Reconnaissance-Level Geotechnical Report
Proposed Chehalis River and
South Fork Dam Sites
Lewis County, Washington

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EXECUTIVE SUMMARY

This report provides reconnaissance-level geotechnical considerations and recommendations for two potential dam sites in western Lewis County, Washington. The proposed structures include a 280-foot-high dam on the main stem of the Chehalis River about 2 miles south of Pe Ell, and a 200-foot-high dam on the South Fork Chehalis River about 11 miles south of Curtis. The primary purpose of the dams would be flood control and summertime flow augmentation, with a secondary purpose of hydroelectric power generation.

At this phase of the project, geotechnical considerations related to constructing a dam and reservoir at a particular site include:

- Evaluating the advantages and disadvantages of various dam types,
- Evaluating the availability of construction materials,
- Identifying methods to mitigate natural hazards, and
- Identifying design challenges related to construction of the dam and its appurtenances.

In our opinion, zoned earthfill dams and possibly earthfill-rockfill dams are technically feasible at both sites. A roller-compacted concrete (RCC) dam is technically feasible at the Chehalis River site. Additional studies are necessary to identify appropriate and sufficient volumes of embankment dam material, sources of low-permeability core material, and aggregate for the RCC alternative.

Dam intake structures will need to be designed to resist the expected ground motions associated with a long-return-interval earthquake. Intake structure alternatives include sloping structures on the upstream embankment face, partially buried structures in or near an abutment, and a vertical shaft in an abutment.

Selecting the type and location of spillway(s) and the intake structure at both sites will require additional study and assessment. The emergency spillway and outlet works will be significant cost components of the overall project.

Landslides are present at both dam sites and within both reservoir areas. In our opinion, the hazards posed by slope instability can be mitigated by engineering and/or operational controls.

Based on our reconnaissance-level geotechnical study, we did not identify fatal flaws that would preclude construction of the proposed dams at either the Chehalis River or South Fork sites. Additional studies are required to confirm our assumptions and to move from a qualitative to a quantitative feasibility assessment.

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1.0 INTRODUCTION

1.1 Purpose

This report presents reconnaissance-level geotechnical considerations and recommendations for two potential dam sites in western Lewis County, Washington (Figure 1). One dam site is located on the main stem of the Chehalis River, about 2 miles south of the town of Pe Ell. The other dam site is located on the South Fork Chehalis River (South Fork), about 11 miles south of the unincorporated town of Curtis.

1.2 Scope of Services

Shannon & Wilson developed and presented a scope of services to EES Consulting, Inc. (EES) and the Lewis County Public Utility District No. 1 (PUD) in February 2009. The geotechnical scope of services, accepted by the PUD and EES and funded by the Chehalis River Basin Flood Authority (CRBFA), includes the following tasks:

- Estimating the engineering characteristics of soil and bedrock materials at the dam sites,
- Developing a preliminary assessment of seismicity at each site,
- Discussing general geotechnical considerations related to dam construction at each site,
- Recommending additional studies
- Attending meetings with EES and the PUD, and
- Preparing this report.

Subsurface explorations were not conducted as part of this reconnaissance level site assessment.

1.3 Authorization

Shannon & Wilson's work for the PUD was authorized by Mr. John J. Snyder of EES on April 21, 2009. Shannon & Wilson is a subconsultant to EES, which is contracted to the PUD, and authorized and funded by the CRBFA.

1.4 Related Studies and Reports

As part of the overall project, Shannon & Wilson performed preliminary geologic studies, including interpretation of aerial photographs, geologic reconnaissance, and mapping at each site. The results of the geologic study are presented in our Geologic Reconnaissance Study Report dated October 27, 2009.

2.0 BACKGROUND INFORMATION

2.1 History

The Chehalis River basin has historically experienced seasonal flooding as a result of winter storms. Flood events in December 2007 and January 2009 were particularly severe. Flooding has adversely impacted local residents and businesses, as well as public infrastructure, fisheries and natural resources. Extensive flood damage has occurred during the past two winters (December 2007 and January 2009) in the Chehalis/Centralia urban areas, in the main stem valley and tributaries to the west, as well as downstream of Centralia in Thurston and Grays Harbor Counties.

Discussions are underway to address this long-standing problem. Among the potential solutions being considered are the raising of the Skookumchuck Dam to the east of Centralia and the construction of levees along the Interstate 5 (I-5) corridor, both of which are being studied by the U.S. Army Corps of Engineers. The construction of flood retention structures elsewhere in the basin is being examined by the CRBFA.

EES evaluated the concept of developing flood control dams to reduce the flooding hazard in the Chehalis River basin in 2008. EES concluded that significant flood reduction and summertime flow augmentation could be achieved by constructing dams on the main stem of the Chehalis River near Pe Ell and the South Fork, south of Curtis. Flood reduction benefits noted by EES include:

- Avoided costs for property damage,
- Avoided costs for flood victims,
- Avoided crop loss,
- Increased property values,
- Avoided infrastructure damages, and
- Avoided impacts to fisheries and degradation of water quality.

In addition to the benefits of flood control and summertime flow augmentation, EES investigated whether the dams could be outfitted with hydropower generation facilities. The PUD has expressed interest in developing this potential electric power resource, but only as a secondary benefit to flood control and summertime flow augmentation. Geotechnical and environmental evaluations related to the potential dam sites are in progress. EES is currently performing preliminary environmental studies. Under contract to EES, Shannon & Wilson is performing geotechnical studies, of which this report is a part.

2.2 Proposed Dam Sites

The two potential dam sites are located west of Chehalis in Lewis County, as shown in Figure 1. The Chehalis River dam site is located about 2 miles south of Pe Ell, in the northwest quarter of Section 10, Township 12N, Range 5W (Willamette Meridian). Approximately 75 percent of the proposed dam footprint is located on land owned by Mr. Vincent Panesko. The remaining 25 percent of the proposed dam footprint is on land owned by the Weyerhaeuser Company. The proposed dam would be located in a constriction of the valley known as Charlie's Hump. The land that would be flooded by the reservoir is owned by the Weyerhaeuser Company.

The South Fork dam site is located at the southern end of the Boistfort Valley, about 11 miles south of Curtis, in the middle third of the eastern half of Section 19 Township 11N, Range 3W (Willamette Meridian). The entire dam footprint is on land owned by Sierra Pacific Industries. The land that would be flooded by the reservoir is also owned by Sierra Pacific Industries.

3.0 GENERAL CONSIDERATIONS

3.1 Dam Type

The geometry of the proposed dam site, strength of the foundation, and availability of borrow are typically the major factors in selecting the type of dam for a particular site. For example, concrete arch dams are generally practical in narrow canyons with competent rock, while zoned earth embankments are typically preferable in wider valleys where large quantities of soil are available for borrow.

In our opinion, there are four types of dams that may be feasible at one or both sites. The following sections a briefly describe each dam type. Figure 2 provides schematic cross sections of each dam type.

3.1.1 Zoned Earthfill

A zoned earthfill dam typically includes a low-hydraulic conductivity core (generally composed of clay), with granular upstream and downstream shells and internal filter drains. The clay core provides water retention, while the shells provide stability and protect the core. Water that seeps through the core is collected in a chimney drain placed between the core and the downstream shell. The chimney drain is connected to a blanket drain, which carries seepage below the downstream shell to a location where it can be safely discharged. The gradation of aggregate used for the chimney and blanket drains is selected so that it also functions as a filter. Two or more different zones of aggregate may be required to satisfy both the filter and drainage design requirements of the chimney and blanket drains. The chimney filter zone protects the core from internal erosion by preventing clay particles from migrating into the downstream shell. Filters constructed around the blanket drain prevent foundation erosion. A layer of bedded riprap is commonly placed on the upstream slope to protect the dam face from erosion by wave action.

3.1.2 Earthfill-Rockfill

An earthfill-rockfill dam embankment is similar to a zoned earth embankment, except that the shells are composed of large-diameter (up to 24-inch-diameter) particles. Because of the large variation in grain size between the core and the shells, one or more transition zones are often required on both sides of the core. Because coarse rockfill has a higher internal friction angle than soil, the upstream and downstream slopes can typically be constructed at a steeper angle than the slopes of a zoned earthfill dam, which reduces the overall volume of the embankment. Rockfill dams are preferable where the volume of soil is limited (but suitable for a core), and a relatively large volume of competent rock is available.

3.1.3 Rockfill

A rockfill dam is composed almost entirely of rock particles, with water retention often provided by upstream facing placed against a finer transition zone. Reinforced concrete is commonly used for the upstream face, although other materials (including steel plates and asphalt) have also been used. The upstream facing material may be underlain by a geosynthetic membrane. Several rockfill dams in Norway (and other countries) have been constructed with relatively thin central cores comprised of asphalt. As a viscoelastic-plastic material, compacted bituminous concrete (asphalt) is resistant to damage from earthquakes. Rockfill dams assume that the rock particles are competent and will not break down over time resulting in excessive embankment settlement.

3.1.4 Roller-compacted Concrete (RCC)

RCC is a dry mix of the same ingredients as traditional concrete: Portland cement, aggregate, and water. The stiff mix can be transported and spread using haul trucks and bulldozers. RCC is compacted by vibratory rollers and does not contain steel reinforcement. The downstream face of an RCC dam is typically stair-stepped and the upstream face is typically near-vertical. To reduce the potential for seepage along horizontal contacts between lifts of RCC and near-vertical shrinkage cracks produced during and following construction, conventional concrete facing (often with a geomembrane water barrier) is typically applied to the upstream face of an RCC dam.

RCC is typically more expensive per cubic yard than earthfill or rockfill. Overburden removal, blasting, crushing, screening, and washing for aggregate production; cement; and mixing of aggregate and cement to produce RCC contribute to the relatively high cost per cubic yard for RCC. However, the overall volume of material required to construct the dam is typically much less than for earthfill and rockfill dams because RCC dams can be constructed with much steeper upstream and downstream slopes.

3.2 Appurtenances

Dams require several appurtenant structures in addition to the embankment. Some are only required during the construction phase, although most are critical components for long-term operation. The following sections provide a brief discussion the major appurtenances that will likely be required for construction and operation of the proposed dams and reservoirs.

3.2.1 Diversion Structure

Because a portion of the dam foundation will be within the existing river channel, stream flows need to be diverted during dam construction. Typically, an upstream cofferdam is constructed and water is directed around the dam site. Depending on dam site geometry, construction sequence, and flow volume, water can either be diverted into restricted portion(s) of the stream channel (such as was done for Grand Coulee Dam), into a tunnel around the dam site (such as was done for Hoover Dam), or into a conduit (pipe).

The cofferdam can be a temporary structure, used only during construction, or, depending on how it is constructed, incorporated as part of the dam. It is sometimes possible to re-use a diversion tunnel or conduit as part of the outlet works or service spillway.

3.2.2 Service Spillway

The purpose of a service spillway is to convey normal river flows and minor floods over, around, or through the dam. Depending on the hydrology of the site, service spillways are typically either a conduit through the dam, a tunnel through an abutment, or an open channel. For earth and rockfill dams, open channels are typically located on an abutment or other location away from the main embankment. Sometimes the service spillway is a low-flow section of a larger emergency spillway channel. Service spillways may utilize gates that can be opened or closed to regulate the water level in the reservoir.

3.2.3 Emergency Spillway

The purpose of an emergency spillway is to pass river flows that exceed the capacity of the service spillway (major floods). An emergency spillway is typically an open channel, although some dams utilize tunnels. Open channels are typically located on an abutment or other location away from the main embankment. For RCC and concrete dams, a portion of the dam structure can be designed as an overflow section where water flows directly over the dam. Emergency spillways are typically uncontrolled, such that water begins flowing once the level of the reservoir reaches the elevation of the control weir.

3.2.4 Outlet Works

The outlet works are used to regulate the reservoir level. The outlet works is controlled by gates and/or valves, and in an emergency the low-level outlet can be used to drain the reservoir. Water discharged through the outlet works gates and valves is released through a pressure conduit near the base of dam elevation. Routine water releases to meet minimum in-stream flow requirements are often made using the outlet works, although stream flows can be supplemented by discharge from a hydroelectric generating facility when it is in operation. The outlet works typically include either a tower or shaft with multiple inlets so that water can be selectively released from different levels in the reservoir to manage downstream water quality and temperature. For dam safety reasons, it is preferable that the outlet works conduit be founded on bedrock, at the base of the embankment or be installed in a tunnel through an abutment. For an outlet works conduit that is below the embankment, it is preferable that the conduit be straight and perpendicular to the axis of the dam crest.

3.2.5 Penstocks and Powerhouse

If the dam is used for electricity generation, a powerhouse will be located downstream of the dam. Penstocks would be constructed to convey water from the reservoir to the turbines and generators. The penstock inlets are typically located to allow for operation even when the reservoir is not completely full. In some cases, the penstock to supply water to a powerhouse is connected to the low-level outlet conduit such that water can be directed to the powerhouse, released directly to the river, or both.

3.2.6 Fish Passage Facility

Many dams include a facility to allow fish to bypass the dam while migrating upstream. A "fish ladder" typically includes a series of pools in a stair step configuration on one of the abutments. The fish ladder extends from the tailwater pool at the bottom of the dam to the reservoir. Water is diverted through the fish ladder, and fish can swim and jump from one pool to the next until they have bypassed the dam. As an alternative, fish could be collected from the river downstream of the dam and transported to the reservoir using a "trap and haul" system.

3.3 Natural Hazards

3.3.1 Seismic

In general, the most direct seismic hazard to any dam is failure of the embankment or an appurtenant structure in response to either displacement or ground motion caused by fault rupture. Other seismic-related hazards to be considered during design include liquefaction of foundation soils leading to deformation, overtopping of an earth or rockfill dam, cracking of an RCC dam, and stability of the embankment and reservoir slopes under seismic loading. The dam and appurtenant structures need to be designed to resist seismic loads.

3.3.2 Slope Instability

Landslides and landslide debris are present at both proposed dam sites, as shown in the geologic reconnaissance maps (Figures 3 and 4). Landslides and landslide debris at the proposed dam sites will need to be removed from within the core trench excavation for an embankment dam, or from below the entire foundation for an RCC dam. Provided that soil within a landslide mass that would remain below an embankment dam is sufficiently dense that neither settlement nor liquefaction is of concern, it is sometimes possible to construct the embankment shells directly against and over landslide debris. Excavation in and adjacent to existing landslides and landslide susceptible terrain to construct the dam core and shape abutment surfaces prior to embankment construction may activate a landslide. The potential for slope instability caused by dam construction, and costs associated to prevent or mitigate these instabilities, should be considered as part of site selection.

Landslides in the reservoir area are a potential hazard. Saturating soil in reservoir slopes and existing landslides within the reservoir will tend to reduce stability. Slope movement could occur in response to wetting, reservoir level fluctuations, and if the reservoir pool level drops too quickly, creating a rapid drawdown condition. In extreme cases, rapid slope movement into the reservoir can create a wave (seiche) with the potential to overtop the dam embankment. Slow movement, while less likely to cause catastrophic damage, can reduce the capacity of the reservoir and reduce the flood storage benefit. Reservoir slope stability and potential to activate existing landslides should be evaluated as part of the final dam site selection process. Where the potential exists, outlet works intakes should be designed to prevent them from being plugged by underwater mass movement.

3.4 Dam Site Geometry

3.4.1 Depth to Bedrock

Based on our observations, the depth to bedrock at both sites appears to be relatively shallow. This assessment is supported by the results of a seismic refraction survey, as described in Section 4.3.1 of this report and in Appendix A of our Geologic Reconnaissance Study Report. To provide a positive cutoff, the core of embankment dams constructed at these sites should be founded on bedrock or key into low permeability weathered rock or soil. For an RCC dam, the entire foundation should preferably be founded on bedrock to reduce the potential for cracking due to differential settlement. For both dam types, the foundation includes those portions of both the valley bottom and the abutment slopes that are underneath the dam.

3.4.2 Slope Angle

Steep abutment slopes and abutments with abrupt slope breaks slopes can be problematic for earthfill and rockfill dams. This is because abrupt slope breaks have the potential to create stress concentrations within the embankment that can lead to cracking of the core. Foundations and abutments should be prepared during construction such that abrupt slope breaks are removed.

3.5 Seepage Potential

The McIntosh Formation is present at both the Chehalis River and South Fork sites. It is a thick sequence of locally tuffaceous marine siltstone and claystone. Our past experience with this formation includes observations of seeps and springs forming shortly after major precipitation events. The location and volume of several of the springs were surprising because the recharge area is relatively small. These observations suggest that the McIntosh Formation has relatively high porosity and permeability, and that the potential for seepage around the dam or from the reservoir into adjacent drainages will need to be addressed as the project moves forward. Seepage is also possible along vertical cooling joints or interflow zones within the basalt bedrock at both sites.

3.6 Borrow Materials

3.6.1 General

The economic feasibility of building a dam often depends on the availability of obtaining construction materials from sources in relatively close proximity to the site. For earthfill, earthfill-rockfill, or rockfill dam alternatives, the shells will require the largest volume of borrow material. Because the dam shells can accommodate a wide variety of soil types and particle sizes, material suitable for the dam shells is likely available at either site. The most critical material to locate to assess the suitability of earthfill or earthfill-rockfill dams is low-permeability soil for the dam core. For an RCC dam, identifying an on-site source for the production of concrete aggregate is advantageous. Additional studies and reconnaissance are necessary to verify suitability of potential sources of material that could be used for dam core material and RCC aggregate.

Locating a source of borrow from within the reservoir footprint is ideal, as excavation increases the reservoir storage volume, and reclamation requirements are minimal because the borrow areas will be submerged. Borrow source selection should also consider the haul distance, because a large portion of the overall cost of embankment fill is transportation.

It is advantageous if sources of riprap, filter, and drain material can be located on-site. These materials typically require a significant amount of processing but comprise a relatively small volume of the overall embankment. Whether or not on site material can be used for these applications depends on the volume required, suitability of on-site materials, and material processing challenges and costs. Because of the specific properties required for filter material, it is often more cost-effective to import them from commercial pits and quarries. Additional studies and reconnaissance are necessary to identify potential sources of material for riprap, filters, chimney drains, and blanket drains. Other materials, such as Portland cement, will need to be imported. Portland cement will be used for subsurface grouting of the geologic formations in the dam foundations, in concrete required for appurtenant structures, and in RCC (if used).

For preliminary site selection assessment, the estimated volume of available borrow material should exceed the estimated quantity required by a factor of at least 2. This analysis should consider the "shrinkage factor" between a unit volume of material at its natural density in the borrow area and volume of the same quantity of soil after it has been compacted in the embankment. Additionally, organic soil is unsuitable for use in the dam embankment, so volume estimates also need to consider the thickness of topsoil that will need to be stripped off of the borrow area. Material volume estimates would be conducted as part of additional studies performed as the site selection process proceeds.

3.6.2 Chehalis River and South Fork Sites

Geology at both sites is generally similar. Based on our preliminary geologic reconnaissance study and a review of National Resources Conservation Service (NRCS) soil maps of the area, we identified several soil units that may be suitable for construction of a low-permeability core for each dam. The NRCS information only extends to a maximum depth of 5 feet below the existing ground surface. Because our scope of services did not include subsurface explorations, we have not characterized the soils within the potential borrow areas nor are we able to estimate the volume of material available.

McIntosh Formation bedrock is relatively weak and will likely break down under compactive effort. We do not believe that the McIntosh Formation will provide a suitable source for rockfill or riprap. If sufficiently broken down, it may be suitable for use in the shells of a zoned earthfill or earthfill-rockfill dam.

Our field observations and limited Schmidt hammer testing suggests that volcanic rocks at the sites, primarily basalt of the Crescent Formation and intrusive gabbro, have variable compressive strength ranging from about 6,000 pounds per square inch (psi) to 18,000 psi. In our opinion, rocks at the low end of this range are marginal for use as rockfill, riprap, chimney or blanket drains, or concrete aggregate. The higher strength volcanic rock may be suitable for some of these applications, assuming a sufficiently large source can be identified. On-site quarrying would need to consider the economic feasibility of sorting these materials, because the harder rock is commonly mixed with weathered, sheared, and scoriaceous rock.

4.0 CHEHALIS RIVER SITE

4.1 Proposed Dam Dimensions

The proposed dam axis, as presented to us by EES, is oriented approximately N80W. The proposed crest length is about 2,150 feet. The crest elevation is about elevation 720 feet, resulting in a dam height of about 280 feet above the existing stream bed at the maximum section. Upstream and downstream slopes are shown at approximately 2.3 Horizontal to 1 Vertical (2.3H:1V) and 2H:1V, respectively; however, the slopes have not been projected to intersect topography. The proposed reservoir extends south about 5 miles from the dam.

4.2 Geologic Hazards

The primary geologic hazards at the proposed Chehalis River dam site are related to seismicity and slope stability.

4.2.1 Earthquakes

Earthquake-related hazards that may affect a given site include:

- Liquefaction and associated effects (loss of shear strength, bearing capacity failures, loss of lateral support, ground oscillation, lateral spreading, etc.)
- Settlement
- Landsliding
- Ground surface fault rupture
- Ground shaking

The risk posed by soil liquefaction and settlement is low, in our opinion, because we anticipate that the dams would be founded on bedrock.

Areas of landslide risks under static conditions also pose a hazard under earthquake loading conditions. Landslide risk is presented in the slope instability section of this report.

Risk to a dam constructed at the proposed site associated with fault rupture is low, in our opinion. As discussed in the Geologic Reconnaissance Report for the dam sites, the only known fault with evidence of Quaternary displacement within 20 miles of the site is the Doty Fault, which is about 8 miles from the dam site. During our geologic investigation, we observed a fault zone beneath the central part of the downstream shell of the proposed dam footprint. The zone is just over 100 feet wide and is bounded by low-angle (25- to 40-degree dip angle), west-northwest-trending faults. Based on the nature of this fault zone in the limited exposure in the valley bottom, we do not believe that this fault is active.

The geologic map by Wells (1981) indicates three additional high-angle faults within the study area. We were unable to directly observe these faults during our field reconnaissance; however, geomorphic evidence, such as low saddles, linear drainages, and landslides along the mapped fault traces, generally support the presence of these structures.

We characterize the ground shaking hazard at the site with probabilistic and deterministic maximum credible earthquake (MCE) peak ground acceleration (PGA) for rock site conditions. Earthquake sources contributing to the site ground motion hazard include shallow crustal, Cascadia Subduction Zone (CSZ) mega-thrust, and CSZ intraplate sources. These sources are discussed in the Geologic Reconnaissance Report for the dam sites. These sources were modeled in the 2008 U.S. Geological Survey (USGS) probabilistic ground motion hazard analyses (PSHA) (Petersen et al., 2008). We queried the results of the USGS PSHA to obtain a PGA for a ground motion return period of 5,000 years. For comparison, we also calculated the PGA for a M_W 9.0 CSZ mega-thrust MCE and a M_W 7.0 Doty Fault MCE. For the CSZ MCE, we used a site-to-source distance of 34 kilometers (km). For the Doty Fault MCE, we used a M_W of 7.0 based on a fault rupture length of about 42 to 51 km and rupture/magnitude relationships by Wells and Coppersmith (1994); a site-to-source distance of 13 km; and an assumption that the fault is a reverse fault with the dam located on the footwall. The CSZ and Doty Fault MCE PGAs were calculated using the mega-thrust and crustal ground motion attenuation relationships that were used for these sources in the 2008 USGS PSHA. The probabilistic and deterministic MCE PGAs are:

- 0.71g – 5,000 year period ground motions (2008 USGS PSHA)
- 0.65g – CSZ mega-thrust MCE
- 0.25g – Doty Fault MCE

A more detailed discussion of local and regional faults is provided in our Geologic Reconnaissance Study Report.

4.2.2 Slope Instability

Slope stability hazards at the site include debris chutes and moderate- to deep-seated landslides. Based on our geologic reconnaissance, we suspect that the right (east) abutment of the dam is located in a landslide deposit, and that debris chutes are present on the left (west) abutment within the proposed footprint of the dam. In addition, several large landslides will be inundated or partially submerged by the reservoir.

In our opinion, the presence of debris chutes, landslides, and landslide debris does not constitute a fatal flaw to locating a dam at this site. However, dam construction will require excavating landslide debris from the core trench or the RCC dam footprint and mitigation to prevent other portions of the landslide from adversely effecting dam construction, dam performance, and appurtenant structures.

4.3 Other Design Considerations

4.3.1 Depth to Bedrock

Under subcontract to Shannon & Wilson, Philip H. Duoos completed a seismic refraction survey along a portion of the proposed dam crest axis. (A copy of the Seismic Refraction Survey Map is included in our Geologic Reconnaissance Study Report.) The survey lines were generally in the valley bottom and up a portion of the right abutment. Our interpretation of the depth to bedrock is based on the results of this seismic refraction survey. As with any geophysical technique, the results are derived from indirect measurements that require interpretation and should be confirmed by subsurface investigations (i.e., drilling or test pits).

Downcutting action by the Chehalis River has exposed bedrock in the river channel. Across the lower and upper alluvial terraces in the valley bottom, seismic refraction suggests that the depth to bedrock varies from about 10 to 20 feet. The geophysical survey suggests that from the base of the valley slope to a point about 350 feet east of the new Weyerhaeuser Road, depth to bedrock increases to as much as 60 feet. This is likely a lobe of landslide debris; however, an alternate interpretation is that this lower velocity layer may be weathered bedrock. Subsurface investigations will be required to verify the depth to competent bedrock.

4.3.2 Abutment Slopes

The left abutment slope at this site is relatively steep (averaging about 1H:1V with locally steeper areas). The steeper areas generally correspond to locations of basalt outcrops. Colluvial cover on this abutment appears to be relatively shallow. Topographically, the lower portion of the right abutment immediately above the river is also relatively steep. The seismic refraction survey suggests that the river has incised into landslide debris or possibly weathered rock at this location. Based on the seismic survey, the average slope of the higher velocity layer underlying the lower right abutment, interpreted to be relatively more competent bedrock, is less steep than the average slope of the existing ground surface. The upper portion of the right abutment slope averages about 3H:1V.

4.4 Reconnaissance-level Recommendations

Recommendations at this phase of the project are based on geologic reconnaissance, surficial observations of a heavily wooded site, a limited geophysical study, literature review, and our experience. In the absence of subsurface investigations, these recommendations should be considered very preliminary and subject to significant modification as more information becomes available.

4.4.1 Dam Type

In our opinion, the most technically feasible type of dam to construct at this site is a zoned earthfill embankment. Additional exploration and testing is required to evaluate the feasibility of an earthfill-rockfill or rockfill dam at this site.

In our opinion, an RCC dam may also be technically feasible at this site. However, the relative economic feasibility of an RCC dam is difficult to quantify. Although less material is required to construct the dam, significant excavation may be required to prepare the dam foundation and access rock suitable for RCC aggregate. An RCC dam would require blasting, crushing, and processing of rock, and importing a large quantity of Portland cement.

4.4.2 Outlet Works

The outlet works includes both an intake structure and a conduit around or under the dam. Based on the geophysical survey and our observations of the river channel, the depth to bedrock at the maximum section of the dam is relatively shallow. In our opinion, a steel pipe founded on rock and encased in concrete is feasible for a portion of the outlet works conduit. For an RCC structure, the outlet works intake structure can be incorporated into the upstream face of dam itself. For an embankment dam, the intake structure may present some of the most significant design challenges associated with the project.

Given the expected seismic ground motions at the site, structural design of a 300-foot-tall free-standing intake tower will likely be challenging and potentially impracticable. An alternative to a free-standing tower may be a sloping intake structure built on the upstream dam face of an earthfill or rockfill dam. This structure would need to be designed to accommodate embankment settlement. Another alternative may be to locate the intake in the left abutment.

For this alternative, the outlet works would include a shaft through bedrock with inlets to the shaft constructed at multiple elevations by tunneling from the reservoir slope face to the shaft. A tunnel would be constructed through the left abutment for the outlet conduit. A concrete intake tower might extend above the ground over the shaft to provide intake gates at higher elevations. This design helps address structural challenges by reducing the height of the tower, but adds expense for tunneling.

We do not consider the challenges associated with design of an intake structure for an embankment dam to be a fatal flaw. Selecting the preferred intake and outlet works structure alternative will require balancing the technical feasibility of the alternatives against construction cost.

4.4.3 Spillways

Design of the spillway(s) depends on the volume and flow rate of the design flood, both of which are currently unknown.

In our opinion, combining both the service and emergency spillways into a single structure over one of the abutments would likely be the most practical alternative for earthfill, earthfill-rockfill, and rockfill dam alternatives. The emergency spillway could be constructed as an overflow section of an RCC dam.

4.4.4 Powerhouse

A logical location for a powerhouse would be at or near the downstream toe of the dam. Other than the potential for a landslide or debris flow originating on the slopes above the powerhouse, we did not identify other significant constraints to the location of a powerhouse at this site.

4.4.5 Fish Passage Facility

It is our opinion that a fish passage facility can be incorporated into the design of this project. The type and location will need to consider the locations of other major appurtenant structures.

5.0 SOUTH FORK SITE

5.1 Proposed Dam Dimensions

The proposed dam axis as presented to us by EES is oriented approximately N10W. The proposed crest length is about 1,920 feet. The crest elevation is at about elevation 620 feet, resulting in a dam height of about 200 feet above the existing stream bed at the maximum section. Upstream and downstream slopes are shown at approximately 3H:1V and 2.5H:1V, respectively; however, the slopes have not been projected to intersect topography. The proposed reservoir extends about 4 miles south and west from the dam.

5.2 Geologic Hazards

Similar to the Chehalis River site, the primary geologic hazards at the proposed South Fork dam site are related to seismicity and slope stability.

5.2.1 Earthquakes

Earthquake-related hazards that may affect a given site include:

- Liquefaction and associated effects (loss of shear strength, bearing capacity failures, loss of lateral support, ground oscillation, lateral spreading, etc.)
- Settlement
- Landsliding
- Ground surface fault rupture
- Ground shaking

The risk posed by soil liquefaction and settlement is low, in our opinion, because we anticipate that the dams would be founded on bedrock.

Areas of landslide risks under static conditions also pose a hazard under earthquake loading conditions. Landslide risk is presented in the slope instability section of this report.

Risk to a dam constructed at the proposed site posed associated with fault rupture is low, in our opinion. As discussed in the Geologic Reconnaissance Report for the dam sites, the only known fault with evidence of Quaternary displacement within 20 miles of the site is the Doty Fault, which is about 18 miles from the dam site. The geologic map by Wells (1981) indicates an older (potentially Miocene age), northwest-trending fault that crosses the South Fork on the upstream side of the proposed dam. We were unable to directly observe this fault during our field reconnaissance.

We characterize the ground shaking hazard at the site with probabilistic and deterministic MCE PGA for rock site conditions. Earthquake sources contributing to the site ground motion hazard include shallow crustal, CSZ mega-thrust, and CSZ intraplate sources. These sources are discussed in the Geologic Reconnaissance Report for the dam sites. All of these sources were modeled in the 2008 USGS PSHA (Petersen et al., 2008). We queried the results of the USGS PSHA to obtain a PGA for a ground motion return period of 5,000 years. For comparison, we also calculated the PGA for a M_W 9.0 CSZ mega-thrust MCE and a M_W 7.0 Doty Fault MCE. For the CSZ MCE, we used a site-to-source distance of 53 km. For the Doty Fault MCE, we used a M_W of 7.0 based on a fault rupture length of about 42 to 51 km and rupture/magnitude relationships by Wells and Coppersmith (1994); a site-to-source distance of 28 km; and an assumption that the fault is a reverse fault with the dam located on the footwall. The CSZ and Doty Fault MCE PGAs were calculated using the mega-thrust and crustal ground motion attenuation relationships that were used for these sources in the 2008 USGS PSHA. The probabilistic and deterministic MCE PGAs are:

- 0.63g – 5,000 year period ground motions (2008 USGS PSHA)
- 0.40g – CSZ mega-thrust MCE
- 0.14g – Doty Fault MCE

5.2.2 Slope Instability

Slope instability at the South Fork dam site area includes shallow slope failures in narrow channels on steep slopes (i.e., debris chutes) and deep-seated landsliding. During our reconnaissance, we observed debris chutes, debris fans, and shallow slope failures on some of the steeper slopes within the proposed dam footprint and on moderate slopes north of the north abutment. We also observed several landslides in the immediate vicinity of the proposed dam footprint, along with areas of soil creep in the vicinity of the right abutment.

Landsliding is common in the South Fork basin upstream of the proposed dam. There are numerous occurrences of shallow, rapid landslides as well as 12 deep-seated landslides that could be affected by the flooding of the valley.

Similar to the Chehalis River site, it is our opinion that while some mitigation will be required during construction, these features do not constitute a fatal flaw to locating a dam and reservoir at this site.

5.3 Other Design Considerations

5.3.1 Depth to Bedrock

Similar to the Chehalis River site, downcutting action by the South Fork has exposed bedrock in the river channel. Based on the seismic refraction survey by Philip H. Duoos, the depth to bedrock across the valley bottom on a line subparallel to the dam crest is about 10 to 15 feet.

A second seismic refraction line was oriented about 60 degrees from the proposed dam crest axis on the upstream portion of the left abutment. This line suggests that between the river channel and a gravel road, the depth to bedrock is about 15 to 20 feet. Above the road, the depth to bedrock increases. At the uphill end of the seismic refraction line, the ground surface is at about Elevation 562 and the interpreted top of bedrock is at Elevation 520.

5.3.2 Abutment Slopes

The abutment slopes at the South Fork site are less steep than at the Chehalis River, averaging between 2H:1V and 4H:1V.

5.4 Reconnaissance-level Recommendations

Recommendations at this phase of the project are based on geologic reconnaissance and surficial observations of a heavily wooded site, a limited geophysical study, literature review, and our past experience. In the absence of subsurface investigations, these recommendations should be considered very preliminary and subject to significant modification as more information becomes available.

5.4.1 Dam Type

In our opinion, the most technically feasible dam type to construct at this site is a zoned earthfill dam. A portion of the shells may include small rockfill (up to 6-inch-diameter).

5.4.2 Outlet Works

Based on the geophysical survey and our observations of the river channel, the depth to bedrock at the maximum section of the dam is relatively shallow. In our opinion a steel pipe founded on rock and encased in concrete is feasible for the outlet works conduit.

Although the proposed South Fork dam is not as tall as the dam proposed for the Chehalis River and the expected seismic ground motions are lower, the potential issues associated with design of a free-standing intake tower at the South Fork site are similar to those described above for the Chehalis River site. Challenges associated with a sloping intake structure on the upstream face are also similar.

In our opinion, the moderate slopes of the abutments may not be favorable for constructing the outlet works completely recessed in one of the abutments using a shaft with intake conduits tunneled from the reservoir slope face to the shaft, and an outlet tunnel. Locating the outlet works such that a concrete intake tower extends above the ground over a shaft or cut-and-cover constructed lower elevation portion of the outlet works structure may be practicable. Cut-and-cover excavation would require mass excavation and possibly shoring to construct the lower outlet works portion. Partial burial of the structure would help with structural design considerations for the portion of the intake tower that extends above ground in the reservoir. Constructing an outlet works intake structure that is partially buried and partially above grade would decrease construction costs to construct conduits that connect to lower portions of the intake structure.

5.4.3 Spillways

Design of the spillway(s) depends on the volume and flow rate of the design flood, both of which are currently unknown.

In our opinion, combining both the service and emergency spillways into a single open channel structure over one of the abutments will likely be the most practical alternative.

5.4.4 Powerhouse

A logical location for a powerhouse would be at or near the downstream toe of the dam. Other than the potential for a landslide or debris flow originating on the slopes above the powerhouse, we did not identify other significant constraints to the location of a powerhouse at this site.

5.4.5 Fish Passage Facility

It is our opinion that a fish passage facility can be incorporated into the design of this project. The type and location will need to consider the locations of other major appurtenant structures.

6.0 CONCLUSIONS

Fatal flaws can be either technical or economic. A technical fatal flaw is one that cannot be accommodated or mitigated by engineering controls. An economic fatal flaw is one where the cost of the engineered solution is so expensive that the project becomes economically impractical. At this preliminary stage of the project, it is not possible evaluate economic fatal flaws. Based on our reconnaissance-level study, we did not identify any technical fatal flaws that would preclude construction of the proposed dams at either the Chehalis River or South Fork sites.

Both sites have similar geology. The valley (abutment) slopes are steeper at the Chehalis River site. In our opinion, zoned earthfill dams and possibly earthfill-rockfill dams are technically feasible at both sites, and an RCC dam is technically feasible at the Chehalis River site. Because of the flatter abutment slopes at the South Fork site, in our opinion, this location is less favorable for an RCC dam than the Chehalis River site.

Before proceeding with selection of a preferred dam alternative, additional studies are necessary to identify appropriate and sufficient volumes of embankment dam material. Identifying a source of low-permeability core material is necessary. If sufficient, economically viable, low-permeability core material is not available use of a bituminous concrete core dam at one or both sites might be considered during future site selection studies.

Selecting the type and location of spillway(s) and the intake structure at both sites will require additional study and assessment. Locating emergency spillways on the abutment or through saddles in the ridges some distance from the dam may require significant excavation. Controlling and managing the water and returning it to the river when it reaches the bottom of the spillway needs to be considered, as does the location of the spillway channel connecting the bottom of the spillway to the downstream river.

As a critical component of the dam, the intake structure will need be designed to resist the expected ground motions associated with a long-return-interval earthquake. Given the height of the proposed dams (200 to 280 feet), structural design of a free-standing intake tower will likely be challenging. Alternatives to full-height free-standing intake structures include structures that are partially buried or constructed as a vertical shaft in an abutment. Regardless of the final design, we expect that the emergency spillway and outlet works will be significant cost components of the overall project.

7.0 ADDITIONAL STUDIES AND CONSIDERATIONS

The typical progression for a project of this type is that the reconnaissance-level fatal flaw study is followed by conceptual design; then preliminary design, and ultimately final design and construction. Each of these phases involves progressively more detailed field investigations, laboratory testing, and design analyses.

For this dam siting study, we did not identify all of the potential local, state, and federal agencies that could have regulatory authority over this project, nor did we research the various rules and design standards promulgated by each agency that would apply to this project.

At the state level, dams are regulated by the Department of Ecology, Dam Safety Office. If the project will include electrical generation capability, either initially or at some point in the future, the Federal Energy Regulatory Commission (FERC), Division of Dam Safety and Inspections will also have regulatory authority over the proposed dams. Other agencies, such as the U.S. Army Corps of Engineers, will have permitting authority over various aspects of the project.

As the project advances through and beyond Phase 2B, we recommend evaluating several items, as discussed below. In general, these aspects of the project have the greatest uncertainty as well as the greatest potential for "fatal flaws" that were not identified during our reconnaissance study. Some of these items are directly geological or geotechnical in nature. Some of the items are from other disciplines, but their findings and recommendations will directly influence geotechnical aspects of the project. In general, these recommendations apply to both the Chehalis River and South Fork sites. We recommend:

- Evaluating the dam geometry, including crest height and axis orientation. For one or both sites, a bend or curve in the dam axis may reduce the volume of material required to build the embankment or avoid unfavorable terrain. Likely achievable upstream and downstream slopes that would be applicable for the different dam types should be projected to the existing ground surface to define the upstream and downstream toe of each dam. This would help with estimating excavation and embankment volumes.
- Calculating the 100-year flood and the probable maximum flood for each site. This information is necessary for sizing and locating the spillways.
- Completing subsurface explorations (primarily borings) at both sites. We recommend that subsurface investigations include sampling both soil and bedrock in the valley bottom and higher on the abutments where dams will be founded on the McIntosh Formation. Some explorations should be located near the seismic refraction lines so the geophysical test results can be reevaluated and better correlated to the actual

subsurface conditions. Explorations should also be performed near potential spillway channel alignments and outlet works locations.

- Completing a limited number of subsurface explorations in the reservoirs to assess borrow material suitability and estimate borrow volumes.
- Performing water pressure (packer) tests in selected holes to evaluate the hydraulic conductivity of the foundation rock mass and reservoir slopes.
- Identifying potential borrow sources. Key aspects of this task would be to identify suitable sources of low permeability core material, riprap, filter material, and drainage zone aggregates that have sufficient volume for the alternative dam configurations being considered. Test pits and borings would be performed within the reservoir and at potential off-site borrow sources.
- Performing additional geologic mapping, with a particular focus on identifying possible faults. Fault trenching may be appropriate as part of the field investigation program.
- Completing a suite of engineering and index tests on soil and rock samples collected from the explorations. Index testing may include moisture content, grain size analyses, and Atterberg limits. Tests on bulk samples from test pits may include compaction, permeability, and triaxial compression (CU) testing of remolded samples. Tests on bedrock may include unconfined compression testing of core specimens. Depending on the quality of the rock, Los Angeles abrasion testing of samples collected from existing quarries could be performed to evaluate the suitability of the bedrock for used as concrete aggregate and/or riprap.
- Performing a PSHA. Results will be used for preliminary slope stability analyses and for preliminary assessment of potential seismic event effects on structures. A PSHA will likely be a requirement of the FERC licensing process.
- Performing conceptual-level structural design of an intake tower.
- Developing a preliminary engineer's opinion of probable construction cost for each alternative considered to aid in selecting dam alternatives and for economic feasibility assessment.

Design of a dam is an inherently iterative process. For example, in the case of an embankment dam, the minimum slopes of the upstream and downstream shells depend on both the engineering properties of the embankment soils and the expected seismic ground motion. A significant portion of the construction cost is directly proportional to the total volume of the embankment, which is a function of the upstream and downstream slopes. Likewise, the size, and therefore the cost, of the spillway is a function of the design flood and the available freeboard.

In our opinion, the scope of services recommended above will advance the geotechnical engineering portion of the project to somewhere between conceptual and preliminary design, depending on the scope of the field investigations and the results of the engineering analyses.

8.0 LIMITATIONS

This report was prepared for the exclusive use of EES and the PUD in the preliminary evaluation of the preliminary dam sites.

The discussions, conclusions, and recommendations contained in this report are based on our observation and interpretation of the site conditions we observed during our reconnaissance. No subsurface explorations were performed. It is possible that technical or economic fatal flaws may be identified as a result of additional investigations at the site.

Our conclusions and recommendations are based on our experience with typical engineering practices related to dam construction. This report deals solely with geological and geotechnical issues. We did not evaluate or consider potential impacts to the proposed project related to environmental issues, including, but not limited to, wetlands, endangered or threatened species, impacts to fisheries, etc.

SHANNON & WILSON, INC.

Stanley R. Boyle, Ph.D., P.E.
Vice President

SRW:WTL:SRB/srw

9.0 REFERENCES

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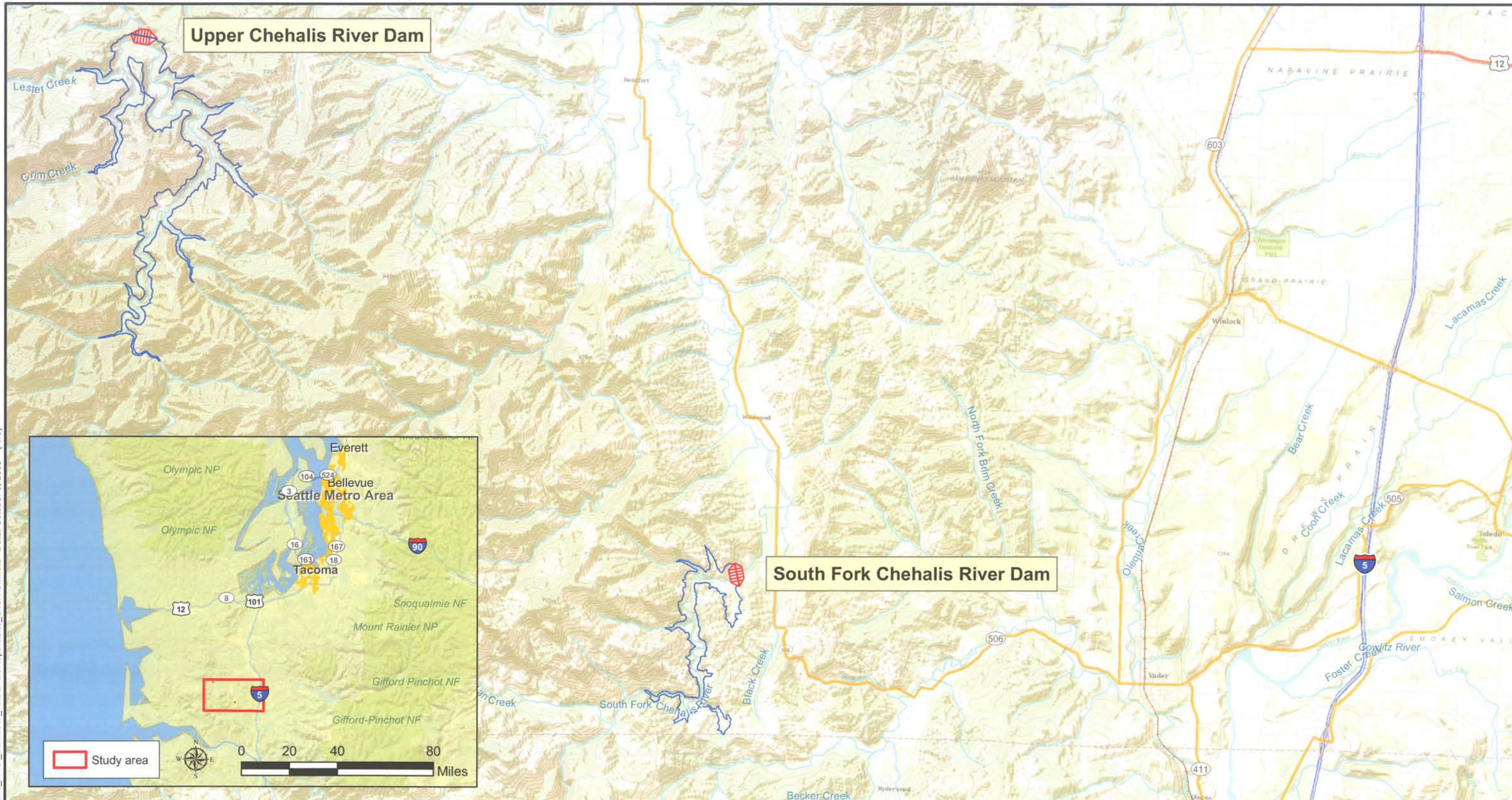

LEGEND

Dam site

Reservoir

N W E S

0 0.75 1.5 3 Miles

Chehalis River Dams Lewis County, Washington	
Vicinity Map	
October 2009	21-1-21160-005
SHANNON & WILSON, INC. GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS	FIG. 1

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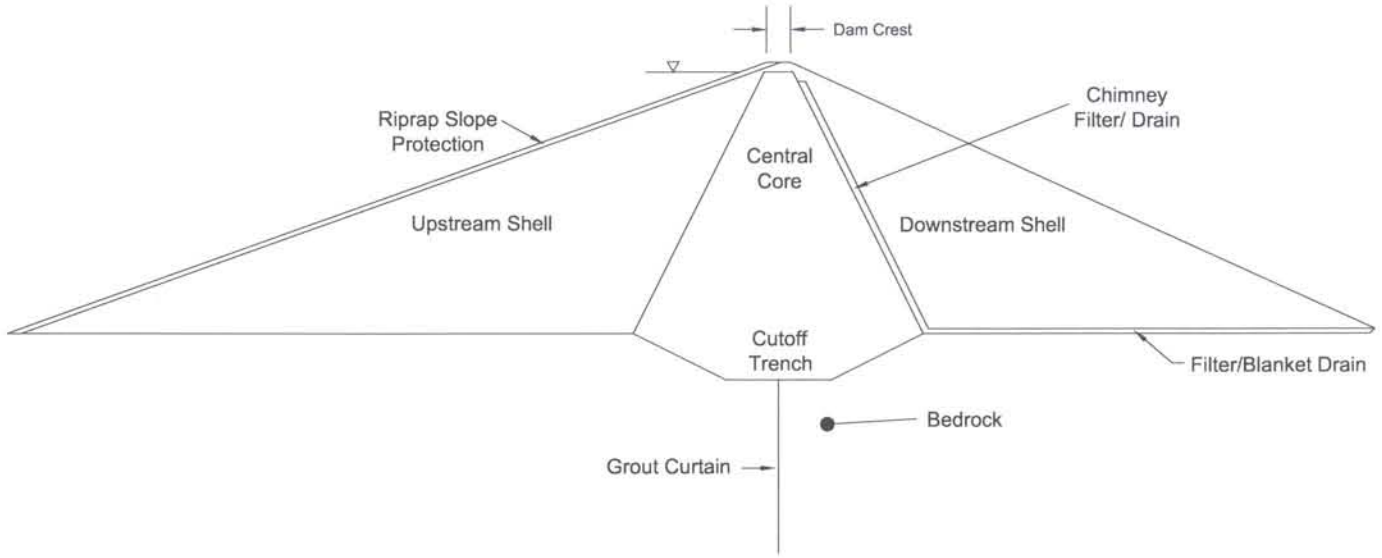
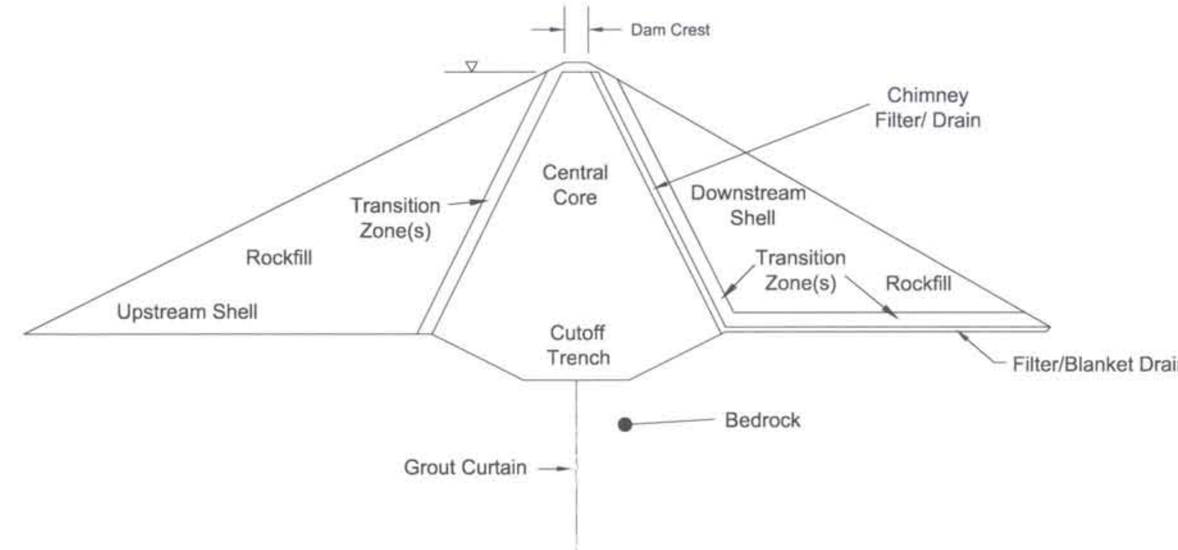
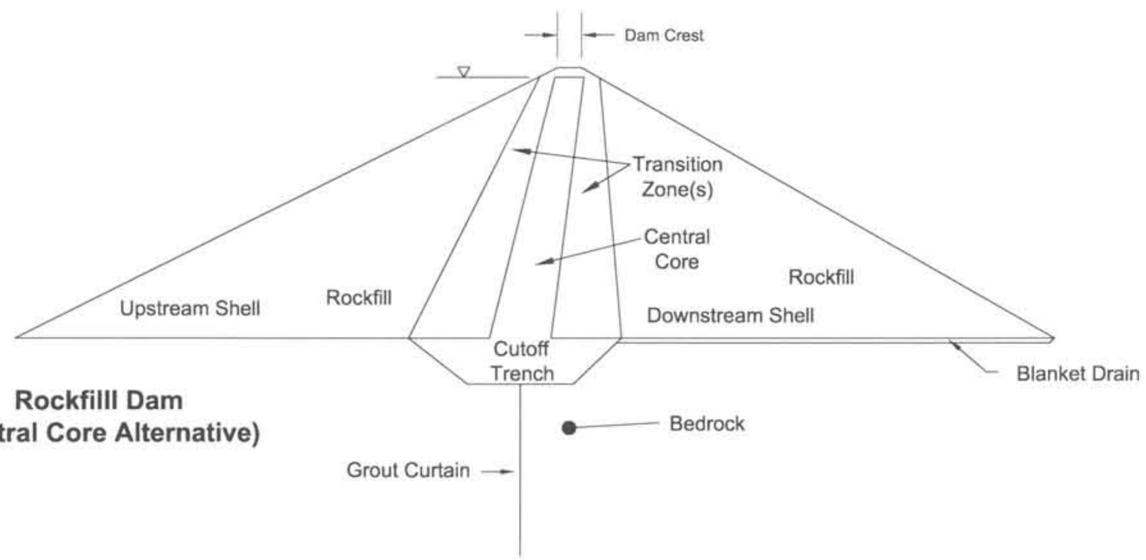


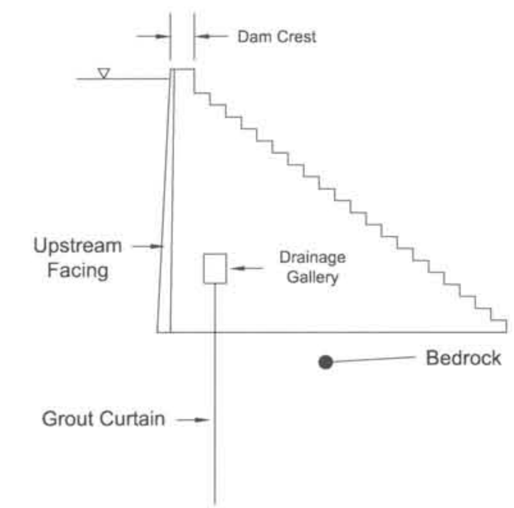
Zoned Earthfill Dam



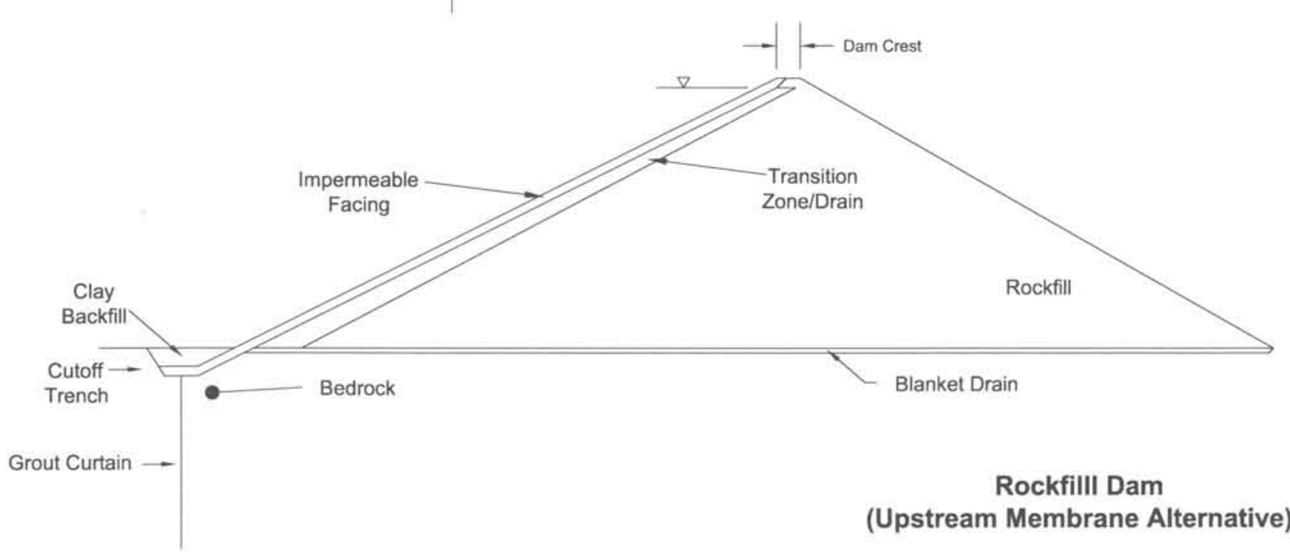
Earthfill-Rockfill Dam



Rockfilll Dam
(Central Core Alternative)



Roller-Compacted Concrete
(RCC) Dam

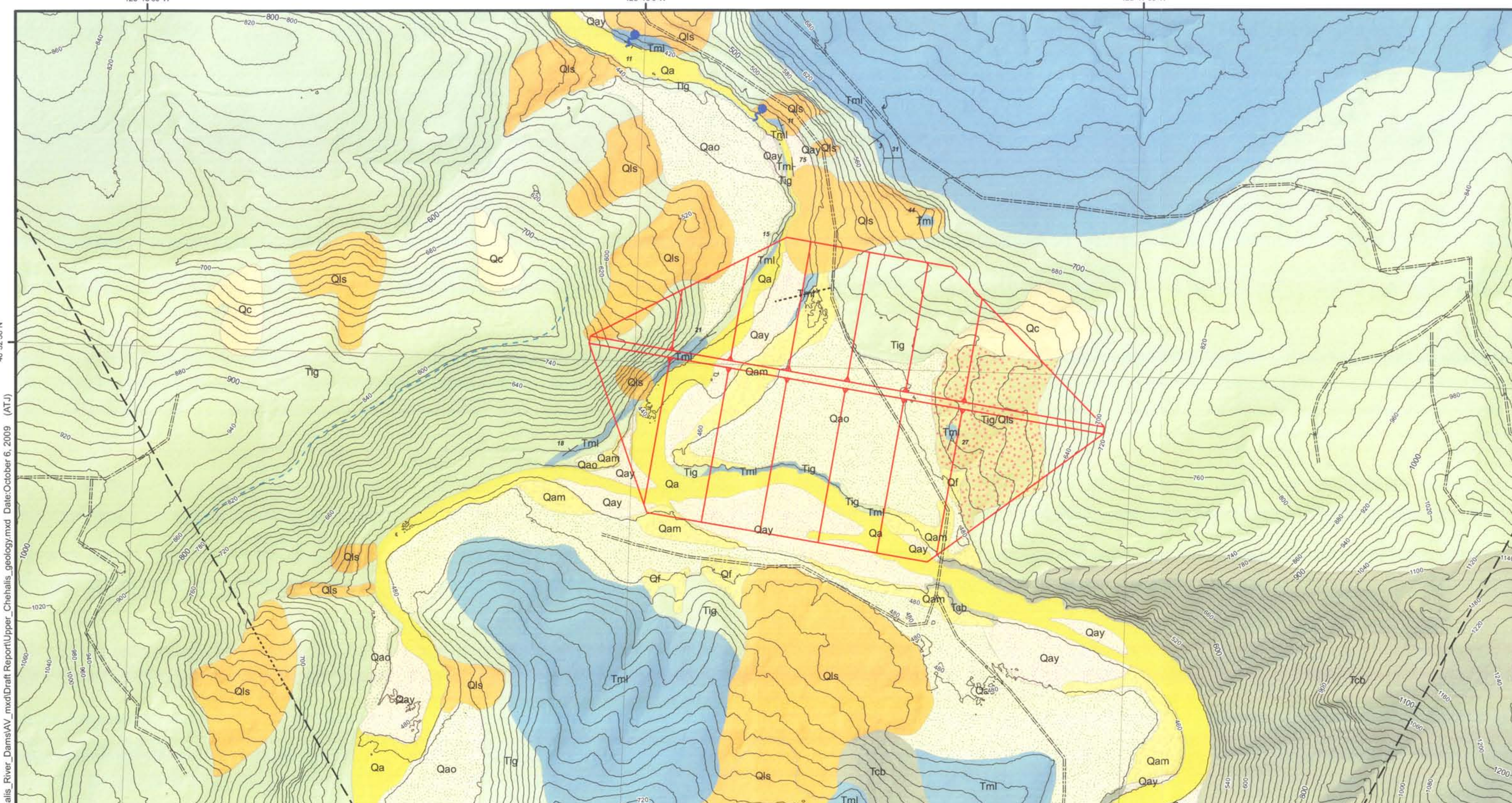


Rockfilll Dam
(Upstream Membrane Alternative)

Note: Diagrams are not to scale.

Proposed Chehalis River and South Fork Dam Sites Lewis County, Washington	
CONCEPTUAL DAM CROSS SECTIONS	
October 2009	21-1-21160-005
SHANNON & WILSON, INC. Geotechnical and Environmental Consultants	**FIG. 2**

Filename: Q:\PROJECTS\21-1-21160 Chehalis\Geotechnical\21-1-21160-005 Figure 2.dwg Date: 08-23-2006 Login: Scott Walker



LEGEND

Qa · Qao · Qc · Qls · Tig · Tig/Qls

Qam · Qay · Qf · Tcb · Tml

Fault - Approximate location, dotted where concealed.

Tml (thin layer within Tig)

18 Bedding Strike and Dip

Seep/Spring

0 200 400 800 Feet

NOTES

1. Faults based primarily on mapping by Wells (1981).
2. See text for description of geologic units.

Chehalis River Dams
Lewis County, Washington

Geologic Reconnaissance Map: Chehalis River Dam

October 2009 | 21-1-21160-005

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FIG. 3

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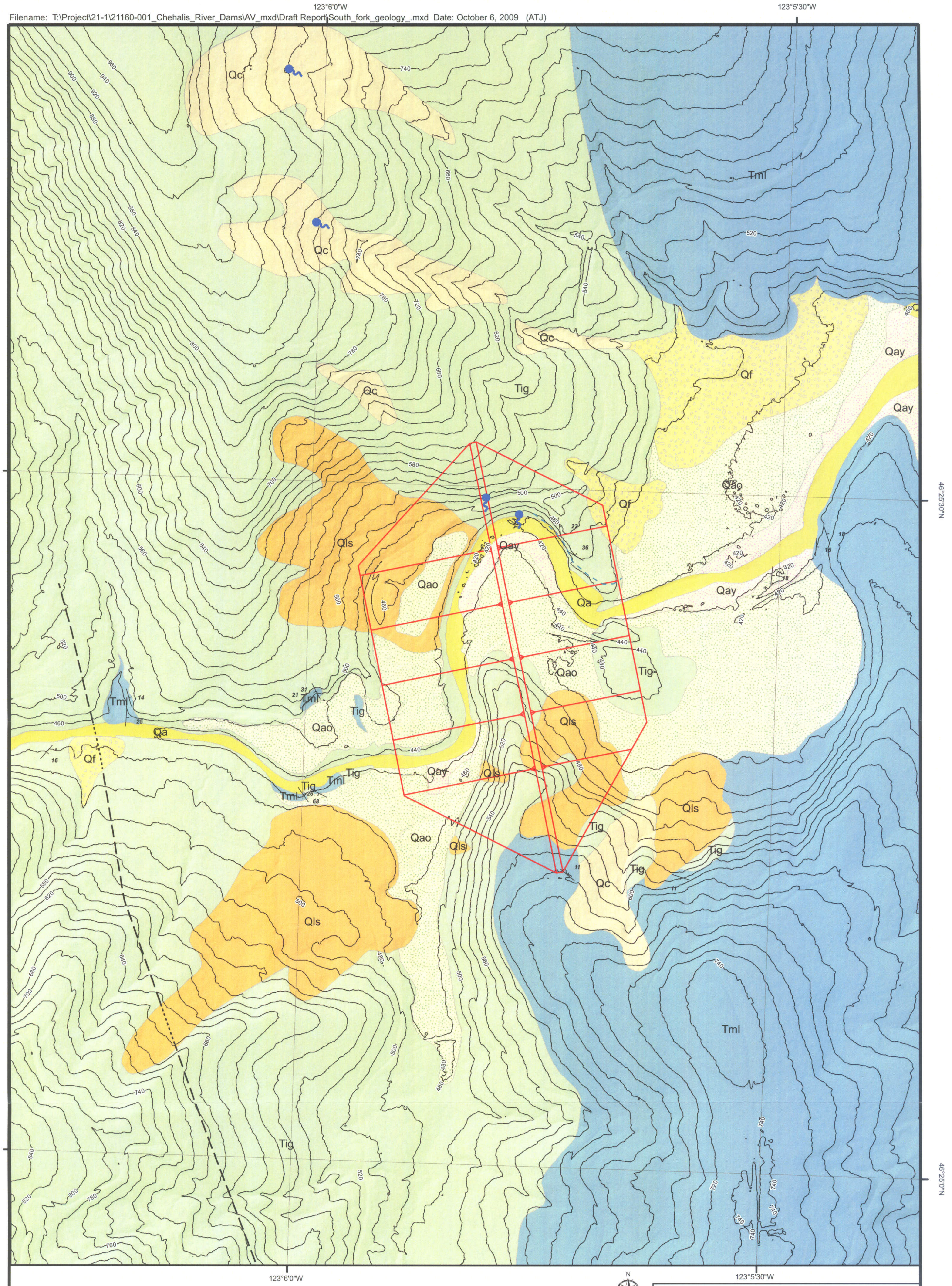
Filename: T:\Project\21-1\21160-001_Chehalis_River_Dams\AV_mxd\Draft Report\South_fork_geology_.mxd Date: October 6, 2009 (ATJ)



LEGEND

	Qa		Qao		Qc		Qls		Tig
	Qam		Qay		Qf		Tcb		Tml

Fault - Approximate location, dotted where concealed.

Tml (thin layer within Tig)

18 Bedding Strike and Dip

Seep/Spring

0 200 400 800 Feet

NOTES

1. Faults based primarily on mapping by Wells (1981).
2. See text for description of geologic units.

Chehalis River Dams
Lewis County, Washington

Geologic Reconnaissance Map: South Fork Chehalis River Dam

October 2009 21-1-21160-005

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FIG. 4