**To:** **Karen Allston, Senior Assistant Attorney General, Quinault Indian Nation**

**From:** Natural Systems Design, Inc and SaturnaH2O

**Date:** April 23, 2020

**Re:** **EARTH DISCIPLINE REPORT - GEOLOGY TECHNICAL ANALYSES REVIEW**

# EXECUTIVE SUMMARY

The Draft Environmental Impact Statement (DEIS) Earth Discipline Report and Chehalis Basin Strategy geotechnical analyses prepared to support the proposed Flood Retention Expandable (FRE) dam project review under the State Environmental Policy Act (SEPA) were analyzed by a qualified technical team; Tim Abbe, PhD, PEG, PHG, Mike Ericsson, MS, PG, Paul Pittman, MS, PEG, Scott Katz, MS, and Aaron Lee, MS, EIT.

The review team concluded that **five critical assumptions were found to be in error which has resounding impacts on the other discipline report findings:**

1. Landslides and landslide potential are underrepresented in the DEIS, and thereby the estimated 840,500 cubic yards of sediment delivered by landslides over the life of the project is underestimated in the impact analyses; ***actual sediment volumes will be much higher (potentially 16 million cubic yards or higher over the life of the project)***. **A significant portion of landslide sediment inputs will be fine grained, that will adversely impact salmonid egg survival. This error is propagated in the sediment transport impact analyses and habitat impact analyses, and not considered in the FRE Operations Plan.**
2. The proposed reservoir pool drawdown rate, stated as 10 feet/day, far exceeds the landscapes ability to remain stable, and is not supported by the site's geologic conditions, or consistent with design standards. **This error is propagated in the sediment transport impact analyses and habitat impact analyses, and not considered in the FRE Operations Plan. *This error could result in unsafe conditions that threaten public safety if landslide-generated displacement waves result*.** Other variables and assumptions used in landslide stability modeling are inconsistent with operations stated in the DEIS and appear to have bias favoring the project by overpredicting slope factor of safety; there is no mention of these uncertainties with the analysis in the DEIS.
3. The loss of topsoil and mature vegetation in the reservoir will decrease the function and benefit they provide for preventing erosion and enhancing slope stability. Landslides and mass wasting will also expose disturbed ground to accelerated erosion. It is our opinion that the erosion process will deliver additional fine-grained sediment (75,092 tons/year after clearing and 23,292 tons/year as willow cover establishes) to the reservoir over the volumes delivered by landslides where it will be mobilized from the reservoir to the downstream reaches and will result in downstream habitat impacts. The addition of fine-grained sediment from erosion processes was not properly characterized, quantified or adequately considered in the DEIS. **This error is propagated in the sediment transport impact analyses and habitat impact analyses.** This condition will be exacerbated by an increase in landslides.

4. An analysis of landslide dam hazards was not adequately considered in the DEIS. Failure to consider this potential impact will misinform hazards and risks for FRE operations and underrepresents potential habitat impacts. **This error is propagated in the sediment transport analysis and operations plan**.
5. The lack of providing sufficient detail of the proposed quarry plans and disclosing and evaluating potential impacts beyond new road impacts, constitutes a significant omission and error. **This error is propagated in the geologic impact analyses, sediment transport impact analyses and habitat impact analyses.** The standards for environmental review of new surface mines proximate to salmon bearing waters is high. The level of disclosure and analysis in the DEIS is inadequate and incomplete.

In general, it was found that:

- The DEIS and supporting technical analyses do not utilize best available science (BAS)
- The DEIS and supporting technical analyses have significant data gaps, errors, and omissions that present considerable uncertainties, for example:
  - FRE Reservoir drawdown is two to three orders of magnitude faster than the hydraulic conductivity of hillslope soils within the reservoir, which will likely trigger widespread mass wasting (deep-seated landslides, shallow landslides, debris flows); there is not consistency between the technical analyses and proposed FRE Operations Plan on drawdown rate in the DEIS, nor was there adequate evaluation on ecological systems or public safety impacts that may result from widespread slope instability
  - The DEIS acknowledges that reservoir operations will increase fine sediment inputs to the river from hillslopes and landslides that will impact water quality. However, predictions of fine sediment inputs are grossly under-estimated, and no fine sediment transport modeling or aquatic habitat impact assessment was conducted. Increase in fine sediment inputs will increase salmonid egg mortality by infiltrating redds within the reservoir and far downstream
  - The DEIS fails to acknowledge that landslides can dam and impound stream channels within the reservoir that could potentially impact the FRE conduits and operations, as well as negatively impacting local and downstream ecological systems
  - The DEIS fails to assess impacts from landslide-generated displacement waves on reservoir shoreline erosion and overtopping of the FRE facility
  - The DEIS fails to assess downstream channel incision and lateral erosion by rapid release of impounded water from the FRE that may increase instability of downstream landslides, such as the large, deep-seated landslide on the western hillslope (left bank) immediately downstream of FRE facility
  - The DEIS fails to provide site plans, volume estimates, proposed footprints, or supporting technical analyses (e.g. vibration, slope stability, stormwater management, erosion control, etc.) for any of the three quarries proposed on steep slopes and adjacent to Type-S waters; nor was there a consideration of potential impacts
- The DEIS does not accurately identify, quantify, disclose and clearly communicate all hazards, impacts, risks, and uncertainties associated with the FRE and proposed operations. For example:
  - The DEIS fails to provide comprehensive identification of <u>all</u> landslide occurrences or landslide potential within the reservoir and its contributing hillslopes. The presence of unstable slopes prone to instability with reservoir operations has significant uncertainties and potentially significant impacts beyond what was reported

  - The DEIS fails to communicate the risk to public safety and ecological systems from landslide-generated displacement waves or FRE dam failure
  - The DEIS does not fully assess or communicate landslide dam and dam-break flood risks to FRE operations, public safety, or ecological systems
  - The DEIS does not assess potential impacts to conduits or associated trash racks, such as plugging, that would increase the duration of water retention in the reservoir and have impacts to FRE dam safety and ecological systems
- The DEIS and supporting technical analyses have not fully integrated applicable state and federal guidance documents, assessment standards, and relevant codes to fully inform decision makers
- The DEIS fails to provide equal and substantive analysis of alternatives
- The DEIS fails to provide mitigation plans adequate for evaluation nor does it establish criteria, targets or objectives for what mitigation plans would need to achieve.

We agree with the conclusions of the DEIS that significant geologic, public safety, and ecological impacts will result from construction and operation actions of the proposed FRE facility, but the magnitude of impacts and degree of significance is underrepresented in the DEIS. These impacts will persist for the life of the project and beyond. It is possible that the impacts resulting from the proposed FRE facility may be so great that fish populations in the Chehalis River are irreparably damaged, if not potentially lost all together in the Upper Chehalis; however, the analyses presented in the DEIS are not sufficient to address this issue with confidence. While the impacts to treaty rights and costs of this project cannot be accurately quantified, they are clearly understated in the DEIS.

The importance of a rigorous evaluation of landslide potential cannot be understated, as this geologic process affects the performance, longevity, public safety, and ecological impacts related to the FRE, infrastructure and resources on hillslopes bordering the reservoir, as well as areas downstream of the FRE. The FRE itself will directly affect the frequency, extent, and potentially the magnitude, of landslides, thereby increasing the risk to the public and ecological systems. Underestimating the potential for landslides will have a rippling, and potentially compounding effect for the other DEIS disciplines.

Based on our review of the DEIS and supporting technical analyses, it is our opinion that the applicant 1) fails to fully consider, quantify, disclose and analyze all impacts; 2) fails to provide mitigation plans to be evaluated by decision makers, and; 3) fails to offer substantive analysis of alternatives. In conclusion, it is our opinion that the DEIS and analyses are incomplete, flawed and misinform decision-makers. ***The impacts to Treaty Rights from this proposed project are significantly underrepresented, but in our opinion, they are likely immense and unmitigable.***

# INTRODUCTION

The Chehalis Basin Strategy has two general goals for managing the Chehalis River; 1) reduce flood damages, and 2) improve degraded fish habitat conditions. An expandable flood retention (FRE) dam facility has been proposed as an alternative to advance one of the goals; reduce flood damages to communities near Chehalis, Washington. Several alternative concepts were proposed, but the Flood Retention Expandable (FRE) facility has been advanced for environmental review under the State Environmental Protection Act (SEPA). The purpose of the FRE will be to store water in the upper Chehalis River watershed during flooding to alleviate damage to some of the developed areas of the lower floodplain near the towns of Centralia and Chehalis.

The DEIS and supporting documents prepared for the SEPA review state the following parameters for use in the impact assessments:

- The FRE is designed for a 100-year hydrologic event, such as the 1996 flood, but **is not designed for larger floods, such as the 2007 flood, which will overtop the structure.**
- The design life of the FRE is assumed to be approximately 50 years (through 2080) based on the DEIS analysis.
- The DEIS reported that the FRE dam structure is expected to **impound water on roughly 33% to 46% of the years** through 2080.
- The 100-year reservoir pool elevation is **627 feet** (mean sea level).
- FRE reservoir has a maximum capacity of **65,000 acre-ft** and hydraulic head of approximately **202 feet** (100-year event).
- The reservoir will be partially to fully inundated episodically, but most likely during the winter rainy season, and the reservoir is estimated to be **inundated approximately 2% of the time for mid-century and 5% of the time** for late century.
- The inundation period of the reservoir will be of variable duration, but the DEIS states that full reservoir drawdown will be **up to 35 days** for single reservoir pool filling events. Multiple-event hydrologic conditions may result in multiple reservoir pool inundations before complete pool drainage occurs; however, this condition was not considered in analyses despite the fact that multiple back-to-back hydrologic events are common with winter "atmospheric river" conditions of the Pacific Northwest.
- The proposed reservoir pool drawdown rate is stated as **10 feet/day (5 inches/hour)** which is 100-1,000 times the stated hydraulic conductivity of hillslope materials.
- The DEIS states that assuming a 6-foot average soil depth, the total volume of soil that could potentially be moved by landslides influenced by the reservoir is **840,500 cubic yards.**

The FRE facility, reservoir operations, and downstream reaches will be <u>impacted by geologic processes</u> (including landslides, earthquakes, floods, and sediment transport). It should also be noted that the geologic conditions and processes will also be <u>impacted by the FRE facility, reservoir operations, and downstream conditions</u> resulting from this project. The USGS describes impacts from landslides in the following way:

> *In spite of improvements in recognition, prediction, mitigative measures, and warning systems, economic losses and casualties due to landslides in the Western Hemisphere appear to be growing as a result of increasing development of landslide-prone areas due to population pressures. Landslides impact the following elements of the natural environment: (1) the topography/morphology of both the subaerial and submarine surfaces of the Earth, (2) rivers, streams, forests, and grasslands, and (3) habitats of native fauna, both on the Earth's surface and in its streams and oceans. Environmental disturbances are results of general tendency toward degradation of the Earth's surface by gravitational mass wasting and erosion. (Schuster et al. 2001).*

# ANALYSIS

The construction and operation of the FRE facility is, in and of itself, a substantial and significant project. The potentially impacted area is of a regional scale. **The potential risk to environmental conditions and public safety is very high**. It is anticipated that the DEIS and technical analyses conducted to support a project of this nature would be of the highest level and include: 1) the use of BAS; 2) a thorough analysis free of significant data gaps and omissions; and 3) the application of appropriate guidelines, standards, and codes.

## Documents Reviewed

**Landslides/Geology/Quarry: Site-Specific Technical Analyses**

Three of site-specific technical studies referenced in the DEIS were available on the public Chehalis Basin Strategy website for review, specifically:

- Landslide Reconnaissance Evaluation of the Chehalis Dam Reservoir (Shannon and Wilson, 2015)
- Phase 2 Chehalis Dam Landslide Evaluation (Shannon and Wilson, 2017a)
- Phase 2 Chehalis Dam Site Characterization Landslide Stability Improvement Evaluation (Shannon and Wilson, 2017b)
- HDR and Shannon and Wilson. 2015. Phase 1 Site Characterization Technical Memorandum
- Chehalis Basin Strategy Phase 3 Landslide Evaluation (Shannon and Wilson, 2019).
- HDR and Shannon and Wilson. 2016. Phase 2 Site Characterization Technical Memorandum

**DEIS Analyses Reviewed**

- Draft EIS - Proposed Chehalis River Basin Flood Damage Reduction Project Summary
- Appendix F - Earth Discipline Report
- Appendix C – Environmental Health and Safety Discipline Report
- Appendix I - Chehalis River Basin Flood Control Combined Dam and Fish Passage Supplemental Design Report FRE Dam Alternative (Parts 1 and 2)

## Best Available Science

Use of BAS is statutorily defined under WAC 365-195 and RCW 90.58. The use of BAS for the Earth Discipline Report and supporting technical analyses were evaluated. Our review and findings are presented below.

### Summary of Best Available Science Findings from Supporting Technical Analyses

The review of the available technical analyses used to support the DEIS led us to conclude that best available science (BAS) was not utilized. There was inadequate consideration of the following in the Shannon and Wilson technical landslide studies (2015, 2019) which were integrated into the DEIS:

- The focus was on relict deep-seated landslides only; use of BAS would have included other mass wasting conditions (e.g. shallow landslides) that could potentially influence FRE design and operations, as well as ecological conditions

- The landslide mapping is incomplete; use of BAS methods for geomorphic interpretation of mass wasting landforms using LiDAR DTM reveals that additional deep-seated landslides and other mass wasting landforms were not identified.
- Landslides identified by others, including DNR (2008) and Weyerhaeuser (1994) were not reviewed, referenced, or included in the mapping
- No reference to DNR slope stability modeling (Shaw and Vaugeois 1999).
- Use of BAS to identify all geologic hazards and potential impacts to provide an understanding of comprehensive potential geologic risks were not disclosed or discussed
- The analyses did not consider appropriate regulatory standards and guidelines for the proposed action; use of BAS would have resulted in acknowledgement of applicable regulatory standards and the use of these standards in presenting information for FRE design considerations and environmental review.

## Applicable Scientific Studies and Knowledge from Other Areas

### *Landslides: Previous Studies in Project Area*

The Shannon and Wilson (2017, 2019) reports failed to reference previous studies and mapping within the project area, or to reference applicable studies pertinent to support the conclusions in their analyses. The use of BAS would have included a review of previous studies, relevant information and citations to support their conclusions. As a result, significant information was omitted from their analyses. For example, there was no mention that a landslide during the December, 2007 storm likely dammed the river within the proposed reservoir footprint. Based on LiDAR before and after 2007, the potential dam would have raised the river at least 20 ft prior to overflowing the dam and triggering a dam break flood. Shannon and Wilson fail to reference or identify the landslide at all, which was mapped by Washington Department of Natural Resources (WA DNR) (Sarikhan et al. 2008). A major debris flow during the same storm occurred immediately upstream, but was not referenced by Shannon and Wilson. Some local resident eye-witness accounts are consistent with a dam-break type event contributing to the 2007 flood peak. The analyses fail to recognize that the landslide dam and debris flows could have contributed to the record flood peak downstream while depositing a large quantity of wood debris and sediment. There is also no mention about how these hazards may influence the Operations Plan and conduit management, including the potential for conduit plugging.

The Shannon and Wilson reports also failed to acknowledge that they reviewed and considered any previous mapping efforts in the watershed. DNR published two documents on slope stability within the project area. These reports and mapping are easily accessible thru the DNR website (www.geologyportal.dnr.wa.gov) and in Sarikhan et al. (2008). These previous studies show that **landslide occurrence is much greater** than what was presented in the Shannon and Wilson reports.

### *Landslides: Applicable Scientific Studies and Knowledge from Other Areas*

The process of filling and draining reservoirs is known to contribute to slope instability if not evaluated and engineered properly (e.g., Schuster 1979, Schuster 2006, Wang et al. 2012., Paronuzzi et al. 2013, Yin et al. 2016, Xiao et al. 2018, USBR and USACE 2019). The potential consequences of landslides occurring within a reservoir or affecting the dam can be catastrophic and lead to significant loss of life, as exemplified in the Vajont landslide displacement wave tragedy that resulted in over a thousand casualties downstream of the dam (Paronuzzi et al. 2013, Exhibit 1a).

**Exhibit 1a. The Vajont Dam, Italy, circa 1960. The landslide visible in the photo was about 700,000 cubic meters in volume and occurred during initial infilling of the reservoir in November 1960. On October 9th, 1963, reservoir operations triggered the 300,000,000 cubic meter Vajont Landslide (Paronuzzi et al. 2013) that displaced much of the reservoir volume, sending a 250 m (820 ft) wave over the dam and killing 1,917 people.**

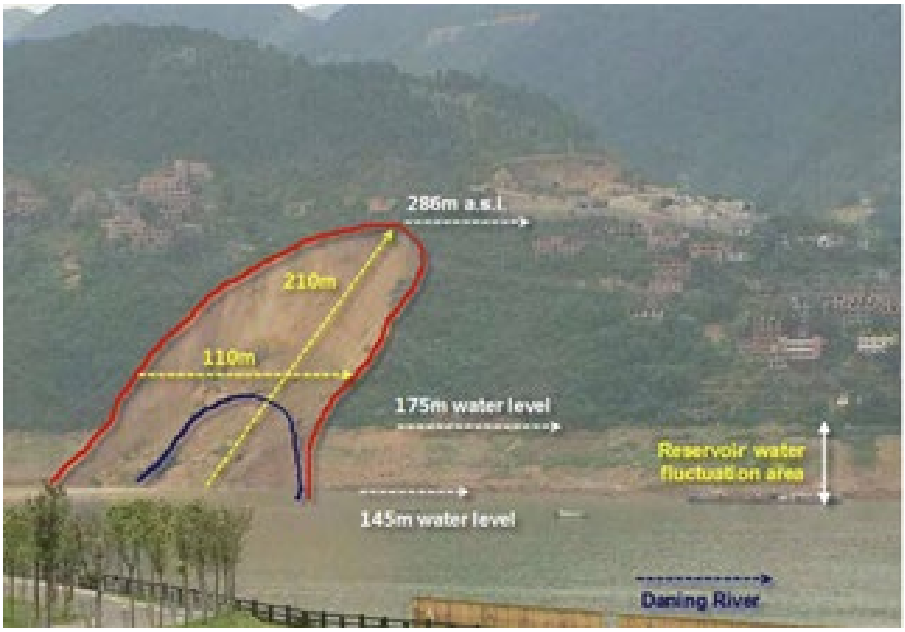


**Exhibit 1b. The June 15, 2015 Hongyanzi landslide along the east bank of the Daning River in the Three Gorges Reservoir, Wushan, China. The landslide extended well above the maximum reservoir pool elevation (175 m) and had a volume of 230,000 cubic meters. Water levels in the reservoir regularly fluctuate 30 m (98 ft). The landslide generated waves up to 6.2 m (20.3 ft) on the opposite banks. Due to early warnings, there was only one fatality (Xiao et al. 2018).**

Within the DEIS and supporting technical analyses, there are few references to previous studies that have pertinent information relating to the methods, conditions, or analyses applicable to evaluating the subject site. For example, in May 12, 2008 the Zipingpu Reservoir landslide in China resulted in a 25 m (82 ft) impulse wave that killed more than 70 people (Wang et al. 2018), a potential that exists with the proposed FRE dam. Much has been learned about landslides in recent decades, particularly with the Three Gorges Dam and other reservoirs affected by landslides triggered during rapid drawdown, such as is proposed for the FRE. There is a large library of literature on landslide initiation induced by reservoir operations and resulting impacts; this library includes everything from landslide-induced waves to landslide dams and dam break flood peaks that can overwhelm downstream infrastructure (Riemer 1992). These dam-break flood peaks "may be higher than those extrapolated from normal run-off or from PMP (probable maximum precipitation" (p.1974 in Riemer 1992). Schuster and Costa (1987) provides an example of a landslide flood that peaked 50 times higher than the normal maximum flood. Xia et al. (2014) shows that “landslide deposits have been observed to reactivate in association with water level fluctuations of reservoirs”. Landslide induced waves within a reservoir have also been studied extensively: Panizzo et al. (2005), Pugh and Harris (1982), Heller et al. (2009). Soil hydraulic conductivity and drawdown rate relationships for slope instability are also well researched (Berilgen 2007).

Failure to understand and integrate BAS results in error, data gaps, and can potentially result in significant impacts. For example, no landslide induced wave analysis was considered in the analyses. It was simply dismissed in the Shannon and Wilson analysis as “unlikely”, but no technical rationale, statistics, or referenced studies were provided to support this dismissal.

The potential for new deep-seated landslides, shallow landslides, and debris flows influenced by reservoir fluctuations are expected to occur within the reservoir, yet this potential wasn't considered or addressed in the Shannon and Wilson technical analyses. The drawdown conditions and rates developed for the Operation Plan should be dependent upon landslide stability, yet recommended drawdown rates were not considered in the proposed Operations Plan.

Numerous studies and guidance documents have outlined recommended assessment methodologies for evaluating landslides within reservoirs, such as Cornforth (2005). Use of models for predicting shallow landslide potential, such as SHALSTAB, or summarized by Milledge et al. (2014) are readily available and regularly used in the geologic profession for planning level assessments to identify potential unstable slopes. The DNR previously conducted a SHALSTAB analysis on the Upper Chehalis River watershed. The USBR references using Corominas et al. (2013) who discusses in detail the data and analysis relevant to assessing the risks associated with landslides. This information is available at: https://paperity.org/p/35203471/recommendations-for-thequantitative-analysis-of-landslide-risk. They also recommend the reviewing recommendations from the Landslide committee of the Canadian Geotechnical Society that collaborates with other professional societies on the current state of the practice in the evaluation of landslides. This information is available at: https://www.nrcan.gc.ca/hazards/landslides.

### *Shallow Landslides, Vegetation Loss and Soil Erosion: Applicable Scientific Studies and Knowledge from Other Areas*

Shallow landslides are important physical processes that influence sediment transfer and erosion, as well as create potential hazards to life and infrastructure (Spiker and Gori 2003). It is well established that reservoir operations increase the probability of landslides and erosion (e.g., Schuster 1979, 2006, Riemer 1992), however, this geologic process was omitted from the Shannon and Wilson technical analyses and only briefly covered in the DEIS. Reservoir inundation fluctuation and loss of vegetation will accelerate these processes. The influence of increased apparent soil cohesion from roots can significantly affect the stability of slopes with shallow soils (Cohen and Schwarz 2017). While the range of root influence is largely dictated by plant species and age, other variables contribute to the stability of slopes and it is difficult to untie the two. Because the composition of roots in the soil directly correlate to the vegetation communities present at the surface, disturbances above ground can propagate below ground (Schmidt et al. 2001). The clearing of trees on forested hill slopes will result in root decay, and a subsequent loss of apparent cohesion leading to increased instability (Amaranthus et al. 1985, Montgomery et al. 2000, Swanston 1988). With little to no root reinforcement, slope failure and erosion is more likely and occurs earlier than it would with roots present (Cohen and Schwarz 2017). Smith (1998) states:

> *Reservoir impacts on the riparian landscape occur both within the reservoir area and upstream and downstream of the reservoir. Upstream of the reservoir, impacts are related to decreased stream energy and subsequent sedimentation in the channel, on the floodplain, and in tributary valleys. Downstream of the dam, streams typically experience bed degradation and subsequent bank erosion as relatively sediment free water is released into a channel reach which had previously transported a suspended and bed load. Additionally, the frequency, magnitude, and duration of natural stream flows of various "geomorphic effectiveness" is substantially modified, reducing the number of large events which are typically important in building and modifying the natural alluvial and erosional features of the valley.*

## Summary of Best Available Science Findings

***The review and use of BAS were not considered in the technical analyses used to support the DEIS***. There was inadequate consideration of previous mapping and studies for the geographical area, there was no reference to BAS applied from other geographical areas, the use of predictive modeling was incomplete, and the analyses did not follow appropriate guidelines, codes, and standards. For example, to admit that a landslide dam and associated dam break flood could occur and yet simply state that "Actions to protect the FRE facility should be taken if landslide dams occur upstream of the FRE structure" is completely inadequate (Shannon and Wilson, 2019). The likelihood of one or more landslide dam or landslide-initiated displacement wave events occurring over the life span of FRE while the reservoir is active is very high. Further information is needed to inform what type of actions may be needed, and what impacts may result, prior to this type of hazard occurring.

Another example is using BAS to inform dam overtopping, which was omitted in the technical analyses and DEIS. Evidence shows that dams fail most often from overtopping, and that the consequences and costs of this are immense (**https://www.fema.gov/why-dams-fail**); more than 200 dam failures of this nature occurred between the 2000 and 2009 (Cannata and Marzocchi 2012). Dam planning and engineering should consider a mechanisms and processes contributing to potential dam overtopping and include dam failure analysis resulting from dam overtopping (Ecology 1993). Dam failure does not necessarily refer to a structural collapse, it also refers to any event in which water overflows out of control (Science Engineering & Sustainability 2019). Detailed analysis of the range in magnitude of these events must be done along with detailed analysis of flood peaks from landslide dams propagating downstream under a range of reservoir levels, including potential impact scenarios resulting from plugged conduits beneath the dam, displacement waves overtopping structures, and probable maximum floods (PMF).

A third example is consideration of impacts from landslides and increased soil erosion resulting from loss of vegetation; impacts that were not considered in the DEIS. These geologic processes have the potential to impact ecological conditions within the aquatic environment, both within the reservoir and downstream. Omitting these geologic processes demonstrates a failure to utilize BAS and a failure to meet the environmental review standards under SEPA.

## Applicable Guidance, Standards, and Codes

### Federal and State Dam Assessment and Design Standards, Guidance, Regulatory Codes

The Washington State Dam Safety Office, United States Bureau of Reclamation (USBR), United States Army Corps of Engineers (USACE), and Federal Emergency Management Association (FEMA) all provide dam design and planning standards that set a high bar because the potential risk from dams is very high. It would be expected that the technical analyses and DEIS supporting a dam project would have reviewed applicable studies and knowledge and integrated the state and federal guidelines and standards into the analyses. For dam construction, the following guidelines and standards were referenced in this analysis to support planning, analysis and considerations for designing dam that should have been considered in the DEIS and supporting technical studies:

1. United States Bureau of Reclamation (USBR) & Army Corps of Engineers (USACE) ***Best Practices in Dam and Levee Safety Risk Analysis*** (2019)
2. Washington State Department of Ecology Dam Safety Office (WADSO) ***Dam Safety Guidelines*** (Ecology 1993).

The state Dam Safety Guidelines “provide dam owners, operators, and design engineers with information on activities, procedures, and requirements involved in the planning, design, construction, operation, and maintenance of dams in the State of Washington.” To meet the requirements identified in the Dam Safety Regulations Chapter 173-175 WAC. The WADSO specifies that "The need for a particular degree of sophistication in a given analysis is a function of the anticipated level of probable ground motion, susceptibility of the soils to strength loss and pore water pressure build up under dynamic loadings and the downstream hazard setting."

The USBR Best Practices in Dam and Levee Safety Risk Analysis states that “Many dams and reservoirs are constructed in steep mountainous terrain where landslides can occur. Landslides, if large enough, can affect the safety of a dam or reservoir if they fail or move. Landslides can be triggered by heavy rainfall, snowmelt, reservoir drawdown, or large earthquakes. Ancient landslides can be reactivated, or if the geologic conditions are adverse, new landslides can be triggered”.

The standards and guidelines in these manuals do not appear to have been followed for the assessment and planning of the FRE dam structure. The WADSO Dam Safety Guidelines - Part IV: Dam Design and Construction and USBR Best Practices in Dam and Levee Safety Risk Analysis should have created the framework for what analyses were conducted. In particular, the following chapters and appendices in the current USBR Best Practices in Dam and Levee Safety Risk Analysis provide guidance and standards that should have been included in the DEIS and supporting technical analyses:

- A-2 Geologic and Geotechnical Information Required for Risk Analysis
- A-3 Potential Failure Mode Analysis
- A-4 Semi-Quantitative Risk Analysis
- A-6 Subjective Probability and Expert Elicitation
- A-7 Probabilistic Stability Analysis (Reliability Analysis)
- A-8 Combining and Portraying Risks
- A-9 Risk Guidelines
- B-1 Reservoir and River Stage Exceedance Probabilities
- B-2 Probabilistic Hydrologic Hazard Analysis
- C-1 Consequences of Flooding
- D-1 Erosion of Rock and Soil
- D-2 Spillway Erosion
- D-3 Flood Overtopping of Dams and Levees
- D-4 Riverine Erosion
- D-5 Embankment Slope Instability
- D-6 Internal Erosion Risks for Embankments and Foundations
- D-7 Foundation Risks for Concrete Dams
- D-8 Seismic Risks for Embankments
- F-1 Hydraulic Failure of Spillway Chutes
- F-2 Overtopping of Walls and Stilling Basin Failure
- H-1 Operational Risks
- H-2 Landslide Risks

The full document can be located here: https://www.usbr.gov/ssle/damsafety/risk/methodology.html
Design standards from both the state and federal manuals establish the level of analysis required to assess risk for the development of new dams. For example, in the State of Washington, all dams must evaluate both the Inflow Design Flood (IDF) and the Probable Maximum Flood (PMF). Washington's guidelines are consistent with well-established international guidelines for large dams and yet were not included in the DEIS documents. These are events that are much greater than the 100-year return interval flood that was considered by Shannon and Wilson (2019) in their analysis of landslides. The PMF is the maximum possible IDF. FEMA dam design guidance provides examples where the PMF should be assumed to be the IDF and a methodology for determining when to select a lower magnitude event as the IDF (FEMA, 2012). The DEIS and supporting technical

analyses considered only the 100-year event conditions, not the PMF for reservoir elevation or inflow conditions.

The proposed FRE has a maximum capacity of 80,176,000 cubic meters (65,000 acre-ft) and hydraulic head of 62 meters (203 ft), making it a Large Dam by international standards and thus meaning the PMF should be used. Note that the flood of record in 2007, determined to be about a 500-year flood, would be the "Standard Project Flood" (SPF) used for an "intermediate dam". The PMF is, by definition, larger than the SPF.

Additionally, the WADSO requires analysis consider maximum credible earthquake (MCE; regionally 7+M) and peak ground acceleration with annual probabilities of exceedance of 1 in 2500 for high risk design standards or 0.35g; we note that the correct standards were referenced in the DEIS, but public access to the supporting analyses were not provided. The use of 100-year (0.01) (or 150-year) exceedance probability design standards considered for landslide recurrences and seismic probability in Shannon and Wilson (2019) analysis are not appropriate for this proposed project given the potential impacts to the public. WADSO design standards state that: "…***where the consequences of failure could be catastrophic with hundreds of lives at risk. In this situation, very extreme design events and loading conditions are appropriate for the extremely high levels of reliability needed to provide proper protection of public safety***. *Design step 8 corresponds to theoretical maximum design events and loading conditions. In those cases where a theoretical maximum does not exist for a design loading under consideration, the maximum design/ performance goal is set at an Average Exceedance Probability of* $10^{-6}$ *(or 0.000001)*"

## Data Gaps, Errors and Omissions

The technical studies utilized by the DEIS to draw conclusions regarding impacts had significant data gaps and omissions. Data gaps, if not acknowledged, constitutes an omission. In particular, the following data gaps and omissions were noted and are considered as having a potentially **significant relevance to the adequacy of DEIS conclusions**:

- Only large, relict landslide landforms were mapped and considered as "geologic hazards" in the supporting Shannon and Wilson technical evaluations; RCW 36.70A.030(5) defines geologically hazardous areas as those "areas susceptible to erosion, sliding, earthquake, or other geological events... that pose a threat to the health and safety of citizens, fish, and wildlife, when incompatible commercial, residential, or industrial development is sited in areas of significant hazard." Analyses failed to identify and describe ALL applicable earth/geologic hazards and risks for new dam consideration as specified in state and federal guidance documents, which constitutes a data gap
- Analyses failed to reference and follow applicable codes, standards, and appropriate guidelines for designs, planning and permitting, which constitutes a data gap
- Analyses failed to identify and describe impacts from geologic processes potentially impacting the public and ecological systems (e.g. erosion, soil loss, increased landslide occurrence, recommended drawdown rates, increased channel migration rates, scour/incision and aggradation, dam outlet management, dam outbreak and overtopping potential, channel maintenance needs, emergency protocols and management, contingencies, water quality degradation, siltation of spawning gravels, loss of aquatic habitat)
- Analyses failed to conduct adequate predictive analysis of anticipated changes in landslide and erosion processes within the reservoir resulting from FRE operations and the resultant potential impacts
- Analyses failed to disclose potential increases in risk to public safety from "new hazards" (e.g. dam failure) resulting from the construction and operations of the FRE

- Analyses failed to identify and evaluate all impacts from reservoir area hillslope deforestation
- Analyses failed to identify and discuss a significant, large landslide prone area that occurs immediately downstream of the proposed dam (left bank) that could potentially impact the dam foundation or be impacted by FRE operations
- Analyses failed to correctly consider seismic conditions in the modeling of landslides other than LS-3 and LS-4; given the potential consequences of landslide occurrence during a full/near full reservoir condition and the high standard for design and risk mitigation, it is appropriate to evaluate the sensitivity of slope stability within the contributing area of the reservoir under the full range of potential conditions, including saturated conditions during reservoir inundation. Seismic analyses were only evaluated for un-saturated conditions (Shannon and Wilson, 2019)
- Analyses failed to provide quantitative evidence (field or modeling outputs) to back up the statement that continued movement of LS-11 is "unlikely to result in rapid delivery of a significant volume of material…" (Shannon and Wilson, 2019)
- Shannon and Wilson (2019) analyses failed to provide rationale for explaining validation discrepancies in modeling and real-world conditions in evaluation of LS-11, which is described as currently active (Factor of Safety (FS) <1.0); model results showed FS>1.0 which indicated that the landslide would be stable, and yet the slide was active
- Landslide induced displacement waves were not evaluated
- There was virtually no presentation of information for the three proposed quarries that would enable an understanding of potential impacts from these project actions and references to applicable regulatory code compliance was incorrect.

Omissions can result in design, and impact assessment error. Five examples of errors resulting from omissions in the technical analyses are provided below.

> Example 1: Underrepresentation of all mass wasting processes (deep-seated landslides, shallow landslides, debris flows, etc.) which results in flawed FRE design, Operations Plan, and DEIS impact analyses.
>
> Example 2: The proposed drawdown rate greatly exceeds the hydraulic capacity of soils, and the drawdown stability analysis considered drawdown operations different than what was presented in the DEIS; the outcome is that drawdown may trigger widespread land-sliding which results in flawed FRE design, Operations Plan, and DEIS impact analyses.
>
> Example 3: Increased mass wasting, vegetation loss, and soil erosion will result in increased sediment delivery to the reservoir which results in flawed FRE design, Operations Plan, and DEIS impact analyses.
>
> Example 4: Omissions of landslide dam occurrence and evaluations results in incomplete and flawed DEIS impact analysis and FRE design/operations considerations.
>
> Example 5: Omission of quarry plans results in an incomplete and flawed DEIS impact analysis.

These data gaps, errors, and omissions affect the conclusions of impact intensity and significance in the DEIS. In the following section, we perform cursory analysis to demonstrate this point.

# ADDITIONAL ANALYSES CONDUCTED

We performed cursory analyses on five data gap/omissions/errors identified in the DEIS and supporting technical analyses review to demonstrate the inadequacy of the DEIS. The omissions we evaluated are; 1) landslide mapping, 2) soil hydraulic conductivity and other modeled conditions for drawdown and slope stability, 3) shallow landslides, vegetation loss, and soil erosion, 4) landslide dam-break conditions and impacts, and 5) quarry impact analyses. These examples show a clear underrepresentation of impacts associated with this proposed project and presented in the DEIS.

## Landslide Mapping

Our review of the landslide mapping by Shannon and Wilson identified omissions of many significant landslides and other mass wasting processes that could impact the FRE dam design, FRE operations, ecological impacts, and impacts to public safety (DEIS Figure F-3). Additional mapping performed by Weyerhaeuser (1994) and WA DNR (Sarikan et al. 2008) and presented in the DEIS (Figure F-5) includes mapping of some recent shallow rapid landslides. It is our opinion that none of these mapping efforts, individually or collectively, are comprehensive and do not accurately represent slope stability conditions, risks, and impacts within the FRE reservoir area. We performed a desktop landslide mapping effort that demonstrates 1) **widespread slope instability** within the watershed, 2) a **greater potential for slope instability** resulting from vegetation removal and fluctuating reservoir levels than was disclosed in the DEIS, and 3) the resulting **underestimation of sediment inputs** into the Chehalis River from landslides.

### Methods

Three licensed geologist utilized LiDAR DTM mapping and orthorectified air photos in a GIS software application to identify and map landforms associated with mass wasting. Mass wasting includes, but is not limited to: deep-seated landslides, shallow landslides, and debris flows. Our mapping analysis utilized two mass wasting categories: Landslides and Shallow Landslides. the Landslides category included deep-seated landslide scarps, slide complexes, and significant debris deposits. The Shallow Landslides category included shallow-rapid type landslides, small slumps, and debris flow deposits.

### Analysis

Figure 1 shows the extent of landslides mapped by Shannon and Wilson (2017). Figure 2 shows landslides mobilized in the 2007 storm and landslide prone areas using SHALSTAB as mapped by the DNR. Figure 3 shows landslides (deep-seated, complexes, shallow-rapid, slumps, and debris flows) mapped by the authors of this memo. Figures 2 and 3 demonstrate that there are significantly more landslides in the areas contributing to the reservoir area than presented in the Shannon and Wilson technical analyses (Figure 1). Figures 2 and 3 also demonstrate that the watershed is very susceptible to slope instability, as evidenced by the pervasive occurrences of landslides throughout the watershed. We observed that shallow-rapid landslides occurred on slopes less than 20 degrees. We also observed geomorphic evidence of retrogressive and sympathetic landslide propagation (e.g. one landslide destabilizes areas above it and a domino of landslides migrating upgradient results). Inundation and drawdown will increase landslide occurrences within the reservoir area and likely increase their magnitude (see Soil Hydraulic Conductivity Analysis below). As a result, there will be more landslides and more sediment delivery to the channel and valley bottom within the reservoir than disclosed in the DEIS. The DEIS calculates 840,500 cubic yards of sediment from landslides potentially influenced by reservoir operation will be contributed to the reservoir as a result of this project (DEIS, page F-64; Figure F-17). The volume calculation assumes that only shallow slides on steep slopes (covering 10% of the reservoir area below the reservoir pool elevation of 627 feet) would be mobilized. However, individual relict landslides mapped by

Shannon and Wilson occurring within 3000 ft of the proposed FRE structure on Crim Creek and the Chehalis River could be influenced by reservoir fluctuations; each of these slides had volumes of in excess of over 200,000 cubic yards; the largest of the Shannon and Wilson mapped landslides has a volume approaching 500,000 cubic yards. These landslides were not considered in the volume estimate. NSD analysis showed significantly more large landslides that Shannon and Wilson mapped; NSD mapped over 20 additional large landslides (45 million square feet of slide area) than the 27 (10.7 million square feet of slide area) landslides mapped by Shannon and Wilson. The Shannon and Wilson mapped relict landslides were not included in the DEIS landslide sediment input volume estimate. The assumption made in the DEIS is that "steep slopes" <u>only</u> below the pool elevation will contribute sediment; an assumption that is false. This assumption does not consider the destabilization of relict deep-seated landslides, new landslides, retrogressive and sympathetic landslides from shallow and deep-seated landslides that migrate upgradient and contribute landslide sediment to the reservoir area and river from <u>above</u> the reservoir pool.

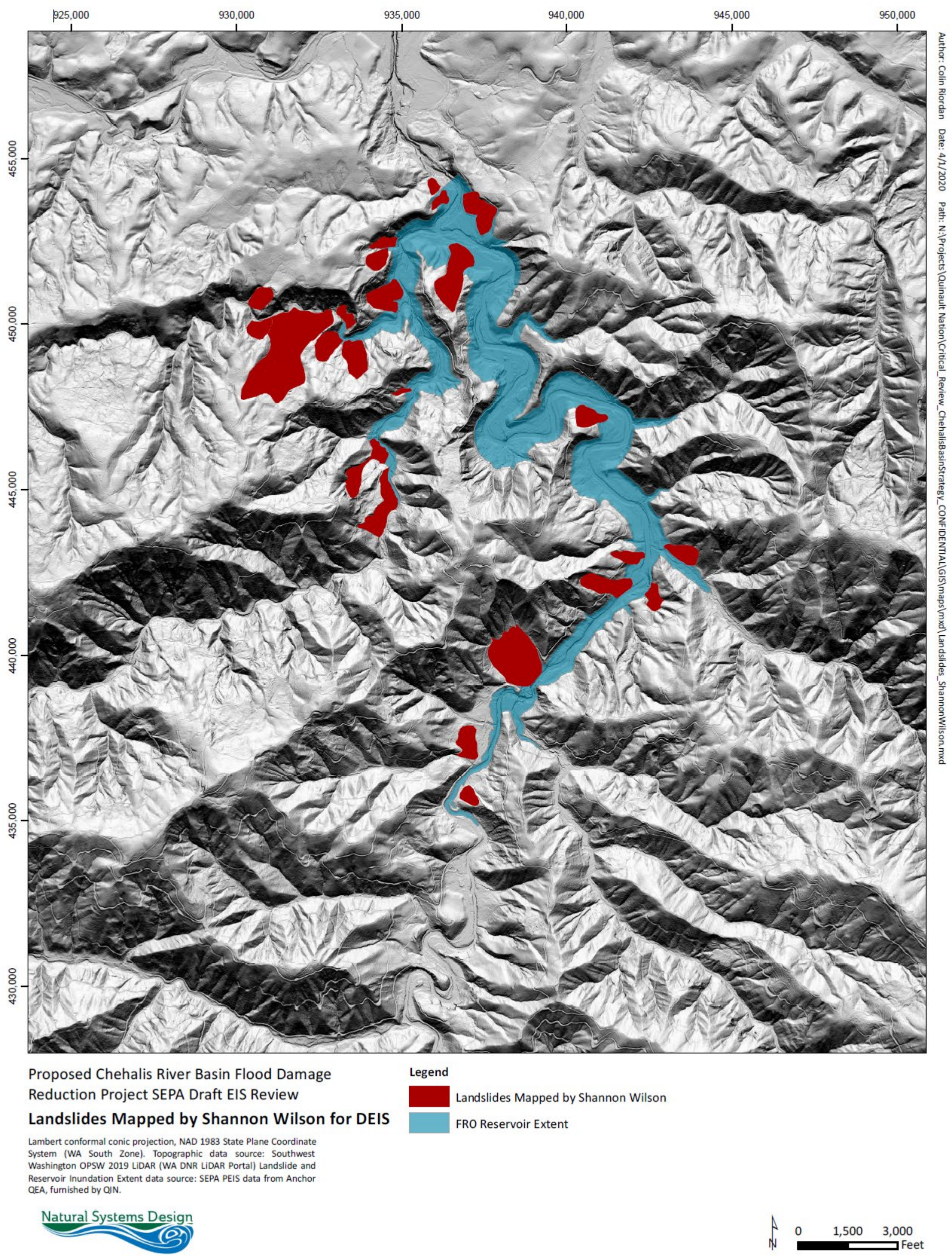


**Figure 1. Shannon and Wilson 2017 Landslide Mapping in FRE Reservoir Area**


**Figure 2. DNR Mapping of landslide hazards (Shaw and Vaugeois 1999) and landslides (Sarikan et al. 2008) in Upper Chehalis River watershed compared with Shannon and Wilson 2017 mapping**

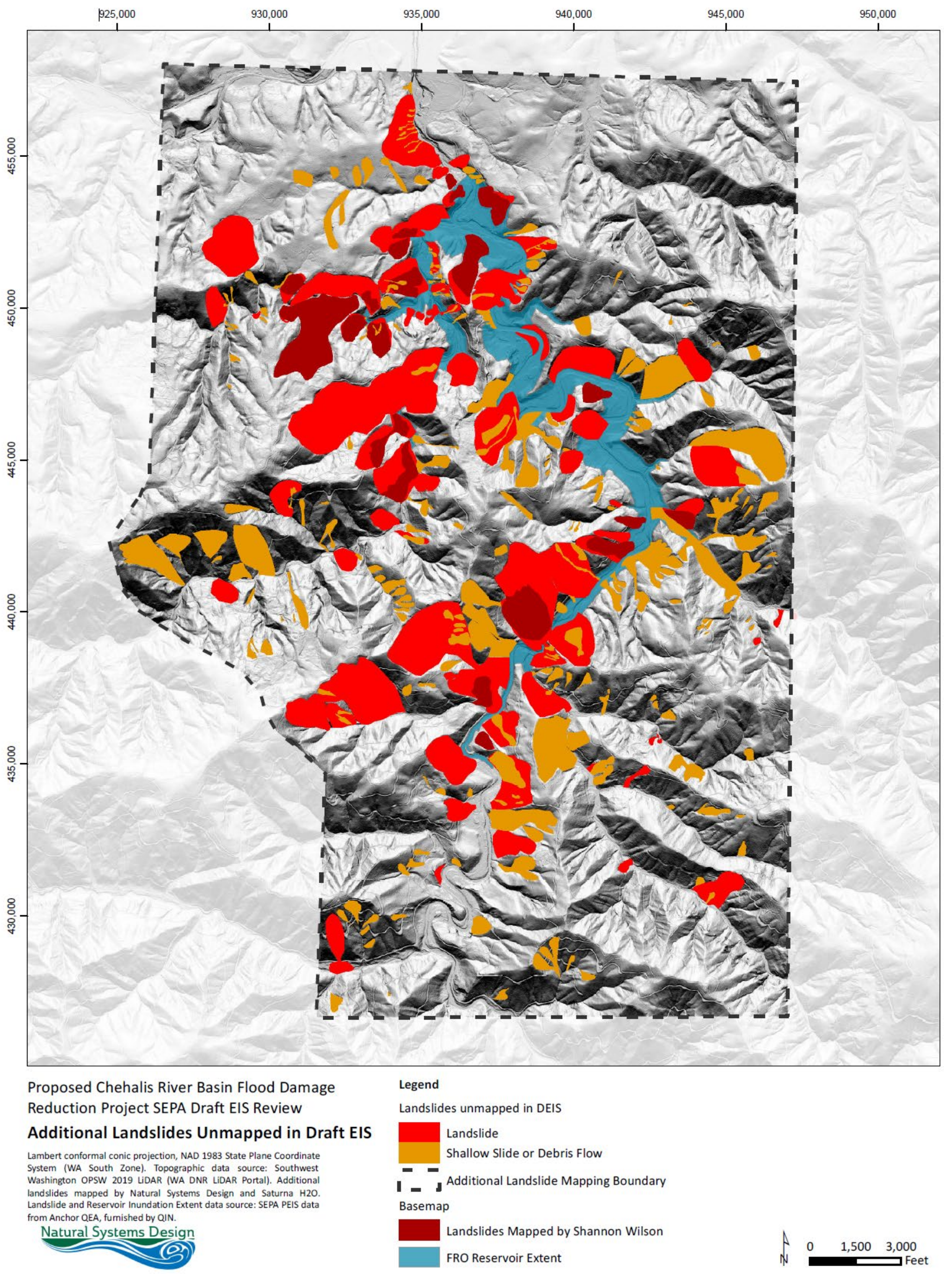


**Figure 3.NSD Mapping of Landslides compared to Shannon and Wilson 2017 mapping**

To demonstrate how the DEIS underrepresents sediment volume from landslides influenced by reservoir operations, we utilized NSD landslide mapping to identify relict deep-seated landslides that could be influenced by reservoir fluctuations; this includes landslides where only the toe of landslide deposits was submerged. The premise is that if a landslide toe fails, retrogressive landslides will result (Xia et al. 2014). We also considered the footprints of past shallow landslides and debris flows that contact the FRE reservoir that may have unstable, unconsolidated materials that could be destabilized by inundation and drawdown operations and experience retrogressive failures or remobilization. We calculated the areas of these landforms and then assumed the 6-foot slide depth to maintain consistency with the value used in the DEIS estimate. Our estimate revealed a volume of approximately **15 million cubic yards** (Table 1) of sediment potentially delivered to the FRE reservoir area from landslides compared to the volume of approximately **840, 000 cubic yards** estimated in the DEIS.

While this volume may over estimate potential sediment delivery in that it assumes every slide becomes mobilized, it is used to contrast the under estimated value from the analysis used in the DEIS which assumes no historic slides will be destabilized or that there would be no retrogressive landslide propagation resulting from slope failures upgradient of the FRE reservoir pool. The volumes presented in Table 1 do not include the potential sediment delivery estimate from steep slopes calculated for the DEIS; therefore, the **total volume of sediment potentially delivered to the Chehalis River by FRE reservoir operations could exceed 16 million cubic yards**. The DEIS estimated volume would be in addition to the volumes estimated in Table 1 from relict landslides.

**Table 1. Summary of volume calculations from mapped landslides potentially influenced by FRE reservoir pool inundation.**

| MAPPED LANDSLIDES QUANTITIES CONTACTING OR WITHIN 100 YEAR FRE RESERVOIR | | | |
|---|---|---|---|
| ***Mapping Source*** | ***Area (sq ft)*** | ***Depth (ft)*** | ***Volume (cy)*** |
| Mapped deep-seated landslides (NSD) | 45,009,419 | 6 | 10,002,093 |
| Mapped deep-seated landslides (S&W) | 10,717,907 | 6 | 2,381,757 |
| Total Mapped LANDSLIDES | 55,727,327 | 6 | 12,383,850 |
| Mapped Shallow Landslide and Debris Flows (NSD only) | 14,209,951 | 6 | 3,157,767 |
| Combined Deep-seated and Shallow Landslide Quantities | 69,937,278 | | 15,541,617 |

Potential "new" large landslides are not included in this volume estimate. Increased surface erosion following landslides as well as soil loss from vegetation removal within the reservoir area is also not included (see Erosion Analysis below). While it is assumed that willow-dominant scrub shrub vegetation will establish, this vegetation type has shallower rooting depths than the vegetation that currently exists in the proposed reservoir area and dense rooting structures, top soils and organisms such as mycorrhizae, that help create soil cohesivity, will decrease with inundation and erosion potential will increase (Smith 1998).

Also, within the reservoir, channel braiding and unstable channel banks are predicted to increase because of vegetation loss and increased sediment loads. Lateral channel migration rates are higher in braided channels with unvegetated, erodible channel banks (Wickert et al. 2013). Based on our landslide mapping, we observed that there are significantly more deep-seated landslides occurring along the main stem of the Upper Chehalis and Crim Creek than in smaller tributaries. Therefore, we concluded that lateral channel migration into the toe of slopes and valley walls is a significant factor affecting slope stability. Increased lateral erosion (channel migration) rates will increase the potential for destabilizing slopes, including deep-seated landslides. None of these factors were considered in the volume estimates in the DEIS or accounted for in our analysis, but each would be expected to increase the potential sediment input into the Chehalis River.

## Results

**There are significantly more landslides and landslide potential than are revealed in the DEIS; thus, there is more sediment delivery potential to the FRE reservoir from landslides than was presented and for which impacts are evaluated in the DEIS.**

The impacts to habitat, FRE dam operations, and public safety from increased sediment delivery from landslides to the channel and reservoir was not accurately disclosed in the DEIS; the impacts will be more widespread and far more significant than was disclosed. Two examples are provided below.

**Ecological Impacts:** The sediment grain-size distribution of mass wasting deposits (deep seated landslides, shallow landslides, and debris flows) is presumed to be predominantly fine-grained, but also comprised of regolith. The fine-grained landslide deposits will be easily eroded by the river, which will result in high turbidity and water quality degradation in the FRE reservoir and downstream of the FRE dam. The turbid waters and fine-grained sediment will degrade aquatic resources. Net sediment deposition within the reservoir is predicted in the DEIS, but is underestimated based on our analysis. The quantity and duration of fine-grained sediment transport from erosion of the landslide deposits is likely to be underrepresented. Erosion, soil loss, and impacts to salmon habitat, such as egg mortality from fine-grained sediment, was not adequately evaluated in the DEIS because of the underestimation of impacts.

**Public Safety Impact:**
Landslides can deliver debris and mass into a filled reservoir that is capable of generating large displacement waves. Displacement wave analysis is required under design guidance manuals (USBR and USACE 2019). Displacement waves can overtop the dam and create life-threatening conditions downstream of the dam as well as potentially damaging dam infrastructure and affecting foundation stability such that a catastrophic dam failure is possible. A May 12, 2008 Zipingpu Reservoir landslide in China resulted in an 82 ft impulse wave that killed more than 70 people (Wang et al. 2018). The discussion of the landslide induced displacement wave hazards and impact analysis in the DEIS is inadequate.

## Soil Hydraulic Conductivity and Slope Stability with Reservoir Fluctuations

Landslide stability within the reservoir is affected by changing reservoir level, which controls the following factors: hydrodynamic pressure; hydrostatic pressure; uplift force; and physical and mechanical properties of soil and rock, including hydraulic conductivity (Wang et al. 2012). Both shallow landslides and some deep-seated landslides can be triggered by positive pore-fluid pressures generated at the soil-bedrock interface during reservoir fluctuations. We reviewed the hydraulic conductivity ($k_s$), friction angles, and groundwater values presented in Shannon and Wilson (2019) and compared them to the field conditions, peer-reviewed literature, and the proposed FRE Operation Plan drawdown rate.

### Methods

We conducted a literature search for BAS, reviewed state and federal guidelines for dam design and operations standards, and reviewed the technical analyses used in the DEIS for assessing impacts.
Reservoir-induced landslides have been documented around the world, resulting from filling and drawdown operations at dams inducing slope failures (Xia et al. 2014, Schuster 1979). The stability of slopes has been found to be a function of the rate of reservoir fluctuation and the hydraulic conductivity of soils (Xia et al. 2014). The greater the rate of reservoir level changes, the lower the factor of safety. During draw-down operations, slope destabilization results from a combination of the loss of external hydrostatic pressure (reservoir buttressing the slope) and excess pore water pressure during rapid draw-down. Whether a slope is partially or totally submerged, the internal and external forces that affect the slope can change as the water level changes. According to Berilgen (2007): "*If the change in external water level happens without allowing the time needed for the drainage of the slope soils, it is called sudden or rapid drawdown (RDD). Due to rapid drawdown there will be a decrease in the slope stability, which may lead to slope failures*."

Hydraulic conductivity rates characterizing the soils mantling the hillsides encircling the proposed reservoir were provided in the Phase 3 Landslide Evaluation (2019), and are shown to be orders of magnitude less (0.001 - 0.1 ft/day) than the stated draw-down rate (10 ft/day). Hydraulic conductivity ($k_s$) for bedrock was assumed to be zero; however, local bedrock is siltstones, sandstones and basalts are known to be bedded, fractured and jointed, thus it is not impermeable. Stability analysis of submerged slopes under drawdown requires consideration of the coupled effects of external loads and seepage forces due to transient flow of water. Both the undrained parameters (total stress analysis) used for the short-term stability analysis and the drained parameters (effective stress analysis) used for the long-term stability analysis need to be considered for rapid drawdown scenarios. Pore water pressure data is needed for effective stress analysis. A comprehensive plan for testing reservoir filling and dewatering rates and a mitigation strategy for how lower drawdown rates could be accommodated should have been included in the DEIS. Given the significant impacts reservoir operations are likely to have on public safety and the environment, omission of this plan is a fatal flaw in the DEIS.

We observed that the drawdown curve used in the Shannon and Wilson analysis is different than is proposed in the DEIS. Shannon and Wilson modeled a 10 ft/day initial drawdown for approximately 4 days following full pool (pool elevations ~605 feet to 565 feet) and then a 2 foot per day reduced drawdown rate until full pool evacuation (approximately 60 days) as shown on the graph below from Shannon and Wilson (2019) (Exhibit 2).

**Figure 4**
**FRE Reservoir Inundation and Drawdown Curves Used for Stability Analysis, 100-Year Flood**

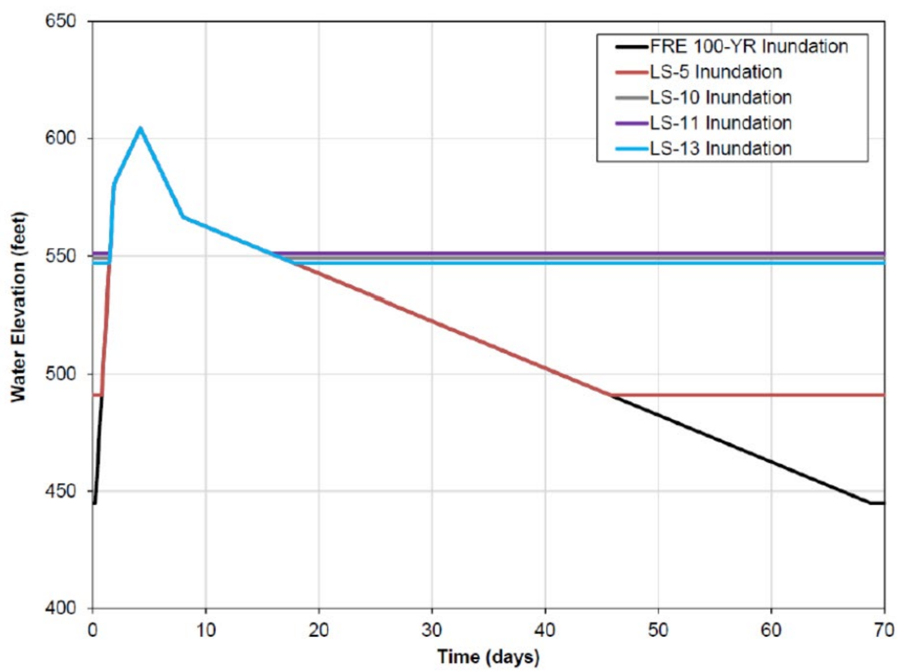


**Exhibit 2. Graph from Shannon and Wilson (2019) showing drawdown rates used in slope stability analyses. Drawdown rate = 10 ft/day between 604.4 ft to 566.5 ft Water Elevation; Drawdown rate = 2 ft/day between 566.5 ft to an empty pool (approx. 445 feet). The DEIS references a different, and much more rapid drawdown scenario (see Table 1 below).**

The FRE Operations Plan stated in the DEIS differs from what was analyzed by Shannon and Wilson (2019) for slope stability. The operation conditions analyzed by Shannon and Wilson would have less impact on slope stability conditions than the conditions proposed in the DEIS. For example, 1) the maximum water elevation is higher in the DEIS than was analyzed and 2) the drawdown rate is more rapid in the DEIS (approximately twice as fast). The Shannon and Wilson analysis needs to model the proposed operation conditions to understand the potential for slope instability; however, the potential for instability caused by reservoir operations will be greater than what was disclosed in the DEIS. The differences are shown in Table 2.

**Table 2: Differences between stated Operations Plan values and values used in stability analyses**

| PROJECT ELEMENT | AS ANALYZED IN SHANNON AND WILSON (2019) | AS STATED IN DEIS |
|---|---|---|
| **Max Water Elevation in Reservoir (feet msl)** | 604.4 feet | 627 feet* |
| **Drawdown Rate** | 10 feet/day<br>(604.4 - 566.5 WSE)<br>2 feet/day<br>(566.5 to ~455 WSE) | 10 feet/day<br>(627’-528’ WSE)<br>2 feet/day for 2 weeks<br>(528’ – approx. 500’ WSE)<br>10 feet/day<br>(~500’ to ~455 WSE) |
| **Duration of the reservoir inundation** | ~60 days*** | 35 days (max) |

Note* The maximum routed Probable Maximum Flood (PMF) reservoir elevation is stated as **650 feet** (msl) in Appendix I – Project Description. Although no “future condition” is referenced or analyzed in this DEIS, it is referenced in design analysis. In the FRE-FC condition, the maximum reservoir pool flood storage elevation is stated at **687 feet** (msl). For analysis that conforms with WADSO analysis standards, the analysis should have at least considered an elevation of 650 feet.

Note** Assumes a single-event, maximum pool fill scenario; days interpreted from the drawdown graph shown in Shannon and Wilson 2019 and presented above in Exhibit 2. Winter storms in the Upper Chehalis can have a frequency of one to two weeks (Figure 4), well within the predicted 35-day draw-down period, thus peak flows that follow an initial reservoir filling event could influence the duration of water retention in the reservoir but is inadequately analyzed in the DEIS.

Note*** Assumes a lower pool elevation for drawdown (604 feet versus 627 feet; at a 2 ft/day rate, this would increase the inundation period by over 10 days).

If the drawdown rates in the Shannon and Wilson analysis are correct, the slopes will be susceptible to failure during drawdown (e.g., Schuster 1979, 2006, Riemer 1992, Paronuzzi et al. 2013, Yin et al. 2016). If the drawdown rates stated in the DEIS are correct, the slopes will be VERY susceptible to failure during drawdown as they are more extreme than the conditions analyzed by Shannon and Wilson. The drawdown rate proposed in the DEIS is very aggressive and the water stored in the soil during high-pool cannot drain quickly enough; the excess pore-water pressure at the base of the soil will induce seepage and result in widespread slope failures. Reservoir management often considers rates of more than one foot per day as rapid, for example the Indiana Dam Safety Inspection Manual, New Jersey Dam Safety Standards, Pennsylvania Division of Dam Safety, and South Carolina Dams and Reservoirs Safety Act Regulations all state that pool level drawdown rates should not exceed one foot per day.

Other parameters utilized within the Shannon and Wilson slope stability analysis have uncertainties that are not disclosed in the DEIS but affect the outcomes of the impact analysis in the DEIS. Four examples are provided to demonstrate these uncertainties.

**Example 1: Assumed values used for friction angle**

Four frictional angles were considered in the Shannon and Wilson stability analysis: 14 degrees, 19 degrees, 25 degrees, and 31 degrees. One site was referenced for model calibration; LS-11, which is active and therefore has a factor of safety (FS) equal to or less than 1.0. It is noted in the analysis that relict, dormant landslides typically have a factor of safety between 1.0 and 1.2. However, when selecting appropriate friction angles, conservative values selected such that it predicted FS greater than 1.2 under existing conditions. For example, a friction angle of 25 degrees was selected for LS-5 which indicated a FS of 2.2 for dormant landslide conditions, substantially higher than would be expected. This would indicate that the friction angle was too high and that a lower friction angle would be more appropriate. In this instance, use of a friction angle of 14 degrees demonstrated a FS of 1.2

under existing conditions and was supported by their assumption; however, using this friction angle resulted in predicted failure during drawdown. In all instances, friction angles were selected such that no slope instability was predicted by the model on drawdown. In two instances, friction angles of 31 degrees were used with no rationale for selecting these high friction angles. Given the widespread and frequent slope instability of the watershed, lower friction angles are likely a better representation of the geologic conditions.

**Example 2: Assumptions about groundwater**
Groundwater would be expected at the surface under filled reservoir conditions; however, groundwater data used in the model was from monitoring data taken the dry season (late summer to early fall). Saturated conditions are a more likely scenario for use in the model given that the reservoir will inundate portions of the landslide and reservoir filling occurs as a result of unusually high precipitation and therefore likely high groundwater conditions. Failure to achieve calibration on LS-11, an active landslide with a FS of 1.0 or less, was explained by having used too low of a groundwater condition in the model. Lastly, analysis does not consider climate change which, based on the DEIS, will result in an increase in precipitation in this watershed (26% increase in hydrograph); therefore, justifying even higher groundwater condition in the wet season in the model.

**Example 3: Assumptions about slab thickness**
Shannon and Wilson described these landslides as “deep-seated”; however, a slab thickness of 5 feet was assumed for the modeling, which is more consistent with shallow landslides. In the DEIS, a shallow landslide slab thickness of 6 feet was assumed. If the landslides are deep-seated, a different geometry and thickness would be appropriate.

**Example 4: Assumptions about reservoir filling frequency**
Reservoir filling frequency and duration can also affect the probability of landslides. The inundation period of the reservoir will be of variable duration depending upon inflow conditions and volume stored. The DEIS states that full reservoir drawdown will be **up to 35 days** for a single reservoir pool filling event (<u>note, this value is different than was analyzed by Shannon and Wilson, 2019</u>). However, the frequency of reservoir filling and draining overtime is underestimated in the DEIS. Multiple back-to-back storms with hydrologic event potential are common with winter “atmospheric river” conditions of the Pacific Northwest. Multiple-event hydrologic conditions may result in multiple reservoir pool inundations before complete pool drainage occurs and therefore result in higher reservoir pool conditions for a longer inundation period. For example, based on the operations triggering filling the reservoir when flows exceed 38,800 cfs at Grand Mound, the reservoir would have been filled twice in both 1990 and 1991 (Figure 4). The two 1990 peak events were a few weeks apart and would have resulted in two FRE dam closures before drawdown from the first event was complete. Hydrological analysis in the DEIS considered only single event conditions with only one peak event per year. Under the predicted increases in peak flows due to climate change, the frequency of closures will increase substantially in the future. For example, the two closures that would have occurred between 1996 and 1999 under the present-day hydrology would be six closures in the late century scenario (Figure 5). Climate change scenarios were not considered in the Shannon and Wilson slope stability analysis. More frequent reservoir inundations occurring over time decreases the factor of safety and the potential for landslides increases (Yin et al. 2016, Exhibit 3).

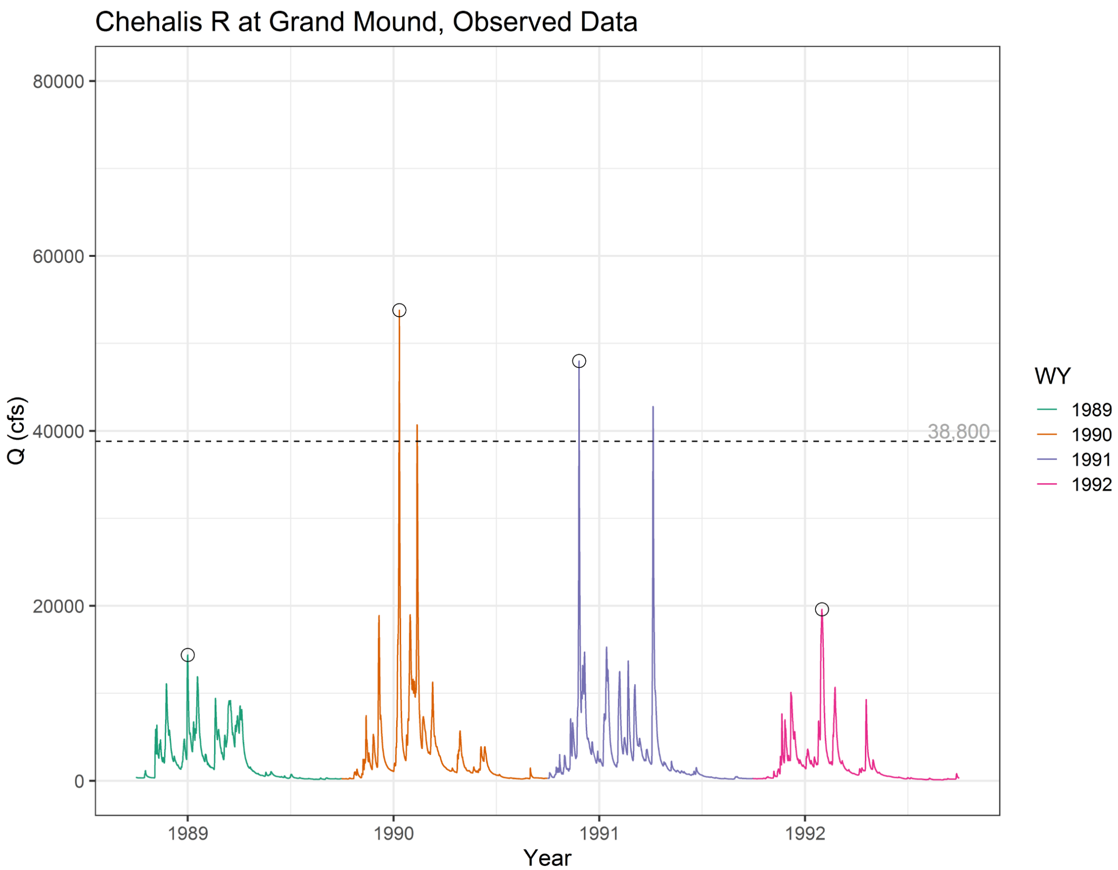


**Figure 4. Partial peak hydrographs (15-min data) for Chehalis River at Grand Mound for 1989 to 1992. Based on operations that close conduit gates in the FRE when flow exceeds 38,800 cfs (dashed line), the proposed reservoir would have been filled twice in both 1990 and 1991 as represented by the peaks that are higher than the dashed line "closure threshold"; however, analyses used in the DEIS would have only considered a single closure event for each of these years (event peaks circled). This underestimates the closure for those two years by half (plot by NSD).**

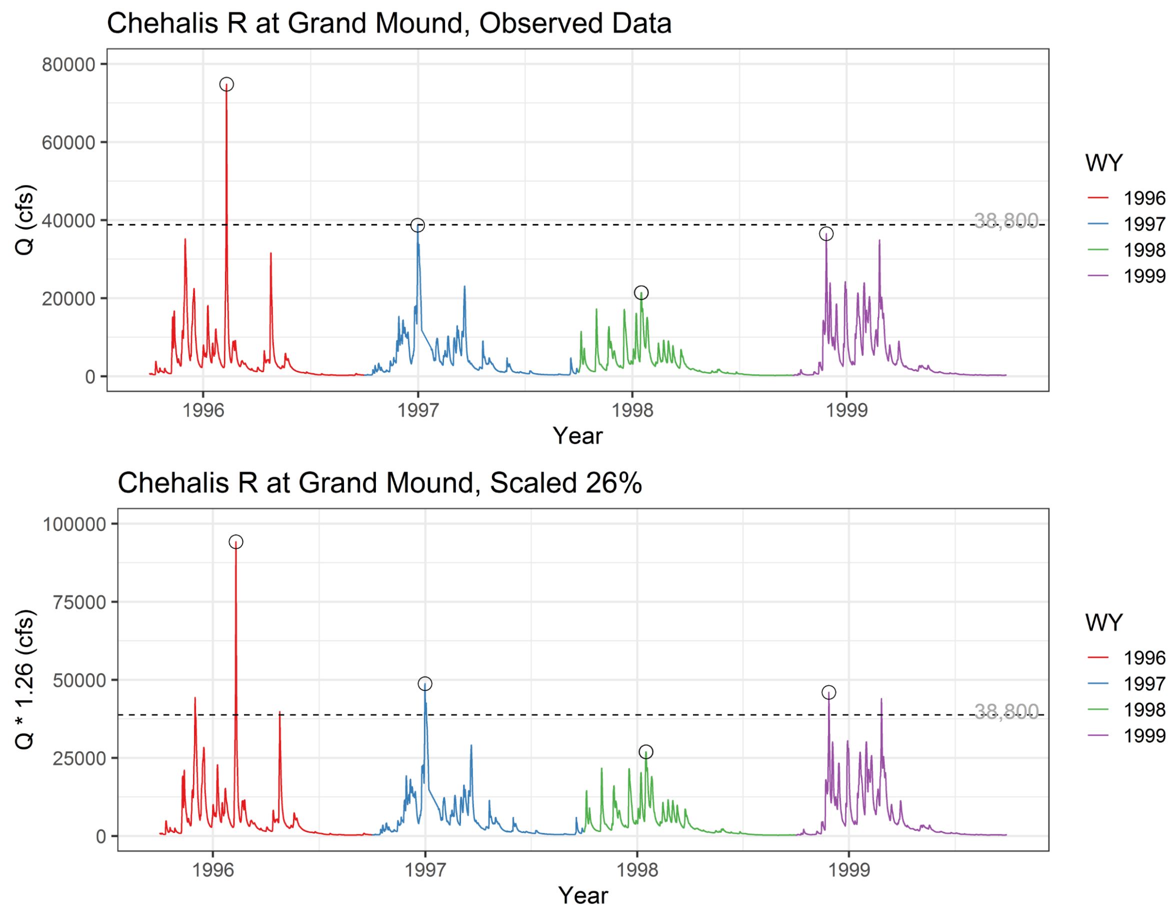


**Figure 5. Partial peak hydrographs from 1996 to 1999 (top) and the same hydrographs adjusted for the late-century climate change scenario peak flow scenario (bottom). Under current hydrologic conditions, the reservoir would have been closed once in 1996 and once in 1997 (top). By late century, the same hydrologic conditions adjusted for climate change would result in increased closures to three times in 1996, once in 1997, and twice in 1999 for a total of six closures. This represents three times more closures than under the current hydrologic regime (plots by NSD).**

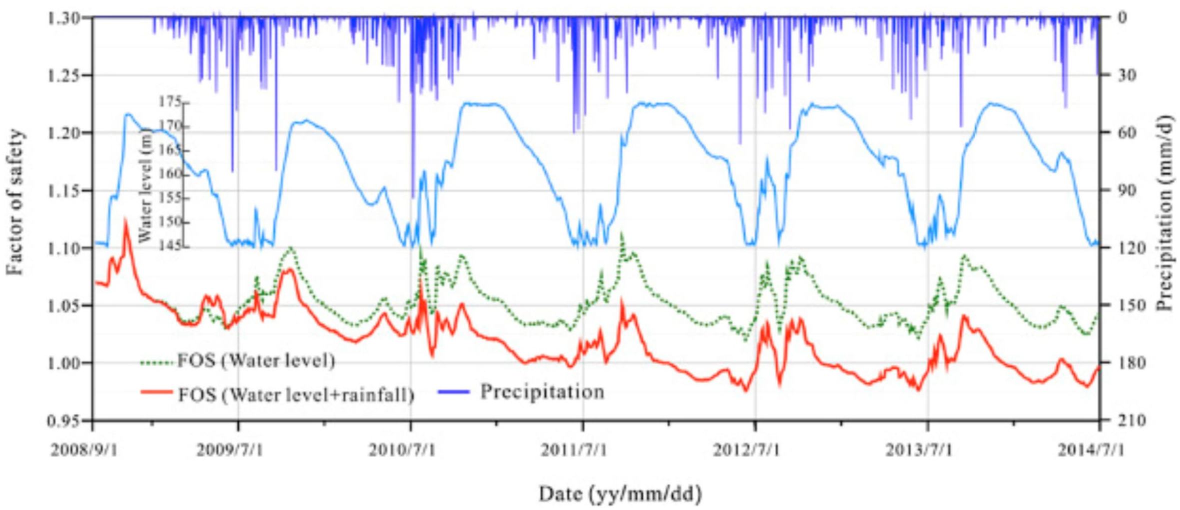


**Exhibit 3. Evolution of factor of safety (FS, red line) of the Shuping landslide in Zigui County, Hubei Province, under effect of reservoir managed water level (green line) and precipitation (blue columns, data recorded from 1 September 2008 to 1 July 2014; from Figure 8 in Yin 2016). Light blue line represents reservoir fluctuation. Note that the FS decreases over time and landslide susceptibility increases with more frequent reservoir fluctuations.**

## Results

***The proposed drawdown rate of 10 feet per day greatly exceeds the hydraulic conductivity reported for the soils and slope instability and widespread land sliding would be expected during reservoir draw down. In addition, overly conservative parameters or incorrect parameters were utilized in the modeling to evaluate slope stability, even when these values contradicted field observations. The potential for multiple-event reservoir inundations and longer impounded periods was not considered.***

Specifically, we found that:

- Conclusions from the slope stability analysis are used throughout the project design and DEIS impact analyses; errors and uncertainties from this analysis would have relevant impacts that greatly under-estimate significance of impacts in the DEIS and the errors would be propagated in the aquatic habitat and public safety impact analyses;
- Uncertainties and risks not identified nor discussed;
- The proposed rapid drawdown rate needs to be reconsidered given the geologic conditions and potential risks and impacts;
- Conservative assumptions were favored throughout the analysis which may underrepresent potential risks and impacts;
- The operations plan and data used in the slope stability analysis are not consistent and no new analysis integrating these changes was presented;
- Displacement waves that might occur as a result of landslide mobilization during reservoir impoundment and the associated risks on FRE operations and facility were not identified nor discussed.
- Neither BAS nor references to state and federal analysis guidelines for dam construction were utilized to the extent that would be expected for a project of this nature.

**Ecological Implications:** The proposed drawdown rate will substantially increase the frequency and extent of landslides within the reservoir during impoundment drawdown. The increased landslide occurrences will dramatically increase the sedimentation rate in the reservoir area. The rapid input of fine sediments to the reservoir following slope failure will affect flows and water exiting the reservoir, likely evacuating a large portion of the suspended sediments from the reservoir. These fine-grained sediments will be transported and deposited downstream where it will have ecological impacts. Landslide management will also affect the Operations Plan. To reduce the occurrence of landslides during drawdown, a slower drawdown rate will have to be adopted. This will result in longer periods of reservoir inundation, which will have significant ecological impacts. In our opinion, the impacts resulting from the physical changes associated with this project will be so great that fish populations in the Chehalis River will be irreparably damaged, if not potentially lost all together. We are unaware of any mitigation actions sufficient to achieve “no net loss” for these impacts.

## Soil Erosion

Hillslope vegetation can reduce erosion by reducing the intensity and magnitude of runoff through rainfall interception and evaporation and transpiration. Root cohesion has the most significant effect on reducing erosion and shallow landsliding and is proportional to root density, depth, diameter and tensile strength (e.g., Schmidt et al. 2001). Clear-cutting a forest can substantially increase the probability of shallow landslides which is recognized in Washington State Forest Practice guidelines that limit harvest on steep and convergent slopes (e.g., Shaw and Vaugeois 1999). After timber harvest hillslopes are at an elevated risk of slope instability until the new trees have established substantial rooting which takes 14-20 years (Schmidt et al. 2001). The proposed plan will permanently remove conifers from the reservoir area even on high risk slopes where cutting would be prohibited under state forest practice guidelines. Hillslopes above the reservoir will still be subject to clear-cutting and periodic landsliding (Exhibit 4), none of which was considered in the DEIS. Within the reservoir area the conversion to a willow-dominated scrub-shrub community will substantially reduce root cohesion due to the shallower and weaker roots of that vegetation. This increase in soil erosion will increase fine sediment production and ultimately loading to the channel, impacting water quality within the FRE and downstream. It is anticipated that land within the FRE will convert to shallow-rooted Willow scrub-shrub assemblage as periodic inundation will prohibit larger, more deeply rooted conifers. These changes in species and rooting characteristics will lead to increases in surface runoff and erosion, and subsequently fine sediment loading. Increases to fine sediment loading can have negative ecologic consequences in the reservoir and downstream by burying salmonid redds and suffocating the eggs therein (Exhibit 5).

**Exhibit 4. Effects of land clearing on erosion and shallow land sliding (Photo by Shane Anderson, circa 2018 from Chehalis River watershed approximately 1-mile upstream of FRE).**

(Credit: Scott Anderson, USGS. Public domain.)

**Exhibit 5. Example of fine-sediment erosion and deposition related to flood reservoir management (Mud Mountain Dam, Washington; USGS).**

## Methods

To estimate predicted increases in soil erosion due to the land cover changes resulting from FRE operations, the RUSLE2 model was employed (USDA 2013). The RUSLE2 model estimates rill and inter-rill soil erosion resulting from overland flow using mass balance and the Universal Soil Loss Equation (USLE). There are four major factors considered in the RUSLE2 model: climate, soil, topography, and land use. Values used in the RUSLE2 model for these parameters are selected from USDA-NRCS databases developed for soils across the US. These parameters can be modified by the user if site conditions justify changes to the default values.

A typical reservoir slope profile was developed for analysis in RUSLE2, extending 620-ft with a slope of 19%. Digital soil databases (SSURGO) were queried to determine soils present within the FRE reservoir and their associated geotechnical properties. Bunker Loam was selected as a typical soil type for this analysis, and climatic data were obtained from the USDA NRCS website (http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm). Changes in anticipated surface soil erosion were assessed by altering management actions and associated vegetative cover types to simulate the changes that would occur following clearing of the conifer forest through conversion to a willow dominant community within the FRE. Because the RUSLE2 program was developed for crop and range management, default values for management options are not representative of forested conditions. The vegetation sub-component for the available management options was modified to represent to local conditions. For the current condition, an "Vegetation, woody, established" option was assumed to be present on the hill slope. Following clear cut, the "bare ground" management option was selected and remained unmodified. The growth of a scrub-shrub dominant cover was simulated using the "Vegetation, shrub, planting and establishment period" option for vegetative cover.

### Results

***With all other variables held constant, altering the surface cover has a dramatic influence on surface soil erosion. The RUSLE2 model predicts an average annual delivery of 4.3 tons/ac/yr for the simulation of the current condition. Immediately following clearing for the FRE, soil erosion will spike more than 25-times the current rate to 110 tons/ac/yr. As the cleared land begins to re-vegetate over time, predicted soil erosion will begin to decrease toward 27 tons/ac/yr, more than 6.3-times the current rate. This simple model clearly demonstrates the importance of land cover on soil erosion rates.***

- The values provided are averages over the year and would likely vary throughout the FRE reservoir and year to year depending on rainfall events. These average values, if applied to the entire reservoir would equate to 3,709 tons/yr under existing conditions. This would spike immediately after clearing to 75,092 tons/yr, reducing to 23,292 tons/yr as willow cover establishes. **These values would be in addition to those calculated in the DEIS, as surface erosion was only considered for those sediments deposited on the surface as the reservoir after filled, not the underlying soil profile.** This increase in fine sediment loading to the channel would negatively impact downstream redds.
- If increases in surface soil erosion were only considered for those slopes found to be susceptible to failure and defined within DNR hazard areas, the increases in fine sediment loading remain apparent:
  - 109 tons/yr from high hazard areas and 767 ton/yr from medium hazard areas within FRE under existing condition
  - This increases to 2,800 tons/yr from high hazard areas and 19,620 ton/yr from medium hazard areas within FRE following clear-cut
  - As the willow cover is establishing erosion is predicted to decrease to 687 tons/yr from high hazard areas and 4,815 ton/yr from medium hazard areas within FRE under existing condition

It should also be noted that unlike a dam with a permanent reservoir, the proposed FRE facility involves repeated filling and drawdown of the reservoir throughout the project lifespan. As explained in this memo, the proposed reservoir operations will elevate sediment discharge to the river well above existing conditions, both during drawdowns and in between reservoir filling events. The proposed FRE operation is analogous to the sediment mobilization effects of repeated dam removals. The numerous dam removal projects throughout the United States have shown that the most significant impact of these otherwise beneficial projects is a temporary increase in sediment load and sedimentation that can cause suffocation and abrasion to various biota and reduce pool depths (e.g., Bednarek 2001, Gregory et al. 2001, Thomson et al. 2005, Tuckerman and Zawiski 2007, Downs et al. 2009, Randle et al. 2015, Warrick et al. 2015, Tullos et al. 2016; Randle and Bountry 2017). Unlike the short-term impacts associated with dam removal projects, the proposed FRE facility would cause these types of repeated and cumulative sediment mobilization impacts into the foreseeable future, while also initiating a cascade of ecosystem-scale impacts to river hydraulics and geomorphology. When the proposed FRE facility is ultimately decommissioned and/or removed, the release of stored sediment will again impact downstream waters, wetlands, and habitats.

## LANDSLIDE DAMS

The Phase 3 landslide evaluation briefly discusses the potential for a landslide dam to occur within the reservoir footprint and damage the proposed dam structure (Shannon and Wilson, 2019). The report states that "Seismic-event-induced instability and excessive movement of landslides and slopes could result in a landslide dam across the Chehalis main stem or one of its tributaries upstream of the FRE [dam] facility." While the report notes that "…actions to protect the [FRE] facility should be taken if landslide dams occur upstream of the [FRE] structure," no analysis was conducted to describe the likelihood of a potential landslide dam occurring and its associated impacts to the river and the proposed FRE facility. Furthermore, there is no mention of how the proposed dam facility will address these potential impacts to its infrastructure and operations in the Combined Dam and Fish passage Supplemental Design report dated September 2018 (Anchor QEA 2018).

Riemer (1992) summarized some of the characteristics and impacts of dam break floods resulting from landslides that impound river channels:

1. Flood peaks from dam break floods may be "higher than those extrapolated from normal run-off"
2. "Hydrographs of landslide floods may differ significantly from normal flood hydrographs, in the worst case rising nearly instantaneously to the peak and thus leaving little time for reaction"
3. "Sediment concentration in a landslide flood does not conform with the normal sediment rating curves which control sediment supply"
4. "Landslide floods may develop a specific transport mechanism enabling them to carry exceptionally large blocks"
5. Therefore, "sediments derived from landslide floods may be too coarse to be flushed from a reservoir and they may cause severe damage on the spilling and outlet structures."

Landslide dam break floods may be large in magnitude, occur rapidly, and be able to transport large volumes of sediment and debris that can severely impact the FRE infrastructure, as well as aquatic habitat. Despite the high consequence of potential impacts from a landslide dam on the proposed dam infrastructure, no analysis on the probability of such events or their potential impacts was conducted in the DEIS. This section seeks to investigate the potential for a landslide dam to have occurred within the proposed reservoir footprint during recent mass-movement events during the December 2007 flood and to quantify the characteristics and potential impacts of such a landslide dam breach on downstream infrastructure.

During the December 2007 flood, 1,645 landslides occurred in the Chehalis River headwaters with the majority (1,394) occurring in the rocks of the Crescent Formation (Sarikhan et al. 2008). The proposed FRE would create a reservoir on the main stem river in an area that is primarily underlain by Crescent Formation Basalt (EV(c)) where numerous landslides have been mapped (WA DNR, 2016). In addition to the susceptible underlying geology, clearing trees from the hillslopes during reservoir construction and fluctuations of the reservoir during dam operations will further increase the probability that landslides and debris flows will occur within the reservoir area which poses a risk to the dam infrastructure and aquatic habitat present when the dam is not impounding water (Shannon and Wilson, 2014, 2015, 2017a, 2017b., 2019; Watershed Geodynamics, 2019).

One of the possible ways in which a landslide/debris flow may impact infrastructure and habitat is when eroded material blocks the river itself – creating a landslide dam. There is evidence that a landslide may have dammed the Upper Chehalis river within the proposed reservoir site during the 2007 flood – causing a flood wave containing a viscous mixture of water and landslide debris (sediment, boulders, trees) to propagate downstream upon breaching of the dam (Figure 6). However, the potential risk of this occurring and the subsequent impacts to the proposed dam structure have not been evaluated by any of the baseline studies supporting the DEIS.

This section investigates the likelihood and impacts of a landslide dam occurring within the proposed reservoir footprint on the Upper Chehalis River by addressing the following questions:

1. Did one or more landslides capable of damming the Chehalis River occur during the 2007 flood in the proposed reservoir area?
2. If so, what is the potential discharge of the flood wave resulting from failure of the 2007 landslide dam and how high would it be in the location of the proposed dam structure?
3. How would future dam breaches impact the dam infrastructure?

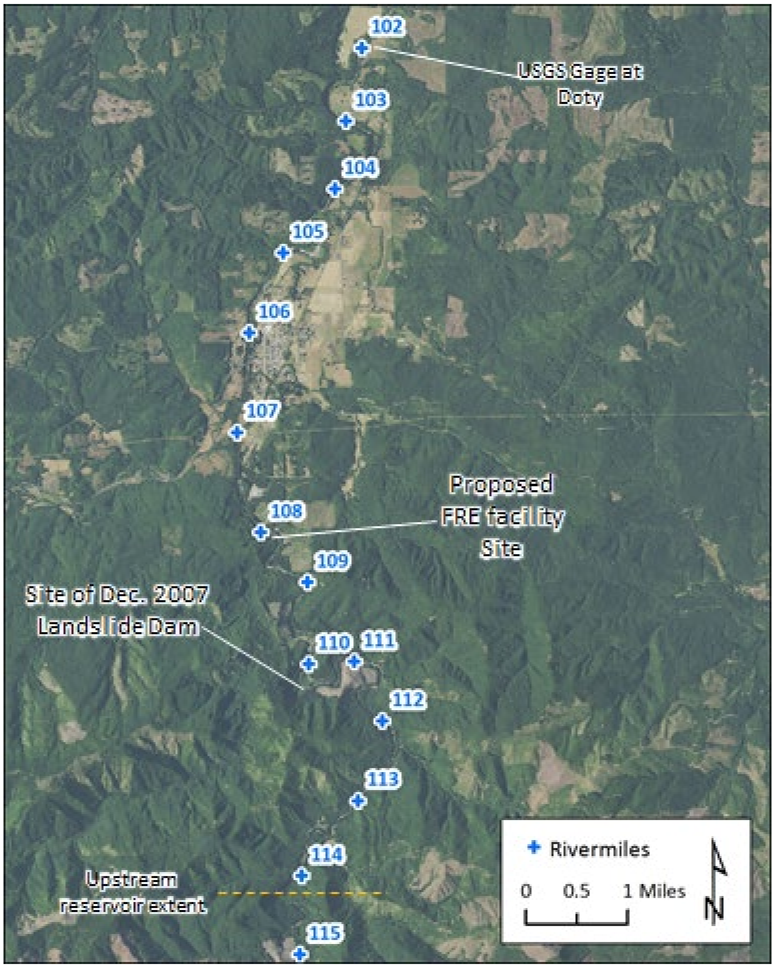


**Figure 6. Location of 2007 landslide dam relative to the proposed FRE**

## Methods

A map of landslides and debris flows that occurred during the 2007 flood developed by the WA DNR was used to identify specific locations within the proposed reservoir where a landslide dam could have occurred (from Sarikhan et al. 2008, accessed on online WA-DNR map portal). The WA DNR map was then overlaid on a difference map developed using 2006 and 2015 LiDAR digital elevation models (DEMs) to visualize and quantify specific changes in topography that occurred within each mapped landslide area. Estimates of erosion and deposition volumes were then calculated for each landslide/debris flow location. These estimates were compared against patterns of topographic change and post flood, site specific valley geometry (from 2015 LiDAR) to determine whether each disturbance area was capable of damming the river. The dimensions of the potential landslide dam were then developed using the volume estimates and 2015 topography.

The hydraulic conditions resulting from the failure of a landslide dam within the proposed reservoir were estimated using a 1-dimensional hydraulic model. The key output from a dam failure (breach) analysis is the resulting outflow hydrograph at the structure and its peak discharge. Discharge is largely influenced by the breach opening geometry and time to fully develop. In this case, the rapid erosion of a landslide embankment dam from overtopping flow is analyzed. The Federal Energy Regulatory Commission (FERC) has published guidelines (FERC 2015) on performing dam breach analyses, which this study follows the outlined approach:

- Estimation of dam breach parameters

- Estimation of the dam breach outflow hydrograph
- Routing of the dam breach hydrograph downstream
- Estimation of downstream inundation extent and severity

Breach parameters estimated by using empirically derived enveloping curves or equations from published literature such as Brunner (2014), Froehlich (1995a, 1995b, 2008), USBR (1998), and Wahl (1998). These estimates provide a range of values that are used in conjunction with physical constraints of the dam site and engineering judgement to define

This study uses industry standard, U.S. Army Corps of Engineers Hydraulic Engineering Center software, HEC-RAS version 5.0.7 to perform the hydraulic analysis. Included in the hydraulic modeling software are the empirical equations to estimate a range of breach parameters (HEC 2016) for the landslide dam. The following design assumptions are as follows:

- Overtopping failure mode at the full reservoir pool
- Landslide dam is composed of erodible earth materials
- Dam crest at elevation 515 ft-NAVD88
- November monthly-average discharge at reservoir inflow
- Dynamic-pool routing
- One-dimensional, unsteady-state hydraulic analysis.

These assumptions consider that the landslide dam material is unconsolidated, non-cohesive sediment, and unvegetated embankment. Probable failure mechanisms of embankment dams are a result of piping or overtopping. Failure due to overtopping represents a high-risk, and probable, scenario due to the rapid formation of the breach opening. The Chehalis River is narrow and confined so a one-dimensional approach is suitable to model this type of reach. In the same vein, dynamic-pool routing is used to more accurately simulate the draining of the reservoir. Baseflow hydrologic conditions (November monthly-average discharge) were used for this analysis so that the influence of the dam breach outflow could be isolated.

A hydraulic model was developed within the proposed reservoir extent to estimate the outflow hydrograph. The 2015 LiDAR DEM was used to define the model topography within the proposed reservoir location between RM 108-112. FERC guidelines recommend a deterministic approach to estimate the potential range of peak outflows resulting from the probable failure mechanism, in this case overtopping. Table 3 is a summary of the dam breach input parameters and calculated peak outflow (Qpeak). The minimum and maximum limits of breach parameters are bounded by physical constraints of the landslide location, and low, medium, and high scenarios refer to the relative likelihood of occurrence.

**Table 3. Summary of overtopping scenarios and corresponding breach parameter inputs. Qpeak is the estimated peak outflow through the breach opening.**

| | MIN | LOW | MED | HIGH | MAX |
|---|---|---|---|---|---|
| Qpeak (cfs) | 6838.88 | 11711.22 | 11472.16 | 13112.52 | 16265.25 |
| Bottom W (ft) | 55 | 55 | 82.5 | 110 | 100 |
| Bottom El (ft, NAVD88) | 493.4 | 493.4 | 493.4 | 493.4 | 493.4 |
| L SS | 0.5 | 0.5 | 1.5 | 3 | 3 |
| R SS | 0.5 | 0.5 | 1.5 | 4 | 4 |
| Breach Weir coeff | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 |
| Formation Time (hr) | 0.5 | 0.1 | 0.25 | 0.5 | 0.1 |
| Breach Prog | Linear | Sine | Sine | Sine | Sine |
| Main channel n-value | 0.04 | 0.04 | 0.05 | 0.06 | 0.06 |

Peak outflow at landslide dam and associated breach parameters used the “high” set in this analysis, which is in accordance with FERC guidelines of dam breach analysis. This assumes a failure and washout of the embankment dam within the main channel, eroding to the elevation of streambed. Note that a larger breach opening takes longer to develop (formation time). All values are within the range of FERC recommendations, empirical equations, and geometry of the site.

The outflow hydrograph was then routed through the Flood Authority HEC-RAS hydraulic model, which has been previously calibrated and verified, in order to assess the downstream impacts caused by the resulting flood wave (WSE, 2013) (Figure 11).

## Results

Our analysis revealed that landslide dams have historically occurred within the watershed and that future occurrences would have significant impacts on the operations and safety of the FRE facility, as well as impacts to habitat. These impacts were not considered in the DEIS.

The results of the landslide analysis revealed one location where a landslide/debris flow that occurred during the 2007 flood likely dammed the Chehalis River (Figure 7). A large landslide/debris flow complex was mapped by DNR along the left bank hillslope of the Chehalis river near RM 110.5. The complex initiated near a convexity in the hillslope roughly 600 ft in elevation above the river and extended ~1,200 ft downslope to the valley bottom. The complex consists of a large mapped landslide and three adjacent mapped debris flows. Topographic change analysis indicates that the landslide eroded roughly 80,000 cubic yards of material from the hillslope and deposited it across the valley bottom. This is supported by evidence of 2-10 ft of deposition that occurred on the terrace across the river valley from the landslide complex in addition to deposition at the toe of the landslide complex itself on the left bank of the river. The matching depositional surface indicates that the landslide deposit likely spanned the entirety of the valley. This conclusion is supported by aerial imagery which shows cleared landslide deposits on both sides of the river in 2009 – 2 years after the 2007 flood (Figure 8).

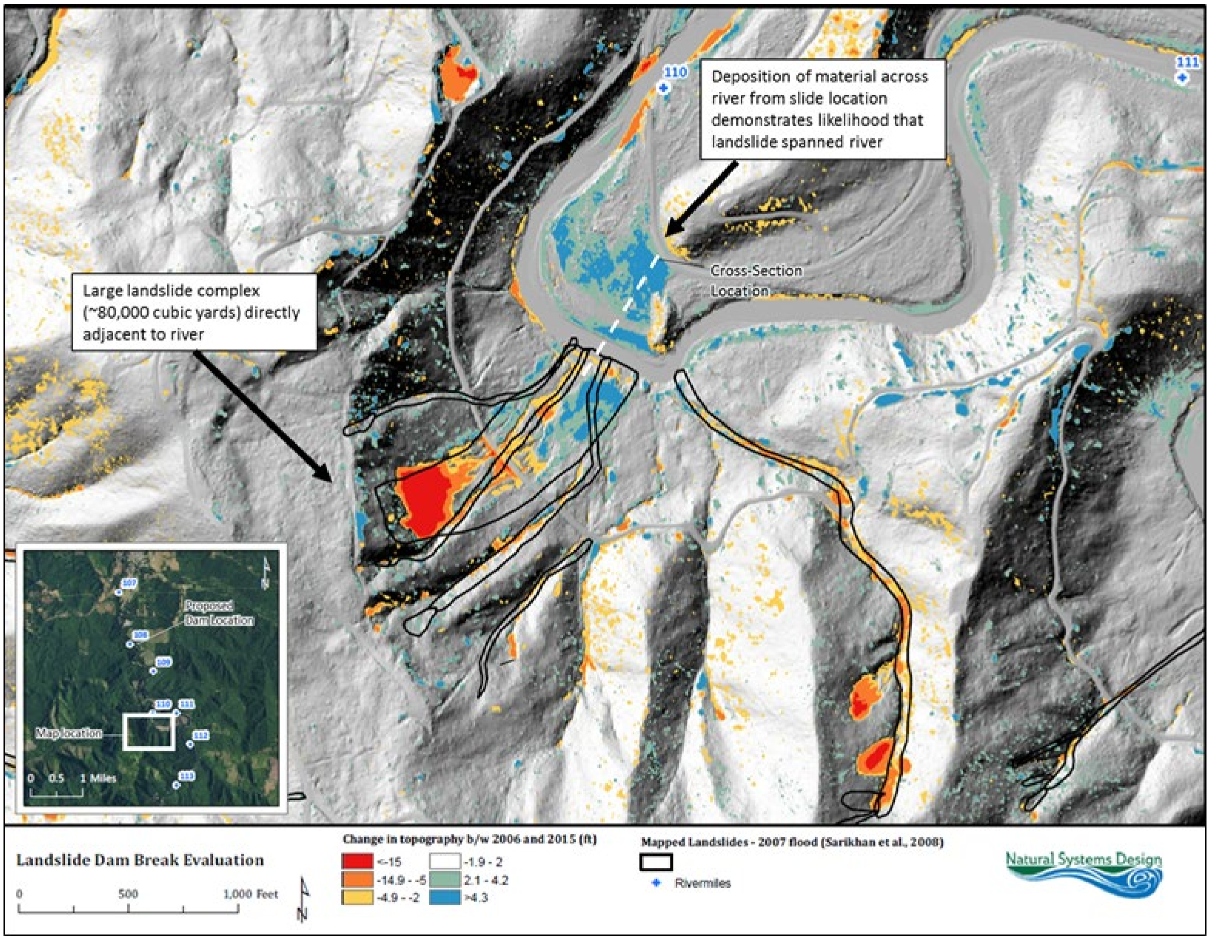


**Figure 7. Location of the likely landslide dam that occurred on the Upper Chehalis River during the December 2007 flood.**

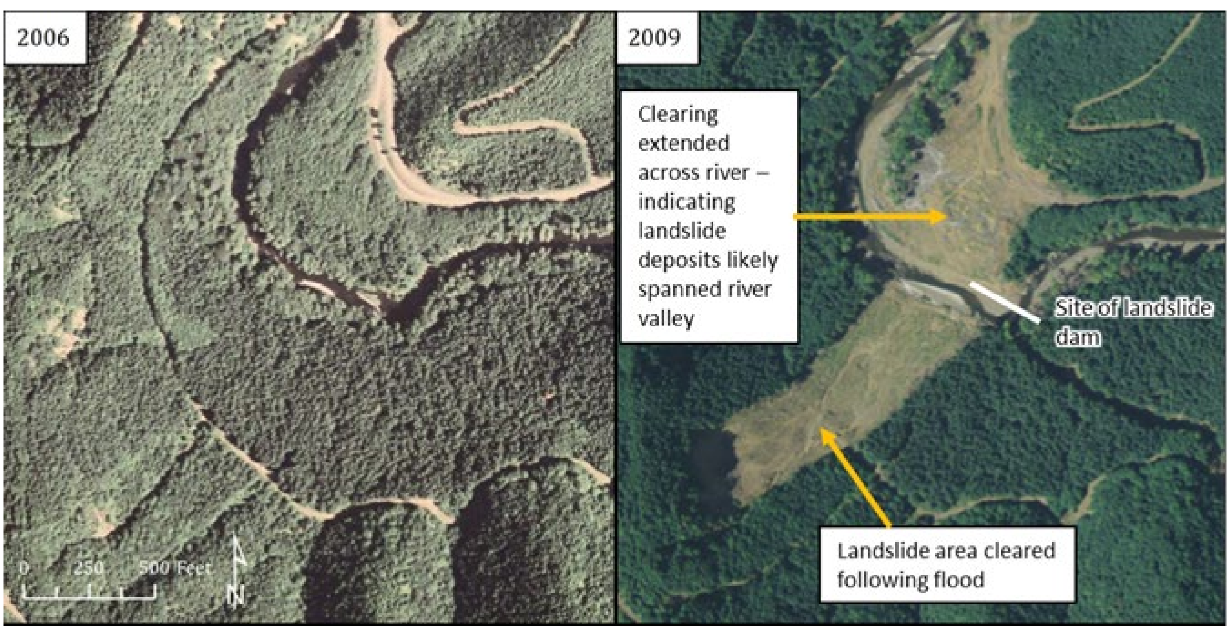


**Figure 8. Aerial imagery showing the path of the landslide that occurred during the December 2007 flood near RM 110.5 on the Upper Chehalis River. The map extent is the same as shown on Figure 6.**

The topographic change analysis was used to estimate that the landslide complex was capable of creating a 20 ft high and 40 ft wide dam 250 ft across the Chehalis River valley (Figure 9 and Figure 10). A landslide of this magnitude would have likely created a temporary barrier to flow in the Chehalis River, effectively acting as an embankment dam. Though the mass of landslide complex could resist the hydrodynamic forces to impound a reservoir, this unconsolidated material is highly erodible. A likely probable failure mechanism of an embankment dam is rapid erosion and subsequent head cutting and mass failure of sides slopes through the embankment structure, due to overtopping flows. The December 2007 flood event had the requisite characteristics to create such an event.

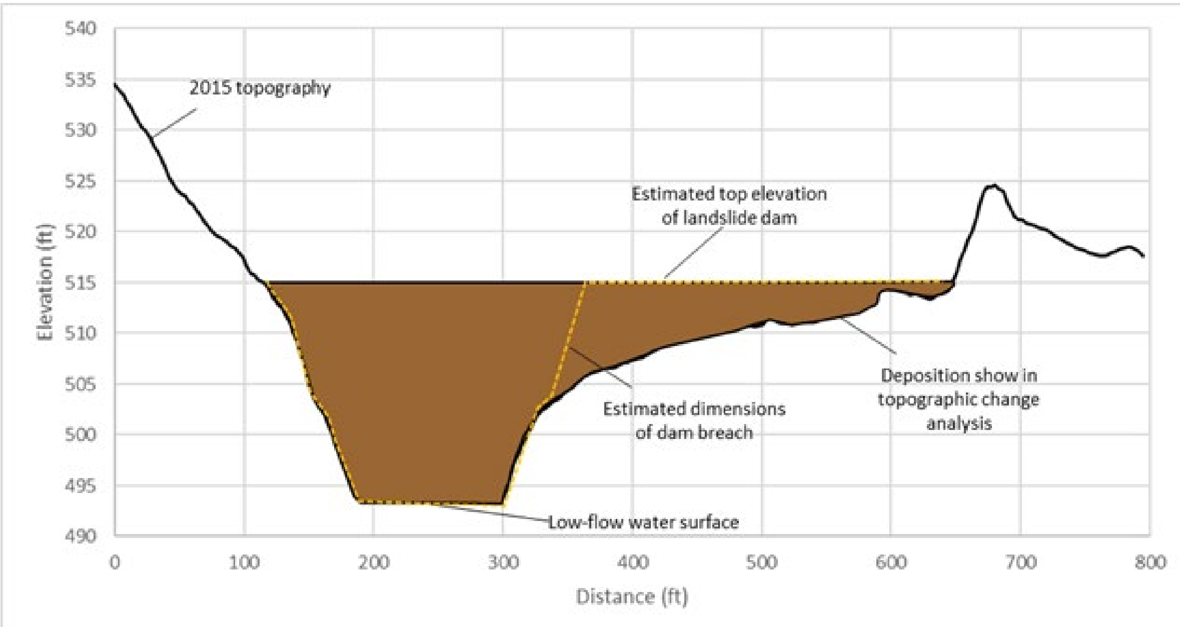


**Figure 9. Cross-sectional view looking downstream of December 2007 landslide that originated on the southwest hillslope and impounded Upper Chehalis River before being over-topped and triggering a dam break flood peak. Cross-section topography was derived from the 2015 LiDAR DEM and is noted on Figure 7. Topographic change analysis was used to estimate the top elevation of the landslide dam. The dimensions of the dam breach were estimated using the parameters outlined in the methods section.**

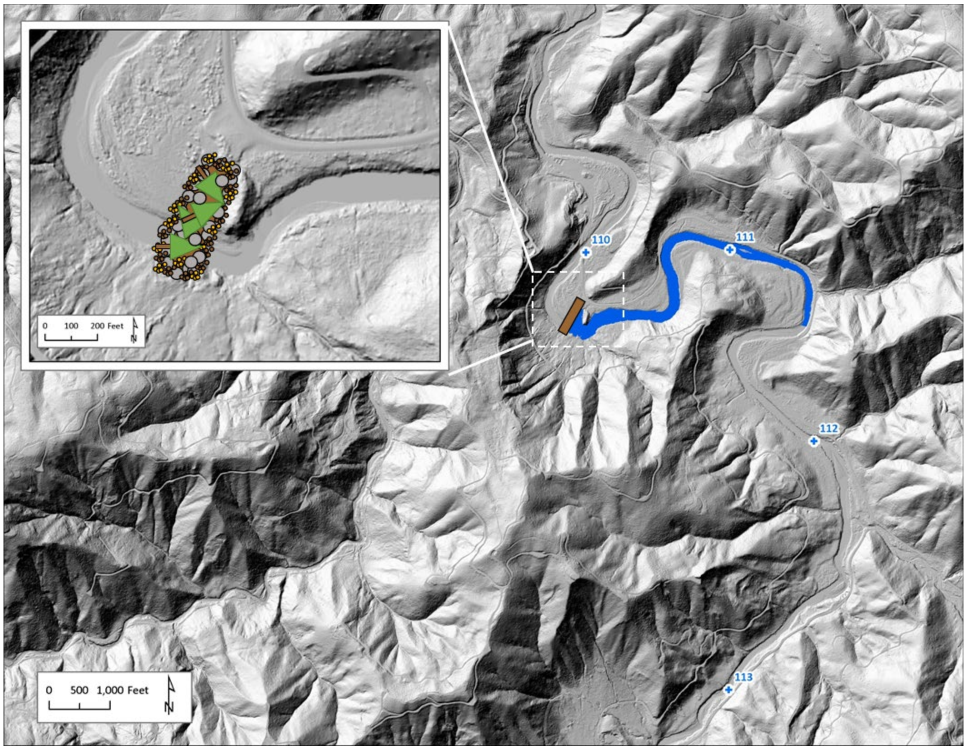


**Figure 10. Simple conceptual illustration of the December 2007 landslide that dammed the Upper Chehalis River from the left (southwest) hillslope. Landslide dam dimensions were estimated using a topographic change analysis between 2006 and 2015 LiDAR DEMs. The upstream inundation boundary was estimated using a 1-dimensional hydraulic HEC RAS model.**

The landslide dam has the potential to block flow in the mainstem channel and create a reservoir that extends approximately 1.5 miles upstream (Figure 10). Once the water reaches the top of the landslide dam, flow would rapidly erode the downstream face of the embankment. This would initiate a headcut that progresses upstream through the upstream face of the landslide dam, and lead to destabilization of side slopes and rapid widening of the breach opening. The hydraulic model estimates that the peak of the flood wave would form in less than 10 minutes from the start of failure. Upon failure, a flood wave containing a viscous mixture of landslide debris and water would quickly form and travel downstream. The flood wave could have a peak discharge of 13,000 cfs at the site of the landslide and 5,700 cfs at the proposed dam site – 2.5 miles downstream near RM 108 (Figure 11). This is equivalent to roughly a 2-year flood occurring at the dam site. A flood wave of this magnitude would increase water surface elevation approximately 6.5 feet above baseflow conditions at the dam site, which poses a threat to human safety and has the potential to significantly damage infrastructure (Figure 12). The flood wave would increase discharge by 2,000 cfs when it reached the USGS gage at Doty near RM 102. While flow attenuation reduces the severity of the flood wave at Doty, the increase in water surface elevation is approximately 4 feet from baseflow conditions.

It should be noted that this analysis was performed under baseflow conditions, assuming a 335 cfs inflow at RM 111. Under a flood scenario, the impoundment of flow from the landslide dam and sudden release from dam failure would result in a significantly larger peak outflow and impacts downstream. Additionally, a landslide that produces a larger reservoir through a higher embankment elevation would generate higher peak outflows from the increased volume of impounded water.

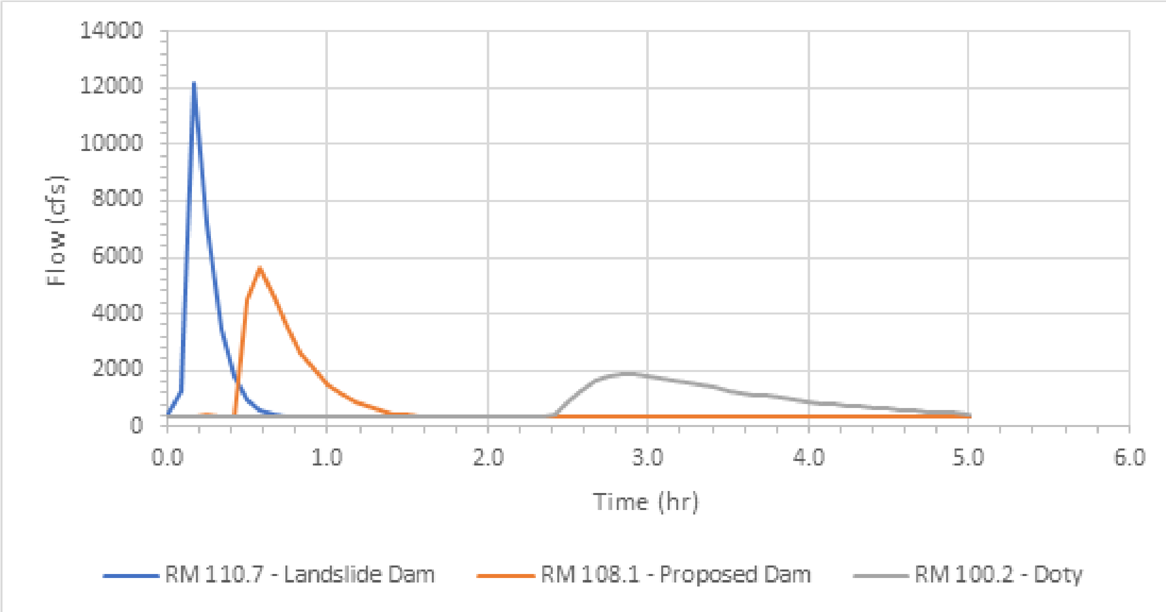


**Figure 11. Hydrographs of the modeled dam breach flood wave initiating at the landslide dam site (RM 110.7), proposed flood control dam site (RM 108.1) and USGS gage at Doty (RM 100.2). The flood wave arrives at proposed dam site approximately 0.5 hr after breaching (wave celerity of speed of about 4.7 miles/hr), and 2.6 hr to Doty (wave celerity of about 2.1 miles/hr). Peak flow at the proposed dam site is approximately 5,700 cfs and nearly 2,000 cfs at Doty. Blue line represents the outflow at the landslide dam site under assumption there is minimal base flow to isolate the dam break hydrograph (in reality there would have substantial base flow). Estimates of water surface elevation and discharge made using a 1-dimensional HEC-RAS hydraulic model.**


**Figure 12a. Simple conceptual depiction of flood wave carrying debris reaching the proposed dam site with flow from right to left.**

The flood wave caused by breaching of a landslide dam would have the potential to cause significant damage to the proposed FRE structure. The wave would likely contain a mixture of landslide debris such as large logs/trees, boulders, and a range of sediments all suspended in flood waters (Figures 12a and 12b). The material has the potential to damage the trash-rack and conduits intended to pass river flow – maybe even clogging the structures and preventing flow from passing at all. Coarser sediment carried by the flood wave than what is typically transported by the river would likely damage the conduits themselves. The impacts would be increased if the landslide dammed the river during a flood in which river levels were elevated but below the threshold for dam closure as the conduits and trash-rack would already be responsible for passing elevated water and debris levels.

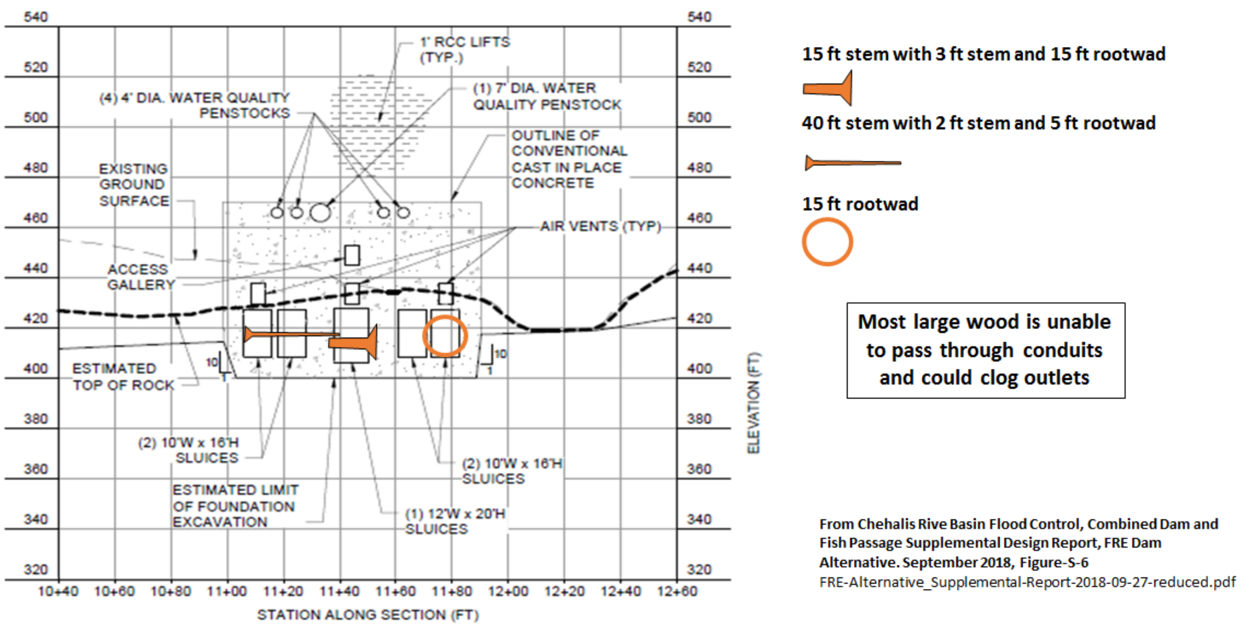


**Figure 12b. The conduits of the FRE as designed are unlikely to pass the size of wood material moving down the river. Illustration shows typical wood scaled to the conduit entrances.**

## Quarry Impact Analyses

Three quarries are proposed as a component of the FRE project. However, neither proposed plans nor detailed descriptions for the three proposed quarries were presented in the DEIS or supporting documents. The DEIS failed to present any meaningful analysis of the impacts associated with providing the materials necessary for construction of the FRE facility.

### Methods

The location of quarries was determined based on DEIS Attachment 1 - Project Description (Figure 1-7; page 1-19). however, fragmented descriptions were located in Appendices F, P, and C which were consolidated for review.

## Results

Potential quarry impacts that would be anticipated for SEPA environmental review and impact analysis but were not identified in the DEIS include:

- Slope stability impacts
- Surface water runoff and water quality impacts
- Ground water impacts
- Erosion impacts
- Vibration impacts
- Blasting and noise impacts
- Fugitive dust impacts
- Traffic impacts
- Cultural resource impacts
- Regulatory compliance and zoning.

Extrapolating from the information given, it is likely that several of the proposed quarry locations occur in areas of known or suspected slope instability and slope stability analysis would be expected in the Earth section of the DEIS. It is also likely that all quarry locations are located adjacent to Type-S Waters and may be within the State of Washington Shoreline Jurisdiction (200 feet from designated waters), so analysis supporting Shoreline Master Program review would be expected in the Land Use section of the DEIS. Plans to address water quality and surface water runoff, even at a conceptual level, would be expected.

Air photo and LiDAR review did not reveal any existing quarry activity in two of the three proposed quarry sites (North and South Quarries), and there are no registered quarries at these locations within the WDNR surface mine database. It is reasonable to assume that the mining footprint and associated surface mining activities, including stockpiling and site access, would exceed 3 acres. Given this assumption, the surface mines will have to be compliant with Lewis County zoning and the Lewis County Comprehensive Plan. Neither of these sites is within designated Mineral Resource Lands; therefore, the Comp-Plan Amendment process and a Conditional Use Permit would be required. The SM-6 process requires that Critical Areas be considered and a Forest Practice Conversion permit will be needed. The standards for permitting surface mines in Washington State are high. The level of disclosure and analysis of potential impacts from development and operation of these quarries in the DEIS is inadequate and incomplete. Given the information provided in the DEIS, it is clear that failure to disclose this information in the DEIS presents a major omission and that potentially significant impacts to aquatic resources are not disclosed.

# CONCLUSIONS

Based on our understanding of the Chehalis River watershed, the proposed FRE project, the applicable standards and guidelines and BAS, the information in the DEIS and supporting technical analyses, and our own analyses, we conclude that the impacts are underrepresented throughout the Earth Discipline of the DEIS. In several instances, omissions, data gaps, failure to follow regulatory standards and use BAS in the technical analyses have resulted in false assumptions and errors in impact analyses. In particular, the following five critical assumptions were found to be in error which has resounding impacts on the other discipline report findings:

1) Landslides and landslide potential are underrepresented in the DEIS and thereby the estimated 840,500 cubic yards of sediment delivered by landslides is underestimated in the impact analyses; actual sediment volumes will be much higher (potentially as high as 16 million cubic yards). This error is propagated in the sediment transport impact analyses and habitat impact analyses and not considered in the FRE Operations Plan.

2) The proposed reservoir pool drawdown rate is stated as 10 feet/day is not supported by site's geologic conditions and is not consistent with design standards. This error is propagated in the sediment transport impact analyses and habitat impact analyses and not considered in the FRE Operations Plan. This error would result in unsafe conditions that threaten public safety. To address this error, the drawdown rate would have to be significantly reduced, thus greatly increasing the impoundment duration. Alternatively, if the stated drawdown rate was maintained, it would have to be disclosed that the project will dramatically increase slope instability and further increase risks and impacts to public safety, FRE operations, and habitat than was disclosed in the DEIS. Other variables and assumptions used in landslide stability modeling are inconsistent with operations stated in the DEIS and appear to have bias favoring the project; there is no mention of uncertainties with the analysis in the DEIS.

3) The loss of topsoil and vegetation in the reservoir will decrease the function and benefit of preventing erosion and providing slope stability. It is our opinion that the fine-grained sediment delivery to the reservoir and mobilized from the reservoir to the downstream reaches will result in downstream habitat impacts that are greater than was considered in the DEIS. This error is propagated in the sediment transport impact analyses and habitat impact analyses. This condition will be exacerbated by an increase in landslides.

4) Landslide dam hazard and analysis was not adequately considered in the DEIS. Failure to consider this potential impact will misinform hazards and risks for FRE operations and underrepresents potential habitat impacts. This error is propagated in the sediment transport analysis and operations plan.

5) The lack of providing sufficient detail of the proposed quarry plans and disclosing and evaluating potential impacts beyond new road impacts, constitutes a significant omission and error. This error is propagated in the geologic impact analyses, sediment transport impact analyses and the wetlands, fish, and wildlife habitat impact analyses. The standards for environmental review of new surface mines proximate to salmon bearing waters is high. The level of disclosure and analysis in the DEIS is inadequate and incomplete.

# REFERENCES

Amaranthus, M.P., Rice, R.M., Barr N.R., Ziemer, R.R. 1985. Logging and forest roads related to increased debris slides in southwestern Oregon. *Journal of Forestry*, April 1985.

Anchor QEA, 2018. Combined Dam and Fish Passage Supplemental Design Report – FRE Dam Alternative. Report prepared by Anchor QEA for Chehalis Basin Workgroup. September 2018.

Bednarek, A. Undamming Rivers: A Review of the Ecological Impacts of Dam Removal. *Environmental Management* 27, 803–814 (2001).

Berilgen, M. 2007. Investigation of stability of slopes under drawdown conditions. Computers and Geotechnics - COMPUT GEOTECH. 34. 81-91. 10.1016/j.compgeo.2006.10.004.

Brunner G. 2014. Using HEC-RAS for Dam Break Studies. USACE HEC Technical Document TD-39. Davis, CA: US Army Corps of Engineers Hydrologic Engineering Center.

Cannata, M., Marzocchi, R. 2012. Two-dimensional dam break flooding simulation: a GIS-embedded approach. Nat Hazards 61, 1143–1159.

Cohen, D.M. Schwarz, M. 2017. Tree-root control of shallow landslides. *Earth Surface Dynamics*. 5, 451-477.

Cornforth, D.H. 2005. Landslides in Practice: Investigation, Analysis, and Remedial/Preventative Options in Soils, John Wiley & Sons, Hoboken, New Jersey.

Corominas, J., Van Westen, C., Frattini, P., Cascini, L., Malet, J.P., Fotopoulou, S., and Smith. J.T., 2013. "Recommendations for the Quantitative Analysis of Landslide Risk," *Bulletin of Engineering Geology and the Environment*, Vol. 73, pp 209-263.

Downs, P.W., Cui, Y., Wooster, J.K., Dusterhoff, S.R., Booth, D.B., Dietrich, W.E. and Sklar, L.S. 2009. Managing reservoir sediment release in dam removal projects: An approach informed by physical and numerical modelling of non-cohesive sediment. *International Journal of River Basin Management* 7(4), 433-452.

Federal Energy Regulatory Commission (FERC). 2015. Engineering Guidelines for the Evaluation of Hydropower Projects, Chapter 2 E.3 - Appendix C, Table 1.

Froehlich, D.C. 1995a, "Embankment Dam Breach Parameters Revisited," Water Resources Engineering, Proceedings, 1st Intl. Conf. on Water Resources Engineering, San Antonio, Texas, August 14-18, 1995, p. 887-891.

Froehlich, D.C. 1995b, "Peak Outflow from Breached Embankment Dam". ASCE Journal of Water Resources Planning and Management, Vol. 121, Issue 1, January 1995, pp 90-97.

Froehlich, D.C. 2008. Embankment Dam Breach Parameters and Their Uncertainties. ASCE, *Journal of Hydraulic Engineering*, Vol 134, No. 12, December 2008, pp 1708-1721.

Gregory, S., Li, H. and Li, J. 2001. The Conceptual Basis for Ecological Responses to Dam Removal: Resource managers face enormous challenges in assessing the consequences of removing large dams from rivers and evaluating management options. BioScience 52(8), 713-723. Available at: https://doi.org/10.1641/0006-3568(2002)052[0713:TCBFER]2.0.CO;2. Accessed 4/12/2020.

Heller, V., Hager, W.H., and Minor, H-E. 2009. Landslide generated impulse waves in reservoirs: basics and computation (Mitteilungen, 211) Zurich, Switzerland. Versuchsanstalt fur Wasserbau 172pp.

Hydrologic Engineering Center (HEC). 2016. HEC-RAS River Analysis System User's Manual, Version 5.0, CPD-68, U.S. Army Corps of Engineers, Institute for Water Resources.

Milledge, D. G., Bellugi, D., McKean, J. A., Densmore, A. L., & Dietrich, W. E. 2014. A multidimensional stability model for predicting shallow landslide size and shape across landscapes. *Journal of Geophysical Research*. Earth surface, 119(11), 2481–2504.

Montgomery, D.R., Schmidt, K.M., Greenberg, H.M., and Dietrich, W.E. 2000. Forest clearing and regional landsliding. *Geology*, 28: 311–314.

Panizzo, A., De Girolamo, P., and Petaccia, A. (2005). Forecasting impulse waves generated by subaerial landslides, J. Geophys. Res., 110, C12025. doi:10.1029/2004JC002778.

Paronuzzi, P., Rigo, E. and Bolla, A. 2013. Influence of filling-drawdown cycles of the Vajont reservoir on Mt. Toc slope stability. *Geomorphology*. 2013. doi: 10.1016/j.geomorph.2013.03.004.

Pugh, C.A. and Harris, D.W. 1982. Prediction of landslide generated water waves. 14 ICOLD *Congress.* Rio de Janeiro QF4(RWO):283-315.

Randle, T.J., and Bountry, J.A. 2017. Dam Removal Analysis Guidelines for Sediment, Advisory Committee on Water Information, Subcommittee on Sedimentation. U.S. Department of the Interior, Bureau of Reclamation. Colorado. Available at: https://acwi.gov/sos/pubs/dam_removal_analysis_guidelines_for_sos_final_vote_2017_12_22_508.pdf Accessed 4/8/2020.

Randle, T.J., Bountry, J.A., Ritchie, A., and Wille, K. 2015. Large-scale dam removal on the Elwha River, Washington, USA: Erosion of reservoir sediment. *Geomorphology*, Volume 246, Pages 709-728.

Riemer, W. 1992. Landslides and reservoirs (keynote paper), in: Proceedings of the 6th International Symposium on Landslides. Christchurch:[sn], pp. 373–2.

Sarikhan, I.Y., Stanton, K.D., Contreras, T.A., Polenz, M., Powell, J., Walsh, T.J., Logan, R.L., 2008. Landslide Reconnaissance Following the Storm Event of December 1–3, 2007, in Western Washington. Wash. Div. Geol. Earth Resource. Open File Report 2008-5, 22.

Schmidt, K.M, Roering, J.J., Stock, J.D., Dietrich, W.E., Montgomery, D.R., Schaub, T. 2001 The variability of root cohesion as an influence on shallow landslide susceptibility in the Oregon Coast Range. Can Geotech J 38:995–1024.

Schuster, R.L. 1979. Reservoir-induced landslides. Bulletin of the International Association of Engineering Geology 20, 8–15.

Schuster, R.L., 2006, Interaction of dams and landslides—Case studies and mitigation: U.S. Geological Survey Professional Paper 1723, 107 p.

Schuster, R.L., Costa, J.E. 1987. The Formation and Failure of Natural Dams. US Geological Survey Open-File Report 87-392. Vancouver, Washington.

Schuster, R.L, and Highland, L. M. 2001. U.S. Geological Survey Open-File Report 01-0276. U.S. Geological Survey, U.S.A.

Science Engineering & Sustainability: Dam break simulation with HEC-RAS: Chepete proposed dam. *Science Engineering & Sustainability*. Retrieved 2019-12-07.

Shannon & Wilson, Inc., 2014, Preliminary Desktop Landslide Evaluation. Report prepared by Shannon & Wilson, Inc., Seattle, WA for Chehalis Basin Workgroup, July 23, 2014.

Shannon & Wilson, Inc., 2015, Landslide Reconnaissance Evaluation of the Chehalis Dam Reservoir. Report prepared by Shannon & Wilson, Inc., Seattle, WA, for Chehalis Basin Workgroup, September 22.

Shannon & Wilson, Inc., 2017a, Technical Memorandum Phase 2 Chehalis Dam Landslide Evaluation Chehalis Dam Basin Workgroup, Pe Ell, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Wash., 21-1-21897-021, for Chehalis Basin Workgroup, June 29.

Shannon & Wilson, Inc., 2017b, Technical Memorandum Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species Project Phase 2 Chehalis Dam Site Characterization Landslide Stability Improvement Evaluation, Pe Ell, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Wash., 21-1-21897-021, for Chehalis Basin Workgroup, June 28.

Shannon & Wilson, Inc., 2019. Chehalis Basin Strategy: Phase 3 Landslide Evaluation. Report prepared by Shannon & Wilson, Inc., Seattle, Wash., 21-1-21897-021, for Chehalis Basin Workgroup, May 10, 2019.

Shaw, S.C. and Vaugeois, L.M. 1999. Comparison of GIS-based models of shallow landsliding for application to watershed management. Project 10 Final Report, Timber Fish & Wildlife. WDNR Forest Practices Division, Olympia, WA. 114 p.

Smith, L. 1998. Reservoir Shoreline Erosion, Willamette River Basin, Oregon: Implications for Cultural Resources Management. US Army Corps of Engineers, Portland.

Spiker, E.C. Gori, P. 2003. National Landslide Hazards Mitigation Strategy, a Framework for Loss Reduction. Reston, Va: U.S. Geol. Surv.

Swanston, D.N. 1988. Timber harvest and progressive deformation of slopes in southwestern Oregon. *Bulletin of the Association of Engineering Geologists*, 25: 371–381. Berkeley.

Thomson, J. Hart, D., Charles, D., Nightengale, T., and Winter, D. (2005). Effects of removal of a small dam on downstream macroinvertebrate and algal assemblages in a Pennsylvania stream. *Journal of The North American Benthological Society* - J N AMER BENTHOL SOC. 24. 192-207. 10.1899/0887-3593(2005)024<0192:EOROAS>2.0.CO;2.

Tuckerman, S. and Zawiski, B. 2007. Case Studies of Dam Removal and TMDLs: Process and Results. *Journal of Great Lakes Research* 33(sp2), 103-116 (1 September 2007).

Tullos, D.D., Collins, M.J., Bellmore, J.R., Bountry, J.A., Connolly, P.J., Shafroth, P.B., and Wilcox, A.C. 2016. Synthesis of Common Management Concerns Associated with Dam Removal. *Journal American Water Resources Association* 52(5), 1179-1206.

United States Bureau of Reclamation (USBR) and United States Army Corps of Engineers (USACE). 2019. Best Practices in Dam and Levee Safety Risk Analysis. Version 4.1.

United States Bureau of Reclamation (USBR), 1998. Prediction of Embankment Dam Breach Parameters, Dam Safety Research Report DSO-98-004, Dam Safety Office, U.S. Department of the Interior.

United States Department of Agriculture (USDA). 2013. Revised Universal Soil Loss Equation Version 2. USDA Agricultural Research Service.

Wahl, T.L. 1998. Prediction of embankment dam breach parameters: A literature review and needs assessment. United States Bureau of Reclamation Dam Safety Rep. No. DSO-98-004, Denver.

Wang, H.D., Yang, Q., Pan, S.H., Ding, W.C., Gao, Y.L., 2012. Research on the Impact of the Water-Level-Fluctuation Zone on Landslide Stability in the Three Gorges Reservoir Area. *Applied Mechanics and Materials* 188, P. 37–44.

Wang, B., Yao, L., Zhao, H. and Zhang, C. 2018. The maximum height and attenuation of impulse waves generated by subaerial landslides. Hindawi Shock and Vibration, article ID 14566579. Available at: doi.org/10.1155/2018/1456579. Accessed 4/8/2020.

Warrick, J.A, Bountry, J., East, A., Magirl, C., Randle, T., Gelfenbaum, G., Ritchie, A., Press, G., Leung, V., and Duda, J. 2015. Large-scale dam removal on the Elwha River, Washington, USA: Source-to-sink sediment budget and synthesis, Geomorphology, Vol 246, October 1 2015. P. 729-750 DOI.

Washington State Department of Ecology (Ecology). 1993. Dam Safety Guidelines - Part IV: Dam Design and Construction. Olympia, WA. Available at: https://fortress.wa.gov/ecy/publications/documents/9255d.pdf. Accessed 4/4/2020.

Weyerhaeuser. 1994. Chehalis Headwaters Watershed Analysis. Weyerhaeuser Corporation, Federal Way, WA. July.

Wickert, A.D., Martin, J.M., Tal, M., Kim, W., Sheets, B., Paola, C. 2013. River channel lateral mobility: metrics, time scales, and controls. Journal of Geophysical Research. Vol. 18, Issue 2. Pp 396-412.

Xia, M., Ren, G.M., Zhu, S.S. 2014. Relationship between landslide stability and reservoir water level variation. Bull Eng Geol Environ 74, 909–917.

Xiao, L., Wang, J., Ward, S.N., and Chen, L. 2018. Numerical modeling of the June 24, 2015 landslide generated impulse waves in Three Gorges Reservoir, China. Landslides. DOI: 10.1007/s10346-018-1057-2.

Yin, Y., Huang, B., Wang, W., Wei, Y., Xiaohan, M., Ma, F., and Zhao, C. 2016. Reservoir-induced landslides and risk control in Three Gorges Project on Yangtze River, China. *Journal of Rock Mechanics and Geotechnical Engineering*, 8(5), 577-595.