APPENDIX I – EAST FORK ROCK CREEK TEMPERATURE MODELING REPORT

Appendix I is based on a report prepared for the DEQ by Tetra Tech, October 2012.

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Acronyms and Abbreviations

DNRC	Montana Department of Natural Resources and Conservation
DEQ	Montana Department of Environmental Quality
EPA	U.S. Environmental Protection Agency
MRLC	Multi-Resolution Land Characteristics Consortium
NLCD	National Land Cover Dataset
QUAL2K	River and Stream Water Quality Model
TMDL	total maximum daily load
TPA	TMDL Planning Area
WET	Water & Environmental Technologies, PC
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

East Fork Rock Creek is in the Rocky Mountains of western Montana, is impaired by elevated water temperatures, and is on Montana's Clean Water Act section 303(d) list. A QUAL2K model was developed to evaluate the instream water temperature response to various model scenarios. The existing conditions scenario was evaluated with existing conditions, low-flow conditions, increased shading, and attaining a 15% water savings from improved irrigation delivery and application efficiencies; and allowing that conserved water to flow down East Fork Rock Creek downstream from the point of the diversion of the East Fork Rock Creek. These model scenarios were evaluated to assess a potential worst-case scenario.

Low-flow conditions scenarios resulted in slightly increased daily maximum and mean temperatures as compared to the existing condition scenario. Increasing to full potential shade resulted in cooler instream water temperatures than both the existing condition and low-flow condition scenarios. Increasing the instream discharge also resulted in cooler temperatures in East Fork Rock Creek.

I1.0 BACKGROUND

This section of the document presents background information including a brief description of the study reach, the applicable water quality standards, and project history. Note that the temperature standards in Montana are in degrees Fahrenheit (°F), and thus, are reported in °F in this section.

I1.1 PROBLEM STATEMENT

East Fork Rock Creek is classified as a B-1 stream. The lower 9.74 miles (MT76E002_020) is partially supporting its Aquatic Life and Primary Contact Recreation designated uses (Montana Department of Environmental Quality, 2012). Six potential causes of impairment have been identified, including water temperature, the subject of this document (Montana Department of Environmental Quality, 2012). DEQ found that, "water temperatures are elevated above the peak growth rate for bull trout during the summer months and [elevated temperatures are] most likely limiting the fishery" (Montana Department of Environmental Quality, 2012, p. 16).

I1.2 MONTANA TEMPERATURE STANDARD

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

The model results will ultimately be compared to these criteria.

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

I1.3 Project History

Temperature and flow data were collected in the East Fork Rock Creek in 2010 by DEQ. Water & Environmental Technologies, PC (WET), under contract with DEQ, prepared a Quality Assurance Project Plan for temperature monitoring and modeling in the Rock Creek TMDL Planning Area in 2011. A field team from WET and DEQ collected data on August 1, 25, 30, and 31 in 2011 to characterize meteorology (i.e., air temperature, dew point, wind speed, and cloud cover), channel geometry, flow, and shade in support of the modeling effort. Tetra Tech was contracted by EPA in February 2012 to develop the QUAL2K temperature model using the data and information compiled by WET and DEQ.

I1.4 Study Area

East Fork Rock Creek is in the Rocky Mountains of western Montana and is part of the Rock Creek TMDL Planning Area (**Figure I-1**). The East Fork Rock Creek watershed is a 12-digit HUC (17010202 07 03) and is in the Flint-Rock 8-digit HUC (17010202). The impaired segment is 9.74 miles long and extends from the outlet of East Fork Reservoir to the mouth.

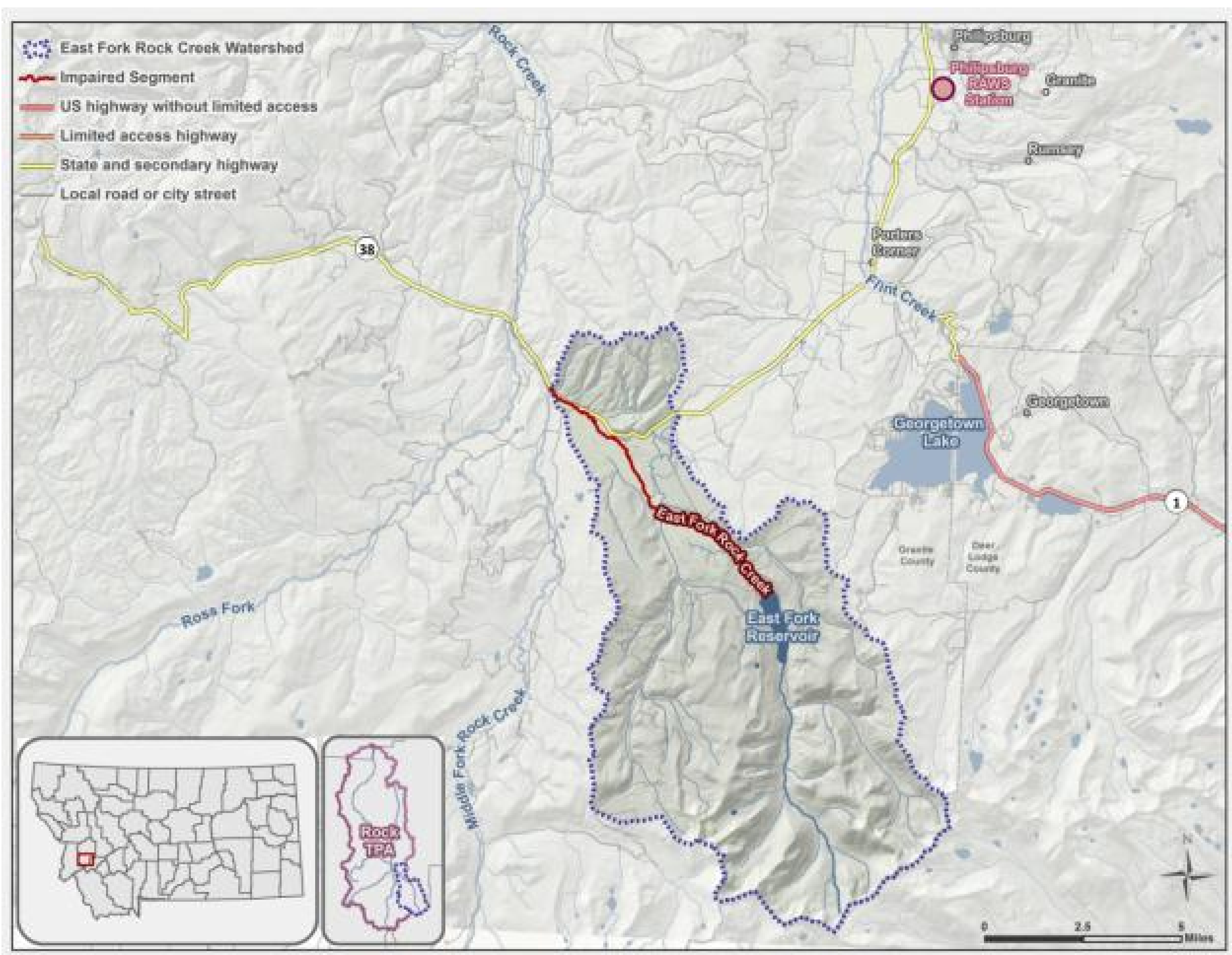


Figure I-1. East Fork Rock Creek watershed.

This stream originates in the high elevations of the Pintler Range (more than 8,000 feet above mean sea level [MSL]) and flows approximately 6 miles through the Beaverhead Deerlodge National Forest. The creek transitions from relatively steep, mountainous, coniferous forest in the headwater to more gentle, open, scrub/shrub/grassland in the lower reaches of the watershed (**Figure I-2**). This transition occurs fairly dramatically just below the East Fork Reservoir, an impoundment constructed in 1938.

A siphon and a transfer pipeline were also constructed in 1939 to facilitate irrigation in the adjacent Flint Creek watershed. The Montana Department of Natural Resources and Conservation (DNRC) manages the reservoir, siphon, and transfer pipeline. The segment (MT76E002_020) addressed in this report begins at the outlet of the dam on East Fork Reservoir and ends at the mouth of East Fork Rock Creek (its confluence with Middle Fork Rock Creek).

Source: (Google, 2013)

Figure I-2. Topography of the East Fork Rock Creek watershed.

The upper half of the East Fork Rock Creek watershed is primarily forested (**Figure I-3** and **Figure I-4**). Most of the valley bottom below the East Fork Reservoir (i.e., the areas along the impaired reach) is irrigated pasture or hay land (**Figure I-3**). The 2006 National Land Cover Dataset (NLCD) erroneously identifies areas of irrigated hay and pasture as cultivated crops. The upland areas in the lower watershed are predominantly open rangeland (scrub/shrub and native grasslands).

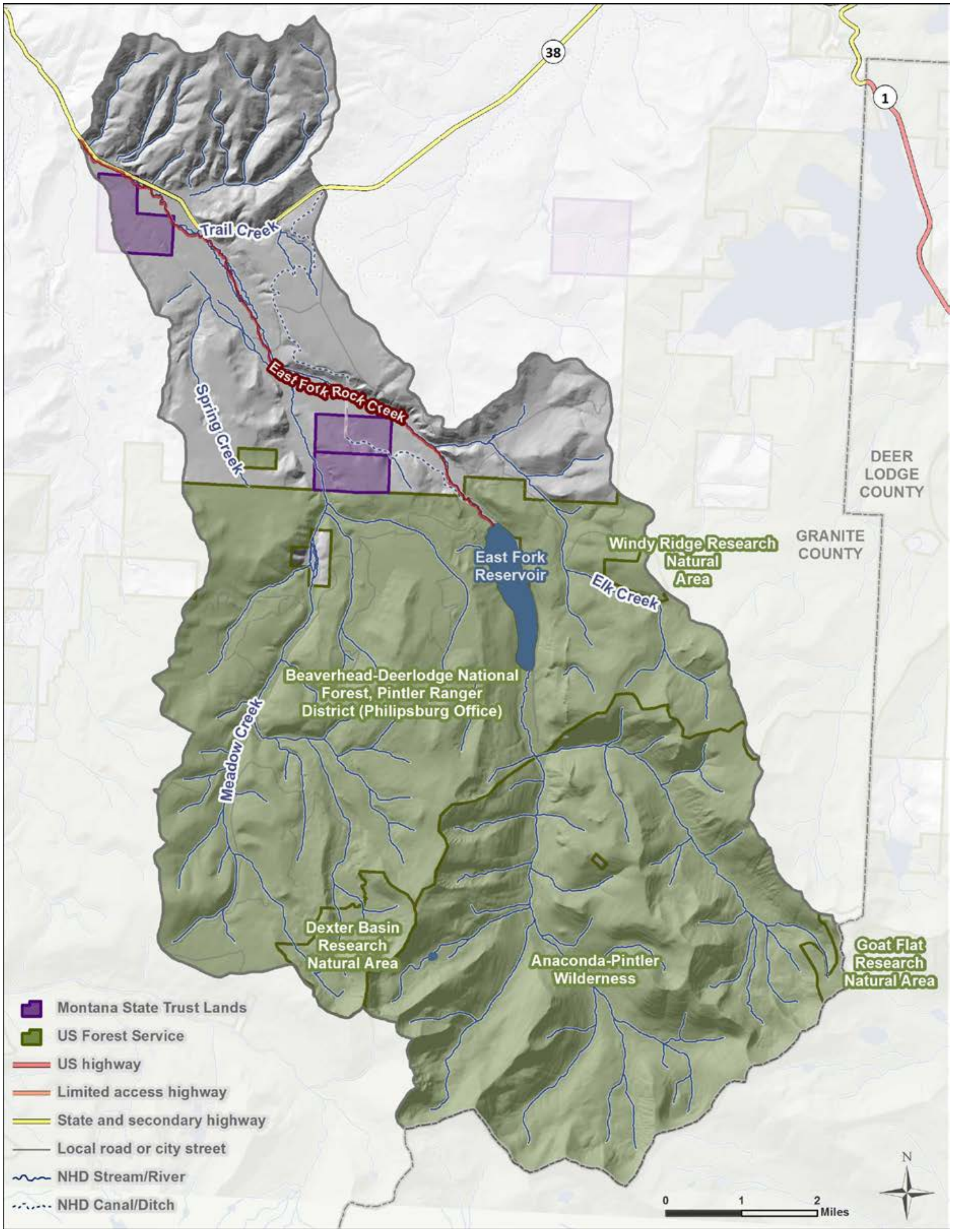
The U.S. Forest Service owns and manages much of the watershed. The upper reaches of the East Fork Rock Creek watershed are in the Anaconda-Pintler Wilderness (**Figure I-5**). Historically, timber harvest has occurred outside the wilderness area, predominantly in the Meadow Creek subwatershed, which drains to the impaired segment of East Fork Rock Creek (**Figure I-4**). With the exception of two small areas in the lower half of the watershed under state ownership, the lower watershed is privately owned.

Source of land cover: NLCD 2006 (Multi-Resolution Land Characteristics Consortium, 2006)
Note: The NLCD 2006 (Multi-Resolution Land Characteristics Consortium, 2006) erroneously identifies areas of irrigated hay and pasture as cultivated crops.

Figure I-3. Land cover in the East Fork Rock Creek watershed.

Source of aerial imagery: 2009 NAIP (Montana State Library, 2013)

Figure I-4. East Fork Rock Creek watershed.



Source of land ownership: (Montana State Library, 2013)

Figure I-5. Land ownership in the East Fork Rock Creek watershed.

I2.0 Factors Potentially Influencing Stream Temperature

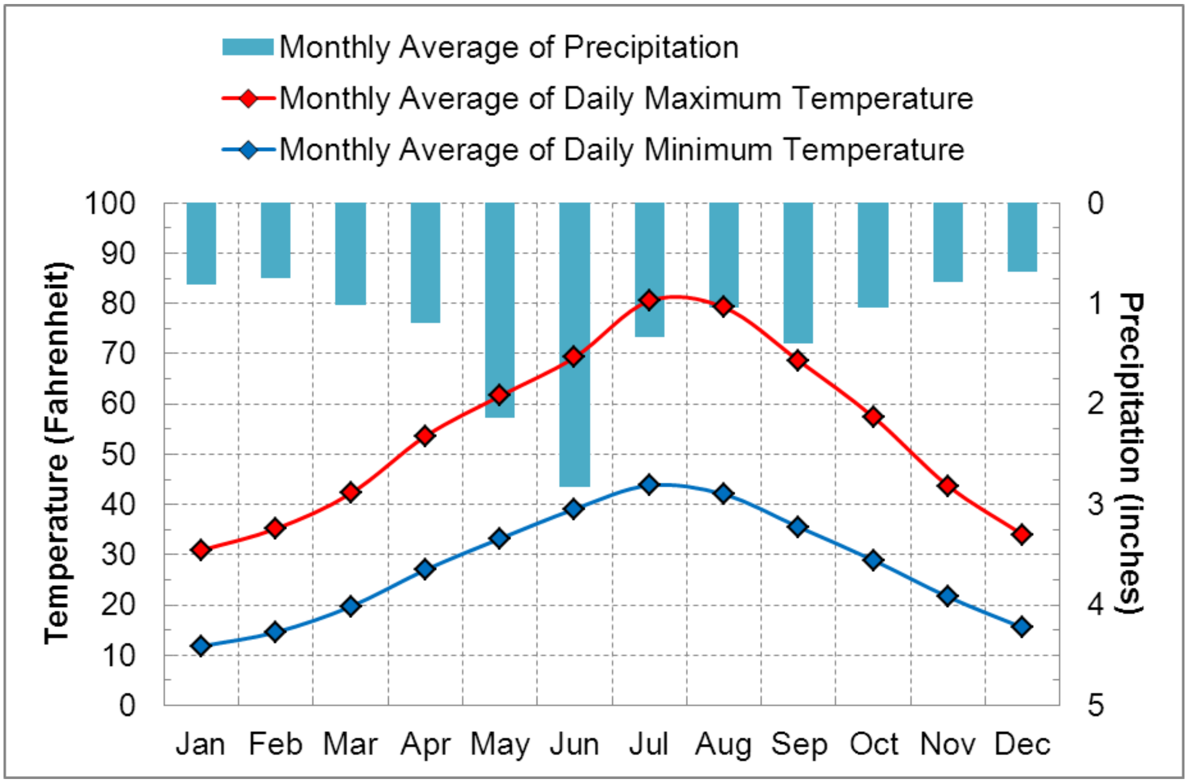
Interactions between external drivers of stream temperature and the internal integrated stream system (i.e., the channel, riparian zone, and alluvial aquifer) ultimately determine stream temperature (Poole and Berman, 2001). The external drivers are climate (e.g., solar radiation, air temperature, and near-stream wind speed), stream morphology, groundwater influences, and riparian canopy condition (Poole and Berman, 2001). External drivers could also be point source discharges, dams, and irrigation withdrawals and returns.

This section provides a summary of the external and internal factors that could influence stream temperature in East Fork Rock Creek. It is necessary to understand these watershed characteristics to adequately simulate the existing conditions and model scenarios that might be needed for TMDL development.

I2.1 Climate

The nearest weather station to the East Fork Rock Creek watershed is 15 miles to the northeast in Philipsburg, Montana: Philipsburg Remote Automated Weather Station (National Weather Service ID 243002). Average annual precipitation is 15.7 inches with the greatest amounts falling in June and July (**Figure I-6**) (Western Regional Climate Center, 2012). Average maximum temperatures occur in July and August and are 80.9 and 79.2 °F, respectively. The most cloud-free days occur between June and September.

Note that the Philipsburg weather station is at an elevation of 5,280 feet above MSL, compared to the impaired reach of East Fork Rock Creek, which ranges in elevation from approximately 5,300 to 6,000 feet above MSL.



Source of monthly data: Western Regional Climate Center 2012

Figure I-6. Monthly average temperatures and precipitation at Philipsburg, Montana.

I2.2 Riparian Vegetation

Riparian vegetation data along the mainstem of East Fork Rock Creek were collected in 2011 to support shade characterization, ultimately for model development (Water & Environmental Technologies, 2011). DEQ collected vegetation/canopy height, canopy density, vegetative cover percent, and channel overhang at three transects each at all six of its sampling locations (shown in **Figure I-7**). These data are presented in **Appendix IA.** A summary of the data that relate to shade estimation is presented in **Section I2.3**.

In addition, a detailed assessment of the riparian vegetation community was performed in 2011 at two sites (EFRC Shade 1 and EFRC Shade 5). At the upper site (EFRC Shade 1), sedges and rushes are abundant along the stream edge, with a willow understory and some young conifers. Grass species occur in abundance upgradient from the stream edge. Weeds are minimal throughout the reach. At the lower site (EFRC Shade 5), the stream edge is dominated by sedges with intermixed rushes. Grass exists on outside bends where sloughing has occurred. The site has no overstory and minimal understory vegetation. Very little willow was observed, with no mature species. Upland grasses are smooth brome, timothy and canary reed grass. Bull thistle and mustard were also observed. Site EFRC Shade 5 is typical of current riparian conditions throughout much of the lower watershed.

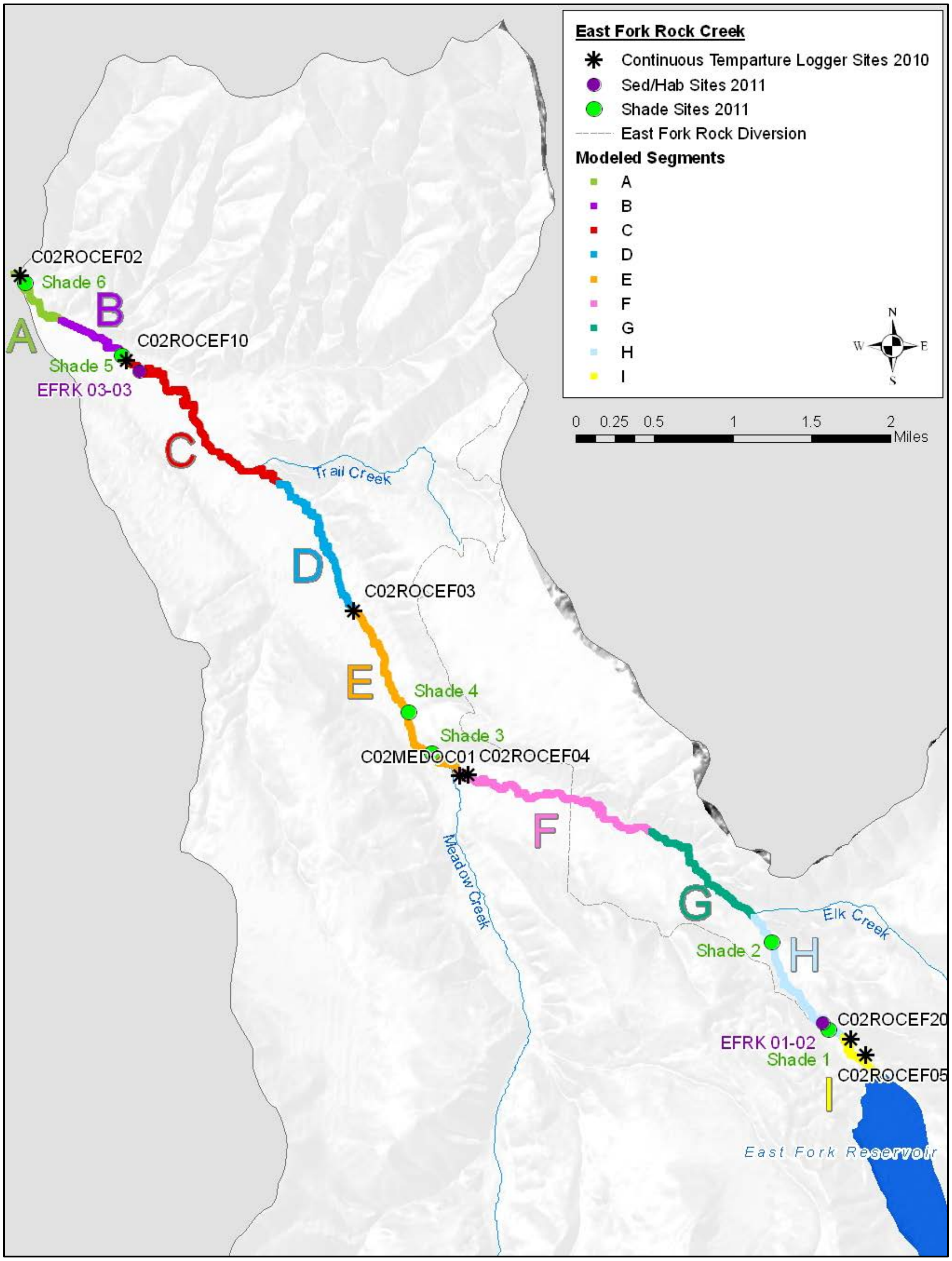


Figure I-7. Shade sites along the mainstem of East Fork Rock Creek.

I2.3 SHADE

Shade is a key input to the QUAL2K model. Shade is defined as the fraction of potential solar radiation that is blocked by topography and vegetation. DEQ used a Solar Pathfinder™ to collect shade data at six sites along East Fork Rock Creek: EFRC 1 through EFRC 6 (**Figure I-7**). Three sets of measurements were recorded at each site; with the exception of EFRC 5, vegetative shade exceeded topographic shade.

An analysis of aerial imagery showed that shading along East Fork Rock Creek was highly variable because of agricultural practices, changes in elevation along the stream, and such. Therefore, shade was also evaluated using the spreadsheet Shadev3.0.xls[2] (referred to throughout as the Shade Model). DEQ collected data to support development of the Shade Model **(Appendix IA**, Water & Environmental Technologies, 2011). The riparian vegetation information (i.e., height, density, and overhang that are displayed in **Appendix IA**) were calculated as the typical values for each category of vegetation on the basis of field work conducted in 2011, except where noted in the following paragraph (Water & Environmental Technologies, 2011).

The Shade Model uses these data with the spatial riparian cover and hydrography data to calculate vegetative shade (Water & Environmental Technologies, 2011). The topographic shade component was calculated using both TTools[3] and field data (Water & Environmental Technologies, 2011). Elevation, aspect, and the directional topographic shades were calculated in TTools using a digital elevation model and the previously mentioned digitized hydrography. Wetted width, near shore zone width and center to left, and channel incision were measured during field work conducted in 2011 (Water & Environmental Technologies, 2011). The Shade Model yielded shade estimates at a finer scale than the available Solar Pathfinder data (i.e., every 15 meters along the creek compared to three sites along the creek)

Figure I-8 presents shade estimates from both the Solar Pathfinder and Shade Model. As estimated by the Shade Model, shade varied over a large range above river mile 7 and varied over fairly constant ranges from river mile 7 to the mouth. The effective shade derived using the spreadsheet tool Shadev3.0.xls was compared to the field measurements from the Solar Pathfinder, aerial imagery, and site photographs. The Shadev3.0.xls output was found to be reasonably accurate (i.e., within 10 percent or less at all sites with Solar Pathfinder data; see **Figure I-8**). Additional plots of these data sets are presented in **Appendix IB**.

[2] Shadev3.0.xls contains Visual Basic for applications routines adapted from the Oregon Department of Environmental Quality (ODEQ) by Washington State Department of Ecology (http://www.ecy.wa.gov/programs/eap/models.html) to calculate topographic and canopy shade using solar time and position relative to the earth, and the solar position relative to the stream position, topographic, and vegetative canopy.

[3] A GIS analysis was performed using TTools (version 7.5.6), developed by the ODEQ in 2009, which is an ArcGIS template, to generate input values for Shadev3.0.xls. TTools requires hydrography that is accurate to a very fine scale (1:5,000 or finer) (Oregon Department of Environmental Quality, 2001). Aerial imagery from 2009 and a digital elevation model were used to digitize the centerline and shores of East Fork Rock Creek. The one-third arc second (approximately 33 feet) digital elevation map was obtained from USGS's National Elevation Dataset. Land cover along the approximately 164-foot-wide riparian corridor was digitized in GIS (Water & Environmental Technologies, 2011).

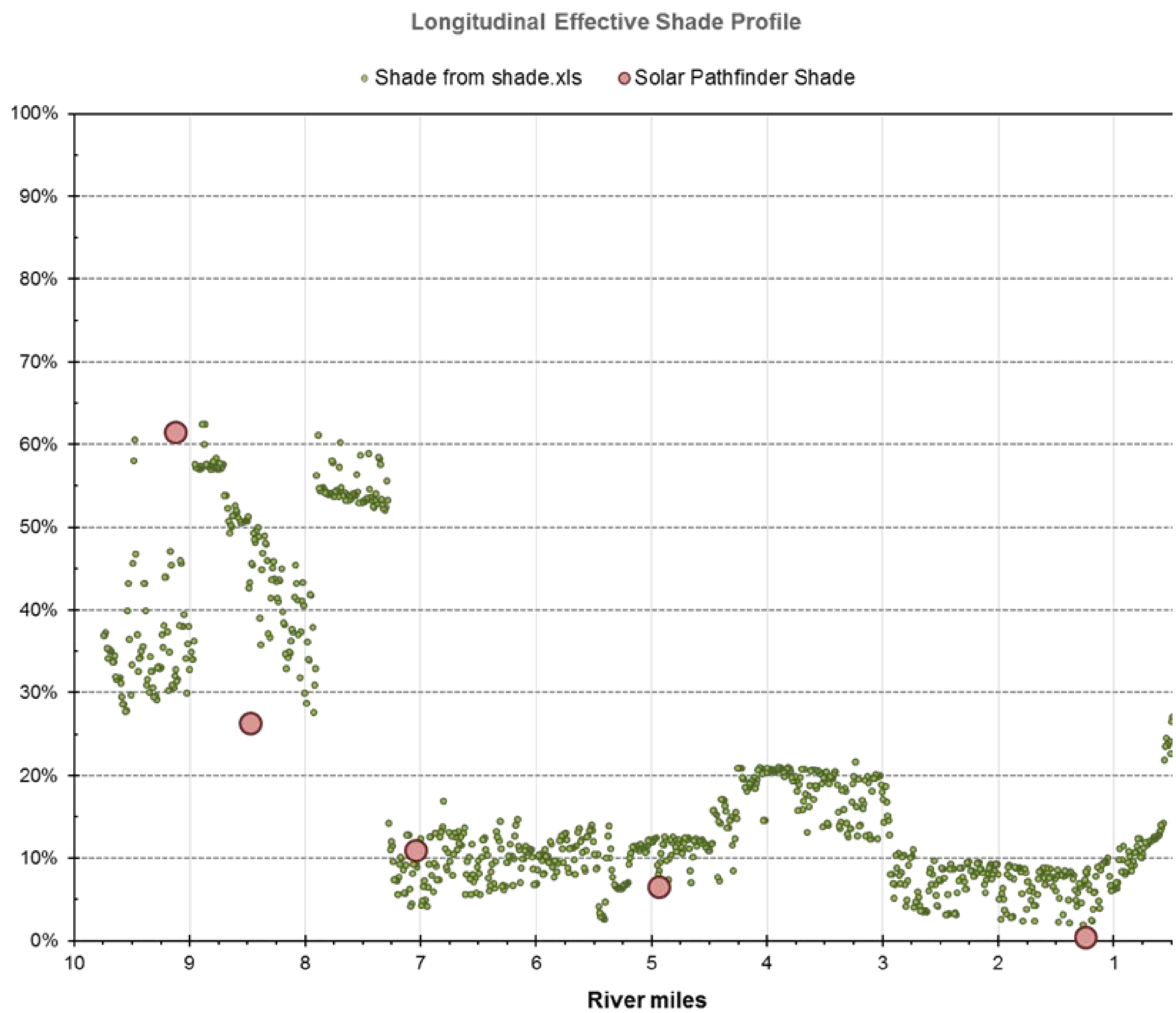


Figure I-8. Effective shade output from Shade.xls.

I2.4 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 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 at five cross-sections at two sites on East Fork Rock Creek, which coincide with EFRC Shade 1 and EFRC Shade 5 (**Figure I-7**). Representative bankfull width to depth ratios for the two sites are based on the reach average of those measurements, which averaged 22.2 at the upper site (EFRC Shade 1) and 14.3 at the lower site (EFRC Shade 5). Field observations are that the channel is overwidened at some discrete locations. However, both of the average reach values are within the acceptable and expected values for East Fork Rock Creek; therefore, no altered channel morphology scenario will be completed in the model to assess the influence of physical geometry on the overall heat balance of the stream.

I2.5 Hydrology

The hydrology of East Fork Rock Creek is significantly affected by anthropogenic flow modification. In 1938, the stream was dammed and a transfer pipeline (siphon) was constructed to move the impounded water to the Flint Creek drainage. The East Fork Rock Creek Dam is owned by DNRC and operated by the Flint Creek Water Users Association. It is an earthen embankment dam, 88 feet high and 1,083 feet long. The reservoir stores 16,040 acre-feet at normal pool covering 390 acres (Montana Department of Natural Resources and Conservation, 2012).

The transfer pipeline diverts about one-quarter of a mile below the dam and follows a northwesterly direction to Trout Creek, which is used as a carrier for the diversion of water by other canals in the Flint Creek valley below (State Engineers Office, 1959). The canal has a maximum capacity of 200 cubic feet per second (cfs) (Norberg, M., personal communication 2012). On the basis of flow data collected by DNRC in 2010 and 2011, water is typically diverted into the canal from late May through September with flow rates in the range of 50 to 150 cfs (Norberg, M., personal communication 2012). In 2010, the canal diverted between 34 and 98 percent (median 94 percent) of the flow discharged from East Fork Reservoir.

DEQ collected instantaneous flow measurements in 2010 during temperature data logger deployment and retrieval; these data are presented in **Table I-1**. Montana DNRC has maintained continuously recording gages on East Fork Rock Creek for most years starting in 1994 at four locations (**Table I-2** and **Figure I-9** [EF Rock above Res, EF Rock below Res, EF Rock Main Channel, and EF Rock above Elk]). **Figure I-10** and **Figure I-11** present DNRC's flow data from the years 2010 and 2011, respectively.[4]

According to DNRC, after spring snowmelt, flow in the creek decreases considerably as much of the flow is diverted to the irrigation canal. Flows are always lowest just below the irrigation canal diversion. The stream gains between 24 and 32 cfs from just below the irrigation diversion canal to the mouth. Flow occasionally decreases or remains relatively constant in the lower half of the creek; this might be because of the cumulative effect of multiple small irrigation withdrawals, which divert to pivot and some flood irrigation (Norberg, M., personal communication 2012).

Table I-1. DEQ instantaneous flow measurements (cfs)

Date	C02ROCEF02	C02ROCEF10	C02ROCEF03	C02MEDOC01	C02ROCEF04	C02ROCEF20	C02ROCEF05
July 26-29, 2010	38.04	38.12	41.51	12.37	25.78	6.18	114.7
August 30, 2010	--	34.62	28.41	--	14.20	--	77.6
September 28, 2010	28.62	30.38	13.61	6.37	11.56	4.97	4.0

Note: DEQ reports that flow was estimated at site C02ROCEF05.

[4] It is noteworthy that DNRC peak flows monitored in 1994 and 1999 through 2004 were considerably lower than peak flows from 1995 through 1998 and 2007 through 2011.

Table I-2. Period of record for DNRC flow gages

Year	EFRC above EFR	EFRC below EFR	Main Canal	EFRC above Elk Creek
1994	Jun 2 – Oct 8	Jun 22 – Oct 8	May 1 – Sep 30	--
1995	May 29 – Oct 19	May 29 – Oct 19	May 1 – Sep 30	--
1996	May 12 – Oct 2	May 12 – Oct 2	May 1 – Sep 30	--
1997	May 12 – Oct 11	May 12 – Oct 11	May 1 – Oct 2	--
1998	May 5 – Oct 23	Apr 22 – Oct 23	May 1 – Sep 30	--
1999	May 20 – Oct 4	May 4 – Oct 4	May 1 – Sep 30	--
2000	May 1 – Oct 4	May 1 – Oct 4	Apr 1 – Sep 30	--
2001	May 10 – Oct 24	May 4 – Oct 24	--	--
2002	May 19 – Sep 29	--	Jul 1 – Sept 30	--
2003	May 29 – Sep 30	May 29 – Oct 28	May 1 – Oct 1	--
2004	Apr 1 – Sep 30	Mar 30 – Sep 30	Apr 29 – Sep 30	--
2005	--	--	--	--
2006	--	--	--	--
2007	Jun 5 – Oct 2	Apr 25 – Oct 2	Apr 11 – Oct 10	--
2008	Jun 2 – Sep 23	Apr 16 – Sep 23	Jun 2 – Sep 8	--
2009	May 28 – Oct 23	Apr 23 – Oct 19	May 22 – Sep 30	--
2010	May 22 – Oct 9	Apr 23 – Oct 27	May 24 – Sep 30	Jun 10 – Oct 27
2011	May 26 – Oct 8	May 3 – Sep 30	May 12 – Sep 30	Apr 14 – Sep 30

Notes: EFRC = East Fork Rock Creek; EFR = East Fork Reservoir

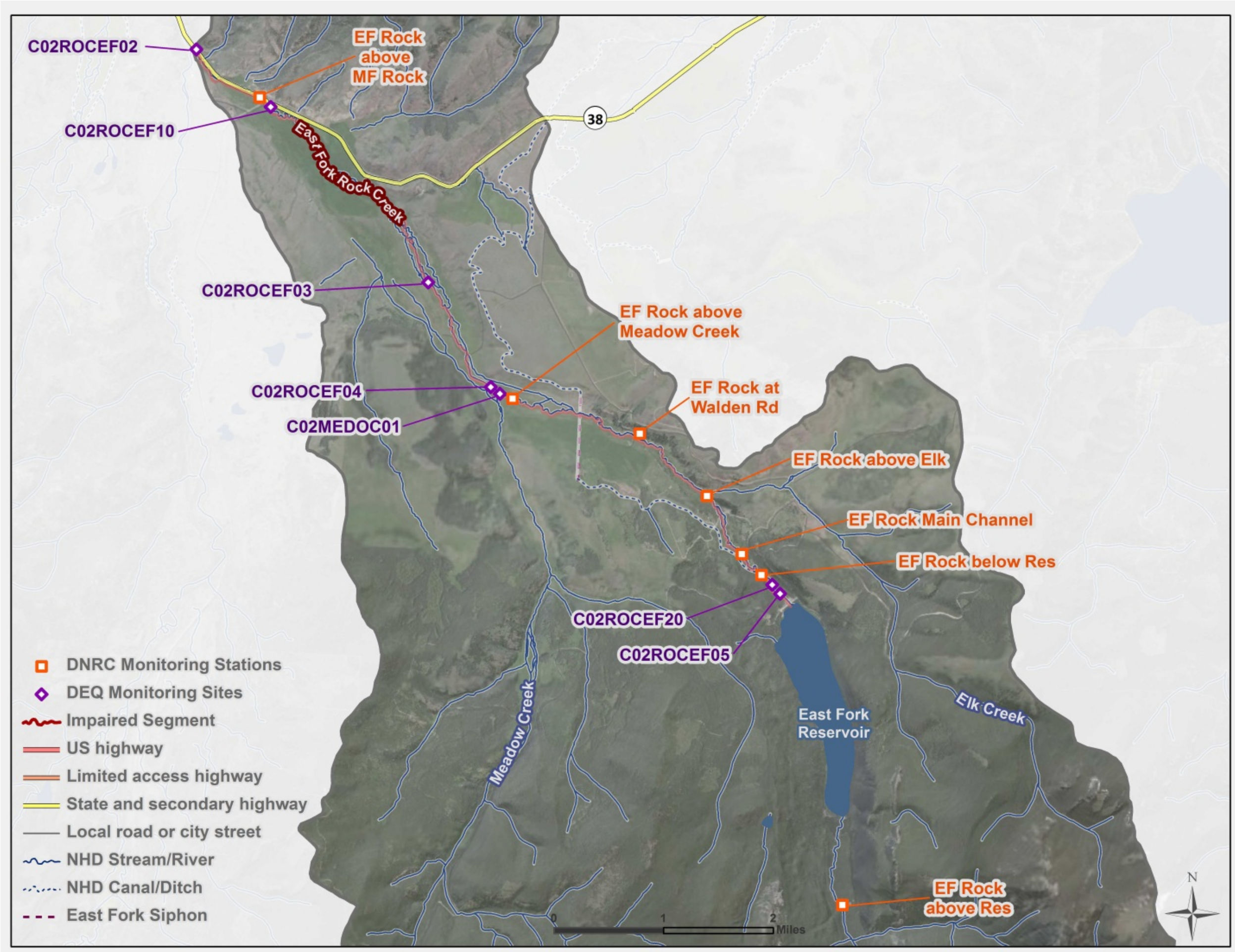


Figure I-9. Flow and temperature monitoring locations.

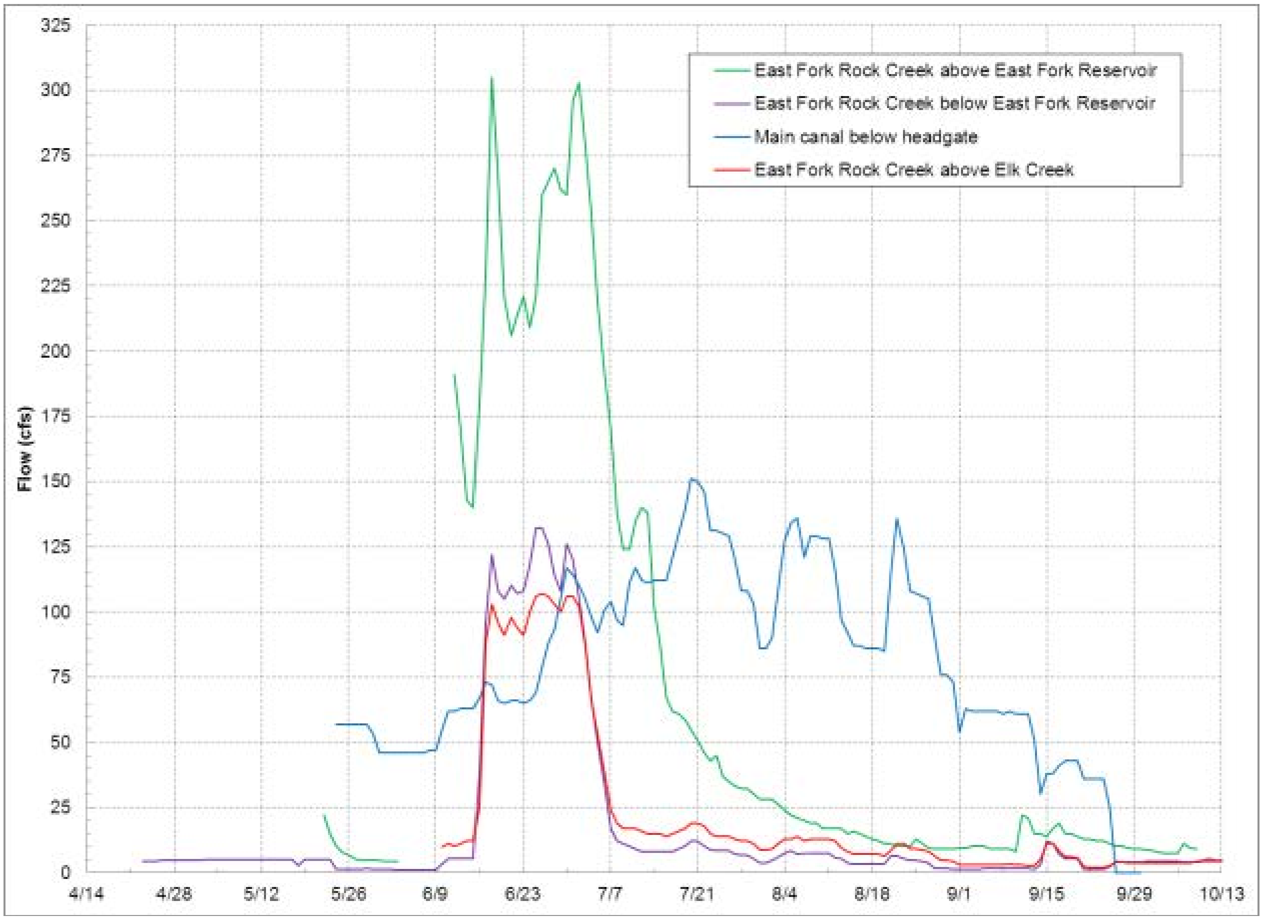


Figure I-10. DNRC continuous flow data collected in 2010.

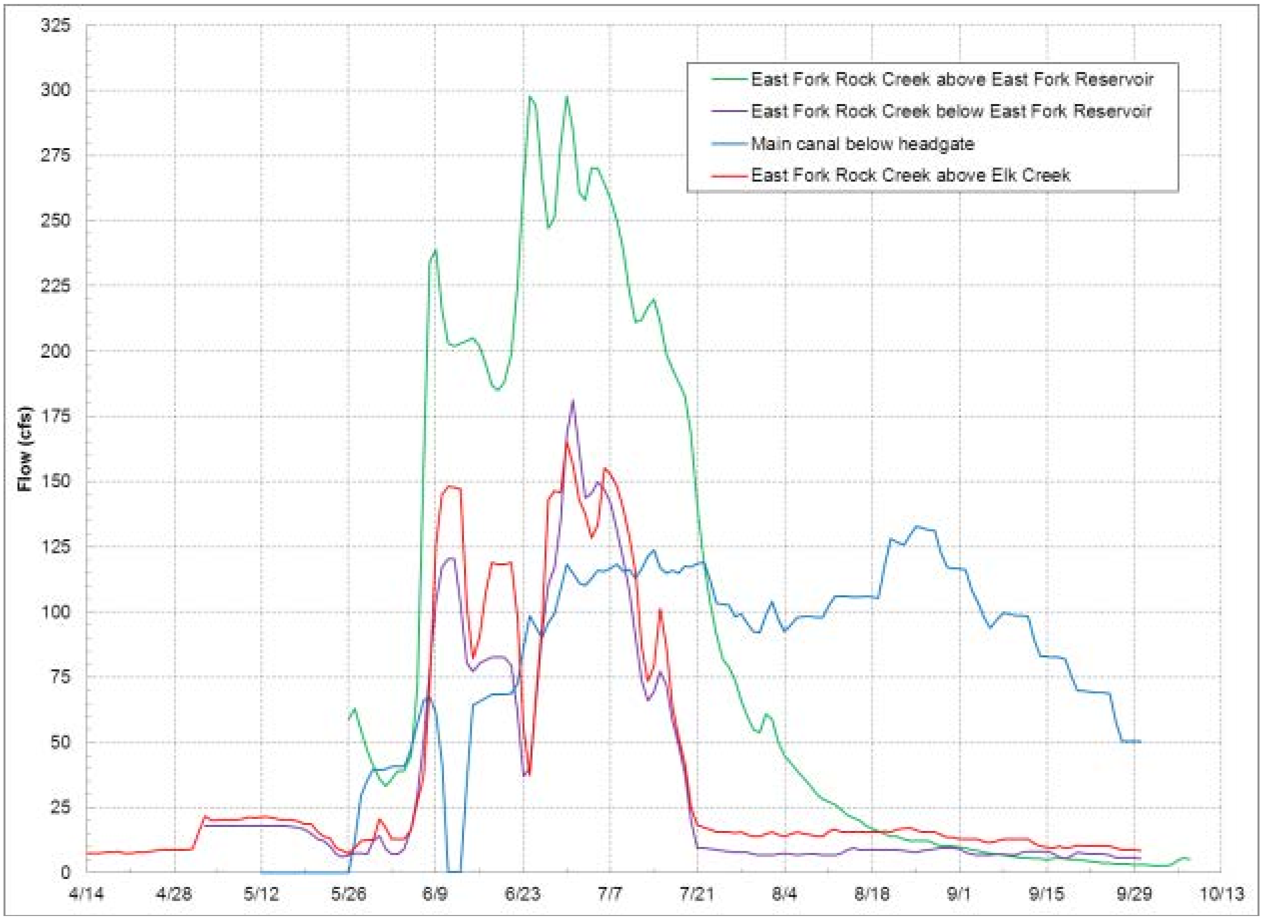


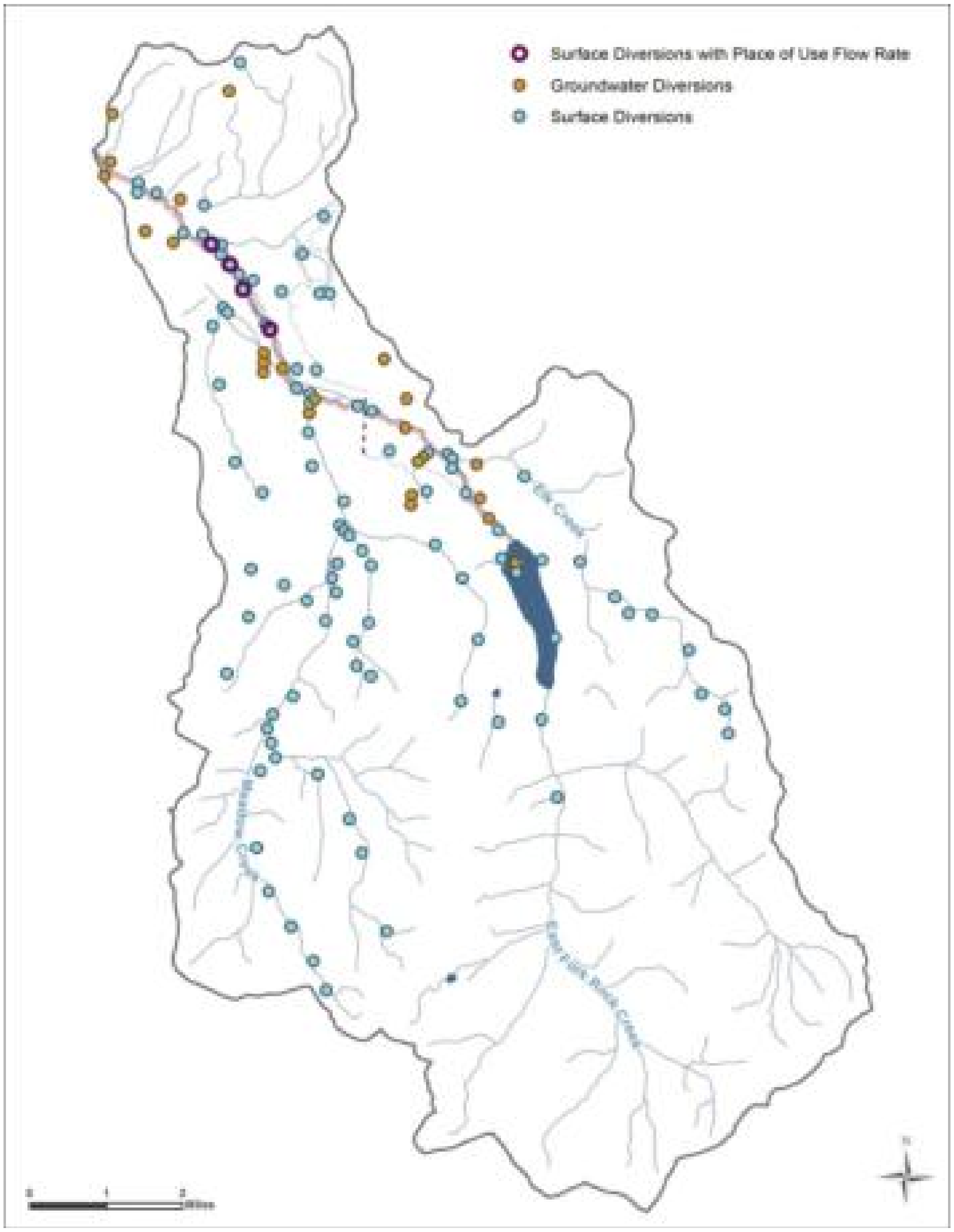
Figure I-11. DNRC continuous flow data collected in 2011.

On the basis of a review of online water rights data (ftp://nris.mt.gov/dnrc), 164 surface and groundwater diversions are in the East Fork Rock Creek watershed (**Figure I-12**). *Points of diversion* and *places of use* spatial data were obtained from the Montana Natural Resource Information System (Montana State Library, 2013). Of the 164 diversions in the East Fork Rock Creek watershed, 44 are directly from East Fork Rock Creek, 35 are along the creek below East Fork Reservoir, and rate and acreage data are available for four of these diversions (**Figure I-12**). These four diversions correspond to places of use, and all four diversions are listed with an active status for flood irrigation. Maximum allowable flow rates for these four diversions are shown in **Table I-3**.

Table I-3. Surface water rights along the mainstem of East Fork Rock Creek

WR ID	WR number	River kilometer	Means of diversion	Rate[a] (cfs)	Acreage[b]
223563	76E 136895 00	7.13	Direct from source	0.75	30
293491	76E 15477 00	5.1	Headgate	5.75	10
205791	76E 116992 00	4.35	Headgate	5.75	8
223563	76E 136895 00	6	Direct from source	8.55	70

Notes: cfs = cubic feet per second; WR = water right.
[a] Maximum water flow rate allowed by the water right.
[b] Acreage of land that is irrigated at the place of use.



Source of points of diversion data: (Montana State Library, 2013)

Figure I-12. Surface and groundwater diversions in the East Fork Rock Creek watershed.

I3.0 STREAM TEMPERATURE

Stream temperature data were collected in 2010 by DEQ and 2011 by DNRC. Monitoring locations are shown in **Figure I-9**. These data are summarized separately below because they represent different periods influenced by weather and hydrology unique to those periods. A brief discussion of all the available temperature data and factors that could be influencing stream temperature follows.

I3.1 2011 Stream Temperature Data

DNRC collected continuous temperature data at six locations along East Fork Rock Creek in 2011: above and below East Fork Reservoir, above Elk Creek, at Walden Bridge, above Meadow Creek, and above the mouth on Middle Fork Rock Creek (**Figure I-9**). Data loggers recorded temperatures every half hour for 4 months between June 20–21, 2011, and October 9–10, 2011. Box plots of these data show that stream temperatures are much cooler above the reservoir than below (**Figure I-13**). Above the reservoir, temperatures ranged from 35.9 to 47.9 °F; below the reservoir temperatures ranged from 37.9 to 62.5 °F. Below the reservoir, median temperatures are fairly constant from the upstream-most site, which is below the reservoir, downstream to the mouth.

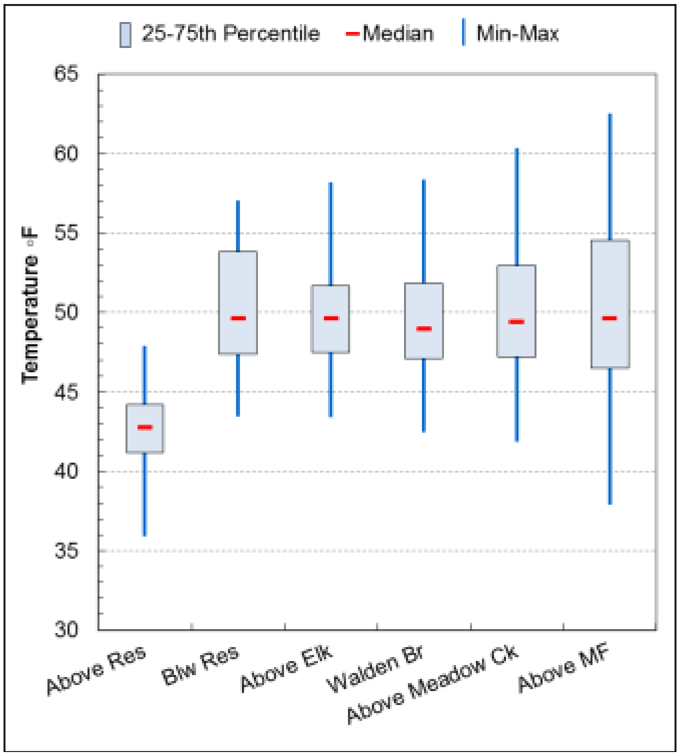


Figure I-13. Box-and-whisker plots of DNRC temperature data collected between June 20 and October 10, 2011.

As shown in **Figure I-13**, maximum temperatures at these monitoring locations appear to increase gradually in a downstream direction from 57.1 to 62.5 °F. Between the beginning of the monitoring period and the end of August, the daily variability in maximum temperatures between sites was high (**Figure I-14**). Beginning in September, the between site variability in daily maximum temperatures virtually disappears.

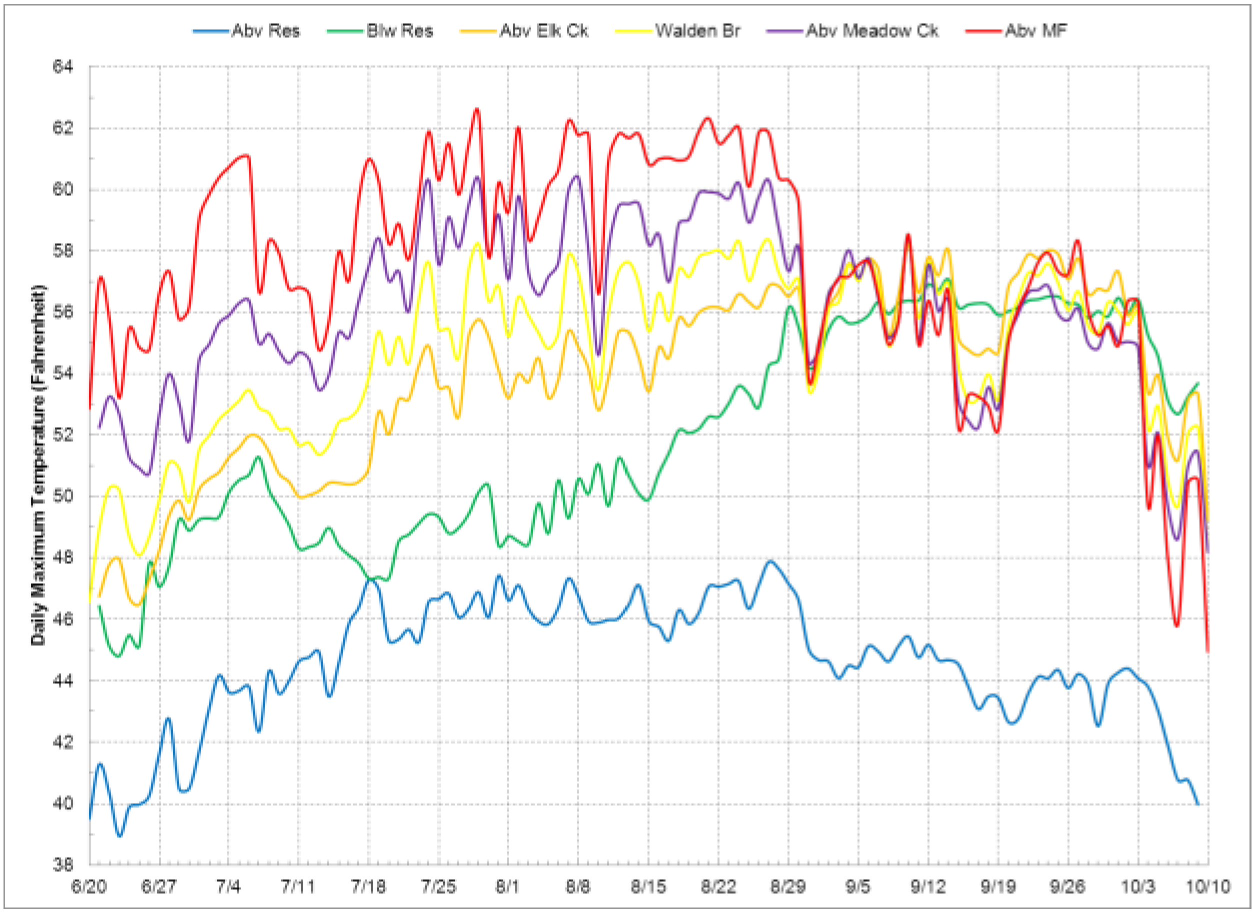


Figure I-14. Daily maximum temperature, East Fork Rock Creek, June 20 to October 10, 2011.

I3.2 2010 Stream Temperature Data

DEQ collected continuous temperature data at six locations along East Fork Rock Creek (i.e., sites C02ROCEF02, C02ROCEF03, C02ROCEF04, C02ROCEF05, C02ROCEF10, and C02ROCEF20) and at one location along Meadow Creek (C02MEDOC01) in 2010 (**Figure I-9**). Data loggers recorded temperatures every half hour for 2 months between July 27 and 28, 2010, and September 26 and 27, 2010. Field parameters (including water temperature) were collected during data logger deployment and retrieval. DEQ also collected instantaneous water temperatures during water quality monitoring in 2004 and 2011. These data are summarized in **Table I-4**.

DEQ's upstream-most site is below the East Fork Dam, upstream of the canal diversion (C02ROCEF05). Maximum recorded temperatures generally increased in a downstream direction ranging from 58.0 °F below the dam (C02ROCEF05) to a maximum of 64.4 °F approximately one mile below the confluence with Meadow Creek (C02ROCEF03). With one exception, unlike 2011, the between-site variability in daily maximum temperatures is relatively constant throughout the 2010 monitoring period. The exception is that the maximum daily temperatures at the two uppermost sites (C02ROCEF05 and C02ROCEF20) are lower than those recorded at the downstream sites between the beginning of the monitoring period and mid-August (**Figure I-15**).

For the monitoring period, the maximum temperatures in Meadow Creek were among the highest (i.e., 63.8 °F).

Table I-4. Instantaneous water temperature measurements (°F)

Station	7/26/ 2004	7/27/2004	7/12/2007	7/26-29/2010	8/30/2010	9/28/2010
C02ROCEF05	--	--	--	47.7	55.9	53.4
C02ROCEF20	59.3	--	--	49.1	--	53.8
C02ROCEF04	--	--	--	52.5	52.7	57.0
C02ROCEF03	--	--	--	50.0	50.7	55.2
C02ROCEF10	--	61.7	64.8	55.4	49.6	49.8
C02ROCEF02	--	--	--	52.7	--	47.5

Note: Temperatures were originally reported in degrees Celsius and were converted to degrees Fahrenheit.

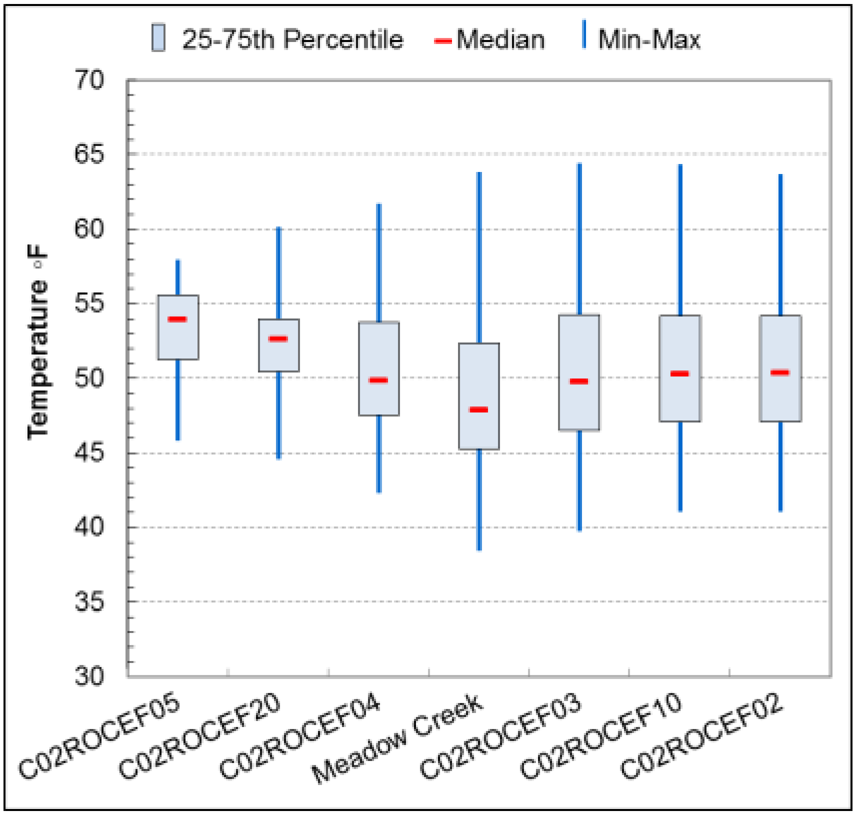


Figure I-15. Box-and-whisker plots of DEQ temperature data collected between July 27 and September 27, 2010.

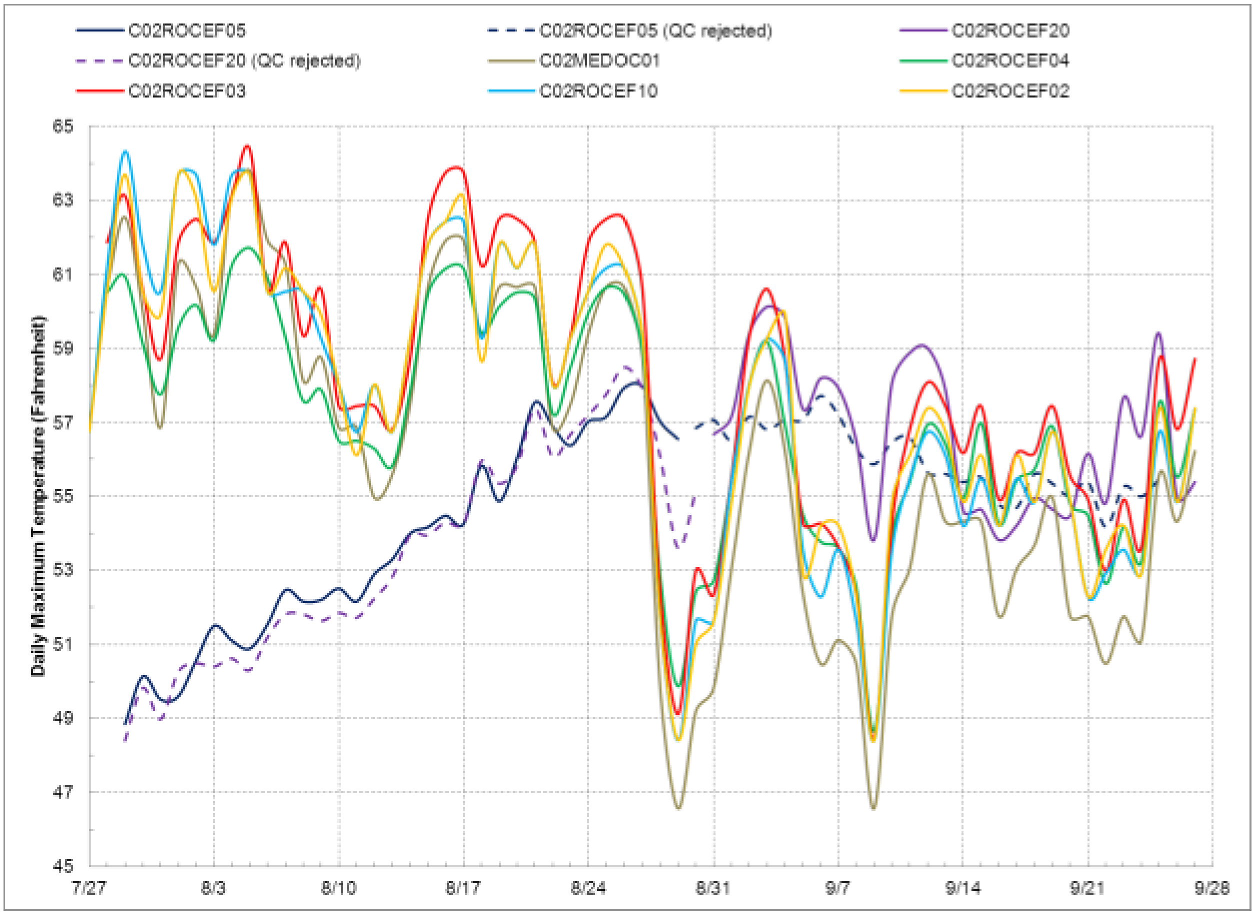


Figure I-16. Daily maximum temperature, East Fork Rock Creek, July 27 to October 27, 2010.

I3.3 Stream Temperature Summary

The 2011 stream temperatures are much cooler upstream of the East Fork Reservoir than downstream (**Figure I-13**). This could be a result of the water warming in the East Fork Reservoir and subsequent release of the warmed water below the dam. It could also be a result of a fairly significant change in landform/topography and vegetation that occurs roughly where the dam was built (i.e., transition from relatively steep, mountainous, coniferous forest in the headwater to more gentle, open, scrub/shrub/grassland in the lower reaches of the watershed). The 2011 data also suggest that diversion of up to approximately 130 cfs into the canal (**Figure I-11**) could be influencing daily maximum stream temperatures downstream from the dam (**Figure I-14**).

The 2010 stream temperature data, especially without data upstream of East Fork Reservoir, do not exemplify similar influences from the East Fork Reservoir or the canal. The most striking observation with the 2010 data is the difference in maximum daily temperatures between the upstream and downstream monitoring sites between the beginning of the monitoring period and mid-August (**Figure I-16**). This suggests some kind of warming influence downstream from site C02ROCEF20. While this could be a natural phenomenon as the stream flows through the more open valley downstream, potential anthropogenic influences are irrigation withdrawals and returns, degradation of the riparian vegetation, and altered stream morphology.

I4.0 MODEL SETUP

EPA and DEQ selected the QUAL2K model to simulate temperatures in East Fork Rock 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 cell. 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. The processes employed in QUAL2K can address nutrient cycles, algal growth, and dissolved oxygen dynamics. QUAL2K also 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, p. 19).

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

The following describes the process that was used to setup the QUAL2K models for East Fork Rock Creek.

I4.1 CHANNEL FLOW-PATH

East Fork Rock Creek, as delineated in the National Hydrography Dataset, is a 19.0-mile perennial stream. The outlet of East Fork Reservoir is at RM 9.7. DEQ evaluated multiple locations along the creek from its mouth upstream to the dam on East Fork Reservoir. DNRC evaluated multiple sites along East Fork Rock Creek from the mouth upstream to the dam and evaluated one site upstream of the reservoir. The QUAL2K model for East Fork Rock Creek was developed for the 9.7-mile portion of the creek from the confluence with Middle Fork Rock Creek upstream to the dam at East Fork Reservoir.

In the National Hydrography Dataset the U.S. Geological Survey has delineated multiple named tributaries to East Fork Rock Creek. Elk Creek (RM 8.2) and Meadow Creek (RM 5.5) were explicitly modeled, as point sources, in the QUAL2K model. All other tributaries were implicitly modeled as part of the net diffuse flow.

The modeled flow path is shown in **Figure I-17**.

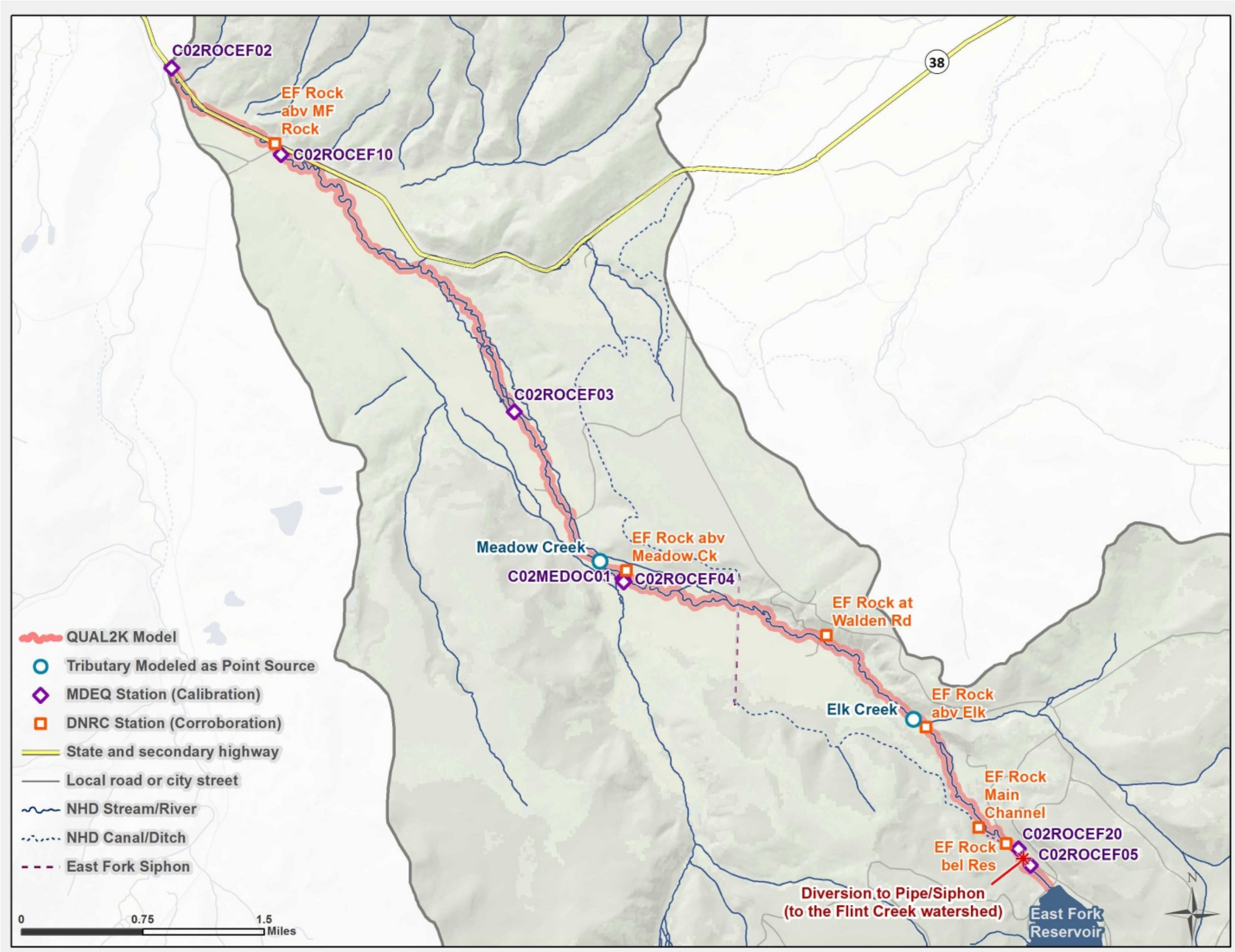


Figure I-17. QUAL2K model.

I4.2 Stream Segmentation

The East Fork Rock Creek's impaired segment was divided into nine linked segments (**Figure I-18**) identified as A, B, C, D, E, F, G, H, and I (mouth to dam on East Fork Reservoir). The segmentation locations were selected on the basis of available diurnal temperature and flow data (available at the DEQ and DNRC sample sites), changes in vegetation (**Figure I-7**), and changes in effective shade (**Figure I-8**). The existing conditions scenario is defined as segments I, H, G, F, E, D, C, B, and A; DEQ collected data along these segments that were used to develop the model.

Each of the eight linked segments was further subdivided into elements or computational units. The number of computational units was 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. The element length was selected to be short enough to increase the spatial resolution and long enough to support model stability.

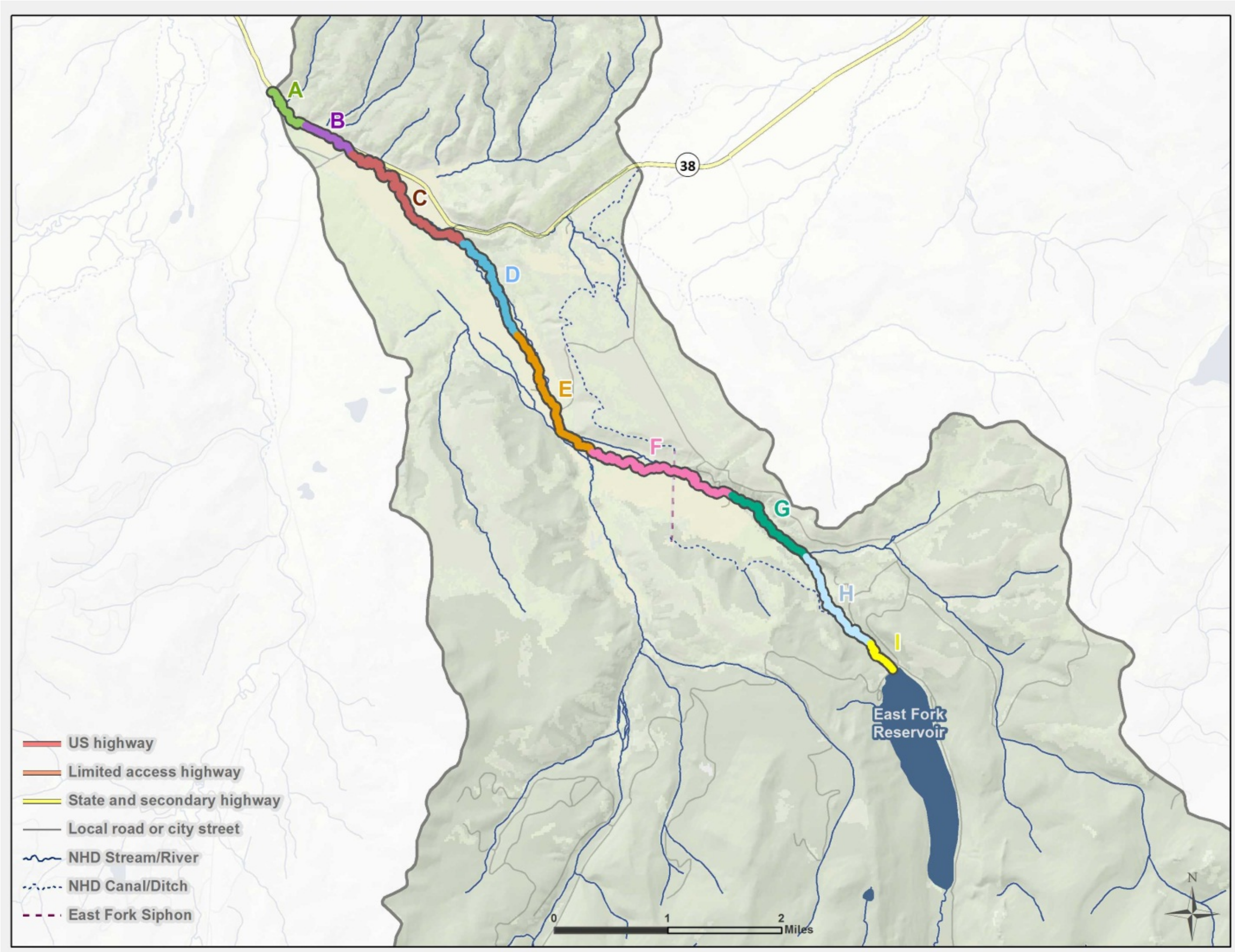
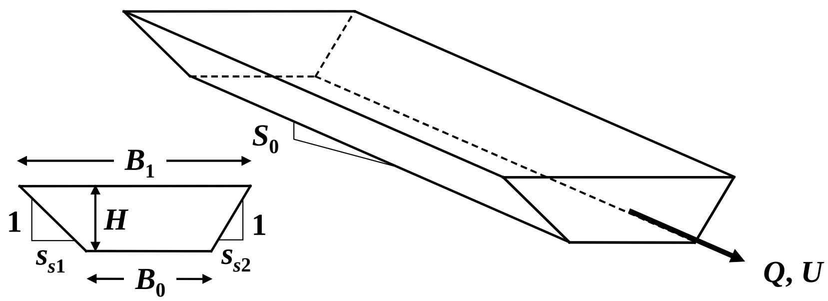


Figure I-18. Model segmentation along East Fork Rock Creek.

I4.3 Channel Geometry

The channel geometry data that was input into QUAL2K was derived from DEQ field work (for the original data, see **Appendix IA**; and for the model inputs and assumptions, see **Appendix IC**). Manning's n was estimated during a field visit (Water & Environmental Technologies, 2011). Channel slope were calculated using field-collected elevation data (Water & Environmental Technologies, 2011). Stream bottom width and the sides of the trapezoidal cross-section assumed for modeling (**Figure I-19**) were estimated using flow-interval data collected when flow was measured at sites C02ROCEF20, C02ROCEF04, C02ROCEF03, C02ROCEF10, and C02ROCEF02 (Water & Environmental Technologies, 2011); these sites are in reaches I, F, E, C, and A, respectively.[5]. The stream bottom widths and sides of the assumed trapezoidal cross-section for modeling for the reaches without flow-interval data were estimated via linear interpolation between the sites with flow-interval data.

[5] The five cross-sections developed from flow-interval data collected on the same day were found to be more representative of the channel and yielded a better calibration than the cross-sections collected at three sites in 2011 (Shade 4, EFRK 01-02, and EFRK 03-03).



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 I-19. Idealized trapezoidal channel assumed in QUAL2K.

I4.4 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 2010 by DEQ and DNRC along the mainstem were used to derive the flow inputs required to run the QUAL2K model for the calibration day of July 29, 2010 (**Appendix IC**, **Table IC-6**)**.** DEQ measured flow at the mouth of Meadow Creek (i.e., C02MEDOC01) on July 29, 2010, and the flow (12.37 cfs) was input into QUAL2K.

The only available flow measurement on Elk Creek occurred on August 30, 2011 (1.53 cfs). Flow for July 29, 2010, was estimated using the drainage area ratio method and the DNRC flow gage on East Fork Rock Creek above East Fork Reservoir. This DNRC flow gage was used with the drainage area ratio method because all other measured flows occurred at sites downstream of East Fork Reservoir. Sites below the reservoir are influenced by reservoir and dam operation and are not suitable for applying the drainage area ratio method.

The headwaters inflow (the upstream boundary condition in QUAL2K) was assumed to be equivalent to the flow estimated at site C02ROCEF05 (114.7 cfs), which was based on a water balance of flows measured at C02ROCEF20 and in the main channel of the diversion canal.

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 was positive (i.e., inflow), whereas diffuse flow from reaches E through A was negative (i.e., outflow). Irrigation diversions are along reaches E through A. The negative flow balances could indicate that the irrigation diversion outflows exceeded the tributary and irrigation return inflows. The flow balance is summarized in **Figure I-20**.

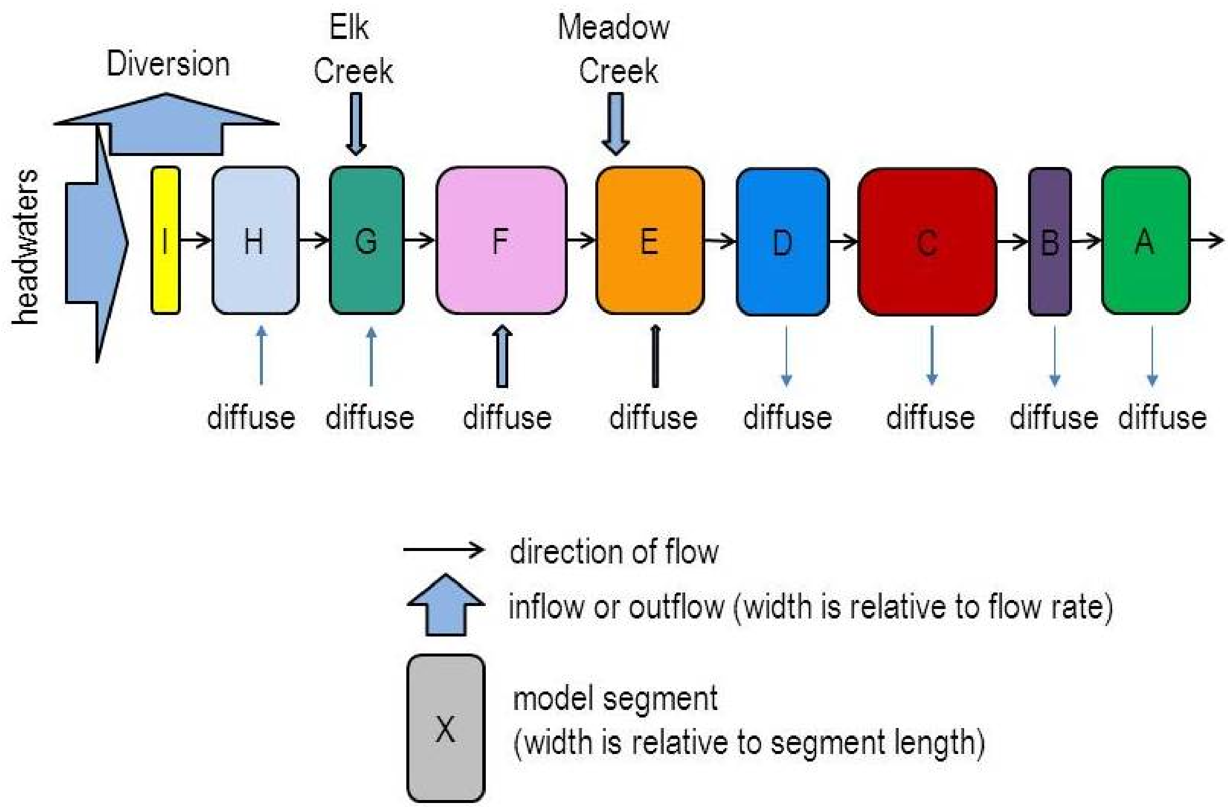


Figure I-20. Schematic representation of inflows and outflows to East Fork Rock Creek.

I4.5 Weather

Weather inputs were compiled from the closest station recording the necessary data (**Appendix IC**, **Table IC-9** and **Table IC-10**). These data were used as model input for the July 29, 2010 critical date. Air temperature, wind speed, relative humidity, and solar radiation data were obtained from the Philipsburg RAWS, which is at an elevation of 5,280 feet (**Figure I-2**). Air temperature and dew point temperature data from this station were corrected to account for the elevation difference between the station and the impaired stream. Wind speed was corrected for the height differences of the sensor at Philipsburg RAWS (reported as 20 feet) and the assumed height in QUAL2K (7 meters, which is approximately 23 feet). Cloud cover was estimated on the basis of available hourly data at the Butte municipal airport (WBAN 24135) 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 Butte municipal airport on July 29, 2010; therefore, zero percent was input for all 24 hours in the QUAL2K model.

I4.6 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. This file contains Visual Basic for applications routines adapted from the Oregon Department of Environmental Quality by Washington State Department of Ecology to calculate topographic and canopy shade using solar time and position relative to the earth, and the solar position relative to the stream position, topographic, and vegetative canopy.

Riparian shade was estimated using GIS and the Shadev3.0.xls (for a discussion of how shade was estimated, see **Section I2.3**). The hourly shade inputs per reach for the proposed QUAL2K model segments are summarized in **Figure I-21**; the input values are also presented in **Appendix IC** in **Table IC-11**.

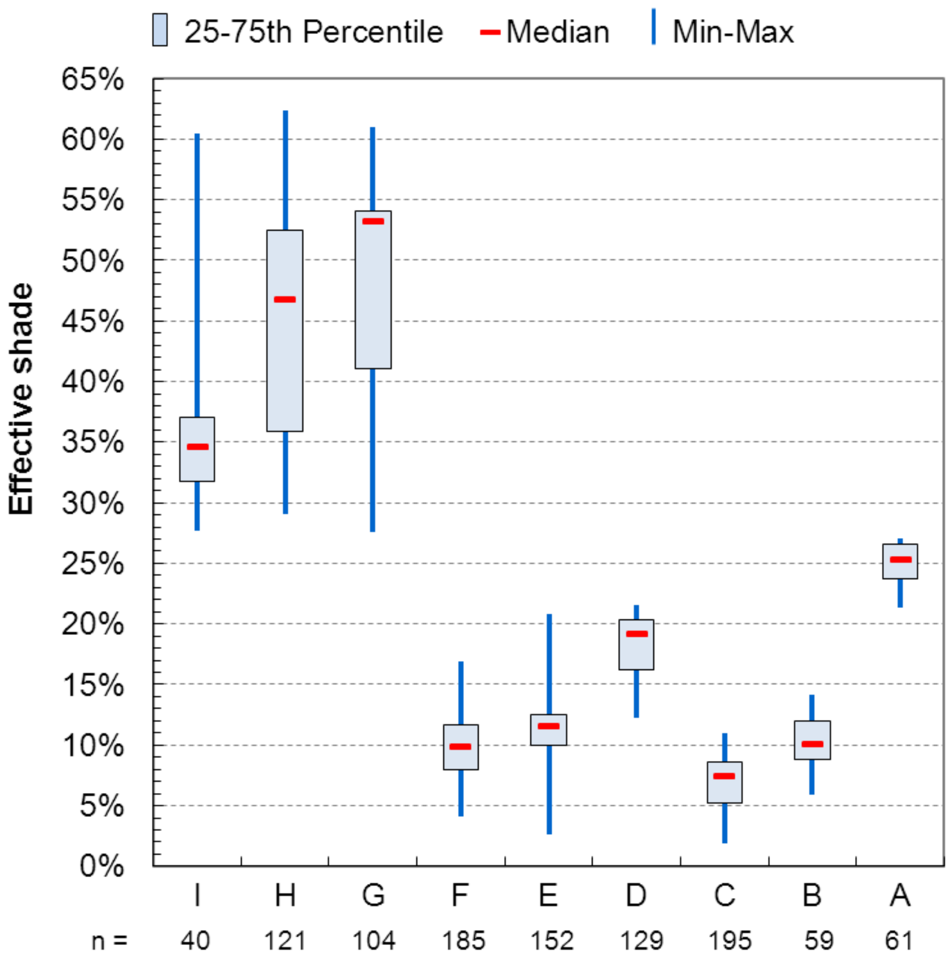


Figure I-21. Box-and-whisker plot evaluation of effective shade output.

I4.7 Heat

QUAL2K users can select various heat transfer model input parameters. For this project, default values recommended by Chapra et al. (2008) were used; the inputs are presented in **Table IC-12** in **Appendix IC**.

I5.0 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 (Council for Regulatory Environmental Modeling, 2009).

Discussions of calibration and validation are in the *Quality Assurance Project Plan for Montana TMDL Support: Temperature Modeling* (Tetra Tech, Inc, 2012).

I5.1 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 East Fork Rock 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 observed value minus the simulated 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, Inc, 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.

I5.2 Calibration and Validation Periods

The period for calibration and validation for developing the temperature QUAL2K model were selected on the basis of the available data. The available flow and stream geometry data suggest that travel time in the East Fork Rock Creek, from East Fork Reservoir to the mouth, is less than one day. Average velocities were calculated from depth-velocity interval data recorded when flow was monitored on 13 occasions across 5 sites. Average velocities, at sites below the pipeline diversion, typically increased from upstream to downstream. Average velocity ranged from 0.81 to 2.57 feet per second, with an average of 1.74 feet per second. Such velocities yield travel times of 5.5 to 28 hours, with an average of 9.3 hours.

Available precipitation data were also considered during the selection of calibration and validation periods (see thermographs with daily precipitation in **Appendix ID**). The warmest stream temperatures occurred during July when there was no precipitation. Precipitation events resulted in cooling, rather than warming, the stream, likely because of cooler ambient air temperatures.

Therefore, a single day each was selected for the calibration period and the validation period. The calibration period (July 29, 2010) and validation period (August 21, 2011) consisted of a warm day without precipitation on that day or preceding days during summer low-flows, which allows for calibration to conditions that would be similar to that of critical conditions (i.e., warm water with low flows). On the calibration period and preceding week, the canal diverted 94 percent of the flow from East Fork Reservoir; similarly, the canal diverted 95 percent of the flow during the validation period and 96 percent of the flow during the week preceding the validation period. The model run-time was three days, with one day of input for all the parameters (calibration or validation period); this ensures that water had enough time to travel through the entire system.

I5.3 Calibration Results

Temperature calibration for the East Fork Rock Creek QUAL2K model relied on a comparison of model predictions to observations at the six temperature loggers in the temperature-impaired segment (C02ROCEF05, C02ROCEF20, C02ROCEF04, C02ROCEF03, C02ROCEF10, and C02ROCEF02).

All the modeled minima, means, and maxima are within 2 °C of the corresponding observed minima, means, and maxima (see **Appendix IC**, **Table IC-13**). All but two of the relative differences are less than 10 percent; these two exceptions are the daily minima at C02ROCEF10 (15 percent) and C02ROCEF02 (11 percent). Therefore, in accordance with the QAPP (Tetra Tech, Inc, 2012), the calibration is acceptable.

The calibration results are displayed in **Figure I-22** and **Table I-5** in Fahrenheit to facilitate comparisons with model scenarios that are discussed in **Section I6.0**.

Table I-5. Model calibration results for July 29, 2010 (°F)

Daily temperature	Source	C02ROCEF*					
		*05	*20	*04	*03	*10	*02
Maximum	QUAL2K	49.6	50.7	58.2	60.4	65.6	66.4
	Observed	48.8	49.8	60.9	63.1	64.3	63.7
	Difference	+0.8	+0.9	-2.7	-2.8	+1.3	+2.7
Mean	QUAL2K	47.4	47.8	50.4	51.9	53.9	54.3
	Observed	47.6	47.4	52.9	53.9	54.9	54.8
	Difference	-0.2	+0.4	-2.5	-2.0	-1.0	-0.5
Minimum	QUAL2K	46.2	46.2	45.6	45.2	44.8	44.9
	Observed	45.8	46.2	46.6	46.5	47.1	46.5
	Difference	+0.4	0.0	-1.0	-1.3	-2.3	-1.6

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree. The difference is calculated as the QUAL2K minus observed.

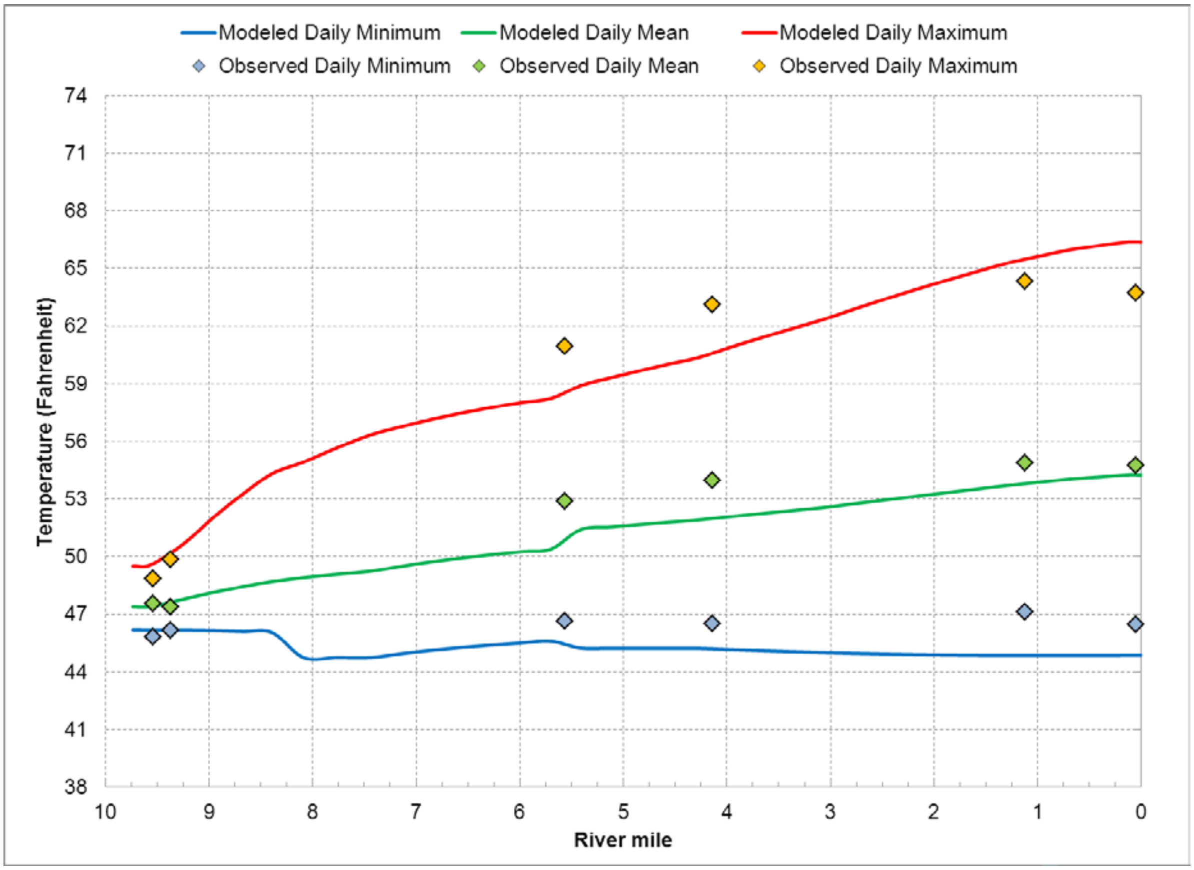


Figure I-22. Calibration time period (July 29, 2010).

I5.4 Validation Results

Model validation was determined by a second model run that was conducted under different hydrological and weather conditions (August 21, 2011). DNRC temperature and flow data were used to validate.

All the modeled minima, means, and maxima are within 2 °C of the corresponding observed minima, means, and maxima (see **Appendix IC**, **Table IC-14**). All but one of the relative differences is less than 10 percent; this exception is the maximum at the site above Elk Creek (11 percent). Therefore, in accordance with the QAPP (Tetra Tech, Inc, 2012), the validation is acceptable.

The validation results are displayed in **Table I-6** and **Figure I-23** in Fahrenheit to facilitate comparisons with model scenarios that are discussed in **Section I6.0**.

Table I-6. Model validation results for August 21, 2011 in Fahrenheit

Daily temperature	Source	blw Res	abv Elk Ck	Walden Br	abv Meadow	abv MF
Maximum	QUAL2K	53.2	53.6	56.0	60.0	62.3
	Observed	52.6	56.2	57.9	59.9	62.3
	Difference	+0.6	-2.6	-1.9	+0.1	0
Mean	QUAL2K	50.4	49.2	49.6	50.5	51.9
	Observed	50.6	50.6	50.9	52.0	53.2
	Difference	-0.2	-1.4	-1.4	-1.5	-1.2
Minimum	QUAL2K	49.0	47.0	46.3	45.5	45.2
	Observed	49.3	47.5	46.8	46.9	45.6
	Difference	-0.3	-0.5	-0.5	-1.4	-0.4

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree. The difference is calculated as the QUAL2K minus observed.

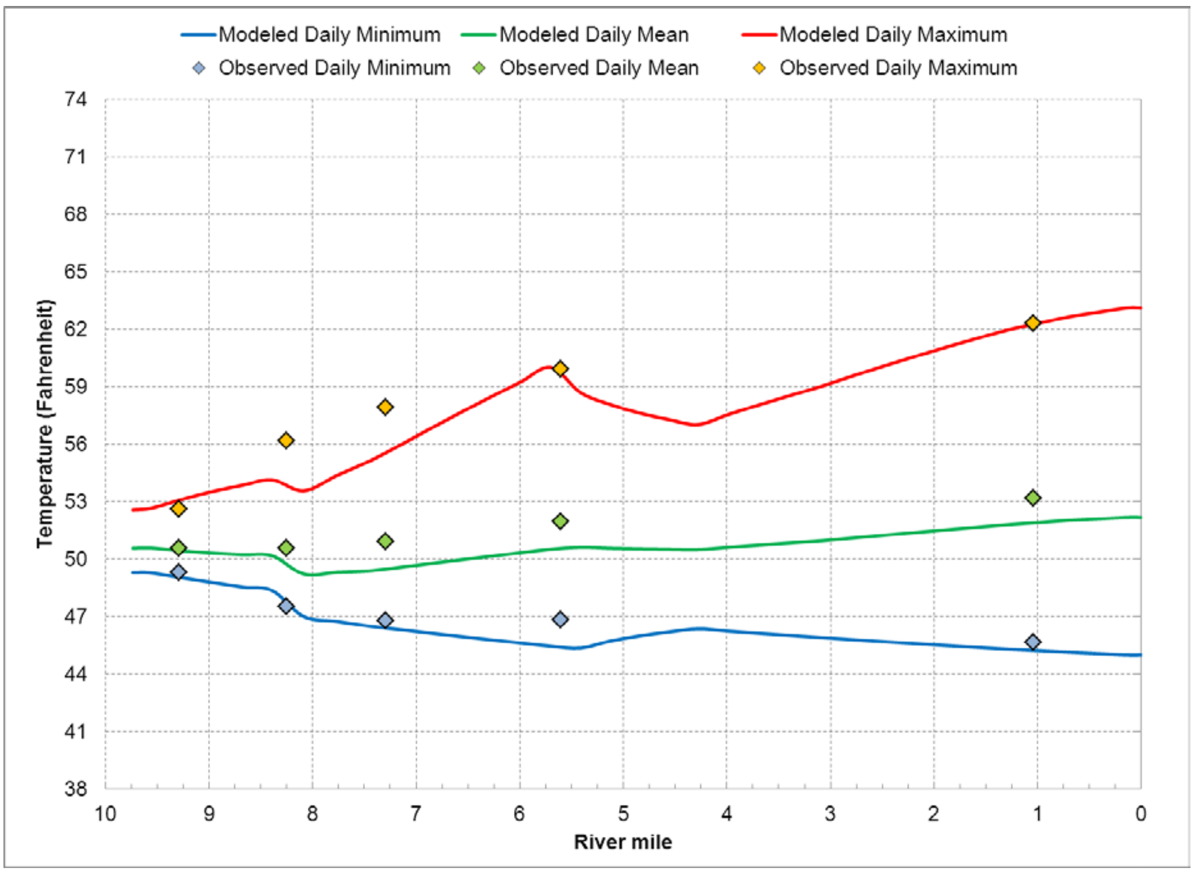


Figure I-23. Validation period (August 21, 2011).

I6.0 Model Scenarios

The East Fork Rock Creek QUAL2K model was used to evaluate instream temperature response associated with the following scenarios in **Table I-7**. The table summarizes the alterations to input parameters for each model scenario.

Table I-7. Model scenarios and summary of inputs

Scenario	Inputs
Existing conditions (calibration)	As discussed in **Section I6.1**
Existing conditions with low flow	Flow below the Flint Creek diversion is set to 5 cfs
Full potential shade	Shade increased in each reach depending on the vegetation
Full potential shade with low flow	Flow below the Flint Creek diversion is set to 5 cfs and shade increased in each reach depending on the vegetation
15% water savings from improved irrigation delivery and application efficiencies, and allowing that water savings to flow down East Fork Rock Creek past the main diversion	Increase inflows (reduce Flint Creek diversion by 15%)
15% water savings and full potential shade	Increase inflows (reduce Flint Creek diversion by 15%) and shade increased in each reach depending on the vegetation

The following sections present a discussion of the modifications to the QUAL2K models and the results for each scenario.

I6.1 Existing Conditions

The calibration model serves as the existing conditions scenario (i.e., baseline) for which to construct the other scenarios and compare the results against. This model represents dry conditions during July. The construction of the model and its inputs are discussed in **Section I4.0**.

I6.2 Existing Conditions with Low Flow

In this scenario, the flow inputs to the QUAL2K model are decreased to represent low-flow conditions, simulating the stream dynamics during an exceptionally dry season. DNRC, which manages East Fork Reservoir and the diversion to the Flint Creek watershed, maintains at least 5 cfs below the diversion. In this scenario, the water balance was altered such that 5 cfs of flow was present in the model just below the diversion.

This low-flow condition scenario resulted in slightly higher temperatures along most of the stream. Daily mean temperatures increased, as compared to the existing condition scenario, by 0.1 °F and the daily maximum temperatures increased between 0.1 and 0.3 °F. **Table I-8** presents the results at the DEQ sample sites and **Figure I-24** presents the continuous results along East Fork Rock Creek.

Table I-8. Low-flow conditions results

Daily temperature	Source	C02ROCEF*					
		*05	*20	*04	*03	*10	*02
Maximum	Existing	49.6	50.7	58.2	60.4	65.6	66.4
	Scenario	49.6	50.9	58.5	60.5	65.9	66.6
	Difference	***<-0.05***	+0.2	+0.3	+0.1	+0.3	+0.2
Mean	Existing	47.4	47.8	50.4	51.9	53.9	54.3
	Scenario	47.4	47.9	50.5	52.0	54.0	54.4
	Difference	***<-0.05***	+0.1	+0.1	+0.1	+0.1	+0.1
Minimum	Existing	46.2	46.2	45.6	45.2	44.8	44.9
	Scenario	46.2	46.2	45.6	45.2	44.8	44.9
	Difference	<+0.05	<+0.05	***<-0.05***	***<-0.05***	<+0.05	<+0.05

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

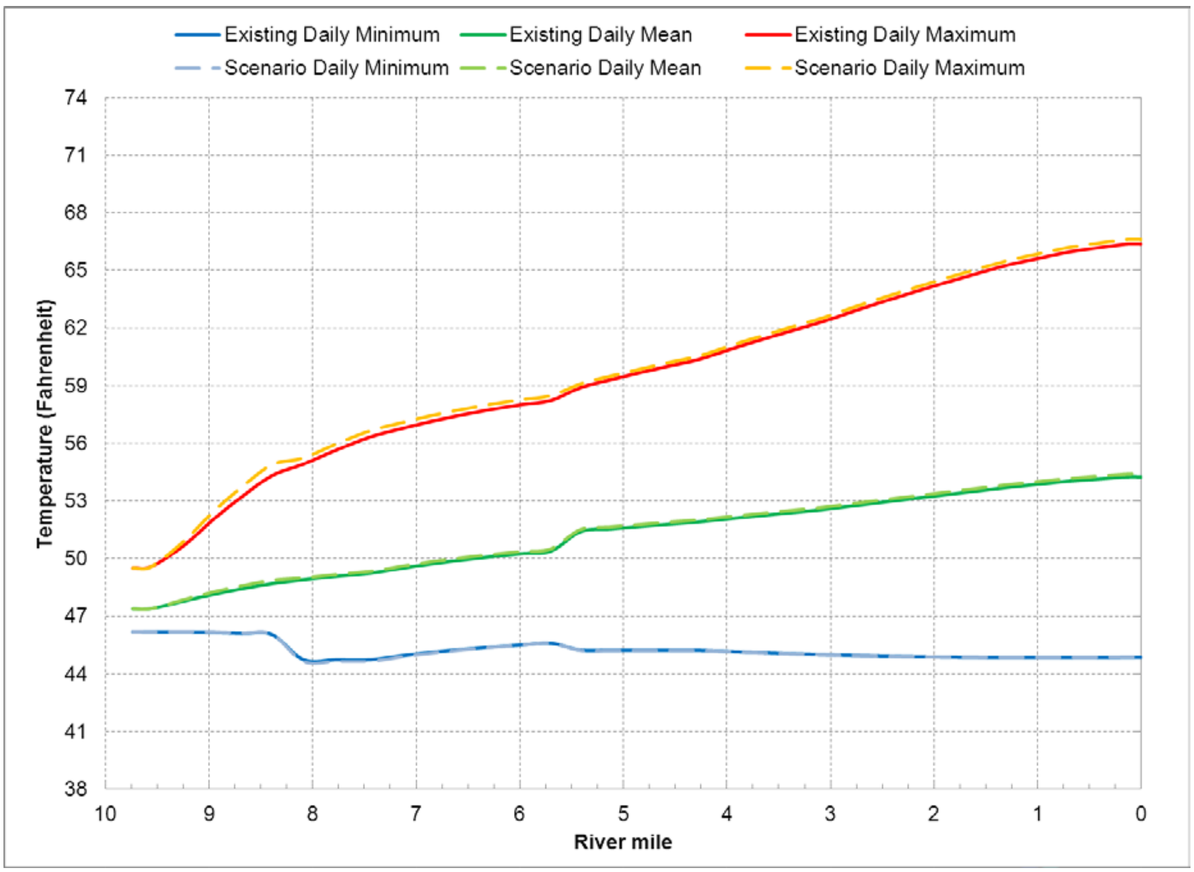


Figure I-24. Low-flow conditions results.

I6.3 Full Potential Shade

The full potential shade scenario uses the existing conditions model and increases shading along the creek depending on the vegetation present in each reach. The shade in reaches A through F was set equivalent to the 24-hour shade input in reach A. The shade in reach G remained the same, and the shade in reaches H and I was set equivalent to the 24-hour shade input in reach H. These full potential shade assignments are based on analyses performed by DEQ; the results of these analyses are summarized in the following paragraph.

On the basis of an DEQ review of the vegetation data and aerial photos, it appears that vegetation conditions similar to the EFRC Shade 1 (see the vegetation map **Figure I-7**), which is characterized by medium conifer in the overstory with dense willows and shrubs in the understory, would be achievable in East Fork Rock Creek below East Fork Reservoir, in reaches H and I. The potential cover for reach G is mixed high level based on data from Shade 2. The potential cover for reaches A through F is based on site Shade 6, which is medium willow and shrub; however, most of the stream along these reaches is below this potential condition.

This scenario resulted in cooler water temperatures along most of East Fork Rock Creek. Daily mean temperatures decreased, as compared to the existing condition scenario, between 0.0 and 0.8 °F and daily maximum temperatures decreased between 0.0 and 1.8 °F. **Table I-9** presents the results at the DEQ sample sites and **Figure I-25** presents the continuous results along East Fork Rock Creek.

Table I-9. Full potential shade results

Daily temperature	Source	C02ROCEF*					
		***05**	***20**	***04**	***03**	***10**	***02**
Maximum	Existing	49.6	50.7	58.2	60.4	65.6	66.4
	Scenario	49.6	50.7	57.6	59.5	63.8	64.6
	Difference	***<-0.05***	***<-0.05***	***-0.6***	***-0.9***	***-1.8***	***-1.8***
Mean	Existing	47.4	47.8	50.4	51.9	53.9	54.3
	Scenario	47.4	47.8	50.1	51.6	53.1	53.5
	Difference	***<-0.05***	***<-0.05***	***-0.3***	***-0.3***	***-0.8***	***-0.8***
Minimum	Existing	46.2	46.2	45.6	45.2	44.8	44.9
	Scenario	46.2	46.2	45.6	45.2	44.8	44.8
	Difference	0	0	***<-0.05***	***<-0.05***	***<-0.05***	***<-0.05***

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree. The difference is calculated as the existing subtracted from the scenario. Negative, ***italic bold*** results indicate that the scenario yields cooler instream temperatures as compared to the existing condition; positive, shaded results indicate that the scenario yielded warmer instream temperatures as compared to the existing conditions.

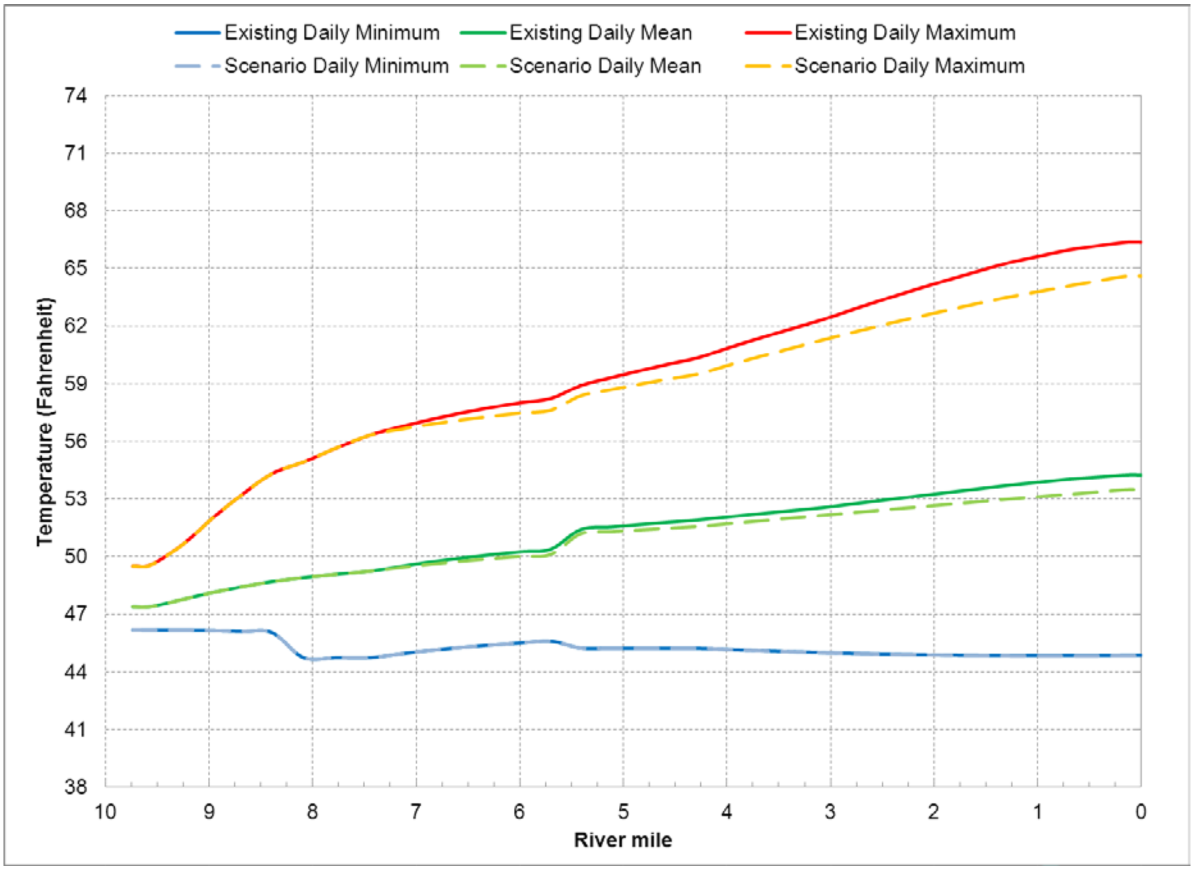


Figure I-25. Full potential shade results.

I6.4 Full Potential Shade with Low-Flow

The full potential shade scenario using low-flow conditions is a combination of the scenarios presented in **Sections I6.2** and **I6.3**. Flow conditions were designed to replicate a dry season, and shading was increased to approximate a mature riparian corridor.

This scenario resulted in cooler water temperatures along the lower portions of East Fork Rock Creek. Daily mean temperatures changed, as compared to the existing condition scenario, between –0.7 and 0.1 °F and daily maximum temperatures changed between –1.6 and 0.2°F. **Table I-10** presents the results at the DEQ sample sites and **Figure I-26** presents the continuous results along East Fork Rock Creek.

Table I-10. Full potential shade with low-flow conditions results

Daily temperature	Source	C02ROCEF*					
		*05	*20	*04	*03	*10	*02
Maximum	Existing	49.6	50.7	58.2	60.4	65.6	66.4
	Scenario	49.6	50.9	57.8	59.7	64.0	64.8
	Difference	***<-0.05***	+0.2	***-0.4***	***-0.7***	***-1.6***	***-1.6***
Mean	Existing	47.4	47.8	50.4	51.9	53.9	54.3
	Scenario	47.4	47.9	50.2	51.7	53.2	53.6
	Difference	***<-0.05***	+0.1	***-0.2***	***-0.2***	***-0.7***	***-0.7***
Minimum	Existing	46.2	46.2	45.6	45.2	44.8	44.9
	Scenario	46.2	46.2	45.6	45.2	44.8	44.8
	Difference	<+0.05	<+0.05	***<-0.05***	***<-0.05***	***<-0.05***	***<-0.05***

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The difference is calculated as the existing subtracted from the scenario. Negative, ***bold italic*** results indicate that the scenario yields cooler instream temperatures as compared to the existing condition; positive, shaded results indicate that the scenario yielded warmer instream temperatures as compared to the existing conditions.

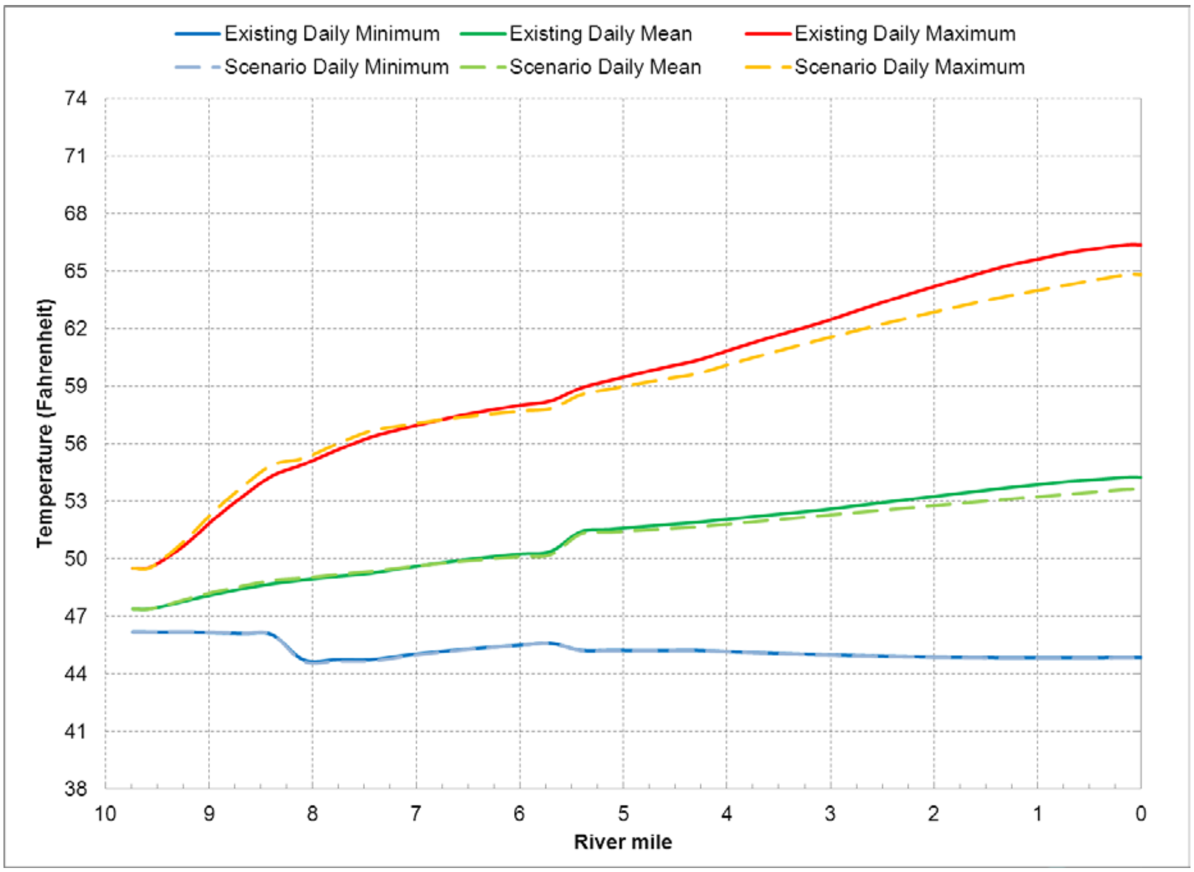


Figure I-26. Full potential shade with low-flow conditions results.

I6.5 Increased Flow Scenario

The increased flow scenario is used to describe the potential thermal effect of water savings and flow augmentation on water temperatures in East Fork Rock Creek. This scenario assumes that improved water delivery and application efficiency could create a water savings of 15% and that the conserved water could be allowed to flow down East Fork Rock Creek past the main diversion, thereby increasing instream flow. For modeling purposes, the diversion flow rate was reduced by 15 percent, and the additional water was allowed to flow down East Fork Rock Creek.

This scenario resulted in cooler water temperatures along most of East Fork Rock Creek. Daily mean temperatures decreased, as compared to the existing condition scenario, between 0.2 and 1.4 °F and daily maximum temperatures decreased between 0.6 and 2.5 °F. **Table I-11** presents the results at the DEQ sample sites and **Figure I-27** presents the continuous results along East Fork Rock Creek.

Table I-11.Increased flow results

Daily temperature	Source	C02ROCEF*					
		***05**	***20**	***04**	***03**	***10**	***02**
Maximum	Existing	49.6	50.7	58.2	60.4	65.6	66.4
	Scenario	49.6	50.1	56.0	58.4	63.2	63.9
	Difference	<+0.05	***-0.6***	***-2.2***	***-2.0***	***-2.4***	***-2.5***
Mean	Existing	47.4	47.8	50.4	51.9	53.9	54.3
	Scenario	47.4	47.6	49.5	50.9	52.6	52.9
	Difference	<+0.05	***-0.2***	***-0.9***	***-1.0***	***-1.3***	***-1.4***
Minimum	Existing	46.2	46.2	45.6	45.2	44.8	44.9
	Scenario	46.2	46.1	45.7	45.4	44.9	44.9
	Difference	***<-0.05***	***<-0.05***	+0.1	+0.2	+0.1	<+0.05

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The difference is calculated as the existing subtracted from the scenario. Negative, ***bold italic*** results indicate that the scenario yields cooler instream temperatures as compared to the existing condition; positive, shaded results indicate that the scenario yielded warmer instream temperatures as compared to the existing conditions.

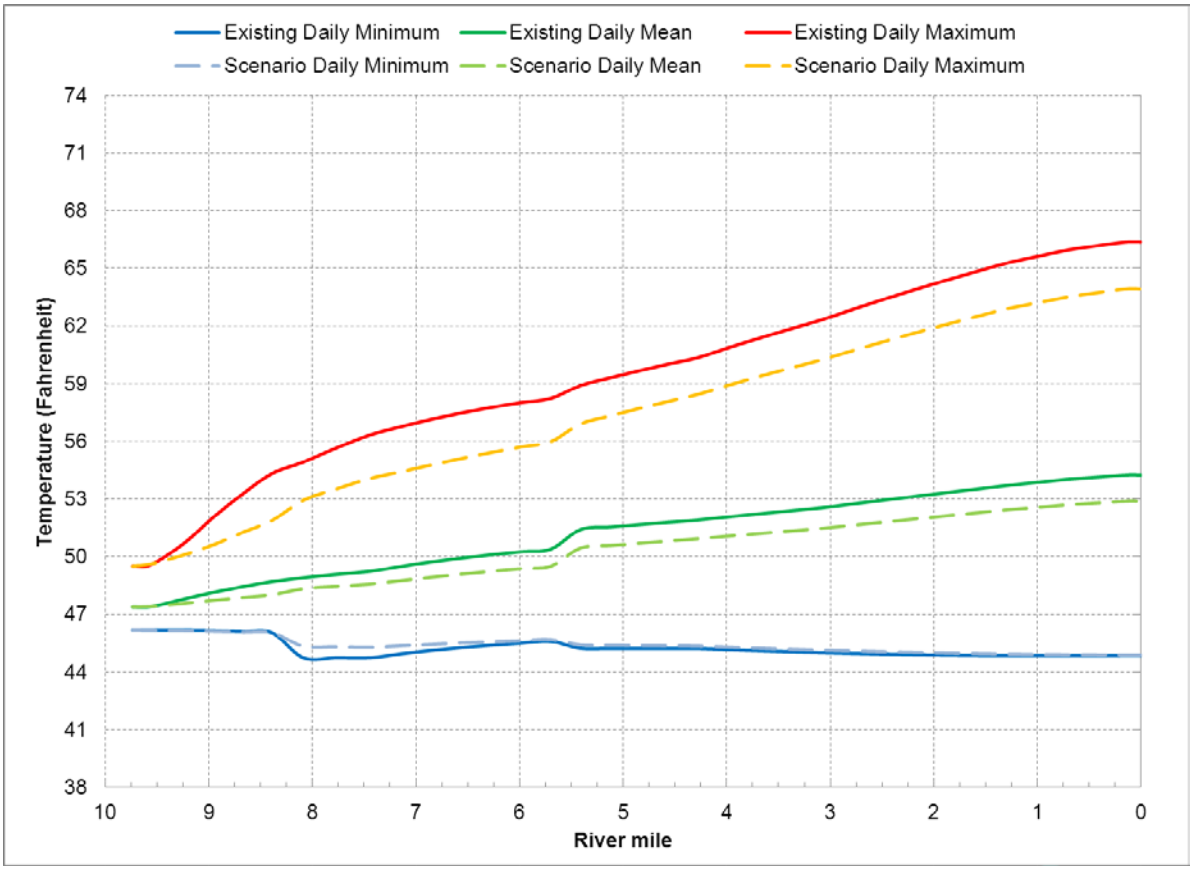


Figure I-27. Increased flow results.

I6.6 Increased Flow with Full Potential Shade

A combination of the scenarios presented in **Sections I6.3** and **I6.5** are used (full potential shade scenario and a 15% water savings). Shading was increased to approximate a mature riparian corridor, and for the 15% water savings, the diversion was reduced by 15 percent in the model.

This scenario resulted in cooler water temperatures along most of East Fork Rock Creek. Daily mean temperatures decreased, as compared to the existing condition scenario, between 0.2 and 2.0 °F and daily maximum temperatures decreased between 0.6 and 3.9 °F. **Table I-12** presents the results at the DEQ sample sites and **Figure I-28** presents the continuous results along East Fork Rock Creek.

Table I-12.Increased flow and full shade results

Daily temperature	Source	C02ROCEF*					
		*05	*20	*04	*03	*10	*02
Maximum	Existing	49.6	50.7	58.2	60.4	65.6	66.4
	Scenario	49.6	50.1	55.6	57.8	61.7	62.5
	Difference	<+0.05	***-0.6***	***-2.6***	***-2.6***	***-3.9***	***-3.9***
Mean	Existing	47.4	47.8	50.4	51.9	53.9	54.3
	Scenario	47.4	47.6	49.3	50.7	52.0	52.3
	Difference	<+0.05	***-0.2***	***-1.1***	***-1.2***	***-1.9***	***-2.0***
Minimum	Existing	46.2	46.2	45.6	45.2	44.8	44.9
	Scenario	46.2	46.1	45.7	45.4	44.9	44.9
	Difference	***<-0.05***	***<-0.05***	+0.1	+0.2	+0.1	<+0.05

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The difference is calculated as the existing subtracted from the scenario. Negative, ***bold italics*** results indicate that the scenario yields cooler instream temperatures as compared to the existing condition; positive, shaded results indicate that the scenario yielded warmer instream temperatures as compared to the existing conditions.

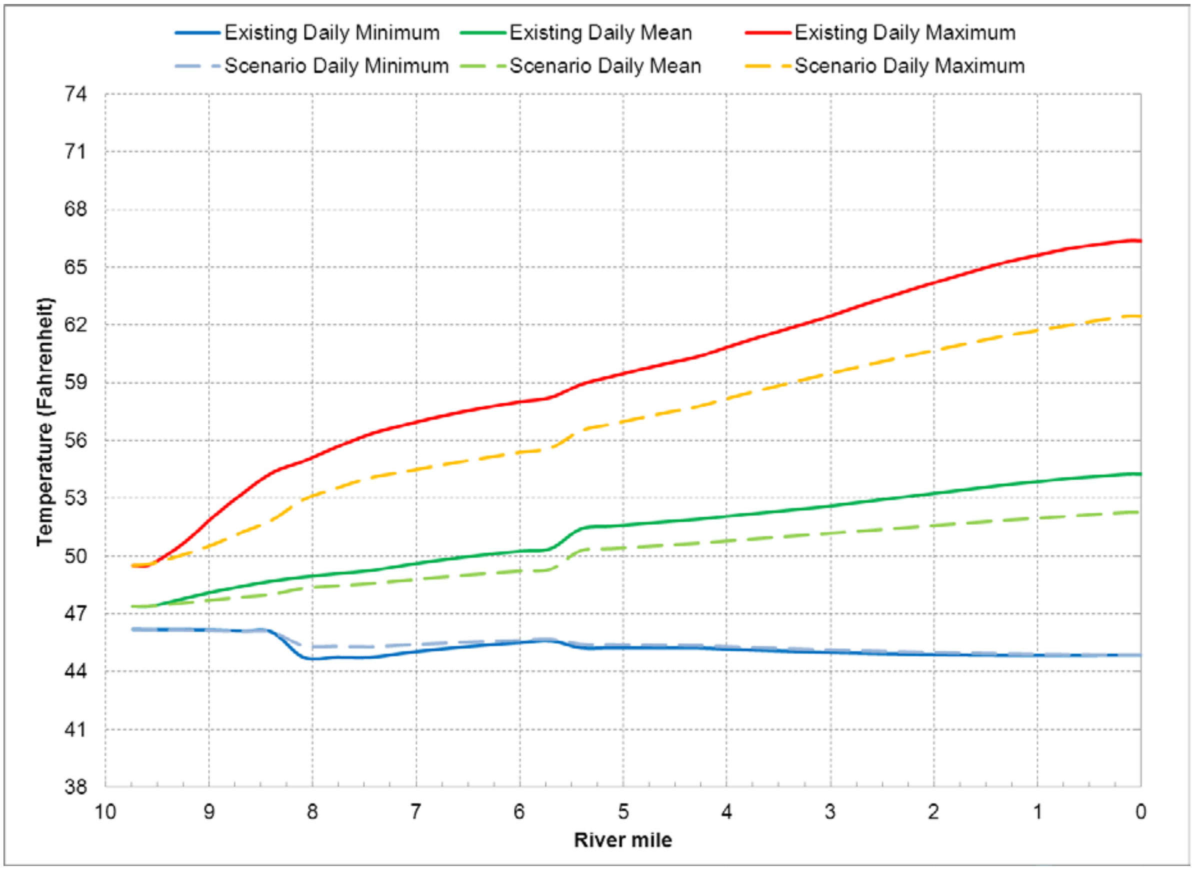


Figure I-28. Increased flow and shade results.

I6.7 Scenario Results and Discussion

Scenarios were developed in QUAL2K to evaluate the impacts of various factors that might affect instream water temperatures in East Fork Rock Creek. Reducing flow such that only 5 cfs was present in East Fork Rock Creek below the main diversion resulted in higher instream temperatures, which increased up to 0.3 °F. Increasing shade to replicate the effect of re-vegetation lowered stream temperatures by as much as 1.8 °F. Increasing shade with critical low-flow conditions resulted in higher instream temperatures in some parts of East Fork Rock Creek, but generally downstream, it reduced the temperatures (by as much as 1.6 °F). Attaining a 15% water savings from improved water delivery and application efficiency, and allowing that conserved water to flow down East Fork Rock Creek past the main diversion, lowered temperatures by as much as 2.5°F. Increasing flow and increasing to full potential shade lowered instream temperatures by as much as 3.9 °F. **Figure I-29** presents a summary of the results.

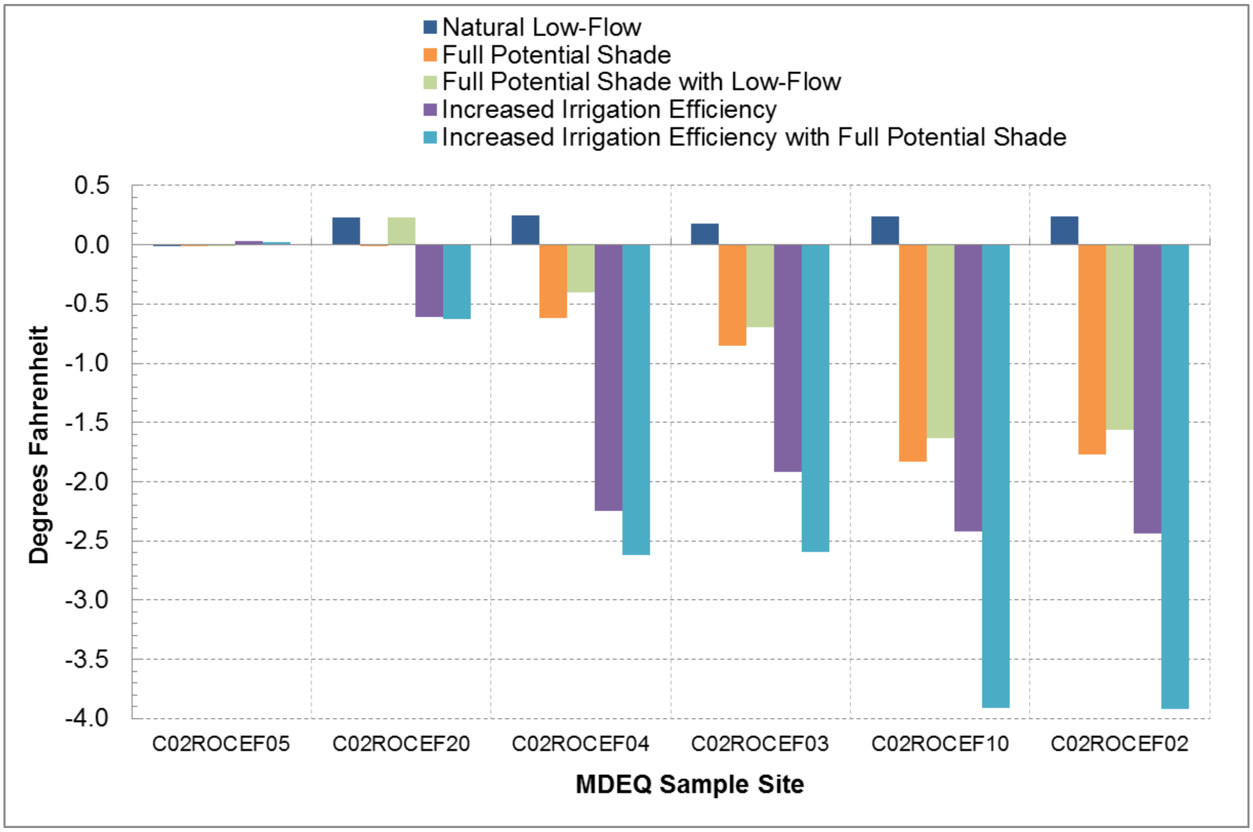


Figure I-29. Comparisons to the existing condition scenario (shown as the difference in simulated maximum daily water temperatures).

I7.0 REFERENCES

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APPENDIX IA. FIELD DATA (WATER & ENVIRONMENTAL TECHNOLOGIES, 2011)

Table IA-1. Shade measurements (Water & Environmental Technologies, 2011)

Site ID	Location and bank	Wetted width (feet)	Vegetation	Vegetation height (feet)	Density (percent)	Bank height (feet)	Overhang (feet)
EFRC Shade -6	A - LB	22	medium willow/shrub	8	65%	3	4
	A - RB	n/a	medium willow/shrub	8	82%	1.5	0
	B - LB	21	medium willow/shrub	8	94%	2.3	5
	B - RB	n/a	grass	3	35%	7.1	0.7
	C - LB	26.5	dense willow/shrub	10	100%	3	2
	C - RB	n/a	dense willow/shrub	13	71%	0.7	1.5
EFRC Shade -5	A - LB	19.3	grass	1.9	47%	1.8	1.1
	A - RB	n/a	grass	2	6%	3.2	0.5
	B - LB	17.7	grass	1.7	7%	1.4	0.8
	B - RB	n/a	grass	1.7	41%	2.4	0.6
	C - LB	17.6	grass	1.7	53%	2.1	1.5
	C - RB	n/a	grass	2	29%	0.9	0.4
EFRC Shade -4	A - LB	19.45	grass	2	100%	1.5	1
	A - RB	n/a	medium willow/shrub	10	76%	9	5
	B - LB	23.5	grass	2.2	35%	1.5	1.5
	B - RB	n/a	grass	2	59%	2.3	1
	C - LB	18.5	grass	2	17.65%	2	0.3
	C - RB	n/a	grass	2	53%	1	0.8
EFRC Shade -3	A - LB	13.5	sparse willow/shrub	7	94%	2	4.5
	A - RB	n/a	medium willow/shrub	12.5	100%	0.7	0
	B - LB	14	grass	1	0%	1.4	0
	B - RB	n/a	sparse willow/shrub	7	53%	1.3	4
	C - LB	17	sparse willow/shrub	11	100%	3.5	0
	C - RB	n/a	sparse willow/shrub	12	100%	0.9	0
EFRC Shade -2	A - LB	18	MHL	13 to 25	100%	0.8	0
	A - RB	n/a	medium conifer	25.5	94%	0.9	0
	B - LB	19.5	medium conifer	23.4	71%	12	0
	B - RB	n/a	medium conifer	52.3	88%	1.1	0
	C - LB	27	MHL	22.3	100%	7	1.5
	C - RB	n/a	MHL	26.7	100%	4.5	0
EFRC Shade -1	A - LB	16	dense willow/shrub	6	100%	12	6
	A - RB	n/a	grass	1.5	29%	1.2	0.7
	B - LB	24.5	medium conifer	37.9	94%	12	0
	B - RB	n/a	sparse conifer	41.4	94%	0.9	0
	C - LB	16	dense conifer	54.9	94%	3	1.5
	C - RB	n/a	sparse conifer	53.3	100%	0.8	0

Table IA-2. Riparian summary (Water & Environmental Technologies, 2011)

Vegetation description	Height	Density	Overhang
	(feet)	(percent)	(feet)
Dense Conifer	54.9	89%	1.5
Medium Conifer	34.8	49%	0
Sparse Conifer	47.4	34%	0
Mixed High Level	24.7	83%	0.5
Dense Willow/Shrub	9.7	75%	3.2
Medium Willow/Shrub	9.3	63%	2.8
Sparse Willow/Shrub	9.3	35%	2.1
Grass	1.9	36%	0.8

Table IA-3. Channel cross-section data, EFRK 01-02 (Water & Environmental Technologies, 2011)

Cell	Feature	Bankfull channel width (feet)	Channel cross-sectional area (square feet)	Bankfull mean depth (feet)	Width/depth ratio	Maximum depth (feet)	Flood-prone width (feet)	Entrenchment ratio
1	riffle	20.7	22.7	1.10	18.9	1.8	68.7	3.3
2	riffle	24.0	24.2	1.01	23.8	1.5	30.0	1.3
3	riffle	26.5	31.7	1.20	22.1	1.6	48.5	1.8
4	riffle	22.0	28.5	1.30	17.0	1.6	28.0	1.3
5	riffle	30.0	31.1	1.04	29.0	1.8	36.0	1.2

Table IA-4. Channel cross-section data, EFRK 03-03 (Water & Environmental Technologies, 2011)

Cell	Feature	Bankfull channel width (feet)	Channel cross-sectional area (square feet)	Bankfull mean depth (feet)	Width/depth ratio	Maximum depth (feet)	Flood-prone width (feet)	Entrenchment ratio
1	riffle	23.5	34.7	1.48	15.9	1.7	57.5	2.4
2	riffle	20.3	30.3	1.49	13.6	2.1	70.3	3.5
3	riffle	21.0	31.3	1.49	14.1	2.0	76.0	3.6
4	riffle	21.8	34.8	1.60	13.7	2.1	141.8	6.5
5	riffle	20.5	29.3	1.43	14.3	2.1	140.5	6.8

APPENDIX IB. SHADE ANALYSES

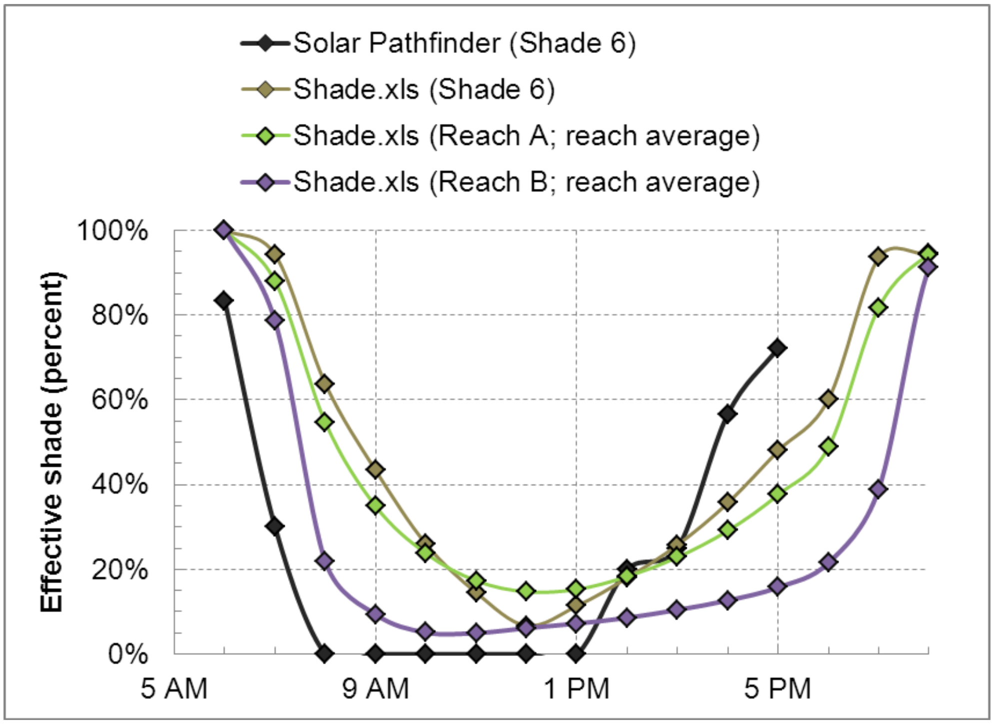

Figure IB-1. Shade analysis in reaches A and B.

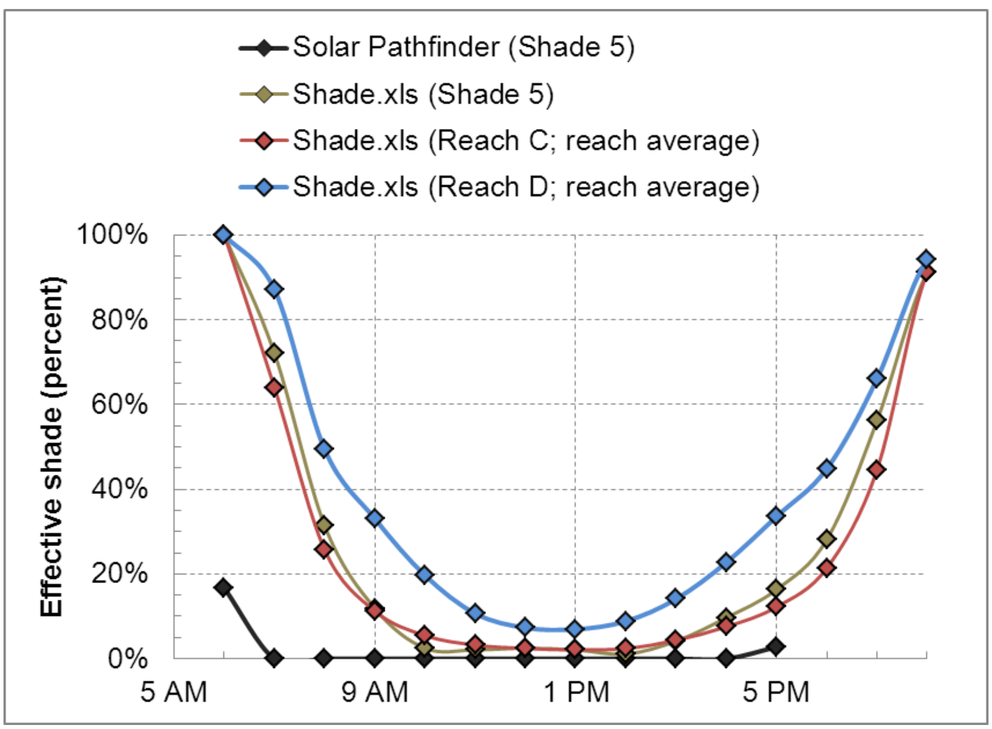

Figure IB-2. Shade analysis in reaches C and D.

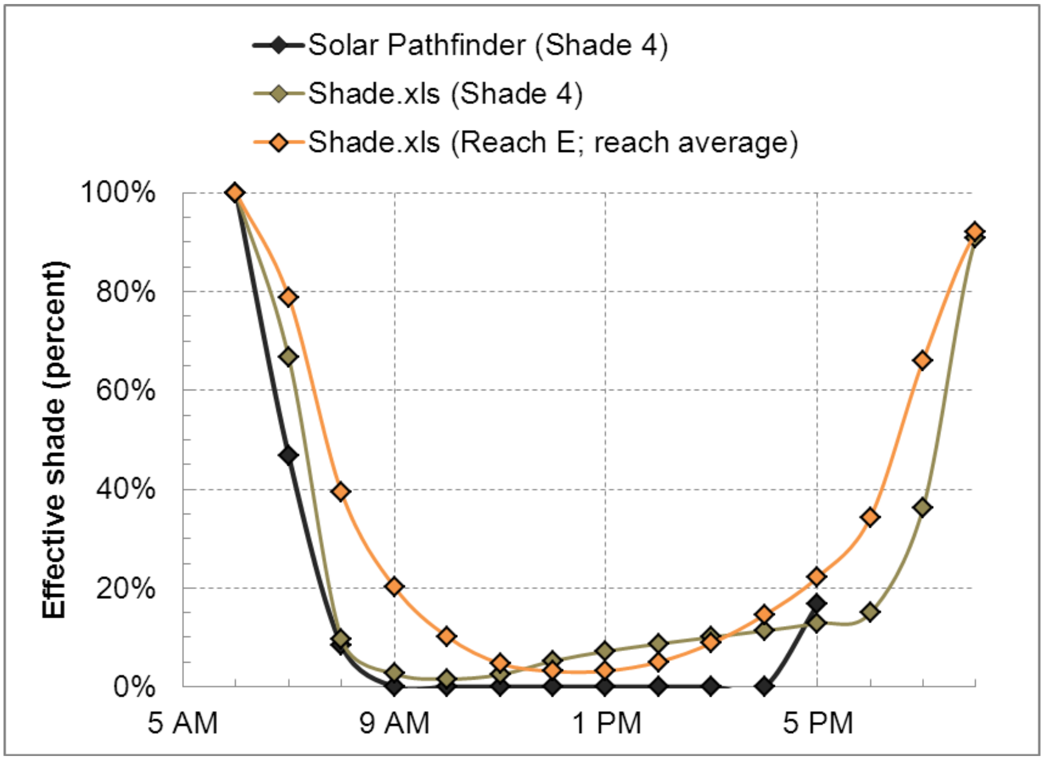

Figure IB-3. Shade analysis in reach E.

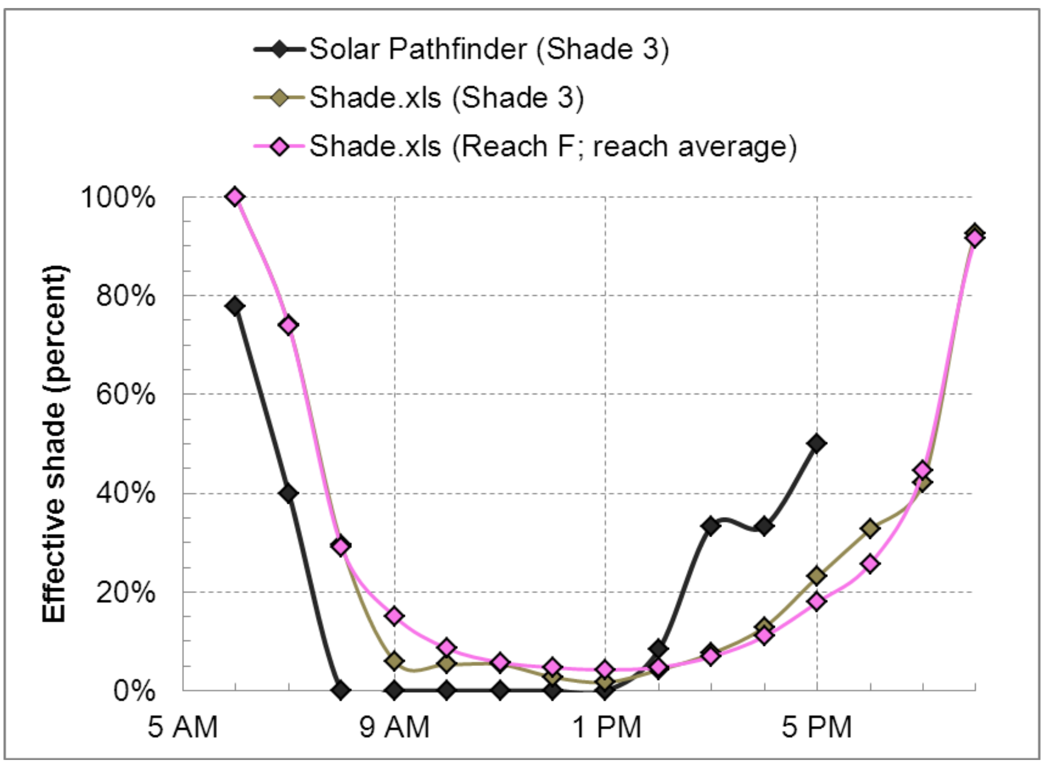

Figure IB-4. Shade analysis in reach F.

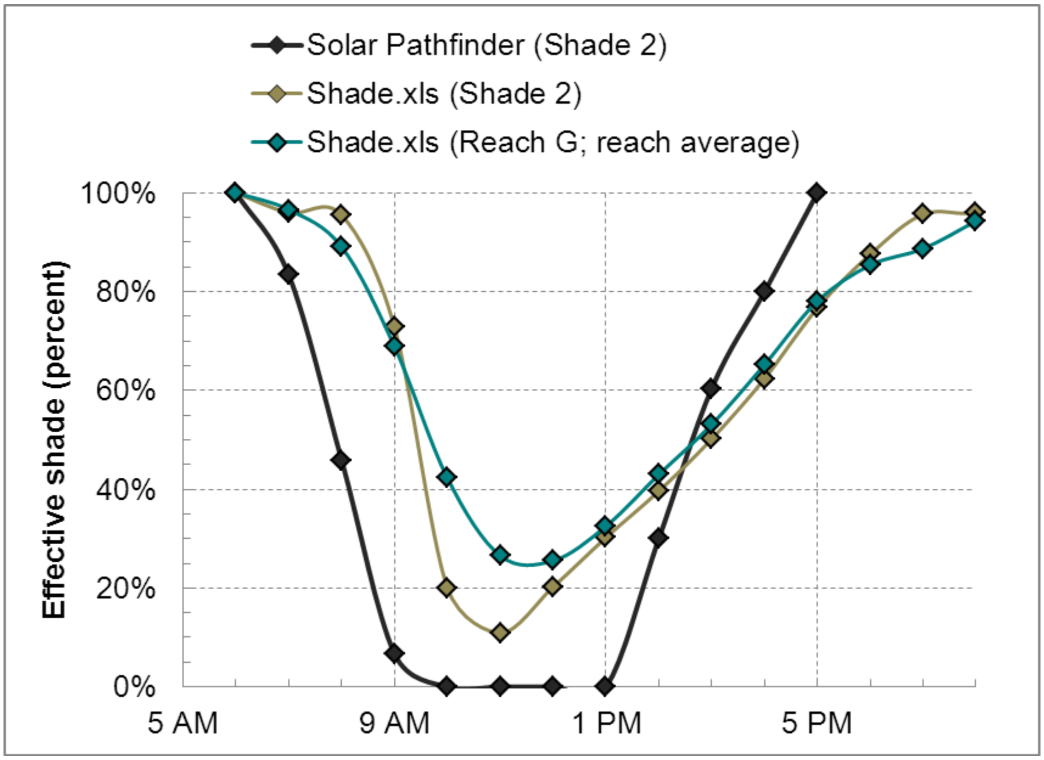

Figure IB-5. Shade analysis in reach G.

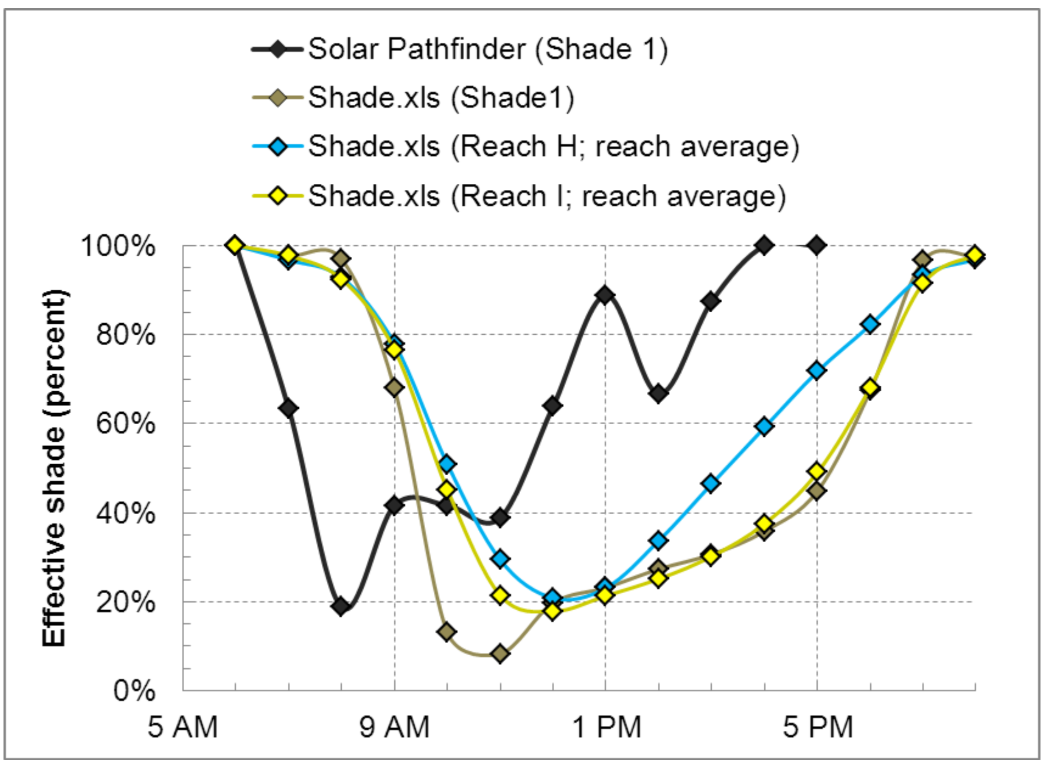

Figure IB-6. Shade analysis in reaches H and I.

APPENDIX IC. QUAL2K MODEL DEVELOPMENT

IC-1. SUMMARY OF THE ASSUMPTIONS AND SOURCES OF INPUT DATA

Table IC-1. Model input parameters

Model parameter	Source of input
Month	July 29, 2010. Warm day without rain during DEQ 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 IC-2. Headwaters input parameters

Model parameter	Source of input
Flow rate	Observed at C02ROCEF05 on July, 29, 2010
Elevation	Calculated with GIS
Channel slope	
Manning roughness coefficient (n)	Estimated (Water & Environmental Technologies, 2011)
Bottom width	Estimated from observed flow-interval data that was collected when flow was measured at C02ROCEF20 on July 29, 2010.
Side slope 1	
Side slope 2	
Hourly water temperatures	Estimated from C02ROCEF05 on July 30, 2010. Logger was deployed on July 29, 2010; subsequent days were evaluated.

Table IC-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 Philipsburg RAWS, corrected for elevation
Hourly dew point temperatures	
Hourly wind speed	Estimated from observations at Philipsburg RAWS, corrected for sensor height
Hourly cloud cover	Estimated from observations at Butte municipal airport
Hourly effective shade	Calculated with Shade3.0.xls
Manning	
Location	Calculated with GIS
Manning roughness coefficient (n)	Estimated (Water & Environmental Technologies, 2011)
Bottom width	Estimated from flow-interval data collected in late July 2010 at sites C02ROCEF20, C02ROCEF04, C02ROCEF03, C02ROCEF10, and C02ROCEF02.
Side slope 1	
Side slope 2	

Table IC-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)	Estimated (Water & Environmental Technologies, 2011)
Point sources and tributaries	
Location	Calculated with GIS
Abstraction (withdrawal)	Diversion: Estimated from DNRC continuous flow and temperature data Elk Creek: Estimated using DNRC above reservoir continuous flow and temperature data as surrogate Meadow Creek: Estimated using DEQ instantaneous flow and continuous temperature data
Inflow	
Mean daily temperature	
One-half range	
Time of daily maximum	

Table IC-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	Default
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)	
Atmospheric transmission coefficient	Default
Downwelling atmospheric longwave infrared radiation	
Atmospheric longwave emissivity model	Default
Evaporation and air convection/conduction	
Wind speed function for evaporation and air convection/conduction	Default
Sediment heat parameters	
Sediment thermal thickness	Default
Sediment thermal diffusivity	Default
Sediment density	Default
Water density	Default
Sediment heat capacity	Default
Water heat capacity	Default

IC-2. MODEL PARAMETER INPUT DATA

Table IC-6. Channel Geometry Inputs

Segment	Channel slope	Manning's n	Stream bottom width (meter/feet)	Side 1[a]	Side 2[a]
I	0.033	0.048	0.61 / 2.00	4.71	2.94
H	0.015	0.048	0.97 / 3.17	5.32	3.08
G	0.019	0.048	1.93 / 6.33	6.96	3.45
F	0.014	0.048	3.05 / 10.00	0.53	2.00
E	0.013	0.048	3.20 / 10.50	1.45	6.36
D	0.009	0.048	3.28 / 10.77	3.61	4.12
C	0.009	0.048	3.35 / 11.00	5.44	2.22
B	0.011	0.048	4.52 / 14.84	2.12	1.37
A	0.010	0.048	4.88 / 16.00	1.11	1.11

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

Table IC-7. Instream flow data used for modeling

Location	Flow	
	(cubic meters per second)	(cubic feet per second)
East Fork Rock Creek		
C02ROCEF05	3.248	114.7
C02ROCEF20	0.175	6.2
C02ROCEF04	0.730	25.8
C02ROCEF03	1.175	41.5
C02ROCEF10	1.079	38.1
C02ROCEF02	1.077	38.0
Elk Creek		
--	0.23	8.1
Meadow Creek		
C02MEDOC01	0.35	12.4

Table IC-8. Estimated diffuse flow for each reach

Segment	Direction	Diffuse flow	
		(cubic meter per second)	(cubic feet per second)
Reach I	Inflow	0.050	1.766
Reach H	Inflow	0.050	1.766
Reach G	Inflow	0.230	8.122
Reach F	Inflow	0.100	3.531
Reach E	Outflow	0.040	1.413
Reach D	Outflow	0.056	1.978
Reach C	Outflow	0.001	0.035
Reach B	Outflow	0.001	0.035
Reach A	Outflow	0.040	1.413

Table IC-9. Hourly weather data for East Fork Rock Creek on July 29, 2010

Time	Air temperature (°C)									Wind speed (meters/second)
Reach	I	H	G	F	E	D	C	B	A	All
12:00 AM	10.78	10.86	11.07	11.27	11.51	11.67	11.82	11.93	11.97	1.37
1:00 AM	9.67	9.75	9.96	10.15	10.40	10.55	10.71	10.81	10.86	0.91
2:00 AM	9.11	9.20	9.40	9.60	9.84	10.00	10.15	10.26	10.31	0.91
3:00 AM	8.56	8.64	8.85	9.04	9.29	9.44	9.60	9.70	9.75	2.74
4:00 AM	8.00	8.09	8.29	8.49	8.73	8.89	9.04	9.15	9.20	0.00
5:00 AM	7.45	7.53	7.74	7.93	8.18	8.33	8.49	8.59	8.64	0.46
6:00 AM	6.89	6.98	7.18	7.38	7.62	7.78	7.93	8.04	8.09	0.91
7:00 AM	10.78	10.86	11.07	11.27	11.51	11.67	11.82	11.93	11.97	0.91
8:00 AM	16.33	16.42	16.63	16.82	17.07	17.22	17.37	17.48	17.53	0.46
9:00 AM	21.33	21.42	21.63	21.82	22.07	22.22	22.37	22.48	22.53	2.28
10:00 AM	22.45	22.53	22.74	22.93	23.18	23.33	23.49	23.59	23.64	3.65
11:00 AM	23.56	23.64	23.85	24.04	24.29	24.44	24.60	24.70	24.75	5.02
12:00 PM	24.67	24.75	24.96	25.15	25.40	25.55	25.71	25.81	25.86	5.48
1:00 PM	25.22	25.31	25.51	25.71	25.96	26.11	26.26	26.37	26.42	4.11
2:00 PM	26.33	26.42	26.63	26.82	27.07	27.22	27.37	27.48	27.53	3.65
3:00 PM	26.33	26.42	26.63	26.82	27.07	27.22	27.37	27.48	27.53	4.56
4:00 PM	26.33	26.42	26.63	26.82	27.07	27.22	27.37	27.48	27.53	5.02
5:00 PM	26.33	26.42	26.63	26.82	27.07	27.22	27.37	27.48	27.53	4.56
6:00 PM	25.78	25.86	26.07	26.27	26.51	26.67	26.82	26.93	26.97	2.74
7:00 PM	24.67	24.75	24.96	25.15	25.40	25.55	25.71	25.81	25.86	0.91
8:00 PM	18.56	18.64	18.85	19.04	19.29	19.44	19.60	19.70	19.75	0.91
9:00 PM	15.22	15.31	15.51	15.71	15.96	16.11	16.26	16.37	16.42	2.28
10:00 PM	13.56	13.64	13.85	14.04	14.29	14.44	14.60	14.70	14.75	1.37
11:00 PM	11.33	11.42	11.63	11.82	12.07	12.22	12.37	12.48	12.53	0.46

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

Table IC-10. Hourly dew point data for East Fork Rock Creek on July 29, 2010

Time	Dew point temperature (°C)								
Segment	I	H	G	F	E	D	C	B	A
12:00 AM	8.56	8.64	8.85	9.04	9.29	9.44	9.60	9.70	9.75
1:00 AM	8.00	8.09	8.29	8.49	8.73	8.89	9.04	9.15	9.20
2:00 AM	6.89	6.98	7.18	7.38	7.62	7.78	7.93	8.04	8.09
3:00 AM	7.45	7.53	7.74	7.93	8.18	8.33	8.49	8.59	8.64
4:00 AM	6.89	6.98	7.18	7.38	7.62	7.78	7.93	8.04	8.09
5:00 AM	6.33	6.42	6.63	6.82	7.07	7.22	7.37	7.48	7.53
6:00 AM	6.33	6.42	6.63	6.82	7.07	7.22	7.37	7.48	7.53
7:00 AM	8.56	8.64	8.85	9.04	9.29	9.44	9.60	9.70	9.75
8:00 AM	11.89	11.98	12.18	12.38	12.62	12.78	12.93	13.04	13.09
9:00 AM	10.78	10.86	11.07	11.27	11.51	11.67	11.82	11.93	11.97
10:00 AM	6.33	6.42	6.63	6.82	7.07	7.22	7.37	7.48	7.53
11:00 AM	4.67	4.75	4.96	5.15	5.40	5.55	5.71	5.81	5.86
12:00 PM	3.56	3.64	3.85	4.04	4.29	4.44	4.60	4.70	4.75
1:00 PM	2.45	2.53	2.74	2.93	3.18	3.33	3.49	3.59	3.64

Table IC-10. Hourly dew point data for East Fork Rock Creek on July 29, 2010

Time	Dew point temperature (°C)								
Segment	**I**	**H**	**G**	**F**	**E**	**D**	**C**	**B**	**A**
2:00 PM	1.89	1.98	2.18	2.38	2.62	2.78	2.93	3.04	3.09
3:00 PM	1.33	1.42	1.63	1.82	2.07	2.22	2.37	2.48	2.53
4:00 PM	-0.33	-0.25	-0.04	0.15	0.40	0.55	0.71	0.81	0.86
5:00 PM	-2.00	-1.91	-1.71	-1.51	-1.27	-1.11	-0.96	-0.85	-0.80
6:00 PM	-1.44	-1.36	-1.15	-0.96	-0.71	-0.56	-0.40	-0.30	-0.25
7:00 PM	0.78	0.86	1.07	1.27	1.51	1.67	1.82	1.93	1.97
8:00 PM	-0.33	-0.25	-0.04	0.15	0.40	0.55	0.71	0.81	0.86
9:00 PM	2.45	2.53	2.74	2.93	3.18	3.33	3.49	3.59	3.64
10:00 PM	1.33	1.42	1.63	1.82	2.07	2.22	2.37	2.48	2.53
11:00 PM	2.45	2.53	2.74	2.93	3.18	3.33	3.49	3.59	3.64

Notes:
Data presented in this table were obtained from the Philipsburg 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 IC-11. Hourly shade results (averaged along model segments)

Time	Shade (percent)								
Model reach	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Up RM	0.55	1.1	2.9	4.1	5.5	7.2	8.2	9.4	9.7
Down RM	0	0.56	1.1	2.9	4.1	5.5	7.2	8.2	9.4
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%	100%	100%	100%	100%	100%	100%	100%	100%
7:00 AM	87.99%	78.60%	63.95%	87.12%	78.85%	73.82%	96.58%	96.77%	97.71%
8:00 AM	54.64%	21.82%	25.68%	49.38%	39.28%	29.11%	89.05%	92.82%	92.46%
9:00 AM	34.89%	9.39%	11.25%	33.04%	20.18%	15.11%	68.86%	77.95%	76.57%
10:00 AM	23.75%	5.11%	5.47%	19.66%	10.15%	8.56%	42.25%	50.90%	45.18%
11:00 AM	17.32%	4.99%	3.24%	10.66%	4.72%	5.78%	26.55%	29.40%	21.43%
12:00 PM	14.72%	6.16%	2.44%	7.32%	3.14%	4.70%	25.54%	20.85%	17.86%
1:00 PM	15.30%	7.24%	2.09%	6.96%	3.20%	4.24%	32.53%	23.13%	21.36%
2:00 PM	18.32%	8.58%	2.42%	8.87%	5.06%	4.77%	42.99%	33.73%	25.16%
3:00 PM	22.88%	10.46%	4.38%	14.11%	8.85%	6.90%	53.09%	46.49%	30.20%
4:00 PM	29.15%	12.68%	7.56%	22.74%	14.55%	11.02%	65.23%	59.17%	37.54%
5:00 PM	37.62%	15.76%	12.23%	33.61%	22.17%	17.92%	78.06%	71.71%	49.06%
6:00 PM	48.82%	21.56%	21.41%	44.84%	34.26%	25.74%	85.37%	82.17%	68.09%
7:00 PM	81.76%	38.94%	44.61%	66.06%	66.09%	44.58%	88.70%	93.29%	91.49%
8:00 PM	94.36%	91.11%	91.10%	94.22%	91.96%	91.61%	94.28%	96.88%	97.76%
9:00 PM	100%	100%	100%	100%	100%	100%	100%	100%	100%
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 IC-12. 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]	0.75
Downwelling atmospheric longwave infrared radiation	
Atmospheric longwave emissivity model	Brunt
Evaporation and air convection/conduction	
Wind speed function for evaporation and air convection/conduction	Brady-Graves-Geyer
Sediment heat parameters	
Sediment thermal thickness (centimeter)[b]	10
Sediment thermal diffusivity (square centimeter per second)[c]	0.005
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]	0.4
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.

IC-3. Calibration and Validation Results

Table IC-13. Model calibration results for July 29, 2010 in Celsius

Daily temperature	Source	C02ROCEF*					
		*05	*20	*04	*03	*10	*02
Maximum	QUAL2K	9.7	10.4	14.9	16.0	18.7	19.1
	Observed	9.4	9.9	16.1	17.3	18.3	17.6
	Abs. Error[a]	***0.4***	***0.5***	***-1.1***	***-1.3***	***0.7***	***1.5***
	Rel. Error[b]	***4%***	***5%***	***7%***	***7%***	***4%***	***8%***
Mean	QUAL2K	8.5	8.8	10.8	11.2	12.2	12.4
	Observed	8.7	8.5	11.6	12.2	12.7	12.6
	Abs. Error[a]	***-0.1***	***0.2***	***-0.8***	***-1.0***	***-0.5***	***-0.3***
	Rel. Error[b]	***1%***	***3%***	***7%***	***9%***	***4%***	***2%***
Minimum	QUAL2K	7.9	7.8	7.4	7.3	7.1	7.1
	Observed	7.7	7.9	8.1	8.1	8.4	8.0
	Abs. Error[a]	***0.2***	***0.0***	***-0.8***	***-0.8***	***-1.3***	***-0.9***
	Rel. Error[b]	***3%***	***0%***	***9%***	***9%***	15%	11%

Notes: Results are reported in degrees Celsius and rounded to the nearest one-tenth of a degree.
Calibration results that meet the acceptance criteria are presented in ***bolded italics***; results that do not meet the acceptance criteria are presented in shaded cells.
[a] Absolute error is calculated as QUAL2K minus observed.
[b] Relative error is calculated as the absolute value of QUAL2K minus observed and then divided by observed.

Table IC-14. Model validation results for August 21, 2010 in Celsius

Daily temperature	Source	blw Res	abv Elk Ck	Walden Br	abv Meadow	abv MF
Maximum	QUAL2K	11.8	12.0	13.3	15.5	16.8
	Observed	11.4	13.4	14.4	15.6	16.8
	Abs. Error[a]	***0.3***	***-1.5***	***-1.1***	***0.1***	***0.0***
	Rel. Error[b]	***3%***	11%	***7%***	***0%***	***0%***
Mean	QUAL2K	10.2	9.6	9.8	10.3	11.1
	Observed	10.3	10.3	10.5	11.1	11.8
	Abs. Error[a]	***-0.1***	***-0.8***	***-0.8***	***-0.8***	***-0.7***
	Rel. Error[b]	***1%***	***7%***	***7%***	***7%***	***6%***
Minimum	QUAL2K	9.5	8.3	8.0	7.5	7.3
	Observed	9.6	8.6	8.2	8.3	7.6
	Abs. Error[a]	***-0.2***	***-0.3***	***-0.3***	***-0.8***	***-0.2***
	Rel. Error[b]	***2%***	***3%***	***3%***	***9%***	***3%***

Notes: Results are reported in degrees Celsius and rounded to the nearest one-tenth of a degree.
Calibration results that meet the acceptance criteria are presented in ***bolded italics***; results that do not meet the acceptance criteria are presented in shaded cells.
[a] Absolute error is calculated as QUAL2K minus observed.
[b] Relative error is calculated as the absolute value of QUAL2K minus observed and then divided by observed.

APPENDIX ID. THERMOGRAPHS OF CALIBRATION AND VALIDATION TIME PERIODS

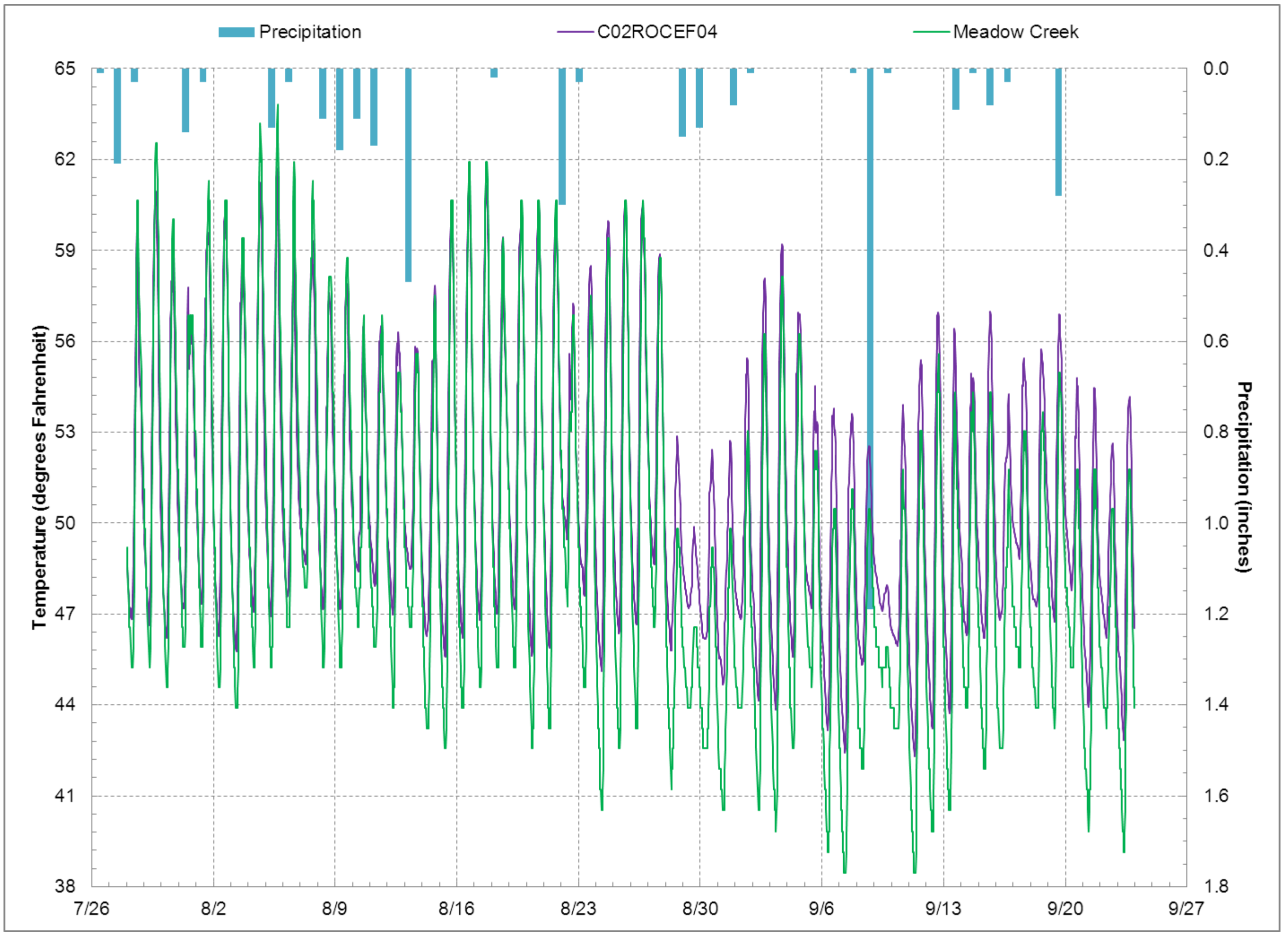

Figure ID-1. East Fork Rock Creek (above the confluence of Meadow Creek) and Meadow Creek in 2010 (DEQ temperature data).

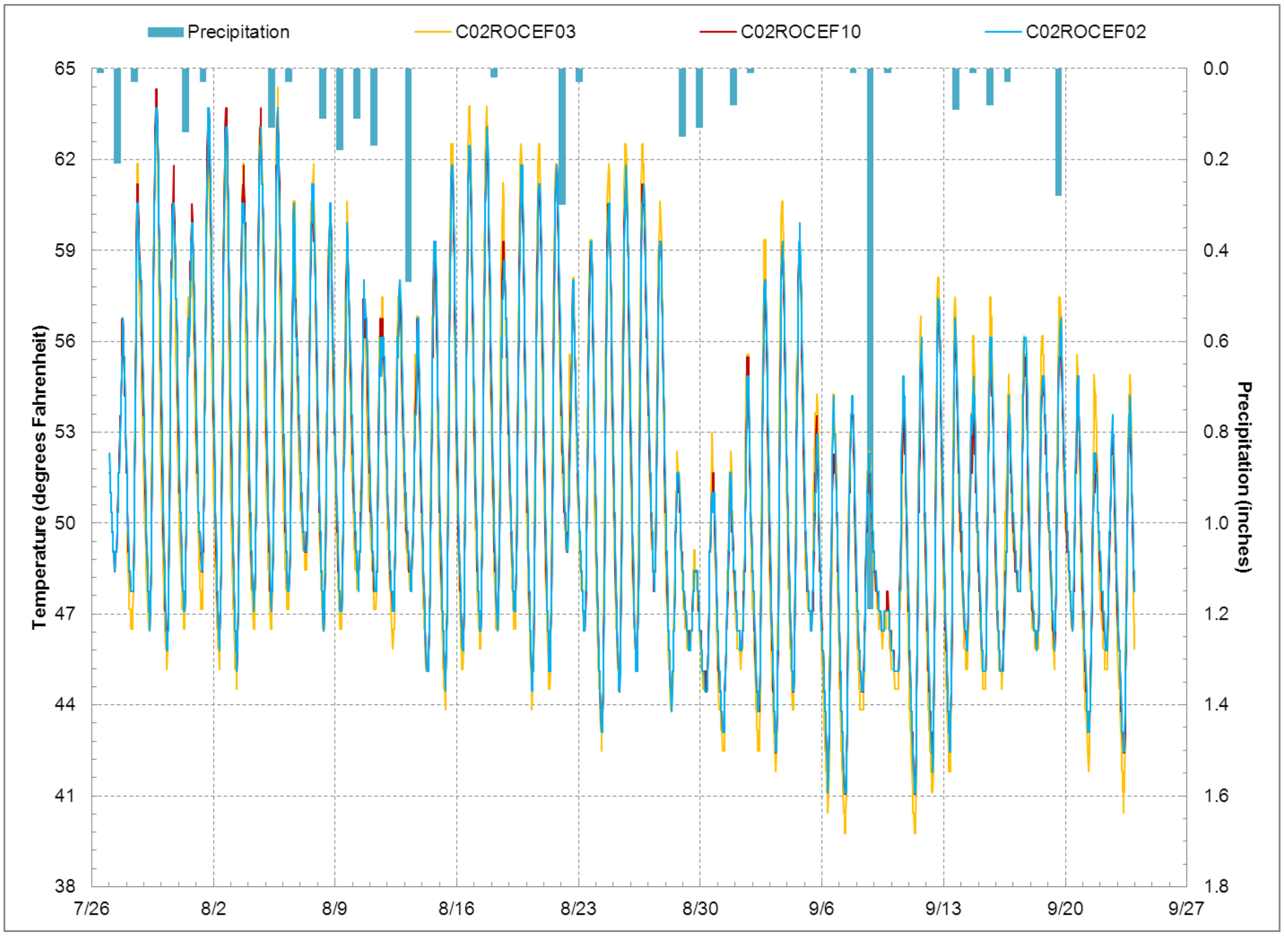

Figure ID-2. Lower East Fork Rock Creek in 2010 (DEQ temperature data).

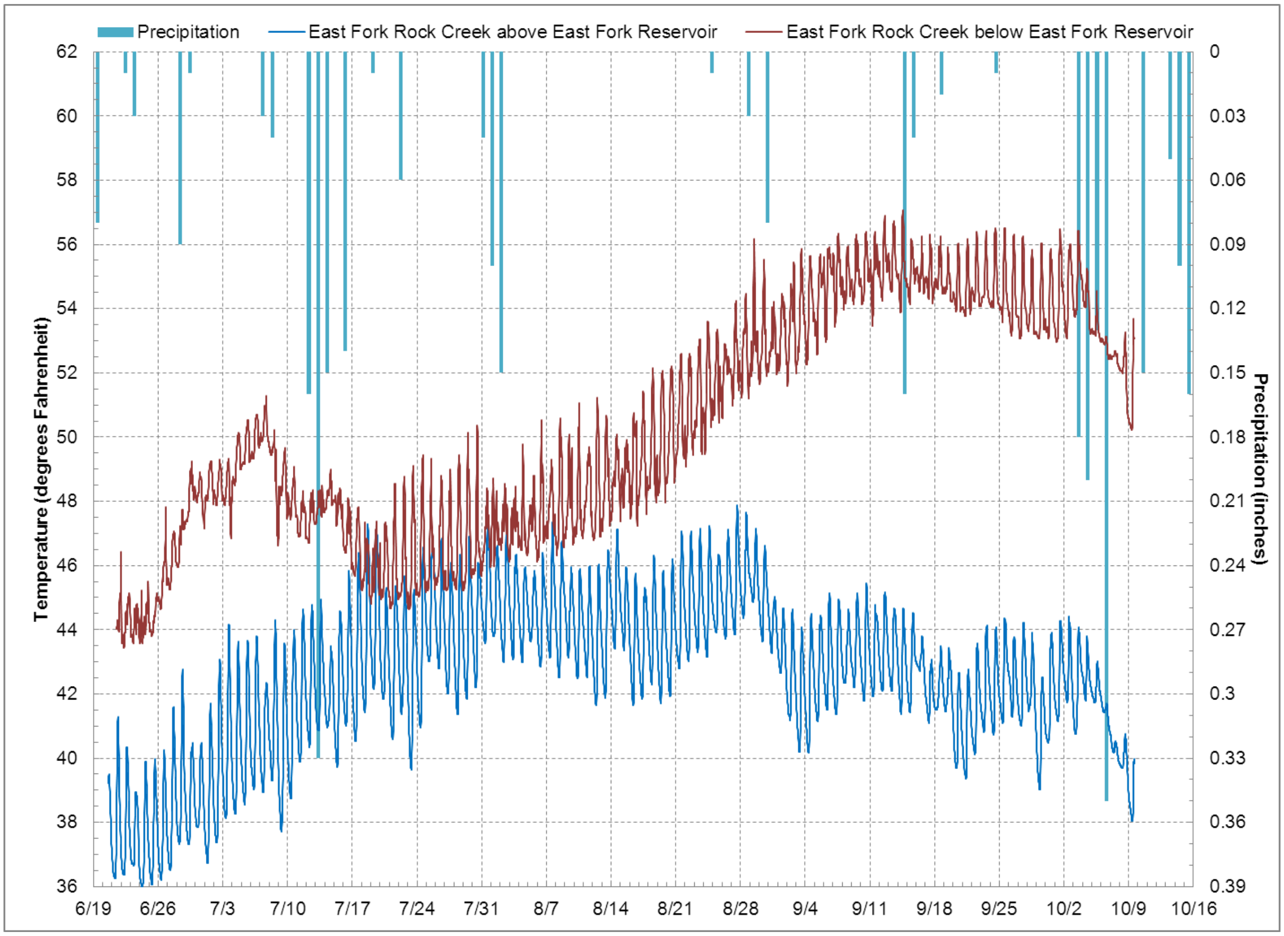

Figure ID-3. Above and below East Fork Reservoir in 2011 (DNRC temperature data).

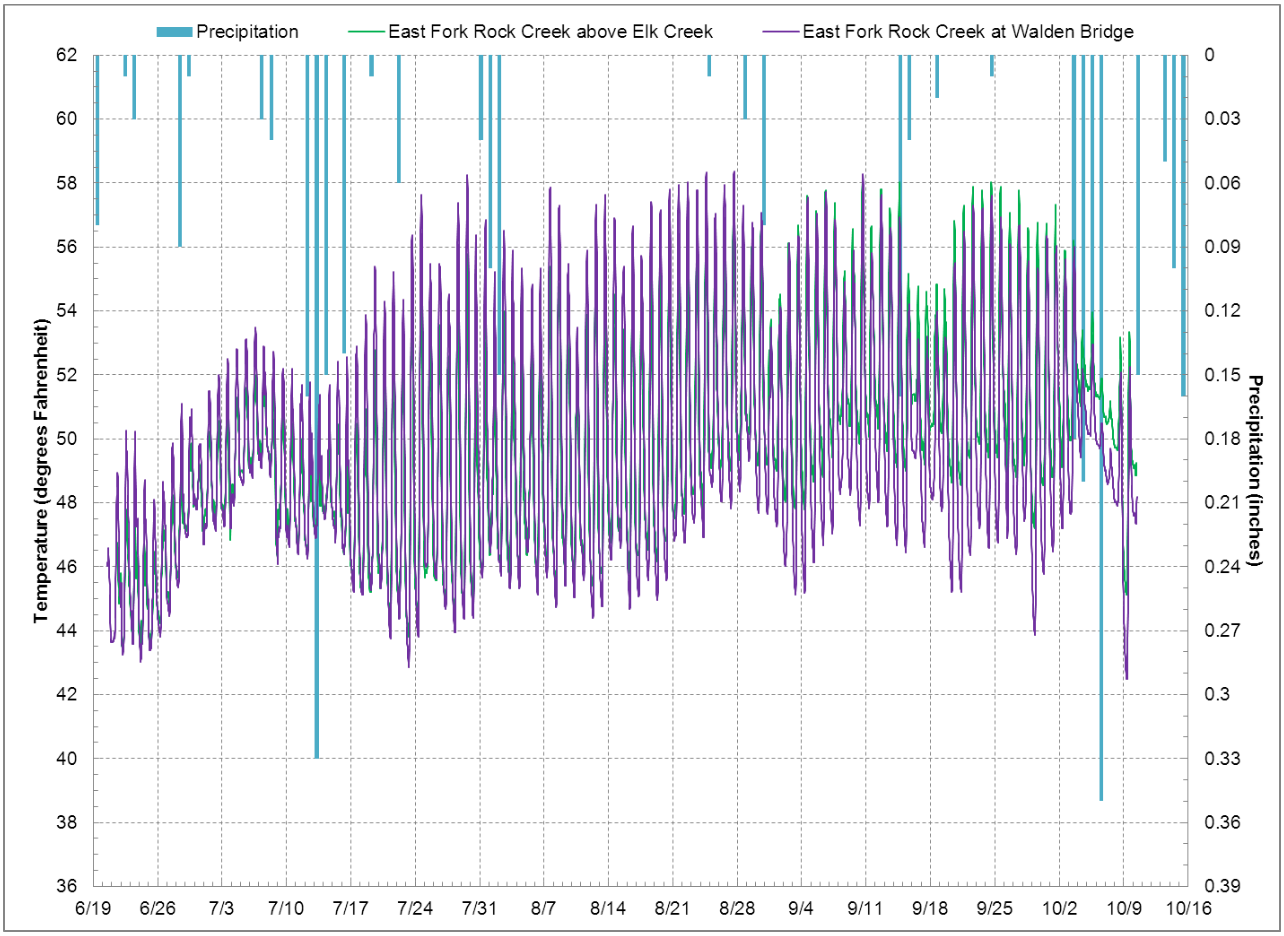

Figure ID-4. East Fork Rock Creek in 2011 (DNRC temperature data).

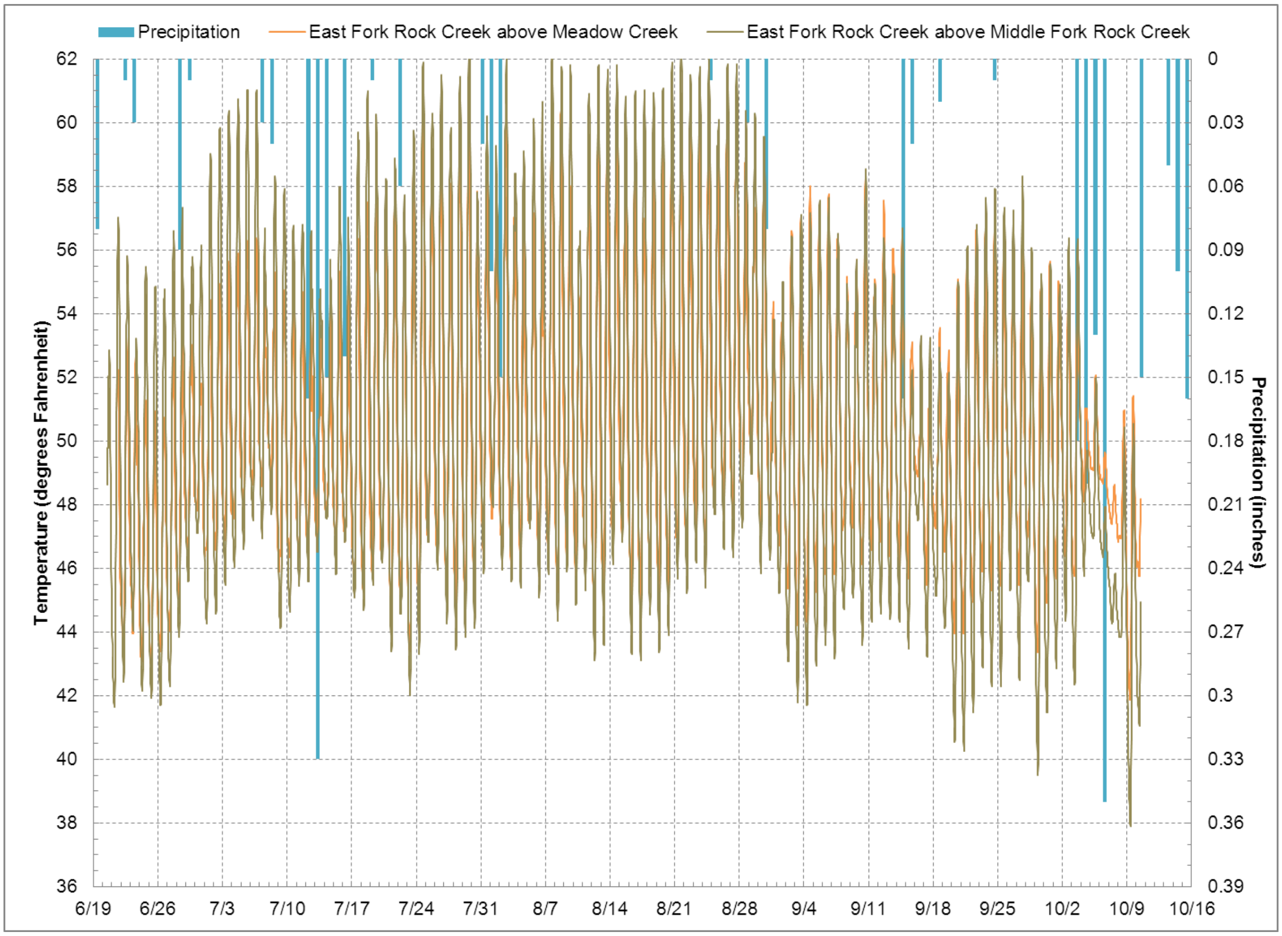

Figure ID-5. Lower East Fork Rock Creek in 2011 (DNRC temperature data).