Appendix I
Discipline Report for Geomorphology

September 2020

Chehalis River Basin Flood Damage Reduction Project

NEPA Environmental Impact Statement

US Army Corps of Engineers

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Discipline Report for Geomorphology

US Army Corps of Engineers

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ACRONYMS AND ABBREVIATIONS

--	no data available
Applicant	Chehalis River Basin Flood Control Zone District
CFR	Code of Federal Regulations
cfs	cubic feet per second
CMC	Chehalis Municipal Code
Corps	U.S. Army Corps of Engineers
CWA	Clean Water Act
DA	Department of the Army
Ecology	Washington Department of Ecology
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
FRE	Flood Retention Expandable
FRO	Flood Retention Only
LCC	Lewis County Code
LiDAR	Light Detection and Ranging
LWM	large woody material
mm	millimeter
N/A	not applicable
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
Proposed Action	Department of Army Permit decision
proposed project	Chehalis River Basin Flood Damage Reduction Project
RCW	Revised Code of Washington
RM	river mile
USC	United States Code
USGS	U.S. Geological Survey

WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WGD	Watershed GeoDynamics
WSE	Watershed Science and Engineering

EXECUTIVE SUMMARY

The Chehalis River Basin Flood Control Zone District (Applicant) has proposed the Chehalis River Basin Flood Damage Reduction Project (the proposed project). The purpose of this discipline report is to describe the affected environment and potential impacts of the National Environmental Policy Act (NEPA) Environmental Impact Statement (EIS) alternatives on fluvial geomorphology (referred to as geomorphology in this report).

Geomorphology refers to the natural process of how the Chehalis River changes over time. The potential impacts addressed in this discipline report include changes over time in the amount, type, and location of sediment in the study area. The analysis also addresses the potential for changes in large woody material (LWM) input and transport and channel width and migration. The modeled results and empirical evaluations presented in this discipline report are not intended to represent exact predictions of changes to geomorphic processes, but rather to provide the ability to make relative comparisons between the No Action Alternative and Alternative 1. This is so that decision-makers may be informed about potential impacts attributable to the proposed action on geomorphology. Impacts of the EIS alternatives on hydrology, geology, habitat, aquatic species, and water quality and quantity are discussed in other published reports and discipline reports for the NEPA EIS (Section 4).

The U.S. Army Corps of Engineers NEPA alternative screening process yielded the two action alternatives for evaluation under NEPA. The alternatives considered include the following:

- No Action Alternative: This represents the conditions anticipated without the proposed project over the course of the analysis period from 2025 through 2080.
- Alternative 1 (Proposed Project): Flood Retention Expandable (FRE) Facility and Airport Levee Improvements. Alternative 1 is the Applicant's proposed project and includes the FRE facility and Airport Levee Improvements. Additional details about FRE facility operation can be found in the *Chehalis River Basin Flood Control, Combined Dam and Fish Passage Supplemental Report, Flood Retention Expendable (FRE) Dam Alternative* (HDR 2018).
- Alternative 2: Flood Retention Only (FRO) Facility and Airport Levee Improvements. Alternative 2 would be the same as Alternative 1, except that the flood retention facility would be built on a smaller foundation. The Alternative 2 facility, called an FRO facility, would not be designed to allow for potential future expansion of flood storage capacity.

This discipline report focuses on the potential impacts from the proposed flood retention facility only. This is because there are minimal impacts on water resources from the Airport Levee Improvements.

For Alternatives 1 and 2, the direct and indirect impacts from construction and operation of the proposed flood retention facility were considered. The expected duration of the impacts (temporary versus permanent) was also determined. If permitted, the Applicant expects flood retention facility construction would begin in 2025 and operation in 2030, and the Airport Levee Improvements construction would occur over a 1-year period between 2025 and 2030. The EIS analyzes probable impacts from the Proposed Action and alternatives for construction from 2025 to 2030 and for operation from 2030 to 2080.

Table ES-1 summarizes the construction and operational impacts for Alternative 1 compared to the No Action Alternative. The construction-related impacts of Alternative 2 would be similar to Alternative 1 but would result in lower impacts because of the reduced size of the flood retention facility and reduced construction duration. The operational impacts are expected to be the same for the two action alternatives.

Construction Impacts Summary

Construction of the FRE facility would require substantial work in and around the Chehalis River over a period of up to 5 years. During this time, the Chehalis River would be diverted through a tunnel around the construction site. Construction would result in alterations to the channel and river hydrology compared to the No Action Alternative.

Construction would also require ground disturbance in and around the river and removal of trees from within the footprint of the temporary reservoir. These activities would result in low to medium increases in sediment load to the Chehalis River. This is because these activities would increase erosion and sedimentation from areas disturbed by construction. The implementation of best management practices would minimize the risk of sediment loading over the course of the 5-year construction period. However, in the event of a larger storm, sediment loading to the river could result in medium impacts.

Under typical flow conditions, Alternative 1 construction would have low temporary impacts to the movement of sediment within the river, bed substrate size, and thalweg elevations. The river would be routed through a diversion tunnel during construction, which is generally expected to match natural flow conditions. However, if a larger storm were to happen during construction, the flow of river water through the diversion tunnel could alter velocities compared to the No Action Alternative. Changes to flow could include backwatering upstream of the tunnel and higher velocities within and immediately downstream of the tunnel.

If this were to happen, Alternative 1 could result in increased sediment deposition and substrate fining upstream of the tunnel and increased erosion and substrate coarsening downstream of the tunnel. If the streamflows were high enough to exceed the design flow for the diversion tunnel, water could flood the construction site and potentially flow around the diversion tunnel. The amount of change to bed substrate would depend on the size of the storm.

Alternative 1 construction would result in high impacts on the recruitment of LWM upstream of the planned facility during construction. As part of the pre-construction vegetation management plan, trees would be removed within the footprint of the temporary reservoir. This would significantly reduce the amount of LWM available for recruitment to the river upstream of the facility during (and after) construction. Low to high impacts to LWM are expected during construction because of use of the diversion tunnel to reroute the river during construction for the same reasons as stated above for impacts to sediment transport and bed substrate size.

There would be no impacts on channel migration upstream and downstream of the FRE facility from construction. This is because streamflows within the river are generally expected to match natural flow conditions while the diversion tunnel is in use.

Operation Impacts Summary

Operation of the FRE facility would also change the way that sediment enters and moves through the river within the study area over time. These changes would happen because the FRE facility would impound the flow of the river upstream of the planned facility reducing the flow downstream during certain periods. Operation would also reduce peak streamflows that would otherwise happen from major or greater floods because floodwater would be released more slowly over time. This process will reduce the magnitude of peak streamflows that occur in the Chehalis River within the impounded area and downstream of the facility. Streamflows would be metered out over a longer period of time at lower streamflows than existing peak flow conditions.

Based on the record from the past 30 years, there are 10 events that would have resulted in impoundment if the FRE facility were in operation. Streamflow at Doty where sediment can be mobilized and transported in the Chehalis River is estimated to be 6,000 cfs, as described in Section 6.2.2.2. Reduction in peak streamflows that are above 6,000 cfs would occur about 3 hours per year on average based because of FRE facility operation. While this impact could be considered low, it is possible that considerable sediment transport, movement of LWM and channel migration could occur during those 3 hours of peak flow conditions which are being muted because of FRE facility operation. In addition, the changes to geomorphic processes that are initiated during those 3 hours may persist for many weeks, months, or years, depending on the magnitude of the event.

Several models were used to predict how river flows, sediment transport, bed substrate, and channel morphology could change. Within the study area, Alternative 1 would have the most substantial impacts above the FRE facility in the reach within the footprint of the temporary reservoir (Reach 1). There would be medium to low impacts moving downstream of the FRE facility within the study area to river mile (RM) 33 (Reaches 2 through 6).

Above the FRE facility (Reach 1), Alternative 1 would have a high impact on geomorphic conditions associated with sediment transport, bed substrate size, and thalweg elevation. This is because there would be medium increases in sediment loading that would be expected to largely remain in Reach 1 over time compared to the No Action Alternative. Sediment loading would increase because there would be fewer trees in the footprint of the temporary reservoir to otherwise reduce erosion. In addition, periodic flooding from FRE facility operation would increase the potential for landslides and erosion from this area. When a major or greater flood happened, the gates would close, and the temporary reservoir would begin to hold water. As the temporary reservoir filled and the flow of water slowed, sediments would start to settle out. Even though some sediments would resuspend and move through the gates once the opened and the temporary reservoir began to draw down, over time, modeling has shown that more sediment would remain in this reach. These impacts would occur to some degree following each major or greater flood. Following each of these floods, a period of recovery would occur where pre-flood geomorphic behavior and conditions would start to return until the next major or greater flood happens. Over the long term, which would include numerous floods, the resulting impacts would include finer bed substrate and a thalweg elevation that would be generally higher in Reach 1 than under the No Action Alternative because of predicted sediment deposition in this reach.

Impacts on sediment transport (erosion and deposition), changes to bed substrate size and thalweg elevation are expected to be low to medium downstream of the FRE facility (Reaches 2A to 6). Generally speaking, there would be a reduced sediment load, coarsening of bed substrate in some areas, and increases or decreases in thalweg elevation (depending on location) compared to the No Action Alternative. This is because of reduction of peak streamflows and increase in duration of moderate streamflows in the system and the decrease in sediment load because of operation of the FRE facility. The severity of impacts may increase at the confluence of tributaries with the mainstem Chehalis River because of potential localized changes to hydraulic and sediment transport processes at these locations during impoundment events. The severity of impacts is expected to decrease in line with distance downstream of the facility. This is because the effects of the FRE facility on water and sediment inputs and transport is expected to be muted by tributary inputs and grade controls at RM 62 and RM 65 (WGD 2012, 2014).

Alternative 1 would also have high impacts to recruitment and transport of LWM upstream of the FRE facility within the footprint of the temporary reservoir down to RM 75 (Reaches 1 through 4C) and medium to high impacts from RM 75 to RM 33. This is because there would be fewer trees in the footprint of the temporary reservoir available for recruitment during floods because of tree removal activities during construction. In addition, LWM would not be able to pass through the FRE facility structure when it was operating (i.e., impounding water). The Applicant has proposed to remove this material to allow for safe operation of the FRE facility. This would remove this LWM from the Chehalis River. LWM would be able to pass through the facility when it is open and not operating. Overall, this means there would be less LWM in the study area because of trapping of the upper watershed LWM load, reduced recruitment above the FRE facility structure, and reduced recruitment below the FRE facility structure because of lower peak streamflows.

Alternative 1 would have low to medium impacts to channel migration (including channel width) because of operation of the FRE facility. Low changes to channel migration are expected upstream of the FRE facility (Reach 1). This is because the current channel is confined within a bedrock reach.

Therefore, while anticipated sediment deposition in the reach will likely result in a more complex channel alignment, large-scale channel migration because of bank erosion is not expected.

Downstream of the FRE facility, Alternative 1 would have a medium impact to channel migration (including channel width) on reaches that are currently characterized by active bank erosion and channel migration (Reaches 2B, 3, 4B, 6, and the lower part of Reach 5). Operation of the FRE facility would reduce peak streamflows during large flow events, but streamflows that have the capacity to move sediment and erode banks would still occur. The reduction in LWM and in sediment load to the river downstream of the facility (because of FRE facility operation) are expected to result in a medium reduction in channel migration in Reaches 2B and 3 and low impacts to reaches farther downstream (Reaches 4B and 6, and the lower part of Reach 5) because the effects of flow changes as the result of FRE facility operation this far downstream diminish. There would be a reduction in LWM available within reaches where active channel migration could occur (Reaches 2B, 3, 4B, 6, and the lower part of Reach 5). This would result in less dynamic reaches and would reduce the number of channels and channel complexity over time.

Table ES-1

Potential Impacts on Geomorphology

ALTERNATIVE 1 (PROPOSED PROJECT): FLOOD RETENTION EXPANDABLE (FRE) FACILITY AND AIRPORT LEVEE IMPROVEMENTS		
RESOURCE AREA	**CONSTRUCTION**	**OPERATION**
Sediment Load to Chehalis River	**Direct Impacts – FRE Facility** • Low temporary increase in sediment load to the Chehalis River because of construction activities after implementation of stormwater and erosion control measures • Impacts could be medium to high if there is a storm that exceeds the capacity of the construction diversion tunnel increasing erosion in the construction area and subsequent sediment load to the Chehalis River **Indirect Impacts – FRE Facility** • Low temporary increase to sediment load to the Chehalis River downstream of the facility from erosion because of construction activities at the facility location and changes to natural flow conditions at the construction diversion tunnel • Impacts could be high if there is a larger storm that exceeds the capacity of the construction diversion tunnel **Airport Levee Improvements** • None	**Upstream of the Proposed FRE Facility (Reach 1)** • Low to medium increase in sediment load because of increased risk of erosion and landslides over time because of flooding at the base of the slopes from impoundment events **Downstream of the Proposed FRE Facility (Reaches 2A through 6)** • Low to medium decrease in sediment load over time to the Chehalis River downstream of the facility because of sediment retention expected upstream of the facility within the footprint of the temporary reservoir **Airport Levee Improvements** • None
Sediment Transport	**Direct Impacts – FRE Facility** • Low temporary fining of bed substrate because of erosion of construction fill materials during construction activities after implementation of stormwater and erosion control measures • Low changes in sediment transport because of potential changes from natural river flow conditions at the construction diversion tunnel • Impacts associated with changes to sediment transport and fining of bed substrate could be medium to high if there is a larger storm that exceeds the capacity of the construction diversion tunnel **Indirect Impacts – FRE Facility** • Same as Direct Impacts downstream of the FRE facility. No impacts expected upstream of the FRE facility	**Upstream of the FRE Facility (Reach 1)** • High changes to sediment transport and fining of bed substrate over time from operation of the FRE facility within the footprint of the temporary reservoir. Increases in sediment deposition are expected in this reach. However, some areas may be more erosional depending on the location in this reach **Downstream of the FRE Facility** • Operation of the FRE facility would result in low to medium impacts on sediment transport and bed substrate size downstream of the FRE facility. Increases and decreases to sediment transport (i.e., erosion and depositional areas) and substrate size are expected depending on the location in these reaches **Airport Levee Improvements** • None

ALTERNATIVE 1 (PROPOSED PROJECT): FLOOD RETENTION EXPANDABLE (FRE) FACILITY AND AIRPORT LEVEE IMPROVEMENTS		
RESOURCE AREA	**CONSTRUCTION**	**OPERATION**
	Airport Levee Improvements • None	
Large Woody Material	**Direct Impacts – FRE Facility** • High decrease of LWM recruitment from the removal of trees within the footprint of the temporary reservoir as part of pre-construction vegetation management activities • Low decrease in transport of LWM because of potential changes from natural river flow conditions at the construction diversion tunnel. • Decrease in transport of LWM could be medium to high if there is a larger storm that exceeds the capacity of the construction diversion tunnel **Indirect Impacts – FRE Facility** • No changes to LWM recruitment from areas downstream of the facility • Low to high decrease in transport of LWM downstream of the proposed FRE facility **Airport Levee Improvements** • None	**Upstream of the FRE Facility (Reach 1)** • High decrease of LWM recruitment and transport within the footprint of the temporary reservoir **Downstream of the FRE Facility (Reaches 2A to 6)** • High decrease in amount of LWM downstream of the facility to approximately RM 75 (Reaches 2A to 4C) at the confluence with the confluence with the South Fork (see Channel Migration) • Medium to high decrease in LWM downstream of the confluence with the South Fork at RM 75 (Reaches 5 to 6). Low to medium decrease to LWM downstream of RM 75 **Airport Levee Improvements** • None

<table>
<tr><th colspan="3">ALTERNATIVE 1 (PROPOSED PROJECT): FLOOD RETENTION EXPANDABLE (FRE) FACILITY AND AIRPORT LEVEE IMPROVEMENTS</th></tr>
<tr><th>RESOURCE AREA</th><th>CONSTRUCTION</th><th>OPERATION</th></tr>
<tr><td>Bank Erosion and Channel Migration</td><td><u>Direct Impacts – FRE Facility</u>
Low impacts to channel migration at the facility location are expected because of filling activities
<u>Indirect Impacts – FRE Facility</u>
No indirect impacts to channel migration are expected upstream or downstream of the facility because of construction of the FRE facility
<u>Airport Levee Improvements</u>
None</td><td><u>Upstream of the FRE Facility (Reach 1)</u>
No impact on channel migration within the footprint of the temporary reservoir (Reach 1); the channel is currently in a confined bedrock reach. Medium impacts to channel width and complexity, with increases to both expected because of sediment deposition and increase in sediment load because of landslides and upland bank erosion
<u>Downstream of the FRE Facility (Reaches 2A to 6)</u>
Low to medium impacts (decrease) to channel migration downstream of the facility in reaches that currently exhibit channel migration and bank erosion under the No Action Alternative. Low impacts to confined reaches
Medium reduction in channel migration in those reaches located just downstream of the facility (2B and 3)
Low reduction in channel migration for those reaches located farther downstream (4B, lower part of 5, and 6)
<u>Airport Levee Improvements</u>
None</td></tr>
</table>

1 INTRODUCTION

The Chehalis River Basin Flood Control Zone District (Applicant) is proposing to construct the Chehalis River Basin Flood Damage Reduction Project (proposed project) in Lewis County, Washington (Figure 1-1). Project construction would require a Department of the Army (DA) Permit (Proposed Action) under Section 404 of the Clean Water Act (CWA). On January 31, 2018, the Seattle District of the U.S. Army Corps of Engineers (Corps) determined that the proposed action had the potential to result in significant impacts on the environment, requiring the preparation of an Environmental Impact Statement (EIS) to meet the requirements of the National Environmental Policy Act (NEPA).

The purpose of this discipline report is to describe the existing geomorphic conditions and identify potential for impacts of the NEPA EIS alternatives on geomorphology in the Chehalis River in the study area. The discussion of existing geomorphology of the Chehalis River and potential impacts from the proposed project will be based primarily on work conducted by others (WGD and Anchor QEA 2012, 2014, 2017; WGD 2019a, 2019b, 2019c) supplemented with targeted additional evaluations conducted by the NEPA team. Uncertainties associated with the available geomorphology evaluations are discussed in appropriate sections of this report.

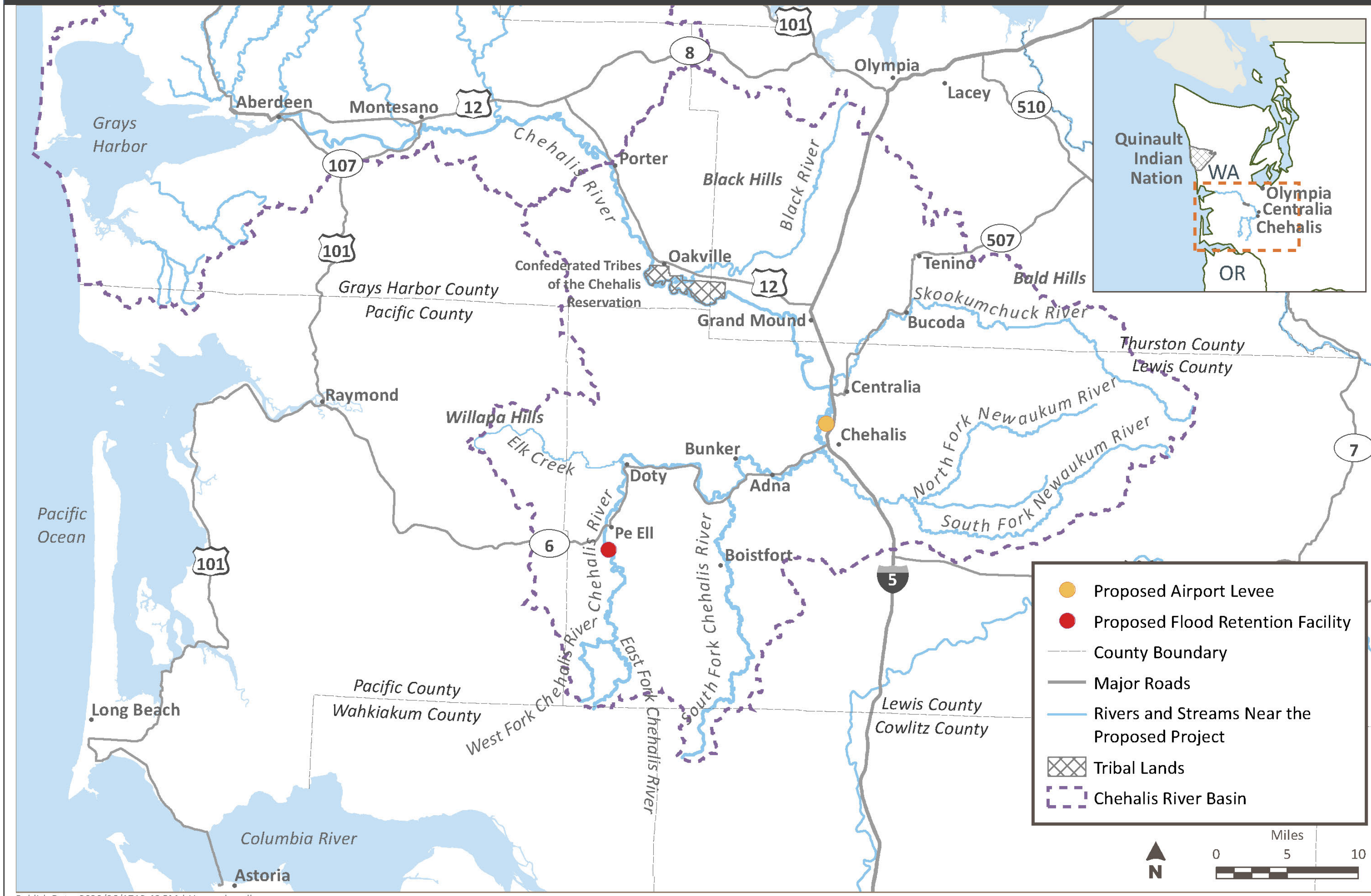
This report includes the following information to support determination of impacts to geomorphology as part of the NEPA EIS:

- Current sediment loads to the mainstem of Chehalis River from sources upstream of the proposed project and landslides/bank erosion within the study area and how these may change as a result of implementing the alternatives
- Current bed substrate conditions within identified geomorphic reaches in the study area and how these may change as a result of implementing the alternatives
- Current peak streamflows and sediment transport characteristics within identified geomorphic reaches of the study area and how these may change as a result of implementing the alternatives
- Current input and transport of large woody material (LWM) within identified geomorphic reaches in the study area and how these may change as a result of implementing the alternatives
- Historical wetted channel width and channel migration (including bank erosion) within identified geomorphic reaches in the study area and how these may change as a result of implementing the alternatives

Potential impacts on geology, water quantity and quality, wetlands, and aquatic species and habitats are addressed in a separate discipline reports that focus on those resources.

Data collection efforts (i.e., substrate, bank erosion, LWM inventory, current velocities), hydrodynamic and sediment transport modeling, and geomorphic analyses (i.e., geomorphic reach analysis, wetted channel width, and channel migration) conducted by Watershed GeoDynamics (WGD); Anchor QEA, LLC; and Watershed Science and Engineering (WSE) have been used to inform the determination of potential impacts summarized in this report. A targeted sensitivity analysis of the sediment transport model developed by WGD (2019a) and an analysis of hydrologic changes because of the proposed action have been completed by Anchor QEA as part of this evaluation. That work is summarized in Attachment 1 and Section 6.2.2.2, respectively. This additional work has been used to supplement geomorphic analyses conducted previously by others to support determination of impacts summarized in this report.

Figure 1-1
Project Vicinity Map



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2 PROPOSED ACTION AND ALTERNATIVES

Three alternatives are evaluated in this report: two action alternatives and a No Action Alternative. Additional details about these alternatives are documented in a memorandum on NEPA EIS alternatives (Anchor QEA 2019). The alternatives include the following:

- No Action Alternative: This represents the conditions anticipated without the proposed project over the course of the analysis period from 2025 through 2080.
- Alternative 1 (Proposed Project): Flood Retention Expandable (FRE) Facility and Airport Levee Improvements. Alternative 1 is the Applicant's proposed project and includes the FRE facility and Airport Levee Improvements. The geomorphic impacts associated with the (future) expansion of the FRE facility are analyzed in this document.
- Alternative 2: Flood Retention Only (FRO) Facility and Airport Levee Improvements. Alternative 2 would be the same as Alternative 1 except that the flood retention facility would be built on a smaller foundation. The Alternative 2 facility, called an FRO facility, would not be designed to allow for potential future expansion of flood storage capacity.

3 REGULATORY CONTEXT AND DEFINITIONS

This section defines the resources addressed in this report and lists the federal, state, and local regulations, permits, and policies that pertain to the topic of the discipline report in the following subchapters.

3.1 Resource Definitions

This discipline report uses the following definitions and assumptions throughout the analysis:

- Sediment load refers to the amount of sediment expected to be introduced into the Chehalis River through bank and bed erosion, landslides, and tributaries. Changes to sediment loads considered in this discipline report refer to: a) changes to sediment input into the Chehalis River within the footprint of the temporary reservoir; and b) changes to sediment input into the mainstem of the Chehalis River downstream of the flood retention facility because of sediment retention upstream of the flood retention facility.
- Sediment transport refers to the rate at which sediment moves through different parts of the river. Sediment transport is evaluated within this discipline report as: a) changes to sediment storage in different areas of the Chehalis River because of FRE facility operation and sediment retention upstream of the flood retention facility; b) changes to the size of the materials that make up the riverbed (referred to as bed substrate); and c) changes to thalweg elevation (elevation of the deepest part of the river channel).
- LWM input refers to the amount of LWM that is added to the Chehalis River because of bank erosion or other processes. Transport of LWM refers to the amount of LWM already in the Chehalis River moving in different parts of the Chehalis River.
- Changes in migration (and width) refer to potential changes in the width and movement of the Chehalis River channel because of reduction of peak streamflows within the footprint of the temporary reservoir and downstream of the flood retention facility.

3.2 Regulations

Table 3.2-1 presents the regulations, statutes, and guidelines applicable to the resources addressed in this report. It is expected that the Applicant would obtain the required permits or approvals as noted in Section 7 and that adherence to applicable conditions would in part mitigate for certain potential impacts as noted in Section 6.

Table 3.2-1
Regulations, Statutes, and Guidelines

REGULATION, STATUTE, OR GUIDELINE	DESCRIPTION
FEDERAL	
CWA Section 402	The CWA establishes the basic structure for EPA to regulate discharges of pollutants into the waters of the United States and regulates water quality standards for surface waters. Section 402 (33 USC 1342) establishes the NPDES program, under which certain discharges of pollutants into waters of the United States are regulated. Section 402 mandates that certain types of construction activities (and operations) comply with the EPA NPDES program. Regulation of construction primarily deals with water quality during construction but includes eroded soils potentially delivered off site via runoff. EPA has designated Ecology the nonfederal authority for the NPDES program in the State of Washington. Responsibilities under Section 402 include development of a stormwater pollution prevention plan and implementation of sediment, erosion, and pollution prevention control measures.
STATE	
Construction General Stormwater Permit (WAC 173-226-050; RCW 90.48)	Ecology issues a Construction General Stormwater permit to ensure that construction site operators follow measures to prevent stormwater from washing soil, nutrients, chemicals, and other harmful pollutants into local water bodies and degrading water quality. Construction site operators are required to be covered by a Construction Stormwater General Permit if they are engaged in clearing, grading, and excavating activities that disturb 1 or more acres and discharge stormwater to surface waters of the state. The permit is also required if clearing, grading, or excavating activities disturb an area smaller than 1 acre if it is part of a "larger common plan of development or sale" that will disturb 1 acre or more and discharge stormwater to surface waters of the state or a conveyance system that drains to surface waters of the state.
Washington State Hydraulic Code (RCW 77.55; WAC 220-660)	Issued by WDFW for projects with elements that may affect the bed, bank, or flow of a water of the state or productive capacity of fish habitat. Considers effects on riparian and shoreline/bank vegetation in issuance and conditions of the permit, including for the installation of piers, docks, pilings, and bank armoring and crossings of streams and rivers (including culverts).
Washington State Growth Management Act (RCW 36.70A)	Defines a variety of critical areas, which are designated and regulated at the local level under city and county critical areas ordinances. These critical areas may include shorelines or portions of fish habitat.
Shoreline Management Act (RCW 90.58)	Regulates and manages the use, environmental protection, and public access of the state's shorelines. The Shoreline Management Act was passed by the Washington State Legislature in 1971 and adopted in 1972. Ecology is the agency responsible for enforcing the Shoreline Management Act.

REGULATION, STATUTE, OR GUIDELINE	DESCRIPTION
LOCAL	
Lewis County Shoreline Permit and Shoreline Management Plan	The Lewis County Shoreline Permit is issued in compliance with the Lewis County Shoreline Management Plan, and it covers all work that occurs landward within 200 feet of the ordinary high water mark of waters of the state and the wetlands associated with these stream segments.
Lewis County Critical Areas Ordinance (LCC 17.35A.685[3])	Provides standards for instream structures, including dams other than those regulated exclusively by the Federal Energy Regulatory Commission. Such structures shall be permitted only when multiple public benefits are provided and ecological impacts are fully mitigated, and instream structures on shorelines of the state shall be regulated in accordance with the Lewis County Shoreline Master Program.
Lewis County Stormwater Management Regulations (LCC 15.45)	Provides for adequate stormwater quality and quantity controls. Helps to protect individual property rights, preserve fish habitat, and promote sound development activities which respect and preserve water quality.
Lewis County Fill and Grade Permit	Regulates fill and grading for construction projects.
City of Chehalis Stormwater and Stormwater Runoff (CMC 15.30)	Provides requirements for including adequate stormwater quantity and quality controls for construction and development activities and outlines the associated City of Chehalis review/permitting procedures.
City of Chehalis Land-Disturbing Activity Regulations (CMC 15.28)	Sets forth rules and regulations to control all land-disturbing activities, including filling and grading, within the City of Chehalis.

4 INFORMATION SOURCES

This section provides the sources used to describe existing conditions and expected future conditions within the study area to support the impact analysis.

The following information sources were used to inform the geomorphic analysis. This includes information about defined geomorphic reaches, bed substrate, sediment load, sediment transport, input and transport of LWM, and peak streamflows in the Chehalis River.

4.1 Geomorphology Information

- *Chehalis River Fish Study: Appendix B: Geomorphology/Sediment Transport/Large Woody Debris Report* (WGD and Anchor QEA 2012)
- *Geomorphology and Sediment Transport Technical Memorandum* (WGD and Anchor QEA 2014)
- *Chehalis Basin Strategy: Geomorphology, Sediment Transport, and Large Woody Debris Report* (WGD and Anchor QEA 2017)
- *Geomorphology and Sediment Transport Report, Chehalis River Basin Flood Damage Reduction Project* (WGD 2019a)
- *Chehalis River Basin: Retrieval of Scour Monitors and Accelerometers Placed in the Chehalis River Over Winter 2018-2019* (WGD 2019b)
- *Geomorphic Mapping of the Chehalis River Floodplain, Cosmopolis to Pe Ell, Grays Harbor, Thurston, and Lewis Counties, Washington* (Slaughter and Hubert 2014)
- *Chehalis River Basin Flood Damage Reduction Project NEPA EIS Scoping Summary Report* (Corps 2019)

4.2 Geology and Geotechnical Information

- *Preliminary Desktop Landslide Evaluation* (Shannon & Wilson 2014a)
- *Phase 2 Chehalis Dam Landslide Evaluation Technical Memorandum* (Shannon & Wilson 2017)

4.3 Hydraulic, Hydrodynamic, and Sediment Transport Modeling Reports and Files

- *Chehalis River Hydraulic Model Development Project, Draft Report* (WSE 2012)
- *Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species – Development and Calibration of Hydraulic Model* (WSE 2014)
- *Hydrologic and Hydraulic Modeling Report, Chehalis River Fish Study, Appendix A* (Anchor QEA 2012a)
- Memorandum: Chehalis River Basin Hydrologic Modeling (WSE 2019a)

- *Chehalis River Existing Conditions RiverFlow 2-D Model Development and Calibration* (WSE 2019b)
- Sediment transport HEC-RAS model input files for sediment transport model described in *Geomorphology and Sediment Transport Report, Chehalis River Basin Flood Damage Reduction Project* (WGD 2019a)
- *ADDENDUM to November 2019 Chehalis River Basin Flood Damage Reduction Proposed Project; Geomorphology and Sediment Transport Report: Chehalis River HEC-RAS Sediment Transport Model 2019 – Model Inputs and Development* (WGD 2019c)

4.4 Design Documents for Proposed Facility

- *Chehalis Basin Strategy: Operations Plan for Flood Retention Facilities* (Anchor QEA 2017)
- *Chehalis River Basin Flood Control, Combined Dam and Fish Passage Supplemental Design Report, FRE Dam Alternative* (HDR 2018)

4.5 Other Information Sources

- *Chehalis Basin Strategy Final Programmatic EIS* (Ecology 2017)
- Literature Review of the Potential Changes in Aquatic and Terrestrial Systems Associated with a Seasonal Flood Retention Only Reservoir in the Upper Chehalis Basin technical memorandum by Anchor QEA and the Washington Department of Fish and Wildlife (WDFW 2017)

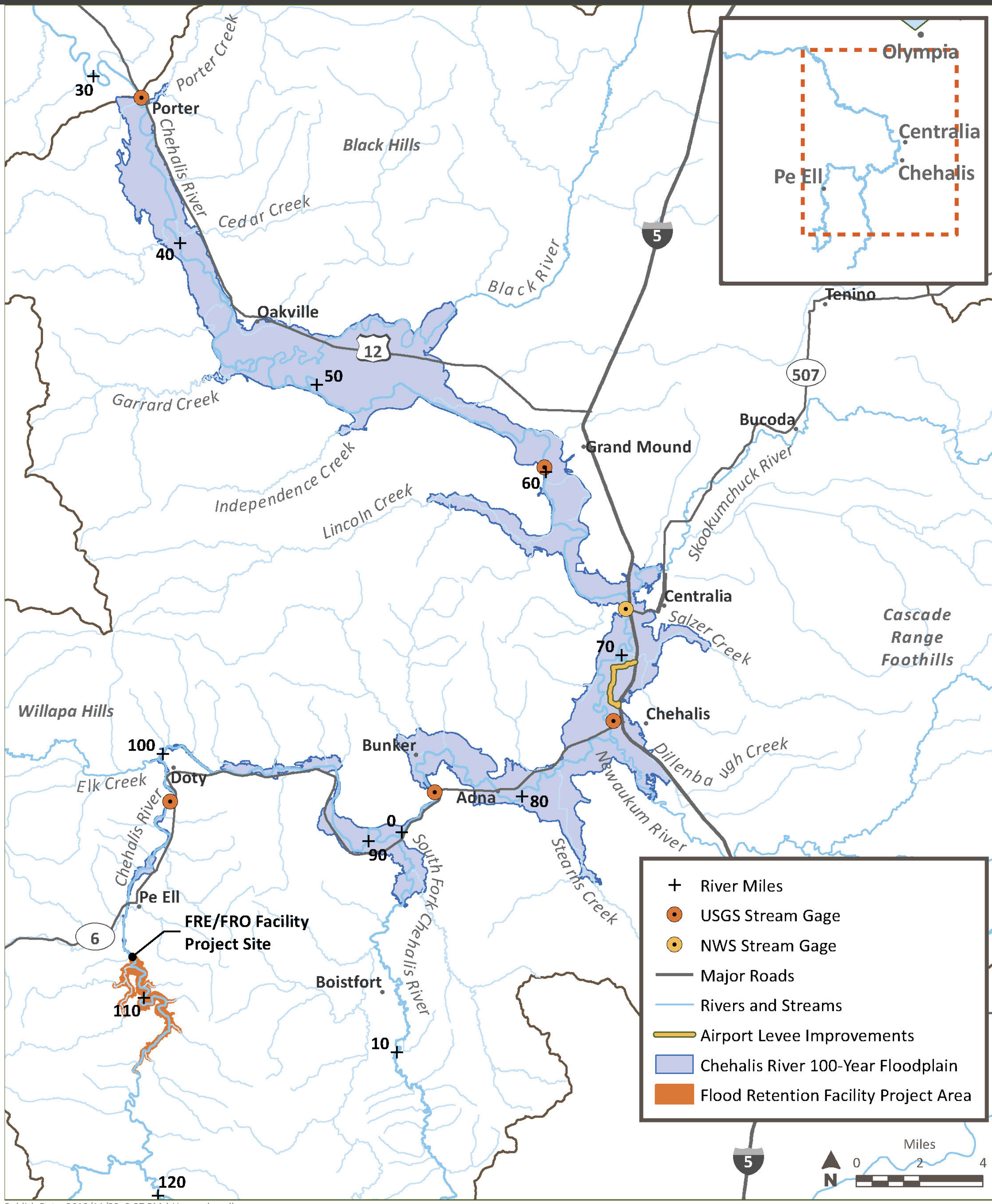
5 AFFECTED ENVIRONMENT

This section describes the affected environment within the study area that defines or has a high impact on geomorphic processes in the study area. These elements include watershed characteristics (i.e., hydrology), sediment loads to the Chehalis River, bed substrate, sediment transport, LWM recruitment and transport, channel width, and channel migration patterns.

5.1 Study Area

The study area for geomorphology consists of the Chehalis River from river mile (RM) 114 to approximately RM 33, near Porter, including the 100-year floodplain (Figure 5.1-1). The study area also includes areas related to the proposed flood retention facility, the full extent of the temporary reservoir, Airport Levee Improvements, and all areas affected by construction (e.g., diversion tunnel site, staging areas, quarries, and improved access roads) and operation, plus a 100-foot buffer around those areas. This also includes the lower ends of several tributaries (South Fork Chehalis, Newaukum, Skookumchuck, and Black rivers and Stearns, Dillenbaugh, Salzer, Lincoln, Independence, Garrard, Cedar, and Porter creeks). The study area is located in the Upper Chehalis Watershed Resources Inventory Area 23.

Figure 5.1-1
Study Area



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5.2 Geomorphic Setting

The reports listed in Section 4.1 provide specific and detailed information about the geomorphology of the Chehalis River. A high-level summary of this information is provided in the below subsections.

5.2.1 Watershed Characteristics and Sediment Sources

This section provides a summary of relevant watershed characteristics and sediment sources as defined by WGD (2012). The Chehalis Basin drains 2,100 square miles in southwestern Washington. The study area covers a drainage area of 1,294 square miles. Major tributaries within the study area include the South Fork Chehalis River, the Newaukum River, the Black River, and Skookumchuck Creek.

Land use in the Chehalis Basin includes forest (timber production) in the headwaters, with agricultural (crops, grazing), residential/urban, and light industrial uses in the broader downstream valleys. The climate is characterized by cool, wet winters and warm, dry summers with mean annual precipitation ranging from 60 to 110 inches. Precipitation is highest in the mountainous areas of the headwaters (western Coast Range areas), and runoff is highest during the November-to-April period. Large rainfall events during the fall, winter, and early spring can result in large peak streamflows.

The majority of the upper watershed of the Chehalis Basin is underlain by Eocene to Miocene (56 to 5 million years ago) volcanic and marine sedimentary rocks. The southern and western portions of the watershed have not been glaciated and are deeply weathered. The volcanic rocks include basalt and intrusive gabbro, which weather to fairly competent cobble and gravel particles with surficial silty to sandy soils. The marine sedimentary rocks include sandstone and siltstone, which weather to soft particles that are easily broken down into sand, silt, and clay particles. These soft particles were observed in several of the instream gravel samples from the upper mainstem Chehalis River and South Fork Chehalis River; some of the gravel-sized particles were soft and easily broken apart by hand, indicating they would not survive transport through the river as gravel but would disintegrate into sand, silt, and clay particles.

Quaternary alpine and continental glacial deposits occur in the Newaukum, Skookumchuck, and lower Chehalis river valleys. Alpine till and outwash from past glaciers on Mt. Rainier and the Cascade Range are prevalent along the lower Newaukum River. Outwash and till from the continental Cordilleran Ice Sheet that filled Puget Sound several times during the Quaternary period are present across the lower Skookumchuck to Black river valleys and also along the margins of the Chehalis River valley downstream of Centralia. These generally unconsolidated deposits include cobble, gravel, sand, and finer material. Meltwater from the Puget Lobe of the Cordilleran Ice Sheet flowed down the Black River valley then north and west along the lower Chehalis River valley, resulting in the wide valley with numerous relic channel features seen in Light Detection and Ranging (LiDAR) data from the area (GeoEngineers and Herrera 2009; Troost et al. 2003). Many large, deep-seated Quaternary (2.6 million years to present) slumps and rotational failures are mapped within the deeply weathered rocks in the headwaters.

Recent shallow rapid landslides and debris torrents also occur within these areas and deliver sediment, large wood, and debris to streams (Sarikhan et al. 2008; Entrix 2009).

5.2.2 Bedrock Controls

The Chehalis River contains a series of bedrock shelves between RM 65.5 and RM 61.7 (WGD and Anchor QEA 2014); these provide a bedrock control that limits any vertical channel adjustments (e.g., limits downcutting) and forms a hydraulic control in the channel (WGD 2019c). These controls result in a very low-gradient reach in Geomorphic Reach 5 between RM 75.5 (approximate confluence with the Newaukum River) and RM 61.7. As a result of the low water surface gradient, transport of gravel or larger particles entering from upstream is limited through this reach. This is supported by substrate mapping, observations while floating the reach and from aerial photographs, particle size sampling on gravel bars, and bedload transport calculations (see Section 5.2.3) that all show a transition to a fine-gravel and sand-bedded channel in this reach. Coarse-grained bedload (gravel/cobble) from upstream sources tends to be deposited in the river as the gradient decreases or is broken down by attrition (WGD and Anchor QEA 2014). Small and medium gravels and sands are transported past this location. Downstream of the bedrock control area, the Chehalis River returns to a gravel/cobble alluvial channel with an ample local supply of coarse sediment as it migrates across a valley formed by glacial outwash deposits.

5.2.3 Identified Geomorphic Reaches

For the purpose of discussing geomorphology of the Chehalis River within this study area and impacts of the proposed alternatives on these processes, the study area extent has been divided into reaches based on geomorphic characteristics within each reach.

Six primary geomorphic reaches have been identified and delineated by WGD. These reaches were identified based on differences in the level of channel confinement, average thalweg (i.e., lowest elevation along the channel) gradient, and major tributary junctions (WGD and Anchor QEA 2012). Geomorphic reaches were also identified to reflect areas that are likely to show geomorphic change when there are changes to streamflows or sediment and LWM loading, such as during operation of the flood retention facility (WGD and Anchor QEA 2014; WGD 2019c). Geomorphic Reaches 2 and 4 were further divided into sub-reaches primarily based on differences in the level of channel confinement (WGD and Anchor QEA 2014). Table 5.2-1 summarizes the characteristics of each of the identified geomorphic reaches. The location and extent of each reach is shown in Figures 5.2-1 and 5.2-2 (taken from WGD and Anchor QEA 2014).

Figure 5.2-1
Map of Geomorphic Reaches, Reaches 1 through 5 (WGD and Anchor QEA 2014)

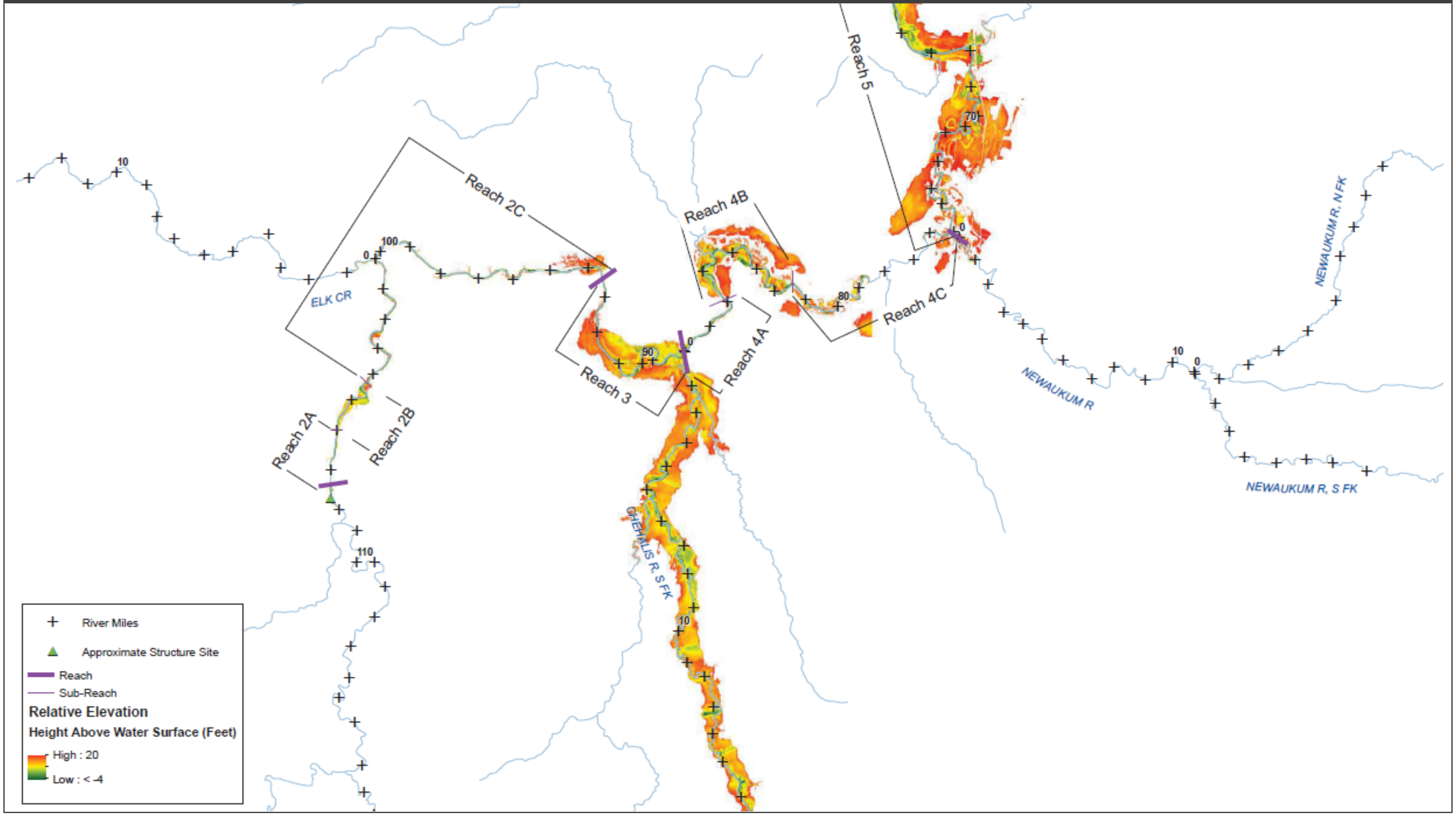


Figure 5.2-2
Map of Geomorphic Reaches, Reaches 5 and 6 (WGD and Anchor QEA 2014)

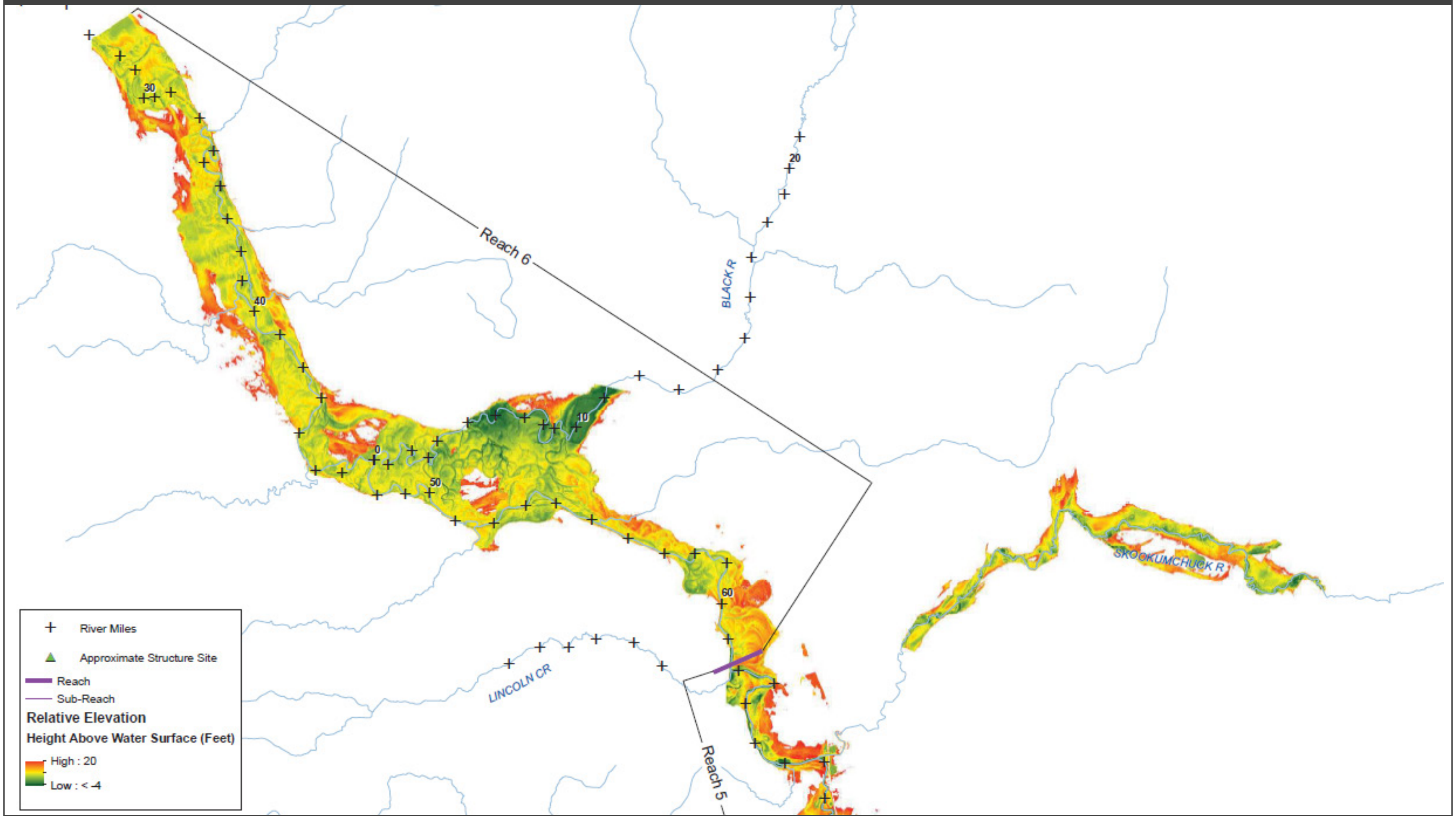


Table 5.2-1

Geomorphic Reach Characteristics[1]

GEOMORPHIC REACH	LOCATION	CHANNEL CONFINEMENT	SEDIMENT TRANSPORT CHARACTERISTICS	AVERAGE THALWEG GRADIENT	DESCRIPTION
1	Headwaters to RM 107.8	Confined	High-gradient transport reach	1.05%	Extends from headwaters to just upstream of Pe Ell. High-gradient reach characterized by cobble and gravel bed. Confined by steep-sided valley with bedrock outcrops. Includes the flood retention facility site.
2A[2]	RM 107.5 to RM 105.9	Confined	Generally a transport reach	0.24%	Sediment from 2007 flood located and being actively reworked in this reach. Pe Ell area.
2B[2]	RM 105.9 to RM 104.4	Unconfined	Deposition, active channel migration	0.21%	Significant channel migration in this reach. A large log jam likely occurred at the downstream end during 2007 flood which resulted in the channel aggrading at that time.
2C[2]	RM 104.4 to RM 93.5	Confined	Generally a transport reach, bedrock, includes Rainbow Falls	0.18%	Elk Creek enters the mainstem Chehalis River in this sub-reach.
3	RM 93.5 to RM 88	Unconfined	Deposition, active channel migration	0.05%	Extends from RM 93.5 to the confluence with the South Fork Chehalis River. This reach is in an unconfined area with a much lower gradient than Reach 2. The bed comprises more gravel and less cobble compared to Reaches 1 and 2.
4A[2]	RM 88 to RM 85.9	Confined	Transport reach	0.14%	South Fork Chehalis River enters at the upstream end of this reach; significant flow and source of sediment.
4B[2]	RM 85.9 to RM 81.6	Unconfined	Deposition reach, active channel migration	0.11%	Near city of Adna.
4C[2]	RM 81.6 to RM 75.3	Moderately confined (entrenched into its own sediments)	Deposition reach, finer-grained substrate	0.05%	Newaukum River enters mainstem Chehalis River at downstream end of this sub-reach. Newaukum River is a sediment-inputting tributary to the Chehalis River.

GEOMORPHIC REACH	LOCATION	CHANNEL CONFINEMENT	SEDIMENT TRANSPORT CHARACTERISTICS	AVERAGE THALWEG GRADIENT	DESCRIPTION
5	RM 75.5 to RM 61.7	Locally confined	No gravel or cobble transport, bedrock control at downstream end	0.03%	Extends from the confluence of the Newaukum River downstream to RM 61.7. This reach is extremely low gradient and the channel is incised in a meandering pattern into Quaternary alluvium. The gradient is controlled by several bedrock shelves that span the river between RM 65.5 and RM 61.7. Substrate is finer than in Reaches 1 through 4. The Skookumchuck River enters this reach at RM 67 and supplies cobble and gravel sediment to the mainstem Chehalis River at the downstream end of the reach.
6	RM 61.7 to RM 33	Unconfined	Very wide floodplain, movement of glacial outwash gravels	0.07%	This reach extends from a bedrock control at RM 61.7 to the end of the study area at Porter (RM 33). The average gradient is steeper than Reach 5 and the river is unconfined, flowing through a 2- to 3-mile-wide valley. Active channel migration exists in some areas. Black River enters mid-reach.

Notes:

1. Table adapted from Section 3.1.1 and Table B-5 of WGD and Anchor QEA (2012) and Section 3.2 and Table 3.1 of WGD and Anchor QEA (2014).
2. Reaches 2 and 4, defined by WGD and Anchor QEA (2012), were further divided into sub-reaches as described by WGD and Anchor QEA (2014).

Geomorphic Reach 1 extends from the headwaters of the Chehalis River to just upstream of Pe Ell. The river is relatively high gradient, cobble to gravel bedded, and confined by a steep-sided valley up to 800 feet wide with numerous bedrock outcrops. Little channel migration occurs in this reach.

Geomorphic Reach 2 extends from Pe Ell to a few miles upstream of the confluence with the South Fork Chehalis River. The channel in this reach varies between confined areas where it is incised into Quaternary alluvial deposits (e.g., near the town of Pe Ell and near the confluence with Elk Creek) and unconfined areas where it flows through a wider valley. There are several bedrock outcrops and grade controls, including Rainbow Falls. The gradient is gentler than upstream, and the bed contains primarily gravel and cobble.

Geomorphic Reach 3 includes the generally unconfined area just upstream of the confluence with the South Fork Chehalis River. The gradient is much lower than the upstream reaches (0.05%), and the bed is comprised of more gravel and less cobble than upstream reaches.

Geomorphic Reach 4 includes alternating confined and unconfined reaches as the river passes through relatively narrow bedrock-controlled reaches (e.g., between RM 86 and RM 88) and unconfined, alluvial reaches. Substrate is increasingly finer grained downstream, with cobble-sized particles comprising less than 10% of the bars.

The Newaukum River enters at the upstream end of Geomorphic Reach 5. This reach has a relatively low gradient (average 0.03%), and the channel is incised in a meandering pattern into the wide Quaternary alluvium plain with several relic oxbows. The gradient is controlled by several bedrock shelves that span the river near the downstream end of the reach (at approximately RMs 65.5 and 61.7). The Skookumchuck River enters at RM 67 and provides a source of cobble and gravel particles to the downstream end of the reach.

Geomorphic Reach 6 extends from the bedrock control at RM 61.7 to the end of the study reach at Porter (RM 33). The valley in this reach of the river has been shaped by large glacial rivers flowing off the Quaternary Cordilleran ice sheet that filled Puget Sound. These rivers were braided and deposited gravel/cobble outwash, which has since been reworked by the Chehalis River. Bed sediments in this reach are dominated by gravel and cobble supplied to this area from many sources, including upstream tributaries like the Skookumchuck and Newaukum Rivers. The average channel gradient is steeper than in Geomorphic Reach 5, and the river is unconfined as it flows through the extremely wide valley (2 to 3 miles wide) originally formed by the glacial rivers.

Additional detail on delineation of geomorphic reaches is provided in WGD and Anchor QEA (2012) and WGD and Anchor QEA (2014).

5.3 Flood Hydrology

Flood flow conditions in the Chehalis River are summarized in this section to provide context for the geomorphology evaluation. Additional information on this topic is provided in the *Chehalis River Basin Flood Damage Reduction Project NEPA EIS Discipline Report for Water Quality and Quantity* (Corps 2020a).

Current (No Action Alternative) flood streamflows are summarized in Section 5.3.1, including discussion of the long-term flow record that was used as input to the sediment transport model discussed later in this document. Section 5.3.2 provides a summary of how flood flow conditions are expected to be changed based on proposed operation of the flood control facility.

The upper Chehalis River watershed is defined as all lands draining to the U.S. Geological Survey (USGS) gage near Porter. Because this gage lies within a narrow valley with well-defined bedrock walls, the gage measures most of the annual runoff from the upper watershed. Major tributaries to the upper Chehalis River are the South Fork Chehalis, Newaukum, Skookumchuck, and Black rivers. The headwaters of the South Fork Chehalis River originate in the Willapa Hills. The headwaters of the Newaukum and Skookumchuck rivers originate in the Bald Hills, a western spur of the Cascade Range, and the Black River drains from the Black Hills.

There are nine active USGS gages that provide streamflow rates and water surface elevations for the upper Chehalis River. The following three of these are typically used to define the flow of the upper Chehalis River because of their location in the watershed (Figure 5.1-1):

- Doty: USGS Gage 12020000
- Grand Mound: USGS Gage 12027500
- Porter: USGS Gage 12031000

Additional active USGS and Washington Department of Ecology (Ecology) gages are located on tributaries. There are also multiple gages throughout the Chehalis Basin that measured streamflow data in the past and provide historical data. Generally, river flows in the study area are highest from November to March and lowest during the summer dry season from July to September. Average monthly streamflows for the Chehalis River measured at the three referenced gages are shown in Table 5.3-1.

Table 5.3-1
Average Monthly Flow at USGS Gage Locations

GAGE	JAN (CFS)	FEB (CFS)	MAR (CFS)	APR (CFS)	MAY (CFS)	JUNE (CFS)	JULY (CFS)	AUG (CFS)	SEPT (CFS)	OCT (CFS)	NOV (CFS)	DEC (CFS)
Doty	1,230	1,110	920	585	275	145	68	45	77	285	956	1,260
Grand Mound	6,380	5,690	4,650	3,060	1,440	835	384	243	348	962	3,950	6,270
Porter	9,320	8,120	6,800	4,620	2,240	1,250	619	414	540	1,330	5,470	8,780

Notes:
Monthly data at Doty was available from 1939 to January 2019, at Grand Mound from 1928 to January 2019, and at Porter from 1952 to January 2019.
Sources: USGS 2019a, 2019b, 2019c

Table 5.3-2 lists the estimated peak streamflows associated with 10-year and 100-year floods at the three referenced USGS gages. Peak streamflows for three recent significant floods are also provided for context.

Table 5.3-2
Peak Streamflows at USGS Gage Locations During Key Floods (to the Nearest 100 cfs)

FLOOD	DOTY (CFS)	GRAND MOUND (CFS)	PORTER (CFS)
2-year	9,900	--	--
10-year	19,800	45,350	51,680
100-year	39,300	75,000	89,500
1996	28,900	74,800	80,700
2007	52,600	79,100	86,500
2009	20,100	50,700	58,700

Notes:
The streamflow values provided are from WSE 2014a. See WSE 2014a for details.
Sources: WSE 2014a; Corps 2003; USGS 2019a, 2019b, 2019c

In addition to discrete flood streamflows, a 30-year continuous hourly flow record (March 1988 to March 2018) from the three gages listed in Table 5.3-1 was used to characterize long-term flow conditions in the study area. This information was used for input to the sediment transport model because of the number and magnitude of high-flow events in the record (Section 6.2.2.2).

5.4 Sediment Loads to Chehalis River

Sediment loads into the study area were estimated for the mainstem Chehalis River and primary tributaries based on existing data. This information was used to characterize the study area and as inputs to the sediment transport model used to evaluate impacts to sediment transport and bed substrate from the proposed project (WGD and Anchor QEA 2017; WGD 2019a, 2019b, 2019c). Existing data, analysis, and limitations associated with sediment load information for the study area are discussed in the following subsections.

5.4.1 Suspended Sediment Measurements

Suspended sediment measurements were made by USGS at 19 gaging stations in the Chehalis Basin between 1961 and 1965 (Glancy 1971) for peak streamflows up to 10,000 cfs at the Doty gage. The suspended sediment rating curve developed by Glancy (1971) is provided in Figure 5.4-1.

Figure 5.4-1
Suspended Sediment Rating Curve at Doty Gage Developed by Glancy (1971)

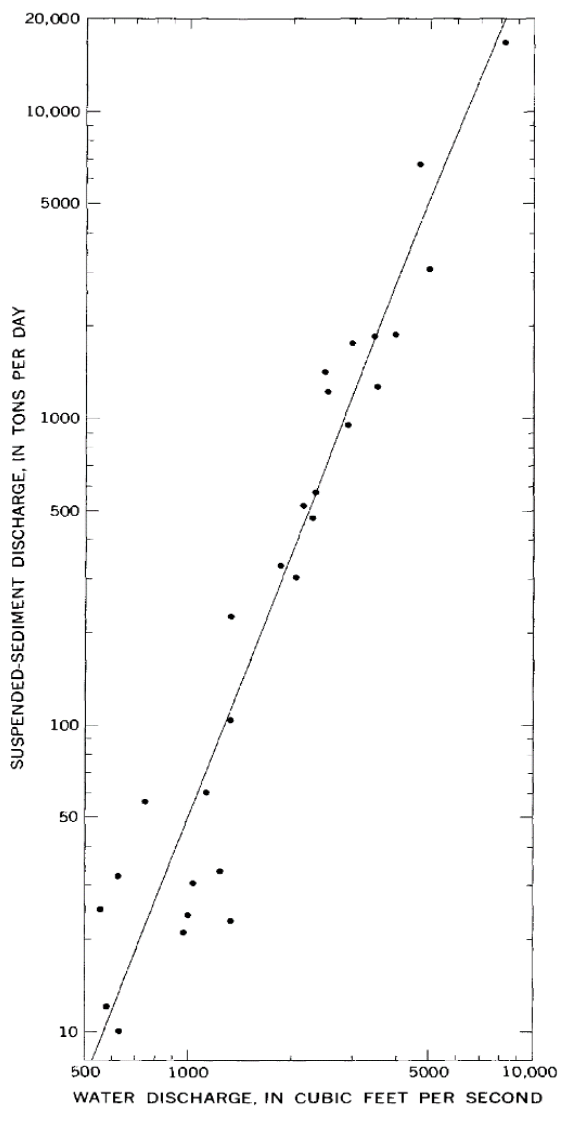


FIGURE 4.—Relation between water discharge and suspended-sediment discharge for Chehalis River near Doty.

The average annual yields (tons per square mile) at the three gages on the Chehalis River and four major tributaries (South Fork Chehalis, Newaukum, Skookumchuck, and Black rivers) were compiled to help determine sediment yields from different parts of the watershed. These values developed by Glancy (1971) and reported by WGD and Anchor QEA (2012) are provided in Table 5-4.1.

Table 5.4-1
Measured Suspended Sediment Transport, 1962 to 1965

GAGE LOCATION	DRAINAGE AREA (SQUARE MILES)	AVERAGE ANNUAL YIELD, 1962 TO 1965 (TONS/SQUARE MILE/YEAR)	AVERAGE ANNUAL TOTAL (TONS/YEAR)
12020000 Chehalis River at Doty (RM 101.8)	113	490	55,370
12021100 South Fork Chehalis River at Curtis	48	380	18,240
12025000 Newaukum River near Chehalis (RM 4.9 of the Newaukum River)	155	237	36,735
12026600 Skookumchuck River at Centralia	61.7	137	8,453
12027500 Chehalis River near Grand Mound (RM 59.9)	895	150	134,250
12029200 Black River	136	20	2,720
12031000 Chehalis River at Porter (RM 33.3)	1,294	98	126,812

Note:
Values taken directly from USGS study (Glancy 1971)

Measurements of suspended sediment by Glancy (1971) show that the majority of suspended sediment was transported during peak streamflows, with suspended sediment concentrations generally increasing as water discharge increased, except at the Grand Mound and Porter gages where the suspended sediment concentration often peaks before peak flow discharges. The dominant particle size carried in suspension in the upper basin and South Fork Chehalis and Newaukum rivers was sand. Silt dominated suspended sediment transport in the Skookumchuck River and at the Grand Mound and Porter gage sites. Glancy (1971) concluded that the majority of suspended sediment transported during peak streamflows came from reworking of the riverbeds and bank erosion. Episodic inputs from mass wasting events were another source in the upper watersheds.

5.4.2 Suspended Sediment Input from Landslides

Available suspended sediment measurements in the study area exist for streamflows only up to 10,000 cubic feet per second (cfs) at Doty. In order to develop estimates of suspended sediment load at higher streamflows, WGD conducted a study to estimate sediment loading to streams in the upper

Chehalis River watershed based on inputs from landslides in the upper Chehalis Basin (Ward and Russell 1994; Clark 1999; WGD and Anchor QEA 2017). Landslides were inventoried using the 1955, 1965, 1978, 1987, 1993, 1987, 2009, and 2013 aerial photographs, as described in Section 2.3.2 of WGD and Anchor QEA 2017. A summary of estimated landslide inputs taken from Table 2.4 of WGD and Anchor QEA 2017 is provided in Table 5.4-2.

Table 5.4-2
Estimated Landslide Inputs to the Upper Chehalis Basin (Upstream of Impoundment)

AERIAL PHOTOGRAPH YEAR	RECURRENCE INTERVAL OF LARGEST PEAK FLOW EVENT DURING AERIAL PHOTO PERIOD[a]	ESTIMATED TOTAL LANDSLIDE AMOUNT (TONS)	ESTIMATED INPUT TO STREAMS (TONS/DAY)
1955	5	457,800[b]	137,340
1965	5	402,900[b]	120,859
1978	21	2,197,000[b]	659,232
1987	5	347,900[b]	104,378
1993	42	1,099,000[b]	329,616
1997	75	366,200[c]	109,872
2007	500	4,558,000[d]	1,367,385
2009	13	30,800[d]	9,240

Notes:
a. Aerial photo time period is the years between the listed year and the prior year as listed in the table. This value for 1955 was assumed to be the same as 1965, since no prior year was available.
b. Based on Ward and Russell 1994
c. Based on Clark 1999
d. Based on WGD and Anchor QEA 2012, 2014

These values are difficult to use directly in a flow/sediment input relationship because they are based on aerial photograph periods that included multiple peak flow events, and there is not a direct relationship between the magnitude of peak streamflows that occurred during the aerial photograph period and the magnitude of estimated sediment inputs. In addition, not all of the sediment from the slides was delivered to the streams. To provide a reasonable way to convert total landslide volume to amount of sediment input to streams, it was assumed that 60% of the total volume was delivered to streams in the basin over a 2-day period to produce an estimate of total tons per day (Table 5.3-2). This assumption was developed by WGD based on review of aerial photography of past landslides and visual inspection of the migration of landslide material from the 2007 flood (WGD and Anchor QEA 2014).

The Washington Department of Natural Resources (WDNR) conducted an aerial reconnaissance to map landslides in parts of the Chehalis Basin following the 2007 storms (Sarikhan et al. 2008) and provided their data as a GIS shapefile to WGD. This shapefile was compared to the 2008 digital aerial photographs and edited to provide an updated coverage of landslides from the 2007 storm. This coverage was annotated with estimated percent delivery to a stream for each slide based on proximity to mapped streams and percent vegetative cover in 2008 and 2013 to determine revegetation and stabilization of the slide scars through time. An estimate of sediment input from the December 2007 storm was made by multiplying the area of each landslide polygon by the average depth for that type of slide (6.2 feet for debris slides and 6.5 feet for debris torrents; WGD and Anchor QEA 2012) and estimated delivery to obtain estimated slide volume. Slide volumes were converted to tons using an average bulk density of 0.8 ton per cubic yard. Both the WDNR watershed analyses and the 2007 landslide analysis were partitioned into bedload and suspended sediments based on grain size properties of dominant soils reported by Natural Resources Conservation Service GIS soil map layers, and grain sizes of three grab samples were analyzed as part of WGD and Anchor QEA 2012. The results of these calculations were used to develop the average assumptions (i.e., 60% of slide material entering the steam over 2 days) used to estimate sediment load to the Chehalis River because of landslides summarized in Table 5-4.2.

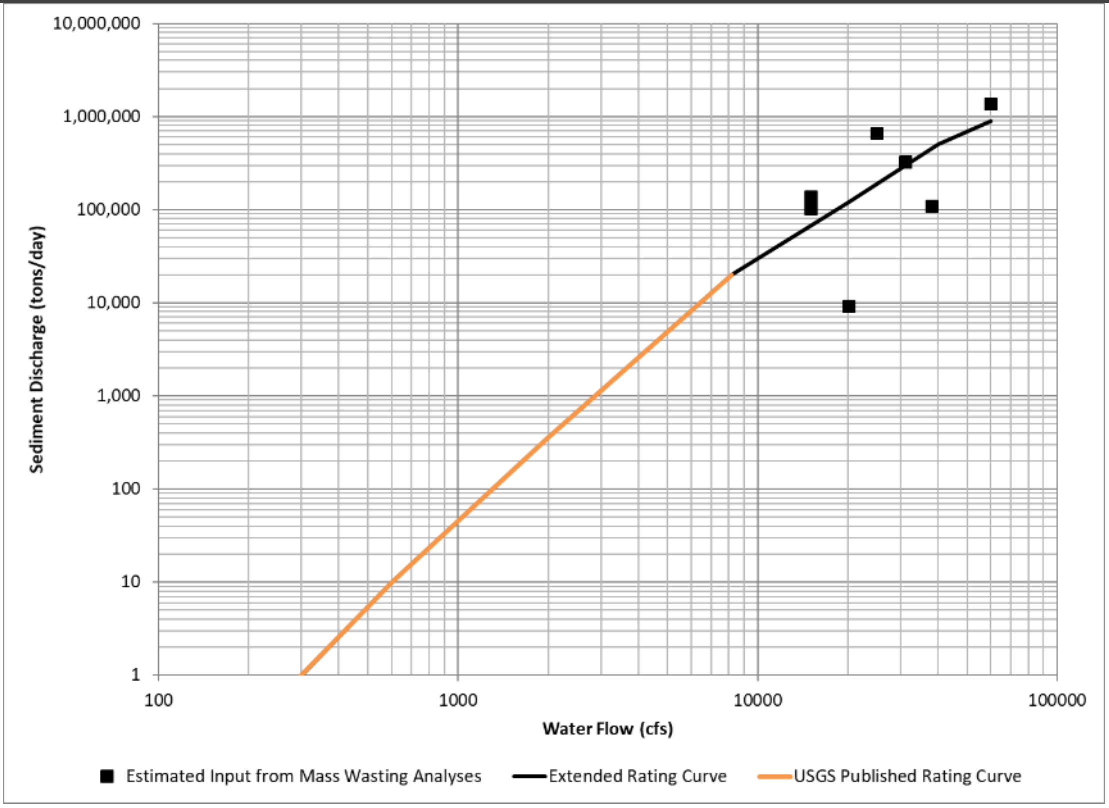
5.4.3 Bedload

Bedload was assumed to be 10% of the suspended sediment load (WGD 2019a) based on studies in other rivers in the Pacific Northwest (King et al. 2004; Emmett 1981) and a sensitivity analysis conducted as part of the reservoir sediment transport modeling described in WGD and Anchor QEA 2017. As part of that work, a range of bedload input from 5% to 10% of suspended load was used to test model sensitivity to this variable. Ten percent provided the most reasonable long-term patterns of deposition and transport compared to available site data.

5.4.4 Sediment Rating Curve

Incoming sediment loads were estimated using published suspended sediment load measurements (Section 5.4.1; Glancy 1971) and extended to higher streamflows based on estimated input from landslides during storm events (Table 5-4.1; Section 5.4.2; WGD and Anchor QEA 2017). Bedload input was assumed to be 10% of the total load (Section 5.4.3). This sediment load information was used to develop total load sediment rating curve for input to the HEC-RAS model, which is shown in Figure 5.4-2.

Figure 5.4-2
Sediment Rating Curve Compiled from Glancy (1971) Suspended Sediment Data and Estimated Landslide Inputs (WGD and Anchor QEA 2017)



Using the general sediment rating curve shown in Figure 5.4-2, sediment input rating curves were developed for each tributary selected as a sediment input point in the model. These tributaries were selected based on aerial photograph and field evidence indicating that a tributary was a substantial source of sediment to the modeled reach of the Chehalis River. Aerial photographs following the 2007 flood (2008 aerials) were reviewed to identify tributaries with substantial amounts of mass wasting within their drainage area and/or evidence of sediment sluicing or deposits. Tributary junctions between RM 118 and the Skookumchuck River were visited during field inventories and/or float trips to further assess field evidence that indicated they were or were not a source of coarse sediment; pebble counts of deposits at selected tributary junctions were taken to provide additional information on relative sediment gradations (WGD 2019c).

The sediment rating cures developed for tributaries and the inflow from headwaters to the Chehalis River are shown in Table 5.4-3. These rating curves were used as sediment input conditions (at the designated RM location in the table) for the sediment transport model described in Section 6.2.2.

Table 5.4-3
Sediment Rating Curves for Chehalis River and Identified Sediment Input Tributaries

AREA	FLOW (CFS)	SEDIMENT DISCHARGE (TONS/DAY)	AREA	FLOW (CFS)	SEDIMENT DISCHARGE (TONS/DAY)
RM 118.174 (Inflow from Headwaters)	186	3	RM 106.8 (Rock Creek)	90	0.5
	620	119		300	18
	2,542	7,260		1,230	1,100
	6,200	43,560		3,000	6,600
	12,400	181,500		6,000	27,500
	18,600	326,700		9,000	49,500
RM 117.339 (Thrash Creek)	48	1	RM 101.12 (Jones Creek)	378	0
	160	43		1,260	1.5
	656	2,640		5,166	88
	1,600	15,840		12,600	528
	3,200	66,000		25,200	2,200
	4,800	118,800		37,800	3,960
RM 113.89 (Rogers Creek)	36	1	RM 100.16 (Elk Creek)	306	1
	120	43		1,020	24
	492	2,640		4,182	1,474
	1,200	15,840		10,200	8,844
	2,400	66,000		20,400	36,850
	3,600	118,800		30,600	66,330
RM 112.7 (Big Creek)	30	1	South Fork Chehalis River (RM 5.84 on South Fork Chehalis River)	186	3
	100	40		620	119
	410	2,420		2,542	7,260
	1,000	14,520		6,200	43,560
	2,000	60,500		12,400	181,500
	3,000	108,900		18,600	326,700
Crim Creek (RM 3.16 on Crim Creek)	90	1	Stearns Creek (RM 4.62 on Stearns Creek)	200	0
	300	18		1,000	2
	1,230	1,100		10,000	270
	3,000	6,600		49,500	4,040
	6,000	27,500		--	--
	9,000	49,500		--	--

Notes:
Sediment rating curves were developed from the general sediment rating curve developed for the system shown in Figure 5.4-2 and modified as described in WGD 2014.
RMs designate locations where these sediment rating curves were used as input to the sediment transport model described in Section 6.2.2.

5.5 Bed Substrate Type and Grain Size

5.5.1 Grain Size Data

Grain size data were collected in 2010, 2015, and 2018 by WGD. This information was used to characterize the study area and as input to the sediment transport model developed by WGD (2017, 2019), as discussed in Section 6.2.2. Sample locations were selected on gravel and cobble bars in the Chehalis River and select tributaries, as these locations are expected to show consistent information along the study area of material sizes being mobilized because of bedload. Additional information was collected in 2015 and 2018 to fill in spatial data gaps in the 2010 dataset, including the area around the proposed facility.

In 2010, grain size distribution was evaluated for 28 gravel/cobble bars along the Chehalis River and five bars along the South Fork Chehalis River from September 24 to 29, 2010 (WGD and Anchor QEA 2012). Streamflows in the Chehalis River during the sampling period (at Grand Mound) ranged between approximately 500 and 620 cfs. Samples were taken at the upstream end of the gravel bars near the waterline; one armor (i.e., surface) and one sub-armor (i.e., subsurface) sample was collected at each location. A total of 66 gravel samples were collected, one armor and one sub-armor for 33 locations between RM 33.8 and RM 114.5 in the Chehalis River and RM 0 and RM 17.1 in the South Fork Chehalis River. Exact locations for sampling sites were determined in the field, based on hydraulics at each location, to be representative of bedload movement. Figure B-1 of WGD and Anchor QEA 2012 shows the locations of gravel sample sites.

Grain size distribution of the armor layer was determined using the Wolman (1954) method and random selection of 100 surface rocks that were run through a gravelometer. Each rock was classified into one of the following seven size categories:

- <2 millimeters (mm)
- 2 to 4 mm
- 4 to 8 mm
- 8 to 16 mm
- 32 to 64 mm
- 64 to 128 mm
- 128 to 256 mm (largest rock sampled was 256 mm)

Sub-armor samples were collected by scraping the armor layer away and excavating one 5-gallon bucket of underlying material. Sub-armor samples were bagged in the field and run through a laboratory sieve analysis using 10 sieve sizes ranging from 31.5 mm to 0.063 mm. Plots of the particle size distributions for all armor and sub-armor samples are provided in Attachment B-1 of WGD and Anchor QEA 2012.

Additional pebble count data were collected in 2015 at discrete sites between RM 105 and RM 118 (in Reach 1). Some samples were collected at the same RM sampled in 2010 but at different bar locations (WGD and Anchor QEA 2017); a total of 14 additional armor layer samples were collected.

Additional pebble counts of the armor layer were collected in 2018 between RM 108.5 (just upstream of the proposed impoundment location) to RM 75 (just downstream of the Newaukum River) as well as in Crim Creek, Elk Creek, and the Skookumchuck River just upstream of the junction with the Chehalis River (WGD 2019a).

The median (D_{50}) and 65th percentile grain size (D_{65}; 65% of the particles are finer than this size) and percent of the sample that is cobble, gravel, and sand from all samples (2010, 2015, and 2018) are shown in Table 5.5-1 and are illustrated in Figures 3.1 and 3.2 of WGD 2019.

Table 5.5-1
Grain Size Distribution of Samples

SAMPLE DESIGNATION	GEOMORPHIC REACH	RIVER MILE	D_{50} (MM)	D_{65} (MM)	COBBLE (64 TO 256 MM)	GRAVEL (2 TO 64 MM)	SAND (0.063 TO 2 MM)
SAMPLE YEAR 2010							
Chehalis 1	Reach 6	33.8	27	34	1%	99%	0%
Chehalis 2		36.8	28	37	4%	94%	2%
Chehalis 3		40	31	41	3%	95%	2%
Chehalis 4		42.9	26	36	4%	92%	4%
Chehalis 5		46.2	51	59	27%	73%	0%
Chehalis 7		53.4	30	45	18%	82%	0%
Chehalis 8		54.7	47	56	21%	79%	0%
Chehalis 9		57.1	53	64	35%	65%	0%
Chehalis 10		61	71	88	56%	44%	0%
Chehalis 11	Reach 5	63.2	48	55	18%	82%	0%
Chehalis 12		65.8	51	64	35%	65%	0%
Chehalis 12.5		73.4	11	13	0%	100%	0%
Chehalis 13	Reach 4C	75.2	2	24	0%	100%	0%
Chehalis 14		77.7	13	16	0%	100%	0%
Chehalis 15		81.4	28	38	7%	72%	21%
Chehalis 16	Reach 4B	82.5	35	44	5%	95%	0%
Chehalis 17		84.8	37	46	5%	94%	1%
Chehalis 18	Reach 4A	87.5	25	31	4%	96%	0%
Chehalis 19	Reach 3	88.4	40	50	12%	88%	0%
Chehalis 20		91.2	34	45	9%	91%	0%
Chehalis 21		93.8	19	24	0%	94%	6%
Chehalis 22	Reach 2C	97.5	38	54	26%	69%	5%
Chehalis 23		99.6	50	70	38%	53%	9%
Chehalis 24		100.3	52	63	34%	61%	5%
Chehalis 25	Reach 2B	104.6	77	97	60%	38%	2%

SAMPLE DESIGNATION	GEOMORPHIC REACH	RIVER MILE	D_{50} (MM)	D_{65} (MM)	COBBLE (64 TO 256 MM)	GRAVEL (2 TO 64 MM)	SAND (0.063 TO 2 MM)
SAMPLE YEAR 2015							
RM 108.5 Panesko Bridge	Reach 1	108.5	31	43	9%	91%	0%
RM 110 Sorting Yard Bridge		110	22	26	1%	99%	0%
Chehalis 27		110	21	27	0%	99%	1%
RM 111		111.2	28	37	11%	89%	0%
RM 112 (current bed [finer])		112.2	29	38	7%	93%	0%
RM 112 (pre-2007 bed [coarser])		112.2	53	64	35%	65%	0%
RM 113		113.1	27	32	12%	88%	0%
Chehalis 28		114.5	42	51	12%	88%	0%
RM 114		114.7	53	75	41%	59%	0%
RM 116 (scour monitor site)		115.8	28	39	10%	90%	0%
RM 116 (spawning-sized deposit)		115.9	25	31	7%	93%	0%
RM 117		117.1	74	111	54%	45%	1%
RM 118		118.1	36	54	27%	72%	1%
RM 105	Reach 2B	105.5	40	49	11%	89%	0%
SAMPLE YEAR 2018							
RM 108.5	Reach 1	108.5	27	31	2%	98%	0%
RM 101.3	Reach 2C	101.3	25	28	1%	99%	0%
RM 96.1	Reach 2C	96.1	34	47	16%	81%	3%
RM 87.9	Reach 4A	87.9	60	80	46%	54%	0%
RM 84.6	Reach 4B	84.6	31	42	10%	86%	4%
RM 82.3	Reach 4B	82.3	25	31	1%	99%	0%
RM 80.9	Reach 4C	80.9	35	44	5%	94%	1%
RM 77.8	Reach 4C	77.8	12	14	0%	97%	3%
RM 75.3	Reach 5	75.3	2	21	0%	100%	0%
RM 74.9	Reach 5	74.9	20	24	0%	100%	0%
RM 105	Reach 2B	105	26	37	5%	95%	0%
RM 100.5	Reach 2C	100.5	23	28	2%	98%	0%
RM 92.3	Reach 3	92.3	41	51	17%	83%	0%
RM 77.8 Scour Monitor	Reach 4C	77.8	20	25	0%	100%	0%
RM 81.5 Scour Monitor	Reach 4C	81.5	21	25	1%	99%	0%
Crim Creek	N/A	0	48	71	38%	59%	3%
Elk Creek	N/A	0	38	47	7%	93%	0%
South Fork Chehalis 30	N/A	0.8	40	51	19%	81%	0%
South Fork Chehalis 31	N/A	4.2	37	49	16%	84%	0%
South Fork Chehalis 32	N/A	9.9	5	7	0%	81%	19%

SAMPLE DESIGNATION	GEOMORPHIC REACH	RIVER MILE	D_{50} (MM)	D_{65} (MM)	COBBLE (64 TO 256 MM)	GRAVEL (2 TO 64 MM)	SAND (0.063 TO 2 MM)
South Fork Chehalis 33	N/A	13.8	11	15	0%	85%	15%
South Fork Chehalis 34	N/A	17.1	29	44	17%	74%	9%
Skookumchuck River	N/A	0.1	42	55	25%	75%	0%

Note:
Table taken from WGD and Anchor QEA 2017

Armor layers of sampled bars were dominated by gravel-sized particles, with cobble and sand as secondary components (see Figure B-3a of WGD and Anchor QEA 2012). The sub-armor layer was also dominated by gravel, with sand and cobble secondary (see Figure B-3b of WGD and Anchor QEA 2012). The general trend in rivers is a fining-downstream pattern, with coarser sediment in the steeper headwaters progressing finer sediment in lower-gradient mainstem reaches. A two-part trend can be seen in the Chehalis River with a general decrease in cobble particles from the RM 104.6 sample to the RM 81.4 sample, then another decreasing trend from the RM 61 sample to the RM 33.8 sample. The transition between the two trends coincides with bedrock sills observed in the river between RM 62 and RM 65 (Figure B-1 of WGD and Anchor QEA 2012). This two-part trend is consistent with field observations conducted by WGD (WGD and Anchor QEA 2012).

The large input from landslides that occurred at the headwaters of the Chehalis River during the December 2007 flood has also had an influence on substrate and bar composition downstream in the Chehalis River. A large landslide occurred immediately upstream from the RM 110 sample location. The gravel bars sampled at RM 110 and RM 106.7 in 2010 and 2015 (Table 5.4-1) were composed of gravel and sand with very little cobble-sized particles (WGD and Anchor QEA 2012). The sediment input to the Chehalis River from that large landslide will continue to be reworked and transported downstream for many years.

5.5.2 Substrate Mapping

WGD mapped substrate conditions using non-motorized boats or on foot in the Chehalis River between RM 75 and RM 108 in late August 2018 (WGD 2019a); which is the spatial extent of the sediment transport model developed for the project (see Section 6.2.2). Substrate type was mapped based on the observed upper and lower range of substrate size using the following categories:

- Sand
- 8 mm (medium gravel)
- 16 mm (coarse gravel)
- 32 mm (very coarse gravel)
- 64 mm (fine cobble)
- 128 mm (coarse cobble)
- 256 mm (fine boulder)

- 512 mm (medium boulder)
- 1,024 mm (coarse boulder)
- Bedrock (basalt, conglomerate, sandstone)

Locations of eroding riverbanks and hardened banks (e.g., with riprap or other erosion protection) were also mapped. This information was used to provide information on riverbed grain size distribution and define initial bed substrate conditions at each of the HEC-RAS cross-section locations in the sediment transport model, as discussed in Section 6.2.2, developed by WGD (2019). Figures illustrating the results of the substrate mapping are provided in Appendix B of WGD 2019.

Surficial substrate consisted of gravel and cobble particles with some sand in low-gradient areas. Substrate in general fined in a downstream direction over the 30+ miles of river mapped, but as in most rivers, there were areas of coarser and finer substrate associated with local variations in slope and hydraulics. In several locations, bedrock spanned the river and provided grade controls, with locally finer substrate upstream of the grade controls. Grade controls were observed at RM 65.5, RM 86, RM 93.5, RM 98, and in several locations between RM 107 and RM 108. In addition, bedrock was observed on riverbanks or partially spanning the river bottom in locations near RM 86, RM 90.5 to RM 103, RM 104 to RM 104.5, and RM 108.4 to RM 106. In these areas, the bedrock limits lateral channel migration on one or both banks.

5.6 Scour Monitors and Accelerometers

Scour monitors were installed and monitored in the Chehalis River during two separate time periods: October through December of 2015 and August 2018 through August 2019. Accelerometers were also installed in the Chehalis River during the 2018/2019 data collection effort. This information was used to assist in calibration of the sediment transport model, as discussed in Section 6.2.2.

Sliding-bead monitors provide direct measurement of bed scour of the riverbed. A rod and attached string of beads is driven into the riverbed (Nawa and Frissell 1993). The peak flow over the measurement period scours the riverbed and exposes the beads to the flow, which slides the beads to the end of the attached cable. The length of the beads exposed by the flow equals the depth of scour at that location. Accelerometers are instruments that measure the change in velocity as the sensor is moved and can be used to measure initiation of motion under specific streamflows.

5.6.1 2015 Scour Monitors

Sliding bead scour monitors (Schuett-Hames et al. 1999) were deployed at six locations between RM 88 (just upstream of the Ceres Hill Bridge) and RM 116 (near the upper end of potential impoundment) to measure gravel scour and accretion (Figures 2.2a to 2.2c of WGD and Anchor QEA 2017). Two monitors were installed at each location (RM 88—Ceres Hill Bridge; RM 105.5—Doty Sewage Plant; RM 107.5—Weyerhaeuser office; RM 108.5—Panesko Bridge; RM 110—Sorting Yard Bridge; and RM 116—south of

Cutoff Road). Monitors were placed in late October 2015 and checked on November 6, 2015, and December 2, 2015, following high streamflows (Table 2.2 of WGD and Anchor QEA 2017).

Monitors at the six sites in the Chehalis River recorded a range from no scour or fill to up to 0.4 foot of scour and 1 foot of fill following a flow of 5,840 cfs at the Doty gage and 5,830 cfs at the Mahaffey Creek gage. Following a flow of 14,000 cfs at the Doty gage (estimated to be 9,230 cfs at the Mahaffey Creek gage), a minimum of 1 foot of scour and 0.5 foot of fill was recorded, but only 4 of the 12 scour monitors were found after the 14,000 cfs flow. Visual observations suggested that the channel had filled and buried the monitors. Substrate up to 64 mm was mobilized during the 5,840 cfs flow event and up to 300 mm during the 14,000 cfs flow event (Section 3.2 and Table 3.4 of WGD and Anchor QEA 2017).

5.6.2 2018 to 2019 Scour Monitors and Accelerometers

Sliding bead scour monitors (Schuett-Hames et al. 1999) were deployed at eight locations in the mainstem Chehalis River between RM 75 (near the confluence with the Newaukum River) and RM 108 (just downstream of the proposed temporary reservoir) to measure gravel scour and accretion. At seven of these locations, accelerometers were also installed that could record the initiation of movement of the monitors. Scour monitors were buried in the riverbed with the uppermost bead at the surface of the bed and the top of the accelerometers were buried 2 to 4 inches below the bed surface. Monitors were placed in late August 2018 and retrieved in May and June 2019. Results of this effort, summarizing observed scour and initiation of movement, are provided in Table 1 of WGD 2019b.

The highest instantaneous flow during the 2018 to 2019 deployment period was 6,390 cfs at Doty and 12,500 cfs at Adna (USGS provisional data), which is less than a 2-year recurrence interval peak flow. Substrate at all of the sites where data were recovered (between approximately RM 108 and RM 78), except the site near Adna, showed at least low movement at one or more of the scour monitors or accelerometers during this flow event. Several locations showed movement at lower streamflows. This suggests that the existing substrate in the mainstem river is quite mobile, even under average annual peak flow conditions. This is consistent with observations by WDFW personnel conducting spawner surveys in the upper river who have reported mobile substrate conditions. It is likely that the texture of the existing substrate still reflects the large quantities of sediment that were transported downstream during the 2007 flood and will continue to reflect these conditions for several more decades.

5.7 Large Woody Material

5.7.1 Watershed Analysis

The upper Chehalis River watershed analyses—as well as a summary of limiting factors in the Chehalis River—report that current levels of LWM in the Chehalis River are low (Weyerhaeuser 1994a, 1994b; Smith and Wenger 2001). These reports are consistent with the inventory of large instream wood performed (Appendix A, WGD and Anchor QEA 2017), which found low levels of LWM within most of the study area.

Sources of LWM to the mainstem Chehalis River include input of logs and stumps from landslides and debris torrents in the headwater streams and input of trees as a result of bank erosion and channel migration in the lower-gradient alluvial parts of the channel. All of these input processes are episodic, providing wood during large storm/flow events and little wood input during non-storm/peak flow times. Past timber harvest and cutting of trees in the riparian zones have left a limited supply of very large trees in the watershed. However, large storms (such as in December 2007) supply wood to the channel.

Entrix (2009) reported 700 acres of landslides that delivered wood to the channel in the Chehalis River headwaters, Stillman Creek, and South Fork Chehalis River watersheds with at least 213 acres of woody debris jams remaining in the channel and floodplain upstream of RM 88 after the 2007 storm. Much of the wood from that storm was deposited on the floodplain. This wood was subsequently cleared from the channel and floodplain. In the lower watershed, wood is supplied by bank erosion and channel migration. Areas with active channel migration include portions of Reaches 3, 4, and 6 (see Section 5.8). Input of trees from sloughing of the steep banks in Reach 5 was observed during the gravel sampling field work. The dead trees in the channel in this reach appear to be fairly stable, possibly with roots still attached to a slump block on the riverbed. LWM in other geomorphic reaches appears to have been mobile during large floods and is primarily deposited on gravel bars either as single pieces or in occasional jams.

5.7.2 Data Inventory and Input Estimates Upstream of the Flood Retention Facility

Inputs of wood and debris upstream of the proposed flood retention facility site (RM 108.2) were estimated by WGD (2017) based on estimates of past landslide rates. Landslides were inventoried using the 1955, 1965, 1978, 1987, and 1993 aerial photographs (Ward and Russell 1994). The data on each landslide area and forest stand age category from the Ward and Russell report were compiled for the current analysis. These data were supplemented with landslides that were digitized from the 1996 digital orthophotographs and 2007 landslides provided in the WDNR landslide database (Sarikhan et al. 2008; GIS data provided by WDNR). The 2007 WDNR landslide database was further edited by comparing with the 2008 digital orthophotographs to add missing landslides and remove landslides that were not present on the orthophotographs. Detailed description of methods used to develop estimates of average woody debris input for each stand age category is provided in Section 2.1.2 of WGD and Anchor QEA 2017; results are provided in Table 5.7-1. This information was used to help inform the impacts evaluation of the proposed project to recruitment and transport of LWM in the study area.

A LWM inventory was not conducted downstream of the flood retention facility. Information described in Section 5.7.1 was also used to inform the impacts determination for LWM downstream of the proposed flood retention facility.

Table 5.7-1
Estimated Volume of Wood and Debris per Landslide Event for Different Stand Age Categories

STAND AGE CATEGORY	VOLUME OF WOOD AND DEBRIS
0 to 20 years	5,750 cubic yards
20 to 50 years	11,500 cubic yards
>50 years	17,250 cubic yards

5.8 Channel Migration

Channel migration is a natural occurrence in unconfined reaches of meandering rivers, including Reaches 3 through 6 of the Chehalis River. Channel migration is sometimes seen as undesirable by people living close to a river because the process results in bank erosion and movement of the river channel, which can affect fields and structures within the migration zone. Channel armoring is often used to reduce bank erosion and migration. The following two analyses of historical channel migration were conducted to inform this discipline report:

- Qualitative historical analysis using aerial photographs for Reaches 1 through 6. This was conducted by WGD (2012).
- Quantitative historical analysis using aerial photographs to estimate channel migration rates to better inform habitat evaluation for specific sections of the study area where channel migration is currently ongoing (in Reaches 2B, 3, 4A, and 4B). This was also conducted by WGD (2017).

5.8.1 Qualitative Analysis of Entire Study Area

Channel migration and watershed conditions were assessed using historical aerial photographs and maps. Four sets of maps and photos were chosen to span the period of 1856 to 2009 (WGD and Anchor QEA 2012). The 1876 survey map and 1945 orthophotos were scanned and georeferenced using township/range corners. The centerline of the Chehalis River channel was digitized from the 1876 survey map, 1945 orthophotos, 1990 orthophotos, and 2009 orthophotos. Some error in river position was introduced through the georeferencing process, and the location of the river in a few of the 1856 to 1876 survey maps was suspect, but the results do provide insights into areas with active channel migration.

Historic channel migration was assessed in the Chehalis River between Porter (RM 33) and Pe Ell (RM 108) by comparing the location of the main channel on an 1876 survey map and 1945, 1990, and 2009 orthophotos (Figure B-2 of WGD and Anchor QEA 2012). Note that the 1945 photos did not cover the entire study area, and the location of the channel in the 1876 survey is suspect in several locations. There was little to no channel migration noted in Reaches 1 or 2 where the river is confined by a narrow valley or bedrock features. Up to 300 feet of channel movement was noted in two unconfined locations between 1990 and 2009 in Reach 3, upstream of the confluence with the South Fork Chehalis River. The channel was freer to move in the unconfined portions of Reach 4; migration of up to 600 feet was measured in the active zone from RM 81 to RM 86 between 1945 and 2009, and up to 1,000 feet of movement was measured between 1876 and 1945. There was little movement of the extremely low gradient incised channel between RM 66 and RM 75 in Reach 5 from 1945 to 2009 (the position shown for the 1876 channel is questionable in this reach). Up to 600 feet of movement was noted between RM 61 and RM 66. Reach 6 had the most active channel migration, with up to 1,500 feet of movement in many locations between 1945 and 2009 and several instances of channel avulsion (abrupt changes from one channel location to another, in these cases more than 4,000 feet away) between 1876 and 1945.

5.8.2 Quantitative Analysis of Target Areas

Channel migration was assessed by WGD (2014) using a series of digital aerial photographs for the river upstream of the Mellen Street Bridge (approximately RM 67.5). Ten sets of photographs were chosen to span the period of 1945 to 2013, as described in Table 5.8-1. The aerial photographs were analyzed using GIS to define the active and wetted channel areas in each photograph year. The active channel was digitized with the edge of the active channel defined as the boundary between vegetated areas along the channel and either water or unvegetated bars. For areas with large overhanging trees, the edge of the channel was assumed to be just riverward of the tree crown. The wetted channel was digitized to delineate wetted versus bars in each photograph set.

Table 5.8-1
Digital Aerial Photograph Used in Channel Migration Analysis

PHOTOGRAPH DATE	APPROXIMATE FLOW AT DOTY IN CFS	COVERAGE USED IN ANALYSIS
1945	Unknown	Mellen Street Bridge to RM 87.5
July 9, 1990	95	Upstream of Mellen Street Bridge
1996	Unknown	Upstream of Mellen Street Bridge
July 31, 2005	40	Upstream of Mellen Street Bridge
June 23, 2006	79	Upstream of Mellen Street Bridge
2008	Unknown	Upstream of Mellen Street Bridge
June 25, 2009	91	Upstream of Mellen Street Bridge
July 8, 2010	117	Upstream of Mellen Street Bridge
September 25, 2011	37	Upstream of Mellen Street Bridge
July 14, 2013	64	Upstream of Mellen Street Bridge

Channel migration was assessed for the four following areas that showed active migration:

- RM 104 to RM 105, downstream from Pe Ell (Reach 2B)
- RM 90 to RM 91, around the Ceres Hill Road Bridge (Reach 3)
- RM 86.3 to RM 87.8, upstream from the confluence with the South Fork (Reach 4A)
- RM 83 to RM 86, near Adna (Reach 4B)

The average rate of channel migration between each set of aerial photographs was calculated for each analysis area by overlaying the active channel margins for the two successive aerial photographs (i.e., 1945 to 1990, 1990 to 1996, etc.) and determining the area newly occupied by channel. This area was divided by the length of each assessment area and number of years between photographs to provide average channel migration rate in feet per year.

Detailed maps of channel changes through time at each of the four areas are included in Appendix B of WGD and Anchor QEA 2017. Average channel migration rates were estimated by WGD and are summarized in Table 5.8-2.

Table 5.8-2
Average Channel Migration Rates (WGD and Anchor QEA 2017)

CHANNEL LOCATION	AVERAGE CHANNEL MIGRATION RATE (FEET/YEAR) DURING PERIOD									
	1945 TO 1990	1990 TO 1996	1996 TO 2005	2005 TO 2006	2006 TO 2008	2008 TO 2009	2009 TO 2010	2010 TO 2011	2011 TO 2013	AVERAGE RATE BY LOCATION
Reach 2B: RM 104 to RM 105	N/A	8.2	5.1	15.9	67.7	9.9	8.3	5.2	6.4	15.8
Reach 3: RM 90 to RM 91	N/A	5.2	4.2	12.4	12.4	3.5	6.7	3.9	8.4	7.0
Reach 4A: RM 87.8 to RM 86.3	N/A	3.2	6.0	7.9	9.6	5.7	4.3	6.3	8.0	6.3
Reach 4B: RM 83 to RM 86	2.1	5.4	7.1	9.1	14.3	1.8	3.6	3.8	5.1	6.2
Average Rate by Year	2.1	5.5	5.6	11.3	26.0	5.2	5.7	4.8	7.0	8.9

Average channel migration rates varied from 1.8 to 67.7 feet per year over the analysis period. Channel migration rates for all locations were highest during the 2006 to 2008 time frame, which included the 2007 flood. However, average channel migration rates during the other time periods did not correlate directly with the peak flow between photographic periods, suggesting that channel migration occurs even during small peak streamflows with a recurrence interval of 1 to 2 years. Channel migration in most of the areas occurred as progressive, slow bank erosion on the outside of meander bends. The only avulsion (rapid change to a new channel) occurred in the RM 104 to RM 105 area during the 2007 flood.

5.9 Channel Width

Following the example of Nelson (2013), the margins of the active and wetted mainstem Chehalis River channel between the bridge at RM 113 and the Mellen Street bridge at RM 67.5 were estimated by WGD (2014). The channel width was mapped based on the same aerial photographs used to evaluate channel migration. Figures showing predicted temporal changes in reach-averaged active channel and wetted channel width and changes in unvegetated bars are provided in Figures 3.4 through 3.6 of WGD and Anchor QEA (2014), respectively.

The width of the active channel (includes wetted channel and all unvegetated bars) increased markedly following the 2007 flood. The change in active channel width was most noticeable in unconfined areas where channel migration is most active (RM 81.5 to RM 85.9, RM 91.5 to RM 93.5, RM 104.3 to RM 105.9) and in the headwater areas upstream of RM 105.9 where the channel widened from an average of 78 feet in 2006 to 123 feet in 2008. The wetted channel width remained relatively constant through time in all reaches. The percent of the channel occupied by gravel bars shows the marked increase in gravel bars upstream of RM 91.5 between the 2006 and 2008 photographic periods. The change in bar area is the result of both aggradation, removal of encroaching vegetation by the floodwaters, and channel migration which builds new bars on the inside of meander bends.

5.10 Climate Variability

This section provides a discussion of the historical and current climate of the study area, including an analysis of how it could potentially change under future climate variability conditions. The analysis focuses on the potential changes in the climate of the Chehalis Basin as a result of modeled climate variability in the 21st century (2000 to 2099) relative to historical conditions. This information is summarized in this discipline report because of how changes in the climate may affect the potential for impacts on aquatic habitat and species as discussed in Section 6.

5.10.1 Temperature and Temperature Extremes

The Chehalis Basin is typically characterized as having relatively cool winters and moderately warm summers. Historically, seasonal variation in average temperatures has ranged from approximately 41°F in January and 75°F in August (USGS 2019d). Over the last century (1901 to 2000), both annual average maximum (i.e., daytime high) and the annual average minimum (i.e., nighttime low) temperatures in the Pacific Northwest have increased by approximately 1.5°F (Vose et al. 2017). Temperature extremes (e.g., cold snaps, heat waves) occur in the Chehalis Basin, with cold extremes typically occurring less frequently than warm extremes (Vose et al. 2017; Peterson et al. 2013; Bumbaco 2013). Over the last century (1901 to 2000) the occurrence of cold extremes has decreased over time while warm extremes, especially nighttime heat waves, have increased in frequency.

Future climate variability is expected to result in an increase in air temperature across the United States with warming expected to be slightly greater in summer months and amplified in the northern parts of the United States (Vose et al. 2017). In the Pacific Northwest, potential increases in annual average air temperatures are projected to be between 3.7°F and 4.7°F by mid-century (2036 to 2065) and 5.0°F and 8.5°F by late-century (2071 to 2100; Vose et al. 2017). In the counties that contain the Chehalis Basin, projected average increases in the annual mean minimum (winter) air temperatures is expected to be 2.2°F to 2.8°F by 2040 and 4.1°F to 6.8°F by 2080 (USGS 2019d). The average potential increase in the annual mean maximum (summer) air temperature in the Chehalis Basin area is expected to be 2.2°F to

2.9°F by 2040 and 4.2°F to 7.0°F by 2080 (USGS 2019d). Overall, climate variability is expected to result in greater temperature extremes.

Climate variability is also projected to result in more extreme heat events in the summer and fewer extreme cold events in the winter. Historically rare extreme high temperatures are projected to become more common, with the Chehalis Basin potentially experiencing up to 10 additional days of temperatures above 90°F in the summer (Vose et al. 2017).

Projected increases in both minimum and maximum temperatures and extreme heat events in the Chehalis Basin would increase evapotranspiration during the spring and summer. Such conditions would reduce soil moisture and increase the likelihood of droughts and wildfires. Hotter summer conditions would also lead to higher water temperatures in rivers and streams. Warmer temperatures during the winter would cause wintertime precipitation to shift from snow to rain in the higher elevation portions of the basin. This shift could increase winter streamflow and contribute to higher downstream flows and increased flooding potential.

5.10.2 Precipitation and Precipitation Extremes

In the Chehalis Basin, precipitation varies considerably between seasons as evidenced by the occurrence of very wet winters and dry summers. In Lewis County, monthly average precipitation ranges from approximately 1.1 inches in July to 10.9 inches in January (USGS 2019d). Although annual precipitation has not changed significantly over the last century, the amount of precipitation that falls in the winter and summer has slightly declined while spring precipitation amounts have slightly increased (Easterling et al. 2017). Atmospheric river events have historically caused abnormally high (extreme) rainfall in the Chehalis Basin, but the frequency and intensity of such events has not changed much over the last century.

As a result of future climate variability, annual precipitation amounts in the Pacific Northwest are projected to increase by 5% to 8% by the latter part of the 21st century relative to the 1979 to 1990 baseline (May et al. 2018). The largest precipitation increases in the Chehalis Basin are projected to occur during the winter months with potential increases of up to 10% above baseline amounts by the latter half of the century (2070 to 2099; Easterling et al. 2017). During this same period, summer precipitation is projected to decrease by 10% to 20% (Easterling et al. 2017). Climate models have less confidence in predicting changes in precipitation than changes in temperature, especially with the confounding influence of such events as El Niño and La Niña, which strongly influence precipitation over seasonal and interannual time periods in the region.

The frequency of extreme precipitation events is also projected to increase in the future. This is because of both projected increases in atmospheric water vapor and convective energy resulting from higher temperatures, and projected increases in the frequency and intensity of atmospheric river events along the west coast. Such events are also expected to become more intense.

The projected increases in winter precipitation and the frequency and intensity of atmospheric river events would both contribute to an increased risk of winter and spring flooding in the Chehalis Basin. Decreased summer precipitation coupled with higher summer temperatures would reduce flow in rivers and streams and likely increase instream water temperatures.

5.10.3 Snowfall

The Chehalis Basin is rain-dominated (i.e., rain produces more runoff than snow), in part because most of the basin is low lying and maintains relatively warm temperatures because of the moderating influence of the Pacific Ocean. However, the Chehalis Basin does have a few areas that accumulate snowpack during the fall, winter, and early spring. Those areas occur at higher elevations in headwater streams of the southern Olympic Mountains, Cascade foothills, and a very small portion of the Willapa Hills (Perry et al. 2016). Historically, snowfall in those portions of the Chehalis Basin typically begins in November, with peak snowfall amounts occurring between February and late March (USGS 2019d). Snowfall then tapers off until June.

Projected changes in snowfall because of climate variability include decreases in annual snowpack, future snow water equivalent, number of extreme snowfall events, and number of snowfall days (Georgakakos et al. 2014; Easterling et al. 2017). In the counties that contain the Chehalis Basin, projected decreases in snowfall range from an average of 1.9 to 2.4 inches by mid-century (2025 to 2049) to 2.8 to 3.3 inches by late-century (2050 to 2074; USGS 2019d). It is expected that there will be a shift from snow to rainfall in the Chehalis Basin over time, reducing the amount of water retained in snow from fall and winter storms.

As a result of these projected changes in snowfall, winter streamflows in headwater streams in portions of the Chehalis Basin that currently support snowpack accumulation would be expected to increase as precipitation contributes directly to runoff instead of being retained as snowpack. When coupled with increased winter precipitation through the rest of the Chehalis Basin, this could in turn lead to an increased potential for winter flooding and landslides in downstream portions of the Chehalis Basin. In addition, the reduction in snowpack may also lead to increased drought risk because of less water availability from snow melt in the spring and summer.

6 ENVIRONMENTAL CONSEQUENCES

6.1 Assumptions

The following assumptions, at a minimum, will be used in the impact analysis on geomorphology.

6.1.1 Construction and Operation of the Proposed Facility

- Construction of proposed facilities and associated structures will occur within the identified footprint, including staging areas and other temporary excavation.
- The proposed project would be designed and built under the State of Washington standards for the construction of flood retention facilities and consistent with Lewis County's standards for geologically hazardous areas.
- The impacts analysis will not consider breach scenarios during construction or operation.
- The analysis of indirect impacts from operation of the flood retention facility will assume that the temporary reservoir would fill to the maximum extent for up to 32 days every time the facility is triggered.
- Hydraulic operation of the FRE facility alternative (Alternative 1) and FRO facility alternative (Alternative 2) will be identical. Therefore, indirect impacts from operation of the FRO facility or FRE facility will be the same.
- The estimated temporary reservoir inundation zones identified in the August 31, 2016 *Proposed Flood Retention Facility Pre-construction Vegetation Management Plan* (Anchor QEA 2016) were used to define the areas proposed for tree removal.
  - Prior to construction, the Applicant would remove all trees from the inundation zone that have a 5% chance of being flooded in a year (20-year flood). That zone occurs between elevations of 424 and 584 feet NAVD88 and is estimated to be approximately 485 acres.
  - Tree removal would occur during the construction phase of the project.
- Following initial tree removal, replanting of flood-tolerant native shrubs and trees would be performed in areas susceptible to increased risk of landslides and erosion.
- For the project duration, all trees greater than 6 inches diameter at breast height located below the 20-year flood elevation, including those that may have been replanted, would be periodically (approximately every 7 to 10 years) removed.
- The direct impacts assessment was based on current understanding of the means and methods for construction of the facility and design of the diversion channel (HDR 2018).

6.1.2 Streamflows in the Chehalis River and Major Tributaries

- Prediction of sediment transport and geomorphologic change in the future based on No Action Alternative and action alternative conditions can be completed using historical long-term flow data.

- Changes in impacts related to future flow conditions because of predicted climate variability will be addressed qualitatively, where applicable.

6.1.3 Bed Substrate

- Bed substrate size estimated using pebble counts at the surface and just under the surface is representative of bed substrate sizes within the Chehalis River.
- Bed substrate size in the Chehalis River can be interpolated between sampling locations which can be used for model input.
- Changes in bed substrate size can be evaluated on a reach scale based on model results using geomorphic reaches identified by WGD (2014).

6.1.4 Sediment Loads and Transport

- Sediment input from tributaries will be the same as the No Action Alternative over the lifetime of the project.
- Changes in sediment transport/sediment storage can be evaluated on a reach scale based on model results using geomorphic reaches identified by WGD (2014).
- Measurements of suspended sediment data from the late 1960s are adequate to evaluate relative impacts.
- Information and analyses conducted on landslide inputs to the River by WGD (2014, 2017) are adequate to predict sediment load because of floods for use as input to the sediment transport model.

6.1.5 Large Woody Material Input and Transport

- Within the temporary reservoir footprint, it is assumed all trees would be removed from the areas that have a 5% chance of being flooded in a year (20-year flood). Trees in the area of the temporary reservoir that has a 1% chance of being flooded in a year (100-year flood) would be left in place. In total, it is assumed that approximately 485 acres of vegetation would be removed.

6.1.6 Channel Migration

- Historical channel migration patterns were assumed to provide reasonable representations of existing/No Action Alternative conditions for the purposes of comparison with Alternative 1. This is because predictions were not used to assess future hydrology (e.g., from increased climate variability). Potential changes related to increased climate variability are addressed qualitatively.

6.1.7 Airport Levee Improvements

- Construction of the Airport Levee Improvements would be conducted outside of the flow channel (i.e., in the dry) and will be along the existing levee alignment. Therefore, no impact on geomorphology within the Chehalis River is expected because of construction of the Airport Levee Improvements.

6.2 Methods and Approach

Direct and indirect impacts on geomorphology were assessed using site-specific data, reach-scale geomorphic analysis, and hydrodynamic and sediment transport modeling results. The potential impacts were evaluated in terms of how the alternatives would affect sediment loads to the Chehalis River, bed substrate, sediment transport, LWM input and transport, and channel migration/channel width. Specific methods are described in the follow subsections.

6.2.1 Impact Types

6.2.1.1 Direct and Indirect Impacts

Direct impacts are those that would occur as the result of and at the same time and place as the activities authorized by the DA permit (40 Code of Federal Regulations [CFR] 1508.8). This would include activities related to construction activities, including the construction and use of the diversion of the Chehalis River into the diversion tunnel and the discharge of fill material into surface waters from constructing the proposed flood retention facility and levee improvements. Indirect impacts are those that would occur later in time or farther in distance but that are attributable to the authorization of a proposed project by the DA permit (40 CFR 1508.8). Indirect impacts would include effects that would occur as the result of operating the proposed project over time (e.g., changes in sediment load downstream of the planned facility).

6.2.1.2 Permanent and Temporary Impacts

Permanent impacts would impact geomorphology in the mainstem of the Chehalis River to such a degree that the identified processes would not return to preconstruction conditions during the EIS analysis period (2025 to 2080). Temporary impacts would result in short-term disturbance to geomorphology but would not prevent the re-establishment of conditions similar to those associated with the No Action Alternative in the affected areas.

6.2.2 Overview of Hydrologic, Hydrodynamic and Sediment Transport Modeling

Hydrodynamic and sediment transport modeling of existing and proposed (with the flood retention facility) conditions has been completed for the study area. This analysis was used to inform the potential impacts of proposed alternatives on geomorphology in the study area. These models have been developed by several organizations between 2012 and 2019 and have also been used in part to inform impacts evaluation of the proposed project on flooding, water quality, habitat, and other resources as part of the ongoing environmental review process. Model uncertainties are discussed in Section 6.2.4.

A high-level summary of each model is provided in the following subsections, including references to detailed modeling documentation where available.

6.2.2.1 Reservoir Routing Model

The HEC-ResSIM model (software developed by the Corps) was used by Anchor QEA to model the operation of the proposed flood retention facility and to route streamflows in the upper Chehalis River to the Doty gage (Anchor QEA 2017, 2019b). Flow rates out of the temporary reservoir predicted by the model were used as input to the 1-D HEC-RAS model used to evaluate hydraulics (Section 6.2.2.2) and sediment transport (Section 6.2.2.4) in the Chehalis River downstream of the proposed flood retention facility.

Development and results of this modeling work are provided in Anchor QEA (2019b). Results of the geomorphic evaluation summarized in this report reflect these operational plans.

The proposed flood retention facility would retain river flows temporarily, only during floods that have a flow rate exceeding 38,800 cfs at the Chehalis River as measured at the USGS gage at Grand Mound, Washington. A flow rate of 38,800 cfs is equivalent to about a 7-year recurrence interval event at that gage (15% chance of occurrence in any year). After flooding diminishes, the contents of the temporary reservoir would be discharged. In non-flood conditions, no water would be impounded, and the Chehalis River would flow through the footprint of the temporary reservoir unimpeded. Table 6.2-1 provides information about specific floods where the proposed facility would have been operating (i.e., peak streamflows of 38,800 cfs or greater), based on the flow record at Ground Mound between March 1988 and October 2015.

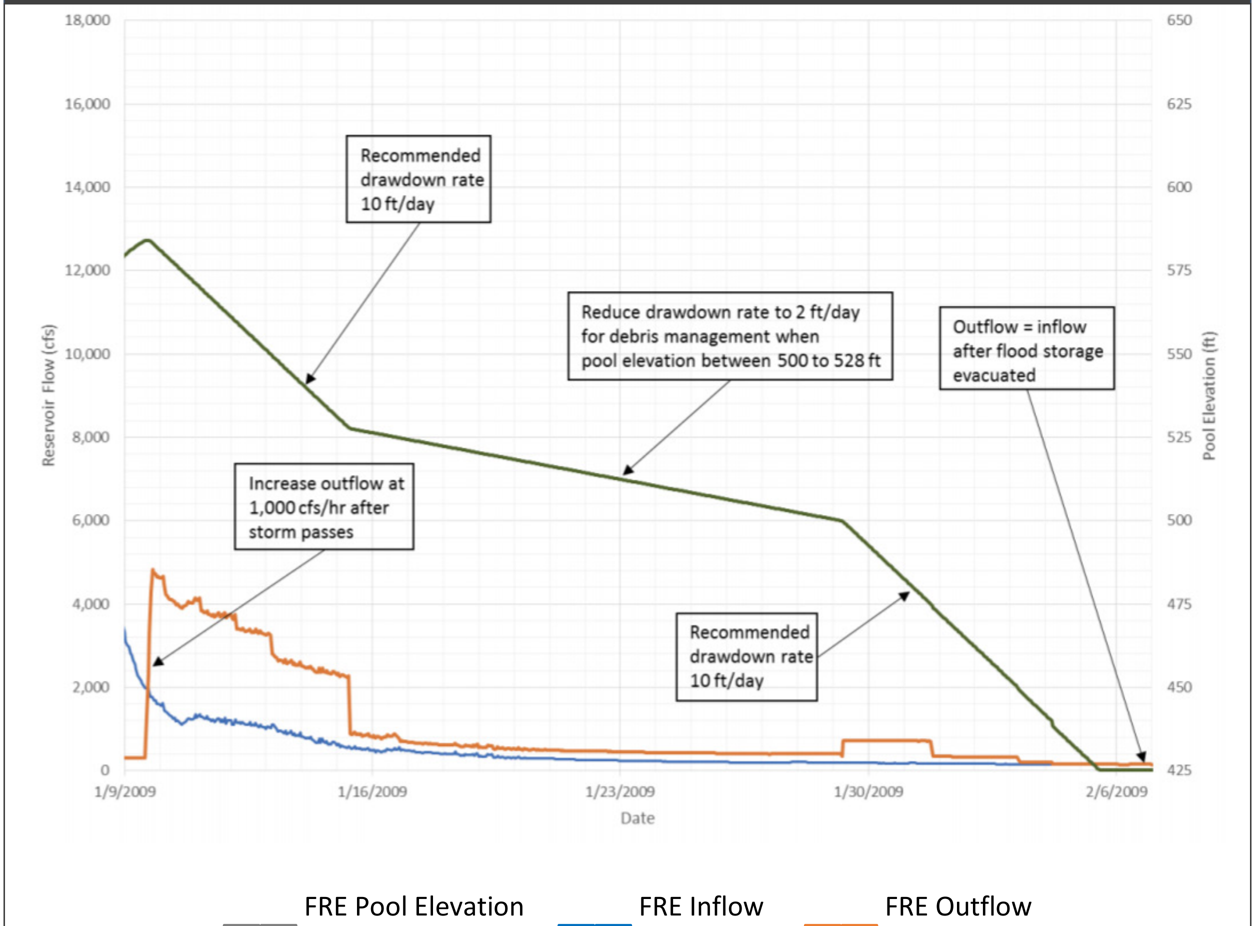
Table 6.2-1
Floods When the Daily Mean Flow at Grand Mound has Exceeded the Major Flood Peak Flow of 38,800 cfs

START MONTH AND YEAR	FLOW AT GRAND MOUND (CFS)
January 1990	53,800
February 1990	40,700
November 1990	48,000
April 1991	42,800
February 1996	74,800
December 2007	79,100
January 2009	50,700

Figure 6.2-1 shows predicted changes in flood flows because of proposed FRE facility operation based on the December 2007 flood (Anchor QEA 2017). The blue line in the figure shows inflow into the temporary reservoir, which represents the existing (No Action Alternative) flood flow hydrograph for the December 2007 flood at the proposed flood retention facility location. The orange line in the figure shows flow out of the temporary reservoir, which represents the project hydrograph at the proposed facility location. The black line in the figure shows the predicted pool elevation in the reservoir. As

shown in Figure 6.2-1, the proposed facility operation would reduce the peak flow from the flood but shows increased streamflows (compared to No Action Alternative conditions) during drawdown of the temporary reservoir. Specific information about facility operation, including drawdown procedures, is available in the *Operations Plan for Flood Retention Facilities* (Anchor QEA 2017).

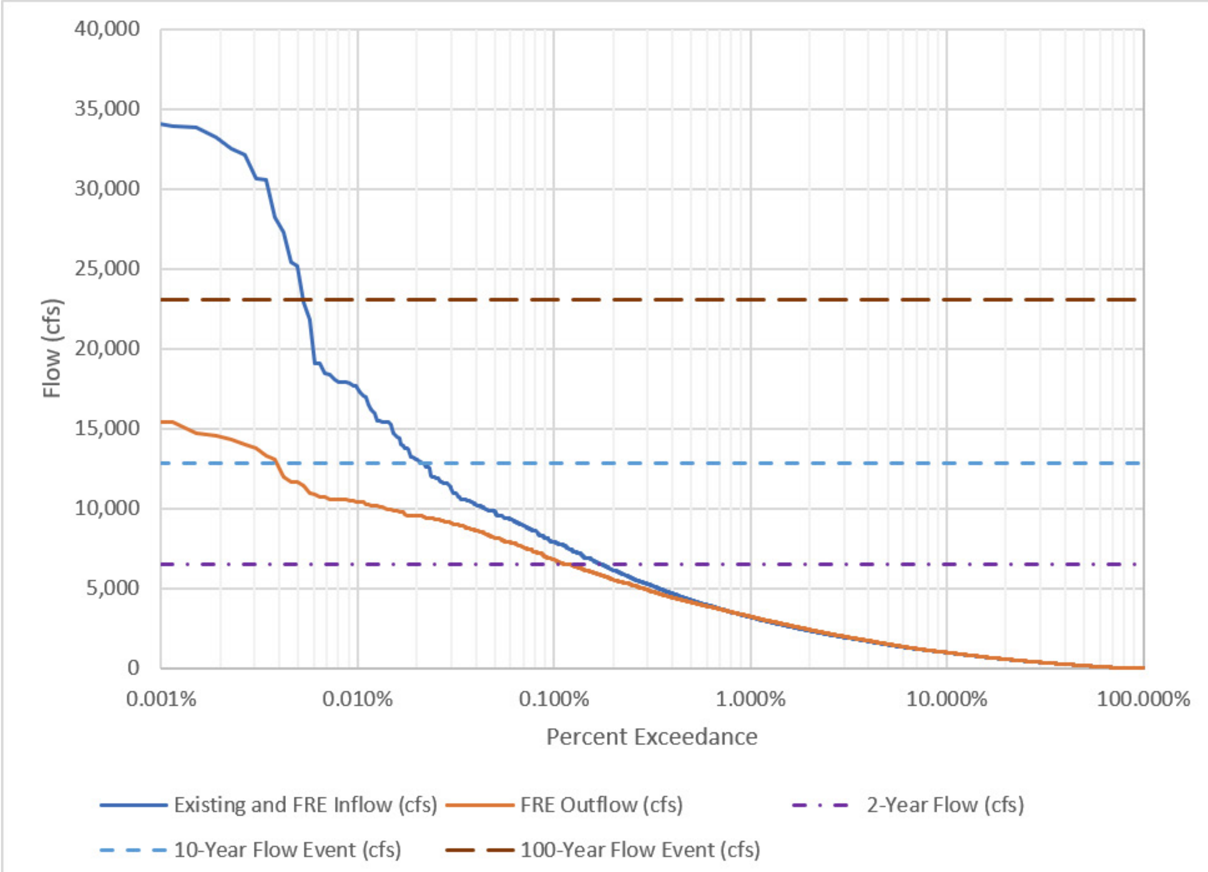
Figure 6.2-1
Predicted Flood Flows Because of Proposed Flood Retention Facility Operation, December 2007 Flood (Anchor QEA 2017)



6.2.2.2 Hydrologic Changes as a Result of the Proposed Flood Retention Facility

An analysis was done to assess hydrology changes because of operation of the proposed flood retention facility compared to existing hydrologic conditions (Anchor QEA 2019b). As a part of these efforts, a flow exceedance curve for the existing and proposed flow conditions was developed. This was done by comparing the flow exceedance relationship for the past 30 years of daily flow records at Doty (flows into the FRE facility location) to the estimated flow exceedance relationship of outflows from the FRE facility predicted by the reservoir model for the same 30-year time period. Figure 6.2-2 shows this comparison and represents the change in flow exceedance downstream of the FRE facility because of facility operation over the 30-year time period.

Figure 6.2-2
Flow Exceedance at Doty for the Past 30 Years and Simulated Conditions with the Flood Retention Facility in Place



The information in Figure 6.2-2 was used to estimate the amount of time the flow exceeds the sediment transport threshold for both existing/No Action Alternative conditions (blue line in Figure 6.2-2) and with FRE facility conditions (orange line in Figure 6.2-2). The sediment transport threshold is defined as the flow where the critical bed shear stress is exceeded and bedload transport begins, on average, in the Chehalis River. This comparison is relevant from a geomorphic perspective. If the amount of time the streamflows in the Chehalis River are at or above the sediment transport capacity is reduced because of FRE facility operation, this can reduce the amount of sediment transport that will occur in the river.

Sediment moves in the Chehalis River at streamflows well below the floods where the FRE facility would be operating. For the Chehalis River, sediment begins to move at or above streamflows equal to 6,000 cfs at Doty, which is equivalent to 4,000 cfs at the FRE facility location (WGD 2019a). Using the exceedance values for both curves shown in Figure 6.2-2 for 4,000 cfs, it was estimated that there are 82 hours over the 30-year record where streamflows of 4,000 cfs or higher were reduced below 4,000 cfs by FRE facility operation. This averages to about 3 hours per year. While this impact could be considered low, it is likely that high sediment transport, movement of LWM, and channel migration could occur during those 3 hours of peak flow conditions which are being muted because of FRE facility operation. In addition, the changes to geomorphic processes that are initiated during those 3 hours may persist for many weeks, months, or years, depending on the magnitude of the event. These data are summarized in Table 6.2-2.

Table 6.2-2
Effects of the Flood Retention Facility on Streamflows Above the Sediment Transport Threshold at the Flood Retention Facility Site

	FLOW EXCEEDANCE /PERCENT OF RECORD	HOURS	DAYS	HOURS PER YEAR
Existing conditions exceed transport capacity	0.58%	1538	64	51
With-facility conditions exceed transport capacity	0.55%	1456	60	48
Percent Difference	**5.3%**	**82**	**3.4**	**2.7**

Based on these findings, the effects of the flood retention facility (changes in sediment transport regime) would be limited to a short period of time per given year and would not likely be high. The hydrologic conditions in many annual cycles would likely not be affected. The variability within these natural cycles may overshadow or mask the effects of this change.

However, it is important to note that sediment transport is not a linear dynamic and that the magnitude of flow above the transport threshold may or may not play a role in the long-term transport capacity of the river system. It is possible that considerable sediment transport, recruitment and movement of LWM and channel migration could occur during the short period of time peak flow conditions are being muted because of FRE facility operation. It is also important to note that sediment transport, while quantifiable, is not an exact science. Many factors can affect sediment routing in a natural river system, and many of these factors are not representable in a computer model simulation. Additional discussion of uncertainties for this evaluation are provided in Section 6.2.4.

6.2.2.3 1-D Hydrodynamic Modeling

Two 1-D unsteady state hydrodynamic models (HEC-RAS) developed by WSE were combined by WGD to develop the 1-D sediment transport model used for the geomorphic evaluation of the proposed alternatives (WGD 2019a).

The first hydraulic model, developed by WSE and WGD in 2017 (WGD and Anchor QEA 2017), focuses on the study area upstream of the proposed flood retention facility, including the extent of the temporary reservoir. This model covers a reach of the river from RM 117 (HEC-RAS Station 118.17) to RM 107.4 (HEC-RAS Station 107.43), which extends from downstream of the proposed flood retention facility site to upstream of the proposed temporary reservoir. Cross-sections 107.43 through 108.53 were part of the original model developed by WSE for the Flood Authority in 2012 using survey data collected in 2011 by Minister & Glaeser Surveying (WSE 2012). WSE extended the model from RM 108.53 to RM 118.17 using new cross sections developed from three sources. Three cross sections were surveyed by WGD. Fifteen additional cross sections were surveyed by Pacific Geomatics Services during the winter of 2016 to 2017. For the remaining cross sections without surveyed bathymetry, a shallow triangular channel with maximum depth of 2 feet was cut into the wetted area of the LiDAR surface to approximate the low-flow channel. Discharge in the river was low (100 to 200 cfs at the Mahaffey Creek gage) during the LiDAR acquisition. Therefore, this channel geometry is assumed to be sufficiently accurate for sediment transport modeling because sediment movement occurs primarily during high-flow events, and any errors introduced by the low-flow channel approximation would be negligible. The model cross sections and their data sources are shown in Figure 2.3 of WGD and Anchor QEA 2017. Further discussion of calibration and validation of the upper Chehalis River HEC-RAS model is found in WGD and Anchor QEA (2017).

The second hydraulic model, developed by WSE in 2014 (WSE 2014), focuses on the study area downstream of the proposed flood retention facility (below Station 107.43). This model was used by WGD to develop a sediment transport model of the Chehalis River downstream of the facility location to approximately RM 75 (Reaches 2A through 4C). Updates to the hydraulic model in 2014 included topography and location and number of model cross sections; the updated model was calibrated as described in WSE 2014.

6.2.2.4 1-D Sediment Transport Modeling

The 1-D unsteady state hydrodynamic models (HEC-RAS) described in Section 6.2.2.2 were used to develop two separate 1-D sediment transport models to evaluate changes to bed substrate and sediment transport (i.e., sediment storage) in the Chehalis River as a result of the proposed flood retention facility. The first sediment transport model extended from the proposed facility location (approximate RM 107) upstream to RM 118. Development and results of this modeling effort are discussed in WGD and Anchor QEA 2017. The second sediment transport model was developed by extending the 2017 sediment transport model downstream to RM 75. This model extends from RM 118 downstream to RM 75. Discussion of model development and model results for the second model is provided in WGD 2019a and 2019c.

Impacts to geomorphology discussed in this report were evaluated based in part on results of the 2019 sediment transport model (WGD 2019a) that extends from RM 118 to RM 75. This will be referred to as the sediment transport model in following sections. A brief summary of development and boundary conditions for the sediment transport model is provided in the following paragraphs.

Several modifications to the HEC-RAS hydraulic models developed by WSE (used to create the 2019 sediment transport model) were made by WGD to facilitate development of the sediment transport model (Section 2.3.1 of WGD 2019a), summarized as follows:

- The existing geometry file was modified to reduce the size of the model domain by truncating the model just upstream of the confluence with the Newaukum River (approximately RM 75). The model was truncated at this location because WGD estimated changes to bed transport capacity and predicted shear stress because of proposed flood retention facility operation (based on 1-D and 2-D hydrodynamic modeling results by WSE) which showed minimal changes compared to existing conditions downstream of RM 75. Detailed information and rationale for truncating the model at RM 75 is provided in Section 4 of WGD 2019c.

- Storage areas that were not compatible with the quasi-unsteady flow model were also removed.
- The geometry file for flood retention facility conditions was modified to add a cross section representing the facility with a representative gate and spillway (i.e., lateral flow input) to allow for quasi-unsteady flow model simulations needed for the sediment transport simulations.
- Hourly streamflows were modified to represent daily peak flow conditions for use as input to the sediment transport model (called quasi-static flow conditions) for the 30-year period of record between March 1988 and March 2018.
- Streamflows out of the temporary reservoir were updated to represent the results of the reservoir simulation model conducted by Anchor QEA in 2019 (Anchor QEA 2019b). Based on results of this modeling for the 30-year flow record from 1988 to 2018 used in the sediment transport model, the temporary reservoir would have impounded water seven times during this 30-year period (Table 6-2-1). Specific information about the duration and pool elevation for the 2007 flood is shown in Figure 6.3-2 of this report. Figures showing similar information for other events are provided in Anchor QEA 2017 and 2019b and WGD 2019c.

The Ackers-White formula was used as the sediment transport formula in the sediment transport model. Model simulations were conducted and compared using various sediment transport formulas available in HEC-RAS, and the Ackers-White formula produced results most similar to the scour monitor data (WGD 2019c). Model simulations were also conducted and compared with the Ackers-White formula by varying the critical shear stress in an attempt to improve agreement between model predictions and scour monitor results. This did not appreciably improve model simulations, so the default values of the Ackers-White formula were used for subsequent sediment transport model runs.

The sediment transport model was calibrated upstream of RM 108 as discussed in WGD and Anchor QEA 2017 (Section 2.3.1 and Table 2.1 of WGD and Anchor QEA 2017). The sediment transport model was calibrated downstream of RM 108 using high water marks surveyed after two high flow events in 2016 and 2017 (8,930 cfs and 13,800 cfs at Doty, respectively). These measured elevations were compared to predicted water surface elevations from the sediment transport model at several cross sections. Discussion of the model calibration below RM 108 is discussed in Section 6 of WGD (2019c).

Boundary and input conditions for the modeling are summarized in Table 6.2-3.

Table 6.2-3
Input and Boundary Conditions for Sediment Transport Model

INPUT/BOUNDARY CONDITION	DESCRIPTION	REFERENCE
Flow conditions for mainstem Chehalis River and tributaries, existing conditions/No Action Alternative	Flow records from gages listed in Table 5.5.-1 from March 1988 to March 2018 (Section 5.2.3)	Section 2.3.2 of WGD and Anchor QEA 2017
Flow condition for Mainstem Chehalis River downstream of the proposed flood retention facility, (Alternatives 1 and 2)	Outflow from proposed facility predicted by HEC-ResSIM model (Figure 6.2-1; Section 6.2.2.1)	Anchor QEA 2017, 2019b
Initial conditions, bed substrate	Bed substrate data (Section 5.4.1) and substrate mapping (Section 5.4.2)	Section 3.2 of WGD and Anchor QEA 2017 and Appendix B of WGD 2019
Sediment inputs/loads (volume)	Total sediment discharge rating curves at approximately RM 118, RM 113, RM 112, RM 106, RM 101, RM 100, South Fork Chehalis River, Crim Creek, and Stearns Creek (Section 5.4.4)	Section 2.3.1.2 and Table 2.1 of WGD 2019
Sediment loads (gradation)	Based on suspended sediment proportions measured by the USGS at Doty and bed substrate data closest to the incoming sediment load location (Section 5.3).	Section 2.3.2 of WGD and Anchor QEA 2017
Transport equations	Ackers-White formula, default parameters used	Section 2.3.2 of WGD and Anchor QEA 2017

6.2.3 Technical Approach

This section describes the specific information, including modeling results and qualitative information, used to make the determination of impacts described in Sections 6.3 and 6.4 of this discipline report.

6.2.3.1 Changes to Sediment Load to Chehalis River in Reservoir Extent from Shallow-Rapid Landslides

WGD evaluated potential increases to sediment load to the Chehalis River within the footprint of the temporary reservoir because of increased landslides (WGD 2019). This analysis concluded that areas within the footprint of the temporary reservoir may be at increased risk of landslides compared to existing conditions (No Action Alternative) because of inundation when the flood retention facility is impounding water. Figure 3.5 in WGD (2019) shows potentially mobile soil volume by percent of time it would be inundated. Risk of increased landslides would be increased by removal of trees within the footprint of the temporary reservoir as part of pre-construction activities.

6.2.3.2 Changes to Sediment Load to the Chehalis River Downstream of Facility from Sediment Retention in the Temporary Reservoir

Changes to sediment load because of FRE facility operation from RM 118 to RM 77 were evaluated qualitatively using results of transport modeling conducted by WGD (2019). The model is discussed in Section 6.2.2.4. Indirect impacts upstream of the planned facility were also informed by empirical information and evaluation regarding landslide sediment input into this area (Reach 1).

The 1-D sediment transport model was used to estimate changes in sediment storage between existing conditions/No Action Alternative and action alternative conditions from RM 118 to RM 77 for three time periods: 1) at the end of the 30-year model simulation; 2) just prior to the 2007 flood, which was a record-breaking flood in the Chehalis Basin; and 3) just after the 2007 flood. These time periods were selected to understand how the impacts observed over the 30-year model simulation were impacted by the 2007 flood. Figure 6.2-3 shows the changes in sediment storage at the end of the 30-year model simulation at each model cross-section (which represents the net change in both the bed and floodplain sediment volumes), where positive changes infer increased storage and negative changes infer decreased storage because of the flood retention facility. Figures 6.2-4 and 6.2-5 show the same information just prior to and just after the 2007 flood, respectively. Model results are variable from cross-section to cross-section. Therefore, a trend line has been added to both figures that represents a moving average over 15 model cross-sections to add clarity to the discussion of results.

The model results for all time periods show increased sediment storage upstream of the flood retention facility and decreased sediment storage downstream of the flood retention facility (on average) because of impoundment events. However, comparison of results of all three time periods show that the sediment deposition observed at the end of the 30-year simulation is very similar to what was observed just after the 2007 flood, which implies that longer-term deposition was most likely dominated by deposition that occurred during the 2007 flood.

The results just prior to the 2007 flood show less storage upstream of the FRE facility, which is to be expected. At RM 91, which is the confluence with the South Fork Chehalis River with the mainstem Chehalis River, model results after the 30-year model simulation (Figure 6.2-3) show increased sediment storage upstream of the confluence with corresponding decrease in storage downstream of the confluence. This implies that sediment accretion upstream of the South Fork during floods is not being moved downstream for with-FRE facility conditions, likely because of muting of peak streamflows by FRE facility operation. Model results at this same location prior to the 2007 flood do not show this pattern at the confluence with the South Fork Chehalis, but this pattern is clearly visible just after the 2007 flood. This implies that accretion upstream of the South Fork Chehalis predicted by the model is a result of the large sediment load introduced into the model by the 2007 flood and may not represent a typical response of the Chehalis River to more typical major flood conditions. Little to no change in sediment storage is predicted by the model downstream of approximately RM 85 for all three time periods. However, an overall sediment deficit is still predicted by the model in this area (Figure 6.2-4).

In addition, the model ended at RM 75 and it is possible that boundary conditions at RM 75 influenced model results some distance upstream of this boundary. Sediment storage impacts downstream of RM 75 were inferred from model results from RM 85 to RM 75.

Figure 6.2-3
Difference in Sediment Storage Along the Mainstem Chehalis River at the end of the 1988 to 2018 HEC-RAS Model Simulation (30 years), With FRE (Alternative 1) Minus No FRE Facility (No Action Alternative) Results, RM 118 to RM 75 (WGD 2019)

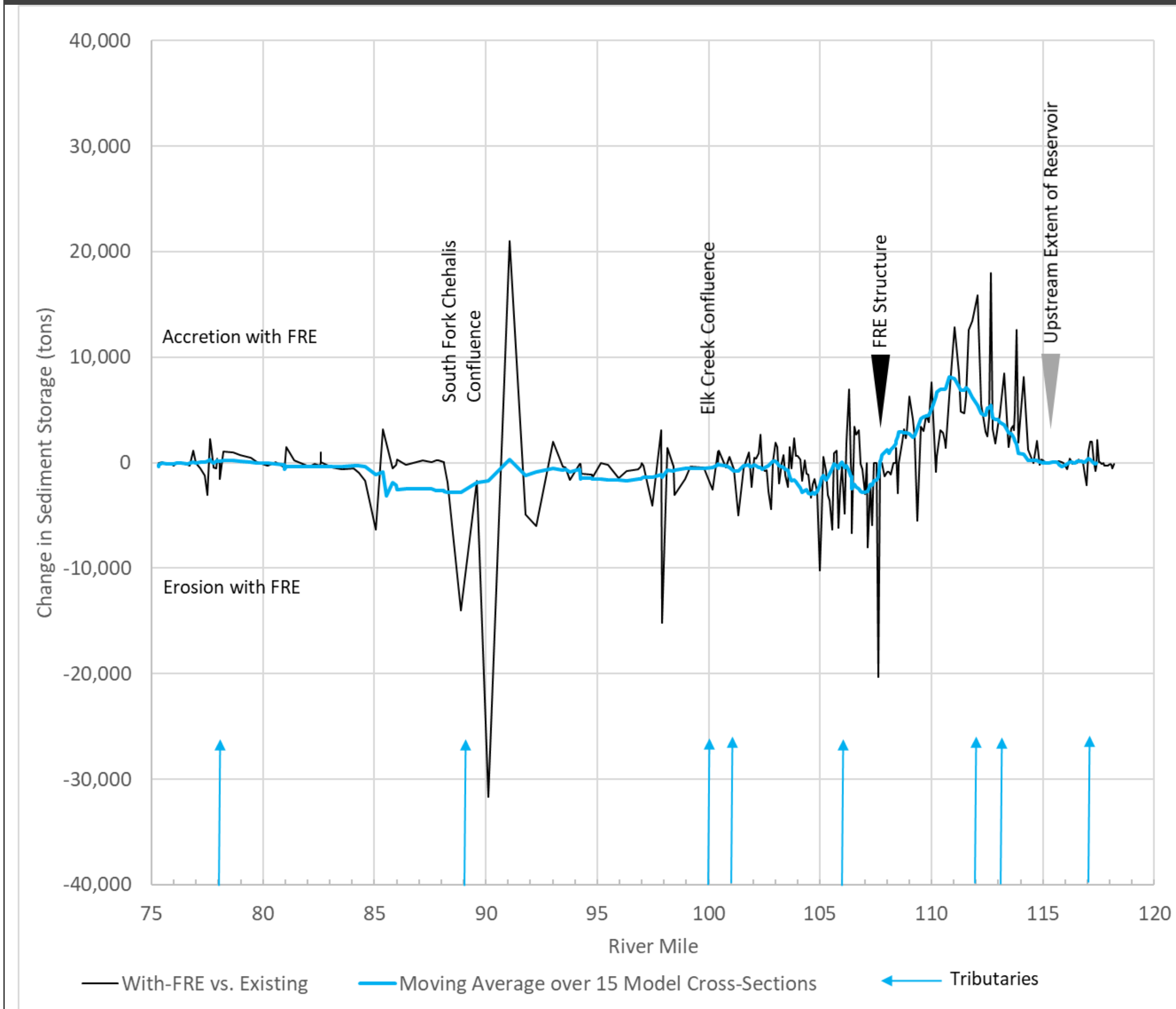


Figure 6.2-4
Difference in Sediment Storage Along the Mainstem Chehalis River just prior to the 2007 Flood in HEC-RAS Model Simulation, With FRE (Alternative 1) Minus No FRE Facility (No Action Alternative) Results, RM 118 to RM 75 (WGD 2019)

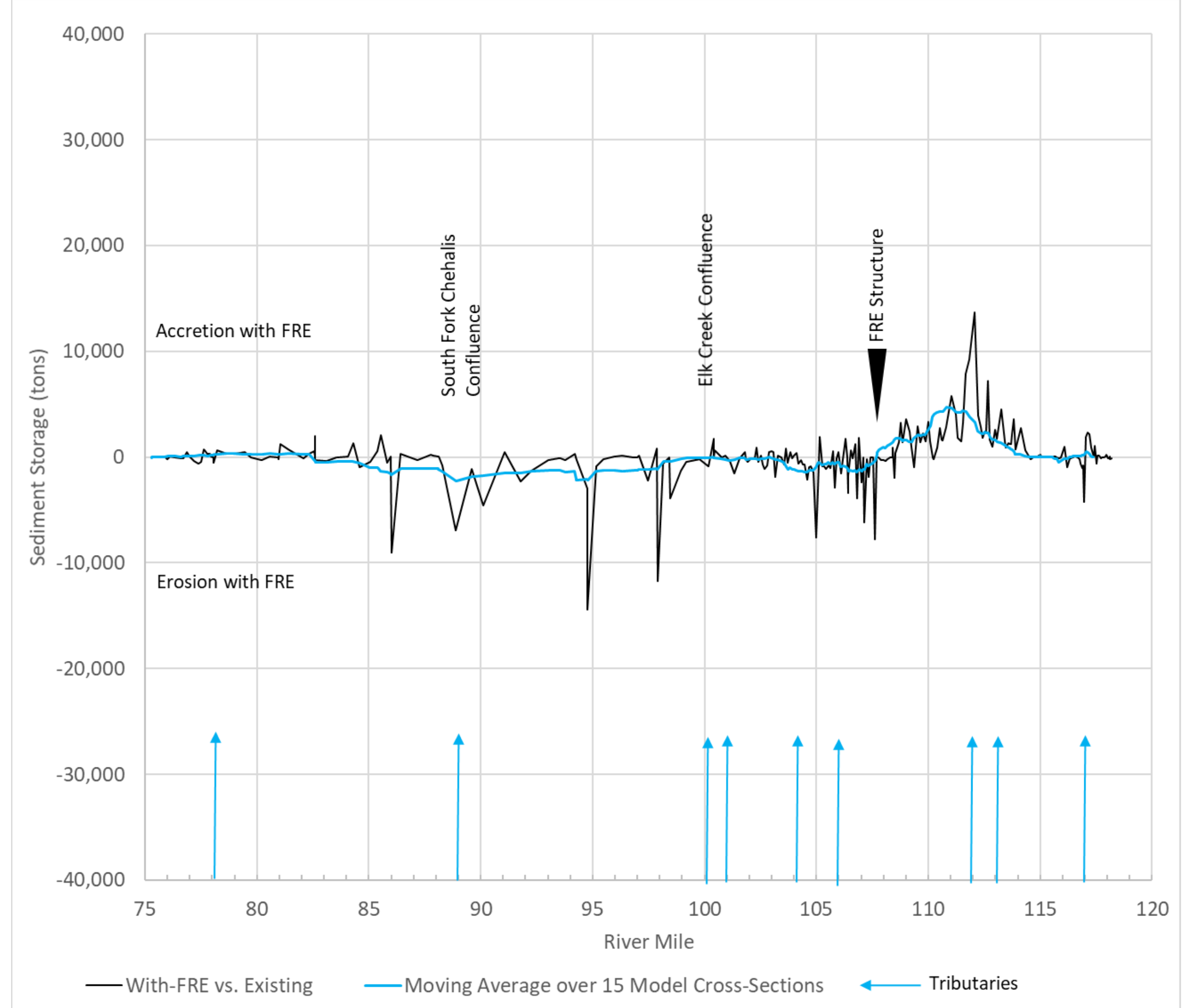


Figure 6.2-5
Difference in Sediment Storage Along the Mainstem Chehalis River just after the 2007 Flood in HEC RAS Model Simulation, With FRE (Alternative 1) Minus No FRE Facility (No Action Alternative) Results, RM 118 to RM 75 (WGD 2019)

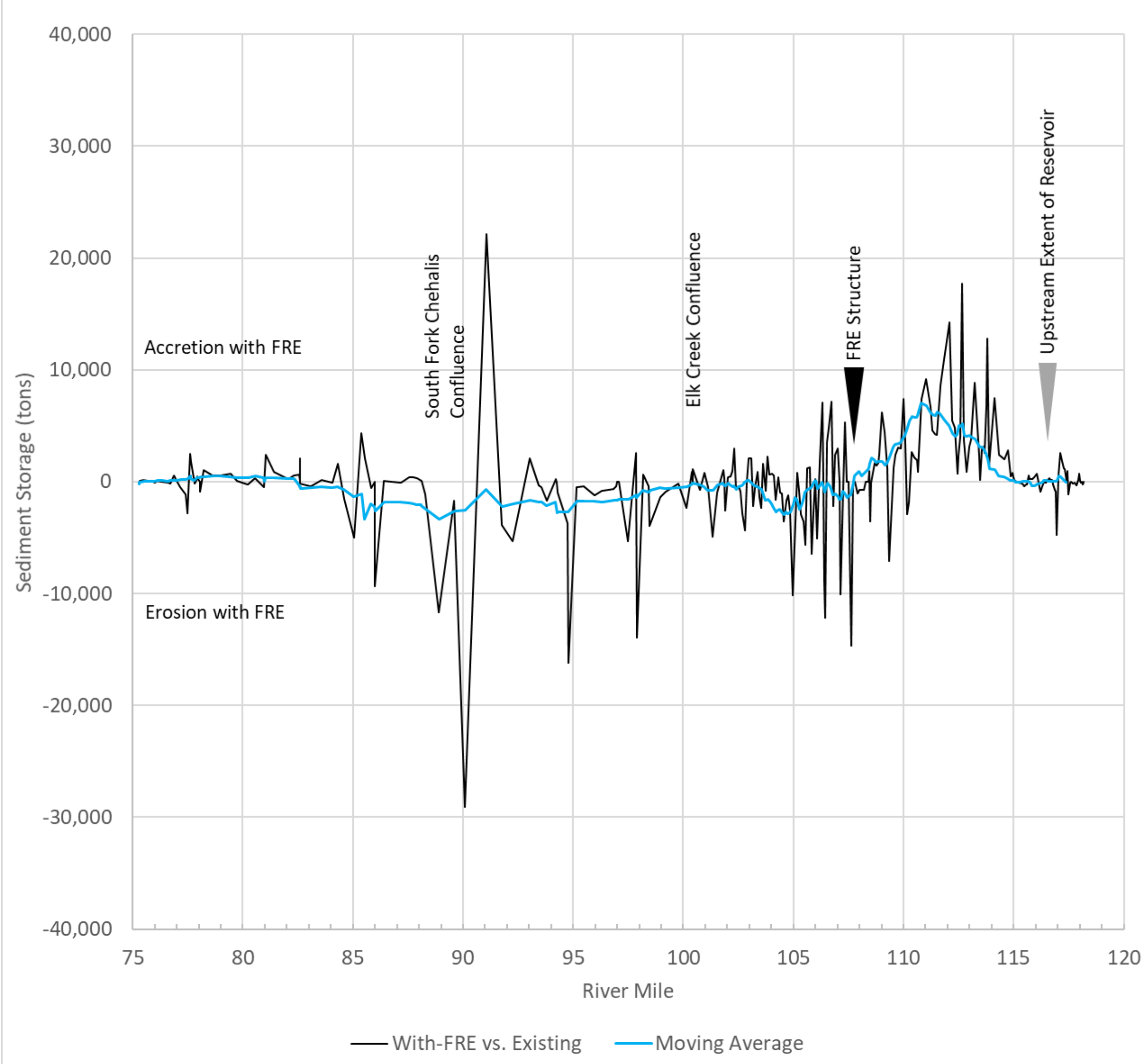
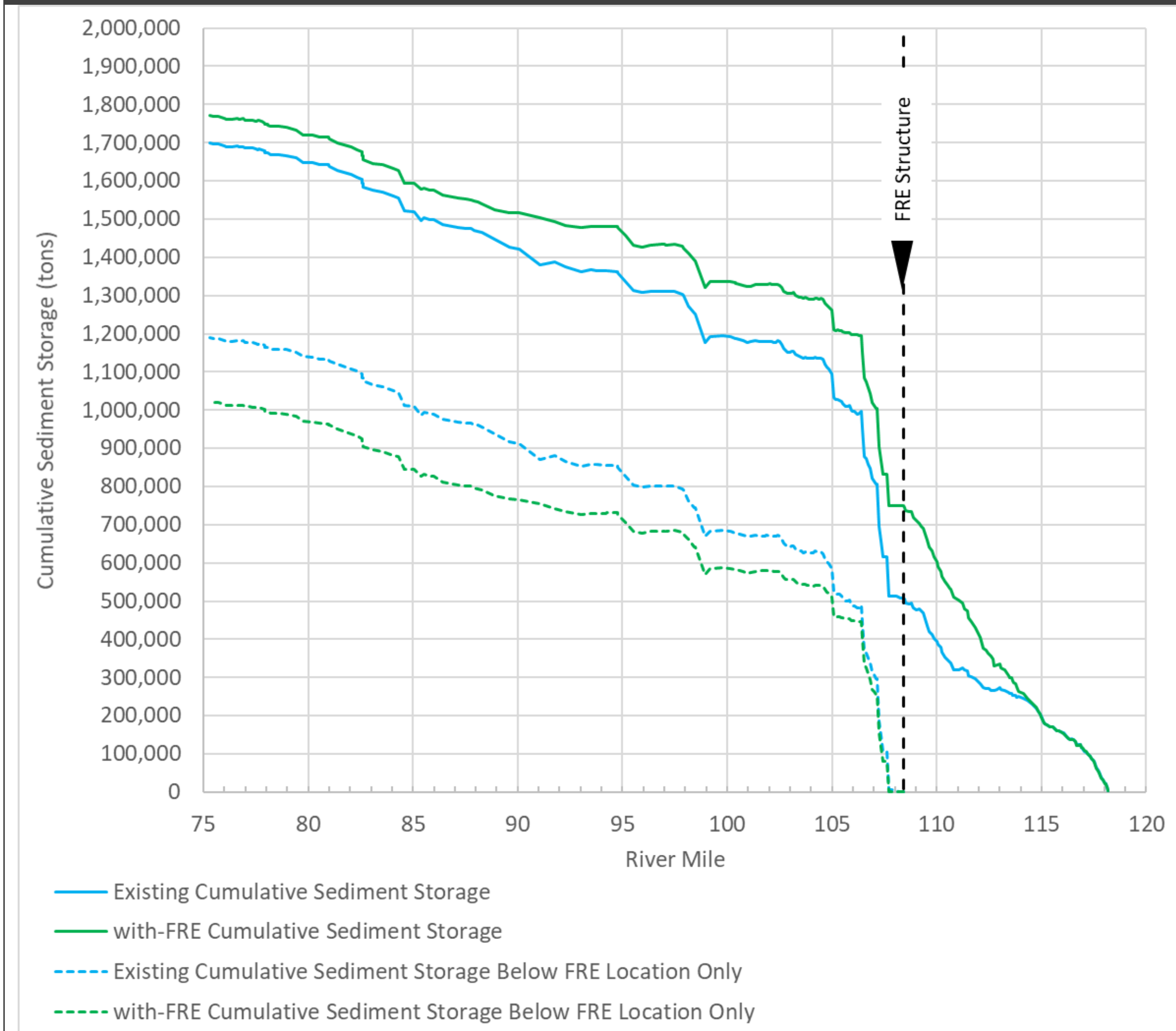


Figure 6.2-6 shows the model-predicted longitudinal cumulative sediment storage for the existing conditions/No Action Alternative and with-FRE facility conditions at the end of the 30-year model simulation. Two types of model results are shown in the figure. The solid lines represent cumulative storage starting from the upstream extend of the model at RM 118. Because there would be sediment retention upstream of the FRE facility in the with-FRE facility conditions model, this influences the cumulative sediment storage plot downstream to RM 75. If the sediment retention upstream of the facility is removed from the cumulative sediment storage results (the dashed lines in Figure 6.2-6), the model results show a sediment deficit downstream of the facility location. These model results show

that the increased sediment storage upstream of the FRE facility removes the retained sediment from the system and reduces sediment supply downstream of the facility to approximately RM 85. From that location, cumulative sediment storage remains relatively unchanged down to RM 77.

Figure 6.2-6
Cumulative Sediment Storage Along the Mainstem Chehalis at End of 1988 to 2018 HEC-RAS Model Simulation (30 years), for No FRE Facility (No Action Alternative) and With FRE Facility (Alternative 1) Conditions, RM 118 to RM 75 (WGD 2019)



6.2.3.3 Changes to Sediment Load to the Chehalis River Downstream of Facility Because of Surface Erosion after the Temporary Reservoir Drains

WGD (2019) conducted an evaluation of potential changes to fine sediment input to the Chehalis River downstream of the FRE facility because of surface erosion during higher streamflows after the temporary reservoir drains. WGD used the WEPP model to estimate rainfall erosion potential for sand-sized particles deposited during a flood with the magnitude of the 2009 flood (normal flood) and the 2007 flood (extreme flood). An upper-bound erosion scenario (steep 60% slope) and lower-bound estimate (5% slope) were calculated.

If an average-annual rainstorm or a 10-year rainstorm occurred immediately after the temporary reservoir drained and before any vegetation regrew, erosion of sand-sized particles is estimated to range from approximately 100 to 6,000 tons (Table 3.2 in WGD 2019). Therefore, there may be an increase in the supply of fine sediment to the Chehalis River at the location of the FRE facility during rainfall events following an impoundment event. These sediments could be transported downstream of the FRE facility, increasing turbidity of the water during those times. It is difficult to predict the magnitude and timing of these releases. As time passes following inundation of the temporary reservoir, annual vegetation (e.g., grasses and other ground cover) would grow and cover the deposits, which may reduce erosion potential of sands deposited in the temporary reservoir.

6.2.3.4 Changes to Sediment Transport

Changes to sediment transport because of the proposed FRE facility were evaluated through analysis of changes to bed storage (discussed in Section 6.2.3.1) as well as changes to bed substrate size and bed elevation in the Chehalis River to the extent possible with existing information and sediment transport modeling results.

Changes to bed substrate size and bed elevation because of construction activities were evaluated qualitatively. Changes to bed substrate size and bed elevation because of FRE facility operation are discussed in following subsections.

6.2.3.4.1 Bed Substrate

Changes in bed substrate grain size (substrate) often occur within and downstream of water storage reservoirs if sediment is retained within the reservoir. The flood retention facility would retain water and sediment during flood flows but would allow sediment to be transported downstream during non-impounding events. Changes to bed substrate because of operation of the proposed FRE facility from RM 118 to RM 75 were evaluated quantitatively using sediment transport modeling conducted by WGD (2019). Changes to bed substrate downstream of RM 75 were evaluated qualitatively using sediment transport model results at the lower extent of the model (RM 75 to RM 82) and the evaluation of hydrologic effects of the flood retention facility operation on sediment transport discussed in Section 6.2.2.2.

The 1-D sediment transport model was used to develop a comparison of bed substrate size (median diameter of sub-armor material just under surface) from RM 118 to RM 75 for existing (No Action Alternative) and with-FRE facility conditions. These results were plotted for the same three time periods as sediment storage: 1) the end of the 30-year model simulation time (Figure 6.2-7A and B); 2) just prior to the 2007 flood (Figure 6.2-8A and B); and 3) just after the 2007 flood. Also, similar to the sediment storage plots, a trendline representing a moving average over 15 model cross-sections was added to both figures.

While the predicted change in bed substrate is highly variable between cross-sections, some general information about potential changes to bed substrate because of flood retention facility operation have been developed from these model results. Bed substrate size is predicted to change at some of the modeled cross-sections at the end of the 30-year simulation time frame (Figures 6.2-7A and B). In general, model results at the end of the 30-year simulation (Figures 6.2-7A and B) indicate slightly coarser substrate just upstream of the FRE facility, fining of sediment at the upstream end of the fluctuation zone, and coarser substrate upstream of the extent of the reservoir from the flood retention facility structure. Similar patterns are seen in the model results just prior to the 2007 flood (Figures 2.6-8A and B), except that the location of the fining or coarsening along the Chehalis River is different likely because of the size of the impoundment during the historic 2007 flood included in the 30-year model results. For both time periods, only small changes to substrate size over the 30-year model simulation are predicted by the model downstream of the facility, except at some tributary locations, including Elk Creek and the South Fork Chehalis. At the confluence of Elk Creek, for example, the model predicts fining of sediment upstream of the confluence and coarsening of bed substrate downstream of the confluence because of FRE facility operation. This is in line with deposition upstream of tributaries shown in Figures 6.2-3 through 6.2-5. There are some notable large changes to sediment substrate predicted at some single cross-sections in the model (i.e., near RM 98) which may be attributed to model uncertainties. It is also worth noting that magnitude of some of the changes shown in Figures 6.2-7A and B and Figures 6.2-8A and B may be within the accuracy of the model.

Figure 6.2-7A
Difference in Median (D50) Grain Size of Subsurface Layer at End of 1988 to 2019 HEC-RAS Model Simulation – for With FRE minus No Action Alternative Conditions (RM 118 to RM 77)

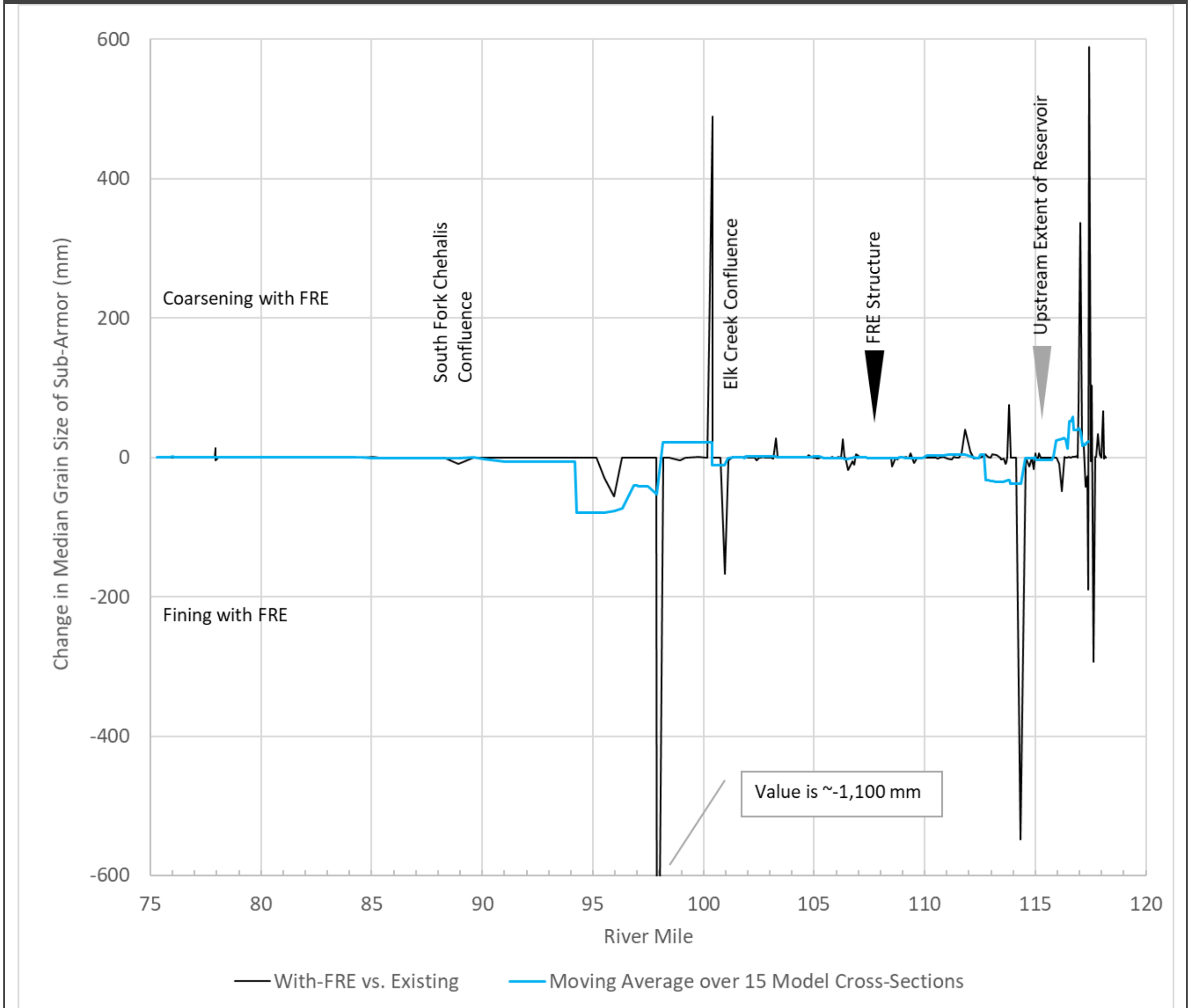


Figure 6.2-7B
Difference in Median (D50) Grain Size of Subsurface Layer at End of 1988 to 2019 HEC-RAS Model Simulation – for With FRE minus No Action Alternative Conditions (RM 118 to RM 77), Scaled to Show Changes in Grain Size Between -80 and 80 mm

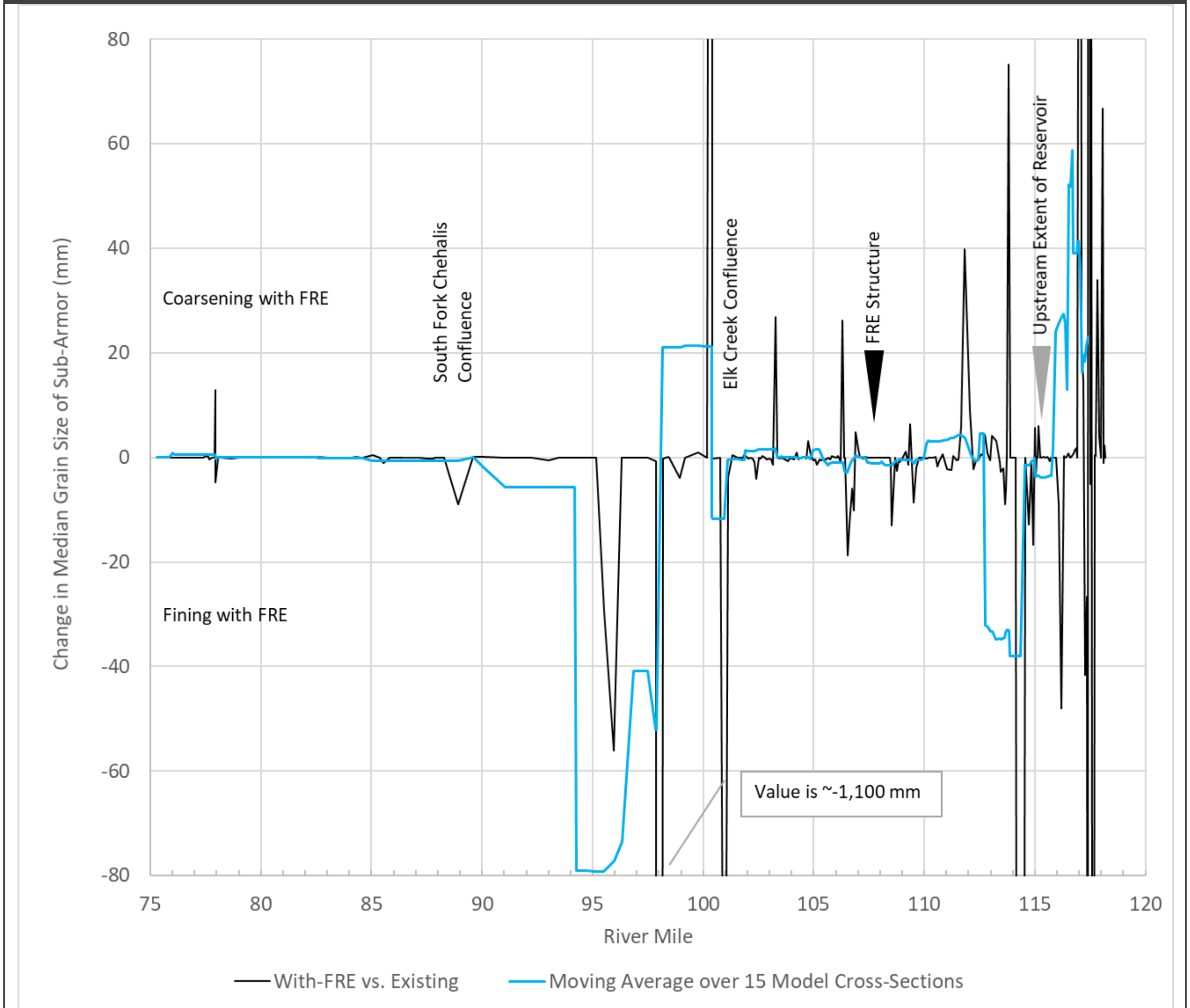


Figure 6.2-8A
Difference in Median (D50) Grain Size of Subsurface Layer Just Prior to 2007 Flood HEC-RAS Model Simulation – for With FRE minus No Action Alternative Conditions (RM 118 to RM 77)

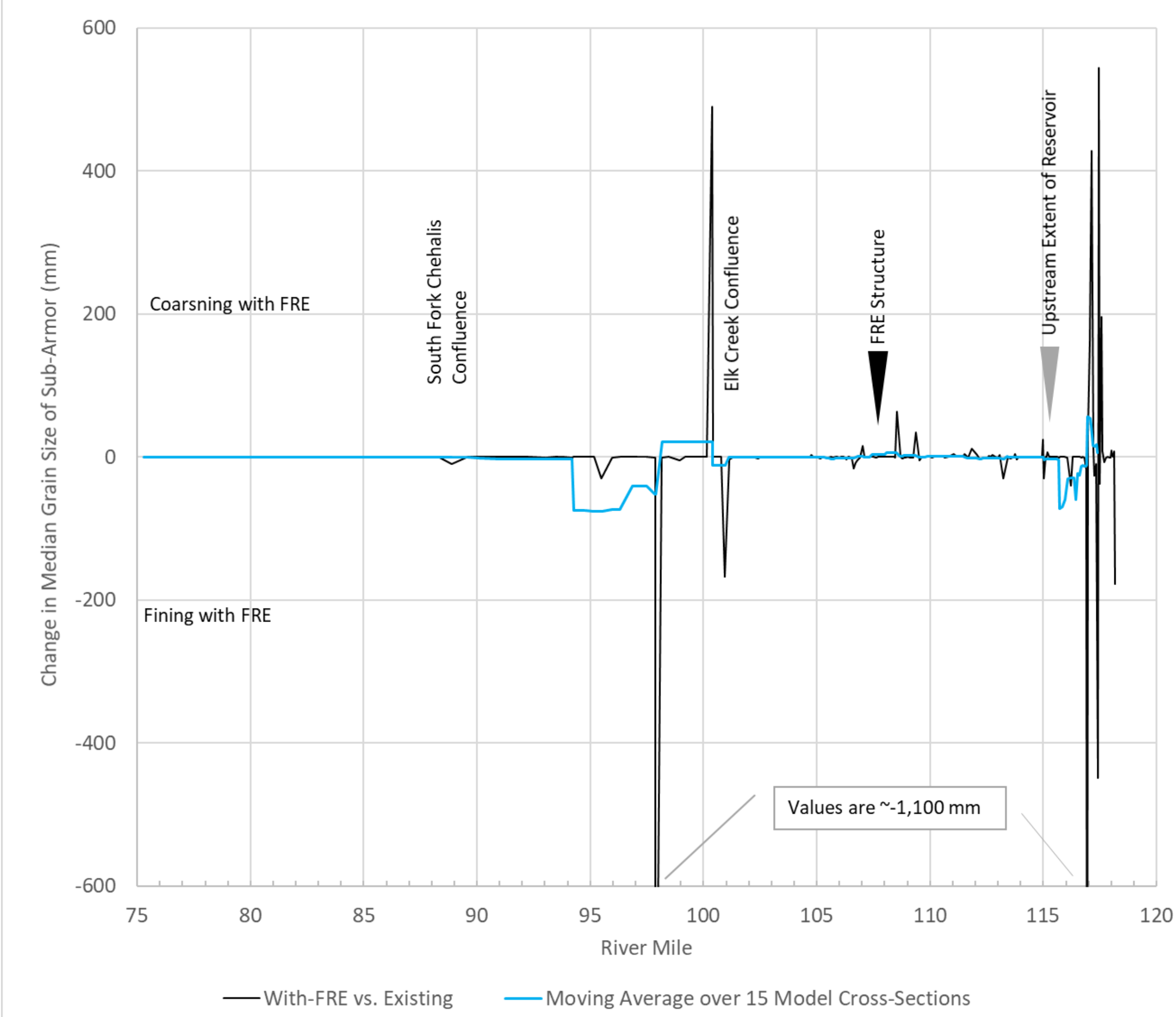
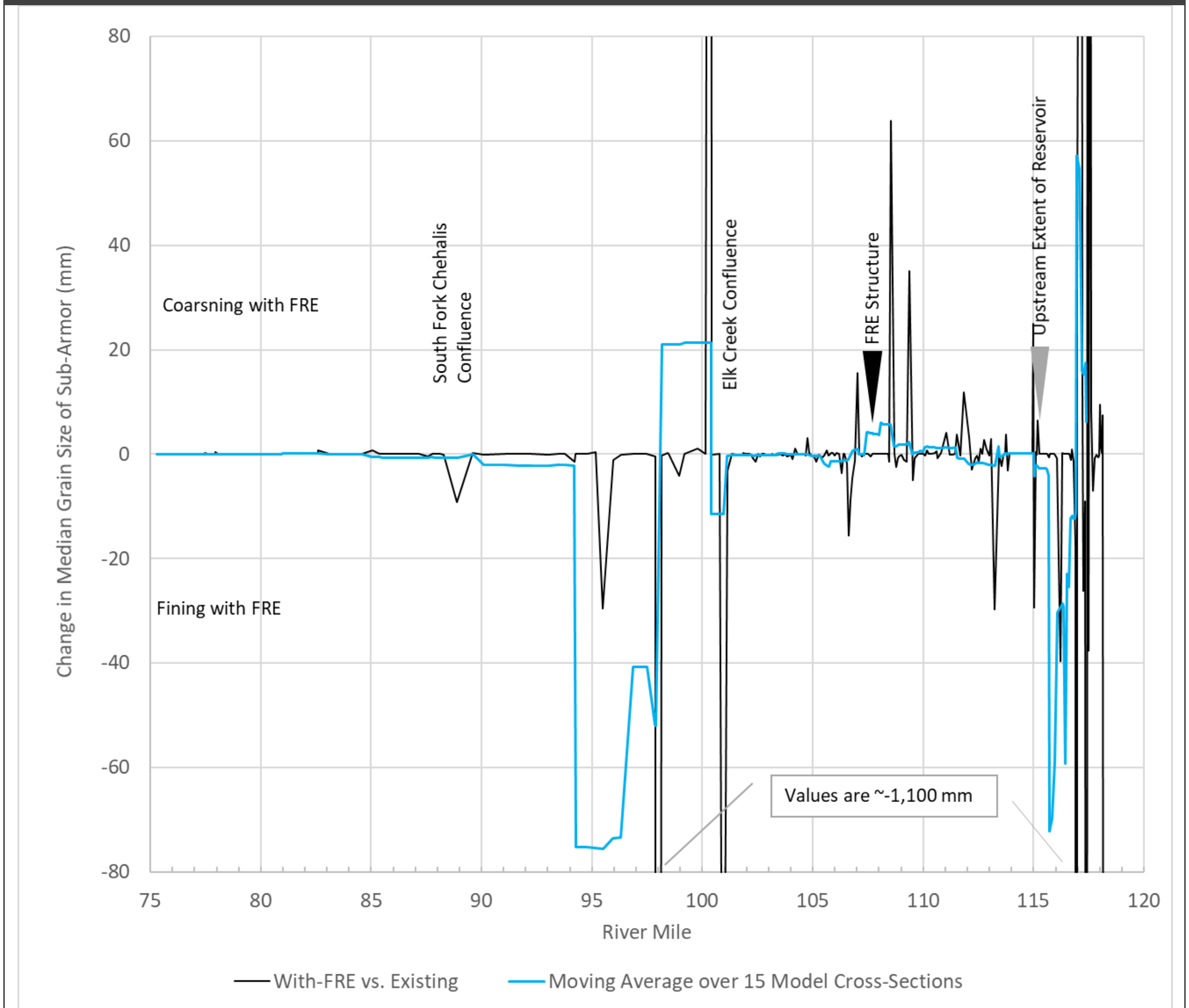


Figure 6.2-8B
Difference in Median (D50) Grain Size of Subsurface Layer Just Prior to 2007 Flood HEC-RAS Model Simulation – for With FRE minus No Action Alternative Conditions (RM 118 to RM 77), Scaled to Show Changes in Grain Size Between -80 and 80 mm



6.2.3.4.2 *Thalweg Elevation*

Removal of sediment from the system downstream of the flood retention facility could increase sediment erosion in the channel and lower the thalweg elevation. Erosion in mainstem channels could result in channel incision and lowering of the thalweg (the deepest part of a river cross section). If incision and channel lowering is extensive, nearby tributary stream junctions could be affected, and headcutting or incision of tributary stream channels could occur.

In order to evaluate the possibility of changes to the thalweg along the mainstem Chehalis River as a result of flood retention facility operation, the difference in thalweg elevation between the No Action Alternative and with-flood retention facility model runs was plotted for the same two time periods as sediment storage and bed substrate changes; after the 30-year model simulation (Figure 6.2-9) and just prior to the 2007 flood (Figure 6.2-10). A trend line representing a moving average of model results over 15 model cross-sections is shown on each of these figures.

As with model results for bed substrate size, there is variability in impacts from cross-section to cross-section, but some conclusions can be inferred from model results of thalweg elevation changes. Model results from both time periods show a general lowering of the thalweg elevation upstream of the FRE facility location within the temporary reservoir extent. Model results for both time periods also show that sediment is being deposited in the Chehalis River in this location based on review of predicted sediment storage in this area (Figures 6.2-4 and 6.2-5). This implies that sediment is most likely being deposited higher up on the banks of the river during impoundment events. Upstream of the extent of the temporary reservoir, the thalweg elevation shows increases for both time periods considered. This suggests that sediment is depositing in the channel upstream of the temporary reservoir during impoundment events when river flows would be slowed down where they meet the pool.

Model results show high variability of predicted changes downstream of the facility to RM 102 for both time periods. Downstream of RM 102, model results for both time periods little change to thalweg elevations, on average, except in the vicinity of some tributaries. Prior to the 2007 flood (Figure 6.2-9), the thalweg elevation is generally lower downstream of RM 102. This is in line with other model results for the same time period that show sediment retention upstream of the facility and sediment deficit downstream of the facility. Model results downstream of RM 102 at the end of the 30-year simulation, which include the record-breaking 2007 flood, show slight increases in thalweg elevation downstream of RM 102. This difference is likely because of the influence of such a large flood on model behavior and results. In addition, changes to thalweg elevation downstream of RM 102 are less than 0.25 foot and are likely within the accuracy of the model.

Model results at some tributary junctions downstream of the facility generally show an increase in mainstem thalweg elevation of about 1 foot at the end of the 30-year model simulation (Figure 6.2-9). Prior to the 2007 flood (Figure 6.2-10), model results show lowering of the thalweg elevation at certain tributaries, such as RM 85 (Bunker Creek). There is a possibility that changes in thalweg depth of this magnitude at these tributary mouths could result in incision at the mouths of these streams because of major floods and FRE facility operation. Differences in model results between the two time periods are likely because of the influence of such a large flood on model behavior and results. Model results prior to the 2007 flood are likely more representative of future behavior because the 2007 flood was such a rare occurrence.

The thalweg elevations of the Chehalis River within the footprint of the temporary reservoir would vary in response to operation of the FRE facility. It is likely that tributary junctions in the temporary reservoir footprint would also experience periods of deposition and erosion.

Figure 6.2-9
Differences in Thalweg (deepest part of channel) Elevation along the Mainstem Chehalis River at the end of the 1988 to 2018 HEC-RAS Model Simulation, for With FRE Facility Minus No Action Alternative Conditions (RM 118 to RM 75)

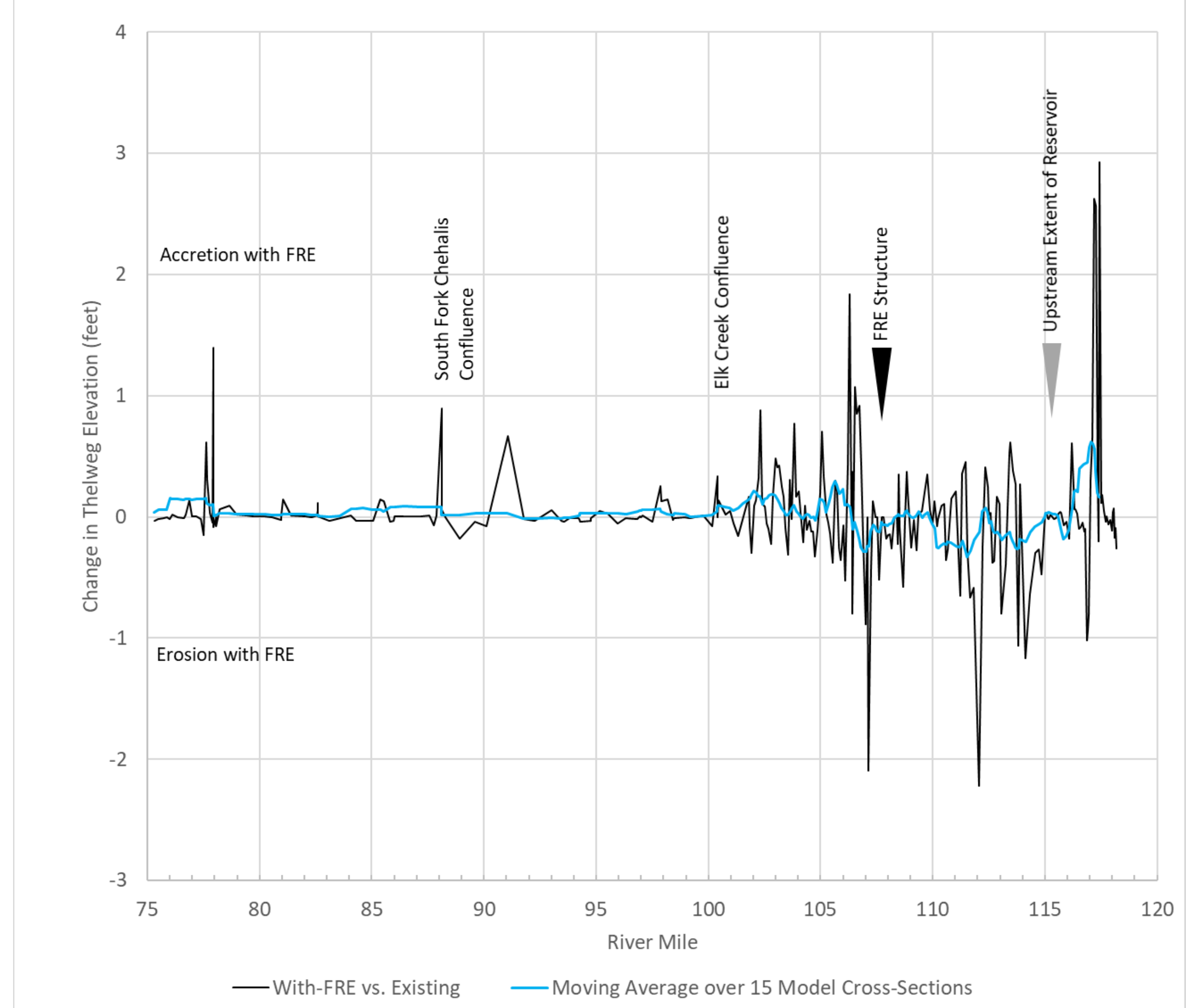
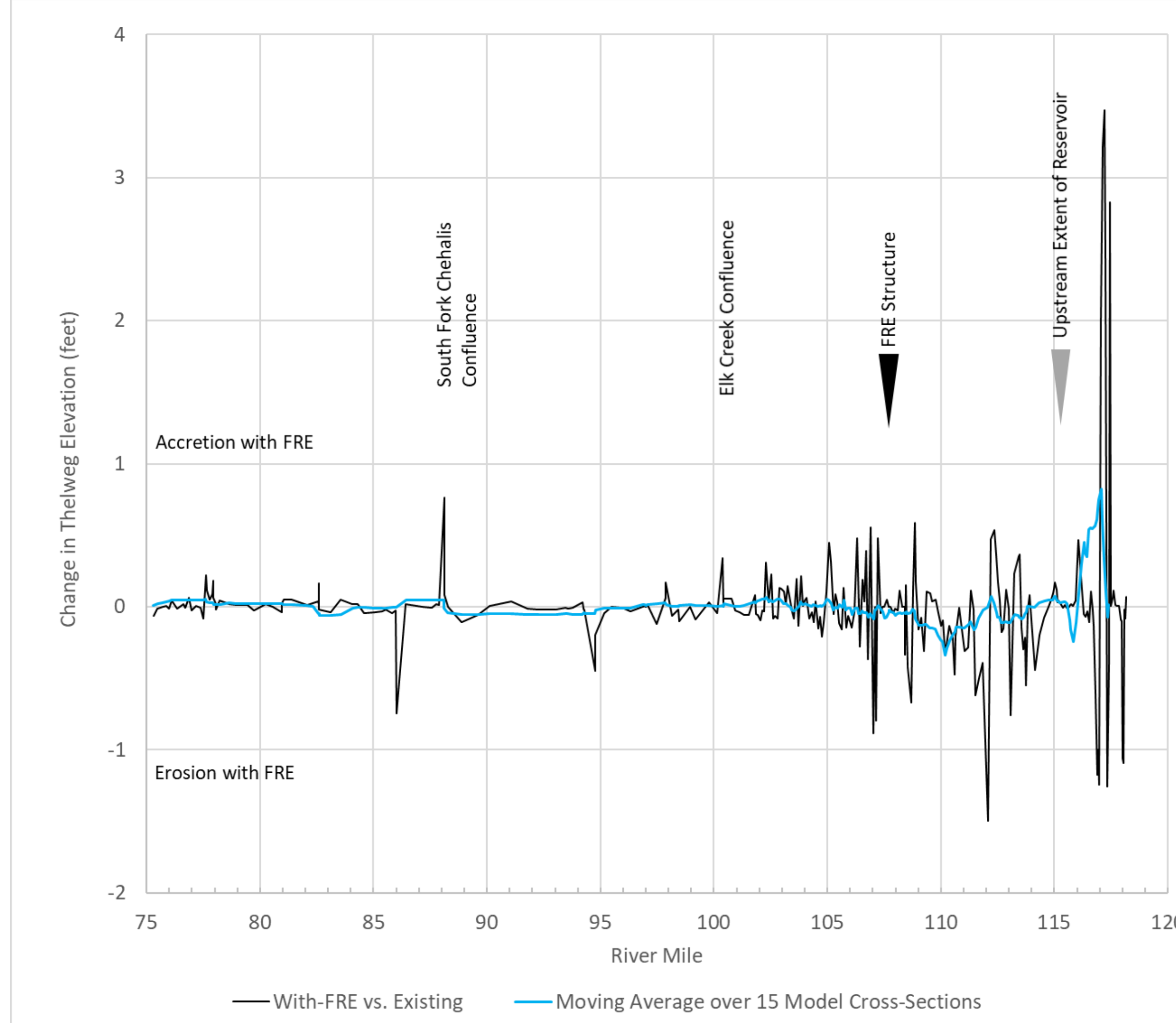


Figure 6.2-10
Differences in Thalweg (deepest part of channel) Elevation along the Mainstem Chehalis River Just Prior to the 2007 Flood HEC-RAS Model Simulation, for With FRE Facility Minus No Action Alternative Conditions (RM 118 to RM 75)



6.2.3.5 Changes to Large Woody Material Recruitment and Transport

Direct and indirect impacts of construction of the proposed facility on LWM recruitment and transport for the study area were qualitatively assessed based on current understanding of the means and methods that have potential to impact LWM, including tree removal within the flood retention facility footprint and footprint of the temporary reservoir, and use of the diversion channel.

Changes to LWM recruitment and transport because of the proposed flood retention facility were evaluated qualitatively based on the following information:

- Watershed scale qualitative analysis conducted by WGD (2012), as summarized in Section 5.6.1. This includes an evaluation of LWM loading because of landslides (WGD and Anchor QEA 2017)
- Data inventory of LWM in the study area, as described in Section 5.6.2
- Operational information of the proposed facility (i.e., what size LWM can be passed through the opening in the facility at lower (no impoundment) streamflows (Anchor QEA 2017)

6.2.3.6 Changes to Channel Migration

Changes to channel migration during construction were assessed qualitatively.

Indirect impacts to channel migration because of the operation of the proposed flood retention facility were evaluated qualitatively for the entire study area based on the analysis of changes to LWM recruitment and transport in the Chehalis River because of FRE facility operation and historic channel migration evaluation conducted by WGD (2012, 2014), summarized in Sections 5.7.1 and 5.7.2, and expected changes to river flows because of flood retention facility operation.

6.2.4 Uncertainties

The modeled results and empirical evaluations presented in this discipline report are not intended to represent exact predictions of changes to geomorphology processes, but rather to provide the ability to make relative comparisons between the No Action Alternative and Alternative 1. This is so that decision-makers may be informed about potential impacts attributable to the proposed action on geomorphology. Uncertainties are inevitable in any numerical modeling or empirical evaluation of sediment transport or geomorphology. In addition to general uncertainties associated with these types of evaluations, specific considerations associated with the analyses used in this discipline report are summarized in the list below. The results from these evaluations may overpredict or underpredict changes to geomorphic processes depending on the uncertainty or consideration. However, these factors were considered when interpreting the model results and are adequate for the purposes of evaluating relative comparisons between the No Action and proposed action alternatives:

1. Geomorphology and geomorphic processes (e.g., sediment transport, bed substrate changes) take place over a period of many decades. Changes evaluated over a shorter time period (i.e., 30 years) provide information about how the system may respond to these circumstances but do not necessarily represent the specific long-term changes anticipated to occur to geomorphic conditions and processes.
2. The sediment transport model was developed from a 1-D HEC-RAS hydraulic model that was calibrated based on water surface elevation data. To develop the sediment transport model, the hydraulic model was modified to exclude connected overbank storage areas and was not re-calibrated because of a lack of data and model limitations.
3. The sediment transport model was run as a quasi-static simulation to allow for efficient use of the model for a long term (30-year) simulation. The model simulation was used to inform how

the proposed facility could affect processes over a 50-year analysis period and may not reflect specific conditions at the end of the analysis period.

4. An assumed stage-flow rating curve was used to represent conditions at the downstream boundary of the sediment transport model. This location is subject to stochastic influences of tributary backwater and sediment inputs and actual sediment transport rates could be significantly higher or lower for a given river discharge than indicated by the modeling.
5. The sediment loading data (i.e., rating curve) used as upstream inputs to the model (WGD 2019) were selected to represent a reasonable value within the broader range of variability that has been observed in the system. Based on Figure 5.4-2, the range of variability in sediment inputs into the model could be an order of magnitude from what was input. This variability does not take into account additional variability and uncertainty in the suspended sediment transport and land wasting data used to develop the rating curve.
6. Increase in sediment loads to the Chehalis River because of changes in landslide frequency because of operation of the FRE facility were not explicitly included in the sediment loading data used in the model.
7. Impacts to geomorphology downstream of RM 75 were evaluated using hydraulic 1D HEC-RAS model results at discrete cross-sections in this area. Impact assessments were based on information and calculations only at these discrete cross-sections, which were considered representative of the Chehalis River between RM 33 and RM 75. This analysis does not include tributary sediment inputs or potential changes to these inputs.

6.3 No Action Alternative

The No Action Alternative represents future conditions in the Chehalis River without the proposed action. This would include some small-scale projects and programs and changes anticipated to occur from 2030 to 2080.

Under the No Action Alternative, certain projects and programs would provide local relief from flooding (e.g., elevating structures). These projects and programs are not expected to have a high impact on hydrodynamics (e.g., flow velocities and water levels), bed substrate size/type, sediment loads and transport, LWM input and transport, or channel migration in the study area. This is because the scale of each project is small relative to the overall Chehalis River mainstem and floodplain. Sediment input from erosion of upland slopes may slightly decrease in some areas because of continued implementation of the WDNR Forest Practices Habitat Conservation Plan. Over time, this plan would lead to larger trees in forested areas, which would help to reduce erosion. The movement of sediment in the river and distribution of sediment sizes in the river would remain similar to existing conditions.

For these reasons, the No Action Alternative is not expected to have substantial impacts on geomorphology over the EIS analysis period. Those processes are expected to continue in a similar manner to those described in Section 5.

The way the river system currently functions may change over time based on the quantity and rate of precipitation and runoff, for example, as a result of climate variability. Climate variability projections (Section 5.10) predict increases in winter precipitation and extreme precipitation events driven by atmospheric river events. If these increases were to occur to the extent that the major and catastrophic floods become larger in the future, increased impacts from floods (e.g., damage to property and closure of roads) would be expected.

As discussed in Section 5.10, there could be hotter summer air conditions and decreased summer precipitation. If this happens, there could be reduced streamflows in the summer months. This summer reduction in streamflows should not substantially impact geomorphic processes in the Chehalis River, but would be impactful to water quality and aquatic species and habitat.

If warmer temperatures occurred in the winter, wintertime precipitation may shift from snow to rain in the higher elevation portions of the Chehalis Basin. This shift would increase winter streamflow and contribute to higher downstream flows and increased potential for channel and bank erosion, recruitment and transport of LWM, and channel migration in unconfined reaches. Additionally, winter precipitation and the frequency and intensity of atmospheric river events have also been predicted to increase. This would contribute to an increased risk of winter and spring flooding in the Chehalis Basin. Increased instream flow during the winter and spring could lead to more frequent occurrence of major and catastrophic floods that would cause both short-term negative and longer-term beneficial impacts.

6.4 Alternative 1 (Proposed Project): Flood Retention Expandable (FRE) Facility and Airport Levee Improvements

These sections address the potential for changes in sediment load to the Chehalis River, bed substrate, sediment transport, LWM recruitment and transport, and channel migration width over time because of Alternative 1 compared to the No Action Alternative. Because the Airport Levee Improvements would not impact surface waters or floodplains, this section focuses on the impacts because of construction and operation of the proposed FRE facility.

6.4.1 Sediment Load to Chehalis River

6.4.1.1 Construction

Low to medium temporary direct impacts on sediment load to the Chehalis River are expected because of construction of the FRE facility. This would occur as the result of increased risk of erosion and sedimentation from disturbing soils during construction and as the result of removing vegetation from the footprint of the temporary reservoir. In-water work, grading, stockpiling, and pre-construction vegetation management have the potential to increase erosion and cause a temporary increase in sediment load to the Chehalis River. With the implementation of best management practices during construction, the potential increase would be low. However, as noted in the *Chehalis River Basin Flood*

Damage Reduction Project NEPA EIS Discipline Report for Geology (Corps 2020b), if a larger storm were to occur during construction, there could be medium potential impacts from increased erosion and contribution to sediment load to the Chehalis River.

In addition, streamflows through the construction diversion tunnel could have low temporary indirect impacts on sediment load to the Chehalis River. During construction of the FRE facility, a diversion tunnel would be used to carry water in the Chehalis River at the location of the planned facility. This diversion tunnel would not directly mimic the natural flow of the river but under most flow conditions, velocities through the tunnel would be similar to those under the No Action Alterative. However, if streamflows in the Chehalis River are greater than the design streamflows (2.7-year flood) identified for the diversion channel (HDR 2018), it is possible that the construction site could be flooded. Depending on the extent of the flood, there could be more substantial impacts on sediment load from a storm.

6.4.1.2 Operation

6.4.1.2.1 Upstream of the Proposed FRE Facility

Alternative 1 would have low to medium increases in sediment loads to the Chehalis River upstream of the FRE facility within the footprint of the temporary reservoir. An increase in the frequency and magnitude of shallow-rapid landslides is anticipated to result in increased sediment load to the reservoir impoundment area (Reach 1) (WGD and Anchor QEA 2014). This is because the anticipated vegetation removal would result in an increased risk of erosion in this area (Corps 2020b) over time. In addition, when the FRE facility impounds water, the soil in the temporary reservoir would become saturated. As the temporary reservoir drains, these saturated soils would no longer be kept in place by the reservoir water and could be susceptible to shallow-rapid landslides (WGD and Anchor QEA 2014). Approximately 10% of the temporary reservoir area was estimated to contain soil on slopes steep enough that they may become unstable as a result of the temporary reservoir periodically impounding water (Figure 3.4 of WGD and Anchor QEA 2014). This may increase the likelihood of these types of landslides and therefore sediment input to the Chehalis River, resulting in a low to medium impact.

After tree removal in the temporary inundation zone, the tree roots would decay over several years, which would reduce the strength they provide to the soil. The replanting program would include some trees whose roots would increase slope cohesion over time. However, landslides would occur along steeper slopes of the harvested portion of the inundation zone for several years. The material would move downslope and, depending on location, would be delivered to local streams and the Chehalis River. The impact would be low to medium depending on location (i.e., proximity to streams).

In addition, the sediment transport model predicts that some portion of sediment input upstream of the footprint of the temporary reservoir would be retained within the temporary reservoir area following impoundment events. This would also increase the sediment load within the temporary reservoir area.

6.4.1.2.2 Downstream of the Proposed FRE Facility

Potential impacts downstream of the proposed FRE facility would be low to medium as the result of decreases in sediment load over time because of retention of sediment upstream of the facility during impoundment events that is not transported downstream during other lower flow events. These decreases were predicted by the sediment transport model (Figures 6.2-3 through 6.2-5).

As noted in Section 6.2.3, the sediment transport model (Figures 6.2-3 through 6.2-5) predicts a net accumulation within the temporary reservoir footprint over time. This includes a total of approximately 240,000 tons of additional sediment storage (much of it fine sediment) over the simulation period under with FRE facility conditions (compared to existing conditions). Downstream of the FRE facility, the model predicts a net reduction of approximately 70,000 tons in sediment storage over time. It is expected that impacts of this sediment deficit would diminish with distance downstream of the facility and will change from medium just downstream of the facility to low some distance downstream of the facility. However, there is not enough information to determine precisely where downstream impacts become low.

6.4.2 Sediment Transport

6.4.2.1 Construction

During construction of the FRE facility, a diversion tunnel would be used to convey water in the Chehalis River at the location of the planned facility. This diversion tunnel would not directly mimic the natural flow of the river, and would have high flow velocities through the tunnel during frequent high-flow events. Therefore, streamflows through the construction diversion tunnel could have low temporary indirect impacts to sediment transport (i.e., erosion and deposition of sediment in the Chehalis River) and bed substrate size. These impacts would be because of changes from natural flow conditions because of the tunnel. Streamflows may backwater at the upstream end of the tunnel, which could result in sediment deposition upstream of the tunnel and fining of bed substrate in that location. Streamflows out of the tunnel may erode the bed and sediment may coarsen just downstream of the tunnel where the river transitions from a hard bottom (the tunnel) to the natural river bed. Sediments eroded from just downstream of the tunnel may deposit some distance downstream of the tunnel. However, if streamflows in the Chehalis River exceed design streamflows identified for the diversion channel, the diversion channel may cause higher levels of backwatering upstream of the tunnel and high exit velocities at the downstream side of the tunnel. For extremely high flow events, the river may flow around the diversion channel. In either case, increased channel erosion and coarsening of bed substrate would be expected to be medium to high impacts.

6.4.2.2 Operation

Operation of the FRE facility would result in low to high impacts on sediment transport (i.e., changes to erosion/deposition and bed substrate size) within the study area, depending on the reach.

Impacts to sediment transport upstream of the facility within the footprint of the temporary reservoir (lower part of Reach 1) and downstream of the facility to RM 75 (Reaches 2A to 4C) were evaluated using results of the sediment transport model discussed in Sections 6.2.3.2 and 6.2.3.4, which provide changes to sediment storage and bed substrate size/elevation at the end of the 30-year model simulation and just prior to the 2007 flood. Impacts to sediment transport downstream of RM 75 were evaluated using an empirical and semi-qualitative analysis of changes to river flows because of FRE facility operation, as discussed in Section 6.2.2.2.

Table 6.4-1 summarizes impacts to sediment transport by reach and identifies specific information in Section 6.2 used to make the impacts determination. Uncertainties in the evaluations that influence these impact determinations are provided in Section 6.2.4.

Table 6.4-1
Potential Impacts of Alternative 1 on Sediment Transport by Reach

GEO-MORPHIC REACH	LOCATION	IMPACTS	EXPLANATION OF IMPACT
1	Headwaters to RM 107.8, which is the location of the FRE facility	High impact within the extent of the temporary reservoir and just upstream of the reservoir where the pool meets the free flow of the Chehalis River. No impacts upstream of the footprint of the temporary reservoir.	Sediment transport model results at the end of the 30-year simulation time period and just prior to the 2007 flood show increased sediment deposition within the footprint of the temporary reservoir because of impoundment events (Figures 6.2-3 through 6.2-5). Bed substrate is predicted to become finer within the impounded area and coarser upstream of the impoundment. Thalweg elevation is predicted to decrease in the impounded area, which suggests that sediment is depositing higher up on the banks during impoundment events (Figures 6.2-7A to 6.2-10). The thalweg elevation is predicted to increase where the pool meets the free flow of the Chehalis River. These impacts are large compared to most other areas in the Chehalis River even though they are highly variable between cross-sections.
2A	RM 107.5 to 105.9	Medium impacts	Sediment transport model results at the end of the 30-year simulation time shows a sediment deficit in these reaches (compared to no action conditions) because of sediment retention upstream of the
2B	RM 105.9 to RM 104.4	Medium impacts	
2C	RM 104.4 to 93.5	Medium impacts	
3	RM 93.5 to 88	Medium impacts	
4A	RM 88 to 85.9	Medium impacts	
4B	RM 85.9 to 81.6	Medium impacts	

GEO-MORPHIC REACH	LOCATION	IMPACTS	EXPLANATION OF IMPACT
			facility (Figures 6.2-3 through 6.2-5). This is also shown in model results prior to the 2007 flood, but to a lesser magnitude. Changes to bed substrate size and thalweg elevation predicted by the model at the end of the 30-year simulation and prior to the 2007 flood (Figures 6.2-7A to 6.2-10) are highly variable from cross-section to cross-section to about RM 102. From RM 102 to RM 81.6, changes are low on average. Results prior to the 2007 flood show lowering of thalweg and little to no change in bed substrate size (on average) downstream of RM 102. Changes to thalweg elevation and bed substrate are more notable near tributaries for both time periods modeled.
4C	RM 81.6 to 75.3	Low to medium impacts	Sediment transport model results at the end of the 30-year simulation time and prior to the 2007 flood show little to no change in sediment storage within this reach (Figures 6.2-3 through 6.2-5). Changes to bed substrate size and thalweg elevation predicted for the same two time periods (Figures 6.2-7A through 6.2-10) are small compared other areas of the Chehalis River. It is uncertain where precisely downstream of the facility impacts change from medium to low.
5	RM 75.5 to RM 61.7	Low to medium impacts	Sediment transport model does not include these reaches. Impacts to sediment transport are expected to decrease in-line with distance downstream of the facility. This is because the effects of the FRE facility on water and sediment inputs and transport is expected to be muted by tributary inputs and
6	RM 61.7 to RM 33	Low to medium impacts	

GEO-MORPHIC REACH	LOCATION	IMPACTS	EXPLANATION OF IMPACT
			grade controls at RM 62 and RM 65 (WGD 2012, 2014). It is uncertain where precisely downstream of the FRE facility impacts change from medium to low.

6.4.3 Large Woody Material

6.4.3.1 Construction

Construction of the FRE facility, including temporary access and staging areas and operation of the construction diversion channel, could have medium to high direct impacts to recruitment of LWM and low indirect impacts to transport of LWM during construction. As part of the proposed construction activities, existing trees within the footprint of the temporary reservoir would be removed. Removing trees reduces the potential supply and transport of LWM into the Chehalis River over time.

During construction of the FRE facility, a diversion tunnel would be used to divert the Chehalis River around the proposed FRE facility construction site. Under typical flow conditions, this diversion tunnel would be similar to the natural flow of the river. Under higher flow conditions, water would backwater upstream of the tunnel location, which could reduce the transport of LWM from upstream to downstream of the facility, resulting in low impacts.

6.4.3.2 Operation

High impacts to recruitment and transport of LWM are expected within the footprint of the temporary reservoir (Reach 1). Under operation of the FRE facility, LWM and small woody material moving through the system upstream of the FRE facility during operation of the temporary reservoir would initially be trapped within the temporary reservoir. As the temporary reservoir is drawn down following an impoundment event, some LWM may settle above the low-flow channel and some would be transported downstream. As a result, there would likely be little input of LWM into the channel within the impoundment area. In addition, LWM that settles above the low-flow channel during a drawdown event would be manually removed from the temporary reservoir, which would further reduce the availability of LWM to the Chehalis River.

High impacts to recruitment and transport of LWM are also expected downstream of the facility to approximately RM 75 (Reach 2A to Reach 4C). Medium to high impacts to LWM are expected downstream of RM 75 (Reach 5 to Reach 6). Because much of the LWM input into the impoundment area would likely be retained in that area, there would be less LWM available for transport downstream during higher flow events (based on observations, LWM begins to move at streamflows of approximately 10,000 cfs at the Doty gage). LWM movement in the system would be interrupted and transport of LWM downstream of the FRE facility would be reduced because the largest peak streamflows would be reduced. Because LWM levels are low under current conditions, this could result in a further reduction in channel complexity and aquatic habitat diversity where LWM is currently present in the Chehalis River. The potential impacts on aquatic species and habitat are addressed in the *Chehalis River Basin Flood Damage Reduction Project NEPA EIS Discipline Report for Aquatic Species and Habitats* (Corps 2020c).

6.4.4 Channel Migration

6.4.4.1 Construction

No impacts on channel migration (downstream of the FRE facility) are expected. Although there would be some alterations to the channel that would occur to construct the diversion tunnel and reroute the river around the construction site, the changes would not alter the channel width above or below the FRE facility structure. This is because the riverbanks in the flood retention facility project area are incised and largely made of bedrock. Once construction was complete, the river would be allowed to flow freely unless major or greater floods were to happen.

6.4.4.2 Operation

Based on the analysis of migration rates between 1945 and 2013, it appears that channel migration takes place during even small peak floods in unconfined areas in response to flow against banks on the outside of meanders. Major channel avulsion takes place in response to channel-spanning log jams that usually occur during extreme floods when large amounts of LWM can be supplied to the river from upstream landslides. With FRE facility operation, it is likely that bank erosion and channel migration will continue to occur because there will be negligible reductions in the 1- to 2-year peak flow magnitudes (Section 6.2.2.2). Over time, encroachment of riparian vegetation as a result of the reduction of large flood peaks may stabilize some banks and reduce the channel migration. This effect will be most pronounced in upstream areas. Major channel avulsions may occur less frequency under with-FRE facility conditions because LWM moving during large floods will be trapped, at least temporarily, in the temporary reservoir. Therefore, channel-spanning log jams would be less likely to form (WGD and Anchor QEA 2014).

Upstream of the planned facility, the channel is primarily bedrock within the footprint of the temporary reservoir. Flooding of the temporary reservoir would occur during floods greater than about a 7-year return period flood (instead of seasonally). Channel migration upstream of the FRE facility (i.e., movement of the main channel location) is not expected to be impacted by FRE facility operation. However, the wetted channel is expected to become wider and shallower over time because of FRE facility operation.

FRE facility operation would have low to medium impacts to channel migration. Upstream of the facility within the footprint of the temporary reservoir (Reach 1), no impact is expected to channel migration because the channel is currently a confined bedrock reach. Medium widening and increases in complexity of the channel are expected in this area because sediment deposition within this area is predicted from FRE facility operation. Therefore, while anticipated sediment deposition in the reach would likely result in a more complex channel alignment, large-scale channel migration because of bank erosion is not expected upstream of the FRE facility.

Downstream of the FRE facility, reaches that are currently characterized by active bank erosion and channel migration (Reaches 2B, 3, 4B, 6, and the lower part of Reach 5) would have low to medium impacts to channel migration because of FRE facility operation. Operation of the FRE facility would reduce peak streamflows during large flow events, but streamflows that have the capacity to move sediment and erode banks would still occur. The reduction in LWM and in sediment load to the Chehalis River downstream of the facility (because of FRE facility operation) are expected to result in a medium reduction in channel complexity and migration in Reaches 2B and 3 and low impacts to reaches farther downstream (Reaches 4B and 6, and the lower part of Reach 5). This is because the effects of flow changes from FRE facility operation this far downstream would diminish.

6.4.5 Climate Variability

As a result of increased winter precipitation and the increased frequency of extreme precipitation events expected in the system (Section 5.10), the frequency and magnitude of floods that would trigger temporary impoundment at the FRE facility could also increase. To the extent that the major and catastrophic floods become larger in the future, the FRE facility may impound water more often, and may impound more water per event (up to the spillway level), upstream of the FRE facility. This could result in additional hours each year (on average) when the FRE facility would limit streamflows above the sediment transport threshold (6,000 cfs at Doty) in the Chehalis River (Section 6.2.2.2). This could result in more frequent operation that could increase the magnitude of impacts on sediment load, sediment transport, recruitment and transport of LWM, and channel migration in the mainstem Chehalis River.

As noted in Section 6. 3, the degree to which geomorphology would be adversely affected compared to the No Action Alternative is difficult to predict. However, Alternative 1 is expected to have impacts to some geomorphic processes in the Chehalis River compared to the No Action Alternative. These impacts from FRE operation could become more pronounced with increased climate variability.

6.5 Alternative 2: Flood Retention Only (FRO) Facility and Airport Levee Improvements

Alternatives 1 and 2 will employ the same hydraulic retention capabilities and flow release regime after construction. The only difference between the two alternatives considered as part of this evaluation is the difference in the structure bases. Alternative 2 would have a smaller base overall. However, the difference would be negligible with respect to the potential to alter geomorphology.

Direct and indirect impacts are expected to be the same as those described for Alternative 1.

7 REQUIRED PERMITS AND APPROVALS

The following permits and approvals are anticipated related to geomorphology. Permits and approvals related to geology are addressed in the *Chehalis River Basin Flood Damage Reduction Project NEPA EIS Discipline Report for Geology* (Corps 2020b).

7.1 Federal

- CWA Section 402 NPDES Construction Stormwater General Permit

7.2 State

- Hydraulic Project Approval

7.3 Local

- Lewis County Shoreline Substantial Development Permit
- Lewis County Grading Permit
- City of Chehalis Stormwater and Stormwater Runoff Permit
- City of Chehalis Grading Permit

8 REFERENCES

Anchor QEA (Anchor QEA, LLC), 2017. *Chehalis Basin Strategy: Operations Plan for Flood Retention Facilities*. June 2017.

Anchor QEA, 2019a. Memorandum to: Chehalis River Basin Flood Damage Reduction Project NEPA EIS Team. Regarding: Chehalis NEPA EIS Alternatives and Assumptions. June 24, 2019.

Anchor QEA, 2019b. Memorandum to: Diane Butorac, Chehalis River Basin Operations Modeling for Current Conditions and the Flood Retention Expandable Facility, August 28, 2019.

Anchor QEA and WDFW (Anchor QEA, LLC, and Washington Department of Fish and Wildlife), 2017. Memorandum regarding: Literature Review of the Potential Changes in Aquatic and Terrestrial Systems Associated with a Seasonal Flood Retention Only Reservoir in the Upper Chehalis Basin. March 2017.

Bumbaco, K.A., K.D. Dello, and N.A. Bond, 2013. "History of Pacific Northwest heat waves: Synoptic pattern and trends." *Journal of Applied Meteorology and Climatology* 52(7):1618–1631. Accessed at: https://dx.doi.org/10.1175/jamc-d-12-094.1.

Clark, J., 1999. *Watershed Analysis Five-Year Review Mass Wasting Assessments for Chehalis Headwaters, Willapa Headwaters and Stillman Creek.* Report prepared for Weyerhaeuser. June 11, 1999.

Corps, 2019. *Chehalis River Basin Flood Damage Reduction Project NEPA EIS Scoping Summary Report*. January 2019.

Corps (U.S. Army Corps of Engineers), 2020a. *Chehalis River Basin Flood Damage Reduction Project NEPA EIS Discipline Report for Water Quality and Quantity*. September 2020.

Corps, 2020b. *Chehalis River Basin Flood Damage Reduction Project NEPA EIS Discipline Report for Geology*. September 2020.

Corps, 2020c. *Chehalis River Basin Flood Damage Reduction Project NEPA EIS Discipline Report for Aquatic Species and Habitats*. September 2020.

Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner, 2017. "Precipitation change in the United States." *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. Editors, D.J. Wuebbles, D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock. Washington, DC: U.S. Global Change Research Program, pp. 207-230. Accessed at: https://dx.doi.org/10.7930/J0H993CC.

Ecology (Washington Department of Ecology), 2017. *Chehalis Basin Strategy Final Programmatic Environmental Impact Statement*. June 2017. Accessed at: http://chehalisbasinstrategy.com/programmatic-eis/.

Entrix, 2009. *Assessment of the December 2007 Flood Event in the Upper Chehalis Basin.* Technical Memo prepared for Washington Forest Law Center, Seattle, Washington. September 14, 2009.

GeoEngineers, Inc., and Herrera Environmental Consultants, Inc., 2009. *Comprehensive Flood Hazard Management Plan for the Confederated Tribes of the Chehalis Reservation.* Unpublished report prepared for the Confederated Tribes of the Chehalis. March 17, 2009.

Georgakakos, A., P. Fleming, M. Dettinger, C. Peters-Lidard, T.C. Richmond, K. Reckhow, K. White, and D. Yates, 2014. "Ch. 3: Water Resources." *Climate Change Impacts in the United States: The Third National Climate Assessment*. Editors, J.M. Melillo, T.C. Richmond, and G.W. Yohe. Washington, D.C.: U.S. Global Change Research Program; pp. 69–112.

HDR, 2018. *Chehalis River Basin Flood Control, Combined Dam and Fish Passage Supplemental Report, FRE Dam Alternative.* September 2018.

May, C., C. Luce, J. Casola, M. Chang, J. Cuhaciyan, M. Dalton, S. Lowe, G. Morishima, P. Mote, A. Petersen, G. Roesch-McNally, and E. York, 2018. "Northwest." *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Editors, D.R. Reidmiller, C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart. Washington, DC: U.S. Global Change Research Program; pp. 1036–1100. Accessed at: https://dx.doi.org/10.7930/NCA4.2018.CH24.

Nawa, R., and Frissell, C., 1993. "Measurement Scour and Fill of Gravel Streambeds with Scour Chains and Sliding Beads Monitors." *North American Journal of Fisheries Management* 13(3):634–639.

Perry, G., J. Lundquist, and R.D. Moore, 2016. *Review of the Potential Effects of Forest Practices on Stream Flow in the Chehalis River Basin*. Accessed at: https://depts.washington.edu/mtnhydr/people/Perry_Chehalis_forest_streamflow.pdf.

Peterson, T.C., R.R. Heim, Jr., R. Hirsch, D.P. Kaiser, H. Brooks, N.S. Diffenbaugh, R.M. Dole, J.P. Giovannettone, K. Guirguis, T.R. Karl, R.W. Katz, K. Kunkel, D. Lettenmaier, G.J. McCabe, C.J. Paciorek, K.R. Ryberg, S. Schubert, V.B.S. Silva, B.C. Stewart, A.V. Vecchia, G. Villarini, R.S. Vose, J. Walsh, M. Wehner, D. Wolock, K. Wolter, C.A. Woodhouse, and D. Wuebbles, 2013. "Monitoring and Understanding Changes in Heat Waves, Cold Waves, Floods and Droughts in the United States: State of Knowledge." *Bulletin of the American Meteorological Society* 94:821–834. Accessed at: https://dx.doi.org/10.1175/BAMS-D-12-00066.1.

Sarikhan, I.Y., K.D. Stranton, T.A. Contreras, M. Polenz, J. Powell, T.J. Walsh, and R.L. Logan, 2008. *Landslide Reconnaissance Following the Storm Event of December 1-3, 2007, in Western Washington.* Washington DNR Open File Report 2008-5. November 2008.

Schuett-Hames, D., R. Conrad, A. Pleus, and K. Lautz, 1999. *TFW Monitoring Program Method Manual for Salmonid Spawning Gravel Scour Survey.* Prepared for the Washington State Department of Natural Resources under the Timber, Fish, and Wildlife Agreement. TWF-AM9-99-008; DNR#110. December 1999.

Shannon & Wilson, 2014a. *Preliminary Desktop Landslide Evaluation*.

Shannon & Wilson, 2017. *Phase 2 Chehalis Dam Landslide Evaluation Technical Memorandum*.

Slaughter, S., and Hubert, I.J., 2014. *Geomorphic Mapping of the Chehalis River Floodplain, Cosmopolis to Pe Ell, Grays Harbor, Thurston, and Lewis Counties, Washington.* Washington Division of Geology and Earth Resources, Information Circular, 118. July 2014.

Troost, K.G., D.B. Booth, and W.T. Laprade, 2003. "Quaternary Geology of Seattle." *Western Cordillera and Adjacent Areas.* Editor, T.W. Swanson. Boulder, Colorado: Geological Society of America Field Guide 4, pp. 267–284.

USGS (U.S. Geological Survey), 2019a. Water Science School: The Fundamentals of the Water Cycle. Accessed September 30, 2019. Accessed at: https://www.usgs.gov/special-topic/water-science-school/science/fundamentals-water-cycle?qt-science_center_objects=0#qt-science_center_objects.

USGS, 2019b. National Water Information System (Washington): National Weather Service Flood Stages. Accessed September 30, 2019.
Accessed at: https://waterdata.usgs.gov/wa/nwis/current?type=floodstg.

USGS, 2019c. Surface-Water Monthly Statistics for Washington USGS 12020000 Chehalis River Near Doty, WA. Accessed August 26, 2019.
Accessed at: https://waterdata.usgs.gov/wa/nwis/inventory/?site_no=12020000&agency_cd=USGS.

USGS, 2019d. National Climate Change Viewer (NCCV).
Accessed at: https://www2.usgs.gov/landresources/lcs/nccv/viewer.asp.

Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner, 2017. "Temperature changes in the United States." *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. Editors, D.J. Wuebbles, D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock. Washington, DC: U.S. Global Change Research Program; pp. 185-206.
Accessed at: https://dx.doi.org/10.7930/J0N29V45.

Ward, J., and P. Russell, 1994. *Chehalis Headwaters Watershed Analysis Mass Wasting Assessment*. June 27, 1994.

WGD (Watershed GeoDynamics), 2019a. *Geomorphology and Sediment Transport Report, Chehalis River Basin Flood Damage Reduction Project*. October 2019a (Revised from May 2019).

WGD, 2019b. *Chehalis River Basin: Retrieval of Scour Monitors and Accelerometers Placed in the Chehalis River over Winter 2018–2019.* Memorandum Dated September 3, 2019.

WGD, 2019c. *ADDENDUM to November 2019 Chehalis River Basin Flood Damage Reduction Proposed Project; Geomorphology and Sediment Transport Report: Chehalis River HEC-RAS Sediment Transport Model 2019 – Model Inputs and Development*. Draft. January 6, 2020.

WGD and Anchor QEA (Watershed GeoDynamics and Anchor QEA, LLC), 2012. *Chehalis River Fish Study: Appendix B: Geomorphology/Sediment Transport/Large Woody Debris Report.* Prepared for the Chehalis River Basin Flood Authority. April 2012.

WGD and Anchor QEA, 2014. *Geomorphology and Sediment Transport Technical Memorandum*. June 2014.

WGD and Anchor QEA, 2017. *Chehalis Basin Strategy: Geomorphology, Sediment Transport, and Large Woody Debris Report*. June 2017.

WSE (Watershed Science and Engineering), 2014. *Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species – Development and Calibration of Hydraulic Model, 2014.*

WSE, 2019a. Memorandum: Chehalis River Basin Hydrologic Modeling. February 2019.

WSE, 2019b. *Chehalis River Existing Conditions RiverFlow 2-D Model Development and Calibration*. February 2019.

Attachment 1
Additional Modeling and Analyses

ATTACHMENT 1: ADDITIONAL MODELING AND ANALYSES

September 2020

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ACRONYMS AND ABBREVIATIONS

Corps	U.S. Army Corps of Engineers
FRE	Flood Retention Expandable
NEPA	National Environmental Policy Act
RM	river mile
WGD	Watershed GeoDynamics

1 PURPOSE

This appendix summarizes additional evaluations that were conducted for the National Environmental Policy Act (NEPA) Environmental Impact Statement to complement technical geomorphology studies conducted by others for the Chehalis River and the Chehalis River Basin Flood Damage Reduction Project between 2012 and 2019, summarized in a series of geomorphology and sediment transport studies conducted by Watershed GeoDynamics (WGD; WGD and Anchor QEA 2012, 2014, 2017; WGD 2019a, 2019b). These additional evaluations were conducted to evaluate the stability of the sediment transport model used (along with other lines of evidence) to inform impact assessments for the discipline report for geomorphology. These evaluations are not intended to replace or alter conclusions within the referenced previous work.

This appendix summarizes the results from the targeted sensitivity review of the 1-D HEC-RAS sediment transport model developed by WGD (2019a).

2 TARGETED SENSITIVITY REVIEW OF SEDIMENT TRANSPORT MODEL

The sediment transport model was developed by WGD and is based on the U.S. Army Corps of Engineers (Corps) HEC-RAS 1-D sediment transport model (WGD 2019a). The model extends from the upper extent of the river above the proposed reservoir footprint (river mile [RM] 118) downstream to the confluence with the Newaukum River (RM 75), and uses rating curves of flow rate versus total sediment loading and corresponding grain size as sediment transport boundary conditions input. The model was used to perform a 30-year simulation of the measured flow rates in the river and tributaries, occurring between 1988 and 2018. The 30-year simulation was performed for both the existing conditions (no Flood Retention Expandable [FRE] facility) and post-construction conditions (with FRE/Flood Retention Only facility) scenarios. At the end of each 30-year simulation, the predictions of total sediment storage and surface and subsurface median grain size (D_{50}) and thalweg elevation were compared at each cross-section for each scenario. The results of the sediment transport modeling efforts are described in the *Geomorphology and Sediment Transport Report, Chehalis River Basin Flood Damage Reduction Project* (WGD 2019a).

To provide additional information on model stability, model simulations were conducted to examine how the sediment transport results respond to reasonable changes to select input parameters. Changes made to input parameters used in this evaluation do not reflect the potential variability in these input values and this evaluation was not intended to be an uncertainty analysis. Instead, relatively small changes to input parameters were made in order to identify large changes in model results, if any, that could be associated with poor model stability. If the model is stable, then changes to input parameters will result in changes in model results that are on the same order of magnitude as the changes to input parameters. If small changes to model inputs result in unexplained and very large changes to model results, then the model is not stable and model results would be unreliable. A complete sensitivity and uncertainty analysis of the sediment transport model was not conducted as part of this evaluation.

Three scenarios were conducted for both no-FRE and with-FRE conditions as follows: 1) increase in all sediment input loads; 2) decrease in all sediment input loads; and 3) order of flood events in the 30-year flow record. These input conditions were selected for the targeted sensitivity analysis because they are expected to have significant impacts on model results compared to other parameters. Specifics of the three sensitivity model simulations are described as follows:

1. All sediment load inputs were increased by 20% (rating curves) (Table 5.4-3 in the *Discipline Report for Geomorphology*). All other model parameters were unchanged from baseline simulations.

2. All sediment loads were decreased 20% (rating curves) (Table 5.4-3 in the *Discipline Report for Geomorphology*). All other model parameters were unchanged from baseline simulations.
3. The historical 30-year flow record used in the baseline modeling (Section 6.2.2.4 in the *Discipline Report for Geomorphology*) was reversed such that all flows, including the flood events, occurring between 1988 and 2018 occurred in reverse order. All other model parameters were unchanged from baseline simulations.

The results of each scenario were compared to the baseline simulations with the sediment loading and hydraulics developed by WGD (2019a).

The results show that changing the total sediment load (plus or minus 20%) and reversing the order of the hydraulic flows generally does not significantly change the long-term sediment storage or grain size trends. This suggests that the model predictions may not be highly sensitive to the sediment loading quantity and grain size input boundary conditions in the model, which were developed from a compilation of collected data over several years. The results of this evaluation are summarized in the following sections.

2.1 Sediment Storage Results

Figure 2.1-1 (taken from WGD 2019) shows the sediment storage results at the end of the 30-year simulation time period for each cross section in tons of sediment for the baseline simulations for the existing conditions (no FRE facility) model and the with-FRE facility model. This information is provided for comparison with following figures showing the change in predicted sediment storage between baseline conditions and the sensitivity model simulations.

Figure 2.1-1
Sediment Storage Results for Existing Baseline (No-FRE) and With-FRE Scenarios (WGD 2019a) At the End of the 1998 to 2018 Model Simulation

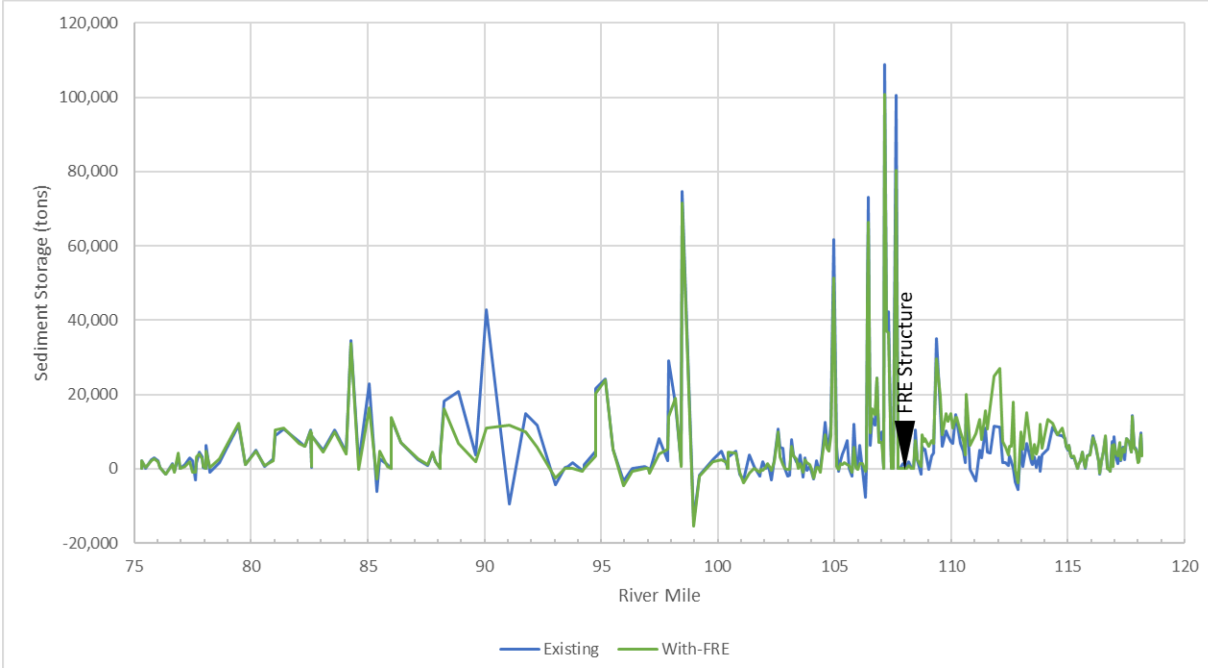


Figure 2.1-2 shows the difference in sediment storage results from baseline conditions (existing, no FRE facility) for the three different sensitivity simulations: 1) 20% increase in all sediment loads; 2) 20% decrease in all sediment loads; and 3) reversed hydraulic inflow conditions (flow record from existing conditions run in reverse order). The results show overall higher storage for the scenario with an approximate 20% increase in total load, with up to 20,000 tons of additional storage compared to baseline existing conditions near the location of the proposed FRE facility (RM 108). Likewise, there is a decrease in sediment storage up to 21,000 tons near the FRE facility for the scenario with sediment supply reduced by 20%. The reversed hydraulics inflow simulation shows an overall reduction (up to a 6,000-ton reduction) in sediment storage near the location of the proposed FRE facility (not included in these model simulations) but fluctuates between a minor increase or minor decrease in storage elsewhere in the river compared to the changes induced by changing sediment load.

Figure 2.1-2
Difference in Computed Storage as Compared to Baseline (Existing Conditions) for the Three Sensitivity Model Simulations

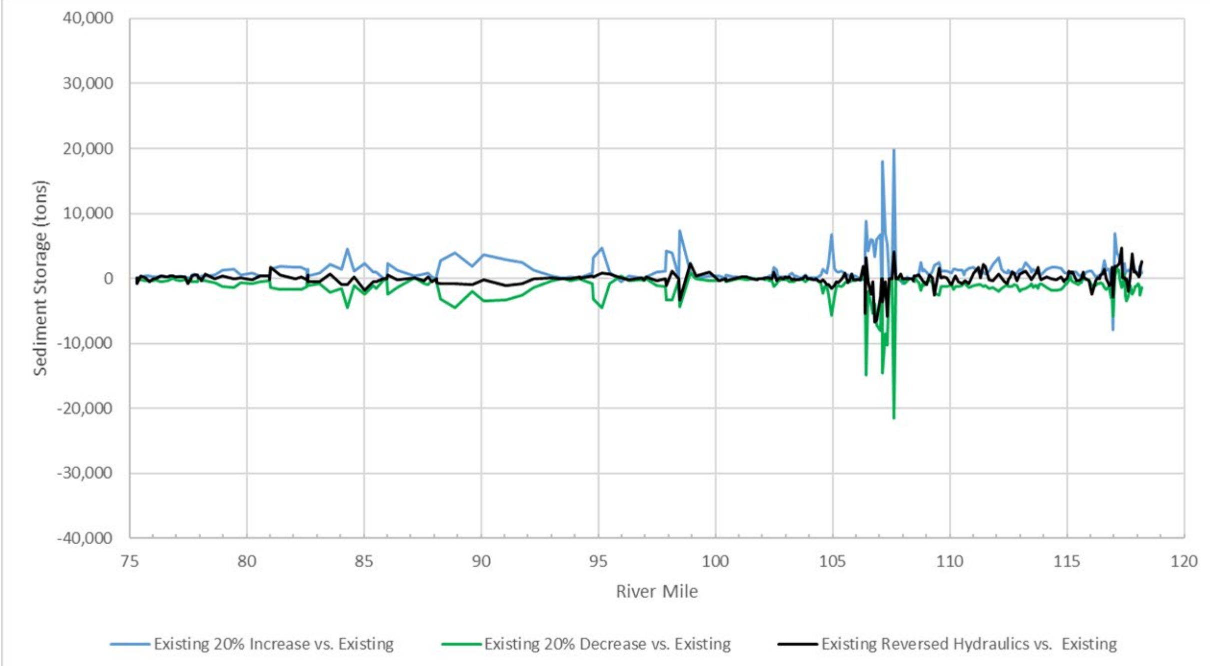


Figure 2.1-3 shows the difference in sediment storage results from original FRE facility model simulations for the three different sensitivity simulations: 1) 20% increase in all sediment loads; 2) 20% decrease in all sediment loads; and 3) reversed hydraulic inflow conditions (flow record from existing conditions run in reverse order). The results show overall higher storage for the scenario with a 20% increase in total load, with up to 20,000 tons of additional storage compared to baseline with-FRE facility conditions near the FRE facility (RM 208). Likewise, there is a decrease in sediment storage up to 22,000 tons near the FRE facility for the scenario with sediment supply reduced by 20%. The reversed hydraulics inflow simulation shows an overall reduction in sediment storage near the FRE facility (up to a 12,000-ton reduction) but fluctuates between a minor increase or minor decrease in storage elsewhere in the Chehalis River. The variability in the sediment storage for the three sensitivity simulations is larger (two times the variability of the existing conditions simulation) in the temporary reservoir area upstream of the proposed FRE facility.

Figure 2.1-3
Difference in Computed Storage as Compared to With-FRE Facility Conditions for the Three Sensitivity Model Simulations

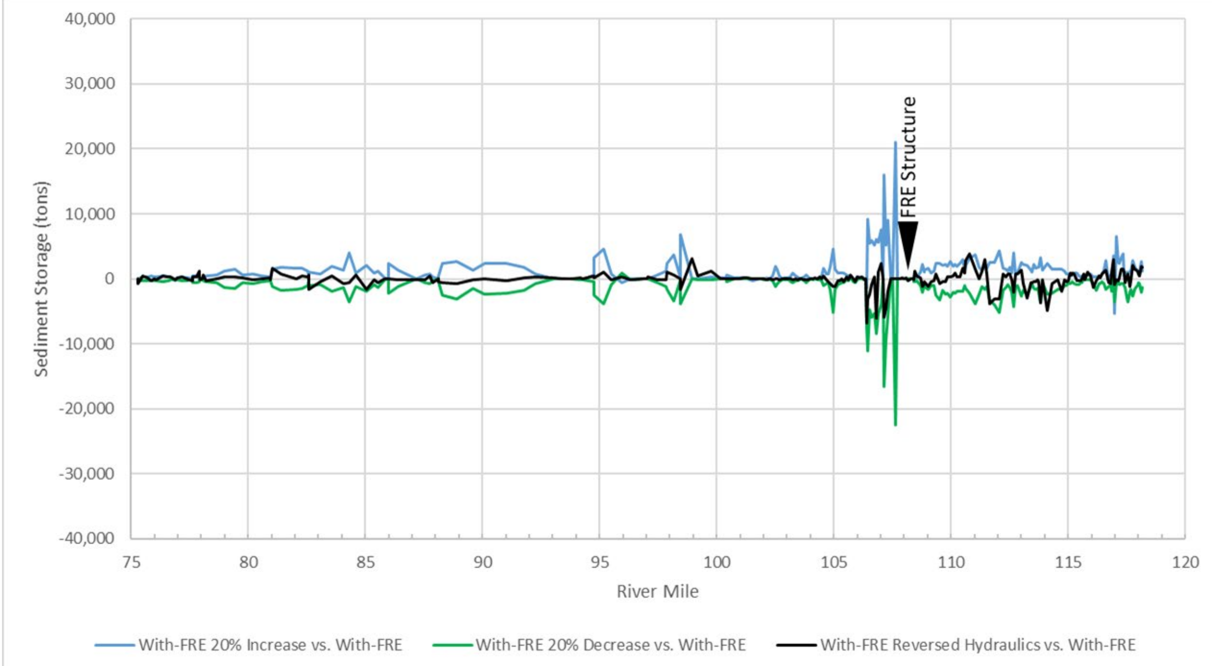
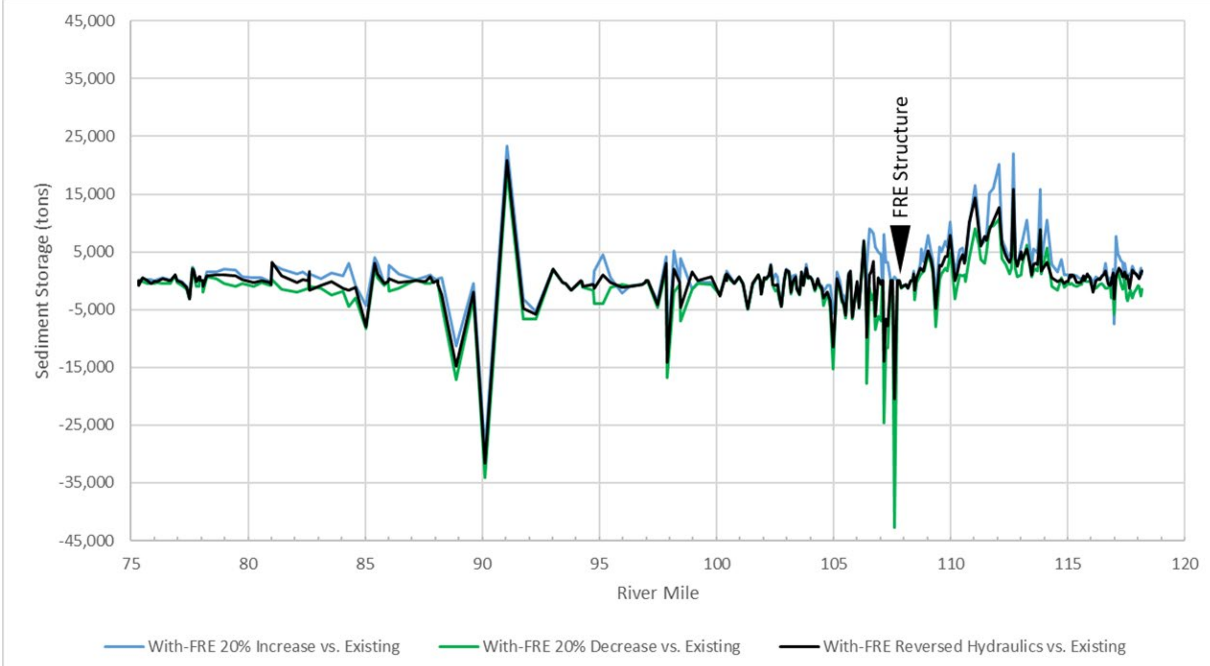


Figure 2.1-4 shows the difference of total predicted sediment storage between the three with-FRE facility sensitivity simulations and the existing baseline no-FRE facility scenario.

Figure 2.1-4
Difference in Computed Storage of the Three FRE Facility Sensitivity Model Simulations Compared to Baseline (Existing) Conditions



Compared to the magnitude of sediment storage at each river cross-section (Figure 2.1-1), the effects of the with-FRE facility scenario are relatively minor. The largest predicted variation from the modeled no-FRE facility scenario occurs between RM 92 and RM 89, with up to a 25,000-ton increase at RM 91 and a 30,000-ton reduction in sediment storage at RM 90. All simulations show this impact, which is likely due to backwater of the South Fork hindering sediment transport in this area during larger floods. The magnitude of the variations between the sensitivity scenarios compared to the baseline no-FRE facility scenario are minimal with the exception of the 20% increased sediment load scenario, which shows up to 20,000 tons of increased storage downstream of the FRE facility. The results of this sediment storage evaluation suggest that the model's overall predicted storage results are influenced the most by increasing the sediment supply. However, the overall changes in predicted sediment storage observed for the sensitivity simulations are less than the changes predicted between the baseline with-FRE facility and no-FRE facility scenarios.

2.2 Cumulative Sediment Transport

Table 2.2-1 summarizes the cumulative sediment transport flux out of the system (through cross-section 75.31) for the no-FRE facility conditions and with-FRE facility scenarios for the 30-year flow record as well as for each of the sensitivity simulations. Sediment flux is reported for three computational time steps over the 30-year simulation, as follows:

- Immediately before the 2007 flood (November 25, 2007)
- Immediately after the 2007 flood (December 14, 2007)
- At the end of the simulation (September 13, 2018)

Table 1.1-2
Cumulative Sediment Flux Out of Cross-Section 75.31 (near RM 75) in Tons and Comparison of With-FRE Facility to No-FRE Facility Results

MODEL SIMULATION		SIMULATION TIMESTEP		
FRE CONDITIONS	SENSITIVITY CONDITIONS	PRE-2007 FLOOD (11/25/2007)	POST-2007 FLOOD (12/14/2007)	END OF 30-YEAR SIMULATION (9/13/2018)
No-FRE	• Baseline Inputs	968,500	988,900	1,420,700
	• -20% Sediment Input	776,100	792,500	1,139,000
	• +20% Sediment Input	1,159,400	1,183,800	1,699,900
	• Reversed Flow Record	432,100	453,900	1,419,600
With-FRE	• Baseline Inputs	1,010,400	1,079,900	1,511,400
	• -20% Sediment Input	802,900	858,600	1,201,300
	• +20% Sediment Input	1,200,000	1,282,100	1,793,900
	• Reversed Flow Record	429,800	495,800	1,497,600

MODEL SIMULATION		SIMULATION TIMESTEP		
COMPARISON CONDITIONS	**SENSITIVITY CONDITIONS**	**PRE-2007 FLOOD (11/25/2007)**	**POST-2007 FLOOD (12/14/2007)**	**END OF 30-YEAR SIMULATION (9/13/2018)**
With-FRE Compared to No-FRE results (% Difference in Cumulative Sediment Flux)	• Baseline Inputs	4%	9%	6%
	• -20% Sediment Input	3%	8%	5%
	• +20% Sediment Input	4%	8%	6%
	• Reversed Flow Record	-1%	9%	5%

Note: For the reversed flow record simulation, the 2007 flood occurred in year 1999. The pre-flood conditions were extracted on July 22, 1999, and the post-flood conditions results were extracted on August 15, 1999. This resulted in much lower cumulative sediment quantities for the two reversed flow record simulations.

For all simulations except the reversed flow simulation just prior to the 2007 flood, sediment flux out of the model at cross-section 75.31 (near RM 75) is higher for with-FRE facility conditions than existing (baseline) conditions by between 3% and 9%. The lower end of this range occurs just prior to the 2007 flood and at the end of the 30-year model simulation and the high end of range occurs just after the 2007 flood. The reversed flow record simulation shows less sediment flux than the no-FRE facility scenario just prior to the 2007 flood, likely because the 2007 flood occurred much earlier in the simulation when the flow record is reversed.

Other than the reversed flow simulation just prior to the 2007 flood, the comparison of the difference in sediment flux out of the model between existing and with-FRE facility conditions changes very little based on relatively small changes to sediment load and the reversed flow record. This suggests that the sediment transport model is not very sensitive to these types of changes and that the model appears to be relatively stable based on reasonable changes to these input conditions.

These results also show that more sediment is moving out of the model and downstream of about RM 75 in the with-FRE facility conditions model than the existing (baseline) conditions model by about 3% to 4% of the baseline sediment flux. This suggests that more sediment may be moving through the system (between RM 118 and RM 75) because of FRE facility operations compared to existing conditions. However, these results are uncertain based on uncertainties in the sediment transport modeling outlined in the main body of the discipline report.

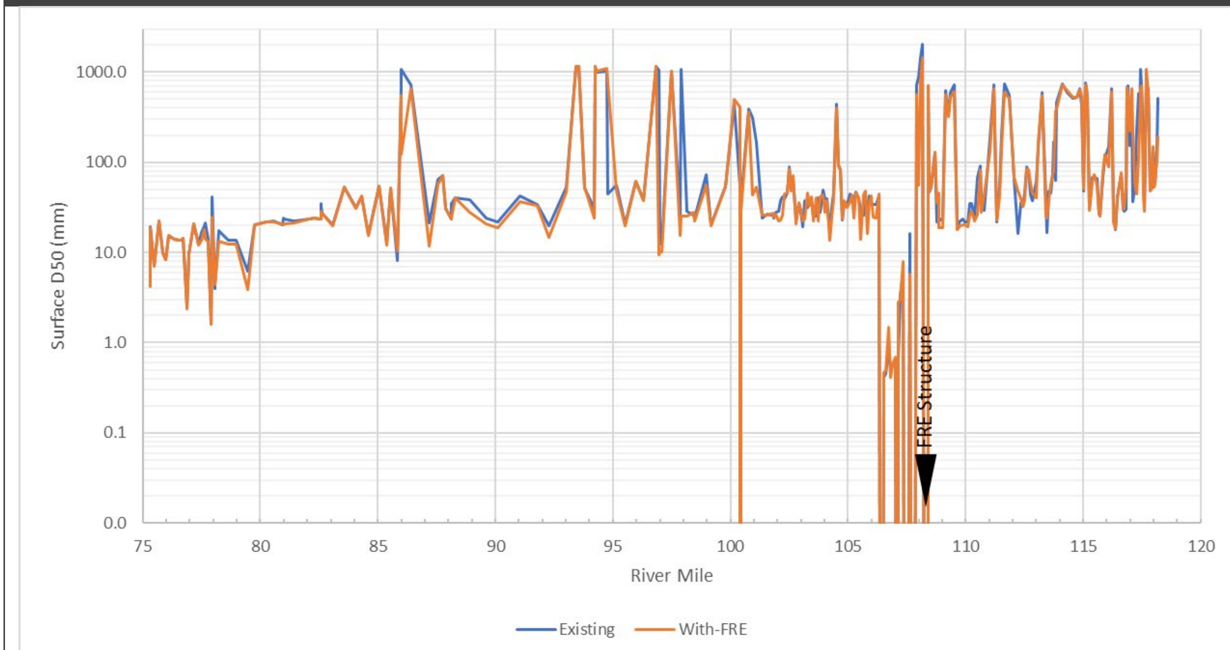
2.3 Grain Size Results

The sediment transport model was also used to evaluate the responsiveness of sediment grain size in the channel to the sensitivity input scenarios. Both surface median grain size and subsurface median grain size were evaluated.

2.3.1 Surface Grain Size

Figure 2.3-1 shows the predicted surface median grain size (D_{50}) for each variable input scenario at the end of the 30-year simulation for existing conditions (no-FRE facility) and with-FRE facility baseline scenarios.

Figure 2.3-1
Surface Median Grain Size (D_{50}) Results for Existing Baseline and With-FRE Conditions

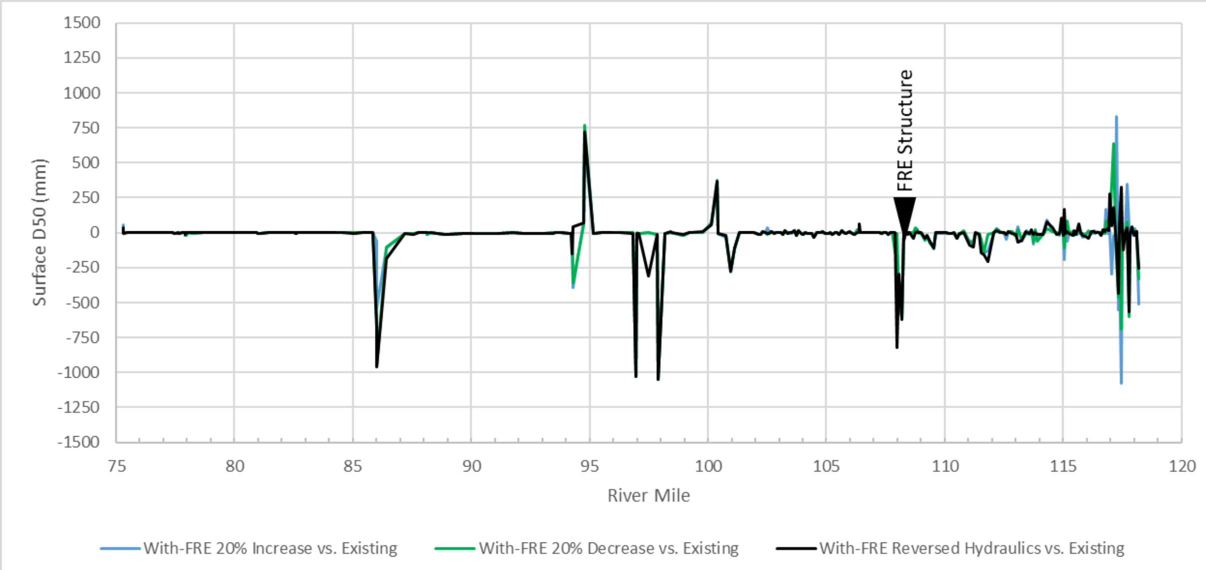


Note: Median surface grain size is close to zero, but not equal to zero, for many cross-sections in the model simulation. This may be an artifact of the modeling itself and not reflect a realistic prediction of system behavior.

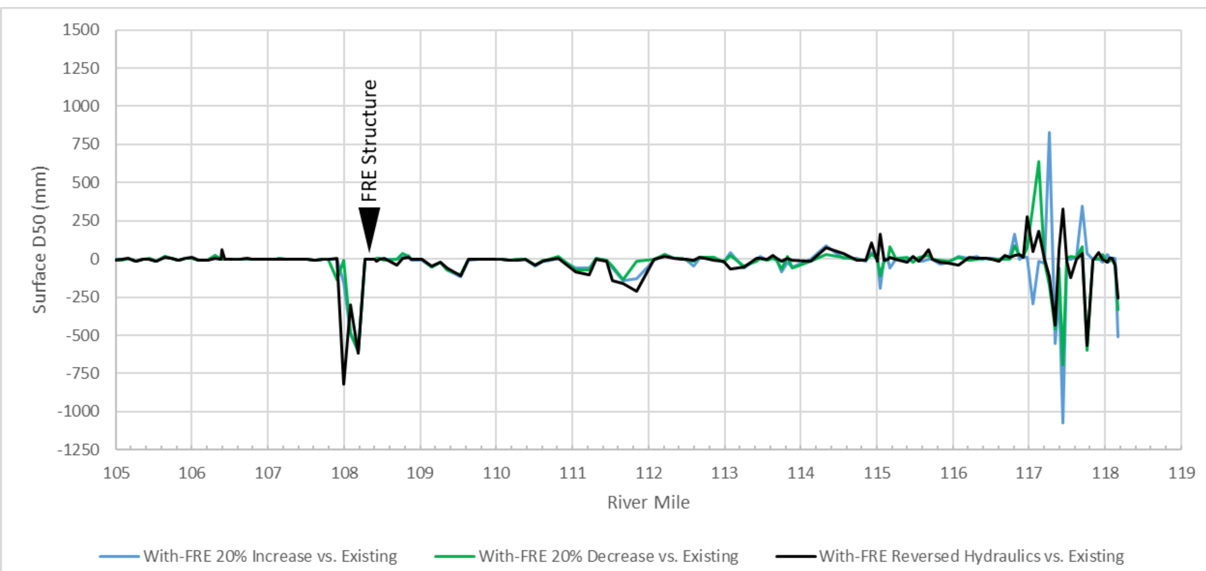
The results show that the with-FRE facility scenario results in a grain size reduction in certain sections of the model. There are no obvious trends in predicted grain size over large reaches of the river because of the FRE facility. The peaks upstream of the FRE facility near RM 108 and peaks near RM 97 and RM 87 show reductions in the large boulder-sized materials for the with-FRE facility scenario compared to the existing baseline conditions. The with-FRE facility variable input scenarios (20% increase, 20% decrease, and reversed hydraulic inflow conditions), as well as the with-FRE facility baseline scenario were compared to the existing conditions baseline scenario. The differences in median grain size between these simulations are shown in Figure 2.3-2.

Figure 2.3-2
Surface Grain Size D_{50} Comparisons for With-FRE Sensitivity and Existing Baseline Scenarios

All Sections:



RM 105 to RM 119:

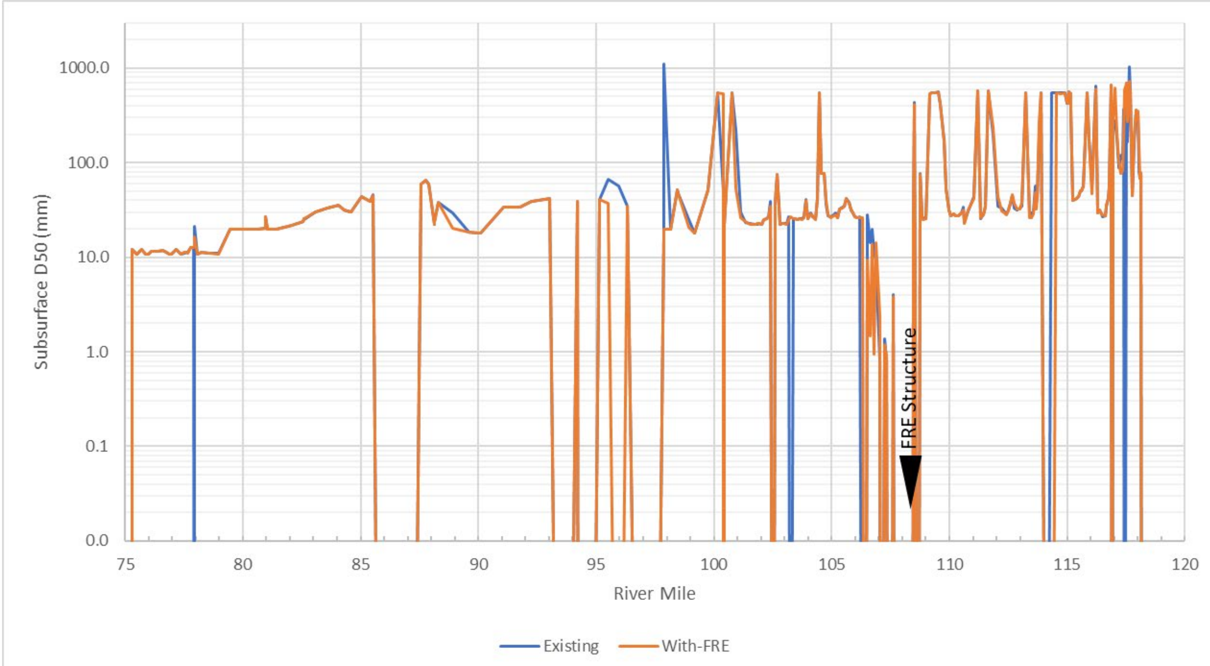


The sensitivity results show that the change in surface median grain size is primarily affected by the changes in hydraulics because of the FRE facility. Overall, only minimal changes in surface median grain size were observed due to the sensitivity conditions, notably at the upstream end of the model above the temporary reservoir, with the 20% decrease and 20% increase in sediment load scenarios showing more variability in surface median grain size compared to the scenario with the 30-year hydrograph reversed.

2.3.2 Subsurface Grain Size

Only minimal changes to the subsurface median grain size (D_{50}) due to the variable input scenarios were predicted at the end of the 30-year simulation. Figure 2.3-3 shows the subsurface median grain size for existing baseline (no-FRE facility) conditions and the with-FRE facility scenario.

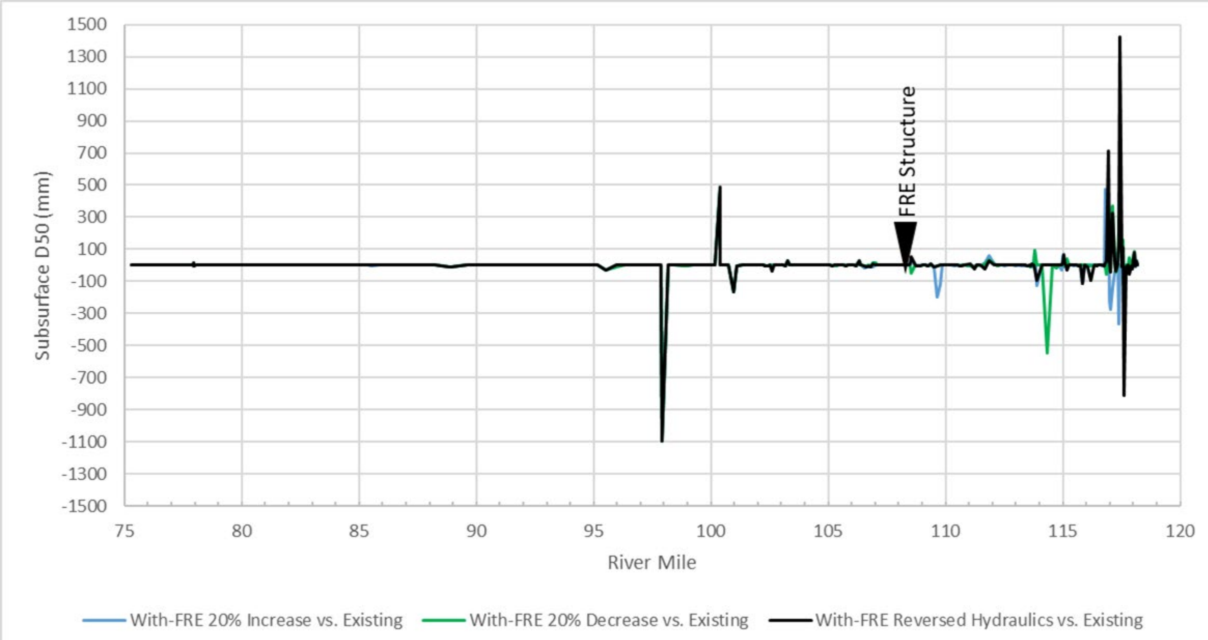
Figure 2.3-3
Subsurface Median Grain Size (D_{50}) Results for Existing Conditions and With-FRE Conditions



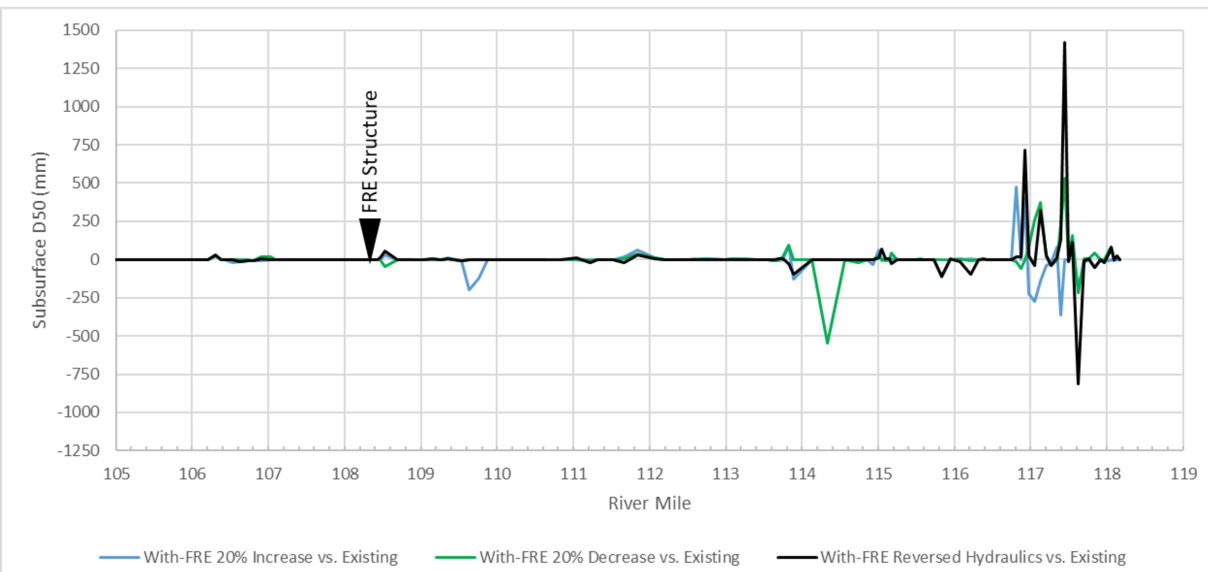
The subsurface grain size predicted for the input variation scenarios and with-FRE facility baseline scenario were compared to the existing conditions baseline scenario. The comparisons are shown in Figure 2.3-4.

Figure 2.3-4
Subsurface Median Grain Size (D_{50}) Comparison for With-FRE Scenario Compared to Existing Conditions

All Sections:



RM 105 to RM 119:



The results show that the subsurface grain size shows the most variation because of the sensitivity scenarios at the upstream end of the impounded reservoir area (RM 114 to RM 117). Overall, the subsurface grain size shows minimal effects due to the sensitivity scenarios. Only minimal variations in subsurface grain size are predicted downstream of the FRE facility, and variations in subsurface grain size are small compared to the changes from the FRE facility.

3 CONCLUSIONS

The results of the model stability review described in this appendix suggest that some relatively small changes to model parameters (sediment input and order of flow events) do not result in significantly large or unexpected results in model output. Therefore, sediment transport model results should be reliable within the uncertainty of the input values themselves. Uncertainties in the model input parameters and other aspects of model development (i.e., model calibration) and how these affect the results of the sediment transport model are discussed in the Uncertainties section in the main body of the discipline report.

4 REFERENCES

WGD and Anchor QEA (Watershed GeoDynamics and Anchor QEA, LLC), 2012. *Appendix B: Geomorphology/Sediment Transport/Large Woody Debris Report of the Chehalis River Fish Study*. Prepared for the Chehalis River Basin Flood Authority. April 2012.

WGD and Anchor QEA, 2014. *Geomorphology and Sediment Transport Technical Memorandum.* Prepared for the Chehalis Basin Workgroup. June 2014.

WGD and Anchor QEA, 2017. *Geomorphology, Sediment Transport, and Large Woody Debris Report*. Prepared as part of the Chehalis Basin Flood Strategy for the Washington State Recreation and Conservation Office. June 2017.

WGD, 2019a. *Geomorphology and Sediment Transport Report, Chehalis River Basin Flood Damage Reduction Project*. October 2019.

WGD, 2019b. *Chehalis River Basin: Retrieval of scour monitors and accelerometers placed in the Chehalis River over winter 2018-2019*. September 2019.