February 2020

Proposed Chehalis River Basin Flood Damage Reduction Project

SEPA Draft Environmental Impact Statement

Appendix F
Earth Discipline Report

Publication No.: 20-06-002

DEPARTMENT OF ECOLOGY
State of Washington

Accommodation Requests

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About this Document

This discipline report has been prepared as part of the Washington Department of Ecology's (Ecology's) State Environmental Policy Act (SEPA) Environmental Impact Statement (EIS) to evaluate a proposal from the Chehalis River Basin Flood Control Zone District (Applicant).

Proposed Action

The Applicant seeks to construct a new flood retention facility and temporary reservoir near Pe Ell, Washington, and make changes to the Chehalis-Centralia Airport levee in Chehalis, Washington. The purpose of the Applicant's proposal is to reduce flooding originating in the Willapa Hills and improve levee integrity at the Chehalis-Centralia Airport to reduce flood damage in the Chehalis-Centralia area.

Time Frames for Evaluation

If permitted, the Applicant expects Flood Retention Expandable (FRE) facility construction would begin in 2025 and operations in 2030, and the Airport Levee Changes 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 during the years 2025 to 2030 and for operations from 2030 to 2080. For purposes of analysis, the term "mid-century" applies to the operational period from approximately 2030 to 2060. The term "late-century" applies to the operational period from approximately 2060 to 2080.

Scenarios Evaluated in the Discipline Report

This report analyzes probable significant environmental impacts from the Proposed Action, the Local Actions Alternative, and the No Action Alternative under the following three flooding scenarios (flow rate is measured at the Grand Mound gage):

- **Major flood:** Water flow rate of 38,800 cubic feet per second (cfs) or greater
- **Catastrophic flood:** Water flow rate of 75,100 cfs
- **Recurring flood:** A major flood or greater that occurs in each of 3 consecutive years

The general area of analysis includes the area in the vicinity of the FRE facility and temporary reservoir; the area in the vicinity of the Airport Levee Changes; and downstream areas of the Chehalis River to approximately river mile 9, just west of Montesano.

Local Actions Alternative

The Local Actions Alternative represents a local and nonstructural approach to reduce flood damage in the Chehalis-Centralia area. It considers a variety of local-scale actions that approximate the Applicant's purpose through improving floodplain function, land use management actions, buying out at-risk properties or structures, improving flood emergency response actions, and increasing water storage from Pe Ell to Centralia. No flood retention facility or Airport Levee Changes would be constructed.

No Action

Under the No Action Alternative, no flood retention facility or Airport Levee Changes would be constructed. Basin-wide large and small scale efforts would continue as part of the Chehalis Basin Strategy work, and local flood damage reduction efforts would continue based on local planning and regulatory actions.

SUMMARY

This report evaluates geology and geomorphology. Geology means the earth, the materials of which it is made, their structure, and the processes that act upon it such as landslides and earthquakes. Geomorphology includes landslides, erosion, sediment transport, and channel migration in streams and rivers. These processes affect water quality, people, fish, and aquatic habitat. The discussion in this discipline report describes existing conditions and probable impacts on geology and geomorphology.

Geology

The study area for the geology analysis includes two distinct areas: the proposed Flood Retention Expandable (FRE) facility and the Airport Levee Changes. The area of the proposed FRE facility is defined by: 1) the footprint of the FRE facility structure, its related facilities, and the excavation waste sites; 2) the area of the temporary reservoir maximum inundation level outline (elevation 627 feet) and adjacent slopes; and 3) three potential rock quarry sites and their connecting roads to the FRE facility. The area of the proposed Airport Levee Changes is the levee surrounding the airport where it is proposed to be raised and the ground adjacent to the toe of the levee.

Through reconnaissance, subsurface explorations, geophysical field testing, laboratory testing, and engineering analysis, the following geologic issues were analyzed:

- Potential for increased sedimentation due to excavation, mining at the quarry sites, and travel on quarry roads
- Deep-seated landslides in the vicinity of the Proposed Action and the landslide instability due to fluctuating water levels
- Potential for increased sediment generation from shallow landslides due to fluctuating water levels around the perimeter of the temporary reservoir
- Potential earthquakes near the facility and their impact on the FRE facility

Geomorphology

The study area for the geomorphology analysis includes areas potentially affected by the Proposed Action: the Chehalis River and hillslopes within the proposed FRE facility (including associated access, construction, and maintenance areas); the area of the predicted maximum inundation for the temporary reservoir; the area of the proposed Airport Levee Changes; and the Chehalis River upstream and downstream from the proposed actions that could be affected by construction or operations, extending from approximately river mile (RM) 118 to RM 9, just west of Montesano.

Using surveys, data analysis, and modeling, the following geomorphic issues were analyzed:

- Potential for increased erosion within the temporary reservoir from changes to vegetation and reservoir fluctuations

- Sediment input, transport, and deposition (changes to sediment transport rates and substrate grain size within the potential inundation area and downstream of structure)
- Potential for channel incision downstream of the FRE facility and destabilizing alluvial fans at tributary junctions due to changes in sediment input and transport
- Changes to movement and accumulation of large woody material (LWM) from upstream sources due to retention within the temporary reservoir and changes to LWM input downstream of the FRE facility due to changes in channel migration rates
- Changes to channel-forming processes and channel migration rates from reduced peak flows downstream of the FRE facility

This report also describes probable impacts to geology and geomorphology from the Proposed Action and alternatives (Local Actions Alternative and No Action Alternative). These impacts are summarized in Tables F-1 and F-2.

Table F-1
Summary of Geology and Geomorphology Impacts from the Proposed Action

IMPACT	IMPACT FINDING	MITIGATION PROPOSED (SUMMARIZED, SEE SECTIONS 3.2.4 AND 6.2.4)	SIGNIFICANT AND UNAVOIDABLE ADVERSE IMPACT
PROPOSED ACTION (FRE FACILITY AND AIRPORT LEVEE CHANGES) – CONSTRUCTION			
Permanent alteration of 0.3 acre of river channel at FRE facility site.	**Significant**	**WATER-1**: Develop and implement a Surface Water Quality Mitigation Plan. **FISH-1**: Develop and implement a Fish and Aquatic Species and Habitat Mitigation Plan. **WET-2:** Develop and implement Stream and Stream Buffer Mitigation Plan.	**Yes, unless mitigation is feasible**
Erosion from construction, clearing of the temporary reservoir area, and use of unpaved roads during construction.	Moderate to Minor	**WATER-1:** Develop and implement a Surface Water Quality Mitigation Plan.	No

IMPACT	IMPACT FINDING	MITIGATION PROPOSED (SUMMARIZED, SEE SECTIONS 3.2.4 AND 6.2.4)	SIGNIFICANT AND UNAVOIDABLE ADVERSE IMPACT
Excavation of soil and rock for the foundations of the FRE facility, including spoils from the temporary bypass tunnel, would create sediment that could enter the Chehalis River.	Moderate	**WATER-1:** Develop and implement a Surface Water Quality Mitigation Plan. **EARTH-1:** Identify unstable ground in the proximity of the FRE facility and either excavate and haul this material to a waste disposal site or stabilize the ground.	No
Impacts from large woody material transport during construction.	Moderate	**EARTH-3:** Develop and implement a Large Woody Material Management Plan.	No
Local alteration to sediment transport when river flow is routed through bypass tunnel.	Minor	None	No
No geology or geomorphology impacts from construction of the Airport Levee Changes.	None	None	No
PROPOSED ACTION (FRE FACILITY AND AIRPORT LEVEE CHANGES) – OPERATIONS			
While very unlikely, an earthquake greater than design happening at the same time the temporary reservoir is holding water would adversely affect communities, environment, and infrastructure downstream of the FRE.	**Significant**	**EJ-1:** To target outreach efforts for the Proposed Action, mitigation is proposed for the Applicant to develop an inclusive public involvement strategy tailored to the communities who may be affected from a catastrophic event causing the FRE facility to breach or fail while the temporary reservoir is holding water. **EHS-3:** Develop and implement a breach flood warning system for Pe Ell, Centralia, and Chehalis. **EHS-4:** Provide training to local emergency response officials for dam breach scenarios.	**Yes**
Water quality impacts, including fine sediment input, due to higher	**Significant**	**WATER-1:** Develop and implement a Surface Water Quality Mitigation Plan.	**Yes, unless mitigation is feasible**

IMPACT	IMPACT FINDING	MITIGATION PROPOSED (SUMMARIZED, SEE SECTIONS 3.2.4 AND 6.2.4)	SIGNIFICANT AND UNAVOIDABLE ADVERSE IMPACT
turbidity levels downstream of the FRE facility than upstream when the temporary reservoir drains.		**FISH-1:** Develop and implement a Fish and Aquatic Species and Habitat Mitigation Plan.	
Water quality impacts due to increased turbidity from deep and shallow landslides in the temporary reservoir caused by fluctuating water level.	**Significant to moderate**	**WATER-1:** Develop and implement a Surface Water Quality Mitigation Plan. **EARTH-2:** Develop and implement a Landslide Stabilization Plan.	**Yes, unless mitigation is feasible**
Changes to sediment transport and substrate in the river channel within the temporary reservoir.	**Significant**	**FISH-1**: Develop and implement a Fish and Aquatic Species and Habitat Mitigation Plan. **WILDLIFE-1**: Develop and implement a Vegetation Management Plan.	**Yes, unless mitigation is feasible**
Decreased large woody material levels within and downstream of the FRE facility to the South Fork confluence.	**Significant**	**EARTH-3:** Develop and implement a Large Woody Material Management Plan.	**Yes, unless mitigation is feasible**
Decreased channel formation downstream of the FRE facility to the South Fork confluence from reduced flow, large woody material, and sediment.	**Significant**	**EARTH-3:** Develop and implement a Large Woody Material Management Plan. **FISH-1:** Develop and implement a Fish and Aquatic Species and Habitat Mitigation Plan. **WET-2**: Develop and implement Stream and Stream Buffer Mitigation Plan.	**Yes, unless mitigation is feasible**
Changes to sediment transport and substrate between the FRE facility and RM 85.	Moderate	None	No
Decreased channel migration in Reaches 2B and 3.	Moderate	None	No

IMPACT	IMPACT FINDING	MITIGATION PROPOSED (SUMMARIZED, SEE SECTIONS 3.2.4 AND 6.2.4)	SIGNIFICANT AND UNAVOIDABLE ADVERSE IMPACT
Increased channel migration in a few locations in the FRE facility delta accumulation areas.	Moderate	None	No
Changes to sediment transport and substrate downstream of RM 85.	Minor	None	No
Changes to channel migration in Reaches 2A, 2C, 4, 5, and 6.	Minor	None	No
Channel incision/changes at tributary junctions.	Moderate within FRE fluctuation zone; minor downstream of FRE facility.	None	No

Table F-2

Summary of Geology and Geomorphology Impacts from Alternatives

IMPACT	IMPACT FINDING
LOCAL ACTIONS ALTERNATIVE	
Flooding would continue to influence geology and geomorphology. Flood events would continue to cause landslides and erosion.	**Continuing substantial flood risk**
Changes to riparian habitat, substrate, large woody material, and channel migration as a result of reforestation, riparian restoration, construction removal, and channel migration protection measures.	Minor
Construction activities near steep slopes could cause slope instability.	Moderate to Minor
Erosion from construction of projects.	Moderate to Minor
NO ACTION ALTERNATIVE	
Flooding would continue to influence geology and geomorphology. Flood events would continue to cause landslides and erosion.	**Continuing substantial flood risk**

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Geology

1 INTRODUCTION

1.1 Resource Description

Geology is the study of the earth, the materials of which it is made, their structure, and the processes that act upon them. In the Chehalis Basin, geologic material includes volcanic and sedimentary rock and glacially and alluvially deposited Quaternary-aged sediment, deposited by a variety of processes: continental glaciers, alpine glaciers, rivers, and landslides. Seismic processes are characterized by two tectonic convergence regimes; the combined effects of the two tectonic motions produce complex and diverse deformation in the Basin. Landslides are also common in the Chehalis Basin during high-intensity storms when rain—often in combination with melting snow (i.e., rain-on-snow events)—saturates surface soil layers or contributes to streamflow, which can undercut the toes of adjacent landslide areas.

1.2 Regulatory Context

Federal, state and local regulations applicable to the geology analysis are identified in Table F-3.

Table F-3
Regulations, Statutes, and Guidelines for Geology

REGULATION, STATUTE, GUIDELINE	DESCRIPTION
FEDERAL	
Section 402 of the Clean Water Act	• Establishes the National Pollutant Discharge Elimination System (NPDES) program, under which certain discharges of pollutants into waters of the United States are regulated. • Regulation of construction primarily deals with water quality during construction, but includes eroded soils potentially delivered off site via runoff. • U.S. Environmental Protection Agency (EPA) has designated the Washington Department of Ecology (Ecology) as the nonfederal authority for the NPDES program in Washington. • Also includes a Sand and Gravel Permit, which covers the discharge of pollutants from sand and gravel mining operations and related facilities into waters of the state.
Section 404 of the Clean Water Act EPA Clean Water Act Section 404(b)(1) Guidelines (40 Code of Federal Regulations 230)	Regulates the placement of dredged or fill material into waters of the United States; evaluation will be conducted under auspices of the Section 404(b)(1) Guidelines.

REGULATION, STATUTE, GUIDELINE	DESCRIPTION
STATE	
Washington State Water Code (Revised Code of Washington [RCW] 90.03)	Establishes water policy for the state of Washington, which is administered by Ecology; RCW 90.03.350 establishes oversight for the construction or modification of a storage dam of 10-acre feet or more of water, resulting in a Dam Safety Permit.
Washington State-Administered Section 401 of the Clean Water Act	Delegates authority to the State of Washington to approve, condition, or deny proposed projects that may result in discharge to waters of the United States that are under Clean Water Act jurisdiction.
Shoreline Management Act (RCW 90.58)	Requires all counties and most cities with shorelines to develop and implement Shoreline Master Programs.
Washington State Hydraulic Code	Serves to protect aquatic resources by requiring all actions that use, divert, obstruct, or change the natural flow or bed of salt or fresh state waters to obtain a Hydraulic Project Approval from the Washington Department of Fish and Wildlife.
Surface Mining Act (RCW 78.44 and Washington Administrative Code 332-18)	Requires a permit for each mine that: 1) results in more than 3 acres of mine-related disturbance; or 2) has a high-wall that is both higher than 30 feet and steeper than 45 degrees; this would include local government approval of surface mining, issuance of a Washington Department of Natural Resources Surface Mining Reclamation Permit, and issuance of an Exploration Reclamation Permit.
Washington State Growth Management Act	Requires all cities and counties in Washington to adopt development regulations, according to best available science, that protect critical areas as defined in RCW 36.70A.030(5), including geologically hazardous areas.
LOCAL	
Lewis County Municipal Code Chapter 17.38 (Critical Areas); Chapter 17.25 (Shoreline Management); Chapter 15.45 (Stormwater Management)	Lewis County Code Title 17 (Land Use and Development Regulations) classifies and designates critical areas in Lewis County in Chapter 17.38. Chapter 15.45 advises stormwater quality and quantity controls for new development or redevelopment in Lewis County.
Chehalis Municipal Code Chapter 17.21 to 17.27 (Critical Areas); Chapter 17.18 (Shoreline Substantial Development Permit); Chapter 15.30 (Stormwater and Stormwater Runoff)	Chehalis Municipal Code Chapter 17 (Uniform Development Regulations) establishes regulations pertaining to the development of critical areas to protect Chehalis's environmentally sensitive resources and regulate development within the shoreline zone. Chapter 15.30 (Stormwater and Stormwater Runoff) establishes requirements designed to control the adverse impacts associated with increased stormwater runoff.
TRIBAL AUTHORITY	
Chehalis Tribal Code, Chapter 11.05, Permitting	Requires environmental review for activities that have the potential to affect sensitive areas within the jurisdiction and use areas of the Confederated Tribes of the Chehalis Reservation.

2 METHODOLOGY

2.1 Study Area and Affected Environment

The study area for geology consists of two distinct areas: the proposed FRE facility and the Airport Levee Changes (Figure F-1). The area between these two sites is not discussed in the context of geology, but it is addressed in reference to geomorphology.

The area of the proposed FRE facility is defined by: 1) the footprint of the FRE facility structure, its appurtenant facilities, and the excavation waste sites; 2) the area of the temporary reservoir maximum inundation level outline (elevation 627 feet) and adjacent slopes; and 3) three potential rock quarry sites and their connecting haul roads to the FRE facility. Geologic conditions have an impact on the proposed activities during construction and operation, and the project activities in these areas could potentially affect the geology.

The area of the proposed Airport Levee Changes is the levee surrounding the airport where it is proposed to be raised and the ground adjacent to the toe of the levee. Because of the minor amount of fill to be added to the top of the levee and the toe, the area of concern related to geology is limited to the levee footprint and the area(s) near the toe(s) of the levee.

2.1.1 Regional Geology

The Chehalis Basin encompasses approximately 2,700 square miles and is one of the largest river basins in Washington. It contains both Tertiary-age volcanic and sedimentary rock and glacially and alluvially deposited Quaternary sediment. Tertiary rocks are typically basalt formed on the oceanic floor overlain by marine and nearshore sandstone and siltstones. One basalt flow reached Southwestern Washington overland from Eastern Washington. Quaternary sediments were deposited by a variety of processes: continental glaciers, alpine glaciers, rivers, and landslides (Figure F-2).

The northern part of the Willapa Hills in the area of the proposed FRE facility is primarily composed of two formations: the volcanic Crescent Formation (basalt) and seafloor and nearshore sedimentary McIntosh Formation (Wells and Sawlan 2014). The McIntosh Formation is composed of siltstone, shale, and sandstone with interbeds of basalt flows and basaltic sandstone. Although not common, coal seams are found within the McIntosh Formation. North of the Willapa Hills, Grande Ronde Basalt (part of the Columbia River Basalt Group) overlies these older rocks. Uplift of the volcanic and sedimentary rocks resulted in the higher topography of the Willapa Hills compared to surrounding areas.

Figure F-1
Geology Study Area

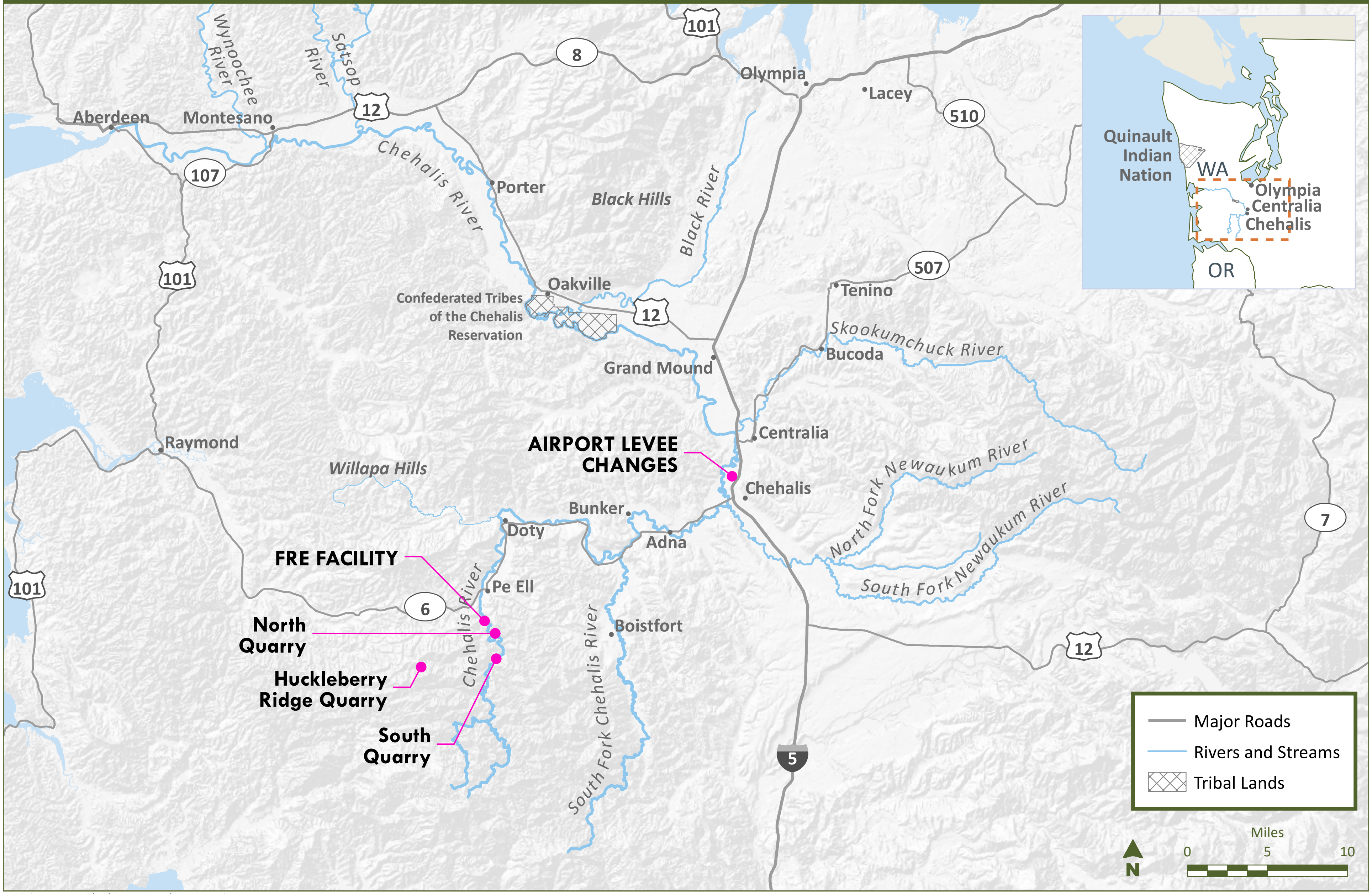

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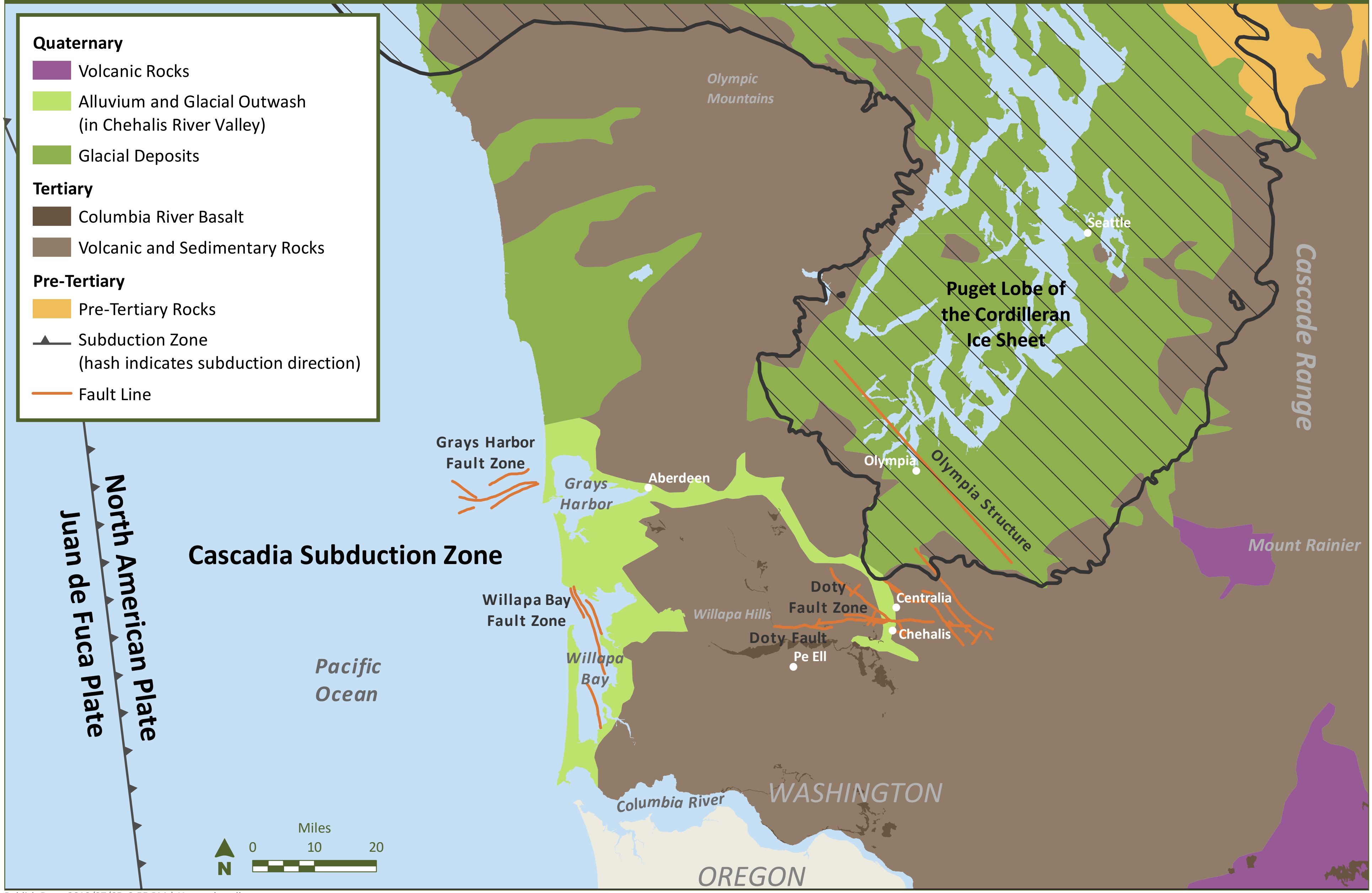
Figure F-2
Geologic Features of Southwestern Washington



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The eastern side of the Chehalis Basin is bounded by the Cascade Range. The foothills are composed of Tertiary volcanic rocks and continental (not deposited in marine waters) sedimentary rocks, typically sandstone and conglomerate. Some of the sedimentary formations, most notably the Skookumchuck Formation are coal bearing (DNR 2010).

The Olympic Mountains along the northern edge of the Chehalis Basin are similar in composition to the Willapa Hills. The core of the mountains is Tertiary marine sedimentary rocks, consisting of sandstone, siltstone, claystone, shale, mudstone, and locally derived conglomerate and volcanic breccia (DNR 2010).

In the northern and eastern portions of the Chehalis Basin, the current landscape was mostly formed by alpine and continental glaciations during the last ice age. The Basin was subject to both the continental Cordilleran Ice Sheet from the north and alpine glaciations from the Olympic Mountains and the Cascade Range.

Several times, the Puget Lobe of the Cordilleran Ice Sheet extended into the northern portion of the Chehalis Basin (Figure F-2; Gendaszek 2011 and references therein). The last advance of the Puget Lobe occurred approximately 17,000 years ago and reached the Chehalis Basin, with the southern extent of the glacier marked by terminal moraine deposits north of Rochester (Gendaszek 2011). As the Puget Lobe retreated northward, starting about 16,000 years ago, glacial meltwaters drained to the south through the current Chehalis River valley and deposited thick layers of recessional outwash (coarse sand and gravel) in the valley bottom (Gendaszek 2011).

As the Puget Lobe retreated, meltwater channels were routed through the terminal moraine creating a series of spillways and valleys, and depositing recessional glacial outwash in the Chehalis River and its tributaries (Skookumchuck River, Black River, Satsop River, and Scatter Creek; Gendaszek 2011). These recessional outwash deposits from the ice sheet were deposited as far south as Centralia and created a natural blockage that formed glacial Lake Chehalis. This lake extended from the Chehalis River/Skookumchuck River confluence to the Chehalis River/Newaukum River confluence. Alpine glaciers from the Cascade Range and the Olympic Mountains also advanced into the Chehalis Basin and deposited several sequences of glacial drift in headwaters and valleys. It is thought that advances from glaciers from the Olympic Mountains have occurred at least four times, with the deposition of glacial till and outwash across the northwestern portion of the Chehalis Basin (Gendaszek 2011).

2.1.2 Topography

The topography in the Chehalis Basin is quite variable. In the headwaters of the Basin, slopes are very steep. Where basalt is dominant, such as the Willapa Hills and the southern edge of the Olympic Mountains, slopes are steepest (80% or steeper). Where sedimentary rocks are present, slopes are slightly gentler, but still steep (60% to 80%). In the foothills, slope gradients are highly variable, from about 30% to 60%. The Chehalis Basin is topographically dominated by a relatively level valley floor. The valley is mostly low gradient (0% to 5%), except where tributary rivers and creeks enter the valley, in which case surface gradients may reach 10%. The Chehalis River is locally incised into the valley alluvium a few to 30 feet, the slope of which may be near vertical locally.

2.1.3 *Geologic Units at the FRE Facility*

Knowledge of the geologic units at the FRE facility site comes from observation of logging road cut slope exposures, existing Weyerhaeuser rock pit exposures, extensive drilling and sampling of soil and rock at the potential dam site and rock quarry sites, and laboratory testing of soil and rock obtained from the explorations.

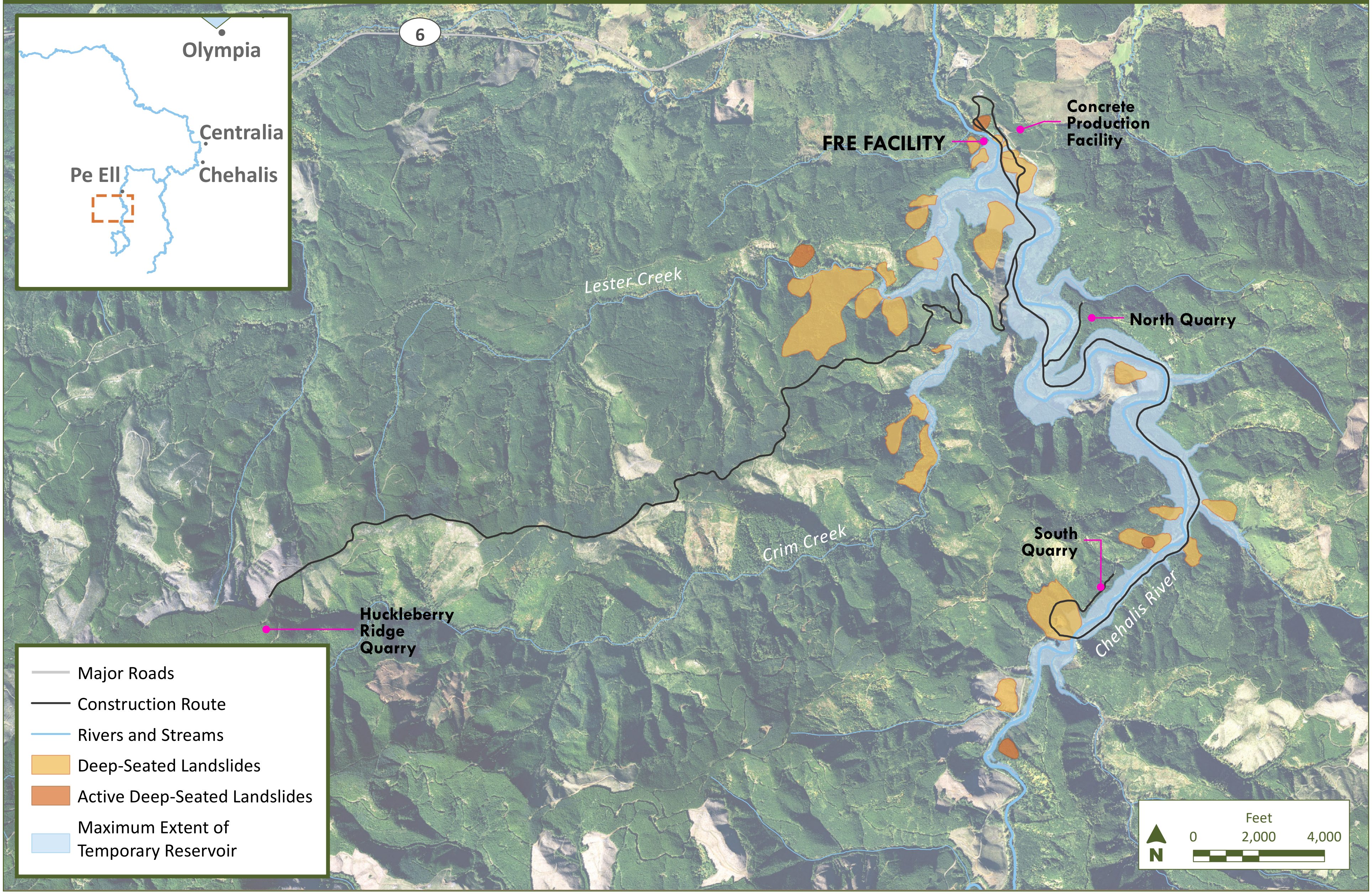
2.1.3.1 Landslides/Mass Wasting

Within the Chehalis Basin, landslides/mass wasting deposits are present in the Willapa Hills, Cascade Range, and the Olympic Mountains. There are many mapped and unmapped deep-seated and shallow, surficial landslides. Landslide deposits are composed of heterogeneous, mostly unsorted, and unstratified debris that is commonly identified by the presence of hummocky topography, closed depressions, springs or seeps, and an elongated landform with the base wider than the top of the landslide (Shannon & Wilson 2009). Landslides are commonly triggered by above-normal precipitation and/or undercutting of a slope, but they can be exacerbated by human disturbance such as clearing vegetation and building roads. For instance, during the 2007 storm, 12 to 26 inches of rain fell in a 4-day period in parts of the Chehalis Basin (Watershed Science & Engineering 2014) and more than 1,000 landslides occurred (Sarikhan et al. 2008).

Three types of landslides are found in the study area: 1) deep-seated; 2) shallow; and 3) debris flows. The largest in size of these three types are the deep-seated landslides, although they range from small to very large. The definition used herein for “deep-seated” is a landslide that is deeper than the tree root depth, commonly considered to be 6 to 10 feet. In general, in Western Washington, deep-seated landslide movement results from long-term wet periods, such as one or more winters with above normal rainfall, not single-storm downpours. Deep-seated landslides near the proposed FRE facility were evaluated in a three-step process, starting with a desktop study using Light Detection and Ranging (LiDAR) hillshade maps (Shannon & Wilson 2015), followed by field verification of identified deep-seated features (Shannon & Wilson 2016), and explorations/slope stability engineering studies (Shannon & Wilson 2017, 2019). Two of the originally identified deep-seated landslides were not considered further because field verification showed they were not landslides, but landforms that mimicked landslides. The deep-seated landslides as currently understood within or close to the temporary reservoir are presented in Figure F-3.

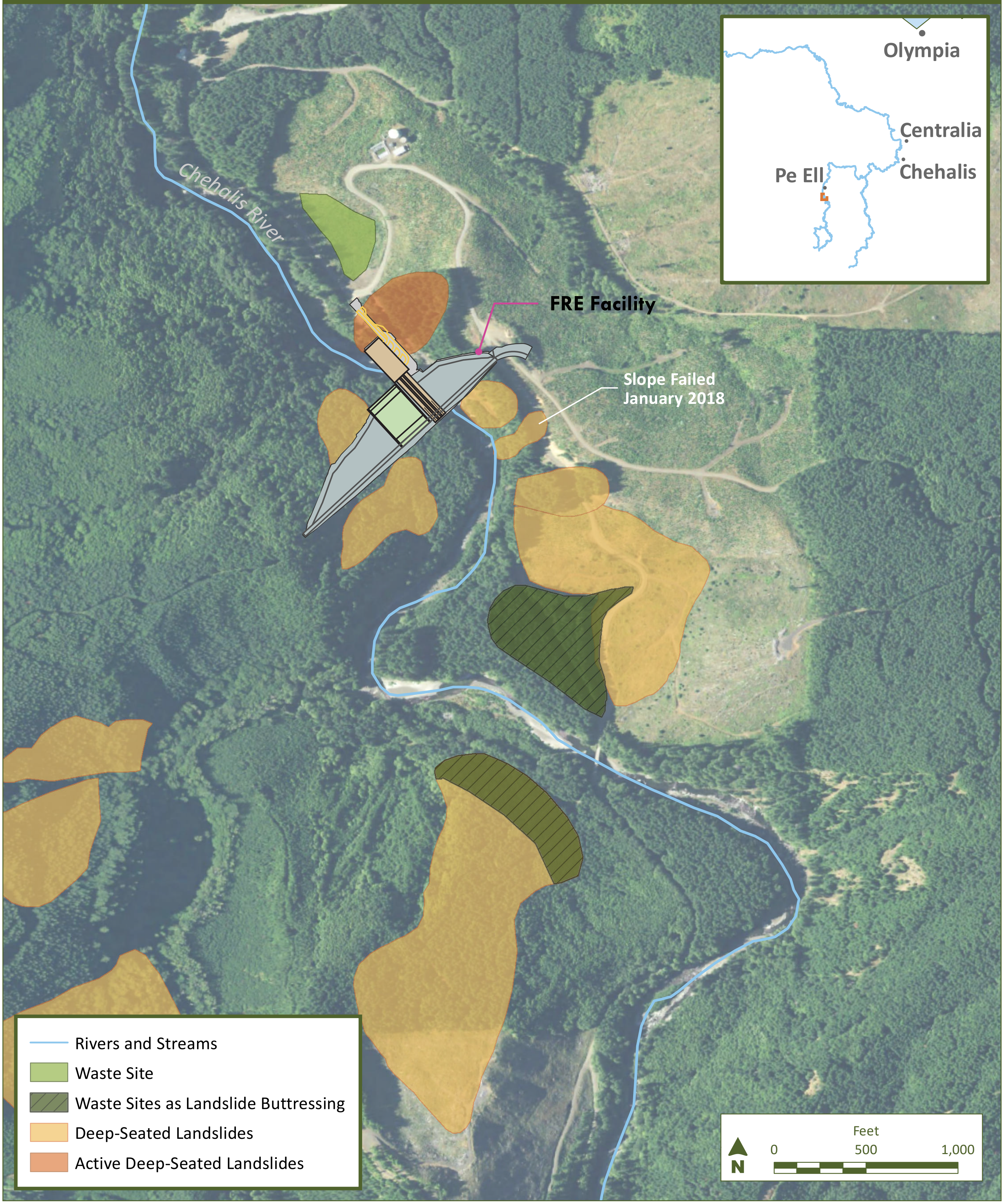
Of the 27 landslides shown in Figure F-3, four show signs of activity. The others are dormant or relict. Of all the landslides studied in the temporary reservoir area, six could have a potential effect on the FRE facility (Figure F-4).

Figure F-3
Deep-Seated Landslides and Prospective Quarry Sites



Source: Shannon & Wilson 2017 (deep-seated landslides)

Figure F-4
Geologic Impacts and Potential Landslide Buttressing Areas Near FRE Facility



Sources: Shannon & Wilson 2017 (deep-seated landslides); CBS 2017 (landslide buttressing areas); HDR 2017 (facility drawing)

Shallow landslides have been active in the past based on landslide inventories performed by Weyerhaeuser (1994a) and the Washington Department of Natural Resources (DNR) Washington Geological Survey (Sarikhan et al. 2008). The Weyerhaeuser inventory was performed as one module of the *Chehalis Headwaters Watershed Analysis* (Weyerhaeuser 1994a). The Chehalis headwaters was one of 53 drainage basins completed state-wide to assess the impact of timber harvesting and other forest activities on the natural and built resources. In that inventory, Weyerhaeuser geologists identified 12 shallow, rapid landslides that could have affected the potential temporary reservoir. Following the significant storm of 2007, Washington Geological Survey geologists mapped 35 landslides in the same area of interest (Sarikhan et al. 2008).

As shown in Figure F-5, deposits of seven of these shallow, rapid landslides and deposits of 15 shallow landslides could potentially be affected by mid- or late -century major or catastrophic floods. The rest of the shallow landslides initiated in topographical concavities at a higher elevation than the late-century catastrophic flood elevation (627 feet).

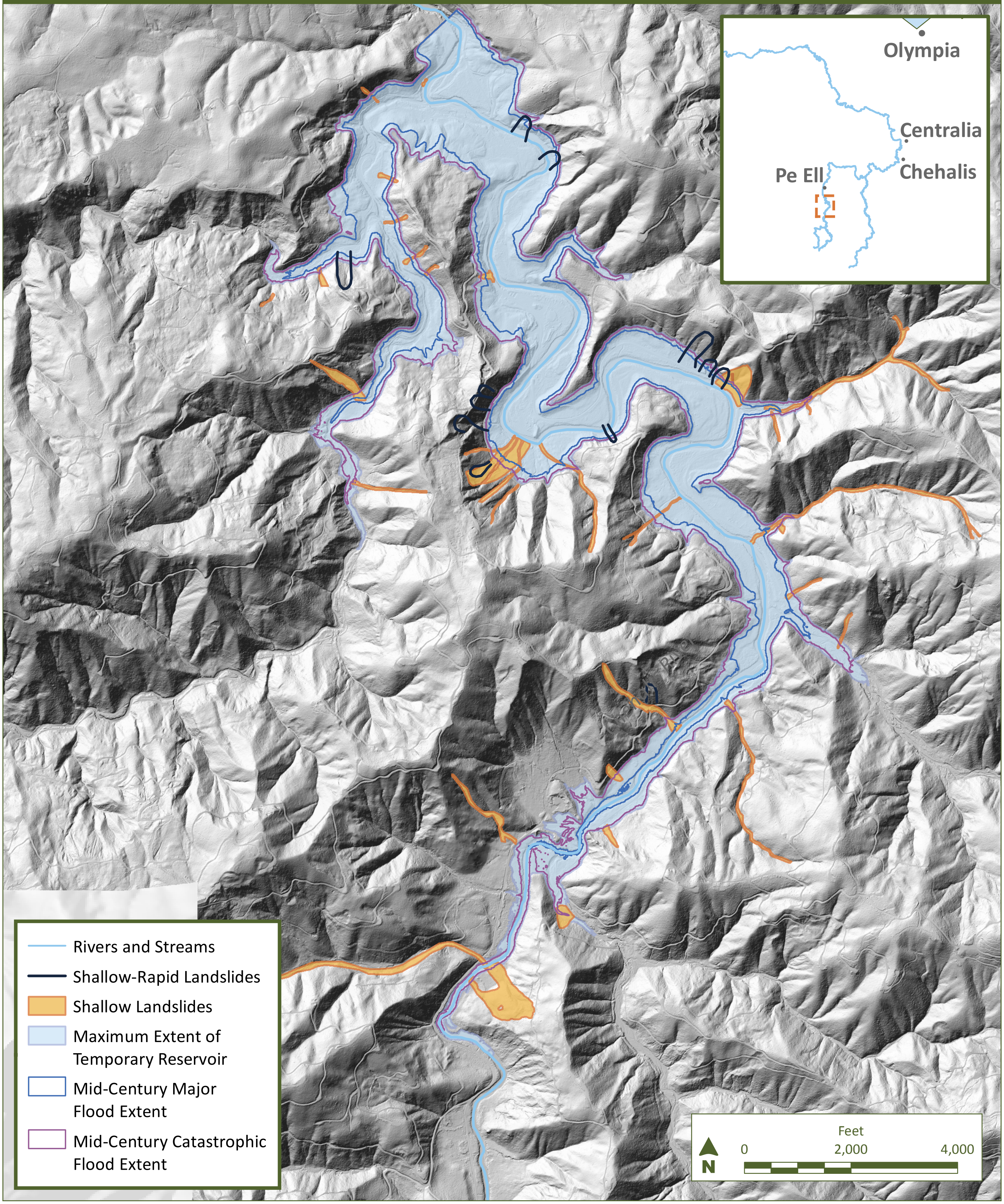
Debris flows are landslides that originate at a higher elevation, originally as debris avalanches or shallow landslides, but transform into debris flows along a channel, bulking into a larger mass and commonly traveling substantial distances. Of the 47 shallow landslides, 21 were the debris flow subset. All these events started outside of the temporary reservoir area at the late-century catastrophic flood level.

Most landslides in the forestlands of Western Washington occur during high-intensity storms when rain, often in combination with melting snow (i.e., rain-on-snow events), saturates soil layers or contributes to streamflow, which can undercut the toes of adjacent landslide areas. For example, recently harvested areas or poorly designed roads on marginally stable slopes are more likely to result in shallow landslides during normal storms than areas that are forested or void of roads. However, in recent years, changes in forest practices to avoid harvesting and road building on unstable ground have improved the management of areas and reduced the potential of landslides (Dubé 2016).

2.1.3.2 Stream Alluvium

Stream alluvium is located along the valley floors of the Chehalis River, including the airport levee area, and its tributary streams and consists primarily of very loose to loose, stratified, slightly silty fine sand, gravelly sand, and sandy gravel. Organics are present locally. Larger clasts range from pebbles to boulders; some as large as 3 to 4 feet. Modern Quaternary alluvium is present in the active channels, and older alluvium is found in terraces as high as 15 feet above the modern stream channel.

Figure F-5
Existing Shallow Landslides Within Temporary Reservoir Area



Sources: Weyerhaeuser 1994a (shallow-rapid landslides); Sarikhan et al. 2008 (shallow landslides)

2.1.3.3 Colluvium

Colluvium consists of poorly sorted, loose to dense, sandy to gravelly clay or silt deposited on or at the base of hillslopes, primarily through the gravity-driven transport of weathered rock and soil. These deposits may contain high percentages of subangular, basalt, or gabbro boulders. Landslide deposits are one type of colluvium.

2.1.3.4 Intrusive Igneous Volcanic Rocks

Gabbro is a high- to very-high-strength, dark gray to black, fine- to medium-grain rock that ranges from massive to blocky. It was only identified in one boring.

2.1.3.5 McIntosh Formation

The McIntosh Formation represents a thick sequence of locally tuffaceous marine siltstone and claystone interbedded with arkosic and basaltic sandstone. It is found above the right abutment, where local surface exposures are highly to completely weathered and weak. It is thought to be interbedded with basalt of the Crescent Formation at depth.

2.1.3.6 Crescent Formation and Interbedded Siltstone/Claystone

The Crescent Formation is characterized by massive basalt flows, pyroclastic flows, and tuffaceous sandstone. Crescent basalt is commonly found in the form of pillow basalt but can also be intrusive. Basalt ranges from weak to very strong, sometimes in close proximity. It is a dark gray to gray-green, fine- to medium-grain, closely to widely spaced rock with high- to low-angle joints. The basalt is fresh to slightly weathered with scattered moderately to highly weathered zones.

In between basalt flows, local volcanic rocks weathered and were eroded and deposited as silt and clay, ultimately becoming siltstone/claystone within the Crescent Formation. These sedimentary interbeds are more consolidated and stronger than the overlying McIntosh Formation rocks.

2.1.4 Seismic Setting

The seismic characteristics of the Chehalis Basin are important when evaluating the proposed FRE facility. There are two tectonic convergence regimes that deform the Chehalis Basin and the rest of Western Washington: 1) east-west contraction across the Cascadia Subduction Zone (CSZ); and 2) north-south shortening from the Juan de Fuca Plate that is subducting at an oblique northeast direction relative to the Washington coast (Figure F-2). The combined effects of the two tectonic motions produce complex and diverse deformation and can trigger large, damaging earthquakes within or close to the Chehalis Basin.

2.1.4.1 Cascadia Subduction Zone

The subduction of the oceanic Juan de Fuca Plate beneath the continental North American Plate triggers earthquakes in three sources: 1) at the subduction plate interface; 2) within the subducting slab; and

3) within the shallow, overriding continental crust. At the subduction plate interface, the two plates are locked together by friction. The potential for a 9.0-magnitude (mega-thrust) earthquake exists if the frictional strength of the fault is exceeded and the fault slips (Wang et al. 2003; Atwater and Hemphill-Haley 1997; Goldfinger et al. 2003). Along the coast, this fault slip can trigger sudden land subsidence, strong ground shaking, tsunami inundation, liquefaction, and submarine landslides. Based on studies by Shannon & Wilson, the shaking on the CSZ will control the seismic design of the FRE structure (HDR and Shannon & Wilson 2015).

2.1.4.2 Doty Fault Zone

The Doty Fault Zone (DFZ) is an east-west trending crustal fault zone that initiates about 3 miles (5 kilometers [km]) northwest of Doty and extends just east of Chehalis. It is the closest fault to the proposed FRE facility (approximately 9 miles [15 km]) and the only fault zone suspected of being active in the Chehalis Basin (HDR and Shannon & Wilson 2015). The eastward extension of the DFZ disappears beneath the Chehalis River valley, then continues east for another 6 miles (10 km) for a total length of 25 to 31 miles (40 to 50 km). The DFZ is capable of producing a 6.9-magnitude earthquake (Wells and Coopersmith 1994). Other fault zones are present in the vicinity of the Chehalis Basin, such as the Grays Harbor Fault Zone, Willapa Bay Fault Zone, and the Olympia Structure (Figure F-2). Geologic and geophysical studies of the DFZ are being conducted by the Washington Geological Survey.

2.2 Studies and Reports Referenced/Used

Multiple studies evaluating area geology and geologic processes were developed and used to support the technical analysis in this discipline report, including the following:

- *Chehalis Basin Strategy Programmatic Environmental Impact Statement* (Ecology 2017)
- *Reconnaissance-Level Geotechnical Report, Proposed Chehalis River and South Fork Dam Sites, Lewis County, Washington* (Shannon & Wilson 2009)
- *Preliminary Desktop Landslide Evaluation* (Shannon & Wilson 2014a)
- *Quarry Rock Desktop Study* (Shannon & Wilson 2014b)
- *Landslide Reconnaissance Evaluation of the Chehalis Dam Reservoir* (Shannon & Wilson 2015)
- *Phase 1 Site Characterization Technical Memorandum* (HDR and Shannon & Wilson 2015)
- *Phase 2 Chehalis Dam Geotechnical Data Report* (Shannon & Wilson 2016)
- *Phase 2 Site Characterization Technical Memorandum* (HDR and Shannon & Wilson 2016)
- *Phase 2 Chehalis Dam Landslide Evaluation Technical Memorandum* (Shannon & Wilson 2017)
- *Rock Quarry Characterization, Potential RCC Aggregate Sources for Dam Site* (Shannon & Wilson 2019a)
- *Phase 3 Chehalis Dam Geotechnical Data Report* (Shannon & Wilson 2019b)

The technical analysis helped provide an understanding of existing conditions and evaluate potential impacts from the Proposed Action and alternatives, including the following:

- Evaluation of foundation conditions for the FRE facility to ensure safe construction and operation
- Evaluation of potential impacts from seismic activity near and far from the FRE facility
- Evaluation of suitable quality concrete aggregate from rock borrow pits within and outside the temporary reservoir
- Potential for reactivation of deep-seated landslides and landslide deposits due to fluctuating reservoir levels
- Potential for triggering reservoir-induced earthquakes
- Potential for increased sediment within the temporary reservoir due to shallow landslides caused by fluctuating reservoir levels (geology and geomorphology)
- Potential for stockpiled soils excavated from the FRE facility to cause increased sediment delivery to waterbodies

2.3 Technical Approach

The approach summarized here was informed by studies and analyses conducted from 2009 to 2019.

2.3.1 Proposed FRE Facility Site

2.3.1.1 Reconnaissance

Geologists and geotechnical engineers have performed ground reconnaissance at the potential FRE facility site including the temporary reservoir area several times since the initial studies started in 2009. The first site geologic mapping was conducted by three geologists (Shannon & Wilson 2009). A subsequent reconnaissance was completed by geotechnical engineers to characterize the properties of the rock exposures at the site in 2015. During the subsequent drilling program in 2016 (as described in the following section), additional reconnaissance was carried out to confirm previous observation and conclusions.

2.3.1.2 Subsurface Explorations

Two phases of subsurface exploration, consisting of 18 borings, were completed at the potential FRE facility site (HDR and Shannon & Wilson 2016). The borings were drilled and sampled along the dam centerline, the bypass tunnel, the overflow structure, and the saddle dam (which has since been eliminated from the design). Sampling included soil sampling with a split-spoon sampler and rock coring. At the completion of each boring, water pressure testing was performed to evaluate the hydraulic conductivity of the rock formation. To supplement the rock core samples, downhole geophysical testing was completed, consisting of acoustic and optical televiewers for the borehole walls and sonic suspension logging to obtain compressional and shear wave velocities of the surrounding rock. Vibrating wire piezometers (VWPs) were installed in each boring to monitor groundwater levels. The data from the VWPs are uploaded annually. These data were combined in a comprehensive log for each boring.

2.3.1.3 Geophysical Field Testing

Seismic refraction tomography was conducted on four alignments for potential dam structure: along the dam centerline, the bypass tunnel, overflow structure, and the saddle dam (HDR and Shannon & Wilson 2016; Global Geophysics 2015, 2016). The velocity of seismic (shear and compression) waves travelling through rock provided an indication of the competency and rippability of the rock and can also provide an indication of the degree of fracturing and weathering in the rock. This testing also helps establish the depth to competent bedrock and foundation excavation limits as well as identify highly fractured zones that may require foundation treatment.

2.3.1.4 Laboratory Testing

Laboratory testing was performed to establish engineering properties for the natural materials encountered at the potential FRE facility site. Index testing consisting of water contents, grain-size analysis, and Atterberg limits was performed on the overburden soils. Testing on rock cores included unconfined compressive strength, slake durability testing, direct shear tests, point load tests, specific gravity tests, and petrographic analysis.

2.3.1.5 Engineering Analyses

For the potential FRE facility, elastic response models of two dam cross-sections were developed and response spectra analyses were performed with the computer program SAP2000 (Computers & Structures 2000), then checked with a spreadsheet model based on Fenves and Chopra's *Simplified Earthquake Analysis of Concrete Gravity Dams* (1987; Appendix A) and hand calculations. Appendix B (Fenves and Chopra 1987) was used for estimating stresses during earthquake loading, overturning and sliding stability.

Nonlinear analyses of the two cross-sections were performed using the program EAGD-SLIDE (Geoengineer) to model the compressible water-foundation-structure dynamic response with base sliding for combined loading of hydrostatic pressures, uplift pressure distributions, and horizontal and vertical earthquake input motions (Chavez and Fenves 1995).

The *Combined Dam and Fish Passage Conceptual Design Report* prepared for the Chehalis Basin Strategy describes the seismic evaluation of a Flood Retention Flow Augmentation (FRFA) concept (CBS 2017). Because the FRFA has a permanent pool, it is considered the critical condition for the analysis.

A basic gravity analysis was performed to evaluate dam stability for the FRFA with water standing at normal pool elevation (627 feet) and for probable maximum flood (PMF) flowing through the spillway (687 feet). Gravity analyses for the normal pool and PMF water elevations show that the non-overflow and overflow sections of the dam remain in compression along the base and, therefore, meet foundation compression criteria under normal pool and flood loading conditions. Because the FRE facility would have a temporary pool, it would have the same or less compression than the conditions for the FRFA with a permanent pool, so this analysis addresses the FRE facility as well.

Response spectra analysis (using SAP2000) was performed for 500-, 2,500-, 5,000-, and 10,000-year return periods with water at the assumed normal pool elevation for the FRE (627 feet). Based on an assumed 45-degree friction angle, the response spectra analyses indicated the potential for sliding in both upstream and downstream directions during earthquakes. Because of the potential impact of earthquakes on the effectiveness of the drain system and resulting uplift pressures, "no drain" and "with drain" conditions were evaluated for the site. An extreme uplift scenario was also evaluated, which assumes full upstream water pressure below the structure extending to the downstream toe of the structure. The response spectra analysis for these three uplift scenarios yielded estimated post-earthquake factor of safety (FOS) for sliding under normal pool loading conditions. With an assumed friction angle of 45 degrees, post-earthquake FOS are 1.8 for the "no drain" condition and 2.1 for the "with drain" condition. For the extreme uplift scenario and a friction angle of 30 degrees, the post-earthquake FOS is 1.1. A friction angle of approximately 40 degrees would be required to ensure a post-earthquake FOS exceeding 1.5. The FRE facility would have acceptable factors of safety for project earthquake stability criteria.

A non-linear time-history analysis was performed (using EAGD-SLIDE) to evaluate the effects of earthquakes over time. Assuming a rigid base, this analysis shows sliding of about 0.43 foot for the 2,500-year return period, 1.07 feet for the 5,000-year return period, and 4.91 feet for the 10,000-year return period. This analysis shows sliding of less than 0.05 foot for the 2,500-year return period, 0.08 foot for the 5,000-year return period, and 0.53 foot for the 10,000-year return period. The actual friction angle between the foundation and base rock could be higher or lower than the assumed value of 45 degrees and should be confirmed during final design using direct shear testing with representative concrete and bedrock materials.

2.3.2 Rock Aggregate Quarry Sites

2.3.2.1 Reconnaissance

Evaluation of rock aggregate quarry sites was performed in a three-step process: 1) a desktop study using available public information and visits to two commercial quarries (Shannon & Wilson 2014b); 2) field reconnaissance of existing Weyerhaeuser rock quarries and natural and roadcut rock exposures (Shannon & Wilson 2016); and 3) subsurface explorations at potentially favorable sites (Shannon & Wilson 2017, 2019a).

2.3.2.2 Subsurface Explorations

After identifying rock outcrops on existing Weyerhaeuser quarry sites that appeared to have suitable rock for the roller-compacted concrete (RCC) mixture, drilling was performed to obtain rock core samples for visual evaluation and testing. Four quarry sites were explored: North Quarry (four borings), South Quarry (one boring), Huckleberry Ridge Quarry (one boring), and Rock Creek Quarry (two borings). The North Quarry, South Quarry and Huckleberry Ridge Quarry are shown in Figure F-1. Based on the results of poor quality rock from drilling and laboratory testing, Rock Creek Quarry was eliminated as a potential quarry rock source for the potential FRE facility. VWPs were installed in each boring to monitor groundwater levels. The data from the VWPs are uploaded annually. In 2017, seismic refraction tomography was performed at the North Quarry and the Huckleberry Ridge Quarry to determine the depth to bedrock between borings.

2.3.2.3 Laboratory Testing

The rock samples obtained from selected rock outcrops, Weyerhaeuser and commercial stockpiles, and rock cores were subjected to testing for suitability as RCC aggregate. Testing included specific gravity, absorption, unconfined compressive strength, Los Angeles (LA) abrasion, and alkali-silica reactivity (ASR). The results are presented in Table F-4.

2.3.3 Landslides

2.3.3.1 Desktop Study

In 2014, Shannon & Wilson performed a desktop study of deep-seated landslides using LiDAR hillshade images. Twenty-seven deep-seated landslides were identified by their landform characteristics, such as headscarps, bulbous toes, and hummocky ground surfaces.

2.3.3.2 Reconnaissance

In 2015, Shannon & Wilson completed field reconnaissance of the landslides identified in the desktop study. In the field, geologists observed signs of unstable ground, such as earth cracks or fissures, springs, hummocky ground surface, toe bulging, diagnostic tree species, split trees, tree bowing or tilting, stream undercutting, unusual drainage patterns, and rock/soil exposures. Two of the identified landforms were determined in the field not to be landslides; just landforms that appeared to be landslides on LiDAR images. Of the remaining landslides, four showed signs of activity. In January 2018, a new landslide occurred near the right abutment of the potential FRE facility structure, as shown in Figure F-4.

2.3.3.1 Subsurface Explorations

Borings were completed at 14 landslides to characterize the subsurface conditions and to install landslide monitoring instruments (Shannon & Wilson 2019). Borings were extended down through the soil overburden to 10 to 20 feet into bedrock. Soil samples were taken in the overburden and then rock cored below the soil/rock contact. After completion of the drilling, an inclinometer casing was installed to allow monitoring of the lateral movement of the landslide mass, and a VWP was attached to the outside of the casing to monitor groundwater levels. Data are collected annually from these installations.

Seismic refraction tomography was performed at eight of the landslides in 2017 to determine the depth to bedrock and the potential slip plane of the landslide or landslide deposit.

Table F-4

Prospective Quarry Lab Test Results

BORING	SAMPLE DEPTH (FEET)	SPECIFIC GRAVITY	SLAKE DURABILITY (%)	ABSORPTION (%)	LA ABRASION (%)	ASR (16 DAY) (% LENGTH CHANGE)	ROCK TYPE
BNQ-18-301	93.5-95.9	--	--	--	--	--	altered amygdaloidal basalt
	105.0-105.2	--	--	--	--	--	altered amygdaloidal basalt
	80-100	2.50	--	6.8	19.8	--	--
	100-120	2.69	--	4.8	21.5	--	--
RNQ-18-302	64.6-64.8	--	--	--	--	--	altered amygdaloidal basalt
	81.5-82.5	--	26.5, Type III --	--	--	--	siltstone
	75-92.4	2.51		8.85	18.5	0.055	
RNQ-18-303	80.3-80.5	--	--	--	--	--	altered amygdaloidal basalt
	50-64.6	2.72	--	5.08	18.9	0.049	
QB-1, North Quarry*	38-50	2.60	--	6.46	27.1	0.08	--
	84-95	2.65	--	4.69	26.8	0.076	--
	127-140	2.49	--	8.26	27.5	0.124	--
QB-2 Huckleberry Ridge*	15-27	2.69	--	4.04	24.8	0.034	--
	45-55	2.71	--	3.72	24.1	0.036	--
RSQ-18-301	55.7-55.9	--	--	--	--	--	altered amygdaloidal basalt
	154.0-154.2	--	--	--	--	--	altered amygdaloidal basalt
	50.2-70	2.71	--	3.3	20.5	0.042	
	100-118.2	2.80	--	2.9	18.9	0.047	--
	149.8-171.2	2.63	--	4.9	20.4	0.042	--
1020 Road Cut	Grab	2.72	--	2.35	18.4	0.254	--
RCQ-18-301	75.6-75.9	--	--	--	--	--	altered basalt
	120.95-121.2	--	--	--	--	--	altered mafic volcaniclastic
RCQ-18-302	160.5-160.7	--	--				altered amygdaloidal basalt
	51.6-52.5	--	86.8, Type II	--	--	--	siltstone
	83.3-84.2	--	87.7, Type II	--	--	--	siltstone
	151-167.7	2.52		3.21	19.2	0.31	

Notes:

0–0.10 innocuous, 0.11–0.20 acceptable if supplemental testing confirms expansion is not due to ASR, >0.20 requires additional testing.

*Boring names from previous years' testing

2.3.3.2 Laboratory Testing

Soil samples obtained in landslides and landslide deposits were subjected to the following tests to determine their engineering characteristics: water contents, grain-size analyses, combined sieve analysis, direct shear testing, Atterberg limits, and ring shear tests. The results were used in slope stability analyses.

2.3.3.3 Stability Analyses and Potential Remedial Measures

To evaluate the effects of a fluctuating reservoir level on the stability of the identified deep-seated landslides, slope stability analyses were performed using SEEP/W for groundwater simulation and SLOPE/W for stability modeling (Geo-Slope International 2014a, 2014b). Ten landslides were selected for evaluation based on their proximity to the proposed FRE facility and enough volume that, if fully mobilized, would be unstable and could threaten the integrity of the dam. For each landslide, the initial stability of a slope under the highest reservoir pool was determined, and each landslide was also assessed for stability during inundation and drawdown.

For most of the landslides, the landslide mass/deposit was stable under the drawdown conditions; however, in two cases, modeling indicated that reservoir drawdown would create instability. In both cases, applying standard slope stabilization methods (earth and rock buttressing and drainage) in the model proved to be successful in increasing the safety factor to a suitable factor of safety of 1.3 to 1.5 based on geotechnical industry standards (Cornforth 2005). Stabilization of landslides near the FRE facility would be required in the Dam Safety Construction Permit.

2.3.4 Seismic

To provide seismic parameters for the preliminary design of the FRE facility, geotechnical studies were completed (HDR and Shannon & Wilson 2015). The primary seismic hazards for the FRE facility are ground motion and fault rupture. A seismic hazard analysis was performed to identify the potentially active faults near the site and the seismogenic effects on the structure. The conclusion was that several faults in Western Washington could potentially have an effect on the FRE facility, namely the CSZ plate interface, the CSZ intraslab, the Olympia Fault, and the Doty Fault. The study concluded that the controlling maximum credible earthquake is a CSZ interface event.

Design earthquake time histories were provided for probabilistic ground motions with a 2,500-year return period as well as other return periods ranging from 500 to 10,000 years. Deterministic maximum credible earthquake ground motions were created for a magnitude 8.9 CSZ interface earthquake, a magnitude 7.5 CSZ intraslab earthquake, a magnitude 7.1 Olympia Fault earthquake, and a magnitude 6.9 Doty Fault earthquake (HDR and Shannon & Wilson 2015).

Earthquakes have been generated by deep reservoirs in other parts of the United States and the world. Studies of these phenomena show that such earthquakes are localized and low magnitude. In general, reservoir-induced seismicity is considered to be a potential impact when the reservoir pool is about

250 to 300 feet deep and is permanent, not temporary (Gupta 1992). The hypothesized cause for such earthquakes is the deep penetration of fluids into the underlying geologic formation. The potential depth of the temporary reservoir is 88 feet for a major flood and 202 feet for a catastrophic flood.

3 TECHNICAL ANALYSIS AND RESULTS

3.1 Overview

This section describes the probable geology impacts from the Proposed Action (Section 3.2), Local Actions Alternative (Section 3.3), and No Action Alternative (Section 3.4). This section also evaluates required permit conditions and planning document requirements that could address the impacts identified (Section 3.2.3). When probable significant adverse environmental impacts remain after considering these, the report identifies mitigation measures that could avoid, minimize, or reduce the identified impact below the level of significance (Section 3.2.4).

3.2 Proposed Action

3.2.1 Impacts from Construction

3.2.1.1 FRE Facility

The excavation of soil and rock for the foundations of the FRE facility and appurtenant facilities, including spoils from the temporary bypass tunnel, would modify the existing geological conditions and create sediment that could enter the Chehalis River. The National Pollutant Discharge Elimination System (NPDES) Construction Stormwater General Permit would require sediment created by the excavation waste to be kept below water quality thresholds; therefore, the impact would be **moderate to minor**.

The excavation of rock for the structure's foundation, mining of rock at the quarries, and the temporary bypass tunnel would require the use of explosives. Undetonated ammonia and nitrate (commonly preferred explosive components) on and in the exposed rock would potentially be washed into the Chehalis River, with potentially harmful effects on fish in the river. The NPDES Construction Stormwater General Permit would require runoff created by the blasting meet water quality thresholds; therefore, the impact would be **moderate to minor**. The impact would be mitigated through the use of one or more best management practices (BMPs), such as controlling spillage of explosives, use of packaged explosives, and efficient blast design that ensures complete detonation (Revey 1996).

The mining of rock quarry sites, expanding forest roads, and travel on haul roads between the quarry sites and the FRE facility construction site would create sediment that could reach creeks and the Chehalis River. Widening roads to rock quarry sites would also modify existing geological conditions. Mining could also cause localized destabilization and sediment through excavation. The NPDES Construction Stormwater General Permit would require these actions to meet water quality thresholds, and the Forest Practices Permit would require forest roads to use BMPs to reduce sediment; therefore, the impact would be **moderate to minor**.

Implementation of the Proposed Action would include application of BMPs during construction to address potential impacts from sediment entering streams (from excavation of overburden and rock in RCC aggregate quarries during construction). The Chehalis River Basin Flood Control Zone District (Applicant) will be required to meet applicable local, state, and federal regulations and to implement erosion and sediment control measures, largely associated with permits or other regulatory approvals, including but not limited to the following:

- Timing construction activities to avoid disturbing soils during wet weather
- Using straw bales, silt fencing, or other suitable sedimentation control or containment devices
- Washing truck tires to reduce tracking of sediment and aquatic invasive species from construction sites
- Covering exposed soil stockpiles and exposed slopes
- Using straw mulch and erosion control matting to stabilize graded areas where appropriate
- Retaining vegetation where possible to minimize soil erosion
- Seeding or planting appropriate vegetation on exposed areas as soon as possible after work is completed
- Constructing temporary sedimentation ponds to detain runoff waters where appropriate
- Installing and operating dewatering facilities to eliminate the potential for slope stability impacts associated with excavation
- Using berms, ditching, and other on-site measures to prevent soil loss
- Monitoring downstream turbidity during construction to document the effectiveness of implemented measures
- Visually monitoring for signs of erosion and for correct implementation of control measures

3.2.1.2 Airport Levee Changes

No adverse impacts on geology from construction of the Airport Levee Changes are anticipated.

3.2.2 Impacts from Operation

3.2.2.1 FRE Facility

Locations where probable deep-seated landslides could occur were evaluated in three landslide reports (Shannon & Wilson 2014a, 2015, 2017), based on LiDAR hillshade image interpretation and field reconnaissance. These reports evaluated areas with potential for deep-seated landslides; however, there remains a possibility that deep-seated landslides could occur in other locations. The fluctuating water level in the temporary reservoir could result in deep-seated landslide instability, and damage to the FRE facility from a landslide-induced seiche (oscillation of a water body). The changes in water level could also result in shallow landslides around the perimeter of the reservoir. The Applicant's project design includes using excavated material from the bypass tunnel and FRE facility to create stabilizing buttresses for the two landslides just upstream of the FRE facility, and placing the remainder in a stockpile downstream of the structure and to the east of the Chehalis River (see Figure F-4). While this is proposed by the Applicant, it is not certain if the material would be considered clean under Hydraulic Project Approval (HPA) standards. If this material is used in or near water, the HPA would require the material to be clean, appropriately sized, and fish-safe. Testing could be required to ensure the cleanliness of the materials. If the material does not meet cleanliness standards, it cannot be used. While operations of the FRE facility control the release of water from the reservoir to reduce the potential for landslides, the potential for landslides to occur would remain and these would have a **significant to minor** adverse impact on water quality due to increased turbidity.

Mitigation is proposed for the Applicant to develop a Surface Water Quality Mitigation Plan to mitigate impacts to water quality from landslides in the temporary reservoir; however, there is uncertainty if the implementation of a plan is technically feasible or economically practicable. Therefore, the Proposed Action would have **significant and unavoidable** adverse environmental impacts on water quality, unless the Applicant develops a Surface Water Quality Mitigation Plan that meets regulatory requirements and for which implementation is feasible.

Over the life of the FRE facility, an earthquake on the CSZ to the west or DFZ to the north could occur, causing damage to the FRE facility due to strong shaking. The estimated 2,475- and 10,000-year return period peak ground accelerations (PGAs) from the probabilistic hazard analysis for various sources are summarized in Table F-5 and the *Phase 1 Site Characterization Technical Memorandum* (HDR and Shannon & Wilson 2015).

Table F-5
2,475- and 10,000-Year Return Period Peak Ground Acceleration at the Chehalis Dam Site

SOURCE	ESTIMATED PGA (G) 2,475-YEAR RETURN PERIOD	ESTIMATED PGA (G) 10,000-YEAR RETURN PERIOD
Crustal Faults	0.1	0.18
Crustal Background	0.2	0.3
CSZ Intraslab	0.25	0.39
CSZ Interface	0.4	0.79
Total Aggregated Hazard from PSHA	0.49	0.83
MCE Hazard from DSHA	-	more than 0.3

Notes:
DSHA: deterministic seismic hazard analysis
G: standard gravitational acceleration
MCE: maximum credible earthquake
PGA: peak ground acceleration
PSHA: probabilistic seismic hazard analysis

The 2,475- and 10,000-year return period ground motions are approximately equivalent to 4% and 1% probability of exceedance in 100 years. Among the major hazard sources, a potential magnitude 8.9

CSZ interface with a single full rupture event within approximately 42 miles (70 km) from the FRE facility is capable of generating a PGA value of 0.31g (84th percentile) at the FRE facility.

These earthquakes could cause damage to the FRE facility that would require repair and potentially cause a temporary shutdown. If an earthquake were to occur when the reservoir was full, the structure would be expected to contain water under current dam design standards. However, while very unlikely, if a breach of the FRE structure occurred while the reservoir was holding water, the adverse impacts could not be mitigated and would be **significant and unavoidable**. The *Environmental Health and Safety Discipline Report* (ESA 2020a) identifies the potential impacts to downstream communities in more detail. Given the potential depth and the temporary nature of the reservoir, it is unlikely, based on criteria in Gupta (1992), that the FRE facility would cause an earthquake.

3.2.2.2 Airport Levee Changes

No adverse impacts on geology or geologic processes due to Airport Levee Changes are anticipated.

3.2.3 Required Permits

The following permits would be required for the Proposed Action:

- **Dam Safety Construction Permit (Ecology):** A dam safety construction permit is required before constructing, modifying, or repairing any dam or controlling works for storage of 10 or more acre-feet of water, liquid waste, or mine tailings. Ecology reviews and administers all dam safety permits in Washington to ensure compliance with state and federal construction and operation requirements. The FRE facility would require a dam safety permit prior to the start of construction.
- **Earth-Moving Permit (City of Chehalis):** An Earth-Moving Permit would be required for land disturbance that would be necessary to construct the Airport Levee Changes.
- **Exploration Reclamation Permit (DNR):** This permit will allow for exploration and reclamation of exploration sites for the dam site and the potential quarry sites, because trees may have to be removed and disturbance to the forest floor could occur without regulation and reclamation.
- **Hydraulic Project Approval (Washington Department of Fish and Wildlife [WDFW])**: The Proposed Action would use, divert, obstruct, and change the natural flow and bed of freshwaters of the state and therefore would require a Hydraulic Project Approval from WDFW under the state's hydraulic code rules. The Hydraulic Project Approval would include conditions intended to minimize impacts on instream and riparian habitat and functions.
- **Local Land Use and Development Permits (Lewis County and City of Chehalis):** The Proposed Action would affect water-related resources regulated by Lewis County (FRE facility) and the City of Chehalis (Airport Levee Changes) under Shoreline Master Programs, Critical Areas Ordinances, and floodplain and stormwater management codes. Permits from both local governments would be needed in accordance with their local development codes.
- **Lewis County Fill and Grade Permit:** This permit is required for excavating soil and rock for the dam foundations and related structures, and for placing waste materials in three designated

locations. Excavation will also be performed for three potential rock borrow pits that supply aggregate for the dam concrete.

- **NPDES Construction Stormwater General Permit (Ecology)**: Construction of the Proposed Action would result in more than 1 acre of ground disturbance and involve stormwater discharges to surface waters. Therefore, coverage under an Ecology Construction Stormwater Permit would be required. The NPDES permit would include conditions requiring the permittee to prepare a Stormwater Pollution Prevention Plan and implement appropriate erosion, sediment, and pollution control measures for the duration of construction.
- **NPDES Sand and Gravel Permit (Ecology):** FRE facility construction would require quarry development to provide aggregate for the FRE facility. Mining of concrete aggregate and concrete production would require coverage under Ecology's Sand and Gravel General Permit, which is a NPDES and State Waste Discharge Permit. The Sand and Gravel Permit includes conditions requiring the permittee to prepare a Stormwater Pollution Prevention Plan and implement best management practices to control pollutants from process water, mine dewatering water, and stormwater. The permit includes effluent limits and monitoring requirements for process water and mine dewatering discharges for parameters including pH, turbidity, total suspended solids, oil, and total dissolved solids.
- **Section 401 Clean Water Act Water Quality Certification (Ecology)**: Because a federal (U.S. Army Corps of Engineers [Corps] Section 404) permit would be needed to construct the Proposed Action, a Section 401 Water Quality Certification from Ecology would be needed to document the state's review of the project and its concurrence that the Applicant has demonstrated that the Proposed Action will meet state water quality standards. This certification is intended to provide reasonable assurance that the Applicant's project will comply with state water quality standards and other requirements for protecting aquatic resources, and covers both construction and operation of the facility.
- **Section 404 Clean Water Action Permit (Corps)**: Section 404 requires discharges of dredged/fill material to waters of the U.S. be done only under the authorization of a permit. Because construction of the FRE facility would involve excavation and fill placement in the Chehalis River, and construction of the Airport Levee Changes may involve fill placement in wetlands, the Proposed Action would require a Section 404 permit from the Corps.
- **Surface Mining Reclamation Permit (DNR):** This permit is required for the establishment and reclamation of the three potential aggregate borrow pits (North Quarry, South Quarry, and Huckleberry Ridge Quarry).

3.2.4 Proposed Mitigation Measures

This section describes mitigation measures proposed for the Applicant to implement that would reduce impacts related to geology from construction and operation of the Proposed Action. These mitigation measures would be implemented in addition to compliance with environmental permits, plans, and authorizations described in Section 3.2.3 that would be required for the Proposed Action.

The Applicant will implement the following measures to mitigate impacts on geology:

- **EARTH-1:** To reduce potential impacts on water quality from slope instability at the FRE facility during construction, mitigation is proposed for the Applicant to identify unstable ground in the proximity of the FRE facility and to either excavate and haul this material to a waste disposal site or stabilize the ground by methods such as soil nails, tieback shoring, rock bolts, shotcrete, bracing, and scaling.
- **EARTH-2:** To reduce impacts to the FRE facility from unstable deep-seated landslides, mitigation is proposed for the Applicant to develop a plan to stabilize landslides using, but not limited to, the following methods: 1) excavate unstable soil where adjacent to the FRE facility; 2) add buttressing and drainage to increase slope stability where adjacent to the FRE facility; and 3) monitor landslide activity where distant from the FRE facility. Ecology would approve the Landslide Stabilization Plan and it would be required to be implemented prior to or during construction.

Other Related Mitigation Plan:

- **WATER-1 (Surface Water Quality Mitigation Plan):** To reduce probable impacts to surface water quality and designated aquatic life uses of the Chehalis River and Crim Creek from construction and operation of the Proposed Action, mitigation is proposed for the Applicant to develop and implement a Surface Water Quality Mitigation Plan (for details, see *Water Discipline Report* [ESA 2020b]).

3.2.5 Significant and Unavoidable Adverse Environmental Impacts

- A breach of the FRE structure may occur at the same time water is impounded in the temporary reservoir. The risk of a breach is extremely low, even during a major earthquake, because the FRE structure would be designed to contain water under current dam design standards. However, if a breach of the FRE structure did occur when the temporary reservoir was holding water, the result would be a **significant and unavoidable adverse** environmental impact.
- There is uncertainty if mitigation is feasible; therefore, the Proposed Action would have **significant and unavoidable** adverse environmental impacts on surface water quality. The Applicant may provide a Surface Water Quality Mitigation Plan as described above. If Ecology determines the plan is feasible and meets the requirements of the Clean Water Act then the impacts would be addressed as part of the permitting processes.

3.3 Local Actions Alternative

No adverse impacts on geologic processes from construction or operation of the Local Actions Alternative are anticipated.

3.4 No Action Alternative

Under the No Action Alternative, flooding would not be significantly reduced. Geology or geological processes would continue to experience **substantial flood risk** under the No Action Alternative.

Geomorphology

4 INTRODUCTION

4.1 Resource Description

Geomorphology is the study of earth's surface processes. In the Chehalis Basin, the processes of concern include landslides, surface erosion, sediment transport and riverbed materials, and LWM in streams and rivers. These processes are important because they affect water quality, fish, and aquatic habitat.

4.2 Regulatory Context

Regulations pertaining to erosion and geomorphic change are listed in Table F-6.

Table F-6
Regulations, Statutes, and Guidelines for Geomorphology

REGULATION, STATUTE, GUIDELINE	DESCRIPTION
FEDERAL	
Section 402 of the Clean Water Act	• Establishes the NPDES program, under which certain discharges of pollutants into waters of the United States are regulated. • 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 Washington. • The NPDES Permit would include conditions requiring the permittee to implement appropriate erosion, sediment, and pollution control measures for the duration of construction.
Section 404 of the Clean Water Act EPA Clean Water Act Section 404(b)(1) Guidelines (40 Code of Federal Regulations 230)	Regulates the placement of dredged or fill material into waters of the United States; evaluation will be conducted under auspices of the Section 404(b)(1) Guidelines.
STATE	
Washington State Water Code (RCW 90.03)	Establishes water policy for the state of Washington, which is administered by Ecology; RCW 90.03.350 establishes oversight for the construction or modification of a storage dam of 10-acre feet or more of water, resulting in a Dam Safety Permit.
Washington State-Administered Section 401 of the Clean Water Act	Delegates authority to the State of Washington to approve, condition, or deny proposed projects that may result in discharge to waters of the United States that are under Clean Water Act jurisdiction.

REGULATION, STATUTE, GUIDELINE	DESCRIPTION
Shoreline Management Act (RCW 90.58) and Washington Administrative Code 173-26-221)	Requires all counties and most cities with shorelines to develop and implement Shoreline Master Programs; includes provisions for delineating channel migration zones and minimizing development and actions to limit channel migration as part of flood damage reduction efforts.
Washington State Hydraulic Code	Serves to protect aquatic resources by requiring all actions that use, divert, obstruct, or change the natural flow or bed of salt or fresh state waters to obtain an HPA from the Washington Department of Fish and Wildlife; the HPA would include conditions intended to minimize impacts on instream and riparian habitat and functions.
Washington State Growth Management Act	Requires all cities and counties in Washington to adopt development regulations, according to best available science, that protect critical areas as defined in RCW 36.70A.030(5), including geologically hazardous areas.
Washington Forest Practices Act (RCW 76.09)	Timber harvest within the proposed reservoir pool would be subject to Washington Forest Practices regulations.
LOCAL	
Lewis County Municipal Code Chapter 17.38 (Critical Areas); Chapter 17.25 (Shoreline Management); Chapter 15.45 (Stormwater Management)	Lewis County Code Title 17 (Land Use and Development Regulations) classifies and designates critical areas in Lewis County in Chapter 17.38. Chapter 15.45 advises stormwater quality and quantity controls for new development or redevelopment in Lewis County.
Chehalis Municipal Code Chapter 17.21 to 17.27 (Critical Areas); Chapter 17.18 (Shoreline Substantial Development Permit); Chapter 15.30 (Stormwater and Stormwater Runoff)	Chehalis Municipal Code Chapter 17 (Uniform Development Regulations) establishes regulations pertaining to the development of critical areas to protect Chehalis's environmentally sensitive resources and regulate development within the shoreline zone. Chapter 15.30 (Stormwater and Stormwater Runoff) establishes requirements designed to control the adverse impacts associated with increased stormwater runoff.
TRIBAL AUTHORITY	
Chehalis Tribal Code, Chapter 11.05, Permitting	Requires that environmental review take place for activities that have the potential to affect sensitive areas within the jurisdiction and use areas of the Confederated Tribes of the Chehalis Reservation.

5 METHODOLOGY

5.1 Study Area and Affected Environment

The study area for geomorphology includes the mainstem Chehalis River from upstream of the potential temporary reservoir area (approximately RM 117) to Montesano (approximately RM 9) as well as the reservoir area (Figure F-6). Water, sediment, and wood inputs to the mainstem Chehalis River from major tributaries are considered in the analysis, but tributary streams themselves are not included in the analysis.

5.1.1 Geomorphic Setting

5.1.1.1 Watershed Characteristics

The Chehalis Basin drains 2,100 square miles in Southwestern Washington. The study area for the geomorphology analysis includes the watershed upstream of RM 9, a drainage of approximately 2,000 square miles. About 1,500 feet of major tributaries from the Chehalis River are located within the study area, including junctions of the South Fork Chehalis River, Newaukum River, Skookumchuck Creek, Black River, Satsop River, and Wynoochee River.

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 during the fall, winter, and early spring can result in large peak flows.

Most of the upper watersheds of the Chehalis Basin are underlain by Eocene to Miocene (56- to 5-million-year-old) volcanic and marine sedimentary rocks (DNR 2010). 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 and South Fork Chehalis River. The gravel-sized soft particles were 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 Mount 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 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 the watershed and deliver sediment, large wood, and debris to streams (Sarikhan et al. 2008; Entrix 2009).

5.1.1.2 Geomorphic Reaches

Seven geomorphic reaches were delineated along the Chehalis River within the study area based on valley confinement, gradient, and major tributary junctions (Figure F-7 and Table F-7). Anthropomorphic confinements (e.g., levees, bridges, or revetments) were not considered as permanent confinement and not used as a basis for delineating geomorphic reaches. Subreaches within Reaches 2 and 4 were delineated to provide additional details of transport/response reaches in these areas of high fish use.

Valley confinement refers to the extent that a river can or cannot migrate freely, and was differentiated based on visual assessment of topography in the geographic information system (GIS) database (using the LiDAR data), mapped geology (e.g., narrow bedrock valley versus wide alluvial valley), assessment of aerial photographs, and field observations. Confined reaches are those where the river has little opportunity to meander or migrate due to bedrock or valley walls. Unconfined areas are those where the river flows through wide, flat alluvial, and/or outwash valleys and can migrate across the floodplain. Some reaches were generally unconfined but had local, short, confined reaches (e.g., Reaches 4 and 5). Major tributary junctions were also considered in the geomorphic reach delineation because they often provide large inputs of water, sediment, and wood that can change the character of the mainstem river.

Figure F-6
Geomorphology Study Area

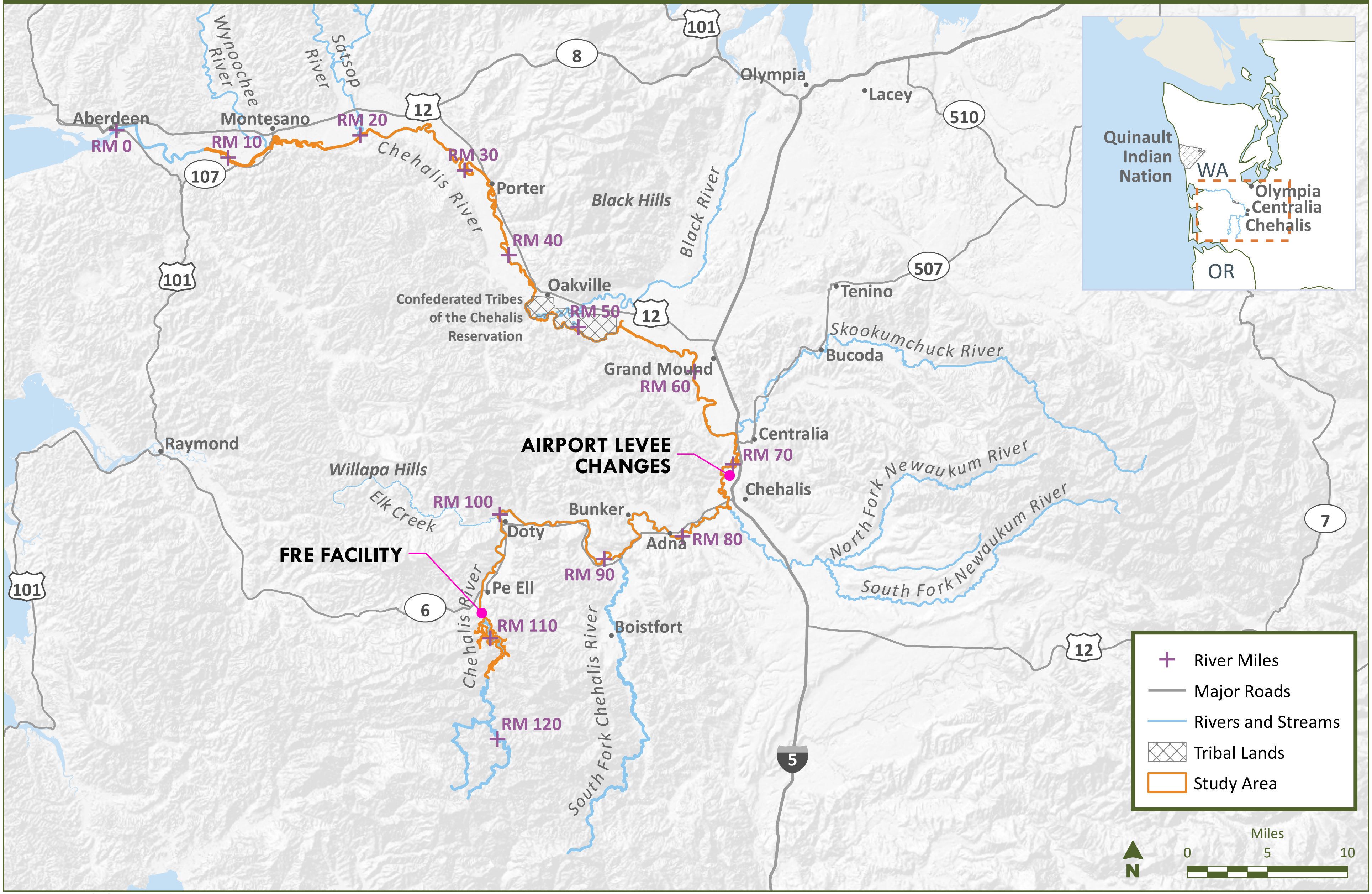


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Figure F-7
Geomorphic Reaches on the Chehalis River in the Study Area

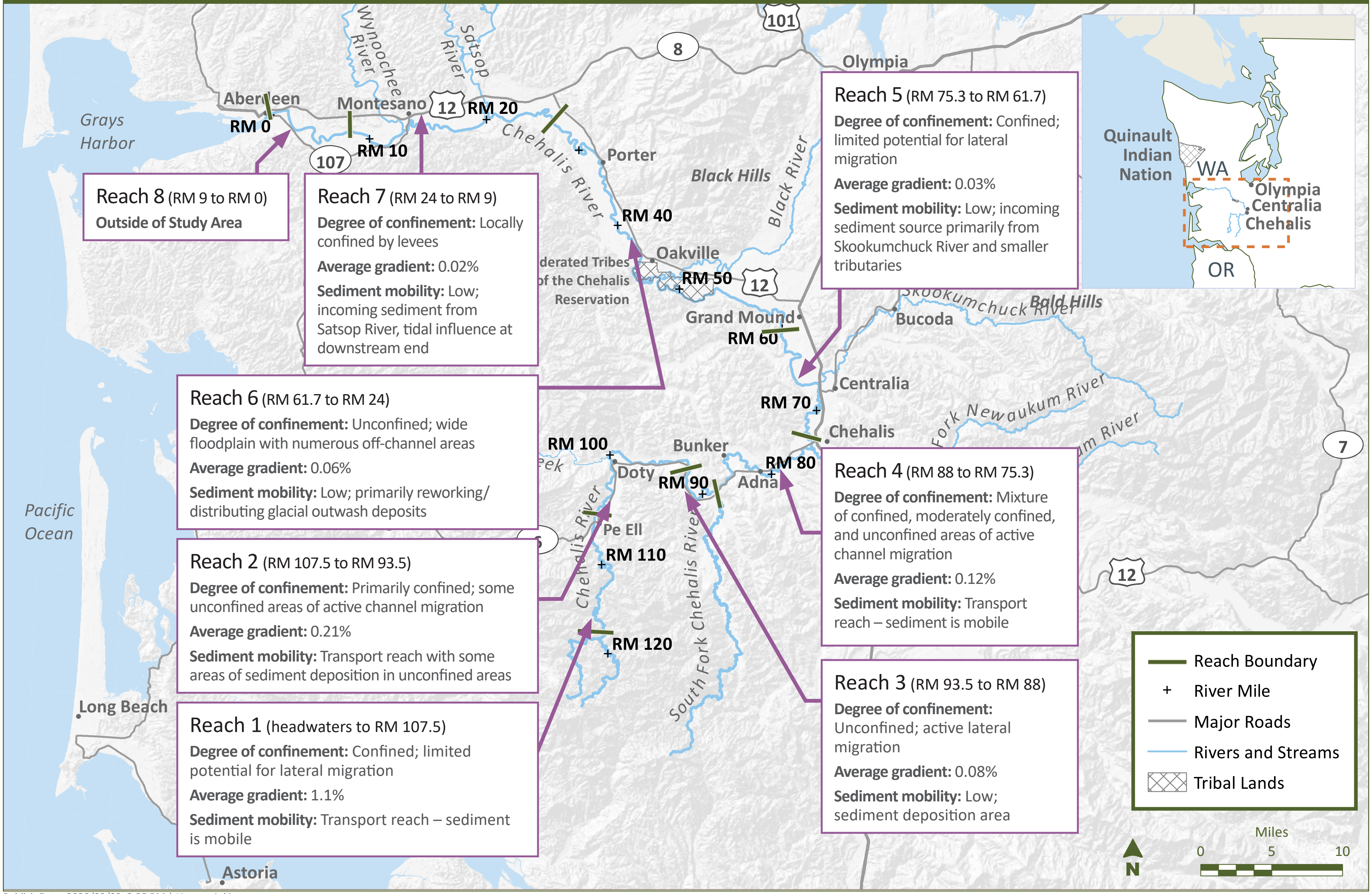

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Table F-7
Geomorphic Reach Characteristics on the Chehalis River in the Study Area

REACH	LOCATION (RM)	CONFINEMENT	CHARACTERISTICS	AVERAGE GRADIENT	COMMENTS
1	Headwaters to 107.5	Confined	Higher-gradient transport reach; headwaters	1.1%	Includes FRE facility site; currently still reworking 2007 sediment input
2A	107.5 to 105.9	Confined	Generally a transport reach	0.24%	Reworking sediment deposition from 2007 flood, Pe Ell area
2B	105.9 to 104.4	Unconfined	Deposition/active channel migration	0.21%	Likely a large log jam at downstream end in 2007; aggraded, major channel migration
2C	104.4 to 93.5	Confined	Generally a transport reach; bedrock; includes Rainbow Falls	0.18%	Elk Creek enters in this reach
3	93.5 to 88	Unconfined	Deposition reach; active lateral migration	0.08%	Includes Ceres Hill Bridge
4A	88 to 85.9	Confined	Transport reach	0.14%	South Fork Chehalis River enters at upstream end (major flow, sediment input)
4B	85.9 to 81.6	Unconfined	Deposition reach; active migration	0.11%	Near Adna
4C	81.6 to 75.3	Moderately confined	Finer-grained substrate as gradient drops	0.03%	Newaukum River enters and channel incised at downstream end
5	75.3 to 61.7	Locally confined	No gravel or cobble transport; bedrock control at downstream end	0.03%	Incised channel; Skookumchuck River enters mid-reach
6	61.7 to 24	Unconfined	Very wide floodplain; reworking Pleistocene glacial outwash gravels	0.06%	Black River enters mid-reach
7	24 to 9	Locally confined by levees	Wide floodplain with levees; meanders in unleveed areas	0.02%	Satsop River enters mid-reach; tidal influence downstream from RM 13

Reach 1

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. There is little channel migration in Reach 1.

Reach 2

Reach 2 extends from Pe Ell to a few miles upstream of the South Fork Chehalis River confluence. The channel here varies between confined, where it is incised into bedrock and alluvial deposits (Subreaches 2A and 2C), and an unconfined area where it flows through a wider valley (Subreach 2B).

There are many bedrock outcrops and grade controls in Subreaches 2A and 2C, including Rainbow Falls. The gradient is gentler here than upstream, and the bed contains primarily gravel and cobble.

Reach 3

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 characterized by more gravel and less cobble than upstream reaches. There is active channel migration in Reach 3.

Reach 4

Reach 4 includes alternating confined and unconfined reaches as the river passes through relatively narrow bedrock-controlled reaches (Subreaches 4A and 4C) and an unconfined, alluvial reach near Adna (Subreach 4B). Substrate is increasingly finer-grained downstream, with cobble-sized particles comprising less than 10% of the bars. There is active channel migration and bank erosion in Subreach 4B.

Reach 5

The Newaukum River enters at the upstream end of Reach 5. This reach is extremely 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 RM 65.5 and RM 61.7). Substrate is silt, sand, and gravel. The Skookumchuck River enters at RM 67 and provides a source of cobble and gravel particles to the downstream end of the reach.

Reach 6

Reach 6 extends from the bedrock control at RM 61.7 to RM 24). 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 Quaternary glacial rivers were braided and deposited gravel/cobble outwash, which has since been reworked by the Chehalis River, resulting in a bed dominated by gravel and cobble. The average channel gradient is steeper than in Reach 5, and the river is unconfined as it flows through the extremely wide valley (2 to 3 miles wide), which was originally formed by the glacial rivers. There is active channel migration in some parts of Reach 6.

Reach 7

Reach 7 extends from the Wakefield Road Bridge at RM 24 to the end of the study reach at approximately RM 9. The valley in this reach is wide, but levees confine the mainstem Chehalis River to the left side of the valley in some parts of the reach. The Satsop River enters at RM 20, providing a large source of gravel to the Chehalis. Downstream of approximately RM 13 tidal effects control river gradient, flow, and sediment deposition.

5.1.1.2.1 Existing Grain Size

Gravel bars on the Chehalis River were sampled from the headwaters down to about RM 33 to provide information on the grain size distribution of armor and sub-armor layers (Watershed GeoDynamics 2019a). Sampled bars were dominated by gravel-sized particles, with cobble and sand as secondary components (Figure F-8). The general trend in rivers is a fining-downstream pattern, with coarser sediment in the steeper headwaters progressing to gravel and sand in the 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 118.1 sample to the RM 73.4 sample, then another decreasing trend from the RM 65.8 sample to the RM 33.8 sample. This two-part trend is consistent with field observations of the extremely low-gradient, sand/silt bedded portions of the river between approximately RM 66 and RM 73. The bedrock sills observed in the river between RM 62 and RM 65 create a permanent grade control for the river and control the upstream gradient and bedload transport capability.

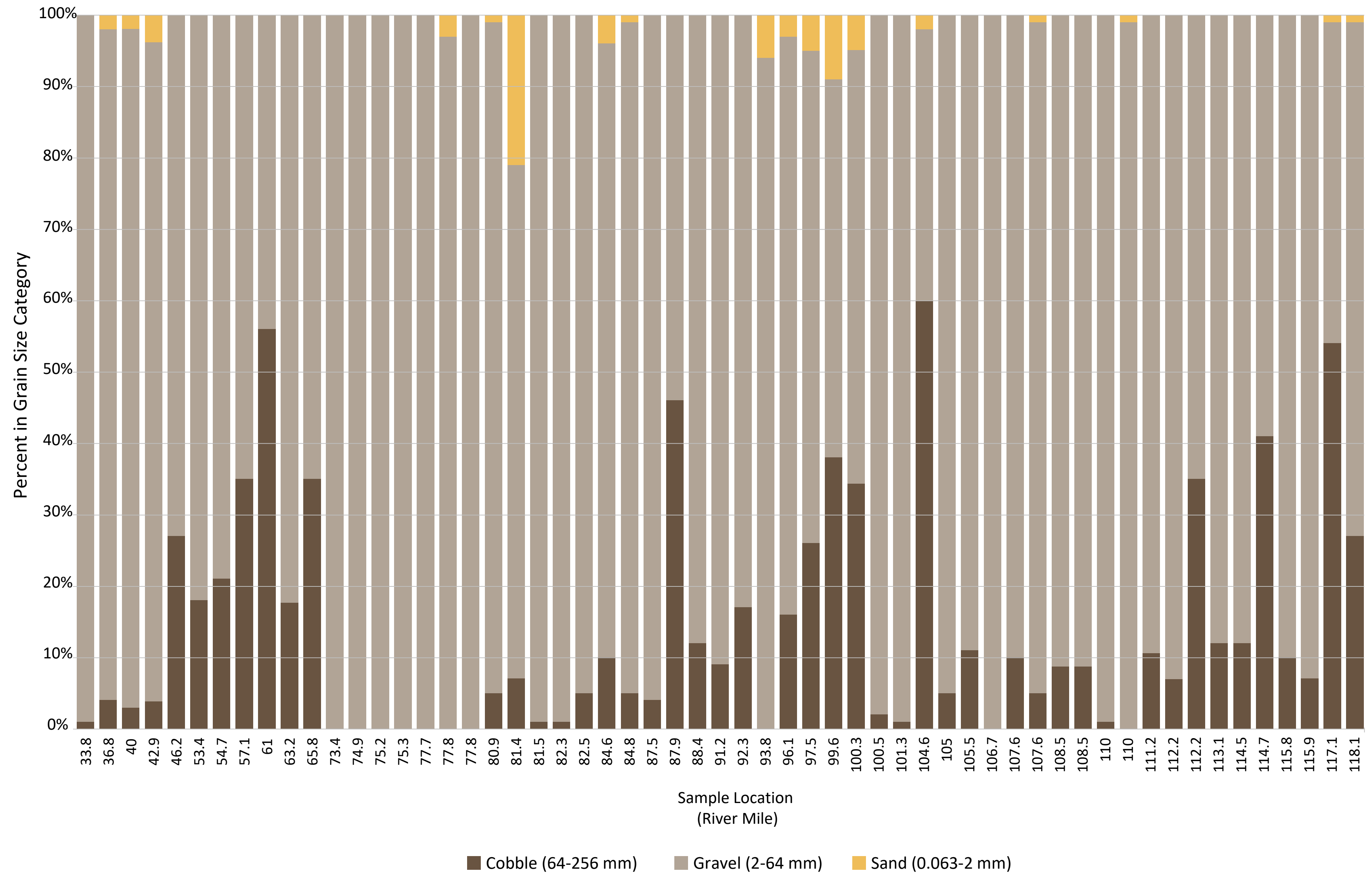
Based on the river bar samples, it appears the upstream supply of cobble-sized particles can be transported to approximately RM 80, and gravel can be transported to approximately RM 73. Downstream of the RM 62 to RM 65 bedrock controls, the Chehalis River can again adjust its gradient, and the input of coarser bedload sediment from the Skookumchuck River and erosion of the coarser alluvium and outwash through bank erosion and channel migration results in resetting the bedload component to a second downstream-fining cobble/gravel pattern. Cobble-sized material becomes a relatively minor component of the bars downstream of approximately RM 44.

Another way to look at changes in grain size along the Chehalis River is by plotting the median (D_{50}) grain size of the armor and sub-armor layers. Figure F-9 shows a fining-downstream trend between the headwaters and the RM 62 to RM 65 bedrock control, and then again between the bedrock control and Porter. No gravel samples were taken downstream of about RM 33, but the river substrate continues to get finer downstream as the river gradient decreases and larger particles are deposited on the river bed. The Satsop River provides a local source of coarser material near RM 20.

5.1.1.2.2 Effects of the 2007 Flood on Channel Conditions

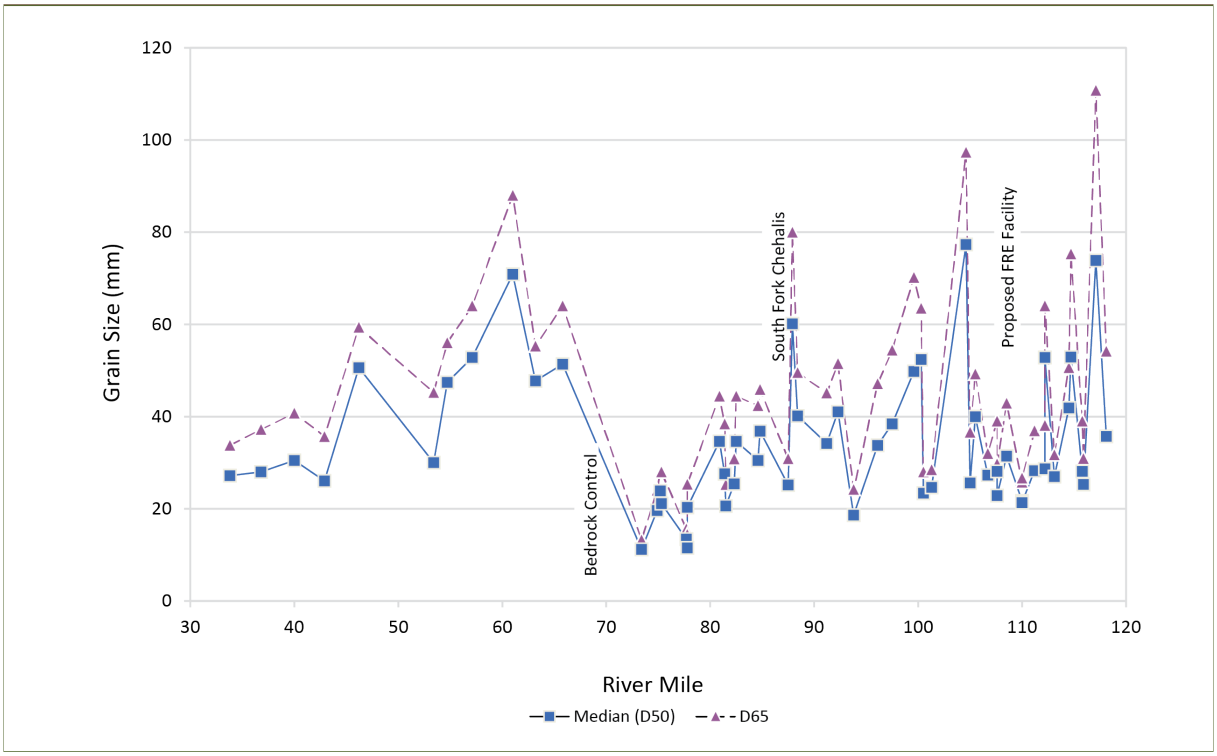
The December 2007 flood had a profound effect on the Chehalis River channel and floodplain that will last for several decades; understanding this flood is important to provide a context for existing channel and substrate conditions.

Figure F-8
Chehalis River Armor Layer Grain Size Distribution



Source: Watershed GeoDynamics 2019

Figure F-9
Chehalis River Armor and Sub-Armor Median Grain Size



The 2007 flood was the result of intense rainfall from a classic "pineapple express" storm that brought heavy rainfall to the Willapa Hills area, with the most extreme precipitation in the headwaters of the upper Chehalis Basin. The 2007 storm set records for 24-hour precipitation in the upper Chehalis Basin; and more than 14 inches of rain was recorded in a 48-hour period at gages in the area (Reiter 2008). This intense rainfall resulted not only in flooding, but in many landslides that delivered large amounts of sediment and debris (trees, stumps, small wood debris) to the Chehalis River. The combination of water, sediment, and woody material resulted in geomorphic changes throughout the Chehalis River system.

Peak flows during the 2007 flood were the largest in the historical record for the gages at Grand Mound (79,100 cubic feet per second [cfs]), Porter (86,500 cfs), Doty (63,100 cfs), and South Fork Chehalis (12,200 cfs based on U.S. Geological Survey reported data and Elliot 2014). The estimate of the peak discharge on the Chehalis River near Doty (52,600 to 63,100 cfs) is about double the next highest flood in the 74-year record (28,900 cfs in 1996).

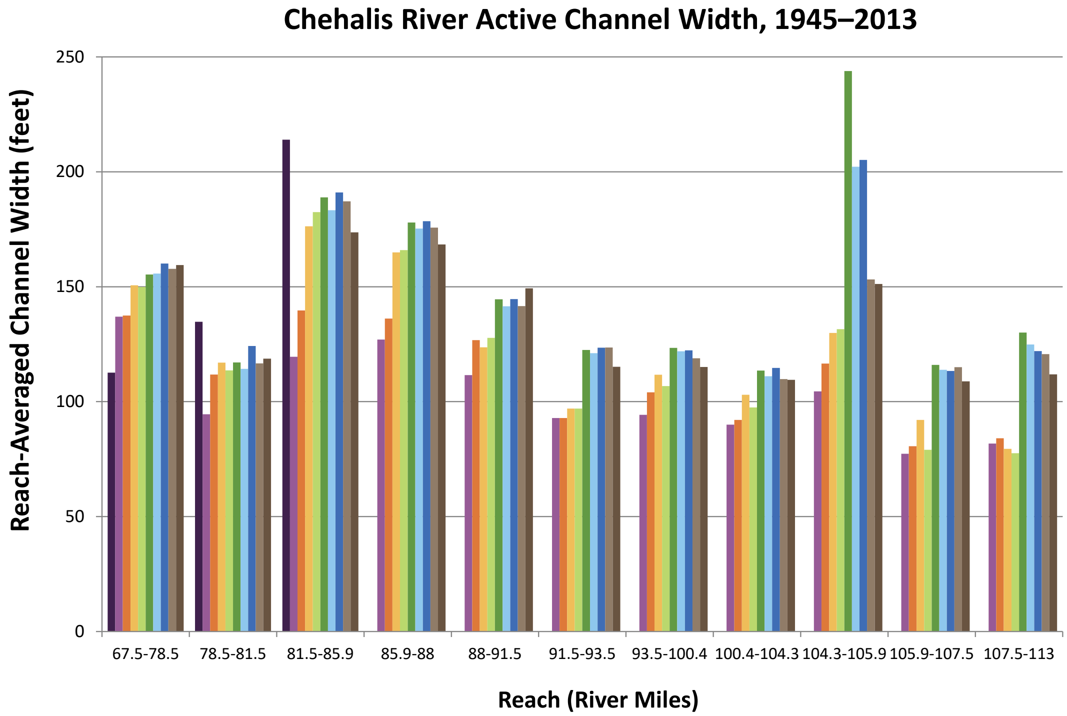
For the late-century catastrophic flood scenario in the EIS, rainfall and runoff projections are modeled statistically throughout the Chehalis Basin, with peak flows distributed in all areas in the basin, and not focused on a particular area. Because rain for the 2007 flood event was focused in one area, the estimated peak flows in 2007 are higher at Doty than peak flows under the late-century catastrophic flood scenario, but lower at Grand Mound. Thus, while the numbers at the Grand Mound gage are similar, the 2007 flood was much larger than the catastrophic flood modeled for this EIS.

Extreme rainfall resulted in more than 1,000 landslides in the Chehalis Basin (Sarikhan et al. 2008) and provided a huge input of sediment and woody material to headwater areas of the Chehalis watershed. An estimate of the input of sediment during the 2007 flood was made based on the area of landslides originally mapped by the DNR and updated in the *Geomorphology, Sediment Transport, and Large Woody Debris Report* (Watershed GeoDynamics and Anchor QEA 2017). The resulting estimated sediment input provides context for the magnitude of the 2007 storm input compared to major and catastrophic storm and peak flow conditions.

An estimated 5.7 to 8.7 million tons of sediment from landslides were supplied to the Chehalis headwaters (upstream of the proposed FRE facility) during the 2007 flood (Watershed GeoDynamics and Anchor QEA 2017). Because of the deeply weathered soils in the Chehalis Basin and the relatively shallow depth of most of the landslides, much of this sediment was fine-grained clay, silt, and sand, which was transported as suspended load through the river system or deposited as overbank deposits on downstream floodplain areas. An estimated 3.3 to 5 million tons of cobble and gravel material (coarser than 2 millimeters [mm]) was supplied to the channel. Some of this coarser material was transported downstream, but the huge volume of material exceeded the sediment transport capacity of the channel, and is still in storage in the stream valley and bed, primarily upstream of RM 104 (including within the proposed FRE inundation zone between RM 108.4 and RM 115).

The margins of the active and wetted mainstem Chehalis River channel between the bridge at RM 113 (middle of Reach 1) and the Mellen Street Bridge at RM 67.5 (lower portion of Reach 5) were mapped on a series of 10 historical aerial photographs to look at changes in channel width and river bar area through time (Watershed GeoDynamics and Anchor QEA 2017). The width of the active channel (including wetted channel and all unvegetated bars) increased following the 2007 flood from the headwaters (RM 113) to the confluence with the South Fork (RM 88; Figure F-10). The change through time in active channel width was most noticeable in unconfined areas where channel migration is most active (RM 91.5 to RM 93.5 [upper part of Reach 3], RM 104.3 to RM 105.9 [Reach 2]) and in the confined 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 (Figure F-10). The percent of the channel occupied by gravel bars (Figure F-11) 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 flood waters, and channel migration that builds new bars on the inside of meander bends.

Figure F-10
Temporal Changes in Channel Widths



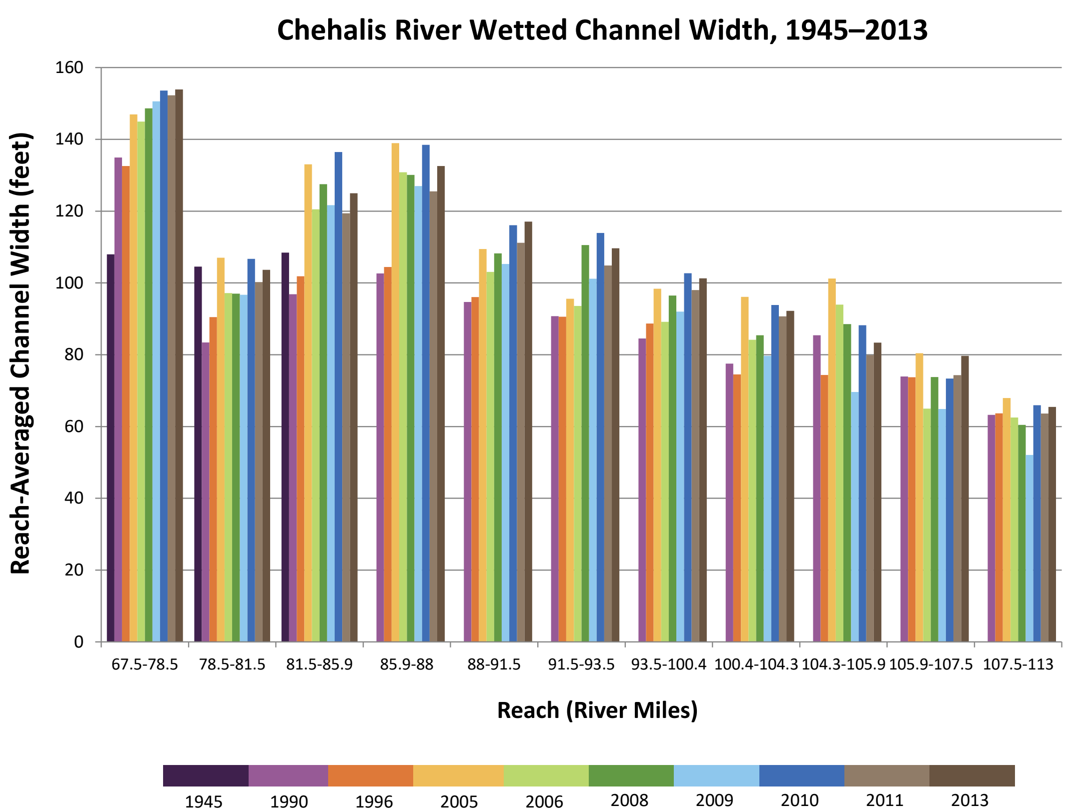
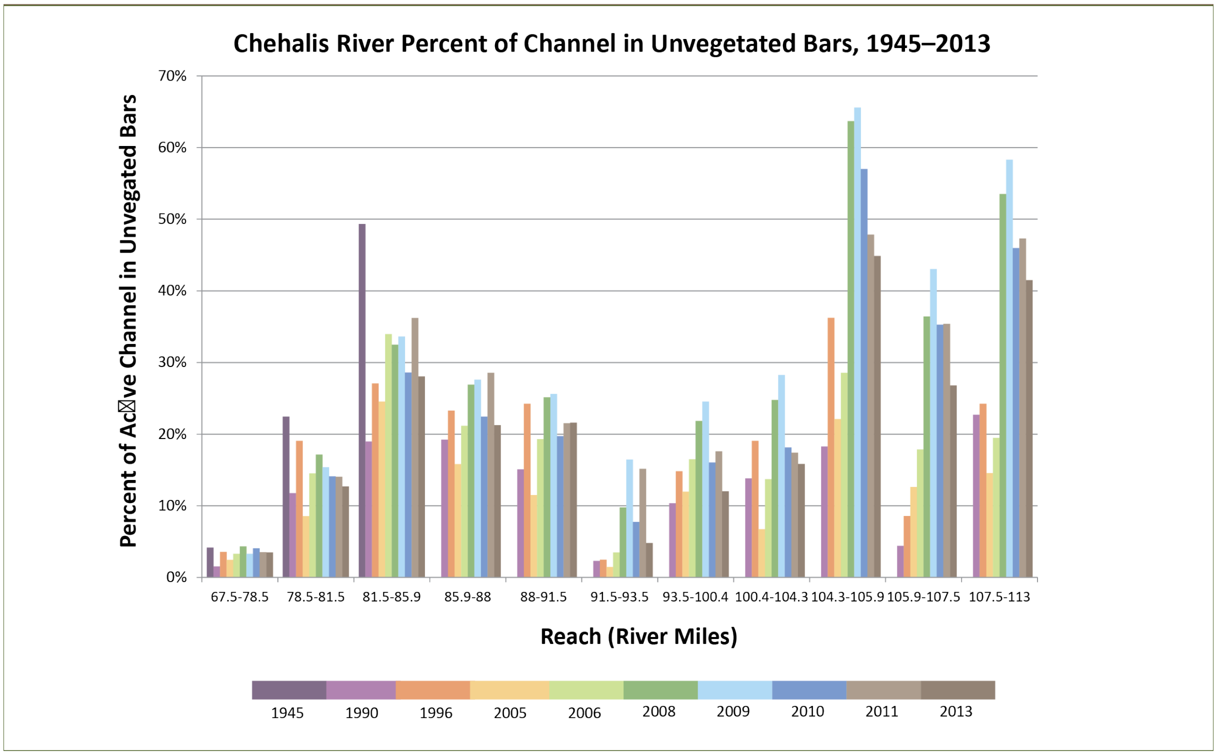


Figure F-11
Temporal Changes in Unvegetated Bars



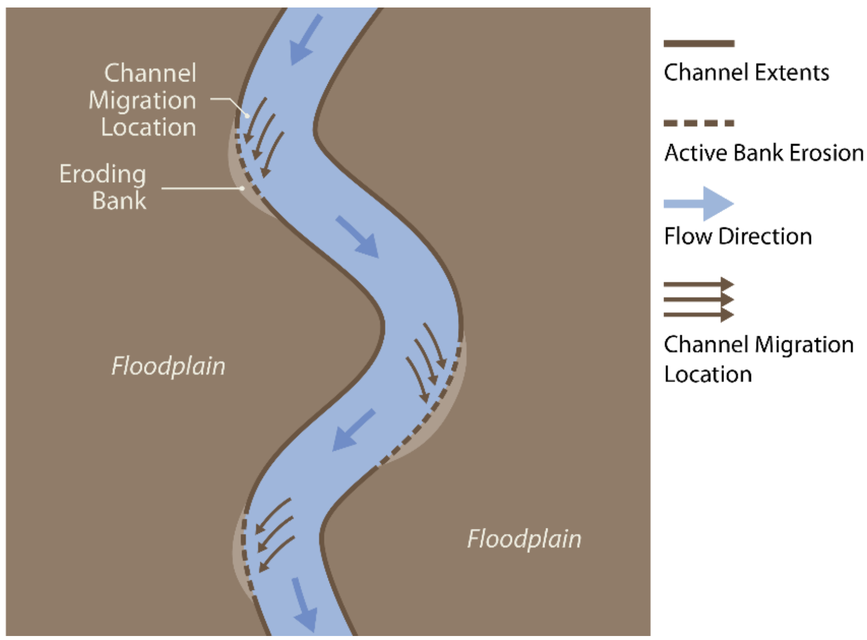
Following the 2007 flood, the channel has slowly been narrowing as vegetation grows on the gravel bars. Through time, the gravel deposits within the active channel in the upper watershed will be slowly transported downstream during peak-flow events, and the current finer-grained substrate will gradually coarsen to a cobble/gravel size similar to that noted prior to 2007. Based on an estimate of the amount of stored sediment and average bedload transport rates, it will likely take several decades for the channel to return to pre-2007 coarser substrate and channel conditions.

The landslides during the 2007 flood also delivered a huge amount of woody material in the form of fresh and decaying logs and stumps to the channel. Entrix (2009) reported 700 acres of landslides delivered wood to the channel in the Chehalis River headwaters, Stillman Creek (a tributary to the South Fork Chehalis River), and South Fork Chehalis River watersheds, with at least 213 acres of woody material and jams remaining in the channel and floodplain upstream of RM 88 (where the South Fork Chehalis River joins the mainstem Chehalis River) after the event. Much of the wood from the 2007 flood was stored on the floodplain, and it is likely that temporary log jams formed in some areas of the channel. The 2008 aerial photographs show large accumulations of wood in the RM 104 to RM 105 area, the RM 88 to 91 area, along parts of the South Fork Chehalis River, and smaller amounts in the RM 84 to RM 86 area near Adna. Much of the wood was subsequently mechanically cleared from the channel and floodplain.

5.1.1.1 Channel Migration

Channel migration (Figure F-12) is a natural occurrence in unconfined reaches of meandering rivers where banks are composed of easily erodible materials. 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 bank protection or revetments are often used to reduce bank erosion and migration.

Figure F-12
Channel Migration Illustration



Historical channel migration areas were identified between Porter (RM 33) and Pe Ell (RM 107) from 1876, 1945, 1990, and 2009 maps/digital aerial photographs (Watershed GeoDynamics and Anchor QEA 2012) and in areas downstream from RM 33 based on current LiDAR data. Most migration occurred in unconfined portions of Reaches 2A, 3, 4B, and 6 as well as in the unleveed portions of Reach 7. Channel migration rates through time were assessed between the Mellen Street Bridge (RM 67.5; middle of Reach 5) and the headwaters (bridge at RM 113 within Reach 1) using a series of 10 digital aerial photographs spanning from 1945 to 2013 (Watershed GeoDynamics and Anchor QEA 2017).

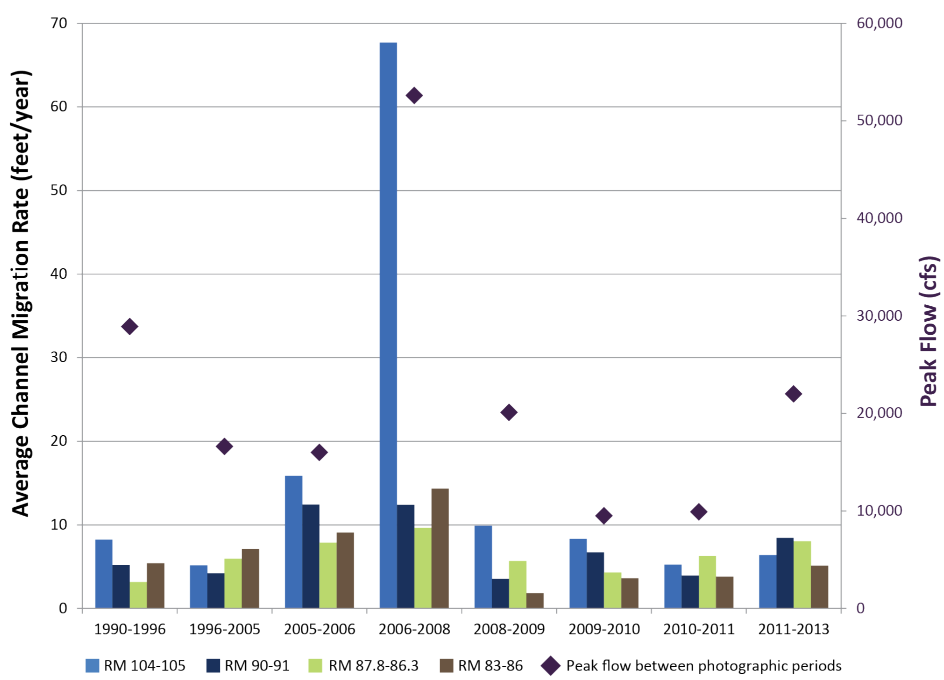
Average channel migration rates in the unconfined portions of the analysis reaches varied from 1.8 to 67.7 feet per year over the analysis period (Table F-8). There was not any measurable channel migration in other areas of the analyzed reaches. Channel migration rates for all locations were highest 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 (Figure F-13), suggesting channel migration occurs even during small peak flows with a recurrence interval of 1 to 2 years. Note that under with-FRE conditions, the FRE facility would have been impounding water during the 1990 to 1996, 2006 to 2008, and 2008 to 2009 time periods but not during the other time periods shown in Figure F-13. 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) noted occurred in the RM 104 to RM 105 area during the 2007 flood in response to the huge wood load in the channel that caused channel-spanning jams.

Table F-8
Average Channel Migration Rates Through Time

CHANNEL LOCATION	AVERAGE CHANNEL MIGRATION RATE (FOOT/YEAR)								
	1945-1990	1990-1996	1996-2005	2005-2006	2006-2008	2008-2009	2009-2010	2010-2011	2011-2013
RMs 104 to 105	N/A	8.2	5.1	15.9	67.7	9.9	8.3	5.2	6.4
RMs 90 to 91	N/A	5.2	4.2	12.4	12.4	3.5	6.7	3.9	8.4
RMs 87.8 to 86.3	N/A	3.2	6.0	7.9	9.6	5.7	4.3	6.3	8.0
RMs 83 to 86	2.1	5.4	7.1	9.1	14.3	1.8	3.6	3.8	5.1
Average Rate	**2.1**	**5.5**	**5.6**	**11.3**	**26.0**	**5.2**	**5.7**	**4.8**	**7.0**

Note:
N/A: Not applicable

Figure F-13
Channel Migration Rates and Highest Peak Flow (Chehalis River at Doty) Between Analysis Periods



The most active channel migration area shown in the 1990 to 2013 aerial photographs was the RM 104 to RM 105 location. This is a rural area with agricultural land use. This is the first unconfined reach downstream of the confined headwaters channel, and the high activity is likely due to deposition of sediment from upstream source and transport reaches. A narrow channel downstream of this location results in a backwater effect that limits bedload transport capacity, resulting in deposition. During the 2007 flood, at least one channel-spanning log jam was reported to have formed in this reach, resulting in the formation of a new meander pattern and causing the extremely high bank erosion rate and deposition as the river cut a new channel around the jam. This response to wood loading suggests that while slow channel migration takes place in response to peak-flow-induced bank erosion, major channel avulsions are the result of LWM jams, high energy, and sediment transport, similar to observations in other river systems.

The channel at the RM 90 to RM 91 location has a meander that has been moving downstream toward the Ceres Hill Bridge for decades. The bridge alignment pins the channel at the downstream end of this meander, so the wavelength of the meander has been shortening through time, causing scour of the bridge abutments and bank erosion in a field near the road alignment. Lewis County recently installed riprap and buried groins at this location to protect the bridge abutments and road alignment.

Meanders in the unconfined area at and just upstream of the junction of the mainstem and South Fork Chehalis River channels (RM 87.8 to RM 86.3) are likely the result of the input of sediment from the South Fork and a backwater effect from the downstream-confined valley causing deposition of sediment.

Migration in the Adna area (RM 83 to RM 86) is the result of a slow progression of bank erosion as meanders migrate across the floodplain.

A detailed analysis of channel migration rates was not performed downstream of RM 83 (Mellon Street Bridge, within geomorphic Reach 4). However, comparison of 1945, 1990, and 2009 channel positions showed that many areas of the channel in Reach 6 are migrating across the unconfined floodplain.

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. This is consistent with research in other gravel-bedded river systems that suggests flows of approximately 1.5-year to 5-year peak flow recurrence interval do the most "work" over the long term at controlling and maintaining channel form (Schmidt and Potyondy 2004; Surian et al. 2009). Local areas of sediment deposition also play a role in channel migration. Major channel avulsions take place in response to channel-spanning log jams, high energy, and sediment movement that occur during catastrophic floods when huge amounts of LWM are supplied to the river from upstream landslides.

5.1.1.2 Large Woody Material

LWM plays an important role in the geomorphology of a river and provides aquatic habitat diversity. Interactions between large wood, sediment and streamflow have implications for the ecology and channel morphology of river systems (Gurnell et al. 2002). Strong linkages between wood and fish abundance and diversity demonstrate the ecological importance of wood in channels and stream ecosystems (Montgomery and Piégay 2003).

Watershed characteristics, including riparian forest characteristics, and a range of geomorphological processes largely dictate wood recruitment. Slope processes such as landslides, bank erosion, and undercutting of living trees, along with transport processes such as floatation and debris torrents, all contribute to wood in the river and spatial variability (Comiti et al. 2016, Gurnell et al. 2002, Hogan and Luzi 2010). However, the rates at which wood is recruited to a river are highly variable. Rates are connected to climatic events (e.g. wind storms) and discharge events (e.g. floods, mass failures; Comiti et al. 2016, Gurnell et al. 2002). Flow regime influences the degree and frequency with which various wood sources can be accessed and controls the depth and power of flows available to mobilize and transport the wood (Gurnell et al. 2002). Infrequent, high magnitude floods can mobilize considerable amounts of wood from slopes and eroded banks (Comiti et al. 2016). This sporadic delivery of large amounts of wood influences the spatial and temporal variability of stream channel conditions (Hogan and Luzi 2010).

Once recruited to the channel, the dynamics and storage of wood are highly dependent on river flow and sediment transport regimes, as well as the water depth in comparison with the wood size (Gurnell et al. 2002). At low flows, wood remains relatively stable in the river system, providing ecological benefits (Comiti et al. 2016); however, wood size, shape, and density as well as channel dimensions, geomorphological characteristics, and flow regime of the river, influence the mobilization, transport, and deposition of wood (Gurnell et al. 2002, Hogan and Luzi 2010). Density controls whether and how well wood floats. Density also controls the energy required to mobilize the wood (Gurnell et al. 2002).

LWM is common in many forested streams (Hogan and Luzi 2010) and can be found in lowland rivers as well (Montgomery and Piégay 2003). Abbe (2000) indicates that woody material jams historically were an important part of large alluvial rivers in Western Washington, forming pools, bars, mid-channel islands, and local hydraulic controls. LWM and log jams were removed from the Chehalis River as far back as the 1890s to improve navigation and allow timber harvested in the headwaters to be floated downstream (Secretary of War 1892 as reported in Corps 2003). Splash dams on the Chehalis River, South Fork Chehalis River, Skookumchuck River, and smaller tributaries were used from the 1880s through the 1920s to transport timber (Wendler and Deschamps 1955 as reported in Corps 2003). The floods of logs and water resulting from the use of splash dams affected downstream channel dynamics by scouring substrate and woody material from the channel.

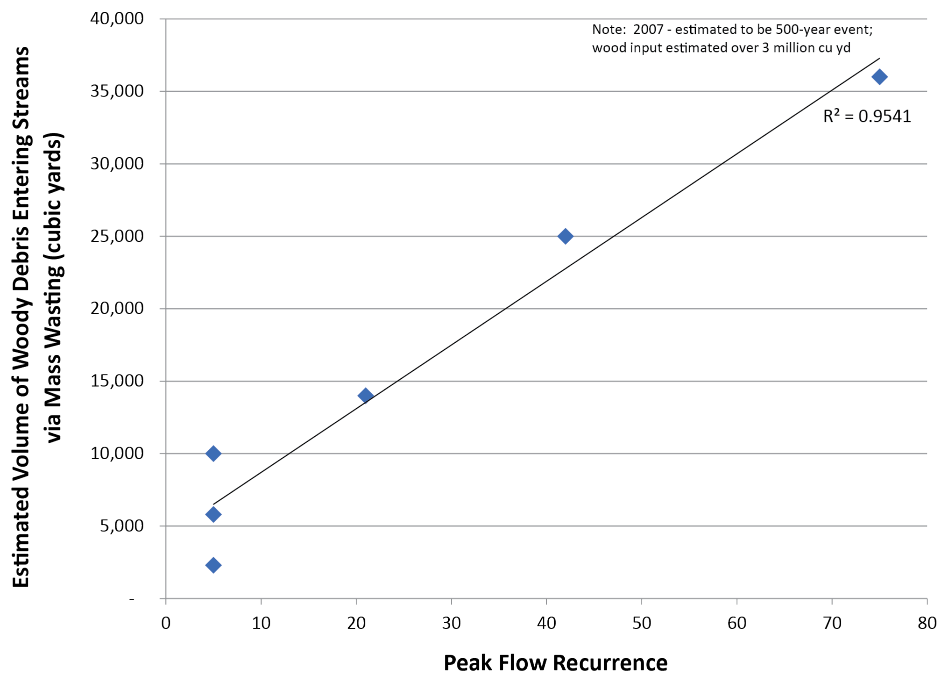
Current levels of LWM in the Chehalis River are low, likely due to the effects of historical splash dams and more recent river clearing (Weyerhaeuser 1994a, 1994b; Smith and Wenger 2001). During the 2007 storm event, Entrix (2009) reported landslides delivered wood to the channel in the Chehalis River headwaters, Stillman Creek, and South Fork Chehalis River watersheds with at least 213 acres of woody material jams remaining in the channel and floodplain upstream of RM 88 after the flood. Much of the wood from the 2007 flood was stored on the floodplain. This wood was subsequently cleared from the channel and floodplain, likely contributing to the current low levels of woody material in the channel. Existing Forest Practices Rules establish harvest prescriptions that include protective buffers for most riparian areas and steep slopes in upland forest areas. With these standard rules, trees grow undisturbed in sensitive areas such as unstable slopes and next to all fish and parts of non-fish-bearing streams. In short, a source of wood continues to be available in the upper Chehalis River basin and is maturing as riparian forests recover from being clearcut under historical practices.

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. The input of LWM from landslides and debris torrents is episodic, providing large volumes of wood during large storms/flow events and little wood input during non-storm/peak flow times. The input of LWM from bank erosion and channel migration is a progressive process, and may occur under more moderate flow conditions. Historical timber harvesting and cutting of trees in the riparian zones have left a limited supply of very large trees in the watershed. Average size and density for trees located on hillslopes and within the riparian areas in the upper Chehalis basin are not available to determine the potential for recruitment and in-channel function or the flows needed for mobilization, but as riparian zones mature the future potential for sources of large wood will increase. Additionally, large storms (such as the December 2007 storm) provide a key supply of LWM to the Chehalis. In the upper watershed, large wood is delivered by landslides and debris torrents. Landslides and debris torrents are critical mechanisms for nourishing the mainstem Chehalis and floodplain with the scale and volume of large wood necessary for meaningful aquatic habitat complexity.

Little information on the rate of LWM input or transport is available in the Chehalis River. Transport will depend on wood size, shape, and density as well as flow. Observations of wood movement suggest that at least some input and movement of LWM takes place during flows of 9,000 cfs, as measured at the Doty gage (Watershed GeoDynamics and Anchor QEA 2014). In the lower watershed, wood is supplied by bank erosion and channel migration. Input of trees from sloughing of the steep banks in Reach 5 was observed during field surveys (Watershed GeoDynamics 2019a). 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 was primarily deposited on gravel bars either as single pieces or in occasional jams.

The source of LWM in the watershed upstream of the proposed FRE facility is primarily landslides. Because most of the reaches are confined, there is little LWM input from channel migration in the upper watershed. An estimate of woody material input to the area upstream of the FRE facility during floods of different magnitudes was made by Watershed GeoDynamics and Anchor QEA (2017). Input ranged from less than 10,000 cubic yards of woody material in a 5-year recurrence interval peak flow to more than 35,000 cubic yards during a 75-year recurrence peak flow (Figure F-14). Woody material input during the 2007 storm was estimated to be more than 3 million cubic yards.

Figure F-14
Estimated Woody Material Input to Watershed Upstream of FRE Facility During Peak Flows



Note: R^2 is a statistical measure of how close the data are to the fitted regression line. The closer the R^2 is to 1, the better the fit between the data and the regression line.

5.1.1.3 Channel-Forming Flows

The effects of dams on downstream aquatic habitats are widely studied, with the literature generally showing far-reaching negative impacts for aquatic systems. Several broad syntheses provide holistic overviews of documented effects of regulated streamflow releases from dams (e.g., Bunn and Arthington 2002; Lytle and Poff 2004; Poff and Zimmerman 2010). However, there is minimal published research on the effects of losing high peak flows in dammed systems.

The natural flow regime is basic to maintaining river ecosystem health (Poff et al. 1997) and variability in flows is critical to ecosystem function (Ward et al. 2002). The magnitude, frequency, duration, timing, and rate of change of hydrologic conditions are fundamental elements of an unregulated flow regime, and the variability in those component elements regulates ecological processes (Poff et al. 1997).

A wide range of flows and frequencies creates and maintains different habitat features (Poff et al. 1997). High flow pulses and flushing flows occur annually and provide in-channel functions such as moving organic material and fine sediment. Channel-maintenance flows are peak flows that occur on a 1.5- to 2-year recurrence interval and that form and maintain many channel features, such as riffle-pool sequences (Poff et al. 1997; Wald 2009). Channel-forming flows are peak flows that have a 10- to 25-year recurrence interval; these flows structure channel networks and other geomorphic features that shape the landscape (Ward et al. 2002).

Prominent among channel-forming flow processes are avulsions and channel migrations. Both avulsion and lateral channel migration play critical roles in shaping floodplain topographic features, influencing successional trajectories, and determining the turnover rates of landscape elements (Ward et al. 2002). Major avulsions that occur with large-magnitude floods have a key role in maintaining the long-term dynamic between creation and loss of off-channel habitats. A 10- to 25-year peak flow event typically has enough depth, velocity, and stream power to recruit LWM into the channel, which in turn affects local sediment erosion and deposition rates (Wohl et al. 2015; Poff et al. 1997; Wald 2009; Naiman et al. 2008). The dynamic interaction of water, sediment, and wood shapes channel morphology, bed conditions and heterogeneity, disturbance regime, and water quality (Wald 2009, Wohl et al. 2015). Hence, less frequent greater magnitude flood events, coupled with bedload sediment and LWM, facilitate channel migration and avulsions that renew river habitat via creation and reconnection of abandoned channels, bars and islands, oxbows, and meander scrolls (Ward et al. 2002).

Channel-forming flow processes maintain landscape patches in differing successional trajectories, providing diverse habitat structure for aquatic organisms, thereby creating diverse and resilient ecological communities (Ward et al. 2002). These processes also create off-channel rearing habitats and viable spawning areas, in addition to facilitating the input of terrestrial nutrients to the stream. The influence of channel-forming processes on aquatic habitat is described in the *Fish Species and Habitats Discipline Report* (Anchor QEA 2020a). The effects of channel-forming processes on vegetation and riparian habitat are described in the *Wildlife Species and Habitats Discipline Report* and *Wetlands Discipline Report* (Anchor QEA 2020b, 2020c). Changes to the inundation of wetlands and open water aquatic habitats are quantified in the *Wetlands Discipline Report*.

5.2 Studies and Reports Referenced/Used

The following studies and reports were used to provide information on the geomorphic setting and to help evaluate potential geomorphic effects of the Proposed Action:

- *Chehalis Basin Strategy Programmatic Environmental Impact Statement* (Ecology 2017)
- *Appendix B: Geomorphology/Sediment Transport/Large Woody Debris Report of the Chehalis River Fish Study* (Watershed GeoDynamics and Anchor QEA 2012)
- *Geomorphology and Sediment Transport Technical Memorandum* (Watershed GeoDynamics and Anchor QEA 2014)
- *Geomorphology, Sediment Transport, and Large Woody Debris Report* (Watershed GeoDynamics and Anchor QEA 2017)
- *Geomorphology and Sediment Transport* (Watershed GeoDynamics 2019a)

5.3 Technical Approach

The evaluation of potential effects of alternatives is based on the geomorphic and sediment transport studies and methods conducted for previous project planning efforts (Watershed GeoDynamics and Anchor QEA 2012, 2014, 2017; Watershed GeoDynamics 2019a). A full description of the technical and modeling approaches is described in these documents; a summary is included in the following sections.

5.3.1 Erosion Within the Temporary Reservoir Area

Erosion within the temporary reservoir area following construction was assessed for the following four types of erosion:

- Shallow-rapid landslides
- Surface erosion from wave action on flood deposits in the reservoir area as it is emptied
- Surface erosion from rainfall on flood deposits left in the reservoir area after it is emptied
- Erosion in the river channel in the reservoir area as it is emptied

5.3.1.1 Shallow-Rapid Landslides Within the Temporary Reservoir Area

The potential for shallow-rapid landslides in response to inundation within the temporary reservoir was evaluated based on infinite slope analyses for shallow landslides (depth of slide plane was 6 feet, based on observations of existing shallow landslides in the area and soil depths). Assuming a saturated slope (after inundation) with uniform sheet flow, a cohesion value of 50 pounds per square foot for soils in the reservoir area, and a phi angle of 31 degrees, hillslopes with a slope angle over 20 degrees were calculated to have a factor of safety less than 1 and could become unstable. This calculation does not include any root strength factor from shrubs or trees on the hillslope, which would contribute to increased slope stability as vegetation grows, but would not contribute when vegetation dies off after inundation events.

Geographic information system (GIS) coverage of the hillslope angle within the temporary reservoir was examined to evaluate areas with a slope angle of more than 20 degrees for landslide potential. Areas immediately adjacent to the mainstem Chehalis River consisting of river terrace were removed from the potential landslide area, because the calculations assume native poorly-drained soils and terraces around the river are composed of well-drained gravel deposits. The gravel terrace deposits also have a higher phi angle than the surrounding valley wall soils, making them more stable at higher slopes.

The resulting potentially unstable slope coverage was overlain with elevation to identify potentially unstable areas by elevation. This information was combined with the frequency that each elevation was predicted to be inundated (for mid- and late-century major and catastrophic flood scenarios) to evaluate potentially unstable hillslope area by inundation frequency.

5.3.1.2 Surface Erosion Within the Temporary Reservoir Area

Sediment deposited on the valley walls within the temporary reservoir could be eroded and transported back into the reservoir or river during or after draining. The two mechanisms for this erosion are wave action along the shoreline as the reservoir is lowered, and erosion of sediment on valley walls after the reservoir drains during subsequent rainfall.

5.3.1.3 Wave Erosion

There are no specific models for evaluating wave erosion as reservoirs are drawn down, but based on observations at multiple reservoirs, the majority of fine-grained sediments (silt and clay) deposited on the valley walls when the reservoir is full would be resuspended and moved into the reservoir as the water is lowered, to be redeposited within the reservoir at a lower elevation. This process would continue until the reservoir is fully drained following the reservoir operations plan that outlines varying reservoir draining rates to minimize landslide potential and allow for handling of LWM. Sediment deposition within impounded reservoirs for the 2007 and 2009 floods was estimated as part of water quality modeling using the CE-QUAL-W2 model (see details in Anchor QEA 2019). Two floods were selected as representative of a normal impoundment event (2009) and an extreme impoundment event (2007).

To evaluate subsequent wave erosion of the deposited sediment as the reservoir was lowered, it was assumed that all silt- and clay-sized particles deposited on the valley walls in the CE-QUAL-W2 simulation of each of the two flood impoundment events would be moved down the slope by wave action, mixed with the reservoir water, and subsequently flow out of the reservoir as it drained. The total mass of deposited silt and clay was assumed to be resuspended by wave erosion. This would provide a conservative (high) estimate of turbidity in the Chehalis River as the reservoir drains.

It is likely that some portion of the total deposited silt and clay would remain on the sides of the reservoir if it is trapped by existing vegetation or microtopography during the draining period. Because wave energy acts on all parts of the reservoir shoreline and is higher than rainfall energy (Section 5.3.1.4), any fine-grained sediment (silt/clay) that remained trapped on the sides of the reservoir after it drained would likely remain trapped by existing vegetation and microtopography during subsequent rainfall and would not be eroded.

5.3.1.4 Rainfall Erosion

In addition to silt and clay discussed in the previous section, sand-sized sediment is predicted to settle on the bottom and side slopes of the reservoir. The CE-QUAL-W2 model (Anchor QEA 2019) was again used to predict sand deposition. This section analyzes erosion during rainfall that would occur subsequent to impoundment events.

To evaluate erosion from reservoir hillsides (i.e., valley walls) during rainfall after the reservoir drained, it was assumed that the CE-QUAL-W2 model-predicted sand-sized sediment remaining on the reservoir hillslopes would be subject to hillslope erosion and transport during subsequent rainfall. Silt and clay were assumed to be eroded due to wave action as the reservoir recedes (Section 5.3.1.3) or be trapped by vegetation or microtopography, and therefore they are not considered in this section, which is specific to erosion during subsequent (non-impounding) rainfall.

The Water Erosion Prediction Project (WEPP) model was used to evaluate the potential for erosion of sand from reservoir hillslopes. The WEPP model is an interagency model initially developed to calculate surface erosion from agricultural lands. The U.S. Forest Service has developed model input variables that are appropriate to use to calculate erosion from forested hillslopes that are either undisturbed or disturbed by timber harvesting, fire, or other activities that disrupt soil cover. The U.S. Forest Service Disturbed WEPP interface was run in batch mode to evaluate erosion from reservoir hillsides following inundation. Reservoir hillslope conditions were based on the vegetation management plan (Kuziensky et al. 2016), which foresees a transition within the reservoir area from non-flood-tolerant species to flood-tolerant species.

It was assumed that sediment deposited on the reservoir bottom and side slopes more than 200 feet away from the mainstem river or a tributary (e.g., uphill of the stream channel) would be redeposited on the hillslope and would not enter a stream or river. This assumption is based on studies of sediment transport distances in forested watersheds (Megahan and Ketcheson 1996; Brake et al. 1997), which found sediment was trapped by vegetation and microtopography features and transported less than 200 feet across the forest floor. For areas within 200 feet of a river or tributary, erosion and sediment transport into the channel could occur.

A variety of hillside slopes and configurations were entered into the interface based on the range of hillslopes within the potential inundation zone. The WEPP model's Rock:CLIME function was used to generate a custom climate representative of the reservoir area based on a location and elevation mid-reservoir. A sandy loam soil profile was used based on output from the CE-QUAL-W2 model. The modeled 200-foot-long slope was split into two zones: 1) an upper 100-foot-long (30-meter) zone of shrub/perennial with 40% cover representative of the reservoir hillsides; and 2) a lower 100-foot-long zone of skid trail (representative of sand deposits on the reservoir bottom) with 10% cover and 5% rock fraction.

Bounding estimates of hillside slope were based on slope gradients within the reservoir, obtained from LiDAR topography data and ranged from a constant 5% slope (as a lower bound, representing most of the floodplain on either side of the mainstem Chehalis River) to a constant 60% slope (as an upper bound, representing steep hillsides around smaller tributaries). The vegetation conditions (shrub/perennial and skid trail) were based on assumptions of vegetation cover following treatments described in the vegetation management plan (Kuziensky et al. 2016)—removing non-flood-tolerant Douglas fir tree species in areas below the 100-year inundation level; these areas would transition to shrub/willow. All these scenarios provide bounding estimates of erosion rates.

The WEPP model was run for a 100-year simulated climate to evaluate potential erosion of previously deposited solids during storms of different recurrence intervals that could occur following reservoir draining. Two recurrence intervals were selected for evaluation: the average annual rainstorm/peak flow (i.e., 1.01-year) and a 10-year storm. The resulting rainfall-induced erosion rates under average annual flow rate conditions and under a 10-year storm were applied to the inundated area.

5.3.1.5 River Channel Erosion Within the Temporary Reservoir Area

Deposition and erosion within the river channel (when the temporary reservoir impounds water resulting in sediment deposition and when that sediment is resuspended within the river channel as the reservoir drains) was evaluated using the HEC-RAS model described in Section 5.3.2.1.

5.3.2 Sediment Transport and Channel/Tributary Aggradation and Incision

Sediment transport within the mainstem Chehalis River between approximately RM 118 (upstream of the temporary reservoir area) and the confluence with the Newaukum River (approximately RM 75) was evaluated using a one-dimensional (1D) HEC-RAS Version 5.07 model for the No Action Alternative and the Proposed Action FRE facility operations under three flood scenarios as well as long-term flows for the mid- and late-century periods.

Based on analyses of sediment transport (Watershed GeoDynamics and Anchor QEA 2012, 2014), from a geomorphology standpoint there would be minimal changes in peak flow magnitude, sediment input, and sediment transport downstream of the Newaukum River under FRE facility operations because the effects of the FRE facility operations on water and sediment inputs and transport would be muted by tributary inputs and the bedrock grade controls at RM 62 to RM 65. The potential for aggradation or incision within the mainstem Chehalis River or at tributary junctions was assessed based on the results of cross-section bed change using the HEC-RAS model.

5.3.2.1 HEC-RAS Modeling

The 2015 1D unsteady flow HEC-RAS Version 5.0 model of the Chehalis Basin produced by Watershed Science & Engineering (Elliot and Karpack 2014) was modified for use as a 1D HEC-RAS Version 5.07 quasi-unsteady flow sediment transport model. The quasi-unsteady sediment transport function was chosen because a long period of flow record was needed to determine long-term changes to substrate, channel profiles, and sediment transport. This long period of record would not be feasible to analyze using the unsteady flow model. The following sections detail the modifications that were made to the Watershed Science & Engineering unsteady model to evaluate sediment transport.

5.3.2.1.1 Geometry Input

The geometry file was modified to remove portions of the river downstream of the confluence with the Newaukum River (approximately RM 75) and storage areas that were not compatible with the quasi -unsteady flow model. The geometry file for the Chehalis River upstream of the Crim Creek confluence (approximately RM 108.5) was augmented with cross-sections for 1 RM upstream of the potential reservoir inundation zone (to approximately RM 117) to allow for consideration of river dynamics upstream of the highest reservoir pool area (Watershed GeoDynamics and Anchor QEA 2017). The cross-sections used in the sediment transport model are shown in Figure F-15.

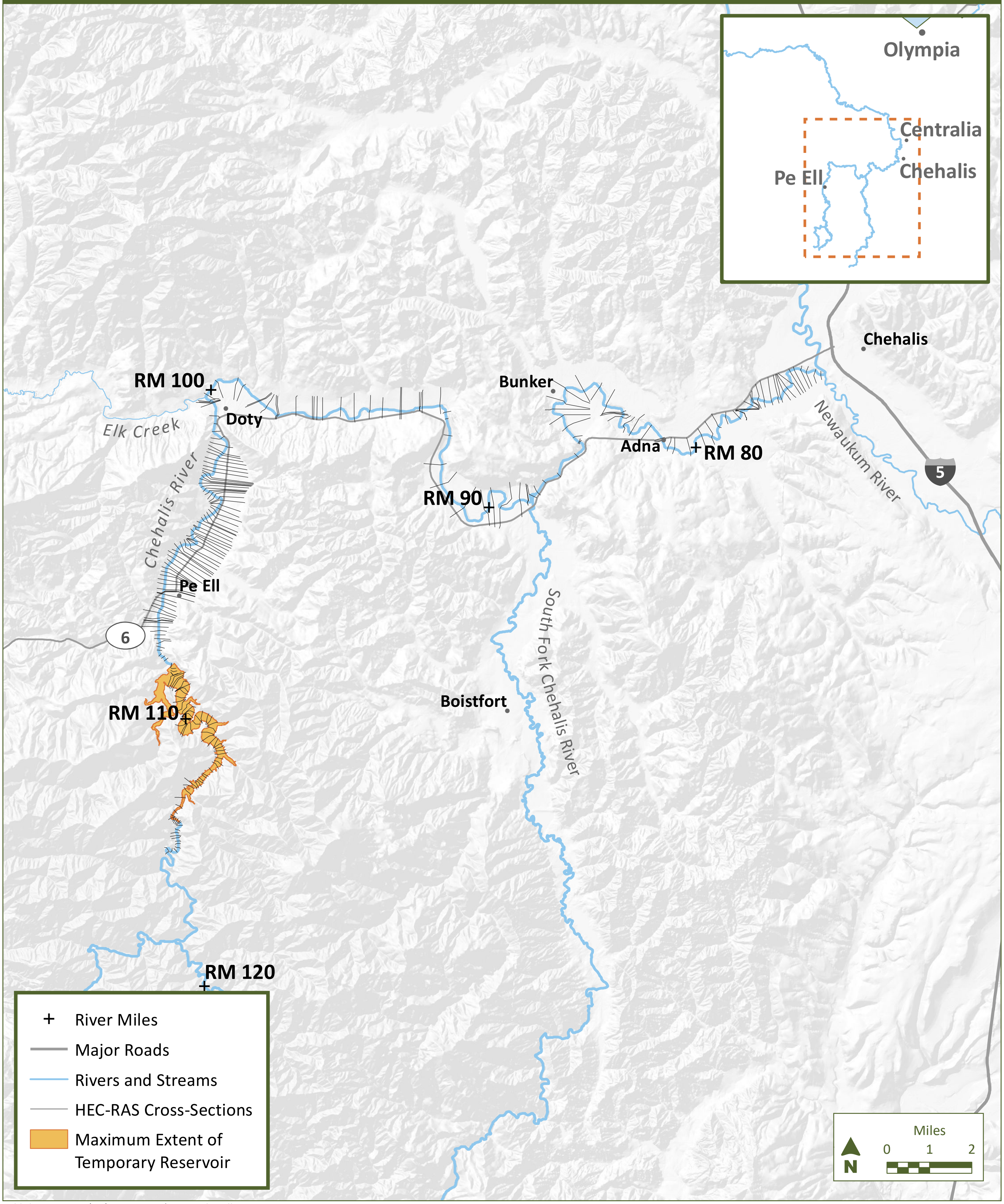
The geometry file for FRE facility conditions was also modified to add a cross-section representing the FRE facility with a representative gate and spillway. Since the quasi-unsteady flow model uses a series of steady flows, it does not compute or allow for reductions in flow downstream of the FRE facility as the reservoir fills with water or increases in river flow as the FRE facility drains and outflow from the facility is higher than inflow. To account for these flow differences in the analysis for the FRE facility, the geometry file was modified to include a lateral flow input point just downstream of the FRE facility cross-section that either subtracted an appropriate amount of flow from the river during times when the reservoir was filling or added an appropriate amount of flow back into the mainstem river as the reservoir was draining.

5.3.2.1.2 Hydrology Input

A 30-year flow record was derived from existing historical flows in the Chehalis Basin (October 1, 1988 through September 30, 2018) and used to develop mid- and late-century conditions that include projections for precipitation from climate change (Hill and Karpack 2019). Flow was apportioned into 24 different input locations that represented inflow at the upstream end of the model, inflow at tributary junctions, or overland flow (uniform lateral inflow) based on drainage area of each input location. Since most sediment transport takes place during high-flow conditions and time required to complete each HEC-RAS model run is dependent upon the number of time-steps, the calculation time step and flow input was set to 1 day (24 hours) for times when the average daily flow at the Doty gage was less than 2,000 cfs, and a 1-hour time step and flow input when mean daily flows were greater than 2,000 cfs. This resulted in 15,569 individual flow time steps for the 30-year climate change flow record. These data were entered into the quasi-unsteady function of the HEC-RAS model to represent the mid- and late-century scenarios.

For the model runs on the Proposed Action, the results of a reservoir simulation model (Hill and Karpack 2019) were used to obtain hourly reservoir inflow, outflow, and lake elevations for each instance when the reservoir would have impounded water based on the 30-year flow record under the mid- and late-century scenarios. These data were used to predict the gate opening required for the HEC-RAS model to compute the appropriate reservoir elevation at each time step as well as increased or decreased flow downstream of the FRE facility as a result of water impoundment or release.

Figure F-15
HEC-RAS Cross Section Locations



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5.3.2.1.3 Sediment Input

Sediment data in the HEC-RAS model consist of bed gradation data to define substrate on the riverbed and incoming sediment loads to define sediment entering the river based on flow conditions.

Bed gradation data in the model was determined by grain size data and substrate mapping in the Chehalis River (Watershed GeoDynamics 2019a). The bed gradation (that was most representative of conditions mapped at each cross-section) was assigned and maximum scour depths were set to 0 to 5 feet (as appropriate for each cross-section based on the presence of bedrock near the bed of the river as observed during field mapping). Left and right bed stations were adjusted as needed using an iterative approach to represent the width of the mobile channel at each cross-section.

Incoming sediment loads were estimated using published suspended sediment load measurements (Glancy 1971) and extended to higher flows based on estimated input from landslides during storms (Watershed GeoDynamics and Anchor QEA 2017). Because the HEC-RAS model uses a rating-curve approach to predict sediment input, the higher peak flows under mid- and late-century scenarios will predict proportionately higher sediment inputs that represent the likely higher incidence of landslides under climate change conditions. Potential landslide input as a result of reservoir inundation was not explicitly included in these input values because most of the coarse sediment (sand and larger) would be deposited in the reservoir and likely not make it into the mainstem Chehalis River. However, the analysis of past landslide input used to estimate incoming loads does include storm-induced landslides within the temporary reservoir.

Bedload was assumed to be 10% of the total load, based on studies in other gravel-bedded rivers and sensitivity analysis performed for the 2017 report. Input amounts used in the HEC-RAS model are shown in Table F-9. Grain size for incoming loads were set based on the sand, silt, and clay proportions measured by the U.S. Geological Survey at the Doty and South Fork Chehalis River gages and surficial pebble count data measured in the Chehalis River closest to the incoming sediment load location. Because actual sediment load during any particular flood or storm is highly variable, the sediment loads computed by HEC-RAS model likely overestimate input for some storms or floods and underestimate it for others. Sediment load in the model is underestimated for a storm similar to the 2007 flood, which had extremely high sediment concentrations that are beyond the capabilities of the HEC-RAS model.

5.3.2.1.4 Sediment Transport Function

The 1D quasi-unsteady flow sediment transport model in HEC-RAS Version 5.07 was run using the Ackers-White total load function, Thomas sorting method, and Report 12 fall velocity method. Bed change options were set to allow deposition outside the moveable bed limits to represent overbank deposition during floods. Pass-through nodes were set for river cross-sections that were lined with bedrock or showed unrealistic deposition (e.g., near bridges where cross-sections are located very close together to represent hydraulic conditions and are therefore subject to unrealistic computations of sediment transport).

Table F-9
Flow Versus Total Sediment Discharge (tons per day) Input Rating Curves for HEC-RAS Model

AREA	FLOW (CFS)	SEDIMENT DISCHARGE (TONS/DAY)	AREA	FLOW (CFS)	SEDIMENT DISCHARGE (TONS/DAY)
RM 118.174	186	3	RM 106.8	90	.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 117.3395	48	1	RM 101.12	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	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 112.75	30	1	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	90	1	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			

There were limited sediment transport data available to calibrate the sediment transport results of the HEC-RAS model. Scour monitor data from 2014 and 2018 were used to compare predicted and modeled initiation of movement (Watershed GeoDynamics and Anchor QEA 2014; Watershed GeoDynamics 2019b). One set of bedload transport measurements was made in 2014, which included 1 day of a high flow event. Due to the inability to capture sand-sized sediment, the bedload transport measurements were not used to calibrate the sediment transport model.

Initiation of gravel/cobble movement in the HEC-RAS model started at a few cross-sections under moderate flow conditions, but transport at most cross-sections upstream of RM 100 started at flows of approximately 6,000 cfs at Doty and was widespread to RM 88 (South Fork confluence) at flows of approximately 8,000 cfs at Doty. Gravel movement was initiated in downstream reaches at flows of approximately 15,000 to 18,000 cfs at the Adna gage. These results are in reasonable agreement with the limited scour monitoring data collected to date. Additional bedload transport calibration data would improve the accuracy of HEC-RAS model results.

5.3.3 Large Woody Material

The FRE facility would trap LWM supplied from the watershed upstream while it is impounding water. During times when the reservoir was not impounding water, LWM up to 3 feet in diameter and 15 feet in length would be able to move through the facility outlet tunnel. If a trash rack is added it would further reduce the size of LWM that could pass through the outlet tunnel. Reductions in LWM input under FRE facility operations were evaluated based on estimated wood input versus peak flows (Figure F-14) and projected future peak flows.

5.3.4 Channel Migration

As compared to the No Action Alternative, operation of the FRE facility would reduce peak flows, sediment accumulations, and LWM levels in downstream reaches while the facility impounds water (during major floods or greater). The potential for changes in channel migration rates under FRE facility operations was evaluated based on calculated historical channel migration rates versus peak flows (Figure F-13) and changes to peak flows and sediment deposition areas under FRE facility operations.

5.3.5 Channel-Forming Flow

Flows would be unimpeded when the FRE outlets are open, thereby maintaining unmodified flushing and channel-maintenance flows. Closure of the FRE outlet gates would begin within 48 hours of a forecasted peak flow of 38,800 cfs at Grand Mound. Because the Grand Mound gage measures flow from the Chehalis River, the Newaukum River, and the Skookumchuck River, the reading of 38,800 cfs would include water from all three rivers. Based on the historical record, when the Grand Mound gage reads 38,800 cfs, the flow at the FRE site has ranged from 10,000 to 15,000 cfs. During FRE flood operations, streamflows necessary for most channel-forming processes are reduced. This reduction in peak flows, and corresponding reduction in large wood and sediment transport, would directly impact creation of habitats that depend on those channel-forming processes. This is addressed qualitatively in the analysis.

5.4 Impact Thresholds

Impacts for geomorphology characteristics were assessed based on the potential for change to each characteristic within each geomorphic reach. The following geomorphic characteristics were considered:

- Erosion at construction sites and within the temporary reservoir area
- Sediment transport processes and river substrate (including incision)
- Large wood load, transport, or recruitment potential
- Channel complexity and geomorphic function (including channel migration)

6 TECHNICAL ANALYSIS AND RESULTS

6.1 Overview

This section describes the probable geomorphology impacts from the Proposed Action (Section 6.2), Local Actions Alternative (Section 6.3), and No Action Alternative (Section 6.4). This section also evaluates required permit conditions and planning document requirements that could address the impacts identified (Section 6.2.3). When probable significant adverse environmental impacts remain after considering these, the report identifies mitigation measures that could avoid, minimize, or reduce the identified impact below the level of significance (Section 6.2.4).

6.2 Proposed Action

6.2.1 Impacts from Construction

6.2.1.1 Direct

Construction of the FRE facility and Airport Levee Changes would result in erosion as a result of soil disturbance at the FRE facility site, the airport levee site, use of unpaved roads to access the construction site and haul materials from the proposed quarry sites, and clearing vegetation within portions of the potential temporary reservoir area. Changes to transport of LWM at and downstream from the FRE facility would also occur.

Soil would be disturbed to construct the FRE facility, and up to 13.5 miles of unpaved access roads would be widened for quarry and construction access (up to 21.15 acres of clearing to widen roads). Construction activities at the FRE facility site are anticipated to occur over 5 years. Use of the diversion tunnel during the 3 years of construction would affect the transport of LWM downstream.

Fine-grained sediment (sand, silt, clay) in the disturbed construction site areas would be subject to erosion during rainfall if not covered or protected. Since much of the construction area is close to the Chehalis River, eroded sediment could enter the river if adequate erosion control measures are not used.

An estimated 134,000 to 181,000 heavy truck trips are anticipated on at least some parts of the unpaved roads during the 5-year construction period. Road surface erosion would result from the heavy truck use. Estimated erosion rates for heavy truck traffic on unpaved gravel roads in Washington varies, but a rate of 3 tons per acre per year is appropriate for the climate, geology, and surfacing in the Chehalis area (Dubé et al. 2004). The 13.5 miles of access road would be widened to 20 feet; erosion from these 33 acres of road surface is estimated to be 100 tons per year. Erosion control measures such as silt fences, coir rolls, settling ponds, and hydroseeding would be installed as part of permit requirements for construction sites and road widening (Washington Forest Practices and NPDES Permits) and would reduce delivery of eroded sediment to streams and wetlands.

Erosion associated with removal of non-flood-tolerant trees from approximately 485 acres of the temporary reservoir would be similar to existing levels of erosion associated with logging in the area under current land use practices. However, removal of all trees from within riparian areas is not permitted under current Forest Practices regulations and likely would result in additional erosion due to removal of near-channel vegetation causing loss of root strength and reducing the stability of streambanks. Eroded sediment could enter streams or wetlands if soil is disturbed within 200 feet of these areas. The potential for erosion resulting from removal of riparian and upland vegetation was analyzed as part of operational impacts (see Section 6.2.2) since the effects would be similar.

A total of 114,500 cubic yards of fill would be deposited at the airport levee construction site. Fine-grained sediment (sand, silt, clay) in the fill would be subject to erosion during rainfall if not covered or protected. Since this site is on a flat floodplain area, eroded soil would not be transported far from the construction site, but could enter any streams or wetlands nearby. Levee construction is anticipated to last for 1 year in the 5-year construction window.

Erosion from construction activities could impact waterbodies by increasing turbidity, particularly within the FRE facility construction and reservoir area and associated roadways. Water quality and Forest Practices Permits would include erosion control BMPs such as silt fences, coir rolls, settling ponds, and hydroseeding are installed as part of permit requirements for construction sites and road widening. Tree removal in 487 acres of the temporary reservoir footprint during construction would also cause erosion. Tree removal near rivers and streams during construction would likely result in additional erosion because it would reduce root strength and the stability of streambanks. Eroded sediment could enter streams or wetlands if soil is disturbed within 200 feet of streams or wetlands. Tree removal in 600 acres of the temporary reservoir area during construction would also cause erosion. Tree removal near rivers and streams during construction would likely result in additional erosion because it would reduce root strength and the stability of streambanks. Eroded sediment could enter streams or wetlands if soil is disturbed within 200 feet of streams or wetlands. The NPDES Permit would require actions to ensure the water quality standards are not exceeded.

The Chehalis River flow and associated sediment load would be directed through a bypass tunnel around the facility site during the 5-year FRE facility construction period. The bypass tunnel would be 20 feet wide by 20 feet high with a 1% slope and would allow sediment transport, so there would be **minor** effects to upstream or downstream sediment transport or geomorphology. The river channel at the FRE facility site would be disturbed permanently due to the construction of the structure and resulting in **significant adverse impacts** to substrate and geomorphic processes at that location; these impacts would be localized at the site. The change in LWM transport during construction would result in a **moderate adverse impact** to geomorphic processes downstream.

Mitigation is proposed for the Applicant to develop a Fish and Aquatic Species and Habitat Mitigation Plan, Large Woody Material Management Plan, and a Surface Water Quality Mitigation Plan to mitigate impacts to the Chehalis River channel at the FRE facility site; however, there is uncertainty if the implementation of a plan is technically feasible or economically practicable. Therefore, the Proposed Action would have significant and unavoidable adverse environmental impacts on the river channel, unless the Applicant develops a Fish and Aquatic Species and Habitat Mitigation Plan and a Surface Water Quality Mitigation Plan that meet regulatory requirements and for which implementation is feasible.

6.2.1.2 Indirect

No indirect impacts from construction on geomorphic processes are anticipated.

6.2.2 Impacts from Operation

6.2.2.1 Direct

Anticipated direct impacts associated with operation of the FRE facility are detailed in the following sections and include:

- Erosion within the temporary reservoir from changes to vegetation and reservoir deposition and subsequent erosion of deposited sediment
- Changes to sediment transport rates and substrate grain size within the potential inundation area and downstream of FRE facility
- Changes to LWM movement and accumulation from upstream sources due to retention within the ponded reservoir and changes to LWM input downstream of the FRE facility due to removal of woody material during impoundment events and changes to channel migration rates
- Changes to channel migration rates and channel-forming processes from altered peak flows, sediment accumulation rates, and LWM accumulation rates downstream of the FRE facility
- Any channel incision in the mainstem Chehalis River within and downstream of the FRE facility and the potential for destabilizing alluvial fans at tributary junctions due to changes in sediment input and transport

There are **no anticipated direct impacts** from operations of the Airport Levee Changes on geomorphic processes because the levee is several hundred feet away from the Chehalis River channel and would not result in significant changes to geomorphic processes in the mainstem Chehalis River.

6.2.2.1.1 Erosion Within the Temporary Reservoir Area

The temporary reservoir would be subject to several different sediment deposition and subsequent erosion mechanisms when the FRE facility is impounding water and after impoundment events. The magnitude and frequency of impoundments for two different long-term flow periods (mid-century for 2030 to 2060 and late-century for 2060 to 2080) are shown in Figure F-16. The long-term flow periods were used to look at long-term trends, which are important for geomorphic analyses. The long-term flow periods include floods of different magnitudes, including major and catastrophic floods. Under mid-century conditions, the temporary reservoir would impound a substantial amount of water during 33% of the years. Under late-century conditions, the FRE facility would impound a substantial amount of water during 46% of the years. The reservoir simulation model also predicted several additional small impoundments that would last for a few days when inflow exceeds the FRE facility outlet capacity.

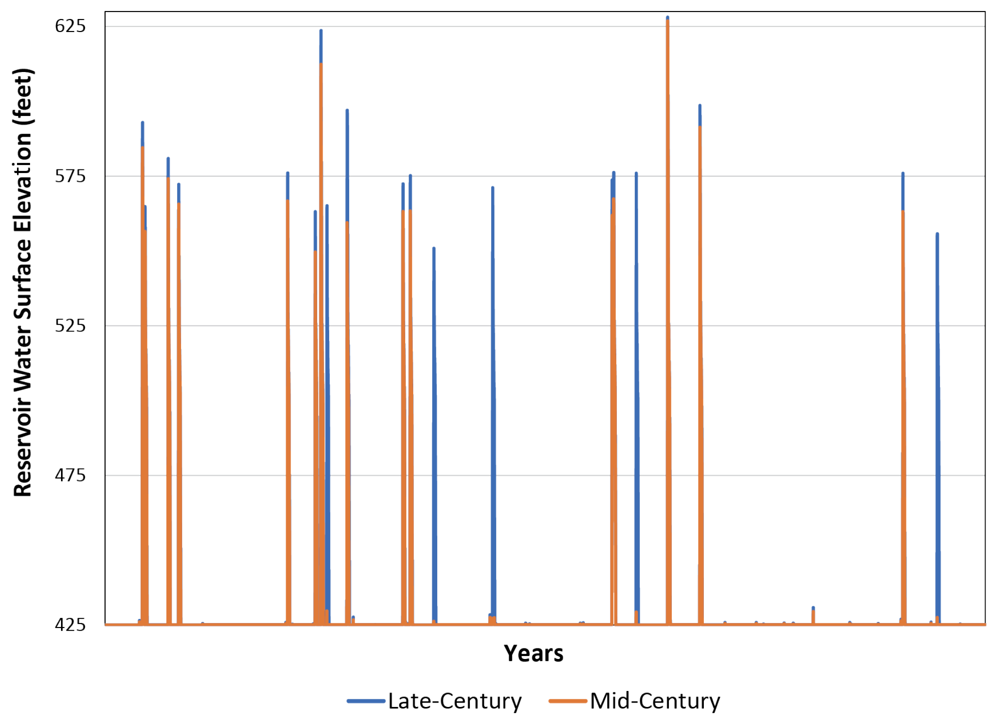
Operation of the FRE facility would change sediment transport and channel forming processes by eliminating large peak flows at the FRE location during major or greater flood events. For example, the estimated peak flow at the FRE facility site during the 2007 flood event was 34,700 cfs, and if the FRE had been in place the outlet gates would have been closed. Flows of this magnitude would be reduced to the levels described below for the closed and drawdown periods.

Estimates of the maximum flow through the FRE outlets would vary under different conditions. These are based on the historical record and are estimates for the late-century catastrophic flood scenario.

- When FRE gates are open: up to 18,520 cfs. The FRE gates would be closed when the water level at the Grand Mound gage is predicted to be 38,800 cfs. However, if the prediction is less than 38,800 cfs, the flow through the outlet could be up to 18,520 cfs, based on the historical record.
- When FRE gates are being closed: 300 to 6,000 cfs
- When FRE gates are closed: 300 cfs
- During FRE drawdown periods: 4,320 to 10,600 cfs

During times when the reservoir impounds water, sediment from inflowing water would be deposited in the reservoir pool area, reducing turbidity and sediment loads downstream of the FRE facility. Cobble, gravel, and coarse sand would be deposited in a delta where the mainstem Chehalis River and inflowing tributaries (e.g., Crim/Lester creeks, Big Creek, Roger Creek, Thrash Creek) intersect the reservoir pool elevation. Finer-grained clay, silt, and fine-sand that was suspended in the inflowing streams would be carried out into the main body of the reservoir, and some of it would be deposited there. Some of the finest particles would remain suspended and flow through the reservoir with outflowing water. The amount of deposition of each grain size would change through the flood and impoundment event and would depend upon the reservoir pool area as it fills and drains as well as inflowing water volume and sediment load.

Figure F-16
Estimated Magnitude and Frequency of Temporary Reservoir Impoundments



Note: Years in the chart are representative of a hypothetical 30-year period, simulated for mid-century and late-century conditions, in order to estimate impoundment magnitudes and frequencies.

As the reservoir drains, some of the finest-grained silt and clay particles that would be deposited on the bottom of the reservoir would be exposed to wave action, resuspended in the draining reservoir water, and moved down the emerging hillslopes. The reservoir will be drained at a rate of 10 feet/day to elevation 528 feet, then at a rate of 2 feet/day for 2 weeks to allow for large wood and debris management, then the rate would be increased to 10 feet/day until the pool drained. The controlled maximum rate of outflow would be 5,000 to 6,500 cfs. This is less than the maximum amount of water (8,500 cfs) that can pass through the FRE outlets without surcharge when the gates are fully open during non-flood conditions. Maximum duration of the impoundment is predicted to be 35 days. Wave strength would depend upon wind speed and direction as well as local topography as the reservoir drained. Coarser sand-sized particles would likely remain on the hillslopes and become trapped by vegetation and microtopographic features. Sediment that remained on the emerging hillslopes could be eroded by high-intensity rainfall after the reservoir drained; again, some of the sediment would remain trapped by vegetation and topography and would be deposited on lower-gradient slope areas along the mainstem Chehalis River valley.

Soil in the temporary reservoir could become saturated depending on how long each area is inundated. Areas at lower elevations would be inundated for the longest amount of time (up to 35 days) and most frequently. As the reservoir drained, saturated soils could become unstable on steep slopes, particularly if root strength and cohesion are low. These slopes could be subjected to shallow-rapid landslides. Each landslide would move downslope until it reached either a low-gradient area where the soil would be deposited or the reservoir.

Vegetation conditions that could affect erosion within the temporary reservoir area would change from current conditions as a result of clearing of trees in the lowest elevation areas that would be inundated most frequently (485 acres) and selective harvesting at higher elevations within the potential reservoir pool during construction to remove non-flood-tolerant trees. Vegetation conditions would also likely change following impoundment events, because some plants that are inundated for a long period of time would not survive. Loss of vegetation and temporary loss of root strength would reduce soil cover and stability. As vegetation regrows with flood-tolerant species and annual vegetation grows between inundation periods, root strength and soil cover would increase, decreasing the potential for both landslides and surface erosion.

The potential for erosion within the temporary reservoir as a result of impoundments was evaluated using several different methods depending on the mechanism of erosion (landslides, surface erosion, and resuspension of sediment within the river channel).

Shallow-Rapid Landslides Within the Temporary Reservoir Area

When the temporary reservoir impounds water, the soil in areas that are underwater will become saturated. As the reservoir drains, these saturated soils will no longer be supported by the reservoir water and could be susceptible to shallow-rapid landslides. An analysis of deep-seated landslides is included in Section 3.2.2.1. An analysis of areas within the temporary reservoir that may be susceptible to shallow-rapid landslides was made based on a conservative assumption of poorly drained soil with no root strength (representative of areas with all timber harvested) to determine the slope angle that could be susceptible to sliding as the reservoir drains. Since most of the reservoir would retain at least some root strength, these assumptions likely overestimate the potential for landslides.

Approximately 10% of the reservoir area contains soil on slopes steep enough that they may be unstable if saturated and all root strength was removed (Figure F-17). Most of these areas are along tributary valleys with steep slopes. Assuming a 6-foot average soil depth, the total volume of soil that could potentially be mobilized is 840,500 cubic yards. The likelihood of mobilization of each portion of the susceptible slope area is based on whether or not it would be inundated during an impoundment event because smaller floods would not fill the entire reservoir. The percentage of time the susceptible areas would be inundated (based on a long-term period) ranges from up to 2% for mid-century and 5% for late-century; Figure F-18 shows potentially mobile soil volume by percent of time it would be inundated.

However, it is expected there would be fewer landslides and less of the reservoir hillslopes susceptible to sliding than shown in Figures F-17 and F-18 because the plan for the reservoir is to harvest non-flood-tolerant trees in areas that would be inundated more frequently and replace them with flood-tolerant shrub-scrub vegetation, so there would be some root strength (the analysis assumed no root strength) and less area susceptible to landslides. In addition, based on observations at Mud Mountain Dam on the White River, which operated as a flood control-only facility, much of the material that would mobilize and move downslope would be deposited on lower-gradient slopes and river terraces, not entering rivers or streams.

While shallow-rapid landslides could be triggered on the steep valley walls of the reservoir by precipitation that occurred while the reservoir is filling, those landslides would not necessarily be the result of the reservoir fluctuations, but instead triggered only by rainfall. There is a possibility that saturation of soils could result in initiation of slides that move up the hillslope above the reservoir water level; however observations of the slopes within the FRE facility footprint and analysis of the locations of past shallow-rapid landslides under moderate and extreme (2007) rainfall (Weyerhaeuser 1994a; Sarikhan et al. 2008) indicate that most of the shallow-rapid landslides initiated from high on the valley walls in colluvial hollows, unrelated to toe saturation.

Surface Erosion Within the Temporary Reservoir Area

Wave Erosion While Reservoir Impounds and Drains

During times when the temporary reservoir impounds water, some portion of the fine-grained sediment (silt and clay) that flows into the reservoir from the Chehalis River and tributaries would be deposited on the bottom of the reservoir. As the reservoir drains, this portion of sediment would be subject to wave erosion along the slowly lowering shoreline and resuspended into the lowering reservoir.

An estimate of wave erosion was made for the historic 2009 flood conditions (representative of an average impoundment event) and the 2007 flood conditions (representative of an extreme impoundment event). The wave erosion estimate assumes that all silt and clay deposited on the valley walls is reworked within the draining reservoir and added to the total volume of outflow as the reservoir drains. As the reservoir elevation decreases, the estimated total erosion of silt and clay from this mechanism is 8,470 tons for the 2009 flood and 143,000 tons for the 2007 flood, which had a much larger amount of fine sediment input into the reservoir, and therefore more deposition and resuspension as the reservoir dropped.

The actual amount of sediment re-eroded into the reservoir by wave erosion may be substantially less than the predicted amounts if: 1) some of the deposited fines are trapped due to roughness elements on the reservoir valley floor such as vegetation, rocks, logs, and sticks; or 2) wind velocities are low, causing reduced erosion due to reduced wave energy.

Figure F-17
Areas Within Temporary Reservoir Area Potentially Susceptible to Shallow-Rapid Landslides

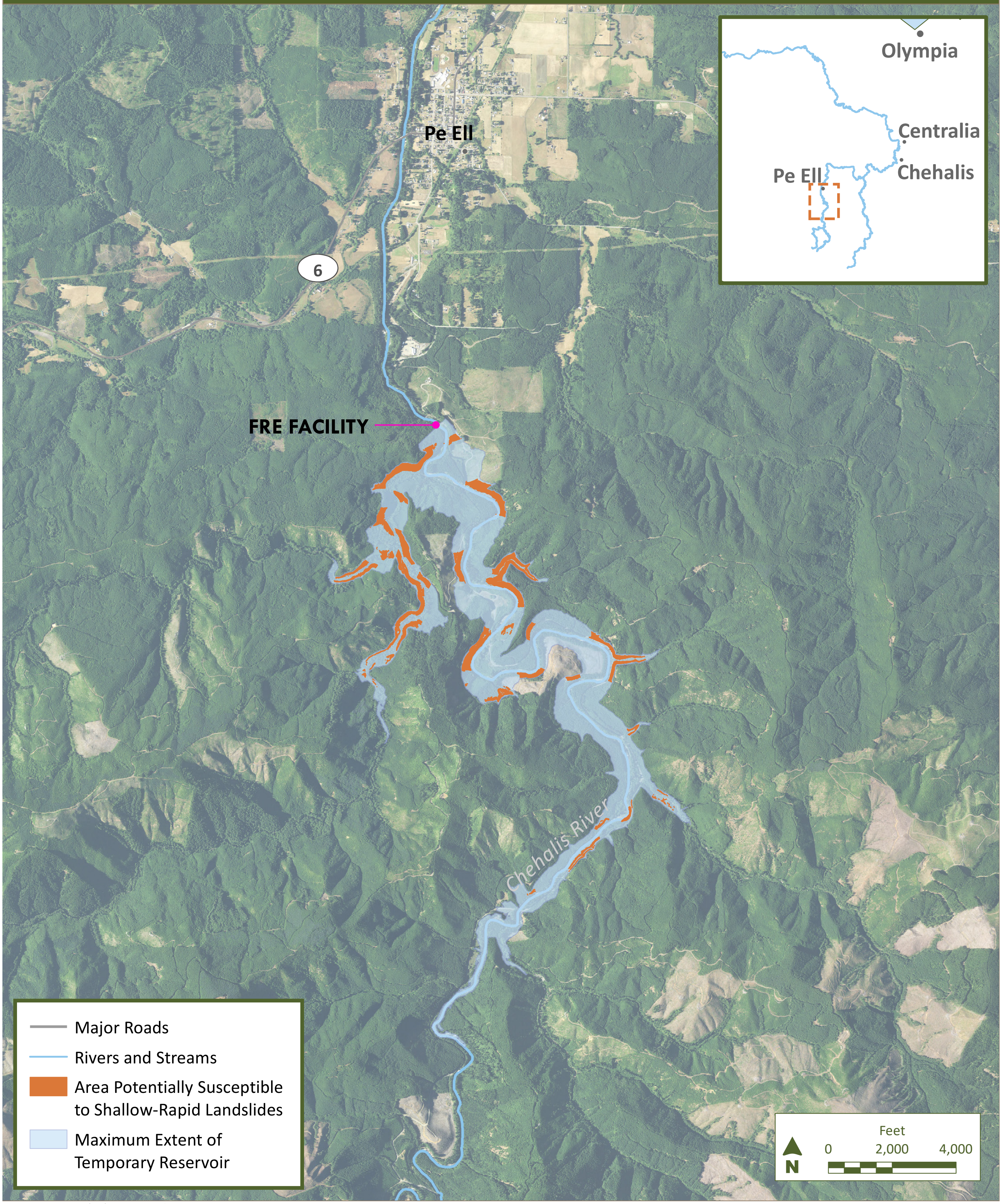


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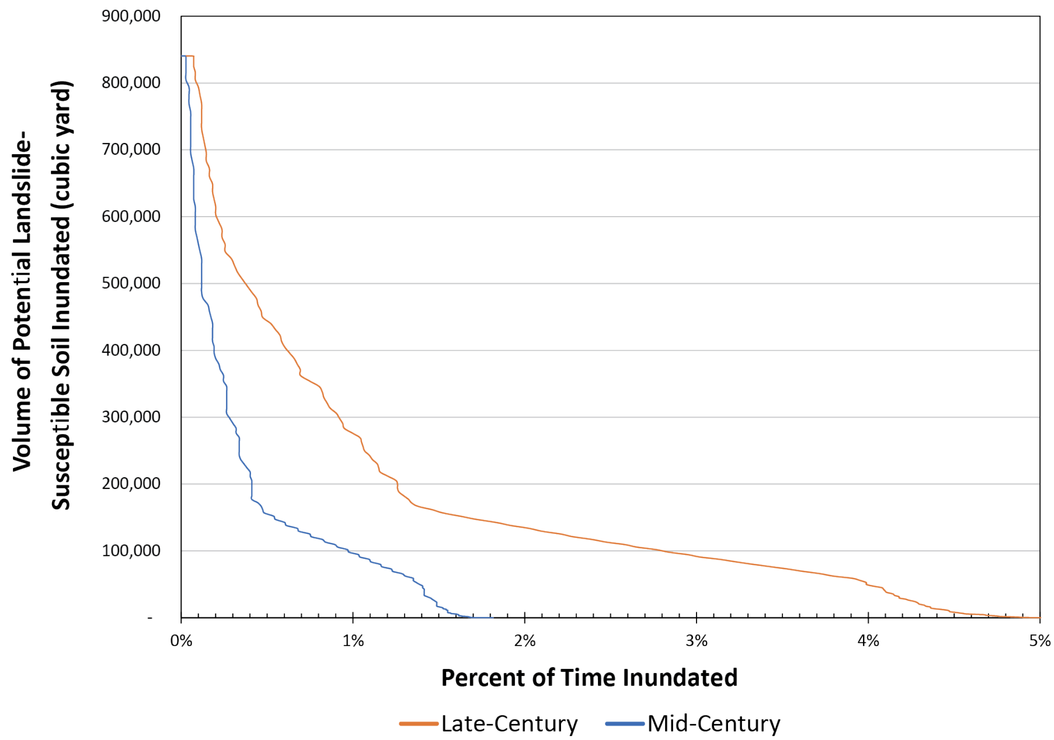
Figure F-18
Volume of Potential Shallow-Rapid Landslide-Susceptible Soil by Percent of Time Inundated



Surface Erosion After Reservoir Drains

After the reservoir is fully drained, any deposited sediment that remains and is not trapped by vegetation could potentially be eroded during subsequent rainfall. Since it was assumed that wave erosion would erode all silt and clay particles that were not trapped by vegetation, the remaining sediment on the hillslopes was assumed to be sand-sized particles. The WEPP model was used to estimate rainfall erosion potential for sand-sized particles deposited during a flood with the magnitude of the 2009 flood (normal) and the 2007 flood (extreme). An upper-bound erosion scenario (steep 60% slope) and lower-bound estimate (5% slope) were calculated.

Estimated sand-sized particles eroded, if an average-annual rainstorm or a 10-year rainstorm (major storm) occurred immediately after the reservoir drained and before any vegetation regrew, ranged from 127 to 5,830 tons (Table F-10). The erosion amounts from rainfall erosion would likely be substantially less than the upper-bound estimates listed in Table F-10. This is due to actual slopes not being as uniformly steep as the assumed 60% on hillslopes and to the trapping of some deposited sands on the reservoir valley floor by roughness elements such as vegetation, rocks, logs, and sticks. In addition, as time passes after reservoir inundation, annual vegetation (e.g., grasses and other groundcover) will grow and cover the deposits, further reducing erosion potential.

Table F-10
Estimated Surface Erosion Following Impoundment

FLOOD CAUSING DEPOSITION	HILLSIDE SLOPE SCENARIO	SUBSEQUENT STORM CAUSING EROSION	ESTIMATED SAND ERODED (TONS)
2009	Upper Bound Erosion Rate Scenario[1]	10-year (major) storm	1,760
	Lower Bound Erosion Rate Scenario[2]		380
	Upper Bound Erosion Rate Scenario[1]	Average annual storm	1,760
	Lower Bound Erosion Rate Scenario[2]		127
2007	Upper Bound Erosion Rate Scenario[1]	10-year (major) storm	5,830
	Lower Bound Erosion Rate Scenario[2]		380
	Upper Bound Erosion Rate Scenario[1]	Average annual storm	2,400
	Lower Bound Erosion Rate Scenario[2]		127

Notes:
1. The upper-bound erosion rate scenario assumes a constant 60% slope (representing steep hillsides around smaller tributaries).
2. The lower-bound erosion rate scenario assumes a constant 5% slope (representing most of the floodplain on either side of the mainstem Chehalis River).

The net effect of these erosion mechanisms during FRE facility operation would be to decrease sediment input to the mainstem Chehalis River downstream of the FRE facility during impoundment events and increase fine sediment input in the mainstem Chehalis River as the temporary reservoir drains and during one or two intense rainstorm after the temporary reservoir is drained. Increased fine sediment input effects would be moderate during all of these time periods (reservoir draining and one or two subsequent intense rainstorm) but could be significant during the latter parts of the reservoir draining period if incoming turbidity levels are low because eroded sediment could exceed 10% of background input. The fine sediment impacts would have a **significant adverse impact** on turbidity (water quality).

Mitigation is proposed for the Applicant to develop a Surface Water Quality Mitigation Plan to mitigate impacts to water quality from fine sediments in the temporary reservoir and downstream; however, there is uncertainty if the implementation of a plan is technically feasible or economically practicable. Therefore, the Proposed Action would have **significant and unavoidable** adverse environmental impacts on water quality, unless the Applicant develops a Surface Water Quality Mitigation Plan that meets regulatory requirements and for which implementation is feasible.

Sediment Transport and Substrate Changes with FRE Facility Operations

The FRE facility temporary reservoir would impound water when flows at the Grand Mound gage are predicted to exceed 38,800 cfs and outlet gates are closed or when inflow to the FRE facility exceeds approximately 8,500 cfs and temporary ponding forms. Water would be impounded until the flow at Grand Mound is below 38,800 cfs, at which point the reservoir would be drawn down. Based on modeling for a long-term flow record under mid-century and late-century periods, the reservoir would impound water 33% and 46% of the years, respectively (Figure F-16; Hill and Karpack 2019).

During times when the temporary reservoir is not impounding water (floods smaller than a major flood), sediment would be transported through the lower outlet structures of the FRE facility and transported downstream. Sediment transport would be similar to what occurred during past smaller floods and in non-flood conditions.

When the temporary reservoir is impounding water, sand and coarser sediment would be deposited in the reservoir delta areas. Incoming sediment would be deposited in the channel at the elevation of the reservoir as the impoundment filled, and then the deposited sediment would be transported downstream as the reservoir emptied if inflow was large enough to transport the deposited sediment (approximately a 2-year flood or 6,500 cfs at the FRE outlet for existing substrate conditions). The operating range of the FRE facility is between elevation 425 to 627 feet; the resulting reservoir fluctuation zone extends between the FRE facility at RM 108.2 and approximately RM 115.

Downstream of the reservoir, the peak flow would be attenuated during major or greater floods that trigger the FRE facility operation, or when inflow exceeds approximately 8,500 cfs and ponding may occur, and sediment load and transport rates would be lower. Periods of impoundment are shown in Figure F-16. As the reservoir drains following a flood, flows and sediment loads downstream of the reservoir may be higher than when the FRE facility is not in operation.

HEC-RAS modeling of long-term sediment transport trends under mid- and late-century conditions as well as sediment transport trends under specific floods were used to compare the No Action Alternative with the potential FRE facility. The following flow periods were analyzed as representative of the range of effects:

- Total long-term change at end of long-term flow record
- Major flood
- Catastrophic flood
- Three consecutive years with major floods

6.2.2.1.2 Long-Term Trends

Figure F-19 shows the difference in sediment storage along the river channel at the end of the long-term flow record between the computed No Action Alternative and the potential FRE facility plotted longitudinally along the channel for the mid-century and late-century time frames. The HEC-RAS model predicts there would be net accumulation of sediment within the temporary reservoir (Figure F-20), a decrease in storage in the confined bedrock canyon for 0.5 mile downstream of the facility, and then alternating areas of more and less sediment storage with the FRE facility compared to the No Action Alternative to approximately RM 85, resulting in an overall net decrease from the FRE facility to RM 85. The model predicts little change in stored sediment within the mainstem Chehalis River downstream of approximately RM 85. The net accumulation in the temporary reservoir area and net decrease in sediment storage downstream of the FRE facility are higher for late-century flows than the mid-century flows, but patterns of net increases and decreases in storage are similar.

Figure F-19
Difference in Sediment Storage Along the Mainstem Chehalis at End of Long-term HEC-RAS Model Runs

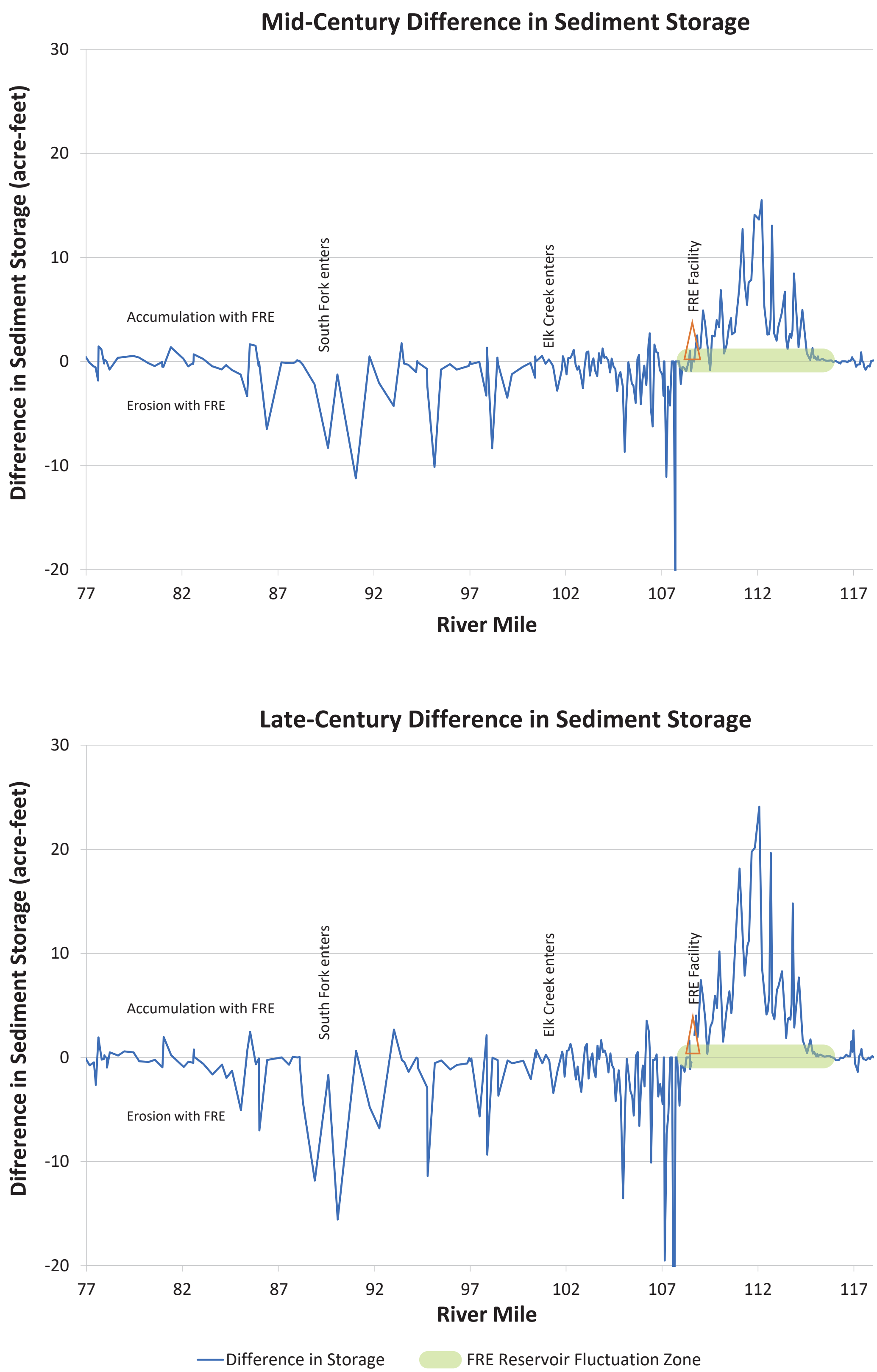
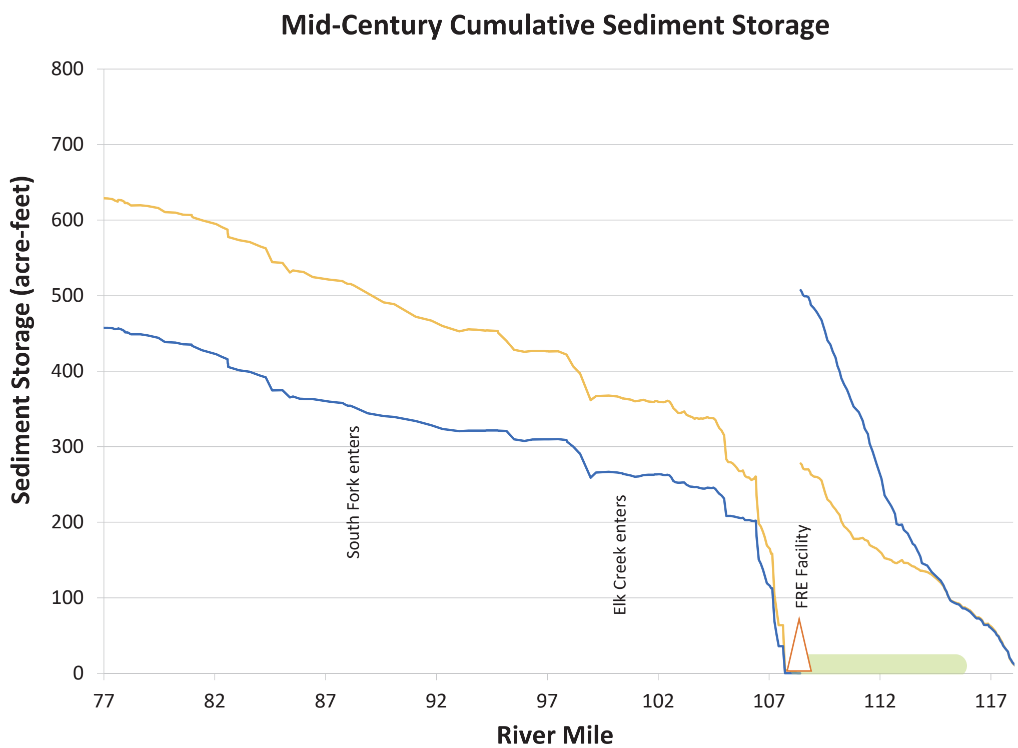
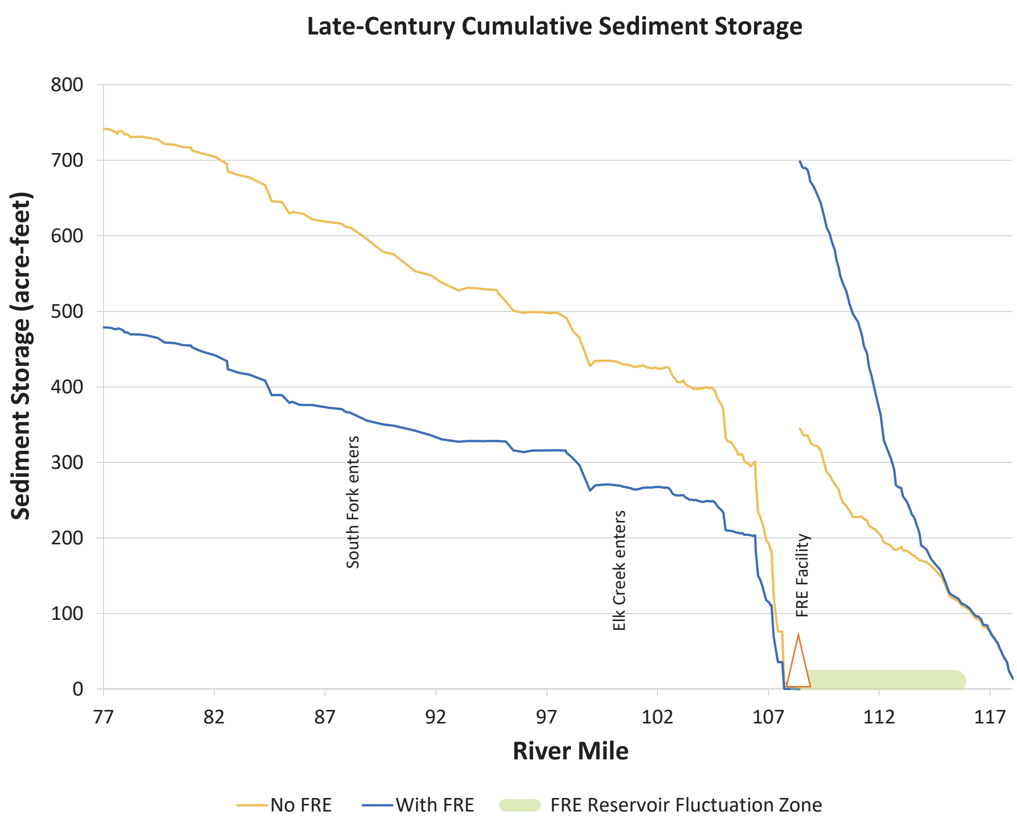


Figure F-20
Cumulative Sediment Storage Along the Mainstem Chehalis at End of Long-term HEC-RAS Model Runs





Changes in river-bottom grain size (substrate) often occur within and downstream of storage reservoirs. The HEC-RAS model output provides the median (D_{50}) grain size of the cover and subsurface layer used for calculations of sediment transport at each time step. The cover layer grain size in HEC-RAS varies dramatically from time step to time step as sediment moves through the model; the subsurface grain size does not vary as dramatically and is likely a better representation of average grain size conditions that might be expected on the riverbed.

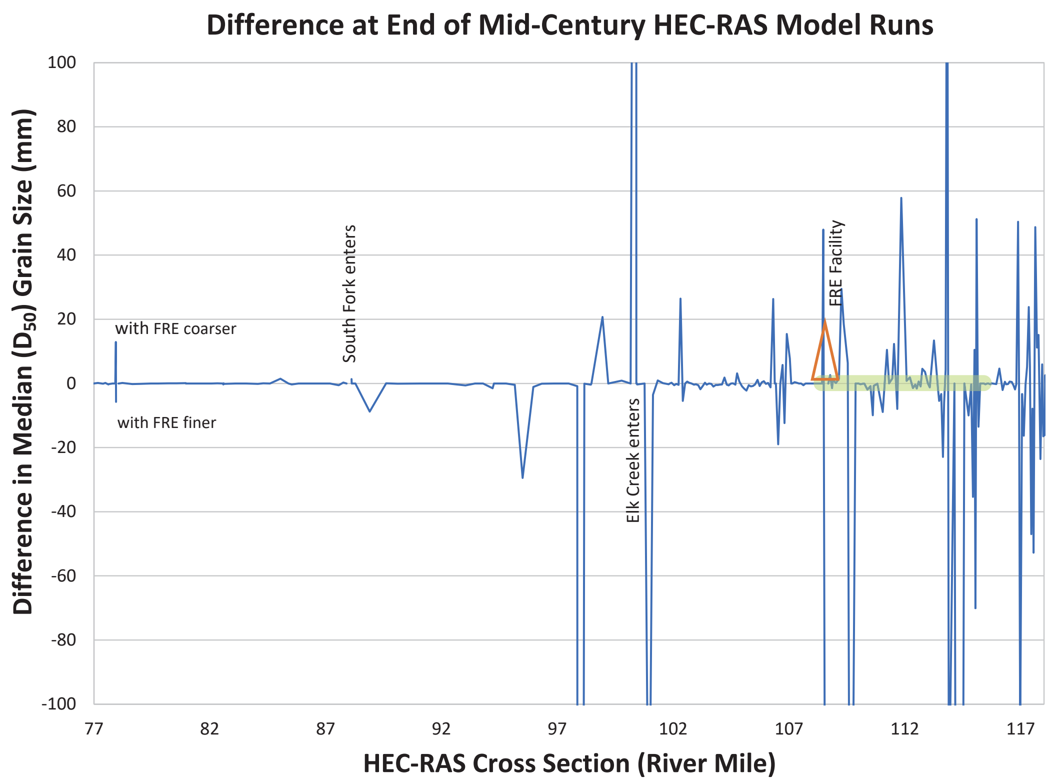
Long-term differences in median grain size between the No Action Alternative and the FRE facility model runs under the mid- and late-century long-term flow scenarios are shown in Figure F-21. The vertical axis on the figures is truncated at +/- 100 mm to show subtle changes in grain size that are most important for fish and aquatic habitat values. Changes of over +/- 100 mm indicate major changes in substrate conditions, such as changes from a boulder or bedrock bed to a gravel bed or vice versa. Under mid-century flow conditions (Figure F-21), the subsurface median grain size shows large variations in grain size, both finer and coarser, upstream of approximately RM 114 and at the FRE facility as sediment is deposited in and eroded from the channel in the temporary reservoir. The model predicts only **minor** changes in subsurface grain size downstream of approximately RM 102. Under the late-century flow conditions, HEC-RAS predicts large variations in some transects upstream of the FRE facility and minor coarsening of some transects between the FRE facility and RM 102 (Figure F-21). Little change in grain size is predicted downstream of RM 102.

6.2.2.1.3 Changes During Specific Floods

During a major flood (similar to the 2009 flood), a catastrophic flood (similar to the 1996 flood), or 3 consecutive years with major floods, the FRE facility would impound water. The cumulative change in sediment storage at the end of each of these flood scenarios, under mid- and late-century climate change flows immediately after the reservoir is finished draining and at the end of the following summer, are shown in Figure F-22. During all of the flood scenarios, sediment would be stored in the reservoir area (upstream of the FRE facility) during the impoundment period and some of the stored sediment subsequently transported out of the reservoir area and into the downstream channel by the end of the following summer.

Changes to subsurface median grain sizes during the major, catastrophic, and 3 consecutive years with major floods are shown in Figure F-23 for mid- and late-century flows. Upstream of approximately RM 113 (within and upstream of the temporary reservoir) there would be changes to substrate, both fining and coarsening depending upon location, at the end of the impoundment period compared to pre-flood conditions. Downstream of the FRE facility, the HEC-RAS model predicts only minor changes to grain size conditions following the modeled floods.

Figure F-21
Difference in Median Grain Size of Subsurface Layer



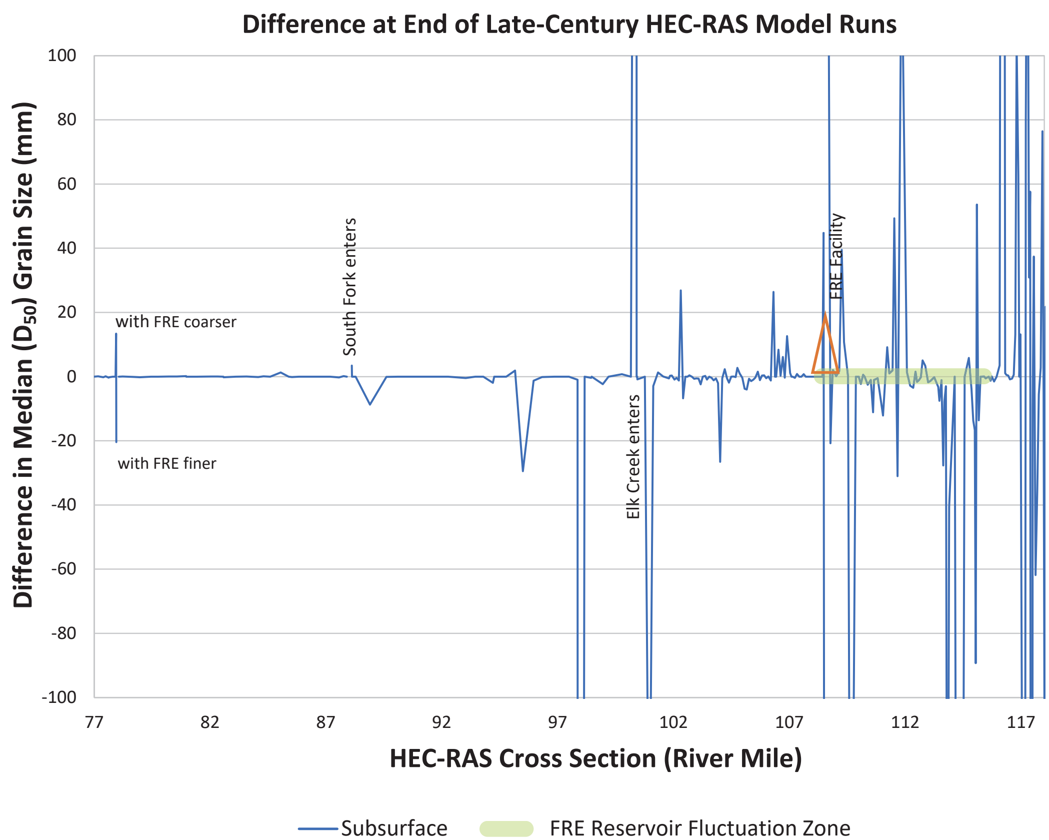


Figure F-22
Cumulative Sediment Storage at the End of Flood Scenarios and the Following Summer

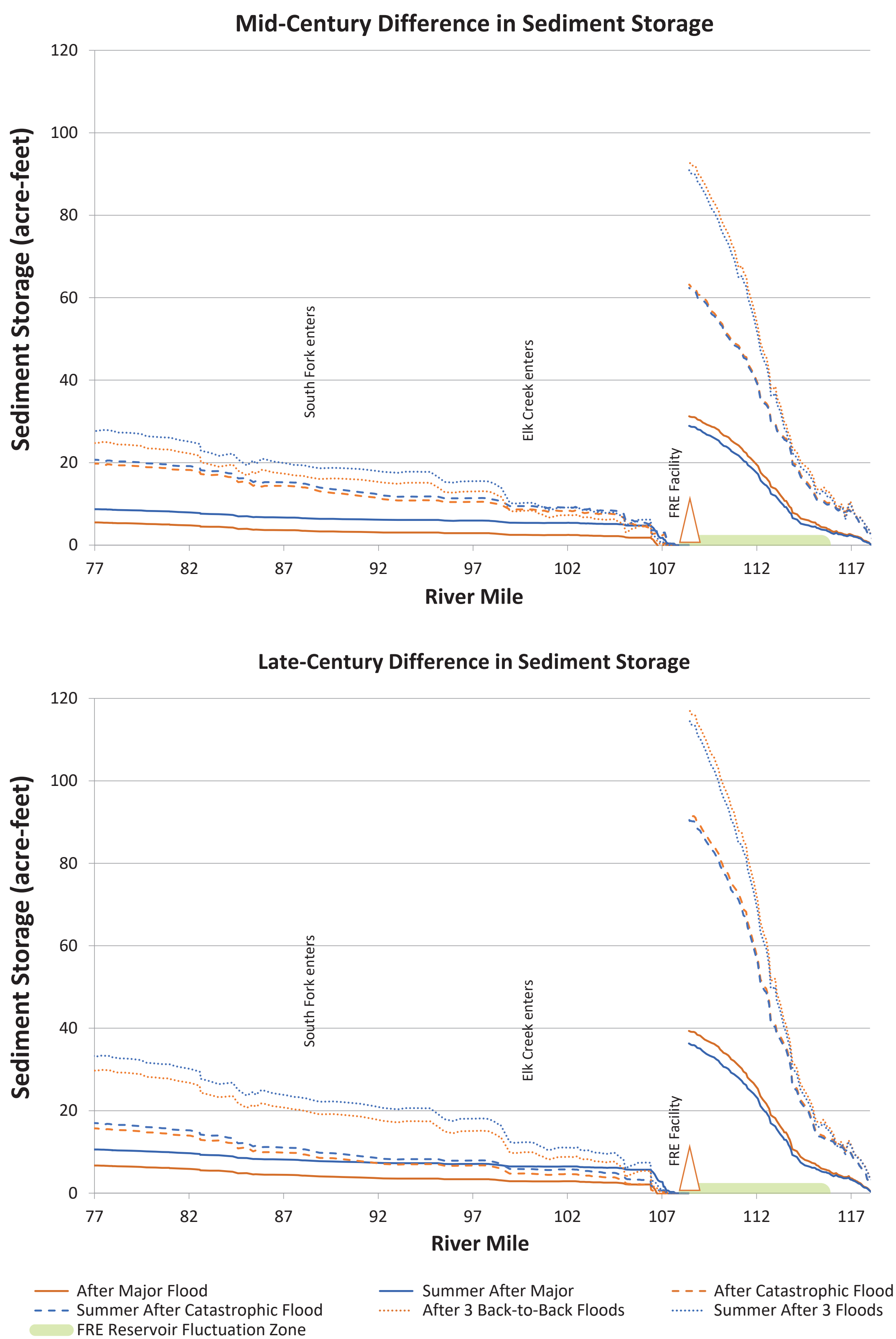
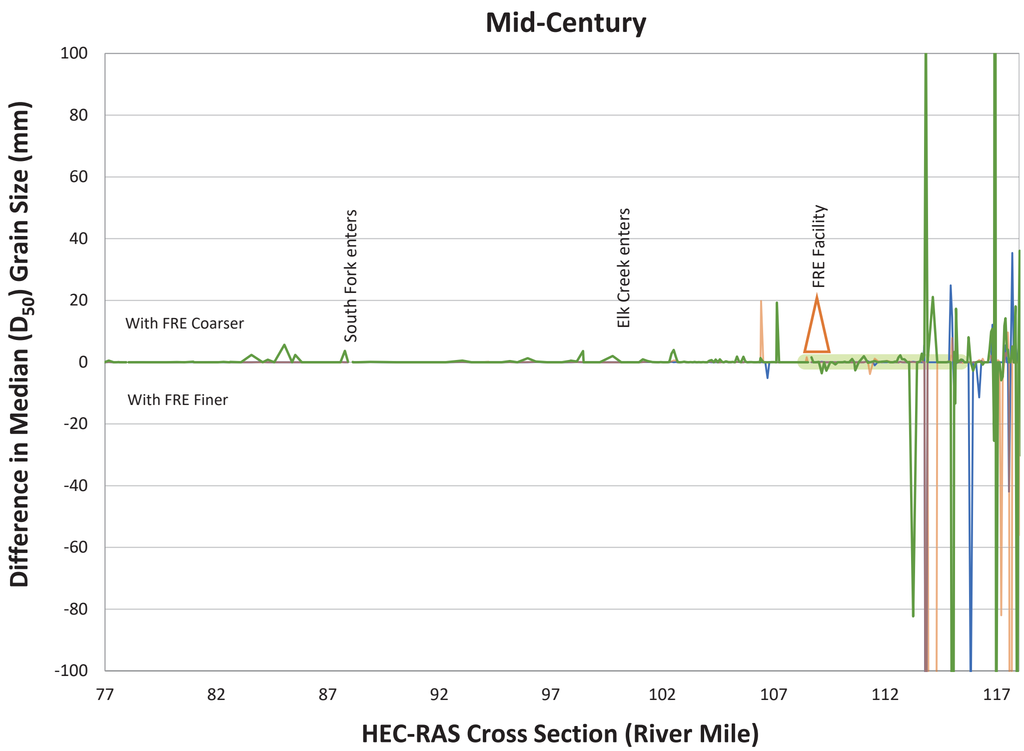
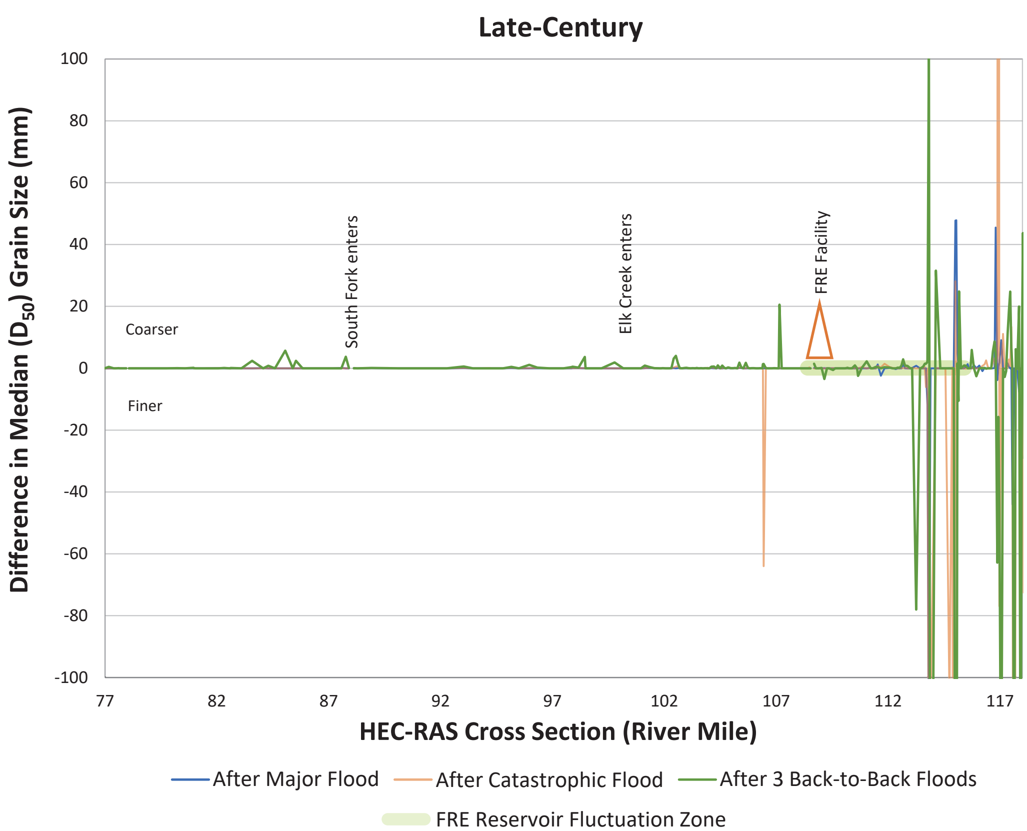


Figure F-23
Difference in Median Grain Size of Subsurface Layer for Flood Scenarios





Overall, the HEC-RAS modeling predicts **significant adverse impacts** to sediment transport and substrate characteristics within the temporary reservoir fluctuation zone. These significant impacts could be detrimental to fish and aquatic habitat by increasing fine sediment deposition in the riverbed (substrate). The model predicts **moderate** impacts to geomorphology between the FRE facility and approximately RM 85. This would have **significant** adverse effects on fish and aquatic habitat as described in the *Fish Species and Habitats Discipline Report*.

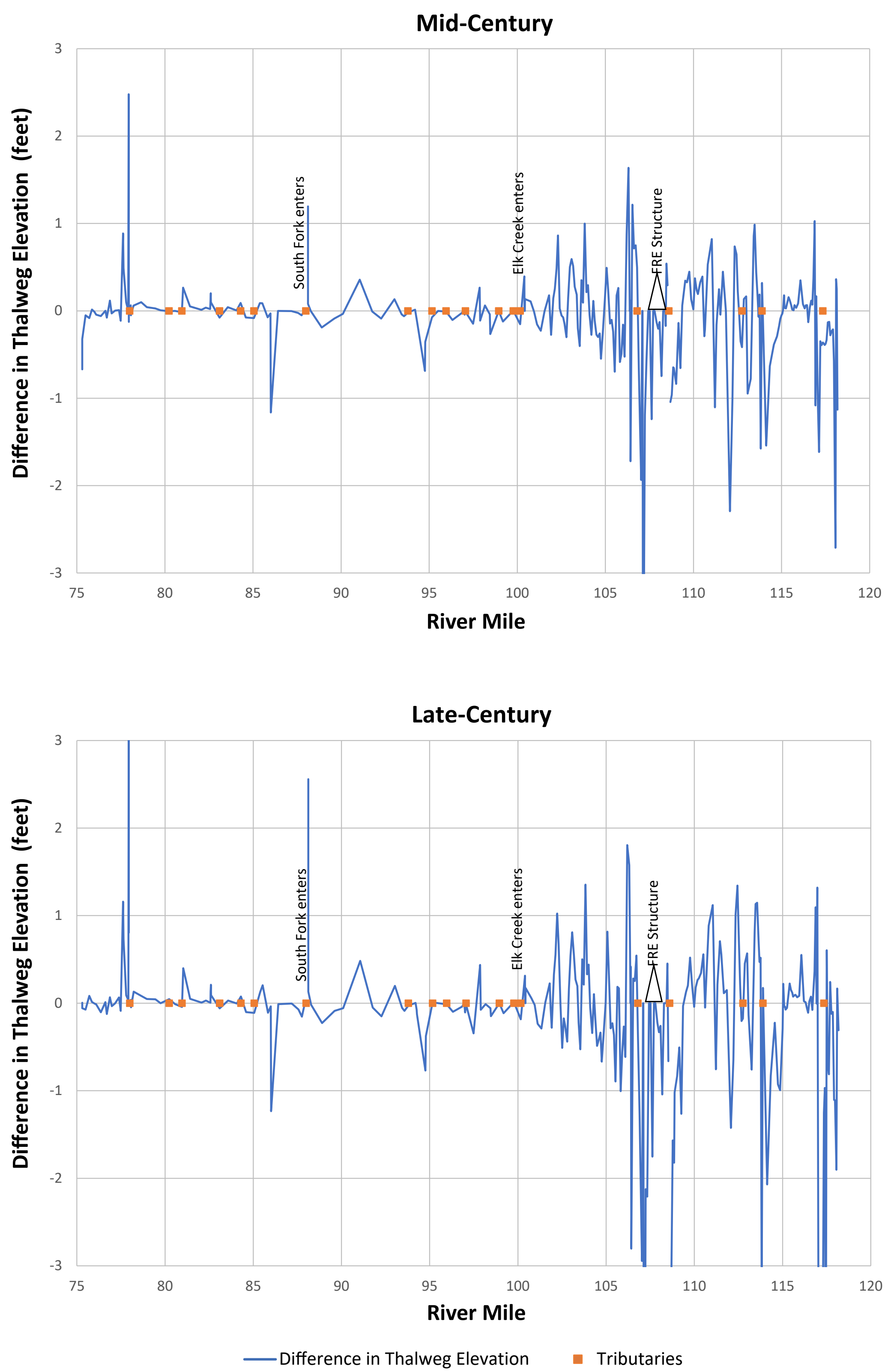
Mitigation is proposed for the Applicant to develop a Fish and Aquatic Species and Habitat Plan and a Surface Water Quality Mitigation Plan to mitigate impacts to sediment transport and substrate characteristics within the temporary reservoir fluctuation zone; however, there is uncertainty if the implementation of a plan is technically feasible or economically practicable. Therefore, the Proposed Action would have **significant and unavoidable** adverse environmental impacts on sediment transport and substrate characteristics, unless the Applicant develops a Fish and Aquatic Species and Habitat Plan and a Surface Water Quality Mitigation Plan that meet the requirements described in Section 6.2.3 and for which implementation is feasible.

6.2.2.1.4 Channel and Tributary Incision

Erosion in mainstem channels can result in channel incision and lowering of the thalweg (the deepest part of a river cross-section). If incision and channel lowering are extensive, nearby tributary stream junctions can be affected and headcutting or incision of tributary stream channels can occur. The potential for incision of the mainstem Chehalis River or tributary deltas/junctions was evaluated using the change in thalweg (deepest part of the channel) predicted by the HEC-RAS model for the mid- and late-century long-term flow record. Changes in thalweg elevation for the FRE facility compared to the No Action Alternative are shown in Figure F-24. Positive numbers indicate the FRE facility scenario thalweg at that HEC-RAS transect location was higher in elevation than the No Action Alternative thalweg; negative numbers indicate a lower thalweg. Orange dots are locations of tributary junctions.

At most tributary junctions, the HEC-RAS model predicts either little change in thalweg elevation in the mainstem or aggradation. However, at one tributary junction in the FRE inundation zone, a drop in mainstem thalweg elevation of 1.2 feet is predicted. There is a possibility that a change in thalweg depth of this magnitude could result in incision at the mouth of this stream, but tributaries within the temporary reservoir would undergo periods of deposition and erosion depending on the occurrence of reservoir operations. The thalweg elevations of the Chehalis River within the temporary reservoir would vary in response to operations; it is likely that the Thrash Creek and other tributary junctions in the temporary reservoir would also experience periods of deposition and erosion, resulting in **moderate** adverse impacts to tributary junctions. The HEC-RAS model predicts no major long-term incision in the mainstem Chehalis River at the tributary junction locations downstream of the FRE facility, suggesting tributary incision would be **minor** with operation of the FRE facility (minor adverse impacts).

Figure F-24
Difference in Thalweg Elevations



6.2.2.1.5 Large Woody Material

Strong linkages among LWM, fish abundance, and aquatic species diversity demonstrate the ecological importance of wood in channels and stream ecosystems (Montgomery and Piégay 2003). The complex physical structure of channel morphology and LWM provides a diversity of habitat patches that support a wide range of organisms and life stages (Gurnell et al. 2002). Large wood is essential for growth and survival of salmon and steelhead; it helps provide cooler stream temperature, decreases fine sediment, and helps form and maintain many channel and floodplain features such as river bars and riffle-pool sequences. Wood also provides juvenile fishes refuge from high flows and from predation, and slower water to enable successful feeding (Wohl et al. 2015; Poff et al. 1997; Wald 2009; Gurnell et al. 2002). The influence of LWM on fish and aquatic habitat is described in *Fish Species and Habitats Discipline Report*.

LWM up to 3 feet in diameter and 15 feet long would be able to pass through the low level outlets when the FRE facility is not impounding water. If a trash rack is added it would further reduce the size of LWM that could pass through the outlet tunnel. Based on observations in the Chehalis River near the FRE facility, LWM begins to move in the upper Chehalis River at approximately a 2-year recurrence interval flow (approximately 10,000 cfs at the Doty gage), although transport initiation of each piece will depend on size, shape, and density. The FRE facility would begin impounding water during approximately a 7 year recurrence interval flow (approximately 38,800 cfs at the Grand Mound gage) or when inflow to the FRE facility exceeds approximately 8,500 cfs with the outlet gates open. When the FRE facility is in operation and impounding water for flood control, all woody material would be trapped in the reservoir and removed as the reservoir level drops. As a result, very little wood from the watershed upstream from the FRE facility would move downstream into the mainstem Chehalis River.

An estimate of woody material volumes that would be trapped and removed from the reservoir during different magnitude floods is shown in Figure F-14. LWM in the mainstem Chehalis River channel and tributary channels within the impoundment area would be reduced compared to current conditions because all flood intolerant trees will be harvested removing the local source of LWM from the FRE impoundment area (LWM would still be transported into the temporary reservoir and possibly downstream channels from sources upstream of the FRE facility). LWM would be removed from the impoundment area as the reservoir levels dropped.

Interactions between LWM and fluvial processes have important implications for the ecology of the Chehalis River. Since wood transport is dependent on the flow regime and the size, shape, and density of the wood, management practices such as flow regulation are key to interactions between flow, sediment, and wood (Gurnell et al. 2002). At 8,500 cfs water would begin to back up behind the facility when the outlet gates are open. Higher flows can pass through the outlet gates with a corresponding increase in backwater ponding. The outlet gates would be closed when peak flows are forecasted to be 38,800 cfs at Grand Mound within 48 hours.

It is unknown if the controlled flow regime at the FRE facility, regardless if the outlet gates are open or closed, will provide the water depths and velocity needed to transport the LWM downstream of the facility as it currently does. In addition, the low level outlet size limitation would reduce the size of LWM that would be transported through the outlets and into downstream reaches when the FRE facility is not operating. The addition of a trash rack would also limit the future size of LWM transported through the facility and downstream. Lack of mobilization of the available large wood from the watershed above the FRE facility to the river below would further reduce channel complexity and diversity of the Chehalis River mainstem, particularly between the FRE facility and the South Fork Chehalis River. Operation of the FRE facility would have a **significant adverse impact** on LWM loading and function.

Mitigation is proposed for the Applicant to develop a Large Woody Material Management Plan to mitigate impacts to LWM transport and channel complexity on the mainstem Chehalis River downstream of the FRE facility; however, there is uncertainty if the implementation of a plan is technically feasible or economically practicable. Therefore, the Proposed Action would have **significant and unavoidable** adverse environmental impacts on LWM transport and channel complexity, unless the Applicant develops a Large Woody Material Management Plan that meets regulatory requirements and for which implementation is feasible.

6.2.2.1.6 Channel Migration and Bank Erosion

Channel migration occurs in areas with erodible banks as a result of one or more of these factors:

- Peak flows that impinge upon erodible banks at meander bends
- LWM pieces or jams that direct high flows at erodible banks
- Accumulation of coarse sediment that directs high flows at erodible banks

Areas of the mainstem Chehalis River that are susceptible to bank erosion and channel migration are Reaches 2B, 3, 4B, 6, and the lower part of Reach 5. Operation of the FRE facility would reduce large magnitude floods downstream of the FRE facility, but small and moderate floods would not be reduced. LWM loading would be reduced, and sediment accumulations would decrease between the FRE facility and the confluence with the South Fork Chehalis River. Because bank erosion and channel migration is the result of a complex interaction of high flows, LWM loading, and sediment accumulation, it is anticipated that operation of the FRE facility would slightly decrease channel migration in Reaches 2B and 3 and have little noticeable effect on channel migration downstream of the South Fork. Over time, encroachment of riparian vegetation in the Chehalis River between the FRE facility site and the South Fork confluence as a result of the reduction of large flood peaks may stabilize some banks and further reduce channel migration. This effect would be most pronounced in upstream areas.

It is likely that major channel avulsions such as those that occurred during the 2007 flood as a result of LWM jams would not occur upstream of the South Fork Chehalis River because large peak flows would be reduced and LWM moving during large floods would be trapped in the reservoir so channel-spanning log jams would be unlikely to form. Downstream of the South Fork Chehalis River confluence, bank erosion, channel migration, and avulsions would likely be similar to existing rates.

Operation of the FRE facility would have **moderate** impacts on bank erosion and channel migration in Reaches 2B and 3 below the FRE facility by reducing bank erosion and channel migration rates slightly, and **minor** effects on bank erosion and channel migration in other geomorphic reaches. A reduction in bank erosion and channel migration rates may be considered a beneficial effect for landowners and infrastructure and an adverse effect on natural geomorphic and aquatic habitat-forming processes.

Within the temporary reservoir, there are few areas that are subject to channel migration under current conditions. Deposition of sediment in the form of deltas during inundation events within the impoundment area would result in an increase in channel migration in the delta areas between RM 115 and RM 108 if they are in relatively unconfined reaches. The magnitude of these effects would be minor to moderate in most reaches but could be significant in a few isolated relatively unconfined reaches by increasing channel migration rates in areas where little channel migration occurs at present. The overall impact of increasing channel migration in the temporary reservoir area would be **moderate.** There is no infrastructure within the temporary reservoir area that would be impacted by channel migration. The increased channel migration and bank erosion could be considered detrimental to natural geomorphic and aquatic habitat-forming processes.

6.2.2.1.7 Channel-Forming Processes

River channels form as the result of the interaction of water, wood, and sediment moving through a river valley that provides the underlying structure for channel formation. In the Chehalis River, the river valley varies from being confined by bedrock to unconfined alluvial reaches as described in previous sections. Operation of the FRE facility would change the input of water, wood, and sediment within the FRE footprint and downstream of the FRE facility.

Flows would be unimpeded when the FRE outlets are open, thereby maintaining unmodified flushing and channel-maintenance flows. Closure of the FRE outlet gates would begin when flows are forecasted to be above 38,800 cfs at Grand Mound within a 2-day time window. Because the Grand Mound gage measures flow from the Chehalis River, the Newaukum River, and the Skookumchuck River, the reading of 38,800 cfs would include water from all three rivers. Based on the historical record, when the Grand Mound gage reads 38,800 cfs, the flow at the FRE site has ranged from 10,000 to 15,000 cfs. Flows up to 8,500 cfs would pass through the FRE low-level outlets without surcharging. Above this river flow, surcharging could occur, and water could back up at the upstream entrance to the outlets. Therefore, during FRE flood operations, streamflows necessary for most channel-forming processes would be reduced.

This reduction in peak flows, and corresponding reduction in large wood and sediment transport, would directly impact creation of habitats that depend on those channel-forming processes. Because flows of

12,500 cfs or less still move fine sediment (Poff et al. 1997) capable of filling off-channel aquatic habitats, this reduction in peak flows would shift the dynamic between the creation and loss of off-channel habitats slowly toward their elimination over the long term. In addition, major avulsions that occur during large magnitude floods would be lost. The controlled releases would decrease the magnitude, delay the timing, extend the duration, and decrease the rate of change associated with normal peak flows, creating a new flow regime for the river. The greatest adverse impact would occur in Reaches 2 and 3 of the upper Chehalis River mainstem from the FRE facility to the confluence with the South Fork Chehalis River and would diminish as major tributary flows enter the mainstem in Reaches 4, 5, and 6 moving downstream.

The *Draft Chehalis Basin Strategy Aquatic Species Restoration Plan* (ASRPSC 2019) identified protecting and restoring natural habitat-forming processes, in-channel processes, and floodplain connectivity as critical to the health of the ecosystem. Elimination of peak flows would dramatically reduce the process of channel migration and the formation of floodplain habitats within the study area. Flows from smaller floods at the FRE facility would still act on the river channel and floodplain to the extent that some habitat can be shaped by these more frequent, lower energy flows. However, truncating peak flows during operation of the FRE facility would have a **significant adverse impact** on the channel-forming flow process and their important habitat-creation functions, primarily in Reaches 2B and 3 within the upper mainstem Chehalis River.

Mitigation is proposed for the Applicant to develop a Large Woody Material Management Plan, Riparian Habitat Mitigation Plan, and Fish and Aquatic Species and Habitat Mitigation Plan to mitigate impacts to channel formation on the mainstem Chehalis River from the FRE facility to the South Fork Chehalis River; however, there is uncertainty if the implementation of a plan is technically feasible or economically practicable. Therefore, the Proposed Action would have **significant and unavoidable** adverse environmental impacts on channel formation, unless the Applicant develops the plans described above and they meet regulatory requirements and are feasible to implement.

6.2.2.2 Indirect

No indirect impacts from operation on geomorphic processes are anticipated.

6.2.3 Required Permits

- **Forest Practices Permit (DNR):** Timber harvest within the proposed reservoir pool would be subject to Washington Forest Practices regulations and permits.
- **Hydraulic Project Approval (WDFW):** The Proposed Action would use, divert, obstruct, and change the natural flow and bed of freshwaters of the state and therefore would require a Hydraulic Project Approval from WDFW under the state's hydraulic code rules. The Hydraulic Project Approval would include conditions intended to minimize impacts on instream and riparian habitat and functions.

- **Local Land Use and Development Permits (Lewis County and City of Chehalis):** The Proposed Action would affect water-related resources regulated by Lewis County (FRE facility) and the City of Chehalis (Airport Levee Changes) under Shoreline Master Programs, Critical Areas Ordinances, and floodplain and stormwater management codes. Permits from both local governments would be needed in accordance with their local development codes.
- **NPDES Construction Stormwater General Permit (Ecology):** Construction of the Proposed Action would result in more than 1 acre of ground disturbance and involve stormwater discharges to surface waters. Therefore, coverage under an Ecology Construction Stormwater Permit would be required. The NPDES permit would include conditions requiring the permittee to prepare a Stormwater Pollution Prevention Plan and implement appropriate erosion, sediment, and pollution control measures for the duration of construction.
- **Section 401 Clean Water Act Water Quality Certification (Ecology):** Because a federal (Corps Section 404) permit would be needed to construct the Proposed Action, a Section 401 Water Quality Certification from Ecology would be needed to document the state's review of the project and its concurrence that the Applicant has demonstrated that the Proposed Action will meet state water quality standards. This certification is intended to provide reasonable assurance that the Applicant's project will comply with state water quality standards and other requirements for protecting aquatic resources, and covers both construction and operation of the facility.
- **Section 404 Clean Water Action Permit (Corps):** Section 404 requires a permit to authorize discharges of dredged/fill material to waters of the United States. Because construction of the FRE facility would involve excavation and fill placement in the Chehalis River, and construction of the Airport Levee Changes may involve fill placement in wetlands, the Proposed Action would require a Section 404 permit from the Corps.
- **Shoreline Master Programs (Lewis County):** These include provisions for delineating channel migration zones (CMZs) as well as minimizing development within CMZs and actions that limit channel migration. Actions associated with the FRE facility and bank protection associated with the Local Actions Alternative would affect channel migration.

6.2.4 Proposed Mitigation Measures

This section describes mitigation measures proposed for the Applicant to implement that would reduce impacts related to geomorphology from construction and operation of the Proposed Action. These mitigation measures would be implemented in addition to compliance with environmental permits, plans, and authorizations described in Section 6.2.3 that would be required for the Proposed Action.

- **EARTH-3 (Large Woody Material Management Plan):** To mitigate the impacts of construction and operation of the Proposed Action on large woody material and habitat, mitigation is proposed for the Applicant to develop and implement a Large Woody Material Management Plan. The plan must be developed in coordination with and approved by WDFW, and in consultation with DNR, and be ready to implement prior to the start of construction. The measures described in the plan will include a range of mitigation options. Mitigation will be implemented along the mainstem Chehalis River and in appropriately sized tributaries. The mitigation will include, but is not limited to, the following:

- To minimize impacts during construction, a plan will be developed to address large woody material transport and the diversion tunnel.
- To minimize impacts on channel-based processes, the large woody material that accumulates in the reservoir will be placed within the river channel and upland habitats identified in the plan within 60 days of completing drawdown following each inundation event.
- This plan will be developed in conjunction with management and mitigation plans for vegetation, wetlands and wetland buffers, streams and stream buffers, fish and aquatic species and habitat, wildlife species and habitat, riparian habitat, and surface water quality.

Other Related Mitigation Measures

- **FISH-1 (Fish and Aquatic Species and Habitat Plan):** To mitigate the impacts to fish and aquatic species and habitats associated with construction and operation of the Proposed Action, mitigation is proposed for the Applicant to develop and implement a Fish and Aquatic Species and Habitat Plan (for details, see *Fish Species and Habitats Discipline Report)*.
- **WATER-1 (Surface Water Quality Mitigation Plan)**: To reduce probable impacts to surface water quality and designated aquatic life uses of the Chehalis River and Crim Creek from construction and operation of the Proposed Action, mitigation is proposed for the Applicant to develop and implement a Surface Water Quality Mitigation Plan (for details, see *Water Discipline Report*).
- **WET-2 (Stream and Stream Buffer Mitigation Plan):** To mitigate the impacts to streams and stream buffers from construction and operation of the Proposed Action, mitigation is proposed for the Applicant to develop and implement a Stream and Stream Buffer Mitigation Plan (for details, see *Wetlands Discipline Report)*.
- **WILDLIFE-1 (Vegetation Management Plan):** To mitigate the impacts to habitat from construction and operation of the FRE facility and temporary reservoir, mitigation is proposed for the Applicant to develop and implement a Vegetation Management Plan (for details, see *Wildlife Species and Habitats Discipline Report)*.
- **WILDLIFE-3 (Riparian Habitat Mitigation Plan):** To mitigate the impacts to riparian habitat from construction and operation of the Proposed Action, mitigation is proposed for the Applicant to develop and implement a Riparian Habitat Mitigation Plan (for details, see *Wildlife Species and Habitats Discipline Report)*.

6.2.5 Significant and Unavoidable Adverse Environmental Impacts

There is uncertainty if mitigation is technically feasible and economically practicable; therefore, the Proposed Action would have **significant and unavoidable** adverse environmental impacts on geomorphology, as follows:

- Water quality exceedances of turbidity in the Chehalis River as the temporary reservoir drains and during subsequent rainstorms
- Sediment transport and substrate characteristics within the Chehalis River and streams in the temporary reservoir area
- Reductions in channel-forming processes and large woody material in the Chehalis River to the confluence of the South Fork

The Applicant may provide mitigation plans as described above. If agencies determine the plans meet the regulatory requirements and implementation is feasible, then the impacts would be addressed as part of the permitting processes.

6.3 Local Actions Alternative

This section analyzes the potential impacts from operation and implementation of local actions. The Local Actions Alternative elements that could affect erosion or geomorphic processes include reforestation, riparian restoration, constriction removal, and channel migration protection. Because the specific magnitude and location of these actions are not known, general impacts are discussed here.

6.3.1 Impacts from Construction

6.3.1.1 Direct

Any construction activities near streams or waterbodies would have the potential for increased erosion. Permits would be required that would include erosion control measures, and therefore erosion impacts would be **moderate to minor**.

6.3.1.2 Indirect

No indirect impacts from erosion or geomorphic processes are anticipated.

6.3.2 Impacts from Operation

6.3.2.1 Direct

Under the Local Actions Alternative, changes to sediment and water input from climate change would occur, and the Chehalis River would continue to adapt to the effects of the 2007 flood. Reforestation and riparian restoration activities could provide additional LWM and bank protection over the long term. Constriction removal could have local effects on sediment transport and deposition. Channel migration protection structures would reduce bank erosion and channel migration potential, affecting natural geomorphic processes by decreasing channel migration. These impacts are all anticipated to be **minor** and local.

6.3.2.2 Indirect

No indirect impacts on erosion or geomorphic processes are anticipated

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6.4 No Action Alternative

Actions that could affect erosion or geomorphic processes under the No Action Alternative include continued timber harvesting in managed forests and riparian and stream restoration actions. Landslides and erosion from large storm events and flooding would continue to occur. Changes to the Chehalis River channel and streams, such as avulsions and channel migration, would continue to occur. Under the No Action Alternative, changes to sediment and water input from floods would occur, and the Chehalis River would continue to adapt to the effects of the 2007 flood. Under the No Action Alternative, flooding would not be significantly reduced and flood frequency and severity are predicted to increase in the future. Geomorphological processes would continue to experience **substantial flood risk** under the No Action Alternative.

Geology and Geomorphology

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