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Chehalis River and Tributary Water Quality and Hydrodynamic Modeling: Model
Setup, Calibration Analysis for 2013-2015

by

Tel Jensen

A thesis submitted in partial fulfillment of the
requirements for the degree of

Master of Science
in
Civil and Environmental Engineering

Thesis Committee:
Scott Wells, Chair
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Portland State University
2020

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Abstract

The Chehalis River is located in southwest Washington State. Its headwaters are in the Willapa Hills, and it drains parts of the Doty Hills, the western foothills of the Cascade Mountains, and the southern Olympic Mountains. The Chehalis River is over 125 miles long and its basin is over 2000 square miles spanning parts of seven counties and diverse land uses.

CE-QUAL-W2 is a widely used two-dimensional (vertical and longitudinal) hydrodynamic and water quality model developed by the US Army Corp of Engineers and the Water Quality Research Group at Portland State University. Version 4.2 includes the ability to run waterbodies in sequence rather than simultaneously, which improves model run times.

This study expands and refines the work of Van Glubt et al. (2017). Model calibration was extended an additional year through 2015. Flow and temperature correlations used to fill model data gaps were updated with new data. 2018 dye study and periphyton data collected by the Washington State Department of Ecology were used to improve model calibration. Temperature and flow models of four large tributaries of the Chehalis River were created.

There remains room for improvement to the mainstem and tributary models. Better characterization of tributary water quality would improve the mainstem model's predictive ability. Model geometry in mainstem and tributary models could be further refined. Measurement of tributary flow rate and temperature at upstream boundaries would improve the utility of the tributary models.

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All the critters, but especially the critter. And Scott. Thanks.

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1. Introduction

Chehalis River Model Background

Van Glubt et al. (2017) developed a hydrodynamic and water quality model of the upper Chehalis River in southwest Washington State for the years 2013-2014 that was used to evaluate scenarios associated with flood hazard reduction and aquatic species restoration and enhancement. The Chehalis River Basin is located in southwest Washington State (see Figure 1). The upper Chehalis River basin covers 1,293 square miles, including parts of five counties: Lewis, Thurston, Grays Harbor, Pacific, and Cowlitz (WADOE, 2001). The Chehalis River originates in the Willapa Hills of the Coast Range east of Willapa Bay, and also drains the western foothills of the Cascades and the southern Olympic Mountains. The Chehalis ultimately flows into Grays Harbor and the Pacific Ocean, totaling over 125 miles in length.

Figure 1. Chehalis River study area from near Doty, through Centralia to Aberdeen in southwestern Washington State (Google earth, 2017).

The larger tributaries of the Chehalis River include the South Fork Chehalis River, Newaukum River, Skookumchuck River, and Black River (see Figure 2). Smaller tributaries include many creeks, such as Elk, Bunker, Mill, Stearns, Salzer, China, Scammon, Lincoln, Prairie, Scatter, Independence, Garrard, Cedar, Rock, Gibson, and Porter.

The land uses in the Chehalis river basin are diverse, including residential, agricultural, industrial, and logging and forest (WADOE, 2001). The river passes through urban areas, including the cities Centralia and Chehalis. In the study area, four municipal wastewater treatment plants (Pe Ell, Chehalis, Centralia, and Grand Mound) and one industrial wastewater treatment plant (Darigold) discharge to the river. Wastewater land application is required as an alternative for the Chehalis and Darigold wastewater treatment plant during periods of low river flows. National Frozen Foods has a state waste discharge permit to land apply wastewater in fields bordering the river between Chehalis and Centralia.

Figure 2. Chehalis River basin and associated tributaries (adapted from Dustin Bilhimer, 2015)

The mainstem Chehalis River in the study area has three distinct reaches based on their unique physical characteristics of slope and depth. The upper reach, beginning upstream of Pe Ell and extending to Chehalis, WA, has steep gradients with riffles and pools. The middle reach, beginning just below the Newaukum River near Chehalis, WA and extending to the just above the Skookumchuck River, has slow, deep, lake-like conditions that at times exhibit stratification. The lower reach, beginning near the Skookumchuck River and extending to Porter, WA, is similar to the upper reach, with faster velocities and riffles and pools (Pickett, 1994).

The model used by Van Glubt et al. (2017) was the CE-QUAL-W2 Version 4 and it was used to assess flow, water level, temperature, and water quality conditions along the Chehalis River.

The model grid reflected the character of the Chehalis River channel (see Figure 3) and was made up of 302 segments in 10 branches (collections of model segments with similar channel slope) and nine waterbodies (collections of model branches with similar water level fluctuations and different meteorological conditions).

Figure 3. Longitudinal profile of the Chehalis River thalweg (vertical lines show model branch breaks) from Van Glubt et al. (2017).

The model grid was based on more than 350 river cross sections provided by Anchor QEA (2011). Three weather monitoring stations were used for meteorological data. 21 tributaries were included as well as discharges from five wastewater treatment plants and groundwater inputs along the whole length of the model. Data gaps were filled with linear regressions to nearby monitoring stations where feasible. Several tributaries were entirely un-gaged. Flow in these un-gaged tributaries was estimated using a ratio of the tributaries' catchment area to that of a gaged flow and assuming the ratio of flow between the two is the same. Temperatures in un-gaged tributaries were assumed to be the same as temperatures measured in a tributary with similar flow.

This current study expands on the work of Van Glubt et al. (2017) by performing the following additional tasks:

- Extend the original model calibration from 2013-2014 to include 2015. Hence, all boundary conditions were developed for the low-flow critical year of 2015.
- Develop and calibrate flow and temperature models of 4 tributaries: South Fork Chehalis, Newaukum, Skookumchuck, and Black Rivers for 2013-2015.
- Use field data from Washington Department of Ecology from 2018 to inform the 2013-2015 model calibration. These field data include a dye study to assess travel times and a periphyton study to assess biomass densities. These data were used to compare to model results of travel time and periphyton densities and to adjust the model calibration as needed for the 2013-2015 period.

This report is divided into the following sections:

1. Chehalis River model updates for the 2013-2015 period
2. Results of the 2018 time-of-travel dye study and application to the Chehalis River

3. Development of models for the tributaries of the Chehalis: Newaukum, Skookumchuck, South Fork and Black Rivers for 2013-2015
4. Model calibration for the mainstem Chehalis, South Fork Chehalis, Newaukum, Skookumchuck, and Black Rivers for 2013-2015 for temperature and flow. Model calibration of the mainstem Chehalis River for water quality (dissolved oxygen, nutrients such as $\text{NH}_4\text{-N}$, $\text{NO}_2\text{+NO}_3\text{-N}$, PO_4 , TP, TN, algae, periphyton, suspended solids)

Model Capabilities

CE-QUAL-W2 is a two-dimensional, laterally averaged hydrodynamic and water quality numerical model (Cole and Wells, 2018). CE-QUAL-W2 was developed by the US Army Corps of Engineers and the Water Quality Research Group at Portland State University. The model predicts the following hydrodynamic variables:

- water surface elevation
- longitudinal and vertical velocities
- temperature

A wide variety of water quality constituents can be simulated using CE-QUAL-W2. 47 state variables are included, along with more than 60 derived variables. Any combination of these constituents can be simulated.

2. 2013-2015 Model updates

2015 boundary conditions were added to extend the 2013-2014 model an additional year. The summer of 2015 was warm and dry, leading to low flow and high temperature conditions in the river, making it useful for calibrating the model to these extreme conditions.

Existing boundary condition correlations that were used to fill in data gaps were adjusted to include additional field data that was collected after the 2013-2014 model was developed. This led to many updates to the correlations used for the

earlier model. Hence, all model boundary conditions from Van Glubt et al. (2017) were re-evaluated and re-done.

Boundary condition correlations

The model tributaries in the Chehalis River model are shown in Table 1. These are shown schematically in Figure 4.

Table 1. River mile and segment locations for upstream boundary, tributaries, dischargers, and groundwater inputs to the Chehalis River (Van Glubt et al. 2017)

Description	Model Segment	River Mile
Upstream boundary	2	108
Pe Ell WWTP	15	107
Elk Creek	38	100
South Fork Chehalis River	89	88
Bunker Creek	105	85
Stearns Creek	134	78.1
Mill Creek	135	78
Newaukum River	145	75.2
Darigold WWTP	150	75
Dillenbaugh Creek	150	74.4
Chehalis WWTP	150	74.3
Salzer Creek	171	69.2
China Creek	181	67.5
Skookumchuck River	182	66.8
Scammon Creek	187	65.5
Lincoln Creek	205	61.8
Centralia WWTP	207	61.25
Grand Mound WWTP	218	59.17
Prairie Creek	222	58.2
Scatter Creek	236	55.2
Independence Creek	250	50
Black River	267	47
Garrard Creek	275	44.9
Rock Creek	300	39.3
Cedar Creek	302	38.7
Gibson Creek	308	37.3
Porter Creek	321	33.3

Description	Model Segment	River Mile
Groundwater – Upstream of Elk Creek to downstream Boundary at Porter	35 – 321	101.9 – 33.3

Figure 4. Schematic of tributaries to the model reach of the Chehalis River and their corresponding river miles (WEST Consultants, 2011 and WADOE, 2001). Note: figure is not to scale.

Temperature

Since many of the tributaries in the model did not have complete temperature data from 2013-2015, these were estimated by correlating known data to other more complete temperature records. These temperature correlations with field data are summarized in Table 2. Temperature correlations for the following stations: 4-UCH, 11-UCH, 13-CH, 18-CH, 22-UCH, the Black River, Elk Creek, Newaukum, Scatter Creek, Skookumchuck River and the Chehalis River downstream of Darigold WWTP are shown in Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, and Figure 14, respectively. The temperature records from the Darigold WWTP were the most complete and were used to fill in several data gaps. Of the two gages there (upstream and downstream of the WWTP discharge), regressions to data from the downstream gage (Ch R.DS Darigold) gave better coefficients of correlation than did data from the upstream gage. Where temperature data from a gage closer to the tributary than the Darigold gages were available, they were used regardless of which data gave the best coefficient of correlation. Where two or more regressions are given in Table 2, the regression using data from the gage nearest the tributary was used first and the Ch R.DS Darigold regression was used to fill in the remaining gaps.

Table 2. Temperature Regression Relationships for tributaries along the Chehalis mainstem at the upstream boundary, Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, Scatter Creek, and Black River. Other station correlations at Darigold, 22-CH (river mile 75.3), and 18-CH (river mile 50.5) were used for distributed un-gaged flow inputs. Old refers to those regressions used in Van Glubt et al. 2017, while new refers to the updated one used in this study. Where multiple regressions for one tributary are shown, the regressions were used in order of proximity to the tributary for which temperature is being estimated.

Tributary	Regression Equation		R ²
Chehalis River Downstream of Darigold	old	$T_{Ch\ R.DS\ Darigold} = 1.048 * T_{Ch\ R.Porter} - 1.135$	0.988
Upstream boundary (station 11-UCH)	old	$T_{Ch\ R.(11-UCH)} = 1.0191 * T_{CHL-PEL-US\&3-UCH} - 0.5085$	0.978
	new	$T_{Ch\ R.(11-UCH)} = 1.0250 * T_{CHL-PEL-US} - 0.6180$	0.934
	new	$T_{Ch\ R.(11-UCH)} = 1.0230 * T_{3-UCH} - 0.5430$	0.977
	old	$T_{Ch\ R.(11-UCH)} = 0.8186 * T_{Ch\ R.DS\ Darigold} + 1.0174$	0.954
	new	$T_{Ch\ R.(11-UCH)} = 0.8222 * T_{Ch\ R.DS\ Darigold} + 0.7120$	0.955
Elk Creek	old	$T_{Elk\ Creek} = 0.7681 * T_{Ch\ R(4-UCH)} + 1.7319$	0.974
	new	$T_{Elk\ Creek} = 0.6501 * T_{Ch\ R(4-UCH)} + 3.7124$	0.958
	old	$T_{Elk\ Creek} = 0.7383 * T_{Ch\ R.DS\ Darigold} + 1.6909$	0.979
	new	$T_{Elk\ Creek} = 0.7320 * T_{Ch\ R.DS\ Darigold} + 1.7934$	0.977
South Fork Chehalis River	old	$T_{SF\ Chehalis} = 0.9627 * T_{Ch\ R.DS\ Darigold} + 0.583$	0.988
	new	$T_{SF\ Chehalis} = 0.9544 * T_{Ch\ R.DS\ Darigold} + 0.7173$	0.987
Newaukum River	old	$T_{Newaukum} = 0.9521 * T_{Ch\ R.DS\ Darigold} + 0.5257$	0.978
	new	$T_{Newaukum} = 0.9502 * T_{Ch\ R.DS\ Darigold} + 0.4918$	0.987
Skookumchuck River	old	$T_{Skookumchuck} = 0.67 * T_{Ch\ R.DS\ Darigold} + 4.7899$	0.969
	new	$T_{Skookumchuck} = 0.6438 * T_{Ch\ R.DS\ Darigold} + 5.2135$	0.952
Black River	old	$T_{Black} = 0.7406 * T_{Ch\ R.(18-CH)} + 3.2796$	0.836
	new	$T_{Black} = 0.7405 * T_{Ch\ R.(18-CH)} + 3.2827$	0.836
	old	$T_{Black} = 0.8222 * T_{Ch\ R.DS\ Darigold} + 2.3484$	0.967
	new	$T_{Black} = 0.8138 * T_{Ch\ R.DS\ Darigold} + 2.4735$	0.965
Scatter Creek	new	$T_{Scatter\ Creek} = 0.8599 * T_{Ch\ R.DS\ Darigold} + 1.7380$	0.947
22-CH	new	$T_{CH-22} = 0.9974 * T_{Ch\ R.DS\ Darigold} + 0.2083$	0.996
18-CH	new	$T_{CH-18} = 0.9258 * T_{Ch\ R.DS\ Darigold} + 1.2311$	0.983

Figure 5. Temperature correlation between the station 4-UCH and the Chehalis River downstream of Darigold WWTP between 2013-2015.

Figure 6. Temperature correlation between the station 11-UCH (upstream boundary) and the Chehalis River downstream of Darigold WWTP between 2013-2015.

Figure 7. Temperature correlation between the station 13-CH and the Chehalis River downstream of Darigold WWTP between 2013-2015.

Figure 8. Temperature correlation between the station 18-CH and the Chehalis River downstream of Darigold WWTP between 2013-2015.

Figure 9. Temperature correlation between the station 22-UCH and the Chehalis River downstream of Darigold WWTP between 2013-2015.

Figure 10. Temperature correlation between the station Black River tributary and the Chehalis River downstream of Darigold WWTP between 2013-2015.

Figure 11. Temperature correlation between the station Elk Creek tributary and the Chehalis River downstream of Darigold WWTP between 2013-2015.

Figure 12. Temperature correlation between the station Newaukum tributary and the Chehalis River downstream of Darigold WWTP between 2013-2015.

Figure 13. Temperature correlation between the station Scatter Creek and the Chehalis River downstream of Darigold WWTP between 2013-2015.

Figure 14. Temperature correlation between the station Skookumchuck River and the Chehalis River downstream of Darigold WWTP between 2013-2015.

Flow

When flow data were missing, the missing data were filled in using field data correlations with flow rates at another monitoring station. In updating the correlations from Van Glubt et al. (2017) with new data in 2015, some of these correlations were adjusted for the entire time period. A summary of these correlations is shown in Table 3.

Table 3. Tributary flow correlations that were updated from the work of Van Glubt et al. (2017) using new data from 2015. "Old" refers to those regressions used in Van Glubt et al. 2017, while "new" refers to the updated one used in this study.

Tributary		Regression	r^2
Chehalis at Mahaffey Creek	old	$Q_{Ch.R. Mahaffey} = 0.8262 * Q_{Chehalis@Doty} - 0.3337$	0.980
	new	$Q_{Ch.R. Mahaffey} = 0.7635 * Q_{Chehalis@Doty} - 0.1505$	0.973
Elk Creek	old	$Q_{Elk Creek} = 0.3254 * Q_{Chehalis@Doty}$	0.765
	new	$Q_{Elk Creek} = 0.3218 * Q_{Chehalis@Doty}$	0.900
South Fork Chehalis	old	$Q_{SF Chehalis} = 0.1818 * Q_{Chehalis@Doty}$	0.845
	new	$Q_{SF Chehalis} = 0.2239 * Q_{Chehalis@Doty}$	0.915
Black River	old	$Q_{Black} = 0.0956 * Q_{Chehalis@Grand Mound}$	0.469
	new	$Q_{Black} = 0.09242 * Q_{Chehalis@Grand Mound}$	0.775

Figure 15 shows flow rate correlations between the Black River and the mainstem Chehalis River at Grand Mound; Figure 16 shows flow rate correlations between Elk Creek and the mainstem Chehalis River at Doty; and Figure 17 shows flow correlations between the mainstem Chehalis River near Mahaffey Creek and the mainstem Chehalis River at Doty.

Figure 15. Flow correlation between Black River and Chehalis River at Grand Mound between 2013-2015.

Figure 16. Flow correlation between Elk Creek and Chehalis River at Doty between 2013-2015.

Figure 17. Flow correlation between Chehalis River near Mahaffey Creek and Chehalis River at Doty between 2013-2015.

Water Quality Constituents

Changes to Van Glubt's (2017) water quality constituent input files are limited to wastewater treatment plant discharges and groundwater tributaries in waterbody 3. A sensitivity analysis lead to decreasing the PO_4^{3-} concentration from 0.09 mg/l by half to 0.045 mg/l in groundwater tributaries 27-51. This improved model phosphorus and algae predictions. Treatment plant discharge files were updated with 2015 water quality data. Very little tributary water quality data was available for 2015, so 2013 and 2014 data were averaged to extend constituent files through 2015.

3. 2018 Dye study

The Washington Department of Ecology performed dye studies along the Chehalis mainstem during 2018. Details of these studies were provided by Nuri Mathieu (2019) from Washington Department of Ecology and are shown in Appendix B. The regions of the Chehalis mainstem where the dye studies were conducted are shown in Figure 18.

Figure 18. Locations of four dye studies along the Chehalis River mainstem during August 2018.

In order to run the model for the August 2018 dye study, the flow regime had to be adjusted to that measured at the USGS gages during the dye study. We used the temperatures from the 2015 time period with flows from 2018. Hence, flows had to be developed for the 2018 period of the dye study. Also, in 2018 a new flow monitoring location was added at Adna that was not available for the 2013-2015 flow comparisons.

The 2018 model prediction of flow rates at Doty, Adna, Grand Mound, and Porter gage stations compared to field data are shown in Figure 19. Table 4 shows excellent mean error (ME, goal of 0 m³/s) and low absolute mean error (AME) relative to the flow rate. For example, at Porter, the average flow rate during the dye

study was about 8.5 m³/s, hence the AME error divided by the average flow rate was about 1.4%.

Table 4. Flow rate errors (see Appendix C) between model predictions and field data for flow rate at Doty, Grand Mound, and Porter for August 2018 during the dye study of Mathieu (2018).

Gage	Number of comparisons	ME, m ³ /s	AME, m ³ /s	RMS, m ³ /s
Doty	970	0.00042	0.01336	0.02027
Adna	970	0.00664	0.04766	0.06167
Grand Mound	783	0.02781	0.03468	0.04793
Porter	783	0.05199	0.11679	0.15159
weighted	3506	0.01978	0.05071	0.06723

Figure 19. Flow rate model predictions during August 2018 dye study compared to field data in the mainstem Chehalis River at (a) Doty, (b) Adna, (c) Grand Mound, and (d) Porter.

The dye was modeled as particles representing the dye mass. The particle transport algorithm (Cole and Wells, 2018) allows particles to move through the system without being constrained by segment boundaries rather than as a continuum,

which would increase numerical spreading. This algorithm moves particles based on fluid motion and random motion based on turbulence intensity in the x, y and z directions.

There were 4 dye releases as shown in Figure 18 and in Appendix A. The resulting dye concentrations (data from Mathieu, 2019) measured at each sampling site are shown in the following Figure 20 and Figure 21. Mathieu did not have confidence in the data from Ceres Canyon, so it was excluded from further analysis. The primary goal of this modeling effort was to obtain similar travel time of the peak and particle spread (dispersion). Figure 23, Figure 24, Figure 25, Figure 26, Figure 27, Figure 28, and Figure 29 show cumulative dye mass compared to modeled cumulative particle mass fraction at each of the monitoring points. As evident from these graphs, some sites (such as at Newaukum) did not exhibit expected dye response behavior either because of missing the peak during sampling or flow complexities.

Figure 20. Dye concentration curves at (a) Elk Creek, (b) Hope Creek, (c) Ceres Canyon, and (d) Adna during 2018 dye study.

Figure 21. Dye concentration curves at (a) Newaukum River, (b) Skookumchuck River, (c) Prather Road, and (d) Oakville Boat Launch during 2018 dye study.

Modeling dye transport by adding particles instead of adding a mass of dye to a model cell allows greater resolution of the dye transport. Converting particles to

concentration in order to compare to field data was based on the following conversion:

$$C = \frac{M}{\#particles\ released} \frac{1}{Q\Delta t} \sum particles$$

where particles represent those particles passing a sensor location during a time period Δt , Q is the flow rate, M is the total mass of dye released, and $\#particles\ released$ is the total number released to represent the dye study. This method did not allow easy comparison of model results and field data, because of the difficulty in estimating a volume for converting from modeled particle mass to concentration. Figure 22 shows dye modeled as both a conservative tracer and as particles compared to field data. Modeling dye as a conservative tracer caused to much dispersion, while converting particle paths to concentrations required arbitrarily

scaling to match field data.

Figure 22. Modeled dye concentration using two methods compared to dye study field data. The particle concentration was arbitrarily scaled.

Instead of comparing concentration versus time with the field data, the cumulative dye mass measured in the field was compared to cumulative particle mass in the model. The cumulative mass was computed from the model particle release as

$$CumulativeMass = \frac{M}{\#particles\ released} \sum particles$$

The dye study data were converted to cumulative mass using the following:

$$CumulativeMass = \sum CQ\Delta t$$

Where C is the dye concentration, Q is the flow rate, and Δt is the time interval between measurements.

With the exception of the Skookumchuck sample site, the mass of dye calculated to have passed the probe was lower than the mass of dye released for the study. To account for this mass loss, first-order decay was assumed for particles in the model as in

$$\frac{\partial M}{\partial t} = -Mk$$

where $\frac{\partial M}{\partial t}$ is the time rate of change of dye mass and k is a first-order decay constant.

Integrating this equation and solving for k gives

$$k = \frac{\ln \frac{M_0}{M}}{t - t_0}$$

where M_0 is the mass of dye released and t_0 is the time of dye release.

If it appeared that most of the dye plume had been captured in the field data, the total mass calculated was used for M and the time that half of the mass had passed the sample site was used for t . If it did not appear that the whole plume had been captured, the time of peak concentration was used for t , and twice the cumulative mass at that point was used for M . The decay constants calculated this way are shown in Table 5. No decay constant was used for Skookumchuck, because more dye mass was measured there than was released.

Table 5. First-order decay constants applied to model particles to approximate dye loss.

Station	k , day ⁻¹
Elk Creek Rd	0.30
Hope Creek	0.29
Adna	0.47
Newaukum	0.23
Prather Rd	0.15
Oakville Boat Launch	0.098

Figure 23. Cumulative mass from dye release compared to model predictions at Elk Creek RM 100.4.

Figure 24. Cumulative mass from dye release compared to model predictions at Hope Creek RM 94.8.

Figure 25. Cumulative mass from dye release compared to model predictions at Adna RM 81.5.

Figure 26. Cumulative mass from dye release compared to model predictions at Newaukum RM 75.1.

Figure 27. Cumulative mass from dye release compared to model predictions at Skookumchuck RM 67.

Figure 28. Cumulative mass from dye release compared to model predictions at Prather Road RM 59.9.

Figure 29. Cumulative mass from dye release compared to model predictions at Oakville Boat Launch RM 42.4.

Four parameters were adjusted to match the results of the dye study conducted in August 2018: hydraulic equivalent branch slope (Table 6), waterbody bottom elevation (Table 7), spillway elevation (Table 8), and longitudinal eddy diffusivity (Table 9). In most cases the dye results showed that transport of mass and heat downstream in the Van Glubt et al. (2017) model was too fast and did not allow enough dispersion.

Table 6. Adjustments in CE-QUAL-W2 model adjusted hydraulic equivalent slope (SLOPEC) from the Van Glubt et al. (2017) model based on the results of the dye study.

model branch	SLOPEC	
	old	new
1	0.003	0.001600
2	0.0004	0.000216
3	0.0006	0.000294
4	0.00095	0.000048
5	0.00055	0.000496
6	0.000001	0.000001
7	0.000001	0.000001
8	0.00055	0.000081
9	0.000769	0.000127
10	0.00077	0.000077

Table 7. Adjustments in CE-QUAL-W2 model reference bottom elevation (EBOT) from the Van Glubt et al. (2017) model based on the results of the dye study.

waterbody	EBOT, meters	
	old	new
1	111.06	111.06
2	93.34	93.34
3	71.15	71.15
4	46.68	46.68
5	39.77	39.77
6	38.08	36.207
7	35.32	35.32
8	14.96	14.96
9	3.28	3.280

Table 8. Adjustments in CE-QUAL-W2 model adjusted elevation of the spillway between branches (ESP) from the Van Glubt et al. (2017) model based on the results of the dye study.

Spillway	ESP, meters	
	old	new
1	8.770	8.770
2	95.84	96.34
3	112.55	111.00
4	n/a	46.557
5	n/a	48.905
6	n/a	73.25
7	n/a	43.55
8	n/a	28.50
9	n/a	21.96

Table 9. Adjustments in CE-QUAL-W2 model dispersion coefficient (DX) from the Van Glubt et al. (2017) model based on the results of the dye study.

Waterbody	DX, m ² sec ⁻¹	
	old	new
1	1.00	10.0
2	1.00	6.50
3	1.00	1.27
4	1.00	4.50
5	1.00	3.70
6	1.00	2.65
7	1.00	90.0
8	1.00	41.0
9	1.00	10.0

4. Tributaries of the Chehalis: South Fork Chehalis, Newaukum, Skookumchuck, and Black Rivers

Models were developed for the four largest tributaries in the mainstem Chehalis River model domain.

Tributary Bathymetry

Bathymetry for the South Fork Chehalis, Newaukum, Skookumchuck and Black Rivers was developed using existing HEC-RAS cross-sections. The grids were developed from the most upstream HEC-RAS cross-section downstream to the confluence with the Chehalis River. Figure 30 through Figure 33 show the model segments of the tributary grids and the HEC-RAS cross-section locations for the South Fork Chehalis, Newaukum, Skookumchuck, and Black Rivers, respectively. The thalweg elevations of the tributary HEC-RAS cross-sections are plotted in Figure 34 through Figure 37. Layer thicknesses were 1m, and segment length varies from 174.52 m to 282.22 m. Table 10 lists the grid characteristics for each tributary.

Figure 30. South Fork Chehalis River HEC-RAS cross sections (black triangles), segment locations (red triangles), and lower model segment locations (blue triangles). Numbers represent CE-QUAL-W2 model segments in the Chehalis River (blue) and in the South Fork Chehalis River (red).

Figure 31. Newaukum River HEC-RAS cross sections (black triangles), segment locations (red triangles), and lower model segment locations (blue triangles). Numbers represent CE-QUAL-W2 model segments in the Chehalis River (blue) and in the Newaukum River (red).

Figure 32. Skookumchuck River HEC-RAS cross sections (black triangles), segment locations (red triangles), and lower model segment locations (blue triangles). Numbers represent CE-QUAL-W2 model segments in the Chehalis River (blue) and in the Skookumchuck River (red).

Figure 33. Black River HEC-RAS cross section locations (black triangles), segment locations (red triangles), and lower Chehalis River model segment locations (blue triangles). Numbers represent CE-QUAL-W2 model segments in the Chehalis River (blue) and in the Black River (red).

Figure 34. South Fork Chehalis River thalweg elevations of HEC-RAS cross-sections.

Figure 35. Newaukum River thalweg elevations of HEC-RAS cross-sections.

Figure 36. Skookumchuck River thalweg elevations of HEC-RAS cross-sections.

Figure 37. Black River thalweg elevations of HEC-RAS cross-sections.

Table 10. Characteristics of tributary grids.

Parameter	South Fork Chehalis River	Newaukum River	Skookumchuck River	Black River
Grid length	5.84 miles (9,399 m)	9.76 miles (15,707 m)	21.77 miles (35,036 m)	10.87 miles, (17,498 m)
Number of active segments	37	90	155	62
Longitudinal grid spacing	254.02 m	174.52 m	226.04 m	282.22 m
Number of branches/waterbodies	1/1	2/1	1/1	1/1
Vertical layer thickness	1 m	1 m	1 m	1 m

Tributary Boundary Conditions

Data from a number of gages in the Upper Chehalis Basin (Figure 2) were available, including flow and temperature data useful for this project for calibration. In many cases, though, the location of the gages and time of their deployment meant that when temperature data were available, flow data were not and vice versa.

The upstream boundary conditions for flow rate and temperature for the South Fork Chehalis, Newaukum, Skookumchuck, and Black Rivers were absent in most cases. Hence, we tried to estimate upstream conditions when they were missing by using downstream data to infer upstream conditions or by using data from above the upstream model boundary. This meant that the model calibrations for the rivers over three years were largely approximate since detailed boundary conditions were usually not available.

Flow

Where flow data from more than one gage were available for a tributary, the furthest downstream data were used for flow calibration and upstream data were used for the upstream boundary condition. Where flow data were only available from one gage (usually near the mouth of the Lower Chehalis mainstem), those data were used for both calibration and the upstream boundary condition.

South Fork Chehalis

There are a number of tributaries of the South Fork Chehalis River between the USGS 12020800 gage at river mile 16.2 and the WSDOE 23K060 gage at river mile 0.1 near the confluence of the South Fork Chehalis with the mainstem Chehalis

River. Because these tributaries are not gaged and their catchments are not well-characterized, their flow was estimated using a single distributed tributary that added flow to each of the model segments scaled to the segment's surface area. The distributed tributary flow was the difference between the modeled flow without a distributed tributary and the estimated flow at the end of the model before entering the Chehalis mainstem. Flow at the confluence was estimated using a regression of flow data from WSDOE gage 23K060 to flow data from the USGS gage at Doty (USGS 12020000).

Different rating tables appear to have been used for the Ecology 23K060 data before and after water year 2017 (Figure 38). A considerable amount of these data also had QC flags indicating that they are outside the range of the gage's rating table. Three flow estimates were created using Doty data with subsets of the 23K060 data: all available data, all data tagged with either "Good quality REVIEWED data" or "Good quality provisional data", and all data from the 2018 water year onward termed "late" data (see Figure 39). These flow estimates (using the "late" data) were used during the calibration to assess model performance near the mouth.

The estimated flow rate used in the South Fork model upstream boundary was from USGS 12020800 gage at river mile 16.2 and is shown in Figure 40.

Figure 38. Flow data from WADOE 23K060 gage on the South Fork Chehalis River at Highway 6 showing difference before and after the end of 2017 water year.

Figure 39. South Fork Chehalis River flow estimates at Ecology 23K060 gage showing regressions to fill in data gaps. Regressions used all the data (all data), those data that passed quality control (good data), or only 2018 and 2019 data (late data).

Figure 40. Estimated South Fork Chehalis River flow rates at upper boundary of model for 2013-2015.

Newaukum River

The USGS 12025000 gage is at river mile 4.1 in model segment 54. There are additional USGS gages in the North Fork Newaukum River (river mile 7.7) and South Fork Newaukum River (river mile 22.8). These are too far upstream from both the fork at Newaukum river mile 10.9 and the upstream end of the model at Newaukum river mile 9.76 to be used for an upstream boundary condition. The estimated flow rate used in the Newaukum model upstream boundary is shown in Figure 41 which is based on the USGS gage at RM 4.1 with data gaps filled by regression.

Figure 41. Estimated Newaukum River flow rates at upper boundary of model for 2013-2015.

Skookumchuck River

The USGS 12026400 gage is at river mile 6.4 in model segment 111. USGS 12026150 is at river mile 20.7 in model segment 9, about one mile downstream from the upstream end of the model. The estimated flow rate used in the Skookumchuck model upstream boundary is based on USGS 12026150 at RM 20.7 and is shown in Figure 42 with data gaps filled by regression.

Figure 42. Estimated Skookumchuck River flow rates at upper boundary of model between 2013-2015.

Black River

The WADOE 23E060 gage is at river mile 2.0 in model segment 53. No flow data from the 2014 water year was available from this gage. This data gap was filled in using a regression to USGS 12027500 on the mainstem Chehalis River near Grand Mound. The estimated flow rate used in the Black River model upstream boundary is shown in Figure 43 and is the WADOE 23E060 gage with data gaps filled by regression.

Figure 43. Estimated Black River flow rates at upper boundary of model between 2013-2015.

Temperature

No direct measurements of water temperature at the upstream boundary were available for any of the tributaries for the 2013-2015 time period. What temperature data did exist did not cover the entire model period. Hence, we explored using nearby field data, using in-model domain temperatures, and using a synthetic approach based on the meteorological data. We attempted to develop synthetic input temperatures based on a filtered equilibrium approach of Adams and Wells (1984). This technique is shown in Appendix A. But this technique usually needs some field data to assess its efficacy. An example of this approach using 30, 60 and 90-day averages of the filtered equilibrium temperature are shown in Figure 44. The averaging period reflected the weighted average of the meteorological data, meaning stream temperature memory extended back in time over the weighted averaging period. These often were inadequate to predict downstream

temperatures accurately. Hence, in some cases, when available, field data measured near the downstream boundaries were used for the upstream boundary when available.

The next sections show the available field data and the temperatures used for the upper boundary for each tributary.

Figure 44. Filtered equilibrium temperature at 30, 60 and 90 day averaging period using meteorological data from the Chehalis River model.

South Fork Chehalis River

There were temperature data from both WDFW and WADOE gages on the South Fork Chehalis River. The WDFW SFCHEH-2 gage was closest to the upstream model boundary. The location of temperature sampling locations on the South Fork is shown in Figure 45. The data available from this gage overlapped with the model period from 30 April 2015 to 31 December 2015 and are shown in Figure 46.

The final estimated upstream temperatures were the data collected nearest the upstream boundary (for 2015 WDFW SFCHEH-2 gage and for parts of 2013-2014 WADOE gage nearer the mouth) with data gaps filled in using 90-day filtered equilibrium temperatures and are shown in Figure 47.

Figure 45. Temperature sampling locations in the South Fork River. Red triangles are model segments in the South Fork model. Blue triangles are model segments in the lower Chehalis River mainstem model.

Figure 46. Temperature at SFCHEH-2 on the South Fork Chehalis River.

Figure 47. Estimated upstream temperature boundary condition for the South Fork Chehalis River between 2013-2015.

Newaukum River

There were several temperature monitoring locations at different time periods in the Newaukum River as shown in Figure 48. The WDFW NEW-1 gage is in model

segment 60 and field data existed between August 2014 through fall of 2015 (see Figure 49). NWK-MOUTH is in model segment 92 and data were available between the summer of 2013 and the summer of 2014 (see Figure 49). Also, there were upstream temperature data at NFNEW2.

The final estimated upstream temperatures were NFNEW-2 data where it existed filled in with NWK-MOUTH data (gaps in this time series were filled in using a regression to Darigold temperatures from the mainstem) and are shown in Figure 50.

Figure 48. Temperature sampling stations (green dots) along the Newaukum River. Red triangles are model segments in the Newaukum model. Blue triangles are model segments in the lower Chehlis River mainstem model.

Figure 49. Temperature in the Newaukum River at NEW-1, model segment 60 and NWK-MOUTH, model segment 92.

Figure 50. Estimated temperature used for Newaukum River upstream boundary condition between 2013-2015.

Skookumchuck River

There were 3 sets of temperature data in the model domain for the Skookumchuck River from WDFW gages: SKOOK-1 near model segment 124 measured between May 2015 to October 2015, SKOOK-2 near model segment 78 measured between May 2015 and October 2015, and SKOOK-3 near model segment 24 measured between May 2015 to December 2015 (Figure 51). These temperature data are shown in Figure 52.

The final estimated upstream temperatures were the data collected nearest the upstream boundary with data gaps filled using 90-day filtered equilibrium temperatures and are shown in Figure 53.

Figure 51. Temperature sampling stations (green dots) along the Skookumchuck River. Red triangles are model segments in the Skookumchuck model. Blue triangles are model segments in the lower Chehalis River mainstem model.

Figure 52. Skookumchuck River WDFW temperature data from (a) SKOOK-1, (b) SKOOK-2, and (c) SKOOK-3.

Figure 53. Estimated upstream temperature boundary condition for the Skookumchuck River between 2013-2015.

Black River

There were 2 sets of temperature data for the Black River: WDFW BLACK-1 in model segment 53 between July 2014 and December 2014 and between May 2015 to August 2015; and BLACK-2 at model segment 21 between May 2015 and October 2015. The locations of these gages are shown in Figure 54, and the temperature field data are shown in Figure 55.

The estimated upstream temperatures for the Black River were the data collected nearest the upstream boundary with data gaps were filled in using 60-day filtered equilibrium temperatures and are shown in Figure 56.

Figure 54. Location of temperature measuring locations (green dots) BLACK-1 and BLACK-2 on the Black River. Model segments are in light blue for the lower Chehalis River model and red for the Black River model.

Figure 55. Black River WDFW temperature data from (a) BLACK-1 and (b) BLACK-2.

Figure 56. Estimated upstream temperature boundary condition for the Black River between 2013-2015.

5. Model calibration for 2013-2015

Following the work of Van Glubt et al. (2017), the model calibration was assessed by evaluating the errors between model predictions and field data. Appendix C shows the definitions of the error statistics used in these model-data comparisons. Model-data comparisons were made for flow rate, water level, temperature, and water quality for the Chehalis mainstem. For the tributary models (South Fork Chehalis, Newaukum, Skookumchuck, and Black Rivers), only model-data flow rate and temperature comparisons were made.

Also, a new version of CE-QUAL-W2 was used (Version 4.2), that allowed for a reduction in model run times by up to 90%. This required splitting the 9 waterbodies in the model into separate directories as shown in Figure 57. Running the model for temperature for 3 years used to take about 250 min of time, but with the new version this was reduced to about 25 min. Similar reductions were noted running water quality simulations, even though it still took a working day to complete a full water quality run for the 3 year period. A description of this process is shown in Appendix D.

- Convert 1 model to multiple WB models

- Debug each WB by using preprocessor to check for errors
- Note: each WB must have a downstream spillway or gate to pass Q, T, and C to the downstream WB

Figure 57. Using the new CE-QUAL-W2 model framework for running the Chehalis River model.

Flow rate

In general, the model calibration for flow rate followed this approach: using estimated upstream boundary flow rates, the model predicted flow at a downstream gaging station was compared to field data. The error in flow was ascribed to distributed flows (either positive or negative) between the gage locations. This distributed flow was then added back to the model to match flow rate field data.

South Fork Chehalis River

In Figure 58, the model predicted flow rate of the South Fork Chehalis River near the mainstem of the Chehalis was compared to flow estimated based on a regression with field data in 2018 and 2019 (termed the “late” data). The flow rate error statistics at South Fork are shown in Table 11.

Table 11. Flow rate error statistics (see Appendix C) of field data compared to model predictions at model segment 38 at South Fork Chehalis River near the mainstem Chehalis.

Count	ME, m ³ /s	AME, m ³ /s	RMS, m ³ /s
104700	-0.0003	0.651	2.696

Figure 58. Flow rate comparison between linear regression flow estimate, upstream flow boundary condition, and model predictions for South Fork Chehalis River near the Chehalis mainstem.

Newaukum River

The model predicted flow rate in the Newaukum River near the confluence with the mainstem of the lower Chehalis River was compared to field data in Figure 59. The flow rate error statistics at model segment 93 are shown in Table 12.

Table 12. Flow rate error statistics (see Appendix C) of field data compared to model predictions at model segment 93 at Newaukum River near the mainstem Chehalis.

Count	ME, m ³ /s	AME, m ³ /s	RMS, m ³ /s
104122	-0.070	1.520	4.555

Figure 59. Flow rate comparison between field data and model predictions in the Newaukum River at USGS 12025000. Data from this gage was used for the upstream boundary condition and to compare with model output at segment 54.

Skookumchuck River

The model predicted flow rate at the Skookumchuck River near the mainstem of the Chehalis was compared to field data in Figure 60. The flow rate error statistics for the Skookumchuck model are shown in Table 13.

Table 13. Flow rate error statistics (see Appendix C) of field data compared to model predictions at model segment 111 at Skookumchuck River near the mainstem Chehalis.

Count	ME, m ³ /s	AME, m ³ /s	RMS, m ³ /s
87493	0.180	0.768	3.104

Figure 60. Flow rate comparison between field data and model predictions in the Skookumchuck River at USGS 12026400. Flow data from USGS 12026150 was used for the upstream boundary condition. The modeled flow at the mouth of the Skookumchuck River is also included.

Black River

The model predicted flow rate at the Black River near the mainstem of the Chehalis was compared to field data (Gage 23E060) in Figure 61. The flow rate error statistics of this comparison are shown in Table 14.

Table 14. Flow rate error statistics (see Appendix C) of field data compared to model predictions at model segment 53 at Black River near the mainstem Chehalis.

Count	ME, m ³ /s	AME, m ³ /s	RMS, m ³ /s
104624	-0.010	0.445	2.106

Figure 61. Flow rate comparison between field data and model predictions in Black River at 23E060.

Mainstem Chehalis River

Flow rates predicted by the model were compared to the 3 main flow gages on the Chehalis River at Doty, Grand Mound, and Porter in Figure 62. Table 15 shows the associated flow prediction errors at Doty, Grand Mound, and Porter gage locations for 2013-2015. The mean errors at the Doty, Grand Mound, and Porter gages were 0.007%, 0.084%, and 0.052% of the average flow during the model period at these gages, respectively. Absolute mean errors were 5.06%, 3.50%, and 6.14% of average flow.

Figure 62. Flow rate comparison between field data and model predictions in mainstem Chehalis River at (a) Doty, (b) Grand Mound, and (c) Porter between 2013-2015.

Table 15. Model errors (see Appendix C) of flow rate at Doty, Grand Mound, and Porter between 2013-2015.

Gage	Count	ME, m ³ /s	AME, m ³ /s	RMS, m ³ /s
Doty	104698	0.0016	0.7701	3.1872
Grand Mound	103444	-0.0161	2.9592	8.95255
Porter	103794	-0.0265	7.3106	19.2839
Weighted errors	311936	-0.0136	3.6723	10.4462

Water Level

Model predictions of water level to field data are shown in Figure 63 and Figure 64 for Doty, Adna, Chehalis WWTP, Centralia, Grand Mound, Rochester, and Porter. As

was done in Van Glubt et al. (2017), the datum was adjusted based on the mean model elevation since there was uncertainty over the exact position of the datum.

Figure 63. Water level comparison between field data adjusted by mean error and model predictions in the mainstem Chehalis River at (a) Doty, (b) Adna, (c) Chehalis WWTP, and (d) Centralia between 2013-2015.

Figure 64. Water level comparison between field data adjusted by mean error and model predictions in the mainstem Chehalis River at (a) Grand Mound, (b) Rochester, and (c) Porter between 2013-2015.

Model water elevations did not match field data well at all gauges. In the upper reach at Doty, the error may be a result of not accurately modeling the pool-and-riffle nature of the river channel. To more accurately model pools and riffles, finer resolution bathymetry data would be required than was available. The model grid would also need to be divided into many more water bodies, complicating model development. Instead, adjustments to SLOPEC (hydraulic equivalent slope) were used to approximate this channel structure. The model grid also does not include

flood storage in the upper reaches, leading to modeled water levels exceeding gauge data during high flow events.

The poor match at Grand Mound may be due to omitting off-channel flood storage, other mismatches between modeled and actual channel geometry, and/or datum issues. We were unable to resolve this issue in the current study, but further investigation is warranted.

Temperature

The variation of temperature in the Chehalis River tributaries was most often controlled by water depth predicted by the hydrodynamic model, light extinction, shading and how much of the heat went into the bed substrate. These models used meteorological data that were developed for the Chehalis mainstem model (see Wells et al., 2019). The results that follow show model-field data comparisons of temperature between January 1, 2013 and December 31, 2015 for the South Fork Chehalis River, Newaukum River, Skookumchuck River, Black River, and mainstem Chehalis River.

South Fork Chehalis River

The predicted temperature at the South Fork Chehalis River at WDFW SFCHEH-1 and near the mainstem of the Chehalis River was compared to field data in Figure 65. The temperature error statistics at South Fork Chehalis are shown in Table 16 . From the limited temperature field data and the lack of boundary conditions for upstream temperatures, the model predicts the mean temperature over the period with a ME under to 0.5 °C at each gage. The AME is close to 1 °C even though we have no upstream temperature boundary conditions.

Table 16. Temperature error statistics (see Appendix C) of field data compared to model predictions at SFCHEH-1 and 23K060 in South Fork Chehalis River.

Gage	Count	ME, °C	AME, °C	RMS, °C
SFCHEH-1	6488	-0.224	0.996	1.294
23K060	12484	0.415	1.049	1.570
SF-CHL-MOUTH	17049	-0.020	0.802	1.083

Figure 65. Temperature comparison between field data and model predictions in South Fork Chehalis River at (a) SFCHEH-1, (b) 23K060, and (c) SF-CHL-MOUTH.

Newaukum River

The predicted temperature at the Newuakum River near the mainstem of the Chehalis was compared to field data in Figure 66. The temperature error statistics at Newaukum are shown in Table 17. From the limited temperature field data and the lack of boundary conditions for upstream temperatures, the model predicts the mean temperature over the period with a ME close to 0 °C and an AME close to 1 °C.

Table 17. Temperature error statistics (see Appendix C) of field data compared to model predictions at model segment 92 at Newaukum River near the mainstem Chehalis.

Gage	Count	ME, °C	AME, °C	RMS, °C
NEW-1	19965	0.139	1.008	1.331
NWK-MOUTH	14696	0.142	0.995	1.269

Figure 66. Temperature comparison between field data and model predictions in the Newaukum River at (a) NEW-1 and (b) NWK-MOUTH.

Skookumchuck River

The predicted temperature at the Skookumchuck River near the mainstem of the Chehalis was compared to field data in Figure 67 . The temperature error statistics at Skookumchuck are shown in Table 18. From the limited temperature field data and

the lack of boundary conditions for upstream temperatures, the model predicts the mean temperature over the period with a low ME. Since there were no temperature field data during the peak summer period, little can be said about the summer temperature dynamics.

Table 18. Temperature error statistics (see Appendix C) of field data compared to model predictions in the Skookumchuck River at SKOOK-1 and SKOOK-2.

Gage	Count	ME, °C	AME, °C	RMS, °C
SKOOK-1	5834	0.127	0.897	1.169
SKOOK-2	6332	-0.523	1.273	1.728

Figure 67. Temperature comparison between field data and model predictions in Skookumchuck River at (a) SKOOK-1 and (b) SKOOK-2.

Black River

The predicted temperature at the Black River near the mainstem of the Chehalis was compared to field data in Figure 68. The temperature error statistics at Black River are shown in Table 19. From the limited temperature field data and the lack of

boundary conditions for upstream temperatures, the model predicts a low ME over the model period. The AME is under 1 °C even though we have no upstream temperature boundary conditions. Much of the bias and error is a result of the model systematically being too cool during the winter of 2014-2015.

Table 19. Temperature error statistics (see Appendix C) of field data compared to model predictions at BLACK-1 and BLACK-2 in the Black River.

Gage	Count	ME, °C	AME, °C	RMS, °C
BLACK-1	13181	0.128	0.983	1.330
BLACK-2	5044	-0.509	0.885	1.155

Figure 68. Temperature comparison between field data and model predictions in Black River at (a) BLACK-1 and (b) BLACK-2.

Mainstem Chehalis River

The variation of temperature in the Chehalis River was most often controlled by water depth predicted by the hydrodynamic model, light extinction, shading and how much of the heat went into the bed substrate. The results that follow show

model-field data comparisons of temperature between January 1, 2013 and December 31, 2015.

The Chehalis River model of Van Glubt et al. (2017) was adjusted to include 2015, updated boundary conditions, and bathymetry and other adjustments after the dye study calibration. The wind sheltering coefficient was set to 0.25 for model water bodies 1, 2, 3, 4, and 5, and 0.5 for water bodies 6, 7, 8, and 9. Table 20 shows the model errors (see Appendix C) for each sampling station along the Chehalis River mainstem. In general, our goal was to have less than a 1 °C absolute mean error (AME) error for all these aggregate stations and a mean error (ME) approaching 0.0 °C. The model is performing adequately for the entire system with a ME of -0.01 °C and an AME error of 0.74 °C using over 688,000 model-data comparisons.

Table 20. Temperature errors (see Appendix C) along the mainstem Chehalis River between 2013-2015.

Gage	Count	ME, °C	AME, °C	RMS, °C
11-UCH	22219	0.058	0.146	0.215
3-UCH	23417	-0.094	0.461	0.578
CHL-PEL-US	17052	-0.301	0.503	0.610
CHL-PEL-DS	17487	-0.153	1.038	1.335
13-CH	22177	-0.265	0.810	1.070
CHL-WOODSTEAD	11373	-0.200	0.776	0.989
4-UCH	22076	-0.373	0.869	1.111
CHL-DOTY	10108	-0.321	1.002	1.255
23A160	8167	-0.682	1.051	1.291
15-CH	6037	-0.898	1.141	1.378
CHL-RAINBOW-FALLS	30620	-0.386	0.777	0.946
19-CH	9207	-0.359	0.961	1.227
CHL-CERES-HILLS	10114	0.313	0.939	1.265
CHL-ADNA	17044	0.044	0.905	1.125
21-CH	13538	-0.345	1.044	1.242
CHL-US-NWK	17083	-0.032	0.842	1.037
22-CH	39837	0.029	0.682	0.873
Darigold Upstream	98034	-0.259	0.627	0.811

Gage	Count	ME, °C	AME, °C	RMS, °C
Darigold Downstream	98421	0.221	0.598	0.778
16-CH	36099	0.518	0.878	1.144
CHL-GLV	17091	0.455	0.757	1.063
17-CH	7277	0.462	0.885	1.070
CHL-US-BLK	17143	0.321	0.720	0.887
18-CH	19656	0.042	0.872	1.087
CHL-OAK	16895	0.219	0.779	0.970
23-CH	42395	0.411	0.872	1.054
23A70 Porter	37938	0.275	0.768	0.960
Weighted error	688505	0.014	0.735	0.933

Figure 69 shows temperature field data compared to model predictions at the mainstem Chehalis River stations: 11-UCH, upstream of Pe Ell, downstream of Pe Ell, 13-CH, Woodstead, upstream of Elk Creek, and Doty. Figure 70 shows model temperature predictions compared to field data at the mainstem Chehalis River stations: 15-CH, Dryad, Rainbow Falls, 19-CH, Ceres Hills Road, and Adna. Figure 71 shows model temperature predictions compared to field data at the mainstem Chehalis River stations: 21-CH, near Newaukum confluence, 22-CH, upstream of Darigold, downstream of Darigold, and upstream of Skookumchuck. Figure 72 shows model temperature predictions compared to field data at the mainstem Chehalis River stations: Galvin Bridge, 17-CH, upstream of Black River, 18-CH, Oakville and Porter.

Figure 69. Temperature comparisons between field data and model predictions in the mainstem Chehalis River at (a) 11-UCH, (b) upstream of Pe Ell, (c) downstream of Pe Ell, (d) 13-CH, (e) Woodstead, (f) upstream of Elk Creek, and (g) Doty between 2013-2015.

Figure 70. Temperature comparisons between field data and model predictions in the mainstem Chehalis River at (a) 15-CH, (b) Dryad, (c) Rainbow Falls, (d) 19-CH, (e) Ceres Hills Road, and (f) Adna between 2013-2015.

Figure 71. Temperature comparison between field data and model predictions in the mainstem Chehalis River at (a) 21-CH, (b) Newaukum River, (c) 22-CH, (d) upstream of Darigold, (e) downstream of Darigold, and (f) upstream of Skookumchuck River between 2013-2015.

Figure 72. Temperature comparison between field data and model predictions in the mainstem Chehalis River at (a) Galvin Bridge, (b) 17-CH, (c) upstream of Black River, (d) 18-CH, (e) Oakville, and (f) Porter between 2013-2015.

In the pool area of the Chehalis River, vertical temperature profiles were obtained in 2014. The CE-QUAL-W2 model comparisons to temperature profiles in the pool area are shown in Figure 73, Figure 74, Figure 75, and Figure 76. In many comparisons the model reasonably predicts stratification in the pool. In others it is clear the model fails to mix vertically when it should. The primary goal in this section was to ensure that stratification was predicted reasonably since stratification affects water quality dynamics shown later in this report. The mixing in the pool is very dependent on the wind in the vicinity, and there were no wind data in the pool area. Hence, we did not excessively tune the model wind to reproduce the temperature dynamics day by day.

Figure 73. Vertical temperature profiles of field data and model predictions in the pool area at RM 74.7 (Route 6 Bridge) model segment 149, RM 74.5 (HL-14) model segment 150, and RM 73.75 (HL-13) model segment 153 in 2013 and 2014.

Figure 74. Vertical temperature profiles of field data and model predictions in the pool area at RM 73 (HL-12) model segment 157, RM 72.5 (HL-11) model segment 158, RM 72.25 (HL-10) model segment 160, RM 71.5 (HL-9) model segment 162, and RM 71 (HL-8) model segment 164 in 2014.

Figure 75. Vertical temperature profiles of field data and model predictions in the pool area at RM 70.5 (HL-7) model segment 166, RM 70 (HL-6) model segment 168, RM 69.25 (HL-5) model segment 171, RM 68.75 (HL-4) model segment 173, and RM 68.25 (HL-3) model segment 177 in 2014.

Figure 76. Vertical temperature profiles of field data and model predictions in the pool area at RM 67.75 (HL-2) model segment 179, RM 67.5 (Mellen Road Bridge) model segment 180, and RM 67.25 (HL-1) model segment 181 in 2013 and 2014.

Water quality

Water quality model predictions between 2013 and 2015 were compared to field data for dissolved oxygen, NO₂+NO₃-N, PO₄-P, TP, TN, TSS, and chlorophyll *a*. Also, periphyton field data from 2018 were compared to model predictions of averaged periphyton for 2013-2015 to assess whether the model is predicting the correct order of magnitude of the periphyton impact on the Chehalis River.

The water quality parameters used in the model calibration are shown in Table 21.

Table 21. CE-QUAL-W2 model water quality parameters in the Chehalis River Model.

Variable	Description	Units	Typical values*	Value from Glubt et al. (2017)	Value used in this study
AX	Longitudinal eddy viscosity (for momentum dispersion)	m ² /sec	1	1	Variable between 1-10
DX	Longitudinal eddy diffusivity (for dispersion of heat and constituents)	m ² /sec	1	1	Variable between 1-90
CBHE	Coefficient of bottom heat exchange	Wm ² /sec	0.30	0.30	0.30
TSED	Sediment (ground) temperature	°C		11.5	11.5
WSC	Wind sheltering coefficient		0.85	0.25	0.25 and 0.5
BETA	Fraction of incident solar radiation absorbed at the water surface		0.45	0.45	0.45
EXH20	Extinction for water	/m	0.25-0.45	0.25	0.25
AG1	Algal growth rate for group #1	/day	1-3	1.5	1.25
AM1	Algal mortality rate for group #1	/day		0.1	0.1
AE1	Algal excretion rate for group #1	/day	0.014-0.044	0.04	0.04
AR1	Algal dark respiration for group #1	/day	0.01-0.92	0.04	0.04
AS1	Algal settling rate for group #1	/day	0.02-1.00	0.1	0.1
ASAT1	Algae Saturation intensity at maximum photosynthetic rate for group #1	W/m ²	10-170	150	150

Variable	Description	Units	Typical values*	Value from Glubt et al. (2017)	Value used in this study
APOM1	Fraction of algal biomass lost by mortality to detritus for algae for group #1		0.8	0.8	0.8
AT1_1	Lower temperature for algal growth for group #1	°C		3	3
AT2_1	Lower temperature for maximum algal growth for group #1	°C		7	7
AT3_1	Upper temperature for maximum algal growth for group #1	°C		20	20
AT4_1	Upper temperature for algal growth for group #1	°C		30	30
AK1_1	Fraction of algal growth rate at AT1 for group #1		0.1	0.1	0.1
AK2_1	Fraction of maximum algal growth rate at AT2 for group #1		0.99	0.99	0.99
AK3_1	Fraction of maximum algal growth rate at AT3 for group #1		0.99	0.99	0.99
AK4_1	Fraction of algal growth rate at AT4 for group #1		0.1	0.1	0.1
ALGP1	Stoichiometric equivalent between organic matter and phosphorus for algae group #1		0.005	0.01	0.01
ALGN1	Stoichiometric equivalent between organic matter and nitrogen for algae group #1		0.08	0.08	0.08

Variable	Description	Units	Typical values*	Value from Glubt et al. (2017)	Value used in this study
ALGC1	Stoichiometric equivalent between organic matter and carbon for algae group #1		0.4-0.5	0.5	0.5
AG2	Algal growth rate for group #2	/day	1-3	2	2
AM2	Algal mortality rate for group #2	/day		0.1	0.1
AE2	Algal excretion rate for group #2	/day	0.014-0.044	0.04	0.04
AR2	Algal dark respiration for group #2	/day	0.01-0.92	0.04	0.04
AS2	Algal settling rate for group #2	/day	0.02-1.00	0.1	0.1
ASAT2	Algae Saturation intensity at maximum photosynthetic rate for group #2	W/m ²	10-170	150	150
APOM2	Fraction of algal biomass lost by mortality to detritus for algae for group #2		0.8	0.8	0.8
AT1_2	Lower temperature for algal growth for group #2	°C		7	7
AT2_2	Lower temperature for maximum algal growth for group #2	°C		15	15
AT3_2	Upper temperature for maximum algal growth for group #2	°C		30	30
AT4_2	Upper temperature for algal growth for group #2	°C		35	35

Variable	Description	Units	Typical values*	Value from Glubt et al. (2017)	Value used in this study
AK1_2	Fraction of algal growth rate at AT1 for group #2		0.1	0.1	0.1
AK2_2	Fraction of maximum algal growth rate at AT2 for group #2		0.99	0.99	0.99
AK3_2	Fraction of maximum algal growth rate at AT3 for group #2		0.99	0.99	0.99
AK4_2	Fraction of algal growth rate at AT4 for group #2		0.1	0.1	0.1
ALGP2	Stoichiometric equivalent between organic matter and phosphorus for algae group #2		0.005	0.01	0.01
ALGN2	Stoichiometric equivalent between organic matter and nitrogen for algae group #2		0.08	0.08	0.08
ALGC2	Stoichiometric equivalent between organic matter and carbon for algae group #2		0.4-0.5	0.5	0.5
LDOMDK	Labile DOM decay rate	/day	0.04-0.12	0.08	0.08
LRDDK	Labile to refractory decay rate	/day	0.001	0.01	0.01
RDOMDK	Maximum refractory decay rate	/day	0.001	0.001	0.001
LPOMDK	Labile Detritus decay rate	/day	0.04-0.1	0.06	0.06
POMS	Detritus settling rate	m/day	0.2-2	0.75	0.75

Variable	Description	Units	Typical values*	Value from Glubt et al. (2017)	Value used in this study
RPOMDK	Refractory detritus decay rate	/day	0.001	0.001	0.001
OMT1	Lower temperature for organic matter decay	°C	4	4	4
OMT2	Lower temperature for maximum organic matter decay	°C	30	25	25
OMK1	Fraction of organic matter decay rate at OMT1		0.1	0.1	0.1
OMK2	Fraction of organic matter decay rate at OMT2		0.99	0.99	0.99
PO4R	Anaerobic sediment release rate of phosphorus as fraction of SOD			0.001	0.001
AHSP1	Algal half-saturation constant for phosphorus for group #1	g/m ³	0.002-0.01	0.003	0.003
AHSP2	Algal half-saturation constant for phosphorus for group #2	g/m ³	0.002-0.01	0.003	0.003
NH4DK	Ammonia decay rate (nitrification rate)	/day	0.001-1.3	0.8	0.8
AHSN1	Algal half-saturation constant for nitrogen for group #1	g/m ³	0.014	0.014	0.014
AHSN2	Algal half-saturation constant for nitrogen for group #2	g/m ³	0.014	0.014	0.014
NH4T1	Lower temperature for ammonia decay	°C	5	5	5

Variable	Description	Units	Typical values*	Value from Glubt et al. (2017)	Value used in this study
NH4T2	Lower temperature for maximum ammonia decay	°C	20	25	25
NH4K1	Fraction of nitrification rate at NH4T1		0.1	0.1	0.1
NH4K2	Fraction of nitrification rate at NH4T2		0.99	0.99	0.99
NO3DK	Nitrate decay rate (denitrification rate)	/day	0.05-0.15	0.03	0.03
NO3T1	Lower temperature for nitrate decay	°C	5	5	5
NO3T2	Lower temperature for maximum nitrate decay	°C	20	25	25
NO3K1	Fraction of denitrification rate at NO3T1		0.1	0.1	0.1
NO3K2	Fraction of denitrification rate at NO3T2		0.99	0.99	0.99
O2NH4	Oxygen stoichiometric equivalent for ammonia decay		4.57	4.57	4.57
O2OM	Oxygen stoichiometric equivalent for organic matter decay		1.4	1.4	1.4
O2AR1	Oxygen stoichiometric equivalent for dark respiration for group #1		1.1	1.1	1.1

Variable	Description	Units	Typical values*	Value from Glubt et al. (2017)	Value used in this study
O2AR2	Oxygen stoichiometric equivalent for dark respiration for group #2		1.1	1.1	1.1
O2AG1	Oxygen stoichiometric equivalent for algal growth for group #1		1.4	1.6	1.6
O2AG2	Oxygen stoichiometric equivalent for algal growth for group #2		1.4	1.6	1.6
O2LIM	Dissolved oxygen concentration at which anaerobic processes begin	g/m ³	0.1	0.07	0.07
SEDK	First order sediment compartment decay rate	/day		0.03	0.1
SOD	Zeroth order sediment oxygen demand	g/m ² /day	0.3-6	0.3-1.9	0.3-1.9
SEDBR	Sediment burial rate	/day		0.01	0.01
* Cole and Wells (2018)					

DO, nutrients, chlorophyll *a*, pH and TSS

Figure 77 through Figure 94 show the model results for dissolved oxygen, ammonia, nitrates, TKN, phosphate, total phosphorus, chlorophyll *a*, pH, and TSS at the Chehalis River stations: upstream of Pe Ell, downstream of Pe Ell, Dryad, upstream of the South Fork Chehalis River, Adna, upstream of the Newaukum River, Route 6 bridge, upstream of Skookumchuck River, Galvin Road bridge, upstream of Black

River, Oakville, and Porter. Model predictions of alkalinity (there were no field data comparisons) are shown in Figure 95 and Figure 96.

Figure 77. Model dissolved oxygen predictions compared to field data in mainstem Chehalis River at (a) upstream of Pe Ell, (b) Dryad, (c) upstream of South Fork Chehalis River, (d) Adna, (e) upstream of Newaukum River, and (f) Route 6 bridge between 2013-2015.

Figure 78. Model dissolved oxygen predictions compared to field data in the mainstem Chehalis River at (a) upstream of Skookumchuck River, (b) Galvin Road bridge, (c) upstream of Black River, (d) Oakville, and (e) Porter between 2013-2015.

Figure 79. Model ammonia predictions compared to field data in mainstem Chehalis River at (a) upstream of Pe Ell, (b) Dryad, (c) upstream of South Fork Chehalis River, (d) Adna, (e) upstream of Newaukum River, and (f) Route 6 bridge between 2013-2015.

Figure 80. Model ammonia predictions compared to field data in the mainstem Chehalis River at (a) upstream of Skookumchuck River, (b) Galvin Road bridge, (c) upstream of Black River, (d) Oakville, and (e) Porter between 2013-2015.

Figure 81. Model NO₂-N+NO₃-N predictions compared to field data in mainstem Chehalis River at (a) upstream of Pe Ell, (b) Dryad, (c) upstream of South Fork Chehalis River, (d) Adna, (e) upstream of Newaukum River, and (f) Route 6 bridge between 2013-2015.

Figure 82. Model NO₂-N+NO₃-N predictions compared to field data in the mainstem Chehalis River at (a) upstream of Skookumchuck River, (b) Galvin Road bridge, (c) upstream of Black River, (d) Oakville, and (e) Porter between 2013-2015.

Figure 83. Model TKN predictions compared to field data in the mainstem Chehalis River at (a) upstream of Pe Ell, (b) upstream of South Fork Chehalis River, (c) Adna, (d) upstream of Newaukum River, and (e) Route 6 bridge between 2013-2015.

Figure 84. Model TKN predictions compared to field data in the mainstem Chehalis River at (a) upstream of Skookumchuck River, (b) Galvin Road bridge, (c) upstream of Black River, and (d) Oakville between 2013-2015.

Figure 85. Model PO4-P predictions compared to field data in the mainstem Chehalis River at (a) upstream of Pe Ell, (b) downstream of Pe Ell, (c) Dryad, (d) upstream of South Fork Chehalis River, (e) Adna, and (f) upstream of Newaukum River between 2013-2015.

Figure 86. Model PO4-P predictions compared to field data in the mainstem Chehalis River at (a) Route 6 bridge, (b) upstream of Skookumchuck River, (c) Galvin Road bridge, (d) upstream of Black River, (e) Oakville, and (f) Porter between 2013-2015.

Figure 87. Model total phosphorus predictions compared to field data in the mainstem Chehalis River at (a) upstream of Pe Ell, (b) Dryad, (c) upstream of South Fork Chehalis River, (d) Adna, (e) upstream of Newaukum River, and (f) Route 6 bridge between 2013-2015.

Figure 88. Model total phosphorus predictions compared to field data in the mainstem Chehalis River at (a) upstream of Skookumchuck River, (b) Galvin Road bridge, (c) upstream of Black River, (d) Oakville, and (e) Porter between 2013-2015.

Figure 89. Model chlorophyll a predictions compared to field data in the mainstem Chehalis River at (a) upstream of Pe Ell, (b) upstream of South Fork Chehalis River, (c) Adna, (d) upstream of Newaukum River, and (e) Route 6 bridge between 2013-2015.

Figure 90. Model chlorophyll *a* predictions compared to field data in the mainstem Chehalis River at (a) upstream of Skookumchuck River, (b) Galvin Rd bridge, (c) upstream of Black River, and (d) Oakville between 2013-2015.

Figure 91. Model pH predictions compared to field data in the mainstem Chehalis River at (a) upstream of Pe Ell, (b) Dryad, (c) upstream of South Fork Chehalis River, (d) Adna, (e) upstream of Newaukum River, and (f) Route 6 bridge between 2013-2015.

Figure 92. Model pH predictions compared to field data in the mainstem Chehalis River at (a) upstream of Skookumchuck River, (b) Galvin Road bridge, (c) upstream of Black River, (d) Oakville, and (e) Porter between 2013-2015.

Figure 93. Model total suspended solids predictions compared to field data in the mainstem Chehalis River at (a) upstream of Pe Ell, (b) Dryad, (c) upstream of South Fork Chehalis River, (d) Adna, (e) upstream of Newaukum River, and (f) Route 6 bridge between 2013-2015.

Figure 94. Model total suspended solids predictions compared to field data in the mainstem Chehalis River at (a) upstream of Skookumchuck River, (b) Galvin Road bridge, (c) upstream of Black River, (d) Oakville, and (e) Porter between 2013-2015.

Figure 95. Model alkalinity predictions in the mainstem Chehalis River at (a) downstream of Pe Ell, (b) downstream of Pe Ell, (c) Dryad, (d) upstream of South Fork Chehalis River, (e) Adna, and (f) upstream of Newaukum River between 2013-2015.

Figure 96. Model alkalinity predictions in the mainstem Chehalis River at (a) Route 6 bridge, (b) upstream of Skookumchuck River, (c) Galvin Road bridge, (d) upstream of Black River, (e) Oakville, and (f) Porter between 2013-2015.

Continuous dissolved oxygen data

Model predictions compared to continuous DO field data at the Chehalis River mainstem stations downstream of Pe Ell, at Route 6 Bridge, and at Mellen Road Bridge are shown in Figure 97, Figure 98, and Figure 99. The dynamics were reasonable except at Pe Ell around Julian day 260 where our dynamics were low compared to the field data.

Figure 97. Continuous dissolved oxygen model predictions compared to field data in the mainstem Chehalis River at downstream of Pe Ell between 2013-2015.

Figure 98. Continuous dissolved oxygen model predictions compared to field data in the mainstem Chehalis River at Route 6 bridge between 2013-2015.

Figure 99. Continuous dissolved oxygen model predictions compared to field data in the mainstem Chehalis River at Mellen Road bridge between 2013-2015.

Vertical dissolved oxygen profiles

Vertical profile data were available at the same locations as temperature.

Comparisons of vertical DO profiles to field data at the mainstem stations at Route 6 Bridge, HL-14, HL-13, HL-12, HL-11, HL-10, HL-9, HL-8, HL-7, HL-6, HL-5, HL-4, HL-3, HL-2, Mellen Road Bridge, and HL-1 are shown in Figure 100, Figure 101, Figure 102, and Figure 103. As evident from the temperature profile comparisons, if the

temperature was not simulated correctly, the dissolved oxygen was also not correct as stratification affects the vertical dissolved oxygen distribution.

Figure 100. Vertical dissolved oxygen model predictions compared to field data in the mainstem Chehalis River pool area in 2013 and 2014 in the pool area.

Figure 101. Vertical dissolved oxygen model predictions compared to field data in the mainstem Chehalis River pool area in 2014.

Figure 102. Vertical dissolved oxygen model predictions compared to field data in the mainstem Chehalis River pool area in 2014.

Figure 103. Vertical dissolved oxygen model predictions compared to field data in the mainstem Chehalis River pool area in 2013 and 2014.

Algae Dynamics

The model prediction of algae growth is largely a function of the limiting nutrient for algae. The model predicted nitrogen and phosphorus limitation (from 0 to 1) at several sampling stations along the mainstem Chehalis River between 2013-2015 as shown in Figure 104 and Figure 105; Figure 106 and Figure 107, respectively. Generally, phosphorus is limiting except between the Dryad and upstream of the Newaukum where nitrogen limits algae growth.

Figure 104. Model predicted nitrogen limitation for algal growth in the mainstem Chehalis River at (a) upstream of Pe Ell, (b) downstream of Pe Ell, (c) Dryad, (d) upstream of South Fork Chehalis River, (e)

Adna, and (f) upstream of Newaukum River between 2013-2015. A value of 1 shows it is not limiting. Whichever value (N, P, or light) is the lowest is the limiting nutrient.

Figure 105. Model predicted nitrogen limitation for algal growth in the mainstem Chehalis River at (a) Route 6 bridge, (b) upstream of Skookumchuck River, (c) Galvin Road bridge, (d) upstream of Black

River, (e) Oakville, and (f) Porter between 2013-2015. A value of 1 shows it is not limiting. Whichever value (N, P, or light) is the lowest is the limiting nutrient.

Figure 106. Model predicted phosphorus limitation for algal growth in the mainstem Chehalis River at (a) upstream of Pe Ell, (b) downstream of Pe Ell, (c) Dryad, (d) upstream of South Fork Chehalis River,

(e) Adna, and (f) upstream of Newaukum River between 2013-2015. A value of 1 shows it is not limiting. Whichever value (N, P, or light) is the lowest is the limiting nutrient.

Figure 107. Model predicted phosphorus limitation for algal growth in the mainstem Chehalis River at (a) Route 6 bridge, (b) upstream of Skookumchuck River, (c) Galvin Road bridge, (d) upstream of Black

River, (e) Oakville, and (f) Porter between 2013-2015. A value of 1 shows it is not limiting. Whichever value (N, P, or light) is the lowest is the limiting nutrient.

Periphyton

Model predicted periphyton densities for 2013-2015 at sampling sites along the mainstem Chehalis River are shown in Figure 108 and Figure 109. There were no field data to compare to model results. Upstream of the pool section, phosphorus was often the limiting nutrient for model periphyton growth during spring, while nitrogen was more often limiting during summer.

Figure 108. Model periphyton density predictions in the mainstem Chehalis River at (a) upstream of Pe Ell, (b) downstream of Pe Ell, (c) Dryad, (d) upstream of South Fork Chehalis River, (e) Adna, and (f) upstream of Newaukum River between 2013-2015.

Figure 109. Model periphyton density predictions in the mainstem Chehalis River at (a) Route 6 bridge, (b) upstream of Skookumchuck River, (c) Galvin Road bridge, (d) upstream of Black River, (e) Oakville, and (f) Porter between 2013-2015.

As a result of this lack of field data, a periphyton study was conducted by the Washington State Department of Ecology between July and September 2018. Three samples were collected from each of six sites between river mile 76.4 and river mile 106.2. Figure 110 shows the three-year average of model results between 2013-2015 with the 2018 WSDOE field data in order to show that the order of magnitude of the model predictions were reasonable at the 6 sampling sites corresponding to model segments 11, 36, 59, 90, 111, 137. In general, the model predicted periphyton densities were of a similar magnitude as the field data.

Figure 110. Periphyton field data for 2018 compared with model average periphyton output in the mainstem Chehalis River at model segments 11, 36, 59, 90, 111, and 137 for 2013-2015.

6. Summary

The Chehalis River hydrodynamic and water quality model of Van Glubt et al. (2017) was updated as follows:

- All model boundary conditions were updated to include 2015 since the original model development only included 2013 and 2014
- New correlations for flow and temperature were made to fill in data gaps for missing flow and temperature at some of the model input locations for 2013-2015
- A dye study by Mathieu (2018) was used to adjust travel time and dispersion throughout the Chehalis River mainstem. The travel time in the Van Glubt et al. (2017) model was generally too fast with little dispersion. Hence, the travel time was reduced and dispersion increased to match some of the dye study data.
- The model run times were reduced by using a new feature of CE-QUAL-W2 Version 4.2 that allowed the model to run in a cascade of multiple waterbodies. Run times were reduced by up to 90%.
- Tributary models were developed and calibrated for the South Fork Chehalis, Newaukum, Skookumchuck, and Black Rivers for hydrodynamics and temperature.
- Tributary models performed well despite inadequate upstream temperature and flow boundary condition data.

The updated models were then run from January 1, 2013 through December 31, 2015 for flow and temperature. Only the mainstem Chehalis model was run for water quality between 2013-2015.

Tributary model calibration was primarily accomplished with estimates of boundary conditions rather than model coefficients. Model coefficients that were varied included the wind sheltering coefficient (WSC) which reduced wind, a factor that accounts for absorption of heat into the bed sediment (TSEDF), evaporation coefficients (AFW, BFW, CFW), the light extinction for water in m^{-1} (EXH20), the fraction of short waver solar absorbed on the surface (BETA), and Manning's friction factor (see Table 22).

Table 22. Model coefficients used in the CE-QUAL-W2 model of the tributaries. WSC is the wind sheltering coefficient, TSEDF is a factor that accounts for absorption of heat into the bed sediment, AFW, BFW and CFW were evaporation coefficients, EXH2O is the light extinction coefficient for water in m^{-1} , and BETA is the fraction of short wave solar absorbed on the surface.

Model	WSC	TSEDF	AFW	BFW	CFW	EXH2O	BETA	Manning's friction
South Fork Chehalis	0.25-1.0	0.125	1.2	0.46	2	0.25	0.45	0.04
Newaukum	0.5	0.5	9.2	0.46	2	0.25	0.45	0.04
Skookumchuck	0.5	0.24	7	0.46	2	0.25	0.45	0.04
Black	0.75	0.1	9.2	0.46	2	0.45	0.45	0.035

The model predictions were compared to flow rate data at gages between 2013-2015. Generally, the model performed very well in predicting flow rates. This was especially important for the low flow summer flow periods. Flow percent mean error was below 1% of model average flow at each gage, and absolute mean error was below 4%. Flow root mean square error was below 7%.

In the Chehalis mainstem, the model predicted water levels between 2013-2015 were compared with gage data. In general, the comparisons were reasonable at several stations, even though there was uncertainty in the gage datum. Water level at Grand Mound and Doty could still be refined further with better local bathymetric data.

Model predictions were also compared to nearly 690,000 temperature field data points between 2013-2015 at over 27 monitoring stations along the mainstem Chehalis. For the mainstem Chehalis, the mean error (ME) was -0.03°C , and the absolute mean error (AME) was 0.72°C . Root mean square error was 0.91°C . For

the tributaries with no upstream temperature data, the mean errors were all below ± 0.5 °C and the AME varied from 0.89 to 1.27 °C.

In the Chehalis mainstem, the model predicted water quality conditions during 2013-2015. Dissolved oxygen and nutrient levels were well reproduced. The model predicted phosphorus limitation of phytoplankton except between Adna and upstream of the Newaukum River, where it was nitrogen limited.

The periphyton levels predicted from the model were compared to field data from 2018 to see whether periphyton were an important part of the Chehalis ecosystem. The 2018 field data agreed well qualitatively with average model predictions between 2013-2015. Periphyton was phosphorus limited in the first two model waterbodies, and alternated between phosphorus and nitrogen limitation further downstream.

The model can still be improved. The following items would improve the model predictive ability:

- Since there was a lot of uncertainty in water quality boundary conditions, a better understanding of the water quality of the tributaries would improve the water quality predictive ability. Many of the tributaries relied on neighboring tributaries or on sparse data that was interpolated. For 2015, some of the tributaries had no measured water quality data and an average of 2013 and 2014 was used.
- The model geometry used an average hydraulic slope for the upstream segments. In contrast the model could be made more complex by dividing the model into many different pools and riffle elements (many more waterbodies) to more closely describe the water level and flow dynamics in the upper sections
- Even though the model predicted stratification in the pool area, some of the model-data comparisons showed that the model did not capture all of the dynamics. This could be a result of local wind or flow conditions in the pool

area compared to that used by the model. This could mean that wind data in the pool or a different allocation of distributed flows as a result of performing the water balance may improve the predictive behavior of the model.

- For flood flows, the model could include lateral spillways to flood neighboring fields or oxbow lakes during peak storm events rather than being constrained to the top width of the cross-section. This would allow the model to predict lower peak water levels during large storm events.
- Measurement of flow rate and temperature at tributary model upstream boundaries.
- Tributary flow rates assumed to flow into the mainstem Chehalis River were not always measured at the confluence but were not corrected for this discrepancy. Studying the change between gaged flows and confluences with the mainstem would improve model accuracy.
- As the relationship between flow in a river and any of its tributaries is unlikely to be linear, using linear models used to estimate tributary flows introduces error to the model. Alternative methods of estimating these flows may give better results.
- Shade files should be developed for tributary models to improve temperature calibration.
- Additional adjustments to better replicate the 2018 dye study.

7. References

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Appendix A: Estimating stream temperatures by the filtered equilibrium technique

Since the inflow temperature records from field data were not available during the model calibration period, a synthetic temperature was determined from meteorological conditions. A filtered equilibrium temperature approach was used based on a technique of Adams and Wells (1984). This section discusses background information on the equilibrium temperature and the filtered equilibrium estimation technique based only on meteorological data, the approximate depth of the stream and the averaging period.

The equilibrium temperature

The net heat flux entering or leaving the water surface is a function of the incoming short wave solar radiation, the incoming long wave radiation, evaporation, conduction and back radiation. One equation incorporating all of these processes is the following heat balance equation (assuming Ryan-Harleman evaporation equation):

$$\phi_n [W / m^2] = 0.94\phi_{sc} (1 - 0.65C^2) + 5.15 \cdot 10^{-13} (T_{air} + 273)^6 (1 + 0.17C^2) - 5.51 \cdot 10^{-8} (T_s + 273)^4 - \left[2.7(T_{sv} - T_{av})^{1/3} + 3.2W_2 \right] (e_s - e_2) \left[1 + 0.61 \frac{T_s - T_2}{e_s - e_2} \right]$$

where T_{air} is the air temp in deg C, T_s is the surface temp in deg C, e_s is the saturated vapor pressure at water surface temp, T_{sv} and T_{av} are the virtual surface and air temperatures in deg K, C is cloud cover fraction from 0 to 1. The equilibrium temperature is defines as that value of T_s (surface temperature) for which the net heat flux, ϕ_n , is zero. Since the equation cannot be solved for explicitly for that temperature, a root finding bi-section technique is used to determine T_{eq} . This is illustrated in Figure A111.

The equilibrium temperature concept was a mathematical approach to surface heat transfer that linearized the Φ_n term which was a function of $T_{surface}$ to the 4th power to a function of $T_{surface}$ to the 1st power. This allowed analytical solutions to temperature models to be used and introduced another term, K called the surface heat transfer coefficient. This term dictates the speed at which the water body responds to the temperature.

$$\Phi_n = -K(T_s - T_E)$$

Another approach for computing T_E is to use an approximate technique from Brady et al. (1969):

$$T_E = \frac{\phi_{sn}}{23 + f(W)(\beta + 0.255)} + T_d$$

where ϕ_{sn} : net short wave solar in Btu/ft²/day

T_d : dew point temperature °F

$f(W)$: wind speed function = $17W_2$ Lake Hefner model, in Btu/ft²/day/mm Hg

$$\beta = 0.255 - 0.0085T^* + 0.000204T^{*2}$$

$$T^* = 0.5(T_w + T_d)$$

T_w : water surface temperature

T_d : dew point temperature

W_2 : wind speed at 2 m in mph

K can be computed from the slope of net flux vs temperature or can be obtained using an approximate formula (Brady et al., 1969):

$$K = 23 + (\beta_w + 0.255)17W_2$$

$$\text{where } \beta_w = 0.255 - 0.0085T_w + 0.000204T_w^2$$

units of K are in Btu/ft²/day/°F

This approximate approach was used to compute T_E and K for each hour of the meteorological record.

Figure A111. The definition of equilibrium temperature.

The filtered equilibrium temperature

An approach described in Adams and Wells (1984) was used to predict inflow tributary temperatures. This approach consisted of an exponential filter based on the equilibrium temperature and surface heat exchange coefficient. For example, the temperature of the tributary, $T_{\text{tributary}}$, at a particular hour computing using the following equation:

$$T_{\text{tributary}} = \frac{\sum_{n=1}^{t_{\text{residence}}/\Delta t} T_e(t - n\Delta t) \exp(-(n-1)\bar{k}\Delta t)}{\sum_{n=1}^{t_{\text{residence}}/\Delta t} \exp(-(n-1)\bar{k}\Delta t)}$$

where T_e : equilibrium temperature (defined as the value of temperature for which the net surface heat flux is zero)

Δt : time step (usually one hour)

$\bar{k}$: kinematic surface heat exchange coefficient (average over preceding residence time)

$$= \frac{\bar{K}}{\rho c_p h} \text{ where } K \text{ is the surface heat exchange coefficient, } \rho \text{ is the density, } c_p \text{ is the specific heat at constant pressure, } h \text{ is the average depth of the water}$$

$t_{\text{residence}}$: residence time of fluid exposed to meteorological conditions

n: number of time steps to “average” the meteorological conditions

The kinematic heat exchange coefficient was calculated using the meteorological file for the water body.

Appendix B: Washington Department of Ecology Dye Study 2018

Mathieu (2018) provided preliminary information on a time-of-travel dye study performed on the Chehalis River in 2018. Even though this was outside the calibration period of the model, the dye information was useful in comparing the movement of water in the Chehalis River to that in the model.

A description of the dye releases in the Chehalis mainstem and the travel time between reaches is shown in Table B23. The times were daylight savings time. The model though used Pacific Standard time for all model inputs.

Table B23. Description of 4 dye releases on the Chehalis River in August 2018 by Mathieu (2018) based on provisional data.

Sonde#	Site	~ USGS RM	Time of Leading Edge	Time of Peak (or release)	JDAY Peak or release	Time of Tail (10% of peak)	Segment Peak travel time (days)	Cumulative Peak travel time (days)	Segment Avg Velocity (ft/s)	Peak Concentration (ppb)	Release Volume (L)	Mass added, gm
Release #4 - Pe Ell												
n/a	SR6-Pe Ell	106.2	n/a	8/7/2018 20:33	2045.8563	n/a	n/a	0.0	n/a	200,000,000	0.5	100
26	Elk Cr Rd	100.4	8/8/2018 17:00	8/8/2018 22:15	2046.927	8/9/2018 10:00	1.1	1.1	0.33	3.16		
21	Hope Creek	94.8	8/9/2018 22:00	8/10/2018 7:15	2048.302	unknown	1.4	2.4	0.25	0.9		
26	Ceres Canyon	87.4	not discernable	8/12/2018 9:30	2050.396	unknown	2.1	4.5	0.22	0.58		
Release #3 - Ceres Canyon												
n/a	Ceres Canyon	87.4	n/a	8/7/2018 19:50	2045.8264	n/a	n/a	4.5	n/a	200,000,000	0.5	100
15	Adna- WH Trail	81.5	8/9/2018 5:00	8/9/2018 16:00	2047.667	unknown	1.8	6.4	0.20	0.55		
41	Newaukum/Alexander	75.1	8/11/2018 2:00	8/11/2018 17:30	2049.729	unknown	2.1	8.4	0.19	0.27		
Release #2 - Newaukum/Alexander Park												
n/a	Newaukum/Alexander	75.1	n/a	8/6/2018 20:50	2044.8681	n/a	n/a	8.4	n/a	200,000,000	2	400
37	Skookumchuck/F.Borst	67	8/11/2018 17:00	8/13/2018 20:45	2051.865	unknown	7.0	15.4	0.07	0.535		
Release #1 - Skookumchuck/Fort Borst Park												
n/a	Skookumchuck	66.65	n/a	8/6/2018 20:05	2044.8368	n/a	n/a	15.4	n/a	200,000,000	2	400
21	Prather Rd	59.9	8/8/2018 0:30	8/8/2018 11:30	2046.479	unknown	1.6	17.1	0.25	1.32		
33	Oakville Boat launch	42.4	8/10/2018 16:00	8/11/2018 11:45	2049.490	8/13/2018 10:00	3.0	20.1	0.36	0.32		

Flow rates during the dye study were very low compared to historical flow rates as shown in Figure B112. After the dye release at Pe Ell (RM 106.2), the resulting provisional measured dye concentrations downstream over time at the sampling

station Elk Creek (RM 100.4), Hope Creek (RM 94.8) and Ceres Canyon (RM 87.4) are shown in Figure B113, Figure B114, and Figure B115, respectively. Whereas the dye concentrations at Elk Creek and Hope Creek were typical of river systems, the concentrations at Ceres Canyon show that flow dynamics were highly complex. Other dye profiles for the three other dye releases were found in Matheiu (2018).

Figure B112. USGS flow rates in the Chehalis mainstem during the August 2018 dye study.

Figure B113. Measured dye concentrations in ppb at Elk Creek RM 100.4 in August 2018 after release at Pe Ell RM 106.2 on 8/7/2018 at 20:33.

Figure B114 Measured dye concentrations in ppb at Hope Creek RM 94.8 in August 2018 after release at Pe Ell RM 106.2 on 8/7/2018 at 20:33.

Figure B115. Measured dye concentrations in ppb at Ceres Canyon RM 87 in August 2018 after release at Pe Ell RM 106.2 on 8/7/2018 at 20:33.

Appendix C: Error Statistics

The closeness of model predicted temperature to field data was evaluated with error statistics such as the mean error (ME), absolute mean error (AME), and the root mean square error (RMSE).

These were calculated using the equations described below.

$$ME = \frac{1}{N} \sum (Q_{model} - Q_{field\ data})$$

where N is the number of model-field data comparisons, Q_{model} is the model output value, and $Q_{field\ data}$ is the field data value.

$$AME = \frac{1}{N} \sum |(Q_{model} - Q_{field\ data})|$$

$$RMS = \sqrt{\frac{1}{N} \sum (Q_{model} - Q_{field\ data})^2}$$

Weighted average mean error, absolute mean error, and root mean square error values were computed using

$$ME_{weighted} = \frac{\Sigma(ME \times N)}{\Sigma N}$$

$$AME_{weighted} = \frac{\Sigma(AME \times N)}{\Sigma N}$$

$$RMSE_{weighted} = \frac{\Sigma(RMSE \times N)}{\Sigma N}$$

These weighted errors were used in looking at all model-data errors in aggregate over all model stations.

Appendix D: Using Multiple Processors for a Cascade of Waterbodies

If the model user has a cascade of waterbodies (see Figure D116), such as reservoirs in series or even a river system with a cascade of reaches where the backwater from a downstream waterbody does not affect an upstream waterbody, then the model user can use a model feature to reduce overall model run time.

Figure D116. Cascade of reservoirs or multiple waterbodies.

There are 3 options now for simulating this series of waterbodies as shown in Table D24.

Table D24. Techniques for using CE-QUAL-W2 to simulate a cascade of waterbodies.

Option #	Option Description	Advantages	Disadvantages
1	Have one system model with multiple waterbodies and one control file	Entire model is under one control file, w2_con.npt , simpler to manage	The time step for stability will be dictated by one of the waterbodies, causing other waterbodies to run at the lowest time step. Run times may be long.
2	Have separate waterbodies in separate directories, use a batch file to automatically transfer the output from one waterbody (withdrawal output files) as the input to the next waterbody	Each waterbody runs according to its own minimum time step and hence will result in faster simulation time compared to option 1. Also, the model user can tune for faster DLTMAX in some waterbodies.	Must break model into multiple models, one for each waterbody. Each waterbody must wait until the upper one is completed before starting.
3	Have separate waterbodies in separate directories, use the input file (multiple_WB.npt) for multiple waterbodies to point to inflow from upper waterbody	Each waterbody runs according to its own minimum time step and does not have to wait until the upper waterbody is complete before proceeding. Hence the model will run faster compared to option 1 and 2. Also, the model user can tune for faster DLTMAX in some waterbodies. Each model will usually be running on different cores of a multiple core processor.	Must break model into multiple models, one for each waterbody.

The third option shown above allows the downstream model to run even before the upstream model has completed. The downstream model, by means of the input file, '**multiple_WB.npt**', which tells the downstream model where to obtain the

upstream inflow boundary condition. How the CE-QUAL-W2 model processes this is shown in Figure D117. In model tests with multiple waterbodies, speed improvements from 22-90% have been seen.

Caveat: This assumes that water level in downstream WB does not influence upstream WB

Figure D117. Concept of running multiple waterbodies simultaneously.

How to Set up a Simulation

In order to allow this to work, the model user must set up a simulation with multiple waterbodies in separate directories. After this is complete, then the following steps are required:

1. Each waterbody must set up a Withdrawal outflow by setting the withdrawal output control [**WDOC**] to ON (see '**w2_con.npt**') and setting the outlet segment as a withdrawal outflow. These outflow files contain information for the withdrawal flows, temperatures and/or constituent concentrations as a time series. These files will be used as input to the downstream waterbody. Make sure the output frequency is set to a short time since the model is writing out instantaneous flows, temperatures, and concentrations rather than integrated values between output times.
2. The downstream waterbody must set as the inflow flow rate, temperature and concentration, the name of the withdrawal outlet file in the upstream waterbody. Just the filenames are required, one does not set the directory path since these are copied into the directory of the downstream waterbody by the CE-QUAL-W2 model. Hence, if the upstream waterbody has set for the **WDOFN** '**wdo.csv**', and the withdrawal output segment is 6, then the upstream model will write out files: qwo_6.csv, two_6.csv, and cwo_6.csv. The downstream model will use these names as **QINFN**, **TINFN**, and **CINFN**, respectively. When you run the preprocessor for the downstream waterbody, it will give you an

error, such as ‘Could not open branch 1 inflow file qwo_6.csv’ since the file does not exist (similarly for the temperature and concentration input files). This can be ignored since the model will supply the file during run time.

3. The downstream model will also have a file called ‘**multiple_WB.npt**’ that contains information on running the series of waterbodies. This is described below.
4. Then, the model user starts the upstream waterbody by double-clicking the executable. A dialog box for the first waterbody then starts. Then in the downstream waterbody directory, double click the executable in that directory. Then once, that waterbody starts to run, then start the next downstream W2 executable. You must wait to execute the downstream waterbody exe only after the upstream model starts generating output.

Input File multiple_WB.npt

The input file, **multiple_WB.npt**, is a text file with the following format:

```
Multiple WB wait ON or OFF (only 2 spaces read)
ON
Number of input types to wait for (at least 1)
1
Specific inputs to wait for: branch inflow [BR] or trib [TR], branch/trib index number, and directory (max 240 characters)
BR, 1, ..\WB1
Buffer time to run program, days (wait until at least XX days available)
2
Delay time in seconds to wait for buffer and recheck
60
```

Each header between lines is used for comments and is ignored by the model. Each input field is described below in Table D25.

Table D25. Description of input file multiple_WB.npt.

Variable	Description
Multiple WB wait ON or OFF	ON or OFF. This turns ON or OFF the multiple waterbody run.
Number of input types to wait for (at least 1)	Specifies the number of input file types to wait for.
DIRECTORY OF INPUT FILES (MAX 240 CHARACTERS)	This specifies the directory of the upstream waterbody and the type of input (branch or tributary). In the example above, relative directory path was used. ‘..\WB1’ means to go up one directory to a subdirectory WB1. One can also give an absolute directory path.
Buffer Time in days	How many days of output data from the upper waterbody is required before you start running the downstream waterbody.
Delay time in s to wait for checking upstream boundary	This is the time in s for the downstream waterbody to pause before checking to see if the buffer time is satisfied. If one chose a 2 day buffer time, the downstream model would check at ‘delay time’ intervals to see if the

Variable	Description
	required number of output days are complete before continuing to run.

Output file WaitForRunLog.opt

An output file '**WaitForRunLog.opt**' is produced showing how the downstream model copied files from the upstream waterbody. This is merely for debugging model errors. An example of this file is shown below:

```

1.0000 COPY ..\WB1\qwo_6.csv
1.0000 COPY ..\WB1\two_6.csv
Execution stopped at 10.900 WAITING FOR RESTART
10.9000 COPY ..\WB1\qwo_6.csv
10.9000 COPY ..\WB1\two_6.csv
Execution stopped at 22.350 WAITING FOR RESTART
22.3500 COPY ..\WB1\qwo_6.csv
22.3500 COPY ..\WB1\two_6.csv
Execution stopped at 32.850 WAITING FOR RESTART
32.8500 COPY ..\WB1\qwo_6.csv
32.8500 COPY ..\WB1\two_6.csv
Execution stopped at 43.080 WAITING FOR RESTART
43.0800 COPY ..\WB1\qwo_6.csv
43.0800 COPY ..\WB1\two_6.csv
Execution stopped at 53.000 WAITING FOR RESTART
53.0000 COPY ..\WB1\qwo_6.csv
53.0000 COPY ..\WB1\two_6.csv

```

Appendix E: Model files

Model input and output files are tabulated with brief descriptions below. More detailed descriptions follow.

Mainstem Chehalis River

The mainstem Chehalis River model is divided into nine folders, one for each waterbody. Table E26 through Table E43 show the input and output filenames for each waterbody with short descriptions of each file. "XX" replaces Julian day or model segment number in filenames that have several to many iterations.

Table E26. Mainstem Chehalis River waterbody 1 model input files.

Filename	Description
bth_wb1.csv	bathymetry
cdt_br1.npt	distributed tributary concentrations
cin_br1.csv	mainstem Chehalis River inflow concentrations
graph.npt	graph input
met_wb1.npt	meteorology
qdt_br1.csv	distributed tributary flow
qin_br1.npt	mainstem Chehalis River inflow
shade_WB1.csv	shade file
tdt_br1.npt	distributed tributary temperature
tin_br1.npt	mainstem Chehalis River inflow temperature
w2_con.npt	control file
wsc_WB1.csv	wind sheltering coefficients

Table E27. Mainstem Chehalis River waterbody 1 model output files.

Filename	Description
cpl_wb1.opt	contour plot
cwo_6.csv	withdrawal active concentration
cwo_sp1_seg6.csv	spillway active concentration
dwo_6.csv	withdrawal derived concentration
dwo_sp1_seg6.csv	spillway derived concentration
flowbal.csv	flow balance
flx_wb1.opt	constituent flux
kflux_wb1.csv	constituent kinetic fluxes
massbal.csv	nitrogen and phosphorus mass balance
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREw2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
ProfLongJDX.csv	longitudinal profile plots
qwo_6.csv	withdrawal outflow
qwo_sp1_seg6.csv	spillway outflow
snp_wb1.opt	snapshot
tsr_1_seg4.csv	time series
two_6.csv	withdrawal temperature
two_sp1_seg6.csv	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
wl.opt	water level

Table E28. Mainstem Chehalis River waterbody 2 model input files.

Filename	Description
bth_wb2.csv	bathymetry
cdt_br2.npt	branch distributed tributary concentrations
ctr_tr1.npt	Pe Ell WWTP concentrations
cwo_6.csv	branch inflow concentrations
graph.npt	graph input
met_wb2.npt	meteorology
multiple_WB.npt	multiple waterbody control
qdt_br2.csv	branch distributed tributary inflow
qtr_tr2.npt	Pe Ell WWTP inflow
qwo_6.csv	branch inflow
shade_WB2.csv	shade file
tdt_br2.npt	distribute tributary temperature
ttr_tr1.npt	Pe Ell WWTP temperature
two_6.csv	branch inflow temperature
w2_con.npt	control file
wsc_WB2.csv	wind sheltering coefficients

Table E29. Mainstem Chehalis River waterbody 2 model output files.

Filename	Description
cpl_wb2.opt	contour plot
cwo_21.csv	withdrawal active concentrations
cwo_sp1_seg21.csv	spillway active concentrations
dwo_21.csv	withdrawal derived concentrations
dwo_sp1_seg21.csv	spillway derived concentrations
flowbal.csv	flow balance
flx_wb2.opt	constituent flux
kflux_wb1.csv	constituent kinetic fluxes
massbal.csv	nitrogen and phosphorus mass balance
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREw2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
ProfLongJDX.csv	longitudinal profile plots
qwo_21.csv	withdrawal outflow
qwo_sp1_seg21.csv	spillway outflow
snp_wb2.opt	snapshot
tsr_X_segX.csv	time series
two_21.csv	withdrawal temperature
two_sp1_seg21.csv	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
WaitForRunLog.opt	multiple waterbody wait log
wl.opt	water level

Table E30. Mainstem Chehalis River waterbody 3 model input files.

Filename	Description
bth_wb3.csv	bathymetry
cdt_br3.npt	branch distributed tributary concentrations
ctr_tr2.npt	Elk Creek concentrations
ctr_tr27.npt- ctr_tr51.npt	groundwater concentrations
cwo_21.csv	branch inflow concentrations
graph.npt	graph input
met_wb3.npt	meteorology
multiple_WB.npt	multiple waterbody control
qdt_br3.npt	branch distributed tributary inflow
qtr_tr2.npt	Elk Creek inflow
qtr_tr27.npt- qtr_tr51.npt	groundwater inflow
qwo_21.csv	branch inflow
shade_WB3.csv	shade file
tdt_br3.npt	branch distributed tributary temperature
ttr_tr2.npt	Elk Creek temperature
ttr_tr27.npt- ttr_tr51.npt	groundwater temperature
two_21.csv	branch inflow temperature
w2_con.npt	control file

wsc_WB3.csv	wind sheltering coefficients
-------------	------------------------------

Table E31. Mainstem Chehalis River waterbody 3 model output files.

Filename	Description
cpl_wb3.opt	contour plot
cwo_30.csv	withdrawal active concentrations
cwo_sp1_seg30.csv	spillway active concentrations
dwo_30.csv	withdrawal derived concentrations
dwo_sp1_seg30.csv	spillway derived concentrations
flowbal.csv	flow balance
flx_wb3.opt	constituent flux
kflux_wb1.csv	constituent kinetic fluxes
massbal.csv	nitrogen and phosphorus mass balance
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREw2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
ProfLongJDX.csv	longitudinal profile plots
qwo_30.csv	withdrawal outflow
qwo_sp1_seg30.csv	spillway outflow
snp_wb3.opt	snapshot
tsr_X_segX.csv	time series
two_30.csv	withdrawal temperature
two_sp1_seg30.csv	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
WaitForRunLog.opt	multiple waterbody wait log
wl.opt	water level

Table E32. Mainstem Chehalis River waterbody 4 model input files.

Filename	Description
bth_wb4.csv	bathymetry
cdt_br4.npt	branch distributed tributary concentrations
ctr_tr3.npt	South Fork Chehalis River concentrations
ctr_tr13.npt	Bunker Creek concentrations
ctr_tr52.npt- ctr_tr118.npt	groundwater concentrations
cwo_30.csv	branch inflow concentrations
graph.npt	graph input
met_wb4.npt	meteorology
multiple_WB.npt	multiple waterbody control
qdt_br4.npt	branch distributed tributary inflow
qtr_tr3.npt	South Fork Chehalis River inflow
qtr_tr13.npt	Bunker Creek inflow
qtr_tr52.npt- qtr_tr118.npt	groundwater inflow
qwo_30.csv	branch inflow
shade_WB4.csv	shade file
tdt_br4.npt	branch distributed tributary temperature

ttr_tr3.npt	South Fork Chehalis River temperature
ttr_tr13.npt	Bunker Creek temperature
ttr_tr52.npt- ttr_tr118.npt	groundwater temperature
two_30.csv	branch inflow temperature
w2_con.npt	control file
wsc_WB4.csv	wind sheltering coefficients

Table E33. Mainstem Chehalis River waterbody 4 model output files.

Filename	Description
cpl_wb4.opt	contour plot
cwo_68.csv	withdrawal active concentrations
cwo_sp1_seg68.csv	spillway active concentrations
dwo_68.csv	withdrawal derived concentrations
dwo_sp1_seg68.csv	spillway derived concentrations
flowbal.csv	flow balance
flx_wb4.opt	constituent flux
kflux_wb1.csv	constituent kinetic fluxes
massbal.csv	nitrogen and phosphorus mass balance
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREw2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
ProfLongJDX.csv	longitudinal profile plots
qwo_68.csv	withdrawal outflow
qwo_sp1_seg68.csv	spillway outflow
snp_wb4.opt	snapshot
tsr_X_segX.csv	time series
two_68.csv	withdrawal temperature
two_sp1_seg68.csv	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
WaitForRunLog.opt	multiple waterbody wait log
wl.opt	water level

Table E34. Mainstem Chehalis River waterbody 5 model input files.

Filename	Description
bth_wb5.csv	bathymetry
ctr_tr4.npt	Newaukum River concentrations
ctr_tr14.npt	Stearns Creek concentrations
ctr_tr119.npt- ctr_tr133.npt	groundwater concentrations
cwo_68.csv	branch inflow concentrations
graph.npt	graph input
met_wb5.npt	meteorology
multiple_WB.npt	multiple waterbody control
qtr_tr4.npt	Newaukum River inflow
qtr_tr14.npt	Stearns Creek inflow
qtr_tr119.npt-	groundwater inflow

qtr_tr133.npt	
qwo_68.csv	branch inflow
shade_WB5.csv	shade file
ttr_tr4.npt	Newaukum River temperature
ttr_tr14.npt	Stearns Creek temperature
ttr_tr119.npt- ttr_tr133.npt	groundwater temperature
two_68.csv	branch inflow temperature
w2_con.npt	control file
wsc_WB5.csv	wind sheltering coefficients

Table E35. Mainstem Chehalis River waterbody 5 model output files.

Filename	Description
cpl_wb5.opt	contour plot
cwo_16.csv	withdrawal active concentrations
cwo_sp1_seg16.csv	spillway active concentrations
dwo_16.csv	withdrawal derived concentrations
dwo_sp1_seg16.csv	spillway derived concentrations
flowbal.csv	flow balance
flx_wb5.opt	constituent flux
kflux_wb1.csv	constituent kinetic fluxes
massbal.csv	nitrogen and phosphorus mass balance
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREw2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
ProfLongJDX.csv	longitudinal profile plots
qwo_16.csv	withdrawal outflow
qwo_sp1_seg16.csv	spillway outflow
snp_wb5.opt	snapshot
tsr_X_segX.csv	time series
two_16.csv	withdrawal temperature
two_sp1_seg16.csv	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
WaitForRunLog.opt	multiple waterbody wait log
wl.opt	water level

Table E36. Mainstem Chehalis River waterbody 6 model input files.

Filename	Description
bth_wb6.csv	bathymetry
ctr_tr5.npt	Darigold WWTP concentrations
ctr_tr6.npt	Chehalis WWTP concentrations
ctr_tr8.npt	Skookumchuck River concentrations
ctr_tr134.npt- ctr_tr177.npt	groundwater concentrations
cwo_16.csv	branch inflow concentrations
graph.npt	graph input
met_wb6.npt	meteorology

multiple_WB.npt	multiple waterbody control
qtr_tr5.npt	Darigold WWTP inflow
qtr_tr6.npt	Chehalis WWTP inflow
qtr_tr8.npt	Skookumchuck River inflow
qtr_tr134.npt- qtr_tr177.npt	groundwater inflow
qwo_16.csv	branch inflow
shade_WB6.csv	shade file
ttr_tr5.npt	Darigold WWTP temperature
ttr_tr6.npt	Chehalis WWTP temperature
ttr_tr8.npt	Skookumchuck River temperature
ttr_tr134.npt- ttr_tr177.npt	groundwater temperature
two_16.csv	branch inflow temperature
w2_con.npt	control file
wsc_WB6.csv	wind sheltering coefficients

Table E37. Mainstem Chehalis River waterbody 6 model output files.

Filename	Description
cpl_wb6.opt	contour plot
cwo_28.csv	withdrawal active concentrations
cwo_47.csv	withdrawal active concentrations
cwo_sp1_seg47.csv	spillway active concentrations
dwo_28.csv	withdrawal derived concentrations
dwo_47.csv	withdrawal derived concentrations
dwo_sp1_seg47.csv	spillway derived concentrations
flowbal.csv	flow balance
flx_wb6.opt	constituent flux
kflux_wb1.csv	constituent kinetic fluxes
massbal.csv	nitrogen and phosphorus mass balance
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREw2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
ProfLongJDX.csv	longitudinal profile plots
qwo_28.csv	withdrawal outflow
qwo_47.csv	withdrawal outflow
qwo_sp1_seg47.csv	spillway outflow
snp_wb6.opt	snapshot
tsr_X_segX.csv	time series
two_28.csv	withdrawal temperature
two_47.csv	withdrawal temperature
two_sp1_seg47.csv	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
WaitForRunLog.opt	multiple waterbody wait log
wl.opt	water level

Table E38. Mainstem Chehalis River waterbody 7 model input files.

Filename	Description
bth_wb7.csv	bathymetry
cdt_br8.npt	distributed tributary concentrations
ctr_tr7.npt	Centralia WWTP concentrations
ctr_tr17.npt	Lincoln Creek concentrations
ctr_tr178.npt- ctr_tr196.npt	groundwater concentrations
cwo_47.csv	branch inflow concentrations
graph.npt	graph input
met_wb7.npt	meteorology
multiple_WB.npt	multiple waterbody control
qdt_br8.npt	distributed tributary inflow
qtr_tr7.npt	Centralia WWTP inflow
qtr_tr17.npt	Lincoln Creek inflow
qtr_tr178.npt- qtr_tr196.npt	groundwater inflow
qwo_47.csv	branch inflow
shade_WB7.csv	shade file
tdt_br8.npt	distributed tributary temperature
ttr_tr7.npt	Centralia WWTP temperature
ttr_tr17.npt	Lincoln Creek temperature
ttr_tr178.npt- ttr_tr196.npt	groundwater temperature
two_47.csv	branch inflow temperature
w2_con.npt	control file
wsc_WB7.csv	wind sheltering coefficients

Table E39. Mainstem Chehalis River waterbody 7 model output files.

Filename	Description
cpl_wb7.opt	contour plot
cwo_20.csv	withdrawal active concentrations
cwo_sp1_seg20.csv	spillway active concentrations
dwo_20.csv	withdrawal derived concentrations
dwo_sp1_seg20.csv	spillway derived concentrations
flowbal.csv	flow balance
flx_wb7.opt	constituent flux
kflux_wb1.csv	constituent kinetic fluxes
massbal.csv	nitrogen and phosphorus mass balance
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREw2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
ProfLongJDX.csv	longitudinal profile plots
qwo_20.csv	withdrawal outflow
qwo_sp1_seg20.csv	spillway outflow
snp_wb7.opt	snapshot
tsr_X_segX.csv	time series
two_20.csv	withdrawal temperature
two_sp1_seg20.csv	spillway temperature

w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
WaitForRunLog.opt	multiple waterbody wait log
wl.opt	water level

Table E40. Mainstem Chehalis River waterbody 8 model input files.

Filename	Description
bth_wb8.csv	bathymetry
ctr_tr9.npt	Grand Mound WWTP concentrations
ctr_tr10.npt	Scatter Creek concentrations
ctr_tr11.npt	Black River concentrations
ctr_tr18.npt	Independence Creek concentrations
ctr_tr19.npt	Garrard Creek concentrations
ctr_tr25.npt	Prairie Creek concentrations
ctr_tr197.npt- ctr_tr262.npt	groundwater concentrations
cwo_20.csv	branch inflow concentrations
graph.npt	graph input
met_wb8.npt	meteorology
multiple_WB.npt	multiple waterbody control
qtr_tr9.npt	Grand Mound WWTP inflow
qtr_tr10.npt	Scatter Creek inflow
qtr_tr11.npt	Black River inflow
qtr_tr18.npt	Independence Creek inflow
qtr_tr19.npt	Garrard Creek inflow
qtr_tr25.npt	Prairie Creek inflow
qtr_tr197.npt- qtr_tr262.npt	groundwater inflow
qwo_20.csv	branch inflow
shade_WB8.csv	shade file
ttr_tr9.npt	Grand Mound WWTP temperature
ttr_tr10.npt	Scatter Creek temperature
ttr_tr11.npt	Black River temperature
ttr_tr18.npt	Independence Creek temperature
ttr_tr19.npt	Garrard Creek temperature
ttr_tr25.npt	Prairie Creek temperature
ttr_tr197.npt- ttr_tr262.npt	groundwater temperature
two_20.csv	branch inflow temperature
w2_con.npt	control file
wsc_WB8.csv	wind sheltering coefficients

Table E41. Mainstem Chehalis River waterbody 8 model output files.

Filename	Description
cpl_wb8.opt	contour plot
cwo_67.csv	withdrawal active concentrations
cwo_sp1_seg67.csv	spillway active concentrations
dwo_67.csv	withdrawal derived concentrations

dwo_sp1_seg67.csv	spillway derived concentrations
flowbal.csv	flow balance
flx_wb8.opt	constituent flux
kflux_wb1.csv	constituent kinetic fluxes
massbal.csv	nitrogen and phosphorus mass balance
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREw2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
ProfLongJDX.csv	longitudinal profile plots
qwo_67.csv	withdrawal outflow
qwo_sp1_seg67.csv	spillway outflow
snp_wb8.opt	snapshot
tsr_X_segX.csv	time series
two_67.csv	withdrawal temperature
two_sp1_seg67.csv	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
WaitForRunLog.opt	multiple waterbody wait log
wl.opt	water level

Table E42. Mainstem Chehalis River waterbody 9 model input files.

Filename	Description
bth_wb9.csv	bathymetry
cdt_br10.npt	distributed tributary concentrations
ctr_tr12.npt	Rock Creek concentrations
ctr_tr20.npt	Cedar Creek concentrations
ctr_tr21.npt	Porter Creek concentrations
ctr_tr26.npt	Gibson Creek concentrations
ctr_tr263.npt- ctr_tr299.npt	groundwater concentrations
cwo_67.csv	branch inflow concentrations
graph.npt	graph input
met_wb9.npt	meteorology
multiple_WB.npt	multiple waterbody control
qdt_br10.npt	distributed tributary inflow
qtr_tr12.npt	Rock Creek inflow
qtr_tr20.npt	Cedar Creek inflow
qtr_tr21.npt	Porter Creek inflow
qtr_tr26.npt	Gibson Creek inflow
qtr_tr263.npt- qtr_tr299.npt	groundwater inflow
qwo_67.csv	branch inflow
shade_WB9.csv	shade file
tdt_br10.npt	distributed tributary temperature
ttr_tr12.npt	Rock Creek temperature
ttr_tr20.npt	Cedar Creek temperature
ttr_tr21.npt	Porter Creek temperature
ttr_tr26.npt	Gibson Creek temperature
ttr_tr263.npt- ttr_tr299.npt	groundwater temperature

two_67.csv	branch inflow temperature
w2_con.npt	control file
wsc_WB9.csv	wind sheltering coefficients

Table E43. Mainstem Chehalis River waterbody 9 model output files.

Filename	Description
cpl_wb9.opt	contour plot
cwo_38.csv	withdrawal active concentrations
cwo_sp1_seg38.csv	spillway active concentrations
dwo_38.csv	withdrawal derived concentrations
dwo_sp1_seg38.csv	spillway derived concentrations
flowbal.csv	flow balance
flx_wb9.opt	constituent flux
kflux_wb1.csv	constituent kinetic fluxes
massbal.csv	nitrogen and phosphorus mass balance
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREw2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
ProfLonglDXX.csv	longitudinal profile plots
qwo_38.csv	withdrawal outflow
qwo_sp1_seg38.csv	spillway outflow
snp_wb9.opt	snapshot
tsr_X_segX.csv	time series
two_38.csv	withdrawal temperature
two_sp1_seg38.csv	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
WaitForRunLog.opt	multiple waterbody wait log
wl.opt	water level

South Fork Chehalis River

Table E44 and Table E45 show South Fork Chehalis River model input and output filenames, respectively, with brief descriptions of each. “XX” replaces the Julian day of output in longitudinal profile plot filenames.

Table E44. South Fork Chehalis River model input files.

Filename	Description
bth_wb1.csv	bathymetry
graph.npt	graph input
met_wb9.npt	meteorology
qdt_br1.csv	distributed tributary inflow
qin_br1.npt	branch inflow
shade.csv	shade file
tdt_br1.csv	distributed tributary temperature
tin_br1.csv	branch inflow temperature
w2_con.npt	control file
wsc.csv	wind sheltering coefficients

Table E45. South Fork Chehalis River model output files.

Filename	Description
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREW2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
prf_wb1.opt	profile plot
ProfLongJDXX.csv	longitudinal profile plots
qwo_38.opt	withdrawal outflow
qwo_sp1_seg38.opt	spillway outflow
snp_wb1.opt	snapshot file
tsr_X_segX.csv	time series
two_38.opt	withdrawal temperature
two_sp1_seg38.opt	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
wl.opt	water level

Newaukum River

Table E46 and Table E47 show Newaukum River model input and output filenames, respectively, with brief descriptions of each. “XX” replaces the Julian day of output in longitudinal profile plot filenames.

Table E46. Newaukum River model input files.

Filename	Description
bth_wb1.csv	bathymetry
graph.npt	graph input
met_wb1.npt	meteorology
qdt_br1.csv	distributed tributary inflow
qdt_br2.csv	distributed tributary inflow
qin_br1.npt	branch inflow
shade.csv	shade file
tdt_br1.npt	distributed tributary temperature
tdt_br2.npt	distributed tributary temperature
tin_br1.csv	branch inflow temperature
w2_con.npt	control file
wsc.npt	wind sheltering coefficients

Table E47. Newaukum River model output files.

Filename	Description
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREW2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
prf_wb1.opt	profile plot
ProfLongJDXX.csv	longitudinal profile plots
qwo_23.opt	withdrawal outflow

qwo_60.opt	withdrawal outflow
qwo_93.opt	withdrawal outflow
qwo_sp1_seg93.opt	spillway outflow
snp_wb1.opt	snapshot file
tsr_X_segX.csv	time series
two_23.opt	withdrawal temperature
two_60.opt	withdrawal temperature
two_93.opt	withdrawal temperature
two_sp1_seg93.opt	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
wl.opt	water level

Skookumchuck River

Table E48 and Table E49 show Skookumchuck River model input and output filenames, respectively, with brief descriptions of each. “XX” replaces the Julian day of output in longitudinal profile plot filenames.

Table E48. Skookumchuck River model input files.

Filename	Description
bth_wb1.csv	bathymetry
graph.npt	graph input
met_wb9.npt	meteorology
qdt_br1.csv	distributed tributary inflow
qin_br1.npt	branch inflow
shade.csv	shade file
tdt_br1.npt	distributed tributary temperature
tin_br1.csv	branch inflow temperature
w2_con.npt	control file
wsc.csv	wind sheltering coefficients

Table E49. Skookumchuck River model output files.

Filename	Description
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREW2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
prf_wb1.opt	profile plot
ProfLongJDX.csv	longitudinal profile plots
qwo_156.opt	withdrawal outflow
qwo_sp1_seg156.opt	spillway outflow
snp_wb1.opt	snapshot file
tsr_X_segX.csv	time series
two_156.opt	withdrawal temperature
two_sp1_seg156.opt	spillway temperature
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
wl.opt	water level

Black River

Table E50 and Table E51 show Black River model input and output filenames, respectively, with brief descriptions of each. “XX” replaces the Julian day of output in longitudinal profile plot filenames.

Table E50. Black River model input files.

Filename	Description
bth_wb1.csv	bathymetry
graph.npt	graph input
met_wb9.npt	meteorology
qdt_br1.csv	distributed tributary inflow
qin_br1.npt	branch inflow
shade.csv	shade file
tdt_br1.npt	distributed tributary temperature
tin_br1.csv	branch inflow temperature
w2_con.npt	control file
wsc.csv	wind sheltering coefficients

Table E51. Black River model output files.

Filename	Description
cpl_wb1.opt	contour plot
pre.opt	preprocessor output
pre.wrn	preprocessor warning
PREW2CodeCompilerVersion.opt	preprocessor compiler version, build date, and compile date
prf_wb1.opt	profile plot
ProfLongJDX.csv	longitudinal profile plots
snp_wb1.opt	snapshot file
tsr_X_segX.csv	time series
w2.wrn	W2 warning
W2CodeCompilerVersion.opt	W2 compiler version, build date, and compile date
wl.opt	water level

Input file descriptions

bth_wb1.csv: Bathymetry file. Includes segment length [DLX], initial water surface elevation [ELWS], segment orientation angle in radians [PHIO], segment Manning’s friction factor [FRICT], layer height in meters, and layer width in meters.

cdt_br1.npt: Branch distributed tributary concentration file. Contains a time series of water quality constituent concentrations for a branch’s distributed tributary.

cin_br1.npt: Branch inflow concentration file. Contains a time series of water quality constituent concentrations for a branch’s inflow.

ctr_tr1.npt: Tributary inflow concentration file. Contains a time series of water quality constituent concentrations for a tributary's inflow.

cwo_1.csv: Withdrawal outflow active concentration file. Contains a time series of active constituent concentrations output by the model at the downstream end of each waterbody. Used as an upstream boundary condition for the next waterbody.

graph.npt: Graph input file. Controls output formats for the model output variables. Includes hydraulic variables and concentration multipliers for each active and derived constituent.

met_wb1.npt: Waterbody meteorology file. Contains a time series of meteorology data: air temperature, °C [TAIR]; dewpoint temperature, °C [TDEW]; wind speed, m s⁻¹ [WIND]; wind direction, radians [PHI]; cloud cover, 0 to 10 [CLOUD]; and incident short wave solar radiation, W m⁻² [SRO].

multiple_WB.npt: Multiple waterbody control file. Contains a switch for the Multiple WB wait function and fields for input file directory, buffer time in days, and delay time to wait for buffer in seconds.

preW2-V41_64.exe: W2 preprocessor.

qdt_br1.csv: Branch distributed tributary inflow file. Contains a time series of flow rates for a branch's distributed tributary in m³ s⁻¹.

qin_br1.npt: Branch inflow file. Contains a time series of flow rates for a branch's inflow in m³ s⁻¹.

qtr_tr1.npt: Tributary inflow file. Contains a time series of flow rates for a tributary's inflow in m³ s⁻¹.

qwo_1.csv: Withdrawal outflow file. Contains a time series of flow rates output by the model at the downstream end of each waterbody. Used as an upstream boundary condition for the next waterbody.

shade_WB1.csv: Waterbody shade input file. Contains the following data: segment number [SEG]; dynamic shading or static shading [DYNsh]; vegetative elevation left bank, meters [VEL]; vegetative elevation right bank, meters [VER]; distance to vegetation left bank, meters [DL]; distance to vegetation right bank, [DR]; shade reduction factor #1 left bank [SRFL1]; shade reduction factor #2 left bank [SRFL2]; shade reduction factor #1 right bank [SRFR1]; shade reduction factor #2 right bank [SRFR2]; topographic angle #1 at 0°, radians [TOPO1]; topographic angle #2 at 20°, radians [TOPO2]; topographic angle #3 at 40°, radians [TOPO3]; topographic angle #4 at 60°, radians [TOPO4]; topographic angle #5 at 80°, radians [TOPO5]; topographic angle #6 at 100°, radians [TOPO6]; topographic angle #7 at 120°, radians [TOPO7]; topographic angle #8 at 140°, radians [TOPO8]; topographic angle

#9 at 160° [TOP09]; topographic angle #10 at 180°, radians [TOP010]; topographic angle #11 at 200°, radians [TOP011]; topographic angle #12 at 220°, radians [TOP012]; topographic angle #13 at 240°, radians [TOP013]; topographic angle #14 at 260°, radians [TOP014]; topographic angle #15 at 280°, radians [TOP015]; topographic angle #16 at 300°, radians [TOP016]; topographic angle #17 at 320°, radians [TOP017]; topographic angle #18 at 340°, radians [TOP018]; starting date for SRF#1, Julian day [JDSRF1]; and starting date for SRF#2, Julian day [JDSRF2].

tdt_br1.npt: Branch distributed tributary temperature file. Contains a time series of temperatures for a branch's distributed tributary in °C.

tin_br1.npt: Branch inflow temperature file. Contains a time series of temperatures for a branch's inflow in °C.

ttr_tr1.npt: Tributary inflow temperature file. Contains a time series of temperatures for a tributary's inflow in °C.

two_1.csv: Withdrawal outflow temperature file. Contains a time series of temperatures output by the model at the downstream end of each waterbody. Used as an upstream boundary condition for the next waterbody.

w2_con.npt: Control file.

wsc_WB1.csv: Wind sheltering coefficient file. Specifies wind-sheltering as a function of model segment and time.

[Output file descriptions](#)

cwo_1.csv: Withdrawal outflow active concentration file.

cwo_sp1_seg1.csv: Spillway outflow active concentration file. For this model, this file contains the same time series as **cwo_1.csv**.

dwo_1.csv: Withdrawal outflow derived concentration file.

dwo_sp1_seg1.csv: Spillway outflow derived concentration file. For this model, this file contains the same time series as **dwo_1.csv**.

flowbal.csv: Flow balance output file. Contains a time series of inflow volume to waterbody from qin files in m³, inflow volume from precipitation in m³, outflow volume from outlet structures in m³, output volume from withdrawals in m³, output volume from evaporation in m³, input volume from distributed tributaries in m³, input volume from tributaries in m³, and the volume of ice formation/ice melting in m³ (this is zero if [ICEC] is OFF). Volumes between Julian days are cumulative.

flx_wb1.opt: Kinetic flux file. Contains a time series of fluxes for active constituents at each segment in a waterbody in kg day⁻¹ averaged over the time interval of flux output.

kflux_wb1.csv: Waterbody kinetic flux file. Contains a time series of fluxes for active constituents summed over the entire water body in kg day^{-1} averaged over the time interval of flux output.

massbal.csv: Waterbody nutrient mass balance file. Contains a time series of nitrogen and phosphorus sources and sinks summed over the entire waterbody in kg. Masses are cumulative between Julian days.

pre.err: Preprocessor error file.

pre.opt: Preprocessor output file.

pre.wrn: Preprocessor warning file.

ProfLongJD1.00.csv: Longitudinal profile plot file. Contains, for each segment in a waterbody at the specified Julian day, water surface elevation in meters, flow rate in $\text{m}^3 \text{s}^{-1}$, temperature of the surface layer in $^{\circ}\text{C}$, depth in meters, volume weighted temperature in $^{\circ}\text{C}$, and concentrations of state variables and derived variables at the surface layer.

qwo_1.csv: Withdrawal outflow file.

qwo_sp1_seg1.csv: Spillway outflow file. Contains the same time series as **qwo_1.csv**.

rso.opt: Restart file.

snp_wb1.opt: Snapshot file. Contains information about timestep, meteorology, and inflow/outflow parameters; balances, geometry, water surface, and temperature/water quality at intervals specified in **w2_con.npt**.

tsr_1_seg1.csv: Time series file. A time series output for the specified model segment of timestep (s), water surface elevation (m), temperature ($^{\circ}\text{C}$), flow rate ($\text{m}^3 \text{s}^{-1}$), shortwave solar radiation incident on the surface (W m^{-2}), light extinction coefficient (m^{-1}), depth to bottom of channel (m), surface width (m), shade fraction (0 to 1), vertically volume-weighted temperature ($^{\circ}\text{C}$), net radiation at surface of segment (W m^{-2}), evaporative heat flux at surface (W m^{-2}), net long wave radiation at surface (W m^{-2}), active constituents, derived constituents, kinetic fluxes (kg day^{-1}), and algae growth limitation fraction for phosphorus, nitrogen, and light (0 to 1) for each algae group.

two_1.csv: Withdrawal outflow temperature file.

two_sp1_seg1: Spillway outflow temperature file.

w2.err: W2 error file.

w2.wrn: W2 warning file.

WaitForRunLog.opt: A log of model wait actions output when the multiple waterbody wait function is used.

wl.opt: Water level output file. Records the water surface elevation of every model segment at intervals specified for time series output.