# Geologic Reconnaissance Study
# Proposed Chehalis River and South Fork Dam Sites
# Lewis County, Washington

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## EXECUTIVE SUMMARY

This report offers an initial geologic evaluation of two potential dam sites on the Chehalis River and South Fork Chehalis River in Lewis County, Washington. Every potential dam site has its geological and engineering challenges. Given that fact, what we look for in our analysis in this stage are geologic fatal flaws. In our opinion, no geologic conditions or processes were found in this initial evaluation that would preclude the development of dams at the two prospective sites. Additional studies, including subsurface explorations, are required to further examine the potential for the sites and the challenges that will have to be addressed.

The two potential dam sites, Chehalis River and South Fork Chehalis River (South Fork), are located in bedrock constrictions in their respective narrow valleys close to where those valleys open onto broader alluvial floodplains. Bedrock, either volcanic or sedimentary, is exposed in the river bottoms and coarse alluvial cover is relatively thin (5 to 30 feet). Volcanic rocks include Crescent Basalt and gabbro intrusions. Sedimentary rocks include siltstone and claystone.

This area was not glaciated; therefore, the rock is weathered to some degree. Modern geologic processes include alluvial deposition close to the existing channel and mass wasting (landsliding and erosion) on the hillsides. Both dam sites have landslides on steep slopes under or adjacent to the footprints of the proposed dam sites. These issues need to be addressed in more detail as project planning progresses.

Faults, only one of which is under the footprint of the Chehalis River site, have been mapped near the sites previously. These mapped faults are thought to have been active about 10 to 20 million years ago. The only nearby fault that is considered to be potentially active is the Doty Fault, located about 8 miles north of the Chehalis River site and 18 miles north of the South Fork site.

Details about the geologic conditions at the proposed dam sites are explored in greater detail in the rest of this geologic reconnaissance study. This geologic reconnaissance study describes the geologic conditions at the proposed dam sites. Conclusions and recommendations regarding the feasibility of the two sites for water impoundments are presented in "Reconnaissance-level Geotechnical Report, Proposed Chehalis River and South Fork Dam Sites, Lewis County, Washington." This second report also includes recommendations for further geologic and geotechnical investigations and next steps. These two reports should be used in concert.

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# GEOLOGIC RECONNAISSANCE STUDY
# PROPOSED CHEHALIS RIVER AND SOUTH FORK DAM SITES
# LEWIS COUNTY, WASHINGTON

## 1.0 INTRODUCTION

### 1.1 Purpose

This report presents a preliminary evaluation of the geologic conditions at two potential dam sites in western Lewis County, Washington (Figure 1). One dam site is located on the main stem of the Chehalis River, 2 miles south of the town of Pe Ell. The other dam site is located on the South Fork Chehalis River, about 11 miles south of the unincorporated town of Curtis. The purpose of this geologic reconnaissance study is to provide a geologic framework of the two potential dam sites as a foundation from which to make preliminary geotechnical engineering conclusions and recommendations regarding the feasibility of construction of dams at these two sites. Those conclusions and recommendations are presented in an accompanying report entitled, *Reconnaissance-level Geotechnical Report, proposed Chehalis River and South Fork Dam Sites, Lewis County, Washington.*

### 1.2 Scope of Services

A scope of services by Shannon & Wilson, Inc. was presented to EES Consulting, Inc. (EES) and the Lewis County Public Utility District No. 1 (PUD) in February 2009. This scope of services, accepted by the PUD and EES and funded by the Chehalis River Basin Flood Control Authority, included the following tasks:

- Preliminary team meeting
- Geologic and soils literature search and review
- Meetings and/or discussions with landowners
- Review of available aerial photograph stereopairs
- Field geologic reconnaissance
- Seismic refraction survey
- Preliminary geologic report preparation
- Presentation of the results of the preliminary geologic studies

Additional work related to the geotechnical engineering aspects of the proposed dam sites was also authorized.

Field geologic reconnaissance was carried out July 13 through 22, 2009. Seismic refraction surveys were completed on August 20, 2009.

### 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 Chehalis Basin Flood Control Authority.

## 2.0 PROJECT BACKGROUND AND DESCRIPTION

### 2.1 Project Background

The Chehalis River basin has incurred increased flooding, particularly in Lewis County, causing severe economic impact on local residents, public infrastructure, fisheries, and natural resources. Extensive flood damage in the past two winters (December 2007 and January 2009) has occurred in the Chehalis/Centralia urban area and 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 are the raising of the Skookumchuck Dam to the east of Centralia and the construction of levees along the Interstate 5 corridor, both of which are being studied by the U.S. Army Corps of Engineers. The addition of flood retention structures elsewhere in the basin is being examined by the Chehalis Basin Flood Authority.

The need for and position of flood retention dams was studied by EES in 2008. EES concluded that significant flood reduction could be achieved by building dams on the main stem of the Chehalis River near Pe Ell and the South Fork Chehalis River (South Fork) south of Curtis. Benefits that they noted included (a) avoided costs for property damage, (b) avoided costs for flood victims, (c) avoidance of crop loss, (d) increased property values, (e) avoided infrastructure damages, and (f) avoided impacts to fisheries and degradation of water quality.

In addition to the flood control aspects and summertime flow augmentation, EES investigated whether the dam could be outfitted with hydropower generation facilities. The PUD is interested in developing potential hydropower generation facilities, but only as a secondary benefit to flood control and in-stream flow augmentation. Two major components of dam siting, geotechnical and environmental, were not addressed in the 2008 EES study. EES is presently performing

preliminary environmental studies. Shannon & Wilson is completing the preliminary geotechnical studies for EES and the PUD.

### 2.2 Dam Site Descriptions

The two potential dam sites are located in Lewis County to the west of Chehalis, as shown in the Vicinity Map, Figure 1. The Chehalis River dam site is located about 2 miles south of Pe Ell, in the northwest corner of T12N, R5W, Section 10. About three-quarters of the dam footprint is on land owned by Vincent Panesko and the northern one-quarter is owned by the Weyerhaeuser Company. The dam would be located in a constriction of the valley known as Charlie's Hump (Photo 1) (Appendix B). The proposed dam axis is oriented approximately N80W and the crest is about 2,150 feet long. The abutments of the dam crest would be at about elevation 720 feet, resulting in a height of about 280 feet above the existing river bed. The reservoir would extend about 5 miles south of the impounding structure (Figure 2a).

The South Fork site is located at the southern end of the Boistfort Valley, about 11 miles south of Curtis, in the middle, eastern edge of T11N, R3W, Section 19. The entire dam footprint would be on Sierra Pacific Industries land. The proposed dam would be located in a bedrock constriction of the valley (Photo 2) (Appendix B). The dam axis is oriented approximately N10W and the crest is about 1,920 feet long. The abutments of the dam crest would be at about elevation 620 feet, resulting in a height of about 200 feet above the existing riverbed. The reservoir would extend about 4 miles west and south of the impounding structure (Figure 2b).

## 3.0 OVERVIEW OF GEOLOGY

### 3.1 Previous Geologic and Soils Mapping

The geology of the western headwaters of the Chehalis River has been mapped three times, starting in 1957. The western part of Lewis County and eastern part of Grays Harbor County were mapped by Pease and Hoover (1957). This effort covered the proposed dam site at the main stem of the Chehalis River, but only extended about 3 miles south of the dam site.

The immediate area around Pe Ell was mapped as a fulfillment of a Masters thesis in geology by Strong (1967). This map covered an area from about 12 miles north of Pe Ell to about 2 miles south, including Charlie's Hump, the location of the main stem proposed dam.

A third map was created by Wells (1981) for a large area extending from about Doty southward to the Columbia River. This map covers both proposed dam sites, and it also portrays a dense array of faults, nearly all of which are reported to be inactive (Figures 3a and 3b) (Wells, 2009). The reportedly active Doty Fault is just north of the northern boundary of the area mapped by Wells.

No additional geologic mapping has been done in the project areas, but Wells (2009) reports that new mapping will be performed in 2010 by the U.S. Geological Survey (USGS) in support of studies of the Doty Fault, located about 6 miles north of Pe Ell.

The Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service, mapped the soils in the two drainage basins, the results of which are presented in the *Soil Survey of Lewis County Area, Washington* (Evans and Fibich, 1987). These soil surveys describe the soils in the upper 5 feet of the subsurface. For purposes of this report, they are useful as an indication of the potential suitability of materials for constructing the dam, particularly fine-grained soils for use in the core of an embankment dam at each site. The maps of the soils, highlighting the fine-grained materials, are presented in Figures 4a and 4b for the two dam proposed sites. Figure 4c is a legend of the soil types shown on these maps.

### 3.2 Geologic Overview

The two proposed dam sites are situated in the northern and eastern sides of the Willapa Hills, the dominant physiographic and structural feature of southwestern Washington. The Willapa Hills represent a very large upwarped anticline, extending from the Columbia River on the south to the eastern reach of the Chehalis River Valley between Doty and Chehalis (Pease and Hoover, 1957; Strong, 1965; Wells, 1981). The axis of the anticline is located in the heart of the Willapa Hills near such topographic high points as Boistfort Peak and Little Onion. The proposed Chehalis River dam site is located on the northern limb of the large, gentle fold, such that the rocks (volcanic and overlying sedimentary) dip about 10 to 30 degrees towards the north. The proposed South Fork dam site is located on the eastern side of the uplift, such that the dips of similar rocks, though variable, dip predominantly 10 to 20 degrees to the east.

The core of the Willapa Hills is made of Eocene-age (about 49 million-year-old) intrusive and extrusive volcanic rocks, typically moderately strong to very strong and forming steep slopes. They are comprised of the Crescent Formation, which is widespread throughout southwest Washington and the Olympic Peninsula, and gabbro that intruded the older volcanic and sedimentary rocks. Around the edges of the Willapa Hills are siltstone and claystone sedimentary

rocks of the McIntosh Formation (Snavely, et al., 1959), which are relatively weak and tend to form more gentle slopes. This formation overlies the Crescent Formation, but such weak sedimentary layers also occur as relatively thin interbeds between basalt flows.

Younger, Quaternary (last 2 million years) surficial deposits, such as stream alluvium, colluvium, debris fans, and landslide deposits, are present along the valley floor and many slopes. They commonly mask over the underlying bedrock, except where the overburden has been stripped by mass wasting (landsliding and erosion) or where slopes are too steep to develop a soil cover.

### 3.3 Description of Geologic Units

The following descriptions are based on our field observations as well as previous mapping as described above in Section 3.1. The two- to three-letter abbreviations are used on the geologic maps included herein.

**Stream Alluvium (Qa/Qay/Qam/Qao).** Stream alluvium is found along the valley floors of the main stem the Chehalis River, South Fork of the Chehalis River, and their tributary streams. Alluvium consists primarily of very loose to loose, light- to dark-brown, stratified slightly silty fine sand (Photo 3) (Appendix B), gravelly sand, and sandy gravel. Organics, from finely divided particles to tree trunks and limbs, are present locally. Larger clasts range from pebble size to boulders up to about 3 to 4 feet in maximum dimension and are typically subrounded to rounded. Modern alluvium (Qa) is found in active stream channels; young alluvium (Qay) comprises low-lying adjacent terraces 5 to 10 feet above the modern stream channel; moderate-age alluvium (Qam) is found in terraces up to about 15 feet above the modern stream channel; and older alluvium (Qao) underlies terraces more than 15 feet above the modern stream channel. The combined thickness of all the alluvial units is approximately 30 feet (Photo 4) (Appendix B), based on exposures along the rivers and by adding the heights of the terraces. Maximum thicknesses along the seismic refraction surveys (Appendix A) are about 13 feet at the South Fork site and about 20 feet at the Chehalis River site.

The alluvium observed at these two sites is highly permeable, with very scattered zones or pockets of open-work gravel. Locally, fine sand or silt lenses or layers separate the coarser strata. These fine-grained layers can inhibit vertical permeability; however, their lateral extent may not be great. On the valley edges, where landslides contribute material to the valley floor, permeability of the alluvium is likely to be lower due to mixing with finer-grained soils.

**Colluvium (Qc).** Colluvium consists of poorly sorted, loose to dense, light-brown to reddish-brown, sandy to gravelly clay or silt deposited on or at the base of hillslopes, primarily through gravity-driven transport of weathered rock and soil. Locally, these deposits may be bouldery. Clasts in colluvium are primarily basalt or gabbro (Tig or Tcb), as these lithologies are more competent than claystone and siltstone (Tml), which break down more readily. The clasts are typically subangular and may range in size to more than 2 feet in maximum dimension. Thickness of the colluvium is estimated to be approximately 25 to 30 feet, notably near the toes of the valley sidewalls. Seismic refraction surveys (Appendix A) indicate maximum thicknesses are about 13 feet at the South Fork site and about 15 feet at the Chehalis River site. The permeability of this deposit is highly variable.

**Landslide Deposits (Qls).** Landslide deposits consist of heterogeneous, mostly unsorted, and unstratified debris that is commonly characterized by hummocky (uneven) topography, closed depressions, springs or seeps, and a lobate form. The deposits are generally characterized by loose to dense, light-brown to reddish-brown, sandy to bouldery clay or silt. Clasts are primarily basalt or gabbro (Tig or Tcb) in composition and may be several feet in maximum dimension. Slope failures probably involve slippage along weaker claystone/siltstone beds in the McIntosh Formation (Tml) and interbeds with volcanic rocks (Tig). Some landslide deposits are relatively thin (generally less than 10 feet thick) slope failures involving colluvium or residuum on steep slopes, whereas larger, deep-seated failures are more than 40 feet thick. Because many of the landslides in this area are located in the fine-grained McIntosh Formation, the landslide debris has low to very low permeability. Where the gabbro and basalt have become part of the displaced mass, there can be local zones of higher permeability. Seismic refraction surveys (Appendix A) indicate maximum thicknesses are about 15 feet at the South Fork site and could be as thick as 60 feet at the Chehalis River site.

**Debris-flow Deposits (Qf).** Debris-flow deposits consist of generally poorly sorted, weakly to unstratified, loose to dense, light-brown to reddish-brown, clayey to silty gravel deposited primarily by water during storm events in distinct fans at the mouths of small tributaries or at the bases of debris chutes on steep valley walls. These deposits may contain cobbles and small boulders, as well as woody debris. Debris-flow deposits are likely less than 20 feet thick in the vicinity of the dam sites.

**Intrusive Volcanic Rocks (Tig).** Intrusive volcanic rocks in the vicinity of the two proposed dam sites consist primarily of gabbro (Tig), a dark-colored igneous rock that intrudes both the McIntosh (Tml) and Crescent (Tcb) Formations. The gabbro is high to very high strength, dark gray to black, occasionally white or black-speckled, aphanitic to medium-grained and massive to

columnar or blocky jointed (Photo 5) (Appendix B). Locally, quartz and calcite veins and quartz-filled cavities up to approximately 6 inches in maximum dimension were observed.

Schmidt hammer tests were performed on seven gabbroic rock outcrops. Assuming a dry unit weight of 160 pounds per cubic foot (pcf), test results indicate compressive strengths ranging from 5,800 to 18,000 pounds per square inch (psi), with a median compressive strength of about 9,000 psi. This wide range of compressive strengths reflects compositional differences in the bedrock and/or various levels of weathering in the rock.

Exposures of the gabbro at both dam sites ranged from (a) fresh to slightly weathered with fairly tight columnar jointing, (b) moderately weathered blocky rubble with open joints commonly exhibiting black or reddish-brown iron-oxide staining, (c) highly weathered spheroids enclosed by weathering rinds several inches thick (Photo 6) (Appendix B), and (d) completely weathered residuum (soil), characterized primarily by medium dense to hard, dark reddish-brown, slightly silty, slightly sandy, lean clay and slightly sandy, clayey silt (Photo 7) (Appendix B).

Weathering of the gabbro was typically observed to be related to stratigraphic depth. Near-surface, the gabbro was typically completely weathered to soil residuum ranging from about 3 to 10 feet thick. A zone of highly weathered bedrock as thick as 5 feet was commonly found underlying the residuum. Beneath the highly weathered zone, we locally observed moderately weathered blocky rubble in zones roughly 5 to 8 feet thick. Relatively fresh bedrock was most commonly about 5 to 10 feet or more below ground surface.

Owing to the clayey nature of the gabbroic residuum, permeability of this zone is likely low. Highly weathered or moderately weathered blocky gabbro generally has moderate to high permeability. Where exposed along river and tributaries stream valleys, the gabbro was generally fresh and tight with relatively low expected permeability. Where exposed by excavations and/or blasting activities along roadway cuts, the gabbro tended to be blocky with open fractures and columnar joints, with a correspondingly higher expected permeability. These artificially created blocky zones likely transition to fresh gabbro several feet behind the cut face.

**McIntosh Formation(Tml).** The McIntosh Formation represents a thick sequence of locally tuffaceous marine siltstone and claystone with interbedded arkosic sandstone and basaltic sandstone; however, in the vicinity of the two proposed dam sites, only claystone and siltstone were observed (Photo 8) (Appendix B). The claystone is very low to low strength, light olive-gray, laminated, commonly highly weathered, and commonly exhibits black and/or dark red magnesium and iron-oxide staining. The siltstone is low to medium high strength, dark olive-

brown to light olive-gray, laminated, and also exhibits oxide staining. Both rock types are locally fissile and highly fractured, breaking down to form small, roughly cubic chips commonly less than ½ inch in maximum dimension. Soil derived from the McIntosh Formation is generally dense to hard, gray to light reddish brown, slightly sandy, silty, lean clay or slightly clayey silt.

Most exposures of this formation were too weathered and low strength to allow use of the Schmidt hammer; however, we were able to complete tests on three somewhat more competent claystone/siltstone outcrops. Assuming a dry unit weight of 130 pcf, our test results indicate compressive strengths ranging from 2,700 to 8,000 psi, with a median compressive strength of about 4,870 psi.

The McIntosh Formation commonly exhibited or a fissile structure or blocky jointing, with individual blocks less than 1 to 2 inches in maximum dimension. Joint aperture was typically tight to only slightly open. Overall, vertical permeability is likely low to moderate, but horizontal permeability could be higher along sandy lenses or beds.

**Crescent Formation (Tcb).** Massive basalt flows, pyroclastic flows, and tuffaceous sedimentary rocks comprise the Crescent Formation. It crops out only in the vicinity of the Chehalis River dam site where it is characterized primarily by basalt flows that form high cliffs and steep slopes. The basalt is high to very high strength, dark gray to black, aphanitic to fine-grained, generally massive and locally exhibits pillow structures up to 10 feet in diameter (Photo 9) (Appendix B). In other existing quarry sites south of the main stem dam site, agglomerate or breccias were dominant with the matrix of the rock significantly weaker than the basalt clasts. Exposures along the river were observed to be slightly weathered. Where observed in a road cut exposure above elevation 1,000 feet, the basalt was highly weathered with thick weathering rinds developed around the margins of individual pillow structures. Permeability of the weathered basalt is likely moderate, whereas fresh basalt has relatively low permeability.

### 3.4 Seismic Refraction Summary

A seismic refraction survey was performed by Mr. Philip Duoos, consulting geophysicist, to supplement the surface reconnaissance by Shannon & Wilson geologists. The geophysical work was scheduled after the completion of the reconnaissance, so the locations of the seismic refraction lines would provide optimal complementary information to the reconnaissance observations.

The results of the seismic refraction study are presented in Appendix A. The results confirm that the valley bottoms at the two sites are underlain at shallow depth by competent bedrock. No chasms are identified to be incised into the bedrock surface and no low-velocity fault or weathered zones were interpreted. This bedrock surface is overlain by coarse alluvium.

The presumed abutment areas are shown to be underlain by weathered bedrock (sedimentary and volcanic) and by landslide debris deposits, both of which overlie competent bedrock. Refer to Appendix A for interpretive profiles and descriptive text for each dam site.

# 4.0 DAM SITE GEOLOGIC CONDITIONS

## 4.1 Chehalis River Dam Site

The area upstream of the proposed Chehalis River dam is characterized by moderate to precipitous slopes ranging in elevation from approximately 440 feet along the valley floor near the dam axis to more than 1,200 feet on the eastern (right) abutment. Downstream of the proposed dam, topography is generally subdued. This topography reflects the geologic conditions that exist at the site, which consist primarily of volcanic rocks (Tig and Tcb) that typically form steep slopes (60 percent to vertical) and siltstone and claystone sedimentary rocks (Tml) that tend to form more gentle slopes (20 to 60 percent). Younger surficial deposits, such as stream alluvium, colluvium, debris fans, and landslide deposits, are present throughout the dam site area (Figure 5).

### 4.1.1 Slope Stability

Types of slope instability in the Chehalis River dam site area include rockfall, shallow slope failures in narrow channels on steep slopes (i.e., debris chutes), and moderate to deep-seated landsliding.

Cliffs or steep slopes in volcanic rocks (Tig and Tcb) are susceptible to rockfall. In most areas, dense vegetation conceals cliff exposures and reduces the risk of rockfall. The risk to the completed dam and appurtenances is likely very low, as there are no significant cliff exposures above either dam abutment. Rockfall initiated from cliff exposures upstream of the proposed dam are unlikely to be large enough in magnitude to cause significant displacement of reservoir water, so the risk of overtopping due to rockfall is also very low. However, during construction, activities resulting in the removal of vegetation end exposure of cliffs or steep slopes could result in increased rockfall activity, which could pose a risk to worker safety.

Numerous debris chutes, debris fans, and shallow slope failures were observed on slopes underlying the west (left) abutment, along the tributary stream (Crim/Lester Creek) that enters the Chehalis River near the west abutment, and immediately south of the upstream dam toe. Debris chutes are predominantly steep-gradient, entrenched, or v-shaped channels that serve to focus surface water and debris mobilized during storm events and spring snowmelt. Over time, rock, soil, and wood debris (Qc) has accumulated in these channels and adjacent slopes, and water saturation of this debris has lead to several slope failures. Debris chutes are not shown in Figure 5 due to relative scale. The slope failures are commonly less than 50 feet wide, 10 to 15 feet deep, have a well-defined headscarp, and normally form a fan-shaped depositional area (Qf) at the base of the slope. The relatively small volume of material transported by these slope failures is unlikely to adversely affect the dam structure or displace enough reservoir water to cause overtopping.

There are several landslides in the immediate vicinity of the proposed dam footprint. As described above in Section 3.3, these slides are characterized by hummocky topography, closed depressions, springs, and a lobate form, and probably involve slippage along claystone/siltstone beds (Tml). As shown on Profile 2 in the Seismic Refraction Survey (Appendix A), it is possible that a thick lobe of landslide debris underlies the eastern side of valley, beneath the dam footprint. A scar on the hillside to the east of this deposit is obvious on the hillshade map (Map 1) of this geophysical report. This scar could be the source of the landslide deposit.

The large slide mapped upstream from the south toe of the proposed dam site is approximately 500 feet wide and over 2,000 feet long (extending south of the map extent shown in Figure 5). The overall slide mass has a well-defined lobate morphology and a generally subdued hummocky topography suggestive of older slide activity. Internally, low scarps and discrete areas of more pronounced hummocky terrain in the lower part of the slide mass suggest localized slide activity during more recent times. Soil and rock debris in this slide could be a possible source of material for construction of the dam. Excavations into the slide mass could trigger movement, so appropriate care should be taken to minimize slide risk during construction activities.

A number of large- and small-scale landslides occur on the downstream side of the proposed dam footprint; the two largest measure approximately 800 feet long by 250 feet wide (west) and 675 feet long by 200 feet wide (east). Several of these slides moved as recently as 2007, and possibly 2009, disrupting stream flow and destroying local roadways and water supply lines. Construction activities, as well as future heavy rainfall events during and following construction, could readily trigger additional slide movement. Careful siting of the dam footprint

and appropriate construction practices will be necessary to mitigate risks associated with these landslides.

There are eight existing deep-seated landslides that could be affected by flooding of the valley (Figure 6). They were identified by analysis of a time-series of aerial photographs supplied by the Weyerhaeuser Company and Light Detection and Ranging (LiDAR) images (to the extent of the coverage) and most were field-verified. Although shallow, colluvial instability is active in this reservoir area, there does not appear to be much deep-seated mass wasting, perhaps owing to the relatively high strength of the rock in this basin. Movement of the deep-seated slides is likely to be reactivated when their toes are inundated, followed by a drop in the elevation of the pool. It is likely that movement will be slow, but steady, causing turbidity and a decrease in the volume of the pool. It is very unlikely that movement would be rapid and pose a hazard to the dam.

#### 4.1.2 Faults

During our field reconnaissance, we noted a fault zone beneath the central part of the downstream shell of the proposed dam footprint (Figure 5). The fault zone is just over 100 feet wide and is bound by low-angle (25 to 40 degrees), west-northwest-trending faults. Internally, the fault zone encompasses additional low-angle faults, tightly folded beds of claystone/siltstone interlayered with gabbro, and a 45-foot-wide zone of breccia, consisting of angular gabbro and claystone/siltstone rock fragments in a gabbroic matrix. Seepage was observed along both of the faults bounding the fault zone, but the area in between the bounding faults was otherwise dry. We were not able to trace the fault zone with any certainty beyond its limited exposure along the river due to cover by vegetation and surficial deposits. Given that the breccia is in a gabbroic matrix, we infer that the fault zone is likely contemporaneous with intrusion of volcanic rocks (Tig) during early or middle Eocene time (approximately 34 to 50 million years ago).

The geologic map by Wells (1981) indicates three additional faults within the study area; all three are high-angle faults (Figure 3a). We were unable to directly observe these faults during our field reconnaissance, but geomorphic evidence, such as low saddles, linear drainages, and landslides along the mapped fault traces generally support the presence of these structures. Pease and Hoover (1957) suggest that similar faults in the Doty-Minot Peak area to the north experienced recurrent movement throughout Tertiary Period and that latest known movement on most structures was likely during middle Miocene time (approximately 10 to 20 million years ago).

### 4.1.3 Groundwater

Subsurface investigations were not completed as part of this project, and as such, groundwater conditions are not known. We did observe springs and areas of seepage, particularly within or adjacent to landslide and colluvial deposits and along the margins of the fault zone described in Section 4.1.2. Refer to Figure 5 for the location of observed springs and seeps.

### 4.1.4 Borrow Materials

Three general types of materials are needed to construct a dam at the Chehalis River site: (a) fine-grained soils for a low permeability core of an earthfill or rockfill dam; (b) coarse-grained soil, such as sand and gravel for filter layers within an earthfill or rockfill dam and for concrete aggregate; and (c) rock for the shell of an earthfill or rockfill dam, erosion protection and for concrete aggregate.

Hard rock, such as the Crescent Formation basalt and intrusive gabbro, is inconsistent, but may provide sufficient rock for the project. Sedimentary rock of the McIntosh Formation or interbeds within the volcanics is unsuitable as a source of hard, competent rock for construction purposes.

Fine-grained soils are widespread owing to the weathering of the underlying rocks. The distribution of soils as shown in Figure 4a is taken from the *Soil Survey of Lewis County Area, Washington* (Evans and Fibich, 1987). The soils considered to be potentially useful as low permeability construction material are highlighted, and their NRCS numeral designations are noted in the legend. In general, they are soils that are low to high plasticity silt and clay. Some of the soils may also contain some percentage of sand and/or gravel.

Two fine-grained soils make up a large portion of the project area in and around the proposed dam site: Bunker loam (29 and 30) and Olympic silty clay loam (155, 156, and 157). Both of these soils are residuum and colluvium derived from basalt and basalt breccias. Five other soils are scattered throughout the same area: Boistfort clay loam (21 and 22), residuum developed in basalt; Walville silt loam (238), colluvium derived from basalt and tuff; Galvin silt loam (89), derived from a mixture of alluvium, siltstone and basalt; Thrash silty clay loam (224), residuum developed in basalt breccias and tuff; and Lytell silt loam (124 and 125), residuum and colluvium in siltstone. Bunker and Lytell soils are reported to be 40 to 60 inches deep. The other soils are indicated to be 60 inches or more thick; however, their actual depths may be more, as NRCS logs do not extend deeper than 60 inches. In other locations, the soil horizons may not

extend to 60 inches, depending on the site-specific weathering conditions. Subsurface explorations will be necessary to field verify the thickness and engineering properties of these soils.

Coarse-grained soils are found along the alluvial valley bottom of the Chehalis River. These soils have been reworked from colluvium and glacial outwash deposits. Winston loam (242) and gravelly loam (243) follow the river valley and some of its larger tributaries. They represent older alluvial terraces and modern alluvium in the present channel.

## 4.2 South Fork Dam Site

The area upstream of the proposed South Fork dam is characterized by moderate to steep slopes ranging in elevation from approximately 400 feet along the valley floor to just under 1,000 feet above the north (left) abutment and 750 feet above the south abutment. Downstream of the proposed dam, topography is generally subdued. This topography reflects the geologic conditions that exist at the site, which consist primarily of volcanic rocks (Tig) that typically form steeper slopes and siltstone and claystone sedimentary rocks (Tml) that form more gentle slopes. Younger surficial deposits, such as stream alluvium, colluvium, debris fans, and landslide deposits, are present throughout the dam site area (Figure 7).

### 4.2.1 Slope Stability

Slope instability in the proposed South Fork dam site area may include shallow slope failures in narrow channels on steep slopes (i.e., debris chutes) and landsliding. Debris chutes, debris fans, and shallow slope failures similar to those described above in Section 4.1.1 were observed on some of the steeper slopes within the proposed dam footprint and on moderate slopes north of the north abutment. These relatively small slope failures and material mobilized during debris flow events are unlikely to pose significant risk to the dam.

Of greater concern are several landslides in the immediate vicinity of the proposed dam site. The largest and seemingly most active landslide underlies the northwest corner of the proposed dam footprint. The slide is approximately 975 feet long by 750 feet wide and is characterized by hummocky topography, fresh scarps several feet high internal to the main slide mass, seeps, closed depressions, and trees with bowed trunks. Recurrent movement on the slide is such that maintenance crews placed riprap to buttress the hillside and protect the roadway where it passes through the lower half of the landslide. Dam construction activities could exacerbate slide movement; however, much, if not all, of the unstable material would need to be

removed for the north abutment, and fill placed to construct the dam would serve to buttress the hillside.

Another large landslide occurs southwest of the proposed dam. The active portion of this slide is approximately 650 feet long by 900 feet wide, and an older landslide extends as much as 1,000 feet further uphill. Debris incorporated into this slide complex could be a possible source of material for construction of the dam. Excavations into the slide mass could trigger movement and appropriate care should be taken to minimize slide risk during construction activities.

Two landslides and areas of soil creep were observed in the vicinity of the south (right) abutment. Landslide deposits falling within the dam footprint will likely need to be removed prior to construction of the dam and appropriate construction practices will be necessary to reduce the risk of slope failure during construction.

Landsliding is common in the upper basin of the South Fork. There are numerous occurrences of shallow, rapid landslides; however, they are unlikely to have a significant effect on the dam or the reservoir. Failure of such soil masses could cause local turbidity. They are unlikely to affect a large area of the proposed lake or the dam and intake.

There are 12 existing deep-seated landslides that could be affected by the flooding of the valley (Figure 8). They were identified by analysis of a time-series of aerial photographs supplied by Sierra Pacific Industries and LiDAR images, and most were field-verified. Two landslides on the western side of Section 30 were not obvious on the aerial photographs, but were identified in the field. These slides are likely to be reactivated when their toes are inundated, followed by a drop in the elevation of the pool. It is likely that movement will be slow, but steady, causing turbidity and reducing reservoir capacity. It is unlikely that movement would be rapid and pose a hazard to the dam.

#### 4.2.2 Faults

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 (Figure 3b). We were unable to directly observe this fault during our field reconnaissance. Although the tributary drainage on the north side of the South Fork is quite linear, claystone/siltstone beds at the mouth of the tributary and along the tributary floor were observed to be undeformed. Similarly, volcanic outcrops adjacent to the mouth of the tributary appeared to be undeformed. Surficial deposits obscure the bedrock geology further upstream and downstream of this tributary, so the presence of a fault cannot be entirely ruled out.

We also traversed the slopes south of the dam site to look for evidence of a through-going fault. These slopes were generally covered in dense vegetation or slash, and direct observation of the underlying bedrock was not possible. We noted a break in slope inclination at about elevation 620 feet: above this bench, soil was observed to be consistent with residuum derived from volcanic rocks; below the bench, scattered chips of siltstone were observed in the soil. It is unclear if this topographic break represents a stratigraphic contact or a fault contact.

The geologic map by Wells (1981) covers a much broader area than does our limited reconnaissance at the South Fork dam site, and the aforementioned fault extends several miles northwest and southeast of the proposed dam. Therefore, we have included this fault on our map based on the assumption that Wells (1981) observed evidence for faulting in areas beyond our limited study area.

#### 4.2.3 Groundwater

As mentioned previously, subsurface investigations were not completed as part of this project, and as such, groundwater conditions are not known. We did observe a few springs and areas of seepage particularly within or adjacent to landslide and colluvial deposits. Refer to Figure 7 for the location of observed springs and seeps.

#### 4.2.4 Borrow Materials

Three general types of materials are needed to construct a dam at this site: (a) fine-grained soils for a low permeability core of an earthfill or rockfill dam; (b) coarse-grained soil, such as sand and gravel for filter layers within an earthfill or rockfill dam and for concrete aggregate; and (3) rock for the shell of an earthfill or rockfill dam, erosion protection and for concrete aggregate.

Hard rock, such as the Crescent Formation basalt and intrusive gabbro, is inconsistent, but may provide sufficient rock for the project. Sedimentary rock of the McIntosh Formation or interbeds within the volcanics is unsuitable as a source of hard, competent rock for the construction purposes.

Fine-grained soils are widespread owing to the weathering of the underlying rocks. The distribution of soils as shown in Figure 4b is taken from the *Soil Survey of Lewis County Area, Washington* (Evans and Fibich, 1987). The soils considered to be potentially useful as low permeability construction material are highlighted and their NRCS numeral designations are

noted in the legend. In general, they are soils that are low to high plasticity silt and clay. Some of the soils may also contain some percentage of sand and/or gravel.

Three fine-grained soils make up a large portion of the project area in and around the proposed dam site: Bunker loam (29 and 30), Melbourne loam (131 and 132), and Olympic silty clay loam (155, 156, and 157). Bunker and Olympic soils are residuum and colluvium derived from basalt and basalt breccias. Melbourne soil is residuum developed in marine siltstone. Three other soils that are scattered throughout the same area: Boistfort clay loam (21 and 22), residuum developed in basalt; Reed silty clay loam (172), derived from fine-grained alluvium; and Baumgard silt loam (9 and 10), residuum and colluvium from basalt. Bunker soils are reported to be 40 to 60 inches deep. The other soils are indicated to be 60 inches or more thick; however, their actual depths are unknown, as NRCS logs do not extend deeper than 60 inches. In other locations, the soil horizons may not extend to 60 inches, depending on the site-specific weathering conditions. Subsurface explorations will be necessary to field verify the thickness and engineering properties of these soils.

Coarse-grained soils are found along the alluvial valley bottom of the Chehalis River. These soils have been reworked from colluvium and glacial outwash deposits. Winston gravelly loam (243) follows the river valley. It represents older alluvial terraces and modern alluvium in the present channel.

## 5.0 SEISMOLOGICAL SETTING

The dam sites are located in a moderately active tectonic region that has been subjected to numerous earthquakes of low to moderate strength and occasional strong shocks during the brief 170-year historical record in the Pacific Northwest. The tectonics and seismicity of the region are the result of ongoing, oblique, relative northeastward subduction of the Juan de Fuca Plate beneath the North American Plate along the Cascadia Subduction Zone. The convergence of these two plates not only results in east-west compressive strain, but also results in dextral shear, clockwise rotation, and north-south compression of accreted crustal blocks that form the leading edge of the North American Plate (Wells et al., 1998). The subduction zone extends from Northern California to central Vancouver Island in British Columbia. Western Washington is located in the continental fore-arc of the Cascadia Subduction Zone. The fore-arc consists of accreted sedimentary and volcanic rocks (i.e., Olympic Mountains and Willapa Hills) in front of a landward mountainous, active volcanic arc (Cascade Mountains).

Within the present understanding of the regional tectonic framework and historical seismicity, three seismogenic sources have been identified. These include:

- A shallow crustal zone within the North American Plate.
- A deep subcrustal zone (intraslab) in the subducted Juan de Fuca Plate and Gorda plates.
- A mega-thrust source at in interface between the North American and Juan de Fuca plates in the Cascadia Subduction Zone.

## 5.1 Shallow Crustal Earthquakes

Shallow crustal earthquakes within the North American Plate beneath western Washington have historically occurred in a diffuse pattern, typically within 12 miles of the earth's surface. The largest historic event is the 1872 North Cascades earthquake (estimated magnitude about 7 in the vicinity of Lake Chelan). However, surface rupture from this large event or other historic shallow crustal earthquakes western Washington has not been observed.

There are numerous Tertiary Faults within the 20 miles of the dam sites. However, with the exception of the Doty Fault, none are indicated to have evidence of Quaternary movement (Lidke et al., 2003). The Doty Fault is an east-west trending structure located approximately 8 miles north of the Chehalis River dam site and approximately 18 miles north of the South Fork dam site. The Doty fault is mapped as at least 26 miles long and may be up to 32 miles long (Gower et al., 1985). It has been postulated that this fault is a north-dipping reverse or thrust fault and is associated with a series of active Holocene reverse/strike slip faults (e.g., Tacoma, Seattle, South Whidbey Island faults) farther north below the Puget Lowland that accommodate the rotation and north-south compression within the North American Plate in western Washington. We understand that this USGS intends to conduct field studies in the near future to investigate the activity of the Doty Fault (Wells, 2009).

## 5.2 Cascadia Subduction Zone Intraslab Earthquakes

Deep subcrustal intraslab earthquakes can occur in the subducted portions of the Juan de Fuca Plate beneath the North American Plate, typically at depths of 25 to 38 miles. The region in which the dams are located is situated above this zone. Earthquakes within this zone are associated with tensional forces that develop in the subducted plate due to mineralogical and density changes in the plates at depth. The largest historic earthquakes to affect the corridors include the magnitude ($M_s$) 7.1 Olympia earthquake of April 13, 1949, the magnitude ($m_b$) 6.5 Seattle-Tacoma earthquake of April 29, 1965, and the recent February 28, 2001, magnitude ($M_W$)

6.8 Nisqually earthquake. All three of these events were located in the subducted Juan de Fuca slab beneath the Lowland at depths of 32 miles and greater. Ludwin et al. (1991) estimate that the maximum magnitude from this source zone would be about 7.5.

### 5.3 Cascadia Subduction Zone Mega-thrust Earthquakes

The third seismogenic source is the interface between the subducting Juan de Fuca and North American Plates along the Pacific Northwest coast line on which potential mega-thrusts may occur. No large earthquakes have occurred in this zone during historic times (170 years). Geologic evidence suggests that coastal estuaries have experienced rapid subsidence at various times within the last 2,000 years (e.g., Atwater, 1987; Atwater and Hemphill-Haley, 1997) as a result of tectonic movement associated with mega-thrust earthquakes on the Cascadia Subduction Zone (CSZ). It appears that ruptures of this zone have occurred at irregular intervals that span from about 100 to more than 1,200 years with an average recurrence interval of about 400 to 600 years (Atwater and Hemphill-Haley, 1997). Rupture of this zone could result in earthquakes with magnitudes on the order of 8½ to 9. Based on historical tsunami records in Japan (Satake et al., 1996) the most recent interplate event on the CSZ was a magnitude 9 event on January 26, 1700. Because of the significant uncertainty pertaining to the landward extent of a potential rupture surface, estimates of the closest distance between the project and potential rupture surface range from about 20 to 55 miles.

## 6.0 LIMITATIONS

The visual observations, conclusions and recommendations contained in this preliminary geology report are based on site conditions as they presently exist. No subsurface explorations were performed. During subsequent investigations, interpretations of the conditions may change.

We recommend that we be retained to perform additional geotechnical explorations, including subsurface drilling and trenching, in subsequent phases of the work at these two potential dam sites. Recommendations for additional work will be contained in a reconnaissance-level geotechnical report prepared in concert with this preliminary geology report.

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

Shannon & Wilson, Inc. has included Appendix C, "Important Information About Your Geotechnical/Environmental Report," to assist you and others in understanding the use and limitation of our reports.

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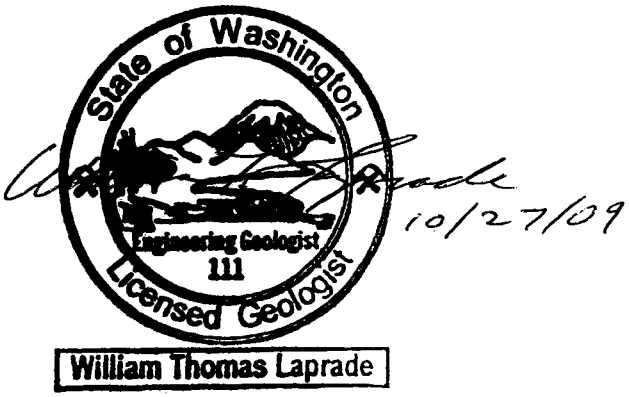


William T. Laprade, L.E.G.
Senior Vice President

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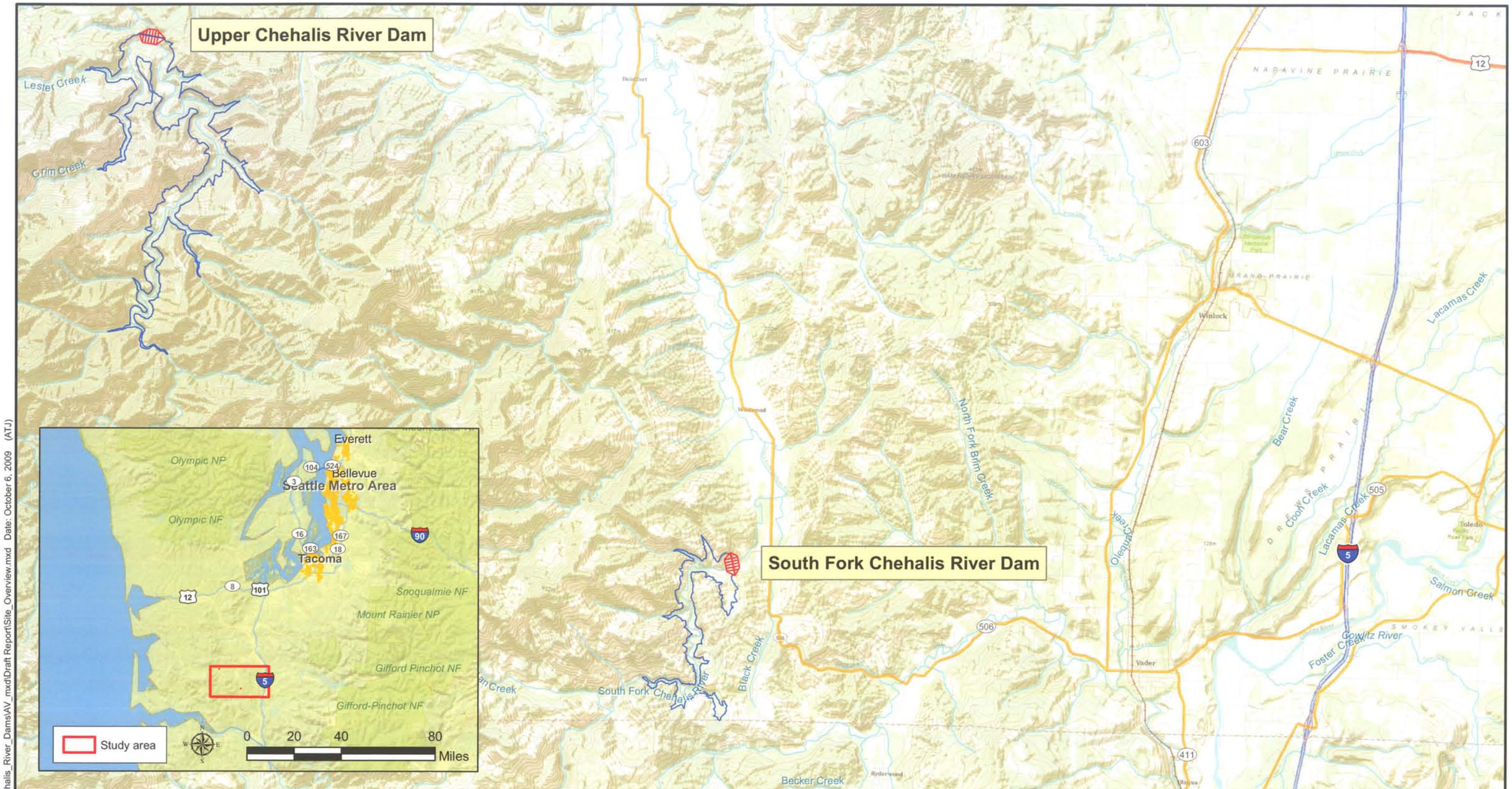


## LEGEND

Dam site

Reservoir

Chehalis River Dams
Lewis County, Washington

**Vicinity Map**

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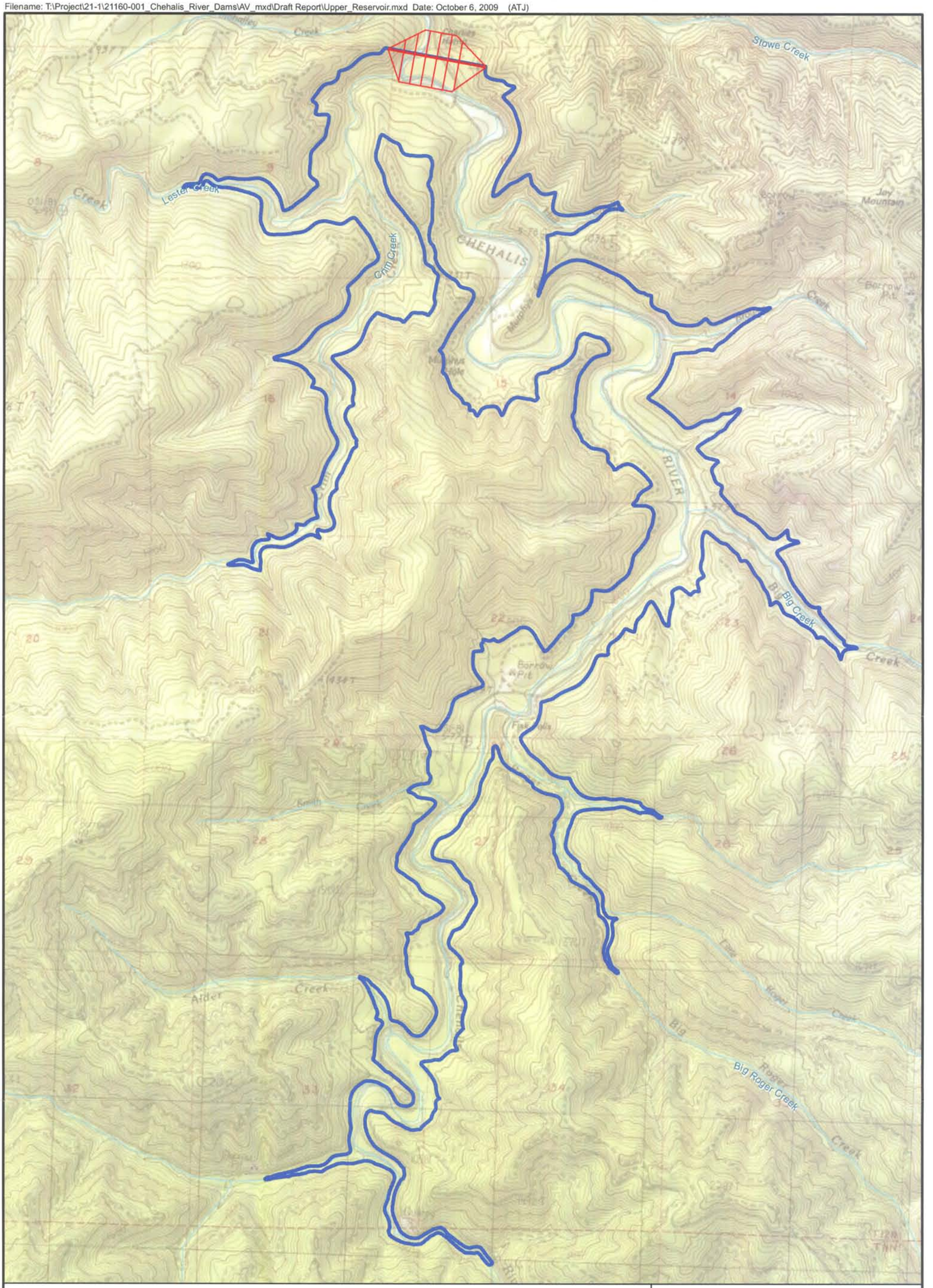
FIG. 1

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

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




## LEGEND

Dam site

Reservoir

N
W E
S

0 1,000 2,000 4,000 Feet

Chehalis River Dams.
Lewis County, Washington

**Reservoir Map:**
**Chehalis River Dam**

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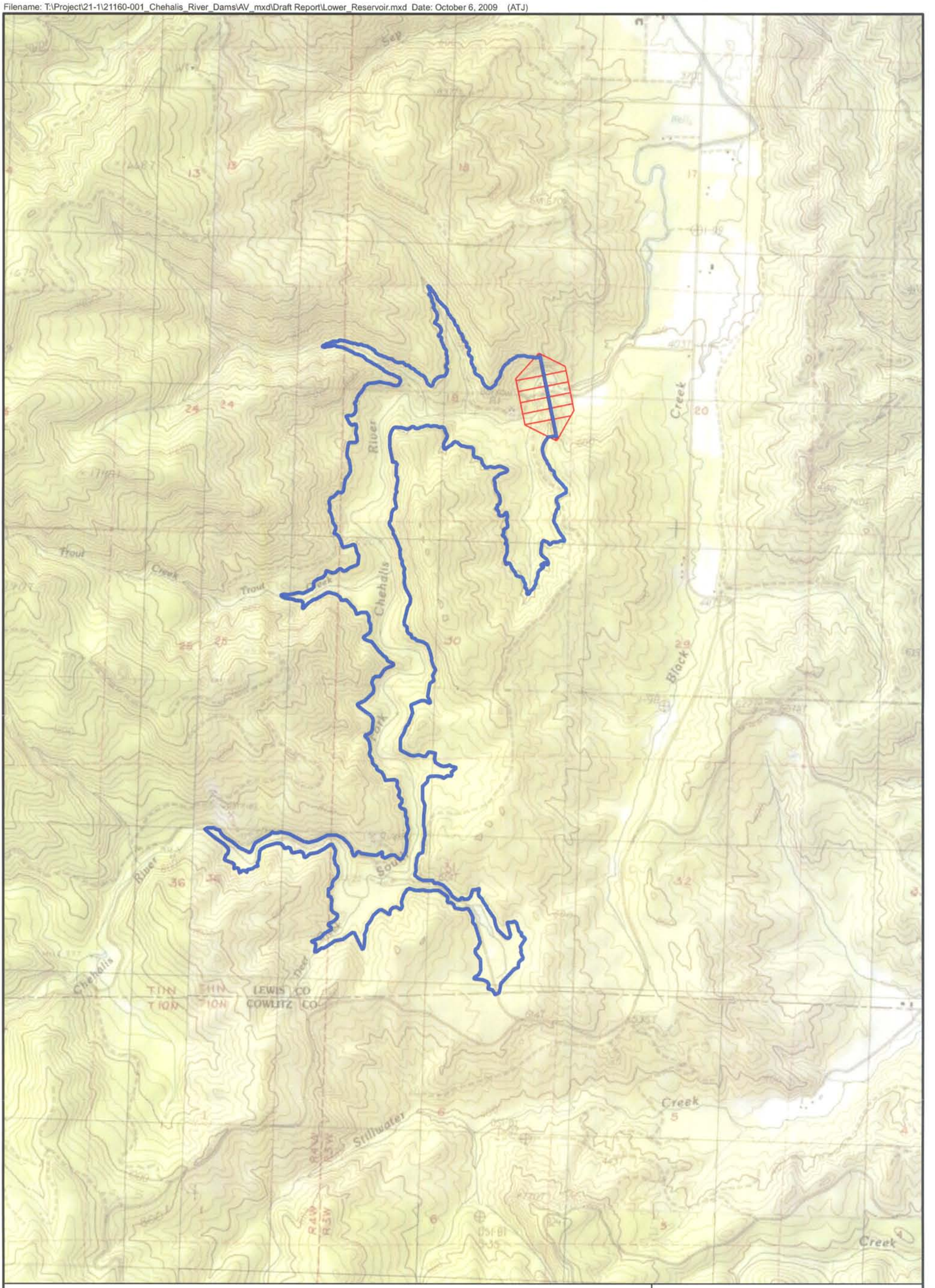
**FIG. 2a**

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




## LEGEND

Dam site

Reservoir

N
W E
S

0 1,000 2,000 4,000 Feet

Chehalis River Dams.
Lewis County, Washington

**Reservoir Map:**
**South Fork Chehalis River Dam**

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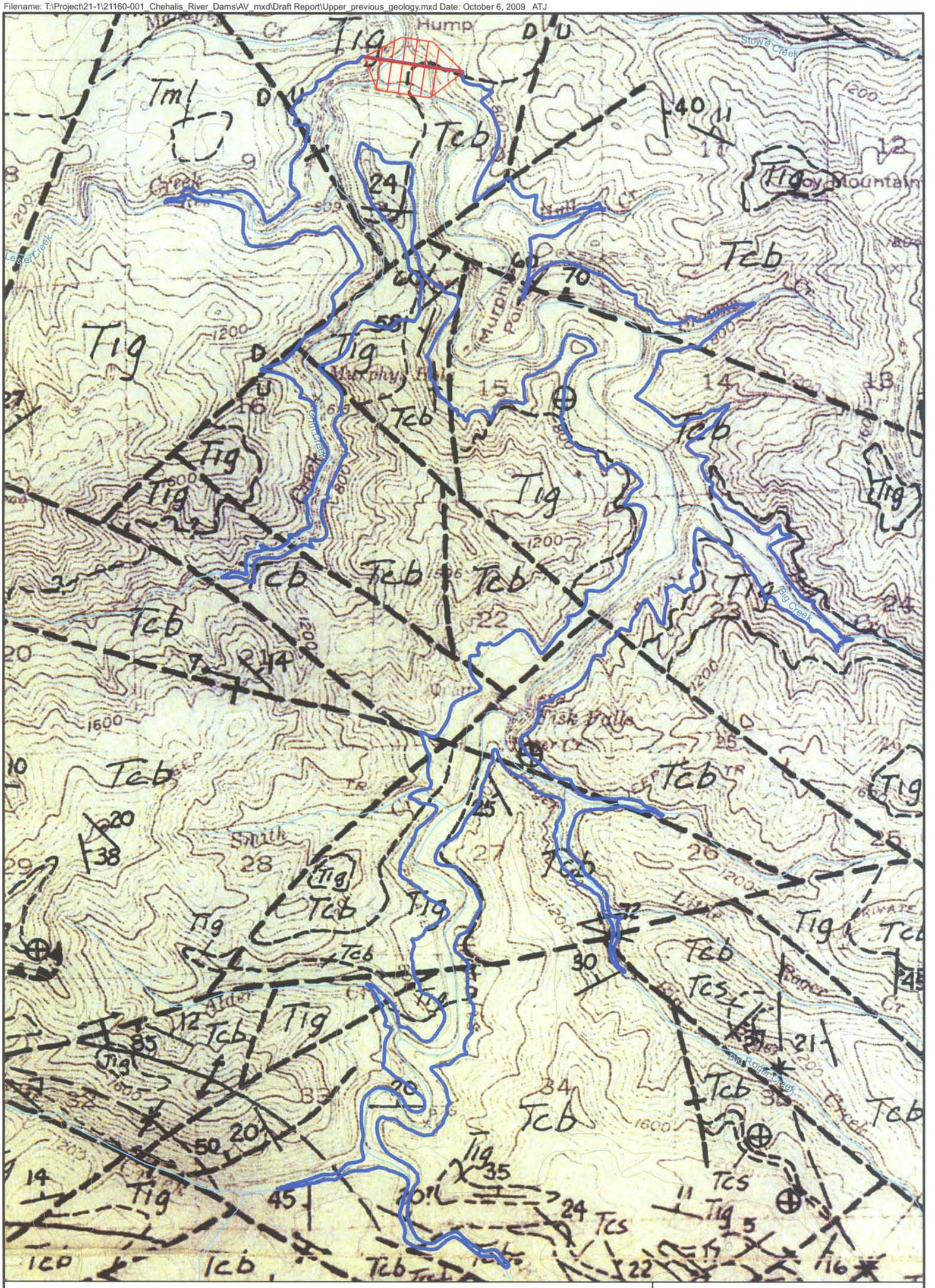
FIG. 2b

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




## LEGEND

- **Tml -** Mcintosh formation, lower member
- **Tcb -** Crescent formation
- **Tcs -** Siltstone
- **Tig -** Gabbro and basalt intrusive rocks

NOTES

1. Geologic mapping by Wells (1981).

N W E S

0 1,000 2,000 4,000 Feet

Chehalis River Dams.
Lewis County, Washington

**Previous Geologic Mapping: Chehalis River Dam**

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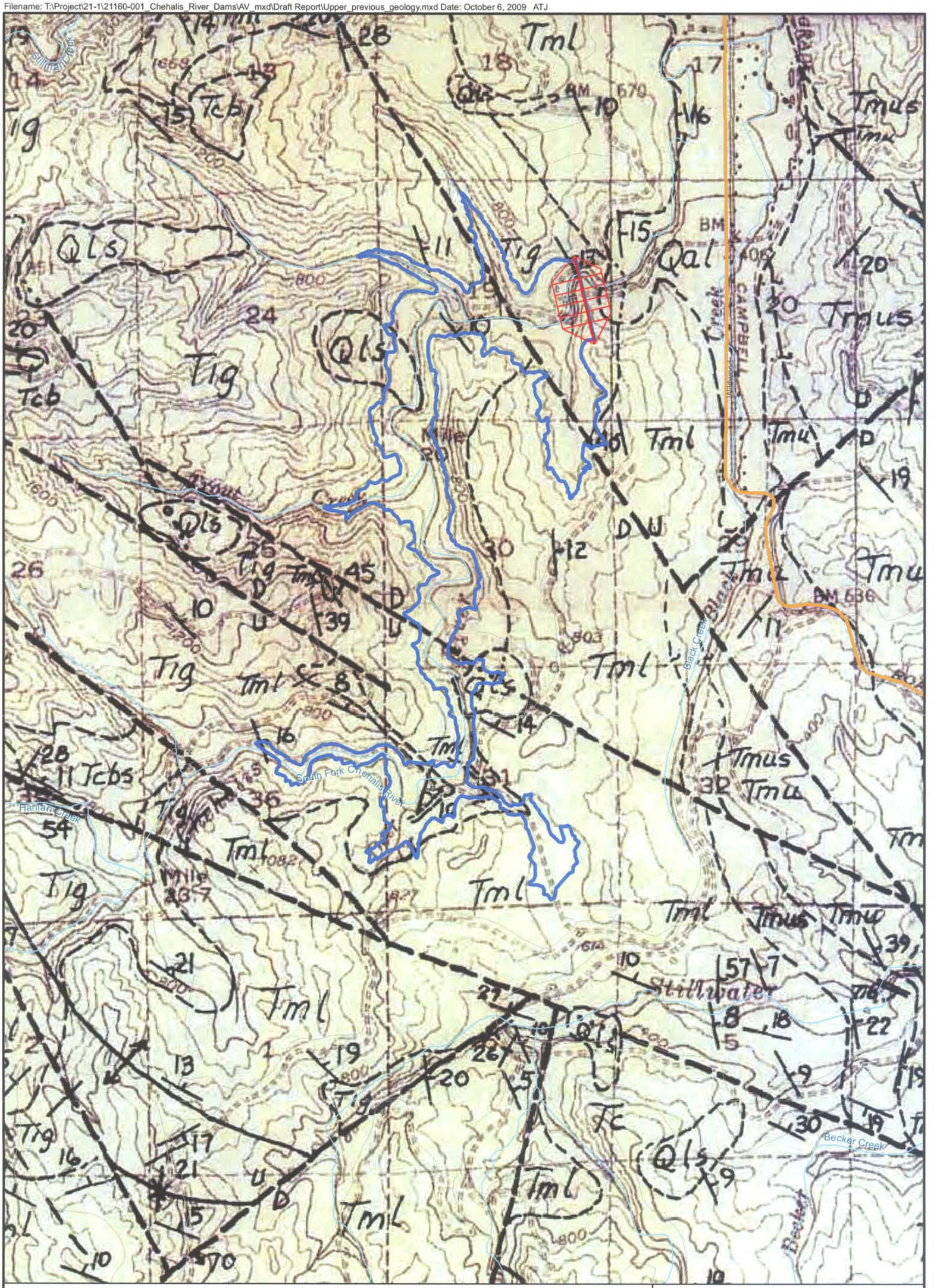
**FIG. 3a**

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




## LEGEND

- **Tig -** Gabbro and basalt intrusive rocks
- **Tml -** Mcintosh formation, lower member
- **Qal -** Alluvial deposits
- **Qls -** Landslide debris

NOTES

1. Geologic mapping by Wells (1981).

N W E S

0 1,000 2,000 4,000 Feet

Chehalis River Dams.
Lewis County, Washington

**Previous Geologic Mapping:**
**South Fork Chehalis River Dam**

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**FIG. 3b**

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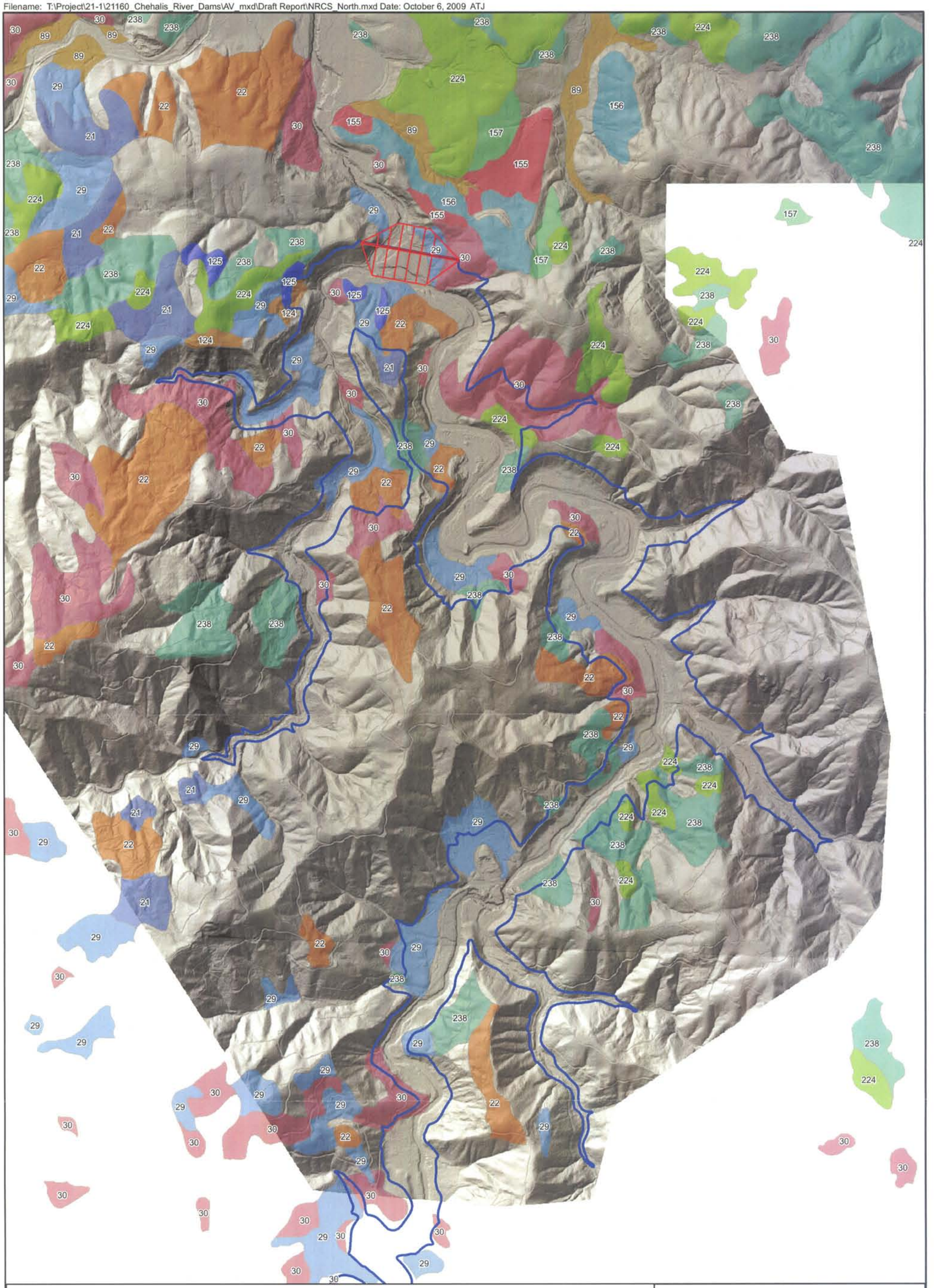

## LEGEND

Dam site

Chehalis Reservoir

NRCS Soil Code

| | | |
|---|---|---|
| 21 | 124 | 156 |
| 22 | 125 | 157 |
| 29 | 131 | 172 |
| 30 | 132 | 224 |
| 89 | 155 | 238 |

NOTES

1. Soils information was taken from "Soil Survey of Lewis County Area Washington" (Evans and Fibich, 1987) and Web Soil Survey ( NRCS, 2009).
2. See figure 4c for soil codes.

N W E S

0 1,000 2,000 4,000 Feet

Chehalis River Dams
Lewis County, Washington

**NRCS Soils Map:**
**Chehalis River Dam,**
**Fine Grained Cohesive Soil Units**

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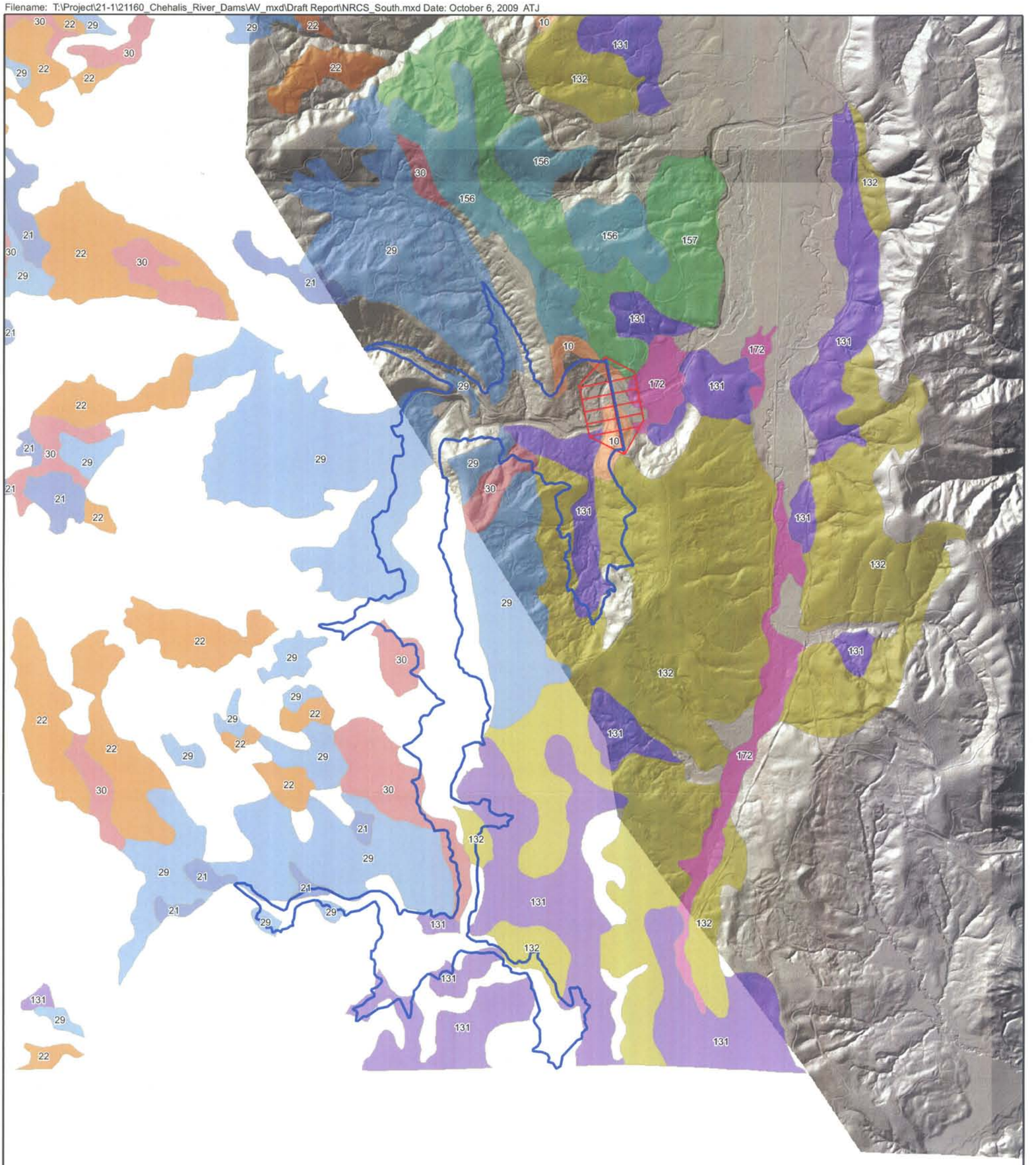
FIG. 4a

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



## LEGEND

Dam site

South Fork Chehalis Reservoir

NRCS Soil Code

| | |
|---|---|
| 10 | 131 |
| 21 | 132 |
| 22 | 156 |
| 29 | 157 |
| 30 | 172 |

NOTES

1. Soils information was taken from "Soil Survey of Lewis County Area Washington" (Evans and Fibich, 1987) and Web Soil Survey (NRCS, 2009).
2. See figure 4c for soil codes.

N W E S

0 1,000 2,000 4,000 Feet

Chehalis River Dams
Lewis County, Washington

**NRCS Soils Map:**
**South Fork Chehalis River Dam,**
**Fine Grained Cohesive Soil Units**

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FIG. 4b

# NRCS Soil Code Legend

- 10 Baumgard silt loam, very deep, 30 to 65 percent slopes
- 21 Boistfort clay loam, 0 to 8 percent slopes
- 22 Boistfort clay loam, 8 to 30 percent slopes
- 29 Bunker loam, 8 to 30 percent slopes
- 30 Bunker loam, 30 to 65 percent slopes
- 89 Galvin silt loam, 0 to 8 percent slopes
- 124 Lytell silt loam, 8 to 30 percent slopes
- 125 Lytell silt loam, 30 to 65 percent slopes
- 131 Melbourne loam, 8 to 15 percent slopes
- 132 Melbourne loam, 15 to 30 percent slopes
- 155 Olympic silty clay loam, 0 to 8 percent slopes
- 156 Olympic silty clay loam, 8 to 15 percent slopes
- 157 Olympic silty clay loam, 15 to 30 percent slopes
- 172 Reed silty clay loam
- 224 Thrash silty clay loam, 8 to 30 percent slopes
- 238 Walville silt loam, 30 to 65 percent slopes
- 242 Winston loam, 0 to 8 percent slopes
- 243 Winston gravelly loam, 0 to 8 percent slopes

NOTES

1. Data from Web Soil Survey (NRCS 2009)

Chehalis River Dams
Lewis County, Washington

**NRCS Soils Legend**

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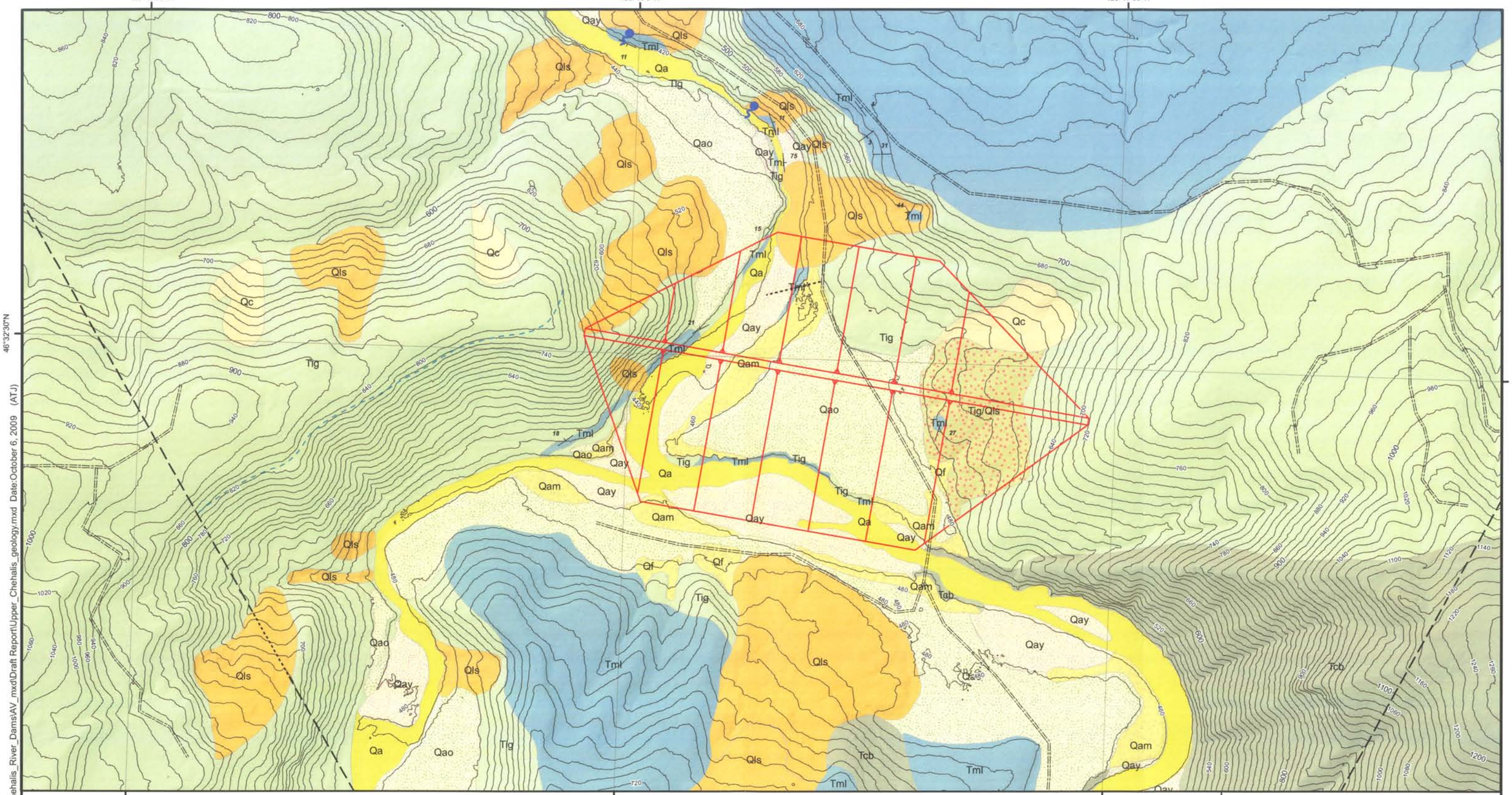
FIG. 4c




## 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

NOTES

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

0 200 400 800 Feet

Chehalis River Dams
Lewis County, Washington

**Geologic Reconnaissance Map: Chehalis River Dam**

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**FIG. 5**

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

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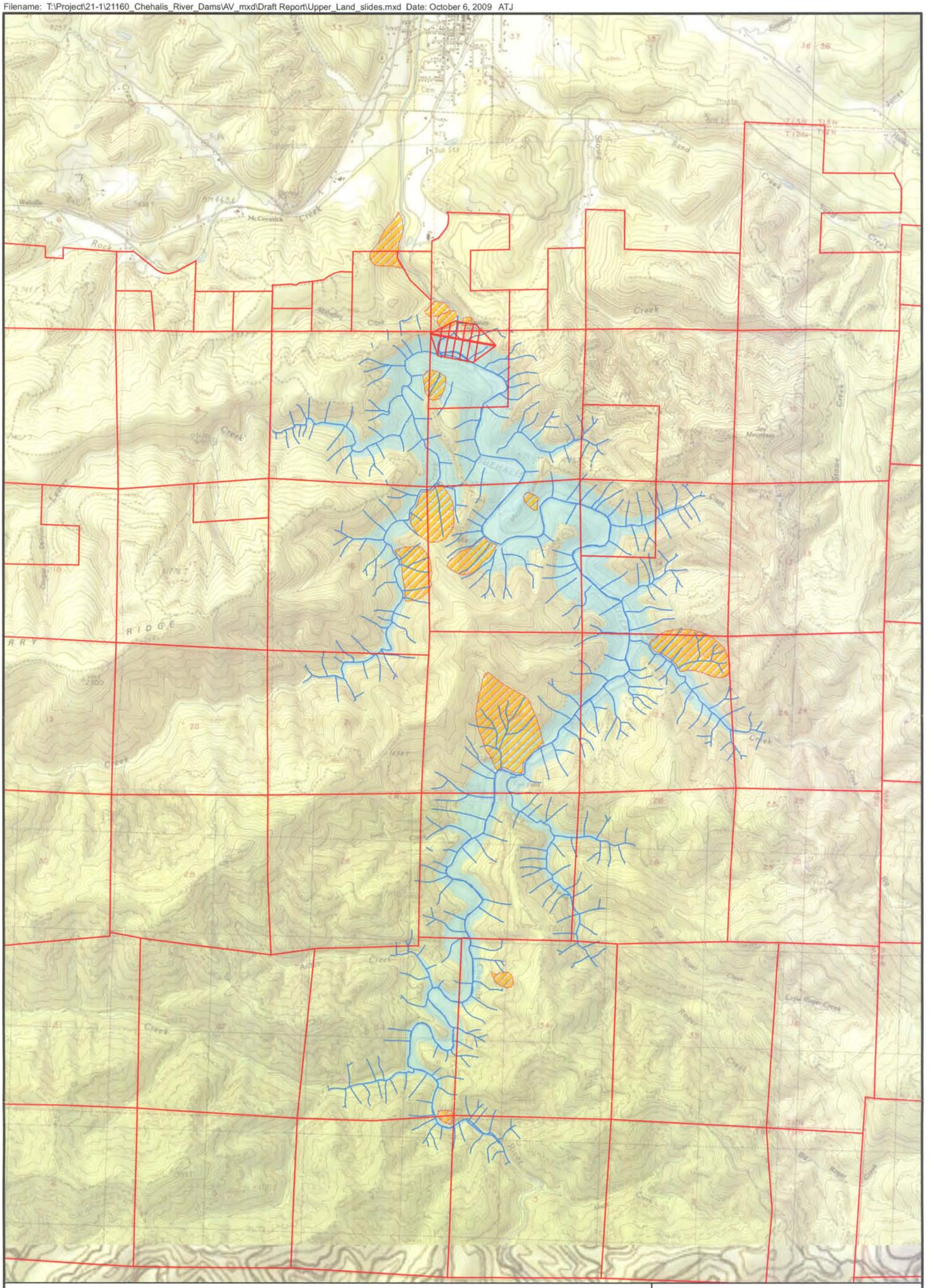


## LEGEND

- Deep-seated landslides
- Chehalis reservoir
- Streams
- Property lines

NOTES

1. Deep-seated landslide areas based on aerial photographs provided by Weyerhaeuser Company, LIDAR images, and field reconnaissance.

N W E S

0 1,500 3,000 6,000 Feet

Chehalis River Dams.
Lewis County, Washington

**Map Showing Deep-Seated Landslides: Chehalis River Dam**

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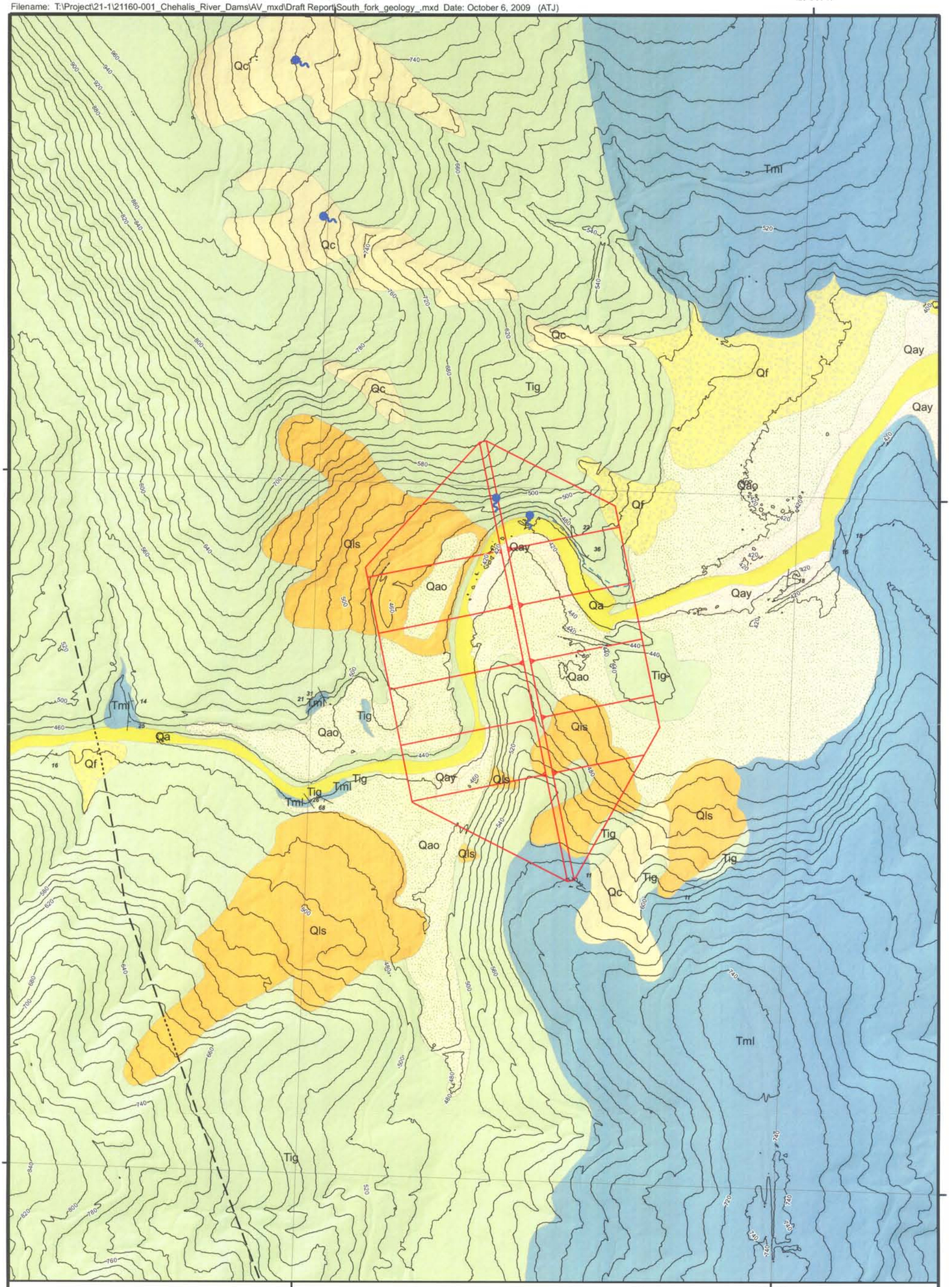
FIG. 6

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, Qam, Qao, Qay, Qc, Qf, Qls, Tcb, Tig, Tml

Fault - Approximate location, dotted where concealed.

Tml (thin layer within Tig)

18 Bedding Strike and Dip

Seep/Spring

NOTES

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

0 200 400 800 Feet

Chehalis River Dams
Lewis County, Washington

**Geologic Reconnaissance Map: South Fork Chehalis River Dam**

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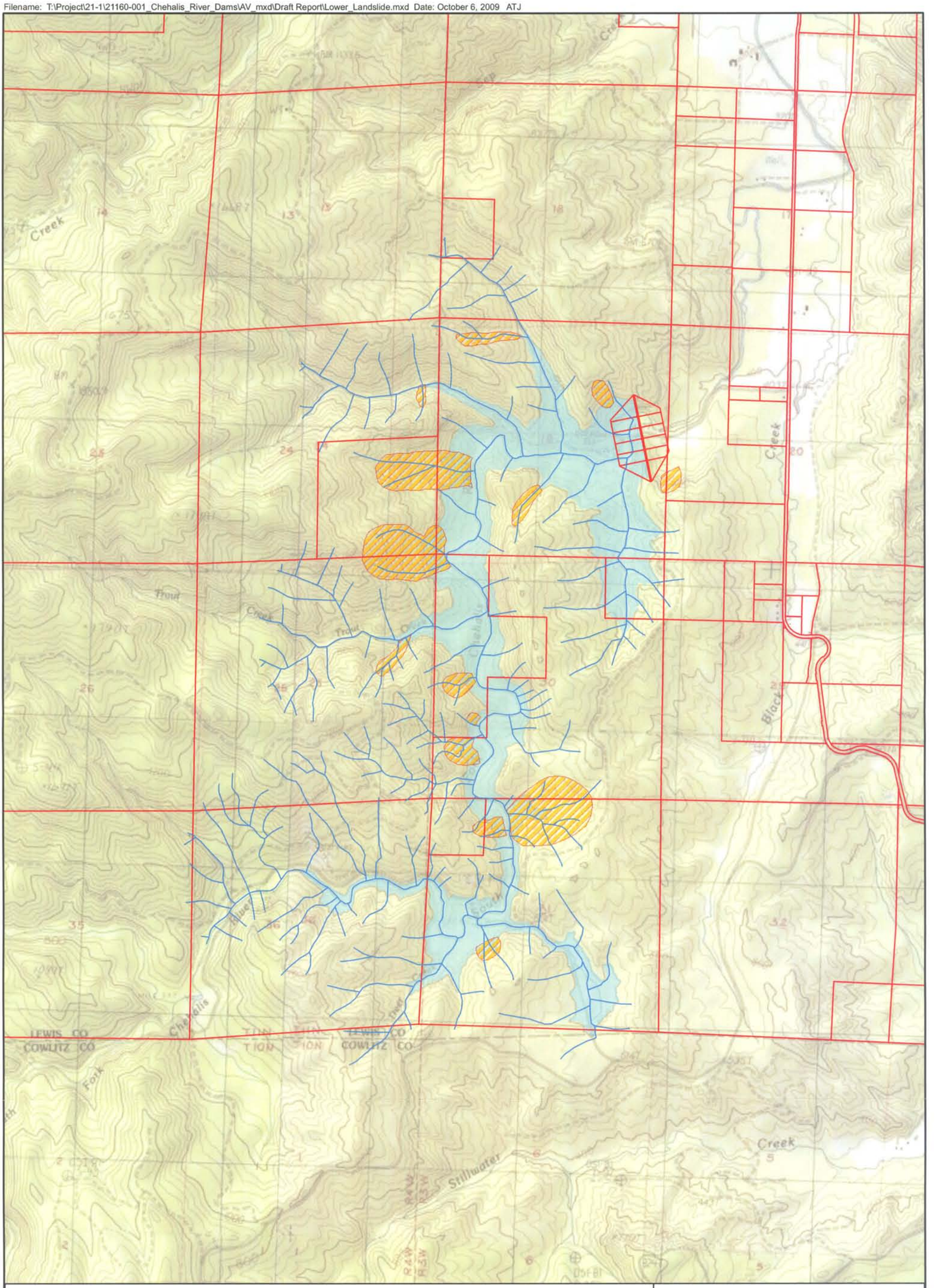
FIG. 7

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




## LEGEND

- Deep-seated landslides
- South fork reservoir
- Streams
- Property lines

NOTES

1. Deep-seated landslide areas based on aerial photographs provided by Weyerhaeuser Company, LIDAR images, and field reconnaissance.

N W E S

0 1,000 2,000 4,000 Feet

Chehalis River Dams.
Lewis County, Washington

**Map Showing Deep-Seated Landslides: South Fork Chehalis River Dam**

October 2009 | 21-1-21160-004

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

FIG. 8

# APPENDIX A

## SEISMIC REFRACTION SURVEY
## CHEHALIS RIVER DAM SITE PROJECT
## MAIN FORK AND SOUTH FORK SITES
## LEWIS COUNTY, WASHINGTON
## BY PHILIP H. DUOOS, GEOPHYSICAL CONSULTANT

# SEISMIC REFRACTION SURVEY

## CHEHALIS RIVER DAM SITE PROJECT

### MAIN FORK AND SOUTH FORK SITES
### LEWIS COUNTY, WASHINGTON

FOR

SHANNON & WILSON, INC.
SEATTLE, WASHINGTON

SEPTEMBER 2009

PHILIP H. DUOOS
GEOPHYSICAL CONSULTANT

PHILIP H. DUOOS GEOPHYSICAL CONSULTANT

September 11, 2009 Our Ref: 858-09

Mr. Bill Laprade
Shannon & Wilson, Inc.
400 North 34th Street, Suite 100
PO Box 300303
Seattle, Washington 98103

REPORT: Seismic Refraction Survey
Chehalis River Dam Site Project
Main Fork and South Fork Sites
Lewis County, Washington

Dear Mr. Laprade:

This letter report contains the results of the seismic refraction survey that I performed at the two sites in Lewis County on August 17 – 20. The purpose of the investigation was to determine the depth to competent rock and other materials in the vicinity of two proposed dam sites. The Main Fork Site is located south of Pe Ell, and the South Fork Site is located west of the town of Vader at the south end of the Boistfort Valley. Two seismic lines were performed at each site. A description of the seismic refraction method is attached (Attachment A).

**Field Methodology**

The approximate locations of the seismic lines are shown on the Site Maps. Map 1 shows the Main Fork Site with the two seismic lines (MF-1 and MF-2) along one continuous alignment, about 1400 feet long, along the potential dam axis. Map 2 shows the South Fork Site and the two separate seismic lines SF-1 and SF-2. Line SF-1 was located along the potential dam axis. Line SF-2 is in an area that you suspect to be a landslide. The seismic lines were located in the field with your assistance prior to the seismic survey. A brushing crew provided by a local construction company cleared the lines of heavy brush before we laid out the seismic cables.

The seismic lines were laid out using 300-foot tape measures and bearings obtained using a Brunton compass. Each of the geophone locations were marked using pin flags for later reference if necessary. Relative elevation changes to each geophone location were obtained using a hand-level, and are estimated to be within +/- 0.5 feet of the actual elevation changes. An approximate elevation was determined using a road or other visible feature on the contour map as a reference for the hand-level data. The reference elevation, based on the map with five-foot contours, is probably accurate to within a few feet.

The field investigation was performed using a 48-channel digital seismograph to record the data. A slide-hammer source was used to generate a seismic wave at 100 to 200 foot intervals along each seismic spread, and also at some distance from both ends of each spread. The seismic spreads used a typical geophone spacing of 15 to 20 feet, with shorter spacings in some locations to provide better information on the shallow materials.

Philip H. Duoos
PH/FAX: (425) 882-2634
13503 NE 78th Place, Redmond, Washington, 98052
Email: geopyg@aol.com

## Interpretation Results

The results of the seismic survey are shown on the interpretation profiles (Profiles 1 – 4). The profiles show the geophone locations along the ground surface, the calculated depth points below each geophone, and the interpreted interfaces (dashed lines).

The basic geologic units were identified based on the interpreted compressional wave velocities (in feet/second), the limited site-specific information (visible outcrops), and results from other seismic surveys I have performed in the region. Their probable classification is indicated on the following tables.

### TABLE 1

### MAIN FORK AREA, SOUTH OF PE ELL

| SYMBOL | SEISMIC VELOCITY (feet per second) | PROBABLE CLASSIFICATION |
|---|---|---|
| O1 | 1,050 - 1,500 | Unconsolidated soil; dry, loose overburden (colluvium, sand and gravel) and alluvium |
| O2 | 2,100 - 2,900 | More consolidated overburden, possible landslide debris. Possibly highly weathered siltstone or sandstone. |
| O3 | 4,300 - 4,500 | Similar to O2 layer but more consolidated; and/or possibly weathered sedimentary rock. |
| BX-1 | 7,400 - 10,300 | Moderate velocity bedrock, competent sedimentary rock (shale, sandstone, etc.) or weathered basalt. |
| BX-2 | 15,100 | High velocity bedrock, competent basalt. |

### TABLE 2

### SOUTH FORK AREA, SOUTHERN BOISTFORT VALLEY

| SYMBOL | SEISMIC VELOCITY (P-wave, fps) | PROBABLE CLASSIFICATION |
|---|---|---|
| O1 | 1,100 - 2,800 | Unconsolidated soil; dry, loose overburden (colluvium, sand and gravel) |
| O2 | 3,900 - 4,600 | More consolidated overburden, possible landslide debris or colluvium. Possibly weathered siltstone or sandstone. |
| BX-2 | 12,800 – 15,000 | High velocity bedrock, competent basalt. |

The interpreted results profiles for the Main Fork Site are provided on Profiles 1 and 2 (Seismic Line MF-1 and MF-2, respectively). The South Fork Site profiles are provided on Profiles 3 and 4 (Lines SF-1 and SF-2, respectively).

The probable materials classification for the various seismic velocities is difficult with no boring information and limited visible outcrops. At the Main Fork Site however, the profiles (Profile 1 and 2) show conditions that are similar to results from a seismic survey that I did at the nearby Weyerhaeuser access road and water pipe washout from March 2008. The lower bedrock velocities (7,400 to 10,300 fps) are similar to the sedimentary rocks observed at the washout site, and the 15,100 fps velocity is probably basalt. The thick O2 overburden layer observed on Line MF-2 may be old landslide debris. However, the seismic velocities are also in the range of weathered sedimentary rock (volcaniclastic sandstone) that I observed at a large landslide along Highway SR-6 just west of Pe Ell in January 2008. The O2 layer is interpreted to outcrop (or be very close to the surface) in the steep slope to the west of the new Weyerhaeuser road near Line MF-2, Geophone #20 (about Station 925').

At the South Fork Site (Profiles 3 and 4) the bedrock velocities are higher and more consistent, and probably indicate competent basalt. The O2 overburden layer observed on Line SF-2 may be weathered sedimentary rock and/or old landslide debris.

While the accuracy of the interpretation depends on site-specific conditions, geophysical methods in general provide an accuracy of +/- 10% under good conditions. Extreme changes in topography or depth to subsurface interfaces will affect the accuracy. The seismic data from the slide-hammer energy source was excellent at these sites and free of noise from wind, vehicles or the flowing river water.

As with any geophysical technique, these results are interpretive in nature and represent the best estimate of subsurface conditions considering the limitations of the geophysical method employed. Only direct observations using borings or other means can ultimately characterize subsurface conditions, using the geophysical results as a guide. Review of this report by a geologist or other qualified person familiar with the geology of this area may provide additional information on the interpreted results. The seismic results should also be reviewed upon completion of any subsequent borings.

Please feel free to contact me if you have any questions or comments regarding this information, or if you require further assistance. I appreciated the opportunity to work with you on this project.

Sincerely,

Philip H. Duoos
Geophysical Consultant

State of Washington
561
Licensed Geologist
Philip H. Duoos

Attachments

Attachment A: Seismic Refraction Methodology
Map 1: Main Fork Site Map
Map 2: South Fork Site Map
Profiles 1 & 2: Main Fork Seismic Profiles
Profiles 3 & 4: South Fork Seismic Profiles

ATTACHMENT A

# SEISMIC REFRACTION METHODOLOGY

## Overview

The seismic refraction method is used to evaluate numerous subsurface conditions; including depth to and strength (rippability) of rock, depth to water, and general subsurface stratigraphy.

The seismic refraction method uses an induced shock wave. As the shock wave propagates through the earth, it is affected by the materials through which it passes. Geophones placed on the ground surface record the ground motion caused by the resultant wave. A seismograph measures the time required for the resultant wave to arrive at each geophone. These geophones are located at selected distances from the wave source. Analysis of the data (travel times and distances) provides seismic velocities of subsurface material and depths to significant velocity interfaces.

Geologic conditions yielding higher seismic velocities include increased amounts of water, clay, cobbles, and rock fragments, greater compaction of overburden materials, and greater competency of rock. Several factors can affect the effectiveness of the seismic method including the proximity of cultural interferences (such as powerlines and traffic noise), surface conditions (such as loose soil), the size and depth of the target, and the seismic wave velocity contrast between stratigraphic units. Seismic velocities must increase with depth for a reliable interpretation of the data.

## Calculations

The description of the travel of seismic refraction waves through the earth uses the same equation that describes the refraction of light: Snell's Law. The following is a brief summary of the basic theory for a simple two-layer geologic model as discussed by Redpath (Redpath, 1973).

Snell's Law is stated as:

$$\frac{SIN\alpha}{SIN\beta} = \frac{V_1}{V_2}$$

and at the critical angle of incidence for a refracted seismic wave ($\beta$=90°), it becomes:

$$SIN\alpha = \frac{V_1}{V_2}$$

where $V_1$ and $V_2$ are the seismic wave velocities for the upper and lower layers, respectively.

The seismic refraction method measures the amount of time it takes the seismic energy to travel from the energy source to the geophones placed along the ground surface. The arrival time for the seismic wave at each geophone is plotted corresponding to the distance of the geophone from the energy source, creating a time-distance graph (Figure 1).

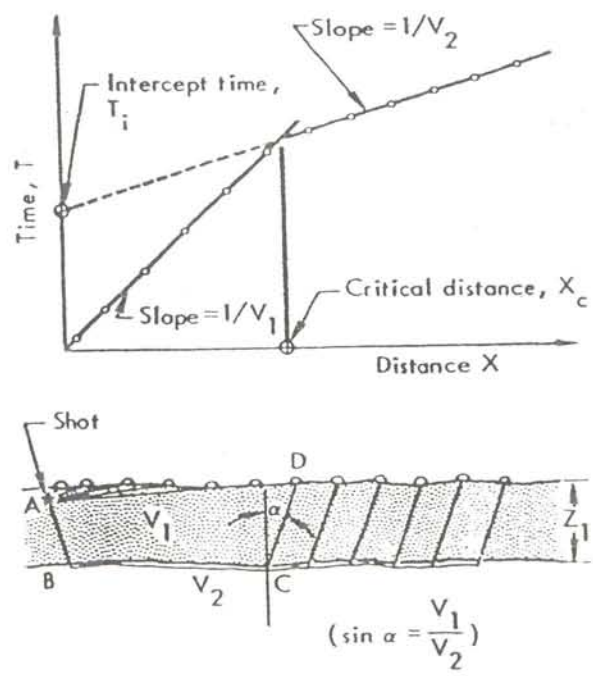



Figure 1: Two-layer geologic model and associated time-distance graph (Redpath, 1973).

The time required for the energy to reach the geophones near the source (direct wave arrivals) is based only on the seismic velocity of the energy traveling though the upper (low velocity) layer. At a certain distance from the source, called the critical distance, the first seismic waves to reach the

geophones will be those that have refracted from a deeper, higher velocity layer. Although these waves have traveled a greater distance than the direct waves, they have traveled at a greater velocity over most of their path, and thus arrive before the slower direct arrivals to the geophones farther from the source. Successively deeper layers with higher velocities affect the time-distance graph in a similar manner.

Using the time-distance graph, the velocities of the layers can be calculated (based on the slope of the arrival times), and the layer thicknesses can be calculated using the intercept times. The equation used in the time-intercept method to determine thicknesses is:

$$Z_1 = \frac{T_1 V_1}{2COS(SIN^{-1} V_1 / V_2)} + \frac{\text{SHOT DEPTH}}{2};$$

Figure 2 is a sketch of a multiple layer case and the corresponding time distance curve showing the intercept times.

For more complex geologic models, as is usually observed, additional energy source locations are required at both ends of a seismic line as was done for this survey. The layer velocities are calculated using the data from all of the time-distance curves (delay-time method).

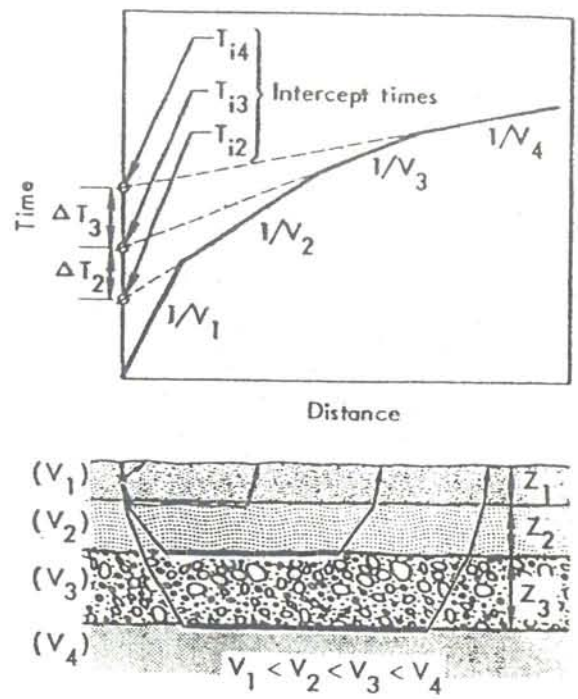



Figure 2: Multiple layer geologic model and associated time-distance graph (Redpath, 1973).

## Limitations

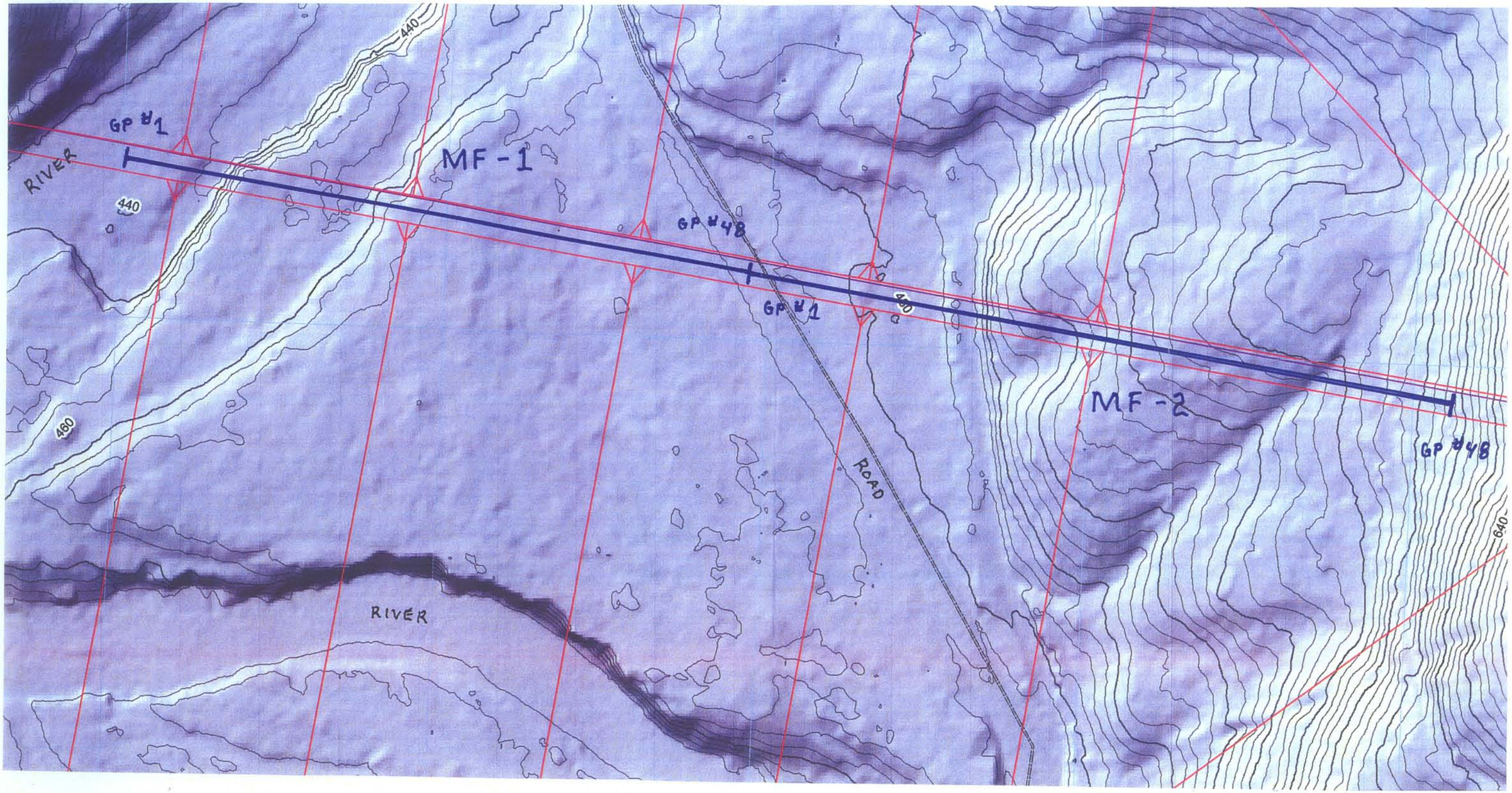
Two types of geologic conditions can cause a *hidden zone* problem. One type of hidden zone is a layer with a lower velocity than the layer above it. Energy approaching the layer at the critical angle will pass through the layer, and will not be refracted back to the surface until it encounters a deeper layer with a higher velocity, so no first arrivals are observed from the low-velocity layer. The presence of an unknown low-velocity layer will cause the calculated depths to be greater than the actual depths.

The other type of hidden zone is a layer with a greater velocity than the layer above it, but one that is too thin and/or does not have a large enough velocity contrast. The effect of a thin layer will cause the calculated depths to be shallower than the actual depths.

In areas with hidden zones, the amount of error can be determined based on direct observations (such as test pits or boreholes), and can be compensated for over the rest of the seismic lines.

References

Redpath, Bruce B. (1973). "Seismic Refraction Exploration for Engineering Site Investigations." *Tech. Report E-73-4*, U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Livermore, CA



0 50 100 200 300 400 Feet

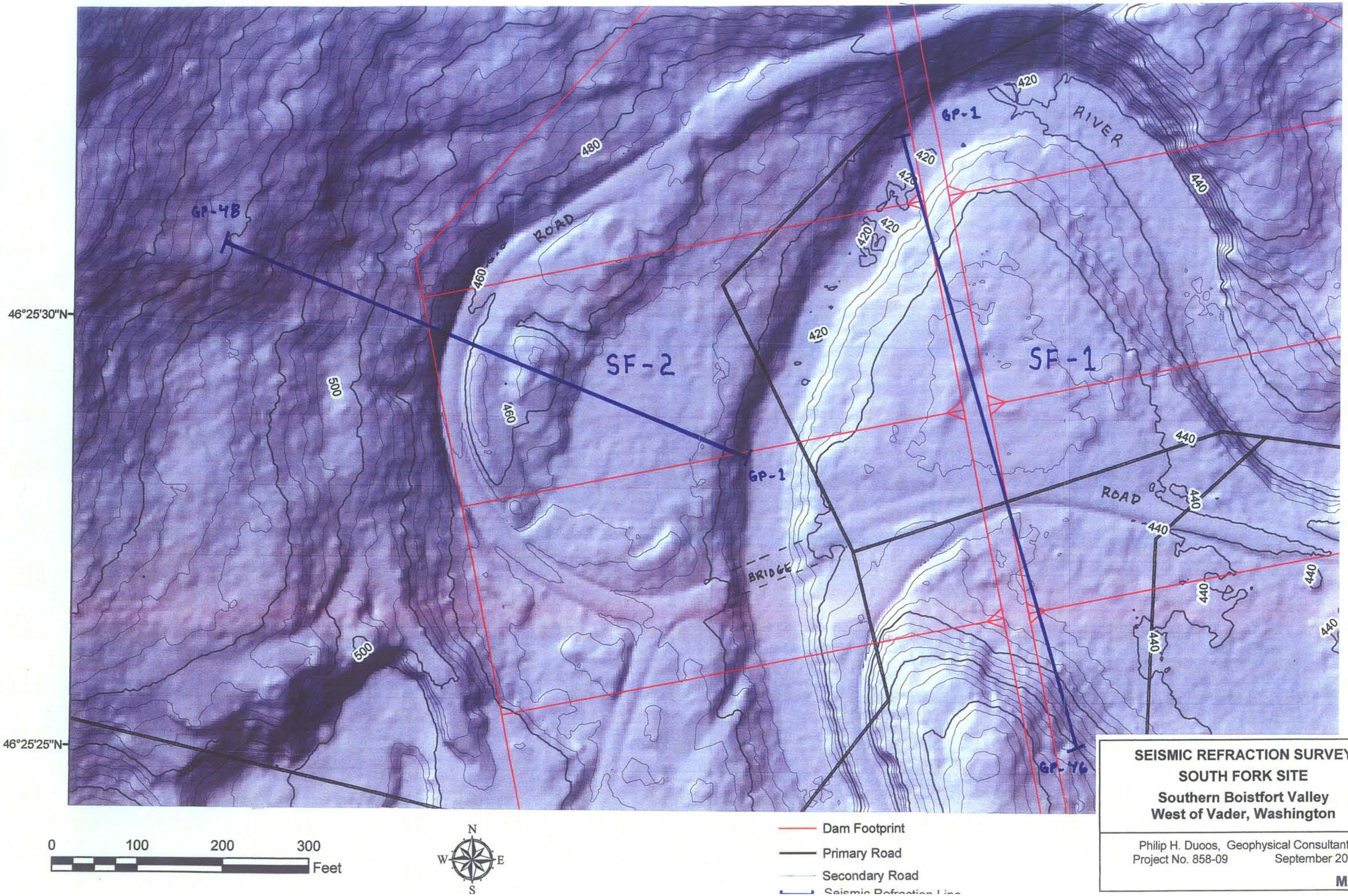
**Legend**

- Primary Road
- Secondary Road
- Dirt Roads
- Dam Footprint
- Seismic Refraction Line

**SEISMIC REFRACTION SURVEY**
**MAIN FORK SITE**
**South of Pe Ell, Washington**

Philip H. Duoos, Geophysical Consultant
Project No. 858-09 September 2009

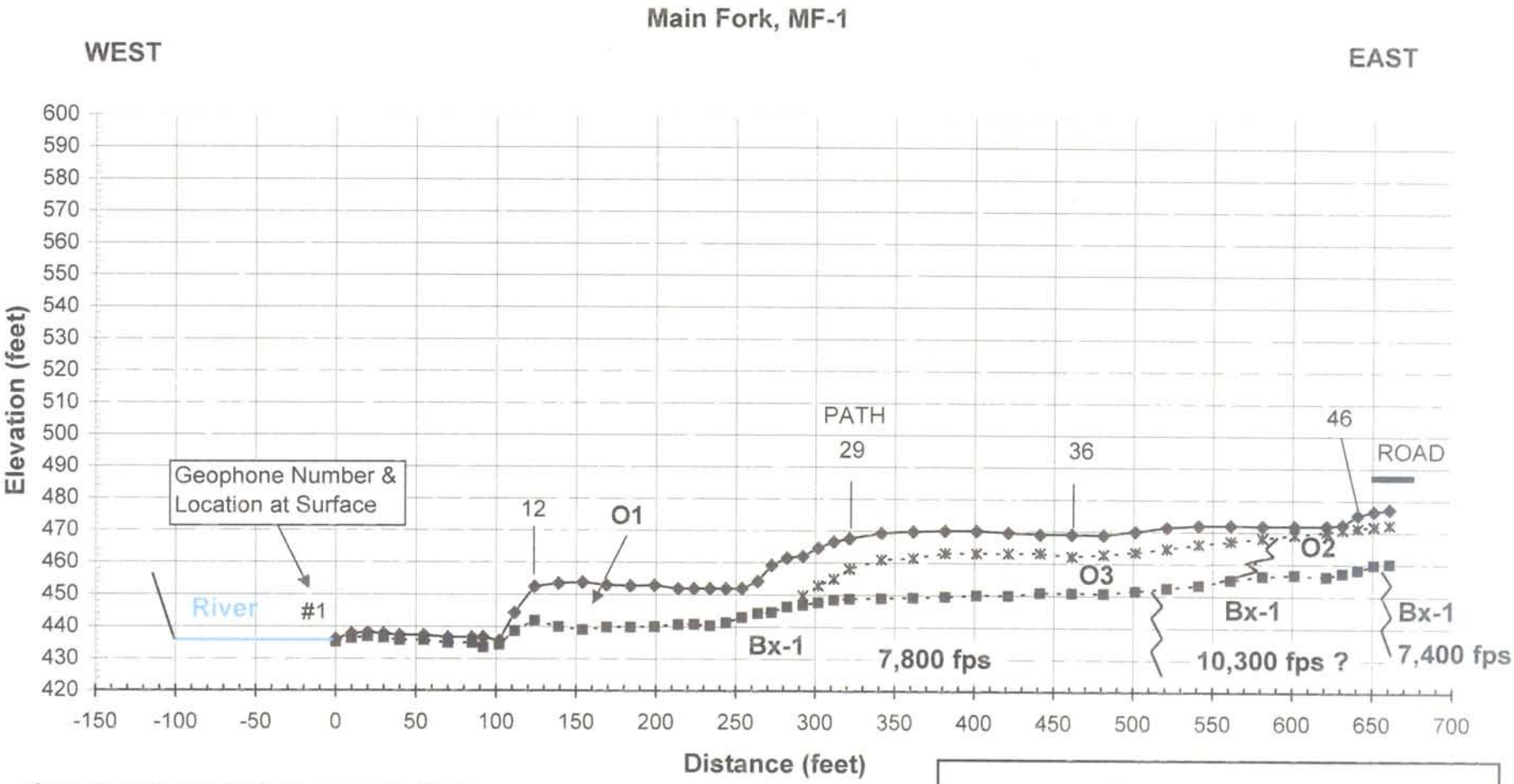
**MAP 1**




**SEISMIC REFRACTION SURVEY**
**SOUTH FORK SITE**
**Southern Boistfort Valley**
**West of Vader, Washington**

Philip H. Duoos, Geophysical Consultant
Project No. 858-09 September 2009

**MAP 2**




Ground surface elevations are approximate using contour map and hand level measurements.

| Seismic Layer Velocities | | |
|---|---|---|
| O1 | 1,050 - | 1,200 fps |
| O2 | 2,100 - | 2,900 fps |
| O3 | 4,300 - | 4,500 fps |
| Bx-1 | 7,400 - | 10,300 fps |

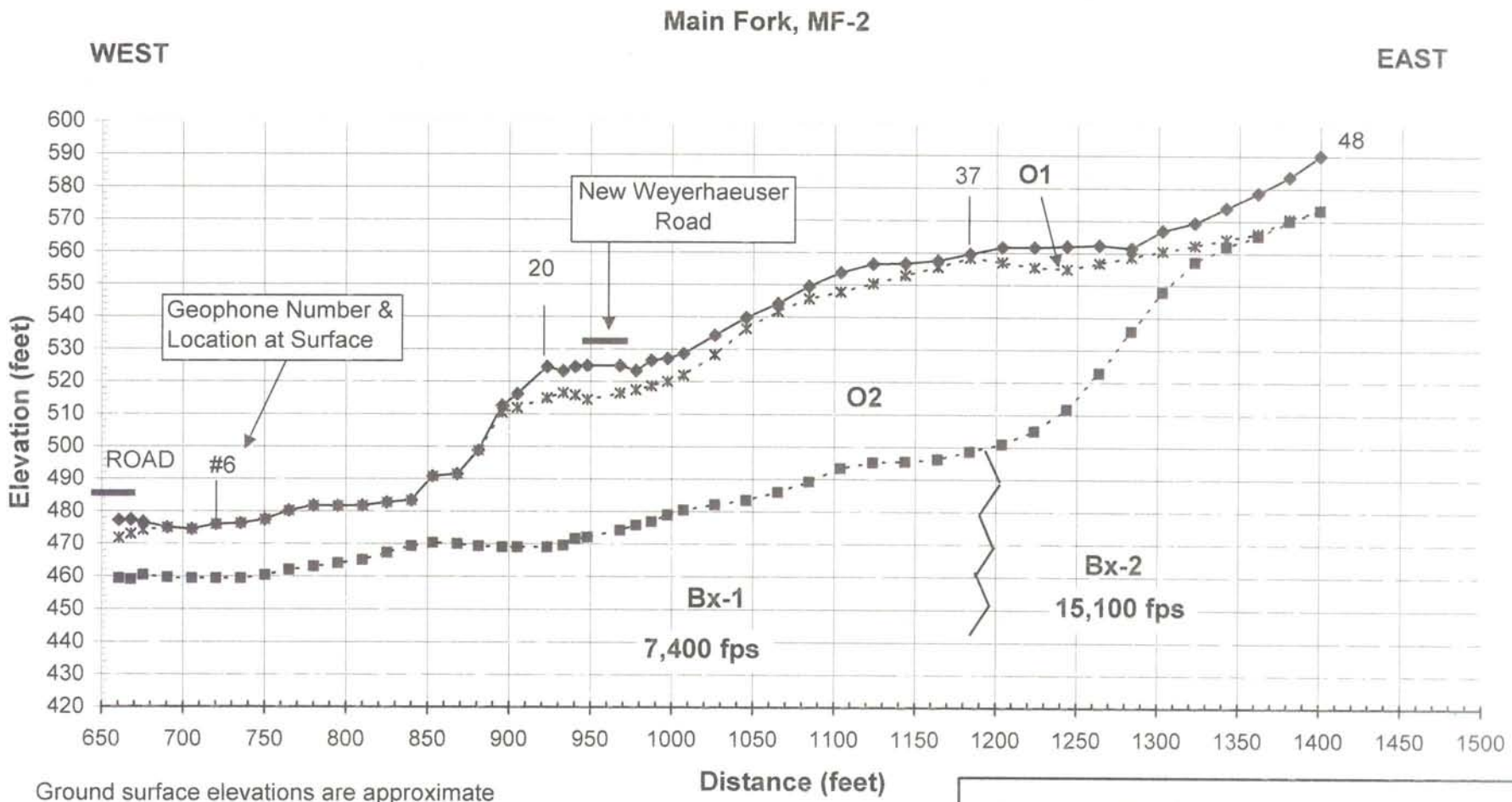
Horizontal Scale: 1" = 100'
Vertical Scale: 1" = 50'

**MAIN FORK, LINE MF-1**

**CHEHALIS RIVER RESERVOIR PROJECT**
**SOUTH OF PE ELL, WASHINGTON**

SEISMIC INTERPRETATION PROFILE
Phil Duoos, Geophysical Consultant
PN 858-09, September 2009

**PROFILE 1**




Ground surface elevations are approximate using contour map and hand level measurements.

| Seismic Layer Velocities | | |
|---|---|---|
| O1 | 1,150 - | 1,500 fps |
| O2 | 2,100 - | 2,900 fps |
| Bx-1 | | 7,400 fps |
| Bx-2 | | 15,100 fps |

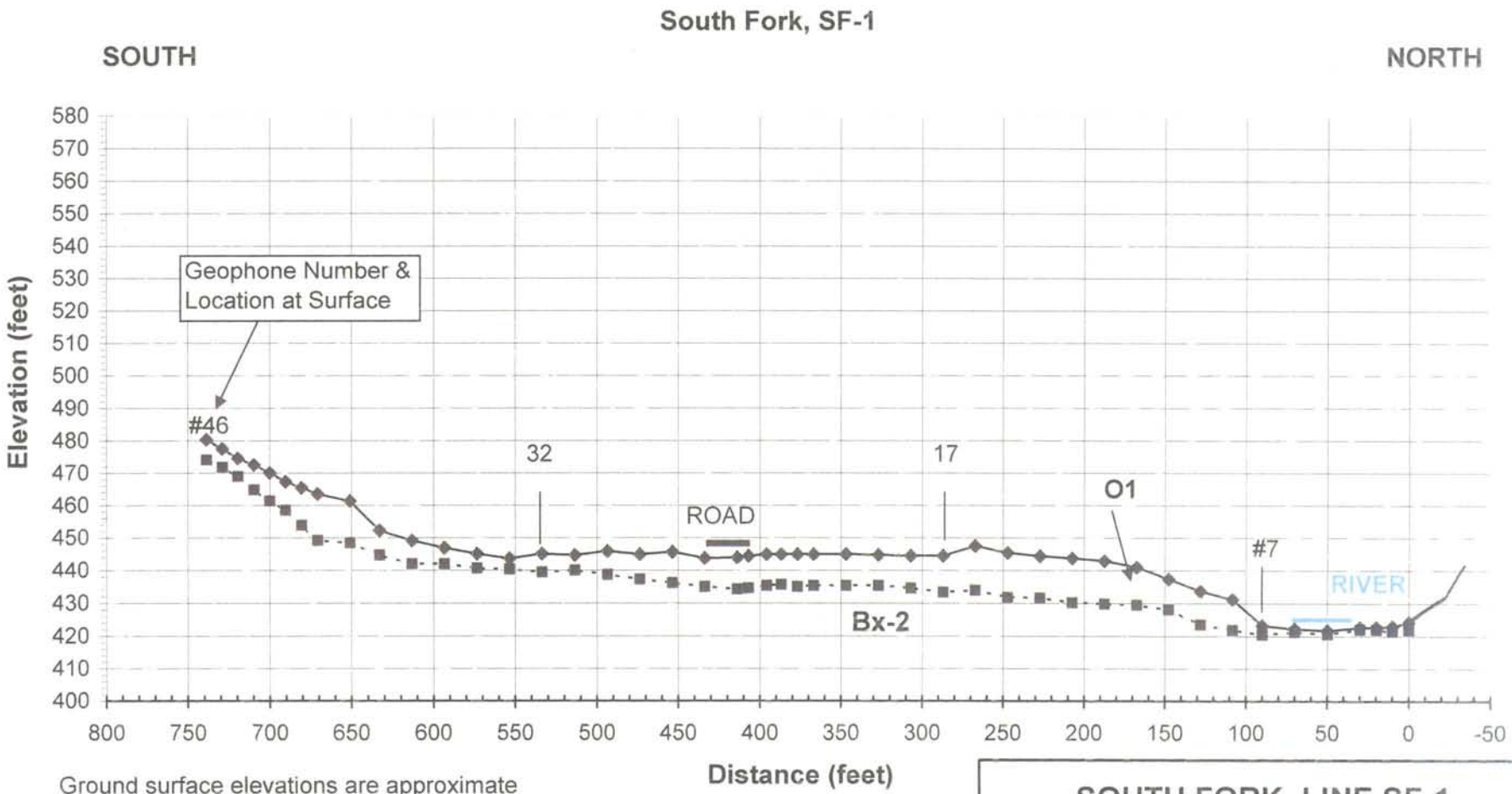
Horizontal Scale: 1" = 100'
Vertical Scale: 1" = 50'

## MAIN FORK, LINE MF-2

**CHEHALIS RIVER RESERVOIR PROJECT**
**SOUTH OF PE ELL, WASHINGTON**

SEISMIC INTERPRETATION PROFILE
Phil Duoos, Geophysical Consultant
PN 858-09, September 2009

**PROFILE 2**




Ground surface elevations are approximate using contour map and hand level measurements.

| Seismic Layer Velocities | | | |
|---|---|---|---|
| O1 | 1,200 | - | 2,800 fps |
| Bx-2 | 12,800 | - | 13,400 fps |

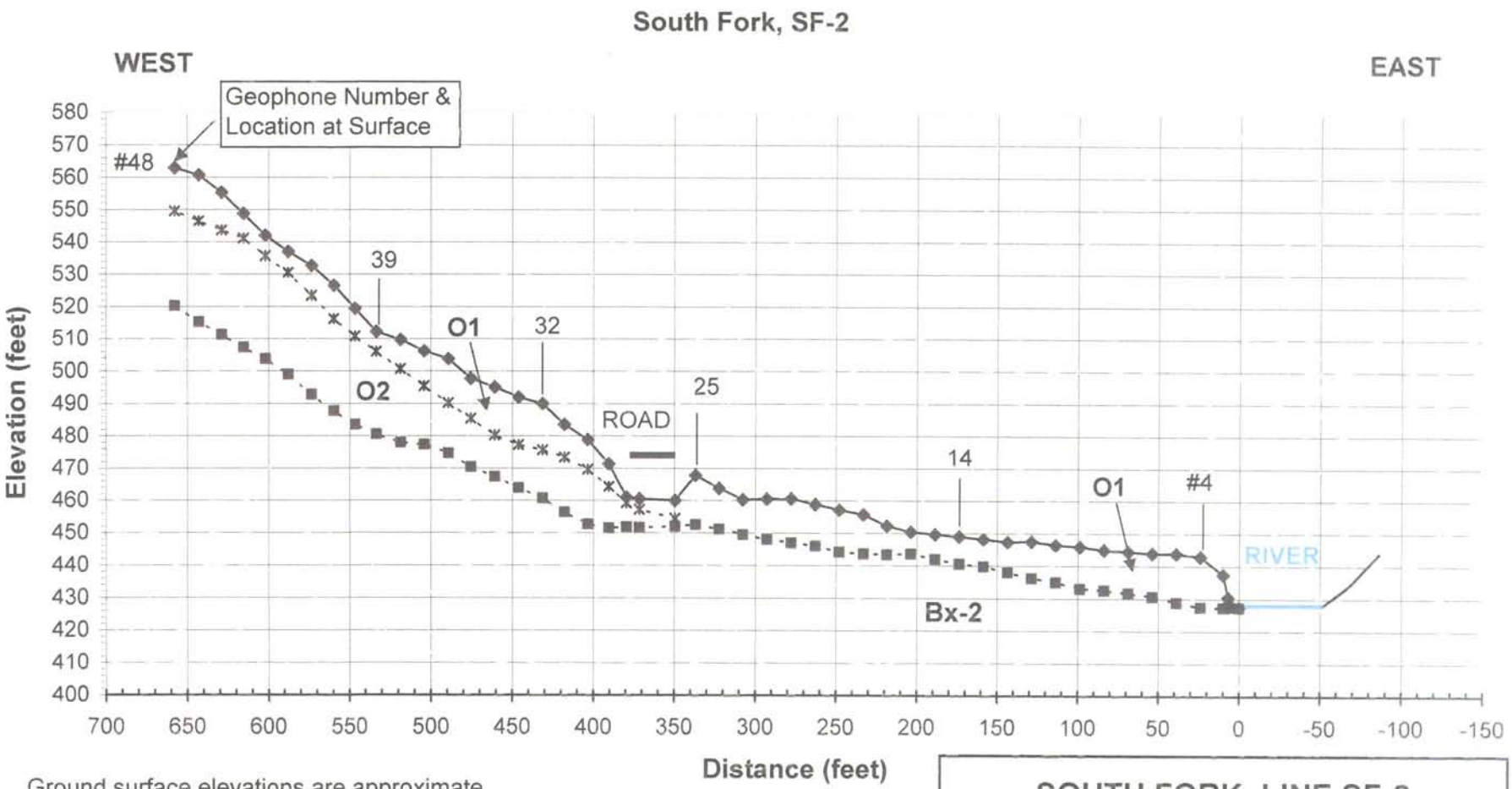
Horizontal Scale: 1" = 100'
Vertical Scale: 1" = 50'

## SOUTH FORK, LINE SF-1

**CHEHALIS RIVER RESERVOIR PROJECT**
**SOUTHERN BOISTFORT VALLEY**
**WEST OF VADER, WASHINGTON**

SEISMIC INTERPRETATION PROFILE
Phil Duoos, Geophysical Consultant
PN 858-09, September 2009

**PROFILE 3**




Ground surface elevations are approximate using contour map and hand level measurements.

| Seismic Layer Velocities | | |
|---|---|---|
| O1 | 1,100 - | 1,300 fps |
| O2 | 3,900 - | 4,600 fps |
| Bx-2 | 13,800 - | 15,000 fps |

Horizontal Scale: 1" = 100'
Vertical Scale: 1" = 50'

## SOUTH FORK, LINE SF-2

**CHEHALIS RIVER RESERVOIR PROJECT**
**SOUTHERN BOISTFORT VALLEY**
**WEST OF VADER, WASHINGTON**

SEISMIC INTERPRETATION PROFILE
Phil Duoos, Geophysical Consultant
PN 858-09, September 2009

**PROFILE 4**

# APPENDIX B

# SELECTED RECONNAISSANCE PHOTOGRAPHS

# APPENDIX B

## SELECTED RECONNAISSANCE PHOTOGRAPHS

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## PHOTOS

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| B-2 | Photo 3. Alluvium (fine sand) |
| B-2 | Photo 4. Alluvium (boulder gravel, exposed thickness ~25 feet) |
| B-3 | Photo 5. Columnar jointing in volcanic rocks (Tig) |
| B-4 | Photo 6. Spheroidal weathering in volcanic rocks (Tig) |
| B-5 | Photo 7. Residuum soil developed overlying volcanic rocks |
| B-5 | Photo 8. Claystone/siltstone beds of the McIntosh Formation (Tml) underlying and baked by gabbroic intrusion (Tig) |
| B-6 | Photo 9. Weathered pillow basalt (Tcb) |

**Photo 1. Overview of proposed Chehalis River dam site. Arrows indicate approximate location of dam abutments. View is to the north.**

**Photo 2. Overview of proposed South Fork dam site. Arrows indicate approximate location of dam abutments. View is to the east.**

**Photo 3. Alluvium (fine sand)**

**Photo 4. Alluvium (boulder gravel, exposed thickness ~25 feet)**

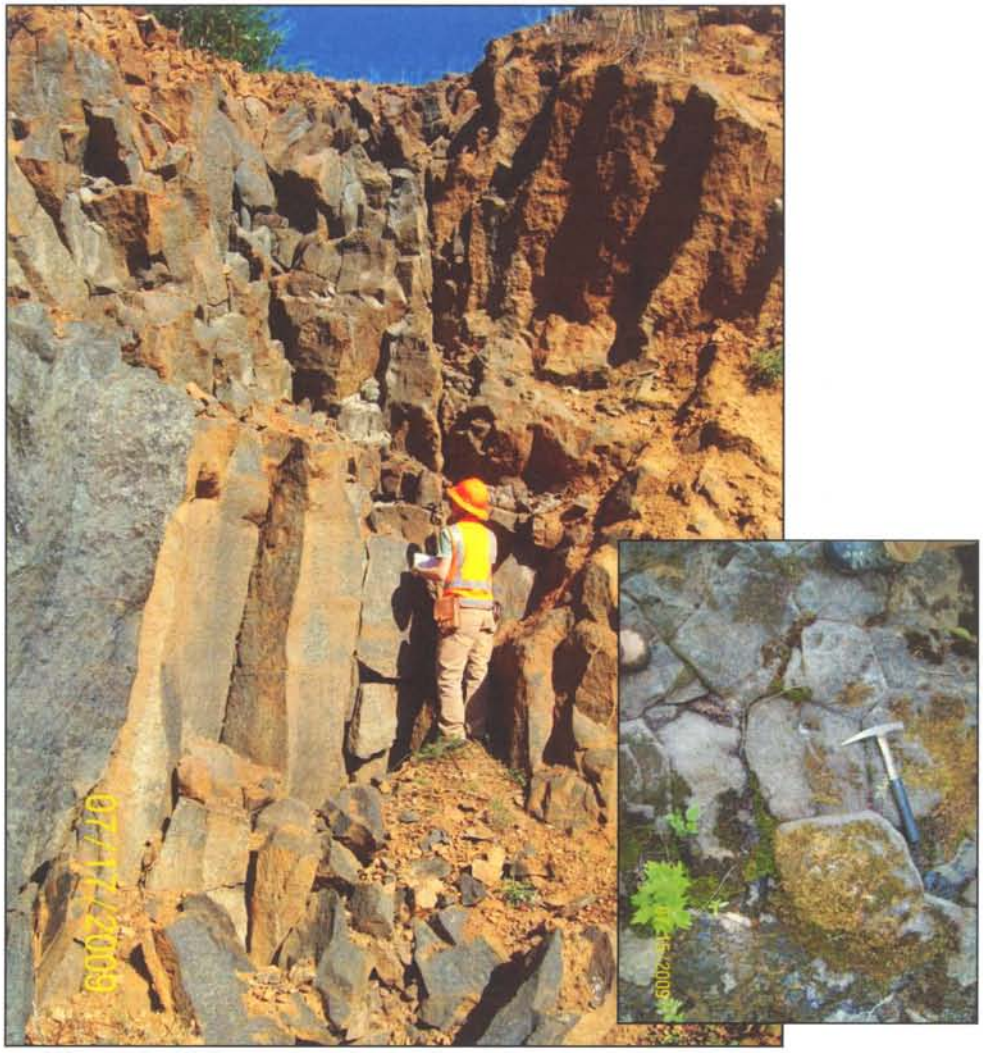


**Photo 5. Columnar jointing in volcanic rocks (Tig)**

**Photo 6. Spheroidal weathering in volcanic rocks (Tig).**

**Photo 7. Residuum soil developed overlying volcanic rocks**

**Photo 8. Claystone/siltstone beds of the McIntosh Formation (Tml) underlying and baked by a gabbroic intrusion (Tig).**

**Photo 9. Weathered pillow basalt (Tcb).**

# APPENDIX C

## IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL/ENVIRONMENTAL REPORT

# IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL/ENVIRONMENTAL REPORT

## CONSULTING SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES AND FOR SPECIFIC CLIENTS.

Consultants prepare reports to meet the specific needs of specific individuals. A report prepared for a civil engineer may not be adequate for a construction contractor or even another civil engineer. Unless indicated otherwise, your consultant prepared your report expressly for you and expressly for the purposes you indicated. No one other than you should apply this report for its intended purpose without first conferring with the consultant. No party should apply this report for any purpose other than that originally contemplated without first conferring with the consultant.

## THE CONSULTANT'S REPORT IS BASED ON PROJECT-SPECIFIC FACTORS.

A geotechnical/environmental report is based on a subsurface exploration plan designed to consider a unique set of project-specific factors. Depending on the project, these may include: the general nature of the structure and property involved; its size and configuration; its historical use and practice; the location of the structure on the site and its orientation; other improvements such as access roads, parking lots, and underground utilities; and the additional risk created by scope-of-service limitations imposed by the client. To help avoid costly problems, ask the consultant to evaluate how any factors that change subsequent to the date of the report may affect the recommendations. Unless your consultant indicates otherwise, your report should not be used: (1) when the nature of the proposed project is changed (for example, if an office building will be erected instead of a parking garage, or if a refrigerated warehouse will be built instead of an unrefrigerated one, or chemicals are discovered on or near the site); (2) when the size, elevation, or configuration of the proposed project is altered; (3) when the location or orientation of the proposed project is modified; (4) when there is a change of ownership; or (5) for application to an adjacent site. Consultants cannot accept responsibility for problems that may occur if they are not consulted after factors which were considered in the development of the report have changed.

## SUBSURFACE CONDITIONS CAN CHANGE.

Subsurface conditions may be affected as a result of natural processes or human activity. Because a geotechnical/environmental report is based on conditions that existed at the time of subsurface exploration, construction decisions should not be based on a report whose adequacy may have been affected by time. Ask the consultant to advise if additional tests are desirable before construction starts; for example, groundwater conditions commonly vary seasonally.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes, or groundwater fluctuations may also affect subsurface conditions and, thus, the continuing adequacy of a geotechnical/environmental report. The consultant should be kept apprised of any such events, and should be consulted to determine if additional tests are necessary.

## MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

Site exploration and testing identifies actual surface and subsurface conditions only at those points where samples are taken. The data were extrapolated by your consultant, who then applied judgment to render an opinion about overall subsurface conditions. The actual interface between materials may be far more gradual or abrupt than your report indicates. Actual conditions in areas not sampled may differ from those predicted in your report. While nothing can be done to prevent such situations, you and your consultant can work together to help reduce their impacts. Retaining your consultant to observe subsurface construction operations can be particularly beneficial in this respect.

## A REPORT'S CONCLUSIONS ARE PRELIMINARY.

The conclusions contained in your consultant's report are preliminary because they must be based on the assumption that conditions revealed through selective exploratory sampling are indicative of actual conditions throughout a site. Actual subsurface conditions can be discerned only during earthwork; therefore, you should retain your consultant to observe actual conditions and to provide conclusions. Only the consultant who prepared the report is fully familiar with the background information needed to determine whether or not the report's recommendations based on those conclusions are valid and whether or not the contractor is abiding by applicable recommendations. The consultant who developed your report cannot assume responsibility or liability for the adequacy of the report's recommendations if another party is retained to observe construction.

## THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

Costly problems can occur when other design professionals develop their plans based on misinterpretation of a geotechnical/environmental report. To help avoid these problems, the consultant should be retained to work with other project design professionals to explain relevant geotechnical, geological, hydrogeological, and environmental findings, and to review the adequacy of their plans and specifications relative to these issues.

## BORING LOGS AND/OR MONITORING WELL DATA SHOULD NOT BE SEPARATED FROM THE REPORT.

Final boring logs developed by the consultant are based upon interpretation of field logs (assembled by site personnel), field test results, and laboratory and/or office evaluation of field samples and data. Only final boring logs and data are customarily included in geotechnical/environmental reports. These final logs should not, under any circumstances, be redrawn for inclusion in architectural or other design drawings, because drafters may commit errors or omissions in the transfer process.

To reduce the likelihood of boring log or monitoring well misinterpretation, contractors should be given ready access to the complete geotechnical engineering/environmental report prepared or authorized for their use. If access is provided only to the report prepared for you, you should advise contractors of the report's limitations, assuming that a contractor was not one of the specific persons for whom the report was prepared, and that developing construction cost estimates was not one of the specific purposes for which it was prepared. While a contractor may gain important knowledge from a report prepared for another party, the contractor should discuss the report with your consultant and perform the additional or alternative work believed necessary to obtain the data specifically appropriate for construction cost estimating purposes. Some clients hold the mistaken impression that simply disclaiming responsibility for the accuracy of subsurface information always insulates them from attendant liability. Providing the best available information to contractors helps prevent costly construction problems and the adversarial attitudes that aggravate them to a disproportionate scale.

## READ RESPONSIBILITY CLAUSES CLOSELY.

Because geotechnical/environmental engineering is based extensively on judgment and opinion, it is far less exact than other design disciplines. This situation has resulted in wholly unwarranted claims being lodged against consultants. To help prevent this problem, consultants have developed a number of clauses for use in their contracts, reports and other documents. These responsibility clauses are not exculpatory clauses designed to transfer the consultant's liabilities to other parties; rather, they are definitive clauses that identify where the consultant's responsibilities begin and end. Their use helps all parties involved recognize their individual responsibilities and take appropriate action. Some of these definitive clauses are likely to appear in your report, and you are encouraged to read them closely. Your consultant will be pleased to give full and frank answers to your questions.

The preceding paragraphs are based on information provided by the
ASFE/Association of Engineering Firms Practicing in the Geosciences, Silver Spring, Maryland