Paradise Creek Natural Background Temperature

Modeling Stream Temperature under System Potential Shade

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October 2015

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    - Analyzed existing and system potential shade
    - Provided the calculation method for new effluent limits
    - Reviewed the model results
    - Provided valuable input throughout the project
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Executive Summary

Paradise Creek in the Palouse River subbasin (hydrologic unit code 17060108) of northern Idaho flows from its headwaters on Moscow Mountain, through the city of Moscow and across the Washington state border to its confluence with South Fork Palouse River near Pullman, Washington. As an interstate water, Paradise Creek must meet Washington's water quality standards at the state line. Under the 2011 Washington Administrative Code (WAC) 173-201A-200, Paradise Creek is designated as having an aquatic life use of "salmonid spawning, rearing, and migration", with a temperature criterion of 17.5°C. This temperature criterion is interpreted as the highest annual running 7-day average of daily maximum temperatures (7DADMax). If natural conditions exceed the criterion, there is a 0.3 °C allowance (WAC 173-201A-200(1)(c)(i)).

In Idaho, Paradise Creek is designated for cold water aquatic life and secondary contact recreation (IDAPA 58.01.02.120.01). Idaho's water quality standards dictate stream temperature criteria to protect the cold water aquatic life beneficial use at 22 ºC maximum and 19 ºC average (IDAPA 58.01.02.250.02.b).

The Moscow Wastewater Treatment Plant (MWWTP) outfall received temperature wasteload allocations in the Paradise Creek total maximum daily load (DEQ 1997). The wasteload allocation was equal to the instream temperature criterion of 18 °C, which was the Washington state standard at that time. The MWWTP also received temperature effluent limits under the US Environmental Protection Agency's National Pollutant Discharge Elimination System permit number ID0021491 to meet the 18 °C temperature criterion:

> . . .by either requiring the temperature of the effluent discharged to the stream to be at or below 18°C, or if the ambient temperature of the stream is less than 18°C by determining the effluent flow volume that can be discharged to the stream without causing an exceedance of the criterion.

This study uses modeling to identify the temperatures in Paradise Creek upstream of MWWTP that would occur under system potential shade for the entire stream. New temperature wasteload allocations and effluent limits will be based on a 0.3 °C increase above natural background temperatures, according to provisions in Washington (WAC 173-201A-200(1)(c)(i)) and Idaho (IDAPA 58.01.02.401.01.c).

The Idaho Department of Environmental Quality (DEQ) develops temperature load allocations by determining system potential shade (i.e., expected shade under natural conditions). However, using shade as a surrogate measure does not identify the stream temperatures under system potential shade. Shade is only one component affecting the heat load to the stream. A model that simulates all of the heat exchange processes will identify stream temperature under system potential shade.

DEQ used the QUAL2Kw model (Pelletier and Chapra 2008a, 2008b) to simulate water temperatures for this study. Data sources for the study included the following:

- Streamflow and velocity; channel width and depth; and existing shade conditions collected during DEQ site visits
- Reach details such as elevation, location, and slope, and existing and potential shade identified by DEQ geographic information system analysis

- Inputs such as ground water inflow and temperature from DEQ model analysis
- DEQ continuous data for stream and air temperatures in 2013
- MesoWest meteorological data for the 2013 model period

The QUAL2Kw model scenario used to describe natural background stream temperatures was April through September 2013 for the lower reach of Paradise Creek through Moscow, where flow is generally perennial.

Results for the Idaho DEQ QUAL2Kw stream temperature model for Paradise Creek can be summarized as follows:

- Modeled potential stream temperatures predict a maximum stream temperature of 20.5°C in July in the stream reach above MWWTP for the model period April through September 2013

- System potential shade would provide less than 1°C cooling to current stream temperatures

- Response temperature of Paradise Creek to 35 years of meteorological data predict a 90th percentile 7-day average daily maximum stream temperature of 20.5°C in July in the stream reach above MWWTP

1 Introduction—Stream Temperature

Stream temperature is an important part of stream ecology. Temperature drives instream processes such as metabolism and decomposition, affects plant growth, and influences habitat for aquatic life (Sinokrot and Stefan 1993; Bogan et al. 2003). Human alterations of natural landscapes increase stream temperatures. When aquatic life depends on cooler temperatures, increased heating restricts available habitat (Poole and Berman 2001a).

The Idaho Department of Environmental Quality (DEQ) implements Idaho's water quality standards for cold water aquatic life, which dictate that human activities may not cause water temperatures to exceed 22 °C at any time or exceed a daily average of 19 °C (IDAPA 58.01.02.250.02.b). All surface waters of the state of Idaho are presumed to support cold water aquatic life (IDAPA 58.01.02.101.01.a).

Air and water temperatures are highly correlated, showing the same daily and seasonal patterns. However, air temperature is not the primary driver of water temperature. Heat exchange between air and water is from convection, which is only a small part of the overall heat flux. Incoming solar energy—shortwave radiation—is the primary driver of stream temperature (Sinokrot and Stefan 1993; Younus et al. 2000). Because shortwave solar radiation is the largest thermal input to air and water temperatures, clear skies and unshaded streams will result in the highest water temperatures (Johnson 2003). Other components of stream temperature include the following:

- Longwave radiation (i.e., reflected solar radiation) that is reflected into a stream from the surroundings but is also reflected back into the surroundings from the stream.
- Evaporation from the stream surface that causes cooling.
- Convection heat exchange with the atmosphere.
- Conduction heat exchange between the streambed and the water.
- Hyporheic exchange, an alternative flow path of surface water through permeable substrates under and near the streambed. Flow in the hyporheic zone can come from the stream itself or from water percolating to the stream from the surroundings (Evans and Petts 1997).

A graphic representation of these heat fluxes is shown in Figure 1. This figure is an output of the QUAL2Kw model that can be shown for any day of the model simulation period to identify the primary sources of heating and cooling.

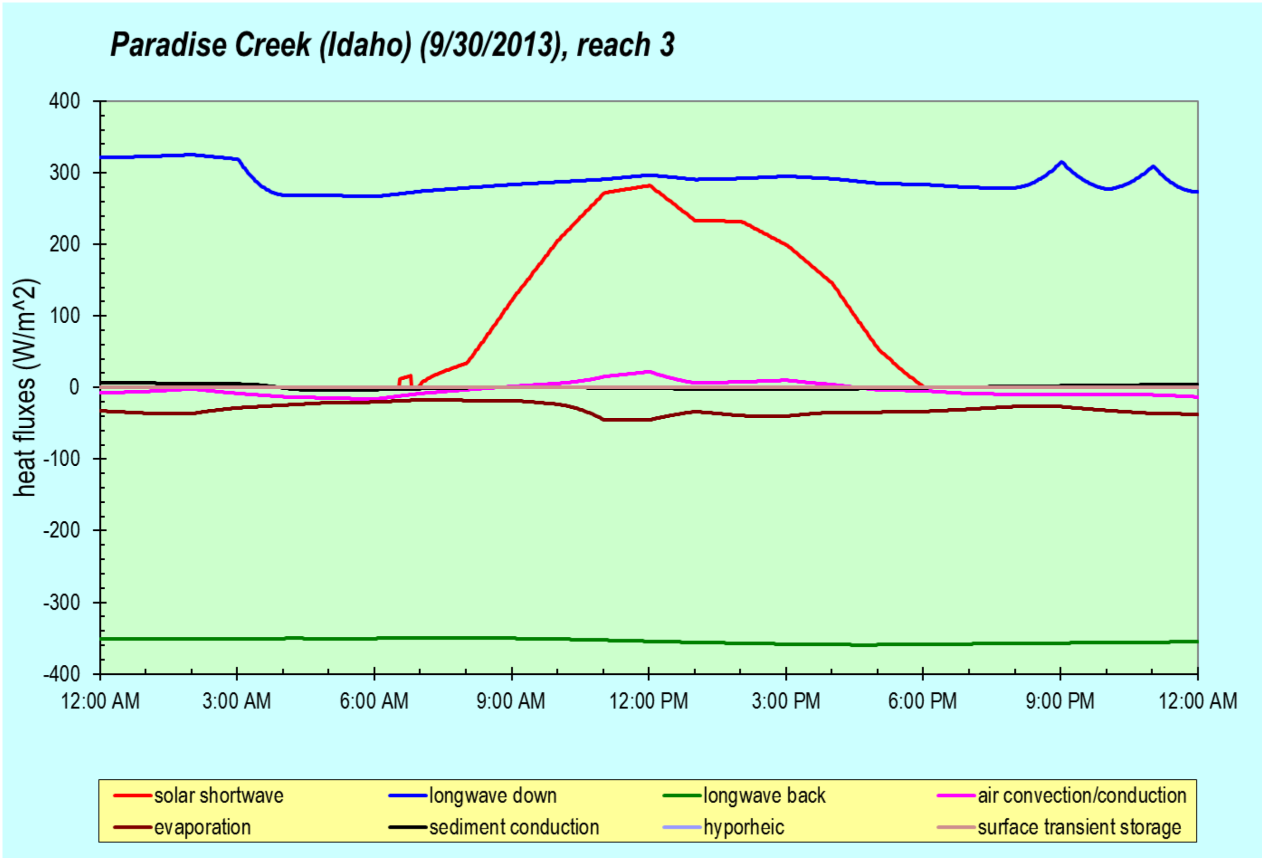

Figure 1. Heat exchange processes that affect stream temperature.

In this example of one Paradise Creek reach, shortwave is the primary source of heat that varies diurnally, while longwave radiation from the atmosphere is a steady heat source. Longwave radiation reflected back from the water surface is a steady heat sink that offsets longwave radiation from the atmosphere. Air convection and conduction, evaporation, sediment conduction, and hyporheic flow have lesser impacts to stream temperature in this scenario.

Heat exchange processes are affected by physical features such as the following:

- Stream width, depth, and other channel parameters
- Ground water volume and temperature, along with any near-surface seepage
- Meteorological parameters like air temperature, relative humidity, and wind speed
- Shade provided by topography or canopy cover from riparian vegetation

Johnson (2004) showed that substrate and shading affect temperature in small streams. Experimental shading of the stream caused the largest magnitude of change in maximum stream temperatures. In this study, substrate type and hyporheic flow had a dampening effect on minimum and maximum temperatures, decreasing the diurnal variation. The moderating influence of hyporheic flow has a proportionately larger effect in smaller streams. Other studies underline the importance of hyporheic flow in influencing stream temperatures (Malard et al. 2001; Younus et al. 2000).

2 Paradise Creek Watershed

Paradise Creek in Latah County flows from its headwaters in Moscow Mountain through Moscow, Idaho, across the Washington state line to its confluence with South Fork Palouse River near Pullman, Washington (Figure 2). In the headwaters, granitic rock forms the northern part of the watershed. The rest of the drainage consists of fine-grained silt-loam soils overlying basalt flows. Paradise Creek is characterized by low elevation plateaus and rolling topography, with agriculture as the predominant land use.

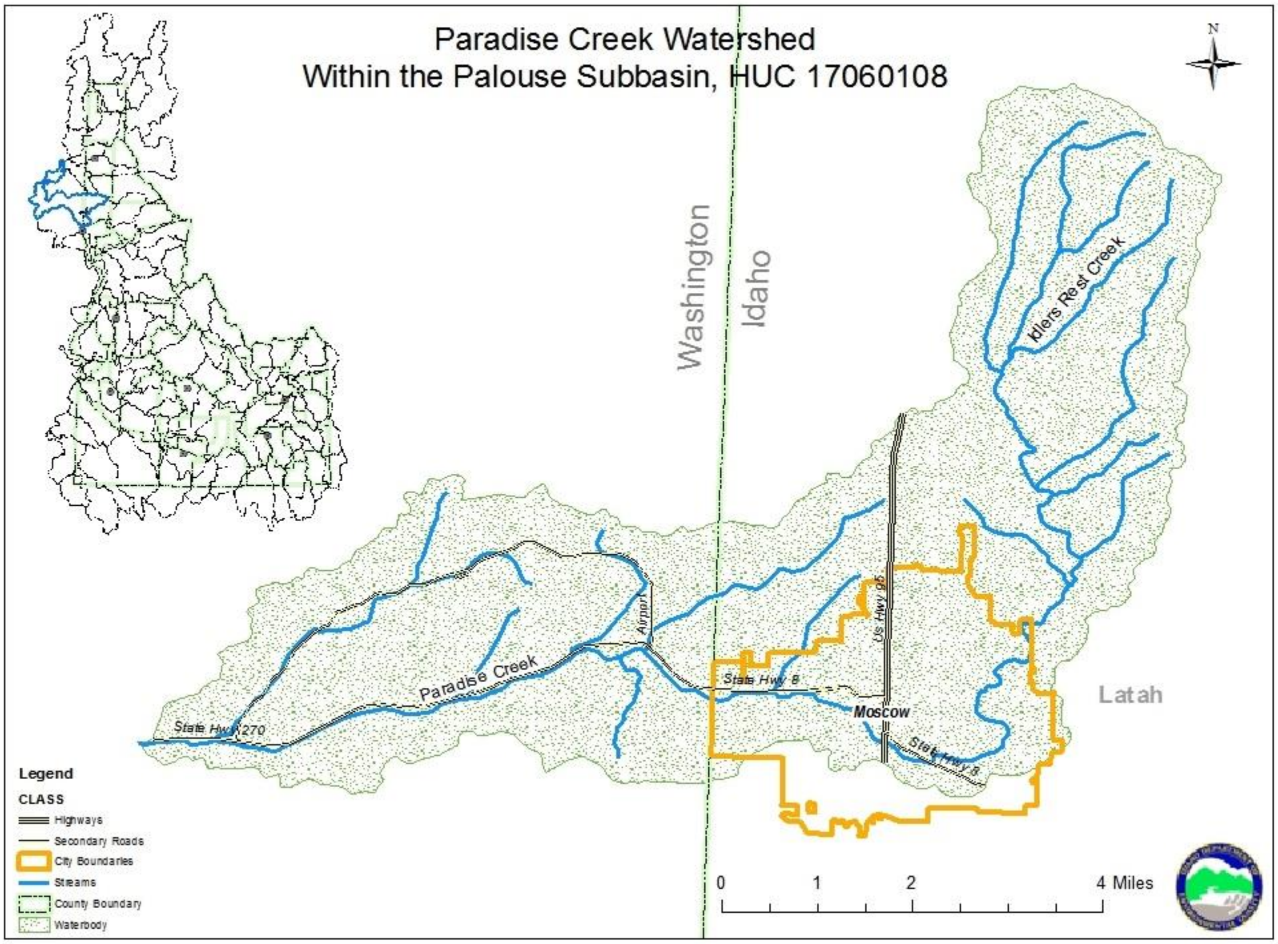

Figure 2. Paradise Creek watershed in north Idaho.

The US Geological Survey (USGS) operates a stream gage at the University of Idaho in Moscow approximately 0.8 miles east of the Idaho-Washington border (Figure 3). This real-time stream gage has a period of record from October 1, 1978, to 2015. The gage is located 0.2 miles upstream of the Moscow Wastewater Treatment Plant (MWWTP) outfall.

Figure 3. USGS stream gage 13346800, Paradise Creek at University of Idaho at Moscow, Idaho.

The mean monthly discharge is low, with an historic high in February of 24 cubic feet per second (cfs) and low flows less than 1 cfs in July, August, and September (Figure 4).

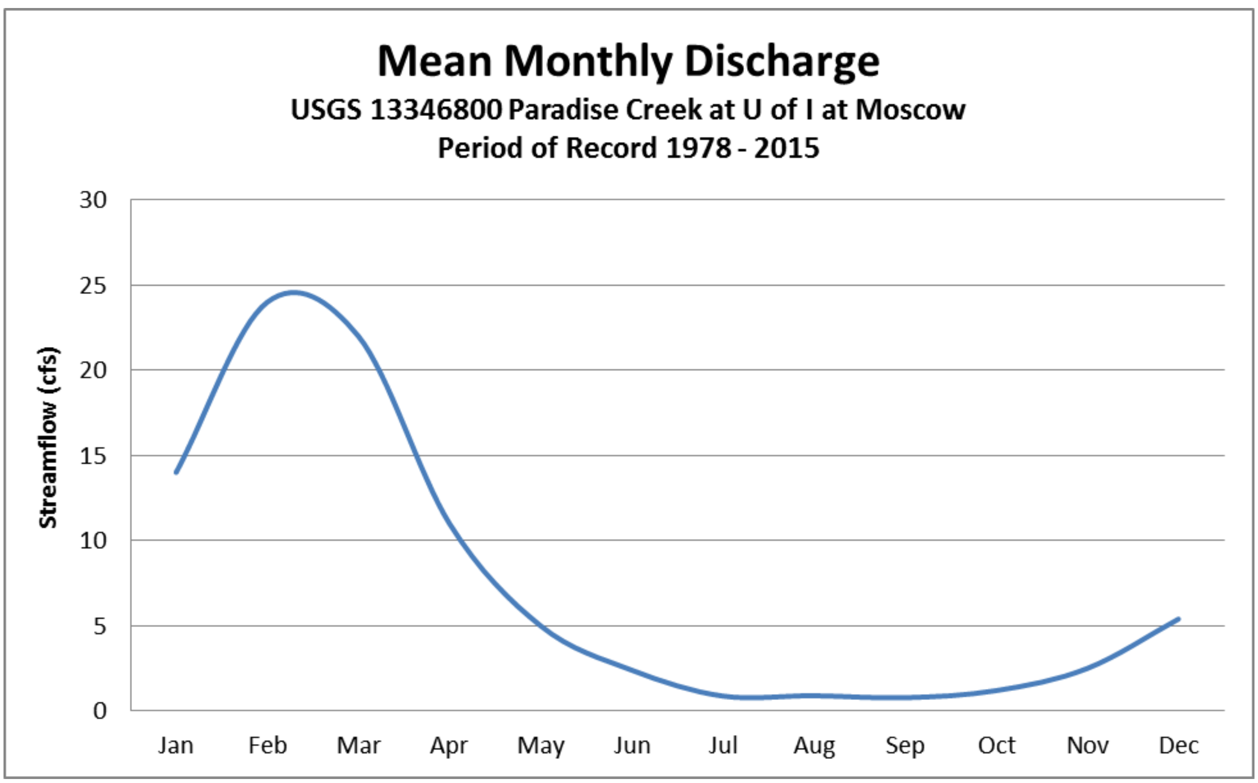

Figure 4. Mean monthly discharge at Paradise Creek USGS stream gage 13346800.

However, the historic record of daily data show peak flows over 100 cfs, mainly in January and February (Figure 5). Pulse flows are typical of the daily record.

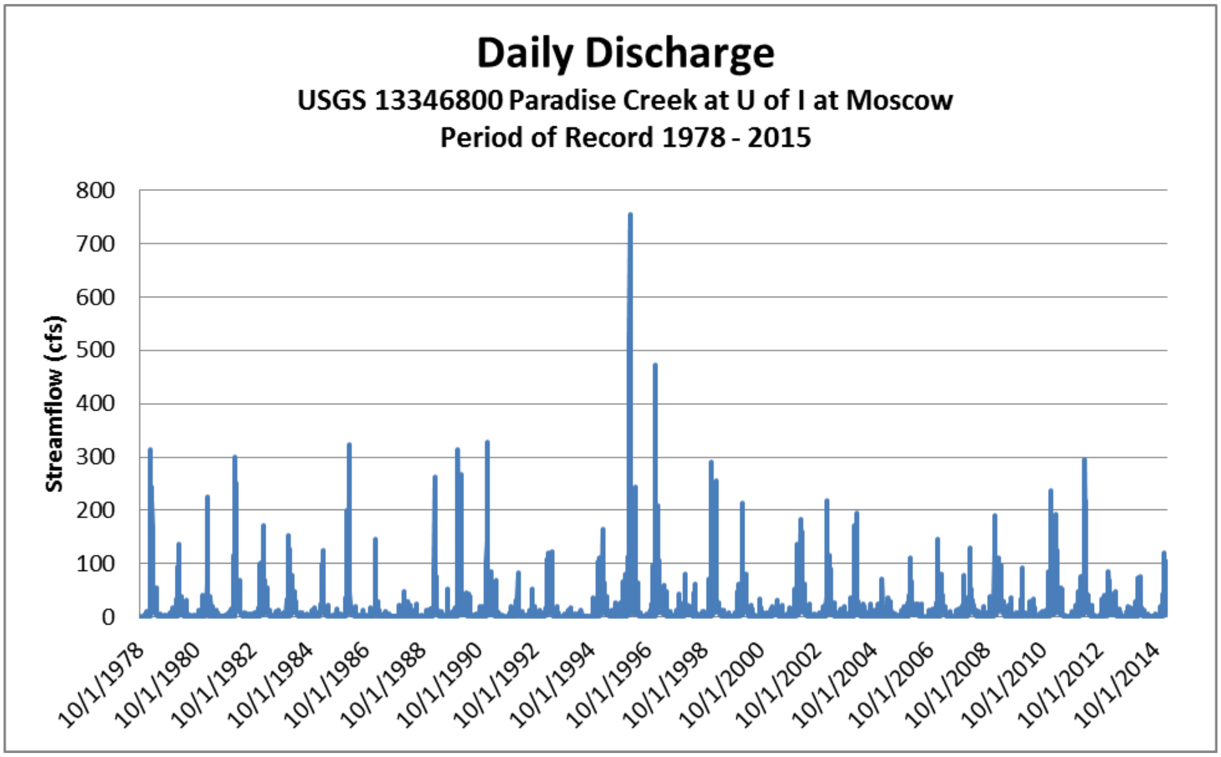

Figure 5. Daily discharge at Paradise Creek USGS stream gage 13346800.

Precipitation is highest in December and January from either snow or rain and snow, and the melting winter snowpack causes high flows. Often, the causes of peak flows within the watershed are rainfall onto frozen soil and rain-on-snow events. Above Moscow, Paradise Creek is intermittent, running from the spring thaw until May or June. During intermittent flow, some residual pools remain between reaches of dry streambed (DEQ 1997).

A study of ground water recharge in the Moscow area has shown that basalt flows and low permeability fine sediments are overlain with sediments of high permeability. This causes infiltration to enter the near-surface sediments and flow laterally before discharging into local streams like Paradise Creek, or by intersecting the land surface as spring discharge (Fairley et al. 2006). This near-surface, shallow runoff has an influence in streamflow response depending on land uses. The highest aquifer recharge potential occurs in the urbanized reach through Moscow according to a study by Dijksma et al. (2011).

2.1 Temperature Regulatory Issues

As an interstate water, Paradise Creek must meet Washington’s water quality standards at the state line. Under the 2011 Washington Administrative Code (WAC) 173-201A-200, Paradise Creek is designated as having an aquatic life use of “salmonid spawning, rearing, and migration”, with a temperature criterion of 17.5°C. This temperature criterion is interpreted as the highest annual running 7-day average of daily maximum temperatures (7DADMax). If natural conditions exceed the criterion, there is a 0.3 °C allowance (WAC 173-201A-200(1)(c)(i)).

In Idaho, Paradise Creek is designated for cold water aquatic life and secondary contact recreation (IDAPA 58.01.02.120.01). The water quality standards set stream temperature criteria to protect the cold water aquatic life beneficial use at 22 °C maximum and 19 °C average (IDAPA 58.01.02.250.02.b).

2.1.1 Point Source Wastewater Treatment Temperature Provisions

The MWWTP outfall enters Paradise Creek about 0.2 miles upstream of the Idaho-Washington border. The MWWTP outfall received temperature wasteload allocations in the Paradise Creek total maximum daily load (TMDL) (DEQ 1997) based on an instream temperature criterion of 18 °C, which was the Washington state standard at that time. MWWTP also received temperature effluent limits under the US Environmental Protection Agency's National Pollutant Discharge Elimination System permit number ID0021491 to meet the 18 °C temperature criterion:

> . . .by either requiring the temperature of the effluent discharged to the stream to be at or below 18°C, or if the ambient temperature of the stream is less than 18°C by determining the effluent flow volume that can be discharged to the stream without causing an exceedance of the criterion.

In Idaho's water quality standards, natural background conditions occur when no human sources of pollution have affected the watershed. The temperature provision for point source wastewater treatment requirements under IDAPA 58.01.02.401.01.c states:

> If temperature criteria for the designated aquatic life use are exceeded in the receiving waters upstream of the discharge due to natural background conditions, then wastewater must not raise the receiving water temperatures by more than three tenths (0.3) degrees C. (3-29-12)

2.1.2 Land Uses Impacting Stream Temperature

The Paradise Creek watershed is affected by human activities including roads, recreation, agriculture, and urban land uses. Alterations to the stream channel by roads, structures, and cropland change the width, depth, and other channel parameters. Constructed subsurface drainages installed to aid agriculture change the natural hydrology. Construction with impermeable surfaces also alters ground water and surface water runoff patterns. Human activities alter shade provided by canopy cover from its natural background condition.

Of all of these factors affected by human land uses, shade has the most potential for reducing stream temperatures:

- Shade is easier to increase by management practices than it would be to restore ground water, overland runoff, and channel parameters to natural background conditions.
- Blocking shortwave radiation from the sun has the most potential for creating a heat sink to the stream, as shown by research (Johnson 2004) and the heat fluxes modeled during this study.

Natural background hydrology and channel dimensions will not be addressed by this study. With extensive human impacts, it is not feasible to return to historic hydrologic conditions. With the minimal baseflow averaging less than 1 cfs in Paradise Creek above the MWWTP outfall, surface heat exchange will be more important than heat transport. Therefore, solar shortwave radiation has the largest effect on heating for Paradise Creek. Increasing shade has the most direct impact on reducing the amount of solar radiation reaching the stream. As a result, system potential shade will be evaluated to identify natural background stream temperatures for regulatory purposes.

3 Paradise Creek—Stream Temperature Model

This study uses modeling to identify the stream temperatures in Paradise Creek that would occur under system potential shade conditions for the stream. These model results will identify the natural background conditions in the receiving waters upstream of the discharge.

3.1 Model Selection

The QUAL2Kw model (Pelletier and Chapra 2008a, 2008b) simulates all of the heat exchange processes to identify stream temperature:

- Hourly shortwave solar radiation, weather parameters, and shade
- Atmospheric longwave radiation, evaporation, convection, and conduction
- Thermal conductivity and thermal diffusivity terms
- Hyporheic exchange modeled as two-zone transient storage (Neilson et al. 2010)

QUAL2Kw is maintained and supported by civil and environmental engineers at the Washington Department of Ecology. DEQ is using Version 6 of QUAL2Kw with dynamic capabilities, release version qual2kw60b08a03.xlsm.

3.2 Data Sources and Analysis

Data sources DEQ used to develop this stream temperature model are shown in Table 1.

Table 1. Data parameters and sources input to the QUAL2Kw model for simulating stream temperature.

Parameter		Data Source
Flow/location	Discharge	DEQ site visits and USGS 13346800
	Diffuse sources inflow	DEQ model analysis
	Elevation and location	DEQ GIS analysis
Physical	Channel azimuth	DEQ GIS analysis
	Cross-sectional area	DEQ site visits
	Geometric coefficients	DEQ model analysis
	Reach length and slope	DEQ GIS analysis
Temperature	Temperature—diffuse sources	DEQ model analysis
	Temperature—stream	DEQ continuous data
	Temperature—air	DEQ continuous data and Mesowest
	Shade—existing and potential	DEQ site visit
Weather	Relative humidity	DEQ continuous data and Mesowest
	Percent cloud cover	Mesowest
	Solar radiation	Mesowest
	Wind speed	Mesowest

Notes: Idaho Department of Environmental Quality (DEQ); US Geological Survey (USGS); geographic information system (GIS)

3.2.1 Streamflow, Channel, and Temperature Measurements

DEQ collected data for existing conditions at the monitoring locations shown in Figure 6. Other monitoring locations not shown in this figure are on tributaries to Paradise Creek—Idler's Rest Creek and an unnamed tributary. Alternative model scenarios using these data showed that the upper monitoring locations did not provide heat transport to the reach above the MWWTP outfall during critical periods when exceedances typically occur. Even though continuous temperature datasets are recorded in the upper locations, discharge was not perennial during the 2013 monitoring period. The final model scenario used temperature data from monitoring locations 10 through 14 where discharge is perennial. Site 10 is accessed from the parking lot of Mountain View Park. Site 11 is downstream of Mountain View Road in a park-like urban setting. Site 12 is accessed from a bridge near West 6th Street and South Line Street on the University of Idaho campus. Site 13 is upstream of the MWWTP outfall where effluent enters Paradise Creek and Site 14 is just east of the Washington state line.

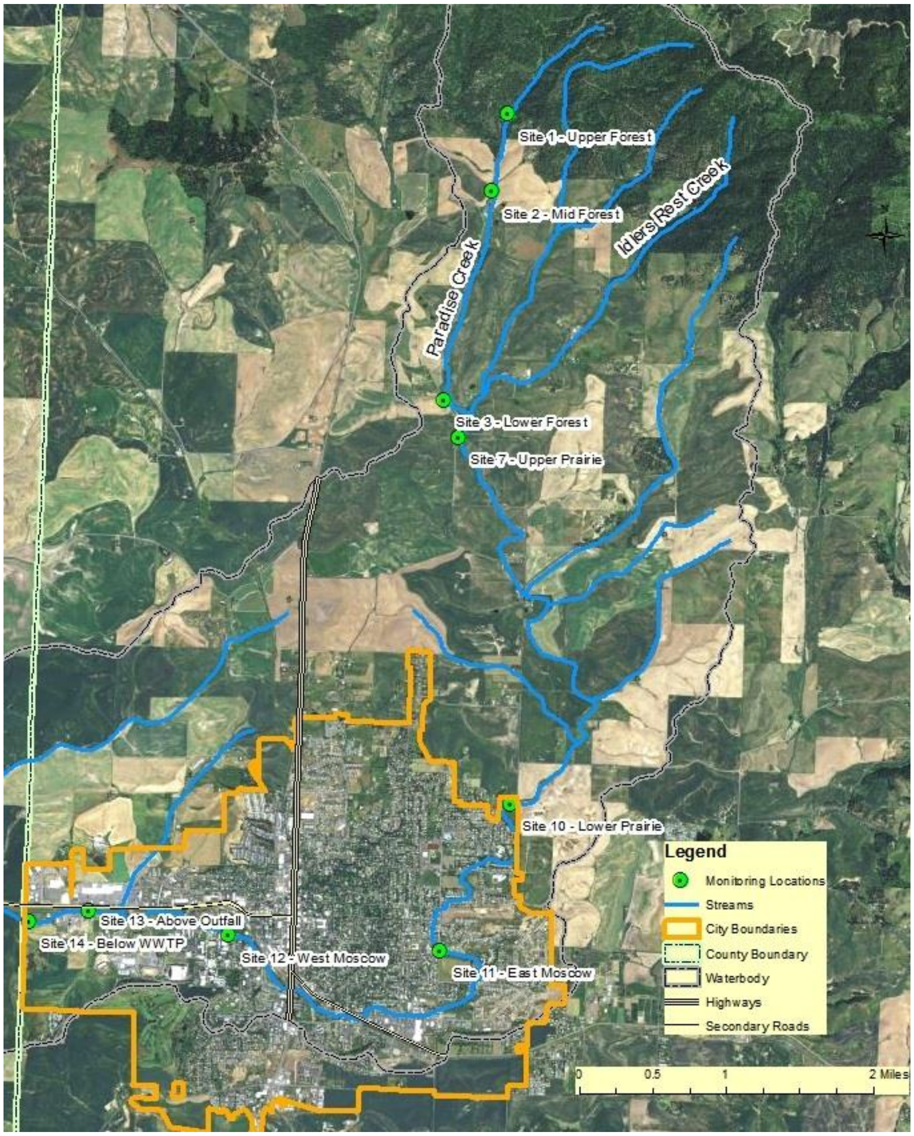

Figure 6. Paradise Creek monitoring locations for temperature study.

The monitoring location designations are based on the ecoregional vegetation potential. Sites 1 through 3—designated upper, mid, and lower forest—are located in the Grassy Potlatch Ridges Level 4 Ecoregion (McGrath et al. 2001) where volcanic ash and loess soils would naturally be vegetated with Idaho fescue, bluebunch wheatgrass, bluegrass, and snowberry. Ponderosa pine would occur in patches on cooler, moister sites. The primary land use activities are small grain farming, hay operations, livestock grazing, and residential housing. Sites 7 and 10—designated upper and lower prairie—are located in the Palouse Hills Level 4 Ecoregion of the Columbia Plateau where un-forested loess is rich in organic matter and very productive. This ecoregion is extensively used for wheat farming with dry channels maintained for drainage in the farming complex. Monitoring sites 11 through 14 in the city of Moscow are also in the Palouse Hills ecoregion. For more information on ecoregional vegetation potential of the upper Palouse River region and the Paradise Creek watershed in Latah County, Idaho, see the *Paradise Creek Temperature TMDL Addendum to the Paradise Creek Subbasin Assessment and TMDL* (DEQ 2015a).

DEQ deployed stream temperature data loggers in these locations to characterize stream temperatures throughout the watershed in March through October 2013. Paired quality assurance units were deployed at sites 2, 7, 10, and 13. Methods followed DEQ protocol for placement and retrieval of temperature data loggers in Idaho streams (DEQ 2013a). Air temperature loggers were included at sites 1, 7, 10, 12, and 13 during the same time frame. Also, DEQ deployed data loggers to collect relative humidity and dew point temperatures from July through September at sites 10, 12, and 13. Streamflow and channel measurements were taken from March through October, and these field data are shown in Appendix A. The streamflow and channel measurements follow DEQ methods documented in the *Beneficial Use Reconnaissance Program Field Manual for Streams* (DEQ 2013b).

DEQ developed continuous streamflow datasets for stream reaches by validating the USGS stream gage data with the instantaneous streamflow field measurements. The USGS stream gage is 0.2 miles upstream of monitoring location 13, and DEQ developed continuous hourly streamflow datasets for each monitoring location upstream of this stream gage as follows:

- Format the USGS discharge into hourly streamflows from April 1 through September 30
- Find the ratio of instantaneous streamflow field measurements at each monitoring location compared to continuous streamflow records at the gage near site 13
- Develop a dataset for each monitoring location validated by field measurements
- Convert cubic feet per second to cubic meters per second (cms) because the model uses metric units

For the final modeling scenario, DEQ simulated stream temperatures for April through September 2013 for the four stream reaches shown in Figure 7.

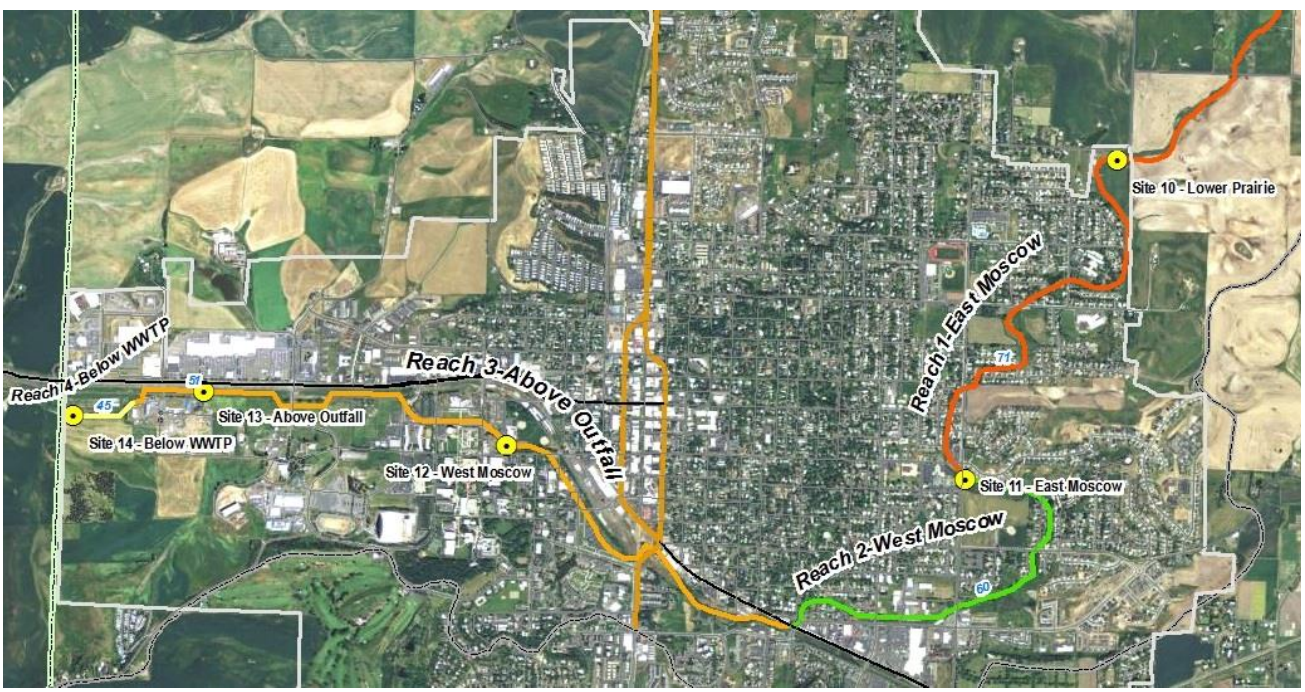

Figure 7. Four stream reaches for stream temperature model scenario.

Monthly streamflow values summarized from these continuous datasets are shown in Table 2.

Table 2. Summary of derived continuous discharge data used in the Paradise Creek QUAL2Kw model.

Discharge	Site 1	Site 2	Site 3	Site 7	Site 10	Site 11	Site 12	Site 13	Site 14
	Upper Forest	**Mid-Forest**	**Lower Forest**	**Upper Prairie**	**Lower Prairie**	**East Moscow**	**West Moscow**	**Above MWWTP Outfall**	**Below MWWTP Outfall**
	46.816 -116.971	**46.807 -116.976**	**46.783 -116.982**	**46.781 -116.980**	**46.744 -116.972**	**46.729 116.979**	**46.731 -117.010**	**46.732 -117.034**	**46.731 117.040**
April streamflow (cms)									
Mean	0.020	0.020	0.020	0.197	0.267	0.267	0.282	0.282	0.479
Min	0.009	0.009	0.009	0.085	0.116	0.116	0.122	0.122	0.207
Max	0.193	0.193	0.193	1.928	2.616	2.616	2.754	2.754	4.681
May streamflow (cms)									
Mean	0.006	0.006	0.006	0.038	0.054	0.054	0.077	0.077	0.161
Min	0.003	0.003	0.003	0.021	0.030	0.030	0.042	0.042	0.089
Max	0.036	0.036	0.036	0.223	0.312	0.312	0.446	0.446	0.937
June streamflow (cms)									
Mean					0.006	0.006	0.060	0.060	0.181
Min					0.000	0.000	0.004	0.004	0.012
Max	0	0	0	0	0.135	0.135	1.345	1.345	4.035
July streamflow (cms)									
Mean					0.000	0.000	0.006	0.006	0.060
Min					0.000	0.000	0.002	0.002	0.023
Max	0	0	0	0	0.004	0.004	0.070	0.070	0.701
August streamflow (cms)									
Mean					0.001	0.001	0.010	0.010	0.102
Min					0.000	0.000	0.003	0.003	0.027
Max	0	0	0	0	0.016	0.016	0.268	0.268	2.676
September streamflow (cms)									
Mean					0.002	0.002	0.041	0.041	0.409
Min					0.000	0.000	0.003	0.003	0.034
Max	0	0	0	0	0.056	0.056	1.111	1.111	11.114

Notes: Moscow Wastewater Treatment Plant (MWWTP); cubic meters per second (cms)

The model scenario used the derived streamflow dataset for site 10 as the headwaters flow of the model. Compared to the continuous data record at USGS stream gage 13346800 near site 13, the ratio of flow at site 10 headwaters equaled:

- 0.95 cms in April
- 0.70 cms in May
- 0.10 cms in June
- 0.10 cms in July
- 0.06 cms in August
- 0.05 cms in September

3.2.2 Shade Data

Mark Shumar (DEQ) developed nonpoint source temperature load allocations based on riparian shade targets and associated solar loads in kilowatt-hours per day for the Paradise Creek TMDL 5-year review to replace the 1997 temperature TMDL (DEQ 2015a). He established effective target shade levels based on the concept of maximum shading under potential natural vegetation (PNV) resulting in natural background temperature levels. Effective shade curves for the Clearwater National Forest breaklands forest informed shade targets for the forested reaches and a black hawthorn plant community was used for the Palouse rolling topography lower in the watershed. Existing shade was determined from aerial photo interpretation, field verified with Solar Pathfinder data. Target and existing shade were compared to determine the shade needed to bring Paradise Creek into compliance with the temperature TMDL. Methods for determining PNV community types are documented in Shumar and De Varona (2009). These vegetation communities describe potential riparian vegetation in the absence of human disturbances and do not necessarily describe the existing riparian vegetation.

Figure 8 shows the existing shade evaluations, verified by Solar Pathfinder measurements at the monitoring locations. Figure 8 and Figure 9 are duplicated from the draft *Paradise Creek Temperature TMDL Addendum to the Paradise Creek Subbasin Assessment and TMDL* (DEQ 2015a).

Target shade determined from stream width and shade curves for the identified potential natural plant communities are shown in Figure 9.

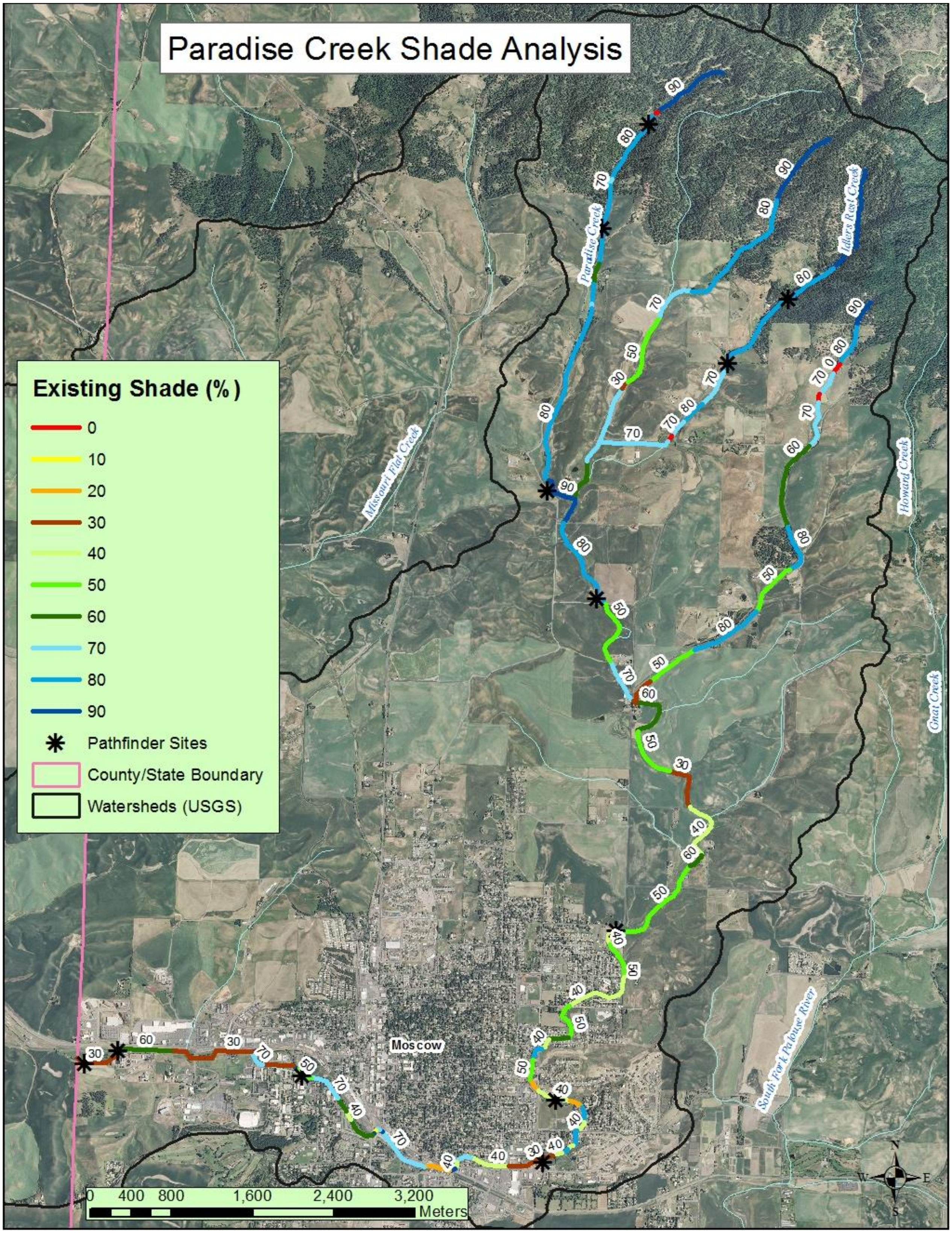

Figure 8. Existing shade estimated for Paradise Creek by aerial photo interpretation.

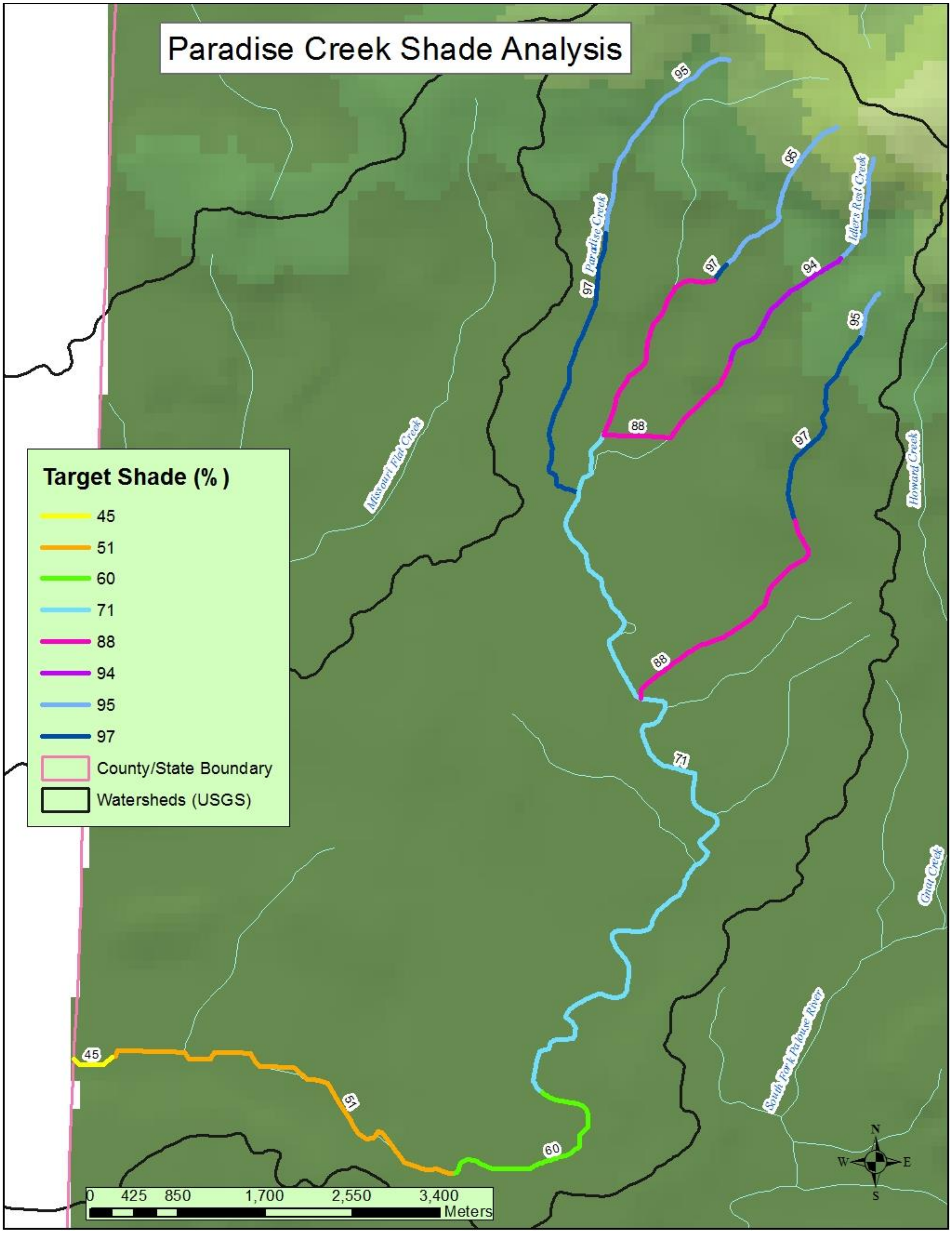

Figure 9. Target shade for Paradise Creek.

In developing an existing shade dataset for the model, weighted average existing shade values were developed by finding the product of the percent total length of each stream segment and its associated shade value. Weighted average shade is more reasonable for temperature simulation since the temperature at one monitoring location is expected to represent cumulative factors upstream of the monitoring site. Poole et al. (2001b) provides the cumulative factors affecting stream temperature. The weighted average existing and potential shade percentages are shown in Table 3.

Table 3. Weighted average existing and system potential shade for the model reaches identified from potential natural vegetation analysis.

Model Reach	Existing Shade	System Potential Shade
Reach 1 – East Moscow	53.7	71.0
Reach 2 – West Moscow	46.9	60.0
Reach 3 – Above Outfall	50.8	51.0
Reach 4 – Below MWWTP	30.0	45.0

DEQ developed model stream reaches based on the target shade reaches. The existing shade measurements were used in developing the QUAL2Kw model of existing stream temperatures. During model calibration, these existing shade measurements were adjusted with the help of Jim Carroll of the Washington Department of Ecology to better match measured stream temperatures. The PNV method provides a 6-month shade estimate, but Paradise Creek riparian vegetation differs throughout the seasons. Where reed canary grass predominates, it provides a continuous canopy cover in mid-July through September. In the urban park-like settings, shade is more open earlier in the season, dappled in summer, and more continuous by September. Once the model was calibrated for existing conditions, the shade values for system potential shade were input to model stream temperature under natural background shade conditions. The calibrated percent shade values are shown in Table 4. The shade decrease in September for existing conditions is not due to actual leaf drop, but most likely an artifact of the calibration process that reflects temperature decreases not captured elsewhere in the model. Microclimate conditions near the water surface tend to become cooler and moister in the fall, and this decrease in shade simulates the cooling effect.

Table 4. Existing and system potential shade adjusted during calibration to vary seasonally.

			Existing			
Reach	**April**	**May**	**June**	**July**	**August**	**September**
1	53.7	53.7	53.7	53.7	53.7	43.0
2	46.9	46.9	46.9	56.3	56.3	42.2
3	50.8	50.8	61.0	71.1	71.1	40.6
4	30.0	30.0	36.0	36.0	36.0	24.0
			Potential			
Reach	**April**	**May**	**June**	**July**	**August**	**September**
1	71.0	71.0	71.0	71.0	71.0	56.8
2	60.0	60.0	60.0	72.0	72.0	54.0
3	51.0	51.0	61.2	71.4	71.4	40.8
4	45.0	45.0	54.0	54.0	54.0	36.0

3.2.3 Meteorological Data

Meteorological data for the model period April–September 2013 were downloaded from the MesoWest website (MesoWest 2013). Air temperature, dew point temperature, and wind speed data came from station C8815 in Moscow operated by the Citizen Weather Observer Program. Solar radiation data came from station POTI1 in Potlatch operated by the Interagency Remote Automatic Weather Stations network. Weather observations that were converted to cloud cover for the model came from KPUW in Pullman operated by the National Weather Service and Federal Aviation Administration. Data used in the model are summarized in Table 5.

Table 5. Summary of meteorological data.

Parameter	April	May	June	July	August	September
Air temperature (°C)	Mean 5.3 Min -3.3 Max 18.7	Mean 11.5 Min -1.5 Max 26.3	Mean 14.6 Min 5.0 Max 29.5	Mean 21.7 Min 8.9 Max 34.8	Mean 20.9 Min 10.6 Max 33.3	Mean 15.5 Min 3.3 Max 32.0
Dew point temperature (°C)	Mean -0.4 Min -10.9 Max 8.4	Mean 4.2 Min -5.0 Max 11.7	Mean 8.0 Min -1.7 Max 19.1	Mean 7.0 Min -5.2 Max 22.8	Mean 8.8 Min 0.04 Max 13.7	Mean 7.5 Min 0.5 Max 16.7
Wind speed (meters/second)	Mean 1.2 Min 0 Max 5.5	Mean 0.7 Min 0 Max 3.8	Mean 0.7 Min 0 Max 6.9	Mean 0.5 Min 0 Max 4.9	Mean 0.6 Min 0 Max 4.5	Mean 1.0 Min 0 Max 5.4
Solar radiation (watts/square meter)	Mean 183.8 Min 0 Max 863	Mean 246.4 Min 0 Max 1024.6	Mean 311.3 Min 0 Max 937	Mean 325.0 Min 0 Max 921.7	Mean 266.4 Min 0 Max 885.7	Mean 146.5 Min 0 Max 772.9

Dew point temperature measured in the same location as air temperature is necessary for calibrating the diurnal variation of stream temperature in the model. Although DEQ had deployed air and dew point temperature loggers during 2013, some of the dew point temperature data were not continuous for portions of the model scenario. DEQ data were used to validate surrounding weather stations and to determine which datasets would make the model representative of ambient conditions during the model periods.

More information about data quality assurance is provided in the *Quality Assurance Project Plan: QUAL2Kw Analysis for the Paradise Creek Natural Background Temperature Model* (DEQ 2015b). This document also provides quality assurance documentation for existing data and a list of model, import file, and other data spreadsheets used in the model calibration and prediction scenarios.

3.3 Model Calibration

Once all of the input variables were entered into the worksheets and the best literature values and equations were selected, the model was run and output compared to existing data. This process is used to calibrate the model to ensure accurately modeled stream temperatures. Error statistics are reported as **bias** based on the difference of the residuals for water quality data and model predictions and **root-mean-squared error** (RMSE). The goal is for the model performance to be within 1.0°C of observed temperatures.

3.3.1 Channel Parameters

Channel measurements made on the Washington side of Paradise Creek (Ecology 2006) provided the rating curves for the hydraulic model. The power equations in QUAL2Kw are referenced in Pelletier and Chapra (2008b, page 13) relating mean velocity and depth to streamflow as shown in the equation below:

$U = \mathrm{a}Q^b$ and $H = \alpha Q^\beta$

Where

U and H are velocity and height
a, b, α, and β are empirical coefficients determined from velocity-discharge and stage-discharge rating curves, respectively.

Table 6 shows the coefficient and exponent values used for the Paradise Creek rating curves, calibrated to fit streamflow to measured data.

Table 6. Values used for Paradise Creek hydraulic model.

Rating Curves			
Velocity		Depth	
Coefficient	Exponent	Coefficient	Exponent
1.5	0.8	0.5	0.1
1.5	0.8	0.5	0.1
0.5	0.8	0.8	0.1
0.37	0.8	0.6	0.1
0.65	0.8	0.38	0.1

3.3.2 Discharge

DEQ used the QUAL2Kw continuous source feature to simulate discharge gains and losses. Gains to the stream from MWWTP effluent are well characterized, but gains and losses from nonpoint source runoff and ground water recharge must be estimated. DEQ estimated net loss to the aquifer from basin characteristics identified by StreamStats (USGS 2015). The StreamStats basin characterization report and streamflow prediction statistics are provided in Appendix B. The StreamStats 80th percentile low flow averages 0.03 cms for April through September, and this value was used as a conservative assumption for the continuous abstraction for reach 3 for the entire model period. The highest aquifer recharge potential occurs in the urbanized reach through Moscow according to a study by Dijksma et al. (2011), which validates estimating net loss to the aquifer in this model reach.

Continuous inflow rate and temperature for reach 3 were calculated from the MWWTP hourly effluent records for 2013. Although the inflow input to the model was greater than the abstraction for each day, it was important to the calibration to represent the abstraction because it buffered the diurnal temperature variation. These data are summarized in Table 7.

Table 7. Summary of MWWTP effluent temperature and flow for April through September 2013.

Parameter	April	May	June	July	August	September
Effluent temperature (°C)	Mean 14.3 Min 12.9 Max 17.3	Mean 16.4 Min 13.0 Max 19.0	Mean 18.1 Min 15.8 Max 21.6	Mean 20.7 Min 19.0 Max 26.3	Mean 21.2 Min 19.6 Max 22.6	Mean 20.4 Min 17.4 Max 22.4
Effluent flow (converted to cubic meters per seconds for the model)	Mean 0.11 Min 0.03 Max 0.20	Mean 0.07 Min 0.01 Max 0.14	Mean 0.05 Min 0.01 Max 0.12	Mean 0.04 Min 0.01 Max 0.14	Mean 0.05 Min 0.01 Max 0.13	Mean 0.07 Min 0.01 Max 0.15

Calibrating channel parameters and streamflow are important for increasing the accuracy of temperature predictions. Discharge error statistics are shown in Figure 10.

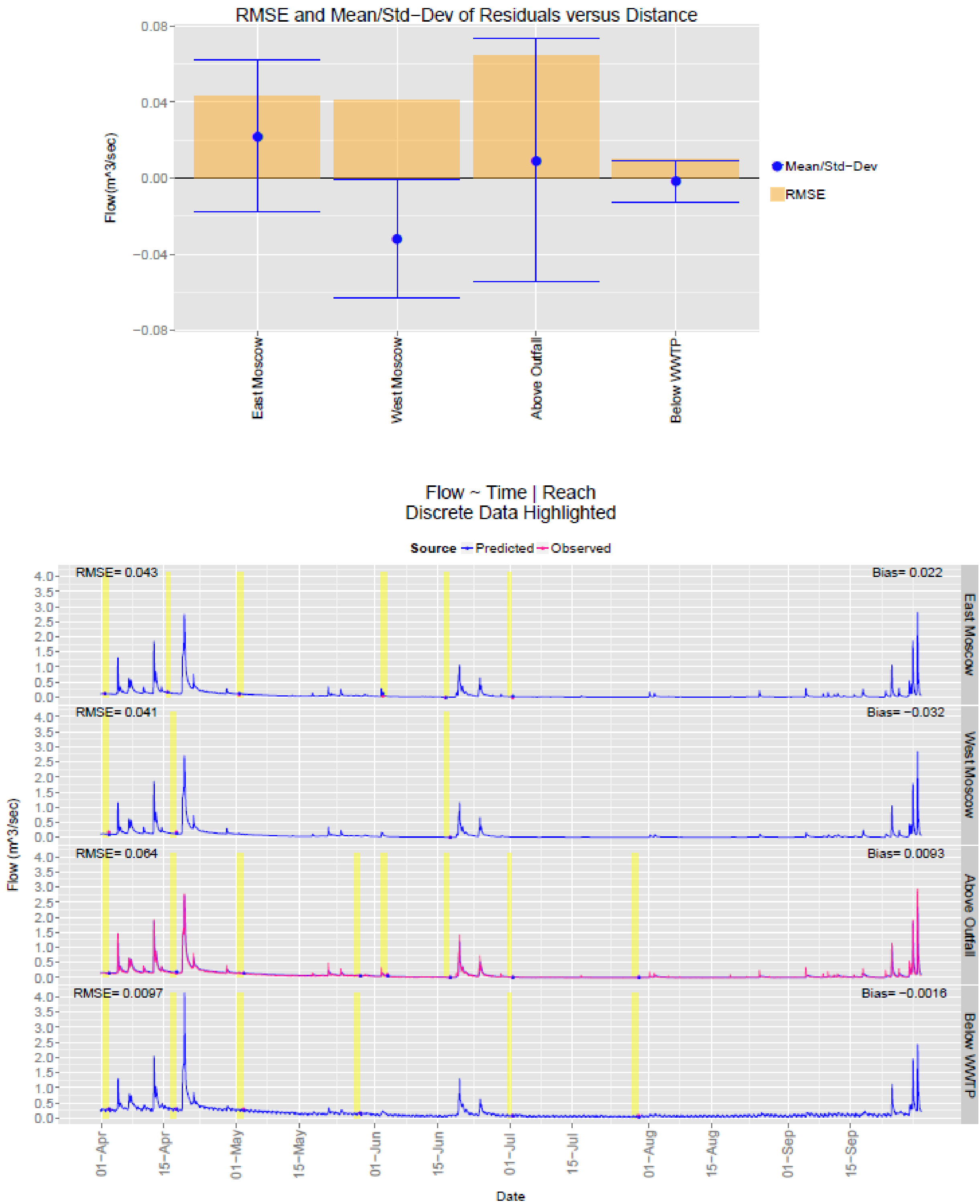

Figure 10. Discharge error statistics.

There were six instantaneous discharge measurements for the East Moscow model reach 1 and the RMSE for these data equals 0.043 cms. For the three instantaneous discharge measurements for the West Moscow model reach 2, the RMSE is 0.041. Model reach 3 above the MWWTP outfall has a continuous observed data series from USGS 13346800 and the predicted data series equates very well with the observed data at RMSE = 0.064. Model reach 4 below the MWWTP outfall had 6 instantaneous discharge measurements and the simulation RMSE = 0.0097. Discharge in this reach equals the USGS measured discharge plus the hourly MWWTP effluent recorded discharge. Error statistics for the difference between predicted and observed values demonstrate accurate discharge predictions.

3.3.3 Stream Temperature

During stream temperature calibration, the existing shade values were adjusted to better match model results, as described earlier and shown in Table 4. The PNV method allows latitude in shade estimations.

With data input for shade, headwaters temperature and flow, climatological conditions, and channel parameters, the model provides a continuous dynamic time series of temperature predictions. A summary of the error statistics for each model reach is provided in Figure 11, showing the overall mean, standard deviation, and RMSE for each model reach.

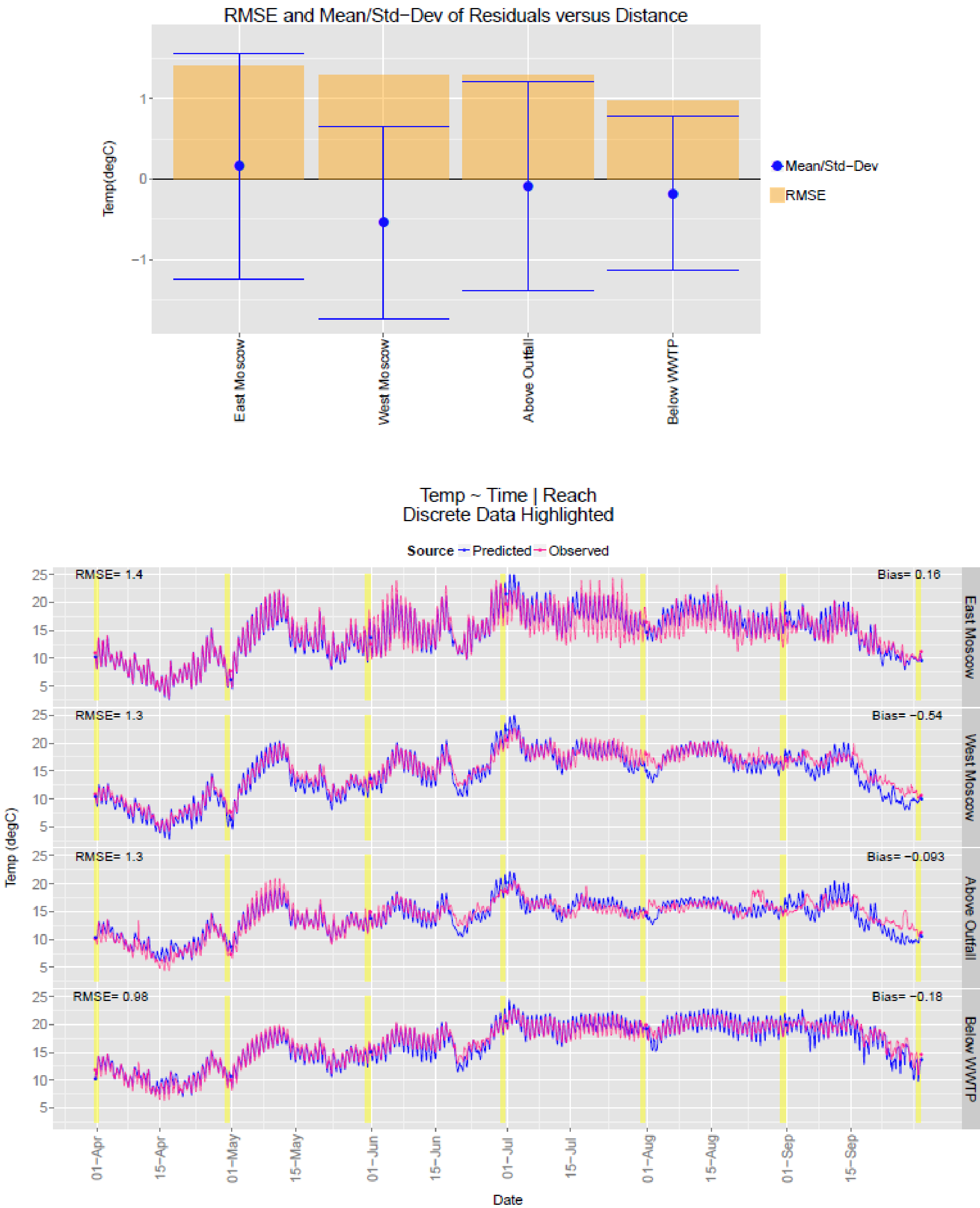

Figure 11. Summary of temperature error statistics.

Residuals are the difference between modeled and measured data for each interval—hourly, in this case. The bias describes the average difference in residuals over the model period. The accuracy goal for temperature simulation is to be within ±1.0°C of measured values, and the bias of the hourly predictions meets this goal. Bias for the model reaches equals:

- 0.16°C for east Moscow
- -0.54°C for west Moscow
- -0.093°C for the reach above the MWWTP outfall
- -0.18°C for the reach below the MWWTP outfall

RMSE is 1.4°C for the east Moscow reach. The RMSE statistic emphasizes outliers. This error statistic is higher than the bias because the observed data showed a greater diurnal variation than the predicted temperature, especially during June and July. For the next two model reaches above the MWWTP, RMSE = 1.3°C, and the predicted diurnal variation is generally greater than observed values through June, July, and August. RMSE = 0.98°C for the model reach below the MWWTP outfall, where the predicted diurnal variation is greater than observed values mainly in August and September.

These error statistics show that the model is performing adequately for hourly intervals over a dynamic time series to make predictions about stream temperature under existing conditions and can be applied to alternative management scenarios geared toward increasing riparian shade.

3.4 Model Results

With an adequately calibrated model for existing conditions, DEQ modeled the system potential shade to identify natural background stream temperatures. For all of the scenarios and reaches, stream temperatures showed a decrease under system potential shade. Idaho's water quality standards will be interpreted above the MWWTP outfall. The monthly temperature reductions under increased shade are reported for the average of the three model reaches above the outfall in Table 8.

Table 8. Average temperature reductions under system potential shade above MWWTP outfall.

Month	Average Temperature Reduction for Model Reaches 1 through 3	
	Predicted (°C)	Bias (°C)
April	0.1	-0.2
May	0.3	-0.5
June	0.7	-0.6
July	1.2	-1.0
August	1.0	+0.8
September	0.3	-0.9
6-month average	0.6	-0.4

Figure 12, Figure 13, and Figure 14 summarize the difference between daily stream temperatures under system potential shade and existing conditions for each reach throughout the model period.

East Moscow in April and May shows little difference in stream temperature between existing and system potential shade. Cooling effects increase in June through August and decrease in September (Figure 12).

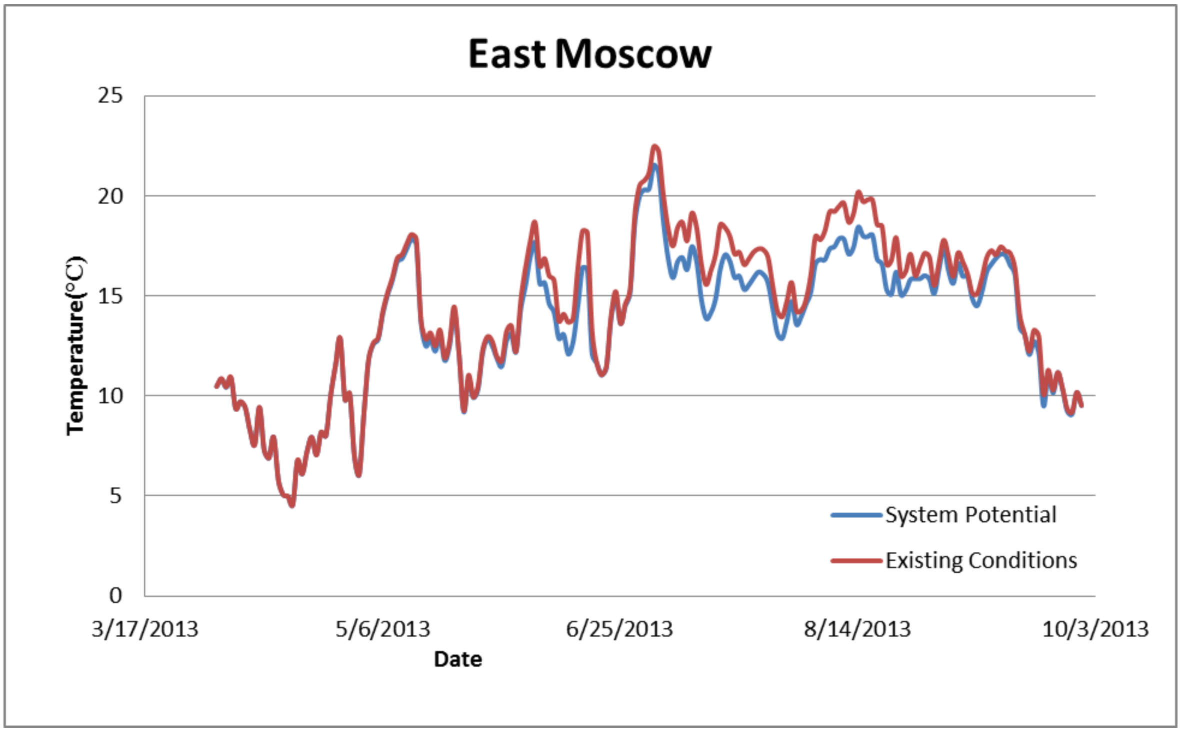

Figure 12. Paradise Creek east Moscow reach stream temperature reductions under system potential shade.

The West Moscow model reach shows similar patterns with the greatest cooling effects from system potential shade in June through August (Figure 13).

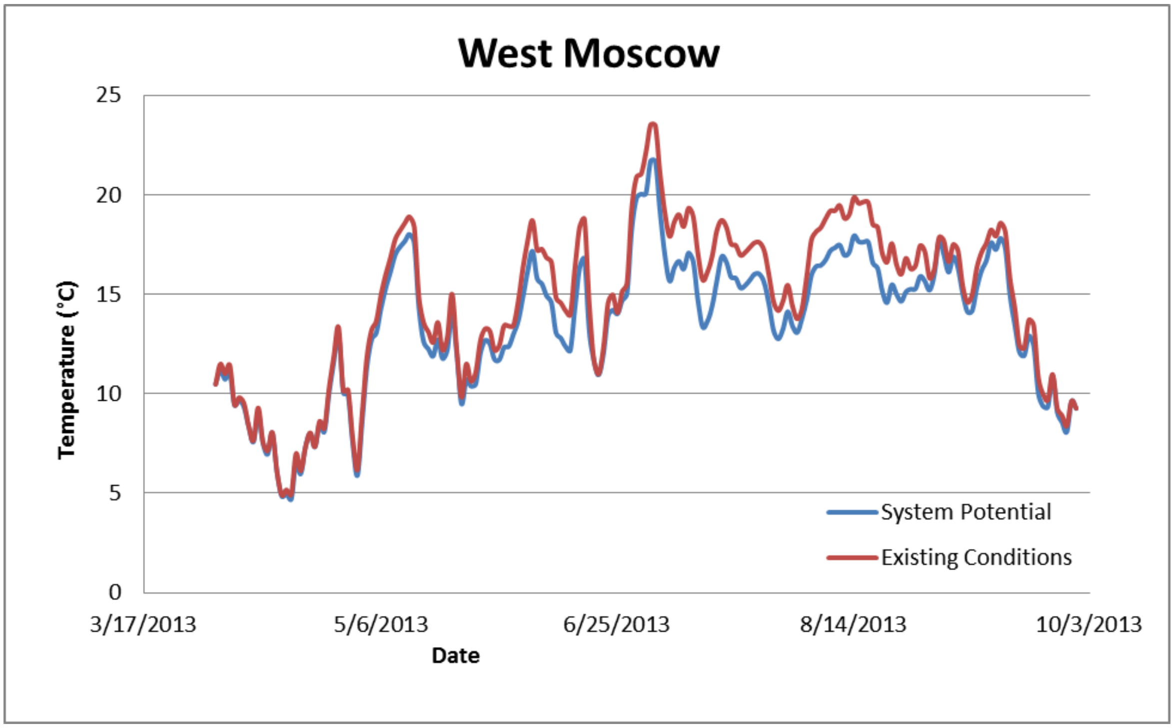

Figure 13. Paradise Creek west Moscow reach stream temperature reductions under system potential shade.

In the stream reach above the MWWTP outfall, system potential shade provides less than 0.5 °C cooling to surface water temperatures (Figure 14).

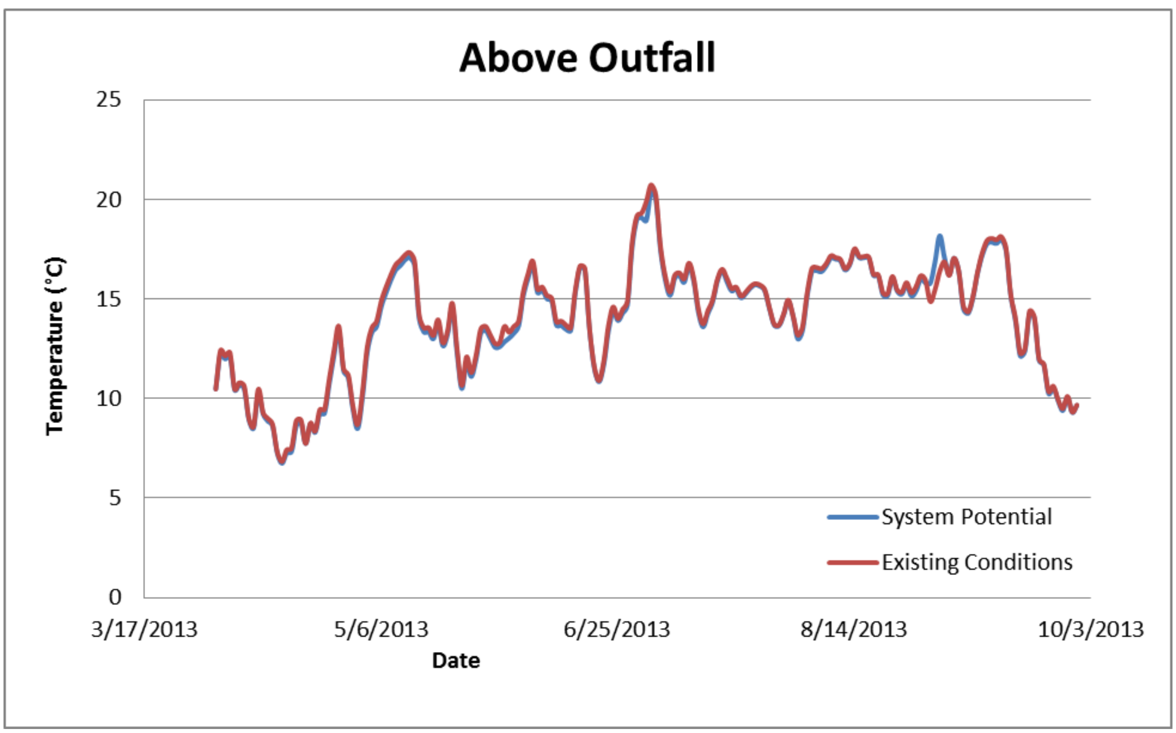

Figure 14. Paradise Creek above outfall reach stream temperature reductions under system potential shade.

This stream reach immediately above the MWWTP outfall is cooler than the more upstream reaches. The City of Moscow has provided a map of Hog Creek which flows through culverts in the urbanized area north of the stream (Figure 15), which is the probable source of the cooler inflow between Site 12 and 13.

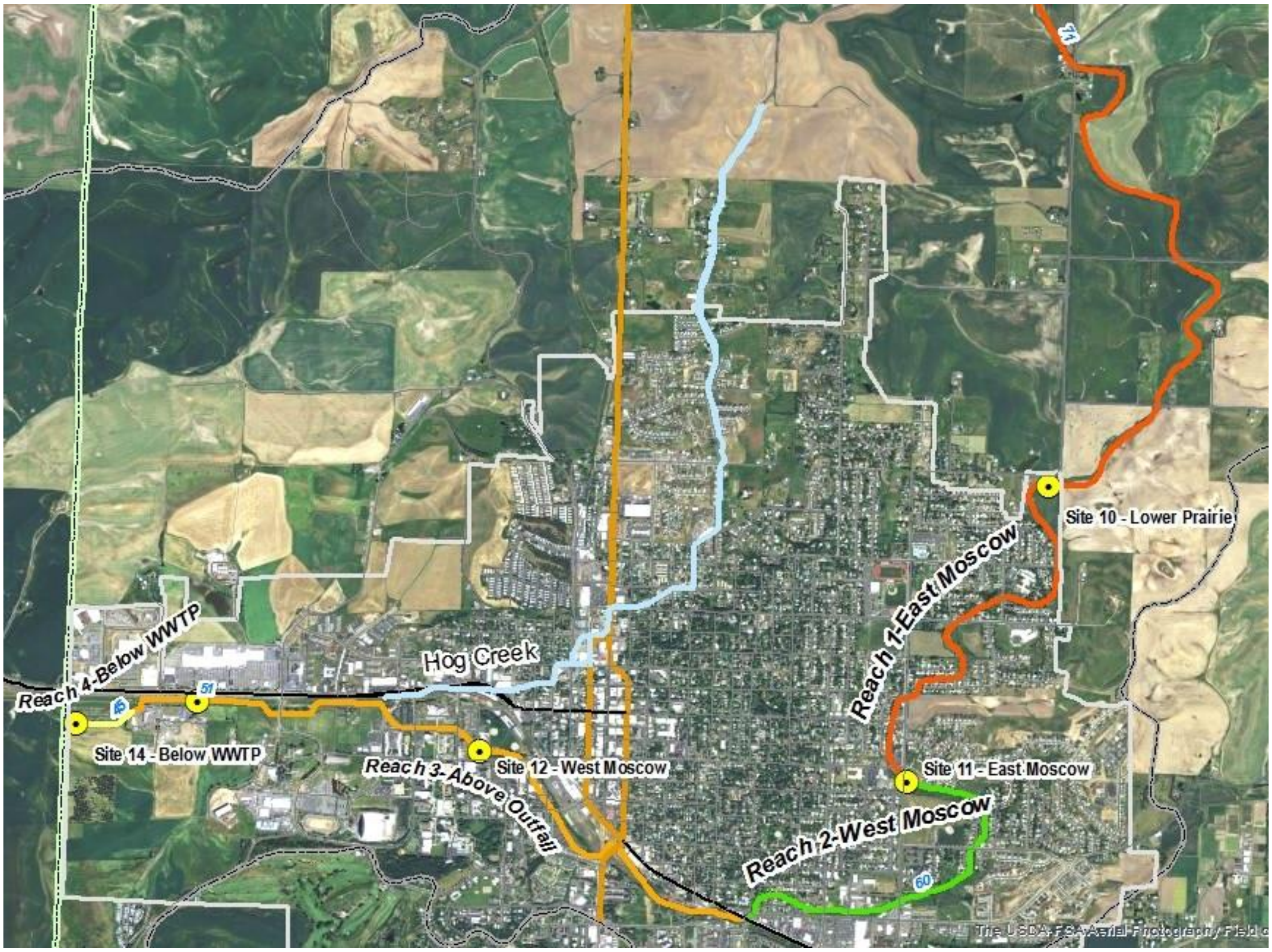

Figure 15. Hog Creek inflow north of Paradise Creek in the reach above the MWWTP outfall.

Stream temperature data collected by DEQ in 2013 demonstrates this cooler source between site 12 and site 13, shown in Figure 16 and Figure 17.

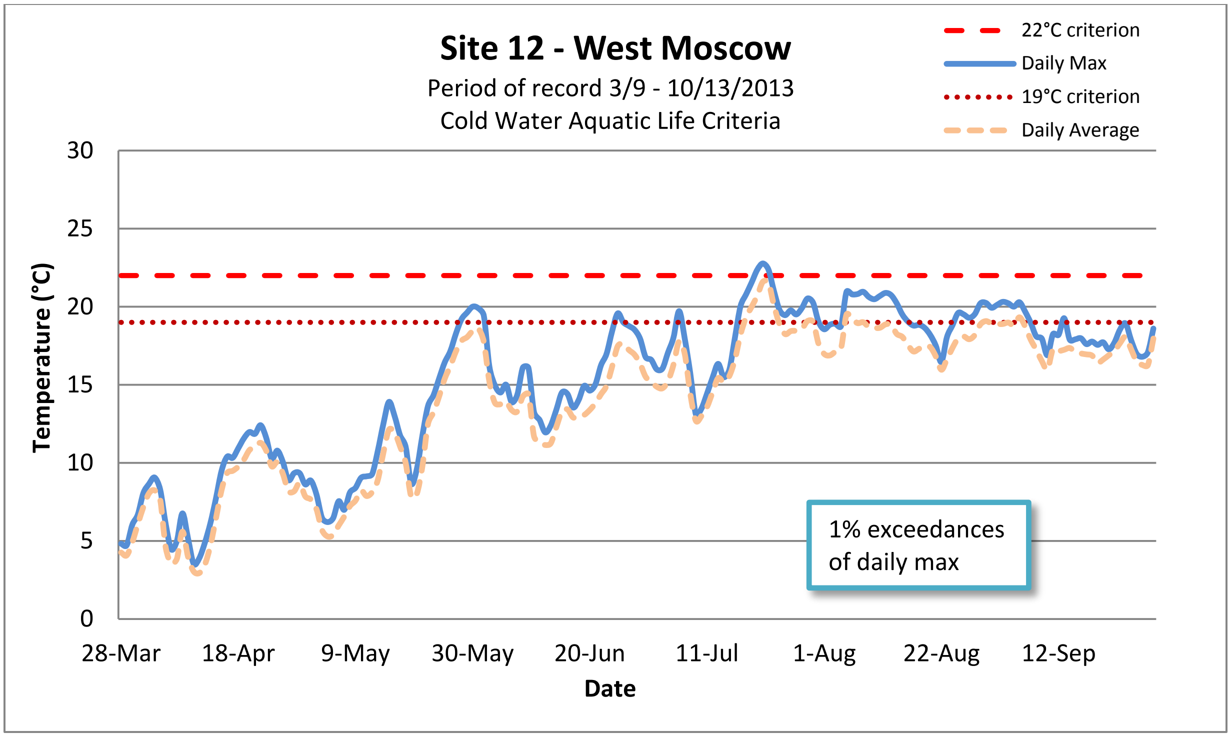

Figure 16. Stream temperatures from site 12–west Moscow with 1% exceedances of daily maximum criterion.

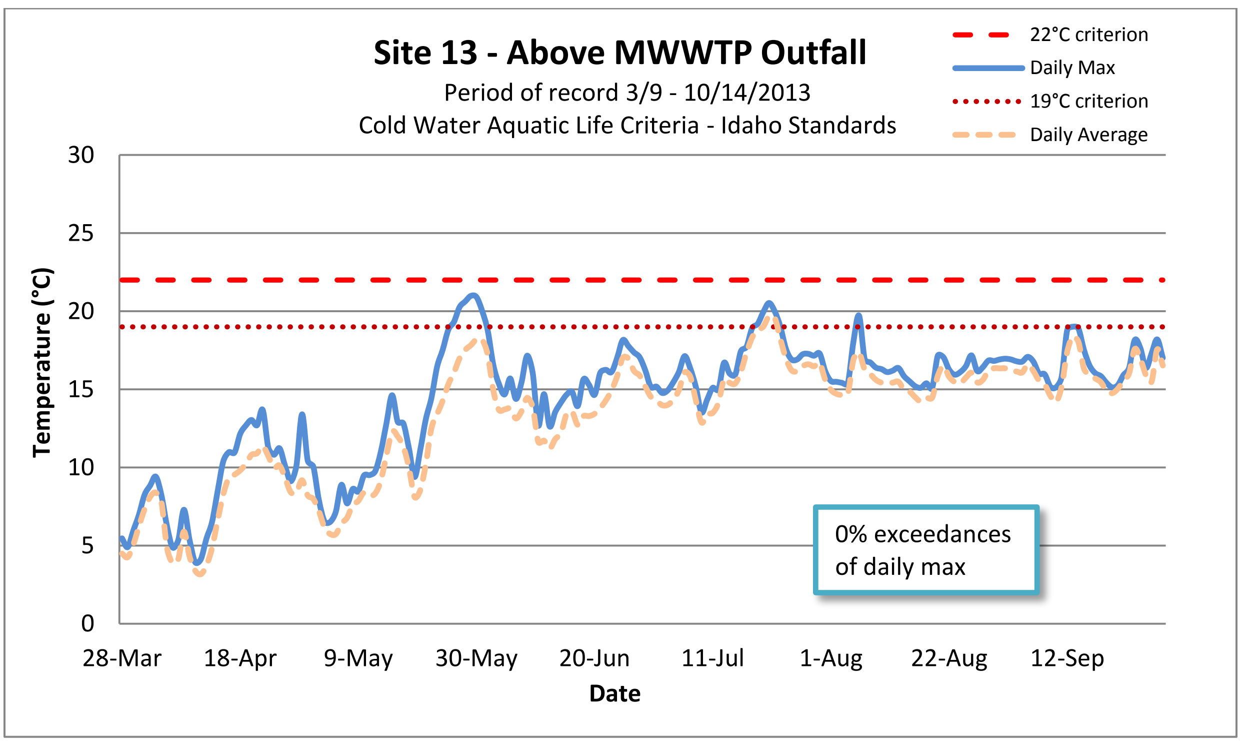

Figure 17. Stream temperatures from site 13–above MWWTP outfall with no exceedances of daily maximum criterion.

Average monthly temperatures cooled between sites 12 and 13 by 2.5 °C in July and 1.7 °C in August when exceedances of temperature criteria can occur. In addition to this cooler inflow, shade is close to system potential in this reach. Therefore, system potential shade has less effect on the reach immediately above the MWWTP outfall than on other stream reaches.

The modeled stream temperatures under system potential shade calculated on a 7dADMax to conform to Washington state standards are shown in Figure 18 for the reach above the MWWTP outfall.

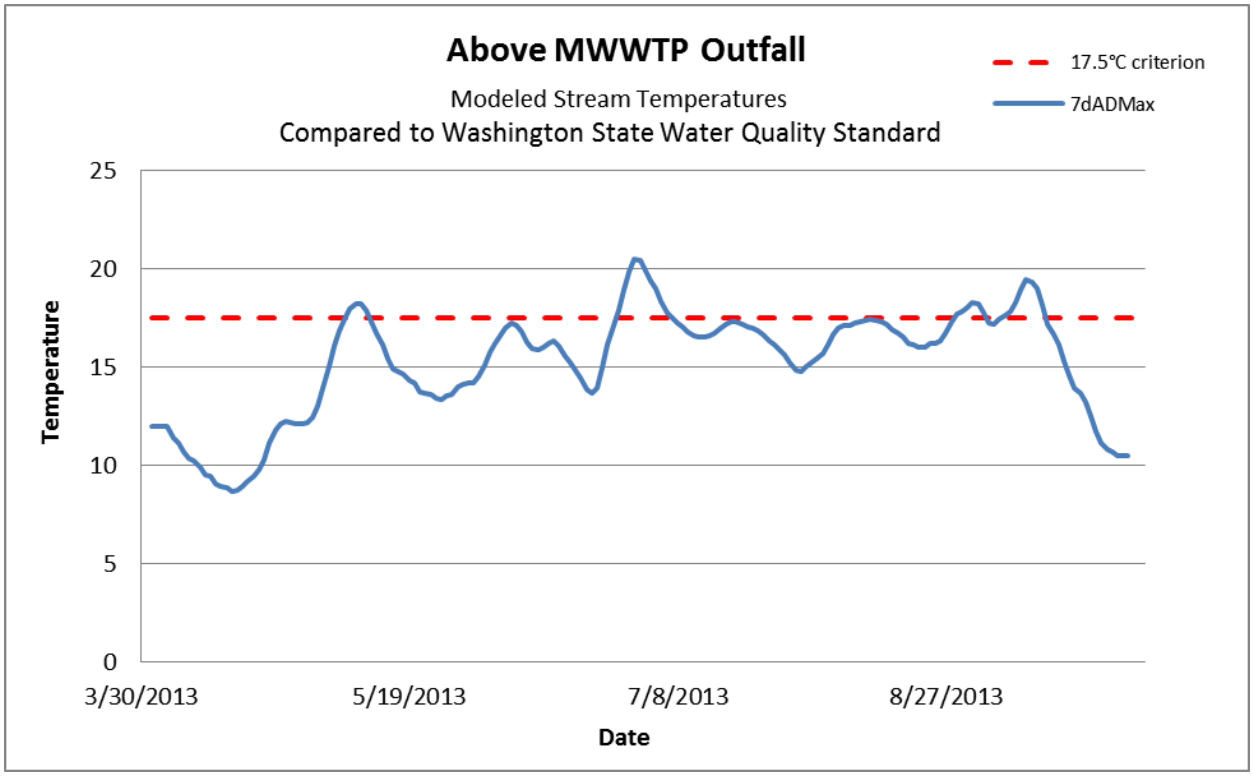

Figure 18. 7dADMax modeled stream temperature under system potential shade above the MWWTP outfall.

Modeled potential stream temperatures predict a maximum stream temperature of 20.5 °C in July in the stream reach above MWWTP. The stream temperature prediction is a time series that changes for each day of the model period—April 1 through September 30, 2013—and does not designate one temperature as a target.

This model is based on the hydrology and climate of 2013 and a small stream like Paradise Creek is more affected by air and dewpoint temperature and solar inputs than a larger stream would be. A monthly climate summary for Moscow for 1981 – 2010 from the Western Regional Climate Center is shown in Figure 19. For comparison, the monthly average temperatures from the weather station used for the model period are included.

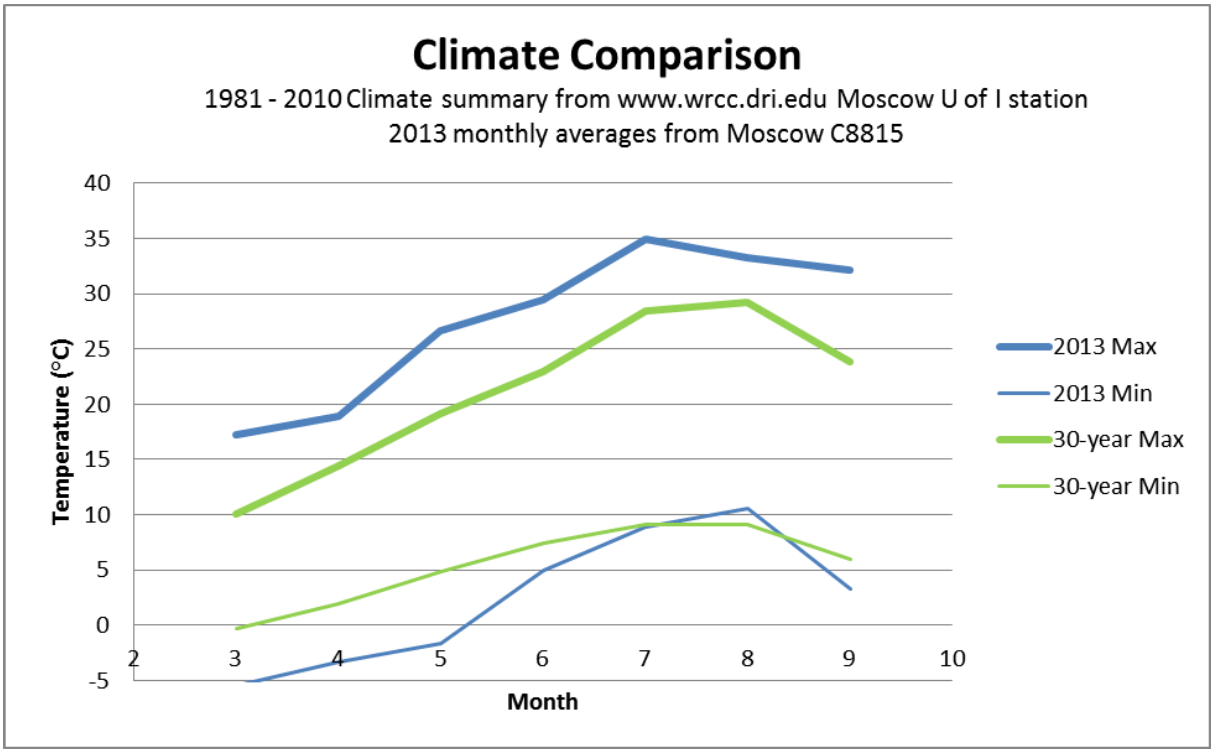

Figure 19. Comparison of 30-year average air temperatures with year 2013.

Apparently, 2013 had a higher range of minimum and maximum temperatures than the 30-year average. Maximum temperatures were consistently warmer in 2013 than over a 30-year average. Minimum temperatures were cooler in 2013 than over the 30-year average except for July and August when they were warmer.

This model was developed in collaboration with the Washington Department of Ecology modeler Jim Carroll, who has built a QUAL2Kw model of Paradise Creek on the Washington side. In addition, he has developed an Rtemp model of Paradise Creek with 35 years of meteorological data from the Pullman, Washington weather station, which is about 4.5 miles northwest of the MWWTP. Rtemp is a response temperature model developed by Greg Pelletier of the Washington Department of Ecology based on Edinger et al (1974) that describes surface water temperature response where heat fluxes are the only heat transfer process. Results for Mr. Carroll's Rtemp model of Paradise Creek are summarized in Figure 20. The response temperature of Paradise Creek to the 35-year record of meteorological data displays peak temperatures in late July, typically July 25th or 26th.

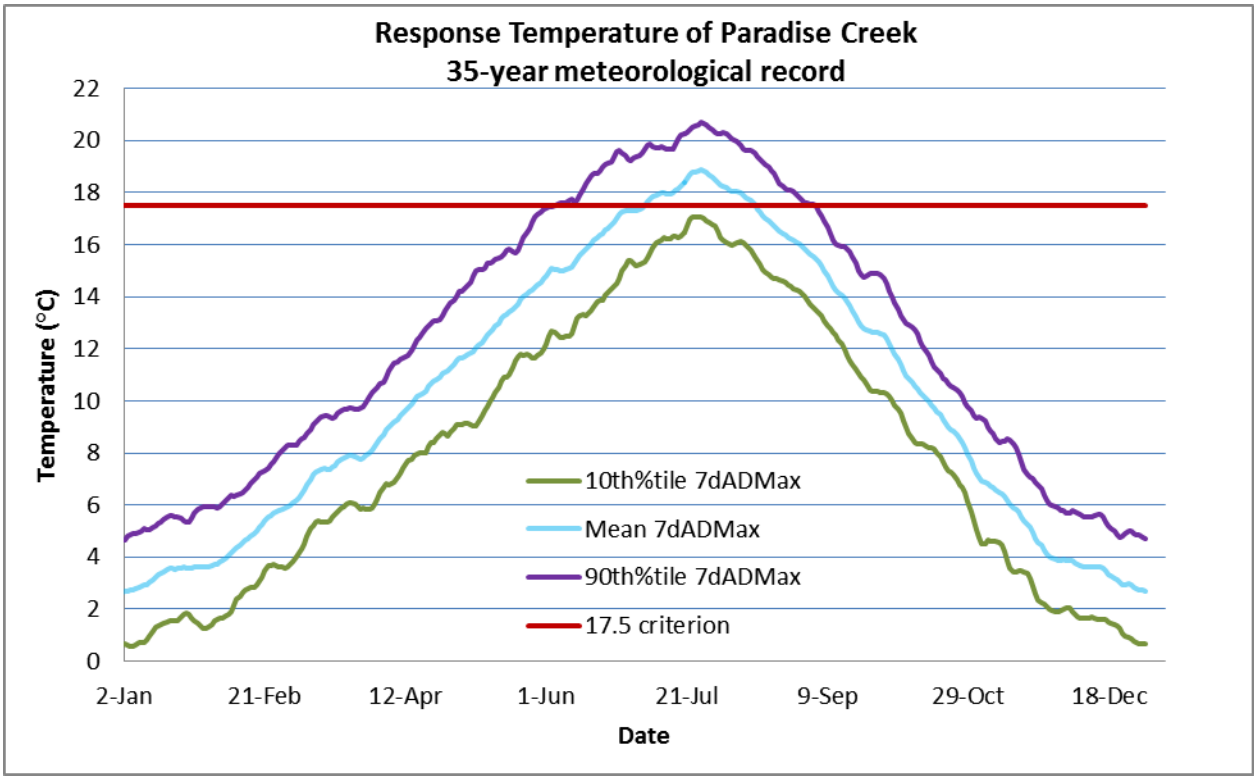

Figure 20. Response temperature of Paradise Creek to 35-year meteorological record.

Mean 7-day average daily maximum temperatures would exceed the 17.5°C criterion during summer months of most years. Mr. Carroll has provided a statement interpreting his model results:

> "Based on my analysis of 35 years of climate data (1973-2008) of the site in Paradise Creek above the Moscow POTW treatment plant, the 7DADmax for the current site potential water temperature would be above the 17.5 degree C Washington State criterion during June through August of most years. However, there would be some years (at least 10% on the average) when the 7DADmax would be below the 17.5 degree C criterion."

Results for the Idaho DEQ QUAL2Kw stream temperature model for Paradise Creek can be summarized as follows:

- Modeled potential stream temperatures predict a maximum stream temperature of 20.5°C in July in the stream reach above MWWTP for the model period April through September 2013
- System potential shade would provide less than 1°C cooling to current stream temperatures
- Response temperature of Paradise Creek to 35 years of meteorological data predict a 90th percentile 7-day average daily maximum stream temperature of 20.5°C in July in the stream reach above MWWTP

4 Conclusion

This study uses modeling to identify the stream temperatures in Paradise Creek that would occur under natural background conditions immediately upstream of MWWTP. The model showed that stream temperatures under system potential shade would be cooler than existing temperatures by 1°C or less. That is, existing stream temperatures are near to system potential temperatures in most scenarios.

The observed data showed low diurnal variation between minimum and maximum temperatures from mid-June through September. During low flow periods, much of Paradise Creek exhibits minimal flow connecting zones of standing water. These residual pools are where the 2013 temperature data were collected and would seem to be areas where exchanges with near surface seepage are greater. One would expect little diurnal variation in an area dominated by near surface runoff. During these low flow periods, little heat transport occurs, and model reaches 1 through 3 are dominated by surface heat exchange. Modeling a small system with minimal flows is difficult. Model reach 4 is dominated by effluent from MWWTP, and heat transport is more easily simulated in this reach.

DEQ modeled many alternative scenarios before settling on the final model scenario as the most reliable to calibrate to existing conditions. Spatial and temporal results varied, but in all scenarios, stream temperatures under system potential shade were cooler than existing temperatures. The cooling effects were greater in the forested reaches on Moscow Mountain and less in extremely low flow reaches and seasons. Overall, cooling effects of system potential shade were less than 1°C. Since the same relative results were found throughout alternative model scenarios, DEQ is confident that the dynamic temperature model has a strong predictive power.

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Glossary

7dADMax	7-day average of the daily maximum temperatures. This is the arithmetic average of seven consecutive measures of daily maximum temperatures. The 7-DADMax for any day is calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the 3 days prior and the 3 days after that date.
Baseflow	The portion of streamflow that includes ground water and base runoff. This is the average streamflow that occurs most of the year. It is the remainder of the streamflow after peak runoff is over.
Bias	The average of the difference between hourly measured values and modeled predictions.
Diurnal	Recurring every day; daily—related to actions that are completed in the course of a calendar day and typically recur every calendar day. For instance, diurnal temperature increases during the day and decreases during the night.
Effective shade	The fraction of incoming solar shortwave radiation that is blocked from reaching the surface of a stream of other defined area.
Effluent	Outflow of waste or water from a treatment facility or the outflow of sewage from a sewer system
Hyporheic flow	Water from a stream channel that enters the streambed and reemerges downstream—this is the area where surface water and ground water meet. The thickness of this region is the hyporheic zone, and processes that exchange materials or heat are referred to as hyporheic exchange.
Longwave	The infrared energy radiated by the earth and the atmosphere; a reflection of shortwave solar radiation
MDAT	Maximum daily average temperature, which is 19 °C (66°F) for the cold water aquatic life beneficial use.
MDMT	Maximum daily maximum temperature, which is 22 °C (72°F) for the cold water aquatic life beneficial use.
Nonpoint source	Pollution that enters waters of the state from an unidentifiable source. Nonpoint sources can include atmospheric dispersion, stormwater runoff from parking lots, roofs, and streets, or surface water runoff from agricultural lands. Generally, any unconfined and diffuse source of contamination.
Point source	Pollution that comes from specific locations such as pipes, outfalls, and conveyance channels to surface water. Point sources can include municipal wastewater treatment plants or stormwater systems.
Reach	Any length of stream; specifically, a length of the channel uniform in discharge, depth, area, slope, or riparian condition

Residuals	The absolute difference between measured and modeled results
Riparian	Relating to the banks along a course of water
Root-mean-square error (RMSE)	The difference between measured and modeled values, or residuals. This statistic is found by summing the squares of the residuals at each interval and taking the square root of the sum.
Salmonid	Any fish that belong to the family *Salmonidae*.
Sediment	Soil or rocks in a range of sizes consisting of fragments of weathered minerals suspended, transported, or deposited by water or air
Shortwave	The radiant energy emitted from the sun
StreamStats	A US Geological Survey web-based geographic information systems regression analysis that predicts streamflow response based on basin characteristics like basin size, precipitation, elevation aspect, slope, percent vegetative cover, urban, and impervious surfaces.
System potential	An approximation of the conditions that was present before European settlement. The simulation of system potential stream temperature uses best estimates of mature riparian vegetation that would occur without any human alteration, including some level of natural age-class diversity and disturbance history. System potential shade is a broad scale view of shade conditions along a stream.
Total maximum daily load (TMDL	In common usage, a TMDL also refers to the written document that contains the statement of loads and supporting analyses, often incorporating TMDLs for several water bodies and/or pollutants within a given watershed.
Wasteload allocation	The portion of receiving water's load capacity that is allocated to one of its existing or future point sources of pollution. Wasteload allocations specify how much pollutant each point source may release to a water body.

Appendix A. Channel and Velocity Field Measurements

Table A-1. Paradise Creek stream width.

Date	Site 1	Site 2	Site 3	Site 7	Site 10	Site 11	Site 12	Site 13	Site 14
	Site Name and Location								
	Upper Forest	**Mid-Forest**	**Lower Forest**	**Upper Prairie**	**Lower Prairie**	**East Moscow**	**West Moscow**	**Above MWWTP Outfall**	**Below MWWTP Outfall**
	46.816 -116.971	**46.807 -116.976**	**46.783 -116.982**	**46.781 -116.980**	**46.744 -116.972**	**46.729 116.979**	**46.731 -117.010**	**46.732 -117.034**	**46.731 117.040**
	Stream Width (feet)								
3/18/2013	—	—	—	—	—	—	—	14.0	—
4/2/2013	1	2	1.5	2.5	3.5	5	5.5	11.0	12.0
4/16/2013	—	—	1.5	—	4.5	5.5	—	—	—
4/17/2013	1.5	2.5	—	—	—	—	5.5	12.0	12.0
5/2/2013	2	—	1.0	—	2.5	—	—	11.0	12.0
5/28/2013	—	—	—	—	—	—	—	10.0	12.0
6/3/2013	—	1.5	1.5	—	2.5	—	—	7.0	—
6/17/2013	1	—	1.0	Dry	1.5	—	4.0	9.0	—
7/1/2013	0.5	—	1.5	—	0.5	—	—	8.0	11.0
7/17/2013	0.25	—	—	—	—	—	—	—	—
7/29/2013	—	—	—	—	—	—	—	10.0	12.0
9/30/2013	—	—	—	Dry	—	—	—	—	—
10/15/2013	—	—	—	—	—	—	2.0	—	10.0

Table A-2. Paradise Creek stream average depth.

Date	Site 1	Site 2	Site 3	Site 7	Site 10	Site 11	Site 12	Site 13	Site 14
	Upper Forest	Mid-Forest	Lower Forest	Upper Prairie	Lower Prairie	East Moscow	West Moscow	Above MWWTP Outfall	Below MWWTP Outfall
	46.816 -116.971	46.807 -116.976	46.783 -116.982	46.781 -116.980	46.744 -116.972	46.729 116.979	46.731 -117.010	46.732 -117.034	46.731 117.040
	Average Depth (feet)								
3/18/2013	—	—	—	—	—	—	—	1.183	—
4/2/2013	0.35	0.140	0.362	1.283	0.656	0.0945	0.304	1.192	1.269
4/16/2013	—	—	0.462	—	0.670	0.887	—	—	—
4/17/2013	0.325	0.192	—	—	—	—	0.296	1.073	1.088
5/2/2013	0.310	—	0.367	—	0.692	—	—	1.075	1.161
5/28/2013	—	—	—	—	—	—	—	0.845	1.092
6/3/2013	—	0.081	0.125	—	0.125	—	—	0.437	—
6/17/2013	0.150	—	0.233	Dry	0.083	—	0.040	1.062	—
7/1/2013	0.075	—	0.262	—	0.1	—	—	0.750	0.737
7/17/2013	0.25	—	—	—	—	—	—	—	—
7/29/2013	—	—	—	—	—	—	—	1.050	0.892
9/30/2013	—	—	—	Dry	—	—	—	—	—
10/15/2013	—	—	—	—	—	—	0.130	—	0.950

Table A-3. Paradise Creek stream average velocity.

Date	Site 1	Site 2	Site 3	Site 7	Site 10	Site 11	Site 12	Site 13	Site 14
	Site Name and Location								
	Upper Forest	**Mid-Forest**	**Lower Forest**	**Upper Prairie**	**Lower Prairie**	**East Moscow**	**West Moscow**	**Above MWWTP Outfall**	**Below MWWTP Outfall**
	46.816 -116.971	**46.807 -116.976**	**46.783 -116.982**	**46.781 -116.980**	**46.744 -116.972**	**46.729 116.979**	**46.731 -117.010**	**46.732 -117.034**	**46.731 117.040**
	Average Velocity (feet per second)								
3/18/2013	—	—	—	—	—	—	—	0.407	—
4/2/2013	0.608	0.946	2.93	0.521	1.623	0.727	3.118	0.278	0.550
4/16/2013	—	—	1.046	—	1.246	0.799	—	—	—
4/17/2013	0.754	1.125	—	—	—	—	2.802	0.299	0.629
5/2/2013	0.557	—	0.812	—	1.493	—	—	0.284	0.568
5/28/2013	—	—	—	—	—	—	—	0.154	0.337
6/3/2013	—	0.283	0.351	—	1.050	—	—	0.203	—
6/17/2013	0.148	—	0	Dry	0.025	—	0.021	0.009	—
7/1/2013	0.559	—	0.038	—	0.393	—	—	0.066	0.242
7/17/2013	0.572	—	—	—	—	—	—	—	—
7/29/2013	—	—	—	—	—	—	—	0	0.148
9/30/2013	—	—	—	Dry	—	—	—	—	—
10/15/2013	—	—	—	—	—	—	0.168	—	0.278

Table A-4. Paradise Creek total streamflow.

Date	Site 1	Site 2	Site 3	Site 7	Site 10	Site 11	Site 12	Site 13	Site 14
	Site Name and Location								
	Upper Forest	Mid-Forest	Lower Forest	Upper Prairie	Lower Prairie	East Moscow	West Moscow	Above MWWTP Outfall	Below MWWTP Outfall
	46.816 -116.971	46.807 -116.976	46.783 -116.982	46.781 -116.980	46.744 -116.972	46.729 116.979	46.731 -117.010	46.732 -117.034	46.731 117.040
	Total Streamflow (cubic feet per second)								
3/18/2013	—	—	—	—	—	—	—	9.519	—
4/2/2013	0.310	0.365	0.481	2.326	4.711	4.440	5.678	4.728	9.511
4/16/2013	—	—	0.939	—	5.431	4.851	—	—	—
4/17/2013	0.538	0.737	—	—	—	—	5.498	5.408	9.674
5/2/2013	0.423	—	0.382	—	3.218	—	—	4.635	9.503
5/28/2013	—	—	—	—	—	—	—	1.773	5.122
6/3/2013	—	0.057	0.097	—	0.370	—	—	1.122	—
6/17/2013	0.035	—	0	Dry	0.004	—	0.012	0.113	—
7/1/2013	0.026	—	0.018	—	0.032	—	—	0.622	2.381
7/17/2013	0.043	—	—	—	—	—	—	—	—
7/29/2013	—	—	—	—	—	—	—	0	1.687
9/30/2013	—	—	—	Dry	—	—	—	—	—
10/15/2013	—	—	—	—	—	—	0.051	—	3.173

Appendix B. StreamStats Predictions

Basin Characteristics Report

Date: Thu Apr 9 2015 11:58:08 Mountain Daylight Time
NAD27 Latitude: 46.7310 (46 43 51)
NAD27 Longitude: -117.0383 (-117 02 18)

Parameter	Value
Area that drains to a point on a stream, in square miles	19.06
Mean annual precipitation, in inches	24.3
Minimum Basin Elevation in feet	2520
Maximum Basin Elevation in feet	4350
Mean Basin Elevation in feet	2830
Maximum - minimum elevation, in feet	1830
Mean basin slope computed from 10 m DEM, in percent	14
Mean basin slope. Computed from 10 m DEM and adjusted to approximate earlier values computed from 30 m DEM.	12.7
Percent of area having slope greater than or equal to 30 percent, computed from 10 m DEM	9
Percent of area with slopes greater than 30 percent. Computed from 10 m DEM and adjusted to approximate earlier values based on 30 m DEMs	6.38
Percentage of area having slopes greater than 50 percent, computed from 30 m DEMs	0.16
Percent of area having North-facing slopes greater than or equal to 30 percent, computed from 10 m DEM	2
Percent of area having North-facing slopes greater than or equal to 30 percent. Computed from 10 m DEM and adjusted to approximate values computed from 30 m DEM.	1
10-85 slope based on longest flow path computed using 10 m DEMs, in feet per mile	24.8
10-85 slope, in feet per mile. Computed based on longest flow path using 10 m DEMs and adjusted to approximate earlier measurements done using BASINSOFT.	29.5
Percent of drainage area as surficial volcanic rocks as defined in SIR 2006-5035	32.1
Percent of area covered by forest	12
Agricultural Land in Percentage of Drainage Area	64.2
Developed Land in Percentage of Drainage Area from 1992 NLCD data	18.1
Percentage of area covered by water or perennial ice or snow from NLCD1992	0.0511
Percentage of impervious area determined from NLCD 2001 impervious dataset	7.91
Percentage of urban land cover determined from NLCD 2001 land cover dataset	25.2

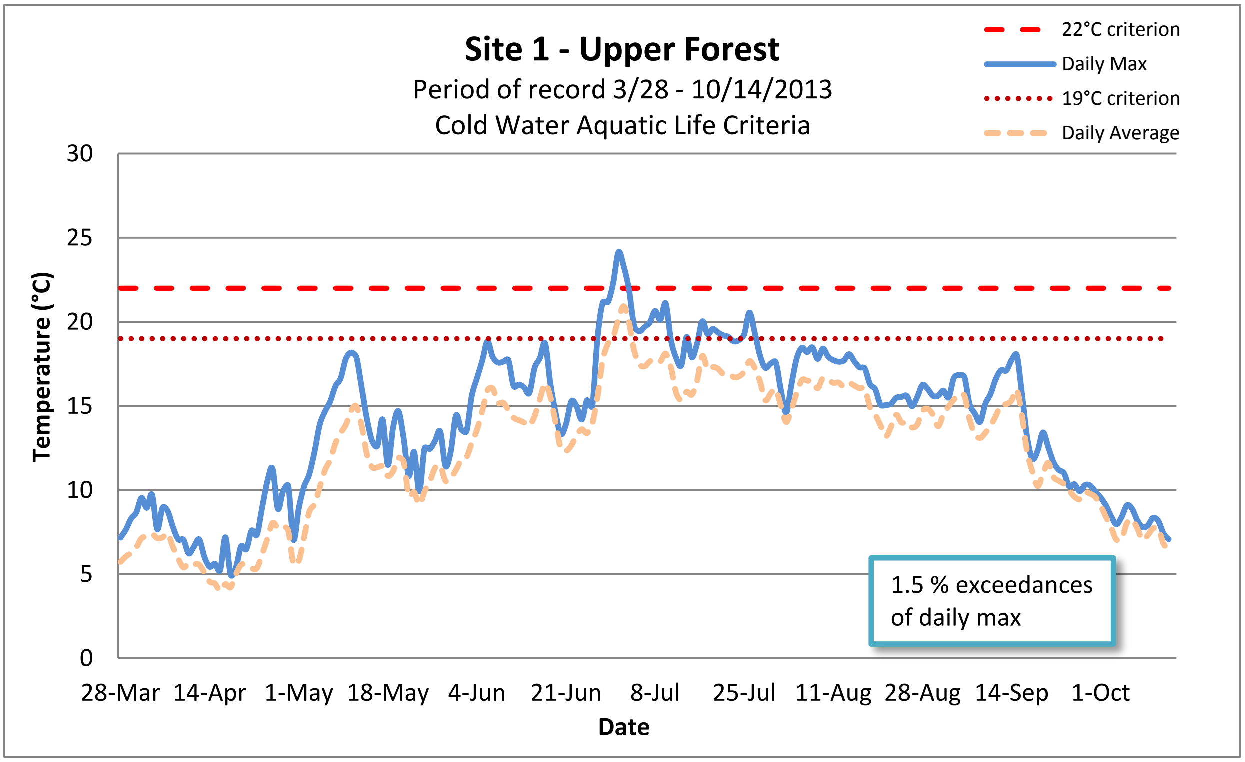
Monthly and Annual Streamflow Statistics

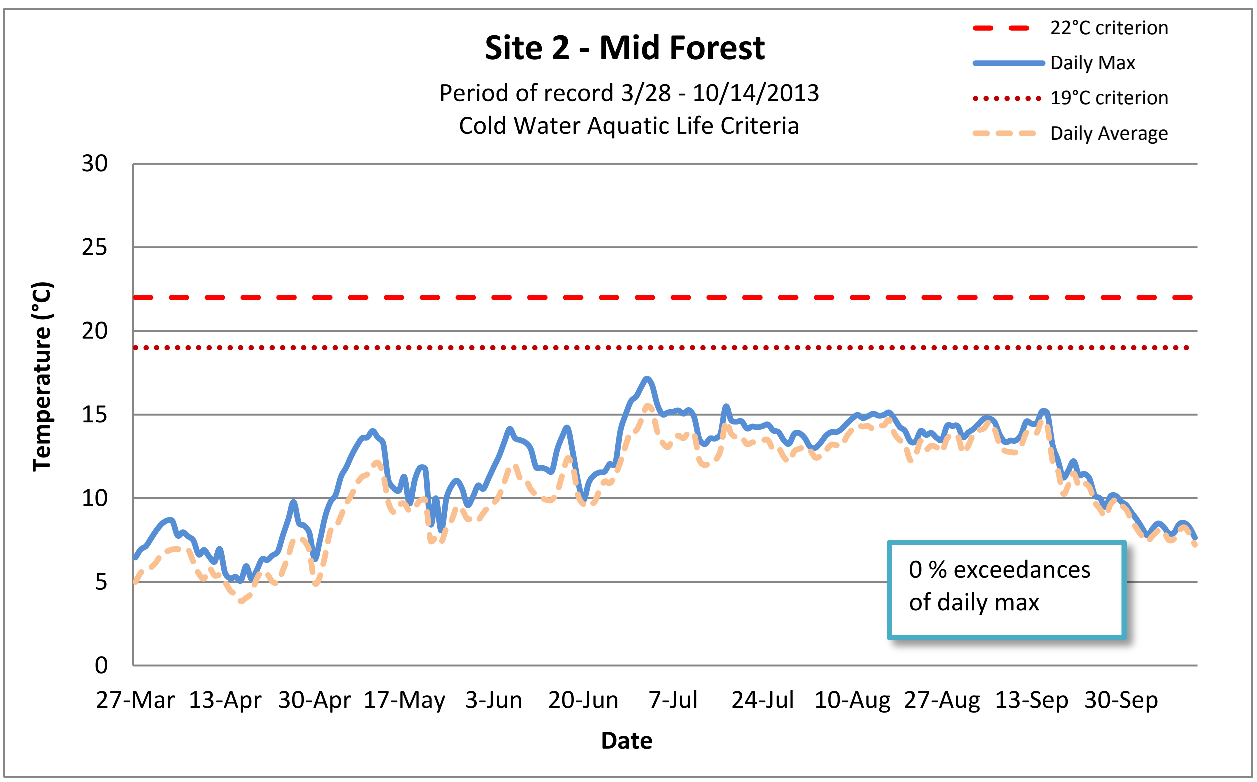
Statistic	Flow (ft^3/s)	Estimation Error (percent)
APRD20	11.3	44
APRD50	5.01	46
APRD80	2.39	61
MAYD20	3.75	61
MAYD50	1.69	51
MAYD80	1.08	44
JUND20	1.79	43
JUND50	1.19	30
JUND80	0.93	36
JULD20	1.03	21
JULD50	0.96	30
JULD80	0.97	50
AUGD20	1.01	28
AUGD50	1.03	44
AUGD80	1.07	96
SEPD20	1.04	22
SEPD50	1.02	33
SEPD80	1.02	63
DECD80	0.96	22

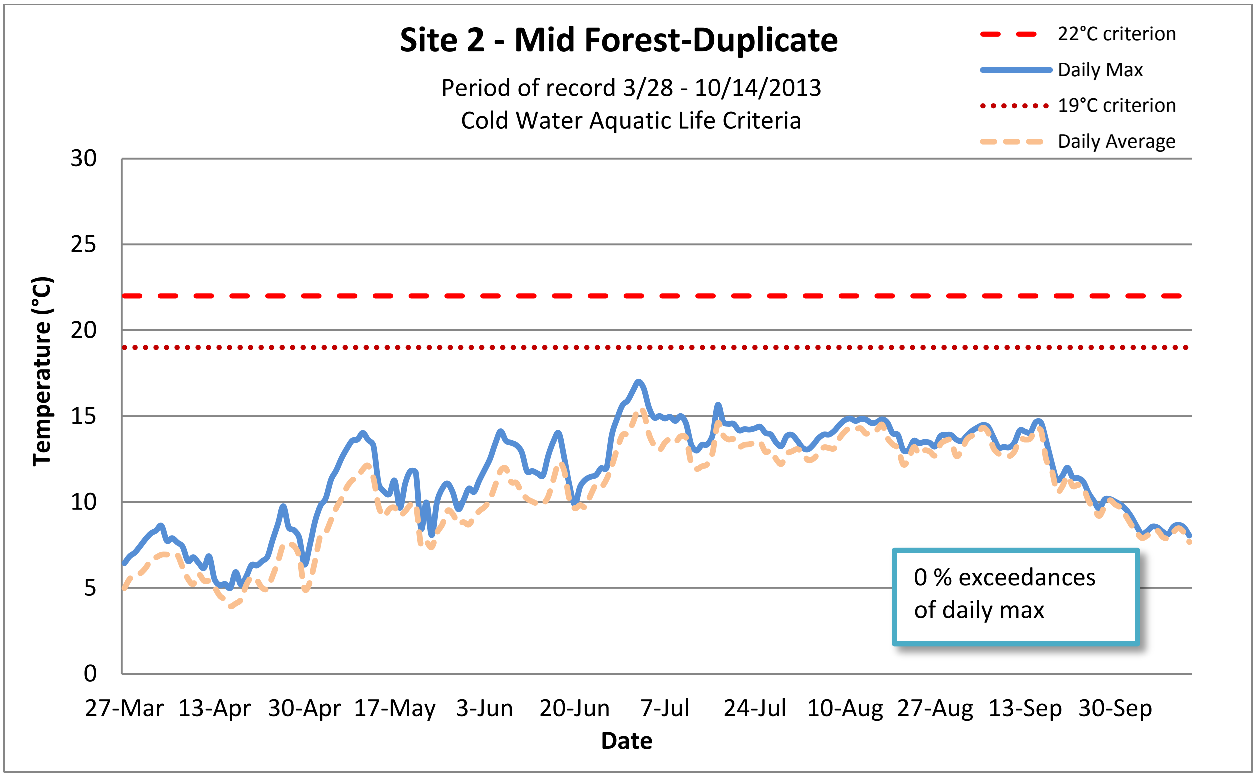
DEQ Analysis of 80th Percentile Streamflow Predictions

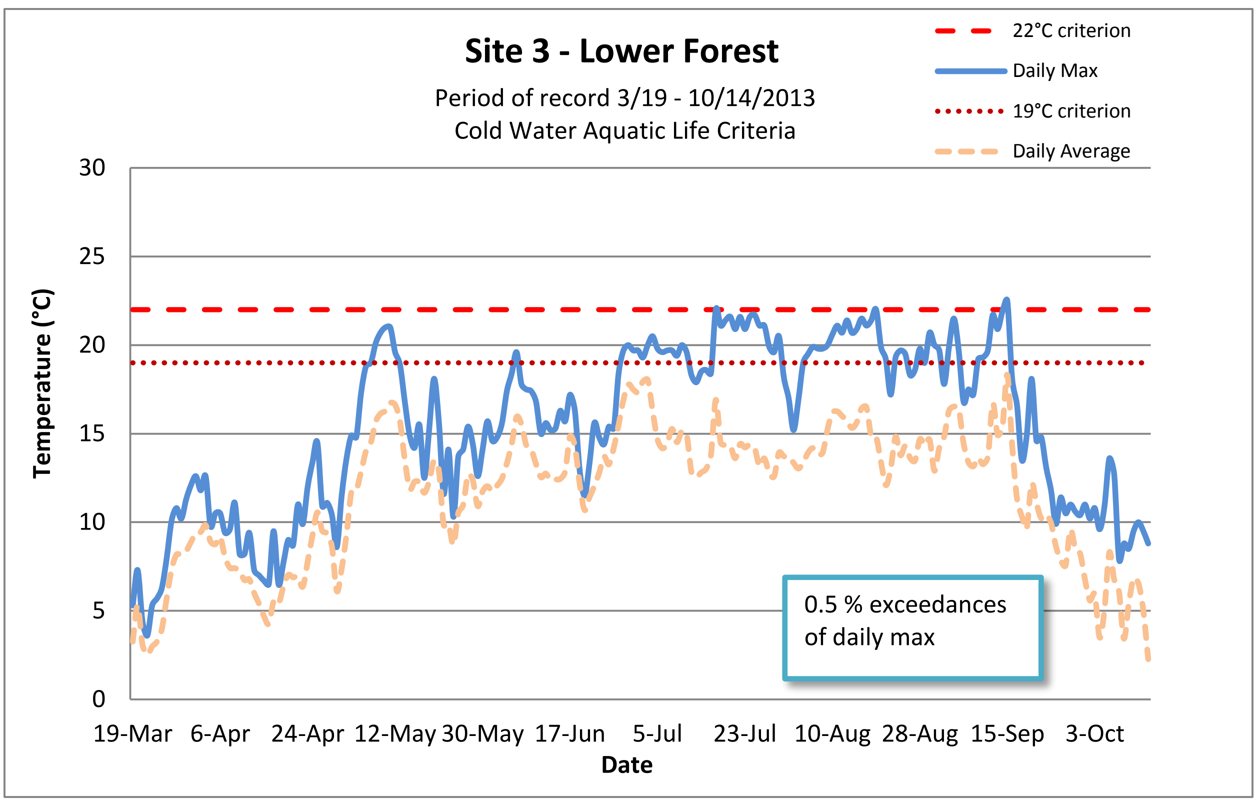
	Site 14		Site 12		Site 11		Site 10	
	cfs	cms	cfs	cms	cfs	cms	cfs	cms
4/30/2013	2.39	0.067677	1.97	0.055784	1.81	0.051253	1.55	0.043891
5/31/2013	1.08	0.030582	0.9	0.025485	0.83	0.023503	0.75	0.021238
6/30/2013	0.93	0.026335	0.83	0.023503	0.79	0.02237	0.75	0.021238
7/31/2013	0.97	0.027467	0.95	0.026901	0.94	0.026618	0.94	0.026618
8/31/2013	1.07	0.030299	1.13	0.031998	1.17	0.033131	1.23	0.03483
9/30/2013	1.02	0.028883	1.06	0.030016	1.09	0.030865	1.14	0.032281
6-month average		0.035207		0.032281		0.03129		0.030016

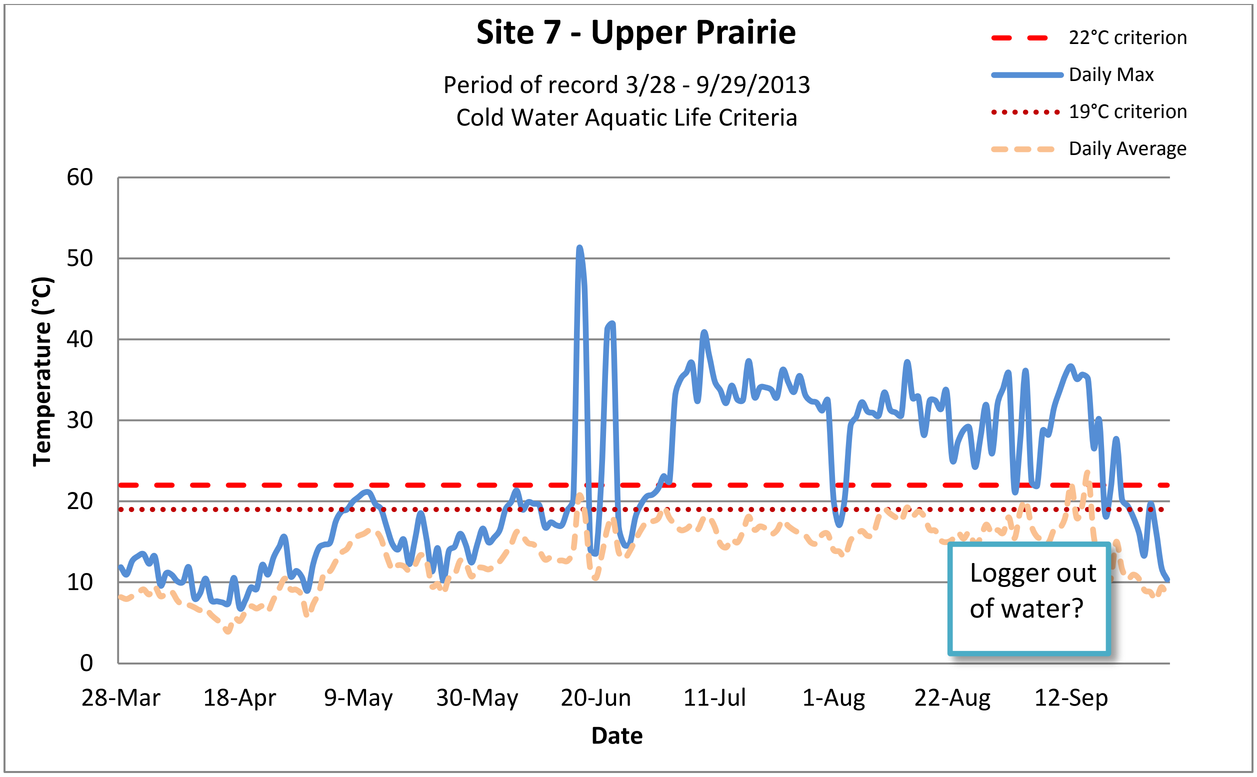
Appendix C. DEQ Stream Temperature Data Summaries



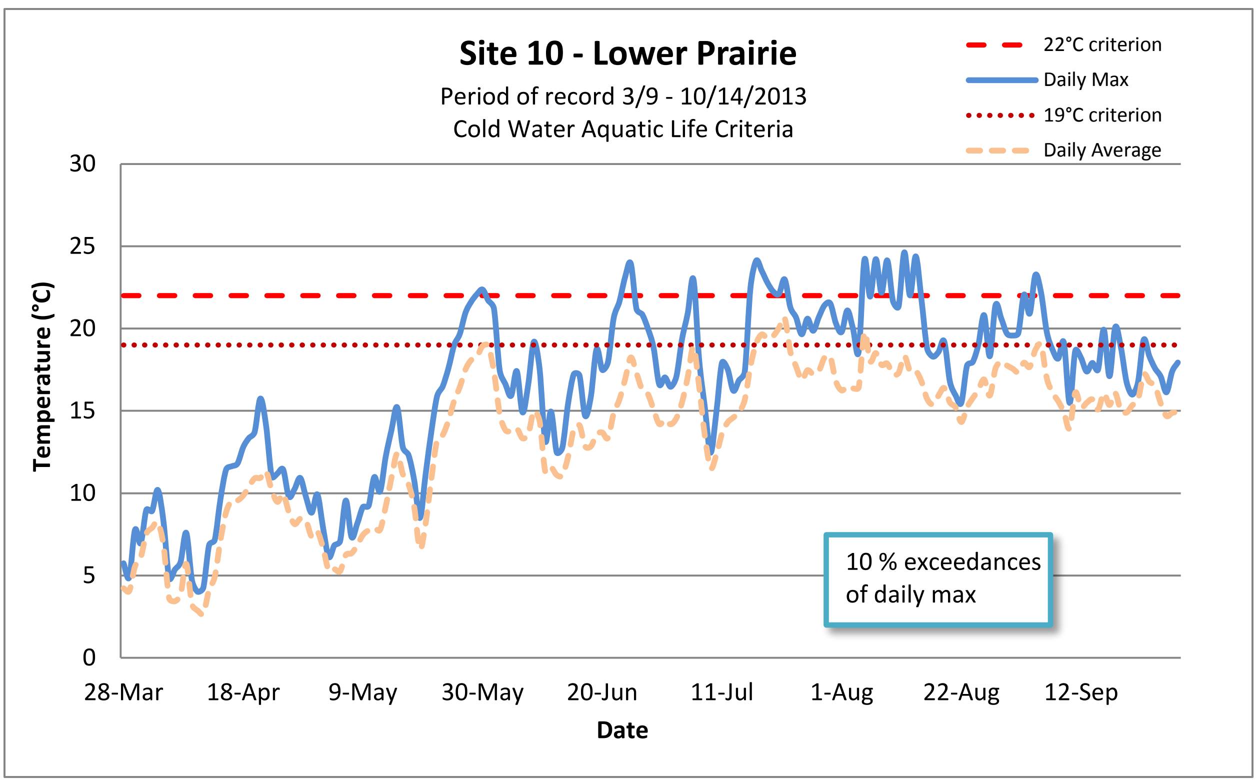



Site 2 - Mid Forest-Duplicate
Period of record 3/28 - 10/14/2013
Cold Water Aquatic Life Criteria
22°C criterion
Daily Max
19°C criterion
Daily Average
Temperature (°C)
30
25
20
15
10
5
0
0 % exceedances of daily max
27-Mar
13-Apr
30-Apr
17-May
3-Jun
20-Jun
7-Jul
24-Jul
10-Aug
27-Aug
13-Sep
30-Sep
Date

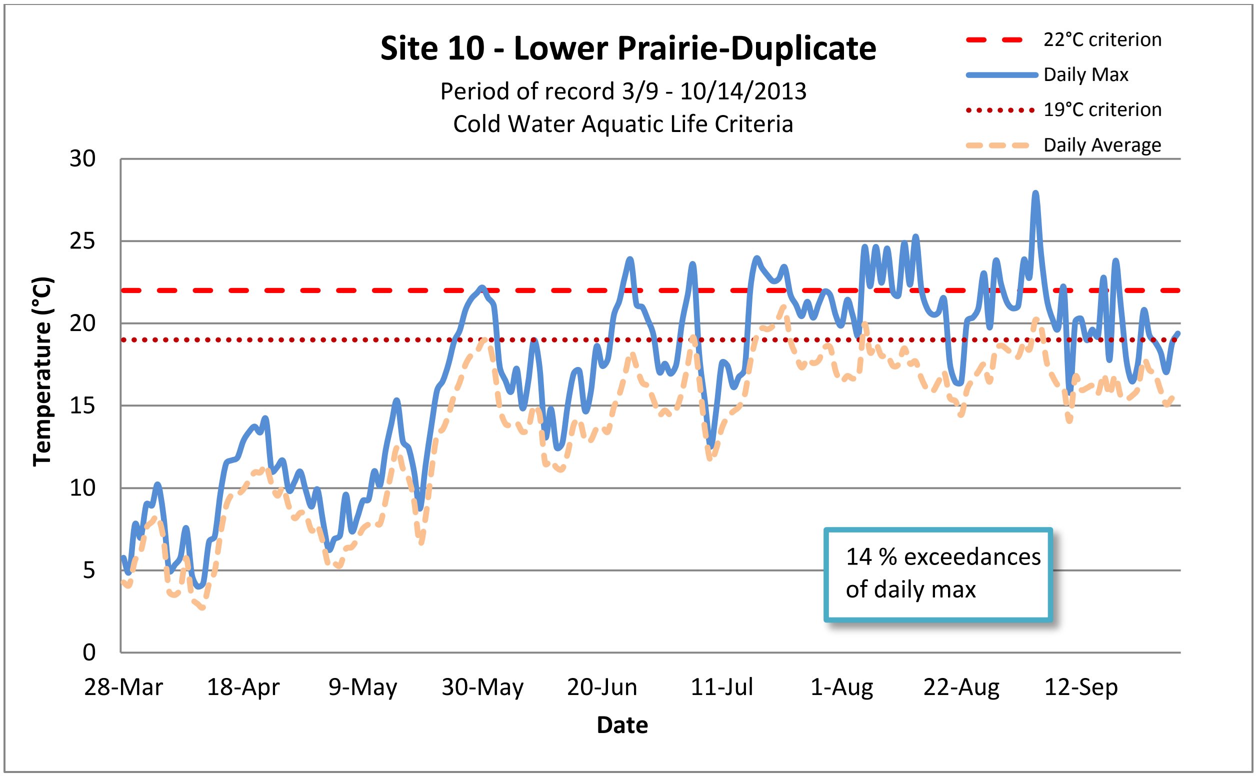

Site 3 - Lower Forest
Period of record 3/19 - 10/14/2013
Cold Water Aquatic Life Criteria
22°C criterion
Daily Max
19°C criterion
Daily Average
Temperature (°C)
30
25
20
15
10
5
0
0.5 % exceedances of daily max
19-Mar
6-Apr
24-Apr
12-May
30-May
17-Jun
5-Jul
23-Jul
10-Aug
28-Aug
15-Sep
3-Oct
Date



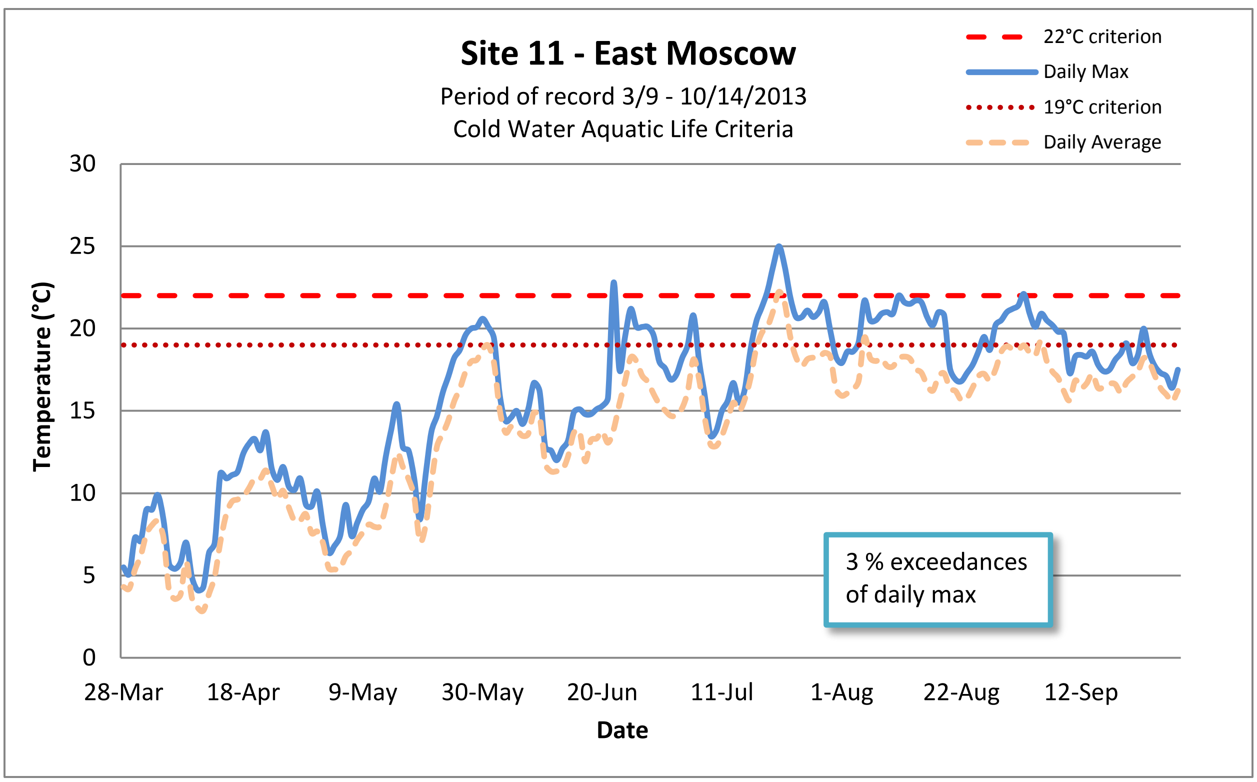
Site 7 - Upper Prairie
Period of record 3/28 - 9/29/2013
Cold Water Aquatic Life Criteria
22°C criterion
Daily Max
19°C criterion
Daily Average
Temperature (°C)
60
50
40
30
20
10
0
28-Mar
18-Apr
9-May
30-May
20-Jun
11-Jul
1-Aug
22-Aug
12-Sep
Date
Logger out of water?



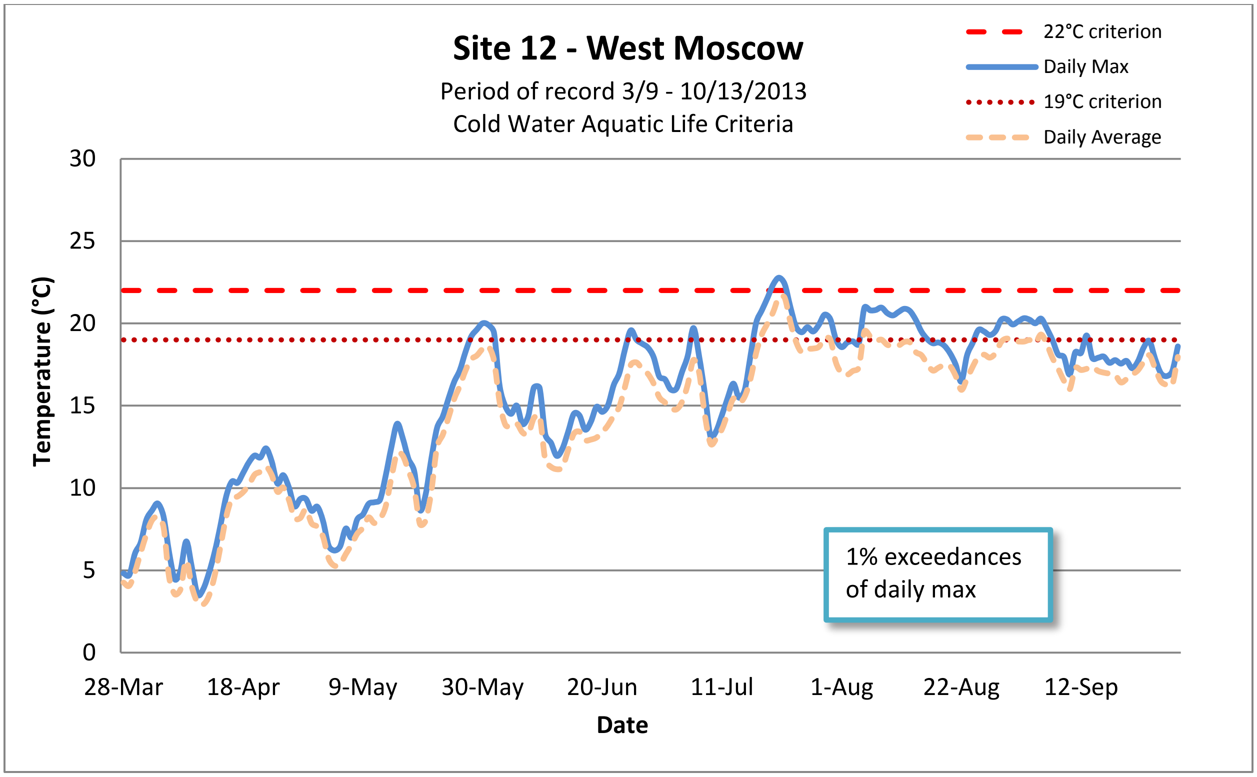
Site 10 - Lower Prairie
Period of record 3/9 - 10/14/2013
Cold Water Aquatic Life Criteria
22°C criterion
Daily Max
19°C criterion
Daily Average
Temperature (°C)
30
25
20
15
10
5
0
28-Mar
18-Apr
9-May
30-May
20-Jun
11-Jul
1-Aug
22-Aug
12-Sep
Date
10 % exceedances of daily max

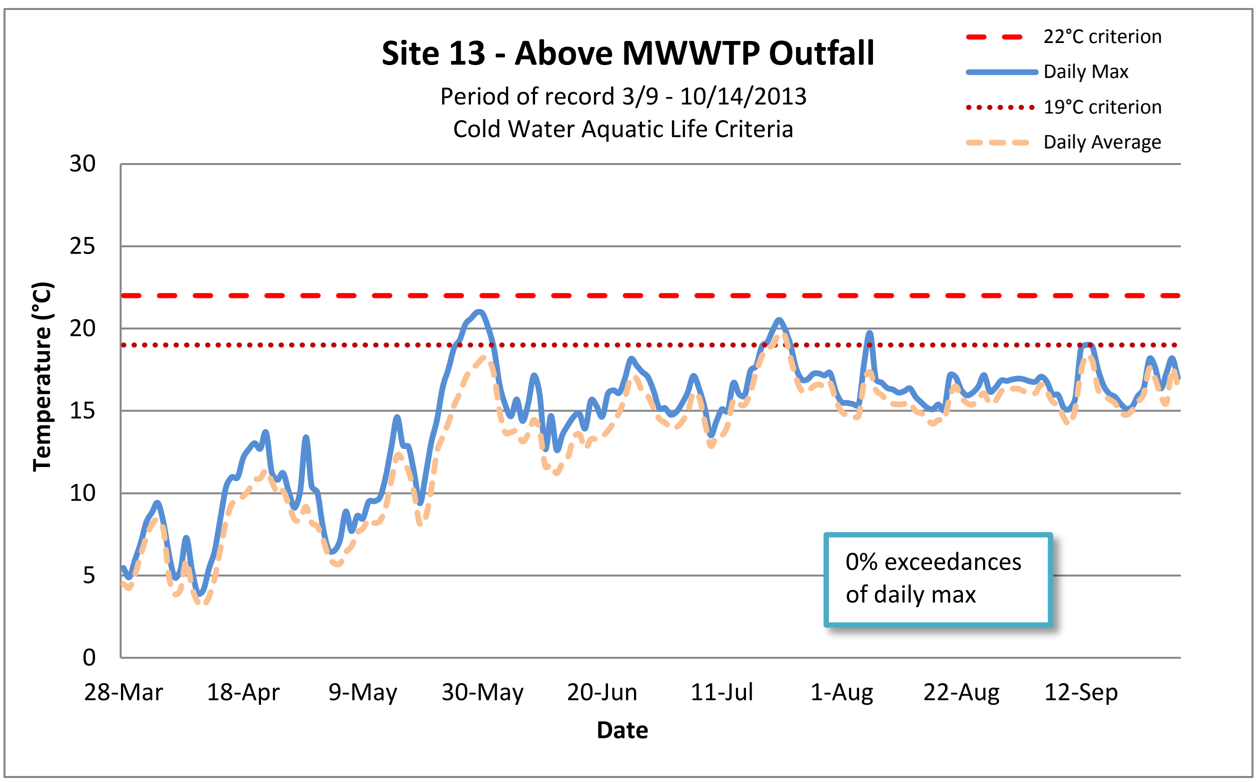


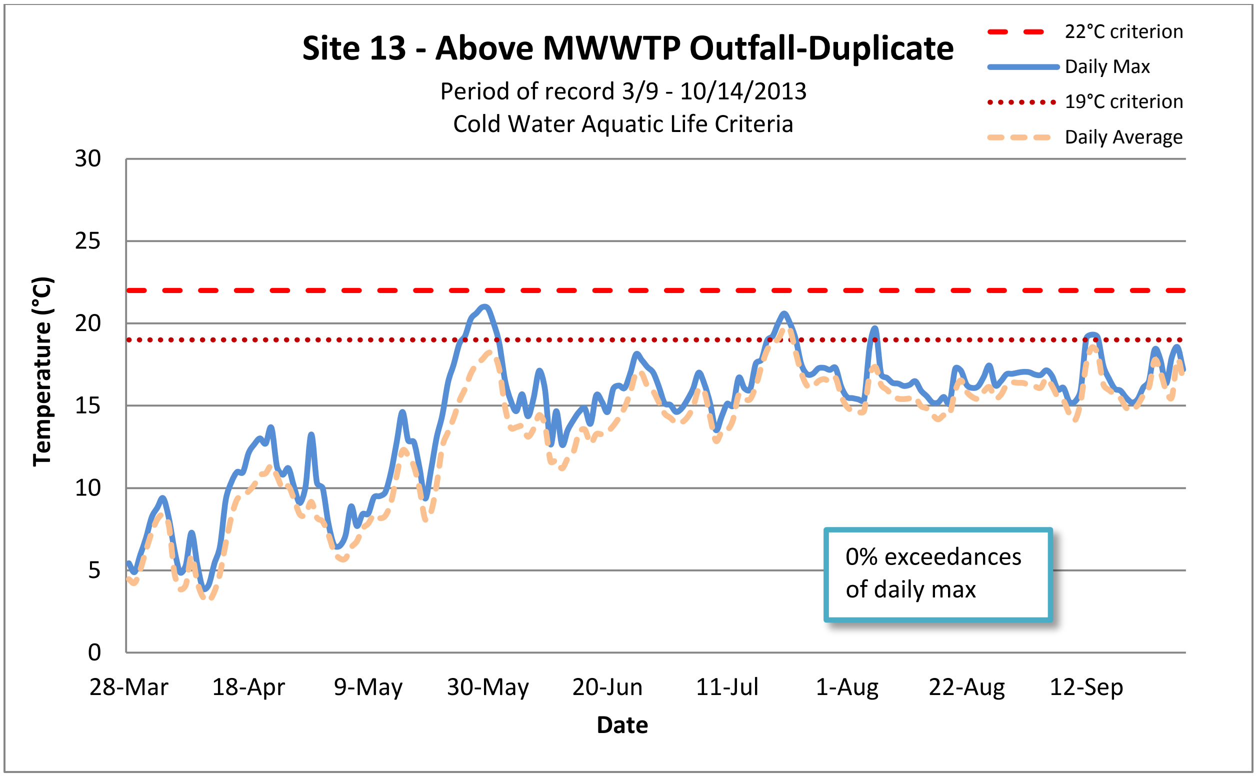
Site 10 - Lower Prairie-Duplicate
Period of record 3/9 - 10/14/2013
Cold Water Aquatic Life Criteria
22°C criterion
Daily Max
19°C criterion
Daily Average
Temperature (°C)
30
25
20
15
10
5
0
28-Mar
18-Apr
9-May
30-May
20-Jun
11-Jul
1-Aug
22-Aug
12-Sep
Date
14 % exceedances of daily max

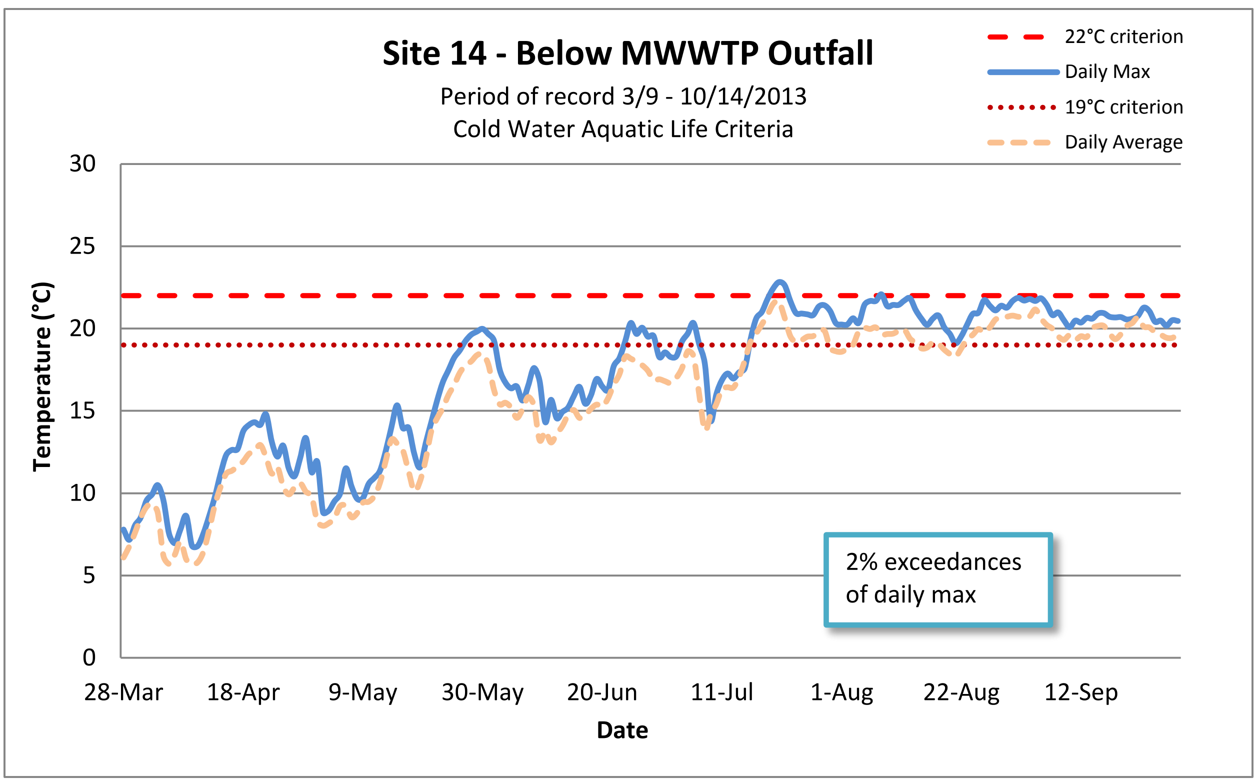


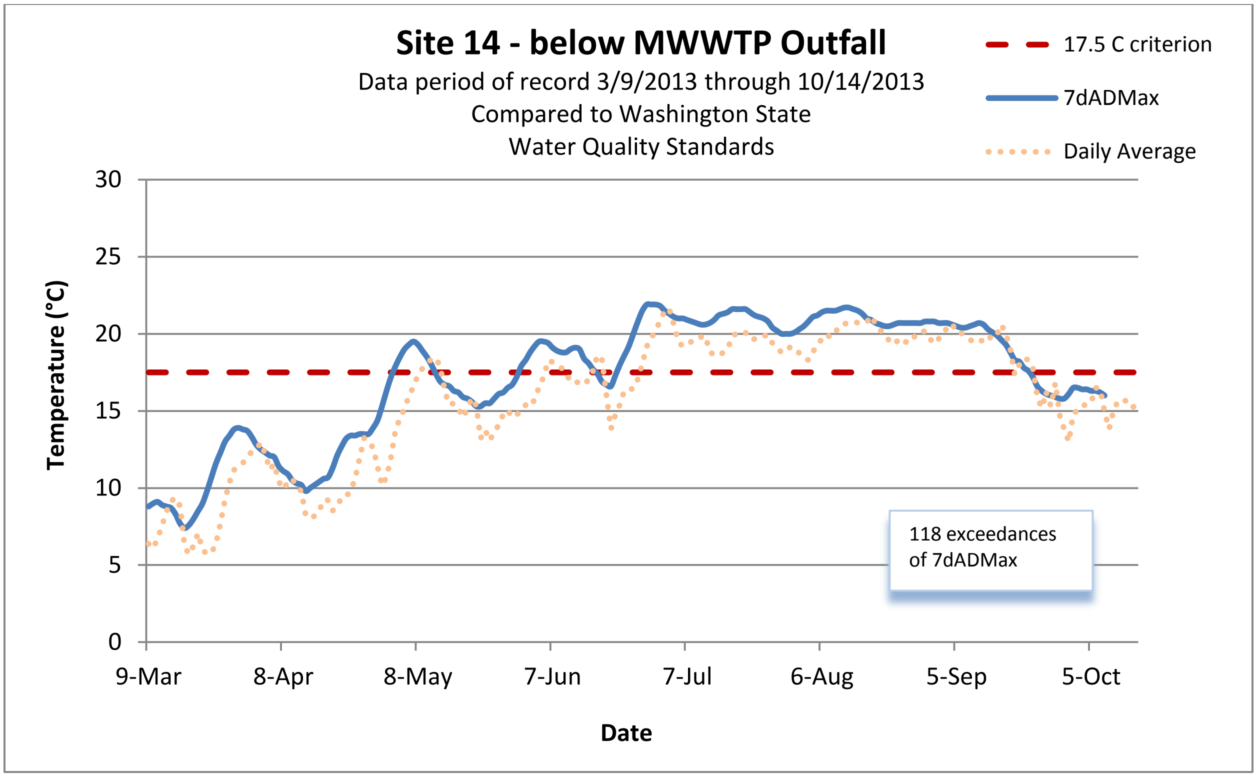
Site 11 - East Moscow
Period of record 3/9 - 10/14/2013
Cold Water Aquatic Life Criteria
22°C criterion
Daily Max
19°C criterion
Daily Average
Temperature (°C)
30
25
20
15
10
5
0
28-Mar
18-Apr
9-May
30-May
20-Jun
11-Jul
1-Aug
22-Aug
12-Sep
Date
3 % exceedances of daily max


Site 12 - West Moscow
Period of record 3/9 - 10/13/2013
Cold Water Aquatic Life Criteria
22°C criterion
Daily Max
19°C criterion
Daily Average
Temperature (°C)
30
25
20
15
10
5
0
28-Mar
18-Apr
9-May
30-May
20-Jun
11-Jul
1-Aug
22-Aug
12-Sep
Date
1% exceedances
of daily max


Site 13 - Above MWWTP Outfall
Period of record 3/9 - 10/14/2013
Cold Water Aquatic Life Criteria
22°C criterion
Daily Max
19°C criterion
Daily Average
Temperature (°C)
30
25
20
15
10
5
0
28-Mar
18-Apr
9-May
30-May
20-Jun
11-Jul
1-Aug
22-Aug
12-Sep
Date
0% exceedances
of daily max


Site 13 - Above MWWTP Outfall-Duplicate
Period of record 3/9 - 10/14/2013
Cold Water Aquatic Life Criteria
22°C criterion
Daily Max
19°C criterion
Daily Average
Temperature (°C)
30
25
20
15
10
5
0
0% exceedances of daily max
28-Mar
18-Apr
9-May
30-May
20-Jun
11-Jul
1-Aug
22-Aug
12-Sep
Date


Site 14 - Below MWWTP Outfall
Period of record 3/9 - 10/14/2013
Cold Water Aquatic Life Criteria
22°C criterion
Daily Max
19°C criterion
Daily Average
Temperature (°C)
30
25
20
15
10
5
0
2% exceedances of daily max
28-Mar
18-Apr
9-May
30-May
20-Jun
11-Jul
1-Aug
22-Aug
12-Sep
Date



Site 14 - below MWWTP Outfall
Data period of record 3/9/2013 through 10/14/2013
Compared to Washington State
Water Quality Standards
17.5 C criterion
7dADMax
Daily Average
118 exceedances of 7dADMax
Temperature (°C)
30
25
20
15
10
5
0
9-Mar
8-Apr
8-May
7-Jun
7-Jul
6-Aug
5-Sep
5-Oct
Date

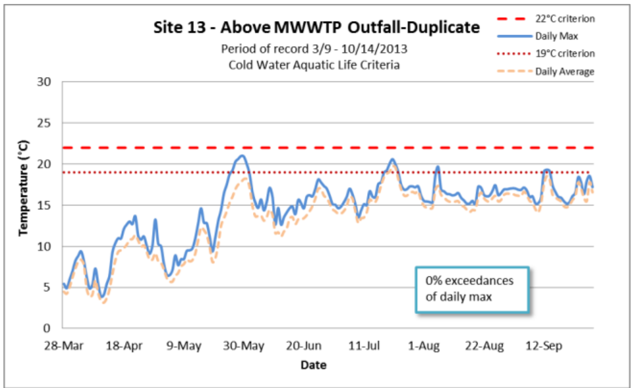
Appendix D. Responses to Comments

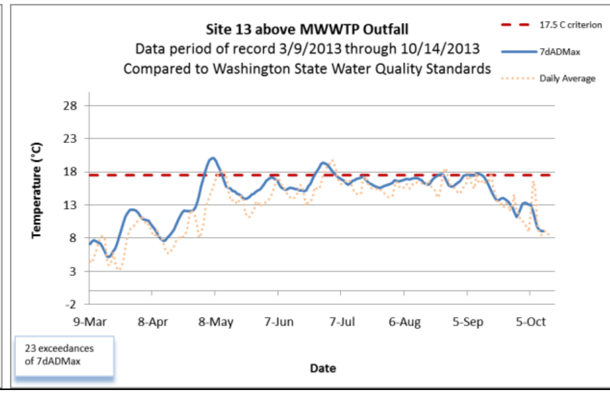
<table>
<tr><th colspan="2">Comments and Response Table</th></tr>
<tr><td colspan="2">5/19/2015 Elaine Snouwaert, Washington Department of Ecology</td></tr>
<tr><td>Section</td><td>Comment</td></tr>
<tr><td>General</td><td>It appears the calibration used is not the most up-to-date one from when Jim Carroll was assisting Darcy with model setup and calibration.</td></tr>
<tr><td colspan="2">Response 1: I have updated the calibration to be the most current one in this final model report</td></tr>
<tr><td>Executive Summary 1st, paragraph, 3rd sentence</td><td>Washington doesn’t use the classification system or the term “Class A” in current standards. Washington standards are now used based. In other words criteria are set to protect a beneficial use rather than a stream class. Paradise Creek is designated as having an aquatic life use of “salmonid spawning, rearing, and migration” and the temperature criteria of 17.5˚C 7-DADMax to protect for that use</td></tr>
<tr><td colspan="2">Response 2: Thank you—I have updated the Washington standards references to the appropriate aquatic life use.</td></tr>
<tr><td>section 2.1 (page 5, last paragraph)</td><td>See previous comment.</td></tr>
<tr><td colspan="2">Response 3: I have updated the Washington standards references to the appropriate aquatic life use.</td></tr>
<tr><td>Section 2.1.2, 1st bullet and 1st sentence of last paragraph on page 6:</td><td>According to the Oregon lawsuit findings, application of natural conditions need to consider these other factors if WLAs are to be based on them.</td></tr>
<tr><td colspan="2">Response 4: This comment refers to the fact that natural background hydrology and channel dimensions are not addressed by this study. The hydrology of the Paradise Creek watershed has been altered since human settlement. There was no channel for Paradise Creek through the City of Moscow according to data from an 1873 state boundary General Land Office survey. This survey indicated that a broad marsh occurred in this area and no distinct channel crossed the Idaho-Washington boundary. There is no ability to go back to natural hydrology for the Paradise Creek watershed.

Statewide, Idaho addresses temperature effects on water quality with potential natural vegetation TMDLS that compute temperature load allocations based on system potential shade. TMDL implementation projects to increase shade work to reduce water temperature in the vast majority of cases and helps habitat and other aspects of stream health as well. Idaho’s temperature TMDLs are based on accepting the current hydrologic conditions, other than that natural bankfull widths are estimated for regional hydrology curves to estimate system potential shade.

This is a system potential investigation rather than a natural background investigation. As such, system potential shade is the only component of the heat load to be analyzed in this model.</td></tr>
</table>

<table>
<tr><td>page 8, 1st paragraph</td><td>Explain reason sites 4, 5, and 6 are omitted from the analysis. How can site 3 be in both forested reach and in prairie reach? How can site 10 be in both prairie reach and urban (Moscow) reach?</td></tr>
<tr><td colspan="2">Response 5: I have revised this entire section to explain the monitoring location naming conventions based on ecosystem potential and that sites 4, 5, and 6 are on Idler’s Rest tributary and as such are a source to the model rather than included in the model.</td></tr>
<tr><td>page 18, Section 3.4, 1st sentence</td><td>It states the modeling was used to identify natural background stream temperatures. However, if water diversions, channel morphology changes, discharges, and other factors are not considered it isn’t really natural background, especially in light of Oregon lawsuit.</td></tr>
<tr><td colspan="2">Response 6: See Response 4: This is an investigation of system potential shade—not natural background hydrology.</td></tr>
<tr><td>page 24</td><td>The model should be used to model the segment below the WWTP outfall to determine the resulting in-stream temperatures based on the values in Table 8.</td></tr>
<tr><td colspan="2">Response 7: The stream temperature under system potential shade upstream of the WWTP outfall is the compliance point for wasteload allocations</td></tr>
<tr><td colspan="2">8/13/2015 Leigh Woodruff, Environmental Protection Agency Region 10</td></tr>
<tr><td>EPA comment:</td><td>Paradise Creek temperatures were monitored at several locations in 2013, a year in which summer air temperatures were much warmer than the 30 year average condition.</td></tr>
<tr><td colspan="2">Response 8: The current model report includes an analysis of system potential stream temperatures in Paradise Creek above the MWWTP outfall based on 35 years of climate data (1978 – 2008). This extends the analysis beyond the meteorological conditions of 2013. The results of the response temperature—which is the stream temperature under system potential shade—of Paradise Creek to 35 years of climate data is that the 7DADmax criterion of 17.5°C would be exceeded 90% of the time.</td></tr>
<tr><td>EPA comment:</td><td>The Paradise Creek temperature measured just above the Moscow WWTP exceeded the Idaho numeric average criteria in 2013 for only a few days in July (see Fig 16, p.22) and never exceeded the maximum temperature criteria.</td></tr>
<tr><td colspan="2">Response 9: The MWWTP is responsible for meeting Washington water quality standards, which is currently 17.5°C 7-day average of daily maximum temperatures (WAC 173-201A-200) with a 0.3°C allowance if natural conditions exceed the criterion (WAC 173-201A-200(1)(c)(i))</td></tr>
<tr><td>EPA comment:</td><td>The Moscow WWTP discharge is just upstream of the WA state line and the previous TMDL was based on meeting the WA criteria (18 C). The current WA criteria (17.5 C avg of 7 day max; 0.3C HUA) is more stringent than the ID criteria. Although the calculations were not directly presented in the document we reviewed, it is likely that stream temperatures exceeded the WA criteria upstream of the WWTP for a longer period than the Idaho standard.</td></tr>
<tr><td colspan="2">Response 10: Immediately upstream above the MWWTP outfall for the stream temperature period of record 3/9/2013 through 10/14/2013, there were no exceedances of the state of Idaho daily maximum temperature criterion of 22°C, but 23 exceedances of the Washington 7DADmax temperature criterion of 17.5°C, see figures below.</td></tr>
</table>





EPA comment: The TMDL is silent on when the increased allocation would apply. DEQ modeling suggests that the numeric criteria would only be exceeded naturally for 2 days (ID criteria), or 29 days (WA criteria). Given this information, our thinking is that you could not justify a WLA above the Idaho criteria (19 daily avg) for more than 2 days.

Response 11: The WLA will be presented in the TMDL instead of this model report, but the allowable volume of MWWTP discharge will be based on the volume and temperature of Paradise Creek above the outfall and the temperature of the MWWTP effluent.

EPA comment: In selecting the natural temperatures to assign as a revised WLA, IDEQ chose the single highest modeled temperature for the entire season (20.5 C) and applied it at all times in setting revised WLAs.

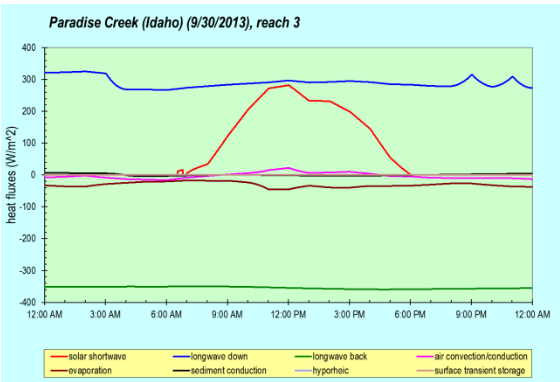
- This ignores that the natural temperature will be lower at other times when the WLA would apply,
- Choosing the maximum value is clearly not conservative in setting revised WLAs.

Response 12: This is not how the wasteload allocation will be calculated in the TMDL. The allowable volume of MWWTP discharge is based on the volume and temperature of Paradise Creek above the outfall and the temperature of the MWWTP effluent.

EPA comment: Statements made in the document imply that natural conditions were not modeled i.e., “shade is easier to manage”, “natural background hydrology and channel dimensions will not be addressed by this study”, “With extensive human impacts, it is not feasible to return to prehistoric hydrologic conditions.”. Therefore appears that the temperature estimates presented in the draft document likely do not represent natural conditions, and are not consistent with the notion that the TMDL would be able to achieve natural conditions based targets and allocations. It is highly likely that estimated natural condition stream temperatures would be lower if factors identified in the TMDL were included in the modeling effort, including: 1) natural groundwater/hyporheic inputs and natural hydrology (i.e., “Constructed subsurface drainages installed to aid agriculture change the natural hydrology.” “Construction with impermeable surfaces also alters ground water and surface water runoff patterns.” from page 6 in the draft revised TMDL); 2) narrower channels resulting in greater shade levels, as well as smaller surface area exposed to sun light and air temperatures (i.e., “Alterations to the stream channel by roads, structures, and cropland change the width, depth, and other channel parameters” from p. 6 in the draft revised TMDL), and 3) not using air temperatures from a year (i.e., 2013) which is much greater than the observed average air temperature over the past 30 years for an input parameter into the model estimating natural stream temperature conditions (i.e.., “Maximum temperatures were consistently warmer in 2013 than over a 30-year average.” from p. 5 in the document titled “Additional Paradise Analysis”.)

Response 13:

With the low flow of Paradise Creek, heat exchange in any give location is more important than heat transfer. There is not enough flow to transfer heat from one reach to another. The most significant contribution to the heat load is solar shortwave energy. The figure below shows the typical daily heat exchange for the reach above the MWWTP outfall. Solar shortwave inputs can be reduced by shade provided by topography or canopy cover from riparian vegetation.



For questions of modeling natural background hydrology, see Response 4 above: This is an investigation of system potential shade—not natural background hydrology.

EPA comment:	Finally, we are wondering if this effort been coordinated with Washington Ecology, e.g. interpretation of how their NC provision might be invoked, what their plans are for writing a WA temperature TMDL for Paradise Creek? Given that this TMDL may invoke the Washington natural conditions provision, and would likely be a significant factor in a Washington temperature TMDL, it seems essential to coordinate with Ecology on the standards and related issues.

Response 14: Idaho has coordinated with Ecology throughout the modeling process. Ecology has been present at a Palouse WAG meeting and presented their plans for their TMDL as well as providing comments on this model report on 5/19/2015. Ecology modelers Jim Carroll has collaborated with me (Darcy Sharp) during the development of the model scenarios reported here and provided much valuable advice and help on improving the dynamic temperature results. He has also provided the rtemp analysis of the response temperature of Paradise Creek to 35-years of meteorological data at Pullman, WA that is included in this report.

8/20/2015 City of Moscow: comment below derived from a conference call with LRO DEQ staff, City of Moscow representatives, and me.

	Monitoring data in the reach above the MWWTP outfall show an increased volume of cooler water. An earlier draft of the modeling report had speculated as to the source, but City of Moscow staff indicated that there is a perennial stream regionally known as Hog Creek.

Response 15: The National Hydrography Dataset layer at a 1:24,000 scale did not indicate a channel where Hog Creek is regionally known to exist. Subsequently, the City of Moscow Engineering Division has provided a current representation of the stream channel based on their record maps of pipes corrected visually with 2009 and 2012 aerial photos at a 0.5-foot resolution where surface flow occurs. I have replaced the NHD imagery in Figure 15 with the layer provided showing the Hog Creek channel.

	City of Moscow expresses concern that future watershed improvement projects that would daylight portions of Hog Creek may impact the system potential temperature of Paradise Creek.

Response 16: The volume and temperature of Hog Creek is an input to the model of existing conditions for the current model scenario but is not itself modeled. However, that does not preclude a future modeling project. If Hog Creek streamflow and temperature data were to be collected, we could always revisit this QUAL2Kw model to include the existing and potential conditions of Hog Creek and evaluate its impact on Paradise Creek stream temperature under alternative management scenarios.