scenario with the existing condition scenario). Similar to Scenario 2, this scenario was developed only to assess model sensitivity and not a management goal.

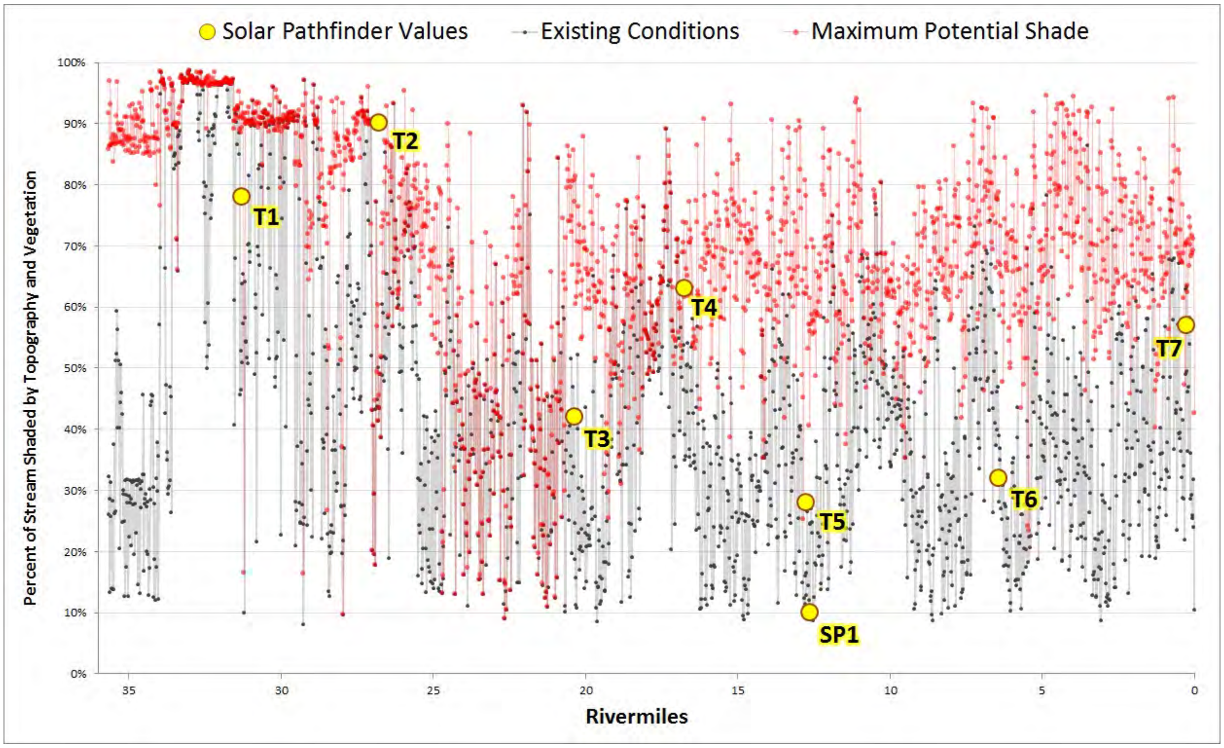


Figure B-22. Longitudinal estimates of effective shade for existing conditions and the maximum shade scenario along Fortine Creek

Table B-12. Comparison of effective shade per model segment between existing (1) and maximum shade scenario (3)

Model segment	Existing Condition (scenario 1)	Maximum Shade (scenario 3)
I (near headwaters)	82%	98%
H	55%	72%
G	47%	79%
F	73%	78%
E	48%	83%
D	52%	79%
C	49%	86%
B	42%	88%
A (mouth)	53%	83%

Maximum Shade Scenario Results

The results of this scenario indicate the Fortine Creek QUAL2K model is much more sensitive to changes in riparian shade than to increases in streamflow. This scenario results in cooler water temperatures along all of Fortine Creek. Under this scenario, the daily maximum temperatures range from 52.7°F to 62.1°F. Daily mean temperatures along Fortine Creek decrease, as compared to the existing condition scenario, between 0.4°F and 5.7°F (river mile-weighted average[9] decrease of 3.7°F). Daily maximum temperatures decrease between 0.6°F and 7.9°F (river mile-weighted average decrease of 5.8°F) and daily minimum temperatures decrease, between less than 0.1°F to 3.6°F (river mile-weighted average

[9] The river mile-weighted average is calculated with the temperature change per element and length per element.

decrease of 2.0 °F). **Table B-13** presents the results at the temperature logger sites and **Figure B-23** presents the continuous results along Fortine Creek.

Table B-13. Comparison of model results between existing (1) maximum shade scenario (3)

Daily temperature	Source	FRTNC-*						
		*T1	*T2	*T3	*T4	*T5	*T6	*T7
Maximum	Existing	59.5	60.8	62.5	64.1	67.0	68.2	66.1
	Scenario	57.7	54.1	58.7	60.2	59.4	60.4	58.8
	Difference	**-1.8**	**-6.7**	**-3.8**	**-4.0**	**-7.6**	**-7.8**	**-7.3**
Mean	Existing	55.3	53.8	59.2	59.2	61.7	63.0	62.7
	Scenario	54.5	51.0	56.2	56.4	56.9	57.5	57.1
	Difference	**-0.8**	**-2.8**	**-3.0**	**-2.8**	**-4.8**	**-5.5**	**-5.6**
Minimum	Existing	51.5	49.2	59.2	55.1	56.5	58.3	58.7
	Scenario	51.4	48.6	54.1	53.5	54.0	55.0	55.1
	Difference	**-0.1**	**-0.6**	**-5.2**	**-1.6**	**-2.5**	**-3.3**	**-3.6**

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The difference (bolded) is calculated as the existing subtracted from the scenario. Negative results indicate that the scenario yields cooler instream temperatures as compared to the existing condition.

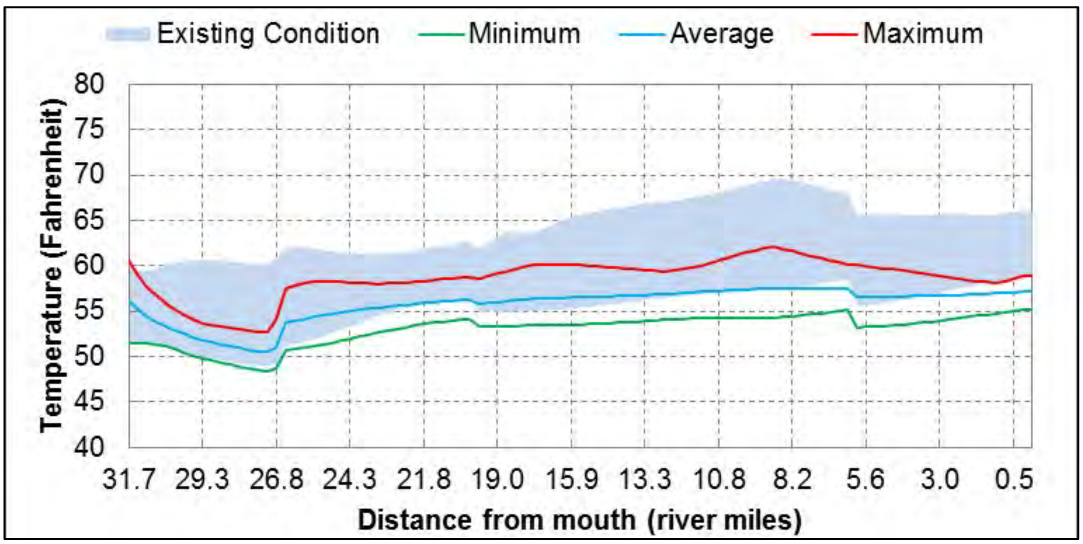


Figure B-23. Comparison of existing model results to Scenario 3: Maximum Shade

B5.3 Scenario 4: Improved Shade

The improved shade scenario consists of the existing condition scenario with a 50-foot buffer along the stream channel where vegetation is allowed to grow to its potential. All vegetation communities, with the exception of hydrophytic shrubs, roads, and railroads, are transformed to medium density trees within 50 feet of the streambanks. Beyond 50 feet, existing condition vegetation remains. This scenario was selected based on areas of reference riparian health in various portions of the watershed and documented removal of much of the overstory trees in the valley (DEQ 2014), as well as the NRCS recommendation for buffers with medium to high shade value (NRCS 2011a; 2011b). Considering the variability in potential vegetation and shade, medium density trees was used as a surrogate to represent the average achievable shade condition; effective shade is the result of topography and vegetative height and density, so the results of this scenario could be achieved by a large combination of vegetation types and densities.

To estimate the change in effective shade under this scenario, the Shade Model was re-run using this vegetation configuration (see **Figure B-24** and **Table B-14** for a comparison of the effective shade under the improved shade scenario with the existing condition scenario). The 50-foot buffer was selected to be generally consistent with Montana's Streamside Management Zone Law, which limits clearcutting within 50 feet of the ordinary high water mark in order to provide large woody debris, stream shading, water filtering effects, and to protect stream channels and banks. This scenario is intended to represent application of *all reasonable land, soil and water conservation practices* relative to shade.

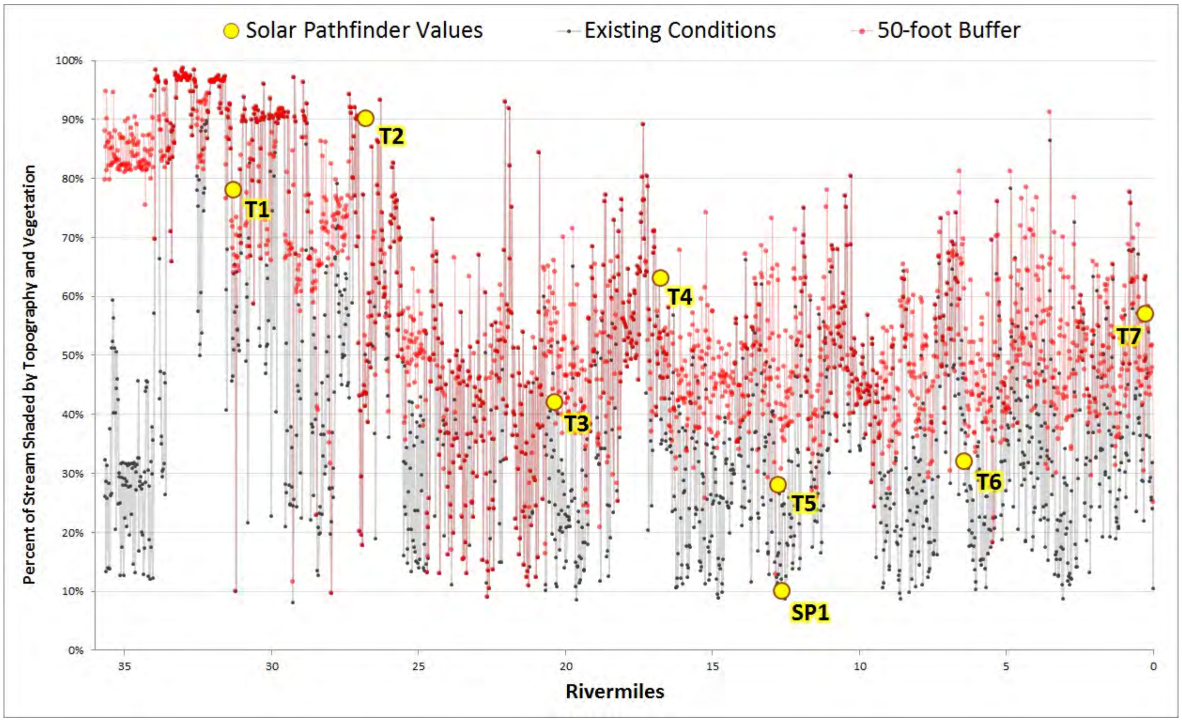


Figure B-24. Longitudinal estimates of effective shade for existing conditions and the improved shade scenario along Fortine Creek

Table B-14. Comparison of effective shade per model segment between existing (1) and improved shade scenario (4)

Model segment	Existing Condition (scenario 1)	Improved Shade (scenario 4)
I (near headwaters)	82%	86%
H	55%	62%
G	47%	61%
F	73%	74%
E	48%	60%
D	52%	61%
C	49%	63%
B	42%	60%
A (mouth)	53%	63%

Improved Shade Scenario Results

Similar to the maximum shade scenario, the improved shade scenario results in cooler water temperatures along all of Fortine Creek. Under this scenario, the daily maximum temperatures range from 57.1°F to 66.3°F. Daily mean temperatures throughout Fortine Creek decrease, as compared to the existing condition scenario, between 0.2°F and 2.3°F (river mile-weighted average[10] decrease of 1.6°F). Daily maximum temperatures decrease between 0.3°F and 3.5°F (river mile-weighted average decrease of 2.6°F). The 0.3°F decrease is the only change less than 1.0°F and occurs at the most upstream element, which represents approximately 0.2 miles of stream. The daily minimum temperatures decrease at all but the uppermost mile of the stream, between less than 0.1°F and 1.3°F (river mile-weighted average decrease of 0.8°F). **Table B-15** presents the results at the temperature logger sites and **Figure B-25** presents the continuous results along Fortine Creek.

Table B-15. Comparison of model results between existing (1) and improved shade scenario (4)

Daily temperature	Source	FRTNC-*						
		*T1	*T2	*T3	*T4	*T5	*T6	*T7
Maximum	Existing	59.5	60.8	62.5	64.1	67.0	68.2	66.1
	Scenario	58.1	58.0	60.5	62.4	63.6	64.8	62.7
	Difference	**-1.4**	**-2.7**	**-2.0**	**-1.7**	**-3.4**	**-3.4**	**-3.4**
Mean	Existing	55.3	53.8	59.2	59.2	61.7	63.0	62.7
	Scenario	55.0	52.7	57.8	57.9	59.6	60.8	60.4
	Difference	**-0.3**	**-1.0**	**-1.4**	**-1.3**	**-2.1**	**-2.2**	**-2.3**
Minimum	Existing	51.5	49.2	59.2	55.1	56.5	58.3	58.7
	Scenario	51.6	49.0	55.4	54.3	55.4	57.1	57.4
	Difference	**0.1**	**-0.2**	**-3.9**	**-0.8**	**-1.1**	**-1.2**	**-1.3**

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The difference (bolded) is calculated as the existing subtracted from the scenario. Negative results indicate that the scenario yields cooler instream temperatures as compared to the existing condition and positive results indicate the scenario yields warmer instream temperatures as compared to the existing condition.

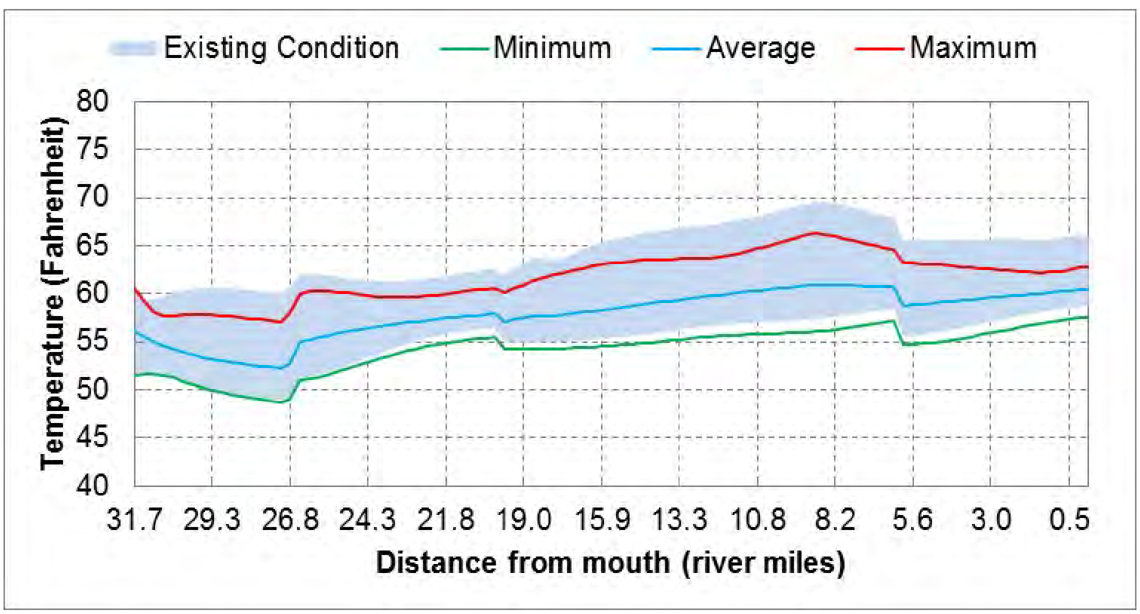


Figure B-25. Comparison of existing model results to Scenario 4: Improved Shade

[10] The river mile-weighted average is calculated with the temperature change per element and length per element.

B5.4 Scenario 5: Improved Water Management

In this scenario, the point source abstractions representing the withdrawals (see **Table B-6** for the withdrawals) in the QUAL2K model are reduced by 15 percent. The 0.94 cfs previously withdrawn daily (i.e., 15% of 6.24cfs) is now allowed to flow down Fortine Creek. This improvement is based on the low end of what research has shown to be achievable for typical improvements to irrigation efficiency (Economic Research Station, 1997; Negri et al., 1989). This scenario is intended to represent application of *all reasonable land, soil, and water conservation practices* relative to water use.

Improved Water Management Scenario Results

As indicated by the limited temperature changes in the no irrigation scenario (i.e., Scenario 2), the model is much less sensitive to increases in streamflow associated with water use than in riparian shade. This scenario results in very minor changes in temperature. The daily maximum temperatures are almost identical to the existing condition scenario with modeled differences typically only at the hundredths place; they range from 59.4°F to 69.6°F. Daily mean temperatures in Fortine Creek change as compared to the existing condition scenario from a decrease of 0.02°F to an increase of 0.03°F (river mile-weighted average[11] change is 0.0°F). Daily maximum temperatures change from a decrease of 0.06°F to an increase of 0.02°F (river mile-weighted average decrease of 0.02°F). The largest decrease in daily maximum temperatures occurs between loggers FRTNC-T5 and FRTNC-T6 near Brimstone Creek and river mile 9.0, which is where the largest withdrawal is located. The change in daily minimum temperatures ranges from 0.0°F to an increase of 0.06°F (river mile-weighted average increase of 0.01°F). **Table B-16** presents the results at the temperature logger sites and **Figure B-26** presents the continuous results along Fortine Creek.

Table B-16. Comparison of model results between existing (1) and improved water management scenario (5)

Daily temperature	Source	FRTNC-*						
		*T1	*T2	*T3	*T4	*T5	*T6	*T7
Maximum	Existing	59.5	60.8	62.5	64.1	67.0	68.2	66.1
	Scenario	59.5	60.8	62.5	64.1	67.0	68.1	66.1
	Difference	**0**	**0**	**-0.001**	**-0.01**	**-0.02**	**-0.02**	**-0.04**
Mean	Existing	55.3	53.8	59.2	59.2	61.7	63.0	62.7
	Scenario	55.3	53.8	59.2	59.2	61.7	63.0	62.7
	Difference	**0**	**0**	**-0.0004**	**0.001**	**-0.01**	**-0.01**	**-0.002**
Minimum	Existing	51.5	49.2	59.2	55.1	56.5	58.3	58.7
	Scenario	51.5	49.2	56.3	55.1	56.5	58.3	58.7
	Difference	**0**	**0**	**-2.9**	**0.01**	**0.003**	**-0.0004**	**0.03**

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The difference (bolded) is calculated as the existing subtracted from the scenario. Negative results indicate that the scenario yields cooler instream temperatures as compared to the existing condition and positive results indicate the scenario yields warmer instream temperatures as compared to the existing condition.

[11] The river mile-weighted average is calculated with the temperature change per element and length per element.

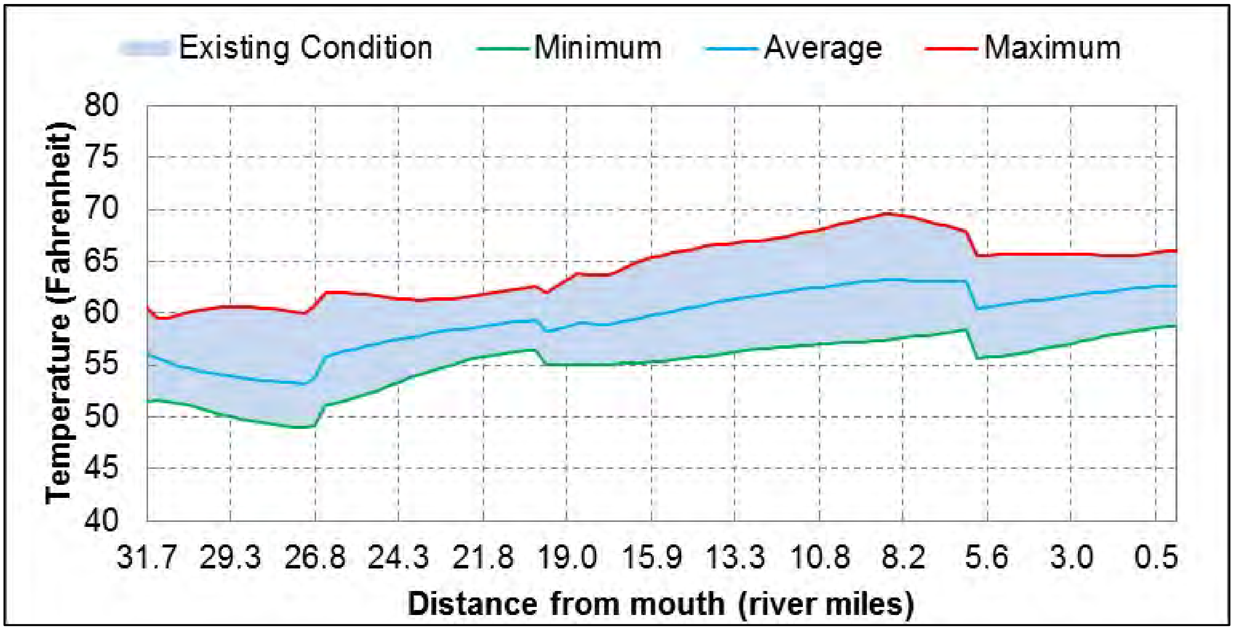


Figure B-26. Comparison of existing model results to Scenario 5: Improved Water Management

B5.5 Scenario 6: Naturally Occurring Condition

The naturally occurring scenario combines scenarios 4 and 5 (i.e., improved shade and improved water management, respectively) and is intended to represent application of *all reasonable land, soil, and water conservation practices* relative to the temperature impairment.

This scenario results in cooler mean and maximum water temperatures along all of Fortine Creek and indicates the maximum naturally occurring temperature ranges from 57.1°F in the upper watershed to 66.3°F near the mouth. Daily mean temperatures in Fortine Creek decrease, as compared to the existing condition scenario, between 0.2°F and 2.3°F (river mile-weighted average[12] decrease of 1.6°F). Daily maximum temperatures decrease between 0.3°F and 3.5°F (river mile-weighted average decrease of 2.6°F). The 0.3°F decrease is the only change less than 1.0°F and occurs at the most upstream element, which represents approximately 0.2 miles of stream (see white dot on **Figure B-28**). Daily minimum temperatures decrease at all but the upper mile between less than 0.1°F and 1.3°F (river mile-weighted average decrease of 0.8°F). **Table B-17** presents the results at the temperature logger sites and **Figure B-27** presents the continuous results along Fortine Creek. Largely driven by shade improvements, the largest decreases in temperature that can be achieved under the naturally occurring condition relative to existing conditions is in the upper watershed (upstream of Swamp Creek) and from downstream of site FRTNC-T5 near Trego to the mouth (**Figure B-28**). The maximum decrease is near Brimstone Creek and river mile 8, which is between loggers FRTNC-T5 and FRTNC-T6.

Table B-17. Comparison of model results between existing (1) and naturally occurring scenario (6)

Daily temperature	Source	FRTNC-*						
		*T1	*T2	*T3	*T4	*T5	*T6	*T7
Maximum	Existing	59.5	60.8	62.5	64.1	67.0	68.2	66.1
	Scenario	58.1	58.0	60.5	62.4	63.6	64.8	62.7
	Difference	**-1.4**	**-2.8**	**-2.0**	**-1.7**	**-3.4**	**-3.4**	**-3.4**

[12] The river mile-weighted average is calculated with the temperature change per element and length per element.

Table B-17. Comparison of model results between existing (1) and naturally occurring scenario (6)

Daily temperature	Source	FRTNC-*						
		***T1**	***T2**	***T3**	***T4**	***T5**	***T6**	***T7**
Mean	Existing	55.3	53.8	59.2	59.2	61.7	63.0	62.7
	Scenario	55.0	52.7	57.8	57.9	59.6	60.8	60.4
	Difference	**-0.3**	**-1.0**	**-1.4**	**-1.3**	**-2.1**	**-2.3**	**-2.3**
Minimum	Existing	51.5	49.2	59.2	55.1	56.5	58.3	58.7
	Scenario	51.6	49.0	55.4	54.3	55.4	57.1	57.5
	Difference	**0.1**	**-0.2**	**-3.9**	**-0.8**	**-1.1**	**-1.2**	**-1.2**

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The difference (bolded) is calculated as the existing subtracted from the scenario. Negative results indicate that the scenario yields cooler instream temperatures as compared to the existing condition and positive results indicate the scenario yields warmer instream temperatures as compared to the existing condition.

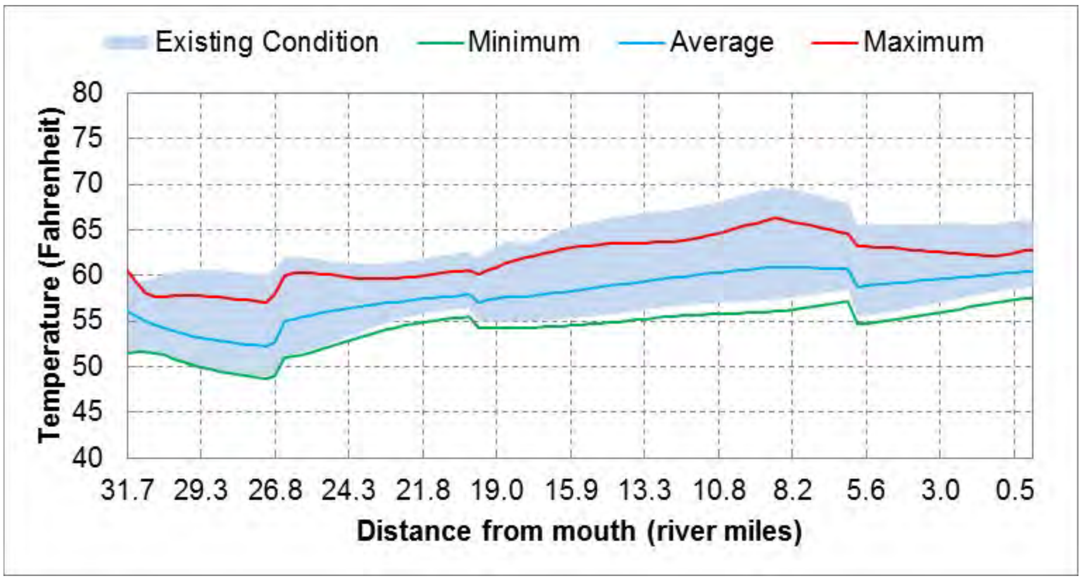


Figure B-27. Comparison of existing model results to Scenario 6: Naturally Occurring Condition

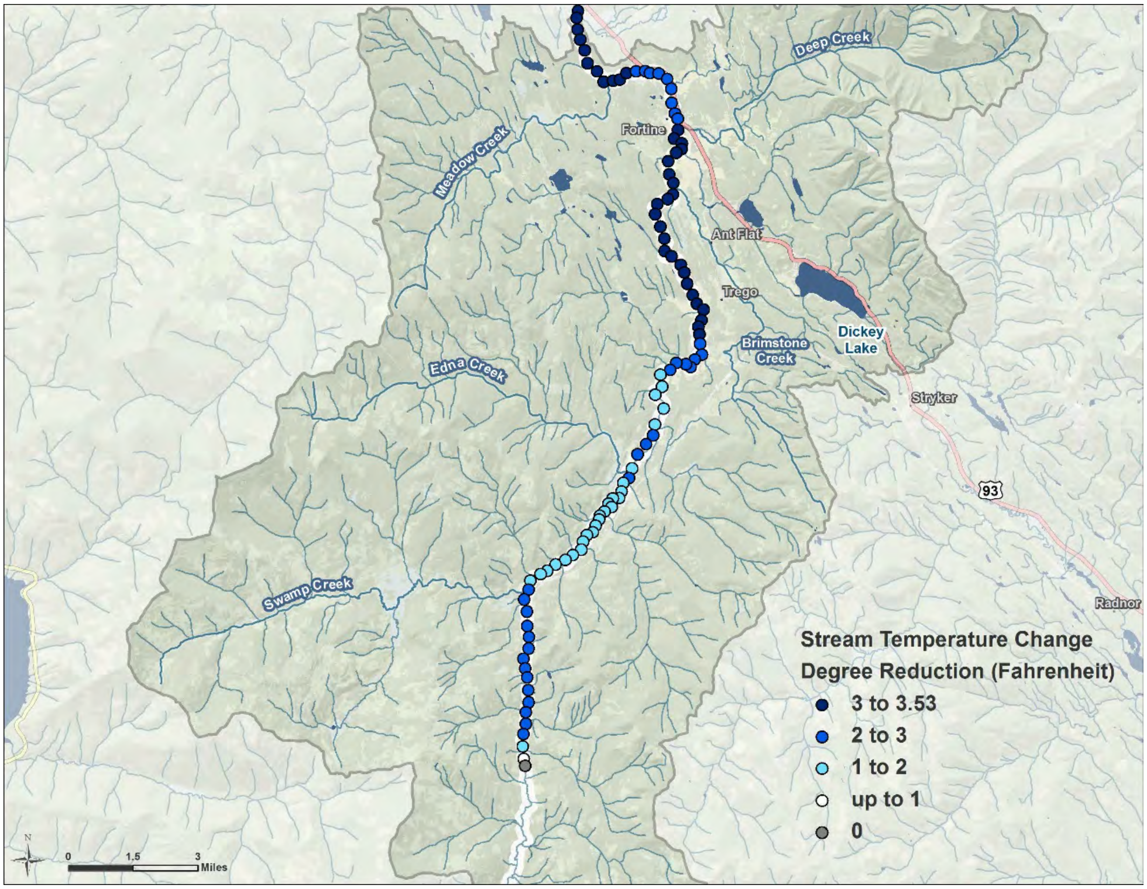


Figure B-28. Temperature reductions that can be obtained under naturally occurring conditions (relative to the baseline scenario)

B5.6 Scenario 7: Low Flow Existing Condition (Alternative Baseline)

Because streamflow conditions in 2012 were well above average (87th percentile flow, see **Figure B-8**) and a goal of the model is to evaluate stream temperatures when aquatic life are most likely to be stressed, Scenario 7 was developed to represent low flow baseline conditions. This scenario uses existing shade and climate conditions (which were applied in the existing conditions scenario (#1)) but inflow to Fortine Creek was reduced by 56 percent, which is estimated to be the 25th percentile flow. This reduction is based upon the low flow analysis for August 10 at the nearby Tobacco River USGS gage 12301300 (as discussed in **Section B2.3.4**). The August 10, 2012 flow of 199 cfs was reduced by 56 percent to 88 cfs, which is the 25th percentile flow for August 10 at gage 12301300 across its period of record (WY 1959-2012). Therefore, no measurements were used directly from the stream gage but instead its long term flow record was used to estimate the reduction to apply to measured flows in Fortine Creek.

Since the amount of water in the stream channel affects its ability to buffer incoming solar radiation, and less water will heat up faster, the alternative baseline scenario results in warmer water temperatures along all of Fortine Creek relative to the existing conditions (Scenario 1). The daily maximum temperatures range from 60.5°F to 77.5°F. Daily mean temperatures throughout Fortine Creek increase, as compared to the existing condition scenario, between 0.1°F and 4.4°F (river mile-weighted average[13] increase of 2.8°F). Daily maximum temperatures increase between 1.2°F and 8.0°F (river mile-weighted average increase of 5.1°F). Daily minimum temperatures decrease in the upper five miles by up to 1.3°F but increase throughout the rest of Fortine Creek from 0.2°F and 2.2°F (river mile-weighted average increase of 1.1°F). **Table B-18** presents the results at the temperature logger sites and **Figure B-29** presents the continuous results along Fortine Creek.

Table B-18. Comparison of model results between existing (1) and low flow existing baseline scenario (7)

Daily temperature	Source	FRTNC-*						
		*T1	*T2	*T3	*T4	*T5	*T6	*T7
Maximum	Existing	59.5	60.8	62.5	64.1	67.0	68.2	66.1
	Scenario	62.2	64.4	67.1	69.3	73.5	73.5	72.9
	Difference	**2.7**	**3.6**	**4.6**	**5.2**	**6.5**	**5.3**	**6.8**
Mean	Existing	55.3	53.8	59.2	59.2	61.7	63.0	62.7
	Scenario	55.5	55.2	62.4	61.9	65.9	66.6	66.3
	Difference	**0.3**	**1.4**	**3.1**	**2.8**	**4.2**	**3.5**	**3.6**
Minimum	Existing	51.5	49.2	59.2	55.1	56.5	58.3	58.7
	Scenario	51.4	48.8	58.0	56.2	58.7	60.2	60.0
	Difference	**-0.1**	**-0.4**	**-1.2**	**1.1**	**2.2**	**1.9**	**1.3**

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The difference (bolded) is calculated as the existing subtracted from the scenario. Negative results indicate that the scenario yields cooler instream temperatures as compared to the existing condition and positive results indicate the scenario yields warmer instream temperatures as compared to the existing condition.

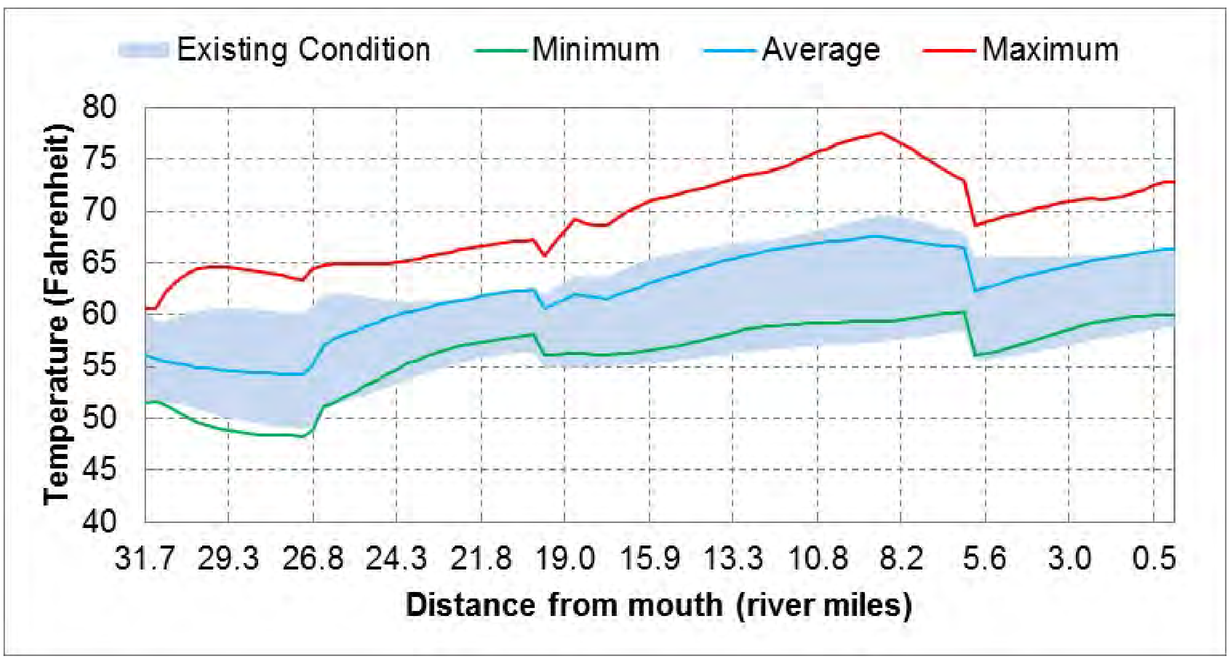


Figure B-29. Comparison of existing model results to Scenario 7: Low flow Existing Condition

[13] The river mile-weighted average is calculated with the temperature change per element and length per element.

B5.7 Scenario 8: Naturally Occurring Low Flow Condition

The naturally occurring low flow scenario combines scenarios 6 and 7 (i.e., naturally occurring and low flow existing conditions, respectively) and is intended to represent application of all reasonable land, soil, and water conservation practices during low flow conditions.

Similar to Scenario 6, the naturally occurring condition, this scenario results in cooler water temperatures along Fortine Creek. The decreases in the mean, maximum, and minimum temperatures under this scenario are all greater in magnitude than the naturally occurring condition relative to the existing baseline (i.e., Scenario 6 to 1). This means that under lower streamflows than measured in 2012, improvements in shade and streamflow have a more pronounced effect. Under this scenario, the daily maximum temperatures range from 59.0°F to 73.1°F. Daily mean temperatures throughout Fortine Creek decrease, as compared to the low flow existing condition scenario (scenario 7), between 0.3°F and 3.4°F (river mile-weighted average[14] decrease of 2.4°F). Daily maximum temperatures decrease between 1.7°F and 5.4°F (river mile-weighted average decrease of 3.9°F) and daily minimum temperatures decrease, at all but the upper 0.5 miles, between 0.1°F and 2.0°F (river mile-weighted average decrease of 1.3°F). **Table B-19** presents the results at the temperature logger sites and **Figure B-30** presents the continuous results along Fortine Creek.

Table B-19. Comparison of model results between low flow existing (7) and naturally occurring low flow scenario (8)

Daily temperature	Source	FRTNC-*						
		*T1	*T2	*T3	*T4	*T5	*T6	*T7
Maximum	Low flow existing	62.2	64.4	67.1	69.3	73.5	73.5	72.9
	Scenario	59.7	60.6	64.2	66.9	68.4	68.5	68.3
	Difference	**-2.5**	**-3.8**	**-2.9**	**-2.6**	**-5.1**	**-5.0**	**-4.6**
Mean	Low flow existing	55.5	55.2	62.4	61.9	65.9	66.6	66.3
	Scenario	54.9	53.4	60.2	60.1	62.8	63.5	62.9
	Difference	**-0.6**	**-1.8**	**-2.1**	**-1.8**	**-3.1**	**-3.1**	**-3.4**
Minimum	Low flow existing	51.4	48.8	58.0	56.2	58.7	60.2	60.0
	Scenario	51.4	48.1	56.5	55.1	57.0	58.4	58.0
	Difference	**0.01**	**-0.74**	**-1.5**	**-1.2**	**-1.7**	**-1.8**	**-2.0**

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The difference (bolded) is calculated as the existing subtracted from the scenario. Negative results indicate that the scenario yields cooler instream temperatures as compared to the existing condition and positive results indicate the scenario yields warmer instream temperatures as compared to the existing condition.

[14] The river mile-weighted average is calculated with the temperature change per element and length per element.

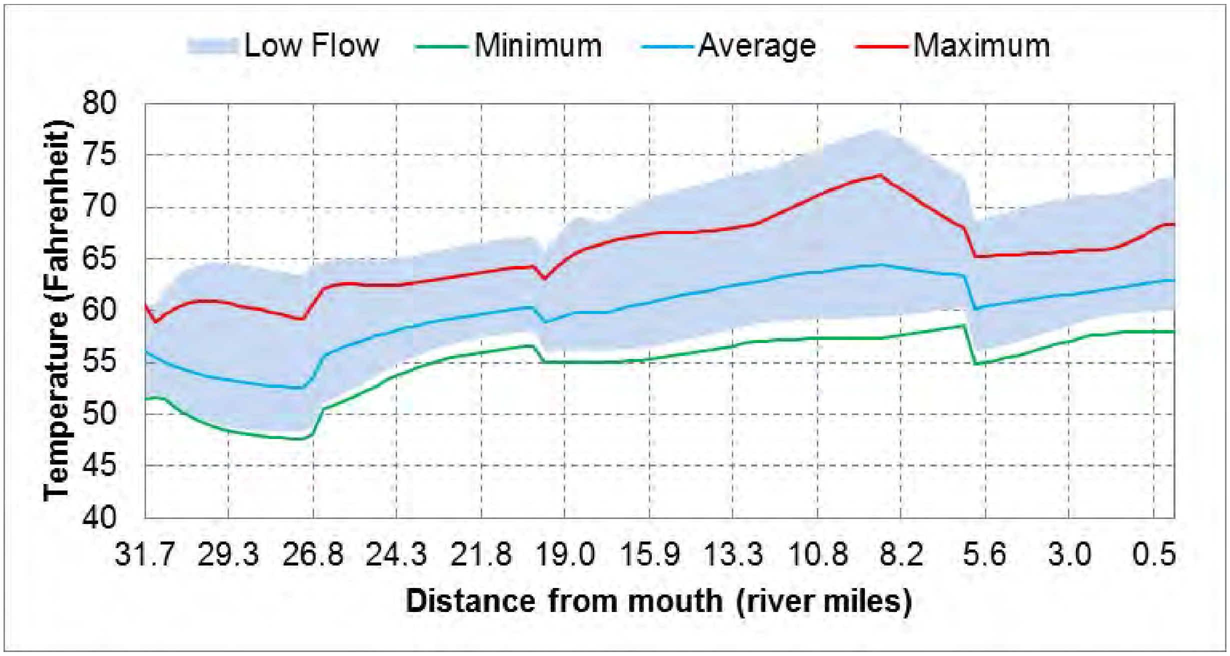


Figure B-30. Comparison of low flow existing model results to Scenario 8: Naturally occurring low flow

B6.0 Scenario Results and Discussion

Model scenarios were developed and evaluated for two primary purposes: to assess model sensitivity and to simulate potential temperature changes associated with reasonable application of best management practices. The model sensitivity scenarios (Scenarios 2 and 3) are discussed in the following section (**B7.0**) but are not summarized here since they were not management scenarios developed to assist with TMDL development.

Generally, scenarios representing increased shading (i.e., scenarios 4, 6, and 8) showed decreased water temperatures throughout Fortine Creek, including at all of the logger sites, as compared to the existing conditions. Scenarios representing alterations of water use (scenarios 5, 6, and 8) showed much smaller changes in water temperatures, resulting in water temperatures under the improved shade scenario (#4) essentially matching temperatures under the naturally occurring scenario (#6). The low flow baseline scenario (# 7) caused a fairly large increase in maximum temperatures throughout Fortine Creek relative to the existing condition, and also resulted in shade improvements under the low flow naturally occurring scenario (#8) having a much greater effect than those under the naturally occurring scenario. **Figures B-31** and **B-32** summarize all of the management scenario results in maximum daily temperature and the temperature difference relative to the baseline, while **Figures B-33** and **B-34** summarize the maximum daily temperature for just the existing conditions and naturally occurring scenario results and the temperature difference between those scenarios.

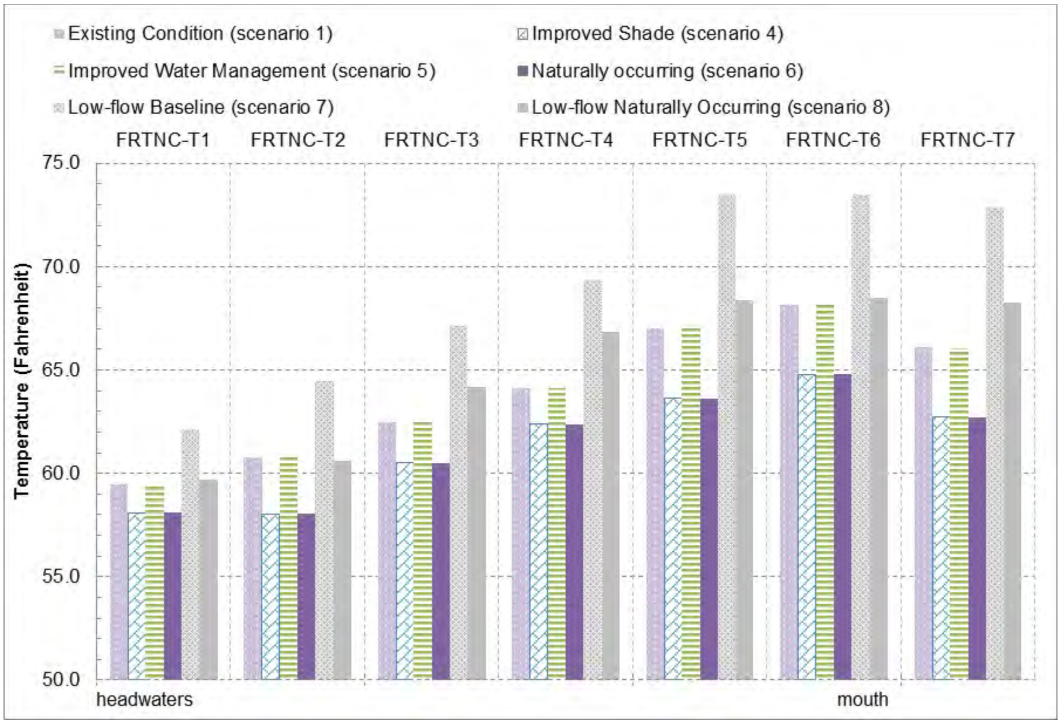


Figure B-31. Maximum daily water temperature along Fortine for each scenario

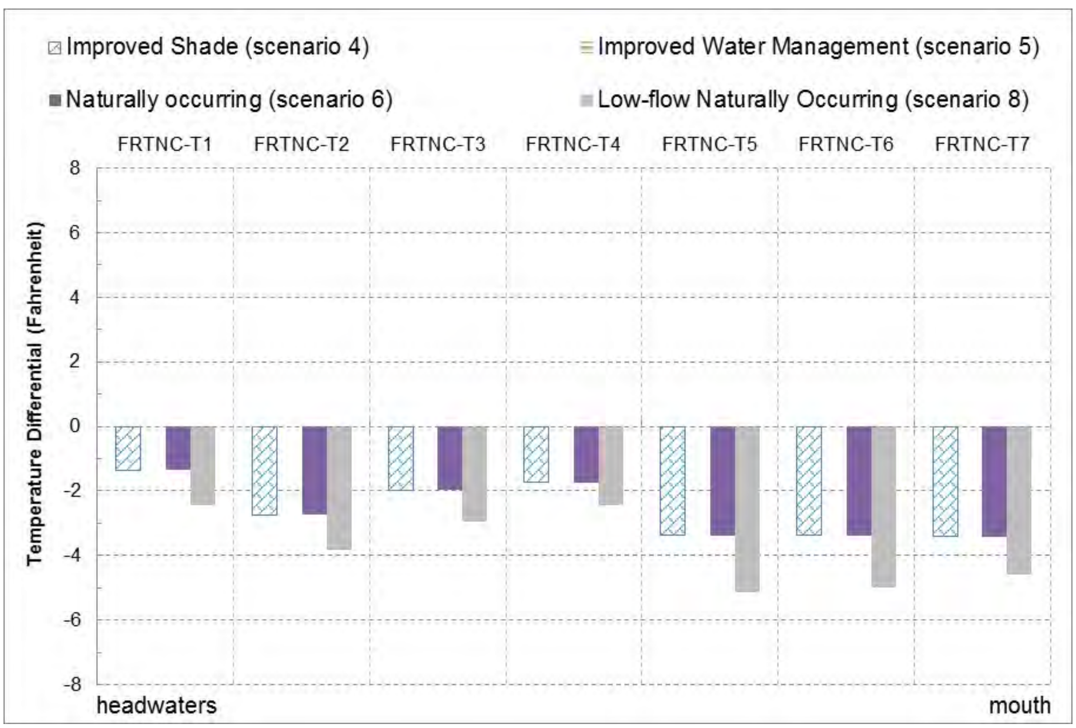


Figure B-32. Difference in simulated maximum daily temperatures relative to the existing condition scenario, except for Scenario 8 which is relative to the low flow existing condition

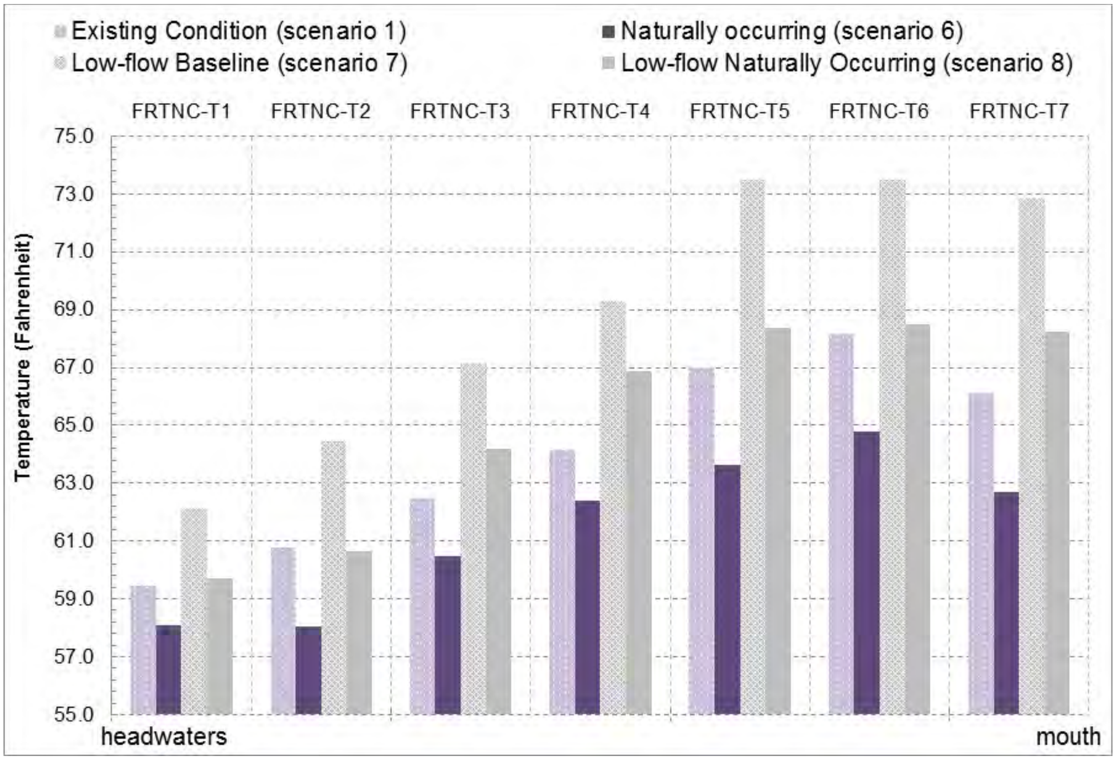


Figure B-33. Maximum daily temperature along Fortine Creek for both baseline scenarios (1 and 7) and their respective naturally occurring scenarios (6 and 8)

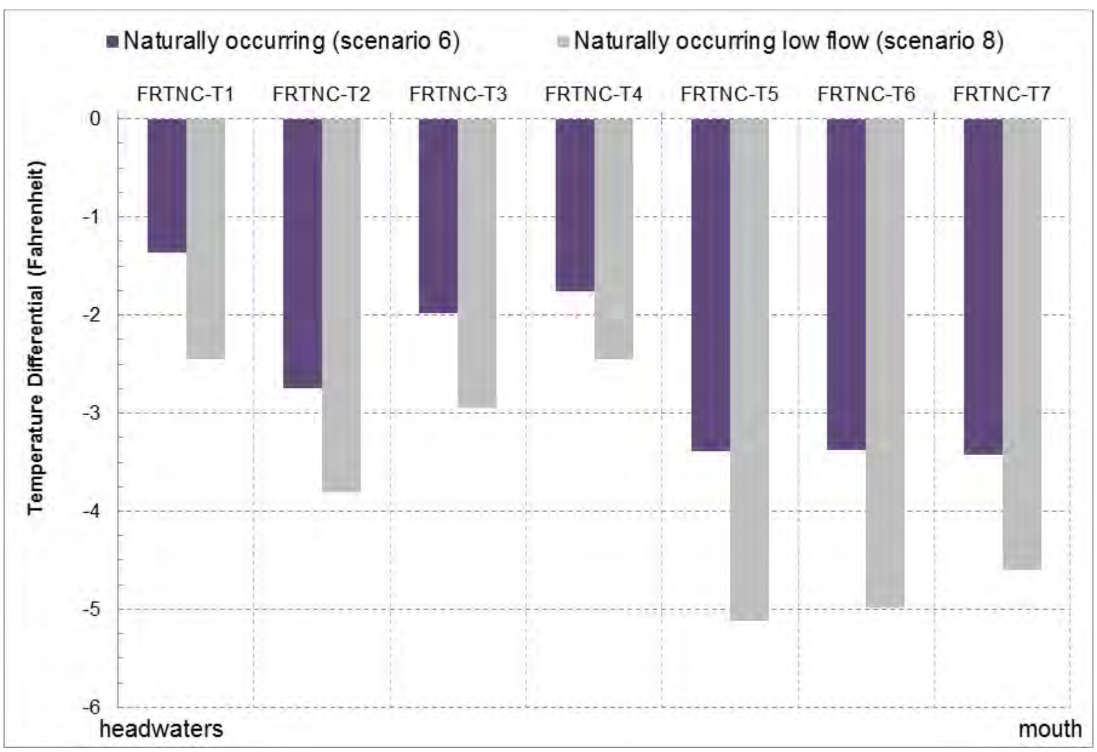


Figure B-34. Temperature difference between both naturally occurring scenarios (6 and 8) and their respective baseline scenarios (as simulated maximum daily water temperatures)

B7.0 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 2012). As discussed in the QAPP (Tetra Tech 2012), the QUAL2K model code has a long history of testing and application, so outright errors in the coding of the temperature model is unlikely. The Shade Model has also been widely used so a similar sentiment exists. A potentially significant amount of the overall prediction uncertainty is due to uncertainty in the observed data used for model setup, calibration, and validation.

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

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

- Field measurements collected at discrete locations were representative of segments of Fortine Creek. Thus, segments were homogenous (as there were not sufficient channel geometry data to develop a more detailed model).
- Flow was assumed uniform within each reach using Manning's equation and a unique Manning's roughness coefficient was selected for each reach. Thus, segments were homogenous (as there were not sufficient depth, flow, and channel geometry data to develop a more detailed model).
- Stream meander and hyporheic flow paths (both of which may affect depth-velocity and temperature) were sufficiently represented during the estimation of various parameters (e.g., stream slope, channel geometry, and Manning's roughness coefficient) for each segment.
- Weather conditions at the Eureka RAWS, which were elevation-corrected, were representative of local weather conditions along Fortine Creek.
- Shade Model results were representative of riparian shading along segments of Fortine Creek. Riparian vegetation communities were identified from visual interpretation of aerial imagery and density was estimated using the NLCD and best professional judgment.
- All of the cropland associated with water rights is fully irrigated. No field measurements of irrigation withdrawals or returns were available.
- Groundwater temperatures were based upon GWIC records for nearby wells.

These sources of uncertainty are largely unavoidable, but do not invalidate the use of the model for decision purposes. Instead, as specified in the QAPP (Tetra Tech 2012, p. 18), the performance of the QUAL2K temperature models is evaluated (in lieu of using numeric acceptance criteria) and model performance guides the role of the model results in answering the principal study questions.

The most widely applied parameter uncertainty analysis approach for complex simulation models is sensitivity analysis; however, sensitivity analysis is limited in its ability to evaluate nonlinear interactions among multiple parameters. Model sensitivity of shade and water withdrawals (i.e., the key thermal mechanisms and stressors of the principal study questions [Tetra Tech 2012, p.10]) is presented below.

B7.1 Sensitivity

Stream temperatures appear to be sensitive to larger changes in flow. Existing instream temperatures increased substantially (i.e., an average of 5°F and maximum of 8°F) when stream inflows were reduced by 56 percent to represent low flow conditions (scenario 7). However, instream temperatures did not vary much (i.e., maximum decrease of 0.4°F and an average decrease of 0.1°F) when water withdrawals were eliminated (scenario 2). The total summation of water withdrawals was 6.2 cfs, which is approximately 11 percent of the 59.3 cfs monitored near the mouth of Fortine Creek on August 10, 2012.

Stream temperatures also appear to be sensitive to changes in shade provided by riparian vegetation. Although it is unlikely that the riparian corridor was ever dominated by dense tree cover, simulating such a scenario suggests that instream temperatures are heavily influenced by shade. Increasing all vegetation communities (except hydrophytic shrubs and ignoring water, roads, and railroads) to high density forest resulted in significantly cooler water temperatures; the river-mile weighted average of daily maximum temperatures was a decrease of 5.8°F.

B7.2 Application of Best Management Practices

Increases in streamflow with changes in irrigation practices (which was simulated within the model by a 15% increase in streamflow) may be feasible, however, the model indicates negligible improvements in water temperature would result. However, providing a 50-feet buffer dominated by medium density vegetation along the stream corridor is considered generally feasible along most of Fortine Creek and would greatly improve stream temperatures. Exceptions are areas where roads, railroads and structures already exist. The naturally occurring scenario combines these two concepts and represents the implementation of *all reasonable land and soil water conservation practices* (scenario 6). Both the naturally occurring scenario and improved shade scenario suggest that Fortine Creek could be up to 3.5°F cooler than the existing condition. As shown in **Figure B-28**, the magnitude of difference between these scenarios and the existing condition scenario varies spatially. Based on the model results, this is largely due to variations in existing shade. The shade deficit between the naturally occurring and existing condition scenarios is shown in **Figure B-35**. Note, the low flow model scenarios indicate that during years with a lower amount of streamflow, shade improvements would have an even greater effect and could decrease temperatures by up to 5.4°F.

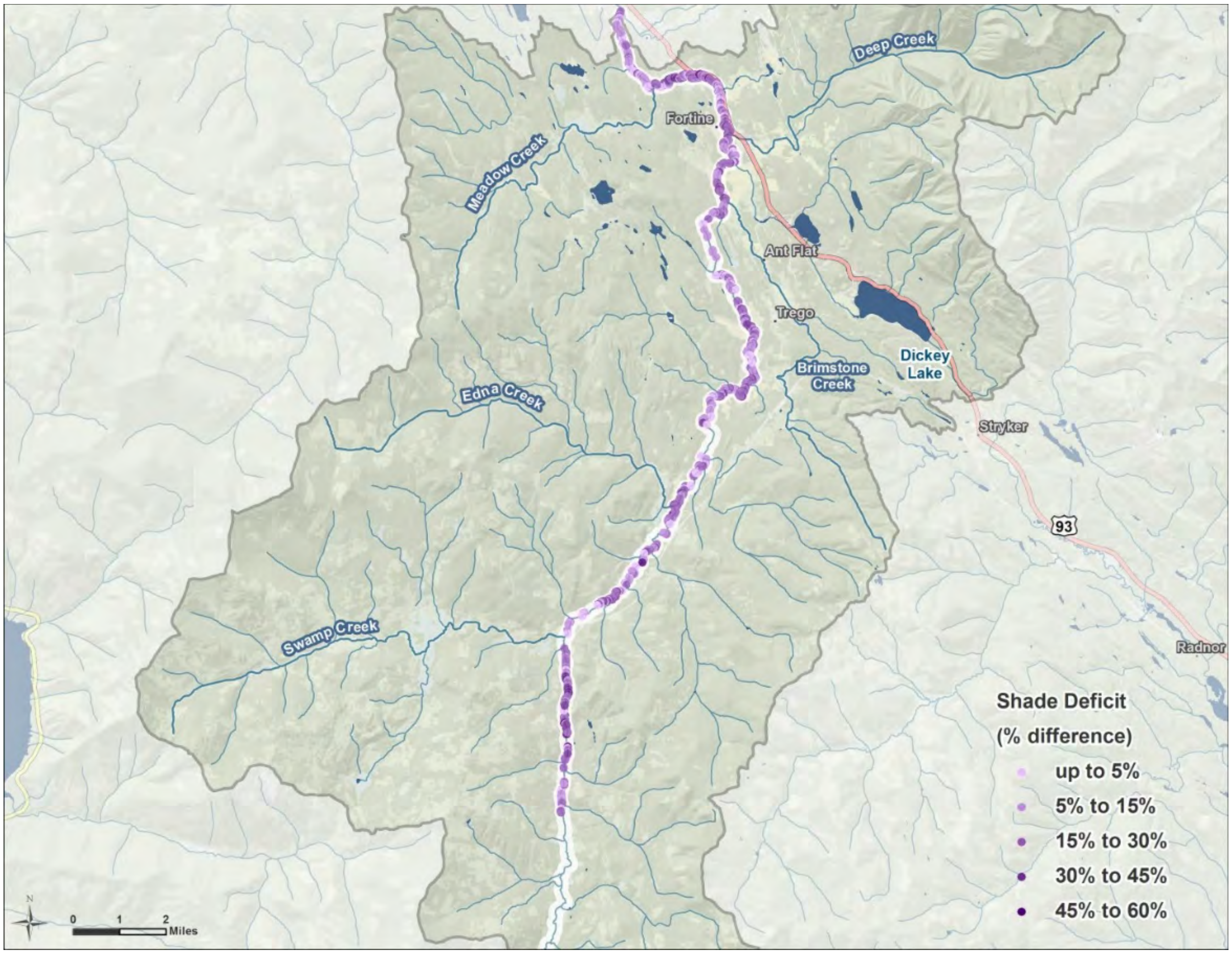


Figure B-35. Shade deficit of the existing condition from the naturally occurring scenario

B8.0 Model Use and Limitations

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

1. What is the sensitivity of 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 principal study question can be answered using the calibrated and validated QUAL2K model for Fortine Creek. As previously discussed, Fortine Creek is sensitive to shade. The second principal study questions can be answered using the calibrated QUAL2K model and the scenarios developed to assess shade. Increasing riparian shading will decrease instream temperatures; however, there is uncertainty in the magnitude of temperature reduction necessary to achieve the temperature standard caused by uncertainty in the Shade Model results and QUAL2K model results. While a “good” model calibration was achieved, the overall AME for the maximum daily temperature was 1.3°F.

Montana's temperature standard as applied to Fortine Creek is limited to an increase of 1.0°F. The model results, therefore, should be used with caution relative to the second primary question. However, in spite of the uncertainty, the magnitude of difference between the maximum daily temperatures under existing condition scenarios and naturally occurring scenarios (as well as the shade improvement scenario) is greater than the AME for all but a 0.2 mile section near the headwaters of Fortine Creek (**Figure B-36**). The model results indicate that on average[15], a reduction of 2.6°F (range: 1.4° F to 3.5° F) in maximum daily temperatures is necessary to achieve the temperature standard in Fortine Creek.

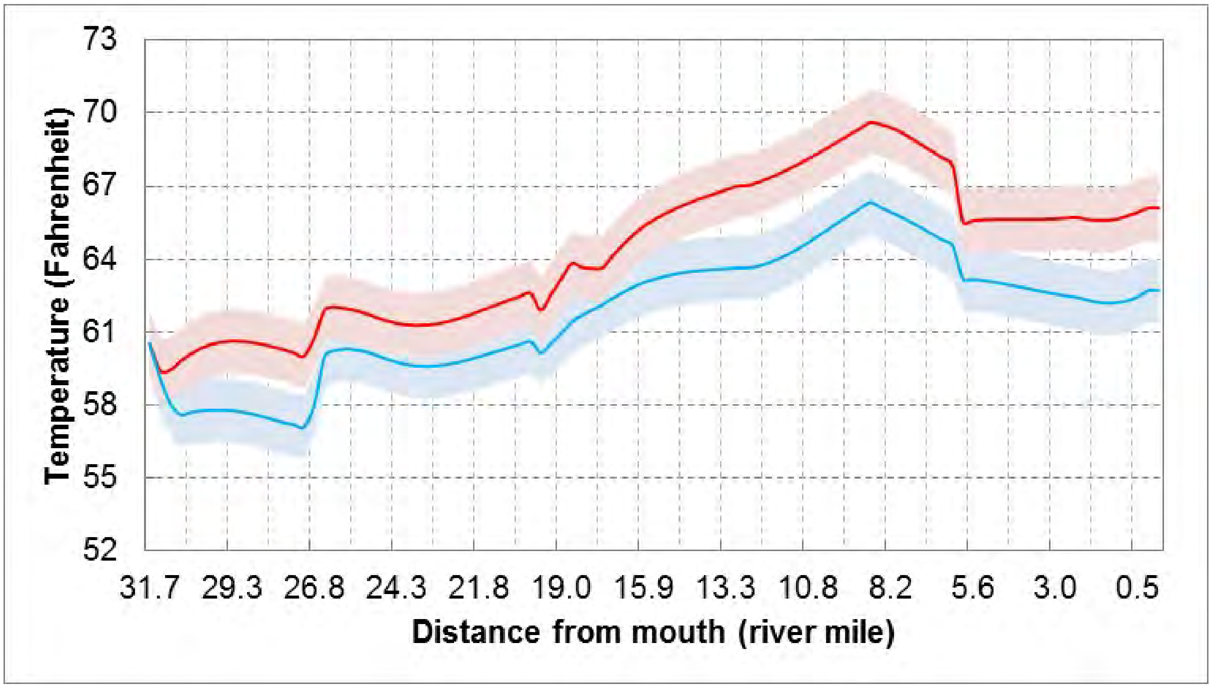


Figure B-36. Simulated daily maximum water temperatures from the existing condition (red; scenario 1) and naturally occurring condition scenario (blue; scenario 6).

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

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ATTACHMENT B-1

This attachment contains instantaneous flow measurements that were not collected as part of this project but were used to evaluate the water balance in Fortine Creek and to develop a pre-modeling understanding of the hydrology. Recent flow measurements that were used include those collected by DEQ in 2003, 2007, 2008 and 2012 (**Tables B1-1** and **B1-2**) and by the USFS for Deep Creek in 2011 (**Table B1-3**) and Edna and Fortine creeks in 2012 (**Table B1-4**).

Table B1-1. DEQ instantaneous flow measurements (cfs) from 2003 and 2012

Date	K01SWMPC02 [a]	K01LIMEC03 [b]	K01LIMEC04 [b]	K01LIMEC01 [b]	K01DEEPC01 [c]
August 12, 2003	1.5*	--	2.64	--	--
August 13, 2003	--	--	1.57	--	--
July 12, 2012	--	0.16	1.01	--	--
August 23, 2012	--	0.11	--	4.8	--
September 19, 2012	--	--	--	2.05	6*

Notes: An asterisk (*) indicates an estimated value.
[a]. Site is located on Swamp Creek, a tributary to Fortine Creek.
[b.] Site is located on Lime Creek, a tributary to Fortine Creek.
[c.] Site is located on Deep Creek, a tributary to Fortine Creek.

Table B1-2. DEQ instantaneous flow measurements (cfs) from 2007 and 2008

Date	TOBACCO-NUT2 [a]	TOBACCO-NUT1	TOBACCO-NUT3 [b]	TOBACCO-LIME2 [c]	TOBACCO-NUT4 [c]	TOBACCO-NUT5	TOBACCO-NUT6	TOBACCO-NUT7 [d]	TOBACCO-NUT15 [e]	TOBACCO-NUT8
September 11-13, 2007	1.17	0.33	2.76	--	--	7.19	3.87	4.73	--	10.59
October 15-17, 2007	1.67	0.5	2.9	--	--	6.43	8.58	5.46	--	17.57
June 3-5, 2008	27.09	32.08	20.19	0.52	1.98	93.46	107	83.87	1.39	--
August 5-7, 2008	2.17	0.85	2.98	0.63	0.59	9.04	8.7	9.39	0*	19.55
October 1-7, 2008	1.48	0.44	2.06	0.45*	0.62	5.66	6.5	5.03	0*	13.86

Notes: An asterisk (*) indicates an estimated value.
[a.] Site is located on Swamp Creek, a tributary to Fortine Creek.
[b.] Site is located on Edna Creek, a tributary to Fortine Creek.
[c.] Site is located on Lime Creek, a tributary to Fortine Creek.
[d.] Site is located on Deep Creek, a tributary to Fortine Creek.
[e.] Site is located on Meadow Creek, a tributary to Fortine Creek.

Table B1-3. USFS instantaneous flow measurements from Deep Creek

Date	Stage (feet)	Discharge (cfs)
May 23, 2011	1.01	70.03
June 1, 2011	0.95	53.35
June 22, 2011	1.36	77.19
June 24, 2011	1.39	79.86
July 8, 2011	1.36	77.20

Table B1-4. USFS instantaneous flow measurements from Edna and Fortine creeks

Date	Edna Creek		Fortine Creek	
	Stage (feet)	Discharge (cfs)	Stage (feet)	Discharge (cfs)
4/20/2012	1.65	39.9	3.02	170.1
4/26/2012	2.12	98.8	3.13	178.1
5/10/2012	1.87	62.7	2.58	138.2
5/18/2012	1.76	50.4	2.41	125.9
5/23/2012	1.69	43.5	2.29	117.2
6/7/2012	1.59	34.9	2.39	124.5
6/13/2012	1.52	29.6	2.13	105.6
6/28/2012	1.55	31.8	2.85	157.8
7/10/2012	1.33	18.3	1.19	37.6
7/23/2012	1.34	18.8	0.98	22.4
9/11/2012	1.12	9.8	0.71	2.8

ATTACHMENT B-2

This attachment summarizes inputs and results in tabular form for the Fortine Creek QUAL2K Model developed for this project.

Table B2-1. Model input parameters

Model parameter	Source of input
Month	August 10, 2012. Warm day without rain during EPA and USFS temperature logger deployment when synoptic flows were monitored.
Day	
Year	
Local time hours to UTC	Calculated using time zone of sample locations
Daylight savings time	Enabled
Calculation step	Estimated according to monitored instream velocities
Final time	

Table B2-2. Headwaters input parameters

Model parameter	Source of input
Flow rate	Observed at FRTNC-T1 on August 10, 2012
Elevation	Calculated with GIS
Channel slope	
Manning roughness coefficient (n)	Assumed to be equivalent to Manning's n calculated for segment I
Bottom width	Assumed wetted with at site FRTNC-T1 (measured on September 12-13) was equivalent to bottom width
Side slope 1	Assumed sides were equivalent to 1.
Side slope 2	
Hourly water temperatures	Observed at FRTNC-T1 on August 10, 2012

Table B2-3. Model segment input parameters

Model parameter	Source of input
Location	
Upstream location	Calculated with GIS
Downstream location	
Upstream elevation	
Downstream elevation	
Downstream latitude	
Downstream longitude	
Weather	
Hourly air temperatures	Estimated from observations at Eureka RAWS, corrected for elevation
Hourly dew point temperatures	
Hourly wind speed	Estimated from observations at Eureka RAWS, corrected for sensor height
Hourly cloud cover	Estimated from observations at Kalispell Glacier Park International Airport
Hourly effective shade	Calculated with Shade3.0.xls as segment medians
Manning	
Location	Calculated with GIS
Manning roughness coefficient (n)	Calculated using Cowan (1956) and Chow (1959) methods as published in Marcus et al (1992)
Bottom width	Assumed wetted width at eight Solar Pathfinder™ sites (measured on September 12-13, 2012) were equivalent to bottom width
Side slope 1	Assumed sides were equivalent to 1.

Table B2-3. Model segment input parameters

Model parameter	Source of input
Side slope 2	

Table B2-4. Groundwater, point sources, and tributaries segment input parameters

Model parameter	Source of input
Groundwater inflow and outflow	
Upstream location	Calculated with GIS
Downstream location	
Diffuse abstraction (outflow)	Estimated from water balance
Diffuse inflow	
Temperature (for inflows)	Calibration parameter, based in part upon available GWIC data
Point sources and tributaries	
Location	Calculated with GIS
Abstraction (withdrawal)	Diversions: Estimated using acreages of potentially irrigated land per diversion and crop water uptake information, see **Section 0** Edna Creek: Observed , USFS logger and flow data Deep Creek: Observed , USFS logger and flow data Swamp Creek: Observed , EPA logger and flow data
Inflow	
Mean daily temperature	
One-half range	
Time of daily maximum	

Table B2-5. Light parameters and surface heat transfer models

Model parameter	Source of input
Solar Shortwave Radiation Model	
Atmospheric attenuation model for solar	Best professional judgment
Bras solar parameter (used if Bras solar model is selected)	
Atmospheric turbidity coefficient	Not applicable (Bras was not selected)
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)	
Atmospheric transmission coefficient	Calibration parameter
Downwelling atmospheric longwave infrared radiation	
Atmospheric longwave emissivity model	QUAL2K recommendation
Evaporation and air convection/conduction	
Wind speed function for evaporation and air convection/conduction	Calibration parameter
Sediment heat parameters	
Sediment thermal thickness	Calibration parameter
Sediment thermal diffusivity	Calibration parameter
Sediment density	Default
Water density	Default
Sediment heat capacity	Calibration parameter
Water heat capacity	Default

Table B2-6. Channel geometry

Segment	Channel slope	Manning's n	Stream bottom width (meter/feet)	Side 1[a]	Side 2[a]
HW[b]	0.00581	0.0700	3.65 / 12.0	1	1
I	0.00582	0.0700	2.41 / 7.9	1	1
H	0.00019	0.0700	2.41 / 7.9	1	1
G	0.00133	0.0700	3.46 / 11.4	1	1
F	0.00142	0.0700	5.49 / 18.0	1	1
E	0.00099	0.0700	4.49 / 14.7	1	1
D	0.00472	0.0700	4.49 / 14.7	1	1

Table B2-6. Channel geometry

Segment	Channel slope	Manning's n	Stream bottom width (meter/feet)	Side 1[a]	Side 2[a]
C	0.00738	0.0700	3.91 / 12.8	1	1
B	0.00135	0.0910	6.15 / 20.2	1	1
A	0.00300	0.0910	8.00 / 26.2	1	1

Notes: Segments are listed from top to bottom of the column as headwaters to mouth

[a.] Adjacent side ratio (relative to one) based on the trapezoidal cross section (**Figure B-16**). Both sides for each model segment were set to 1.

[b.] Headwaters boundary condition; the headwaters boundary condition channel slope was set equal to the channel slope for model segment I.

Table B2-7. Streamflow data

Location	Flow	
	(cubic meters per second)	(cubic feet per second)
Fortine Creek		
FRTNC-T1	0.1048	3.7
FRTNC-T2	0.2322	8.2
FRTNC-T3	0.5550	19.6
below Edna Creek	0.7759	27.4
FRTNC-T4	0.8778	31.0
FRTNC-T5	0.8099	28.6
FRTNC-T6	0.9883	34.9
FRTNC-T7	1.6792	59.3
Deep Creek		
DEEP	0.4757	16.8
Edna Creek		
calculation [a]	0.2209	7.8
Swamp Creek		
SWAMP	0.1019	3.6

Notes:

All flows used for modeling were collected by EPA.

[a.] EPA did not monitor flow on Edna Creek. Flows monitored on Fortine Creek above and below Edna Creek were subtracted to estimate flow in Edna Creek.

Table B2-8. Estimated abstractions

Diversion	Location (km)	Abstraction	
		(cubic meters per second)	(cubic feet per second)
76D 24066 00	39.72	0.0014	0.049
76D 23038 00	33.81	0.0014	0.049
76D 12420 00	32.67	0.0164	0.579
76D 48084 00	31.89	0.0003	0.011
76D 7265 00	31.59	0.0023	0.081
76D 7266 00	31.59	0.0011	0.039
76D 143758 00	30.00	0.0011	0.039
76D 141663 00	23.37	0.0006	0.021
76D 39692 00	22.35	0.0127	0.448
76D 43048 00	22.35	0.0059	0.208
76D 108116 00	20.73	0.0147	0.519
76D 140151 00	12.87	0.0875	3.09
76D 142683 00	9.24	0.0170	0.600

Table B2-8. Estimated abstractions

Diversion	Location (km)	Abstraction	
		(cubic meters per second)	(cubic feet per second)
76D 30025754	5.22	0.0008	0.028
76D 6780 00	0.63	0.0130	0.459

Table B2-9. Estimated diffuse flow and temperature

Segment	Direction	Diffuse flow		Temperature
		(cubic meter per second)	(cubic feet per second)	(Celsius)
Reach I	Inflow	0.1274	4.50	9.0
Reach H	Inflow	0.2401	8.48	12.0
Reach G	Inflow	0.0108	0.38	12.0
Reach F	Inflow	0.0959	3.39	13.0
Reach E	Outflow	0.0340	1.20	--
Reach D	Inflow	0.0355	1.25	14.0
Reach C	Inflow	0.2304	8.14	14.0
Reach B	Inflow	0.1679	5.93	15.0
Reach A	Inflow	0.0781	2.76	15.0

Table B2-10. Hourly weather data for Fortine Creek on August 10, 2012

Time	Air temperature (°C)									Wind speed (meters/sec)
Reach	I	H	G	F	E	D	C	B	A	All
12:00 AM	8.81	9.21	9.35	9.42	9.56	9.84	10.06	10.16	10.31	0.00
1:00 AM	7.71	8.11	8.25	8.32	8.46	8.74	8.96	9.06	9.21	0.45
2:00 AM	6.61	7.01	7.15	7.22	7.36	7.64	7.86	7.96	8.11	0.00
3:00 AM	5.51	5.91	6.05	6.12	6.26	6.54	6.76	6.86	7.01	0.45
4:00 AM	3.81	4.21	4.35	4.42	4.56	4.84	5.06	5.16	5.31	0.89
5:00 AM	3.81	4.21	4.35	4.42	4.56	4.84	5.06	5.16	5.31	0.45
6:00 AM	7.21	7.61	7.75	7.82	7.96	8.24	8.46	8.56	8.71	0.89
7:00 AM	13.31	13.71	13.85	13.92	14.06	14.34	14.56	14.66	14.81	0.00
8:00 AM	16.61	17.01	17.15	17.22	17.36	17.64	17.86	17.96	18.11	0.00
9:00 AM	18.81	19.21	19.35	19.42	19.56	19.84	20.06	20.16	20.31	0.45
10:00 AM	21.61	22.01	22.15	22.22	22.36	22.64	22.86	22.96	23.11	0.89
11:00 AM	22.71	23.11	23.25	23.32	23.46	23.74	23.96	24.06	24.21	0.45
12:00 PM	26.11	26.51	26.65	26.72	26.86	27.14	27.36	27.46	27.61	1.34
1:00 PM	27.71	28.11	28.25	28.32	28.46	28.74	28.96	29.06	29.21	0.89
2:00 PM	28.81	29.21	29.35	29.42	29.56	29.84	30.06	30.16	30.31	1.34
3:00 PM	29.91	30.31	30.45	30.52	30.66	30.94	31.16	31.26	31.41	1.34
4:00 PM	29.41	29.81	29.95	30.02	30.16	30.44	30.66	30.76	30.91	1.34
5:00 PM	28.81	29.21	29.35	29.42	29.56	29.84	30.06	30.16	30.31	1.34
6:00 PM	23.81	24.21	24.35	24.42	24.56	24.84	25.06	25.16	25.31	0.89
7:00 PM	19.41	19.81	19.95	20.02	20.16	20.44	20.66	20.76	20.91	0.00
8:00 PM	15.51	15.91	16.05	16.12	16.26	16.54	16.76	16.86	17.01	0.00
9:00 PM	12.71	13.11	13.25	13.32	13.46	13.74	13.96	14.06	14.21	0.89
10:00 PM	12.71	13.11	13.25	13.32	13.46	13.74	13.96	14.06	14.21	0.00
11:00 PM	11.11	11.51	11.65	11.72	11.86	12.14	12.36	12.46	12.61	0.89

Note: Data presented in this table were obtained from the Eureka RAWS and were converted to Celsius for QUAL2K input.

Table B2-11. Hourly dew point data for Fortine Creek on August 10, 2012

Time	Dew point temperature (°C)								
Segment	I	H	G	F	E	D	C	B	A
12:00 AM	6.43	6.84	6.98	7.04	7.19	7.48	7.69	7.79	7.93
1:00 AM	6.33	6.74	6.88	6.94	7.09	7.38	7.59	7.69	7.83
2:00 AM	5.43	5.84	5.98	6.04	6.19	6.48	6.69	6.79	6.93
3:00 AM	5.13	5.54	5.68	5.74	5.89	6.18	6.39	6.49	6.63
4:00 AM	4.53	4.94	5.08	5.14	5.29	5.58	5.79	5.89	6.03
5:00 AM	4.43	4.84	4.98	5.04	5.19	5.48	5.69	5.79	5.93
6:00 AM	5.43	5.84	5.98	6.04	6.19	6.48	6.69	6.79	6.93
7:00 AM	6.23	6.64	6.78	6.84	6.99	7.28	7.49	7.59	7.73
8:00 AM	7.43	7.84	7.98	8.04	8.19	8.48	8.69	8.79	8.93
9:00 AM	6.63	7.04	7.18	7.24	7.39	7.68	7.89	7.99	8.13
10:00 AM	7.93	8.34	8.48	8.54	8.69	8.98	9.19	9.29	9.43
11:00 AM	7.03	7.44	7.58	7.64	7.79	8.08	8.29	8.39	8.53
12:00 PM	6.73	7.14	7.28	7.34	7.49	7.78	7.99	8.09	8.23
1:00 PM	1.63	2.04	2.18	2.24	2.39	2.68	2.89	2.99	3.13
2:00 PM	-1.47	-1.06	-0.92	-0.86	-0.71	-0.42	-0.21	-0.11	0.03
3:00 PM	-0.67	-0.26	-0.12	-0.06	0.09	0.38	0.59	0.69	0.83
4:00 PM	1.13	1.54	1.68	1.74	1.89	2.18	2.39	2.49	2.63
5:00 PM	0.63	1.04	1.18	1.24	1.39	1.68	1.89	1.99	2.13
6:00 PM	6.03	6.44	6.58	6.64	6.79	7.08	7.29	7.39	7.53
7:00 PM	5.93	6.34	6.48	6.54	6.69	6.98	7.19	7.29	7.43
8:00 PM	7.13	7.54	7.68	7.74	7.89	8.18	8.39	8.49	8.63
9:00 PM	6.53	6.94	7.08	7.14	7.29	7.58	7.79	7.89	8.03
10:00 PM	4.53	4.94	5.08	5.14	5.29	5.58	5.79	5.89	6.03
11:00 PM	5.53	5.94	6.08	6.14	6.29	6.58	6.79	6.89	7.03

Notes: Data presented in this table were obtained from the Eureka RAWS and were converted to Celsius for QUAL2K input.
A negative dew point temperature means that the ambient air is dry enough that it would have to cool to below freezing to become saturated such that water condenses to ice crystals (instead of water droplets).

Table B2-12. Hourly shade results (hourly medians along model segments)

Time	Shade (percent)								
Model reach	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Up RM	**2.2**	**6.0**	**8.7**	**12.8**	**17.0**	**18.3**	**20.1**	**26.9**	**31.7**
Down RM	**0.0**	**2.2**	**6.0**	**8.7**	**12.8**	**17.0**	**18.3**	**20.1**	**26.9**
12:00 AM	100%	100%	100%	100%	100%	100%	100%	100%	100%
1:00 AM	100%	100%	100%	100%	100%	100%	100%	100%	100%
2:00 AM	100%	100%	100%	100%	100%	100%	100%	100%	100%
3:00 AM	100%	100%	100%	100%	100%	100%	100%	100%	100%
4:00 AM	100%	100%	100%	100%	100%	100%	100%	100%	100%
5:00 AM	100%	100%	100%	100%	100%	100%	100%	100%	100%
6:00 AM	100%	95%	95%	97%	94%	94%	94%	93%	94%
7:00 AM	100%	93%	71%	97%	92%	92%	88%	70%	91%
8:00 AM	100%	75%	58%	97%	65%	68%	68%	42%	59%
9:00 AM	90%	56%	46%	94%	39%	44%	44%	26%	29%
10:00 AM	70%	36%	33%	67%	22%	25%	24%	20%	18%
11:00 AM	60%	20%	23%	50%	16%	16%	12%	14%	11%

Table B2-12. Hourly shade results (hourly medians along model segments)

Time	Shade (percent)								
Model reach	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Up RM	**2.2**	**6.0**	**8.7**	**12.8**	**17.0**	**18.3**	**20.1**	**26.9**	**31.7**
Down RM	**0.0**	**2.2**	**6.0**	**8.7**	**12.8**	**17.0**	**18.3**	**20.1**	**26.9**
12:00 PM	50%	11%	10%	37%	11%	10%	14%	13%	13%
1:00 PM	40%	10%	8%	23%	8%	12%	11%	14%	15%
2:00 PM	50%	12%	8%	26%	10%	17%	13%	16%	24%
3:00 PM	70%	21%	11%	45%	18%	27%	19%	22%	33%
4:00 PM	90%	36%	21%	65%	28%	38%	26%	26%	45%
5:00 PM	90%	54%	39%	87%	39%	55%	42%	30%	59%
6:00 PM	100%	80%	61%	97%	58%	68%	59%	40%	75%
7:00 PM	100%	93%	84%	97%	76%	84%	79%	60%	93%
8:00 PM	100%	95%	93%	97%	92%	94%	93%	88%	95%
9:00 PM	100%	95%	95%	97%	94%	95%	95%	94%	97%
10:00 PM	100%	100%	100%	100%	100%	100%	100%	100%	100%
11:00 PM	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table B2-13. Heat parameters and transfer models

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]	0.9
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
Sediment heat parameters	
Sediment thermal thickness (centimeter)[b]	16
Sediment thermal diffusivity (square centimeter per second)[c]	0.008
Sediment density (gram per cubic centimeter)[d]	1.6
Water density (gram per cubic centimeter)[d]	1
Sediment heat capacity (calorie per [gram by degree Celsius])[d]	0.55
Water heat capacity[d]	1

Notes
[a] Atmospheric transmission coefficient default is 0.8; typical range is 0.70 to 0.91.
[b] Sediment thermal thickness default is 10 centimeters.
[c] Sediment thermal diffusivity default is 0.005 square centimeter per second
[d] These values are the model defaults.

ATTACHMENT B-3

Table B3-1. Fortine Creek Solar Pathfinder site supplemental data (Field data collected September 12 and 13, 2012. Shaded sites are at potential).

Site ID	Map ID	Reach ID	GIS Classification		Field Verification		Potential		Field Notes	Average % Shade
			Veg Type	Veg Density	Veg Type	Veg Density	Veg Type	Veg Density		
FRTNC-T1	FSP-T1	FID 2	Coniferous	Dense	Mixed Coniferous/ Deciduous	Dense (100%)	Mixed Conif/ Deciduous	Dense	This site is at potential. The floodplain is dominated by alder (50 – 100% cover) with spruce/fir immediately up gradient (75-100% cover).	78
FRTNC-T2	FSP-T2	FID 6	Coniferous	Dense	Coniferous	Dense (100%)	Coniferous	Dense	This site is at potential. This is a spruce/fir dominated forest (100% cover) with an occasional larch. There are some alders in the immediate floodplain, but spotty coverage due to dense tree canopy. A natural mass wasted bank was observed just upstream from this site on the right bank.	90
FRTNC-T3	FSP-T3	FID 10	Marsh/ Meadow	Moderate	Shrub	Dense (100%)	Shrub	Dense	The immediate floodplain shrub community (dogwood dominated with some alder and willow – 100% cover) is at potential. However, there is some grazing upgradient which resulted in converting shrub habitat to meadow. Some older beaver activity was noted. GIS interpretation erroneously identified marsh.	42

Table B3-1. Fortine Creek Solar Pathfinder site supplemental data (Field data collected September 12 and 13, 2012. Shaded sites are at potential).

Site ID	Map ID	Reach ID	GIS Classification		Field Verification		Potential		Field Notes	Average % Shade
			Veg Type	Veg Density	Veg Type	Veg Density	Veg Type	Veg Density		
FRTNC-T4	FSP-T4	FID 11	Coniferous	Dense	Coniferous	Dense (100%)	Coniferous	Dense	This site is at potential. Relatively mature spruce/fir forest (100% cover) with sparse (25% cover) alder in the floodplain. A steep (approx. 100’) bench along left bank.	63
FRTNC-SP11	FSP-SP1	FID 21			NA	NA	NA	NA	SP site was downstream of the temp logger, below the bridge. The site was heavily grazed. Alders were browsed and broomed, grass was heavily grazed. Single cottonwood trying to sprout at the site. The potential for this site is mixed coniferous/deciduous (i.e., upstream from the bridge.	10
FRTNC-T6	FSP-T6	FID 17	Mixed Conf/ Rangeland	Poor/Mod	Left bank mixed disturbed veg community	Poor/Mod	Mixed Conif/ Deciduous	Dense	A road, powerline, and railroad are adjacent to the left bank. Railroad grade (elevated fill material) currently limits vegetation potential of the left bank. The right bank includes alder, dogwood and reed canary grass in the floodplain with a deciduous/conifer mix upgradient (75% cover). A timber harvest unit exists approximately 150 from stream on right bank.	32

Table B3-1. Fortine Creek Solar Pathfinder site supplemental data (Field data collected September 12 and 13, 2012. Shaded sites are at potential).

Site ID	Map ID	Reach ID	GIS Classification		Field Verification		Potential		Field Notes	Average % Shade
			Veg Type	Veg Density	Veg Type	Veg Density	Veg Type	Veg Density		
FRTNC-T7	FSP-T7	FID 0	Coniferous	Dense	Mixed deciduous/ Coniferous	Moderately Dense	Mixed deciduous/ Coniferous	Moderately Dense	This site is at potential. Broad floodplain dominated by cottonwood/conifer mix (75% cover) with an alder understory on right bank (50% cover). Very similar on left bank but missing the conifer component and there is a cleared powerline corridor >150’ from left bank. 50% cottonwood/50% cover alder on left. Diversion noted near this site.	57
FRTNC-T5	FSP-T5	FID 21	Mixed Conif/ Deciduous	Dense	Mixed Conif/ Deciduous	Moderately dense	Mixed Conif/ Deciduous	Moderately dense	This site is at potential and is a good reference site for SP1. The floodplain is predominantly alder/dogwood (50-100% cover). A few conifers are interspersed in the floodplain (25-50% cover). There are some open grassy areas on old point bars. Transitions to conifer dominated in uplands and upstream from this site.	28