APPENDIX B – WHITE PINE CREEK QUAL2K REPORT

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ACRONYMS AND ABBREVIATIONS

AME	absolute mean error
EPA	U.S. Environmental Protection Agency
DEQ	Montana Department of Environmental Quality
MPDES	Montana Pollutant Discharge Elimination System
QUAL2K	River and Stream Water Quality Model
REL	relative error
TMDL	total maximum daily load
USGS	U.S. Geological Survey (U.S. Department of the Interior)

UNITS OF MEASURE

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

EXECUTIVE SUMMARY

White Pine Creek was identified by the Montana Department of Environmental Quality (DEQ) as being impaired due to elevated water temperatures. The cause of the impairment was attributed to grazing in riparian or shoreline zones, streambank modification/destabilization, natural sources, and watershed runoff following forest fire (Montana Department of Environmental Quality, Water Quality Planning Bureau, 2014). The U.S. Environmental Protection Agency (EPA) contracted with Tetra Tech to develop a QUAL2K water quality model to investigate the relationship between flow, shade, and instream water temperature.

Field studies were carried out in 2013 to support water quality model development for the project. A QUAL2K water-quality model was then developed for White Pine Creek to evaluate management practices suitable for meeting state temperature standards. The QUAL2K model was constructed, in part, using field-collected data from the summer of 2013. Shade v3.0 models were also developed to assess shade conditions using previously collected field data. The calibrated and validated QUAL2K model met previously designated acceptance criteria. Once developed, various water temperature responses were evaluated for a range of potential watershed management activities. Four scenarios were considered:

- Scenario 1: Baseline condition (i.e., measured August flow and weather conditions).
- Scenario 2: Baseline with a 15 percent reduction of water withdrawals.
- Scenario 3: Baseline with improved riparian vegetation in certain segments based upon reference segments.
- Scenario 4: An improved flow and shade scenario that combines the potential benefits associated with a 15 percent reduction in water withdrawals with improved shading along certain segments.

In comparison to scenario 1, results ranged from minimal change in water temperature (scenario 2) to considerable reductions (scenarios 3 and 4). The improved flow and shade scenario (scenario 4), which combined the potential benefits associated with a 15 percent reduction in water withdrawals (scenario 2) with improved shading to certain segments based upon reference segments (scenario 3) to represent application of conservation practices, resulted in overall reductions along the entire reach that ranged from no effect to 2.6° F. Generally, small changes in shade or inflow had minimal effects on water temperature while large increases in shade had a considerable effect on water temperature.

B1.0 INTRODUCTION

Tetra Tech, Inc. is under contract with the U.S. Environmental Protection Agency (EPA) to set up, calibrate, validate, and conduct scenario analysis with a temperature model (QUAL2K) for White Pine Creek in support of total maximum daily load (TMDL) development by the Montana Department of Environmental Quality (DEQ). Background information is provided in the following section (**Section B2.0**). A summary of model set up and calibration is provided in **Section B3.0** and a series of model scenarios and results are presented in **Section B4.0**.

B2.0 BACKGROUND

This section presents background information to support QUAL2K model development.

B2.1 PROBLEM STATEMENT

White Pine Creek is in western Montana and is part of the Lower Clark Fork Tributaries TMDL Planning Area. The White Pine Creek watershed is in the Lower Clark Fork 8-digit HUC (17010213). The impaired segment is 12.37 miles long and extends from the headwaters to the mouth on Beaver Creek (Montana Department of Environmental Quality, Water Quality Planning Bureau, 2014) (**Figure B-1**).

White Pine Creek has a B-1 use class. The impaired segment is not supporting its Aquatic Life use (Montana Department of Environmental Quality, Water Quality Planning Bureau, 2014). Three potential causes of impairment are identified in the assessment record, including water temperature (Montana Department of Environmental Quality, Water Quality Planning Bureau, 2014). The potential sources of the water temperature impairment are: grazing in riparian or shoreline zones, streambank modification/destabilization, natural sources, and watershed runoff following forest fire (Montana Department of Environmental Quality, Water Quality Planning Bureau, 2014). Large forest fires occurred in 1889 and 1910 and a large flood occurred in 1916; “elevated stream temperature may be linked to historic riparian logging and relatively recent stand replacing fires” (Montana Department of Environmental Quality, Water Quality Planning Bureau, 2014, p. 62).

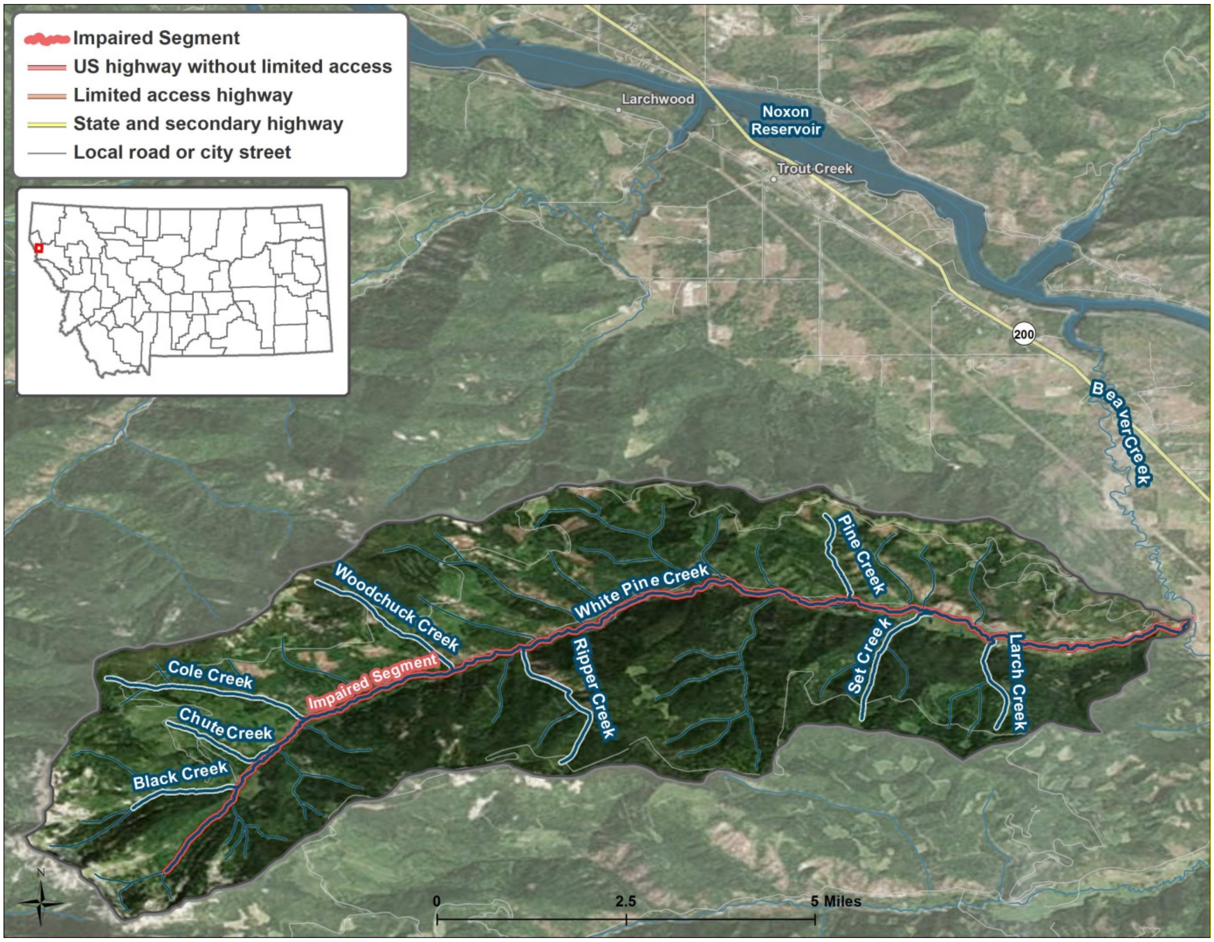

Figure B-1. White Pine Creek watershed.

B2.2 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 occurring2 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.

B2.3 PROJECT HISTORY

Tetra Tech was contracted by EPA in May 2013 to develop the QUAL2K temperature model using data and information that was collected in the summer of 2013. Temperature and flow data were collected in White Pine Creek in 2013 by EPA and DEQ. Field teams collected data on July 25-26, 2013, August 13-14, 2013, and September 10, 2013 to characterize flow and shade in support of the modeling effort.

B2.4 FACTORS POTENTIALLY INFLUENCING STREAM TEMPERATURE

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

The following factors that may have an influence on stream temperatures in White Pine Creek were evaluated prior to model development and are further discussed in **Attachment B-1**:

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

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[1] ARM 17.30.623(e).

[2] "Naturally occurring" means conditions or material present from runoff or percolation over which man has no control or from developed land where all reasonable land, soil and water conservation practices have been applied.

B2.5 OBSERVED STREAM TEMPERATURES

EPA and DEQ collected stream temperature data using instream loggers at multiple locations in the White Pine Creek watershed. These data are presented and summarized in the following sections.

B2.5.1 Available Temperature Data

In 2013, EPA and DEQ collected continuous temperature data at seven sites along White Pine Creek and at one tributary site (Chute Creek) in support of this modeling effort (**Figure B-2**). During logger deployment, the following tributaries were observed to flow to subsurface (go underground) instead of discharging to White Pine Creek: Larch, Set, Ripper, and Cole creeks. Thus, loggers were not deployed on these streams as originally planned, and no field data were acquired. Additionally, an unnamed tributary was observed to be dry. White Pine Creek itself was observed to be dry at site WPC-T5; thus, no logger was deployed nor field data acquired.

During the mid-season data collection, White Pine Creek was observed to be dry at loggers WPC-T6 and WPC-T7; the loggers were recovered and no field data were acquired. Logger WPC-T8 was found to be partially exposed to ambient air; the logger was moved upstream 25 feet and was then fully submerged.

Data loggers recorded temperatures every one-half hour for two months between June 25-26 and September 10, 2013. EPA and DEQ also collected instantaneous temperatures from White Pine Creek and three of its tributaries (Chute, Pine, and Woodchuck creeks; **Attachment B1**). Temperatures varied spatially and temporally; generally, the warmest instantaneous temperatures were detected in September. Additionally, Montana DEQ recorded an instantaneous temperature of 44.7° F on September 22, 2004, at the C13WPINC10 station.

White Pine Creek ran dry at loggers WPC-T6 and WPC-T7. Temperature data from time periods in which the loggers were suspected to be exposed to ambient air were excluded from analyses. The valid data for logger WPC-T6 are from June 26-27, 2013. The valid data for logger WPC-T7 are from June 26, 2013 to July 9, 2013. These two subsets of data were included in the analyses described in this section.

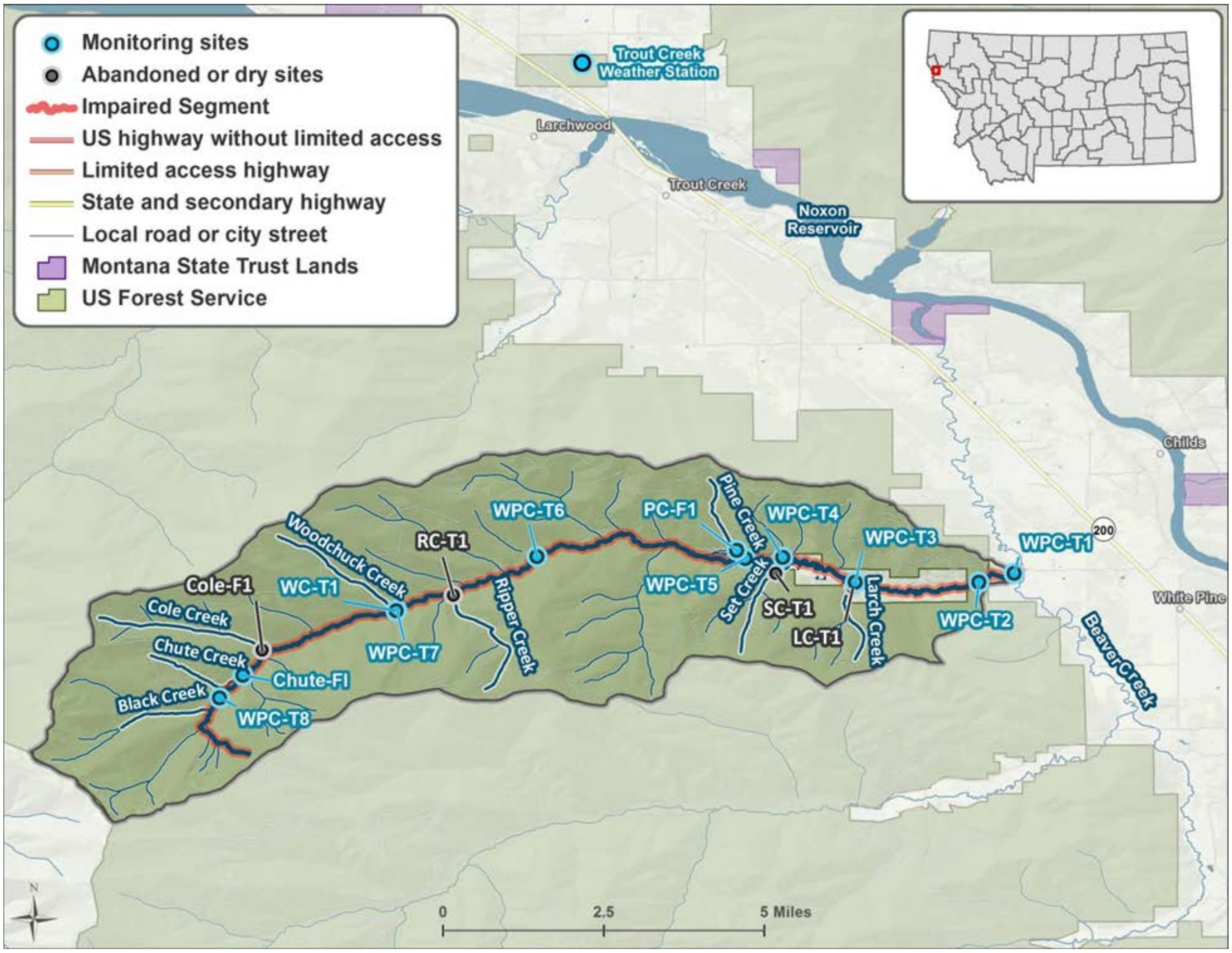
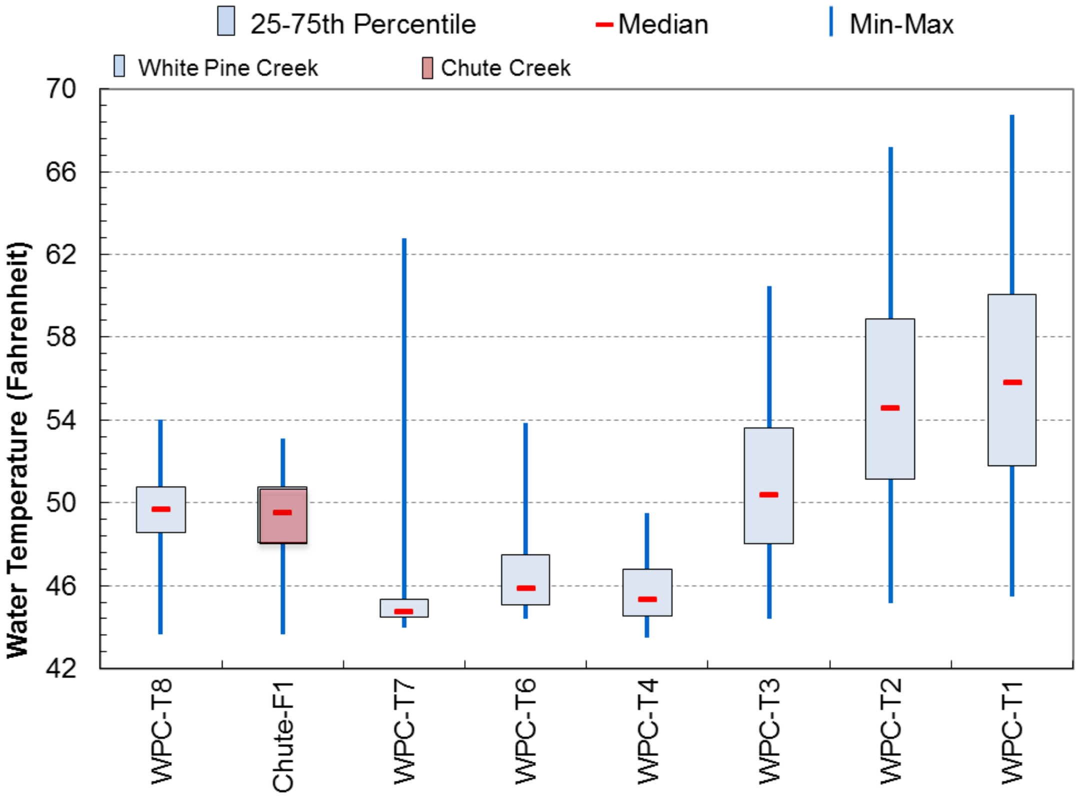


Figure B-2. Temperature loggers in the White Pine Creek watershed.

B2.5.2 Temperature Data Analysis

Stream temperatures in White Pine Creek generally increase from its source downstream to its mouth. No trends are apparent along White Pine Creek from just below the confluence of Chute Creek to near the confluence of Set Creek; some of the reaches of White Pine Creek along this segment ran dry. A summary of the continuous temperature data collected by EPA and DEQ is provided in (**Figure B-3**). Excluding loggers WPC-T6 and WPC-T7, median temperatures in White Pine Creek ranged from approximately 45.5° F to approximately 55.8° F in 2013 (**Figure B-3**).



Note:

- Logger WPC-T6 was likely exposed to ambient air from June 29, 2013 through August 13, 2013, when it was observed in a dry channel. The data presented in this figure are limited to a subset of the monitored temperatures, from June 26, 2013 through June 27, 2013.
- Logger WPC-T7 was likely exposed to ambient air from July 10, 2013 through August 14, 2013, when it was observed in a dry channel. The data presented in this figure are limited to a subset of the monitored temperatures, from June 26, 2013 through July 9, 2013.
- Logger WPC-T8 may have been exposed to ambient air prior to the mid-season field data acquisition on August 14, 2013 when the logger was observed to be partially exposed to ambient air. The logger was moved and was then fully submerged. No data were excluded from this figure.

Figure B-3. Box-and-whisker plots of summer 2013 continuous temperature data.

Maximum daily temperatures in White Pine Creek ranged from approximately 49.5° F to 68.7° F (**Table B-1** and **Figure B-4**). The highest maximum temperatures were recorded at near the mouth at logger WPC-T1 on August 10, 2013. With the exception of WPC-T6 and WPC-T7, the warmest temperatures were detected in the second or third week of August. The warmest weeks were generally the third week of August (excluding loggers WPC-T6 and WPC-T7 that were in dry channels by mid-August). As shown in **Figure B-5**, the diurnal variation in White Pine Creek in the upper watershed (as shown with WPC-T8) is considerably smaller than the diurnal variation in the lower watershed (as shown with logger WPC-T1). All loggers showed a considerable decrease in stream temperatures between July 31 and August 4, 2013.

Table B-1. Maximum & maximum weekly temperatures in White Pine Creek and Chute Creek

Temperature logger site	Maximum temperatures [a]		Maximum weekly maximum temperature [b]	
	Temperature (°F)	Date	Temperature (°F)	Date
WPC-T8 [c] (upper segment)	54.0	Aug 11	52.6	Aug 9-15
Chute-F1	53.1	Aug 17	52.5	Aug 14-20
WPC-T7 [d]	50.4	Jul 9	46.9	Jul 3-9
WPC-T6 [e]	53.9	Jun 27	--	--
WPC-T4	49.5	Aug 19	49.2	Aug 15-21
WPC-T3	60.5	Aug 19	59.8	Aug 15-21
WPC-T2	67.2	Aug 10	66.2	Aug 14-20
WPC-T1 (mouth)	68.7	Aug 10	67.3	Aug 14-20

Notes

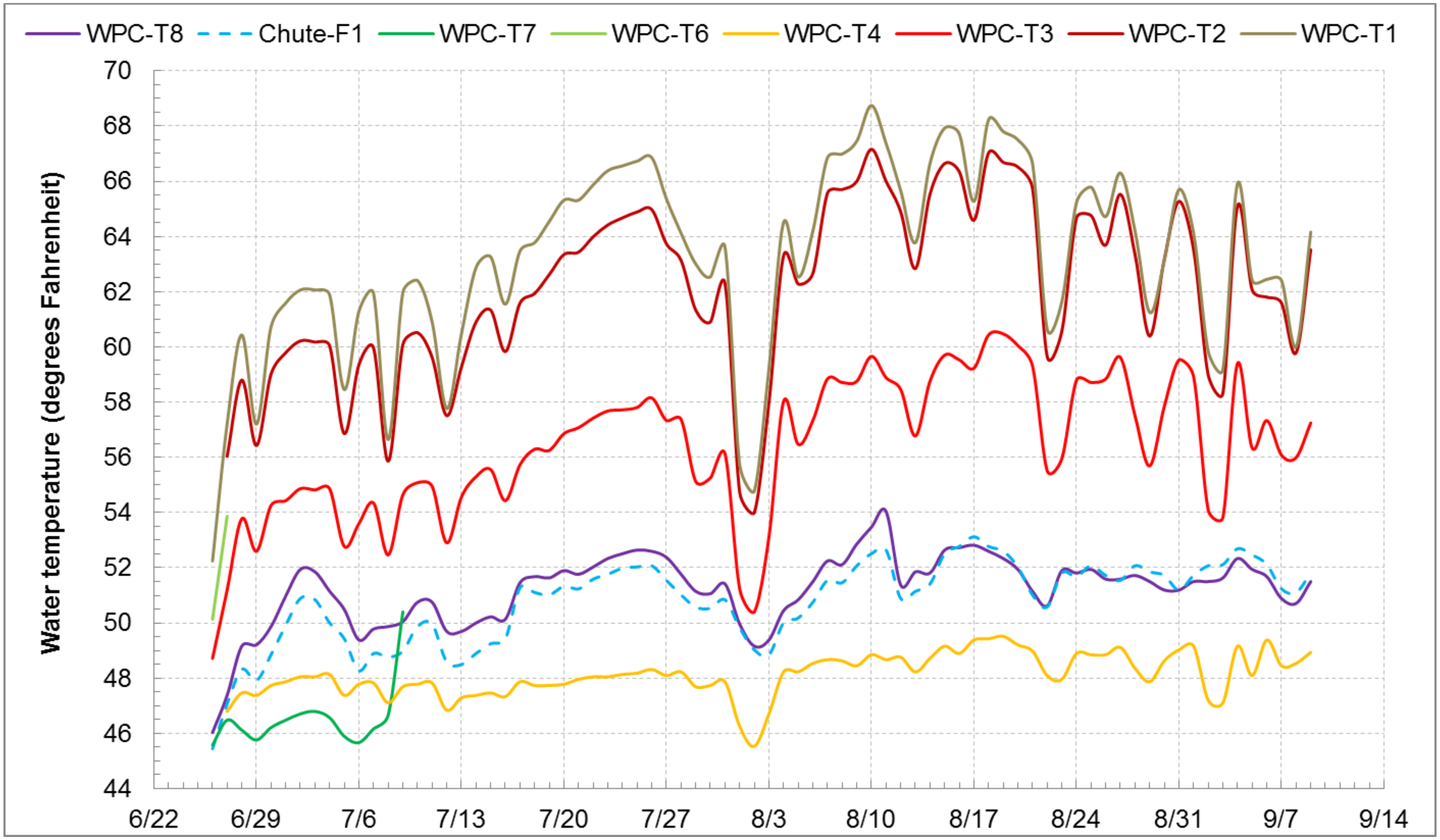
a. Maximum temperature is the maximum of recorded one-half hourly temperatures.

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

c. Logger WPC-T8 may have been exposed to ambient air prior to the mid-season field data acquisition on August 14, 2013 when the logger was observed to be partially exposed to ambient air. The logger was moved and was then fully submerged. No data were excluded from this table.

d. Logger WPC-T7 was likely exposed to ambient air from June 10, 2013 through the August 14, 2013, when it was observed in a dry channel. The data presented in this table are limited to a subset of the monitored temperatures from June 26, 2013 through July 9, 2013.

e. Logger WPC-T6 was likely exposed to ambient air from June 29, 2013 through the August 13, 2013, when it was observed in a dry channel. The data presented in this figure are limited to a subset of the monitored temperatures from June 26, 2013 through June 27, 2013.



Notes

A rainstorm occurred on August 2, 2013 with 0.92 inch of rain and ambient air temperatures decreased considerably.

Logger WPC-T6 was likely exposed to ambient air from June 29, 2013 through the August 13, 2013, when it was observed in a dry channel.

Logger WPC-T7 was likely exposed to ambient air from June 10, 2013 through the August 14, 2013, when it was observed in a dry channel.

Logger WPC-T8 may have been exposed to ambient air prior to the mid-season field data acquisition on August 14, 2013 when the logger was observed to be partially exposed to ambient air. The logger was moved and was then fully submerged. No data were excluded from this figure.

Figure B-4. Daily maximum temperatures, White Pine Creek and a tributary (dashed line), June 25-26 to September 10, 2013.

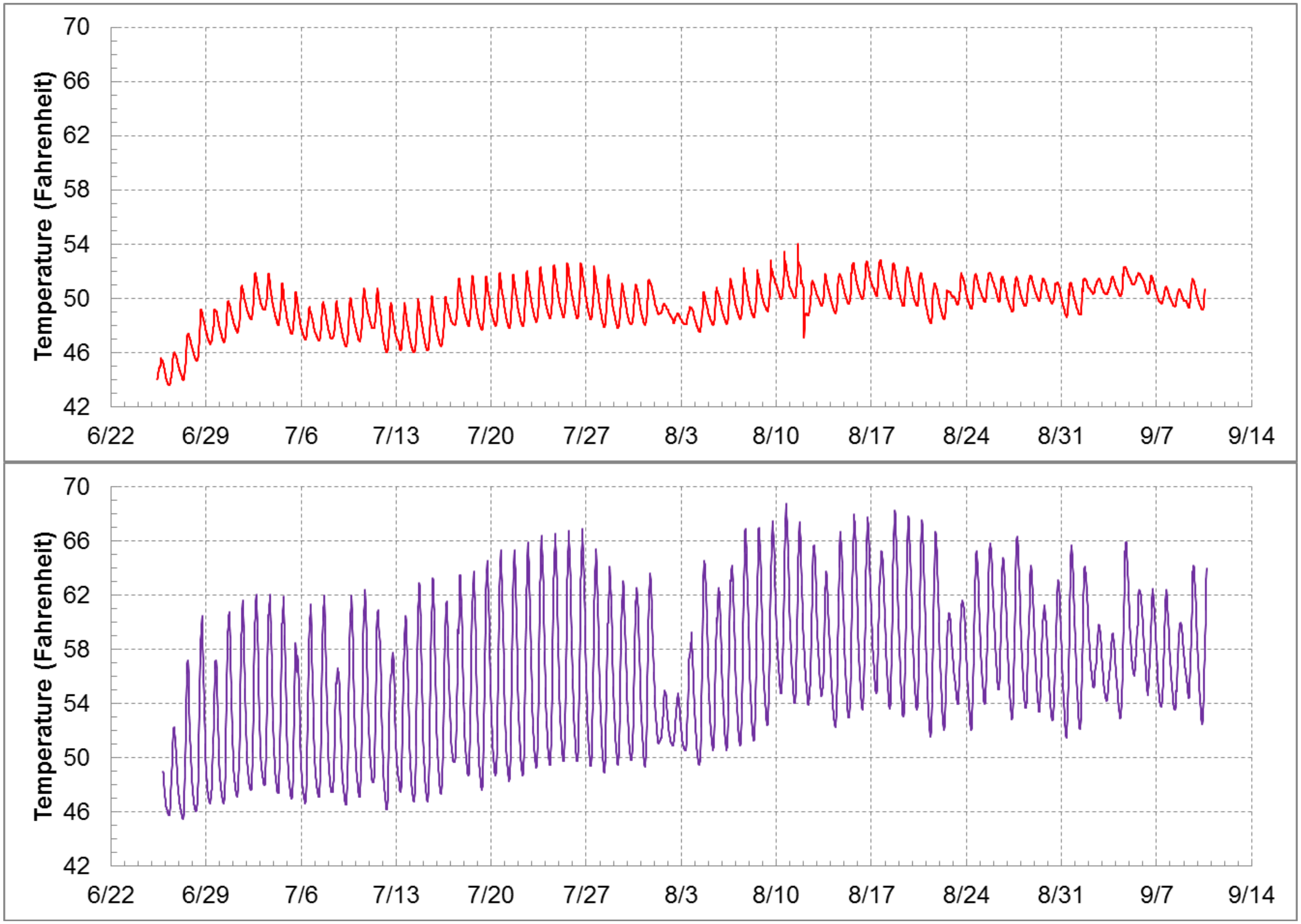


Figure B-5. Continuous temperature at logger WPC-T8 (top) in upper White Pine Creek and logger WPC-T1 (bottom) in lower White Pine Creek, June 26-27 to September 10, 2013.

B3.0 QUAL2K MODEL DEVELOPMENT

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

The current release of QUAL2K is version 2.11b8 (January 2009). The model is publicly available at http://www.epa.gov/athens/wwqtsc/html/QUAL2K.html and http://qual2k.com/. Additional information regarding QUAL2K is presented in the *Quality Assurance Project Plan for Montana TMDL Support: Temperature Modeling* (Tetra Tech, Inc., 2012)

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

B3.1 MODEL FRAMEWORK

The QUAL2K model (Chapra et al., 2008) was selected for modeling White Pine Creek. The modeling domain was limited to the mainstem below WPC-T4, which is approximately RM 3.7, to the mouth (refer back to **Figure B-2** for a map of the White Pine Creek watershed). The reaches of White Pine Creek upstream of about RM 3.7 ran dry during the summer of 2013 and were excluded from the model domain.

Data were specifically collected to support the QUAL2K model for the White Pine Creek. Flow, shade, and continuous temperature were acquired during June, August, and September 2013.

B3.2 MODEL CONFIGURATION AND SETUP

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

B3.2.1 Modeling Time Period

The calibration and validation steady-state model periods were June 27, 2013 and August 14, 2013, respectively. These dates were selected since they had the most complete datasets that could be used for model setup, calibration, and validation. Flow and logger temperature data were available for most sites on those dates and weather data were also available for those dates.

B3.2.1.1 Calibration Period

The calibration period was June 27, 2013 and was selected due to the availability of flow and temperature data (**Attachment B1**). Flow was monitored at the loggers on June 25-26, 2013. The first full day of temperature data for all the loggers was June 27, 2013. Flows monitored on June 25-26 were assumed to be representative of flow conditions on June 27, 2013 as no precipitation was recorded July 25-27, 2013[3].

B3.2.1.2 Validation Period

The validation period was August 14, 2013 and was selected due to the availability of flow and temperature data (**Attachment B1**). Flow was monitored at the loggers on August 14, 2013. No precipitation was recorded on August 14, 2013[4]. The loggers recorded the full 24-hours on this date.

B3.2.2 Segmentation

Segmentation refers to discretization of a waterbody into smaller computational units (e.g., reaches and elements). Reaches in QUAL2K have constant hydraulic characteristics (e.g. slope, bottom width) and each reach is further divided into elements that are the fundamental computational units in QUAL2K. The White Pine Creek mainstem from WPC-T4 downstream to the mouth was segmented into reach lengths of 984 feet (300 meters), which were sufficient to incorporate any point inputs to the waterbody and to maintain Courant stability. In addition since shading is applied at the reach level this allowed for better representation of the spatial variability observed in the Shade Model results along White Pine Creek (see **Attachment B1** for shade modeling discussion). Refer back to **Figure B-2** for a map that shows the White Pine Creek mainstem and its tributaries.

B3.2.3 Streamflow and Hydraulics

The flow rates were estimated through flow mass balance (continuity) calculations at the loggers and other sites where flows were monitored. The rating curve method was used to relate the depth and the velocity to the flow rate in a reach. This method requires specification of the empirical coefficients and exponents based on numerous measurements of depths, velocities, and flows. Due to the limited amount of field data, coefficients of the rating curve were treated to be the calibration parameters against the observed depths and velocities.

Typical exponents for velocity (0.43) and depth (0.45) are described in the QUAL2K manual (Chapra et al., 2008). Exponents were also calculated for two nearby U.S. Geological Survey (USGS) gages of similar size to White Pine Creek, which is 31 square miles (**Table B-2**). The exponents were set to the averages calculated from the two USGS gages: 0.49 for velocity and 0.26 for depth.

Table B-2. Calculated exponents for nearby USGS gages

Gage ID	Gage name	Drainage area (square miles)	Exponents	
			Velocity	Depth
12353820	Dry Creek near Superior, MT	44.76	0.46	0.28
12374250	Mill Creek above Bassoo Creek near Niarada, MT	19.60	0.52	0.23

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[3] Precipitation data reported for June 25, 2013 at the Cabinet (Trout Creek) RAWS were possibly erroneous. Weather data were also retrieved from National Weather Service station 243380, which is 7 miles north White Pine Creek; no precipitation occurred at or just before the selected calibration period.

[4] No precipitation was recorded at the National Weather Service station 248380 and 0.01 inch was reported at the Cabinet (Trout Creek) RAWS. For the purpose of model development, it was assumed that no precipitation occurred.

B3.2.4 Boundary Conditions

Boundary conditions represent external contributions to the waterbody being modeled. A flow and temperature input file was therefore configured for inputs to White Pine Creek. Boundary conditions were specified at the upstream terminus of the modeled reach of White Pine Creek (at logger WPC-T4) and for diffuse sources along the creek. There are many small tributaries in the watershed; however, monitoring data were only available for a few major tributaries upstream of logger WPC-T4, which is outside of the model domain. These are further discussed in the following sections.

QUAL2K requires specification of the headwater flow and temperature. Diurnal temperatures (June 27, 2013 for calibration and August 14, 2013 for validation) at the upstream boundary were specified using observed data from the instream logger at site WPC-T4. A flow of 31.85 cubic feet per second (cfs) was specified for the calibration period and 6.55 cfs was specified for the validation period. **Figure B-6** shows the headwater temperatures specified in the model.

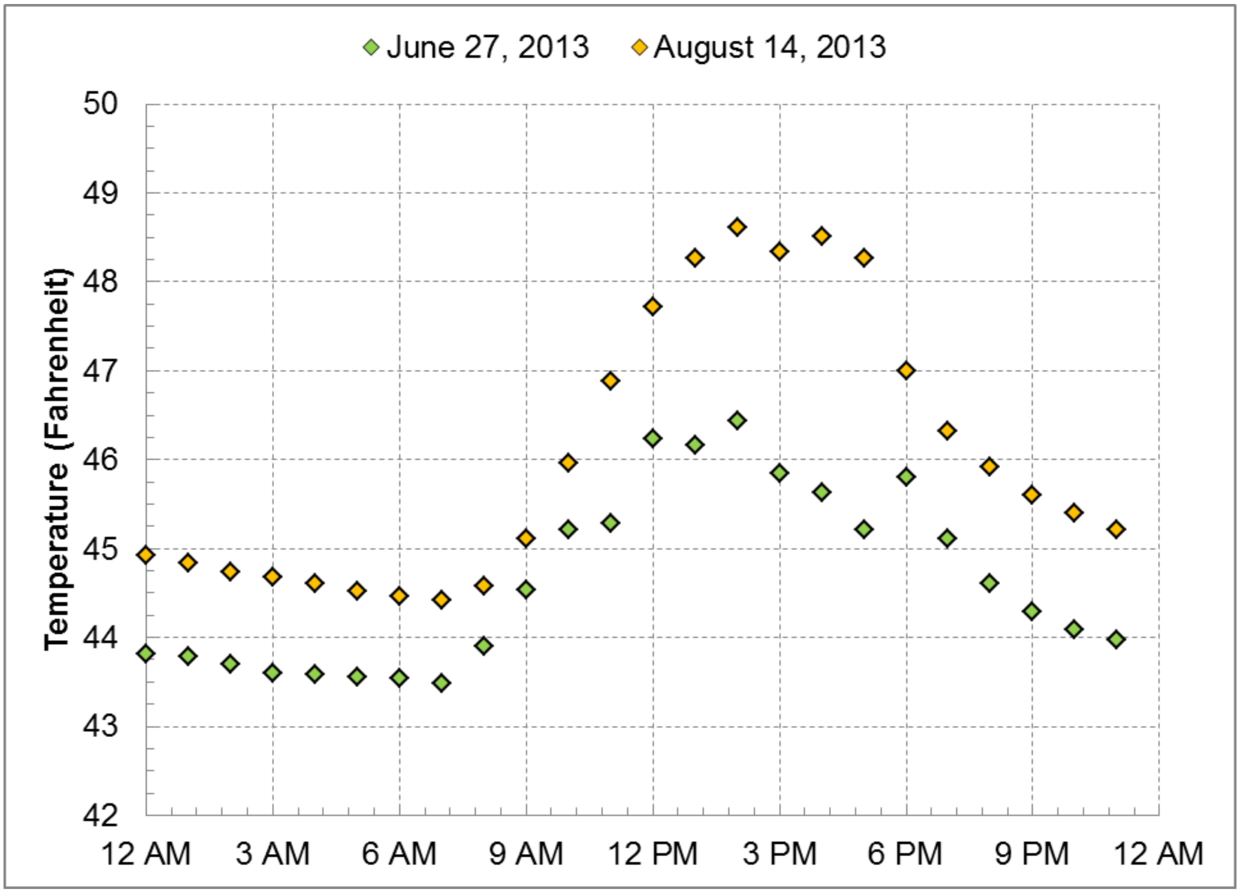

Figure B-6. Diurnal temperature at the headwaters boundary condition for the White Pine Creek model.

B3.2.5 Irrigation Inputs

Irrigation withdrawals from White Pine Creek were also identified (see **Attachment B1** for a discussion of these withdrawals) and assigned in the model. Net irrigation requirements to irrigate the fields were queried from the Montana Natural Resource Information System for the months of June and August. A maximum daily flow rate was estimated using the net irrigation requirements and the maximum area irrigated (50 acres[5]). For the irrigation withdrawal (row identified as *irrigation withdrawal* in **Table B-3**), it was calculated that up to 0.26 cfs may be withdrawn from White Pine Creek on a daily basis during June and 0.34 cfs in August.

The two other withdrawals from the simulated segment of White Pine Creek were for a fishery and domestic use. A total of 1.85 cfs may be withdrawn in June and 1.93 cfs in August. More information on the withdrawals can be found in **Attachment B1**.

Table B-3. QUAL2K model flow and temperature inputs to White Pine Creek - Withdrawals

Description	Location	Point sources [a]		Temperature [b]		
		Abstraction	Inflow	Daily mean	½ daily range	Time of maximum
	(RM)	(cfs)	(cfs)	(°F)	(°F)	(hour)
June 27, 2013						
irrigation withdrawal	2.02	0.26	--	--	--	--
fishery	1.65	1.54	--	--	--	--
domestic	0.45	0.05	--	--	--	--
August 14, 2013						
irrigation withdrawal	2.02	0.34	--	--	--	--
fishery	1.65	1.54	--	--	--	--
domestic	0.45	0.05	--	--	--	--

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

B3.2.6 Diffuse Sources

Groundwater, irrigation return flows, and other sources of water not accounted for in the tributaries can be specified along the length of the waterbody using the Diffuse Sources worksheet in the QUAL2K model. A flow balance was constructed using the observed flows along White Pine Creek and its tributary. The amount of diffuse flow along White Pine Creek was calculated for June 27, 2013 and August 14, 2013.

The initial diffuse flow temperature was selected as the maximum reported groundwater temperature (range: 45.7° F to 56.5° F) from nearby wells, which was further evaluated during calibration. A diffuse inflow temperature of 49.1° F was selected to account for potentially warmer, open channel irrigation return flows. The final flow and water temperature assignment are shown below in **Table B-4**.

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[5] The 50 acres of irrigated land was calculated using the "places of use" data associated with the "points of diversion" data available from the Natural Resources Information System (http://nris.mt.gov/gis/gisdatalib/gisDataList.aspx).

Table B-4. QUAL2K model flow and temperature inputs to White Pine Creek - Diffuse sources

Segment	Location [a]		Diffuse	Diffuse Inflow	
	Upstream	Downstream	Abstraction	Inflow	Temp
	(RM)	(RM)	(cfs)	(cfs)	(°F)
June 27, 2013					
WPC-T4 to WPC-T3	3.72	2.41	--	7.41	49.1
WPC-T3 to WPC-T2	2.41	0.69	--	6.71	49.1
WPC-T2 to WPC-T1	0.69	0.13	--	15.15	49.1
August 14, 2013					
WPC-T4 to WPC-T3	3.72	2.41	--	4.05	49.1
WPC-T3 to WPC-T2	2.41	0.69	--	0.35	49.1
WPC-T2 to WPC-T1	0.69	0.13	--	2.42	49.1

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

B3.2.7 Meteorological Data

Forcing functions for heat flux calculations are determined by the meteorological conditions in QUAL2K. The QUAL2K model requires hourly meteorological input for the following parameters: air temperature, dew point temperature, wind speed, and cloud cover. One of the nearest weather stations in the vicinity of the White Pine Creek watershed is the Cabinet (Trout Creek) RAWS (National Weather Service ID 241210), which is 7 miles to the north of the White Pine Creek watershed at an elevation of 2,350 feet above mean sea level. The other nearby weather station is the Trout Creek Ranger Station (National Weather Service ID 24830); however, its dataset does not include hourly data for the pertinent weather parameters. Since the Cabinet (Trout Creek) RAWS has a complete hourly dataset, the RAWS was used to develop the QUAL2K model (refer to **Attachment B1** for more discussion of these two weather stations).

The Cabinet (Trout Creek) RAWS records hourly air temperature, dew point temperature, wind speed and solar radiation. Therefore, the Cabinet (Trout Creek) RAWS hourly observed meteorological data were used to develop the QUAL2K model after appropriate unit conversions.

The wind speed measurements at the Cabinet (Trout Creek) RAWS were measured at 20 feet (6.10 meters) above the ground. QUAL2K requires that the wind speed be at a height of 7 meters. The wind speed measurements ($U_{w,z}$ in meters per second) taken at a height of 6.10 meters (z_w in meters) were converted to equivalent conditions at a height of z = 7 meters (the appropriate height for input to the evaporative heat loss equation), using the exponential wind law equation suggested in the QUAL2K user's manual (Chapra et al., 2008):

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

B3.2.8 Shade Data

The QUAL2K model allows for spatial and temporal specification of shade, which is the fraction of potential solar radiation that is blocked by topography and vegetation. A Shade Model was developed and calibrated for White Pine Creek. The calibrated Shade Model was first run to simulate shade estimates for June 27, 2013 to simulate hourly shade every 49 feet (15 meters, the resolution of the Shade Model) along White Pine Creek. Reach-averaged integrated hourly effective shade results were then computed at every 0.19 mile (300 meters; i.e., each reach). The reach-averaged results were then input into each reach within the QUAL2K model. A more detailed discussion on the shade modeling can be found under **Attachment B1**.

B3.3 MODEL EVALUATION CRITERIA

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

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

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

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

B3.4 MODEL CALIBRATION AND VALIDATION

The time periods selected for calibration and validation were June 27, 2013 and August 14, 2013; the travel times were 3.1 hours and 9.8 days, respectively. The June 27, 2013 travel time reflects the high flow conditions during spring melt, which are not representative of summer low-flow conditions. These dates were selected as they had the most comprehensive datasets available for modeling and corresponded to the synoptic study done for White Pine Creek, which included collecting flow, temperature, and shade.

Flow, depth, velocity and temperature data were available at four locations along the mainstem of White Pine Creek. **Table B-5** shows the monitoring sites used for calibration.

Table B-5. Temperature calibration locations

Site name	Distance (river mile)	Available Data	Source
WPC-4	3.71	Flow, depth, velocity and temperature	EPA
WPC-3	2.40	Flow, depth, velocity, and temperature	EPA
WPC-2	0.68	Flow, depth, velocity, and temperature	EPA
WPC-1	0.12	Flow, depth, velocity, and temperature	EPA

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

After the mass balance of the flow rates, the modeled velocity and depth were simulated using the previously described rating curve method. To summarize, the exponents of the rating curve for the depth and the velocity were set to be 0.26 and 0.46 respectively. While the exponents were not varied during the model calibration, the rating curve coefficients were modified and evaluated against the observed data. The model results indicated a reasonable model representation. The calibrated coefficients were deemed appropriate since they were based upon observed data and yielded reasonable fits of velocity and depth. The model results indicated a reasonable model simulation as shown in **Figure B-7** and **Figure B-8.**

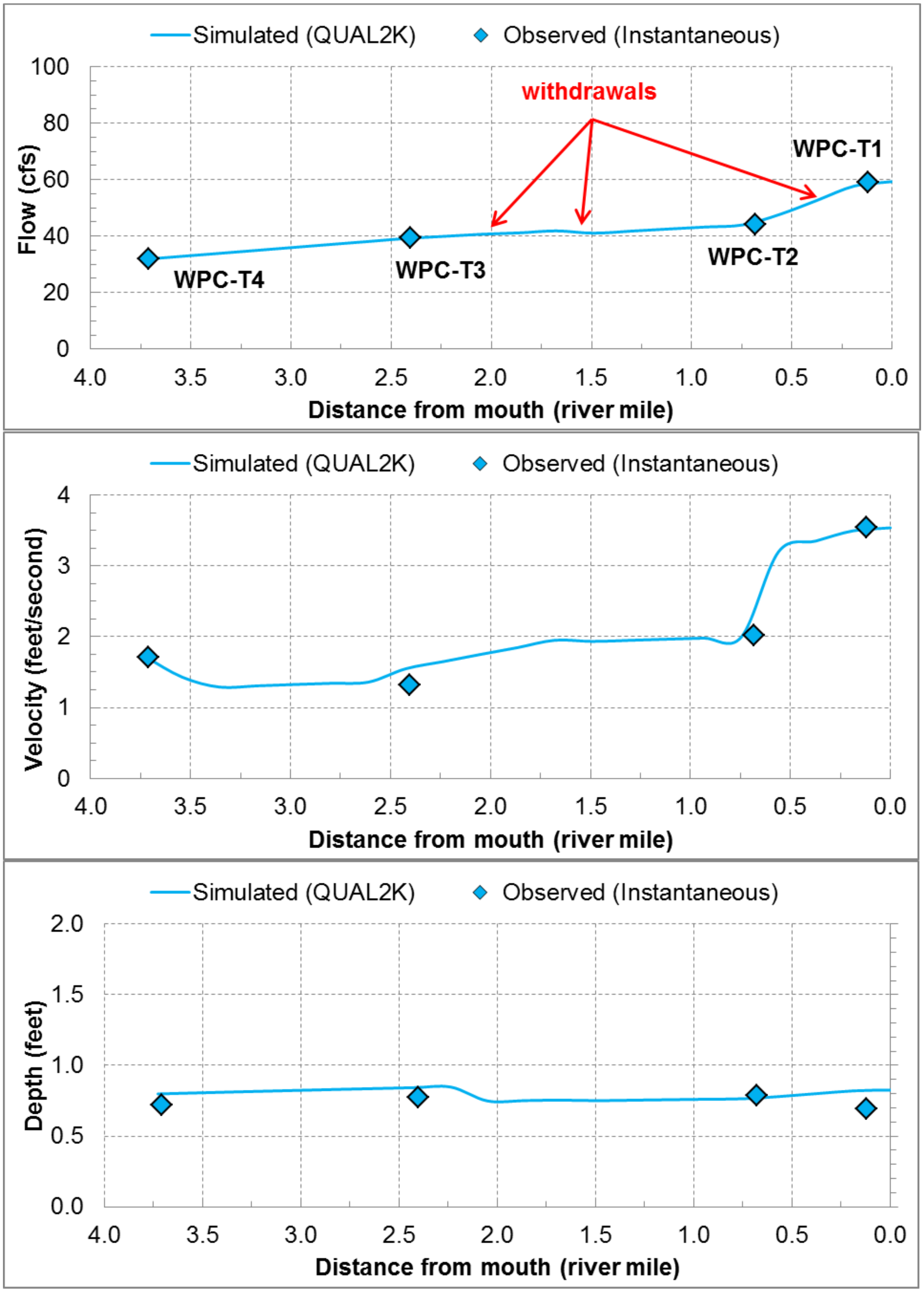

Figure B-7. Observed and predicted flow, velocity, and depth on June 27, 2013 (calibration).

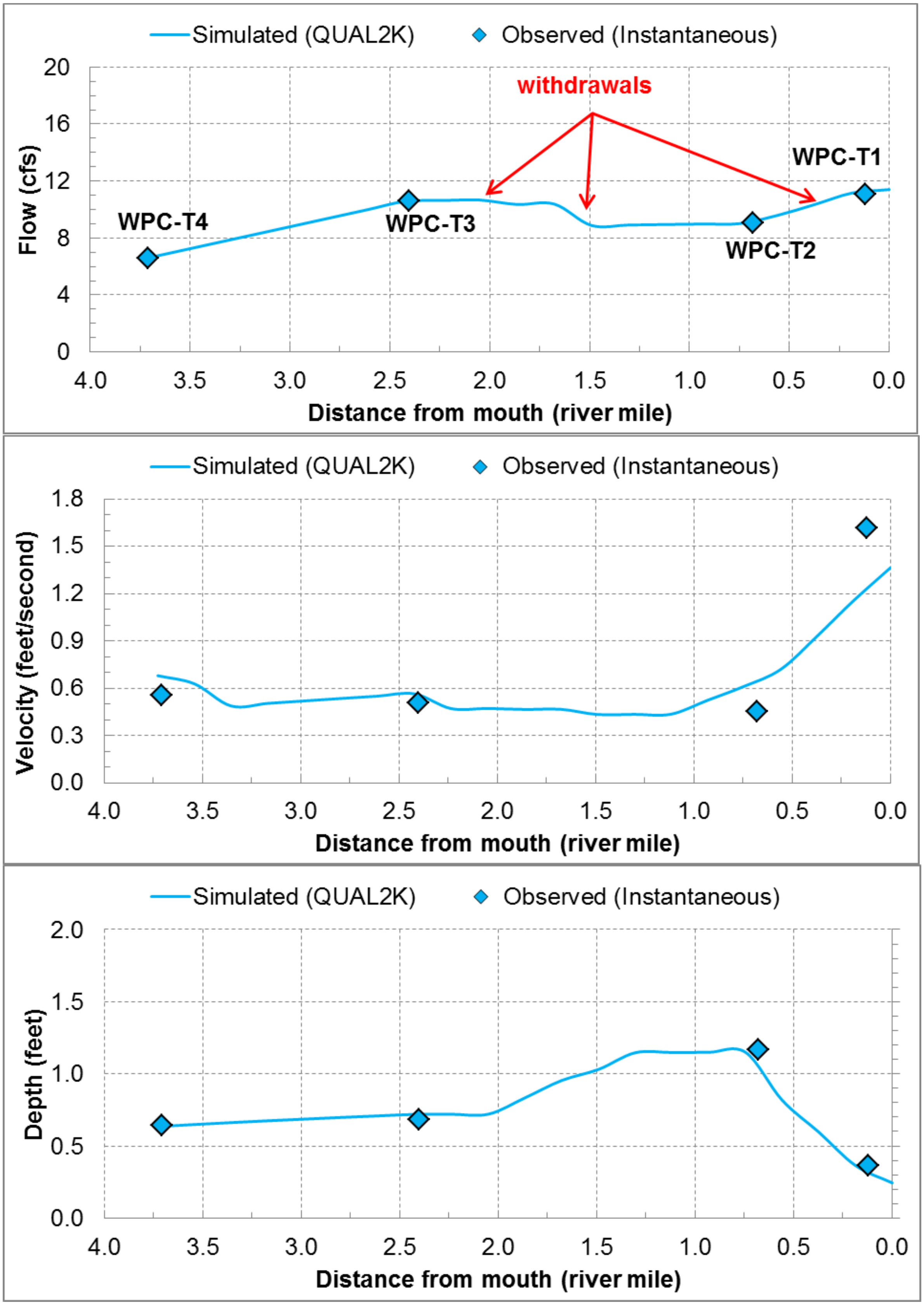

Figure B-8. Observed and predicted flow, velocity, and depth on August 13, 2013 (validation).

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

Hourly solar radiation is an important factor that affects stream temperature. The QUAL2K model does not allow for input of solar radiation. Instead the model calculates short wave solar radiation using an atmospheric attenuation model. For White Pine Creek, the Ryan-Stolzenbach model was used to calculate the solar radiation. The calculated solar radiation values (without stream shade) for the calibration and validation were compared with observed solar radiation measurements at the Cabinet (Trout Creek) RAWS. **Figure B-9** and **Figure B-10** show the observed and predicted solar radiation for the calibration and validation, respectively. The Ryan-Stolzenbach atmospheric transmission coefficient was set at 0.85 for the calibration to reflect the atmospheric conditions (i.e., cloudy) to minimize the deviation between the observed and modeled short wave solar radiation. Cloud cover was also adjusted to ensure the model simulated solar radiation was similar to the solar radiation reported for the RAWS.

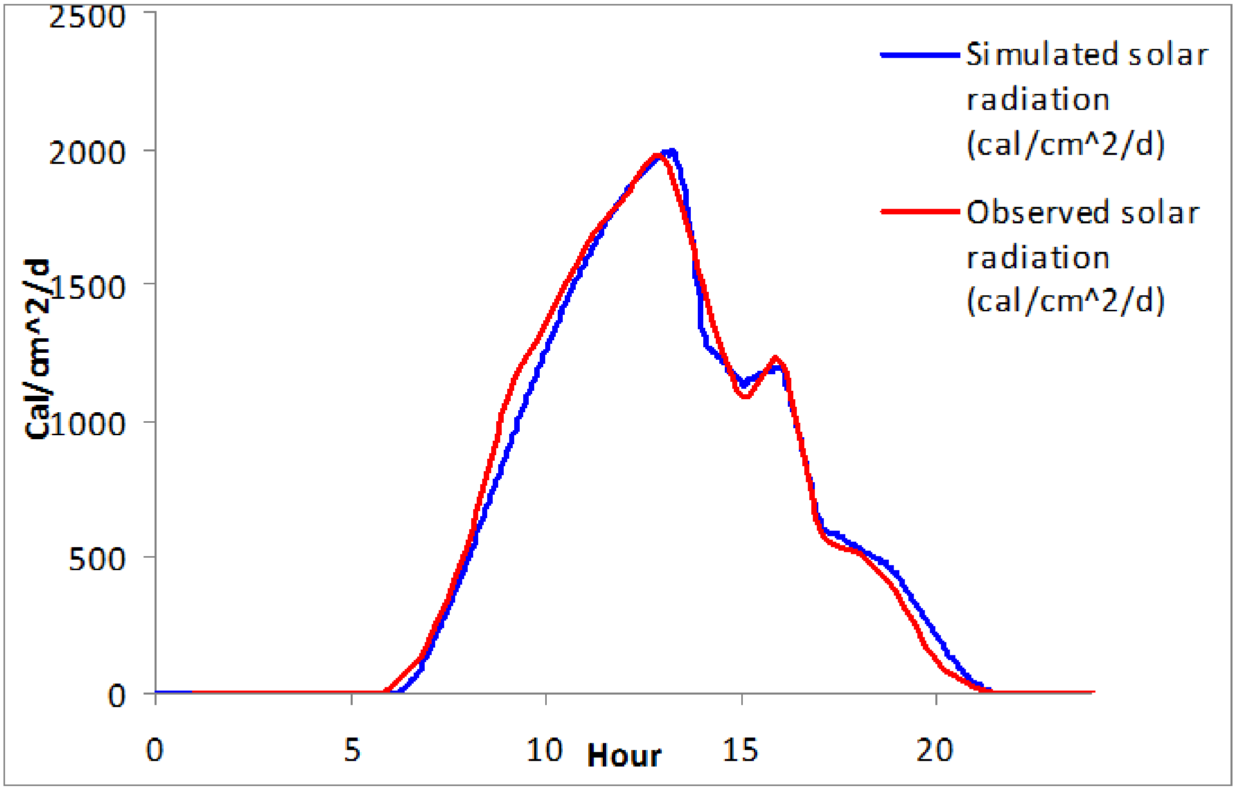

Figure B-9. Observed and predicted solar radiation on June 27, 2013 (calibration).

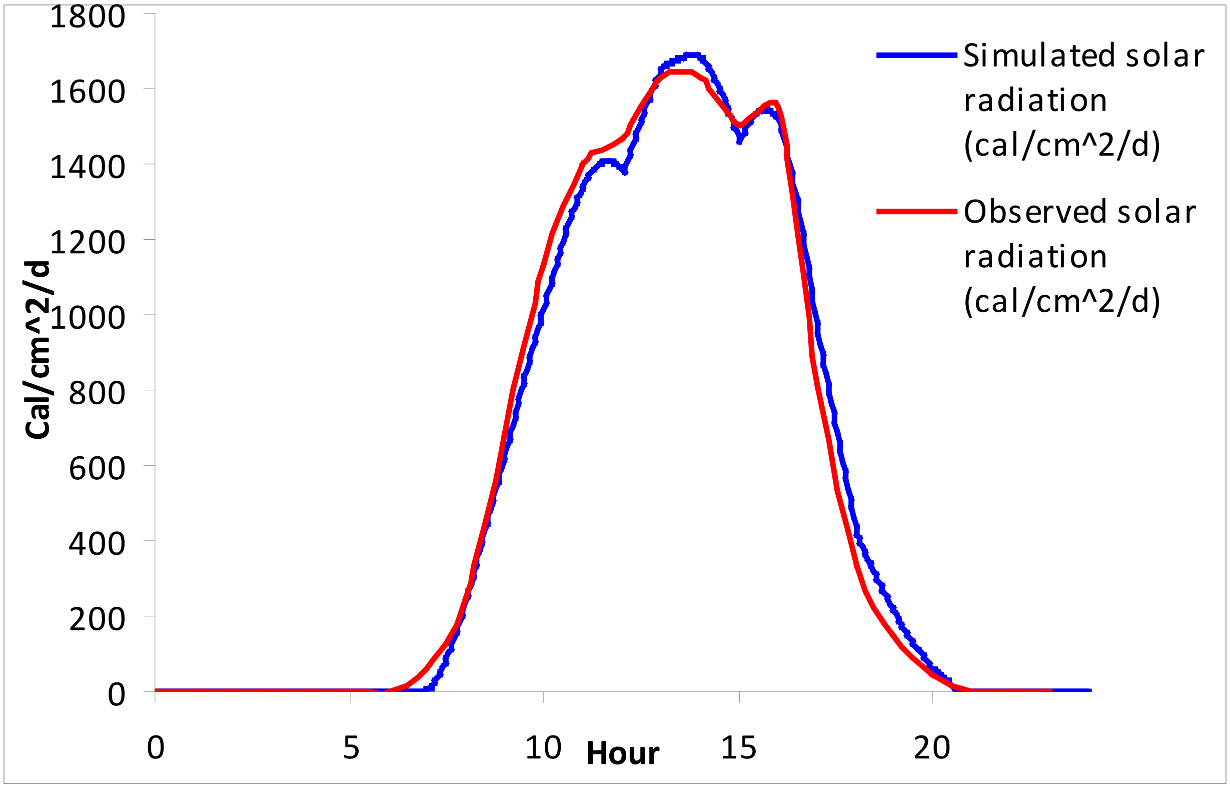

Figure B-10. Observed and predicted solar radiation on August 14, 2013 (validation).

The longwave solar radiation model and the evaporation and air conduction/convections models were kept at the default QUAL2K settings. The solar radiation settings are shown in **Table B-6**.

Table B-6. Solar radiation settings

Parameter	Value
Solar Shortwave Radiation Model	
Atmospheric attenuation model for solar	Ryan-Stolzenbach
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)	
Atmospheric transmission coefficient [a]	0.85
Downwelling atmospheric longwave infrared radiation	
Atmospheric longwave emissivity model	Brutsaert
Evaporation and air convection/conduction	
Wind speed function for evaporation and air convection/conduction	Adams 2

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

The sediment heat parameters were also evaluated for calibration. In particular the sediment thermal thickness, sediment thermal diffusivity, and sediment density were adjusted during calibration. The sediment thermal thickness was increased from the default value of 10 cm to 20 cm, and the sediment heat capacity of all component materials of the stream was set to 0.4 calories per gram per degree Celsius, which is the QUAL2K default (Chapra et al., 2008).

The sediment density was set to 2.04 grams per cubic centimeter (g/cm^3). Based on the field photographs, the surface layer of the stream substrate was estimated to be composed of 80 percent rock gravel and 20 percent of silt and clay. The following calculation was conducted:

$$\begin{aligned}\text{sediment density} &= (\text{ratio} * \text{density})_{\text{gravel}} + (\text{ratio} * \text{density})_{\text{silt and clay}} \\ &= (0.80 * 2.00\ \text{g/cm}^3) + (0.20 * 2.20\ \text{g/cm}^3) \\ &= 2.04\ \text{g/cm}^3\end{aligned}$$

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

The sediment thermal diffusivity was set to a value of 0.0112 square centimeters per second (cm^2/s; Chapra et al. 2008). The following calculation was conducted:

$$\begin{aligned}\text{thermal diffusivity} &= (\text{ratio} * \text{thermal diffusivity})_{\text{rock+gravel}} + (\text{ratio} * \text{thermal diffusivity})_{\text{sand}} \\ &\quad + (\text{ratio} * \text{thermal diffusivity})_{\text{silt}} \\ &= (0.80 * 0.0118\ \text{cm}^2/\text{s}) + (0.097 * 0.0079\ \text{cm}^2/\text{s}) + (0.103 * 0.0098\ \text{cm}^2/\text{s}) \\ &= 0.0112\ \text{cm}^2/\text{s}\end{aligned}$$

where 0.118 cm^2/s is the thermal diffusivity of rock, 0.0079 cm^2/s is the thermal diffusivity of sand, and 0.0098 cm^2/s is the thermal diffusivity of clay, which is assumed to be representative of silt.

These adjustments helped in improving the minimum temperatures simulated.

Calibration was followed by validation. The validation provides a test of the calibrated model parameters under a different set of conditions. Only those variables that changed with time were changed during validation to confirm the hydraulic variables. This included headwater instream temperatures, air and dew point temperatures, wind speed, cloud cover, solar radiation, and shade. All other inputs were based on observed data June 28, 2013. Groundwater temperatures, for which there were no direct observed data, were unchanged since they are not expected to vary greatly.
Figure B-11 and **Figure B-12** show the calibration and validation results along White Pine Creek. The temperature calibration and validation statistics of the average, maximum, and minimum temperatures are shown in **Table B-7** and **Table B-8**, respectively.

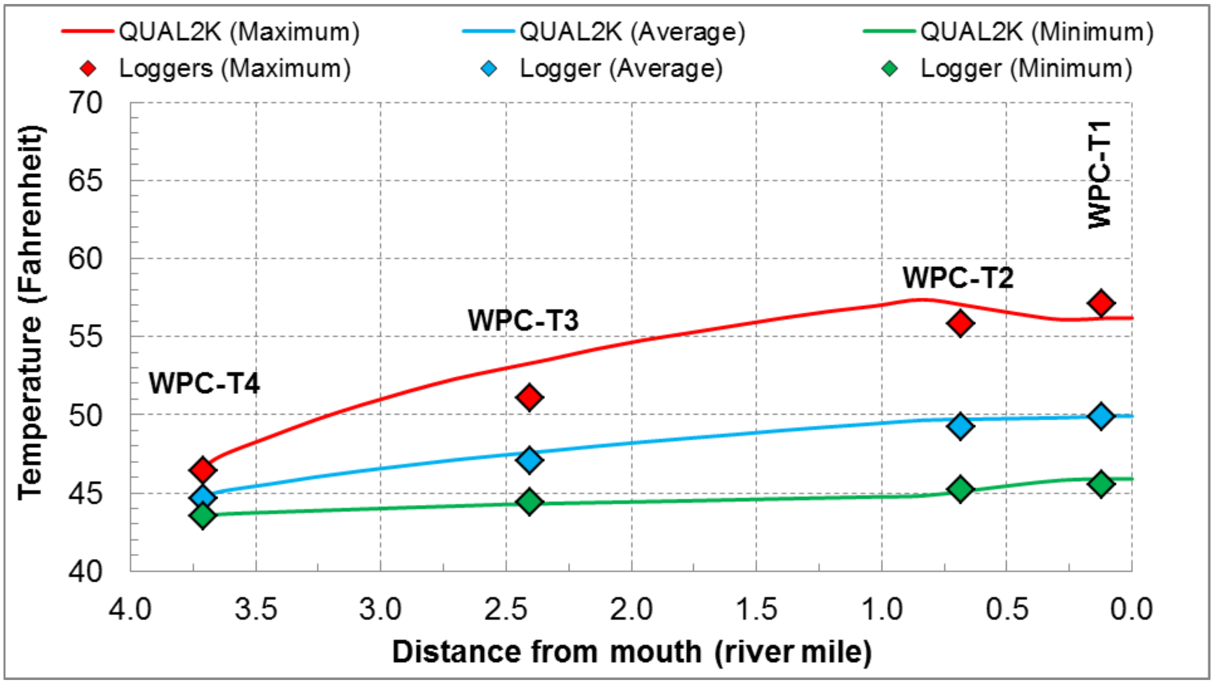

Figure B-11. Longitudinal profile of the temperature calibration (June 27, 2013).

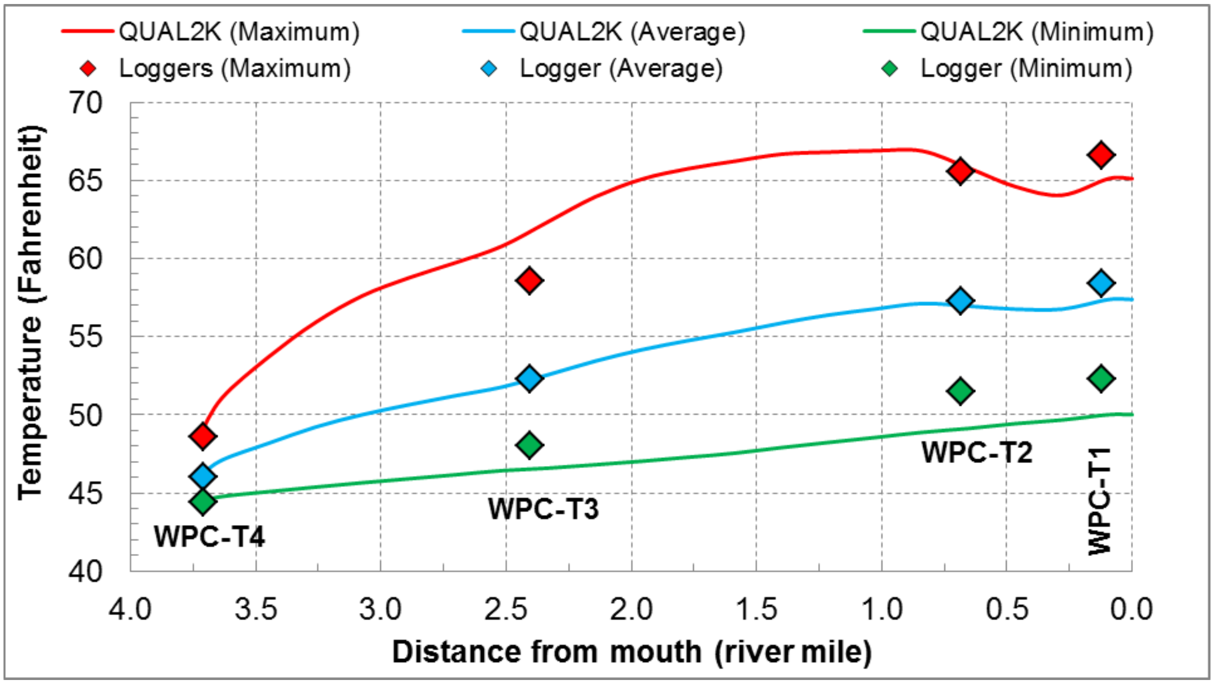

Figure B-12. Longitudinal profile of the temperature validation (August 14, 2013).

Table B-7. Calibration statistics of observed versus predicted water temperatures

Site name	RM	Average daily temperature		Maximum daily temperature		Minimum daily temperature	
		AME (°F)	REL (%)	AME (°F)	REL (%)	AME (°F)	REL (%)
WPC-T4	3.71	0	0%	0.01	<0.1%	0	0%
WPC-T3	2.40	0.65	1.4%	2.45	4.8%	0.08	0.2%
WPC-T2	0.68	0.51	1.0%	1.12	2.0%	4.51	10.0%
WPC-T1	0.12	0.02	0%	0.95	1.7%	0.41	0.9%
Overall Calibration		**0.39**	**0.8%**	**1.51**	**2.8%**	**1.67**	**3.7%**

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

Table B-8. Validation statistics of observed versus predicted water temperatures

Site name	RM	Average daily temperature		Maximum daily temperature		Minimum daily temperature	
		AME (°F)	REL (%)	AME (°F)	REL (%)	AME (°F)	REL (%)
WPC-T4	3.71	0	0%	0	0%	0	0%
WPC-T3	2.40	0.30	0.6%	3.83	3.6%	1.39	2.9%
WPC-T2	0.68	0.99	0.5%	0.26	0.4%	2.27	4.6%
WPC-T1	0.12	0.28	1.7%	1.51	2.3%	2.26	4.3%
Overall Validation		**0.9**	**0.52%**	**1.87**	**2.9%**	**2.01**	**4.0%**

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

Based upon the calibration results, the model is able to simulate the flow, depth, and velocity and the minimum, mean, and maximum temperatures reasonably well. The model over-predicts the maximum temperature at loggers WPC-T2 and WPC-T3 and under-predicts the maximum temperature at WPC-T1. The calibration results showed an overall 2.8 percent relative error with an AME of 1.51° F for the maximum temperatures (**Table B-7**); thus, the model simulation is acceptable.

The model results for the validation are similar to those of the calibration. The model over-predicts the maximum temperatures at loggers WPC-T2 and WPC-T3 and under-predicts the maximum temperature at logger WPC-T1. The validation results showed an overall 2.9 percent relative error with an AME of 1.87° F for the maximum temperatures (**Table B-8**).

B3.5 MODEL SENSITIVITY

Sensitivity analysis measures the relative importance of parameters, such as shade and water withdrawals, on model response. Model sensitivity was generally evaluated by making changes to shade[6] and water use[7] (i.e., the key thermal mechanisms [Tetra Tech 2012]) in separate model runs and evaluating the model response. Model sensitivity analyses with similar QUAL2K models for streams in western Montana (Fortine, Wolf, and McGregor creeks) suggest that the QUAL2K models developed with the data typically available for the Montana temperature projects are not very sensitive to changes in water use but are sensitive to changes in shade. The sensitivity of water withdrawals and shade were

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[6] To assess model sensitivity to shade, all vegetation was converted to high density trees (with the exception of roads and hydrophytic shrubs) to represent the maximum potential shade.

[7] To assess model sensitivity to water withdrawals, the point source abstractions representing the withdrawals were removed and the existing condition model was run to represent the maximum achievable change in water temperatures from changes in water use.

explored with the White Pine Creek QUAL2K model during model development and the results were generally consistent with previous Montana streams QUAL2K projects.

B4.0 MODEL SCENARIOS AND RESULTS

The White Pine Creek QUAL2K model was used to evaluate instream temperature response associated with multiple management scenarios. **Table B-9** summarizes the alterations for each model scenario. The following subsections present discussions of the modifications to the QUAL2K models and the results for each scenario.

Table B-9. QUAL2K model scenarios for White Pine Creek

Scenario[a]		Description	Rationale
Baseline Scenario			
1	Existing Condition	Existing shade and irrigation practices under validation model flows[b] and weather.	The baseline model simulation from which to construct the other scenarios and compare the results against.
Water Use Scenario			
2	15 % reduction in withdrawals	Reduce existing withdrawals by 15 percent	Represent application of conservation practices for agricultural and domestic water use.
Shade Scenario			
3	Shade increased to reference levels	Increase anthropogenically influenced reaches' shade to that of a conifer/shrub reference reach at site WPC-T2	Represent application of conservation practices for riparian vegetation.
Improved Flow and Shade			
4	Improved flow and shade	Existing conditions with 15% reduction in withdrawals (scenario 2) and increase to reference levels (scenario 3).	Represent application of conservation practices for water withdrawals and riparian vegetation.

Notes

a. Scenarios were developed in accordance with electronic correspondence from the DEQ project manager Eric Sivers to Tetra Tech's project manager Ron Steg on May 12, 2014.

b. Based on an analysis of discharge records from a nearby USGS gage (Prospect Creek at Thompson Falls [12390700]), flows in White Pine Creek during the validation timeframe were likely below average.

B4.1 BASELINE SCENARIO

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

The Cabinet (Trout Creek) RAWS has hourly data available for the period from January 2004 through May 2014[8]. Since the weather data extends only for a period of 10 years, a nearby station with long-term meteorological data (Missoula International Airport [1988-2013]) was queried to confirm if the years from 2004 to 2013 were (1) not anomalously warm or cold and (2) similar to the overall historical normal. Additionally, comparisons with the year 2013 (during which the QUAL2K model calibration period occurs) were made to ensure that 2013 was not an anomalous year. The long-term monthly

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[8] Data are available for a few months in the years 2001, 2002, and 2003.

median and maximum air temperatures for the period from 2004 to 2013 and for the year 2013 were estimated to be similar to the overall period from 1988 through 2013 (**Figure B-13**)[9]. The monthly maximum air temperatures in the summer of 2013 were cooler than the monthly long-term maximum of monthly maximum air temperatures of the years 1988-2013 and 2004-2013 (**Figure B-13**). Therefore, since neither the period from 2001 through 2013 nor the summer of 2013 was substantially anomalous, it is appropriate to use the Cabinet (Trout Creek) RAWS data for QUAL2K modeling.

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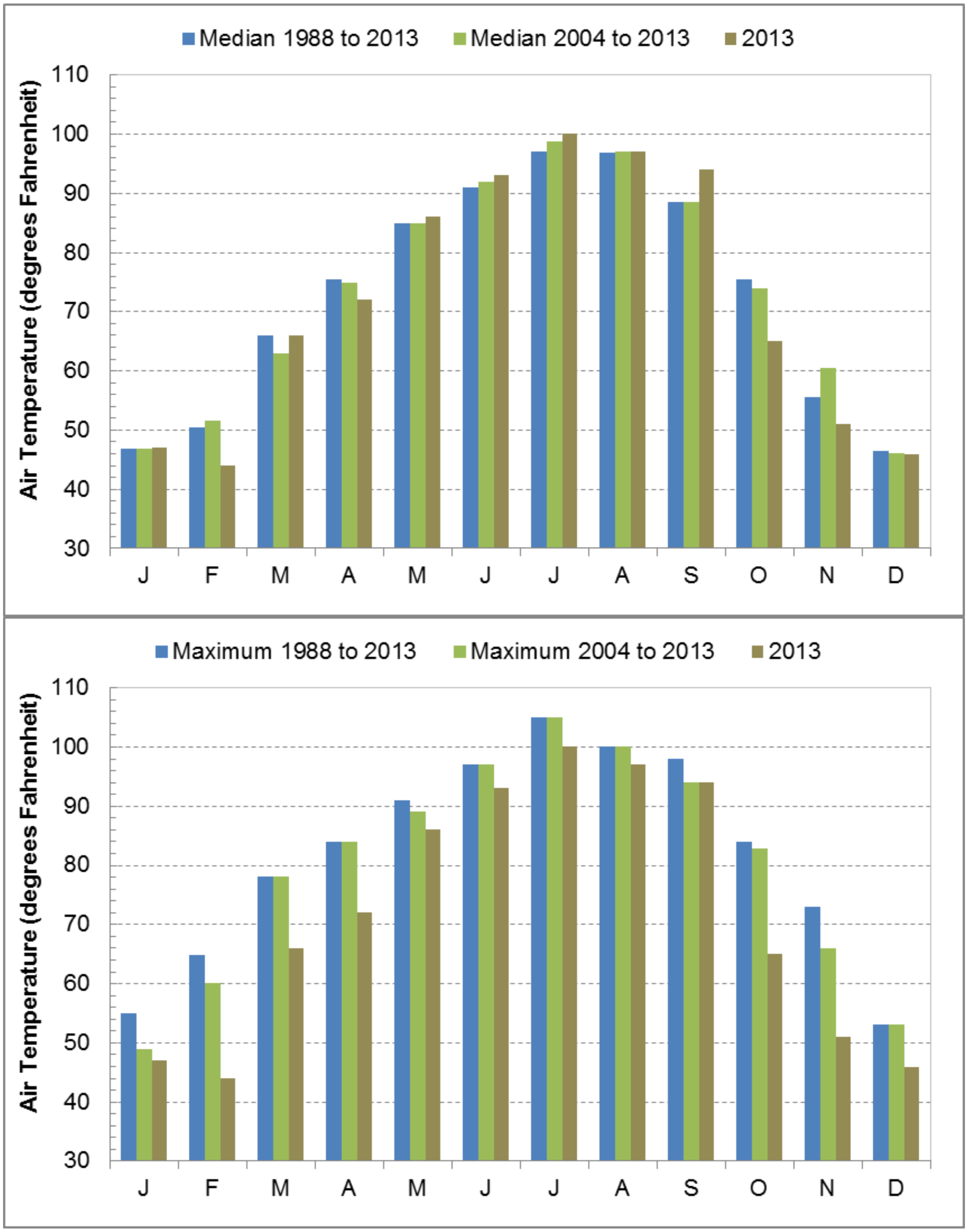
[9] Hourly average air temperatures were obtained for the Missoula International Airport (KMSO). Monthly maximum air temperatures were calculated for each month from January 1988 through December 2013 using the hourly average air temperatures. Monthly long-term medians and maximums were calculated from the 26 years of monthly maximums of hourly average air temperatures.



Note: Hourly average air temperatures were obtained for the Missoula International Airport (KMSO). Monthly maximum air temperatures were calculated for each month from January 1988 through December 2013 using the hourly average air temperatures. Monthly long-term medians and maximums were calculated from the 26 years of monthly maximums of hourly average air temperatures.

Figure B-13. Long-term median (chart on top) and maximum (chart on bottom) of monthly maximum air temperature at Missoula.

Existing conditions weather (August 14, 2013) used for the validation model was also used for the baseline model.

No continuous flow datasets are available in the White Pine Creek watershed. The closest continuously recording USGS gage in a watershed of similar size is gage 12390700 (Prospect Creek at Thompson Falls; water years 1957-2013). The daily average flow on August 14, 2013 at gage 12390700 was low (38th percentile) as compared to the daily average flows on all August 14ths on record. The daily average flow for August 2013 at USGS gage 12390700 was also low (34th percentile) as compared to the daily average flow for all Augusts on record (see **Attachment B1, Section B6**). The existing condition flow was used for the analysis.

The modeled water temperatures for the baseline scenario are shown below in **Figure B-14**. The simulated maximum temperatures ranged from 48.6° F to 68.2° F. The warmest temperature (67.2° F) occurred at river mile 0.84, just upstream of logger WPC-T2).

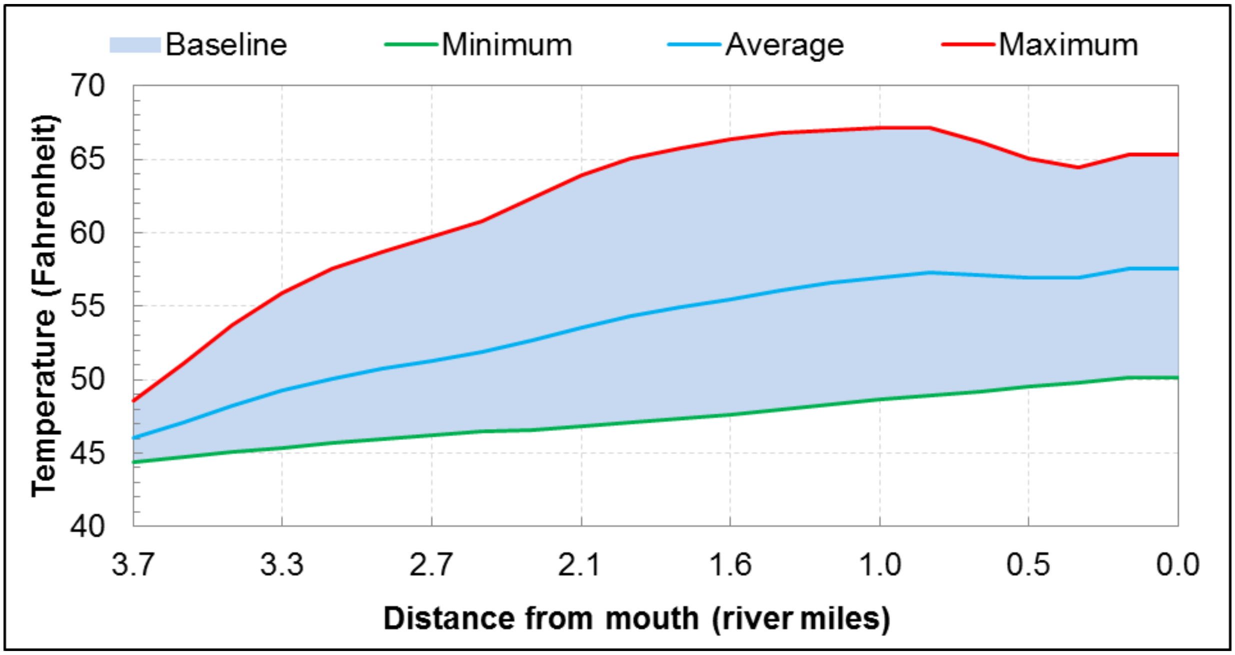


Figure B-14. Simulated water temperature for baseline condition (August 14, 2013).

B4.2 WATER USE SCENARIO

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

In this scenario, the point sources abstractions representing the withdrawals (see **Attachment B1** and **Table B-3** for the withdrawals) in the QUAL2K model are reduced by 15 percent (Natural Resources Conservation Service, 1997). The water previously withdrawn is now allowed to flow down White Pine Creek. This scenario is intended to represent application of conservation practices relative to water use.

The water temperatures under this scenario generally were the same as the baseline scenario (**Figure B-15**). The maximum change in the maximum daily water temperature is representative of the worst case conditions. A maximum change in the maximum daily water temperature of 0.04° F from the existing condition was observed at RM 0.8. The temperature difference of the daily maximums was less than 0.5° F for the entire stream of the stream.

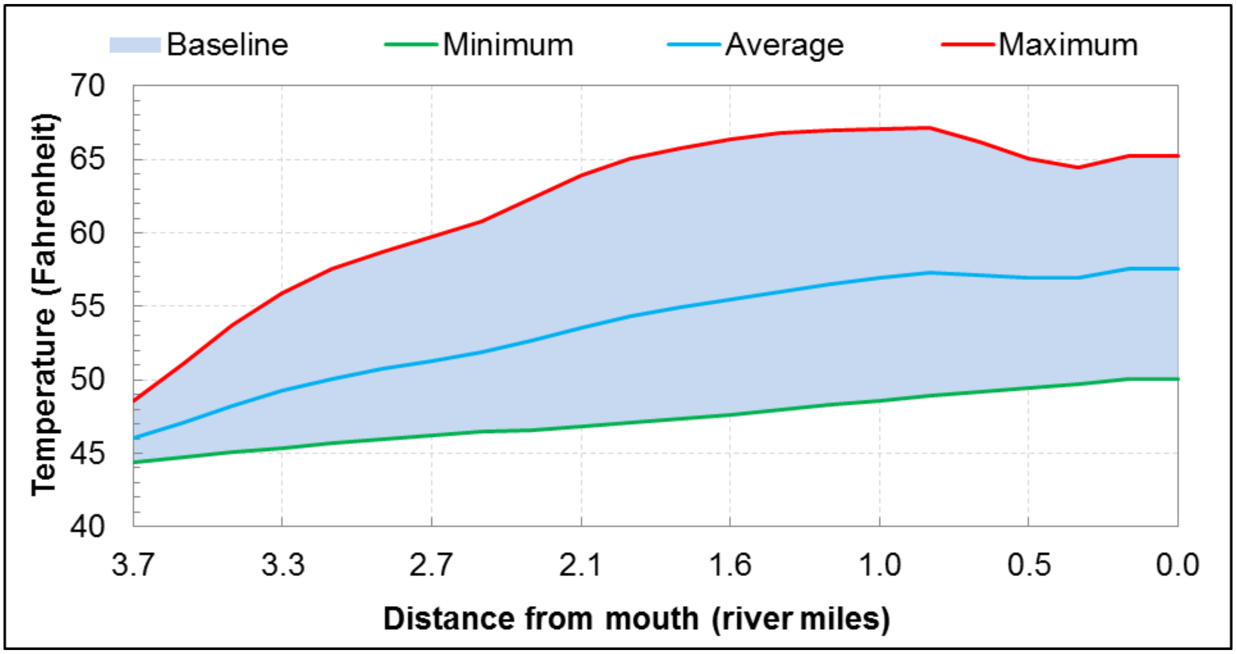


Figure B-15. Simulated water temperatures for the baseline (scenario 1) and 15-percent withdrawal reduction (scenario 2).

B4.3 SHADE SCENARIO

The riparian plant community blocks incoming solar radiation, which directly reduces the heat load to the stream. A single shade scenario was modeled to evaluate the potential benefits associated with increased shade along certain segments of White Pine Creek.

Based on an assessment including site reconnaissance and review of historic aerial photographs, Water Consulting, Inc.(2002) concluded the following regarding the condition of riparian vegetation in the lower reaches of White Pine Creek (i.e., the reach that was modeled[10]):

> *Poor cottonwood and willow recruitment in the lower watershed contrasts with the diverse gallery forest in upper White Pine Creek. Restoring this diversity in the lower watershed should be a priority for the restoration effort.*

Water Consulting recommended a re-vegetation plan, following a multi-year schedule directed at redirecting plant succession towards a riparian forest. Specifically, they recommended the following re-vegetation steps:

- Conifer plantings in senescent alder stands

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[10] Given intermittent flow in the upper reaches of White Pine Creek, only the lower reach (i.e., below WPC-T4) of White Pine Creek has been modeled.

- Shrub and conifer plantings in moist-soil/tall grass sites
- Shrub and conifer plantings in sand and gravel floodplains
- Shrub and conifer plantings on well-drained, short grass/knapweed dry terraces

Water Consulting's assessment suggests that the vegetative potential for the lower reaches of White Pine Creek is a mixed conifer, cottonwood, and shrub community.

Based on site reconnaissance work conducted by EPA and DEQ during the summer of 2013, Shade Monitoring Site WPC-T2 represents a mixed conifer/shrub community that was at potential within the lower reach of White Pine Creek. Average daily shade measured at WPC-T2 was approximately 70%, compared to approximately 30% at the other three sites in the lower reach of White Pine Creek (WPC-T1, WPC-T3, and WPC-T4). In the Improved Shade Scenario, modeled shade in the vicinity of WPC-T2 is the reference condition that will be applied to anthropogenically impacted reaches in lower White Pine Creek.

The White Pine Creek QUAL2K model was re-run using the altered shade inputs, based upon the findings presented above (**Table B-10**. This scenario is intended to represent application of conservation practices relative to shade although it is important to note that even in natural forested conditions, there are still openings in the canopy and some areas without vegetation. Hence this is likely an upper limit to what plausibly could occur from vegetation management practices.

Table B-10. Average daily shade inputs per model segment

Segment	Existing condition (scenario 1)	Shade (scenario 3)
WPC-T4 to WPC-T3	37%	45%
WPC-T3 to WPC-T2	29%	45%
WPC-T2 to WPC-T1	45%	45%
WPC-T1 to mouth	33%	45%

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

Water temperatures in White Pine Creek downstream of logger WPC-T4 decreased (**Figure B-16**). A maximum change in the maximum daily water temperature of 2.6° F from the baseline was observed at RM 0.8. The difference in the daily maximum water temperature between the baseline and shade scenario was greater than 0.5° F from RM 3.5 to the mouth, which is almost the entire length of the modeled stream. It is important to note the caveats previously stated: that this is likely the largest improvement that could be observed through vegetation management practices.

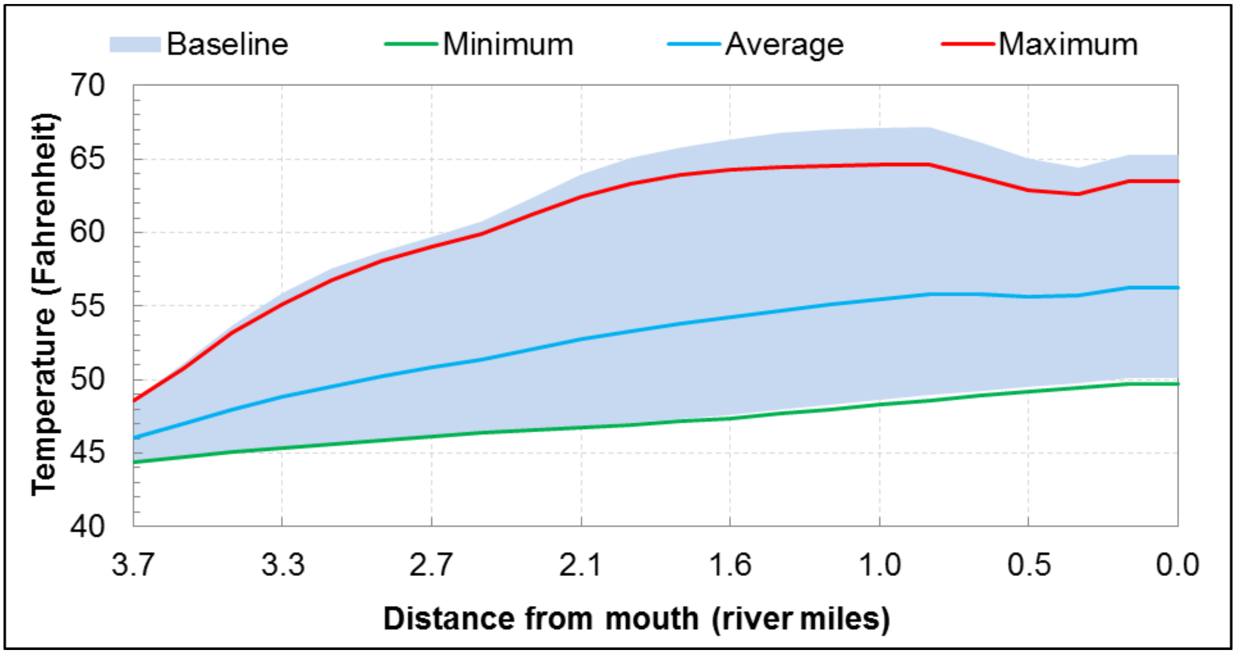


Figure B-16. Simulated water temperatures for the baseline (scenario 1) and increased shade (scenario 3).

B4.4 IMPROVED FLOW AND SHADE SCENARIO

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

Simulated maximum daily temperatures ranged from 48.6° to 64.6° from logger WPC-T4 at rivermile 3.7 to the mouth. As per the temperature standard discussed in **Section B2.2**, anthropogenic activities may increase the instream temperatures by 1.0° F for the segment from rivermile 3.7 to the mouth.

In this scenario, water temperatures in White Pine Creek decrease throughout much of the system (**Figure B-17** and **Figure B-18**). A maximum change in the maximum daily water temperature of 2.6° F from the baseline was observed at RM 0.8. The difference in the daily maximum water temperature between the baseline and the improved flow and shade scenario was greater than 0.5° F from RM 3.5 to the mouth, which is almost the entire length of the modeled stream.

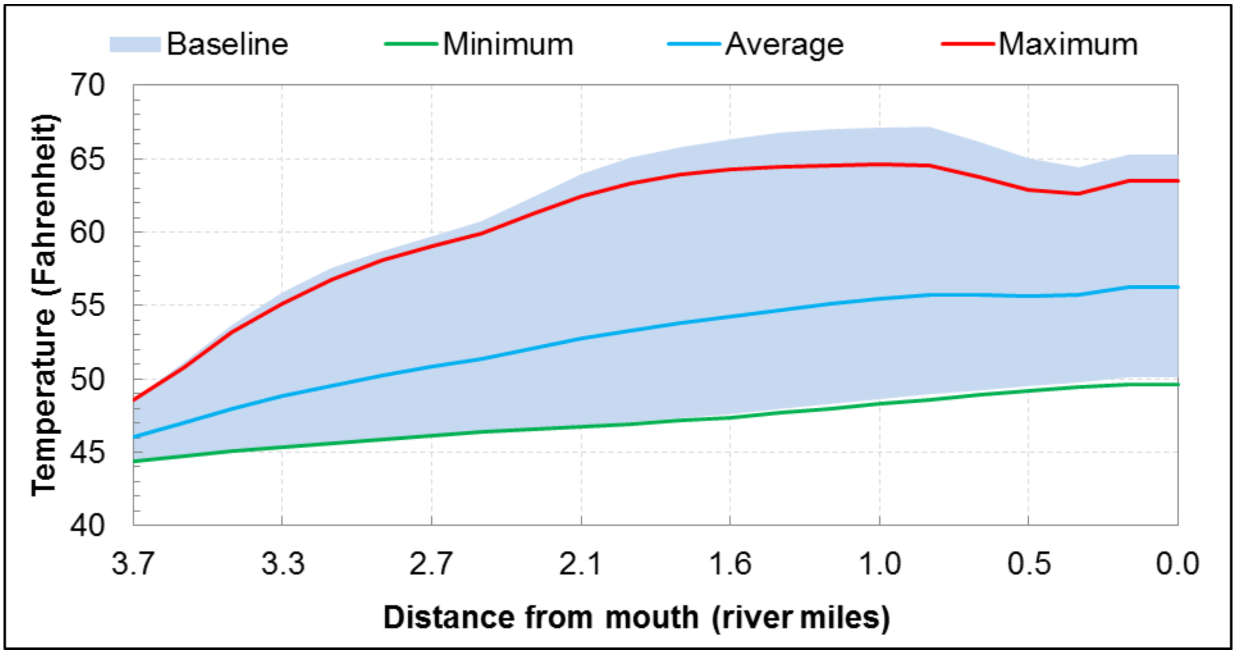


Figure B-17. Simulated water temperature for the baseline (scenario 1) and the improved flow and shade scenario (scenario 4).

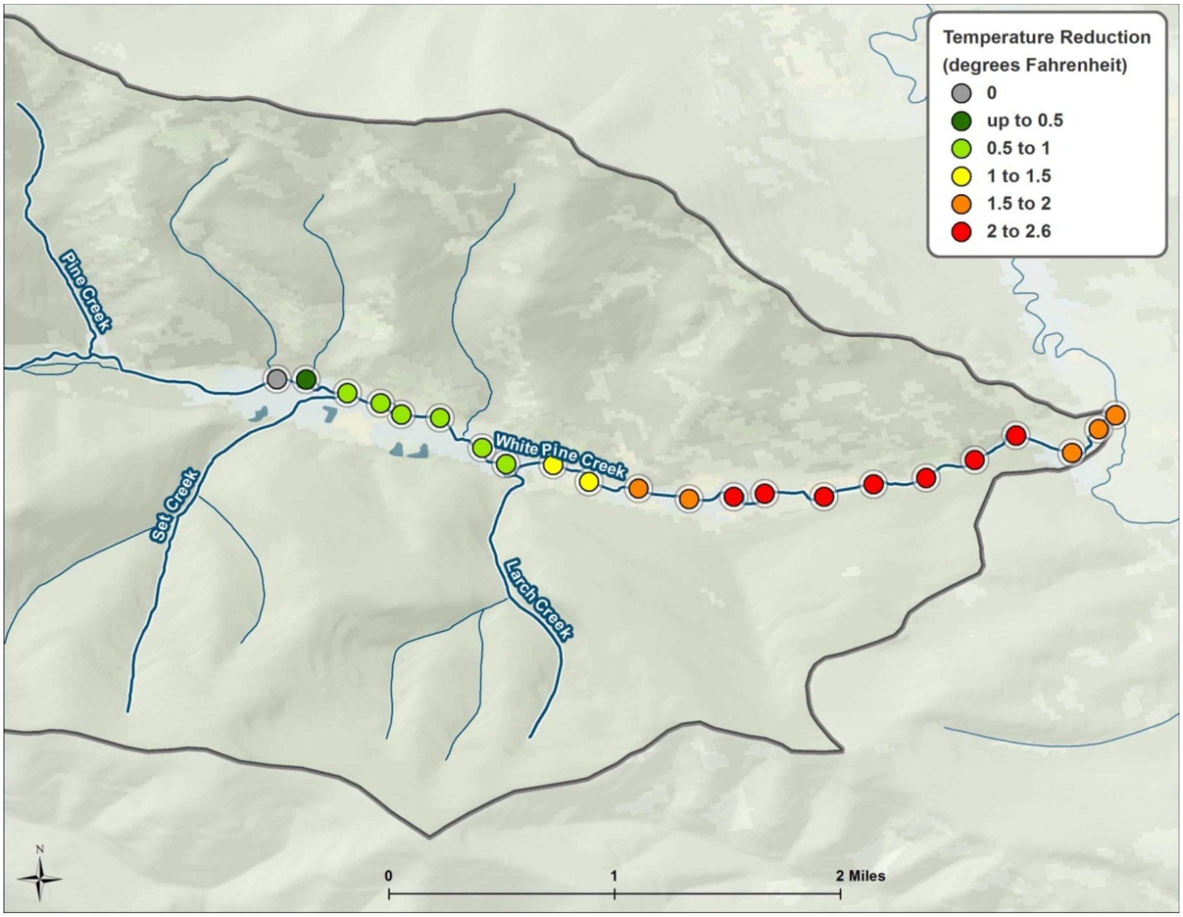


Figure B-18. Instream temperature difference from the baseline (scenario 1) to the improved flow and shade scenario (scenario 4).

B5.0 ASSUMPTIONS AND UNCERTAINTY

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

B5.1 UNCERTAINTY WITH MODEL DEVELOPMENT

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

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

- The lower portion of White Pine Creek can be divided into distinct segments, each considered homogeneous for shade, flow, and channel geometry characteristics. Monitoring sites at discrete locations were selected to be representative of segments of White Pine Creek.
- Spatial variability of velocity and depth (e.g. stream meander and hyporheic flow paths) are represented through exponents and coefficients of the selected rating curves for each segment.
- Weather conditions at the Cabinet (Trout Creek) RAWS are representative of local weather conditions along White Pine Creek.
- Shade Model results are representative of riparian shading along segments of White Pine Creek. Shade Model development relied upon the following three estimations of riparian vegetation characteristics:
    - Riparian vegetation communities were identified from visual interpretation of aerial imagery.
    - Tree height and percent overhang were estimated from other similar studies conducted outside of the White Pine Creek watershed.
    - Vegetation density was estimated using the National Land Cover Dataset (Multi-Resolution Land Characteristics Consortium 2001) and best professional judgment.
- Shade Model results were corroborated with field measured Solar PathfinderTM results and were found to be reasonable. The average absolute mean error is 6 percent. (i.e., the average error from the Shade Model output and Solar PathfinderTM measurements was 5 percent daily average shade).
- Simulated diffuse flow rates are representative of groundwater inflow/outflow, irrigation diversion, irrigation return flow, and other sources of inflow and outflow not explicitly modeled. Diffuse flow rates were estimated using flow mass balance equations for each model reach.

B5.2 UNCERTAINTY WITH SCENARIO DEVELOPMENT

The increased shade scenario (scenario 3) assumes that the shade from vegetation along the reference segment is achievable in the segments with anthropogenically diminished shade. The increased shade scenario (scenario 3) represents the feasible temperature benefit that could be achieved over a time period long enough to allow vegetation to mature (tens of years). Therefore, temperature improvements in the short term are likely to be less than those identified in the scenario 3 results. Natural events such as flood and fire may also alter the maximum potential for the riparian vegetation or shift the time needed to achieve the maximum potential. This condition may not be achievable for all areas due to the coarse scaled used to identify the current and potential shade conditions and the fact that even natural systems tend to have spatial patchiness of tree canopy cover.

B6.0 MODEL USE AND LIMITATIONS

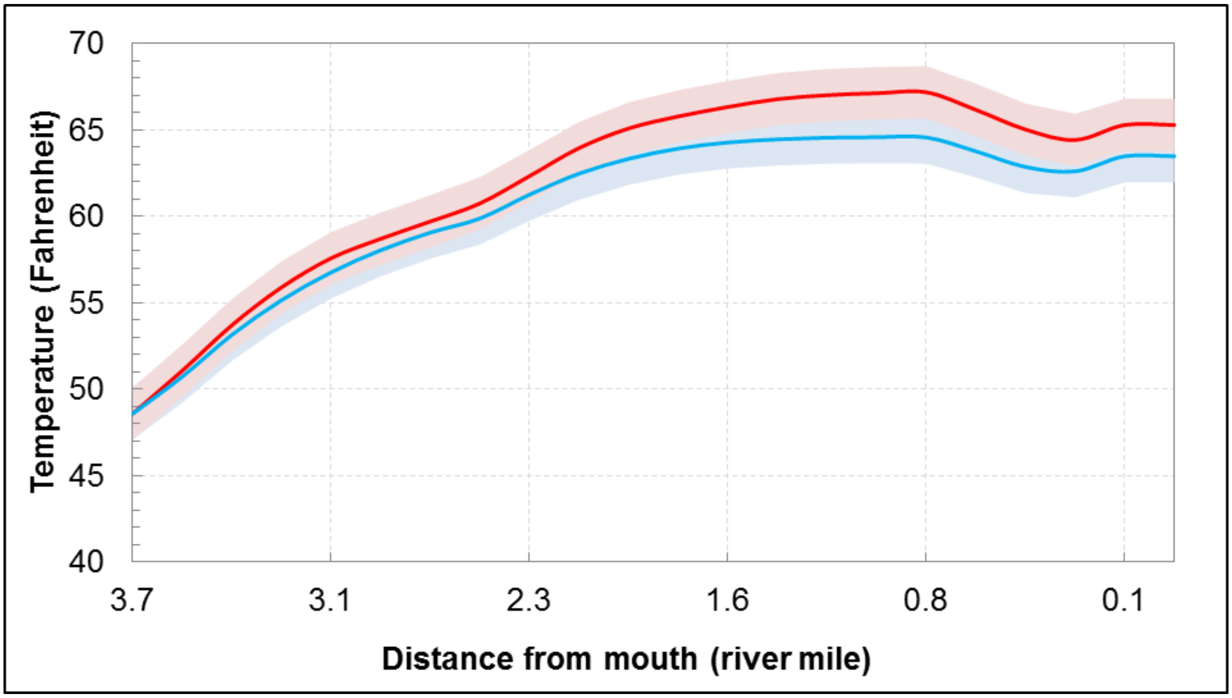
The model is only valid for summertime, warm-weather conditions and should not be used to evaluate high flow or other conditions. As described above, steps were taken to minimize uncertainty as much as possible. Despite the uncertainty, the model adequately addresses the primary questions:

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

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

The second question can be answered using the validated QUAL2K model and the scenarios developed to assess water use and shade. In this instance, increasing riparian shading will decrease instream temperatures significantly (generally between 0.6°F and 2.6°F); however, there is uncertainty in the magnitude of temperature reduction as estimates are contingent on what was considered to be reference shade. While a “good” model calibration was achieved, the overall Absolute Mean Error (AME) for the maximum daily temperature was 1.5° F.

Figure B-19 graphically summarizes the comparison between the baseline condition and improved flow and shade scenario. Based on these results, and the fact that Montana’s temperature standard as applied to White Pine Creek is limited to an increase of 1° F, it is appears that impacts are occurring to the stream. Since the scenarios are sometimes within the AME, it is difficult to draw conclusions between the improved flow and shade scenario and the baseline. Regardless, the mechanism to address elevated stream temperatures will be the mitigation of stream shade through plantings or riparian enhancement and reduction of irrigation withdrawals to allow more water to flow down the stream. Continued monitoring should be done in conjunction with these activities to ensure that they are of benefit, in particular given that model results are uncertain as described previously.



Note: The baseline (scenario 1) is the red line and the improved flow and shade scenario (scenario 4) is the blue line. The shaded areas are plus or minus the average AME (1.5° F).

Figure B-19. Simulated daily maximum water temperatures from the baseline (red; scenario 1) and improved flow and shade scenario (blue; scenario 4).

B7.0 CONCLUSIONS

The scenarios resulted in water temperatures reductions as much as 2.6° F.

A flow scenario representing irrigation efficiency was evaluated and the locations that showed the greatest potential for improvement were localized to areas just downstream of the existing withdrawals. However, the 15-percent reductions in water use did not result in appreciable reductions to the temperature in the middle segments of White Pine Creek. The largest reductions (<1° F) occurred from RMs 1.4 to 0.7.

The shade scenario showed the greatest extent and impact (reduction) to water temperatures along much of the stream. Reductions of 0.5° F occurred from RM 3.5 to the mouth and reductions of 1.0° F to 2.6° F occurred from RM 2.3 to the mouth.

The improved flow and shade scenario that combined the potential benefits associated with a 15 percent reduction in water withdrawals (scenario 2) with increased shading based upon reference levels (scenario 3) to represent application of conservation practices relative to the temperature impairment was also simulated. This scenario resulted in overall reductions along the most of the stream, which ranged from <0.1° F to 2.6° F (**Table B-11**). The scenario shows that reductions in water temperatures are achievable throughout the stream: reductions of 0.5° F are achievable from RMs 3.5 to 2.3 and reductions of 1.0° F are achievable from RM 2.3 to the mouth. Refer back to **Figure B-18** for a map of potential temperature reductions. The greatest potential improvement (i.e., reduction) occurs at RM 0.8 (2.6 ° F improvement) (**Figure B-20**). Above logger WPC-T4 (about RM 3.7), segments of White Pine Creek ran dry and were not modeled. The difference in shading due to differing vegetation scenarios is shown on **Figure B-21**. Efforts should be focused on re-vegetation in areas of lower White Pine Creek most amenable to this type of restoration activity.

Table B-11. Instream temperature difference from the baseline scenario

Scenario ID	Scenario name	Daily maximum			Daily average		
		Range of change[a]	Average change[b]	Median change[c]	Range of change[a]	Average change[b]	Median change[c]
2	Water Use	<-0.1 to <+0.1	<-0.1	0	<-0.1 to 0	<-0.1	0
3	Shade	-0.3 to -2.6	-1.6	-1.8	-0.2 to -1.5	-0.9	-1.1
4	Improved Flow and Shade	-0.3 to -2.6	-1.6	-1.8	-0.2 to -1.6	-0.9	-1.1

Notes

Results are reported in degrees Fahrenheit. Negative values represent scenario results that were cooler than the Baseline scenario while positive values represent scenario results that were warmer than the baseline scenario.

[a] The range of temperature changes along White Pine Creek as compared with the baseline scenario.

[b] The distance-weighted average temperature change along White Pine Creek as compared with the baseline scenario.

[c] The distance-weighted median temperature change along White Pine Creek as compared with the baseline scenario.

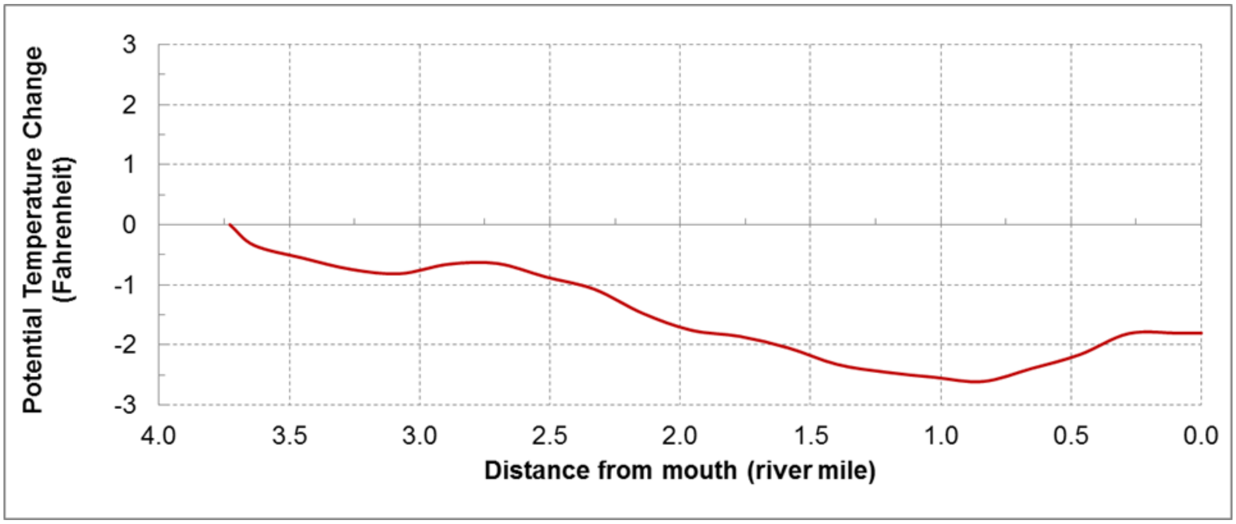


Figure B-20. Simulated water temperature reduction from the baseline (scenario 1) to the improved flow and shade scenario (scenario 4).

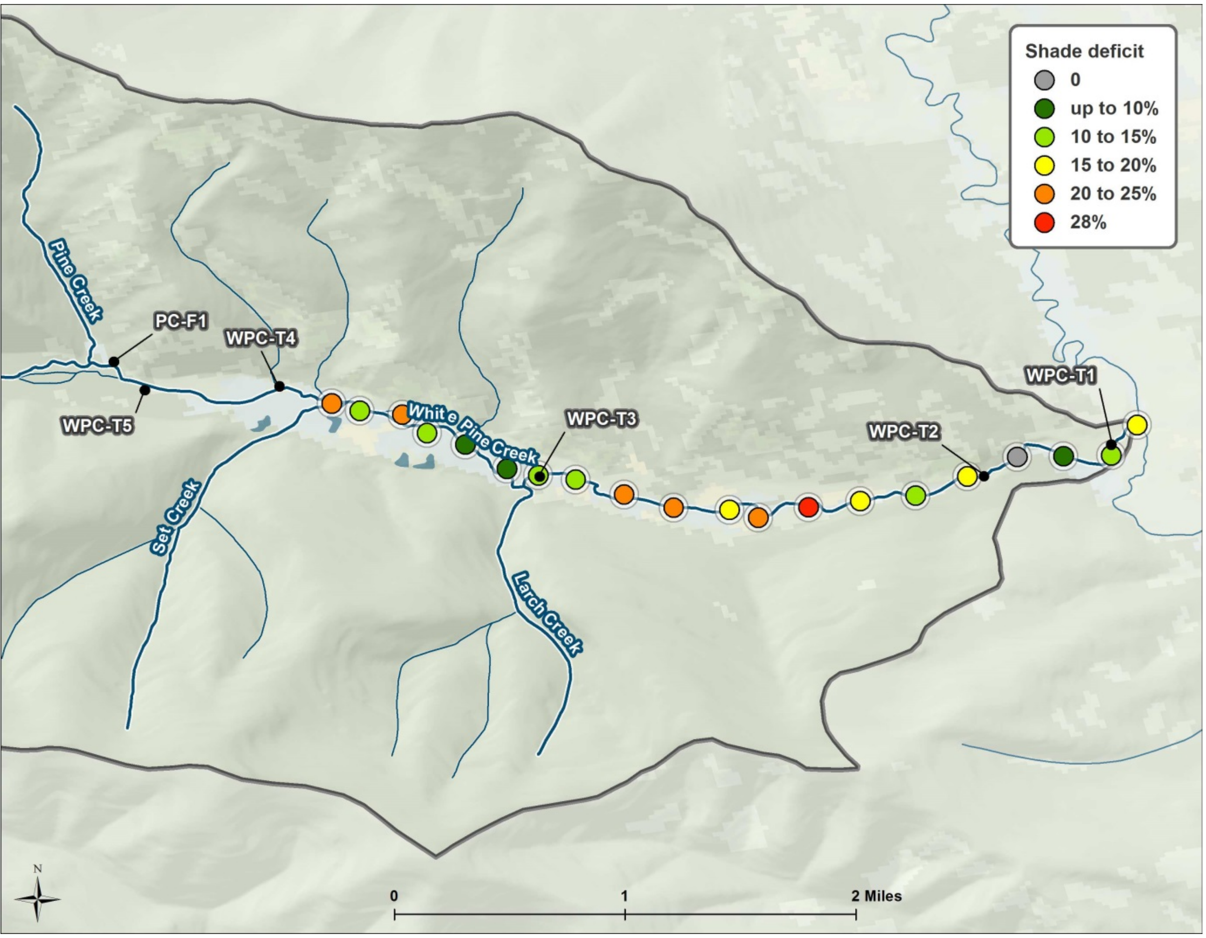


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Figure B-21. Shade deficit of the baseline (scenario 1) from the improved flow and shade scenario (scenario 4).

ATTACHMENT B1 – FACTORS POTENTIALLY INFLUENCING STREAM TEMPERATURE IN WHITE PINE CREEK

B1-1.0 INTRODUCTION

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

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

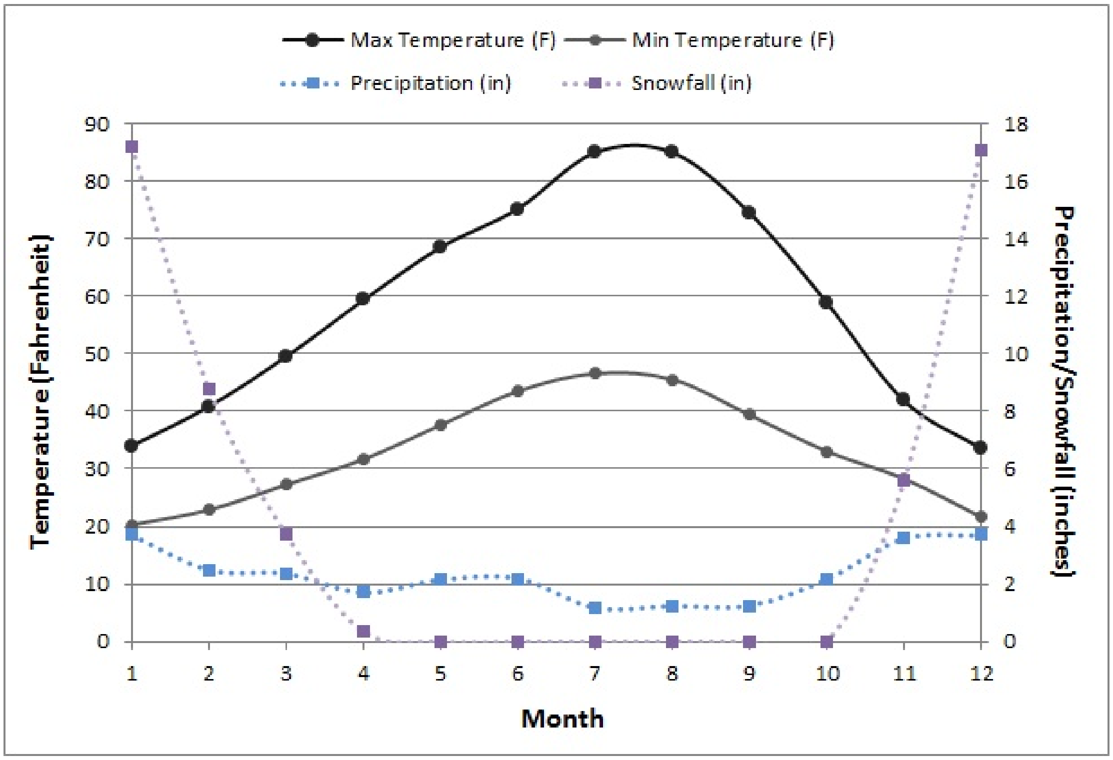
- Local/regional climate
- Land ownership
- Land use
- Riparian vegetation
- Shade
- Hydrology
- Point sources

B1-2.0 CLIMATE

The nearest weather station to the White Pine Creek watershed (**Figure B1-1**) is at the Ranger Station in the city of Trout Creek, Montana (National Weather Service station 24830). Average annual precipitation is 27.7 inches with the greatest amounts falling in December and January (**Figure B1-2**, National Climate Data Center, 2012). Average maximum temperatures occur in July and August and are both 84.9 ºF.

It should be noted that the Trout Creek weather station is at an elevation of 2,356 feet above MSL, compared to White Pine Creek that ranges in elevation from approximately 2,500 to 6,500 feet above MSL.

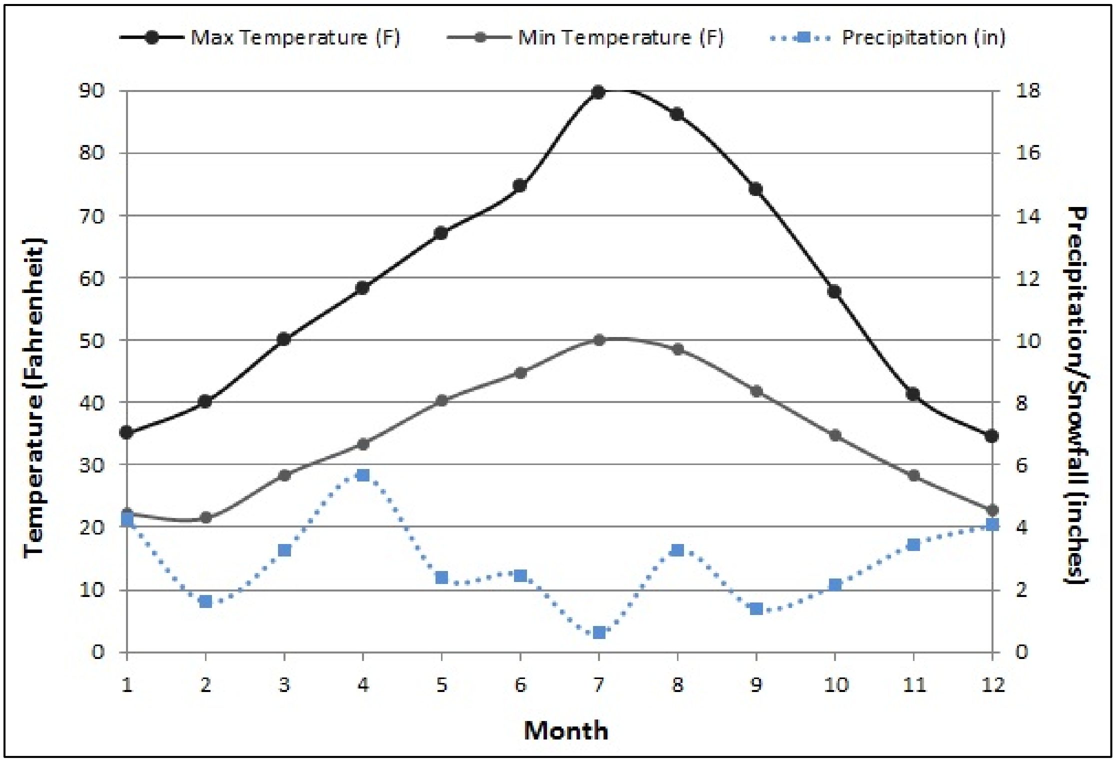
Figure B1-1. White Pine Creek watershed.



Source: Summary of GHCN Daily Summaries from 1970 to 2012 at station 24830 (National Climate Data Center, 2013).

Figure B1-2. Monthly average temperatures and precipitation at Trout Creek Ranger Station, Montana

As briefly discussed in the main report, the Trout Creek Ranger Station only has hourly air temperature data and does not have additional hourly datasets necessary for QUAL2K modeling. The Cabinet (Trout Creek) RAWS (National Weather Service station 241210) records hourly air temperature, dew point temperature, wind speed and solar radiation and these data were used to develop the QUAL2K model. RAWS data are summarized in **Figure B1-3**.

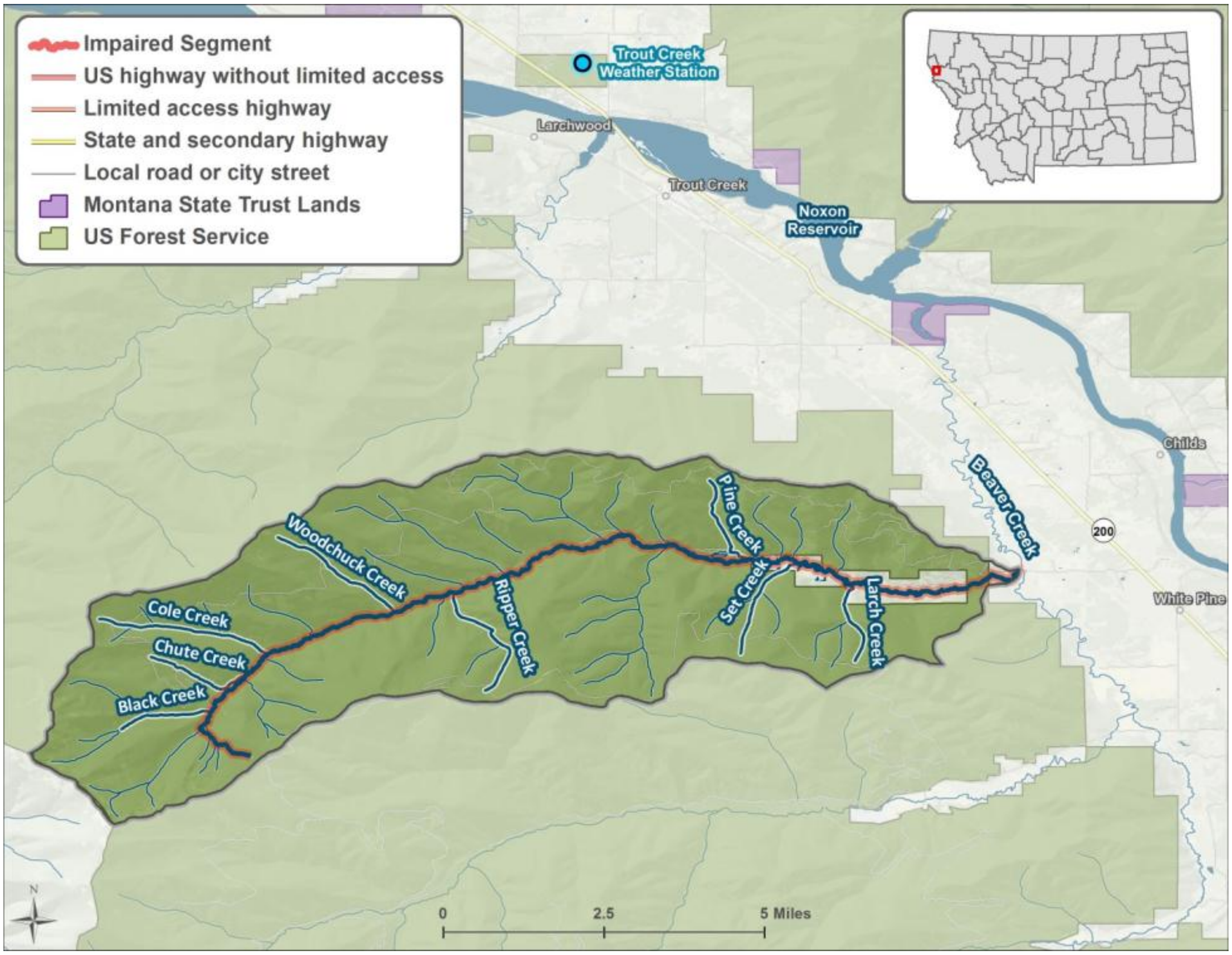


Source: RAWS weather data from 2001 to 2013 at Cabinet (Trout Creek) station (Western Regional Climate Center, 2013).

Figure B1-3. Monthly average temperatures and precipitation at Cabinet (Trout Creek) RAWS.

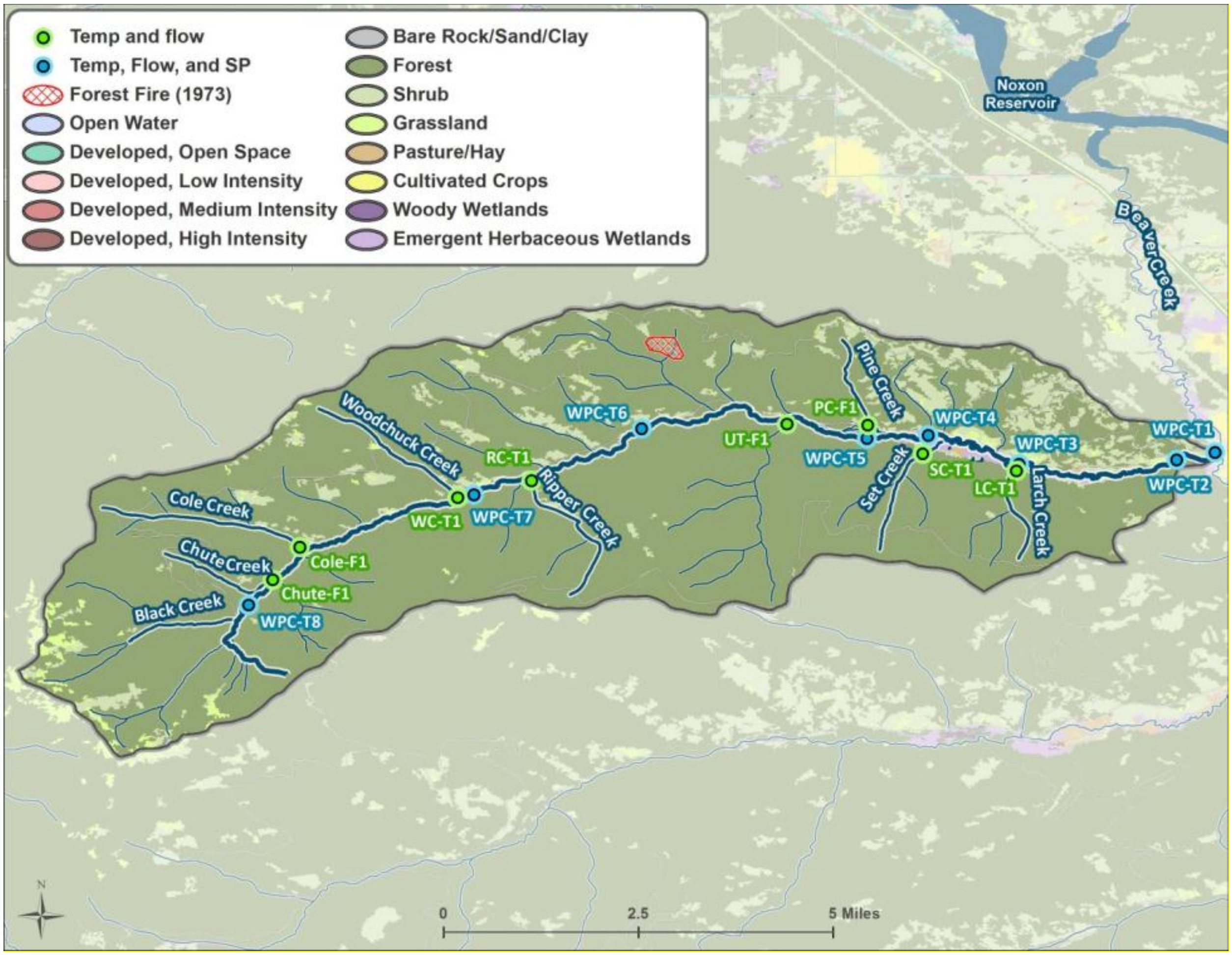
B1-3.0 LAND OWNERSHIP AND LAND USE

The majority of the White Pine Creek watershed is owned by the U.S. Forest Service (97 percent) and is predominantly forested (**Figure B1-4** and **Figure B1-5**). One fire, covering 38 acres (0.2 percent of the watershed) has occurred in recent history (1973) within the watershed (U.S. Department of Agriculture, Forest Service, 2008) (**Figure B1-5**). Several small ranches and residences are within the small section of privately owned land surrounding the riparian zone in the lower reaches of the watershed.



Source of land ownership: NRIS 2012.

Figure B1-4. Land ownership in the White Pine Creek watershed.



Source of land cover: 2006 National Land Cover Dataset (Multi-Resolution Land Characteristics Consortium, 2006).
Figure B1-5. Land cover and land use in the White Pine Creek watershed.

B1-4.0 EXISTING RIPARIAN VEGETATION

A comprehensive inventory and assessment of the current riparian vegetation communities adjacent to White Pine Creek was not conducted as part of this project. Riparian vegetation communities, however, were qualitatively assessed, and the height and density of the dominant vegetation were measured at the five shade monitoring sites in August 2013. A summary of the observed characteristics of the vegetation communities is provided in **Table B1-1**.

The impaired reach of White Pine Creek is 12.37 miles in length. The upper nine miles flow through the Kootenai National Forest. Although an unimproved road parallels the stream for much of this length, the riparian corridor appears to be largely intact, dominated by dense conifers, and at potential. A review of historic aerial photographs conducted by Watershed Consulting, Inc. (2002), indicate that the riparian zone in this upper reach has recovered from a fire in 1910 and a substantial flood in 1916. It appears that the channel has narrowed and the riparian vegetation increased in density since the 1940s (Water Consulting, Inc., 2002). This portion of White Pine Creek is represented by sites WPC-T6, WPC-T7, and WPC - T8.

Downstream, White Pine Creek flows out of the Kootenai National Forest and onto private property for the remainder of its length. The lower reach flows through a complex floodplain with a broad riparian zone composed of low-density residential and agricultural land uses. With the exception of one reach (dominated by conifer forest) where the valley narrows as White Pine Creek flows through a small parcel of U.S. Forest Service land (WPC-T2), vegetation in the lower reach is typified by alder-grass monoculture with varying degrees of disturbance. The greatest disturbance was observed at site WPC-T1. The riparian zone in the vicinity of WPC-T1 is currently grazed.

Based on review of aerial photography (GoogleEarth^{TM} 2013) and site reconnaissance, it appears that site WPC-T3 may represent a vegetation community that has recovered from past grazing practices. Evaluation of historic aerial photography (Water Consulting, Inc., 2002) suggests that, over the years, lower White Pine Creek was subjected to alterations of the riparian corridor due to anthropogenic activities. The following anthropogenic activities may have influenced the riparian vegetation community: floodplain filling, bridge and road construction, timber harvest, grazing, vegetation removal, and bank armoring. They also suggest that cottonwood and willow recruitment has been limited by past and current anthropogenic activities in the lower watershed.

Table B1-1. Observed characteristics of the White Pine Creek riparian vegetation community

Station ID	Site Name	Dominant Vegetation	Vegetation at potential?	Average Vegetative Density[a]	Dominant Vegetation Height (feet)[a]	Dominant Vegetation Overhang (feet)[a]	Description
WPC-T1	White Pine Cr near mouth	Shrub	N	25	20	4	Grazed alder community. Mosaic of alders (25 - 50% cover) and meadow.
WPC-T2	White Pine Cr near USFS boundary	Tree	Y	82	48	8	Conifer forest set back approximately 25 feet from the bank. Sparse shrub (alder) cover and grass along bank.
WPC-T3	White Pine Cr at Larch Creek Lane	Shrub	N	78	19	--	Monotypical alder swamp. In close proximity to driveway (openings) and meadows on private property. Appears to possibly be recovered grazing land.
WPC-T4	White Pine Cr near Set Cr	Shrub	N	78	15	12	Monotypical alder swamp.
WPC-T5	White Pine Cr near Pine Cr	Dry channel. No observations recorded.					
WPC-T6	White Pine Cr	Dry channel. No observations recorded.					
WPC-T7	White Pine Cr near Woodchuck Cr	Dry channel. No observations recorded.					
WPC-T8	White Pine Cr near headwaters	Tree (conifer dominated)	Y	86	70	12	Dense conifer forest with shrub understory.

Note: a. Average of field measurements.

Vegetation communities between the shade monitoring sites were visually characterized based on aerial imagery (GoogleEarth™ 2012). Observed vegetative communities within 150 feet of the stream centerline were classified as trees, shrubs, or herbaceous. Areas without vegetation, such as bare earth or roads, were also identified. Trees were further divided into the following classes based on percent canopy cover derived from the 2001 NLCD (**Figure B1-6**):

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

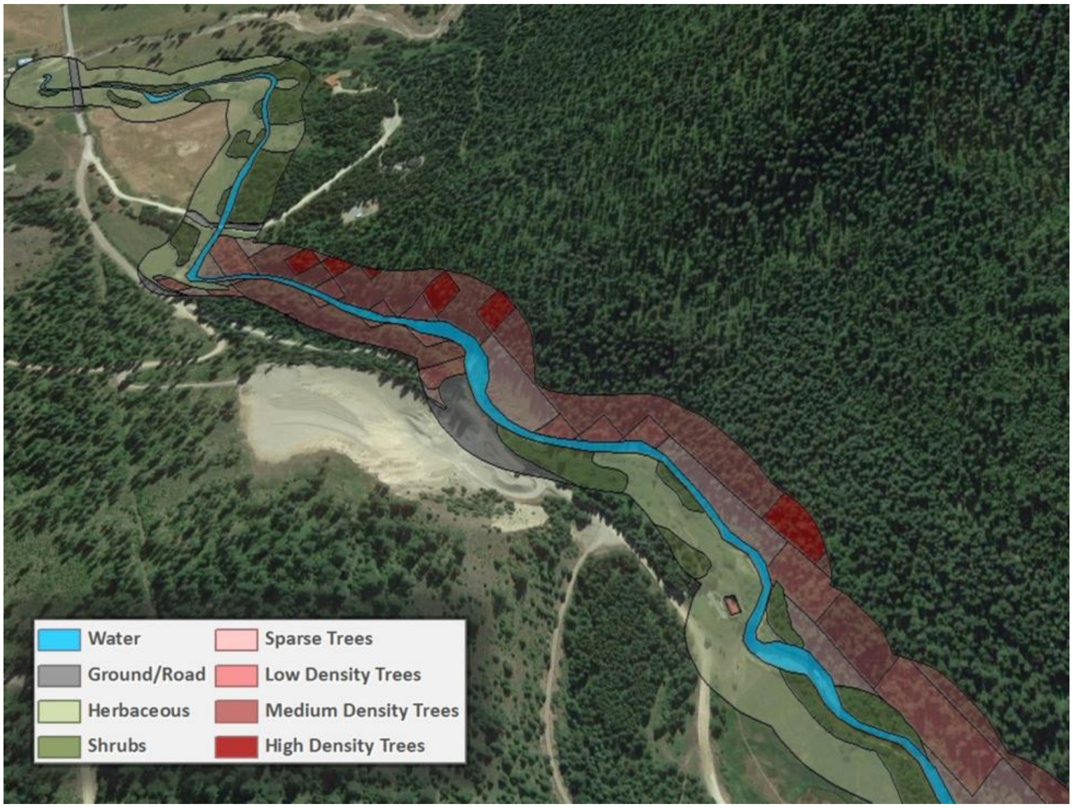


Figure B1-6. Vegetation mapping example for White Pine Creek.

High Density Trees (32 percent), Medium Density Trees, (18 percent), Shrubs (15 percent), and Herbaceous (14 percent) are the most common cover types along White Pine Creek (**Table B1-2**). All tree classes combine to account for 66 percent of the total watershed area.

Table B1-2. Land cover types in the White Pine Creek riparian zone

Land cover type	Area (acres)	Relative area (percent)
Bare ground	7.1	1.6%
Herbaceous	62.7	13.9%
Roads	17.8	3.9%
Shrub	66.7	14.7%
Sparse trees	31.4	6.9%
Low density trees	40.9	9.0%
Medium density trees	81.2	17.9%
High density trees	144.6	31.9%

B1-5.0 SHADE

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

B1-5.1 MEASURED SHADE

EPA and DEQ collected shade characterization data on August 13 and 14, 2013 at five monitoring locations along White Pine Creek using a Solar Pathfinder™ (**Figure B1-7**). Hourly shade estimates based on the Solar Pathfinder™ measurements are summarized in **Table B1-3**.

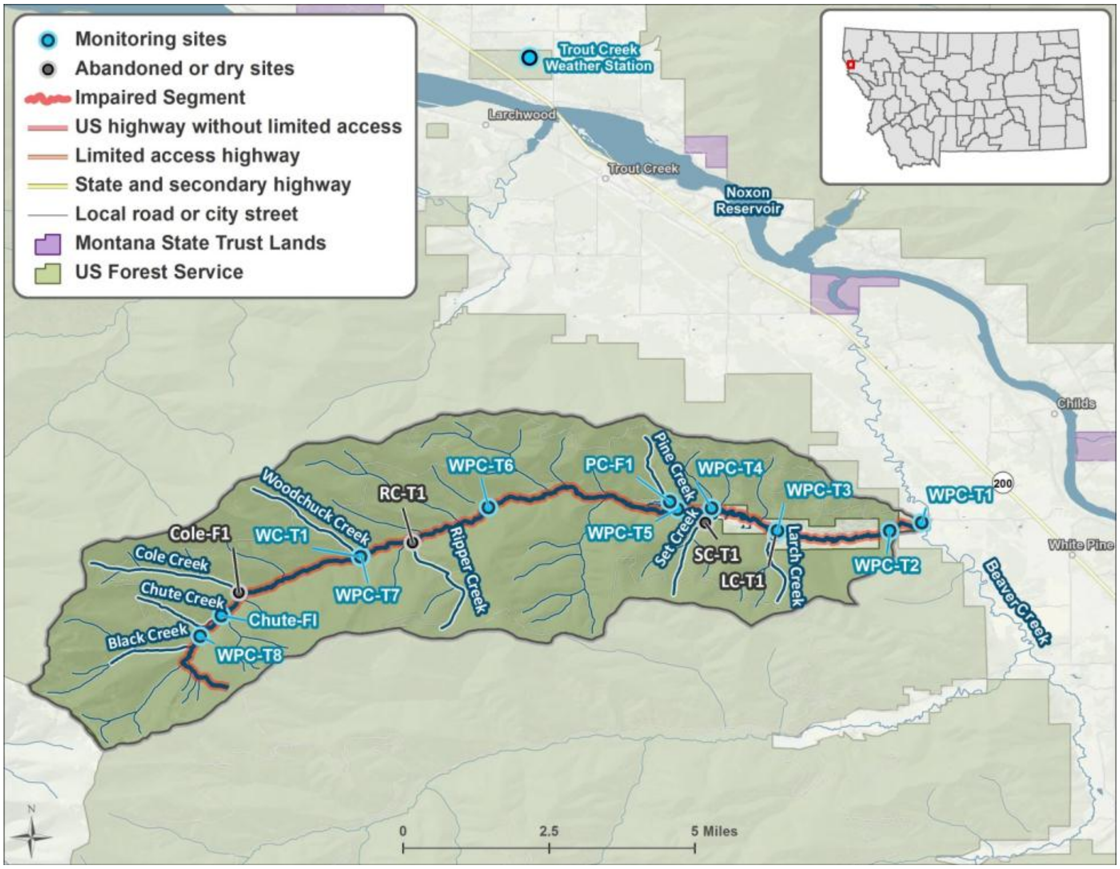


Figure B1-7. EPA flow, shade, and continuous temperature monitoring locations.

Table B1-3. Average shade per reach from Solar Pathfinder™ measurements

Site ID	Average daily shade (averaged across daylight hours)
WPC-T1	30.0
WPC-T2	67.8
WPC-T3	27.1
WPC-T4	30.3
WPC-T8	90.4

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

B1-5.2 SHADE MODELING

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

B1-5.2.1 Available Data

The application of the Shade Model to White Pine Creek relied upon the vegetation data and analysis described in Section A-4, aerial imagery from GoogleEarth^{TM} (GoogleEarth, 2013), tree canopy density information (Multi-Resolution Land Characteristics Consortium, 2006), and a digital elevation model (U.S. Geological Survey, 2014).

B1-5.2.2 GIS Pre-Processing

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

Wetted width was estimated by digitizing both the right and left banks from aerial imagery in GoogleEarth^{TM}. TTools then calculates wetted width based on the distance between the stream centerline and the left and right banks. Topographic shade was calculated using TTools with the stream centerline file and a DEM.

B1-5.2.3 Riparian Input

The Shade Model requires the description of riparian vegetation: a unique vegetation code, height, density, and overhang (OH). The results in the field study report and the above described vegetation mapping were used to develop a riparian description table (**Table B1-4**). Vegetation descriptions used the average value for tree/shrub height and overhang from field observation.

Table B1-4. Vegetation input values for the Shade Model

Attribute	Value	Basis
Trees		
Height	18 meters (59 feet)	Average of measured values
Density	Variable	2006 NLCD
Overhang	1.8 meters (5.9 feet)	Estimated as 10% of height (Stuart, 2012).
Shrubs		
Height	5.5 meters (18 feet)	Average of measured values
Density	77%	Average of measured values
Overhang	1.4 meter (4.5 feet)	Estimated as 25% of height (Shumar and de Varona, 2009)
Herbaceous		
Height	1 meter (3.3 feet)	Estimated.
Density	100%	
Overhang	0 meters	

B1-5.2.4 Shade Input

The Shade Model inputs are riparian zones, reach length, channel incision, elevation, aspect, wetted width, near-stream disturbance zone width, distance from the bank to the center of the stream, and topographic shade. Input for the riparian zone is presented above in Error! Reference source not found.. The Shade Model requires reach lengths be an equal interval. The reaches in the field study report were not at an equal interval and were very widely spaced. A uniform reach length interval of 30 meters (98 feet) was used. Channel incision was estimated from an examination of field photos. Incision is the vertical drop from the bankfull edge to the water surface, and was estimated at 0.3 meter (1 foot). The remaining variables were computed as part of the GIS pre-processing described above.

B1-5.3 SHADE MODEL RESULTS

The current longitudinal effective shade profile generated from the Shade Model and the Solar Pathfinder^{TM} measurements are presented in **Figure B1-8**.

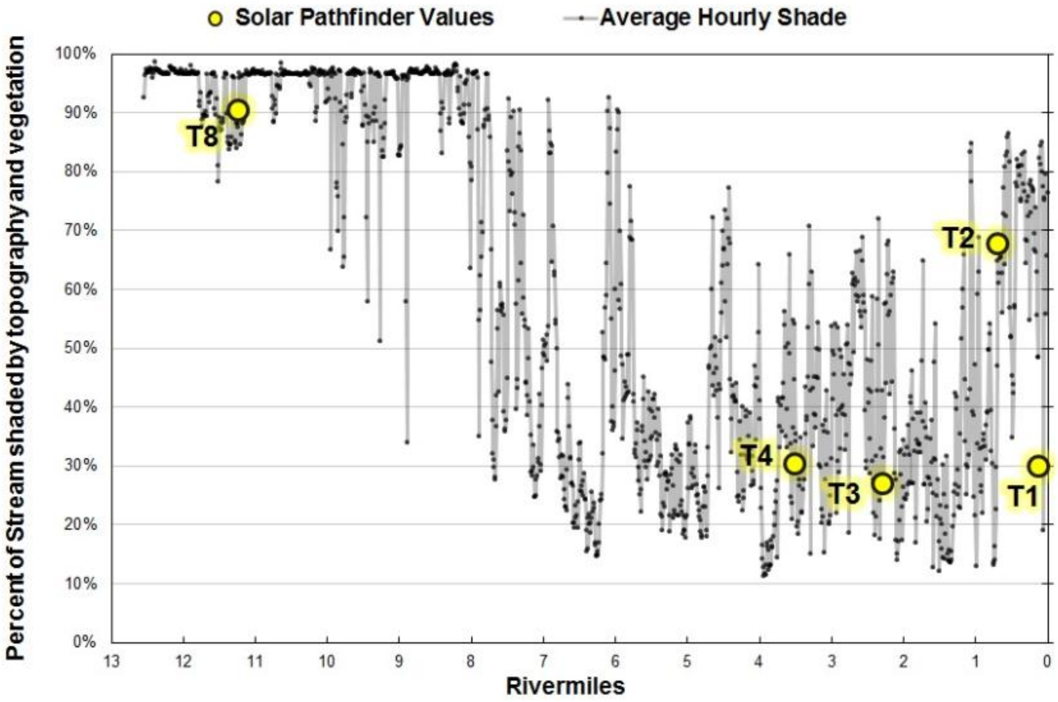


Figure B1-8. Longitudinal estimates of observed and simulated effective shade along White Pine Creek.

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

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

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

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

where

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

Model error statistics are provided in **Table B1-5** and suggest a good fit between observed and predicted average effective shade values. The average absolute mean error is 6 percent. (i.e., the average error from the Shade Model output and Solar Pathfinder^{TM} measurements was 6 percent daily average shade; see **Table B1-5**).

Table B1-5. Shade model error statistics

Error Statistic	Formula	Result	Units
Mean Error (ME)	$(1/N)*\Sigma(P_n-O_n)$	4%	percent of percent shade
Average Absolute Mean Error (AME)	$(1/N)*\Sigma\vert(P_n-O_n)\vert$	6%	percent shade
Root Mean Square Error (RMSE)	$[(1/N)*\Sigma(P_n-O_n)^2]^{1/2}$	9%	percent of percent shade

B1-6.0 STREAM TEMPERATURES

In 2013, EPA and DEQ collected continuous temperature data at seven locations in White Pine Creek (sites WPC-T1, WPC-T2, WPC-T3, WPC-T4, WPC-T6, WPC-T7, WPC-T8) and at one tributary (Chute Creek, Chute-F1)[11]. One location on White Pine Creek (WPC-T5) was observed to be dry and no temperature logger was deployed. Data loggers recorded temperatures every one-half hour for approximately two months between June 25 and September 10, 2013. Instantaneous temperatures were also monitored by EPA and DEQ in June, August, and September 2013 on White Pine Creek (**Table B1-6**) and three of its tributaries: Chute-F1 on Chute Creek, PC-F1 on Pine Creek, and WC-T1 on Woodchuck Creek (**Table B1-7**). Four locations on tributaries to White Pine Creek were observed to be dry and no instantaneous data were collected: Cole-F1 on Cole Creek, LC-T1 on Larch Creek, RC-T1 on Ripper Creek, and SC-T1 on Set Creek. Finally, DEQ sampled White Pine Creek in 2004 (**Table B1-8**).

Table B1-6. EPA instantaneous water temperature measurements (°F) from White Pine Creek, summer 2013

Date	WPC-T1	WPC-T2	WPC-T3	WPC-T4	WPC-T6	WPC-T7	WPC-T8
June 25, 2013	49.05	47.35	46.65	44.56	48.00	44.58	43.95
August 13-14, 2013 [a]	--	--	--	--	Dry	Dry	--
September 10, 2013	63.81	63.84	59.31	49.46	Dry	Dry	50.43

Note: a. Temperature data rejected due to quality control issues with the temperature probe calibration.

Table B1-7. EPA instantaneous water temperature measurements (°F) from tributaries to White Pine Creek, summer 2013

Date	Chute-F1 (Chute Creek)	WC-T1 (Woodchuck Creek)	PC-F1 (Pine Creek)
June 25, 2013	44.17	42.71	45.99
August 13-14, 2013 [a]	--	Dry	Dry
September 10, 2013	50.38	Dry	Dry

Note: a. Temperature data rejected due to quality control issues with the temperature probe calibration.

Table B1-8. DEQ instantaneous water temperature measurements (°F) in support of other studies

Date	C13WPINC10	C13WPINC30
September 22, 2004	44.7	47.5

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

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[11] Loggers WPC-T6 and WPC-T7 were observed in dry channels on August 13-14, 2013 and were removed from White Pine Creek at that time.

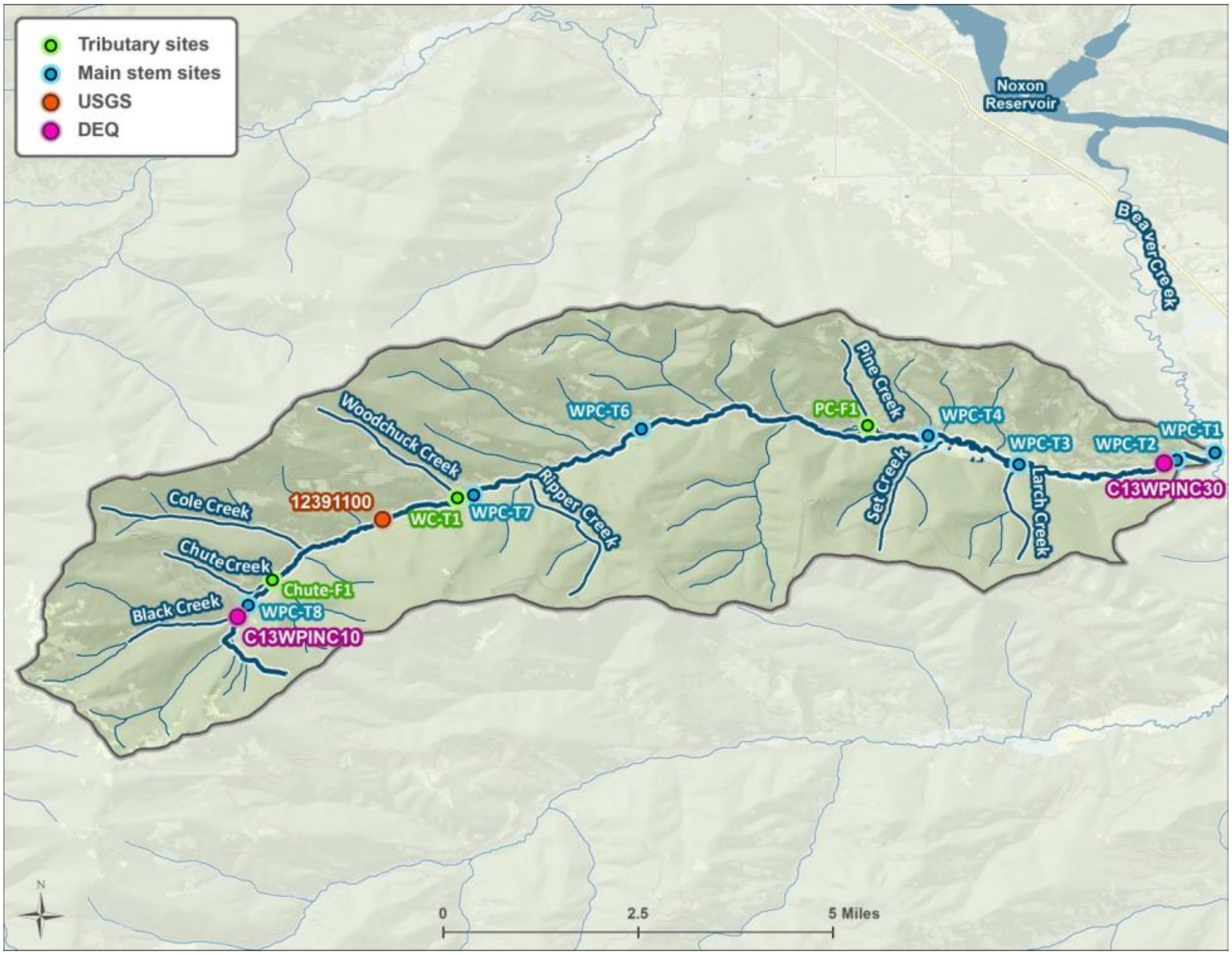


Figure B1-9. Temperature and flow monitoring locations in the White Pine Creek watershed.

B1-7.0 HYDROLOGY

No active U.S. Geological Survey (USGS) continuously recording gages are located on White Pine Creek. EPA collected instantaneous flow measurements in 2013, during temperature data logger deployment and retrieval, as well as during mid-season site visit (**Table B1-9** and **Table B1-10**). DEQ and USGS also monitored flow in support of other studies (**Table B1-11** and **Table B1-12**). Locations of the flow measurements are shown in **Figure B1-9**.

Table B1-9. EPA instantaneous flow measurements (cfs) from White Pine Creek, summer 2013

Date	WPC-T1	WPC-T2	WPC-T3	WPC-T4	WPC-T6	WPC-T7	WPC-T8
June 25, 2013	59.10	44.21	39.26	31.85	3.19	16.79	25.35
August 13-14, 2013	11.10	9.03	10.60	6.55	Dry	Dry	1.51
September 10, 2013	5.04	6.02	6.08	22.71	Dry	Dry	0.72

Table B1-10. EPA instantaneous flow measurements (cfs) from tributaries to White Pine Creek, summer 2013

Date	Chute-F1 (Chute Creek)	WC-T1 (Woodchuck Creek)	PC-F1 (Pine Creek)
June 25, 2013	1.48	2.16	1.83
August 13-14, 2013	0.24	Dry	Dry
September 10, 2013	0.06	Dry	Dry

Table B1-11. DEQ instantaneous flow measurements (cfs) in support of other studies

Date	C13WPINC10	C13WPINC30
September 22, 2004	8.06	2.13

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

Table B1-12. USGS instantaneous flow measurements (cfs) in support of other studies

Date	12391100
June 14, 1975	161.0
December 4, 1975	51.0
April 26, 1977	23.4
June 7, 1978	20.2
May 6, 1979	3.2
April 24, 1980	1.4
December 26, 1980	116.0
May 18, 1982	21.1
May 26, 1983	15.9
May 21, 1984	3.0

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

Based on field observations, flow in White Pine Creek was intermittent upstream from the confluence with Set Creek during the summer of 2013. Two dry reaches were observed on August 13 and 14, 2013 (**Figure B1-10**).

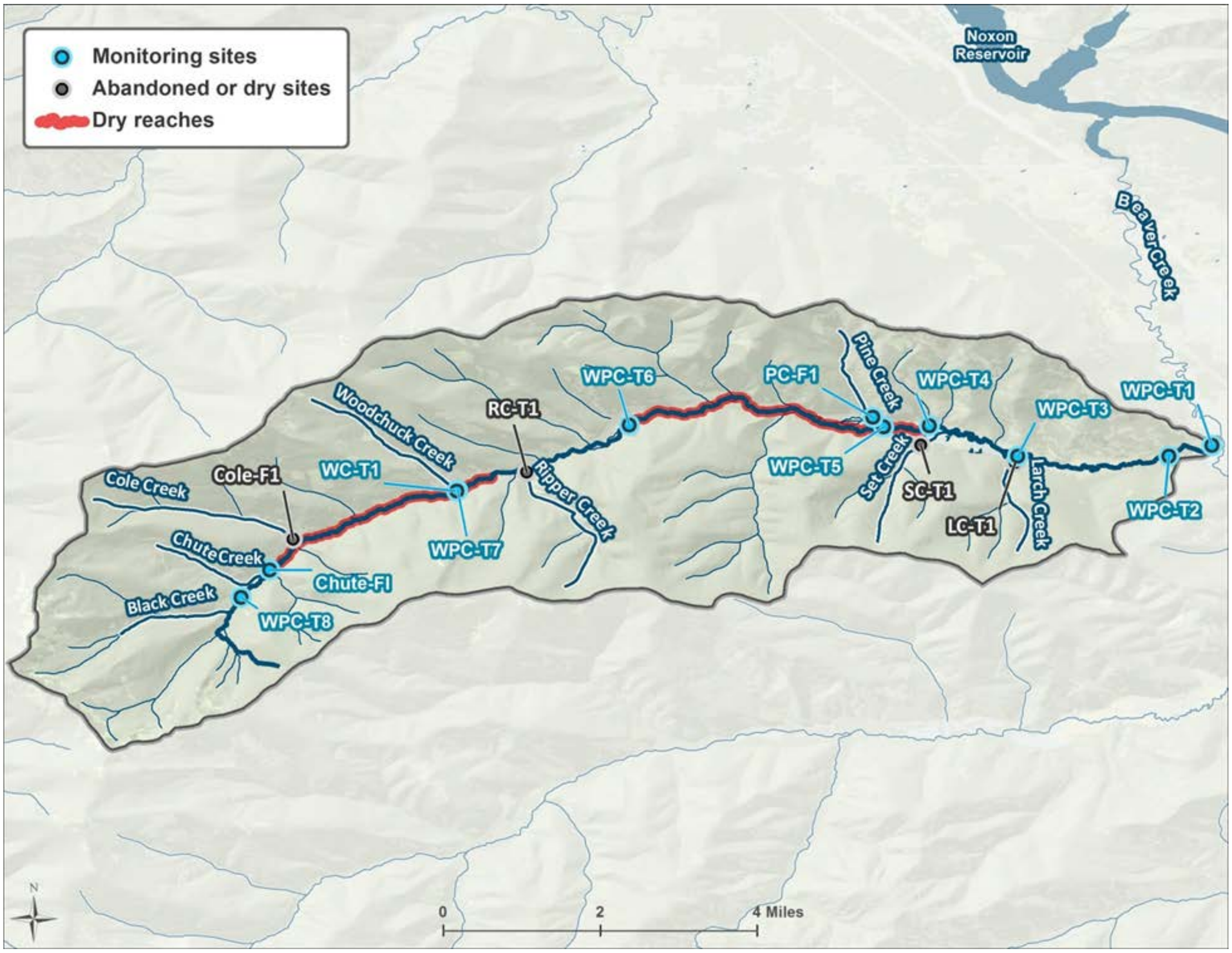
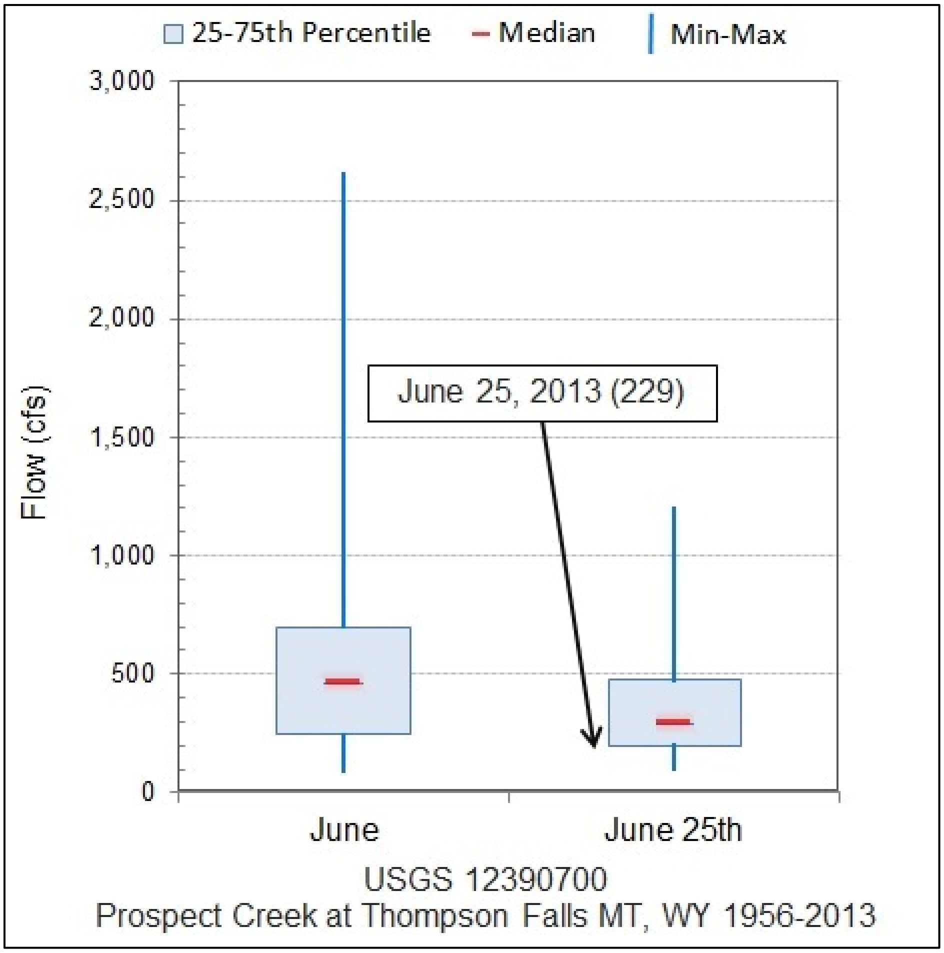


Figure B1-10. Dry reaches of White Pine Creek observed August 13 and 14, 2013.

Continuous flow data monitored on Prospect Creek at USGS gage 12390700 were evaluated with instantaneous discharge data from White Pine Creek to assess the hydrologic conditions of White Pine Creek during the summer of 2013. USGS gage 12390700 was used as a surrogate to represent regional hydrologic conditions. Statistics were calculated for the average daily flows (per year) for the month of June and for June 25th from water years 1956 through 2013 at the gage (**FigureB1-11**).

The flow at gage 12390700 on June 25, 2013 (the calibration date for the QUAL2K model) was 229 cfs, which is near the 25th percentile of flows on June 25th across the period of record.

A similar analysis was performed for August 14, 2013 (the date for the baseline scenario in QUAL2K) and the month of August. The flow at gage 12390700 on August 14, 2013 was 80 cfs, which is the 38th percentile of flows on August 14th across the period of record. The average flow in August of 2013 was 77 cfs, which is the 34th percentile of flows for August across the period of record.

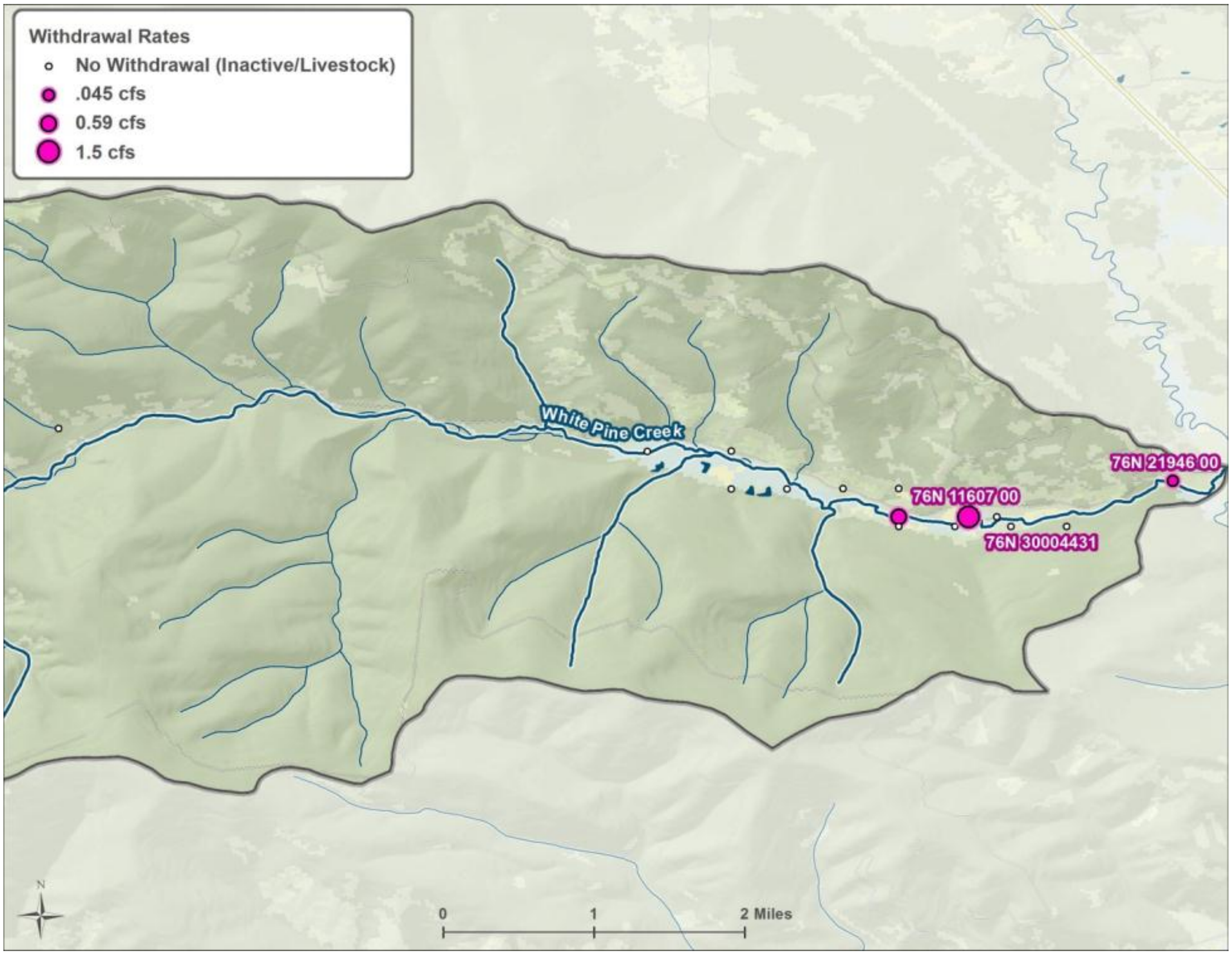


Note: “June” represents the daily average flow for the month of June per year (i.e., the average of 30 daily average flows)

Figure B1-11. Average daily flows for the month of June and for June 25th for the full period of record at USGS gage 12390700 (Prospect Creek), compared to flows on June 25, 2013.

B1-8.0 FLOW MODIFICATION

Based on review of aerial photographs and online water rights data (ftp://nris.mt.gov/dnrc), there are 15 surface diversion permits from White Pine Creek that support a variety of uses. “Points of diversion” and “places of use” spatial data were obtained from the Montana Natural Resource Information System (Natural Resource Information System, 2012). Three of the permitted locations are actively withdrawing water (**Figure B1-12** and **Table B1-13**). It is estimated that up to 2.79 cfs may be withdrawn from White Pine Creek on a daily basis during the month of July (**Table B1-13**).



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

Figure B1-12. Surface diversions along White Pine Creek

Table B1-13. Summary of diversions from White Pine Creek

WRNUMBER	Purpose	Irrigation type	Means of withdrawal	Max area (acres)	Max flow rate (cfs)	Volume (acre-ft/yr)	Est. daily volume applied[a] (cf)	Est. daily flow rate[b] (cfs)
76N 11607 00	Irrigation	F	H	50	1.9	125	49,724	0.59
76N 11608 00	Stock[d]	--	L	--	--	--	--	--
76N 11609 00	Domestic[c]	--	P	--	--	--	--	--
76N 21946 00	Domestic	--	P	--	0.045	1.5	--	0.045
76N 30004431	Fishery	--	H	--	1.5	504	--	1.5
76N 52209 00	Stock[d]	--	D	--	--	--	--	--
Total Withdrawal								***2.79***

Source: NRIS 2012

Notes

F = flood; H = headgate; P = pump; D = Dam; L = livestock direct from source.

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

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

[c] Water right withdrawn.

[d] Livestock direct from source uses were not considered in this analysis.

B1-9.0 POINT SOURCES

There are no permitted discharges in the White Pine Creek watershed. One abandoned mine, Golden Roc Mine, is present in the White Pine Creek watershed, located near Woodchuck Creek. In the past it was a gold, silver, lead, and copper producer. The mine is not expected to have an influence on stream temperature and is not considered further.

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