Technical Memorandum

Date:	April 27, 2021
Project:	Chehalis River Basin Flood Damage Reduction Project
To:	Chehalis Basin Flood Control Zone District
From:	HDR
Subject:	Slope Stabilization Mitigation

1.0 Introduction and Purpose

As part of a strategy to reduce flood damage in the Chehalis River Basin, the Chehalis River Basin Flood Control Zone District (District) is proposing to construct a flood retention facility near the town of Pe Ell on the mainstem of the Chehalis River. Numerous studies and technical information have been developed to evaluate anticipated impacts on abiotic and biologic resources associated with construction and operation of the proposed flood retention expandable (FRE) facility (i.e., the proposed project). In evaluating the area upstream of the proposed FRE facility, several steep slopes and landslides have been documented.

Landslides in the Upper Chehalis can add sediment to the river and effect turbidity and potentially effect spawning redds. Climate change has the potential to increase precipitation levels that will contribute to the vulnerability of slopes.

Previous studies have indicated that there are slopes near failure or that have already started to move. With or without construction of the FRE facility, slope movement will occur in the Upper Chehalis that can add sediment to the Chehalis River. Climate change will increase the potential for landslide movement. Construction of the FRE and storage of flood water can increase the potential landslides initiating, however several landslide areas will be removed or stabilized as part of FRE construction and there are opportunities to mitigate more as part of the construction progress.

This Technical Memorandum provides a summary of landslide identification and evaluations that have been completed within the proposed flood retention expandable (FRE) reservoir basin.

There are four primary sources of geotechnical information used: Shannon & Wilson 2015, 2017a, 2017b, and 2019.

> **Shannon & Wilson 2015**- Preliminary desktop study to identify potentially unstable slopes in the proposed FRE facility and reservoir area. A two-geologist team recorded characteristics of each landslide and identified which slopes could potentially destabilize during the rising and falling of the reservoir waters.

Shannon & Wilson 2017a – Borings were drilled at four of the identified landslides near the proposed FRE facility, and seismic refraction surveying was done at 11 of the identified landslides. Slope stability analyses were performed at 10 landslides.

Shannon & Wilson 2017b – Development of concept alternatives for stability improvements for some of these landforms where reservoir operation could decrease stability and movement could impact FRE facility construction and operation.

Shannon & Wilson 2019 - Eight borings were drilled to assess subsurface conditions at eight identified landforms in and adjacent to the potential FRE facility reservoir. Laboratory testing was performed to determine index parameters, strength parameters, and hydraulic conductivity of soils encountered in the borings. Slope stability analyses were performed to augment the work performed in 2017a for refined analyses with additional information or analysis of landsides not previously addressed.

The FRE flood retention structure concept and its operation is described in more detail in HDR 2018. Additional detail on construction, excavation, and cost estimates are included in HDR 2017a and HDR 2018.

2.0 Facility Operations

The FRE reservoir would be comprised of a roller compacted concrete (RCC) flood retention structure with flood control outlet works, an ungated spillway, and supplemental fish passage facilities. The FRE's primary components are the following:

- A FRE facility sized for flood storage with a crest at elevation estimated maximum structural height of 254 to 270 feet depending on final foundation elevation
- An RCC dam crest length of approximately 1,225 feet
- A dam section that is contained entirely within the river valley and would not require a saddle dam along the right abutment ridge line to provide closure
- An ungated overflow spillway, designed to pass the PMF without crest overtopping, including a spillway chute, flip bucket, and plunge pool
- Construction diversion tunnel through right abutment
- Low-level outlet sluices for sediment and fish passage, as well as flood control operations
- Fish passage facilities designed for free passage upstream and downstream prior to and after flood, and trap and haul during flood regulation periods
- Target flood detention storage capacity of 65,000 acre feet
- Crest elevation is 651 feet msl (mean sea level)
- Estimated maximum routed PMF reservoir elevation is 650 feet msl
- Spillway crest elevation is 628 feet msl

- Minimum flood storage reservoir elevation is natural riverbed elevation
- Maximum flood storage elevation with no spillway flow is 628 feet msl
- Low-level flood regulation sluices design flow is 15,000 cfs, which is the maximum controlled flow through the dam (not including the spillway)

During non-regulated flood conditions (flows below the threshold for water retention), the FRE facility would convey the full flow of the Chehalis River through its conduits and accommodate upstream and downstream fish passage. During major floods that trigger FRE operations, the conduit gates at the base of the FRE facility would be mostly closed to regulate river flows and reduce downstream flooding. During these periods of operation, floodwaters (with the exception of minimum instream flows released downstream) would be temporarily stored behind the FRE facility. Following the flood event, debris removal activities would be performed, and stored floodwaters would be released downstream over a period of several weeks.

The FRE facility operation would be implemented to impound water when the river is forecasted to rise above 38,800 cfs within 48 hours at the downstream river monitoring gage at Grand Mound, Washington. The source of the forecast for major flooding would be the Northwest River Forecast Center, operated by NOAA, which makes daily forecasts for river systems based on temperature and precipitation.

During operation, the FRE conduit gates would be closed and outflow would be reduced at a rate of 300 cfs per hour unless flows over the spillway begin to occur

After the flood event, reservoir evacuation will occur in three stages:

1. Initial Reservoir Evacuation (maximum pool water surface elevation level (WSEL) 628 without spillway flow, to WSEL 528 feet): To evacuate the temporary reservoir after a major flood event, the partially closed reservoir outlet gates will open and increase outflow by 1,000 cfs per hour, from 300 cfs (minimum outflow during flood operations) to a maximum outflow of 5,000 to 6,500 cfs. This will cause drawdown of the temporary reservoir from its peak WSEL at the maximum pool at a maximum rate of 10 feet per day (5 inches per hour) to reduce the risk of triggering landslide movements. This rate can be modified through the adaptive management process to adjust for climate change or to avoid observed negative environmental impacts. The maximum WSEL for each major flood event will vary depending on the intensity of the flood event. During all major flood events, the 10 feet per day drawdown rate will continue until the storage pool elevation reaches 528 feet. Once the storage pool elevation reaches 528 feet, debris management operations will begin.
2. Debris Management Evacuation (WSEL 528-500 feet): During major flood events, debris from surrounding tributaries and hillsides will likely be swept into the reservoir. Debris management procedures will be used to minimize large woody debris impacts on reservoir flood operations, or cause damage to the FRE facility. During debris management activities, drawdown rates will be slowed to a maximum of 2 feet per day (about 1 inch per hour) for a 14-day period. During this period, crews will use a boat to

manage/move large debris from the reservoir to an existing log extraction and sorting yard. This is an area that was previously operated by Weyerhaeuser for timber management activities. The slowed drawdown rate will continue until the storage pool elevation reaches an elevation of 500 feet. Once the storage pool elevation reaches 500 feet, debris management operations will conclude.

3. Final Reservoir Evacuation (WSEL 500-425 feet): During all major flood events, once the temporary reservoir reaches WSEL of 500 feet, drawdown rates will increase to 10 feet per day (5 inches per hour) once debris management operations are complete. Drawdown will continue at this rate until the storage pool has emptied and the pool elevation returns to 425 feet. At this time, the reservoir will no longer be impounding water and the Chehalis River will return to a free-flowing state.

3.0 Site Description and Review of Previous Landslide Studies

3.1 Site Description

The headwaters of the Chehalis River begin in the Willapa Hills. The East and West forks of the Chehalis River drain from the headwaters to form the upper mainstem Chehalis River where the proposed FRE facility would be located, at approximately river mile (RM) 108. This reach of the Chehalis River is relatively high gradient and confined by a steep-sided valley with numerous bedrock outcrops (USACE 2020). Upstream of the proposed FRE site, several tributaries enter the Chehalis River.

3.2 Review of Landslide Studies

Figure 1 (taken from Shannon & Wilson 2019 and located at the end of this memorandum) shows the locations of the 27 identified landslides along with the anticipated 100-year flood limits. Some are near the FRE facility. Visual observation allows classification into the following general three categories.

Construction zone, to be remediated as part of the flood retention structure construction, (6 landslides); LS-1 and LS-1a, LS-3 and LS-3a, LS-26 and LS-27. These landslides are anticipated to be removed or treated to meet construction excavation objectives, remove any landslide material in the immediate vicinity of the outlet conduits that may cause failure of their operation, or that may create an unsafe work environment.

Landslide with a significant extent within 100-year flood inundation area (6 landslides); LS-2, LS-4, LS-5, LS-11, LS-13, LS-21 **and Landslide with only the toe (lowest portion) within 100-year flood inundation area** (10 landslides); LS-9, LS-10, LS-12, LS-15, LS-18a and LS 18b, LS-20, LS-22, LS-23, LS-24, LS-25. These landslides are within the reservoir basin and will be partially inundated during the 100-year flood or only the toe of the landslide will be inundated. The likelihood of the slope failure during inundation of the landslides with only the toe being inundated is less likely than the ones that are partially within the reservoir considering the frequency of inundation (and the

extent of the slope saturated. Landslides LS-2, LS-4, LS-5 are relatively close to the construction facility and are more easily mitigated as part of the construction process.

Entire slide above 100-year flood (7 landslides); LS-6, LS-7, LS-8, LS-14, LS-16, LS-17, LS-19. The entire landslide is above the 100-year flood and unlikely to be affected by flood retention activity. The risk of these landslides affecting the reservoir is not changed by construction of the FRE project.

3.3 Landslide Mitigation Included in Flood Retention Structure Construction

There are several identified landslides near the proposed FRE facility location. Landslides on the north (downstream) side of the FRE facility will be removed or stabilized as part of the construction of the FRE facility including the outlet works, fish passage facilities and outlet tunnel. An allowance for landslide mitigation costs have mostly been included as part of the earthwork for those features. Landslides 3 and 3a (see Attachment A) upstream of the right abutment are near the approach channel and headworks of the diversion tunnel. No specific stabilization costs were itemized in the cost estimate; however, it should be noted that during the FRE facility construction, the estimated cost to place excess excavated material in a berm of sufficient size to stabilize these landslides is small and accommodated within the construction cost contingencies currently included in the cost estimate.

Other excess excavated material required to achieve the foundation objective will also be available to be placed to buttress vulnerable landslide areas near the construction site.

The landslides within the construction zone of the FRE facility will be mitigated. The excavation of the foundation of the facility will remove those slides completely to provide a stable foundation for the FRE facility. The slides around the future reservoir are not impacted by the construction of the facility. The environmental impact for prevention measures to stabilize some of the landslides have the potential to be higher than leaving them in place as they are. The decision whether to mitigate or not will be evaluated based on potential disturbance during mitigation weighed against the benefit of the mitigation considering the vulnerability and failure mechanism of each slope.

3.4 Review of Landslide Stability Analyses

Shannon & Wilson performed two separate landslide stability analyses documented in Shannon & Wilson 2017a and 2019. These landslide stability analyses were performed for conceptual engineering purposes only and were based on limited subsurface and laboratory strength testing information.

Shannon & Wilson evaluated ten of the 27 landslides including LS-1, LS-1a, LS-2, LS-3, LS-4, LS-5, LS-10, LS-18 (split into LS-18a, and LS-18b), LS-26 and LS-27 in 2016-2017. These landslides were (a) at elevations within the flood retention pool limits for the FRFA option (no longer being considered) that could experience elevated groundwater conditions during rapid drawdown, and (b) have enough volume that, if fully mobilized, could threaten operation of the flood retention structure.

A summary of the results of these evaluations is as outlined below. Note that when a factor of safety (FS) falls below 1, instability or movement of the landslide is expected to occur.:

- LS-1, Mitigated during construction through excavation.
- LS-1a, Mitigated during construction through excavation.
- LS-2, Could be mitigated during construction by adding buttressing. The slide was observed to be an actively moving slope and analysis indicated a FS below 1 before inundation and/or drawdown. Given the low factor of safety and proximity to the construction site, this landslide is a good candidate for mitigation.
- LS-3, Mitigated during construction through excavation and buttressing to meet excavation objectives and create a safe construction site. Analysis indicates the FS is near or below 1 before inundation and/or drawdown.
- LS-4, Potentially mitigated during construction by adding downstream buttress, low FS for lower portion of landslide, failure mass relatively small. Given the low factor of safety and proximity to the construction site, this landslide is a good candidate for mitigation. If the slide moves during a none flood event, it will not reach the river to cause sedimentation issues due to its proximity to the river.
- LS-5, Re-analyzed in 2019 with more data.
- LS-10, Re-analyzed in 2019 with more data.
- LS-18a and LS 18b, only evaluated for FRFA in the analysis. This landslide is only impacted at the toe of the slope for high flow events for the FRE configuration.
- LS-26, Mitigated during construction through excavation.
- LS-27, Mitigated during construction through excavation.

Based on the results of those analyses, Shannon & Wilson (2017b) developed concept alternatives for stability improvements for some of these landforms where reservoir operation could decrease stability and movement could impact FRE facility construction and operation.

Landsides evaluated or re-evaluated in 2019 included the following:

1. LS-5, Judged to be likely to stay in place during inundation and drawdown.
2. LS-10, Judged to be likely to stay in place during inundation and drawdown.
3. LS-11, FS above 1.0 and low likelihood of retrogressive failure. Given the distance from the reservoir, it is unlikely to affect the water quality of the river.
4. LS-13, FS above 1.0 and low likelihood of retrogressive failure.

Shannon & Wilson 2019 summarizes slope stability analyses for LS-5, LS-10, LS-11, and LS-13 that indicate these landslides/landforms will likely remain stable during FRE facility operation during a 100-year storm event resulting in reservoir inundation and drawdown. The analyses results also indicated that while the lower slopes of LS-11 and LS-13 will likely have a FS greater than 1.1 during reservoir inundation/drawdown, they may be susceptible to retrogressive failure should lower slope movement begin to occur. Overall, based on the geologic interpretation and analyses results, should movement of these four landslides occur, the movement is unlikely to be rapid or impact the FRE facility or its operation.

3.5 Landslide Monitoring Program

A monitoring program for landslides in the planned reservoir pool area with a significant extent within 100-year flood inundation limits and with only the landslide toe (lowest portion) within 100-year flood inundation area may be implemented. The monitoring program would be established at landslides that have an estimated level of safety that does not require construction remediation. The monitoring program would track water levels within the landslide and if movement begins to occur indicating some reduction in safety. Monitoring equipment would be installed in the landslides to track water levels and movement on a regular basis. If conditions degrade, movement is detected, or if failure is expected to occur during flood pool operation, a mitigation program could be proactively implemented. The monitoring program is not anticipated to provide landslide risk reduction benefits during actual flooding events.

Creating access to the candidate landslides for monitoring implementation may be costly. Remote areas are more difficult to mobilize equipment to install the monitoring instrumentation. Additional site characterization and analyses will be needed to identify landslides suitable for implementation of a monitoring program along with the number, type, location and other installation details for the monitoring instruments. After the actual installation of the instrumentation, a periodic monitoring program will have to be implemented and maintained.

4.0 Summary and Conclusion

The area within the reservoir basin of the proposed FRE facility includes steep slopes with identified landslides. Investigations over several years have identified up to 27 landslides in the reservoir basin by use of LiDAR aerial photography and follow up site visits. Analyses have been performed to explore the vulnerability existing conditions and vulnerability during inundation events. Not all of these landslides will be impacted during flood retention or be within the construction limits for the FRE facility.

The three major groups of slides that have been identified are 1) the ones that will be mitigated during construction, 2) within or partially within the 100-year flood zone, and 3) outside the 100-year flood zone. Landslides within or that are partially inundated by the flood pool limits of the FRE have been evaluated and mitigation strategies have been developed that would minimize or eliminate project impacts associated with a 100-year (or less) flood pool inundation or related facility operation procedures, though there remains the potential for minor landslides within the basin both with and without flood retention.

Construction plans for the FRE construction site include landslide/slope stabilization, mitigation through excavation of unsuitable materials, or buttressing vulnerable slopes using excess material taken from construction excavation to achieve construction objectives and maintain safe construction conditions for use to remove or stabilize several landslides.

The decision whether to further mitigate landslides within the reservoir basin (for larger flood events) prior to Project operation will largely depend on the Project owner's tolerance of uncertainty and risk associated with the timing of potential landslide mitigation or cleanup costs. Landslides are not anticipated to have a significant effect on Project operations; however, there

are potential maintenance costs including clean-up and restoration activities following limited landslides and localized stream restoration that may be necessary. Additional explorations, strength testing, in situ hydrologic testing, and analyses may be required for final design if mitigation of landsides are considered important. Cost effective solutions are often drainage, infiltration protection, and/or toe berm, and these measures should be evaluated to mitigate landslide potential, particularly for those relatively close to the FRE construction site

With or without construction of the FRE facility, slope movement will occur in the Upper Chehalis that can add sediment to the Chehalis River. Erosion is a natural process that can have both positive (such as streambed nourishment) and negative impacts (through turbidity and excessive fine material). Higher precipitation due to climate change is expected to increase the potential for landslides. Construction of a flood retention structure will have similar effects as climate change considering the increased landslide likelihood from the reservoir water retention and drawdown, and on the other hand the decreased likelihood from landslide removal, stabilization and the opportunities for mitigation.

5.0 Literature Cited

HDR. 2017a. Combined Dam and Fish Passage Conceptual Design Report. Bellevue, Washington.

HDR. 2017b. Phase 2 Site Characterization Technical Memorandum.

HDR. 2018. Combined Dam and Fish Passage Supplemental Design Report FRE Dam Alternative

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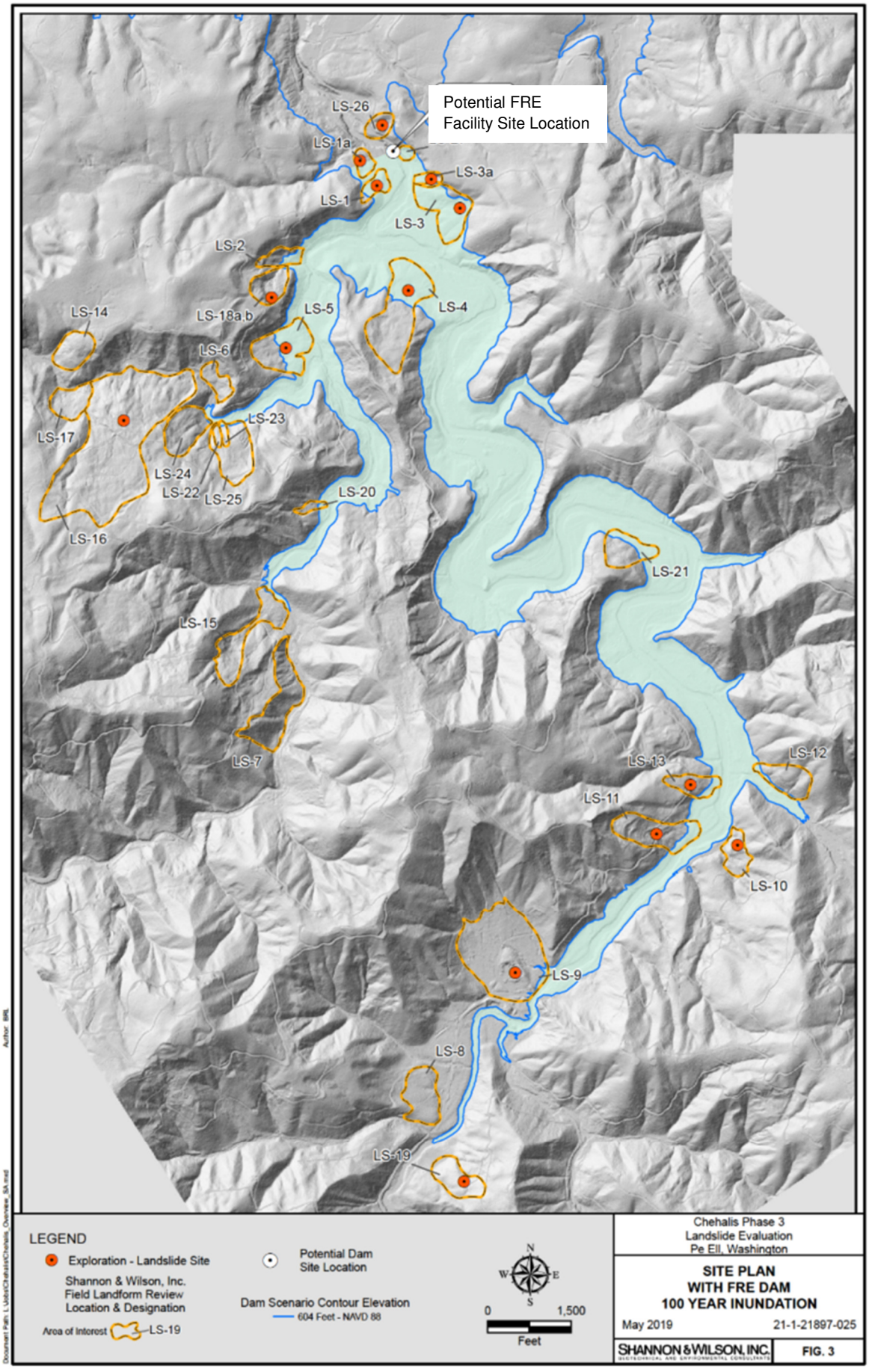
Shannon & Wilson, Inc. 2019. Phase 3 Chehalis Dam Geotechnical Data Report. Report prepared by Shannon & Wilson, Inc., Seattle, Wash., for the Office of the Chehalis Basin. March 5, 2019.

USACE (US Army Corps of Engineers). 2020a. Chehalis River Basin Flood Damage Reduction Project. NEPA Environmental Impact Statement. Appendix I. Discipline Report for Geomorphology. September 2020.

Attachment A. Figures


Potential FRE
Facility Site Location
LS-26
LS-1a
LS-3a
LS-1
LS-3
LS-2
LS-14
LS-18a,b
LS-5
LS-4
LS-6
LS-23
LS-17
LS-24
LS-22
LS-25
LS-20
LS-16
LS-21
LS-15
LS-7
LS-13
LS-12
LS-11
LS-10
LS-9
LS-8
LS-19
LEGEND
Exploration - Landslide Site
Shannon & Wilson, Inc.
Field Landform Review
Location & Designation
Area of Interest
LS-19
Potential Dam
Site Location
Dam Scenario Contour Elevation
604 Feet - NAVD 88
N
W
E
S
0
1,500
Feet
Chehalis Phase 3
Landslide Evaluation
Pe Ell, Washington
SITE PLAN
WITH FRE DAM
100 YEAR INUNDATION
May 2019
21-1-21897-025
SHANNON & WILSON, INC.
FIG. 3