Draft Technical Support Document

Appendix D: Bull Run River (USGS 14138850 to confluence with Sandy River) Temperature Model Report

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

PWB Documentation – Benjamin Beal

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This report prepared by:

Portland Water Bureau
1120 SW 5th Street
Portland, OR 97204

Contact:
Benjamin Beal
Benjamin.beal@portlandoregon.gov

Table of Contents

List of Tables

List of Figures

1. Overview

This document contains changes made to the Middle River model and Lower River model of the Bull Run River in CEQUAL-W2. This report concentrates primarily on input data for the models, originally developed by Portland State University (Annear, Wells, & Evonuk, 1999). Changes to model boundary condition data was performed to update the model with the 2016 meteorological and flow conditions. Changes to the parameters of the models were in efforts to modernize aspects of the model to: increase model stability, bring parameter values within plausible bounds, and improve temperature calibration in 2016 in the Lower River model.

2. Available Data

2.1 Field Data

2.1.1 Continuous stream temperature

Continuous stream temperature data were used to:

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

Continuous water temperature data was gathered from various sources for use in the 2016 model. Sources of stream temperature include:

1) PWB data temperature loggers at the diversion pool (location of headworks).
2) PWB temperature loggers at the Lamprey barrier (~300 ft downstream of the diversion pool).
3) PWB temperature loggers in the piping for the “south tower” (this is located inside the piping of the south tower which draws water from the lowest portion of reservoir two. The water is piped down past the diversion pool and is released into the Bull Run River ~250’ upstream of the lamprey barrier).
4) USGS temperature records from the stations: 14138850, 14139800, 14138900,14138870,14140020, and 14141500.
5) Three temporary in-situ probe installations located at: South Side Bridge (

Table 1. Stream temperature monitoring sites in the Bull Run supporting model development.

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
14138850	Bull Run River near Multnomah Falls, OR	45°29'54"	122°00'40"	USGS
14139800	South Fork Bull Run River	45°26'41"	122°06'30"	USGS
14138900	North Fork Bull Run River	45°29'40"	122°02'05"	USGS
14138870	Fir Creek	45°28'49"	122°01'28"	USGS
14141500	Little Sandy River	45°24'56"	122°10'13"	USGS
14140020	Larson’s Bridge	45°25'55"	122°11'39"	USGS

Monitoring Location ID	Monitoring Location Name	Latitude	Longitude	Source
HDWTI024	Diversion Pool	45.449266	122.152702	PWB
HDWTI020	South Tower Wet Well	45.448601	122.146847	PWB
HDWTI025	Lamprey Barrier (primary)	45.448941	122.154977	PWB
HDWTI025B	Lamprey Barrier (backup)	45.448941	122.154977	PWB
PWB_BR_SS_BR	Bull Run South Side Bridge	45.437752	122.178867	PWB
PWB_BR_BWMN_BR	Bull Run Bowman's Bridge	45.425093	122.216761	PWB
PWB_BR_DODGE	Bull Run at Dodge Park	45.443895	122.246630	PWB

2.1.2 Stream flow rate– continuous and instantaneous measurements

Continuous and instantaneous stream flow rates were collected by PWB/USGS at several sites during the 2016 model year. The measurements at these sites (Table A2 and Table A3) were used to support boundary condition flow inputs, and generation/validation of ungaged streamflows along the model domain.

Table 2. Continuous flow rate measurement sites in the Bull Run used to support model development.

Station ID	Station Name	Latitude	Longitude	Source
14138850	Bull Run River near Multnomah Falls, OR	45°29'54"	122°00'40"	USGS
14139800	South Fork Bull Run River	45°26'41"	122°06'30"	USGS
14138900	North Fork Bull Run River	45°29'40"	122°02'05"	USGS
14138870	Fir Creek	45°28'49"	122°01'28"	USGS
14141500	Little Sandy River	45°24'56"	122°10'13"	USGS
14140000	Bull Run River, Bull Run	45°26'14"	122°10'46"	USGS
HDWTI025	Lamprey Barrier (primary)	45.448941	122.154977	PWB

Table 3. Instantaneous flow rate measurements collected in the Bull Run used to support model development.

Site	Latitude	Longitude	Date	Time	Flow (cfs)
Bear Creek	45.486866	122.083788	Years 1979-1991	Various	Various
Deer Creek	45.491111	122.059411	Years 1979-1991	Various	Various
Cougar Creek	45.490428	122.061903	Years 1979-1991	Various	Various
Camp Creek	45.460585	122.099608	Years 1979-1991	Various	Various
Fivemile Creek	45.482657	122.092064	Years 1979-1991	Various	Various

2.1.3 Vegetation and habitat surveys

A vegetation survey was conducted along banks of the Bull Run River between headworks and the Sandy River in conjunction with the original development of the Lower River Model. Field data associated with this effort is no longer available, leaving only the compiled shade file for the Lower River Model as a product. It is understood that the level of effort and thoroughness put into this survey and the development of the shade file was very high, therefore we are using the shade file as is.

2.2 GIS and Remotely Sensed Data

2.2.1 Light Detection and Ranging (LiDAR)

Light Detection and Ranging (LiDAR) is a remote sensing method that uses pulses of light to calculate the elevation of ground and surface features with a high degree of accuracy and resolution. LiDAR data is used to develop high resolution digital surface models (DSM) and DEMs which can then be used to derive canopy height.

A 3 meter DEM of both bare earth and highest hit were used to establish vegetation heights and vegetation top elevations. This data was used in generating shading angles in the creation of the dynamic shading files.

2.2.2 Aerial Imagery

Aerial imagery was used to:

- Map stream features such as stream position, channel edges and wetted channel edges,
- Map near stream vegetation,
- Locate position of in-situ probes and stream gages and their relative location in the model domain.

2.3 Derived Data

Several datasets used for model setup were derived or sampled from landscape scale GIS data. Sampling density was user-defined and generally matched any GIS data resolution and accuracy. The derived parameters used in the stream temperature analysis were:

- Stream position and aspect
- Stream elevation and gradient
- Maximum topographic shade angles (Left and Right bank)
- Maximum vegetation shade elevations (Left and Right bank)
- Channel width
- Landcover classification and mapping

2.3.1 Stream Position and Channel Width

Stream position was estimated using the following steps:

Step 1. Stream geometry from the original rendition of the model (circa 2000) for the Lower and Middle river models were projected in a mapping tool (leaflet in R) based on length and angle of each segment, the linkage of segments in the W2 control file, and an estimated datum location (start point of the model) to achieve best fit between the model defined structure of the model and the readily available mapping of the stream from OpenMaps.

Step 2. Lengths and/or angles were adjusted the minimum possible to correct small errors in the original model stream geometry to generate a better fit.

Channel width was estimated using the following steps:

Step 1. Using aerial imagery, channel edges were digitized by hand in GIS.

Step 2. Using the corrected model segment lines from step 2.3.1 part 1, polygons were generated along the river with “tops” and “bottoms” based on the upstream and downstream locations of each stream segment from the model. The “sides” of the polygons are based on the left and right bank digitization of the stream in step 1.

Step 3. Area (in square meters) is calculated in GIS for every segment polygon generated in step 2, and the area is divided by the associated length of the stream segment (in meters) to generate the average channel width (in meters).

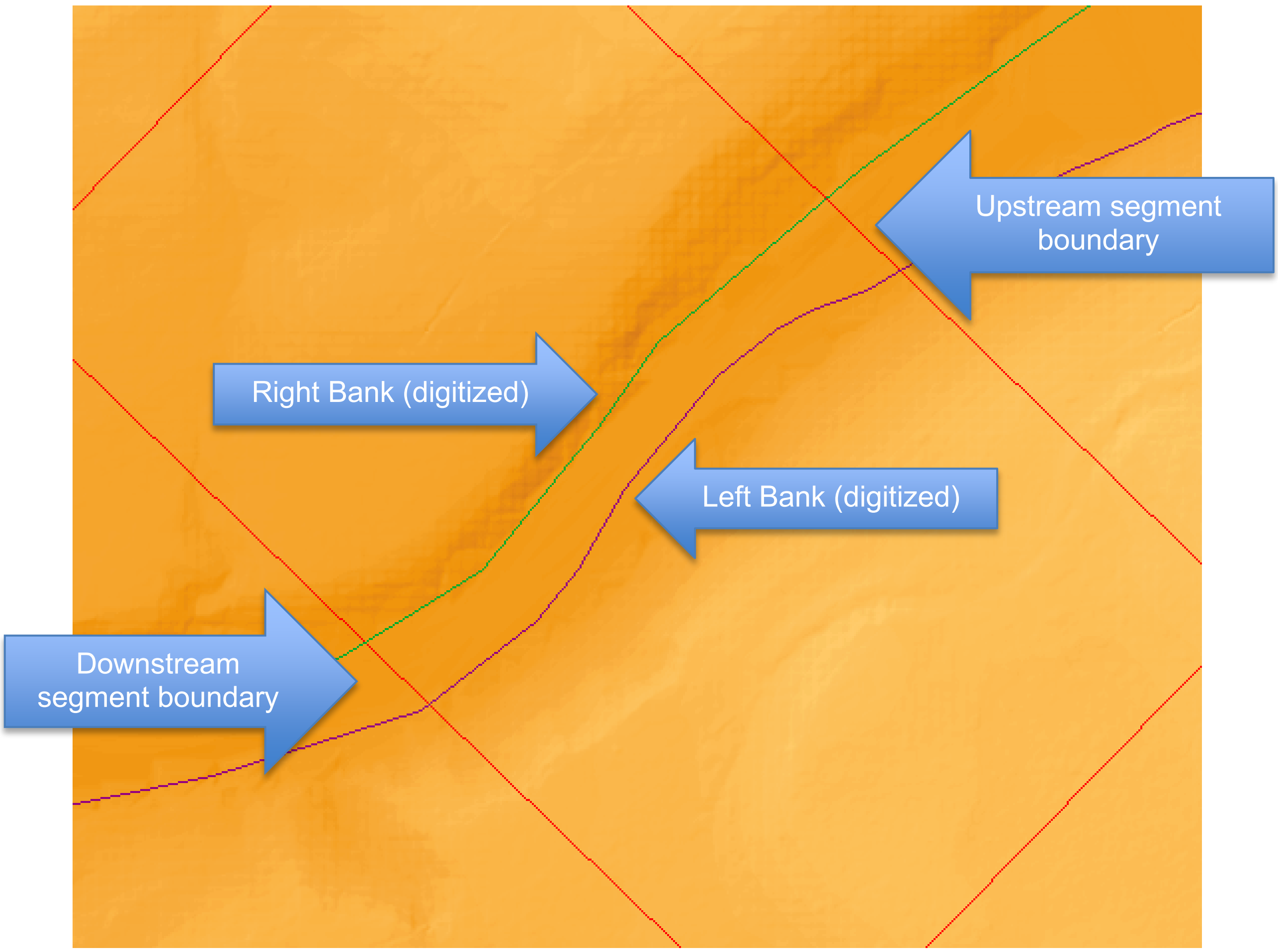


Figure 1: Example of digitized channel, flowline, and stream nodes.

2.3.2 Channel Bottom Width

Channel bottom width in CEQUAL-W2 is a user definable measurement. Bathymetry can be set at various vertical intervals to generate a triangular/trapezoidal shape. Original stream bathymetry in the models was coarse with vertical intervals of 1-2 meters and rather wide widths. This in general resulted in very wide and very thin wetted segments during the low flow portions of the model run. The shallow depths in the model appeared to be causing most of the model instability, which was keeping CEQUAL from completing a simulation, regardless of the maximum time step.

To combat this issue, the bathymetry was adjusted to represent a more trapezoidal shape by generating interpolated layers based on the original layer widths and vertical locations. The total number of vertical layers was set to 19 (KMZ) and the interval spacing in the Z direction for the layers was changed in order to increase the number of layers near the channel bottom and gradually increase the vertical interval spacing as the channel widens. This process in general creates many small layers on the bottom of the channel which appear to significantly assist in model stability during low flows.

During calibration, many different sets of vertical intervals were tested, with the final version providing good model stability for all years and scenarios tested as well as keeping the total number of layers small enough that the model does not take an unnecessarily long time to run. Below are the vertical layer intervals used in the final calibration, as well as several intervals sets that were tested, but not ultimately used. Note that for the Lower River Model, water body 4 uses the original bathymetry file from the PSU generation of the model. This is due to the somewhat odd bathymetry where a rather wide and deep plunge pool is connected to a relatively shallow and narrow active main channel.

Table 4: Vertical intervals for bathymetry files

Final Calibration		Test 1		Test 2		Test 3		Test 4	
Distance from BOT	Interval	Distance from BOT	Interval	Distance from BOT	Interval	Distance from BOT	Interval	Distance from BOT	Interval
0		0		0		0		0	
0.1	0.1	0.5	0.5	1	1	1	1	1	1
0.2	0.1	1	0.5	1.25	0.25	2	1	2	1
0.3	0.1	1.5	0.5	1.5	0.25	2.4	0.4	3	1
0.4	0.1	2	0.5	1.75	0.25	2.8	0.4	3.2	0.2
0.5	0.1	2.5	0.5	2	0.25	3.2	0.4	3.4	0.2
0.725	0.25	3	0.5	2.25	0.25	3.6	0.4	3.6	0.2
1	0.25	3.5	0.5	2.5	0.25	4	0.4	3.8	0.2
1.25	0.25	4	0.5	2.75	0.25	4.4	0.4	4	0.2
1.5	0.25	4.5	0.5	3	0.25	4.8	0.4	4.2	0.2
2	0.5	5	0.5	4	1	5.2	0.4	4.4	0.2
3	1	5.5	0.5	5	1	5.6	0.4	4.6	0.2
4	1	6	0.5	7	2	6	0.4	5	0.4
6	2	8	2	9	2	8	2	6	1
8	2	12	4	12	3	11	3	10	4
10	2	16	4	16	4	15	4	14	4
14	4	20	4	20	4	19	4	18	4
18	4	24	4	24	4	24	5	24	6

Stream Elevation and Gradient

Stream elevation and stream gradient were derived from the original PSU model, no adjustments were made to the elevation/gradient of EBOT (the bottom elevation of the channel) nor the slope of the channel. In some cases, slight adjustments were made to the length of a channel segment in order to bring the channel geometry into agreement with modern mapping of the stream. In these cases, the slope was not adjusted, nor were the EBOT values adjusted. This will have resulted in slightly different gradients (SLOPE) than the original PSU values.

More important than the SLOPE values are the SLOPEC values which are effectively the hydraulic grade line and has a substantial impact on the velocity of the flow. This value was changed considerably and served as a tuning factor for the model. By using a conservative tracer in the model, concentrations of tracer where released coinciding with the release of cold water pulses during the 2016 calibration. Due to considerable effort and experience with sending cold water down the Bull Run between Headworks and Larson's bridge, PWB has developed approximate times of travel for pulses of cold water relative to the quantity of water released. Therefore, by measuring the model output of conservative tracer and calculating the time between half of the model release at headworks, and half of the tracer reaching Larson's bridge, a time of travel is computed.

Several changes were made to the model associated with trying to improve the time of travel. First, due to changing the manning's n values from the original values (as high as 0.21) down to 0.07 based on the recommendation by TetraTech in their review of the model, the velocity of the water increased greatly. To slow the water back down, the SlopeC values were reduced across the model domain in steps to attempt to match the timing between Headworks and Larson's bridge tracer timing to that of our expected tracer timings. During this it was additionally discovered that the internal weirs which serve as a pool/riffle control in the model were causing a sort of damming of cold water within the channel. This was discovered by calculating the conservative tracer travel time between every segment and noticing that where some of these internal weirs existed, the time of travel would take exceptionally long moving between two segments split by a weir. To deal with this issue, the top elevation of the weir was gradually dropped by 0.5m at a time until the effect to the tracer timing was no longer considered to be erroneous. SlopeC values were dropped down to their current value of 0.0016 after a significant number of calibration runs using this iterative process of altering internal weirs and SlopeC values while keeping Manning's n values constant.

Figure 2 below demonstrates an example of some results of the conservative tracer tests showing the tracer timing using the original model calibration (blue) alongside more modern versions of the model (green and red). Note the effect of internal weirs between segments 1&2, 4&6, and 9&10 from the original model calibration generating very large jumps in travel time (due to the internal weirs).

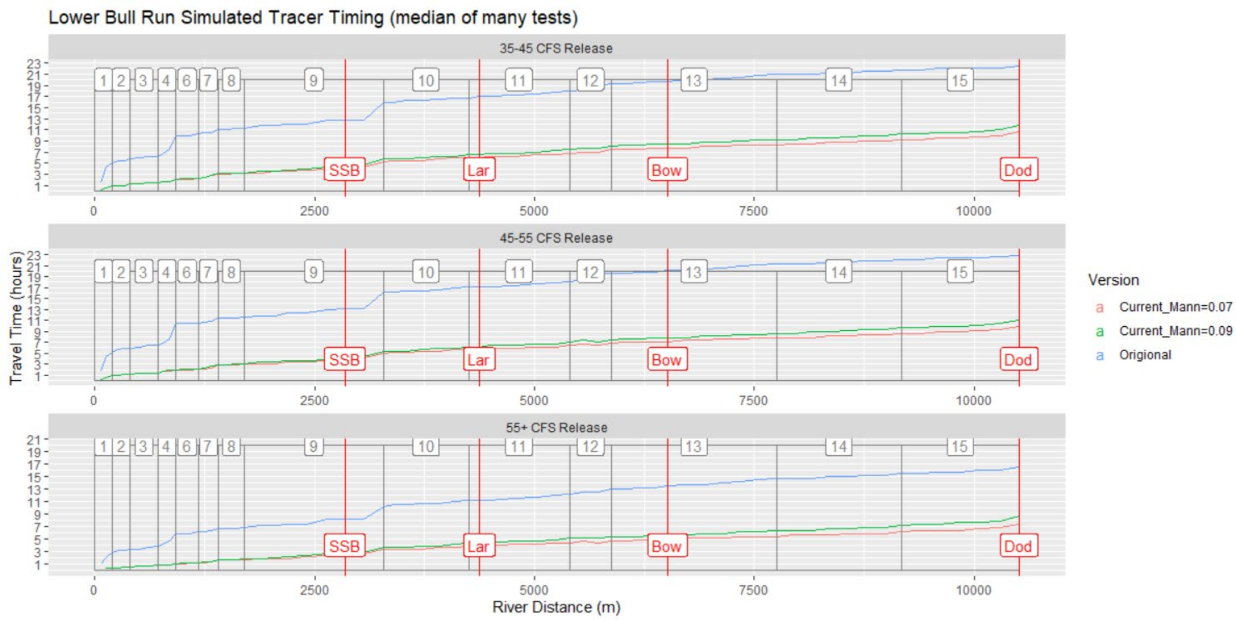


Figure 2: Examples of 2016 simulated tracer tests on different versions of the Lower River model

2.3.3 Topographic Shade Angles

The topographic shade angle represents the vertical angle to the highest topographic feature as measured from a flat horizon. At this angle and smaller the topographic feature will cast a shadow over the stream node as the sun moves behind it. Topographic shade angle was calculated using **Equation A2** below using sampled geometry statistics from Arcmap and solving for maximum angles of effect in R. Elevations were sampled from (Sciences, 2014). The maximum topographic shade angle in each direction for each stream node was found by sampling every raster cell out as far as 1000m in 18 directions (20 degree vectors) from each stream node.

$$\theta_T = \tan^{-1}\left(\frac{Z_T - Z_S}{d}\right)$$ **Equation A1**

where,

$\theta_T =$ The topographic shade angle (degrees)

$Z_T =$ The elevation (meters) at the topographic feature.

$Z_S =$ The elevation (meters) at the stream node.

$d =$ Horizontal distance (meters) from the stream node to the topographic feature.

2.3.4 Vegetation Shade Angles

The vegetation shade angle represents the vertical angle to the highest vegetation feature as measured from a flat horizon. At this angle and smaller the vegetation feature will cast a shadow over the stream node as the sun moves behind it. Vegetation shade angle was calculated using **Equation A2** above using sampled geometry statistics from Arcmap and solving for maximum angles of effect in R. Elevations were sampled from (Sciences, 2014). The maximum vegetation shade angle was computed for both left bank and right bank for each stream segment by sampling 3m wide polygon bands which conform to the shape of the shoreline and extend away from the stream. Vegetation was sampled out to 100m to find the highest vertical angle.

2.3.5 Land Cover Mapping

2.3.5.1 Modified No Dam DEM

A terrain dataset of Reservoirs 1 and 2 was created from bathymetry elevation data (Associates, 1991) and air borne lidar point cloud data (Sciences, 2014). The two reservoir terrain datasets were combined to create a continuous elevation model from Station 18 to Diversion Pool as a 3-ft grid in NAVD88. Dam structures were removed from landscape to reconstruct the river channel and to calculate shading in the Restored Condition and No Dam scenarios. The DEM was modified by hand digitizing polygons over the dams that were referenced to adjacent 10-ft contours. Each polygon was assigned an elevation and rasterized to create a modifier grid. The modifier grid was smoothed using local filters and then combined with the continuous DEM using conditional logic. The resulting modified DEM contains stair-step artifacts where the dams were located and is considered a rough approximation, but suitable for the scale of modeling.

2.3.5.2 Historic River Channel

The inundated historic channel centerline of the Bull Run River was hand digitized from the (Associates, 1991) point cloud by connecting the lowest value of each horizontal transect. The channel bottom elevations were interpolated from the reservoir bathymetry DEM. Historical maps were referenced to confirm the approximate river channel. ArcHydro Tools were applied to the modified DEM for additional confirmation of channel flow, and to identify sinks within the DEM. Minor adjustments were applied to the stream centerline based on the confirmation sources.

The riverbanks were approximated by creating a Relative Elevation Model (REM) using the Inverse Distance Weighting method. The REM is a detrended DEM based on the elevation of the stream centerline. A riverbank contour line was derived from the REM at an elevation that matched the channel bank above the influence of Dam 1. The left and right banks were hand digitized from the riverbank contour line to generalize and adjust areas around the dam. A polygon was created from the riverbank lines to represent the historic river channel.

2.3.5.3 Land Cover for Restored Conditions and No Dam

The Restored Conditions land cover codes were assigned using a combination of DEQ land cover restoration codes and the historical river channel polygon. DEQ provided a table with typical land cover code transitions from Current Conditions to Restored Conditions. This table was used to populate an attribute field of restored conditions land cover codes (RC_LCC) that are maintained separately from the current condition codes (CC_LCC). Geometry for the dam structures and areas inundated by the reservoirs were added by overlaying the historic river polygon with the land cover polygons. The new polygons were assigned a Restored Condition land cover code using nearby restored land cover.

The No Dam scenario is a combination of the Current Conditions and Restored Conditions. Two additional attribute fields were added to combine these fields. A dam filter field identified dam structures and reservoir inundated polygons (Dam Filter= ‘Yes’). The second field stored the No Dam land cover codes (ND_LCC) which were assigned using conditional logic (where: RC_LCC when Dam Filter is ‘Yes’, otherwise is CC_LCC).

2.3.6 Derived Tributary Stream Flow

Derived Tributary Stream Flows follows the process developed by PSU found in pages 61,62, & 67 (Annear, Wells, & Evonuk, 1999).

2.3.7 Derived Tributary Temperatures

Derived Tributary Stream Temperatures follows the process developed by PSU found in pages 67&68 (Annear, Wells, & Evonuk, 1999).

3. Model setup and calibration

3.1 Lower & Middle River Model

3.1.1 Model extent

Model extent for the Lower River model runs from present day headworks at the location of the diversion pool down to the confluence of the Sandy River. Model extent for the Middle River model runs from USGS station 14138850 on the Bull Run River down to present day headworks.

3.1.2 Spatial and temporal resolution

Spatial resolution of the lateral (length relative to the direction of flow) varies between about 50m and 250m per segment. Vertical resolution varies less for the entire model (except for waterbody 4, see section 2.3.2 for more details). Vertical resolution is between 0.1m and 4.0m. Temporal resolution for boundary condition data is hourly.

3.1.3 Meteorological inputs

Meteorological inputs are generated using a variety of different sensors and methods. See each subsection for an explanation.

Cloud data was extrapolated from PDX Airport area ASOS/AWOS Surface Weather Observation Station (KTTD). This entails converting descriptive cloud coverages from different samplings of the atmosphere (such as clear, overcast, cloudy, etc), and converting those to a density by using the highest density for any given timestep.

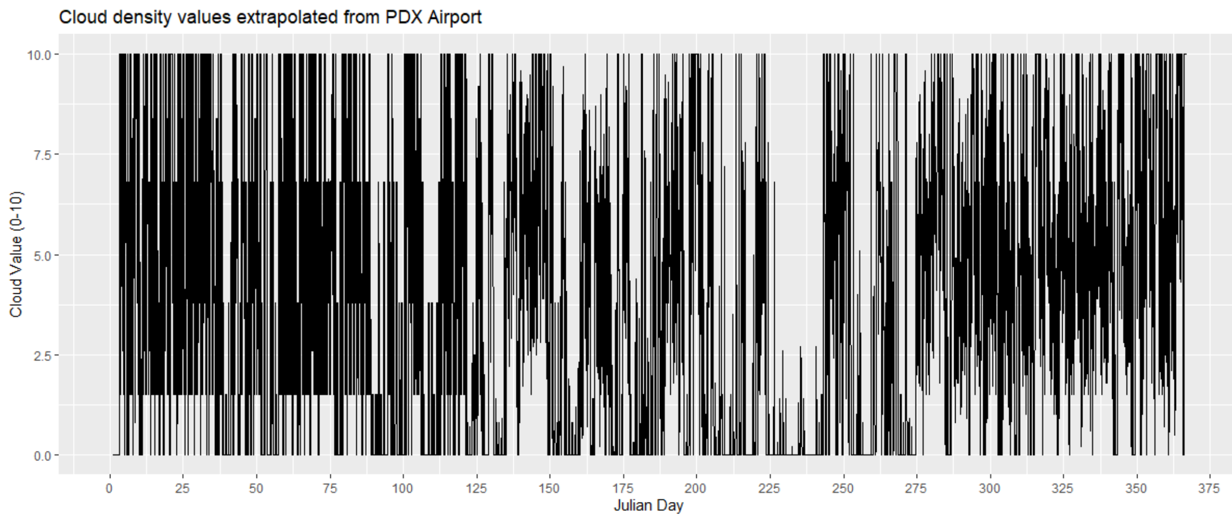


Figure 3: Cloud Data from near PDX airport

Air Temperature data comes from a meteorological station located on top of the dam at reservoir 2 which collects air temperature, relative humidity, wind speed, wind direction, and solar radiation. Air temperature data is screened for outliers. Single outliers are removed and replaced with linear interpolation.

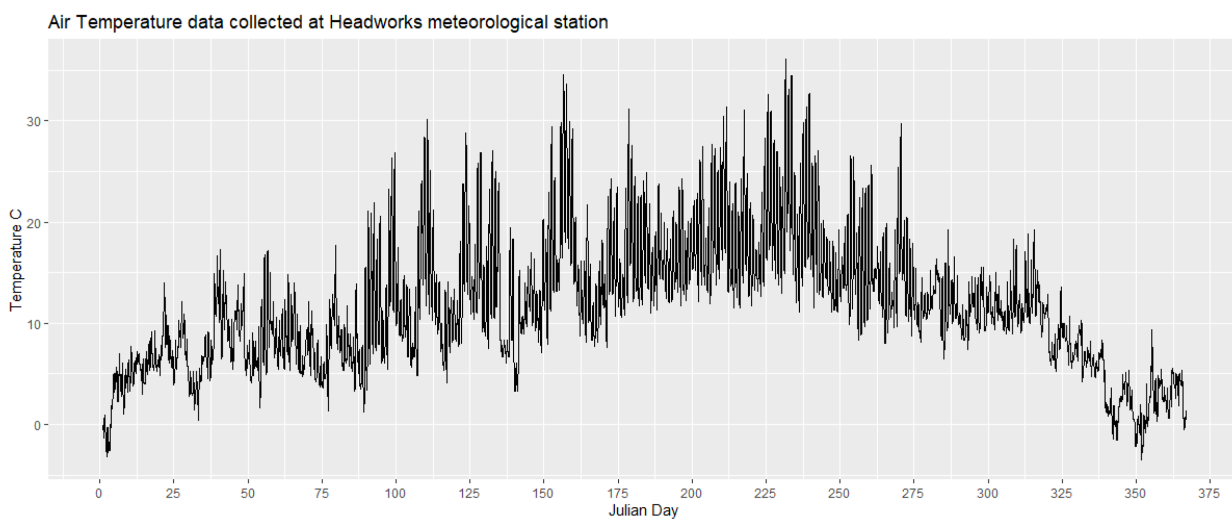


Figure 4: Air temperature data from Headworks/Dam 2

Model setup dew point temperature

Dew point temperatures are not collected at the Headworks/Dam2 weather gage, but are derived using Air Temperature and Relative Humidity using a function in R from the weathermetrics package (weathermetrics::humidity.to.dewpoint)

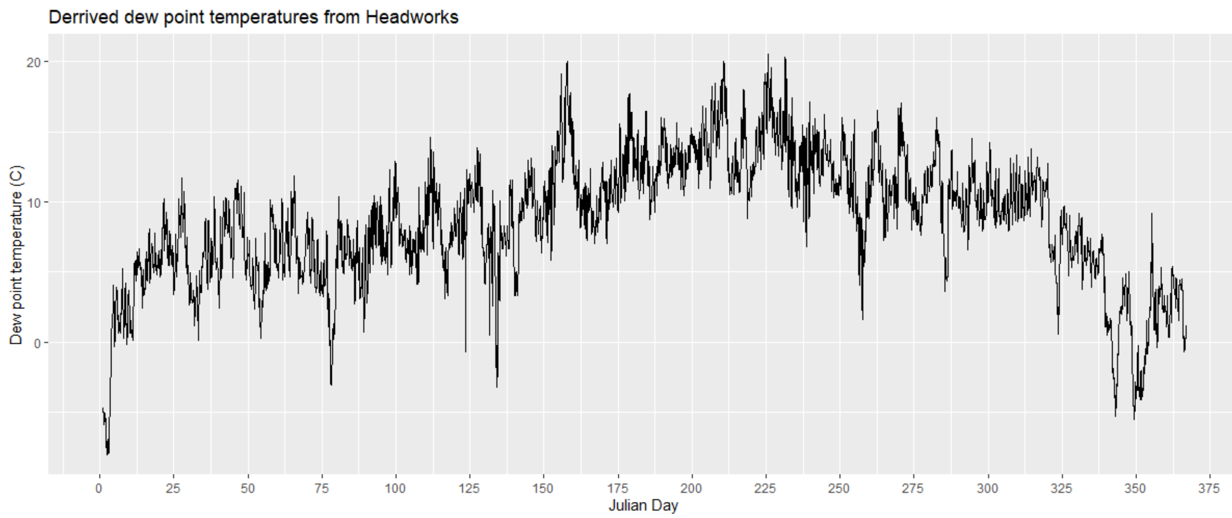


Figure 5: Derived dew point temperature data

Model setup solar radiation.
Solar radiation data at headworks is collected from the meteorological station located on top of Dam 2. Periodic spikes in the data are removed by comparing recorded data with a calibrated potential solar radiation model developed by GeoSyntec who were involved in the creation and updating of the Bull Run model. In the comparison with the potential solar radiation model, any observed solar radiation values that exceed the potential maximum solar radiation are reduced to the value of the potential maximum solar radiation.

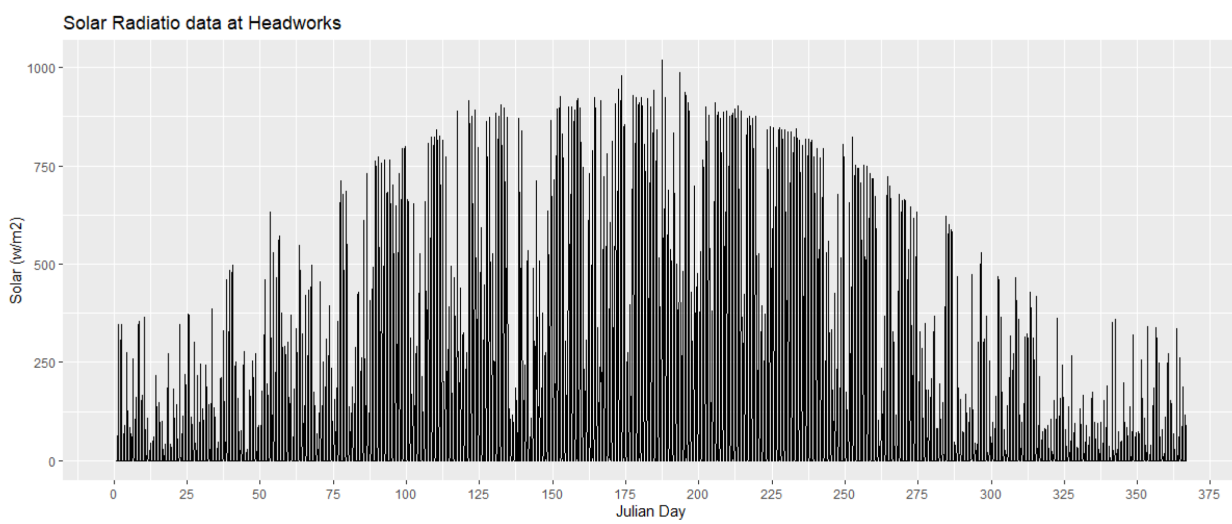


Figure 6: Derived solar radiation at Headworks

3.1.4 Temperature inputs

Model setup tributary and boundary condition temperatures.

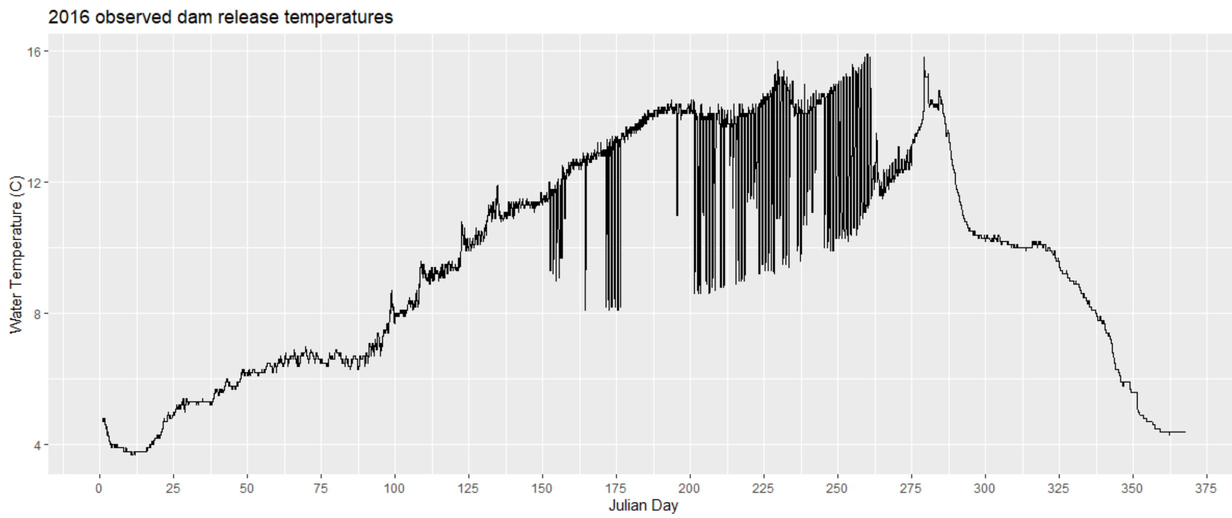


Figure 7: Observed 2016 Dam release temperatures (used for the 2016 model calibration)

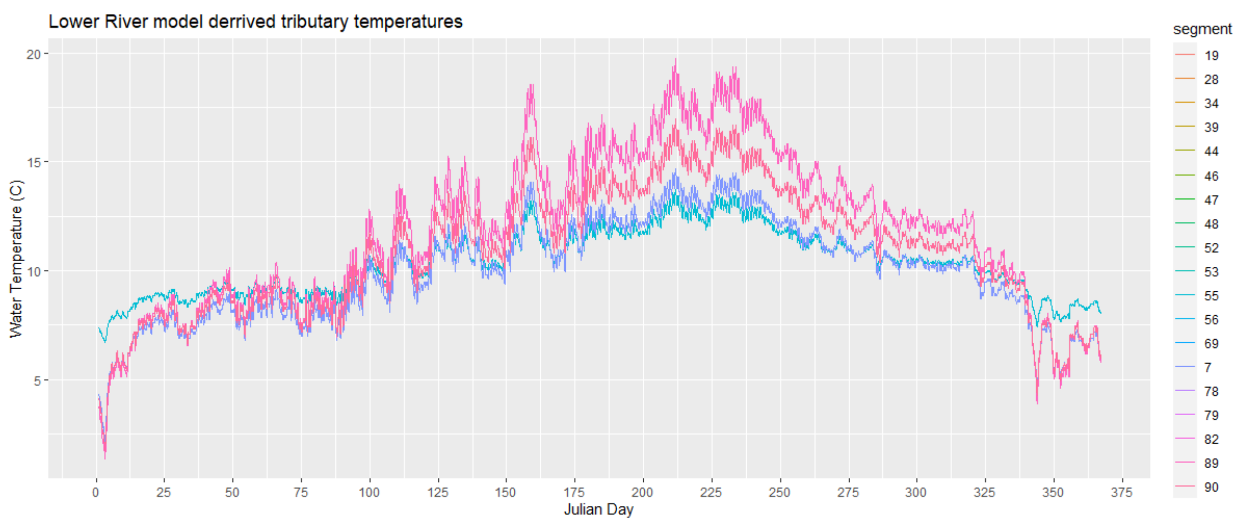


Figure 8: Derived tributary temperatures used for both calibration and scenario model runs

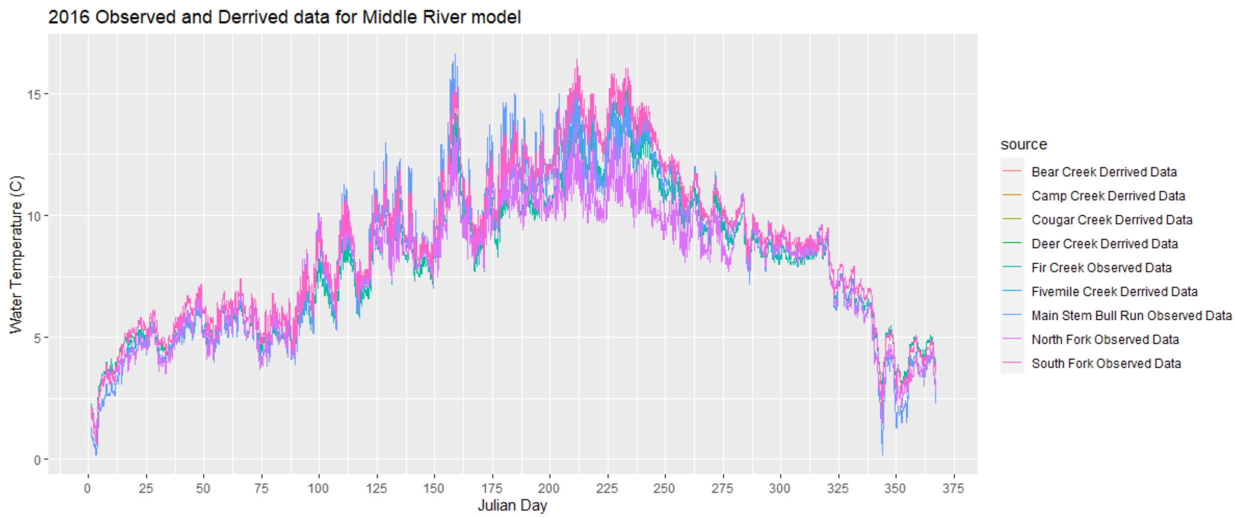


Figure 9: Derived and Observed tributary temperatures used for the Middle River model

3.1.5 Flow inputs

Model setup tributary and boundary condition flow rates.

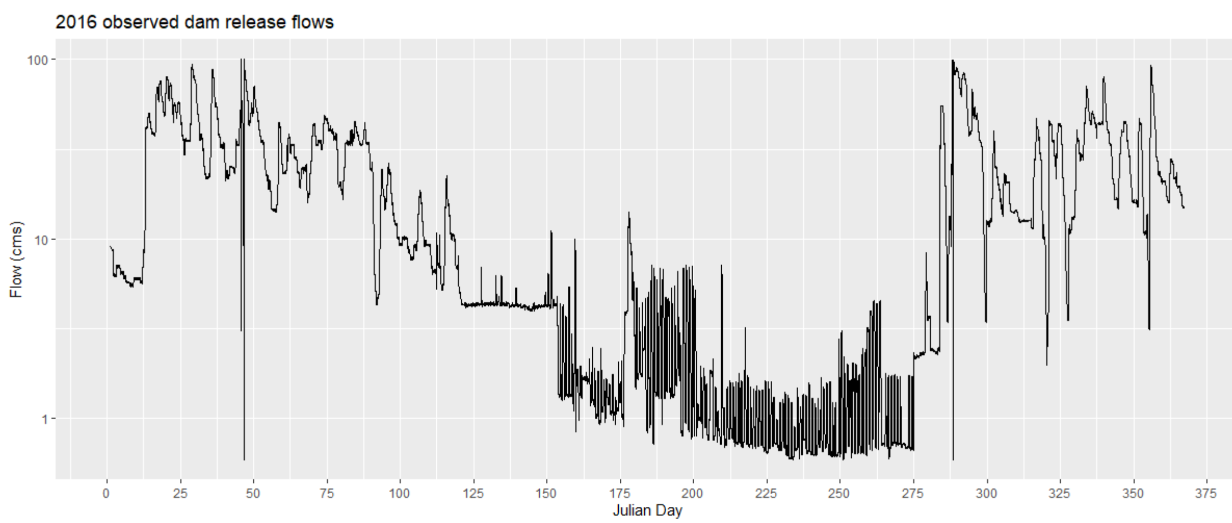


Figure 10: 2016 observed releases from Dam 2 in cubic meters per second

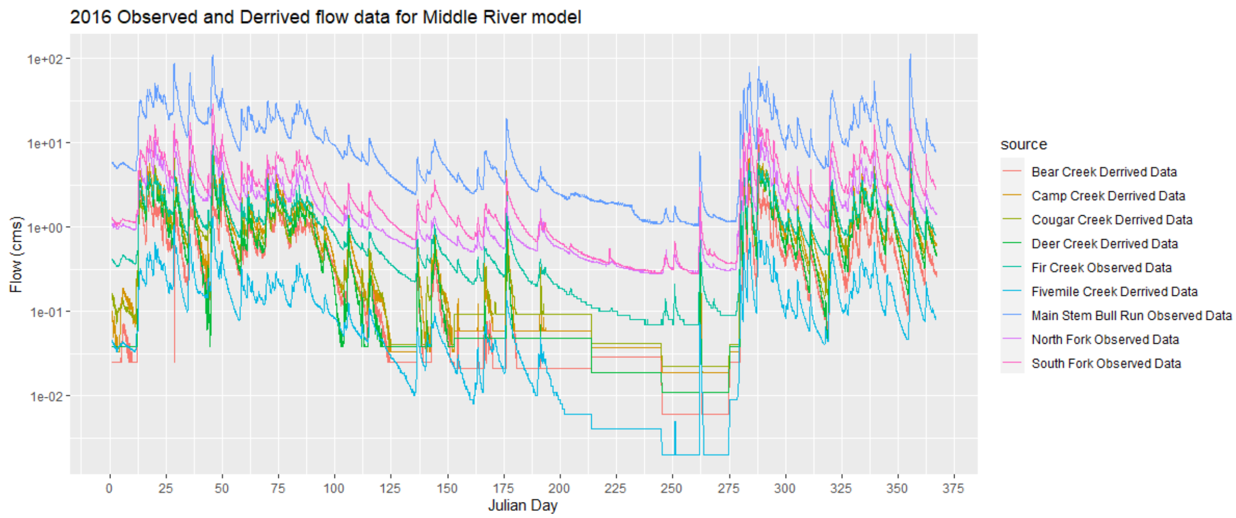


Figure 11: Observed and derived flows for the Middle River model in cubic meters per second

3.1.5.1 Model setup for groundwater/accretion/distributed flow rates.

Distributed/accretion/groundwater flows are included as tributary flows in the Middle and Lower river model.

3.1.5.2 Model setup for withdrawal flow rates.

There are no withdrawals in either the middle river or lower river model.

3.1.6 Point source inputs

There are no point source effluents in either the model domain for the middle and lower river models.

3.1.7 Topographic shade inputs

Model setup topographic shade angles.

Table 5: Topographic shading angles for Middle River model

Segment	0 degrees (North)	20 degrees	40 degrees	60 degrees	80 degrees	100 degrees	120 degrees	140 degrees	160 degrees	180 degrees (South)	200 degrees	220 degrees	240 degrees	260 degrees	280 degrees	300 degrees	320 degrees	340 degrees
2	0.291	0.227	0.091	0.415	0.641	0.798	0.874	0.88	0.804	0.636	0.227	0.087	0.181	0.261	0.376	0.419	0.383	0.379
3	0.28	0.207	0.084	0.374	0.464	0.47	0.392	0.304	0.253	0.166	0.078	0.144	0.263	0.31	0.37	0.395	0.424	0.386
4	0.23	0.171	0.177	0.219	0.157	0.225	0.308	0.298	0.248	0.14	0.085	0.183	0.325	0.4	0.474	0.412	0.384	0.278
7	0.183	0.152	0.135	0.135	0.158	0.266	0.331	0.316	0.263	0.191	0.113	0.06	0.107	0.165	0.268	0.24	0.19	0.254
8	0.171	0.139	0.102	0.118	0.255	0.311	0.384	0.38	0.364	0.335	0.214	0.119	0.038	0.088	0.184	0.229	0.227	0.243
9	0.286	0.253	0.123	0.102	0.145	0.274	0.299	0.282	0.228	0.226	0.202	0.132	0.03	0.121	0.233	0.284	0.294	0.315
10	0.402	0.333	0.173	0.081	0.129	0.244	0.279	0.245	0.204	0.199	0.133	0.1	0.045	0.218	0.359	0.436	0.46	0.457
11	0.462	0.366	0.21	0.065	0.116	0.323	0.507	0.732	0.858	0.808	0.56	0.377	0.053	0.198	0.312	0.42	0.489	0.498
12	0.386	0.296	0.19	0.138	0.185	0.346	0.377	0.357	0.31	0.3	0.195	0.085	0.071	0.242	0.341	0.38	0.421	0.427
13	0.258	0.202	0.116	0.067	0.211	0.361	0.391	0.417	0.509	0.437	0.329	0.068	0.095	0.192	0.238	0.3	0.303	0.308
14	0.126	0.133	0.093	0.172	0.419	0.628	0.76	0.74	0.643	0.541	0.272	0.081	0.097	0.157	0.215	0.239	0.233	0.128
17	0.201	0.114	0.087	0.215	0.328	0.389	0.359	0.348	0.264	0.237	0.151	0.096	0.22	0.273	0.302	0.337	0.317	0.272
18	0.444	0.126	0.069	0.15	0.207	0.237	0.292	0.318	0.274	0.258	0.218	0.137	0.319	0.527	0.596	0.667	0.707	0.629
19	0.132	0.13	0.096	0.124	0.231	0.335	0.474	0.567	0.664	0.65	0.55	0.385	0.193	0.053	0.08	0.146	0.141	0.129
20	0.122	0.105	0.095	0.086	0.137	0.244	0.352	0.417	0.491	0.552	0.495	0.498	0.38	0.107	0.09	0.148	0.153	0.142
21	0.21	0.2	0.168	0.101	0.098	0.135	0.224	0.258	0.266	0.24	0.19	0.133	0.053	0.083	0.18	0.229	0.242	0.204
22	0.467	0.332	0.142	0.076	0.086	0.132	0.223	0.261	0.25	0.248	0.165	0.106	0.063	0.095	0.295	0.4	0.476	0.486
23	0.26	0.236	0.158	0.086	0.075	0.144	0.412	0.537	0.61	0.475	0.357	0.185	0.047	0.147	0.175	0.227	0.298	0.261
24	0.324	0.259	0.168	0.084	0.1	0.159	0.219	0.193	0.181	0.147	0.072	0.09	0.313	0.479	0.611	0.581	0.52	0.45
25	0.203	0.159	0.125	0.185	0.207	0.215	0.239	0.206	0.189	0.157	0.25	0.325	0.322	0.217	0.133	0.204	0.272	0.267
26	0.206	0.139	0.07	0.121	0.154	0.298	0.422	0.484	0.482	0.39	0.26	0.067	0.047	0.116	0.146	0.195	0.25	0.263

27	0.226	0.132	0.067	0.092	0.243	0.329	0.385	0.415	0.363	0.245	0.121	0.059	0.081	0.187	0.282	0.336	0.347	0.324
28	0.169	0.109	0.057	0.138	0.171	0.279	0.334	0.27	0.243	0.193	0.138	0.078	0.042	0.107	0.181	0.213	0.223	0.196
29	0.116	0.086	0.062	0.072	0.124	0.221	0.327	0.411	0.359	0.28	0.165	0.094	0.048	0.084	0.156	0.221	0.231	0.167
30	0.193	0.111	0.061	0.055	0.103	0.168	0.208	0.211	0.201	0.188	0.137	0.109	0.062	0.096	0.131	0.229	0.26	0.271
31	0.226	0.127	0.056	0.05	0.094	0.165	0.214	0.236	0.177	0.251	0.222	0.127	0.073	0.11	0.141	0.178	0.249	0.245
32	0.204	0.142	0.051	0.053	0.108	0.193	0.282	0.386	0.443	0.424	0.362	0.16	0.073	0.136	0.158	0.185	0.204	0.231
33	0.198	0.151	0.05	0.053	0.299	0.534	0.627	0.667	0.593	0.487	0.408	0.214	0.078	0.154	0.165	0.187	0.168	0.215
34	0.206	0.151	0.046	0.045	0.229	0.347	0.464	0.502	0.469	0.437	0.385	0.223	0.108	0.201	0.234	0.196	0.19	0.184
37	0.206	0.151	0.046	0.045	0.229	0.347	0.464	0.502	0.469	0.437	0.385	0.223	0.108	0.201	0.234	0.196	0.19	0.184
38	0.206	0.151	0.046	0.045	0.229	0.347	0.464	0.502	0.469	0.437	0.385	0.223	0.108	0.201	0.234	0.196	0.19	0.184
39	0.206	0.151	0.046	0.045	0.229	0.347	0.464	0.502	0.469	0.437	0.385	0.223	0.108	0.201	0.234	0.196	0.19	0.184
40	0.206	0.151	0.046	0.045	0.229	0.347	0.464	0.502	0.469	0.437	0.385	0.223	0.108	0.201	0.234	0.196	0.19	0.184
41	0.206	0.151	0.046	0.045	0.229	0.347	0.464	0.502	0.469	0.437	0.385	0.223	0.108	0.201	0.234	0.196	0.19	0.184
44	0.185	0.147	0.054	0.158	0.527	0.666	0.765	0.795	0.715	0.513	0.175	0.028	0.145	0.27	0.339	0.355	0.275	0.242
45	0.206	0.137	0.083	0.321	0.482	0.49	0.615	0.529	0.504	0.447	0.287	0.033	0.13	0.272	0.37	0.41	0.394	0.331
46	0.238	0.125	0.1	0.431	0.617	0.691	0.75	0.722	0.616	0.502	0.246	0.03	0.15	0.203	0.274	0.326	0.372	0.336
47	0.214	0.113	0.17	0.29	0.394	0.493	0.515	0.493	0.458	0.28	0.178	0.031	0.158	0.202	0.202	0.209	0.246	0.233
48	0.164	0.104	0.102	0.225	0.333	0.397	0.392	0.375	0.408	0.374	0.216	0.03	0.145	0.271	0.3	0.258	0.212	0.16
49	0.244	0.118	0.064	0.143	0.287	0.439	0.485	0.479	0.431	0.286	0.098	0.068	0.229	0.34	0.435	0.501	0.48	0.402
50	0.262	0.106	0.061	0.28	0.41	0.471	0.509	0.489	0.372	0.25	0.132	0.123	0.302	0.394	0.441	0.431	0.41	0.378
51	0.258	0.215	0.054	0.222	0.292	0.333	0.357	0.4	0.384	0.339	0.202	0.104	0.128	0.191	0.211	0.275	0.282	0.218
52	0.172	0.129	0.107	0.107	0.128	0.178	0.198	0.237	0.238	0.208	0.204	0.149	0.175	0.221	0.242	0.257	0.23	0.207
53	0.226	0.133	0.078	0.108	0.157	0.204	0.251	0.275	0.285	0.24	0.117	0.109	0.2	0.248	0.27	0.28	0.259	0.249
54	0.256	0.179	0.059	0.098	0.245	0.357	0.508	0.488	0.481	0.405	0.213	0.15	0.22	0.275	0.279	0.282	0.276	0.244
55	0.187	0.104	0.049	0.191	0.21	0.241	0.202	0.131	0.092	0.098	0.291	0.332	0.37	0.396	0.391	0.354	0.342	0.27
56	0.121	0.117	0.206	0.248	0.258	0.261	0.233	0.188	0.13	0.083	0.309	0.471	0.567	0.593	0.568	0.412	0.254	0.202
57	0.106	0.16	0.33	0.466	0.545	0.544	0.49	0.294	0.193	0.122	0.071	0.202	0.24	0.305	0.289	0.267	0.249	0.181
58	0.094	0.09	0.142	0.18	0.206	0.199	0.23	0.263	0.197	0.135	0.146	0.269	0.365	0.458	0.485	0.444	0.326	0.206
59	0.086	0.115	0.159	0.259	0.358	0.42	0.426	0.386	0.301	0.215	0.165	0.341	0.369	0.403	0.394	0.312	0.244	0.169

60	0.139	0.075	0.236	0.402	0.518	0.604	0.624	0.607	0.516	0.392	0.156	0.084	0.151	0.26	0.272	0.266	0.215	0.161
61	0.131	0.063	0.13	0.263	0.394	0.498	0.503	0.461	0.372	0.249	0.155	0.1	0.165	0.275	0.332	0.336	0.313	0.225
62	0.241	0.178	0.078	0.189	0.279	0.333	0.341	0.304	0.253	0.252	0.135	0.131	0.18	0.296	0.32	0.328	0.297	0.271
63	0.242	0.16	0.067	0.161	0.215	0.239	0.326	0.351	0.271	0.149	0.099	0.186	0.254	0.345	0.37	0.329	0.315	0.339
64	0.434	0.23	0.06	0.124	0.233	0.273	0.28	0.227	0.118	0.094	0.167	0.286	0.389	0.405	0.488	0.56	0.569	0.516
65	0.162	0.072	0.109	0.201	0.272	0.287	0.259	0.148	0.129	0.211	0.297	0.403	0.512	0.585	0.599	0.526	0.417	0.287
66	0.123	0.165	0.25	0.354	0.404	0.419	0.307	0.168	0.141	0.218	0.332	0.392	0.389	0.378	0.377	0.347	0.291	0.207
67	0.264	0.477	0.596	0.603	0.646	0.567	0.476	0.332	0.159	0.125	0.1	0.193	0.284	0.353	0.306	0.297	0.254	0.161
68	0.084	0.268	0.34	0.386	0.378	0.331	0.242	0.182	0.178	0.137	0.152	0.079	0.028	0.111	0.197	0.24	0.259	0.176
69	0.246	0.225	0.186	0.204	0.166	0.111	0.158	0.179	0.234	0.247	0.153	0.122	0.071	0.124	0.212	0.258	0.289	0.243
70	0.444	0.349	0.192	0.139	0.12	0.175	0.243	0.28	0.274	0.225	0.171	0.113	0.146	0.24	0.292	0.368	0.449	0.466
71	0.292	0.265	0.167	0.103	0.098	0.128	0.154	0.168	0.151	0.134	0.107	0.174	0.303	0.409	0.463	0.495	0.513	0.431
72	0.201	0.148	0.092	0.099	0.109	0.111	0.164	0.179	0.181	0.147	0.127	0.086	0.142	0.167	0.212	0.264	0.318	0.275
73	0.157	0.094	0.073	0.087	0.107	0.149	0.196	0.207	0.23	0.19	0.197	0.133	0.059	0.069	0.17	0.209	0.242	0.223
74	0.183	0.103	0.064	0.068	0.103	0.16	0.202	0.254	0.358	0.374	0.323	0.233	0.111	0.096	0.163	0.212	0.239	0.217
75	0.222	0.152	0.083	0.06	0.06	0.116	0.16	0.185	0.197	0.171	0.105	0.072	0.044	0.146	0.2	0.256	0.292	0.285
76	0.277	0.193	0.093	0.041	0.057	0.104	0.155	0.169	0.18	0.133	0.094	0.101	0.149	0.199	0.234	0.285	0.317	0.324
77	0.288	0.288	0.104	0.07	0.172	0.248	0.362	0.427	0.453	0.438	0.352	0.222	0.197	0.289	0.288	0.305	0.386	0.369
78	0.379	0.377	0.263	0.117	0.088	0.208	0.343	0.43	0.547	0.619	0.631	0.584	0.451	0.291	0.271	0.279	0.301	0.328
81	0.084	0.268	0.34	0.386	0.378	0.331	0.242	0.182	0.178	0.137	0.152	0.079	0.028	0.111	0.197	0.24	0.259	0.176
82	0.084	0.268	0.34	0.386	0.378	0.331	0.242	0.182	0.178	0.137	0.152	0.079	0.028	0.111	0.197	0.24	0.259	0.176
83	0.084	0.268	0.34	0.386	0.378	0.331	0.242	0.182	0.178	0.137	0.152	0.079	0.028	0.111	0.197	0.24	0.259	0.176
84	0.084	0.268	0.34	0.386	0.378	0.331	0.242	0.182	0.178	0.137	0.152	0.079	0.028	0.111	0.197	0.24	0.259	0.176
85	0.084	0.268	0.34	0.386	0.378	0.331	0.242	0.182	0.178	0.137	0.152	0.079	0.028	0.111	0.197	0.24	0.259	0.176
86	0.084	0.268	0.34	0.386	0.378	0.331	0.242	0.182	0.178	0.137	0.152	0.079	0.028	0.111	0.197	0.24	0.259	0.176
87	0.084	0.268	0.34	0.386	0.378	0.331	0.242	0.182	0.178	0.137	0.152	0.079	0.028	0.111	0.197	0.24	0.259	0.176

Table 6: Lower River Model Topographic Angles

Segment	0 degrees (North)	20 degrees	40 degrees	60 degrees	80 degrees	100 degrees	120 degrees	140 degrees	160 degrees	180 degrees (South)	200 degrees	220 degrees	240 degrees	260 degrees	280 degrees	300 degrees	320 degrees	340 degrees
2	0.486	0.49	0.414	0.295	0.191	0.149	0.134	0.296	0.353	0.359	0.329	0.25	0.12	0.123	0.242	0.298	0.31	0.414
3	0.501	0.505	0.476	0.383	0.201	0.121	0.122	0.231	0.257	0.221	0.136	0.083	0.101	0.166	0.258	0.318	0.361	0.427
4	0.599	0.583	0.566	0.458	0.478	0.469	0.409	0.296	0.246	0.221	0.18	0.077	0.137	0.289	0.35	0.433	0.53	0.588
7	0.468	0.427	0.371	0.286	0.183	0.345	0.454	0.504	0.487	0.4	0.268	0.159	0.163	0.312	0.399	0.416	0.445	0.466
8	0.468	0.418	0.332	0.251	0.127	0.185	0.23	0.255	0.247	0.197	0.102	0.134	0.253	0.427	0.522	0.536	0.534	0.5
9	0.462	0.392	0.304	0.218	0.196	0.229	0.272	0.224	0.162	0.12	0.062	0.271	0.396	0.567	0.645	0.701	0.667	0.561
12	0.393	0.31	0.236	0.216	0.228	0.228	0.25	0.222	0.169	0.119	0.283	0.558	0.736	0.809	0.77	0.699	0.668	0.564
13	0.271	0.229	0.182	0.247	0.329	0.37	0.344	0.294	0.238	0.189	0.111	0.177	0.29	0.358	0.397	0.431	0.391	0.357
14	0.243	0.19	0.215	0.346	0.394	0.425	0.428	0.405	0.372	0.287	0.162	0.068	0.21	0.288	0.297	0.308	0.324	0.302
17	0.194	0.173	0.171	0.26	0.346	0.437	0.493	0.529	0.443	0.279	0.217	0.089	0.042	0.124	0.21	0.3	0.287	0.314
18	0.184	0.162	0.103	0.187	0.28	0.392	0.365	0.271	0.299	0.311	0.246	0.128	0.051	0.155	0.197	0.3	0.281	0.285
19	0.188	0.174	0.173	0.149	0.223	0.254	0.228	0.328	0.367	0.237	0.152	0.101	0.061	0.211	0.244	0.31	0.326	0.309
22	0.165	0.174	0.092	0.157	0.272	0.241	0.264	0.388	0.42	0.438	0.392	0.17	0.065	0.113	0.211	0.295	0.313	0.297
23	0.153	0.157	0.082	0.161	0.287	0.235	0.286	0.428	0.449	0.477	0.499	0.52	0.413	0.282	0.172	0.282	0.3	0.286
24	0.139	0.135	0.083	0.189	0.29	0.234	0.32	0.475	0.511	0.513	0.42	0.419	0.312	0.185	0.139	0.267	0.287	0.274
27	0.19	0.153	0.098	0.132	0.239	0.274	0.41	0.364	0.287	0.245	0.232	0.154	0.105	0.172	0.328	0.419	0.37	0.299
28	0.355	0.22	0.087	0.118	0.231	0.289	0.299	0.343	0.408	0.413	0.336	0.25	0.186	0.09	0.143	0.274	0.338	0.349
29	0.235	0.269	0.132	0.131	0.209	0.377	0.549	0.692	0.77	0.789	0.764	0.679	0.537	0.356	0.15	0.265	0.333	0.328
32	0.299	0.264	0.279	0.182	0.115	0.166	0.259	0.314	0.423	0.497	0.524	0.504	0.409	0.224	0.185	0.296	0.356	0.373
33	0.397	0.374	0.296	0.246	0.13	0.136	0.186	0.232	0.339	0.371	0.313	0.21	0.077	0.125	0.258	0.342	0.391	0.414
34	0.568	0.491	0.361	0.225	0.138	0.119	0.157	0.256	0.257	0.212	0.147	0.056	0.114	0.261	0.404	0.509	0.577	0.6
37	0.485	0.384	0.267	0.162	0.1	0.2	0.279	0.295	0.254	0.207	0.152	0.063	0.176	0.402	0.541	0.596	0.577	0.536
38	0.366	0.263	0.175	0.144	0.266	0.334	0.383	0.378	0.374	0.304	0.221	0.142	0.001	0.112	0.241	0.344	0.378	0.392
39	0.362	0.244	0.144	0.14	0.252	0.372	0.451	0.494	0.496	0.477	0.433	0.286	0.035	0.061	0.199	0.299	0.346	0.374
42	0.369	0.28	0.18	0.278	0.137	0.238	0.34	0.322	0.289	0.24	0.171	0.064	0.001	0.081	0.21	0.308	0.369	0.378

43	0.357	0.308	0.184	0.074	0.105	0.152	0.171	0.252	0.268	0.201	0.175	0.057	0.002	0.102	0.221	0.307	0.369	0.386
44	0.309	0.263	0.132	0.113	0.12	0.172	0.238	0.285	0.283	0.239	0.206	0.074	0	0.103	0.2	0.264	0.326	0.343
45	0.304	0.242	0.127	0.056	0.112	0.201	0.265	0.301	0.275	0.28	0.197	0.088	0.015	0.125	0.205	0.257	0.301	0.326
46	0.306	0.237	0.116	0.043	0.08	0.148	0.269	0.259	0.297	0.278	0.164	0.066	0.025	0.127	0.229	0.275	0.304	0.322
47	0.322	0.261	0.132	0.051	0.065	0.135	0.235	0.262	0.288	0.238	0.121	0.037	0.065	0.167	0.282	0.308	0.348	0.339
48	0.289	0.227	0.111	0.05	0.102	0.199	0.224	0.306	0.303	0.234	0.133	0.043	0.055	0.151	0.28	0.318	0.32	0.319
49	0.287	0.224	0.09	0.017	0.07	0.181	0.263	0.299	0.272	0.203	0.098	0.05	0.105	0.194	0.287	0.405	0.364	0.328
52	0.261	0.161	0.06	0.046	0.12	0.221	0.318	0.329	0.292	0.23	0.15	0.068	0.085	0.169	0.222	0.288	0.377	0.304
53	0.244	0.162	0.068	0.05	0.153	0.264	0.319	0.339	0.336	0.298	0.223	0.125	0.039	0.122	0.195	0.259	0.307	0.353
54	0.312	0.19	0.112	0.051	0.151	0.257	0.299	0.297	0.278	0.196	0.143	0.113	0.082	0.19	0.298	0.344	0.377	0.37
55	0.266	0.143	0.06	0.143	0.212	0.277	0.336	0.359	0.331	0.281	0.256	0.219	0.125	0.021	0.087	0.176	0.254	0.274
56	0.257	0.206	0.092	0.06	0.154	0.244	0.283	0.402	0.478	0.493	0.461	0.386	0.238	0.084	0.079	0.166	0.245	0.277
57	0.319	0.285	0.222	0.139	0.089	0.193	0.229	0.238	0.267	0.245	0.2	0.184	0.104	0.025	0.126	0.258	0.297	0.324
60	0.413	0.349	0.219	0.127	0.174	0.291	0.391	0.507	0.635	0.633	0.564	0.383	0.142	0.062	0.153	0.236	0.345	0.404
61	0.416	0.374	0.309	0.175	0.062	0.156	0.19	0.272	0.315	0.324	0.286	0.22	0.041	0.119	0.213	0.337	0.405	0.432
62	0.287	0.267	0.193	0.096	0.109	0.252	0.404	0.482	0.53	0.514	0.465	0.353	0.148	0.128	0.239	0.236	0.251	0.28
63	0.27	0.249	0.179	0.085	0.224	0.293	0.488	0.565	0.636	0.641	0.59	0.429	0.161	0.177	0.264	0.277	0.277	0.294
64	0.467	0.417	0.34	0.185	0.061	0.238	0.41	0.508	0.487	0.326	0.226	0.106	0.208	0.258	0.337	0.401	0.411	0.475
65	0.335	0.277	0.179	0.087	0.16	0.359	0.359	0.289	0.19	0.184	0.146	0.201	0.349	0.426	0.573	0.648	0.641	0.532
68	0.257	0.187	0.139	0.179	0.309	0.336	0.255	0.256	0.238	0.236	0.193	0.194	0.345	0.505	0.57	0.542	0.483	0.387
69	0.255	0.146	0.104	0.21	0.279	0.16	0.119	0.249	0.305	0.292	0.24	0.202	0.501	0.65	0.588	0.625	0.585	0.468
70	0.401	0.18	0.07	0.195	0.183	0.334	0.319	0.356	0.386	0.364	0.308	0.627	0.795	0.876	0.994	1.015	0.959	0.774
73	0.287	0.359	0.321	0.446	0.598	0.61	0.683	0.771	0.603	0.567	0.529	0.456	0.411	0.168	0.062	0.202	0.256	0.314
74	0.347	0.326	0.336	0.297	0.195	0.208	0.328	0.403	0.458	0.61	0.603	0.494	0.336	0.119	0.068	0.157	0.238	0.337
75	0.378	0.409	0.35	0.197	0.122	0.161	0.252	0.453	0.497	0.477	0.436	0.35	0.226	0.117	0.085	0.169	0.282	0.353
76	0.391	0.406	0.328	0.236	0.137	0.132	0.273	0.279	0.349	0.402	0.406	0.378	0.307	0.163	0.117	0.229	0.293	0.361
77	0.731	0.729	0.66	0.479	0.227	0.078	0.193	0.205	0.209	0.196	0.167	0.201	0.194	0.135	0.405	0.629	0.7	0.721
78	0.544	0.472	0.34	0.21	0.088	0.148	0.217	0.315	0.345	0.299	0.236	0.258	0.248	0.152	0.165	0.351	0.511	0.56
79	0.378	0.423	0.357	0.201	0.064	0.139	0.178	0.224	0.244	0.25	0.308	0.354	0.31	0.204	0.105	0.225	0.286	0.346

80	0.26	0.319	0.298	0.223	0.116	0.119	0.167	0.273	0.324	0.41	0.467	0.505	0.452	0.404	0.303	0.097	0.113	0.182
81	0.618	0.71	0.715	0.681	0.539	0.328	0.114	0.165	0.246	0.41	0.501	0.549	0.446	0.351	0.216	0.101	0.208	0.498
82	0.455	0.466	0.46	0.551	0.523	0.358	0.088	0.155	0.307	0.429	0.484	0.485	0.494	0.412	0.31	0.172	0.114	0.279
85	0.658	0.718	0.775	0.702	0.488	0.363	0.235	0.114	0.252	0.402	0.45	0.456	0.427	0.489	0.602	0.718	0.711	0.685
86	0.418	0.584	0.685	0.717	0.658	0.592	0.387	0.135	0.223	0.358	0.458	0.503	0.381	0.368	0.293	0.241	0.217	0.141
87	0.051	0.196	0.394	0.542	0.578	0.543	0.389	0.185	0.167	0.196	0.289	0.38	0.413	0.395	0.376	0.371	0.335	0.162
88	0.078	0.141	0.172	0.296	0.347	0.339	0.284	0.266	0.189	0.125	0.205	0.267	0.355	0.459	0.497	0.468	0.331	0.099
89	0.124	0.2	0.221	0.187	0.248	0.198	0.198	0.18	0.075	0.164	0.345	0.469	0.573	0.554	0.493	0.422	0.306	0.129
90	0.192	0.263	0.303	0.325	0.378	0.389	0.24	0.142	0.095	0.123	0.321	0.447	0.491	0.493	0.396	0.25	0.07	0.056
91	0.171	0.239	0.274	0.29	0.337	0.331	0.264	0.111	0.057	0.245	0.392	0.463	0.467	0.425	0.324	0.131	0.027	0.073
94	0.175	0.266	0.314	0.284	0.25	0.215	0.136	0.096	0.086	0.276	0.367	0.358	0.289	0.227	0.168	0.087	0.006	0.102
95	0.207	0.25	0.289	0.313	0.263	0.187	0.113	0.068	0.147	0.268	0.349	0.421	0.447	0.438	0.374	0.219	0.011	0.093
96	0.213	0.28	0.337	0.364	0.343	0.255	0.142	0.055	0.176	0.245	0.288	0.3	0.292	0.221	0.113	0.017	0.035	0.108
97	0.158	0.198	0.192	0.239	0.24	0.187	0.099	0.074	0.151	0.241	0.32	0.298	0.236	0.151	0	0.025	0.082	0.12
98	0.124	0.139	0.139	0.153	0.18	0.151	0.059	0.183	0.225	0.235	0.231	0.179	0.112	0.034	0.038	0.011	0.116	0.094
99	0.051	0.038	0.049	0.095	0.159	0.125	0.052	0.108	0.182	0.18	0.14	0.066	0.063	0.061	0.064	0.071	0.139	0.115

3.1.8 Channel setup

Model setup stream channel elevation (m) and gradient.

Table 7: Lower River Model - Channel bottom elevation and slope

Segment	Channel bottom elevation (m)	Slope	Angle	Mannings n
2	220	0	1.75	0.07
3	220	0	2.16	0.07
4	220	0	1.22	0.07
7	217.34583	0.001	1.28	0.07
8	217.27083	0.001	1.36	0.07
9	217.21	0.001	1.04	0.07
12	210.39994	0.009	5.82	0.07
13	209.46997	0.009	3.14	0.07
14	208.54	0.009	0.04	0.07
17	194.5	0	1.05	0.07
18	194.5	0	0.99	0.07
19	194.5	0	0.88	0.07
22	194.5	0	2.45	0.07
23	194.5	0	2.45	0.07
24	194.5	0	2.45	0.07
27	198.33	0.012	1.05	0.07
28	197.25	0.012	1.11	0.07
29	196.17	0.012	1.57	0.07
32	188.85	0	2.26	0.07
33	188.85	0	2.04	0.07
34	188.85	0	1.29	0.07
37	187.7775	0.011	0.41	0.07
38	186.6225	0.011	0.72	0.07
39	185.55	0.011	0.92	0.07
42	182.6024	0.00841	1.29	0.07
43	181.3409	0.00841	1.06	0.07
44	180.0794	0.00841	0.37	0.07
45	178.3133	0.00841	0.72	0.07
46	176.2949	0.00841	1.07	0.07
47	174.6129	0.00841	1.57	0.07
48	172.7627	0.00841	1.02	0.07
49	170.9125	0.00841	1.05	0.07
52	169.5625	0.01125	0.08	0.07
53	167.9875	0.01125	1.28	0.07
54	165.9625	0.01125	1.14	0.07
55	163.825	0.01125	0.73	0.07
56	161.8	0.01125	1.75	0.07
57	160	0.01125	1.91	0.07
60	135.3333	0.005	1.11	0.07
61	134.7333	0.005	1.01	0.07
62	133.39165	0.005	0.42	0.07
63	132.05	0.005	1	0.07
64	131	0.005	1.57	0.07
65	130.2	0.005	0.56	0.07
68	129.21	0	0.59	0.07
69	129.21	0	0.55	0.07
70	129.21	0	0.68	0.07
73	105.48125	0.0035	0.61	0.07
74	104.92125	0.0035	2.68	0.07
75	104.36125	0.0035	1.57	0.07
76	103.80125	0.0035	1.79	0.07

77	103.075	0.0035	1.47	0.07
78	102.34875	0.0035	1.02	0.07
79	101.6225	0.0035	1.2	0.07
80	100.9225	0.0035	1.88	0.07
81	100.19625	0.0035	1.93	0.07
82	99.47	0.0035	2.25	0.07
85	96.257546	0.01024	2.5	0.07
86	94.257059	0.01024	2.5	0.07
87	92.055459	0.01024	2.45	0.07
88	89.751459	0.01024	3.55	0.07
89	87.750973	0.01024	2.85	0.07
90	85.750486	0.01024	2.5	0.07
91	83.75	0.01024	2.73	0.07
94	80.710188	0.00663	2.68	0.07
95	79.293025	0.00663	2.5	0.07
96	77.701825	0.00663	2.5	0.07
97	76.284663	0.00663	1.87	0.07
98	74.627163	0.00663	1.79	0.07
99	73.21	0.00663	2.85	0.07

Table 8: Middle River Model - Channel bottom elevation, slope, orientation angle (phi), and roughness n

Segment	Channel bottom elevation (m)	Slope	Angle	Mannings n
2	312.91	0.00758	1.16	0.07
3	311.20	0.00758	0.84	0.07
4	309.50	0.00758	0.62	0.07
7	310.86	0.00636	0.75	0.07
8	309.43	0.00636	1.37	0.07
9	308.00	0.00636	1.78	0.07
10	306.57	0.00636	1.29	0.07
11	305.14	0.00636	1.39	0.07
12	303.71	0.00636	1.12	0.07
13	302.29	0.00636	1.09	0.07
14	300.86	0.00636	1.15	0.07
17	299.00	0.00825	0.97	0.07
18	297.15	0.00825	0.84	0.07
19	295.30	0.00825	1.7	0.07
20	293.44	0.00825	1.93	0.07
21	291.59	0.00825	1.86	0.07
22	289.74	0.00825	1.16	0.07
23	287.89	0.00825	1.68	0.07
24	286.03	0.00825	1.35	0.07
25	284.18	0.00825	0.34	0.07
26	282.33	0.00825	1.3	0.07
27	280.47	0.00825	1.09	0.07
28	278.62	0.00825	1.01	0.07
29	276.77	0.00825	1.33	0.07
30	274.91	0.00825	1.34	0.07
31	273.06	0.00825	1.18	0.07
32	271.21	0.00825	1.19	0.07
33	269.35	0.00825	1.37	0.07
34	267.50	0.00825	1.43	0.07
37	284.62	0.01024	0.31	0.07
38	283.59	0.01024	5.92	0.07
39	282.56	0.01024	5.63	0.07
40	281.53	0.01024	5.59	0.07
41	280.50	0.01024	5.18	0.07

44	267.03	0.00524	0.88	0.07
45	265.93	0.00524	0.9	0.07
46	264.83	0.00524	0.92	0.07
47	263.72	0.00524	1	0.07
48	262.62	0.00524	0.92	0.07
49	261.51	0.00524	0.78	0.07
50	260.41	0.00524	1.34	0.07
51	259.31	0.00524	1.48	0.07
52	258.20	0.00524	1.42	0.07
53	257.10	0.00524	0.79	0.07
54	256.00	0.00524	1.33	0.07
55	254.89	0.00524	0.71	0.07
56	253.79	0.00524	6.03	0.07
57	252.68	0.00524	0.34	0.07
58	251.58	0.00524	0.52	0.07
59	250.48	0.00524	0.15	0.07
60	249.37	0.00524	0.91	0.07
61	248.27	0.00524	1.02	0.07
62	247.16	0.00524	1.11	0.07
63	246.06	0.00524	1.18	0.07
64	244.96	0.00524	0.76	0.07
65	243.85	0.00524	0.21	0.07
66	242.75	0.00524	5.86	0.07
67	241.64	0.00524	0.1	0.07
68	240.54	0.00524	1.33	0.07
69	239.44	0.00524	1.77	0.07
70	238.33	0.00524	1.6	0.07
71	237.23	0.00524	0.81	0.07
72	236.12	0.00524	0.44	0.07
73	235.02	0.00524	0.58	0.07
74	233.92	0.00524	1.53	0.07
75	232.81	0.00524	1.77	0.07
76	231.71	0.00524	1.86	0.07
77	230.60	0.00524	1.56	0.07
78	229.50	0.00524	0.9	0.07
81	246.51	0.00501	1.96	0.07
82	245.67	0.00501	1.81	0.07
83	244.84	0.00501	2.2	0.07
84	244.00	0.00501	2.64	0.07
85	243.17	0.00501	1.86	0.07
86	242.33	0.00501	2.69	0.07
87	241.50	0.00501	2.7	0.07

3.1.9 Other model parameters

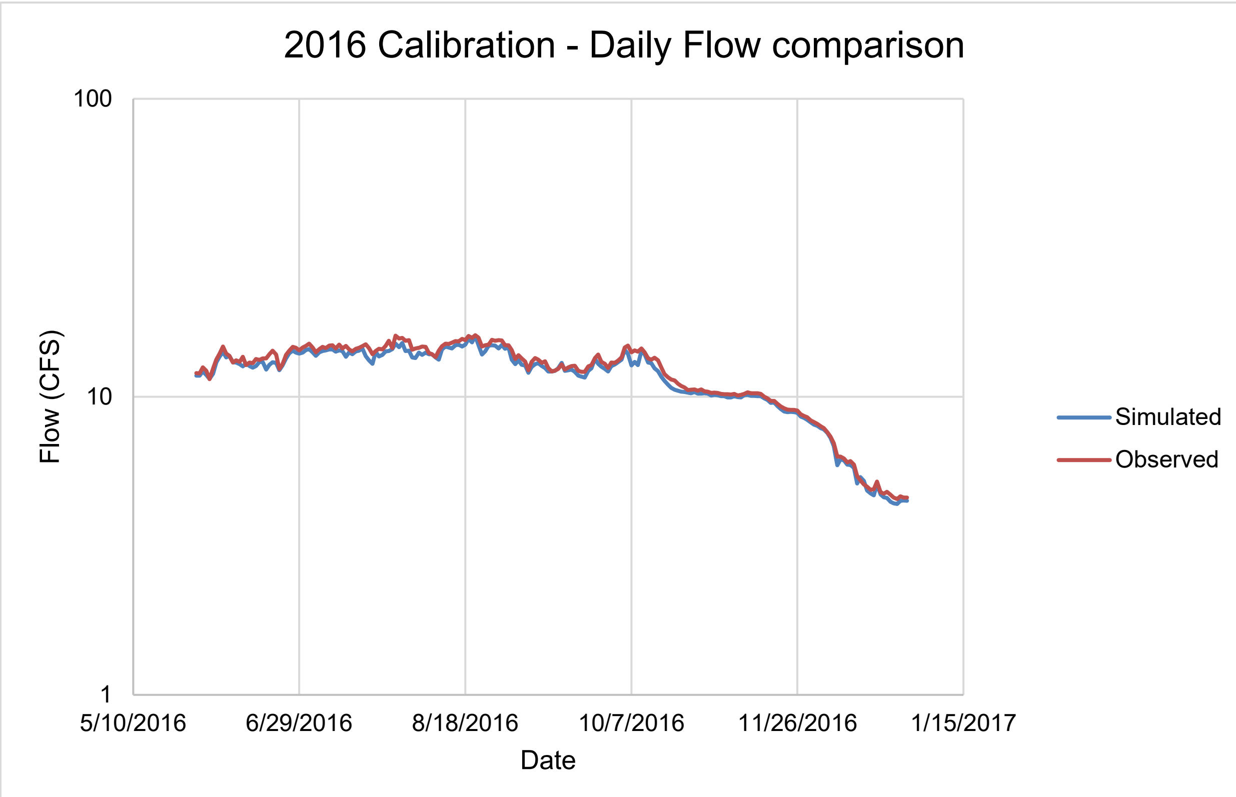
Most model parameters were kept as their original values from the PSU creation/calibration of the model. Of noteworthy change are:

TSEDF & TSED: These parameters which dictate the fraction of sediment temperature that is imparted on the water body (TSEDF 0-1) and temperature of the sediment in degrees C (TSED) were altered for the 2016 observed calibration of the model. TSED was set to the average annual air temperature of 2016 as recommended in the CEQUAL-W2 model literature. A range of TSEDF factors was tested between 0.1 to 1 (by 0.1 intervals) and results were compared. It was found that low values of TSEDF resulted in an overall cold bias to the calibration whereas high values of TSEDF resulted in an overall warm bias. A value of 0.5 for TSEDF (for all water bodies) was found to have the best results based on model goodness of fit tests. The Middle River model was therefore also given the same TSEDF and TSED parameters.

3.1.10 Calibration results

3.1.10.1 Flow

Figure A12. Field observed and model predicted mean daily flow rates.



Flow rate goodness of fit statistics comparing field observed and model flow rates

Table 9: Daily Flow Statistics comparing simulated and measured flows at Bowman's Bridge (USGS 14140000)

Daily Flow Statistics			
Bias	MAE	RMSE	NSE
-0.44	0.45	0.57	0.97

Temperature

Field observed and model predicted daily maximum temperatures at four different stations where in-situ probes collected continuous temperature data for most of 2016.

Table A10. Stream temperature goodness of fit statistics comparing field observed and model predicted temperatures.

Figure 13: Daily maximum water temperatures at 4 key observed stations for the 2016 calibration

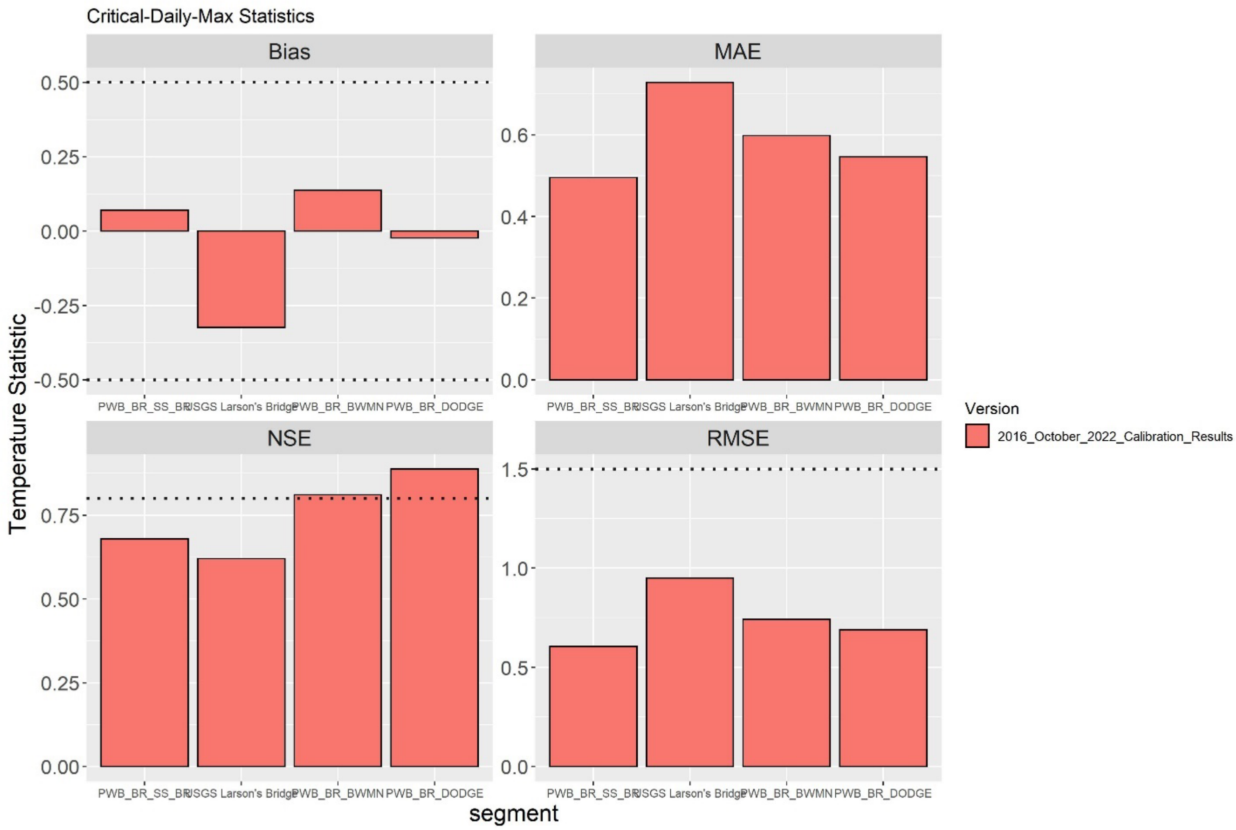


Figure 14: Goodness of fit statistics for observed vs. simulated daily maximum water temperatures at 4 key stations. Dates being considered are based on the "critical period" between 6/1/2016 - 10/15/2016

4. Model scenarios

4.1 Scenario descriptions

Three different scenarios were generated for this project utilizing two different models (Middle River model and Lower River model). All the scenarios utilize the weather year 2016 but differ in many ways.

2016 calibration – The model calibration scenario is based on 2016 as observed conditions. Therefore, this model considers the presence of the dams, the release of the dams, and is the basis for decisions made to the model parameters to make the best possible match for daily maximum temperatures. This scenario only considers the Lower River model. A significant difference between the 2016 calibration model and the other versions of the model apart from the shade files is the upstream boundary condition. Figure 15 below shows the relative locations of Branch 1 and 2 in the Lower River model. In this figure, Branch 1, also known as the diversion pool, is a short, controlled pool between Dam 2, and the diversion dam. Flow can pass either over the diversion dam or through the diversion dam via a valve. In addition, water from the reservoir can be routed either to the diversion pool, or just past the diversion pool in Branch 2. Branch 2 is a channel length with the upstream boundary being the downstream side of the diversion dam, and the downstream boundary being another weir called the Lamprey barrier. Since all flows that are sent downstream are accounted for at the Lamprey barrier (both flow and temperature), it makes a much more consistent point from which to use as the upstream boundary condition for the Lower River model instead of trying to accommodate the complicated routing associated with flows into branch 1 and routing that bypasses branch 1. The boundary condition data for the model is primarily based on the flow and temperature data from the Lamprey barrier (locations 3 & 4 on the figure below). Since the model already contains Branch 1, and branch 1 is still important for the scenarios which consider no dams, instead of rebuilding the model to exclude branch one from the geometry, the input boundary condition data is just set to start at Branch 2. Branch 1 in the 2016 calibration is essentially a stagnant pool of water with no inputs or outputs, all simulated results from Branch 1 (segment 2, 3, & 4) should be ignored.

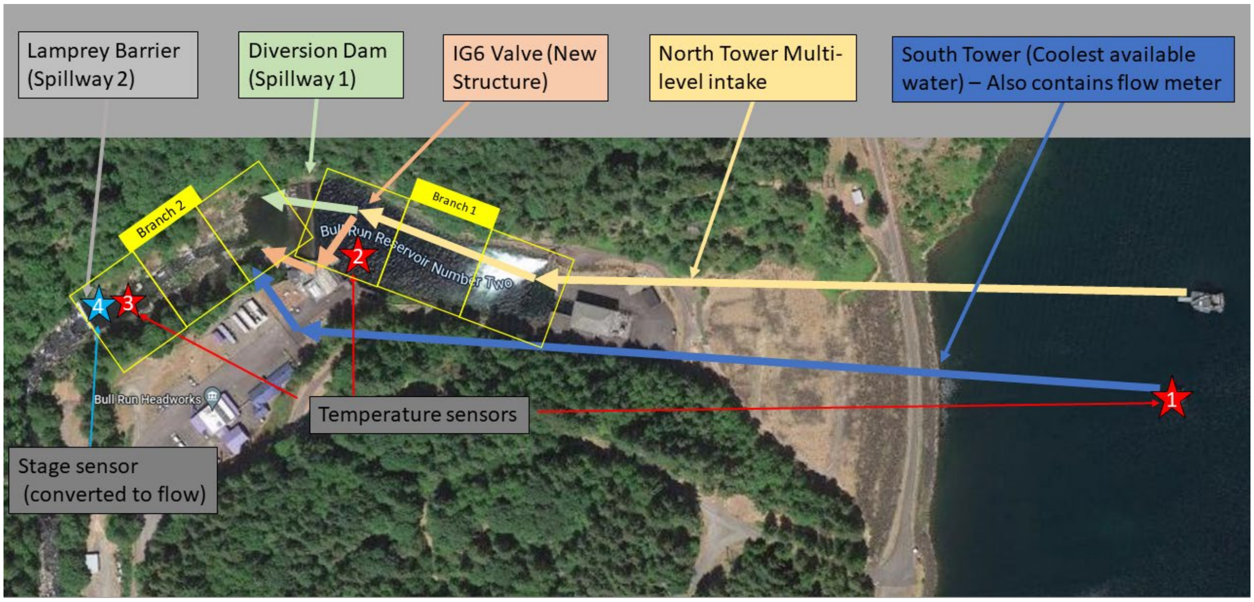


Figure 15: Headworks area of the Lower River model

2016 Current Conditions – This scenario considers both the Middle River model and Lower River model running in tandem. The Current Conditions model utilizes natural flows through the Middle River model through model channel morphology that is our best estimate of what a natural stream channel would look like in the absence of the two reservoirs and dams. The current conditions shade file considers current day vegetation elevations as measured using LiDAR where available and utilizing Restored Conditions vegetation elevations where the current day reservoirs are located (most of the Middle River Model). Temperature and flow outputs from the Middle River Model at spillway 4 are used as input data for the Lower River model at Tin_BR1 and Qin_BR1 respectively.

2016 Restored Conditions – This scenario considers both the Middle River model and Lower River model running in tandem. The restored conditions model utilizes natural flows through the Middle River model through model channel morphology that is our best estimate of what a natural stream channel would look like in the absence of the two reservoirs and dams. The restored conditions shade file considers current day vegetation elevations and restored condition vegetation elevations. In all areas, the higher of the two vegetation elevations is used for computing vegetation shade angles. Since the vegetation shade angles are based on a height of vegetation relative to a distance from centerline, vegetation elevations are not always higher in the restored conditions file, but the associated angle which takes into account elevation and distance from centerline is always higher (or the same) in the restored conditions file. Temperature and flow outputs from the Middle River Model at spillway 4 are used as input data for the Lower River model at Tin_BR1 and Qin_BR1 respectively.

4.2 Scenarios results

Two different scenarios were run using the Middle and Lower river model.

Scenario 1 was using a shade file that represented the No-Dam Conditions (current condition vegetation heights)

Scenario 2 was using a shade file that represented the Restored Conditions (restored condition vegetation, or current condition vegetation, whichever is higher)

Comparisons across the model domain for both scenarios showed very small differences in model results for temperature. The Middle River Model shade files for the two scenarios are nearly identical because most of the Middle River Model vegetation heights were given the Restored Condition vegetation heights because they reside underneath the current day reservoir. The Lower River Model therefore has upstream boundary conditions from the two different scenarios that are nearly identical. Interestingly, maximum daily temperatures did not differ significantly between the two scenarios in the Lower River Model.

The resulting daily maximum water temperatures for the Middle River and Lower River models were combined together. Extrapolating the DX (distance) values from the corresponding bathymetry files, daily maximum water temperature at each segment was converted to daily maximum water temperature at each segment centroid's distance downstream (river mile) with the starting point being the upstream boundary of the Middle River model. Side branches from both models were removed from this analysis as their impact is incorporated in the main stem at their individual confluence points.

The figure below displays the daily maximum water temperature at all the points along the combined model domain (excluding side branches) for various dates throughout the "critical period" of June through mid-October. What is most evident is the increase in temperature from the Middle River model in the area just before headworks (where modern-day Reservoir 2 is). This location appears to see the maximum water temperatures during the Summer with daily maximum temperatures exceeding 22 C. At the end of the Middle River model, results indicate that water begins to cool off leading to the end of the model domain (headworks). The Lower River model continues to cool off the hot conditions from the Middle River model nearly until the end of the Lower River model.

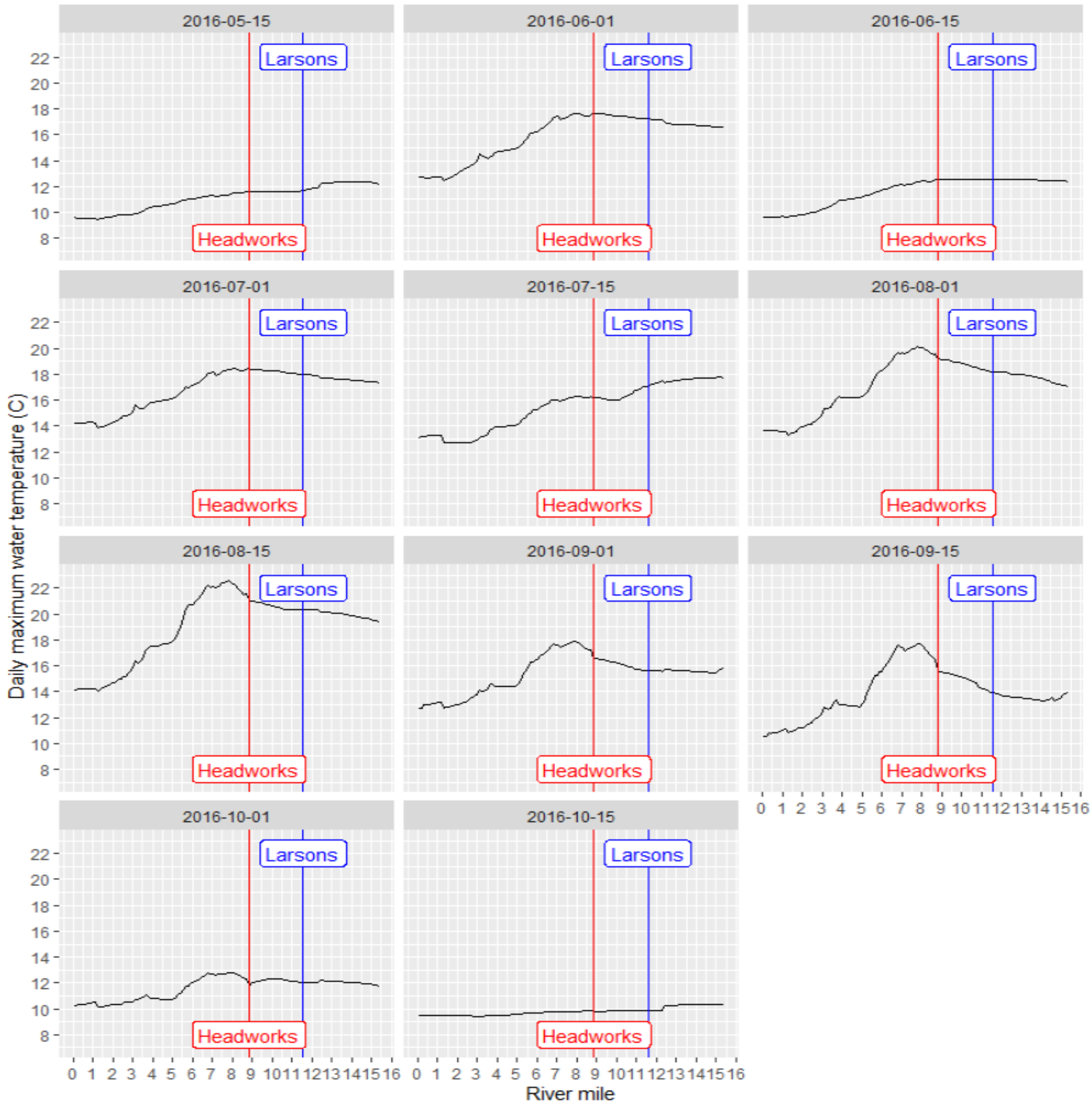


Figure 16: Combined Restored Conditions results for 2016 over various dates

5. References

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