Draft Technical Support Document

Appendix B: Sandy River Temperature Model Configuration and Calibration Report

Temperature Total Maximum Daily Loads for the Lower Columbia-Sandy Subbasin

100-WTR-T94501.3
June 21, 2022

PRESENTED TO

US Environmental Protection Agency, Region 10

and

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TETRA TECH

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1.0 INTRODUCTION

Tetra Tech assisted the Oregon Department of Environmental Quality (ODEQ) and USEPA Region 10 with technical and modeling activities to support the development of TMDLs for temperature impairments in the Sandy River (Figure 1-1) These TMDLs are part of a group of 15 Oregon temperature TMDLs that cumulatively address over 700 temperature impaired segments, all of which are being replaced pursuant to a court order and judgement issued October 4, 2019. The TMDLs must be replaced over an eight-year period.

The Sandy River is in northwestern Oregon and flows through Clackamas and Multnomah Counties. The Sandy River originates from glaciers on the western slopes of Mt. Hood at an approximate elevation of 6200 feet above sea level and travels 56 miles before flowing into the Columbia River near the City of Troutdale (ODEQ, 2005). Major tributaries to the Sandy River include the Zigzag, Salmon, and Bull Run Rivers (Figure 1-1). This report describes the technical approach used to develop the Sandy River model, summarizes available data, and documents the Sandy River mainstem model configuration and calibration.

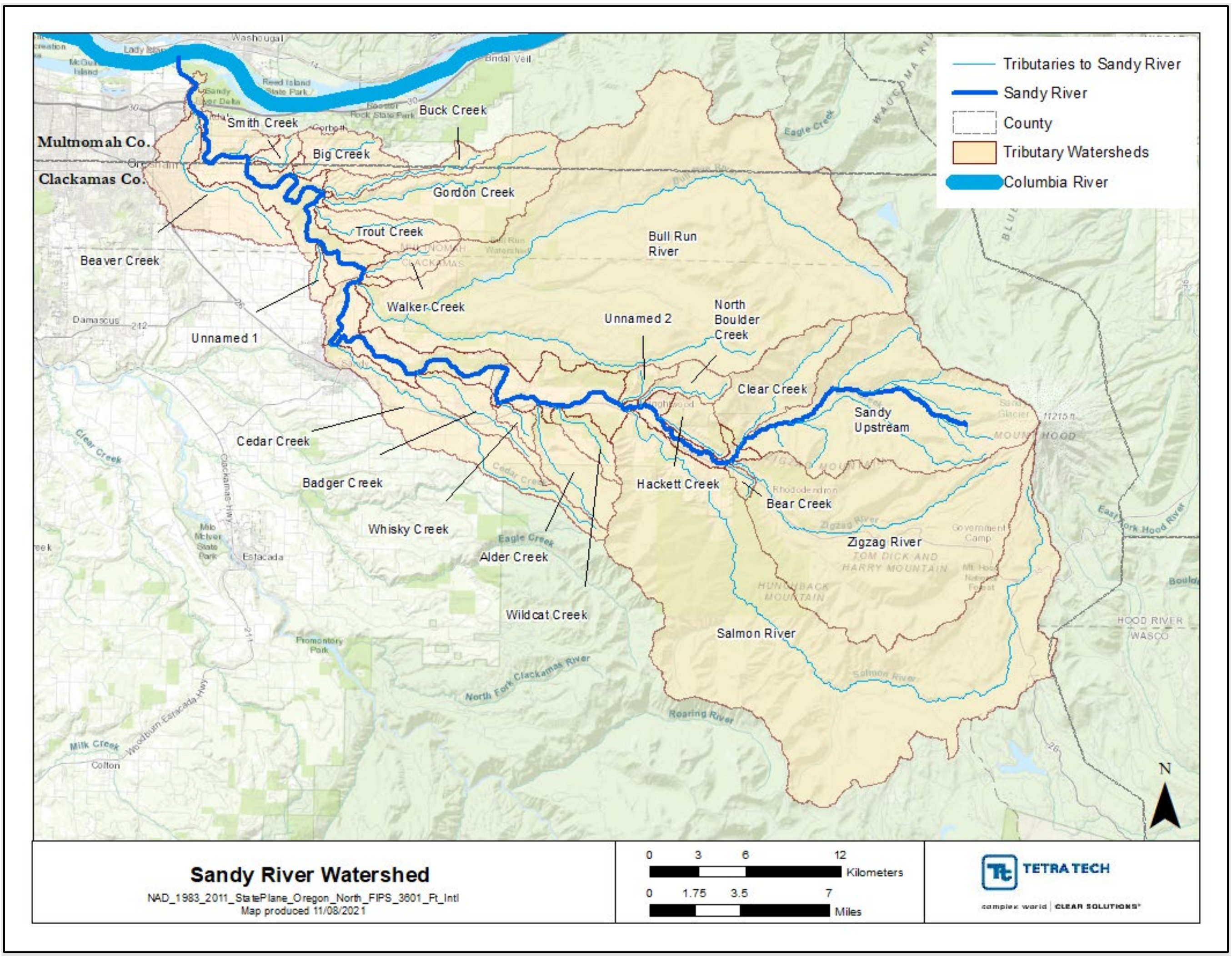


Figure 1-1: Sandy River Watershed

2.0 TECHNICAL APPROACH

Given the number of TMDLs to be replaced and the mandated schedule, EPA and ODEQ agreed that the approach to complete these TMDLs would rely on previous technical work as much as possible. In general, there was no new modeling or data collection unless this was essential to characterize sources or develop allocations. Updates to the model or technical analysis were made only to characterize new major sources (e.g., new NPDES source) or if a significant source or condition change occurred compared to the previous TMDL (e.g., dam removal, NPDES source discharge discontinuation). EPA and ODEQ agreed that model updates were potentially needed to improve restored landscape conditions characterization and/or background temperature estimates. Technical approach details are documented in the Sandy River TMDL QAPP (DEQ, 2021).

The replacement TMDLs retain the estimates of thermal loading/warming from existing sources or source categories if the sources existed when the original TMDL was developed. Existing TMDL surrogate measures (e.g., shade curves, channel morphology targets) were retained and used in the replacement TMDLs.

For the 2005 Sandy River Basin TMDL (DEQ, 2005), the computer model Heat Source version 6.5.1 (HS6) was used to simulate the 2001 stream temperatures. The HS6 model includes multiple modules that simulate open channel hydraulics and flow routing, in-stream heat exchange processes, effective shade (topographic and vegetation), and stream temperatures (Boyd and Kasper, 2003). The HS6 modeling time period was a single day and was developed to simulate conditions for August 8, 2001.

The HS6 model was developed before the Marmot Dam was removed, which occurred during 2008-2009. Within the Marmot Dam impoundment and approximately 2 km downstream, monitoring has shown altered channel morphology from major downstream sediment transport following dam removal (Major et al., 2012). The model also included withdrawals from the Sandy River to the Little Sandy River that no longer exist.

Due to these significant changes to the river system versus the conditions present under the original TMDL, a new Heat Source Model version 8.0.8 (HS8) was developed for the Sandy River to characterize current hydrology and channel morphology and support TMDL replacement in its subbasin. In addition, the model includes NPDES-permitted point sources to the Sandy River, which were included in the original TMDL but not modeled with HS6. The HS8 model is discussed in Section 2.1.

2.1 HEAT SOURCE MODEL VERSION 8

The HS8 and HS6 models use similar parameters, yet HS8 has several improvements, with examples listed below. Detailed differences between HS8 and HS6 are documented in the QAPP (DEQ, 2021).

- A major difference is that HS8 uses Python 2.5 and C code instead of Visual Basic (DEQ, 2008) with Excel as the interface;
- HS8 can simulate an unlimited number of days vs. a single day simulation under HS6.
- Star pattern landcover input with variable landcover height, density, and ground elevation inputs;
- Variable discharge time-series inputs allowed on boundary conditions and tributaries;
- Model nodes require latitude, longitude, and aspect inputs;
- Manning’s equation used exclusively to calculate channel hydraulics;
- Cloudiness included as a meteorological input whereas HS6 assumes clear skies;
- Groundwater (accretion) and diversion inputs are allowed;
- Includes additional morphology parameters, e.g., bottom width, sediment parameters, channel gradient;
- Includes bed conduction inputs, e.g., hyporheic exchange parameters; and
- LiDAR data allowed for vegetation density, height, and overhang.

3.0 MODEL CONFIGURATION

3.1 GIS DATA

Multiple GIS datasets were used to develop the HS8 model, which required data-intensive inputs including channel morphology and landcover data. The GIS datasets included existing stream and landcover shapefiles, high-resolution LiDAR, digital orthophotos, bare-earth hill-shade, and aerial imagery data. The data were used to digitize stream centerline and banks, landcover, and to sample/derive stream morphology data, e.g., channel alignment, dimensions, elevation, and shade. Table 3-1 lists the spatial datasets and briefly describes their use in HS8 model development. Given observed stream channel morphology changes since the previous HS6 model, stream centerlines and banks were re-digitized with updated, higher-resolution aerial imagery and LiDAR data, with the 2005 model's digitized landcover used for reference.

Table 3-1: Data used to develop Heat Source model inputs

Spatial data	Source	Application	Remarks
Streams (2001)	DEQ	Stream centerline & alignment, stream banks	
Bare Earth (DSM) OR Dept. of Geology and Mineral Industries (DOGAMI)[1]	DEQ	Estimate topographic shade angles & elevation	3 x 3-ft LiDAR data
Bare Earth Hillshade	DEQ	Delineate stream centerline & stream banks	ArcGIS layer file
Vegetation (DHM) DOGAMI[1]	DEQ	Derive canopy height data	3 x 3-ft LiDAR data
National Agriculture Imagery Program (NAIP) orthophotos	NAIP, 2016	Support landcover digitization & delineate stream centerline & stream banks	2016
Oregon Statewide Imagery Program (OSIP)	OSIP, 2018	Primary DOQs to digitize landcover & delineate stream centerline & stream banks	2018 1'-resolution color Digital Orthophoto Quadrangles (DOQ).
Digitized landcover classification (2001)	DEQ	Guide to interpret vegetation codes to digitize vegetation for Heat Source	2001 landcover classification shapefile
Building Footprint	Metro 2021	Acquire building footprints	Oregon Regional Land Information System (RLIS) building footprint shapefile

[1] Datasets used from various collection years were: OLC 2009 covering years 2007-2009; OLC Sandy River 2011, OR LIDAR project; OLC WASCO 2014 and 2015 LiDAR project. Several pre-processing steps completed before sampling geospatial datasets to provide Heat Source model inputs (discussed in the following sections).

3.2 MODEL TIME PERIOD AND EXTENT

The model was developed for the period from July 15 -- September 05, 2016, which corresponded to hourly water temperature data collected by Portland State University (PSU) at five locations along the Sandy River, as listed in the QAPP (DEQ, 2021). Further, this water temperature data period of record covered the critical summer and spawning period. Hourly stream temperature data were also collected at several major (e.g., Bull Run River, Salmon River, Zig Zag River) and minor tributaries and used to configure model boundaries.

The model domain extent is the Sandy River from the mouth at the Columbia River to just upstream of Clear Creek. The upstream boundary was defined by the location of available stream temperature data. The Sandy River channel was digitized using a combination of LiDAR digital terrain model data, 2016 National Agriculture Imagery Program (NAIP) orthophotos, and Oregon Statewide Imagery Program (OSIP) 2018 one-foot-resolution color Digital Orthophoto Quadrangles (DOQs). Figure 3-1 shows the extent of the Sandy River model.

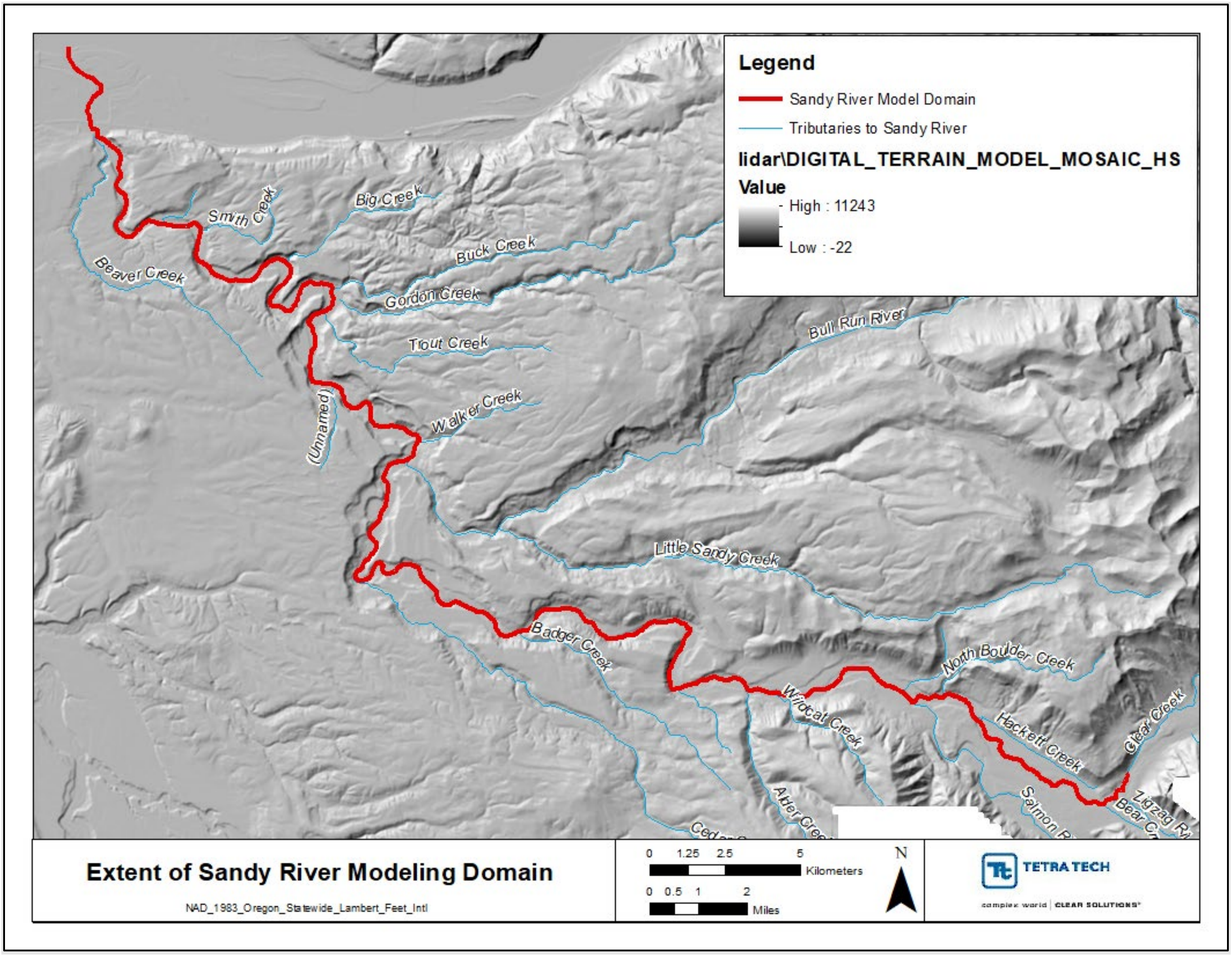


Figure 3-1: Extent of Sandy River modeling domain

3.3 DIGITIZATION OF STREAM CENTERLINE AND STREAM BANKS

Stream reaches were digitized using a combination of DOQs (OSIP, 2018) and high-resolution OR bare-earth hill-shade data provided by DEQ. Digitization was performed at a scale finer than 1:1000. In cases where the stream was braided, the dominant channel was chosen. Stream left and right banks were digitized to follow the wetted perimeter where discernable or according to active channel boundaries. In cases where the stream bank lines were concealed in the imagery, the best estimate of active channel bank lines was digitized. In these cases, the high-resolution bare-earth hill-shade allowed for viewing the channel widths. NAIP 2016 images, along with stream channel centerlines and stream banks from the 2005 TMDL, were also used for reference as necessary to inform digitization. Figure 3-2 shows a stream bank digitization example. Stream segment distances along the centerline and stream widths were measured with TTools every 50 m. All river kilometer designations were calculated using this more recent high-resolution stream delineation and revised modeling extent and therefore may not match historical river kilometer designations.

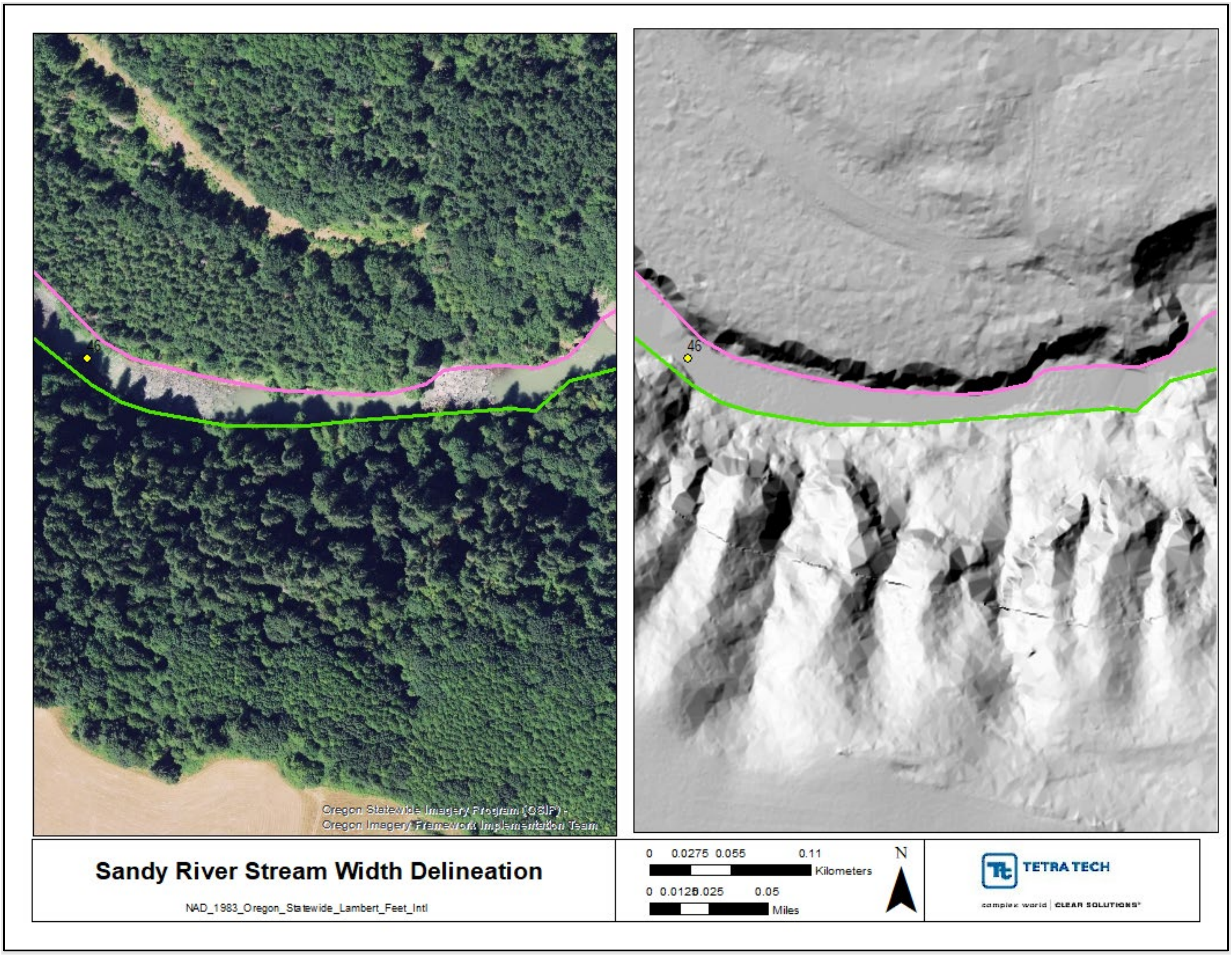


Figure 3-2: Digitization of stream bank edges

3.4 LANDCOVER PROCESSING

The primary land use along the Sandy River is forest, which accounts for ~81% of the near-stream area (DEQ 2021). A landcover raster was created using a combination of digitized landcover and vegetation height data derived from LiDAR. A unique landcover code consisting of landcover type and height was created for each observed parameter combination. Vegetation raster development is discussed in the following sections.

3.4.1 Landcover Mapping

The stream was buffered 100 m from each bank and the resulting buffer was divided into polygons based on the various landcover types. Landcover was digitized using the OSIP 2018 DOQ imagery layer divided into polygons to map the various vegetation and other landcover types (e.g., hardwood/conifer/mixed, developed residential/industrial/commercial). Building footprints were derived from the RLIS building footprint shapefile (Metro, 2021), which contains regional building footprint data from local jurisdictions or created and compiled by Watershed Sciences from regional LiDAR data with average building heights. The building footprints were added to the layer via an ArcGIS union of the shapefile with the 100 m buffer corridor. Finally, the digitized vegetation was assigned landcover type codes for different land use types. The original TMDL (DEQ, 2005) landcover digitization was referenced to guide the updated digitization and characterization of the vegetation species and landcover code assignments. Landcover codes used in the mapping are similar to those in the 2005 TMDL. Note that there are multiple heights associated with each landcover code. The final landcover codes used in the calibrated model are a concatenation of two codes: landcover type and landcover height as determined from LiDAR. An example landcover code is shown below where the current condition landcover type (600 - Hardwood - High Dense) and the current height (20 m) is concatenated as landcover code 600020.

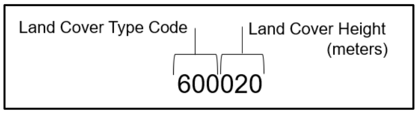


Table 3-2 shows the codes used in the assignment. It was assumed that there is no in-stream or overhanging vegetation. Figure 3-3 shows an example of the near-stream landcover digitization.

Table 3-2: Landcover code assignment

Landcover Code	Description	Height (m)	Density (%)	Overhang (m)
101	Utility[3]	LiDAR-derived	60%	0.0
102	Bridge - Over Water[3]	LiDAR-derived	100%	0.0
300	Pastures/Cultivated Field	LiDAR-derived	75%	0.0
301	Water - Non Active Channel	LiDAR-derived	0%	0.0
302	Water - Active Channel Bottom	LiDAR-derived	0%	0.0
305	Barren – Embankment	LiDAR-derived	0%	0.0
308	Barren – Clearcut	LiDAR-derived	75%	0.0
309	Barren – Soil	LiDAR-derived	0%	0.0
348	Development - Residential	LiDAR-derived	100%	0.0
349	Development - Industrial/Commercial	LiDAR-derived	100%	0.0
352	Dam/Weir	LiDAR-derived	100%	0.0
355	Canal	LiDAR-derived	0%	0.0
400	Barren – Road	LiDAR-derived	0%	0.0
401	Barren - Forest Road	LiDAR-derived	0%	0.0
500	Mixed Conifer/Hardwood - High Dense	LiDAR-derived	60%	0.0
550	Mixed Conifer/Hardwood - Medium Dense	LiDAR-derived	30%	0.0
555	Mixed Conifer/Hardwood - Low Dense	LiDAR-derived	10%	0.0
600	Hardwood - High Dense	LiDAR-derived	75%	0.0
650	Hardwood - Low Dense	LiDAR-derived	30%	0.0
700	Conifer - High Dense	LiDAR-derived	60%	0.0
750	Conifer - Low Dense	LiDAR-derived	30%	0.0
800	Upland Shrubs - High Dense	LiDAR-derived	75%	0.0
850	Upland Shrubs - Low Dense	LiDAR-derived	25%	0.0
900	Grasses – Upland	LiDAR-derived	75%	0.0
950	Grasses – Wetland	LiDAR-derived	75%	0.0

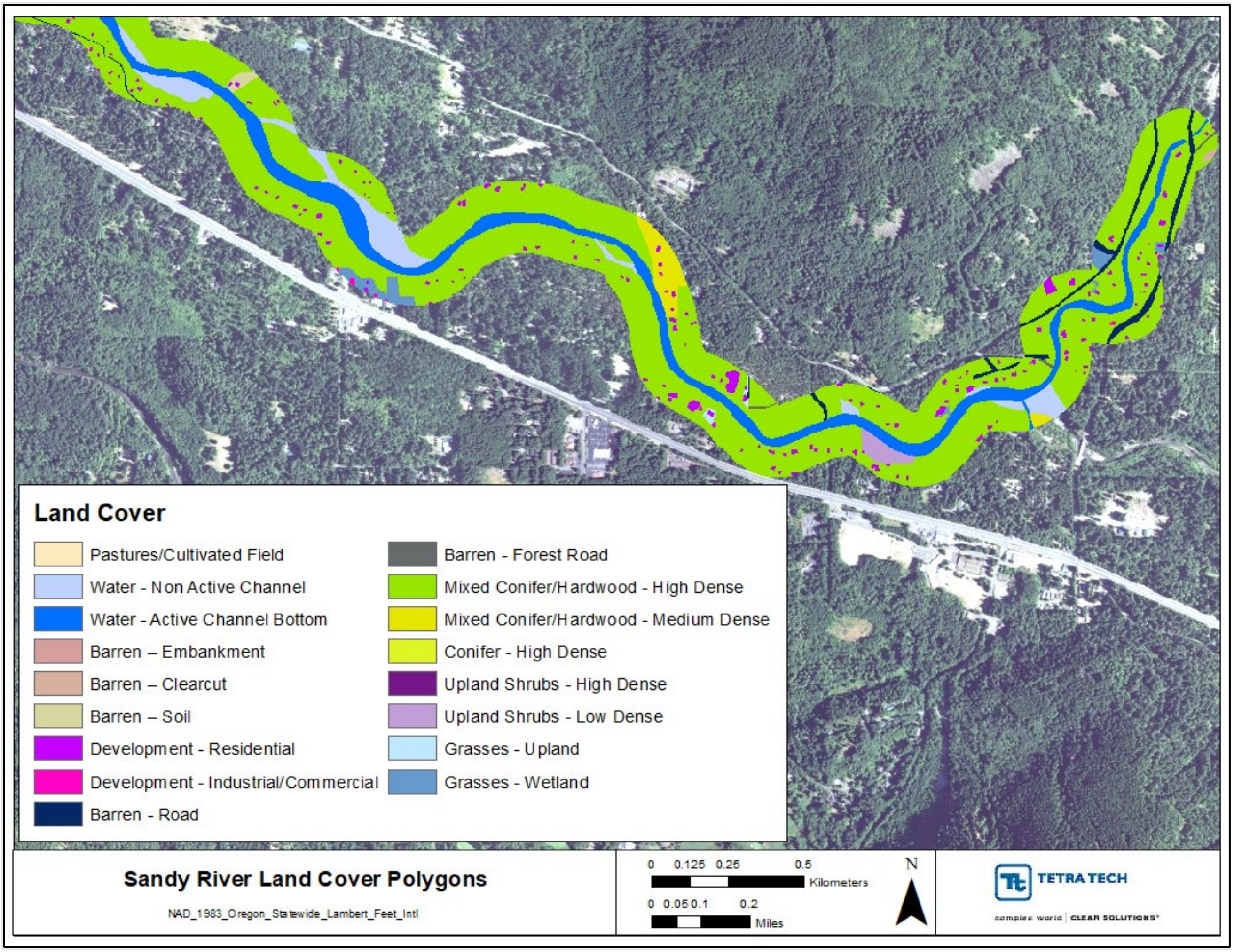


Figure 3-3: Digitized riparian landcover polygons

3.4.2 Vegetation Height

DEQ provided the processed vegetation height raster layer. Tree height information was derived from 3-foot resolution LiDAR data from 2017. The LiDAR first and last returns are processed to generate two data sets: a Digital Ground Model (DGM) representing the first return and a Digital Surface Model (DSM) representing the last return. The DGM was subtracted from the DSM to generate a Digital Height Model (DHM) that represents the above-ground height of features such as trees. This vegetation height raster (DHM) was further processed to remove any “no-data” values and clipped to match the stream corridor buffer area.

3.4.3 Vegetation Raster

A vegetation raster layer was finally created using the digitized landcover and vegetation height layers. First, the landcover shapefile was converted to a raster. Then, this raster was combined with the vegetation height raster layer using raster addition in ArcGIS to create a new raster with new codes as follows: [veg_raster_code x 1000 + vegetation height]. Next, the resulting codes were converted to integers to reduce the number of codes generated due to decimal (float) values. For example, the code 500033 represents map pixels with Mixed Conifer/Hardwood – High density landcover type with a height of 33 m (rounded to nearest meter). A total of 2,030 unique landcover codes were created. TTools (step 5) was used to sample vegetation from the resulting processed layer as discussed in the next section.

3.5 HEAT SOURCE MODEL INPUT CREATION USING AUTOMATED GIS SAMPLING

DEQ's TTools utility was used to create channel-related HS8 model inputs. TTools samples geospatial data and allows assembly of high-resolution data for use as HS8 model inputs. TTools comprises a set of Python-automated GIS sampling tools to create an input database for direct feed into HS8. TTools includes five steps to sample/extract data at user-defined intervals along the stream, as outlined here:

Step 1 of TTools established channel centerline sampling points (nodes) every 50 m beginning at the upstream end of the delineated channel centerline and the stream length between each node. Each node was then populated with the point latitude/longitude and aspect. Figure 3-4 shows the stream sampling nodes every 50 m, along with reference points every 1 km. The Sandy River generally flows to the northwest. Aspect is used to calculate the solar flux on the stream surface based on its orientation. Figure 3-5 shows the calculated channel aspect.

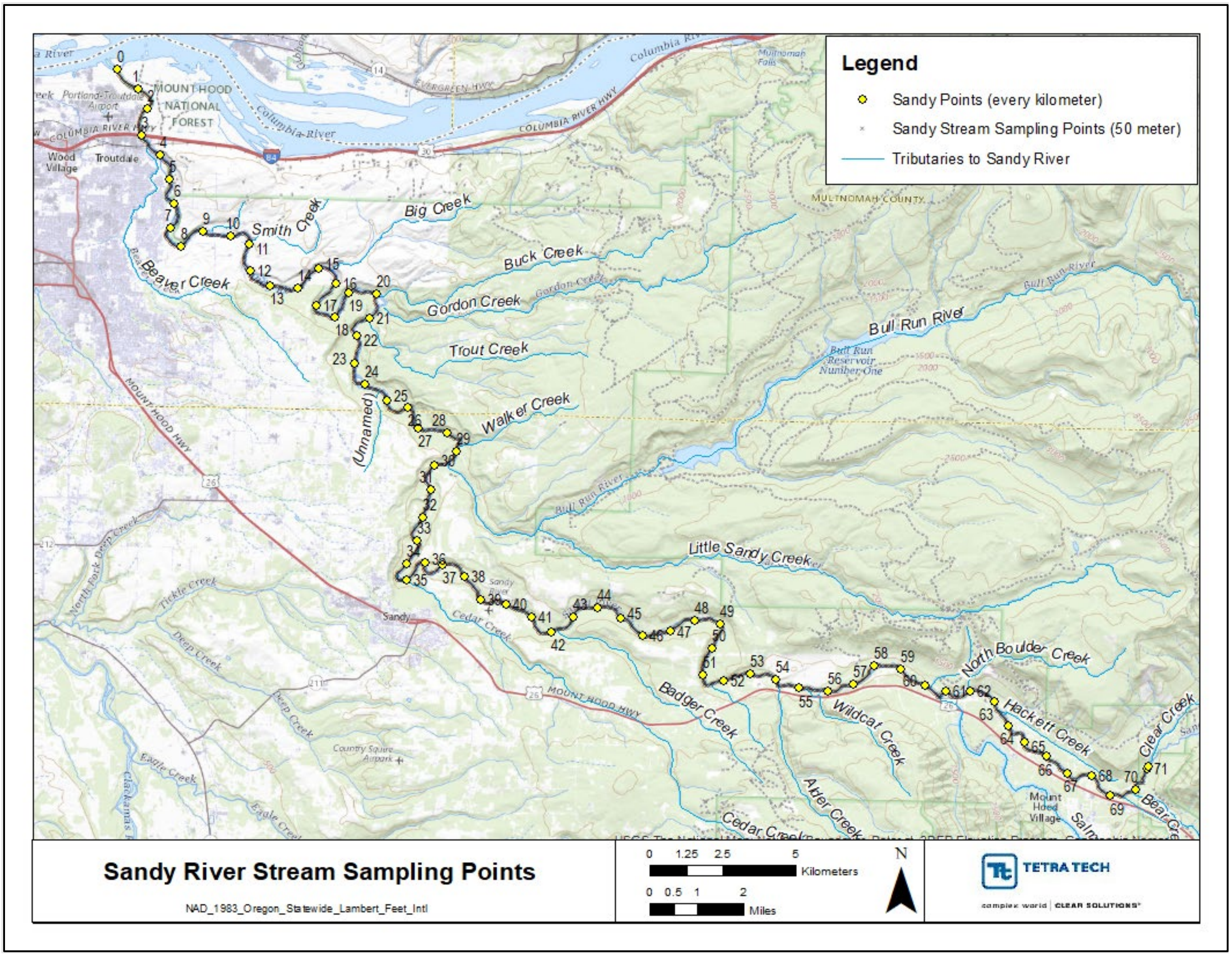


Figure 3-4: Sandy River stream sampling nodes

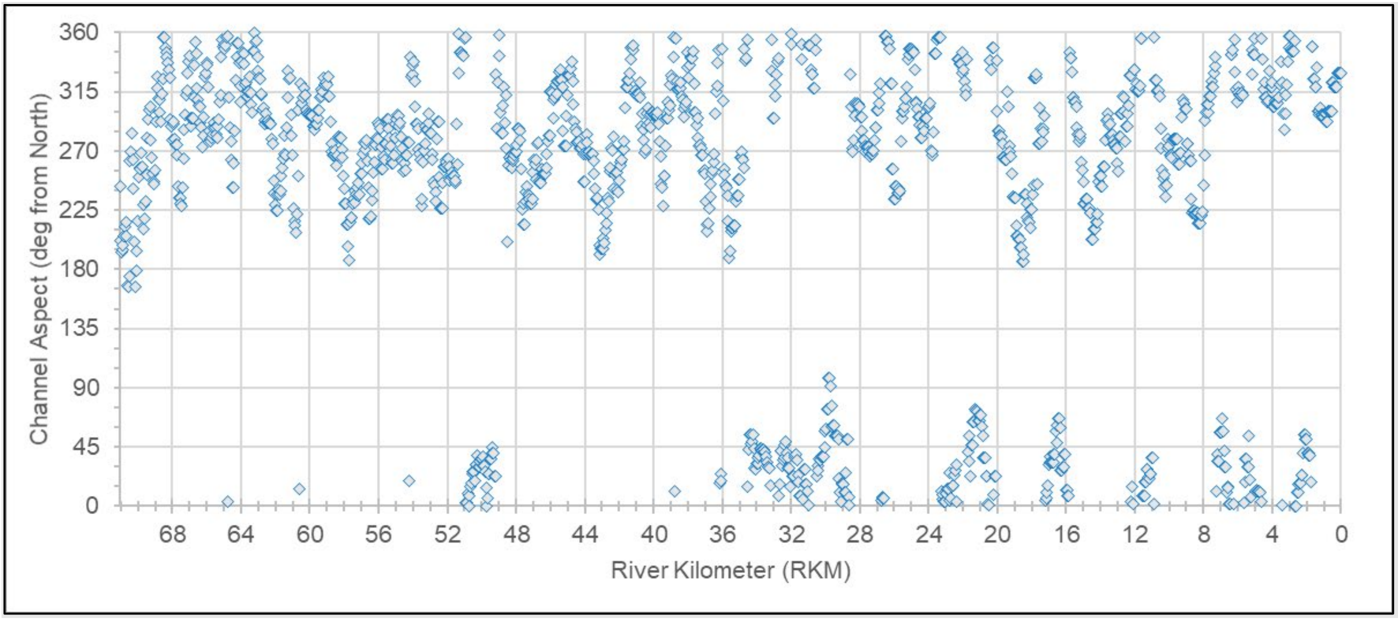


Figure 3-5: Sandy River calculated channel aspects

Step 2 calculated the channel width at each node as the distance between the delineated left and right banks established with a line perpendicular to the aspect at that node. Figure 3-6 shows the calculated channel widths (m) for Sandy River, which ranged from 13.2--279.9, with a mean of 55.6 and median of 47.6.

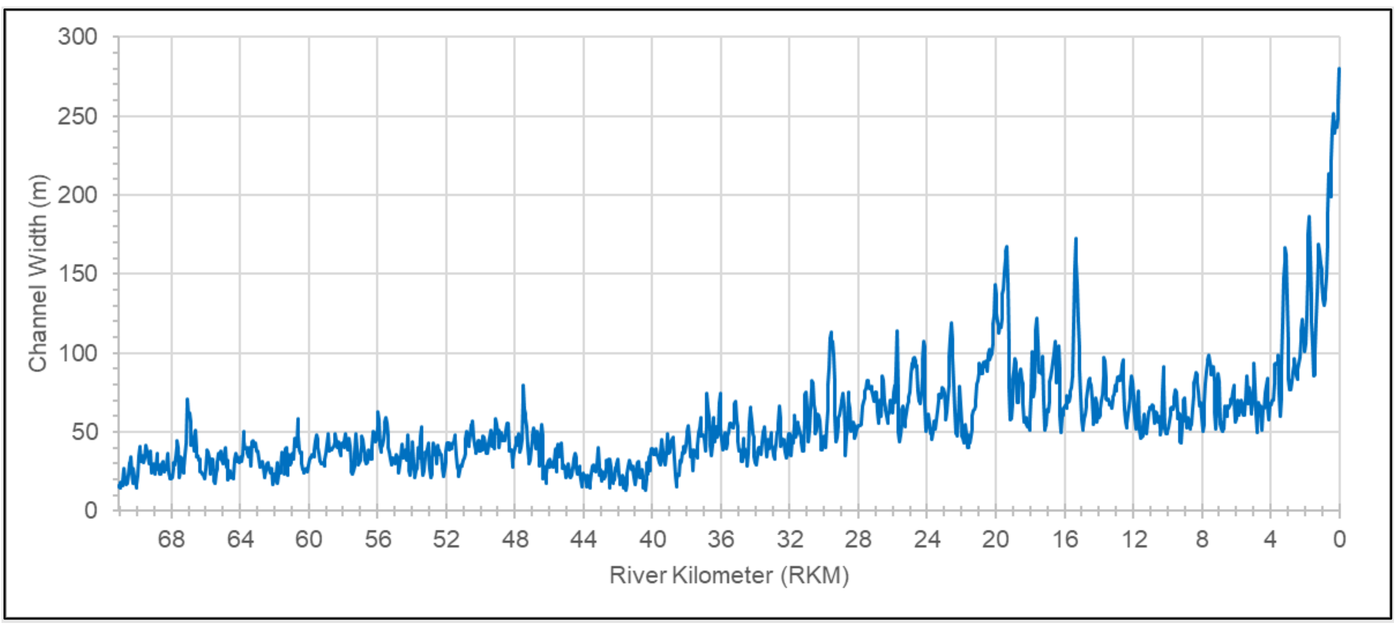


Figure 3-6: Sandy River calculated widths

The stream channel is represented as a trapezoidal cross-section in Heat Source. Unlike previous versions where the bank-full width is a model input, the HS8 model requires a channel bottom width input. DEQ provided a separate macro that uses the Heat Source version 7 methodology to calculate channel bottom widths from the TTools-estimated bank-full widths at a given width:depth ratio (W:D=8) and channel angle (z=1). These channel bottom widths were further refined during calibration. The final channel bottom widths (m) used in the model ranged from 7.5-198, with a mean of 36.4 and median of 28.5.

Step 3 sampled channel elevation at each node from the bare earth LiDAR DEM (3' x 3') from the cell containing the point (nine cell setting for minimum elevation setting). Figure 3-7 shows the computed stream channel elevations and gradients. As evident over the 71.08 RKM stretch, the channel changes from a high-gradient cobble-boulder channel upstream to a low-gradient channel downstream (~0.0006 m/m gradient and 4 m elevation) before its confluence with the Columbia River. Between the Marmot site (~48.4 RKM) and RKM ~40, the channel flows through a high-gradient gorge area (Sandy River Gorge) that is characterized by a narrower channel width, below which it widens and lowers in gradient.

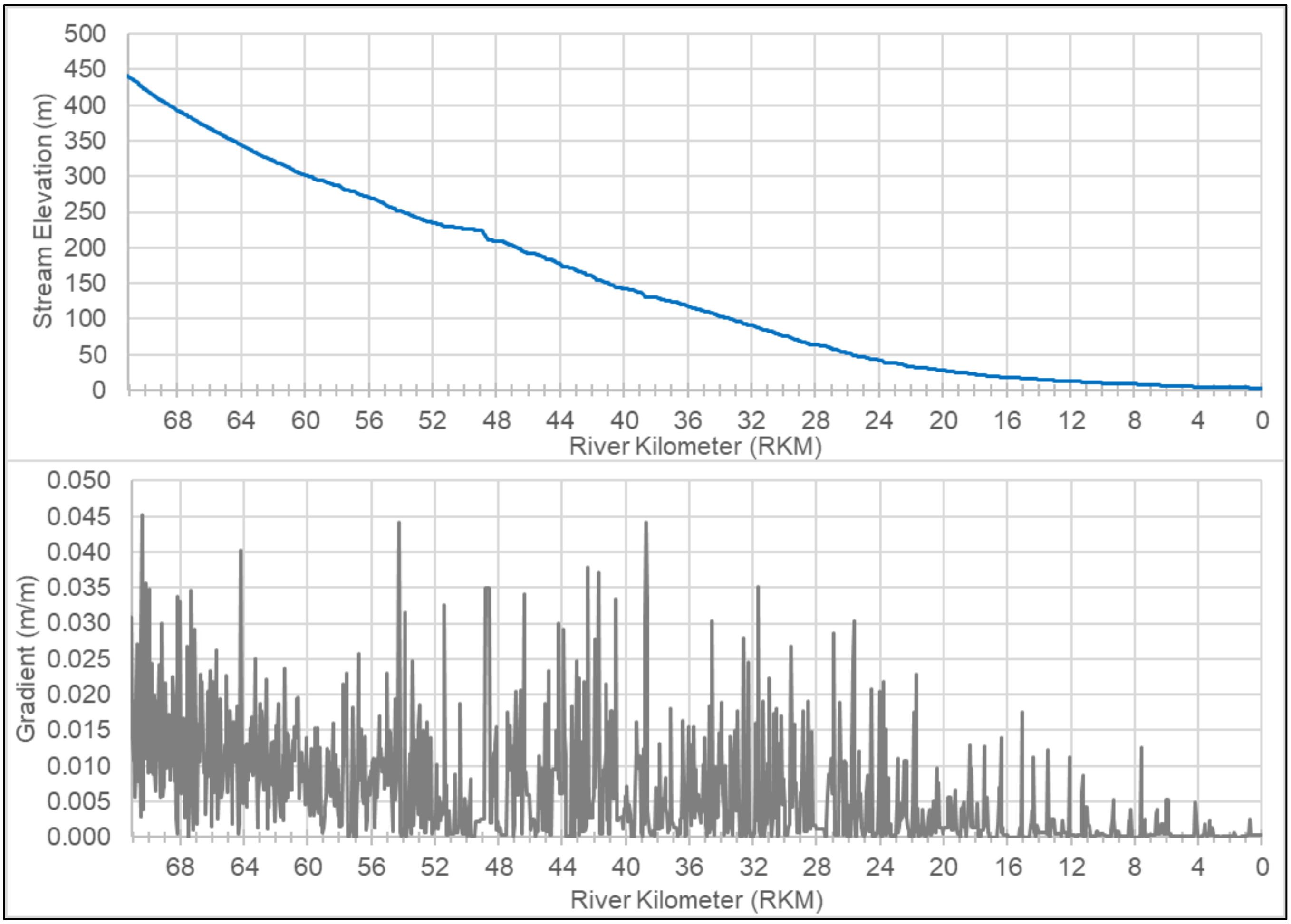


Figure 3-7: Sandy River longitudinal elevation and gradient

Step 4 sampled topographic shade angles to the east, west, and south of each node in a 10-km search radius using the bare earth LiDAR DEM (3' x 3'). Figure 3-8 shows the topographic shade angles for the Sandy River. The Sandy River generally flows northwest with the smallest topographic shade angles to the west and the greatest to the south in the vicinity of the Sandy River Gorge, i.e., ~RKM 48 -- 40.

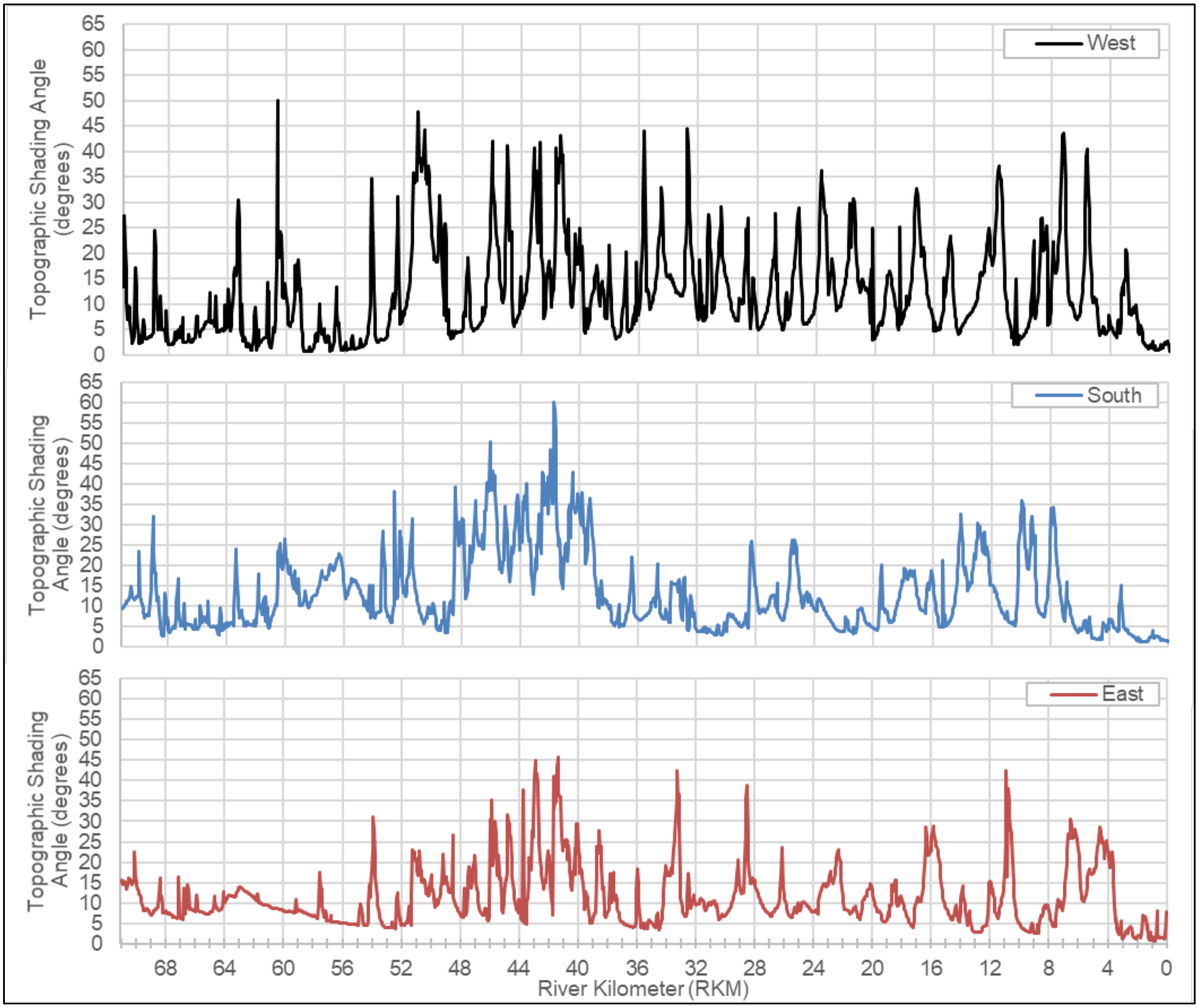


Figure 3-8: Sandy River calculated topographic shade angles

Step 5 sampled landcover from the 3-ft resolution vegetation raster layer at each node using a dense radial sampling pattern. Fifteen (15) transverse vegetation samples were taken in 8-m increments in each of seven (7) directions (i.e., NE, E, SE, S, SW, W, NW). Vegetation raster generation was discussed in Section 3.4.3.

3.6 FLOW DATA

In the Sandy River watershed, flow data for the 2016 modeling period were available at limited locations. Specifically, flow data were available for the Bull Run River and Beaver Creek tributaries and unavailable for any remaining tributary inputs (n=19) specified in the HS8 model. The Bull Run River and Salmon River flows from their respective calibrated current conditions (CCC) models (Figure 3-9 and Figure 3-10) comprised the corresponding tributary input data for the Sandy River model; this was to maintain a consistent baseline to compare with scenarios that reflected changes to the Salmon and Bull Run River models (e.g., for the restored vegetation and no dams scenarios). For the Bull Run River W2 model, time-series flow data were extracted from segment 98 because the last active segment (99) does not include corresponding flow data.

No flow data were available to configure the upstream (headwater) boundary condition. The two available Sandy River flow gages were used for flow calibration purposes. Table 3-3 provides an inventory of the available flow data and their model applications. Note that the sum of the Little Sandy and Bull Run Rivers gages' flows equals the total estimated Bull Run River inflows to the Sandy River.

Table 3-3: List of available flow data in the Sandy River watershed used in Heat Source model development

Station ID	Lat/Long	Source	Use
Little Sandy R. (14141500)	45.4154/ -122.172	USGS	Boundary condition
Bull Run R. (14140000)	45.4373/ -122.180	USGS	
Beaver Cr. (14142800)	45.5193/ -122.389	USGS	Boundary condition
Blazed Alder Cr. (14138800)	45.4526/ -121.892	USGS	Boundary condition derivation
Sandy River near Marmot (14137000)	45.3996/ -122.137	USGS	Boundary condition derivation, calibration
Sandy R. below Bull Run R. near Bull Run (14142500)	45.4490/ -122.245	USGS	Boundary condition derivation, calibration

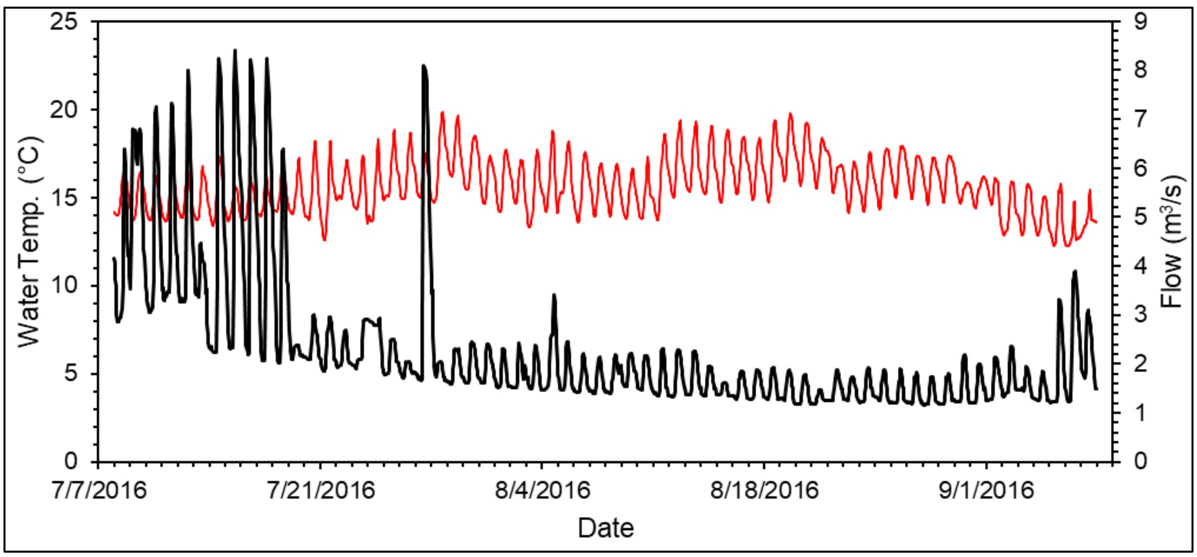


Figure 3-9: Bull Run W2 CCC flow and water temperature outputs at the mouth (RKM 0, i.e., segments 98 & 99).

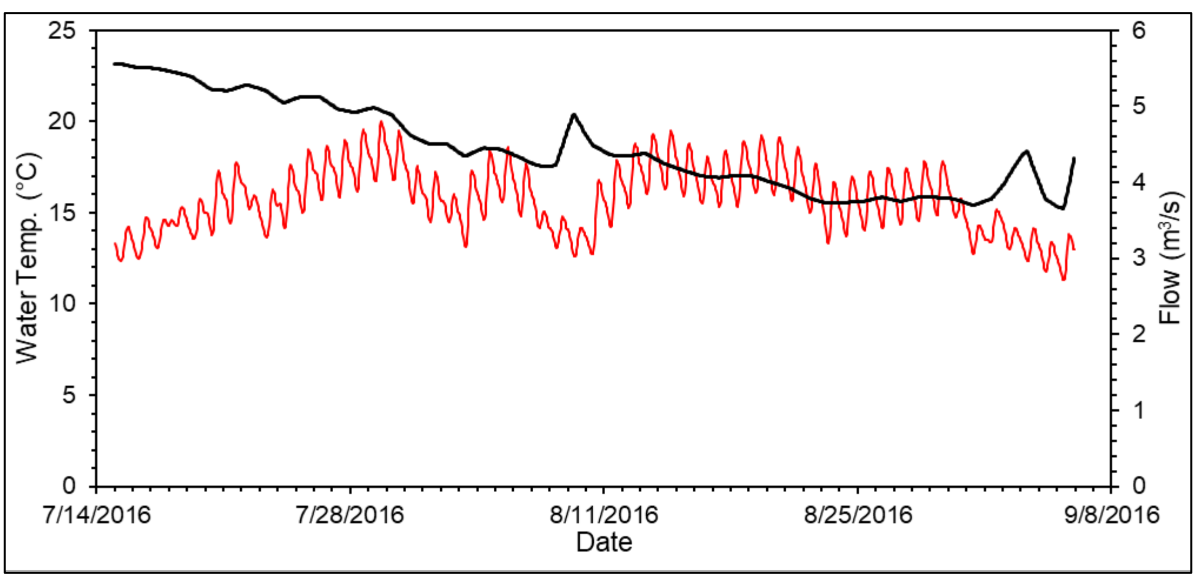


Figure 3-10: Salmon River HS8 CCC flow and water temperature outputs at the mouth (RKM 0).

3.6.1 Flow Estimation

Due to the lack of available flow data to configure the mode for most of the system, streamflows were estimated at certain locations. Three USGS flow gages with continuous data during the model period were evaluated for use as data sources to derive model flow inputs (Figure 3-11, Table 3-3): Beaver Creek (14142800), Blazed Alder Creek (14138800) and Sandy River near Marmot (14137000). Beaver Creek and Blazed Alder Creek had the added benefit of long-term flow records. Beaver Creek is a Sandy River tributary and Blazed Alder Creek is an unmanaged headwater tributary to the Bull Run River.

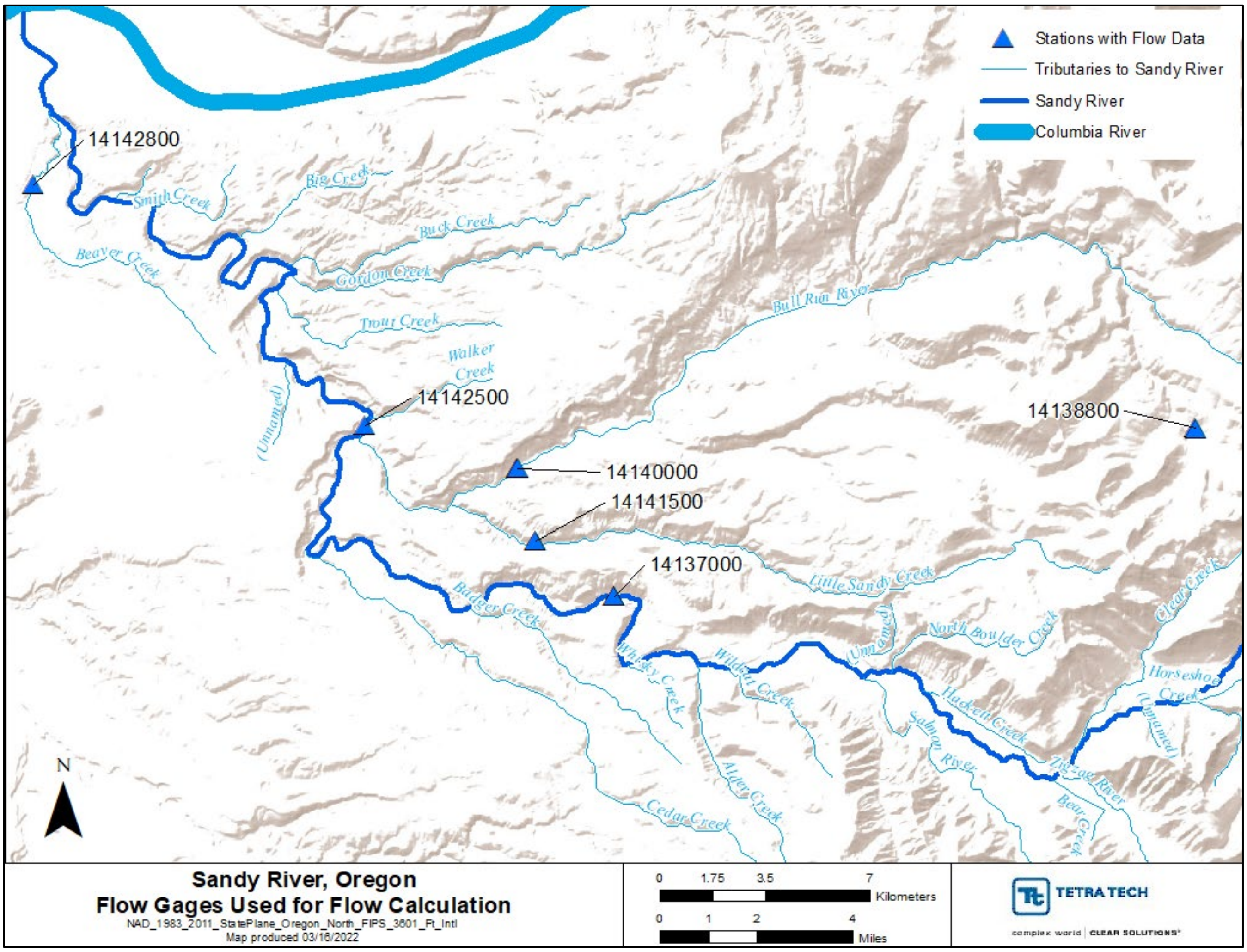


Figure 3-11: Flow gages used for flow calculations

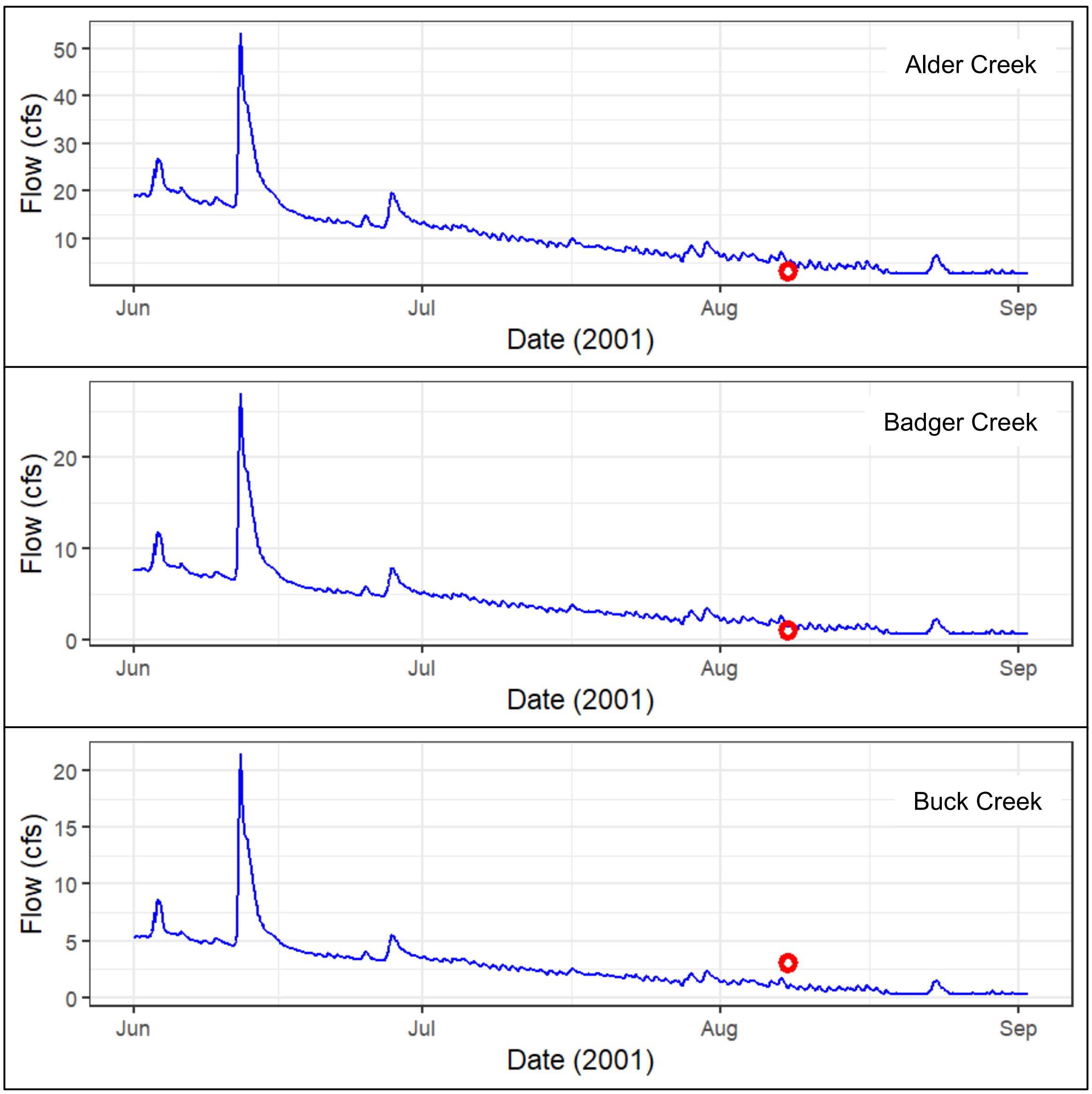
The Beaver Creek gage was not used to derive flows for other tributaries as it had a large adjacent urban landcover area while the other tributaries were predominantly undeveloped. Two time-series flow input derivation methods were tested for each ungaged model input:

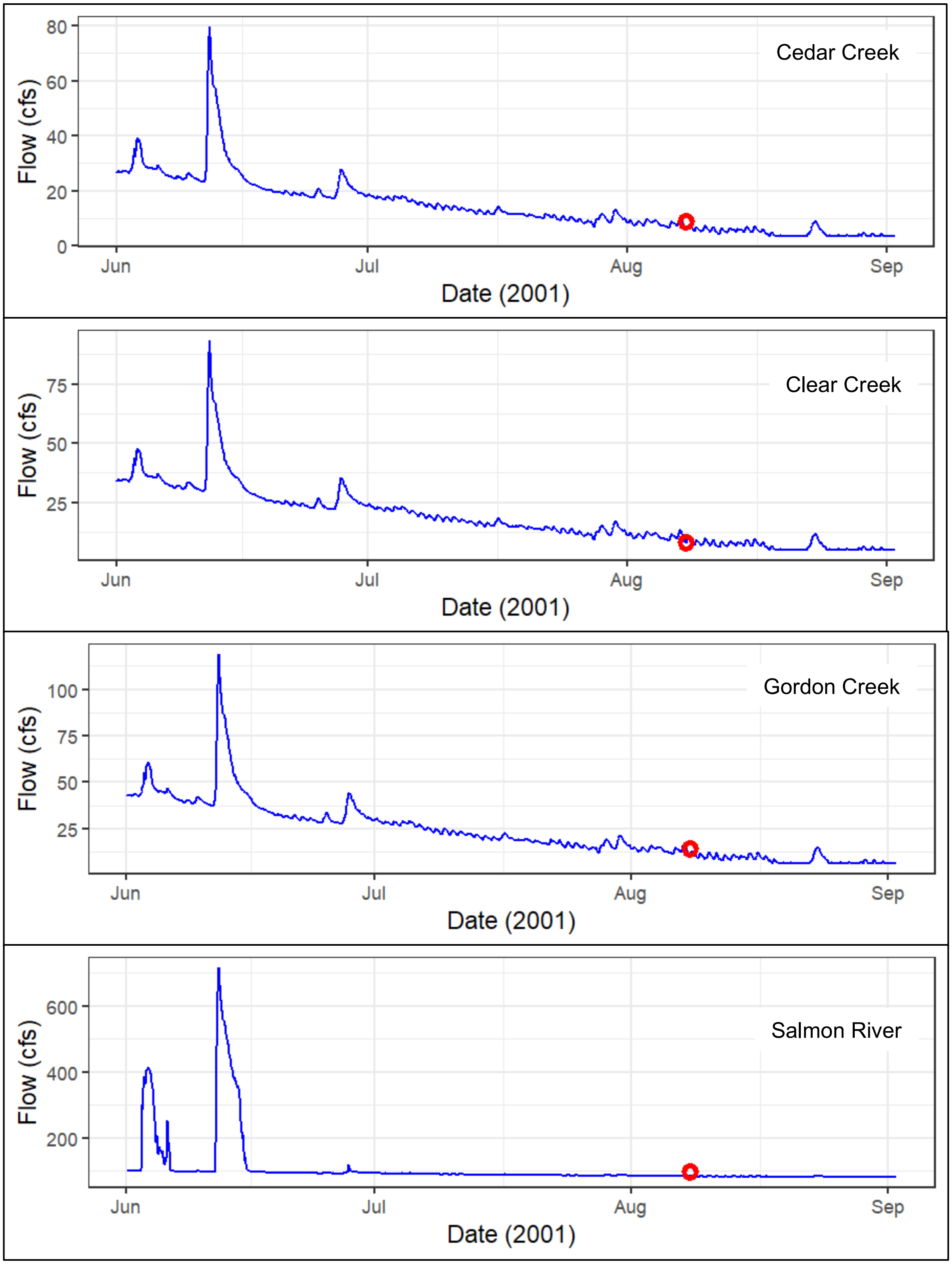
1. Apply flow duration information retrieved from StreamStats (Risley et al., 2008) to the source gage flows (i.e., the “StreamStats method”), based on methods discussed in Lorenz & Ziegeweid (2016), Gazoorian (2015), and Stuckey (2016).

2. Apply a coefficient equal to the drainage area ratio to the source gage flows (the “area-ratio method”).

Each method was applied to both the Sandy River and Blazed Alder Creek gage time-series, for a total of four unique time-series options tested for each input. First, observed flow data from the 2001 Sandy River HS6 model were compared to the estimated June-September 2001 time-series data. The StreamStats method results with the Sandy River at Marmot gage as reference station showed the best overall agreement with observed 2001 flows (Figure 3-12, Table 3-4). Thus, the StreamStats method was selected as the preferred input flow time-series derivation method for the ungaged streams.

For the 2016 model period, the StreamStats-derived time-series based on either the Sandy River at Marmot or Blazed Alder Creek gage were very similar, with the Sandy River at Marmot-derived time-series providing a finer resolution of flow values. The 2016 time-series derived from the Sandy River at Marmot flows also had a greater flow rate resulting from a storm in the second week of August, compared to those using the Blazed Alder Creek gage as a source station. Mean daily flow rates were calculated for each time-series, which were then smoothed by linear interpolation of hourly flow rates from the mean daily flows.




Cedar Creek
Flow (cfs)
0
20
40
60
80
Jun
Jul
Aug
Sep
Date (2001)
Clear Creek
Flow (cfs)
25
50
75
Jun
Jul
Aug
Sep
Date (2001)
Gordon Creek
Flow (cfs)
25
50
75
100
Jun
Jul
Aug
Sep
Date (2001)
Salmon River
Flow (cfs)
200
400
600
Jun
Jul
Aug
Sep
Date (2001)

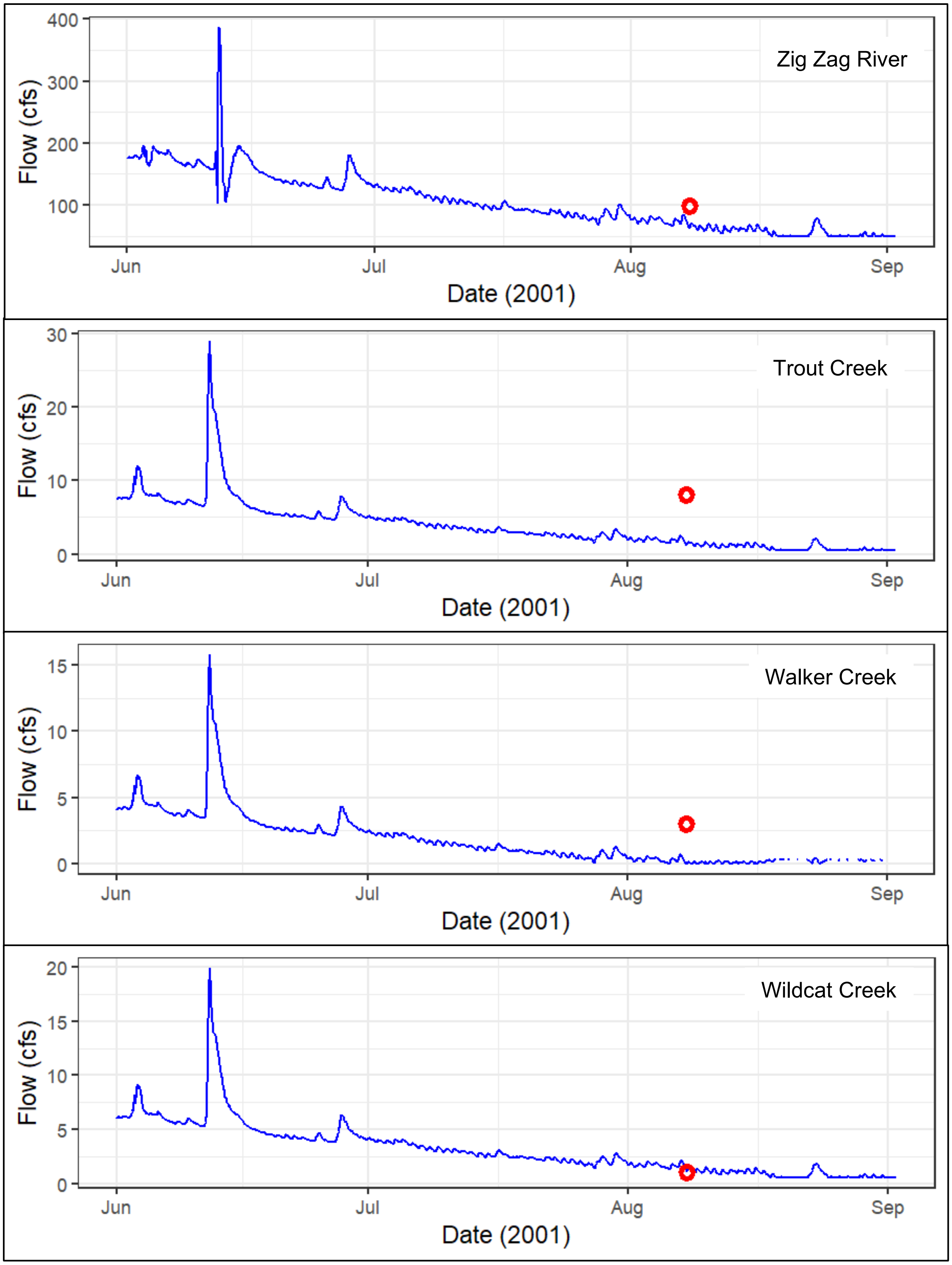


Figure 3-12: Estimated Summer 2001 flows (blue) and observed flows used in 2001 model (red).

Table 3-4: Observed and Estimated flows on August 8, 2001

Name	Observed Flow (cfs)	Estimated Flow (cfs)
Alder Creek	3.2	4.8
Badger Creek	1.0	1.5
Bear Creek	8.0	0.2
Buck Creek	3.0	1.0
Cedar Creek	9.0	6.5
Clear Creek	8.0	8.8
Gordon Creek	14.0	11.1
Salmon River	96.1	83.4
Trout Creek	8.0	1.4
Walker Creek	3.0	0.1
Wildcat Creek	1.0	1.3
Zigzag River	98.4	65.7

3.6.2 Flow Balance

Flow estimates for 19 tributaries were derived based on reference gages; these may be subject to error due to the applied estimation methods. A flow balance calculation was completed to assess the agreement between the sum of the modeled input flows and the observed flows at the two Sandy River gages for each timestep. The 2016 model input flows were estimated with the StreamStats method with the Sandy River near Marmot gage as the source station, and were then adjusted to match the flow balance.

First, the flow balance between the Sandy River near Marmot (14137000) and the Sandy River below Bull Run River (14142500) gages was evaluated. Flows from the Little Sandy River (14141500) and Bull Run River (14140000) gages were summed, and the area-ratio method was used to account for additional drainage area between the Bull Run's confluences with the Little Sandy River and the Sandy River. Raw estimated flows from Badger and Cedar Creeks were added to the observed flows from the Marmot gage and the area-scaled sum of the Bull Run and Little Sandy Rivers. The sum of these flows closely matched the observed flows at the Sandy River gage below Bull Run (Figure 3-13), validating the estimated flow inputs based on the observed Marmot gage flows across this model portion. Any minor differences between gage 14142500 and the summed flows (Figure 3-13) were then distributed among the model flow input time-series (Bull Run, Badger, and Cedar), weighted by drainage area, to match gage 14142500.

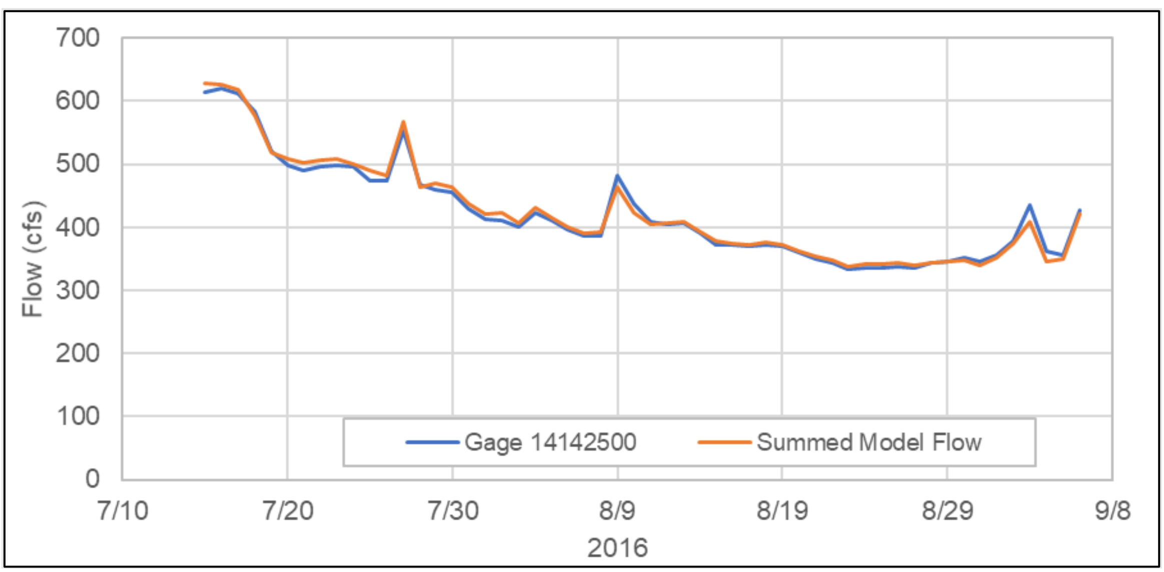


Figure 3-13: Summed model flows vs. observed flows below the Sandy River – Bull Run River confluence

A flow balance was then conducted for the model inputs upstream of the Marmot gage. The sum of the raw, unadjusted headwater and tributary flow estimates upstream of Marmot were notably lower than the observed

Marmot gage flows (Figure 3-14). Further examination of flow records and estimates was performed to identify the origin of the flow deficits. It was hypothesized that the unaccounted flows may be due to groundwater or surface water inputs represented inadequately by the StreamStats method for these upstream tributaries. Further comparison of historical flow records at the (now inactive) Salmon River headwater gage (14134000) with StreamStats-estimated flows showed a similar deficit (Figure 3-15).

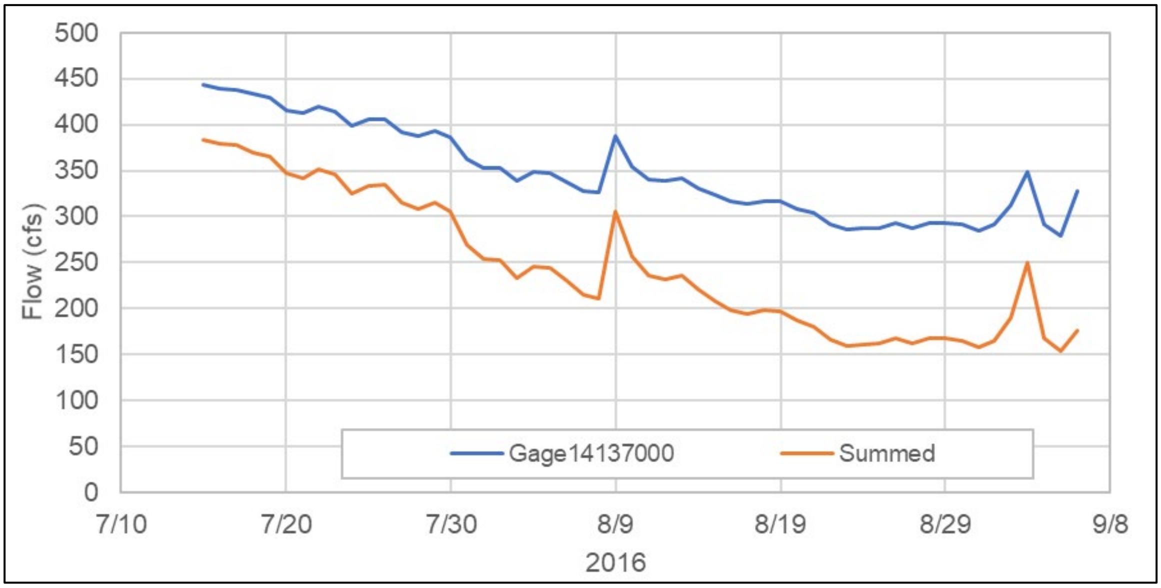


Figure 3-14: Comparison of unadjusted estimated headwater and tributary flows to the Marmot gage with Marmot gage data.

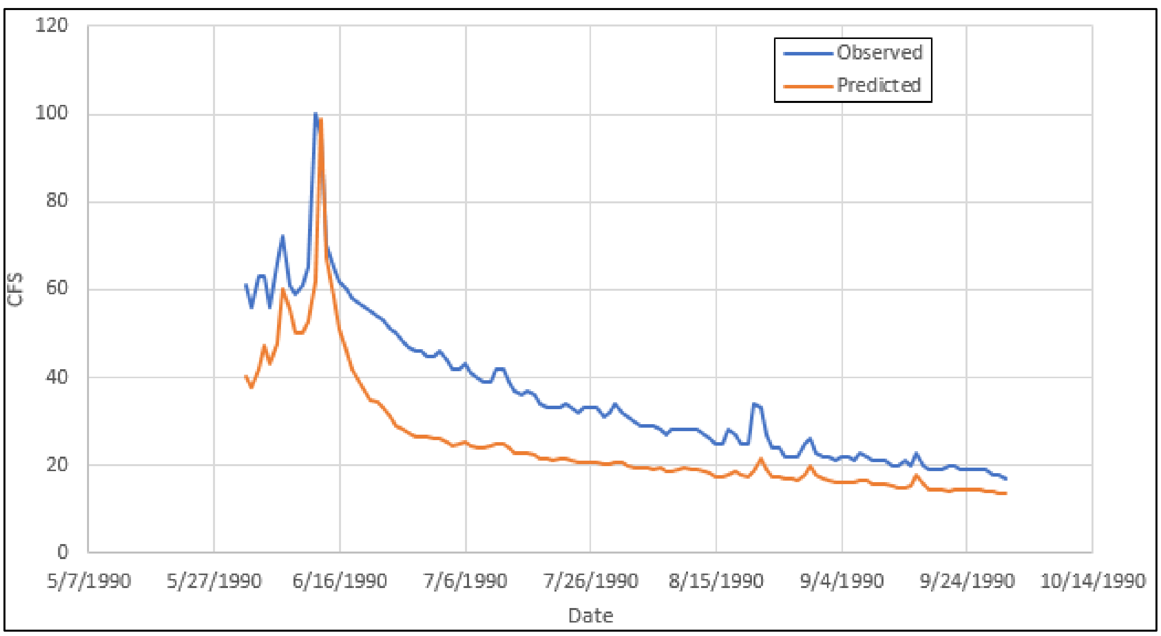
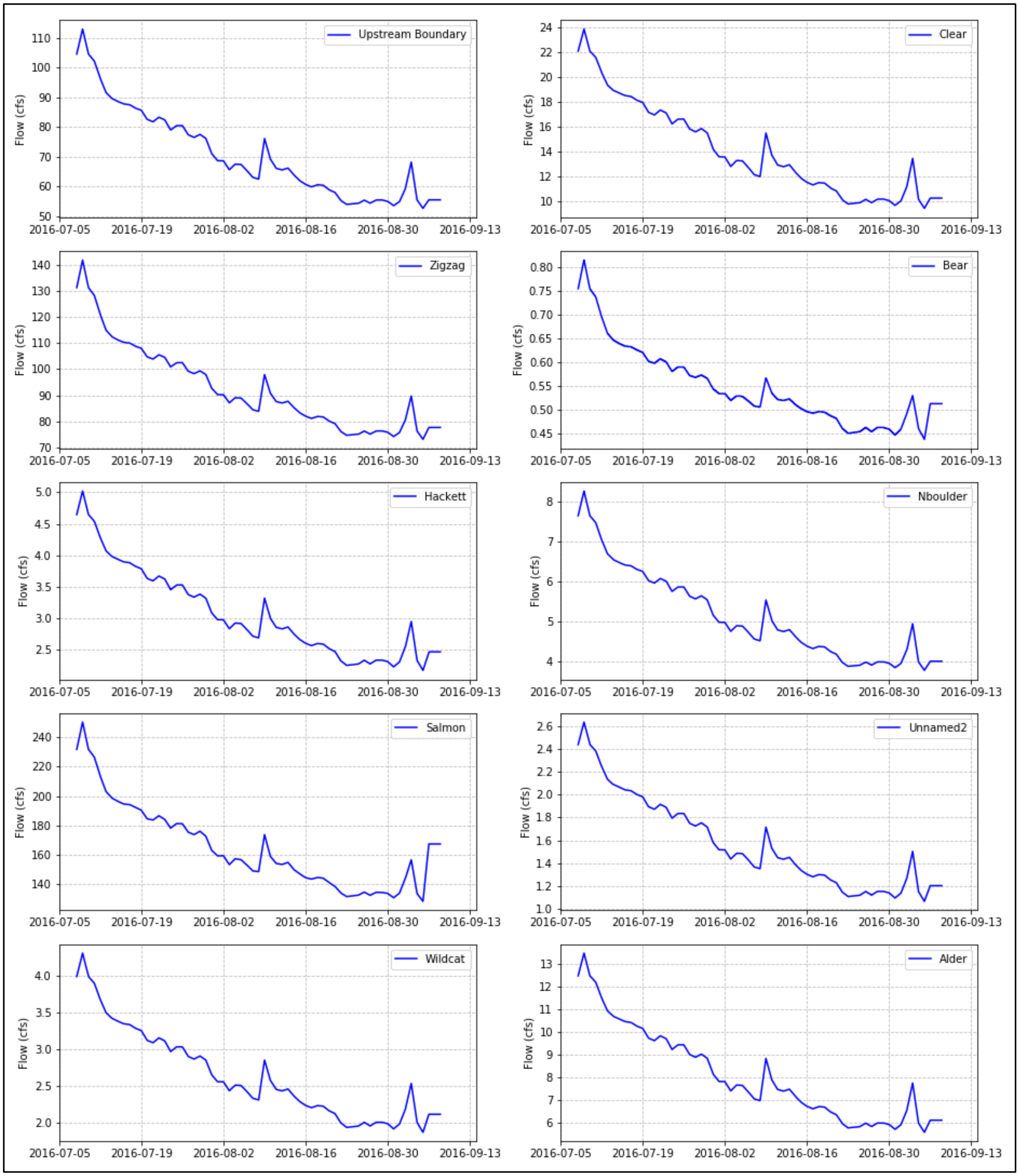
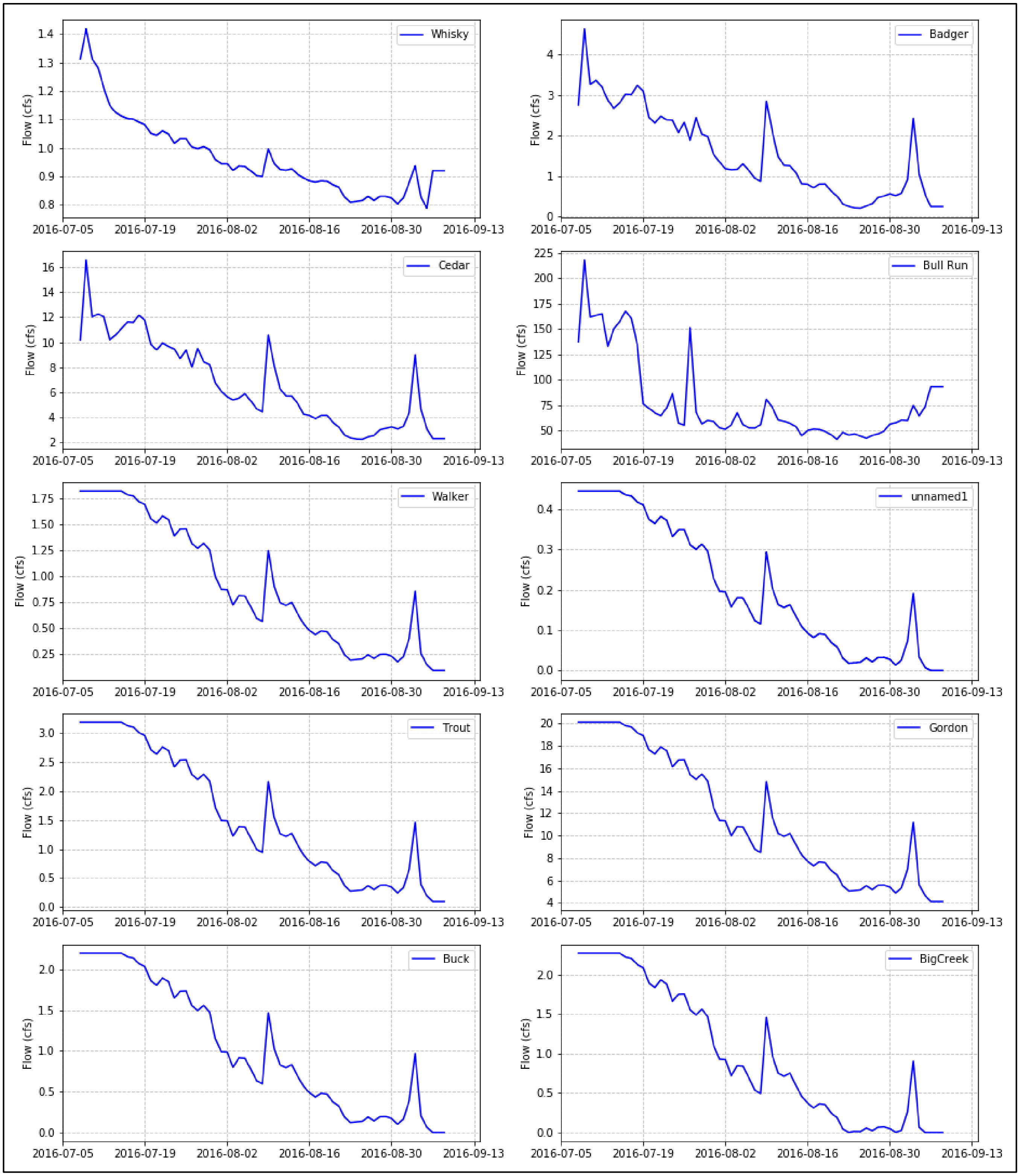


Figure 3-15: Comparison of 2001 observed vs. estimated flows at Salmon R. headwater gage (14134000)

Due to the StreamStats flow underestimations for these upstream areas, and evidence that the deficit is attributable to other upstream tributaries along with the Sandy mainstem, the inputs upstream of the Sandy River at Marmot gage were adjusted. First, the difference between the summed estimated tributary flows and the observed flow at the Marmot gage was calculated. It was not possible to determine if the differences were due to surface or groundwater contributions; thus the differences were then distributed among the model flow input time-series for the upstream tributaries and upstream model boundary, weighted by drainage area. The sum of the resulting adjusted model flows upstream of the Marmot gage equaled the observed flows at the Marmot gage. No further adjustments were made to flow inputs downstream of the Marmot gage given the consistent flow balances and absence of additional downstream flow gages. The resulting flow time-series for model tributaries are presented in Figure 3-16.




Whisky
Badger
Cedar
Bull Run
Walker
unnamed1
Trout
Gordon
Buck
BigCreek
Flow (cfs)
2016-07-05
2016-07-19
2016-08-02
2016-08-16
2016-08-30
2016-09-13

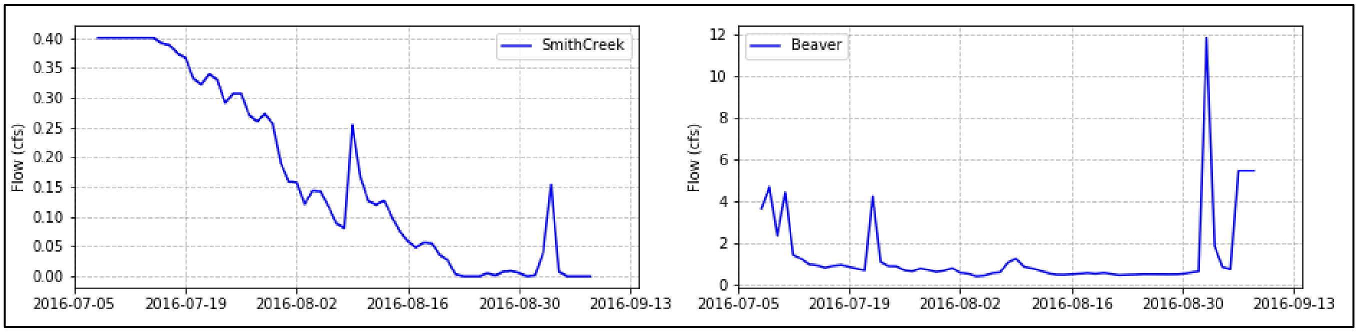


Figure 3-16: Estimated longitudinal flows for model tributaries, 2016 model period

3.7 WATER TEMPERATURE BOUNDARY CONDITION

Observed hourly water temperature time-series data were available from various agencies to support this modeling effort. Data were available from PSU, East Multnomah Soil and Water Conservation District, City of Portland Water Bureau, and the US Forest Service - Mt. Hood National Forest region. Figure 3-17 shows the various stream temperature monitoring locations used as boundary conditions for model configuration or calibration. Table 3-5 inventories the water temperature data used for model development; nine stations were available to configure model boundary conditions, and five stations along the Sandy River were available for model calibration. Although water temperature data were only available for nine of the 22 tributaries, these data covered the major tributaries to the Sandy River, e.g., the Zig Zag, Salmon, and Bull Run Rivers. Figure 3-18 shows the observed stream temperature time-series data for the 2016 model period.

Stream water temperatures for the remaining tributaries were derived from either a linear regression approach or a direct surrogate from a proximal tributary watershed. Alder, Badger, and Wildcat Creek estimates were derived via regression (Figure 3-19) against limited air and water temperature observations from August 8, 2001 available in the 2005 TMDL (DEQ, 2005).

Table 3-5: Inventory of available water temperature data locations used to configure the Sandy R. model

Station ID	Station Description	RKM	Lat/Long	Source	Type
Beaver_0.0	Beaver Cr. at Mouth	3.55	45.5410 / -122.383	PSU	Boundary
EMSWCD_Smith_Murphy	Smith Cr. d/s of Christensen Rd.	10.85	45.5154/ -122.326	E. Multnomah SWCD	Boundary
EMSWCD_Big_Black	Big Cr. @ Hurlburt Rd.	15.45	45.5084/ -122.287	E. Multnomah SWCD	Boundary
PWB_Gordon_Mouth	Gorden Cr. ~600' u/s of Gordon Cr. Rd bridge	20.45	45.4915/ -122.274	Portland Water Bureau	Boundary
PWB_BR_DODGE	Bull Run R. ~500' u/s of Sandy R. confluence	29.45	45.4444/ -122.248	Portland Water Bureau	Boundary
Salmon_0.5	Salmon R. above Sandy Brightwood Bridge	60.7	45.3730/ -122.021	PSU	Boundary
MHNF-099	ZigZag R at Forest Boundary_LTWT	69.85	45.3388/ -121.923	USFS	Boundary
MHNF-024	Clear Cr. trap HOBO temp. site	70.8	45.3581/ -121.938	USFS	Boundary
No Station ID [CedarCrk_usHatchery]	Cedar Cr. 10' u/s of Sandy R. Fish Hatchery Outfall	34.75	45.4039/ -122.251	ODFW	Boundary
MHNF-080	Sandy R at Forest Boundary_LTWT	71.08	45.35631/ -121.938	USFS	u/s Boundary
Sandy_3.0	Sandy R. above Beaver Cr.	3.8	45.5398/ -122.379	PSU	Calibration
Sandy_29.4	Sandy R. below Marmot Dam	47.90	45.3988/ -122.139	PSU	Calibration
Sandy_29.6	Sandy R. at Marmot Dam	48.30	45.3990/ -122.135	PSU	Calibration
Sandy_36.1	Sandy R. at Barlow Tr. bridge below Salmon R.	59.15	45.3839/ -122.046	PSU	Calibration
Sandy_42.5	Sandy R. u/s of Zigzag R.	70.10	45.3497/ -121.944	PSU	Calibration

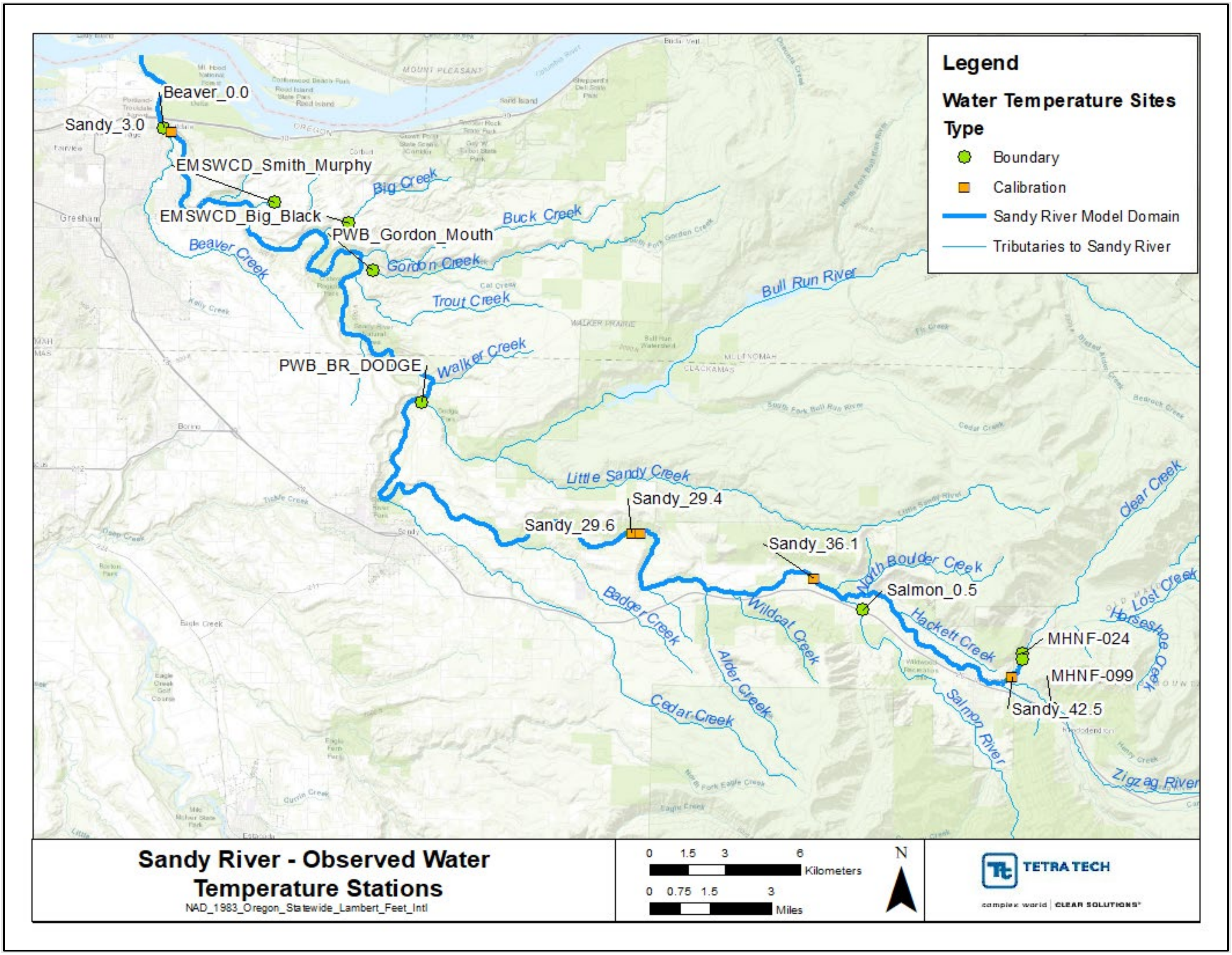


Figure 3-17: Sandy River observed water temperature locations

The regression equations developed for Badger and Alder Creeks were then used to derive hourly stream temperatures for 2016 using observed air temperature from the MesoWest station Sandy DW4118. The relationship developed for Wildcat Creek was not used as the r^2 value was low (a r^2 value of <0.4 was not considered for this study). Wildcat Creek was assigned the same stream temperatures as Alder Creek.

The Cedar Creek water temperature boundary to the Sandy River was derived by constructing a mass balance using estimated Cedar Creek flows (Figure 3-16) and data provided by the Oregon Department of Fish and Wildlife (ODFW) for the Sandy River Hatchery, which discharges to Cedar Creek. The Sandy River Hatchery is located close to the Cedar Creek mouth before its confluence with the Sandy River. The ODFW data consisted of Cedar Creek ambient temperature observed 10' upstream of the hatchery outfall (Figure 3-18) and water flow and temperature measurements from the hatchery outfall (Figure 3-20).

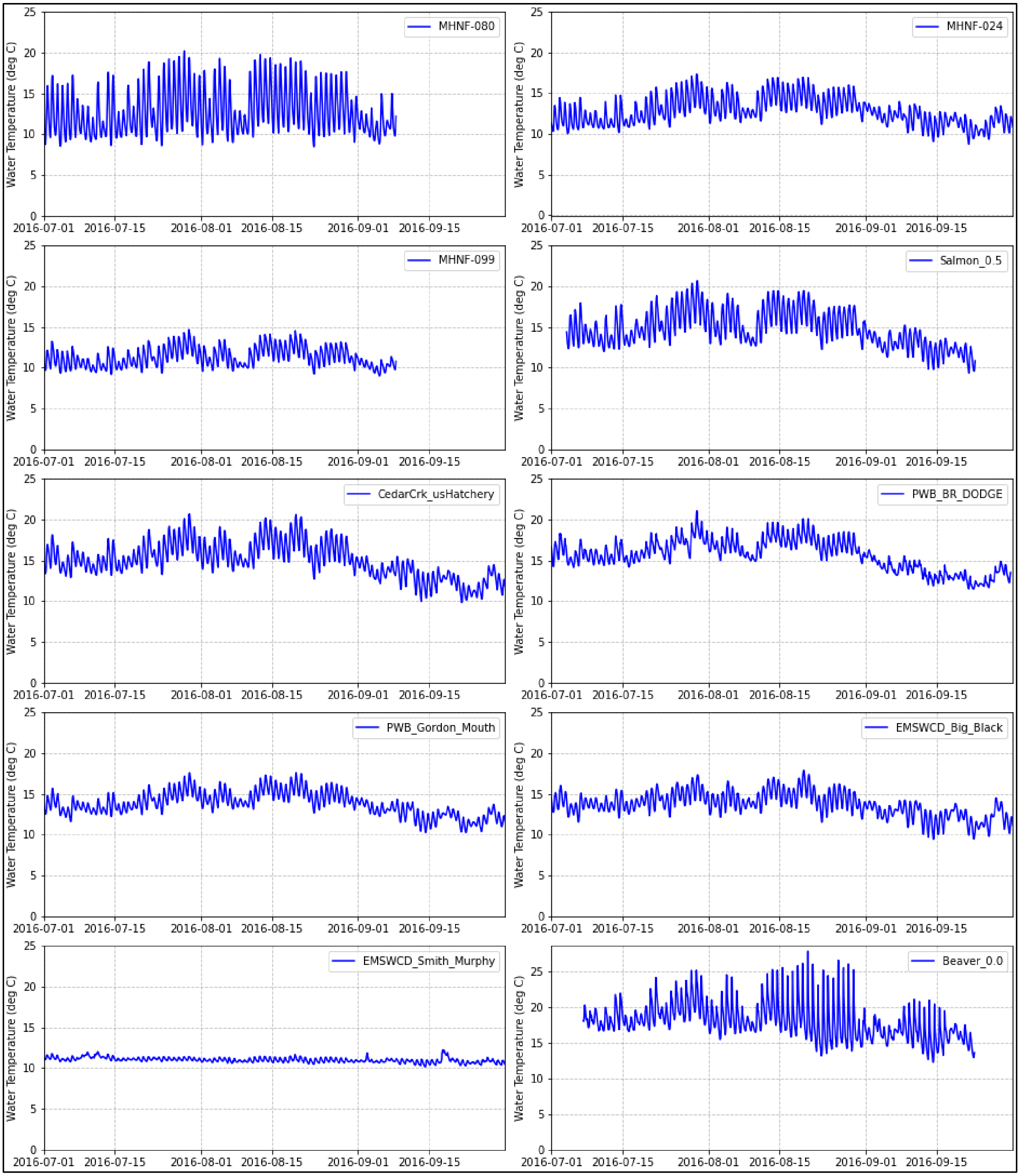


Figure 3-18: Observed hourly water temperatures, Sandy River model tributaries

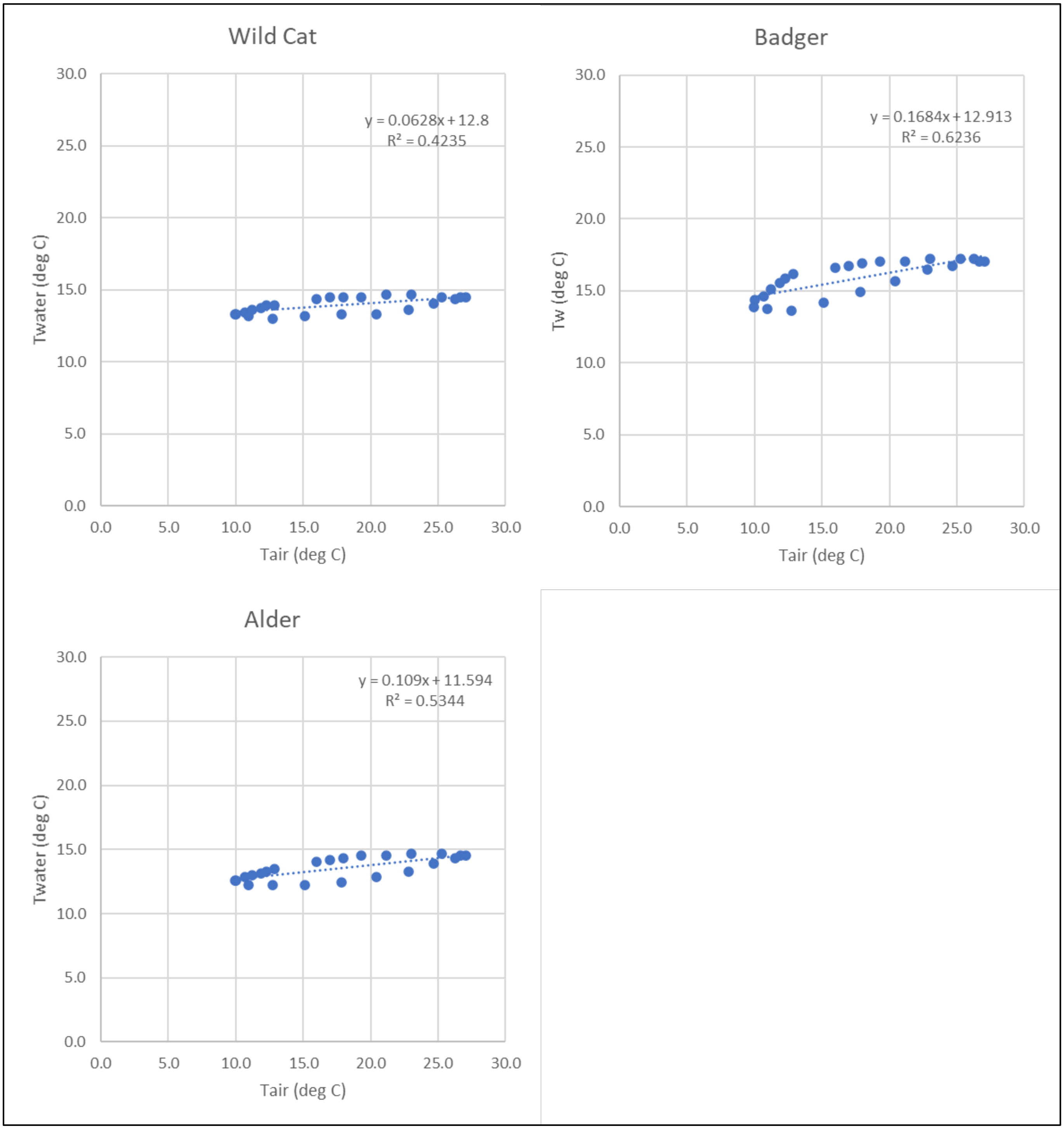


Figure 3-19: Regression between air & water temperatures at Wildcat, Badger, and Alder Creeks, 8/8/2001

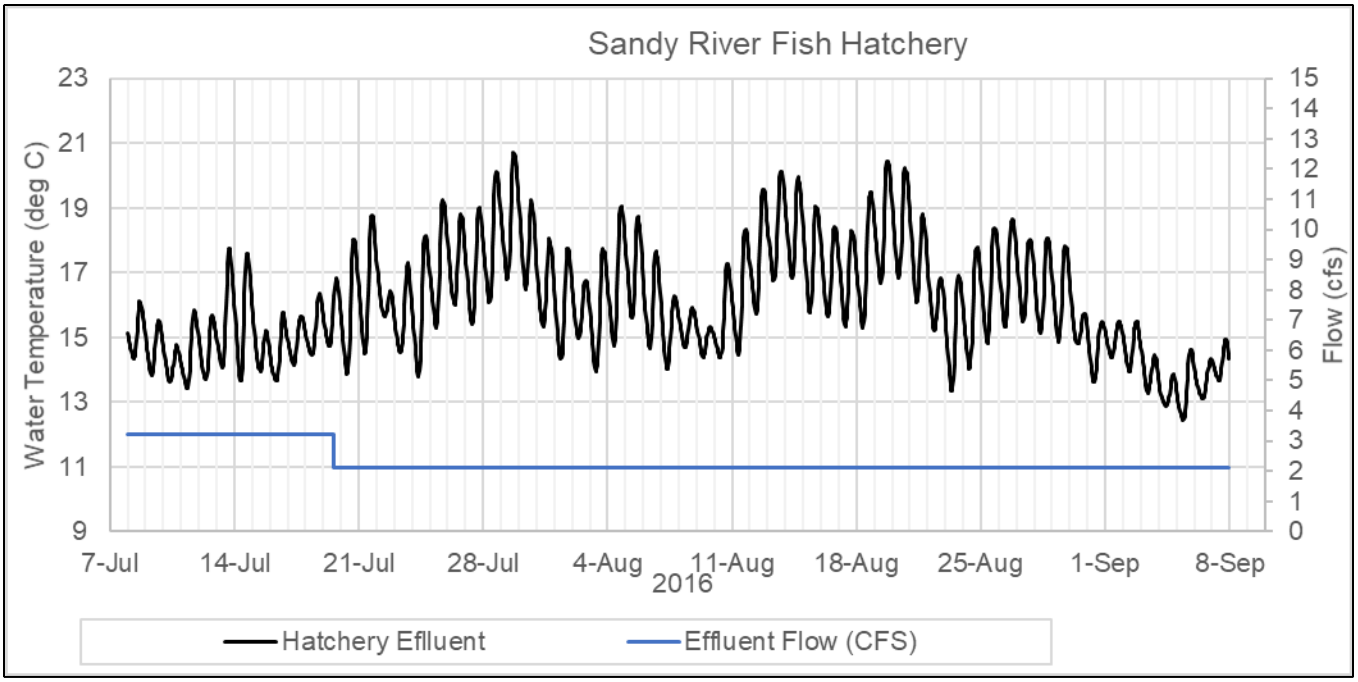


Figure 3-20: Sandy River Fish Hatchery hourly flow & water temperature data

The mass balance was constructed as follows to calculate the water temperature downstream of the hatchery:

$$T = \frac{Q_r \cdot T_r + Q_e \cdot T_e}{Q_r + Q_e}$$

Where:
Q_r = Cedar Creek flow (cfs)
T_r = Cedar Creek temperature (°C)
Q_e = Hatchery effluent flow (cfs)
T_e = Hatchery effluent water temperature (°C)
T = calculated Cedar Creek water temperature (°C) downstream of the Hatchery

Figure 3-21 shows the estimated stream temperatures for Cedar, Badger, and Alder Creeks. The remaining creeks were assigned a direct surrogate based on proximity to the creek. Table 3-6 shows the model stream temperature input assignments used to construct the model for each of the tributaries.

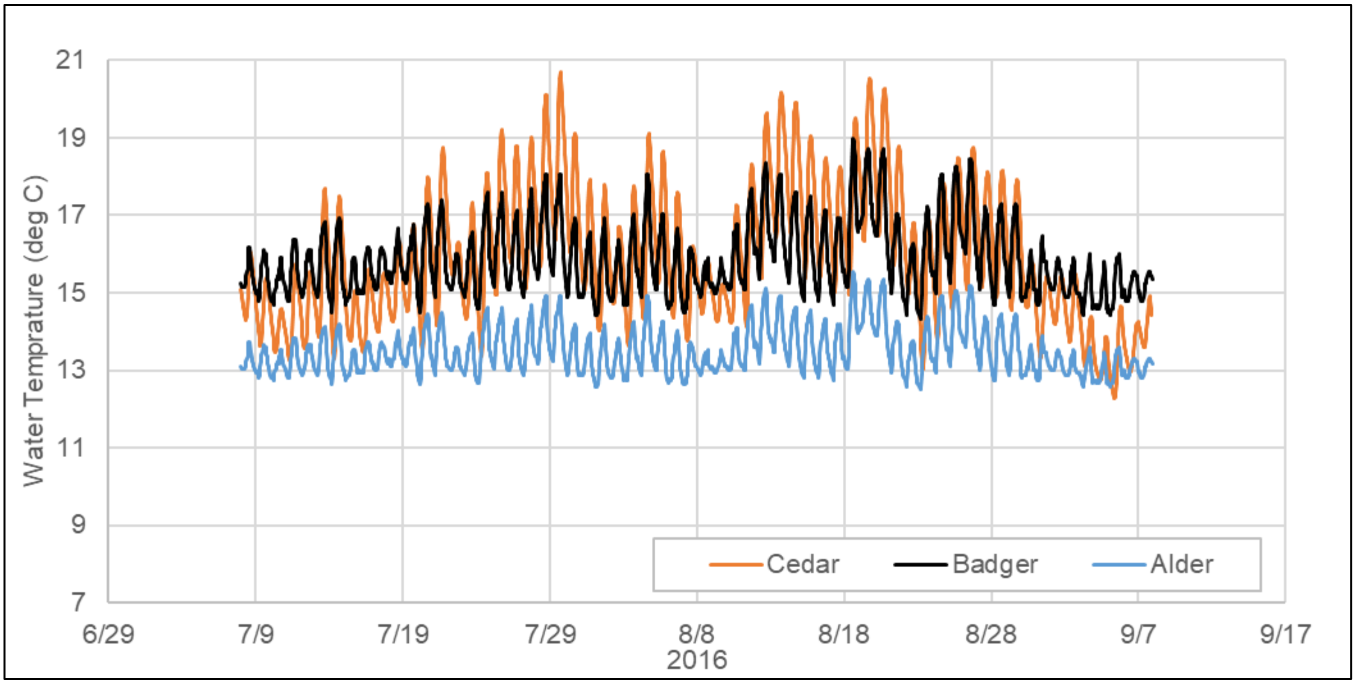


Figure 3-21: Estimated stream temperature for Cedar, Badger, and Alder Creeks

Table 3-6: Stream temperature boundary condition and tributary input assignments

Model Location	Model Location (RKM)	Data Source	Notes
u/s boundary	71.08	Observed data	MHNF-080
Clear	70.80	Observed data	MHNF-024
Zigzag	69.85	Observed data	MHNF-099
Bear	69.50	2005 TMDL	Derived constant, 12.0 °C. (same as DEQ 2005)
Hackett	63.35	Same as Bear	Derived - direct surrogate
Nboulder	61.85	Same as Bear	Derived - direct surrogate
Salmon	60.70	Salmon R. model	Salmon_0.5
Unnamed2	60.20	Same as Bear	Derived - direct surrogate
Wildcat	55.20	Same as Alder	Derived - direct surrogate
Alder	54.30	2005 TMDL	Est'd via regression of T_a and T_w data from DEQ 2005 model
Whisky	51.55	Same as Badger	Derived - direct surrogate
Badger	42.25	2005 TMDL	Est'd via regression of T_a and T_w data from DEQ 2005 model
Cedar	34.75	2005 TMDL	Est'd via regression of T_a and T_w data from DEQ 2005 model
Bull Run	29.45	Bull Run R. model	PWB_BR_DODGE
Walker	28.75	Same as Cedar	Derived - direct surrogate
unnamed1	24.55	Same as Cedar	Derived - direct surrogate
Trout	21.00	Same as Gordon	Derived - direct surrogate
Gordon	20.45	Observed data	PWB_Gordon_Mouth
Buck	20.10	Same as Gordan	Derived - direct surrogate
BigCreek	15.45	Observed data	EMSWCD_Big_Black
SmithCreek	10.85	Observed data	EMSWCD_Smith_Murphy
Beaver	3.55	Observed data	Beaver_0.0

3.8 POINT SOURCE DISCHARGES

There are two active NPDES-permitted point sources that discharge to the Sandy River: the City of Troutdale Water Pollution Control Facility (WPCF) and the Hoodland Sewage Treatment Plant (STP) (Table 3-7, Figure 3-22).

Table 3-7: Summary of individual NPDES permitted discharges to the Sandy River

Facility # (EPA #)	Facility Name	Lat/Long	Permit Type & Description	Model RKM
39750 (OR0031020)	WES (Hoodland STP)	45.3464/ -121.969	NPDES-DOM-Da: Sewage, <1 MGD	67.4
89941 (OR0020524)	City of Troutdale Water Pollution Control Facility	45.5535/ -122.387	NPDES-DOM-C2a: Sewage, ≥1 MGD and < 2 MGD	2.15

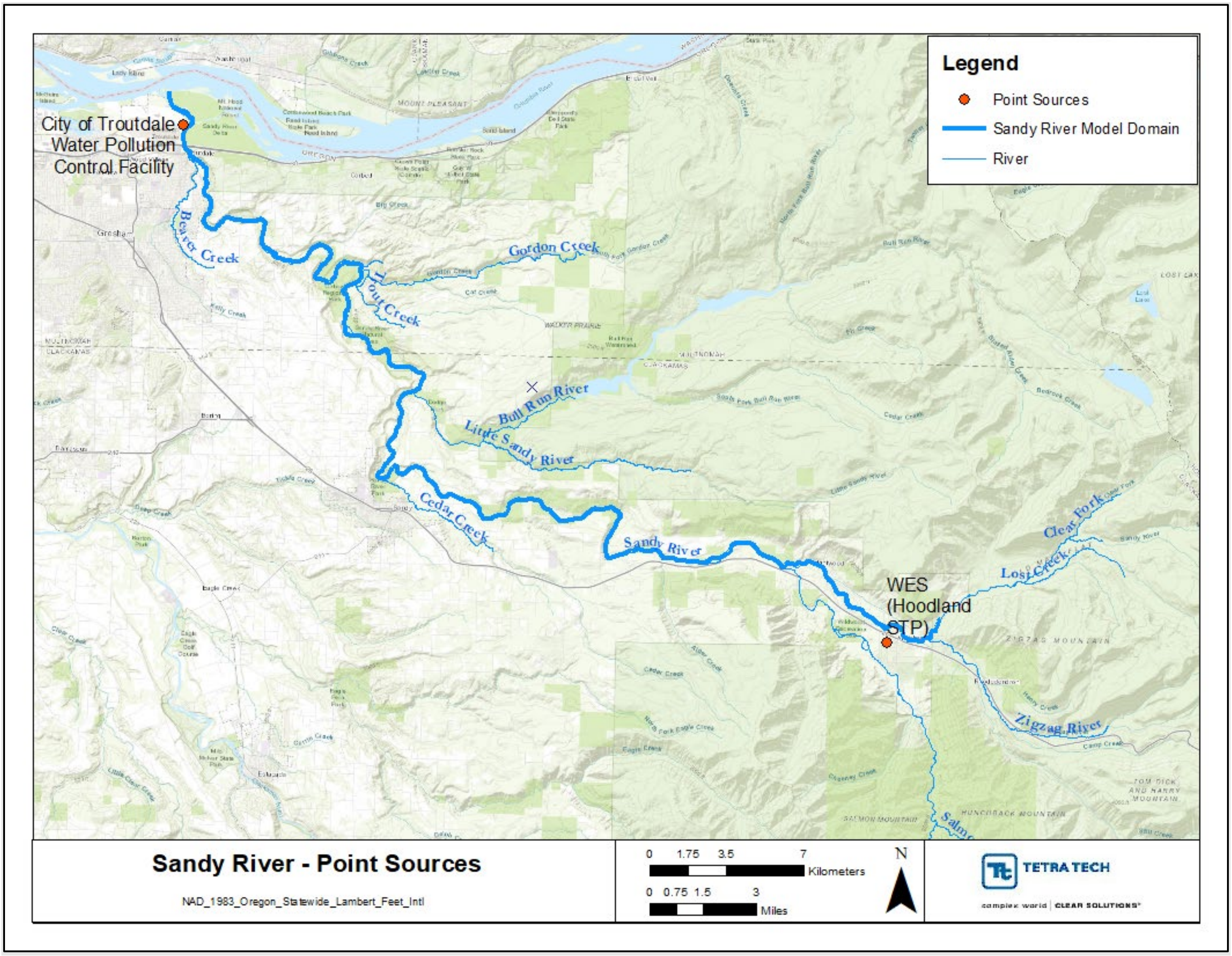


Figure 3-22: Sandy River point source locations

The Hoodland STP discharges treated municipal wastewater from communities along the HWY 26 corridor into the Sandy River near Welches (DEQ, 2005). The outfall is located on Sandy River near model RKM 67.4, upstream from the confluence of the Salmon River and downstream from the confluence of the Zigzag River (Figure 3-22). Daily flow and water temperature from monthly DMR data were provided by Hoodland STP. Note that water temperature provided was daily maximum water temperature. Typically, hourly water temperature timeseries are desired but since hourly data were not available, the daily maximum was used as it was the best information available. The daily data were compiled along with appropriate unit conversion, and then linearly interpolated to create hourly time series of flow and water temperature for specification into the model. Figure 3-23 shows the flow and water temperature data specified in the model for the Hoodland STP.

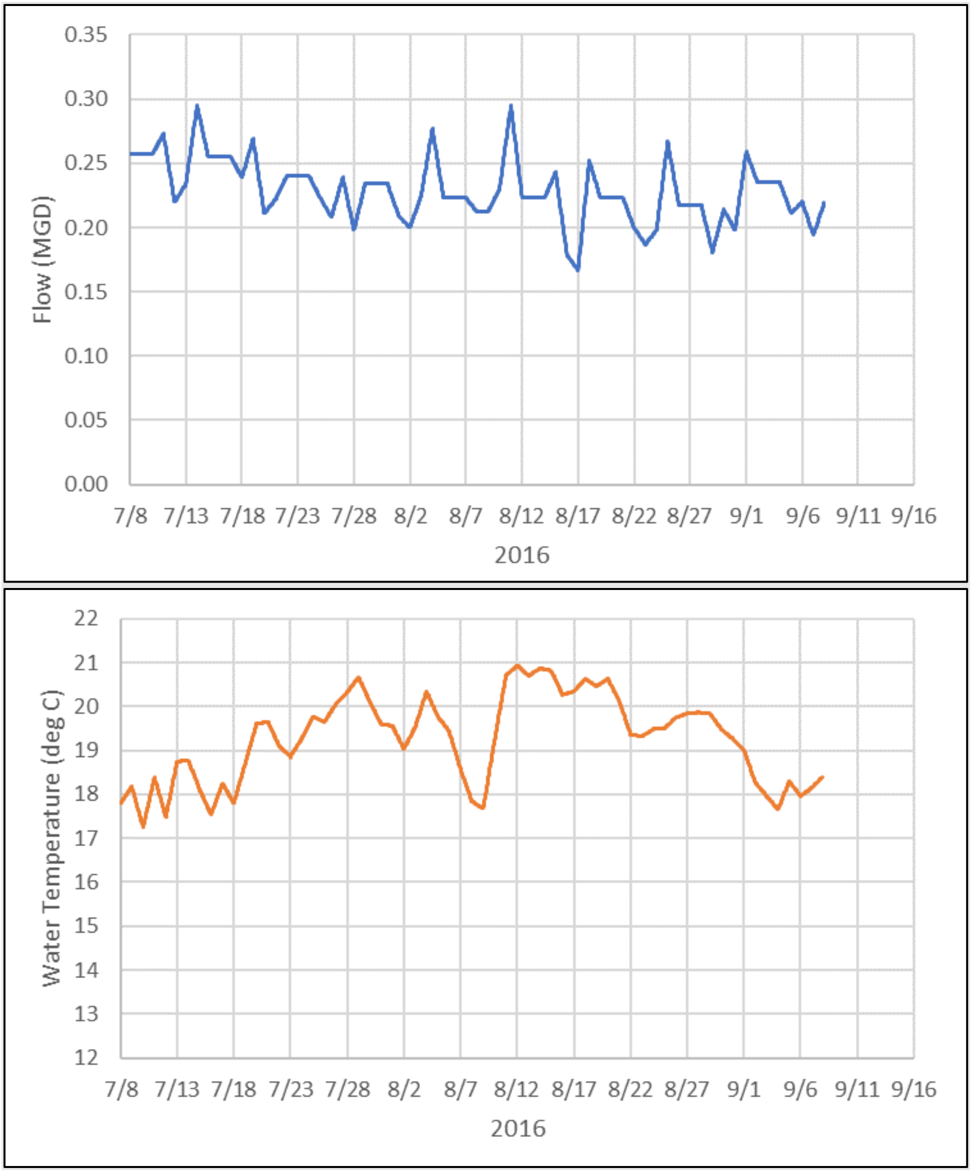


Figure 3-23: Hoodland STP hourly flow and water temperature used in the model

The City of Troutdale Water Pollution Control Facility discharges treated municipal wastewater from the Troutdale area into Sandy near model RKM 2.15 (Figure 3-22). Monthly DMRs containing daily flow data in pdf format and hourly water temperature in digital format were provided by City of Troutdale Water Pollution Control Facility. These data were compiled and then processed after appropriate unit conversion to create hourly time series of flow and water temperature for specification in the model. Figure 3-24 shows the flow and water temperature data specified in the model for the Troutdale point source.

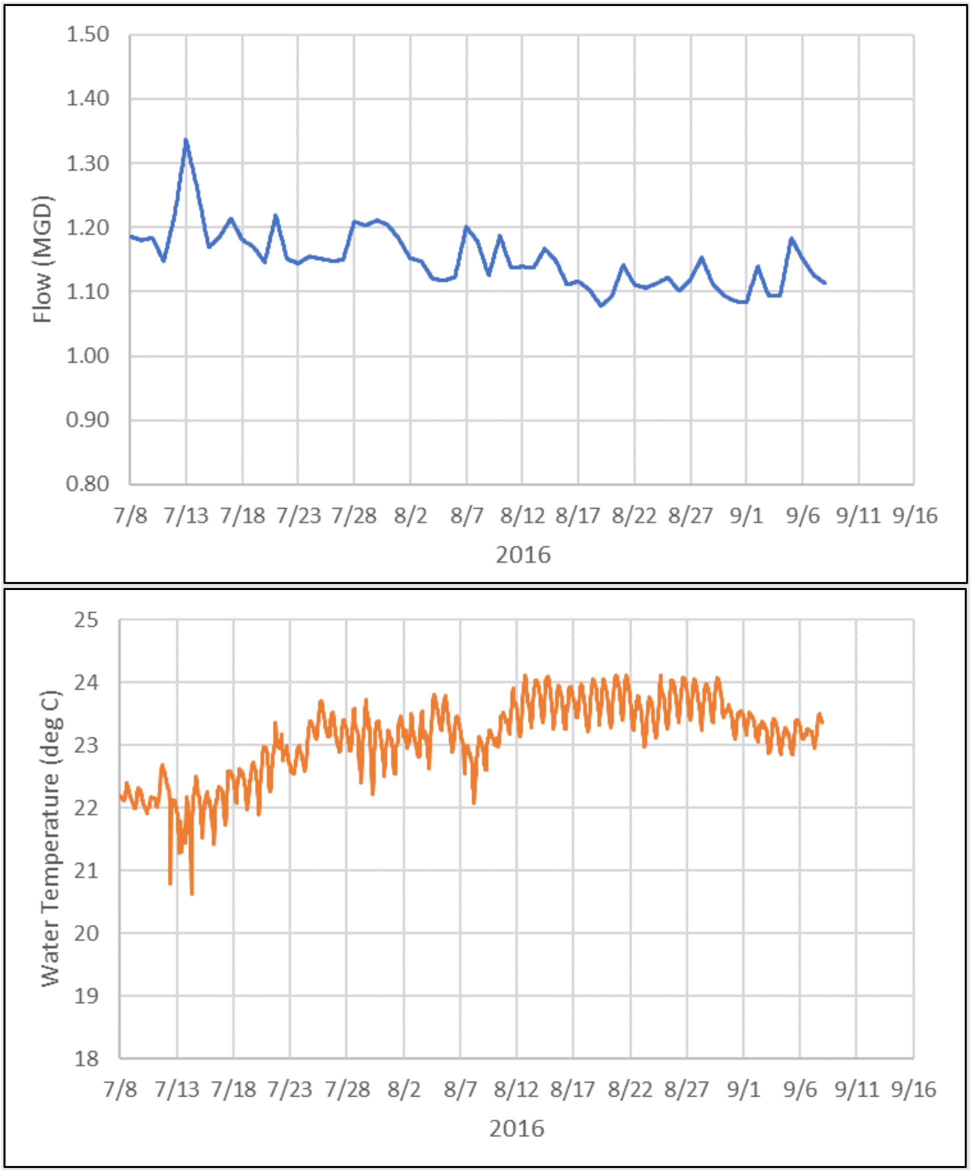


Figure 3-24: City of Troutdale hourly flow and water temperature used in the model

3.9 METEOROLOGICAL DATA

Meteorological data required for HS8 include air temperature, relative humidity, cloudiness, and wind speed. Available data from the National Oceanic and Atmospheric Association (NOAA) National Climatic Data Center (NCDC), and University of Utah MesoWest database were queried. The obtained NCDC data include the Local Climatological Dataset (LCD) (NOAA, 2005) that includes hourly quality-controlled data from airports. The Automatic Position Reporting System WX NET/Citizen Weather Observer Program (APRSWXNET/CWOP) aggregated stations served via MesoWest were queried for stations proximal to the model area.

Table 3-8 lists available meteorological data from these sources along the Sandy River model extent for the required period. Elevations vary widely from east to west along the Sandy River, ranging from 12’ at the mouth to 4000’ near the headwaters on the western slopes of Mt. Hood. Weather stations along the Sandy River mainstem were identified such that these variable elevations can be accounted for with the observed meteorological data (Table 3-8 and Figure 3-25).

Table 3-8: Inventory of available Meteorological Station Data in the Sandy River

Station ID	Station Name	Lat/Long	Elev. (m)	Frequency	Available Data	Source
24242	Portland Troutdale Airport	45.5511/-122.409	8.8	Hourly	Air Temp., Wind Speed, Sky Conditions, Rel. Humidity	NCDC-LCD
D9403	DW9403 Corbett	45.5040/-122.270	218.0	15-minute	Air Temp., Wind Speed, Rel. Humidity	MesoWest, APRSWXNET/CWOP
D4118	DW4118 Sandy	45.3915/-122.108	381.1	15-minute	Air Temp., Wind Speed, Rel. Humidity	MesoWest, APRSWXNET/CWOP
E6654	EW6654 Rhododendron	45.3463/-121.951	430.2	15-minute	Air Temp., Wind Speed, Rel. Humidity	MesoWest, APRSWXNET/CWOP

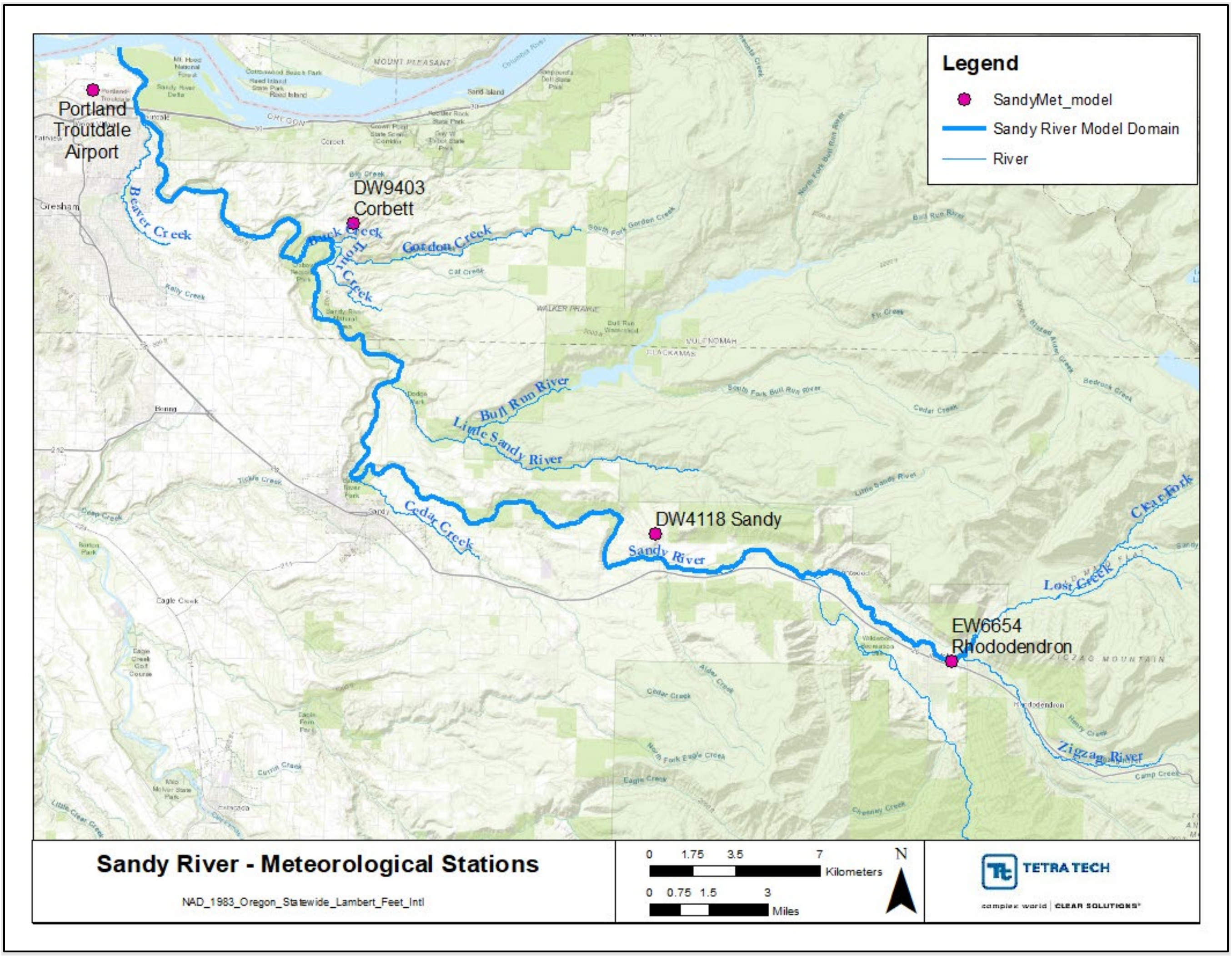


Figure 3-25: Sandy River meteorological stations

As expected, air temperatures increased from the headwaters to the mouth due to elevation change (Figure 3-26). Monthly mean daily maximum air temperatures were greatest in August followed by July and September. Average daily maximum temperatures in August ranged from 24.41°C (Rhododendron) to 26.02°C (Sandy) to 29.28°C (Troutdale). In September, the average daily maximum temperature ranged from 18.45°C (Rhododendron) to 19.50°C (Sandy) to 23.02°C (Troutdale) (Figure 3-27).

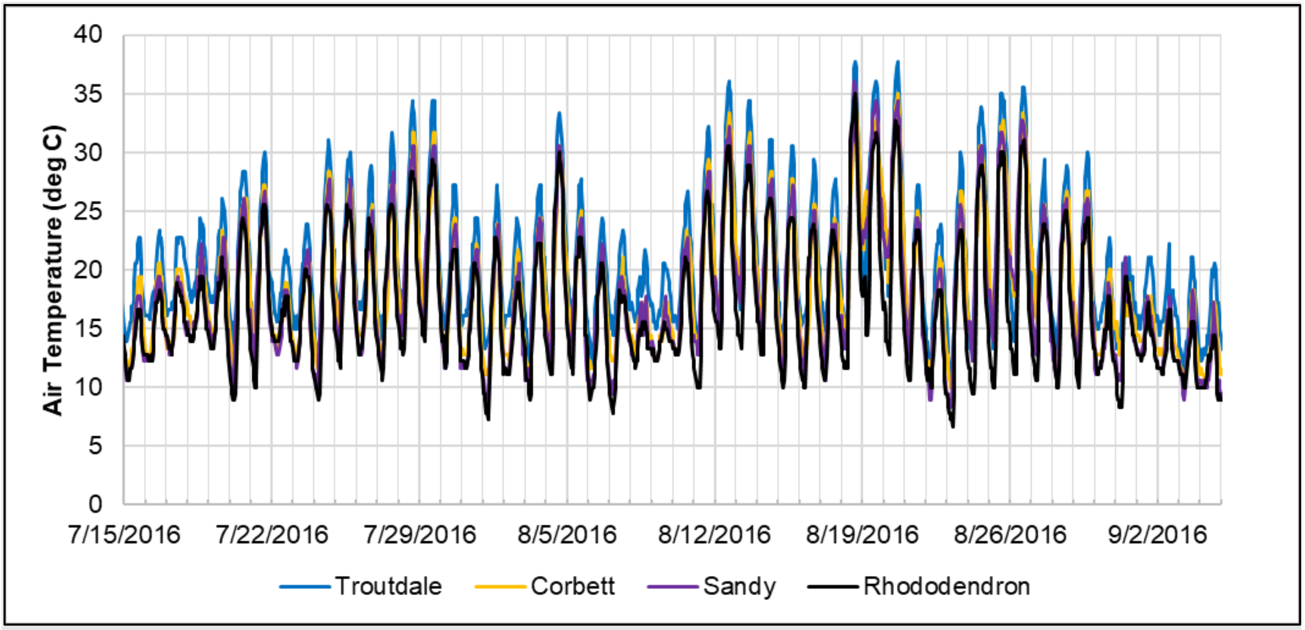


Figure 3-26: Observed hourly air temperature

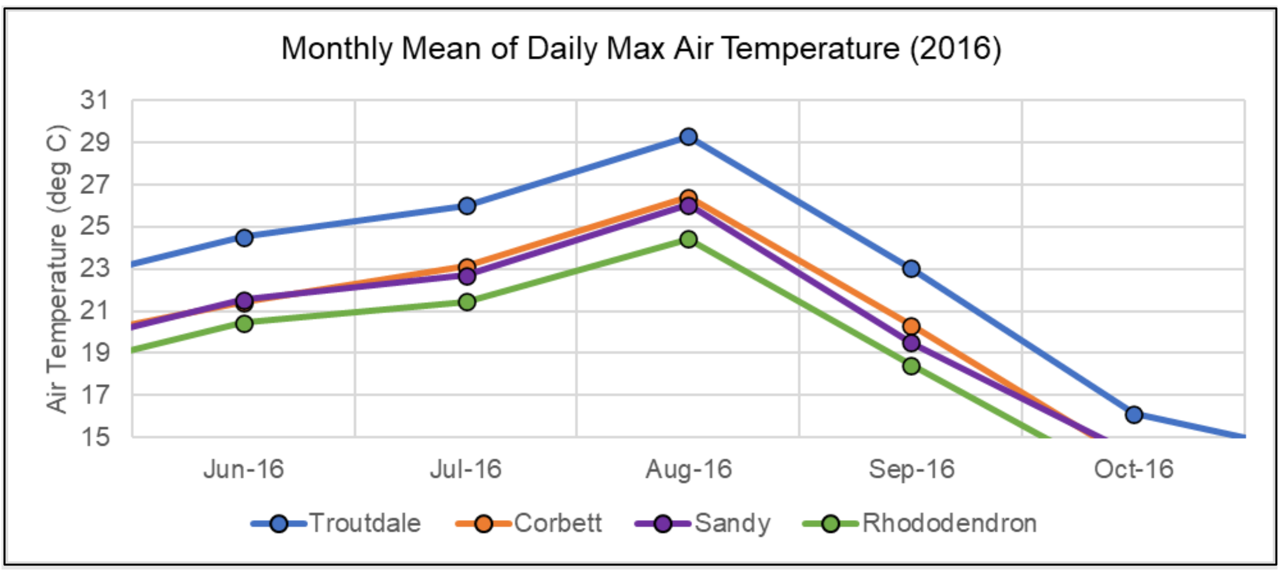


Figure 3-27: Monthly mean of the daily max. air temperature

Relative humidity and wind speed data were available from all identified stations, but cloud cover data were only available for the Troutdale Airport NCDC station. These data were available as sky cover descriptions, which were transformed to tenths on a scale of 0-1 for HS8 input. The wind speed data served by MesoWest indicated that wind speed was typically recorded at 0.45 m/sec precision/increments. The data were dominated by “zero” values that appear associated with wind speeds below the detection threshold. The Rhododendron wind speed data contained the most zero values. No data flags were associated with the MesoWest wind speed data. The NCDC wind speed data at Troutdale, in contrast, had greater resolution and variability, with some gusts at values ~12 m/sec.

Data were generally available at all selected meteorological stations for the modeling period with few missing data. When data were missing for a few hours, e.g., as noted for the Rhododendron station, the gaps were populated via linear interpolation. Figure 3-28, Figure 3-29, Figure 3-30, and Figure 3-31 show the HS8 meteorological inputs for the respective Rhododendron, Sandy, Corbett, and Troutdale Airport locations.

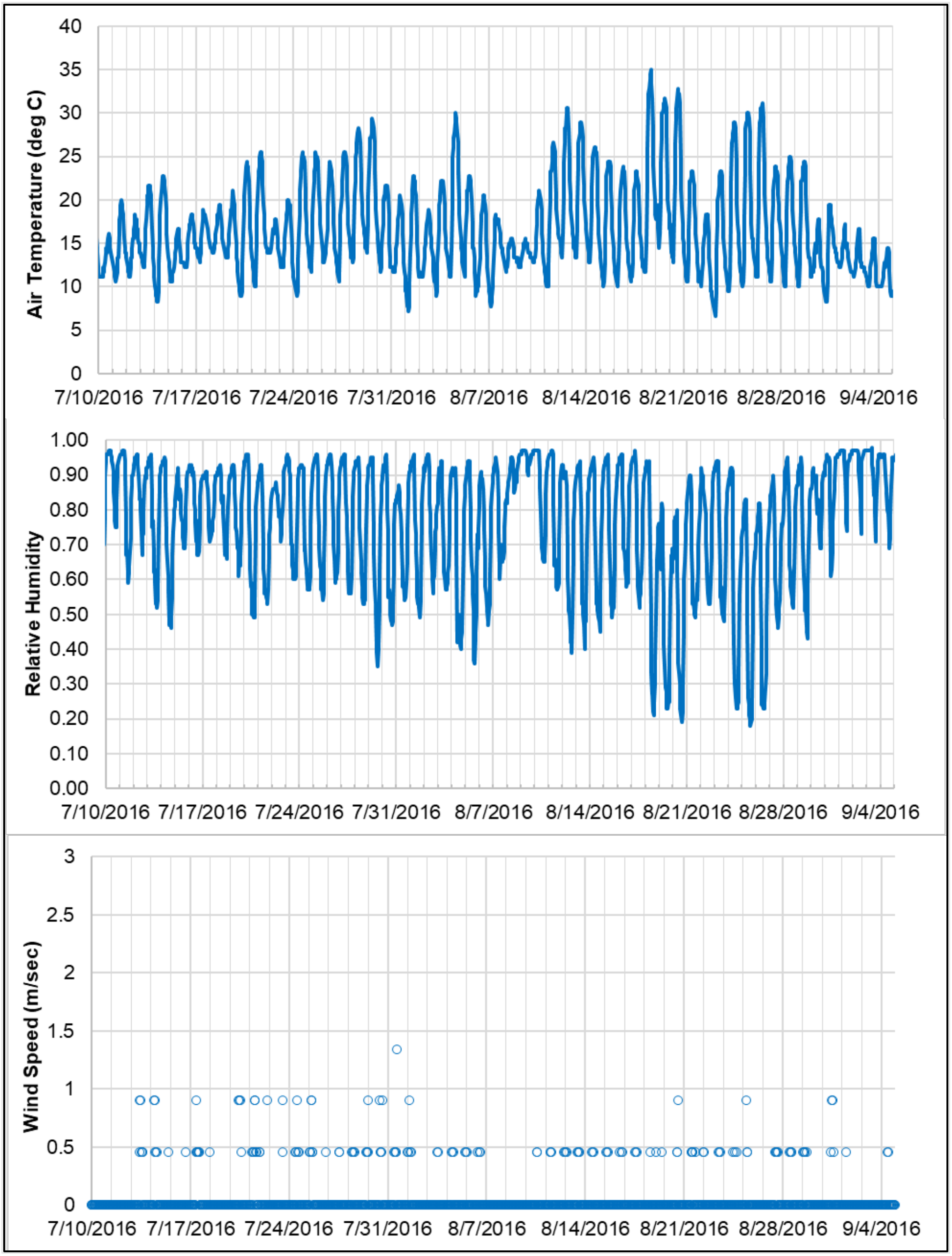


Figure 3-28: Hourly air temperature, relative humidity and wind speed at Rhododendron

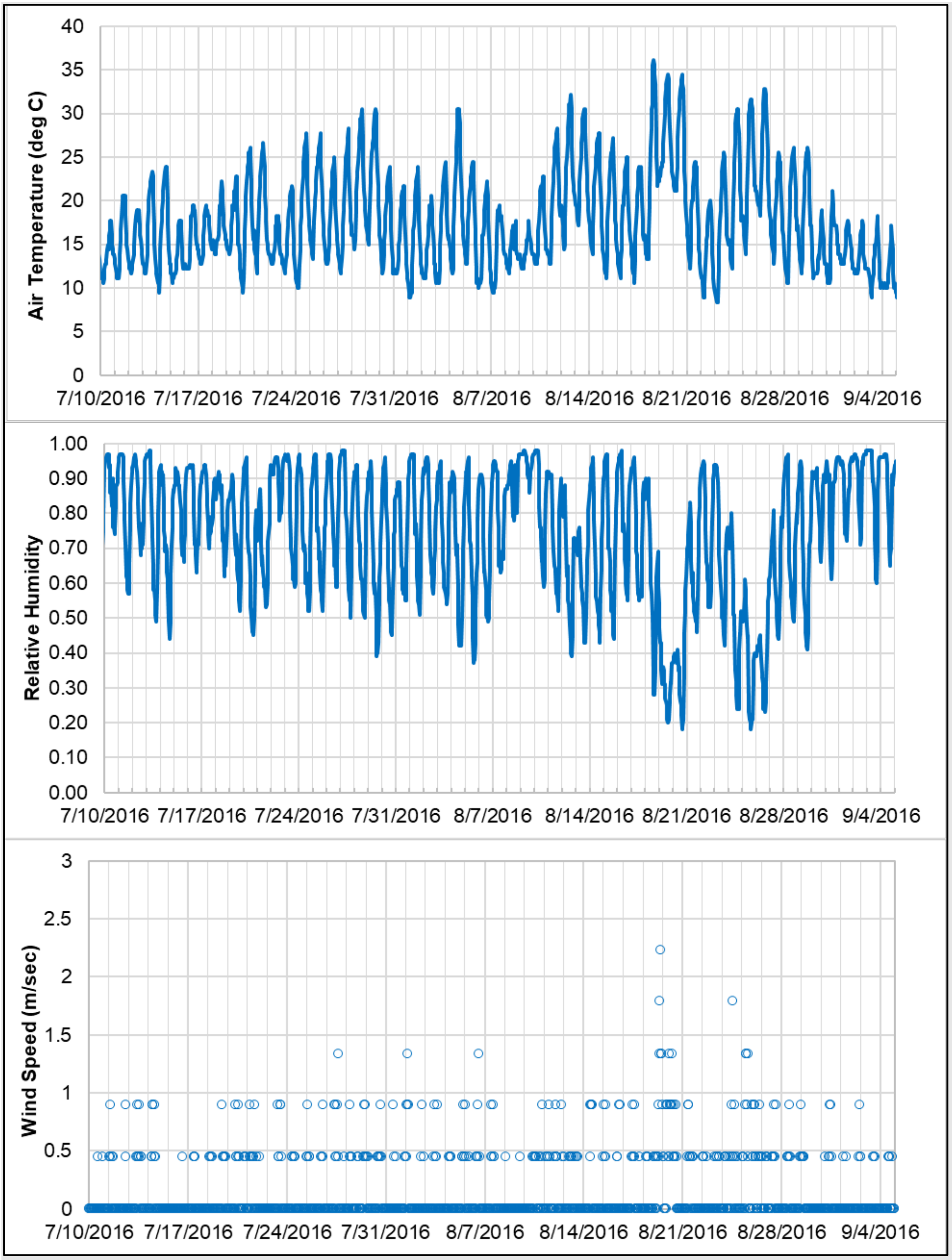


Figure 3-29: Hourly air temperature, relative humidity and wind speed at Sandy

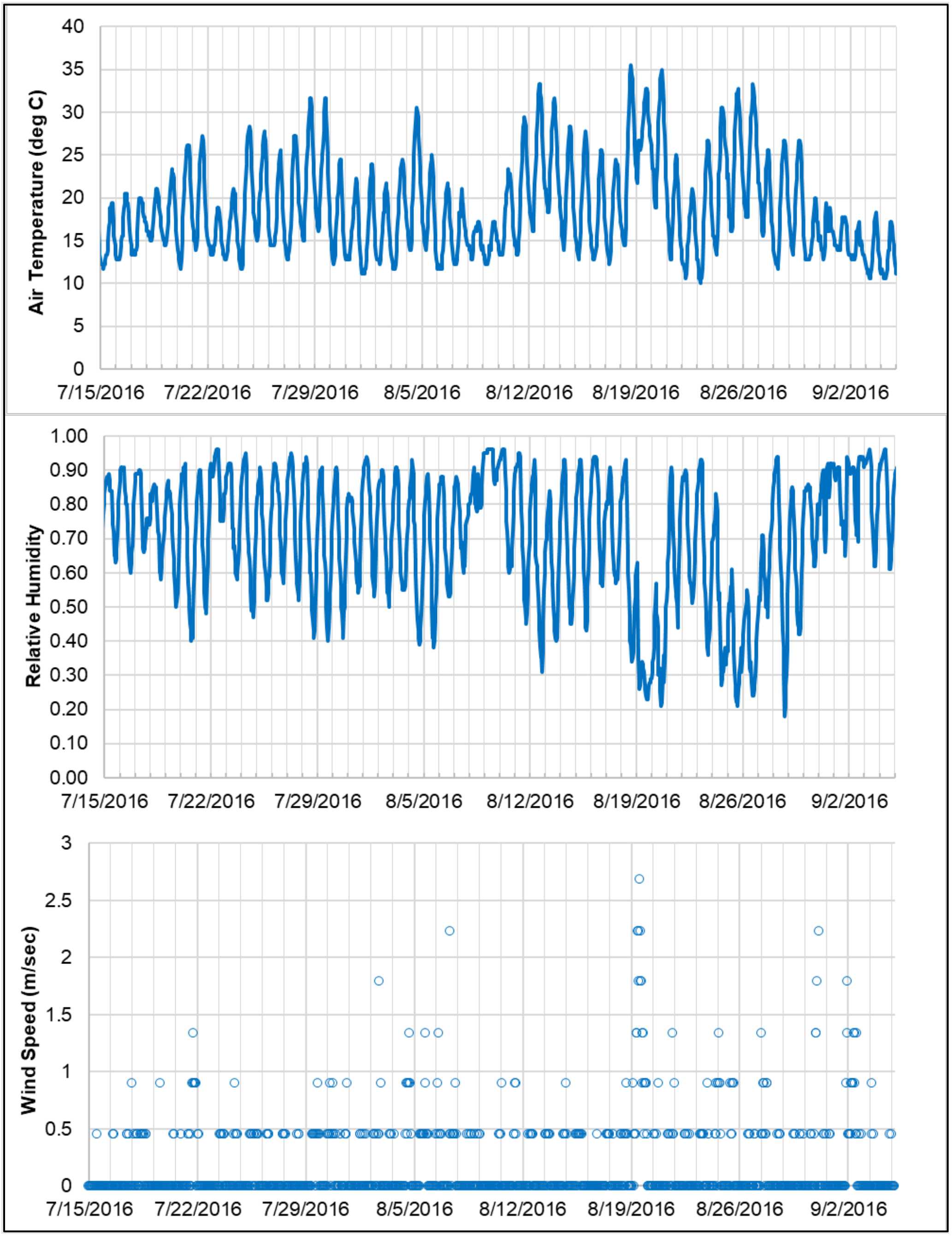


Figure 3-30: Hourly air temperature, relative humidity and wind speed at Corbett

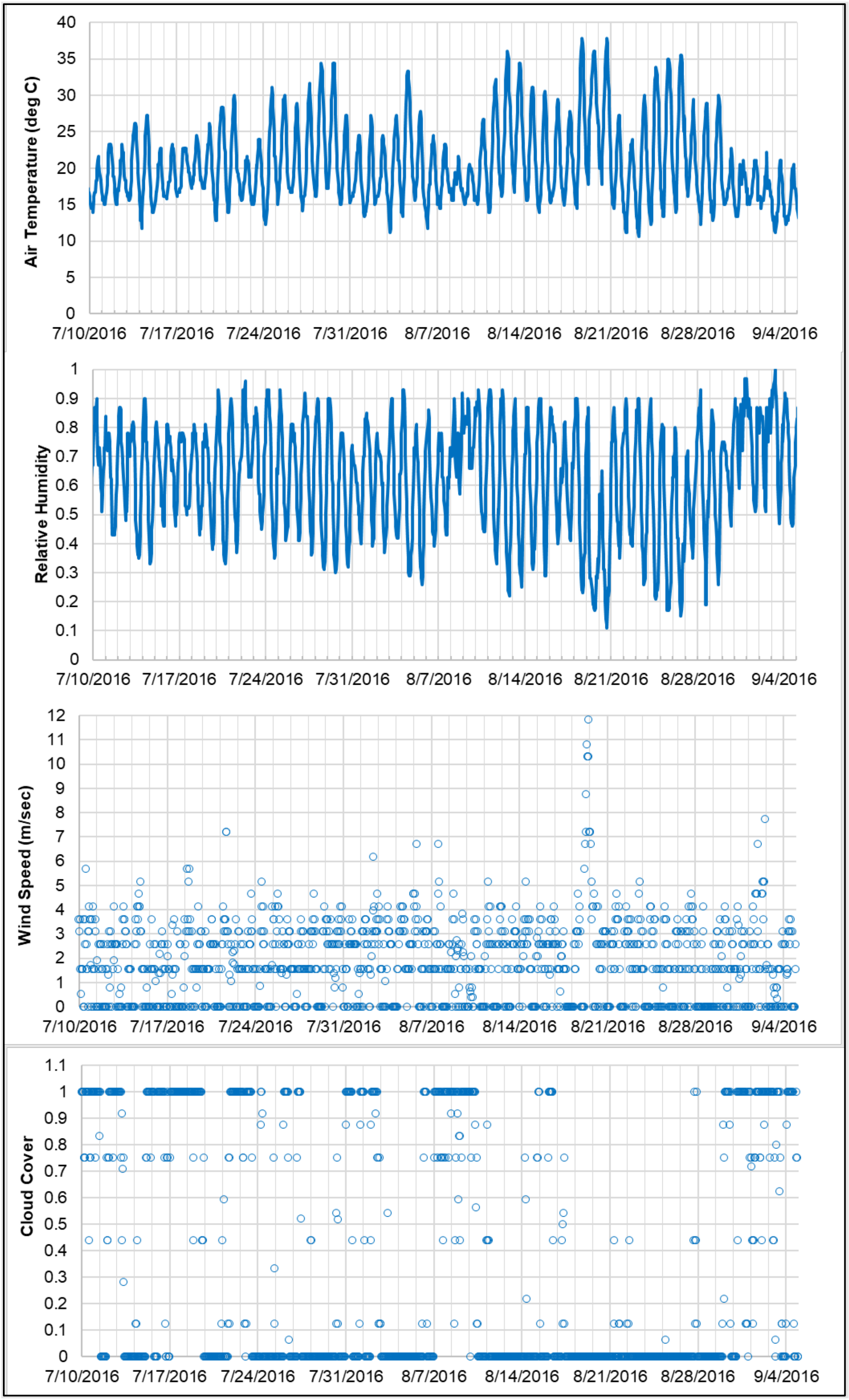


Figure 3-31: Hourly air temperature, relative humidity, wind speed, and cloudiness at Troutdale Airport

4.0 MODEL CALIBRATION

The Sandy River HS8 model was simulated for the period from July 15, 2016, to September 5, 2016, over the 71 km model extent from just upstream of Clear Creek to the mouth at the Columbia River. The model incorporated spatially variable hourly meteorology inputs for six locations and hourly stream flow and temperature inputs for 21 locations including the upstream boundary, major tributaries (e.g., the Zig Zag, Salmon, and Bull Run Rivers), and two NPDES-permitted point sources to the system.

The model was then calibrated against observed data. Model calibration refers to the comparison of observed data to modeled values. Table 4-1, Figure 3-11, and Figure 3-17 show the sites used for the Sandy River HS8 model flow, water temperature, and effective shade calibration. There were no effective shade measurements available for calibration for 2016. Instead, observed effective shade measurements collected in August 2001 at three Sandy River locations were used for rough comparison with predicted 2016 shade values.

Table 4-1: Calibration sites used in the Sandy River HS8 model calibration

Station ID	Description	Lat/Long	Model RKM	Data Type	Source
Hourly Flow					
14137000	Sandy R. near Marmot	45.3996/-122.137	48.05	Hourly Flow	USGS
14142500	Sandy R. below Bull Run R. near Bull Run	45.4490/-122.245	29.1	Hourly Flow	USGS
Hourly Water Temperature					
Sandy_3.0	Sandy R. above Beaver Cr.	45.5398/-122.379	3.8	Hourly Water Temperature	PSU
Sandy_29.4	Sandy R. below Marmot Dam	45.3988/-122.139	47.90	Hourly Water Temperature	PSU
Sandy_29.6	Sandy R. at Marmot Dam	45.3990/-122.135	48.30	Hourly Water Temperature	PSU
Sandy_36.1	Sandy R. at Barlow Tr. bridge below Salmon R.	45.3839/-122.046	59.15	Hourly Water Temperature	PSU
Sandy_42.5*	Sandy R. u/s of Zigzag R.*	45.3497/-121.944	70.10	Hourly Water Temperature	PSU
Effective Shade Measurements					
10676	Sandy above Salmon near Brightwood	45.3786/-122.013	62.4	August 2001(Observed:0%)	DEQ
26422	Sandy above Clear Cr. at Lolo Pass Rd.	45.3565/-121.938	70.95	August 2001 (Observed:61%)	DEQ
N/A	Sandy R. at Troutdale STP	45.4982/-122.01	3.8	August 2001 (Observed:11%)	DEQ

* Ultimately, this station was not used to evaluate model performance as its calibration statistics exceeded the ≤1°C criteria, due to tidal influences that HS8 cannot simulate (refer to text under the Temperature Calibration section).

The model was run at 0.25 min timesteps and outputs were generated hourly at 50m increments. Modeled streamflows were calibrated first, followed by stream temperature. Channel morphology-related inputs (e.g., elevation, Manning's n, and channel bottom width) were identified for calibration purposes as channel hydraulics are important to predict flow and temperatures. Channel hydraulics govern the water surface area that may receive solar radiation, the exposure time, and the degree of light penetration into the water column. HS8 is a one-dimensional model and channel configuration is represented in a trapezoidal shape.

Channel elevations were not adjusted as they were derived from high-resolution LiDAR data. In-channel Manning's n values (that represent channel roughness and other flow factors) and estimated channel bottom widths were adjusted for calibration. Manning's n was initially set to the default 0.3 to prevent model instability due to channel dewatering. Through calibration, this value was reduced a value within typical literature values (< 0.1). A final Manning's n of 0.068 was arrived at through iterative adjustment. During calibration it was found that the modeled diurnal water temperature range was overpredicted vs. observed data. To reduce the predicted diurnal range and better-correspond with observed data, the estimated model bottom widths were scaled down at some segments. The initial bottom width inputs were scaled down by 10% from RKM 71 to RKM 50, and by 20% from RKM 50 to RKM 25. This resulted in increased channel depths and better diurnal temperature range predictions. The bottom widths for RKM 25 to the mouth (RKM 0) were not adjusted; here, bottom width reductions did not improve the temperature calibration of the most-downstream station, perhaps due to the relatively large channel widths. Figure 4-1 shows the initial and final calibrated channel bottom widths.

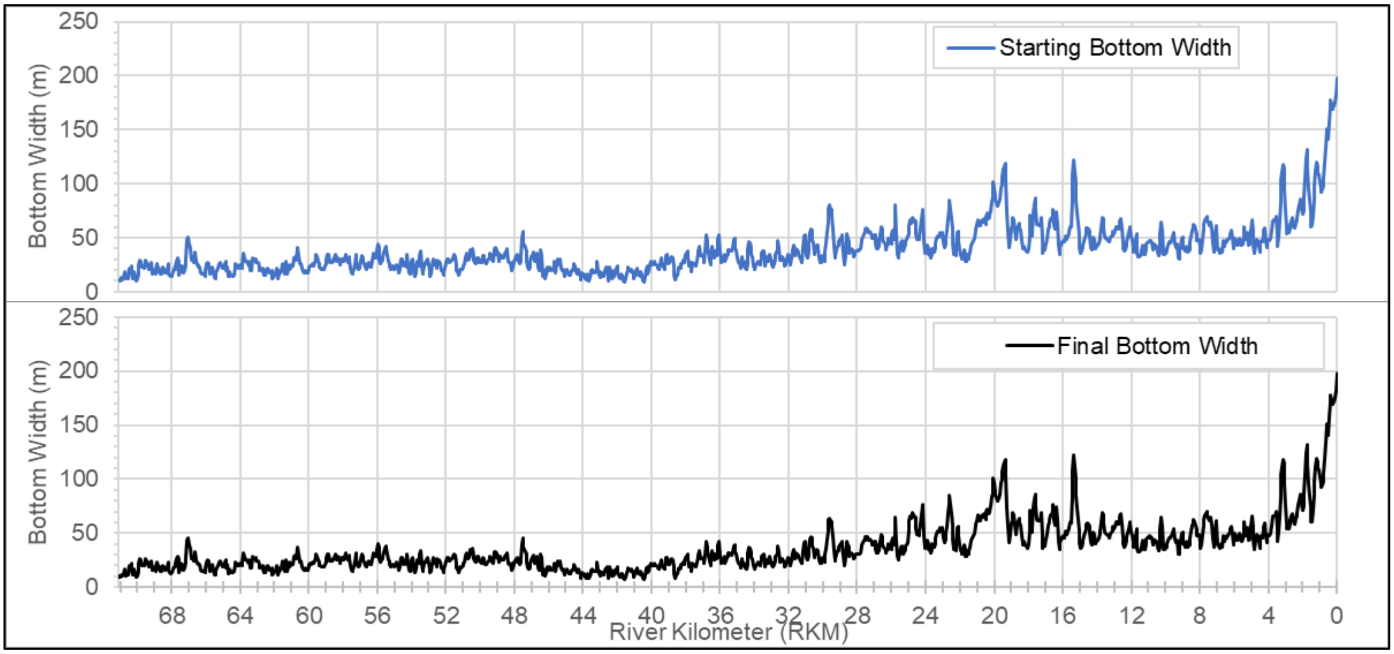


Figure 4-1: Sandy River initial and final calibrated longitudinal bottom widths.

The sediment heat exchange parameters, i.e., sediment thermal conductivity and diffusivity, and wind coefficients were retained at default values. Table 4-2 shows some parameter values used in the HS8 model and applicable literature references.

Table 4-2: Parameters, constants, and ranges used in HS8 model

Parameter	Value/Range	Reference
Channel bottom width [m]	7.5 - 198	Estimated
Sediment thermal diffusivity [cm2/sec]	0.0064	Default (Pelletier et al. 2006 as noted in the model)
Sediment thermal conductivity [W/m/°C)]	1.57	Default (Pelletier et al. 2006 as noted in the model)
Manning's n	0.068	Estimated (Chow, 1959, Jarrett, 1985, suggest range: 0.035 - 0.070)
Wind function coefficient a	1.505×10^{-9}	Default (Boyd and Kasper, 2003)
Wind function coefficient b	1.600×10^{-9}	Default (Boyd and Kasper, 2003)

A combination of visual assessment and computed error (goodness-of-fit) statistics was used to assess the model calibration. HS8 model fitness was summarized using mean error squared (MES), mean absolute error (MAE), root-mean-square error (RMSE), and the Nash-Sutcliffe efficiency coefficient (NSE) as measures of the deviation of modeled from observed values. These statistics are explained in detail in the QAPP (DEQ 2021). They are calculated as follows:

$$ME = \frac{1}{n}\sum(P - O) \qquad MAE = \frac{1}{n}\sum|P - O| \qquad RMSE = \sqrt{\frac{1}{n}\sum(P - O)^2} \qquad NSE = 1 - \frac{\sum(P-O)^2}{\sum(O-\bar{O})^2}$$

where

P = model predicted values
O = observed values
$\bar{O}$ = the mean of observed values
n = number of samples

4.1 FLOW BALANCE

Modeled and observed hourly flow values were compared against each other at the two Sandy River flow calibration stations (Table 4-1) as shown in Figure 4-2 and Figure 4-3. The model-simulated daily flows were nearly identical to the observed gages' data because those observed datasets constituted the initial values for the streamflow balance calculations (Section 3.6.1). Table 4-3 provides the flow calibration statistics.

Table 4-3: Sandy River HS8 model flow (m^3/s) calibration statistics

Statistic	Sandy R. near Marmot (USGS 14137000)	Sandy R. below Bull Run R. near Bull Run (USGS 14142500)
MES	0.02	0.04
MAE	0.06	0.14
RMSE	0.09	0.21
NSE	0.99	0.98

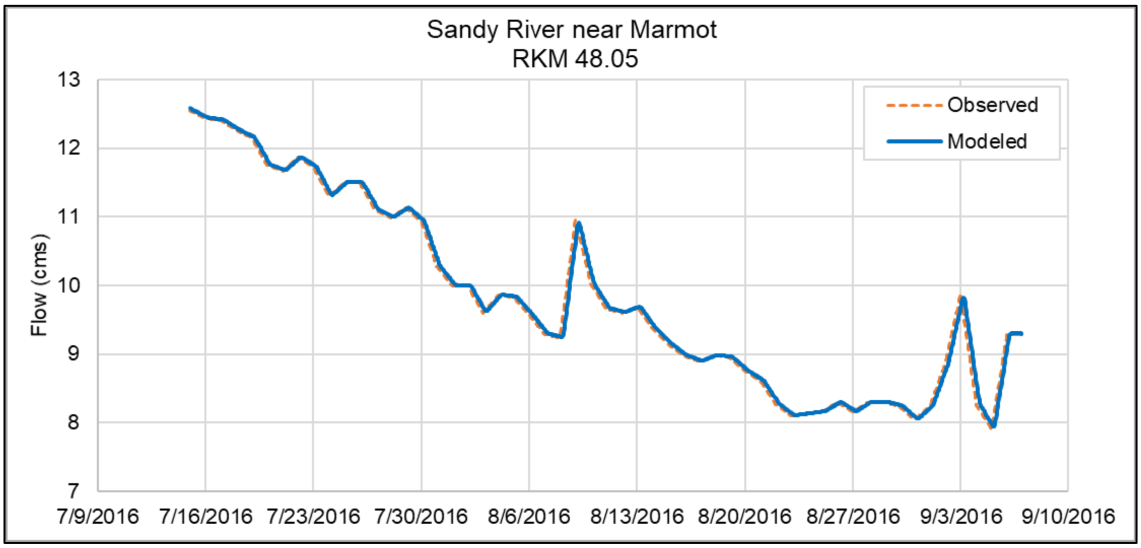


Figure 4-2: Sandy River Near Marmot (USGS 14137000)

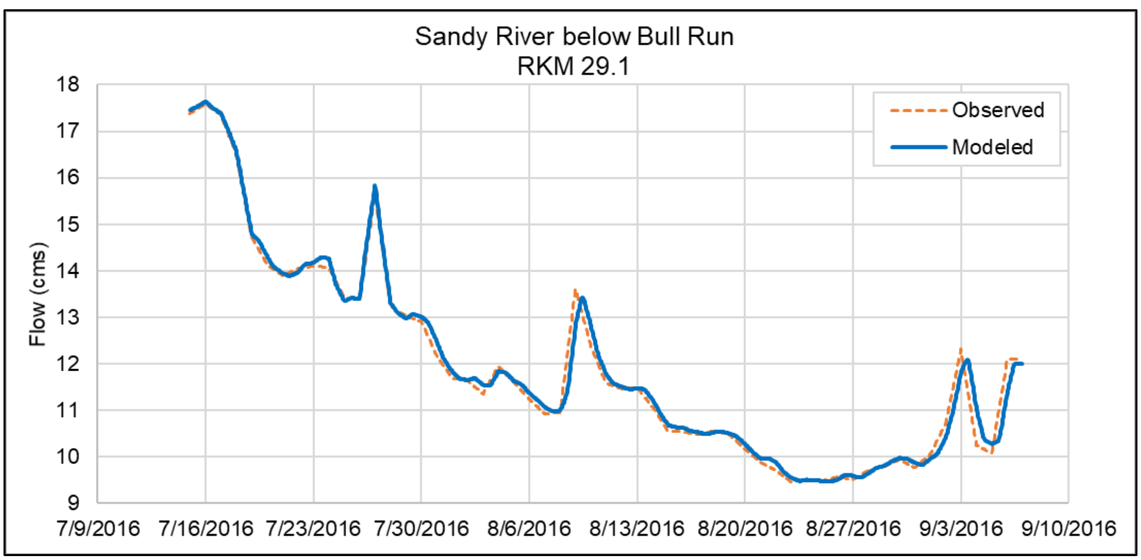


Figure 4-3: Sandy River below Bull Run River, near Bull Run (USGS 14142500)

4.2 EFFECTIVE SHADE

Effective shade represents the percentage of potential daily solar radiation (flux) that is blocked by vegetation and topography. No effective shade measurements were made for the 2016 model period. Shade measurements were collected in August 2001 at three Sandy River locations using a Solar Pathfinder (Table 4-4). These observed data were compared to daily shade predictions for 2016 (Figure 4-4).

For the three effective shade measurement sites, TetraTech reviewed available aerial photos to compare vegetation conditions in 2000 to 2016. Based on this analysis, the vegetation conditions did now show significant changes; thus, use of 2001-collected shade data as a rough guide for model calibration was appropriate.

Note that the observed effective shade value was 0% at the "Sandy above Salmon near Brightwood" station. Aerial photos, however, show vegetation in the immediate area surrounding this station; thus, some shade is expected here. Figure 4-5 shows the location of the station. It was thus determined that the zero value was likely a transcription error and it was omitted for calibration.

Table 4-4: Sandy River effective shade data collected on Aug. 8, 2001, and predicted for Aug. 2016

Site ID	Site Name	Lat	Long	Month	Year	Obs. (%)	Predicted (%)
10676-ORDEQ	Sandy above Salmon near Brightwood	45.3786	-122.013	August	2001	0	10
26422-ORDEQ	Sandy above Clear Cr. at Lolo Pass Rd.	45.3565	-122.938	August	2001	61	58
N/A	Sandy R. at Troutdale STP	45.4982	-122.01	August	2001	11	8.6

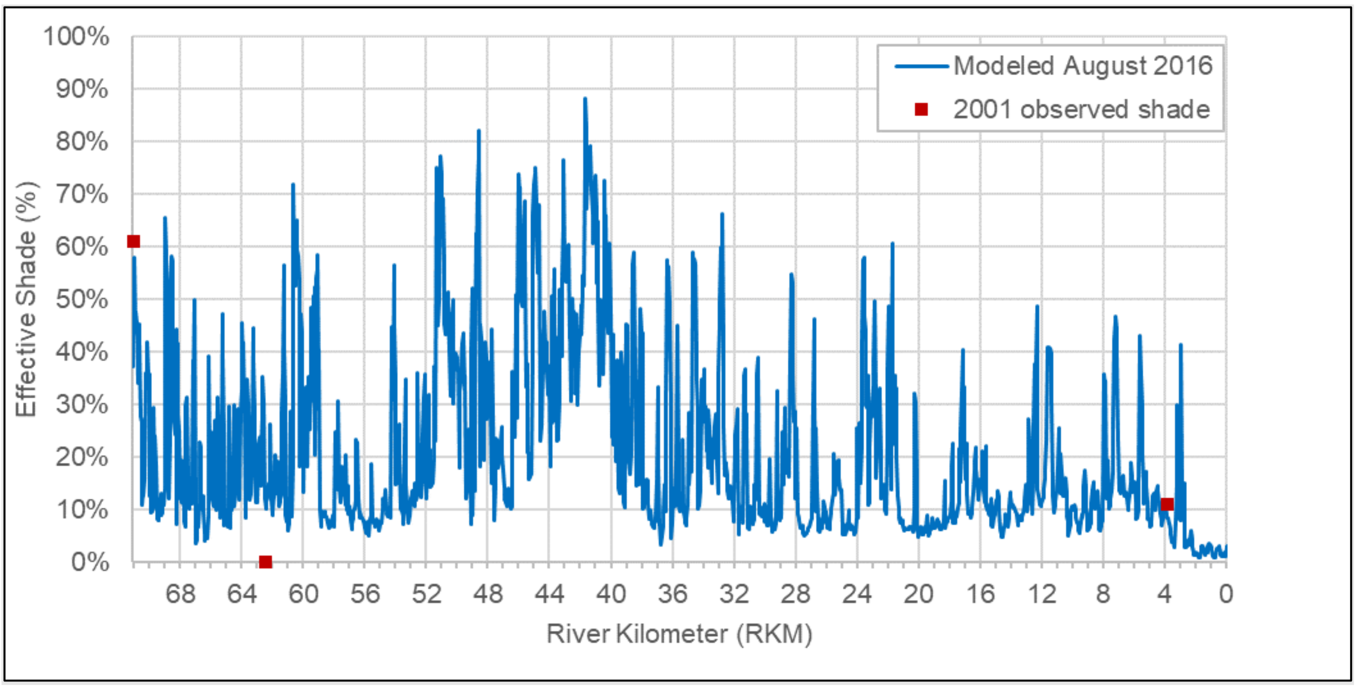


Figure 4-4: Sandy River modeled shade (Aug. 8, 2001, observed and 2016 modeled)

Figure 4-5: Sandy River near Brightwood shade measurement station location (model RKM 62.4)

The cloud cover data indicated several entirely clear (i.e., 24h) days in the model period (7/20, 7/29, 8/4-5, 8/12-13, 8/18-20, 8/23-24, 8/26, 8/28-29). Figure 4-6 shows average daily shade values for several such days along the longitudinal model extent.

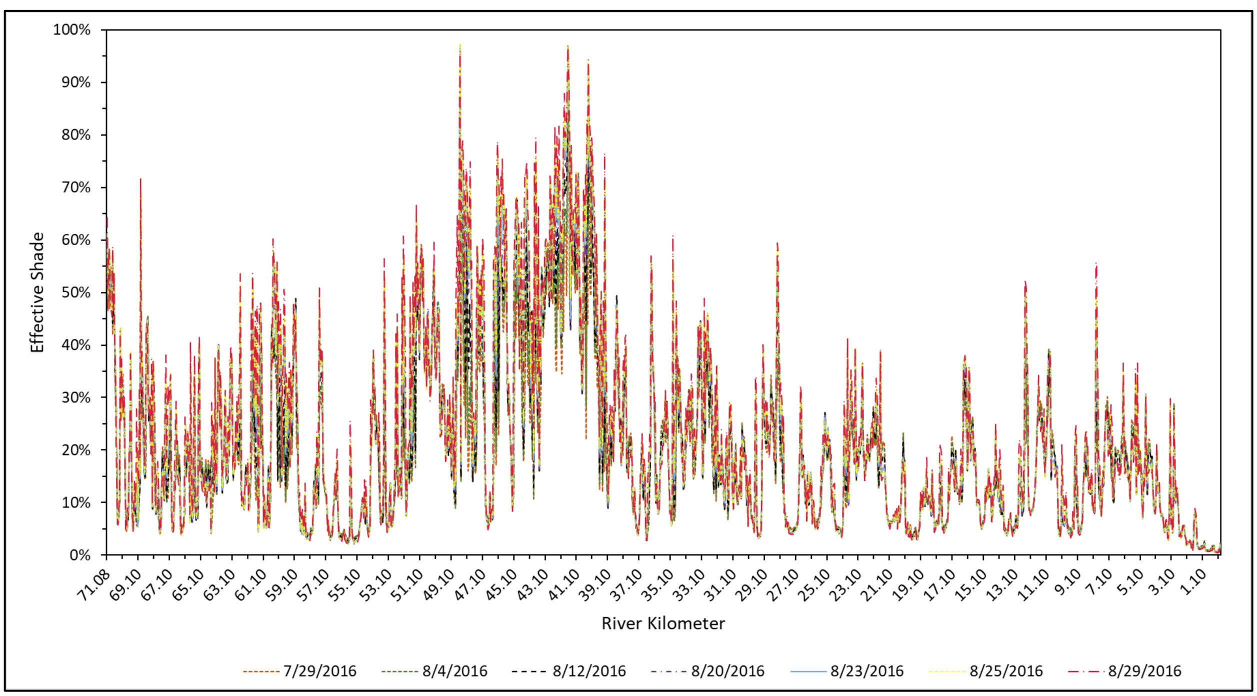


Figure 4-6: Average daily predicted shade by node for several non-cloudy days in the 2016 model period

4.3 TEMPERATURE CALIBRATION

Observed and modeled hourly stream temperature data were compared at each calibration station (Figure 3-17, Table 4-1). Note that site Sandy_3.0 was not used to evaluate overall model performance, as discussed in the next paragraph. Among the remaining four stations, the model performed well regarding the diurnal patterns and daily maxima at the two upstream stations, shown in Figure 4-7 and Figure 4-8. At the two stations upstream (Figure 4-9) and downstream (Figure 4-10) of the former Marmot Dam, however, the model underpredicted some temperatures for two high-flow events in early August and early September. Yet overall, all four stations sufficiently captured the daily maxima, especially in low-flows. The calculated error statistics (Table 4-5) show all MAEs and RMSEs were <1°C. The NSE at all four stations was ≥0.9 for the hourly and daily maxima, except the respective hourly NSEs were 0.83 and 0.79 above and below the Sandy River Marmot dam sites and the daily NSE at Sandy River km 36.1 was 0.87.

The stream temperature comparison at the most downstream calibration location (RKM 3.0, Figure 4-11) showed that the model did not effectively predict observed hourly temperatures. The hourly and daily maxima RMSEs were 0.98°C and 0.94°C, respectively, while the respective NSEs were 0.74 and 0.79, which did not meet calibration objectives. Further investigation determined that the hourly temperature pattern at this station was notably different than upstream stations and that it was located on a portion of the Sandy River that is tidally-influenced by the Columbia River. DEQ confirmed that the tidal influence extends ~2 RKM above I-84 (i.e., to ~5.0 RKM) and thus affects the station; the DEQ mapper (WR Map Tool (state.or.us) indicates that the head of the tide is near the East Columbia River Highway. As previously mentioned, HS8 is a 1D model and does not model tidal influences; this likely explains why the model did not capture the observed temperature patterns at the downstream station. Given this tidal influence confounder, no further model adjustments were made for this station, and overall model performance was assessed via the four remaining upstream stations.

Table 4-5: Hourly and daily max. stream temperature calibration statistics for Sandy River HS8 model

Statistic	Sandy_42.5 (Sandy R. u/s of Zigzag R.)	Sandy_36.1 (Sandy R. at Barlow Tr. bridge below Salmon R.)	Sandy_29.6 (Sandy R. at Marmot Dam)	Sandy_29.4 (Sandy R. below Marmot Dam)	Sandy_3.0 (Sandy R. above Beaver Cr.)[a]
Hourly Temperatures (°C)					
ME	0.04	-0.20	-0.58	-0.61	-0.39
MAE	0.30	0.43	0.67	0.73	0.78
RMSE	0.36	0.56	0.81	0.86	0.98
NSE	0.98	0.92	0.83	0.79	0.74
Daily Maximum Temperatures (°C)					
ME	0.01	0.16	-0.21	-0.06	-0.26
MAE	0.13	0.56	0.47	0.45	0.77
RMSE	0.16	0.69	0.56	0.54	0.94
NSE	1.00	0.87	0.90	0.90	0.79

a: This station was not used to evaluate overall model performance as its calibration statistics exceeded the ≤1°C criteria, due to tidal influences that HS8 cannot simulate (refer to text under the Temperature Calibration section).

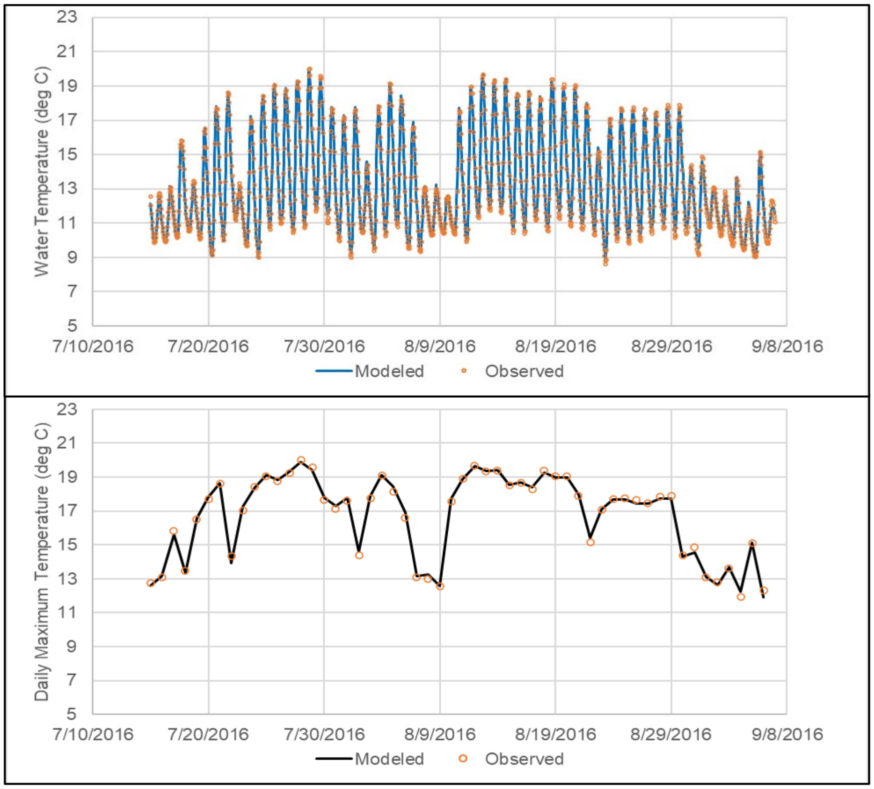


Figure 4-7: Hourly & daily max. observed vs. modeled water temp., Sandy R. upstream of Zig Zag R. (RKM 70.1)

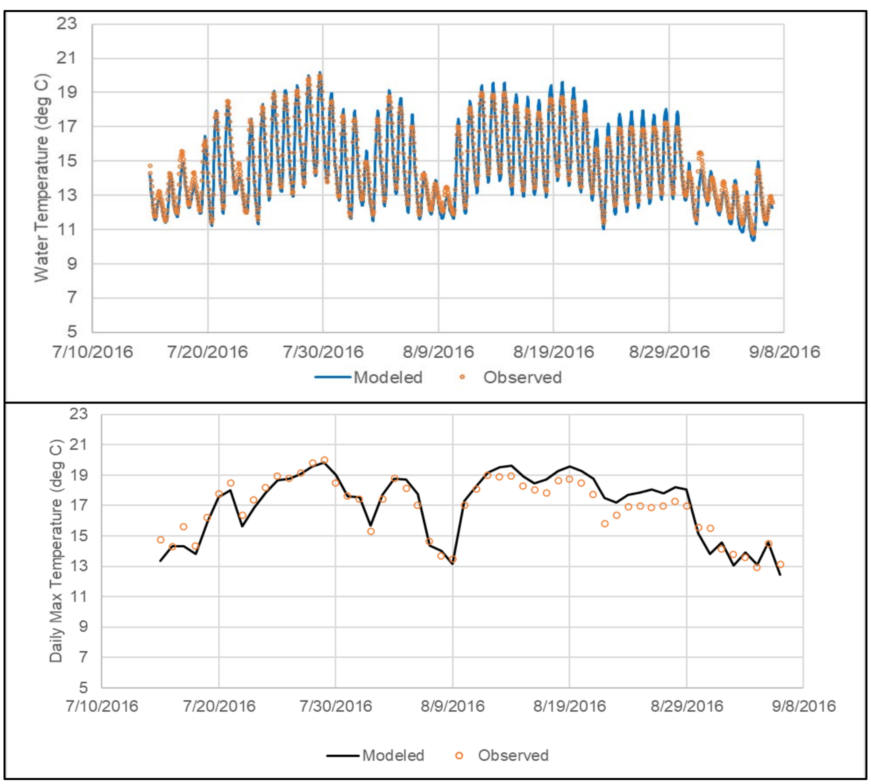


Figure 4-8: Hourly & daily max. observed vs. modeled water temp., Sandy R. at Barlow Trail bridge below Salmon R. (RKM 59.15)

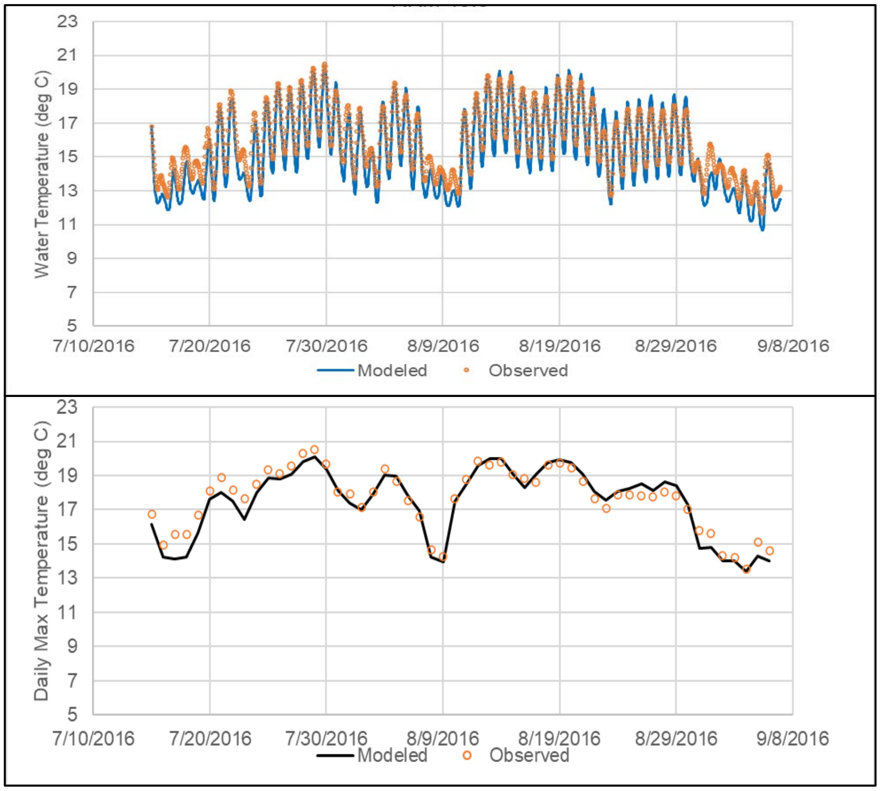


Figure 4-9: Hourly & daily max. observed vs. modeled water temp., Sandy R. at Marmot Dam site (RKM 48.3)

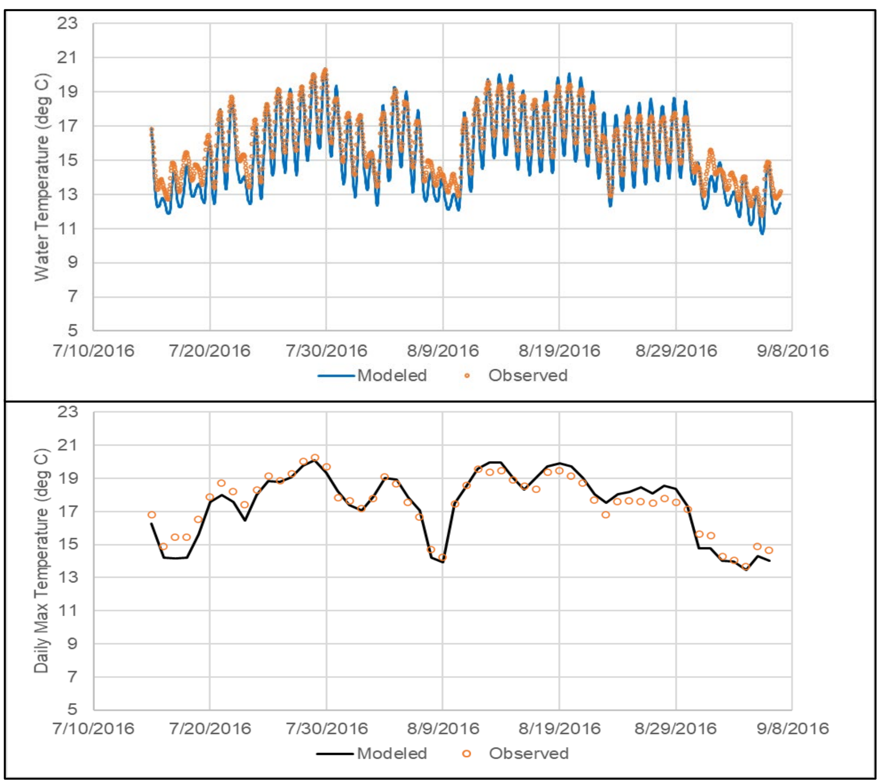


Figure 4-10: Hourly & daily max. observed vs. modeled water temp., Sandy R. below Marmot Dam (RKM 47.9)

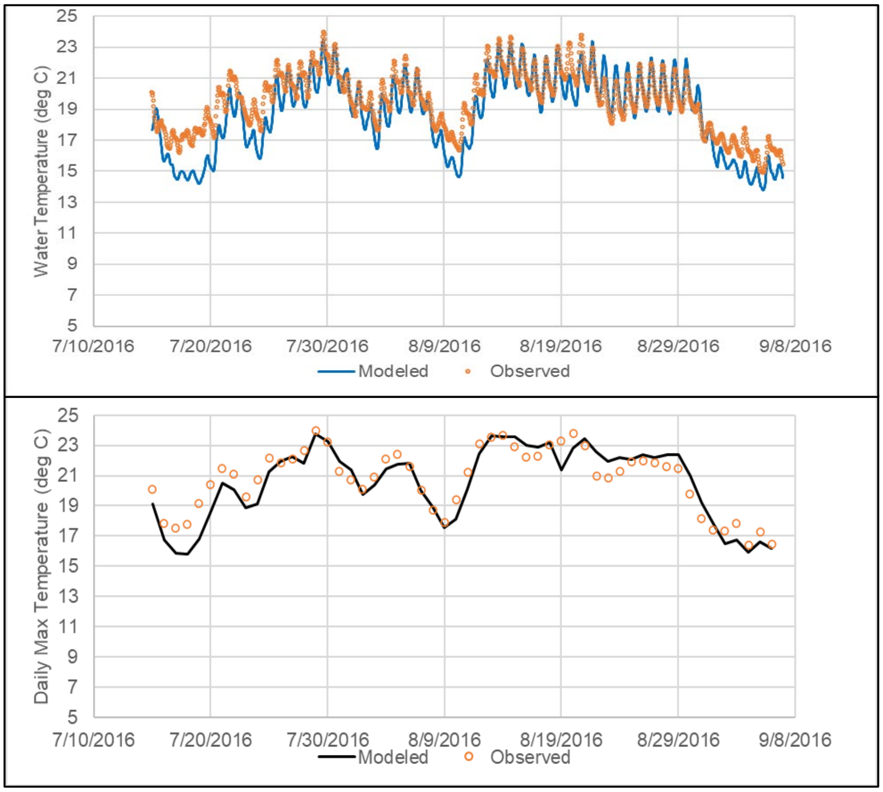


Figure 4-11: Hourly and daily max. observed vs. modeled water temp., Sandy R. above Beaver Cr. (RKM 3.0)

5.0 SUMMARY

A Heat Source version 8 effective shade and water temperature model was developed for the Sandy River to support TMDL development for previously identified water temperature impairments. The model extent was from the Sandy River mouth at the Columbia River to just upstream of Clear Creek (RKM 71.08). The model period reflected the critical summer and spawning period in 2016 for which data were available for model development. The modelling effort used high-resolution LiDAR and orthophotos to quantify and configure stream morphology, riparian vegetation, and topography data inputs to simulate shade and temperature with the Heat Source model. Observed meteorological data from four stations on the Sandy River were used to account for elevation differences from the headwaters to the mouth. The model used discharge monitoring report (DMR) data from two active NPDES-permitted point sources that discharge to the Sandy River, i.e., the City of Troutdale WPCF and the Hoodland STP. Flow data required to configure boundaries for all model tributaries were not available and were thus estimated using the StreamStats flow estimation method with a reference gage near Marmot. Model water temperature boundary conditions were configured with observed hourly temperature data available for nine of the 22 tributaries. Water temperatures for the remaining tributaries were derived using either linear regression or a direct surrogate from a proximal stream.

The model was calibrated against observed hourly water temperatures from four locations on the Sandy River mainstem. Overall and based on pre-determined calibration fitness objectives, the diurnal temperature patterns and daily maxima were well-predicted at each location, especially during low-flows. The model underpredicted some temperatures for two high-flow events at the two Marmot stations (in early August and early September). Generally, the calculated MAE and RMSE statistics were <1°C for each calibration location. The calibration station locations for the 2001 model were different from those for the 2016 model, except for the Marmot sites. The 2016 hourly Marmot calibration MAEs (Table 4-5) were similar to those from the 2001 model (0.67°C). Additionally, in the 2016 model, the station below the Salmon River had an MAE of 0.43°C, whereas in 2001 the station was above the Salmon River and had an MAE of 0.67°C. Note that the 2001 statistics were based on a single 24-hr period (August 8, 2001), whereas the 2016 statistics were based on hourly data from July 15 - Sept 7. The NSE at all four stations in the 2016 model were ≥0.9 for the hourly and daily maxima, except the respective hourly NSEs were 0.83 and 0.79 above and below the Sandy River Marmot dam sites and the daily NSE at Sandy River km 36.1 was 0.87. Finally, a fifth water temperature station at Sandy River kilometer 3.0 was omitted from the calibration because it is tidally-influenced.

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