Total Maximum Daily Loads for the Lower Columbia-Sandy Subbasin

Technical Support Document Appendix A: Model Report

August 2024

State of Oregon
DEQ Department of Environmental Quality

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1 Overview

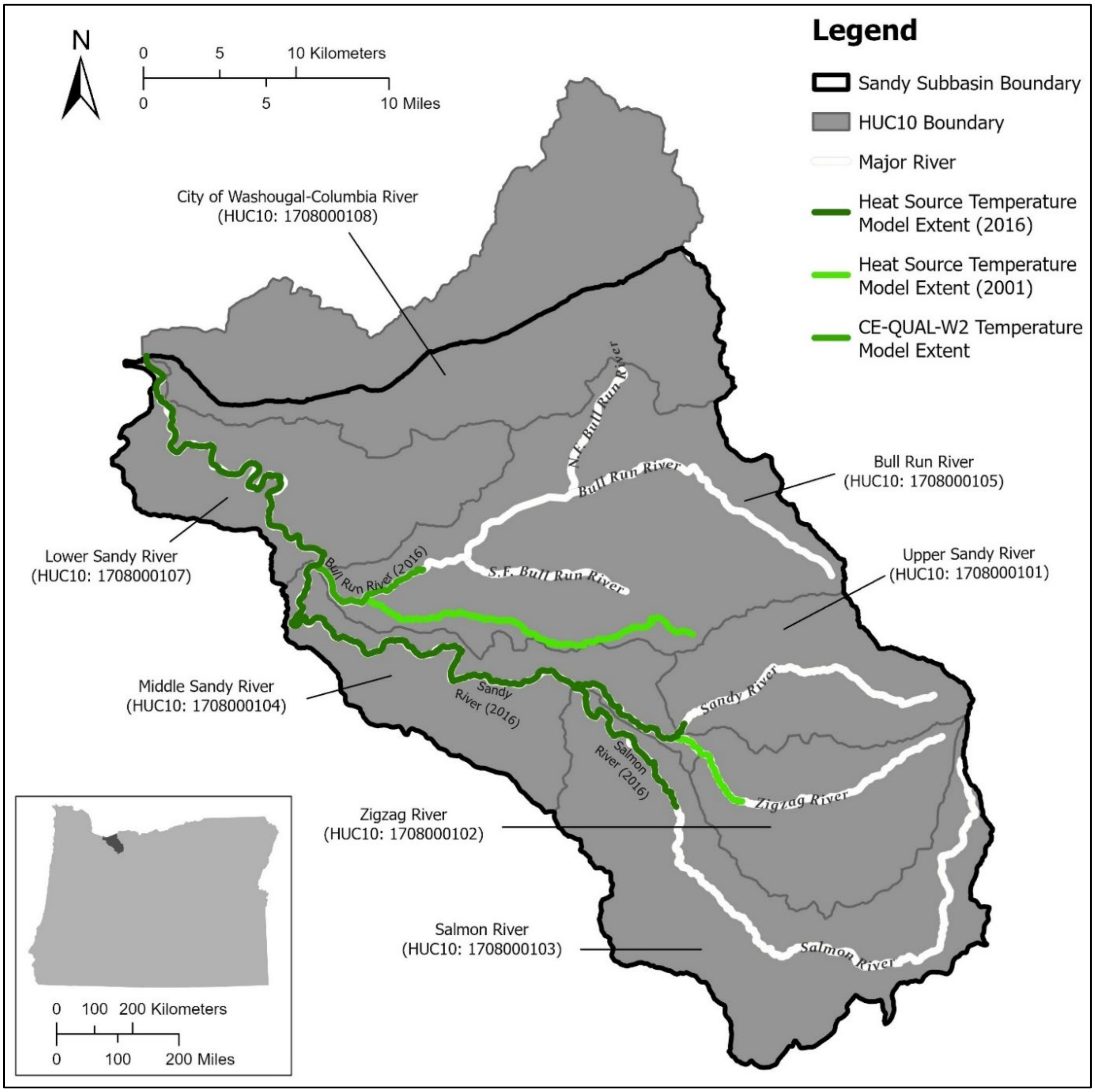

Figure 1-1: Overview of Sandy Subbasin TMDL project area with stream temperature model extents.

This document, Appendix A to the Technical Support Document (TSD) for the Lower Columbia-Sandy Subbasin (17080001) temperature Total Maximum Daily Load (TMDL) replacement project, summarizes the numerical modeling and analytic methods applicable to the TMDL. This includes subbasin-wide and river-specific descriptions of data and data sources; current conditions model setup and calibration; and alternative scenario models and results comparisons. **Figure 1-1** and **Figure 1-2** depict the Sandy Subbasin project area including the modeled streams and subbasins. Updated analyses were completed for the Sandy River, Salmon River, and Bull Run River subbasins. The Salmon River model results are provided herein. For the Little Sandy River and Zigzag River subbasins, the analyses from the 2005 TMDL (DEQ, 2005) were retained and are summarized herein. For the Sandy River, TSD

Appendices B and C provide details on the current conditions model and various model scenarios, respectively. For the Bull Run River, TSD Appendix D documents the configuration and results of the current conditions model and various model scenarios, while Section 4.6 of this document provides additional information on scenario results and comparisons.

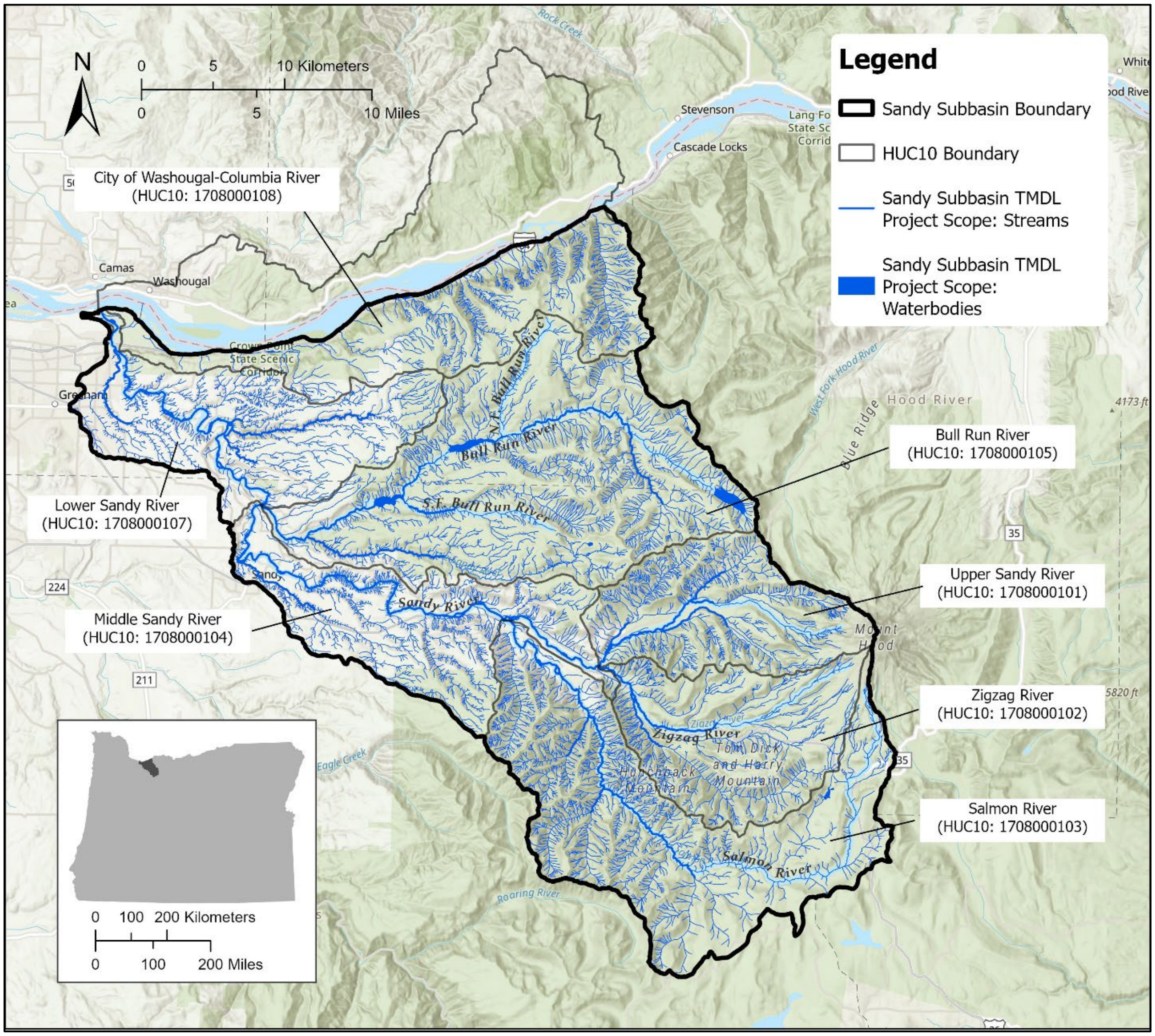

Figure 1-2: Scope of surface waters within the temperature TMDL project area.

2 Acquired data

This section describes the field collected (2.1), remotely acquired (2.2), and derived (2.3) data that were available and applied to support this TMDL modeling effort.

2.1 Field data

2.1.1 Continuous stream temperature

Continuous stream temperature data were retrieved from DEQ's Ambient Water Quality Monitoring System (AWQMS), USGS's National Water Information System (NWIS), or obtained during the data solicitation for DEQ's Temperature TMDL Replacement Project. Temperature data retrieved from DEQ's AWQMS database were coded with a Data Quality Level (DQL) of A, B or E, and a result status of "Final" or "Provisional" as outlined in DEQ's Data Quality Matrix for Field Parameters (DEQ, 2013a). For TMDL development, only temperature results with a DQL of A or B were used without further review (DEQ, 2021). Data of unknown quality were used per professional judgment following specific quality assessment and control review. Stream temperature datasets are available from DEQ by request.

Available continuous stream temperature monitoring site data are listed in the respective model setup sections. These data were used:

- To evaluate if the waterbody achieves temperature water quality standards,
- As model inputs for tributary inflows and/or the upstream boundary condition,
- To assess model performance and goodness-of-fit by comparing observed to predicted stream temperature data.

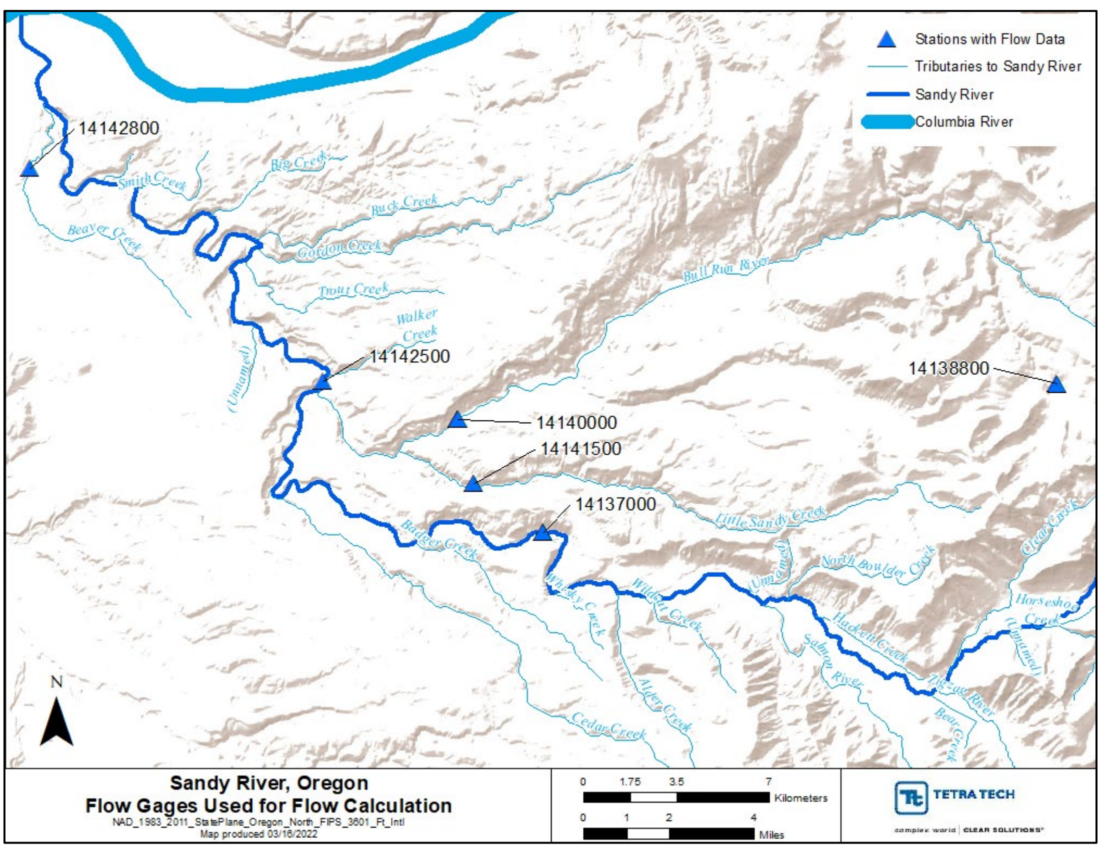

Figure 2-1: Sandy Subbasin streamflow measurement sites.

2.1.2 Streamflow – continuous and instantaneous measurements

Continuous and instantaneous streamflow data were collected by various entities at several sites (**Figure 2-1**, **Table 2-1**) during the 2016 Sandy Subbasin model period. These measurements supported DEQ estimations of flow mass balances, tributary inputs, and other parameters required for the temperature models.

Table 2-1: Sandy Subbasin model development: Continuous streamflow measurement sites.

Subbasin	Station ID	Station name	Latitude	Longitude	Data source
Bull Run	PWB_BR_DNSTM_PP	Bull Run Dam 2 outflow	45.4444	-122.159	PWB
Bull Run	14138850	Bull Run R. near Multnomah Falls	45.4983	-122.011	USGS
Bull Run	14139800	S. Fork Bull Run R.	45.4447	-122.108	USGS
Bull Run	14138900	North Fork Bull Run R.	45.4944	-122.035	USGS
Bull Run	14138870	Fir Creek	45.4803	-122.025	USGS
Bull Run	14141500	Little Sandy R. near Bull Run	45.4154	-122.171	USGS
Bull Run	14140000	Bull Run R. near Bull Run	45.4373	-122.18	USGS
Bull Run	HDWTI025	Lamprey Barrier (primary)	45.4489	-122.155	PWB
Sandy	14142800	Beaver Cr.	45.5193	-122.389	USGS
Sandy	14137000	Sandy R. near Marmot	45.4000	-122.1373	USGS
Sandy	14142500	Sandy R. below Bull Run R., near Bull Run	45.4490	-122.2451	USGS

2.1.3 Point source discharges

Table 2-2 identifies NPDES permittees currently covered by an individual permit or registered under the general GEN03 (industrial wastewater-fish hatcheries). These permittees are required to submit annual Discharge Monitoring Reports (DMR). DEQ used DMRs and other permittee-submitted information including monitoring data (when applicable) to characterize relevant point source discharges for the TMDL modeling effort.

Table 2-2: Sandy Subbasin model development: Instantaneous NPDES discharge data sources.

Subbasin	WQ file #	NPDES permittee	Latitude	Longitude	Data source
Sandy	39750	WES (Hoodland STP)	45.3464	-121.969	2016 Discharge Monitoring Report
Sandy	89941	City Of Troutdale Water Pollution Control Facility	45.5535	-122.387	2016 Discharge Monitoring Report
Sandy	34136	Government Camp STP	45.3023	-121.776	Response to Data Solicitation
Sandy	64550	ODFW Sandy R. Fish Hatchery	45.4070	-122.254	Response to Data Solicitation
Sandy	78615	Sandy WWTP	45.4064	-122.320	Response to Data Solicitation

2.2 GIS and remotely sensed data

This TMDL modeling effort entailed inclusion of various GIS and remotely-acquired data types as described in **Table 2-3** and the remainder of Section 2.2.

Table 2-3: Sandy Subbasin model development: Remotely acquired data.

Spatial data type	Applications
Digital elevation models (DEM), 3-ft	Measure stream elevation and gradient, topography, and shade
Light detection and ranging (LiDAR)	Map, measure, and/or derive ground and surface feature elevations, stream depths, bathymetry, and vegetation heights; develop DEMs

Spatial data type	Applications
Aerial imagery – digital orthophoto quads	Map/digitize vegetation, stream channels, development, and infrastructure
Thermal infrared radiometry (TIR) stream temperature data	Measure/confirm surface temperatures; develop longitudinal temperature profiles; identify significant thermal features (e.g., springs)

2.2.1 3-ft Digital Elevation Model (DEM)

A digital elevation model (DEM) comprises digital information that provides a uniform matrix of terrain elevation values. It provides basic quantitative data for deriving terrain and stream elevations, stream slope, and topographic information. A 3 ft DEM contains a land surface elevation value for each 3 ft square (i.e., 3 ft resolution). DEMs for this TMDL were produced by DEQ, the DEQ consultant (TetraTech), and the City of Portland from Oregon LiDAR Consortium (OLC) LiDAR data hosted by the Oregon Department of Geology and Mineral Industries (OLC, 2022a) and Portland State University (OLC, 2022b).

2.2.2 Light Detection and Ranging (LiDAR)

Light detection and ranging (LiDAR) is a remote sensing method that uses light pulses to calculate ground and surface feature elevations to a high degree of accuracy and resolution. LiDAR data are used to develop high-resolution digital surface models (DSM) and DEMs that can be used to derive canopy height and other parameters. DOGAMI oversees the OLC, which develops cooperative agreements for LiDAR collection and provides a LiDAR data download portal (OLC, 2022a). For the updated analysis, LiDAR data collected in 2015, 2014, 2012, 2011, and 2009 were used to characterize vegetation height, ground elevations, and stream depth and bathymetry.

2.2.3 Aerial imagery – Digital Orthophoto Quads (DOQs)

A digital orthophoto quad (DOQ) is a digital image of an aerial photograph from which displacements caused by the camera angle and terrain have been removed. DOQs are projected in map coordinates, thus combining photographic image characteristics with map geometric qualities. For the updated analysis, DEQ obtained color DOQs representing 2018-collected imagery and data from the DOGAMI portal (OLC, 2022a). For the original TMDL analysis (DEQ, 2005), DOQs collected in 1997 and 2000 were used. These were used to:

- Map/digitize stream features such as position, channel edges, and wetted channel edges,
- Map/digitize near-stream vegetation, and
- Map/digitize instream structures such as dams, gages, and unmapped diversions/withdrawals.

2.2.4 Thermal Infrared Radiometry (TIR) temperature data

Thermal infrared radiometry (TIR) stream temperature data were used to:

- Develop continuous spatial temperature data sets,
- Calculate longitudinal heating profiles/gradients,
- Visually observe complex stream temperatures distributions at a large landscape scale,
- Map/identify significant thermal features,

- Develop flow mass balances, and
- Validate simulated stream temperatures.

A powerful use of TIR-derived stream temperature data is the direct observation of spatial temperature patterns and thermal gradients. In a longitudinal stream temperature profile, thermally significant areas can be identified and directly ascribed to specific sources (e.g., water withdrawal, tributary confluence, vegetation patterns). Areas where stream and subsurface water mix (e.g., hyporheic and spring inflows) are typically apparent in TIR data. TIR-represented thermal changes are quantifiable as specific stream temperature changes, or gradients that reflect a temperature change over a specific distance. TIR data can be viewed as GIS point coverages or TIR imagery.

TIR imagery measures the surface temperature of waterbodies or objects captured in the TIR image (i.e., ground, vegetation, and stream). TIR data were acquired via a helicopter-mounted sensor that collected digital data directly to an on-board computer at a rate that ensured the imagery maintained a continuous image overlap of ≥40% with a resolution of <0.5 m/pixel (Watershed Sciences, 2001). The TIR detected and recorded emitted radiation levels at 8-12 µm wavelengths (long-wave) as a digital image across the sensor's full 12-bit dynamic range. Each image pixel contained a measured value that was converted directly to a temperature value. A visible video sensor captured the same field-of-view as the TIR sensor, with GPS time and coordinates encoded on the imagery. In-stream temperature data loggers were installed throughout the survey in each subbasin to verify the TIR-measured radiant temperatures. Data collection was timed to capture maximum daily stream temperatures, which typically occur between 1400h-1800h. The helicopter was flown longitudinally over the stream channel center with the sensors in a vertical (or near-vertical) position. Generally, flight altitude was maintained so the stream channel comprised ~20-40% of the image frame, with ~300 m minimum flight altitude maintained for safety and maneuverability. If a stream split into two channels that could not be contained in a single field of view, the survey was completed on the larger of the two channels. The TIR survey reports contain detailed flight information, results discussions, sample imagery, and longitudinal temperature profiles. TIR datasets are available by request from DEQ.

DEQ utilized TIR data collected in 2001 in the Sandy Subbasin (**Table 2-4**). Longitudinal river temperatures were sampled with TIR in separate flights for each stream. Temperature data sampled from the TIR imagery revealed that spatial patterns varied due to localized stream heating, tributary mixing, and groundwater influences. Thermal stratification was identified in TIR imagery and by comparison with the instream temperature loggers. For example, TIR imagery may reveal a sudden cooling at a riffle or downstream of a structure where water was relatively stagnant or deep just upstream of a dam.

Table 2-4: Sandy Subbasin model development: TIR survey extents and collection dates.

Stream	Survey extent	Survey date	Time	Survey distance (mi)	Survey distance (km)
Bull Run R.	Mouth to Bull Run Lake	2001-08-08	13:54-14:36	23.42	37.69
Little Sandy R.	Mouth to headwaters	2001-08-08	14:44-14:59	15.05	24.22
Salmon R.	Mouth to headwaters	2001-08-08	15:11-16:24	32.36	52.08
Sandy R.	Mouth to headwaters	2001-08-09	14:02-14:31	53.33	85.83
S. Fork Bull Run R.	Mouth to headwaters	2001-08-09	14:38-15:50	6.31	10.15
S. Fork Salmon R.	Mouth to headwaters	2001-08-09	14:58-15:08	5.18	8.34
Zigzag R.	Mouth to headwaters	2001-08-09	15:57-16:19	12.38	19.92

2.3 Derived data

For model setup, several spatial datasets were derived from landscape-scale GIS data. Sampling density was user-defined and typically matched GIS data resolution and accuracy. As detailed in Sections 2.3.1-2.3.8, the derived parameters used in stream temperature analyses were:

- Stream position and morphology, e.g., aspect, elevation, gradient, width,
- Land cover classification and designated management agency (DMA),
- Maximum topographic shade angles, i.e., East, South, West, and
- Vegetation type, height, and canopy density

2.3.1 Stream position and channel width

Stream position and active channel width were estimated and applied at 50 m increments via the following steps:

1. Stream right and left banks (relative to downstream) were digitized at a 1:2,000 or smaller map scale from a combination of USDA National Agricultural Imagery Program (NAIP) aerial imagery and hillshade data derived from LiDAR data. Digitized streambanks corresponded to the active channel width, i.e., width between shade-producing riparian vegetation and/or the low-flow channel edge.

2. The stream center flowline was digitized at a 1:2,000 or smaller map scale by following the volume-estimated center of the active channel.

3. The stream center flowline was segmented into 50 m reaches, each separated by a node, using Python TTools scripts (Michie, R., 2022; DEQ, 2012). These nodes (e.g., in **Figure 2-2)** defined the discrete modeling locations and flow path.

2.3.2 Channel bottom width

The Heat Source 8 model (DEQ, 2012) assumes a trapezoidal channel shape and required channel bottom width inputs (b_2) (**Figure 2-3**) that were estimated with **Equation 2-1**. For **Equation 2-1**, the active channel width (b_1) was the digitized channel width (Section 2.3.1). Mean depth (D) was calculated as b_1/(width:depth) (measured or estimated) at each node. Channel angle (z) and the width:depth ratios are estimated model calibration parameters.

Equation 2-1

$$b_2 = b_1 - 2 \cdot z \cdot \mathrm{D}$$

where,

$b_2 =$ Bottom width (m)

$b_1 =$ Active channel width (m)

$\mathrm{D} =$ Mean active channel depth (m). Estimated as b_1/(width:depth).

$z =$ Channel angle (unitless), defined as the horizontal distance change per unit vertical distance change of the channel side slope.

Figure 2-2: Example: Digitized channel (blue line) and stream nodes (green dots) for Heat Source 8.

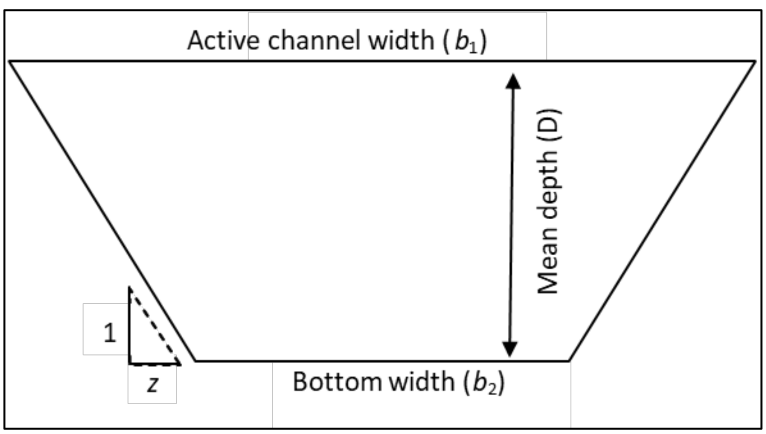

Figure 2-3: Equation 2-1 conceptual diagram: Trapezoidal channel and terms.

2.3.3 Stream elevation and gradient

For the Sandy and Salmon Rivers, stream elevation and gradient were derived for each stream node from the 3 ft LiDAR data (OLC, 2022a, 2022b). Stream gradients were calculated as the inter-node elevation change divided by the inter-node distance (50 m).

2.3.4 Topographic shade angles

A topographic shade angle represents the vertical angle from a node along a flat horizon to the highest (visible) topographic feature in each direction. When the sun's angle is less than or equal to the topographic shade angle, the referenced topographic feature casts a shadow over the referenced stream node. Topographic shade angles were used to derive effective shade information for the current conditions model and various modeled scenarios.

For the Salmon and Sandy Rivers, topographic shade angles were calculated for three directions (W, S, E) using **Equation 2-2** with Python TTools scripts (Michie, R., 2022). Elevations were sampled from the 3 ft LiDAR bare earth data (OLC, 2022a, 2022b). For each stream node and direction, the derived topographic shade angle was the maximum value calculated among all raster cells typically within 10 km of the node in that direction.

Equation 2-2

$$\theta_T = \tan^{-1}\left(\frac{Z_T - Z_S}{d}\right)$$

where,

$\theta_T =$ The topographic shade angle (°).
$Z_T =$ The elevation (m) at the topographic feature.
$Z_S =$ The elevation (m) at the stream node.
$d =$ Horizontal distance (m) from stream node to topographic feature.

Because there is a direct and quantifiable relationship between effective shade and thermal flux, OAR 340-042-0030(14) and OAR 340-042-0040(5)(b) allow the use of effective shade as a surrogate measure target for thermal loading targets. One benefit of this surrogate measure use is that it is simpler and therefore more feasible for many practitioners to assess effective shade than thermal loading in their management areas.

2.3.5 Land cover mapping

DEQ and contractor staff developed and mapped land cover type and above-ground elevation data for all 3 ft square areas within 300 ft of the channel edges as follows:

1. Staff manually digitized GIS polygons and polylines via visual analysis of DOQs and aerial images at a 1:5,000 map scale or less. Each polygon was bounded to include a single land cover type.
2. A categorical land cover type (number) and density was assigned to each polygon. Land cover types (**Table 2-5**) included various vegetation groups (e.g., conifers, hardwoods, shrubs, grasses, barren), development types (e.g., industrial/commercial, residential, roads, bridges, dams), and surface waters.
3. Land cover heights were calculated for each 3 ft cell from LiDAR data analysis.
4. Staff generated a series of six-digit codes to represent each combination of land use type/density (digits 1-3) and height (digits 4-6) present in the near-stream area (i.e., within 300 ft of channel edges).
5. In the updated analysis, for each node, TTools was used to sample the six-digit code of each (3 ft) cell every 8 m in a 120 m radius in seven directions: NE, E, SE, S, SW, W, and NW. This sampling rate resulted in 3360 land cover measurements per stream km. In the original TMDL analysis, TTools sampled every ~4.6 m from the stream node perpendicular to both stream banks up to ~36.5 m from the channel edge for a total of 948 land cover measurements per stream km. These data served as land cover inputs for Heat Source models.

Table 2-5: Land cover codes used in land cover mapping.

Code	Description	Height (m)	Density (%)	Overhang (m)
101	Utility - Over Land	from LiDAR	60	0.0
102	Bridges - Over Water	from LiDAR	100	0.0
300	Pastures/Cultivated Field	from LiDAR	75	0.0
301	Water – Non-Active Channel	from LIDAR	0	0.0
302	Water - Active Channel Bottom	from LIDAR	0	0.0
305	Barren - Embankment	from LIDAR	0	0.0
308	Barren - Clearcut	from LIDAR	75	0.0
309	Barren - Soil	from LIDAR	0	0.0
348	Development - Residential	from LIDAR	100	0.0
349	Development - Industrial/Commercial	from LIDAR	100	0.0
352	Dam/Weir	from LIDAR	0	0.0
355	Canal	from LIDAR	0	0.0
400	Barren - Road	from LIDAR	0	0.0
401	Barren - Forest Road	from LIDAR	0	0.0
500	Mixed Conifer/Hardwood - High Density	from LIDAR	60	0.0
550	Mixed Conifer/Hardwood - Medium Density	from LIDAR	30	0.0
555	Mixed Conifer/Hardwood - Low Density	from LIDAR	10	0.0
600	Hardwood - High Density	from LIDAR	75	0.0
650	Hardwood - Low Density	from LIDAR	30	0.0
700	Conifer - High Density	from LIDAR	60	0.0
750	Conifer - Low Density	from LIDAR	30	0.0
800	Shrub - High Density	from LIDAR	75	0.0
850	Shrub - Low Density	from LIDAR	25	0.0
900	Grasses - Upland	from LIDAR	75	0.0
950	Grasses - Wetland	from LIDAR	75	0.0

2.3.6 Effective shade curves

Effective shade curves are plots that present the maximum possible effective shade as a function of natural near-stream vegetation type, active channel width, and stream aspect. Separate plots were produced for each natural vegetation type expected in the TMDL project area, i.e., conifer – high density, conifer – low density, upland grasses and wetlands, hardwood – high density, mixed conifer/hardwood – high density, and mixed conifer/hardwood – medium density. For each vegetation type, a plot was produced from a Heat Source 6 shade model output that was parameterized with every combination of active channel width (in increments from 0.2-564 m) and stream aspect (i.e., N/S, NW/SE, E/W, or SE/NW). Channel width is plotted on the x-axis, effective shade is on the y-axis, and each line represents a different stream aspect. As channel width increases effective shade decreases. The plots are called effective shade curves because they resemble gentle downward sloping curves.

The effective shade curve approach can be used almost anywhere in the watershed to quantify background solar radiation loading and the effective shade necessary to eliminate temperature increases from anthropogenic near-stream vegetation removal or disturbance. It can also be used to develop lookup tables to quantify the effective shade resulting from other combinations of vegetation height, density, overhang, and buffer widths. These lookup tables provide convenience for TMDL readers to estimate effective shade for current conditions without using the model. Additionally, lookup tables can be used to reverse-lookup the required vegetation height, density, and/or buffer width to achieve a specific effective shade. The lookup tables and plots are provided in the main TMDL document.

2.3.6.1 Spatial and temporal extent

The effective shade model period is a single day (August 1, 2001). This time frame was chosen to characterize the solar loading when maximum stream temperatures are observed, the sun altitude angle is highest, and the solar exposure period is longest. The Lower Columbia-Sandy model location (45.4026, -122.1803) was selected for solar altitudes and azimuths appropriate to the project area.

2.3.6.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

2.3.6.3 Important assumptions

The effective shade curve models assumed no clouds and no topographic shade. The modeled terrain is assumed flat so there is no ground elevation difference between the stream and adjacent vegetation buffer area. The vegetation density, height, overhang, and buffer width are assumed equal on both stream banks. The active channel width is assumed to equal the distance from the near-stream vegetation on one stream bank to that on the other.

2.3.6.4 Model inputs

Effective shade curve model input values for vegetation height, density, overhang, and buffer width correspond to the values presented in **Table 2-6**. These vegetation assumptions are the same as those presented in the Sandy River Basin TMDL (DEQ, 2005).

Table 2-6: Vegetation height, density, overhang, and horizontal distance buffer widths used to derive generalized effective shade curve targets.

Landcover code	Vegetation type	Height (m)	Height (ft)	Density (%)	Overhang (m)	Buffer width (m)
500	Mixed Conifer/Hardwood - High Density	26.7	87.6	60	3.3	36.8
550	Mixed Conifer/Hardwood - Medium Density	26.7	87.6	30	3.3	36.8
555	Mixed Conifer/Hardwood - Low Density	26.7	87.6	10	3.3	36.8
600	Hardwood - High Density	20.1	65.9	75	3.0	36.8
650	Hardwood - Low Density	20.1	65.9	30	3.0	36.8
700	Conifer - High Density	35.1	115.2	60	3.5	36.8
750	Conifer - Low Density	35.1	115.2	30	3.5	36.8
800	Shrub – High Density	1.8	5.9	75	0.0	36.8
850	Shrub – Low Density	1.8	5.9	25	0.0	36.8
975	Grasses or Wetlands	0.9	2.0	90	08	36.8

2.3.7 Derived tributary streamflows

When flow data were unavailable for a given tributary to a modeled stream for the model period, streamflow was estimated based on historical data for the stream or model period data from proxy monitoring sites. For small tributary inputs, a constant flow was often ascribed if detailed proxy or historical data were unavailable. In some cases, constant flow rates were derived using TIR data and a mass balance approach. Otherwise, flows were estimated using StreamStats v4 (USGS, 2019) and the flow-percentile-percentile-flow (QPPQ) method to derive time-series data for target unmonitored locations from proxy (monitored) locations based on their relative characteristics and the proxy streamflow data (Lorenz and Ziegeweid, 2016; Ziegeweid et al, 2015). Staff identified suitable proxy stations for StreamStats parameterization based on between-location similarities of location, stream aspect, land cover, and watershed size. Proxy information for locations represented by derived flow data is provided in Section 3 under each stream model's "Flow Inputs" subsection.

2.3.8 Derived tributary temperatures

For each modeled stream's tributaries, if 2016 model period temperature data were unavailable, estimated values were applied based on direct substitution of contemporaneous data from proxy locations; linear regression of the target tributary's 2001 data against a proxy location's 2001 and 2016 data; TIR data (input as constant temperature), or calibrated Heat Source model results for the tributary. Proxy information for all such locations is provided in Section 3 under each stream model's "Temperature Inputs" subsection.

3 Model setup, calibration, and results

3.1 Background and general set-up methods

3.1.1 General background, purpose, and objectives

Stream temperature TMDLs are generally scaled to the subbasin- or basin-scale since water temperatures are influenced by cumulative effects of upstream and local sources. Accordingly, this TMDL considers all surface waters that affect the temperatures of 303(d)-listed waterbodies (e.g., the Sandy River) in the subbasin. To address listings in this TMDL, the analysis considers all upstream waters of the state and applies TMDL allocations through the entire stream network. The TSD and its appendices report on new models developed (with 2016 data) for this TMDL (i.e., for the Bull Run River, Salmon River, and Sandy River). Results from pre-existing models for the Little Sandy River and Zigzag River (developed with 2001 data) are also described herein.

A primary purpose of this modeling is to provide quantitative stream heat source assessments that differentiate various background and anthropogenic source contributions. Another is to determine seasonal variation and delineate periods when any applicable temperature criterion/criteria, called "biologically-based temperature criteria" (BBNC), are or will be exceeded at various locations. Ultimately, this modeling is used to evaluate loading capacity allocations, which specify the amount of heat that relevant waterbodies can receive and still meet water quality standards. This also allows quantification of the effects that various modifications to watershed parameters would have on the flow and water temperature regimes overall and for critical periods and in-stream locations. Modeling these *potential* conditions is referred to as "scenario modeling" and is discussed in Section 4.

Anthropogenic nonpoint and NPDES-permitted point sources may not heat a waterbody more than 0.30°C above the applicable BBNC, cumulatively at the point of maximum impact (POMI). Modeling determines the portion of the human use allowance (HUA) allocated to each source in the TMDL. These are translated into numeric or narrative wasteload allocations (WLAs) for each NPDES permittee.

For this TMDL, general modeling requirements include the ability to evaluate and/or predict hourly:

1) Solar radiation flux and daily effective shade at ≤100 m longitudinal resolution.
2) Stream temperatures over several months at ≤500 m longitudinal resolution.
3) Stream temperature responses to upstream in-catchment changes to:
    a. Streamside vegetation/shade,
    b. Water withdrawals and tributary flows,
    c. Channel morphology, and
    d. NPDES-permitted facilities' effluent temperatures and flows.

3.1.2 General model inputs and parameters

3.1.2.1 CE-QUAL-W2

The Bull Run River was modeled by the City of Portland Water Bureau using the CE-QUAL-W2 v4.2 two-dimensional hydrodynamic and water quality model (Wells, S.A., 2022). The model was updated from a previous version developed by Portland State University. Documentation of the model, set-up, and input and calibration parameters is described in TSD Appendix D.

3.1.2.2 Heat Source

Heat Source version 8.0.8 was used to model temperatures on the Salmon River and Sandy River (TSD Appendix B). Heat Source version 6 was used to model temperatures on the Zigzag River and Little Sandy River. The models for the Little Sandy River and Zigzag River were originally developed for the Sandy River Basin TMDL (DEQ, 2005). These existing models were not modified.

The primary input parameter types for Heat Source include tributary temperature and flow, meteorology, stream morphology, vegetation, and more general geographic, geologic, and spatiotemporal parameters and boundaries. The acquisition and development of the corresponding datasets are described in Section 0. Stream-specific procedures and characteristics are discussed for the Salmon River in Section 3.2 and the Sandy River in Appendix B, Section 3.

Model calibration was conducted when basic model setup was complete. The basic approach to calibration was to compare actual available field data for water and temperature in the modeled stream (i.e., calibration data) to the model results for the same parameters and locations as existing calibration data. Calibration data and model results are compared using goodness-of-fit procedures in the R statistical software environment (R Core Team, 2023) and visually to assess model precision, accuracy, and identify specific results (e.g., certain times or stream locations) where model accuracy should be improved. To improve model fitness, different model iterations reflecting variations of specific DEQ-identified model parameters were completed.

Model output was reassessed, and the optimal model, based on the aforementioned goodness-of-fit and other model output assessments, was selected as the final calibrated model. Stream-specific calibrations are discussed in Section 3.2.10 (Salmon River), Section 3.3.8 (Little Sandy River), Section 3.4.8 (Zigzag River), TSD Appendix B (Sandy River), and TSD Appendix D (Bull Run River). Calibration parameters included meteorological (e.g., wind speed, air temperature, cloudiness), hydrological (e.g., tributary temperatures, withdrawal rates), and stream morphological (e.g., channel gradient and width, Manning's roughness coefficient, hyporheic zone thickness and porosity, and sediment thermal conductivity) parameters.

Heat Source models the effective shade parameter. Because Heat Source modeling can determine thermal loading under current conditions and various scenarios, which includes quantification of the TMDL for the modeled area, and because effective shade is accepted as a surrogate measure for thermal loading, this modeling also allows determination of effective shade targets (that will effectively meet the Temperature TMDL). The effective shade achieved under current conditions and various potential conditions (model scenarios) can thus be compared to effective shade targets to determine (i) if a given area meets its shade target (i.e., meets the TMDL requirement), and (ii) the amount of any "shade gap" between the modeled condition and the target.

3.1.3 Significant digits and rounding

The TMDL analysis and interpretation of all model and scenario results accounted for significant digits and rounding. To evaluate HUA attainment, DEQ calculates and records values to the hundredths (0.01°C). Because DEQ assigns some HUAs to the hundredths, attainment must be tracked with equal precision. DEQ has a permit-related internal management directive (IMD) on rounding and significant digits (DEQ, 2013b). The TMDL analysis follows the rounding procedures outlined in this IMD, which states that for "calculated values" (which includes model results), if the digit being dropped is a "5," it is rounded up. For example, for water withdrawals DEQ is proposing a 0.05°C HUA allocation. If the model shows warming equal to 0.054°C, it is rounded down to 0.05°C and the result is attainment. If the model shows warming equal to 0.055°C, it is rounded up to 0.06°C, and the result is non-attainment.

3.1.4 Calculating the 7-day average daily maximum temperature (7DADM)

TMDL analyses often assess 7-day average daily maximum temperatures (7DADM), which were calculated for this TMDL using hourly model outputs or continuous temperature data results. The 7DADM was calculated with the procedure outlined in DEQ's temperature IMD (DEQ, 2008). That is, the daily maximum for each day is calculated, then the 7-day rolling average of the daily maximums is calculated for each calendar day as the average (mean) of the daily maximums for that day and the preceding 6 days. When a use period changes, (e.g. transition to spawning use) the 7-day rolling period is reset and the first six days are not reported. If daily maximums are not available for any of the 7 days, then a 7DADM is not calculated. For single day models such as those used for the Zigzag River and Little Sandy River, the daily maximums are used instead.

3.2 Salmon River

The Salmon River temperature model was developed by DEQ using Heat Source 8.0.8.

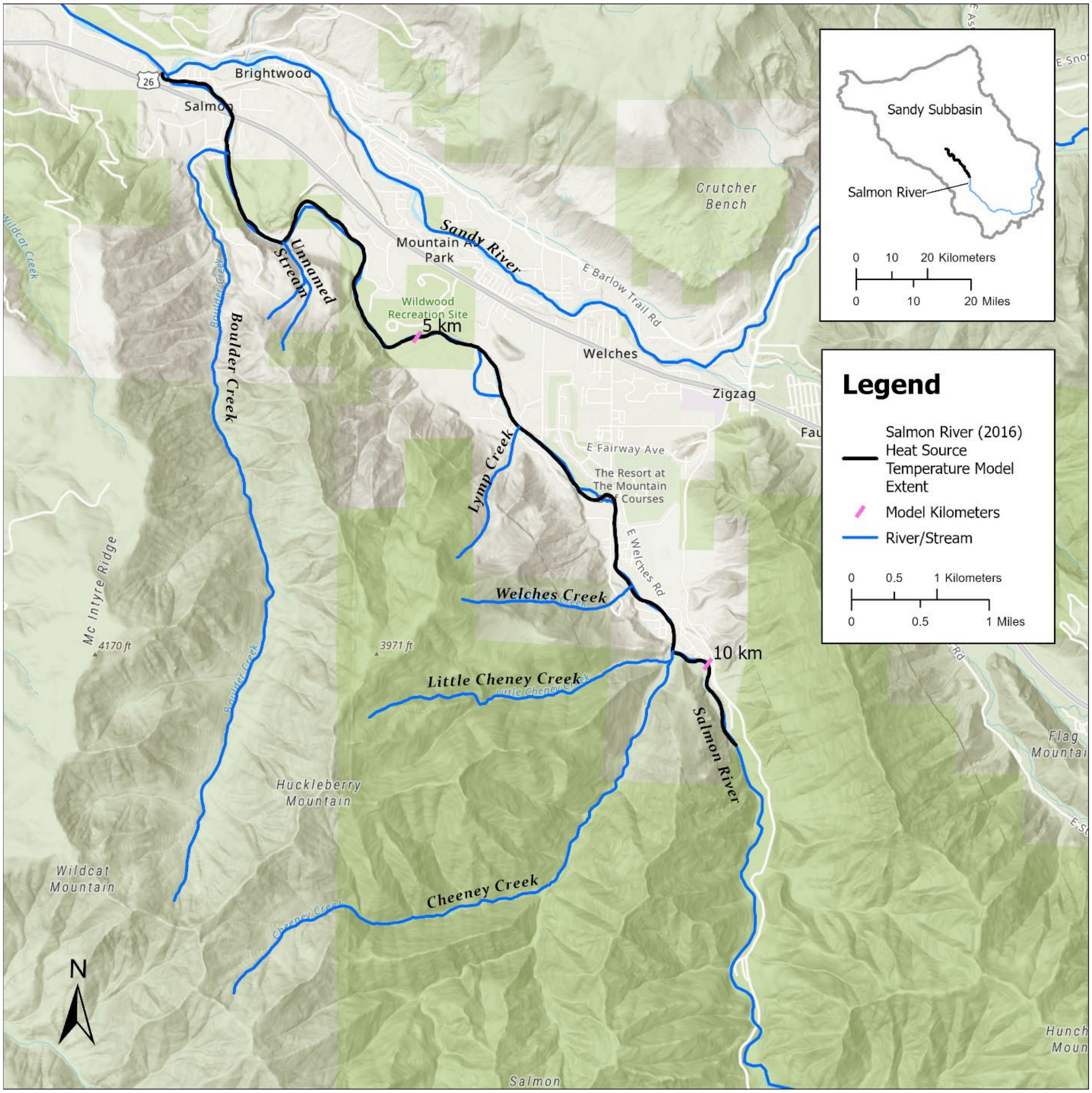

Figure 3-1: Salmon River model extent.

Table 3-1: Salmon River model inputs: Meteorology, water temperature, and streamflow.

Station ID	Station	Model location (km)	Lat/Long	Input type	Parameter(s)	Data source
10009634	Portland Troutdale Airport	13.08	45.5511/-122.409	Meteorological	Air temperature, relative humidity, wind speed	MesoWest
EW6654	Rhododendron	13.08	45.3463/-121.951	Meteorological	Cloudiness	NCDC
MHNF-077	Salmon R. at Forest Boundary_LTWT	13.08	45.3072, -121.944	Boundary condition	Flow	Derived: proxy ORWD 14134000

Station ID	Station	Model location (km)	Lat/Long	Input type	Parameter(s)	Data source
						(USGS StreamStats)
MHNF-077	Salmon R. at Forest Boundary_LTWT	13.08	45.3072, -121.944	Boundary condition	Water temperature	USFS
MHNF-048	LinneyCr_LTWT		45.2189, -121.859	Proxy for other tributaries	Water temperature	USFS;
26411-ORDEQ	Boulder Cr. at mouth	1.50	45.3687, -122.023	Tributary	Water temperature, flow	Derived by linear regression (temp), USGS StreamStats (flow)
26413-ORDEQ	Cheeney Cr.	11.45	45.31662, -121.954	Tributary	Water temperature, flow	Proxy: MHNF-048
	Lymp Cr.	7.85	45.33931, -121.977	Tributary	Water temperature, flow	Proxy: MHNF-048
	Spring Brook (LB) from TIR image sfsa0215	6.05	45.3493, -121.991	Tributary	Water temperature, flow	TIR-derived constant (15.9°C)
	Spring in TIR image sfsa0199 (LB) (TIR)	5.60	45.3481, -121.996	Tributary	Water temperature, flow	TIR-derived constant (13.3°C)
	Unnamed Stream (LB)	2.85		Tributary	Water temperature, flow	Derived

3.2.1 Spatial and temporal extent

The Salmon River model extent is from its mouth to the USFS boundary at monitoring site MHNF-077, as shown in **Figure 3-1**. The model period is July 15 to September 5, 2016.

3.2.2 Spatial and temporal resolution

The model input spatial resolution (dx) is 50 m. Outputs are generated every 50 m. The model time step (dt) is 1 minute and outputs are generated every hour.

3.2.3 Meteorological inputs

Meteorological data (i.e., cloudiness, air temperature, and relative humidity) from Portland Troutdale Airport (10009634) were used for the Salmon River model extent and period (**Figure 3-2**, **Figure 3-3**, **Figure 3-4**, **Table 3-1**). Although wind speed data were available, wind speed was used as a model calibration parameter given the distance from the data source to the Salmon River calibration locations. Cloud cover data were also modified during calibration under the same rationale.

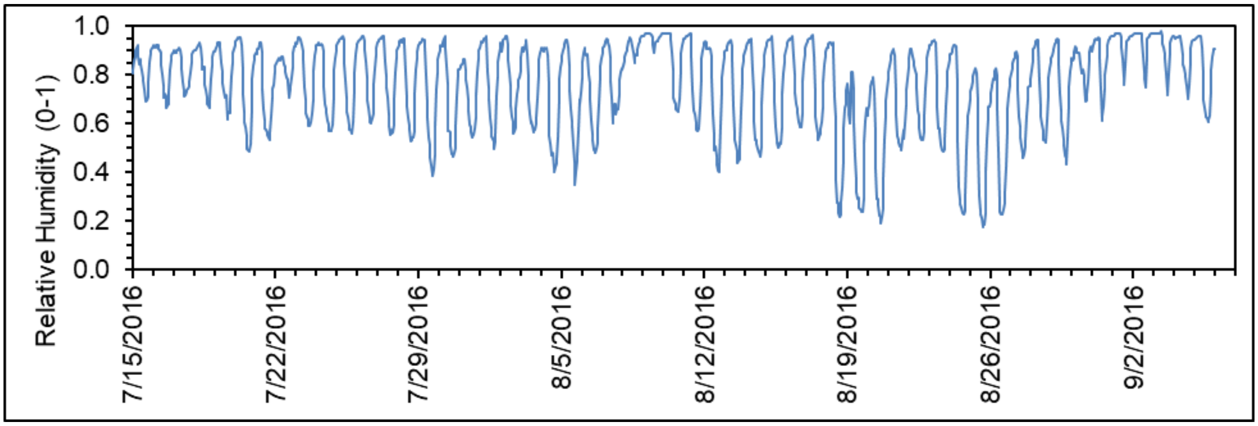

Figure 3-2: Salmon River model inputs: Relative humidity.

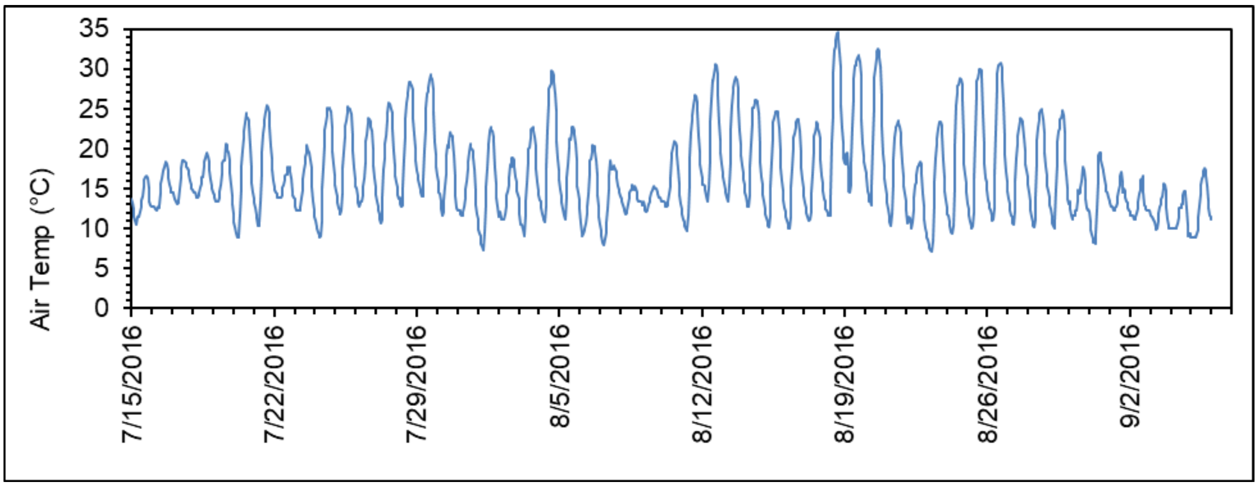

Figure 3-3: Salmon River model inputs: Air temperature.

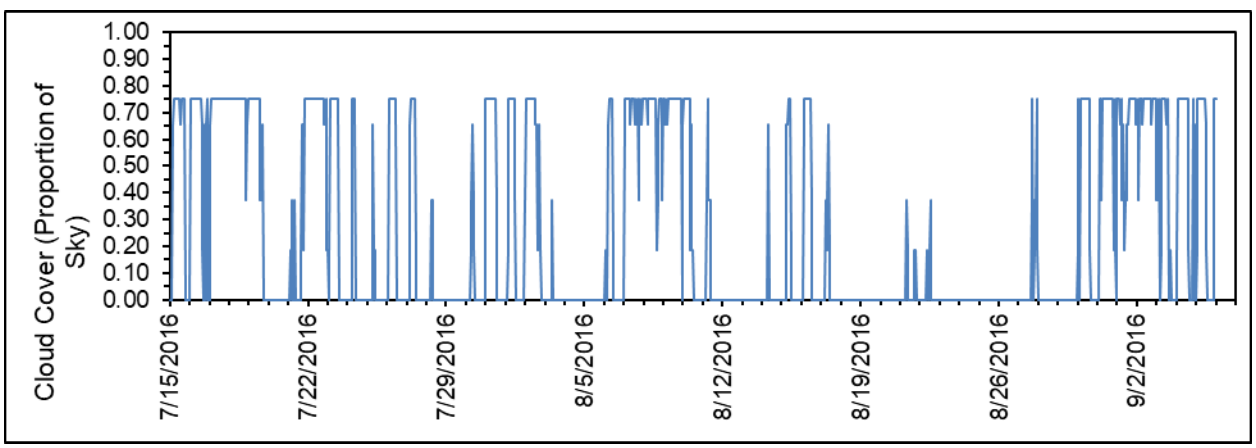

Figure 3-4: Salmon River model inputs: Cloudiness.

3.2.4 Temperature inputs

Stream temperatures for seven in-stream locations were input for the model period, including the upstream model boundary and six tributaries (**Figure 3-5**, **Table 3-1**). Only the upstream boundary location had direct temperature monitoring data available. Temperatures for the tributaries were ascribed based on a constant TIR-derived temperature (Salmon 6.05, Salmon 5.6, and Salmon 2.85), surrogate location data (Salmon 11.45 and Salmon 7.85), or linear regression of 2001 data vs. 2001 and 2006 data from a nearby station (Salmon 1.5).

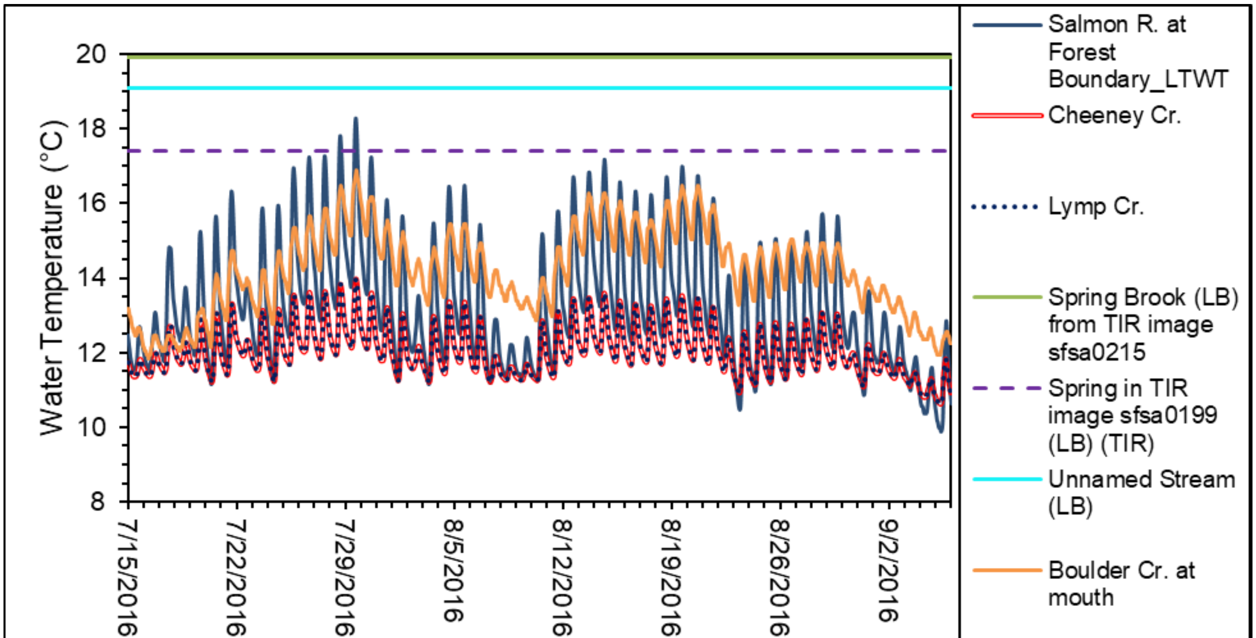

Figure 3-5: Salmon River model inputs: Tributary and boundary condition temperatures.

3.2.5 Flow inputs

Streamflows for seven locations were input for the model period (**Figure 3-7**, **Table 3-1**). For six locations, streamflow data were derived using StreamStats v4 (USGS, 2019) as described in Section 2.3.6 with the StreamStats-identified reference locations. At the seventh location (a spring at Salmon River km 5.6), a constant value (0.0284 m^3/s) was applied. This flow rate was calculated based on a mass balance using available TIR data. Note that for each in-stream location, there was a direct drainage area and discharge associated with the between-location streambank length (**Figure 3-8**). These were included in the model with parameters of flow rate calculated by relative drainage area and water temperature corresponding to the nearest upstream tributary location. **Figure 3-9** shows the locations of the various streamflow monitoring locations used in model setup or calibration.

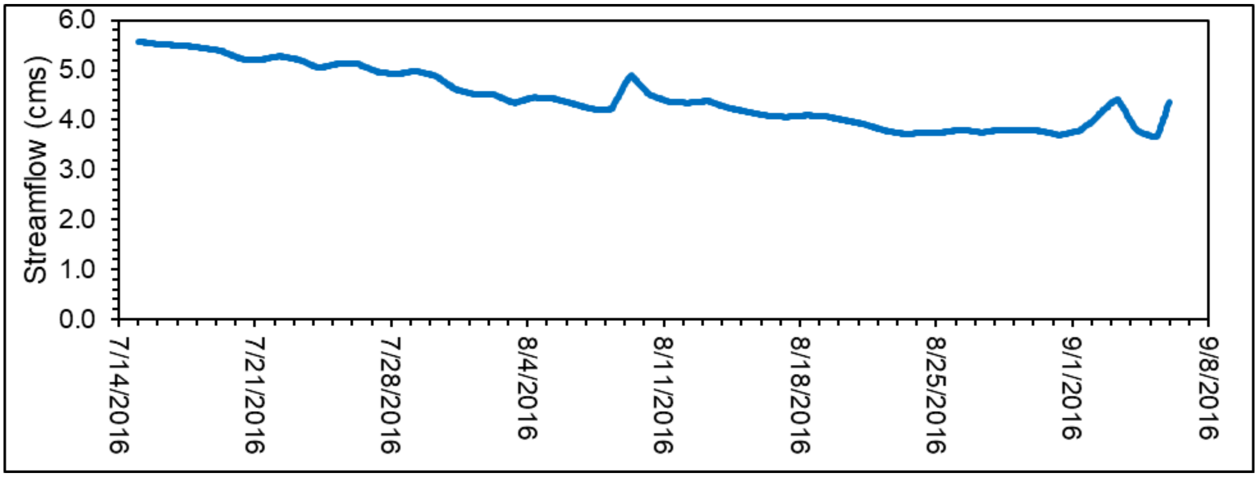

Figure 3-6: Streamflow, Salmon River mouth.

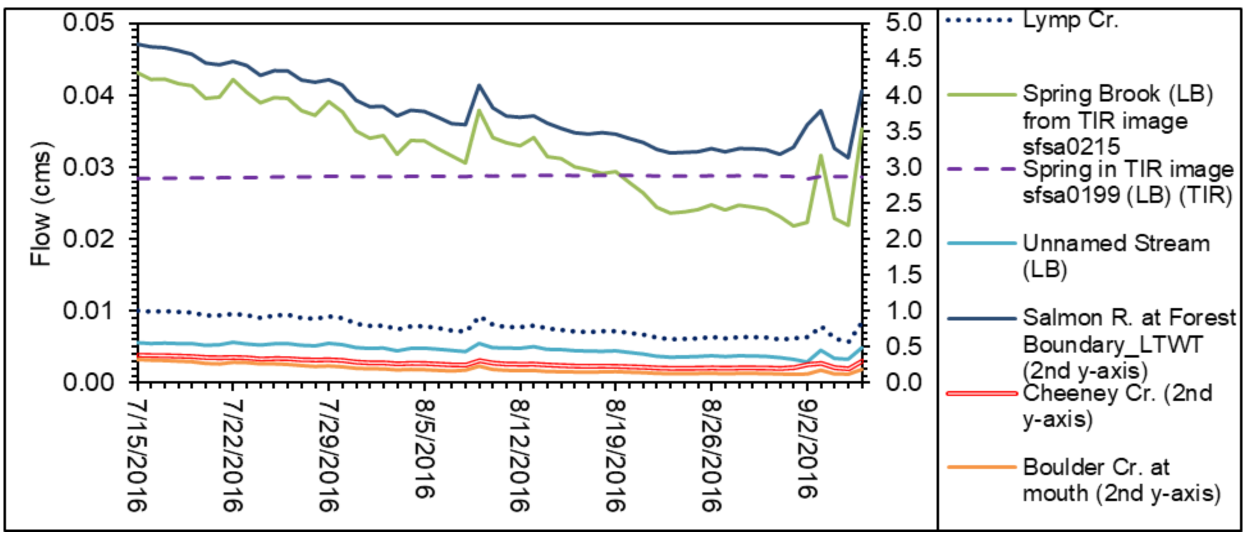

Figure 3-7: Salmon River model inputs: Tributary and boundary condition streamflows.

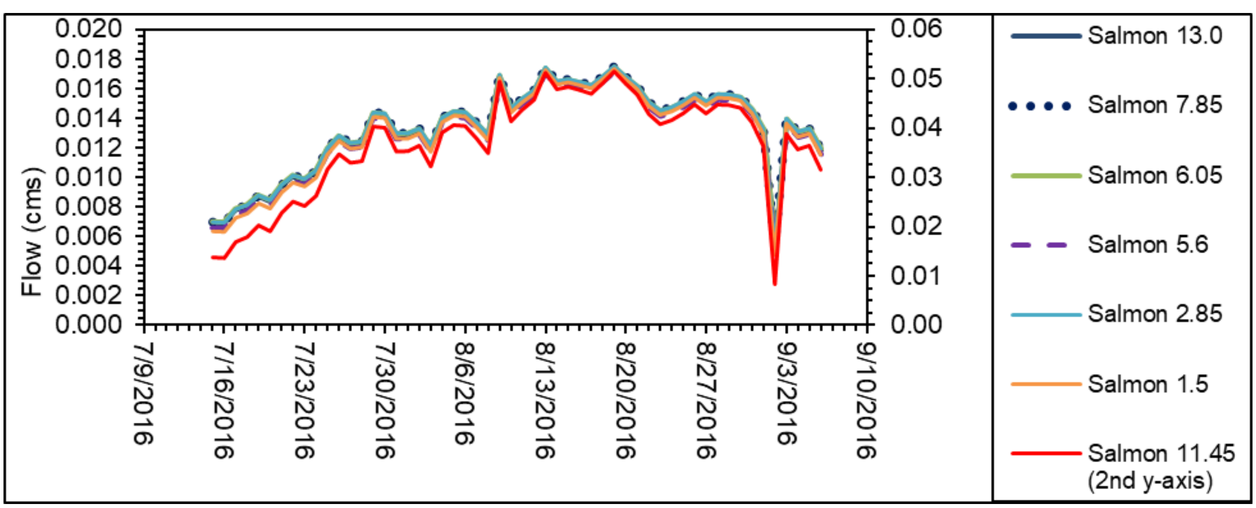

Figure 3-8: Salmon River model inputs: Between-tributary direct drainage area streamflows.

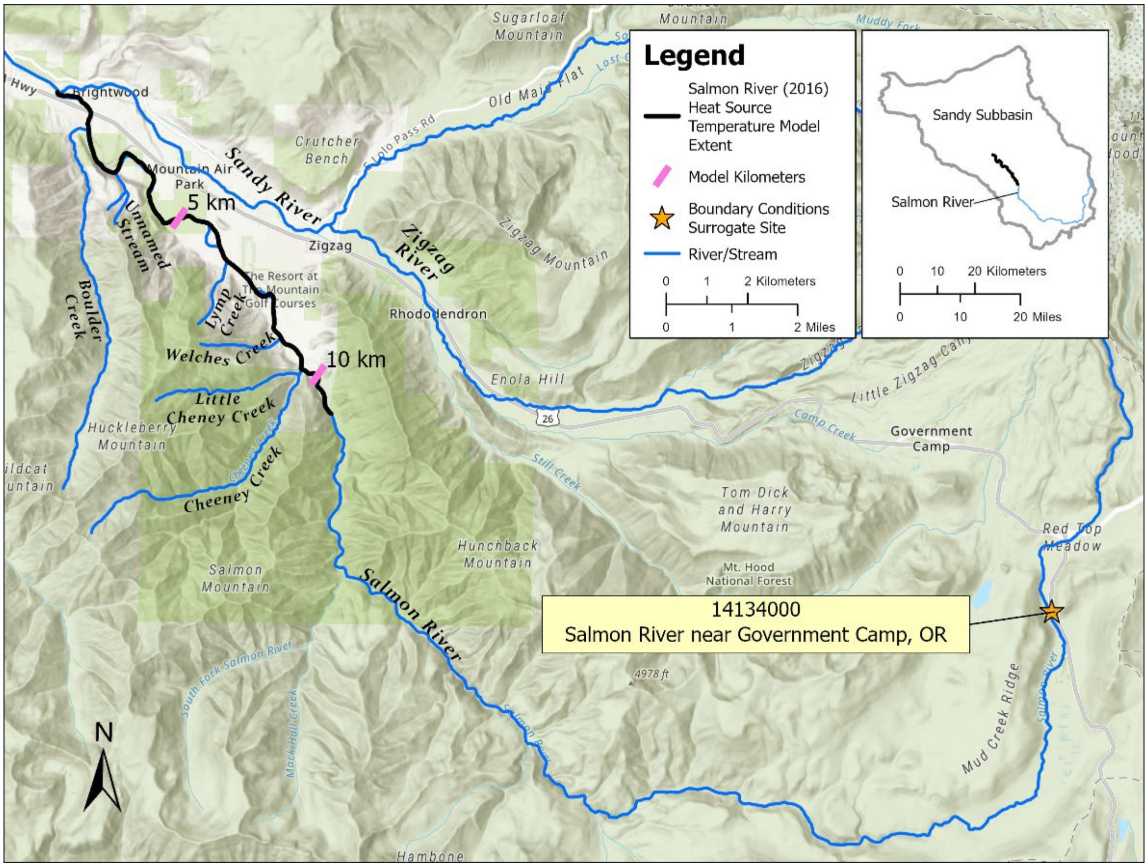

Figure 3-9: Salmon River model setup and calibration: Streamflow monitoring locations.

3.2.6 Point source inputs

There were no active point source inputs on the Salmon River from the model period to present day.

3.2.7 Landcover and topographic shade inputs

Topography and land cover data were derived as described in Sections 2.3.4 to 2.3.5. **Figure 3-10** and **Figure 3-11** present these results for the Salmon River.

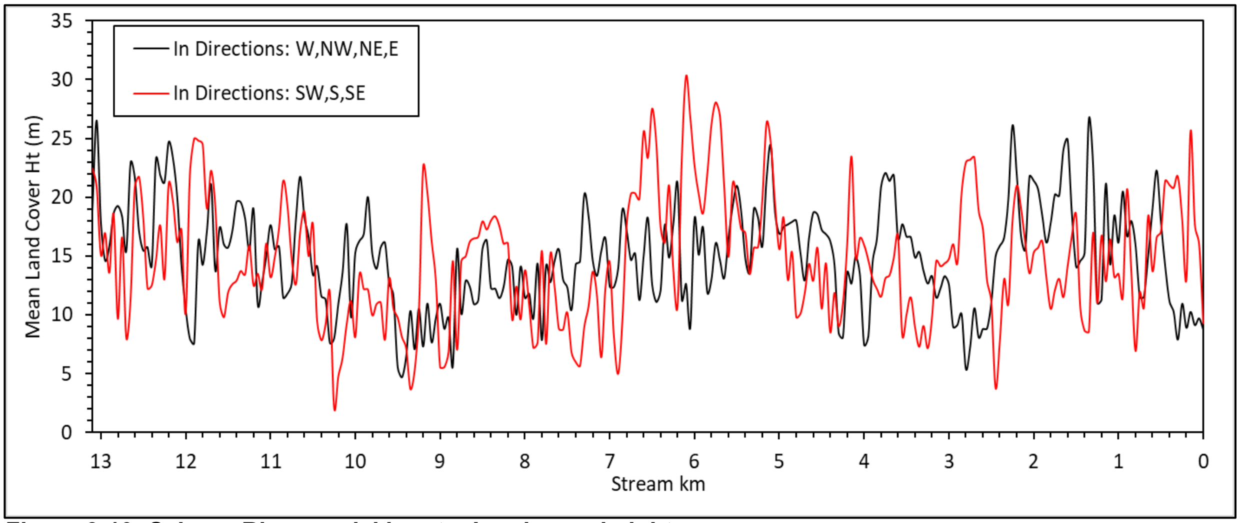

Figure 3-10: Salmon River model inputs: Landcover height.

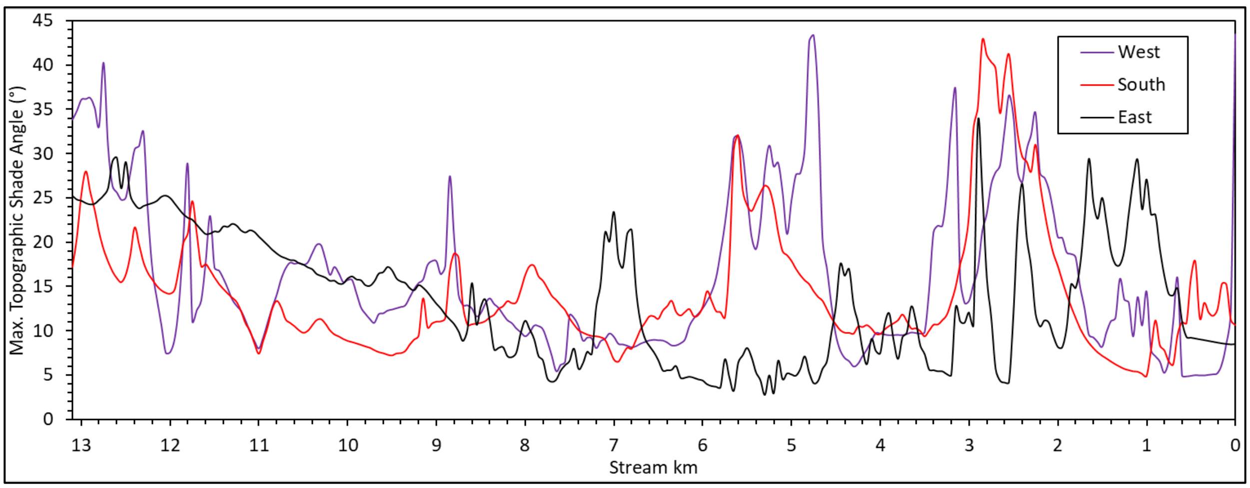

Figure 3-11: Salmon River model inputs: Topographic shade angles.

3.2.8 Channel setup

Channel morphology model input data were derived as described in Sections 2.3.2 to 2.3.3. **Figure 3-12** and **Figure 3-13** present these results for the Salmon River.

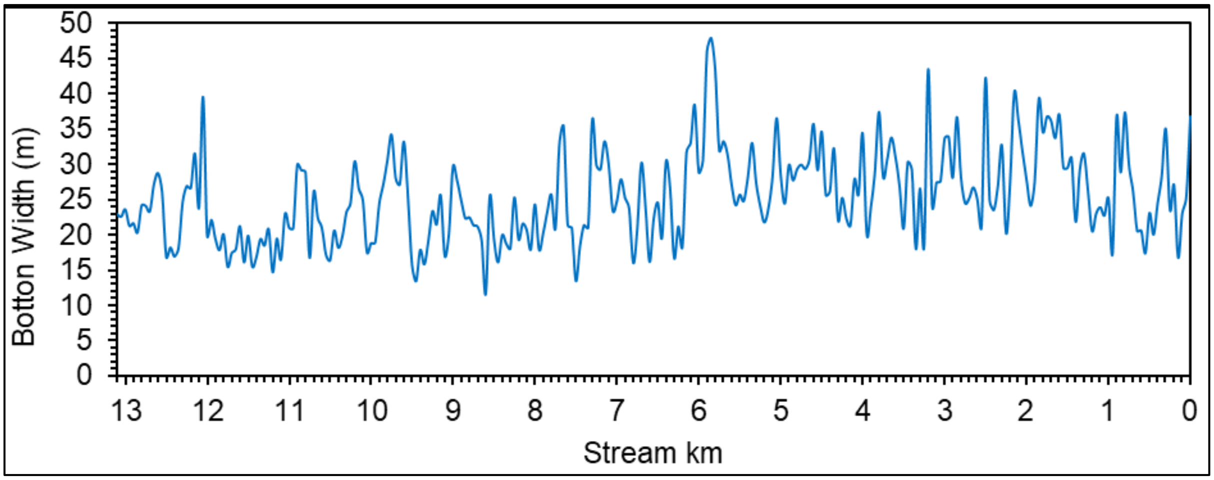

Figure 3-12: Salmon River model inputs: Bottom width.

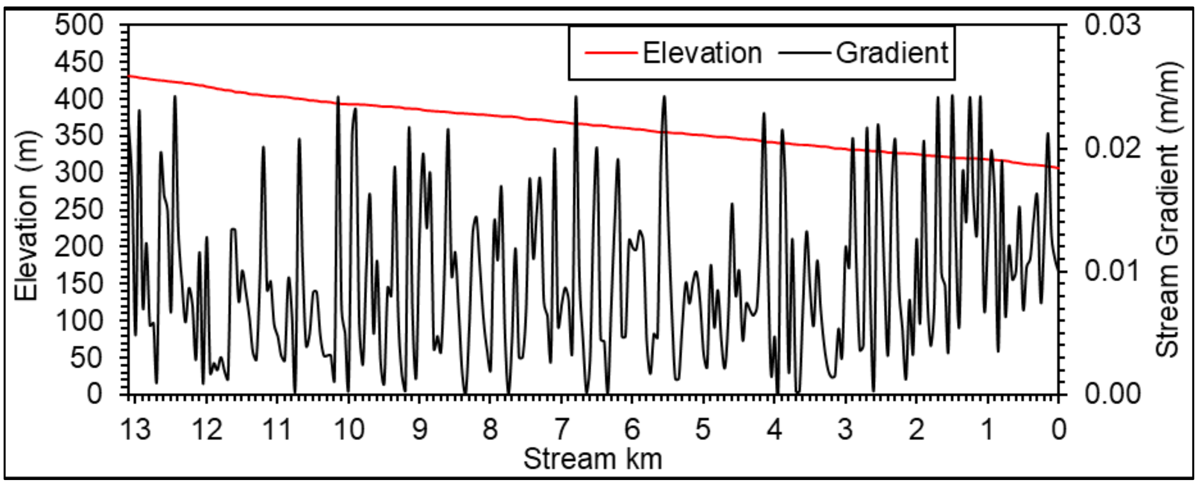

Figure 3-13: Salmon River model inputs: Stream channel elevation and gradient.

3.2.9 Other model parameters

Table 3-2 lists additional hydrologic, benthic, and meteorologic parameters included in Salmon River Heat Source modeling. These values were determined based on ranges identified through literature review. Several of these parameters (e.g., Manning's n, channel angle, hyporheic zone thickness) were used as calibration parameters for CCC model calibration.

Table 3-2: Salmon River model inputs: Miscellaneous constant parameters.

Parameter name (units)	Value
Wind function coefficient a	1.51×10^{-9}
Wind function coefficient b	1.60×10^{-9}
Channel angle	1.4
Sediment thermal conductivity (W/(m*°C))	1.67
Sediment thermal diffusivity (cm^2/sec)	0.0070
Manning's roughness coefficient (n)	0.205
Sediment hyporheic zone thickness (m)	0.200

Hyporheic exchange (%)	0.015
Porosity	0.35

3.2.10 Salmon River model calibration and results

3.2.10.1 Temperature calibration

Observed stream temperature data for two locations were available to calibrate the 2016 Salmon River model (**Table 3-3**, **Figure 3-14**). Modeled and observed data were compared for these locations during the model period (**Figure 3-15**, **Figure 3-16**, **Figure 3-17**, **Figure 3-18)**. Calibration fitness for the daily maximum temperature and hourly temperature parameters at the two locations was assessed with goodness-of-fit statistics, i.e., the Nash-Sutcliffe efficiency coefficient (NSE), the mean absolute error (MAE), and the root mean square error (RMSE) (**Table 3-4**). Target goodness-of-fit values were NSE >0.8, MAE <0.5, and RMSE <1.5.

Table 3-3: Salmon River model calibration: Water temperature sites.

Station ID	Station description	Model location (km)	Lat.	Long.	Source
MHNF-078	Salmon R. trap WT site	3.25	45.3623	-122.011	USFS
Salmon_0.5	Salmon R. above Sandy Brightwood Bridge	0.50	45.3730	-122.021	PSU

When necessary to improve model fitness, adjustments to parameters, i.e., tributary and corresponding direct drainage area water temperatures, Manning's n, cloudiness, wind speed, and stream morphology were tested. Testing was done by making incremental model setup parameter adjustments, rerunning the adjusted model, and selecting the optimal model among all model runs based on the goodness-of-fit statistics. The final calibrated current conditions (CCC) model reflected adjustments to all Manning's n (0.205), cloud cover (coefficient of 0.75 applied to proxy data), and wind speed (all values set to zero) inputs. Stream gradient values were adjusted for 11 of the 263 nodes, including eight extreme high (adjusted to 0.242 based on the maximum values of the non-adjusted nodes) and three extreme low calculated values (adjusted to 0.0001 based on the minimum values of the non-adjusted nodes). For water temperatures, if a given location's values were adjusted, then all time-series temperature data for that location were adjusted by a single constant value. Specifically, temperature adjustments comprised the following values for the following tributary locations and corresponding direct drainage areas: Salmon 11.45 km by +3.3°C, Salmon 7.85 km by +3.3°C, Salmon 6.05 km by +4.0°C, and Salmon 5.6 km by +4.1°C. No other parameters were adjusted for model calibration. The final CCC model met the target goodness-of-fit criteria (**Table 3-4**) and showed the best goodness-of-fit among tested model iterations.

Table 3-4: Salmon River model calibration: Goodness-of-fit, observed vs. predicted temperature (°C).

Monitoring location ID	Constituent	ME	MAE	RMSE	NSE	n
MHNF-078 & Salmon_0.5	7DADM temperature	-0.77	0.77	0.88	N/A	106
MHNF-078		-0.98	0.98	1.07		53
Salmon_0.5		-0.56	0.56	0.63		53
MHNF-078 & Salmon_0.5	Daily maximum temperature	-0.75	0.88	1.04	N/A	106
MHNF-078		-0.94	1.14	1.26		53
Salmon_0.5		-0.55	0.63	0.76		53
MHNF-078 & Salmon_0.5	Hourly temperature	-0.05	0.57	0.71	0.88	2544
MHNF-078		-0.09	0.6	0.76	0.87	1272
Salmon_0.5		-0.01	0.54	0.66	0.88	1272

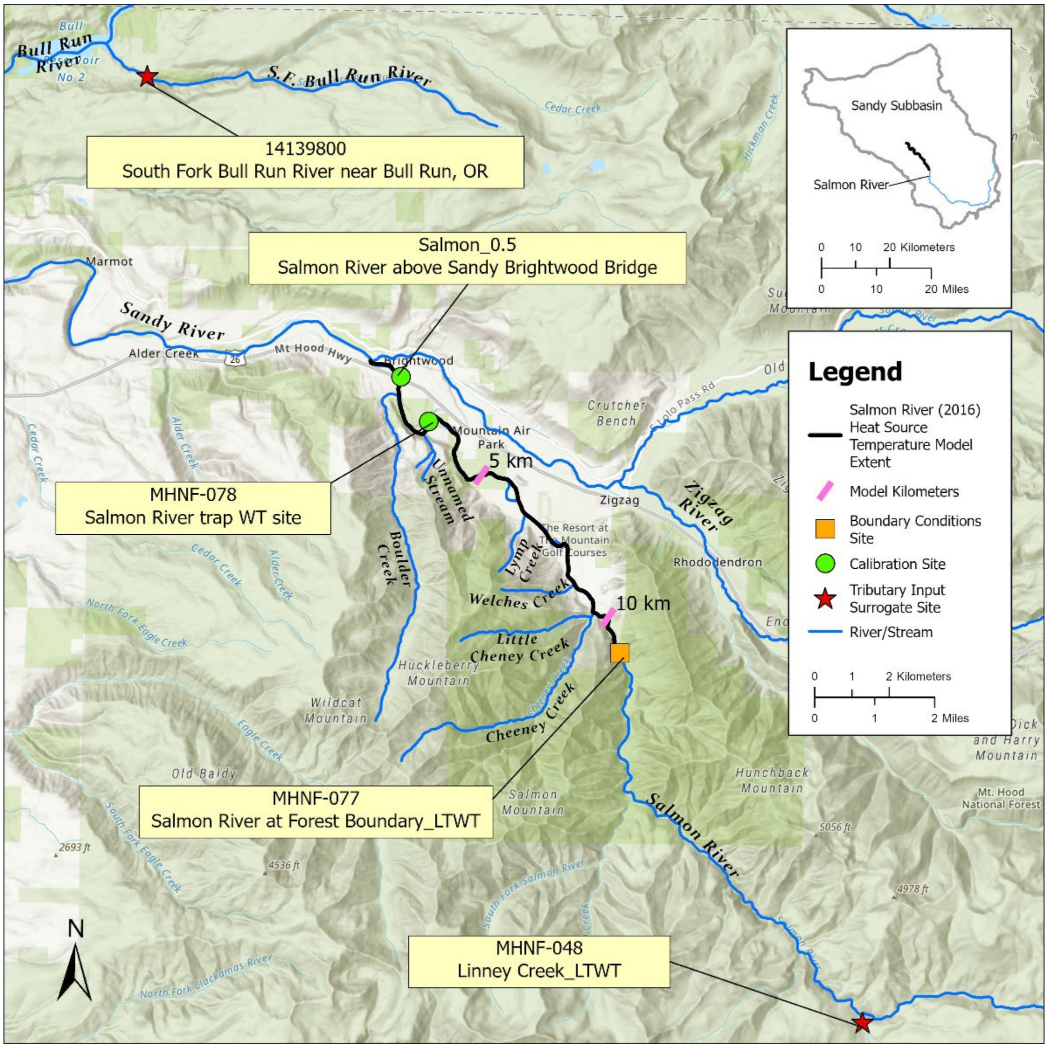

Figure 3-14: Salmon River model inputs and calibration: Temperature monitoring locations.

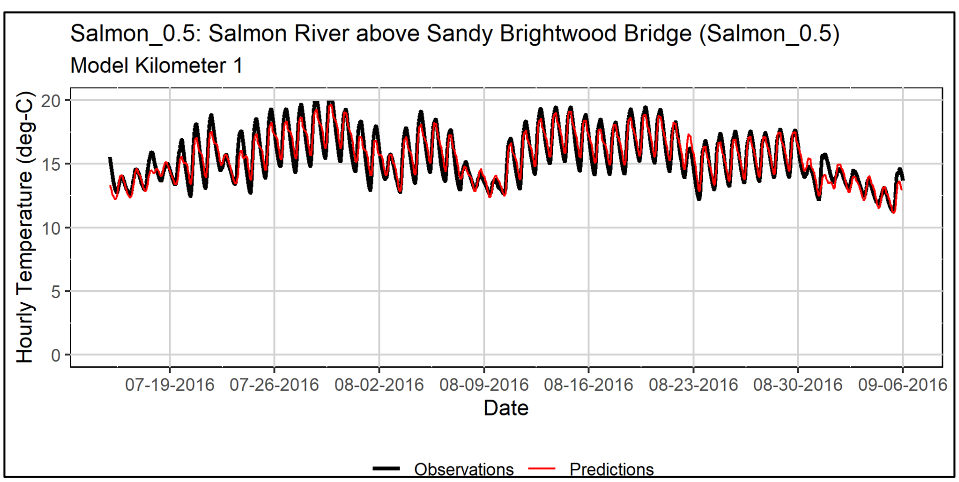

Figure 3-15: Salmon River above Sandy Brightwood Bridge: Modeled vs. observed hourly temperatures.

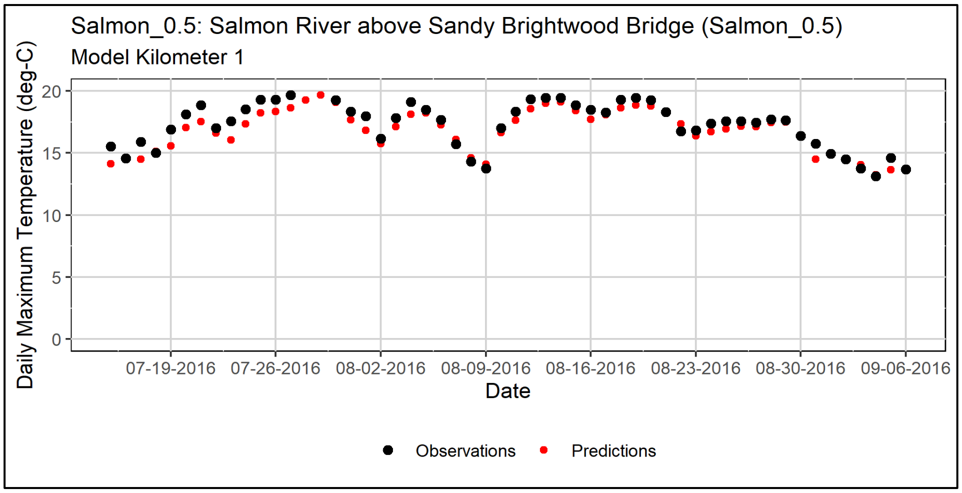

Figure 3-16: Salmon River above Sandy Brightwood Bridge: Modeled vs. observed daily maximum temperatures.

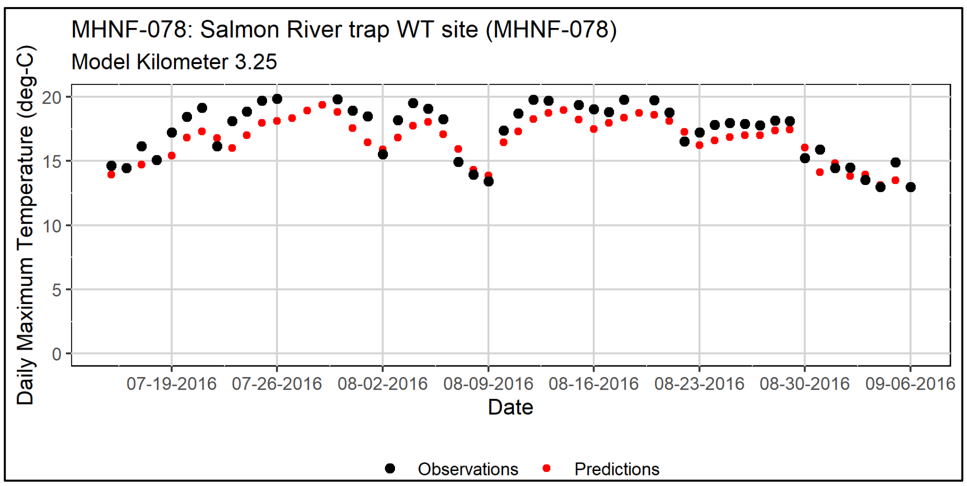

Figure 3-17: Salmon River trap WT site: Modeled vs. observed daily maximum temperatures.

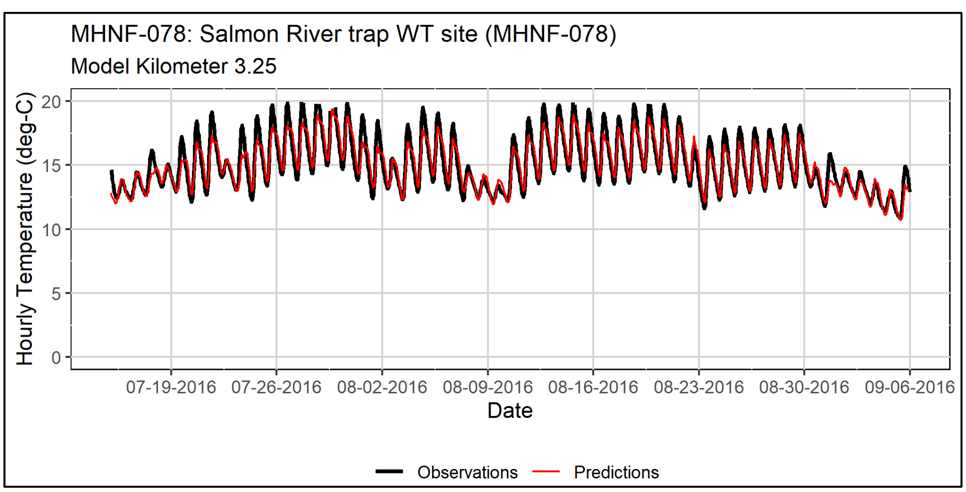

Figure 3-18: Salmon River trap WT site: Modeled vs. observed hourly temperatures.

3.2.10.2 Results – Effective shade

Effective shade for the Salmon River was modeled for July 29, 2016, with Heat Source 8. Heat Source 8 applies information on coordinates, meteorology, stream morphology, surrounding topography, and existing and potential restored near-stream vegetation to estimate effective shade (%) for each modeled stream node (**Figure 3-19**). As discussed in Section 2.3.4, effective shade is an accepted surrogate measure for thermal loading in Oregon. Thus, the effective shade results from the CCC model are compared to target effective shade values that will meet the TMDL and to effective shade estimated under various potential conditions (model scenarios, discussed in Section 4).

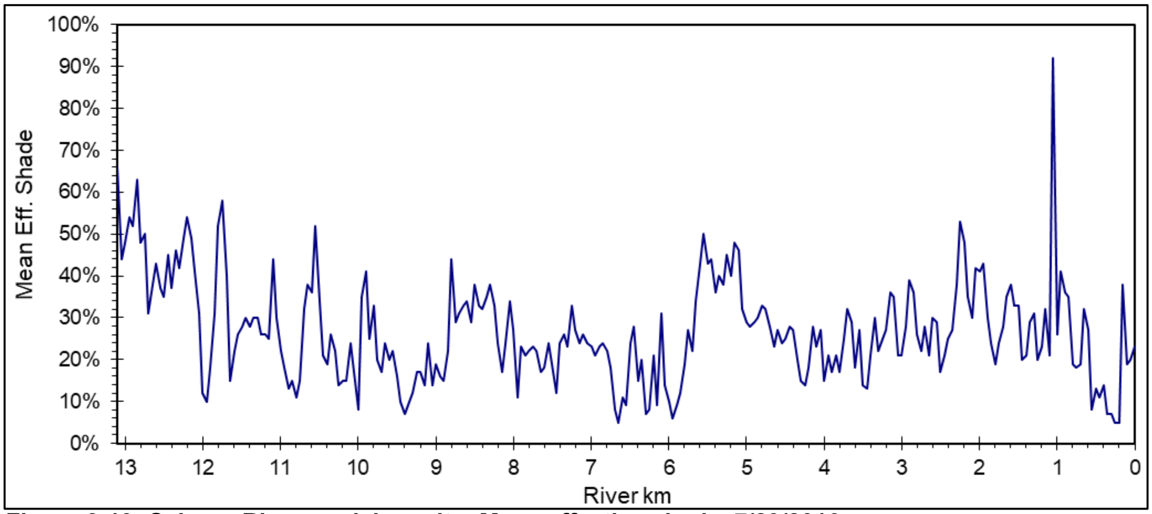

Figure 3-19: Salmon River model results: Mean effective shade, 7/29/2016.

3.2.10.3 Results - Stream temperature

Stream temperatures were modeled every 50 m in one-minute increments with Heat Source 8, with hourly outputs. The stream temperature data were also summarized as daily maxima and 7DADM throughout the model spatial and temporal extent. **Figure 3-20** summarizes the maximum 7DADM modeled at each node along the Salmon River longitudinal extent under the CCC model.

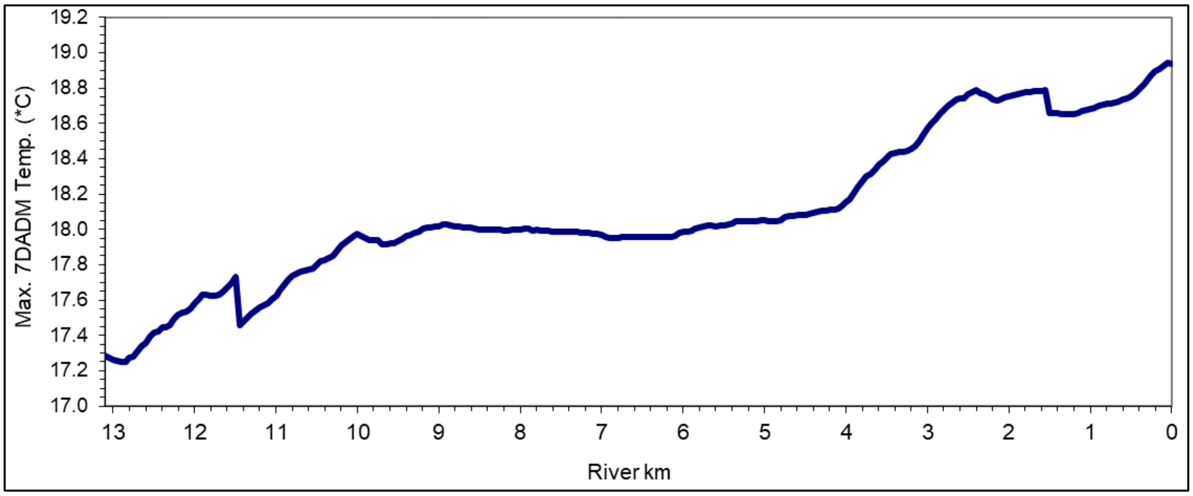

Figure 3-20: Salmon River model results: Longitudinal max. 7DADM temperatures, 2016 model period.

3.3 Little Sandy River

The Little Sandy River temperature model was developed by DEQ using Heat Source 6.5.1.

3.3.1 Spatial and temporal extent

The Little Sandy River model domain extent is from its mouth upstream to USNF Road 14 (approximately 17.1 km, **Figure 3-21**). The model period is a single day: August 9, 2001.

3.3.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.3.3 Meteorological, water temperature, and flow inputs

Table 3-5, Figure 3-22, and **Figure 3-23** summarize the model meteorological, water temperature, and flow inputs and data sources. Model meteorology inputs include hourly air temperature, relative humidity, and wind speed. A dry adiabatic lapse rate adjustment was applied to air temperature data to account for elevation differences between the measurement and model input locations. Wind speeds were adjusted with a wind-sheltering coefficient to account for wind speed differences between monitored and modeled locations.

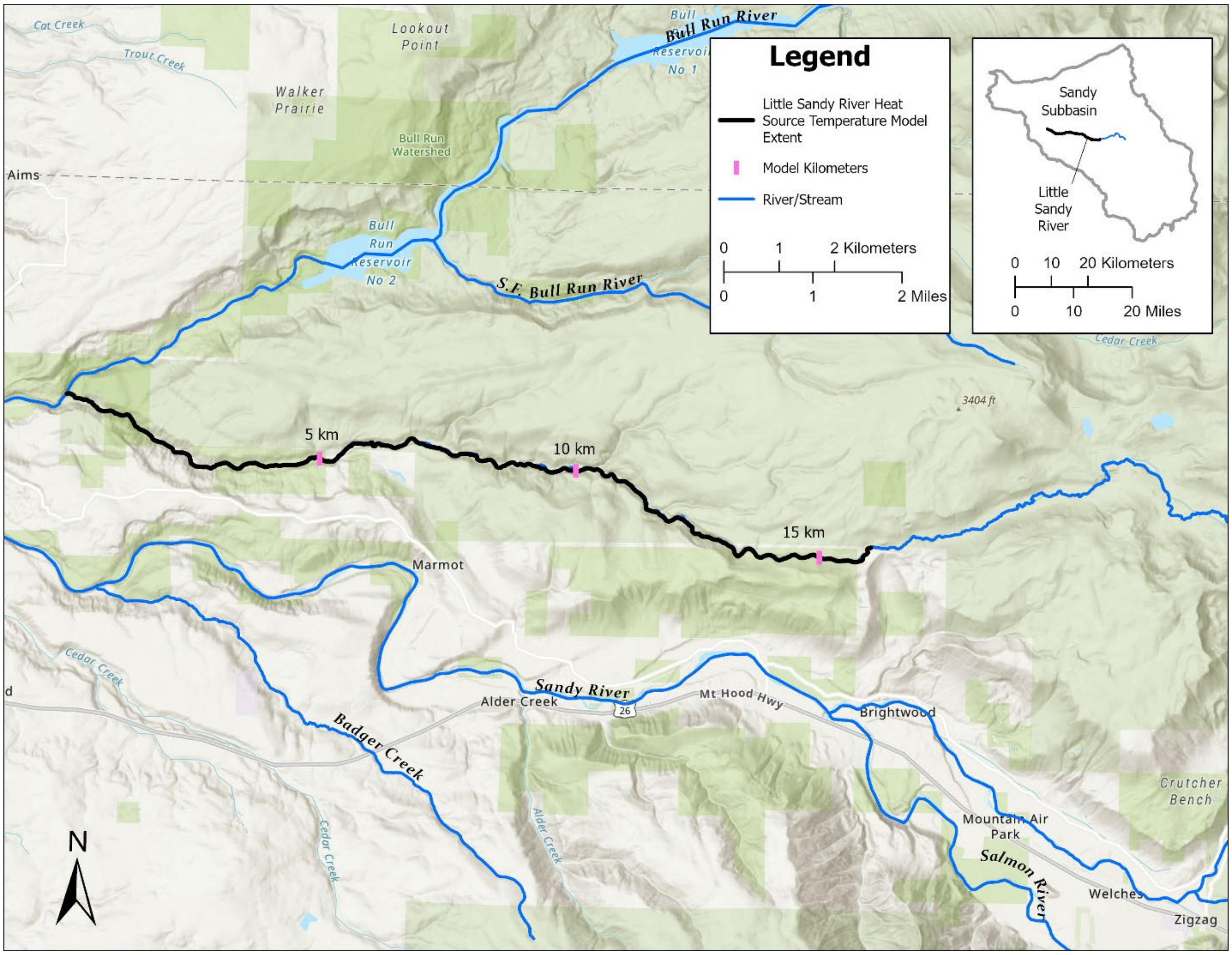

Figure 3-21: Little Sandy River model extent.

Table 3-5: Little Sandy River model inputs: Meteorology, water temperature, and streamflow.

Station ID	Model locations (km)	Input type	Parameter	Data source
14140000	17.13, 3.02, 0.00	Meteorological	Air temperature relative humidity, wind speed	USGS
Little Sandy at USNF Rd 14 (26391-ORDEQ)	17.13	Boundary condition	Water temperature	DEQ
Spring	15.58	Tributary	Flow	Derived constant (0.028 m^3/s)
Spring	13.05	Tributary	Flow	Derived constant (0.198 m^3/s)
Spring	12.92	Tributary	Flow	Derived constant (0.057 m^3/s)
Unnamed site	12.41	Tributary	Flow	Derived constant (0.127 m^3/s)
Marmot inflow	2.8	Tributary	Flow	Derived constant (5.098 m^3/s)
Groundwater accretion	1.37	Tributary	Flow	Derived constant (0.028 m^3/s)
Groundwater accretion	0.76	Tributary	Flow	Derived constant (0.003 m^3/s)
Spring	15.58	Tributary	Water temperature	TIR-derived constant (7.5°C)
Spring	13.05	Tributary	Water temperature	TIR-derived constant (7.2°C)
Spring	12.92	Tributary	Water temperature	Constant (12.0°C)
Unnamed site	12.41	Tributary	Water temperature	26407-ORDEQ (proxy)
Marmot inflow	2.8	Tributary	Water temperature	26408-ORDEQ (proxy)
Groundwater accretion	1.37	Tributary	Water temperature	Constant (13.0°C)
Groundwater accretion	0.76	Tributary	Water temperature	Constant (13.0°C)

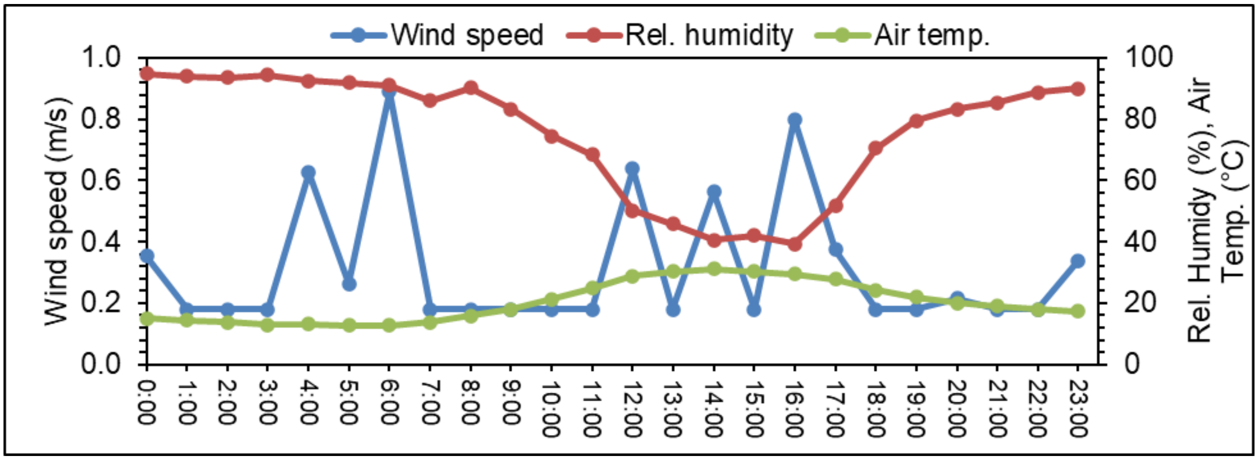

Figure 3-22: Little Sandy River model inputs: Meteorological parameters.

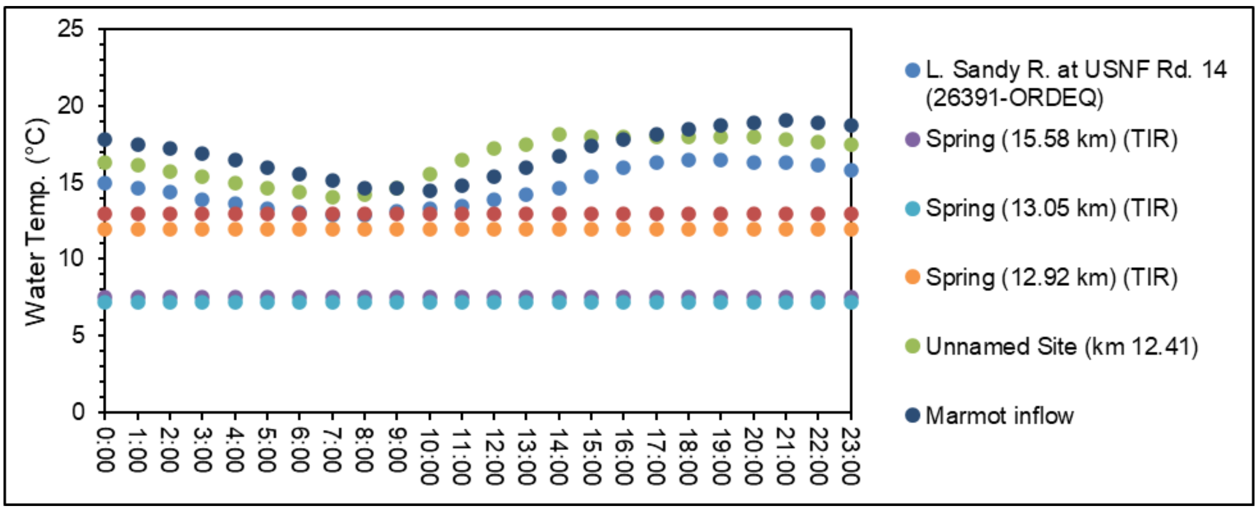

Figure 3-23: Little Sandy River model inputs: Boundary condition and tributary temperatures.

3.3.4 Point source inputs

There are no NPDES-permitted point sources along the Little Sandy River model extent.

3.3.5 Landcover and topographic shade inputs

Figure 3-24 summarizes the topographic shade angles derived with Heat Source 6 that are used as current condition model inputs. **Figure 3-25** shows the model inputs for land cover height.

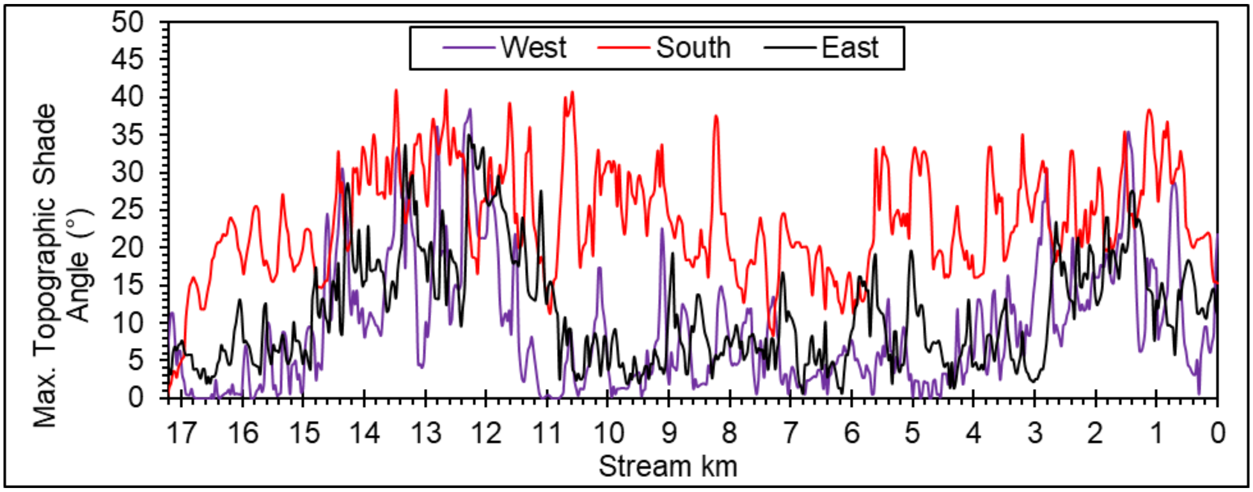

Figure 3-24: Little Sandy River model inputs: Maximum topographic shade angles.

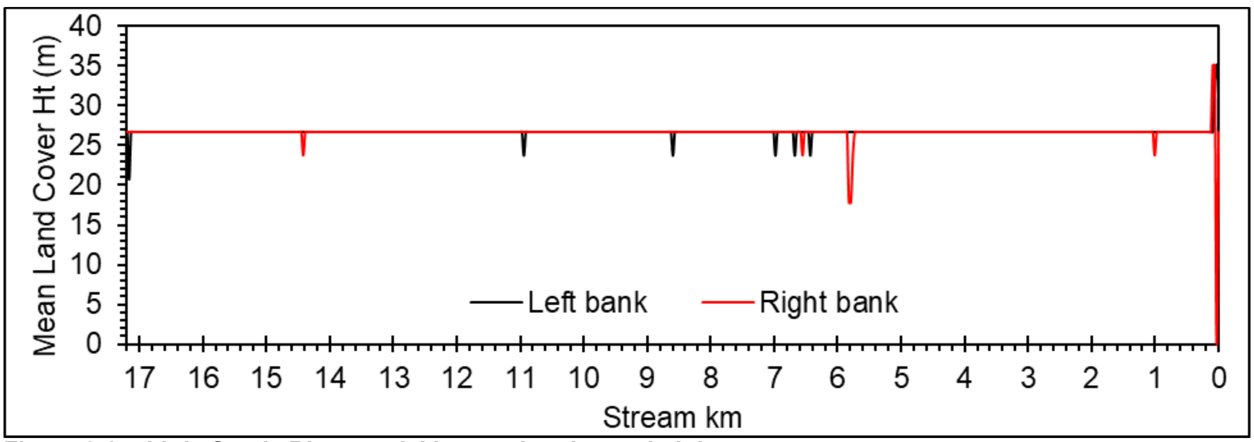

Figure 3-25: Little Sandy River model inputs: Landcover height.

3.3.6 Channel setup

Figure 3-26 and **Figure 3-27** present the Little Sandy River model channel morphology inputs. Manning's n was used as a CCC model calibration parameter.

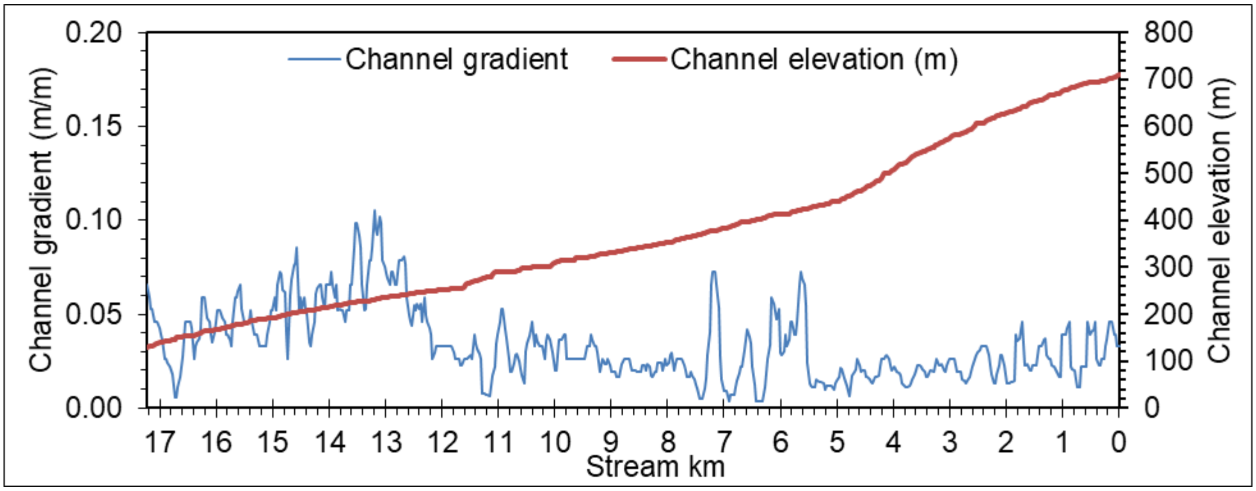

Figure 3-26: Little Sandy River model inputs: Channel gradient and elevation.

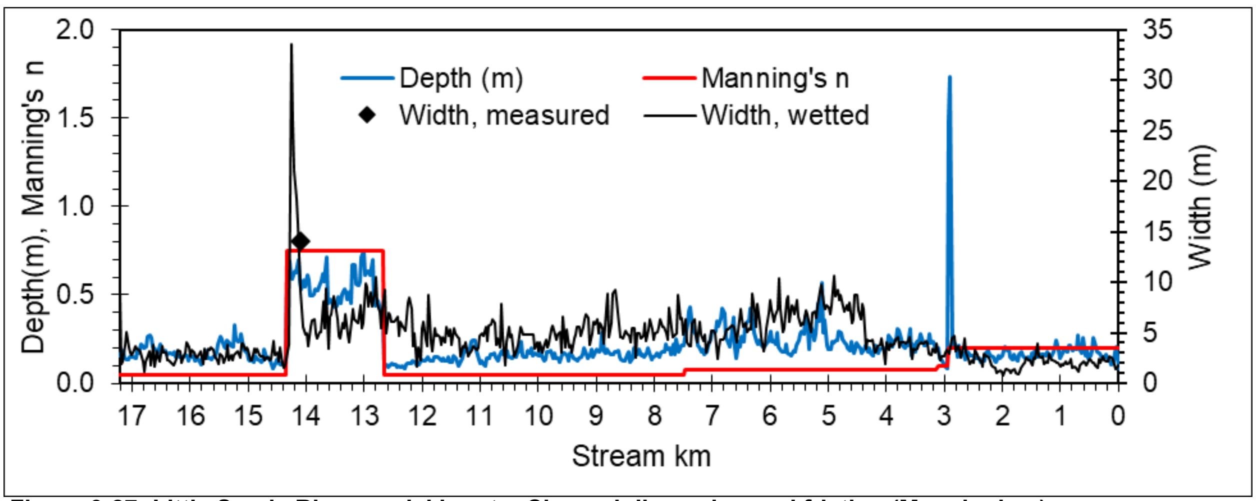

Figure 3-27: Little Sandy River model inputs: Channel dimension and friction (Manning's n).

3.3.7 Other model parameters

Table 3-6 lists additional stream morphology parameters included in the Heat Source 6 model.

Table 3-6: Little Sandy River model inputs: Miscellaneous constant parameters.

Parameter name (units)	Value
Bedrock (%)	0
Riparian zone width (m)	4.57
Riparian zones per node per bank transect	9
Channel incision (m)	0.0

3.3.8 Model calibration

Observed water temperature data for two sites and TIR water temperature data for the entire model extent (Watershed Sciences, 2001) were available to calibrate the 2001 Little Sandy River model (**Table 3-7, Figure 3-28**). **Table 3-8** includes available effective shade calibration data. The modeled and observed temperature data were compared for the model period (**Figure 3-29, Figure 3-30, Figure 3-31**). Calibration fitness for the hourly temperature parameter was assessed with goodness-of-fit statistics (**Table 3-9**). Target goodness-of-fit values were NSE >0.8, MAE <0.5, and RMSE <1.5.

Table 3-7 Little Sandy River model calibration: Available water temperature data.

Station ID	Station	Stream km	Lat/Long	Data source
26389-ORDEQ	Little Sandy R. at mouth	0	45.4261/-122.207	City of Portland
26390-ORDEQ	Little Sandy R. above Diversion	3.1	45.4153/-122.171	DEQ
Little Sandy R. TIR	Little Sandy R. TIR	Model extent		Watershed Sci. (2001)

Table 3-8: Little Sandy River model calibration: Available effective shade data.

Station ID	Station	Stream km	Lat/Long	Effective shade (%)	Data source
26389-ORDEQ	L. Sandy at mouth	0	45.4261/-122.207	100	City of Portland
26390-ORDEQ	L. Sandy above PGE Diversion	3.1	45.4153/-122.171	56	DEQ
26391-ORDEQ	L. Sandy at USNF Rd 14	17.2	45.4037/-122.172	69	DEQ

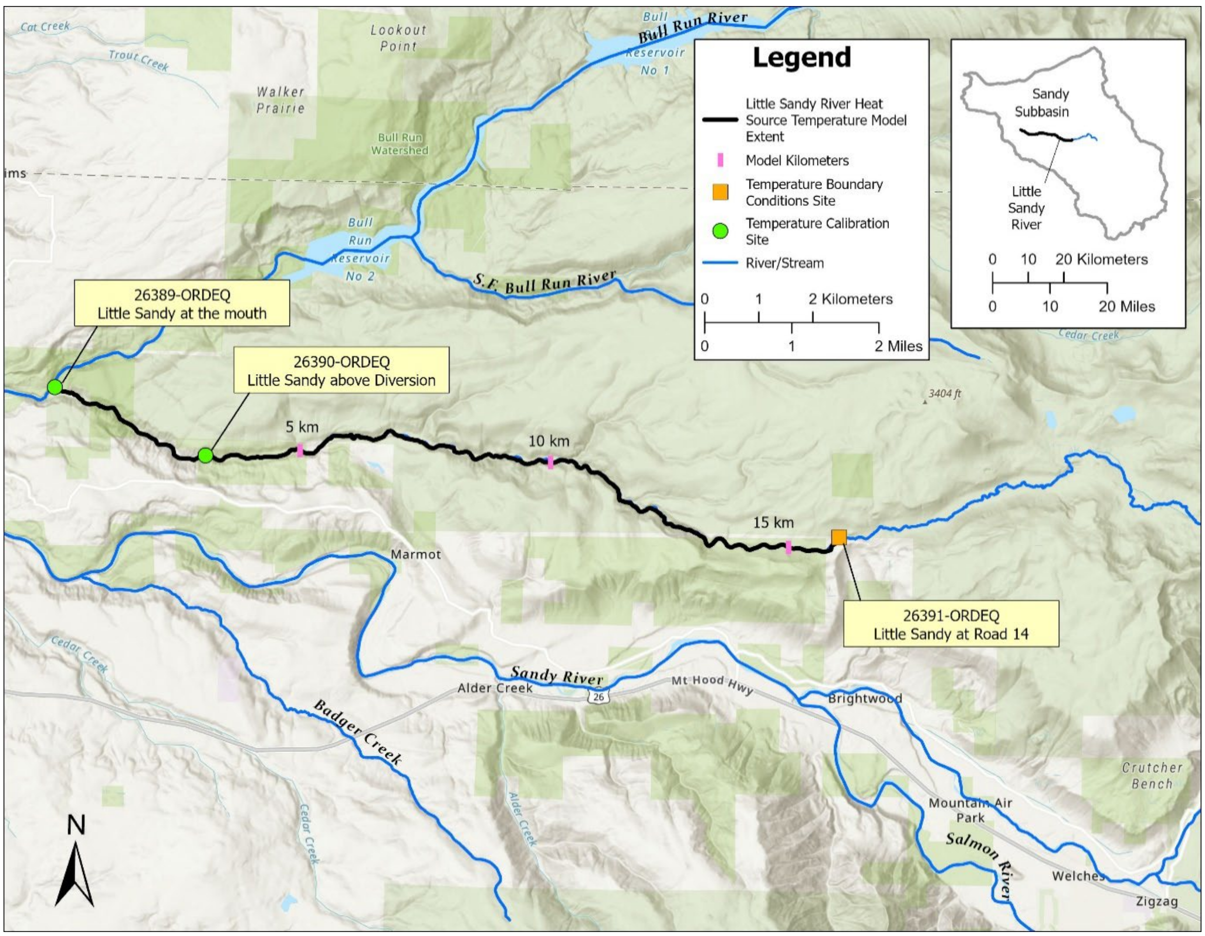

Figure 3-28: Little Sandy River model setup and calibration: Temperature monitoring locations.

Table 3-9: Little Sandy River model calibration: Goodness-of-fit, observed vs. modeled temperatures.

Monitoring location ID	Constituent	ME	MAE	RMSE	NSE	n
TIR	Hourly Temperature	0.06	0.34	0.44	0.90	173
All monitoring stations	Hourly Temperature	-0.66	0.92	1.07	0.47	48

Little Sandy above Diversion	Hourly Temperature	-0.60	0.78	0.89	0.71	24
Little Sandy, Mouth	Hourly Temperature	-0.73	1.05	1.22	-5.89	24

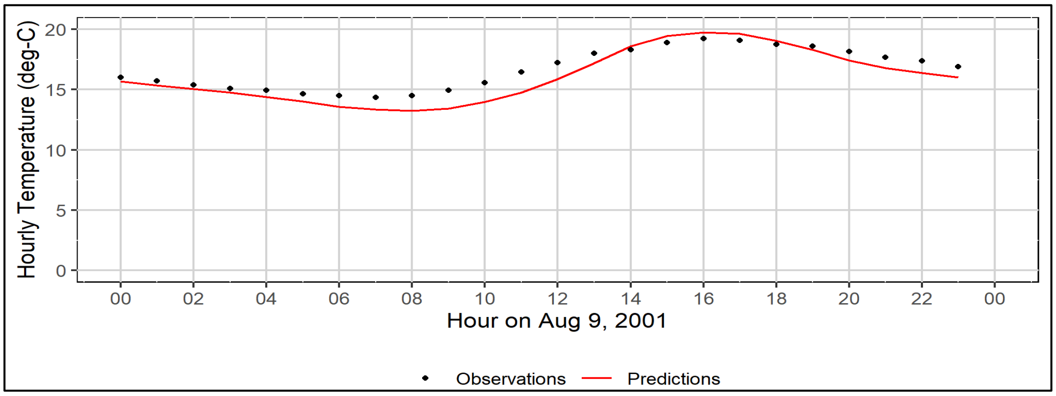

Figure 3-29: Little Sandy River above PGE diversion (river km 3.1): Modeled vs. observed hourly

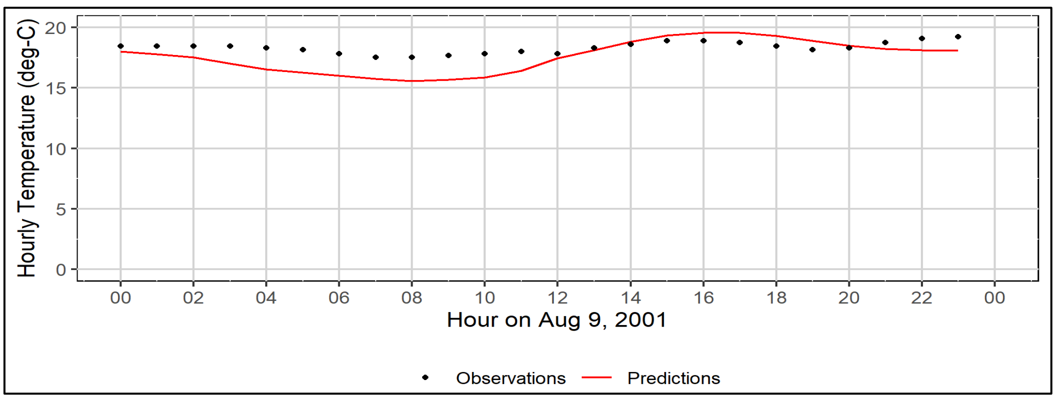

Figure 3-30: Little Sandy River at mouth (river km 0.1): Modeled vs. observed hourly

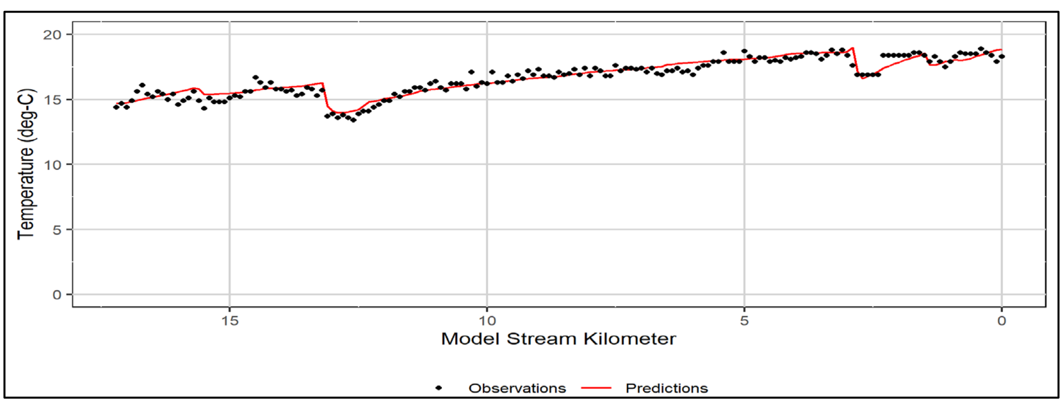

Figure 3-31: Little Sandy River longitudinal temperatures: Modeled vs. TIR-observed, 2pm 8/9/2001.

3.3.9 Model results – effective shade and longitudinal temperature

Figure 3-32 shows modeled Little Sandy River effective shade for Aug 9, 2001. **Figure 3-33** shows the modeled daily maximum temperatures for each Little Sandy River stream node for Aug 9, 2001. For reference, the applicable BBNC for the Little Sandy River model per OAR 340-041-0028(4)(a)-(b) are:

- 13.0°C from the mouth to km 2.93 from Jan 1 to June 15 and Aug 15 to Dec 31,
- 16.0°C from the mouth to km 2.93 from June 15 to Aug 14 and year-round from km 2.93 to the upstream boundary.

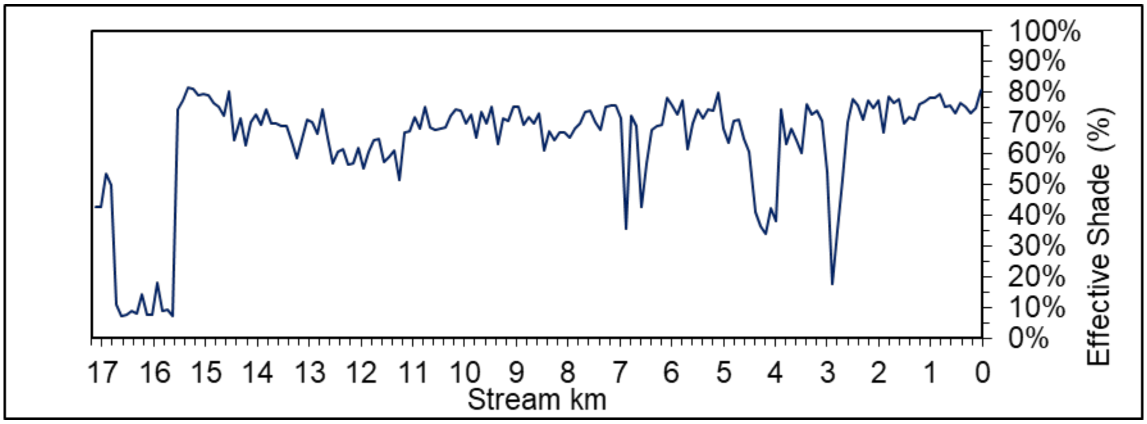

Figure 3-32: Little Sandy River model results: Longitudinal effective shade, 8/9/2001.

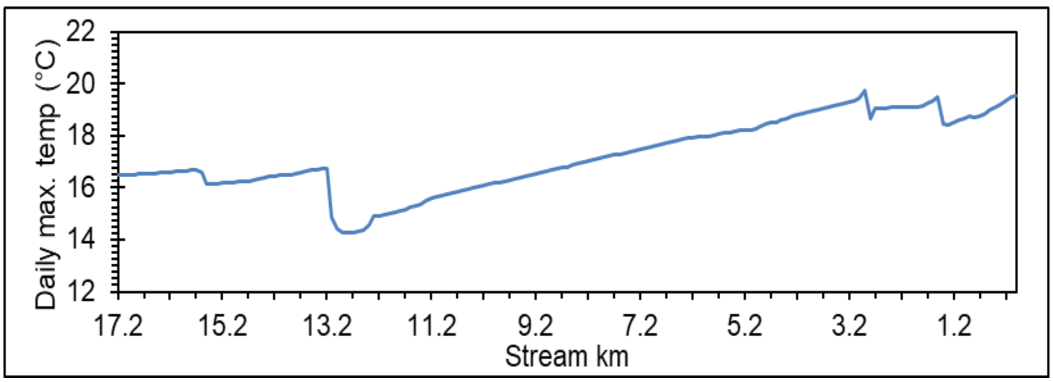

Figure 3-33: Little Sandy River model results: Longitudinal daily maximum temperatures, 8/9/2001.

3.4 Zigzag River

The Zigzag River model is a temperature model developed by DEQ using Heat Source 6.5.1.

3.4.1 Spatial and temporal extent

The model domain extent is the Zigzag River from the mouth to just upstream of Camp Creek at Highway 26. The model extent is shown in **Figure 3-34**. The model period is a single day: August 9, 2001.

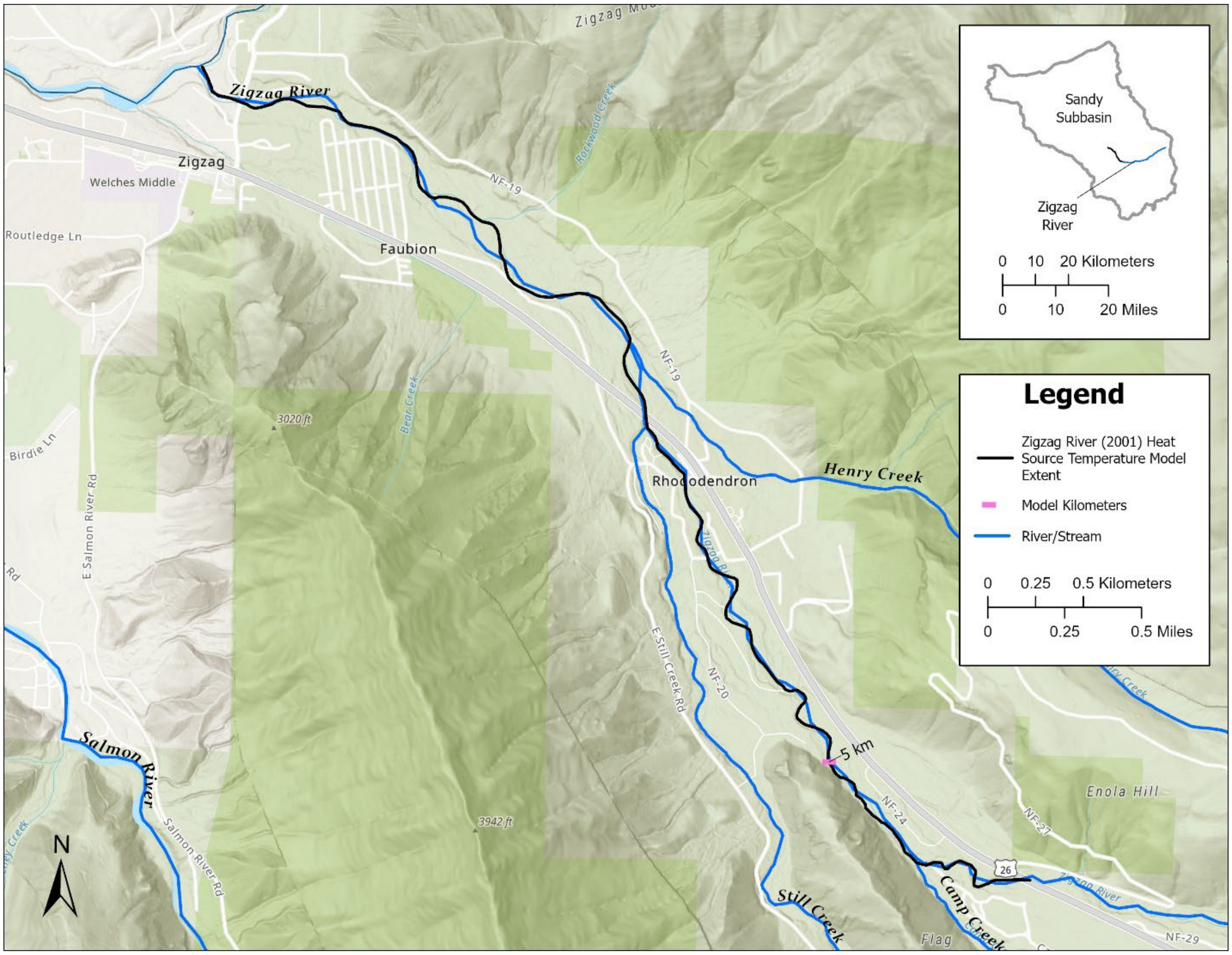

Figure 3-34: Zigzag River model extent.

3.4.2 Spatial and temporal resolution

The model input spatial resolution (*dx*) is 30 m. Outputs are generated every 100 m. The model time step (*dt*) is 1 minute and outputs are generated every hour.

3.4.3 Meteorological, water temperature, and flow inputs

Table 3-10, **Figure 3-35**, and **Figure 3-36** summarize the model meteorological, water temperature, and flow inputs and data sources.

Table 3-10: Zigzag River model inputs: Meteorology, water temperature, and streamflow.

Station ID	Model locations (km)	Input type	Parameter	Data source
14140000	7.01, 3.54, 0.00	Meteorological	Air temperature, relative humidity, wind speed	USGS
Zigzag above Camp Cr./Hwy 26	7.32	Boundary condition	Water temperature	26420-ORDEQ
Camp Creek	6.22	Tributary	Water temperature	26419-ORDEQ
Still Creek	3.14	Tributary	Water temperature	26417-ORDEQ
Henry/No Name	2.62	Tributary	Water temperature	TIR-derived constant (12.9°C)

Station ID	Model locations (km)	Input type	Parameter	Data source
Spring	1.46	Tributary	Water temperature	TIR-derived constant (11.7°C)
Spring	1.13	Tributary	Water temperature	TIR-derived constant (13.1°C)
Unnamed tributary	1.07	Tributary	Water temperature	TIR-derived constant (17.4°C)
Spring	0.82	Tributary	Water temperature	TIR-derived constant (13.7°C)
Camp Creek	6.22	Tributary	Flow	0.473 m^3/s
Still Creek	3.14	Tributary	Flow	0.877 m^3/s
Henry/No Name	2.62	Tributary	Flow	0.057 m^3/s
Spring	1.46	Tributary	Flow	0.028 m^3/s
Spring	1.13	Tributary	Flow	0.028 m^3/s
Unnamed tributary	1.07	Tributary	Flow	0.170 m^3/s
Spring	0.82	Tributary	Flow	0.014 m^3/s

Model meteorology inputs included hourly air temperature, relative humidity, and wind speed (**Figure 3-35**). A dry adiabatic lapse rate adjustment was applied to air temperature data to account for elevation differences between the measurement and model input locations. Wind speeds were adjusted with a wind-sheltering coefficient to account for wind speed differences between monitored and modeled locations.

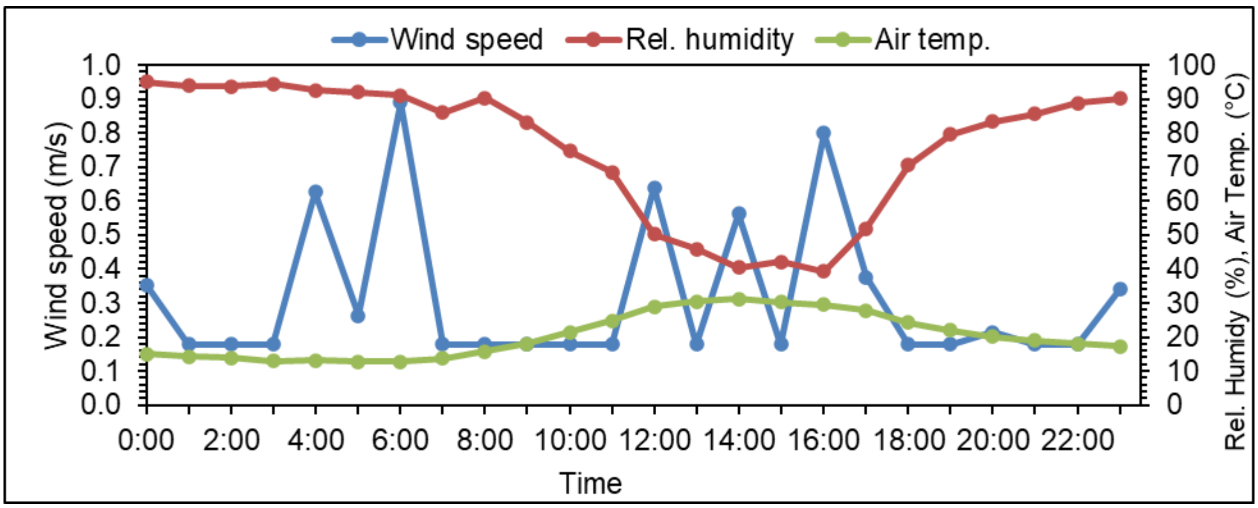

Figure 3-35: Zigzag River model inputs: Meteorological parameters.

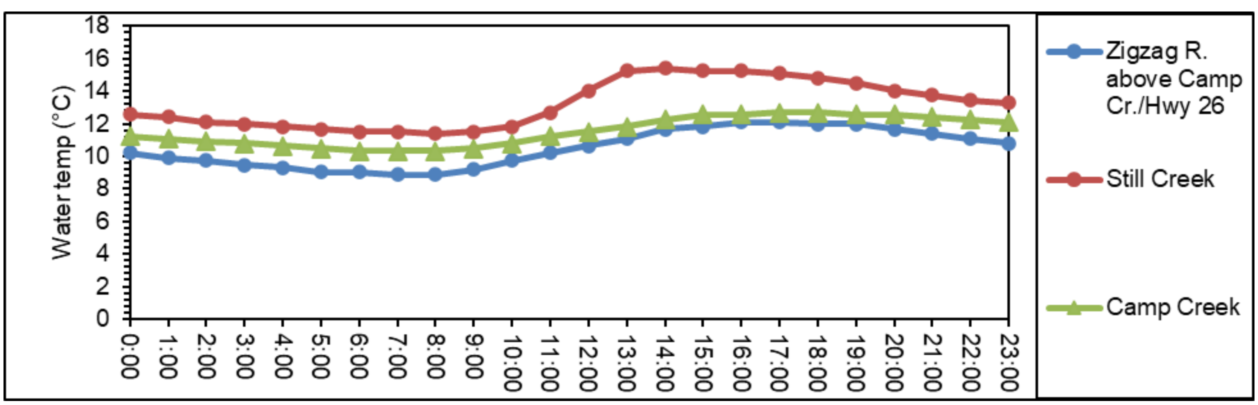

Figure 3-36: Zigzag River model inputs: Water temperatures.

3.4.4 Point source inputs

There are no NPDES-permitted point sources along the Little Sandy River model extent.

3.4.5 Landcover and topographic shade inputs

Figure 3-37 and **Figure 3-38** show the topographic shade and land cover height inputs for the 2001 Zigzag River model.

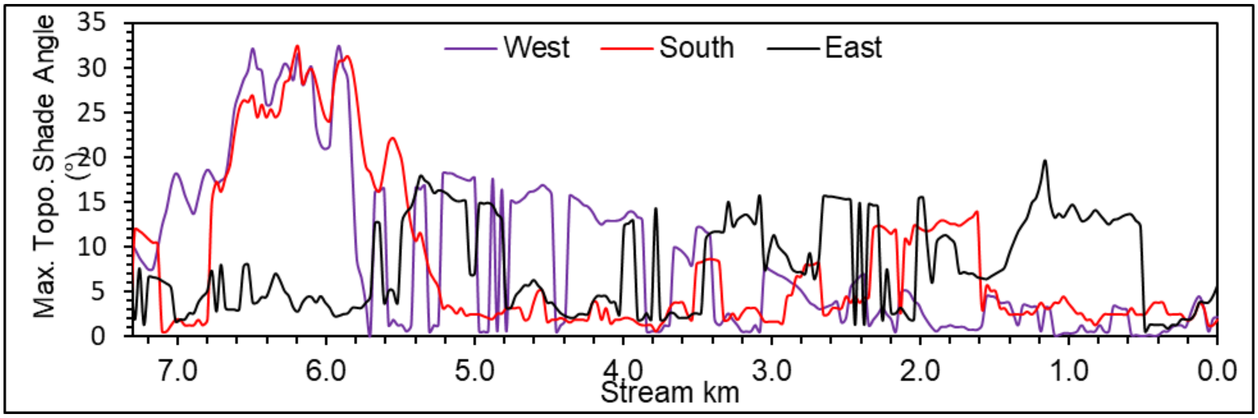

Figure 3-37: Zigzag River model inputs: Maximum topographic shade angles.

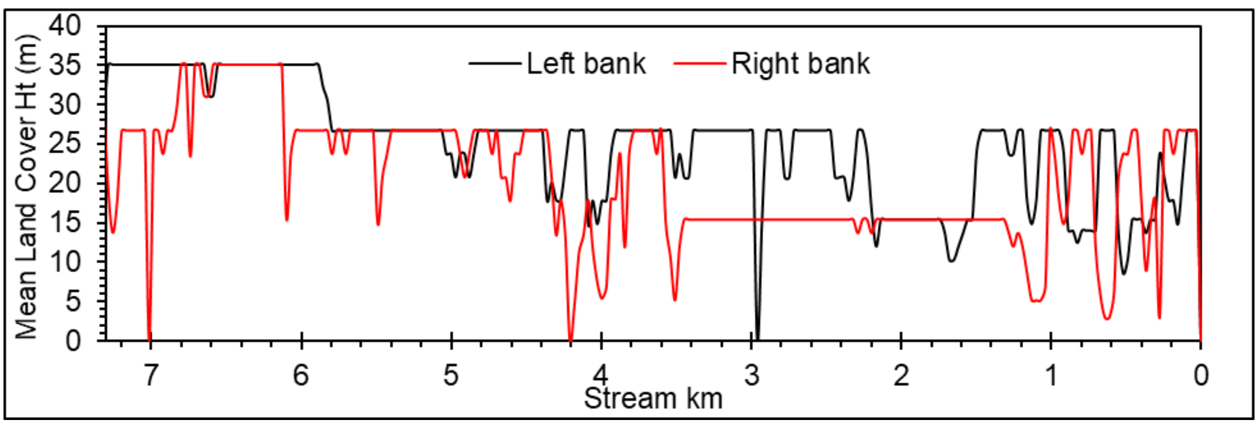

Figure 3-38: Zigzag River model inputs: Landcover height.

3.4.6 Channel setup

Figure 3-39 and **Figure 3-40** show the channel morphology inputs for the 2001 Zigzag River model.

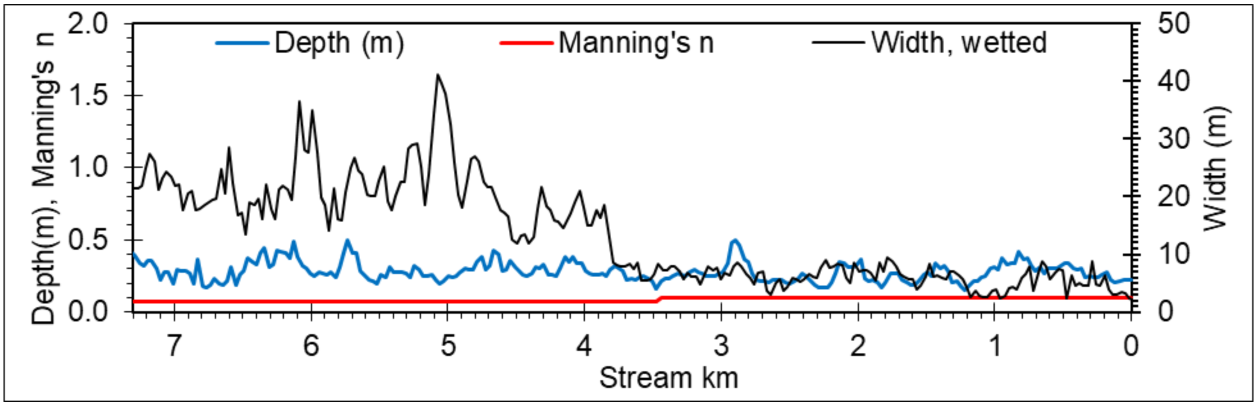

Figure 3-39: Zigzag River model inputs: Channel dimensions and friction (Manning's n).

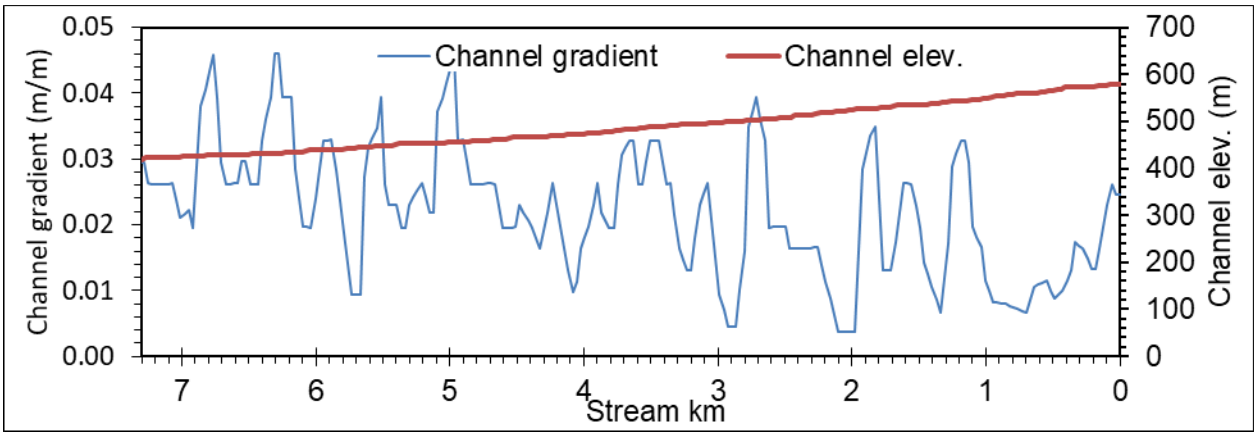

Figure 3-40: Zigzag River model inputs: Channel gradient and elevation.

3.4.7 Other model parameters

Table 3-11 lists additional stream morphology parameters included in the Heat Source 6 model.

Table 3-11: Zigzag River model inputs: Miscellaneous constant parameters.

Parameter name (units)	Value
Bedrock (%)	50
Riparian zone width (m)	4.57
Riparian zones per node per bank transect	9
Channel incision (m)	0.0

3.4.8 Model calibration

Observed stream temperature data for two sites were available to calibrate the 2001 Zigzag River model (**Table 3-12**, **Figure 3-41**). Additionally, TIR water temperature data were available for the model extent (**Figure 3-44)** (Watershed Sciences, 2001). **Table 3-13** provides effective shade calibration data. Modeled and observed data were compared for these locations during the model period (**Figure 3-42**, **Figure 3-43**, **Figure 3-44**). Calibration fitness for the daily maximum temperature and hourly temperature parameters was assessed with goodness-of-fit statistics (**Table 3-14**). Target goodness-of-fit values were NSE >0.8, MAE <0.5, and RMSE <1.5.

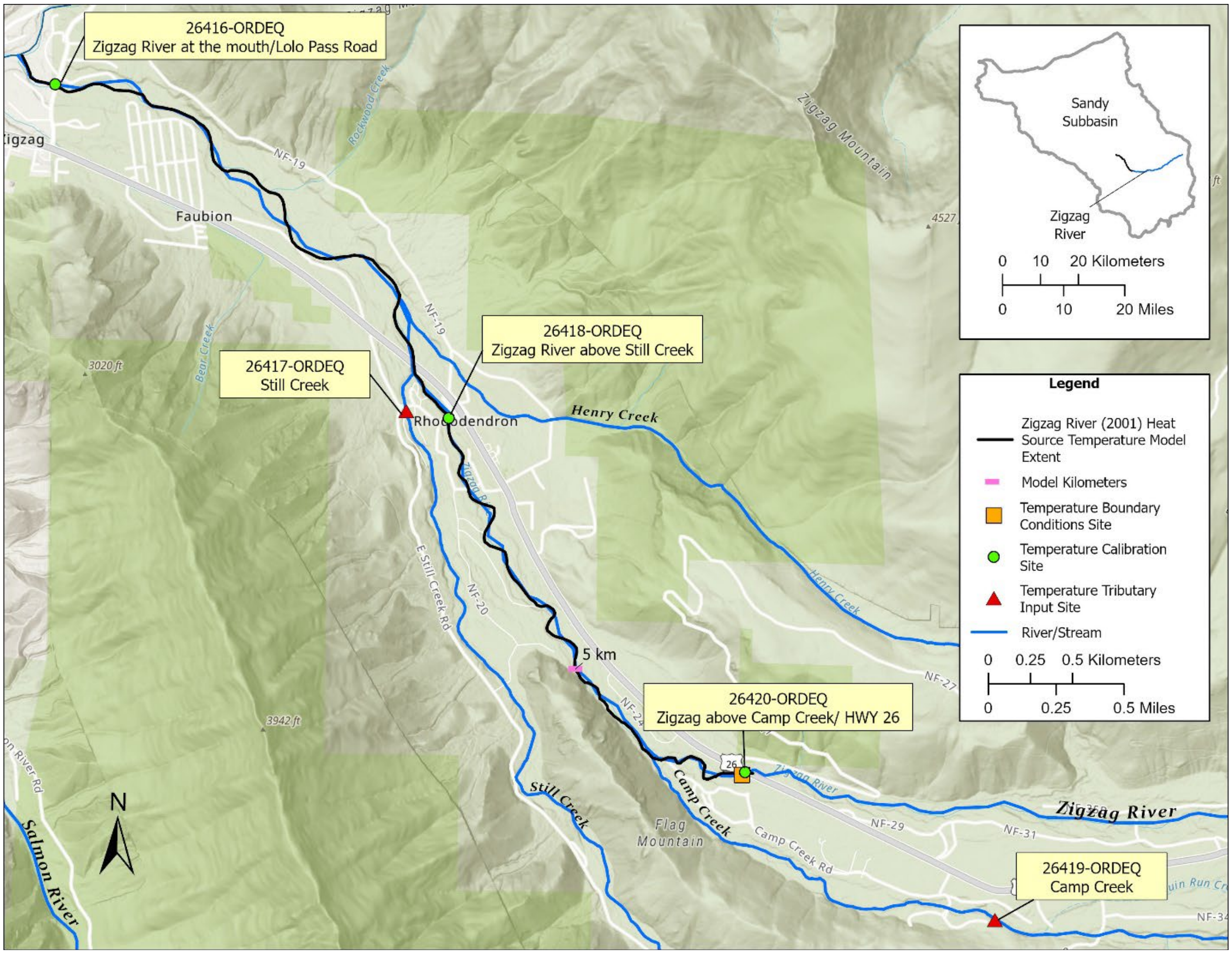

Figure 3-41: Zigzag River model setup and calibration: Temperature monitoring locations.

Table 3-12: Zigzag River model calibration: Available water temperature data.

Station ID	Station	Model location (km)	Data source
26416-ORDEQ	Zigzag R. at mouth Lolo Pass Rd.	0.00	DEQ
26418-ORDEQ	Zigzag R. above Still Cr.	3.14	DEQ
Zigzag R. TIR	Zigzag R. TIR	Model extent	Watershed Sciences (2001)

Table 3-13: Zigzag River model calibration: Available effective shade data.

Station ID	Station	Latitude/Longitude	Effective shade (%)	Data source
26416-ORDEQ	Zigzag R. at mouth Lolo Pass Rd.	45.3471, -121.942	19	DEQ
26418-ORDEQ	Zigzag R. above Still Cr.	45.3297, -121.912	72	DEQ
26420-ORDEQ	Zigzag R. above Camp Cr. Hwy 26	45.311, -121.89	95-100	DEQ

Table 3-14: Zigzag River model calibration: Goodness-of-fit, observed vs. predicted temperatures.

Monitoring location ID	Constituent	ME	MAE	RMSE	NSE	n
TIR	Hourly Temperature	0.16	0.33	0.39	0.94	173
26416-ORDEQ, 26418-ORDEQ	Hourly Temperature	0.30	0.42	0.51	0.90	48
26416-ORDEQ	Hourly Temperature	0.66	0.66	0.69	0.84	24
26418-ORDEQ	Hourly Temperature	-0.05	0.19	0.22	0.97	24

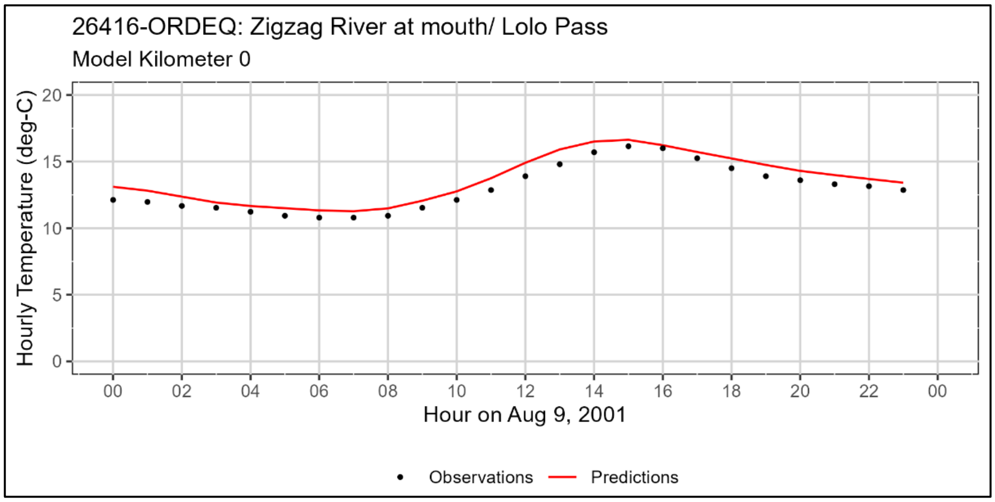

Figure 3-42: Zigzag River at Mouth: Modeled vs. observed hourly temperatures.

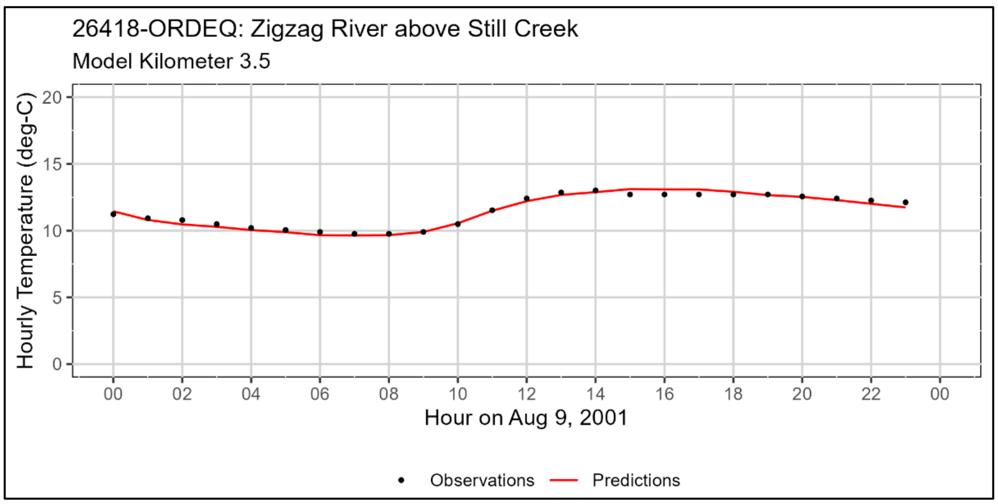

Figure 3-43: Zigzag River above Still Creek: Modeled vs. observed hourly.

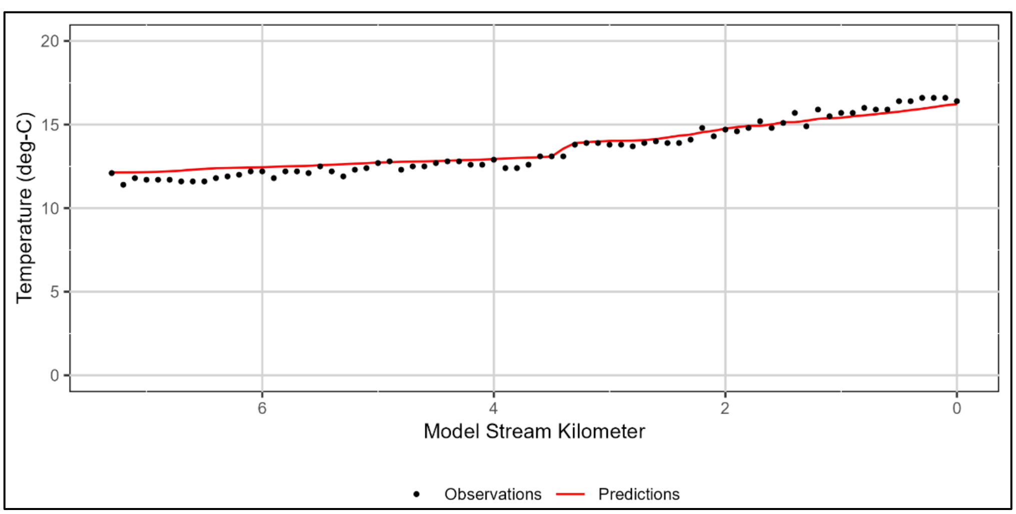

Figure 3-44: Zigzag River longitudinal temperatures: Modeled vs. TIR-observed, 4pm 8/9/2001.

3.4.9 Model results – effective shade and longitudinal temperature

Figure 3-45 shows the modeled daily maximum temperature for each Zigzag River stream node for Aug 9th, 2001. **Figure 3-46** shows modeled Zigzag River effective shade for Aug 9, 2001. For reference, the applicable BBNC for the modeled Zigzag River extent are 16.0°C from June 16 to Aug 14 and 13.0°C for the rest of the year (Jan 1 to June 15 and Aug 15 to Dec 31).

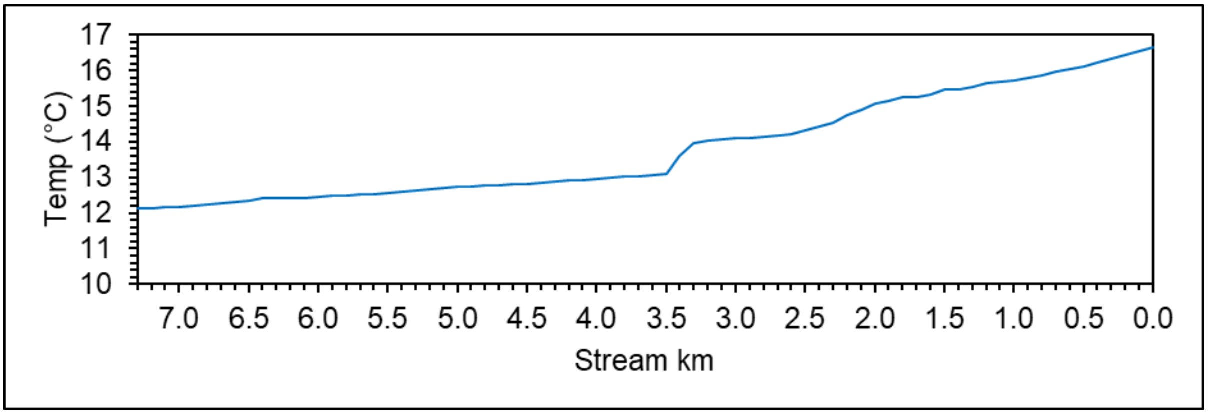

Figure 3-45: Zigzag River model results: Longitudinal daily maximum temperatures, 8/9/2001.

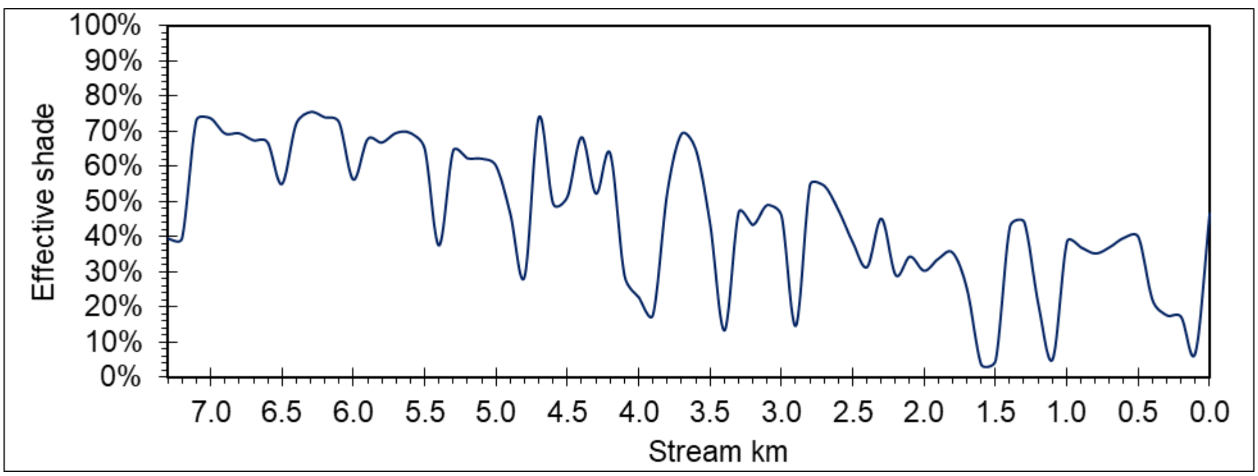

Figure 3-46: Zigzag River model results: Longitudinal effective shade, 8/9/2001.

4 Model scenarios and results

4.1 Analysis and interpretation methods

4.1.1 Significant digits and rounding

The TMDL analysis and interpretation of all model and scenario results accounted for significant digits and rounding. To evaluate HUA attainment, DEQ calculates and records values to the hundredths (0.01°C). Because DEQ assigns some source sector HUAs to the hundredths, attainment is tracked with equal precision. The TMDL analysis follows the rounding procedures outlined in a DEQ permit-related IMD on rounding and significant digits (DEQ, 2013b). This IMD says that for “calculated values” (which includes model results), if the digit being dropped is a “5,” it is rounded up. For example, if an HUA allocation is set at 0.05°C and the model shows warming equal to 0.054°C, the value is rounded down to 0.05°C and the result is attainment. If the model shows warming equal to 0.055°C, the value is rounded up to 0.06°C and the result is non-attainment.

4.1.2 Calculating the 7-day average daily maximum temperature

For each scenario, 7DADM temperatures were calculated using the hourly model output. The 7DADM was calculated using the procedure outlined in DEQ’s Temperature IMD (DEQ, 2008). As outlined in this IMD, the 7DADM temperature is calculated by (i) calculating the daily maximum for each day and each location, then (ii) calculating a 7-day rolling average of the daily maximums, the result for which lands on the 7th day and is considered the 7DADM for that day. Following transition to a new fish use designation period (e.g., spawning), the first day that the 7DADM is reported occurs on the 7th day after the new fish use designation begins. For example, if spawning begins October 15, the first 7-day period would be October 15 to 21, with the first 7DADM temperature reported on October 21.

4.1.3 Comparing temperature between two scenarios

When comparing the hourly results from two model scenarios to determine the temperature change, the following steps were taken:

1. Calculate the 7DADM or daily maximum temperatures for scenario 1 at every model output location for every day of the model period.
2. Calculate the 7DADM or daily maximum temperatures for scenario 2 at every model output location for every day of the model period.
3. For allocation scenarios, the HUA is defined as the maximum allowable increase above the applicable BBNC. Thus, to determine the maximum temperature change in relation to HUAs, only days when the applicable BBNC was exceeded were considered; thus, days when 7DADM or daily maximum river temperatures did not exceed the BBNC were excluded. Note that the BBNC varied spatially and temporally and this was accounted for in the assessment.
4. Compute the difference between the 7DADM or daily maximum temperatures of scenario 1 and scenario 2 only for days that exceed the BBNC.
5. Round the differences to two decimals Celsius (i.e., 0.0x°C), based on the adopted rounding procedure discussed in Section 4.1.1.

The 7DADM is the preferred temperature metric for comparing two scenarios. If the model period or available data were less than 7 days, the daily maximum temperature metric was used instead. It was assumed that the daily maximum temperatures approximate 7DADM results.

4.2 Scenario background and descriptions

DEQ and supporting organizations developed models that reflect various possible scenarios (i.e., sets of conditions) to understand the potential in-stream water temperature effects of variation in, e.g., anthropogenic water withdrawals and discharges, vegetation shading and removal, presence of dams, and other anthropogenic or natural conditions in the TMDL area.

This allowed DEQ to quantify the actual or potential effects of these scenario variables on instream temperatures in the modeled streams. Each scenario reflected specific potential management action(s) and/or natural processes in a model river. Scenario models and current conditions model outputs were compared to determine the effects of specific variables on instream temperatures.

For stream temperature modeling, the POMI is the longitudinal stream location and date associated with the greatest in-stream 7DADM temperature difference between the current conditions model output and a given scenario's model output. The maximum allowable anthropogenic 7DADM instream temperature change (i.e., HUA) is 0.30°C above the applicable BBNC at the POMI, cumulatively for all point and nonpoint sources. To summarize differences between current conditions and a hypothetical scenario model (e.g., fully restored riparian vegetation), the temperature change at the POMI is expressed in terms of the maximum 7DADM. Because this is an assessment of maximum *impact*, the POMI determination for all between-scenario comparisons is limited to days when the modeled 7DADM water temperature of the alternative scenario exceeds the applicable BBNC (OAR 340-041-0028).

Table 4-2 outlines the various Sandy Subbasin scenarios and methods, and **Table 4-3** summarizes the topic(s) addressed by various scenario comparisons. Note that certain scenarios were inapplicable to certain streams. The results of applicable scenarios and their comparisons are summarized for the Salmon River, Little Sandy River, and Zigzag River in Sections 4.3, 4.4, and 4.5, respectively. Sandy River scenario results are provided in Appendix C. Bull Run River scenario results are provided in Appendix D with an addendum in Section 4.5.1 of this report. Here is a brief description of the various scenarios considered for this TMDL modeling effort:

Future Point Source (FPS): This scenario, which is only applicable to the Sandy River mainstem model, is identical to the CCC model except that a proposed City of Sandy WWTP discharge was added to the model at river km 38.5. It is discussed further in TSD Appendix C.

No Point Sources (NoPS): This scenario, which is only applicable to the Sandy River mainstem model, is equivalent to the CCC model with all point source discharges to the stream system (**Table 2-2**) removed. It is discussed further in TSD Appendix C.

TMDL Wasteload Allocations (WLA): This scenario, which is only applicable to the Sandy River mainstem model, is equivalent to the CCC model except that NPDES-permitted point source discharges were modified to reflect DEQ-proposed WLAs. It is discussed further in TSD Appendix C. The results of the WLA and NoPS scenarios were compared to determine the instream temperature effects of NPDES-permitted point sources meeting WLAs.

Restored Vegetation (RV): This scenario is equivalent to the CCC model setup for all parameters except land cover code assignments and vegetation heights and densities. The purpose of this scenario is to assess the effects of current human-related vegetation alteration on instream temperatures in the model extent. A corollary purpose is to assess the potential improvements to instream water quality (temperature) that may be achieved with different degrees of vegetation restoration.

To that end, two restored vegetation scenarios were modeled. Restored vegetation scenario "A" (RV_A) represented vegetation as attaining its potential growth in the absence of human disturbance, i.e., anthropogenically altered land use types (e.g., buildings, roads) were restored to their natural types (e.g., forests) and typical natural heights and canopy densities (**Table 4-1**).

Table 4-1 provides information on the land cover types included in CCC models and the adjustments simulated by the RV_A scenario.

Restored vegetation scenario “B” (RV_B) setup was identical to RV_A except that areas associated with residential and industrial/commercial development, roads, bridges, and utility corridors were left unchanged and retained the codes, heights, and densities as defined in the CCC model (i.e., they were not restored) (**Table 4-1**). RV_A and RV_B results are compared to quantify instream temperature effects of existing infrastructure-associated riparian vegetation alteration and determine if it meets the infrastructure-specific HUA (Sandy River: 0.05°C, Salmon River: 0.06°C, all other Sandy Subbasin waterbodies: 0.02°C).

Table 4-1: Model inputs: Land cover and vegetation height/density, CCC, RV_A, and RV_B model scenarios.

	Current Calibrated Conditions			Restored Vegetation “A” scenario[1]		
Land cover type code	**Landcover description**	**Height (m)**	**Canopy cover (Density) (%)**	**Landcover description**	**Restoration height[2] (m)**	**Canopy cover (Density) (%)**
101	Utility[3]	LiDAR-derived	60	Mixed Conifer/Hardwood, High Density	26.7	60
102	Bridge - Over Water[3]	LiDAR-derived	100	Water, Active Channel	LiDAR-derived	0
300	Pasture/Cultivated Field	LiDAR-derived	75	Mixed Conifer/Hardwood, High Density	26.7	60
301	Water, Non-Active Channel	LiDAR-derived	0	Water, Non-Active Channel	LiDAR-derived	0
302	Water, Active Channel	LiDAR-derived	0	Water, Active Channel	LiDAR-derived	0
305	Barren, Embankment	LiDAR-derived	0	Mixed Conifer/Hardwood, High Density	26.7	60
308	Barren, Clearcut	LiDAR-derived	75	Mixed Conifer/Hardwood, High Density	26.7	60
309	Barren, Soil	LiDAR-derived	0	Mixed Conifer/Hardwood, High Density	26.7	60
348	Development, Residential[3]	LiDAR-derived	100	Mixed Conifer/Hardwood, High Density	26.7	60
349	Development, Industrial/Commercial[3]	LiDAR-derived	100	Mixed Conifer/Hardwood, High Density	26.7	60
352	Dam/Weir	LiDAR-derived	100	Mixed Conifer/Hardwood, High Density	26.7	60
355	Canal	LiDAR-derived	0	Mixed Conifer/Hardwood, High Density	26.7	60
400	Barren, Road[3]	LiDAR-derived	0	Mixed Conifer/Hardwood, High Density	26.7	60
401	Barren, Forest Road[3]	LiDAR-derived	0	Mixed Conifer/Hardwood, High Density	26.7	60
500	Mixed Conifer/Hardwood, High Density	LiDAR-derived	60	Mixed Conifer/Hardwood, High Density	26.7	60
550	Mixed Conifer/Hardwood, Medium Density	LiDAR-derived	30	Mixed Conifer/Hardwood, Medium Density	26.7	30
555	Mixed Conifer/Hardwood, Low Density	LiDAR-derived	10	Mixed Conifer/Hardwood, Low Density	26.7	10
600	Hardwood, High Density	LiDAR-derived	75	Hardwood, High Density	20.1	75
650	Hardwood, Low Density	LiDAR-derived	30	Hardwood, Low Density	20.1	30
700	Conifer, High Density	LiDAR-derived	60	Conifer, High Density	35.1	60
750	Conifer, Low Density	LiDAR-derived	30	Conifer, Low Density	35.1	30
800	Shrub, High Density	LiDAR-derived	75	Shrubs, High Density	1.8	75
850	Shrub, Low Density	LiDAR-derived	25	Shrubs, Low Density	1.8	25
900	Grasses, Upland	LiDAR-derived	75	Mixed Conifer/Hardwood, High Density	26.7	60
950	Grasses, Wetland	LiDAR-derived	75	Grasses, Wetland	1.6	75

[1] Parameters that change under restored vegetation scenario “A” from current conditions are formatted with light-orange fill; other parameters remain as current.
[2] Values in this column are the minimum restoration heights by land cover type. Where the existing LiDAR-derived vegetation height was greater than the default restoration height, the existing vegetation height was retained.
[3] For RV_B scenario, this land cover type remained as it was under the CCC model, i.e., it was not “restored.”

No Dams: This scenario, which is applicable to the Bull Run River and Sandy River mainstem models, is equivalent to the CCC model except that the Bull Run River's morphological parameters (e.g., channel dimensions, gradients, and elevations) are adjusted to represent stream morphology as if Bull Run River Dams #1 and #2 were not present. Further details on the Bull Run River setup for this scenario are provided in TSD Appendix D. Results of this scenario and the CCC model are compared to quantify the effects of existing dams and reservoirs on instream temperature in the Bull Run and Sandy Rivers.

Restored Flow: This scenario is equivalent to the CCC model setup for all parameters except that boundary and tributary inflows reflect estimated median natural monthly flows (i.e., undeveloped conditions) and all human water withdrawal rates equal zero. For the purposes of this scenario, median monthly natural flows were estimated with USGS StreamStats (USGS, 2019). Results of this scenario and the Water Withdrawals scenario are compared to quantify the instream temperature effects of consumptive water withdrawals on the modeled streams.

Water Withdrawals: This scenario is identical to the RQ model setup except that all boundary, tributary, and hence instream flows are modified iteratively to reflect various rates of consumptive water withdrawals. Results of this scenario and the RQ scenario are compared to quantify the instream temperature effects of water withdrawals on the modeled streams. The purpose of these model iterations is to determine the maximum consumptive withdrawal rates that would still attain (A) the HUA for permitted withdrawals (0.05°C) at a stream reference location (Sandy River model km 29.10), (B) the overall HUA (0.30°C), and (C) current consumptive uses. This scenario is only applicable to the Sandy River and is discussed in TSD Appendix C.

Background: This scenario evaluates the stream temperature response from background sources only. The BG conditions scenario was developed to estimate the magnitude of background excess load relative to anthropogenic load. Background sources include all sources of thermal loading not originating from human activities. This scenario is equivalent to the CCC model setup for all parameters except that all human-altered vegetation is restored (as in the RV_A scenario), dams are removed (as in the ND scenario), and point source discharges are set to zero (as in the NoPS scenario). The results of this scenario are compared to the applicable BBNC to identify the extent and magnitude of temperature exceedances that would occur in the absence of anthropogenic influences, i.e., due to background factors.

Protected Vegetation: This scenario was applied only to the Salmon River for this modeling effort. The protected vegetation scenarios evaluate the stream temperature response only from streamside vegetation that is currently protected by statute, rule, ordinance, or some other approved management plan. The purpose of this scenario is to determine the stream temperature warming or cooling contributed by removal of streamside vegetation in unprotected areas and if existing management strategies are sufficient to achieve allocations and surrogate measure effective shade targets. Two unique versions were applied to the Salmon River (PV_A, PV_B). Both PV_A and PV_B assume restored vegetation in the protected zone. In areas outside of the protection zone, PV_A assumes current vegetation, where PV_B assumes no vegetation. The specific buffer distance assumed for different jurisdictions and land management agencies are summarized in **Table 4-4**. The rules and regulations reviewed by DEQ are complex and in the case of Clackamas County have varying requirements that may be applied differently given the location and site-specific situation. For the PV model scenarios, DEQ worked with Clackamas County planning staff to interpret the rules and identify the buffer width most applicable to situations on the Salmon River.

Topography: This scenario is equivalent to the CCC model setup for all parameters except that all land cover heights and densities are set to 0 (zero). The results of this scenario and the CCC model are compared to quantify the instream temperature effects associated with current vegetation in the modeled stream areas.

Tributary Temperatures: This scenario is equivalent to the CCC model setup for all parameters except for any tributaries associated with applicable temperature standard exceedances in the model extents and period. For any such tributaries, their entire temperature dataset, used as a model tributary input, is reduced by the maximum exceedance that occurred in that tributary during the model period. The results of this scenario and the CCC model are compared to quantify the instream temperature effects of tributary temperature standard exceedances on the modeled streams.

Table 4-2: Sandy Subbasin scenarios: Descriptive summary.

Scenario #	Scenario	ID	Equivalent to CCC except:
2	Future Point Source[1]	FPS	With new planned point source (City of Sandy WWTP) as modified tributary input
3	No Point Sources[1]	NoPS	No NPDES-permitted point source discharges
4	TMDL Wasteload Allocations[1]	WLA_A; WLA_B	NPDES-permitted point source discharges reflect proposed WLAs
5	Restored Vegetation A	RV_A	Fully restored vegetation in all human-affected areas
	Restored Vegetation B	RV_B	Fully restored vegetation in all human-affected areas except existing infrastructure (i.e., buildings, roads, utility corridors)
6	No Dams[2]	ND	**Bull Run R.**: ND model represents stream morphology w/o Bull Run River Dams #1 & #2 ; **Sandy R.:** Bull Run R. tributary inputs reflect Bull Run R. ND model outputs.
7	Natural Flow[1]	NQ	Boundary & tributary flows reflect median natural monthly flows (i.e., no anthropogenic hydromodification or water withdrawals)
8	Water Withdrawals[1]	WW_A; WW_B, WW_C	Same as NQ but accounts for consumptive use water withdrawals of: (A) 1.90%; (B) 10.10%, and (C) current consumptive uses, 28% (July), 29% (Aug.), and 34% (Sept.)
9	Background	BG	Equivalent to combined RV_A, NoPS, & ND scenarios.
10	Protected Vegetation A[3]	PV_A	Protected areas have riparian vegetation restoration as described for the RV_B scenario[3]; unprotected areas have CCC vegetation.
	Protected Vegetation B[3]	PV_B	Protected areas have riparian vegetation restoration as described for the RV_B scenario [3]; unprotected areas have no vegetation.
11	Topography	Topo	All vegetation heights & densities are set to 0 (zero)
12	Tributary Temps.	TT	For any tributaries with applicable temperature standard exceedances in the model period, their entire temperature dataset is reduced by the maximum exceedance.

[1] Scenario only applies to the Sandy River Mainstem model.
[2] Scenario does not apply to Salmon River.
[3] Federal DMAs have 300 ft protected stream buffer; protected Clackamas County and ODF-Private DMAs area have 100 ft protected stream buffer.

Table 4-3: Sandy Subbasin scenarios: Explanation of comparisons.

Scenario 1	Scenario 2	Question/topic addressed
FPS	CCC	Effect of proposed City of Sandy WWTP discharge.[1]
ND	CCC	Effect of existing dams & reservoirs.[2]
NoPS	CCC	Effect of NPDES-permitted point sources.[1]
BG	BBNC	Effect of background (non-anthropogenic) sources.
Topo	CCC	Effect of current shading.
TT	CCC	Effect of tributary temperature standard exceedances.
WLA (A&B)	CCC	Effect of achieving HUAs.[1]
WLA (A&B)	NoPS	Effect of point source discharge at WLAs levels.[1]
NQ	WW_A	Effect of water withdrawals based on percent consumptive use (1.90%) that attain the allocation of 0.05 HUA. [1]
NQ	WW_B	Effect of water withdrawals based on percent consumptive use (10.10%) that attain 0.3 HUA. [1]
NQ	WW_C	Effect of water withdrawals based on current percent consumptive use. [1]
RV_A	CCC	Effect of current anthropogenic riparian vegetation alteration.
RV_A	RV_B	Effect of unrestored vs. restored vegetation in infrastructure zones.
RV_A	PV_A[3,4]	Effects of fully restored vegetation in protected & unprotected areas (RV_A) vs. TMDL shade targets in currently protected areas & CCC veg in unprotected areas (PV_A).[5]
RV_A	PV_B[3,4]	Effects of fully restored vegetation in protected & unprotected areas (RV_A) vs. TMDL shade targets in currently protected areas & no veg in unprotected areas (PV_B).[5]
PV_A[3,4]	CCC	Effects of RV_B vegetation in protected areas and CCC vegetation in unprotected areas (PV_A) vs. current conditions.
PV_B[3,4]	CCC	Effects of RV_B vegetation in protected areas and no vegetation in unprotected areas (PV_B) vs. current conditions.
PV_A[3,4]	PV_B[3,4]	Effect of removal of unprotected areas' shade vegetation [5]

[1] Comparison applies only to the Sandy River Mainstem model.
[2] Comparison applies only to the Sandy and Bull Run Rivers.
[3] Federal DMAs have 300 ft protected stream buffer; protected Clackamas County and ODF-Private DMAs area have 100' protected stream buffer.
[4] Protected vegetation scenarios are currently only applicable to Salmon River.
[5] Comparison applies only to the Salmon River model.

Table 4-4: Protected Vegetation scenario setup for Salmon River.

DMA	Protected buffer width (ft)	Protected buffer width (m)	Buffer information source
Clackamas County	100	30.5	Clackamas County ZDO Section 704, 706, and 709, personal communication Ben Blessing
ODF - Private	100	30.5	ORS 527.610 through 527.992, and OAR 629-600 through 629-665
US BLM	300	91.4	BLM (2016)
USFS	300	91.4	USFS and BLM (1994)
ODOT	0	0	No change from CCC. Road right of way

4.3 Salmon River

For Salmon River modeled current conditions and each modeled scenario, **Table 4-5** provides: maximum 7DADM at the mouth; and the maximum temperature differences between current conditions and each scenario at the mouth and POMI. Scenarios that were inapplicable to the Salmon River were: restored stream flow, no point sources, TMDL wasteload allocations, and no dams. This is because there were insignificant permitted withdrawals, no permitted discharges, and no dams present on the Salmon River.

4.3.1 Restored Vegetation (RV)

Comparisons were made among the RV_A, RV_B, and CCC model results. These were completed to address several questions, including:

- RV_B vs. CCC: What are the effects of current human-related vegetation alteration (except existing transportation, buildings, and utility infrastructure and easements) on instream temperatures within the model extent?
- RV_A vs. RV_B: What are the instream temperature effects of existing infrastructure-associated riparian vegetation alteration? Does this meet the infrastructure-specific HUA target (0.06°C on the Salmon River)?

Results of these comparisons are summarized in **Table 4-5** to **Table 4-7** and **Figure 4-1** to **Figure 4-6**. The POMI refers to the stream node (km) with the greatest in-stream temperature change under a given condition. For the comparison of the Salmon River restored vegetation "B" scenario vs. CCC results, the POMI was at river km 6.10 and corresponded to a maximum 7DADM change of 1.21°C on August 29, 2016 (**Table 4-7**, **Figure 4-3)**. At the river mouth, the maximum 7DADM during the model period under current conditions was 18.93°C on July 31, 2016, and under restored vegetation B conditions was 18.55°C on July 30, 2016 (**Table 4-7**). The mean effective shade difference between RV_B and CCC results was 12% along the Salmon River model extent (**Table 4-5, Figure 4-1**, **Figure 4-2**).

Comparing the RV_A and RV_B results, the mean effective shade difference was 0% **(Table 4-6**). The maximum 7DADM difference of +0.06°C between RV_B and RV_A at the POMI (river km 5.95) on August 29, 2016 (**Table 4-7**, **Figure 4-6**) met the infrastructure-specific HUA (0.06°C).

Table 4-5: Salmon River scenario results: Effective shade, RV_B minus CCC.

Extent	Shade (%): RV_B	Shade (%): CCC	Shade gap (%)	Stream km assessed	Total stream km in below shade gap range			
					0-15%	16-25%	26-50%	51-100%
Study Area	39	27	12	13.1	9.5	2.4	1.2	0
Clackamas Cty.	37	25	12	6.8	4.7	1.5	0.6	0
ODF - Private	43	27	16	1.2	0.6	0.4	0.2	0
US BLM	36	27	9	4.3	3.6	0.5	0.2	0
USFS	56	41	15	0.7	0.5	0	0.2	0

Table 4-6: Salmon River scenario results: Effective shade, RV_A minus RV_B.

Extent	Shade (%): RV_A	Shade (%): RV_B	Shade gap (%)	Stream km assessed	Total stream km in below shade gap range			
					0-15%	16-25%	26-50%	51-100%
Study Area	39	39	0	13.1	0	0	0	0
Clackamas Cty.	38	37	1	6.8	6.8	0	0	0
ODF - Private	43	43	0	1.2	1.2	0	0	0
US BLM	36	36	0	4.3	4.3	0	0	0
USFS	56	56	0	0.7	0.7	0	0	0

Table 4-7:Salmon River scenario results: Temperature, CCC, RV_A, and RV_B.

Scenario	Value type	Location	Model km	Maximum 7DADM	
				Date	WT (°C)
Current Condition (CCC)	CCC	Mouth	0	07/31/2016	18.93
Restored Vegetation (RV_B)	RV_B	Mouth	0	07/30/2016	18.55
	CCC - RV_B	Mouth	0	08/30/2016	0.69
		POMI	6.10	08/29/2016	1.21
Restored Vegetation, Modified (RV_A)	RV_A	Mouth	0	07/30/2016	18.57
	RV_B - RV_A	Mouth	0	09/04/2016	0.01
		POMI	5.95	08/29/2016	0.06

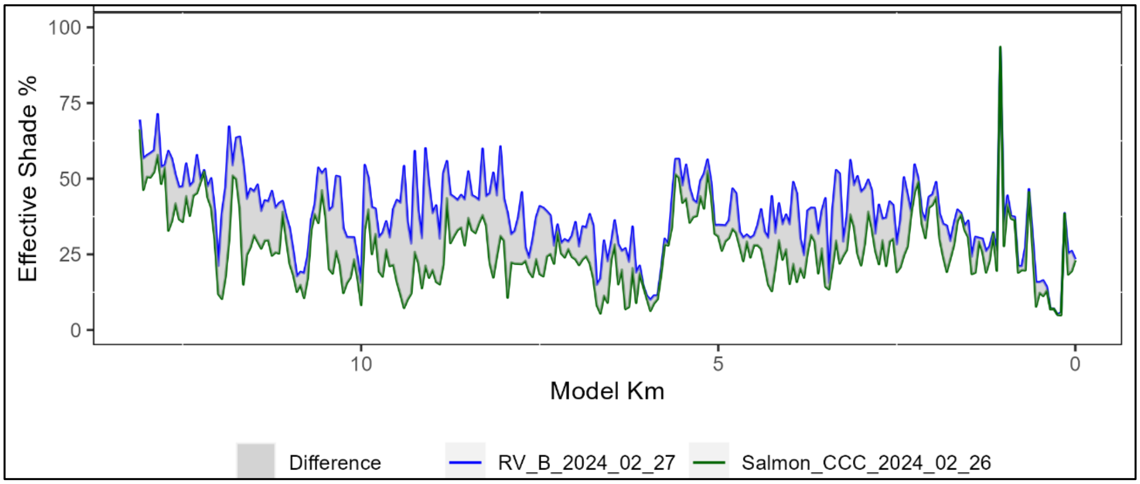

Figure 4-1: Salmon River scenario results: Longitudinal effective shade, RV_B and CCC.

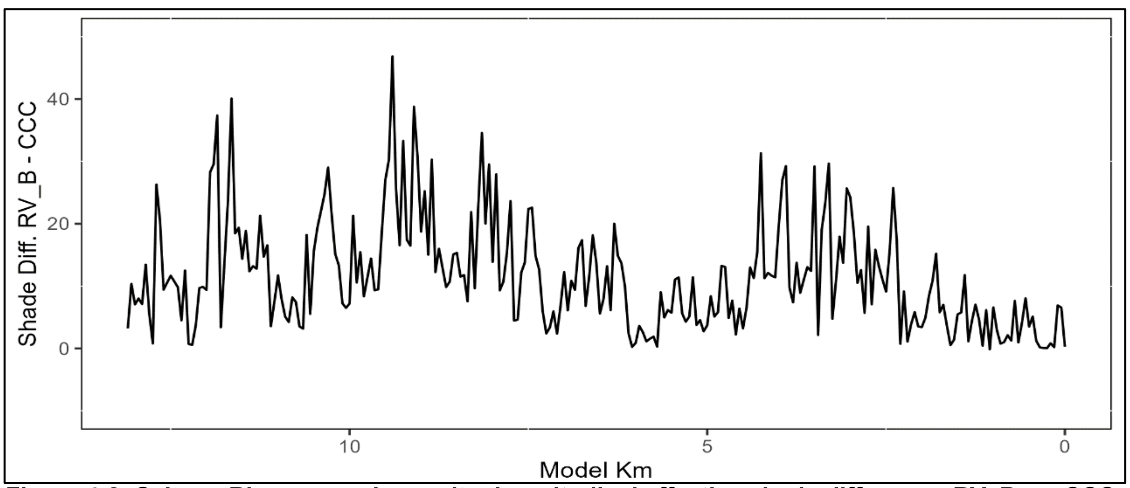

Figure 4-2: Salmon River scenario results: Longitudinal effective shade difference, RV_B vs. CCC.

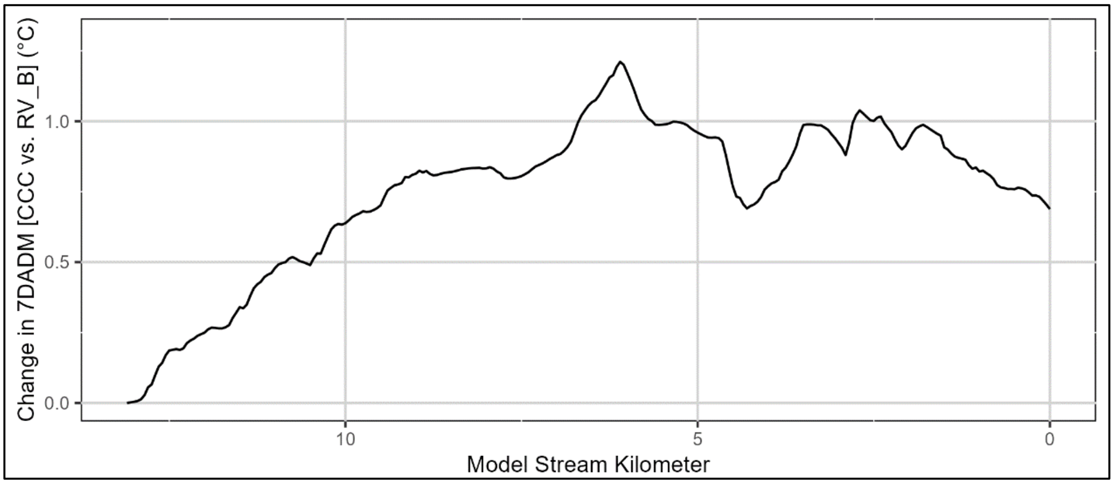

Figure 4-3: Salmon River scenario results: Longitudinal 7DADM temperature differences, CCC vs. RV_B.

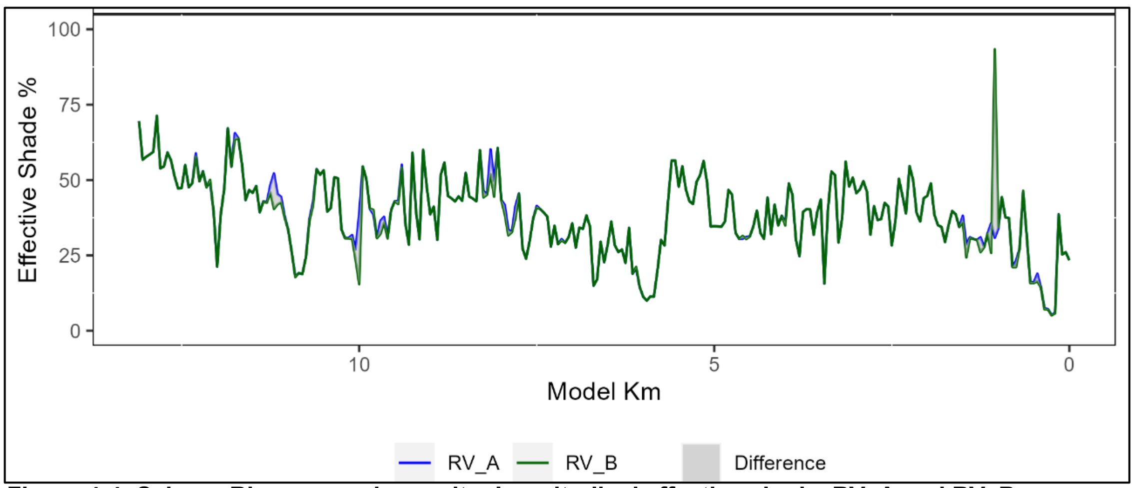

Figure 4-4: Salmon River scenario results: Longitudinal effective shade, RV_A and RV_B.

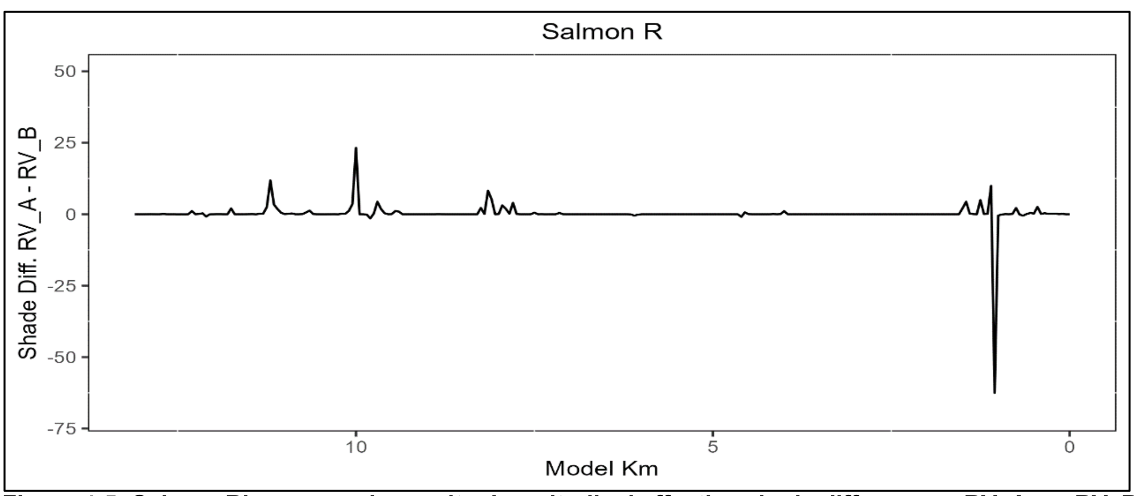

Figure 4-5: Salmon River scenario results: Longitudinal effective shade differences: RV_A vs. RV_B.

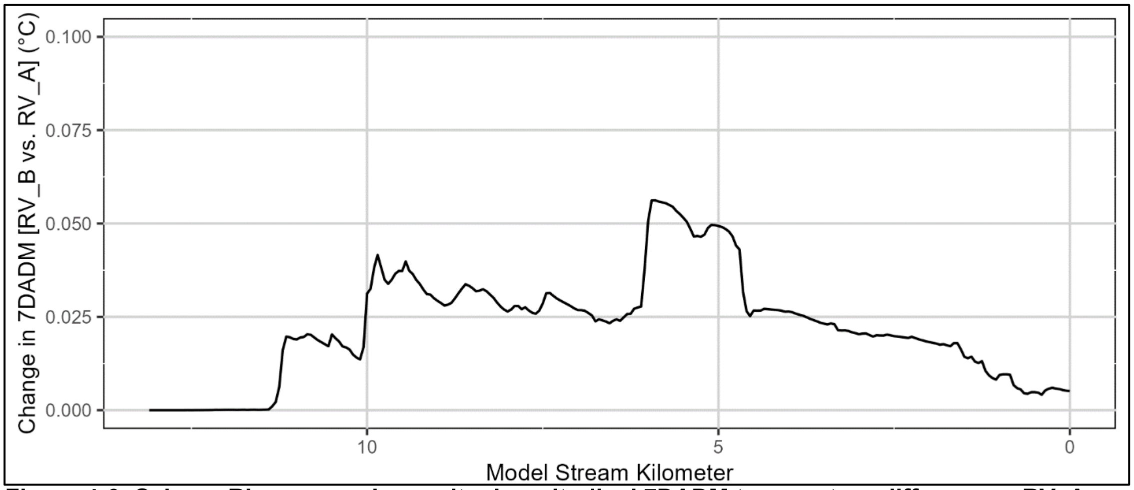

Figure 4-6: Salmon River scenario results: Longitudinal 7DADM temperature differences, RV_A vs. RV_B.

4.3.2 Protected Vegetation (PV)

Several comparisons were made among the various protected vegetation (PV), restored vegetation (RV), and CCC model scenarios' results. These were completed to address several questions, including:

- PV_A vs. CCC: Compared to current conditions, what effect would the RV_B scenario have if only in currently protected areas?
- PV_B vs. CCC: Compared to current conditions, what effect would the RV_B scenario in currently protected areas with vegetation removal in unprotected areas have?
- PV_A vs. RV_B: Will the RV_B scenario in currently protected areas attain the overall TMDL effective shade targets and allocated HUA if vegetation in unprotected areas remains as-is (i.e., under CCC)?
- PV_B vs. RV_B: Will the RV_B scenario in currently protected areas attain the TMDL effective shade targets and allocated HUA if land cover in unprotected areas is removed?
- PV_A vs PV_B: What effect would removal of unprotected areas' vegetation have if existing protection measures (as in RV_B scenario) are fulfilled in protected areas?

Results of these comparisons are presented in **Table 4-8**, **Table 4-9**, and **Figure 4-7** to **Figure 4-15**.

Table 4-8: Salmon River Protected Vegetation scenario results: Effective shade comparisons.

	Shade results (%) by scenario		Shade gap (%)	Stream km assessed	Total stream km in below shade gap range			
					0-15%	16-25%	26-50%	51-100%
Extent	**PV_A**	**CCC**						
Study Area	37	27	10	13.1	10.1	2.5	0.6	0
Clackamas Cty.	34	25	9	6.8	5.6	0.9	0.2	0
ODF - Private	42	27	15	1.2	0.4	0.6	0.2	0
US BLM	37	27	10	4.3	3.5	0.8	0.1	0
USFS	54	41	13	0.7	0.5	0.1	0	0
Extent	**PV_B**	**CCC**						
Study Area	36	27	9	13.1	10.1	2.5	0.6	0
Clackamas Cty.	33	25	8	6.8	5.6	1	0.1	0
ODF - Private	42	27	15	1.2	0.6	0.5	0.2	0
US BLM	36	27	9	4.3	3.5	0.8	0.1	0
USFS	54	41	13	0.7	0.5	0.1	0	0
Extent	**PV_A**	**PV_B**						
Study Area	37	36	1	13.1	13	0	0	0
Clackamas Cty.	34	33	1	6.8	6.7	0	0	0
ODF - Private	42	42	0	1.2	1.2	0	0	0
US BLM	37	36	1	4.3	4.3	0	0	0
USFS	54	54	0	0.7	0.7	0	0	0
Extent	**RV_B**	**PV_A**						
Study Area	39	37	2	13.1	12.9	0.1	0.1	0
Clackamas Cty.	37	34	3	6.8	6.6	0.1	0.1	0
ODF - Private	43	42	1	1.2	1.2	0	0	0
US BLM	36	37	-1	4.3	4.3	0	0	0
USFS	56	54	2	0.7	0.7	0	0	0
Extent	**RV_B**	**PV_B**						
Study Area	39	36	3	13.1	12.7	0.3	0.1	0
Clackamas Cty.	37	33	4	6.8	6.4	0.2	0.1	0
ODF - Private	43	42	1	1.2	1.2	0	0	0
US BLM	36	36	0	4.3	4.3	0	0	0
USFS	56	54	2	0.7	0.7	0	0	0

Table 4-9: Salmon River scenario results: Temperature, CCC, RV_A, PV_A, and PV_B.

Scenario	Value type	Location	Model km	Maximum 7DADM	
				Date	WT (°C)
Current Condition (CCC)	**CCC**	Mouth	0	07/31/2016	18.93
Protected Vegetation version A (PV_A)	**PV_A**	Mouth	0	07/30/2016	18.58
	CCC - PV_A	Mouth	0	08/30/2016	0.61
		POMI	2.70	08/26/2016	0.97
	PV_A - RV_B	Mouth	0	08/31/2016	0.08
		POMI	6.00	08/29/2016	0.29
Protected Vegetation version B (PV_B)	**PV_B**	Mouth	0	07/30/2016	18.70
	CCC - PV_B	Mouth	0	08/30/2016	0.47
		POMI	2.70	08/26/2016	0.91
	PV_B - RV_B	Mouth	0	08/30/2016	0.22
		POMI	6.00	08/29/2016	0.36
	PV_A - PV_B	Mouth	0	08/27/2016	0.15
		POMI	0.00	08/27/2016	0.15

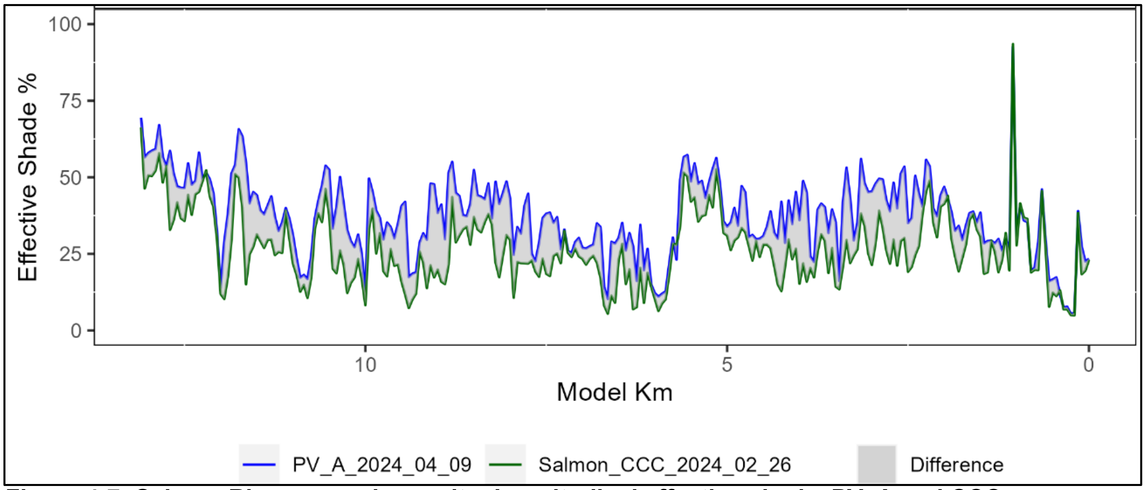

Figure 4-7: Salmon River scenario results: Longitudinal effective shade, PV_A and CCC.

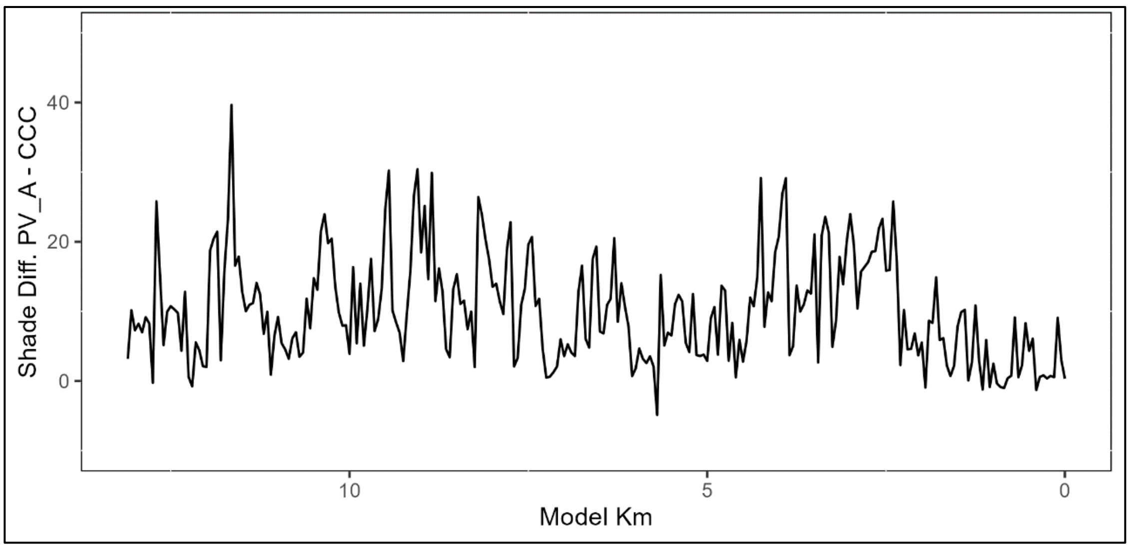

Figure 4-8: Salmon River scenario results: Longitudinal effective shade differences, PV_A vs. CCC.

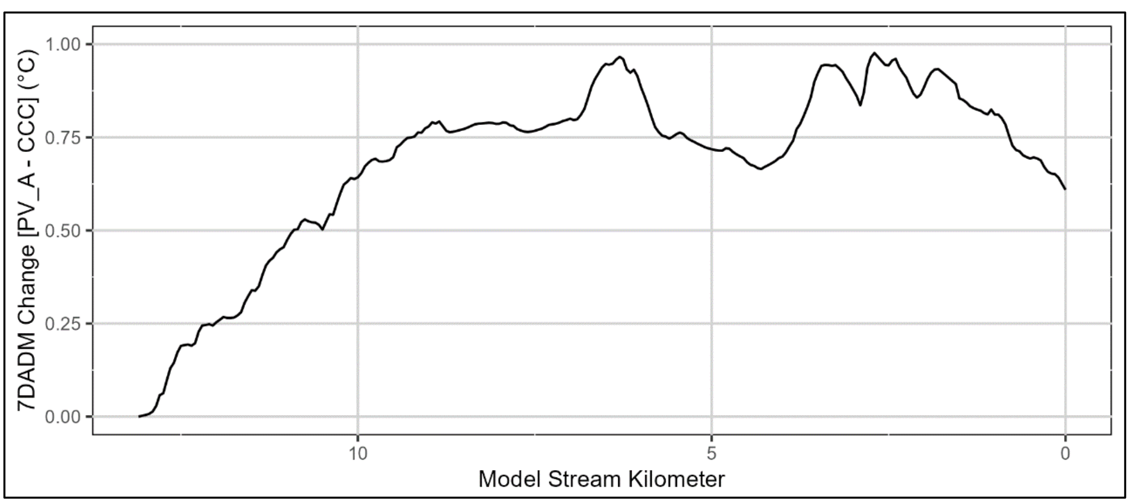

Figure 4-9: Salmon River scenario results: Longitudinal 7DADM temperature differences, PV_A vs. CCC.

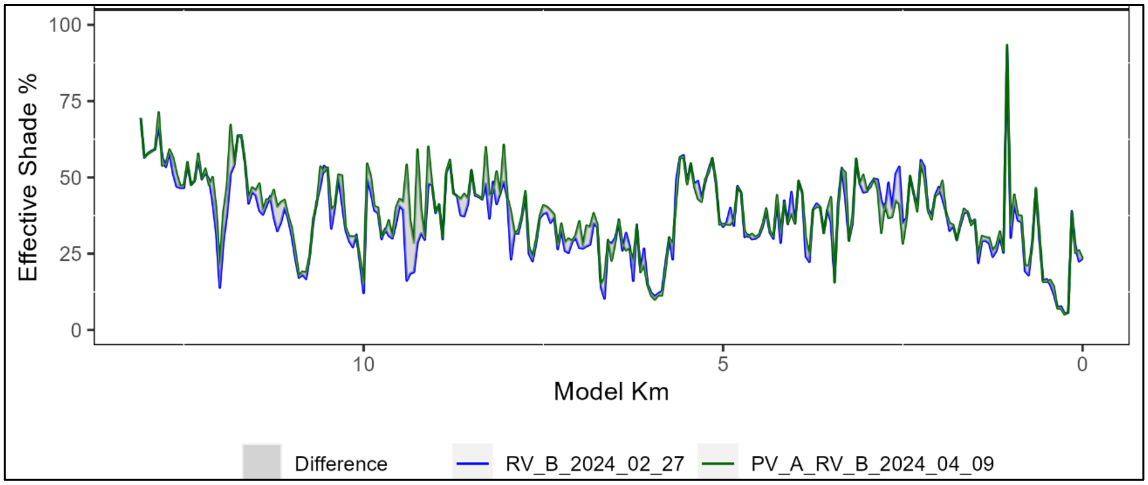

Figure 4-10: Salmon River scenario results: Longitudinal effective shade, RV_B and PV_A.

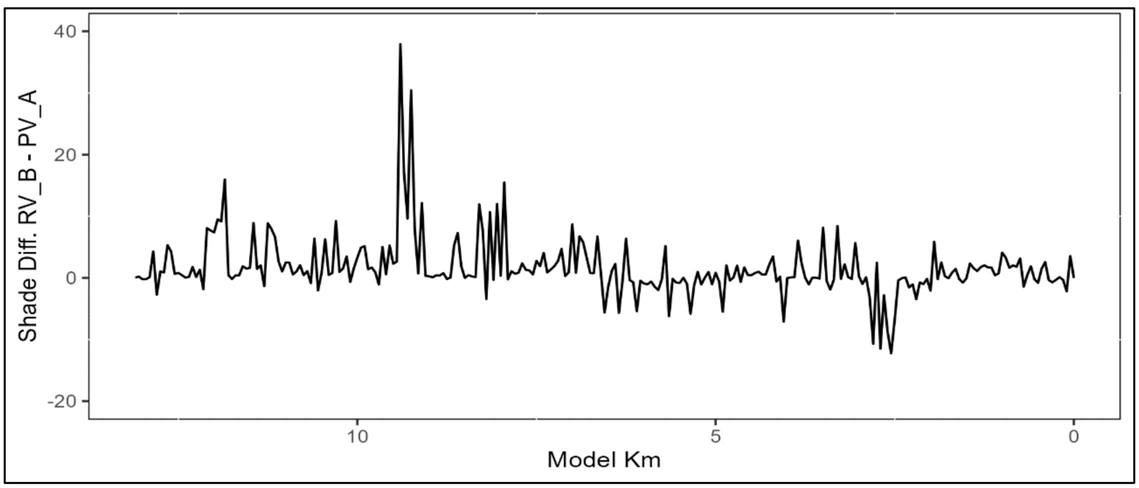

Figure 4-11: Salmon River scenario results: Longitudinal effective shade differences, RV_B vs. PV_A.

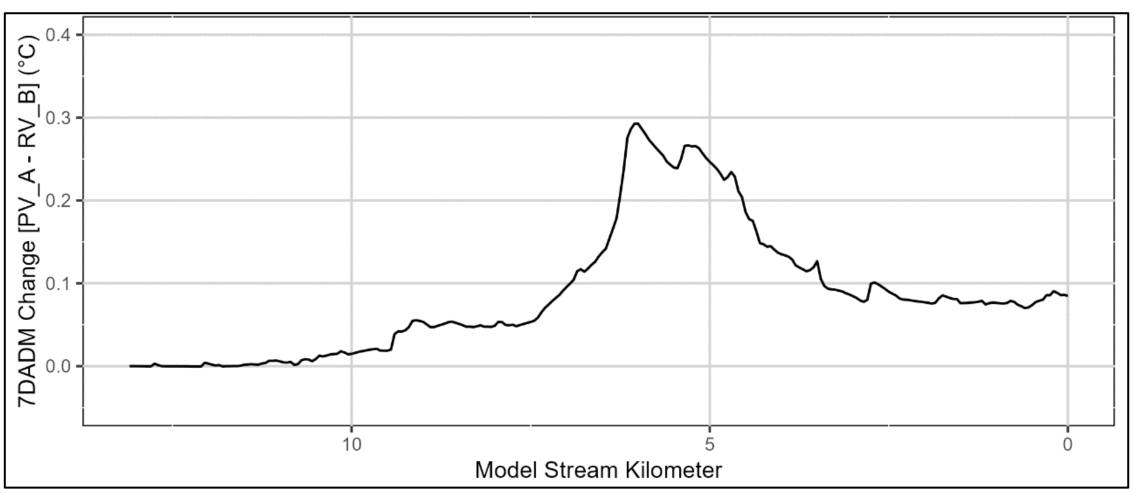

Figure 4-12: Salmon R scenario results: Longitudinal 7DADM temperature differences: PV_A vs. RV_B.

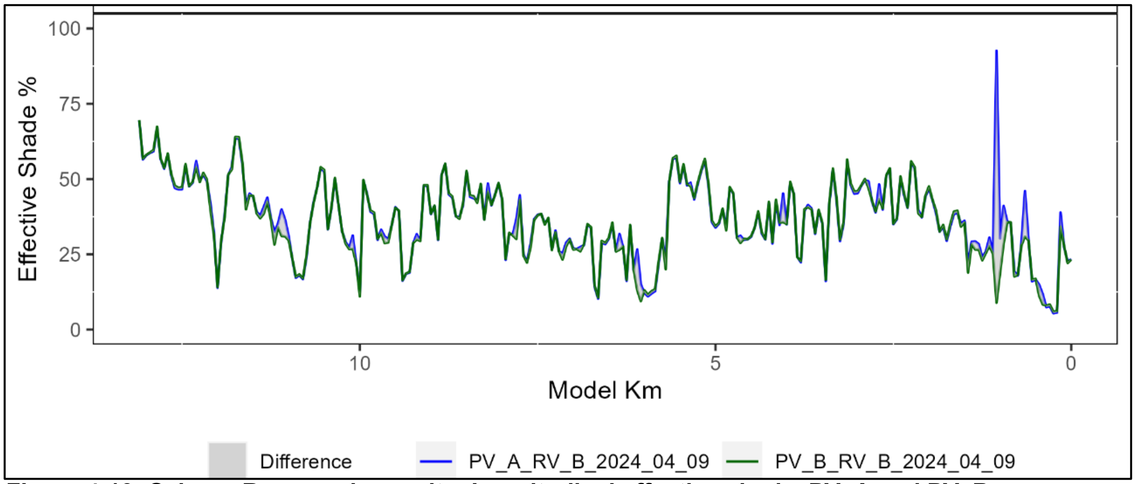

Figure 4-13: Salmon R. scenario results: Longitudinal effective shade, PV_A and PV_B.

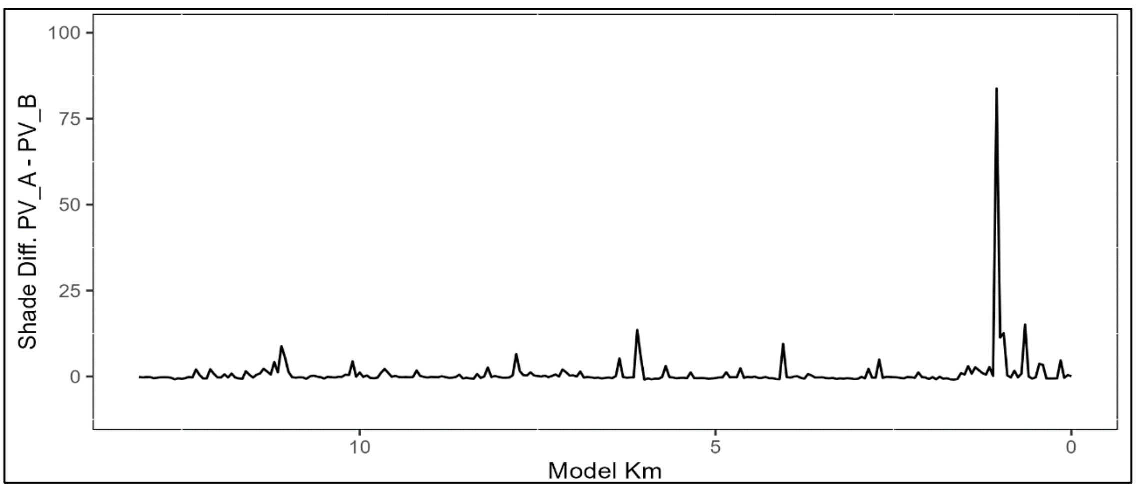

Figure 4-14: Salmon River scenario results: Longitudinal effective shade differences, PV_A vs. PV_B.

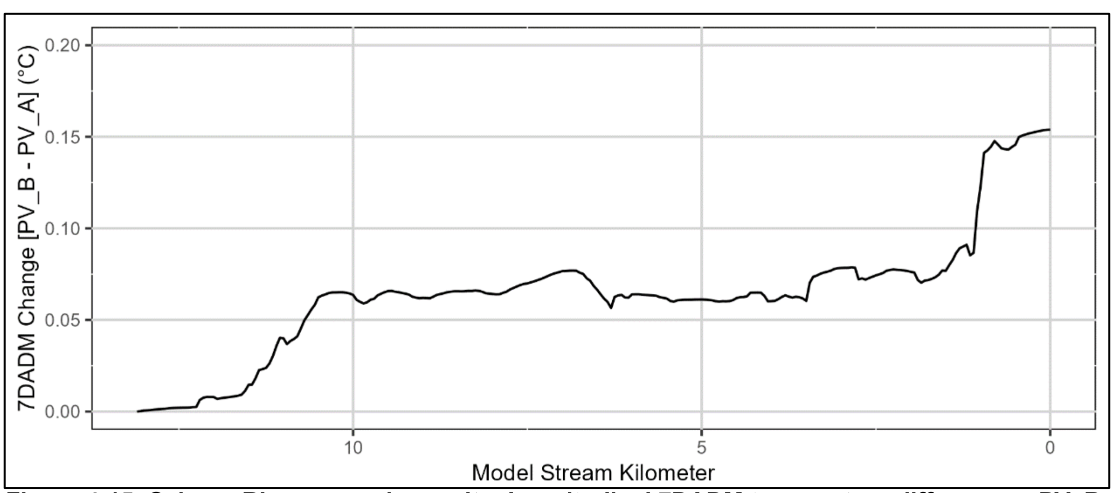

Figure 4-15: Salmon River scenario results: Longitudinal 7DADM temperature differences: PV_B vs. PV_A.

4.3.3 Topography (Topo)

Results of the Topography and CCC models were compared to determine the maximum 7DADM temperature effect of existing vegetative shading that is under human control. The results indicated a mean effective shade gap of 19% (**Table 4-10**, **Figure 4-16, Figure 4-17**) across the Salmon River model area that was associated with a maximum 7DADM change of 1.58°C at the POMI (RKM 0.60) on August 29, 2016 (**Table 4-11**, **Figure 4-18**).

Table 4-10: Salmon River model results: Effective shade, CCC vs. Topography scenario.

Extent	Shade (%): Topo	Shade (%): CCC	Shade gap (%)	Stream km assessed	Stream km: 0-15% Shade Gap	Stream km: 16-25% Shade Gap	Stream km: 26-50% Shade Gap	Stream km: 51-100% Shade Gap
Study Area	8	27	19	13.1	4.8	5	3.2	0
Clackamas Cty.	7	25	18	6.8	2.4	2.9	1.4	0
ODF - Private	9	27	18	1.2	0.5	0.5	0.2	0
US BLM	8	27	19	4.3	1.8	1.6	1	0
USFS	16	41	25	0.7	0.1	0.1	0.5	0

Table 4-11: Salmon River scenario results: Temperature, Topo vs. CCC.

Scenario	Value type	Location	Model km	Maximum 7DADM	
				Date	WT (°C)
Current Condition (CCC)	**CCC**	Mouth	0	07/31/2016	18.93
Topography	**Topo**	Mouth	0	08/19/2016	20.02
	Topo - CCC	Mouth	0	08/29/2016	1.47
		POMI	0.60	08/29/2016	1.58

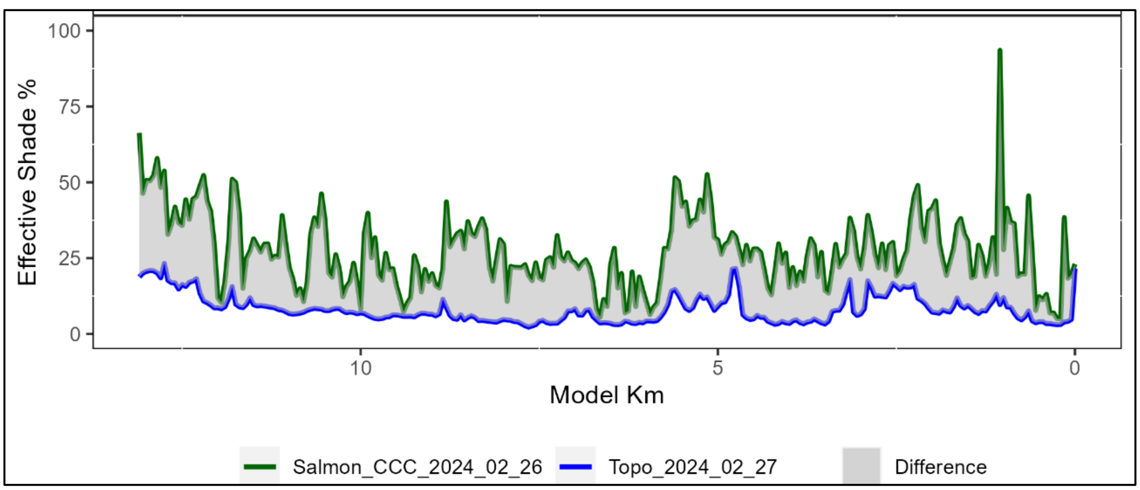

Figure 4-16: Salmon River scenario results: Longitudinal effective shade, Topography vs. CCC.

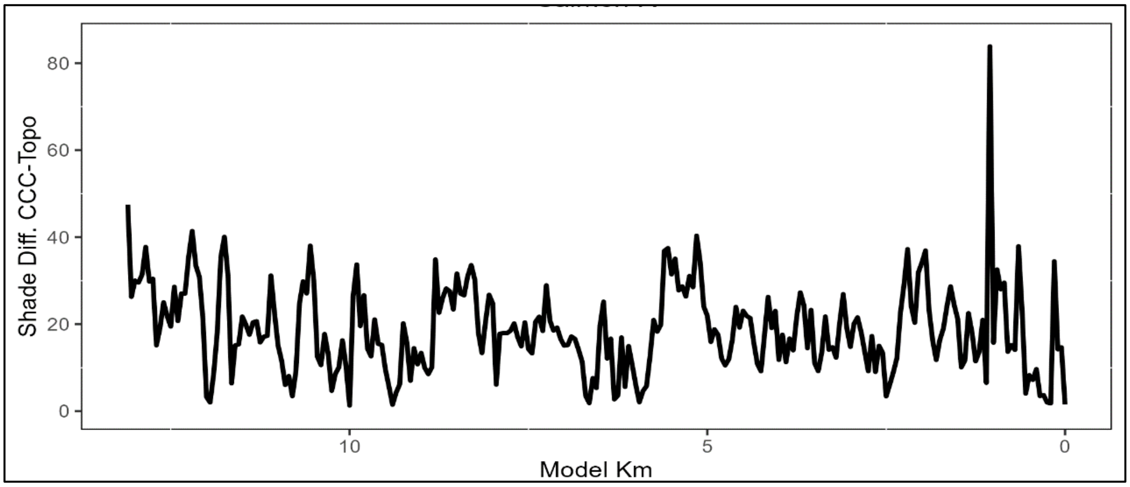

Figure 4-17: Salmon River scenario results: Longitudinal effective shade differences, Topography vs. CCC.

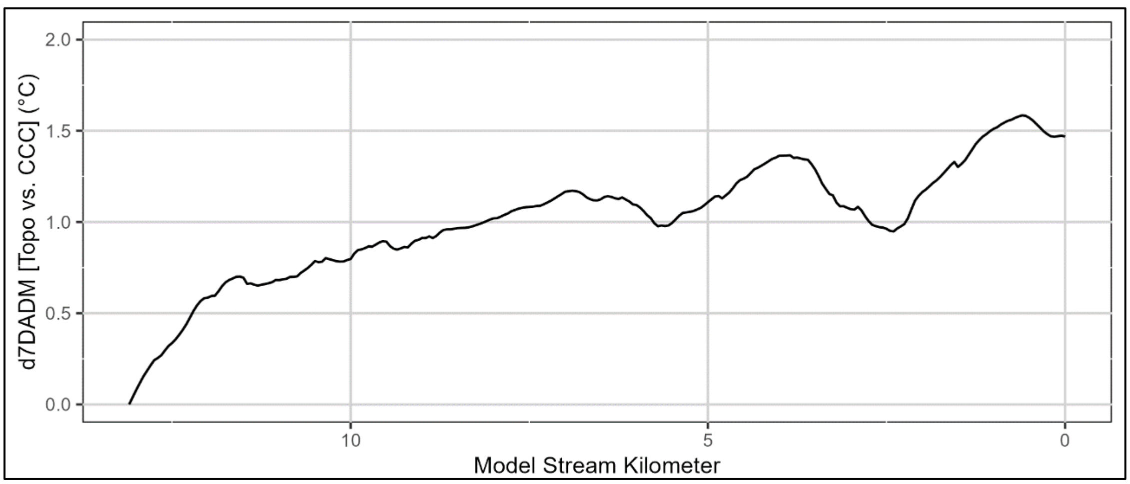

Figure 4-18: Salmon River scenario results: Longitudinal 7DADM temp differences, Topography vs. CCC.

4.3.4 Tributary temperatures (TT)

Results of the TT and CCC models were compared to determine the effect of tributary temperature standard exceedances on Salmon River water temperatures in terms of maximum 7DADM change. The results indicated a maximum 7DADM change of 4.00°C at the POMI (river km 13.10) on July 27, 2016 (**Table 4-12**, **Figure 4-19)**.

Table 4-12: Salmon River scenario results: Temperature, Tributary Temps. vs. CCC.

Scenario	Value type	Location	Model km	Maximum 7DADM	
				Date	WT (°C)
Current Condition (CCC)	CCC	Mouth	0	07/31/2016	18.93
Tributary Temperatures (TT)	TT	Mouth	0	08/19/2016	15.76
	CCC - TT	Mouth	0	07/23/2016	3.23
		POMI	13.10	07/27/2016	4.00

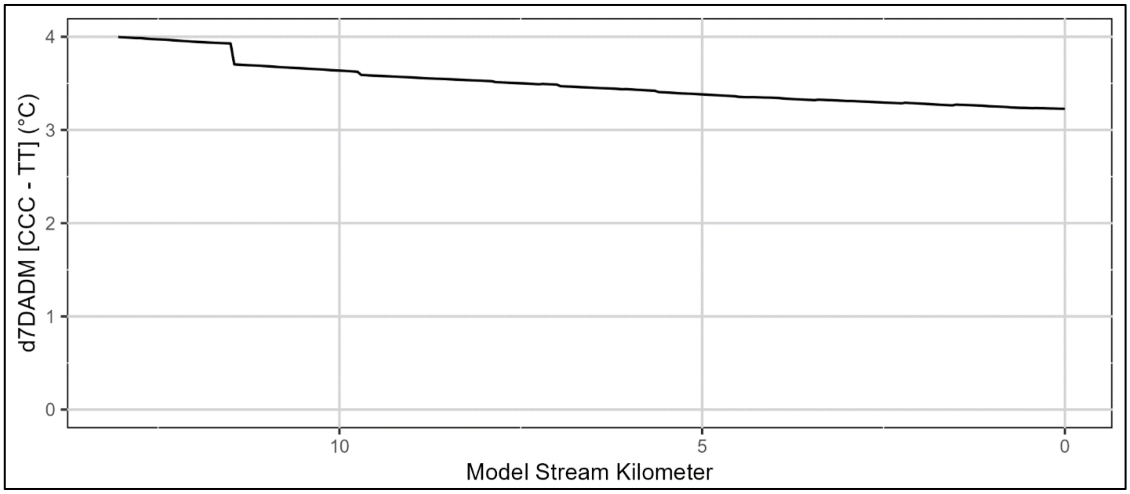

Figure 4-19: Salmon River scenario results: Longitudinal 7DADM temperature differences, TT vs. CCC.

4.3.5 Background (BG)

For the Salmon River, the BG scenario conditions are equal to the RV_A conditions and the results are identical to those presented in Section 4.3.1. The BG scenario results were compared to the applicable BBNC to identify the extent and magnitude of temperature exceedances that would occur in the absence of anthropogenic influences, i.e., due to background factors. **Figure 4-20** shows the 7DADM maximum for each node on the Salmon River extent and the applicable BBNCs by date. The maximum 7DADM exceedance (5.11°C) occurred on August 21, 2016, at river km 0.00, which corresponded to a 7DADM of 18.11°C. Thus, background influences were estimated to result in a maximum temperature exceedance of 5.11°C. From **Figure 4-20**, it is also evident that the modeled background conditions would result in applicable BBNC exceedances through the entire Salmon River model extent at least sometime(s) during the model period.

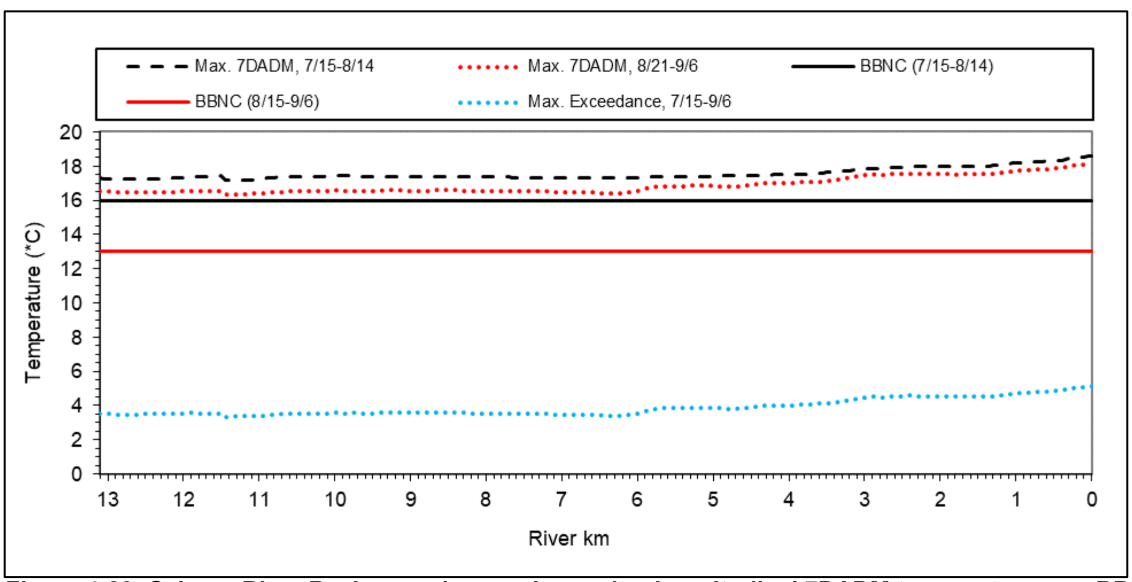

Figure 4-20: Salmon River Background scenario results: Longitudinal 7DADM temperatures vs. BBNC.

4.4 Little Sandy River

Results of the RV and CCC models were compared to determine the maximum 7DADM effect of existing vegetative shading that is under human control. The results indicated a mean effective shade gap of 6% (**Table 4-13**, **Figure 4-21**) across the Little Sandy River model area that was associated with a maximum 7DADM change of 0.72°C at the POMI (river km 2.90) (**Table 4-14**, **Figure 4-22)**.

A comparison of the RV scenario results to the applicable BBNC (16.0°C for Aug. 9) was completed as an estimate of the influence of background factors on temperature exceedances. **Table 4-13**, **Table 4-14**, and **Figure 4-22** indicate that the daily maximum temperature (20.03°C) would exceed the applicable BBNC by 4.03°C at the POMI, and that exceedances occurred from river km 1.7 to the mouth (0.0). Note that the daily maximum temperature value is not directly comparable to the BBNC, which is based on the 7DADM temperature.

Table 4-13: Little Sandy River model results: Effective shade, CCC vs. RV_A.

Extent	Shade (%): CCC	Shade (%): RV_A	Shade gap (%)	Stream km assessed	Total stream km in below shade gap range			
					0-15%	16-25%	26-50%	51-100%
Study Area	64	69	6	17.2	15.7	0.3	0.2	1.1
ODF - Private	74	74	0	1.3	1.3	0	0	0
US BLM	54	66	12	6.4	5.1	0.1	0.1	1.1
USFS	69	71	2	9.6	9.5	0.1	0	0

Table 4-14: Little Sandy River model results: Temperature, CCC vs. RV_A.

Scenario	Value type	Location	Model km	Daily maximum temperature (°C)
Current Condition (CCC)	CCC	Mouth	0.0	19.64
		POMI	2.9	20.16
Restored Vegetation (RV_A)	RV_A	Mouth	0.0	20.03
		POMI	2.9	19.43
Comparison	RV_A - CCC	Mouth	0.0	-0.39
		POMI	2.9	0.72

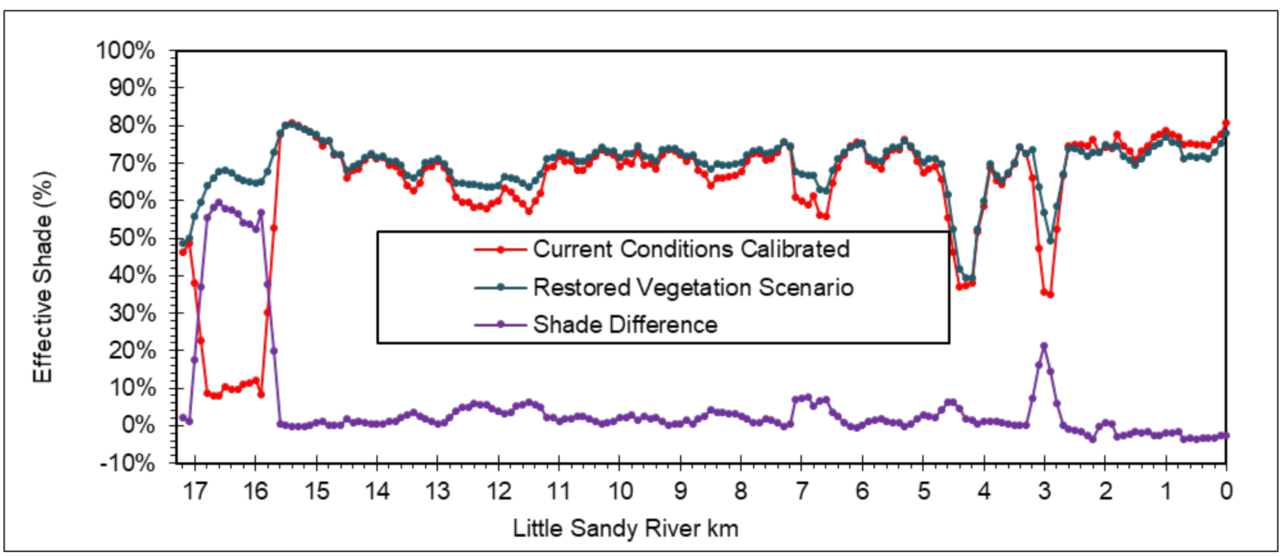

Figure 4-21: Little Sandy River model results: Longitudinal effective shade, CCC and RV scenario.

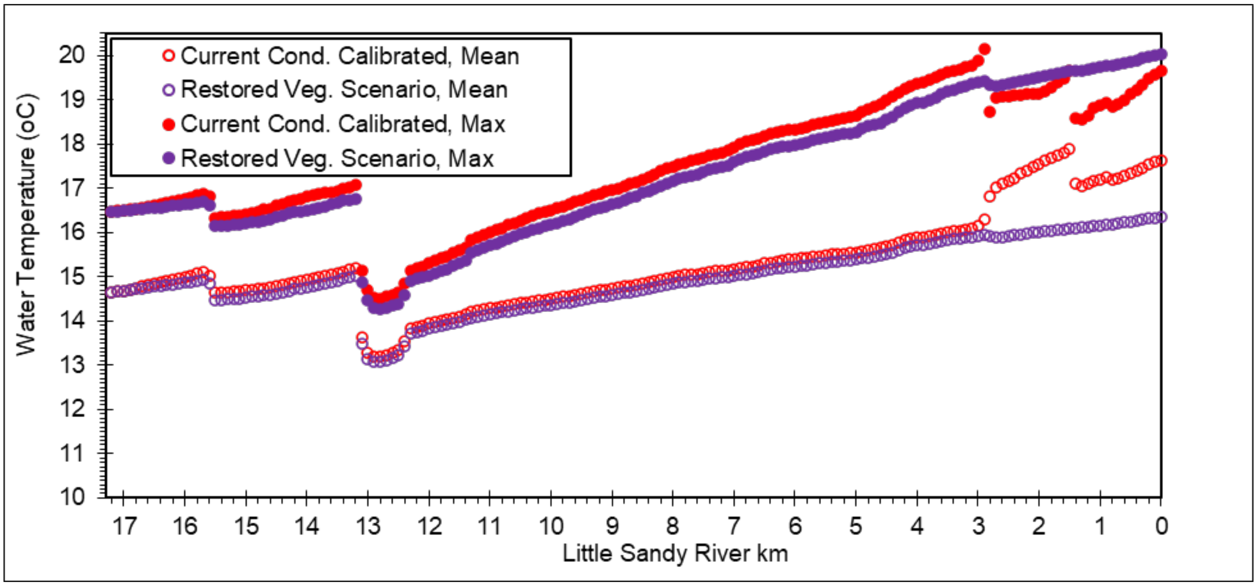

Figure 4-22: Little Sandy River model results: Longitudinal temperature, CCC and RV scenario.

4.5 Zigzag River

Results of the RV and CCC models were compared to determine the maximum 7DADM effect of existing vegetative shading that is under human control. The results indicated a mean effective shade gap of 13% (**Table 4-15**, **Figure 4-23**) across the Zigzag River model area that was associated with a maximum 7DADM change of 0.55°C at the POMI (river km 0.00 (mouth)) (**Table 4-16**, **Figure 4-24**).

A comparison of the RV scenario results to the applicable BBNC (16.0°C for August 9) was completed to estimate the influence of background factors on temperature exceedances. **Table 4-16** and **Figure 4-24** indicate that the daily maximum temperature (16.08°C) would exceed the applicable BBNC by 0.08°C at the POMI, and that exceedances occurred from river km 1.7 to the mouth (0.0). Again, note that the daily maximum temperature value is not directly comparable to the BBNC, which is based on the 7DADM temperature.

Table 4-15: Zigzag River model results: Effective shade, CCC vs. RV_A.

Extent	Shade (%), CCC	Shade (%), RV_A	Shade gap (%)	Stream km assessed	Total stream km in below shade gap range			
					0-15%	16-25%	26-50%	51-100%
Study Area	46	59	13	7.3	5.5	0.8	1.0	0.0
Clackamas Cty.	32	52	20	1.5	0.9	0.1	0.5	0.0
ODF – Private	22	37	15	0.2	0.1	0.1	0.0	0.0
USFS	50	62	12	5.6	4.5	0.6	0.5	0.0

Table 4-16: Zigzag River model results: Temperature, CCC vs. RV_A.

Scenario	Value type	Location	Model km	Daily maximum temperature, (°C)
Current Condition (CCC)	CCC	Mouth/POMI	0.0	16.63
Restored Vegetation (RV_A)	RV_A			16.08
Comparison	RV_A - CCC			0.55

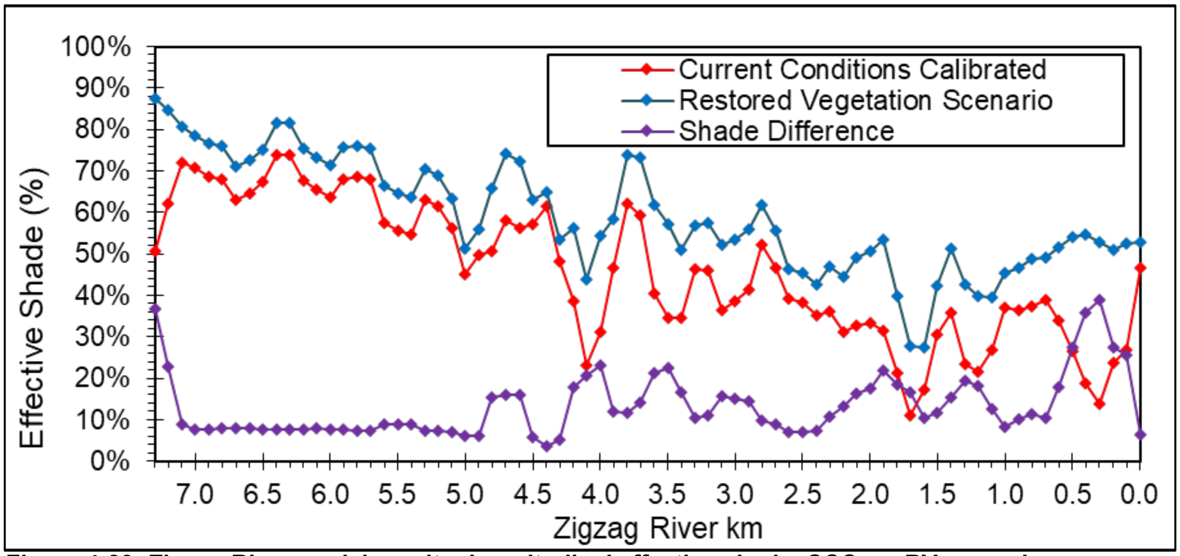

Figure 4-23: Zigzag River model results: Longitudinal effective shade, CCC vs. RV scenario.

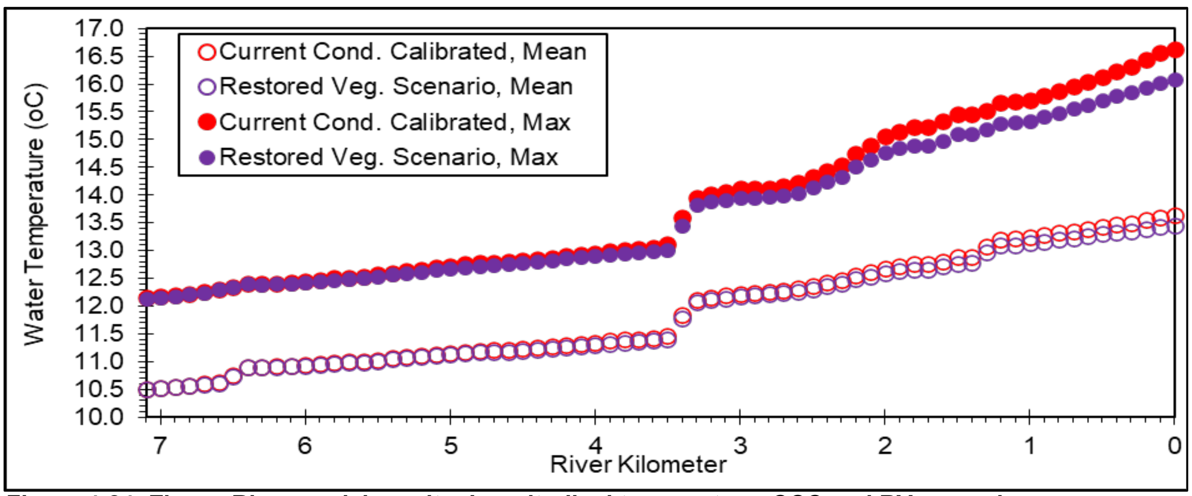

Figure 4-24: Zigzag River model results: Longitudinal temperature, CCC and RV scenario.

4.5.1 Wasteload allocations

The Zigzag River WLA model scenario evaluated the impact of the Government Camp STP WLA discharge (to Camp Creek) on the Zigzag River (downstream) by increasing the Camp Creek (mouth) tributary temperatures by 0.20°C (i.e., the HUA assigned to Government Camp STP) compared to the CCC model. This 0.20°C increase assumed no heat dissipation (an implicit MOS) between the Government Camp STP outfall (Camp Creek km 10.2) and the Camp Creek mouth (km 0.0) where it flows into the Zigzag River. The results of the WLA scenario and the CCC model were compared; again, these models were identical except for the 0.20°C increase to Camp Creek temperatures in the WLA model. The comparison showed a maximum Zigzag River temperature increase of 0.03°C above the applicable BBNC. The only modeled Zigzag River BBNC (16.0°C) exceedances occurred toward its mouth (i.e., river km 0.0 to 0.6), thus the 0.03°C POMI is located in this region.

4.6 Bull Run River

4.6.1 No Dam

Results of the CCC model and the No Dams scenario were compared to determine the effect of existing dams and reservoirs on the Bull Run in terms of maximum 7DADM change. The results indicated a maximum 7DADM change of 1.31°C at the POMI (model segment 98 (the mouth)) on September 14, 2016, due to the presence of existing dams and reservoirs (**Table 4-17**, **Figure 4-25**). **Figure 4-26** shows the spatial (x-axis) and temporal (y-axis) distribution of 7DADM temperatures (as color gradients) in the CCC (upper panel) and No Dams scenarios (lower panel). Likewise, **Figure 4-27** shows the spatial and temporal distribution of the 7DADM temperature changes between the CCC and No Dam scenarios. The upper plot in **Figure 4-27** shows the change for each segment and date, while the bottom plot shows the change only for days when No Dam 7DADM temperatures exceeded the applicable BBNC. The thick black lines in **Figure 4-27** delineate transitions between warming and cooling impacts. The **Figure 4-26** and **Figure 4-27** legends show temperature intervals (ranges) as (x, y] in which the first number is not included in the interval and the second number is included; e.g., (10, 11] includes numbers >10 and ≤11. **Figure 4-27** shows that 7DADM warming attributable to 2016 dam operations mostly begins in September in the lower Bull Run River, especially when considering only warming that contributes to in-stream BBNC exceedances (lower panel). From May to late August, the dams had a cooling effect on 7DADM temperatures except for a few reaches and days. See TSD Appendix D for the No Dam scenario setup details.

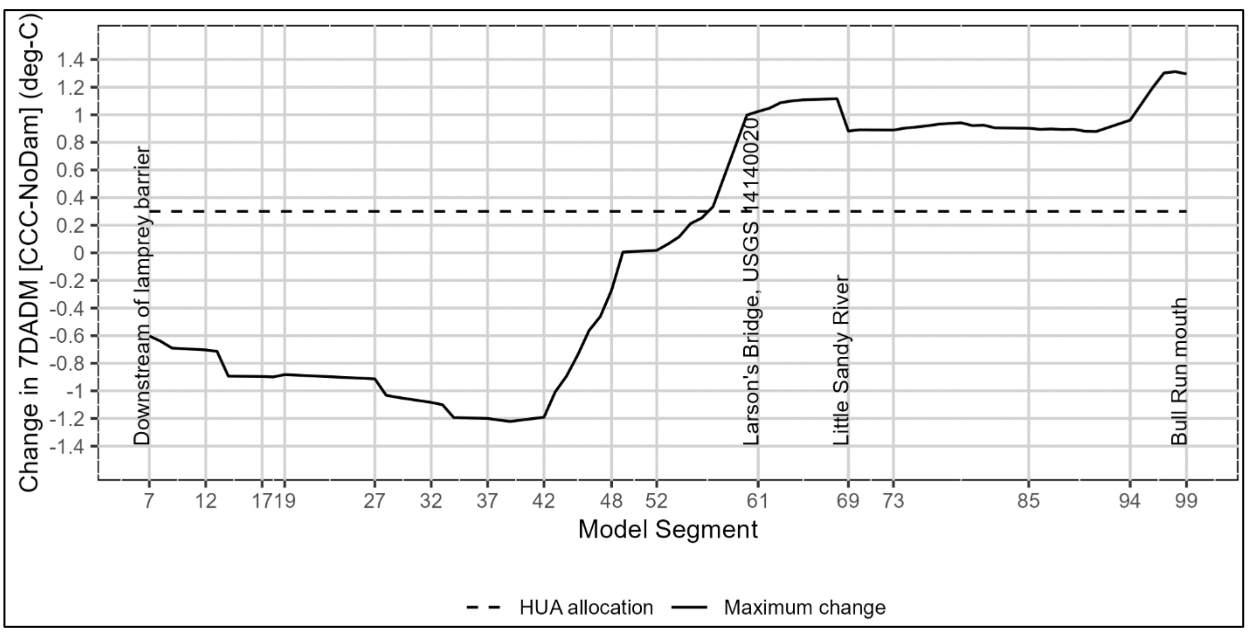

Figure 4-25: Bull Run River model results: Longitudinal maximum 7DADM temp differences, CCC minus No Dams.

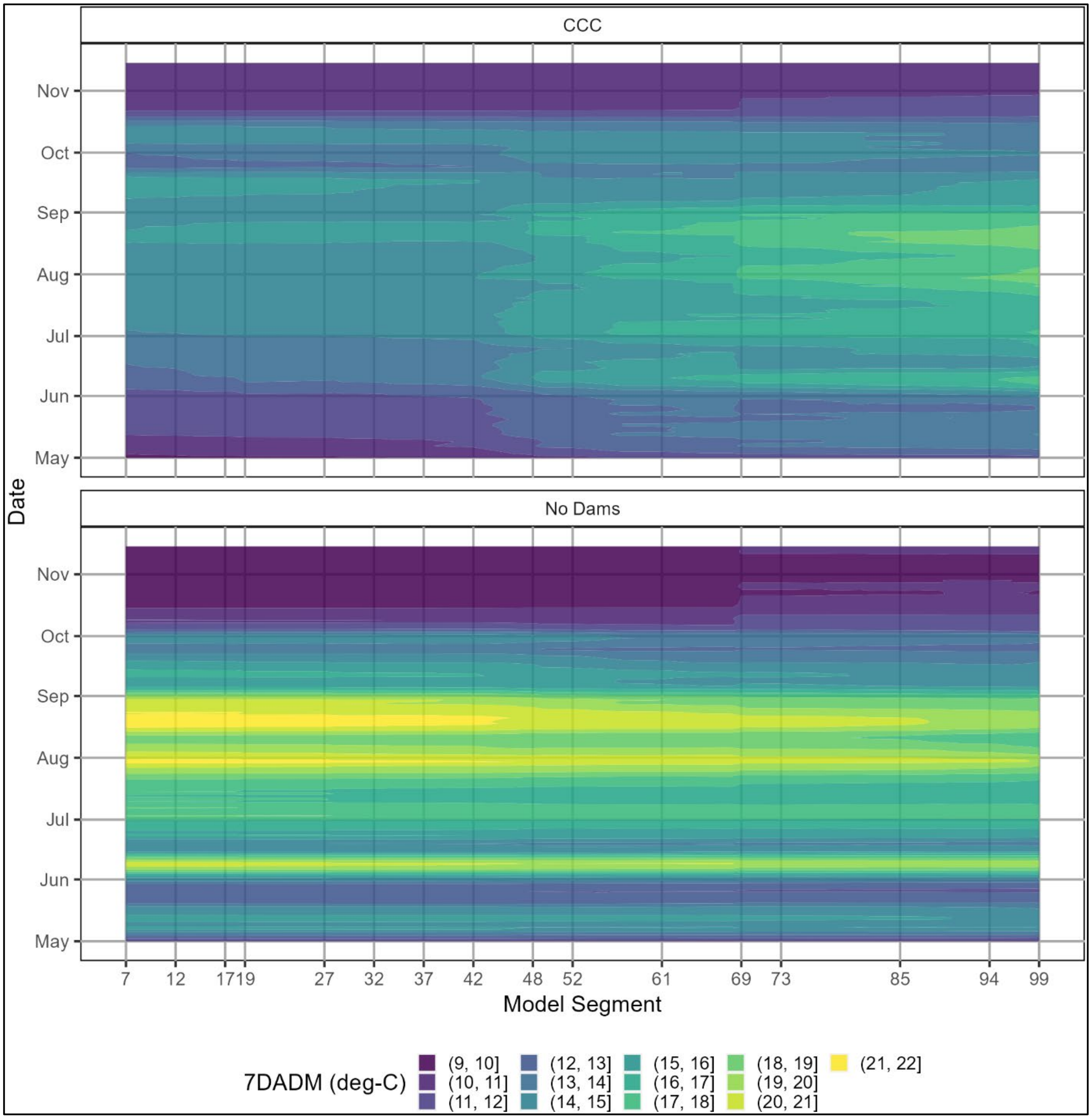

Figure 4-26: Bull Run River CCC and No Dam 7DADM temperatures.

Table 4-17: Bull Run River model results: Temperature, CCC vs. No Dams.

Scenario	Location	Segment	Date	Maximum 7DADM temperature (°C)
CCC	Mouth	99	08/19/2016	18.96
No Dams			08/22/2016	19.84
CCC – No Dams (temp change)			09/14/2016	1.30
CCC	POMI	99	08/19/2016	18.96
No Dams		7	08/20/2016	21.47
CCC – No Dams (temp change)		98	09/07/2016	1.31

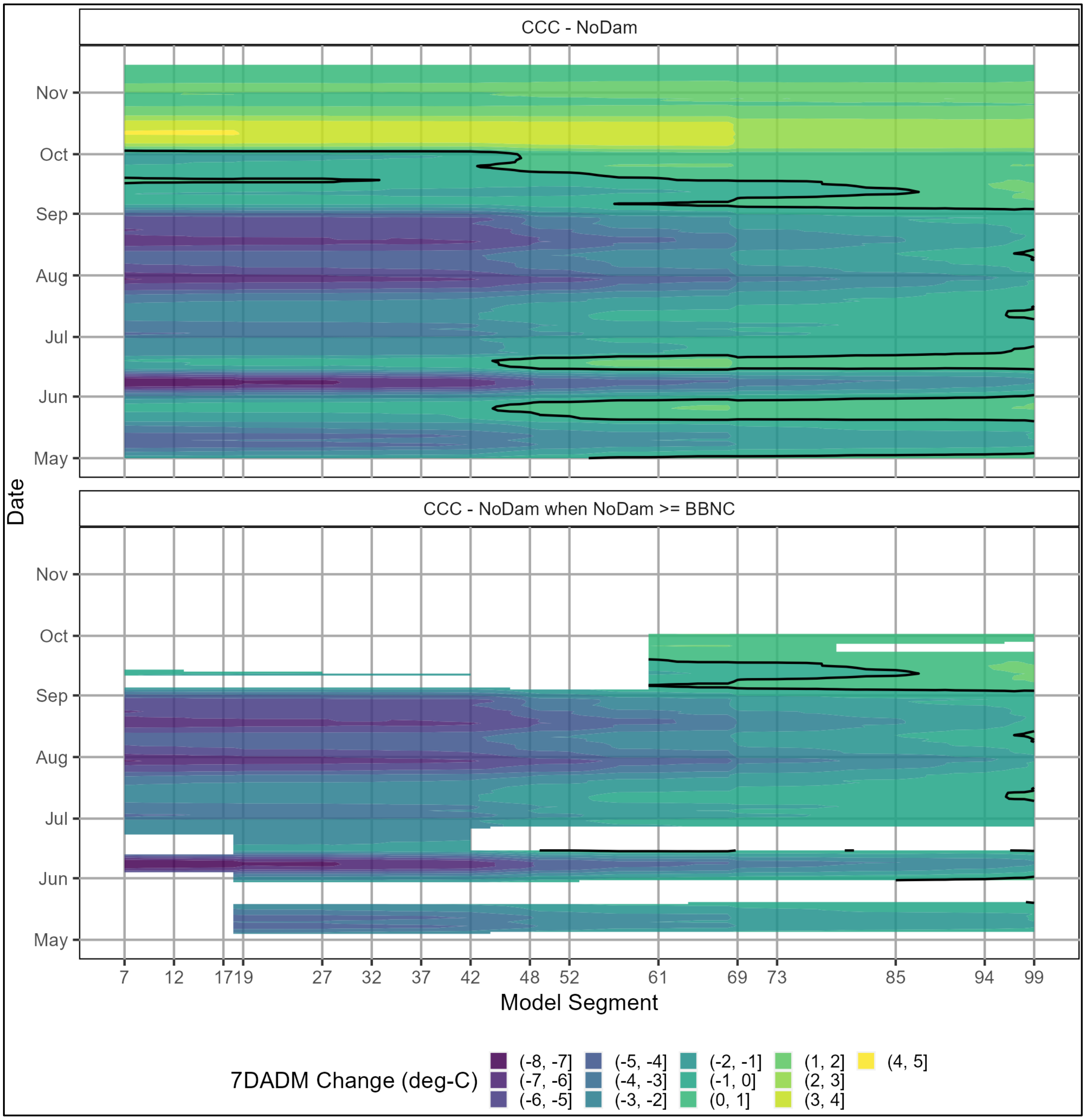

Figure 4-27: Bull Run River model results: 7DADM temp differences, CCC minus No Dams.

4.6.2 Restored Vegetation (RV)

Results of the RV and CCC models, which both included upstream flow boundary conditions that matched observed 2016 dam releases, were compared to determine the maximum 7DADM effect of existing vegetative shading that is under human control. See TSD Appendix D for details on the Bull Run River RV scenario setup. Results indicated a maximum 7DADM change of 0.85°C at the POMI (model segment 56) on August 27, 2016 (**Table 4-18**, **Figure 4-28**).

Table 4-18: Bull Run River model results: Temperatures, CCC vs. RV_A.

Scenario	Location	Segment	Date	Maximum 7DADM temperature (°C)
CCC	Mouth	99	08/19/2016	18.96
RV_A			08/20/2016	18.47
CCC - RV_A (temp change)			08/07/2016	0.68
CCC	POMI	23	08/24/2016	20.43
RV_A		23	08/24/2016	19.94
CCC - RV_A (temp change)		56	08/27/2016	0.85

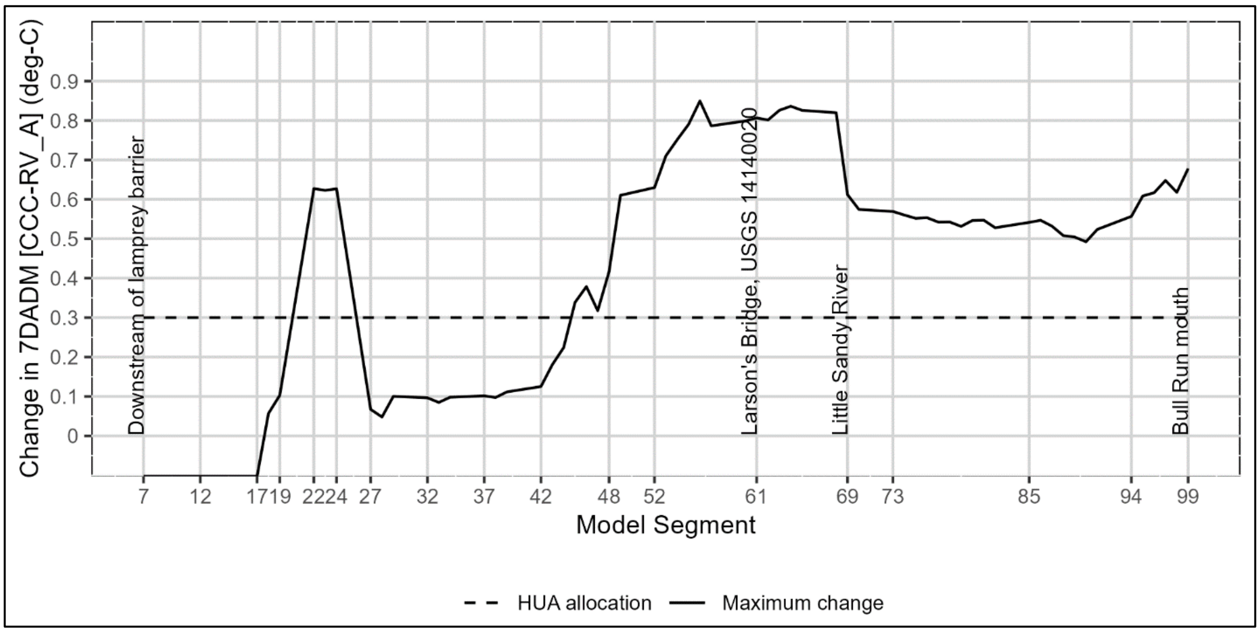

Figure 4-28: Bull Run River model results: Longitudinal maximum 7DADM temperature differences, CCC vs. RV_A.

4.6.3 Background (BG)

For the Bull Run River, the BG conditions scenario combined the No Dams and Restored Vegetation scenarios and was provided by the City of Portland. See Section 4.2 for a BG scenario description, and TSD Appendix D for setup details. The BG and CCC models' results were compared to estimate the cumulative impacts of current vegetation reduction/removal and dam and reservoir operations on Bull Run River temperatures (**Table 4-19**, **Figure 4-30**, and **Figure 4-32**). Also, the BG results were compared to the applicable BBNC to estimate the influence of background factors on temperature standard exceedances (**Table 4-19** and **Figure 4-31**).

Figure 4-29 shows the spatial (x-axis) and temporal (y-axis) distribution of 7DADM temperatures (as color gradients) in the BG scenario. Likewise, **Figure 4-31** shows the spatial and temporal distribution of 7DADM temperature *differences* between the BG scenario and applicable BBNC; and **Figure 4-32** shows these differences but between the CCC and BG scenarios. The upper plot in **Figure 4-32** shows the change for all segments and days, while the bottom plot shows the change only for days when BG 7DADM temperatures exceeded the applicable BBNC. The thick black lines in **Figure 4-31** and **Figure 4-32** delineate transitions between warming and cooling impacts. The **Figure 4-29**, **Figure 4-31**, and **Figure 4-32** legends show temperature intervals (ranges) as (x, y] in which the first number is not included in the interval and the second number is included; e.g., (10, 11] includes numbers >10 and ≤11.

Results (**Table 4-19**) indicated that the dams and lack of vegetation together increased 7DADM temperatures by a maximum of 1.44°C near the mouth (POMI: segment 97, September 7, 2016). Background sources resulted in a maximum 7DADM exceedance of 7.67°C (segment 68, August 18, 2016). The maximum 7DADM BG temperature was 21.46°C (POMI: segment 7, August 20, 2016). Exceedances frequently occurred across most or all calibrated model lengths from May through October (**Figure 4-31**).

Table 4-19: Bull Run River model results: Temperature, BG scenario.

Scenario	Location	Segment	Date	Maximum 7DADM temperature (°C)
BG	Mouth	99	7/30/2016	19.84
BG – BBNC			6/09/2016	6.61
CCC - BG			9/14/2016	1.43
BG	POMI	7	8/20/2016	21.46
BG – BBNC		68	8/18/2016	7.67
CCC - BG		97	09/07/2016	1.44

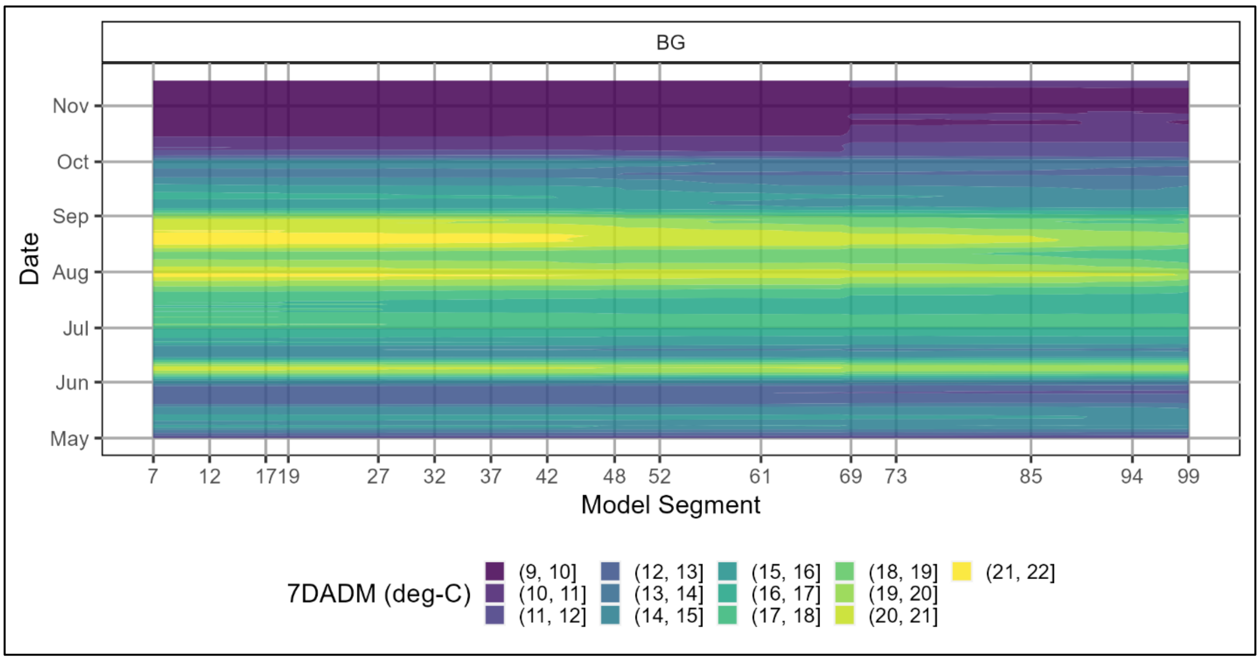

Figure 4-29: Bull Run River BG 7DADM temperatures by model segment and date.

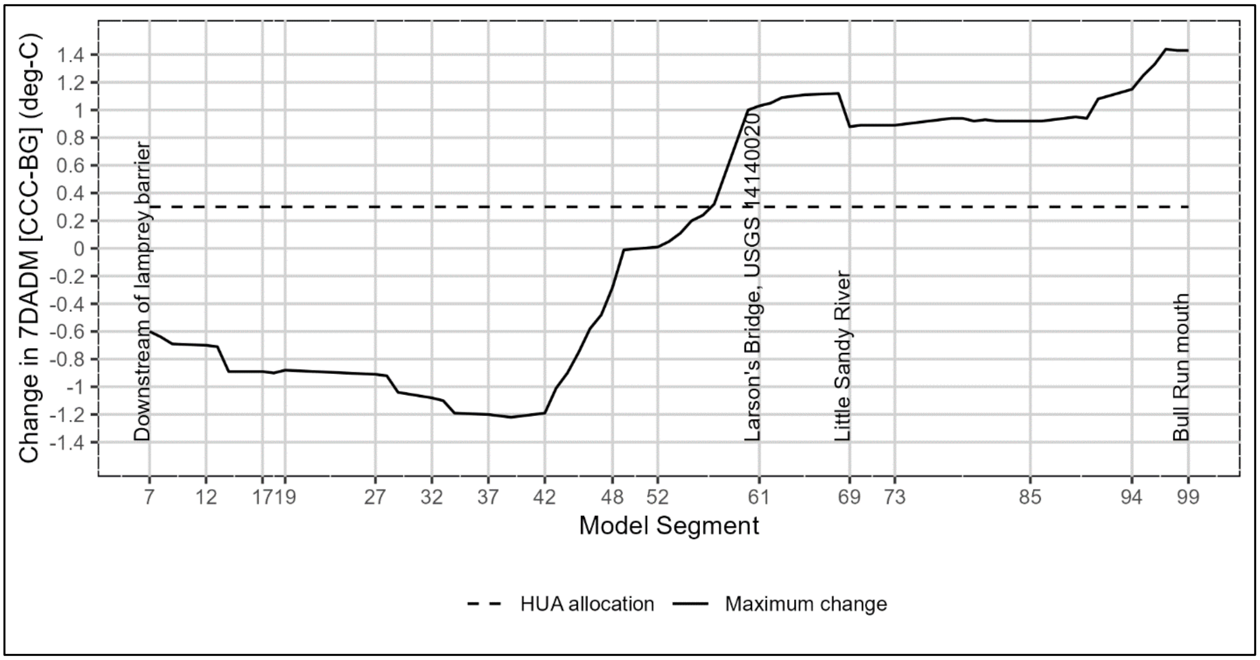

Figure 4-30: Bull Run R. model results: Longitudinal maximum 7DADM temperature, CCC minus BG scenario

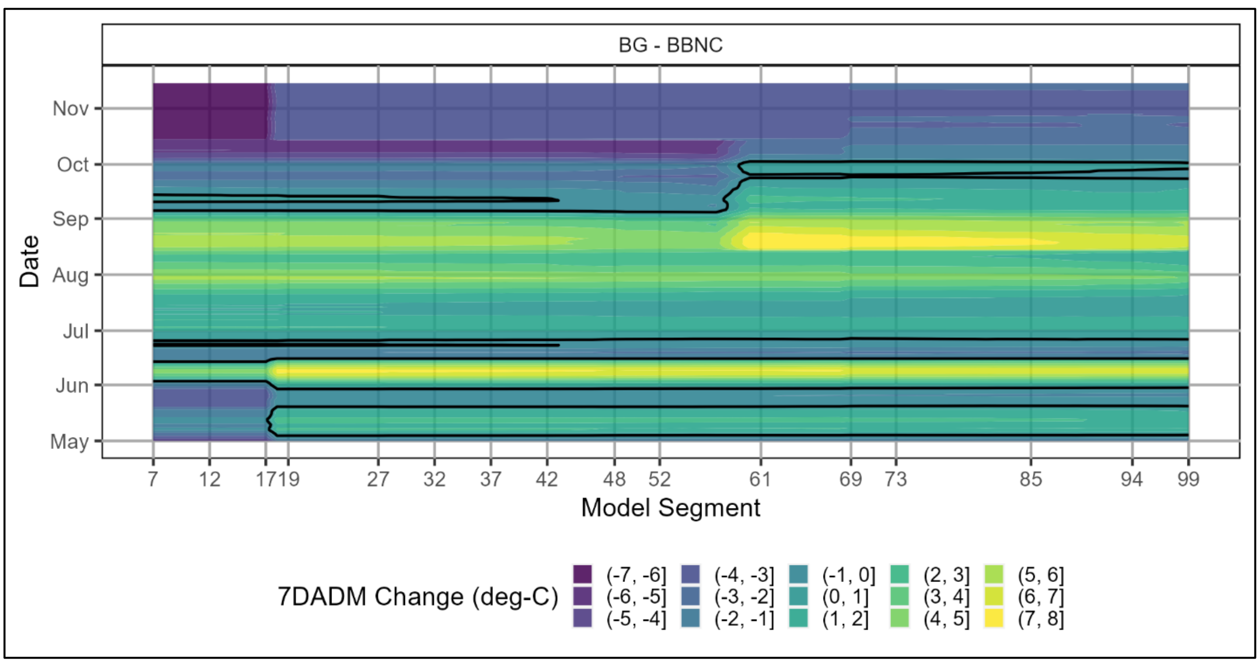

Figure 4-31: Bull Run River model results: 7DADM temp differences, BG minus BBNC by model segment and date.

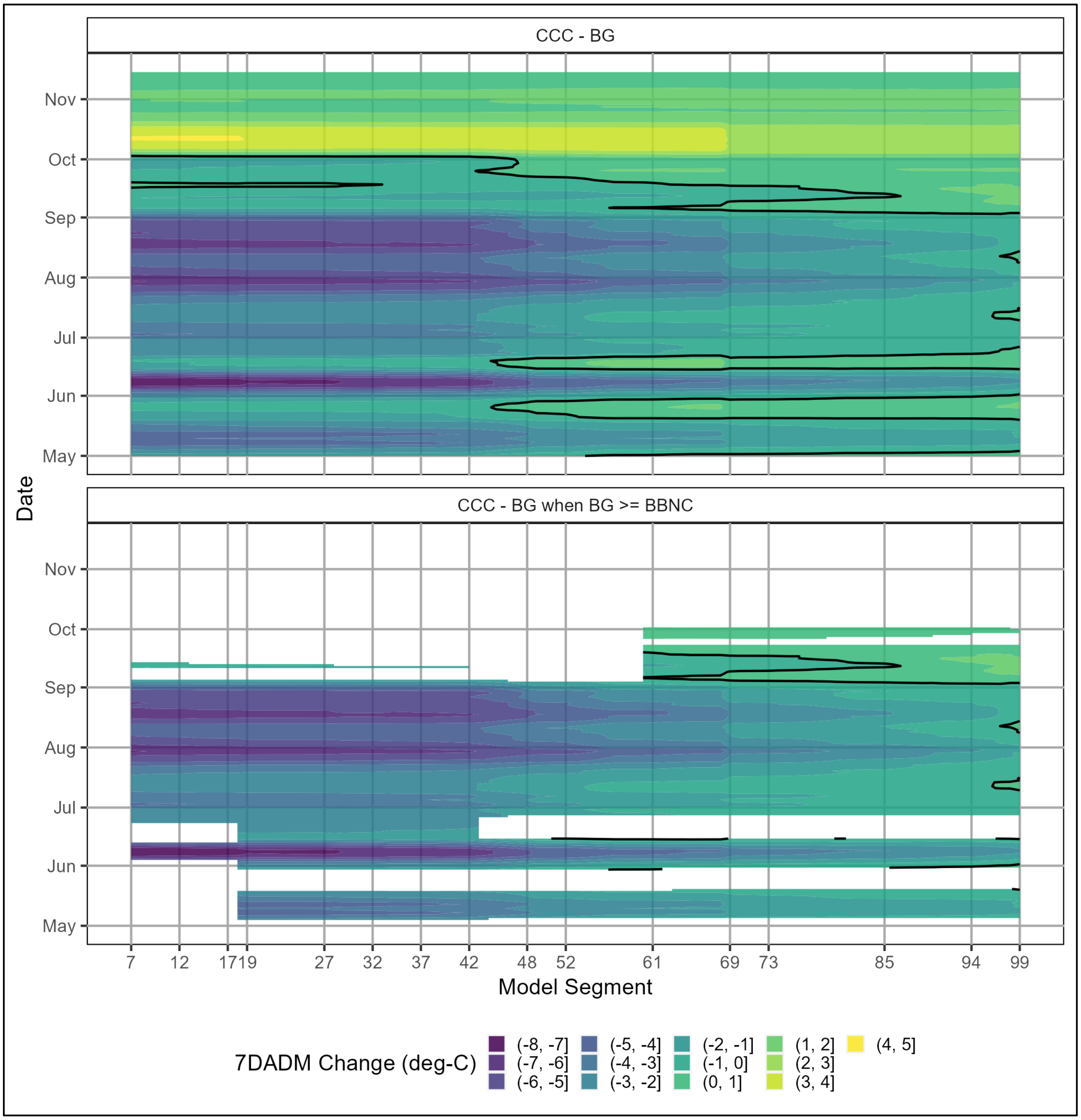

Figure 4-32: Bull Run River model results: 7DADM temperature differences, CCC minus BG by model segment and date.

4.6.4 Dam Surrogate Measure Attainment

Finally, DEQ modeled a “Dam Surrogate Measure Attainment” scenario for the Bull Run River, which estimated temperatures downstream from the Bull Run River dams and reservoirs with the assumption that their discharges attain surrogate measure targets (see TSD Appendix E for details). Results of the Dam Surrogate Measure Attainment scenario and the Bull Run River No Dams scenario were compared to determine if surrogate measure attainment at the lower dam would result in attainment of the applicable BBNC and the 0.30°C HUA from the dam downstream to the Bull Run River mouth. The maximum 7DADM increase was 0.30°C near the dam, downstream of the lamprey barrier (segment 7). At the mouth (segment 99), the maximum 7DADM increase was 0.07°C (**Table 4-20**, **Figure 4-33**). Thus, DEQ concluded that the Bull Run River dam and reservoir operations are unlikely to result in exceedances to the assigned HUA if the surrogate measure is attained.

Table 4-20: Bull Run River model results: Temperatures, Surrogate Measure Attainment vs. No Dams.

Scenario	Location	Segment	Date	Maximum 7DADM temperature (°C)
Surrogate Measure Attainment (SMA)	Mouth	99	08/21/2016	19.03
No Dams (ND)			07/30/2016	19.84
SMA – ND (temperature change)			10/11/2016	0.07

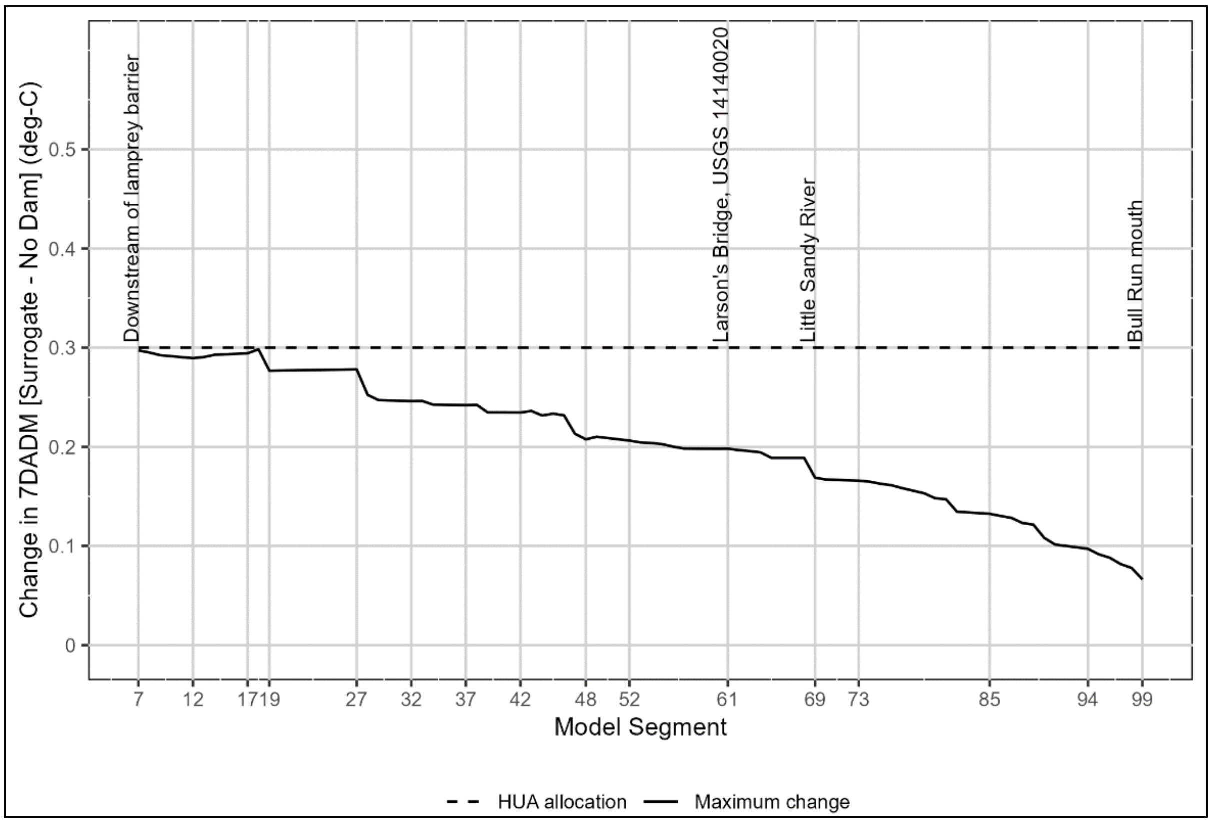

Figure 4-33: Bull Run River maximum 7DADM temperature changes above the applicable criteria due to Bull Run River dams and reservoirs with discharges attaining the surrogate measure.

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