APPENDIX G

Geology

TECHNICAL MEMORANDUM

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TO: Mr. Jesse Hamashima, Pierce County

CC: Mr. Dan McReynolds, P.E., Parametrix

FROM: Edward J. Heavey, P.E., and James A. Wilson, P.E.

DATE: September 19, 2006

**RE: GEOLOGIC AND GEOTECHNICAL ASSESSMENT
RHODES LAKE ROAD CORRIDOR STUDY
PIERCE COUNTY, WASHINGTON**

INTRODUCTION

This technical memorandum summarizes our geologic and geotechnical assessment of the proposed Rhodes Lake Road Corridor in Pierce County, Washington. The purpose of our services was to review readily available geologic and geotechnical information in the study area, complete a limited visual reconnaissance of the general study area, and identify and evaluate the geologic and geotechnical issues within the proposed study area that could have an impact on feasibility and alignment selection for a roadway within the corridor.

The purpose of this memorandum is to provide geologic and geotechnical framework to assist Parametrix and Pierce County (County) staff in route selection and planning for the Rhodes Lake Road Corridor Draft Environmental Impact Statement (EIS). The data provided in this memorandum is not intended to support engineering design. When and if a preferred alternative is established by the Pierce County Council, additional geotechnical explorations should be completed along the route of the preferred alternative in the preliminary design phase of project development to better define the surface and subsurface conditions affecting design of the roadway corridor.

PROJECT UNDERSTANDING

We understand that the County may decide to establish a new transportation corridor in the vicinity of Rhodes Lake Road, connecting the area south of Bonney Lake with SR 162 (see Figure 1). Three of the alternatives would extend westward from the upland area east of the Puyallup River Valley (the Orting Plateau), down a relatively steep slope to the Puyallup River Valley, and across the valley to SR 162. These alternatives would require building a new bridge structure or widening an existing bridge across the Puyallup River. One of the proposed alternatives would connect the Orting Plateau via a southern connection in the vicinity of Bridge Street in Orting. This alternative would require building a new bridge across the Carbon River. The area of study for this investigation is bounded by the base of the hillside along the east side of the Puyallup and Carbon Rivers, 198th Avenue East on the east, the 17400 Street East block on the south, and Fennel Creek on the north. The alternatives being considered are described below:

- Alternative A is the Baseline (No Build) Alternative. With this alternative roadway improvements currently planned in the area would be built, but a new roadway corridor connecting the Orting Plateau to the Puyallup River Valley would not be established.
- Alternative B is planned to cross the Puyallup River in the vicinity of 116th Street East, extend southeast up the steep slope east of the Puyallup River through an existing gravel mine. The route generally parallels the north side of the Tacoma Public Utility (TPU) pipeline road and roughly follows the pipeline alignment to connect with the existing Falling Water Boulevard East and then Rhodes Lake Road East in the vicinity of 188th Avenue Court East. Alternative B would terminate at the connection with 198th Avenue East.
- Alternative C would extend across the Puyallup River at about 128th Street East, then northward along McCutcheon Road about 2,000 feet, then up the hillside through the existing gravel mine and tie into Alternative B near the top of the slope.
- Alternative D would both cross the Puyallup River in the vicinity of 128th Street East. After crossing the Puyallup River, Alternative D extends southward up the hillside along the east side of the Puyallup River to the top of the slope, where the route turns eastward for about 2,500 feet, then northeast for about 5,000 feet to where it ties into Alternative B.
- Alternative E would cross the Carbon River in the vicinity of Bridge Street Southeast and would extend north up the slope to 160th Street East. Alternative E would follow 160th Street East and connect to 198th Avenue East.

Alternatives F1, F2, and F3 are combinations of the alignments described above.

- Alternative F-1 - Combines Alternatives B and E
- Alternative F-2 - Combines Alternatives C and E
- Alternative F-3 - Combines Alternatives D and E

SCOPE OF SERVICES

Landau Associates was contracted by Parametrix to provide geotechnical engineering services for the project. Our services were provided in accordance with our November 21, 2002 and our November 1, 2005 proposals and Standard Subconsultant Agreement for Professional Services between Landau Associates and Parametrix. Our services included the following:

- Compiled and reviewed available geologic and geotechnical information in the general project vicinity. Sources of information are listed in the References section of this technical memorandum.
- Completed a limited visual reconnaissance of the study area to observe existing conditions and field verify the mapped geologic conditions.
- Prepared and submitted this revised technical memorandum summarizing our findings and conclusions relating to the roadway corridor.

EXISTING CONDITIONS

The following sections provide a description of the surface conditions observed during our March 25, 2003, and April 25, 2006 site reconnaissance and general surficial geologic conditions within the study area.

Surface Conditions

The Rhodes Lake Road study area extends from the floor of the Puyallup/Carbon River Valley eastward to the Orting Plateau. Major topographic features within the study area were formed by various glacial and non-glacial processes, modified by post-glacial processes. In the area of the proposed northern routes, the topography rises sharply upward from the valley floor about 400 to 500 feet to a plateau occupied by Canyon Falls Creek, then upward to an elevation of about 700 feet to the Orting Plateau to the east. The slopes along the east side of the Puyallup River Valley are generally heavily forested with the exception of the gravel mine between Fennel Creek and Canyon Falls Creek. At the time of our reconnaissance in March 2003, the area was mostly undeveloped and forested. Some areas had recently been logged. Other then the gravel mine, the only other significant development within the area of the north routes is a privately-owned fish hatchery on Canyon Falls Creek. We understand that several major housing developments are planned for areas north and south of Canyon Falls Creek.

During our reconnaissance, we did not observe indications of recent slope instability along the east wall of the Puyallup River Valley. We did not observe any active springs or seeps along the east wall of the Puyallup River Valley, though springs and seeps may be obscured by the heavy forest cover.

In the area of the Alternative E, the topography rises sharply upward from the valley floor to an elevation of about 500 to 600 feet, then less steeply to the upland area at an elevation of about 800 feet. At the time of our reconnaissance in April 2006, the area was mostly undeveloped and forested, with scattered residences at the end of 186th Avenue East and in the vicinity of 193rd Avenue East and 166th Street East.

During the April 2006 reconnaissance, we did not observe indications of large-scale instability of the slope along the east side of the Carbon River, though several areas of shallow, surficial slope failures were observed along the east side of the Carbon River, mostly as a result of undercutting by the river. Several isolated zones of seepage were observed along the lower portion of the slope. Most of the seeps emanated above the contact with the Orting Drift (Qor). Groundwater seepage was observed as high as about elevation 350 feet during our April 2006 reconnaissance.

Geologic Setting

Our understanding of the geology within the study area is based on conditions observed during our March 25, 2003, and April 25, 2006 site reconnaissance, review of published geologic maps (Crandell 1963), review of water well logs (Landau Associates 1998), and geotechnical and geologic investigations completed in the study area by others (AESI 1997 and GeoEngineers 1984).

The geology within the study area is relatively complex and a result of multiple past glaciations that have occurred over the last 2 million years. The surficial geology was extensively mapped by Crandell (1963). Crandell's work identified four separate continental glaciations (Orting, Stuck, Salmon Springs, and Vashon) and three major interglacial periods (Alderton, Puyallup, and Holocene) in the study area. The mapped geology was found to be generally consistent with conditions observed during our reconnaissance, with the exception of the area north of the Fish Hatchery and at the Maranatha Surface Mining Facility. The mapped surficial geology is illustrated on Figure 2.

Within the study area, the surficial geology is dominated by Vashon drift deposited during the last glaciation about 16,000 to 13,000 years before present (ybp), and post Vashon age (Holocene) deposits. Older, non-glacial deposits of the Alderton and Puyallup Formations were mapped by Crandell (1963) along the base of the slopes in the lower reach of Fennel Creek. Older glacial and non-glacial deposits likely underlie the Vashon and post Vashon deposits at depth. As shown on Figure 2, Vashon glacial till is present in the upland area south and east of Canyon Falls Creek and Fennel Creek. Ice contact stratified drift and proglacial stratified drift are present along the western edge of the upland area and form the east wall of the Puyallup River Valley within the study area. Recent alluvial deposits form the Puyallup River Valley floor and the floor of the lower reach of Fennel Creek. Osceola mudflow deposits are present within the upper portion of the Fennel Creek drainage. Electron mudflow deposits are present in the Puyallup River Valley floor.

The following provides a general description of the various geologic units mapped within the study area, from oldest to youngest. Figures 3 through 6 illustrate the inferred geologic conditions along several of the alternatives being considered for the Rhodes Lake Road Corridor. The geology shown on Figures 3 through 6 is based on interpretation, extrapolation, and interpolation of widely spaced water logs. Actual geologic conditions could vary significantly from that shown of the geologic profiles.

Orting Drift (Qor)

As described by Crandell (1963), the Orting Drift consists of about a maximum of 260 feet of deeply oxidized sand and gravel, and minor amounts of sand and compacted till deposited by Puget glacial lobe. In the study area, the Orting Drift has been mapped along the base of the slopes in the area of the Alternative E along the east side of the Carbon River.

Alderton Formation (Qad)

As described by Crandell (1963), the Alderton Formation consists of interbedded volcanic mudflows, alluvium, peat, lake sediments, and volcanic ash. The sequence is interpreted to represent deposition of nonglacial sediments derived from Mount Rainier. In the study area, the Alderton Formation has been mapped along the base of the slopes in the lower reach of the Fennel Creek drainage.

Puyallup Formation (Qpy)

The Puyallup Formation is described by Crandell (1963) as consisting of about 135 feet of alluvial and lacustrine sand, alluvial gravel, mudflows, volcanic ash, and peat. Where exposed on the walls of the Fennel Creek ravine, the unit consists mostly of coarse-grained deposits above basal lacustrine beds about 3-feet thick. The lower 85 feet consists of several mudflows separated by thin sand layers.

Vashon Drift (Qgt, Qpf, Qpd, Qpa, Qpv, Qil/Qit)

Mapped deposits of Vashon Drift within the study area consist of glacial till, ice contact stratified drift, and proglacial stratified drift. Glacial till is present in the upland area south and east of Canyon Falls Creek and Fennel Creek. As described by Crandell (1963), glacial till in the study area generally consists of very compact, unsorted and unstratified mixture of gravel and cobbles in a matrix of silt and sand. Randomly distributed boulders are present, but not common. Till thickness in the study area likely varies from a few feet to over 30 feet.

According to Crandell (1963), ice contact stratified drift was deposited in ice-walled depressions and left behind as an irregular group of mounds that are present along the east wall of the Puyallup River Valley. The deposits underwent severe collapse as the glacial ice retreated. The chaotic topography along the slope is a result of this collapse. In the study area, ice contact deposits extend from about Fennel Creek south to the southern extent of the Orting Plateau. The ice contact deposits are described as poorly sorted sand and gravel deposits with cobbles and scattered boulders as large as 8 feet in diameter.

Proglacial stratified drift was deposited in a delta complex along the margin of a proglacial lake, referred to as Glacial Lake Puyallup. The lake occupied the Puyallup River Valley near the end of the Vashon glaciation and drained westward through a spillway, west of present day Orting. Melt water streams flowed southward through the present day Fennel Creek drainage and into Glacial Lake Puyallup, forming an extensive delta complex that extends along the east valley wall slope from just north of Fennel Creek to about 2½ miles south of Fennel Creek. Proglacial stratified drift is described as consisting of sand and gravel with cobbles and scattered boulders.

Osceola Mudflow Deposits (Qom)

Osceola mudflow deposits are mapped along the valley floor of the upper reach of Fennel Creek and extend southward to about Victor Falls. The deposits are described by Crandell (1963) as consisting of unsorted and unstratified mixture of gravel, cobbles, silt, and sand, with randomly distributed boulders. In the study area, the Osceola mudflow deposits are likely underlain by proglacial stratified drift. There was no readily available information regarding possible thickness of Osceola mudflow unit in the study area, based on explorations completed elsewhere in the general study area, we expect the thickness to be generally less than 20 feet.

Electron Mudflow Deposits (Qem)

Electron mudflow deposits are mapped as isolated occurrences along the Puyallup River Valley floor generally west of SR 162. The deposits are similar to the Osceola mudflow deposits and are described by Crandell (1963) as consisting of unsorted and unstratified mixture of gravel, cobbles, silt, and sand, with randomly distributed boulders and are about 10 to 15 feet thick in the study area. In the Alderton area, Electron and Osceola mudflow deposits are separated by about 10 feet of sand and gravel deposited by the Puyallup River (Crandell 1963).

Alluvium (Qal)

Alluvial deposits are mapped along the valley floor of the Puyallup River, the valley floor of the lower reach of Fennel Creek, and in the vicinity of Rhodes Lake. In the Puyallup River Valley and the lower reach of Fennel creek, alluvium generally consists of interbedded and interfingered deposits of gravel, sand, and silt with occasional layers of organic soil. In the Puyallup River Valley, alluvium is interbedded with both Electron and Osceola mudflow deposits. In the vicinity of Rhodes Lake, Alluvium has been described by Crandell (1963) as chiefly peat.

Surficial Soil

Surficial soil within the study area formed over relatively young glacial deposits of the Vashon glaciation and post Vashon deposits and generally exhibit a direct relationship to the underlying parent material, topography, climate, and vegetation. The following soil types have been mapped in the general study vicinity by the U.S. Department of Agriculture Soil Conservation Service (1979):

- Alderwood Series
- Everett Series
- Indianola Series

- Kapowsin Series
- Kitsap Series
- Xerochrepts
- Various Alluvial Soils

Each of the above soil series is described in greater detail in the following sections. Figure 7 illustrates the distribution of the various soil units within the study area.

Alderwood Series (1)

These soils typically consist of gravelly sandy loams and typically form by weathering of the underlying glacial till parent material. Alderwood soil 1B, 0 to 6 percent slopes; 1C, 6 to 15 percent slopes; and 1D, 15 to 30 percent slopes; are mapped on the upland area south of Canyon Falls Creek and along the upper portion of the slope north of Rhodes Lake Road, west of Fennel Creek, and along the proposed route for Alternative E.

These soils are generally moderately well drained becoming poorly drained above the underlying parent material. A perched groundwater table tends to form on the underlying parent material during the winter/spring months. Surface water runoff is very slow to slow and the erosion hazard is slight on slopes of 6 percent or less. On slopes of 6 to 15 percent, surface water runoff is medium and the erosion hazard is moderate. Surface water runoff is medium to rapid and the erosion hazard is moderate to severe on slopes of 15 to 30 percent.

Everett Series (13)

These soils typically consist of gravelly sandy loam and typically form by weathering of the underlying glacial outwash parent material. Everett soils 13B, 0 to 6 percent slopes; 13C, 6 to 15 percent slopes; and 13D, 15 to 30 percent slopes, are mapped on the upland area between Fennel and Canyon Falls Creek, south of Canyon Falls Creek, and along the proposed route for Alternative E.

These soils are somewhat excessively drained. Surface water runoff is slow with little or no erosion hazard on slopes of 6 percent or less. On slopes of 6 to 15 percent, surface water runoff is slow and the erosion hazard is slight. Surface water runoff is medium and the erosion hazard is moderate on slopes of 15 to 30 percent.

Indianola Series (18)

These soils typically consist of loamy sand and typically form by weathering of the underlying glacial outwash parent material. Indianola soils are similar to Everett Series, but contain less gravel. Indianola soils 18C, 6 to 15 percent slopes; and 18E, 15 to 45 percent slopes; are mapped on the upland mainly in the vicinity of Rhodes Lake, though a few scattered areas are mapped on the slope above the Puyallup River and along a portion of the slope south of Fennel Creek.

These soils are somewhat excessively drained. Surface water runoff is medium and the erosion hazard is moderate on slopes of 6 to 15 percent; on slopes of 15 to 45 percent, surface water runoff is medium to rapid and the erosion hazard is moderate to severe.

Kapowsin Series (19)

These soils typically consist of gravelly loam and typically form by weathering of the underlying glacial till parent material. Kapowsin soils 19B, 0 to 6 percent slopes is mapped along the slope above the headwaters of Canyon Falls Creek; and, 19C, 6 to 15 percent slopes; and 19D, 15 to 30 percent slopes; are mapped on the lower portion of the slope above the Puyallup River Valley, north of Rhodes Lake Road.

These soils are generally moderately well drained becoming poorly drained above the underlying parent material. A perched groundwater table tends to form on the underlying parent material during the winter/spring months. Surface water runoff is slow and the erosion hazard is slight on slopes of 6 percent or less. On slopes of 6 to 15 percent, surface water runoff is medium and the erosion hazard is moderate. Surface water runoff is medium to rapid and the erosion hazard is moderate to severe on slopes of 15 to 30 percent.

Kitsap Series (20)

These soils typically consist of silt loam and typically form by weathering of the underlying glacially consolidated lake sediment parent material. Kitsap soils 20C, 8 to 15 percent slopes and Kitsap soils 20D, 15 to 30 percent slopes, are mapped in the area in the vicinity of Alternative E generally on the upper portion of the slope that rises upward from the Carbon River. On slopes of 8 to 15 percent, the soil is moderately well drained. Surface water runoff is slow to medium and erosion hazard is slight to moderate. On slopes of 15 to 30 percent, the soil is moderately well drained. Surface water runoff is medium to rapid and erosion hazard is moderate to severe.

Xerochrepts (47F)

These soils form on steep slopes with gradients of 45 to 70 percent. These soils are formed in both glacial till and glacial outwash materials and are moderately well drained. Xerochrepts are mapped on the steep slopes along the sidewalls of the Fennel Creek drainage, and along the base of the slope along the east side Puyallup River and Carbon River Valleys on both sides of the mouth of the Fennel Creek ravine. Surface water runoff is rapid and the erosion hazard is very severe.

Alluvial Soil

Several types of alluvial soil are mapped in the study area. Sehiahmoo Muck (37A) and Shalcar Muck (38A) are mapped around Rhodes Lake. These soils are poorly drained and contain significant organics. These soils form in depressions and backwaters. Surface water runoff is ponded to very slow and there is no erosion hazard.

Philchuck fine sand (29A), Puyallup fine sandy loam (31A), and Sultan silt loam (42A), are mapped along the Puyallup and Carbon Rivers. These soils are typically deposited in the relatively level area west of the base of the slope. These soils are moderately to excessively drained. Surface water runoff is very slow to rapid and the erosion hazard is generally slight.

Orting loam (28A) is mapped in the level area of the Puyallup River Valley. The soil is formed in the Electron mudflow deposits. The soil is poorly drained, and surface water runoff is very slow. There is no erosion hazard.

Groundwater

Our understanding of groundwater conditions in the area is based on review of available water well logs obtained from the Department of Ecology and review of available geotechnical and hydrogeologic reports in the area.

Hydrogeologic conditions in the study area consist of a relatively complex sequence of glacial and interglacial deposits. The properties of the soil layers vary in their ability to transmit groundwater. In the study area, the hydrogeology can be generally defined by three aquifers (water bearing zones) separated by two aquitards (low permeable units). These aquifers consist of a near-surface water bearing zone present within the recessional sand and gravel deposits that overly a low permeable glacial till that is present along a short segment of Alternative D and along the upland portion of Alternative E. The near-surface water bearing zone forms a shallow, discontinuous water bearing zone that has a significant impact on the underlying shallow aquifer. Portions of the near-surface water bearing zone are seasonal and disappear during the late summer to early fall.

The shallow aquifer is formed at the base of the advance outwash (Qpa) deposits that underlie the glacial till and are exposed in the Canyon Falls Creek drainage. The shallow aquifer is underlain by a series of low permeable units to form the primary aquitard that underlies the study area. Based on review of widely spaced water well logs, the shallow aquifer is generally unconfined and the water table is typically encountered in the vicinity of the northern routes at about 250 feet below the ground surface (BGS) and at about 125 to 250 feet BGS in the area of Alternative E. The shallow aquifer is the primary source of Canyon Falls Creek. The primary aquitard, which generally consists of the Puyallup Formation (Qpy), and/or Alderton Formation (Qad), separates the shallow aquifer. The primary aquitard contains scattered sand and gravel units that provide sufficient water to function as an aquifer for limited supply needs, such as family domestic use. The deep aquifer is formed in sand and gravel deposits that underlie the primary aquifer.

Seismotectonic Setting

The Rhodes Lake Corridor area is located within a convergent plate margin known as the Cascadia subduction zone. Tectonic stresses in Western Washington and Oregon are mostly controlled by the northward movement of the Pacific plate system relative to the North American continental plate. In the Pacific Northwest, geologic processes are further influenced by the interaction and deformation of several subplates. As these plates converge, diverge and subduct beneath each other, the stresses created are relieved by such processes as earthquakes and faulting, tectonic uplift (mountain building), and volcanism.

Of particular significance is the Juan de Fuca plate, which is being driven eastward and thrust beneath the North American plate, to lie as a great tilted slab beneath the entire western portion of Washington, Oregon, the southern portion of British Columbia, and the northern portion of California. The movement of the plates directly affects the seismic activity of the region. Deep events, greater than about 40 kilometers (25 miles) in depth, are associated with the subducting slab, while shallow events, less than 30 kilometers (19 miles) in depth, are attributed to crustal deformation in combination with regional compressive stress within the crust of the overriding North American plate. The zones of high seismicity are separated by a relatively quite zone between 30 and 40 kilometers in depth, indicating that the events are physically uncoupled.

In the tectonic environment of the Pacific Northwest, three distinct potential earthquake zones are possible:

- Subduction earthquakes occurring at the interface of the North American plate and the subducting Juan de Fuca plate. The most recent of these reportedly occurred in about 1700 and was recorded by drowned forest along the Washington coast and by a tsunami that reached Japan.

- Deep subcrustal earthquakes occurring within the subducting Juan de Fuca plate, such as the 1949 Olympia, 1965 Seattle, and 2001 Nisqually earthquakes.

- Shallow crustal earthquakes occurring within the North American plate, such as the 1995 magnitude 5.1 earthquake that occurred in the Federal Way area, and the 1996 magnitude 5.3 earthquake that occurred in the Duvall area.

Lack of historical data regarding subduction earthquakes occurring along the interface between the North American plate and the Juan de Fuca plate has created considerable uncertainty regarding magnitude, epicentral distance, and probability of occurrence of these events. Based on studies of other subduction zones, the potential location of the rupture zone would be at a depth of about 30 to 40 kilometers. This would place the source zone about 100 kilometers offshore, or about 160 to 240 kilometers (100 to 150 miles) west of the corridor. Earthquakes with moment magnitudes of between 8.0 and 9.0 are considered possible, depending on the length of the rupture between the two plates. Data suggested that subduction earthquakes along the Cascadia subduction zone have an average recurrence interval of about 600 years, with the latest event occurring in A.D. 1700 (Goldfinger et al. 2003). Maximum peak horizontal ground accelerations of about 16 to 18 percent of gravity (0.16g to 0.18g) would be likely in the project area as a result of magnitude 9.0 subduction earthquake (Frankel 2003).

Deep subcrustal earthquakes occur within the subducting Juan de Fuca plate at hypocentral depths of between 45 and 70 kilometers (30 and 45 miles) due to tensional forces within the subducting plate. The most recent subcrustal events include the 1949 Olympia earthquake (magnitude 7.1), the 1965 Seattle earthquake (magnitude 6.5), and the 2001 Nisqually earthquake (magnitude 6.8). The maximum credible earthquake for a deep subcrustal event is estimated at about magnitude 7.5 (Woodward-Clyde 1992). Given the depth of the deep subcrustal earthquakes, maximum peak horizontal ground accelerations in the project area are expected to be up to 0.30g.

Because of the thickness of Quaternary sediments overlying much of the bedrock surface in Western Washington, information regarding the location, distribution, and character of shallow crustal faults in Puget Sound lowlands is sparse. Recent research, summarized by Brocher et al. (2001), has identified several generally west to northwest-east to southeast trending crustal fault systems. The fault systems include the Olympia Fault, Tacoma Fault, Seattle Fault, and South Whidbey Island Fault. The Tacoma Fault zone has been mapped as generally trending northwest/southeast through about the center of the Port of Tacoma area then eastward toward the Auburn area (Sherrod et al. 2003). The fault zone is generally north of the Rhodes Lake Road Corridor. The Tacoma Fault is a complex structural zone associated with the southwest dipping Rosedale monocline which is interpreted as a fault-bend fold forming above a deep thrust fault (Johnson et al. 2004). The Tacoma fault is regarded as a north dipping backthrust to the Seattle Fault, so that slip on the deep master thrust fault could result in movement on the Tacoma Fault, the Seattle Fault, or both faults.

The maximum credible earthquake occurring on the Tacoma Fault is estimated at about magnitude 7 (Sherrod et al. 2003). Recent research indicates that an earthquake occurred along the Tacoma Fault between about 850 to 1,250 ybp (Sherrod et al. 2003), though no estimate as to the earthquake magnitude or possible average recurrence interval for earthquakes on the fault has been established. A magnitude 7 plus earthquake occurring on the Tacoma Fault could produce peak horizontal ground accelerations in the project area in excess of 0.5 g (50 percent of gravity).

Fault Rupture

The only mapped fault in the vicinity of the project area capable of producing a surface rupture is the Tacoma Fault Zone. Currently, the Tacoma Fault Zone is mapped north of the project corridor. At this time, no Holocene surface ruptures have been found within the project vicinity.

GEOTECHNICAL ASSESSMENT

The following sections provide a discussion of the geologic hazard areas within the study area and geotechnical considerations for development of the roadway corridor.

Geologic Hazard Areas

The following sections provide a discussion of the identified geologic hazard areas (erosion, landslide, seismic, and volcanic) within the study area.

Erosion Hazard

As defined in Title 18E.40.020 of the Pierce County Code, erosion hazard areas are defined as those areas classified as having moderate to severe, or very severe erosion potential by the Soil Conservation Service. Mapped soil types with moderate to severe or very severe erosion potential include Alderwood 15 to 30 percent slopes (1D); Indianola, 15 to 45 percent slopes (18E); Kapowsin, 15 to 30 percent slopes (19D); Kitsap, 15 to 30 percent slope (20D); and Xerochrepts 45 to 70 percent slopes (47D). These soil types with moderate to very severe erosion potential have been mapped in portions of the study area as described previously.

With the implementation of best management practices, both during and after construction, the site erosion potential can be kept low. Best management practices include restricting earthwork activities to the drier portion of the year (late April through mid October), limiting the size of cleared areas, use of silt fencing, sedimentation ponds, and other applicable erosion control methods (to prevent sediment transport from cleared areas), and revegetating and/or covering cleared areas as soon-as-practical to prevent wind and/or water erosion.

Landslide Hazard

Many of the slopes within the study area will meet the criteria in Title 18E.40.020 of the Pierce County Code for landslide hazard areas. Nine different criteria are used to identify landslide hazard areas. Many of the slopes within the study area meet one to three of the nine criteria. These criteria include:

1) Areas of historic failures, including areas of unstable old and recent landslides
2) Areas with all three of the following characteristics:
    a) Slopes steeper than 15 percent
    b) Hillsides intersecting geologic contacts with a relatively permeable sediment overlying a relatively impermeable sediment or bedrock; and
    c) Springs or groundwater seepage
3) Any area with a slope of 30 percent or steeper and with a vertical relief of 10 or more feet. A slope is delineated by establishing the toe and top and measured by averaging the inclination over at least 10 feet of vertical height.

Most of the slopes meeting the above criteria are present along the east slope of the Puyallup River/Carbon River Valley margin, the valley walls composing the Fennel Creek drainage, and along the south and east sides of Canyon Falls Creek drainage. Landslide hazard areas are associated with mapped soil units Alderwood series, 15 to 30 percent slopes (1D); Everett series, 15 to 30 percent slopes (13D); Indianola series, 15 to 45 percent slopes (18E); Kapowsin series, 15 to 30 percent slopes (19D); Kitsap series, 15 to 30 percent slopes (20D); and Xerochrepts series 45 to 70 percent slopes. The expected type of slope instability within the study area is expected to include shallow debris slumps and/or debris flows, and raveling. Though large-scale, deep-seated failures are possible in this area, there are no known mapped features of this type within the study area.

It is beyond the scope of this report to individually identify slopes within the study area meeting one or more of the above criteria. Additional investigations will be necessary to quantify the landslide hazard once a preferred alternative is selected.

Seismic Hazard

Per Title 18E.40.030 of the Pierce County Code, seismic hazard areas are those that are subject to severe risk of damage as a result of earthquake-induced ground shaking, slope failure, settlement, or liquefaction.

Steep slopes within the study area may be affected by ground shaking during a large earthquake. Seismically-induced slope failure could include shallow debris slumps and flows, and possibly deep-seated, rotation slope movements. It is beyond the scope of this report to individually identify slopes within the study area meeting one or more of the above criteria. Additional investigations will be necessary to quantify the landslide hazard once a preferred alternative has been selected. In our opinion, the overall risk of seismically induced slope failures within the study area is low to moderate.

Liquefaction is a process where a saturated soil looses strength as a result of ground shaking. The liquefaction susceptibility of the soil within the Puyallup River Valley, in the valley floor of the lower reach of the Fennel Creek drainage, and around Rhodes Lake is mapped as Category I (Dragovich et al. 1995). These soils have a high susceptibility to liquefaction during a seismic event. Portions of the east valley wall are mapped as Category II. These soils include Holocene lacustrine and mass waste deposits and late Pleistocene sandy glacial lacustrine sediment, and have a moderate susceptibility to liquefaction during a seismic event. The remainder of the study area is mapped as Category III. These soils have a low susceptibility to liquefaction during a seismic event.

Volcanic Hazard

Per Title 18E.40.050 of the Pierce County Code, volcanic hazard areas are those that are subject to mudflows of similar magnitude to the historic Electron Mudflow. Based on mapping by Scott and Vallance (1995), the maximum mudflow extent is represented by the Osceola mudflow and represents a worst-case scenario. They define an average recurrence interval for this type of event at 10,000 years. A flow of this size is expected to inundate the entire Fennel Creek drainage and the Puyallup River Valley. The Electron mudflow is assigned an average recurrence interval of 500 to 1000 years. A flow of similar size to the Electron mudflow is expected to possibly inundate the lower reach of the Fennel Creek drainage and the Puyallup River Valley.

Geotechnical Considerations

Based on preliminary roadway cross-sections developed by Parametrix, substantial cuts of possibly over 50 to 60 feet may be necessary to accommodate the design grades as the roadway rises upward from the valley floor for Alternatives B, C, and D and over 100 feet for Alternative E. In addition, significant fills for up to 100 plus feet will be necessary at the base of the hillside for embankments for Alternatives B and E. Fills of less than about 30 feet will be necessary at the base of the hillside for Alternatives C and D. A significant fill will also be necessary along Alternative 2 where it crosses Canyon Falls Creek to accommodate design grades.

Based on available information regarding expected subsurface soil conditions in the area of the northern routes, excavations into the hillside along the Puyallup River to establish planned road grades are expected to encounter glacial ice contact stratified drift and proglacial stratified drift. These geologic units generally are present on the hillside to about elevation 500 feet. The ice contact deposits are mapped as extending to about elevation 600 feet along the east wall of the Fennel Creek drainage and the southern portion of the Orting Plateau. On the flanks of the lower hillside, the deposits can be over several hundred feet in thickness, while on the plateau and the east wall of the Fennel Creek drainage, the thickness is expected to be variable. Well log data indicates that the deposits on the upper portion of the hillside may be upwards of 100 feet thick. These soils are expected to consist predominately of sandy gravel to gravelly sand, occasionally with silt. Advance outwash and ice contact stratified drift is expected to be present along most of the upland portions of Alternative B, and on the eastern portion of Alternative D. The material makes excellent borrow.

Overall, the glacial ice contract stratified drift, proglacial stratified drift, and advance outwash have low moisture sensitivity (can be worked during wet weather), are readily compactable, and provide excellent foundation support of pavement and retaining wall foundations. The material often contains oversized particles (cobbles and boulders). Screening of oversized material is generally necessary for use as retaining wall backfill and for trench backfill. Stormwater infiltration is generally feasible in these materials.

Temporary excavation slopes in glacial ice contact stratified drift, proglacial stratified drift, and advance outwash can stand as steep as 1½H:1V (horizontal to vertical). At these inclinations, the surface material tends to ravel. Permanent slopes should be no steeper than 2H:1V. Steeper slopes tend to ravel and it can be difficult to establish vegetation for erosion control.

For Alternative E, several geologic units would be encountered in cuts on the hillside face. In the lower portion of the hillside, Orting Drift (Qor), Stuck Drift (Qst) which is not shown on the surficial geology map but has been mapped elsewhere in the study area to overlie the Orting Drift, the Puyallup Formation, and ice contact (Qil) deposits are expected to be present. These soils are expected to consist of very dense sand and gravel with varying silt content, silty sand with variable gravel content and occasional lacustrine deposits. In the upper portion of the hillside, glacial till is expected to be encountered in cuts. Most of the excavated soil from road cuts could be reused as road fill and trench backfill material. The siltier soils will exhibit moisture sensitivity and their use will be limited to drier portions of the year. The siltier soils will make for poor retaining wall backfill.

Temporary excavation slopes in the various geologic units along the proposed route for Alternative E can stand as steep as 1½H:1V (horizontal to vertical). At these inclinations, the surface material tends to ravel. Permanent slopes should be no steeper than 2H:1V. Steeper slopes tend to ravel and it can be difficult to establish vegetation for erosion control.

Glacial till is expected to be present along a portion of Alternative D, along the eastern portion of Alternative B, east of Canyon Falls Creek, and on most of the upland portion of Alternative E. Glacial till typically consists of very dense, silty to very silty sand with variable gravel content. When disturbed, the soil can be highly erodible. The soil is highly moisture sensitive (difficult to work with during wet weather), and the soil may need moisture conditioning (drying) to achieve compaction. When properly compacted, the soil provides good support of pavement. The permeability of the soil is generally very low and not well suited for use as wall backfill. Stormwater infiltration is generally impractical. The soil is generally suitable as trench backfill during the summer/early fall, but difficult to compact during wet weather. Moisture conditioning is often necessary.

Temporary excavation slopes in glacial till can stand as steep as 1H:1V in the absence of groundwater seepage. Groundwater seepage can result in unstable slopes. Permanent slopes may be steeper than 1½H:1V, but it can be difficult to establish vegetation on the slope. Temporary excavation slopes need to be covered to protect against erosion. Permanent slopes should be vegetated as soon as practical slopes to limit erosion.

Groundwater may be encountered in deep cuts along the face of the hillside along the northern routes if the saturated portion of the advance outwash deposits (Qpa) is exposed in the excavation. If encountered, significant groundwater seepage could result in increased erosion and possibly slope instability.

Along Alternative E, groundwater may be encountered in deep cuts along the face of the hillside if the saturated portion of the advance outwash deposits (Qpa) is exposed in the excavation and possibly near the top of the Orting Drift. Groundwater seeps were observed as high as about elevation 350 feet during our 2006 reconnaissance. If encountered, significant groundwater seepage could result in increased erosion and possibly slope instability.

In the upland area south of Canyon Falls Creek, the elevation of the groundwater tables slopes downward toward the creek. Excavation to establish road grades for Alternative D may encounter significant groundwater if excavations are near or below the water level in Canyon Falls Creek, approximately elevation 420 to 440 feet. North of Canyon Falls Creek, the elevation of the groundwater table is expected to slope downward towards Fennel Creek and groundwater levels are likely lower than on the south side of Canyon Falls Creek.

USE OF THIS TECHNICAL MEMORANDUM

This technical memorandum was prepared for the exclusive use of Parametrix and Pierce County for specific application to this project. The use by others, or for purposes other than intended, is at the user's sole risk. The findings, recommendations, and opinions presented herein are based on conditions observed during our site reconnaissances and review of readily available geologic and geotechnical information. Within the limitations of scope, schedule, and budget, the analyses, conclusions and recommendations presented in this technical memorandum were prepared in accordance with generally accepted professional engineering principles and practices in the Puget Sound area at the time this report was prepared. We make no other warranty either express or implied.

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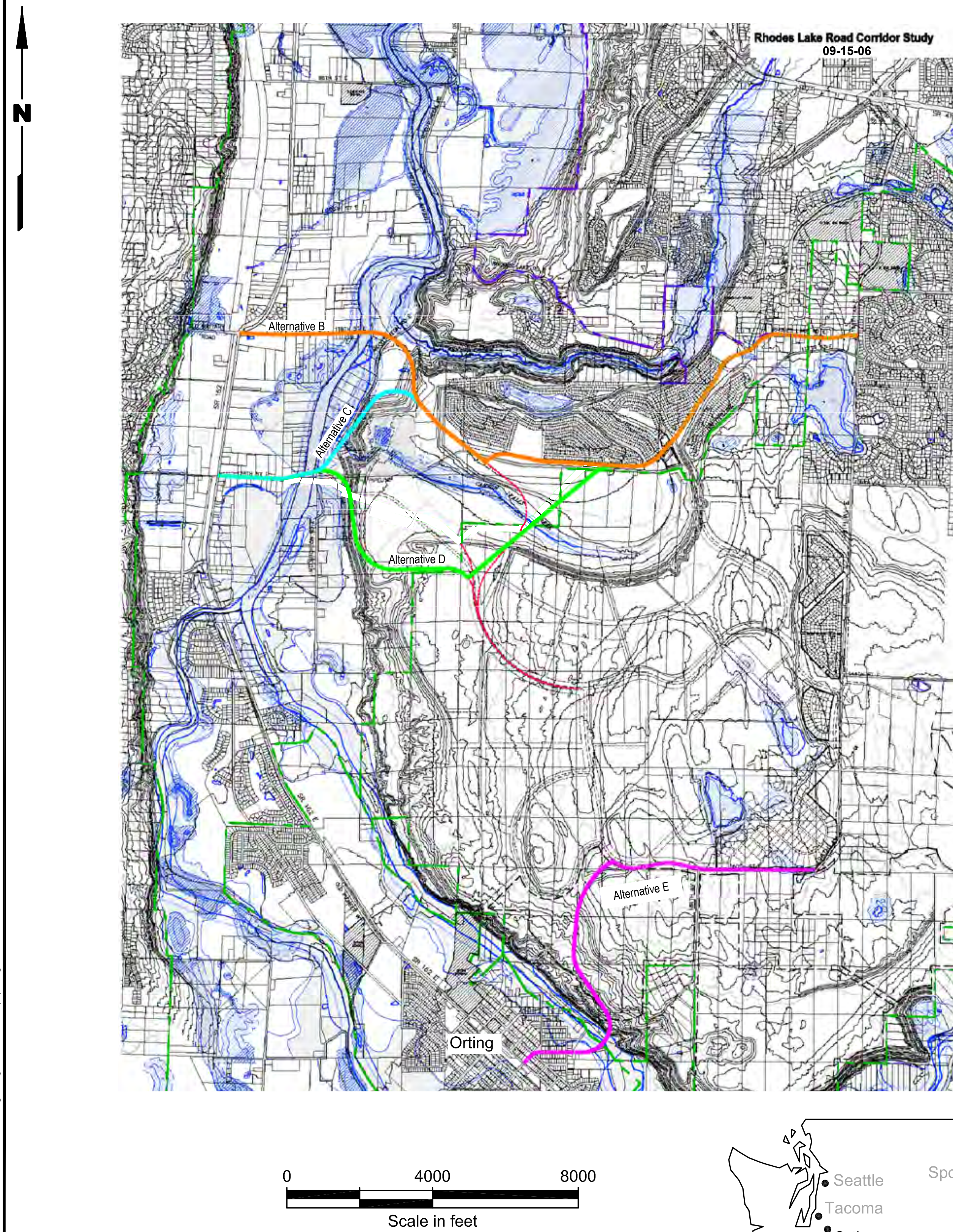
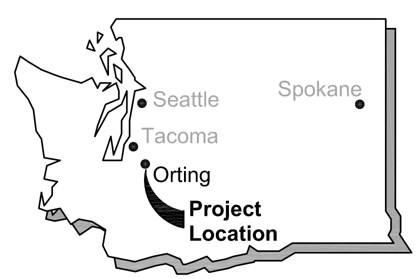
ATTACHMENTS

Figure 1 - Vicinity Map
Figure 2 - Geologic Map
Figure 3 – Alternative B Geologic Profile
Figure 4 – Alternative C Geologic Profile
Figure 5 – Alternative D Geologic Profile
Figure 6 – Alternative E Geologic Profile
Figure 7 - Distribution of Surface Soil Classifications

Rhodes Lake Road Alternative Map





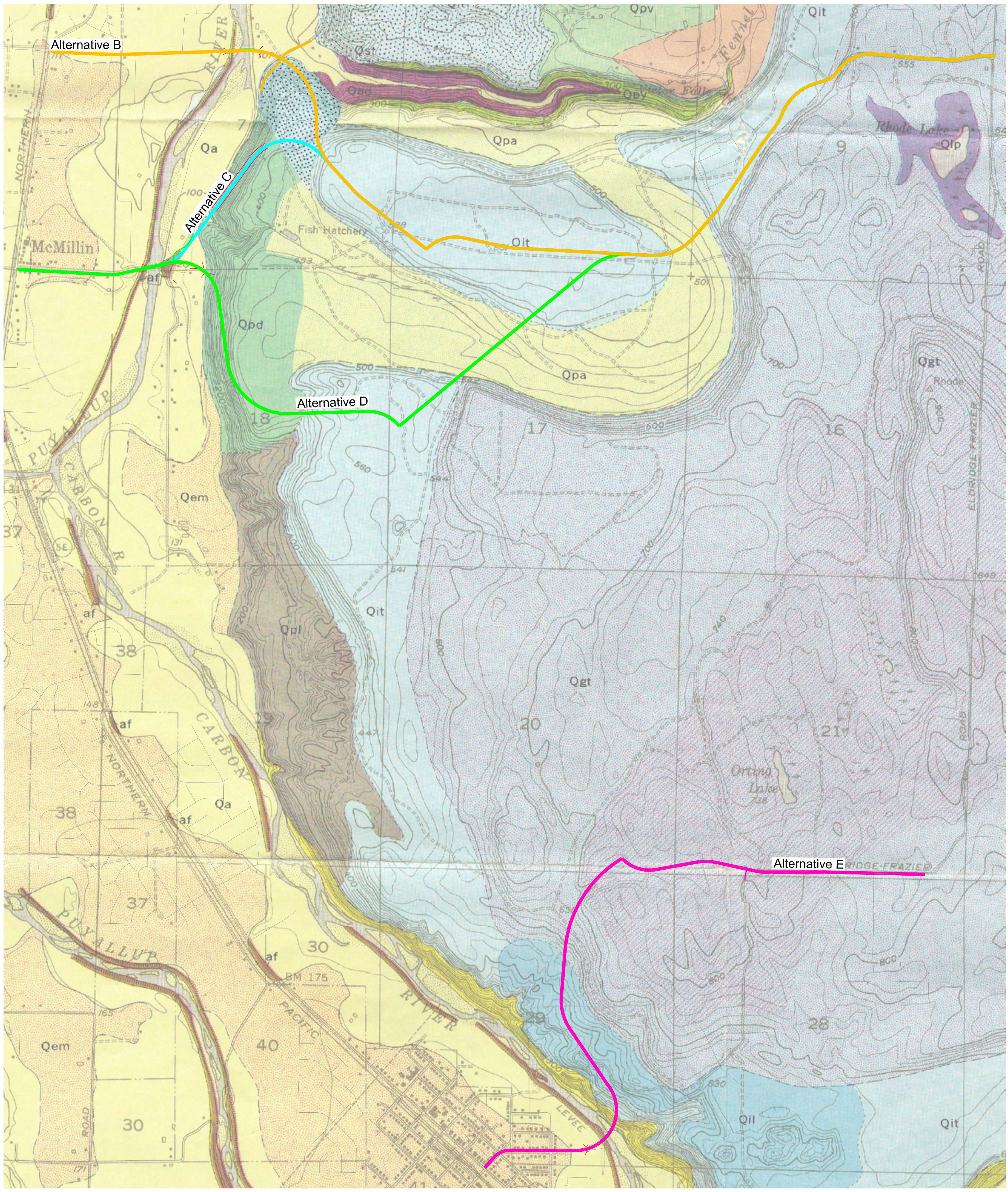
Base map source: PMX 2006

Rhodes Lake Road | Y:\193\034.020\Drawings\Figure 1.DWG (A) "Figure 1" 7/31/2006

Landau Associates

Rhodes Lake Road Corridor Pierce County, Washington	**Vicinity Map**	Figure 1

N



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Scale in Feet

Legend

af	af	Artificial Fill
Qa	Qa	Alluvium
Qlp	Qlp	Lacustrine Deposits
Qem	Qem	Electron Mudflow
Qom	Qom	Osceola Mudflow
Qil/Qit		Ice-contact Stratified Drift
Qpv	Qpv	Proglacial Stratified Drift
Qpa	Qpa	Proglacial Stratified Drift
Qpd	Qpd	Proglacial Stratified Drift
Qpl	Qpl	Proglacial Stratified Drift
Qgt	Qgt	Glacial Drift, Chiefly Till
Qpy	Qpy	Puyallup Formation
Qad	Qad	Alderton Formation
Qor	Qor	Orting Drift
Alternative B		Geologic Profile (See Figures 3 Through 6)

Note

1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

2. Geologic Map was altered to reflect observations made in the field.

Base map source: Crandell 1963, Pierce County GIS 2005, PMX 2006

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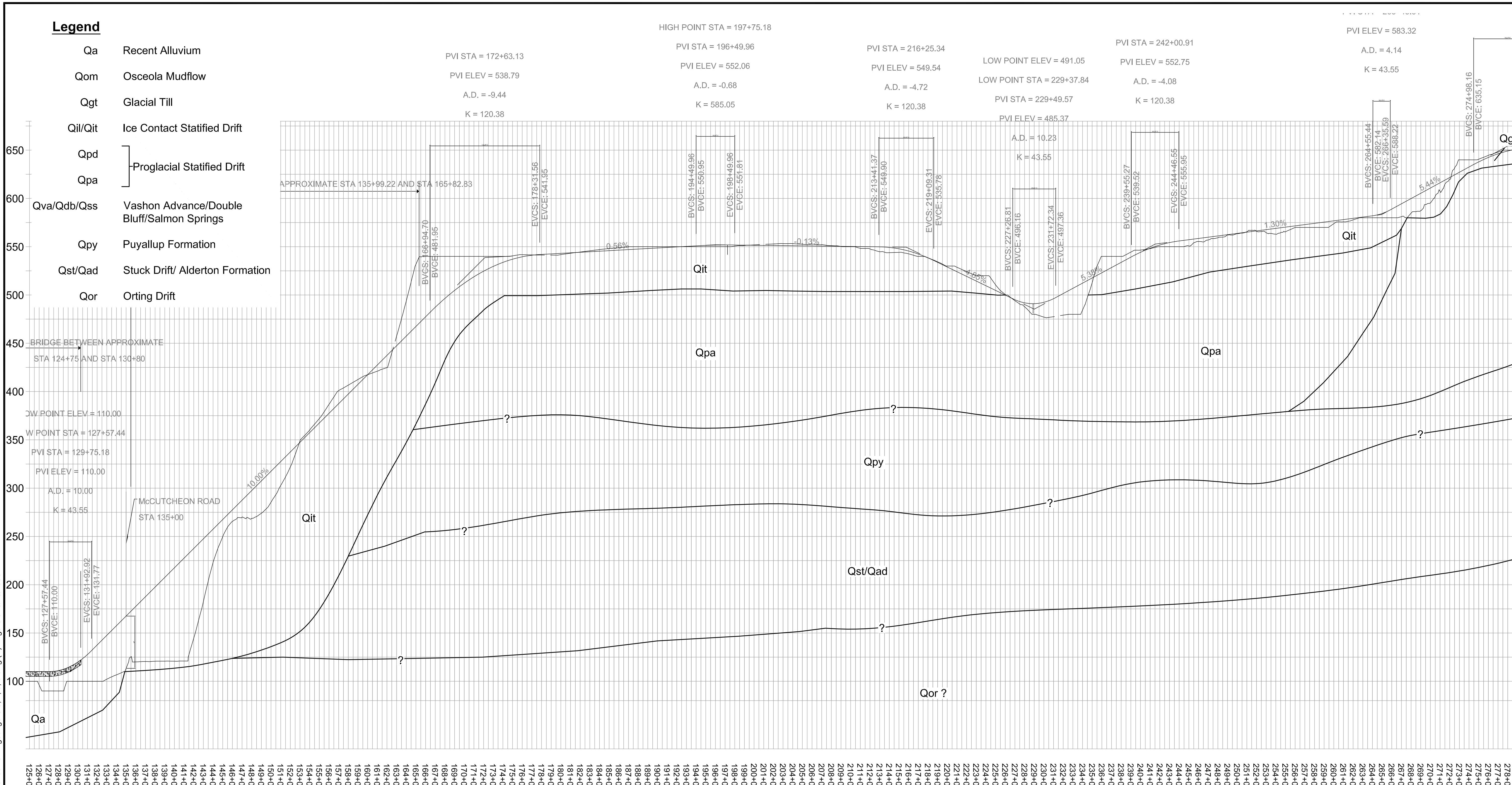
Rhodes Lake Road Corridor Pierce County, Washington	**Geologic Map**	Figure 2



Note

1. This profile is based on interpretation, extrapolation and interpolation of widely spaced water well logs, the mapped surfical geology, and our understanding of the regional geology. Actual conditions may vary significantly from those shown on the profile

0 1000 2000
Scale in Feet
Vertical Exaggeration 10X

Landau Associates

Rhodes Lake Road Corridor
Pierce County, Washington

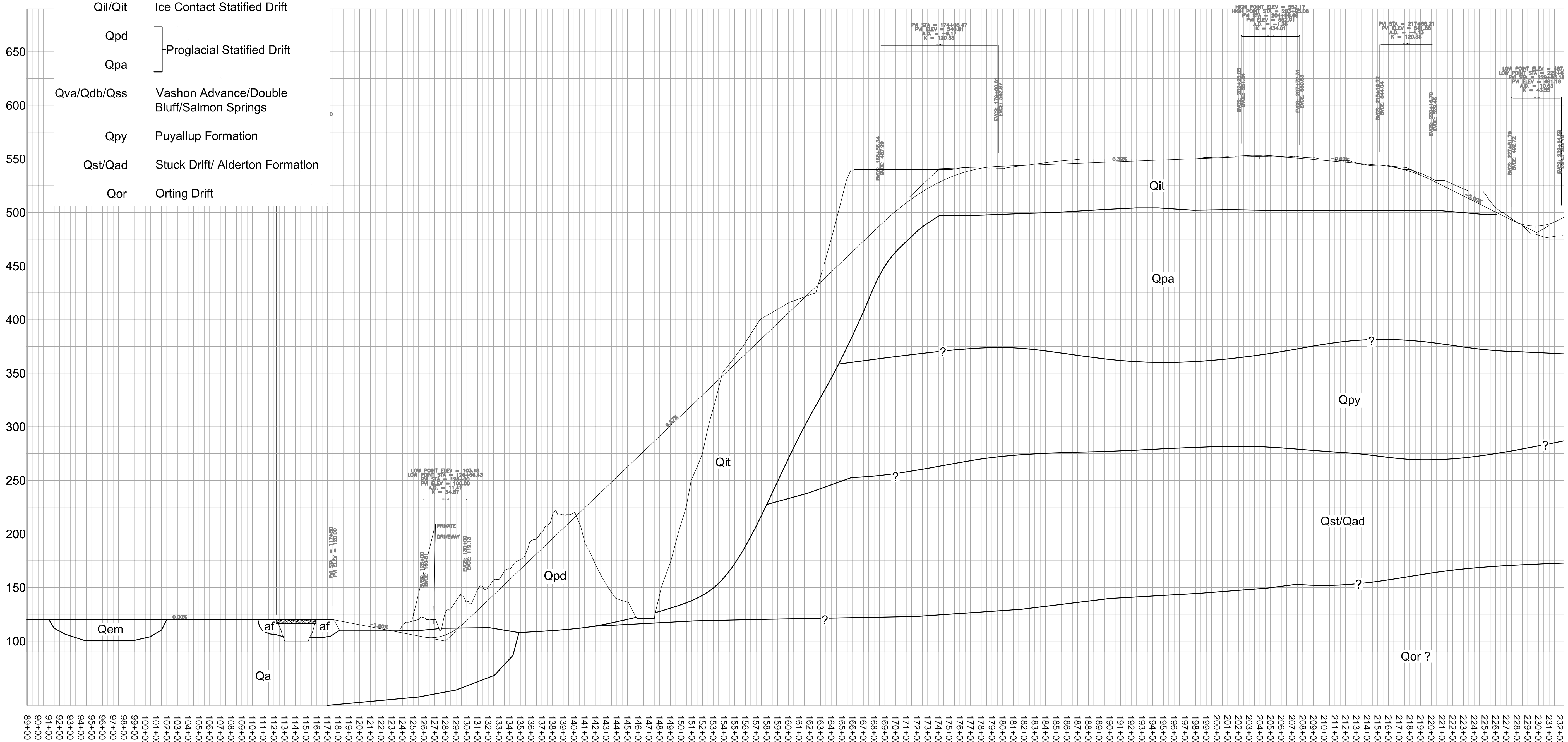
Geologic Profile Alternative B

Figure 3

Rhodes Lake Road | Y:\193\034.020\Drawings\Figure 3, 4, 5, 6.dwg (A) "Figure 3" 8/18/2006

Legend

Qa	Recent Alluvium
Qom	Osceola Mudflow
Qgt	Glacial Till
Qil/Qit	Ice Contact Statified Drift
Qpd	Proglacial Statified Drift
Qpa	Proglacial Statified Drift
Qva/Qdb/Qss	Vashon Advance/Double Bluff/Salmon Springs
Qpy	Puyallup Formation
Qst/Qad	Stuck Drift/ Alderton Formation
Qor	Orting Drift



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Note

1. This profile is based on interpretation, extrapolation and interpolation of widely spaced water well logs, the mapped surfical geology, and our understanding of the regional geology. Actual conditions may vary significantly from those shown on the profile

0 1000 2000
Scale in Feet
Vertical Exaggeration 10X

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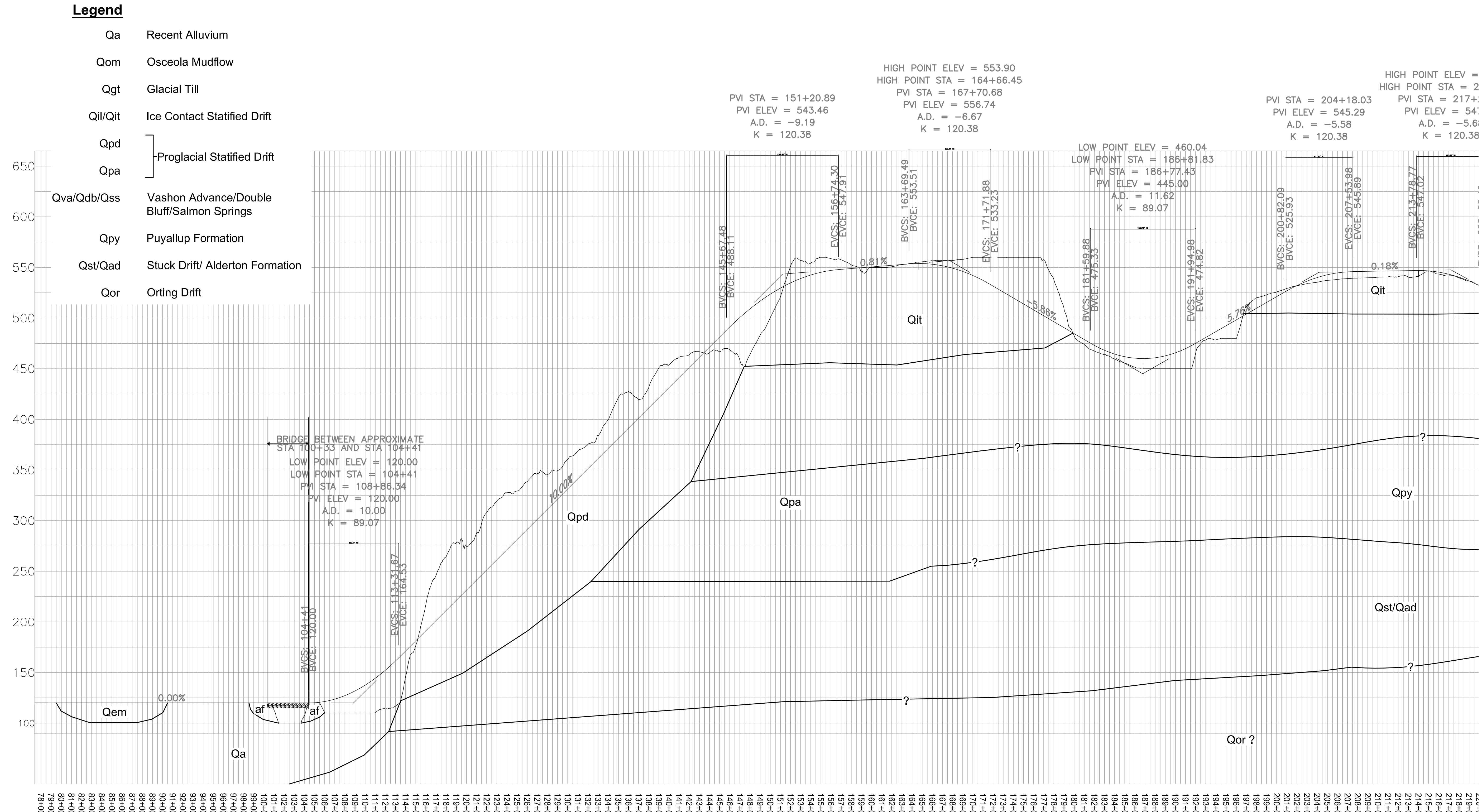
Rhodes Lake Road Corridor
Pierce County, Washington

Geologic Profile Alternative C

Figure 4

Rhodes Lake Road | Y:\193\034.020\Drawings\Figure 3, 4, 5, 6.dwg (A) "Figure 5" 8/18/2006



Note

1. This profile is based on interpretation, extrapolation and interpolation of widely spaced water well logs, the mapped surfical geology, and our understanding of the regional geology. Actual conditions may vary significantly from those shown on the profile

LANDAU ASSOCIATES

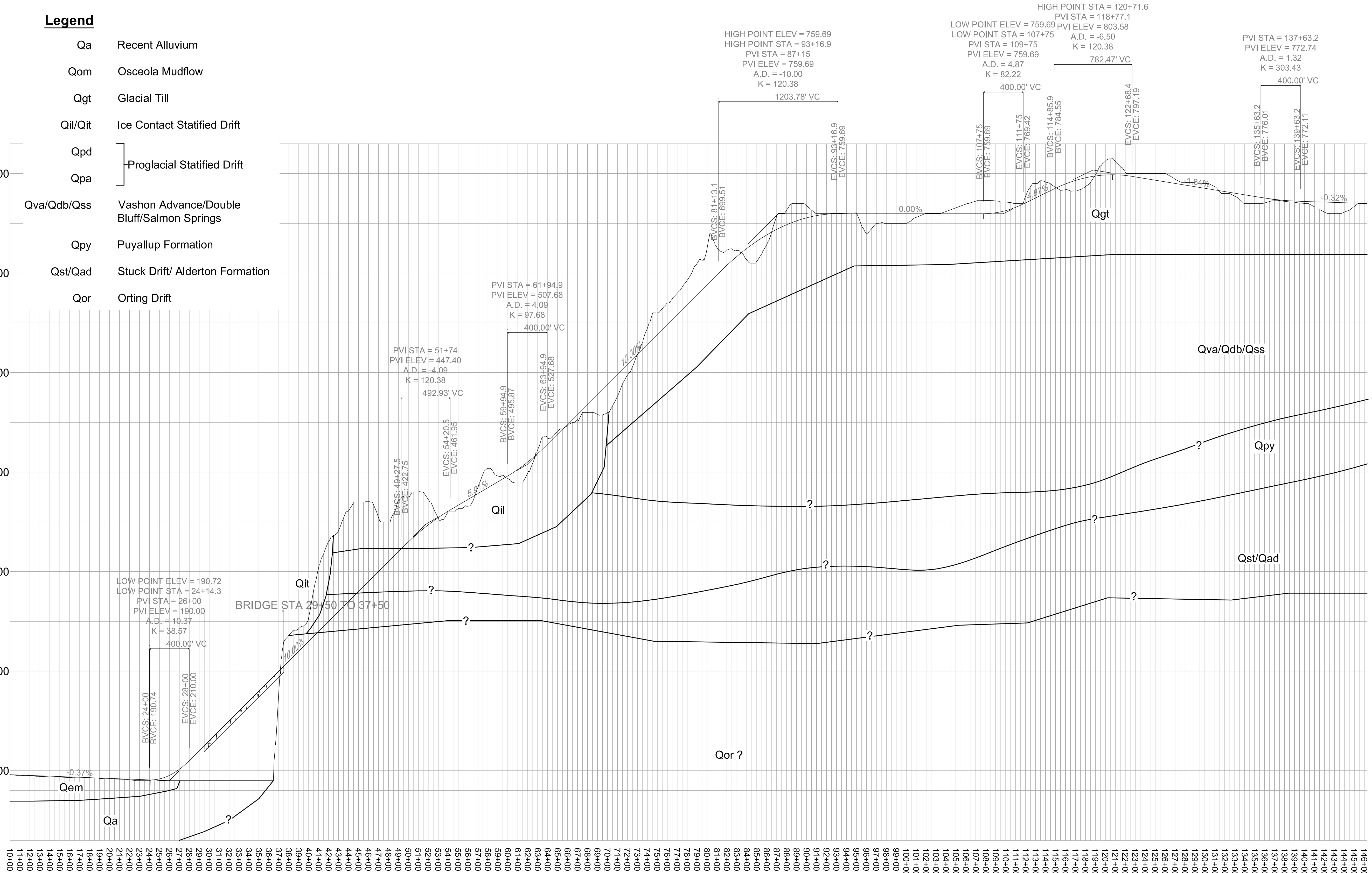
0 1000 2000

Scale in Feet
Vertical Exaggeration 10X

Rhodes Lake Road Corridor Pierce County, Washington	**Geologic Profile Alternative D**	Figure 5

Legend

Qa	Recent Alluvium
Qom	Osceola Mudflow
Qgt	Glacial Till
Qil/Qit	Ice Contact Statified Drift
Qpd Qpa	Proglacial Statified Drift
Qva/Qdb/Qss	Vashon Advance/Double Bluff/Salmon Springs
Qpy	Puyallup Formation
Qst/Qad	Stuck Drift/ Alderton Formation
Qor	Orting Drift



Rhodes Lake Road | Y:\193\034.020\Drawings\Figure 3, 4, 5, 6.dwg (A) "Figure 6" 8/18/2006

Note

1. This profile is based on interpretation, extrapolation and interpolation of widely spaced water well logs, the mapped surfical geology, and our understanding of the regional geology. Actual conditions may vary significantly from those shown on the profile

0 1000 2000
Scale in Feet
Vertical Exaggeration 10X

Base map source: Parametrix 2006

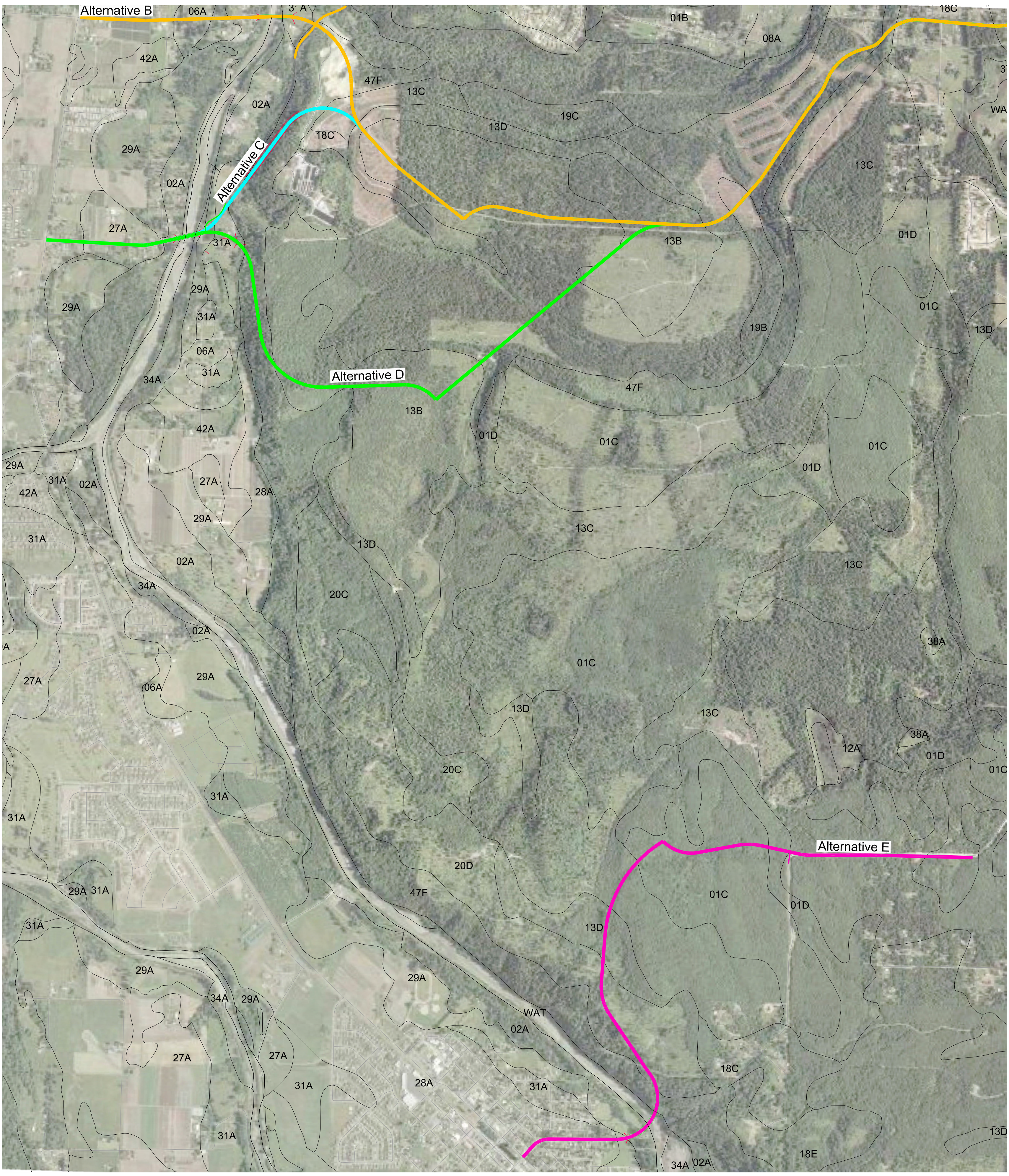
Landau Associates

Rhodes Lake Road Corridor
Pierce County, Washington

Geologic Profile Alternative E

Figure 6

N



Legend

13C USDA Soil Classification
See Text for Description

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Scale in Feet

Base map source: Pierce County GIS 2005, PMX 2006

LANDAU ASSOCIATES

Rhodes Lake Road Corridor Pierce County, Washington	**Distribution of Surface Soil Classifications**	Figure 7