APPENDIX J – SOUTH FORK ANTELOPE CREEK TEMPERATURE MODELING REPORT

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

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ACRONYMS AND ABBREVIATIONS

DEM	digital elevation model
EPA	U.S. Environmental Protection Agency
HUC	hydrologic unit code
DEQ	Montana Department of Environmental Quality
ODEQ	Oregon Department of Environmental Quality
QAPP	quality assurance project plan
TMDL	total maximum daily load
TPA	TMDL Planning Area
WET	Water & Environmental Technologies, PC

UNITS OF MEASURE

cfs	cubic feet per second
°C	degrees Celsius
°F	degrees Fahrenheit

EXECUTIVE SUMMARY

South Fork Antelope Creek, a small mountain stream 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 natural low-flow conditions and increased shading conditions. Data for model setup and calibration are limited upstream of the monitoring station that is most upstream; available field data are not sufficient to determine how far upstream a channel might exist. These model scenarios were evaluated to assess a potential worst-case scenario.

Natural low-flow conditions scenarios resulted in increased daily maximum and mean temperatures as compared to the existing condition scenario. Increasing to full potential shade had little effect on instream water temperatures in comparison to both the existing condition and natural low-flow conditions scenarios.

J1.0 BACKGROUND

This section presents background information including a brief description of the water quality problem, the applicable water quality standards, project history, and study area.

J1.2 PROBLEM STATEMENT

South Fork Antelope Creek has a B-1 use class. It is not supporting its Aquatic Life or Primary Contact Recreation designated uses (Montana Department of Environmental Quality, 2012). Five potential causes of impairment are identified in the assessment record, including alteration in streamside or littoral vegetative covers and water temperature (Montana Department of Environmental Quality, 2012). The potential sources of the water temperature impairment are unknown. In a 2004 assessment, DEQ found that the stream temperature at the mouth was approximately 54 degrees Fahrenheit (°F), which is sufficiently cold for westslope cutthroat trout. However, it was thought that this temperature measurement may not represent the most problematic time period for temperature stress (Montana Department of Environmental Quality, 2012, p.16).

J1.3 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 which 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] ARM 17.30.623 (2)(e).

The model results will ultimately be compared to these criteria.

J1.4 Project History

Temperature and flow data were collected in South Fork Antelope Creek in 2010 by DEQ. Water & Environmental Technologies, PC (WET), under contract with DEQ, prepared a Quality Assurance Project Plan (QAPP) for temperature monitoring and modeling in the Rock TPA in 2011. A field team from WET and DEQ collected measurements on August 24th, 25th, 30th, and 31st 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 based on the data and information compiled by WET and DEQ.

J1.5 Study Area

South Fork Antelope Creek (MT76E002_060) is in the Rocky Mountains of western Montana and is part of the Rock Creek TPA (**Figure J1**). The creek is in the Rock Creek–Mallard Creek 12-digit hydrologic unit code (HUC) (17010202 12 01), in the Flint-Rock 8-digit HUC (17010202). The impaired segment is 2.9 miles long and extends from the headwaters to the mouth. Roughly half of the South Fork Antelope Creek watershed is forested (**Figure J2** and **Figure J3**). The remaining area is either shrub or grassland, exhibiting various stages of regrowth from timber harvesting as visible on the aerial image in **Figure J3.** Approximately two-thirds of the watershed is privately owned (**Figure J4**). The remainder is owned by the U.S. Bureau of Land Management.

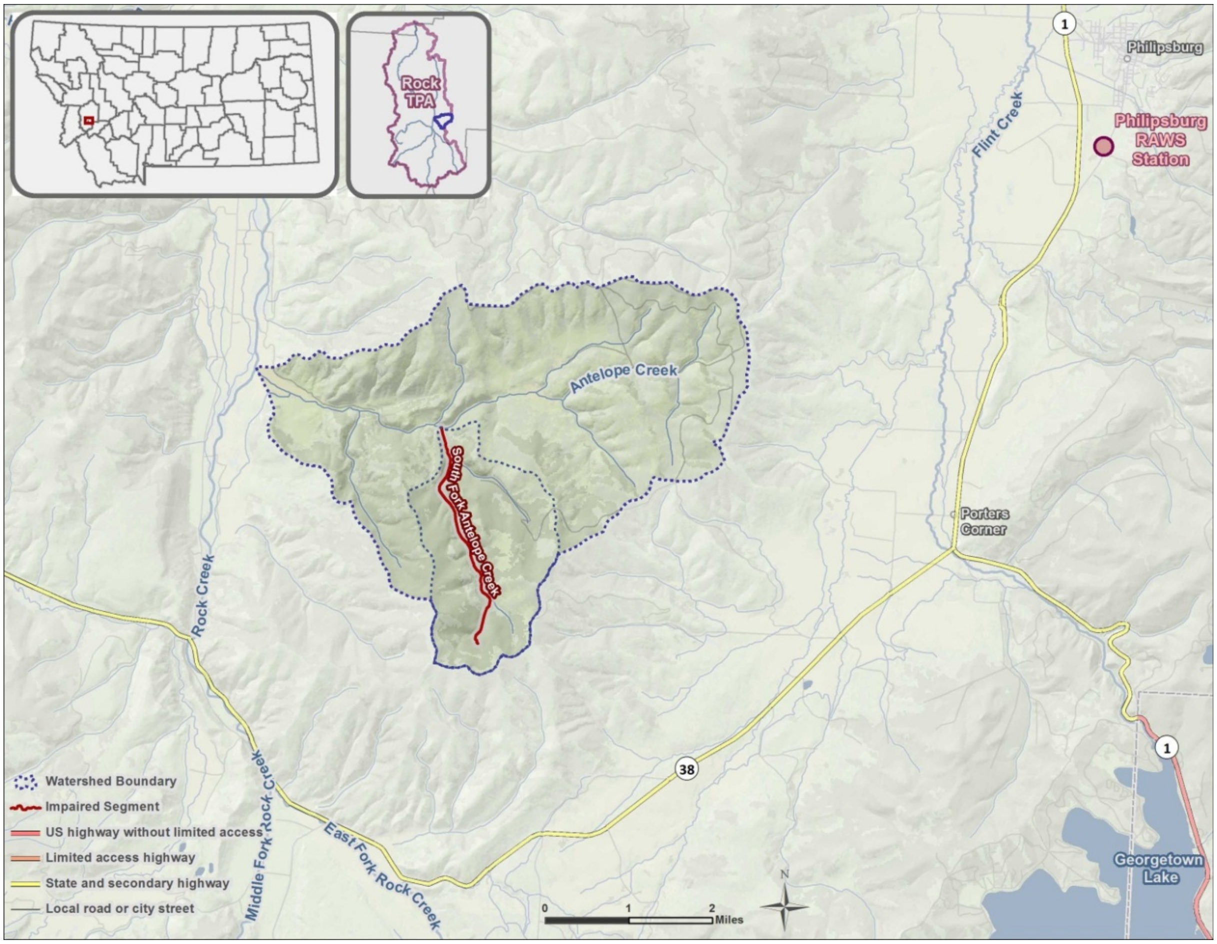


Figure J-1. South Fork Antelope Creek watershed.

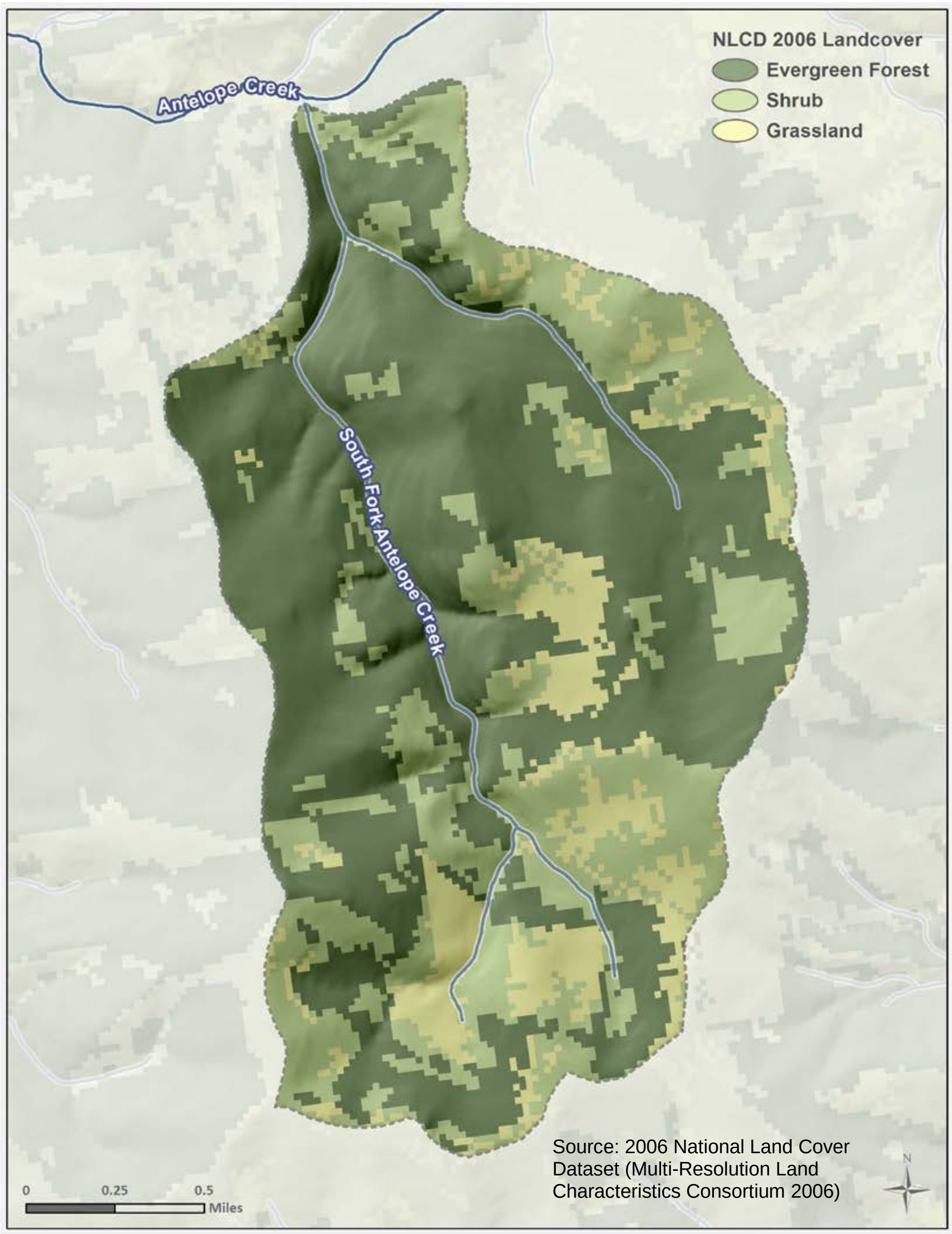


Figure J-2. Land cover in the South Fork Antelope Creek watershed.

Figure J-3. Aerial view of the South Fork Antelope Creek watershed.

Source: NRIS 2012

Figure J-4. Land ownership in the South Fork Antelope Creek watershed.

J2.0 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 (Pool and Berman, 2001). The external drivers include climate (e.g., solar radiation, air temperature, and near-stream wind speed), stream morphology, groundwater influences, and riparian canopy condition (Pool 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 South Fork Antelope 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.

J2.1 Climate

The nearest weather station to the South Fork Antelope Creek watershed is 9 miles to the northeast, in Philipsburg, Montana. Average annual precipitation is 15.02 inches with the greatest amounts falling in May and June (**Figure J5**); Western Regional Climate Center 2012). Average maximum air temperatures occur in July and August and are 80.9 and 79.2 °F, respectively. Most cloud-free days occur between June and September.

Note that the Philipsburg weather station's elevation is 5,280 feet above mean sea level, compared to the impaired reach of South Fork Antelope Creek, which ranges in elevation from approximately 5,500 to 6,600 feet above mean sea level.

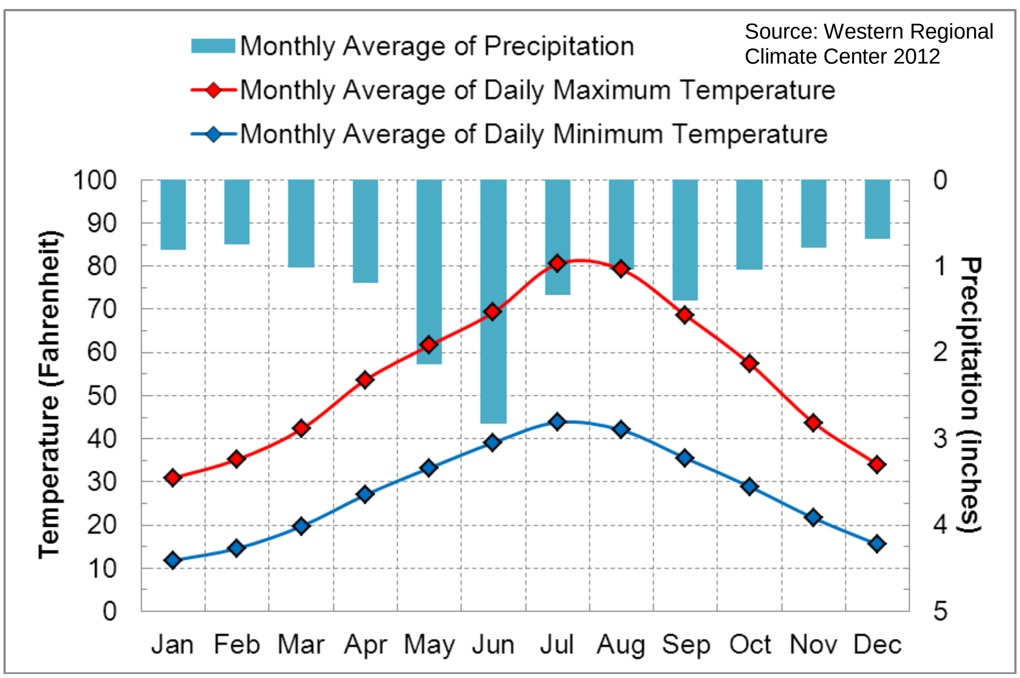


Figure J-5. Monthly average air temperatures and precipitation at Philipsburg, Montana.

J2.2 Riparian Vegetation

Riparian vegetation data along the mainstem of South Fork Antelope 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 four of their sampling locations. These data are presented in **Appendix JA.** The vegetative community types occurring in the riparian corridor, as identified in aerial imagery, are shown in **Figure J6** (Water & Environmental Technologies, 2011).

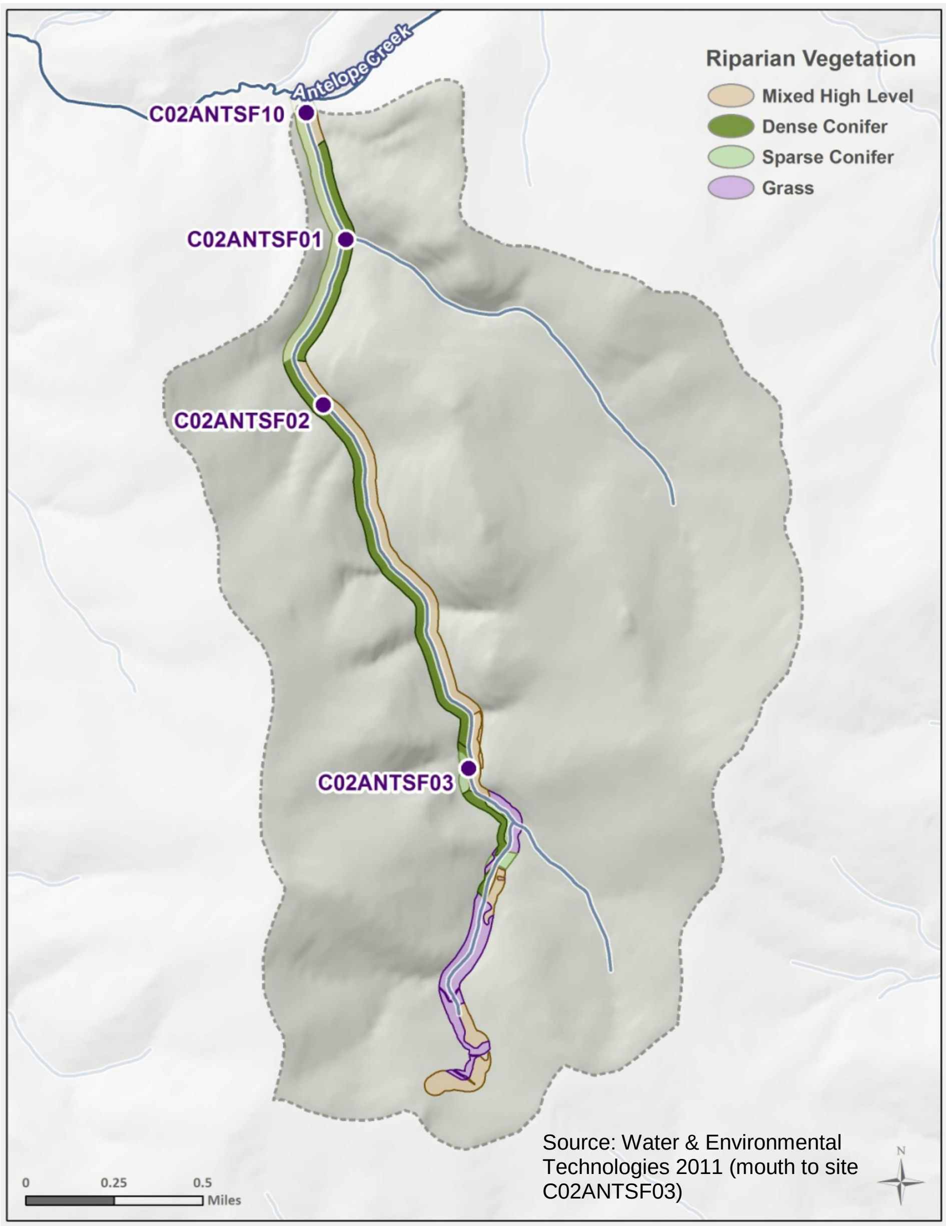


Figure J-6. Riparian vegetation along the mainstem of South Fork Antelope Creek.

J2.3 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 three sites along South Fork Antelope Creek: C02ANTSF10, C02ANTSF01, and C02ANTSF02. Three sets of measurements were recorded at each site; only vegetative shade was observed at these sites.

An analysis of aerial imagery showed that shading along South Fork Antelope Creek was highly variable because of timber harvest and changes in elevation along the stream. Therefore, shade data were also collected at three sites (C02ANTSF10, C02ANTSF01, andC02ANTSF02) and 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 JA**, Water & Environmental Technologies, 2011); these data are discussed throughout the remainder of this section. The riparian vegetation information (i.e., height, density, and overhang that are displayed in **Appendix JA**) 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 (DEM) and the previously mentioned digitized hydrography (for the TTools results, see **Appendix JC: Table JC-1**). 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 J7 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 2.0, varied over a constant range from river mile 2.0 to river mile 0.2, and decreased considerably from river mile 0.2 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 J7**). Additional plots of these data sets are presented in **Appendix JB**.

[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 South Fork Antelope 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).

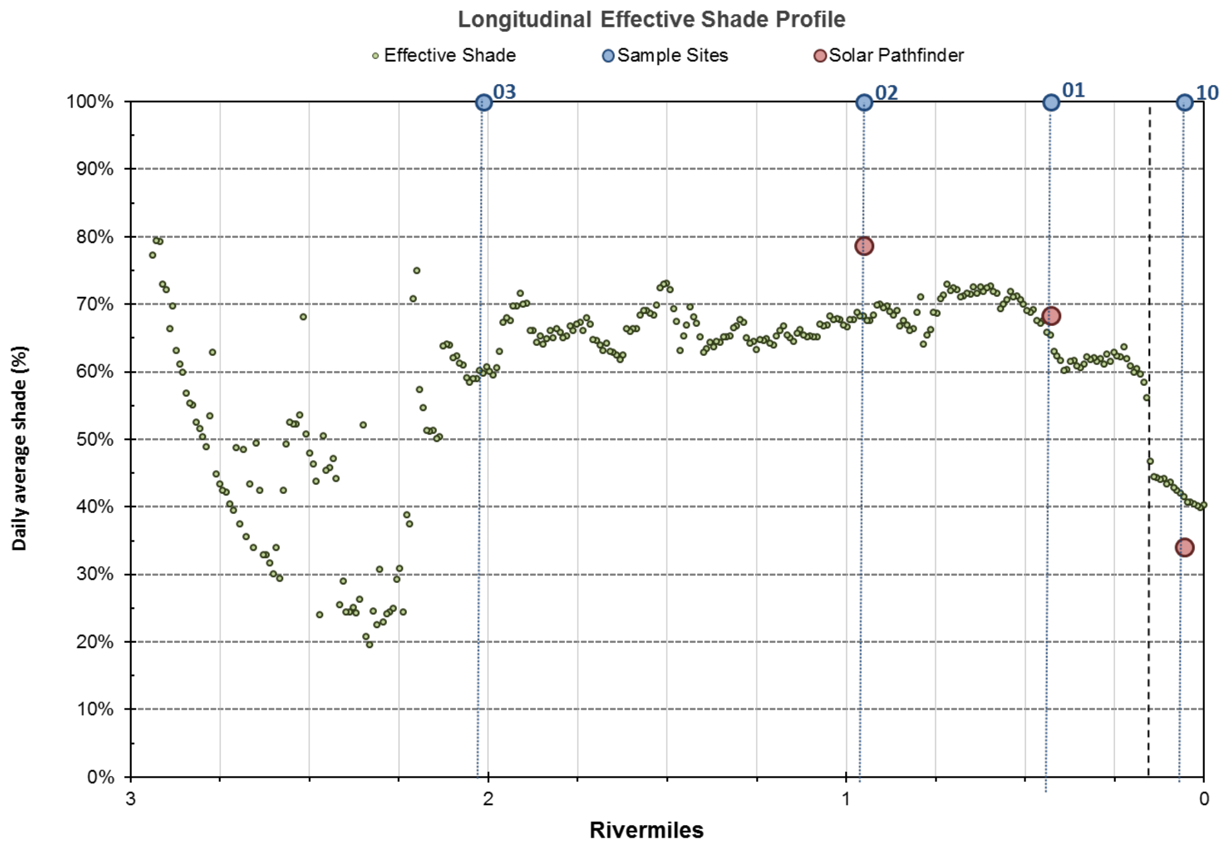


Figure J-7. Effective shade output from Shadev3.0.xls and Solar Pathfinder data.

J2.4 Hydrology

Flow data for the South Fork Antelope Creek are limited to 16 instantaneous measurements. DEQ measured streamflow on three dates in South Fork Antelope Creek in 2010 (July 15, August 26/27, and September 24) and two dates in 2011 (August 1 and August 31/September 1). Monitoring locations are shown in **Figure J8** along with the locations of two springs that DEQ identified (Water & Environmental Technologies, 2011). Measured flows ranged from approximately 0.1 to 0.6 cubic feet per second (cfs) in 2010 and from 0.3 to 3.5 cfs in 2011 (**Figure J9**).

On the basis of a review of online water rights data (ftp://nris.mt.gov/dnrc), two surface diversions are in the South Fork Antelope Creek watershed. *Points of diversion* and *places of use* spatial data were obtained from the Montana Natural Resource Information System. Of the two diversions in the South Fork Antelope Creek watershed, one is directly from South Fork Antelope Creek and is used for livestock. No data are available defining the quantity of water diverted. For the purposes of this modeling study, it is assumed that the quantity is very small because it is for livestock watering.

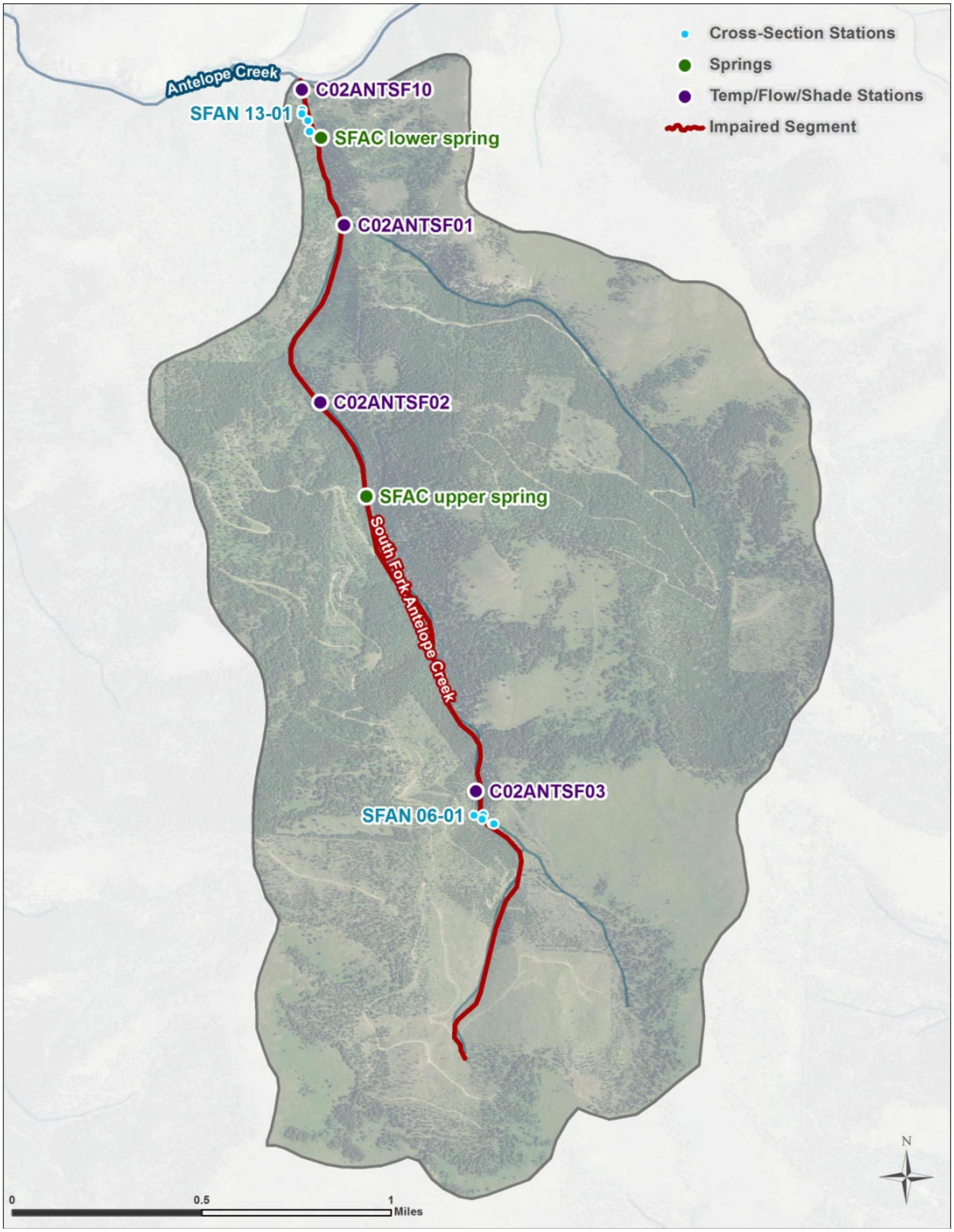


Figure J-8. Flow and temperature monitoring locations.

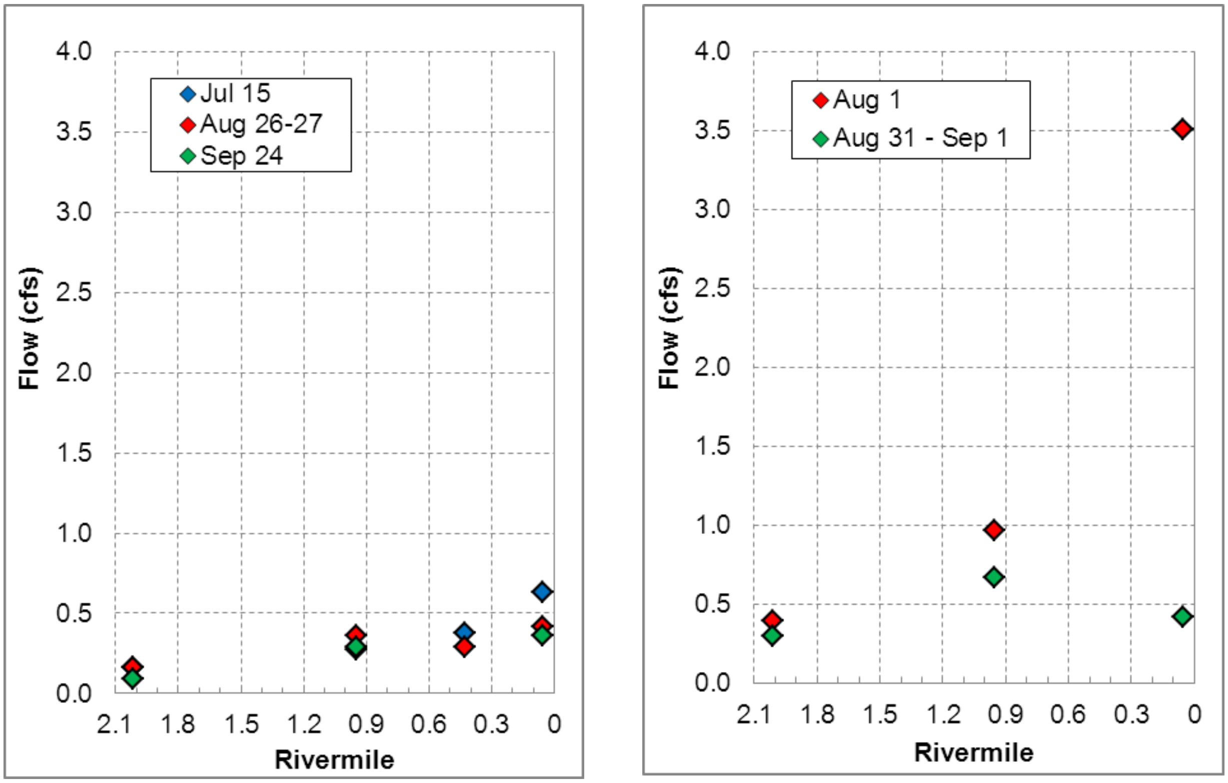


Figure J-9. DEQ flow measurements in South Fork Antelope Creek in 2010 (left) and 2011 (right).

J3.0 Stream Temperature

DEQ collected stream temperature data in 2010. Monitoring locations are shown in **Figure J8**. A brief discussion of all the available temperature data and factors that could be influencing stream temperature follows.

J3.1 Stream Temperature Data

DEQ collected continuous temperature data at four locations along South Fork Antelope Creek in 2010 (i.e., sites C02ANTSF10, C02ANTSF01, C02ANTSF02, and C02ANTSF03 shown on **Figure J8**). Loggers recorded temperatures every half hour for 2 months between July 15 and 16, 2010, and September 23 and 24, 2010 (i.e., 70 days); these data are summarized in **Figure J10**. Daily maximum temperatures were the coolest and varied the least (between approximately 44.0 and 55.0 °F) at the site that is most downstream (C02ANTSF10). The highest maximum temperatures were at the site that is most upstream (C02ANTSF03) and ranged from approximately 44.0 to 61.0 °F. The largest range of maximum daily temperatures was also observed at the site that is most upstream (C02ANTSF03).

Additionally, temperature grab samples were collected from two springs along Antelope Creek in 2011. DEQ also collected instantaneous water temperatures during water quality monitoring in 2004, 2010, and 2011. These data are summarized in **Table J-1**.

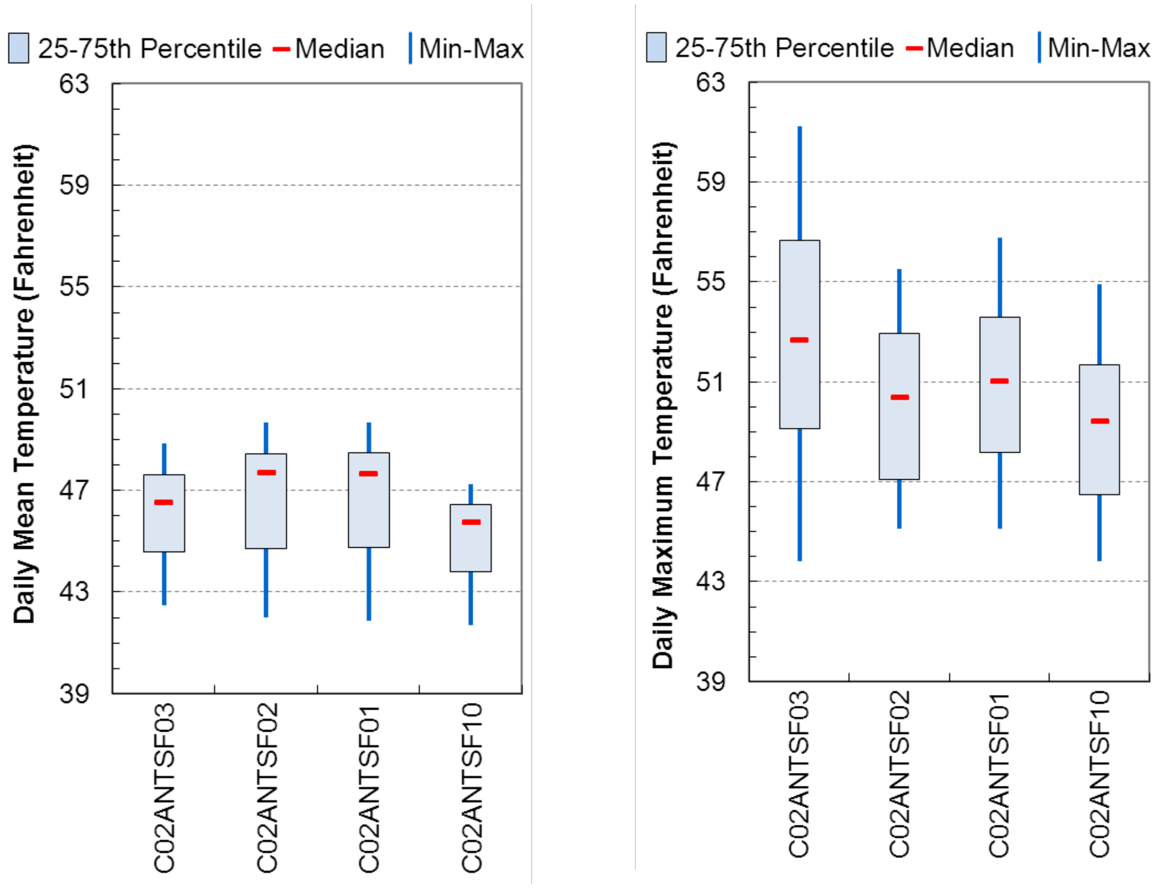


Figure J-10. Daily mean (left) and maximum (right) temperatures calculated at loggers along South Fork Antelope Creek in 2010.

Table J-1. Instantaneous water temperature measurements (°F)

Location	7/24/2004	7/15/2010	8/26/2010	9/24/2010	8/1/2011	8/31/2011
C02ANTSF10	54.3	--	--	--	--	--
C02ANTSF01	--	50.2	42.4	--	--	--
C02ANTSF02	--	53.8	51.6	43.9	48.7	45.3
C02ANTSF03	--	52.0	44.8	50.4	50.7	45.5
Upper Spring	--	--	--	--	--	43.5
Lower Spring	--	--	--	--	--	44.1

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

J3.2 Stream Temperature Data Analysis

South Fork of Antelope Creek is a small, shallow mountain stream. The coolest recorded stream temperatures were observed at the station that is most downstream, which corresponds to the lowest effective shade (**Figure J7**). The warmest recorded maximum temperatures were observed at the most upstream station where effective shade values are among the highest (**Figure J7**). This suggests that shade might not be the most important factor in moderating stream temperatures in South Fork Antelope Creek. It appears that the dominant factor affecting instream temperatures is the ambient air temperature.

Figure J-11 and **Figure J-12** show the instream temperature response to the cooler air temperatures and addition of rainwater. The headwaters of the creek (site C02ANSF03) are very shallow, and instream temperatures directly correspond to the ambient air temperature. Temperatures logged in the lower segments of the South Fork of Antelope Creek also typically vary with temperature but are generally cooler than the headwaters segments during the day and warmer than the headwaters during the night.

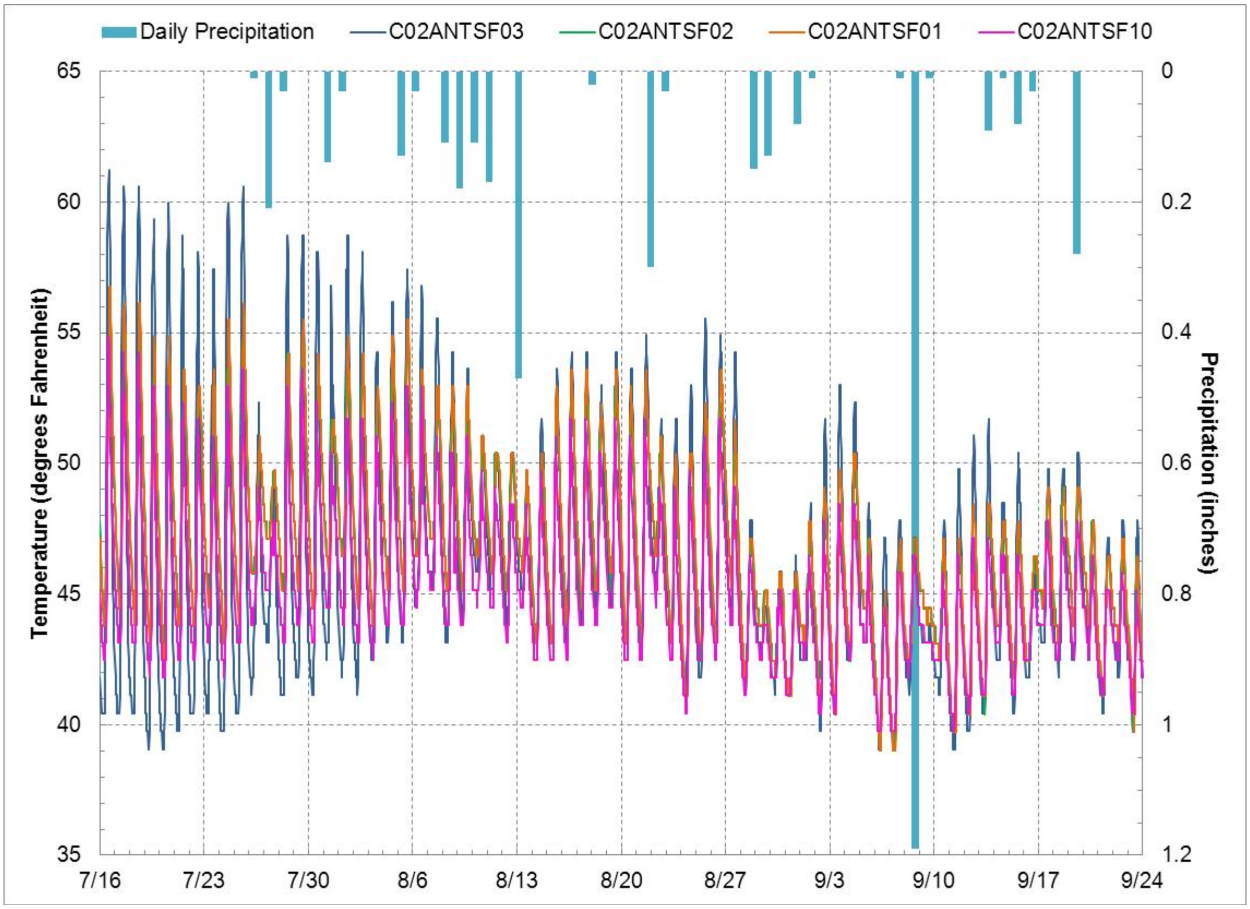
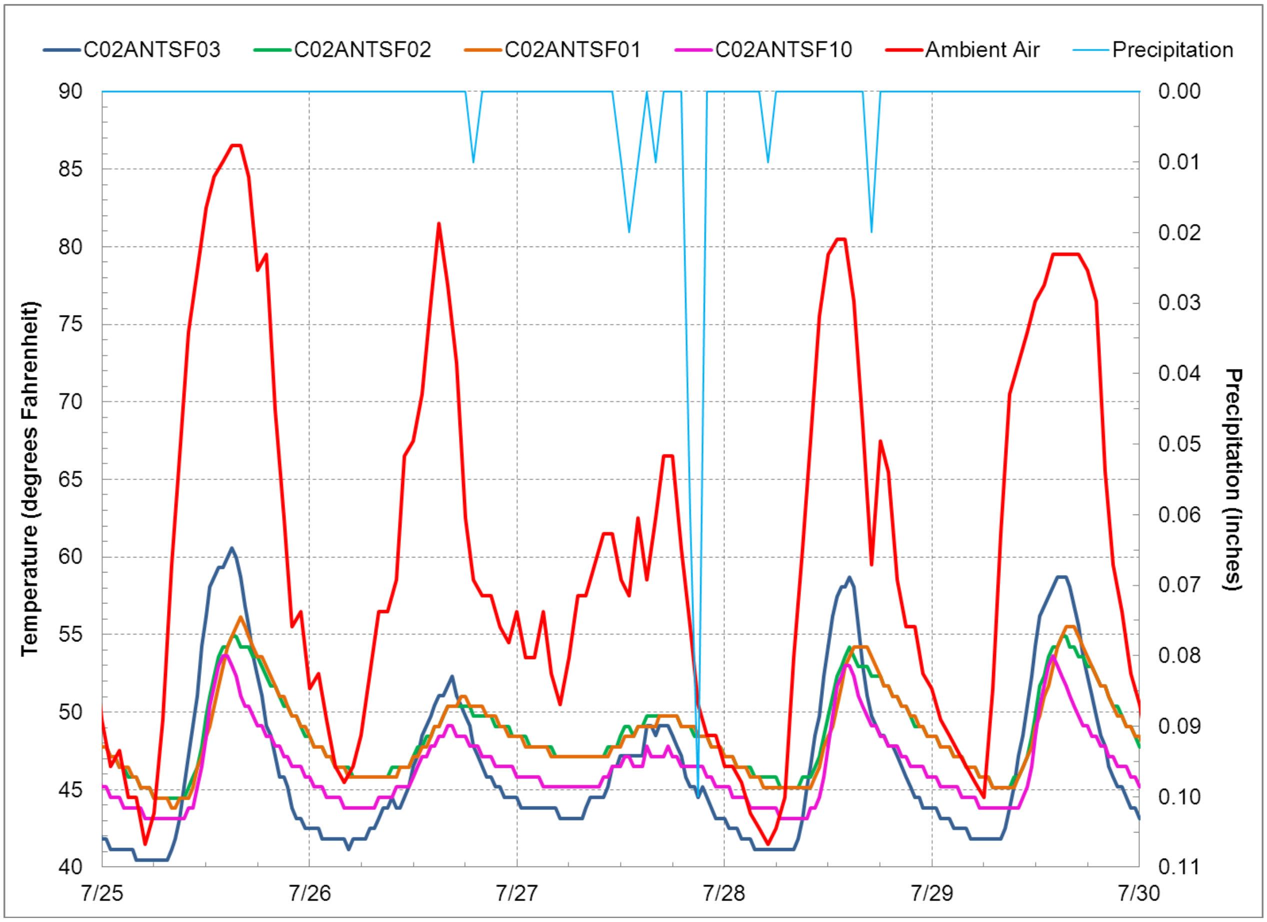


Figure J-11. Hourly water temperatures at the four loggers and daily precipitation at the Philipsburg RAWS (July 16 to September 24, 2010).



Notes: Hourly ambient air temperature data were acquired from the Philipsburg RAWS and were elevation-corrected. Hourly precipitation data were acquired from the Philipsburg RAWS.

Figure J-12. Hourly water and ambient air temperatures and precipitation (July 25-30, 2010).

J4.0 Model Setup

The QUAL2K model was selected to simulate temperatures in South Fork Antelope 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, 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, 2012).

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

J4.1 Channel Flow Path

South Fork Antelope Creek, as delineated in the National Hydrography Dataset, is a 2.9-mile perennial stream. DEQ evaluated multiple locations along the creek from its mouth upstream to river mile 2.01, which is site C02ANTSF03. The upper 0.9 mile has not been visited, and it is not known how far upstream of river mile 2.0 that the defined channel persists. Therefore, the QUAL2K model for South Fork Antelope Creek was developed for the 2.01-mile portion of the creek (i.e., from the mouth on Antelope Creek to DEQ sample site C02ANTSF03).

Two unnamed tributaries to South Fork Antelope Creek were delineated by the U.S. Geological Survey (USGS) in the National Hydrography Dataset. The confluences of the tributaries are at approximately river miles 0.4 and 2.3 along South Fork Antelope Creek. The unnamed tributary at river mile 0.4 was modeled implicitly as diffuse flow because it was assumed to contribute minimal flow. The tributary at river mile 2.3 was not directly addressed but is included in the headwaters boundary conditions.

Finally, two springs were identified by DEQ during the 2011 field visit (Water & Environmental Technologies, 2011). The springs were modeled as point inputs at river miles 0.19 and 1.24. The modeled flow path is shown graphically in **Figure J-13**.

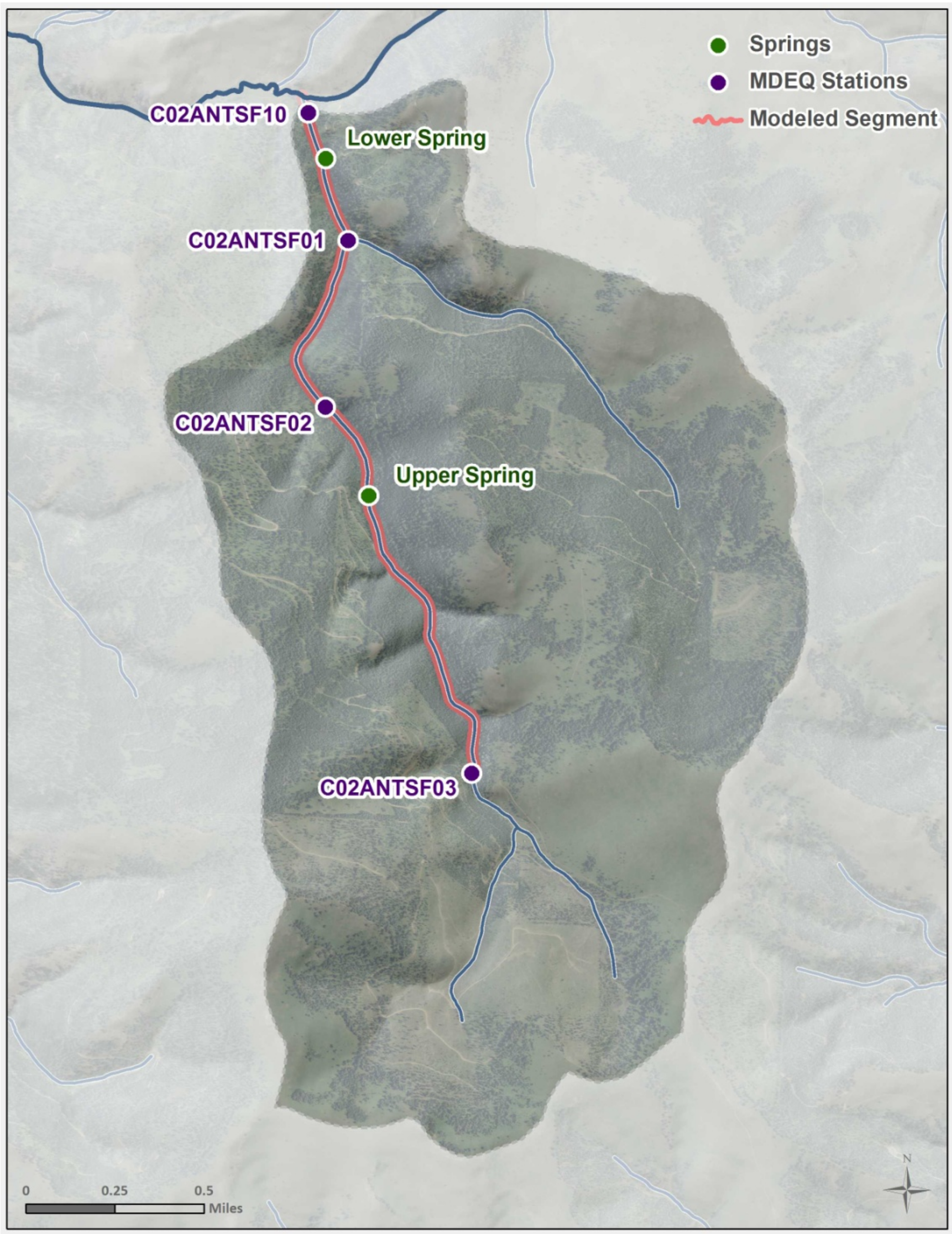


Figure J-13. Schematic of the surface hydrography of South Fork Antelope Creek.

J4.2 Stream Segmentation

South Fork Antelope Creek was divided into four linked segments (**Figure J-14)**; identified as D, C, B, and A [headwaters to mouth]). The segment locations were selected on the basis of available diurnal temperature and flow data (available at the four sample sites), changes in vegetation, and changes in effective shade. The existing conditions scenario is defined as segments D, C, B, and A; DEQ collected data along these segments that were used to develop the model.

Each of the linked segments is further subdivided into five equally spaced elements or computational units. The number of computational units was determined on the basis of the estimated velocity and computational time-step to ensure the containment of the heat load calculation in 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.

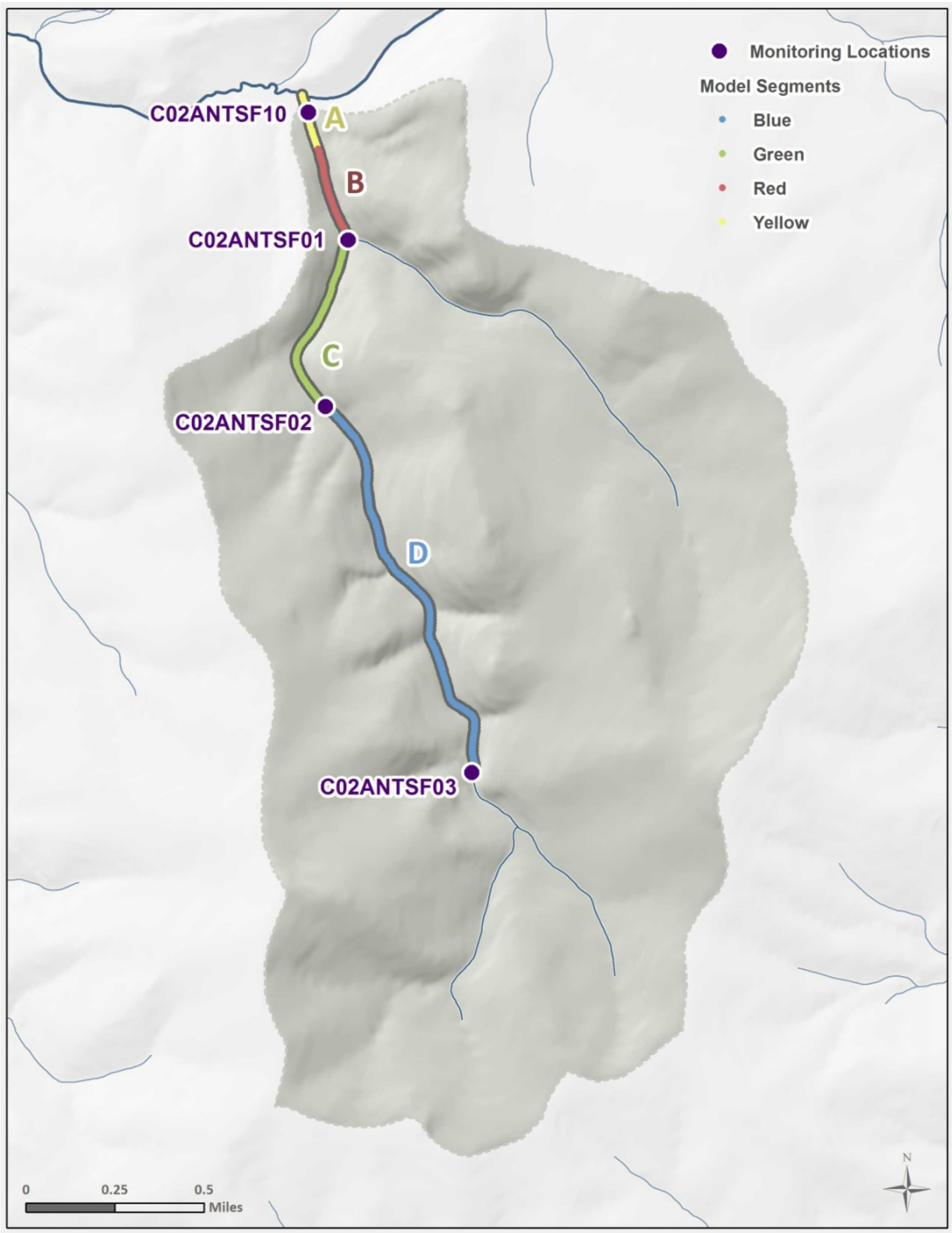
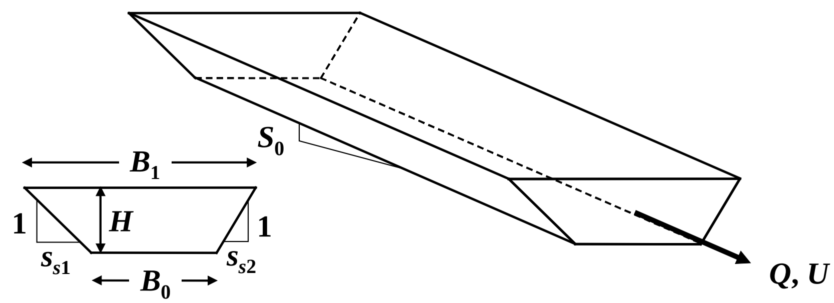


Figure J-14. Model segmentation along South Fork Antelope Creek.

J4.3 Channel Geometry

Channel geometry inputs for QUAL2K for reaches A, B, C, and D were derived using field-measured data and DEQ's cross-sections (Water & Environmental Technologies, 2011) (for the original data, see **Appendix JA** and for the model inputs, see **Appendix JC**). No channel geometry data were available upstream of sample site C02ANTSF03.

Manning's roughness coefficient (n) was estimated during a field visit (Water & Environmental Technologies, 2011). Channel slope was 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 J-15**) were estimated using cross-sectional profile data collected during field work (Water & Environmental Technologies, 2011).



Source: (Chapra, 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 J-15. Idealized trapezoidal channel assumed in QUAL2K.

J4.4 Hydrologic Simulation

Although flow and related parameters (i.e., velocity and depth) can be reasonably simulated in QUAL2K, there are 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 at four locations along the mainstem on July 15, 2010, were used to derive all the flow inputs required to run the QUAL2K model for the calibration day of July 16, 2010 (**Appendix JC, Table JC-3).** The difference in flow between each observation was assumed to be diffuse flow (**Appendix JC, Table JC-4**). The headwaters inflow was assumed to be 1.7 cfs and was calculated on the basis of an area ratio with the flow monitored at C02ANTSF03. Note that the tributary at river mile 0.43 was not explicitly modeled and is represented in the diffuse flow to reach B.

Two springs were observed during field work (Water & Environmental Technologies, 2011). The flow rates for input into the QUAL2K model were based on qualitative observations during field work. The upper spring was calculated as 8 percent of the mainstem flow; during field work, the contribution was estimated to be 6 to 10 percent of the mainstem flow. The lower spring was observed to discharge very small flow; the spring was calculated as 1 percent of the mainstem flow (**Appendix JC**, **Table JC-5**).

Diffuse inflow (i.e., groundwater) temperatures were estimated on the basis of available groundwater temperature data in the Ground Water Information Center database (Water & Environmental Technologies, 2011). An average temperature of 8.13 °C was assigned equally to all diffuse inflows. The spring temperatures (both the upper and lower springs) were estimated by averaging the two field-collected instantaneous temperatures.

Figure J-16 is a graphical summary of the hydrologic inputs.

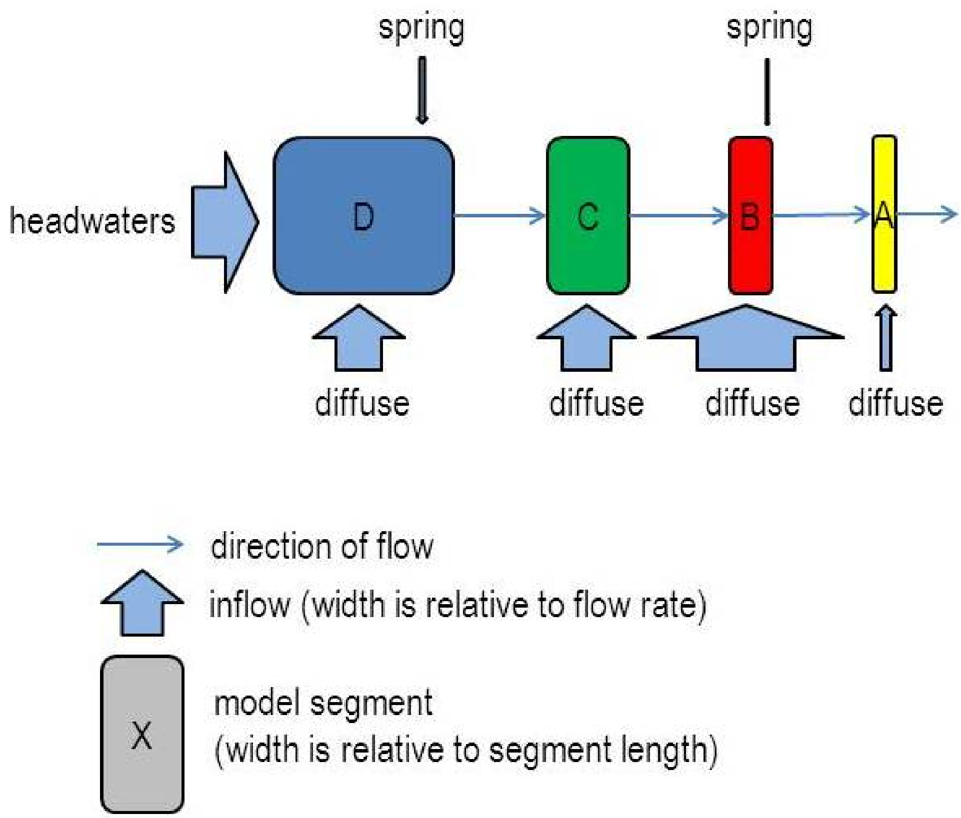


Figure J-16. Schematic representation of inflows to South Fork Antelope Creek.

J4.5 Weather

Weather inputs were compiled from the closest station recording the necessary data (**Appendix JC**, **Table JC-6**and **Table JC-7**). These data were used as model input for the July 16, 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. 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 (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 16, 2010; therefore, zero percent was input for all 24 hours in the QUAL2K model.

J4.6 Shade

Riparian shade was estimated using a geographical information system and the Shadev3.0.xls (for a discussion of how shade was estimated, see **Section J2.3**. The hourly shade inputs per reach for the proposed QUAL2K model segments are summarized in **Figure J-17** (for the inputs for QUAL2K, see **Appendix JC Table JC-8**).

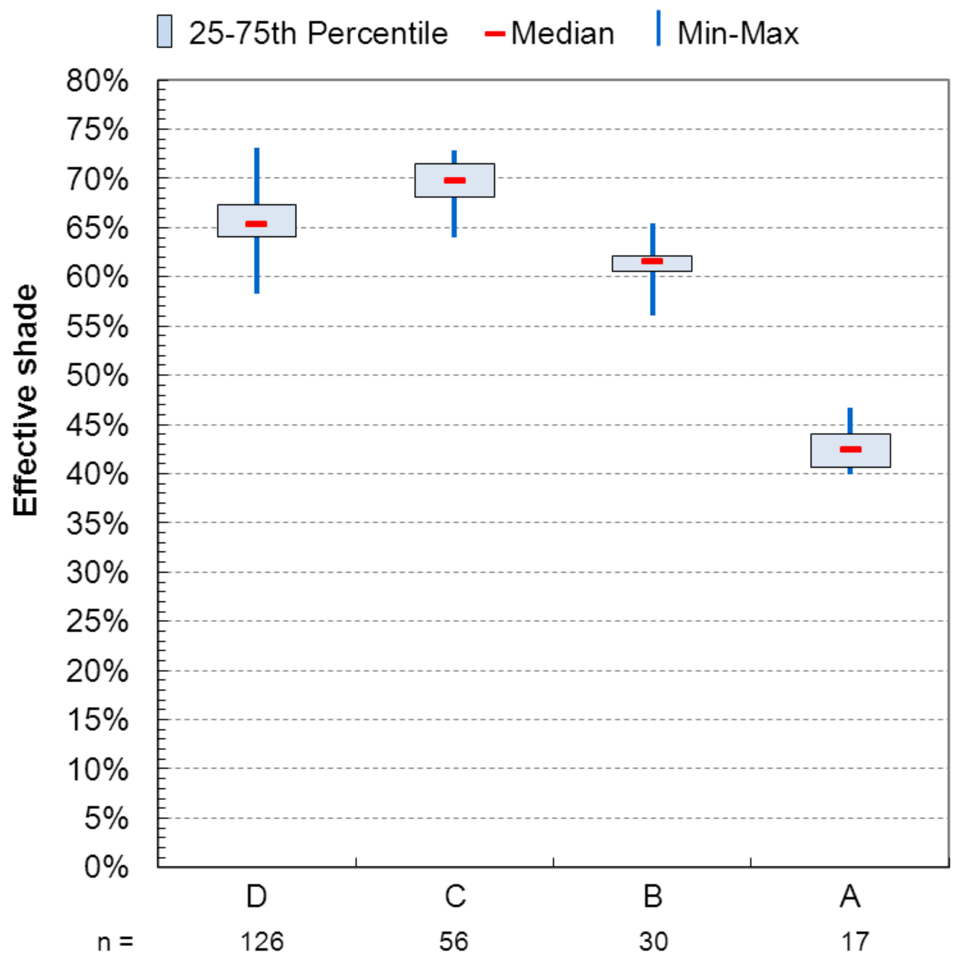


Figure J-17. Box and whisker plot evaluation of effective shade output.

J4.7 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 JC-9** in **Appendix JC**.

J5.0 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 investigations of how a system would likely respond to a perturbation from its current state. To provide a credible basis for prediction and the evaluation of 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, 2012).

J5.1 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 particularly 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 South Fork Antelope 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, 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 °C or a relative error of less than 10 percent for higher temperatures. These criteria were applied in this project.

J5.2 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 times in the stream, from headwaters to mouth, is less than one day. Average velocities were calculated from depth-velocity interval data recorded when flow was monitored on 11 occasions. Average velocity ranged from 0.21 to 1.4 feet per second, with an average of 0.67 foot per second. Such velocities yield travel times of 3.5 to 22 hours, with an average of 7.2 hours.

Available precipitation data were also considered when selecting calibration and validation periods (**Figure J-18**). The warmest stream temperatures occurred in July when there was no precipitation (**Figure J-18**). 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 16, 2010) and validation period (August 26, 2010) 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).

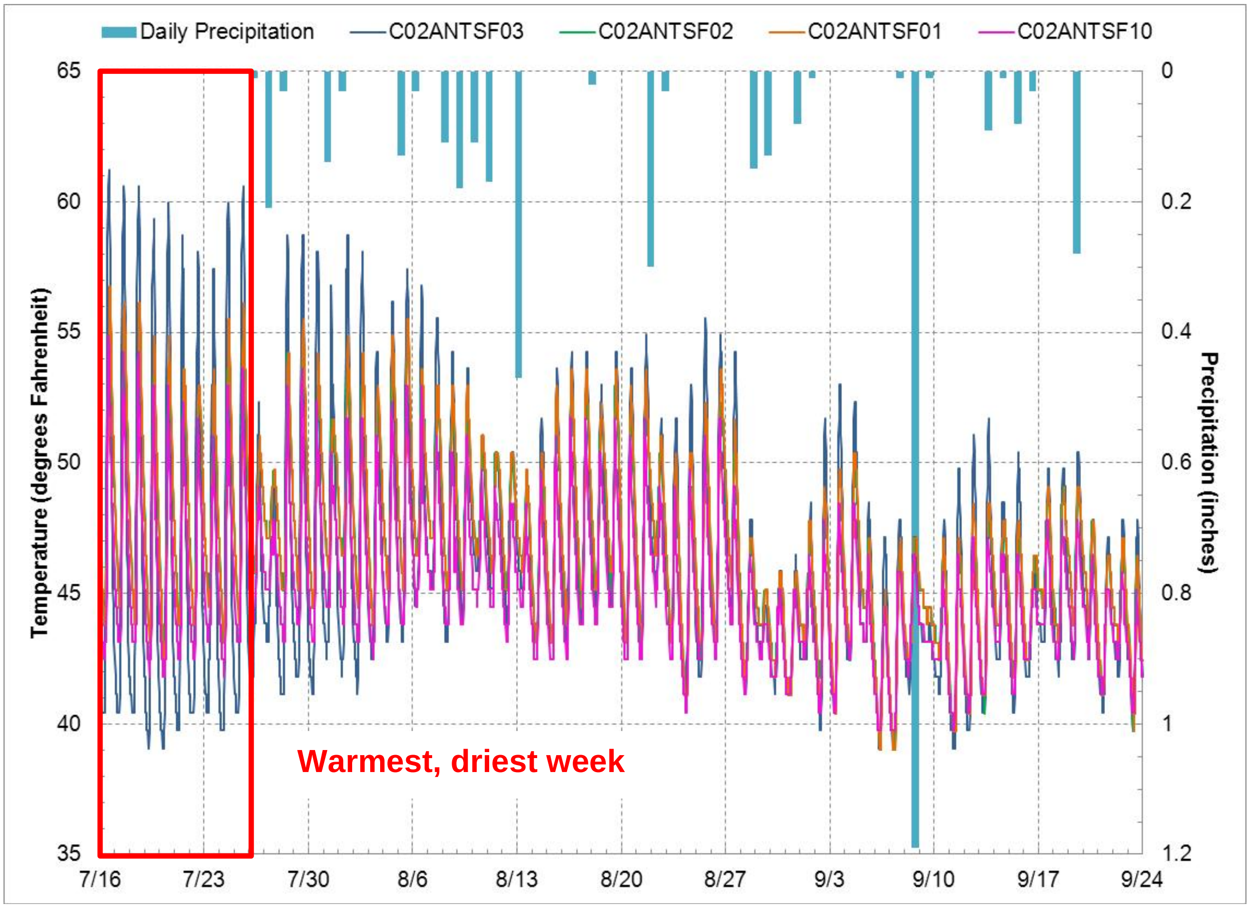


Figure J18. Daily precipitation and instream temperature along South Fork Antelope Creek.

J5.3 Calibration Results

Temperature calibration for the South Fork Antelope Creek QUAL2K model relied on a comparison of model predictions to observations at the four temperature loggers in the temperature-impaired segment (C02ANTSF03, C02ANTSF02, C02ANTSF01, and C02ANTSF10).

All the modeled minima, means, and maxima are within 2 °C of the corresponding observed minima, means, and maxima (**Table JC-10**). All but two of the relative differences are less than 10 percent. Therefore, in accordance with the QAPP (Tetra Tech, 2012), the calibration is acceptable.

The calibration results are displayed in **Table J-2** and **Figure J-19** in Fahrenheit to facilitate comparisons with model scenarios that are discussed in **Section J6.0.**

Table J-2. Model calibration results for July 16, 2010 (°F)

Daily temperature	Source	Fahrenheit			
		C02ANTSF03	C02ANTSF02	C02ANTSF01	C02ANTSF10
Maximum	QUAL2K	60.3	57.1	55.1	53.3
	Observed	61.2	55.5	56.8	54.9
	Difference	-1.0	+1.6	-1.7	-1.6
Mean	QUAL2K	47.9	47.7	47.6	47.4
	Observed	47.9	49.0	49.0	46.9
	Difference	-0	-1.3	-1.5	+0.5
Minimum	QUAL2K	40.5	41.5	42.7	43.7
	Observed	40.4	43.8	43.8	42.5
	Difference	-0	-2.3	-1.1	+1.2

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.

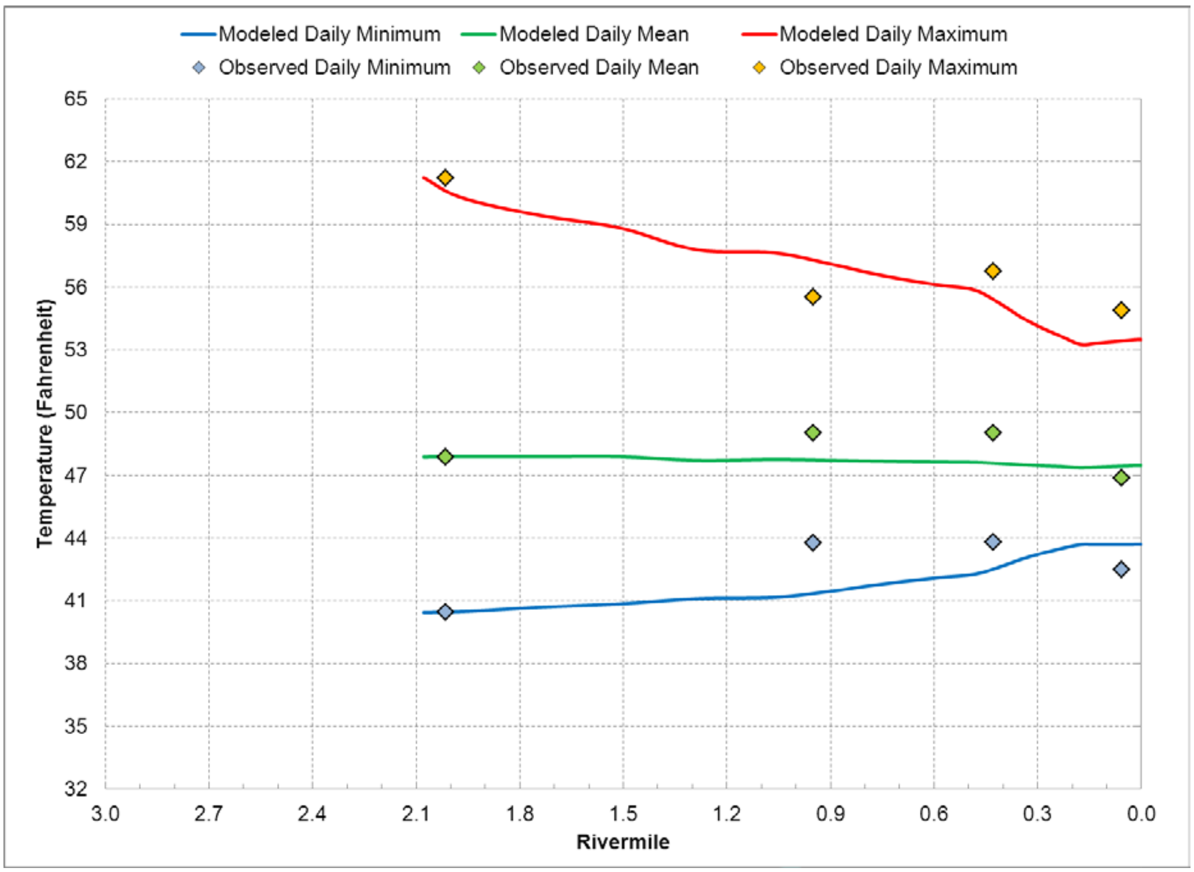


Figure J-19. Calibration period (July 16, 2010).

J5.4 Validation Results

Model validation was determined by a second model run that was conducted under different hydrological and weather conditions (August 26, 2010). Instantaneous flow measurements were collected at three of the four DEQ sites on August 26, 2010. Flow was not monitored at C02ANTSF02 nor was flow monitored at the springs. Flow at these un-gaged sites was estimated using the relationship between flows at the un-gaged sites from July 16, 2010, and the other monitored sites from July 16, 2010, and the flows monitored on August 26, 2010. Weather data for August 26, 2010, were obtained from the same weather stations as for July 16, 2010.

All the modeled minima, means, and maxima are within 2 °C of the corresponding observed minima, means, and maxima (**Table JC-11**). All but one of the relative differences is less than 10 percent. Therefore, in accordance with the QAPP (Council for Regulatory Environmental Modeling, 2009), the validation is acceptable.

The calibration results are displayed in **Table J-3** and **Figure J-20** in Fahrenheit to facilitate comparisons with model scenarios that are discussed in **Section J6**.

Table J-3. Model validation results for August 26, 2010 (°F)

Daily temperature	Source	Fahrenheit			
		C02ANTSF03	C02ANTSF02	C02ANTSF01	C02ANTSF10
Maximum	QUAL2K	54.2	53.8	54.5	53.1
	Observed	54.9	52.3	53.6	51.7
	Difference	-0.7	+1.5	+1.0	+1.4
Mean	QUAL2K	47.6	47.7	47.8	47.6
	Observed	48.1	47.8	48.1	46.6
	Difference	+0.5	-0.1	-0.4	+0.9
Minimum	QUAL2K	43.0	42.9	42.7	43.6
	Observed	43.1	43.1	43.1	42.5
	Difference	+0.1	-0.2	-0.5	+1.1

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.

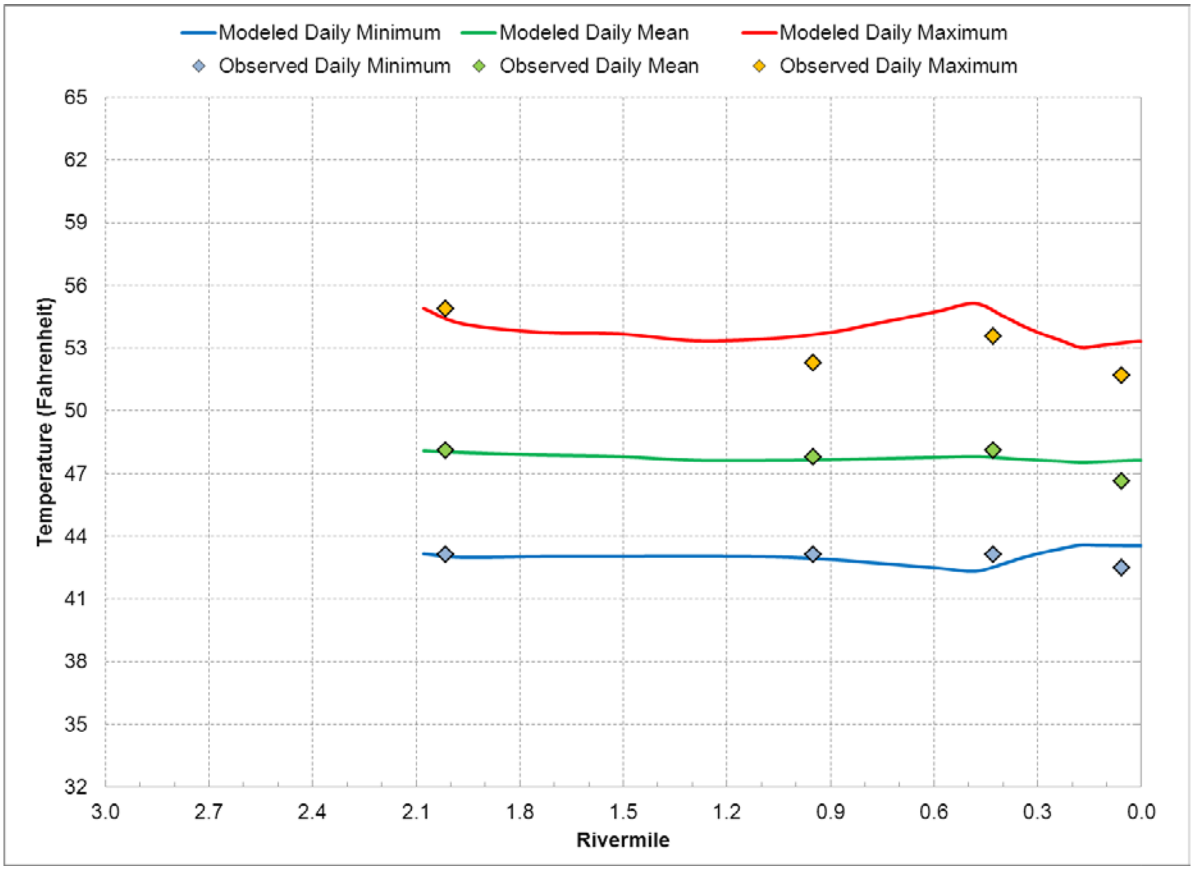


Figure J-20. Validation period (August 26, 2010).

J6.0 Model Scenarios

The South Fork Antelope Creek QUAL2K model was used to evaluate instream temperature response associated with the following scenarios:

- Existing condition
- Existing condition with low flow
- Full potential shade
- Full potential shade with low flow

Table J-4 summarizes the alterations to input parameters for each model scenario. The following sections present a discussion of the modifications to the QUAL2K models and the results for each scenario.

Table J-4. Model scenarios and summary of inputs

Scenario	Inputs
Existing conditions (calibration)	As previously discussed in Section J5.3
Existing conditions with low flow	Reduce inflows by 20 and 37 percent
Full potential shade	Increase shade in all reaches to be equivalent to the reach with the most shade
Full potential shade with low flow	Reduce all inflows by 37 percent and increase shade in all reaches to be equivalent to the reach with the most shade

Throughout this section, the differences between the simulated existing conditions and scenarios are reported. The difference is calculated as the scenario results minus the existing conditions results. A negative value means that the scenario resulted in cooler temperatures than were simulated with the existing conditions; a positive value means that the scenario resulted in warmer temperatures than were simulated in the existing conditions.

J6.1 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 J4**.

J6.2 Existing Conditions with Low Flow

In this scenario, the flow inputs to the QUAL2K model are decreased to represent critical low-flow conditions, simulating the stream dynamics during an exceptionally dry season. An evaluation of monthly flows at the USGS gage on the Middle Fork Rock Creek near Philipsburg, Montana (12332000) showed that low-flow conditions (represented by the monthly 25th percentile flow) were 37 percent smaller than the average conditions (represented by the monthly mean flow) for July; for August, 20 percent smaller. The headwaters inflow, diffuse flow (i.e., groundwater) and springs' inflow were reduced by 37 percent (July) and 20 percent (August).

These low-flow condition scenarios resulted in higher daily maximum and daily mean temperatures along the entire stream, with a greater increase in temperature corresponding to a greater decrease in flow. The uniform decrease in minimum temperatures might be related to the increased influence of cooler groundwater during low-flow conditions. **Table J-5** and **Table J-6** present the scenario results at DEQ's sample sites; **Figure J21** presents the continuous results along South Fork Antelope Creek.

Table J-5. Low-flow conditions results for 20 percent reduction in flow (August – Validation)

Daily temperature	Source	Fahrenheit			
		C02ANTSF03	**C02ANTSF02**	**C02ANTSF01**	**C02ANTSF10**
Maximum	Existing	60.3	57.1	55.1	53.3
	Scenario	60.4	57.5	55.6	53.8
	Difference	**+0.1**	**+0.4**	**+0.4**	**+0.5**
Mean	Existing	47.9	47.7	47.6	47.4
	Scenario	47.9	47.8	47.6	47.5
	Difference	**+0**	**+0.1**	**+0.1**	**+0.1**
Minimum	Existing	40.5	41.5	42.7	43.7
	Scenario	40.4	41.2	42.5	43.5
	Difference	**-0.1**	**-0.2**	**-0.2**	**-0.2**

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The term "+0" represents a difference of less than +0.05 degree.

Table J-6. Low-flow conditions results for 37 percent reduction in flow (July – Calibration)

Daily temperature	Source	Fahrenheit			
		C02ANTSF03	C02ANTSF02	C02ANTSF01	C02ANTSF10
Maximum	Existing	60.3	57.1	55.1	53.3
	Scenario	60.5	58.0	56.2	54.4
	Difference	**+0.2**	**+0.8**	**+1.1**	**+1.0**
Mean	Existing	47.9	47.7	47.6	47.4
	Scenario	47.9	47.9	47.7	47.6
	Difference	**+0**	**+0.2**	**+0.2**	**+0.2**
Minimum	Existing	40.5	41.5	42.7	43.7
	Scenario	40.3	40.9	42.2	43.3
	Difference	**-0.2**	**-0.5**	**-0.5**	**-0.4**

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The term "+0" represents a difference of less than +0.05 degree.

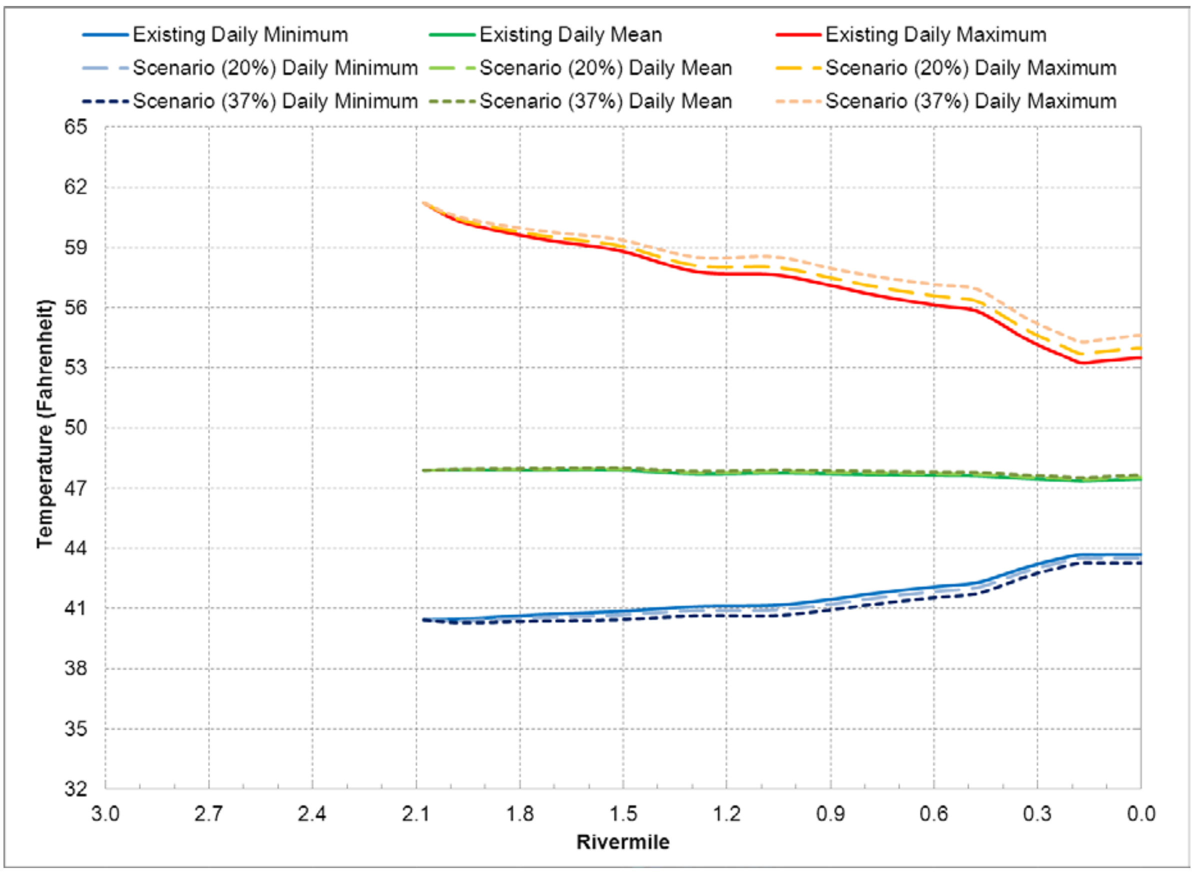


Figure J-21. Low-flow conditions results.

J6.3 Full Potential Shade

This shade scenario uses the existing conditions model and increases shading along the creek. In this scenario, the shading of all the reaches was increased to the level of shading in the reach with the highest levels of estimated shading. The 24-hour shade input for reaches A, B, and C were set to the same as the 24-hour shade input for reach D.

This full potential shade scenario had little to no effect on water temperatures along South Fork Antelope Creek. While the scenario results in small decreases of maximum daily water temperatures in the lower half of the watershed, the daily minimum and most of the daily mean water temperatures remained the same. **Table J7** presents the scenario results at DEQ's sample sites; **Figure J-22** presents the continuous results along South Fork Antelope Creek.

Table J-7. Full potential shade results

Daily temperature	Source	Fahrenheit			
		C02ANTSF03	C02ANTSF02	C02ANTSF01	C02ANTSF10
Maximum	Existing	60.3	57.1	55.1	53.3
	Scenario	60.3	57.1	54.9	53.0
	Difference	**0**	**0**	**-0.2**	**-0.3**
Mean	Existing	47.9	47.7	47.6	47.4
	Scenario	47.9	47.7	47.6	47.4
	Difference	**0**	**0**	**+0.1**	**0**
Minimum	Existing	40.5	41.5	42.7	43.7
	Scenario	40.5	41.5	42.7	43.7
	Difference	**0**	**0**	**0**	**0**

Note: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.

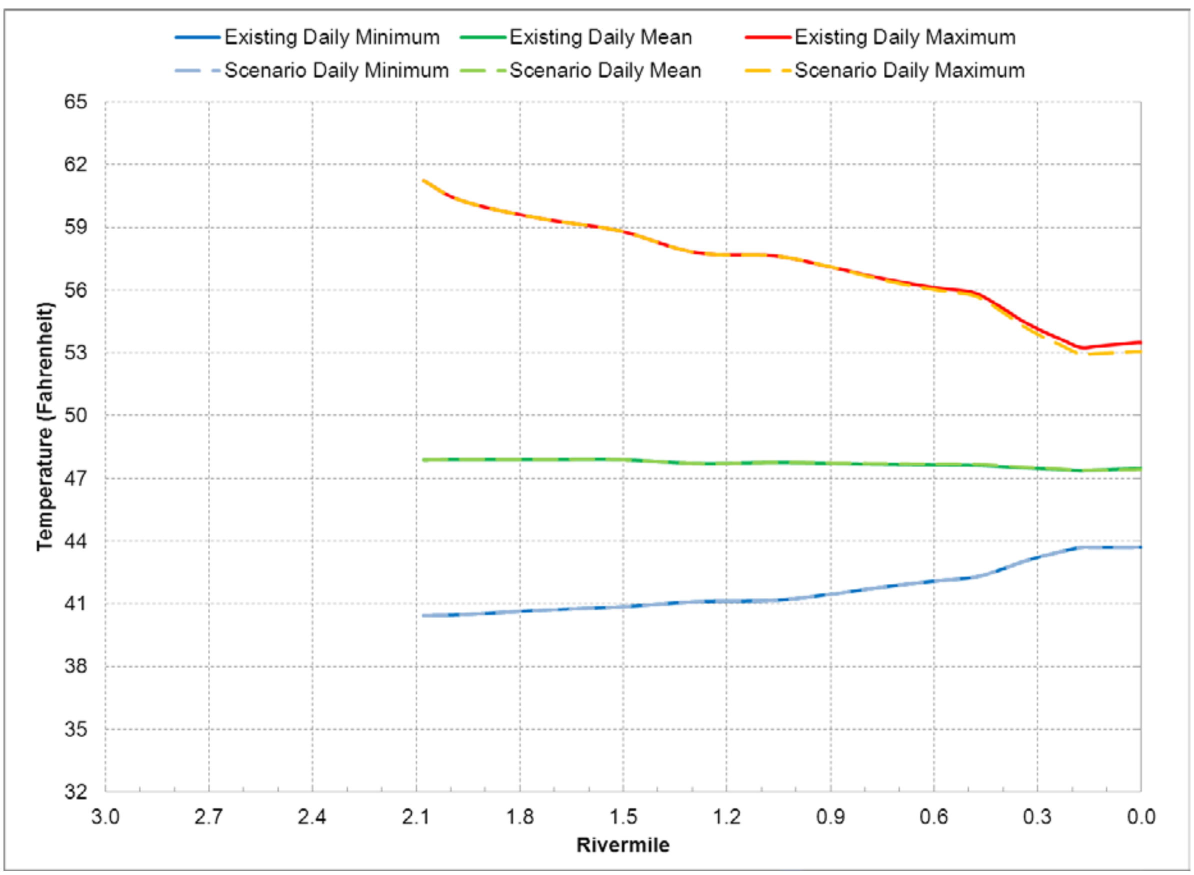


Figure J-22. Full potential shade results.

J6.4 Full Potential Shade with Low Flow

This scenario is the combination of the scenarios presented in **Sections J6.3** and **J6.2**. The 24-hour shade input for reaches A, B, and C were set to the same as the 24-hour shade input for reach D and the headwaters inflow, diffuse flow (i.e., groundwater) and springs' inflow were reduced by 37 percent.

The results of this scenario indicate a slight decrease of minimum daily temperatures and an increase in maximum daily temperatures. **Table J-8** presents the scenario results at DEQ's sample sites; **Figure J-23** presents the continuous results along South Fork Antelope Creek.

Table J8. Low-flow conditions (37 percent reduction) and full potential shade results

Daily temperature	Source	Fahrenheit			
		C02ANTSF03	C02ANTSF02	C02ANTSF01	C02ANTSF10
Maximum	Existing	60.3	57.1	55.1	53.3
	Scenario	60.5	58.1	56.1	54.0
	Difference	**+0.2**	**+1.0**	**+1.0**	**+0.7**
Mean	Existing	47.9	47.7	47.6	47.4
	Scenario	47.9	47.9	47.8	47.6
	Difference	**+0**	**+0.2**	**+0.2**	**+0.2**
Minimum	Existing	40.5	41.5	42.7	43.7
	Scenario	40.3	40.9	42.2	43.3
	Difference	**-0.2**	**-0.5**	**-0.5**	**-0.4**

Notes: Results are reported in degrees Fahrenheit and rounded to the nearest one-tenth of a degree.
The term "+0" represents a difference of less than +0.05 degree.

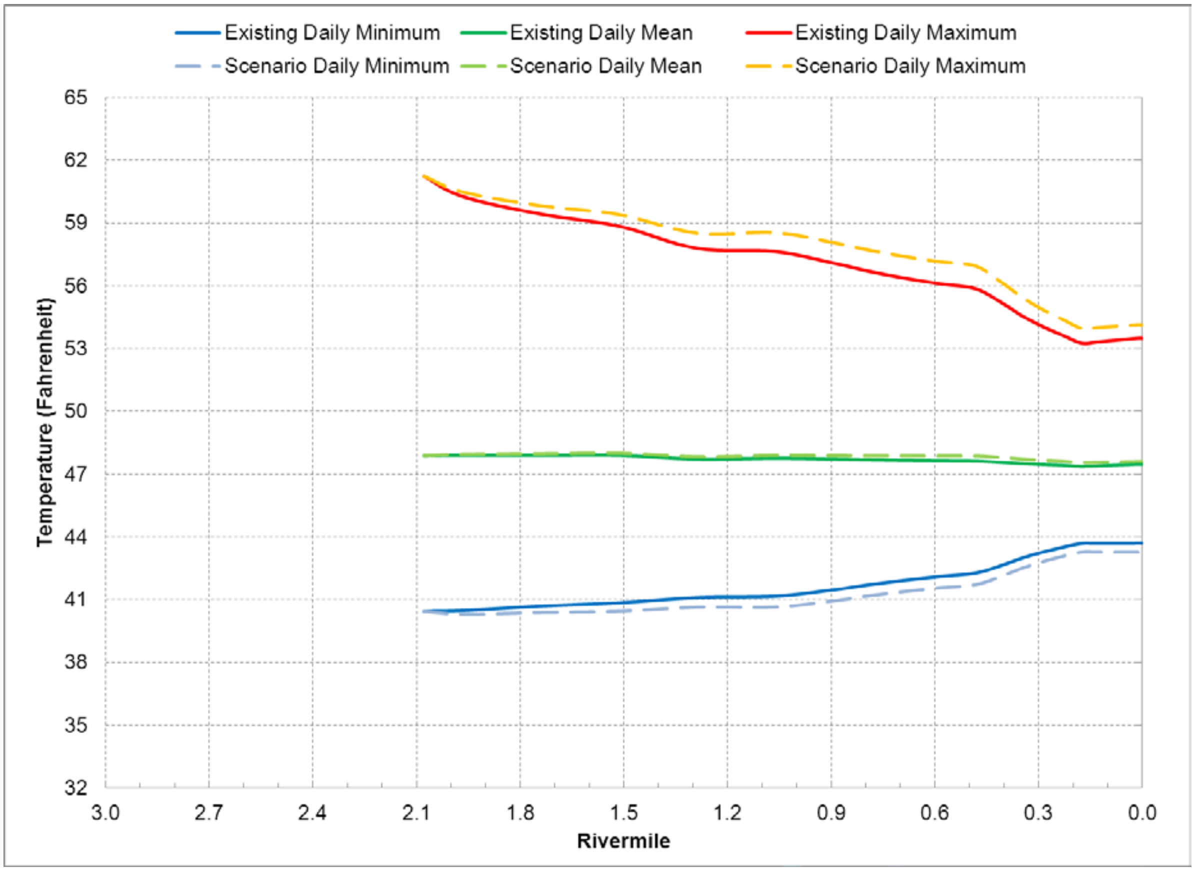


Figure J-23. Low-flow conditions (37 percent reduction) and full potential shade results.

J6.5 Scenarios Results and Discussion

Scenarios were developed in QUAL2K to evaluate the impacts of various factors that could affect instream water temperatures in South Fork Antelope Creek. Reducing flows by 20 to 37 percent to simulate natural low-flow or drought conditions resulted in increases of up to 1.1 °F. Increasing shade to replicate the effect of re-vegetation after timber harvest resulted in little change (≤ 0.4°F) when compared to both the existing condition scenario and the natural low-flow scenarios.

J7.0 References

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

Table JA-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)
C02ANTSSF02	A - LB	1.25	Sparse Conifer	97.8	82%	ridge 168ft	1
	A - RB	N/A	Sparse Conifer	156	88%	0.6	0
	B - LB	7.5	Sparse Conifer	89	94%	0.3	0
	B - RB	N/A	Medium Conifer	98	88%	0.8	0
	C - LB	7.2	Sparse Conifer	98	94%	0.7	0
	C - RB	N/A	Medium Conifer	112	100%	1.2	0
CO2ANTSF10	A - LB	1.8	Dense conifer	70.4	100%	1	0
	A - RB	N/A	Sparse Conifer	24.23	100%	1	0
	B - LB	0.9	Mixed High Level	51.2	88%	0	0.9
	B - RB	N/A	Mixed High Level	11.5	76%	0	0
	C - LB	2.5	Sparse Conifer	58.7	100%	2.9	0
	C - RB	N/A	Mixed High Level	32.8	71%	2.6	0
CO2ANTSF01	A - LB	2.4	Mixed High Level	48.3	100%	0.6	1
	A - RB	N/A	Mixed High Level	77	82%	0.9	0
	B - LB	7	Medium Conifer	70.8	100%	4	0
	B - RB	N/A	Sparse Conifer	78.4	94%	2.3	0
	C - LB	3.5	Sparse Conifer	15.5	94%	1.2	0
	C - RB	N/A	Sparse Conifer	96.5	94%	0.6	0
C02ANTSF03	A - LB	1.9	Dense conifer	73.6	94%	0	0
	A - RB	N/A	Dense conifer	27.9	94%	0	0
	B - LB	2	Sparse Conifer	19.8	47%	0	0
	B - RB	N/A	Dense conifer	39.7	88%	0	0
	C - LB	2.8	Dense conifer	56.3	88%	0	0
	C - RB	N/A	Dense conifer	54.5	88%	0	0

Source: (Water & Environmental Technologies, 2011)
Note: LB = left bank; n/a = not available; RB = right bank

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

Vegetation description	Height	Density	Overhang
	(feet)	(percent)	(feet)
Dense Conifer	70.4	74%	0.0
Mixed High Level	44.2	43%	0.4
Medium Conifer	70.4	70%	0.0
Sparse Conifer	70.4	45%	0.1
Blank	0.0	0%	0.0

Source: (Water & Environmental Technologies, 2011)

Table JA-3. Channel cross section data, SFAC 06-01 (Water & Environmental Technologies, 2011)

Cell	Feature	Bankfull channel width (feet)	Cross-sectional area (sq. feet)	Bankfull mean depth (feet)	Width / depth ratio	Maximum depth (feet)	Floodprone width (feet)	Entrenchment ratio
1	Riffle	2.4	1.20	0.50	4.8	0.7	19.4	8.1
2	Riffle	4.4	1.02	0.23	18.9	0.6	13.4	3.0
3	Riffle	4.0	1.16	0.29	13.8	0.6	13.0	3.3
4	Riffle	3.5	1.33	0.38	9.2	0.7	18.5	5.3
5	Riffle	3.5	1.09	0.31	11.3	0.6	19.5	5.6

Source: (Water & Environmental Technologies, 2011)

Table JA-4. Channel cross section data, SFAC 13-01 (Water & Environmental Technologies, 2011)

Cell	Feature	Bankfull channel width (feet)	Cross-sectional area (sq. feet)	Bankfull mean depth (feet)	Width / depth ratio	Maximum depth (feet)	Floodprone width (feet)	Entrenchment ratio
1	Riffle	7.0	3.64	0.52	13.5	1.1	31.0	4.4
2	Riffle	4.0	2.60	0.65	6.2	1.1	21.0	5.3
3	Riffle	8.5	4.59	0.54	15.7	1.4	21.5	2.5
4	Riffle	5.0	2.05	0.41	12.2	1.2	18.0	3.6
5	Riffle	8.0	4.72	0.59	13.6	1.4	63.0	7.9

Source: (Water & Environmental Technologies, 2011)

APPENDIX JB. SHADE ANALYSES

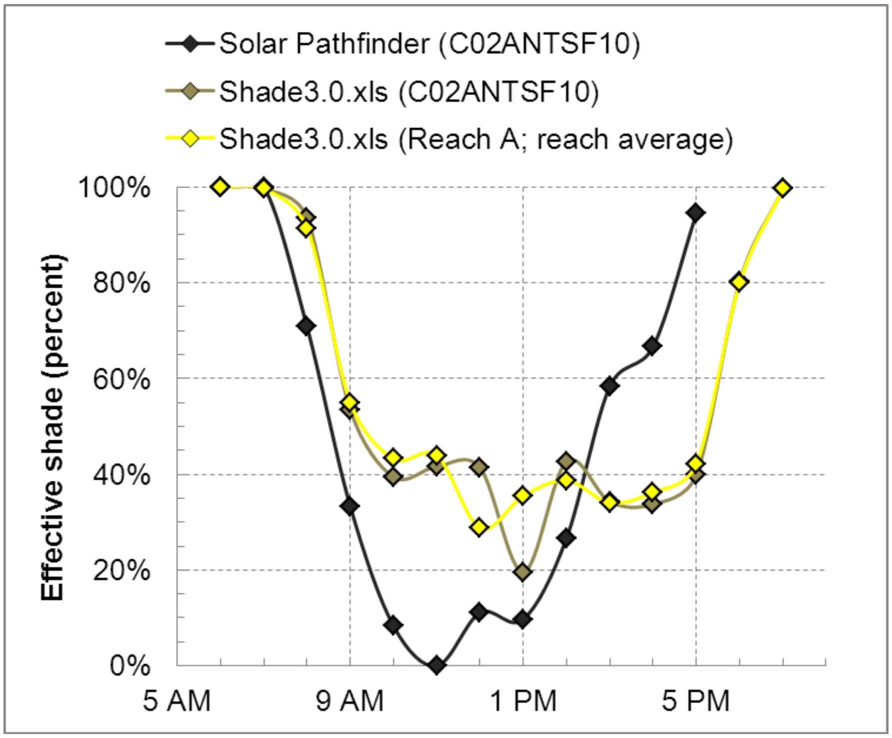

Figure JB - 1. Shade analysis in Reach A.

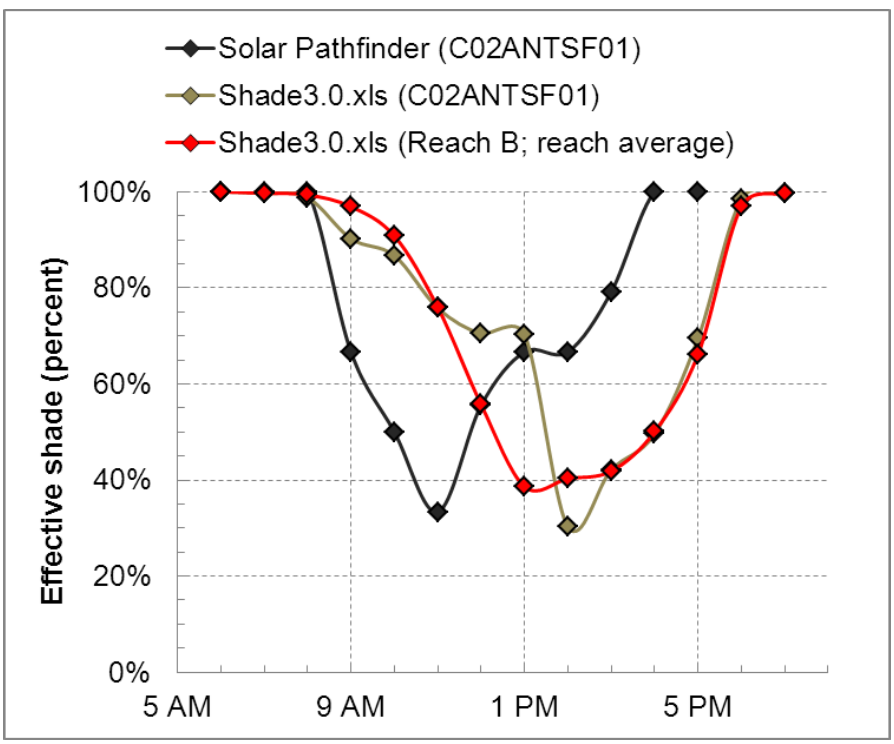

Figure JB - 2. Shade analysis in Reach B.

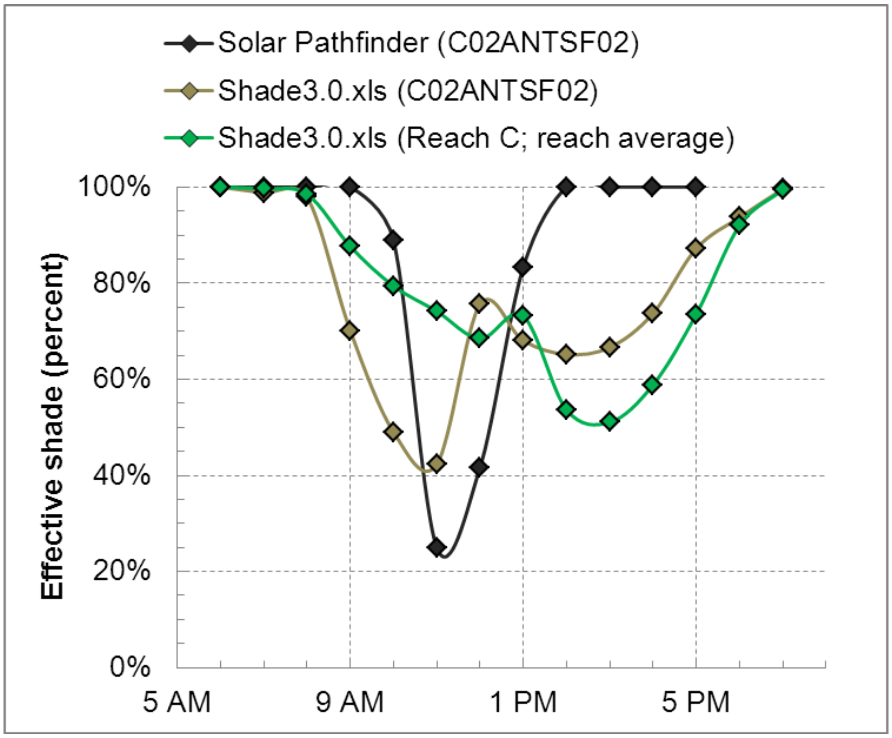

Figure JB - 3. Shade analysis in Reach C.

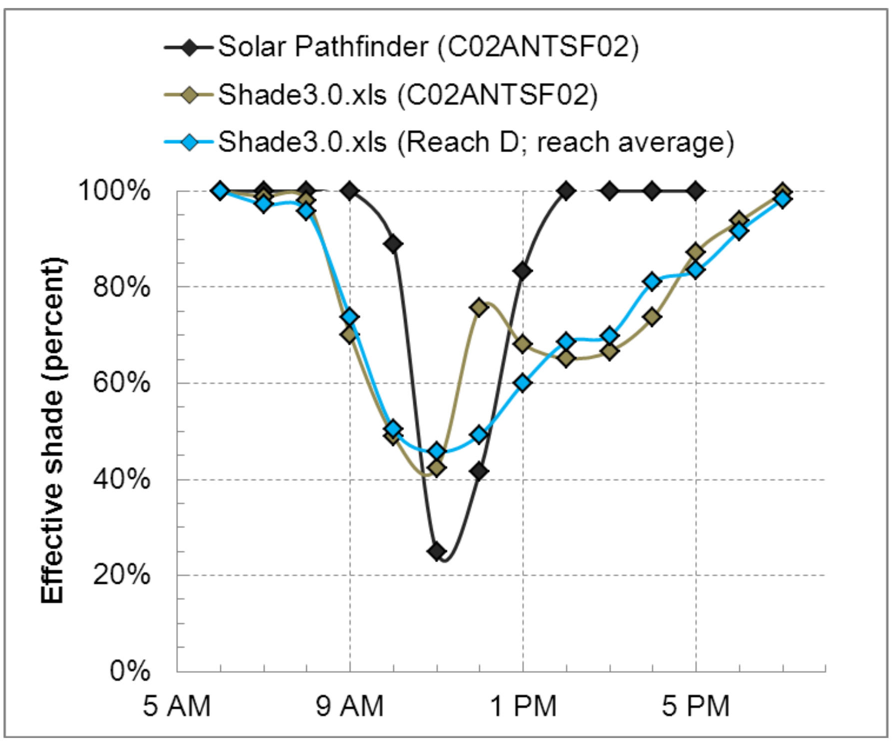

Figure JB - 4. Shade Analysis in Reach D.

APPENDIX JC. QUAL2K MODEL DEVELOPMENT

Table JC-1. Input parameters for Shadev3.0.xls (at each sampling location)

Sample station	Elevation (meters)	Aspect (degrees)	Wetted width (meters)	NSDZ width (meters)	Center to left NSDZ (meters)	Channel incision (meters)	Topographic shade West (degrees)	Topographic shade South (degrees)	Topographic shade East (degrees)
C02ANTSF 03	1,916	8	0.68	1.16	0.58	0.00	17.51	8.87	23.07
C02ANTSF 02	1,794	313	1.62	1.62	0.81	0.22	14.92	16.25	20.10
C02ANTSF 01	1,719	12	1.31	1.84	0.92	0.49	24.43	13.93	18.36
C02ANTSF 10	1,671	355	0.53	2.00	1.00	0.38	5.62	11.96	15.54

Notes: Sites are listed from top to bottom as headwaters to mouth.
NSDZ = near-shore disturbance zone

Table JC-2. Channel geometry inputs for QUAL2K

Segment	Channel slope	Manning's n	Stream bottom width (meters)	Side 1a	Side 2a
Headwaters inflow	0.073	0.0740	0.76	10.00	3.75
D	0.073	0.0740	0.76	10.00	3.75
C	0.089	0.0540	1.37	0.83	1.67
B	0.085	0.0468	1.37	0.83	1.67
A	0.058	0.0528	0.30	5.00	2.50

Notes: Segments are listed from top to bottom of the column as headwaters to the mouth
[a] Adjacent side ratio (relative to one) based on the trapezoidal cross section (**Figure J-15**).

Table JC-3. Observed instream flow data used for modeling

Location	Flow (cubic meters per second)
C02ANTSF03	0.048
C02ANTSF02	0.084
C02ANTSF01	0.117
C02ANTSF10	0.192

Table JC-4. Estimated diffuse flow for each reach for QUAL2K

Segment	Diffuse flow (cubic meter per second)
Reach D	0.0310
Reach C	0.0330
Reach B	0.0665
Reach A	0.0070

Table JC-5. Estimated springs' flow

Spring	Diffuse flow (cubic meter per second)
Upper	0.0039
Lower	0.0012

Table JC-6. Hourly weather data for South Fork Antelope Creek on July 16, 2010

Time	Air temperature (°C)				Wind speed (meters/second)
Reach	D	C	B	A	All
12:00 AM	9.39	10.17	10.56	10.69	1.37
1:00 AM	8.28	9.06	9.44	9.58	1.37
2:00 AM	7.17	7.95	8.33	8.46	0.46
3:00 AM	6.62	7.39	7.78	7.91	0.46
4:00 AM	6.62	7.39	7.78	7.91	0.00
5:00 AM	5.51	6.28	6.67	6.80	0.91
6:00 AM	7.17	7.95	8.33	8.46	1.37
7:00 AM	11.62	12.39	12.78	12.91	0.91
8:00 AM	15.51	16.28	16.67	16.80	0.91
9:00 AM	19.95	20.72	21.11	21.24	0.91
10:00 AM	24.39	25.17	25.56	25.69	1.83
11:00 AM	27.17	27.95	28.33	28.46	3.65
12:00 PM	27.73	28.50	28.89	29.02	5.93
1:00 PM	28.28	29.06	29.44	29.58	5.93
2:00 PM	29.39	30.17	30.56	30.69	5.93
3:00 PM	29.39	30.17	30.56	30.69	6.85
4:00 PM	28.84	29.61	30.00	30.13	4.56
5:00 PM	27.73	28.50	28.89	29.02	4.56
6:00 PM	26.62	27.39	27.78	27.91	4.11
7:00 PM	24.95	25.72	26.11	26.24	1.83
8:00 PM	21.06	21.84	22.22	22.35	0.46
9:00 PM	17.73	18.50	18.89	19.02	2.28
10:00 PM	15.51	16.28	16.67	16.80	1.83
11:00 PM	14.95	15.72	16.11	16.24	1.37

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

Table JC-7. Hourly dew point temperature data for South Fork Antelope Creek on July 16, 2010

Time	Dew point temperature (°C)			
Segment	**D**	**C**	**B**	**A**
12:00 AM	-2.27	-1.50	-1.11	-0.98
1:00 AM	-0.61	0.17	0.56	0.69
2:00 AM	-0.61	0.17	0.56	0.69
3:00 AM	0.51	1.28	1.67	1.80
4:00 AM	0.51	1.28	1.67	1.80
5:00 AM	2.17	2.95	3.33	3.46
6:00 AM	2.73	3.50	3.89	4.02
7:00 AM	3.84	4.61	5.00	5.13
8:00 AM	6.62	7.39	7.78	7.91
9:00 AM	7.17	7.95	8.33	8.46
10:00 AM	7.73	8.50	8.89	9.02
11:00 AM	3.28	4.06	4.44	4.58
12:00 PM	2.17	2.95	3.33	3.46
1:00 PM	2.17	2.95	3.33	3.46
2:00 PM	0.51	1.28	1.67	1.80
3:00 PM	-2.27	-1.50	-1.11	-0.98
4:00 PM	-0.61	0.17	0.56	0.69
5:00 PM	1.62	2.39	2.78	2.91
6:00 PM	1.62	2.39	2.78	2.91
7:00 PM	-0.05	0.72	1.11	1.24
8:00 PM	-0.05	0.72	1.11	1.24
9:00 PM	-0.05	0.72	1.11	1.24
10:00 PM	0.51	1.28	1.67	1.80
11:00 PM	-0.61	0.17	0.56	0.69

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 JC-8. Hourly shade results (averaged along proposed model segments)

Time	Shade (percent)			
Segment	D	C	B	A
12:00 AM	100%	100%	100%	100%
1:00 AM	100%	100%	100%	100%
2:00 AM	100%	100%	100%	100%
3:00 AM	100%	100%	100%	100%
4:00 AM	100%	100%	100%	100%
5:00 AM	100%	100%	100%	100%
6:00 AM	100%	100%	100%	100%
7:00 AM	97%	100%	100%	100%
8:00 AM	96%	99%	99%	91%
9:00 AM	74%	88%	97%	55%
10:00 AM	50%	79%	91%	43%
11:00 AM	46%	74%	76%	44%
12:00 PM	49%	68%	56%	29%
1:00 PM	60%	73%	39%	35%
2:00 PM	69%	54%	40%	39%
3:00 PM	70%	51%	42%	34%
4:00 PM	81%	59%	50%	36%
5:00 PM	83%	74%	66%	42%
6:00 PM	92%	92%	97%	80%
7:00 PM	98%	99%	100%	100%
8:00 PM	99%	100%	100%	100%
9:00 PM	100%	100%	100%	100%
10:00 PM	100%	100%	100%	100%
11:00 PM	100%	100%	100%	100%

Table JC-9. 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.

Table JC-10. Model calibration results for July 16, 2010 in Celsius

Daily temperature	Source	Celsius			
		C02ANTSF03	C02ANTSF02	C02ANTSF01	C02ANTSF10
Maximum	QUAL2K	15.7	14.0	12.8	11.8
	Observed	16.2	13.1	13.8	12.7
	Abs. Error[a]	***-0.5***	***+0.9***	***-0.9***	***-0.9***
	Rel. Error[b]	***3%***	***7%***	***7%***	***7%***
Mean	QUAL2K	8.8	8.7	8.6	8.6
	Observed	8.8	9.5	9.5	8.3
	Abs. Error[a]	***0.0***	***-0.7***	***-0.8***	***+0.3***
	Rel. Error[b]	***0%***	***8%***	***9%***	***4%***
Minimum	QUAL2K	4.7	5.3	5.9	6.5
	Observed	4.7	6.5	6.6	5.8
	Abs. Error[a]	***0.0***	***-1.3***	***-0.6***	***+0.7***
	Rel. Error[b]	***0%***	20%	***10%***	12%

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 ***bold 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 JC-11. Model validation results for August 26, 2010 in Celsius

Daily temperature	Source	Celsius			
		C02ANTSF03	C02ANTSF02	C02ANTSF01	C02ANTSF10
Maximum	QUAL2K	12.3	12.1	12.5	11.7
	Observed	12.7	11.3	12.0	10.9
	Abs. Error[a]	***-0.4***	***+0.8***	***+0.5***	***+0.8***
	Rel. Error[b]	***3%***	***7%***	***4%***	***7%***
Mean	QUAL2K	8.7	8.7	8.8	8.6
	Observed	8.9	8.8	9.0	8.1
	Abs. Error[a]	***-0.3***	***-0.1***	***-0.2***	***+0.5***
	Rel. Error[b]	***3%***	***1%***	***2%***	***6%***
Minimum	QUAL2K	6.1	6.1	5.9	6.4
	Observed	6.2	6.2	6.2	5.8
	Abs. Error[a]	***-0.1***	***-0.1***	***-0.3***	***+0.6***
	Rel. Error[b]	***1%***	***2%***	***4%***	***10%***

Notes:
Results are reported in degrees Celsius and rounded to the nearest one-tenth of a degree.
Validation results that meet the acceptance criteria are presented in ***bold 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.