APPENDIX A

MIDDLE COLUMBIA HOOD (MILES CREEKS) SUBBASIN
STREAM TEMPERATURE ANALYSIS

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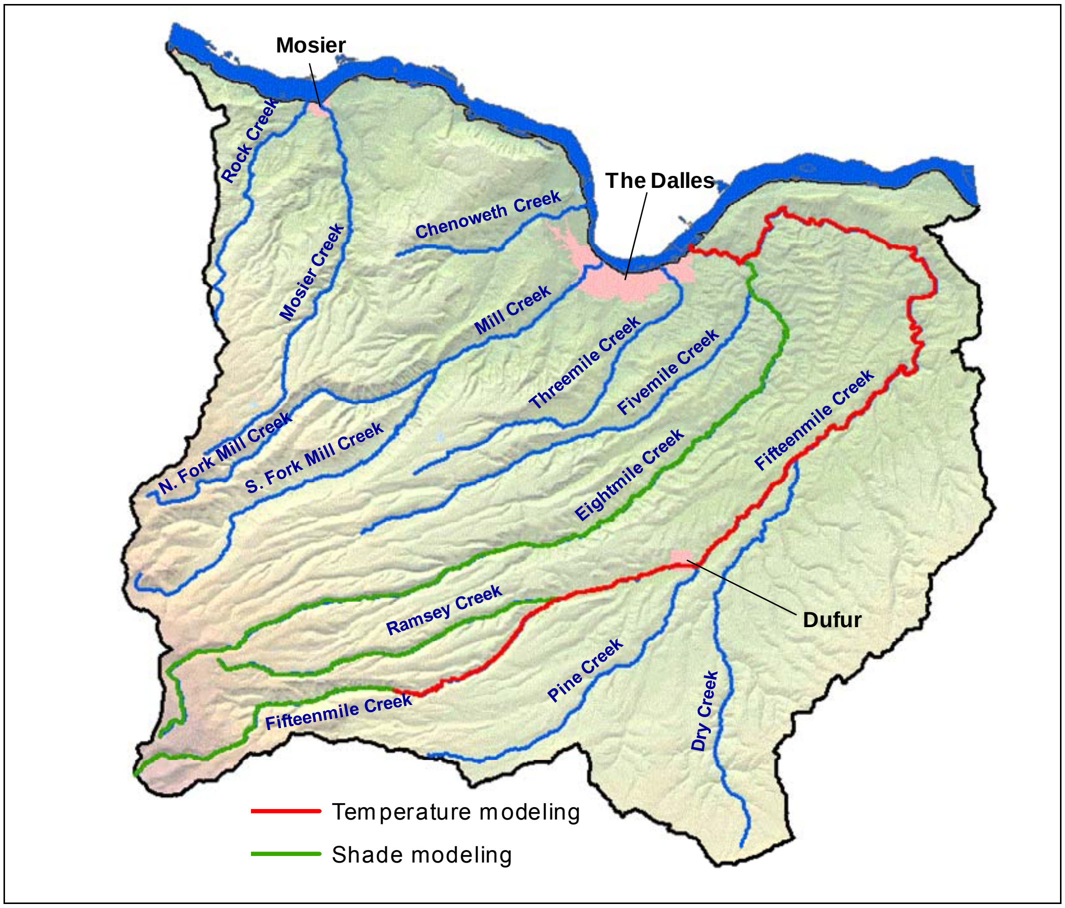
CHAPTER A1. INTRODUCTION

This appendix provides information about the temperature and shade assessment for the Miles Creeks portion of the Middle Columbia-Hood Subbasin. The assessment was completed to support the Total Maximum Daily Load (TMDL) and implement the Oregon water quality standard for temperature. The specific required components of the TMDL are provided in **Chapter 3** of the TMDL document. This appendix provides additional background information about stream heating processes, the methodology and data used for temperature TMDL development, and stream simulation results.

The Miles Creeks portion of the Middle Columbia-Hood Subbasin encompasses an area of approximately 587 square miles located primarily in Wasco County, although the western edge falls within Hood River County. This area falls within the fifth field HUCs 1707010502, 1707010503, 1707010504, 1707010505, and 1707010512 (REO, 2002). The Miles Creeks area actually consists of several distinct watersheds draining to the Columbia River, all of which originate on the east slopes of the Hood River. These watersheds are the Fifteenmile Creek, Threemile Creek, Mill Creek, Chenoweth Creek, Mosier Creek and Rock Creek Watersheds. While the stream temperature TMDL considers all surface waters within the Miles Creeks area, the stream temperature analysis focuses on the lower 70 kilometers of Fifteenmile Creek (**Figure A-1**). Site specific daily effective shade analyses were conducted on Fifteenmile Creek (in its entirety), Eightmile Creek, and Ramsey Creek (**Figure A-1**).

Figure A-1. Longitudinal extent of temperature and shade modeling in the Miles Creeks area.

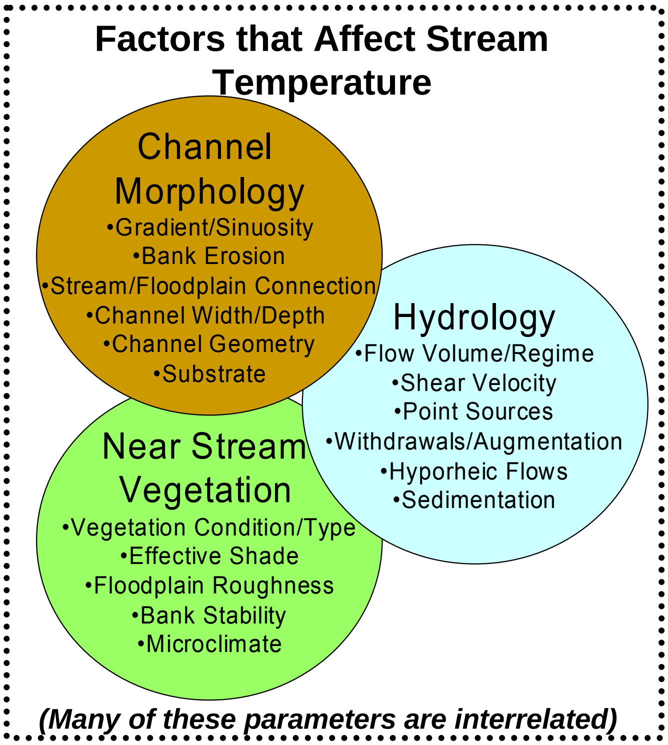


A1.1 OVERVIEW OF TEMPERATURE AND STREAM HEATING PROCESSES

Parameters that affect stream temperature can be grouped as near-stream vegetation and land cover, channel morphology, and hydrology (**Figure A-2**). Many of these stream parameters are interrelated (i.e., the condition of one may impact one or more of the other parameters). These parameters affect stream heat transfer processes and stream mass transfer processes to varying degrees. The analytical techniques employed to develop this temperature TMDL are designed to include all of these parameters, along with latitude, elevation, humidity, air temperature and wind speed.

Many parameters exhibit considerable spatial variability. For example, channel width measurements can vary greatly over small stream lengths. Some parameters can have a diurnal and seasonal temporal component as well as spatial variability. The current analytical approach developed for this stream temperature assessment relies on ground level and remotely sensed spatial data. Techniques employed in this effort are statistical and deterministic modeling of hydrologic and thermal processes.

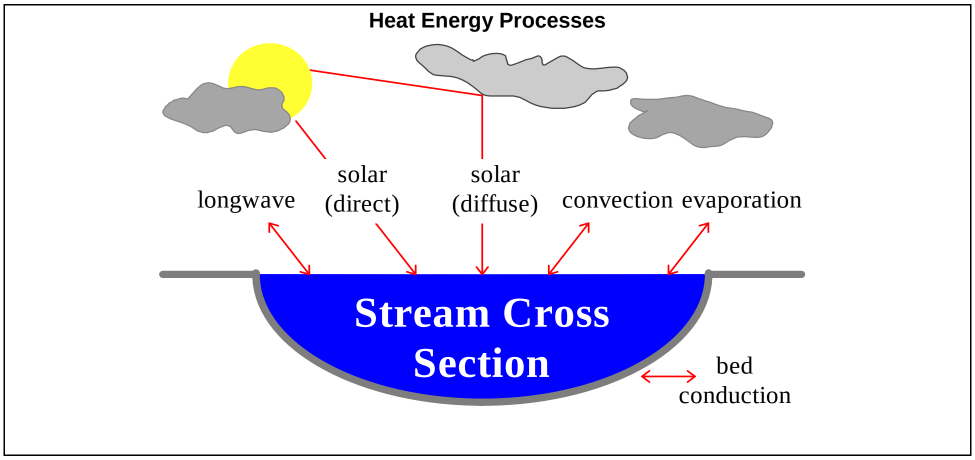
Figure A-2. Factors that affect stream temperature.



A1.1.1 Stream Heating Processes

Stream temperature is an expression of heat energy per unit volume, which in turn is an indication of the rate of heat exchange between a stream and its environment. The heat transfer processes that control stream temperature include solar radiation, long wave radiation, convection, evaporation and bed conduction (Wunderlich, 1972; Jobson and Keefer, 1979; Beschta and Weatherred, 1984; Sinokrot and Stefan, 1993; Boyd, 1996, Johnson, 2004). With the exception of solar radiation, which only delivers heat energy, these processes are capable of both introducing and removing heat from a stream. **Figure A-3** displays the stream heat transfer processes, along with mass transfer, that are considered in this analysis.

Figure A-3. Heat transfer processes



When a stream surface is exposed to midday solar radiation, large quantities of heat will be delivered to the stream system (Brown 1969, Beschta et al. 1987). Some of the incoming solar radiation will reflect off the stream surface, depending on the elevation of the sun. All solar radiation outside the visible spectrum (0.36µ to 0.76µ) is absorbed in the first meter below the stream surface and only visible light penetrates to greater depths (Wunderlich, 1972). Sellers (1965) reported that 50% of solar energy passing through the stream surface is absorbed in the first 10 cm of the water column. Removal of riparian vegetation, and the shade it provides, contributes to elevated stream temperatures (Rishel et al., 1982; Brown, 1983; Beschta et al., 1987, Johnson and Jones, 2000, Johnson, 2004). Channel widening can similarly increase the solar radiation load. The principal source of heat energy delivered to the water column is solar energy striking the stream surface directly (Brown 1970). Exposure to direct solar radiation will often cause a dramatic increase in stream temperatures. The ability of riparian vegetation to shade the stream throughout the day depends on vegetation height, width, density and position relative to the stream, as well as stream aspect.

Both the atmosphere and vegetation along stream banks emit long wave radiation that can heat the stream surface. Water is nearly opaque to long wave radiation and complete absorption of all wavelengths greater than 1.2µ occurs in the first 5 cm below the surface (Wunderlich, 1972). Long wave radiation has a cooling influence when emitted from the stream surface. The net transfer of heat via long wave radiation usually balances so that the amount of heat entering is similar to the rate of heat leaving the stream (Beschta and Weatherred, 1984; Boyd, 1996).

Evaporation occurs in response to internal energy of the stream (molecular motion) that randomly expels water molecules into the overlying air mass. Evaporation is the most effective method of dissipating heat from a given volume of water (Parker and Krenkel, 1969). As stream temperatures increase, so does the rate of evaporation. Air movement (wind) and low vapor pressures increase the rate of evaporation and accelerate stream cooling (Harbeck and Meyers, 1970).

Convection transfers heat between the stream and the air via molecular and turbulent conduction (Beschta and Weatherred, 1984). Heat is transferred in the direction of decreasing temperature. Air can have a warming influence on the stream when the stream is cooler, or vice versa. The amount of convective heat transfer between the stream and air is low (Parker and Krenkel, 1969; Brown, 1983). Nevertheless, this should not be interpretted to mean that air temperatures do not affect stream temperature.

Depending on streambed composition, shallow streams (less than 20 cm) may allow solar radiation to warm the streambed (Brown, 1969). Large cobble (> 25 cm diameter) dominated streambeds in shallow streams may store and conduct heat as long as the bed is warmer than the stream. Bed conduction may cause maximum stream temperatures to occur later in the day, possibly into the evening hours.

The instantaneous heat transfer rate experienced by the stream is the summation of the individual processes:

$$\Phi_{Total} = \Phi_{Solar} + \Phi_{Longwave} + \Phi_{Evaporation} + \Phi_{Convection} + \Phi_{Conduction}.$$

Solar Radiation (Φ_{Solar}) is a function of the solar angle, solar azimuth, atmosphere, topography, location and riparian vegetation. Simulation is based on methodologies developed by Ibqal (1983) and Beschta and Weatherred (1984). *Longwave Radiation* ($\Phi_{Longwave}$) is derived by the Stefan-Boltzmann Law and is a function of the emissivity of the body, the Stefan-Boltzmann constant and the temperature of the body (Wunderlich, 1972). *Evaporation* ($\Phi_{Evaporation}$) relies on a Dalton-type equation that utilizes an exchange coefficient, the latent heat of vaporization, wind speed, saturation vapor pressure and vapor pressure (Wunderlich, 1972). *Convection* ($\Phi_{Convection}$) is a function of the Bowen Ratio and terms include atmospheric pressure, and water and air temperatures. *Bed Conduction* ($\Phi_{Conduction}$) simulates the theoretical relationship ($\Phi_{Conduction} = K \cdot dT_b / dz$), where calculations are a function of thermal conductivity of the bed (K) and the temperature gradient of the bed (dT_b/dz) (Sinokrot and Stefan, 1993). Bed conduction is solved with empirical equations developed by Beschta and Weatherred (1984).

The primary source of heat energy is solar radiation, both diffuse and direct. Secondary sources of heat energy include long-wave radiation from the atmosphere and streamside vegetation, streambed conduction and in some cases, groundwater exchange at the water-stream bed interface. Several processes dissipate heat energy at the air-water interface, namely: evaporation, convection and back radiation. Heat energy is acquired by the stream system when the flux of heat energy entering the stream is greater than the flux of heat energy leaving. The net energy flux provides the rate at which energy is gained or lost per unit area and is represented as the instantaneous summation of all heat energy components.

A1.1.2 The Dynamics of Shade

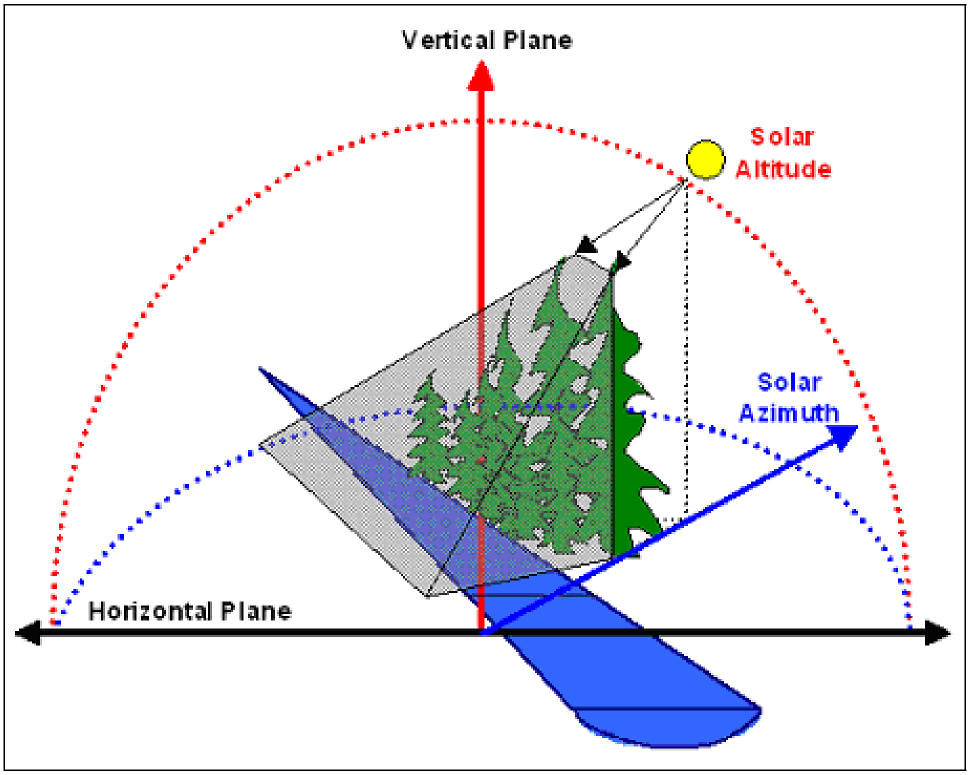
Stream surface shade is a function of several landscape and stream geometric relationships. Some of the factors that influence shade are listed in **Table A-1**. Geometric relationships important for understanding the mechanics of shade are displayed in **Figure A-4**. In the Northern Hemisphere, the earth tilts on its axis toward the sun during summertime months allowing longer day length and higher solar altitude, both of which are functions of solar declination (i.e., a measure of the earth's tilt toward the sun). Geographic position (i.e., latitude and longitude) fixes the stream to a position on the globe, while aspect provides the stream/riparian orientation. Riparian height, width and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation (produce shade). The solar position has a vertical component (altitude) and a horizontal component (azimuth) that are both functions of time/date (solar declination) and the earth's rotation (i.e., hour angle). While the interaction of these shade variables may seem complex, the math that describes them is relatively straightforward geometry, much of which was developed decades ago by the solar energy industry.

Solar altitude and solar azimuth are two measurements of the sun's position. When a stream's orientation, geographic position, riparian condition and solar position are known, shading characteristics can be simulated.

Table A-1. **Factors that influence stream surface shade**

Description	*Measure*
Season/Time	Date/Time
Stream Characteristics	Aspect, Near-Stream Disturbance Zone Width
Geographic Position	Latitude, Longitude
Vegetative Characteristics	Buffer Height, Buffer Width, Buffer Density
Solar Position	Solar Altitude, Solar Azimuth

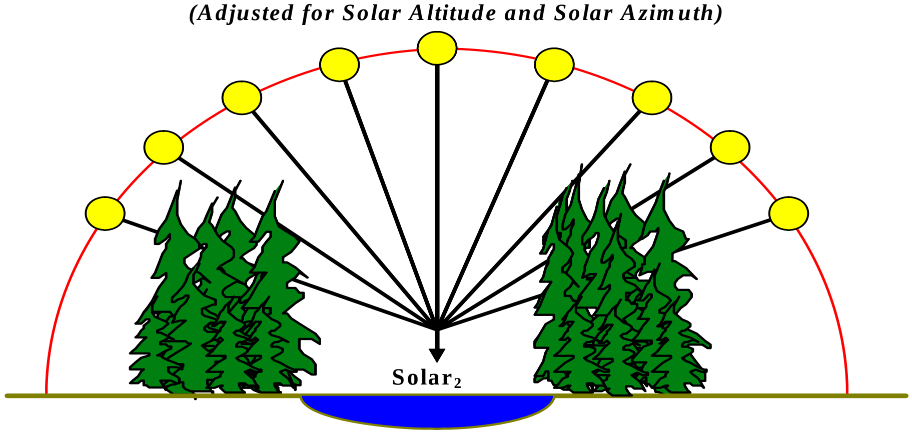
Figure A-4. **Geometric relationships that affect stream surface shade**



Percent effective shade is perhaps the most straightforward stream parameter to monitor and calculate and is easily translated into quantifiable water quality management and geometric relationships that affect stream surface shade recovery objectives. **Figure A-5** demonstrates how effective shade is monitored and calculated. Using solar tables or mathematical simulations, the *potential daily solar load* can be quantified. The *measured solar load (current conditions)* at the stream surface can easily be measured with a Solar Pathfinder© or estimated using mathematical shade simulation computer programs (Boyd, 1996 and Park, 1993).

Figure A-5. Effective shade – defined

$Solar_1$ – Potential Daily Solar Radiation Load
(Adjusted for Solar Altitude and Solar Azimuth)



Effective Shade Defined:

$$\text{Effective Shade} = \frac{(Solar_1 - Solar_2)}{Solar_1}$$

Where,
$Solar_1$: Potential Daily Solar Radiation Load
$Solar_2$: Measured Daily Solar Radiation Load at Stream Surface

A1.1.3 Limitation of Stream Temperature TMDL Approach

The purpose of stream temperature modeling is to (1) determine temperatures for various scenarios including natural thermal potential, (2) assess heat loading for the purpose of TMDL allocation, (3) compute readily measurable surrogates for the allocations, and (4) to better understand heat controls at the local and subbasin scale. Heat Source, version 7.0 (Boyd and Kasper 2003) was the model used for TMDL development. The data used in the models and the simulation results are presented in the remainder of this appendix. Limitations of the data and simulation methodology are mentioned in subsequent sections, however, the Oregon Department of Environmental Quality (DEQ) feels that it is important to acknowledge some of the limitations to this analytical effort up front. The limitations include the following:

1. The scale of this effort is large with obvious challenges in capturing spatial variability in stream and landscape data. Available spatial data sets for land cover and channel morphology are coarse, while derived data sets are limited to aerial photo resolution and human error.
   - Riparian vegetation was mapped from Digital Orthophoto Quads (DOQs) and USFS GIS vegetation data and placed within general height categories. It is not feasible to assign actual heights to each tree mapped using DOQs. These general height categories became Heat Source inputs and are one source of modeling imprecision. Similarly, riparian vegetation densities were also estimated for different vegetation categories, with a single density associated with each category. In the real world, vegetation densities are variable and this variability is not accounted for in the simulations.
   - Heat Source breaks the stream into 50-meter segments. Inputs (vegetation, channel morphology, etc.) are averaged for each 50-meter segment, which means that the simulation may

not account for some of the real world variability. For example, isolated pools or riffles within a 50 meter reach will not be included as unique features.
- Stream elevations and gradients were sampled and calculated from 10-meter digital elevation models (DEMs). DEMs have a certain level of imprecision associated with them and may be a source of uncertainty in the simulation results.

2. Current analytical methods fail to capture some upland, atmospheric and hydrologic processes. At a landscape scale, these exclusions can lead to errors in analytical outputs.

   - Methods are not currently available to simulate riparian microclimates at a landscape scale. Regardless, recent studies (Anderson et al, 2007 and Rykken et al 2007) indicate that forested microclimates play an important, yet variable, role in moderating air temperature, humidity fluctuations and wind speeds.
   - Existing air temperature and relative humidity data were used from various weather stations in the subbasin. This data however may not capture natural variations in air temperature and relative humidity along the stream. For example, temperatures may change as the landscape changes over short distances along the stream. These are similar to the microclimates created by vegetation cover.
   - The actual position of the sun within the sky can only be calculated with an uncertainty of 10-15%. The sun's position is important when determining a stream's effective shade. Solar position is another source of modeling imprecision.
   - Sinuosity change is typically not simulated, because the selected simulation methods are spatially explicit.
   - Heat Source always assumes that the wetted stream is flowing directly down the center of the active channel, and effective shade calculations are based upon that assumption. In reality, a stream migrates all over the active channel. This is another source of modeling imprecision.

3. Quantification techniques for estimating potential subsurface inflows/returns and behavior within substrate are not employed in this analysis. Groundwater exchanges and hyporheic flows are difficult to measure and may not always be accounted for within stream temperature modeling.

4. Current analysis is focused on a defined critical condition – a 3-week period during a single summer. This time period is intended to represent a critical condition for aquatic life when stream flows are low, radiant heating rates are high and ambient conditions are warm. However, there are several other important time periods where fewer data are available and the analysis is less explicit. For example, spawning periods have not received treatment comparable to that of the seasonal maximum stream temperature.

5. Land use patterns vary through the drainage from heavily impacted areas to areas with little human impacts. However, it is extremely difficult to find large areas without some level of either current or past human impacts. The development of Natural Thermal Potential (NTP) conditions that estimate stream conditions when human influences are minimized is statistically derived and based on stated assumptions within this document. Limitations to stated assumptions are presented where appropriate. It should be acknowledged that as better information is developed these assumptions will be refined.

   - In some cases, there is not scientific consensus related to riparian, channel morphology and hydrologic potential conditions. This is especially true when confronted with highly disturbed sites, meadows and marshes, and potential hyporheic/subsurface flows.
   - "Natural" flows were included in the NTP simulations. Estimates were used to create the existing flow mass balances, and withdrawals were estimated for the current condition, based on thermal infrared aerial data, the OWRD points of diversion database, and instream flow measurements. "Natural" flows are estimates based on removing the assumed anthropogenic impacts on the current flow regimes.
   - Stream velocities and depths were calculated by Heat Source for the "natural" flow conditions based on measured channel dimensions and substrate composition. These estimated velocities

and depths for the “natural” flows may have some error associated with them since they have not been verified through field measurements.
- Natural stream conditions may have had more groundwater connection, wetland areas, and hyporheic interactions prior to anthropogenic disturbances. These conditions are not included in the NTP scenarios. Stream restoration may increase groundwater connectivity which could reduce the NTP temperatures.
- Increased channel complexity and more coarse woody debris are not accounted for in the NTP simulations. Including these factors may result in cooler NTP temperatures.

While these assumptions outline potential areas of weakness in the methodology used in the stream temperature analysis, DEQ has undertaken a comprehensive approach. All important stream parameters that can be accurately quantified are included in the analysis. In the context of understanding of stream temperature dynamics, these areas of limitations should be the focus for future studies.

CHAPTER A2. AVAILABLE DATA

A2.1 GROUND LEVEL AND REMOTE SENSING DATA

Stream temperature, flow, habitat and meteorological data have been collected in the Miles Creeks area by the following local stakeholders:

- Oregon Department of Environmental Quality (DEQ)
- Mt. Hood National Forest (MHNF)
- Oregon Department of Fish and Wildlife (ODFW)
- Wasco Soil and Water Conservation District (SWCD)
- Oregon Water Resources Department (OWRD)

The data collection methods include both ground level measurements and remote sensing. Most of the data used in this modeling effort was collected during the summer of 2002, although much of the ground level data has been collected other years as well. The remote sensing data (thermal infrared) was only collected in the Miles Creeks area in 2002. The data used in this assessment is available from DEQ upon request. Much of the temperature data is also available through the DEQ website in the LASAR database (http://www.deq.state.or.us/lab/lasar.htm).

A2.1.1 Stream Temperature

Two types of stream temperature data were collected during 2002 (**Figure A-6**):

- Continuous instream monitoring data
- Thermal infrared (TIR) data

It should be noted that not all of the data collected in 2002 and presented in this section was used in the TMDL simulations described in this Appendix. A summary of the TIR and continuous temperature data collected on Fifteenmile Creek, Eightmile Creek and Ramsey Creek is summarized in this section. Only the Fifteenmile Creek temperature data (and data at the mouths of tributaries) was used in the TMDL temperature simulations.

TIR Data

TIR imagery measures the temperature of the outermost portions of the bodies/objects in the image (i.e., ground, riparian vegetation, and stream). The bodies of interest are opaque to longer wavelengths and there is little, if any, penetration of the bodies.

TIR data was gathered through a sensor mounted on a helicopter that collected digital data directly to an on-board computer at a rate that insured the imagery maintained a continuous image overlap of at least 40%. The TIR detected emitted radiation at wavelengths from 8-12 microns (long-wave) and recorded the level of emitted radiation as a digital image across the full 12-bit dynamic range of the sensor. Each image pixel contained a measured value that was directly converted to a temperature. Each thermal image has a spatial resolution of less than one-half meter/pixel. Visible video sensor captured the same field-of-view as the TIR sensor. GPS time was encoded on the imagery.

Data collection was timed to capture maximum daily stream temperatures, which typically occur between 14:00 and 18:00 hours. The helicopter was flown longitudinally over the center of the stream channel with the sensors in a vertical (or near vertical) position. In general, the flight altitude was selected so that the stream channel occupied approximately 20-40% of the image frame. A minimum altitude of approximately 300 meters was used both for maneuverability and for safety reasons. If the stream split into two channels that could not be covered in the sensor's field of view, the survey was conducted over the larger of the two channels.

In-stream thermistors were distributed prior to the survey to ground truth the radiant temperatures measured by the TIR. TIR data can be viewed as a GIS point coverage or TIR imagery.

Direct observation of spatial temperature patterns and thermal gradients is a powerful application of TIR derived stream temperature data. Thermally significant areas can be identified in a longitudinal stream temperature profile and related directly to specific sources (i.e., water withdrawal, tributary confluence, vegetation patterns, etc.). Areas with stream water mixing with subsurface flows (i.e., hyporheic and inflows) are apparent and often dramatic in TIR data. Thermal changes captured with TIR data can be quantified as a specific change in stream temperature or a stream temperature gradient that results in a temperature change over a specified distance.

Thermal infrared (TIR) stream temperature data was collected for Fifteenmile Creek, Eightmile Creek and Ramsey Creek from August 1-3, 2002 (Watershed Sciences, 2003). The TIR-derived stream temperatures for the three creeks are shown in **Figure A-7**.

In this TMDL analysis, the TIR data were used to: measure surface temperatures; develop longitudinal temperature profiles; develop flow mass balances; map/identify significant thermal features; indicate subsurface hydrology, groundwater inflow and/or springs; and validate simulated stream temperatures.

Continuous Data

Continuous temperature data was collected at a number of locations using thermistors[1]. Data has been collected by some of the organizations listed above for a number of years, with the data record going back as long as 10 years for some sites. The data presented in this TMDL was collected in 2002.

In this TMDL analysis, the continuous data was used to: calibrate stream emissivity for the TIR; calibrate stream statistics and assess the temporal component of stream temperature; and calibrate temperature simulations.

[1] Thermistors are small electronic devised that are used to record hourly stream temperature at one location for a specified time period.

Figure A-6. Temperature monitoring locations and TIR flight paths in 2002.

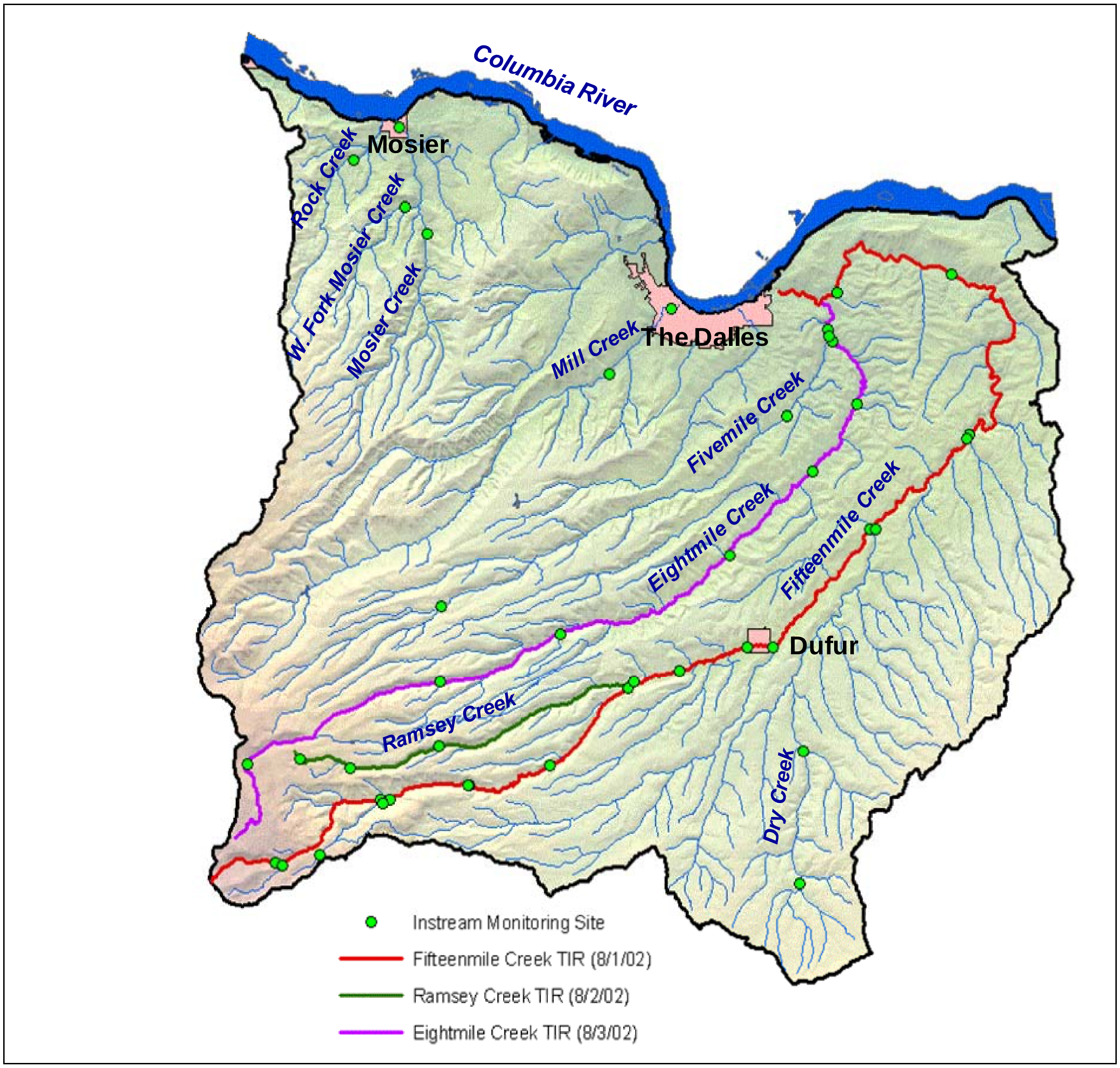
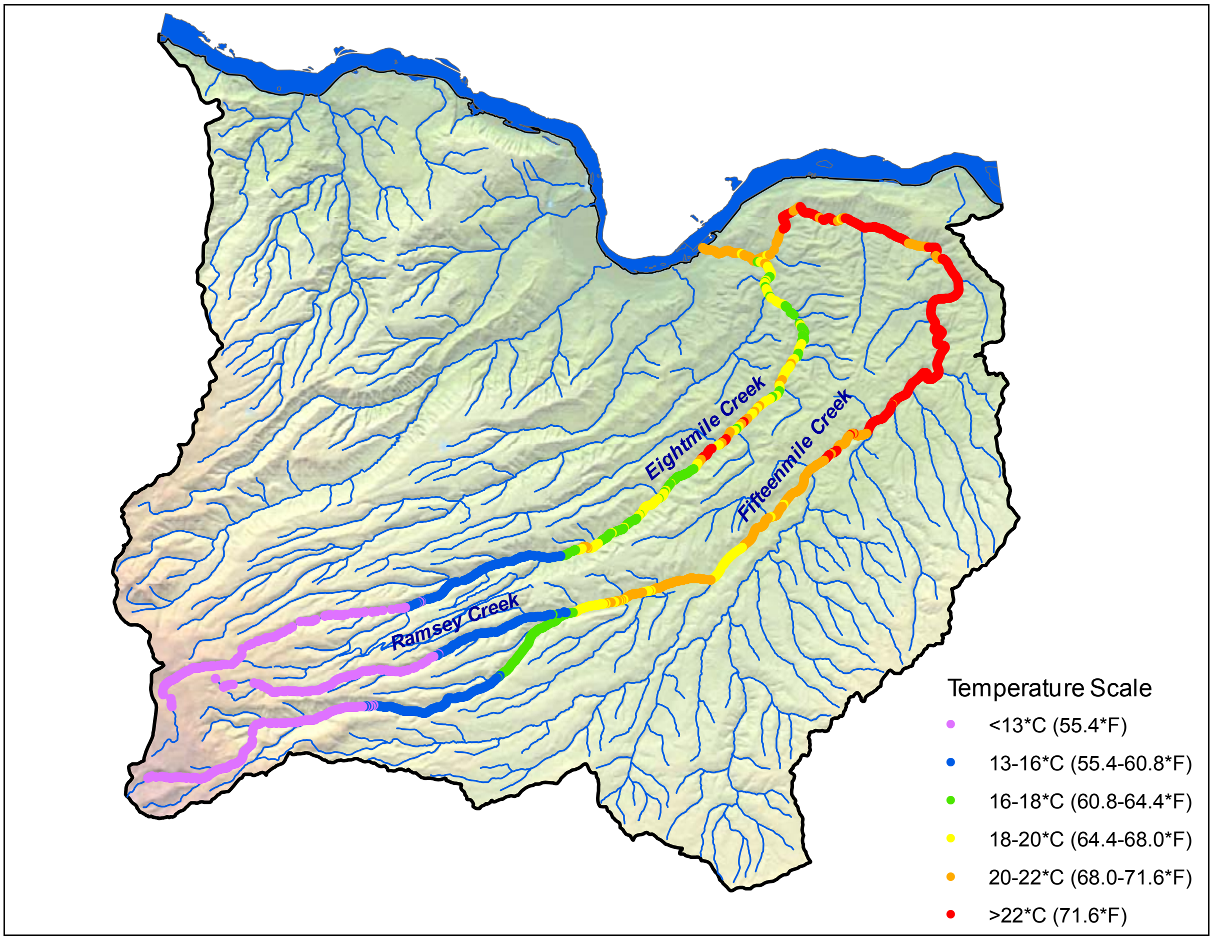


Figure A-7. TIR-derived stream temperatures for Fifteenmile, Eightmile, and Ramsey Creeks, August, 2002.



Fifteenmile Creek

TIR Data

Thermal infrared (TIR) stream temperature data was collected on Fifteenmile Creek from the mouth to the headwaters on August 1, 2002 (1:54 to 3:33 PM). **Figure A-8** shows the TIR temperature profile for the entire length of the flight. Tributary and spring inflows that were sampled during the analysis are labeled on the chart. The profile also shows tributaries that were detected during the analysis but were not sampled due to their size. Overall, stream temperatures in Fifteenmile Creek ranged from ~5.3^{o}C near the headwaters to a survey maximum of ~26.4^{o}C at river kilometer 9.5. The longitudinal temperature profile shows a general pattern of warming from the headwaters downstream to river kilometer 26.4, a distance of ~43.0 kilometers. Although a general warming trend prevails, the profile also shows changes in the longitudinal heating rate along the stream gradient and distinct points with locally cooler water. In the lower 26.4 kilometers, stream temperatures showed a slight cooling trend with a general increase in local spatial temperature variability (i.e. stream temperatures changes > ±1.0^{o}C over distances of < 0.8 kilometers). Inspection of the TIR images revealed that small impoundments and diversions in stream contributed to the local thermal spatial variability observed in the longitudinal temperature profile.

An example of the thermal imagery is presented in **Figure A-9**. This image shows local thermal variability associated with a beaver dam. Stream temperatures were warmer (21.8^{o}C) upstream of the dam and cooler (19.0^{o}C) downstream. The cooler water downstream may suggest thermal stratification immediately behind the impoundment or it could suggest infiltration through and around the impoundment.

Temperature simulations were performed for TMDL development from the mouth to river kilometer 71 near the USFS boundary. The TIR data was used the mass balance analysis and to corroborate the model calibration.

Figure A-8. Thermal infrared (TIR) temperature profile of Fifteenmile Creek, 8/1/2002.

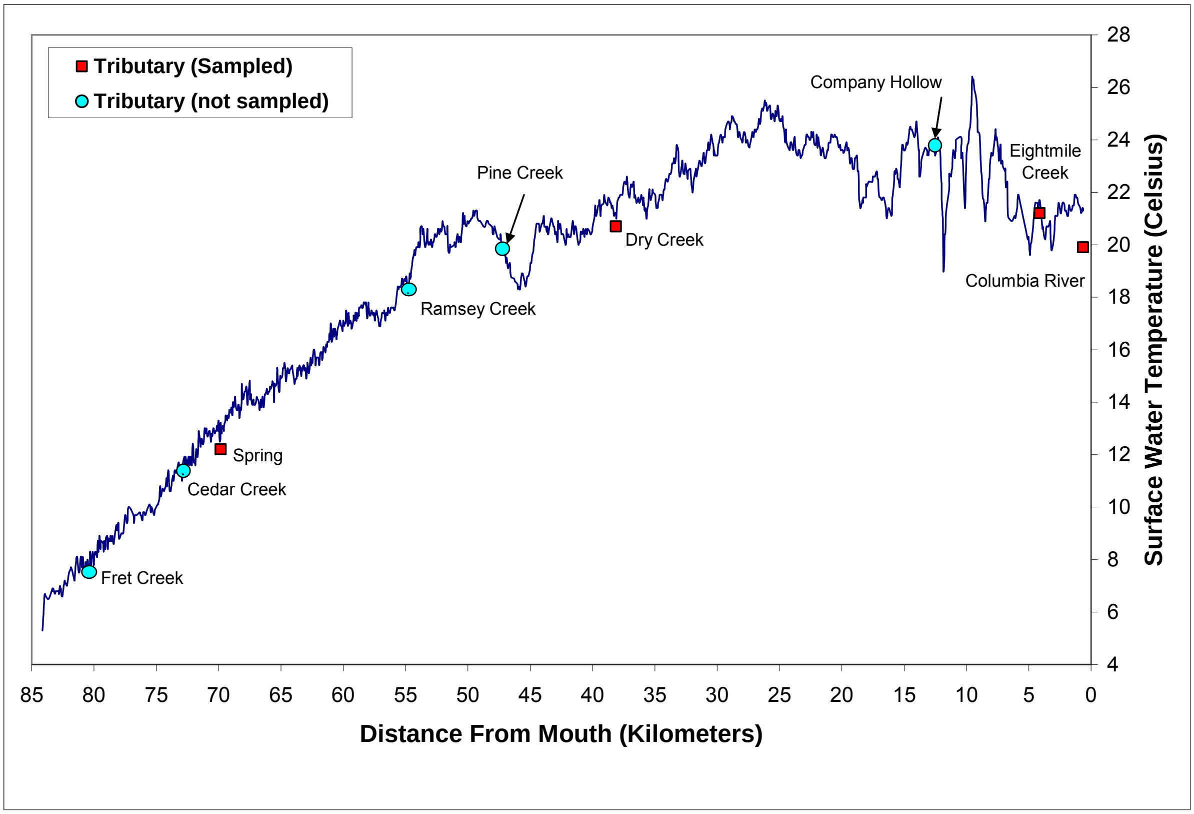
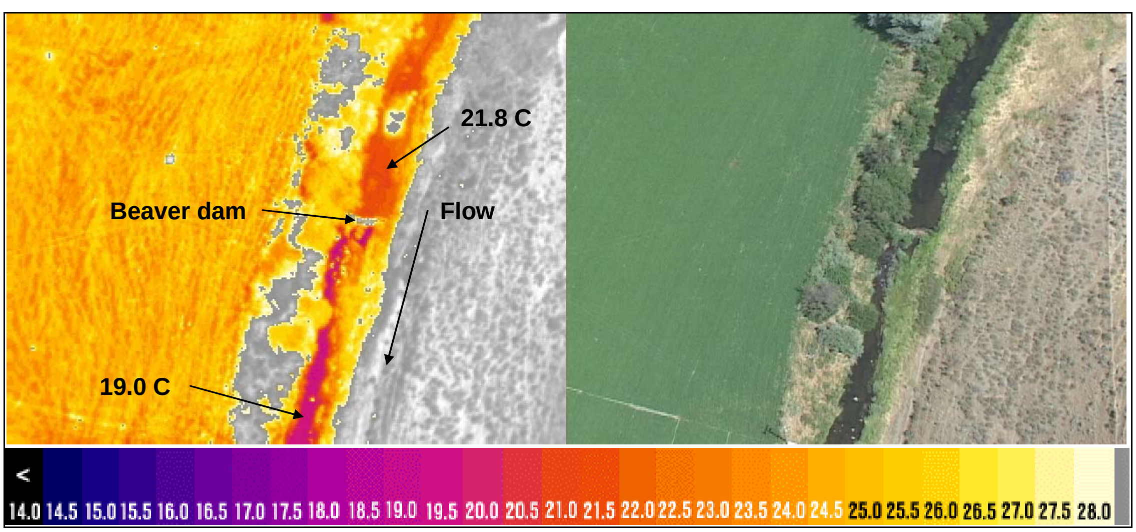


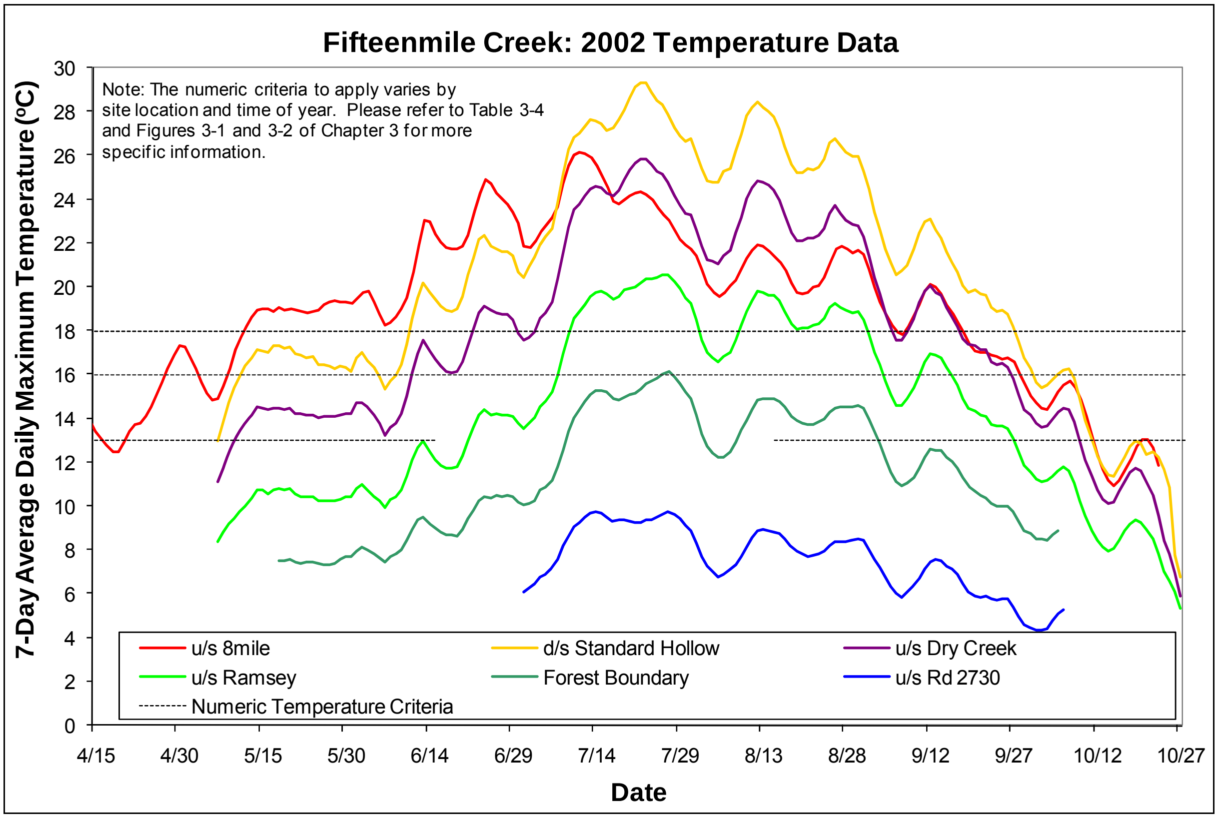
Figure A-9. TIR/color video images showing Fifteenmile Creek near river mile 7.



Instream Temperature Data

Temperature monitoring instruments were deployed by the Wasco SWCD, MHNF, ODFW and DEQ during 2002. The seven day average maximum temperatures were calculated from the continuous data and selected station profiles are plotted in **Figure A-10**. From the mouth to Dry Creek, the rearing and migration criterion (18°C) applies all year and the spawning criterion (13°C) applies from January 1 to May 15. Above Dry Creek, the core cold water habitat criterion (16°C) applies all year and the spawning criterion applies at different times of year depending on stream reach (refer to **Figure 3-2** in **Chapter 3** of the TMDL).

Figure A-10. Fifteenmile Creek seven day average maximum temperatures.



Eightmile Creek

TIR Data

Thermal infrared (TIR) stream temperature data was collected on Eightmile Creek from the mouth to the headwaters on August 3, 2002 (1:28 to 2:54 PM). **Figure A-11** shows the TIR temperature profile for the entire length of the flight. Tributary and spring inflows that were sampled during the analysis are labeled on the chart. The profile also shows tributaries that were detected but not sampled due to their size. Spatial temperature patterns in Eightmile Creek were similar to those observed in Fifteenmile Creek. Stream temperatures were cool near the headwaters at river kilometer 53.7 and showed a general pattern of downstream warming to river kilometer 24.8. Thermal variability increased between river kilometer 24.8 and the mouth with areas of abrupt shifts in the longitudinal heating rate (warming and cooling).

An example of the thermal imagery is presented in **Figure A-12**. Radiant stream temperatures at the upstream end of the image were 21.8°C and 20.4°C at the downstream end. The source of cooling was not obvious from the imagery

Figure A-11. Thermal infrared (TIR) temperature profile of Eightmile Creek, 8/3/2002.

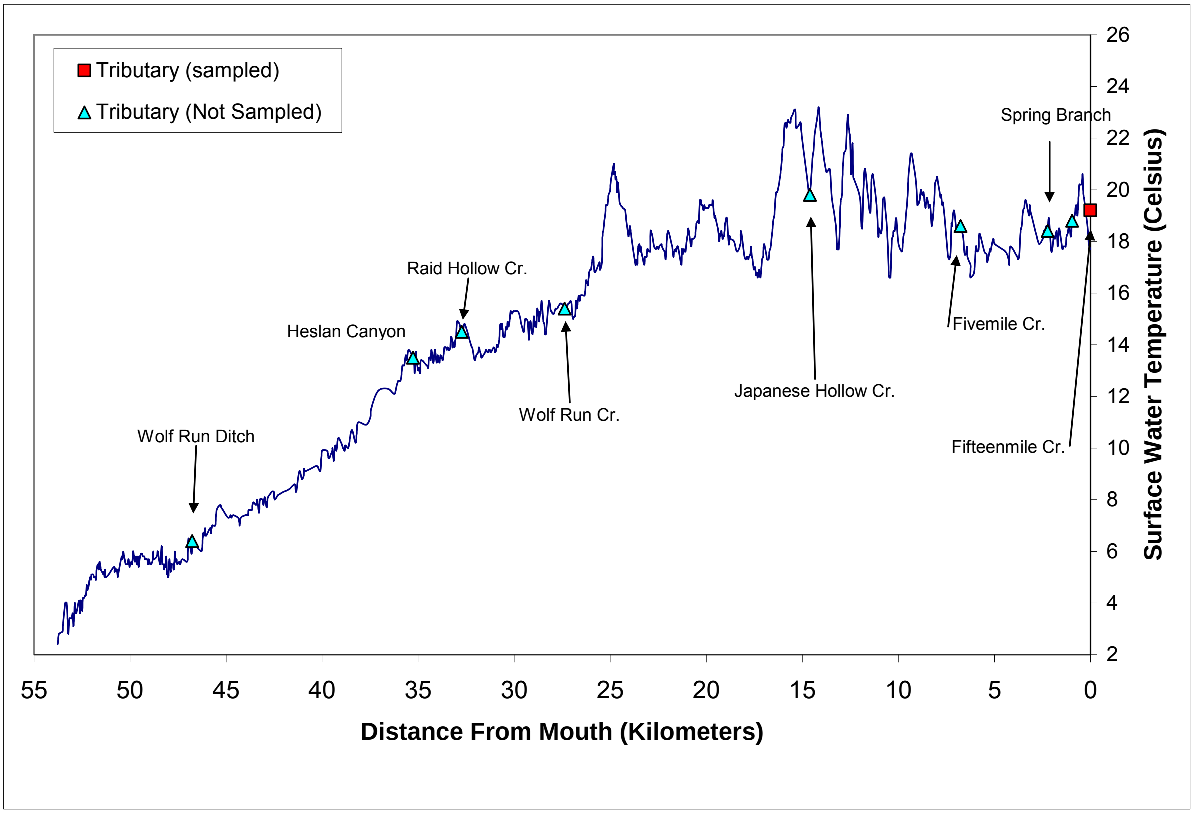
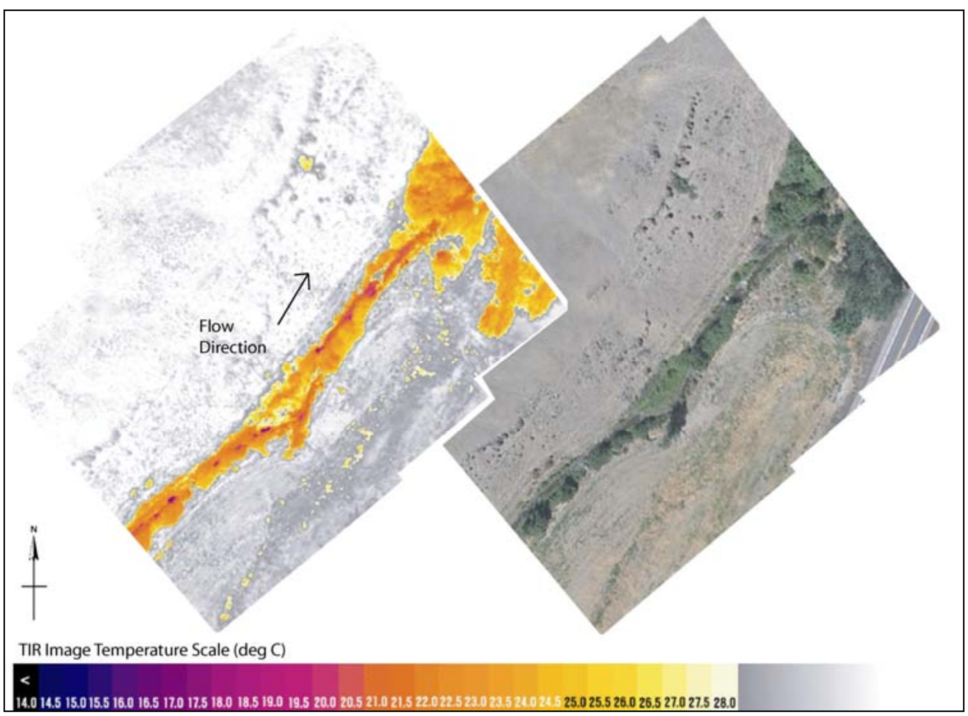


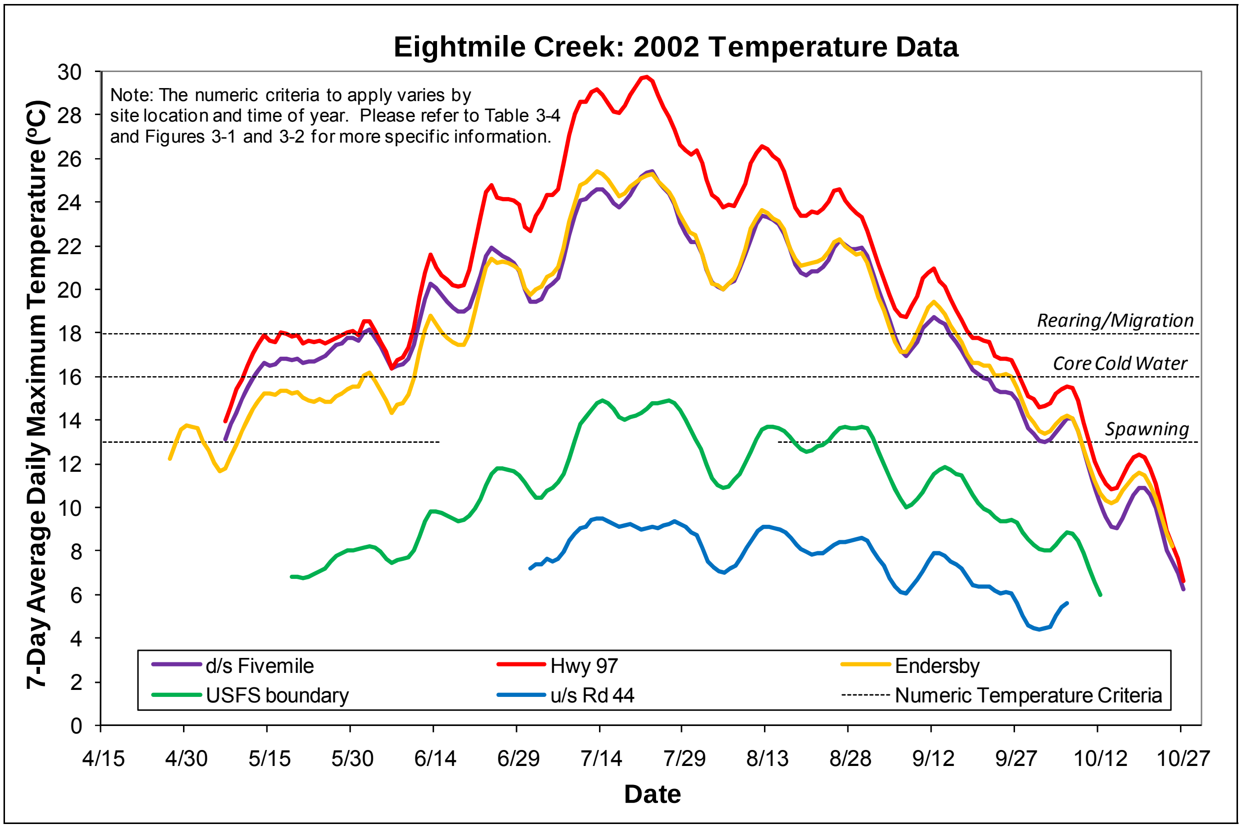
Figure A-12. TIR/color video images showing Eightmile Creek at river kilometer 12.4.



Instream Temperature Data

Temperature monitoring instruments were deployed by the Wasco SWCD, MHNF, ODFW and DEQ during 2002. The seven day average maximum temperatures were calculated from the continuous data and selected station profiles are plotted in **Figure A-13**. From the mouth to approximately river kilometer 9.6, the rearing and migration criterion (18°C) applies all year and the spawning criterion (13°C) applies from January 1st to May 15th. Above this point, the core cold water habitat criterion (16°C) applies all year and the spawning criterion applies at different times of year depending on stream reach (refer to **Figure 3-2** in **Chapter 3** of the TMDL).

Figure A-13. Eightmile Creek seven day average maximum temperatures.

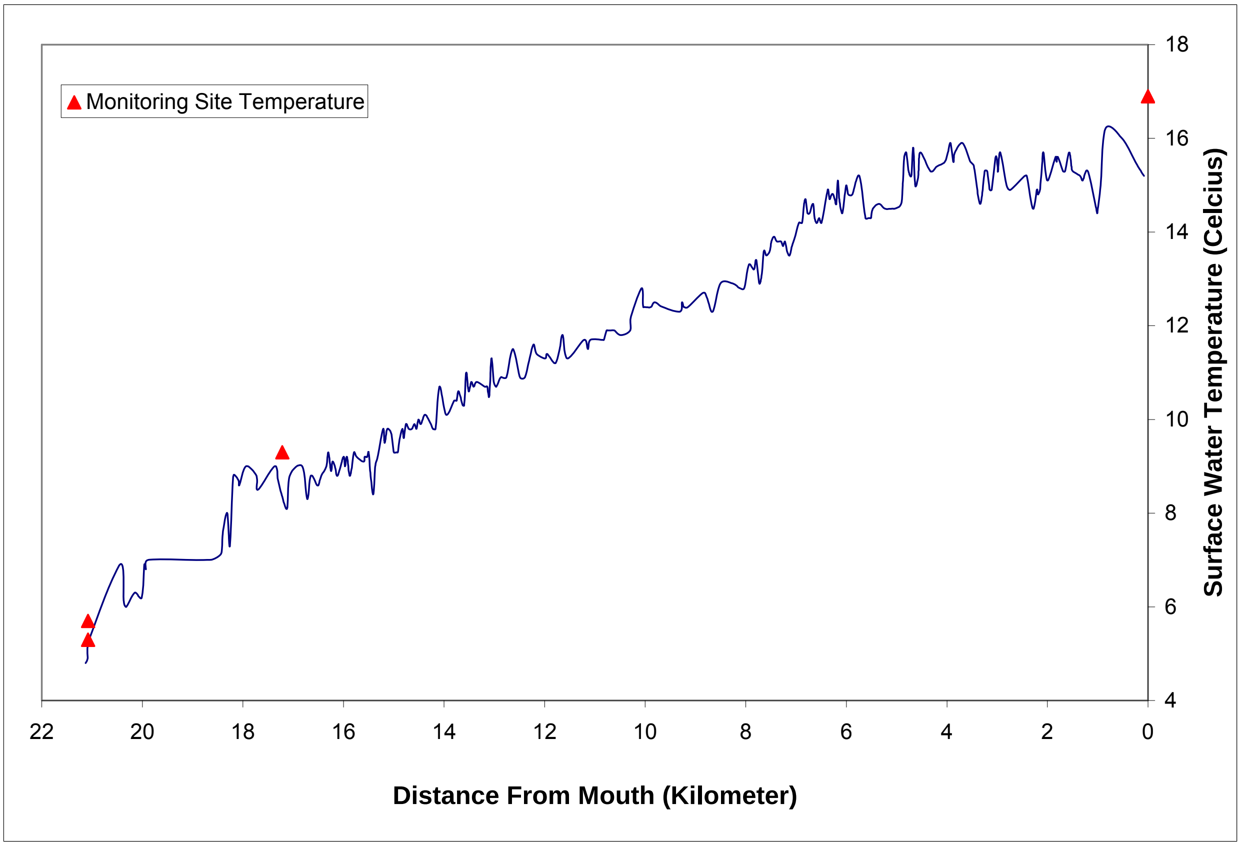


Ramsey Creek

TIR Data

Thermal infrared (TIR) stream temperature data was collected on Ramsey Creek from the mouth to the headwaters on August 2, 2002 (1:19 to1:54 PM). **Figure A-14** shows the TIR temperature profile for the entire length of the flight. No tributaries or other surface inflows were detected during the analysis. The plot also shows the in-stream temperatures at the ground truth locations at the time of the TIR survey and the recorded daily maximum stream temperatures on August 2, 2002. The TIR survey was consistent with maximum daily temperatures at the monitoring sites at river kilometer 17.2 and 21.1, but was 1.8°C cooler than the maximum daily stream temperatures recorded at the mouth of Ramsey Creek. Riparian vegetation intermittently masked the surface of Ramsey Creek throughout the 22-kilometer survey. Consequently, samples were taken when surface water was visible in the images and could not be acquired from every image frame. No tributaries or other surface water inflows were detected during the analysis of the Ramsey Creek imagery.

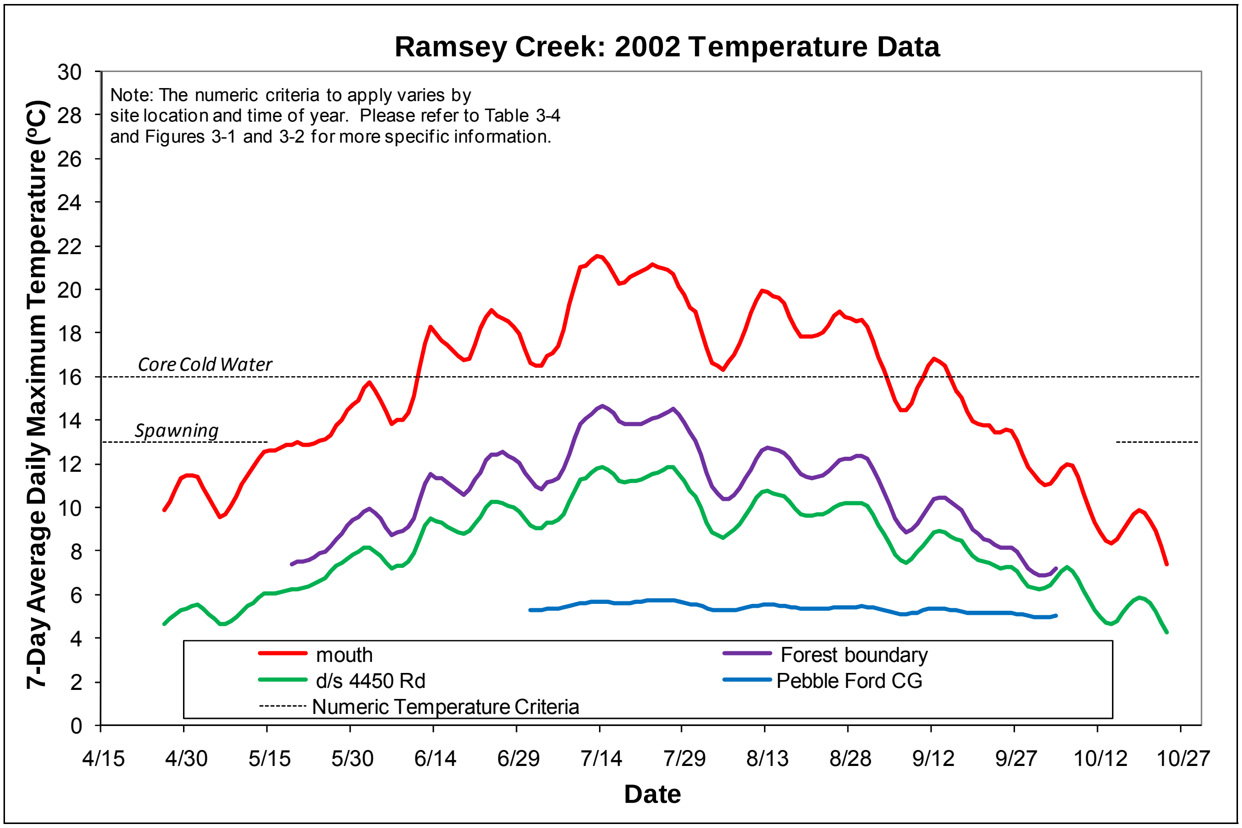
Figure A-14. Thermal infrared (TIR) temperature profile of Ramsey Creek, 8/2/2002



Instream Temperature Data

Temperature monitoring instruments were deployed by the MHNF, ODFW and DEQ during 2002. The seven day average maximum temperatures were calculated from the continuous data and selected station profiles are plotted in **Figure A-15**. The core cold water habitat criterion (16°C) applies year round on Ramsey Creek and the spawning criterion applies from January 1st -June 15th (refer to **Figure 3-2** in **Chapter 3** of the TMDL).

Figure A-15. Ramsey Creek seven day average maximum temperatures.



A2.1.2 Flow Data

Flow rate measurements were made by at a number of locations in the Fifteenmile watershed in a coordinated monitoring effort by DEQ, ODFW, MHNF, OWRD and Wasco SWCD staff (**Figure A-16**) on August 2, 2002. The flow rate measurements were intended to correspond with the thermal infrared (TIR) stream temperature data collection on each stream. There were no active gages in operation in the Miles Creeks area in 2002, although there is historic gage data available.

Table A-2 summarizes the location, dates, and values of the flow measurements. In addition to flow rate data, wetted width, depth and velocity measurements were also made at these sites (see **Section A2.1.3**). This data were used to corroborate the simulated stream hydraulics.

The longitudinal flow profile for Fifteenmile Creek (the only stream where hydraulics were simulated) was based upon the available measured data. The TIR data was used as a supplemental source of information. Tributaries and springs may appear in the TIR data that were not measured in the field. If upstream flows were known, the TIR temperature of upstream, of the source, and of downstream were used within a mass balance equation (see **Section A2.3.6**) to estimate the flow volume or temperature of the tributary or spring.

Figure A-16. Flow measurment locations in 2002.

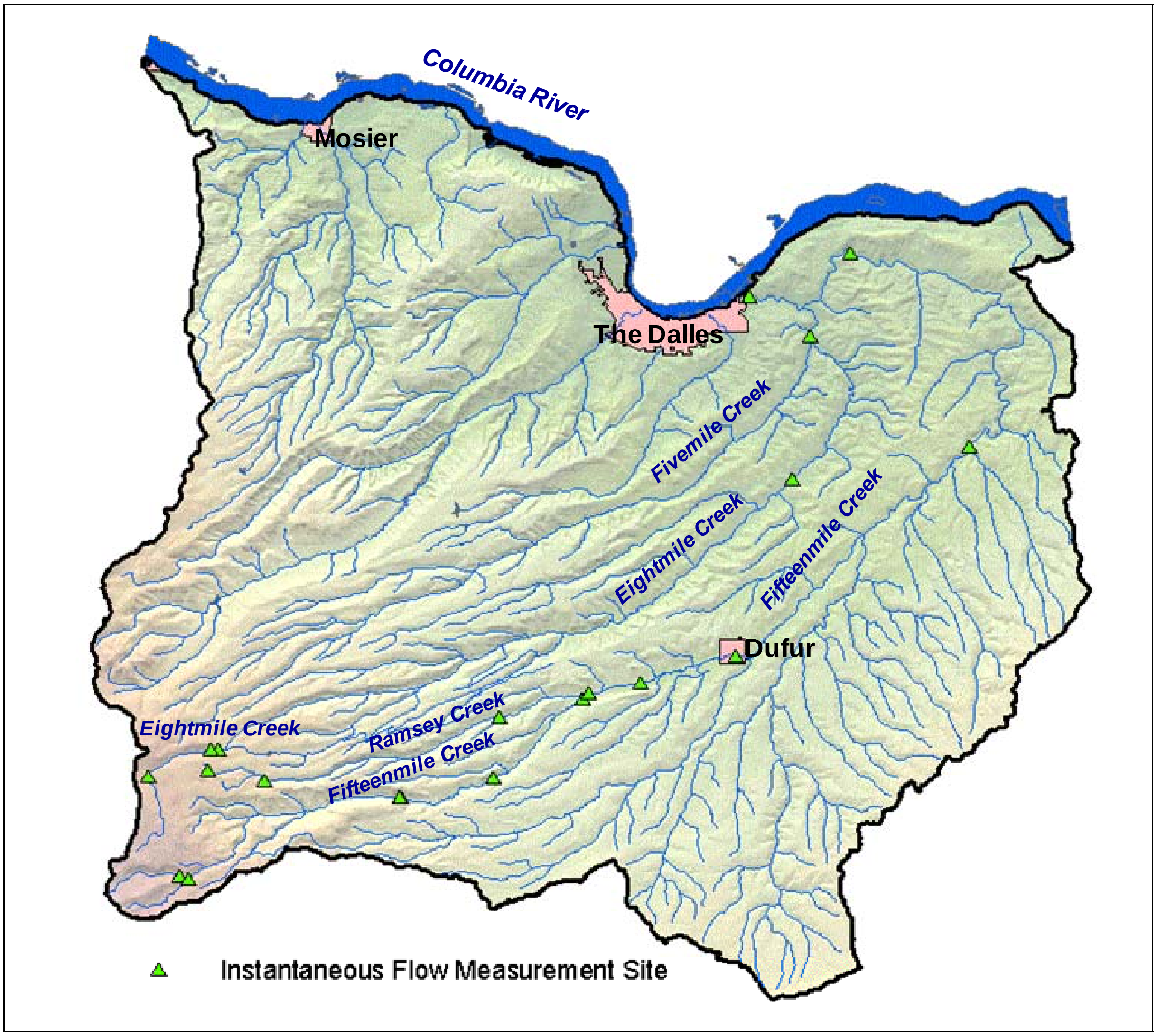


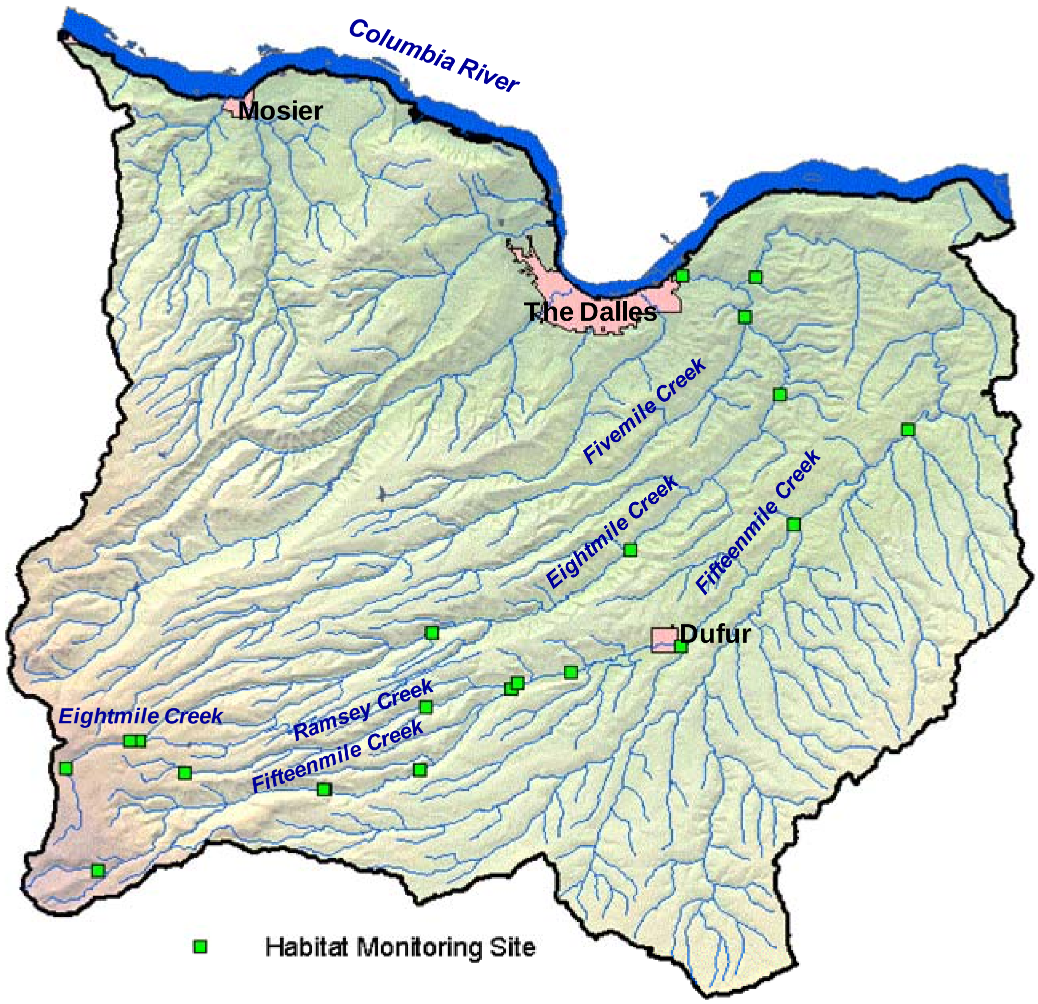
Table A-2. Flow data locations, dates and values.

Location	Date	Time	Flow (cfs)
Fifteenmile Creek upstream of mouth near ODFW Screw Trap	8/2/02	09:15	3.06
Eightmile Creek downstream Fivemile Creek	8/2/02	--	1.03
Eightmile Creek upstream Highway 197	8/2/02	13:00	0.41
Eightmile Creek downstream Wolf Run ditch	8/2/02	14:30	2.28
Eightmile Creek upstream Wolf Run ditch (downstream 4430 Rd)	8/2/02	13:45	8.03
Eightmile Creek upstream 44 Rd.	8/2/02	14:35	3.43
Fifteenmile Creek ~2.5 miles upstream Eightmile Creek	8/2/02	--	1.75
Fifteenmile Creek at Emerson Loop Rd.	8/2/02	11:00	1.03
Dry Creek at mouth	8/2/02	--	dry
Fifteenmile Creek at Dufur City Park	8/2/02	11:55	3.70
Fifteenmile Creek near Rivermile 34	8/2/02	9:58	4.50
Ramsey Creek @ mouth	8/2/02	--	0.52
Ramsey Creek off Ramsey Creek Rd. (new forest boundary)	8/2/02	11:45	2.00
Ramsey Creek downstream 4450 Rd.	8/2/02	13:05	2.15
Ramsey Creek at Pebbleford CG	8/2/02	15:00	1.50
Fifteenmile Creek upstream Ramsey Ck	8/2/02	--	6.69
Fifteenmile Creek downstream Dufur City intake	8/2/02	10:45	7.96
Fifteenmile Creek downstream Lyda Diversion	8/2/02	11:00	6.66
Fifteenmile Creek at forest boundary (u/s Lyda at Rd 4421)	8/2/02	10:10	11.36
Fret Creek Rd. upstream 2730 Rd.	8/2/02	13:00	2.65
Fifteenmile Creek upstream 2730 Rd.	8/2/02	13:30	5.77

A2.1.3 Habitat Data

Habitat data was collected at a number of locations in the Fifteenmile watershed in a coordinated monitoring effort by DEQ, ODFW, MHNF, and Wasco SWCD staff (**Figure A-17**) during the summers of 2000-2002. Vegetation descriptions, effective shade measurements, channel width/depth and substrate information were collected at these sites. This data was used for stream simulation validation and temperature model inputs on Fifteenmile Creek. On Eightmile Creek and Ramsey Creek, effective shade measurements were used to corroborate the shade simulations. In addition, habitat data was collected along the length of Fifteenmile Creek by ODFW in 2001 as part of their Aquatic Inventory Project (AIP) (ODFW, 2001). This data was used as verification for temperature model input.

Figure A-17. Habitat measurment locations in 2000 – 2002 (does not include AIP sites).



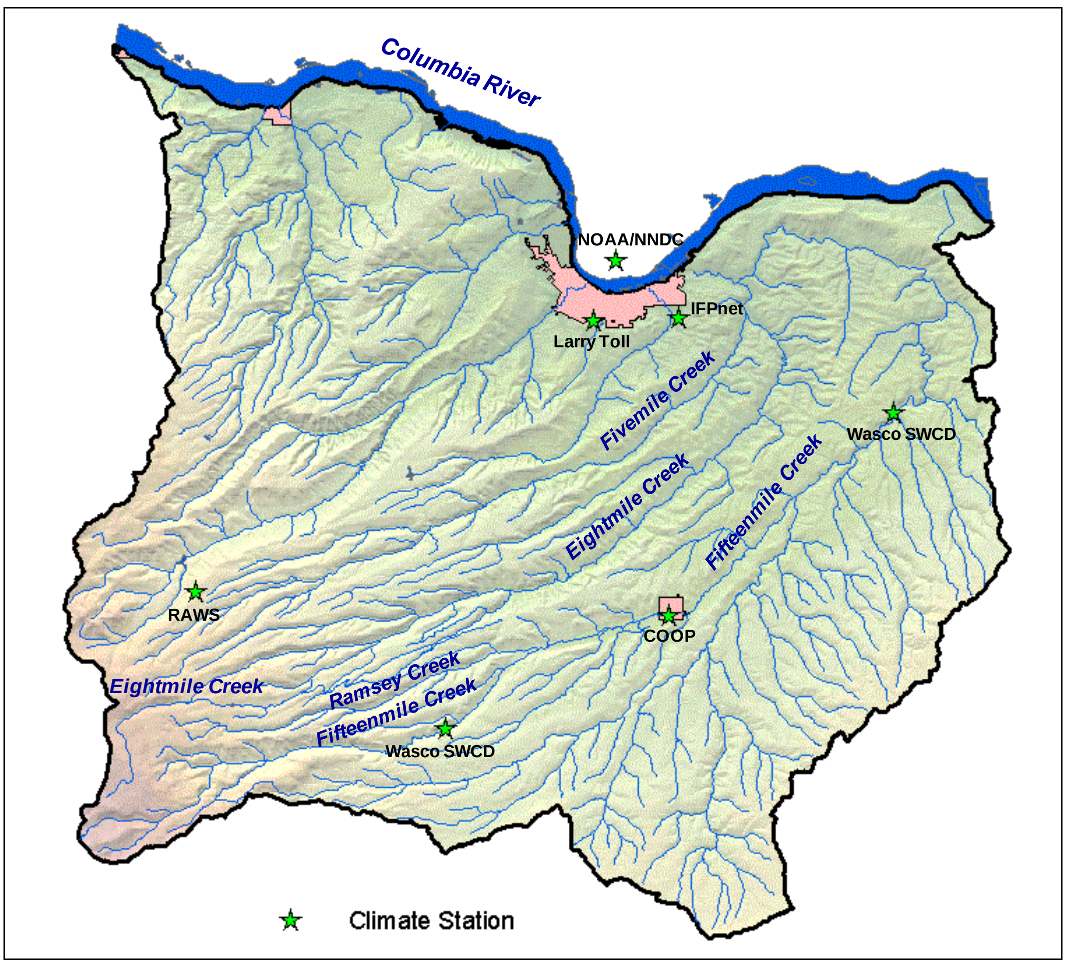
A2.1.4 Climate and Meteorological Data

Climate and meteorological data was collected from seven different sites during the summer of 2002. **Table A-3** and **Figure A-18** show the location of the climate stations and types of data collected at each station. This data was used to establish climate and meteorological conditions in the temperature and effective shade models.

Table A-3. Weather data used in Fifteenmile Creek termperature simulations

Location	Type	Source
RAWS (Pollywog Site)	Air temperature, wind speed/direction, relative humidity, solar radiation	RAWS
Dufur City intake	Air temperature	Wasco SWCD
Dufur	Air temperature	COOP
Emerson bridge	Air temperature	Wasco SWCD
The Dalles airport	Air temperature, wind speed/direction , relative humidity, cloudiness	NOAA/NNDC
Hwy 197 near auction yard	Air temperature, wind speed, relative humidity, solar radiation	IFPnet
The Dalles	Air temperature, wind speed/direction, relative humidity	Larry Toll (watermaster)

Figure A-18. Location of climate stations providing meteorological data for model simulations



A2.2 GIS DATA

This stream temperature TMDL relies extensively on GIS data. Water quality issues are interrelated, complex and spread over many square miles. The TMDL analysis strives to capture these complexities using the highest resolution spatial data available. The GIS data used to develop this TMDL are listed in **Table A-4** and further described below.

Table A-4. Spatial Data and Application

Spatial Data	Application
10-Meter Digital Elevation Models (DEM)	Measure stream elevation and gradient Measure valley shape/ and landform Measure topographic shade angles
Aerial Imagery – Digital Orthophoto Quads	Map near stream vegetation Map stream position and channel edges Map channel morphology and aspect Map roads, development, and other structures
Water Rights Information System (WRIS) and Points of Diversion (POD) Data	Map locations and estimate quantities of water withdrawals

A2.2.1 Elevation Data – 10-meter DEM

Digital Elevation Model (DEM) data files are representations of cartographic information in a raster form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. The U.S. Geological Survey, as part of the National Mapping Program, produces these digital cartographic/geographic data files. Ten-meter DEM grid elevation data is rounded to the nearest meter for ten-meter pixels (vertical resolution is approximately 1 meter in flat terrain).

A2.2.2 Aerial Imagery – Digital Orthophoto Quad

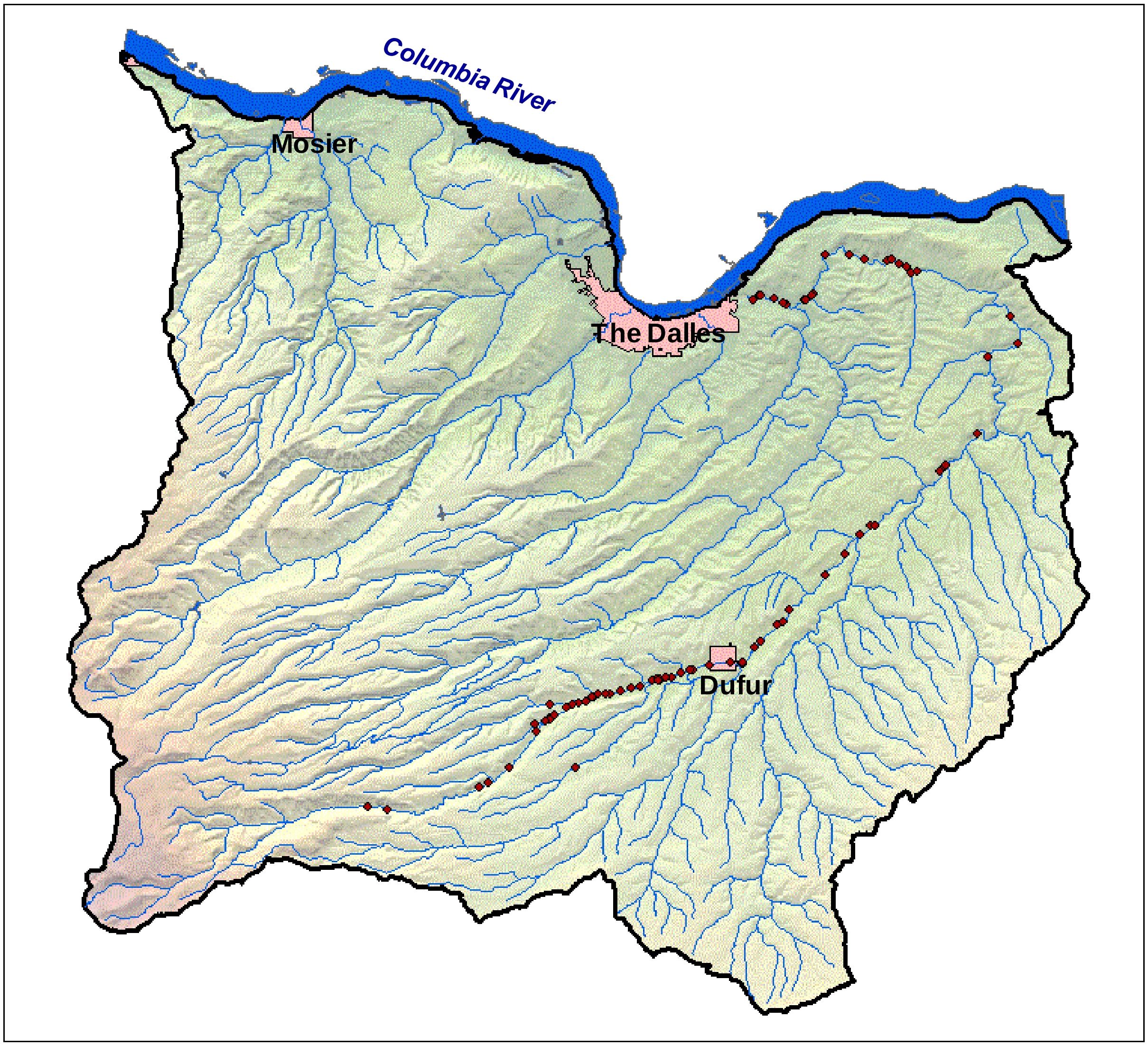
A digital orthophoto quad (DOQ) is a digital image of an aerial photograph in which camera distortion has been removed. In addition, DOQs are projected in map coordinates combining the image characteristics of a photograph with the geometric qualities of a map. The digital orthophotos used in this report were black-and-white with one-meter pixels covering a USGS quarter quadrangle. The images were collected in May through July of 1994, 1995 and 1996, and were provided through the Natural Resources Conservation Service National Cartography and Geospatial Center. Color DOQ imagery (NAIP, 2005) became available in 2007, but were not used in this TMDL because the modeling work had largely been completed.

The mapping and interpretation of the DOQs was aided by frequent reference to high resolution Day TV images, collected with the TIR data. This assisted channel and vegetation delineation where the DOQs lacked sufficient resolution. The Day TV aerial photos were synchronously collected with infrared data from a helicopter, forming thermal infrared radiometry and true color image pairs. The resultant images are not corrected for camera distortion, nor geo-referenced with a coordinate system. However, the images are in color with <0.5 meter/pixel resolution, providing substantially more clarity for vegetation identification and channel delineation.

A2.2.3 WRIS and POD Data – Water Withdrawal Mapping

Flow is diverted from Fifteenmile Creek at multiple points during the summer for irrigation purposes. The OWRD maintains the Water Rights Information System (WRIS). This database includes georeferenced points of diversion (PODs), which DEQ used to map the locations of diversions, rates of water use and types of water use along Fifteenmile Creek (**Figure A-19**). This data was incorporated into a mass balance analysis to generate flow profiles for Fifteenmile Creek (described in **Section 2.3.6**). This data was only generated for Fifteenmile Creek because it was the only creek where hydrology was simulated.

Figure A-19. Mapped points of diversion along Fifteenmile Creek.



A2.3 DERIVED DATA AND SAMPLED PARAMETERS

Sampling numeric GIS data sets for landscape parameters and performing simple calculations was done to derive spatial data for several stream parameters for Fifteenmile Creek, Eightmile Creek and Ramsey Creek. Sampling density was user-defined and generally matched any GIS data resolution and accuracy. The sampled parameters used in this stream temperature/shade analysis were:

- Stream Position and Aspect
- Stream Elevation and Gradient
- Maximum Topographic Shade Angles (East, South, West)
- Channel Width
- TIR Temperature Data Associations
- Near Stream Vegetation

Most of these parameters were derived using TTools (Boyd and Kasper, 2003). TTools is a set of ArcView GIS tools that are designed to automatically sample spatial data sets and assemble an input database for Heat Source modeling. The modeling in this TMDL was done over a three-year time period (2004-2007). During this time, TTools evolved from Version 7.2.1 to Version 7.5.5, so some of the sampling methods used on the three creeks are slightly different. Both versions assembled the same types of datasets, however. TTools Version 7.2.1 was utilized for Fifteenmile Creek and TTools Version 7.5.5 was used on Eightmile Creek and Ramsey Creek. The methodologies used for deriving this data in the Miles Creeks Subbbasin TMDL analysis are described below.

In addition to these derived landscape parameters, stream flows were derived using a mass balance method. Stream flow measurements were taken at a limited number of locations as described in **Section A2.1.2**. The mass balance method was used to calculate stream flows in areas where field measurements were not collected.

A2.3.1 Stream Position and Aspect

Stream position was assessed by digitizing the stream centerline. This polyline was segmented into 50-meter reaches (separated by nodes). The latitude/longitude and aspect (downstream direction) were calculated at each node (**Figure A-20**). An aspect of zero would by north, 90 (east), 180 (south), and 270 (west).

A2.3.2 Stream Elevation and Gradient

Stream elevation was sampled from the 10-meter DEM at each of the segmented TTools nodes. Gradients were calculated from the elevation of the stream node and the distance between nodes (**Figure A-21**).

A2.3.3 Topographic Shade Angle

The maximum topographic shade angles to the west, south and east were measured using the 10-meter DEM at each of the segmented nodes (**Figure A-22**). The topographic angle represents the vertical angle to the highest topographic feature as measured from a flat horizon. On Fifteenmile Creek, the sampling routine extended 32.3 kilometers (20 miles) in each direction. On Eightmile Creek and Ramsey Creek, the sampling routine extended 20 kilometers (12.4 miles). The difference in sampling routine was a function of the different TTools versions used.

Figure A-20. Stream aspects (direction of flow).

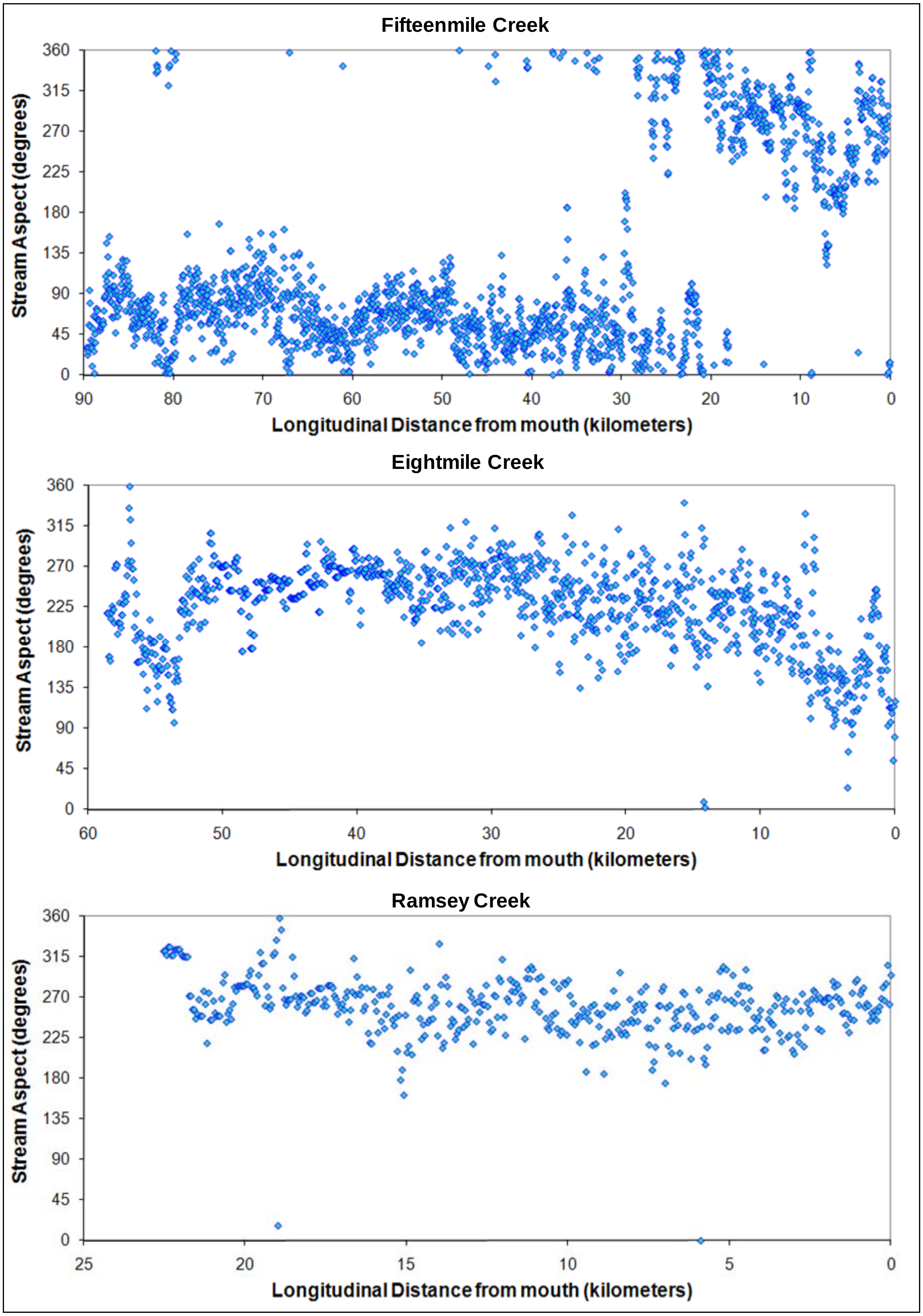


Figure A-21. Stream elevations and gradients.

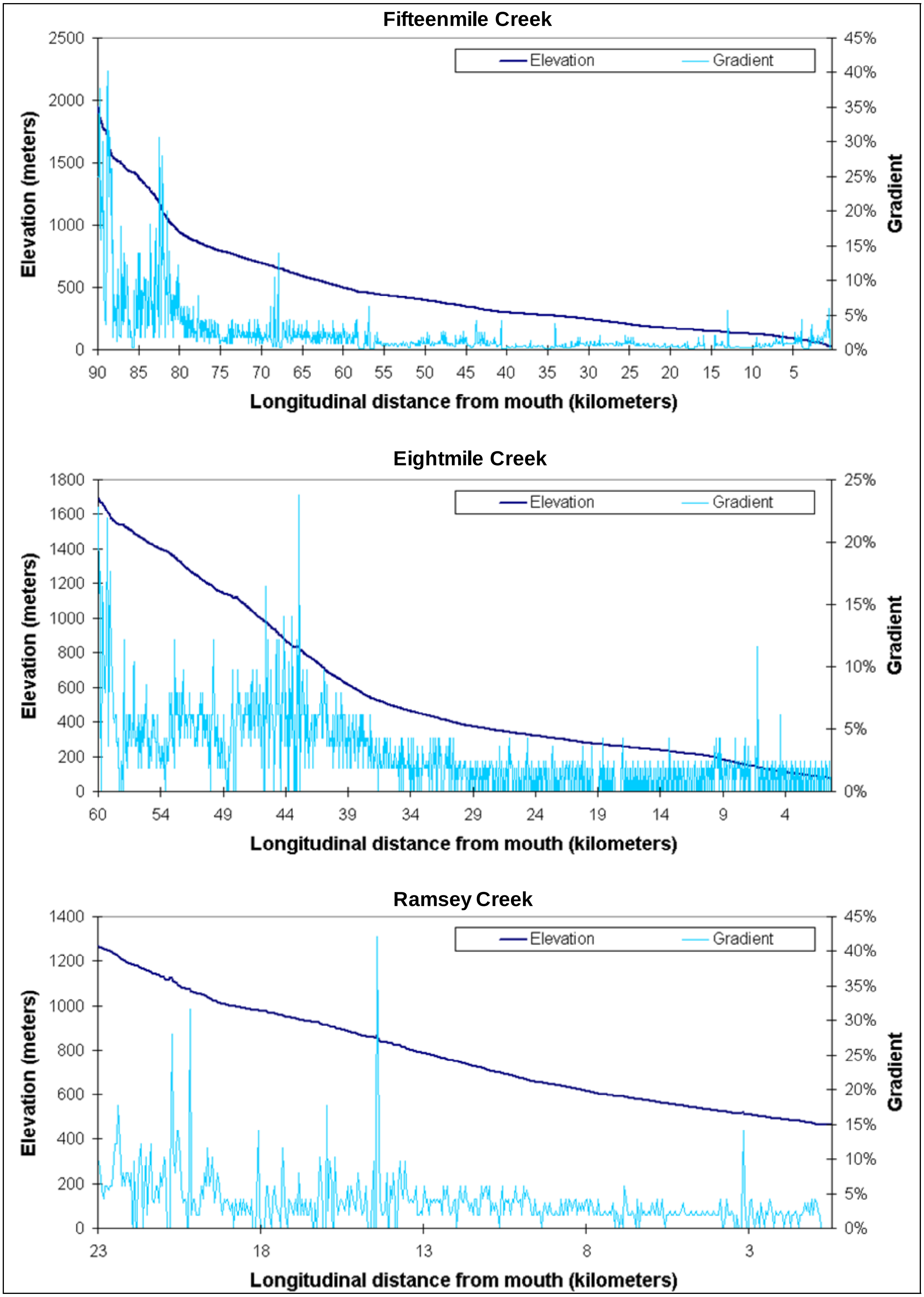
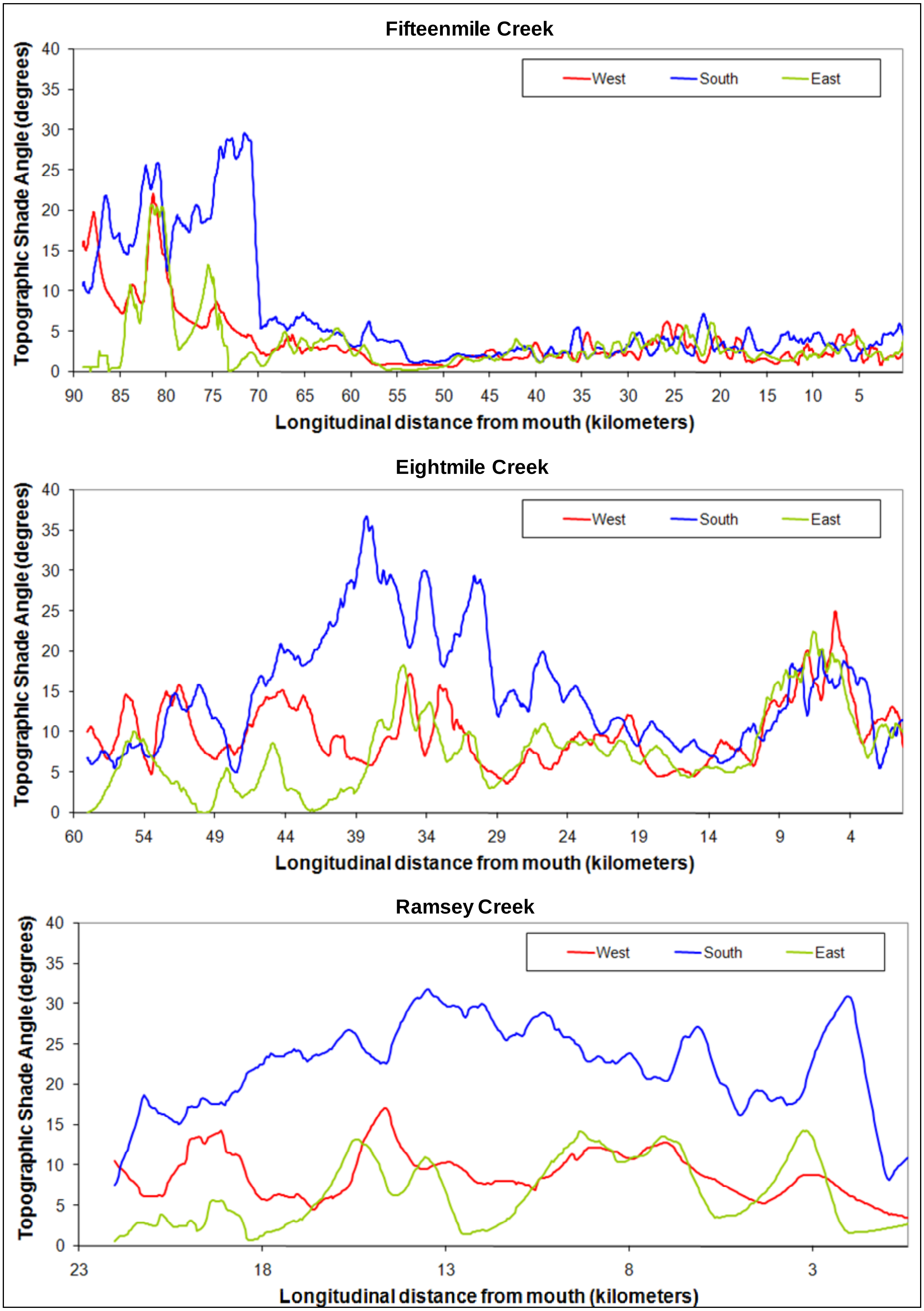


Figure A-22. Topographic shade angles (1-kilometer moving averages).



A2.3.4 Stream Channel Width Assessment

Channel width is an important component in stream heat transfer and mass transfer processes. Effective shade, stream surface area, wetted perimeter, stream depth and stream hydraulics are all highly sensitive to channel width. Accurate measurement of channel width across the stream network, coupled with other derived data, allows a comprehensive analytical methodology for assessing channel morphology. The steps listed below were used for determining channel widths in Fifteenmile Creek, Eightmile Creek and Ramsey Creek.

Step 1. Using the DOQs, the right and left banks (looking in the downstream direction) for each of the creeks were digitized. In some reaches, the creeks were either too narrow or too vegetated to digitize the channel edges. In such cases, the channel widths were estimated based on field data or upstream and downstream comparisons. All digitized line work was completed at a 1:5,000 map scale or less.

Step 2. The distance between each of the digitized banks (perpendicular to the stream aspect) was then measured at each of the segmented TTools nodes. **Figure A-23** shows the digitized stream and channel edges for Fifteenmile Creek at Boyd Loop Rd as example of the digitizing process.

Figure A-23. Digitized stream channels and banks.

A2.3.5 Near Stream Vegetation

The role of near stream vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in scientific literature (Barton et al., 1985; Beschta et al., 1987; Coleman and Kupfer, 1996; Karr and Schlosser, 1978; Malanson, 1993; Osborne and Wiley, 1988; Roth et al., 1996; Steedman, 1988; Zelt et al, 1995). The list of important impacts that near stream vegetation has upon the stream and the surrounding environment is long and warrants listing.

- Near stream vegetation plays an important role in regulating radiant heat in stream thermodynamic regimes.
- Channel morphology is often highly influenced by vegetation type and condition by affecting flood plain and instream roughness, contributing coarse woody debris, and influencing sedimentation, stream substrate compositions and stream bank stability.
- Near stream vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity and lower wind speeds along stream corridors.
- Riparian and instream nutrient cycles are affected by near stream vegetation.

With the recognition that near stream vegetation is an important parameter in influencing water quality, detailed mapping of land cover is a high priority in TMDL development.

A2.3.5.1 Current Condition Vegetation

Variable vegetation conditions require a higher resolution mapping than is currently available with existing GIS data sources. To meet this need, DEQ mapped current condition near stream vegetation along Fifteenmile Creek, Eightmile Creek, and Ramsey Creek using the DOQs at a 1:5,000 scale. The following mapping protocol was used:

Step 1. Using the digitized stream channel, vegetation was mapped 100 meters from each channel edge. Within this zone, polygons were drawn to capture visually alike vegetation features (**Figure A-24**). All digitized line work was completed at a 1:5,000 map scale or less.

Step 2. Basic vegetation types were categorized and assigned to individual polygons. Vegetation types were classified as riparian, upland, deciduous, coniferous, grass, (and other general descriptions) by Ecoregion. Ecoregions of Oregon (Thorson et. al., 2003) was used for the designation of the ecoregions (**Figure A-25**). **Table A-5** summarizes the numeric codes and descriptions used to uniquely identify each of the digitized land cover polygons. Height values and densities were estimated based on field measurements taken during the habitat surveys, as well as the input of local expertise.

Step 3. Automated sampling was conducted on the classified vegetation spatial data set in 2-dimensions using TTools. At each node along the stream centerline, the vegetation polygons were sampled. For Fifteenmile Creek, the polygons were sampled in a radial pattern, using a 15-meter outwards step, up to 60 meters from the stream centerline. For Eightmile Creek and Ramsey Creek, the polygons were sampled in a star pattern using a 7-meter outward step, up to 28 meters from the stream centerline. All streams were sampled every 50 meters longitudinally along the stream path which resulted in 928 radial vegetation samples per stream mile.

Figure A-24. Digitized vegetation polygons.

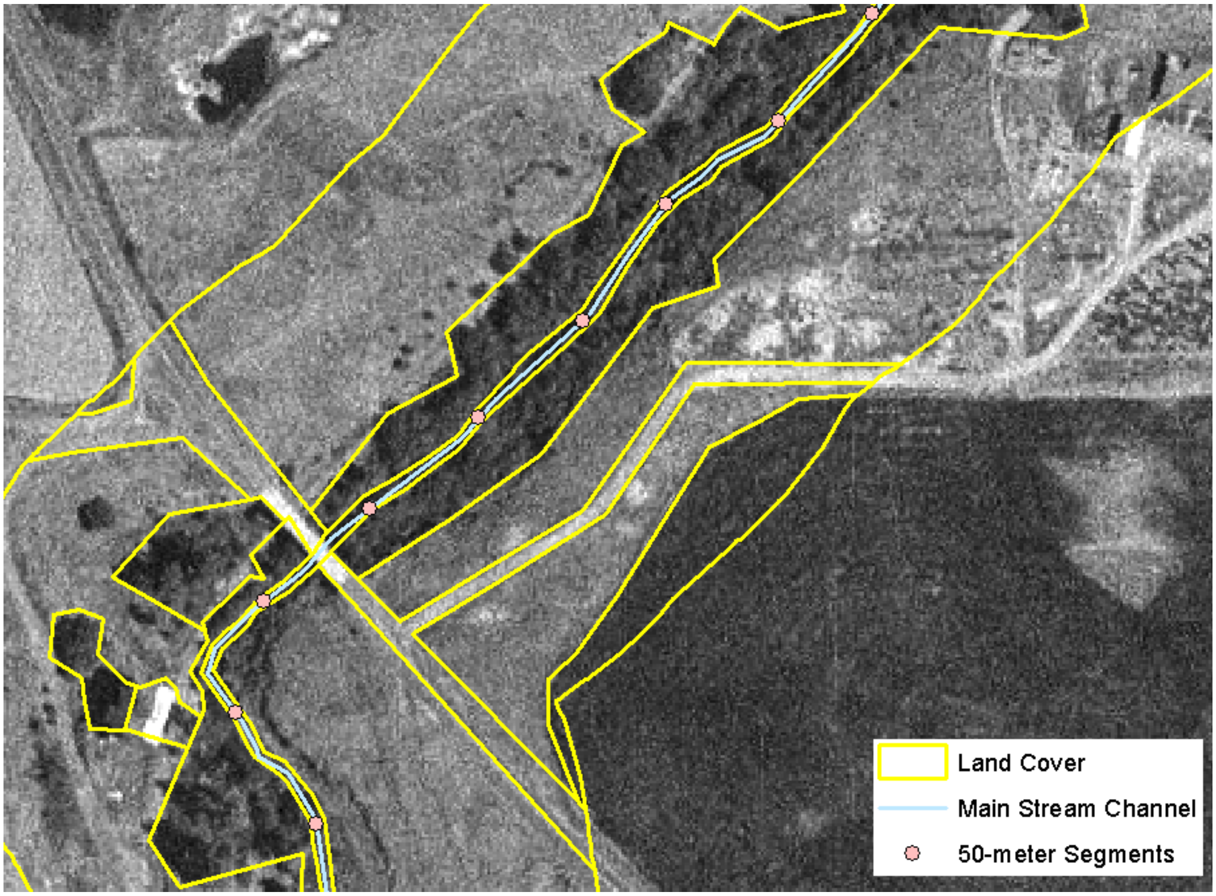


Figure A-25. Ecoregions of Oregon (Thorson, et.al., 2003).

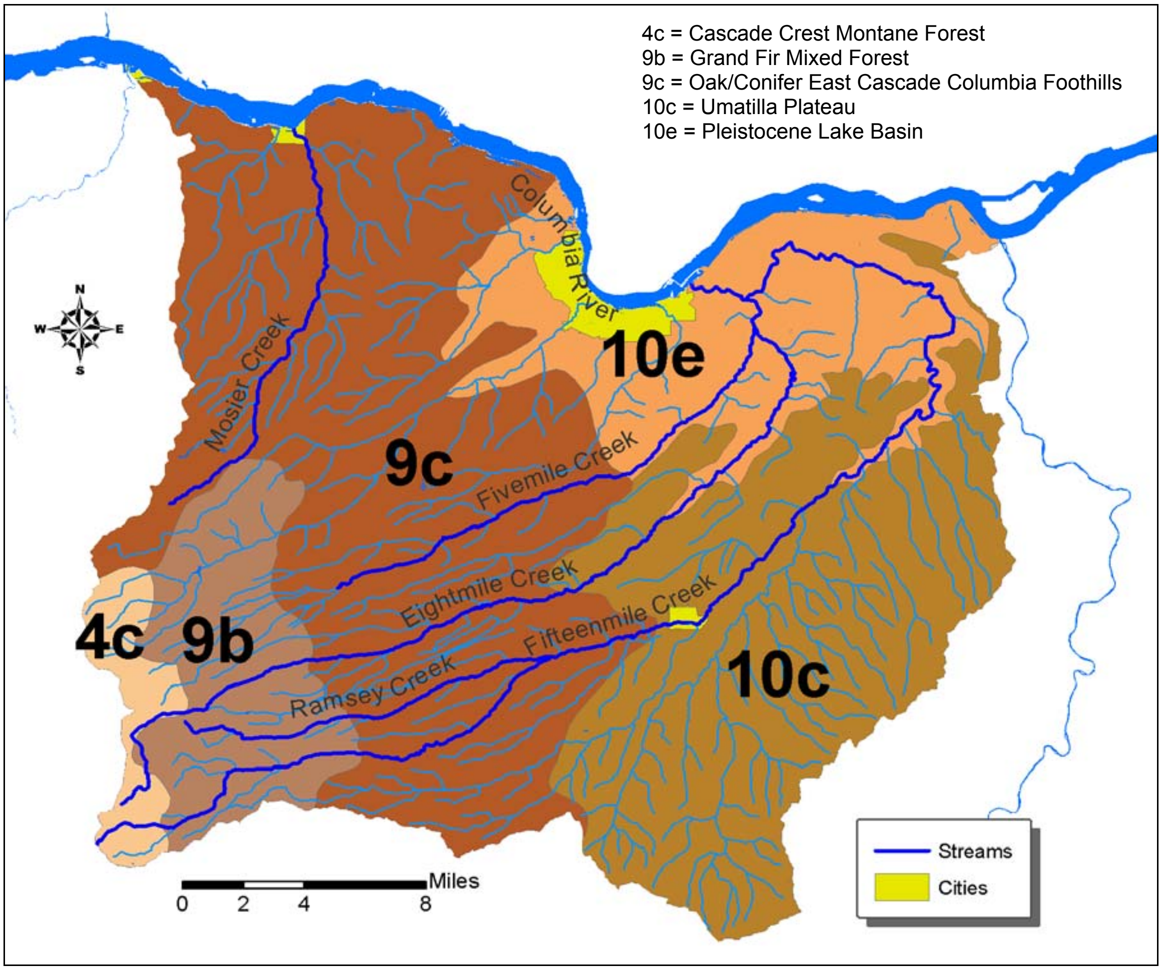


Table A-5. Digitized land cover polygon codes and descriptions.

Land Cover Name	Code	Height (m)	Density (%)	Overhang (m)
Stream	301	0.0	100%	
Agriculture/pasture	302	0.0	100%	
Barren	309	0.0	100%	
House	324	4.6	100%	
Large Building	325	6.0	100%	
Road	350	0.0	100%	
Eco Region 10e Upland	1425	1.5	20%	1.0
Eco Region 10e Upland	1450	1.5	40%	1.0
Eco Region 10e Upland	1475	1.5	60%	1.0
Eco Region 10e Deciduous	1625	10.0	20%	1.5
Eco Region 10e Deciduous	1650	10.0	40%	1.5
Eco Region 10e Deciduous	1675	10.0	60%	1.5
Eco Region 10e Riparian	1825	6.0	20%	1.0
Eco Region 10e Riparian	1850	6.0	40%	1.0
Eco Region 10e Riparian	1875	6.0	60%	1.0
Eco Region 10e Grass	1900	1.0	50%	1.0

Table A-5 (continued). Digitized land cover polygon codes and descriptions.

Land Cover Name	Code	Height (m)	Density (%)	Overhang (m)
Eco Region 10c Upland	2425	1.5	20%	1.0
Eco Region 10c Upland	2450	1.5	40%	1.0
Eco Region 10c Upland	2475	1.5	60%	1.0
Eco Region 10c Deciduous	2625	10.0	20%	1.5
Eco Region 10c Deciduous	2650	10.0	40%	1.5
Eco Region 10c Deciduous	2675	10.0	60%	1.5
Eco Region 10c Riparian	2825	6.0	20%	1.0
Eco Region 10c Riparian	2850	6.0	40%	1.0
Eco Region 10c Riparian	2875	6.0	60%	1.0
Eco Region 10c Grass	2900	1.0	50%	1.0
Eco Region 9c Clear-cut	3308	1.0	40%	0.5
Eco Region 9c Clear-cut early re-growth	3310	4.0	40%	0.5
Eco Region 9c Upland	3425	10.0	20%	1.0
Eco Region 9c Upland	3450	10.0	40%	1.0
Eco Region 9c Upland	3475	10.0	60%	1.0
Eco Region 9c Mixed	3525	11.0	20%	1.0
Eco Region 9c Mixed	3550	11.0	40%	1.0
Eco Region 9c Mixed	3575	11.0	60%	1.5
Eco Region 9c Deciduous	3625	12.0	20%	1.5
Eco Region 9c Deciduous	3650	12.0	40%	1.5
Eco Region 9c Deciduous	3675	12.0	60%	1.5
Eco Region 9c Coniferous	3750	28.0	20%	1.0
Eco Region 9c Coniferous	3770	20.0	55%	1.0
Eco Region 9c Coniferous	3775	28.0	55%	1.0
Eco Region 9c Riparian	3825	8.0	20%	1.0
Eco Region 9c Riparian	3850	8.0	40%	1.0
Eco Region 9c Riparian	3875	8.0	60%	1.0
Eco Region 9c Grass	3900	1.0	40%	1.0
Eco Region 9b Clear-cut	4308	1.0	40%	0.5
Eco Region 9b Clear-cut early re-growth	4310	4.0	40%	0.5
Eco Region 9b Upland	4425	9.0	20%	0.0
Eco Region 9b Upland	4450	9.0	40%	0.0
Eco Region 9b Upland	4475	9.0	60%	1.0
Eco Region 9b Mixed	4550	12.0	60%	1.0
Eco Region 9b Deciduous	4625	12.0	40%	1.0
Eco Region 9b Coniferous	4725	15.0	20%	1.0
Eco Region 9b Coniferous	4750	30.0	60%	1.0
Eco Region 9b Coniferous	4775	30.0	80%	1.5
Eco Region 9b Grass	4900	1.0	40%	0.0
Eco Region 4c Clear-cut	5308	1.0	40%	0.5
Eco Region 4c Clear-cut early re-growth	5310	4.0	40%	0.5
Eco Region 4c Coniferous	5700	30.0	80%	1.5
Eco Region 4c Coniferous	5750	30.0	60%	1.5
Eco Region 4c Grass	5900	1.0	50%	0.0

A2.3.5.2 Site Potential Vegetation

Site potential vegetation refers to the vegetation landcover which can grow and reproduce on a site given the natural plant biology, site elevation, soil characteristics, climate, and natural disturbance regime. Potential near stream vegetation is essentially the mature species composition, height, and density of vegetation that would occur in the absence of human disturbances. Potential near stream vegetation does not include considerations for resource management, human use or other legacy human disturbances.

Since near stream vegetation is a controlling factor in stream temperature regimes, the condition and health of vegetation is considered a primary parameter in the TMDL. Potential vegetation is a key condition targeted in the TMDL. DEQ worked with members of the Miles Creeks TMDL Technical Committee to determine site potential vegetation by TMDL Vegetation Zones (**Figure A-26**). The Vegetation Zones were developed from Ecoregions of Oregon (Thorson et.al., 2003, **Figure A-25**), with further modification based on a consensus process using the local expertise of the Technical Committee (including local staff from ODF, Wasco SWCD, ODFW, the Mt. Hood National Forest and city of The Dalles). Each zone was subdivided into categories, based on location within the zone (riparian or upland) and aspect (south/west or north/east facing). The zone numbers are not sequential because of revisions to the map as the TMDL was developed. Changing the numbers after each revision would have been difficult and labor-intensive because the modeling setup and the zones are intricately linked. **Table A-6** provides detailed information about the vegetation characteristics associated with each zone. It should be noted that the species listed in a particular Vegetation Zone below may vary somewhat on different streams within that zone. The lists provide an indication of the species you might find in that zone.

Figure A-26. Miles Creeks TMDL Vegetation Zones.

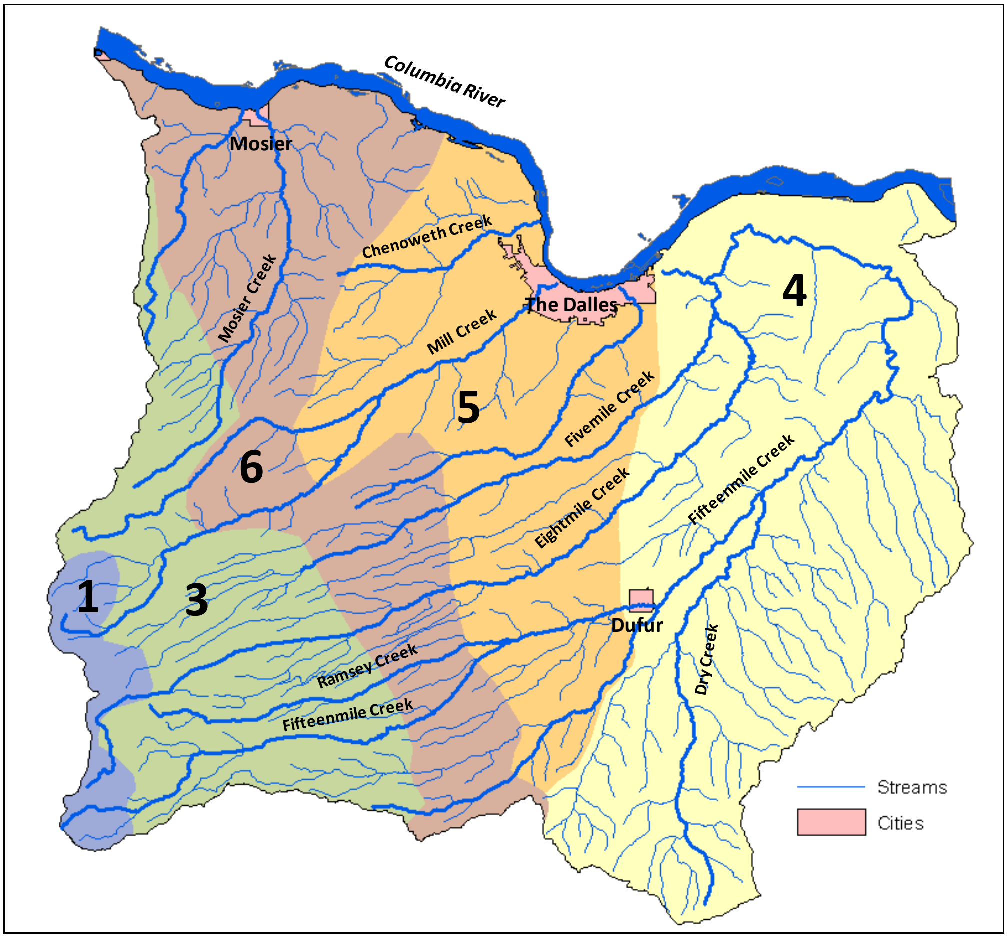


Table A-6. Summary of characteristics of Site Potential Vegetation by TMDL Vegetation Zone.

TMDL Vegetation Zone (related Ecoregion)	Vegetation Code	Site Potential Vegetation Characteristics*			
		Vegetation	Height (feet)	Assumed Canopy Density	Overhang (feet / meters)
Zone 4 Umatilla Plateau (10c)	4050	**Riparian – 0 to 20 feet from to stream** Willow Alder Black Cottonwood Oregon White Oak Ponderosa Pine Assorted shrubs** ***Composite Dimension*** *(95% hardwoods/5% conifers)*	 20 50 90 50 80 6 **40 ft / 12.2 m**	**85%**	**4 ft / 1.2 m**
	4100	**Riparian – 20-100 feet from stream** Willow Alder Black Cottonwood Oregon White Oak Ponderosa Pine ***Composite Dimension*** *(80% hardwoods/20% conifers)*	 50 90 50 80 **65 ft / 19.8 m**	**50%**	
	4200	**Upland – south/west facing slopes** Grass/Sage*** Oregon White Oak Ponderosa Pine ***Composite Dimension*** *(trace % trees/ 98-100% grass/sage)*	 3 50 100 **75 ft / 22.9 m**	**<1%**	
	4250	**Upland – north/east facing slopes** Grass/Sage Oregon White Oak Ponderosa Pine ***Composite Dimension*** *(2-10% trees/90-98% grass/sage)*	 3 50 100 **75 ft / 22.9 m**	**6%**	

* Note: The species listed in a particular Vegetation Zone below will vary somewhat on different streams within that zone. The lists provide an indication of the species you might find in that zone.

** Assorted shrubs include Ocean Spray, Snowberry, and other native species in the riparian zone.

*** Grass/sages are listed where they occur in the upland to accurately reflect the native species composition of these areas. Because these species do not significantly contribute to providing shade to the stream, they are not included in the composite height and canopy density calculations. These composite dimensions reflect the tree species present in each region.

Table A-6 (continued). Summary of characteristics of Site Potential vegetation by TMDL Vegetation Zone.

TMDL Vegetation Zone (related Ecoregion)	**NTP Vegetation Code**	**Site Potential Vegetation Characteristics***			
		Vegetation	**Height (feet)**	**Assumed Canopy Density**	**Overhang (feet/ meters)**
Zone 5 and Zone 6 Oak/Conifer East Cascade Columbia Foothills (9c)	5050 6050	**Riparian – 0 to 20 feet from to stream**			
		Willow / Alder	35-40		
		Black Cottonwood	80-120		
		Ponderosa Pine	80-120		
		Western Red Cedar	80-120		
		Oregon White Oak	50		
		Assorted shrubs**	6		
		Composite Dimension *(50%alder and willow/50% conifers and cottonwood)*	**(Zone 5) 60 ft / 18.3 m (Zone 6) 90 ft / 27.4 m**	**85%**	**(Zone 5) 6 ft / 1.8 m (Zone 6) 9 ft / 2.7 m**
	5100 6100	**Riparian – 20-100 feet from stream**			
		Willow / Alder	35-40		
		Black Cottonwood	80-110		
		Ponderosa Pine	80-110		
		Western Red Cedar	80-110		
		Oregon White Oak	50		
		Composite Dimension *(dominated by conifers)*	**(Zone 5) 70 ft / 21.3 m (Zone 6) 100 ft / 30.5 m**	**70%**	
	5200 6200	**Upland – south/west facing slopes**			
		Grass/shrubs***	3		
		Oregon White Oak	50		
		Ponderosa Pine	100		
		Douglas Fir (trace on west end)	120		
		Composite Dimension	**(Zone 5) 50 ft / 15.2 m (Zone 6) 75 ft / 22.9 m**	**10% (Zone 5) 30% (Zone 6)**	
	5250 6250	**Upland – north/east facing slopes**			
		Grass/shrubs	3		
		Oregon White Oak	50		
		Ponderosa Pine	100-120		
		Douglas Fir	120		
		Composite Dimension	**(Zone 5) 100 ft / 30.5 m (Zone 6) 120 ft / 36.6 m**	**40% (Zone 5) 60% (Zone 6)**	

* Note: The species listed in a particular Vegetation Zone below will vary somewhat on different streams within that zone. The lists provide an indication of the species you might find in that zone.

** Assorted shrubs include Ocean Spray, Snowberry, and other native species in the riparian zone.

*** Grass/sages are listed where they occur in the upland to accurately reflect the native species composition of these areas. Because these species do not significantly contribute to providing shade to the stream, they are not included in the composite height and canopy density calculations. These composite dimensions reflect the tree species present in each region.

Table A-6 (continued). Summary of characteristics of Site Potential vegetation by TMDL Vegetation Zone.

TMDL Vegetation Zone (related Ecoregion)	**NTP Vegetation Code**	**Site Potential Vegetation Characteristics***			
		Vegetation	**Height (feet)**	**Assumed Canopy Density**	**Overhang (feet/meters)**
Zone 3 Grand Fir Mixed Forest (9b)	3050	**Riparian – 0 to 20 feet from to stream**	55		
		Alder/willow (20-30%)	100		
		Black Cottonwood	140		
		Grand Fir	130		
		Western Red Cedar	100		
		Englemann Spruce	80		
		Quaking Aspen			
		Composite Dimension	**100 ft / 30.5 m**	**85%**	**10 ft / 3 m**
	3100	**Riparian – 20-100 feet from stream**	50		
		Oregon White Oak	50		
		Bigleaf Maple	130		
		Ponderosa Pine	150		
		Douglas Fir	140		
		Grand Fir	130		
		Western Red Cedar	100		
		Black Cottonwood	80		
		Quaking Aspen			
		Composite Dimension	**130 ft / 39.6 m**	**85%**	
	3200	**Upland**			
		Oregon White Oak	50		
		Bigleaf Maple	50		
		Ponderosa Pine	130		
		Douglas Fir	150		
		Grand Fir	140		
		Larch	150		
		White Pine	120		
		Composite Dimension	**125 ft / 38.1 m**	**80%**	
	3300	**Meadows**			
		Sedges	3		
		Misc Forbs	1		
		Composite Dimension	**3 ft / 0.9m**	**20%**	
Zone 1 Cascade Crest Montane Forest (4c)	1000	Engelmann Spruce	80-100		
		Douglas Fir	80-100		
		Western Larch	80-100		
		Pacific Silver Fir	80-100		
		Noble Fir	80-100		
		Mt. Hemlock	60-80		
		Lodgepole Pine	80-100		
		Composite Dimension	**90 ft / 27.4 m**	**80%**	**9 ft / 2.7 m (completely overhung)**
	1100	**Wet Meadows**			
		Willow	10		
		Cascade azalea	3-5		
		Sedges	1		
		Misc. forbs	1		
		Composite Dimension	**5 ft / 1.5 m**	**20%**	**1 ft / 0.3 m**

* Note: The species listed in a particular Vegetation Zone below will vary somewhat on different streams within that zone. The lists provide an indication of the species you might find in that zone.

The composite dimension information presented in **Table A-6** was used to modify the current condition vegetation database for Fifteenmile Creek, Eightmile Creek and Ramsey Creek described above in order to develop model input for estimating temperature and heat loads under potential vegetation conditions. In the database, the numeric land cover codes for current conditions (**Table A-5**) were replaced with land cover codes from **Table A-6**, with changes made depending on: location within TMDL Zone (1, 3, 4, 5 or 6); aspect (S/SW or N/NE), and distance from stream (riparian 0-20 ft from stream, riparian 20-100 ft from stream, or uplands). This new site potential vegetation database was then re-sampled in TTools following the steps described in **Section A2.3.5.1** to provide the GIS-derived model input for the site potential vegetation models. Examples of riparian conditions that approximate site potential conditions are shown in **Figure A-27**, **Figure A-28**, and **Figure A-29**.

Figure A-27. Example of site potential vegetation along Ramsey Creek (left) and Fifteenmile Creek (right).

Figure A-28. Example of vegetation on Fivemile Creek at or near the system potential condition.

Figure A-29. Example of near closed canopy vegetation over Fifteenmile Creek.

A2.3.6 Mass Balance Analysis

A mass balance analysis is a methodology to calculate unknown stream flow rates or tributary temperatures when information in the upstream and downstream direction is known. All stream temperature changes that result from mass transfer processes (i.e., tributary confluence, point source discharge, groundwater inflow, etc.) can be described mathematically using the following relationship:

$$T_{mix} = \frac{(Q_{up} \cdot T_{up}) + (Q_{in} \cdot T_{in})}{(Q_{mix})} = \frac{(Q_{up} \cdot T_{up}) + (Q_{in} \cdot T_{in})}{(Q_{up} + Q_{in})}$$

where,

Q_{up}: Stream flow rate upstream from mass transfer process
Q_{in}: Inflow volume or flow rate
Q_{mix}: Resulting volume or flow rate from mass transfer process ($Q_{up} + Q_{in}$)
T_{up}: Stream temperature directly upstream from mass transfer process
T_{in}: Temperature of inflow
T_{mix}: Resulting stream temperature from mass transfer process assuming complete mix

The equation may be rearranged to calculate any single factor if the other factors are known. The TIR sampled stream data provided all water temperatures (i.e., T_{up}, T_{in} and T_{mix}) and flow rates were provided by instream measurements. Water withdrawal flow rates are estimated from field data and the water right information maintained by Oregon Water Resources Department (OWRD).

Discussion of Assumptions and Limitations for Mass Balance Methodology

1. **Small mass transfer processes are not accounted**. A limitation of the methodology is that only mass transfer processes with measured ground level flow rates or those that cause a quantifiable change in stream temperature with the receiving waters (i.e., identified by TIR data) can be analyzed and included in the mass balance. For example, a tributary with an unknown flow rate that cause small temperature changes (i.e., less than $\pm 0.5^{o}$F) to the receiving stream cannot be accurately included. *This assumption can lead to an under estimate of influent mass transfer processes.*
2. **Limited ground level flow data limit the accuracy of derived mass balances**. Errors in the calculations of mass transfer can become cumulative and propagate in the methodology since validation can only be performed at sites with known flow rates. *These mass balance profiles should be considered estimates of a steady state flow condition*.
3. **Water withdrawals are not directly quantified**. Instead, water right data is obtained from the POD and WRIS OWRD databases. An assumption is made that these water rights are being used if water availability permits. *This assumption can lead to an over estimate of water withdrawals.*
4. **Water withdrawals are assumed to occur only at OWRD mapped points of diversion sites.** There may have been additional diversions occurring throughout the stream network. *This assumption can lead to an underestimate of water withdrawals and an under estimate of potential flow rates.*
5. **It is not possible to determine the amount of return flows derived from ground water withdrawals relative to those derived from instream withdrawals.** Some of the irrigated water comes from ground water sources. Therefore, one should assume that portions of the return flows are derived from ground water sources. Return flows can occur over long distances from irrigation application and generally occur at focal points down gradient from multiple irrigation applications. It is not possible to estimate the portion of irrigation return flow that was pumped from ground water rights. In the potential flow condition all return flows are removed from the mass balances. *This assumption can lead to an under estimate of potential flow rates.*

CHAPTER A3. SIMULATIONS

The data sources described in the previous section were used to set up Heat Source models for Fifteenmile Creek, Eightmile Creek, and Ramsey Creek. The scope of the modeling was different on the three creeks as is described below. All solar radiation loads are the clear sky received loads that account for Julian time, elevation, atmospheric attenuation and scattering, stream aspect, topographic shading, near stream vegetation, stream surface reflection, water column absorption and stream bed absorption. An overview of stream heat transfer processes is provided in **Section A1.1**.

Model Used

- Heat Source, version 7.0[2]

Simulation Resolution

- Time step: one minute
- Input distance step: 50 meters
- Output distance step: 100 meters

Simulation Extent and Period

- The simulation extent varied by stream and the type of modeling as shown in **Table A-7** (also refer back to **Figure A-1** for a map showing the streams modeled).

Table A-7. Extent of Heat Source modeling in the Miles Creeks area.

Creek	Simulation Period	Simulation Extent	Effective Shade Modeling kilometers (miles)	Temperature Modeling kilometers (miles)
Fifteenmile Creek	7/17/2002	Mouth to headwaters	89.5 (55.6)	N/A
	7/17/2002 to 8/5/2002	Mouth to Mt. Hood National Forest boundary		70.5 (43.8)
Eightmile Creek	7/17/2002	Mouth to headwaters	58.6 (36.4)	N/A
Ramsey Creek	7/17/2002	Mouth to headwaters	22.5 (14.0)	N/A
Total			**170.6 (106)**	**70.5 (43.8)**

2 *Heat Source* documentation "*Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0*" (Boyd and Kasper, 2003) is available on-line at http://www.deq.state.or.us/wq/TMDLs/tools.htm.

A3.1 EFFECTIVE SHADE ANALYSIS

A3.1.1 Overview - Description of Shading Processes

Effective shade can be thought of as the amount of daily solar radiation directed toward the stream that is blocked by features such as topography and vegetation. Factors that influence stream surface effective shade are incorporated into the simulation methodology, and include the following:

Season/Time: Date/Time
Stream Morphology: Aspect, Channel Width, Incision
Geographic Position: Latitude, Longitude, Topography
Land Cover: Near Stream Land Cover Height, Width, Density
Solar Position: Solar Altitude, Solar Azimuth

A3.1.2 Site Specific Effective Shade Simulations

Site-specific effective shade and heat flux simulations were performed for a total of 106 stream miles every 50 longitudinal meters along Fifteenmile Creek, Eightmile Creek and Ramsey Creek.

Three different effective shade scenarios were simulated, as shown in **Table A-8**. Once current condition effective shade models were calibrated, potential near stream vegetation scenarios were simulated. Natural site potential vegetation was estimated as described in **Section A2.3.5.2**. The amount of shade provided by topographic features was also determined. This scenario provided the lower end of the *Natural Disturbance Range,* indicating the amount of shade that the stream would receive if topography was the only shade-producing feature (i.e., in the absence of vegetation).

Table A-8. Site specific Effective Shade Simulations

Scenario 1:	Current Condition: This simulation establishes current effective shade by modeling the vegetation and anthropogenic landcover that was present at the time of the DOQ was produced (1994/1995).
Scenario 2: (TMDL Loading Capacity)	Site Potential Vegetation: The simulation establishes effective shade that would be possible under natural conditions.
Scenario 3:	Topographic Shade: The scenario establishes the effective shade from natural topography by removing all vegetation and anthropogenic landcover such as houses and buildings.

There are a number of limitations and assumptions which are important to mention before a discussion of the effective shade simulation results:

- Near stream vegetation types and physical attributes were based on ground level (field surveys) and GIS (digitized polygons) data. Each data source has accuracy considerations.
- The DOQs used for digitizing were from 1994/1995. Significant riparian restoration work has been undertaken in the watershed since that time so the “current condition” land cover may under-estimate the riparian vegetation that currently exists.
- The quality of the images using black and white DOQs often made it difficult to accurately distinguish and identify the characteristics of the riparian vegetation. This was particularly challenging in areas where there was only a narrow riparian corridor surrounded by agricultural lands. This may have resulted in the “current condition” land cover underestimating the riparian vegetation that currently exists.

- Associations used for vegetation classification were assigned median values for height and density to describe physical attributes, and in some cases, this methodology significantly underestimates landscape variability.
- The stream channels were too small to digitize from the DOQ orthophotos in some reaches, especially above the Forest boundary. Those reaches had to be estimated by taking several manual measurements off the DOQ orthophotos wherever the stream was visible. Assumed channel widths where they were not measurable from the DOQs may reduce accuracy of the effective shade simulation.
- The simulation is valid for effective shade values in mid-July to early August.

A3.1.2.1 Model Validation – Effective Shade Simulation Accuracy

Effective shade simulation validation was conducted by comparing simulated results with ground level measured shade values. Solar Pathfinder® measurements were collected at 23 different locations on the three creeks. Two or three measurements were taken at each location and averaged for a reach measurement. **Figure A-30, Figure A-31** and **Table A-9** show a comparison of the measured and simulated effective shade on the three creeks. The correlation coefficient between measured and simulated values was reasonably low (R^2=0.3895). The discrepancy observed can largely be attributed to the issues with the DOQ imagery mentioned above.

Figure A-30. Correlation of measured and simulated effective shade for all modeled streams.

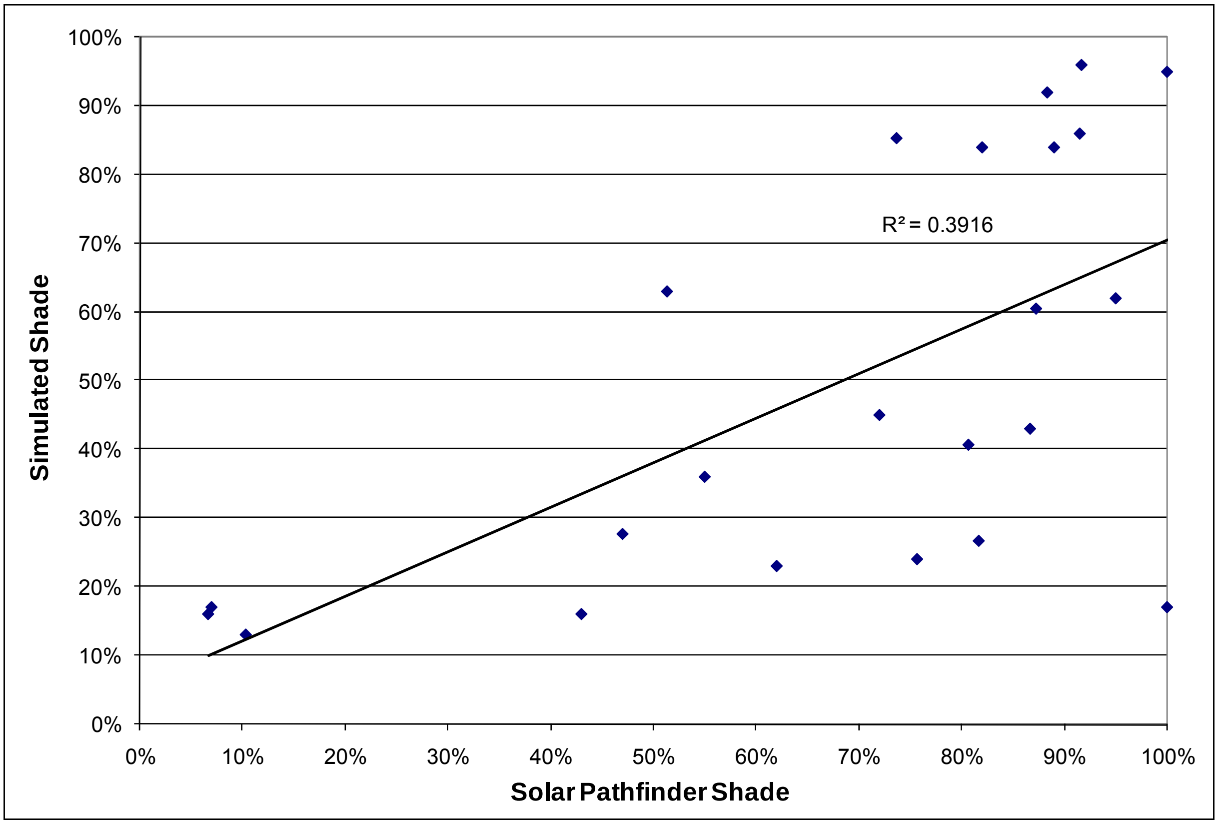


Figure A-31. Measured and simulated effective shade (July 17).

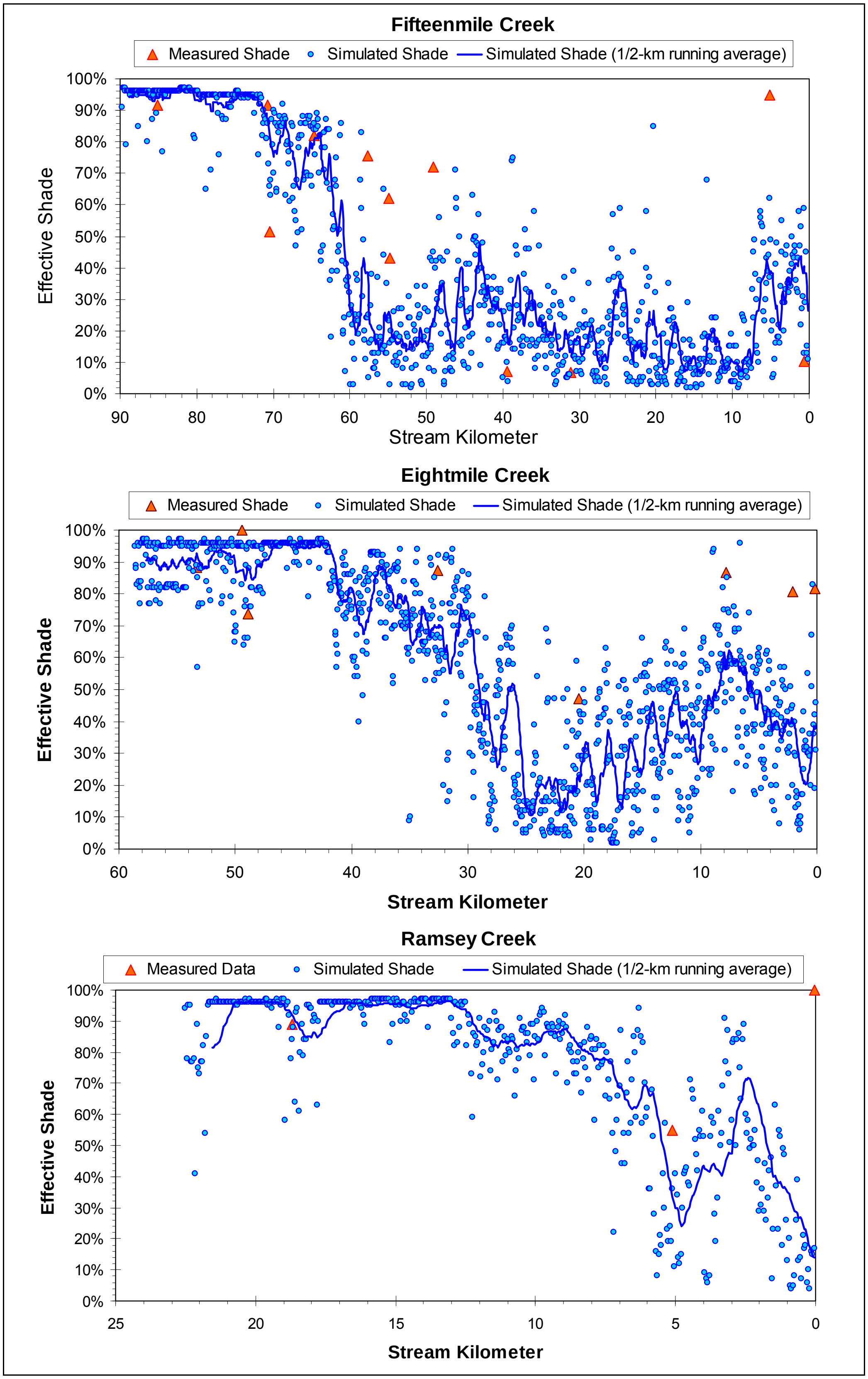


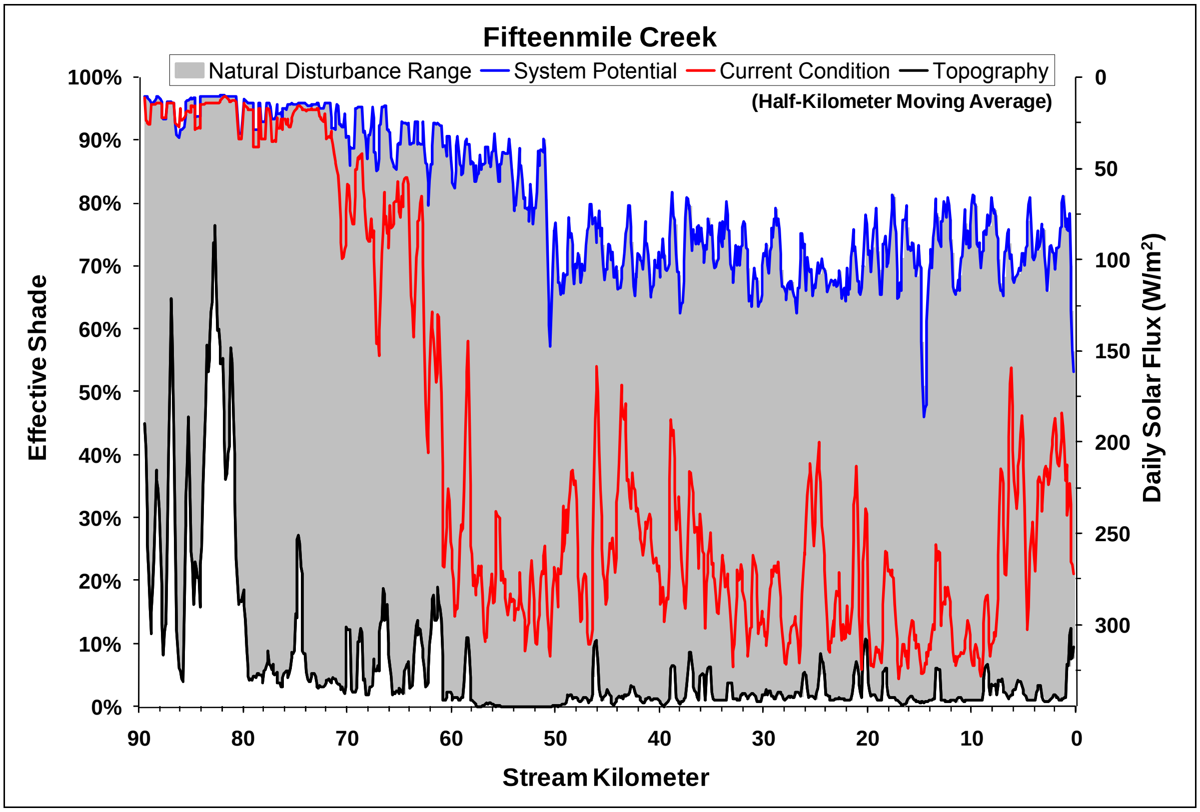
Table A-9. Comparison of measured and simulated effective shade

Location	Stream Kilometer	Solar Pathfinder Measurement	Heat Source 7.0 Simulation
Fifteenmile Creek d/s ODFW screwtrap	0.70	10%	13%
Fifteenmile Creek u/s Eightmile Creek	5.10	95%	62%
Fifteenmile Creek d/s Standard Hollow	31.10	7%	16%
Fifteenmile Creek u/s Dry Ck	39.50	7%	17%
Fifteenmile Creek u/s Hwy 197	49.10	72%	45%
Fifteenmile Creek near Rivermile 34 (Site 2)	54.75	43%	16%
Fifteenmile Creek near Rivermile 34 (Site 1)	54.90	62%	23%
Fifteenmile Creek u/s Ramsey Ck	57.70	76%	24%
Fifteenmile Creek d/s Dufur City intake	64.70	82%	84%
Fifteenmile Creek d/s Lyda Diversion	70.50	51%	63%
Fifteenmile Creek @ Forest boundary	70.75	92%	86%
Fifteenmile Creek u/s 2730 Rd.	85.15	92%	96%
Eightmile Creek u/s Fifteenmile Rd	0.20	82%	27%
Eightmile Creek d/s Fivemile Creek	2.20	81%	41%
Eightmile Creek d/s county bridge	7.80	87%	43%
Eightmile Creek u/s Endersby bridge	20.50	47%	28%
Eightmile Creek @ River Mile 19	32.65	87%	61%
Eightmile Creek d/s Rd. 4430	48.95	74%	85%
Eightmile Creek u/s Rd. 4430	49.45	100%	95%
Eightmile Creek u/s Rd. 44	53.30	88%	92%
Ramsey @ mouth	0.05	100%	17%
Ramsey on Ramsey Creek Rd. (new forest boundary)	5.10	55%	36%
Ramsey d/s Rd 4450	18.70	89%	84%

A3.1.2.2 Effective Shade and Solar Heat Flux Simulations

Effective shade is inversely proportional to solar radiation flux and can be used as a surrogate for solar radiation loading as described in **Section 3.9** of the TMDL document. **Figure A-32** shows the simulation results for Fifteenmile Creek, Eightmile Creek and Ramsey Creek. Effective shade is presented on the left-hand axis and the corresponding heat flux on the right-hand axis.

Figure A-32. Effective Shade – Current Condition and Loading Capacity (System Potential)



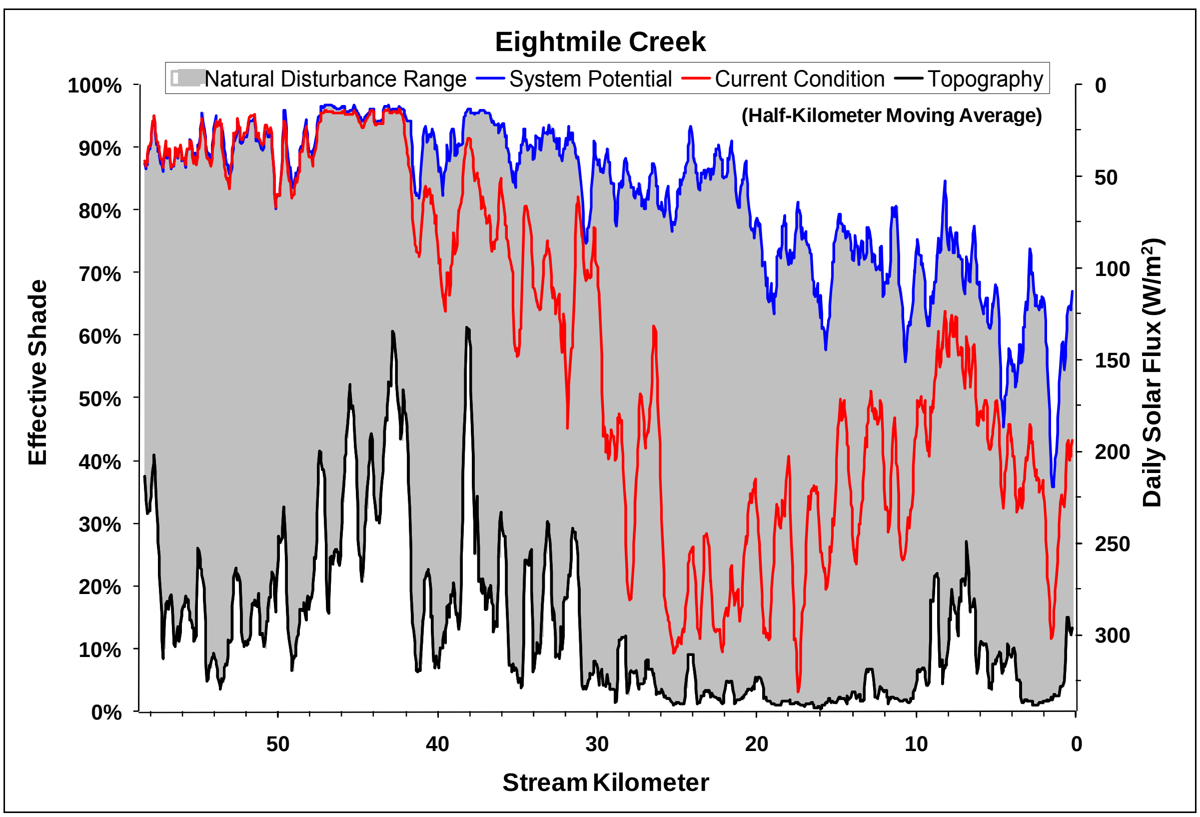
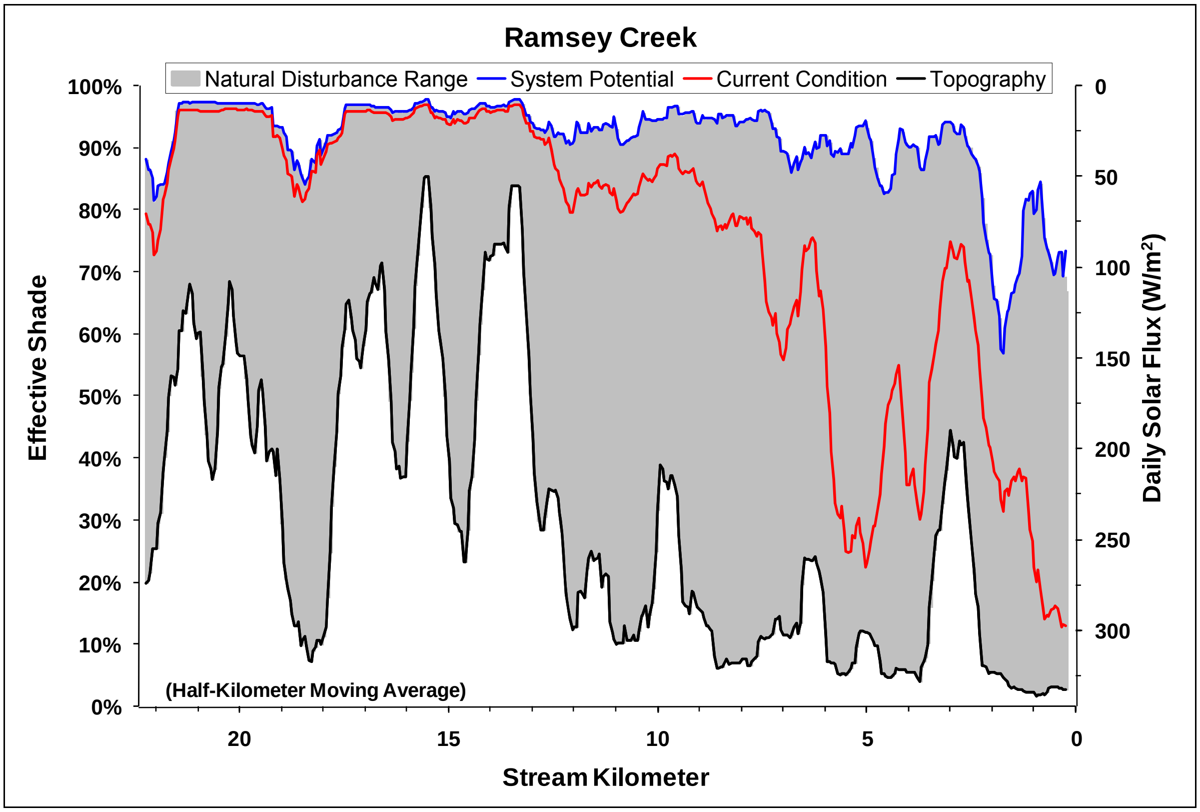


Figure A-32 (continued). Effective Shade – Current Condition and Loading Capacity (System Potential)



A3.1.2.3 Total Daily Solar Heat Load Analysis

The total daily solar heat load is the cumulative (entire stream surface area) solar heat received by a stream over one day during the critical period (i.e., July/August period). For the purposes of this analytical effort, the total solar heat load (H_{solar} in the equation below) is the longitudinal sum of the products of the daily solar heat flux and surface area of exposure for each stream reach (i.e., for each stream data node every 50 meters).

$$H_{solar} = \sum\left(\Phi_{solar} \cdot A_y\right) = \sum\left(\Phi_{solar} \cdot W_{wetted} \cdot dx\right)$$

Background (NTP) levels of solar heat estimate the portion of the total daily solar heat load that occurs when anthropogenic nonpoint sources of heat are minimized. The total daily solar load is calculated for both the current condition (H_{solar}) and the potential condition ($H_{solar}^{Background}$). The anthropogenic nonpoint source total daily solar load is the difference between the existing total daily solar load and the background total daily solar load (see equation below).

$$H_{solar}^{NPS} = H_{solar} - H_{solar}^{Background}$$

where,

A_y : Stream surface area unique to each stream segment (m^2)

dx: Stream segment length and distance step in the methodology (m)

Φ_{solar} : Solar heat flux unique to each stream segment (MW m^{-2})

H_{solar} : Total daily solar heat load delivered to the stream (MW)

H_{solar}^{NPS}: Portion of the total daily solar heat load delivered to the stream that originates from anthropogenic nonpoint sources of pollution (MW)

$H_{solar}^{Background}$: Portion of the total daily solar heat load delivered to the stream that originates from solar input not affected by human activities (MW)

W_{wetted}: Wetted width unique to each stream segment (m)

The total daily heat load analysis was done on Fifteenmile Creek. As further described in **Section 3.8** of the TMDL Document, sixty-five percent of the solar loading that occurs on Fifteenmile Creek is from anthropogenic non-point sources. The remaining portion of the total load originates from background sources.

A3.1.3 Generalized Effective Shade Simulations

Generalized effective shade curves were developed for streams where site-specific effective shade simulations were not completed as described in **Section A3.3.2**. The effective shade curves account for latitude, critical summertime period (July/August), elevation and stream aspect and display effective shade levels for a potential vegetation type as a function of channel width.

The potential vegetation types and the associated height and density were determined by the Miles Creeks TMDL Technical Committee as described in **Section A2.3.5.2**. The results of the shade curve development are shown in **Figure 3-17** in the TMDL document.

A3.2 STREAM TEMPERATURE SIMULATIONS – FIFTEENMILE CREEK

A3.2.1 Model Calibration

As discussed previously, temperature modeling was only conducted on 43.8 miles of Fifteenmile Creek. Site specific shade modeling was done along this reach as described in the previous section. In addition to effective shade and flux, hydraulic parameters and stream temperature were simulated every 50 meters longitudinally along this lower 43.8 miles of the creek. Simulations were completed for the 20-day period of July 17, 2002 to August 5, 2002.

As with the effective shade discussion in **Section A3.1.2**, there are a number of limitations and assumptions that are important to mention relative to the current condition model calibration.

Hydrology Analysis:

- Water withdrawals were not directly quantified
- Water withdrawals were assumed to occur only at OWRD mapped points of diversion.
- No direct measurements exist for the location, temperature, and flow of groundwater and hyporheic exchange on Fifteenmile Creek. However many local experts hypothesize such interactions exist based on their study of the Fifteenmile system (personal communication from Bob Wood -OWRD Watermaster, and the Fifteenmile Watershed Council). DEQ estimated flow for gaining and losing reaches from a mass balance analysis using the TIR imagery. Where PODs and tributary inflows did not balance for instream measurements, the difference was attributed to gaining or losing reaches and evenly spread throughout the reach in question.
- Hyporheic exchange was accounted for in the model in the form of a simultaneous accretion and withdrawal flow. Hyporheic exchange was used as calibration parameter in locations where the TIR data and continuous temperature data indicated abnormally cool temperatures compared to calibration model results without hyporheic flow.
- Inter-annual variations were not simulated.

Stream Temperature Analysis:

- Temperature modeling was only completed on the lower 70.5 stream kilometers. In initial modeling efforts, DEQ attempted to simulate stream temperature all the way to the headwaters. DEQ had a very difficult time getting the forested portions of Fifteenmile Creek to calibrate, so it was decided to start the temperature simulation at the Forest boundary. DEQ was able to complete shade and solar load modeling on Fifteenmile Creek all the way to the headwaters using the Shade-a-lator module of Heat Source (as was described above).
- Stream temperature results are limited to Fifteenmile Creek. Application of the stream temperature output to other streams within or outside of the subbasin is not valid.
- The simulation is valid for the time frame of the simulation or for July-August intervals with similar flow, air temperature, humidity, wind speed and specified riparian conditions.
- Accuracy of the methodology is limited to validation statistics of results described below.

A3.2.1.1 Model Validation – Simulation Accuracy

Hydraulic Parameters
Wetted width, depth, velocity and flow volume were calculated by Heat Source and compared to in-stream measurements (**Figure A-33** to
Figure A-36). The stream roughness coefficient, Manning's n, was adjusted to achieve a close match between measured and calculated values. Hydraulics were calculated from gradient, available volume; and channel width, depth and side slope angle, assuming a trapezoidal channel.

Figure A-33. Fifteenmile Creek measured and simulated stream flows (8/1/2002).

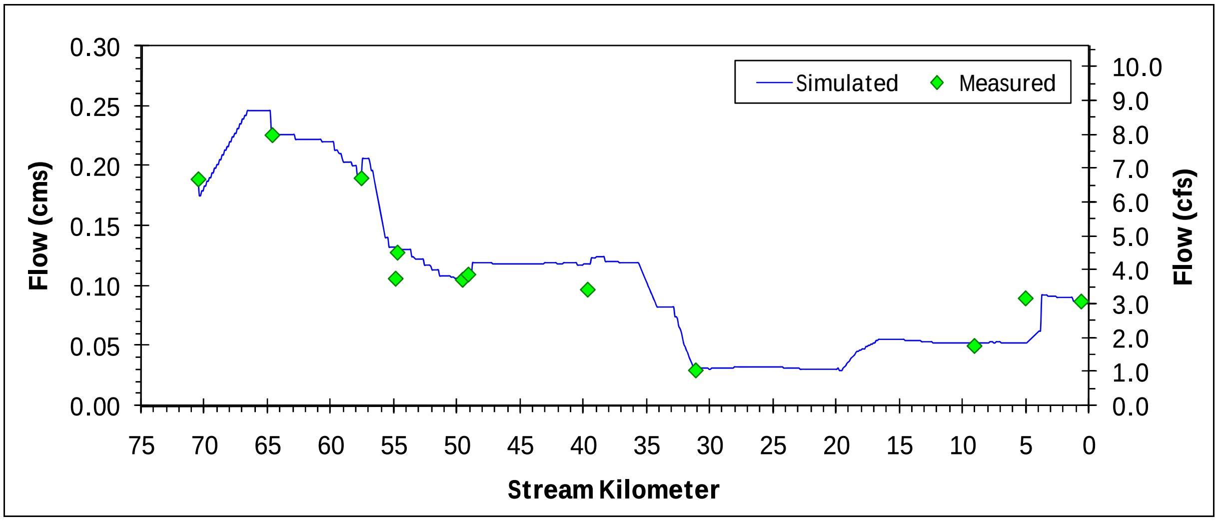


Figure A-34. Fifteenmile Creek measured and simulated stream velocities (8/1/2002).

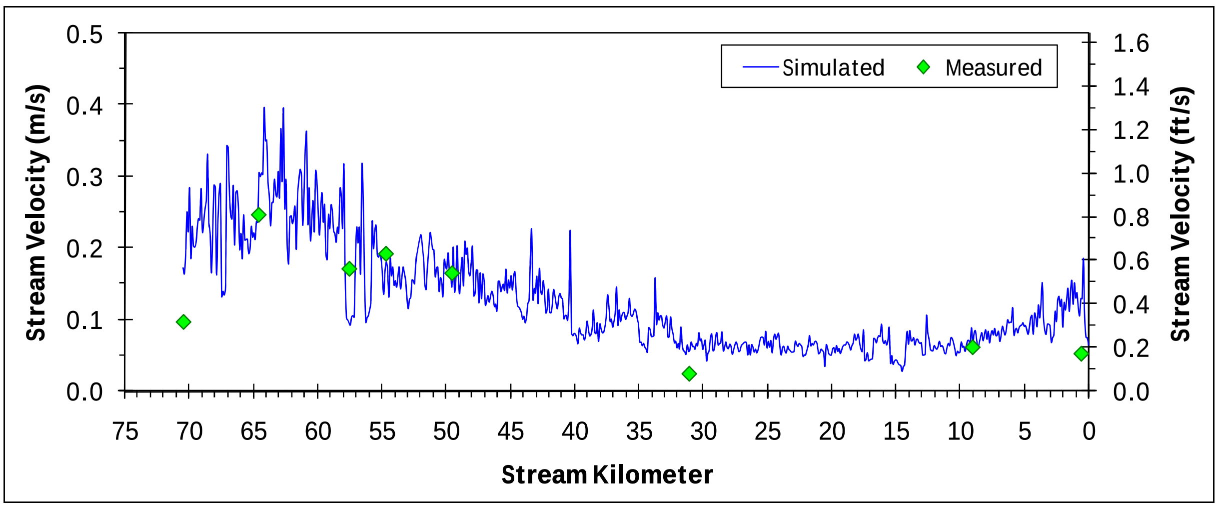


Figure A-35. Fifteenmile Creek measured and simulated wetted widths (8/1/2002).

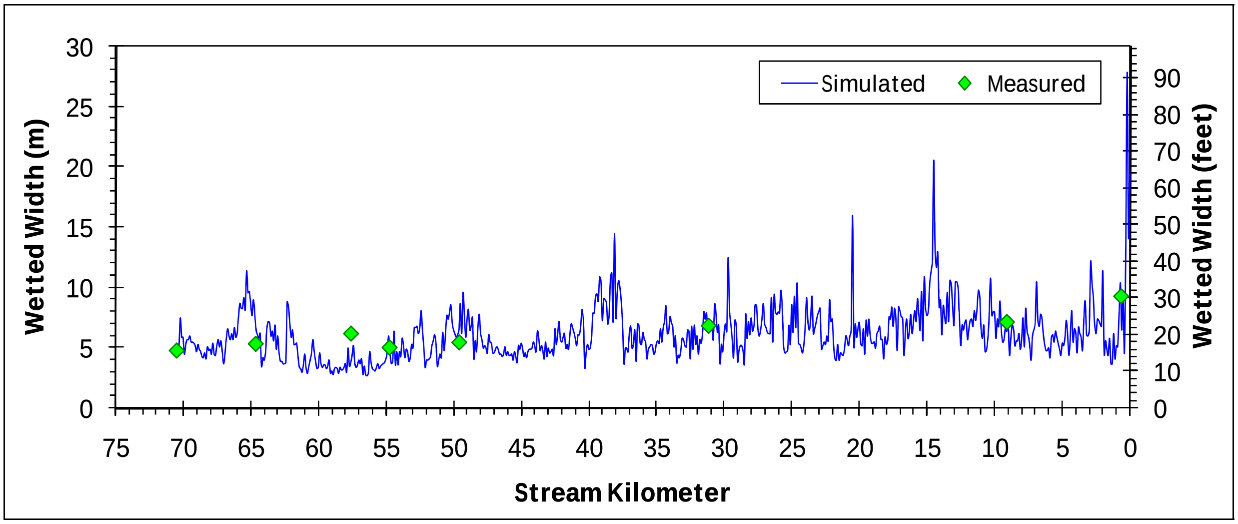
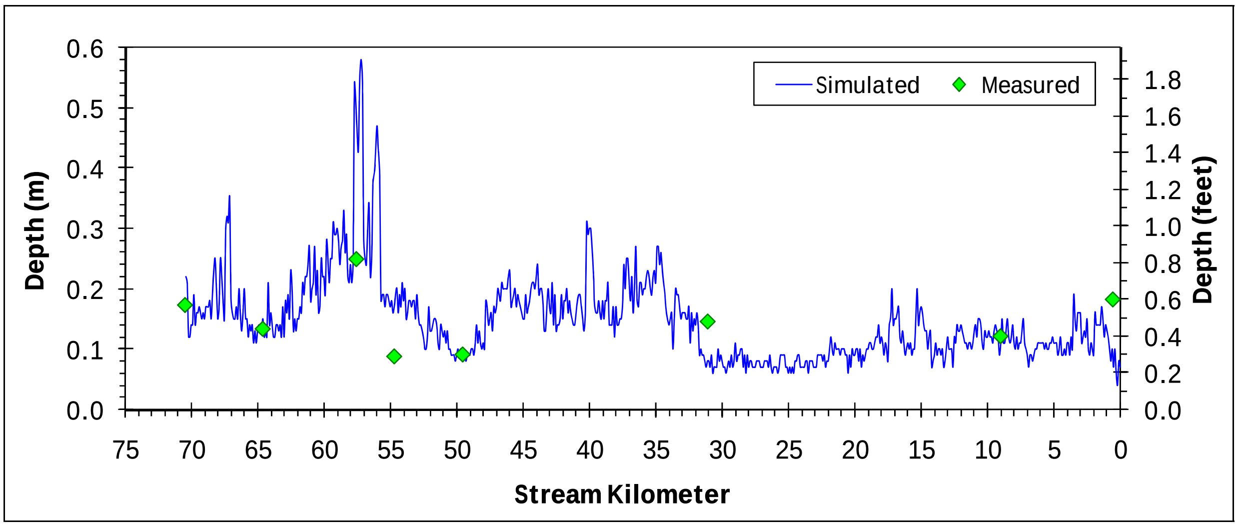


Figure A-36. Fifteenmile Creek measured and simulated stream depths (8/1/2002).



Temperature Parameters

The simulated current condition temperatures were compared to the TIR derived spatial temperature data sets and the instream measured hourly temperature data sets and corroboration statistics were generated (**Table A-10**). Each measurement of temperature is discrete and was used to assess model accuracy. Simulation outputs are only accurate to levels that exceed the validation statistics. A statistically significant simulated result is one that produces a temperature change greater than validation statistics shown in **Table A-10**. **Figure A-37** shows the simulated and measured stream temperatures for the date and time that the TIR data was collected. The root mean square error (RMSE) is 1.28°C for the instantaneous longitudinal temperature data. The simulated and measured hourly stream temperatures are presented in **Figure A-38**. The RMSE for the hourly data ranged from 0.83°C to 2.02°C.

Table A-10. Fifteenmile Creek corroboration statistics.

River KM	Source	Temperature Monitoring Location	ME	MAE	RMSE	NS	N
64.65	SWCD	Fifteenmile at Dufur Reservoir Intake	-0.24	0.70	0.83	0.83	240
58.15	SWCD	Fifteenmile upstream of Ramsey	-0.95	1.22	1.47	0.63	240
54.90	SWCD	Fifteenmile near Rivermile 34	-0.08	0.85	1.06	0.88	240
50.50	ODFW	Fifteenmile upstream of Dufur	-1.40	1.68	1.99	0.65	240
49.15	SWCD	Fifteenmile upstream of Pine Creek	-1.53	1.74	2.02	0.60	240
39.65	SWCD	Fifteenmile upstream of Dry Creek	-0.76	0.94	1.13	0.87	240
31.15	ODFW	Fifteenmile upstream of Standard Hollow	-0.42	1.16	1.40	0.85	240
30.90	SWCD	Fifteenmile downstream of Standard Hollow	-0.59	0.93	1.13	0.90	240
15.20	SWCD	Fifteenmile downstream of Big Spring Gulch	0.09	1.18	1.39	0.87	240
5.05	ODFW	Fifteenmile upstream of Eightmile Creek	-0.92	1.64	1.96	0.37	240

River KM	Source	Temperature Monitoring Location	ME	MAE	RMS	NS	N
0.0 - 70.5	DEQ	Thermal Infrared Radiometry (TIR) 8/01/2002	0.43	1.03	1.28	0.81	706

Mean Error (ME) – A mean error of zero indicates a perfect fit. A positive value indicates on average the model predicted values are less than the observed data. A negative value indicates on average the model predicted values are greater than the observed data. The mean error statistic may give a false ideal value of zero (or near zero) if the average of the positive deviations between predictions and observations is about equal to the average of the negative deviations in a data set. Because of this, the mean absolute error statistic should be used in conjunction with mean error to measure model performance.

$$ME = \frac{\sum_{t=1}^{n}\left(O^t - M^t\right)}{n}$$

Mean Absolute Error (MAE) - A mean absolute error of zero indicates a perfect fit. The magnitude of the mean absolute error indicates the average deviation between model predicted values and observed data. The mean absolute error cannot give a false zero.

$$MAE = \frac{\sum_{t=1}^{n}\left|\left(O^t - M^t\right)\right|}{n}$$

Root Mean Square Error (RMSE) – A root mean square error of zero indicates a perfect fit. Root mean square error is a measure of the magnitude of the difference between model predicted values and observed data.

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}\left(O^t - M^t\right)^2}{n}}$$

Nash-Sutcliffe Error Efficiency Coefficient (NS) – Nash-Sutcliffe efficiencies can range from -∞ to 1. An efficiency of 1 corresponds to a perfect match of modeled predicted value to the observed data. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero occurs when the observed mean is a better predictor than the model.

$$NS = 1 - \frac{\sum_{t=1}^{n}\left(O^t - M^t\right)^2}{\sum_{tn=1}^{T}\left(O^t - \overline{M^t}\right)^2}$$

Where:

M^t = *A single predicted or modeled data value at time t*

O^t = *A single field or observed data value at time t*

n = *Total number of data points or observations*

Figure A-37. Fifteenmile Creek measured and simulated stream temperature data.

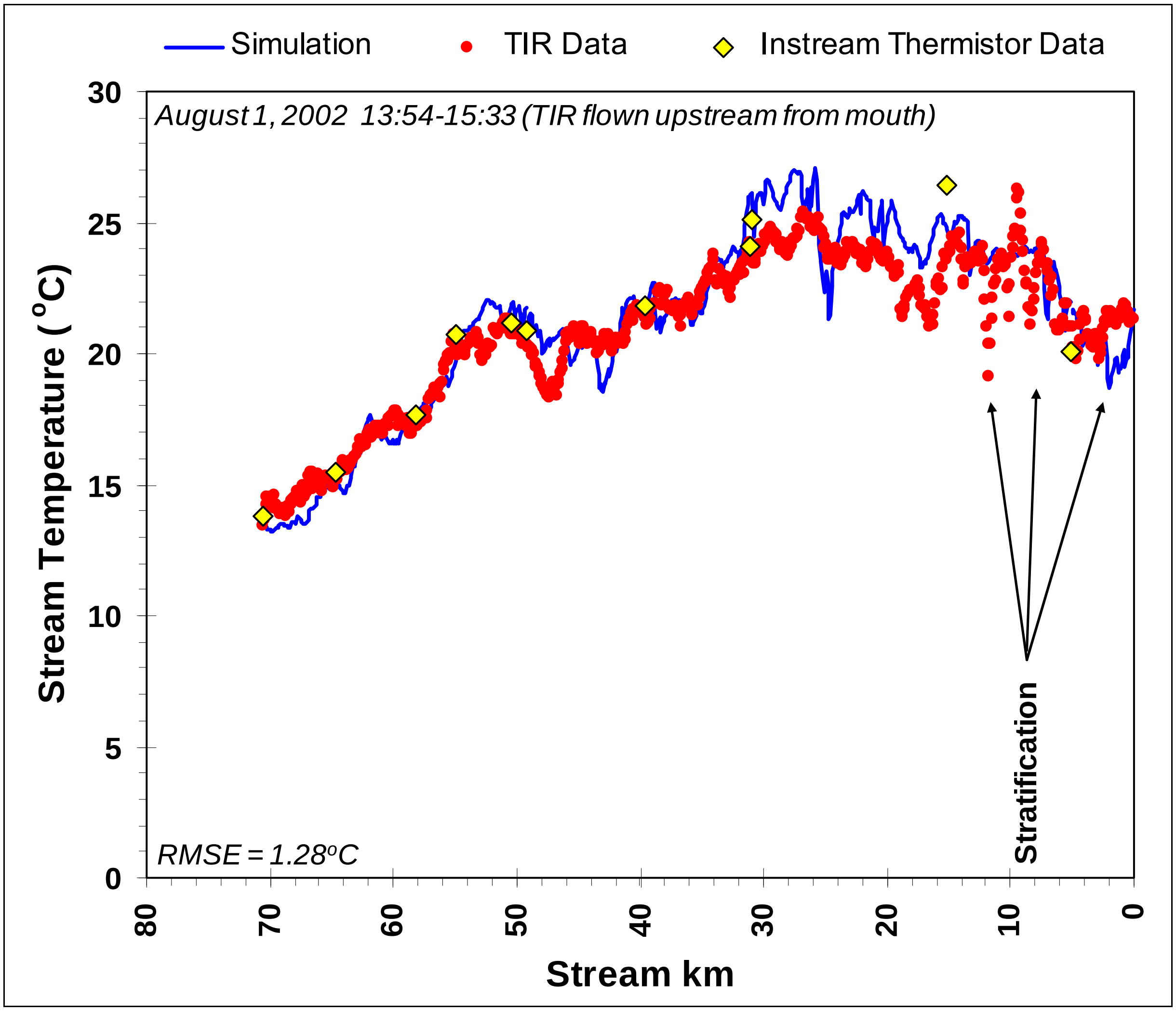


Figure A-38. Fifteenmile Creek measured and simulated hourly stream temperatures.

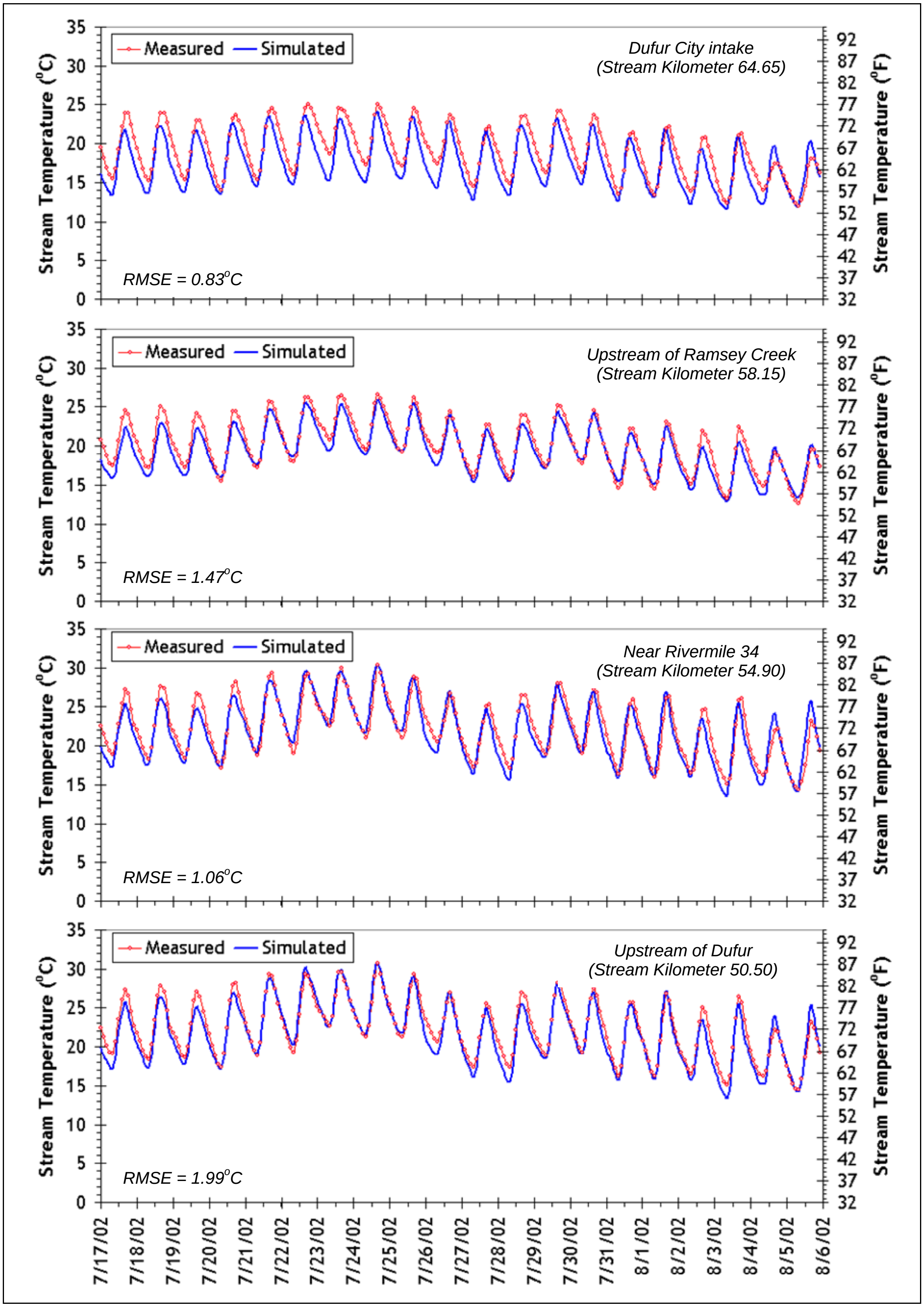


Figure A-38 (continued). Fifteenmile Creek measured and simulated hourly stream temperatures.

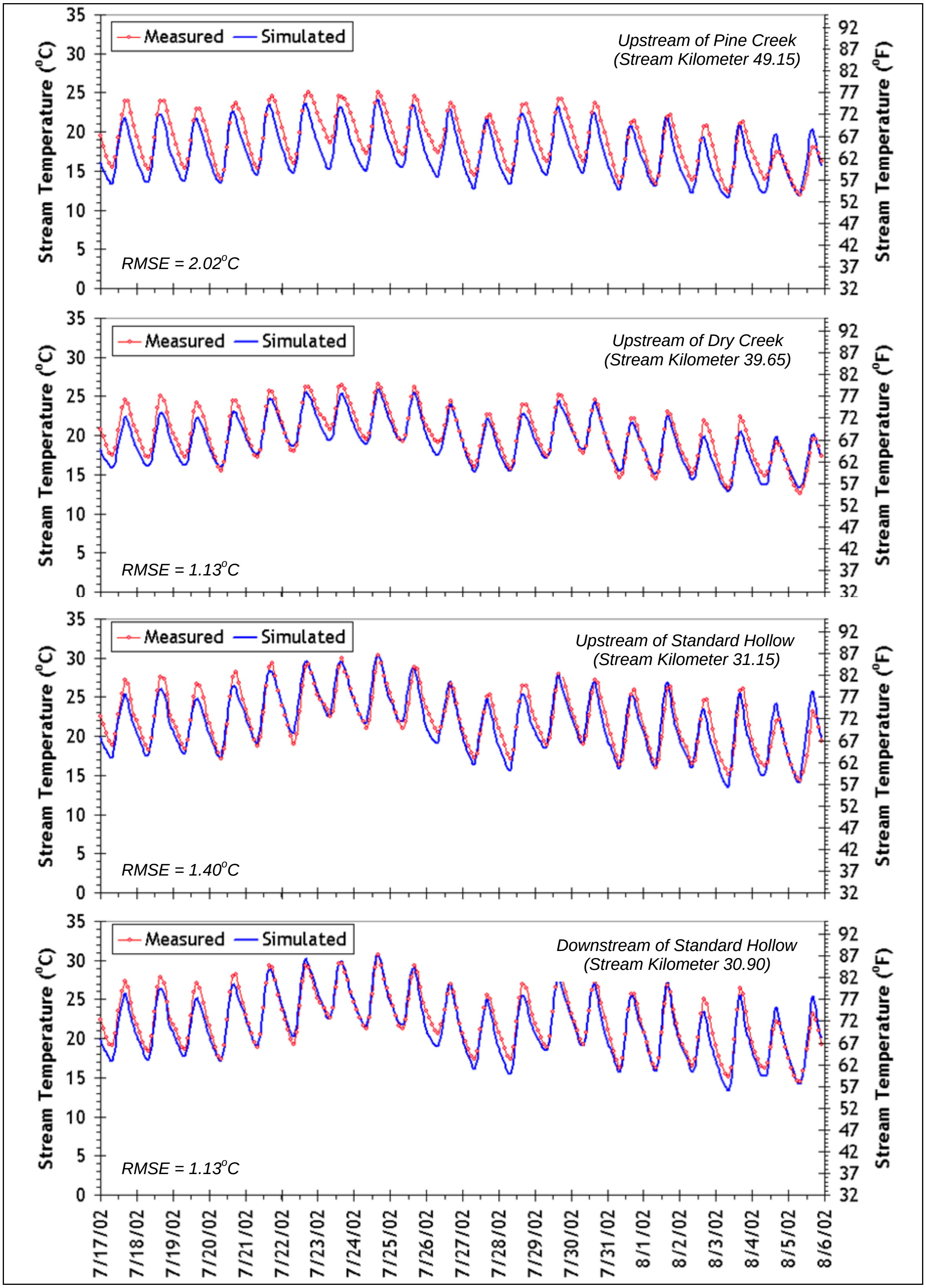
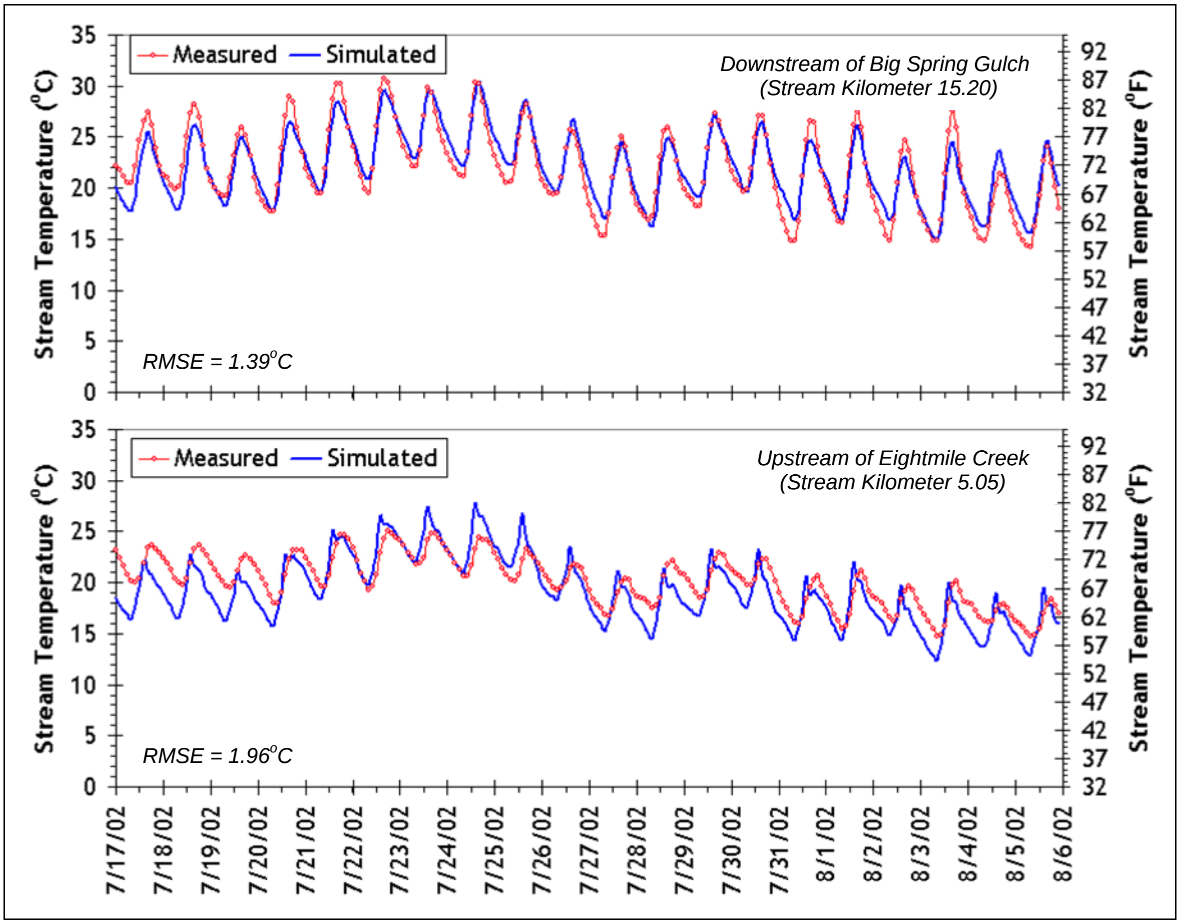


Figure A-38 (continued). Fifteenmile Creek measured and simulated hourly stream temperatures.



A3.2.2 Simulated Scenarios

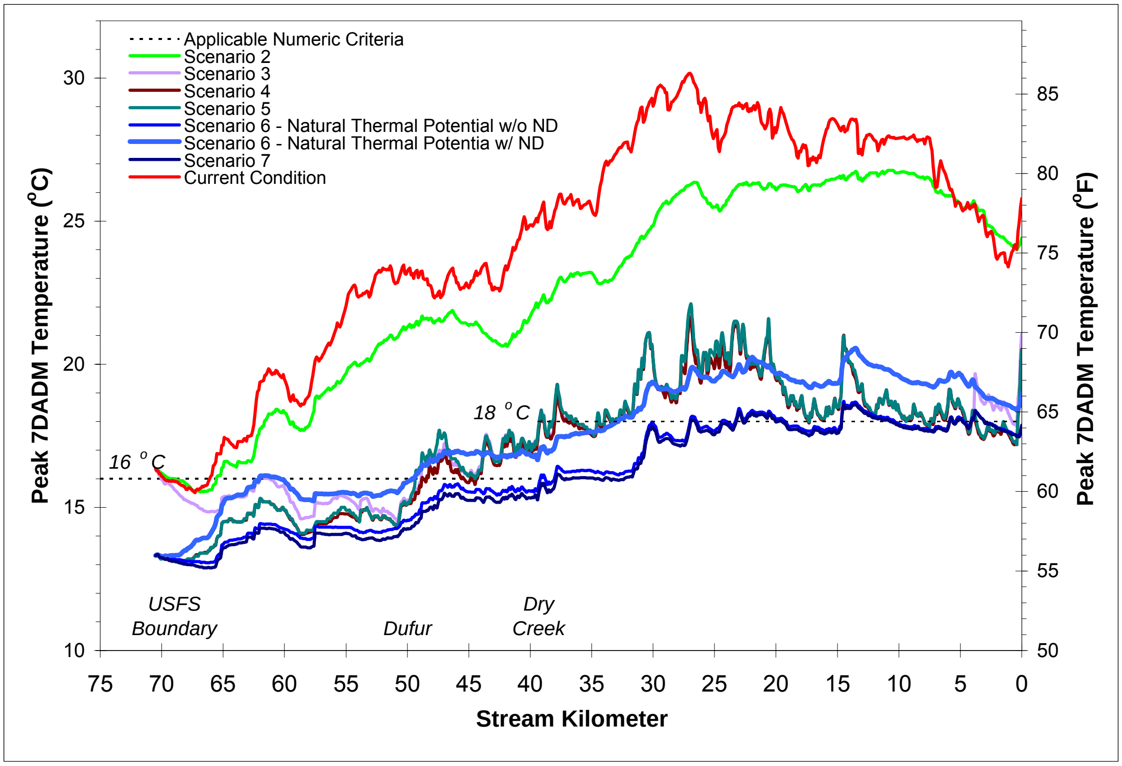
Once the current condition stream temperature model was calibrated for Fifteenmile Creek, seven different scenarios were then simulated by changing one or more stream input parameters and then re-running the model over the 20-day simulation period. Each of the seven simulations is summarized in **Table A-11** and then described more completely in **Sections A3.2.2.1-A32.2.6**.

Table A-11. Summary of simulated scenarios.

Scenario 1	Current Condition (July, 2002)
Scenario 2	Natural Flow Current Vegetation and Land Cover
Scenario 3	Site Potential Vegetation, Current Flows
Scenario 4	Site Potential Vegetation, Current Flows, Reduced Tributary Temperatures
Scenario 5	Same as Scenario 4 except roads/buildings not converted to potential vegetation
Scenario 6 (Natural Thermal Potential)	Site Potential Vegetation, Natural Flows, Reduced Tributary Temperatures, with and without Natural Disturbance
Scenario 7	Site Potential Vegetation, Natural Flows, Reduced Tributary Temperatures, Reduced Groundwater Temperatures

Figure A-39 shows the results of all seven TMDL simulation scenarios for Fifteenmile Creek. Because each simulation was run over a 20-day period, the moving seven-day average of the daily maximums (7DADM) could be calculated. The peak values of the 7DADM were then selected for the simulation period and plotted in **Figure A-39**. The results are intended to represent the critical summer time period when stream temperatures reach their yearly maximums and aquatic life is at the greatest risk of thermal impairment. For reference purposes, the applicable Oregon state water quality criteria are included on the chart. Under current conditions, both the 16°C core cold water habitat criterion and 18°C rearing and migration criterion are exceeded for almost the entire modeled reach.

Figure A-39. Fifteenmile Creek stream temperatures under all seven TMDL simulation scenarios.



The simulated scenarios focused primarily on assessing the in-stream thermal impacts of estimated natural potential conditions for flow, riparian land cover, and tributary temperatures. Scenarios 2 and 3 were run to assess the relative impacts of restoring flow vs restoring riparian land cover. Scenario 4 further modified Scenario 3 by additionally reducing tributary temperatures. Scenario 6 represents the Natural Thermal Potential targeted in the TMDL. It represents the combination of Scenario 2 (natural flows) and Scenario 4 (natural vegetation and tributary temperatures). Scenario 5 was run to assess the thermal impacts of NOT replacing existing roads and buildings with system potential vegetation (as was done in Scenario 4), recognizing that roads and buildings located within the 100 meter riparian buffer used in the model are not likely to be removed. Finally, Scenario 7 was run to assess the potential affects of decreased groundwater temperature. This simulation is intended to inform management decisions rather than predict a true natural condition.

Natural disturbance simulations were also run to estimate the potential temperature increases from these natural events. The natural disturbance methodology is described in **Section A.3.3**. Natural disturbance was simulated on Scenarios 3 and 6. Scenario 3 natural disturbance model runs were utilized to estimate natural tributary input temperatures (as described under Scenario 4). Scenario 6 natural disturbance runs were utilized to estimate the effect of natural disturbance on natural thermal potential temperatures. On average, natural disturbance may increase 7-day average daily maximum natural thermal potential temperatures by 1.4°C. Including natural disturbance, the natural thermal potential temperatures are still much cooler than current conditions.

Because each simulation was run over a 20-day period, the moving 7-day average of the daily maximums (7DADM) and minimums could be calculated. In the discussion of the scenarios that follows, several different types of graphs are used to portray the differences between the simulations using the 7-day data:

- The peak maximum and minimum 7-day values were selected for the simulation period and were plotted in comparison with the same set of values for the current condition simulation (example – **Figure A-41**). The maximum values shown on this type of graph are the same as the peak 7DADM lines shown for each scenario in **Figure A-39**. This type of graph was used to compare potential scenarios to current conditions.
- The 7DADM between two simulations was compared for every 7-day period (there were 14 different 7-day periods during the simulation period). The range of 7DADM differences is shown in each graph (example - **Figure A-42**). In some cases this type of comparison was made to compare a potential scenario to current conditions and in some cases it was used to compare two different potential scenarios.

A3.2.2.1 Scenario 1: Current Condition

The current condition model was calibrated as described above with the stated assumptions.

A3.2.2.2 Scenario 2: Natural Flows

This scenario was run to assess the thermal affects of instream flow on temperature in Fifteenmile Creek. Model input parameters from the current condition model were modified as follows:

- Vegetation was maintained at current conditions
- All water withdrawals in the current condition model were set to zero
- Boundary condition and tributary flows were set to natural (information on natural tributary flows came from the *Fifteenmile Watershed Assessment* , Wasco SWCD, 2003)
- Boundary condition and tributary temperatures were maintained at current conditions
- Groundwater flows and temperature were maintained at current conditions
- Dufur WWTP discharge was set to zero

Figure A-40 shows the range in flows observed over the simulated period (July 17-August 5, 2002). In the simulated reach of Fifteenmile Creek, there are four tributaries which contribute flow to Fifteenmile Creek, either as surface or subsurface flows. These are Ramsey Creek, Pine Creek, Dry Creek and Eightmile Creek. Under the current condition only Dry Creek enters Fifteenmile Creek as subsurface flow. Under natural conditions, Dry Creek would have small surface flow in to Fifteenmile Creek and Eightmile Creek and Ramsey Creek would have much higher flows than under current conditions. Under natural conditions in late July/early August, average flows in Eightmile Creek would be approximately 7.2 cfs, as compared to 1.2 cfs in 2002 and average natural flows in Ramsey Creek would be 1.2 cfs as compared to 0.6 cfs in 2002. Shaded yellow areas in **Figure A-40** represent locations where there might be gaining or losing reaches. At these locations the mass balance analysis could not match measured flow rates when all tributary inputs or diversions were accounted for. The difference was attributed to groundwater inflow or outflow.

Figure A-40. Fifteenmile Creek current and natural flow range (July 17-August 5, 2002).

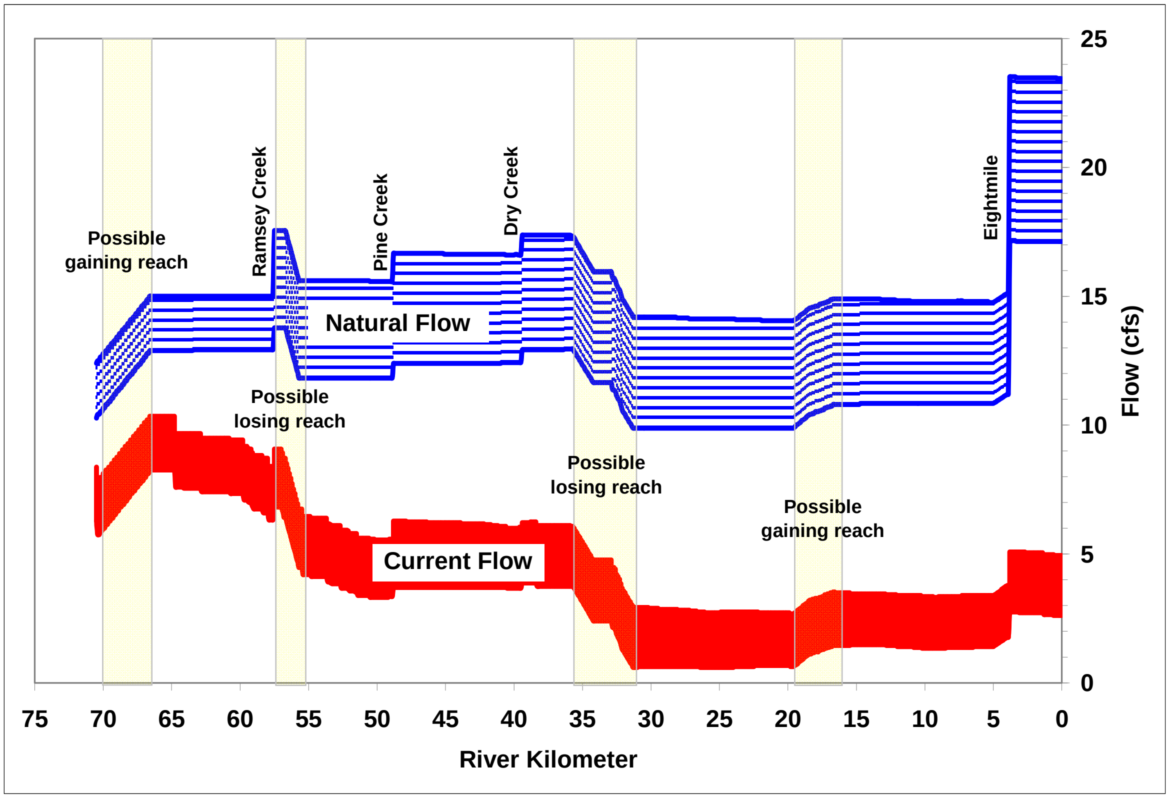


Figure A-41 shows the maximum diel temperature range observed on Fifteenmile Creek under Scenarios 1 and 2. The range of 7DADM differences between the two scenarios is shown in **Figure A-42**. Both figures show that, in general, stream temperatures under natural flows are cooler than under current conditions. There did not appear to be much of a temperature difference below the two scenarios in the lower five kilometers of Fifteenmile Creek, with 7DADM temperatures in the lowest reach actually a bit warmer under natural flows than under current flows.

Figure A-41. Maximum 7-day average diel temperture range in Fifteenmile Creek for Scenarios 1 and 2.

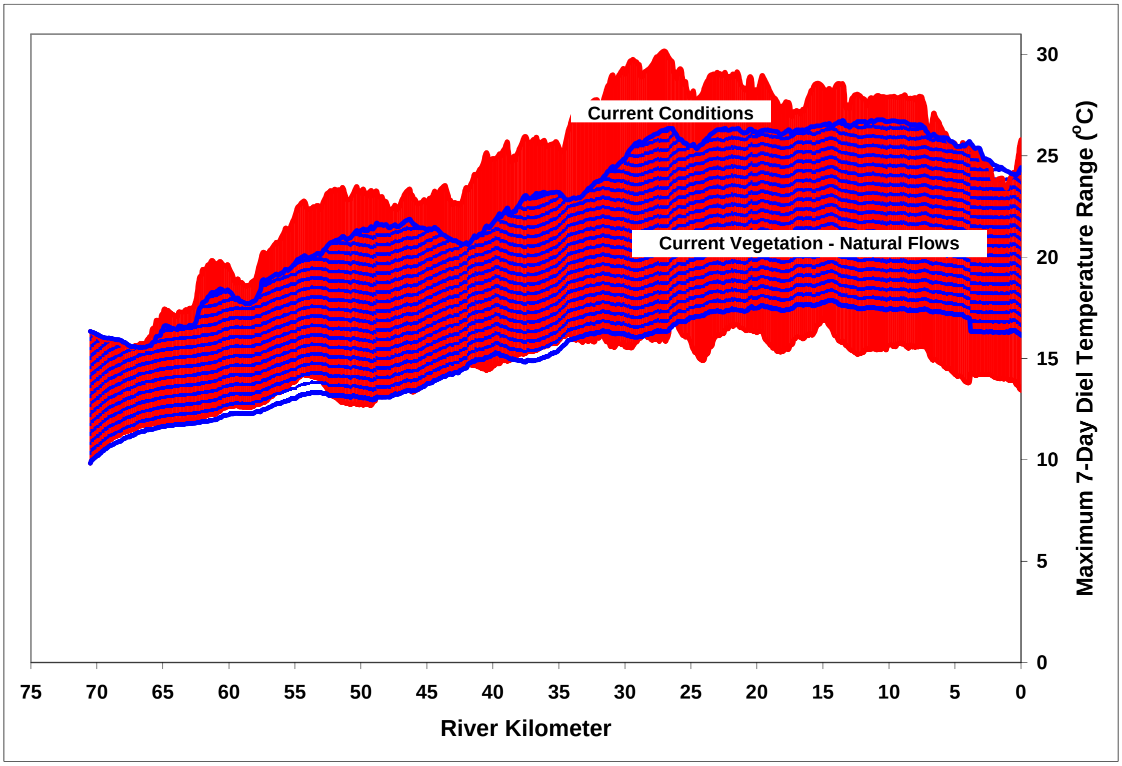
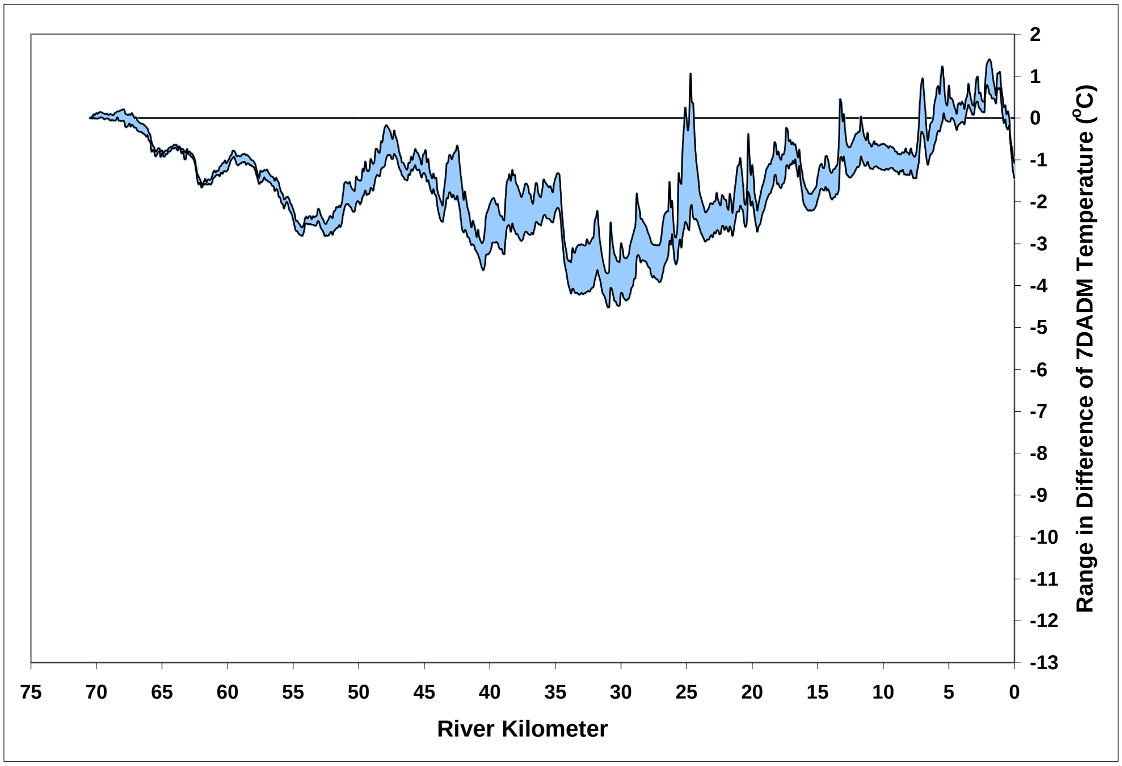


Figure A-42. Comparison of 7DADM Temperatures from Scenarios 1 and 2 for Fifteenmile Creek.



A3.2.2.3 Scenario 3: Site Potential Vegetation

This scenario was run to assess the thermal affects of restoring system potential vegetation in Fifteenmile Creek. Vegetation was the only parameter changed along Fifteenmile Creek in this scenario. No changes were made along any of the tributaries or to the boundary condition. Model input parameters from the current condition model were modified as follows:

- All land cover polygons were set to system potential vegetation conditions, including roads and buildings
- All water withdrawals in the current condition model were maintained at current conditions
- Boundary condition flows and temperatures were maintained at current conditions
- Tributary flows and temperatures were maintained at current conditions
- Groundwater flows and temperature were maintained at current conditions
- Dufur WWTP discharge was set to zero

Figure A-43 shows the maximum diel temperature range observed on Fifteenmile Creek under Scenarios 1 and 3. The range of 7DADM differences between the two scenarios is shown in **Figure A-44**. These figures show that restoring system potential vegetation along the riparian corridor appears to have a significant impact on minimizing stream heating and reducing diel temperature fluctuations.

A comparison of the results of Scenarios 2 and 3 suggests that restoring riparian vegetation will have a greater impact on stream temperatures than restoring stream flow. This does not discount the importance of restoring stream flow as opportunities arise, however. Increased stream flow still moderates stream temperatures to some degree and increased flow is also important for fish habitat.

Scenario 3 was also run with natural disturbance to provide input into the determination of natural tributary temperatures as described below in Scenarios 4-7.

Figure A-43. Maximum 7-day average diel temperture range in Fifteenmile Creek for Scenarios 1 and 3.

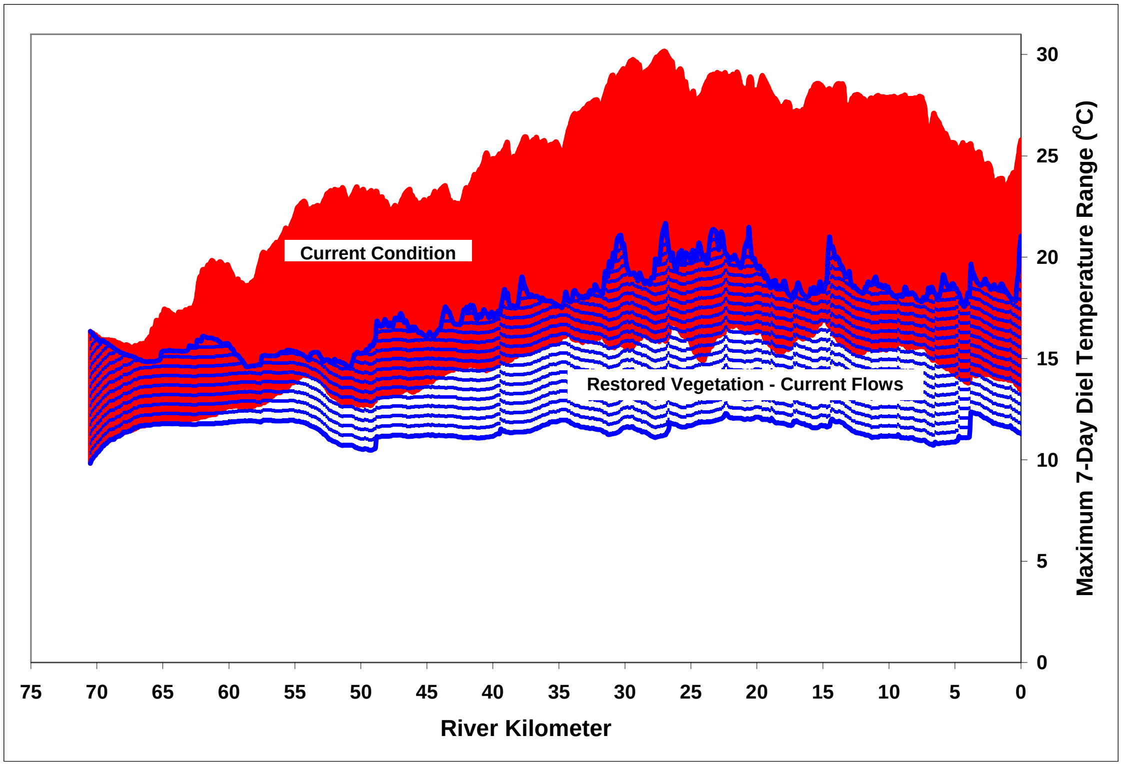
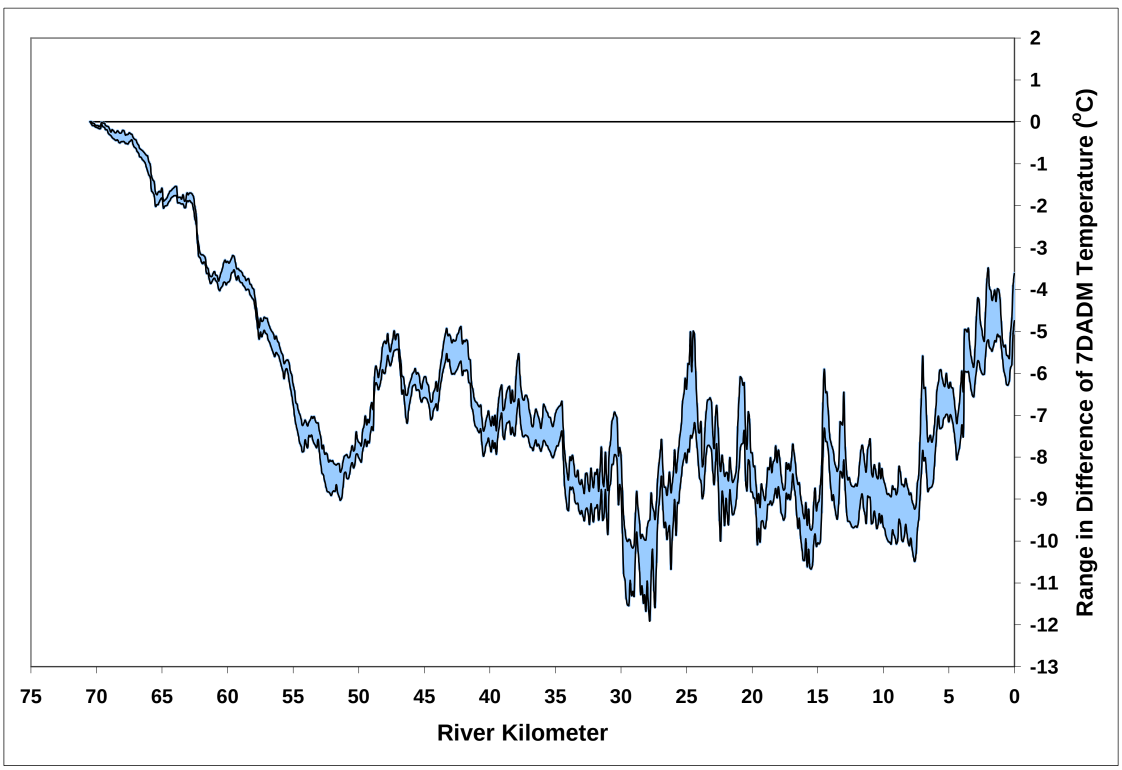


Figure A-44. Comparison of 7DADM Temperatures from Scenarios 1 and 3 for Fifteenmile Creek.



A3.2.2.4 Scenarios 4 and 5: Site Potential Vegetation & Reduced Tributary Temperatures

Scenarios 4 and 5 are both modifications to Scenario 3. Scenario 4 was run to assess the thermal affects of restoring system potential vegetation in Fifteenmile Creek (Scenario 3), while at the same time reducing tributary and boundary condition temperatures to estimated NTP conditions. Since temperature modeling was not done on any of the tributaries, tributary and boundary condition temperatures under potential conditions were estimated as described below. Model input parameters from the current condition model were modified as follows:

- All land cover polygons were set to system potential vegetation conditions, including roads and buildings
- All water withdrawals in the current condition model were maintained at current conditions
- Boundary condition and tributary flows were maintained at current conditions
- Boundary condition and tributary temperatures were set to estimated NTP temperatures. To estimate this, tributary temperatures were reduced by the difference between current conditions (Scenario 1) and Scenario 3 with natural disturbance at the nearest Fifteenmile continuous instream measurement location.
- Groundwater flows and temperature were maintained at current conditions
- Dufur WWTP discharge was set to zero

Scenario 5 further modified Scenario 4 to assess the thermal affects of not removing roads and buildings in the site potential vegetation analysis. This scenario was done recognizing that roads and buildings located within the 100 meter riparian buffer used in the model are not likely to be removed; therefore assessing the thermal impacts of retaining these anthropogenic structures is of interest. Model input parameters were the same as identified in Scenario 4 except roads and buildings were not converted to system potential vegetation conditions.

Figure A-45 shows the maximum diel temperature range observed on Fifteenmile Creek under Scenarios 1 and 4. The range of 7DADM differences between the two scenarios is shown in **Figure A-46.** To better compare the thermal effects of Scenarios 3 and 4, the range of 7DADM differences was calculated comparing these two scenarios to each other (**Figure A-47**). As would be expected, reduced temperatures in Fifteenmile Creek above the boundary condition had noticeable effect on stream temperatures in the simulated reach for quite a ways downstream. Slight reductions in temperature were also observed at Ramsey Creek and Pine Creek, and a greater reduction at Eightmile Creek. Because Dry Creek did have surface flows under current conditions, tributary temperatures were not reduced for Dry Creek in Scenario 4.

Because the thermal differences between Scenarios 4 and 5 are not very great, the only graph provided for Scenario 5 is one showing the range of 7DADM differences between the two scenarios (**Figure A-48**). In should be noted that temperature increases at specific bridge locations may not be representative of the model results. Normally bridges would provide shade over the stream. In the model, bridge locations were modeled exposed to solar radiation because of difficulty in modeling structures over the channel. Bridge footprints are usually small and the model output resolution represents an average over 100 meters. There is uncertainty how much this plays a role in the results. In general the impact of roads and buildings shown in **Figure A-48** represent about 0.1^{o}C increase above natural thermal potential.

Figure A-45. Maximum 7-day average diel temperture range in Fifteenmile Creek for Scenarios 1 and 4.

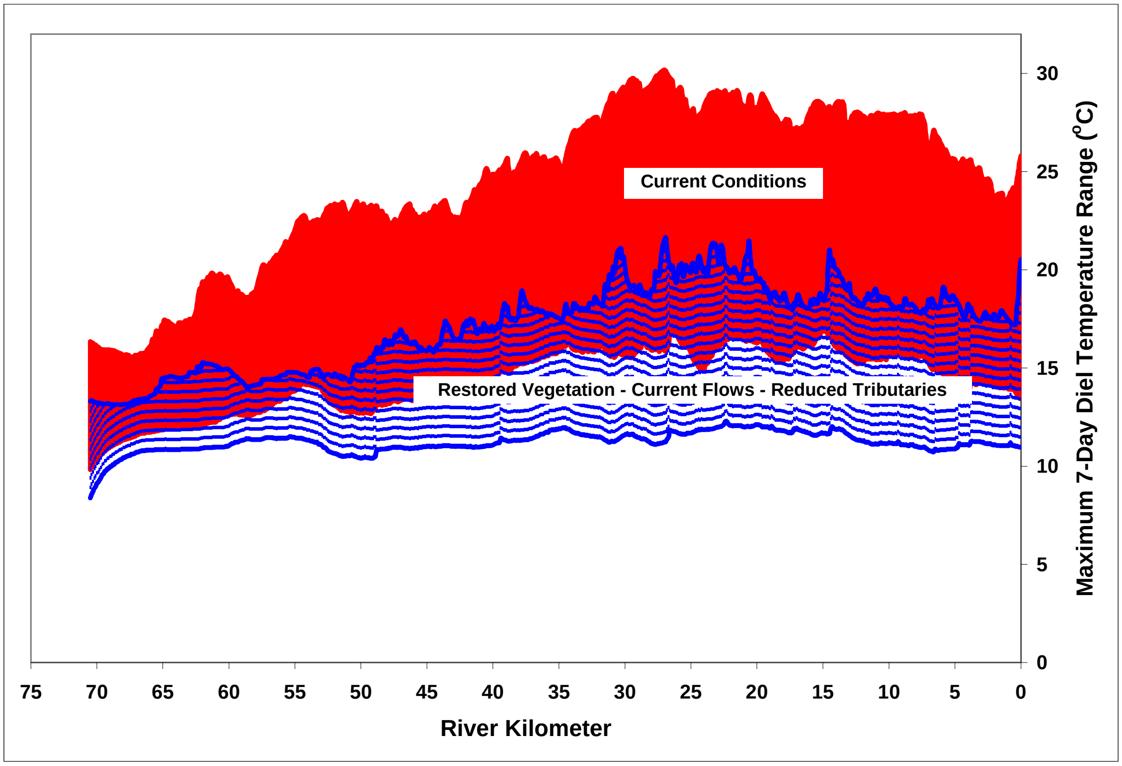


Figure A-46. Comparison of 7DADM Temperatures from Scenarios 1 and 4 for Fifteenmile Creek.

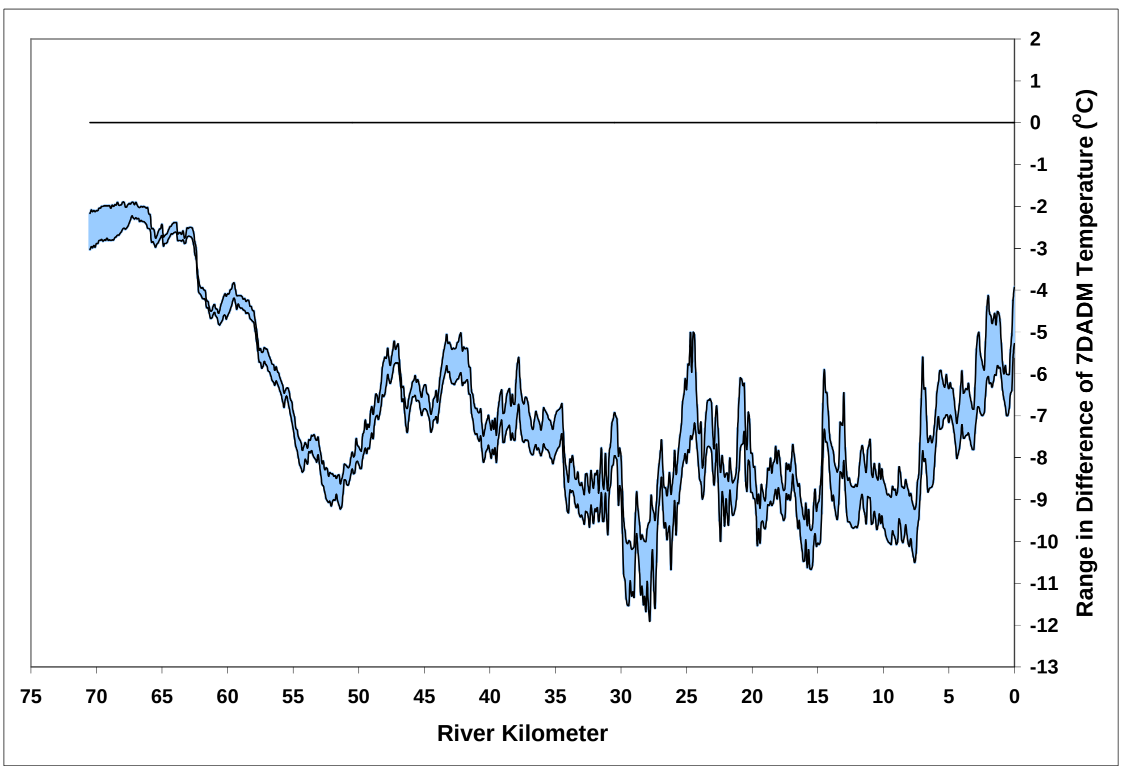


Figure A-47. Comparison of 7DADM Temperatures from Scenarios 3 and 4 for Fifteenmile Creek.

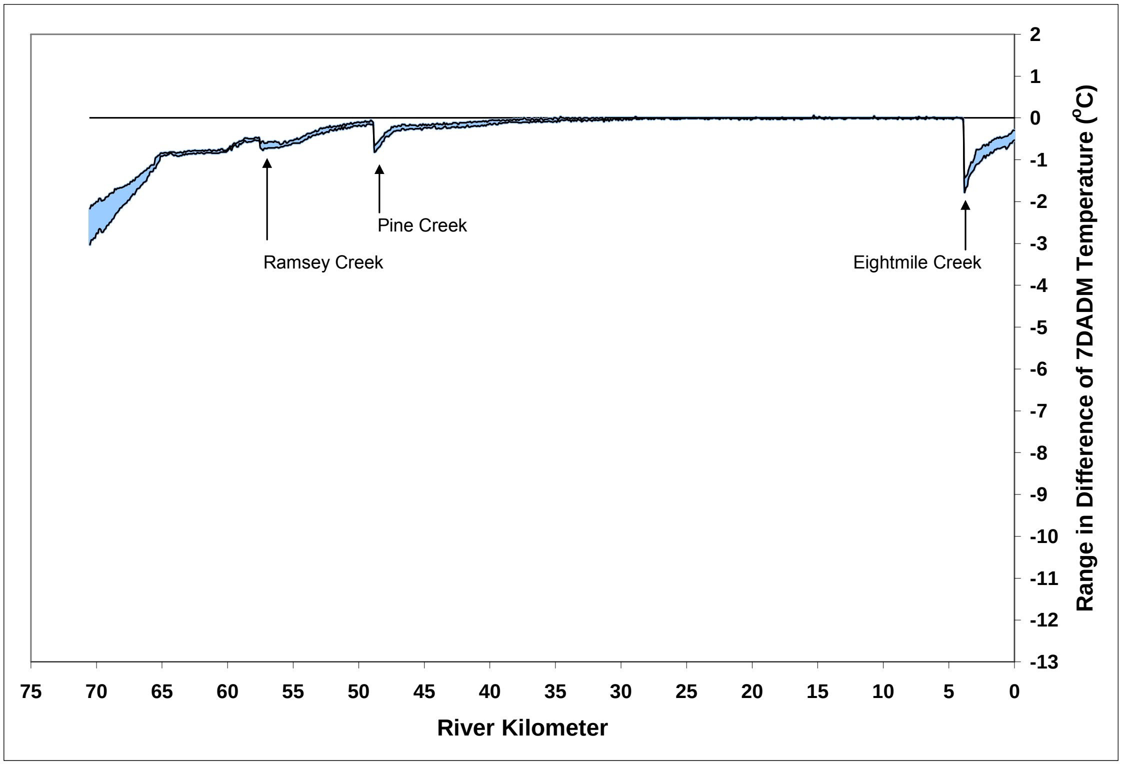
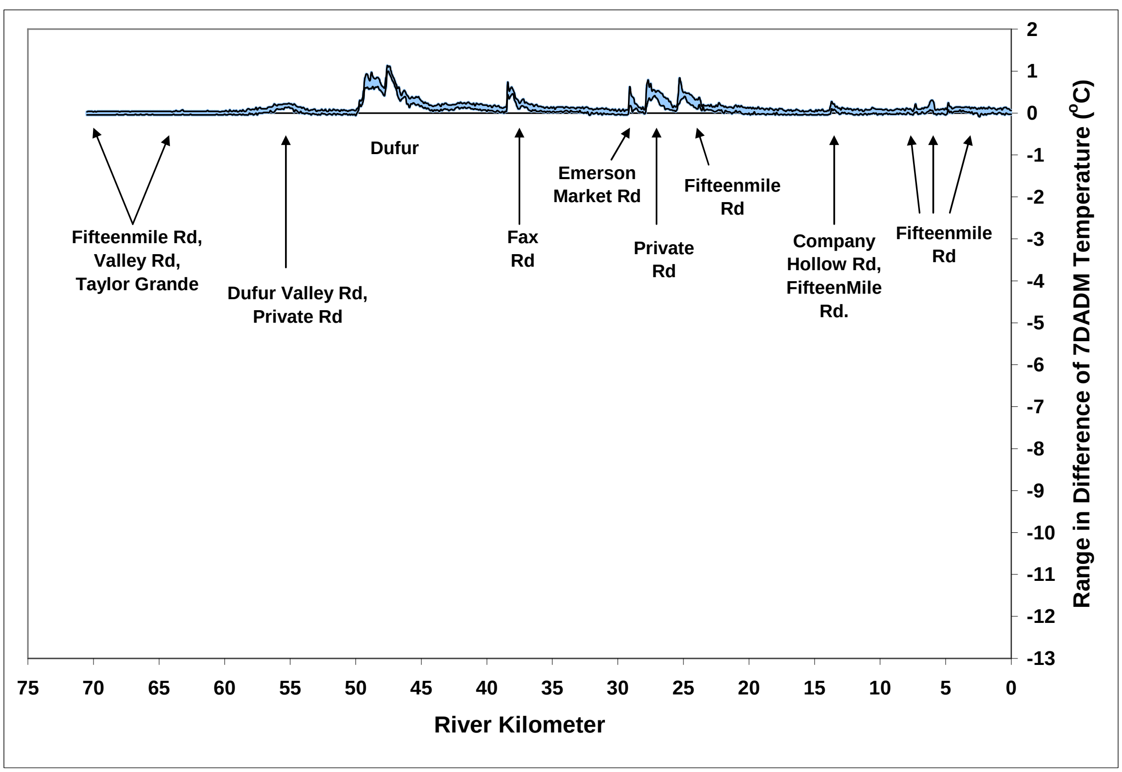


Figure A-48. Comparison of 7DADM Temperatures from Scenarios 4 and 5 for Fifteenmile Creek.



A3.2.2.5 Scenario 6: Natural Thermal Potential Conditions

This scenario was run to assess the combined thermal affects of system potential vegetation, natural flows, and reduced tributary temperatures on temperature in Fifteenmile Creek (Scenarios 2 and 4 combined). This condition represents the natural thermal potential (NTP) targeted in the TMDL. Model input parameters from the current condition model were modified as follows:

- All land cover polygons were set to system potential vegetation conditions, including roads and buildings
- All water withdrawals in the current condition model were set to zero
- Boundary condition and tributary flows were set to natural (information on natural tributary flows came from the *Fifteenmile Watershed Assessment* , Wasco SWCD, 2003)
- Boundary condition and tributary temperatures were set to estimated NTP temperatures. To estimate this, tributary temperatures were reduced by the difference between current conditions (Scenario 1) and Scenario 3 with natural disturbance at the nearest Fifteenmile continuous instream measurement location.
- Groundwater flows and temperature were maintained at current conditions.
- Dufur WWTP discharge was set to zero.

Figure A-49 shows the maximum diel temperature range observed on Fifteenmile Creek under Scenarios 1 and 6. The range of 7DADM differences between the two scenarios is shown in **Figure A-50**. As shown in **Figure A-49** simulations were also run to assess the thermal impacts of natural disturbance under NTP conditions. The natural disturbance simulations are described further in **Section A3.3**. On average, natural disturbances may increase NTP temperature by about 1.4°C.

Figure A-49. Maximum 7-day average diel temperture range in Fifteenmile Creek for Scenarios 1 and 6.

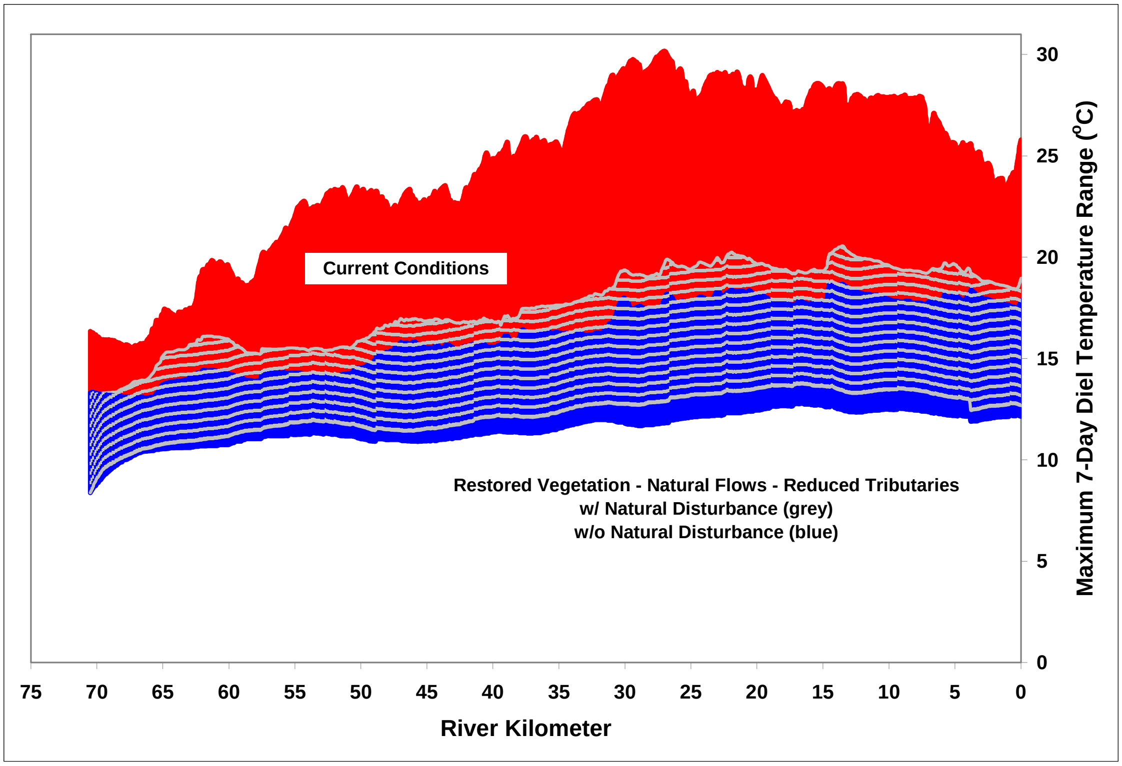
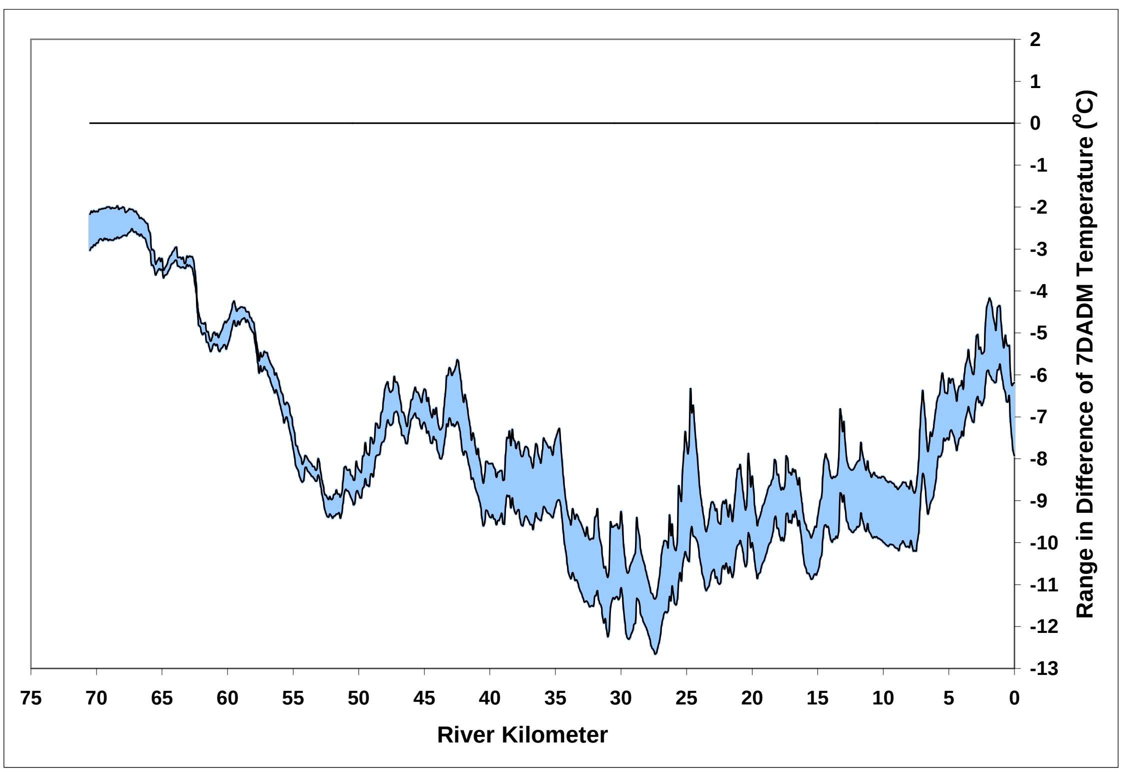


Figure A-50. Comparison of 7DADM Temperatures from Scenarios 1 and 6 for Fifteenmile Creek.



A3.2.2.6 Scenario 7: Potential Near Stream Land Cover, Reduced Tributary Temperatures, Natural Flows and Reduced Groundwater Temperatures

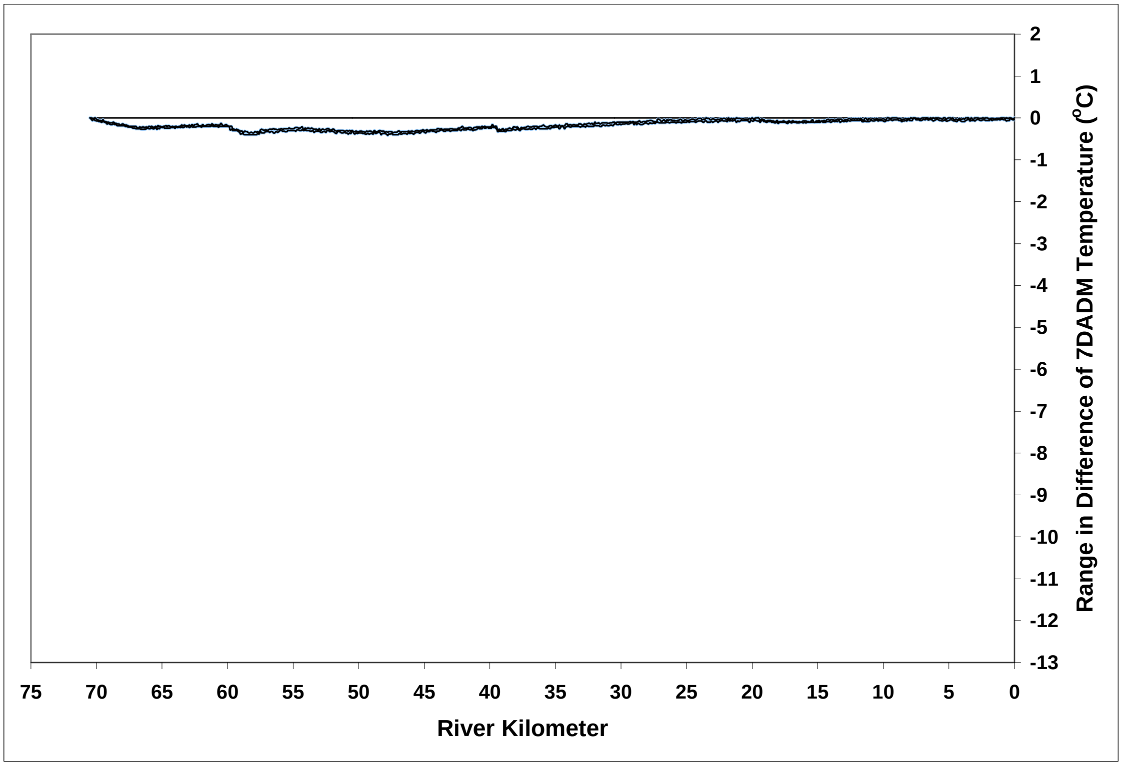
In small streams, hyporheic exchange and groundwater can play an important role in regulating temperature. While estimates of groundwater and hyporheic exchange can be inferred from the mass balance analysis used in the current conditions simulations, values for natural conditions are difficult to impossible to estimate with no direct data. Scenario 7 tries to evaluate the thermal response by reducing current condition groundwater values and hyporheic exchange temperatures. This scenario is intended as an information modeling exercise rather than an attempt to predict a true natural condition or estimate the level of groundwater interaction on Fifteenmile Creek. It is recommended that more data be collected if future work requires more accurate estimates of the influence of groundwater and hyporheic exchange.

Model inputs were the same as identified for Scenario 6 except that the temperature of groundwater and hyporheic exchange within the Fifteenmile Creek substrate was reduced by 1°C. Dry Creek was handled a bit differently because it has both surface and subsurface flows under natural conditions. In Scenarios 1-6, the temperature of the subsurface portion of Dry Creek was set to 16°C. Because most of Dry Creek's flow is subsurface during the summer (personal communication, Bob Wood – OWRD Watermaster), the temperature of Dry Creek's subsurface flow in Scenario 7 was set to 9.6°C (the estimated alluvium temperature based on yearly mean air temperature at Dufur). Model input parameters from the current condition model were modified as follows for this scenario:

- All land cover polygons were set to system potential vegetation conditions, including roads and buildings
- All water withdrawals in the current condition model were set to zero
- Boundary condition and tributary flows were set to natural (information on natural tributary flows came from the *Fifteenmile Watershed Assessment* , Wasco SWCD, 2003)
- Boundary condition and tributary temperatures were set to estimated NTP temperatures. To estimate this, tributary temperatures were reduced by the difference between current conditions (Scenario 1) and Scenario 3 with natural disturbance at the nearest Fifteenmile continuous instream measurement location.
- Groundwater flows were maintained at current conditions; groundwater temperatures were reduced by 1°C at all groundwater/hyporheic input nodes; the subsurface temperature of Dry Creek was set to 9.6°C.
- Dufur WWTP discharge was set to zero

Because the thermal differences between Scenarios 6 and 7 are not very great, only a graph showing the range of 7DADM differences is provided here (**Figure A-51**).

Figure A-51. Comparison of 7DADM Temperatures from Scenarios 6 and 7 for Fifteenmile Creek.



A3.3 NATURAL DISTURBANCE SIMULATIONS

A3.3.1 Introduction

Natural disturbance processes such as fire, floods, insects, disease, and other events are important natural processes that influence the development of riparian vegetation and the persistence of aquatic habitats (Swantson 1997, Gregory et al., 1991, Naiman et al., 1993, Tabacchi et al., 1998).

Disturbance, such as flood cycles, occur within 20-30 years in most riparian floodplains but can vary among stream hydrology and type (Cooper, 2006, Harris and Hubbard, 1983). Floods play an important role for floodplain vegetation, particularly in arid regions. Periodic inundation provides forest regeneration, plant establishment and species diversity through the process of plant replacement and seed dispersal (Reichenbacher, 1984, Skoglund, 1990, Hughes, 1990, Stromberg et al., 1991, and Goodson et al., 2001).

Many species native to the Miles Creeks, such as cottonwoods, alder, and willow, rely on regular flooding. These species generally colonize near the water's edge in areas of recent morphological disturbance. Morphological disturbance might include areas where flooding has removed the herbaceous cover or places of recent depositions of bed material (Lisle, 1989, Stromberg et al.,1991).

Flooding is very likely to be the dominant disturbance type for the Miles Creeks. To better understand the frequency and potential extent of these events, flood frequency discharge was calculated using the methods of (Cooper, 2006). Flood frequency discharge can help estimate the potential area inundated during flood events and help land managers planning restoration projects intended to meet this TMDL's load allocations. Flood frequency discharge for Fifteenmile Creek is shown in **Table A-12**.

Table A-12. Peak Fifteenmile Creek flood discharges for selected frequencies.

Flood Return Period (years)	Peak flow at mouth (cfs)	Peak flow above Eightmile Creek (cfs)	Peak flow above Jamson Canal (cfs)	Peak flow above Ramsey Creek. (cfs)
2	2250	1450	1170	422
5	4800	3270	2530	698
10	7430	5170	3940	954
20	10800	7660	5790	1260
25	12100	8580	6480	1370
50	16500	11900	8930	1750
100	21900	15900	11900	2170
500	38700	28800	21300	3350

Fire is another form of natural disturbance and important ecological process (Agee, 1994). Natural fire occurrence on forested land in the Cascade Crest Montane Forest ecoregion is mostly high intensity and occurs every 200+ years. It is more frequent (35 - 100+ years) at lower elevations in the Grand Fir Mixed Forest Ecoregion. Natural fire regimes in upland and scrub areas tend to be high frequency (0-35+ years) (Hardy et al., 2001, Schmidt et al., 2002). There is little data however, on fire frequency and intensity in the riparian areas in the Umatilla Plateau and Oak/Conifer East Cascade Columbia Foothills Ecoregions, although Dwire and Kauffman (2003) speculate that fire regimes will differ in these riparian areas from those in the upland because of differences in geomorphology, hydrology, vegetation, and microclimate. More study is needed for these vegetation types.

DEQ ran natural disturbance scenarios on Fifteenmile Creek. The purpose of the natural disturbance model simulations were:

1. To estimate the natural thermal potential temperatures which would be present under "natural conditions" as described in the natural conditions criteria in Oregon's temperature standards [OAR 340-041-0028(8)] and under the definition of "Natural Conditions" [OAR 340-041-0002(41)].
2. To mimic natural riparian vegetation that often consists of different plant communities and age classes which often is a result of multiple disturbance events.
3. Recognize the role natural disturbance plays in vegetation communities and present information that might inform ecosystem management decisions.

Natural disturbance scenarios were completed for model Scenarios 3 and 6 only.

A3.3.2 Natural Disturbance Modeling Methodology

DEQ developed an Excel-based visual basic macro that randomly applies natural disturbance events to the riparian vegetation over a 100-year period. The frequency, intensity, and scale of the disturbance events are based on literature values and described in **Table A-13**. Both low and high severity disturbance events are incorporated into the modeling. Overall this resulted in 1270 events over the 100 year period. Water, wetlands, and upland landcover types that were primarily grass were left unchanged after disturbance because they are not large shade producing landcover types. This was also done to speed up model processing time.

The location and year of natural disturbance was generated using a pseudo random number based on the algorithm by B.A. Wichmann and I.D. Hill (1982, 1987). Pseudo-random numbers are those in very long sequence that will eventually be repeated. The algorithm used in this macro will generate about ten trillion numbers before the sequence is repeated. This is within an acceptable range for this application.

The process for applying natural disturbance is as follows:

Step 1. The riparian vegetation at the beginning of the model run (year zero) is set to system potential conditions excluding any disturbance.

Step 2. As the macro run begins, the model cycles through the 100 year period. Vegetation is disturbed based on the set assumptions in **Table A-13**. After vegetation is disturbed, it re-grows based on the growth curves (references in **Table A-14**) shown in **Table A-15** through **Table A-23**. Some vegetation may get disturbed more than once over the entire cycle. At the end of the model run (year 100), riparian vegetation will reflect a diversity of density and heights.

Step 3. The disturbance simulations are repeated 10 times, generating 10 unique disturbed vegetation data sets.

Step 4. Each of the 10 disturbed vegetation data sets are input into the heat source model and used to simulate natural thermal potential stream temperatures with disturbance.

Table A-13. Natural disturbance modeling assumptions

Severity	Disturbance Return Interval (years)	Total Disturbance Events per 100 year cycle	Average disturbance distance along stream per event	Vegetation Height Reduction	Vegetation Density Reduction
Low	25	1129	500 meters	5%	15%
High	100	141	1000 meters	100%	100%

A3.3.3 Vegetation Growth Curves

Vegetation growth curves were used in the natural disturbance simulations to "re-grow" vegetation after a disturbance event. The curves were developed using the references provided in **Table A-14**, with additional review provided by the Oregon Department of Forestry. Composite growth curves for each system potential vegetation class (refer back to **Table A-6**) are shown in **Table A-15** through **Table A-23**.

Table A-14. References used to develop vegetation growth curves.

Tree	Reference
Black Cottonwood	(Murray and Harrington, 1983)
Black Cottonwood	(Burns and Honkala, 1990)
Western Red Cedar	(Thrower et al., 1991)
Alder	(Harrington and Curtis, 1986)
Englemann Spruce (uses white spruce)	(Thrower et al., 1991)
Ponderosa Pine	(Hann and Scrivani, 1987)
White Pine	(Curtis et al., 1990)
Douglas Fir	(Means and Helm, 1985)
Western Larch	(Cochran, 1985)

Table A-15. Composite growth curve for site potential vegetation code 4050.

Code	4050	Riparian - 0 to 20 feet from to stream						
Percent	5	35	20	30	10	100		
Age (years)	Ponderosa Pine S65 Height (m)	Alder S10 Height (m)	Cottonwood Height (m)	Willow Height (m)	Assorted Shrubs Height (m)	Composite Height (m)	Canopy Density (%)	Overhang Distance (m)
5	2.0	3.0	3.0	1.2	3.0	2.4	50%	0.1
10	4.6	5.0	6.0	2.0	5.0	4.3	70%	1.0
15	6.6	7.0	10.0	2.8	6.0	6.2	80%	1.2
20	8.6	10.0	14.0	4.0	6.0	8.5	85%	1.2
25	10.6	12.0	20.0	4.8	6.0	10.8	85%	1.2
30	12.5	13.0	24.0	5.2	6.0	12.1	85%	1.2
35	14.4	14.0	26.0	5.6	6.0	12.2	85%	1.2
40	16.3	15.0	28.0	6.0	6.0	12.2	85%	1.2
45	18.1	15.2	29.6	6.1	6.0	12.2	85%	1.2
50	19.8	15.2	29.6	6.1	6.0	12.2	85%	1.2
55	21.5	15.2	29.6	6.1	6.0	12.2	85%	1.2
60	23.0	15.2	29.6	6.1	6.0	12.2	85%	1.2
65	24.5	15.2	29.6	6.1	6.0	12.2	85%	1.2
70	26.0	15.2	29.6	6.1	6.0	12.2	85%	1.2
75	27.3	15.2	29.6	6.1	6.0	12.2	85%	1.2
80	28.6	15.2	29.6	6.1	6.0	12.2	85%	1.2
85	29.8	15.2	29.6	6.1	6.0	12.2	85%	1.2
90	30.9	15.2	29.6	6.1	6.0	12.2	85%	1.2
95	32.0	15.2	29.6	6.1	6.0	12.2	85%	1.2
100	33.0	15.2	29.6	6.1	6.0	12.2	85%	1.2

Table A-16. Composite growth curve for site potential vegetation code 4100.

Code	4100	Riparian – 20 to 100 feet from stream						
Percent	20	35	30	10	5	100		
Age (years)	Ponderosa Pine S65 Height (m)	Alder S10 Height (m)	Cottonwood Height (m)	Willow Height (m)	Assorted Shrubs Height (m)	Overhang Distance (m)	Canopy Density (%)	Overhang Distance (m)
5	2.0	3.0	3.0	1.2	3.0	2.6	40%	0
10	4.6	5.0	6.0	2.0	5.0	4.9	45%	0
15	6.6	7.0	10.0	2.8	6.0	7.3	50%	0
20	8.6	10.0	14.0	4.0	6.0	10.1	50%	0
25	10.6	12.0	20.0	4.8	6.0	13.1	50%	0
30	12.5	13.0	24.0	5.2	6.0	15.1	50%	0
35	14.4	14.0	26.0	5.6	6.0	16.4	50%	0
40	16.3	15.0	28.0	6.0	6.0	17.8	50%	0
45	18.1	15.2	29.6	6.1	6.0	18.7	50%	0
50	19.8	15.2	29.6	6.1	6.0	19.1	50%	0
55	21.5	15.2	29.6	6.1	6.0	19.4	50%	0
60	23.0	15.2	29.6	6.1	6.0	19.7	50%	0
65	24.5	15.2	29.6	6.1	6.0	19.8	50%	0
70	26.0	15.2	29.6	6.1	6.0	19.8	50%	0
75	27.3	15.2	29.6	6.1	6.0	19.8	50%	0
80	28.6	15.2	29.6	6.1	6.0	19.8	50%	0
85	29.8	15.2	29.6	6.1	6.0	19.8	50%	0
90	30.9	15.2	29.6	6.1	6.0	19.8	50%	0
95	32.0	15.2	29.6	6.1	6.0	19.8	50%	0
100	33.0	15.2	29.6	6.1	6.0	19.8	50%	0

Table A-17. Composite growth curve for site potential vegetation code 5050.

Code	5050	Riparian - 0 to 20 feet from to stream						
Percent	20	10	40	20	10	100		
Age (years)	Ponderosa Pine S65 Height (m)	Western Red Cedar S9 Height (m)	Alder S10 Height (m)	Cottonwood Height (m)	Assorted Shrubs Height (m)	Composite Height (m)	Canopy Density (%)	Overhang Distance (m)
5	2.0	2.0	3.0	3.0	3.0	2.7	50%	0.5
10	4.6	2.9	5.0	6.0	5.0	4.9	70%	1.0
15	6.6	3.8	7.0	10.0	6.0	7.1	80%	1.8
20	8.6	4.7	10.0	14.0	6.0	9.6	85%	1.8
25	10.6	5.5	12.0	20.0	6.0	12.1	85%	1.8
30	12.5	6.3	12.2	24.0	6.0	13.4	85%	1.8
35	14.4	7.0	12.2	26.0	6.0	14.3	85%	1.8
40	16.3	7.7	12.2	28.0	6.0	15.1	85%	1.8
45	18.1	8.4	12.2	29.6	6.0	15.8	85%	1.8
50	19.8	9.0	12.2	29.6	6.0	16.3	85%	1.8
55	21.5	11.6	12.2	29.6	6.0	16.8	85%	1.8
60	23.0	12.3	12.2	29.6	6.0	17.2	85%	1.8
65	24.5	12.9	12.2	29.6	6.0	17.6	85%	1.8
70	26.0	13.5	12.2	29.6	6.0	17.9	85%	1.8
75	27.3	14.0	12.2	29.6	6.0	18.3	85%	1.8
80	28.6	14.5	12.2	29.6	6.0	18.3	85%	1.8
85	29.8	15.0	12.2	29.6	6.0	18.3	85%	1.8
90	30.9	15.5	12.2	29.6	6.0	18.3	85%	1.8
95	32.0	15.9	12.2	29.6	6.0	18.3	85%	1.8
100	33.0	16.4	12.2	29.6	6.0	18.3	85%	1.8

Table A-18. Composite growth curve for site potential vegetation code 5100.

Code	5100	Riparian – 20 to 100 feet from stream						
Percent	40	40	5	5	10	100		
Age (years)	Ponderosa Pine S65 Height (m)	Western Red Cedar S9 Height (m)	Alder S10 Height (m)	Cottonwood Height (m)	Oregon White Oak Height (m)	Composite Height (m)	Canopy Density (%)	Overhang Distance (m)
5	2.0	2.0	3.0	3.0	2.0	2.1	50%	0
10	4.6	2.9	5.0	6.0	5.0	4.1	60%	0
15	6.6	3.8	7.0	10.0	7.0	5.7	65%	0
20	8.6	4.7	10.0	14.0	10.0	7.5	70%	0
25	10.6	5.5	12.0	20.0	12.0	9.2	70%	0
30	12.5	6.3	12.2	24.0	13.0	10.6	70%	0
35	14.4	7.0	12.2	26.0	14.0	11.9	70%	0
40	16.3	7.7	12.2	28.0	15.0	13.1	70%	0
45	18.1	8.4	12.2	29.6	15.2	14.2	70%	0
50	19.8	9.0	12.2	29.6	15.2	15.1	70%	0
55	21.5	11.6	12.2	29.6	15.2	16.8	70%	0
60	23.0	12.3	12.2	29.6	15.2	17.7	70%	0
65	24.5	12.9	12.2	29.6	15.2	18.6	70%	0
70	26.0	13.5	12.2	29.6	15.2	19.4	70%	0
75	27.3	14.0	12.2	29.6	15.2	20.1	70%	0
80	28.6	14.5	12.2	29.6	15.2	20.9	70%	0
85	29.8	15.0	12.2	29.6	15.2	21.3	70%	0
90	30.9	15.5	12.2	29.6	15.2	21.3	70%	0
95	32.0	15.9	12.2	29.6	15.2	21.3	70%	0
100	33.0	16.4	12.2	29.6	15.2	21.3	70%	0

Table A-19. Composite growth curve for site potential vegetation code 6050.

Code	6050	Riparian - 0 to 20 feet from to stream						
Percent	47	2	20	30	1	100		
Age (years)	Ponderosa Pine S65 Height (m)	Western Red Cedar S9 Height (m)	Alder S10 Height (m)	Cottonwood Height (m)	Assorted Shrubs Height (m)	Composite Height (m)	Canopy Density (%)	Overhang Distance (m)
5	2.0	2.0	3.0	3.0	3.0	2.5	50%	0.5
10	4.6	2.9	5.0	6.0	5.0	5.1	70%	1.0
15	6.6	3.8	7.0	10.0	6.0	7.6	80%	2.0
20	8.6	4.7	10.0	14.0	6.0	10.4	85%	2.7
25	10.6	5.5	12.0	20.0	6.0	13.5	85%	2.7
30	12.5	6.3	12.2	24.0	6.0	15.7	85%	2.7
35	14.4	7.0	12.2	26.0	6.0	17.2	85%	2.7
40	16.3	7.7	12.2	28.0	6.0	18.7	85%	2.7
45	18.1	8.4	12.2	29.6	6.0	20.0	85%	2.7
50	19.8	9.0	12.2	29.6	6.0	20.9	85%	2.7
55	21.5	11.6	12.2	29.6	6.0	21.7	85%	2.7
60	23.0	12.3	12.2	29.6	6.0	22.4	85%	2.7
65	24.5	12.9	12.2	29.6	6.0	23.2	85%	2.7
70	26.0	13.5	12.2	29.6	6.0	23.8	85%	2.7
75	27.3	14.0	12.2	29.6	6.0	24.5	85%	2.7
80	28.6	14.5	12.2	29.6	6.0	25.1	85%	2.7
85	29.8	15.0	12.2	29.6	6.0	25.7	85%	2.7
90	30.9	15.5	12.2	29.6	6.0	26.2	85%	2.7
95	32.0	15.9	12.2	29.6	6.0	26.7	85%	2.7
100	33.0	16.4	12.2	29.6	6.0	27.2	85%	2.7

Table A-20. Composite growth curve for site potential vegetation code 6100.

Code	6100	Riparian – 20 to 100 feet from stream					
Percent	84	4	4	4	4	100		
Age (years)	Ponderosa Pine S65 Height (m)	Western Red Cedar S9 Height (m)	Alder S10 Height (m)	Cottonwood Height (m)	Oregon White Oak Height (m)	Composite Height (m)	Canopy Density (%)	Overhang Distance (m)
5	2.0	2.0	3.0	3.0	2.0	2.1	50%	0
10	4.6	2.9	5.0	6.0	5.0	4.6	70%	0
15	6.6	3.8	7.0	10.0	7.0	6.6	80%	0
20	8.6	4.7	10.0	14.0	10.0	8.7	85%	0
25	10.6	5.5	12.0	20.0	12.0	10.8	85%	0
30	12.5	6.3	12.2	24.0	13.0	12.7	85%	0
35	14.4	7.0	12.2	26.0	14.0	14.5	85%	0
40	16.3	7.7	12.2	28.0	15.0	16.2	85%	0
45	18.1	8.4	12.2	29.6	15.2	17.8	85%	0
50	19.8	9.0	12.2	29.6	15.2	19.3	85%	0
55	21.5	11.6	12.2	29.6	15.2	20.8	85%	0
60	23.0	12.3	12.2	29.6	15.2	22.1	85%	0
65	24.5	12.9	12.2	29.6	15.2	23.4	85%	0
70	26.0	13.5	12.2	29.6	15.2	24.6	85%	0
75	27.3	14.0	12.2	29.6	15.2	25.8	85%	0
80	28.6	14.5	12.2	29.6	15.2	26.9	85%	0
85	29.8	15.0	12.2	29.6	15.2	27.9	85%	0
90	30.9	15.5	12.2	29.6	15.2	28.9	85%	0
95	32.0	15.9	12.2	29.6	15.2	29.8	85%	0
100	33.0	16.4	12.2	29.6	15.2	30.5	85%	0

Table A-21. Composite growth curve for site potential vegetation code 3050.

Code	3050	Riparian - 0 to 20 feet from to stream						
Percent	20	25	10	45		100		
Age (years)	Englemann Spruce (white) S20 Height (m)	Alder S10 Height (m)	Cottonwood Height (m)	Western Red Cedar S22 Height (m)		Composite Height (m)	Canopy Density (%)	Overhang Distance (m)
5	2.4	3.0	3.0	3.4		3.1	50%	0.5
10	4.2	5.0	6.0	6.0		5.4	70%	1.0
15	6.3	7.0	10.0	8.5		7.8	80%	1.5
20	8.4	10.0	14.0	10.8		10.5	85%	3.0
25	10.6	12.0	20.0	13.0		13.0	85%	3.0
30	12.7	13.0	24.0	15.0		15.0	85%	3.0
35	14.7	14.0	26.0	16.9		16.7	85%	3.0
40	16.6	15.0	28.0	18.7		18.3	85%	3.0
45	18.4	16.7	30.5	20.4		20.1	85%	3.0
50	20.0	16.7	30.5	22.0		21.1	85%	3.0
55	21.5	16.7	30.5	28.5		24.3	85%	3.0
60	22.9	16.7	30.5	30.1		25.4	85%	3.0
65	24.2	16.7	30.5	31.7		26.3	85%	3.0
70	25.4	16.7	30.5	33.2		27.2	85%	3.0
75	26.4	16.7	30.5	34.5		28.1	85%	3.0
80	27.4	16.7	30.5	35.9		28.8	85%	3.0
85	28.4	16.7	30.5	37.1		29.6	85%	3.0
90	29.2	16.7	30.5	38.3		30.3	85%	3.0
95	30.0	16.7	30.5	39.4		30.5	85%	3.0
100	30.7	16.7	30.5	40.4		30.5	85%	3.0

Table A-22. Composite growth curve for site potential vegetation code 3100.

Code	3100	Riparian – 20 to 100 feet from stream						
Percent	5	50	10	10		75		
Age (years)	Ponderosa Pine S80 Height (m)	Western Red Cedar S22 Height (m)	Douglas Fir S45 Height (m)	Cottonwood Height (m)	Oregon White Oak Height (m)	Composite Height (m)	Canopy Density (%)	Overhang Distance (m)
5	2.0	3.4	2.5	3.0	2.0	3.2	50%	0
10	5.5	6.0	5.9	6.0	5.0	6.0	70%	0
15	7.9	8.5	9.3	10.0	7.0	8.8	80%	0
20	10.4	10.8	12.8	14.0	10.0	11.5	85%	0
25	12.9	13.0	16.1	20.0	12.0	14.3	85%	0
30	15.4	15.0	19.1	24.0	13.0	16.8	85%	0
35	17.8	16.9	22.0	26.0	14.0	18.9	85%	0
40	20.1	18.7	24.7	28.0	15.0	20.9	85%	0
45	22.3	20.4	27.2	30.5	15.2	22.8	85%	0
50	24.4	22.0	29.5	30.5	15.2	24.3	85%	0
55	26.4	28.5	31.6	30.5	15.2	29.0	85%	0
60	28.3	30.1	33.6	30.5	15.2	30.5	85%	0
65	30.1	31.7	35.4	30.5	15.2	31.9	85%	0
70	31.8	33.2	37.1	30.5	15.2	33.2	85%	0
75	33.5	34.5	38.7	30.5	15.2	34.5	85%	0
80	35.0	35.9	40.1	30.5	15.2	35.7	85%	0
85	36.4	37.1	41.5	30.5	15.2	36.7	85%	0
90	37.7	38.3	42.7	30.5	15.2	37.8	85%	0
95	39.0	39.4	43.9	30.5	15.2	38.8	85%	0
100	40.1	40.4	45.0	30.5	15.2	39.6	85%	0

Table A-23. Composite growth curve for site potential vegetation code 3200.

Code	3200	Upland						
Percent	30	40	10	20		100		
Age (years)	Ponderosa Pine S80 Height (m)	Douglas Fir S45 Height (m)	White Pine S50 Height (m)	Western Larch S50 Height (m)		Composite Height (m)	Canopy Density (%)	Overhang Distance (m)
5	2.0	2.5	1.7	3.3		2.5	50%	0
10	5.5	5.9	2.4	4.8		5.2	70%	0
15	7.9	9.3	3.3	6.4		7.7	75%	0
20	10.4	12.8	4.3	8.1		10.3	80%	0
25	12.9	16.1	5.5	9.9		12.8	80%	0
30	15.4	19.1	6.8	11.7		15.3	80%	0
35	17.8	22.0	8.1	13.4		17.6	80%	0
40	20.1	24.7	9.4	15.1		19.9	80%	0
45	22.3	27.2	10.8	16.7		22.0	80%	0
50	24.4	29.5	12.2	18.3		24.0	80%	0
55	26.4	31.6	13.6	19.7		25.9	80%	0
60	28.3	33.6	14.9	21.1		27.6	80%	0
65	30.1	35.4	16.3	22.3		29.3	80%	0
70	31.8	37.1	17.6	23.4		30.8	80%	0
75	33.5	38.7	18.9	24.3		32.3	80%	0
80	35.0	40.1	20.1	25.2		33.6	80%	0
85	36.4	41.5	21.3	26.0		34.8	80%	0
90	37.7	42.7	22.4	26.8		36.0	80%	0
95	39.0	43.9	23.5	27.5		37.1	80%	0
100	40.1	45.0	24.5	28.2		38.1	80%	0

A3.3.4 Natural Disturbance Modeling Results

Natural disturbance scenarios were completed for model Scenarios 3 and 6 only. Scenario 3 natural disturbance model runs were utilized to estimate natural tributary input temperatures. These estimates were used for many of the other simulations scenarios and are described in **Section A3.2.2**. The results for each of the ten natural disturbance simulations for simulation 6 (shown in **Figure A-52**) show that natural disturbance may increase seven day average daily maximum natural thermal potential temperatures on average about 1.4°C. **Figure A-53** shows the reduction to effective shade for each of the ten natural disturbance simulations.

Figure A-52. NTP temperatures resulting from ten natural disturbance simulations on Fifteenmile Creek.

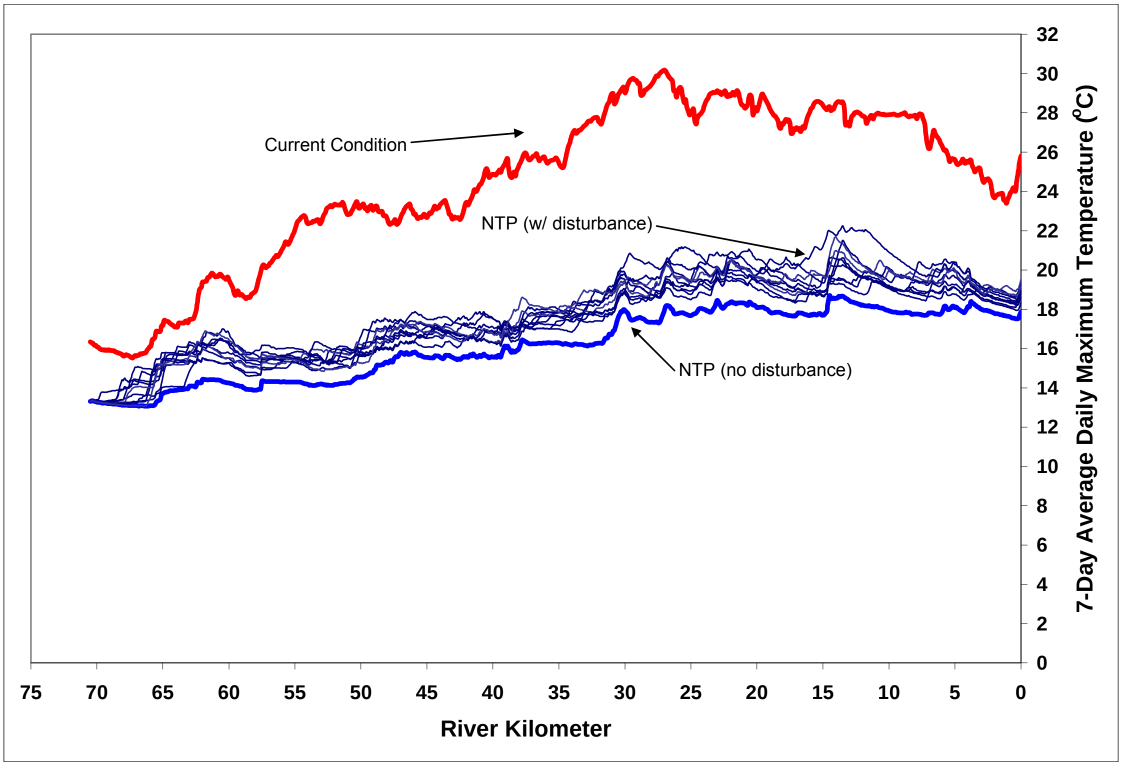
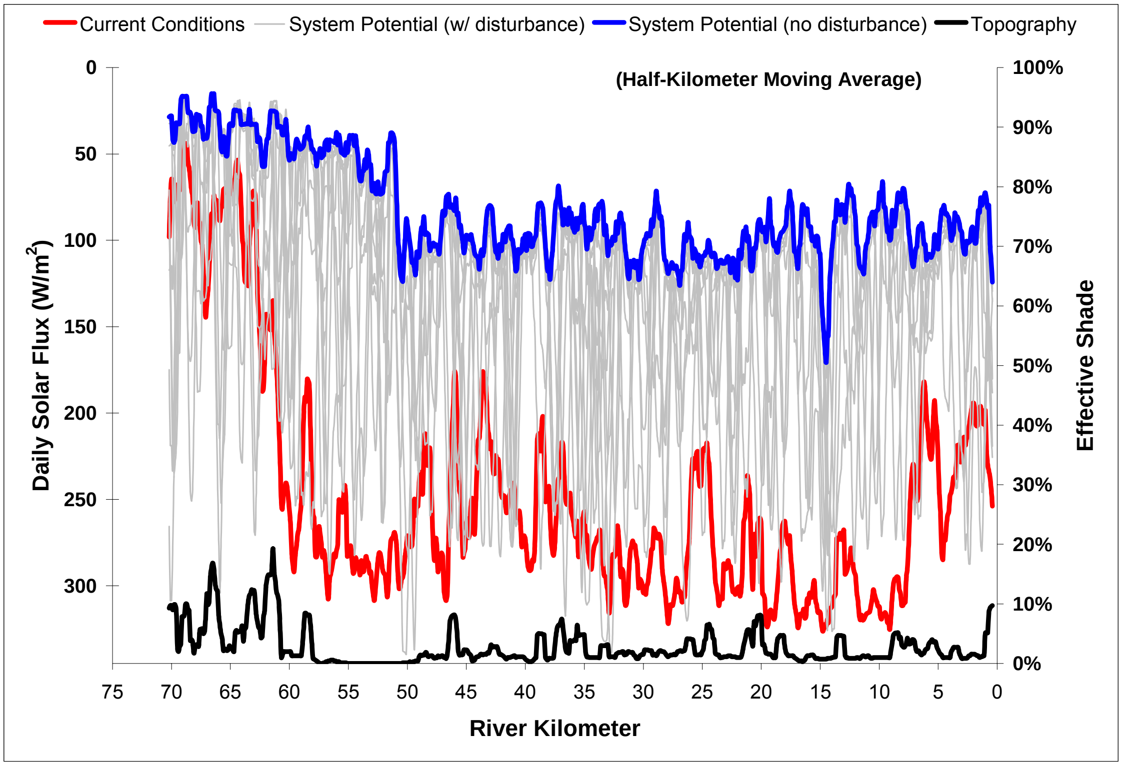


Figure A-53. Effective shade resulting from ten natural disturbance simulations on Fifteenmile Creek.



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