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Hydrodynamic and Water Quality Modeling of the Chehalis River Using CE-QUAL-W2

by

Sarah Van Glubt

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
Chris Berger
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Portland State University
2017

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Abstract

The Chehalis River Basin is located in the southwest region of Washington State, originating in the Olympic Mountains and flowing to Grays Harbor and the Pacific Ocean. The Chehalis River is over 125 miles, exists within five counties, and flows through agricultural, residential, industrial, and forest land areas. Four major rivers discharge to the Chehalis River, as well as many smaller creeks, five wastewater treatment plants, and groundwater flows.

Flooding is a major problem in the relatively flat areas surrounding the cities of Chehalis and Centralia, with severe consequences for property, safety and transportation. As a result, construction of a flood-control dam in the upper basin has been proposed. One major concern of constructing a dam is the potentially severe impacts to fish health and habitat. The Chehalis River has routinely violated water quality standards for primarily temperature and dissolved oxygen, and has had multiple water quality and Total Maximum Daily Load studies beginning in 1990.

CE-QUAL-W2, a two-dimensional (longitudinal and vertical) hydrodynamic and water quality model, was used to simulate the Chehalis River, including free flowing river stretches and stratified (in summer) lake-like stretches. The goals of this research were to assess the flood retention structure's impacts to water quality, as well as river responses to potential climate change scenarios.

In order to use the model to achieve these goals, calibration to field data for flow, temperature, and water quality constituents was performed. This involved developing

meteorological data, riparian shading data, and flow, temperature, water quality records for all tributaries during the calibration period of January 1, 2013 to December 31, 2014. System cross-sectional geometry data were also required for the model grid. Because of the short travel time in the river, the model was sensitive to boundary condition data, wind speed, bathymetry, nutrient kinetics, and algae, epiphyton, and zooplankton kinetics.

Future conditions showed predictions of warmer water temperatures and slight changes to water quality conditions on the river. As fish in the area prefer cooler water temperatures, this could pose a threat to fish health and habitat. Flood retention structures also showed impacts to river temperature and water quality. Structures with the purpose of flood retention only (only operating during times of flooding) gave model predictions for daily maximum temperature higher than structures that employed flood retention and flow augmentation (operating during all times of the year). This suggested the management of flow passage or retention by the dam is important for water quality on the river.

As this research continues improvements will be made, particularly to temperature and water quality constituents. Additional data for the system would be beneficial to this process. Model predictions of temperature were sensitive to meteorological data, including cloud cover, which were largely estimated based on solar radiation. Additional meteorological data throughout the basin would be useful to temperature results. Temperature results were also sensitive to the model bathymetry,

and additional investigations into segments widths and water depths may improve temperature predictions.

Water quality constituent data were largely lacking for the system. Many estimation techniques and approximations were used for input water quality constituents for the model upstream boundary and tributaries when little or no data were available, introducing uncertainty to the model. It was not possible to calibrate pH to field data because alkalinity data were essentially unavailable. However, other constituents had good agreement between model predictions and field data, including dissolved oxygen, nitrates, total phosphorus, and total suspended solids.

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1. Introduction

1.1. Chehalis River Basin Background

The Chehalis River Basin is located in the southwest region of Washington State. The drainage area to the Chehalis River is over 2000 square miles, with area existing within five counties: Lewis, Thurston, Grays Harbor, Pacific, and Cowlitz (WADOE, 2001). On the western end, the basin also overlaps with the Chehalis Tribal Reservation (Pickett, 1994). The Chehalis River originates in the Olympic Mountains and flows into Grays Harbor and the Pacific Ocean, totaling over 125 miles in length (USGS, 2013). The larger tributaries to the Chehalis River include the South Fork Chehalis River, Newaukum River, Skookumchuck River, and Black River. The smaller tributaries include many creeks, such as Elk, Bunker, Mill, Stearns, Salzer, China, Scammon, Lincoln, Prairie, Scatter, Independence, Garrard, Cedar, Rock, Gibson, and Porter.

Figure 1. Study area with major tributaries, from near Doty to Porter, WA

The mainstem Chehalis River has three distinct reaches based on their unique physical characteristics of slope and depth. The upper reach, beginning near Pe Ell and extending to Chehalis, WA, has steep gradients with riffles and pools (Pickett, 1994). The middle reach, beginning near Chehalis, WA and extending to the Skookumchuck River, has slow, deep, lake-like conditions that at times exhibit stratification (Pickett, 1994). 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).

Figure 2, Figure 3, and Figure 4 show examples of the different physical characteristics seen on the Chehalis River.

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 near the river is required as an alternative for the Darigold wastewater treatment plant during periods of low river flows.

Figure 2. Upstream portion of the Chehalis River exhibiting steep gradients with riffles and pools

Figure 3. Middle portion of the Chehalis River near Centralia exhibiting slow, deep, lake-like conditions

Figure 4. Lower portion of the Chehalis River near Porter exhibiting steeper gradients than the middle portion, with swift-moving water

1.2. Fish Criteria

1.2.1. Temperature

Temperature considerations for the river are especially important because of concerns for fish. National and state regulations mandate temperatures that must not be exceeded on the Chehalis River. Water quality criteria are designed to ensure the health of two main fish groups (salmonids and warm-water) during two main life-stages (spawning and rearing) (Collyard and Von Prause, 2010).

Core summer habitat for salmonids include areas during the summer months that are used by salmonids for any of the following purposes: spawning, emergence, or adult holding; summer rearing by at least one adult salmonid; or foraging by an adult or sub-adult salmonid (Collyard and Von Prause, 2010). Salmonid spawning, rearing, or migration habitat include areas outside of the summer months that are used by salmon or trout for spawning and emergence (Collyard and Von Prause, 2010).

The criteria are based on the 7-day average of daily maximum temperature (7-DADMax). For the Chehalis River, temperature criteria include (Anchor, 2014):

- For core summer salmonid habitat, the 7-DADMax may not exceed 16 °C between June 15th to September 15th.
- For salmonid spawning, rearing, and migration habitat, 7-DADMax may not exceed 17.5 °C between September 16th to Jun 14th.

Additional supplemental criteria exist for areas used for salmonid spawning and incubation. Depending on the specific site, these criteria include (Collyard and Von Prause, 2010):

- Between September 15th to July 1st, the 7-DADMax may not exceed 13 °C.
- Between October 1st to May 15th, the 7-DADMax may not exceed 13 °C.
- Between February 15th to July 1st, the 7-DADMax may not exceed 13 °C.

These standards were created because generally salmonid fish species in the Pacific Northwest thrive in cooler water.

1.2.2. Dissolved Oxygen

Dissolved oxygen (DO) is another important water quality constituent for fish survival and health. The criteria for DO are based on fish type and life stage similarly to temperature. For the Chehalis River, the criteria include (Collyard and Von Prause, 2010):

- For core summer salmonid habitat, the lowest daily minimum DO may not be less than 9.5 mg/L between June 15th to September 15th.
- For salmonid spawning, rearing, and migration habitat, the lowest daily minimum DO may not be less than 8.0 mg/L between September 16th to June 14th.

1.3. Problem Statement

Frequent flooding is a major problem for the Chehalis River Basin. Since 1945 there have been 45 floods. Of these, five of the ten worst took place in 1996 (twice), 2006, 2007, and 2009 (Pickett, 2015). The 2007 flood was about the magnitude of a 500-year flood (Pickett, 2015). The flooding has severe consequences for residential and commercial property, safety, and transportation. Interstate-5 has been shut down multiple times as a result of flooding (Pickett, 2015). These flood events led the legislature to create the Chehalis River Basin Flood Authority (CRBFA) in 2008 (Pickett, 2015). The CRBFA has largely focused on investigating the implementation of dams in the upper basin as a flood control technique (Pickett, 2015).

One major concern of dam implementation is the potentially severe impacts on fish and habitat (Pickett, 2015). The Chehalis River has routinely violated water quality standards for temperature and dissolved oxygen, resulting in multiple water quality and Total Maximum Daily Load (TMDL) studies beginning in 1990. DO is crucial for the survival and health of fish and other aquatic species. Many factors impact DO levels, such as loadings of nutrients, especially nitrogen and phosphorus; amount of organic matter; algae and epiphyton growth and respiration; and season and time of day. In the Chehalis system, DO and temperature are particularly of concern in the area of the river near Centralia and Chehalis, where the water becomes deep and slow. Juvenile and adult salmonids require cool water temperatures for survival and health. System geometry, such as velocity and depth, as well as riparian vegetative shade, impact the temperature of a river (WADOE, 2016j). Cooler water temperatures generally result in higher DO levels (WADOE, 2016j).

2. Prior Water Quality Studies

2.1. 1994 TMDL Study

The Chehalis River basin has a history of areas with low dissolved oxygen levels. Thermally stratified regions of the Chehalis River near Centralia, WA have exhibited hypoxic and anoxic conditions in the deeper portions of the water column. The Chehalis River and many of its tributaries have violated water quality standards for dissolved oxygen, temperature, and fecal coliform multiple times.

The purpose of this study (Pickett, 1994) was to evaluate the Chehalis River and the loading sources that resulted in these low DO levels. Data for hydrodynamics, temperature, dissolved oxygen, and other water quality parameters were collected and the mainstem Chehalis River was modeled using WASP5 (EPA). Point sources to the river included National Pollutant Discharge Elimination System (NPDES) regulated sources, including wastewater treatment plants. Non-point sources resulted from land use related to commercial, residential, timber, and waste land-application activities. Additionally, the Centralia Landfill adjacent to Salzer Creek could potentially impact the Chehalis River via groundwater, storm water, or leachate interactions from the site. The landfill was designated as a CERCLA (Superfund) site.

WASP5 is a time-dependent three-dimensional model for oxygen, nutrients, biochemical oxygen demand (BOD), phytoplankton, and conservative parameters. In this case, a steady state mode of the model was implemented. Various nutrients, including

ammonia-nitrogen, nitrate-nitrogen, ortho-phosphate, phytoplankton-carbon, BOD, DO, organic nitrogen, and organic phosphorus were modeled.

Modeling of the Chehalis river using WASP5 indicated that conditions existing during the time of the study would not allow dissolved oxygen standards to be met during mid-summer and early fall. Even if no additional loadings beyond natural background levels existed, model predictions of dissolved oxygen levels showed that water quality standards would still be violated. The DO concentrations in the upper and lower portions of the study area were always predicted to be too low during mid-summer, while in the middle Centralia reach DO concentrations were predicted to be too low during early fall.

2.2. 2001 TMDL Study

The most recent TMDL study is from 2001 (WADOE), conducted due to temperature criteria exceedances. Temperature exceedances have been partially due to inadequate riparian shading, with industrial and municipal discharges also playing a small role. At the time of this TMDL, the upper Chehalis River basin streams were required not to exceed 18 °C due to human impacts. If the temperature exceeded 18 °C due to natural causes, then human induced temperature increase could not exceed 0.3 additional °C.

While river shading data were not widely available, the study estimated that over 30 percent of natural riparian vegetation had been depleted. The solar radiation loading capacity for this study was evaluated as the amount of shade necessary to reduce river temperature values to meet standards. Promoting riparian vegetation would give additional environmental benefits, such as bank stability, reduction of sediment

transport, and increased groundwater recharge capacity of the river. Unfortunately, for three major tributaries to the Chehalis River (South Fork Chehalis River, Newaukum River, and Black River) solely increasing riparian vegetative shade to achievable levels still would not allow temperature standards to be met. This was largely because these tributaries had wide and shallow sections, with slow velocities allowing excess heating. In these cases, reducing river width-to-depth ratios would be important for temperature reduction.

River temperature is very important to the health of many fish species, and adverse impacts are seen in the Chehalis River when stream temperatures increase. For example, there was a reduction in the quality of habitat salmonid fish required for spawning and rearing during summer periods of excessive temperatures. Bull trout were classified as threatened by the U.S. Fish and Wildlife Services and Coho salmon were listed as a potential addition to the federal Endangered Species Act by the National Marine Fisheries Service. In fact, the first TMDL for this basin was motivated largely as a result of a fish kill in 1989 on the Black River.

In determining the necessary amounts of riparian shading to reduce water temperatures, this study made some key assumptions: (1) river flow would not be reduced during critical low-flow periods and (2) the channel morphology would be improved due to riparian vegetation restoration efforts. Using monitoring stations along the river, clear seasonal temperature patterns were seen. The months of June and July were the times when temperature criteria were most often violated.

SNTEMP was the model this study used to predict how altering certain parameters affected stream temperature. SNTEMP is a steady state, one-dimensional heat transport model. The model SSSHADE was used in this study to estimate stream shading as a result of riparian characteristics. Maximum daily stream temperature was found to be most sensitive to changes in air temperature, followed by humidity, then solar radiation. Except for the Chehalis River headwater reach, all other streams in the basin were determined to need increased shading between 12% and 42% to meet temperature criteria.

The TMDL resulted in several requirements for the river: additional withdrawals from the Chehalis River may not be allowed during critical low-flow times; processes influencing channel morphology must remain the same for all streams except for the South Fork Chehalis River, Newaukum River, and Black River, where these processes need to be altered in order to improve channel morphology; sediment transport must be maintained or reduced; watershed hydrology, including flow magnitudes and timing, must not change any further than has already occurred; and the temperature and flow conditions for incoming tributaries to the Chehalis River must not get worse. During critical low-flow periods, temperature restrictions for dischargers become more extreme. The critical period for all existing point dischargers, except Darigold, begins the day after the seven-day average flow drops below 1000 cfs. This period ends the day after this average increases above 1000 cfs and the Centralia Reach daily flow is observed to be more than 2,500 cfs on at least one of the previous seven days. For Darigold, the critical

period begins when the Centralia Reach flow is observed as less than 500 cfs and ends when the Centralia Reach flow increases above 1000 cfs.

2.3. 2014 Anchor QEA Water Quality Studies Report

Constructing a dam in the Chehalis Basin could have many benefits for flood control but impacts on aquatic species. In order to determine the effects from a potential dam, the baseline conditions of the system were evaluated. Multiple water quality studies were conducted within this report (Anchor QEA, 2014) to look specifically at temperature, dissolved oxygen, and water quality in the mainstem Chehalis River. Additionally, nutrient and biochemical oxygen demand from the larger tributaries were monitored. These data could be used to recalibrate existing HEC-RAS and CE-QUAL-W2 models, and evaluate fish habitat and aquatic species impact.

Multiple temperature probes were employed in the summer of 2013, some with adjacent air temperature monitors. Low flow surveys were conducted in the summers of 2013 and 2014 with the goal of characterizing nutrient and BOD loadings along the river. Summer low flow surveys included mainstem data collected just upstream of the larger tributaries. Many detailed water quality profiles were collected in July, 2014 near Centralia, WA, where stratification exists. Groundwater wells were monitored for temperature in reaches identified to be the most highly contributing to river flow. Lastly, meteorological data were collected due to its impact on modeling temperature. Data for wind speed and direction, relative humidity, air temperature, precipitation and incident solar radiation were collected.

Notably, all temperature monitoring locations in areas identified as important summer salmonid habitat had temperature criteria exceedances above 16 °C for the entire 2013 summer period and most of the 2014 summer period. Additionally, spawning and incubation criteria for fall, spring, and early summer were exceeded in the following year during early fall and early summer. However, the reaches and tributaries identified as areas important for salmon spawning, rearing, and migration habitat generally remained below temperature criteria during fall and spring. Spatially, temperature increased from upstream to downstream, though was variable depending on specific conditions such as meteorology and inflowing tributaries. Generally, Elk Creek and South Fork Chehalis River were not determined to have significant impacts on the mainstem Chehalis River temperature. The Skookumchuck River and Black River temperatures were typically lower than at the mainstem confluence locations. The tributaries in the upper Chehalis River reaches were determined to have the most adverse temperature effects.

The three low-flow surveys recorded diurnal patterns of temperature, DO, pH, turbidity, and chlorophyll a. Generally, diurnal variations of temperature, DO, and pH were larger at Pe Ell than in the Centralia reach. At Pe Ell, the temperature criterion was exceeded for the two sampling days. Highest DO values were seen during the day, and the lowest during the night at Pe Ell. The lowest DO values did not meet the criterion. Similar patterns were seen for pH. These patterns suggest photosynthesis and respiration cycles had an impact on DO and pH. Specifically, algae were a more likely contributor to these trends, rather than phytoplankton, due to the fact that turbidity and chlorophyll a

concentrations were nearly zero. At the Centralia reach monitoring locations, similar diurnal trends to Pe Ell were observed for DO, though not for pH. In the Centralia reach, moderate chlorophyll a concentrations were observed. Additionally, in the Centralia reach stratification was observed that resulted in a decline of DO and pH in deeper pools, even during well-mixed times. The turbidity levels were low at these locations, suggesting photosynthesis could take place where water was shallow enough. However, photosynthesis did not generally have a significant impact on DO and pH. Spatially, DO generally decreased moving downstream, and often did not meet the summer salmonid criterion and the salmonid spawning, rearing, and migration criterion. PH, turbidity, and chlorophyll a levels were generally within the applicable criterion.

Thermal stratification was seen between river miles 67 and 70 in the Centralia reach. The most extreme thermal stratification was seen at the deepest reach at river mile 69.25 and showed a surface to bottom temperature difference of 7 °C. Similar DO trends were seen. In upstream locations where no stratification existed, DO values were higher. PH values outside of the stratification area were typically between 6.5 and 8.5. Generally, turbidity was low near the surface, and increased with depth, though never exceeded the criterion.

Solar heating was the main contributor to water temperature, and was a function of riparian vegetation, topography, and channel geomorphology. LiDAR data concluded vegetative shading density was 20% in forested areas and 50% in urban areas. More shading cover would reduce river temperatures. Generally, DO is plentiful in the river,

except where stratification occurs, leading to nearly anoxic levels near the bottom of the channel. PH and turbidity levels were within the aquatic life use criteria throughout the study area.

3. CE-QUAL-W2 Model Overview

3.1. Model Description

CE-QUAL-W2 is a two-dimensional (longitudinal and vertical) hydrodynamic and water quality model applicable to surface waterbodies, such as rivers, reservoirs, lakes, and estuaries (Cole and Wells, 2016). The Version 3 model to Version 3.5 model was developed by a collaboration between the U.S. Army Corps of Engineers and the Water Quality Research Group at Portland State University. Since Version 3.5, the model is now maintained by the Water Quality Research Group at Portland State. The hydrodynamic capabilities of the model include predictions of flow, water surface elevation, velocities, and temperature. The water quality state variables include (Cole and Wells, 2016):

1. any number of generic constituents defined by a 0 and/or a 1st order decay rate and/or a settling velocity and/or an Arrhenius temperature rate multiplier that can be used to define any number of the following:
 - a. conservative tracer(s)
 - b. water age or hydraulic residence time
 - c. N₂ gas and %Total Dissolved Gas
 - d. coliform bacteria(s)
 - e. contaminant(s)
2. any number of inorganic suspended solids groups
3. any number of phytoplankton groups
4. any number of periphyton/epiphyton groups
5. any number of CBOD groups
6. any number of submerged macrophyte groups
7. ammonium
8. nitrate+nitrite
9. bioavailable phosphorus (commonly represented by orthophosphate or soluble reactive phosphorus)
10. silica (dissolved and particulate)
11. labile dissolved organic matter
12. refractory dissolved organic matter
13. labile particulate organic matter

14. refractory particulate organic matter
15. total inorganic carbon
16. alkalinity
17. iron and manganese
18. dissolved oxygen
19. organic sediments
20. gas entrainment
21. any number of macrophyte groups
22. any number of zooplankton groups
23. labile dissolved organic matter-P
24. refractory dissolved organic matter-P
25. labile particulate organic matter-P
26. refractory particulate organic matter-P
27. labile dissolved organic matter-N
28. refractory dissolved organic matter-N
29. labile particulate organic matter-N
30. refractory particulate organic matter-N
31. Sediment and water column CH₄
32. Sediment and water column H₂S
33. Sediment and water column SO₄
34. Sediment and water column Sulfide
35. Sediment and water column FeOOH(s)
36. Sediment and water column Fe⁺²
37. Sediment and water column MnO₂(s)
38. Sediment and water column Mn⁺²
39. Sediment organic P, sediment PO₄
40. Sediment organic N, sediment NO₃, sediment NH₄
41. Sediment Temperature
42. Sediment pH
43. Sediment alkalinity
44. Sediment Total inorganic C
45. Sediment organic C
46. Turbidity correlation to Suspended solids

Additionally, many derived variables are computed, such as pH, Total P, Total N, CBOD_{total}, and total organic carbon (Cole and Wells, 2016).

CE-QUAL-W2 allows the user to include multiple branches, variable layer heights, time-varying boundary conditions, inputs from point or non-point sources, outflows or

withdrawals from the system, and calculations of ice-cover (Cole and Wells, 2016). The hydrodynamic and constituent transport equations are averaged laterally for each layer. Turbulent time-averaged equations employ the Boussinesq and hydrostatic approximations. Vertical velocity is assumed negligible compared to longitudinal velocity. Momentum dispersion, the Coriolis effect, and viscous shear in the fluid domain are neglected. Atmospheric pressure is assumed to be 1 atm and not to vary spatially. Partial differential equations are solved using the finite difference method (Cole and Wells, 2016).

3.2. Governing Equations

3.2.1. X-Momentum

$$\frac{\partial UB}{\partial t} + \frac{\partial UUB}{\partial x} + \frac{\partial WUB}{\partial z} = -\frac{1}{\rho} \frac{\partial BP}{\partial x} + \frac{\partial \left(BA_x \frac{\partial U}{\partial x} \right)}{\partial x} + \frac{\partial B\tau_x}{\partial z}$$

Where

U = longitudinal, laterally averaged velocity, m/s

B = water body width, m

t = time, s

x = longitudinal Cartesian coordinate

z = vertical Cartesian coordinate

W = vertical, laterally averaged velocity, m/s

ρ = density, kg/m³

P = pressure, N/m^2

A_x = longitudinal momentum dispersion coefficient, m^2/s^2

τ_x = shear stress per unit mass, m^2/s^2

3.2.2. Z-Momentum

$$0 = g - \frac{1}{\rho} \frac{\partial P}{\partial z}$$

Where

g = acceleration due to gravity, m/s^2

3.2.3. Continuity

$$\frac{\partial UB}{\partial x} + \frac{\partial WB}{\partial z} = qB$$

Where

q = lateral boundary inflow or outflow, m^3/s

3.2.4. Free-Surface

$$\frac{\partial B_\eta \eta}{\partial t} = \frac{\partial}{\partial x} \int_\eta^h UB dz - \int_\eta^h qB dz$$

Where

B_η = spatially and temporally varying surface width, m

η = free water surface location, m

h = total depth, m

3.2.5. Constituent Transport

$$\frac{\partial B\phi}{\partial t} + \frac{\partial UB\phi}{\partial x} + \frac{\partial WB\phi}{\partial z} - \frac{\partial \left(BD_x \frac{\partial \phi}{\partial x} \right)}{\partial x} - \frac{\partial \left(BD_z \frac{\partial \phi}{\partial z} \right)}{\partial z} = q_\phi B + S_k B$$

Where

ϕ = laterally averaged constituent concentration, mg/L

D_x = longitudinal temperature and constituent dispersion coefficient, m²/s

D_z = vertical temperature and constituent dispersion coefficient, m²/s

q_ϕ = lateral inflow or outflow mass flow rate of constituent per unit
volume, mg/L/s

S_k = kinetics source/sink term for constituent

3.2.6. Equation of State

$$\rho = f(T, \phi_{TDS}, \phi_{SS})$$

Where

T = temperature, °C

ϕ_{TDS} = total dissolved solids concentration, mg/L

ϕ_{SS} = suspended solids concentration, mg/L

For a detailed description of the assumptions and processes in the derivation of these equations, and for other equations used in CE-QUAL-W2, see the user manual (Cole and Wells, 2016).

3.3. Applicability to the Chehalis River

It was important to use a two-dimensional model for the Chehalis River system because of stratification effects seen in the deep pools in the Centralia reach. These could not be accurately described with a one-dimensional model. CE-QUAL-W2 was also employed to model the potential upstream reservoir, allowing for an easy transition between the output data from the reservoir model to the downstream mainstem Chehalis River model. This also helped to assure uniformity between the modeling techniques used for the reservoir and the downstream mainstem Chehalis River.

4. Model Setup

4.1. Bathymetry

The Chehalis River was modeled from upstream of Pe Ell at the proposed dam site (river mile 108) to Porter, WA (river mile 33.3). Only the mainstem Chehalis River was modeled and was discretized into 10 model branches and 9 waterbodies. The physical characteristics of the river varied widely, and multiple branches allowed for separate characteristics (such as branch slope) unique to each branch to be implemented in the model. The upstream reaches had steep gradients with riffles and pools (see Figure 5), while the middle portion near Centralia had slow and deep lake-like conditions (see Figure 6). The longitudinal profile of the river thalweg in Figure 7 shows the varying slopes along the Chehalis River and the locations of the model branches and waterbodies. Figure 8 shows the bottom elevation of the model grid compared to the longitudinal profile of the river thalweg.

Figure 5. Portion of the Chehalis River exhibiting step gradients with pools and riffles

Figure 6 Portion of the Chehalis River exhibiting lake-like conditions

Figure 7. Longitudinal profile of the Chehalis River thalweg (vertical lines show model branch breaks)

Figure 8. Longitudinal profile of the Chehalis River thalweg and the model grid bottom elevation

The model grid was developed based on river cross section data provided by Anchor QEA (2012). This included station and elevation data for over 350 cross sections along the Chehalis River. The model grid consisted of 322 longitudinal segments of 400 m length, each with 20 vertical layers of 1 m thickness. Field cross section data were interpolated to determine layer widths in each model segment. Examples of field cross section data used to calculate model segment layer widths can be seen in Figure 9 for

model segment 140 at river mile 77.92, and Figure 10 for model segment 151 at river mile 76. Figure 11 shows an aerial view of all active model segments along the mainstem Chehalis River.

Figure 9. Example Chehalis River field cross section at river mile 77.92 used to calculate layer widths for model segment 140. The CE-QUAL-W2 model widths are represented by the straight lines for each vertical layer

Figure 10. Example Chehalis River field cross section at river mile 76 used to calculate layer widths for model segment 151. The CE-QUAL-W2 model widths are represented by the straight lines for each vertical layer

Figure 11. Aerial view of the entire model grid, showing active model segments along the mainstem Chehalis River

Field cross sectional data were also used to identify active layers of each model segment and calculate channel slope. Elevation data used in the model were referenced to the NAVD88 datum. Initial water surface depths were set to 2 meters (6.6 feet) for each segment. Table 1 gives a summary of the waterbody and branch segments and layer

dimensions. Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figure 17, Figure 18, Figure 19, Figure 20, and Figure 21 show the model side profile for branch 1, branch 2, branch 3, branch 4, branch 5, branch 6, branch 7, branch 8, branch 9, and branch 10, respectively.

Table 1. Summary of waterbody and branch segments and layers

Water - body	Branch	Starting Active Segment	Ending Active Segment	Branch Length (m)	Number of layers	Vertical layer Thickness (m)	SLOPE	SLOPEC
1	1	2	6	2000	20	1	0.01600	0.003
2	2	9	28	8000	20	1	0.00200	0.0004
3	3	31	59	11600	20	1	0.00200	0.0006
4	4	62	128	26400	20	1	0.00095	0.00095
5	5	131	145	6000	20	1	0.00118	0.00055
6	6	148	174	10800	20	1	0.00000	0.00000
	7	177	193	6800	20	1	0.00000	0.00000
7	8	196	214	7200	20	1	0.00055	0.00055
8	9	217	282	26000	20	1	0.00076	0.00076
9	10	285	321	19200	20	1	0.00077	0.00077

Figure 12. Model branch 1 side profile view, including all segments and layers

Figure 13. Model branch 2 side profile view, including all segments and layers

Figure 14. Model branch 3 side profile view, including all segments and layers

Figure 15. Model branch 4 side profile view, including all segments and layers

Figure 16. Model branch 5 side profile view, including all segments and layers

Figure 17. Model branch 6 side profile view, including all segments and layers

Figure 18. Model branch 7 side profile view, including all segments and layers

Figure 19. Model branch 8 side profile view, including all segments and layers

Figure 20. Model branch 9 side profile view, including all segments and layers

Figure 21. Model branch 10 side profile view, including all segments and layers

4.2. Meteorological Inputs

Meteorological parameters used in this study included air temperature, dew point temperature, wind speed, wind direction, cloud cover, and solar radiation. CE-QUAL-W2 has the capability to internally calculate solar radiation based on cloud cover data and latitude and longitude.

One source of meteorological data was the Remote Automatic Weather Stations (RAWS, 2014) database, with hourly data available (Bowman, 2016 and Breckner, 2016).

Another source of meteorological data was Chehalis River Basin Flood Authority (CRBFA, 2016) at Thrash Creek near the proposed dam site, with data available at 15-minute frequency. Lastly, the National Oceanic and Atmospheric Administration (NOAA, 2015) provided data from the Chehalis-Centralia meteorological station. Table 2 lists the stations used to create input meteorological files.

Table 2. Monitoring stations that provided meteorological data

Organization	Station ID	State Name	Location	Dates with data	Waterbodies applied to in model	River Miles applied to in model
CRBFA	Thrash Creek	Thrash Creek	Near Pe Ell	1/1/13 – 12/31/15	1 & 2	108 – 102
RAWS	HKFW	Huckleberry Ridge	Near Pe Ell	4/2/13 – 12/31/15	-	-
RAWS	CLSW	Chehalis	Near Chehalis	1/1/13 – 12/31/15	3, 4, 5, 6, & 7	102 – 61.7
NOAA	KCLS	Chehalis-Centralia Airport	Chehalis, WA	1/1/13 – 12/31/15	-	-
RAWS	MIPW	Minot Peak	Near Porter	4/9/13 – 12/31/15	8 & 9	61.7 – 33.3

The CRBFA Thrash Creek gage data were applied to model waterbodies 1 and 2; the RAWS Chehalis gage data were applied to waterbodies 3, 4, 5, 6, and 7; and the RAWS Minot Peak gage data were applied to waterbodies 8 and 9. While the RAWS Huckleberry Ridge station and Chehalis-Centralia Airport station data were not used in model input files, they were used to evaluate and compare to the other meteorological stations. Both RAWS and CRBFA had a meteorological data site near Pe Ell. The CRBFA site was used to be consistent with other modeling projects of the Chehalis River and because of its proximity to the upstream boundary. The CLSW station data were used rather than the

airport because CLSW collected data at shorter time intervals. Figure 22 shows the locations of the meteorological stations in relation to the model grid.

Figure 22. Meteorological stations near the Chehalis River that provided data, including Thrash Creek, HKFW, CLSW, Centralia-Chehalis Airport, and MIPW

Since data were required for the entire model time period of January 1, 2013 to December 31, 2014, there were many data gaps that needed to be filled. Linear interpolation was employed to fill in missing data for short time gaps, on the order of hours. For some longer temporal gaps data from another station were used. For example, the first months of the MIPW data set were unavailable, so values from the CLSW data set were used. For other longer time gaps, linear correlation relationships with another station's data were created and used to estimate missing data:

1. For times when both stations had data available, a linear regression equation was created between a station with missing data and the closest station with a full data set.
2. This relationship was used to estimate values for the station with missing data during times when data were unavailable.

Regression relationships were created for air and dew point temperature between the MIPW and CLSW monitoring stations. These regression equations can be viewed in Table 3 and plots of the regression relationships are shown in Figure 23 and Figure 24 for air and dew temperature, respectively.

Table 3. Air and Dew Temperature Regression Relationships for Minot Peak (MIPW) Station Data to Chehalis (CLSW) Station Data

Station with missing data	Regression Equation	R ² Value
Minot Peak (MIPW)	$T_{air_{MIPW}} = 0.6559 * T_{air_{CLSW}} + 1.7891$	0.6562
Minot Peak (MIPW)	$T_{dew_{MIPW}} = 0.6265 * T_{dew_{CLSW}} + 1.8753$	0.4879

Figure 23. Air temperature relationship between Minot Peak (MIPW) and Chehalis (CLSW) RAWS stations when both had data available

Figure 24. Dew point temperature relationship between Minot Peak (MIPW) and Chehalis (CLSW) RAWS stations when both had data available

Cloud cover values were missing for the RAWs stations. These were estimated using solar radiation data. First, theoretical clear sky solar radiation based on latitude and longitude were calculated using code from CE-QUAL-W2 (Cole and Wells, 2016). Then, cloud cover was calculated by comparing solar radiation data with theoretical clear sky solar radiation using (Cole and Wells, 2016):

$$\phi_{s_data} = \phi_{s_clearsky}(1 - 0.65C^2)$$

Where

ϕ_{s_data} is the real short wave solar radiation

$\phi_{s_clearsky}$ is the theoretical clear sky short wave solar radiation

C is the fraction of cloud cover between 0 and 1

Meteorological data including air temperature, dew point temperature, wind speed, wind direction, cloud cover, and solar radiation, for the Thrash Creek, HKFW, CLSW, and MIPW stations are shown in Figure 25, Figure 26, Figure 27, and Figure 28, respectively.

Figure 25. Meteorological data from the Thrash Creek station (including estimated values)

Figure 26. Meteorological data from the HKFW station (raw values only)

Figure 27. Meteorological data from the CLSW station (including estimated values)

Figure 28. Meteorological data from the MIPW station (including estimated values)

4.3. Flow Inputs

Many tributaries discharge to the mainstem Chehalis River within the model reach. The larger tributaries include the Newaukum River, Skookumchuck River, South Fork Chehalis River and Black River. The smaller tributaries include Bunker, Mill, Stearns, Dillenbaugh, Salzer, China, Scammon, Prairie, Lincoln, Scatter, Independence, Garrard, Rock, Cedar, Gibson, and Porter creeks. Five wastewater treatment plants (WWTP) discharge to the river. Four are municipal (Pe Ell, Centralia, Chehalis, and Grand Mound), while the other is industrial (Darigold, Inc.). Groundwater inputs also occur along the Chehalis River, starting upstream of Elk Creek and continuing until the downstream boundary at Porter. The river mile and model segment locations of the tributaries, dischargers, and groundwater inputs can be seen in Table 4. A schematic of the tributaries and dischargers entering the Chehalis River can be seen in Figure 29.

Table 4. River mile and segment locations for tributaries, dischargers, and groundwater inputs to the Chehalis River

Description	Model Segment	River Mile
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

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

Figure 29. 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.

Flow and stage data were available from multiple monitoring stations along the mainstem Chehalis River and for some of the tributaries. Flow data were made available by USGS (2014), WADOE (2014), and Thurston County (2014). WWTP data were provided by the WADOE National Pollutant Discharge Elimination System (NPDES) permit database

and also directly from some of the wastewater treatment plant managers (NPDES, 2016; Phelps, 2016; Hillock, 2016; Bilhimer, 2016; Zentner, 2016; and Patching, 2016).

Groundwater is generally a flow source to the river and varies along the channel. Multiple studies have been conducted that give average groundwater flow values for various reaches of the Chehalis River. These include a TMDL study (Erickson, 1993), an aquifer characterization study (Garrigues, et al., 1998), a Centralia-Chehalis area groundwater study (Pitz et al., 2005), a seepage investigation in the Chehalis River basin (Ely, et al., 2008), and a groundwater/surface water study in the Chehalis River basin (Gendaszek, 2011). Flow data from these studies were generally given as gains and losses of flow for various reaches along the Chehalis River. The most recent data were used from the Gendaszek (2011) report when possible, and then from the Ely, et al. (2008) report to fill in data gaps. Due to lack of continuous data, the estimates of the groundwater flow from these studies were assumed constant over time. These flows were allocated to each applicable model segment, acting as many individual point tributaries. Table 5 lists the stations that provided flow data for tributaries, dischargers, and groundwater inputs.

Table 5. Flow monitoring stations with measured or estimated flow data

Organization	Station ID	Description
USGS	12019310	Chehalis River above Mahaffey Creek
USGS	12020000	Chehalis River near Doty, WA
USGS	12020525	Elk Creek below Deer Creek near Doty, WA
USGS	12020800	South Fork Chehalis River near Wildwood, WA
USGS	12025000	Newaukum River near Chehalis, WA
USGS	12026400	Skookumchuck River near Bucoda, WA
USGS	12027500	Chehalis River near Grand Mound, WA
USGS	12031000	Chehalis River at Porter, WA
Thurston County	55a	Scatter Creek at James Road
WADOE	23E060	Black River at Hwy 12

Organization	Station ID	Description
WADOE	23H060	Salzer Creek at Airport Road
WADOE NPDES	WA0020192	Pe Ell WWTP
WADOE NPDES	WA0037478	Darigold WWTP
WADOE NPDES	WA0021105	Chehalis WWTP
WADOE NPDES	WA0020982	Centralia WWTP
WADOE NPDES	WA0042099	Grand Mound WWTP
USGS	Reach T (Ely, et al.)	Groundwater river mile 101.9 – 100.5
USGS	Reach S (Ely, et al.)	Groundwater river mile 100.5 – 97.9
USGS	Reach R (Ely, et al.)	Groundwater river mile 97.9 – 93.8
USGS	Reach Q (Ely, et al.)	Groundwater river mile 93.8 – 90.2
USGS	Reach P (Ely, et al.)	Groundwater river mile 90.2 – 86
USGS	Reach O (Ely, et al.)	Groundwater river mile 86 – 79.9
USGS	Reach N (Ely, et al.)	Groundwater river mile 79.9 – 75.1
USGS	Reach A (Gendaszek)	Groundwater river mile 75.1 – 66.7
USGS	Reach B (Gendaszek)	Groundwater river mile 66.7 – 64.2
USGS	Reach C (Gendaszek)	Groundwater river mile 64.2 – 61.4
USGS	Reach D (Gendaszek)	Groundwater river mile 61.4 – 59.9
USGS	Reach E (Gendaszek)	Groundwater river mile 59.9 – 58.8
USGS	Reach F (Gendaszek)	Groundwater river mile 58.8 – 57.1
USGS	Reach G (Gendaszek)	Groundwater river mile 57.1 – 55.7
USGS	Reach H (Gendaszek)	Groundwater river mile 55.7 – 54.2
USGS	Reach I (Gendaszek)	Groundwater river mile 54.2 – 52.5
USGS	Reach J (Gendaszek)	Groundwater river mile 52.5 – 51.5
USGS	Reach K (Gendaszek)	Groundwater river mile 51.5 – 50.2
USGS	Reach L (Gendaszek)	Groundwater river mile 50.2 – 49.1
USGS	Reach M (Gendaszek)	Groundwater river mile 49.1 – 47.9
USGS	Reach N (Gendaszek)	Groundwater river mile 47.9 – 47.1
USGS	Reach O (Gendaszek)	Groundwater river mile 47.1 – 46.1
USGS	Reach P (Gendaszek)	Groundwater river mile 46.1 – 45
USGS	Reach Q (Gendaszek)	Groundwater river mile 45 – 44
USGS	Reach R (Gendaszek)	Groundwater river mile 44 – 42.3
USGS	Reach E (Ely, et al.)	Groundwater river mile 42.3 – 34
USGS	Reach D (Ely, et al.)	Groundwater river mile 34 – 33.3

Flow data were required for the entire model time period of January 1, 2013 to December 31, 2014, and gaps needed to be filled when necessary. The nearest mainstem flow monitoring station to the upstream boundary was located on the Chehalis River near Mahaffey Creek (USGS 12019310), with 15-minute frequency flow values. The Chehalis River at Mahaffey Creek, South Fork Chehalis River, Black River, and Elk Creek had flow

records available, though sometimes with sizable data gaps on the order of months. Correlations were developed in order to fill in these gaps, following the same procedure as the meteorological data. The flow regression equations for Chehalis River near Mahaffey Creek, Elk Creek, South Fork Chehalis River, and Black River are shown in Table 6. Plots of the regression relationships can be seen in Figure 30, Figure 31, Figure 32, and Figure 33 for Chehalis River near Mahaffey Creek, Elk Creek, South Fork Chehalis River, and Black River, respectively.

Table 6. Flow Regression Relationships for South Fork Chehalis River, Black River, and Elk Creek to Chehalis River at Doty or Grand Mound

Tributary	Regression Equation	R ² Value
Upstream boundary (Chehalis River at Mahaffey Creek)	$Q_{Ch\ R.\ Mahaffey} = 0.8262 * Q_{Chehalis@Doty} - 0.3337$	0.98
Elk Creek	$Q_{Elk\ Creek} = 0.2659 * Q_{Chehalis@Doty} + 2.4474$	0.8558
South Fork Chehalis River	$Q_{SF\ Chehalis} = 0.1717 * Q_{Chehalis@Doty} + 1.0654$	0.8232
Black River	$Q_{Black} = 0.9034 * Q_{Chehalis@Grand\ Mound} + 3.6102$	0.6611

Figure 30. Flow relationship between Chehalis River near Mahaffey Creek and Chehalis River at Doty when both gaging stations had data available

Figure 31. Flow relationship between Elk Creek and Chehalis River at Doty when both gaging stations had data available

Figure 32. Flow relationship between South Fork Chehalis River and Chehalis River at Doty when both gaging stations had data available

Figure 33. Flow relationship between Black River and Chehalis River at Grand Mound when both gaging stations had data available

Many of the smaller tributaries – including Bunker, Mill, Stearns, Dillenbaugh, Salzer, China, Scammon, Prairie, Lincoln, Scatter, Independence, Garrard, Rock, Cedar, Gibson, and Porter creeks – had little to no flow data available during the model time period, and hence it was not possible to create a regression relationship. In this case, gaged flow data from another tributary and a ratio of drainage area of the ungaged station to the drainage area of the gaged station was employed to estimate the missing tributary flow following the equation below (Anchor QEA, 2012 and WEST Consultants, 2011). The Newaukum River data set was used as the gaged data set since this tributary had data available for the entire model time period. The drainage area values were provided by USGS (2016). Table 7 shows the tributary gaging stations and corresponding drainage areas used to employ this method.

$$Q_{ungaged} = Q_{gaged} \times \frac{Drainage\ Area_{ungaged}}{Drainage\ Area_{gaged}}$$

Table 7. Drainage area values used to calculate flow for tributaries with missing data

Station ID	Station Name	Drainage Area (mi ²)
USGS 12019310	Chehalis River above Mahaffey Creek near Pe Ell, WA	68.9
USGS 12010000	Chehalis River at Doty, WA	113
USGS 12025000	Newaukum River	155
USGS 12022010	Bunker Creek above Deep Creek near Bunker, WA	20.7
USGS 12022500	Stearns Creek near Napavine, WA	14.1
USGS 12023400	Mill Creek at Littell, WA	6.17
USGS 12025075	Dillenbaugh Creek below Berwick Creek near Chehalis, WA	12.4
USGS 12025330	Salzer Creek	16.5
USGS 12025530	China creek near Centralia, WA	1.58
USGS 12026670	Scammon creek at Cooks Hill Road near Centralia, WA	5.13
LNC-CRK	Lincoln Creek	19.3
USGS 12027200	Lincoln creek at RM 1.6 near Galvin, WA	37.1
USGS 12027540	Prairie creek near Grand Mound, WA	3.76

Station ID	Station Name	Drainage Area (mi ²)
USGS 12028150	Independence Creek	13.2
USGS 12029325	Garrard Creek	11
USGS 12030000	Rock Creek	24.8
USGS 12030500	Cedar Creek	38.2
USGS 12030550	Gibson Creek	6.96
USGS 12030950	Porter Creek	39.8

Figure 34 shows the input flow to the model for tributaries with data available, including those where regression estimation techniques were employed. Figure 35, Figure 36, and Figure 37 show the input flow for tributaries where flow values were estimated from drainage areas and Newaukum River data. Figure 38 shows the input flows from the WWTP dischargers, and Figure 39 shows the input flows for groundwater sources to the Chehalis River.

Figure 34. Input flow data where field data were available for Chehalis River at Mahaffey Creek (upstream boundary), Elk Creek, South Fork Chehalis River, Newaukum River, Salzer Creek, Skookumchuck River, and Black River

Figure 35. Input flow based on drainage area ratios to Newaukum River for Bunker Creek, Mill Creek, Stearns Creek, Dillenbaugh Creek, and China Creek

Figure 36. Input flow based on drainage area ratios to Newaukum River for Scammon Creek, Prairie Creek, Lincoln Creek, Scatter Creek, and Independence Creek

Figure 37. Input flow based on drainage area ratios to Newaukum River for Garrard Creek, Rock Creek, Cedar Creek, Gibson Creek, and Porter Creek

Figure 38. Input flow for the Pe Ell, Darigold, Chehalis, Centralia, and Grand Mound wastewater treatment plants

Figure 39. Input flow for groundwater inflows

4.4. Temperature Inputs

Temperature data were also required for the entire model time period for all input flows. Temperature data were available from measurement locations along the mainstem Chehalis River as well as for some of the tributaries. Temperature data were made available by WADOE (2014), Anchor QEA (2014), Washington Department of Fish and Wildlife (WDFW 2014), and Thurston County (2014). WWTP data were provided by the WADOE NPDES permit data base as well as directly from some plant managers (NPDES 2003a, 2003b, 2010, 2011, 2012; Phelps, 2016; Hillock, 2016; Bilhimer, 2016; Zentner, 2016; and Patching, 2016). Groundwater temperature data were provided from the Chehalis River TMDL study (Erickson, 1993), where temperature data were provided for various reaches of groundwater interacting with the Chehalis River. Groundwater temperature data collected from the wells closest to the river for each reach were used. Table 8 lists the gaging stations that were used for the model temperature for tributaries, dischargers, and groundwater inputs.

Table 8. Monitoring stations used to develop model temperature inputs

Organization	Station ID	Description	Dates with data
Anchor QEA	CHL-PEL-US	Chehalis Upstream of Pe Ell	7/31/13 - 3/26/14
Anchor QEA	CHL-PEL-DS	Chehalis Downstream of Pe Ell	7/31/13 - 7/30/14
Anchor QEA	CHL-	Chehalis at Woodstead Farm 01	7/2/13 - 10/28/13
Anchor QEA	CHL-DOTY	Chehalis at Doty	7/3/13 - 10/16/13
Anchor QEA	ELK-CRK	Elk Creek	7/31/13 - 3/26/14
Anchor QEA	CHL-RAINBOW-	Chehalis at Rainbow Falls	7/2/13 - 10/16/13
Anchor QEA	CHL-CERES-HILLS	Chehalis at Ceres Hill Road	7/3/13 - 10/16/13
Anchor QEA	SF-CHL-MOUTH	South Fork Mouth	7/31/13 - 3/26/14
Anchor QEA	CHL-ADNA	Chehalis Near Adna	7/31/13 - 7/21/14
Anchor QEA	CHL-US-NWK	Chehalis Upstream of Newaukum Confluence	7/31/13 - 3/26/14
Anchor QEA	NWK-MOUTH	Newaukum Mouth	9/18/13 - 7/21/14
Anchor QEA	SKM-MOUTH	Skookumchuck Mouth	9/5/13 - 10/15/13
Anchor QEA	CHL-GLV	Chehalis at Galvin Bridge	7/30/13 - 7/21/14
Anchor QEA	CHL-US-BLK	Chehalis Upstream of Black River	7/30/13 - 7/22/14
Anchor QEA	BLK-RT12	Black River Mouth	9/5/13 - 7/22/14
Anchor QEA	CHL-OAK	Chehalis at Oakville	7/30/13 - 7/22/14
WDFW	11-UCH	Upper Chehalis	6/9/14 - 9/15/15
WDFW	3-UCH	Upper Chehalis	5/15/14 - 9/15/15
WDFW	13-CH	Chehalis mainstem	6/10/14 - 9/15/15
WDFW	4-UCH	Upper Chehalis	5/15/14 - 9/15/15
WDFW	15-CH	Chehalis mainstem	6/10/14 - 10/14/14
WDFW	19-CH	Chehalis mainstem	6/18/14 - 9/2/15
WDFW	21-CH	Upper Chehalis	6/11/14 - 9/2/15
WDFW	NEW-1	Newaukum	7/15/14 - 9/4/15
WDFW	22-CH	Upper Chehalis	6/11/14 - 8/5/15
WDFW	16-CH	Chehalis mainstem	6/10/14 - 9/3/15
WDFW	17-CH	Chehalis mainstem	6/10/14 - 9/1/15
WDFW	18-CH	Chehalis mainstem	6/10/14 - 8/26/15
WDFW	23-CH	Chehalis mainstem	7/15/14 - 8/17/15
Thurston County	55a	Scatter Creek at James Road	1/1/13 – 5/19/15
WADOE	23A160	Chehalis River at Dryad	7/1/13 - 9/18/13, 6/24/14 - 9/23/14, & 5/19/15 - 9/15/15
WADOE	23A070	Chehalis River at Porter	10/23/12 - 6/25/13 & 9/18/13 - 5/26/15
WADOE NPDES	WA0020192	Pe Ell WWTP	1/1/13 - 12/31/14
WADOE NPDES	WA0037478	Darigold WWTP	1/1/13 - 9/30/13, & 11/1/13 - 12/31/14

Organization	Station ID	Description	Dates with data
WADOE NPDES	WA0021105	Chehalis WWTP	1/1/13 - 12/31/14
WADOE NPDES	WA0020982	Centralia WWTP	1/1/13 - 12/31/14
WADOE NPDES	WA0042099	Grand Mound WWTP	1/1/13 - 12/31/14
Darigold WWTP	41	Chehalis River Upstream Darigold WWTP	1/1/13 - 11/30/15
Darigold WWTP	40	Chehalis River Downstream Darigold WWTP	1/1/13 - 11/30/15
WADOE	DW03	GW – Bunker Creek to Adna	1993
WADOE	DW08	GW – Adna to Claquato	1993
WADOE	DW07	GW – Claquato to Golf Course	1993
WADOE	DW15	GW – Golf Course to Mellen Street	1993
WADOE	DW18	GW – Centralia/Fords Prairie	1993
WADOE	DW27	GW – Grand Mound to Oakville	1993

Temperature data gaps were filled using the same regression procedure as for meteorological data by creating correlations between stations with missing data and stations with complete data sets. The Chehalis River downstream of Darigold WWTP and the Chehalis River upstream of Darigold WWTP gages had data for the entire model time period and hence were used for correlations with other incomplete data series. However, the regression relationships using the Chehalis River downstream of Darigold WWTP gage to fill in missing data had higher coefficient of determination (R^2) values than when using data from the upstream site. For this reason, the downstream site was used rather than the upstream to fill missing data. The exceptions to this were when closer temperature gages had data available. For Elk Creek this was 4-UCH and for Black River this was 18-CH. When these closer gages did not have data, the downstream Darigold gage was used.

The closest temperature measurement station to the upstream boundary was 11-UCH. When possible, data from 11-UCH was used. The next closest stations were CHL-

PEL-US and 3-UCH, which were close together and were located in the same model segment (length 400 m). A data set including temperature data from CHL-PEL-US from 1/1/13 to 5/14/14 and 3-UCH from 5/15/15 to 9/15/15 was created. One regression relationship was formed between 11-UCH and the CHL-PEL-US and 3-UCH data set. This relationship was used to estimate upstream boundary temperatures when CHL-PEL-US and 3-UCH had data. A second regression relationship was created between 11-UCH and Chehalis River Downstream of Darigold WWTP and was used to estimate upstream boundary temperatures for the remainder of the model time period.

The temperature linear regression relationships for Chehalis River near the upstream boundary (station 11-UCH), Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, and Black River are shown in Table 9. Example plots of the regression relationships are shown for the Chehalis River upstream boundary and South Fork Chehalis River in Figure 40 and Figure 41, respectively.

Table 9. Temperature Regression Relationships for Upstream Boundary, Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, and Black River

Tributary	Regression Equation	R ² Value
Upstream boundary (station 11-UCH)	$Q_{Ch R.(11-UCH)} = 1.0191 * Q_{CHL-PEL-US \& 3-UCH} - 0.5085$	0.978
	$Q_{Ch R.(11-UCH)} = 0.8252 * Q_{Ch R.DS Darigold} + 0.6678$	0.957
Elk Creek	$T_{Elk Creek} = 0.7681 * T_{Ch R.(4-UCH)} + 1.7319$	0.974
	$Q_{Elk Creek} = 0.7479 * Q_{Ch R.DS Darigold} + 1.6611$	0.971
South Fork Chehalis River	$Q_{SF Chehalis} = 0.9657 * Q_{Ch R.DS Darigold} + 0.5376$	0.989
Newaukum River	$Q_{Newaukum R.} = 0.975 * Q_{Ch R.DS Darigold} + 0.3016$	0.987
Skookumchuck River	$Q_{Skookumchuck R.} = 0.6538 * Q_{Ch R.DS Darigold} + 4.9754$	0.974
Black River	$T_{Black} = 0.7406 * T_{Ch R.(18-CH)} + 3.2796$	0.836
	$Q_{Black} = 0.832 * Q_{Ch R.DS Darigold} + 2.2174$	0.968

Figure 40. Temperature relationship between Chehalis River at upstream boundary station 11-UCH and Chehalis River Downstream of Darigold when both gaging stations had data available

Figure 41. Temperature relationship between South Fork Chehalis River and Chehalis River Downstream of Darigold when both gaging stations had data available

For tributaries where no data were available it was not possible to create a regression relationship to estimate temperature values. In these cases, the input temperature file from another tributary with similar flow magnitudes was used instead.

Groundwater reaches typically had one data value for temperature available, and sometimes no data. In order to estimate seasonal variation in groundwater temperature, 2 °C was added to the groundwater temperature data during the summer months.

Figure 42 shows input temperature to the model for tributaries with data available, including those where regression estimation techniques were employed. Figure 43 shows the input temperature for the wastewater treatment plants, and Figure 44 shows the temperature input data for the groundwater sources.

Figure 42. Input temperature data where field data were available for the upstream boundary (station 11-UCH), Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, Scatter Creek, and Black River

Figure 43. Input temperature for the Pe Ell, Darigold, Centralia, Chehalis, and Grand Mound wastewater treatment plants

Figure 44. Input temperature for groundwater inflows

4.5. Constituent Inputs

The water quality state variables modeled included:

- Total dissolved solids (TDS)
- Fecal coliform (FC)
- Inorganic suspended solids (ISS)
- Phosphate (PO₄)
- Ammonia (NH₃)
- Nitrates (NO₃)
- Labile dissolved organic matter (LDOM)
- Refractory dissolved organic matter (RDOM)

- Labile particulate organic matter (LPOM)
- Refractory particulate organic matter (RPOM)
- Biochemical oxygen demand (BOD)
- Biochemical oxygen demand as phosphorus (BOD-P)
- Biochemical oxygen demand as nitrogen (BOD-N)
- Algae
- Dissolved oxygen (DO)
- Alkalinity (alk)
- Zooplankton
- LDOM as phosphorus (LDOM-P)
- RDOM as phosphorus (RDOM-P)
- LPOM as phosphorus (LPOM-P)
- RPOM as phosphorus (RPOM-P)
- LDOM as nitrogen (LDOM-N)
- RDOM as nitrogen (RDOM-N)
- LPOM as nitrogen (LPOM-N)
- RPOM as nitrogen (RPOM-N)

Data were needed for the entire model time period for all flow inputs for all water quality state variables. Some water quality data for various locations along the Chehalis mainstem were available from WADOE (2014) and Anchor QEA (2014). Some of the tributaries had data available from Anchor QEA (2014), including the Newaukum River, Skookumchuck River, South Fork Chehalis River, Black River, Elk creek, and Lincoln Creek. Water quality data for the mainstem Chehalis River and the tributaries were generally point data collected during the summer months, often with only two or three samples collected for a given constituent over the course of the years 2013 and 2014. Some water quality data were available for the wastewater treatment plants and were made available by the WADOE NPDES permit database (2014) and directly from the wastewater treatment plant managers, as either daily point data or monthly averages (Phelps, 2016;

Hillock, 2016; Bilhimer, 2016; Zentner, 2016; and Patching, 2016). Groundwater water quality data were provided from the Chehalis River TMDL (Erickson, 1993). Table 10 lists the stations that provided water quality data.

Table 10. Monitoring stations that provided water quality data

Organization	Station ID	Description	Dates with data
Anchor QEA	CHL-PEL-US	Chehalis Upstream of Pe Ell	8/6/13, 9/17/13, 1/27/14, & 7/22/14
Anchor QEA	ELK-CRK	Elk Creek	8/6/13, 9/17/13, 7/22/14, & 7/30/14
Anchor QEA	SF-CHL-MOUTH	South Fork Mouth	8/6/13, 9/17/13, & 7/22/14
Anchor QEA	NWK-MOUTH	Newaukum Mouth	8/6/13, 9/17/13, & 7/22/14
Anchor QEA	SKM-MOUTH	Skookumchuck Mouth	8/6/13, 9/17/13, & 7/22/14
Anchor QEA	LNC-CRK	Lincoln Creek	8/6/13, 9/17/13, 7/22/14, & 7/30/14
Anchor QEA	BLK-RT12	Black River Mouth	8/6/13, 9/17/13, & 7/22/14
WADOE NPDES	WA0020192	Pe Ell WWTP	1/1/13 - 12/31/14
WADOE NPDES	WA0037478	Darigold WWTP	1/1/13 - 9/30/13, & 11/1/13 - 12/31/14
WADOE NPDES	WA0021105	Chehalis WWTP	1/1/13 - 12/31/14
WADOE NPDES	WA0020982	Centralia WWTP	1/1/13 - 12/31/14
WADOE NPDES	WA0042099	Grand Mound WWTP	1/1/13 - 12/31/14
WADOE	DW03	GW Bunker Creek to Adna reach	11/17/92, 11/18/92, 12/1/92, 12/2/92, & 12/8/92
WADOE	DW08	GW Adna to Claquato reach	11/17/92, 11/18/92, 12/1/92, 12/2/92, & 12/8/92
WADOE	DW07	GW Claquato to Golf Course reach	11/17/92, 11/18/92, 12/1/92, 12/2/92, & 12/8/92
WADOE	DW15	GW Golf Course to Mellen Street reach	11/17/92, 11/18/92, 12/1/92, 12/2/92, & 12/8/92
WADOE	DW18	GW Centralia/Fords Prairie reach	11/17/92, 11/18/92, 12/1/92, 12/2/92, & 12/8/92
WADOE	DW27	GW Grand Mound to Oakville	11/17/92, 11/18/92, 12/1/92, 12/2/92, & 12/8/92
WADOE	AHL145	GW Chehalis R. at Pranthier Rd.	10/05, 5/10/04, 6/7/04, 7/6/04, 8/4/04, 8/31/04, & 10/4/04
WADOE	AHL144	GW Chehalis R. above WWTP outfall	5/10/04, 6/7/04, 7/6/04, 8/4/04, 8/31/04, & 10/4/04
WADOE	AHL143	GW Chehalis R.	5/10/04, 6/7/04, 7/6/04, & 10/4/04
WADOE	AHL142	GW Chehalis R. at Galvin Rd.	5/11/04

Organization	Station ID	Description	Dates with data
WADOE	ABK199	GW Chehalis R. at Mellen St.	5/11/04, 6/15/04, 7/8/04, 8/3/04, 9/2/04, & 10/6/04
WADOE	ABK198	GW Chehalis R. nr. Airport	5/12/04 & 6/9/04
WADOE	AHL146	GW Chehalis R. nr. Airport Rd.	6/9/04, 7/8/04, 8/3/04, 9/2/04, 10/6/04, & 10/6/04
WADOE	ABK197	GW Chehalis R. at State Rte. 6	5/12/04, 6/9/04, 7/7/04, 8/3/04, 9/1/04, & 10/5/04

In order to estimate the state variables of the CE-QUAL-W2 model, many conversions were made from measured to field data. When field data were not available, reasonable estimates were made for a given constituent. The assumptions and estimations employed for the input model constituents are outlined below, including the equations used for making calculations.

- TDS, FC, and BOD were assumed zero for tributaries with no data available.
- To convert 5-day BOD (BOD_5) field data to ultimate BOD (BOD_u), the following typical relationship was used (Cole and Wells, 2016) assuming a BOD decay rate of 0.1 day^{-1} :

$$BOD_u = 2.54 * BOD_5$$

BOD_u was assumed to be 50% dissolved ($BOD_{u \text{ dissolved}}$) and 50% particulate ($BOD_{u \text{ particulate}}$).

- Organic matter (OM) was calculated by (Cole and Wells, 2016):

$$OM = \frac{BOD_u}{1.4}$$

- PO_4 was assumed to equal 1% of the OM concentration when no data were available.

- When NO₃ data were not available for the wastewater treatment plants, values between 0.5 and 1 mg/L were used.

- Algae concentrations (dry weight biomass concentration) were calculated by:

$$Algae = 0.1 * Chlorophyll\ a$$

- Algae concentrations were assumed to be 1% phosphorus (AlgaeP) and 8% nitrogen (AlgaeN).
- Chlorophyll a concentrations for groundwater were assumed to be zero, and so algae, algaeP, and algaeN concentrations were also assumed to be zero.
- ISS were calculated by (Cole and Wells, 2016):

$$ISS = TSS - \frac{BOD_U\ particulate}{1.4} - algae$$

- TSS was assumed zero for groundwater flows, and hence ISS was also assumed zero.
- Dissolved organic matter (DOM) was calculated by (Cole and Wells, 2016):

$$DOM = \frac{BOD_U\ dissolved}{1.4}$$

- Particulate organic matter (POM) was calculated by (Cole and Wells, 2016):

$$POM = \frac{BOD_U\ particulate}{1.4}$$

- DOM was assumed to be 50% labile (LDOM) and 50% refractory (RDOM), and POM was also assumed to be 50% labile (LPOM) and refractory (RPOM). However, for groundwater inflows, POM was zero, implying all OM was dissolved.
- Organic matter as phosphorus (OMP) was calculated by:

$$OMP = TP - PO_4 - AlgaeP$$

Where TP is total phosphorus.

- OMP was assumed to be equally portioned as labile dissolved LDOM-P, RDOM-P, LPOM-P, RPOM-P. LDOM, RDOM, LPOM, and RPOM concentrations were assumed to be 8% nitrogen.
- Total nitrogen (TN) was calculated by:

$$TN = TKN + NO_3$$

Where TKN is total Kjeldahl nitrogen, and equals the sum of ammonia and organic matter as nitrogen.

- Organic matter as nitrogen (OMN) was calculated by:

$$OMN = TN - NH_3 - NO_3 - AlgaeN$$

- OMN was assumed to be equally portioned as labile dissolved LDOM-N, RDOM-N, LPOM-N, RPOM-N. LDOM, RDOM, LPOM, and RPOM concentrations were assumed to be 1% phosphorus.
- Some of the fact sheets for the wastewater treatment plants included alkalinity for the Chehalis River near to the plats. Alkalinity for tributaries were assumed to be an average of these values when no data were available.
- No zooplankton data were available. Zooplankton concentrations were estimated as 0.01 mg/L for tributaries. Zooplankton was assumed to have zero concentration for groundwater inflows.

Techniques for computing pH, alkalinity, or total inorganic carbon are outlined below (Wells, 2016):

Alkalinity [ALK] is usually given in units of mg/L as CaCO₃. By dividing by 50,000 the units are converted to moles/L. The model uses units of mg/L as C for total inorganic C [C_T] and can be converted to moles/L by dividing by 12,000. C_T (in moles/L) is defined as:

$$C_T = [H_2CO_3] + [HCO_3^-] + [CO_3^{2-}]$$

Following equilibrium chemistry (see Stumm and Morgan, 1986), the alkalinity is then defined as:

$$[ALK] = C_T(\alpha_1 + 2\alpha_2) + \frac{K_w}{[H^+]} - [H^+]$$

Where

$$\alpha_1 = \left(\frac{[H^+]}{K_1} + 1 + \frac{K_2}{[H^+]} \right)^{-1}$$

$$\alpha_2 = \left(\frac{[H^+]^2}{K_1 K_2} + 1 + \frac{[H^+]}{K_2} \right)^{-1}$$

$$K_w = 10^{-14} \text{ mol}^2/\text{L}^2 \text{ at } 25^\circ\text{C}$$

$$K_w = 10^{\left[\frac{-5242.39}{T} + 35.3944 - 0.00835T + 11.8261 \log_{10}(T) \right]}$$

$$K_1 = 10^{-6.419} \text{ mol/L at } 15^\circ\text{C}$$

$$K_1 = 10^{(-3404.71/T + 14.8435 - 0.032786 \cdot T)}$$

$$K_2 = 10^{-10.430} \text{ mol/L at } 15^\circ\text{C}$$

$$K_2 = 10^{(-2902.39/T + 6.498 - 0.02379 \cdot T)}$$

T = temperature (°C)

[H⁺] = hydrogen ion concentration

pH = -log[H⁺]

These equations assume the activity corrections for the species concentrations are unity, implying that the inflowing water has a low TDS. By knowing any 2 of the 3 components – pH, alkalinity, or total inorganic carbon – the above equations allow for the computation of the other.

For times when data for a constituent were not available for a tributary or groundwater inflow, averages or medians of the other values were used as an estimate. Tributaries that did not have any water quality data available used an input water quality constituent file from the nearest tributary with data available. For wastewater treatment plants with no data for a constituent, reasonable or typical values were used as an estimate. For reaches of the river with no groundwater data available, data from the closest reach were used.

Input constituent data for ISS, PO₄, NH₃, and NO₃ are shown in Figure 45. Input constituent data for TIC, alkalinity, algae, and DO are shown in Figure 46. Input constituent data for LDOM, RDOM, LPOM, and RPOM are shown in Figure 47. Input constituent data for LDOM-P, RDOM-P, LPOM-P, and RPOM-P are shown in Figure 48. Input constituent data for LDOM-N, RDOM-N, LPOM-N, and RPOM-N are shown in Figure 49. Figure 50 shows tributary field data for pH, BOD₅, and TSS while Figure 51 shows

tributary field data for chlorophyll a, TKN, and TP that were used to calculate constituents with the equations outlined above.

Figure 52 shows model input data for the wastewater treatment plants for FC, ISS, PO₄, and NH₃, while Figure 53 shows NO₃, DO, TIC, and alkalinity. Figure 54 shows the wastewater treatment plant BOD species, including dissolved, particulate, phosphorus, and nitrogen.

Figure 55 shows input constituent data for TDS, PO₄, NH₃, NO₃, BOD and DO for the groundwater inflows. Figure 56 shows data for TIC, alkalinity, and the DOM and POM species (labile, refractory, phosphorus, and nitrogen) for the groundwater inflows. Figure 57 shows field data for pH, BOD₅, and TP used to calculate groundwater constituent concentrations with the equations described above.

Figure 45. Input concentrations for ISS, PO4, NH3, and NO3 for tributaries with data available, including the upstream boundary, Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, Black River, and Lincoln Creek

Figure 46. Input concentrations for TIC, alkalinity, algae, and DO for tributaries with data available, including the upstream boundary, Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, Black River, and Lincoln Creek

Figure 47. Input concentrations for LDOM, RDOM, LPOM, and RPOM for tributaries with data available, including the upstream boundary, Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, Black River, and Lincoln Creek

Figure 48. Input concentrations for LDOM-P, RDOM-P, LPOM-P, and RPOM-P for tributaries with data available, including the upstream boundary, Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, Black River, and Lincoln Creek

Figure 49. Input concentrations for LDOM-N, RDOM-N, LPOM-N, and RPOM-N for tributaries with data available, including the upstream boundary, Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, Black River, and Lincoln Creek

Figure 50. Field data concentrations for pH, BOD5, and TSS used to calculate input water quality concentrations for Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, Black River, and Lincoln Creek

Figure 51. Field data concentrations for chlorophyll a, TKN, and TP used to calculate input water quality concentrations for Elk Creek, South Fork Chehalis River, Newaukum River, Skookumchuck River, Black River, and Lincoln Creek

Figure 52. Model input concentrations for FC, ISS, PO4, and NH3 for the Pe Ell, Darigold, Centralia, Chehalis, and Grand Mound wastewater treatment plants

Figure 53. Model input concentrations for NO₃, DO, TIC, and alkalinity for the Pe Ell, Darigold, Centralia, Chehalis, and Grand Mound wastewater treatment plants

Figure 54. Model input concentrations for dissolved, particulate, phosphorus, and nitrogen BOD for the Pe Ell, Darigold, Centralia, Chehalis, and Grand Mound wastewater treatment plants

Figure 55. Model input concentrations for groundwater reaches with data for TDS, PO4, NH3, NO3, BOD, and DO

Figure 56. Model input concentrations for groundwater reaches with data for TIC, alkalinity, and the DOM and POM species (labile, refractory, phosphorus, and nitrogen)

Figure 57. Field groundwater data for pH, BOD5, and TP used to calculate input water quality concentrations

4.6. Shading

CE-QUAL-W2 requires shading information for each model segment, including left and right bank vegetation elevation, distance to left and right bank vegetation, left and right bank shade reduction factors for leaf on and leaf off conditions, and Julian days when the shade reduction factors apply. The shade reduction factors specified the opacity of the vegetation.

A shading study conducted by Stillwater Sciences for Anchor QEA provided all shading data along the Chehalis River (Merrill, 2014). The data collected in this study were interpolated to the locations of the model segments. Increased shading had a cooling effect on river temperature, while the opposite was true for decreased shading. The upstream, steep gradient portion was especially shaded. Figure 58 and Figure 59 show the elevations of vegetation on the left and right banks of the channel along the thalweg of the Chehalis River, respectively.

Figure 58. Left bank vegetation elevation for each segment input to the model in the shade file

Figure 59. Right bank vegetation elevation for each segment input to the model in the shade file

5. Model Calibration: Flow

The model calibration of flow rate began with upstream portions of the model and moved downstream. By comparing model flow predictions to field flow data along the mainstem of the Chehalis River, locations of excesses and deficiencies of flow were determined. Flow and water level data from the mainstem Chehalis River collected by USGS (2016a, 2016b, 2016c, 2016d, 2016e, 2016h, 2016i) were used for model-data comparisons during the model simulation years 2013 and 2014. Table 11 lists these flow gaging stations. Figure 60 gives a longitudinal view of the locations of the flow and water surface elevation calibration gaging stations along the Chehalis River.

Table 11. Flow and water surface elevation stations on the mainstem Chehalis River used to compare to model predictions

Organization	Station ID	Description	Data Type Provided	Model Segment
USGS	12020000	Chehalis River near Doty, WA	Flow & water level	32
USGS	12021800	Chehalis River near Adna, WA	Water level	97
USGS	12025100	Chehalis River at Chehalis WWTP	Water level	150
USGS	12025500	Chehalis River at Centralia, WA	Water level	181
USGS	12027500	Chehalis River near Grand Mound, WA	Flow & water level	213
USGS	12028060	Chehalis River near Rochester,	Water level	238
USGS	12031000	Chehalis River at Porter, WA	Flow & water level	321

Figure 60. Longitudinal view of the mainstem Chehalis River flow and water surface elevation gaging stations used for flow calibration (vertical lines show model branch breaks)

Figure 61 shows model predictions of flow compared to field data collected at Doty, Grand Mound, and Porter. Figure 62 shows the model water surface elevation predictions compared to field data for gaging stations at Doty, Adna, Chehalis WWTP, and Centralia. Figure 63 shows the water surface elevation comparisons at Grand Mound, Rochester, and Porter. Many water elevation data sets had datums that were not clearly defined or were not tied to a national standard datum. This made it difficult to know whether the

water surface elevations predicted by both the model and the field data were all referenced to the same datum.

Figure 61. Model flow predictions compared to Chehalis River field data at Doty, Grand Mound, and Porter

Figure 62. Model water surface elevation predictions compared to Chehalis River field data at Doty, Adna, Chehalis WWTP, and Centralia

Figure 63. Model water surface elevation predictions compared to Chehalis River field data at Grand Mound, Rochester, and Porter

5.1. Flow Error Statistics

The closeness of model predicted flow to field data was evaluated through error statistics, including mean error (ME), absolute mean error (AME), and 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 flow output value

$Q_{\text{field data}}$ is the field flow data value

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

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

Error statistics for model flow predictions compared to field data at Doty, Grand Mound, and Porter are shown in Table 12. Error statistics for flow predictions at the same locations during the dry season months of May through October can be seen in Table 13. Error statistics for flow predictions at the same locations during the wet season months of November through April can be seen in Table 14. Error statics for model predicted water level compared to field data at Doty, Adna, Chehalis WWTP, Centralia, Grand Mound, Rochester, and Porter mainstem Chehalis River stations are shown in Table 15.

Table 12. Error statistics for model comparisons to field data for flow at Doty, Grand Mound, and Porter

Location	Number of Model-Data Comparisons	Mean Error (m ³ /s)	Absolute Mean Error (m ³ /s)	Root Mean Square Error (m ³ /s)
Doty	69880	0.07	0.67	4.40
Grand Mound	68732	0.50	3.77	16.3
Porter	68839	2.00	7.54	22.0

Table 13. Error statistics for model comparisons to field data for flow at Doty, Grand Mound, and Porter during the months of May through October

Location	Number of Model-Data Comparisons	Mean Error (m ³ /s)	Absolute Mean Error (m ³ /s)	Root Mean Square Error (m ³ /s)
Doty	35138	-0.05	0.29	1.36
Grand Mound	34946	0.02	1.19	5.32
Porter	34072	2.69	5.48	14.5

Table 14. Error statistics for model comparisons to field data for flow at Doty, Grand Mound, and Porter during the months of November through April

Location	Number of Model-Data Comparisons	Mean Error (m ³ /s)	Absolute Mean Error (m ³ /s)	Root Mean Square Error (m ³ /s)
Doty	34362	0.18	1.05	6.13
Grand Mound	33406	1.01	6.48	22.8
Porter	34387	1.24	9.51	27.5

Table 15. Error statistics for model comparisons to water level data at Doty, Adna, Chehalis WWTP, Centralia, Grand Mound, Rochester, and Porter mainstem Chehalis River stations

Location	Number of Model-Data Comparisons	Mean Error (m)	Absolute Mean Error (m)	Root Mean Square Error (m)
Doty	69793	-0.279	0.663	0.806
Adna	40608	-3.06	3.08	3.225
Chehalis WWTP	40608	0.993	1.00	1.09
Centralia	32187	0.198	0.709	0.860
Grand Mound	68740	0.463	0.725	0.877
Rochester	40608	1.21	1.21	1.24
Porter	68847	-0.223	0.287	0.421

5.2. Distributed Flows

The process of adding or subtracting flow was based on comparisons of model predictions to field data at the 3 gages: Doty, Grand Mound, and Porter. The flow error was calculated as field data minus model predicted flow rate for every time field data were available. While all tributaries, dischargers, and groundwater inflows were taken into account with input flow files, not all flow dynamics could be captured this way. For example, there may have been flow inputs to the river in the form of storm events and overland flow. Or there may have been ungaged agricultural withdrawals from the river. In addition to a lack of data for the magnitude of these flow sources and sinks, the precise locations are also unknown. For this reason, the flow error was added or subtracted to

the model as distributed flow along the model branch upstream of the gage location of comparison.

Distributed flows helped to keep the model hydrated, particularly during the summer months when flow in the river became very low and the model was prone to dry up. This was a multiple-iteration process until model predicted flows were in agreement with field data at Doty. First, flow calibration with distributed flows was conducted at Doty, the most upstream flow gage station. Once the Doty location was properly calibrated, the same method was employed for the Grand Mound location. Then, once the Grand Mound location was properly calibrated, the same method was repeated for the Porter gage at the downstream model boundary. Figure 64 shows the distributed tributary flows added to the branches upstream of the flow monitoring locations as part of the calibration process.

Figure 64. Distributed tributary flows input upstream of flow monitoring locations at Doty, Grand Mound, and Porter for model calibration

In general, the distributed flows represented ungaged inflows during storm events. At multiple times the distributed flows for the branch upstream of Porter had large negative magnitudes. There were no clear indications that these large withdrawals were as a result of irrigation. The timing of the large distributed flows in branch 10 happened at times near to when peak water surface elevation occurred at Porter, generally during winter months. Figure 65 shows how water surface elevation varies with distributed flows in branch 10. This figure shows that generally, larger magnitudes of distributed flows correspond to peak water surface elevations.

Figure 65. Water surface elevation at Porter versus distributed flow in branch 9 upstream of Porter

It is thought that storm events resulting in large volumes of overland flow account for the large positive distributed flow values, raising the water surface elevations. Once the water reaches bank-full levels, the water spills out of the river channel flooding the surrounding land, accounting for the large negative distributed flow values. The water spilling out of the river could be draining to natural storage, such as nearby ponds or oxbows. Figure 66 shows examples of many such features located near the Chehalis River.

Figure 66. Map and earth aerial views of ponds and oxbows adjacent to the Chehalis River near Chehalis and Centralia, WA where flooded water may be stored

It is important to note that while the distributed flow was implemented in the branch upstream of Porter, the flow could actually be occurring anywhere between the next upstream calibration station at Grand Mound and the station at Porter, in branches 7 to 10. With a more detailed description of the basin, the distributed flows could be more accurately placed. This is true for all flow calibration locations.

5.3. Bathymetry

The bathymetry, including channel friction, channel slope, and segment depths and widths, all impacted the flow calibration.

5.3.1. Channel Friction

A manning's friction coefficient was specified for every model segment. Increasing friction slowed the travel time of water through the system and increased water depths, keeping the system hydrated during the low flow summer months. This was especially important for the upstream locations where gradients were very steep and water flushed through quickly. Similarly, decreasing friction had the opposite effect of causing water level to decrease and move more quickly through the system. Matching magnitudes as well as timing of flow peaks was important to accurately describe the system. Altering friction helped to match timing of peak flows to field data.

5.3.2. Channel Slope

Each branch in the model had a specified channel slope. This gave the general slope of the branch, for all segments it included. However, the slope may not accurately

capture the hydraulic gradient slope due to real channel characteristics, such as falls, riffles, or other features (Cole and Wells, 2016). Because of this, a separate variable, SLOPEC, was specified for each branch and represented the hydraulic equivalent slope. This variable was used to calculate fluid acceleration in the momentum equations (Cole and Wells, 2016).

Similar to friction, increasing or decreasing SLOPEC either quickened or slowed water moving through the system. This affected timing of flow peaks, water surface levels, and keeping the model hydrated during low flow summer months. In the Centralia reach where the river is slow and deep, the model slope was essentially zero.

5.3.3. Segment Widths and Depths

Model instabilities were more likely to occur when segment depths changed rapidly from one segment to the next. For example, when water moved through segments that were very wide and deep to segments that were suddenly narrow and shallow, water backed up behind this constriction which may not have been the case in reality. Conversely, when water moved through segments that were very narrow and shallow to segments that were suddenly very wide and deep, sometimes the model could dry up under some flow conditions. Scenarios such as these made it necessary to smooth some widths and depths in the bathymetry files so that transitions between wide, narrow, deep, and shallow segments were not abrupt. Additionally, very small widths in segments, such as 5 m or less, required the model to use a smaller time step because of numerical stability

considerations. By removing some very small bottom layers in the bathymetry files, shorter model run times were achieved.

5.3.4. Spillways

Weirs were added at the end of some branches. These had crest elevations that could be raised slightly so that water backed up behind them, allowing the upstream locations to remain more hydrated. The spillways also had a set of user-defined coefficients that affected the way water moved over the spillway and between branches, giving either a retaining or flushing effect. In general, most of the spillways between branches were set so that the spillway crest was on the bottom elevation of the channel. The spillways had the following power functions describing behavior for free flowing conditions and submerged conditions (Cole and Wells, 2016):

$$Q = \alpha_1 \Delta h^{\beta_1} \text{ Free flowing conditions}$$

Where

α_1 and β_1 are empirical coefficients

Δh is the difference between the upstream head and spillway crest elevation

$$Q = \alpha_2 \Delta h^{\beta_2} \text{ Submerged conditions}$$

Where

α_2 and β_2 are empirical coefficients

Δh is the difference between the upstream head and downstream head

First, α_1 was calculated by using the equation for a broad crested weir (Cole and Wells, 2016):

$$\alpha_1 = C_D C_v \frac{2}{3} \sqrt{2g} W$$

Where

C_D is a discharge coefficient (0.84 to 1.06)

C_v is a velocity coefficient (1.0 to 1.2)

g is gravitational acceleration

W is channel width

Figure 67 shows a schematic describing the water and weir heights used in the previous equations. The coefficients C_D and C_v were assumed to equal 1. Width W was calculated as the average bottom three layer widths of the segment where the spillway was located, since these layers were the most commonly occupied by water.

Figure 67. Schematic of water and weir heights for a free flowing submerged weir used with the spillway equations (Cole and Wells, 2016)

Following the methodology outlined in the CE-QUAL-W2 user manual (Cole and Wells, 2016), at a given flow value Q , the previous equations can be combined to give:

$$\alpha_2 = \frac{\alpha_1(H_1 - H_{weir})^{\beta_1 - \beta_2}}{0.33^{\beta_2}}$$

β_1 and β_2 were set equal to each other. This implied:

$$\alpha_2 = \frac{\alpha_1}{0.33^{\beta_2}}$$

By using this process, the spillway or weir coefficients for free flowing and submerged flow were set.

5.4. Groundwater Flow Influences

Groundwater flow magnitudes varied by location. The influence of these flows were assessed by determining how they compared to flow along the mainstem channel. Model-predicted flow values were viewed within each groundwater reach. Then, the percent of the mainstem Chehalis River flow attributed to groundwater was computed. Groundwater flows accounted for a larger portion of the mainstem river during the summer seasons than during the winter seasons. Table 16 shows how the percent of mainstem Chehalis River flow attributed to groundwater varied by season, and for the entire model duration. Negative values are indicative of groundwater losses, or flow moving from the river to an aquifer.

Table 16. Percent of mainstem Chehalis River flow attributed to groundwater throughout the model

Groundwater Reach Segment Range	Groundwater Reach Gain/Loss (m3/s)	% of Mainstem Chehalis River Flow				
		Winter	Spring	Summer	Fall	Overall
35-37	0.025	0.17	0.36	2.03	0.47	0.77
38-47	0.510	0.02	0.04	0.11	0.06	0.06
48-66	-0.221	-0.95	-1.66	-4.73	-2.31	-2.43
67-80	-0.003	-0.01	-0.02	-0.06	-0.03	-0.03
81-97	0.040	0.15	0.25	0.67	0.34	0.36

Groundwater Reach Segment Range	Groundwater Reach Gain/Loss (m3/s)	% of Mainstem Chehalis River Flow				
		Winter	Spring	Summer	Fall	Overall
98-122	-0.082	-0.28	-0.47	-1.32	-0.66	-0.69
123-143	0.388	1.34	2.28	6.10	2.93	3.19
144-181	0.404	0.62	1.17	5.41	1.84	2.28
182-191	-0.460	-0.50	-0.96	-5.33	-1.63	-2.13
192-204	-0.056	-0.06	-0.12	-0.66	-0.20	-0.05
205-210	0.565	0.59	1.12	6.13	1.91	2.46
211-214	0.823	0.84	1.60	8.17	2.64	3.35
224-229	0.567	0.56	1.08	5.31	1.75	2.20
230-235	-0.174	-0.17	-0.33	-1.66	-0.54	-0.68
236-242	0.255	0.23	0.45	2.26	0.74	0.93
243-246	0.326	0.29	0.57	2.85	0.94	1.17
247-251	-0.652	-0.57	-1.16	-5.88	-1.91	-2.41
252-255	0.227	0.20	0.40	2.09	0.67	0.85
256-260	0.058	0.05	0.10	0.53	0.17	0.22
261-264	-0.256	-0.22	-0.46	-2.52	-0.79	-1.01
265-268	-1.368	-1.06	-2.16	-10.52	-3.41	-4.34
269-272	0.962	0.74	1.50	7.07	2.34	2.94
273-276	-0.190	-0.14	-0.29	-1.38	-0.46	-0.57
277-285	0.197	0.15	0.30	1.45	0.48	0.60
286-318	0.799	0.56	1.14	5.36	1.78	2.23
319-321	-0.272	-0.19	-0.39	-1.84	-0.61	-0.76
Average:		0.09	0.17	0.76	0.25	0.33

5.5. Travel time, age, and dispersion

The time it took for a parcel of water to travel through the entire length of the model reach was evaluated by using a tracer. Tracer inputs of 100 mg/L were added over 2.4 hours to the upstream boundary every 30 days. Then the time for each tracer pulse peak to reach various downstream segments was found. The difference between the time a pulse peak appeared at a downstream location and the time it was originally input to the upstream boundary was the travel time. Figure 68 shows examples of how the tracer peak

magnitudes decreased and time of peak occurrence became later moving downstream.

Table 17 gives example values of travel time for various locations in the model and Figure 69 shows how travel time increases moving downstream for various initial upstream input pulse times.

Figure 68. Resulting tracer magnitudes and timing along the river channel for tracer pulses input to the upstream boundary at Julian days 31 and 511

Table 17. Travel times for upstream pulse inputs to reach various downstream locations for various input pulse times

Initial Upstream Pulse Julian Day	Travel Time (days)				
	Segment 43	Segment 124	Segment 193	Segment 249	Segment 321
1	0.7	1.2	2.1	2.6	2.9
31	0.5	1.1	1.9	2.3	2.5
61	0.5	1.1	1.9	2.3	2.6
91	0.7	1.5	2.9	3.3	3.7
121	0.7	1.6	3.2	3.7	4.1
151	0.5	1.3	2.5	3	3.3
181	0.7	1.7	3.9	4.6	5.1
211	1	2	5	5.6	6.1
241	0.9	1.8	4.9	5.5	5.9
271	0.5	1	1.6	2	2.3
301	0.7	1.7	4.2	4.8	5.3
331	0.6	1.5	2.9	3.4	3.8
361	0.7	1.5	2.9	3.4	3.7
391	0.7	1.6	3.2	3.7	4
421	0.5	1.15	2	2.4	2.7
451	0.6	1.3	2.2	2.6	2.8
481	0.4	1	1.7	2.1	2.4
511	0.7	1.6	3.2	3.7	4.1
541	0.8	1.8	4.1	4.7	5.1
571	0.8	1.7	4.7	5.3	5.8
601	1.2	2.2	5.5	6.2	6.75
631	1.2	2.1	4.7	5.2	5.6
661	0.4	0.9	1.6	1.9	2.2
691	0.5	1.2	2.1	2.4	2.7
721	0.4	0.9	1.5	2	2.3

Figure 69. Travel times for tracer pulse peaks at various downstream locations

Water age is a measure of how long water has been in the system, and is similar to travel time in that it is a function of how quickly water moves through the system. However, flow inputs from tributaries or groundwater are set to “new” water or zero water age when they enter the river. For example, the water age may be lower for a segment just downstream of a major tributary than for a segment just upstream of a major tributary. This is because the new flow coming in from the major tributary mixes with the flow already in the mainstem river and reduces the water age. This implies water age will generally be less than travel time. Figure 70 shows how water age generally increases moving downstream, though it is influenced by boundary flows.

Figure 70. Model-predicted water age throughout the model reach

The amount of mixing taking place in the system was evaluated using TDS. TDS is conservative, so any decrease in concentration can be attributed to dilution. All input TDS values were set to zero except for the upstream boundary, which was set to a constant 100 mg/L throughout the entire model time period. The amount that TDS decreased moving downstream was how much dilution was taking place. Table 18 gives example values of percent mixing at various downstream locations at various times throughout the model simulation. Percent mixing was evaluated as the percent of the difference between the remaining TDS concentration compared to the initial 100 mg/L input at the upstream

boundary. Figure 71 shows how TDS and mixing change moving downstream. Generally, mixing increased and TDS concentration decreased moving downstream as more mixing and dilution processes occurred along the channel.

Table 18. Percent mixing at various segments throughout the model at various times during the model simulation

Julian Day	% Mixing				
	Segment 43	Segment 124	Segment 193	Segment 249	Segment 321
1	43	43	43	43	43
31	50.3	60.3	86.9	90.6	94.7
61	33.4	61	87.2	88	91.6
91	46.6	57.6	86.2	88.2	90.5
121	49.5	58.9	85.8	90	91.5
151	32.5	51.1	84	87.4	91.4
181	59	68.4	88.1	91.4	93.7
211	77.7	84.6	94.3	95.9	97.5
241	82.2	84.2	94.9	97.1	98.1
271	59.3	69.4	82.3	85.8	91.6
301	50.2	63.9	87.4	90.3	93.1
331	45.8	56.4	86.1	85.9	88.9
361	51.7	61.3	85.9	87.8	92.4
391	52.8	62.4	88.2	88.5	92.9
421	47.8	58	85.8	87.8	91.1
451	62.9	75	91.5	92.5	93.8
481	27.5	38.1	77.3	75.9	83.9
511	54.4	63.9	87.6	90.0	92.2
541	71.7	80.6	90.4	93.5	95.3
571	57.1	74.2	93.3	94.9	97.6
601	81.5	87.6	94.6	96.7	98.1
631	89.4	91.3	96	97.8	99.0
661	24.8	53.1	80.1	84.3	87
691	60.9	57.8	87	88.4	91.8
721	26.3	44.8	77.8	89.5	91.9

Figure 71. Model-predicted TDS concentrations at various downstream locations after a constant input of 100 mg/L was added to the upstream boundary

6. Model Calibration: Temperature

Temperature was highly dependent on water depths and travel time, and hence was calibrated after the flow rate calibration was finalized. Many water quality state variables were temperature dependent, so it was also important to calibrate temperature before water quality. Similar to flow calibration, field temperature data along the mainstem of the Chehalis River were compared to model predictions moving from upstream to downstream. Table 19 lists the continuous temperature stations on the mainstem Chehalis River that were used to compare to model predictions.

Vertical temperature profile data were provided by Anchor QEA (2014). These data were collected at specific dates in the deeper lake-like region of the river near Chehalis and Centralia, WA. Table 20 lists the vertical temperature stations, locations, and dates when data were collected on the Chehalis River.

Figure 72 shows a longitudinal view of the locations of the mainstem continuous and vertical temperature stations along the Chehalis River.

Table 19. Temperature stations on the mainstem Chehalis River used to compare to model predictions

Organization	Station ID	Description	Dates with data	Model Segment	River Mile
WDFW	11-UCH	Upper Chehalis	6/9/14 - 9/15/15	4	108
WDFW	3-UCH	Upper Chehalis Chehalis mainstem	5/15/14 - 9/15/15	12	108
Anchor QEA	CHL-PEL-US	Chehalis Upstream of Pe Ell	7/31/13 - 3/26/14	12	107
Anchor QEA	CHL-PEL-DS	Chehalis Downstream of Pe Ell	7/31/13 - 7/30/14	15	106
WDFW	13-CH	Chehalis mainstem	6/10/14 - 9/15/15	19	105
Anchor QEA	CHL- WOODSTEAD	Chehalis at Woodstead farm 01	7/2/13 - 10/28/13	24	103
WDFW	4-UCH	Upper Chehalis	5/15/14 - 9/15/15	36	102

Organization	Station ID	Description	Dates with data	Model Segment	River Mile
Anchor QEA	CHL-DOTY	Chehalis at Doty	7/3/13 - 10/16/13	36	101
WADOE	23A160	Chehalis River at Dryad	7/1/13 - 9/18/13, 6/24/14 - 9/23/14, & 5/19/15 - 9/15/15	48	99.5
WDFW	15-CH	Chehalis mainstem	6/10/14 - 10/14/14	47	99
Anchor QEA	CHL-RAINBOW-FALLS	Chehalis at Rainbow Falls	7/2/13 - 10/16/13	50	97.1
WDFW	19-CH	Chehalis mainstem	6/18/14 - 9/2/15	64	95.5
Anchor QEA	CHL-CERES-HILLS	Chehalis at Ceres Hill Road	7/3/13 - 10/16/13	81	90.1
Anchor QEA	CHL-ADNA	Chehalis Near Adna	7/31/13 - 7/21/14	119	81
WDFW	21-CH	Upper Chehalis	6/11/14 – 9/2/15	124	80.6
Anchor QEA	CHL-US-NWK	Chehalis Upstream of Newaukum Confluence	7/31/13 - 3/26/14	144	75.4
WDFW	22-CH	Upper Chehalis	6/11/14 - 8/5/15	145	75.3
Darigold WWTP	41	Chehalis River Upstream Darigold WWTP	1/1/13 - 11/30/15	149	74.7
Darigold WWTP	40	Chehalis River Downstream Darigold WWTP	1/1/13 - 11/30/15	150	74.65
WDFW	16-CH	Chehalis mainstem	6/10/14 - 9/3/15	180	66.7
Anchor QEA	CHL-GLV	Chehalis at Galvin Bridge	7/30/13 - 7/21/14	196	64.1
WDFW	17-CH	Chehalis mainstem	6/10/14 – 9/1/15	213	60.1
Anchor QEA	CHL-US-BLK	Chehalis Upstream of Black River	7/30/13 - 7/22/14	238	54.2
WDFW	18-CH	Chehalis mainstem	6/10/14 - 8/26/15	249	50.5
Anchor QEA	CHL-OAK	Chehalis at Oakville	7/30/13 - 7/22/14	287	42.3
WDFW	23-CH	Chehalis mainstem	7/15/14 - 8/17/15	287	41.3
WADOE	23A070	Chehalis River at Porter	10/23/12 - 6/25/13 & 9/18/13 - 5/26/15	321	33.3

Table 20. Mainstem Chehalis River vertical temperature profile collection locations and dates used in temperature calibration

Organization	Station ID	Description	Dates with data	Model Segment
Anchor QEA	CHL-RT6-BR	Chehalis R. at RT6 Bridge at RM 75.31	8/7/13, 9/18/13, & 7/23/14	149
Anchor QEA	HL-14	Chehalis R. at RM 74.5	7/31/14	150
Anchor QEA	HL-13	Chehalis R. at RM 73.75	7/31/14	153
Anchor QEA	HL-12	Chehalis R. at RM 73	7/31/14	157
Anchor QEA	HL-11	Chehalis R. at RM 72.5	7/31/14	158
Anchor QEA	HL-10	Chehalis R. at RM 74.25	7/31/14	160
Anchor QEA	HL-9	Chehalis R. at RM 71.5	7/31/14	162
Anchor QEA	HL-8	Chehalis R. at RM 71	7/31/14	164
Anchor QEA	HL-7	Chehalis R. at RM 70.5	7/31/14	166
Anchor QEA	HL-6	Chehalis R. at RM 70	7/31/14	168
Anchor QEA	HL-5	Chehalis R. at RM 69.25	7/31/14	171
Anchor QEA	HL-4	Chehalis R. at RM 68.75	7/31/14	173
Anchor QEA	HL-3	Chehalis R. at RM 68.25	7/31/14	177
Anchor QEA	HL-2	Chehalis R. at RM 67.75	7/31/14	179
Anchor QEA	CHL-US-SKM	Chehalis R. at Mellen Road Bridge at RM 66.7	8/7/13, 9/18/13, & 7/23/14	180
Anchor QEA	HL-1	Chehalis R. at RM 67.25	7/31/14	181

Figure 72. Longitudinal view of the mainstem Chehalis River continuous and vertical temperature gaging stations used for temperature calibration (vertical lines show model branch breaks)

Figure 73 shows model predicted temperature versus field data along the mainstem Chehalis River at the stations: 11-UCH, upstream of Pe Ell, downstream of Pe Ell, 13-CH, at Woodstead, upstream of Elk Creek, and at Doty. Figure 74 shows model predicted temperature versus field data along the mainstem Chehalis River at the stations: 15-CH, at Dryad, at Rainbow Falls, 19-CH, at Ceres Hills Road, and at Adna. Figure 75 shows model predicted temperature versus field data along the mainstem Chehalis River at the

stations: 21-CH, near Newaukum Confluence, 22-CH, upstream of Darigold, downstream of Darigold, and upstream of Skookumchuck. Figure 76 shows model predicted temperature versus field data along the mainstem Chehalis River at the stations: at Galvin Bridge, 17-CH, upstream of Black River, 18-CH, at Oakville, 23-CH, and at Porter.

Since daily maximum temperatures are critical for fish habitat, the model predicted daily maximum was compared to daily maximum field temperatures as well. Figure 77 shows model predicted daily maximum temperature versus field data along the mainstem Chehalis River at the stations: 11-UCH, upstream of Pe Ell, downstream of Pe Ell, 13-CH, at Woodstead, upstream of Elk Creek, and at Doty. Figure 78 shows model predicted daily maximum temperature versus field data along the mainstem Chehalis River at the stations: 15-CH, at Dryad, at Rainbow Falls, 19-CH, at Ceres Hills Road, and at Adna. Figure 79 shows model predicted daily maximum temperature versus field data along the mainstem Chehalis River at the stations: 21-CH, near Newaukum Confluence, 22-CH, upstream of Darigold, downstream of Darigold, and upstream of Skookumchuck. Figure 80 shows model predicted daily maximum temperature versus field data along the mainstem Chehalis River at the stations: at Galvin Bridge, 17-CH, upstream of Black River, 18-CH, at Oakville, 23-CH, and at Porter.

Figure 81 shows the model predicted vertical temperature profiles versus field data at the stations: at Route 6 Bridge, HL-14, and HL-13. Figure 82 shows the model predicted vertical temperature profiles versus field data at the stations: HL-12, HL-11, HL-10, HL-9, and HL-8. Figure 83 shows the model predicted vertical temperature profiles versus field

data at the stations: HL-7, HL-6, HL-5, HL-4, and HL-3. Figure 84 shows the model predicted vertical temperature profiles versus field data at the stations: HL-2, at Mellen Road Bridge, and HL-1.

Figure 73. Model temperature predictions compared to field data at the mainstem Chehalis River stations: 11-UCH, upstream of Pe Ell, downstream of Pe Ell, 13-CH, at Woodstead, upstream of Elk Creek, and at Doty

Figure 74. Model temperature predictions compared to field data at the mainstem Chehalis River stations: 15-CH, at Dryad, at Rainbow Falls, 19-CH, at Ceres Hills Road, and at Adna

Figure 75. 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 76. Model temperature outputs versus field data collected at the mainstem Chehalis River stations: at Galvin Bridge, 17-CH, upstream of Black River, 18-CH, at Oakville, 23-CH, and at Porter

Figure 77. Model predictions of daily maximum temperatures compared to field data at the mainstem Chehalis River stations: 11-UCH, upstream of Pe Ell, downstream of Pe Ell, 13-CH, at Woodstead, upstream of Elk Creek, and at Doty

Figure 78. Model predictions of daily maximum temperatures compared to field data at the mainstem Chehalis River stations: 15-CH, at Dryad, at Rainbow Falls, 19-CH, at Ceres Hills Road, and at Adna

Figure 79. Model predictions of daily maximum temperatures 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 80. Model predictions of daily maximum temperatures compared to field data at the mainstem Chehalis River stations: at Galvin Bridge, 17-CH, upstream of Black River, 18-CH, at Oakville, and at Porter

Figure 81. Model versus field data vertical temperature profiles at the mainstem Chehalis River stations: at Route 6 Bridge, HL-14, and HL-13

Figure 82. Model versus field data vertical temperature profiles at the mainstem Chehalis River stations: HL-12, HL-11, HL-10, HL-9, and HL-8

Figure 83. Model versus field data vertical temperature profiles at the mainstem Chehalis River stations: HL-7, HL-6, HL-5, HL-4, and HL-3

Figure 84. Model versus field data vertical temperature profiles at the mainstem Chehalis River stations: HL-2, Mellen Road Bridge, and HL-1

6.1. Temperature Error Statistics

The closeness of model predicted temperature to field data was evaluated with error statistics, following the same procedure as with flow. Weighted average mean error, absolute mean error, and root mean square error values were computed using

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

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

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

Table 21 shows error statistics for model predicted temperature values compared to field data at stations along the mainstem Chehalis River ranging between upstream of Pe Ell and Porter, WA. The error statistics for comparisons of model predicted daily maximum temperatures to field data is shown in Table 22. The model is continuously improving, and as such these results are current, though not final. After further model improvements these errors are expected to decrease. The current results show the model was generally too cold at most locations, especially during the summer months.

Table 21. Error statistics for temperature comparisons between model predictions and field data along the mainstem Chehalis River ranging between upstream of Pe Ell and Porter, WA

Location	Number of Model-Data Comparisons	Mean Error (°C)	Absolute Mean Error (°C)	Root Mean Square Error (°C)
11-UCH	9810	0.067	0.25	0.435
Upstream Pe Ell	17051	-0.031	0.402	0.616
Upstream of Pe Ell as well	11006	-0.163	0.556	0.679
Downstream Pe Ell	17486	-0.037	0.824	1.15
Station 13-CH	9764	-0.680	1.01	1.42
At Woodstead	11372	-0.591	1.03	1.30

Location	Number of Model-Data Comparisons	Mean Error (°C)	Absolute Mean Error (°C)	Root Mean Square Error (°C)
At Doty	10107	-0.810	1.12	1.44
Upstream Elk Creek	11004	-0.900	1.08	1.43
Station 15-CH	6036	-1.89	1.89	2.03
At Dryad	8166	-1.70	1.71	1.86
At Rainbow Falls	30619	-1.22	1.28	1.52
Between Rainbow Falls and Ceres Hills Road	1876	-1.71	1.71	1.84
At Ceres Hills Road	10113	-1.42	1.49	1.76
At Adna	17043	-0.796	0.883	1.10
Station 21-CH	13430	-1.26	1.32	1.59
Upstream of Newaukum	17082	-0.698	0.838	1.024
Station 22-CH	9709	-0.818	0.885	1.08
Upstream of Darigold	60920	-0.632	0.719	0.854
Downstream of Darigold	64513	-0.125	0.452	0.600
Upstream Skookumchuck	9764	-0.814	0.937	1.26
At Galvin Bridge	17090	0.052	0.354	0.481
Station 17-CH	984	0.002	0.653	0.787
Upstream Black River	17142	-0.221	0.530	0.714
Station 18-CH	9757	-0.988	1.19	1.54
At Oakville	16894	-0.445	0.683	0.963
Near Oakville	8080	-1.20	1.36	1.73
At Porter	30909	-0.410	0.693	1.05
Weighted Average Error statistics:		-0.58	0.818	1.04

Table 22. Error statistics for daily maximum temperature comparisons between model predictions and field data along the mainstem Chehalis River ranging between upstream of Pe Ell and Porter, WA

Location	Number of Model-Data Comparisons	Mean Error (°C)	Absolute Mean Error (°C)	Root Mean Square Error (°C)
11-UCH	204	-0.194	0.738	0.985
Upstream Pe Ell	354	-0.315	0.716	0.908
Upstream of Pe Ell as well	228	-0.421	0.800	1.03
Downstream Pe Ell	362	0.470	1.18	1.70
Station 13-CH	202	-0.824	1.17	1.48
At Woodstead	116	-0.422	1.20	1.46
At Doty	103	-1.65	1.69	1.92
Upstream Elk Creek	228	-1.50	1.56	1.83
Station 15-CH	124	-2.25	2.28	2.48

Location	Number of Model-Data Comparisons	Mean Error (°C)	Absolute Mean Error (°C)	Root Mean Square Error (°C)
At Dryad	169	-2.08	2.10	2.31
At Rainbow Falls	104	-1.59	1.59	1.83
Between Rainbow Falls and Ceres Hills Road	40	-1.99	2.07	2.39
At Ceres Hills Road	107	-0.639	1.15	1.46
At Adna	353	-0.459	0.799	0.998
Station 21-CH	201	-1.18	1.27	1.51
Upstream of Newaukum	356	-0.587	0.776	0.944
Station 22-CH	201	-0.668	0.906	1.11
Upstream of Darigold	706	-0.615	0.801	0.962
Downstream of Darigold	703	-0.125	0.579	0.780
Upstream Skookumchuck	202	-0.894	1.16	1.41
At Galvin Bridge	354	0.073	0.589	0.733
Station 17-CH	22	0.647	1.09	1.25
Upstream Black River	355	-0.030	0.645	0.832
Station 18-CH	202	-0.812	1.15	1.49
At Oakville	351	-0.179	0.692	0.920
Near Oakville	167	-0.987	1.24	1.60
At Porter	643	-0.261	0.759	1.08
Weighted Average Error statistics:		-0.517	0.944	1.19

6.2. Flow and Water Level

Flow volumes, depth, and timing were important to temperature calibration, so it was important that flow and water level calibration was as accurate as possible. Areas that were too shallow were often too warm and areas that were too deep were often too cool. Accurate depth predictions were necessary for capturing stratification dynamics. Travel time through the system was important, as water that moved slowly had more time to heat up, while water that moved through the system more quickly had less time to absorb solar radiation.

6.3. Bathymetry

6.3.1. Channel Friction and Slope

Similar to flow calibration, channel friction and slope impacted the timing of peak temperature values. The timing and magnitude of temperature was important for calibration in order to accurately describe the temperature variation.

6.3.2. Segment Widths and Depths

Ensuring the widths of the segment layers were realistic was also important for temperature calibration. Since widths were calculated through interpolation and averaging of field data to model segment locations, it was important to hand check many cross sections and ensure that field data and model estimates of segment geometry were similar. Unrealistic layer widths impacted water depths and temperature. This was especially important for the vertical temperature profiles and continuous monitoring stations during the low flow summer months. Sometimes narrow segment widths caused the water to be deep, so that diurnal temperature swings were not as large as seen in field data. Or conversely, sometimes wide segment widths resulted in shallow water that had diurnal swings in temperature greater than field data showed. Figure 85 shows how widening the lower layers in the bathymetry around the stations at Dryad and Rainbow Falls decreased water depths and resulted in temperature values closer to field data during the summer of 2013.

Figure 85. Comparison of model versus field data at Dryad and Rainbow Falls for before and after bathymetry segment width changes were made

6.4. Boundary Condition Temperature

Accurate input temperature values were important for temperature calibration. Ensuring field data quality and using appropriate temperature estimation techniques was important to this process, especially since so many tributaries lacked temperature field data. For example, the Newaukum River was originally used to create regression relationships to estimate missing tributary data. However, this tributary followed

different trends than other tributaries with the timing of peak and minimum temperatures. This lead to poor results when comparing model temperature predictions to field data. Choosing a different temperature gage on the mainstem Chehalis River produced a vast improvement to temperature results. Figure 86 shows the sensitivity of the model to boundary tributary temperature inputs, giving very different results when missing tributary data were estimated using regression to the Newaukum River versus regression to the Chehalis River Downstream of Darigold WWTP.

Figure 86. Comparison of model versus field data temperature when boundary tributary temperatures were estimated using Newaukum River versus Chehalis River Downstream of Darigold WWTP data

Input temperature values for groundwater also impacted model temperature predictions, especially during the low flow summer months when the cold groundwater accounted for a larger portion of the mainstem flow. Very little temperature data were available for groundwater, with usually only one value for a given reach or no data at all. Thus, seasonal variations in groundwater temperatures were not known. Originally, a single data value was used for groundwater during the entire model simulation. However, adding 2 °C to groundwater inputs during the summer months aided the model in staying warm enough during these seasons.

6.5. Meteorological Data

Meteorological data, such as cloud cover, wind speed, and solar radiation also impacted resulting temperatures predictions. CE-QUAL-W2 was set to interpolate between meteorological input data values, so having small time intervals between values was important. Hence, meteorological data gaps were often filled to improve the temperature calibration.

Cloud cover was important for temperature calibration. When the Thrash Creek cloud cover data set was implemented for the entire system, resulting water temperatures were much too cold. Thrash Creek is located higher at a higher elevation near the upstream boundary, so is generally cloudier than the lower reaches of the river. Estimating cloud cover based off of solar radiation improved model temperature values.

6.6. Wind Sheltering

A wind sheltering function was available in the model that either amplified or reduced the input wind speed values by a multiplier. For example, a wind sheltering coefficient of 0.5 meant the model would use only half the input wind speed in calculations of longitudinal momentum and evaporation. This took into account sheltering characteristics of the river surroundings, such as topography and wind breaks from trees. This was most important in the slow, deep, lake-like section where the river was more sensitive to wind effects. Reducing wind had a warming effect by decreasing summer evaporation.

6.7. Evaporation

Evaporation coefficients were specified for each waterbody, and the amount of evaporation was a function of wind speed. Evaporation was computed from:

$$f(W) = a + bW^c \text{ (Cole and Wells, 2016)}$$

Where

$f(W)$ is a wind speed function in $W \text{ m}^{-2} \text{ mm Hg}^{-1}$

a , b , and c are empirical coefficients

W is the wind speed measured 2 m above the ground

Default model coefficients according to Edinger, et al (1974) as listed in the CE-QUAL-W2 user manual (Cole and Wells, 2016) were initially employed. The a coefficient equaled $9.2 \text{ W m}^{-2} \text{ mmHg}^{-1}$, the b coefficient equaled $0.46 \text{ W m}^{-2} \text{ mmHg}^{-1}$, and the c coefficient

equaled 2.0. The α coefficient was then decreased to $4.5 \text{ W m}^{-2} \text{ mmHg}^{-1}$ in order to aid the model in staying warm during the summer months.

6.8. Sediments

The loss of short wave solar radiation to the channel bottom can affect water temperature predictions. CE-QUAL-W2 allows the user to specify how much incident solar radiation that makes it to the sediments is reradiated back into the water column or absorbed. This was adjusted by altering the TSEDF coefficient, which can range from 0 to 1. When TSEDF equals 1 all incident solar radiation that hits the bottom of the channel is reflected back and available for absorption in the water column. When TSEDF equals 0 all short-wave solar radiation that reaches the bottom of the channel is lost to the sediments (Cole and Wells, 2016). A high TSEDF had a warming effect, while a low TSEDF had a cooling effect. Figure 87, Figure 88, and Figure 89 show model sensitivity to changes in TSEDF values when TSEDF equaled 0.3, 0.6, and 0.8 respectively, at the mainstem Chehalis River stations: downstream of Pe Ell, station 13-CH, at Woodstead, and at Doty. Peak temperatures increased as a result of increasing TSEDF.

Figure 87. Model temperature versus field data at downstream of Pe Ell, station 13-CH, at Woodstead, and at Doty when TSEDf equaled 0.3

Figure 88. Model temperature versus field data at downstream of Pe Ell, station 13-CH, at Woodstead, and at Doty when TSEDf equaled 0.6

Figure 89. Model temperature versus field data at downstream of Pe Ell, station 13-CH, at Woodstead, and at Doty when TSDF equaled 0.8

7. Model Calibration: Water Quality

Similar to flow and temperature calibration, model predictions of water quality constituents were compared to mainstem Chehalis River field data. Data were provided from Anchor QEA (2014) and WADOE (2016g, 2016h). Table 23 lists the water quality sample sites on the mainstem Chehalis River used for comparisons of model predictions and field data. Table 24 lists the vertical dissolved oxygen stations, locations, and dates when data were collected on the Chehalis River. Figure 90 shows a longitudinal view of water quality sample sites along the river.

Table 23. Water quality stations on the mainstem Chehalis River used to compare to model predictions

Organization	Station ID	Description	Data available	Model Segment	River Mile
Anchor QEA	CHL-PEL-US	Chehalis Upstream of Pe Ell	DO, FC, NH3, NO3, OrthoP, pH, TP, & TSS	12	107
Anchor QEA	CHL-PEL-DS	Chehalis Downstream of Pe Ell	OrthoP	15	106
WADOE	23A160	Chehalis River at Dryad	DO, FC, NH3, NO3, OrthoP, pH, TP, & TSS	48	99.5
Anchor QEA	CHL-US-SF	Chehalis River Upstream of South Fork	BOD, chl-a, DO, NH3, NO3, OrthoP, pH, TKN, TP, & TSS	81	90
Anchor QEA	CHL-ADNA	Chehalis Near Adna	BOD, chl-a, DO, NH3, NO3, OrthoP, pH, TKN, TP, & TSS	119	81
Anchor QEA	CHL-US-NWK	Chehalis Upstream of Newaukum Confluence	BOD, chl-a, DO, NH3, NO3, OrthoP, pH, TKN, TP, & TSS	144	75.4
Anchor QEA	CHL-RT6-BR	Chehalis at RT6 Bridge	BOD, chl-a, DO, NH3, NO3, OrthoP, pH, TKN, TP, & TSS	149	74.7
Anchor QEA	CHL-US-SKM	Chehalis at Mellen Road Bridge	BOD, chl-a, DO, NH3, NO3, OrthoP, pH, TKN, TP, & TSS	180	67.5
Anchor QEA	CHL-GLV	Chehalis at Galvin Bridge	BOD, chl-a, DO, NH3, NO3, OrthoP, pH, TKN, TP, & TSS	196	64.1

Organization	Station ID	Description	Data available	Model Segment	River Mile
Anchor QEA	CHL-US-BLK	Chehalis Upstream of Black River	BOD, chl-a, DO, NH3, NO3, OrthoP, pH, TKN, TP, & TSS	238	54.2
Anchor QEA	CHL-OAK	Chehalis at Oakville	BOD, chl-a, DO, NH3, NO3, OrthoP, pH, TKN, TP, & TSS	287	42.3
WADOE	23A070	Chehalis River at Porter	DO, FC, NH3, NO3, OrthoP, pH, TP, & TSS	321	33.3

Table 24. Mainstem Chehalis River vertical dissolved oxygen profile collection locations and dates used in water quality calibration

Organization	Station ID	Description	Dates with data	Model Segment
Anchor QEA	CHL-RT6-BR	Chehalis R. at RT6 Bridge at RM 75.31	8/7/13, 9/18/13, & 7/23/14	149
Anchor QEA	HL-14	Chehalis R. at RM 74.5	7/31/14	150
Anchor QEA	HL-13	Chehalis R. at RM 73.75	7/31/14	153
Anchor QEA	HL-12	Chehalis R. at RM 73	7/31/14	157
Anchor QEA	HL-11	Chehalis R. at RM 72.5	7/31/14	158
Anchor QEA	HL-10	Chehalis R. at RM 74.25	7/31/14	160
Anchor QEA	HL-9	Chehalis R. at RM 71.5	7/31/14	162
Anchor QEA	HL-8	Chehalis R. at RM 71	7/31/14	164
Anchor QEA	HL-7	Chehalis R. at RM 70.5	7/31/14	166
Anchor QEA	HL-6	Chehalis R. at RM 70	7/31/14	168
Anchor QEA	HL-5	Chehalis R. at RM 69.25	7/31/14	171
Anchor QEA	HL-4	Chehalis R. at RM 68.75	7/31/14	173
Anchor QEA	HL-3	Chehalis R. at RM 68.25	7/31/14	177
Anchor QEA	HL-2	Chehalis R. at RM 67.75	7/31/14	179
Anchor QEA	CHL-US-SKM	Chehalis R. at Mellen Road Bridge at RM 66.7	8/7/13, 9/18/13, & 7/23/14	180
Anchor QEA	HL-1	Chehalis R. at RM 67.25	7/31/14	181

Figure 90. Longitudinal view of the mainstem Chehalis River water quality sample sites (vertical lines show model branch breaks)

Figure 91 through Figure 108 show the model results compared to field data for dissolved oxygen, chlorophyll a, ammonia, nitrates, total Kjeldahl nitrogen, phosphate, total phosphorus, pH, and total suspended solids at upstream of Pe Ell, downstream of Pe Ell, at Dryad, upstream of the South Fork Chehalis River, at Adna, upstream of the Newaukum River, at Route 6 bridge, upstream of Skookumchuck River, at Galvin Road bridge, upstream of Black River, at Oakville, and at Porter.

Continuous data were available for DO, chlorophyll a, and pH during select days at the monitoring stations: downstream of Pe Ell, Route 6 Bridge, and Mellen Road Bridge. Model DO comparisons to continuous data are shown in Figure 109, Figure 110, and Figure 111 at the downstream of Pe Ell, Route 6 Bridge, and Mellen Road Bridge stations respectively. Model chlorophyll a comparisons to continuous data are shown in Figure 112, Figure 113, and Figure 114 at the downstream of Pe Ell, Route 6 Bridge, and Mellen Road Bridge stations respectively. Model pH comparisons to continuous data are shown in Figure 115, Figure 116, and Figure 117 at the downstream of Pe Ell, Route 6 Bridge, and Mellen Road Bridge respectively.

Vertical profile data were available at the same locations as temperature. Figure 118 shows model-predicted dissolved oxygen profiles compared to field data at the monitoring stations: Route 6 Bridge, HL-14, and HL-13. Figure 119 shows model-predicted dissolved oxygen profiles compared to field data at the monitoring stations: HL-12, HL-11, HL-10, HL-9, and HL-8. Figure 120 shows model-predicted dissolved oxygen profiles compared to field data at the monitoring stations: HL-7, HL-6, HL-5, HL-4, and HL-3. Figure 121 shows model-predicted dissolved oxygen profiles compared to field data at the monitoring stations: HL-2, HL-1, and Mellen Road Bridge.

Figure 91. Model dissolved oxygen predictions versus field data at upstream of Pe Ell, at Dryad, upstream of South Fork Chehalis River, at Adna, upstream of Newaukum River, and at Route 6 bridge

Figure 92. Model dissolved oxygen predictions versus field data at upstream of Skookumchuck River, at Galvin Road bridge, upstream of Black River, at Oakville, and at Porter

Figure 93. Model ammonia predictions versus field data at upstream of Pe Ell, at Dryad, upstream of South Fork Chehalis River, at Adna, upstream of Newaukum River, and at Route 6 bridge

Figure 94. Model ammonia predictions versus field data at upstream of Skookumchuck River, at Galvin Road bridge, upstream of Black River, at Oakville, and at Porter

Figure 95. Model nitrates predictions versus field data at upstream of Pe Ell, at Dryad, upstream of South Fork Chehalis River, at Adna, upstream of Newaukum River, and at Route 6 bridge

Figure 96. Model nitrates predictions versus field data at upstream of Skookumchuck River, at Galvin Road bridge, upstream of Black River, at Oakville, and at Porter

Figure 97. Model total Kjeldahl nitrogen predictions versus field data at upstream of Pe Ell, upstream of South Fork Chehalis River, at Adna, upstream of Newaukum River, and at Route 6 bridge

Figure 98. Model total Kjeldahl nitrogen predictions versus field data at upstream of Skookumchuck River, at Galvin Road bridge, upstream of Black River, and at Oakville

Figure 99. Model phosphate predictions versus field data at upstream of Pe Ell, downstream of Pe Ell, at Dryad, upstream of South Fork Chehalis River, at Adna, and upstream of Newaukum River

Figure 100. Model phosphate predictions versus field data at Route 6 bridge, upstream of Skookumchuck River, at Galvin Road bridge, upstream of Black River, at Oakville, and at Porter

Figure 101. Model total phosphorus predictions versus field data at upstream of Pe Ell, at Dryad, upstream of South Fork Chehalis River, at Adna, upstream of Newaukum River, and at Route 6 bridge

Figure 102. Model total phosphorus predictions versus field data at upstream of Skookumchuck River, at Galvin Road bridge, upstream of Black River, at Oakville, and at Porter

Figure 103. Model chlorophyll a predictions versus field data at upstream of Pe Ell, upstream of South Fork Chehalis River, at Adna, upstream of Newaukum River, and at Route 6 bridge

Figure 104. Model chlorophyll a predictions versus field data at upstream of Skookumchuck River, at Galvin Road bridge, upstream of Black River, and at Oakville

Figure 105. Model pH predictions versus field data at upstream of Pe Ell, at Dryad, upstream of South Fork Chehalis River, at Adna, upstream of Newaukum River, and at Route 6 bridge

Figure 106. Model pH predictions versus field data at upstream of Skookumchuck River, at Galvin Road bridge, upstream of Black River, at Oakville, and at Porter

Figure 107. Model TSS predictions versus field data at upstream of Pe Ell, at Dryad, upstream of South Fork Chehalis River, at Adna, upstream of Newaukum River, and at Route 6 bridge

Figure 108. Model TSS predictions versus field data at upstream of Skookumchuck River, at Galvin Road bridge, upstream of Black River, at Oakville, and at Porter

Figure 109. Model dissolved oxygen predictions versus continuous field data at the downstream of Pe Ell monitoring station

Figure 110. Model dissolved oxygen predictions versus continuous field data at the Route 6 Bridge monitoring station

Figure 111. Model dissolved oxygen predictions versus continuous field data at the Mellen Road Bridge monitoring station

Figure 112. Model chlorophyll a predictions versus continuous field data at the downstream of Pe Ell monitoring station

Figure 113. Model chlorophyll a predictions versus continuous field data at the Route 6 Bridge monitoring station

Figure 114. Model chlorophyll a predictions versus continuous field data at the Mellen Road Bridge monitoring station

Figure 115. Model pH predictions versus continuous field data at the downstream of Pe Ell monitoring station

Figure 116. Model pH predictions versus continuous field data at the Route 6 Bridge monitoring station

Figure 117. Model pH predictions versus continuous field data at the Mellen Road Bridge monitoring station

Figure 118. Model-predicted vertical dissolved oxygen profiles compared to field data at the monitoring stations: Route 6 Bridge, HL-14, and HL-13

Figure 119. Model-predicted vertical dissolved oxygen profiles compared to field data at the monitoring stations: HL-12, HL-11, HL-10, HL-9 and HL-8

Figure 120. Model-predicted vertical dissolved oxygen profiles compared to field data at the monitoring stations: HL-7, HL-6, HL-5, HL-4 and HL-3

Figure 121. Model-predicted vertical dissolved oxygen profiles compared to field data at the monitoring stations: HL-2, Mellen Road Bridge, and HL-1

Water quality coefficients used in the model are shown in Table 25. Many of these coefficients were adjusted during the course of water quality calibration.

Table 25. W2 Model Water Quality Parameters in the Chehalis River Model

Variable	Description	Units	Typical values*	Values
AX	Longitudinal eddy viscosity (for momentum dispersion)	m ² /sec	1	1
DX	Longitudinal eddy diffusivity (for dispersion of heat and constituents)	m ² /sec	1	1
CBHE	Coefficient of bottom heat exchange	Wm ² /sec	0.30	0.30
TSED	Sediment (ground) temperature	°C		11.5
WSC	Wind sheltering coefficient		0.85	0.25
BETA	Fraction of incident solar radiation absorbed at the water surface		0.45	0.45
EXH20	Extinction for water	/m	0.25-0.45	0.25
AG1	Algal growth rate for group #1	/day	1-3	1.5
AM1	Algal mortality rate for group #1	/day		0.1
AE1	Algal excretion rate for group #1	/day	0.014-0.044	0.04
AR1	Algal dark respiration for group #1	/day	0.01-0.92	0.04
AS1	Algal settling rate for group #1	/day	0.02-1.00	0.1
ASAT1	Algae Saturation intensity at maximum photosynthetic rate for group #1	W/m ²	10-170	150
APOM1	Fraction of algal biomass lost by mortality to detritus for algae for group #1		0.8	0.8
AT1_1	Lower temperature for algal growth for group #1	°C		3
AT2_1	Lower temperature for maximum algal growth for group #1	°C		7
AT3_1	Upper temperature for maximum algal growth for group #1	°C		20
AT4_1	Upper temperature for algal growth for group #1	°C		30
AK1_1	Fraction of algal growth rate at AT1 for group #1		0.1	0.1
AK2_1	Fraction of maximum algal growth rate at AT2 for group #1		0.99	0.99
AK3_1	Fraction of maximum algal growth rate at AT3 for group #1		0.99	0.99

Variable	Description	Units	Typical values*	Values
AK4_1	Fraction of algal growth rate at AT4 for group #1		0.1	0.1
ALGP1	Stoichiometric equivalent between organic matter and phosphorus for algae group #1		0.005	0.01
ALGN1	Stoichiometric equivalent between organic matter and nitrogen for algae group #1		0.08	0.08
ALGC1	Stoichiometric equivalent between organic matter and carbon for algae group #1		0.4-0.5	0.5
AG2	Algal growth rate for group #2	/day	1-3	2
AM2	Algal mortality rate for group #2	/day		0.1
AE2	Algal excretion rate for group #2	/day	0.014-0.044	0.04
AR2	Algal dark respiration for group #2	/day	0.01-0.92	0.04
AS2	Algal settling rate for group #2	/day	0.02-1.00	0.1
ASAT2	Algae Saturation intensity at maximum photosynthetic rate for group #2	W/m ²	10-170	150
APOM2	Fraction of algal biomass lost by mortality to detritus for algae for group #2		0.8	0.8
AT1_2	Lower temperature for algal growth for group #2	°C		7
AT2_2	Lower temperature for maximum algal growth for group #2	°C		15
AT3_2	Upper temperature for maximum algal growth for group #2	°C		30
AT4_2	Upper temperature for algal growth for group #2	°C		35
AK1_2	Fraction of algal growth rate at AT1 for group #2		0.1	0.1
AK2_2	Fraction of maximum algal growth rate at AT2 for group #2		0.99	0.99
AK3_2	Fraction of maximum algal growth rate at AT3 for group #2		0.99	0.99
AK4_2	Fraction of algal growth rate at AT4 for group #2		0.1	0.1
ALGP2	Stoichiometric equivalent between organic matter and phosphorus for algae group #2		0.005	0.01
ALGN2	Stoichiometric equivalent between organic matter and nitrogen for algae group #2		0.08	0.08

Variable	Description	Units	Typical values*	Values
ALGC2	Stoichiometric equivalent between organic matter and carbon for algae group #2		0.4-0.5	0.5
LDOMDK	Labile DOM decay rate	/day	0.04-0.12	0.08
LRDDK	Labile to refractory decay rate	/day	0.001	0.01
RDOMDK	Maximum refractory decay rate	/day	0.001	0.001
LPOMDK	Labile Detritus decay rate	/day	0.04-0.1	0.06
POMS	Detritus settling rate	m/day	0.2-2	0.75
RPOMDK	Refractory detritus decay rate	/day	0.001	0.001
OMT1	Lower temperature for organic matter decay	°C	4	4
OMT2	Lower temperature for maximum organic matter decay	°C	30	25
OMK1	Fraction of organic matter decay rate at OMT1		0.1	0.1
OMK2	Fraction of organic matter decay rate at OMT2		0.99	0.99
PO4R	Anaerobic sediment release rate of phosphorus as fraction of SOD			0.001
AHSP1	Algal half-saturation constant for phosphorus for group #1	g/m ³	0.002-0.01	0.003
AHSP2	Algal half-saturation constant for phosphorus for group #2	g/m ³	0.002-0.01	0.003
NH4DK	Ammonia decay rate (nitrification rate)	/day	0.001-1.3	0.8
AHSN1	Algal half-saturation constant for nitrogen for group #1	g/m ³	0.014	0.014
AHSN2	Algal half-saturation constant for nitrogen for group #2	g/m ³	0.014	0.014
NH4T1	Lower temperature for ammonia decay	°C	5	5
NH4T2	Lower temperature for maximum ammonia decay	°C	20	25
NH4K1	Fraction of nitrification rate at NH4T1		0.1	0.1
NH4K2	Fraction of nitrification rate at NH4T2		0.99	0.99
NO3DK	Nitrate decay rate (denitrification rate)	/day	0.05-0.15	0.03
NO3T1	Lower temperature for nitrate decay	°C	5	5
NO3T2	Lower temperature for maximum nitrate decay	°C	20	25
NO3K1	Fraction of denitrification rate at NO3T1		0.1	0.1

Variable	Description	Units	Typical values*	Values
NO3K2	Fraction of denitrification rate at NO3T2		0.99	0.99
O2NH4	Oxygen stoichiometric equivalent for ammonia decay		4.57	4.57
O2OM	Oxygen stoichiometric equivalent for organic matter decay		1.4	1.4
O2AR1	Oxygen stoichiometric equivalent for dark respiration for group #1		1.1	1.1
O2AR2	Oxygen stoichiometric equivalent for dark respiration for group #2		1.1	1.1
O2AG1	Oxygen stoichiometric equivalent for algal growth for group #1		1.4	1.6
O2AG2	Oxygen stoichiometric equivalent for algal growth for group #2		1.4	1.6
O2LIM	Dissolved oxygen concentration at which anaerobic processes begin	g/m ³	0.1	0.07
SEDK	First order sediment compartment decay rate	/day		0.03
SOD	Zeroth order sediment oxygen demand	g/m ² /day	0.3-6	0.3-1.9
SEDBR	Sediment burial rate	/day		0.01
* Cole and Wells (2016)				

7.1. Boundary Condition Constituents

The model was very sensitive to boundary inflows for constituents and correctly assessing boundary conditions was perhaps the most important task for water quality calibration. Multiple re-evaluations of estimates used for wastewater treatment plants, tributaries, and groundwater flows were necessary.

7.1.1. Wastewater Treatment Plants

Wastewater treatment plants often significantly impacted the resulting conditions in the river, as their constituent concentrations were often much greater than those from the upstream boundary or inputs from tributaries. This was especially important during

the summer months when flow in the river was low. For this reason, careful analysis of wastewater treatment plant data and filling in missing data was an important step for water quality calibration.

Often, constituent data were missing entirely for some wastewater treatment plants. In this case reasonable values were used as an approximation. For example, NO₃ data were completely missing for the Pe Ell, Darigold, and Centralia wastewater treatment plants, so typical values between 0.5 mg/L and 1 mg/L were used as estimates. Adjustments were made to concentrations to aid in water quality calibration, as no data were available for confirmation.

Particulate matter settling and decaying in the upper reaches of the model impacted the calibration of dissolved oxygen and nutrient species, particularly ammonia. When the fraction of BOD assumed to be dissolved was low and the fraction assumed particulate was high, large amounts of organic particulates settled to the bottom of the channel and upon degradation in the sediments released ammonia back into the water. This raised model concentrations of ammonia above field data values. When BOD was assumed to be equally partitioned between dissolved and particulate, resulting ammonia concentrations more closely matched field data.

7.1.2. Tributary Winter Estimations

Generally, tributary water quality data were only available during the summer months. Using summer values as approximations for winter values proved to be inaccurate in many cases. Field data along the mainstem river showed DO, TSS, and

nitrate levels were higher during winter times, while ammonia concentrations were higher during summer times. Presumably, these trends would also be occurring in the tributaries. These seasonal variations were important to include in order to reproduce field data.

When possible, field data collected during winter from the mainstem Chehalis were used as an estimate for other tributaries. For example, an NO₃ value of 0.724 mg/L was sampled on the mainstem river near the upstream boundary during winter. This value was used also in the major tributaries since no other data were available. This value was higher than summer nitrate concentrations, which generally ranged between 0.01 mg/L and 0.5 mg/L. Nitrate concentrations were predicted to be too low when summer values were implemented during winter times. Higher winter nitrate concentrations from runoff from surrounding agricultural land during the winter months may not be captured in data sets containing values only collected during summer.

When it was not possible to use data collected during winter times, reasonable winter values were used as an estimate. For example, TSS data were entirely unavailable during the winter months, so 20 mg/L was used during these times as an approximation. This value was much higher than the summer TSS data, which generally ranged between 1 and 5 mg/L. Higher TSS concentrations are often seen during winter times as rainfall runoff entering the stream often carries additional solids.

Otherwise, TSS values also included the amount of particulate organic matter as some of the BOD was assumed to be particulate. However, one BOD data point collected

on September 17, 2013 was excluded for Elk Creek. This value equaled 24.3 mg/L, and was much higher than any other BOD value collected for this tributary, or any of the other tributaries. This data value seemed unreasonable to apply for a long period of time when no other field data were available. Including this data point produced high model predictions for TSS and issues with other mainstem measured concentrations around the date it was collected.

DO values were only available for tributaries during the summer months, when water temperatures were warmer. Warmer water generally has lower DO concentrations than cooler water, so using summer DO values as approximations for winter times was unrealistic. DO values were estimated for the tributaries based on temperature and assuming 100% saturation. This was done using known relationships and assuming zero chloride concentration (Chapra, 1997).

7.1.3. Groundwater

While groundwater flows were very small, the impacts on water quality in the river were still necessary to consider for calibration, particularly during the low flow summer season. Some constituents had much different magnitudes in groundwater than seen in the rivers and creeks entering the system.

When gaps in groundwater constituents existed, they were generally filled in using averages or medians of other available groundwater measurements. Often, using median values to estimate missing data rather than averages was important for groundwater since many averages gave constituent concentrations biased towards higher values.

Sometimes groundwater constituents were estimated using a value within the range of data available. For example, dissolved oxygen for the groundwater reaches ranged between approximately 0.1 mg/L and 2.6 mg/L, so 2 mg/L was assumed reasonable and implemented for all groundwater inputs.

Groundwater inputs for nitrates were particularly important for the downstream reaches of the model. When estimates of groundwater nitrate were too high, nitrate built up and steadily increased higher than reflected in mainstem river field data in the downstream reaches. Reducing these concentrations helped to match model predictions to field data. The upstream reaches had a groundwater median nitrate value of 0.01 mg/L implemented (Pitz, 2005). The groundwater nitrate concentrations generally ranged from 0.01 mg/L to 1.3 mg/L, so a value of 0.5 mg/L was assumed reasonable for the downstream reaches for groundwater.

7.1.4. Locating Tributaries that Affected In-Stream Water Quality

Since there were a large number of tributary inputs to the model, determining which inputs were affecting in-stream water quality conditions was an important step in water quality calibration.

Figure 122 shows TP values previously predicted by the model. Between the locations at river miles 107 and 98.7 a peak in model-predicted TP occurred near Julian day 220 that persisted downstream. This peak was not reflected in mainstem Chehalis River field data. Between these two locations the only inputs to the model were the Pe Ell wastewater treatment plant and Elk Creek. Around this time the Pe Ell wastewater

treatment plant TP concentration was approximately 0.08 mg/L, while the model-predicted mainstem TP reached approximately 0.1 mg/L. While wastewater treatment plants often had a major influence on water quality in the Chehalis River, in this case the Pe Ell wastewater treatment plant was not the cause for the peak in TP. Elk Creek, however, had TP concentrations exceeding 0.1 mg/L during this time. This was largely due to its organic matter as phosphorus (OMP) concentration. Elk Creek OMP was initially calculated using an average of its available TP field data, with values of 0.11 mg/L, 0.24 mg/L, and 0.008 mg/L. In order to reduce the OMP concentration in Elk Creek, OMP was re-estimated using the 0.008 mg/L value alone. Figure 123 shows TP values predicted by the model after this adjustment was made.

Similar process-of-elimination methods for various constituents and tributaries were conducted in order to determine which inputs to the model were driving water quality in the river. Once the driving influence was located, constituent concentrations were re-evaluated in order to determine whether the original estimation techniques were reasonable or poor.

Figure 122. TP model predictions compared to field data when previous technique was used to estimate OMP for Elk Creek

Figure 123. TP model predictions compared to field data when updated technique was used to estimate OMP for Elk Creek

7.2. Nitrogen, Phosphorus, & Oxygen Fluxes

The ammonia decay rate (NH4DK) and the nitrate decay rate (NO3DK) were important for calibration for ammonia and nitrates. NH4DK specifies the rate at which ammonia is oxidized to nitrate or nitrite. By increasing these decay rates, the concentration of ammonia or nitrates was decreased as the compound decayed more quickly. Conversely, by decreasing these decay rates, concentrations remained higher.

CE-QUAL-W2 allows the user to view outputs of various fluxes throughout the model simulation, giving a view of what processes are important for various constituents. Viewing these fluxes for nitrogen species, phosphorus species, and dissolved oxygen were used for determining what processes were the largest drivers for river conditions.

Phosphate fluxes included algal respiration, algal growth, algal production, epiphyton respiration, epiphyton growth, epiphyton production, decay of particulate organic matter, decay of dissolved organic matter, 1st order sediment compartment decay, zero-order sediment release, and sorbed phosphate from settling.

Ammonia fluxes included algal respiration, algal growth, algal production, epiphyton respiration, epiphyton growth, epiphyton production, ammonia algal uptake, particulate organic matter decay, dissolved organic matter decay, 1st order sediment compartment decay, and zero-order sediment release.

Nitrates fluxes included denitrification, algal growth, epiphyton growth, and 1st order sediment compartment decay.

Dissolved oxygen fluxes included algal production, algal respiration, epiphyton production, epiphyton respiration, particulate organic matter decay, dissolved organic matter decay, nitrification, carbonaceous BOD decay, reaeration, 1st order sediment compartment decay, and zero-order sediment oxygen demand.

Figure 124, Figure 125, Figure 126, Figure 127, Figure 128, Figure 129, Figure 130, Figure 131, and Figure 132 show the model predictions of NH₄, NO₃, and DO fluxes in waterbody 1, waterbody 2, waterbody 3, waterbody 4, waterbody 5, waterbody 6, waterbody 7, waterbody 8, and waterbody 9 respectively. The largest model-predicted NH₄ fluxes were generally attributed to nitrification and periphyton/epiphyton respiration and production. Periphyton/epiphyton growth was generally the dominant model-predicted NO₃ flux. The largest model-predicted DO fluxes were generally from algal respiration, periphyton/epiphyton respiration, reaeration, and zero-order sediments.

Figure 124. Dominant model-predicted NH₄, NO₃, and DO fluxes in waterbody 1

Figure 125. Dominant model-predicted NH₄, NO₃, and DO fluxes in waterbody 2

Figure 126. Dominant model-predicted NH₄, NO₃, and DO fluxes in waterbody 3

Figure 127. Dominant model-predicted NH₄, NO₃, and DO fluxes in waterbody 4

Figure 128. Dominant model-predicted NH₄, NO₃, and DO fluxes in waterbody 5

Figure 129. Dominant model-predicted NH₄, NO₃, and DO fluxes in waterbody 6

Figure 130. Dominant model-predicted NH₄, NO₃, and DO fluxes in waterbody 7

Figure 131. Dominant model-predicted NH₄, NO₃, and DO fluxes in waterbody 8

Figure 132. Dominant model-predicted NH₄, NO₃, and DO fluxes in waterbody 9

7.2.1. Algae, Epiphyton, & Zooplankton Kinetics

The model required many kinetic coefficients to describe algae, epiphyton, and zooplankton dynamics. Algal kinetics included maximum growth rate, maximum respiration rate, maximum excretion rate, maximum mortality rate, settling rate, half-saturation for phosphorus limited growth, half-saturation for nitrogen limited growth, half-saturation for silica limited growth, and light saturation intensity at maximum photosynthesis rate (Cole and Wells, 2016). The algal temperature regime included temperature limits for growth and maximum growth and the fraction of algal growth at each temperature limit. Algal stoichiometry and initial condition concentrations were also input to the model. Similar kinetics, temperature regimes, and stoichiometry were also input for epiphyton and zooplankton.

Water quality calibration was sensitive to the dynamics of algae and periphyton/epiphyton because of their direct interactions with nutrients and dissolved oxygen. Nutrients decreased in the water column as a result of algae and epiphyton uptake during growth and increased as a result of algae and epiphyton respiration and mortality. DO increased in the water column during photosynthetic production, and decreased due to algae and epiphyton mortality as bacteria decayed the resulting organic matter. Correctly assessing the characteristics of algae, epiphyton, and zooplankton involved some trial-and-error. When these constituents created too much decaying biomass, the dissolved oxygen fell much lower than field data showed. When growth rates

were too high and mortality rates were too low, the swings between peak and minimum dissolved oxygen and nutrients were too large.

No data exist for periphyton/epiphyton for the Chehalis River or the tributaries. Periphyton/epiphyton played an important role in model calibration, with uptake of nitrates and ammonia (with a preference for nitrates) during production and release of ammonia during respiration. Confirming the biomass of periphyton/epiphyton would assess whether the current water quality model is realistic.

Algae growth limitation by phosphorus from upstream of Pe Ell to upstream of the Newaukum River can be seen in Figure 133. Algae growth limitation by phosphorus from Route 6 Bridge to Porter can be seen Figure 134. Algae growth limitation by nitrogen from upstream of Pe Ell to upstream of the Newaukum River can be seen in Figure 135. Algae growth limitation by nitrogen from Route 6 Bridge to Porter can be seen in Figure 136. Algae growth limitation by light from upstream of Pe Ell to upstream of the Newaukum River can be seen in Figure 137. Algae growth limitation by light from Route 6 Bridge to Porter can be seen in Figure 138. Lower limitation values indicated more severe limitation.

Algal growth limitation from phosphorus and nitrogen became more important during summer months when light was plentiful. Similarly, algal limitation from light was more important during winter months when solar radiation decreased and cloud cover increased.

Figure 133. Algae growth limitation by phosphorus predicted by the model at upstream of Pe Ell, downstream of Pe Ell, Dryad, upstream of South Fork Chehalis River, Adna, and upstream of Newaukum River

Figure 134. Algae growth limitation by phosphorus predicted by the model at Route 6 Bridge, upstream of Skookumchuck River, Galvin Road Bridge, upstream of Black River, Oakville, and Porter

Figure 135. Algae growth limitation by nitrogen predicted by the model at upstream of Pe Ell, downstream of Pe Ell, Dryad, upstream of South Fork Chehalis River, Adna, and upstream of Newaukum River

Figure 136. Algae growth limitation by nitrogen predicted by the model at Route 6 Bridge, upstream of Skookumchuck River, Galvin Road Bridge, upstream of Black River, Oakville, and Porter

Figure 137. Algae growth limitation by light predicted by the model at upstream of Pe Ell, downstream of Pe Ell, Dryad, upstream of South Fork Chehalis River, Adna, and upstream of Newaukum River

Figure 138. Algae growth limitation by light predicted by the model at Route 6 Bridge, upstream of Skookumchuck River, Galvin Road Bridge, upstream of Black River, Oakville, and Porter

7.2.2. Sediments

Sediment oxygen dynamics were important in the pool area where DO decreased near the channel bottom. Data for oxygen exchanges at the sediments were unavailable, so zero-order sediment oxygen demand (SOD) values were estimated for each segment. While generally SOD values are between 0.1 and 1 $\text{O}_2 \text{ m}^2 \text{ day}^{-1}$, they can sometimes be higher (Cole and Wells, 2016). These values vary depending on sediment characteristics and algal production (Cole and Wells, 2016). SOD values in the pool were set to 1.9 $\text{g/m}^2/\text{day}$ at 20°C and SOD values upstream and downstream of the pool were set to 0.3 $\text{g/m}^2/\text{day}$. These values were important for matching DO values near the bottom of the channel that are seen in vertical profile data from the pool reach.

Large sediment fluxes in the upper waterbodies indicated sediments played a large role in ammonia predictions, due to the settling of particulate organic matter (POM) from wastewater treatment plants. First-order sediment decay was employed in the model. The rate of organic matter settling to the sediments (POMS) and the rate of BOD settling to the sediments (CBODS) were important for DO and nutrient calibration. Increased settling of organic matter to sediments increased oxygen demand as these organics decayed. Settling of organic matter to the sediments was also important for ammonia in the upper reaches. Particulate organic matter and BOD from the Pe Ell wastewater treatment plant settled in the sediments and decayed ammonia back into the water column, resulting in ammonia concentrations greater than seen in field data. By

reducing POMS and CBODS, the particulates from the treatment plant were able to travel further downstream before settling.

The rate of particulate organic matter decay of the sediments (SEDK) was also available for adjustment, as it is possible that decay of organic matter in sediments may not be the same as in the water column. Decreasing SEDK indicated the sediments are more refractory in nature and decay more slowly. This helped with nutrient calibration. Burial of organics essentially locks the organics in the sediments as they settle and makes them unavailable to decay into the water column or take up oxygen. Increasing the rate of sediment burial of particulate organics (SEDBR) helped to reduce the concentration of nutrients released back into the water column during organic decay. This was especially important for ammonia.

7.2.3. Reaeration

The model requires the user to specify a reaeration regime for each waterbody. Each equation corresponds to a set of coefficients that help to describe how DO enters and leaves the water. For the upper waterbodies and lower model waterbodies, river reaeration equations dependent upon stream velocity were used that promoted higher reaeration exchanges. For the middle waterbodies where lake-like conditions exist, and reaeration is controlled by wind speed, lake reaeration equations were used. The lake formulations generally decreased reaeration in the pool area and allowed DO produced by photosynthesis to accumulate. Sometimes, when reaeration was too low, the model

predicted DO levels that were too high. By reassessing the reaeration regime applied to each waterbody, DO was improved.

7.3. Comments About Model Predictions

Some data used for calibration could not be explained from known nutrient sources. For example, mainstem Chehalis River ammonia values were approximately 0.02 mg/L upstream of the Skookumchuck River and upstream of the Newaukum River. However, between these locations at Adna, the ammonia concentrations increased to approximately 0.15 mg/L. With no other data reflecting this increase in ammonia, it was not possible to calibrate the model to replicate the elevated ammonia values seen at Adna.

TKN is the sum of NH₃ and organic matter as nitrogen. Since model predictions reasonably match mainstem NH₃ data, the error in TKN predicts may be more closely related to errors in organic matter estimations.

PO₄ was sensitive to periphyton/epiphyton characteristics. Further information about periphyton/epiphyton in the system would likely improve PO₄ calibration.

Similar to ammonia data, sudden increases or decreases in mainstem constituent data that were not reflected elsewhere in available data were difficult for model predictions reproduce. For example, chlorophyll a increased to approximately 5 µg/L at the upstream of Skookumchuck River station around Julian day 200. The neighboring upstream and downstream monitoring stations, however, had chlorophyll a concentrations of 1 µg/L or less. This chlorophyll a increase was not seen in any other tributary data, so was not

reflected in the model predictions. A similar increase in TP data was seen at the Oakville monitoring station around Julian day 200, and similarly was not reflected in model predictions.

Algae and periphyton/epiphyton alter the pH of the water because of their uptake of carbon dioxide, which produces acidic species in the water column. However, pH is also a function of alkalinity, temperature, and total inorganic carbon. Single alkalinity data values on the Chehalis River were mentioned in some of the wastewater treatment plant fact sheets. These were not sufficient to provide alkalinity data for all of the tributaries entering the river. Because of the lack of data for alkalinity and total inorganic carbon, pH was not fully calibrated in this model.

7.4. Continuous Water Quality

The timing and magnitudes of model predictions were not always in agreement with field data, as seen in the continuous DO field data comparisons. Model DO diurnal variations were very sensitive to cloud cover. Improvements to meteorological data improved the model DO results. It was useful to view the cloud cover to aid calibration. The cloud cover values during the times continuous DO data were collected can be seen in Figure 139 for the waterbodies data were collected in. Additional cloud cover data would improve model predictions, especially since much of the cloud cover data were estimated based on solar radiation data and calculated theoretical clear sky solar radiation. As model improvements continue, investigations to improvements between model predictions and continuous field data will be explored.

Figure 139. Cloud cover for Thrash Creek and CLSW during the times of continuous DO data collection (10 = fully cloudy and 0 = clear sky)

7.5. Vertical Profiles

Confirmation of locations of tributaries and monitoring stations in relation to the model grid would generally improve model results. Vertical profiles were especially sensitive to segment location, even when only off by one or two segments. Improvements to temperature vertical profiles is also important for DO profiles, as DO is a direct function of water temperature. Improvements to meteorological data could thus improve DO predictions.

8. Model Scenarios

8.2. Scenario Descriptions

Multiple scenarios were applied to the model inputs to simulate dam structure regimes for baseline conditions during 2013-2014 and future conditions. The results of these model simulations will allow for more informed management decisions and strategies in regards to dam implementation. Table 26 gives a list of the scenarios applied to the model.

Table 26. Chehalis River scenarios

Scenario	Conditions
Baseline	Current (2013-2014) and Future
FRFA Scenario 1	Current (2013-2014) and Future
FRFA Scenario 2	Current (2013-2014) and Future
FRO – Riparian Shading	Current (2013-2014) and Future
FRO – No Shading	Current (2013-2014) and Future

8.2.1. Flood Retention Only (FRO)

Flood Retention Only (FRO) is one of the dam management regimes. In this case the dam only operates during times when flooding is seen at Grand Mound, with Chehalis River flows greater than 38,800 cfs (Montgomery, 2016). This is approximately a 7-year flood with about 15% probability of occurrence (Montgomery, 2016). Dam outflow during these times would be reduced to 300 cfs. The inundation area for this scenario would have a median value of 187 acres, and could reach a maximum of 778 acres. The pool elevation for this scenario would have a median value of 513 feet, though could reach 520.4 feet at a maximum, which would result in a storage volume of 60,253 acre-feet (Montgomery, 2016).

8.2.2. Flood Retention Flow Augmentation (FRFA)

Flood Retention Flow Augmentation (FRFA) is another dam management regime. Dam operations during flooding follow the same procedure as the FRO scenario. However, the dam would operate during other times as well. Minimum flow releases vary based on season. If the reservoir is not in a flooding operation state, inflows greater than 2,800 would be released. The downstream gage at Doty would be targeted to maintain a minimum flow of 5,000 cfs. Dam releases at a maximum of 15,000 cfs would result in flows at Doty of 23,000 cfs (Montgomery, 2016).

Within the FRFA regime, there are two sub-scenarios. FRFA scenario 1 includes lower dam outflows than FRFA scenario 2 during September and October, has less drawdown, and takes less time for the reservoir to refill during the winter season. Conversely, FRFA scenario 2 has higher dam outflows than FRFA scenario 1 during September and October, has more drawdown, and takes longer for the reservoir to refill during the winter season (Montgomery, 2016). FRFA scenario 1 has an elevation range of 598 to 683 feet; a storage volume range of 44,000 to 59,400 acre-feet, with a mean of 51,386 acre-feet; and an annual drawdown range of 9 to 29 feet. FRFA scenario 2 has an elevation range of 587 to 680 feet; a storage range of 36,800 to 121,700 acre-feet; a minimum storage range of 36,800 to 121,700 acre-feet, with a mean of 46,125 acre-feet; and an annual drawdown range of 8-40 feet (Montgomery, 2016).

8.2.3. Future Conditions

Current and potential future conditions for meteorological, flow, and temperature data were applied to each baseline and dam scenario. Modeling of future scenarios involved simulating one year. Anchor QEA used data made available by the University of Washington (Mauger, 2016) to develop meteorological input files for future climate scenarios. Flow multipliers for future climate scenarios were also provided by Anchor QEA (Hill, 2016), and are shown in Table 27. Tributary flows were multiplied by these values to simulate future flow conditions.

Table 27. Future conditions monthly flow multipliers (Hill, 2016)

Month	Flow Multiplier
January	1.129
February	1.085
March	0.994
April	0.938
May	0.889
June	0.851
July	0.817
August	0.785
September	0.813
October	1.055
November	1.058
December	1.145

As tributary temperatures were not made available for the future climate scenarios, these were assumed to increase by the same magnitude that air temperature increased. The difference in air temperature from baseline conditions to future climate conditions were added to tributary water temperatures from 2014.

Meteorological, flow, and temperature data were the only inputs to the model that were altered to simulate future conditions. All other model conditions and input data remained the same as for the baseline calibration simulations.

8.3. Temperature Predictions

Model predictions of daily maximum temperature of the baseline conditions, FRFA scenarios, and FRO scenarios upstream of Elk Creek are shown in Figure 140 and Figure 141 for current conditions and future conditions respectively. Model predictions of daily maximum temperature of the scenarios at Ceres Hills for current conditions and future conditions are shown in Figure 142 and Figure 143 respectively. Model predictions of daily maximum temperature of the scenarios upstream of the Newaukum River for current conditions and future conditions are shown in Figure 144 and Figure 145 respectively. Model predictions of daily maximum temperature of the scenarios upstream of the Skookumchuck River for current conditions and future conditions are shown in Figure 146 and Figure 147 respectively. Model predictions of daily maximum temperature of the scenarios upstream of the Black River for current conditions and future conditions are shown in Figure 148 and Figure 149 respectively.

The model predicted future climate conditions would increase water temperature for all scenarios. Temperature predictions were lower for the FRFA scenarios than the baseline and FRO scenarios. However, differences in temperature predictions between the scenarios decreased moving downstream.

Figure 140. Model daily maximum temperature predictions upstream of Elk Creek for current conditions: baseline, FRO with no vegetative shading, FRO with riparian shading, FRFA scenario 1, and FRFA scenario 2 simulations

Figure 141. Model daily maximum temperature predictions upstream of Elk Creek for future conditions: baseline, FRO with no vegetative shading, FRO with riparian shading, FRFA scenario 1, and FRFA scenario 2 simulations

Figure 142. Model daily maximum temperature predictions at Ceres Hills for current conditions: baseline, FRO with no vegetative shading, FRO with riparian shading, FRFA scenario 1, and FRFA scenario 2 simulations

Figure 143. Model daily maximum temperature predictions at Ceres Hills for future conditions: baseline, FRO with no vegetative shading, FRO with riparian shading, FRFA scenario 1, and FRFA scenario 2 simulations

Figure 144. Model daily maximum temperature predictions upstream of the Newaukum River for current conditions: baseline, FRO with no vegetative shading, FRO with riparian shading, FRFA scenario 1, and FRFA scenario 2 simulations

Figure 145. Model daily maximum temperature predictions upstream of the Newaukum River for future conditions: baseline, FRO with no vegetative shading, FRO with riparian shading, FRFA scenario 1, and FRFA scenario 2 simulations

Figure 146. Model daily maximum temperature predictions upstream of the Skookumchuck River for current conditions: baseline, FRO with no vegetative shading, FRO with riparian shading, FRFA scenario 1, and FRFA scenario 2 simulations

Figure 147. Model daily maximum temperature predictions upstream of the Skookumchuck River for future conditions: baseline, FRO with no vegetative shading, FRO with riparian shading, FRFA scenario 1, and FRFA scenario 2 simulations

Figure 148. Model daily maximum temperature predictions upstream of the Black River for current conditions: baseline, FRO with no vegetative shading, FRO with riparian shading, FRFA scenario 1, and FRFA scenario 2 simulations

Figure 149. Model daily maximum temperature predictions upstream of the Black River for future conditions: baseline, FRO with no vegetative shading, FRO with riparian shading, FRFA scenario 1, and FRFA scenario 2 simulations

8.4. Water Quality Predictions

DO and nutrients during summer months are discussed in this section. The warmer summer months are when river water quality and fish health and habitat are of the greatest concern. The upstream boundary input constituents remained the same for all scenario runs. Updating the upstream boundary input constituents specific to each scenario would give more accurate water quality results. This will be implemented and these results will be updated as this project continues.

8.4.1. Dissolved Oxygen

Model predictions of DO concentrations were generally higher for the FRFA scenarios than the baseline and FRO scenarios upstream of the Skookumchuck River and upstream of the Newaukum River. The differences between the DO predictions for the scenarios was lowest at the most downstream station upstream of Black River.

The figures in this section contain model-predicted DO concentrations for baseline conditions, FRFA scenario 1, FRFA scenario 2, FRO scenario with riparian shading, and FRO scenario with no riparian shading. DO predictions for the scenarios for current conditions during summer 2013 are shown in Figure 150 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 151 for upstream of the Skookumchuck River and upstream of the Black River. DO predictions for the scenarios for current conditions during summer 2014 are shown in Figure 152 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 153 for

upstream of the Skookumchuck River and upstream of the Black River. DO predictions for the scenarios for future conditions during summer 2014 are shown in Figure 154 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 155 for upstream of the Skookumchuck River and upstream of the Black River.

Figure 150. Model DO predictions for current conditions during summer 2013 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 151. Model DO predictions for current conditions during summer 2013 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 152. Model DO predictions for current conditions during summer 2014 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 153. Model DO predictions for current conditions during summer 2014 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 154. Model DO predictions for future conditions during summer 2014 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 155. Model DO predictions for future conditions during summer 2014 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

8.4.2. Ammonia

Model-predicted NH₄ peaks for the baseline and FRO scenarios were generally higher than the FRFA scenarios at upstream of South Fork Chehalis River during baseline summer 2013 and summer 2014, though were lower during summer 2014 for future conditions. NH₄ values predicted by the model for upstream of the Newaukum River were slightly higher for the FRFA scenarios than the baseline and FRO scenarios during the baseline and future summer 2014 conditions, though the opposite was true during baseline conditions during summer 2013. The model predicted FRFA scenarios had slightly higher summer NO₃ values for baseline and future conditions at upstream of the Skookumchuck River compared to baseline and FRO scenarios.

The figures in this section contain ammonia model predictions for the scenarios: baseline conditions, FRFA scenario 1, FRFA scenario 2, FRO scenario with riparian shading, and FRO scenario with no riparian shading. NH₄ predictions for the scenarios for current conditions during summer 2013 are shown in Figure 156 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 157 for upstream of the Skookumchuck River and upstream of the Black River. NH₄ predictions for the scenarios for current conditions during summer 2014 are shown in Figure 158 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 159 for upstream of the Skookumchuck River and upstream of the Black River. NH₄ predictions for the scenarios for future conditions during summer 2014 are shown in Figure 160 for

upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 161 for upstream of the Skookumchuck River and upstream of the Black River.

Figure 156. Model NH4 predictions for current conditions during summer 2013 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 157. Model NH4 predictions for current conditions during summer 2013 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 158. Model NH₄ predictions for current conditions during summer 2014 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 159. Model NH4 predictions for current conditions during summer 2014 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 160. Model NH₄ predictions for future conditions during summer 2014 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 161. Model NH4 predictions for future conditions during summer 2014 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

8.4.3. Nitrate

Summer model predictions of NO₃ concentrations were generally higher for the baseline and FRO scenarios than the FRFA scenarios during baseline conditions in summer 2013. The FRFA scenarios had generally higher model predictions of NO₃ concentrations at upstream of the Newaukum River and upstream of the Skookumchuck River compared to baseline and FRO scenarios.

The figures in this section contain nitrate model predictions for the scenarios: baseline conditions, FRFA scenario 1, FRFA scenario 2, FRO scenario with riparian shading, and FRO scenario with no riparian shading. NO₃ predictions for the scenarios for current conditions during summer 2013 are shown in Figure 162 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 163 for upstream of the Skookumchuck River and upstream of the Black River. NO₃ predictions for the scenarios for current conditions during summer 2014 are shown in Figure 164 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 165 for upstream of the Skookumchuck River and upstream of the Black River. NO₃ predictions for the scenarios for future conditions during summer 2014 are shown in Figure 166 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 167 for upstream of the Skookumchuck River and upstream of the Black River.

Figure 162. Model NO₃ predictions for current conditions during summer 2013 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 163. Model NO₃ predictions for current conditions during summer 2013 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 164. Model NO₃ predictions for current conditions during summer 2014 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 165. Model NO₃ predictions for current conditions during summer 2014 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 166. Model NO₃ predictions for future conditions during summer 2014 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 167. Model NO₃ predictions for future conditions during summer 2014 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

8.4.4. Phosphate

Generally, model predictions of PO₄ had peaks slightly greater for the baseline and FRO scenarios than the FRFA scenarios for baseline and future conditions.

The figures in this section contain phosphate model predictions for the scenarios: baseline conditions, FRFA scenario 1, FRFA scenario 2, FRO scenario with riparian shading, and FRO scenario with no riparian shading. PO₄ predictions for the scenarios for current conditions during summer 2013 are shown in Figure 168 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 169 for upstream of the Skookumchuck River and upstream of the Black River. PO₄ predictions for the scenarios for current conditions during summer 2014 are shown in Figure 170 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 171 for upstream of the Skookumchuck River and upstream of the Black River. PO₄ predictions for the scenarios for future conditions during summer 2014 are shown in Figure 172 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 173 for upstream of the Skookumchuck River and upstream of the Black River.

Figure 168. Model PO4 predictions for current conditions during summer 2013 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 169. Model PO4 predictions for current conditions during summer 2013 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 170. Model PO4 predictions for current conditions during summer 2014 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 171. Model PO4 predictions for current conditions during summer 2014 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 172. Model PO4 predictions for future conditions during summer 2014 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 173. Model PO4 predictions for future conditions during summer 2014 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

8.4.5. Total Phosphorus

Similar to phosphate predictions, model predictions of TP were slightly greater for the baseline and FRO scenarios than the FRFA scenarios for baseline and future conditions.

The figures in this section contain total phosphorus model predictions for the scenarios: baseline conditions, FRFA scenario 1, FRFA scenario 2, FRO scenario with riparian shading, and FRO scenario with no riparian shading. TP predictions for the scenarios for current conditions during summer 2013 are shown in Figure 174 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 175 for upstream of the Skookumchuck River and upstream of the Black River. TP predictions for the scenarios for current conditions during summer 2014 are shown in Figure 176 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 177 for upstream of the Skookumchuck River and upstream of the Black River. TP predictions for the scenarios for future conditions during summer 2014 are shown in Figure 178 for upstream of the South Fork Chehalis River and upstream of the Newaukum River and Figure 179 for upstream of the Skookumchuck River and upstream of the Black River.

Figure 174. Model TP predictions for current conditions during summer 2013 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 175. Model TP predictions for current conditions during summer 2013 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 176. Model TP predictions for current conditions during summer 2014 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 177. Model TP predictions for current conditions during summer 2014 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 178. Model TP predictions for future conditions during summer 2014 at upstream of the South Fork Chehalis River and upstream of the Newaukum River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

Figure 179. Model TP predictions for future conditions during summer 2014 at upstream of the Skookumchuck River and upstream of the Black River for the scenarios: baseline, FRO with riparian shading, FRO with no shading, FRFA scenario 1, and FRFA scenario 2

9. Model Improvements

This section outlines methods in which the existing model can be improved.

9.1. Flow Data

More flow data are needed to reduce model uncertainty. Improved data regarding unmonitored withdrawals, rainfall overland flow, and groundwater interactions would increase understanding of how water is entering and leaving the system. Additional mainstem monitoring locations would allow for additional comparisons between model flow predictions and field data, allowing more certainty in model results. Additional mainstem monitoring would allow for more precise allocation of distributed flows throughout the model system. Many of the tributaries were completely unmonitored for flow. Monitoring these tributaries rather than estimating flows would be helpful for flow calibration.

9.2. Water Surface Elevation Datums

Datum verification for water surface elevations are necessary to improve model versus field data water level comparisons. Some of the locations with water surface elevation data had local datums that were not referenced to national standard datums, making it difficult to be sure the elevation data were referenced to the same datum as the model.

9.3. Temperature Data

Even though there were an abundance of temperature data in the Chehalis mainstem for 2013-2014, additional temperature monitoring would also be beneficial. Most of the temperature data sets did not span the entire model time period for the years 2013-2014. Many of the sites only had data for certain times in the year, for example only during the summer seasons. It would give a better understanding of the temperature dynamics if the data sets were more complete. Monitoring tributaries that had no temperature data, rather than estimating these values from another tributary, would also help improve temperature calibration.

9.4. Water Quality Data

More continuous water quality data for constituents such a dissolved oxygen, nutrients, algae, zooplankton, organic matter, etc. would be very beneficial. Much of the available water quality data for the mainstem Chehalis River and tributaries were data collected only at a couple times during the 2013-2014 calibration period. This makes it difficult to distinguish specific seasonal and diurnal trends. Without additional data it is impossible to verify that some of these single point values were outliers. Some useful data were missing entirely. For example, periphyton/epiphyton behavior were shown to have important impacts on dissolved oxygen and nutrient results.

The WWTPs have important impacts on many water quality constituents in the river. Many estimations and assumptions were required to fill data gaps for the WWTPs. Sometimes only monthly averages were available for certain constituents. Increased

frequency of data collection would be useful for improving model predictions since these discharges have an important impact on the river.

PH is a function of algae and epiphyton characteristics, temperature, total inorganic carbon, and alkalinity. Properly calibrated values of pH were impossible to achieve because of the lack of alkalinity data. The few mainstem river values available were not sufficient to approximate for all the tributaries entering the system.

A confirmation of quality of data for some constituents would be useful in determining how well the model is calibrated. For example, confirming the abrupt increase and fall of ammonia between the monitoring stations upstream of the Skookumchuck River and upstream of the Newaukum River.

A description of the wastewater involved in land application as an alternative to river discharges during low flow summer months would be useful for characterizing the distributed flows. Currently, the distributed flows use constituent data from a nearby tributary, though the distributed flows may have distinct water quality characteristics.

9.5. Model Grid Confirmation

Confirmation of the model grid location, including segments, locations of tributaries and monitoring stations' locations would be useful to model calibration. River mile values and coordinates associated with various tributaries and monitoring stations came from multiple sources. Some monitoring stations did not have any river mile value attached to them and were estimated based on maps. A cohesive set of river mile values and coordinates for the various inputs and monitoring stations would allow for more precise

calibration, especially for water surface elevation and vertical temperature and DO profile comparisons. These are very sensitive to segment location and can give very different results even when off by only a segment or two.

9.6. Meteorological Data

Improved meteorological data would be very useful for temperature and water quality calibration. Large meteorological data gaps often existed, as well as some data values outside a typical range for a given constituent. For example, while it is expected that specific days will have varied solar radiation values, the overall shape and magnitude of solar radiation over an entire year should be nearly the same from year to year. This was not true for any of the meteorological data sets in comparing solar radiation data sets for 2013 and 2014. Additionally, cloud cover data were only available from the Thrash Creek site near the upstream boundary, which is located at a higher elevation than the rest of the modeled system. Since cloud cover was seen to have a large impact on temperature calibration, a more complete view of the cloud cover throughout the basin would be useful. This would improve model vertical profile temperature results, and thus DO vertical profile predictions.

9.7. Bathymetry

In some cases, temperature was seen to be very sensitive to the bathymetry of the system, including segment widths and water depths. A more detailed look at specific segments, including comparing the model geometry to field data could improve model

predictions. Having as accurate a grid as possible that most represents the real river system would allow for more accurate calibration of flow and depths, temperature, and water quality constituents.

10. Conclusion

The Chehalis River was modeled using CE-QUAL-W2 Version 4.0 from the proposed dam site (river mile 108) to Porter, WA (river mile 33.3). The model was implemented from January 1, 2013 to December 31, 2014 for many state variables, including flow velocities, water level, temperature, dissolved oxygen, nutrients, algae, zooplankton, organic matter, and pH. Simulations with dam outflow scenarios and future climate conditions were conducted to aid in management strategies for the river. The river was discretized into 9 waterbodies, 10 branches, 322 segments of 400 m length, and 20 vertical layers per segment, each with a height of 1 m.

Data collected for meteorological conditions, bathymetry, shading, flow, water level, groundwater characteristics, temperature, and many water quality constituents were used for input data to the model as well as for calibration by comparing model predictions versus field data. Many agencies provided these data, including Washington State Department of Ecology, Anchor QEA, USGS, Washington Department of Fish and Wildlife, Thurston County, wastewater treatment plant operators, RAWs, CRBFA, and NOAA.

Distributed flows made it possible to take ungaged inflows and withdrawals into account. The model predicted flow agreed well with field data at the three monitoring station locations Doty, Grand Mound, and Porter, with absolute mean errors from 0.67 to 7.54 m³/s. These values could improve with additional fine tuning of flow calibration.

Water surface elevations from model predictions and field data were compared at Doty, Adna, at Chehalis WWTP, Centralia, Grand Mound, Rochester, and Porter, with

absolute mean errors from 0.29 to 3.1 m. Resolving uncertainty with the datums of some of the field gages could improve these values.

Temperature results were compared to field data on the river at many locations ranging from near the upstream boundary to the downstream boundary. Absolute mean error values ranged between 0.25 and 1.89 °C. These are expected to improve as this research continues, including as accurately estimating boundary condition temperature values as possible. Vertical profiles of temperatures predicted by the model compared to field data are also expected to improve as cloud cover and bathymetry adjustments are investigated.

Multiple water quality constituents were calibrated for through comparisons of model predictions and field data. This process was made more difficult due to a lack of water quality constituent field data for the mainstem Chehalis River, as well as the many tributaries. Hence, many estimations and approximations were made for model inputs. Due to lack of alkalinity data, pH could not be fully calibrated in the model. However, many constituents had good agreement between model predictions and field data, such as dissolved oxygen, nitrates, total phosphorus, and total suspended solids. Additional water quality data would allow for better model results. Improved temperature predictions would also improve water quality predictions, for example DO vertical profiles would be improved as vertical temperature profiles improve.

Multiple scenarios were applied to simulate potential dam implementation and operation strategies in order to assess their effects on water quality on the Chehalis river.

Future climate conditions were also applied to the baseline model and dam scenarios. Future climate conditions had model predicted daily maximum water temperature values greater than current conditions. The FRFA scenarios gave lower temperature predictions than the baseline and FRO scenarios. However, differences between temperature predictions for the various scenarios decreased moving downstream. DO concentrations were generally higher for the FRFA dam scenarios than the baseline and FRO scenarios. Nutrient predictions, such as ammonia, nitrate, phosphate, and total phosphorus, also varied with the scenarios. These results have important implications for fish health and habitat, especially during critical warm summer months when the river is prone to violating water quality standards.

As this project continues, improvements to model predictions are expected.

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Appendix – Model Control File

PSU W2 Model Version 4.0

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TITLE C .....TITLE.....
      Chehalis River

GRID      NWB      NBR      IMX      KMX      NPROC      CLOSEC
          9        10       322       22         1         OFF

IN/OUTFL   NTR      NST      NIW      NWD      NGT      NSP      NPI      NPU
        299         0         0         0         0         3         0         0

CONSTITU   NGC      NSS      NAL      NEP      NBOD      NMC      NZP
        11         2         2         1        10         0         1

MISCELL    NDAY SELECTC HABTATC ENVIRPC AERATEC INITUWL
        100      OFF      OFF      OFF      OFF      OFF      OFF

TIME CON   TMSTRT  TMEND      YEAR
        1.00000  730.000    2013

DLT CON     NDT    DLTMIN DLTINTR
        18      0.001     ON

DLT DATE    DLTG    DLTG    DLTG    DLTG    DLTG    DLTG    DLTG    DLTG    DLTG
        1.00000    6.0    45.0    150.0   165.0   245.0   265.0   315.0   320.0
          410.0   425.0   445.0   510.0   550.0   605.0   630.0   645.0   655.0

DLT MAX     DLTMAX DLTMAX DLTMAX DLTMAX DLTMAX DLTMAX DLTMAX DLTMAX DLTMAX
          5.0000    19.0    20.0    14.0    11.0     9.0     5.0    13.0    11.0
           3.0     7.0     2.0     9.0     9.0     5.0     3.0     4.0     9.0

DLT FRN     DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
        0.40000    0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6
           0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6

DLT LIM1    VISC    CELC
WB 1        ON      ON
WB 2        ON      ON
WB 3        ON      ON
WB 4        ON      ON
WB 5        ON      ON
WB 6        ON      ON
WB 7        ON      ON
WB 8        ON      ON
WB 9        ON      ON

BRANCH G    US      DS      UHS      DHS      UQB      DQB      NLMIN    SLOPE    SLOPEC
BR1         2        6        0        0        0        0        1 0.01600 0.00300
BR2         9       28        0        0        0        0        1 0.00200 0.00040
BR3        31       59        0        62        0        0        1 0.00200 0.00060
BR4        62      128       59      131        0        0      10.000950 0.00095
BR5       131      145      128      148        0        0      10.001182 0.00055
BR6       148      174      145      177        0        0      10.0000010 0.000001
BR7       177      193      174      196        0        0      10.0000010 0.000001
BR8       196      214      193      217        0        0      10.0005500 0.000550
BR9       217      282      214      285        0        0      10.0007690 0.000769
BR10      285      321      282        0        0        0        1 0.00077 0.00077

LOCATION     LAT      LONG      EBOT      BS      BE      JBDN
WB 1      46.54312123.3002 111.06      1        1        1
WB 2      46.61838123.2791  93.34      2        2        2
WB 3      46.55430123.3082  71.15      3        3        3
WB 4      46.64480123.1745  46.68      4        4        4
WB 5      46.66390122.9917  39.77      5        5        5
WB 6      46.70717122.9785  38.08      6        7        7

```

WB 7	46.80509123.1198	35.32	8	8	8
WB 8	46.8145 123.243	14.96	9	9	9
WB 9	46.94020123.3146	3.280	10	10	10

INIT CND	T2I	ICEI	WTYPEC	GRIDC
WB 1	5.00000	0.00000	FRESH	RECT
WB 2	5.00000	0.00000	FRESH	RECT
WB 3	5.00000	0.00000	FRESH	RECT
WB 4	5.00000	0.00000	FRESH	RECT
WB 5	5.00000	0.00000	FRESH	RECT
WB 6	5.00000	0.00000	FRESH	RECT
WB 7	5.00000	0.00000	FRESH	RECT
WB 8	5.00000	0.00000	FRESH	RECT
WB 9	5.00000	0.00000	FRESH	RECT

CALCULAT	VBC	EBC	MBC	PQC	EVC	PRC
WB 1	ON	ON	ON	OFF	ON	OFF
WB 2	ON	ON	ON	OFF	ON	OFF
WB 3	ON	ON	ON	OFF	ON	OFF
WB 4	ON	ON	ON	OFF	ON	OFF
WB 5	ON	ON	ON	OFF	ON	OFF
WB 6	ON	ON	ON	OFF	ON	OFF
WB 7	ON	ON	ON	OFF	ON	OFF
WB 8	ON	ON	ON	OFF	ON	OFF
WB 9	ON	ON	ON	OFF	ON	OFF

DEAD SEA	WINDC	QINC	QOUTC	HEATC
WB 1	ON	ON	ON	ON
WB 2	ON	ON	ON	ON
WB 3	ON	ON	ON	ON
WB 4	ON	ON	ON	ON
WB 5	ON	ON	ON	ON
WB 6	ON	ON	ON	ON
WB 7	ON	ON	ON	ON
WB 8	ON	ON	ON	ON
WB 9	ON	ON	ON	ON

INTERPOL	QINIC	DTRIC	HDIC
BR1	ON	ON	ON
BR2	ON	ON	ON
BR3	ON	ON	ON
BR4	ON	ON	ON
BR5	ON	ON	ON
BR6	ON	ON	ON
BR7	ON	ON	ON
BR8	ON	ON	ON
BR9	ON	ON	ON
BR10	ON	ON	ON

HEAT EXCH	SLHTC	SROC	RHEVAP	METIC	FETCHC	AFW	BFW	CFW	WINDH
WB 1	TERM	OFF	OFF	ON	OFF	4.50000	0.46000	2.00000	3.53600
WB 2	TERM	OFF	OFF	ON	OFF	4.50000	0.46000	2.00000	3.53600
WB 3	TERM	OFF	OFF	ON	OFF	4.50000	0.46000	2.00000	3.53600
WB 4	TERM	OFF	OFF	ON	OFF	4.50000	0.46000	2.00000	6.09600
WB 5	TERM	OFF	OFF	ON	OFF	4.50000	0.46000	2.00000	6.09600
WB 6	TERM	OFF	OFF	ON	OFF	4.50000	0.46000	2.00000	6.09600
WB 7	TERM	OFF	OFF	ON	OFF	4.50000	0.46000	2.00000	6.09600
WB 8	TERM	OFF	OFF	ON	OFF	4.50000	0.46000	2.00000	6.09600
WB 9	TERM	OFF	OFF	ON	OFF	4.50000	0.46000	2.00000	6.09600

ICE COVE	ICEC	SLICEC	ALBEDO	HWICE	BICE	GICE	ICEMIN	ICET2
WB 1	OFF	DETAIL	0.25000	10.0000	0.60000	0.07000	0.05000	3.00000
WB 2	OFF	DETAIL	0.25000	10.0000	0.60000	0.07000	0.05000	3.00000
WB 3	OFF	DETAIL	0.25000	10.0000	0.60000	0.07000	0.05000	3.00000
WB 4	OFF	DETAIL	0.25000	10.0000	0.60000	0.07000	0.05000	3.00000
WB 5	OFF	DETAIL	0.25000	10.0000	0.60000	0.07000	0.05000	3.00000
WB 6	OFF	DETAIL	0.25000	10.0000	0.60000	0.07000	0.05000	3.00000
WB 7	OFF	DETAIL	0.25000	10.0000	0.60000	0.07000	0.05000	3.00000

WB 8	OFF	DETAIL	0.25000	10.0000	0.60000	0.07000	0.05000	3.00000
WB 9	OFF	DETAIL	0.25000	10.0000	0.60000	0.07000	0.05000	3.00000

TRANSPOR	SLTRC	THETA
WB 1	ULTIMATE	0.55000
WB 2	ULTIMATE	0.55000
WB 3	ULTIMATE	0.55000
WB 4	ULTIMATE	0.55000
WB 5	ULTIMATE	0.55000
WB 6	ULTIMATE	0.55000
WB 7	ULTIMATE	0.55000
WB 8	ULTIMATE	0.55000
WB 9	ULTIMATE	0.55000

HYD COEF	AX	DX	CBHE	TSED	FI	TSEDF	FRICC	Z0
WB 1	1.00000	1.00000	0.30000	11.5000	0.01000	0.30000	MANN	0.00100
WB 2	1.00000	1.00000	0.30000	11.5000	0.01000	0.30000	MANN	0.00100
WB 3	1.00000	1.00000	0.30000	11.5000	0.01000	1.00000	MANN	0.00100
WB 4	1.00000	1.00000	0.30000	11.5000	0.01000	1.00000	MANN	0.00100
WB 5	1.00000	1.00000	0.30000	11.5000	0.01000	1.00000	MANN	0.00100
WB 6	1.00000	1.00000	0.30000	11.5000	0.01000	1.00000	MANN	0.00100
WB 7	1.00000	1.00000	0.30000	11.5000	0.01000	1.00000	MANN	0.00100
WB 8	1.00000	1.00000	0.30000	11.5000	0.01000	1.00000	MANN	0.00100
WB 9	1.00000	1.00000	0.30000	11.5000	0.01000	1.00000	MANN	0.00100

EDDY VISC	AZC	AZSLC	AZMAX	FBC	E	ARODI	STRCKLR	BOUNDFR	TKECAL
WB 1	TKE	IMP	1.00000	3	9.53500	0.43000	24.0000	10.0000	IMP
WB 2	TKE	IMP	1.00000	3	9.53500	0.43000	24.0000	10.0000	IMP
WB 3	TKE	IMP	1.00000	3	9.53500	0.43000	24.0000	10.0000	IMP
WB 4	TKE	IMP	1.00000	3	9.53500	0.43000	24.0000	10.0000	IMP
WB 5	TKE	IMP	1.00000	3	9.53500	0.43000	24.0000	10.0000	IMP
WB 6	TKE	IMP	1.00000	3	9.53500	0.43000	24.0000	10.0000	IMP
WB 7	TKE	IMP	1.00000	3	9.53500	0.43000	24.0000	10.0000	IMP
WB 8	TKE	IMP	1.00000	3	9.53500	0.43000	24.0000	10.0000	IMP
WB 9	TKE	IMP	1.00000	3	9.53500	0.43000	24.0000	10.0000	IMP

N STRUC	NSTR
BR1	0
BR2	0
BR3	0
BR4	0
BR5	0
BR6	0
BR7	0
BR8	0
BR9	0
BR10	0

STR INT	STRIC	STRIC	STRIC	STRIC	STRIC	STRIC	STRIC	STRIC	STRIC
BR1									
BR2									
BR3									
BR4									
BR5									
BR6									
BR7									
BR8									
BR9									
BR10									

STR TOP	KTSTR	KTSTR	KTSTR	KTSTR	KTSTR	KTSTR	KTSTR	KTSTR	KTSTR
BR1									
BR2									
BR3									
BR4									
BR5									
BR6									
BR7									

BR8										
BR9										
BR10										
STR BOT	KBSTR	KBSTR	KBSTR	KBSTR	KBSTR	KBSTR	KBSTR	KBSTR	KBSTR	KBSTR
BR1										
BR2										
BR3										
BR4										
BR5										
BR6										
BR7										
BR8										
BR9										
BR10										
STR SINK	SINKC	SINKC	SINKC	SINKC	SINKC	SINKC	SINKC	SINKC	SINKC	SINKC
BR1										
BR2										
BR3										
BR4										
BR5										
BR6										
BR7										
BR8										
BR9										
BR10										
STR ELEV	ESTR	ESTR	ESTR	ESTR	ESTR	ESTR	ESTR	ESTR	ESTR	ESTR
BR1										
BR2										
BR3										
BR4										
BR5										
BR6										
BR7										
BR8										
BR9										
BR10										
STR WIDT	WSTR	WSTR	WSTR	WSTR	WSTR	WSTR	WSTR	WSTR	WSTR	WSTR
BR1										
BR2										
BR3										
BR4										
BR5										
BR6										
BR7										
BR8										
BR9										
BR10										
PIPES	IUPI	IDPI	EUPI	EDPI	WPI	DLXPI	FPI	FMINPI	WTHLC	DYNPIPE
PIPE UP	PUPIC	ETUPI	EBUPI	KTUPI	KBUPI					
PIPE DOWN	PDPIC	ETDPI	EBDPI	KTDPI	KBDPI					
SPILLWAY	IUSP	IDSP	ESP	A1SP	B1SP	A2SP	B2SP	WTHLC		
SP 1	321	0	8.770	81.784	1.50000	431.41	1.50000	DOWN		
SP 2	28	31	95.84	47.169	1.50000	248.82	1.50000	DOWN		
SP 3	6	9	112.55	28.207	1.50000	154.07	1.50000	DOWN		
SPILL UP	PUSPC	ETUSP	EBUSP	KTUSP	KBUSP					
SP 1	DISTR	0.00000	0.00000	2	16					

SP 2	DISTR	0.00000	0.00000	2	19						
SP 3	DISTR	0.00000	0.00000	2	20						
SPILL DOWN	PDSPC	ETUSP	EBUSP	KTDSP	KBDSP						
SP 1	DISTR	0.00000	0.00000	0	0						
SP 2	DISTR	0.00000	0.00000	2	19						
SP 3	DISTR	0.00000	0.00000	2	19						
SPILL GAS	GASSPC	EQSP	AGASSP	BGASSP	CGASSP						
SP 1	OFF	0	0.00000	0.00000	0.00000						
SP 2	OFF	0	0.00000	0.00000	0.00000						
SP 3	OFF	0	0.00000	0.00000	0.00000						
GATES	IUGT	IDGT	EGT	A1GT	B1GT	G1GT	A2GT	B2GT	G2GT	WTHLC	
GATE WEIR	GTA1	GTB1	GTA2	GTB2	DYNVAR	GTIC					
GATE UP	PUGTC	ETUGT	EBUGT	KTUGT	KBUGT						
GATE DOWN	PDGTC	ETDGT	EBDGT	KTDGT	KBDGT						
GATE GAS	GASGTC	EQGT	AGASGT	BGASGT	CGASGT						
PUMPS 1	IUPU	IDPU	EPU	STRTPU	ENDPU	EONPU	EOFFPU	QPU	WTHLC	DYNPUMP	
PUMPS 2	PPUC	ETPU	EBPU	KTPU	KBPU						
WEIR SEG	IWR	IWR	IWR	IWR	IWR	IWR	IWR	IWR	IWR		
WEIR TOP	KTWR	KTWR	KTWR	KTWR	KTWR	KTWR	KTWR	KTWR	KTWR		
WEIR BOT	KBWR	KBWR	KBWR	KBWR	KBWR	KBWR	KBWR	KBWR	KBWR		
WD INT	WDIC	WDIC	WDIC	WDIC	WDIC	WDIC	WDIC	WDIC	WDIC		
WD SEG	IWD	IWD	IWD	IWD	IWD	IWD	IWD	IWD	IWD		
WD ELEV	EWD	EWD	EWD	EWD	EWD	EWD	EWD	EWD	EWD		
WD TOP	KTWD	KTWD	KTWD	KTWD	KTWD	KTWD	KTWD	KTWD	KTWD		
WD BOT	KBWD	KBWD	KBWD	KBWD	KBWD	KBWD	KBWD	KBWD	KBWD		
TRIB PLA	PTRC	PTRC	PTRC	PTRC	PTRC	PTRC	PTRC	PTRC	PTRC		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		
	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR	DISTR		

[illegible]

[illegible]

SNP	PRINT	SNPC	NSNP	NISNP
WB 1		ON	2	5
WB 2		ON	2	9
WB 3		ON	2	14
WB 4		ON	2	14

WB 5	ON	2	6
WB 6	ON	2	12
WB 7	ON	2	6
WB 8	ON	2	15
WB 9	ON	2	10

SNP DATE	SNPD	SNPD	SNPD	SNPD	SNPD	SNPD	SNPD	SNPD	SNPD
WB 1	1.0	2.0							
WB 2	1.0	2.0							
WB 3	1.0	2.0							
WB 4	1.0	2.0							
WB 5	1.0	2.0							
WB 6	1.0	2.0							
WB 7	1.0	2.0							
WB 8	1.0	2.0							
WB 9	1.0	2.0							

SNP FREQ	SNPF	SNPF	SNPF	SNPF	SNPF	SNPF	SNPF	SNPF	SNPF
WB 1	0.1	7.5							
WB 2	0.1	7.5							
WB 3	0.1	7.5							
WB 4	0.1	7.5							
WB 5	0.1	7.5							
WB 6	0.1	7.5							
WB 7	0.1	7.5							
WB 8	0.1	7.5							
WB 9	0.1	7.5							

SNP SEG	ISNP	ISNP	ISNP	ISNP	ISNP	ISNP	ISNP	ISNP	ISNP
WB 1	2	3	4	5	6				
WB 2	9	12	15	18	20	22	24	26	28
WB 3	32	34	36	38	40	42	44	46	48
	50	52	54	56	58				
WB 4	62	67	72	77	82	87	92	97	102
	107	112	117	122	127				
WB 5	131	134	137	140	143	145			
WB 6	148	155	160	165	170	172	174	177	180
	185	190	193						
WB 7	196	200	204	208	212	214			
WB 8	217	220	225	230	235	240	245	250	255
	260	265	270	275	280	282			
WB 9	285	290	295	300	305	310	315	317	319
	321								

SCR PRINT	SCRC	NSCR
WB 1	ON	1
WB 2	OFF	1
WB 3	OFF	1
WB 4	OFF	1
WB 5	OFF	1
WB 6	OFF	1
WB 7	OFF	1
WB 8	OFF	1
WB 9	OFF	1

SCR DATE	SCRD	SCRD	SCRD	SCRD	SCRD	SCRD	SCRD	SCRD	SCRD
WB 1	1.00000								
WB 2	1.00000								
WB 3	1.00000								
WB 4	1.00000								
WB 5	1.00000								
WB 6	1.00000								
WB 7	1.00000								
WB 8	1.00000								
WB 9	1.00000								

SCR FREQ	SCRF	SCRF	SCRF	SCRF	SCRF	SCRF	SCRF	SCRF	SCRF
WB 1	0.05000								

WB 2	0.50000
WB 3	0.50000
WB 4	0.50000
WB 5	0.50000
WB 6	0.50000
WB 7	0.50000
WB 8	0.50000
WB 9	0.50000

PRF PLOT	PRFC	NPRF	NIPRF
WB 1	ON	23	1
WB 2	OFF	0	0
WB 3	OFF	0	0
WB 4	OFF	0	0
WB 5	OFF	0	0
WB 6	OFF	0	0
WB 7	OFF	0	0
WB 8	OFF	0	0
WB 9	OFF	0	0

PRF DATE	PRFD	PRFD	PRFD	PRFD	PRFD	PRFD	PRFD	PRFD	PRFD
WB 1	100.0	200.0	218.38	218.5	218.71	260.38	260.5	260.71	300.0
	392.38	392.5	392.71	400.0	568.38	568.5	568.71	576.38	576.5
	576.71	577.0	577.5	600.0	650.0				

WB 2
WB 3
WB 4
WB 5
WB 6
WB 7
WB 8
WB 9

PRF FREQ	PRFF	PRFF	PRFF	PRFF	PRFF	PRFF	PRFF	PRFF	PRFF
WB 1	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0
	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0
	500.0	500.0	500.0	500.0	500.0				

WB 2
WB 3
WB 4
WB 5
WB 6
WB 7
WB 8
WB 9

PRF SEG	IPRF	IPRF	IPRF	IPRF	IPRF	IPRF	IPRF	IPRF	IPRF
WB 1	-1								
WB 2									
WB 3									
WB 4									
WB 5									
WB 6									
WB 7									
WB 8									
WB 9									

SPR PLOT	SPRC	NSPR	NISPR
WB 1	OFF	0	0
WB 2	OFF	0	0
WB 3	OFF	0	0
WB 4	OFF	0	0
WB 5	OFF	0	0
WB 6	ON	26	16
WB 7	OFF	0	0
WB 8	OFF	0	0
WB 9	OFF	0	0

SPR DATE	SPRD	SPRD	SPRD	SPRD	SPRD	SPRD	SPRD	SPRD	SPRD
WB 1									
WB 2									
WB 3									
WB 4									
WB 5									
WB 6	1.5	219.38	219.5	219.58	219.67	261.38	261.5	261.58	261.67
	569.38	569.5	569.58	569.67	577.27	577.31	577.33	577.35	577.37
	577.41	577.43	577.44	577.46	577.47	577.49	577.50	577.53	
WB 7									
WB 8									
WB 9									

SPR FREQ	SPRF	SPRF	SPRF	SPRF	SPRF	SPRF	SPRF	SPRF	SPRF
WB 1									
WB 2									
WB 3									
WB 4									
WB 5									
WB 6	1.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	
WB 7									
WB 8									
WB 9									

SPR SEG	ISPR	ISPR	ISPR	ISPR	ISPR	ISPR	ISPR	ISPR	ISPR
WB 1									
WB 2									
WB 3									
WB 4									
WB 5									
WB 6	149	150	153	157	158	160	162	164	166
	168	171	173	177	179	180	181		
WB 7									
WB 8									
WB 9									

VPL PLOT	VPLC	NVPL							
WB 1	OFF	0							
WB 2	OFF	0							
WB 3	OFF	0							
WB 4	OFF	0							
WB 5	OFF	0							
WB 6	OFF	0							
WB 7	OFF	0							
WB 8	OFF	0							
WB 9	OFF	0							

VPL DATE	VPLD	VPLD	VPLD	VPLD	VPLD	VPLD	VPLD	VPLD	VPLD
WB 1									
WB 2									
WB 3									
WB 4									
WB 5									
WB 6									
WB 7									
WB 8									
WB 9									

VPL FREQ	VPLF	VPLF	VPLF	VPLF	VPLF	VPLF	VPLF	VPLF	VPLF
WB 1									
WB 2									
WB 3									
WB 4									
WB 5									
WB 6									
WB 7									

WB 8										
WB 9										
CPL PLOT	CPLC	NCPL	TECPLOT							
WB 1	ON	1	OFF							
WB 2	ON	1	OFF							
WB 3	ON	1	OFF							
WB 4	ON	1	OFF							
WB 5	ON	1	OFF							
WB 6	ON	1	OFF							
WB 7	ON	1	OFF							
WB 8	ON	1	OFF							
WB 9	ON	1	OFF							
CPL DATE	CPLD	CPLD	CPLD	CPLD	CPLD	CPLD	CPLD	CPLD	CPLD	CPLD
WB 1	1.0									
WB 2	1.0									
WB 3	1.0									
WB 4	1.0									
WB 5	1.0									
WB 6	1.0									
WB 7	1.0									
WB 8	1.0									
WB 9	1.0									
CPL FREQ	CPLF	CPLF	CPLF	CPLF	CPLF	CPLF	CPLF	CPLF	CPLF	CPLF
WB 1	30.0									
WB 2	30.0									
WB 3	30.0									
WB 4	30.0									
WB 5	30.0									
WB 6	30.0									
WB 7	30.0									
WB 8	30.0									
WB 9	30.0									
FLUXES	FLXC	NFLX								
WB 1	ON	1								
WB 2	ON	1								
WB 3	ON	1								
WB 4	ON	1								
WB 5	ON	1								
WB 6	ON	1								
WB 7	ON	1								
WB 8	ON	1								
WB 9	ON	1								
FLX DATE	FLXD	FLXD	FLXD	FLXD	FLXD	FLXD	FLXD	FLXD	FLXD	FLXD
WB 1	1.0									
WB 2	1.0									
WB 3	1.0									
WB 4	1.0									
WB 5	1.0									
WB 6	1.0									
WB 7	1.0									
WB 8	1.0									
WB 9	1.0									
FLX FREQ	FLXF	FLXF	FLXF	FLXF	FLXF	FLXF	FLXF	FLXF	FLXF	FLXF
WB 1	30.0									
WB 2	30.0									
WB 3	30.0									
WB 4	30.0									
WB 5	30.0									
WB 6	30.0									
WB 7	30.0									
WB 8	30.0									
WB 9	30.0									

TSR PLOT	TSRC ON	NTSR 2	NITSR 78						
TSR DATE	TSRD 1.0	TSRD 2.00	TSRD	TSRD	TSRD	TSRD	TSRD	TSRD	TSRD
TSR FREQ	TSRF 0.1	TSRF 0.1	TSRF 0.1	TSRF 0.1	TSRF	TSRF	TSRF	TSRF	TSRF
TSR SEG	ITSR 321 15 80 35 287 19 42 220 267	ITSR 57 149 105 78 43 47 74 226 271	ITSR 32 150 124 122 81 145 89 233 275	ITSR 97 144 156 170 149 213 110 239 281	ITSR 150 238 192 12 180 249 133 245 302	ITSR 181 84 95 24 36 36 162 249 320	ITSR 213 125 103 50 64 119 186 253	ITSR 238 198 124 81 155 223 198 258	ITSR 321 48 141 196 4 250 208 263
TSR LAYE	ETSR 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	ETSR 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	ETSR 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	ETSR 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	ETSR 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	ETSR 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	ETSR 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	ETSR 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	ETSR 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
WITH OUT	WDOC ON	NWDO 1	NIWDO 9						
WITH DAT	WDOD 1.0	WDOD	WDOD	WDOD	WDOD	WDOD	WDOD	WDOD	WDOD
WITH FRE	WDOF 0.1	WDOF	WDOF	WDOF	WDOF	WDOF	WDOF	WDOF	WDOF
WITH SEG	IWDO 321	IWDO 28	IWDO 174	IWDO 282	IWDO 193	IWDO 59	IWDO 145	IWDO 128	IWDO 6
RESTART	RSOC ON	NRSO 1	RSIC ON						
RSO DATE	RSOD 20.0	RSOD	RSOD	RSOD	RSOD	RSOD	RSOD	RSOD	RSOD
RSO FREQ	RSOF 20.0	RSOF	RSOF	RSOF	RSOF	RSOF	RSOF	RSOF	RSOF
CST COMP	CCC ON	LIMC OFF	CUF 20						
CST ACTIVE	CAC								
TDS	ON								
Gen1	ON								
Gen2	ON								
Gen3	ON								
Gen4	OFF								
Gen5	OFF								
Gen6	OFF								
Gen7	OFF								
Gen8	OFF								
Gen9	OFF								
Gen10	OFF								

Gen11	OFF
ISS1	OFF
ISS2	ON
PO4	ON
NH4	ON
NO3	ON
DSI	OFF
PSI	OFF
FE	OFF
LDOM	ON
RDOM	ON
LPOM	ON
RPOM	ON
BOD1	ON
BOD2	ON
BOD3	ON
BOD4	ON
BOD5	ON
BOD6	ON
BOD7	ON
BOD8	ON
BOD9	ON
BOD10	ON
BODP1	ON
BODP2	ON
BODP3	ON
BODP4	ON
BODP5	ON
BODP6	ON
BODP7	ON
BODP8	ON
BODP9	ON
BODP10	ON
BODN1	ON
BODN2	ON
BODN3	ON
BODN4	ON
BODN5	ON
BODN6	ON
BODN7	ON
BODN8	ON
BODN9	ON
BODN10	ON
ALG1	ON
ALG2	ON
DO	ON
TIC	ON
ALK	ON
ZOO1	ON
LDOM-P	ON
RDOM-P	ON
LPOM-P	ON
RPOM-P	ON
LDOM-N	ON
RDOM-N	ON
LPOM-N	ON
RPOM-N	ON

CST	DERI	CDWBC	CDWBC	CDWBC	CDWBC	CDWBC	CDWBC	CDWBC	CDWBC	CDWBC
DOC		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
POC		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
TOC		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
DON		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
PON		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
TON		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
TKN		ON	ON	ON	ON	ON	ON	ON	ON	ON
TN		ON	ON	ON	ON	ON	ON	ON	ON	ON
DOP		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

POP	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
TOP	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
TP	ON	ON	ON	ON	ON	ON	ON	ON	ON
APR	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
CHLA	ON	ON	ON	ON	ON	ON	ON	ON	ON
ATOT	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
%DO	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
TSS	ON	ON	ON	ON	ON	ON	ON	ON	ON
TISS	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
CBOD	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
pH	ON	ON	ON	ON	ON	ON	ON	ON	ON
CO2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
HCO3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
CO3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

CST FLUX	CFWBC	CFWBC	CFWBC	CFWBC	CFWBC	CFWBC	CFWBC	CFWBC	CFWBC
TISSIN	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
TISSOUT	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
PO4AR	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4AG	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4AP	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4ER	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4EG	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4EP	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4POM	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4DOM	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4OM	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4SED	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4SOD	ON	ON	ON	ON	ON	ON	ON	ON	ON
PO4SET	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4NITR	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4AR	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4AG	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4AP	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4ER	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4EG	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4EP	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4POM	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4DOM	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4OM	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4SED	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4SOD	ON	ON	ON	ON	ON	ON	ON	ON	ON
NO3DEN	ON	ON	ON	ON	ON	ON	ON	ON	ON
NO3AG	ON	ON	ON	ON	ON	ON	ON	ON	ON
NO3EG	ON	ON	ON	ON	ON	ON	ON	ON	ON
NO3SED	ON	ON	ON	ON	ON	ON	ON	ON	ON
DSIAG	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
DSIEG	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
DSIPIS	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
DSISED	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
DSISOD	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
DSISET	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
PSIAM	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
PSINET	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
PSIDK	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
FESET	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
FESED	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LDOMDK	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LRDOM	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
RDOMDK	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LDOMAP	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LDOMEF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LPOMDK	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LRPOM	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
RPOMDK	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LPOMAP	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LPOMEF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LPOMSET	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

BODN2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
BODN3	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
BODN4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
BODN5	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
BODN6	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
BODN7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
BODN8	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
BODN9	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
BODN10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
ALG1	0.10000	0.10000	0.10000	0.10000	0.10000	0.10000	0.10000	0.10000	0.10000
ALG2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
DO	6.14000	6.14000	6.14000	6.14000	6.14000	6.14000	6.14000	6.14000	6.14000
TIC	5.13000	5.13000	5.13000	5.13000	5.13000	5.13000	5.13000	5.13000	5.13000
ALK	16.5050	16.5050	16.5050	16.5050	16.5050	16.5050	16.5050	16.5050	16.5050
ZOO1	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000
LDOM-P	0.00589	0.00589	0.00589	0.00589	0.00589	0.00589	0.00589	0.00589	0.00589
RDOM-P	0.00589	0.00589	0.00589	0.00589	0.00589	0.00589	0.00589	0.00589	0.00589
LPOM-P	0.00169	0.00169	0.00169	0.00169	0.00169	0.00169	0.00169	0.00169	0.00169
RPOM-P	0.00169	0.00169	0.00169	0.00169	0.00169	0.00169	0.00169	0.00169	0.00169
LDOM-N	0.32450	0.32450	0.32450	0.32450	0.32450	0.32450	0.32450	0.32450	0.32450
RDOM-N	0.32450	0.32450	0.32450	0.32450	0.32450	0.32450	0.32450	0.32450	0.32450
LPOM-N	0.07350	0.07350	0.07350	0.07350	0.07350	0.07350	0.07350	0.07350	0.07350
RPOM-N	0.07350	0.07350	0.07350	0.07350	0.07350	0.07350	0.07350	0.07350	0.07350

CST PRIN	CPRWBC	CPRWBC	CPRWBC	CPRWBC	CPRWBC	CPRWBC	CPRWBC	CPRWBC	CPRWBC
TDS	ON	ON	ON	ON	ON	ON	ON	ON	ON
Gen1	ON	ON	ON	ON	ON	ON	ON	ON	ON
Gen2	ON	ON	ON	ON	ON	ON	ON	ON	ON
Gen3	ON	ON	ON	ON	ON	ON	ON	ON	ON
Gen4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen5	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen6	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen7	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen8	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen9	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen11	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
ISS1	ON	ON	ON	ON	ON	ON	ON	ON	ON
ISS2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
PO4	ON	ON	ON	ON	ON	ON	ON	ON	ON
NH4	ON	ON	ON	ON	ON	ON	ON	ON	ON
NO3	ON	ON	ON	ON	ON	ON	ON	ON	ON
DSI	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
PSI	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
FE	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LDOM	ON	ON	ON	ON	ON	ON	ON	ON	ON
RDOM	ON	ON	ON	ON	ON	ON	ON	ON	ON
LPOM	ON	ON	ON	ON	ON	ON	ON	ON	ON
RPOM	ON	ON	ON	ON	ON	ON	ON	ON	ON
BOD1	ON	ON	ON	ON	ON	ON	ON	ON	ON
BOD2	ON	ON	ON	ON	ON	ON	ON	ON	ON
BOD3	ON	ON	ON	ON	ON	ON	ON	ON	ON
BOD4	ON	ON	ON	ON	ON	ON	ON	ON	ON
BOD5	ON	ON	ON	ON	ON	ON	ON	ON	ON
BOD6	ON	ON	ON	ON	ON	ON	ON	ON	ON
BOD7	ON	ON	ON	ON	ON	ON	ON	ON	ON
BOD8	ON	ON	ON	ON	ON	ON	ON	ON	ON
BOD9	ON	ON	ON	ON	ON	ON	ON	ON	ON
BOD10	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODP1	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODP2	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODP3	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODP4	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODP5	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODP6	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODP7	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODP8	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODP9	ON	ON	ON	ON	ON	ON	ON	ON	ON

BODP10	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODN1	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODN2	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODN3	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODN4	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODN5	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODN6	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODN7	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODN8	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODN9	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
BODN10	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
ALG1	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
ALG2	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
DO	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
TIC	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
ALK	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
ZOO1	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
LDOM-P	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
RDOM-P	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
LPOM-P	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
RPOM-P	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
LDOM-N	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
RDOM-N	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
LPOM-N	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
RPOM-N	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
CIN CON	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC
TDS	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen1	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen2	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen3	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen5	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen6	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen7	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen8	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen9	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Gen11	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
ISS1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
ISS2	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
PO4	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
NH4	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
NO3	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
DSI	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
PSI	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
FE	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
LDOM	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

	OFF								
RDOM	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
LPOM	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
RPOM	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD5	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD6	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD7	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD8	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD9	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP5	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP6	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP7	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP8	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP9	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN5	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN6	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN7	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN8	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN9	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
ALG1	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

[illegible]

[illegible]

Gen3

[illegible]

[illegible]

[illegible]

[illegible]

RPOM-P

[illegible]

RDOM-N

[illegible]

RPOM-N

[illegible]

FE	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
	OFF								
LDM	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
RDM	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
LPOM	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
RPOM	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BOD1	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BOD2	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BOD3	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BOD4	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BOD5	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BOD6	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BOD7	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BOD8	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BOD9	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BOD10	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODP1	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODP2	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODP3	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODP4	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODP5	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODP6	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODP7	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODP8	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODP9	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODP10	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODN1	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODN2	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODN3	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODN4	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODN5	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODN6	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODN7	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODN8	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
BODN9	ON	ON	ON	ON	ON	ON	ON	ON	ON

	ON								
BODN10	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
ALG1	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
ALG2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
DO	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
TIC	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
ALK	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
ZOO1	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
LDM-P	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
RDM-P	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
LPOM-P	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
RPOM-P	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
LDM-N	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
RDM-N	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
LPOM-N	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
RPOM-N	ON	ON	ON	ON	ON	ON	ON	ON	ON
	ON								
CPR CON	CPRBRC	CPRBRC	CPRBRC	CPRBRC	CPRBRC	CPRBRC	CPRBRC	CPRBRC	CPRBRC
TDS	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen5	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen6	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen7	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen8	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen9	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
Gen11	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
ISS1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
ISS2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
PO4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
NH4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
NO3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
DSI	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

	OFF								
PSI	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
FE	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
LDOM	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
RDOM	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
LPOM	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
RPOM	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD5	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD6	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD7	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD8	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD9	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BOD10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP5	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP6	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP7	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP8	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP9	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODP10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN3	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN5	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN6	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN7	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
BODN8	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

BODN9	OFF								
	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
BODN10	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
ALG1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
ALG2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
DO	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
TIC	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
ALK	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
ZOO1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
LDOM-P	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
RDOM-P	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
LPOM-P	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
RPOM-P	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
LDOM-N	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
RDOM-N	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
LPOM-N	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
RPOM-N	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	OFF								
EX COEF	EXH2O	EXSS	EXOM	BETA	EXC	EXIC			
WB 1	0.25000	0.20000	0.20000	0.45000	OFF	OFF			
WB 2	0.25000	0.20000	0.20000	0.45000	OFF	OFF			
WB 3	0.25000	0.20000	0.20000	0.45000	OFF	OFF			
WB 4	0.25000	0.20000	0.20000	0.45000	OFF	OFF			
WB 5	0.25000	0.20000	0.20000	0.45000	OFF	OFF			
WB 6	0.25000	0.20000	0.20000	0.45000	OFF	OFF			
WB 7	0.25000	0.20000	0.20000	0.45000	OFF	OFF			
WB 8	0.25000	0.20000	0.20000	0.45000	OFF	OFF			
WB 9	0.25000	0.20000	0.20000	0.45000	OFF	OFF			
ALG EX	EXA	EXA	EXA	EXA	EXA	EXA			
	0.20000	0.20000							
ZOO EX	EXZ	EXZ	EXZ	EXZ	EXZ	EXZ			
	0.20000								
MACRO EX	EXM	EXM	EXM	EXM	EXM	EXM			
	0.01000								
GENERIC	CGQ10	CG0DK	CG1DK	CGS					
CG 1	0.00000	0.00000	0.00000	0.00000					
CG 2	0.00000	-1.00000	0.00000	0.00000					
CG 3	0.00000	0.00000	0.00000	0.00000					
CG 4	0.00000	0.00000	0.00000	0.00000					
CG 5	0.00000	0.00000	0.00000	0.00000					
CG 6	0.00000	0.00000	0.00000	0.00000					
CG 7	0.00000	0.00000	0.00000	0.00000					
CG 8	0.00000	0.00000	0.00000	0.00000					
CG 9	0.00000	0.00000	0.00000	0.00000					
CG 10	0.00000	0.00000	0.00000	0.00000					
CG 11	0.00000	0.00000	0.00000	0.00000					
S SOLIDS	SSS	SEDRC	TAUCR						

SS# 1	1.00000	OFF	1.00000							
SS# 2	1.00000	OFF	1.00000							

ALGAL RATE	AG	AR	AE	AM	AS	AHSP	AHSN	AHSSI	ASAT	
ALG1	1.50000	0.04000	0.04000	0.10000	0.10000	0.00300	0.01400	0.00000	150.000	
ALG2	2.00000	0.04000	0.04000	0.10000	0.10000	0.00300	0.01400	0.00000	150.000	

ALGAL TEMP	AT1	AT2	AT3	AT4	AK1	AK2	AK3	AK4		
ALG1	3.00000	7.00000	20.0000	30.0000	0.10000	0.99000	0.99000	0.10000		
ALG2	7.00000	15.0000	30.0000	35.0000	0.10000	0.99000	0.99000	0.10000		

ALG STOI	ALGP	ALGN	ALGC	ALGSI	ACHLA	ALPOM	ANEQN	ANPR		
ALG1	0.01000	0.08000	0.50000	0.18000	0.05000	0.80000	1	0.00100		
ALG2	0.01000	0.08000	0.50000	0.18000	0.05000	0.80000	1	0.00100		

EPIPHYTE	EPIC	EPIC	EPIC	EPIC	EPIC	EPIC	EPIC	EPIC	EPIC	
EPI1	ON	ON	ON	ON	ON	ON	ON	ON	ON	

EPI PRIN	EPRC	EPRC	EPRC	EPRC	EPRC	EPRC	EPRC	EPRC	EPRC	
EPI1	ON	ON	ON	ON	ON	ON	ON	ON	ON	

EPI INIT	EPICI	EPICI	EPICI	EPICI	EPICI	EPICI	EPICI	EPICI	EPICI	
EPI1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	

EPI RATE	EG	ER	EE	EM	EB	EHSP	EHSN	EHSSI		
EPI1	1.50000	0.04000	0.04000	0.05000	0.00100	0.00300	0.01400	0.00000		

EPI HALF	ESAT	EHS	ENEQN	ENPR						
EPI1	150.000	5.00000	1	0.00400						

EPI TEMP	ET1	ET2	ET3	ET4	EK1	EK2	EK3	EK4		
EPI1	5.00000	10.0000	25.0000	35.0000	0.10000	0.99000	0.99000	0.10000		

EPI STOI	EP	EN	EC	ESI	ECHLA	EPOM				
EPI1	0.01000	0.06000	0.50000	0.18000	0.05000	0.80000				

ZOOP RATE	ZG	ZR	ZM	ZEFF	PREFP	ZOOMIN	ZS2P			
Zoo1	1.00000	0.10000	0.20000	0.50000	0.50000	0.01000	0.30000			

ZOOP ALGP	PREFA	PREFA	PREFA	PREFA	PREFA	PREFA	PREFA	PREFA	PREFA	
Zoo1	0.50000									

ZOOP ZOOP	PREFZ	PREFZ	PREFZ	PREFZ	PREFZ	PREFZ	PREFZ	PREFZ	PREFZ	
Zoo1	0.00000									

ZOOP TEMP	ZT1	ZT2	ZT3	ZT4	ZK1	ZK2	ZK3	ZK4		
Zoo1	5.00000	25.0000	35.0000	40.0000	0.10000	0.99000	0.99000	0.10000		

ZOOP STOI	ZP	ZN	ZC							
Zoo1	0.00500	0.08000	0.45000							

MACROPHY	MACWBC	MACWBC	MACWBC	MACWBC	MACWBC	MACWBC	MACWBC	MACWBC	MACWBC	
Mac1	OFF	OFF								

MAC PRIN	MPRWBC	MPRWBC	MPRWBC	MPRWBC	MPRWBC	MPRWBC	MPRWBC	MPRWBC	MPRWBC	
Mac1	OFF	OFF								

MAC INI	MACWBCI	MACWBCI	MACWBCI	MACWBCI	MACWBCI	MACWBCI	MACWBCI	MACWBCI	MACWBCI	
Mac1	0.00000	0.00000								

MAC RATE	MG	MR	MM	MSAT	MHSP	MHSN	MHSC	MPOM	LRPMAC	
Mac1	0.30000	0.05000	0.05000	30.0000	0.00000	0.00000	0.00000	0.90000	0.20000	

MAC SED	PSED	NSED								
Mac1	1.00000	1.00000								

MAC DIST	MBMP	MMAX								
Mac1	40.0000	500.000								

MAC DRAG	CDDRAG	DMV	DWSA	ANORM
Mac1	2.00000	70000.0	8.00000	0.30000

MAC TEMP	MT1	MT2	MT3	MT4	MK1	MK2	MK3	MK4
Mac1	5.00000	25.0000	35.0000	40.0000	0.10000	0.99000	0.99000	0.10000

MAC STOICH	MP	MN	MC
Mac1	0.00500	0.08000	0.45000

DOM	LDOMDK	RDOMDK	LRDDK
WB 1	0.08000	0.00100	0.01000
WB 2	0.08000	0.00100	0.01000
WB 3	0.08000	0.00100	0.01000
WB 4	0.08000	0.00100	0.01000
WB 5	0.08000	0.00100	0.01000
WB 6	0.08000	0.00100	0.01000
WB 7	0.08000	0.00100	0.01000
WB 8	0.08000	0.00100	0.01000
WB 9	0.08000	0.00100	0.01000

POM	LPOMDK	RPOMDK	LRPDK	POMS
WB 1	0.06000	0.00100	0.01000	0.07500
WB 2	0.06000	0.00100	0.01000	0.07500
WB 3	0.06000	0.00100	0.01000	0.07500
WB 4	0.06000	0.00100	0.01000	0.07500
WB 5	0.06000	0.00100	0.01000	0.07500
WB 6	0.06000	0.00100	0.01000	0.07500
WB 7	0.06000	0.00100	0.01000	0.07500
WB 8	0.06000	0.00100	0.01000	0.07500
WB 9	0.06000	0.00100	0.01000	0.07500

OM STOIC	ORGP	ORGN	ORGC	ORGS
WB 1	0.00500	0.08000	0.45000	0.18000
WB 2	0.00500	0.08000	0.45000	0.18000
WB 3	0.00500	0.08000	0.45000	0.18000
WB 4	0.00500	0.08000	0.45000	0.18000
WB 5	0.00500	0.08000	0.45000	0.18000
WB 6	0.00500	0.08000	0.45000	0.18000
WB 7	0.00500	0.08000	0.45000	0.18000
WB 8	0.00500	0.08000	0.45000	0.18000
WB 9	0.00500	0.08000	0.45000	0.18000

OM RATE	OMT1	OMT2	OMK1	OMK2
WB 1	4.00000	25.0000	0.10000	0.99000
WB 2	4.00000	25.0000	0.10000	0.99000
WB 3	4.00000	25.0000	0.10000	0.99000
WB 4	4.00000	25.0000	0.10000	0.99000
WB 5	4.00000	25.0000	0.10000	0.99000
WB 6	4.00000	25.0000	0.10000	0.99000
WB 7	4.00000	25.0000	0.10000	0.99000
WB 8	4.00000	25.0000	0.10000	0.99000
WB 9	4.00000	25.0000	0.10000	0.99000

CBOD	KBOD	TBOD	RBOD	CBODS
BOD 1	0.02000	1.02000	1.00000	0.00000
BOD 2	0.02000	1.02000	1.00000	0.03000
BOD 3	0.02000	1.02000	1.00000	0.00000
BOD 4	0.02000	1.02000	1.00000	0.03000
BOD 5	0.02000	1.02000	1.00000	0.00000
BOD 6	0.02000	1.02000	1.00000	0.03000
BOD 7	0.02000	1.02000	1.00000	0.00000
BOD 8	0.02000	1.02000	1.00000	0.03000
BOD 9	0.02000	1.02000	1.00000	0.00000
BOD 10	0.02000	1.02000	1.00000	0.03000

CBOD STOIC	BODP	BODN	BODC
BOD 1	0.00400	0.06000	0.32000

BOD 2	0.00400	0.06000	0.32000
BOD 3	0.00400	0.06000	0.32000
BOD 4	0.00400	0.06000	0.32000
BOD 5	0.00400	0.06000	0.32000
BOD 6	0.00400	0.06000	0.32000
BOD 7	0.00400	0.06000	0.32000
BOD 8	0.00400	0.06000	0.32000
BOD 9	0.00400	0.06000	0.32000
BOD 10	0.00400	0.06000	0.32000

PHOSPHOR	PO4R	PARTP
WB 1	0.00100	0.00000
WB 2	0.00100	0.00000
WB 3	0.00100	0.00000
WB 4	0.00100	0.00000
WB 5	0.00100	0.00000
WB 6	0.00100	0.00000
WB 7	0.00100	0.00000
WB 8	0.00100	0.00000
WB 9	0.00100	0.00000

AMMONIUM	NH4R	NH4DK
WB 1	0.00100	0.80000
WB 2	0.00100	0.80000
WB 3	0.00100	0.80000
WB 4	0.00100	0.80000
WB 5	0.00100	0.80000
WB 6	0.00100	0.80000
WB 7	0.00100	0.80000
WB 8	0.00100	0.80000
WB 9	0.00100	0.80000

NH4 RATE	NH4T1	NH4T2	NH4K1	NH4K2
WB 1	5.00000	25.0000	0.10000	0.99000
WB 2	5.00000	25.0000	0.10000	0.99000
WB 3	5.00000	25.0000	0.10000	0.99000
WB 4	5.00000	25.0000	0.10000	0.99000
WB 5	5.00000	25.0000	0.10000	0.99000
WB 6	5.00000	25.0000	0.10000	0.99000
WB 7	5.00000	25.0000	0.10000	0.99000
WB 8	5.00000	25.0000	0.10000	0.99000
WB 9	5.00000	25.0000	0.10000	0.99000

NITRATE	NO3DK	NO3S	FNO3SED
WB 1	0.03000	0.00100	0.00000
WB 2	0.03000	0.00100	0.00000
WB 3	0.03000	0.00100	0.00000
WB 4	0.03000	0.00100	0.00000
WB 5	0.03000	0.00100	0.00000
WB 6	0.03000	0.00100	0.00000
WB 7	0.03000	0.00100	0.00000
WB 8	0.03000	0.00100	0.00000
WB 9	0.03000	0.00100	0.00000

NO3 RATE	NO3T1	NO3T2	NO3K1	NO3K2
WB 1	5.00000	25.0000	0.10000	0.99000
WB 2	5.00000	25.0000	0.10000	0.99000
WB 3	5.00000	25.0000	0.10000	0.99000
WB 4	5.00000	25.0000	0.10000	0.99000
WB 5	5.00000	25.0000	0.10000	0.99000
WB 6	5.00000	25.0000	0.10000	0.99000
WB 7	5.00000	25.0000	0.10000	0.99000
WB 8	5.00000	25.0000	0.10000	0.99000
WB 9	5.00000	25.0000	0.10000	0.99000

SILICA	DSIR	PSIS	PSIDK	PARTSI
WB 1	0.10000	1.00000	0.30000	0.00000
WB 2	0.10000	1.00000	0.30000	0.00000

WB 3	0.10000	1.00000	0.30000	0.00000
WB 4	0.10000	1.00000	0.30000	0.00000
WB 5	0.10000	1.00000	0.30000	0.00000
WB 6	0.10000	1.00000	0.30000	0.00000
WB 7	0.10000	1.00000	0.30000	0.00000
WB 8	0.10000	1.00000	0.30000	0.00000
WB 9	0.10000	1.00000	0.30000	0.00000

IRON	FER	FES
WB 1	0.50000	2.00000
WB 2	0.50000	2.00000
WB 3	0.50000	2.00000
WB 4	0.50000	2.00000
WB 5	0.50000	2.00000
WB 6	0.50000	2.00000
WB 7	0.50000	2.00000
WB 8	0.50000	2.00000
WB 9	0.50000	2.00000

SED CO2	CO2R
WB 1	1.20000
WB 2	1.20000
WB 3	1.20000
WB 4	1.20000
WB 5	1.20000
WB 6	1.20000
WB 7	1.20000
WB 8	1.20000
WB 9	1.20000

STOICH 1	O2NH4	O2OM
WB 1	4.57000	1.40000
WB 2	4.57000	1.40000
WB 3	4.57000	1.40000
WB 4	4.57000	1.40000
WB 5	4.57000	1.40000
WB 6	4.57000	1.40000
WB 7	4.57000	1.40000
WB 8	4.57000	1.40000
WB 9	4.57000	1.40000

STOICH 2	O2AR	O2AG
ALG1	1.10000	1.60000
ALG2	1.10000	1.60000

STOICH 3	O2ER	O2EG
EPI1	1.10000	1.60000

STOICH 4	O2ZR
Zoop1	1.10000

STOICH 5	O2MR	O2MG
Mac1	1.10000	1.40000

O2 LIMIT	O2LIM
	0.07000

SEDIMENT	SEDC	SEDPRC	SEDCI	SEDK	SEDS	FSOD	FSOD	SEDBR	DYNSDK
WB 1	ON	ON	0.00000	0.03000	0.10000	1.00000	1.00000	0.01000	OFF
WB 2	ON	ON	0.00000	0.03000	0.10000	1.00000	1.00000	0.01000	OFF
WB 3	ON	ON	0.00000	0.03000	0.10000	1.00000	1.00000	0.01000	OFF
WB 4	ON	ON	0.00000	0.03000	0.10000	1.00000	1.00000	0.01000	OFF
WB 5	ON	ON	0.00000	0.03000	0.10000	1.00000	1.00000	0.01000	OFF
WB 6	ON	ON	0.00000	0.03000	0.10000	1.00000	1.00000	0.01000	OFF
WB 7	ON	ON	0.00000	0.03000	0.10000	1.00000	1.00000	0.01000	OFF
WB 8	ON	ON	0.00000	0.03000	0.10000	1.00000	1.00000	0.01000	OFF
WB 9	ON	ON	0.00000	0.03000	0.10000	1.00000	1.00000	0.01000	OFF

[illegible]

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RSI FILE.....RSIFN.....
      rsi.npt

QWD FILE.....QWDFN.....
      qwd.npt - not used

QGT FILE.....QGTFN.....
      qgt.npt - not used

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WSC FILE.....WSCFN.....
    wsc.npt

SHD FILE.....SHDFN.....
    shade.npt

BTH FILE.....BTHFN.....
WB 1    bth_wb1.csv
WB 2    bth_wb2.csv
WB 3    bth_wb3.csv
WB 4    bth_wb4.csv
WB 5    bth_wb5.csv
WB 6    bth_wb6.csv
WB 7    bth_wb7.csv
WB 8    bth_wb8.csv
WB 9    bth_wb9.csv

MET FILE.....METFN.....
WB 1    met_wb1.npt
WB 2    met_wb2.npt
WB 3    met_wb3.npt
WB 4    met_wb4.npt
WB 5    met_wb5.npt
WB 6    met_wb6.npt
WB 7    met_wb7.npt
WB 8    met_wb8.npt
WB 9    met_wb9.npt

EXT FILE.....EXTFN.....
WB 1    ext_1.npt - not used
WB 2    ext_2.npt - not used
WB 3    ext_3.npt - not used
WB 4    ext_4.npt - not used
WB 5    ext_5.npt - not used
WB 6    ext_6.npt - not used
WB 7    ext_7.npt - not used
WB 8    ext_8.npt - not used
WB 9    ext_9.npt - not used

VPR FILE.....VPRFN.....
WB 1    vpr_wb1.npt - not used
WB 2    vpr_wb2.npt - not used
WB 3    vpr_wb3.npt - not used
WB 4    vpr_wb4.npt - not used
WB 5    vpr_wb5.npt - not used
WB 6    vpr_wb6.npt - not used
WB 7    vpr_wb7.npt - not used
WB 8    vpr_wb8.npt - not used
WB 9    vpr_wb9.npt - not used

LPR FILE.....LPRFN.....
WB 1    lpr-wb1.npt - not used
WB 2    lpr-wb2.npt - not used
WB 3    lpr-wb3.npt - not used
WB 4    lpr-wb4.npt - not used
WB 5    lpr-wb5.npt - not used
WB 6    lpr-wb6.npt - not used
WB 7    lpr-wb7.npt - not used
WB 8    lpr-wb8.npt - not used
WB 9    lpr-wb9.npt - not used

QIN FILE.....QINFN.....
BR1    qin_br1.npt
BR2    qin_br2.npt
BR3    qin_br3.npt
BR4    qin_br4.npt
BR5    qin_br5.npt

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BR6 qin_br6.npt
 BR7 qin_br7.npt
 BR8 qin_br8.npt
 BR9 qin_br9.npt
 BR10 qin_br10.npt

TIN FILE.....TINFN.....

BR1 tin_br1.npt
 BR2 tin_br2.npt
 BR3 tin_br3.npt
 BR4 tin_br4.npt
 BR5 tin_br5.npt
 BR6 tin_br6.npt
 BR7 tin_br7.npt
 BR8 tin_br8.npt
 BR9 tin_br9.npt
 BR10 tin_br10.npt

CIN FILE.....CINFN.....

BR1 cin_br1.npt
 BR2 cin_br2.npt
 BR3 cin_br3.npt
 BR4 cin_br4.npt
 BR5 cin_br5.npt
 BR6 cin_br6.npt
 BR7 cin_br7.npt
 BR8 cin_br8.npt
 BR9 cin_br9.npt
 BR10 cin_br10.npt

QOT FILE.....QOTFN.....

BR1 qot_br1.npt - not used
 BR2 qot_br2_avg.npt - not used
 BR3 qot_br3.npt - not used
 BR4 qot_br4.npt - not used
 BR5 qot_br5.npt - not used
 BR6 qot_br6.npt - not used
 BR7 qot_br7.npt - not used
 BR8 qot_br8.npt - not used
 BR9 qot_br9.npt - not used
 BR10 qot_br10.npt - not used

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 TR35 ctr_tr35.npt

TR36	ctr_tr36.npt
TR37	ctr_tr37.npt
TR38	ctr_tr38.npt
TR39	ctr_tr39.npt
TR40	ctr_tr40.npt
TR41	ctr_tr41.npt
TR42	ctr_tr42.npt
TR43	ctr_tr43.npt
TR44	ctr_tr44.npt
TR45	ctr_tr45.npt
TR46	ctr_tr46.npt
TR47	ctr_tr47.npt
TR48	ctr_tr48.npt
TR49	ctr_tr49.npt
TR50	ctr_tr50.npt
TR51	ctr_tr51.npt
TR52	ctr_tr52.npt
TR53	ctr_tr53.npt
TR54	ctr_tr54.npt
TR55	ctr_tr55.npt
TR56	ctr_tr56.npt
TR57	ctr_tr57.npt
TR58	ctr_tr58.npt
TR59	ctr_tr59.npt
TR60	ctr_tr60.npt
TR61	ctr_tr61.npt
TR62	ctr_tr62.npt
TR63	ctr_tr63.npt
TR64	ctr_tr64.npt
TR65	ctr_tr65.npt
TR66	ctr_tr66.npt
TR67	ctr_tr67.npt
TR68	ctr_tr68.npt
TR69	ctr_tr69.npt
TR70	ctr_tr70.npt
TR71	ctr_tr71.npt
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TR73	ctr_tr73.npt
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TR82	ctr_tr82.npt
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TR84	ctr_tr84.npt
TR85	ctr_tr85.npt
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TR88	ctr_tr88.npt
TR89	ctr_tr89.npt
TR90	ctr_tr90.npt
TR91	ctr_tr91.npt
TR92	ctr_tr92.npt
TR93	ctr_tr93.npt
TR94	ctr_tr94.npt
TR95	ctr_tr95.npt
TR96	ctr_tr96.npt
TR97	ctr_tr97.npt
TR98	ctr_tr98.npt
TR99	ctr_tr99.npt
TR100	ctr_tr100.npt
TR101	ctr_tr101.npt
TR102	ctr_tr102.npt
TR103	ctr_tr103.npt

TR104	ctr_tr104.npt
TR105	ctr_tr105.npt
TR106	ctr_tr106.npt
TR107	ctr_tr107.npt
TR108	ctr_tr108.npt
TR109	ctr_tr109.npt
TR110	ctr_tr110.npt
TR111	ctr_tr111.npt
TR112	ctr_tr112.npt
TR113	ctr_tr113.npt
TR114	ctr_tr114.npt
TR115	ctr_tr115.npt
TR116	ctr_tr116.npt
TR117	ctr_tr117.npt
TR118	ctr_tr118.npt
TR119	ctr_tr119.npt
TR120	ctr_tr120.npt
TR121	ctr_tr121.npt
TR122	ctr_tr122.npt
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TR126	ctr_tr126.npt
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TR128	ctr_tr128.npt
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TR130	ctr_tr130.npt
TR131	ctr_tr131.npt
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TR133	ctr_tr133.npt
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TR135	ctr_tr135.npt
TR136	ctr_tr136.npt
TR137	ctr_tr137.npt
TR138	ctr_tr138.npt
TR139	ctr_tr139.npt
TR140	ctr_tr140.npt
TR141	ctr_tr141.npt
TR142	ctr_tr142.npt
TR143	ctr_tr143.npt
TR144	ctr_tr144.npt
TR145	ctr_tr145.npt
TR146	ctr_tr146.npt
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TR148	ctr_tr148.npt
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TR152	ctr_tr152.npt
TR153	ctr_tr153.npt
TR154	ctr_tr154.npt
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TR156	ctr_tr156.npt
TR157	ctr_tr157.npt
TR158	ctr_tr158.npt
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TR161	ctr_tr161.npt
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TR163	ctr_tr163.npt
TR164	ctr_tr164.npt
TR165	ctr_tr165.npt
TR166	ctr_tr166.npt
TR167	ctr_tr167.npt
TR168	ctr_tr168.npt
TR169	ctr_tr169.npt
TR170	ctr_tr170.npt
TR171	ctr_tr171.npt

TR172	ctr_tr172.npt
TR173	ctr_tr173.npt
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TR175	ctr_tr175.npt
TR176	ctr_tr176.npt
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TR178	ctr_tr178.npt
TR179	ctr_tr179.npt
TR180	ctr_tr180.npt
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TR182	ctr_tr182.npt
TR183	ctr_tr183.npt
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TR187	ctr_tr187.npt
TR188	ctr_tr188.npt
TR189	ctr_tr189.npt
TR190	ctr_tr190.npt
TR191	ctr_tr191.npt
TR192	ctr_tr192.npt
TR193	ctr_tr193.npt
TR194	ctr_tr194.npt
TR195	ctr_tr195.npt
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TR206	ctr_tr206.npt
TR207	ctr_tr207.npt
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TR209	ctr_tr209.npt
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TR211	ctr_tr211.npt
TR212	ctr_tr212.npt
TR213	ctr_tr213.npt
TR214	ctr_tr214.npt
TR215	ctr_tr215.npt
TR216	ctr_tr216.npt
TR217	ctr_tr217.npt
TR218	ctr_tr218.npt
TR219	ctr_tr219.npt
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TR221	ctr_tr221.npt
TR222	ctr_tr222.npt
TR223	ctr_tr223.npt
TR224	ctr_tr224.npt
TR225	ctr_tr225.npt
TR226	ctr_tr226.npt
TR227	ctr_tr227.npt
TR228	ctr_tr228.npt
TR229	ctr_tr229.npt
TR230	ctr_tr230.npt
TR231	ctr_tr231.npt
TR232	ctr_tr232.npt
TR233	ctr_tr233.npt
TR234	ctr_tr234.npt
TR235	ctr_tr235.npt
TR236	ctr_tr236.npt
TR237	ctr_tr237.npt
TR238	ctr_tr238.npt
TR239	ctr_tr239.npt

TR240 ctr_tr240.npt
 TR241 ctr_tr241.npt
 TR242 ctr_tr242.npt
 TR243 ctr_tr243.npt
 TR244 ctr_tr244.npt
 TR245 ctr_tr245.npt
 TR246 ctr_tr246.npt
 TR247 ctr_tr247.npt
 TR248 ctr_tr248.npt
 TR249 ctr_tr249.npt
 TR250 ctr_tr250.npt
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 TR262 ctr_tr262.npt
 TR263 ctr_tr263.npt
 TR264 ctr_tr264.npt
 TR265 ctr_tr265.npt
 TR266 ctr_tr266.npt
 TR267 ctr_tr267.npt
 TR268 ctr_tr268.npt
 TR269 ctr_tr269.npt
 TR270 ctr_tr270.npt
 TR271 ctr_tr271.npt
 TR272 ctr_tr272.npt
 TR273 ctr_tr273.npt
 TR274 ctr_tr274.npt
 TR275 ctr_tr275.npt
 TR276 ctr_tr276.npt
 TR277 ctr_tr277.npt
 TR278 ctr_tr278.npt
 TR279 ctr_tr279.npt
 TR280 ctr_tr280.npt
 TR281 ctr_tr281.npt
 TR282 ctr_tr282.npt
 TR283 ctr_tr283.npt
 TR284 ctr_tr284.npt
 TR285 ctr_tr285.npt
 TR286 ctr_tr286.npt
 TR287 ctr_tr287.npt
 TR288 ctr_tr288.npt
 TR289 ctr_tr289.npt
 TR290 ctr_tr290.npt
 TR291 ctr_tr291.npt
 TR292 ctr_tr292.npt
 TR293 ctr_tr293.npt
 TR294 ctr_tr294.npt
 TR295 ctr_tr295.npt
 TR296 ctr_tr296.npt
 TR297 ctr_tr297.npt
 TR298 ctr_tr298.npt
 TR299 ctr_tr299.npt

QDT FILE.....QDTFN.....

BR1 qdt_br1.npt
 BR2 qdt_br2.npt
 BR3 qdt_br3.npt - not used
 BR4 qdt_br4.npt - not used
 BR5 qdt_br5.npt - not used
 BR6 qdt_br6.npt

BR7 qdt_br7.npt - not used
 BR8 qdt_br8.npt - not used
 BR9 qdt_br9.npt - not used
 BR10 qdt_br10.npt

TDt FILE.....TDTFN.....
 BR1 tdt_br1.npt
 BR2 tdt_br2.npt
 BR3 tdt_br3.npt - not used
 BR4 tdt_br4.npt - not used
 BR5 tdt_br5.npt - not used
 BR6 tdt_br6.npt
 BR7 tdt_br7.npt - not used
 BR8 tdt_br8.npt - not used
 BR9 tdt_br9.npt - not used
 BR10 tdt_br10.npt

CDt FILE.....CDTFN.....
 BR1 cdt_br1.npt
 BR2 cdt_br2.npt
 BR3 cdt_br3.npt - not used
 BR4 cdt_br4.npt - not used
 BR5 cdt_br5.npt - not used
 BR6 cdt_br6.npt
 BR7 cdt_br7.npt - not used
 BR8 cdt_br8.npt - not used
 BR9 cdt_br9.npt - not used
 BR10 cdt_br10.npt

PRE FILE.....PREFN.....
 BR1 pre_br1.npt - not used
 BR2 pre_br2.npt - not used
 BR3 pre_br3.npt - not used
 BR4 pre_br4.npt - not used
 BR5 pre_br5.npt - not used
 BR6 pre_br6.npt - not used
 BR7 pre_br7.npt - not used
 BR8 pre_br8.npt - not used
 BR9 pre_br9.npt - not used
 BR10 pre_br10.npt - not used

TPR FILE.....TPRFN.....
 BR1 tpr_br1.npt - not used
 BR2 tpr_br2.npt - not used
 BR3 tpr_br3.npt - not used
 BR4 tpr_br4.npt - not used
 BR5 tpr_br5.npt - not used
 BR6 tpr_br6.npt - not used
 BR7 tpr_br7.npt - not used
 BR8 tpr_br8.npt - not used
 BR9 tpr_br9.npt - not used
 BR10 tpr_br10.npt - not used

CPR FILE.....CPRFN.....
 BR1 cpr_br1.npt - not used
 BR2 cpr_br2.npt - not used
 BR3 cpr_br3.npt - not used
 BR4 cpr_br4.npt - not used
 BR5 cpr_br5.npt - not used
 BR6 cpr_br6.npt - not used
 BR7 cpr_br7.npt - not used
 BR8 cpr_br8.npt - not used
 BR9 cpr_br9.npt - not used
 BR10 cpr_br10.npt - not used

EUH FILE.....EUHFN.....
 BR1 euh_br1.npt - not used
 BR2 euh_br2.npt - not used

```

BR3      euh_br3.npt - not used
BR4      euh_br4.npt - not used
BR5      euh_br5.npt - not used
BR6      euh_br6.npt - not used
BR7      euh_br7.npt - not used
BR8      euh_br8.npt - not used
BR9      euh_br9.npt - not used
BR10     euh_br10.npt - not used

```

TUH FILE.....TUHFN.....

```

BR1      tuh_br1.npt - not used
BR2      tuh_br2.npt - not used
BR3      tuh_br3.npt - not used
BR4      tuh_br4.npt - not used
BR5      tuh_br5.npt - not used
BR6      tuh_br6.npt - not used
BR7      tuh_br7.npt - not used
BR8      tuh_br8.npt - not used
BR9      tuh_br9.npt - not used
BR10     tuh_br10.npt - not used

```

CUH FILE.....CUHFN.....

```

BR1      cuh_br1.npt - not used
BR2      cuh_br2.npt - not used
BR3      cuh_br3.npt - not used
BR4      cuh_br4.npt - not used
BR5      cuh_br5.npt - not used
BR6      cuh_br6.npt - not used
BR7      cuh_br7.npt - not used
BR8      cuh_br8.npt - not used
BR9      cuh_br9.npt - not used
BR10     cuh_br10.npt - not used

```

EDH FILE.....EDHFN.....

```

BR1      edh_br1.npt - not used
BR2      edh_br2.npt - not used
BR3      edh_br3.npt - not used
BR4      edh_br4.npt - not used
BR5      edh_br5.npt - not used
BR6      edh_br6.npt - not used
BR7      edh_br7.npt - not used
BR8      edh_br8.npt - not used
BR9      edh_br9.npt - not used
BR10     edh_br10.npt - not used

```

TDH FILE.....TDHFN.....

```

BR1      tdh_br1.npt - not used
BR2      tdh_br2.npt - not used
BR3      tdh_br3.npt - not used
BR4      tdh_br4.npt - not used
BR5      tdh_br5.npt - not used
BR6      tdh_br6.npt - not used
BR7      tdh_br7.npt - not used
BR8      tdh_br8.npt - not used
BR9      tdh_br9.npt - not used
BR10     tdh_br10.npt - not used

```

CDH FILE.....CDHFN.....

```

BR1      cdh_br1.npt - not used
BR2      cdh_br2.npt - not used
BR3      cdh_br3.npt - not used
BR4      cdh_br4.npt - not used
BR5      cdh_br5.npt - not used
BR6      cdh_br6.npt - not used
BR7      cdh_br7.npt - not used
BR8      cdh_br8.npt - not used
BR9      cdh_br9.npt - not used
BR10     cdh_br10.npt - not used

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SNP FILE.....SNPFN.....
WB 1      snp_wb1.opt
WB 2      snp_wb2.opt
WB 3      snp_wb3.opt
WB 4      snp_wb4.opt
WB 5      snp_wb5.opt
WB 6      snp_wb6.opt
WB 7      snp_wb7.opt
WB 8      snp_wb8.opt
WB 9      snp_wb9.opt

PRF FILE.....PRFFN.....
WB 1      prf_wb1.opt
WB 2      prf_wb2.opt
WB 3      prf_wb3.opt
WB 4      prf_wb4.opt
WB 5      prf_wb5.opt
WB 6      prf_wb6.opt
WB 7      prf_wb7.opt
WB 8      prf_wb8.opt
WB 9      prf_wb9.opt

VPL FILE.....VPLFN.....
WB 1      w2_post_output.w2l
WB 2      vpl_wb2.opt
WB 3      vpl_wb3.opt
WB 4      vpl_wb4.opt
WB 5      vpl_wb5.opt
WB 6      vpl_wb6.opt
WB 7      vpl_wb7.opt
WB 8      vpl_wb8.opt
WB 9      vpl_wb9.opt

CPL FILE.....CPLFN.....
WB 1      cpl_wb1.opt
WB 2      cpl_wb2.opt
WB 3      cpl_wb3.opt
WB 4      cpl_wb4.opt
WB 5      cpl_wb5.opt
WB 6      cpl_wb6.opt
WB 7      cpl_wb7.opt
WB 8      cpl_wb8.opt
WB 9      cpl_wb9.opt

SPR FILE.....SPRFN.....
WB 1      spr_wb1.opt
WB 2      spr_wb2.opt
WB 3      spr_wb3.opt
WB 4      spr_wb4.opt
WB 5      spr_wb5.opt
WB 6      spr_wb6.opt
WB 7      spr_wb7.opt
WB 8      spr_wb8.opt
WB 9      spr_wb9.opt

FLX FILE.....FLXFN.....
WB 1      flx_wb1.opt
WB 2      flx_wb2.opt
WB 3      flx_wb3.opt
WB 4      flx_wb4.opt
WB 5      flx_wb5.opt
WB 6      flx_wb6.opt
WB 7      flx_wb7.opt
WB 8      flx_wb8.opt
WB 9      flx_wb9.opt

TSR FILE.....TSRFN.....

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tsr.csv

WDO FILE.....WDOFN.....
wdo.opt