APPENDIX J - QUAL2K TEMPERATURE ANALYSIS, DESCRIPTION, AND CONSTRAINING PARAMETERS

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J1.0 APPROACH

The QUAL2K modeling approach was used to determine the effects of shade and streamflow conditions on temperatures within Cherry, Moore, and Elk Creeks. QUAL2K incorporates measured air temperature, riparian shading, stream flow, and channel characteristics to predict stream temperatures. Minimum, maximum temperatures were modeled along a longitudinal gradient of each creek for the hottest temperature day during summer 2013. After temperatures were predicted accurately using measured conditions, the effects of changes in temperature with streamflow and shade modifications were evaluated by increasing these to target conditions.

QUAL2K is a one-dimensional river and stream water quality model that assumes the channel is well-mixed vertically and laterally. The QUAL2K model uses steady state hydraulics that simulates non-uniform steady flow. Since hydraulic and flow data was not collected specifically for the modeling of temperature, data collected for each creek by Montana DEQ for other purposes was used in the QUAL2K model. Whenever possible, data was used from a similar timeframe as the day when the temperature was modeled. However, in several cases, the only available data was collected at a different timeframe than the day that was modeled. Differences in modeled and actual temperatures may be partly due to discrepancies in dates between available data.

Model performance was determined using the average absolute relative error, which was the average of the percent difference between temperatures measured in the field and those modeled at the same locations.

Detailed data and parameters used in these models are located at the end of this appendix.

J2.0 DATA METHODS AND LIMITATIONS

The following describe the methods used to determine bounding parameters and conditions for the QUAL2K modeling. The datasets are provided at the end of this appendix.

J2.1 SHADE

Aerial photography with ArcGIS was used to estimate existing effective shade along length of the creek the using the Shade Tool (Washington State Department of Ecology 2007) (**Appendix G**) and validated using percent shade data collected in the field at the stream temperatures sites using a solar pathfinder.

J2.2 STREAM FLOW

Most of the streamflow data used in modeling was collected in the field by Montana DEQ. For Cherry Creek, temperature data was collected on 7/26/2013, while flow data used in modeling was collected on 8/5/2013. For Moore Creek, stream flow collected near the headwater site was not available from Montana DEQ near the date of the warmest temperature (7/3/2013). Therefore, stream flow data collected from Madison Stream Team on 7/3/2013 for their annual report was used in modeling (Madison Stream Team 2013). For Elk Creek, stream flow not available near the time of the highest temperature (7/3/2013) and stream flow collected on 6/12/13 was used in modeling.

Specific permitted irrigation withdrawals were not incorporated into the model. However, when possible, a water abstraction was used to represent the decrease in flow due to water use along the length of the River. For Cherry Creek, flow data from multiple sites on 8/5/2013 was used to estimate water withdrawals. Since Montana DEQ did not have adequate data available for Moore Creek near the date of highest temperature (July 3, 2013), the relative changes in water use for the date of 8/1/2003 was applied to the flow measured by Madison Stream Team. For Elk Creek, not enough data was available to determine relative changes in water consumption along the creek. Therefore, no abstractions were included in the model.

J2.3 HYDRAULIC CHARACTERISTICS

Wetted stream width and stream slope was estimated based on field measurements made by Montana DEQ during stream discharge estimates or habitat surveys. Manning's n was derived from these measurements using the Manning's Equation. When possible, flow and instream measurements taken near the time of the modelled temperature (i.e., the highest temperature day) were applied. Manning's n values were greater than would be expected during high flow conditions but were in the range of those typically observed at lower and mid flows (Chapra et al. 2012). The specific dates of each measurement used in the QUAL2k model are detailed at the tables at the end of this appendix.

J2.4 CLIMATE

Climate data for the modeled days were obtained from the Western Climate Center (https://wrcc.dri.edu/), Ennis Montana Site, including hourly air temperature and dew point temperature. Cloud cover was set at 5% and wind speed was set at 4 mph, which are typical values present on warm temperature days in Montana.

J2.5 WATER TEMPERATURE

Hourly water temperature data was collected using HOBO temperature loggers deployed at temperature monitoring sites in summer 2013 as described in **Appendix G**. Hourly data from the uppermost temperature monitoring site was used as a bounding condition. Minimum, mean, and maximum data from each site on this date was used to evaluate performance of the baseline model.

J2.6 LIGHT AND HEAT PARAMETERS

QUAL2K Default light and heat parameters were used in the models. The exceptions were the Ryan-Stolzenbach solar parameter, which was increased from 0.80 to 0.85, and the thermal thickness parameter, which was increased from 10 cm to 15 cm. Increases in these values improved performance, and were similar to changes employed during other temperature modeling efforts previously done for creeks in western Montana by Montana DEQ.

J3.0 MODELED TARGET SCENARIOS

The potential management scenarios modeled as part of this exercise reflected targets recommended by DEQ, including a 15% increased flow scenario, an increased shade scenario to represent likely shade as a result of riparian restoration, and a scenario that included a combination of actions (15 % increased

flow and increased shade). In addition, for Elk Creek, a reduced width scenario was modeled given that a habitat sampling site (near temperature site 1C) was not meeting target width/depth conditions.

The resulting temperatures were predicted along the longitudinal gradient of each creek. Graphs were used to compare these temperatures with the 7-Day Lethal Temperature for 50% of the population of Cutthroat Trout, and the 24-hour Lethal Temperature for 10% of the Population of Cutthroat Trout. This comparison was made given the importance of this area for Weststlope Cutthroat Trout, which is the most sensitive fish species present in the creeks of interest.

J4.0 RESULTS

J4.1 VALIDATION

Modeled temperatures closely approximated actual temperatures for most temperature loggers (**Tables J-1, J-2,** and **J-3**) The absolute percent error was calculated for the maximum temperature value at each logger location using the formula:

Absolute Percent Error = | (Modeled-Actual)/Actual | 100)*

This was averaged across temperature loggers. The average absolute percent error between modeled and actual maximum temperatures for Cherry, Elk, and Moore Creeks were 1.9%, 2.4%, and 2.7%, respectively.

Table J-1 Difference Between Actual and Modeled Temperatures for Cherry Creek, 7/26/2013

Logger ID	Distance (miles)	Temperature Measure	Actual ˚C	Modeled ˚C
2A	13.5	minimum	11.28	12.89
2A	13.5	average	16.11	15.36
2A	13.5	maximum	18.01	17.76
2B	11.6	minimum	12.41	14.08
2B	11.6	average	15.78	16.41
2B	11.6	maximum	19.18	19.32
2C	1	minimum	15.17	16.88
2C	1	average	20.34	20.06
2C	1	maximum	25.47	24.76

Table J-2 Difference Between Actual and Modeled Temperatures for Elk Creek, 7/3/2013

Logger ID	Distance (miles)	Temperature Measure	Actual ˚C	Modeled ˚C
1B	8.4	minimum	15.8	16.7
1B	8.4	average	20.3	20.6
1B	8.4	maximum	25.4	26.0
1C	7.2	minimum	16.1	17.0
1C	7.2	average	20.1	21.1
1C	7.2	maximum	25.3	25.9
1D	0.6	minimum	18.8	17.4
1D	0.6	average	25.0	23.0
1D	0.6	maximum	30.8	29.9

Table J-3. Difference Between Actual and Modeled Temperatures for Moore Creek,7/3/2013

Logger ID	Distance (miles)	Temperature Measure	Actual ˚C	Modeled ˚C
4A	10.5	minimum	16.7	16.63
4A	10.5	average	18.5	18.25
4A	10.5	maximum	20.3	20.11
4D	7.8	minimum	15.7	16.23
4D	7.8	average	18.9	18.43
4D	7.8	maximum	22.29	20.87
4F	1.8	minimum	14.78	15.75
4F	1.8	average	19.7	19.95
4F	1.8	maximum	25.5	25.24

J4.2 SCENARIO OUTPUTS

J4.2.1 Cherry Creek

Results indicated that the increased flow scenario decreased modeled maximum temperatures by an average of 1.1˚C at the most downstream site, while the increased shade scenario decreased modeled maximum temperatures by 1.5˚ C. The combined scenario decreased modeled maximum temperatures by 1.9 ˚C (**Figure J-1** to **J-4**)

None of the scenarios resulted in a substantial increase in potential stream miles inhabited by Westslope cutthroat trout (The combined scenario resulted in only a ~ 0.5 mile potential increase in usable habitat) although an increase in shade had the most impact. However, given that the modeling represented the warmest day of the year, increased shade could increase the habitable portion of Cherry Creek by a greater amount other parts of the summer with less warm temperatures.

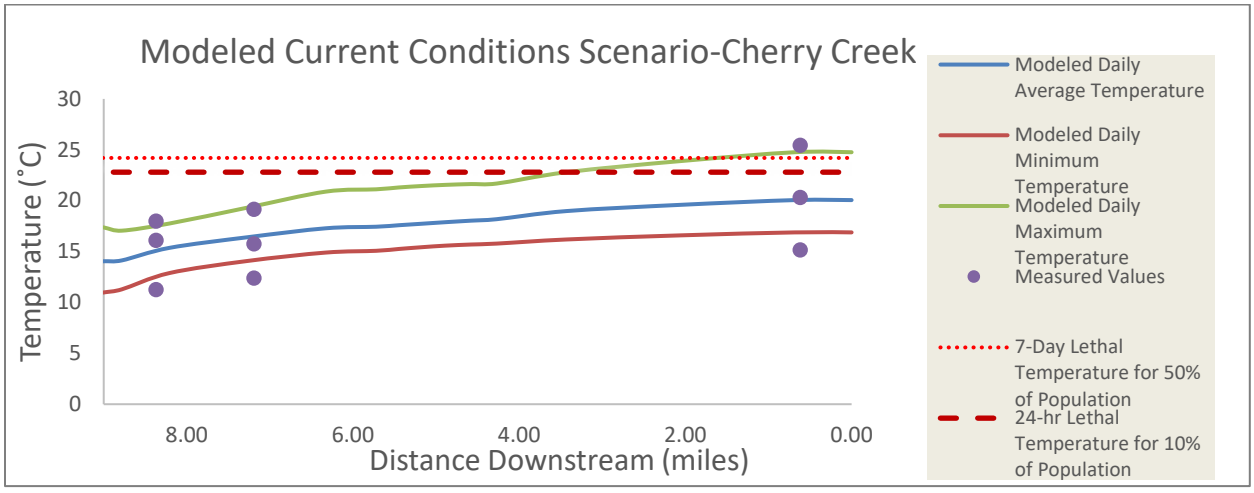

Figure J-1. Model Scenario for Cherry Creek-Current Conditions

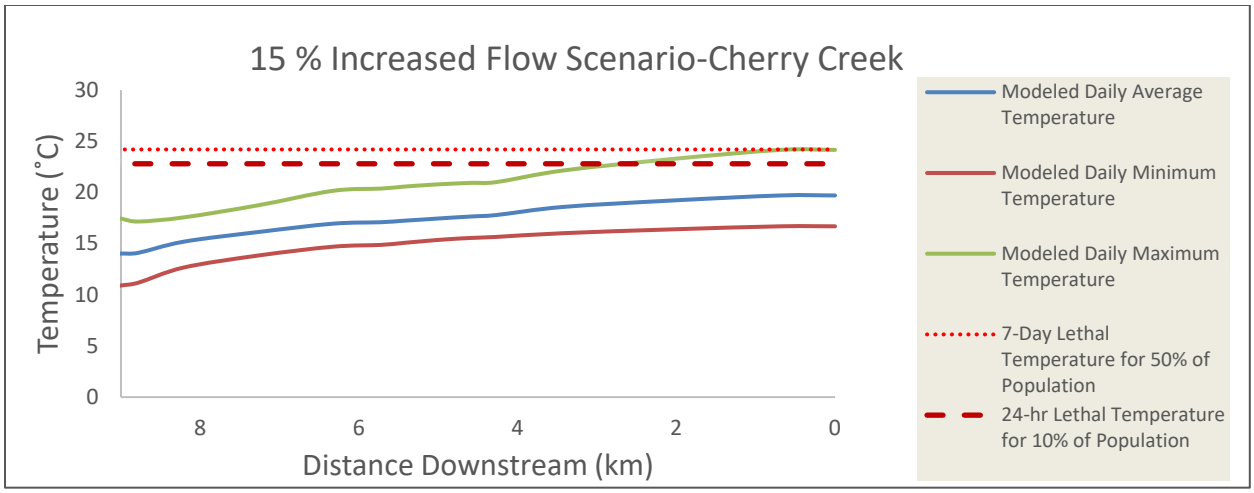

Figure J-2. Model Scenario for Cherry Creek-Increased Flow Conditions

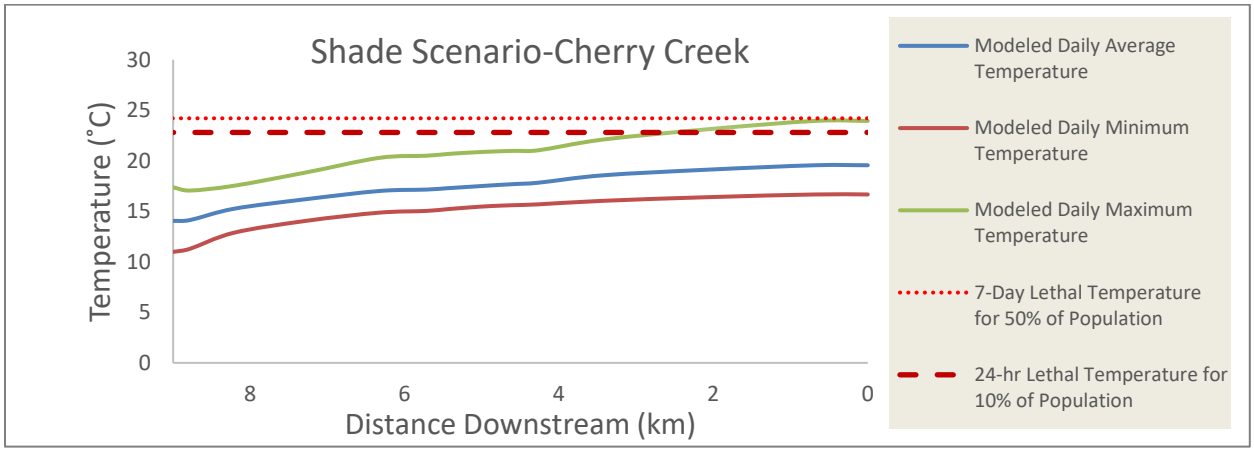

Figure J-3. Model Scenario for Cherry Creek-Increased Shade Conditions

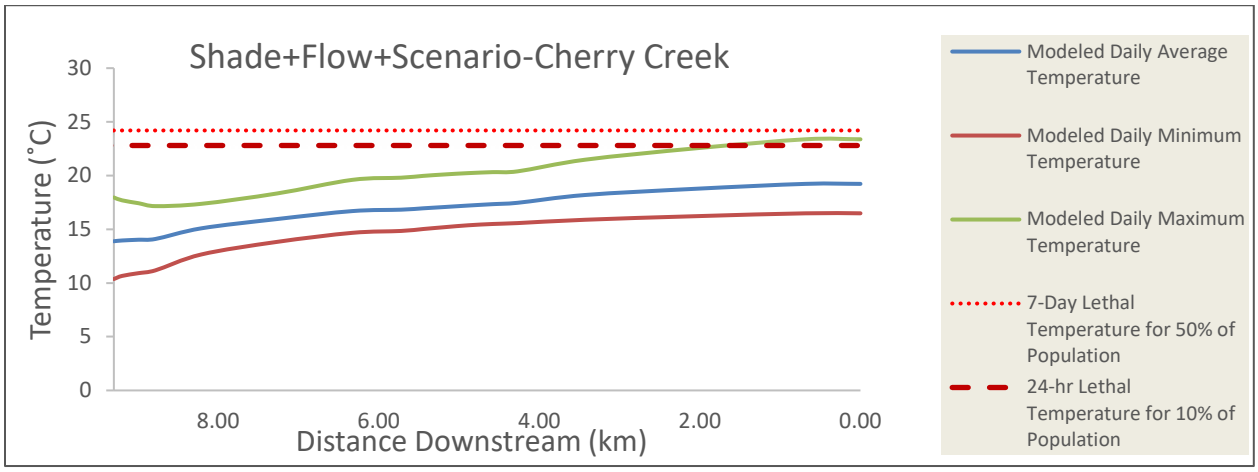

Figure J-4. Model Scenario for Cherry Creek-Increased Shade & Flow Conditions

J4.2.2 Elk Creek

Results indicate that the increased flow scenario decreased maximum temperatures at the most downstream site by 1.1 ˚C, the increased shade scenario decreased temperatures by 4.7 ˚C, and the combination scenario of increased shade and flow and decreased wetted width decreased temperatures by 5.0˚C. (**Figure J-5** to **Figure J-8**)

The increased shade scenario showed a decrease in the maximum temperature below the 7-Day Lethal Temperature for 50% of the population at the most upstream section of the modeled portion (above mile 13). The combination scenario (flow + shade+ width) did not greatly reduce temperatures below values estimated for increased shade alone.

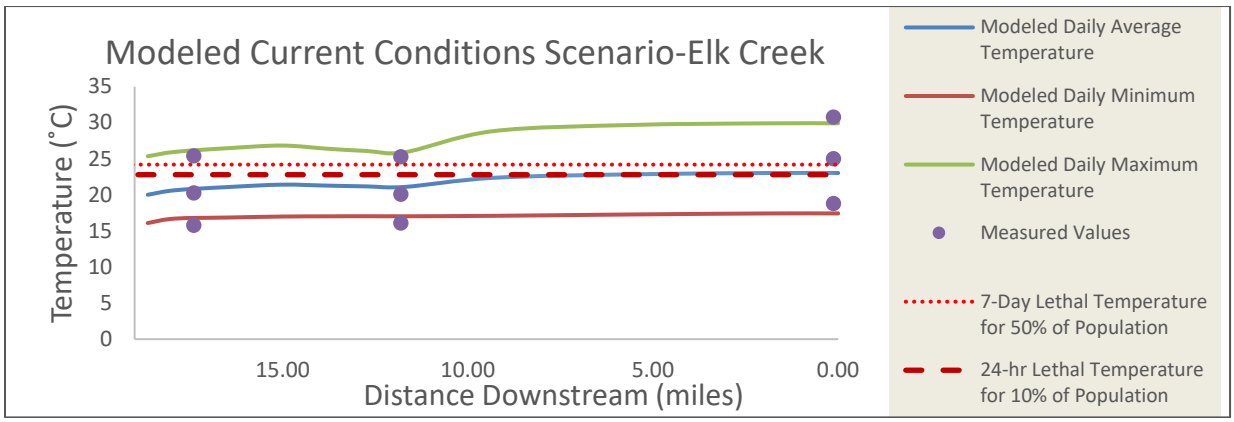

Figure J-5. Model Scenario for Elk Creek-Current Conditions

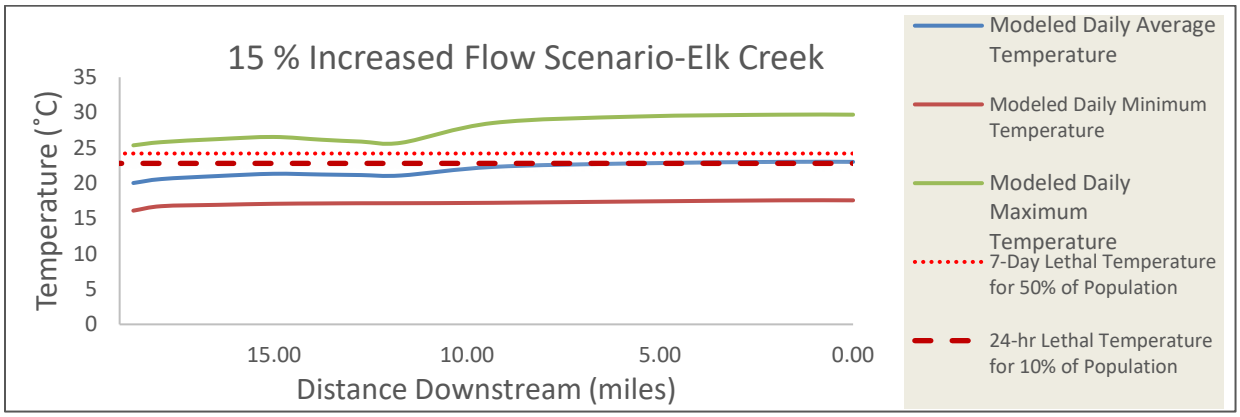

Figure J-6. Model Scenario for Elk Creek-Increased Flow Conditions

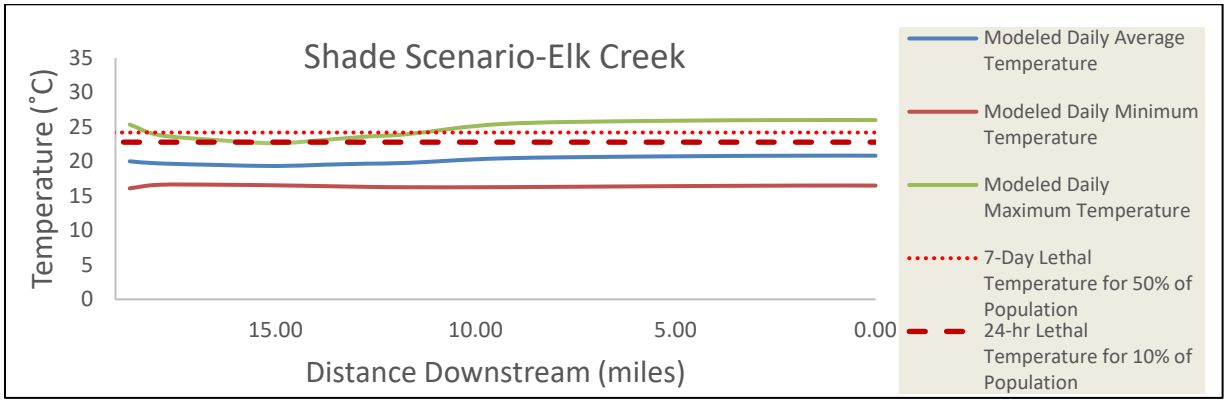

Figure J-7. Model Scenario for Elk Creek-Increased Shade Conditions

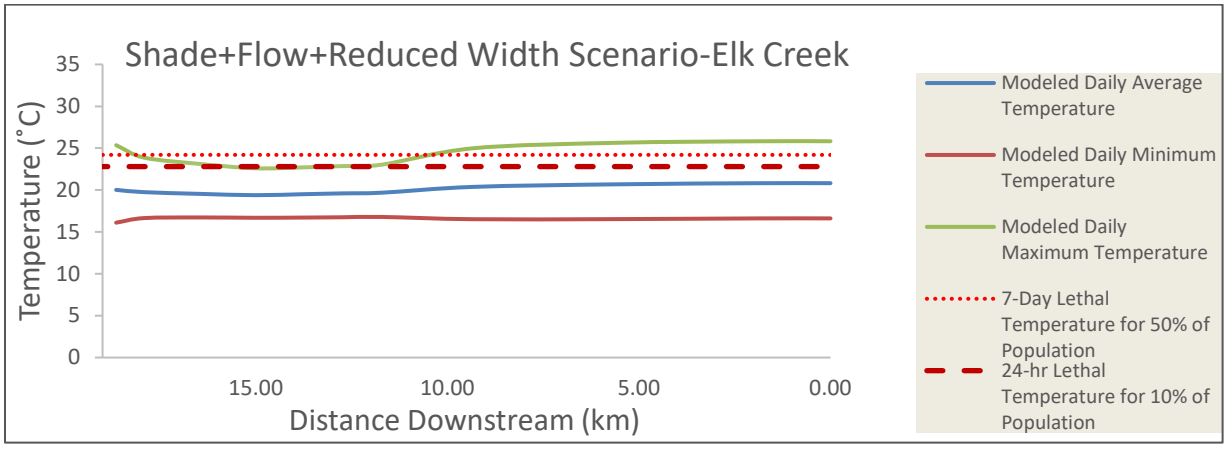

Figure J-8. Model Scenario for Elk Creek-Increased Shade and Flow Conditions

J4.2.3 Moore Creek

Results indicate that the increased flow scenario decreased modeled maximum temperatures at the most downstream site by 0.48˚C, the increased shade scenario decreased modeled maximum temperature by 2.1 ˚C, and the combination scenario decreased modeled maximum temperature by 2.4˚C.

While an increase in shade had a bigger impact on stream temperatures, the combined scenario could decrease the temperature near the mouth to be at or just slightly above the 24-hour Lethal temperature for 10% of the population for Westslope cutthroat trout, and would potentially increase the overall length of stream available to these species during the warmest times by up to 3 miles (**Figure J-9** to **Figure J-12**)

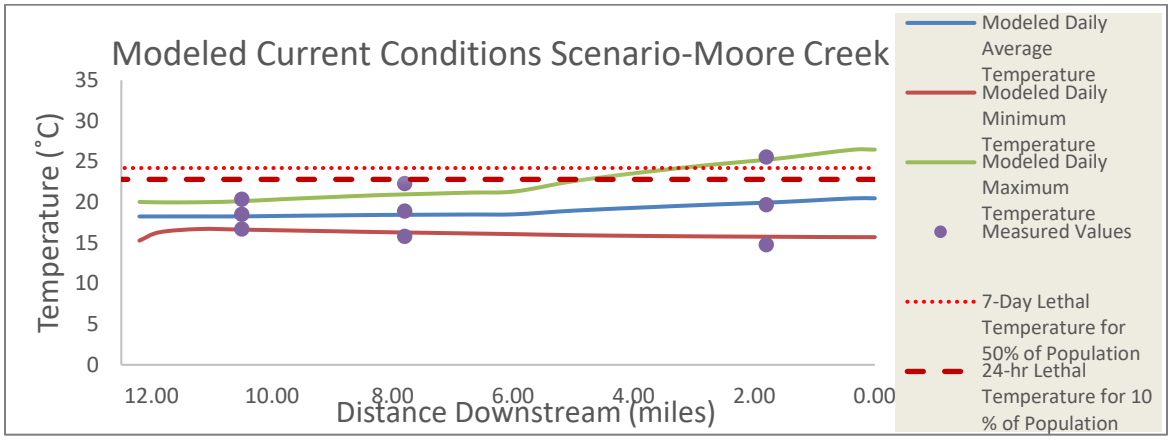

Figure J-9. Model Scenario for Moore Creek-Current Conditions

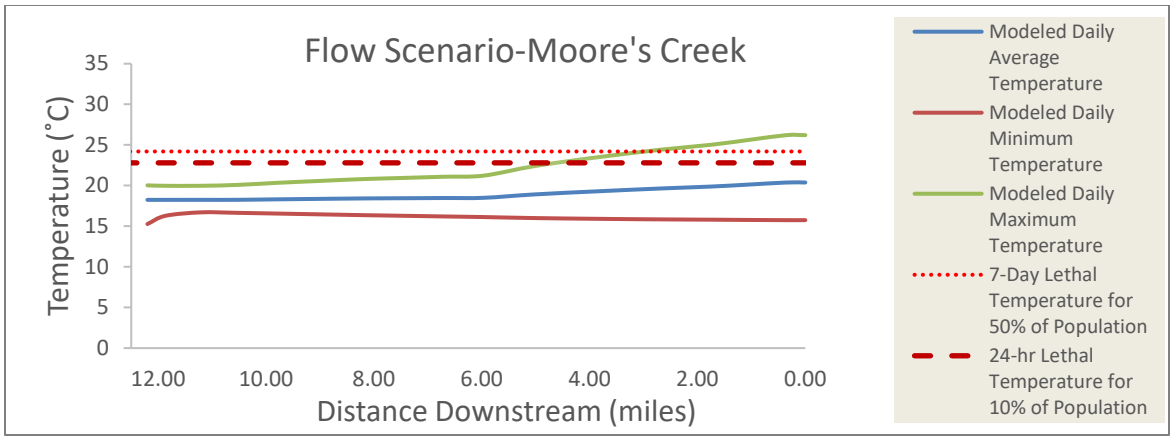

Figure J-10. Model Scenario for Moore Creek-Increased Flow Conditions

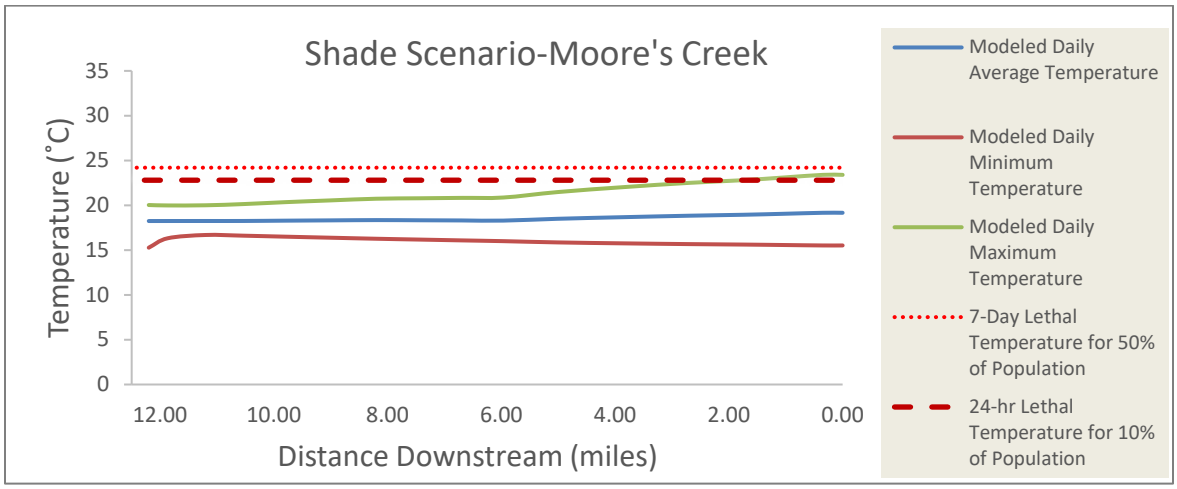

Figure J-11. Model Scenario for Moore Creek-Increased Shade Conditions

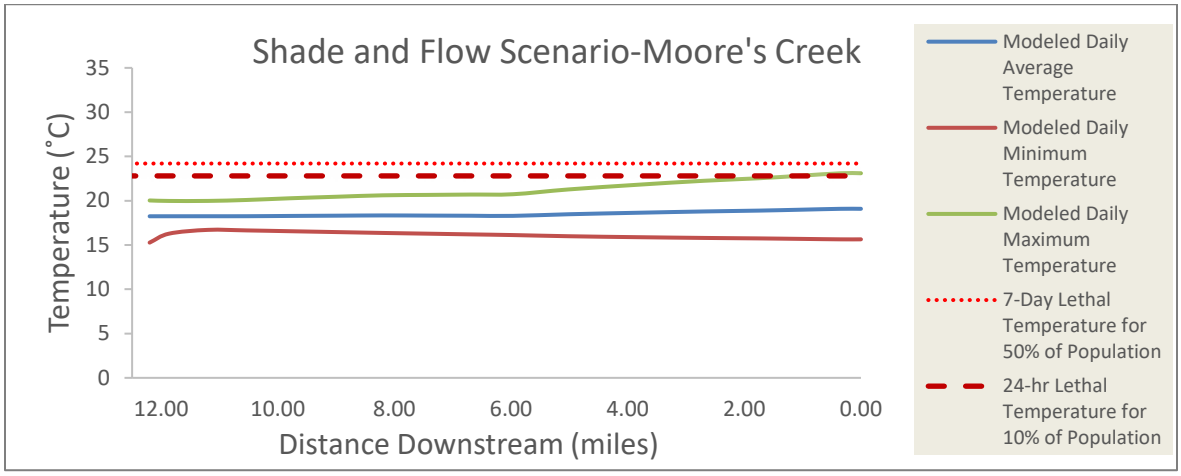

Figure J-12. Model Scenario for Moore Creek-Increased Shade Conditions

J5.0 PARAMETERS

J5.1 CHERRY CREEK

The following tables describe parameters used in the Cherry Creek model, including headwater bounding conditions (**Table J-4**) reach characteristics (**Table J-5**), and hourly climate and shade Conditions (**Table J-6**)

Table J-4 Headwater characteristics for Cherry Creek

Measurement	Original Scenario	Flow Scenario	Data Source
Flow (m^3/s)	0.5	0.58	DEQ: 8/5/2013, site 2C
Flow Abstraction (m^3/s) (3 km-0 km)	0.07	0.07	DEQ 8/5/2013 sites 2A,2B,2C
Elevation (m)	1383	1383	ArgGIS Site 2A
Slope	0.015	0.015	estimated from photos 8/5/2013, site 2C
Manning's n	0.18	0.18	Derived from Mannings Equation
Bottom Width (m)	9	9	DEQ: 8/5/2013, site 2C

Table J-5. Reach Characteristics for Cherry Creek

Upstream Distance (km)	Down stream Distance (km)	Longitude	Latitude	Slope	Bottom Width (m)	Manning's n	Data Sources
15	14	45.5870	111.4702	0.015	8.9	0.18	Bot Width=DEQ: 8/5/2013, Site2C; slope=DEQ: stream photos, Site 2C
14	9.5	45.5968	111.4953	0.015	8.9	0.18	Bot Width=DEQ: 8/5/2013, Site2C; slope=DEQ: stream photos, Site 2C
9.5	8.1	45.5950	111.4893	0.005	5.6	0.18	Bot Width=DEQ: 8/5/2013, Site2B; slope=DEQ:8/5/2014, SITE CHRR18-02
8.1	6.6	45.5916	111.4863	0.005	5.6	0.18	Bot Width=DEQ: 8/5/2013, Site2B; slope=DEQ:8/5/2014, SITE CHRR18-02
6.6	0	45.6184	111.5497	0.006	9	0.09	Bot Width=DEQ: 8/5/2013, Site2A; slope=DEQ:8/5/2014, SITE CHRR20-01

Table J-6 Cherry Creek Hourly Climate and Shade Data 7/26/2013

Parameter	*12:00 AM*	*1:00 AM*	*2:00 AM*	*3:00 AM*	*4:00 AM*	*5:00 AM*	*6:00 AM*	*7:00 AM*	*8:00 AM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	17.8	22.2	21.1	15.6	25.0	26.1	13.3	10.0	5.6
Headwater Temperature (˚C),7/26/2013	14.6	13.8	13.1	12.4	11.7	11.0	10.8	10.5	10.4
Air Temperature (˚C)	13.3	12.2	11.7	9.4	12.2	15.6	18.9	22.8	25.6
Shade (15.0-14.0):Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	65%	65%	65%
Shade (14.0-9.5):Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	16%	16%	16%
Shade (9.5-0.0):Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	16%	16%	16%
Shade (15.0-14.0):Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	65%	65%	65%
Shade (14.0-9.5):Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	22%	22%	22%
Shade (9.5-0):Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	22%	22%	22%

Table J-6 Cherry Creek Hourly Climate and Shade Data 7/26/2013

Parameter	*9:00 AM*	*10:00 AM*	*11:00 AM*	*12:00 PM*	*1:00 PM*	*2:00 PM*	*3:00 PM*	*4:00 PM*	*5:00 PM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	2.8	-0.6	-6.1	-11.1	-11.1	-12.2	-12.2	-12.8	-10.6
Headwater Temperature (˚C),7/26/2013	10.4	10.6	11.1	11.9	12.4	14.1	15.7	16.9	17.7
Air Temperature (˚C)	28.9	31.1	33.3	32.8	33.9	33.9	33.3	30.6	28.3
Shade (15.0-14.0):Original	65%	65%	65%	65%	65%	65%	65%	65%	65%
Shade (14.0-9.5):Original	16%	16%	16%	16%	16%	16%	16%	16%	16%
Shade (9.5-0.0):Original	16%	16%	16%	16%	16%	16%	16%	16%	16%
Shade (15.0-14.0):Shade Model	65%	65%	65%	65%	65%	65%	65%	65%	65%
Shade (14.0-9.5):Shade Model	22%	22%	22%	22%	22%	22%	22%	22%	22%
Shade (9.5-0):Shade Model	22%	22%	22%	22%	22%	22%	22%	22%	22%

Parameter	*6:00 PM*	*7:00 PM*	*8:00 PM*	*9:00 PM*	*10:00 PM*	*11:00 PM*
Cloud Cover (%)	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	-9.4	-8.3	-7.8	-7.8	-4.4	-1.1
Headwater Temperature (˚C),7/26/2013	18.0	18.0	17.8	17.4	16.8	16.2
Air Temperature (˚C)	27.8	26.7	26.7	23.3	21.1	20.0
Shade (15.0-14.0):Original	65%	65%	65%	100.0%	100.0%	100.0%
Shade (14.0-9.5):Original	16%	16%	16%	100.0%	100.0%	100.0%
Shade (9.5-0.0):Original	16%	16%	16%	100.0%	100.0%	100.0%
Shade (15.0-14.0):Shade Model	65%	65%	65%	100.0%	100.0%	100.0%
Shade (14.0-9.5):Shade Model	22%	22%	22%	100.0%	100.0%	100.0%
Shade (9.5-0):Shade Model	22%	22%	22%	100.0%	100.0%	100.0%

J5.2 ELK CREEK

The following tables describe parameters used in the Elk Creek model, including headwater bounding conditions (**Table J-7**) reach characteristics (**Table J-8**), and hourly climate and shade Conditions (**Table J-9**)

Table J-7. Headwater characteristics for Elk Creek

Measurement	Original Scenario	Flow Scenario	Flow and Width Scenario	Data Source
Flow (m^3/s)	0.076	0.087	0.087	DEQ: 6/12/2013, Site1B
Elevation (m)	1577	1577	1577	ArcGIS, site 1B
Slope	0.02	0.02	0.02	DEQ: 08/19/2013, site M06ELK07
Manning's n	0.12	0.12	0.12	Derived from Mannings Equation
Bottom Width (m)	2.22	2.22	2.22	DEQ 6:/12/2013, site 1B

Table J-8. Reach characteristics for Elk Creek

Upstream Distance (km)	Down stream Distance (km)	Latitude	Longitude	Slope	Bottom Width (m)	Manning' s n	Data Sources
30	23	45.6056	111.3968	0.020	2.2	0.14	Bot Width=DEQ: 6/12/2013, Site1B; slope=DEQ: 08/23/2013, Site ELK 11-01
23	18	45.6279	111.4137	0.017	1.9/1.6[1]	0.13	Bot Width=DEQ: 8/15/2013, site1C; slope=DEQ: 08/19/2013, site ELKC 06-02
18	0	45.6539	111.5208	0.017	1.5	0.13	Wet Width=DEQ: 8/15/2013, site1D; slope=DEQ: 2013, site MO6ELKC07

[1] The second value after the / was used in the reduced width scenario.

Table J-9 Elk Creek Hourly Climate and Shade Data 7/3/2013

	12:00 AM	*1:00 AM*	*2:00 AM*	*3:00 AM*	*4:00 AM*	*5:00 AM*	*6:00 AM*	*7:00 AM*	*8:00 AM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	10.6	10.0	9.4	8.3	10.0	12.2	10.6	11.7	12.2
Headwater Temperature (˚C)	19.4	18.8	18.4	17.9	17.5	17.0	16.6	16.2	16.1
Air Temperature (˚C)	20.0	20.0	18.3	18.3	17.8	17.8	21.7	24.4	25.6
Shade (30-23):Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	28%	28%	28%
Shade(23-18):Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	43%	43%	43%
Shade (18-0): Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	17%	17%	17%
Shade (30-23):Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	63%	63%	63%
Shade(23-18):Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	50%	50%	50%
Shade (18-0): Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	42%	42%	42%

	9:00 AM	*10:00 AM*	*11:00 AM*	*12:00 PM*	*1:00 PM*	*2:00 PM*	*3:00 PM*	*4:00 PM*	*5:00 PM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	13.3	9.4	7.2	6.7	7.8	6.1	7.8	8.9	11.7
Headwater Temperature (˚C)	16.4	16.9	17.8	19.6	21.7	23.7	24.9	25.4	24.6
Air Temperature (˚C)	28.9	31.7	32.2	32.8	33.9	32.8	32.2	31.7	30.0
Shade (30-23):Original	28%	28%	28%	28%	28%	28%	28%	28%	28%
Shade(23-18):Original	43%	43%	43%	43%	43%	43%	43%	43%	43%
Shade (18-0): Original	17%	17%	17%	17%	17%	17%	17%	17%	17%
Shade (30-23):Shade Model	63%	63%	63%	63%	63%	63%	63%	63%	63%
Shade(23-18):Shade Model	50%	50%	50%	50%	50%	50%	50%	50%	50%
Shade (18-0): Shade Model	42%	42%	42%	42%	42%	42%	42%	42%	42%

Table J-9 Elk Creek Hourly Climate and Shade Data 7/3/2013

	6:00 PM	*7:00 PM*	*8:00 PM*	*9:00 PM*	*10:00 PM*	*11:00 PM*
Cloud Cover (%)	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	13.3	11.1	11.1	11.7	10.6	11.1
Headwater Temperature (˚C)	23.8	23.2	22.5	21.6	20.6	19.8
Air Temperature (˚C)	28.3	25.6	22.2	22.2	19.4	18.3
Shade (30-23):Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Shade(23-18):Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Shade (18-0): Original	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Shade (30-23):Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Shade(23-18):Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Shade (18-0): Shade Model	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

J5.3 MOORE CREEK

The following tables describe parameters used in the Moore Creek model, including headwater bounding conditions (**Table J-10**) reach characteristics (**Table J-11**), and hourly climate and shade Conditions (**Table J-12**)

Table H.-10. Headwater characteristics for Moore Creek

Measurement	Original Scenario	Flow Scenario	Data Source
Flow (m^3/s)	0.16	0.18	Stream Team, 2013 Report
Elevation (m)	1500	1500	ArcGIS site 4A
Slope	0.01	0.01	DEQ: 09/04/2014, site MOOR 09-01
Manning's n	0.03	0.03	Derived from Mannings Equation
Bottom Width (m)	1.6	1.6	DEQ 08/1/2003, site 4F

Table H-11. Reach Characteristics for Moore Creek

Upstream Distance (km)	Downstream Distance (km)	Latitude	Longitude	Slope	Bottom Width (m)	Manning's n	Data Sources
12.2	10.2	45.3369	111.7411	0.010	1.8	0.06	Bot Width=DEQ: 08/01/2013, site 4F; slope:=DEQ: 09/04/2014, site MOOR 09-01
10.2	7.8	45.3369	111.7411	0.010	1.8	0.06	Bot Width=DEQ:08/01/2013, Site 4F; slope:=DEQ: 09/04/2014, site MOOR 09-01
7.8	5.6	45.3519	111.7295	0.010	1.6	0.05	Bot Width=DEQ: 08/01/2013, site 4D; slope:=DEQ: 09/04/2014, site MOOR 09-01
5.6	2.1	45.4084	111.7092	0.005	2.1	0.05	Bot Width=DEQ: 08/01/2013, site 4A; slope:=DEQ: 09/02/2014, site MOOR 09-02

Table H-11. Reach Characteristics for Moore Creek

Upstream Distance (km)	Downstream Distance (km)	Latitude	Longitude	Slope	Bottom Width (m)	Manning's n	Data Sources
2.1	9	45.4084	111.7092	0.005	2.1	0.05	Bot Width=DEQ: 08/01/2013, site 4A; slope:=DEQ: 09/02/2014, site MOOR 09-02

Table J-12. Moore Creek Hourly Climate and Shade Data 7/3/2013

	12:00 AM	*1:00 AM*	*2:00 AM*	*3:00 AM*	*4:00 AM*	*5:00 AM*	*6:00 AM*	*7:00 AM*	*8:00 AM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C), 7/3/2013	10.6	10.6	10.0	9.4	8.3	10.0	12.2	10.6	11.7
Headwater Temperature (˚C),7/3/2013	19.0	18.7	17.9	17.8	17.6	17.2	17.0	16.8	16.7
Air Temperature (˚C)	20.0	20.0	20.0	18.3	18.3	17.8	17.8	21.7	24.4
Shade (12.2-10.2):Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	67%	67%	67%
Shade(10.2-7.8):Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	57%	57%	57%
Shade (7.8-5.6): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	60%	60%	60%
Shade (5.6-2.1): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	19%	19%	19%
Shade (2.1-0.0): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	16%	16%	16%
Shade (12.2-10.2): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	67%	67%	67%
Shade(10.2-7.8):Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	62%	62%	62%
Shade (7.8-5.6): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	70%	70%	70%
Shade (5.6-2.1): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	47%	47%	47%
Shade (2.1-0.0): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	47%	47%	47%

	9:00 AM	*10:00 AM*	*11:00 AM*	*12:00 PM*	*1:00 PM*	*2:00 PM*	*3:00 PM*	*4:00 PM*	*5:00 PM*
Cloud Cover (%)	5	5	5	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	12.2	13.3	9.4	7.2	6.7	7.8	6.1	7.8	8.9
Headwater Temperature (˚C),7/3/2013	16.8	17.1	17.5	17.8	18.3	18.8	19.4	19.7	19.6
Air Temperature (˚C)	25.6	28.9	31.7	32.2	32.8	33.9	32.8	32.2	31.7
Shade (12.2-10.2):Original	67%	67%	67%	67%	67%	67%	67%	67%	67%
Shade(10.2-7.8):Original	57%	57%	57%	57%	57%	57%	57%	57%	57%
Shade (7.8-5.6): Original	60%	60%	60%	60%	60%	60%	60%	60%	60%
Shade (5.6-2.1): Original	19%	19%	19%	19%	19%	19%	19%	19%	19%
Shade (2.1-0.0): Original	16%	16%	16%	16%	16%	16%	16%	16%	16%
Shade (12.2-10.2): Shade Model	67%	67%	67%	67%	67%	67%	67%	67%	67%
Shade(10.2-7.8):Shade Model	62%	62%	62%	62%	62%	62%	62%	62%	62%

Table J-12. Moore Creek Hourly Climate and Shade Data 7/3/2013

	12:00 AM	*1:00 AM*	*2:00 AM*	*3:00 AM*	*4:00 AM*	*5:00 AM*	*6:00 AM*	*7:00 AM*	*8:00 AM*
Shade (7.8-5.6): Shade Model	70%	70%	70%	70%	70%	70%	70%	70%	70%
Shade (5.6-2.1): Shade Model	47%	47%	47%	47%	47%	47%	47%	47%	47%
Shade (2.1-0.0): Shade Model	47%	47%	47%	47%	47%	47%	47%	47%	47%

	6:00 PM	*7:00 PM*	*8:00 PM*	*9:00 PM*	*10:00 PM*	*11:00 PM*
Cloud Cover (%)	5	5	5	5	5	5
Wind Speed (m/s)	4.0	4.0	4.0	4.0	4.0	4.0
Dew Point (˚C)	11.7	13.3	11.1	11.1	11.7	10.6
Headwater Temperature (˚C),7/3/2013	20.0	20.0	19.8	15.3	19.7	19.4
Air Temperature (˚C)	30.0	28.3	25.6	22.2	22.2	19.4
Shade (12.2-10.2):Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade(10.2-7.8):Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (7.8-5.6): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (5.6-2.1): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (2.1-0.0): Original	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (12.2-10.2): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade(10.2-7.8):Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (7.8-5.6): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (5.6-2.1): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Shade (2.1-0.0): Shade Model	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %

H6.0 LIGHT AND HEAT PARAMETERS, ALL MODELS

Default light and heater parameters were used in all models, except that the Ryan Stolzenbach solar parameter was increased from 0.80 to 0.85 and the sediment thermal thickness was increased from 10 cm to 15 cm (**Table J-13**)

Table J-13 Heat and Light Parameters Used in Models (Copied from Qual2k)

Parameter	Value	Units
Photosynthetically Available Radiation	**0.47**	
Background light extinction	**0.2**	***/m***
Linear chlorophyll light extinction	**0.0088**	***1/m-(ugA/L)***
Nonlinear chlorophyll light extinction	**0.054**	***1/m-(ugA/L)2/3***
ISS light extinction	**0.052**	***1/m-(mgD/L)***
Detritus light extinction	**0.174**	***1/m-(mgD/L)***

Table J-13 Heat and Light Parameters Used in Models (Copied from Qual2k)

Parameter	Value	Units
Solar shortwave radiation model		
atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	**2**	
Ryan-Stolzenbach solar parameter **atmospheric transmission coefficient (0.70-0.91, default 0.8)**	**0.85**	
Downwelling atmospheric longwave IR radiation		
atmospheric longwave emissivity model	**Brutsaert**	
Evaporation and air convection/conduction		
wind speed function for evaporation and air convection/conduction	**Adams 2**	
Sediment heat parameters		
Sediment thermal thickness	**15**	***cm***
Sediment thermal diffusivity	**0.0118**	***cm^2/s***
Sediment density	**2.2**	***g/cm^3***
Water density	**1**	***g/cm^3***
Sediment heat capacity	**0.4**	***cal/(g °C)***
Water heat capacity	**1**	***cal/(g °C)***
Sediment diagenesis model		
Compute SOD and nutrient fluxes	**Yes**	

H7.0 REFERENCES

Chapra, S.C., Pelletier, G.J. and Tao, H. 2012. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.12: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA, Steven.Chapra@tufts.edu.

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