Total Maximum Daily Loads for the Willamette Subbasins

Technical Support Document Appendix J: Tetra Tech Model Calibration Report

August 2024

State of Oregon
DEQ Department of Environmental Quality

Lower Willamette River, Clackamas River, and Long Tom River Temperature Model Configuration and Calibration Report

PREPARED FOR

US Environmental Protection Agency, Region 10

and

Oregon Department of Environmental Quality

March 24, 2023

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TETRA TECH

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1.0 INTRODUCTION

Tetra Tech is assisting 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 Willamette River. 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 entire project area covers the following rivers:

- Multnomah Channel
- Willamette River from the confluence of the Columbia River to confluence of Coast Fork of the Willamette and Middle Fork of the Willamette River (from approximately river mile (RM) 187);
- Clackamas River up to River Mill Dam/Estacada Lake (from approximately RM 26);
- Santiam River (all 12 miles);
- North Santiam River up to Detroit Dam (from approximately RM 49);
- South Santiam River up to Foster Dam (from approximately RM 38);
- Long Tom River to Fern Ridge Dam (from approximately RM 26);
- McKenzie River to confluence with the South Fork McKenzie River (from approximately RM 56);
- South Fork McKenzie River to Cougar Dam (from approximately RM 4);
- Blue River to Blue River Dam (from approximately RM 1.9);
- Middle Fork Willamette to Dexter Dam (from approximately RM 17);
- Fall Creek to Fall Creek Dam (from approximately RM 7);
- Coast Fork Willamette to Cottage Grove Dam (from approximately RM 30);
- Row River to Dorena Dam (from approximately RM 7.5).

ODEQ and USGS developed CE-QUAL-W2 (W2) models to model water temperature on multiple tributaries and the main Willamette River. Figure 1-1 shows the reaches of the project area, the reaches developed with W2 version 3.12, the reaches developed with W2 version 4.2, and other reaches that are not included in any CE-QUAL-W2 models. The models using W2 version 3.12 were calibrated using data collected during model years 2001 and 2002; and the updated models using W2 version 4.2 were used to simulate water temperature from April to November of 2011, 2015, and 2016.

Within the project area, the available W2 models for Lower Willamette River, Clackamas River, and Long Tom River were not developed in version 4.2, and the goal of this project is to update the W2 models for these three rivers to version 4.2. The Lower Willamette River is the last segment of the Willamette River before it flows into the Columbia River. It stretches from the mouth to Willamette Falls (RM 26.5), including the Willamette Channel and the Multnomah Channel. The Clackamas River was modeled from downstream of River Mill Dam/Estacada Lake (approximately river mile 26) to its confluence with the Lower Willamette River. The Long Tom River was modeled from downstream of Fern Ridge Dam (approximately river mile 26) to its confluence with the Willamette River.

This report describes the technical approach used to update the Lower Willamette River, Clackamas River, and Long Tom River models, summarizes available data, and serves as documentation of the model configuration and calibration for all three models.

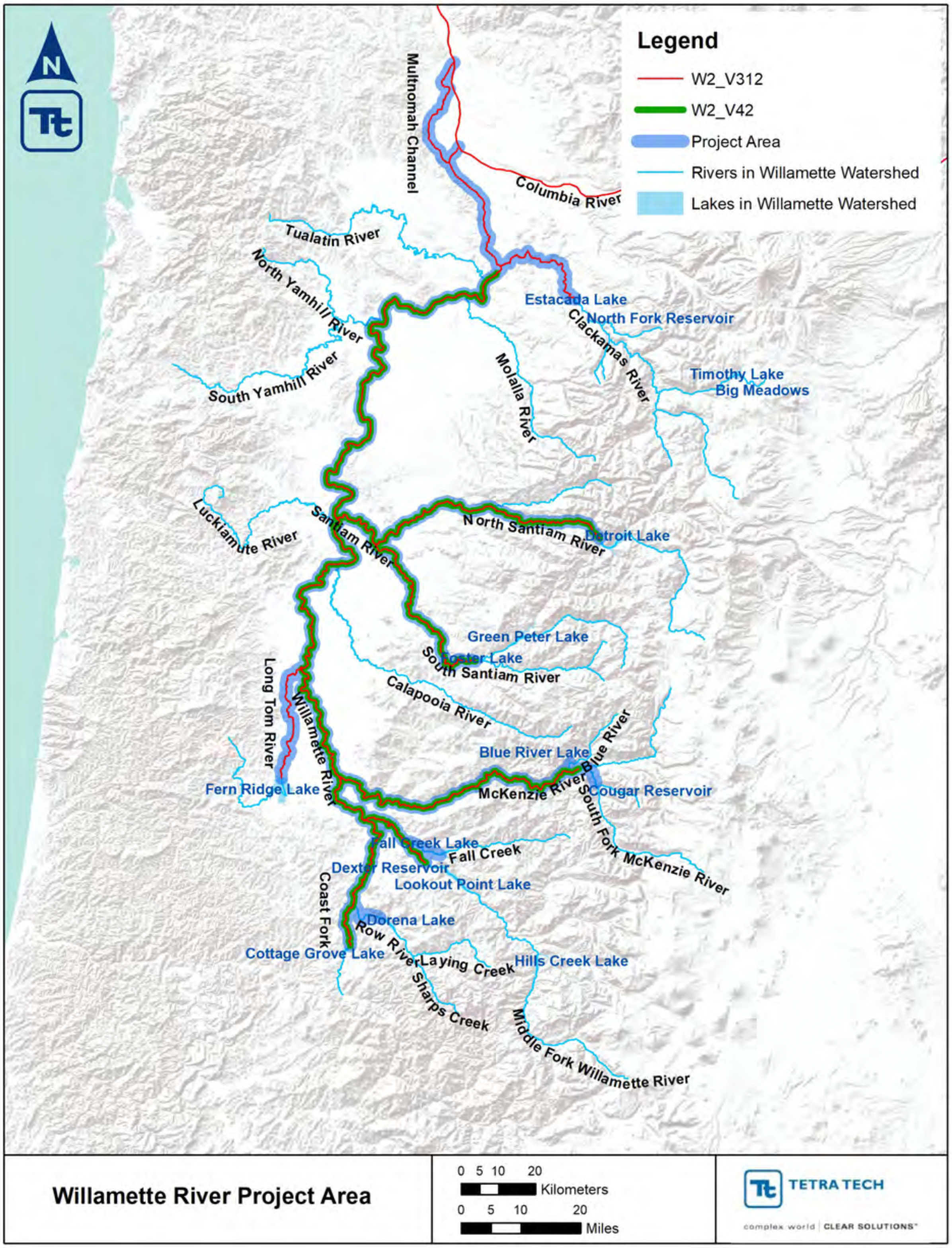

Figure 1-1 Lower Willamette River, Clackamas River, and Long Tom River

2.0 TECHNICAL APPROACH

The modeling framework needs for this project include:

- Prediction of hourly stream temperatures over the summer and spawning use transition period in the fall (approximately May 1 - October 30) in order to evaluate the critical period when stream temperatures most often exceed the applicable temperature criteria.
- Prediction of hourly stream temperatures during low flow periods.
- Ability to evaluate hourly stream temperature response from changes in effluent temperature and effluent flow discharge from NPDES permitted facilities.
- Ability to evaluate hourly stream temperature response from changes in flow and stream temperature at boundary condition tributaries and dams/reservoir operations.
- Ability to model stream temperature and hydrodynamics in stratified, tidal, and well mixed riverine waterbodies.

Due to the number of TMDLs to be replaced and the mandated schedule, EPA and ODEQ requested that Tetra Tech complete the TMDL modeling using previously completed technical work as much as possible. In general, there was no new modeling or new data collection. Updates to the model or technical analysis were only made to characterize major new sources (e.g., new NPDES source), or when a significant change to a source or condition occurred compared to the previous TMDL (e.g., removal of a dam, discontinued discharge by an NPDES source). Details of the technical approach are documented in the Modeling Quality Assurance Project Plan for the Willamette River Mainstem and Major Tributaries Temperature Total Maximum Daily Load (ODEQ 2022).

The updated models retained the estimates of thermal loading/warming from existing sources and source categories if the sources existed at the time the original TMDL was developed.

W2 model version 3.12 was used to model all the project area rivers (except Blue River) for the development of the 2006 Willamette Basin TMDL. The models were calibrated using data collected during model years 2001 and 2002. This set of W2 models was developed for the original temperature TMDL by Portland State University (PSU) (Annear et al. 2004; Berger et al. 2004), the USGS (Sullivan and Rounds 2004), and ODEQ (ODEQ 2006). In 2007, USGS made several improvements to the temperature models (Rounds 2007) and used them to estimate the thermal effects of dams in the Willamette River Basin (Rounds 2010).

Since then, the USGS and U.S. Army Corps of Engineers (USACE) have collaborated to update some of the CEQUAL-W2 models for the USACE's Willamette Valley Project environmental impact statement. The models for the Coast Fork Willamette River, Middle Fork Willamette River, McKenzie River, South Santiam River, North Santiam River, Santiam River, and the Willamette River upstream of Willamette Falls were updated from version 3.12 to W2 version 4.2. The updated USGS models simulate water temperatures from approximately April to November for the years 2011, 2015, and 2016.

Because this series of W2 models already exists and meets all the model framework needs, W2 was selected for stream temperature simulation in the project area. The current TMDL modeling analysis focused on the 2015 calibration year because this model year provided an opportunity to evaluate allocations during critical 7Q10 low flow conditions. Of the three model years, model year 2015 had the most days with flow rates at or below 7Q10; 2011 had no days with flow rates at or below 7Q10; and 2016 had fewer days with flow rates at or below 7Q10 than 2015.

The use of existing models assumes that key calibration assumptions made during the model setup and calibration process by Annear et al. (2004), Berger et al. (2004), ODEQ (2006), and Rounds (2007) are still valid. Configuration and re-calibration of the updated model relied upon many of the same assumptions used to build these models, which are outlined in detail in the Modeling Quality Assurance Project Plan for the Willamette River Mainstem and Major Tributaries Temperature Total Maximum Daily Load (ODEQ 2022.

2.1 W2 VERSION 4.2

W2 is a vertically two-dimensional, longitudinal/vertical, hydrodynamic and water quality model (Cole and Wells 2019). W2 version 4.2 was released in 2019. The model was originally developed by the USACE and is currently maintained by PSU. W2 can simulate water surface elevations, velocities (longitudinal and vertical), temperature, and multiple other water quality constituents including phytoplankton, dissolved oxygen, pH, organic matter, and nutrients in rivers, reservoir, and estuaries with vertically two-dimensional representation.

2.1.1 Model Performance Evaluation Criteria

A combination of visual inspection and model error statistics was used to assess the model performance. Multiple error statistics are available. The mean error (ME), mean absolute error (MAE), root mean square error (RMSE), and the Nash-Sutcliffe efficiency coefficient (NS) are widely used error statistics as measures of the deviation of model results from observed data. Detailed explanations for each of the statistics can be found in the QAPP for this project (ODEQ 2022) and are also provided verbatim below. These model performance measures were calculated as follows:

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

$$ME = \frac{1}{n}\sum(P - O)$$

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

$$MAE = \frac{1}{n}\sum|P - O|$$

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

$$RMSE = \sqrt{\frac{1}{n}\sum(P - O)^2}$$

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

$$NS = 1 - \frac{\sum(P - O)^2}{\sum(O - \bar{O})^2}$$

where

P = model results

O = observed values

$\bar{O}$ = the mean of observed values

n = number of samples

3.0 UPDATE OF THE LOWER WILLAMETTE RIVER MODEL

The Lower Willamette River model is a temperature model developed using W2 version 4.2. The model is the most recent update in a series of W2 models that have been developed since the early 2000s. The original calibrated model used W2 version 3.12 and was developed for the 2006 temperature TMDL (ODEQ 2006) by PSU (Annear et al. 2004; Berger et al. 2004) and ODEQ (ODEQ 2006).

3.1 MODEL DOMAIN

The extent of the model domain is defined by two major waterbodies: (1) The Lower Willamette River from the mouth to Willamette Falls (RM 26.5), including the Willamette Channel and the Multnomah Channel (2) Columbia River from Beaver Army Terminal (Columbia River Mile 53.8) to Bonneville Dam (RM 144.5). The Willamette River enters the Columbia River at Columbia River Miles 87 and 101. Figure 3-1 shows a map of the Lower Willamette River model domain.

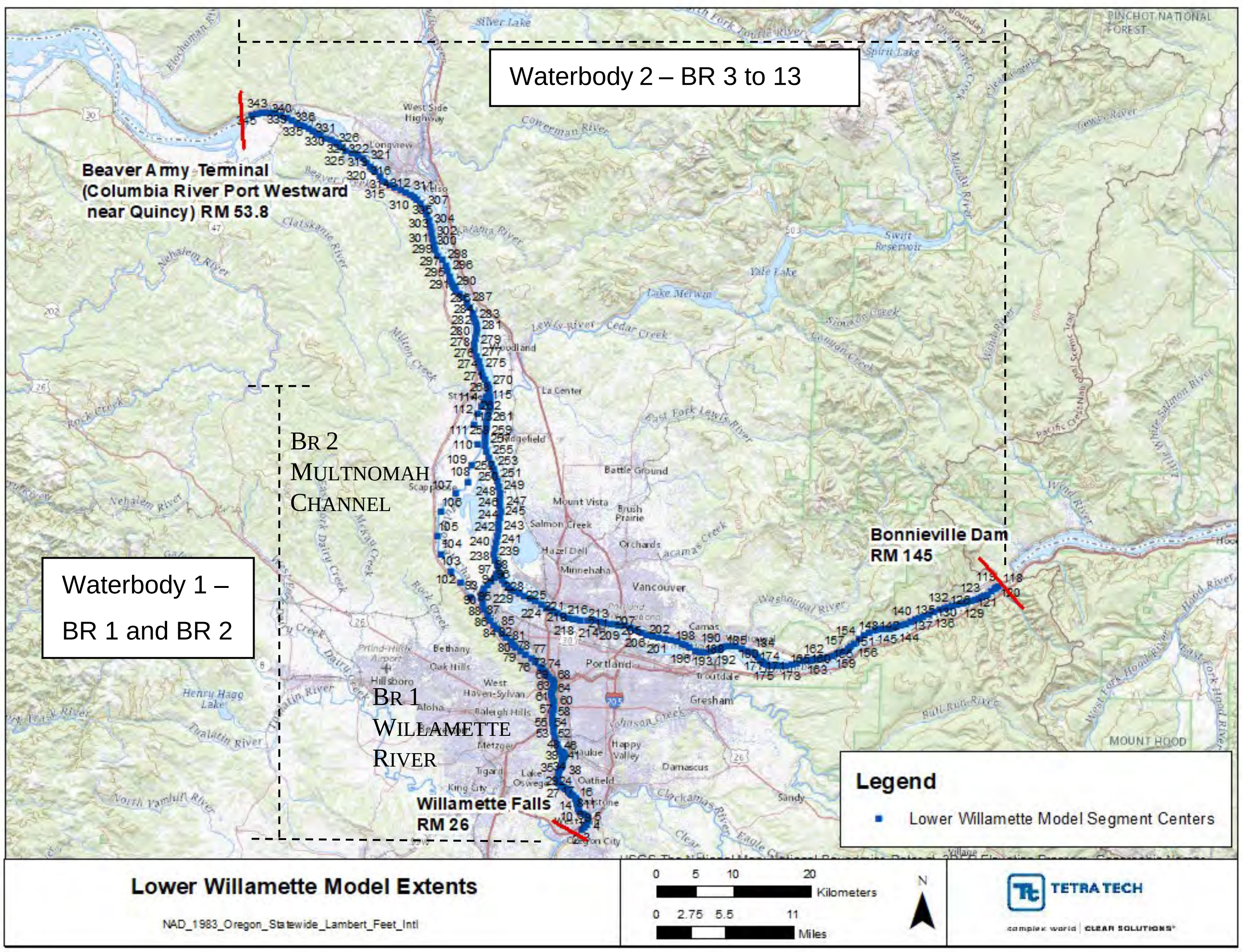

Figure 3-1. Lower Willamette Model Domain

3.2 SPATIAL AND TEMPORAL RESOLUTION

The current model is composed of two W2 waterbodies, with a total of 13 branches. The first water body consists of two branches: the first is the mainstem of the lower Willamette River and the second is Multnomah Channel. The Columbia River represents the second water body with 11 branches i.e., branches 3 through 13. Branch 3 is the main channel of the Columbia River, and the remaining 10 branches are tributary inflow reaches or side channels around islands. Figure 3-1 shows the model branches and segmentation. Note that the side channels around island are not shown in the figure. The model was broken into a total of 461 segments of varying lengths, based on the spacing of the bathymetry data cross sections (Annear et al. 2004). Details of the Lower Willamette River model grid layout specifications can be found in Table 4 of Annear et al. 2004. The model's vertical grid resolution is 2 meters throughout, with a maximum of 28 layers. The model input bathymetry and grid were not updated from the original model used in the 2006 TMDL (ODEQ 2006). Data availability during the years 2015 and 2016 for model configuration were evaluated. The model simulation period was the year 2015. The modeling period was from April 1, 2015, to October 31, 2015.

3.3 MODEL INPUTS

3.3.1 Model upstream and downstream boundary conditions

Model upstream boundary conditions were specified at Beaver Army Terminal (RM 54) on the west and Bonneville Dam (RM 145) on the east along the Columbia River, and at Willamette Falls (RM 26.8) on the Willamette River (Figure 3-1). Flow boundaries were specified for the upstream boundaries at the Willamette River and for the Bonneville Dam outflows, whereas water surface elevations were specified at downstream boundary at the Beaver Army Terminal. Table 3-1 and Figure 3-2 show the stations used to configure the hydrodynamic (flow and water level) and water temperature boundary condition. The following sections describes how each of the data sources were used to configure the model upstream boundary conditions.

Table 3-1. Hydrodynamic and water temperature gage stations used to configure the Lower Willamette River model.

ID	Description	Latitude	Longitude	Source	Type	Notes
14246900	Columbia River At Port Westward, Near Quincy, OR	46.1814	-123.1822	USGS	Water Level	0 feet above NGVD29 [a]; previously named Columbia River at Beaver Army Terminal near Quincy, OR
14144700	Columbia River At Vancouver, WA	45.6208	-122.6722	USGS	Water Level	1.82 feet above NGVD29[a]
14128870	Columbia River Below Bonneville Dam, OR	45.6331	-121.9608	USGS	Water Level	-1 feet above NGVD29 [a]
9440422	Longview, WA	46.1067	-122.955	NOAA	Water Level; Temperature	MLLW [b] datum
BON	Columbia River at Bonneville	45.6442	-121.9406	USACE	Flow	
453630122021400	Columbia River, Left Bank, Near Dodson, OR	45.6083	-121.0372	USGS	Temperature	

ID	Description	Latitude	Longitude	Source	Type	Notes
9439040	Astoria, OR	46.2067	-123.7683	NOAA	Temperature	
14207770	Willamette River Below Falls, at Oregon City, OR	45.3576	-122.6109	USGS	Water Level	
14207740	Willamette River Above Falls, at Oregon City, OR	45.3485	-122.6201	USGS	Water Level	

a: NGVD29 refers to the National Geodetic Vertical Datum of 1929

b: MLLW refers to the Mean Lower Low Water Datum

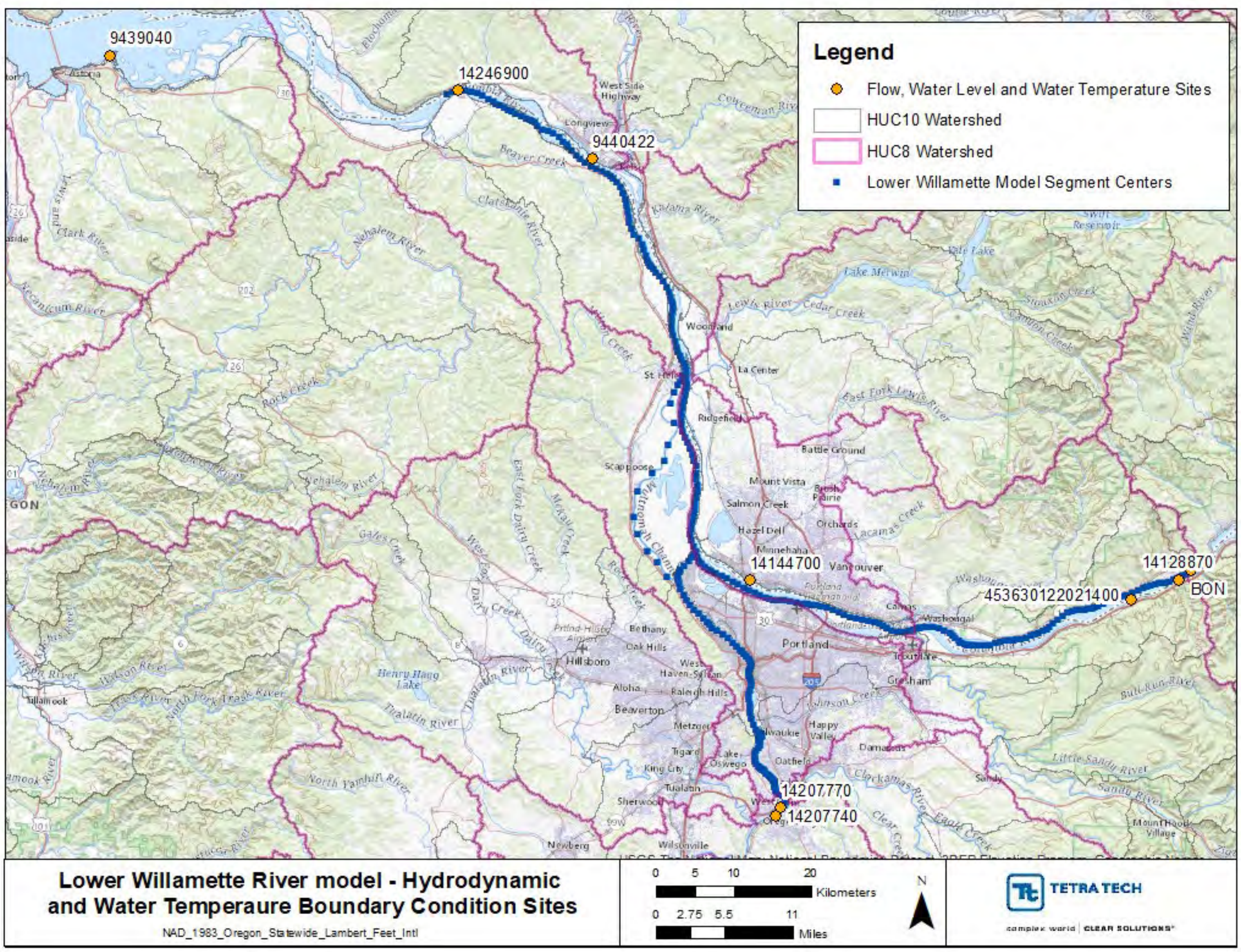

Figure 3-2. Monitoring stations for deriving boundary conditions in the Lower Willamette River Model

Flow Data

Hourly flows for Bonneville Dam were obtained from the USACE website (https://www.nwd-wc.usace.army.mil/dd/common/dataquery/www/?k=bonneville) by querying for the station Bonneville Lock and Dam (BON) for outflow. Figure 3-3 shows the hourly flow time series data specified for Bonneville Dam in the model.

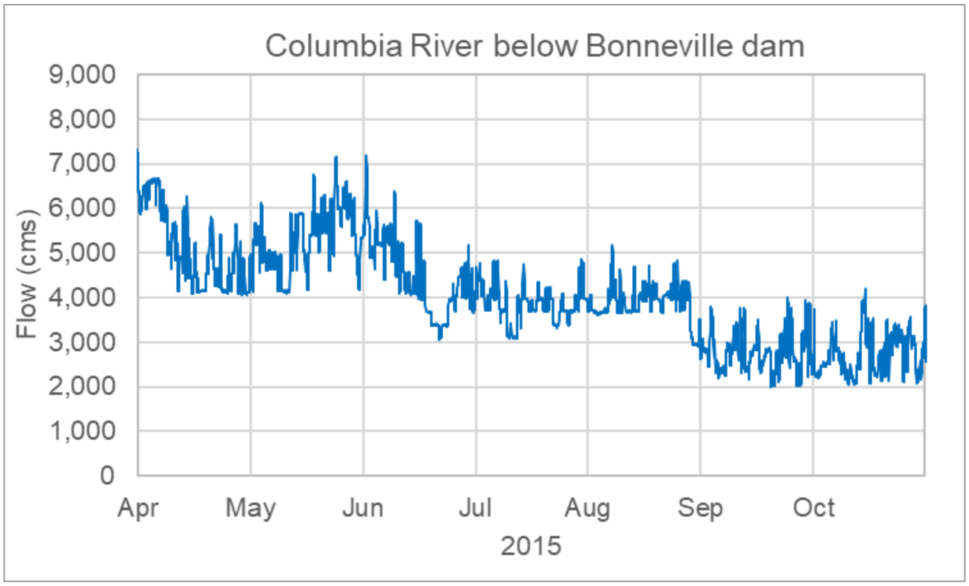

Figure 3-3. Columbia River flow below Bonneville Dam

For the upstream flow boundary condition for the Lower Willamette River near the Willamette Falls, the outflow from the Middle Willamette River model was used. Two USGS gages (USGS 14207740 and 14207770) are located upstream and downstream of the Willamette Falls. However, only water level data were available for the year 2015 at these two stations. Further, the PSU report (Annear et al. 2004) notes that “although there are USGS gages station monitoring stage above (USGS 14207740) and below (USGS 14207770) the Willamette Falls, the gage above the falls is not always accurate”. Therefore, the modeled flow from USGS’s Middle Willamette W2 model were used as the input to the Lower Willamette Model. Figure 3-4 shows the model flows used for characterizing the Willamette River upstream flow boundary condition.

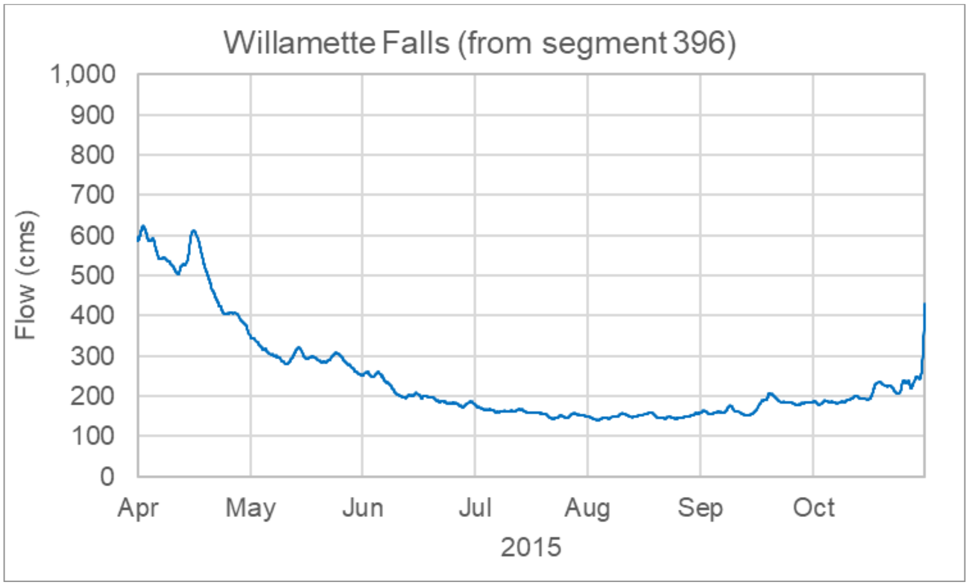

Figure 3-4. Willamette River flows at Willamette Falls (from segment 396 of the Middle Willamette River W2 model.

Water Level Data

Water level data from the Columbia River at Beaver Army Terminal station - USGS 14246900 (now called Columbia River at Port Westward, Near Quincy, OR) were used as the downstream boundary water level. Water level data at this station were available at 15-minute frequency from October 2015 onwards. Therefore, water levels prior to October 2015 were estimated. The correlation developed by Rodriguez, et al. (2001) presented in Annear et al. (2004) was used to fill the gap from January through September. The correlation was developed among the Beaver Army Terminal site, the Vancouver, WA site (USGS 14144700), the Longview, WA site (NOAA 9440422), Columbia River below the Bonneville Dam (USGS 14128870), and the tidal influence on the Columbia River (R^2 =0.83). The tidal influence on the Columbia River represents the sinusoidal frequency of the tidal peaks that are a function of hourly, daily, monthly, and annual cycles. The relationship, presented in Annear et al. (2004), is shown below for reference.

$$BeaverArmyTerminal_{WL_{Elev_m}} = 0.0143 \cdot Hourly + 0.0109 \cdot Daily - 0.0062 \cdot Monthly + 0.0054 \cdot Annually - 0.2922 \cdot Vancouver_{WL_{Elev_m}} + 1.1156 \cdot Longview_{WL_{Elev_m}} + 0.0389 \cdot Bonneville_{WL_{Elev_m}} - 0{,}1942$$

Where:

Hourly is the tidal influence from 12.4 hour tidal cycle estimated as: $\text{Hourly} = \sin\left(\frac{2\pi \cdot JulianDay}{12.4hours/24hours}\right)$

Daily is the daily tidal cycle estimated as: $\text{Daily} = \sin(2\pi \cdot JulianDay)$

Monthly is the monthly tidal cycle estimated as: $\text{Monthly} = \sin\left(\frac{2\pi \cdot JulianDay}{30days}\right)$

Annual is the annual tidal cycle estimated as: $\text{Annual} = \sin\left(\frac{2\pi \cdot JulianDay}{365days}\right)$

The gages used in the development of Beaver Army water level boundary are listed in Table 3-1. The water levels are based on varying datum, and water levels using different datums may have different values. To use the water levels in the model, all the water level data needed to be in the same datum. In the current model, all the water levels use NGVD29 as the datum. All water level data were first converted from their station datum to National Geodetic Vertical Datum of 1929 (NGVD29) and then converted to meters to be used in the development of the model boundary conditions. USGS provides datum information in site descriptions and such information was used to convert USGS level data to NGVD29. NOAA does not directly provide the water level with datum as NGVD29, and it does not provide a conversion from the provided water levels to water levels with datum as NGVD29. However, NOAA provides the difference between mean lower low water (MLLW) to the local Columbia River Datum (CRD). A USGS report (Boudreau et al. 2021) provides conversions of water level from CRD to North American Vertical Datum of 1988 (NAVD88) and from NGVD29 to NAVD88 for NOAA 9440422 at Longview, WA. Using the conversions from CRD to NGVD29 and the information on the difference between MLLW and CRD at NOAA 9440422, the water levels as MLLW at this gage were converted to NGVD29 by adding 0.6 meters (1.97 feet). Figure 3-5 shows the calculated Beaver Army Terminal water surface elevations compared with the observed water surface elevation for which observed data were available (October through December 2015). The calculated water surface elevations were in general under predicted and had a smaller amplitude compared to what was observed at the USGS station. The calculated water surface elevation had an R^2 value of 0.91 (Figure 3-6) and an MAE of 0.18 meters.

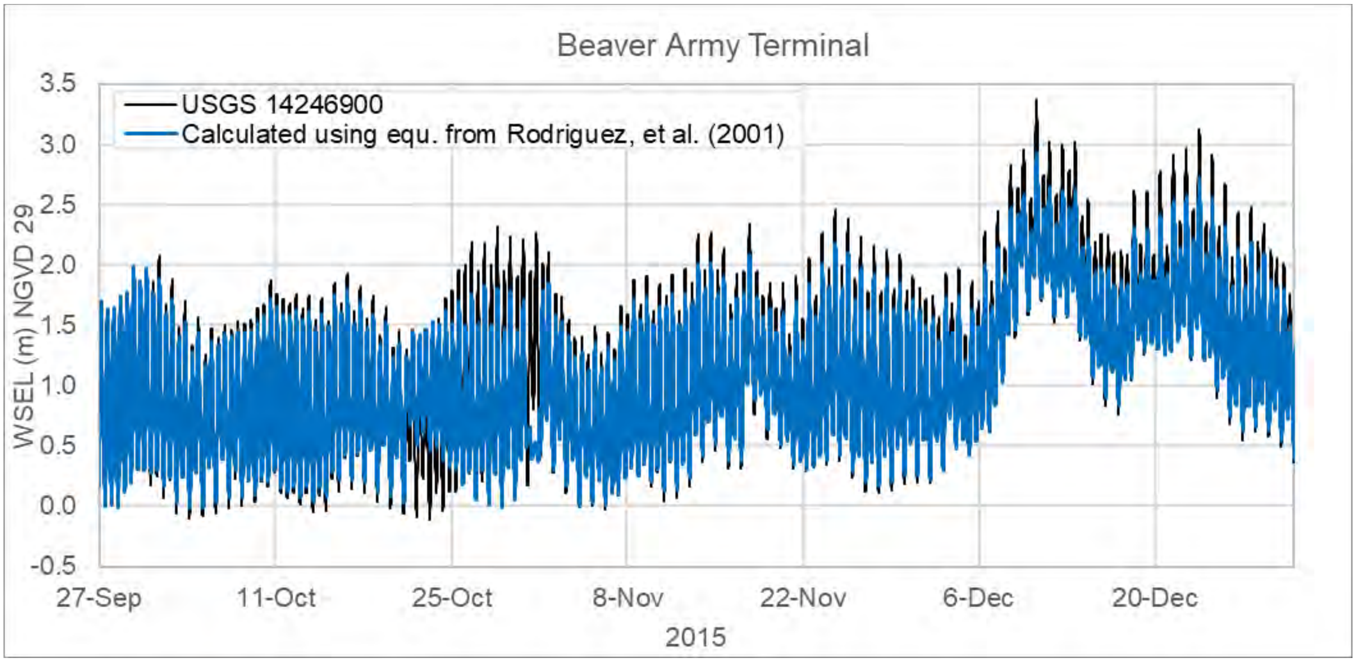

Figure 3-5. Comparison of calculated and observed USGS water surface elevation data at Beaver Army Terminal

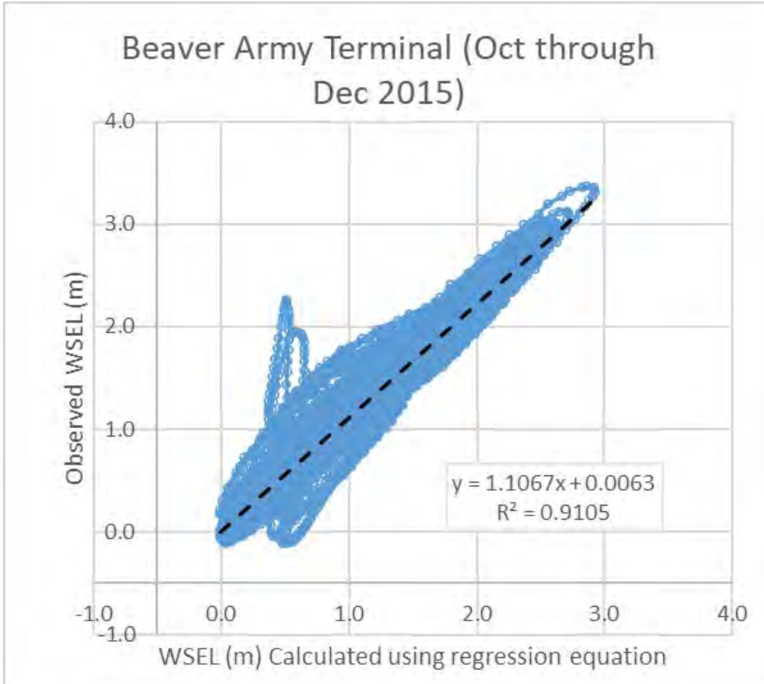

Figure 3-6. Correlation between observed and predicted WSEL at Beaver Army Terminal.

Figure 3-7 shows the water level specified in the model for Beaver Army Terminal which is comprised of the calculated water levels for January through September 2015 and the observed USGS water levels at this station for the remaining part of 2015 from October through December.

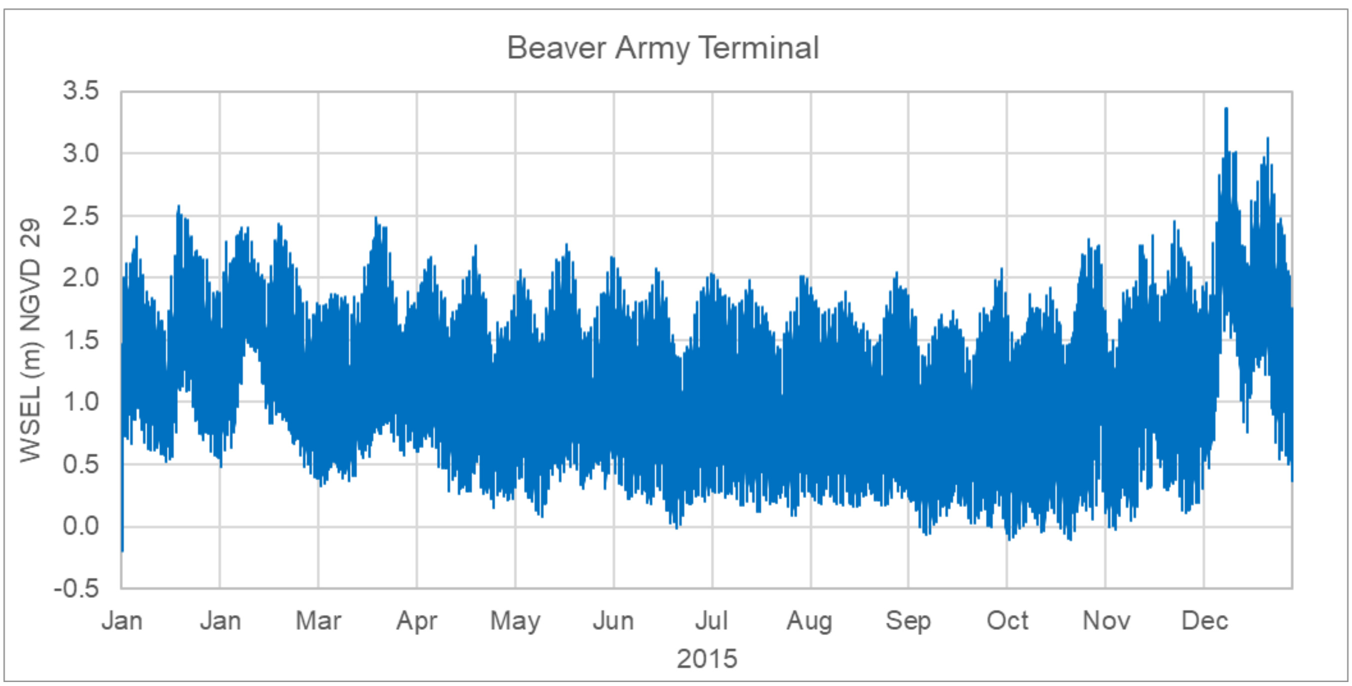

Figure 3-7. Columbia River water surface elevation at Beaver Army Terminal.

Water Temperature Data

Water temperature at Columbia River at Port Westward, near Quincy, OR (USGS14246900) ends on September 30, 2003. This station was previously used to configure the downstream boundary for the Columbia River at Beaver Terminal. The data gap was filled using regression with a nearby station. Candidate stations downstream (Astoria, OR) and upstream (Longview, WA) of the Beaver Army Terminal were considered for use to configure the model for the year 2015. The NOAA station Astoria, OR (NOAA 9439040) is located approximately 35 miles downstream of Beaver Terminal and as of December 31, 2022 had long-term hourly data from November 4, 1993 to the present. The Longview, WA station (NOAA 9440422) is located approximately 12 miles upstream of Beaver Terminal and as of December 31, 2022 had hourly data for the period from June 3, 2005, to July 24, 2014, and from October 16, 2015 to the present. While the Longview station is in closer proximity than the Astoria station, it could not be used since it has a gap during 2015, which would need to be filled (potentially using the Astoria station). For this reason, the Astoria station was used.

The existing model developed for the years 2001 and 2002 used observed water temperature data (available at approximately every two hours) at the Beaver Army Terminal to configure the downstream boundary condition. The water temperature data were extracted, and a regression was developed with temperature data at Astoria, WA for the period from 2001 to 2002 (Figure 3-8). The same relationship was used to recreate the temperature boundary condition for 2015, using the Astoria station. Figure 3-9 shows the estimated water temperatures used to characterize the water temperature boundary condition at Beaver Army Terminal.

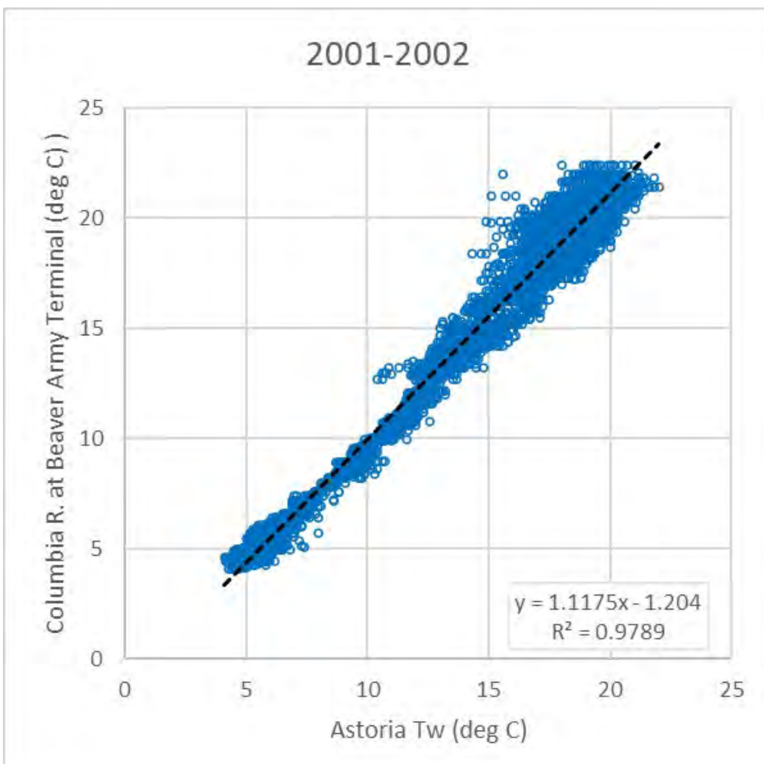

Figure 3-8. Columbia R. at Beaver Army Terminal water temperature correlation using Astoria data (2001-2002)

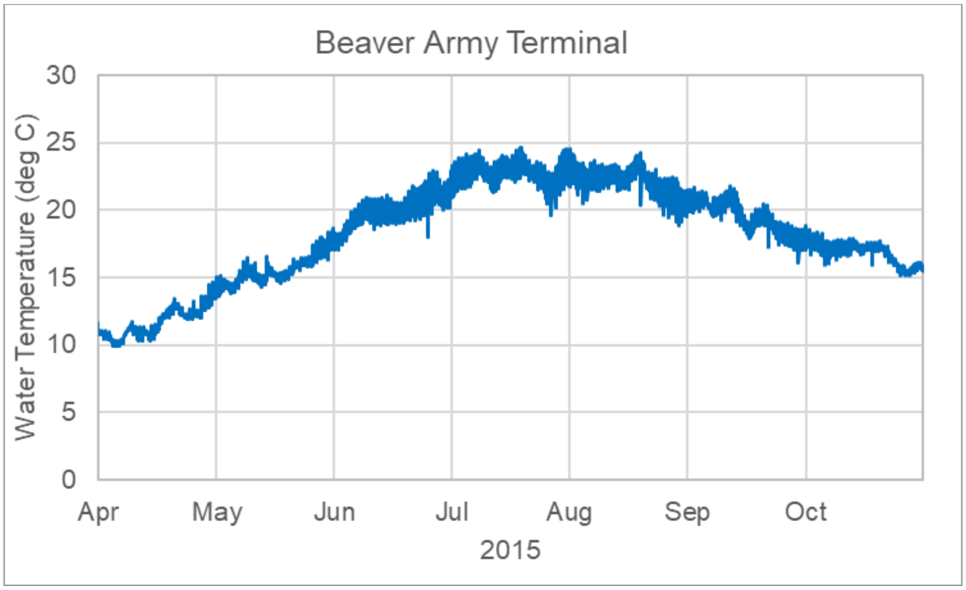

Figure 3-9. Beaver Army Terminal 2015 estimated water temperatures

The water temperature in the flow from Bonneville Dam was characterized using hourly water temperature data from USGS station 453630122021400 near the left bank in the Columbia River near Dodson, OR. Figure 3-10Figure 3-9 shows the observed water temperatures used to characterize the water temperature boundary condition at Bonneville Dam.

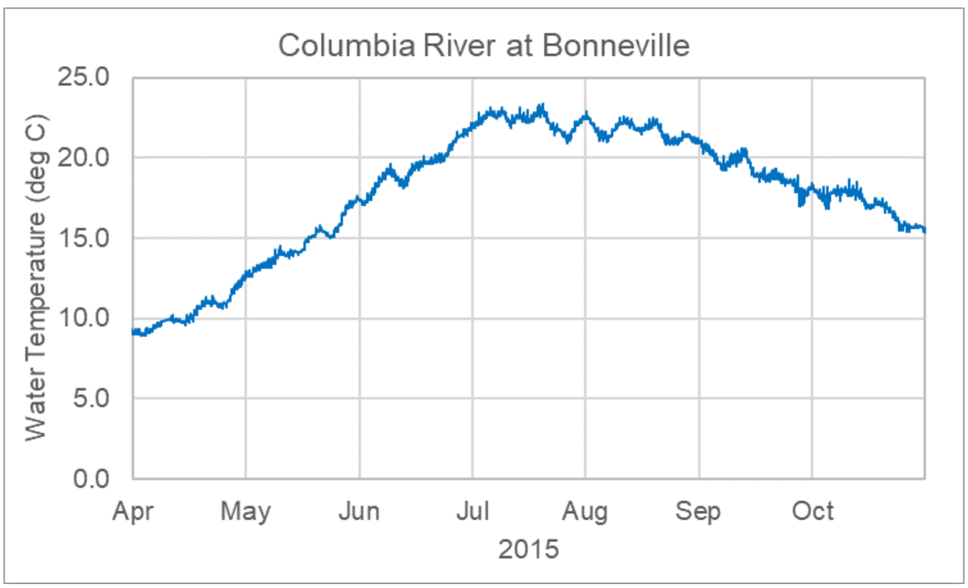

Figure 3-10. Observed water temperature at USGS 453630122021400 – Columbia R. Near Dodson

Similar to the flow, the water temperature from the Middle Willamette River to the Lower Willamette River was from USGS's Middle Willamette River W2 model. Water temperature data from segment 396 of the W2 model were used to characterize the upstream temperature boundary for the Lower Willamette River Figure 3-11Figure 3-9 shows the Middle Willamette Model water temperature results for the Middle Willamette River.

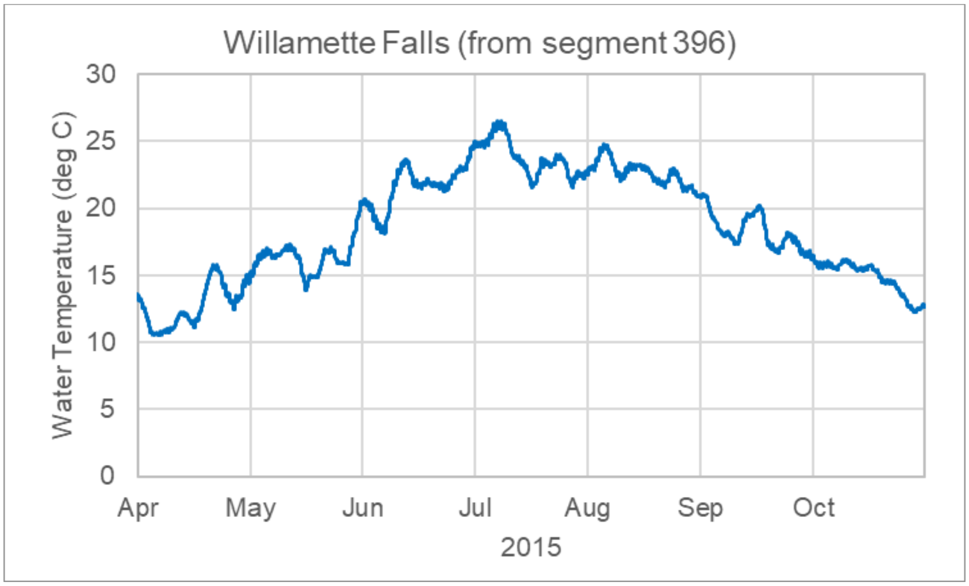

Figure 3-11. Willamette River temperatures at Willamette Falls (from segment 396 of the Middle Willamette River W2 model).

3.3.2 Tributary boundary conditions

The Lower Willamette River model is comprised of 26.8 miles of the Lower Willamette River and 90.7 miles of the Columbia River, with nine tributaries directly entering the two rivers. Three of the nine tributaries, the Clackamas River, Johnson Creek, and the Columbia Slough discharge to the Lower Willamette River. The remaining five major tributaries discharging to the Columbia River are Washougal River, Sandy River, Lewis River, Kalama River, Cowlitz River, and Grays-Elokoman River basin flow. The tributary inflows were characterized by both flow and temperature. Data were available from USGS, Washington Department of Ecology (WDOE), ODEQ, and the City of Portland. There were some smaller basins along the Columbia and Willamette Rivers where no flow data were recorded, nor were historical values available. Flow contributions from the smaller basins were determined to be negligible, i.e., about 0.37% of the entire drainage area (Annear et al. 2004) and were not incorporated into the model as distributed flow. Table 3-2 and Figure 3-12 show the stations used to configure the flow and water temperature tributary boundary conditions. The following sections describe how each of the data sources were used to configure the model tributary boundary conditions.

Table 3-2 Lower Willamette River model tributary flow and water temperature gage stations

ID	Description	Latitude	Longitude	Type	RM	Model Segment	Source
14222500	East Fork Lewis River Near Heisson, WA	45.8370	-122.465	Flow	NA	NA	USGS
14220500	Lewis River At Ariel, WA	45.9519	-122.563	Flow	87.2	265	USGS
14221500	Cedar Creek near Ariel, WA	45.9317	-122.528	Flow	NA	NA	WADOE/USGS
14223000	Kalama River Near Kalama, WA	46.0172	-122.731	Flow	73	301	WADOE/USGS
14243000	Cowlitz River At Castle Rock, WA	46.275	-122.913	Flow	67.33	428	USGS

ID	Description	Latitude	Longitude	Type	RM	Model Segment	Source
14243500	Delameter Creek Near Castle Rock, WA	46.2636	-122.913	Flow	NA	NA	WADOE/USGS
14245000	Coweman River Near Kelso, WA	46.1283	-122.837	Flow	NA	NA	WADOE/USGS
14142500	Sandy River Below Bull Run River, Near Bull Run, OR	46.4492	-122.244	Flow	120.25	192	USGS
14211550	Johnson Creek at Milwaukie, OR	45.4531	-122.642	Flow, Temperature	18.5	49	USGS
14211010	Clackamas River near Oregon City, OR	45.3794	-122.576	Flow, Temperature	24.85	7	USGS
14211820	Columbia Slough At Portland, OR	45.6392	-122.762	Flow	1	96	USGS
14246500	Mill Creek near Cathlamet, WA	46.1944	-123.19	Flow	NA	NA	WADOE/USGS
14246000	Abernathy Creek near Longview, WA	46.2028	-123.154	Flow	NA	NA	WADOE/USGS
14143500	Washougal River Near Washougal, WA	45.6233	-122.296	Flow	120.75	191	USGS
14144000	Little Washougal River Near Washougal, WA	45.6142	-122.357	Flow	NA	NA	USGS
27D090	East Fork Lewis River Near Dollar Corner	45.8146	-122.592	Temperature	87.2	265	WADOE
27B070	Kalama River Near Kalama	46.0476	-122.838	Temperature	73	301	WADOE
26B070	Cowlitz River At Kelso	46.1454	-122.914	Temperature	67.33	428	WADOE
PWB_SR_US_BR	Sandy River approximately 1,900 ft upstream of Bull Run River confluence	45.4444	-122.254	Temperature	120.25	192	City of Portland WB
10674-ORDEQ	Sandy River at Troutdale Bridge	45.5385	-122.377	Temperature	120.25	192	ODEQ

ID	Description	Latitude	Longitude	Type	RM	Model Segment	Source
14211550	Johnson Creek at Milwaukie, OR	45.4531	-122.642	Flow, Temperature	18.5	49	USGS
14211010	Clackamas River near Oregon City, OR	45.3794	-122.576	Flow, Temperature	24.85	7	USGS
VNB	N Vancouver St Bridge (Main Channel - Columbia Slough)	45.585	-122.668	Temperature	1	96	City of Portland WB
CRU	Columbia River upstream of outfall 001	45.6213	-122.689	Temperature	106.5	225	City of Portland WB

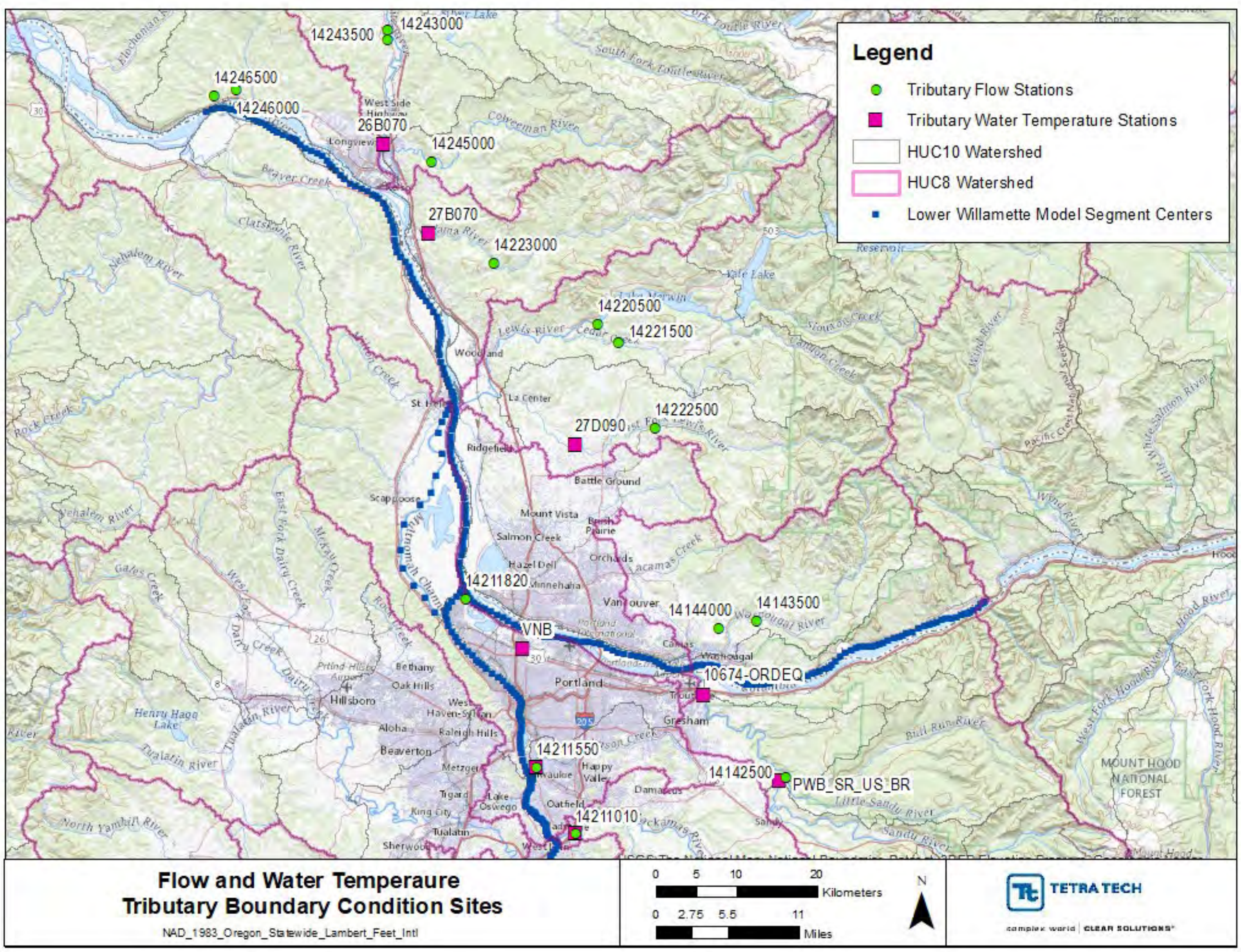

Figure 3-12. Flow and water temperature stations for deriving the tributary boundary conditions

Flow data

The Clackamas River flows into the Willamette River and was characterized by the USGS gage station near Oregon City (USGS 14142500). Flow measurements were recorded every 15-minutes, and there were no data gaps in the 2015 data record. Figure 3-13 shows the Clackamas River flows. Flows during summer in the Clackamas River ranged from 15.00 to 30.00 m^3/s during 2015.

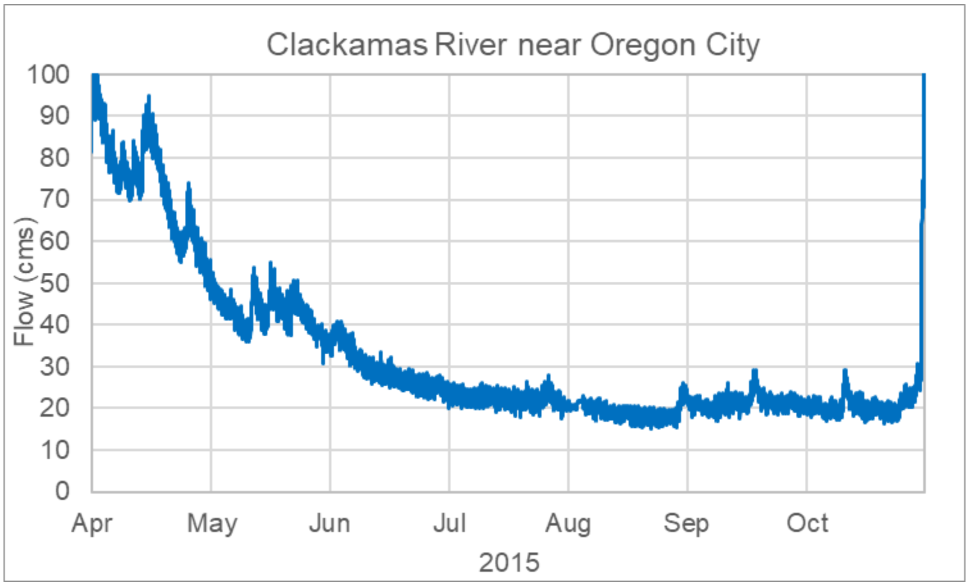

Figure 3-13. Observed flow at Clackamas River near Oregon City, OR USGS 14211010

Johnson Creek flows into the Willamette River. Flow measurements for Johnson Creek were obtained from the USGS gage at Milwaukie, OR (USGS 14211820). Figure 3-14 shows the flow data for Johnson Creek with a typical seasonal pattern seen in the observed flows, e.g., higher spring and fall flows and lower flows during summer. Average summer flows were around 0.35 m^3/s, with occasional peaks to around 2.00 m^3/s. Overall, Johnson Creek flows were much lower than other tributaries in the system.

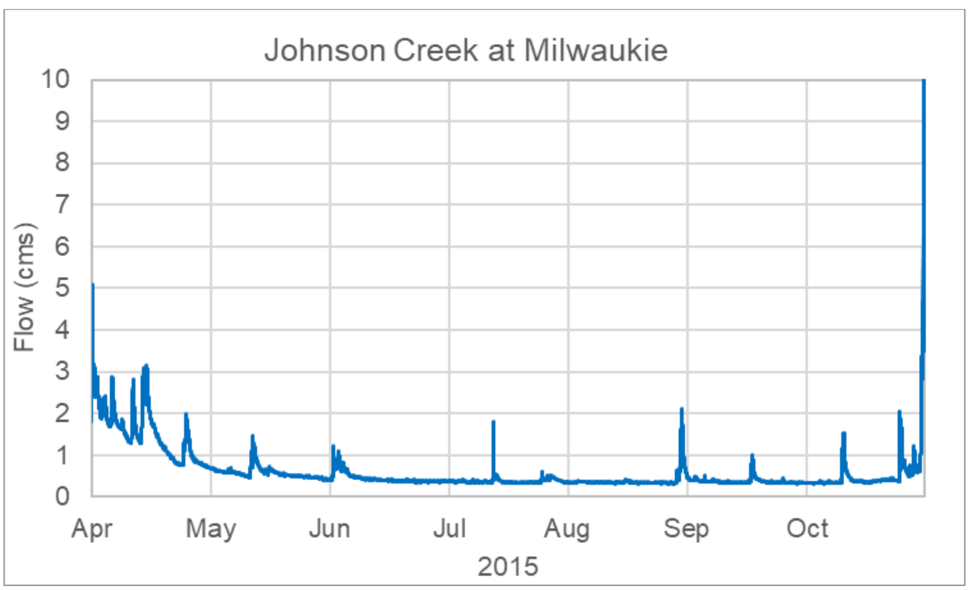

Figure 3-14. Observed flow at Johnson Creek at Milwaukie, OR USGS 14211820

The Columbia Slough flows into the Willamette River, and flow data were obtained from the USGS gage station at the Lombard St Bridge (USGS 14211820). Flow measurements at this station were recorded at a 15-minute frequency, and there were no gaps in the 2015 data. The flows at this station are tidal, with an average flow of 3.15 m^3/s recorded at this gage during 2015. Figure 3-15 shows the flows at the Columbia Slough station.

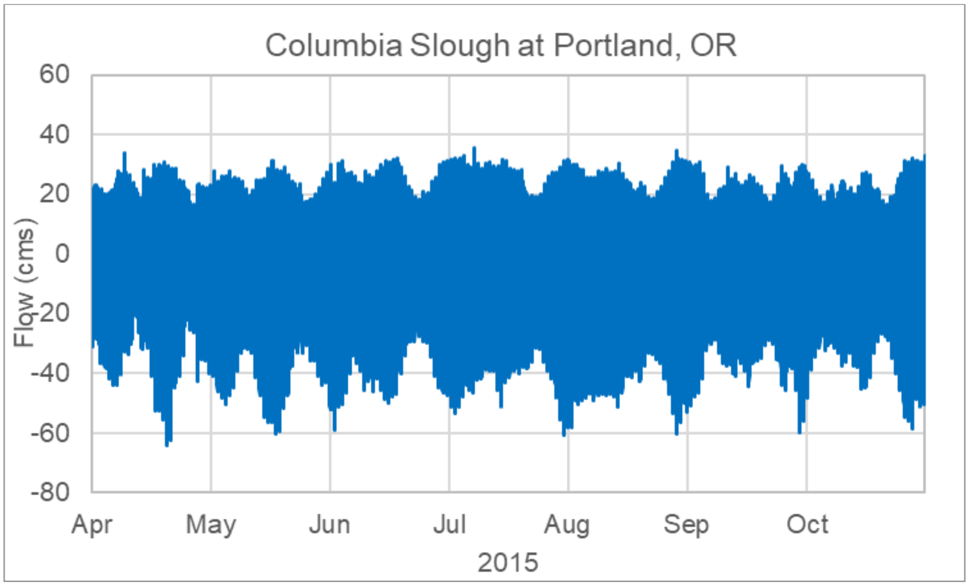

Figure 3-15. Flow at Columbia Slough at Portland, OR near mouth (USGS 14211820)

The Sandy River flow flows into the Columbia River, and the flows from the Sandy River were characterized using the USGS gage station located below the confluence with the Bull Run River near Bull Run (USGS 14142500). Flow measurements were recorded every half-hour, and there were no data gaps in the 2015 data record. Figure 3-16 shows the Sandy flow for the summer of 2015 indicating a drop in flow from spring to summer, with average summer flows around 11.00 m^3/s going into the Columbia River.

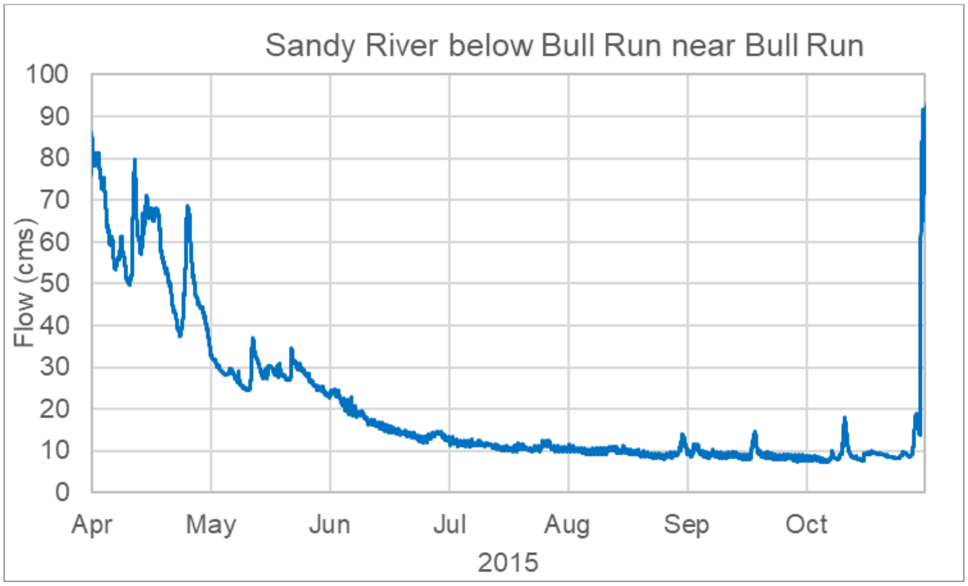

Figure 3-16. Observed flow at Sandy River below Bull Run near Bull Run, OR USGS 14142500

Flow data were not available for five tributaries - Kalama River, Cowlitz River, Lewis River, and Grays-Elokoman basin flow during 2015. All these tributaries are in the State of Washington and feed into the Columbia River. This data gap was also identified in the development of the 2001/2002 model where the base flow data from WDOE (Sinclair and Pitz 1999) were used to fill the gaps in conjunction with continuous flow data that was available at each of the tributaries.

WDOE conducted a study to characterize base flows for rivers and streams in Washington (Sinclair and Pitz 1999). WDOE estimated monthly base flows at several stations along these tributaries, and these were used to develop input flows for the 2001/2002 model. The same approach used for the 2001/2002 model was also used during the development of the current 2015 model since no flow data were available for these stations. Details of the flow time series is outlined in detail in the PSU report (Annear et al. 2004). A brief description of the approach is also summarized below for completeness.

The Grays-Elokoman Basin flows to the Columbia River were characterized using the sum of the monthly averaged base flows from Abernathy Creek near Longview (USGS 14246000) and Mill Creek near Cathlamet (USGS 14246500) estimated by WDOE (Sinclair and Pitz 1999). Figure 3-17 shows the monthly flows for the Grays-Elokoman basin.

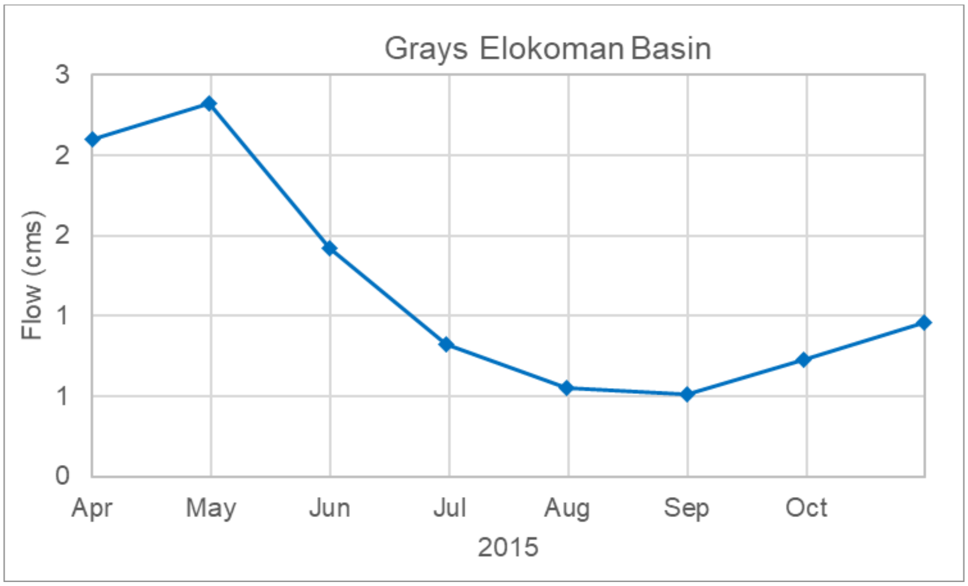

Figure 3-17. Grays-Elokoman Basin flows specified in the model for 2015

The Cowlitz River flows were taken as the sum of the continuous flow measurements from Cowlitz River at Castle Rock (USGS 14243000) and contributions from two small tributaries (Delameter Creek and Coweman River) that feed into the Cowlitz River below this gage just before the Cowlitz River goes into the Columbia River. The Cowlitz River at Castle Rock flows were available for 2015 at a 15-minute frequency interval. The flow data for Delameter Creek (USGS 14243500) and Coweman River (USGS 14245000) were monthly average baseflow measurements from WDOE (Sinclair and Pitz 1999). Figure 3-18 shows the total Cowlitz River flow timeseries specified in the model for 2015.

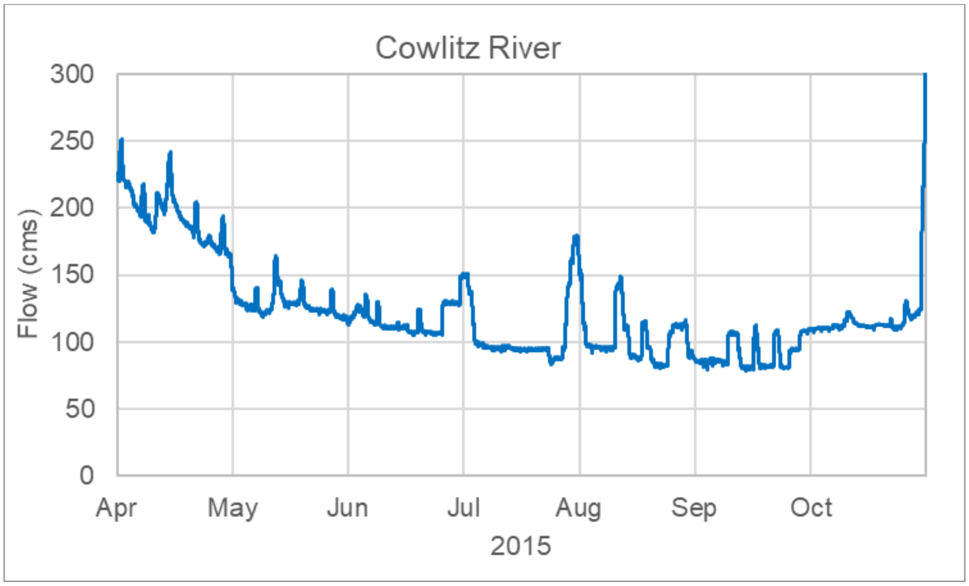

Figure 3-18. Cowlitz River flows specified in the model for 2015

The Kalama River flows to the Columbia River were characterized using monthly averaged base flows estimated from WDOE (Sinclair and Pitz 1999) at the Kalama River near Kalama gage (USGS 14223500). Figure 3-19 shows the monthly flows for Kalama River.

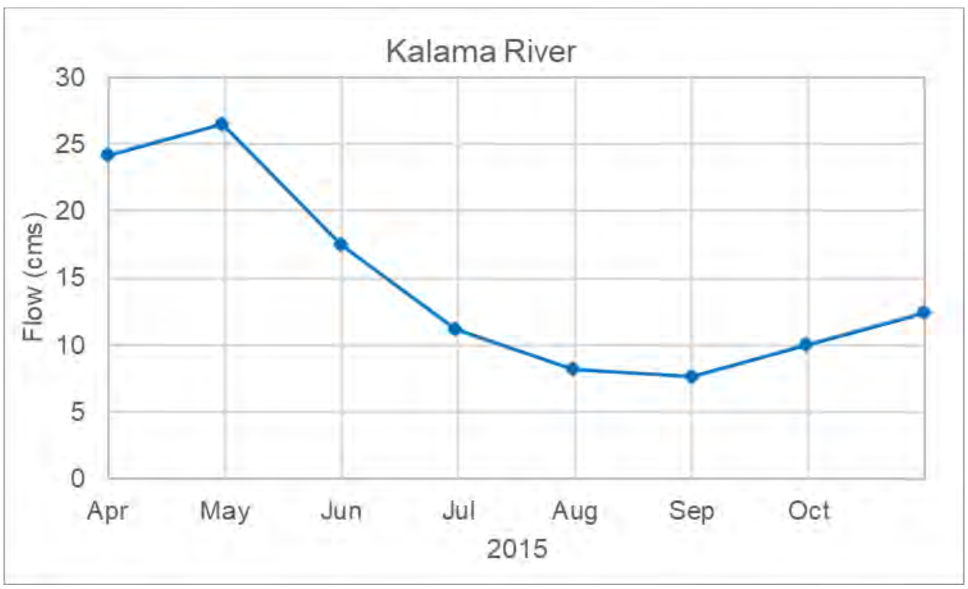

Figure 3-19. Kalama River flows specified in the model for 2015

The Lewis River flows were taken as the sum of the Lewis River at Ariel (USGS 14220500) and the flow from the East Fork at Heisson (USGS 14222500). Continuous flow data were available for 2015 at both these gages at a 15-minute frequency interval. Additionally monthly flows from Cedar Creek near Ariel (USGS 14221500) from WDOE (Sinclair and Pitz 1999) were added to the total Lewis Creek and East Fork flows to make up the total flow contributions from Lewis River to the Columbia River. Figure 3-20 shows the Lewis River flow timeseries.

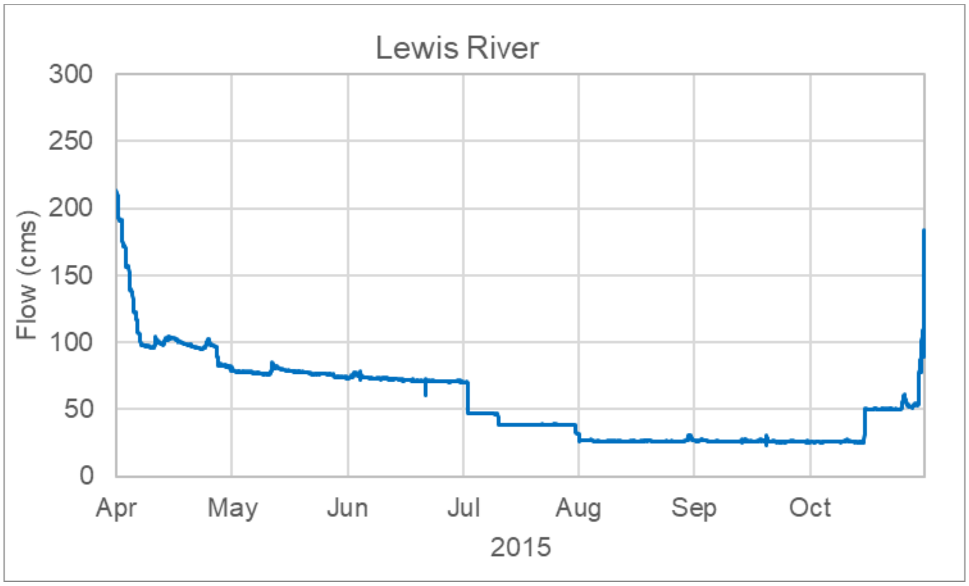

Figure 3-20 Lewis River flows specified in the model for 2015

The Washougal River flows were taken as the sum of the flows from Washougal River (USGS 14143500) and Little Washougal River (USGS 14143500), which is a tributary to the Washougal River. Flow data were not available for either of these stations in 2015. Flows at both these stations were derived by using regression relationships developed previously for both these stations. The regression relationships were established using the USGS gage 14222500 – East Fork Lewis River. The East Fork Lewis River gage was chosen based on proximity of the Lewis River basin to the Washougal River basin and its long-term period of record. The Washougal River flow correlation developed with the East Fork of Lewis River was $Y = 1.2928\ X^{0.9731}$, and the Little Washougal River flow correlation with the East Fork of Lewis River was $Y = 0.1495\ X^{0.9635}$. Details of the correlations can be found in the PSU report (Annear et al. 2004). Figure 3-21 shows the calculated total flows for Washougal River used in the model for 2015.

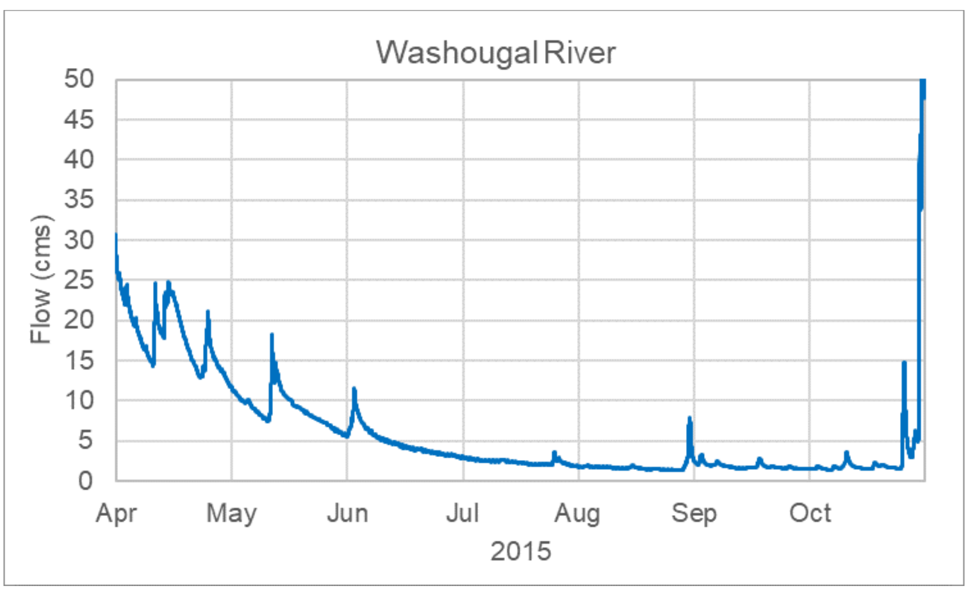

Figure 3-21. Washougal River flows specified in the model for 2015.

Flow contributions from smaller basins in the model were negligible and were not configured in the model. The distributed tributary option within W2 was turned off as there was no direct drainage from smaller tributaries considered. This assumption is consistent with the 2001/2002 model. The PSU report (Annear et al. 2004) notes that "the total drainage area not considered in the model was about 0.34% of the entire watershed drainage and hence not considered in the model as it was relatively small".

Water temperature data

Clackamas River temperature measurements were also monitored at the same USGS gage that monitored flow (USGS 14211010). Water temperatures were measured at a 15-minute frequency interval. Figure 3-22 shows a time series plot of the observed temperatures at the USGS 14211010 gage station for Clackamas River.

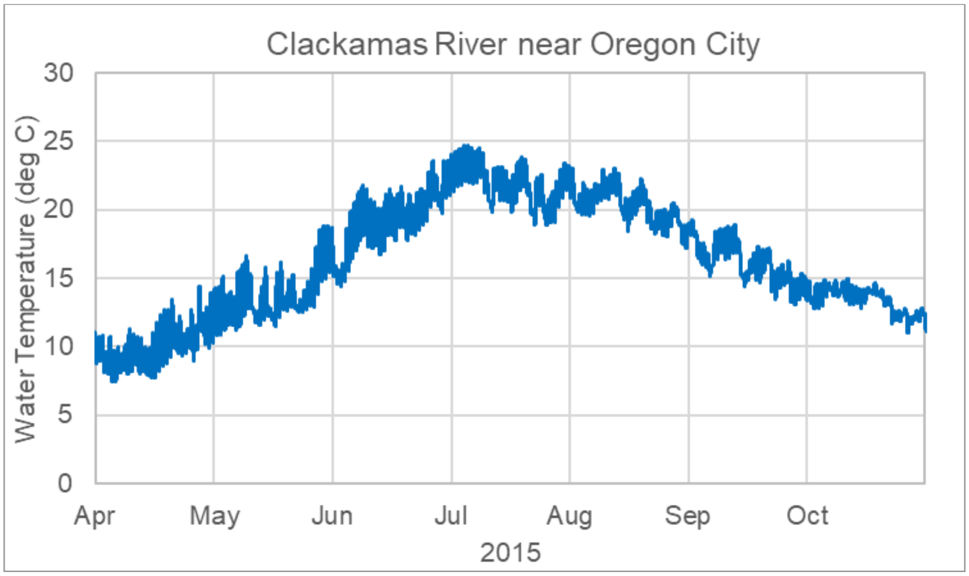

Figure 3-22. Clackamas River water temperature

Johnson Creek temperature measurements were also monitored at the same USGS gage that monitored flow (USGS 14211550). Water temperatures were measured at a 15-minute frequency interval. Figure 3-23 shows a time series plot of the temperatures monitored at the USGS 14211550 gage station for Johnson Creek.

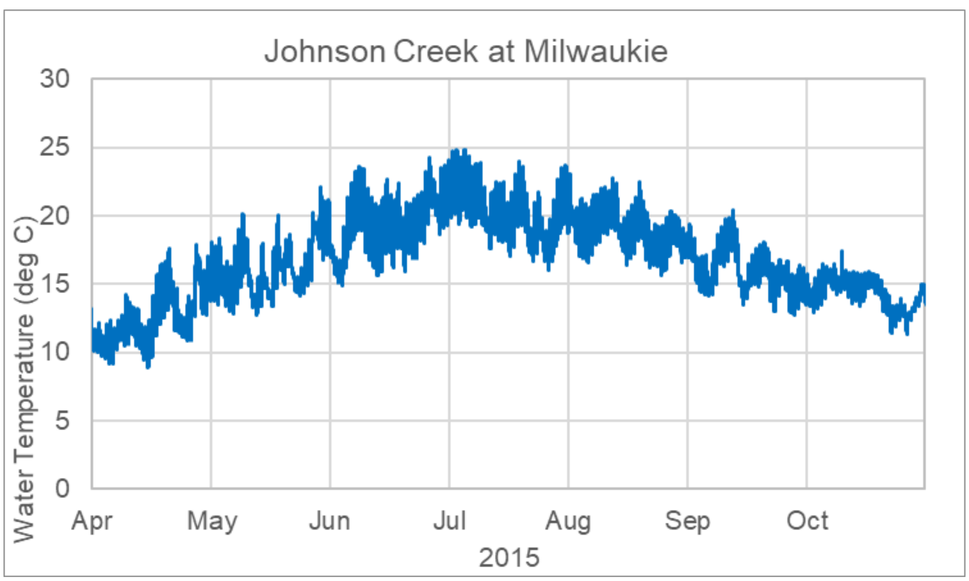

Figure 3-23. Johnson Creek water temperature

The water temperature data for the Columbia Slough during 2001/2002 was characterized using hourly data from two monitoring instruments by ODEQ at the same location: St. John's Landfill Bridge ODEQ-11201 and Metro Regional Govt (SJB). Data collected by the City of Portland from station VNB which is the North Vancouver St. Bridge (Main Channel – Columbia Slough) was used to configure the water temperature for the Columbia Slough for 2015. The VNB station has long-term observed data from 2005 to current, available at a 15-minute frequency. However, data at the VNB station was only available for a few months during the year 2015 and was not available from May through October during 2015. Available data from the VNB station were regressed with the observed data from the St. John's Landfill site that was used in the 2001/2002 model. The year 2001 from the St. John's Landfill site showed a stronger relationship with an R^2 value of 0.72 compared to the regression with the year 2002 data, which had an R^2 value of 0.55. Therefore, the 2001 regression relationship was used to fill gaps in the observed data at VNB. Figure 3-24 shows the regression relationship between the 2001 St. John's Landfill Bridge site and North Vancouver St. Bridge site. The relationship was used to calculate water temperature and fill in the gaps in the VNB data. Figure 3-25 shows the composite temperature time series created for the Columbia Slough tributary.

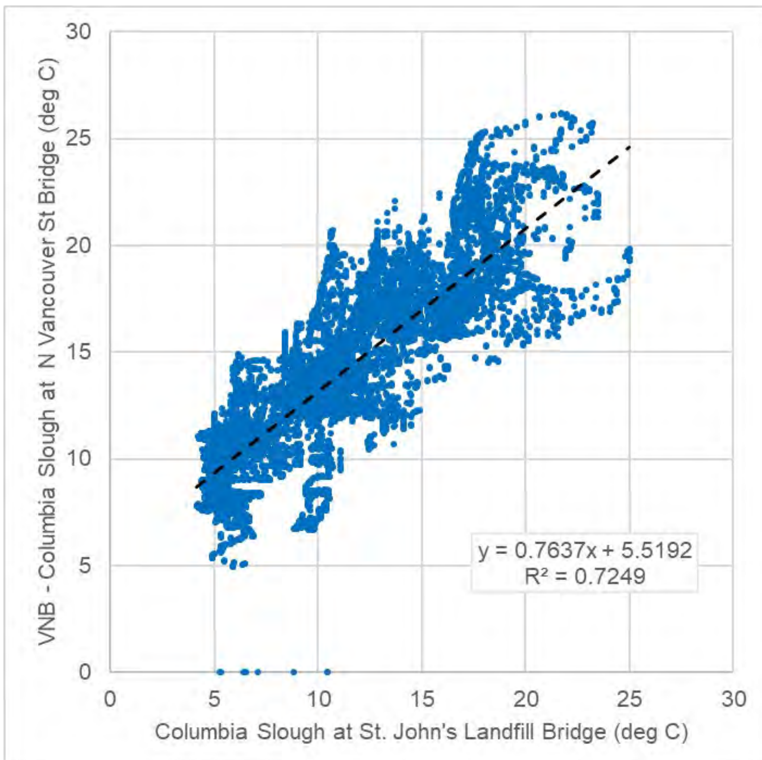

Figure 3-24. Regression relationship between VNB and ODEQ-11201

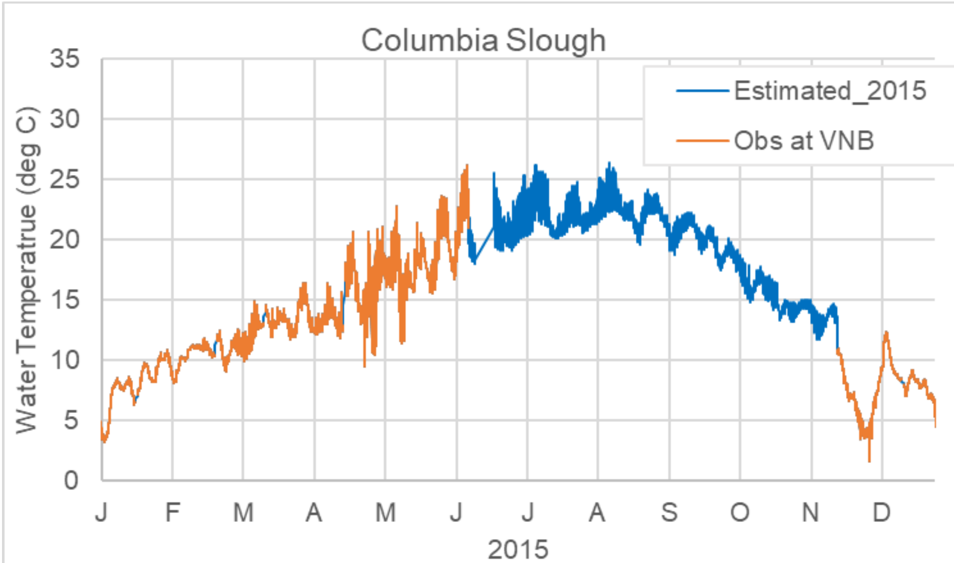

Figure 3-25. Temperature time series developed using observed data and calculated values for Columbia Slough

For Sandy River temperatures, previously data from monitoring stations ODEQ-11780 Sandy River at Dabney Bridge and ODEQ-10674 Sandy River at Troutdale Bridge were used to configure the model for 2001/2002. Data at these stations were not available for 2015. More recent data for 2015 is available from monitoring station 10674-ORDEQ and the City of Portland Water Bureau's station (PWB_SR_US_BR). Available data from the 10674-ORDEQ station were limited and included grab sample data with 6 samples collected during 2015. The PWB_SR_US_BR station is approximately 1,900 ft upstream of Bull Run River confluence. The data at this station were recorded at a 30-minute frequency interval and were only available from August 11, 2015 to October 19, 2015. Data for the remaining period of the year were filled using a regression relationship developed using observed temperatures from Little Sandy River (USGS 14141500) and the PWB_SR_US_BR station. Figure 3-26 shows the relationship between the two stations, which had an R^2 value of 0.86.

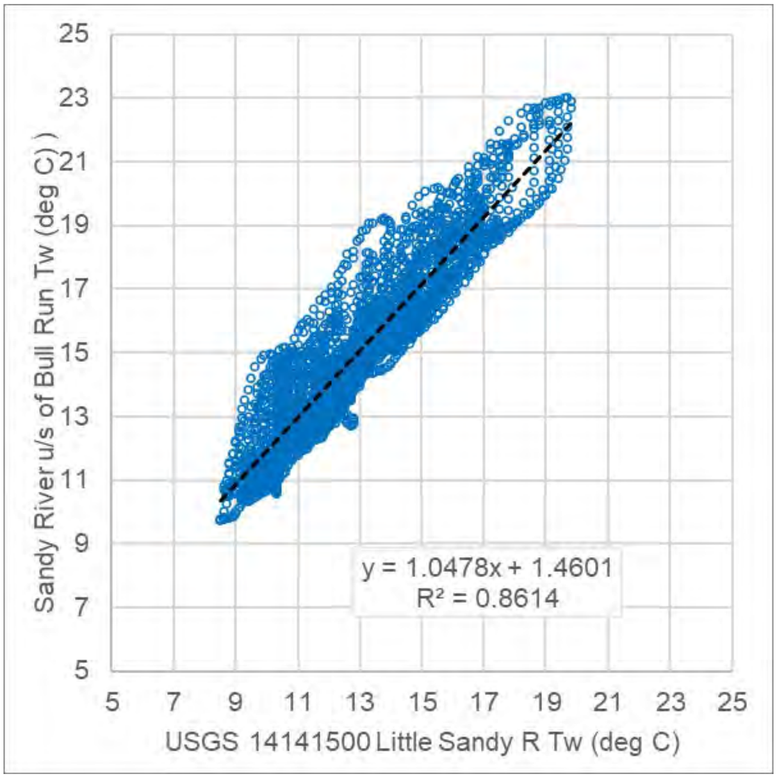

Figure 3-26. Regression relationship between observed temperature at PWB_SR_US_BR and USGS 1414500

Finally, a composite water temperature time series based on measurements from the PWB_SR_US_BR station from August 11, 2015 to October 19, 2015, and the calculated water temperatures for the rest of the year using the relationship between Little Sandy and PWB_SR_US_BR regression relationship was developed for Sandy River (Figure 3-27).

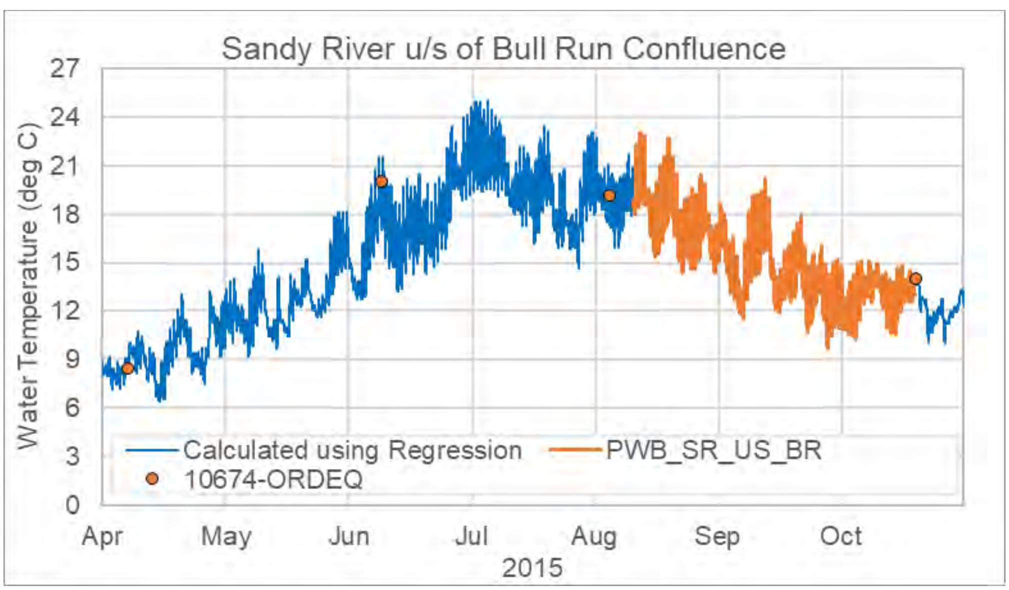

Figure 3-27. Temperature time series developed using observed data and calculated values for Sandy River

Data collected by WDOE were used to configure several tributaries in Washington that feed into the Columbia River. The WDOE monitoring site at Cowlitz River (26B070) had 30-minute temperature data during 2015. This station was also used in the development of the 2001/2002 model. Figure 3-28 shows the Cowlitz River temperature data for 2015 that was used to characterize the Cowlitz River in the model.

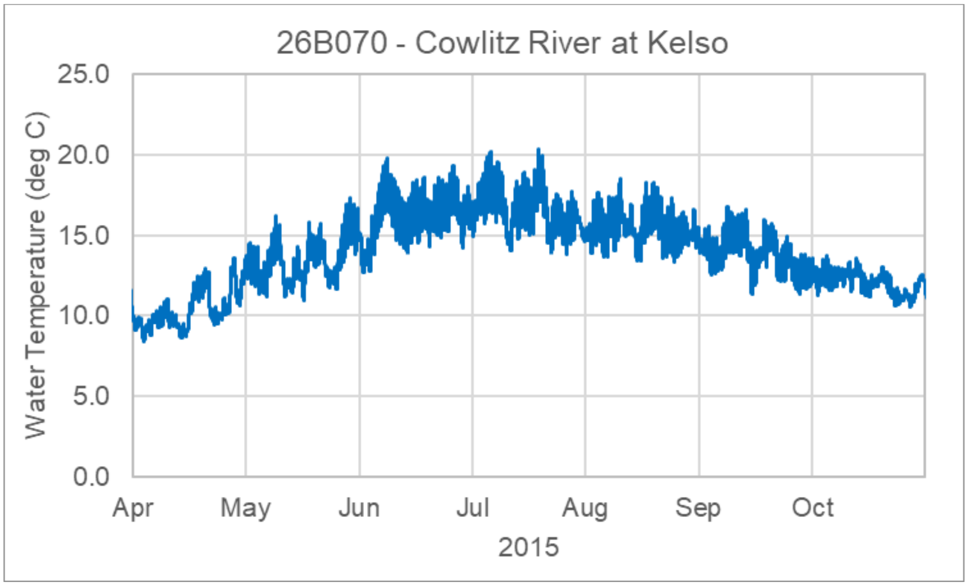

Figure 3-28. Observed temperature at Cowlitz River at Kelso – 26B070

There were no temperature data available for the Washougal River or the Grays-Elokoman basin river, so the Cowlitz River temperature data (Figure 3-28) were used for both tributaries. This is analogous to what was done in the 2001/2002 model development, t

The WDOE monitoring site Kalama River (27B070) had 30-minute temperature data during 2015. This station was also used in the development of the 2001/2002 model. Figure 3-29 shows the Kalama River near Kalama temperature data for 2015 that was used to characterize the Kalama River in the model.

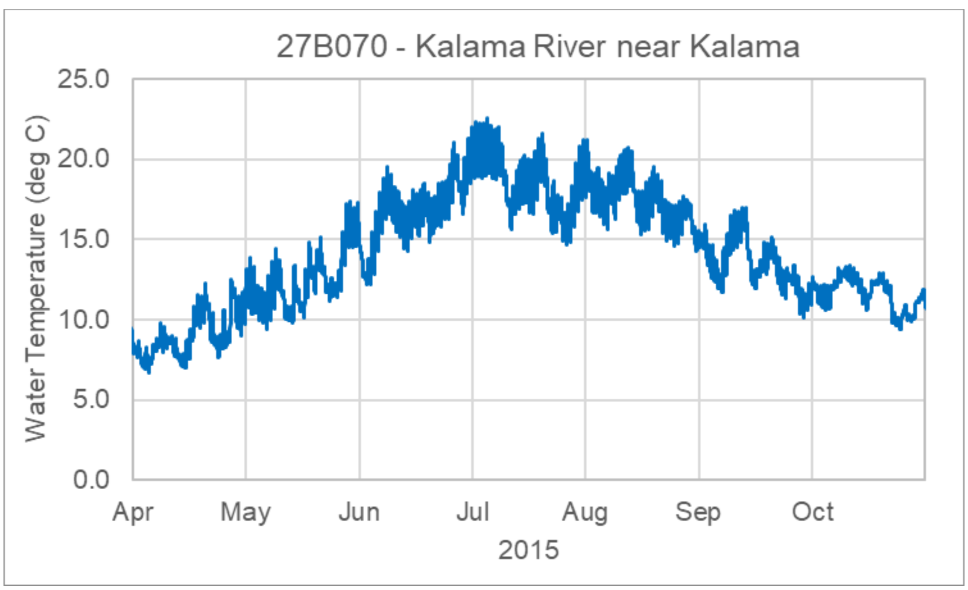

Figure 3-29 Observed temperature at Kalama River near Kalama – 27B070

There was no continuous temperature monitoring station with data for 2015 at the Lewis River. The WDOE monitoring station East Fork of the Lewis River at Dollar Corner (27D090) was monitored for temperature on 30-minute intervals for the year 2015 and was used to configure water temperature for the Lewis River. This assumption is consistent with what was done in 2001/2002 for model development when there was also no water temperature data available for Lewis River. Figure 3-30 shows the temperature time series data for the Lewis River.

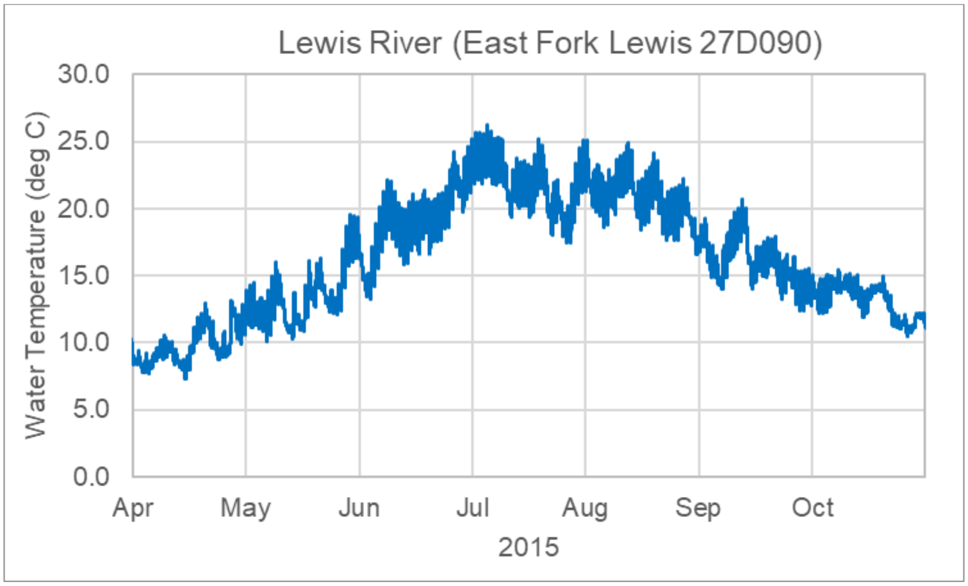

Figure 3-30. Lewis River temperatures (East Fork Lewis River at Dollar Corner – 27D090)

3.3.3 Point Sources

ODEQ provided Tetra Tech with discharge monitoring report (DMR) data for a total of 67 permitted NPDES facilities in the Willamette River watershed. These facilities discharge to various tributaries of the Willamette River and the Willamette River itself. For this current modeling effort, the DMR data for permitted NPDES facilities that discharge to the Lower Willamette River were identified for extraction and inclusion into the model. A total of sixteen permitted facilities discharging to the Lower Willamette River were identified (Table 3-3 and Figure 3-31).

Table 3-3. List of NPDES facilities identified for inclusion in the Lower Willamette River W2 model

WQ File Number	NPDES Permit #	Name	Frequency Flow	Frequency Temperature	Latitude	Longitude	River Mile	Model Waterbody
64905	101007	Evraz Oregon Steel Inc.	Daily	Daily	45.6256	-122.779	2.4	Willamette River: Lower
3690	102465	Ash Grove Cement - Rivergate Lime Plant	Daily when discharging	Continuous when discharging	45.6229	-122.784	3.3	Willamette River: Lower
120589	103061	NW Natural Gas Site Remediation	Daily	Daily Maximum	45.5791	-122.757	6.4	Willamette River: Lower
93450	101128	Siltronic Corporation	Daily	Monthly Maximum	45.5775	-122.755	6.6	Willamette River: Lower
74995	101180	Starlink Logistics Inc (SLLI)	Monthly Average	Daily	45.5665	-122.747	7	Willamette River: Lower
68471	103075	Arkema, Inc	Daily	Daily Maximum	45.5713	-122.745	7.2	Willamette River: Lower

WQ File Number	NPDES Permit #	Name	Frequency Flow	Frequency Temperature	Latitude	Longitude	River Mile	Model Waterbody
68471	100752	Arkema, Inc	NA	NA	45.5713	-122.745	7.4	Willamette River: Lower
70596	101393	Vigor Industrial LLC	Once for each vessel	Once for each vessel	45.5625	-122.716	8.2	Willamette River: Lower
100517	101613	Univar USA Inc	Daily	NA	45.5486	-122.723	9	Willamette River: Lower
78980	100677	Scappoose STP	NA (influent only; effluent during Nov/Dec only)	3/week daily maximum	45.7526	-122.856	10.58	Willamette River: Lower
113611	102833	OHSU Center For Health And Healing	Daily	2/week	45.4994	-122.671	14.46	Willamette River: Lower
109444	101536	BDC Willamette LLC	Monthly	NA	45.479	-122.673	15.8	Willamette River: Lower
16590	100983	WES (Kellogg Creek WWTP)	Daily	Daily (May 1 - Oct 31)	45.4398	-122.642	18.5	Willamette River: Lower
62795	100986	Oak Lodge Water Services Water Reclamation Facility	Daily	Daily	45.4241	-122.652	20.1	Willamette River: Lower
70735	101614	Tryon Creek WWTP	Daily	Daily	45.4213	-122.658	20.3	Willamette River: Lower
89700	101168	WES (Tri-City WWTP)	Daily	Daily (May 1 - Oct 31)	45.3759	-122.589	25.5	Willamette River: Lower
72634	102229	Blue Heron Paper Co.	Monthly	NA	45.3562	-122.611	26.4	Willamette River: Lower

NA = Not applicable

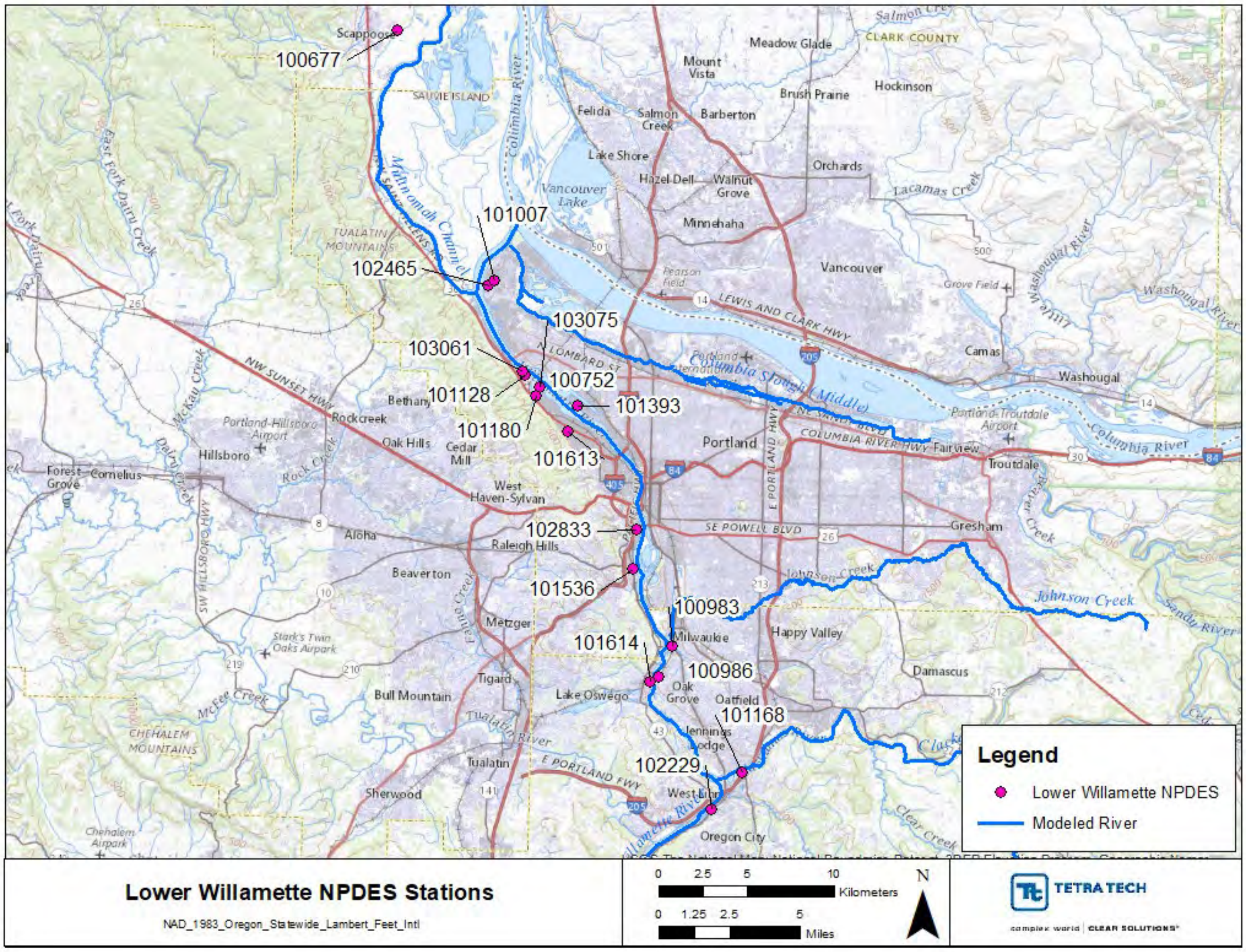

Figure 3-31. NPDES stations discharging to the Lower Willamette River

The DMR data were provided by ODEQ in various formats and sources. Specifically, monthly data from File DMR scans (DMR PDF), data from ODEQ's electronic database (Discharge Monitoring System (DMS)), data from the 2021 ODEQ temperature data solicitation effort, and data from the newer electronic database the NetDMR system were available. The data from the 2021 Oregon temperature data solicitation effort and the DMS data were the most readily useable and complete datasets. Both these datasets were in different formats but were available in long form digital format in a spreadsheet and were the most directly useable. These datasets were queried, with the data from the data solicitation effort queried first followed by the DMS datasets. When data from the DMS and the data solicitation effort were not available for a particular facility, then the data from the DMR PDF were used to extract the relevant data. The DMR PDFs were converted to excel format using OCR software. If the OCR produced data that were readable, then the data were used after checking for accuracy, otherwise the data were entered manually into a spreadsheet (data entered manually were also checked for accurate transfer of values). The NetDMR datasets were the most cumbersome as they included several nested zip files for a range of years with monthly pdf reports within them. The NetDMR datasets did not contain data for 2015 and typically contained data for the most recent years i.e., 2017 onwards. The NetDMR data were only used to fill in missing data, if data were unavailable for 2015.

Each of the facilities listed in Table 3-3 for which data was extracted for 2015 are summarized below. Data extracted for each facility were plotted and are discussed below along with any notes or assumptions that were used to construct the 2015 dataset.

Note that discharges from five facilities–Arkema, Inc (#100752), Vigor Industrial LLC (#101393), Univar USA Inc (#101613), BDC/Willamette LLC (#101536), and Starlink Logistics LLC (#101180) were not included in the model. A review of the DMR data of these facilities showed that these facilities were either intermittently discharging or not discharging. If they were discharging, the flows were small i.e., less than 0.1 cfs. In most cases there were no water temperature available for these facilities. These five facilities are also discussed below.

Evraz Oregon Steel Inc.

Evraz Oregon Steel NPDES Permit #101007 discharges process wastewater, contact cooling water, non-contact cooling water, incidental storm water, and ground water seepage/dewatering (outfall 001) to the Lower Willamette River. Daily effluent flow and water temperature data were available from monthly DMR PDF reports for the year 2015 (Figure 3-32). The discharges from this facility were intermittent with several no discharge days during 2015 (about five to seven discharges were recorded in each month and the remaining days in the year were noted as having no discharge).

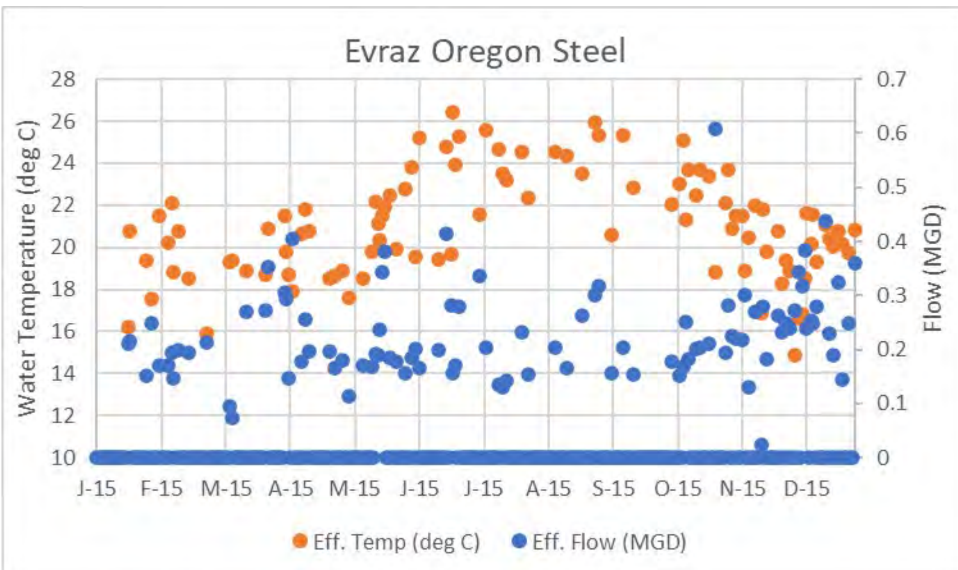

Figure 3-32 Evraz Oregon Steel 2015 flow and water temperature.

Ash Grove Cement – Rivergate Lime Plant

Ash Grove Cement (# 3690) has a condition in their current NPDES permit (#102465) that no discharge is allowed from outfall 001 from May 1 through October 31. ODEQ is currently checking if the discharge prohibition for this facility will be removed at the next permit cycle, which may then require inclusion of this facility during the WLA scenario, where the WLA discharge will need to be developed. Hence, this facility is included in the model with zero discharge, that may be updated in the future.

NW Natural Gas Site Remediation

NW Natural NPDES Permit #103061 discharges treated groundwater and stormwater (outfall 001) to the Lower Willamette River. Daily flows and water temperature (min/max) were extracted from DMR PDFs for the year 2015 (Figure 3-33). Note that the year in daily time stamps for June through September were noted as 2014 in the DMR (120589-DMR-NWNATURALG201501-10&12.pdf), when in fact it should be 2015 based on the DMR monitoring period noted at the beginning of the DMR form. This was corrected before creating the model input time series for the model.

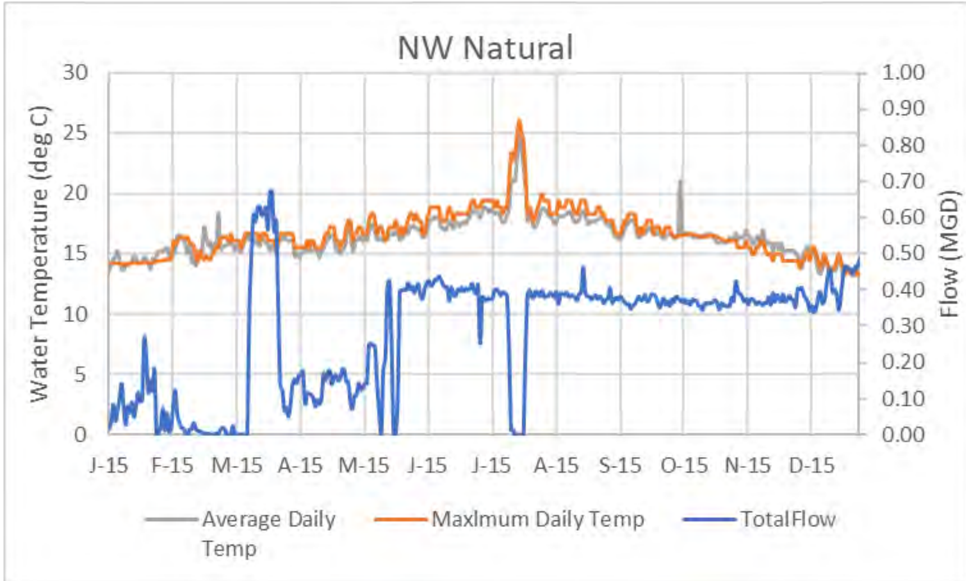

Figure 3-33 NW Natural Gas 2015 flow and water temperature.

Siltronic Corporation

Siltronic Corporation NPDES Permit #101128 discharges process wastewater, non-contact cooling water, stormwater, filter backwash, RODI blowdown, and boiler blowdown to the Lower Willamette River. Data was extracted from the DMS for this facility.

Three outfalls are reported for this facility in the DMS – i) Outfall 001 the daily process effluent (ii) Outfall 002 the daily Boiler flow, and (iii) Outfall 003 which the combined effluent. Daily flows were available for the process effluent and the boiler flow. The flows from the Processed effluent from outfall 001 and Boiler Blow from outfall 002 were combined to calculate a combined daily effluent flow time series (Figure 3-34). Continuous water temperature data were not available. Water temperature from the combined effluent (Outfall 003) was presented as a monthly summary stat (monthly maximum value) in the DMS file, where StatTypeDesc = Maximum and TimePrdDesc = Monthly. These monthly water temperatures (Figure 3-34) were used in the model.

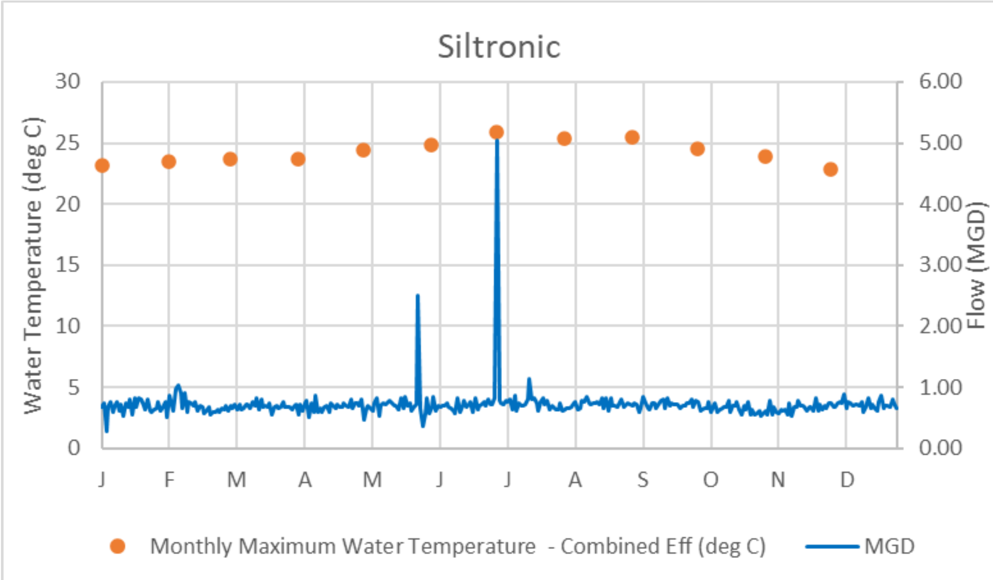

Figure 3-34. Siltronic 2015 flow and water temperature.

Starlink Logistics Inc. – SLLI

Monthly mean flows (in addition to min/max) were available from PDF DMRs. The flows during 2015 were small, with mean flows during summer being less than 0.0005 MGD. No discharge occurred from July through September in 2015. Daily water temperatures were available from the PDF DMRs, with several no flow days reported during the year (Figure 3-35). This facility was not included in the model since the flows were very small.

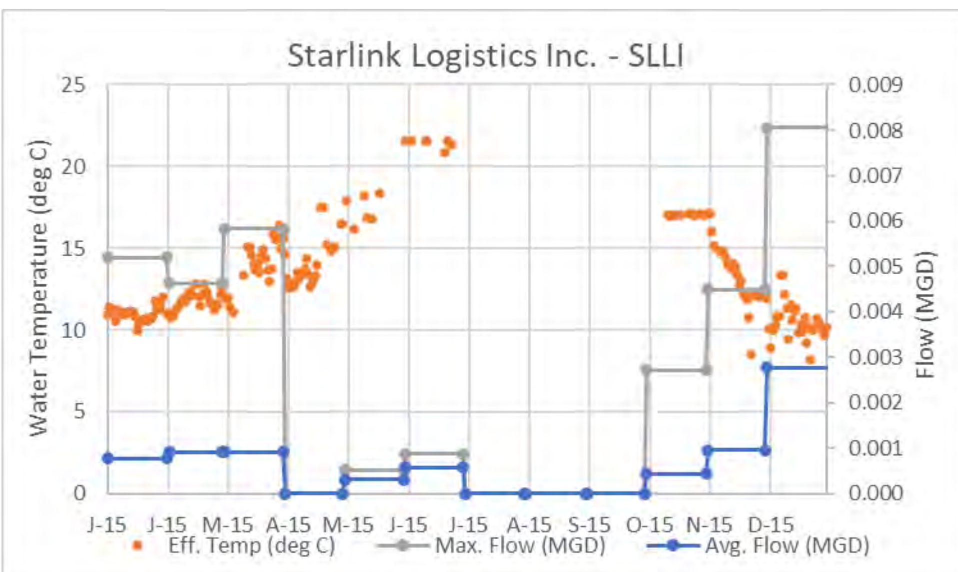

Figure 3-35. Star Link Logistics LLC 2015 flow and water temperature.

Arkema Inc. #103075 & #100752

Arkema Inc. is a former chemical manufacturing facility and has two NPDES permits - #103075 and #100752. Arkema Inc. NPDES Permit #103075 is for treated ground water (outfall 004). Daily flow data from DMR PDFs were available for the period from February through December of 2015. Flows for this facility were intermittent during summer with a maximum reported flow of 0.13 MGD. The DMR records only report daily maximum temperatures which were used to specify the water temperature associated with the discharge from Arkema Inc in the model (Figure 3-36).

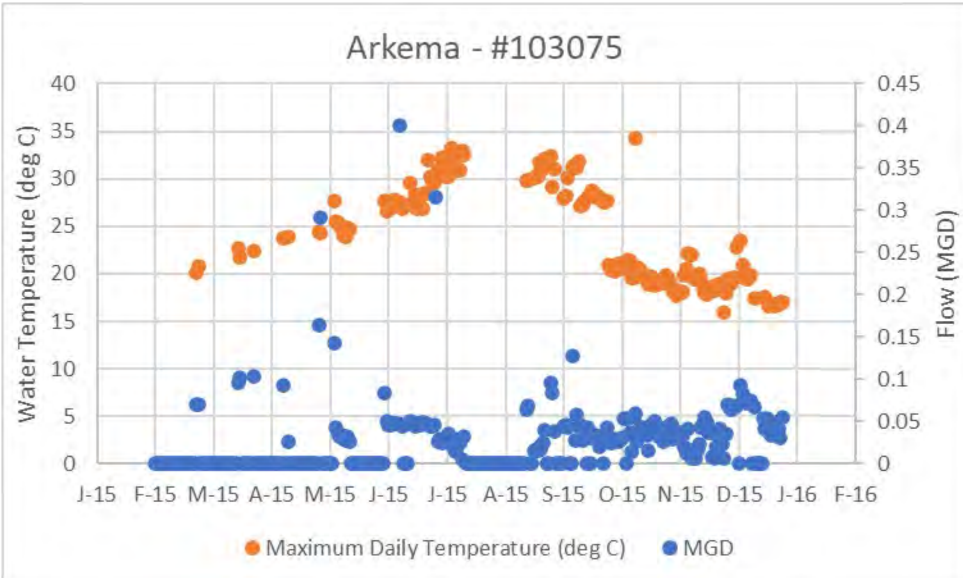

Figure 3-36. Arkema #103075, 2015 flow and water temperature.

Arkema Inc. NPDES Permit #100752 is for multiple stormwater discharge from outfalls (001, 002, 003, and 004) to the Lower Willamette River. There is no DMR data available for 2015. The facility permit does not list temperature in its monitoring and reporting requirements. A review of the NetDMR data from 2020 that was available indicated no discharge occurred in 2020. This facility discharge was not included in the model since no data was available and is not expected to impact the calibration of the model.

Vigor Industrial LLC

Vigor Industrial LLC (NPDES Permit #101393) is a ship repair yard, with multiple discharges to the Lower Willamette. For 2015, discharges from this facility in the DMR are only reported for non-contact cooling water discharges from outfalls 005, 006, 009, 010, and 011. There were no discharges reported during 2015 in the DMR for treated ballast water and tanks wash water (outfall 001) and treated dry dock and buildway process water and stormwater (outfall 002). The flows from the non-contact cooling water are intermittent and were small (<0.1 cfs) during the critical summer period, except for some discharges during March and April with temperatures being generally less than 15 ^{o}C during these two months. The maximum discharge from Vigor for July 2015 was 0.049 MGD (0.078 cfs) (Figure 3-37). This discharge from the facility is small and is not expected to impact the model calibration and hence not included in the model for calibration.

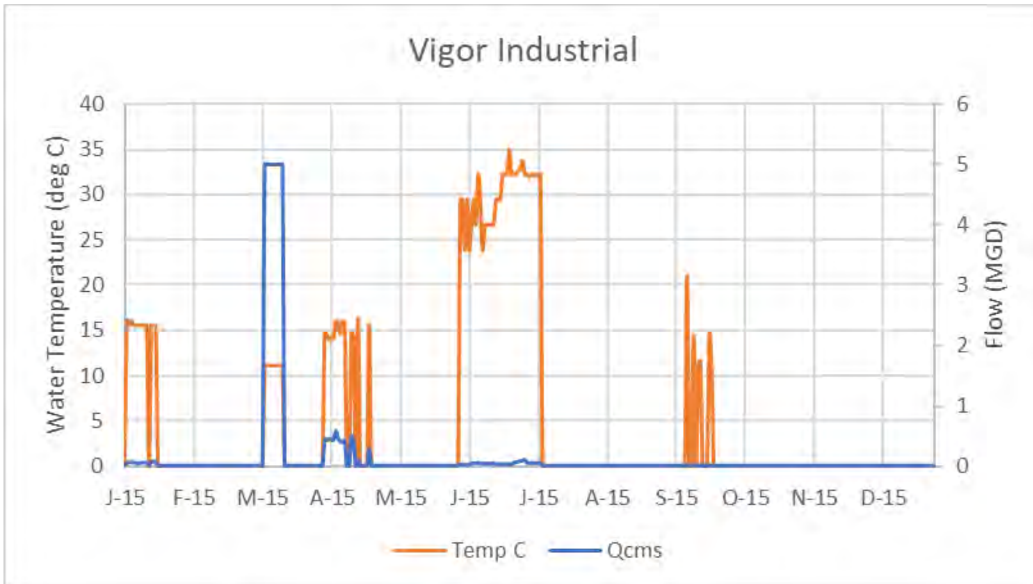

Figure 3-37. Vigor Industrial flow and water temperature during 2015.

Univar USA Inc.

Univar USA Inc. (NPDES Permit #101613) discharges remediated groundwater to the Lower Willamette River. The permit does not require monitoring of water temperature. A query of the DMRs for 2015 showed no water temperature data. NetDMR data for the years 2019 and 2020 also did not include any water temperature observations. The 2015 DMR data in the DMR PDFs show flows during the summer were a constant 0.009 MGD (0.017 cfs). This discharge from the facility is small and is not expected to impact the model calibration and hence not included in the model for calibration.

Scappoose STP

Scappoose STP (NPDES Permit #100677) discharges to the Multnomah Channel. Daily influent flow data and daily effluent water temperature are available. However, during 2015 daily effluent flow data for this facility are only available for November and December. Daily influent flow data were available for the entirety of 2015. For November and December 2015, the mean absolute difference between influent and effluent was found to be about 0.057 MGD, with the inflow flow rate being the larger number in most cases. Since the effluent flow data were unavailable, influent flow data were used to configure the model flows. Daily water temperature for this facility were extracted from DMR PDFs and were available for the period from May through December 2015 (Figure 3-38).

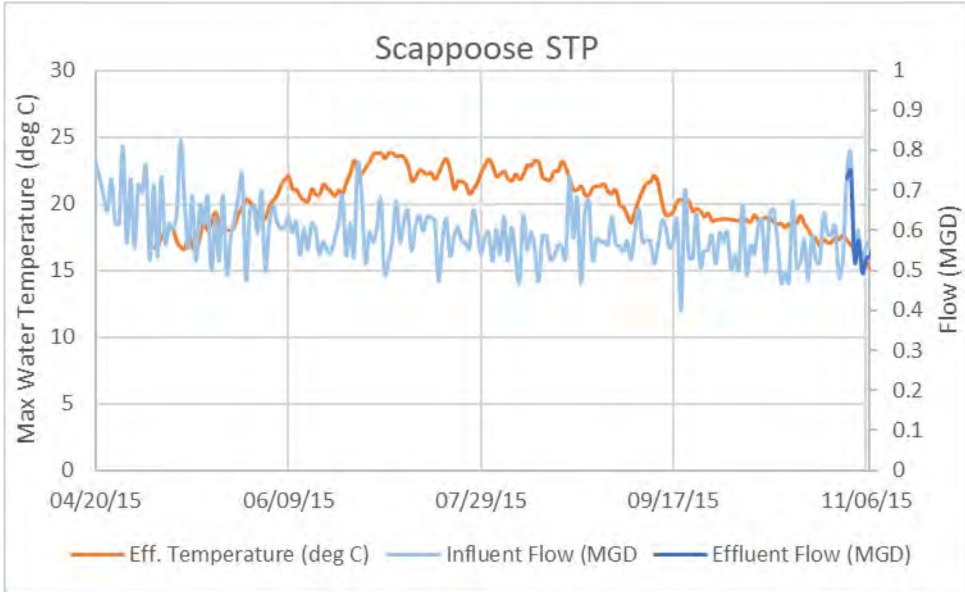

Figure 3-38 Scappoose STP 2015 flow and water temperature.

OHSU Center For Health and Healing

The Oregon Health and Sciences University (OHSU) Permit (NPDES Permit #102833) is for discharge of treated wastewater (outfall 001), emergency effluent and sewage solid discharges (outfall 002), and recycled water use (outfall 003) to the Lower Willamette River. DMR PDFs included total daily effluent flows and bi-weekly water temperature data for the period from January 1, 2015 to November 27, 2015 (Figure 3-39). December data were missing in DMR records. The bi-weekly data were linearly interpolated to daily for specification into the model.

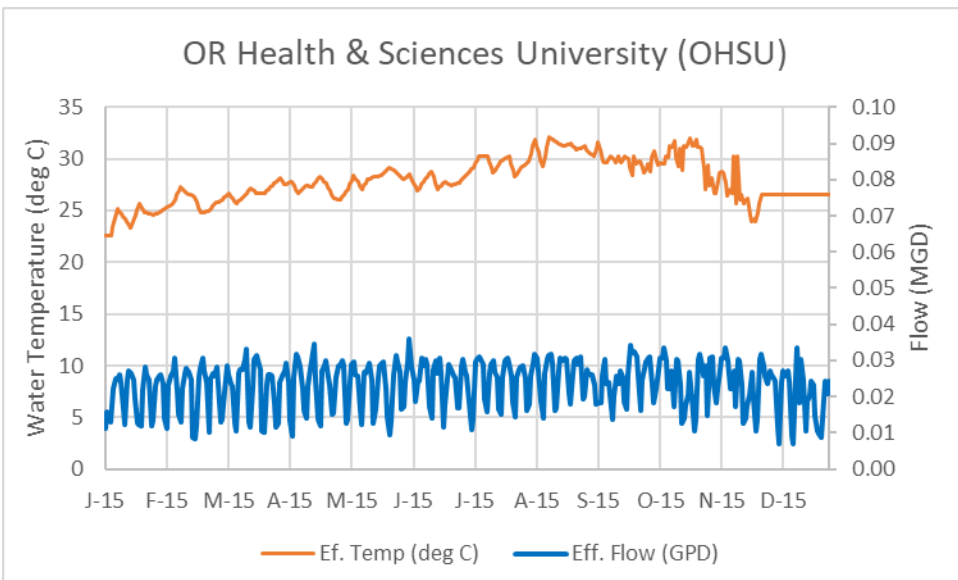

Figure 3-39. OHSU Center for Health and Healing 2015 flow and water temperature.

BDC/Willamette LLC

BDC/Willamette LLC (NPDES Permit #101536) discharges treated groundwater to the Lower Willamette River. The permit does not require monitoring water temperatures. Based on the NetDMR data available for the years 2019 (September only) and 2020 the system was not operational, and there was no discharge from this facility. This facility was not included in the model.

Kellogg Creek WWTP

Kellogg Creek WWTP (NPDES Permit #100983) discharges treated wastewater (outfall 001) to the Lower Willamette River. Data for this facility were available from the 2021 ODEQ temperature data solicitation effort. Daily flow and water temperature (daily mean and maximum) DMR data were available May 1, 2015 to October 31, 2015 (Figure 3-40).

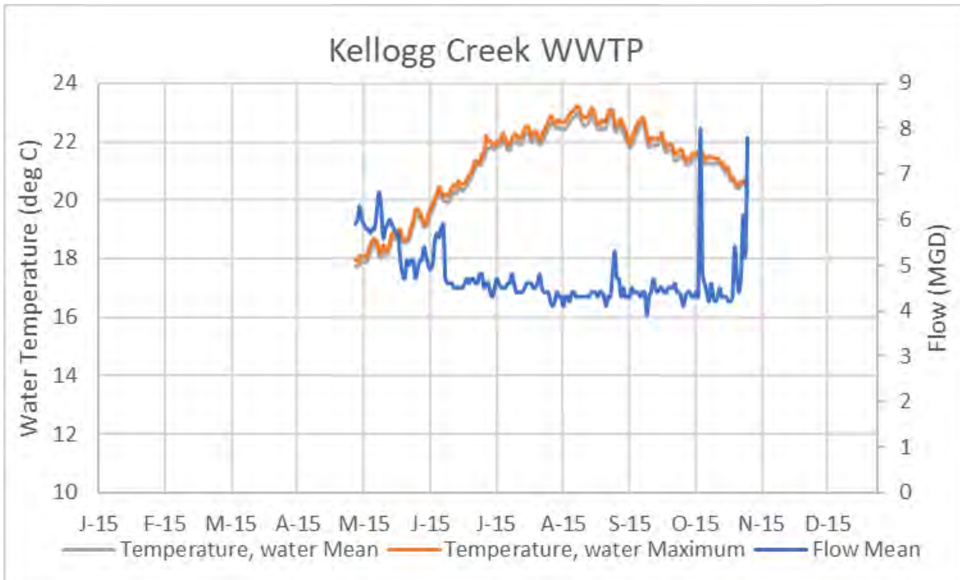

Figure 3-40. Kellogg Creek WWTP 2015 flow and water temperature.

Oak Lodge Water Services District

Oak Lodge Water Services District (NPDES Permit #100986) discharges treated wastewater (outfall 001) to the Lower Willamette River. Daily flows for this facility for 2015 were extracted from the DMS (Figure 3-41). The DMS data for this facility did not include water temperature for the year 2015. Daily average and daily maximum water temperature data were extracted from the DMR PDFs. Water temperatures for the months of May and July were missing and were linearly interpolated. The daily average flows and water temperature were used in the model.

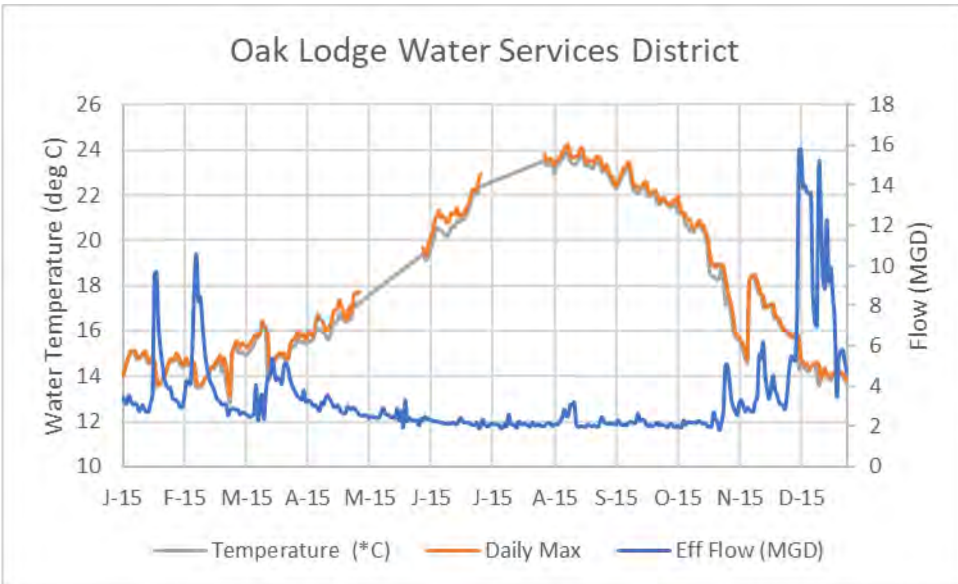

Figure 3-41 Oak Lodge Water Services District 2015 flow and water temperature.

Tryon Creek WWTP

Tryon WWTP (NPDES Permit #101614) discharges treated wastewater (outfall 001) to the Lower Willamette River. Daily flows and water temperature were available from 2004 to 2017 in the DMS data (Figure 3-42). Hourly water temperature data were also available for the period from 2017 to 2020. Since the hourly data were not available for 2015, the daily DMS data which provided a complete dataset for the year 2015 was used to configure the model.

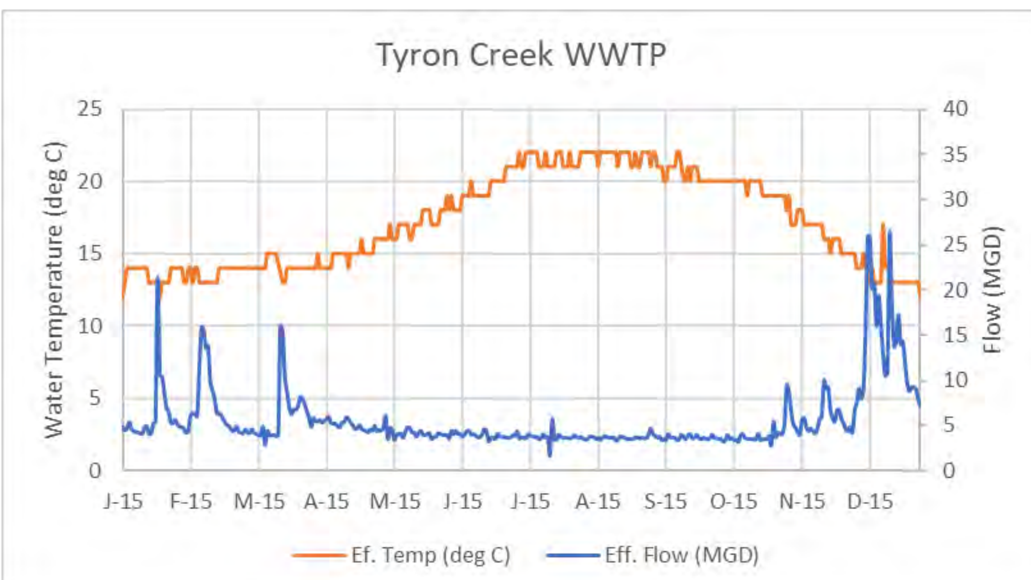

Figure 3-42. Tryon Creek WWTP 2015 flow and water temperature.

Tri-City WWTP

Tri-City WWTP (NPDES Permit #101168) discharges treated wastewater (outfall 001) to the Lower Willamette River. Data for this facility were available from the 2021 ODEQ temperature data solicitation effort. Daily flow and water temperature (daily mean and maximum) DMR data were available May 1, 2015 to October 31, 2015 (Figure 3-43).

Figure 3-43 Tri-City WWTP 2015 flow and water temperature.

Blue Heron Paper Company

Blue Heron Paper Company (NPDES Permit #102229) discharges treated wastewater, cooling water, storm drainage runoff, and other waste sources that have received treatment by an aerated stabilization basin to the Lower Willamette River. The permit is active, but there was no discharge from the facility during 2015, based on the DMS records. This facility is included in the model with zero discharge.

3.3.4 Meteorology data

Meteorological conditions are an important driver in the prediction of water temperature as they determine surface boundary conditions in the W2 model. The meteorological data required are hourly air temperature, dew point temperature, wind speed, wind direction, and cloud cover. The model also requires specification of solar radiation. Solar radiation in the model can be specified directly based on available data or instead the model can compute it internally.

Long term hourly meteorological data were available from the National Climatic Data Center (NCDC) – Local Climatological Dataset (LCD) (NOAA 2005) station located at Portland International Airport, OR (PDX). The station is in the vicinity of the Lower Willamette and Columbia River (latitude: 44.1278, longitude: -123.2206, Elevation = 107.6 m). Figure 3-44 shows the location of the PDX weather station.

Hourly data from the year 2015 were downloaded for this LCD station. The station provided most of the required meteorological parameters (except for solar radiation). In general, the data were complete in terms of missing data, with the exception for three days in July from the 29th to the 31st. The air temperature for the missing days was filled in using daily air temperature data reported at this location. NCDC reports daily minimum and maximum air temperature at the PDX station as part of its Global Historical Climatology Network daily (GHCNd) daily network. The pattern of the hourly diurnal distribution observed at the PDX Airport was used to disaggregate the minimum and maximum air temperature to hourly. The daily min/max values were maintained on each day, but the timing and diurnal pattern from the PDX station was used to create hourly time series. All other parameters i.e., dewpoint temperature, wind speed/direction, and cloud cover were filled in using data reported from the previous 3 days.

Maximum air temperature during 2015 was observed in July (39.56 ^{o}C). Mean monthly maximum air temperatures indicated 30.08 ^{o}C in July, followed by 28.73 ^{o}C August, and 23.27 ^{o}C in September. The 2015 observed wind speed data indicate that daily wind speeds ranged from 0 to 10 meters per second, with upper range wind gusts up to 19 meters per second. Winds come from all directions, but most frequently originate from the northwesterly direction. This is illustrated using a wind rose plot, which provides an overall view of how wind speed and direction are typically distributed at a particular location (Figure 3-45). Presented in a circular format, the wind rose shows the frequency of winds blowing from various directions. The length of each "spoke" (radius) around the circle is related to the frequency (percent of time) that the wind blows from a particular direction. Each concentric circle represents a different frequency, emanating from zero at the center to increasing frequencies at the outer circles. Colors are used to represent wind speed.

The cloud cover data were calculated from hourly descriptive sky cover conditions reported at the PDX Airport station. The W2 model interprets cloud cover on a scale of 0 to 10 (0 being clear and 10 being cloudy). Hourly global solar radiation data from the Portland (PV) Solar Radiation Monitoring Lab (SRML), University of Oregon station site were used as input along with the various surface airways parameters from the Portland Airport to create the W2 meteorological inputs file. Figure 3-46 shows the observed hourly time series used in the model.

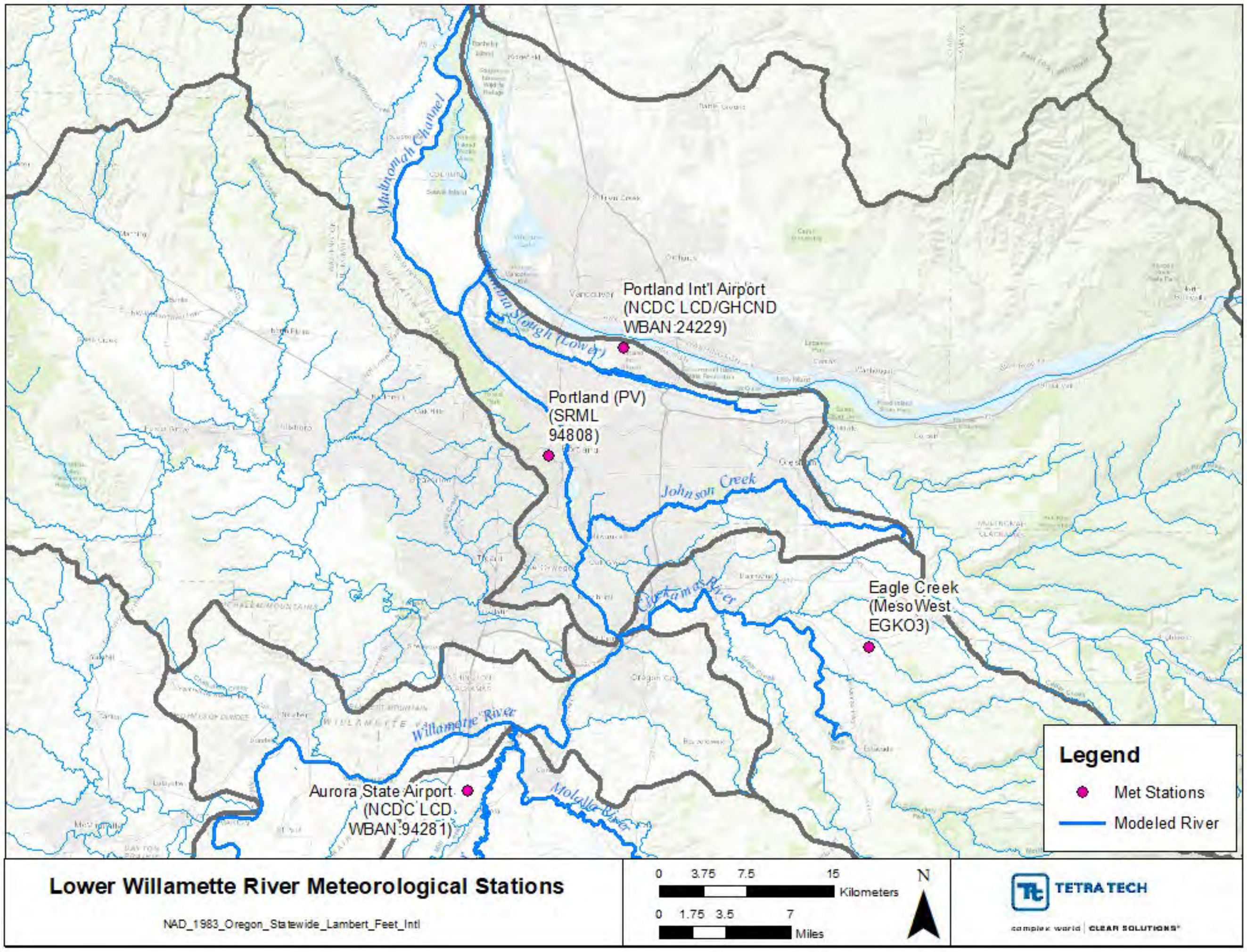

Figure 3-44. Lower Willamette River meteorological stations

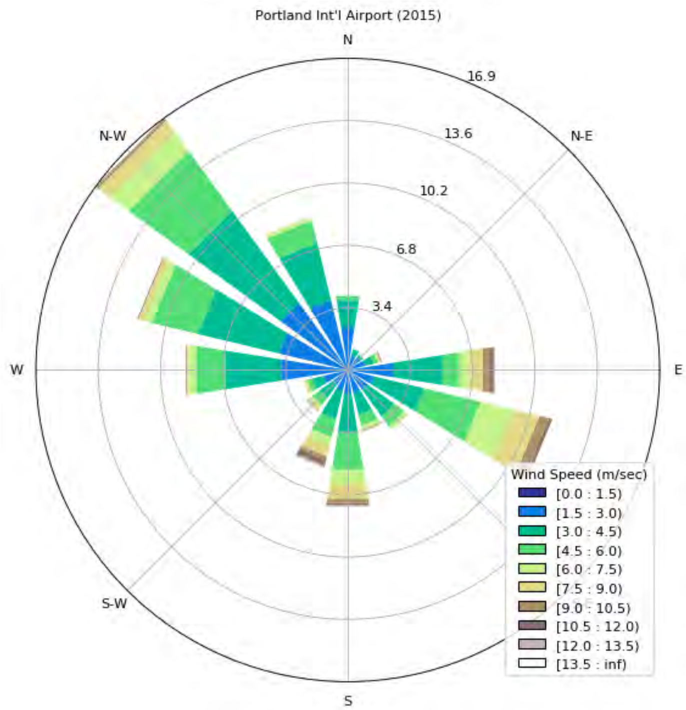

Figure 3-45. Wind Rose for the observed wind data at Portland International Airport for the full 2015 year of record

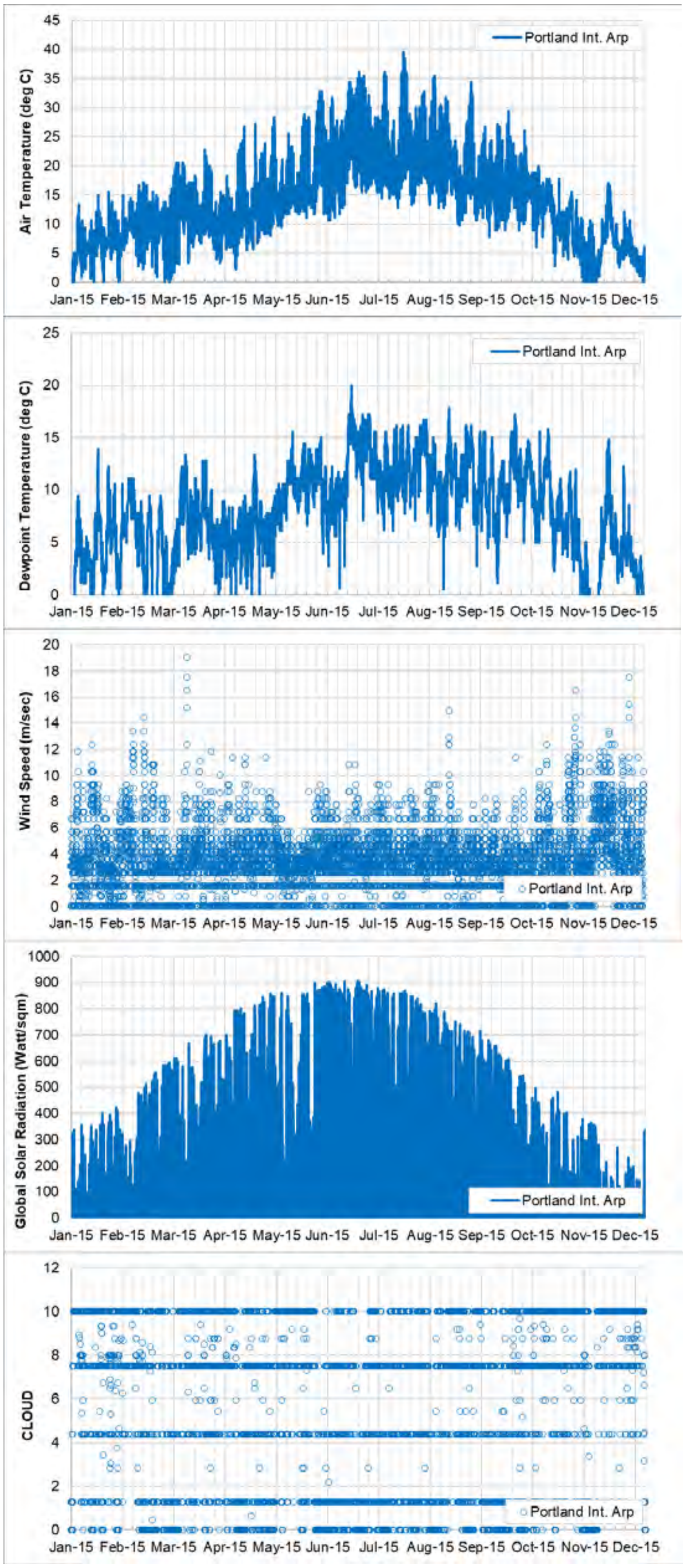

Figure 3-46. Observed Hourly Meteorological data at Portland International Airport (NCDC-LCD) & Solar Radiation from Portland (PV) SRML site

3.4 LOWER WILLAMETTE RIVER MODEL CALIBRATION

Model calibration focused on flow, water level, and water temperature data from calibration sites that had available data during the simulation period. Parameters evaluated during calibration were Manning's coefficient, wind sheltering, evaporation, and sediment temperatures. No changes were made to the current condition calibration parameters (i.e., from 2001/2002) in the 2015 model. Vegetative and topographic shade characteristics were also left unchanged since the model input was developed using a detailed GIS analysis. The model calibration period was from April 1, 2015, to October 31, 2015.

Figure 3-47 shows the locations of all the flow, water level, water temperature calibration locations used during the year 2015. The model calibration locations and available data during the year 2015 are further discussed in the following sections.

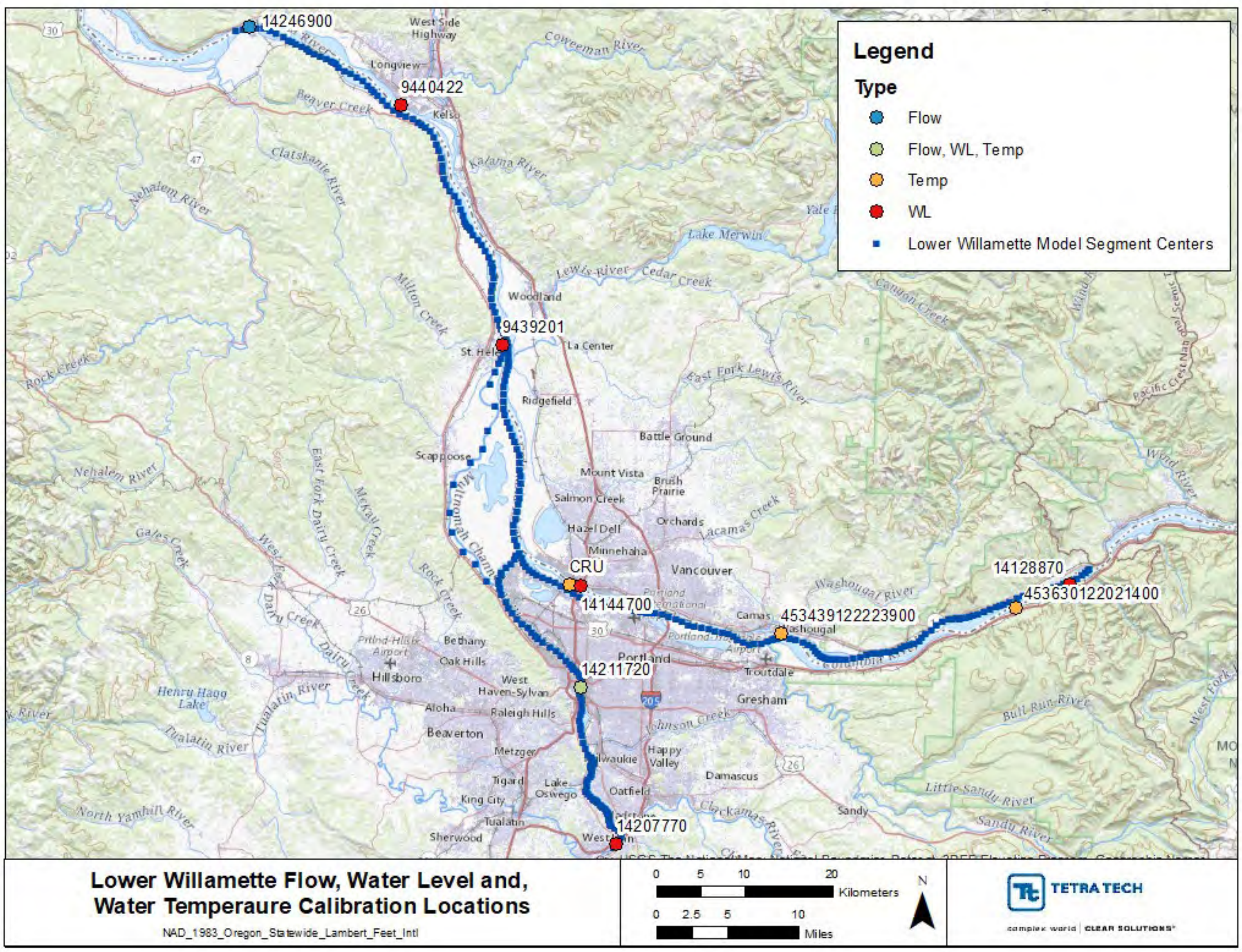

Figure 3-47. Lower Willamette calibration station locations.

3.5 HYDRODYNAMIC CALIBRATION

Hydrodynamic calibration included the calibration of flow and water surface elevation conditions using available data during the simulation period. The Lower Willamette has six gages with continuous water level and one continuous flow gage available for calibrating the model. These stations were the same stations that were used during 2001/2002 (Berger et al. 2004). In addition, continuous flow data from the Willamette River at Portland station (USGS 14211720) were used in the 2015 calibration. Note that flow data from the Willamette River at Portland station were not included in the calibration during the 2001/2002 modeling effort but are included for 2015. Table 3-4 and Figure 3-47 show the hydrodynamic calibration station locations used calibration during 2015.

Table 3-4. Lower Willamette flow and water level calibration sites.

ID	Description	Latitude	Longitude	Type	Source	RM	Model Segment
14246900	Columbia River At Port Westward, Near Quincy, OR	46.1814	-123.182	Flow	USGS	53	347
14211720	Willamette River at Portland, OR	45.5175	-122.669	Flow, WL	USGS	12.50	66
14144700	Columbia River at Vancouver, WA	45.6207	-122.673	WL	USGS	106.5	223
9440422	Longview, WA	46.1067	-122.955	WL	NOAA	66.2	315
9439201	St Helens, OR	45.865	-122.797	WL	NOAA	85.75	270
14207770	Willamette River Below Falls, At Oregon City, OR	45.3576	-122.611	WL	USGS	26.48	2
14128870	Columbia River Below Bonnieville Dam, OR	45.6331	-121.961	WL	USGS	144.5	118

Figure 3-48 and Figure 3-49 show the comparisons of modeled and observed flows and Figure 3-51 through Figure 3-59 show the comparisons of modeled and observed water surface elevations. The model error statistics for the year 2015 Lower Willamette River hydrodynamic calibration were also computed for each station and are presented in Table 3-5. See section 2.1.1 for an explanation of the error statistic metrics used for evaluation. Note that all water levels were first converted to NGVD29 datum before comparison with modeled water levels.

Flows and water surface elevations in the Lower Willamette River are affected by tides in addition to the inflows. For flow, the MAE, RMSE,and ME values are 997 m^3/s, 1323 m^3/s, and 26.4 m^3/s, respectively, at USGS 14246900. It should be noted that maximum flows at this location can be as high as 10,000 m^3/s. Therefore, the relative model errors are very low indicating that model agrees well with data. The range of the fluctuation of the observed flow at the Willamette River at Portland location (USGS 14211720) are higher those from the modeled flows. This station has a documented problem with accurately representing observed flows due to the tidal nature at this location as noted by ODEQ. Note that flows for USGS 14211720 were not included as part of the calibration in the PSU report for the years 2001/2002 but are included here for the purpose of listing all evaluated data.

The model was able to capture the diurnal tidal fluctuations of water surface elevation at the most downstream boundary in the Columbia River at the Port Westward near Quincy (Beaver Army Terminal, USGS 14246900), and also at the below Bonneville dam location. As seen in the calibration figures, the modeled water surface elevations match well with the observed data, with some underestimation of the observed water level data evident at the St. Helens and Longview stations. The MAE for the water levels ranged from 0.048 to 0.54 meters and the RMSE ranged from 0.064 to 0.56 meters (Table 3-5). Both flow and water surface elevation calibration and corresponding error statistics are similar to those calculated for the years 2001 and 2002.

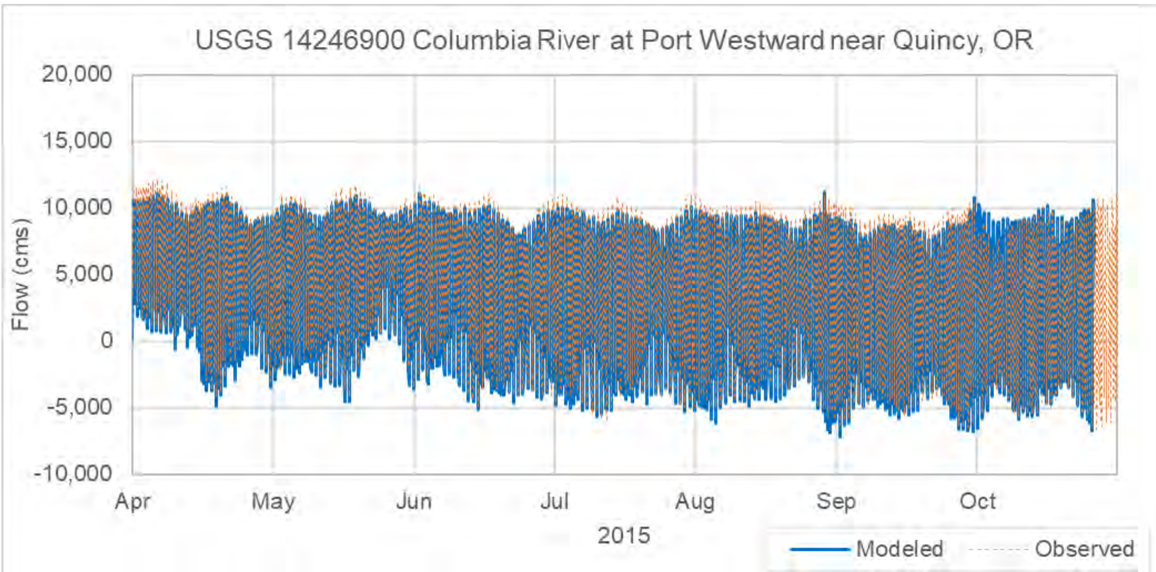

Figure 3-48. Columbia River at Port Westward near Quincy flow comparison, 2015

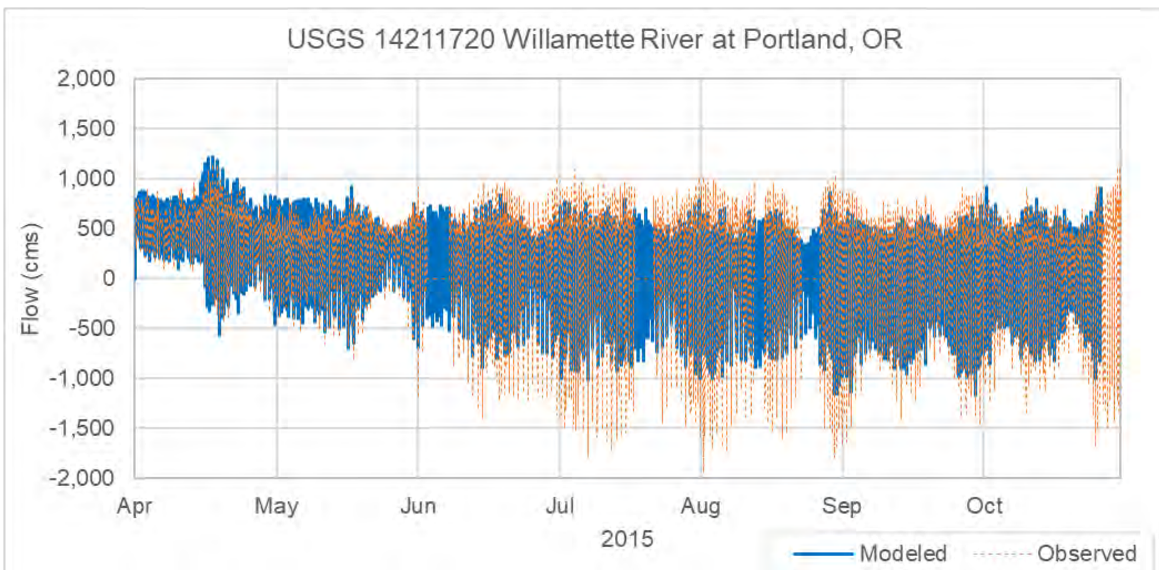

Figure 3-49. Willamette River at Portland flow comparison, 2015

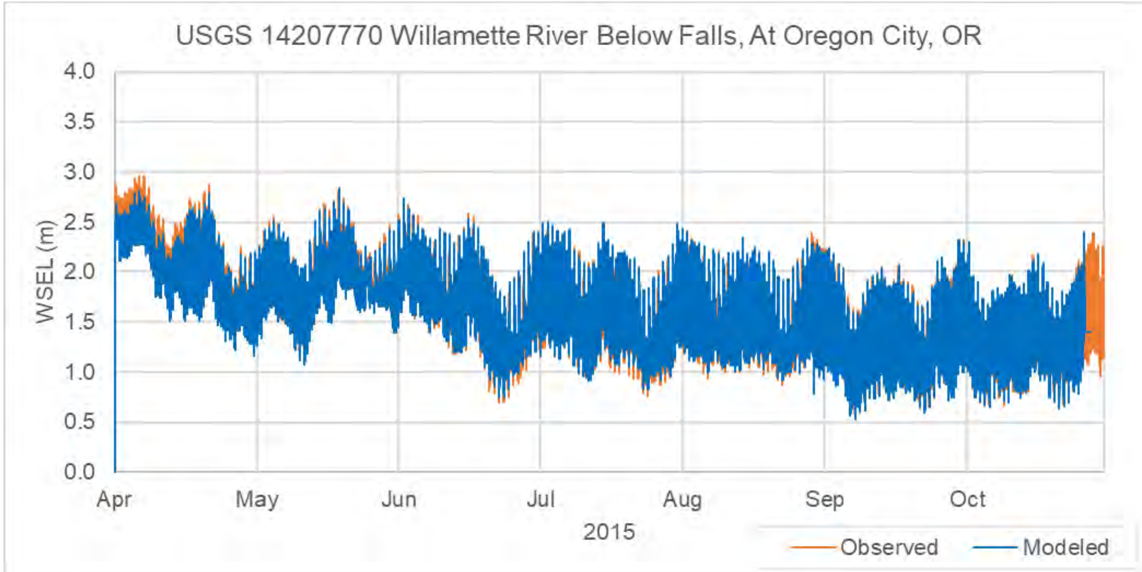

Figure 3-50. Willamette River below Falls at Oregon City water surface elevation comparison, 2015

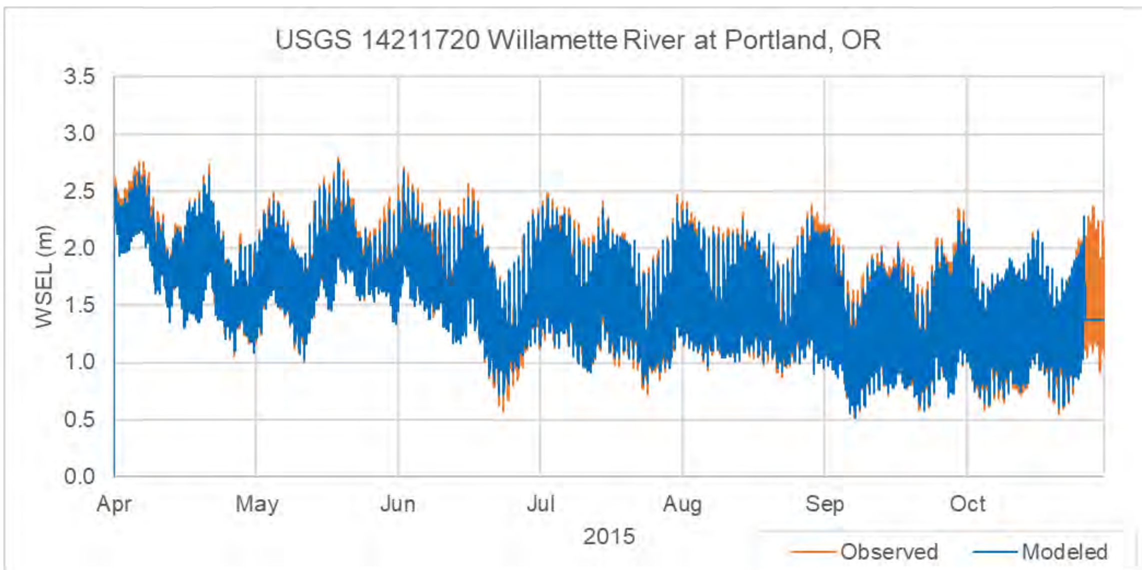

Figure 3-51. Willamette River at Portland water surface elevation comparison, 2015

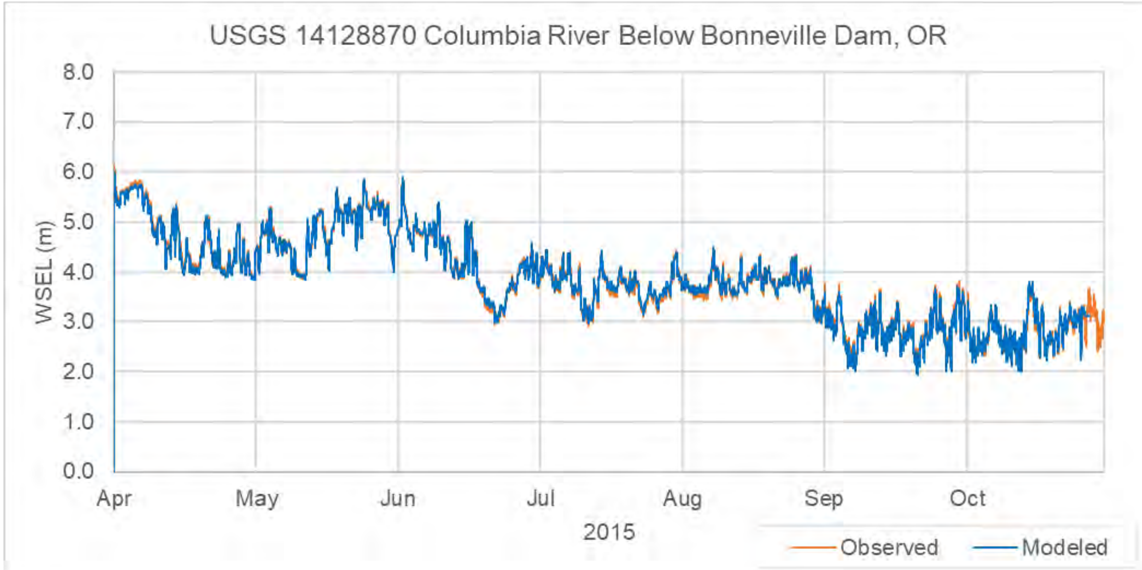

Figure 3-52. Columbia River below Bonneville Dam water surface elevation comparison, 2015

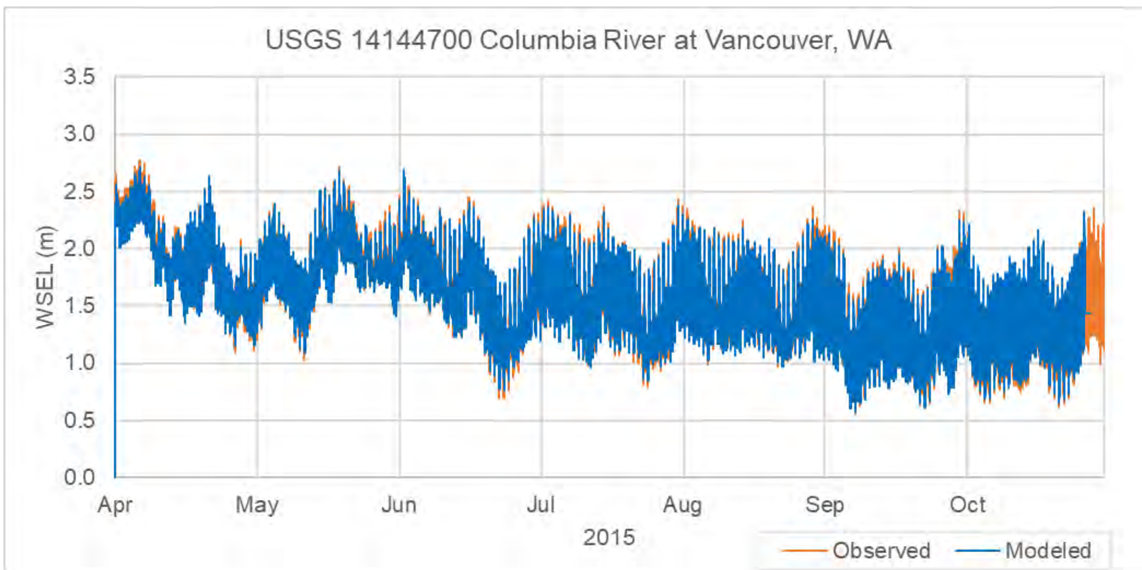

Figure 3-53. Columbia River at Vancouver water surface elevation comparison, 2015

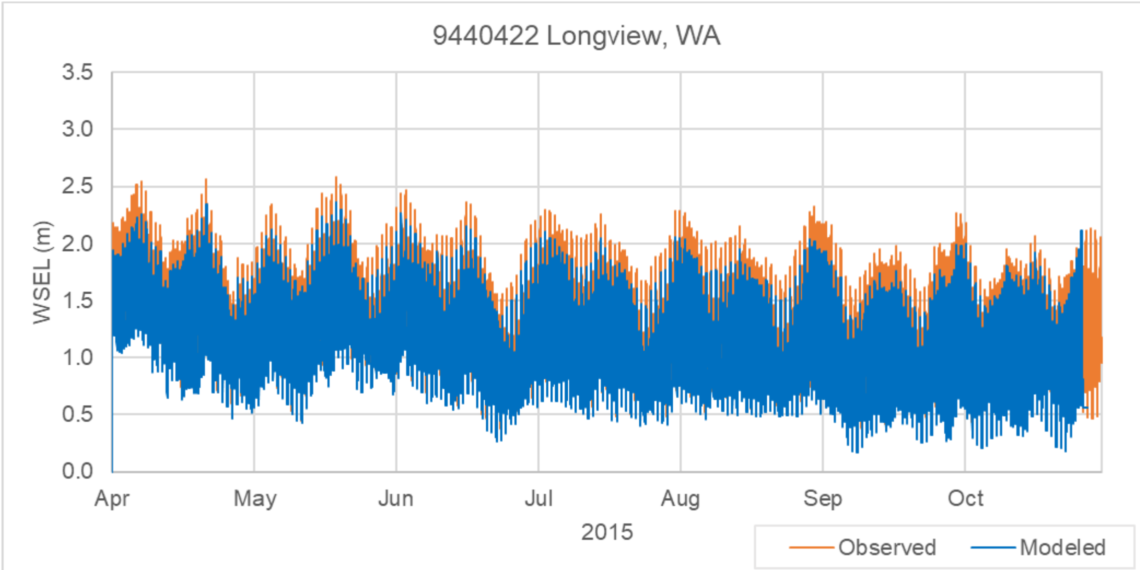

Figure 3-54. Columbia River at Longview water surface elevation comparison, 2015

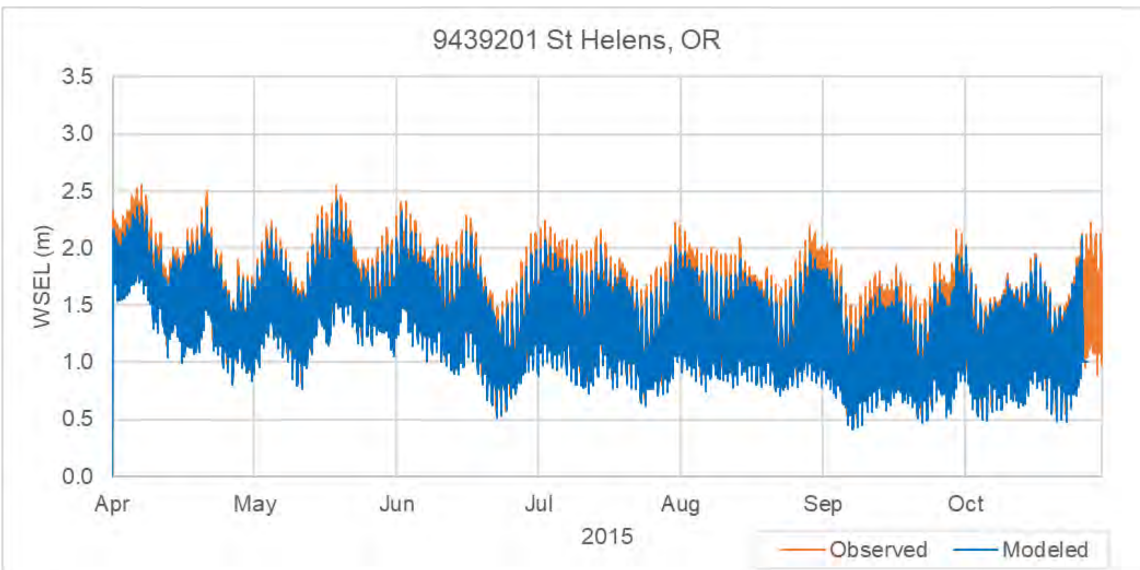

Figure 3-55. Columbia River at St. Helens water surface elevation comparison, 2015

Table 3-5 Lower Willamette River hydrodynamic calibration statistics, 2015

Location	Model Segment	Sample Size (n)	Mean Error	Mean Absolute Error	RMSE Error	Nash Sutcliff Efficiency (%)
Flow (cms)						
USGS 14246900 Columbia River at Port Westward near Quincy, OR	347	5017	26.36	996.89	1323.01	0.92
USGS 14211720 Willamette River at Portland, OR	66	4657	-18.05	189.55	256.89	0.72
Water Surface Elevation(m)						
USGS 14207770 Willamette River Below Falls, At Oregon City, OR	2	20154	-0.042	0.16	0.23	0.76
USGS 14211720 Willamette River at Portland, OR	66	26113	0.42	0.44	0.47	-0.065
USGS 14128870 Columbia River Below Bonneville Dam, OR	118	20156	-0.006	0.048	0.064	0.99
USGS 14144700 Columbia River at Vancouver, WA	223	20160	0.54	0.54	0.56	-0.79
9440422 Longview, WA	315	50400	-0.27	0.28	0.37	0.33
9439201 St Helens, OR	270	5040	-0.21	0.23	0.34	0.23

3.6 TEMPERATURE CALIBRATION

Temperature calibration involved comparisons of modeled temperature and observed water temperature data. Out of the 17 water temperature stations used previously in 2001/2002, only 3 stations had data within the model domain during the year 2015, including only one station on the Willamette River. Several of the water temperature stations were from Oregon's Laboratory Analytical Storage and Retrieval Database (LASAR) and had an associated ID which is similar to the LASAR but only had data during either 2001 and/or 2002 but no data collected during 2015. In addition, a new station maintained by the City of Portland – CRU located near Vancouver was also identified and used in the calibration. Table 3-6 shows the stations used for water temperature calibration.

Table 3-6. Lower Willamette water temperature calibration sites

ID	Description	Latitude	Longitude	Source	RM	Model Segment
14211720	Willamette River at Portland, OR	45.5175	-122.669	USGS	12.5	66
453439122223900	Columbia R., Right Bank at Washougal, WA	45.5773	-122.379	USGS	121.75	188
453630122021400	Columbia R., Left Bank, Near Dodson, OR	45.6082	-122.038	USGS	140.4	134
CRU	CRU – Columbia River upstream of outfall 001	45.6213	-122.689	City of Portland WB	106.5	225

Figure 3-56 through Figure 3-59 show plots of model predicted temperature and data. The figures show that the model captures the temperature fluctuations and seasonal patterns at all the stations. In addition, daily maximum and 7-day average daily maximum (7DADM) observed and modeled water temperature calibration plots can be found in Appendix A. Finally, error statistics comparing model predicted temperatures with continuous temperature data are shown below in Table 3-7. See Section 2.1.1 for an explanation of the error statistic metrics used for evaluation.

The values of the parameters related to heat transfer from the 2001/2002 model are still used for the 2015 model calibration. No adjustments to these parameters were made since the model was able to reflect spawning period conditions well. Continuous hourly temperature error statistics showed that the MAE and RMSE were under 1ºC. The MAE ranged from 0.08 to 0.685 ºC and the RMSE ranged from 0.11 ºC to 0.8 ºC for the Lower Willamette River model across all the calibration stations. The water temperature calibration and corresponding error statistics are similar to those calculated for the years 2001 and 2002. However, at the Willamette River at Portland gage the model was able to match the observed temperatures until about mid-June (with some minor underprediction seen during this period), following which, the model consistently underpredicted the observed water temperatures at this site for the rest of the year. A model testing was conducted to evaluate what could contribute to the underprediction. It was found that the upstream water temperature boundary condition, which represents the water temperature from the Middle Willamette River significantly impacts the water temperature at this location. It should be noted that the current upstream water temperature boundary condition is from the Middle Willamette River W2 model because no reliable observation of water temperature in the outflow of the Middle Willamette River are available.

The heat parameters were adjusted to evaluate the model responses at the Willamette River at Portland station. However, model results did not improve with adjusted parameter values. The upstream boundary temperatures were then evaluated to identify any seasonal trends in the boundary conditions that may be propagating through the system. Note that the flow and water temperature output from the USGS Middle Willamette W2 model were used as input to the Lower Willamette River W2 model as the upstream boundary. The water temperature from the Middle Willamette model showed the same pattern of underprediction i.e., under predicting in the summer of the first half of the model run and underpredicting in the second half of the year during 2015 (see Figure 29 of the USGS report, Stratton Garvin et al. 2022).

A model sensitivity run of the upstream boundary water temperatures for the Lower Willamette River, performed by increasing the water temperature, showed that the temperatures at the Willamette River at Portland station could be potentially improved if the upstream boundary temperatures were higher. When the temperature from the Middle Willamette River is higher, the modeled water temperature at the Portland station becomes correspondingly higher. The observed data from Oregon Department of Fish and Wildlife (ODFW) was also tested as the upstream boundary condition. ODFW recorded water temperature at 7 am at the Willamette Falls Fish ladder location. A regression equation was generated by matching the timing between the ODFW data and Middle Willamette W2 results at Segment 396. The water temperature results at the Portland station were improved using the ODFW data with estimated water temperature derived from the regression equation. However, upon consultation with ODFW it was found that the data were not accurately depicting the temperature in the river. Therefore, the ODFW data were not used for model calibration, and the upstream boundary from Middle Willamette to the Lower Willamette River was left unchanged. In the future, improvements to the water temperatures calibration results in the Middle Willamette River W2 model could potentially improve the model calibration as the temperature out of the Middle Willamette significantly influences the temperatures around the Portland Harbor area in the Lower Willamette.

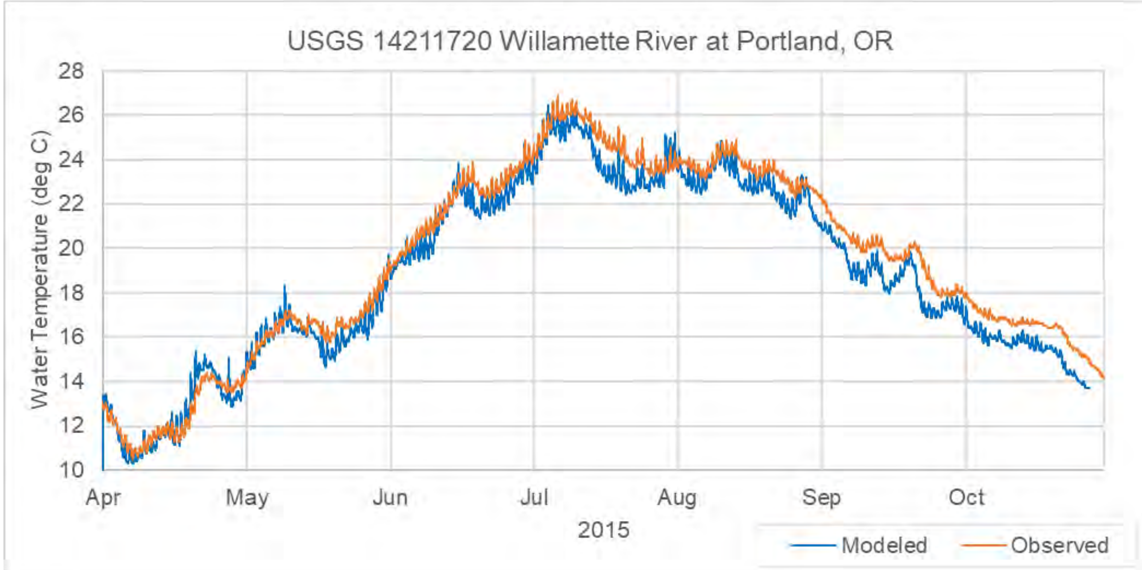

Figure 3-56. Willamette River at Portland water temperature comparison, 2015

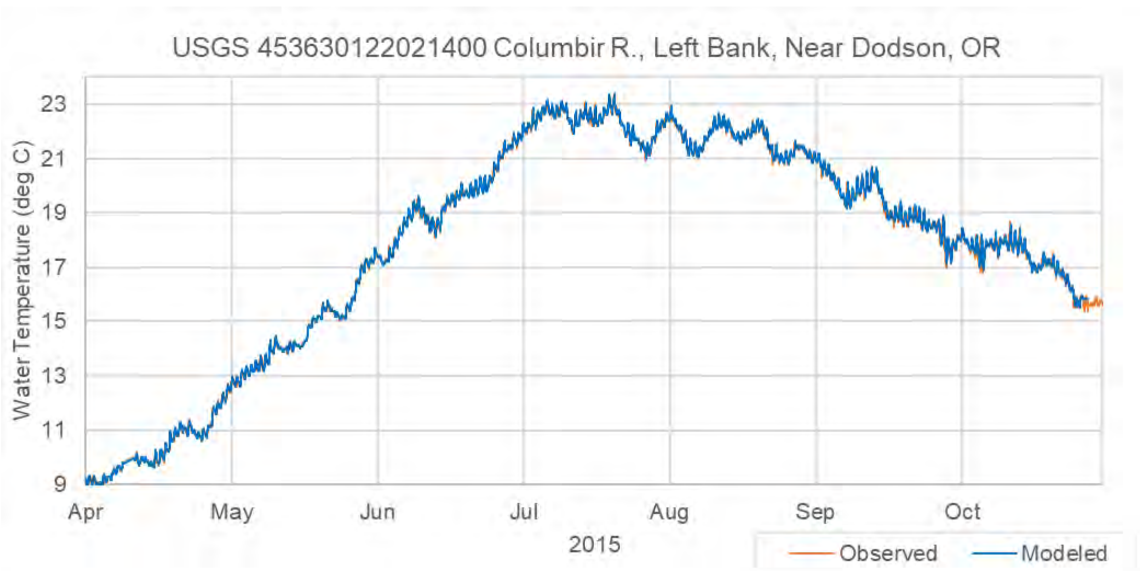

Figure 3-57. Columbia River, left bank, near Dodson water temperature comparison, 2015

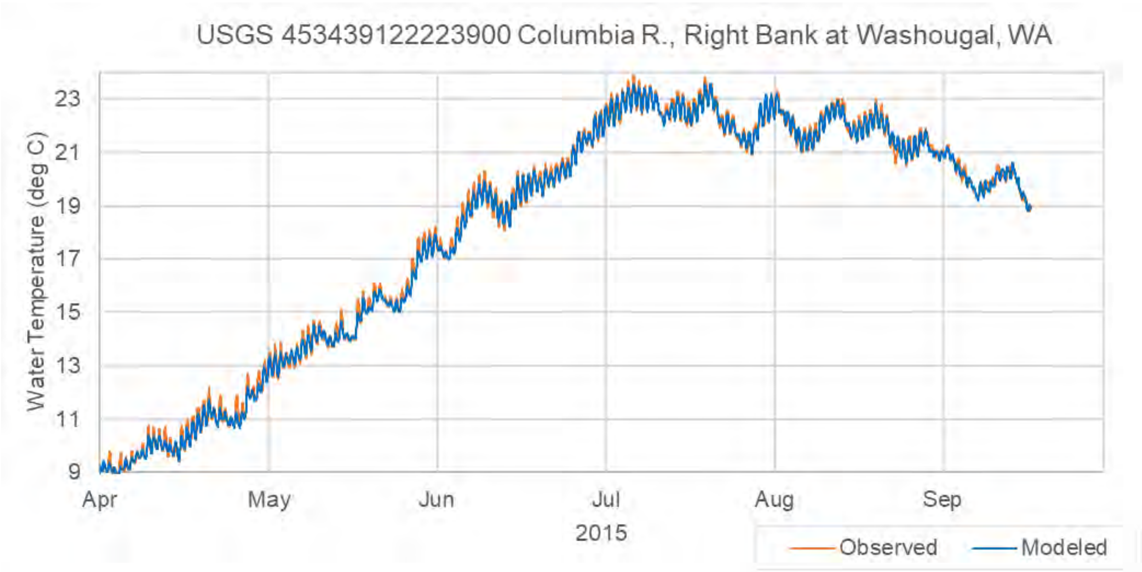

Figure 3-58. Columbia River, right bank at Washougal water temperature comparison, 2015

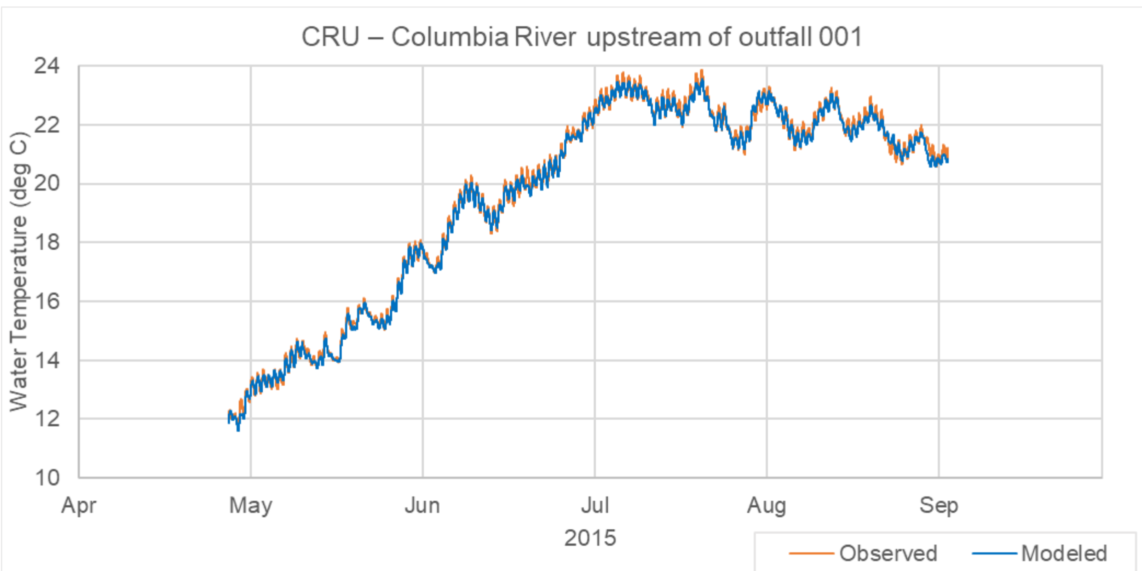

Figure 3-59 Columbia River upstream of outfall 001 water temperature comparison, 2015

Table 3-7 Lower Willamette River water temperature calibration statistics, 2015

Location	Model Segment	Sample Size (n)	Mean Error (ºC)	Mean Absolute Error (ºC)	RMSE Error (ºC)	Nash Sutcliff Efficiency (%)
Hourly Water Temperature (ºC)						
USGS 14211720 Willamette River at Portland, OR	66	10067	-0.58	0.69	0.80	0.96
USGS 453439122223900 Columbia R., Right Bank at Washougal, WA	188	4056	-0.06	0.14	0.18	0.99
USGS 453630122021400 Columbia R., Left Bank, Near Dodson, OR	134	4992	0.02	0.08	0.11	0.99
CRU – Columbia River upstream of outfall 001	225	12278	-0.05	0.11	0.15	0.99
7DADM Water Temperature (ºC)						
USGS 14211720 Willamette River at Portland, OR	66	204	-0.42	0.54	0.64	0.98
USGS 453439122223900 Columbia R., Right Bank at Washougal, WA	188	163	-0.19	0.19	0.21	0.99
USGS 453630122021400 Columbia R., Left Bank, Near Dodson, OR	134	204	0.03	0.04	0.04	0.99
CRU – Columbia River upstream of outfall 001	225	123	-0.17	0.17	0.18	0.99
Daily Maximum Water Temperature (ºC)						
USGS 14211720 Willamette River at Portland, OR	66	210	-0.42	0.61	0.73	0.97
USGS 453439122223900 Columbia R., Right Bank at Washougal, WA	188	169	-0.19	0.20	0.24	0.99
USGS 453630122021400 Columbia R., Left Bank, Near Dodson, OR	134	210	0.03	0.05	0.07	0.99
CRU – Columbia River upstream of outfall 001	225	129	-0.17	0.18	0.21	0.99

4.0 CLACKAMAS RIVER MODEL

The Clackamas River temperature model is an update of an existing W2 version 3.12 model originally calibrated for the period from April through October of 2001 and 2002 and was also used in the TMDL developed during 2006. The model was developed by PSU (Annear et al. 2004 and Berger et al. 2004), with updates to reflect parameters and inputs from a separate W2 model of the Clackamas River developed by Portland General Electric (PGE). For the current effort, the model was updated to version 4.2 of the W2 model. This was done to use the most recent version of W2 and to ensure consistency with the remaining W2 models in the Willamette River watershed, which were also developed using version 4.2. The following sections describe the model configuration and flow and temperature calibration for the year 2015.

4.1 MODEL DOMAIN

The extent of the model domain is the Clackamas River from River Mill Dam (Estacada Lake, Clackamas River RM 22.6) to the river's confluence with the Willamette River. Figure 4-1 shows the Clackamas River model domain.

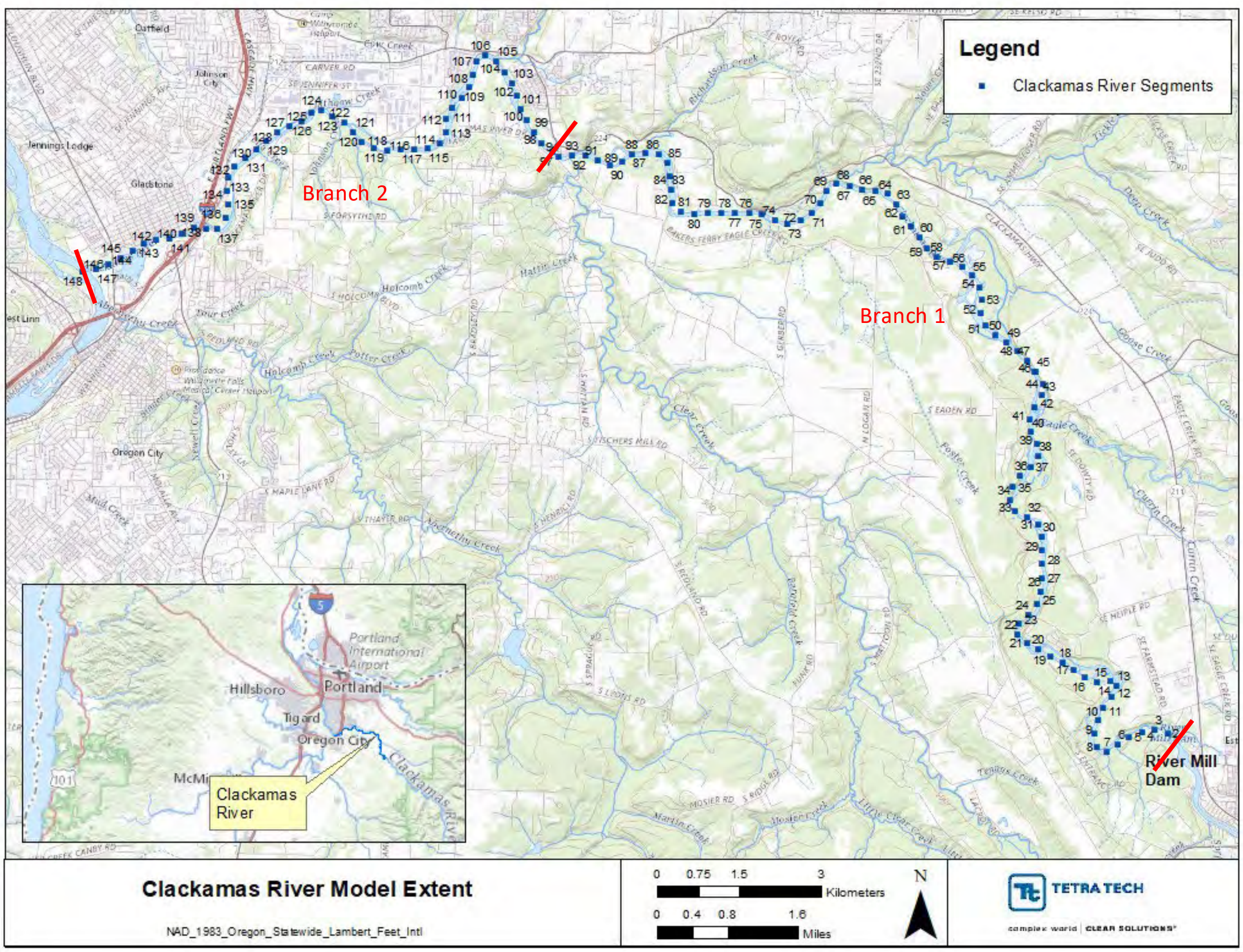

Figure 4-1. Clackamas River Model Domain

4.2 SPATIAL AND TEMPORAL RESOLUTION

The existing 2001/2002 model segmentation included one water body and two branches. The branches were selected based on changes in the channel bottom slope. The model has 149 segments; 145 of which are active (Branch 1 Segments 2 to 94 and Branch 2 Segments 97 to 148); and each segment has a length of 251.06 meters. The upstream boundary condition was configured using the flow and temperature from the USGS gage station at Estacada. The downstream boundary condition was configured as an artificial spillway that discharges to the Willamette River. The model segmentation and bathymetry left unchanged from the original model were used in the 2006 TMDL (Annear et al. 2004 and ODEQ 2006). Data availability during the years 2015 and 2016 were evaluated. The model simulation period is the year 2015. The modeling period was from April through October.

4.3 MODEL INPUTS

4.3.1 Model upstream and downstream boundary conditions

The upstream boundary condition for the Clackamas River model was configured using flow and temperature data from the USGS 14210000 gage station at Estacada, OR. The gage station is just below the Rivermill Reservoir Dam. The station is located at RM 22.22 and records flow data a 15-minute frequency. Figure 4-2 shows the upstream boundary flow used in the Clackamas River Model. The downstream boundary condition was set as an artificial spillway which discharges to the Lower Willamette River (Annear et al. 2004).

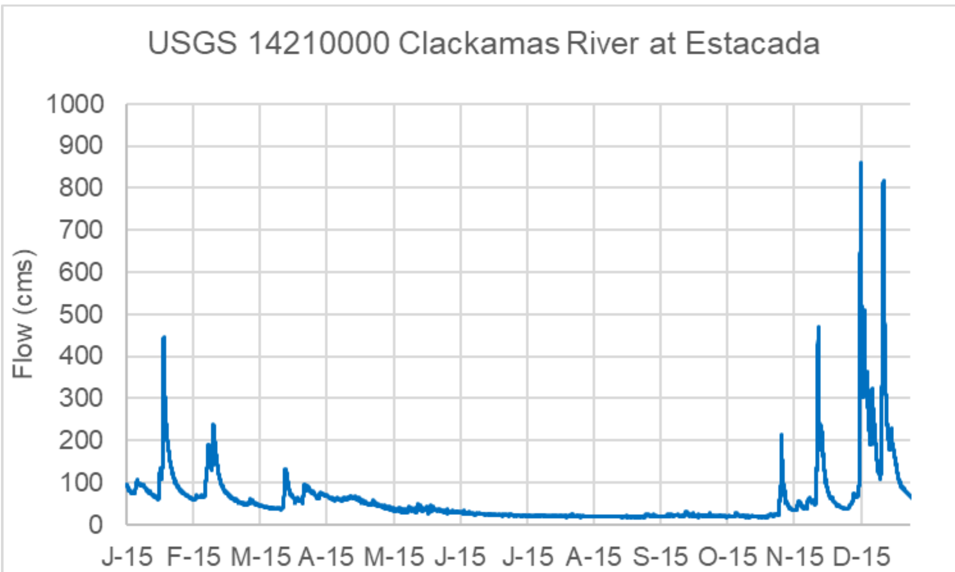

Figure 4-2. Observed flow time series at Clackamas River at Estacada

Like the flow, the upstream boundary water temperature data for the Clackamas River model was configured using data from the USGS station at Estacada 14210000. The station records water temperature at a 30-minute frequency interval. Figure 4-3 shows the upstream boundary water temperature used in the Clackamas River model.

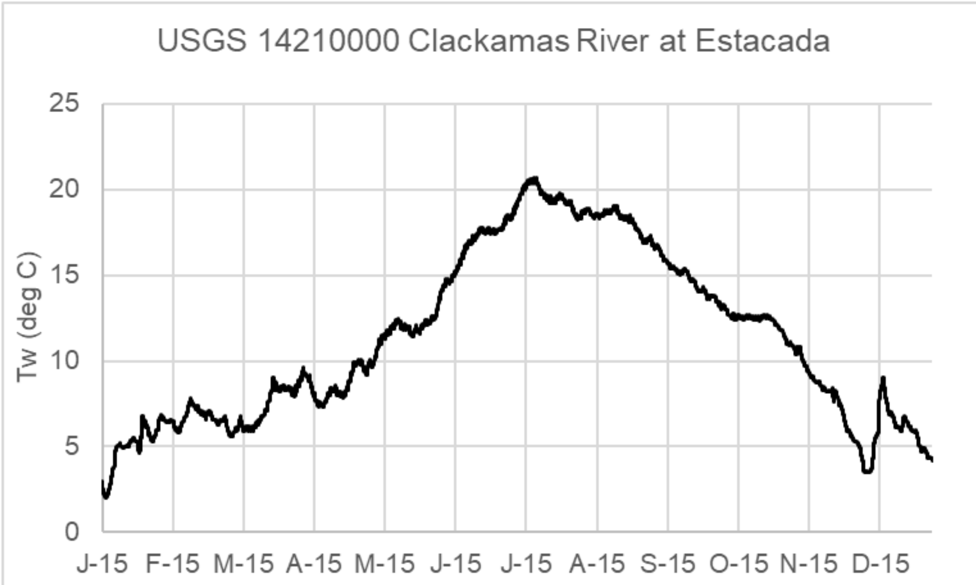

Figure 4-3. Observed water temperature time series at Clackamas River at Estacada

4.3.2 Tributary boundary conditions

Flow data

Tributary flows were specified for four major tributaries that drain into the Clackamas, i.e., Deep Creek, Clear Creek, Eagle Creek, and Rock Creek (Figure 4-4). Daily flow values were developed for Deep Creek, Clear Creek, and Eagle Creek using the same methodology described in the previous PSU report (Annear et al. 2004). In the previous modeling effort, flow relationships were developed using the USGS gage at Estacada to fill in gaps during the development of the current condition calibration model for 2001.

For the current modeling effort, the flow correlations developed with Estacada were used to develop tributary flow boundaries for the 3 tributaries (Eagle Creek, Deep Creek, and Clear Creek) in the 2015 model. The calculated flows for these tributaries are shown in Figure 4-5. Rock Creek flows were estimated using the fractional flow from the Deep Creek basin, as was done previously. The Deep Creek basin is adjacent to the Rock Creek basin, and both basins are on the northern side of the catchment and are more likely to share similar topography and rainfall patterns (Annear et al. 2004). The Rock Creek basin area (0.021 km^2) is 16.57% of the size of the Deep Creek basin area (0.127 km^2). Rock Creek flows were estimated based on the area-weighted proportional flows from the Deep Creek basin. Table 4-1 shows the different regression relationships and associated statistics developed in Annear et al. (2004) that were used for developing the tributary flow boundary conditions for 2015.

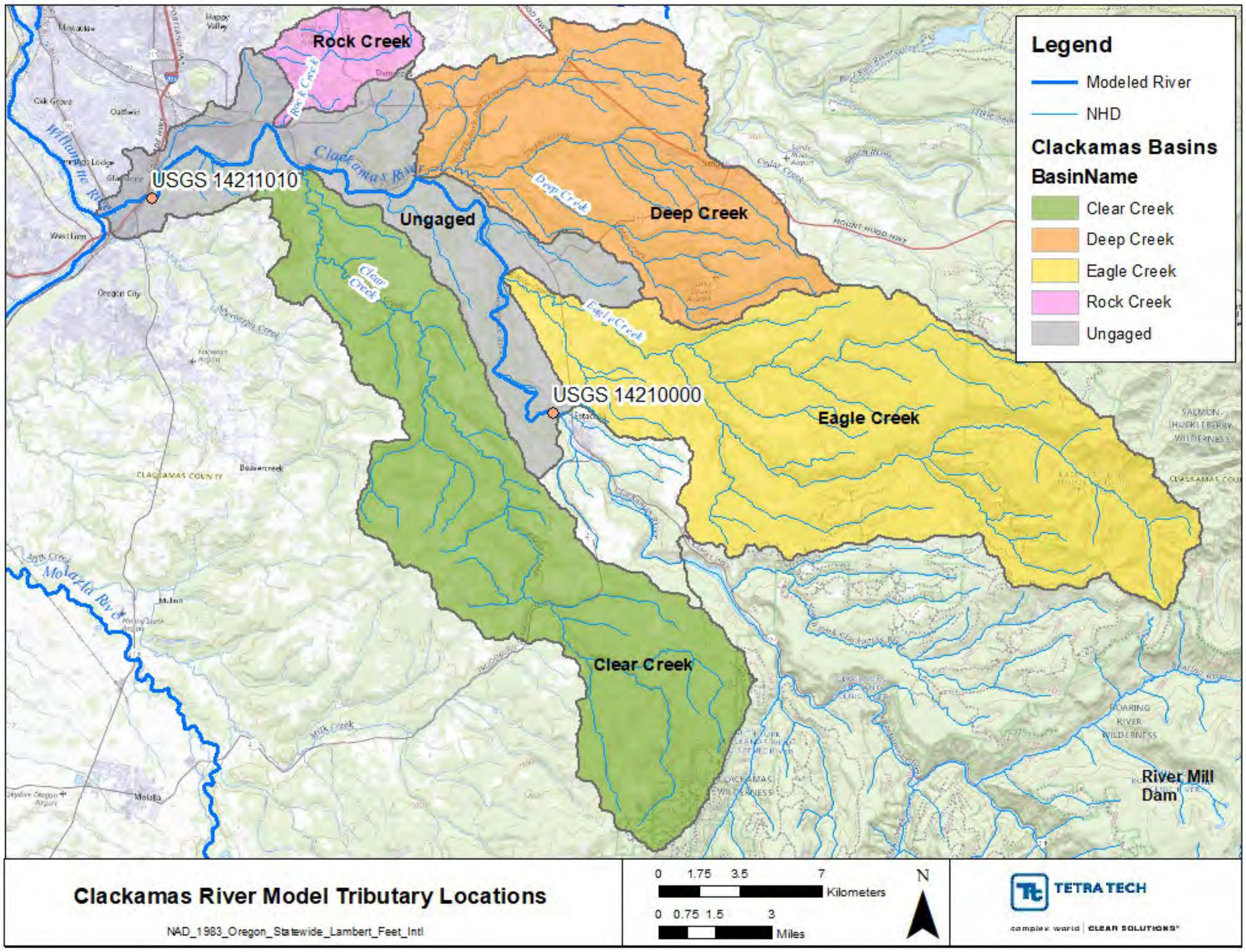

Figure 4-4 Clackamas River Model Tributary Locations

Table 4-1. Regression relationships used to develop the tributary flow for the Clackamas River Model

Tributary	Regression relationship for flow with the Estacada USGS site	Number of Points used	R^2 value
Eagle Creek	$Y = 0.1262\ X - 1.3816$	518	0.721
Deep Creek	$Y = 0.0306\ X - 0.2739$	518	0.564
Clear Creek	$Y = 0.0559\ X - 0.5337$	518	0.708
Rock Creek	Based on area ratio with Deep Creek		

Note: For details on how the individual equations were developed see (Annear et al. 2004)

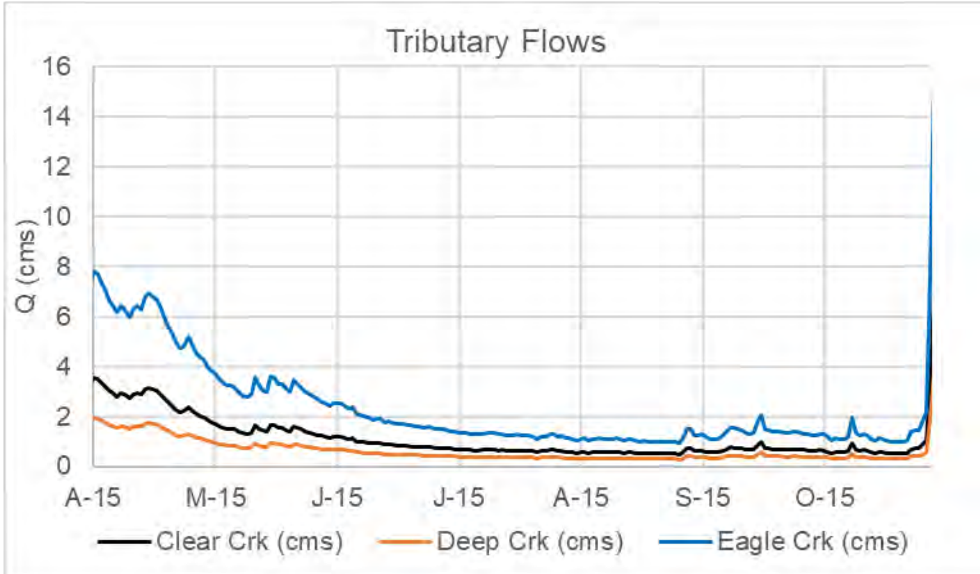

Figure 4-5. Tributary flow assignment in the Clackamas River model.

In addition to tributary flows, there were also five daily withdrawals (one of which was the Clackamas Hatchery withdrawal) and distributed tributaries assigned in the previous model. No withdrawal data were available for 2015 and withdrawal values were kept the same as the 2001 model. An exception to this was the Clackamas Hatchery, which was updated with flows for 2015 (the Hatchery is discussed under Section 4.3.3). The ungaged flows distributed along the Clackamas River were specified as a distributed tributary in the model. The daily flows from the USGS gage at Estacada at the upstream boundary, the daily flows from the various tributaries, and the withdrawals were summed up and then subtracted from the daily flows at the USGS Oregon City gage at the downstream boundary. The resulting total additional flow was then attributed to the ungaged area and assigned as distributed tributary. The distributed tributaries for the two branches in the Clackamas River model were derived by dividing the total additional flow by the segment length; Model Branch 1 was 14.39 miles long and Branch 2 was 7.94 miles long of a total of 22.33 miles. Figure 4-6 shows the distributed tributary flows for the Branch 1 and Branch 2 assigned in the model.

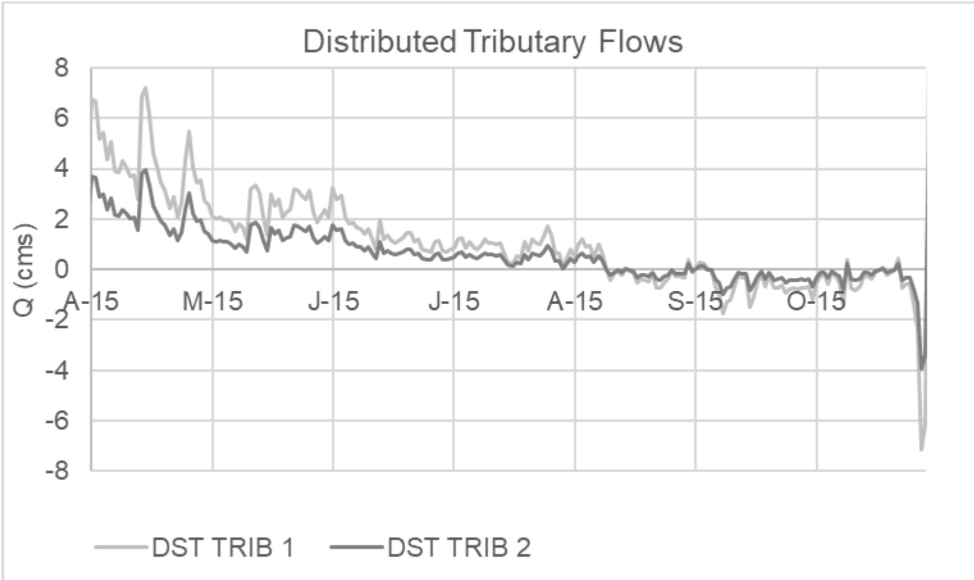

Figure 4-6. Distributed tributary flows assigned in the Clackamas River model.

Water temperature data

Water temperature data for each of the four tributaries that was previously available from PGE during 2001/2002 was not available for 2015/2016. Water temperature at Eagle Creek, Deep Creek, and Clear Creek were estimated using regression relationships previously developed between temperature data from the respective tributary and the Estacada USGS site. Table 4-2 shows the regression relationships and associated statistics developed in the previous modeling effort (Annear et al. 2004). They were used for developing the tributary water temperature boundary conditions for 2015. For Rock Creek, data from Deep Creek were directly used as surrogates for this tributary and were therefore set the same as Deep Creek. Figure 4-7 shows the tributary water temperature boundaries used in the 2015 Clackamas River model.

Table 4-2. Regression relationships used to develop the tributary water temperature for the Clackamas River Model

Tributary	Regression relationship for water temperature with the Estacada USGS site	Number of Points used	R^2 value
Eagle Creek	$Y = 0.9156X^{1.0343}$	4413	0.715
Deep Creek	$Y = 0.9122\ X^{1.0188}$	2541	0.787
Clear Creek	$Y = 1.2867\ X - 2.7753$	4367	0.793
Rock Creek	Assumed to be same as Deep Creek		

Note: For details on how the individual equations were developed see (Annear et al. 2004)

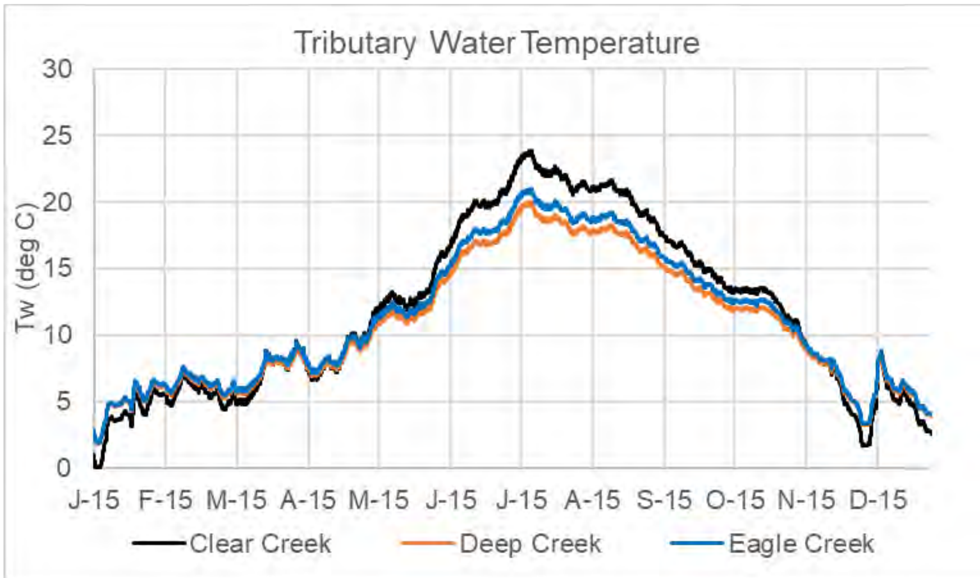

Figure 4-7. Tributary water temperature boundaries used in the Clackamas River model.

Previously distributed tributary temperatures collected by PGE during 2000 and 2001 were used to configure the model for the years 2001 and 2002. Groundwater monitoring water temperature data were not available for 2015, so the same water temperatures were used to configure the model for 2015 (as shown in Figure 4-8).

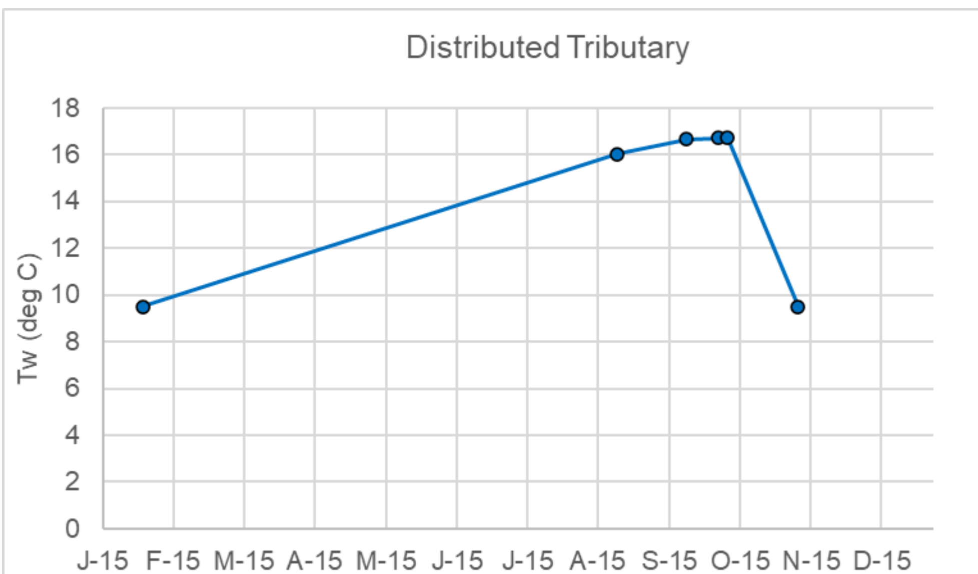

Figure 4-8. Distributed tributary temperature assignment for the 2015 Clackamas River model

4.3.3 Point Sources

There is one permitted individual NPDES point source along the model extent (Table 4-3 and Figure 4-9). The Clackamas River Hatchery NPDES Permit #102663 is an aquatic animal production facility that includes treated and pass-through discharges (outfall 001) to the Clackamas River. This point source input is not discussed in the PSU model documentation (Annear et al. 2004), but this input is included in the model for the 2015 model development. The model includes a Clackamas Hatchery withdrawal from segment 3 and a tributary input at segment 4 just downstream to represent this pass-through point source. Daily flow and water temperature from ODFW were extracted from monthly PDF DMRs. Data were available for the period from April through December for 2015 and were used to configure the model. Figure 4-10 shows the flow and effluent water temperature for the Clackamas River Hatchery. The data were collected daily at around 5 PM as noted in the DMR records.

Table 4-3. Summary of NPDES facility along Clackamas River

WQ File Number	NPDES Permit #	Name	Flow Frequency	Temperature Frequency	Latitude	Longitude	River Mile	Model Waterbody
64442	102663	ODFW - Clackamas River Hatchery	Daily	Daily Maximum	45.2959	-122.362	22.6	Clackamas River

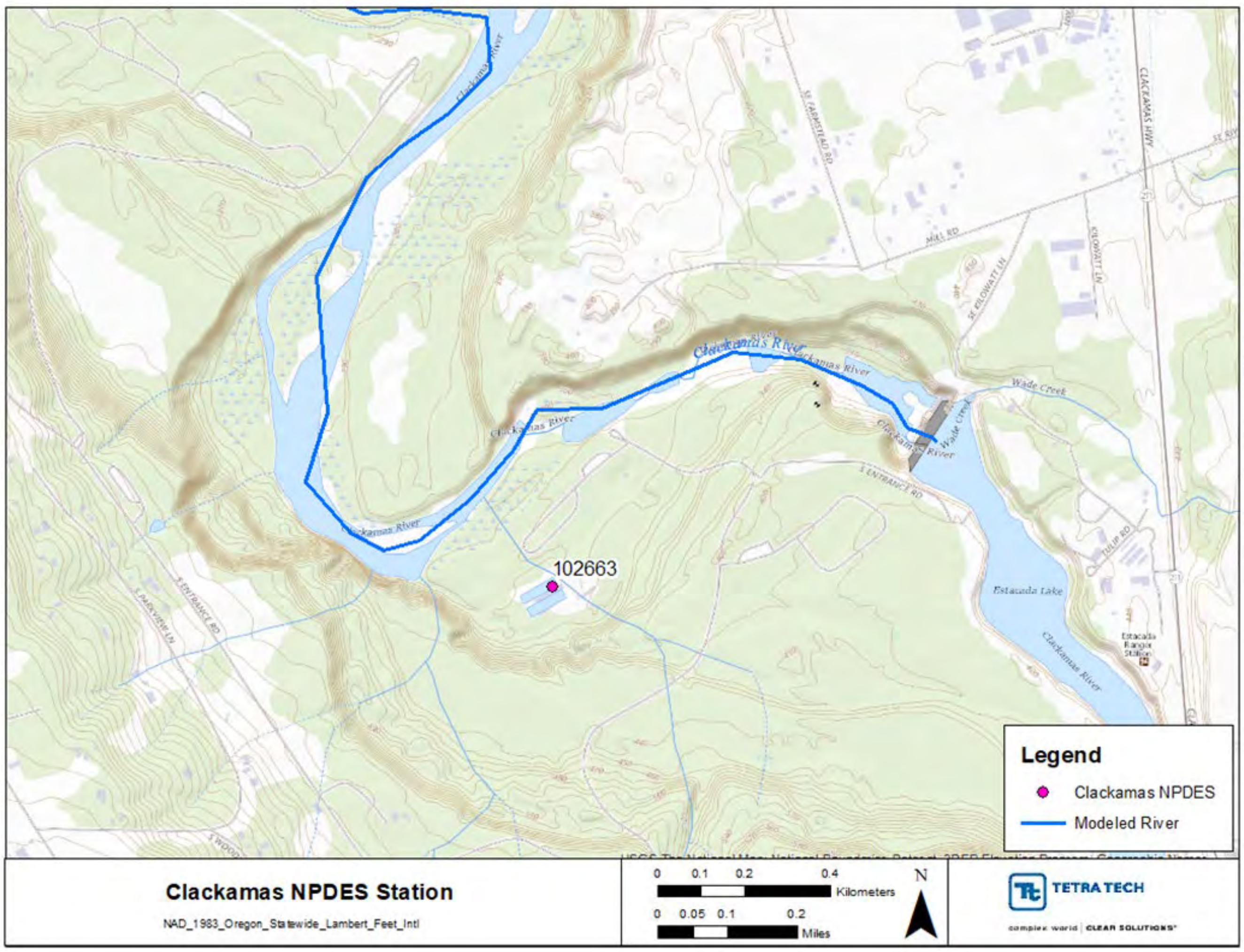

Figure 4-9. NPDES station (Clackamas Hatchery #102663) discharging to the Clackamas River.

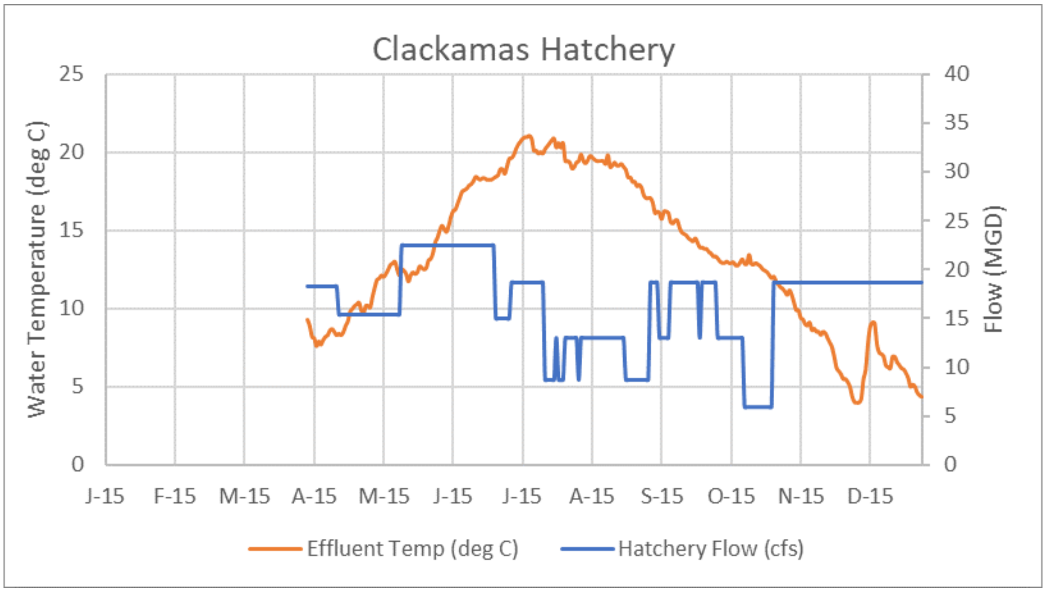

Figure 4-10 Clackamas Hatchery 2015 flow and water temperature.

4.3.4 Meteorology data

Long term hourly meteorological data were available from the MesoWest station located at Eagle Creek (EGK03) near the Clackamas River. The station is located about 3 miles east of the Clackamas River (Latitude: 45.3679, Longitude: -122.331, Elevation: 225.61 m). Figure 4-11 shows the location of the Eagle Creek weather station.

The station provided most of the required meteorological parameters. Data from the year 2015 was downloaded from this station. No missing data were reported for the year 2015. Maximum air temperature during 2015 was observed in July (38.33 ^{o}C). Mean monthly maximum air temperatures indicated 28.94 ^{o}C in July, followed by 27.81 ^{o}C August, and 22.39 ^{o}C in September.

The station also provided observed hourly solar radiation data. The Eagle Creek station does not report cloud condition. The cloud cover data were calculated from hourly descriptive sky cover conditions reported at the NCDC Aurora State Airport station (Figure 4-11). The W2 model interprets cloud cover on a scale of 0 to 10 (0 being clear and 10 being cloudy). Figure 4-12 shows the observed hourly time series used in the model.

The 2015 observed wind speed data indicate that daily wind speeds ranged from 0 to 6 meters per second, with upper range wind gusts up to 13 meters per second. Winds come from all directions, but most frequently originate from either the west-southwest or east-southeast direction. This is illustrated using a wind rose plot (described in Section 3.3.4), which provides an overall view of how wind speed and direction are typically distributed at a particular location (Figure 4-13).

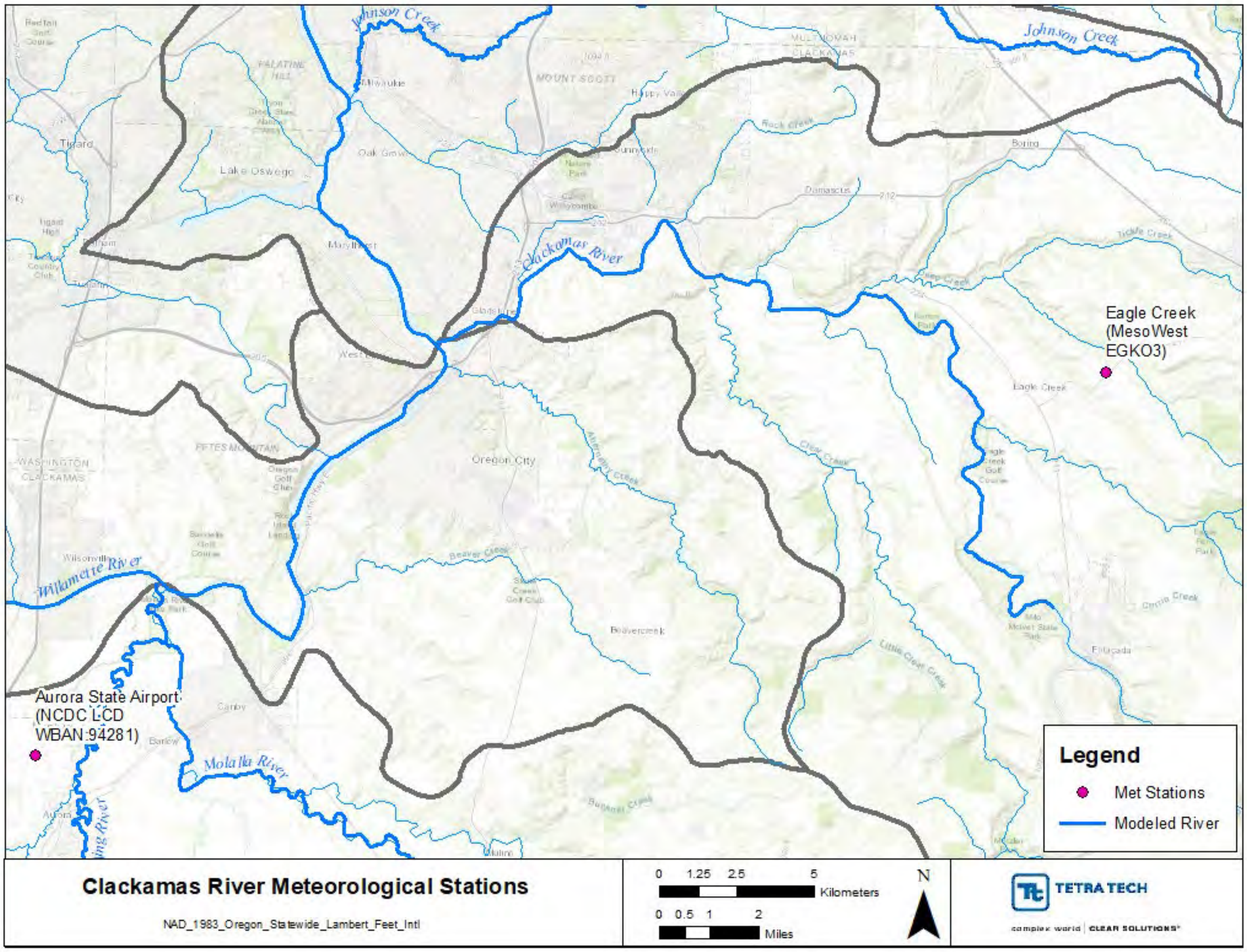

Figure 4-11. Clackamas River meteorological stations

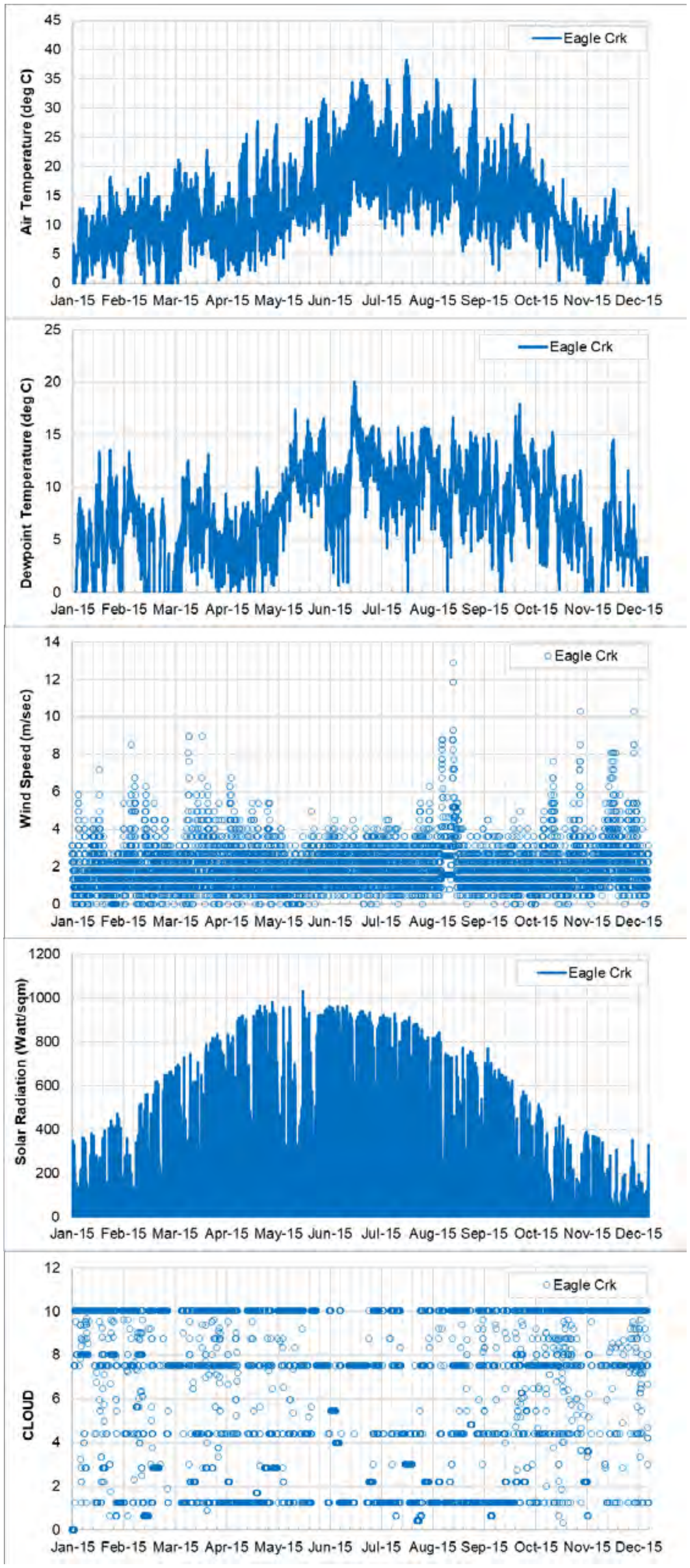

Figure 4-12. Observed Hourly Meteorological data at Eagle Creek MesoWest EGKO3 station

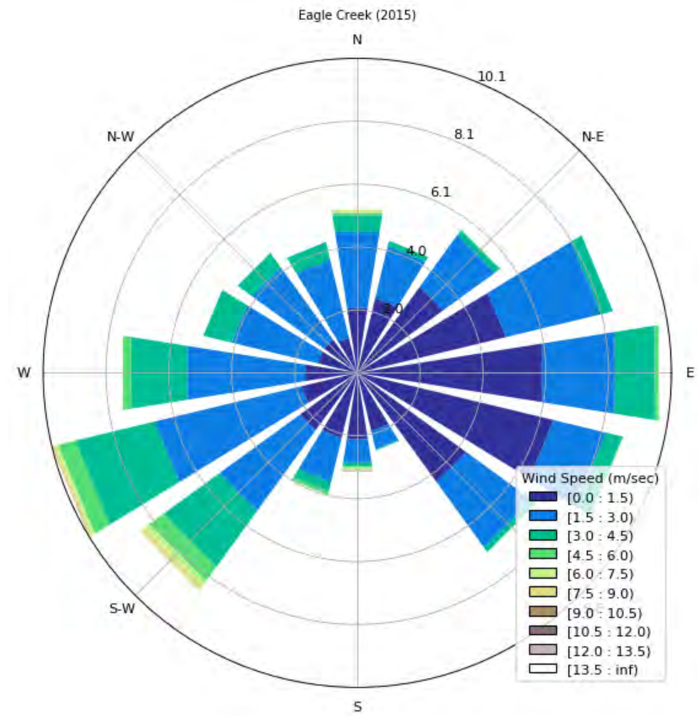

Figure 4-13. Wind Rose for the observed wind data at Eagle Creek for the full 2015 year of record

4.4 CLACKAMAS RIVER MODEL CALIBRATION

Model calibration focused on flow, water level, and water temperature data from calibration sites that had available data during the simulation period. No changes were made to the current condition calibration parameters (i.e., from 2001/2002) e.g., Manning's coefficient, wind sheltering, evaporation, and sediment temperatures in the 2015 model, as it did not further improve the calibration. An exception to this was the SROC parameter. During temperature calibration it was found that the existing model was set to use solar radiation that was internally computed and was not reading in the specified observed solar radiation. This was because the SROC parameter in the model input file was set to OFF. Reading in observed solar radiation improved the water temperature calibration, so SROC was set to ON for the 2015 model. Vegetative and topographic shade characteristics were left unchanged since the model input was developed using a detailed GIS analysis. The model calibration period was from April 1, 2015, to October 31, 2015.

Figure 4-14 shows the locations of all the flow, water level, water temperature calibration stations used in the calibration. The model calibration locations and available data during the year 2015 are further discussed in the following sections.

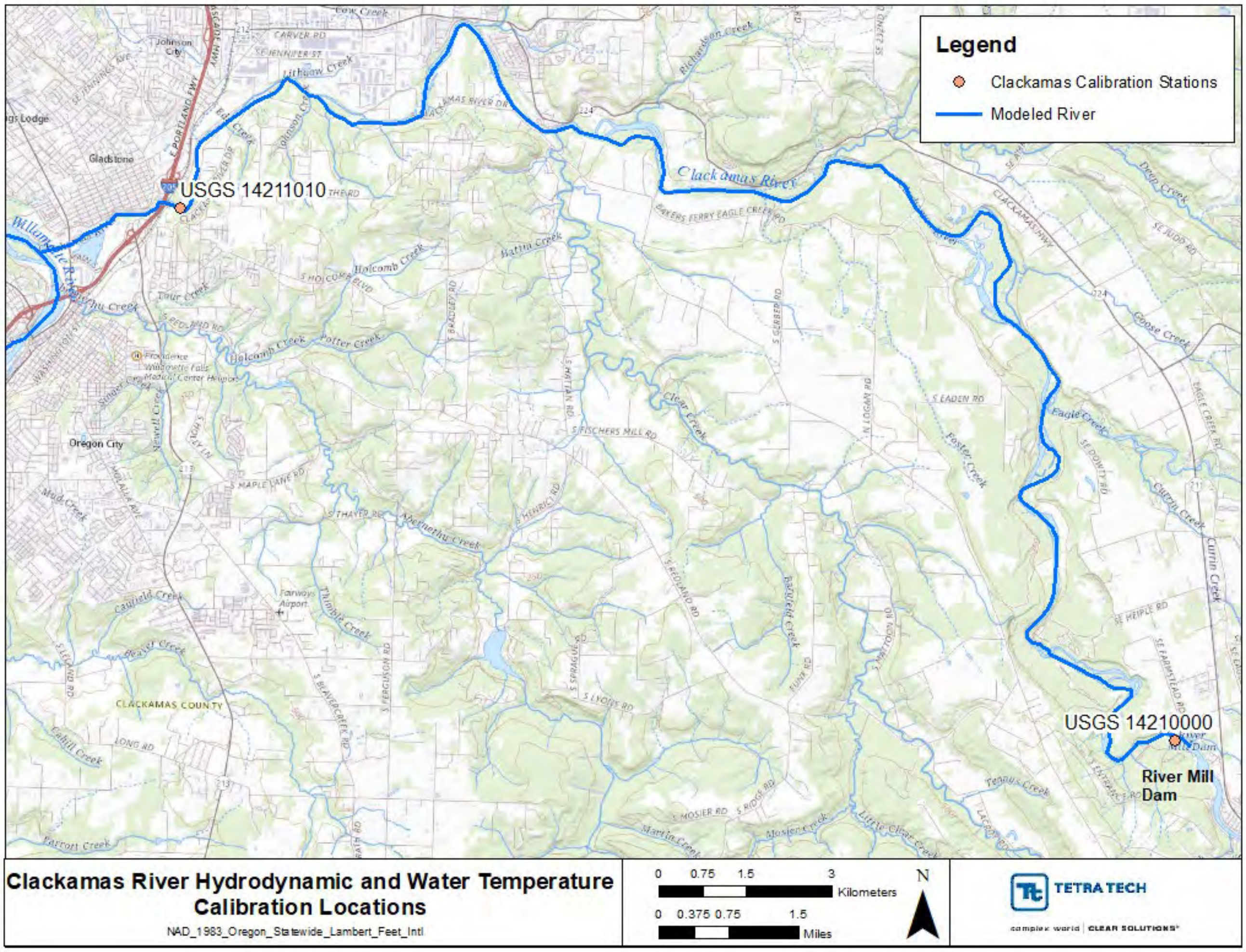

Figure 4-14 Clackamas River Model Hydrodynamic & Water Temperature Calibration Station Locations

4.5 HYDRODYNAMIC CALIBRATION

Hydrodynamic calibration included the calibration of flow and water surface elevation conditions using available data during the simulation period. Hydrodynamic calibration data were available during 2015 for the two calibration stations used during 2001/2002 (Berger et al. 2004).Table 4-4 shows the hydrodynamic calibration station locations used for 2015.

Table 4-4. Clackamas River flow, water level, and water temperature calibration sites

ID	Description	Latitude	Longitude	Model Segment	RM	Source
14210000	Clackamas River at Estacada, OR	45.299844	-122.35398	22.22	2	USGS
14211010	Clackamas River near Oregon City, OR	45.37944	-122.576	2.41	133	USGS

Model calibration was evaluated using a combination of visual inspection of time series plots and model error statistics. Figure 4-15 and Figure 4-16 compare the modeled and observed flows and Figure 4-17 and Figure 4-18 compare the modeled and observed water surface elevations. The model error statistics for the 2015 Clackamas River hydrodynamic calibration for each station are presented in Table 4-5. See section 2.1.1 for an explanation of the error statistic metrics used for evaluation. In general, the model was able to capture the observed flows and patterns of water levels at the two stations well, matching the overall patterns during the year 2015. The model was unable to capture the observed water surface elevations initially during the first month, which is due to the model spin period, after which the model captures the observed water surface elevation patterns. The flows and water levels had an MAE less than 0.04 m^3/s and 0.1 meters, respectively, with the RMSE for the flow and water levels being less than 0.07 m^3/s and 0.15 meters, respectively. Both flow and water surface elevation calibration and corresponding error statistics are similar to those calculated for the years 2001 and 2002.

It should be noted that the datum was adjusted directly by comparing the modeled elevation and observed water surface elevation data. When the USGS datum was used to convert the water surface elevation, the model results are shifted significantly in the vertical direction. It is not clear if the datum on the USGS website is accurate, or if the bathymetry uses a different datum. However, the flow and water temperature results agree well with data. Therefore, no further exploration of the datum difference was conducted.

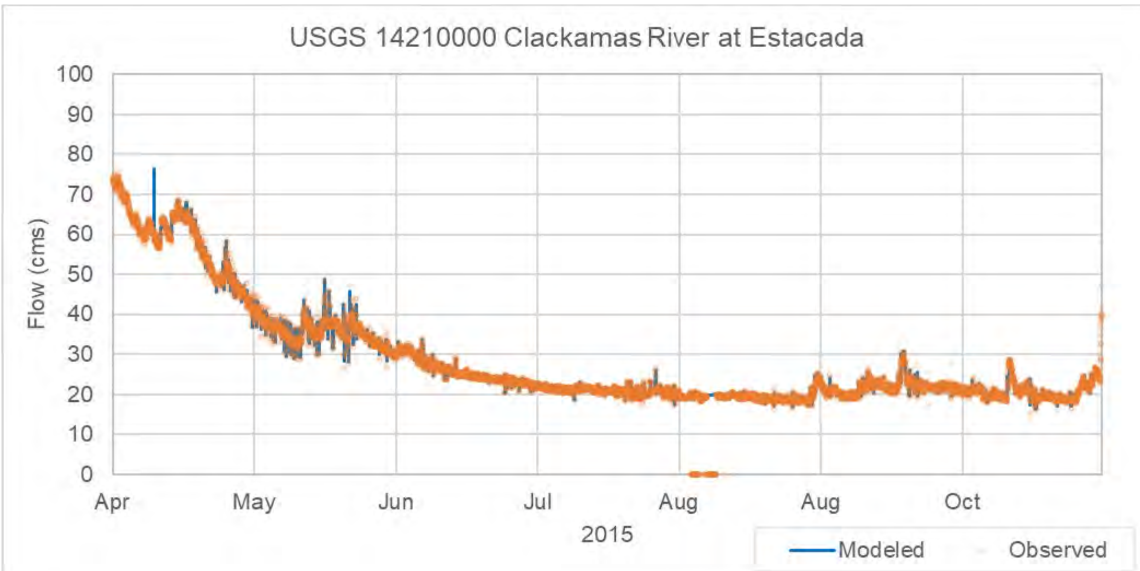

Figure 4-15 Clackamas River at Estacada flow comparison, 2015

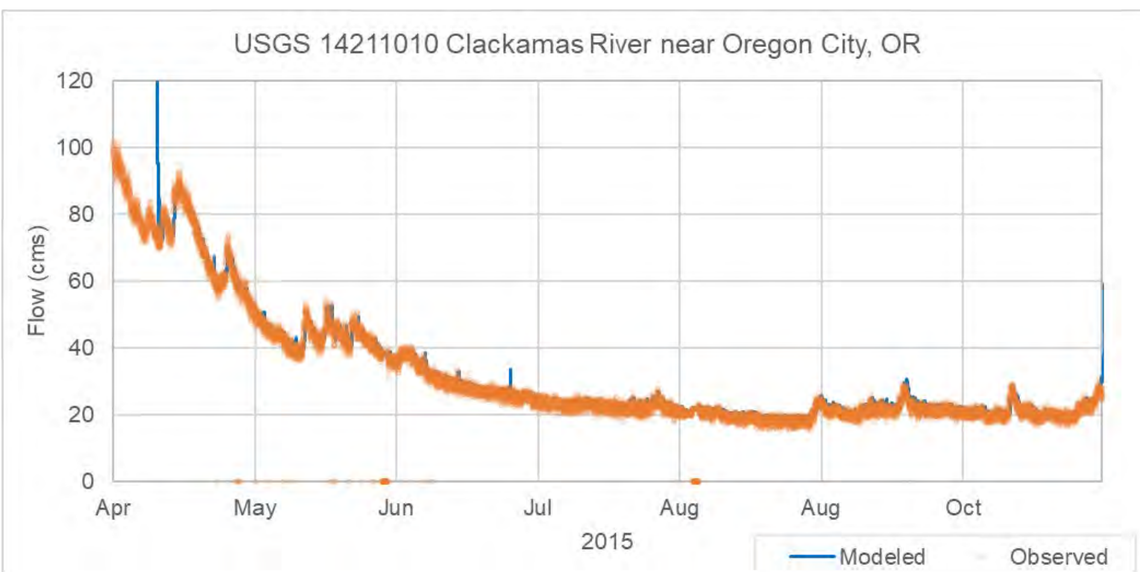

Figure 4-16 Clackamas River near Oregon City flow comparison, 2015

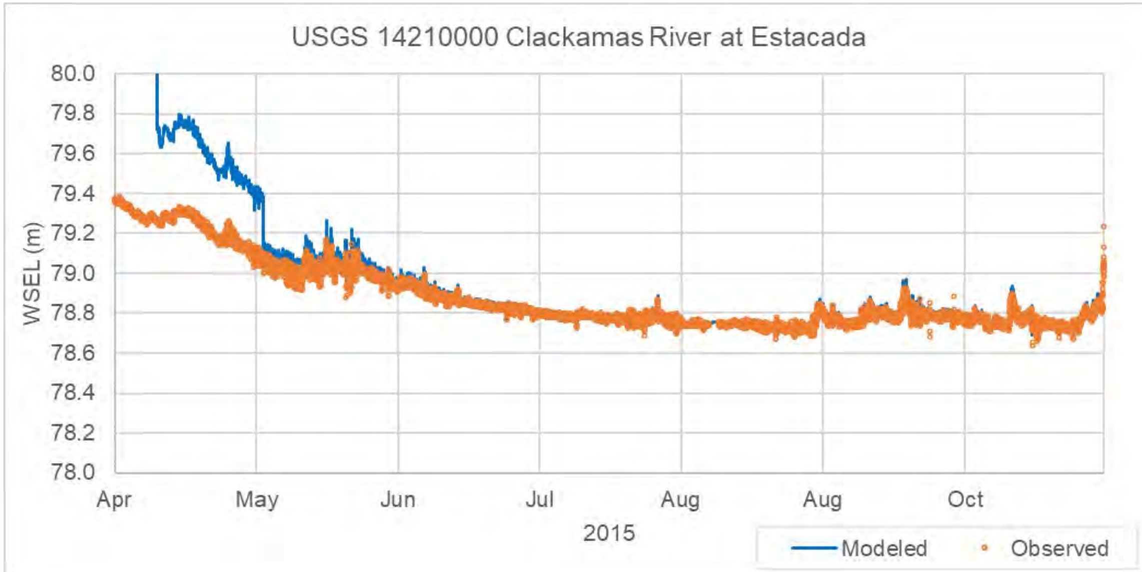

Figure 4-17 Clackamas River at Estacada water surface elevation comparison, 2015

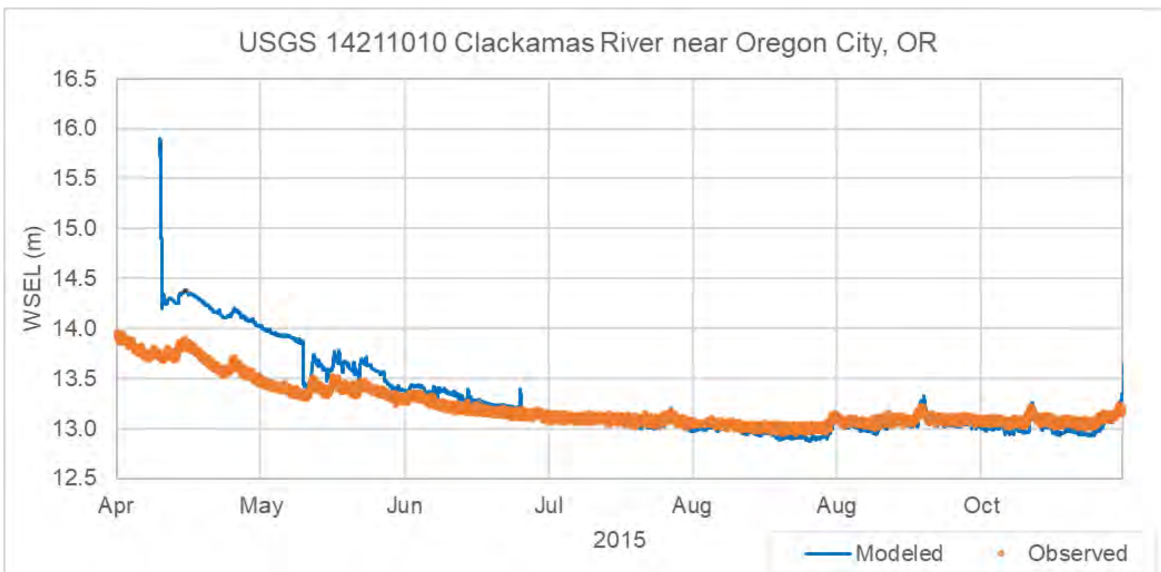

Figure 4-18 Clackamas River near Oregon City water surface elevation comparison, 2015

Table 4-5. Clackamas River hydrodynamic calibration statistics, 2015

Location	Model Segment	Sample Size (n)	Mean Error	Mean Absolute Error	RMSE Error	Nash Sutcliff Efficiency (%)
Flow (cms)						
USGS 14210000 Clackamas River at Estacada	2	17271	0.00	0.01	0.03	0.97
USGS 14211010 Clackamas River near Oregon City, OR	133	17292	0.03	0.04	0.07	0.93
Water Surface Elevation (m)						
USGS 14210000 Clackamas River at Estacada	2	17271	0.0181	0.022	0.043	0.82
USGS 14211010 Clackamas River near Oregon City, OR	133	17462	0.0302	0.10	0.15	0.17

4.6 TEMPERATURE CALIBRATION

Figure 4-19 and Figure 4-20 show plots of model predicted temperature and data. In addition, daily maximum and 7DADM observed and modeled water temperature calibration plots can be found in Appendix B. Finally, error statistics comparing model predicted temperatures with continuous temperature data are shown below in Table 4-6. Continuous temperature error statistics showed that the Estacada station had an MAE of 0.03 °C, and RMSE of 0.04 °C, and the Oregon City station had an MAE of 1.05 °C and a RMSE of 1.23 °C. The figures show that the model captures the temperature fluctuations and seasonal patterns well at the Estacada station but was found to be under predicting at the Oregon City station, especially in terms of the minimums observed in the continuous data. The model temperature calibration and corresponding error statistics are similar to those calculated for the years 2001 and 2002 at Estacada but are larger at Oregon City. However, the modeled daily maximum and 7DADM compared well with observed data with an MAE and RMSE that was less than 1 °C (Table 4-6).

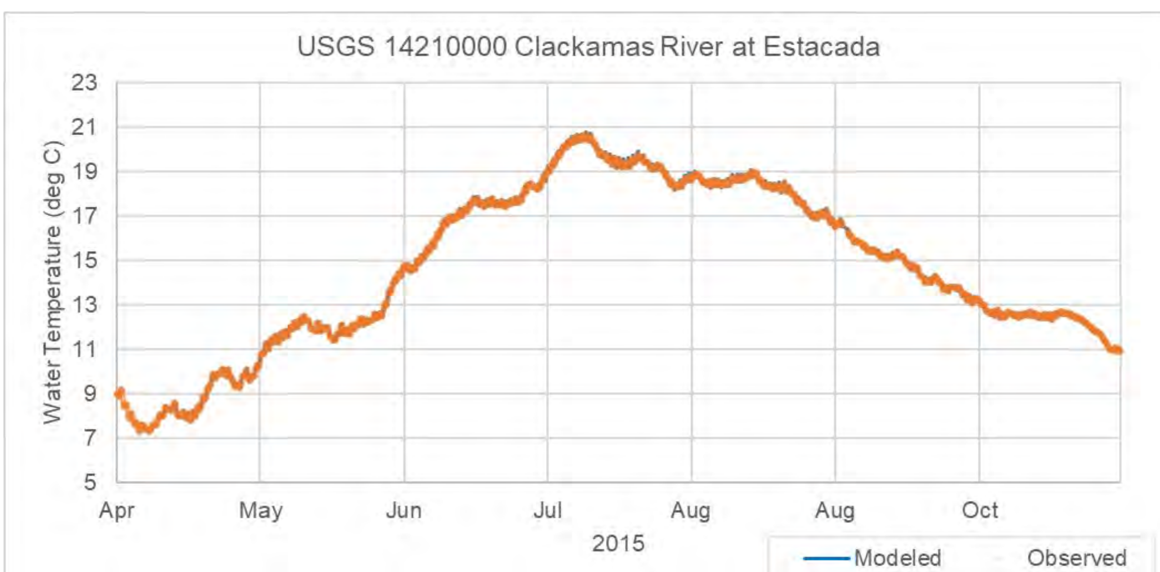

Figure 4-19. Clackamas River at Estacada water temperature comparison, 2015

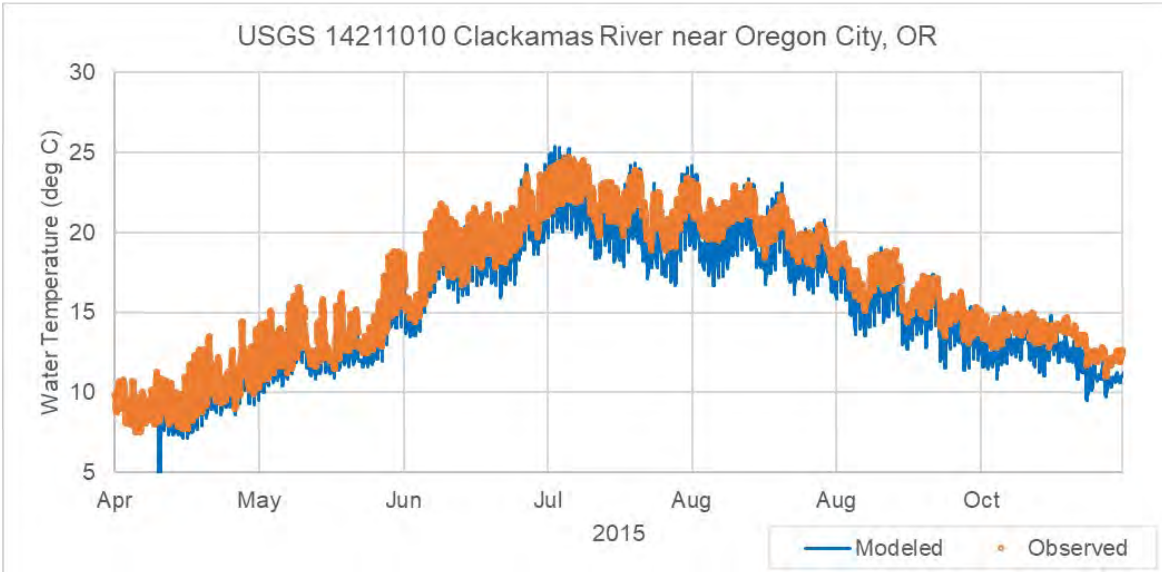

Figure 4-20. Clackamas River near Oregon City water temperature comparison, 2015

Table 4-6. Clackamas River water temperature calibration statistics, 2015

Location	Model Segment	Sample Size (n)	Mean Error (ºC)	Mean Absolute Error (ºC)	RMSE Error (ºC)	Nash Sutcliff Efficiency (%)
Hourly Water Temperature (ºC)						
USGS 14210000 Clackamas River at Estacada	2	8779	0.003	0.03	0.04	0.99
USGS 14211010 Clackamas River near Oregon City, OR	133	17416	-0.99	1.05	1.23	0.88
Daily Maximum Water Temperature (ºC)						
USGS 14210000 Clackamas River at Estacada	2	179	0.025	0.044	0.06	0.99
USGS 14211010 Clackamas River near Oregon City, OR	133	184	-0.25	0.55	0.66	0.97
7DADM Water Temperature (ºC)						
USGS 14210000 Clackamas River at Estacada	2	177	0.03	0.031	0.04	0.99
USGS 14211010 Clackamas River near Oregon City, OR	133	182	-0.24	0.41	0.52	0.98

5.0 LONG TOM RIVER MODEL

The Long Tom River temperature model is an update of an older W2 version 3.12 model originally calibrated for the period of approximately April through October of 2001 and 2002 and was used in the TMDL developed during

2006. The original calibrated model was developed for the 2006 temperature TMDL (ODEQ 2006) by PSU (Annear et al. 2004; Berger et al. 2004) and ODEQ (ODEQ 2006). In 2007, USGS made several improvements to the temperature models (Rounds, 2007). For the current effort, the model was updated to version 4.2 of the W2 model. This was done to use the most recent version of W2 and to ensure consistency with the remaining W2 models in the Willamette River watershed, which were also developed using version 4.2. The following sections describe the model configuration and flow and temperature calibration for the year 2015.

5.1 MODEL DOMAIN

The extent of the model domain is the Long Tom River that extends from Fern Ridge Dam (RM 23.7) to the river's confluence with the Willamette River. Figure 5-1 shows the Long Tom River model domain.

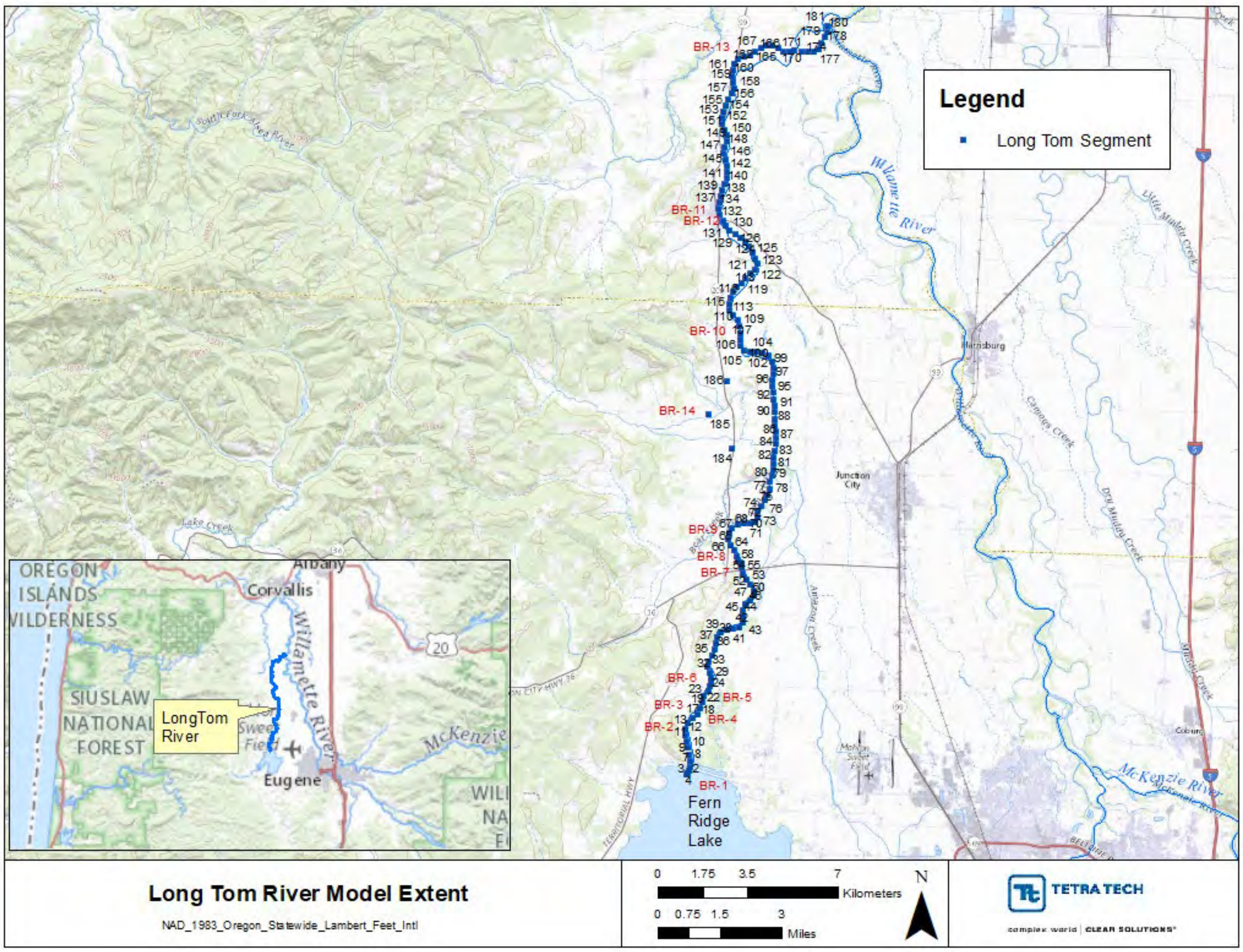

Figure 5-1. Long Tom River model domain.

5.2 SPATIAL AND TEMPORAL RESOLUTION

The current Long Tom model input bathymetry uses one water body and 13 branches along the main river and one branch (branch 14) representing a side channel (Figure 5-1). The branches were incorporated into the model to accurately predict the flow peak timings due to the several weirs/dams that lie along the model domain. The model grid has 187 segments, with segment lengths ranging from 83.88 meters to 251.06 meters. The side channel is composed of 3-segments of 1897, 2590, and 1427 meters. The model's vertical grid resolution is 1-meter throughout, with a maximum of 22-layers.

There are ten spillway structures defined along the systems, and three gates. The model also includes one withdrawal from segment 91 (RM 12.9) (constant 4 ft^3/s). The gates and withdrawals are not discussed in the model documentation (Annear et al. 2004) but are noted here since they exist in the 2001 and 2002 models. The gates and withdrawals were left unchanged for this modeling effort.

For this study, the model input configuration in terms of bathymetry and grid were largely left unchanged from the original model used in the 2006 TMDL (Annear et al. 2004 and ODEQ 2006). Minor changes to the bathymetry were required to make the model run. After converting the model to version 4.2 from version 3.12 it was found that the model encountered stability issues and would not run. The cause for the stability issue was investigated, and it was found that several segments were running dry, which was causing the model to crash. In order to make the model run, narrow artificial layers were added at the bottom of the channel at several segments in the bathymetry to maintain a wet channel, so model can run through the occasional significant low flow periods. Since the added artificial layers are narrow, they are not impacting the overall volume significantly. Data availability during the years 2015 and 2016 were evaluated. The model simulation period is the year 2015. The modeling period was from April through October.

5.3 MODEL INPUTS

5.3.1 Model upstream and downstream boundary conditions

The upstream boundary condition for the Long Tom River model was configured using flow and water temperature from the nearest upstream gage, which was the USGS gage station near Alvadore (USGS 1416999). The gage station is just below the Fern Ridge dam at RM 23.5. The station records flow data at 15-min frequency intervals. Figure 5-2 shows the upstream boundary flow used in the Long Tom River Model.

The downstream boundary condition is configured as an artificial weir that discharges to the Willamette River using the gate option in W2.

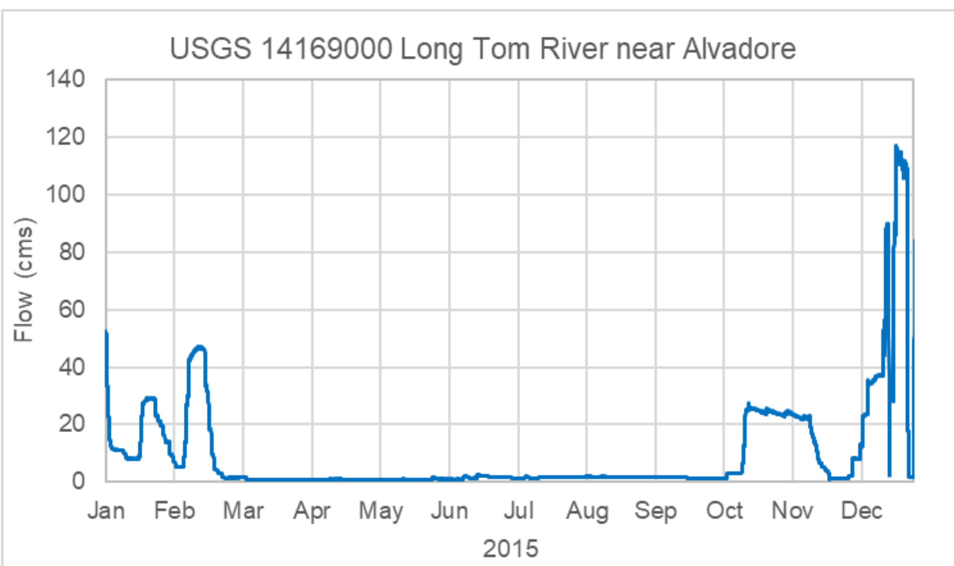

Figure 5-2. Observed flow time series at Long Tom River near Alvadore

Like the flow, the upstream boundary water temperature data for the Long Tom River model was configured using data from the USGS station near Alvadore 14169000. The station records water temperature at a 30-minute frequency. Figure 5-3 shows the upstream boundary water temperature used in the Long Tom River model.

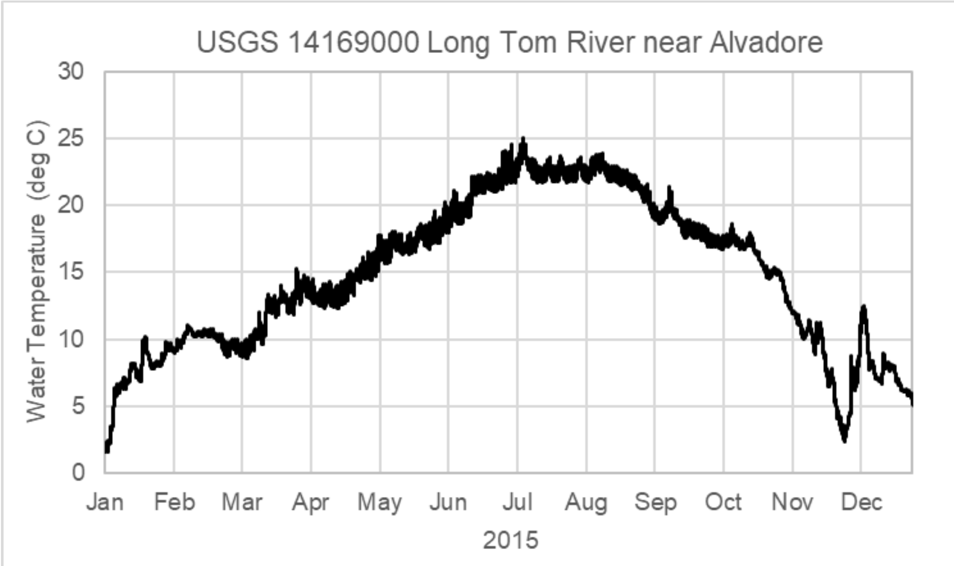

Figure 5-3. Observed water temperature time series at Long Tom River near Alvadore

5.3.2 Tributary boundary conditions

No tributary inflows were directly input to the existing model setup, rather they are included as distributed tributaries. During the model conversion process from version 3.12 to version 4.2, inclusion of several potentially significant tributaries i.e., Ferguson Creek, Bear Creek, and Amazon Creek were investigated. Water temperature data were available for Ferguson Creek and a tributary to Bear Creek from the Long Tom Watershed Council (LWC), no data were available for Amazon Creek. None of the tributaries had associated flow data. Based on information provided by ODEQ, it was noted that natural flows from Bear and Ferguson Creeks could be significant at times other than the critical summer period, and no current or historic discharge gages for these stations were available to characterize these creeks. During the summer, irrigation diversions potentially significantly reduce flows from these streams. Estimating such tributary flows during the summer without gages near the mouths was not possible. During the fall, however, when irrigation flows diminish and rainfall events increase flow rates, flows from these may constitute significant fractions of Long Tom River flow. Flows could only be calculated during the non-summer periods when the diversions were not significant. Flows during the critical summer/early fall period could not be estimated since the flows were managed. Similarly for Amazon Creek, based on information provided by ODEQ, it was noted that most of the flows were being diverted to the Fern Ridge Reservoir and that Amazon Creek do not provide sufficient flows to the Long Tom River. Given the complexity of the flow due to diversion for irrigation, the existing flow balance approach using distributed flows were left unchanged and the observed tributary water temperature were used to setup of the Long Tom W2 model via distributed tributaries.

Flow rates for the distributed tributaries were determined by balancing flows using USGS gaging station data from the Alvador and Monroe (USGS 14170000) locations. Water temperature for the distributed tributaries were assigned using data received from the LWC and USGS. Locations of the flow and water temperature used to configure the distributed tributaries can be found in Figure 5-4.

The model includes a diversion from Ferguson Dam set at a constant value of 0.113 m^3/s which was left unchanged for this setup. In addition, flows release via gates for Old Long Tom, gate weir elevation for Ferguson Dam and downstream boundary condition were also set in the W2 gate input file for the 2001/2002 model. No new data were available for 2015, so the same data were used for 2015.

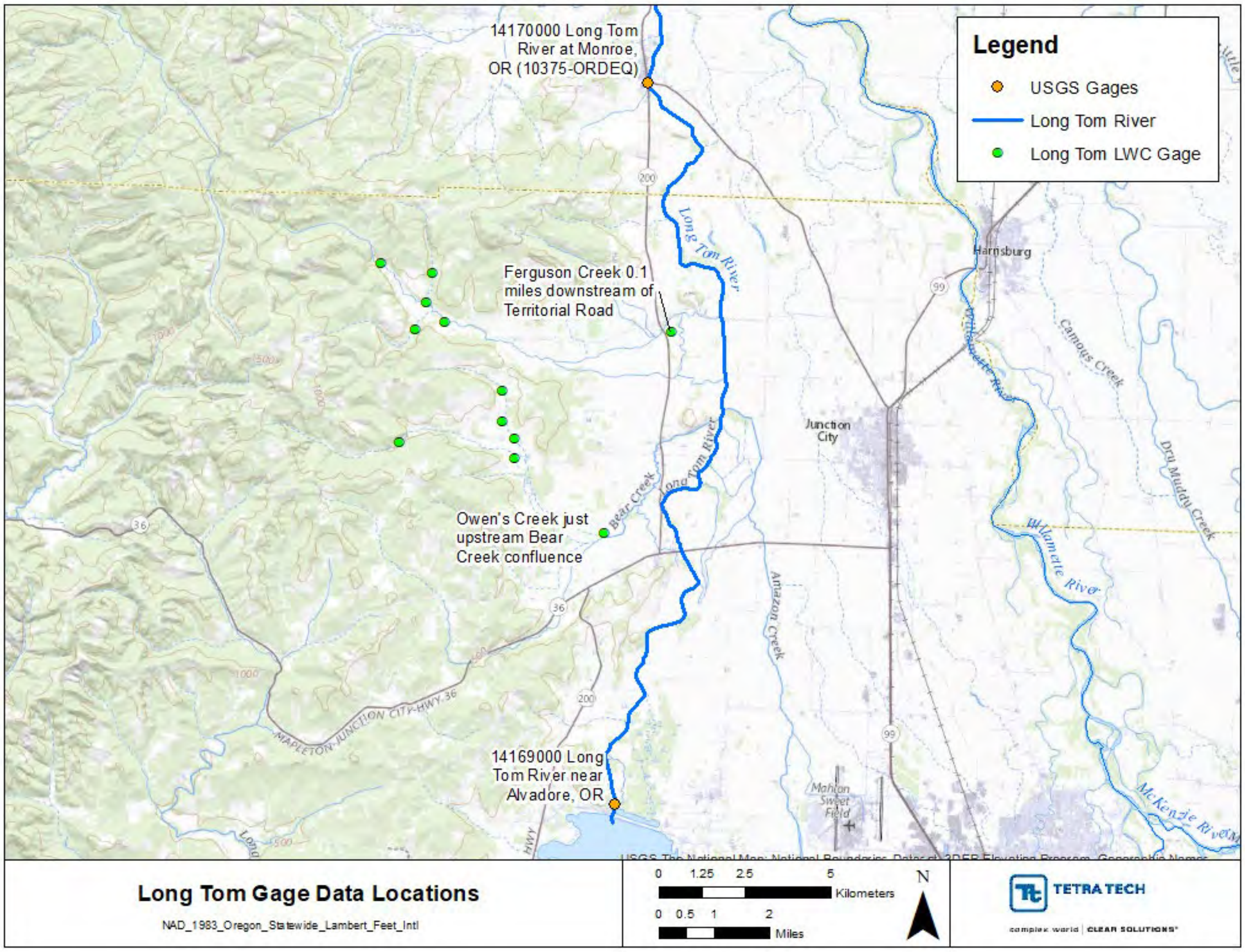

Figure 5-4 Flow and Water Temperature gage locations along the Long Tom River.

Distributed Tributary Flow data

The distributed flows were assigned using flow difference between USGS 14170000 Long Tom River at Monroe, OR (Branch 11) and USGS 14169000 Long Tom River near Alvador, OR (Branch 1). The location of the USGS flow gages used along Long Tom can be found in Figure 5-4. Distributed tributary flows were assigned to W2 Branches 1 through 11 and 14. The flows were distributed among the various branches based on ratio of lengths of each branch as shown in the Table 5-1 below.

Table 5-1. Ratios used to distribute the distributed flows among the various branches

Branch	Ratio	Length (m)
BR1	0.8%	252
BR2	6.1%	2013
BR3	2.3%	755
BR4	2.3%	755
BR5	1.5%	503
BR6	12.2%	4026

Branch	Ratio	Length (m)
BR7	4.6%	1510
BR8	0.8%	252
BR9	22.8%	7549
BR10	12.2%	4026
BR11	16.7%	5536
BR14	17.9%	5914

Note that in the previous model the distributed tributary for Branch 9 was set to OFF, but no reasoning was provided in the documentation; therefore, it was turned on in the current version.

Distributed Tributary Water temperature data

Water Temperature assignment for distributed tributaries was done using data from USGS and LWC (Figure 5-5). The distributed tributary water temperature assignment was based on proximity of the observed station to a specific branch as shown below:

- BR 1, 2, 3, 4, 5 – Water Temperature from USGS Alvador gage data used
- BR 6, 7, 8 – Water Temperature from LWC Bear Creek/Owen Creek data
- BR 9, 10, 11, 14 – Water Temperature from LWC Ferguson Creek data

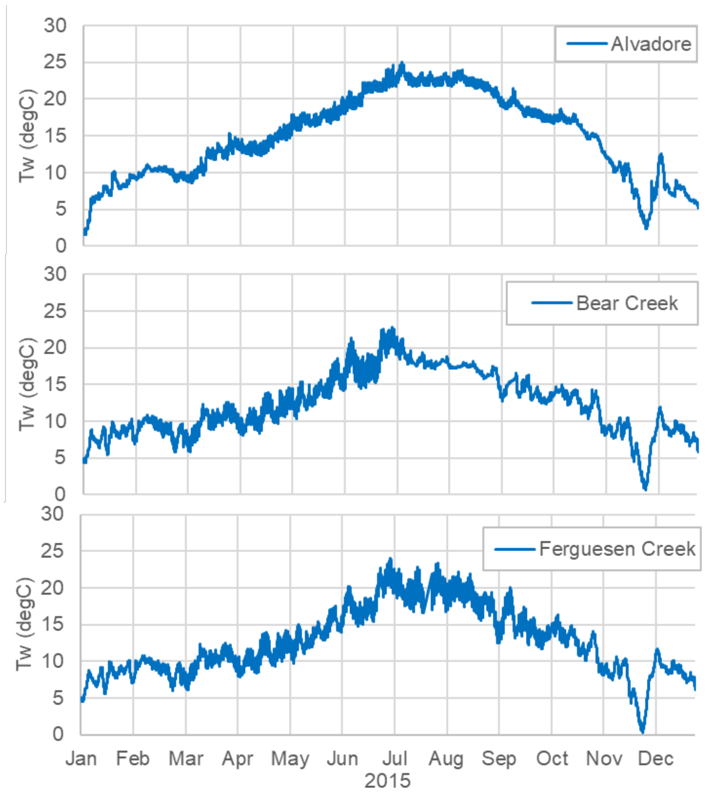

Figure 5-5. Distributed tributary water temperature assignment for the various branches

5.3.3 Point Sources

There is one permitted individual NPDES point source along the model extent, shown in Table 5-2 and Figure 5-6. Daily average flow and bi-weekly water temperature data were available for March and April in 2015. The City of Monroe STP has a condition in their current NPDES permit (#101692) that no discharge is allowed from outfall 001 from May 1 – October 31 unless approved by ODEQ in writing. ODEQ has not authorized discharge. Therefore, the model calibration input was set to zero during this period. ODEQ is currently checking if the discharge prohibition for this facility will be removed at next permit cycle, which may then require inclusion of this facility during the WLA scenario, where the WLA discharge will need to be developed. Figure 5-7 shows the flow and water temperature for the City of Monroe STP.

Table 5-2. Summary of NPDES facility along Long Tom River

WQ File Number	NPDES Permit #	Name	Flow Frequency	Temperature Frequency	Latitude	Longitude	River Mile	Model Waterbody
57951	101692	City Of Monroe STP	Daily	2/Week	44.315	-123.293	6.9	Long Tom River

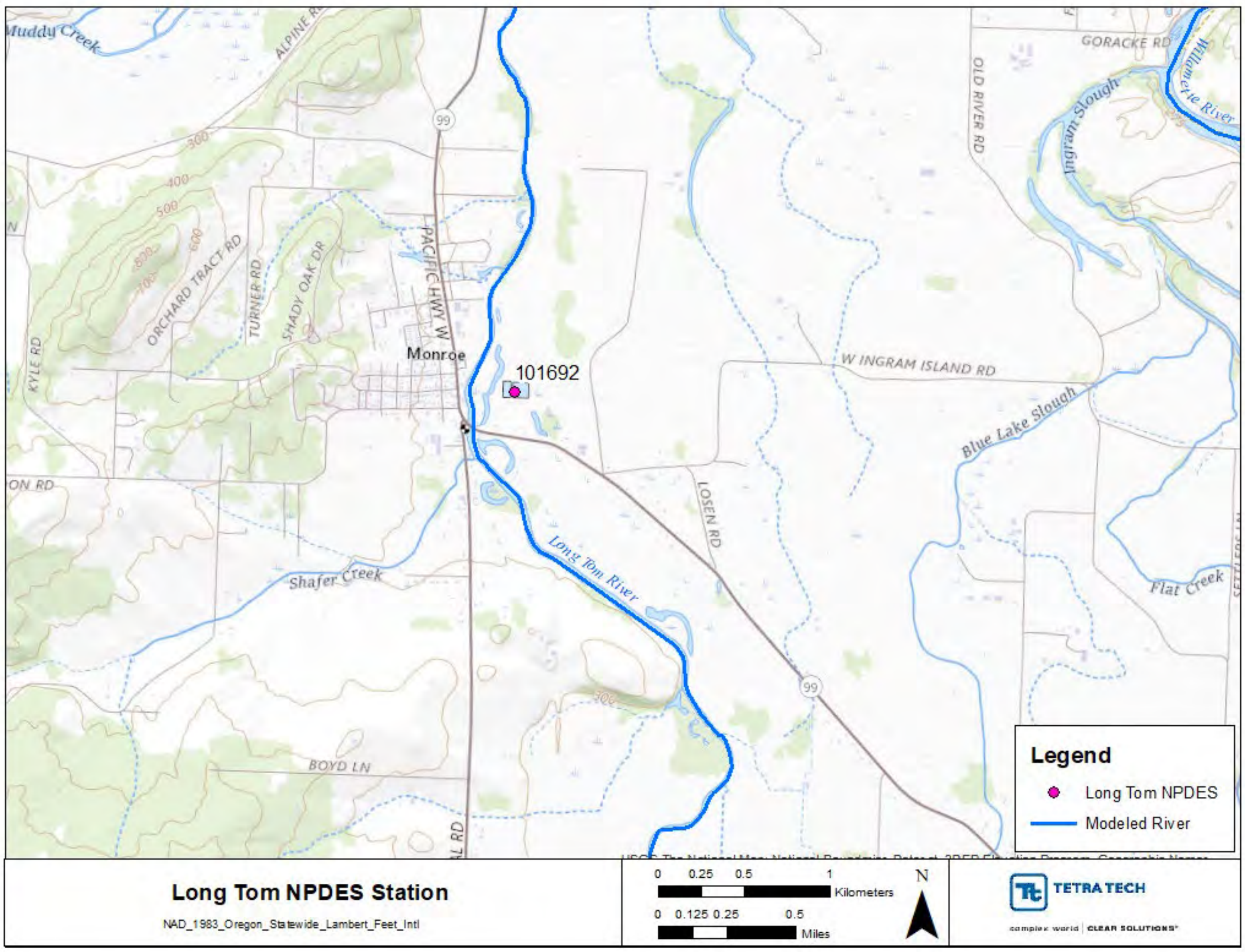

Figure 5-6. NPDES station (City of Monroe STP 101692) discharging to the Long Tom River

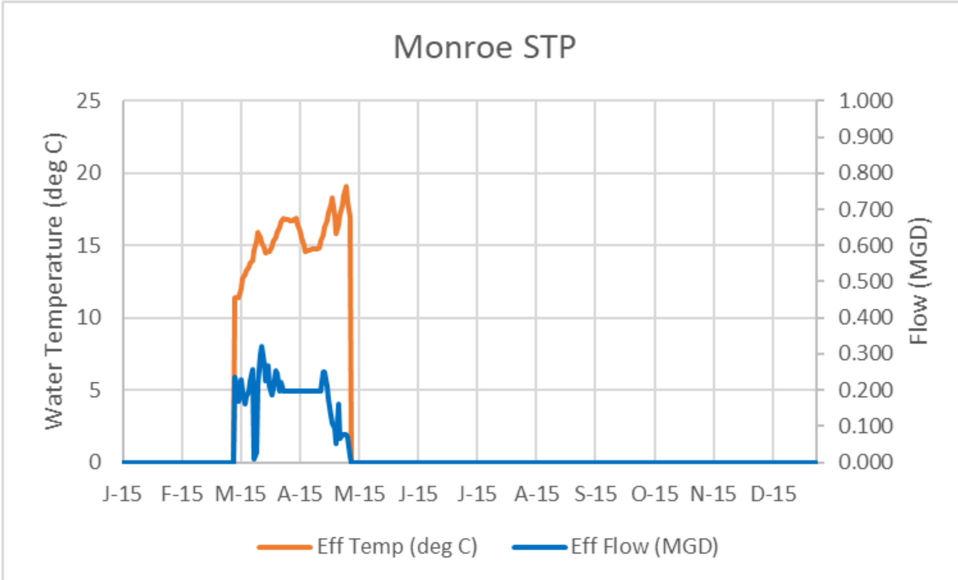

Figure 5-7. City of Monroe STP 2015 flow and water temperature.

5.3.4 Meteorology data

Long term hourly meteorological data were available from the NCDC – Local Climatological Dataset (LCD) (NOAA 2005) station located at Eugene Mahlon Sweet Field Airport near the Long Tom River. The station is located about 4 miles east of the Long Tom River (Latitude: 44.1278, Longitude: -123.2206, Elevation: 107.6 m). Figure 5-8 shows the location of the Eugene Mahlon Sweet Field Airport weather station.

The station provided most of the required meteorological parameters (except for solar radiation). Hourly data from the year 2015 were downloaded from this LCD station. In general, the data were complete in terms of missing data, with the exception of three days in July from the 29th to the 31st. NCDC also reports daily minimum and maximum air temperature at the Eugene station as part of its GHCNd network and was used to fill in the missing air temperature for the three missing days. The pattern of the hourly diurnal distribution observed at the Eugene Airport was used to disaggregate the minimum and maximum air temperature to hourly. The daily minimum and maximum values were maintained on each day, but the timing and diurnal pattern from the Eugene station was used to create hourly time series. All other parameters, i.e., dewpoint temperature, wind speed/direction, and cloud cover, were filled in using data reported from the previous 3 days.

The cloud cover data were calculated from hourly descriptive sky cover conditions reported at the Eugene Airport station. The W2 model interprets cloud cover on a scale of 0 to 10 (0 being clear and 10 being cloudy). Hourly global solar radiation data from the Eugene Solar Radiation Monitoring Lab (SRML), University of Oregon station site were used as input with the Eugene airport data to create the Eugene meteorological inputs. Figure 5-9 shows the observed hourly time series used in the model.

Maximum air temperature during 2015 was observed in July (40.63 °C). Mean monthly maximum air temperatures were 30.76 °C in July, followed by 29.46 °C August, and 24.55 °C in September. The 2015 observed wind speed data indicate that daily wind speeds ranged around 0 to 10 meters per second, with upper range wind gusts up to 16 meters per second. Winds come from all directions, but most frequently originate from either the northernly or southernly direction (Figure 5-10). This is illustrated using a wind rose plot (described in Section 3.3.4), which provides an overall view of how wind speed and direction are typically distributed at a particular location.

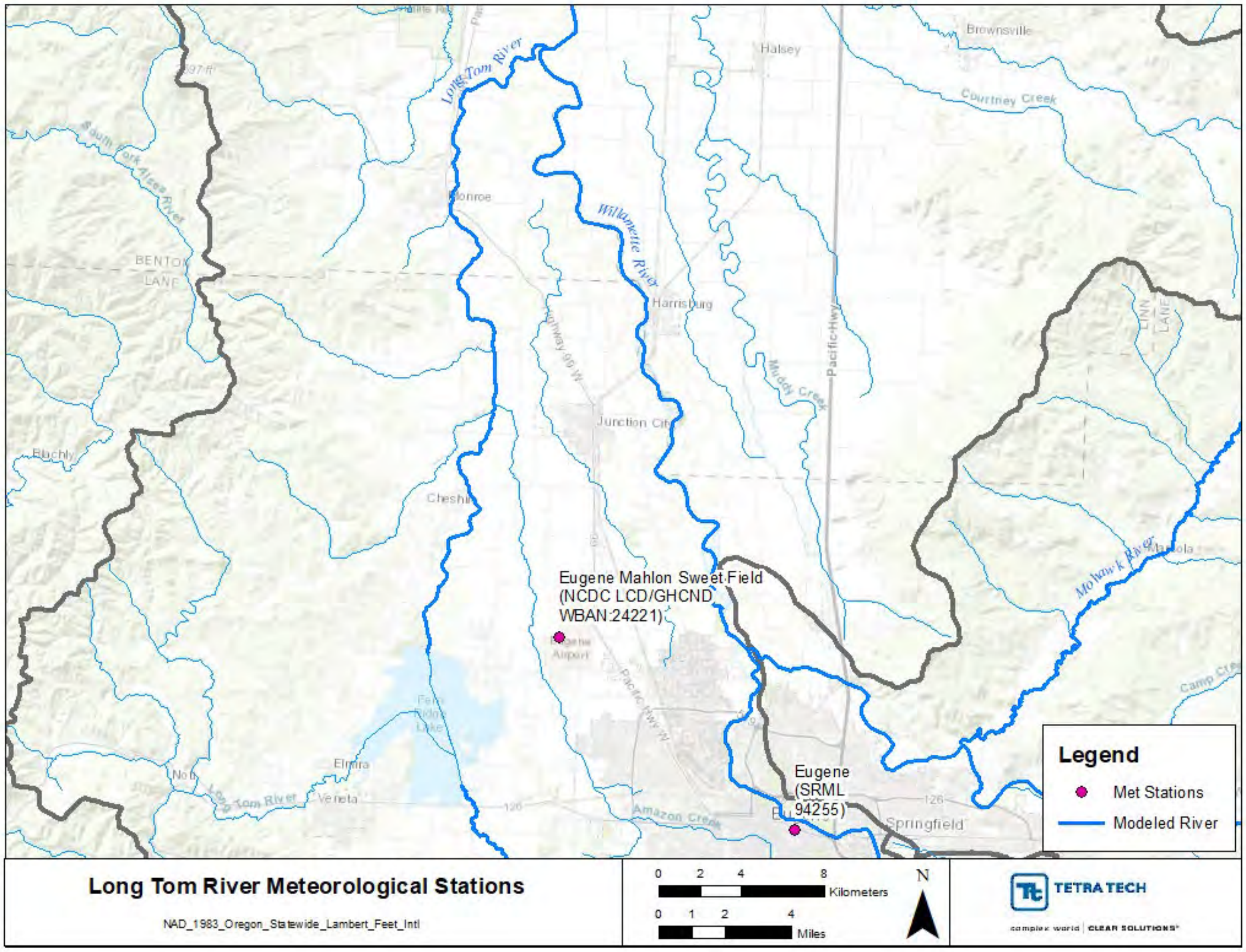

Figure 5-8. Long Tom River meteorological stations

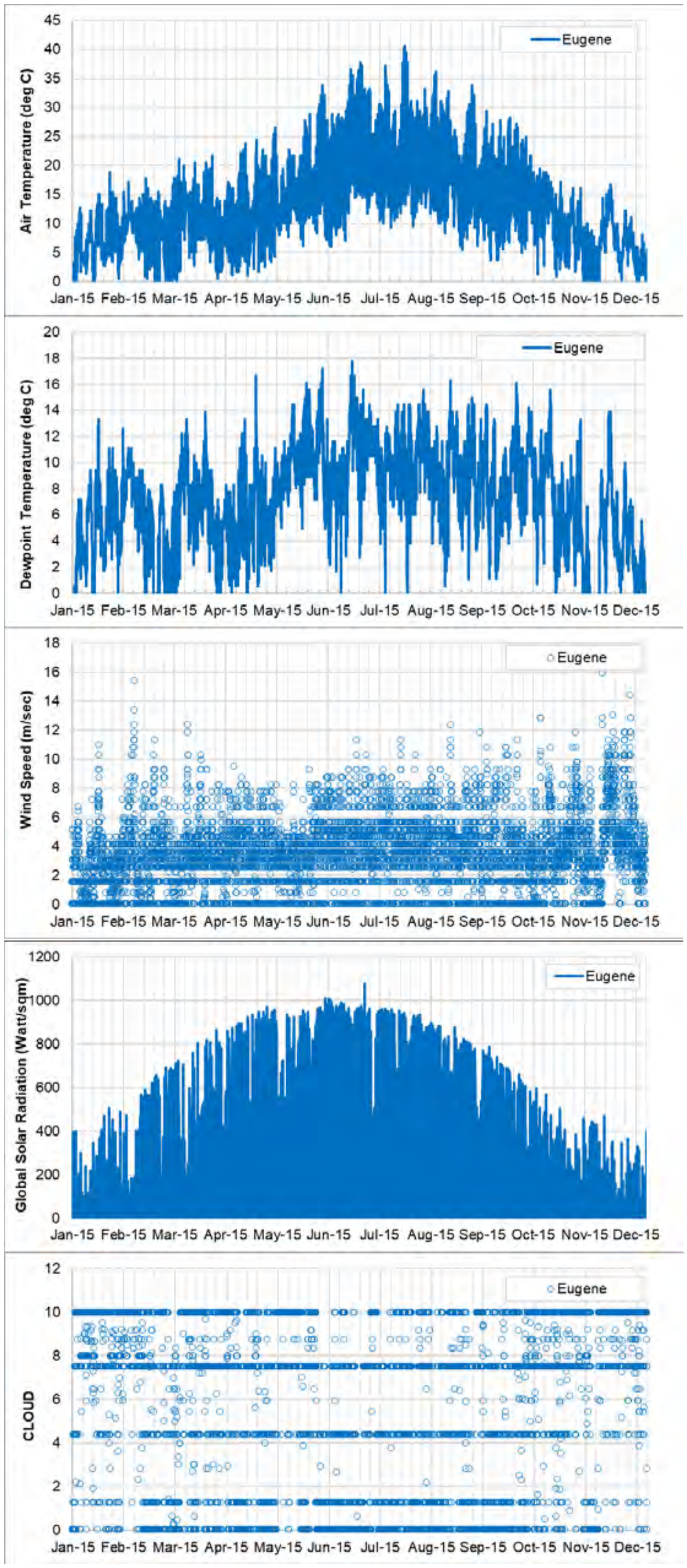

Figure 5-9. Observed Hourly Meteorological data at Eugene Mahlon Sweet Field Airport (NCDC-LCD) & Solar Radiation from Eugene SRML site

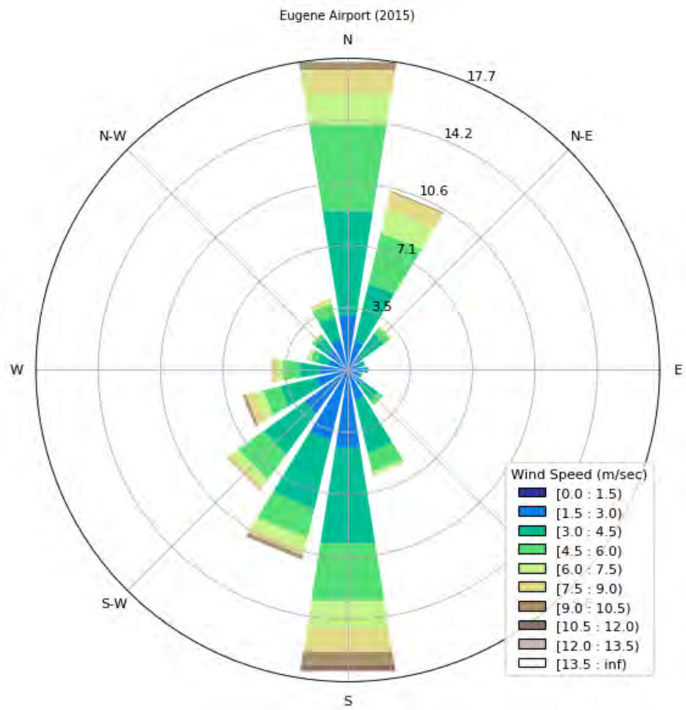

Figure 5-10. Wind Rose for the observed wind data at Eugene Airport for full 2015 year of record

5.4 LONG TOM RIVER MODEL CALIBRATION

Model calibration focused on flow, water level, and water temperature data from calibration sites that had available data during the simulation period. No changes were made to the current condition calibration parameters (i.e., from 2001/2002) e.g. Manning's coefficient, wind sheltering, evaporation, and sediment temperatures, in the 2015 model, as it did not further improve the calibration. An exception to this was the SROC parameter. During temperature calibration it was found that the existing model was set to use solar radiation that was internally computed and was not reading in the specified observed solar radiation. This was because the SROC parameter in the model input file was set to OFF. SROC was set to ON for the 2015 model after comparing the model results using the observed solar radiation and the model results using the W2 internal solar radiation algorithm. Using the observed solar radiation improved the water temperature results, Vegetative and topographic shade characteristics were left unchanged since the model input was developed using a detailed GIS analysis. The model calibration period was from April 1, 2015, to October 31, 2015.

Figure 5-11 shows the locations of all the flow, water level, water temperature calibration locations used for the year 2015. The model calibration locations and available data during the year 2015 are further discussed in the following sections.

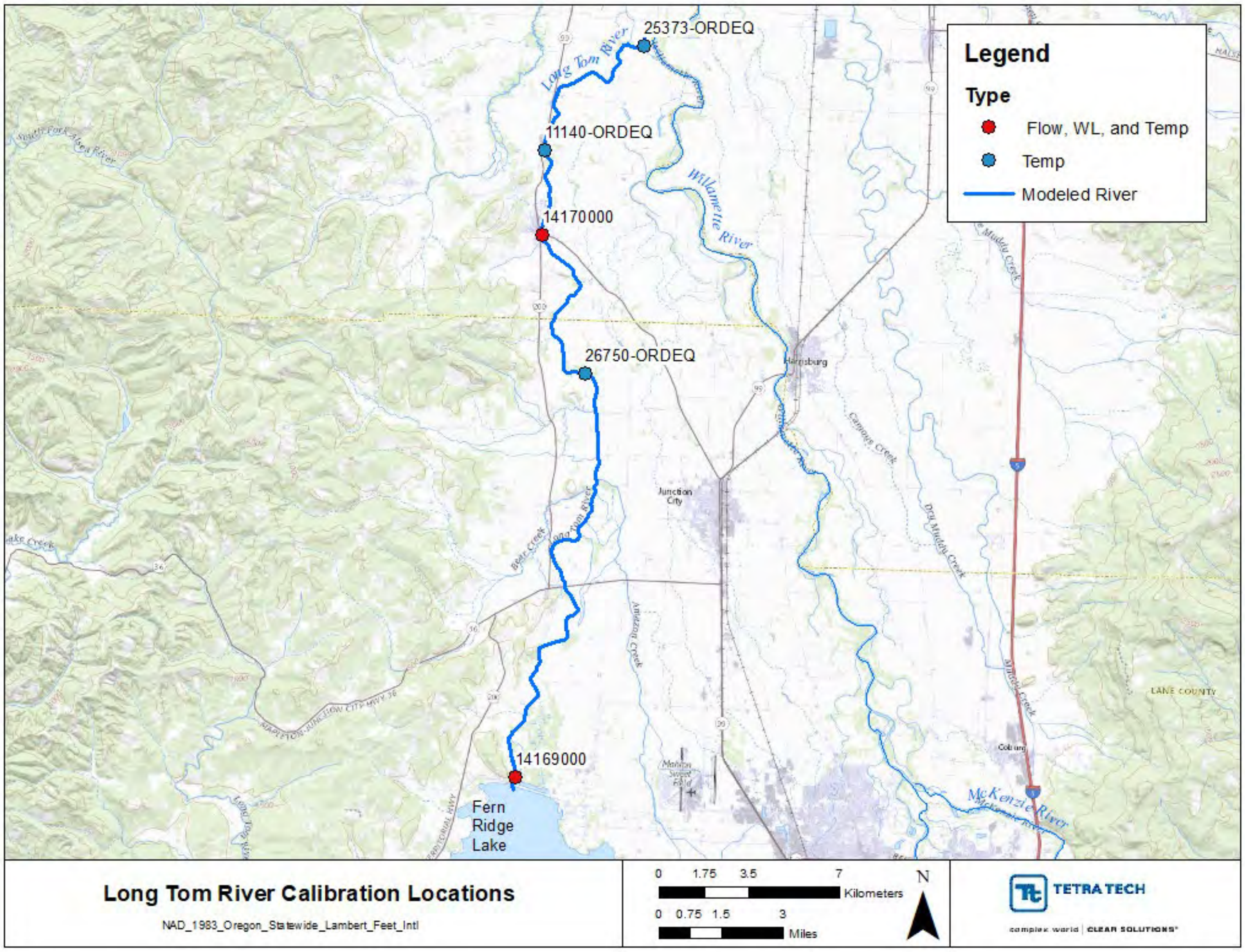

Figure 5-11. Long Tom River flow, water level, water temperature calibration locations.

5.5 HYDRODYNAMIC CALIBRATION

Hydrodynamic calibration included the calibration of flow and water surface elevation conditions using available data during the simulation period. Hydrodynamic calibration data were available during 2015 for the two calibration stations used during 2001/2002 (Berger et al. 2004). Table 5-3 shows the hydrodynamic calibration station locations used for 2015.

Table 5-3. Long Tom River flow and water level calibration sites

ID	Description	Latitude	Longitude	Model Segment	RM	Source
14169000	Long Tom River near Alvadore, OR	44.123457	-123.29982	2	23.7	USGS
14170000	Long Tom River at Monroe	44.31315	-123.296	134	6.86	ODEQ

Model calibration was evaluated using a combination of visual plot comparison and model error statistics. Figure 5-12 and Figure 5-13 compare the modeled and observed flows, and Figure 5-14 and Figure 5-15 compare the modeled and observed water surface elevations. The model error statistics for the year 2015 Long Tom River hydrodynamic calibration for each station are presented in Table 5-4. See section 2.1.1 for an explanation of the error statistic metrics used for evaluation. Note that the observed water levels were first converted to NGVD29 datum from their local datum before comparison with modeled water levels. The model captures the observed flows and water levels at the two stations well, matching the overall patterns during the year 2015. However, the predicted flows at the Monroe station do show an overall underestimation compared to the observed flows, and the model is unable to capture a peak flow event in mid-September. The flows and water levels had an MAE less than 0.2 m^3/s and 0.05 meters, respectively, with the RMSE for the flow and water levels being less than 0.07 m^3/s and 0.15 meters, respectively. Both flow and water surface elevation calibration and corresponding error statistics are similar to those calculated for the years 2001 and 2002.

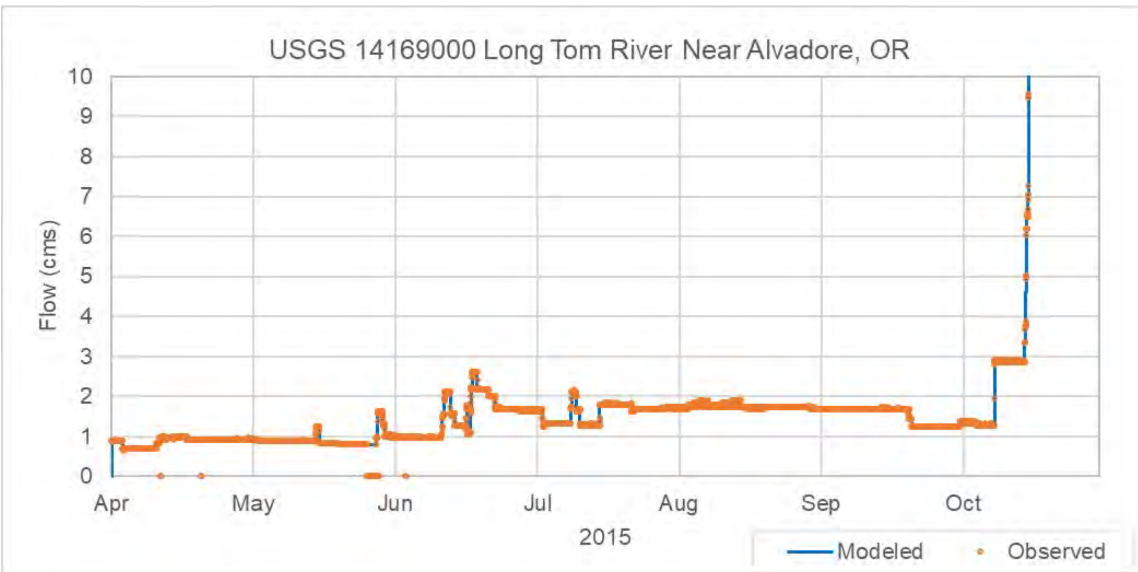

Figure 5-12. Long Tom River near Alvadore flow comparison, 2015

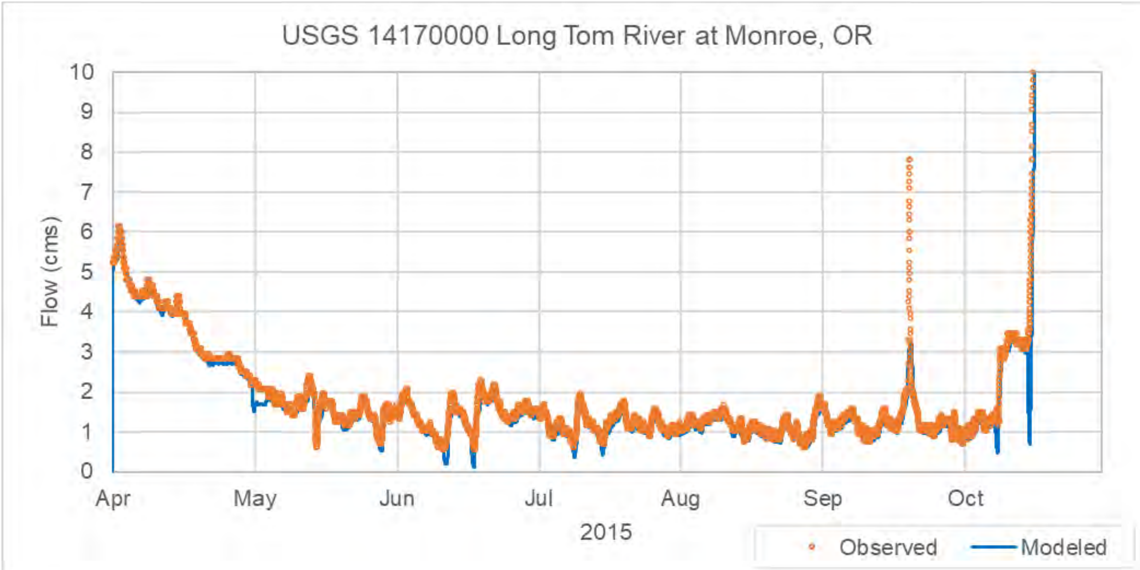

Figure 5-13. Long Tom River at Monroe flow comparison, 2015

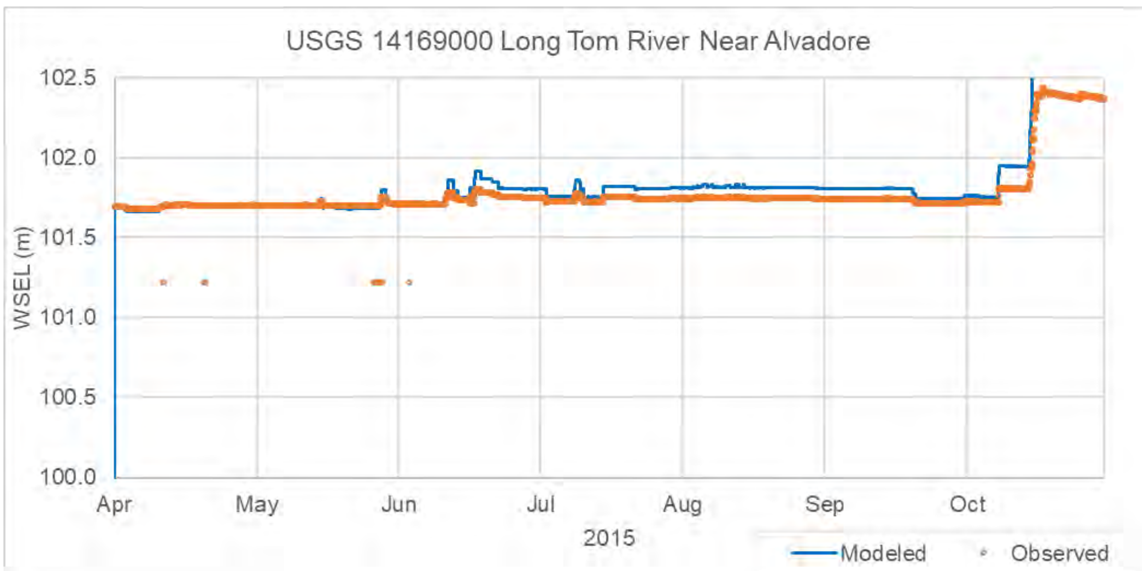

Figure 5-14. Long Tom River at Alvadore water surface elevation comparison, 2015

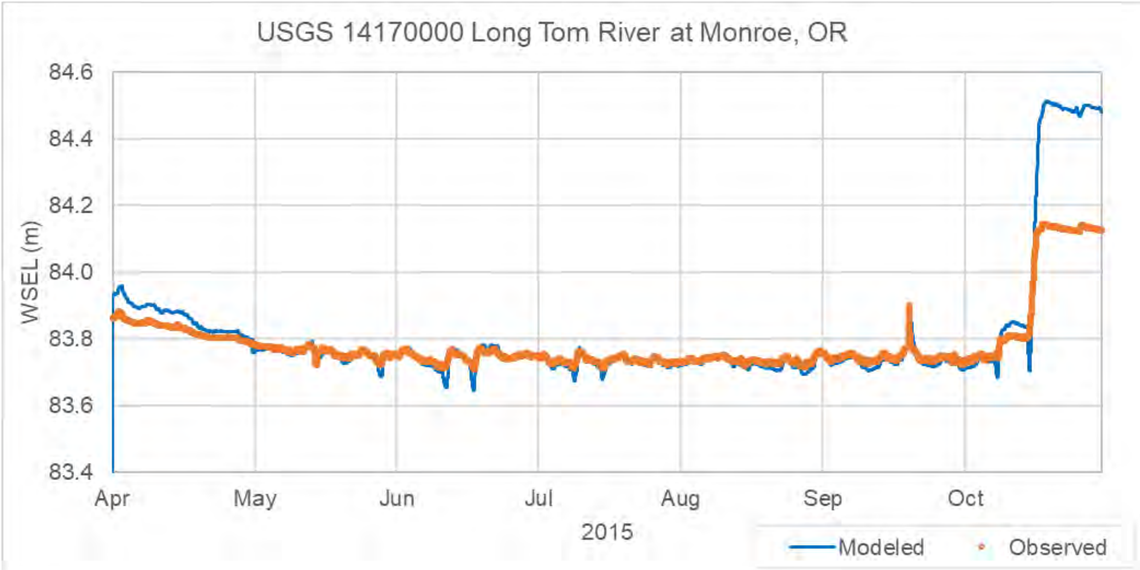

Figure 5-15. Long Tom River at Monroe water surface elevation comparison, 2015

Table 5-4. Long Tom River hydrodynamic calibration statistics, 2015

Location	Model Segment	Sample Size (n)	Mean Error	Mean Absolute Error	RMSE Error	Nash Sutcliff Efficiency (%)
Flow (cms)						
USGS 14169000 Long Tom River Near Alvadore, OR	2	14492	0.01	0.02	0.11	0.94
USGS 14170000 Long Tom River at Monroe, OR	134	14688	-0.14	0.17	0.25	0.63
Water Surface Elevation (m)						
USGS 14169000 Long Tom River Near Alvadore, OR	2	14696	0.04	0.05	0.06	-0.92
USGS 14170000 Long Tom River at Monroe, OR	134	14688	-0.01	0.01	0.01	0.17

5.6 TEMPERATURE CALIBRATION

Temperature calibration involved calibrating to observed water temperature station locations. The previous calibration for the years 2001 and 2002 (Berger et al. 2004) used five water temperature stations (two USGS and three LASAR stations). Out of the two USGS stations only the Alvadore station (14169000) had data during 2015. The other USGS station at Monroe (14170000) only reports daily minimum, maximum, and mean water temperatures starting in 2019 and did not have data for the year 2015. Therefore, the ODEQ station 10375 Long Tom at Monroe was used instead of the USGS station at Monroe for 2015. However, this station had limited data and only collected data in the last week of October and November for 2015.

Out of the three LASAR ODEQ stations (26749, 26750, and 29644) used previously in the calibration during 2001/2002, only station 26750 had data for 2015. Two new ODEQ calibration stations (11140 and 25373) were identified that had limited data (data was only available during September, October, and November) and were also used for calibration. Table 5-5 shows the stations used for water temperature calibration.

Table 5-5. Long Tom River water temperature calibration sites

ID	Description	Latitude	Longitude	Model Segment	RM	Source
14169000	Long Tom River near Alvadore, OR	44.1234	-123.299	2	23.70	USGS
26750-ORDEQ	Long Tom River near River Mile 12.3	44.2652	-123.272	103	12.71	ODEQ
10375-ORDEQ	Long Tom River at Monroe	44.3132	-123.296	134	6.86	ODEQ
11140-ORDEQ	Long Tom River at Stow Pit Road (Monroe)	44.3428	-123.295	153	4.63	ODEQ
25373-ORDEQ	Long Tom River at Bundy Bridge near mouth	44.3802	-123.249	181	0.75	ODEQ

Model calibration was evaluated using a combination of visual plot comparison and model error statistics. Figure 5-16 through Figure 5-20 show plots of model predicted temperature and data. In addition, daily maximum and 7DADM observed and modeled water temperature calibration plots can be found in Appendix C. Finally, error statistics comparing model predicted temperatures with continuous temperature data are shown below in Table 5-6. Continuous temperature error statistics showed an MAE and RMSE of less than 1 ºC across all stations. The MAE ranged from was 0.09 ºC to 0.82 ºC across the stations and RMSE ranged from 0.13ºC to 1ºC. The figures show that the model captures the temperature fluctuations and seasonal patterns well at all stations but were found to be under predicting at the Monroe station especially in terms of the minimums observed in the continuous data. The modeled daily maximum and 7DADM compared well with observed data for all stations with an MAE and RMSE that was less than 1 ºC (Table 5-6). The water temperature calibration and corresponding error statistics are similar to those calculated for the years 2001 and 2002.

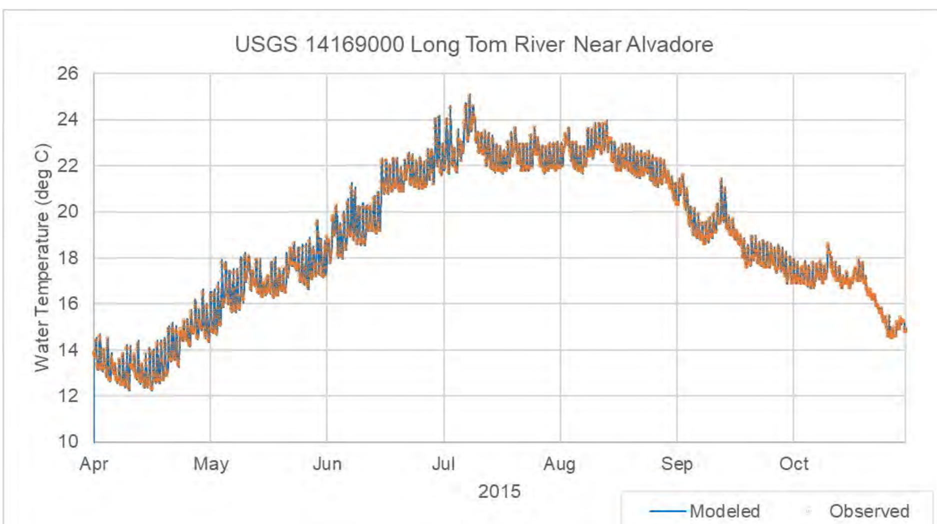

Figure 5-16. Long Tom River near Alvadore water temperature comparison, 2015

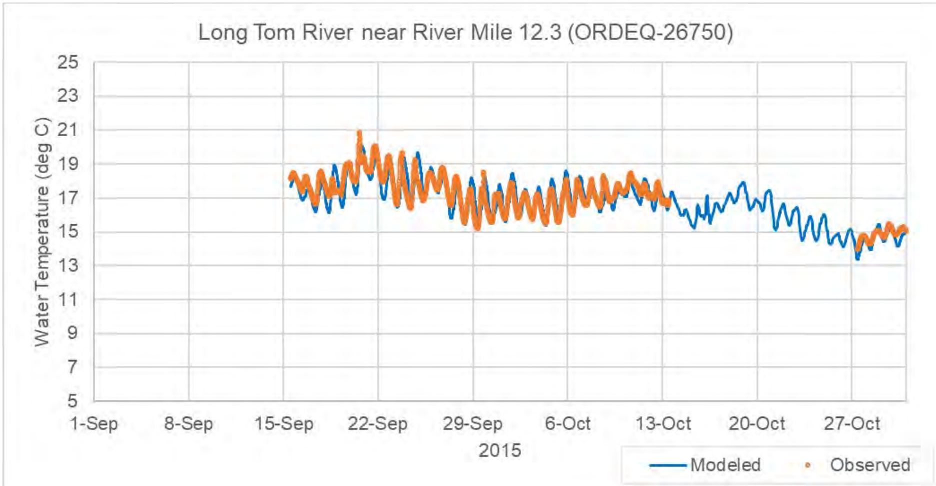

Figure 5-17. Long Tom River near RM 12.3 water temperature comparison, 2015

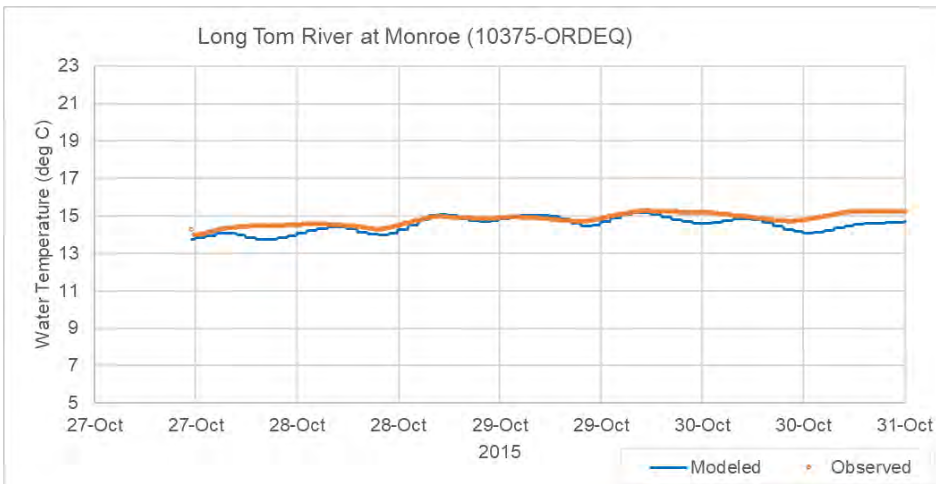

Figure 5-18. Long Tom River at Monroe water temperature comparison, 2015

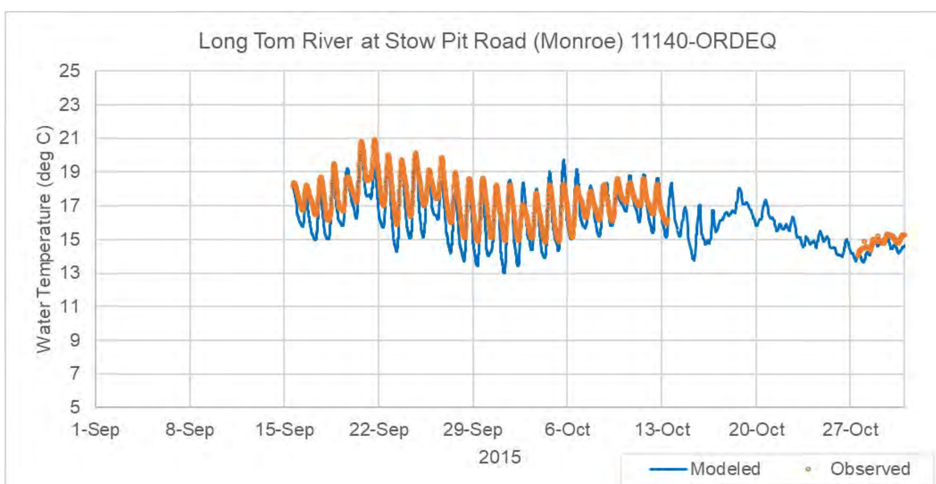

Figure 5-19. Long Tom River at Stow Pit Road water temperature comparison, 2015

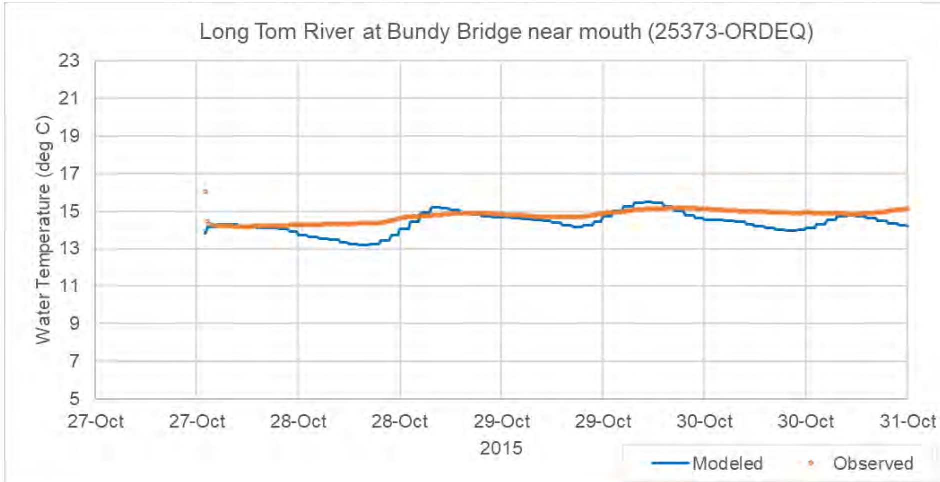

Figure 5-20. Long Tom River at Bundy at Bundy Bridge near mouth water temperature comparison, 2015

Table 5-6. Long Tom River water temperature calibration statistics, 2015

Location	Model Segment	Sample Size (n)	Mean Error (ºC)	Mean Absolute Error (ºC)	RMSE Error (ºC)	Nash Sutcliff Efficiency (%)
Hourly Water Temperature (ºC)						
USGS 14169000 Long Tom River Near Alvadore, OR	2	20554	0.004	0.09	0.13	0.99
26750-ORDEQ - Long Tom River near River Mile 12.3	103	3127	-0.09	0.50	0.63	0.75
10375-ORDEQ - Long Tom River at Monroe	134	434	-0.14	0.29	0.33	-0.04
11140-ORDEQ - Long Tom River at Stow Pit Road (Monroe)	153	3096	-0.67	0.82	1.00	0.50
25373-ORDEQ - Long Tom River at Bundy Bridge near mouth	181	428	-0.34	0.48	0.58	-1.98
Max Water Temperature (ºC)						
USGS 14169000 Long Tom River Near Alvadore, OR	2	210	0.04	0.06	0.07	0.99
26750-ORDEQ - Long Tom River near River Mile 12.3	103	29	0.09	0.37	0.44	0.90
10375-ORDEQ - Long Tom River at Monroe	134	5	0.25	0.25	0.28	0.09
11140-ORDEQ - Long Tom River at Stow Pit Road (Monroe)	153	29	-0.11	0.55	0.70	0.80
25373-ORDEQ - Long Tom River at Bundy Bridge near mouth	181	5	-0.21	0.62	0.84	-3.65
7DADM Water Temperature (ºC)[a]						

Location	Model Segment	Sample Size (n)	Mean Error (ºC)	Mean Absolute Error (ºC)	RMSE Error (ºC)	Nash Sutcliff Efficiency (%)
USGS 14169000 Long Tom River Near Alvadore, OR	2	204	0.05	0.05	0.06	0.99
26750-ORDEQ - Long Tom River near River Mile 12.3	103	24	0.11	0.22	0.27	0.85
11140-ORDEQ - Long Tom River at Stow Pit Road (Monroe)	153	24	-0.07	0.43	0.48	0.60

[a] Insufficient data to calculate 7DADM statistics at 10375-ORDEQ and 25373-ORDEQ

6.0 SUMMARY

This report summarizes the development of W2 water temperature models for the Lower Willamette River, Clackamas River, and Long Tom River. The set of W2 models were developed based on the existing 2001/2002 temperature TMDL models by PSU (Annear et al. 2004; Berger et al. 2004) and ODEQ (2006). The models were converted from an older W2 version 3.12 to version 4.2 to be consistent with the several other W2 models developed by the USGS in the Willamette River basin (Rounds, 2007), which were also developed using version 4.2 for the years 2011, 2015, and 2016.

The model development for the three models was on based on the year 2001/2002 bathymetry and configuration and focused on the development and calibration of the model for the year 2015. The model development used several data sets which included, meteorological data, upstream and downstream gaged boundaries, tributary inputs, and updated point source information. During model development unless new data were available for configuring the input boundaries, the assumptions used for filling in data gaps in the development of the 2001/2002 model were used. In addition, as part of this effort a detailed point source data mining effort was conducted to extract point source data for existing point sources in the model and to identify any additional point sources that needed to be included into the 2015 model.

The model was developed primarily for the calibration period from April 1, 2015, to October 31, 2015. Model calibration involved minimal or no adjustment to the exiting model parameters. Vegetative and topographic shade characteristics were left unchanged since the model input was developed using a detailed GIS analysis. In addition to a few new model calibration locations, model calibration was performed at all locations that were used in the previous modeling effort during 2001/2002. The models were calibrated for hydrodynamics (continuous flows and water surface elevations) and continuous water temperature. The model comparisons were conducted using visual comparison of modeled and observed time series and calibration statistics to establish goodness-of-fit.

In general, the flow, water surface elevation and temperature calibration and corresponding error statistics in this study were found to be similar to those calculated for the years 2001 and 2002. The predicted water temperatures for all three models compared well with the observed data, and the models were able to match observed seasonal patterns. The MAE and RMSE for all three models were calculated to be less than 1 ºC. An exception to this was the Clackamas River near Oregon City USGS station location, where the MAE and RMSE were 1.05 ºC and 1.23 ºC, respectively, for the continuous data comparisons. Similarly for the Long Tom River at Stow Pit Road (Monroe) location where the MAE and RMSE were 0.82 ºC and 1 ºC. At both these locations the model had difficulty predicting the minimum. The modeled daily maximum and 7DADM these both these locations compared well with observed data. The modeled daily maximum and 7DADM temperatures were evaluated for all locations in the three models and compared well with the observed maximum and 7DADM temperatures. The observed maximum and 7DADM showed a better goodness of fit compared to that calculated with continuous temperature comparisons.

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APPENDIX A – LOWER WILLAMETTE RIVER – DAILY MAXIMUM AND 7DADM OBSERVED VS MODELED WATER TEMPERATURE CALIBRATION PLOTS

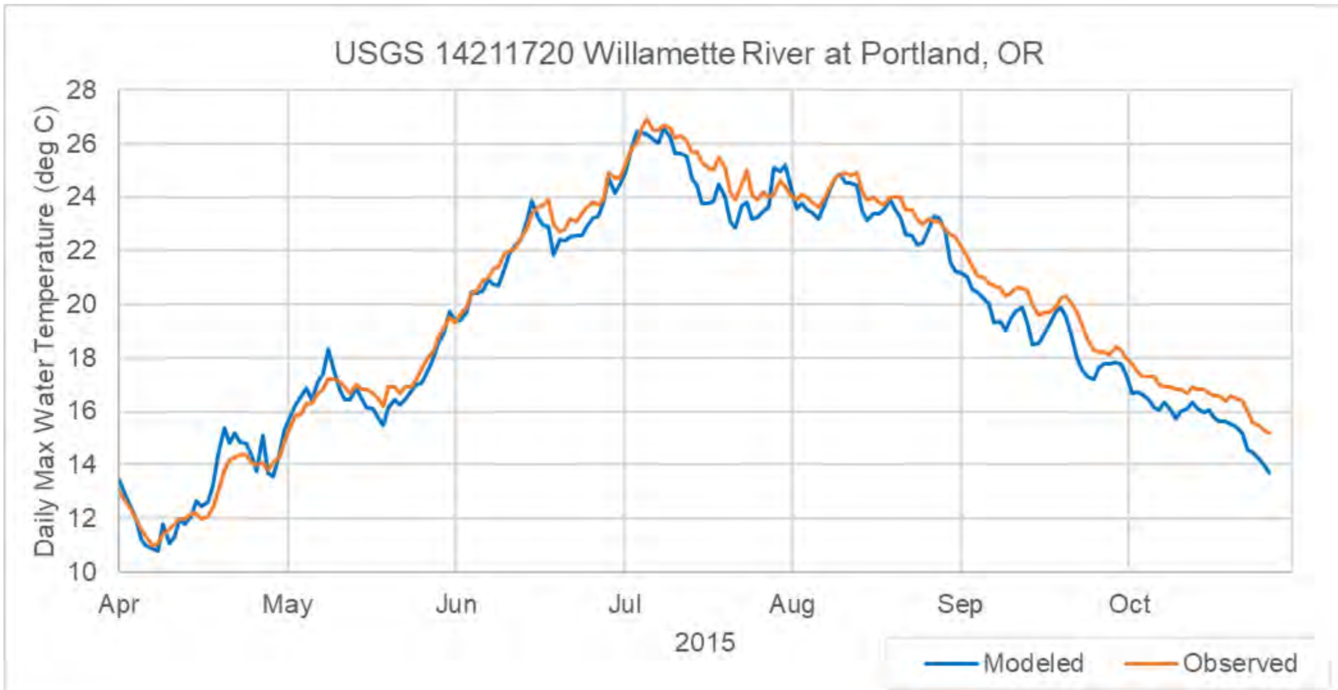

Figure A - 1. Daily Maximum Water Temperature comparison at Willamette River at Portland

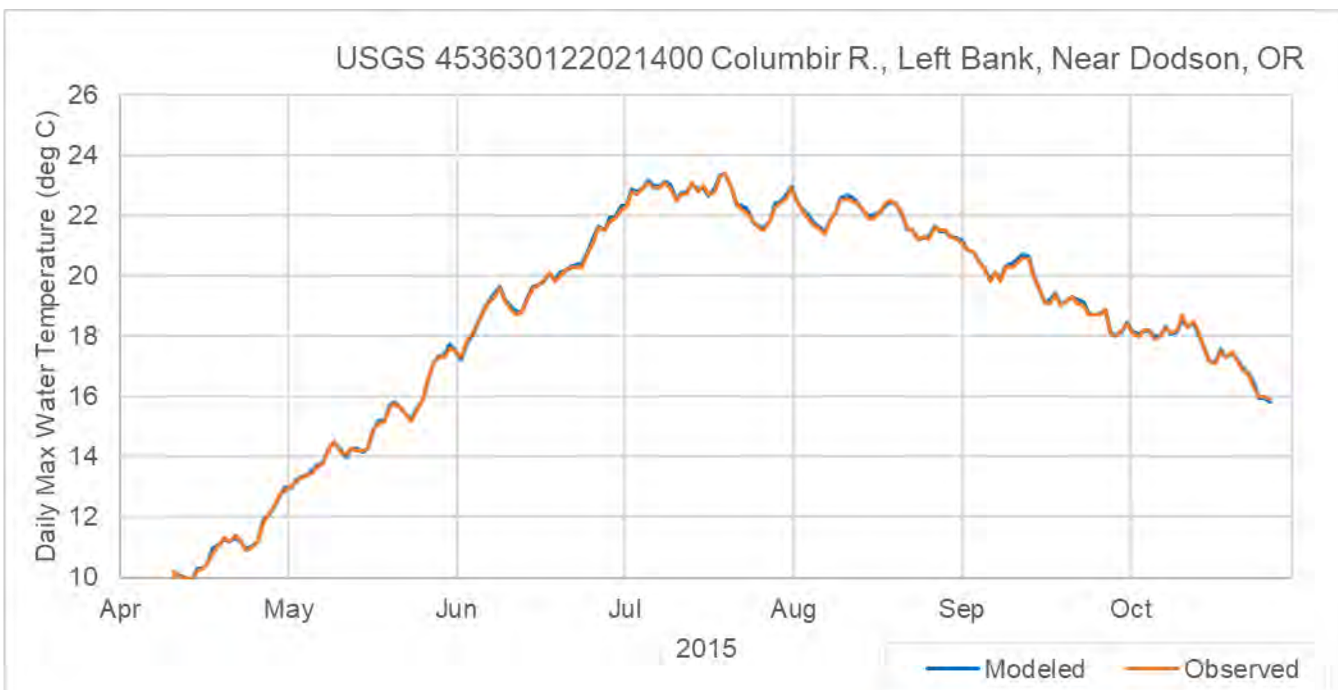

Figure A - 2. Daily Maximum Water Temperature comparison at Columbia River Left Bank, near Dodson, OR

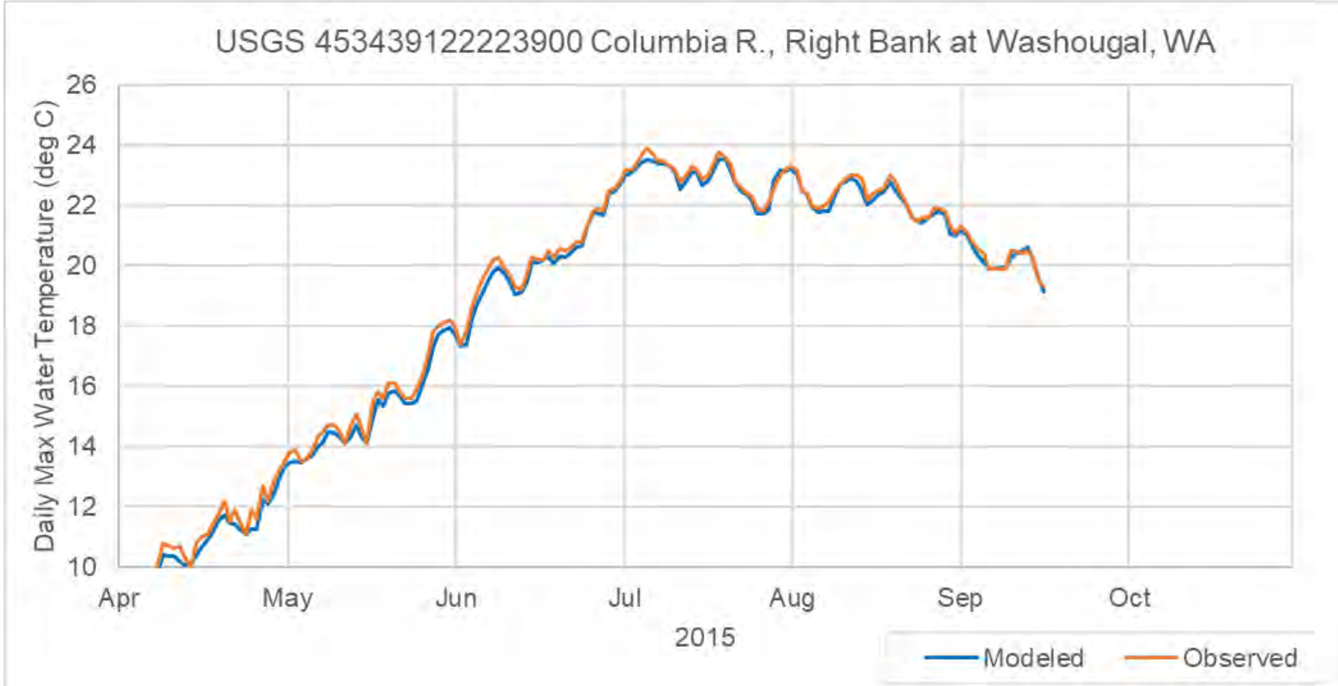

Figure A - 3. Daily Maximum Water Temperature comparison at Columbia River Right Bank, at Washougal, OR

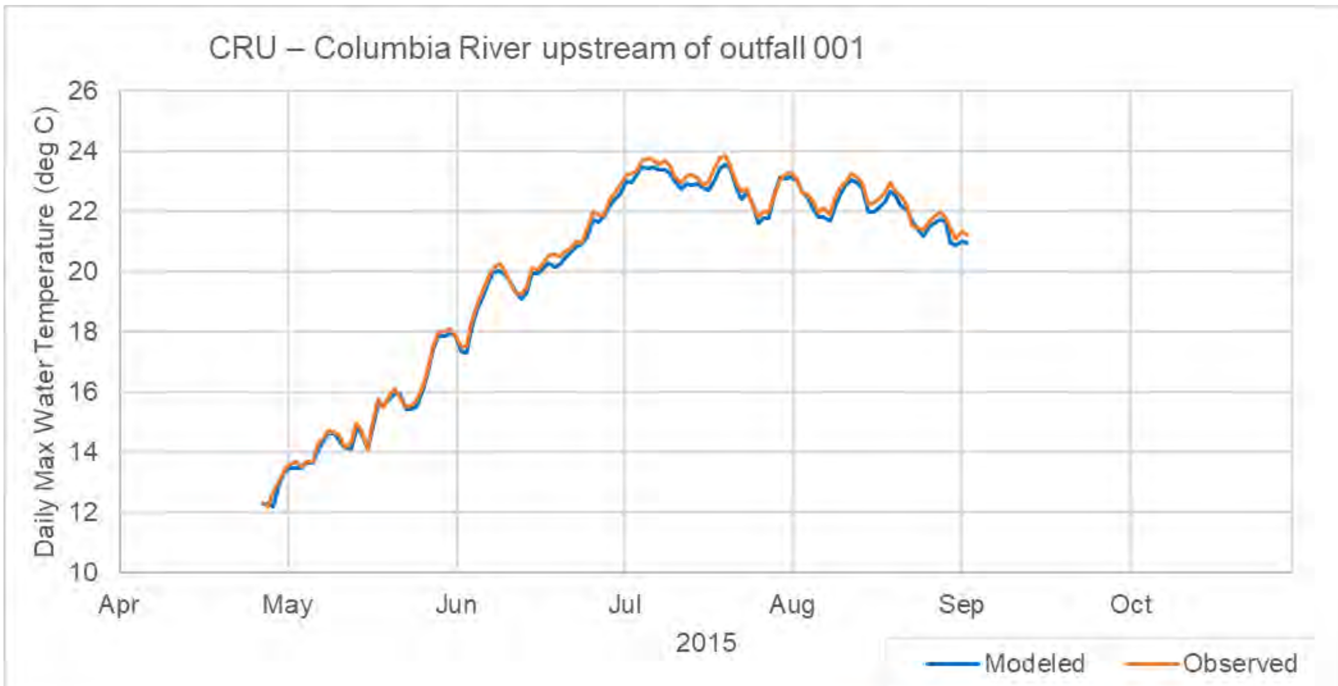

Figure A - 4. Daily Maximum Water Temperature comparison at Columbia River upstream of outfall 001

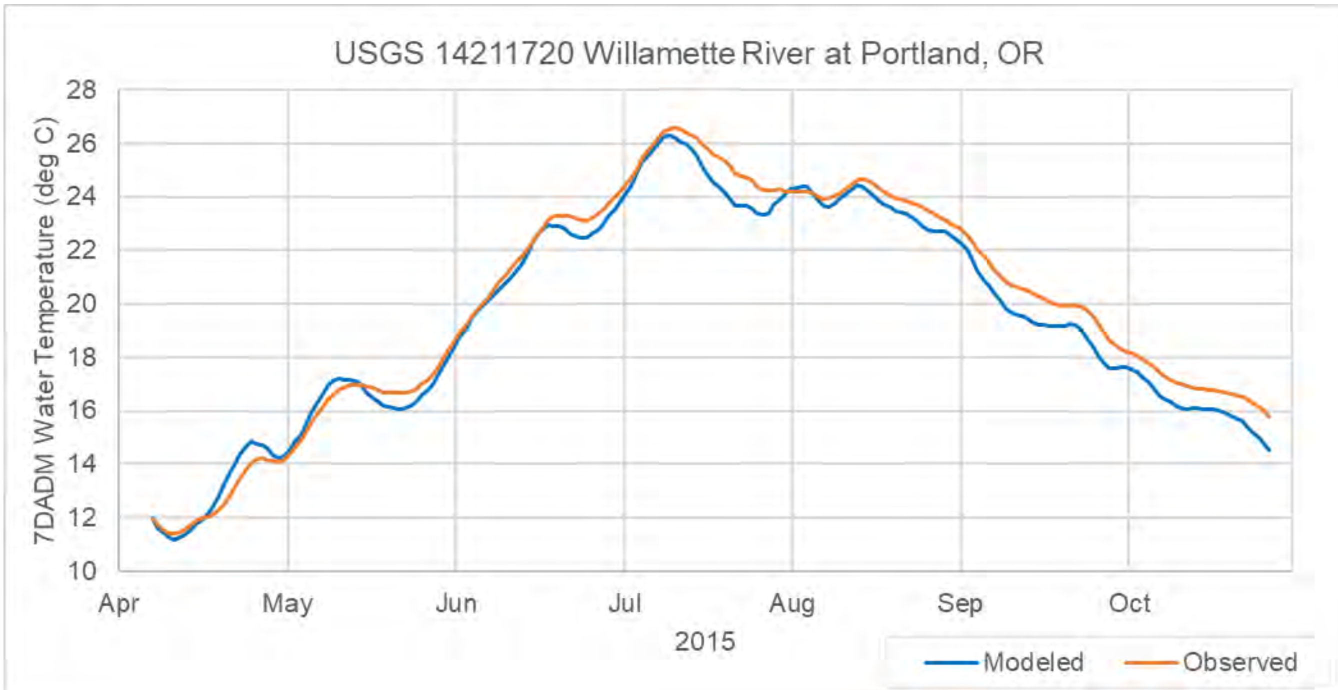

Figure A - 5. 7DADM Water Temperature comparison at Willamette River at Portland

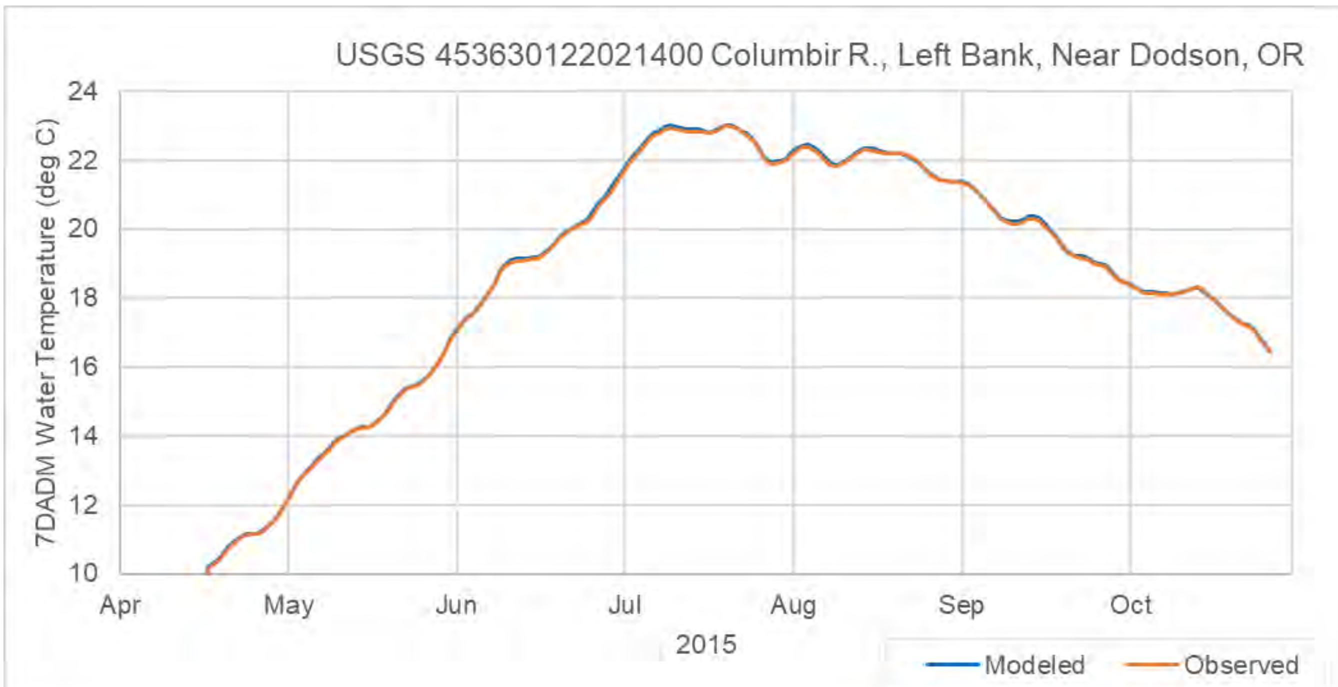

Figure A - 6. 7DADM Water Temperature comparison at Columbia River Left Bank, near Dodson, OR

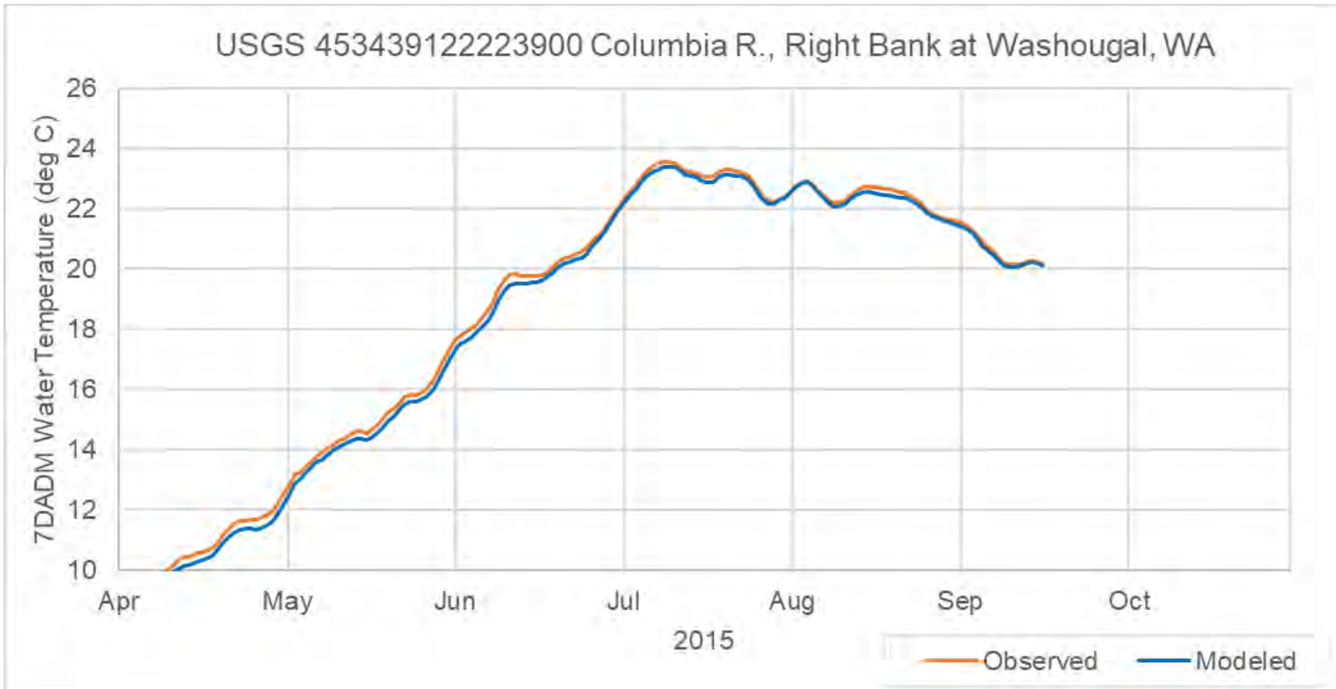

Figure A - 7. 7DADM Water Temperature comparison at Columbia River Right Bank, at Washougal, OR

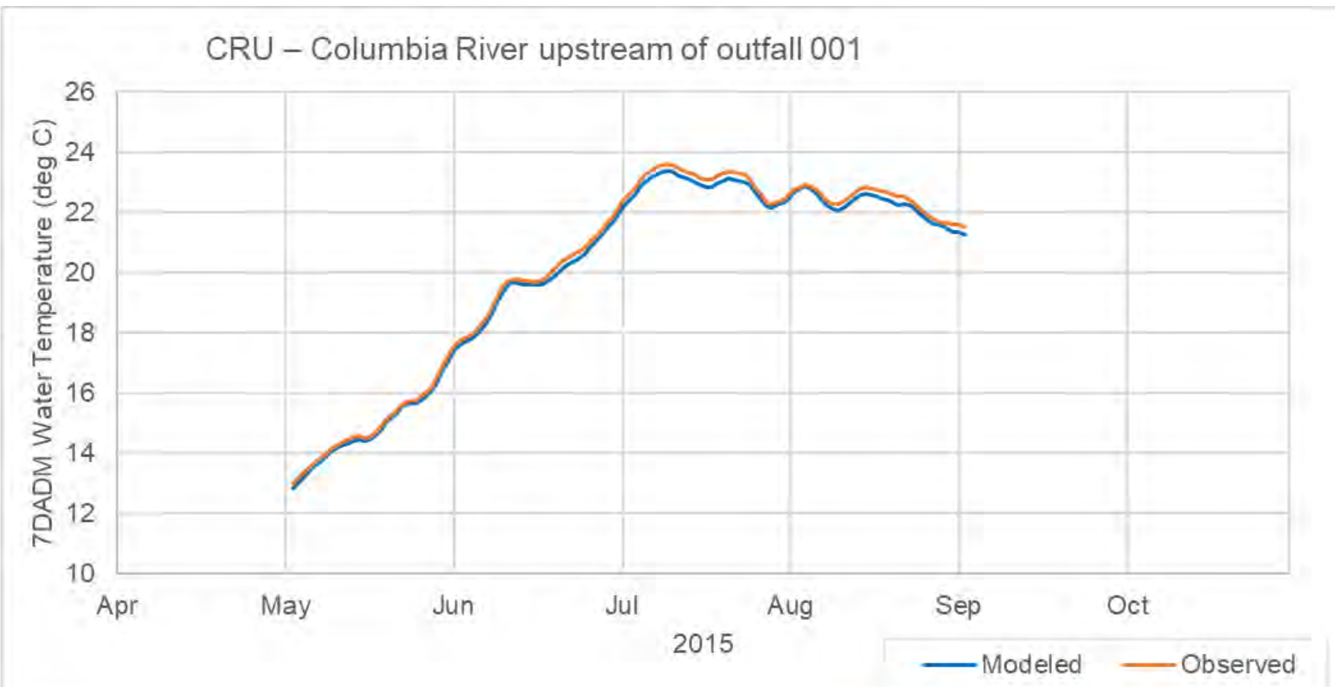

Figure A - 8. 7DADM Water Temperature comparison at Columbia River upstream of outfall 001

APPENDIX B – CLACKAMAS RIVER – DAILY MAXIMUM AND 7DADM OBSERVED VS MODELED WATER TEMPERATURE CALIBRATION PLOTS

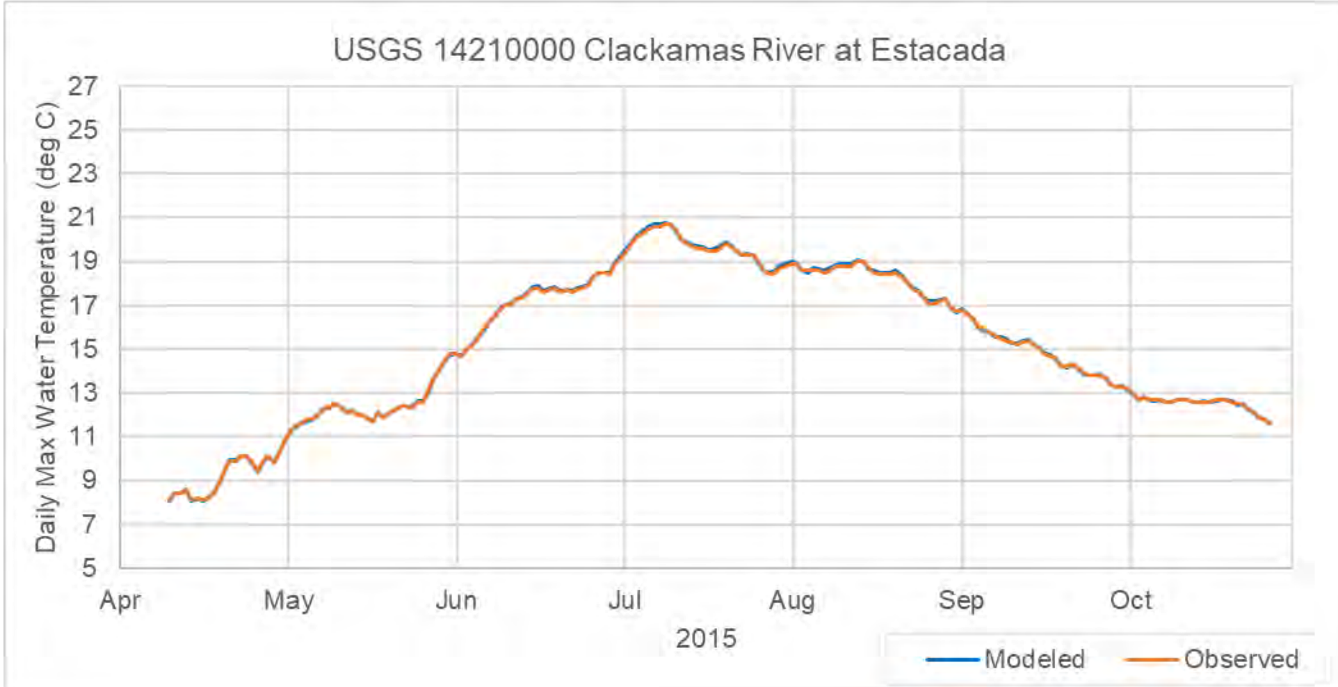

Figure B- 1. Daily Maximum Water Temperature comparison at Clackamas River at Estacada

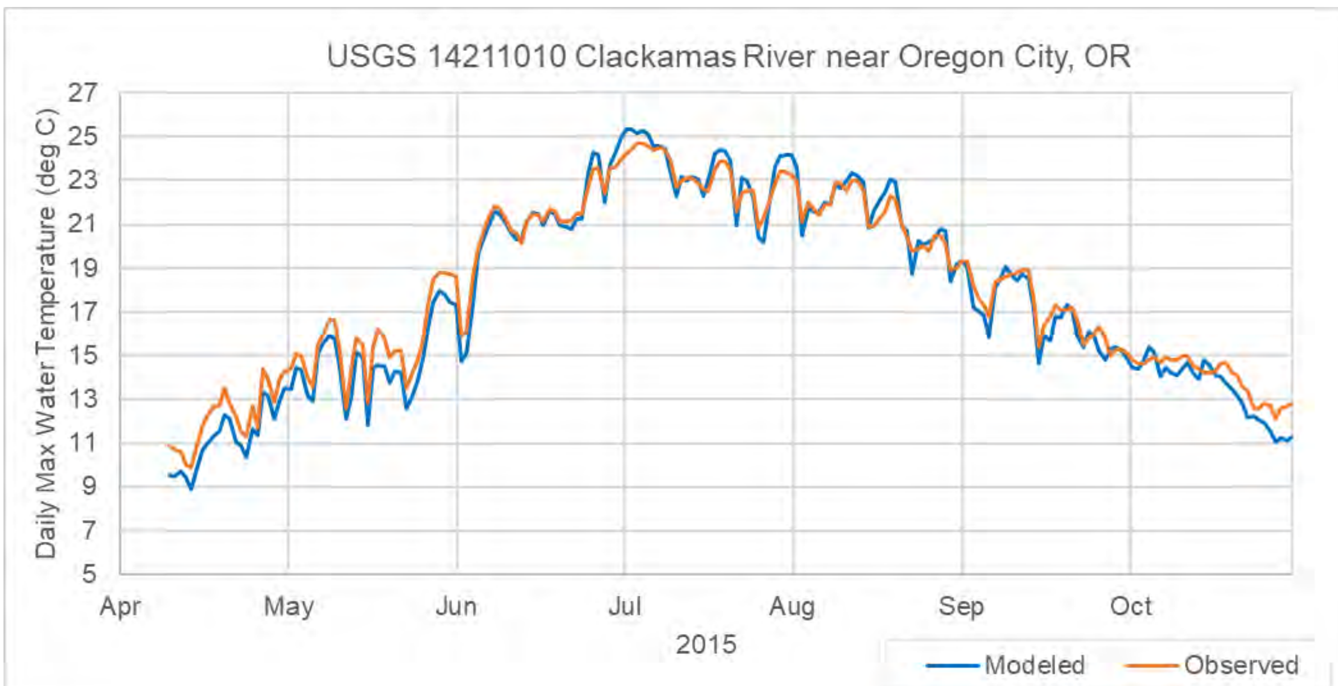

Figure B- 2. Daily Maximum Water Temperature comparison at Clackamas River near Oregon City, OR

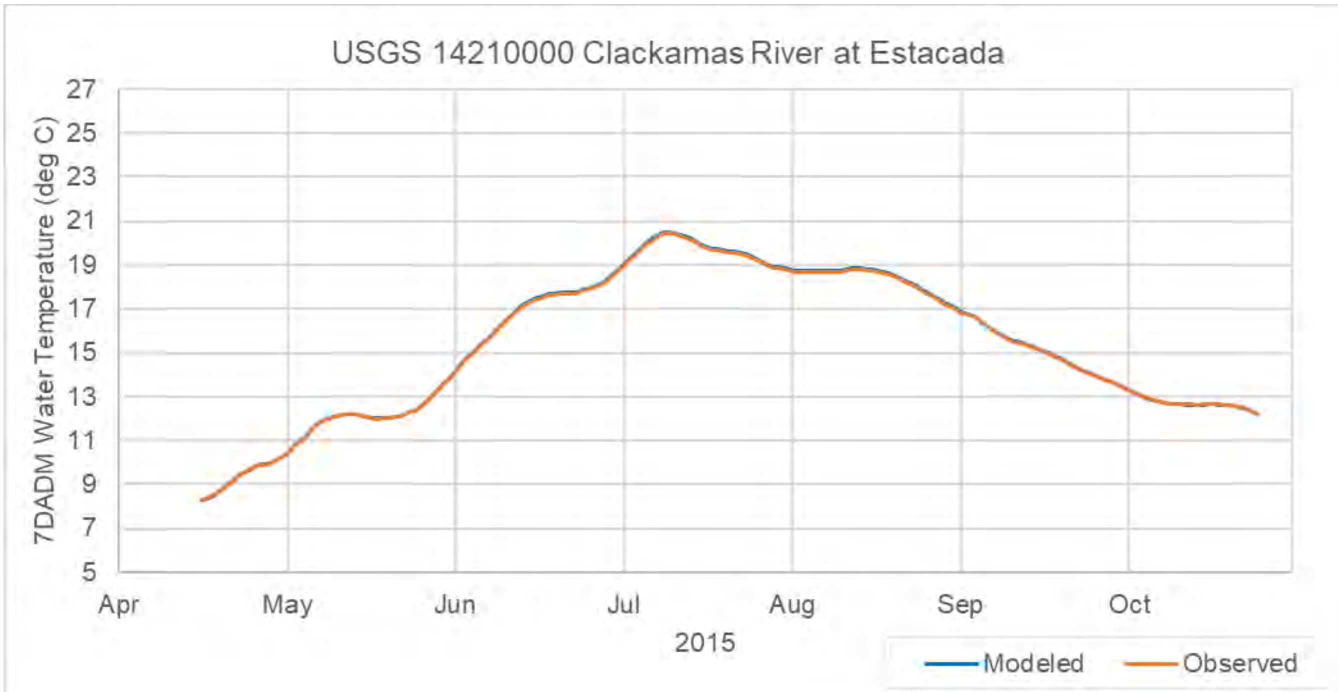

Figure B- 3. 7DADM Water Temperature comparison at Clackamas River at Estacada

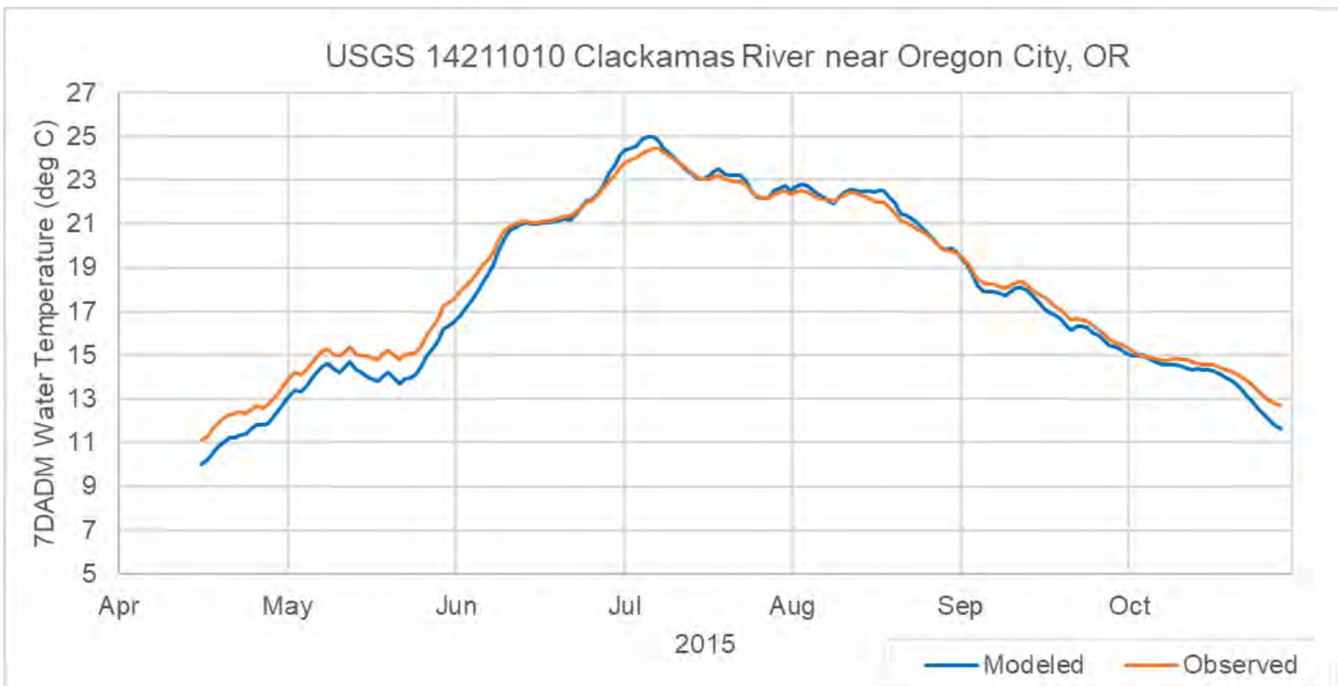

Figure B- 4. 7DADM Water Temperature comparison at Clackamas River near Oregon City, OR

APPENDIX C – LONG TOM RIVER – DAILY MAXIMUM AND 7DADM OBSERVED VS MODELED WATER TEMPERATURE CALIBRATION PLOTS

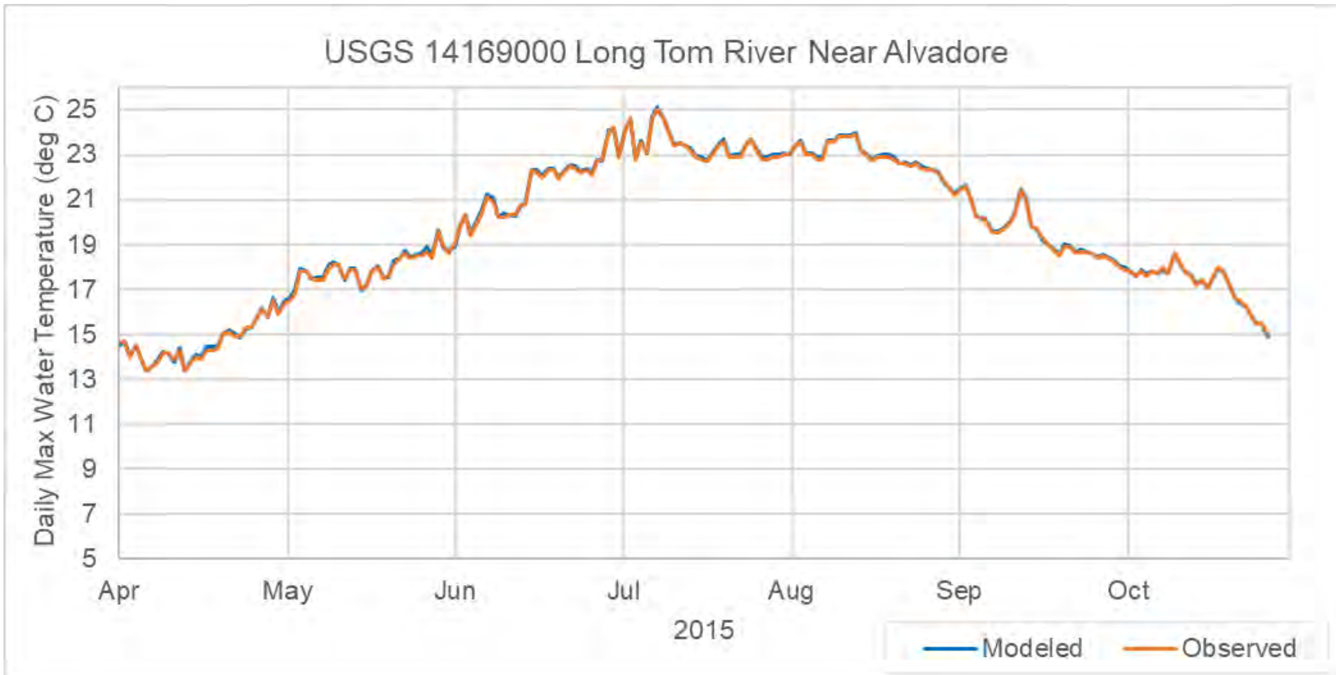

Figure C - 1. Daily Maximum Water Temperature comparison at Long Tom near Alvadore

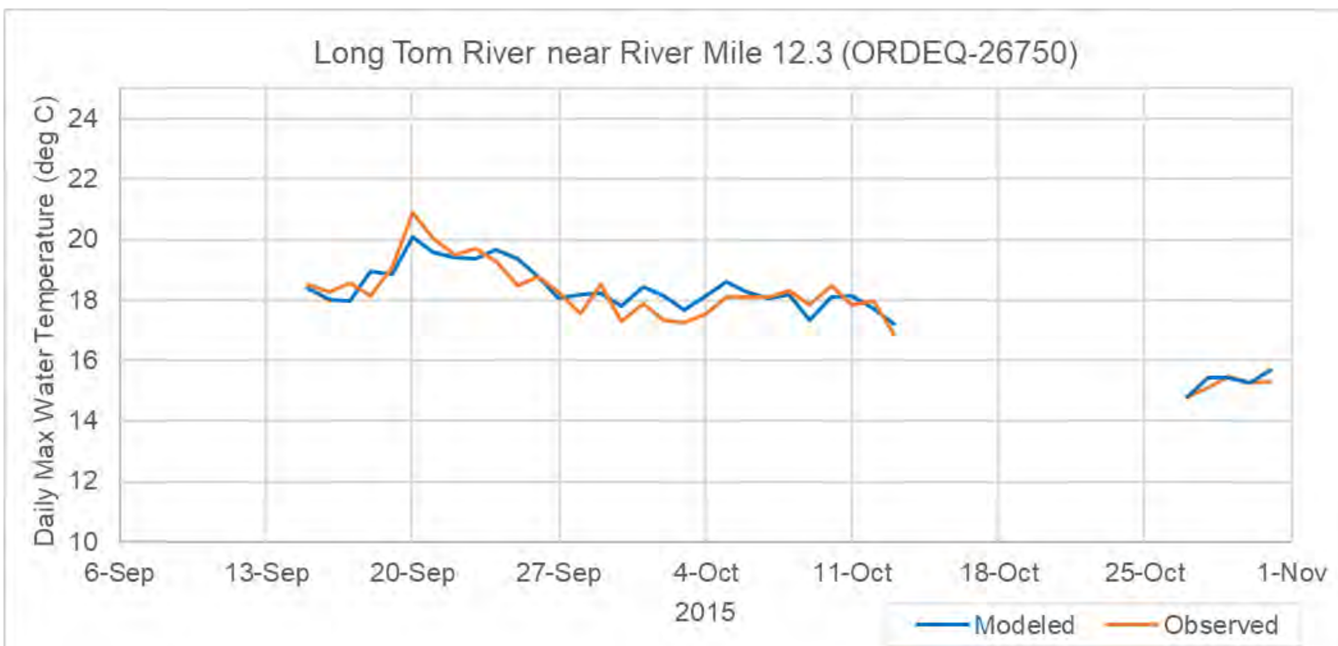

Figure C - 2. Daily Maximum Water Temperature comparison at Long Tom River near RM 12.3

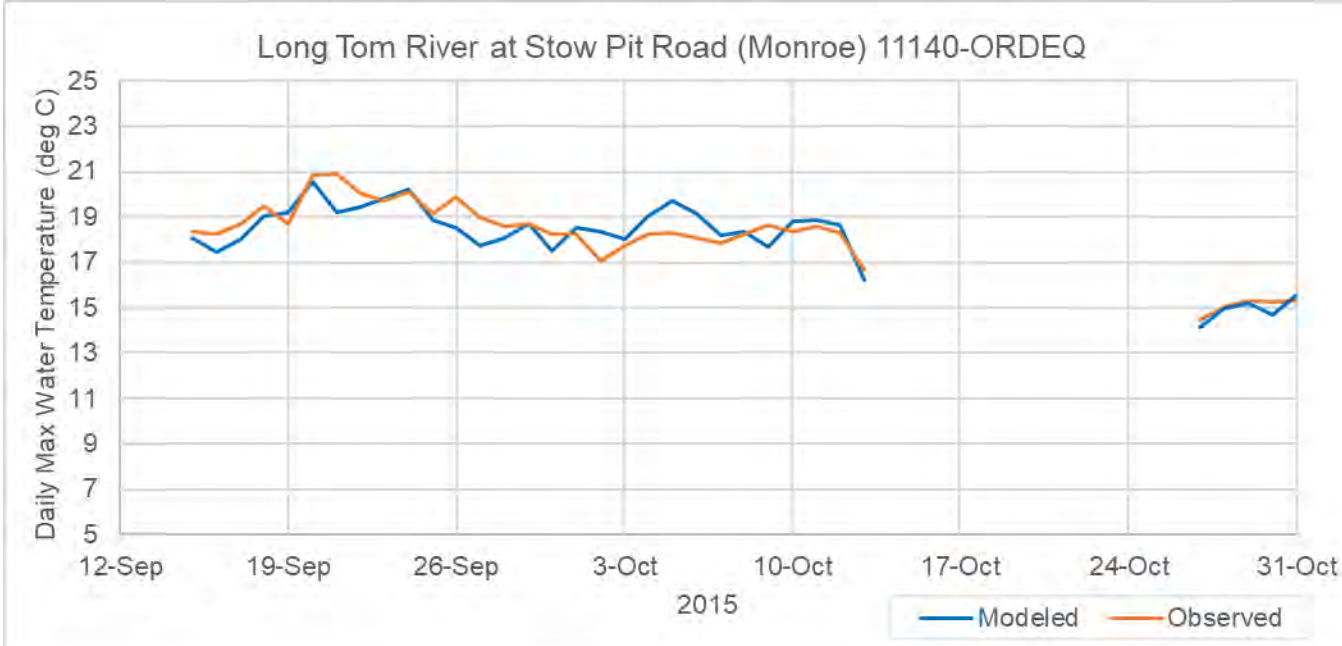

Figure C - 3. Daily Maximum Water Temperature comparison at Long Tom River at Stow Pit Road (Monroe)

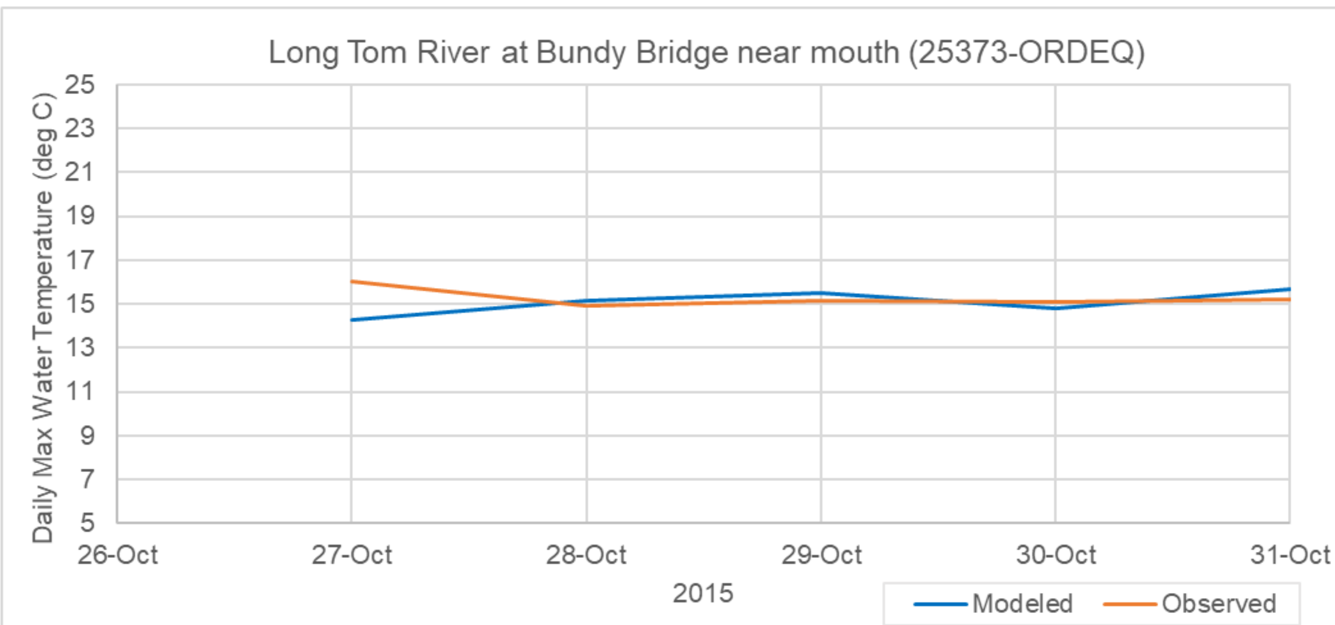

Figure C - 4. Daily Maximum Water Temperature comparison at Long Tom River at Bundy Bridge near mouth

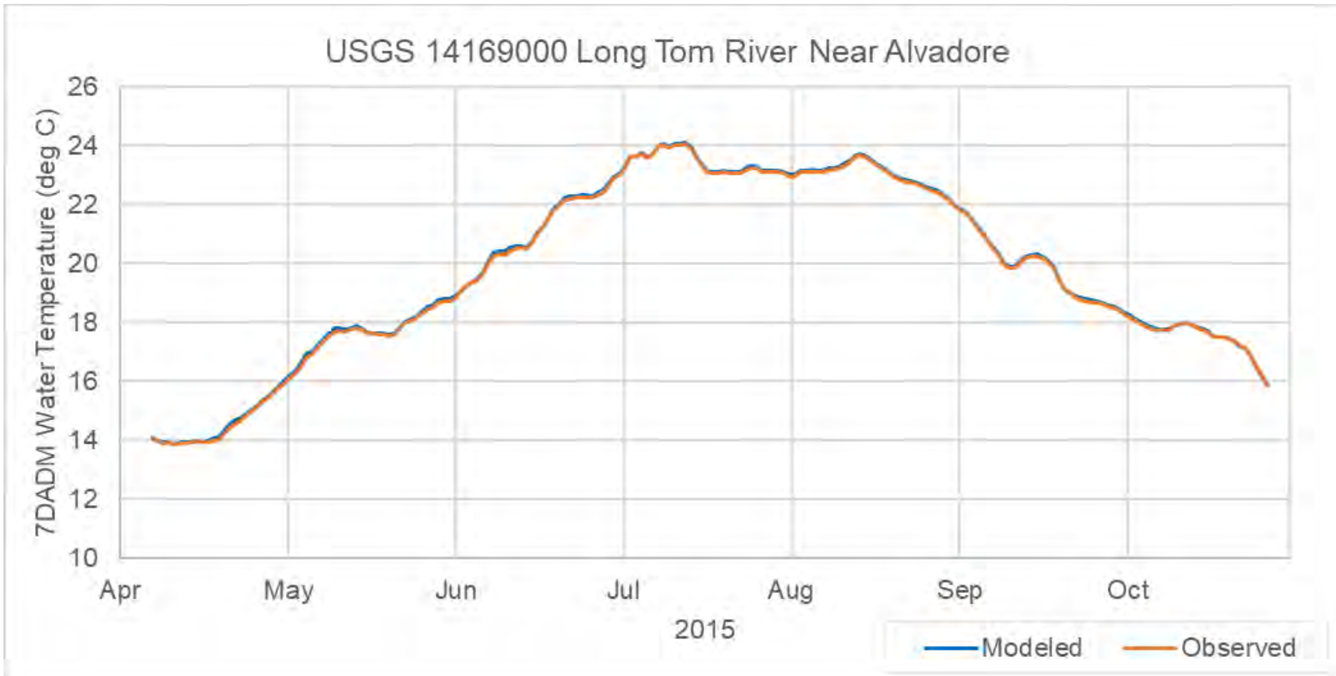

Figure C - 5 7DADM Water Temperature comparison at Long Tom near Alvadore

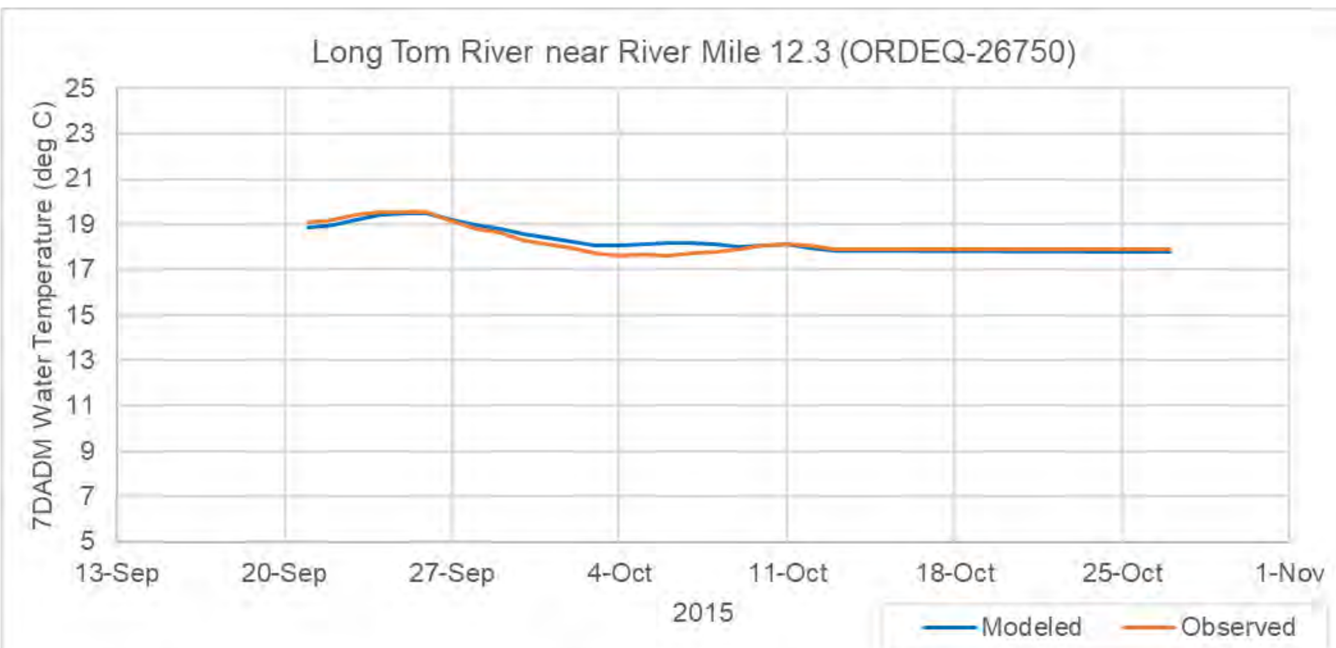

Figure C - 6. 7DADM Water Temperature comparison at Long Tom River near RM 12.3

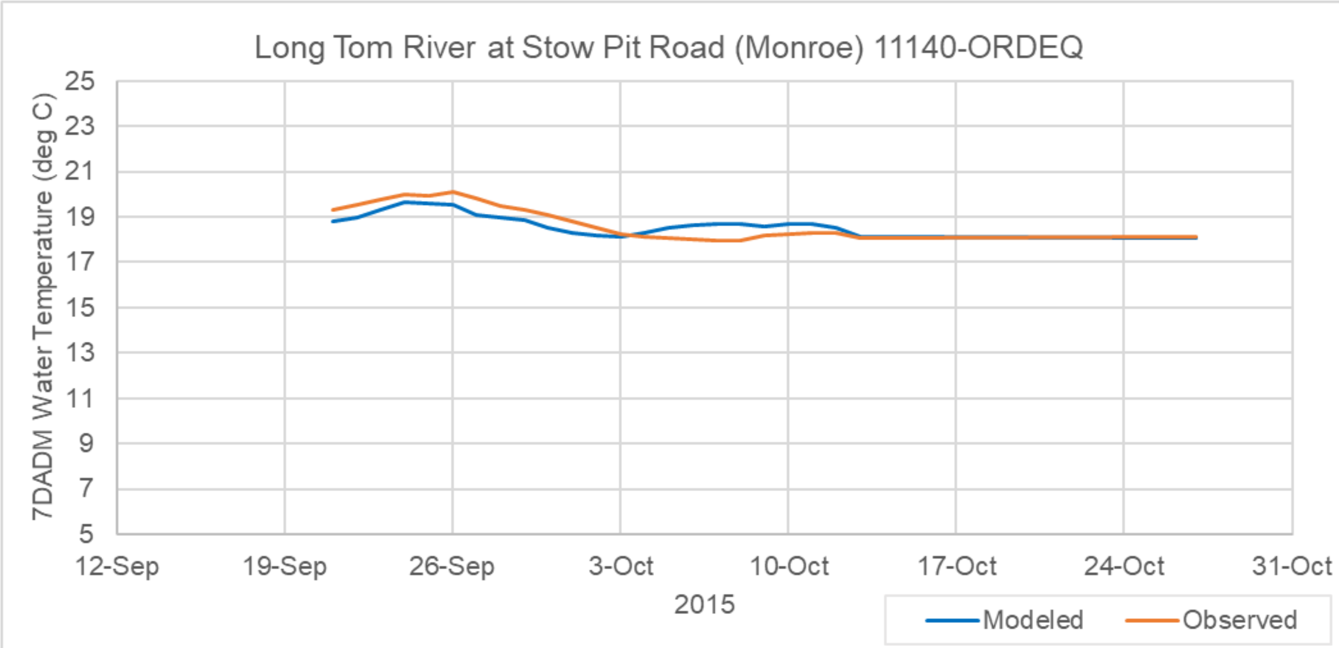

Figure C - 7. 7DADM Water Temperature comparison at Long Tom River at Stow Pit Road (Monroe)