Water Temperature Model Sensitivity Analysis

Chehalis River Basin Flood Damage Reduction Project

Submitted by the Chehalis River Basin Flood Control Zone District

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Preface

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This document contains the Water Temperature Model Sensitivity Analysis for the Chehalis River Basin Flood Damage Reduction Project (proposed project) proposed by the Chehalis River Basin Flood Control Zone District. The purpose of the water temperature modeling is to (1) perform a sensitivity analysis of the modeled water temperature predictions from changes in vegetation heights and (2) provide more refined information to Washington State Department of Ecology (Ecology) and the United States Army Corps of Engineers (USACE) for their consideration when updating the impacts analysis that evaluates the effects of predicted riparian vegetation changes on water temperature presented in the State Environmental Policy Act (SEPA) Draft Environmental Impact Statement (DEIS) (Ecology 2020a) and National Environmental Policy Act (NEPA) DEIS (USACE 2020a).

This document reviews the SEPA and NEPA DEISs impact analysis of the proposed project's impact on water temperature and provides an updated baseline scenario for vegetation in the temporary inundation area. Further, refined assumptions for future vegetation conditions in the temporary inundation area are provided based on additional information pertaining to vegetation management and a review of an existing analog site (Mud Mountain Dam). This document also includes more detailed information regarding the impact of the proposed project and the impact of climate change on water temperature conditions within the temporary inundation area of the downstream reach of the Chehalis River near the proposed Flood Retention Expandable (FRE) facility.

Acronyms and Abbreviations

°C	degrees Celsius
7-DADMax	7-day average of the daily maximum water temperature
CE-QUAL-W2 model	Corps of Engineers-Quality-Width-averaged 2-dimensional model
DEIS	Draft Environmental Impact Statement
DHM	digital height model
District	Chehalis River Basin Flood Control Zone District
DSM	digital surface model
DTM	digital terrain model
Ecology	Washington Department of Ecology
FRE	flood retention expandable
GIS	Geographic Information System
HEC-RAS	Hydrologic Engineering Center – River Analysis System
LiDAR	light detection and ranging
NEPA	National Environmental Policy Act
NRCS	Natural Resources Conservation Service
PSU	Portland State University
SEPA	State Environmental Policy Act
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
VMP	vegetation management plan
WSEL	Water Surface Elevation

Glossary

Boundary Condition – An edge of the modeled region that requires inputs be defined to be able to perform the mathematical computations. For example, a condition usually must be specified at the upstream end of a modeled river reach.

Climate Change Conditions – A modeling condition using the constructed model based on 2014 data but replacing air and dewpoint temperature, flow, and inflow water temperature with estimates representing climate change.

Current Conditions – A modeling condition using the constructed model based on 2013 and 2014 data.

FRE Facility – The proposed flood retention expandable facility dam site.

FRE Site – The operation of a proposed flood retention expandable facility including the dam site and the upstream area that would be temporarily inundated and become a temporary pool during a flood event in which the upland and riparian vegetation may be impacted.

Inputs or Model Inputs – The values used by the model to perform its mathematical computations.

Model – A representation of something or a system. Herein, mathematical equations based on scientific evidence that are coded within a software program to represent the processes that occur in a river. The model used is CE-QUAL-W2.

Modeling or Modeled – The use of a model applied to a specific river to represent conditions within that river either historically or as estimations of climate change, based upon historical data, mathematical equations, scientific evidence, and/or best professional judgment of conditions.

Scenario or Model Scenario – Input(s) to the model are modified to represent an alternative condition, the model is simulated, and the results are examined and compared to the original condition to explore how the model responded to the change in input(s).

Segments or Model Segments – The discretization of an area into gridded blocks or cells for which the model performs the mathematical computations and then routes the results of those computations to the adjoining cells. Usage is when referring to model segments use lower case, when referring to a specific model segment number use upper case; e.g., Segment 111.

Sensitivity or Sensitivity Analysis – A method to analyze the difference an input value causes to predicted output values. Herein, the input value of shade was varied and the effect on the output value of water temperature was evaluated.

Simulation or Run or Model Simulation – The computing of the model mathematical equations as coded within a software program as done in a computer's electronics based on the user's inputs. The computer processing may take from seconds to days depending upon the scope and complexity of the equations and the computer processor. Herein, simulation is the period when the software program is executed or run.

Sub-basin – An area that contributes flow to the river.

Temporary Inundation Area – The area that would be under water due to retention of water during a flooding event.

Water quality – The physical, chemical, and biological processes occurring within a river as indicated by specific parameter(s). Herein the parameter of interest is water temperature.

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1 Introduction and Purpose

As part of a strategy to reduce flood damage to life and property along the Chehalis River, the Chehalis River Basin Flood Control Zone District (District) proposes to construct a flood retention facility near the town of Pe Ell on the mainstem of the Chehalis River. The Draft Environmental Impact Statements (DEISs) prepared by the Washington Department of Ecology (Ecology) and the United States Army Corps of Engineers (USACE) evaluate anticipated impacts on abiotic and biologic resources associated with construction and operation of the proposed flood retention expandable (FRE) facility (i.e., the Chehalis River Basin Flood Damage Reduction Project [proposed project]). The State Environmental Policy Act (SEPA) DEIS (Ecology 2020a) and National Environmental Policy Act (NEPA) DEIS (USACE 2020a) assessed potential impacts on water temperature, dissolved oxygen, turbidity, fecal coliform, and pH from the construction and operation of the proposed FRE facility. Of specific concern are the significant impacts of the proposed project on water temperature based on results from a water quality model and documented in each of the DEISs. Due in part to the projected increases in water temperature, the SEPA and NEPA DEISs subsequently determined that the proposed project will have significant impacts on aquatic resources and anadromous salmonids.

This report reviews the SEPA and NEPA DEISs water temperature impact findings (Section 2.1) and reports on an analysis to assess the sensitivity of water temperature increases to vegetation and shading assumptions used in the water quality modeling. This report presents water temperature modeling results based on more recent information regarding existing vegetation conditions in the temporary inundation area upstream of the proposed FRE facility. In addition, refined shade parameters for the temporary inundation area from those assumed in the SEPA and NEPA DEISs are presented (Section 3) and water temperature results from the sensitivity analysis modeling are described (Section 4). Shade inputs in the sensitivity analysis modeling include inputs that are consistent with anticipated vegetation heights of intended plant communities following implementation of a Conceptual Vegetation Management Plan (VMP) (see Attachment A).[1]

A water quality model developed by Portland State University (PSU) and employed for Ecology and the USACE for preparation of the SEPA and NEPA DEISs was used for this analysis with no changes to its code, inputs, or operation. The model as applied to the Chehalis River was not changed except for the shade inputs established for the sensitivity analysis modeling. The model was run by PSU, and the results were reported to the consulting team.

[1] In 2020, HDR, Inc., in coordination with the District consultant team, developed a Conceptual VMP. The Conceptual VMP has informed the water quality modeling effort described in this report and will subsequently be reflected as a Final VMP to be implemented following further agency and stakeholder coordination.

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2 SEPA and NEPA DEIS Water Temperature Assessment

The SEPA and NEPA DEISs assessed the effects on water temperature in the temporary inundation area when storing water, when not storing water, and downstream of the proposed FRE facility under storage and non-storage conditions. The Corps of Engineers-Quality-Width-averaged 2-dimensional (CE-QUAL-W2) model was used for both DEIS assessments based on suitability and history of use for rivers and reservoirs. CE-QUAL-W2 is a computer model for predicting water flow and quality in rivers, estuaries, lakes, reservoirs, and river basin systems (Cole and Wells 2016, PSU 2017) that is maintained by researchers at PSU. The model operates in two dimensions and includes a complex suite of biological and chemical reactions that describe several regulated and unregulated water quality constituents. However, the SEPA and NEPA DEISs took different approaches in the assessment of the project's impacts with the additional temperature increases due to climate change. The SEPA DEIS included changes to air and dew point temperature, flow, and inflow water temperature when modeling climate change, and the NEPA DEIS did not include a quantitative assessment that included climate change in the water quality modeling.

2.1 SEPA and NEPA DEIS Water Temperature Impact Findings

The SEPA DEIS identified *significant impacts* on water temperature from the removal of vegetation in the upland and riparian areas of the proposed FRE site. The SEPA EIS states that the proposed project results in a 2 to 3 degrees Celsius (°C) increase in water temperature in mid- to late summer in the temporary inundation area and immediately downstream, and a 2 to 5°C increase in Crim Creek.

The NEPA DEIS identified *high impacts* on water temperature from the construction of the proposed FRE facility, *low–high impacts* upstream from the operation of the proposed FRE facility when the facility is both impounding and not impounding water, and *high impacts* downstream. Similar to the SEPA DEIS, the NEPA DEIS attributes the impacts on water temperature to the removal of vegetation in the temporary inundation area. The NEPA DEIS states that the proposed project will result in an increase of up to 2°C in mid-July in the area of the temporary inundation area and immediately downstream, reducing to 1°C at Pe Ell and 0.3°C at the confluence of Elk Creek.

The SEPA and NEPA analyses attribute the increase in water temperature to the reduction of shade due to the removal of vegetation in the temporary inundation area. A previous developed Pre-Construction Vegetation Management Plan (Anchor QEA 2016) informed assumptions made in the SEPA DEIS that construction activities would include the removal of all non-flood-tolerant trees within approximately 420 acres of the temporary inundation area and all other trees greater than 6 inches diameter breast height throughout the temporary inundation area as a conservative approach (Ecology 2020a). The NEPA analysis assumes 485 acres of clearing and limited (2-meter height) vegetative shading throughout the entire temporary inundation area (USACE 2020b).

The SEPA DEIS includes a quantitative analysis of climate change impacts on water temperature. Appendix N of the SEPA DEIS (Ecology 2020b) states that an increase in water temperature of 3 to 4°C in the vicinity of temporary inundation area is expected under climate change, driven by increases in air temperature. However, the SEPA DEIS does not make clear if the modeling results that show a 2 to 3°C increase in water temperature due to the proposed project were determined using discrete modeling runs without climate change. The NEPA DEIS qualifies impacts from climate change, stating that water temperature may increase with climate change, but does not consider this qualitative assessment in the impact analysis and does not provide any quantitative assessment of climate change on water temperature.

2.2 Water Quality Modeling Documentation

The SEPA DEIS included a technical appendix documenting the findings of the water quality modeling and assessment of impacts (Ecology 2020b). Multiple studies and reports are cited as additional references documenting the analysis, including the Chehalis Modeling Technical Memorandum (TM) (PSU 2017). The NEPA DEIS also included a technical appendix documenting the findings of the water quality modeling and assessment of impacts (USACE 2020b).

The SEPA and NEPA DEISs used the same computer model, the application of the CE-QUAL-W2 model configured and run by the same personnel at PSU. The application of the CE-QUAL-W2 model to the Chehalis River relied upon multiple data sources and other models as documented in the Chehalis Modeling TM (PSU 2017). The following is a summary of the model components and data sources.

The conversion of the channel shape into CE-QUAL-W2 model cells was achieved using Hydrologic Engineering Center – River Analysis System (HEC-RAS) input files “cross-sectional data provided by Anchor QEA” (PSU 2017). HEC-RAS is a USACE model commonly used for flood studies. In this case, detailed cross sections were provided as inputs that were then converted into grids for the block representation format used by CE-QUAL-W2. Meteorological inputs used in the CE-QUAL-W2 model included measured data from the Chehalis River Basin Flood Authority Thrash Creek Station. Flow and water temperature inputs were developed by Anchor QEA (2017). No further information about these data were available or documented in the previous modeling reports. Topographic shading input was based on a digital elevation map of the area (PSU 2017). The vegetative shading inputs were estimated and are described further below.

For climate change, Anchor QEA used data made available by the University of Washington to develop air and dewpoint temperature inputs and flow multipliers to adjust the flow inputs. Water temperature was assumed to increase by the same magnitude as the increase in air temperature:

> “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” (PSU 2017).

The methods for evaluating impacts on water quality include the use of the CE-QUAL-W2 model as applied using specific sets of inputs. A brief description of each application is provided in USACE 2020a and include:

- CE-QUAL-W2 applied to the Chehalis River at and upstream of the proposed FRE facility. This model is known as the Chehalis Reservoir Footprint Model (Footprint Model) as named in the Chehalis Modeling TM (PSU 2017).
    - Modeled area is the temporary inundation area during free-flowing conditions.
- CE-QUAL-W2 applied to the Chehalis River at and upstream of the proposed FRE facility with the facility in place. This model is known as the Chehalis Temporary Reservoir Model (PSU 2017).
    - Modeled area is the temporary inundation area during a flood event and the proposed FRE facility is retaining water.
- CE-QUAL-W2 applied to the Chehalis River downstream of the proposed FRE facility. The model is known as the Chehalis River Downstream Model (PSU 2017).
    - Modeled area is downstream of the proposed FRE facility.

The Footprint Model was selected as the appropriate model for the sensitivity analysis of water temperature to shade inputs because the spatial extent of the model includes the temporary inundation area where vegetation management will be implemented. Furthermore, the Footprint Model provides for the assessment of water temperature changes over the course of multiple years (under current conditions) during free-flowing river conditions, including changes to water temperature during late summer low-flow months. The late summer months are when the SEPA and NEPA DEISs identified water temperature increases to be greatest and are therefore an important period to assess the sensitivity analysis of water temperature to shade inputs. The Footprint Model is further described in Section 2.3.

2.3 Footprint Model Framework

The Footprint Model is composed of a grid overlain on portions of the Chehalis River, Crim Creek, Lester Creek, Big Creek, and Roger Creek. This grid is composed of 191 model segments, with each segment being either 150 or 152.4 meters long in the direction of water flow. Some segment numbers are inactive in the model and are of zero length. Figure 1 below provides a map of the Footprint Model segments. Model segments corresponding to specific locations include four mainstem locations along with the upstream and downstream ends of the four tributaries to the mainstem, identified as follows:

- Segment 2 Chehalis River, upstream model boundary, located approximately 8 miles south of Pe Ell, Washington.
- Segment 44, uppermost reach of the temporary inundation area during an extreme flood retention event.

- Segment 111 Chehalis River, location of proposed FRE facility.
- Segment 122 Chehalis River, downstream model boundary.
- Segments 125 and 161 Crim Creek tributary, upstream and downstream model boundaries, respectively.
- Segments 164 and 171 Lester Creek tributary, upstream and downstream model boundaries, respectively.
- Segments 174 and 181 Big Creek tributary, upstream and downstream model boundaries, respectively.
- Segments 184 and 190 Roger Creek tributary, upstream and downstream model boundaries, respectively.

Vegetation heights for the sensitivity analysis (Section 3) are input into the Footprint Model using the references to the segment numbering at the specific locations along the Chehalis River.

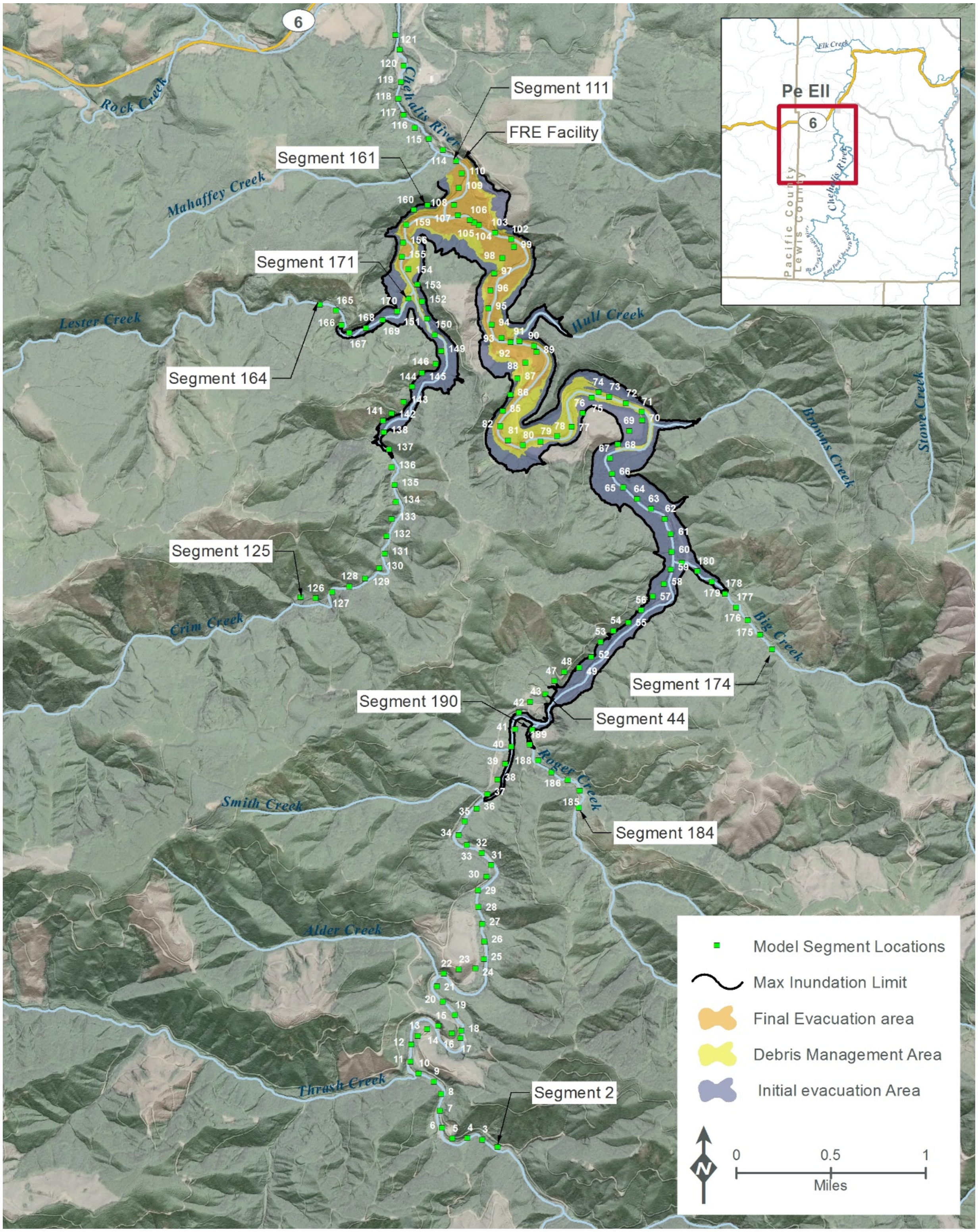

Figure 1. Locations of Footprint Model Segments (Modified from PSU 2017)

Note: The symbology for Model Segment Locations (green squares) signifies the center-point of the model segment. In the model, segments are connected from the upper to lower boundaries, have a length equal to the reach of flow modeled and are oriented in the direction of flow.

2.3.1 Model Computations of Water Temperature

The following provides an overview of how the model works. Inputs are critical to the predictive abilities of the Footprint Model. Inputs such as flow, water temperature, and meteorological conditions are time-varying boundary conditions for which the quality and frequency of data influences the model predictions. Model inputs that affect the computation of water temperature include the following:

- Channel shape, orientation, and latitude as described in the bathymetry input.
- Meteorological inputs, air and dew point temperature, wind speed and direction, and cloud cover, which affect simulated heat fluxes, including short-wave solar radiation, long-wave atmospheric radiation, evaporation, and conduction.
- Flow at the starting locations for the Chehalis River, Crim Creek, Lester Creek, Big Creek, and Roger Creek along with distributed flow along the modeled segments representing unaccounted tributaries, groundwater, seeps, and springs.
- Water temperature associated with each river, creek, and distributed inflow where it enters the modeled system.
- Shading described by vegetation height, distance from water, density or opacity, time of year (i.e., leaf on or off for deciduous species), and topography.

Of the above list of model inputs the only input modified for this study was the input of shading parameters.

Multiple waterbody applications and peer-reviewed papers are documented in the CE-QUAL-W2 manual (Cole and Wells 2016) and demonstrate the capabilities of the model for predicting changes to water temperature. The model calculations include water surface and bottom heat exchange along with solar radiation absorption within the water column. It is important to understand the model computations because while vegetation heights influence water temperature, so do many other factors within the model as the water moves down the Chehalis River. For the sensitivity analysis described in Section 3, only the shade inputs were changed.

2.3.2 Model Scenarios and Assumptions

The following is a summary of the model scenarios and assumptions made during the modeling for the DEISs. After development of the Footprint Model, multiple scenarios were defined to represent a range of conditions, and appropriate model inputs were developed for each scenario (PSU 2017). The Chehalis River scenarios previously simulated by PSU are documented in the Chehalis Modeling TM (see Table 35 of PSU 2017). The subset of these scenarios specific to the proposed FRE facility and shading are summarized in Table 1 below. In addition to the baseline simulation, PSU ran two scenarios identified as riparian shading and no shading, which were run for the current and climate change conditions. (These scenarios, with different shade inputs, were simulated for the sensitivity analysis as described in Section 4.)

The analysis of current conditions simulated two consecutive years (2013 and 2014) using meteorological data measured at Thrash Creek, computed flow for each sub-basin, and estimated inflow water temperature. The years 2013 and 2014 were used because the proposed project study was underway and field sampling had been completed to support the data needs of the model. Meteorological data from Chehalis River Basin Flood Authority at Thrash Creek were used because the data are from near the proposed FRE facility and include data at a 15-minute frequency. Anchor QEA developed total flow at the proposed FRE facility. This total flow was divided between the upstream boundary condition and the tributary inflow. The division was calculated as the fraction of the sub-basin area divided by the total proposed FRE site area multiplied by the total flow.

The model with climate change simulated 1 annual year based on 2014, with changes in the meteorological, flow, and inflow water temperature. The annual year 2014 was used for climate change because the transit time of water to travel the modeled reach was found to be short and simulating 1 year reduced the model run time for simulation. Meteorological inputs were modified by Anchor QEA (2017) and based on data from the University of Washington; flow multipliers were used to change flow; and inflow water temperature was assumed to increase by the same magnitude as the increase in air temperature.

Table 1. Summary of Footprint Model Simulations Used for the DEIS Water Temperature Prediction

DEIS Scenarios	Condition	
	Current	Climate Change
Baseline	Baseline Meteorology Baseline Inflow Baseline Inflow Water Temperature Estimated Existing Shade	Increased Air and Dew Point Temperature Multiplier Inflow Increased Inflow Water Temperature Estimated Existing Shade
Riparian Shading	Baseline Meteorology Baseline Inflow Baseline Inflow Water Temperature Riparian 2-meter Shade	Increased Air and Dew Point Temperature Multiplier Inflow Increased Inflow Water Temperature Riparian 2-meter Shade
No Shading	Baseline Meteorology Baseline Inflow Baseline Inflow Water Temperature No Shade	Increased Air and Dew Point Temperature Multiplier Inflow Increased Inflow Water Temperature No Shade

The model inputs for current and climate change conditions for air temperature, flow, and water temperature are shown on Figure 2, Figure 3, and Figure 4, respectively.[2] The upstream location was selected because it contributes the greatest amount of flow to the temporary inundation area and subsequently is one of the biggest factors contributing to the downstream water temperature. Climate change is represented in Figure 2 with the air temperature higher than the air temperature for current conditions. The air temperature for climate change was based on the 2014 data (current conditions) but are greater than the current conditions by 2.8 to 4.6°C depending on the month. Dewpoint temperature

[2] Figure 2, Figure 3, and Figure 4 have the date shown on the horizontal axis, the parameter on the left vertical axis for the plot of the current and climate change conditions, and the difference between current and climate change conditions for the parameter on the right vertical axis.

inputs were adjusted by a similar amount. Figure 3 shows the flow at the upstream boundary condition. Flow for climate change are the 2014 data (current conditions) but are shifted to reflect anticipated impacts due to climate change. Figure 4 shows water temperature associated with the flow at the upstream boundary condition. Water temperature for climate change was based on the 2014 data (current conditions) but are greater by the same amount as the increase in air temperature depending on the month.

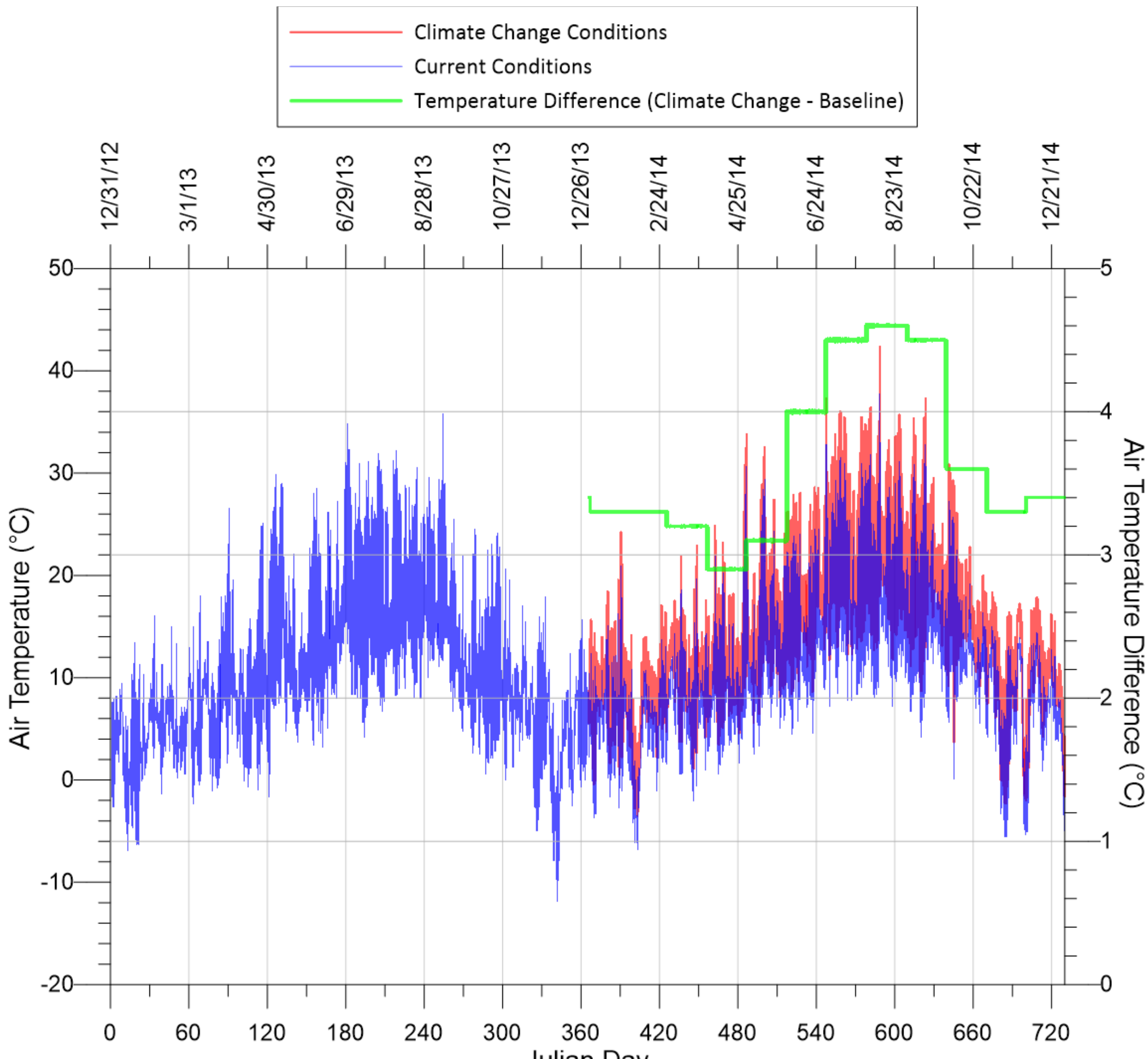

Figure 2. Air Temperature Model Inputs Current and Climate Change Conditions and Difference (second y-axis)

Note: Scenarios with climate change used a 1-year simulation based on 2014.

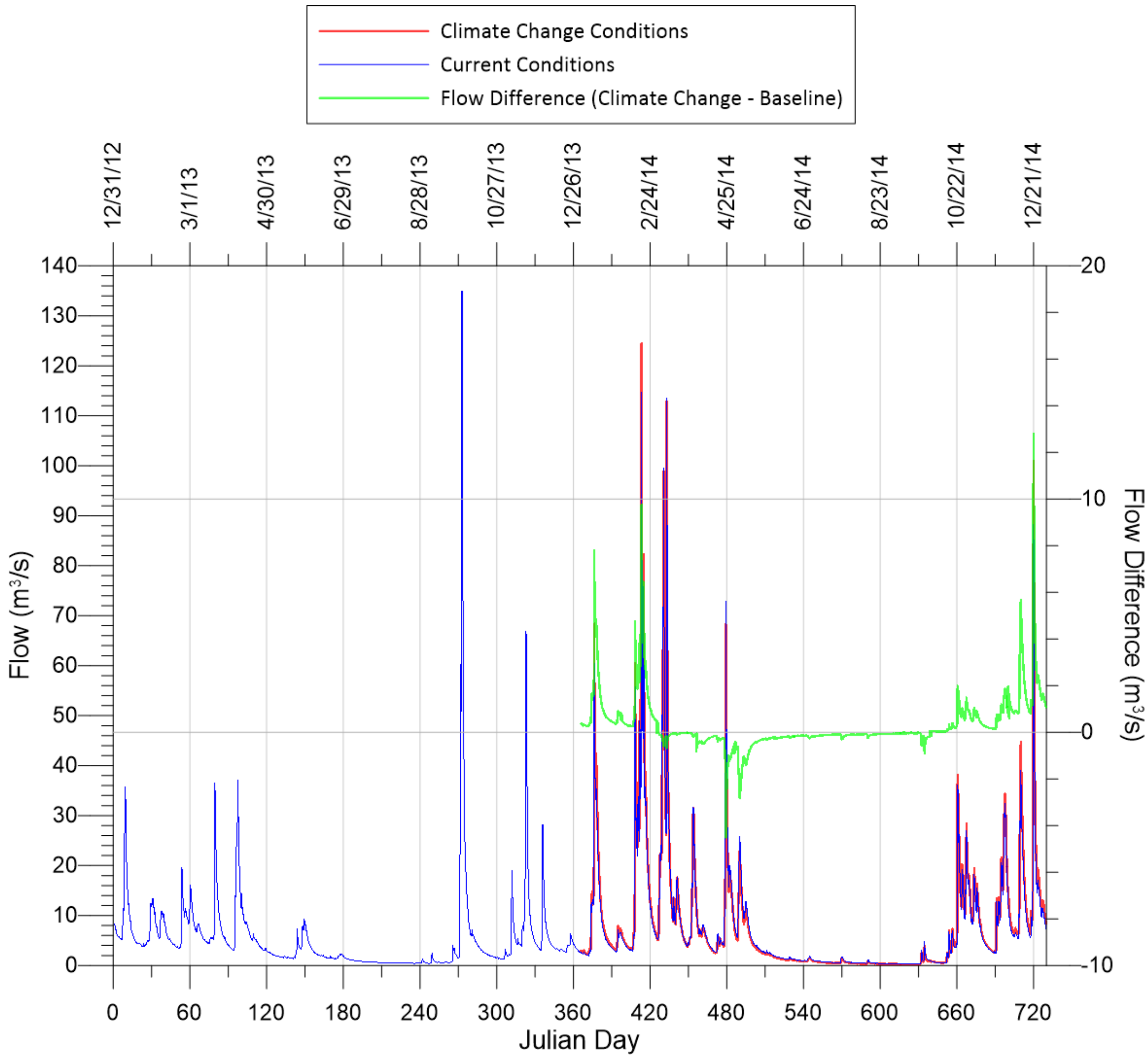

Figure 3. Chehalis River Flow Model Inputs Current and Climate Change Conditions and Difference (second y-axis)

Note: Flow multipliers for climate change (2014) were developed by Anchor QEA. The upstream boundary condition flow and the tributary flow were multiplied by these multipliers for climate change. Flow multipliers were January 1.129x, February 1.085x, March 0.994x, April 0.938x, May 0.889x, June 0.851x, July 0.817x, August 0.785x, September 0.813x, October 1.055x, November 1.058x and December 1.145x.

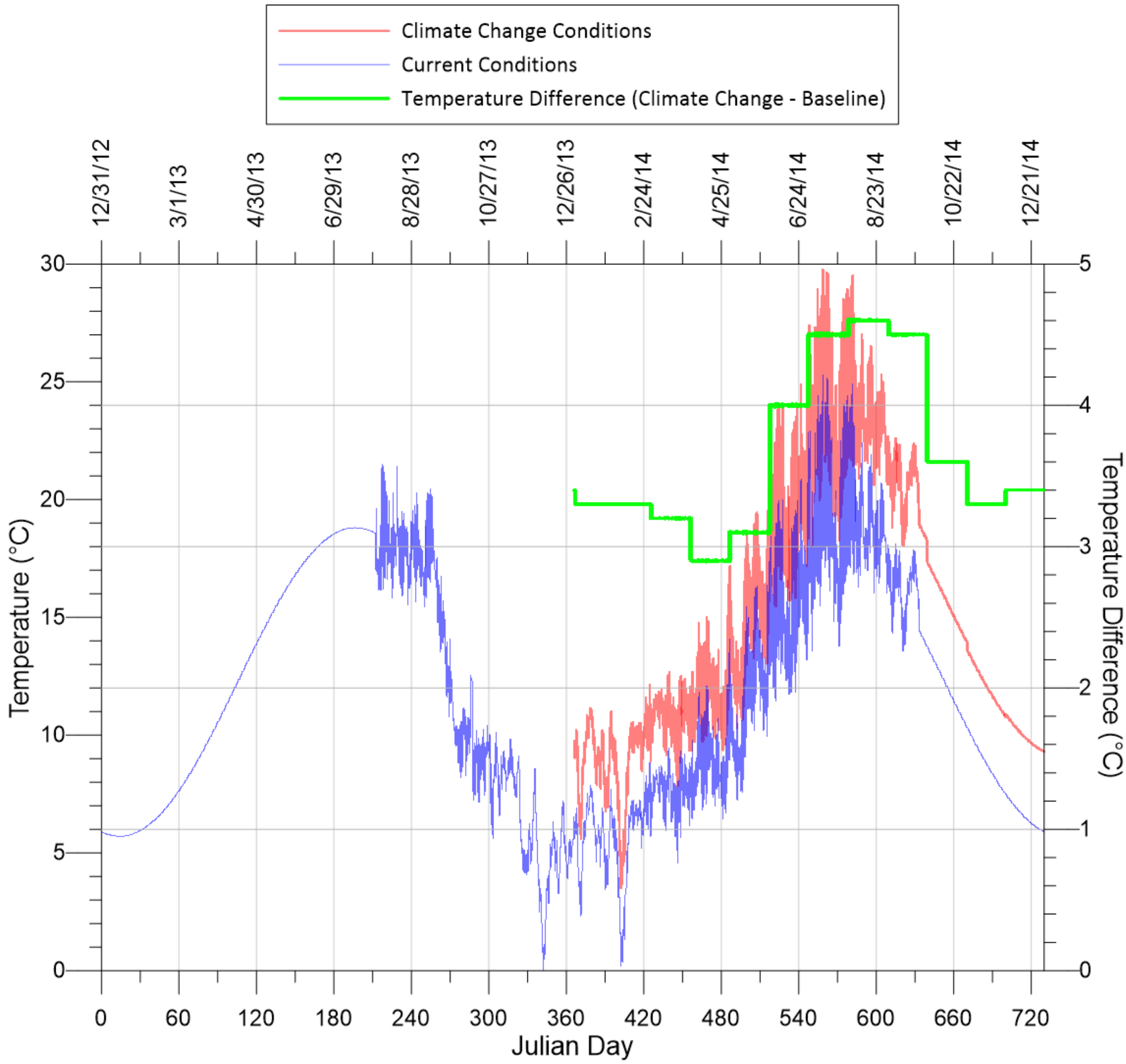

Figure 4. Chehalis River Water Temperature Model Inputs Current and Climate Change Conditions and Difference (second y-axis))

Note: Current conditions inflow water temperature was developed by Anchor QEA (2017) using measured data and a sinusoidal function that was fitted to monthly medians of the historical data (1977 to 2015) when data were not available.

The baseline scenarios under the current and climate change conditions were simulated using estimated vegetation heights for shade. The vegetation heights for the baseline scenarios were based on the following:

> "…vegetative shading data did not exist in the footprint model area. Vegetative shading was assumed to be equivalent to vegetative shade in branch 1 of the downstream model, which is the river reach extending for 2 km directly downstream of the dam location" (PSU 2017).

For the SEPA DEIS, two vegetation scenarios were simulated: riparian shading and no shading. For riparian shading, the "vegetation in the deciduous riparian shrubland area was assumed to be 2-meter high and used a shade reduction factor of 0.5" (PSU 2017). In the model, vegetation heights are inputs for each segment, with one input for the left bank and one input for the right bank. The input vegetation height is the same for the length of the model segment (either 150 meters or 152.4 meters). In the model, each segment has a bottom elevation, and the vegetation height is added to the bottom elevation to calculate the vegetation elevation. The channel-bottom elevation, along with the vegetation elevations in baseline and riparian shading scenarios, are shown in Figure 5, and the vegetation elevations in baseline and no shading scenarios are shown in Figure 6.[3] The model segments for which the riparian shading and no shading scenario elevations are lower than the baseline scenario vegetation elevations correspond to the temporary inundation area. Figure 5 and Figure 6 show the baseline scenario vegetation to be a repeating pattern, and the riparian shading and the no shading scenarios to be of mostly uniform elevations. These elevations do not provide an accurate representation of existing or planned conditions and thus led to the benefit of performing the sensitivity analysis.

[3] Figure 5 and Figure 6 show the model segments along the x-axis with the highest elevation on the left corresponding to the upstream boundary and the lowest elevation on the right corresponding to the proposed FRE facility. Numbering of model segments starts at 2 for the upstream boundary and increases downstream (unlike other numbering systems such as river miles). A list of specific locations corresponding to model segments, such as the proposed FRE facility at Segment 111, is provided in Section 2.3.

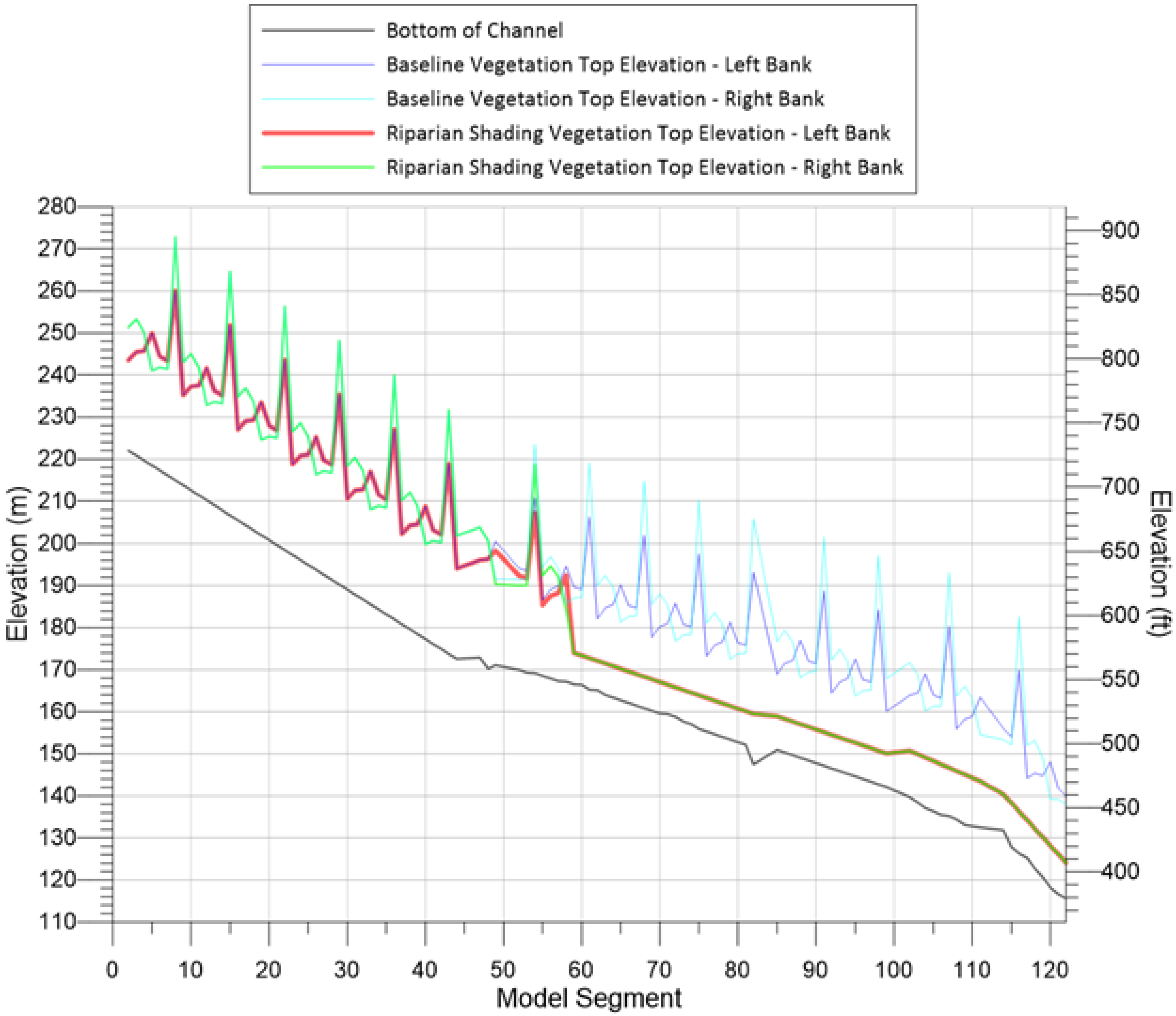

Figure 5. Chehalis River Channel Bottom with Top of Vegetation Elevation Model Inputs for Baseline and Riparian Shading Scenarios

Note: For the "Riparian Shading" scenario, a 2-meter vegetation height was assumed in the temporary inundation area.

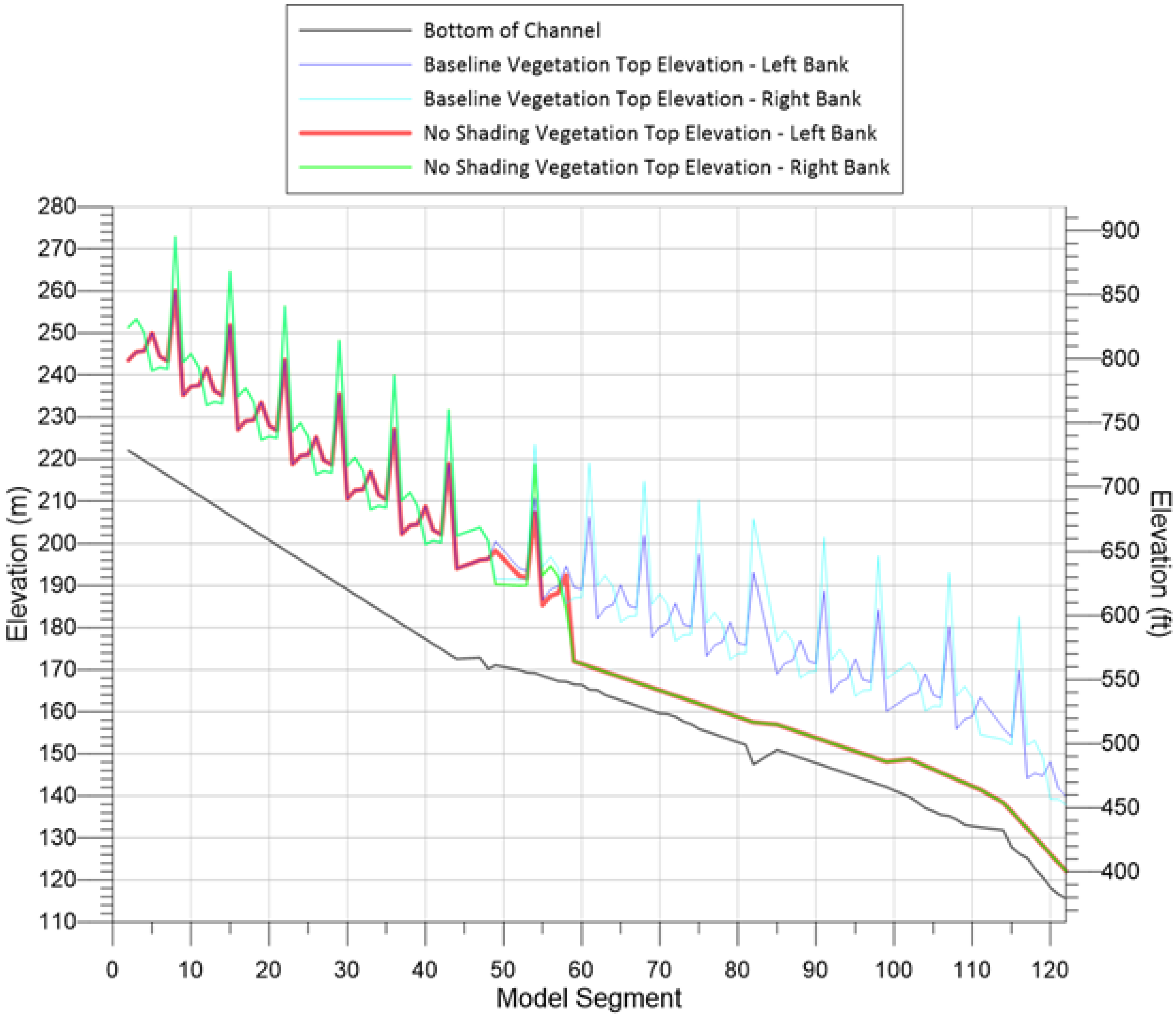

Figure 6. Chehalis River Channel Bottom with Top of Vegetation Elevation Model Inputs for Baseline and No Shading Scenarios

Note: For the "No Shading" scenario, a 0-meter vegetation height was assumed in the temporary inundation area.

2.3.3 CE-QUAL-W2 Model Outputs and Analysis

The model can be set to output water temperature for any segment, time-step, or depth in the water column. For the Footprint Model, "daily maximum temperature predictions at the proposed dam location for current and climate change conditions…" were output and graphed (PSU 2017). The modeling results were provided for the development of the DEISs.

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3 Methods for Water Quality Modeling Sensitivity Analysis

The purpose of the water quality modeling using the Footprint Model is to perform a sensitivity analysis of the modeled water temperature predictions to changes in vegetation heights. If it is determined that water temperature is influenced by changes in vegetation height, then this sensitivity analysis may inform the refinement and implementation of a VMP. The hypothesis is that higher vegetation, when compared to lower vegetation, in the riparian zone provides greater shading; thus, there is less solar radiative heating, and therefore water temperature increases are minimized. As described in Section 2.3, the baseline scenario under current conditions used in the SEPA and NEPA DEISs were estimated using vegetation data from a river reach downstream of the proposed FRE facility. The current modeling work included an updated baseline scenario with vegetation base on recent site-specific information that characterized existing vegetation within the temporary inundation area. The continuous water temperature error statistics from the model for the DEIS analysis were compared with those using the updated baseline vegetation heights and found to have improved by 0.01 to 0.06°C. Model scenarios were developed to investigate the relationship between vegetation height and water temperature. In this context, the vegetation height input to the CE-QUAL-W2 was changed, and the model simulated the specified conditions for each scenario to predict water temperature. The results are summarized in Section 4.

3.1 Existing Riparian Vegetation

An objective of the sensitivity analysis was to use the same Footprint Model scenarios used in the SEPA and NEPA DEISs to evaluate revised riparian shading as proposed by the Conceptual VMP on water temperature. The vegetation heights for the existing conditions modeling (baseline scenario) were reviewed during preparation of the model scenarios for the sensitivity analysis.

A review of available data since the Chehalis Modeling TM (PSU 2017) identified more recent light detection and ranging (LiDAR) data providing a three-dimensional representation of the landscape, including vegetation heights and bare earth elevation. These data were collected between 2015 and 2019 by the Washington Department of Natural Resources, and the resulting data files were used to calculate the updated baseline scenario vegetation conditions. The processing of the LiDAR data consisted of using Geographic Information System (GIS) to plot specific locations (every 10 feet) along the riparian area. These locations are referred to as nodes. A distance of 50 feet offset from the stream edge was used to create the riparian offset buffer.

The process of creating node data started with downloading accurate LiDAR data that have the components of both surface and terrain. Digital surface models (DSM) ignore objects such as trees and give the elevation of the surface of the ground. Digital terrain models (DTM) represent their elevation data including terrain objects such as trees. Using these data, the difference between the two elevation models and the canopy height of trees was calculated.

The Node Data Line is the linear feature that has a Node every 10 feet. This feature is a line that is offset 50 feet from the Observed High-Water Mark . A distance of 50 feet from the edge of the river was chosen because it lies clearly within the riparian buffer, and woody plants (particularly trees) could be expected to shade the river at this distance. Furthermore, this distance is far enough away from the river for the data to reflect more long-term established vegetation and less likely to encounter a roadway or clearcut area. The Node Data are created by placing a data point every 10 feet along the Node Data Line using the ArcGIS tool "Generate Points Along Lines."

An important feature of vegetation management includes expected vegetation survivability based on the depth and duration of inundation when the proposed FRE facility is operating (see Attachment A – Conceptual VMP). The temporary inundation area of the proposed FRE facility are documented in the FRE Facility Temporary Reservoir Inundation and Vegetation Analysis Clarification (HDR 2020).[4] The results of the inundation mapping show that the maximum pool water surface elevation(WSEL) of the Initial Reservoir Evacuation area will range between 620 and 568 feet. The acreage of inundation above 528 feet (lower limit of the Initial Reservoir Evacuation area) will range between 238 and 527 acres, and the duration of inundation will range between 5.9 and 11.1 days. The Debris Management Evacuation area will have 122 acres of inundation between WSEL 528 and 500 feet and will be inundated between 20.2 and 25.2 days. The Final Reservoir Evacuation area will have 159 acres of inundation between WSEL 500 and 425 feet. This area will be inundated at least 26 days under each flood event and up to 32 days under the event of record (historic 2007 flood event). Inundation zones at Mud Mountain Dam were approximated using the same relative distances in elevation as those defined at the proposed FRE facility.

The attributes from the previously mentioned data (DSM, DTM, digital height models [DHM], Evacuation Zone) are added to the Node attributes by using the ArcGIS tool "Extract Values to Points" for all LiDAR-based layers and by using a SQL selection to determine the Inundation Zone into which each point falls. Once the Node Data are established to include the DHM, DTM, DSM, and Inundation Zone values for each specified location in an ArcGIS feature class, the "Table to Excel" tool in Arc Map is used to export the attribute data for the points to an Excel table for data analysis.

Figure 7 presents the mapping results of the temporary inundation area and the Node Data locations at the proposed FRE facility. The results of the GIS analysis of the LiDAR data resulted in a spreadsheet table listing left or right bank, segment reach, DTM elevation (bare earth), DSM (first return), and the DHM (DSM minus DTM). Multiple heights were provided because the GIS analysis used a shorter interval than the model segment length. The heights were averaged for each model segment. The model uses

[4] The District provided the referenced document (HDR 2020) with the District's comments to Ecology's DEIS and also included as Appendix D to the Biological Assessment and the Essential Fish Habitat Assessment submitted to the USACE on September 18, 2020.

one vegetation height value for each of the 138 model segments. An average height was used to approximate vegetation heights across each model segment and discount anomalous vegetation (abnormally high or low) that may have little effect on the shading provided within the entire model segment. The heights for the left and right banks were then paired and aligned to the segment numbers in preparation for the model shade input file, where the variable treetop elevations on the left and right banks were revised for each model segment (see Attachment B).

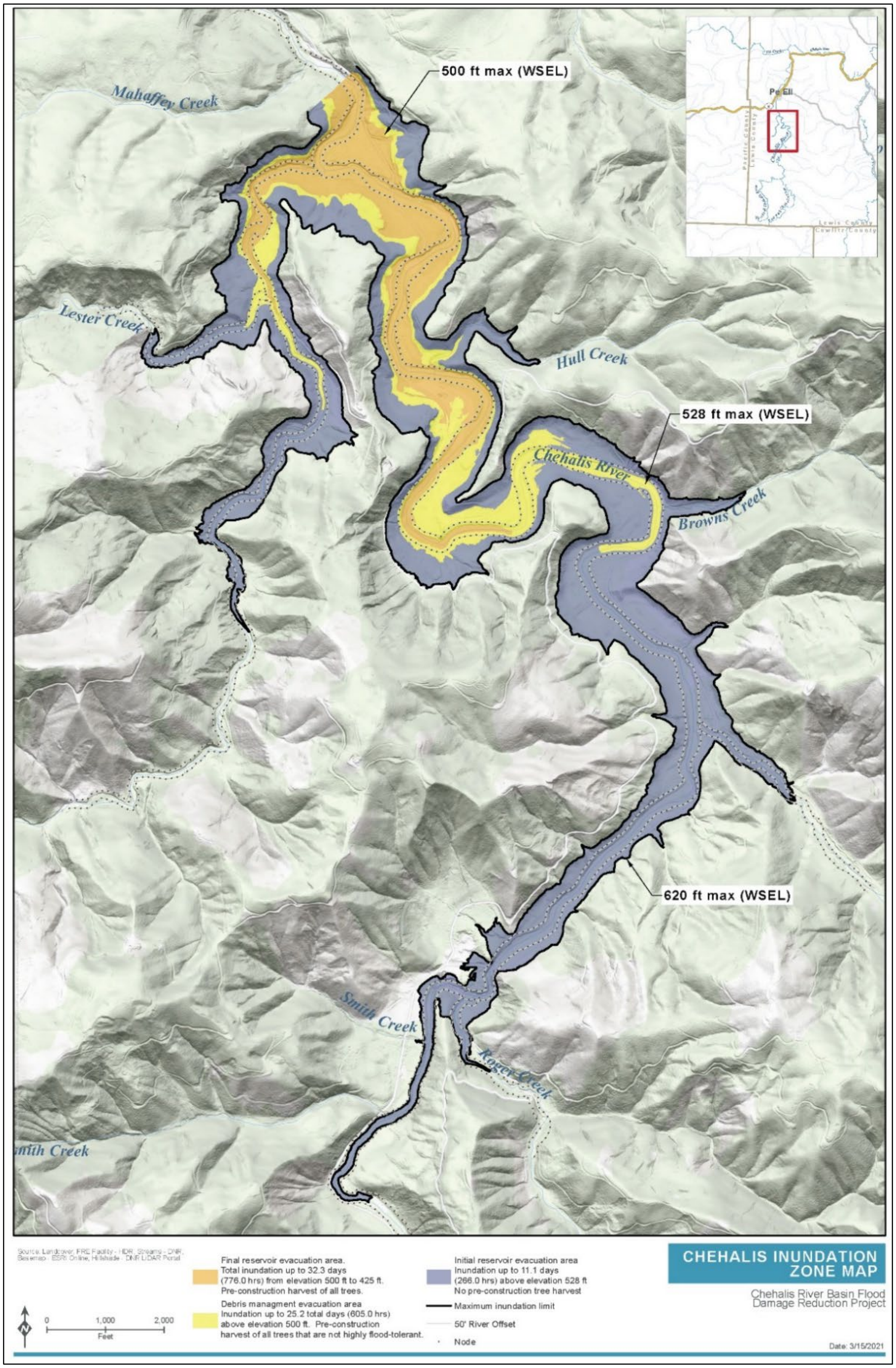

Figure 7. Proposed FRE Site Temporary Inundation Area with Three Inundation Zones with Identified Node Locations for GIS Analysis of Riparian Vegetation

3.2 Scenario Riparian Vegetation

The vegetation scenarios used in the sensitivity analysis were selected to conceptually represent two vegetation conditions: low and high vegetation growth. The low vegetation scenario was selected to represent a volunteer vegetation community comprised mostly of willows throughout the temporary inundation area. The high vegetation scenario was selected to represent a varying height condition that could result from active vegetation management, including active thinning, planting, and replanting flood-tolerant species that reach normal heights in maturity for the temporary inundation area within three inundation zones, the initial evacuation zone, the debris management zone, and the final evacuation zone. The anticipated riparian vegetation height used in this sensitivity analysis was informed by review of the plant communities documented at Mud Mountain Dam, a similar flood storage project located on the White River in western Washington.

3.2.1 Mud Mountain Dam Vegetation as an Analog

Mud Mountain Dam, developed by the USACE in the 1940s, was identified by the project team as a comparative reference facility to help understand how vegetation and specific plant species respond to repeated episodic inundation within a temporary reservoir managed for flood hazard mitigation. Mud Mountain Dam is located in Pierce County and temporarily impounds the White River during storm events. The facility was constructed solely to control flood impacts; it floods to similar depths and for similar durations compared to those of the proposed FRE facility and is located within the same physiogeographic province as the proposed facility. Since its construction in the 1940s, the USACE has not implemented any form of vegetation management within the Mud Mountain Dam reservoir footprint. The vegetation was cleared and removed when the facility was built, and volunteer vegetation established and propagated itself without management resulting in the present-day vegetation communities. An important difference between Mud Mountain Dam and the proposed FRE facility is the frequency of operations and subsequent inundation of vegetation communities. Mud Mountain Dam typically operates multiple times annually, so the vegetation communities are frequently inundated (at least once each year and more than once each year in most years). This is in contrast to the proposed FRE facility, which will operate approximately every 7 years as stated in the SEPA DEIS (Ecology 2020a), resulting in less-frequent inundation of the vegetation communities compared to Mud Mountain.

The Mud Mountain facility is an important reference site to help inform anticipated woody vegetation heights in response to the expected inundation from operation of the proposed FRE facility. Since there are differences in the geology, soil conditions, hydrology, and other characteristics between the Chehalis River Basin and the White River Basin, the Mud Mountain Dam example is not intended to represent an exact comparison of the proposed FRE facility operations. The importance of the Mud Mountain example is to inform the VMP for the proposed FRE facility by suggesting woody plant species that are likely to survive frequent inundation. The specific species can be used to replant the area of the temporary inundation area during implementation of the VMP. In addition, review of the Mud Mountain facility provides a projection of future vegetation communities that are likely to persist in the temporary inundation area.

Mud Mountain was selected as a reference facility to inform assumptions for vegetation heights in the CE-QUAL-W2 model. The project team reviewed the following elements of the Mud Mountain facility:

- Operations
- Vegetation succession based on a recent vegetation study
- Vegetation height data based on LiDAR data
- Mud Mountain flooding regime data

The vegetation distribution within the Mud Mountain temporary reservoir provided by a recent Engineer Research and Development Center study of the Mud Mountain facility (USACE-ERDC, Environmental Laboratory 2019) shows that an assemblage of woody plants is able to survive regular winter inundation events. In the immediate vicinity of the Mud Mountain Dam, plants are typically shorter, increasing in height farther upstream from the facility. Woody plants, particularly Sitka willow (*Salix sitchensis*), occur throughout the reservoir, including at the lowest elevation reach of the facility. Trees, including Black cottonwood (*Populus balsamifera*), Red alder (*Alnus rubra*), and Sitka spruce (*Picea sitchensis*), are established within the flooded part of the reservoir.

Existing vegetation heights at the Mud Mountain Dam inundation area were also calculated using LiDAR data provided by the Washington Department of Natural Resources. Similar methods were used at Mud Mountain to make the data comparable to data for the proposed FRE facility (see Section 3.1). To complete this exercise at Mud Mountain, the edge of the White River through the inundation area was digitized and riparian offset transects (nodes) were developed at which vegetation height data were calculated. The table showing the results of this exercise is included as Attachment C. The heights of vegetation used for the sensitivity analysis were based on the typical mature heights of the species of plant that was mapped at the Mud Mountain facility for each of the flooding regimes. LiDAR data were used to validate the baseline assumption that woody plants would cover the inundation area but were not used to prescribe future tree heights because several other factors, independent of the flooding regime, may influence actual tree heights, including sediment loading, surficial geology, recruitment, and aspect. The tallest tree heights at Mud Mountain appear to be taller than the model inputs, and portions of the inundation area contain low-growing vegetation, but when averaged over the inundation area, the heights were approximately 28 feet. The temporary inundation area with three inundation zones that indicate depths of flooding similar to those at the proposed FRE facility are shown on Figure 8.

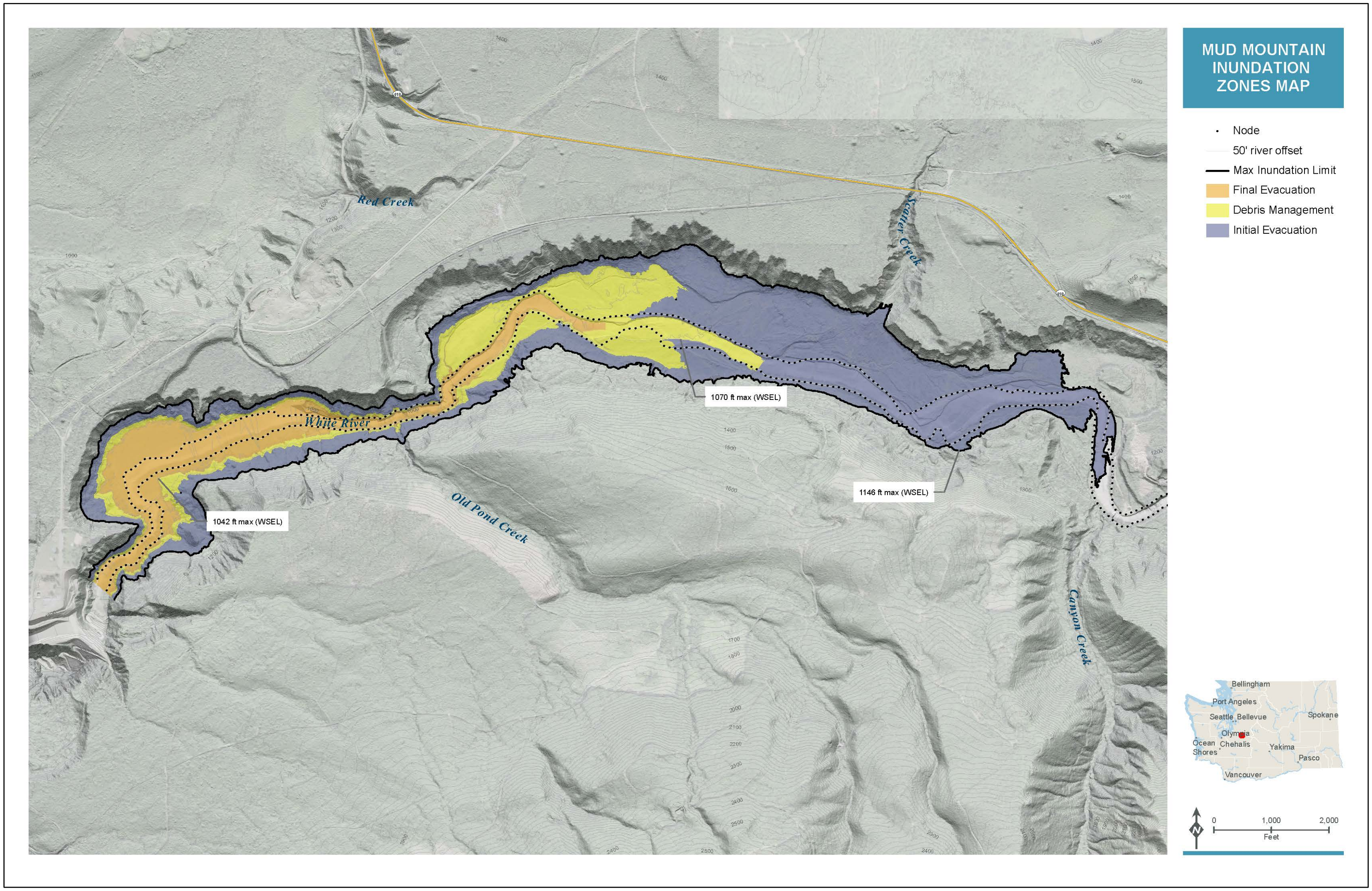

Figure 8. Mud Mountain Temporary Inundation Area with Three Inundation Zones

3.2.1.1 Future Riparian Vegetation Heights

In addition to the 2-meter vegetation height selected for use in the model within the DEIS documents, two other vegetation heights were selected. These include a low vegetation scenario that is based on a lower overall vegetation height composed mostly of volunteer willows, and a high vegetation scenario that anticipates that some woody vegetation and trees may survive inundation and the positive effects introduced by active vegetation management within the temporary inundation area.

The low vegetation scenario vegetation height assumes that existing vegetation will be removed throughout the temporary inundation area because the existing vegetation will not tolerate flooding. Subsequently, woody vegetation, comprised primarily of Sitka willow and other willow species, will recolonize the affected land and will achieve a mature height of at least 20 feet. Sitka willow grow to a mature height of 30 feet according to the United States Department of Agriculture, Natural Resources Conservation Service (USDA, NRCS) PLANTS database (2021). They are a common riparian shrub found throughout the Pacific Northwest and common within the Mud Mountain facility and are appropriate for the proposed FRE site. The 20-foot height is also validated within the Mud Mountain vegetation height data, as the average riparian vegetation height at Mud Mountain is approximately 28 feet, even though some parts of the Mud Mountain facility have lower and higher vegetation.

The high vegetation scenario segregates vegetation heights based on the three inundation zones that were identified in the inundation analysis (HDR 2020) and described in the Conceptual VMP (Attachment A). Under this scenario, the Final Evacuation Area (the lowest part of the temporary reservoir and the area that would be inundated for the greatest duration) would have the lowest vegetation height, modeled at 20 feet. The Debris Management Zone (the middle portion of the temporary reservoir) would be expected to retain some residual vegetation and be actively planted with flood-tolerant species. Riparian vegetation in this zone would be modeled at 60 feet. This height corresponds to the mature height of a Red alder or Oregon ash tree, according to the USDA PLANTS database. The Final Evacuation Zone (the upper part of the temporary inundation area and the area flooded less frequently and inundated for the shortest duration) would be actively managed to promote taller vegetation, and taller trees can be expected to tolerate the flooding conditions anticipated in this zone. A mature vegetation height of 90 feet was selected for the Final Evacuation Zone based on the mature height of Black cottonwood and Sitka spruce. Both species are observed within the upper reaches of the Mud Mountain inundation zone under similar flooding regimes and are present in the vicinity of the proposed FRE facility.

LiDAR estimates of the vegetation heights at the Mud Mountain facility confirm the following:

1) The low vegetation scenario used for the sensitivity analysis is an appropriate worst-case estimation since the average height of vegetation exceeds the model low vegetation height.

2) Taller trees that exceed the model input heights for the high vegetation scenario persist, given the flooding regime.

Choosing the high vegetation height for the input to the model based directly on the observed vegetation heights at Mud Mountain within each flooding zone does not appear to be appropriate. This would ignore the differences in flooding regime, soil type and geomorphology, water temperature, site aspect, and other local factors that affect plant growth. Instead, we selected plant species based on their presence at Mud Mountain and projected these species to an anticipated growth height over a 30-year growth horizon.

3.2.2 Vegetation Scenarios Model Input Shade Files

The baseline shade input file was the starting point for the development of the shade input file for each vegetation scenario. The temporary inundation area corresponds with model Segments 44 (upper limit of the temporary inundation area) through Segment 111 (proposed FRE facility). The baseline vegetation heights were modified only for these segments based on the revised existing vegetation mapping described in Section 3.1. For the low vegetation scenario, the updated baseline vegetation height on both the left and right banks was replaced with a value of 6.1 meters (20 feet) for Segments 44 through 111. For the high vegetation scenario, the updated baseline vegetation on both the left and right banks was replaced with a value of 27.4 meters (90 feet) for Segments 44 through 73, representing the least inundated area with the highest vegetation. The area of intermediate inundation used a value of 18.3 meters (60 feet) for Segments 74 through 86. The area of most frequent and longest-lasting inundation used a value of 6.1 meters (20 feet) for Segments 87 through 111.

The vegetation height is added to the bottom elevation to calculate the vegetation elevation. The channel-bottom elevation along with the vegetation elevations in the updated baseline and low vegetation scenarios are shown in Figure 9, and the vegetation elevations in the updated baseline and high vegetation scenarios are shown in Figure 10[5]. The setup of these figures is the same as described for Figure 5 and Figure 6. Although constant vegetation heights were used, the left and right banks have varying elevations that create the varying vegetation elevations shown in Figure 9 and Figure 10. For the low vegetation scenario, the low elevation of the vegetation in the temporary inundation area is visible. For the high vegetation scenario, the three zones of vegetation heights are visible, although the middle Debris Management Zone is less distinctive due to its short length and variable bank elevations. The segments upstream of the temporary inundation area have the same vegetation elevations as the updated baseline.

[5] Figure 9 and Figure 10 show the model segments along the x-axis with the highest elevation on the left corresponding to the upstream boundary and the lowest elevation on the right corresponding to the proposed FRE facility. A list of specific locations corresponding to model segments, such as the proposed FRE facility at Segment 111, is provided in Section 2.3.

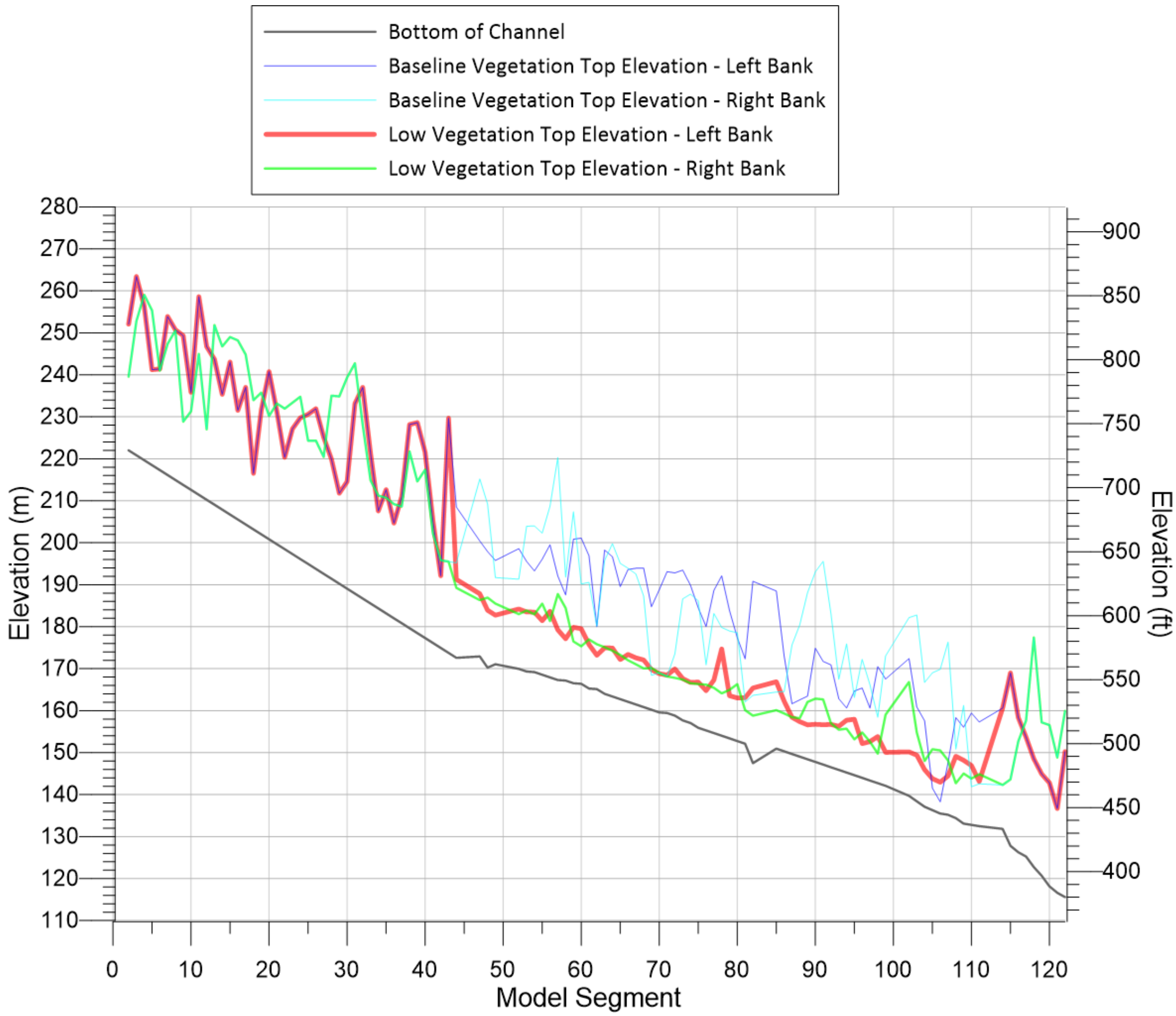

Figure 9. Chehalis River Channel Bottom with Top of Vegetation Elevation Model Inputs for Updated Baseline and Low Vegetation

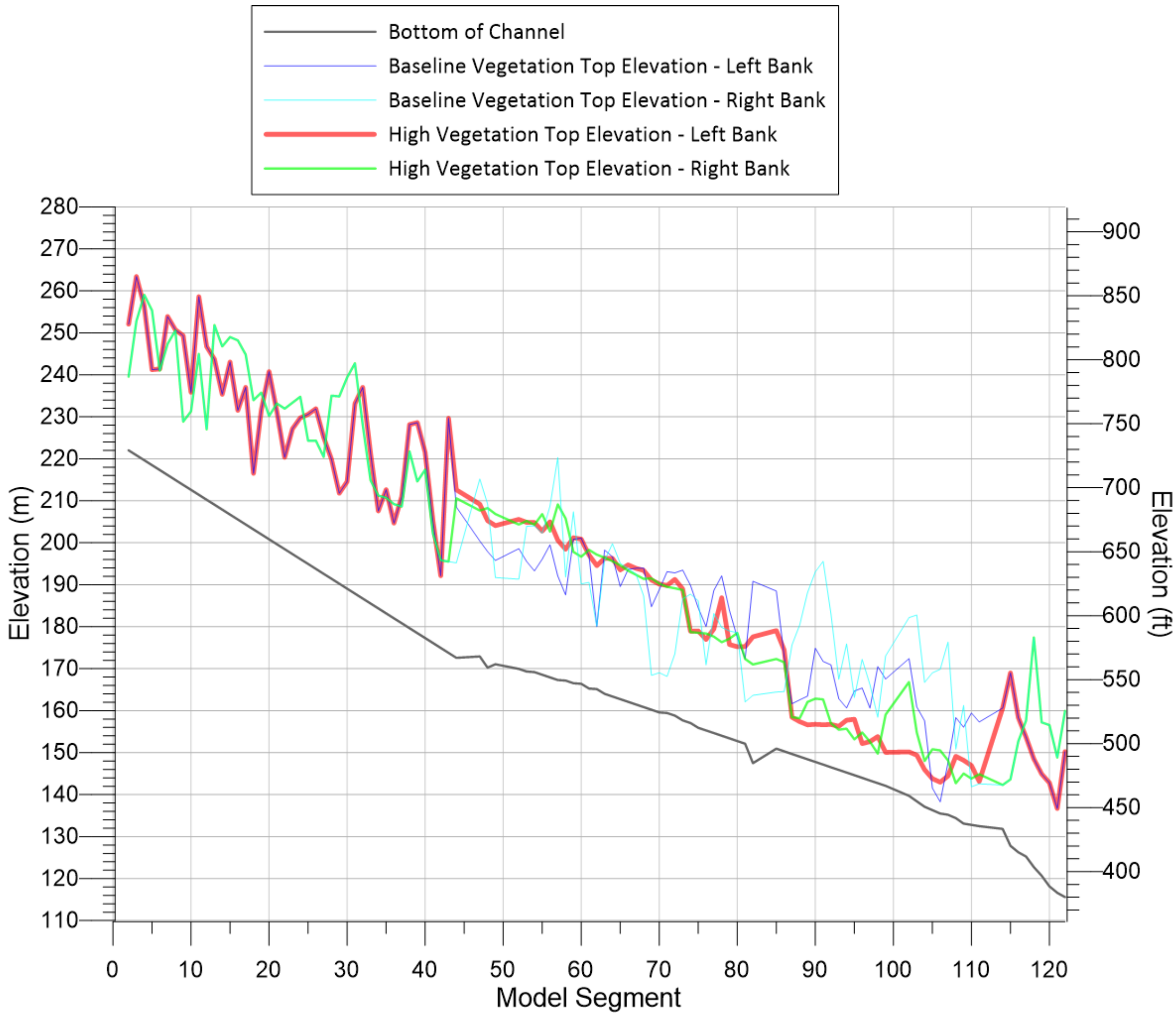

Figure 10. Chehalis River Channel Bottom with Top of Vegetation Elevation Model Inputs for Updated Baseline and High Vegetation

The modeling for the DEIS included a subset of scenarios specific to the proposed FRE facility and shading as summarized in Table 1. For the baseline scenario, the inputs for the vegetation heights were changed to use the vegetation heights calculated based on recent information. Rather than use the DEIS riparian shading and no shading scenarios, the new sensitivity analysis scenarios using vegetation height inputs estimated as high and low vegetation were used. Again, two conditions were simulated for the scenarios—current and climate change—with climate change including increases to air and water temperature inputs and a flow shift. The updated baseline and vegetation scenarios under two sets of conditions resulted in a total of six model simulations for sensitivity analysis, as summarized in Table 2.

Table 2. Summary of Footprint Model Simulations for the Sensitivity Analysis

Sensitivity Analysis Scenarios	Condition	
	Current	Climate Change
Updated Baseline	Baseline Meteorology Baseline Inflow Baseline Inflow Water Temperature Updated Baseline Vegetation	Increased Air and Dew Point Temperature Multiplier Inflow Increased Inflow Water Temperature Updated Baseline Vegetation
High Vegetation (Vegetation Management Plan)	Baseline Meteorology Baseline Inflow Baseline Inflow Water Temperature Riparian Vegetation in Inundation Zones of 6.1, 18.3, or 27.4 meters	Increased Air and Dew Point Temperature Multiplier Inflow Increased Inflow Water Temperature Riparian Vegetation in Inundation Zones of 6.1, 18.3, or 27.4 meters
Low Vegetation (Volunteer Willows)	Baseline Meteorology Baseline Inflow Baseline Inflow Water Temperature Riparian Vegetation in Inundation Area of 6.1 meters	Increased Air and Dew Point Temperature Multiplier Inflow Increased Inflow Water Temperature Riparian Vegetation in Inundation Area of 6.1 meters

4 Model Simulation Results

The CE-QUAL-W2 model was run by PSU using the input scenarios shown in Table 2. Model output (see Attachment D) was post-processed to generate graphs and other statistics of interest. Results of the sensitivity analysis evaluated water temperature response to vegetation shading at the following locations:

- Segment 2 upstream starting location along the Chehalis River.
- Segment 44 the uppermost reach of temporary inundation area during an extreme flood retention event reach.
- Segment 111 proposed FRE facility.
- Segment 122 downstream ending location along the Chehalis River.

These locations provide the model water temperature results upstream of the temporary inundation area, changes through the temporary inundation area, and changes downstream of the proposed FRE facility. Since the regulatory water temperature standard (Washington Administrative Code 173-201A) is based on the 7-day average of the daily maximum water temperature (7-DADMax), the maximum daily water temperature predicted by the model was averaged over a running 7-day period.

4.1 Scenario Results by Location

The 7-DADMax values of the model results are presented for select locations. The comparisons demonstrate the influence of vegetation height on water temperature as predicted by the model for the selected locations.

4.1.1 Segment 2 – Boundary Condition

Water temperature 7-DADMax values at the upstream boundary along the Chehalis River are shown in Figure 11[6]. This location is unaffected by the proposed project and reflects the boundary condition. The scenario results are the same under the current and climate change conditions, respectively, because the vegetation heights were not changed for this location.

[6] Figure 11 and Figure 12 show the approximately 2-year model run time along the x-axis starting 1/1/2013 and ending 1/1/2015 and water temperature (◦C) along the y-axis at the respective model segment. The blue line is the updated baseline scenario under current conditions, and the yellow line is the updated baseline scenario under climate change. The model setup only allowed for climate change to be modeled starting 1/1/2014.

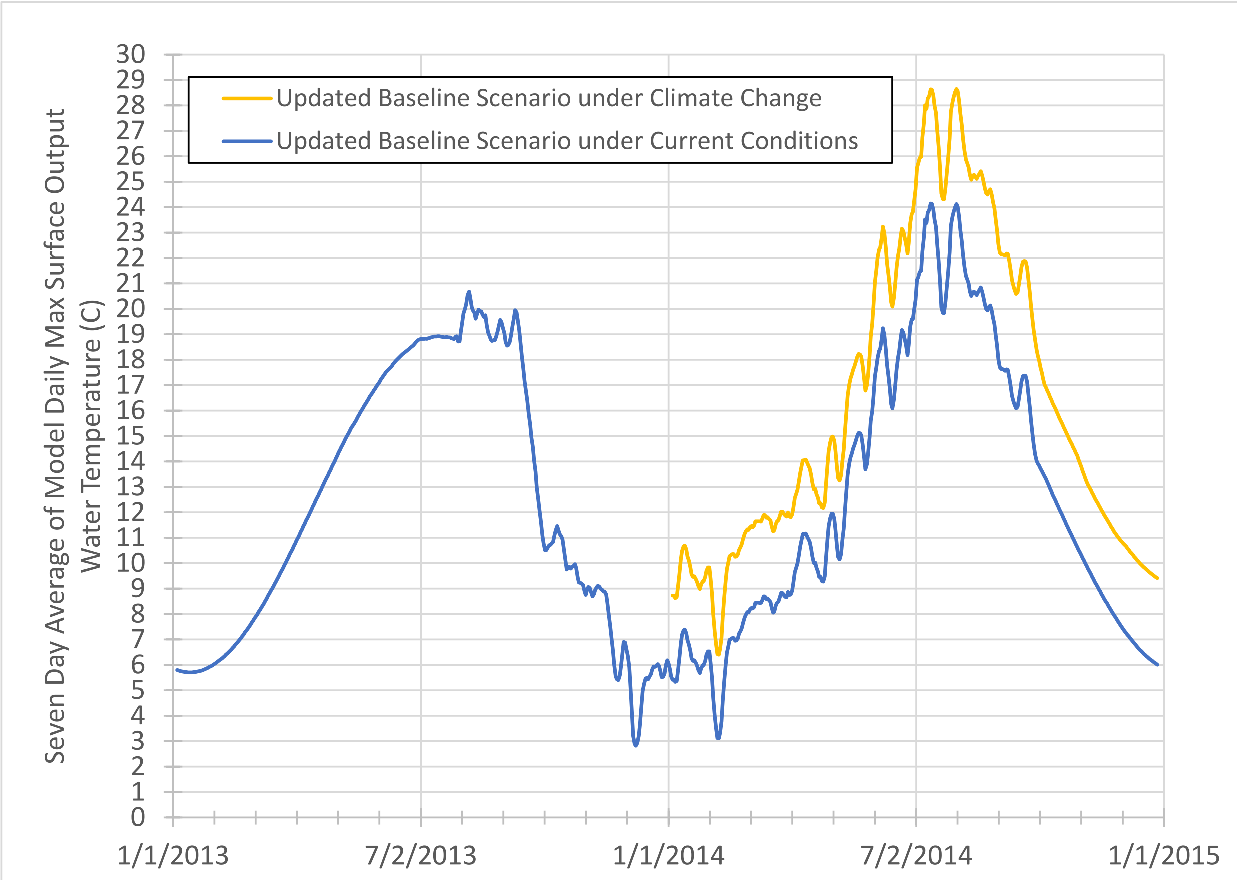

Figure 11. Water Temperature Results as 7-DADMax for Model Scenarios from Segment 2

4.1.2 Segment 44 – Upper Limit of Temporary Inundation Area

Water temperature 7-DADMax values at the uppermost reach of the temporary inundation area during an extreme flood retention event along the Chehalis River are shown in Figure 12. The scenario results are the same under the current and climate change conditions, respectively, because the vegetation heights were not changed for this location or upstream locations.

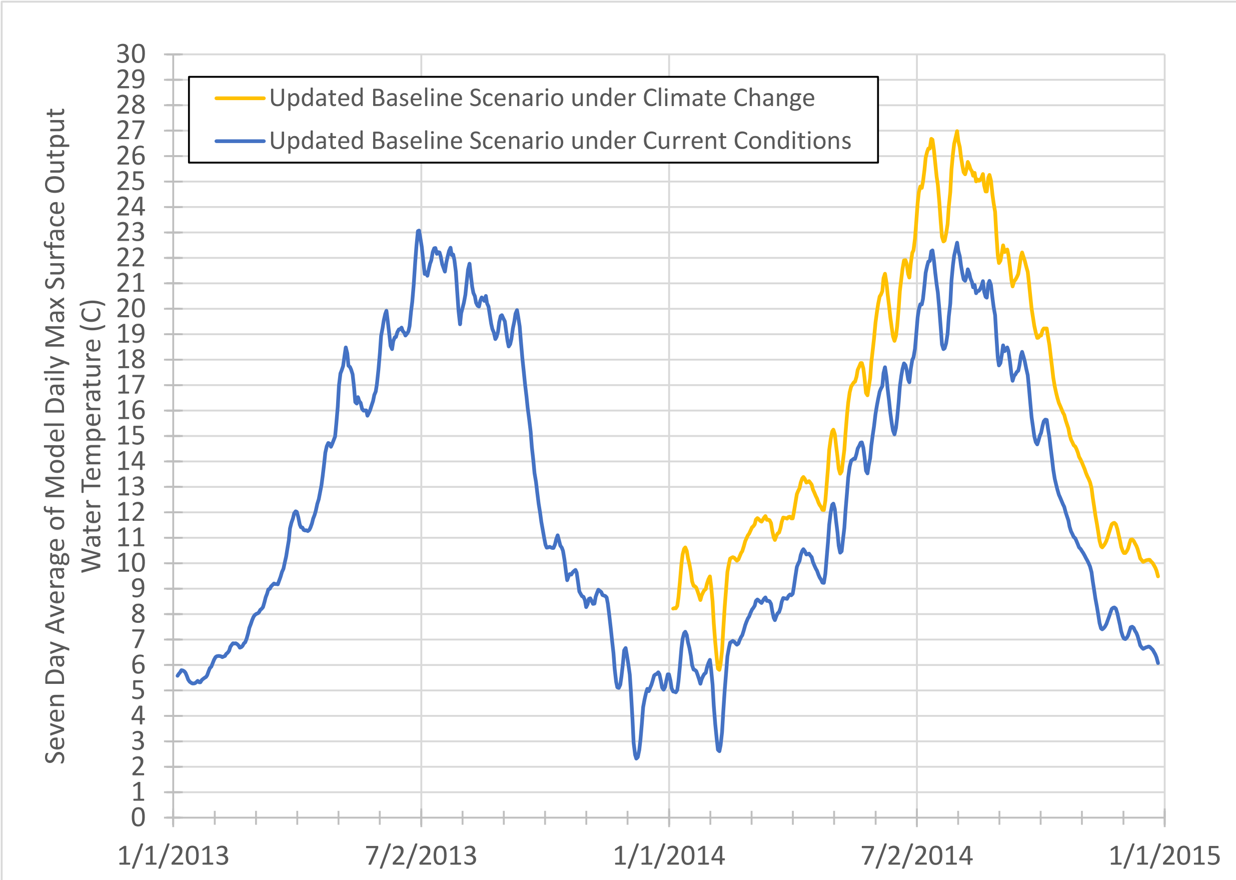

Figure 12. Water Temperature Results as 7-DADMax for Model Scenarios from Segment 44

4.1.3 Segment 111- Proposed FRE Facility

Water temperature 7-DADMax values at the proposed FRE facility along the Chehalis River are shown in Figure 13[7]. At this location, upstream changes to vegetation heights have influenced the model predictions of water temperature. The greatest differences occur between approximately June 20 and September 22. Table 3 provides the statistical differences between the updated baseline scenario and the low vegetation and high vegetation scenarios under both current and climate change conditions during the referenced summer period when flow is lowest. The high vegetation scenarios show an average difference of 0.3°C or less.

[7] Figure 13 and Figure 14 show the approximately 2-year model run (time) along the x-axis starting 1/1/2013 and ending 1/1/2015 and water temperature (◦C) along the y-axis at the respective model segment. In addition to the blue and yellow scenarios provided in the Figure 11 and Figure 12, Figure 13 and Figure 14 provide the additional scenarios for low and high vegetation.

Table 3. 7-DADMax Water Temperature Results at Segment 111 during Low Flow of Summer (June 20 to September 22)

Scenarios Compared	Water Temperature Change (°C)			
	Minimum	Median	Average	Maximum
Low Vegetation Scenario under Climate Change minus Updated Baseline Scenario under Climate Change	0.7	1.0	1.0	1.3
High Vegetation Scenario under Climate Change minus Updated Baseline Scenario under Climate Change	0.1	0.4	0.3	0.5
Low Vegetation Scenario under Current Conditions minus Updated Baseline Scenario under Current Conditions	0.7	1.0	1.0	1.4
High Vegetation Scenario under Current Conditions minus Updated Baseline Scenario under Current Conditions	0.1	0.3	0.3	0.5

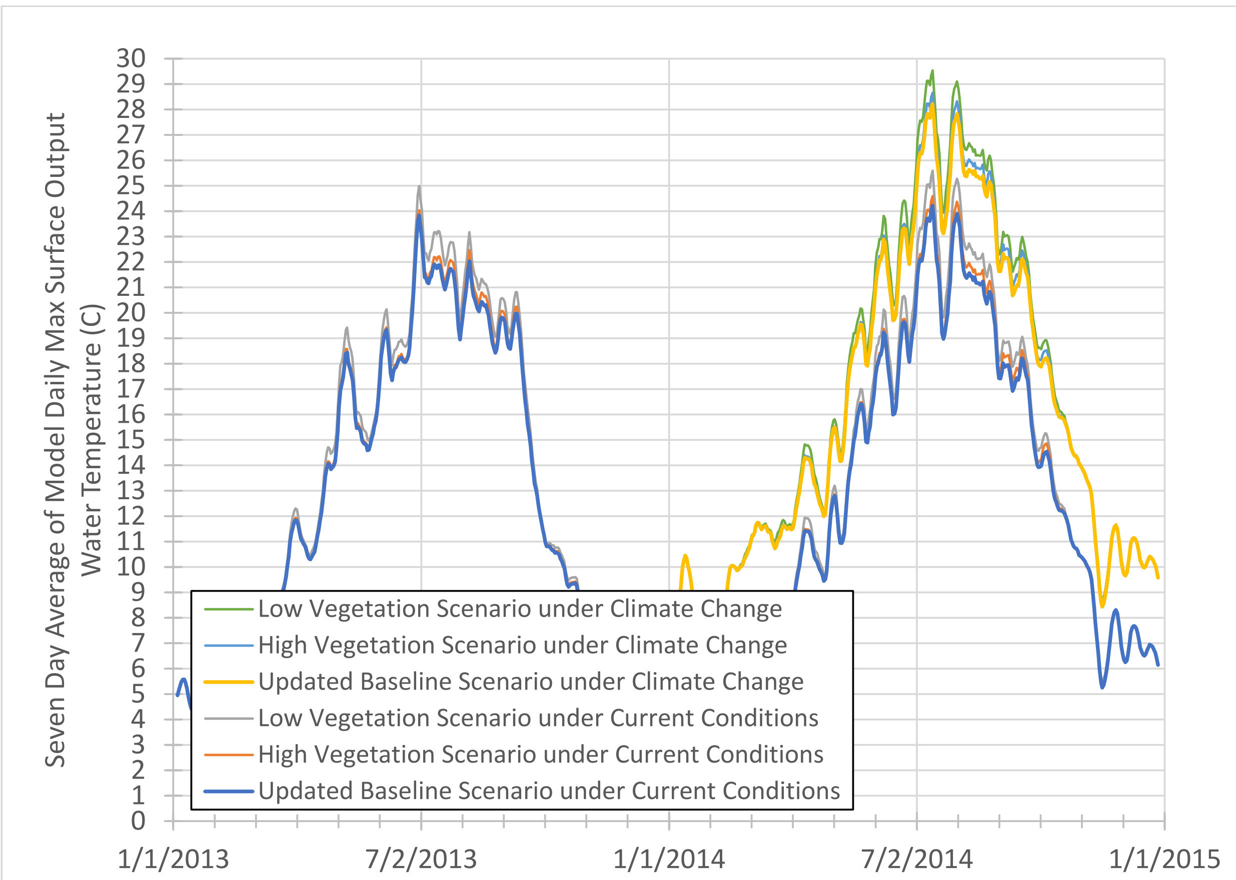

Figure 13. Water Temperature Results as 7-DADMax for Model Scenarios from Segment 111

4.1.4 Segment 122

Water temperature 7-DADMax values at the downstream boundary along the Chehalis River are shown in Figure 14. At this location, upstream changes to vegetation heights have influenced the model predictions of water temperature. The greatest differences occur between approximately June 20 and

September 22. The statistical differences during the referenced summer period are summarized in Table 4. The high vegetation scenarios show an average difference of 0.3°C or less.

Table 4. 7-DADMax Water Temperature Results at Segment 122 during Low Flow of Summer (June 20 to September 22)

Scenarios Compared	Water Temperature Change (°C)			
	Minimum	Median	Average	Maximum
Low Vegetation Scenario under Climate Change minus Updated Baseline Scenario under Climate Change	0.6	0.8	0.8	1.1
High Vegetation Scenario under Climate Change minus Updated Baseline Scenario under Climate Change	0.2	0.2	0.3	0.4
Low Vegetation Scenario under Current Conditions minus Updated Baseline Scenario under Current Conditions	0.6	0.9	0.9	1.1
High Vegetation Scenario under Current Conditions minus Updated Baseline Scenario under Current Conditions	0.1	0.2	0.3	0.4

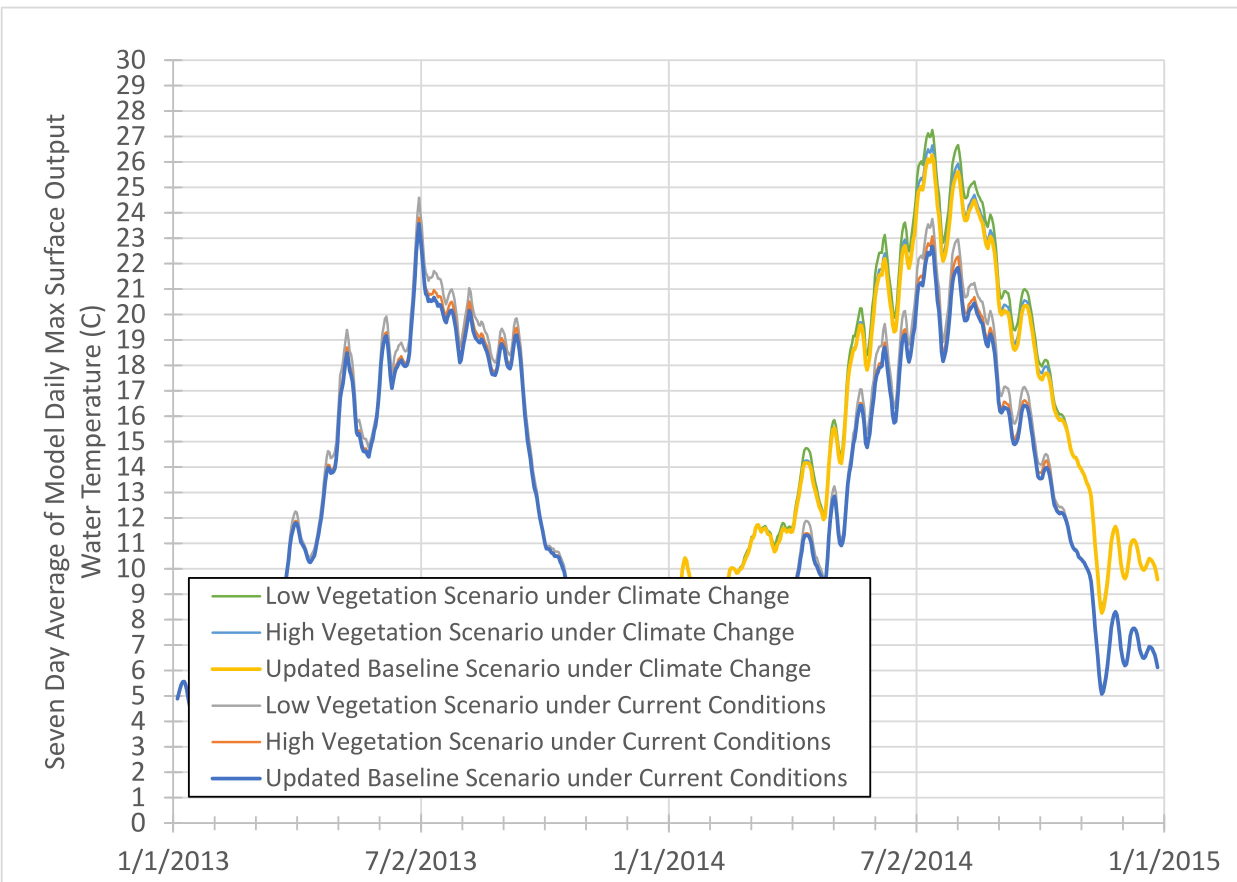

Figure 14. Water Temperature Results as 7-DADMax for Model Scenarios from Segment 122

4.2 Scenario Results Longitudinally

The 7-DADMax values of the model results for the scenarios may be presented as a difference between two select locations as a representation of longitudinal changes. The following figures present the water temperature at Segment 44 (upper limit of the temporary inundation area) and at Segment 111 (proposed FRE facility) from mid-April to mid-October along with the difference. Figure 15 shows the updated baseline scenario. Figure 16 shows the high vegetation scenario. Figure 17 shows the low vegetation scenarios. The three scenarios are under current conditions.

Segment 44 and Segment 111 were selected for the as they represent the upper and lower limits of the temporary inundation area and where vegetation management actions will be implemented. The results are reported for the mid-April to mid-October (2014) as that is when water temperature changes are expected to be greatest due to seasonal variation in solar radiation and hydrologic (flow) conditions.

The results indicate that water temperature moving downstream through the temporary inundation area as exhibited by the difference (green line) between Segment 44 (blue line) and Segment 111 (red line) as shown in Figure 15, Figure 16, and Figure 17[8]. This seasonal variation is expected as water temperature increases in the spring and early summer as the amount of solar radiation increases and the higher angle of the sun results in less shading. The water temperature declines in the late summer and early fall with the differences returning to near zero as the amount of daylight declines, low flow persists, and mixing occurs with the deeper pools in the river.

Figure 15 demonstrates that the updated baseline scenario under current conditions results in an approximate maximum water temperature difference of 1.4°C during the mid-summer period (July), returning to near zero by the fall (October).

[8] Figure 15, Figure 16, and Figure 17 show the 7-Day Average water temperature on the y-axis, over the time period from 4/25/14 to 10/22/2014 on the x-axis. Modeled water temperatures are plotted for Segment 44 (blue line) and Segment 111 (red line). The difference in water temperature between Segment 11 and Segment 44 (green line) is plotted to the 2nd y-axis “Temperature Difference”.

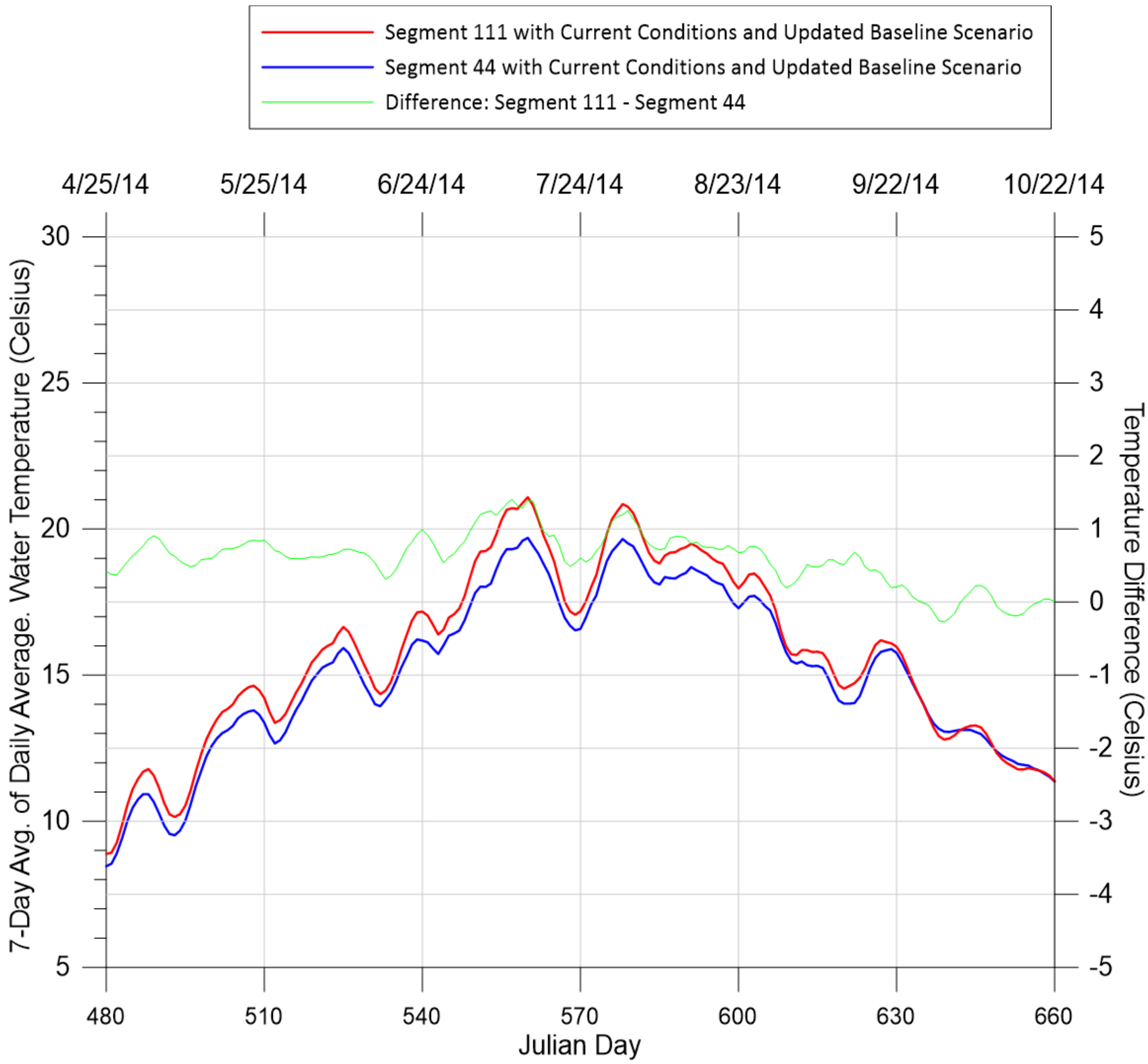

Figure 15. Comparison of Daily Average Water Temperature at Segment 44 (Upper Limit of Temporary Inundation Area) and Segment 111 (Proposed FRE Facility) with Updated Baseline Scenario under Current Conditions

Figure 16 demonstrates that with the high vegetation scenario under current conditions, the maximum water temperature difference between Segment 44 and Segment 111 increases to approximately 1.7°C in mid-summer (July). Figure 17 demonstrates that the low vegetation scenario under current conditions results in an increase to a maximum water temperature difference of approximately 2.5°C in mid-summer (July).

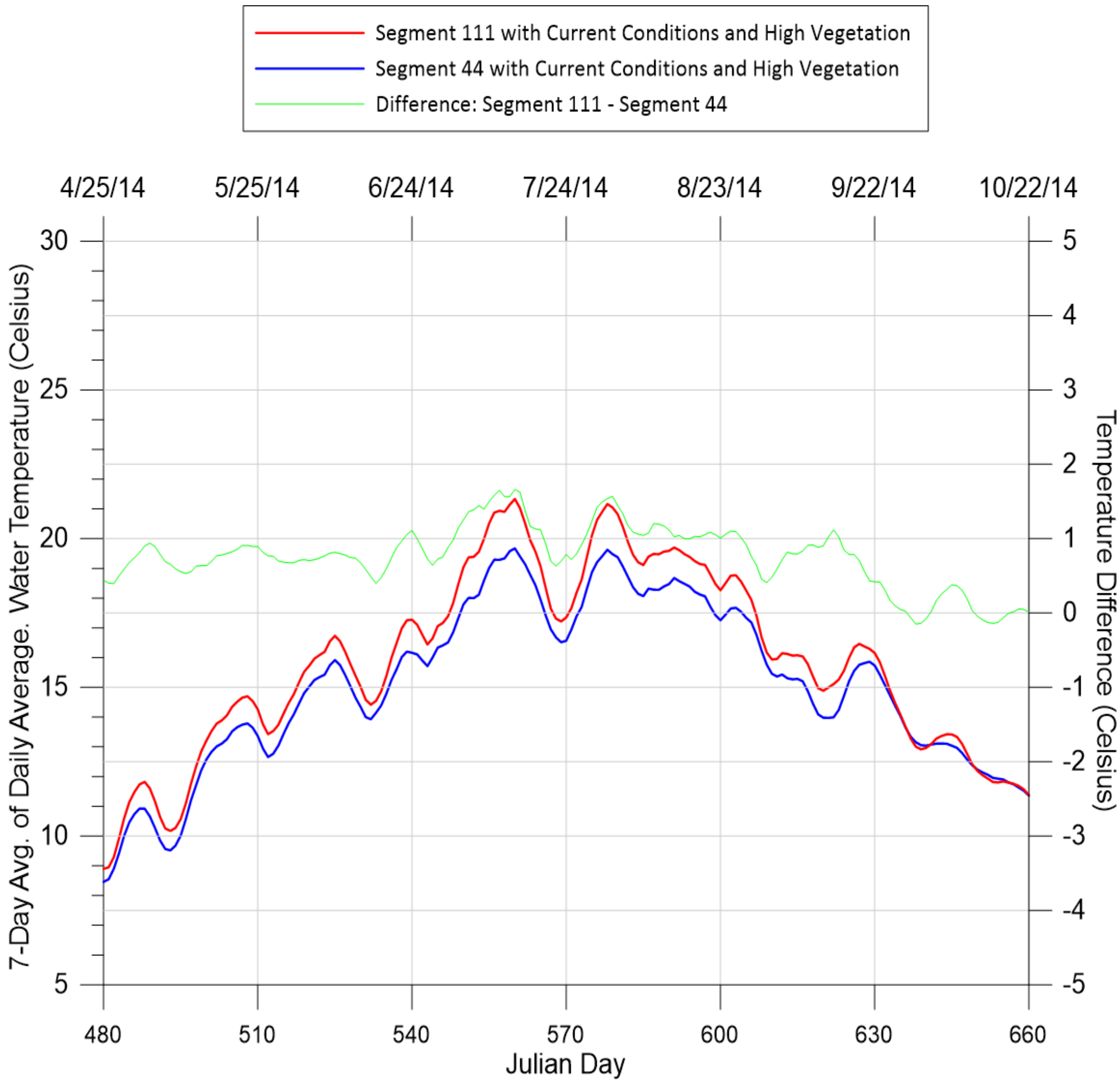

Figure 16. Comparison of Daily Average Water Temperature at Segment 44 (Upper Limit of Temporary Inundation Area) and Segment 111 (Proposed FRE Facility) with High Vegetation Scenario under Current Conditions

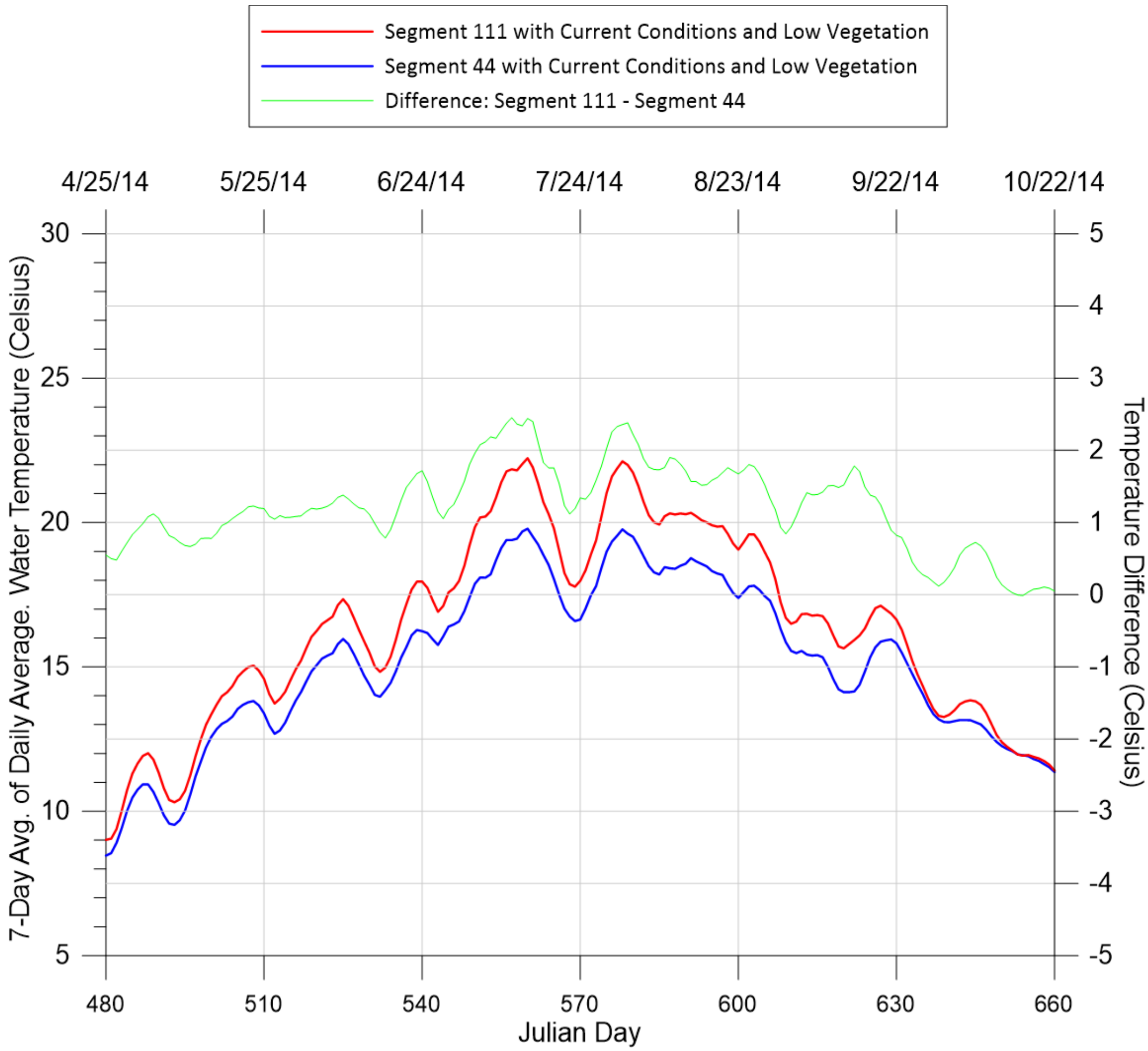

Figure 17. Comparison of Daily Average Water Temperature at Segment 44 (Upper Limit of Temporary Inundation Area) and Segment 111 (Proposed FRE Facility) with Low Vegetation Scenario under Current Conditions

Comparing the results between vegetation scenarios, the warming is greatest the lower the vegetation, as seen by the area between the blue and red lines, and the green difference line in Figure 15, Figure 16 and Figure 17. The largest differences occur in the summer when air temperature is highest, shading is the lowest, and the solar input is the greatest. These peaks align with those in Figure 11 through Figure 14 in Section 4.1, which indicates that vegetation conditions either at a single location or between locations show a similar pattern of seasonal variation from approximately April through October.

Figure 18 provides the water temperature differences between the high vegetation and updated baseline scenarios (black line), and the low vegetation and updated baseline scenarios (green line).[9] Figure 18 demonstrates that with the high vegetation scenario, the water temperature increases between the upper limit of the temporary inundation area (Segment 44) and the FRE facility (Segment 111) are not as great when compared to the low vegetation scenario. This result indicates that with the implementation of the VMP (high vegetation scenario), water temperature increases may be minimized.

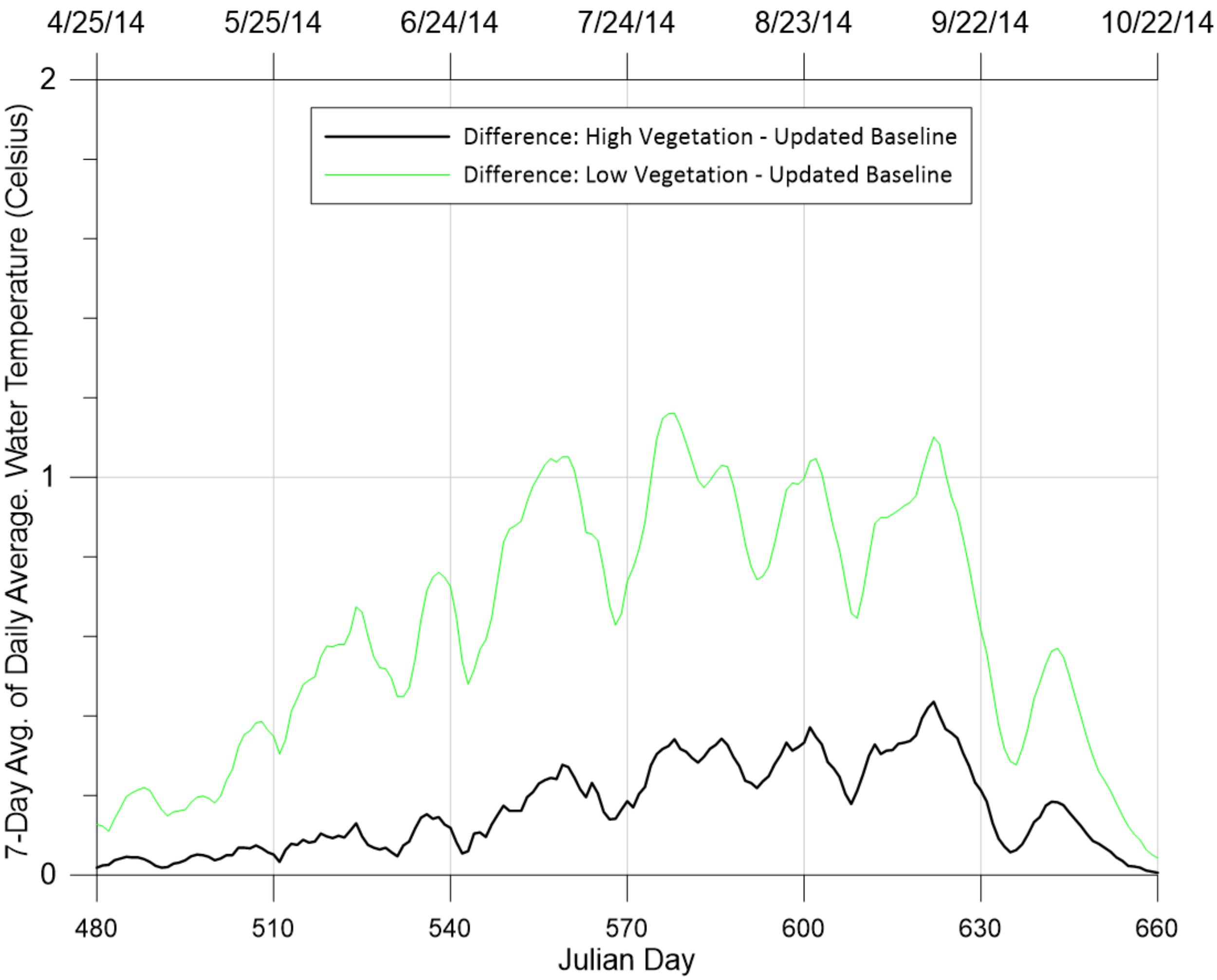

Figure 18: The Differences of Daily Average Water Temperature Differences between Segment 44 (Upper Limit of Temporary Inundation Area) and Segment 111 (Proposed FRE Facility) for the Low and High Vegetation Scenarios with respect to Current Vegetation

Table 5 below provides the statistical results of the water temperature change (using the 7-DADMax) for the high vegetation and low vegetation scenarios with respect to the updated baseline scenario that are

[9] Figure 18 shows the 7-Day Average water temperature on the y-axis, over the time period from 4/25/14 to 10/22/2014 on the x-axis. The differences between Segment 44 and Segment 11 and the modeled vegetation scenarios are plotted.

shown in Figure 18. The low vegetation scenario results in an approximately 0.6°C average water temperature increase, and 1.2°C maximum increase. The high vegetation scenario results in an approximately 0.2°C average water temperature increase, and 0.4°C maximum water temperature increase. The results indicate that the high vegetation scenario (implementation of the VMP) minimizes the water temperature increases that are expected to occur under the low vegetation scenario.

Table 5: Daily Average Water Temperature Differences between Segment 111 (Proposed FRE Facility) and Segment 44 (Upper Limit of Temporary Inundation Area) for the Low and High Vegetation Scenarios with respect to Updated Baseline Vegetation under Current Conditions between 4/25/2014 and 10/22/2014

Scenario	Water Temperature Change (°C)			
	Minimum	Median	Average	Maximum
Low Vegetation Scenario under Current Conditions minus Updated Baseline Scenario under Current Conditions	0.04	0.6	0.6	1.2
High Vegetation Scenario under Current Conditions minus Updated Baseline Scenario under Current Conditions	0.01	0.1	0.2	0.4

Note: Water temperature results from model calculated as 7-DADMax, difference calculated as Segment 111 minus Segment 44 for each scenario, and then difference between scenarios calculated for values shown.

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5 Discussion and Conclusions

The results of the sensitivity analysis indicate that the predictions for water temperature are sensitive to changes in shade parameters representing vegetation heights in the riparian area. This demonstrates that vegetation heights influence the predicted changes to water temperature. Successful management of vegetation, particularly vegetation of greater heights, in the riparian area creates shade, which can minimize increases to water temperature. Additionally, under climate change, the differences due to vegetation heights are estimated to remain similar to those under current conditions. Additional water temperature increases are due to climate change impacts on air and dewpoint temperature, hydrology, and upstream water temperature.

5.1 Water Quality Modeling Considerations

A primary purpose of the sensitivity analysis was to understand the influence of vegetation heights in the riparian area on water temperature as predicted by the Footprint Model used in the SEPA and NEPA DEISs. The sensitivity analysis presented here demonstrates that the modeling of water temperature is sensitive to changes to vegetation height. This finding suggests that with successful implementation of vegetation management actions, water temperature increases due to changes in riparian vegetation may be minimized.

As discussed in Section 2, the DEISs assumed vegetation heights that were a uniform 2 meters (6 feet, 7 inches) across the entire temporary inundation area. However, the District has developed a Conceptual VMP for management of vegetation within the temporary inundation area and will finalize the VMP with input from agency stakeholders prior to construction of the proposed FRE facility. Updating the assumptions for vegetation height in the water quality modeling based on the VMP provides a more accurate assessment of potential water temperature impacts.

Additional work to further refine the VMP may inform the selection of final tree heights to predict water temperature impacts under climate change. Furthermore, this modeling used recent LiDAR data for the updated baseline scenario. These recent data provide a more accurate baseline for assessing shade conditions along the mainstem Chehalis River within the temporary inundation area, compared to the approximated heights used for the water temperature analysis reported in the DEISs. This information is available for subsequent use in the development of the Final EISs.

5.2 Conceptual VMP Development and Implementation

Implementation of the VMP will aim to proactively establish flood-tolerant species of woody plants within the temporary inundation area for different flooding regimes, utilize large woody debris that needs to be removed in local mitigation actions, and establish appropriate habitat types that can be used for the impacts analysis of the proposed project. Furthermore, the VMP is intended to act as the basis for adaptive management within the temporary inundation area. It identifies the existing plant communities and proposes the type of vegetation that can be expected to survive temporary flooding conditions during proposed FRE facility operations. The review of the Mud Mountain Dam inundation zone validates many of the assumptions made within the VMP and refines the list of woody plants that are known to tolerate similar episodic temporary flooding in the region.

An important contribution of this sensitivity analysis is the review of the Mud Mountain regional example to inform vegetation height assumptions within the temporary inundation area of the proposed project. Review of the Mud Mountain analog, with consideration of the proposed vegetation management, indicates that taller vegetation would likely survive the flooding caused by the facility in the upper part of the basin affected by the inundation. The Mud Mountain regional example provides a reasonable pallet of vegetation species that can survive flooding at the depths and durations proposed during the operations of the proposed FRE facility. More direct comparisons between the two facilities' vegetation are not warranted because there are local conditions that influence growing conditions, including local geology, sediment transport, site aspect, soil types, and elevation. These and other factors are likely to determine which species can thrive within those local conditions independent of the flooding regime.

5.3 Climate Change Considerations

An additional value of the water quality sensitivity analysis is to segregate the influence of climate change from the influence of vegetation on water temperature. Climate change is projected to influence stream temperatures because of increases in air temperature and lower summer flows throughout Washington State including the Chehalis River (Isaak et al. 2011, Mauger et al. 2016). The SEPA DEIS included the influence of climate change in the analysis of the projects impacts on water temperature, however, it did not indicate what portion of the increase in water temperature is attributable to the vegetation management actions in the temporary inundation area of proposed project.

The sensitivity analysis documented in Section 4 included modeling scenarios under climate change. Climate change was represented by inputs that increased air and water temperature and shifted flow. The climate change inputs result in a water temperature that is 3 to 5^{o}C higher than the respective scenarios under current conditions. This shift increasing water temperature from under current conditions to under climate change is seen in Figure 11 through Figure 14 in Section 4.1. Climate change results in an increase to water temperature irrespective of the vegetation and independent of the impacts of the proposed project.

Further, the shade inputs result in a water temperature that is 0.3^{o}C higher with the high vegetation scenario and 1^{o}C higher with the low vegetation scenario compared to the updated baseline scenario under both the current and climate change conditions. This increase to water temperature is seen in Table 3 and Table 4 in Section 4.1. The increase to water temperature due to vegetation height (shade) is irrespective of current or climate change conditions. In this case, it is known that the proposed project could affect shading through the removal of vegetation in the temporary inundation area, and as demonstrated through the water quality modeling presented in this report, the development and implementation of the VMP is necessary for minimizing impacts to water temperature.

5.4 Conclusions

The next phase of evaluating the impacts of the proposed project includes the development of Final EIS's by the USACE and Ecology. The final determinations of the proposed project's impacts to water quality (i.e., water temperature) should consider the following significant conclusions of this report:

1. Vegetation heights influence changes to water temperature as predicted in the CE-QUAL-W2 Footprint Model.
2. Shade inputs result in a water temperature that is 0.3°C higher with the high vegetation scenario and 1°C with the low vegetation scenario compared to the updated baseline scenario under both the current and climate change conditions (see Section 4.1).
3. Review of the Mud Mountain analog example confirms that higher vegetation heights then previously assumed in the SEPA and NEPA DEISs are highly likely to result from implementation of the VMP.
4. Higher riparian vegetation (see high vegetation scenario) will minimize water temperature increases in the temporary inundation area and downstream of the FRE facility.
5. Projected increases in water temperature in the Chehalis River due to climate change parameters are significantly greater than the increases in water temperature due to the proposed project.

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Attachment A. Conceptual Vegetation Management Plan. Prepared by HDR for the Lewis County Flood Control Zone District. November 2020

Attachment B. GIS Data concerning Existing Vegetation at Project Reach (Digital copies available upon request)

Attachment C. GIS Data concerning Existing Vegetation at Mud Mountain (Digital copies available upon request)

Attachment D. Modelling Output Data (Digital copies available upon request)