Table 1. Stage 2 Improvements (Continued)

Structure	Location	Approximate Stationing
Stormwater Facilities		**Approximate Station**
Detention Pond FC S2.1	Between Talbot Road and Smithers Avenue	TRS 18+50
Detention Vault FC S2.2	East side of proposed Benson Road, north of I-405 undercrossing	BRS 13+00
Ecology Embankment RT S2.1.1	West side of Talbot Road	TRS 17+00
Ecology Embankment RT S2.1.2	West side of Talbot Road	TRS 20+00
Ecology Embankment RT S2.1.3	East side of Talbot Road, just north of proposed ramp to NB I-405	TRS 20+00
Ecology Embankment RT S2.1.4	SB I-405, just north of Talbot Road overcrossing	1212+40
Ecology Embankment RT S2.2.2	SB I-405 between mainline and ramp to Talbot Road	1219+50
Ecology Embankment RT S2.2.3	Between off-ramp to Talbot Road and Benson Road South	BRS 32+00
Ecology Embankment RT C1.1.1	Between ramp from SB I-405 to Talbot Road and mainline	1225+20
Ecology Embankment RT C.1.2.1	West side of on-ramp from SR 169 to SB 1-405	1273+50

Notes:
Stationing is approximate and referenced to 405 Line unless otherwise noted.
NA indicates information not available at the time this report was prepared.

The proposed improvements are presented on the Site Plans, Figures 3A to 3D. An index to the site plans is provided in Figure 2.

1.3 Scope of Services

The purposes of these geotechnical services are to characterize the existing subsurface conditions and to document the as-built conditions for the existing structures along the project corridor, with limited geotechnical analyses. The specific scope of services is presented in Work Order No. XL2754 of Agreement No. Y-9765, Task No. AA.

1.4 Previous and Current Studies

Numerous geotechnical studies have been completed along the project corridor. Several of the previous geotechnical studies, along with exploration logs, were provided to GeoEngineers by the I-405 Project Team. The geotechnical studies reviewed by GeoEngineers are listed in **Section 8.0** of this report.

Elevation datums presented throughout this report are North American Vertical Datum 1988 (NAVD 88) 88 unless otherwise noted.

2.0 GEOLOGY AND SEISMICITY

2.1 Geologic Setting

The project corridor is located within the central Puget Lowland bordered by the Cascade Mountains to the east and the Olympic Mountains to the west. The Puget Lowland is a north-south trending trough consisting of Holocene period deposits generally overlying a sequence of relatively unweathered glacial and interglacial sediments deposited during the ice ages of the Quaternary period. This region has experienced at least six glaciations in the past 2 million years.

In the central Puget Lowland, the most complete geologic record of the Quaternary period includes the most recent glaciation, the Vashon stade of the Fraser glaciation. The advance and retreat of the Vashon age Puget glacial lobe, approximately 18,000 to 13,000 years ago, deposited most of the near-surface materials and sculpted most of the present landforms within the Puget Lowland. The deposits of this glacial episode reflect a wide range of glacial depositional environments. As the glacier advanced southward, streams deposited sediment that formed a broad plain in front of the advancing glacier. Gravel-size material was deposited close to the glacier, while silt and clay material was transported farther from the glacier. The advance deposits therefore grade from coarse to fine with increasing depth, with silts and clays (lake deposits) at the base, then coarse grained sand and gravel at the top.

Lodgement till, consisting of a non-stratified, well-graded deposit of particle sizes ranging from clay to large boulders, was deposited directly from the glacier itself. The most conspicuous aspect of glacial till is its consolidation, the result of being overridden by the glacial ice. The maximum ice thickness was approximately 3,000 feet in the project vicinity.

As the glacier retreated, the depositional sequence was repeated in the reverse order of the glacial advance, with first coarse grained gravel and sand, then fine grained silts and clays. The retreat was rapid relative to the advance of the glacier, and the recessional deposits are generally not as thick as the advance deposits.

After the Fraser glaciation, Holocene period sediments were deposited over the glacial soils. These deposits typically consist of alluvial soils in river valleys, beach and marine deposits along shorelines, and colluvial deposits (landslide materials) along slopes. Peat and other organic soils occur in numerous depressional areas at the surface. Some of these Holocene period sediments have been modified by human activity, including overexcavation and replacement beneath portions of the project corridor.

Bedrock outcrops are present along I-405 approximately between Benson Road and Cedar Avenue (Yount et al., 1985).

2.2 Published Maps

2.2.1 Geologic Maps

Published geologic information for the project vicinity includes United States Geological Survey (USGS) maps for the Renton quadrangle (Mullineaux, 1965) and a State of Washington Department of Natural Resources (DNR) map for King County, Washington (Livingston, 1971). The maps indicate that six geologic units are present within the project corridor. Listed generally youngest to oldest, these units are:

- **Modified land (m)** consisting of land modified by widespread or discontinuous fill placement.
- **Younger alluvial deposits (Qyal)** consisting of sand and gravel with thin beds of silt and clay deposited by the Cedar River. Locally, the alluvial deposits contain thin peat lenses.
- **Recessional outwash deposits (Qvr, Qvrl and Qvi).** Recessional outwash (Qvr) consisting of loose to medium dense sand and gravel with variable silt and clay content. The recessional outwash is further subdivided into lowland lacustrine deposits and kame-terrace deposits. The lowland lacustrine deposits **(Qvrl)** consist mostly of loose, stratified sand and gravel with silt and clay layers. The kame-terrace deposits **(Qvi)** consist mainly of unconsolidated glaciofluvial sand and gravel deposited against or close to the glacial ice.
- **Glacial drift, undifferentiated (Qvu)** generally consisting of thin deposits of recessional outwash overlying glacially consolidated till, described below.

- **Glacial till (Qvt)** consisting of a very dense, nonsorted mixture of clay, silt, sand, gravel, cobbles and boulders. The upper 2 to 5 feet is often weathered and typically medium dense to dense.
- **Renton formation (Tpr)** (bedrock) consisting of fine- to medium-grained arkosic and feldspathic, micaceous sandstone, but includes some siltstone, sandy shale, and beds of coal and carbonaceous shale.

The mapped alignment geology, based on the DNR Geographic Information System (GIS) Layer and the above-referenced maps, is depicted in Figure 4.

2.2.2 Sensitive Area and Geologic Hazard Area Maps

The majority of the project corridor lies in or adjacent to land designated as sensitive areas or geologic hazard areas. Published sensitive area and geologic hazard areas for the project vicinity include erosion, coal mine hazards, seismic hazards, landslide hazards and steep slope hazards. Severe erosion potential data were obtained from the Natural Resources Conservation Service (NRCS) soils database. The data for the geologic hazards was provided by the City of Renton and King County. The sensitive areas and geologic hazards in the project vicinity are shown in Figures 5 and 6.

Figure 5 identifies several areas along the project corridor as having steep slopes (slopes greater than 40 percent). These areas are mainly along the northbound lanes of I-405. These hazards are likely minor because the Renton formation is located at shallow depths in these areas. If landsliding occurs, the type of landslide would most likely be shallow surficial sliding of the soil overburden or highly weathered, decomposed sandstone.

Figure 6 indicates the areas on either side of the Cedar River are designated as seismic hazard areas because of the potential of the soil to undergo liquefaction during an earthquake event. However, a review of the subsurface soil conditions for the NB and SB Cedar River overcrossings indicates the bridges are founded on dense to very dense sandstone which has a very low potential for liquefaction. A significant portion of the project corridor is within or adjacent to this hazard area.

The Renton formation (bedrock) has been mined for coal throughout the Renton area. The mined areas are shown as coal mine hazards in Figure 6. The mined areas are generally east and/or south of the project corridor. A rock tunnel to access the mined area crosses below I-405 at approximately MP 3.05. According to historical records (Geo. Watkins Evans Consulting, 1919), the entrance of the rock tunnel was located at Elevation 55.3 feet. The tunnel sloped towards the southeast to the first mine level area, located approximately 500 feet east of the project corridor, at Elevation 58.7 feet. Daily records kept by Washington State Department of Transportation (WSDOT) personnel during construction of I-405 note that the rock tunnel was "quite large and will take considerable concrete and material to block it" (WSDOT, September 26). Over the next five working days (WSDOT, September 27 to October 3), they "placed gravel and concreted inside face in the mine tunnel" and "completed placement of gravel at the mine tunnel entrance and placed concrete on the outside face and in the top to seal the tunnel entrance." It is thought that the tunnel diameter was on the order of 25 feet.

As part of this project, WSDOT subcontracted geophysical services in an effort to locate the presence of any voids below the northbound shoulder of the I-405 alignment in the vicinity of the historical mine entrances. Ground penetrating radar (GPR) was used to evaluate the subsurface conditions within about 10 feet of the surface. The presence of a void may indicate the location of the previous tunnel discussed above. The results of the GPR survey did not indicate the presence of a significant void within the upper 10 feet of soil along the northbound shoulder of I-405 (Golder, 2006 Appendix D). Since construction of

I-405, there has been no evidence of roadway subsidence in the vicinity of the rock tunnel. Based on the above information, it appears that there is a moderate coal mine hazard risk along the project corridor.

2.3 GEOLOGIC RECONNAISSANCE

We completed a two-step geologic reconnaissance to identify geologic or other sensitive areas along the project corridor. The first step consisted of a desk-level study that involved reviewing the above geologic, sensitive areas and geologic hazard area maps and available previous explorations and geotechnical reports. In addition, we reviewed "bald earth" Laser Imaging Detection and Ranging (LiDAR) images of the project corridor to aid in assessing geologic hazards.

LiDAR consists of transmitting laser pulses from the air (such as from a helicopter) and then recording the reflected laser pulses as they return from the ground, vegetation, structures and other features. A "bald earth" image can be generated with the recorded data by plotting only those laser pulses that were reflected from the ground. Hence, a "bald earth" image shows the terrain (topography) with the vegetation, structures and other features stripped from the image and can be utilized to reveal previously hidden features such as landslides, faults and erosion hazards.

The second step consisted of field study to define more accurately the geologic features, sensitive areas and hazard areas identified during the desk-level study. Additionally, sensitive and/or hazard areas observed during the field study that were not mapped or apparent during the desk-level study were identified and documented. The field geologic reconnaissance was completed by senior level and staff level personnel from GeoEngineers.

Based on the results of the geologic reconnaissance, it appears that the sensitive areas and geologic hazard areas along the project corridor have been fairly accurately portrayed in the published maps.

In several locations, it was noted that geologic conditions differ from those presented on the published geologic maps (Figure 4). In particular, areas of significant man-made fills (modified land) placed during construction of I-405 and SR 167 are not included on the published geologic maps. This is discussed further in **Section 3.2.7** of this report.

2.4 SEISMICITY

2.4.1 Introduction

The Seattle area is located at the convergent continental boundary known as the Cascadia Subduction Zone (CSZ). The CSZ is an approximately 650-mile-long thrust fault that extends along the Pacific Coast from mid-Vancouver Island to Northern California. The CSZ is the zone where the westward advancing North American Plate is overriding the subducting Juan de Fuca Plate. The interaction of these two plates results in three potential seismic source zones. These three seismic source zones are: (1) the shallow crustal source zone, (2) the Benioff source zone, and (3) the CSZ interplate source zone.

2.4.2 Shallow Crustal Earthquakes

The shallow crustal source zone is used to characterize shallow crustal earthquake activity within the North American Plate. Shallow crustal earthquakes typically occur at depths ranging from 3 to 19 miles (5 to 30 kilometers). The shallow crustal source zone is characterized as being capable of generating earthquakes up to about magnitude 7.5. Large shallow crustal earthquakes are typically followed by a sequence of aftershocks. Shallow crustal faults with known or suspected displacements within the

general project area include the Seattle Fault Zone, the Tacoma Fault and the Southern Whidbey Island Fault.

The Seattle Fault Zone crosses I-405 in the vicinity of the I-90 interchange. The Seattle Fault Zone is a 2½- to 4-mile-wide, east-west trending zone of three or more south dipping reverse faults (Johnson et al., 1999). The Seattle Fault ruptured about 1,100 years ago and caused broad uplift and subsidence on either side of the fault. The rate of recurrence of large earthquakes on the Seattle Fault is thought to be on the order of thousands of years.

The Tacoma Fault is located approximately 12 miles to the south of the I-405/SR 167 interchange. The Tacoma Fault is a west- to northwest-trending reverse-slip fault structure extending from near the southern end of the Hood Canal on the west end to near Auburn on the east end. The fault zone is located just north of downtown Tacoma. It is postulated that if the Tacoma Fault were to rupture along its entire 30-mile length, the earthquake generated would likely be a magnitude 6.5 to 7.5. The most recent major earthquake is estimated to have occurred about 1,100 years ago, resulting in several meters of vertical displacement (Sherrod et al., 2003).

The South Whidbey Island Fault is located approximately 25 miles to the north and west of the I-405/SR 167 interchange. The South Whidbey Island Fault is a northwest trending reverse- and strip-slip fault structure extending from the southern end of Whidbey Island to the Strait of Juan de Fuca. The most recent major earthquake and fault displacement is estimated to have occurred about 3,000 years ago (Kelsey et al., 2003).

The largest known earthquakes associated with the shallow crustal source zone in Western Washington include an event on the Seattle Fault about A.D. 900 and the 1872 North Cascades earthquake. The Seattle Fault event was believed to have been magnitude 7 or greater (Johnson et al., 1999), and the 1872 North Cascades earthquake is estimated to have been between magnitudes 6.8 and 7.4. The location of the 1872 North Cascades earthquake is uncertain; however, recent research suggests the earthquake's intensity center was near the south end of Lake Chelan (Bakun et al., 2002).

2.4.3 Benioff Source Zone Earthquakes

Benioff source zone earthquakes are also referred to as intraplate, intraslab or deep subcrustal earthquakes. Benioff zone earthquakes occur within the subducting Juan de Fuca Plate between depths of 20 and 40 miles and typically have no large aftershocks. Extensive faulting results as the Juan de Fuca Plate is forced below the North American Plate and into the upper mantle.

The Olympia 1949 (magnitude = 7.1), the Seattle 1965 (magnitude = 6.5) and the Nisqually 2001 (magnitude = 6.8) earthquakes are considered to be Benioff zone earthquakes. The Benioff zone is characterized as being capable of generating earthquakes up to magnitude 7.5. The recurrence interval for large earthquakes originating from the Benioff source zone is believed to be shorter than for the shallow crustal and CSZ source zones; on average, damaging Benioff zone earthquakes in Western Washington occur every 30 years or so. The deep focal depth of these earthquakes tends to dampen the shaking intensity when compared to shallow crustal earthquakes of similar magnitudes.

2.4.4 Subduction Zone Earthquakes

CSZ interplate earthquakes result from rupture of all or a portion of the convergent boundary between the subducting Juan de Fuca Plate and the overriding North American Plate. The fault surfaces approximately 50 to 75 miles off the Washington coast. The width of the seismogenic portion of the CSZ

interplate fault varies along its length. As the fault becomes deeper, materials being faulted become ductile and the fault is unable to store mechanical stresses.

The CSZ is considered as being capable of generating earthquakes of magnitude 8 to magnitude 9. No earthquakes on the CSZ have been instrumentally recorded; however, through the geologic records and historical records of tsunamis in Japan, it is believed that the most recent CSZ event occurred in the year 1700 (Atwater, 1996 and Satake et al., 1996). Recurrence intervals for CSZ interplate earthquakes are thought to be on the order of 400 to 600 years. Paleogeologic evidence suggests five to seven interplate earthquakes may have been generated along the CSZ over the last 3,500 years at irregular intervals.

3.0 SUBSURFACE CONDITIONS

3.1 EXISTING DATA

3.1.1 Historical Explorations

Subsurface conditions along the project corridor were evaluated in part by reviewing available geotechnical explorations and laboratory data completed for previous projects. The exploration logs and laboratory data were provided to us by the I-405 Project Team. Approximately 180 explorations (test pits and borings) were completed by others from the late 1960s to 2003. The locations of the historical explorations are presented on the Site Plans, Figures 3A through 3D. An index to the site plans is provided in Figure 2. The logs of the explorations and laboratory test results are not included in this report but are part of the information available to prospective design-build teams from the I-405 Project Team office.

3.1.2 WSDOT I-405 Team Borings Completed as Part of This Study

Eight borings (515-1-06, 515-2-06 and 515-4-06 through 515-9-06) were completed by the WSDOT I-405 team as part of the current study. Eleven additional borings (SRP-2, SRP-3, SRP-5, SRW-1 and SRX-16 through SRX-22) were completed by the WSDOT I-405 team as part of the I-405 Renton Nickel Improvement Project, and two additional borings (SRL-5 and SRL-6) were completed by the WSDOT I-405 team as part of a liquefaction study. The borings were drilled using mud rotary techniques with truck- and track-mounted drilling equipment and were completed to depths of about 24 to 120½ feet below the ground surface. The boring locations were selected by the I-405 Project Team and the WSDOT Geotechnical Division.

Soil samples were obtained from the borings at selected depths using a split-barrel standard penetration test (SPT) sampler with an inside diameter of 1.4 inches. The sampler was driven into the soil using a 140-pound automatic hammer free-falling a vertical distance of 30 inches. The number of hammer blows required to drive the sampler the final 12 inches, or other indicated distance, is recorded on the boring logs. The SPT values presented on the logs are actual field-measured SPT values. They have not been corrected for hammer energy, silt content, rod weight and flexure, or overburden pressures. The two liquefaction borings were observed and logged by GeoEngineers personnel, and the remainder of the borings were observed and logged by WSDOT personnel.

Laboratory tests were completed by WSDOT on selected samples from the borings, except for the liquefaction borings. GeoEngineers completed laboratory tests on selected samples from the liquefaction study borings. Laboratory testing for both studies included determination of the moisture content and Atterberg limits (liquid and plastic limits), as well as particle size analyses.